INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
Task Group on Data Scenario Support for Impact and Climate Analysis (TGICA)

WMO UNEP

IPCC TGICA Expert Meeting
Integrating Analysis of Regional Climate Change and Response Options

Meeting Report

Denarau Island
Nadi, Fiji
20-22 June 2007

Supporting material prepared for consideration by the Intergovernmental Panel on Climate Change. This material has not been subjected to formal IPCC review processes.

Sponsored by
The Global Change System for Analysis, Research and Traning (START)
and The Pacific Center for Environment and Sustainable Development
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IPCC TGICA Expert Meeting
Integrating Analysis of Regional Climate Change and Response Options

June 20-22, Denarau Island, Nadi, Fiji

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(vulnerability, adaptation, economics; USA)

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Crossing Thresholds in Regional Climate Research: Synthesis of the IPCC Expert Meeting on Regional Impacts, Adaptation, Vulnerability, and Mitigation

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Substantial advances have been made in scientific understanding of human caused climate change, the risks it poses to people and ecological systems, and response options to mitigate and adapt, as documented in the 2007 reports of the Intergovernmental Panel on Climate Change (IPCC, 2007a, b, c). The accumulated knowledge provides a sound foundation for international agreements and national policies to confront climate change. However, effective risk management decisions at regional scales are being hampered in many places by lack of accessible information, low confidence in regional projections of future climate, and other uncertainties. Many of the critical knowledge gaps lie at the interfaces of different spatial and temporal scales of analysis and cross-system interactions of physical, ecological, and human systems.

The gaps are being narrowed by research on regional climate, impacts, adaptation, and vulnerability that is approaching, and in some places already crossing, thresholds to supply reliable information at finer spatial and temporal scales and for system interactions that is actionable for adaptation and other decisions at regional and local scales. In June 2007 the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) convened an international meeting of researchers, policymakers, and practitioners to explore needs for and innovative approaches to interdisciplinary research targeted at regional and local information needs for managing climate risks. The meeting had six objectives:

- To identify and explore innovative research approaches for dealing with multi-scale issues and cross-system processes that are relevant to climate change impacts, adaptation, vulnerability and mitigation;
- To continue to foster dialogue among researchers from different fields of climate change research (the climate system; biophysical and human system impacts, adaptation and vulnerability; and mitigation), as well as relevant stakeholder communities;
- To explore the complexities arising from the combination of multiple climatic and non-climatic stressors;
- To engage a growing community of scientists active in observation and modelling of global and regional scale changes in Earth and human systems; climate change and climate variability impacts, adaptation, and vulnerability; climate change mitigation; environment and sustainable development linkages; and related areas of research;
- To identify the ways in which the TGICA can continue to facilitate research, including greater access to observational and model data; and
- To recognize and prepare for future needs of the IPCC, the DDC and related avenues of data dissemination, and the community-at-large.

Attended by more than 40 invited participants (Table 1), the meeting consisted of extensive small and large group discussions, panel sessions, keynote talks (Table 2), and poster presentations of papers by many of the participants. Eight of the papers from the

Table 1. Presentations by Invited Participants by Theme

Participant	Presentation Title
Integration of Observations and Projections	
Patrick Debels	Scenario modeling, economic evaluation and public participation in the context of a river basin twinning project: case study experiences from the Biobío Basin, Chile
Monifa Fiu	Climate Witness in Fiji: developing a generalizable method for assessing vulnerability and adaptation of mangroves and associated ecosystems
Qingzhu Gao	Developing future land use scenarios as effected by climate change and socio-economic scenarios in China, a case study of Ningxia Hui autonomous region
G.O. Magrin	Past and Future Changes in Climate and their Impacts on Annual Crops Yield in South East South America
Gina Ziervogel	Adaptation and development futures: looking ahead
Methodological Constraints	
Lilibeth Acosta-Michlik	Crisis Probability Curves (CPCs): A measure of vulnerability thresholds across space and over time
Cheryl L. Anderson	Evolution of a Climate Risk Management Process in the Pacific: PEAC to PaCIS
Lin Erda	New Approaches for Climate Change Impacts and Adaptation Regional Study – A Case in Ningxia Chin
Bruce Hewitson	Developments in downscaling climate change scenarios
John Ingram	Spatial and Temporal Scales and Levels in Human Systems: Some examples in the context of food security
Atsushi Kurosawa	Methodological issues on linking integrated assessment with life cycle impact assessment

Participant	Presentation Title
L. Limalevu	Integrated Assessment & Action Methodology for Climate Change and Sustainable Development [I AAM for CC & SD]: a Fiji Perspective
Jose A. Marengo	Integrating across Spatial and Temporal Scales in Climate Projections: Challenges for using RCM projections to develop plausible scenarios for future extreme events in South America for vulnerability and impact studies
Claudio G. Menéndez	Simulating soil-precipitation feedbacks in South America
Mark New	Probabilistic regional and local climate projections: false dawn for impacts assessment and adaptation?
Camaren Peter	Using Bayesian networks to model the impact of climate change scenarios on biofuels production from irrigated agriculture - analysing water, energy and food sector interdependencies
R.E.Rodriguez	Integrating data for the Assessment of National Vulnerabilities to the Health Impacts of Climate Change: A Novel Methodological Approach and a Case Study from Brazil
Juliane Zeidler	Climate change adaptation (CCA) activities: some lessons and some questions from the design phase of a first generation CCA pilot in Namibia
Teleconnections	
A.M.G. Klein Tank	Integrating Global and Regional Model Results into Local Climate Change Scenarios for the Netherlands
David Seán Kirby	Interactions between ocean climate and tuna fisheries in the western & central Pacific ocean: understanding variability and predicting change
Luc Vescovi	Climate change science knowledge transfer in support of, vulnerability, impact and adaptation activities on a North American regional scale: Ouranos as a case study
Feedbacks and Couplings	
Martha Yvette Aguilar	Vulnerability and adaptation to climate change of rural people living in the central coastal plain of El Salvador
Lawrence S Flint	Vulnerability and the Social economy: The Potential for Adaptation to climate change in the Upper Zambezi Valley Floodplain
Roger Jones	Risk assessment and decision support
Zbigniew W. Kundzewicz	River floods and their impacts in the changing climate – integrated view
Emilio Lèbre La Rovere	Regional case study on Mitigation & Adaptation synergy: Production of vegetable oils and biodiesel in Northeastern Brazil
Steven McNulty	Interactions Between Climate Change and Other Environmental Stresses on North American Forest and Rangeland Health
Leila M. M. de Albuquerque	Regional climate effects of land cover changes in the Mato Grosso do Sul State, Brazil
Guillermo Podestá	Climate and Complexity in Agricultural Production Systems of the Argentine Pampas
Salvador Enrique Puliafito	Coupling population dynamics to carbon emissions
Roberto Schaeffer	Energy Development Paths and Corresponding Carbon Emissions for Brazil up to 2025
Mark Tadross	Changes in growing-season rainfall characteristics and downscaled scenarios of change over southern Africa: implications for growing maize
A K Theron	Coastal Zone Climate Change Impacts & Response Options in southern Africa- Analysis of Potential Coastal Zone Climate Change Impacts and Possible Response Options in the southern African Region
Rapid Changes	
Mary Louise Gifford	Adaptation in Rain-fed Agriculture Practices: policies and measures for water use efficiency in India
Arthur Webb	Coastal vulnerability and monitoring in Central Pacific Atoll's
Cascading Effects	
Mayowa Fasona	Aspects of Climate Change and Resource Conflicts in the Nigeria Savannah
Benjamin Apraku Gyampoh	Climate Change/variability and vulnerability of livelihoods in the Offin River Basin, Ghana
Patrick D. Nunn	Responding to the Challenges of Climate Change in the Pacific Islands: Management and Technological Imperatives
Dennis Ojima	Cross-System Interactions of Ecosystems and Human Systems" or "Dealing with Climate Change: A Coupled System Response
Florencia B. Pulhin	Impacts, Vulnerability and Adaptation of the Pantabangan-Carranglan Watershed, Philippines to Climate Change: Perspective of the Stakeholders
Youba Sokona	Sustainable Development and Resilience to Climate Stress
Petra Tschakert	Do we recognize a climatic shift when we see one?: Lessons from the Western Sahel

meeting are published in a special issue of *Climate Research*. Here, in this paper, the co-chairs and organizers of the conference present a synthesis of key themes and recommendations that emerged from the discussions.

Engaging Users and Communicating Knowledge

An overarching theme that emerged from the meeting is the importance of improving communication between the science community and society. Better communication is needed to match information (as opposed to data) emanating from the research community to users' needs, to incorporate users' knowledge in research and decision-support analysis, and improve users' understanding, interpretation, and application of tailored information for effective risk management decisions. Users, in this context, include analysts, managers, planners, and decision makers in the public and private sectors who act to manage climate related risks at levels ranging from the local to national to international. They include members of exposed and at-risk communities, including traditional communities, journalists and other knowledge transfer intermediaries, and members of the public at large. Users can also include researchers who require data and knowledge from others as inputs to their own research.

Science that intends to inform users and be applied in risk management decisions needs a coherent communication strategy. The communications need to be multidirectional so that research considers users' needs and knowledge, users gain access to relevant scientific knowledge in forms that are understandable and applicable to the decisions that they face, and the process produces knowledge that is viewed as credible and legitimate by researchers and users alike.

There are many barriers to effective communication of climate information. These include the complexity of the issues, incomplete information, and uncertainties, different information needs, capacities, and languages of different audiences, multiple sources of information with potentially conflicting messages, and other salient and urgent problems that compete for the time and attention of audiences. Messages that emphasize consequences that are many decades in the future, are largely negative, or give little information about feasible response options tend to be ignored.

These barriers can be overcome by developing a communication strategy at the start of a program or project, including persons in the project team who are skilled in knowledge transfer, and allocating adequate financial resources. Communications can be more effective when they provide opportunities for feedback from intended audiences and take into account their current knowledge, concerns, decision contexts, and information needs. Effective communication also gives careful attention to choosing media, format, language, and messages that are appropriate, accessible and actionable for a targeted audience. The appropriate approach will vary depending on the purposes, scope, and resources for a particular program, as well as the capacities, interests, and needs of relevant stakeholder constituencies. Generally, there is a need for enhanced dialogue between researchers and user-communities, and greater collaboration between producers and users of information. Engaging users in framing the research questions early in the process is an important first step. Involvement of users in the design and evaluation of communication materials is also good practice. Common to all these elements is the principle of enabling users – enhancing their capacity – to engage in the interpretation and understanding of communicated information, with full cognizance of caveats and context.

Some research programs have gone further and engaged users at multiple points throughout the research process as sources, co-producers, and evaluators of relevant knowledge who contribute directly to the research endeavour. Although this more intensive, participatory approach to the engagement of users is resource and time consuming, the payoff is potentially large. Advantages of participatory approaches to climate change research and assessment include (i) empowering the participants to make informed personal decisions and participate in public decisions that can reduce their risks, (ii) accessing knowledge not otherwise available to the researchers, leading to a more complete framing and analysis of the problem, (iii) targeting research more effectively to produce information that is actionable by users, (iv) providing greater transparency in the research process, which increases the credibility and legitimacy of the research results among stakeholders, and (v) increasing the likelihood that the research will be used and result in actions that reduce risk.

Table 2. Keynote Presentations

Presenter	Presentation Title
David Wratt, NIWA	Science Challenges Identified by the IPCC AR4
Patrick Nunn, University of South Pacific	Responding to the Challenges of Climate in the Pacific Islands: Technological and Management Imperatives
Bruce Hewitson, UCT	Developments in downscaling climate change scenarios
Jose Marengo, CPTEC/INPE	Integrating Across Spatial and Temporal Scales in Climate Projections
Dennis Ojima, Heinz Center	Cross-System Interactions of Ecosystems and Human Systems or Dealing with Climate Change: A Coupled System Response
John Ingram, GECAFS	Integrating Across Spatial and Temporal Scales in Human Systems
Roberto Schaeffer, COPPE/UFR	Development, energy and mitigation opportunities
Gina Ziervogel, UCT/SEI	Development, Capacity and Adaptation Futures
Mark New, Oxford University	Probabilistic Scenarios of Climate Change
Roger Jones, CSIRO	Risk Assessment and Decision Support

Engagement and communication with traditional communities, and use of traditional knowledge, warrants special consideration. Traditional communities can be among the most vulnerable to climate change and have a compelling need for improved knowledge and other resources for managing and adapting to climate related risks. Members of traditional communities can have intimate knowledge of past variations in climate, the sensitivity of natural systems to climate variations, and the ways their livelihoods and wellbeing are affected by climatic and environmental variations. They can also have knowledge of risk management strategies that are adapted to their specific social, cultural, economic, and environmental circumstances.

Incorporating this knowledge in research, with the consent and for the benefit of traditional communities, engaging members of traditional communities in research, and communicating research-generated knowledge that is actionable by traditional communities are made challenging by a variety of factors. Language is a key constraint, both in terms of the technical lexicon in which scientific information is commonly communicated, and because of differences in the primary languages spoken by traditional and non-traditional communities. Additional hurdles include poor understanding by the research community of the context in which traditional communities live, lack of formal education of many members of traditional communities, concerns about traditional knowledge being stolen, and different perspectives about the attributes that confer credibility, validity, and legitimacy to knowledge. Still, the need is great for engaging traditional communities in processes of knowledge exchange and co-production that can reduce climate risks, and examples of effective collaborations are needed.

In the end the goal is to communicate a message that is credible (as recognisably a possible and realistic outcome), defensible (in that there is a clear process based understanding of the physical and social systems response), and ultimately that is actionable (that is, the message is appropriately tailored to the needs and robust to the point that adaptation action becomes the viable risk management choice).

Uncertainty and Confidence

Uncertainty, as scientifically understood, is an ever-present component in projecting future climate, but in itself does not preclude confidence in the scientific results. Uncertainty is a problematic term, often leading users to conclude erroneously that little is known or understood about the drivers of change, system behaviour, consequences, and feasible response options. This has vexed both researchers and users. Confidence, while not the complete opposite of uncertainty, refers to the degree to which a user may rely on a message. In reality all climate change results are of varying degrees of confidence, with varying proportions of uncertainty.

Researchers generally take pains to caveat their results, noting uncertainties that are introduced by data quality problems, methodological difficulties, untested assumptions, and other sources. But the poor communication of what scientists formally understand as uncertainty results in users not always understanding the limitations, sometimes placing undue confidence in simulations of future conditions despite the caveats, while at other times rejecting valid and potentially useful information as insufficiently substantiated to be actionable. In turn, researchers cannot be knowledgeable about all sources of uncertainty that may influence their results, and users may have information to contribute to a more complete and valid assessment of uncertainty. The IPCC AR4 chapter on regional climate change raised the concept of robust messages, that is, messages which while uncertain in some respects have a core message that is robust on the basis of scientific evidence.

Greater attention is thus needed for communicating such information between researchers and users in forms that are understandable and useable. Users often operate in contexts in which decisions have to be made, even if available information is known to have significant deficiencies. To make effective decisions, users need improved understanding of confidence levels and understanding of the uncertainties associated with the information that they use, along with tools to help bound the range of plausible futures, assess qualitative likelihoods, and assign quantitative probabilities.

Dialogue between users and researchers has brought attention to these needs and is slowly leading to progress in developing necessary tools. Users require both qualitative and quantitative tools for interpreting and representing uncertainties to inform decisions that are robust for a range of potential scenarios. Qualitative, non-probabilistic approaches to representing uncertainties with climate envelopes constructed from ensemble projections of multiple climate models are being developed and warrant exploration.

Quantitative, probabilistic approaches also show promise. While the methods are experimental and in need of improvement and validation, developing probabilistic approaches is a critically important area for collaborative research that can make direct contributions to improved management of climate change risks. Extension of the approach to integrated frameworks is needed to trace uncertainties that cascade from social and economic development paths, to the capacity to mitigate and adapt, to emissions and concentrations of greenhouse gases, to changes in climate, to changes in other Earth systems, to impacts, and back to development paths. Progress in accounting for this cascade of uncertainties would help shed light on questions about the risks associated with exceeding various greenhouse gas concentration levels, the timing of mitigation actions, the participation of large and rapidly growing economies in a new emission reduction regime, and the scale and efficacy of adaptation responses.

System Interactions

The vulnerability of human populations and ecological systems to climate change and variability depend on processes and interactions of multiple systems that are complex, non-linear, incompletely understood, quasi-deterministic, and exceedingly difficult if not impossible to predict. Reflecting this complexity, interdisciplinary and systems-oriented approaches are more commonly applied in climate research than in most other areas of scientific inquiry. Yet practice falls short of where it needs to be.

Researchers typically work most directly with others in the same or closely associated disciplines. Boundaries for research projects often are narrowly drawn to focus on a single system or small number of closely related systems. Observational evidence of system interactions to study and test causal relationships is limited. This leads to the neglect of feedbacks, couplings and cascading effects between social and biophysical systems that have the potential to amplify, dampen, or fundamentally alter system responses. Some research and assessment efforts have attempted to remedy this situation by conducting broadly integrative studies. But these are rare relative to the need, and too often finite resources, time constraints, and lack of researchers with skills to work at disciplinary boundaries have limited cross-disciplinary or cross-system collaborations to mere transfer of data with little opportunity for joint production of new approaches and knowledge.

Progress will require multidisciplinary research efforts that target cross-system and cross-scale interactions and that investigate climate change within a context of multiple stresses. Research that integrates natural and social sciences and applies a framework of coupled human-environment systems is critical. Of particular priority for research is identifying couplings among Earth systems where feedbacks may amplify climate change, such that risk-exceeding thresholds are crossed and systems are abruptly tipped into fundamentally changed states with continental to global ramifications. Examples include carbon cycle feedbacks, cloud feedbacks, ice sheet dynamics, land surface interactions with atmosphere and climate, deep ocean connections to nutrient cycles and the atmosphere, and ocean acidity. Also of priority are couplings between biophysical and human systems that can impact food security, access to water and sanitation, human health, natural hazards, energy, and economic and human development.

Climate Information

Global scale changes in climate will manifest as changes in average climate conditions, changes in variability at daily, seasonal, interannual, decadal, and other time scales, and changes in extremes, all of which will exhibit substantial spatial variation. The temporal and spatial patterns of change will be critical determinants of climate risks, critically as regards exceedence of thresholds of vulnerability. Participants in the meeting observed that climate modeling efforts have generally failed to provide information about future climate with temporal and spatial resolutions needed by users, and have neglected aspects of climate that have important implications for decision making. General Circulation Models (GCMs) traditionally focus on time horizons that are distant relative to most planning horizons and simulate climate at spatial resolutions that are too coarse for assessing vulnerabilities and planning adaptation responses at regional and local scales. The climate data that have been archived from GCM experiments, processed into data products, and disseminated have been selected primarily for understanding climate dynamics and making inter-comparisons of models, with little weight being given to the data needs of end-users. Meeting participants urged a paradigm shift in the climate modeling community to give greater emphasis to the needs of users for climate data that is more directly applicable to risk management decisions in terms of the chosen temporal scale, spatial scale, and variables.

Time scale

Climate projections typically extend a century or more into the future and data products derived from GCM projections emphasize changes in seasonal means averaged over multiple decades. The emphasis on long time horizons and multi-decade averages reflects the temporal scales for which GCMs are considered to be skilled. In contrast, many users are most interested in shorter time horizons that extend a season to a few years, or to one or maybe two decades into the future. Reflecting these tendencies, climate risk reduction and planning efforts generally have relied to a greater degree on historical data of climate variability and trends than on model projections of climate change (see Ziervogel and Zermoglio, this volume). Where they have used outputs of climate models, often these are seasonal projections.

Users are in need of information that can help them anticipate climate variability and change over multiple time horizons, ranging from the very near term to multiple decades. For some regions, such as where there are connections to ENSO variability, seasonal forecasting skill has developed to levels that can be of significant value to users and have been applied in areas such as farm management and famine warning. Further research and refinement of methods and tools for seasonal forecasting are likely to yield important benefits in regions where this technique is feasible. Projecting climate variability at decadal time scales is an emerging area of research that, if successful, would find important applications in risk management and planning. Also needed are techniques or frameworks that enable users to compare projections for short, medium, and long-term time horizons, as well as with data for historical variations and trends, for purposes of evaluating the viability of near-term adaptation measures for continued effectiveness in the future.

Spatial Scale

The coarse scale resolution of GCM projections have been useful for characterizing in general terms the potential impacts of climate change. However, planning adaptive responses that will be effective at reducing risks requires regional and local scale information about exposures and vulnerabilities to climate stresses. Techniques have been developed to 'downscale' the coarse resolution GCM projections to finer spatial scales and produce regional scenarios that correspond to and are consistent with the GCM projections.

Two downscaling approaches have emerged as the most common: nesting a regional climate model (RCM) within a GCM, and empirical, or statistical, downscaling. Both approaches have relative strengths and weaknesses, as outlined in IPCC (2007a), yet may be considered to be of comparable skill. The regional climate models dynamically simulate changes in the regional climate in response to large-scale forcings, as simulated by a GCM experiment, taking into account interactions with regional scale features and processes. Using RCMs for downscaling is well documented in the literature, but requires a significant level of technical skill and computational capacity. For these and other reasons, RCMs are typically not viable for one researcher to adopt and explore the range and envelope of possible future climates across multiple GCM forcings. Statistical downscaling approaches use empirically estimated relationships between large-scale forcings and the regional climate to downscale GCM projections. These approaches lend themselves to rapid implementation with nominal computation requirements, and have an extensive literature.

The implementation of both RCM and statistical downscaling have the potential to significantly influence the quality of the final product, hence it is incumbent on both the producers and recipients of downscaled climate data to understand the limitations and strengths of a particular implementation. There is a need for inter-comparison and evaluation of downscaled climate data and downscaling practices to facilitate convergence on best practices for downscaling. Participants in the meeting agreed that user needs and the utility of downscaled products for decision-making by local and regional entities should be weighed in the evaluation of downscaling. Discussions at the meeting produced a set of attributes and related questions that should be considered in seeking to implement a robust downscaling, which are summarized in Table 3.

Table 3. Attributes for Robust Downscaling of Climate Data

Attribute	Comment
Variance	A downscaling procedure should represent both variance from local scale processes and from large scale synoptic forcing.
Feedbacks	The degree to which local feedbacks may modulate any downscaled response is a critical question that should inform the choice of downscaling approach.
Stationarity	Stationarity may be an important factor potentially undermining a products value. Downscaling products should assess and demonstrate low vulnerability to stationarity in a given context..
Multi-model spread	Multiple model realizations of the future should be sampled. Of special importance is the issue of decadal scale variability, where one forcing model may be sampled at a particular phase of its internal natural decadal variability, and in so doing misrepresent the larger long-term signal of change.
Spatial-temporal cohesion	The capability of a downscaling procedure to reflect spatial auto-correlation between downscaled locations, and the temporal sequencing of the downscaled data should be examined where this is a factor, for example in landscape hydrological response to climate change.
Envelopes and probability	Downscaling should attempt to capture the outer limits of projected change and, if possible, characterize the probability distribution of potential changes.
Practicality	Resource constraints, data availability, data quality, and computational capabilities may limit the practicality of meeting all the preceding attributes for a robust downscaling; the attributes should be prioritized with respect to the context and purpose of the application to guide the choice of method.

Variables of Interest

The most readily accessible outputs of climate models are monthly or seasonally averaged variables such as temperature and precipitation in time series or averaged for pre-determined time slices of 20 to 30 years. These variables are not always directly applicable to the assessment of vulnerabilities or decision-making to manage climate risks. Users often are equally or more concerned with changes in phenomena such as the timing of the start or cessation of the rain season, duration of the rain season, length of dry spells, and frequency, severity, and spatial distribution of extreme events as they are in changes in seasonal means of temperature and precipitation. Greater communication and collaboration is needed among climate modelers, impacts, adaptation, and vulnerability researchers, and end-users to identify climate variables that are of interest.

The research community, facilitated by the TGICA, has begun to compile an extensive list of variables that the impacts and adaptation community need in order to generate useful information (see report of the proceedings of the meeting). The preliminary list has been communicated to relevant organizations and initiatives which will be generating data to use as a basis for much of the IPCC's 5th assessment report.. The IPCC Third and Fourth Assessment Reports are being examined to identify potentially relevant variables. These efforts should be supplemented by mechanisms to reach the wider research community and end-user communities. Possible mechanisms include survey instruments, regional meetings that include researchers and users, and meta-analyses of impacts, adaptation, and vulnerability studies to identify commonly used variables. This effort should also expand to include variables pertinent to the social sciences.

Socioeconomic Information

Research on climate change impacts, adaptation, and vulnerability requires information about past and current social and economic conditions, correlated with climatic and environmental data, to investigate empirically the causes of vulnerability to climate stress, the consequences of exposures, and the efficacy of adaptive strategies that have been used in the past. Information about future social and economic conditions, or socioeconomic scenarios, is needed to examine future impacts, adaptation, and vulnerability. Mitigation research is also dependent on past data and future scenarios of social and economic conditions.

Working with social and economic data poses a number of difficulties for climate change researchers. Multiple entities are involved in the collection of socioeconomic data for multiple purposes, with the result that the variables collected, the protocols for collection, and the definition of variables are not uniformly standardized. The collected data are aggregated for administrative units of varying size and character, often accessible only for national aggregations, and very rarely are the original data spatially referenced. This has made it difficult to construct international datasets with comprehensive, consistent information about key determinants of vulnerability and capacities to adapt and mitigate that can be correlated with spatially gridded climate and environmental data. As a result, efforts to identify who is exposed and who is vulnerable are severely hampered. Improving this situation would greatly benefit research in this area.

Studies of future climate change impacts often have used the SRES scenarios, which are the socioeconomic scenarios that were developed by IPCC to generate greenhouse gas emission projections for input to GCM experiments (Nakicenovic and others, 2000). This has been done to achieve consistency between climate change analyses and assessments of their potential impacts. However, much as the GCM climate projections are too coarse for use in adaptation and vulnerability research, the SRES scenarios are also insufficiently detailed. There are three specific difficulties.

First, the scenarios provide projections of social, economic and other variables for highly aggregated regions and do not provide data even for nation states, much less the sub-national units that are relevant to risk management. Broad mitigation and adaptation policies and objectives may be set at national or even international levels, but many decisions and actions occur at the level of sub-national and local administrative units and individual institutions and actors. This requires information about climate, social, economic, and other variables at finer spatial resolutions than is provided by the SRES scenarios and GCM generated climates.

Second, the set of variables for which projections are available from SRES are insufficient to model changes in exposures, capacities to act, or vulnerability. These characteristics of populations, which are critical for managing risks, are dependent on demographic, social, health, economic, governance, cultural, environmental, and other variables that are far more extensive than provided by SRES.

Third, the generalized story lines that underlie the SRES scenarios do not reflect national and local aspirations and visions of the future. For example, China's development plans call for increased economic development and settlement in the semi-arid, western interior of the country. If and how this aspiration is achieved, will significantly remake China's vulnerability to climate change and must be a factor in China's adaptation planning, but is not a factor in the SRES story lines.

As a consequence of these difficulties, many case studies of vulnerability and adaptation have used scenarios constructed from regional and local considerations that are not readily reconciled with global scenarios used to drive climate change projections. How can scenarios based on local experience be developed in a manner that allows coordination with global scenarios? Sub-global scenarios based on broad rationale, assumptions and outcomes of agreed global scenarios should be developed, but should allow for sub-global deviation where needed. These scenarios also need to be informed by regional, national, and local understanding and information. Some of this information has the potential to change the global scenarios, so there needs to be a two way street between the regional and the global scenario development processes. Such an initiative will require substantial resources, innovative tool development, and consultation among regional stakeholders, including modelers, decision makers, and users.

Capacity Building & Mainstreaming Climate Change

The need for capacity building, as a means for mainstreaming climate change adaptation and mitigation, was a recurrent theme throughout the conference. At the most basic level, there is a need for increased awareness and literacy of the general public about climate change – its causes, the risks it poses to people and the things people value, strategies for reducing the risks, and the benefits, costs, and other consequences of different courses of action. Populations that are particularly vulnerable need an understanding of the contributing factors that create their vulnerable condition, with an objective of empowering people with information and tools to improve their situation. Analysts, managers, planners, and decision makers, acting in areas as diverse as agriculture, water management, public health, emergency preparedness, poverty reduction, urban planning, and economic development need information about climate risks and risk management options, capabilities to interpret and apply this information, and decision support tools. Scientific communities need human and institutional capacity to execute transdisciplinary research, undertake regional and local risk assessments and decision support research, and to implement effective communication strategies.

The capacity building discussions emphasized the needs of the developing countries, where needs are greatest. A variety of approaches have been applied to build climate change related capacity in developing countries, including outreach programs to raise awareness, training workshops for government leaders, young scientists, professionals, educators, and journalists, fellowships, grants for research and assessment projects, and regional conferences, networks, and centers. Particularly effective for building science capacity have been comprehensive programs that emphasize learning by doing through participation in collaborative, interdisciplinary research or assessment projects that are supported with training, networking, and technical assistance. An example is the IPCC sponsored Assessments of Impacts and Adaptations to Climate Change (AIACC; www.aiaccproject.org), which produced more than 100 peer-reviewed publications and enabled participants to initiate a number of follow-on projects. Successful programs such as this warrant replication and expansion.

Existing centers of excellence for climate change research, assessment, and education represent valuable resources for enabling the mainstreaming of climate risk management. Investments in these centers to raise their capabilities, link them with similar centers, engage them with user communities, and orient them to more user-focused research and communication can make them effective resources in their regions for improving risk management. Useful functions that could be performed by regional centers include collecting, producing, interpreting, and disseminating data products, sharing of information about options and best practices for adaptation and mitigation, developing decision support tools, providing access to scientific literature, hosting and training visiting scientists, implementing communication and training programs, coordinating regional research and assessment efforts, advising on adaptation and mitigation projects, integrating climate change into K-12, undergraduate, and graduate education curricula, and leveraging resources to support regional initiatives.

Conclusions and Recommendations

Substantial progress has been made in scientific understanding of observed changes in the Earth's climate, the contributions of human and other forces to the observed changes, the qualitative character and quantified range of possible future changes, the consequences of climate change, options for mitigating and adapting to climate change, and the benefits, costs, and other consequences of these actions. The accumulated knowledge is being used to inform a wide variety of decisions in multiple contexts. However, user needs for information that is relevant and directly applicable to risk management decisions at local to regional scales are not being met.

Discussions at the IPCC Expert Meeting on Regional Impacts, Adaptation, Vulnerability and Mitigation highlighted a number of reasons for this failure and explored possible remedies. A fundamental shift to a more user-oriented focus is needed, with the goal of providing actionable information for adaptation and mitigation decisions. Success will require greater attention to communication between climate researchers, impact, adaptation, vulnerability, and mitigation researchers, users, and affected populations. Participatory models for research and assessment are effective at producing actionable information and warrant wider adoption. Knowledge gaps that are important for risk management decisions and are priorities for focused research are found at the interfaces of different temporal and spatial scales of analysis and cross-system interactions. Users need information at finer temporal and spatial scales than is commonly provided. Couplings between human systems and biophysical systems are critical determinants of vulnerability, but research is hampered by inadequate social and economic data that are comparable across jurisdictions and that can be spatially correlated with climatic and environmental data. Advances are needed in the understanding and communicating uncertainties, and in decision support tools for managing with uncertainty. Progress in the production and up-take of actionable information will require investments to raise the capacities of research and user communities, and for greater collaborations among researchers and users.

Because the meeting was convened by the TGICA, discussions frequently touched on recommendations for TGICA and the IPCC. The meeting did not formally endorse a set of recommendations, but the following suggestions are consistent with the general sense of the discussions over the three-day meeting:

- TGICA should explore options for facilitating the development and effective dissemination of downscaled climate projections that meet high scientific standards and for providing access to downscaled products to researchers and users through the Data Distribution Centre. Suggestions made at the meeting include development of standards and guidance documents for downscaling and using downscaled products, convening regional meetings of experts from research and user communities, and helping to initiate inter-comparison studies of downscaling.
- TGICA should continue its efforts to identify and communicate to the climate modeling community climate variables, time scales, and spatial scales that are most relevant for impacts, adaptation, and vulnerability research. The effort should be expanded to encompass information needs of end-users.
- TGICA should explore options for facilitating the development and dissemination of regional scale datasets and future scenarios of socioeconomic information. There is a need for regional and local data products that integrate and spatially reference socioeconomic, climatic and environmental data, both historical and projections of the future, and that can be related to global scale scenarios that are used to drive GCM experiments.
- TGICA should explore options for facilitating access by researchers and users to studies and examples of adaptation.
- IPCC should develop and implement a more comprehensive and extensive communication strategy that emphasizes communication of climate change risks and risk management responses.

References

IPCC 2007a. Climate Change 2007: The Physical Science Basis. S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M. Tignor, H. Miller, and Z. Chen, eds. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, USA.

IPCC 2007b. Climate Change 2007: Impacts, Adaptation and Vulnerability. M. Parry, O. Canziani, J. Palutikof, P. van der Linden, and C. Hanson, eds. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, USA.

IPCC 2007c. Climate Change 2007: Mitigation of Climate Change. B. Metz, O. Davidson, P. Bosch, R. Dave, and L. Meyer, eds. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, USA.

Nakicenovic, N., and others 2000. Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, USA.

PARTICIPANT PAPERS

Crisis Probability Curves (CPCs): A measure of vulnerability thresholds across space and over time

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The assessment of vulnerability to the impacts of climate change (e.g. floods, droughts, etc.) should be able to identify thresholds by which not only the level of exposure can be measured over time, but also the ability of communities to adapt can be compared across space. So far, much of the vulnerability studies have focused on developing vulnerability maps to present a static view of vulnerability across regions without providing thresholds for the critical state, which can inform policy where and when adaptation actions should be made. The Crisis Probability Curves (CPCs), which are a novel tool for vulnerability assessment, are a convenient yardstick for measuring the vulnerability thresholds across different regions and over a long period. The CPCs are estimated from generalized linear models and represented in contour plots with constant elevation. The functions define the relationship of the magnitude of impacts to (a) the level of environmental exposure (e.g. water stress) and (b) socio-economic adaptive capacity (e.g. income, education, etc.). This paper presents the application of the CPCs to measure vulnerability thresholds in selected case study regions in India, Portugal and Russia. The second section of the paper explains the concepts behind the CPCs. The first part of section 3 discusses the methods applied to estimate the probability curves, specifically maximum likelihood functions, whilst the second part provides a characterisation of the case study areas and a description of the trends in vulnerability components. Section 4 presents the results of the estimated crisis probability functions and the plotted CPCs generated from these functions. The last section concludes the paper and recommends research direction for future application of CPCs in assessing vulnerability.

Within the context of the Security Diagrams Project, the Crisis Probability Curves (CPCs) have been developed and applied as a novel tool for an empirical assessment of vulnerability (Acosta-Michlik et al. 2006). The concept of the Security Diagram provides quantitative meaning to the concept of vulnerability by drawing an empirical link between the level of susceptibility and environmental stress, on the one hand, and the ensuing level of risks, on the other hand. However, it was the use of the CPCs that allows the Security Diagram to provide a holistic empirical approach in the assessment of vulnerability to the impacts of climate change. This is because the CPCs provide an empirical measure for vulnerability thresholds, which is lacking in many vulnerability studies. Along the lines of the IPCC definition of vulnerability, the CPCs are derived from a conceptual thinking that vulnerability is “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes” (IPCC, 2001). Vulnerability and thus the susceptibility of a system to a given climatic stress can be expressed through the following function:

$$[1] \qquad z = f(x, y)$$

where the dependent variable z is a measure of the level of vulnerability. The independent variables x and y are some measurable indicators of the system’s susceptibility and of the environmental stresses to which it is susceptible, respectively. Figure 1 shows a three-dimensional diagram of equation [1]. The two horizontal dimensions represent the two independent (or input) variables x and y, and the vertical dimension represents the outcome z based on the combined influence of the input variables. As Morgan and Henrion (1990) explain, “[t]he surface displays directly how the value of z changes with the variations in the values of its inputs, and is sometimes termed as response surface”. Here, the surface represents the level of vulnerability. For example, given some scaled values of the input variables between 0 and 1, the level of vulnerability is low at point z4 where x and y are low (i.e., below the scale of 0.4). In contrast, vulnerability is high at point z1 where x and y are high (at the scale of 1). The surface of the diagram, which can also be represented in a succession of contours, can be compared to a hill, on which one feels or becomes better off on higher than lower ground. The contour plot (i.e z1, … z4), which shows lines of constant elevation or height, measures the degree of vulnerability at varying combination of susceptibility x and climatic stress y.

When defining the dependent and independent variables in equation [1], it is important to explicitly identify the causes of susceptibility or measures of adaptive capacity (x), the nature of the climatic stress (y), and the impacts on the system (z). This paper assesses socio-economic susceptibility of selected regions in India, Russia and Portugal to droughts (i.e., water stress), which impacts can be quantified among others in terms of crop losses, health risks, reduced income, unemployment, migration, or death. When impacts reach an unprecedented level beyond the capacity of the system to adapt and recover, crisis could occur. Acosta-Michlik et al. (2006, p201) define drought-related crisis as “an unstable or critical economic and human state of affairs caused by the susceptibility of the state and society to water stress, which has serious adverse consequences on economic development and requires national or international emergency support.” Such a condition is likely to occur at points somewhere between (and beyond) z2 and z1, where the levels of stress and susceptibility are highest. Among the different contour lines, they are the most relevant for vulnerability assessment because they define the zone where the combined levels of water stress and socio-economic susceptibility are most likely to cause human crisis. These lines are the Crisis Probability Curves -- the thresholds by which the levels of vulnerability could lead to a crisis due to inability of the system to adapt to the impacts of the stress without any emergency support. The importance of these curves can be emphasized in a two-dimensional representation of the Security Diagram (Figure 2a). As in Figure 1b, the x-axis represents an index (or scaled values) of socio-economic susceptibility (SSI) and the y-axis represents water stress (WSI). The use of indices not only provides equal units for the axes, but also allows representation of a set of susceptibility and stress indicators. The scattered boxes in the diagram show the combined indices of the socio-economic susceptibility and water stress for a given year, thus they represent the level of vulnerability of the region. The low crisis probability curve (CPCL) and high crisis probability curve (CPCH) correspond to z2 and z1 in Figure 1b, respectively. The probability of occurrence of crisis is higher the further the boxes are from the origin and the closer they are to the CPCH, as represented by the grey boxes.

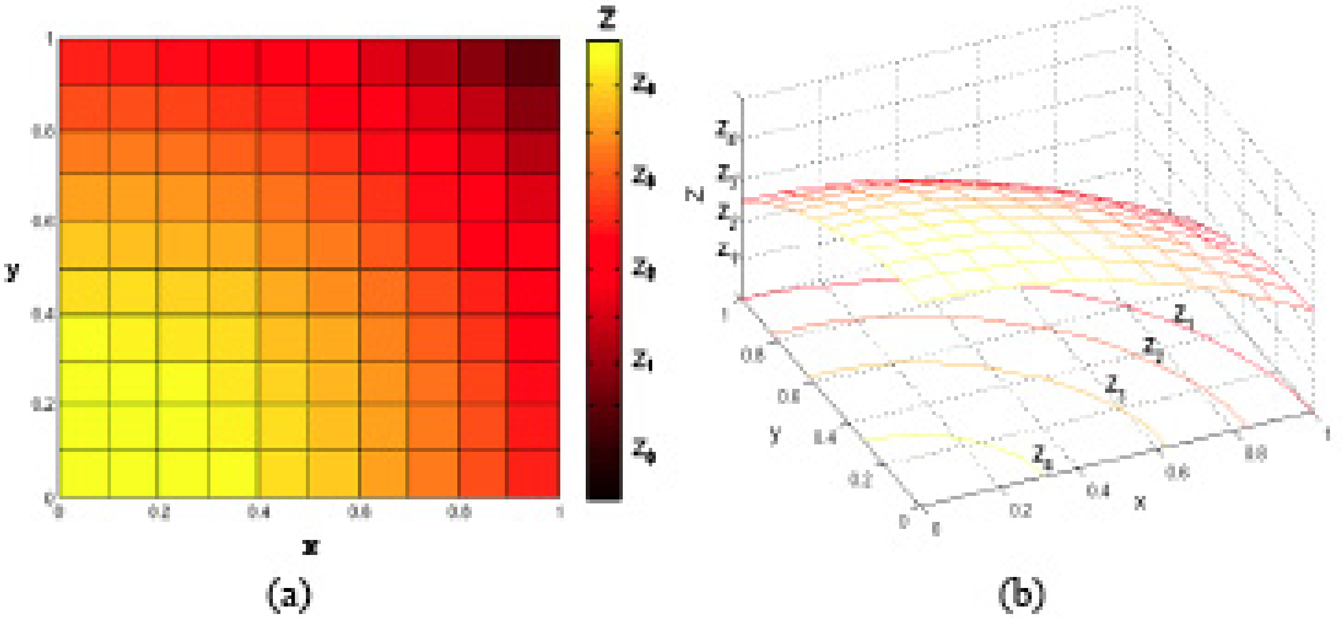

Figure 1. Surface (a) and contour (b) plots of the Security Diagram.

Many vulnerability studies use composite indices of environmental exposure and human adaptive capacity to assess vulnerability. Whilst these indices are generated using some quantitative methods (e.g. indiscriminate aggregation, fuzzy logic, and weighted indicators, etc.), the assessment of vulnerability is not purely based on some explicit empirical criteria. The indices are at best compared, combined or mapped to derive some qualitative indication of the level of vulnerability. There are very few studies that empirically estimate the combined links of the composite indices of susceptibility (or adaptive capacity) and water stress to human impacts over time and across regions. Comparing these indices to some empirically derived thresholds such as the CPCs offers empirically tested and estimated criteria for assessing vulnerability. The vulnerability function in equation [1] was used as a basis for estimating the CPCs for the following regions: Andhra Pradesh in India, Algarve and Alentejo in Portugal, and Volgograd and Saratov in Russia. The identification of relevant indicators for crisis for these regions was challenged not only by the dearth of information on water-stress related crisis, but also by the lack of clear concept and standard indicators of environmental crisis from different sources and for different countries. Considering these problems in measuring drought-related crisis, the dependent variable z in equation [1] becomes a discrete rather than continuous variable, taking the value of 1 to indicate the presence and 0 to indicate the absence of crisis. Such a binary choice model was applied in this paper to identify the shape of the crisis probability curves and to determine their relative position in the Security Diagram. In the binary choice framework, the explanatory variables can have a continuous distribution, as in this case, where both water stress index (WSI) and socio-economic susceptibility index (SSI) are continuous between 0 and 1. A latent variable, measuring some unobservable indicator of the chance that the binary event will take place is linearly regressed on the explanatory variables and the probability of the event is computed by evaluating the latent variable in a function whose values can range between 0 and 1. To elaborate on this, consider the following regression function:

[2] $$Y_t = \beta_o + \beta_1 X_{1t} + \ldots + \beta_x X_{xt} + ut$$

where are the explanatory variables at time t and Yis the unobservable latent variable. The probability that an event, say crisis, will take place will then be:

[3] $$P(D_t = 1) = F(Y_t)$$

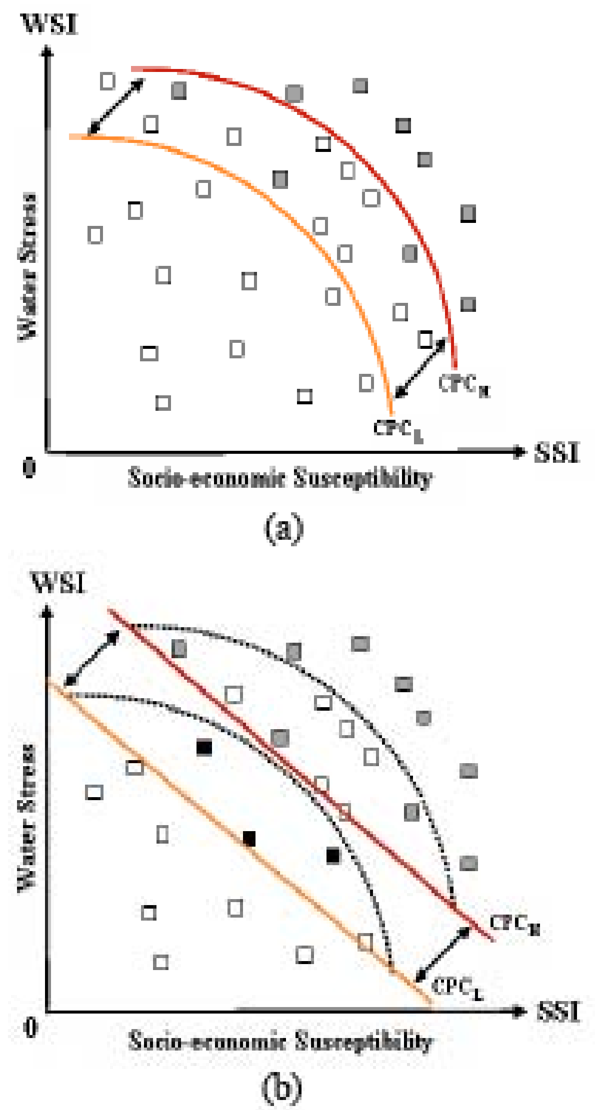

Figure 2. Convex (a) and Straight (b) Crisis Probability Curves.

where D is the binary variable at time t, taking value 1 if the event occurs and 0 if it does not, and is the function mapping the latent variable Yt into the probability of an occurrence. In econometrics literature, there are two common choices for the function : the standard logistic distribution function and the standard normal distribution function, which lead to the so-called "logit" and "probit" models, respectively. Both models can be estimated using maximum likelihood. The logistic and normal distributions are very similar and yield estimates that are relatively comparable after some scaling of the parameters is performed. Nevertheless, both models were estimated to determine which of the two would better represent the probability of drought-related crisis.

It is well known, however, that in a time series framework of this type (i.e., data are observed on a yearly basis and display a high degree of temporal dependency) particular attention must be devoted to verify the stationarity of variables (or the presence of cointegration) to avoid spurious results resulting from the correlation between stochastic trends. Fortunately, in a binary response model, such a concern is not necessary. Park and Phillips (2000) show that maximum likelihood estimators of the parameters of such a model are consistent no matter whether the regressor are stationary or not. Intuitively, this can be explained with the fact that the dependent variable is bounded and that the link function "compresses" the effect of the regressors to the [0,1] interval. However, the presence of a unit root in one or more regressors has some negative effects on the precision of maximum likelihood estimators. The speed of convergence of the estimators in presence of integrated regressors is reduced. So prior to model specification and estimation, a stationarity test of the series has been performed on all the variables to check for eventual unit roots and any ensuing spurious regression. The series of WSI and SSI for India, Portugal and Russia were tested for the presence of a unit root using the standard tool of augmented Dickey-Fuller (ADF) test. These tests appear to display the presence of a unit root in some of the series we analyzed. The result must however be used with caution. It is in fact well known that unit-roots test such as Dickey-Fuller are characterized by having low power, that is they tend to be often prone to the type II error of accepting the null hypothesis when in fact it is not true. This is particularly true in cases where sample size is limited as in our models with only 25 observations. Improving the models by considering longer time series could easily give opposite results in terms of stationarity. Keeping in mind the possible existence of a unit root in several regressors and reduced speed of convergence of maximum likelihood estimators in our model, the results of the logit estimation for the different models are as follows (Note: results of the probit estimation is very similar so they are not presented here):

MODEL 1 (simple)
For India: Yt = -18.18 + 25.50 WSIt + 10.02 SSIt
For Portugal: Yt = -7.53 + 11.00 WSIt + 3.13 SSIt
For Russia: Yt = -8.13 + 9.17 WSIt + 9.37 SSIt

The signs of the intercept and coefficients are consistent for all the countries. The regression intercepts turned out to be statistically significant for all the countries. Generally, the parameters for WSI also display rather high levels of significance. The p-value of the likelihood ratio (LR) tests for the null hypothesis that they are not significant range in fact from 0.0001 to 0.004. Even with somewhat higher p-values (from 0.0007 to 0.09), the LR tests did not provide any reason to strongly reject the null hypothesis on the significance of WSI as explanatory variable for the probability of crisis. However, the statistical significance of the SSI coefficients is rather low with P-values for LR test ranging from 0.30 to 0.67. These results may lead us to doubt about the relevance of these variables in explaining the probability of crisis. However, as mentioned earlier, the limited sample size in the models, which caused the possible presence of a unit root in several regressors, could affect the precision of the estimators.

MODEL 2 (pooled)
For all countries: Yt = -7.73 + 12.04 WSIt + 3.02 SSIt

Again here, whilst the intercept and WSI coefficient (in both cases p-values of LR tests are smaller than 0.01) have very high statistical significance, the SSI coefficient has less established result displaying a high P-value of 0.36.

MODEL 3 (panel)
For all countries: Yt = -9.82(India) -9.65(Portugal) -8.01(Russia) + 12.60 WSIt + 5.70 SSIt

The coefficients of WSI and SSI did not change substantially, but gained statistical significance (e.g., P-value of the SSI parameters drops to 0.27). Meanwhile, the intercepts (all strongly significant with P-values smaller than 0.02) display a small range of variation.

To summarize the results of the estimation of our three specifications, we can single out a series of stylized facts that appear to be common to all different models.

a. The coefficients of both WSI and SSI are generally of positive sign, which is consistent with the theory that water stress and social susceptibility have direct relationship with the probability of water crisis.

b. While the coefficients of WSI are always strongly significant, those of SSI are rather uncertain. There are reasons however not to totally dismissed the importance of SSI in explaining the occurrence of crisis. First, the data set is rather small so asymptotic results have to considered carefully. Second, the suspicion that unit roots are present in our regressors suggests some flexibility in doing inference based on asymptotic normal distributions. Finally, the correct sign of the coefficients suggests that a larger dataset (either based on longer time series or more countries) could improve the significance of SSI explanatory variable.

c. Even without carrying out a formal test of "poolability", including fixed effects for the intercept of each country does not seem to significantly modify the results.

Figure 3 shows an overlay of the vulnerability pattern on the crisis probability curves (CPCs), which were estimated from Model 1. The grey boxes represent the vulnerability levels in which there were occurrences of a water crisis. These boxes are positioned close to the CPCs, which is theoretically consistent. However, there are also few boxes between the low and high probability curves, which do not show any occurrence crisis. This could be attributed to the omission of important indicators, which could have otherwise increased adaptive capacity, or decrease socio-economic susceptibility. Unfortunately, it was beyond the scope of the study to gather adaptation measures that have been applied in the case study regions to specifically overcome the impacts of water stress. The plotted results of Model 1 (simple) in the Security Diagram show that the CPCs of different countries vary significantly in terms of position and inclination. The CPCs for India and Portugal tend to tilt towards the water stress axis, implying that the level of vulnerability tends to be more sensitive to the changes in water stress level than socio-economic susceptibility. The position of the intercept of the high probability curve (CPCH) is a bit lower for India than in Portugal, which means that, for a given water stress level, the probability of crisis occurring in the former is higher than the latter country. The plot of the CPCs for Russia is very different from India and Portugal. The probability curves are almost equally inclined to both water stress and socio-economic susceptibility, implying that both dependent variables have similar influence on the probability of the occurrence of crisis. The distance between the low probability curve (CPCL) and high probability curve (CPCH) are much wider for Portugal and Russia than for India. The power for predicting the probability of crisis in these two countries is thus relatively weaker. Among others, this could be explained by the fact that the indicators chosen to estimate CPCs, particularly with respect

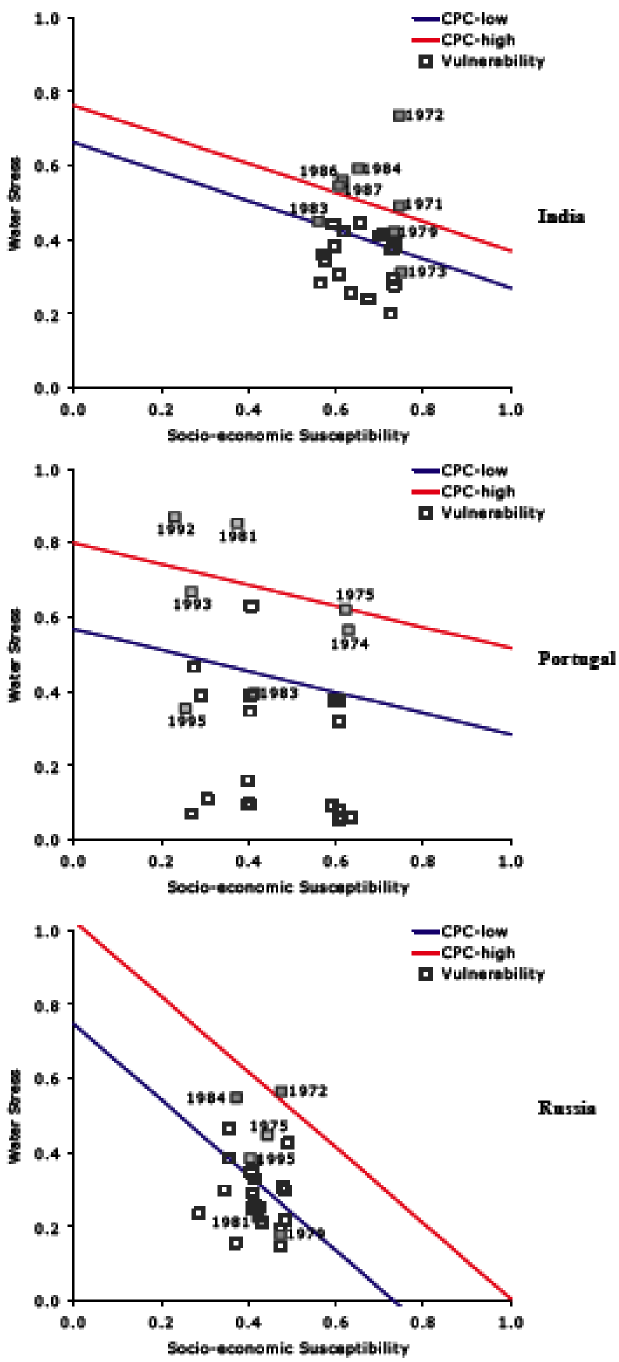

Figure 3. CPCs and vulnerability thresholds for different case studies, 1970-1995.

to socio-economic susceptibility, may be less relevant as determinants of crisis. The results reveal the difficulty of cross-comparison of vulnerability thresholds using the same indicators across countries with different economic development, social structure and institutional system. An indicator that is important in one country may not necessarily be relevant for another. Consequently, adaptation measures for the same type and level of climatic stress will be different for different economic, social and institutional settings.

References

Acosta-Michlik, L., F. Eierdanz, J. Alcamo, R.J.T. Klein, K. Kumar, S. Campe, A. Carius, D. Tänzler and D. Krömker (2006) How vulnerable is India to climatic stress? Measuring vulnerability to drought using the Security Diagram concept. Climate Change and Human Security, DIE ERDE Special Volume on Climate Change, 137(1): 223-252.

Morgan, M. G. and M. Henrion (1990). Uncertainty - a Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. New York, Cambridge University Press.

Park, J. and P. Phillips (2000) Nonstationary Binary Choice, Econometrica, 68 (5): 1249-1280.

Vulnerability and adaptation to climate change of rural people living in the central coastal plain of El Salvador

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The main objective of this paper is to explore more appropriate conceptual frameworks and methodologies to develop integrated assessments of current and future climate vulnerability. The prior to facilitate the inclusion of adaptation into local endogenous development processes, including actions that influence the decision-making process at the national and municipal level.

To assess climate vulnerability of the selected territory[1] (further referred to as territory) a systemic approach was adopted, incorporating the central concept of *adaptive complex system*, and applying it through an inter-disciplinary approach. The territory is considered a human system[2], and as such, it has a dynamic and non-linear behavior and it is able to develop emerging functions (*e.g.*: resilience and adaptive capacity), allowing the system to resist, recover and adapt to change. The territory was identified and characterized through the natural, economic and sociocultural local or inner environments of human populations that live there. Therefore, its boundaries were set based on criteria related to socioeconomic organization and to the prevailing natural dynamics as well. The territory was also considered a social landscape since it includes human systems in which social actors play a fundamental role, considering the inter-linkages between natural and human systems.

Vulnerability of a natural or human system to climate exposure is defined as a dependant variable of three first order-explicative variables, namely: climate exposure, resilience and adaptive capacity. Climate exposure is considered as a local threat. Resilience is the attribute allowing the system to absorb, within a coping range, natural or social shocks and to further recover from disturbances or impacts, conserving the same stability domain[3]. Adaptive capacity refers to the potential of the system to progress and adapt to changes without collapsing, through learning processes that increase its coping range and capacity to self-organization.

Second order-variables are associated to the first order-explicative variables of vulnerability. Climate exposure is addressed through an index, integrating dry and wet climatic extreme events and temperature extremes. Resilience is captured through flexibility (degree), mechanisms of control (type and effectiveness) and structural coupling (type and degree). Adaptive capacity is addressed through three variables, namely: potential of resources (type, availability and accessibility), experimentation and innovation (type and degree) and complexity of organization (type and degree). The integrated assessment incorporates natural and social[4] explicative factors that produce or increase current and future climate vulnerability. The previous facilitates identification and prioritization of adaptation measures and strategies that prevent or minimize impacts related to climate variability and change. The increase of local resilience and adaptive capacity constitutes the basis for the local adaptation strategy.

The methodology to assess climate vulnerability and to develop the adaptation strategy includes the following steps: a) identification of the human system to be assessed and whose adaptation strategy is to be developed, b) integrated assessment of current climate vulnerability, considering baseline socioeconomic and climate scenarios, c) integrated assessment of future climate vulnerability, including local projected socioeconomic dynamics and climate change, and d) development of an adaptation strategy to address the projected local climate change and to be considered and incorporated within the existing local development plans, and eventually at the national or municipal levels.

Participation of local people and organizations in each of these steps was very active, playing an increasingly leading role. Participation included consulting and validation processes, field surveying, information collection and dissemination, education and awareness raising, information and criteria exchange, analysis and prospecting processes. Local knowledge, along with theoretical knowledge, was fully considered in order to: understand local history related to natural and social processes and land use changes; analyze and project economic, sociocultural and natural events and dynamics; and develop strategic planning to face climate change through a local adaptation strategy, as part of an existing development process.

The historical socio-natural dynamics of the territory was preliminary understood to set the appropriate sociocultural, economic and natural criteria to define the territory boundaries. As well, existing coupling and linkages between natural and social dynamics were taken into account. In that regard, geographical areas, where human communities are settled, were selected, taking into account their social network and organization, the dynamics of the local economy and the consolidated local initiatives focused on the promotion of endogenous development[5]. As well, the geographical space of the natural landscape system, referred to as *central coastal plain*[6], was partially considered, and so were those of the four natural landscape sub-systems influencing the natural dynamics of the territory, namely: the two coastal plains *La Libertad-San Vicente* and *Usulután*, and the two volcanic massifs *San Vicente* and *San Miguel-Usulután*. Finally, the seven river basins whose dynamics affect or are somehow linked to the identified human communities, were included, namely: *El Pajarito, El Guayabo, Bajo Lempa, El Espino-Borbollón, El Potrero, Nanachepa y Aguacayo*.

The territory has an area of 1,152.5 km^2 including large extensions of low lands which are up to 2-60 masl along the Pacific coastal fringe. Northward, moderate to high slopes are abundant, presenting elevations from 100 to 1500 masl, near to the volcanic massifs; and 2,100 to 2,300 masl, in the volcanic cones. Some 6,725 rural families are currently living within the territory, which is about 26,900 people, with an average of 4 members per family. A 30-map atlas was developed to support current and future local planning and decision-making process[7], including a zoning of flooding risks areas, in order to illustrate local socio-natural dynamics.

In order to define the socioeconomic and environmental baseline by 2004 and to project it by 2015, a system of variables and indicators, linked to the respective dimensions of the sociocultural, natural and economic inner environments of the territory, was established. The referred system was in turn linked to the appropriate second-order variables of vulnerability, which are associated, to a first-order variable, either resilience or adaptive capacity. A composite vulnerability index (VI) was calculated to estimate the magnitude of current and future climate vulnerability. Climate exposure was integrated to the VI through the calculation of a climatic threat sub-index (CTI), which incorporates five climatic indicators, representing different levels of local threat related to temperature and precipitation extremes (wet and dry events). Among the whole 69-indicator system that characterized current and future territory conditions, 23 refer to the normative, cultural and psychosocial dimensions of the sociocultural environment; 31 are associated to the natural and socio-natural dimensions of the natural environment; and 15 are linked to the productive, distribution-consumption, and commercial dimensions of the economic environment.

The socioeconomic and environmental baseline scenario, by 2004, expresses the territory current state, in terms of strengths and weaknesses contributing to determine the values associated to two of the three explicative variables or sub-indices (resilience and adaptive capacity) of climate vulnerability. The future socioeconomic and environmental scenario expresses the territory projected state by 2015 under climate change conditions; whose associated values could contribute to maintain, increase or decrease current vulnerability level. As well, baseline and future climate scenarios were developed by 2004 and 2015 respectively, to calculate the current and projected values of the five-indicator CTI.

Current and projected conditions of the sociocultural, natural and economic local (inner) environments were determined, through the assignment of current and future values to the 69 indicators and their associated dimensions. Further appropriate regrouping of the indicators, allows calculate current and future values of either resilience or adaptive capacity for each local (inner) environment, and for the whole territory through aggregation.

The three sub-indices, namely: climate exposure (E) , resilience (R) and adaptive capacity (A), were integrated in a unique mathematical expression, to calculate the current and future value of the VI, as follows: $VI = [2E - (R + A) + 2]/4$, with $VI_{max} = 1$ and $VI_{min} = 0$.

Future socioeconomic and environmental scenarios were developed considering the linkages between climatic, socioeconomic and environmental local effects (bottom-up approach) within the general context of national macro-policies (top-down approach). Future scenarios were developed following a four-step process: a) Analysis of current national macro-policies and key indicators (further referred to as driving forces), b) Integrated analysis of the dynamics generated by the national macro-policies and the driving forces projected by 2015, c) Identification of the macro-policies and driving forces local expression, for each dimension and local (inner) environment by 2015, d) Development and local validation of the local socioeconomic scenario by 2015, based on the future values of the 69-indicator system.

In order to develop the local adaptation strategy to face climate change, its nature and scope were defined, including the geographical, temporal and thematic scope. As well, the principles, beneficiaries and the outline of the monitoring and evaluation system were defined. Three specific objectives, linked to the sociocultural, natural and economic local (inner) environments respectively, were identified, to which 8 action lines and 28 adaptation measures were associated and prioritized, based on categorized values of the whole set of indicators by 2015. The strategy was developed by the research team[8] together with local actors and counterparts, who actively participated in identifying, prioritizing, structuring and validating the set of adaptation measures. This process was built on the results of the integrated assessment of current and future vulnerability. Adaptation measures were selected through the identification and prioritization of the main problems associated to the various dimensions for each local (inner) environment. Adaptation action lines and measures were identified with the view to overcome the prioritized problems, which were expressed through the projected values of the 69 indicators by 2015. The adaptation strategy includes a purpose and three specific objectives for the territory. The scope of each adaptation measure includes: specific actions, geographic location and responsibilities for implementation. Some measures are thought to be adopted and executed by rural families and/or their local organizations; others, by the municipal or national public level, in accordance with their legal mandates.

Baseline climate is referred to the 1961-1990 climatology, which is mainly influenced by the Pacific Ocean waters and the meteorological systems associated to the inter-tropical convergence zone (ITCZ), among other atmospheric processes. The territory is one of the most vulnerable areas of the country to climate extreme events, due to the yearly occurrence of droughts and floods. Floods dynamics presents a pattern linked to different factors, such as ITCZ-activity, hurricanes and La Niña event. Local annual mean precipitation is up to 1500 mm close to the coastal fringe, increasing up to 1700 mm northern. During the rainy season, in July and August there are several periods from 5 to 15 consecutive days without rain, which affects local water availability. Maximum mean annual temperatures are

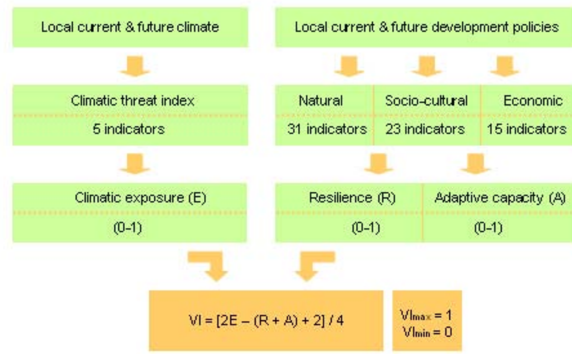

Figure 1: Relational framework to calculate the current/future climatic vulnerability index (VI).

from 31°C, close to the coastal fringe, up to 35-36°C northern along the *Lempa* River banks. Estimated values of linear trends indicate a warming process of approximately 0.04°C per year, which means that the mean annual temperature increased approximately 1.2°C during 1961-1990[9].

Future climate scenarios projected maximum and minimum temperatures and precipitation by 2015, using statistical downscaling techniques, the 1961-1990 and 2006-2035 climate records and the A2 scenario[10]. Climate scenarios generated parameters and criteria used as framework and basis to project by 2020 the 5 indicators of the future CTI, which captures local precipitation and temperature extremes, either for baseline and future climate scenarios. To measure climate impacts by 2015 on productive activities and some environmental processes, mainly hydrologic and hydraulic, future levels of climatic threats were quantified applying some appropriate criteria.

According to the projected future CTI values, the territory would have moderate to high adverse effects on local economy, quality of rural people life, economic infrastructure and natural systems (terrestrial, aquatic and coastal-marine). Current climate impacts would worsen due to the combined effect of the temperature increase and more frequent recurrence of consecutive dry days during the rainy season. Water availability would decrease and therefore there would not be enough water for rural families, crops and livestock, due to the recurrence of extreme dry years which cause increases of evapotranspiration. The frequent recurrence of extreme wet years and floods would increase damages and losses of utilities and equipment; increase sedimentation and damages of existing sewage systems and dams; and damages would be severe on roads, drains, bridges and docks. More frequent fires and plagues would affect forests due to segmentation, and floods would undermine the basement of mangroves which in turn would be deteriorated and reduced. Native and migratory species, mainly birds, would present anomalies in their behavior and development, due to the loss of their habitat. The combined effect of floods and tides would increase sedimentation and erosion of low coastal lands, soils and aquifers. It is worth noting that the future CTI only incorporates indicators related to precipitation and temperature extremes, which would not capture the wide range of climate change-related threats to local human and natural systems (*e.g.*: an eventual sea level rise).

Current and future VI were calculated for each of the 6 geographical areas[11] settled by local organizations within the territory. The future VI would increase in the whole territory by 2015. Both resilience and adaptive capacity would increase their future values, due to existing local processes of autonomous adaptation and projected sustainable development initiatives. However, the value of projected climate exposure (E) would be high enough that it could not be offset by the aggregate increase of resilience (R) and adaptive capacity (A) projected values. Even though the future value of exposure (E) would be the same in the whole territory, the different projected values of the VI within the 6 geographical areas, would be mainly determined by future resilience and adaptive capacity associated to each local (inner) environment.

With regard to future adaptive capacity, by 2015 only the sociocultural local environment would increase its contribution and would contribute the most to improve the adaptive capacity index value (A), in the whole territory. The prior due to local plans directed to consolidate and improve the functioning of the social network and organization. The economic local environment would significantly decrease its contribution to future adaptive capacity due to the lack of relevant public technical assistance, credit, technology transfer and research, and the decline of family incomes. Even though, roads would be improved due to cooperative efforts with municipalities. The natural local environment would hardly contribute to future adaptive capacity, due to the projected increase of environmental deterioration and to the lack of land planning. Such processes would affect the performance of essential environmental functions and of those that support life and human activities[12].

The natural local environment would contribute the less to the future value of the resilience index (R), for the whole territory by 2015, due to the uncontrolled deterioration of the local natural systems. The future economic local environment would significantly contribute to resilience, due to the strengthening of productive organization in some geographical areas, which includes economic and agricultural diversification, improvement of productive efficiency and the adoption of species with a wider coping range to better face climate variations and changes. The sociocultural environment would increase its contribution and would contribute the most to the future value of resilience, in the whole territory by 2015, due to local initiatives promoted by local organizations, which include the strengthening of local capacities and development opportunities; the improvement of local warning systems to face floods; the rescue, dissemination and enrichment of the relevant traditional local knowledge; the appreciation and consolidation of cultural and historical identity; and the broadening of alliances at the national, regional and international level, with other relevant actors dedicated to promote local endogenous development in a sustainable manner.

Even though the levels of climate vulnerability in the whole territory would increase by 2015, they would still remain in an intermediate category, similar to the baseline conditions. The previous due to the fact that projected socioeconomic and environmental scenarios are including local autonomous adaptation. This could explain the relatively high values projected for the resilience and adaptive capacity sub-indices. Would such local efforts not be assumed nor implemented by local actors within their local development initiatives, as they are projected now; the contribution of the three local (inner) environments to the two referred indices would decrease significantly. In that case, under the projected climate change conditions, the future VI would be increasing. Projected values of indicators and associated dimensions and variables, facilitated, for each environment and for the whole territory, the identification of the main weaknesses and strengths whose overcoming or strengthening could contribute to decrease vulnerability associated to future climate change. Adaptation measures included in the proposed local adaptation strategy would be an additional effort to those that already exist or are projected. Such is the case of current autonomous adaptation efforts, incorporated by local actors in their local development planning or initiatives.

The three fundamental principles of the United Nations Framework Convention on Climate Change (UNFCCC) were the basis for developing the local adaptation strategy, which was designed with the view to increase resilience and adaptive capacity of local (inner) sociocultural, natural and economic environments. The previous to prevent, reduce or minimize projected impacts of climate change (as per the *precautionary principle*). As well, adaptation measures were thought to strengthen efforts to improve the quality of life of rural local people (as per the *equity principle*), and to support local efforts directed to take steps to obtain technical and financial support within the UNFCCC multilateral process (as per the *polluter pay principle*). Local rural families would be the beneficiaries of the adaptation strategy and social local organizations would be directly responsible for promoting the strategy and follow up its appropriate implementation. The strategy would contribute to articulate the sociocultural, natural and economic local (inner) environments, setting adaptation measures that strengthen the territory resilience and adaptive capacity, through integrated strategic planning and operative plans and initiatives.

The purpose of the strategy is to strengthen organization and capacities of local rural people to incorporate in their socioeconomic activities adaptation to climate change, within a land planning framework for the territory located in the central coastal plain of El Salvador. The specific objectives of the strategy are: i) to increase the climate change coping range of rural local livelihoods through economic diversification and the adoption of appropriate productive systems, technologies and practices; ii) to strengthen local capacities to incorporate climate change into land management through the improvement of local knowledge on land planning and the setting of criteria and management plans; and iii) to enhance local organization and capacities to influence public policies and priorities at the municipal and national level, through the strengthening, dissemination and appropriate implementation of the relevant legal framework.

The monitoring and evaluation (M&E) system to be set for the implementation of the adaptation strategy would be based on the future follow up of the 69-indicator system, which was established to assess current and future climate vulnerability and adaptation. This would allow local people and other relevant actors, to evaluate the influence or effect of the adopted adaptation measures on the various dimensions that characterize the sociocultural, natural and economic local (inner) environments, and therefore, on the territory vulnerability. The M&E system would identify and incorporate relevant indicators related to impacts, effects, outcomes and progress in order to measure: a) the contribution to decrease vulnerability to climate variability and change (the 69-indicator system); b) the effectiveness of implementing the adaptation strategy, in terms of the timely availability of the various required goods and services; and c) the level of expenditure according to the assigned budget.

Some relevant lessons learned during the 3-year process under the present study are next summarized. The definition and adoption, from the beginning, of a conceptual framework, consistent with the

Table 1. Current (C) and future (F) value of the vulnerability index and its explicative variables, by geographical area.

Geographical area / Variable	West bank of the Lempa River						East bank of the Lempa River					
	Area 1		Area 2		Area 3		Area 4		Area 5		Area 6	
	C	F	C	F	C	F	C	F	C	F	C	F
Resilience	0.586	0.619	0.592	0.611	0.530	0.622	0.465	0.546	0.509	0.626	0.544	0.633
Adaptive capacity	0.514	0.559	0.544	0.579	0.556	0.588	0.554	0.562	0.591	0.584	0.578	0.570
Climate exposure	0.475	0.543	0.475	0.543	0.475	0.543	0.475	0.543	0.475	0.543	0.475	0.543
Vulnerability index	0.463	0.477	0.453	0.474	0.466	0.469	0.483	0.494	0.463	0.469	0.457	0.471

nature of the human systems to be assessed, allowed identify the appropriate criteria to set the geographical boundaries, characterize the territory and address climate vulnerability and adaptation. Since the adopted conceptual framework integrates natural and social processes and identifies the explicative factors of climate vulnerability, it laid the foundations to develop the local adaptation strategy.

The methodological approach developed, was appropriate to national and local circumstances. It facilitated local actors to participate, who play progressively a leading role. The inter-disciplinary approach contributed to enhance national capacities on integrated assessments and strategies, incorporating the inter-actions and couplings between social and natural systems. The rescue and appreciation of the relevant traditional and local knowledge, which has been either orally transmitted or empirically acquired, concerning the history and current trends of natural and social processes; enriched and complemented technical knowledge and proposals, through its appropriate incorporation into the analysis and prospecting processes. Even though the adaptation strategy has been thought as a local process, its scope goes beyond the territory, including some activities directed to influence the public policy-making process, in order to incorporate adaptation to climate change within the development agenda at the national and municipal level.

Endnotes

1 A geographical space, managed under the prevailing economic, social and political dynamics.

2 Human systems are tightly related to human beings and society, having specialized information processes and structures.

3 The system conserves the same structure, functions and control mechanisms.

4 Social refers to economic and sociocultural human activities, including political, technological and scientific issues.

5 Local endogenous development is a process promoting local people to enhance their knowledge and take control of natural and social factors that either determine or impact their territory, and offer opportunities for human development.

6 It is part of the geological landscapes and morpho-structural units of El Salvador. There is no zoning of natural landscapes as per the geo-ecology.

7 A comprehensive database was developed, including the 30-maps related shape files. The database was submitted to local counterparts who were trained in the use of the ArcGis software.

8 It was established under the Regional Adaptation Project named Strengthening capacities for Stage II Adaptation to Climate Change in Central America, México and Cuba, which in the case of El Salvador, was implemented by the Ministry of Environment and Natural Resources (MARN). The referred project was funded by the GEF through the UNDP, from July 2003 to April 2007.

9 Centella, A. et Al, 1998.

10 A2 is a family of emission scenarios, according to the IPCC Special Report on Emissions Scenarios, 2000.

11 The two main social organizations (counterparts to the present study) have established 6 geographical areas in both banks of the Lempa River.

12 They are referred to as goods and services as per the environmental economics.

Evolution of a Climate Risk Management Process in the Pacific: PEAC to PaCIS

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Abstract

Building on work spanning more than a decade, the Pacific Islands have established an integrated climate risk management process that emphasizes actions towards community resilience and adaptation. The process incorporates climate work of the Pacific ENSO Applications Center, the Pacific Regional Integrated Science and Assessment program, regional climate assessments, and the meteorological services. The emergence of the Pacific Climate Information System required using trusted relationships established by resource and disaster management communities, engaging in dialogue with experts from all areas of society on equal grounding, developing a means of communicating technical information, cultural concepts, indigenous knowledge, and societal needs through shared learning processes, and strengthening partnerships across the region irrespective of political boundaries.

1.0 Introduction

With extensive experience in managing disaster risks, the US Pacific Islands have strived to integrate these concepts into the approach for managing climate risks. As knowledge grew about climate variability and change, researchers and government representatives used networks developed in managing coastal resources and natural hazards to initiate a dialogue with the island communities about the potential for integrating climate information into their management activities. The outcome of this dialogue enabled the implementation of a pilot project known as the Pacific ENSO Applications Center (PEAC) to provide climate forecast information to the US-affiliated Pacific Islands (USAPI) in 1994. The successes of PEAC and subsequent climate work engaging the disaster and resource management communities have resulted in an integrated climate risk management process called the Pacific Climate Information System (PaCIS).

Founded on integrated, interdisciplinary methodologies that emphasize dialogue among local experts to inform the development of scientific information and research products, the emerging climate information system addresses a wide spectrum of issues that assess risks to local economies, social vulnerability, culture, infrastructure, agriculture, natural resources, and public health. Developing a dialogue required searching for a common, understandable language that makes climate information accessible within the general public. It further demanded outreach and training that focused on building capacity to understand climate forecast information and use it to make decisions. The approach used impact analysis and risk assessment methods to build an experiential knowledge base for making decisions.

Work with governments and communities in awareness and capacity building has fostered collaboration and partnerships while simultaneously institutionalizing climate risk management in planning and operations. Participation of local agencies, villages, non-governmental organizations, and regional organizations has resulted in the evolution of a climate risk management process as part of sustainable development in island communities.

2.0 Employing Established Networks for Climate Service

Several networks had been established in the US Pacific Islands to address locally relevant, island-specific issues. These included environmental protection, natural resource management, and disaster management sectors. These communities overlapped and involved many of the same people who held relevant agency positions. For example, the coastal zone management community, which was associated primarily with the US National Oceanic and Atmospheric Administration (NOAA), would hold annual Pacific Basin meetings that included the local environmental protection agencies that obtained funding and oversight from the US Environmental Protection Agency (EPA). The local resource management agencies considered natural hazards within their mandated activities and developed initiatives for hazard mitigation. Most of the US federal agencies used annual regional meetings that rotated among the island jurisdictions as opportunities for program development, problem-focused discussions, and training. As climate scientists associated with federal agencies improved climate forecasting models, they used these venues as a forum for discussing potential uses of climate information.

2.1 Establishing the Pacific ENSO Applications Center

In the early 1990s, a dialogue began with these climate-dependent sectors and governments. The information was not forced upon the communities, but rather presented as new climate information that had become available. The workshop participants were then questioned as to how they might use this information, what types of decisions could be made, and what formats would be helpful for presenting information. Using a stakeholder-driven methodology, governments, universities, and the private sector established the Pacific ENSO Applications Center (PEAC) in 1994 as a pilot project. The primary US Pacific Island governments include: American Samoa, the Northern Mariana Islands, Guam, Hawaii, the Federated States of Micronesia, the Republic of Palau, and the Republic of the Marshall Islands.

The governments requested a quarterly newsletter, "Pacific ENSO Update," as the primary product. Initially, it provided rainfall forecasts for each island jurisdiction. The PEAC outreach officer worked with the island governments to format the newsletter and to educate readers about climate information so they could effectively use information for planning. In the beginning years of the effort, the newsletter was faxed to the weather service offices (WSOs) and mailed to several hundred clients in agencies and organizations. As more jurisdictions acquired better internet connectivity, PEAC posted the newsletter on the website. The remoteness of the islands and inconsistency with internet connectivity still warrants information distribution by facsimile and posted mail. In addition, PEAC officers, working with the NOAA Climate Prediction Center, developed a rainfall atlas of 66 stations in the Pacific that served as a tool for understanding local island climatologies. More recently, readers requested sea level forecasts associated with the ENSO signals and these have been incorporated into the newsletter along with tropical cyclone outlooks (PEAC 2007).

2.2 PEAC's Experience with the 1997-1998 ENSO Warm Event

During the 1997-1998 ENSO warm event, PEAC issued the rainfall forecasts more frequently and held teleconferences using the PEACESAT satellite communications network to discuss ways to address impacts. PEAC researchers from the University of Guam Water and Environmental Research Institute conducted briefings with the governments in Micronesia, which resulted in the formation of drought task forces to deal with impacts of climate variability. By constantly maintaining communication with the island communities, PEAC adapted products and information to provide clients with response options.

Because of the severe drought and wildfires experienced with the ENSO warm event in 1997-1998, PEAC researchers worked with the disaster management communities to conduct impact assessments. The first rapid impact assessments occurred in late August 1998 throughout the US Micronesian Islands (Hamnett, Anderson, and Guard 1999). The forecast information and education prepared the US Pacific Islands for dealing with the drought and other impacts. In comparison with the 1982-1983 ENSO event, in which people died from waterborne diseases, there were no lives lost during the 1997-1998 event. Partners, therefore, deemed the forecast and warning efforts of PEAC successful. Other Pacific Islands used the PEAC newsletter and adapted information for responses in their own jurisdictions. Discussions with partners in the disaster management community led to additional impact assessments in Fiji and to a regional workshop with partnering organizations in the Pacific region in 1999.

2.3 PEAC's Network for Regional Collaboration

From the initial PEAC pilot project, an adaptive climate information system became established in the Pacific region. Even though the newsletters intended to serve a limited number of islands that had political affiliation with the United States, many other island nations requested the newsletter in order to extrapolate information. For example, fisheries migrate east during an El Niño bringing fish into the waters of the Marshall Islands and Kiribati, which makes the information useful to Kiribati for planning and budgeting. Other political parameters make little sense geographically, such that information for American Samoa would be close to the information for Samoa. With some geographically-specific modifications, climate information provided by PEAC could be used throughout the Pacific Islands region.

Islands in the Pacific began requesting information similar to the PEAC newsletter with their specific climate information. The National Institute of Water and Atmospheric Research (NIWA) in New Zealand developed a newsletter, "Island Climate Update," for the islands outside of PEAC's mandate, and began publishing it in 2000. To ensure agreement throughout the Pacific Islands region, NIWA convenes a monthly teleconference with PEAC, the Bureau of Meteorology in Australia (BoM), the Fiji Met Service, the Pacific Regional Environment Programme (SPREP), the Pacific Islands Applied Geoscience Commission (SOPAC), and the island meteorological services and government officials interested in participating. The network ensures that there's some agreement and widespread understanding about the meaning of the models. The discussions provide added opportunities to think about the variety of expected impacts.

In addition to the collaboration on seasonal to interannual forecasts and climate variability, the regional partners have developed Pacific regional components of the global observing systems for climate and oceans. The Pacific Islands Applied Geoscience Commission (SOPAC) hosts the Pacific Islands Global Ocean Observing System (PI-GOOS) and the Pacific Regional Environment Programme (SPREP) hosts the Pacific Islands Global Climate Observing System (PI-GCOS). The United States contribution through the Pacific Integrated Ocean Observing System (Pac IOOS) enabled further interaction among this network, using the workshops (discussed in section 3) as a means of assessing research and data needs that contribute to the information in the observing systems. The information has become more fluid as the partners in climate information continue to network.

Inasmuch as these networks have helped to improve climate information, the integration of social science information to deal with changes in climate and to understand issues of vulnerability has emerged through the Pacific Regional Integrated Science and Assessment program (Pacific RISA). The research has focused on extreme climate events with attention to understanding societal impacts and means of building resiliency. The Pacific RISA and PEAC used established networks to conduct a series of workshops in the US Pacific Islands on climate variability and change in 2005 and 2006 (Pacific RISA 2007).

The web of interaction focused on climate variability and change has extended Pacific-wide through collaboration with meteorological services and regional environmental and disaster management organizations to produce similar types of information products in other islands. Climate variability and change have been natural extensions to programmatic missions and work undertaken in the Pacific in the realms of natural resource and disaster risk management. Furthermore, the islands recognize the relationship of climate on all sectors and functions in the Pacific Islands.

3.0 Engaging in Dialogue with Stakeholders as Process

To understand and use climate information for decision making, PEAC focused on public education and capacity building. The process that was being developed depended on local people comprehending the information that scientists and researchers conveyed about climate and then translating that information into action. This could be problematic given that the conventional approaches involved the development of complicated statistical models that were built for larger land masses, such as North America and Europe. Finding appropriate language and terminology that adequately conveyed information, enabled those in the islands to assess their risks, and respected the cultural contexts of each place became challenging.

In addition to PEAC, the development of the Pacific Regional Integrated Science and Assessment program (Pacific RISA) developed to begin filling the role in linking social science, physical science, and practice in climate risk management. Research on the ability of boundary organizations to fill the role in ensuring information flow and knowledge transfer in environmental management suggests that PEAC, Pacific RISA, and ultimately the Pacific Climate Information System may be boundary organizations (Cash 2000). In addition, the researchers and public agencies involved in these climate risk management projects have emphasized the importance of communication and information flow with island communities, or stakeholders, to develop richer knowledge about island climate systems. Stakeholder dialogue involves extensive translation of scientific, cultural, and practitioner knowledge in a shared learning process.

3.1 Developing Comfort with the Language of Climate

The PEAC outreach officer and researchers began the process by employing visualizations in discussions of climate variability with an emphasis on the El Niño-Southern Oscillation (ENSO) cycle. The weather service offices and disaster management organizations had invested in education and awareness about reducing risks from tropical cyclones. By looking at the years for storm tracks, it became clear that cyclones generated further east during ENSO years and many of these storm systems strengthened as they moved through the Micronesia Islands. By beginning the climate discussion with extreme events in which there was familiarity and context, PEAC staff could transition to a discussion about El Niño and further engage island communities in developing an understanding of climate.

Color graphics showing the movement of warm water through the ocean and the dry areas during strong ENSO events helped the islanders understand some of the expected impacts (see PEAC 2007; CPC 2007; PMEL 2007). The rainfall atlas enabled participants to look at precipitation trends in a localized area to see variation in rainfall over time (He et al. 1998). The labels “warm” and “cold” were laid under the timeline to represent approximations for the event, and this demonstrated the temporal variation and precipitation differences among the islands during an ENSO event. Once participants could visualize trends and understand seasonal to interannual variation in climate, they began to relate these experientially to impacts.

Because of the educational process initiated by PEAC about ENSO events, when the El Niño began to occur in 1997 and PEAC staff began briefing officials in the newsletter, local agencies and organizations knew what they could expect and how to inform the public. Each of the island governments formed an ENSO Drought Task Force populated by directors and representatives from agencies and ministries including water resource management, disaster management, agriculture, public health, environmental health, education, meteorological or weather service, fisheries, and community non-governmental organizations. The primary emphasis of these task forces centered on getting information to the public about what they should do as quickly as possible.

The practice of discussing climate through impact analysis of extreme climate events developed a foundation for considering changes in climate. Researchers, meteorologists, and climatologists built on experiences with tropical storms, hurricanes, and typhoons to bridge information with a focus on climate variability and ENSO cycles. The more that the island communities have become familiar with their particular island climates, the better able they have been to use climate forecasts and adapt the information to plan for their specific needs. In using this foundational knowledge, it has been possible to expand the discussions to focus on climate adaptation.

3.2 Bridging Information from the Public Sector to Communities

The ENSO Drought Task Forces developed locally-relevant, culturally-sensitive methods for increasing public awareness about climate variability and ENSO. Even as they worked to reduce vulnerability to drought in their specific sectors, the task forces developed public awareness strategies. Throughout the Pacific Islands region, this message was delivered using a variety of medium and mechanisms.

In the Federated States of Micronesia, one of the most well-known demonstrations of the public awareness campaign involved the posting of a sign about El Niño in a highly trafficked area using both English and Pohnpeian languages (see Figure 1). In addition to the sign, the local radio and television stations issued public service announcements about water conservation in addition to explaining water treatment methods. The task force set up a hotline staffed with volunteers who could explain the concerns of impending drought, provide information on specifications for household water catchment units, and instruct people on water treatment. A member of the task force composed a song about El Niño that was used in the production of service announcements. The song became so popular that the local people called the hotline to find out where to get copies of the song, but reassured volunteers that they already knew how to conserve and treat their water. The hospital records in Pohnpei show a reduction in the incidence gastrointestinal diseases during the drought.

In the other states of the Federated States of Micronesia, where there are numerous remote atoll islands without electricity, the government used the VHF radios to discuss potential water shortages. Preparations were made with the water utility corporation to bring in reverse osmosis units that could be used to distribute water with the field trip cargo ships.

The task force in the Republic of the Marshall Islands went to church meetings and schools to present information on ENSO and the drought. During the worst part of the drought, the island of Majuro---the RMI capitol---had only one hour of water running every fourteen days. Reverse osmosis units had to be flown into the island. Nonetheless, advanced knowledge of the drought helped businesses to advance order bottled water and enabled the government to address concerns faster than they would have without the awareness.

Figure 1.

The task forces worked with local non-governmental and community organizations. In the Republic of Palau, village elders trained the youth on drought coping methods for their local crop resources. NGOs also helped with inexpensive alternatives for watering plants, like using water bottles with small holes for drip irrigation. Many of the communities had memory of coping with drought in previous years. With advanced warning, they were able to marshal traditional techniques and local knowledge for coping with drought.

3.3 Strengthening Knowledge through Participatory Workshops

The most effective method for building awareness and developing climate programs in the Pacific has been the use of participatory workshops. Participatory methods range in technique and have been well developed for use in development and community planning as ways to engage stakeholders in sharing knowledge (Chambers 1994; Axinn and Pearce 2006). Because of the vast distances among islands, the workshops have been developed as ways to engage the island communities, local practitioners, government and village leaders, regional organizations, private sector, and climate scientists. These workshops serve as forums for discussion, tools for assessing needs and risks, and arenas for training. Due to the vast distances between the islands, even within the same nation, the workshop format provides unique opportunities to interact professionally and personally. The design of the agendas incorporates a blend of formal presentations and group discussions, as well as time for informal interaction at coffee breaks, lunches, or receptions, because sharing food is culturally important in this region. The space to establish relationships that strengthen programmatic efforts and initiates collaboration often emerges from these workshops.

3.3.1 Pacific Regional Drought Impact Assessment Workshop

Following the drought associated with the 1997-98 ENSO warm event, PEAC worked with SOPAC and the Fiji Meteorological Service to convene a Pacific Islands regional workshop to assess impacts and determine mitigation strategies for future events. Workshop organizers invited water resource managers and hydrologists, disaster managers, and climatologists to participate in the workshop.

The first phase of the workshop involved conducting impact assessments. It was clear that there was extensive variation among the islands in terms of impacts and experiences. One participant from the Federated States of Micronesia noted that even though they had used the forecasts to prepare for the drought and they had fared better than the 1982-83 ENSO event, people still suffered severely (SOPAC 1999). The objectives emerging from the workshop were to address the gaps witnessed during the event and improve resource management to eliminate future suffering and hardship.

The second part of the workshop focused on building communications skills among the three communities to strengthen their interactions in the future. The meteorologists and climatologists worked as a group to understand and develop climate forecasts. They presented these forecasts to the water resource and disaster managers, who then discussed the information and tried to determine what actions they would take. The exercise helped to determine the relationship between the chronology of the ENSO cycle and the synchronization with the decision making timeline. In addition, the exercise improved the comfort of the participants in using climate forecasts.

The concept of improving communication about climate information through facilitated simulations became incorporated into the Pacific Climate Training Institute designed by Eileen Shea. Through several years of revision (2001, 2004, 2005, and 2006), "The Rains of Tomorrow," a simulation exercise, was developed in collaboration with training institute organizers and has become an effective tool in building confidence among participants to engage in climate risk management.

3.3.2 Pacific Islands Regional Assessment of the Consequences of Climate Variability and Change

In 2001, a report was published on the potential consequences of climate variability and change in the Pacific Islands, which detailed the types of consequences in specific primary sectors of island society. The organizers framed the workshop in the context of understanding vulnerability to the impacts of climate variability and change (Shea et al. 2001).

In addition to using participatory methods to shape the workshop, the organizers incorporated indigenous and other alternative research methods that validate knowledge from multiple varying perspectives to develop a shared learning process (Haraway 1988; Smith 1999). The workshop opened with a cultural view of climate as a local kumuhula---practitioner and instructor of hula---chanted and performed in Hawaiian with translations into English (Ka'imikaua and Minton 2000). He shared stories of the ways in which Hawaiians could forecast drought when they saw a particular species of seaweed come ashore. With development and coastal changes, the seaweed no longer appears. The climatologist followed with a presentation about ENSO and climate variability. Yet, when he paused to acknowledge that they might be able to use the oral histories to determine changes related to El Niño events, he opened the dialogue throughout the workshop between scientists and practitioners in various sectors.

Participants included representatives from resource management, the private sector, disaster management, climate science, and community organizations. The workshop framed the discussion within the following sectors:

- Providing Access to Fresh Water
- Protecting Public Health
- Ensuring Public Safety & Protecting Community Infrastructure(extreme events)
- Sustaining Tourism
- Sustaining Agriculture
- Promoting Wise Use of Coastal & Marine Resources

All of the working groups determined that water was critical for their functions. The strategies developed by each working group for considering near-term mitigation and long-term adaptation to changes in climate involved protection of the water system.

Workshop participants improved their understanding about regional vulnerability to changes in climate, yet they realized that variation throughout the Pacific demanded more detailed, localized attention to address these issues. One of the recommendations resulting from the workshop was to engage in similar assessments in each United States Pacific Island jurisdiction. Actions needed to be taken at the community level to build resilience.

Even though the workshop documents were published in 2001, they are referenced extensively and still have relevance. The climate models have improved since then and there are efforts underway to downscale the information for use in islands. Nonetheless, the design of the discussions, sectoral applications, and recommendations continue to support ongoing climate work in the Pacific.

3.3.3 Climate Variability and Change Workshops in the US Pacific Islands

As part of the Pacific RISA and other climate-related initiatives, a series of six workshops at the national or territorial level were undertaken in the US Pacific Islands to refine this stakeholder-driven methodology that promotes community resiliency and climate adaptation. The workshops enabled the islands to think about impacts particular to their islands and develop local strategies to deal with changes in climate (Pacific RISA 2007).

The first day of the workshop focused on understanding impacts from climate variability. Participants discussed the effects from the ENSO events and considered ways to address the problems through mitigation actions. As participants became accustomed to discussing climate variability and using forecast information, they realized the importance of considering longer term climate changes where more frequent extremes in variability might occur.

The second day of the workshop reviewed the third report of the Intergovernmental Panel on Climate Change and considered climate change and adaptation strategies. Many of the participants expressed concerns with coastal inundation and erosion that have significantly altered their shorelines, but did not know whether this was the result of climate change and sea level rise or might be attributed to other factors. The participants discussed some of the climate adaptation pilot projects that SPREP has initiated. The adaptation strategies work from the top-down with support from the government and from the bottom-up with actions taking place in local communities.

As a result of the workshops, each jurisdiction formed a task force or working group to look at climate change adaptation strategies from a local perspective. The workshops provided an additional forum to sustain the established relationships within the climate community. Participants highlighted data gaps and research needs for improving management. The workshops served to maintain connections and develop climate adaptation projects using trusted networks (Anderson and Shea 2006).

4.0 Establishing the Pacific Climate Information System (PaCIS)

Ultimately, these methods and programs in climate risk management have merged into the Pacific Climate Information System (PaCIS). Three working groups have been formed in areas of operational product development, research and assessment, and public education and awareness. The Steering Committee and working groups encourage widespread participation and collaboration across sectors at multiple levels that bridge regional organizations, user communities, local knowledge, cultural context, and partners in a system geared towards the integration of climate information into all sectors and decision making processes.

The guiding framework builds on linking information and knowledge, as shown in Figure 2. Climate information will be mainstreamed across sectors though networking and information sharing that respects cultural and local knowledge. PaCIS builds on established participatory methods to engage stakeholders in continued dialogue as part of an ongoing risk management process.

PaCIS builds on established networks and streamline the work on climate. PEAC and Pacific RISA become integral parts of the overall climate information system. The focus during the first few years will be to downscale information and products to improve knowledge about climate. The ultimate goal of the risk management process is to build resilient communities in the Pacific that can adapt to changes in climate.

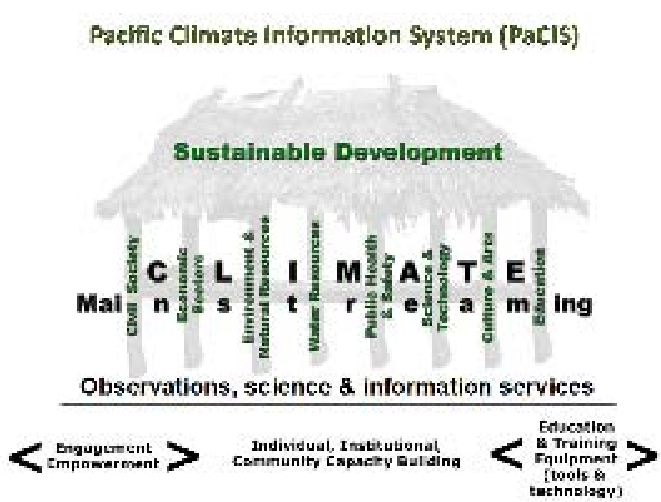

Figure 2.

References

Anderson, C.L. and E.L. Shea. 2006. Executive Summary for the U.S. Pacific Island Workshops on Climate Variability and Change. Pacific Regional Integrated Science and Assessment (Pacific RISA). Honolulu: East-West Center. Supported by NOAA Climate Program Office, http://research.eastwestcenter.org/climate/risa/, accessed August 23, 2007.

Axinn, W.G. and L.D. Pearce. 2006. Mixed Method Data Collection Strategies. Cambridge: Cambridge University Press.

Cash, David W. 2000. "'In Order to Aid in Diffusing Useful and Practical Information…': Cross-scale Boundary Organizations and Agricultural Extension." Belfer Center for Science and International Affairs (BCSIA) Discussion Paper 2000-10, Environment and Natural Resources Program, Kennedy School of Government, Harvard University. Available at http://environment.harvard.edu/gea, accessed August 22, 2007.

Chambers, R. 1994. "The Origins and Practice of Participatory Rural Appraisal." World Development 22(7): 953-969.

Climate Prediction Center (CPC), National Weather Service, National Oceanic and Atmospheric Administration. 2007, access. El Niño-Southern Oscillation, http://www.cpc.noaa.gov/products/precip/CWlink/MJO/enso.shtml, accessed August 23, 2007.

Hamnett, M.P., C.L. Anderson, and C.P. Guard. 1999. "The Pacific ENSO Applications Center and the 1997-98 ENSO Warm Event in the US-Affiliated Micronesian Islands: Minimizing Impacts through Rainfall Forecasts and Hazard Mitigation." Honolulu: PEAC.

Haraway, Donna. 1988. "Situated Knowledge: The Science Question in Feminism and the Privilege of Partial Perspective," in Feminist Studies, 14 (Fall 1988): 575-599.

He, Y, A.G Barnston, and A.C. Hilton. 1998, February. A Precipitation Climatology for Stations in the Tropical Pacific Basin: Effects of ENSO. US Department of Commerce, NCEP/Climate Prediction Center Atlas No. 5. Camp Springs, Maryland and Honolulu, Hawaii: Climate Prediction Center, National Centers for Environmental Prediction and the Pacific ENSO Applications Center.

Ka'imikaua, J, and N. Minton. 2000. A Mau a Mau: To Continue Forever. Video Format. Honolulu: Nalani Minton, Robert Oshita, Alphamedia, and Nā Maka o Ka 'Aina.

NIWA Science. October 2000 – Present. Island Climate Update. National Institute of Water and Atmospheric Research National Climate Centre. http://www.niwascience.co.nz/ncc/icu.

Pacific ENSO Applications Center (PEAC). 2007, access. The Pacific ENSO Update. http://www.soest.hawaii.edu/MET/Enso/peu/update.html. January 1995 – Present. Hosted by the University of Hawaii School of Ocean, Earth Science, and Technology Department of Meteorology.

Pacific Islands Global Climate Observing System (PI GCOS). 2007, access. Hosted by the Pacific Regional Environment Programme (SPREP), http://www.sprep.org/vacancies/PacificIslands-GlobalClimateObservingSystem.htm.

Pacific Islands Global Ocean Observing System (PI GOOS). 2007, access. Hosted by the Pacific Islands Applied Geoscience Commission (SOPAC), http://www.sopac.org/tiki/tiki-index.php?page=Pacific+Island+Global+Ocean+Observing+System+PI-GOOS.

Pacific Marine Environmental Laboratory (PMEL), National Oceanic and Atmospheric Administration. 2007, access. TAO Project. http://www.pmel.noaa.gov/tao/proj_over/ensodefs.html.

Pacific Regional Integrated Science and Assessment (Pacific RISA). 2007, access. Honolulu: East-West Center. Supported by NOAA Climate Program Office, http://research.eastwestcenter.org/climate/risa/.

South Pacific Applied Geoscience Commission (now Pacific Islands Applied Geoscience Commission) (SOPAC). 1999, November. ENSO Impact on Water Resources in the Pacific Region Workshop Report. Nadi, Fiji: SOPAC Miscellaneous Report 336. Supported by the British High Commissioner and the U.S. NOAA Office of Global Programs.

Shea, E.L., G. Dolcemascolo, C.L. Anderson, A.G. Barnston, C.P. Guard, M.P. Hamnett, S.T. Kubota, N.D. Lewis, J. Loschnigg, and G. Meehl. 2001. Preparing for a Changing Climate: National Consequences to Climate Variability and Change (Pacific Islands Assessment). Honolulu: East-West Center. http://www.eastwestcenter.org/res-rp-publicationdetails.asp?pub_ID=1298, accessed August 23, 2007.

Smith, Linda Tuhiwai. 1999. Decolonizing Methodologies: Research and Indigenous Peoples. London and New York: Zed Books, Ltd.

Scenario modeling, economic evaluation and public participation in the context of a river basin twinning project: case study experiences from the Biobío Basin, Chile

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Abstract

In the context of a river basin twinning project, hydrological impacts of change scenarios were modeled and combined with a multi-stakeholder vulnerability assessment for a case study from the Biobío Basin, Chile. Model skill was tested and its potential for use in impact studies was evaluated. Regionalized output from 7 General Circulation Models under 6 different emission scenarios was used to generate an envelope of plausible future rainfall conditions. A preliminary analysis was conducted on the potential effects of using coarse-scale regionalized versus downscaled change scenarios, based on currently available output for the study area from a Regional Climate Model run. Future land use scenarios were developed using expert judgment and logistic regression analysis, and an attempt was made to incorporate climate change projections into the scenario development. Modeling of land use & climate scenarios was performed. Results allow extending the methodology for economic impact assessment of the new Biobío Water Quality Standard to potential future conditions of river discharge. Based on the previous analyses, a first assessment of vulnerability was made in the context of a public participation process. Lessons learned are described. Methodological flowcharts are provided as a reference for future work.

1. Introduction

1.1. TWINBAS

The TWINBAS project (European 6th Framework Programme, EC FP6) aims at filling distinct knowledge gaps that currently hamper the implementation of enhanced, basin-level sustainable Integrated Water Resources Management (IWRM) in a series of twinned river basins. It uses a harmonized framework for conducting research (Fig. 1), which is inspired on the process for the implementation of the European Water Framework Directive (WFD; 2000/60/EC).

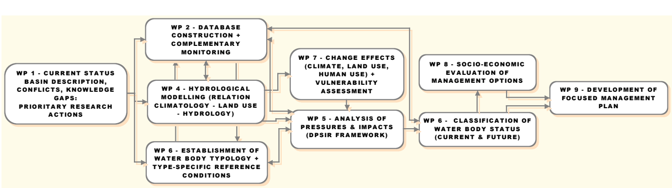


Figure 1. TWINBAS framework for conducting IWRM research; the framework is to be backboned by a public participation process.

The present manuscript details on an approach for scenario modeling and impact assessment, which has been developed under TWINBAS for the Biobío Basin, Chile, and which is proposed as a reference for further implementation, extension and/or modification in other river basins from around the world.

1.2. Case Study from the Biobío Basin: description of the study area

The Biobío Basin (24.371 km^2) is located in a climatic transition zone (*Mediterranean to Temperate Humid*) between 36°45’ - 38°49’ S and 71º00’ - 73º20’ W. It stretches from the continental divide in the east (Chilean-Argentinean border) to the Pacific Ocean in the west (Fig. 2) and comprises three main geomorphologic units: the *Andes*, Central Valley and Coastal Mountain Range. Over the past decades, important land use conversions have taken place, transforming the Biobío Basin -with ~1.000.000 ha of plantations- into the centre of exotic species forestry in Chile. Agricultural activities remain important in many parts of the Central Valley.

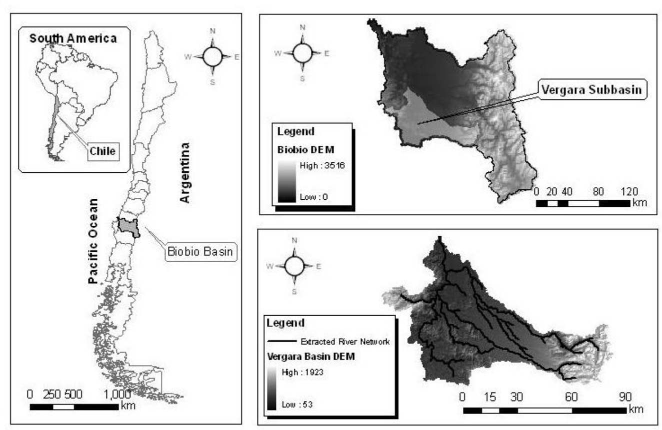


Figure 2. Location of the Biobio Basin and of the Vergara Subbasin, Chile.

1.3. Water resources and society in the Biobío Basin

Pronounced seasonality of rainfall in the Biobío Basin leads to substantial increases in runoff during winter and spring and reduced river flows during the Austral Summer (particularly March). As water resources from the Biobío Basin are of high strategic importance for Chilean economical & social development, a better understanding of regional hydrological processes and their (inter-)annual variability is urgently required: in 2005, the basin provided on average 30% of all electricity of the Chilean Inter-Connected System SIC, which covers the energetic demand of 43% of the Chilean Territory and 93% of the total population. Downstream of the hydropower plants, irrigation practices are widespread. The river network further serves as a receiving body for urban and industrial wastewaters, while near the river mouth, the city of Concepción depends almost completely on the Biobío River for its drinking water.

Development in the basin is fast and ongoing: a considerable expansion of the forestry industry is foreseen, and further hydropower development is being planned. But development will also need to consider increasing environmental consciousness of Chilean society, with recent advances in Chilean environmental legislation such as the Secondary Standard for (in-river) Water Quality about to become implemented. In addition, in the 2005 Reform of the Chilean Water Code, the concept of ecological discharge rates was explicitly introduced. Although limited in scope, this is recognition to the fact that a balanced use of basin water resources is essential for maintaining the ecosystem functioning of the river network. A major challenge for water management in the Biobío Basin will thus be to find equilibrium between ecosystem and societal needs, in a context of increasing environmental change.

2. Methodology

2.1. Generic approach

The generic framework for the [scenario modeling, economic analysis and public participation] approach is described below, and illustrated trough a series of flow charts.

Figure 3 provides details on the hydrological modeling process used for the scenario impact assessment. The selection of the hydrological modeling tool is based on both available data for the study area, as well as on the model's capacity for addressing local stakeholder needs. A model application for the case study site is then built. In cases were important land use conversions have been taken place in the past, the application is built (at least) twice: once for current land use, and once for historic land use conditions. The model is then subjected to a calibration and double validation process. Model capacity for impact assessment with respect to land use and climate changes is analyzed.

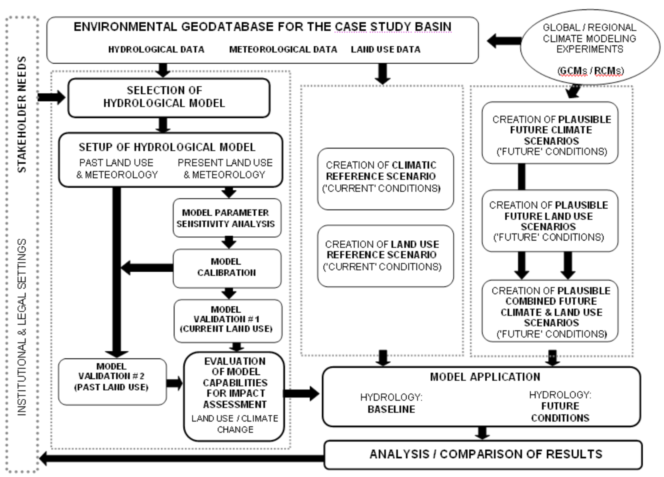


Figure 3. Generic framework used for the hydrological modeling approach..

Reference scenarios for both climatology and land use are then generated. The climatic reference may consist of observed data, or be based on the outcome from a model or stochastic weather generator. Plausible future climate scenarios need then to be constructed; different methods can be used for this purpose: e.g. change factor method, statistical downscaling, (results from) dynamical downscaling, etc. Future land use scenarios can be randomly generated, for sensitivity analyses, or can be based on e.g. expert judgment or logistic regression. Results from both reference and future scenario modeling can then be analyzed and compared, and feedback provided to the local or national water resources stakeholder community. In this last step, care should be taken in adequately informing about the limitations of the approaches used, as to allow stakeholders to better evaluate the value & meaning of the presented results.

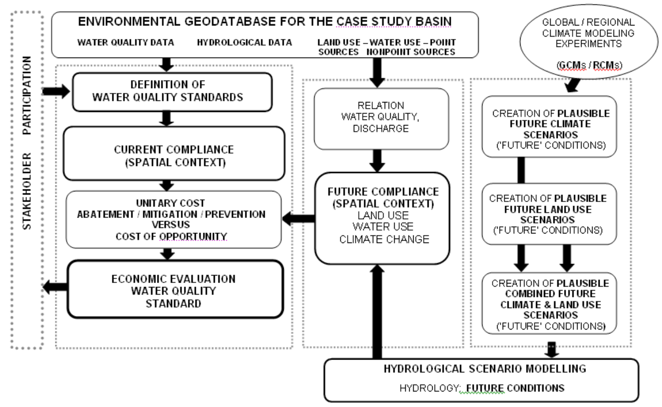


Figure 4. Generic framework used for the economical assessment approach.

Figure 4 shows by means of the example of a new water quality standard how the economic impact of the implementation of environmental laws can be assessed, and how this economic impact can be affected by climate change.

Figure 5 finally shows how the results from both previous efforts can be used as input for a preliminary assessment of the vulnerability of different sectors of water users in the Basin. First, the results from scenario generation and hydrological impact modeling are used for evaluating the 'exposure' component of vulnerability. The second component, the 'sensitivity' of the different stakeholders or sectors, then needs to be determined. This can be done through a basic (e.g., qualitative or semi-quantitative) approach, by asking stakeholders how they perceive the 'sensitivity' of their sector to changes in 'exposure' (availability & quality of water resources). Alternatively, additional information can be provided from e.g. the evaluation of the economic impacts of these changed hydrological conditions, in order to assist the stakeholders in the sensitivity assessment process. Finally, the third component can again be assessed using the simplified approach (qualitative or semi-quantitative questionnaires). Other more advanced approaches, based on additional (modeling) results, have not yet been developed for the case study basin, but might be applied by other future users of the framework.

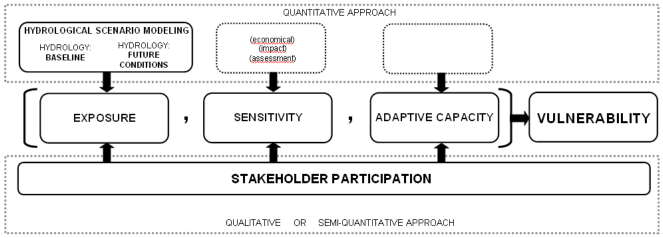


Figure 5. Generic framework used for the vulnerability assessment approach.

2.2. Hydrological model development

A hydrological model application was developed for the Vergara Basin (4.000 km^2), a subbasin of Biobío located in the Central Valley, with headwaters in the Andean foothills (Fig. 2). The basin has been characterized by important land use conversions from agriculture to forestry over the past decades. Vergara was selected for the model application because of the following factors: *(i)* important, major sub-basin; *(ii)* relatively good coverage with meteorological & hydrological data, needed for model calibration & validation; *(iii)* absence of major modifications to the natural flow regime, allowing for a simpler modeling approach; *(iv)* the important land use conversions cited above; *(v)* important water uses downstream of the modeled outlet.

For modeling purposes, the Soil and Water Assessment Tool (SWAT, Arnold *et al*., 1998; Di Luzio *et al*., 2002; Neitsch *et al*., 2005[a]; Neitsch *et al*., 2005[b]) was chosen, as minimum input requirements for SWAT correspond well with the typically restricted data availability in many parts of the world, including Chile (i.e. daily temperature and precipitation time series only). Model skill for adequately representing monthly discharge time series for the Vergara Basin was tested near the outlet and at 3/4 internal control points, through a calibration and double validation process. Data from multiple time windows within the period 1977-2002 were used in order to assess the capability of the model to adequately reproduce basin hydrology under different conditions of land use. Prior to the calibration exercise, a sensitivity analysis was executed in order to select the 8 most relevant calibration parameters.

Sensitivity of the model to land use changes was tested, in order to evaluate the models' potential for assessing impacts of land use changes on mean monthly river discharge.

2.3. Scenario development

For the assessment of the potential impacts on river discharge of plausible future scenarios of climate and land use, the following methodology was applied:

2.3.1. Climate change scenarios

To date, a major number of impact studies have used information provided by GCM simulations without any further regionalization processing. This is primarily because of the readily availability of this information and the relatively recent development of regionalization techniques (Mata and Nobre, 2006). The most straightforward means of obtaining higher spatial resolution scenarios is indeed to apply coarse-scale climate change projections to a high resolution observed climate baseline – *the change factor method* (e.g. Arnell, 2003[a,b]; Arnell and Reynard, 1996; Diaz-Nieto and Wilby, 2004). This method is often used when RCM output are unavailable, for sensitivity studies, or whenever rapid assessments of multiple climate change scenarios (and/or GCM experiments) are required (Wilby *et al*., 2004). However, at the local scale, climate changes may be different from the regional results obtained from GCMs: for fine-scale regional assessments, the climate change impacts community has long been dissatisfied with the inadequate spatial scale of scenarios produced from GCMs (e.g. Mearns *et al*., 2001). Even so, the importance of high resolution climate scenarios for impacts and adaptation studies remains to be thoroughly explored in South America (Marengo and Ambrizzi, 2006). Contributions in this sense can be expected over the coming years, as results from the first RCM runs for South-America are gradually becoming available (Marengo and Ambrizzi, 2006; Nuñez *et al*., 2006; DGF-CONAMA, 2007). Some of the limitations of these RCM applications, however, are: *(i)* they are typically based on just one of the many available GCMs; *(ii)* a limited number of emission scenarios is being considered (typically A2 and B2); *(iii)* projections are typically produced for the end of the XXI^{th} Century; however stakeholders may be more interested in what is to be expected 'in the short(er) term', i.e. over the next decades.

A double approach, based on the application of the *change factor method* (with change factors derived from multiple GCMs and emission scenarios), together with a more detailed modeling exercise based on the outcome from the Regional Models (RCMs), may combine the advantages from both methods and, through a careful interpretation of the obtained results, many of their respective disadvantages may be attenuated.

In the present case study, regionalized output from the simulation of results for 7 GCMs/6 SRES marker scenarios (IPCC, 2000) was obtained from the combined climate model and regionalization tool MAGICC/SCENGEN 4.1. (Wigley and Raper, 1997; Wigley, 2003). The used output consisted of change signals for annual mean precipitation and temperature, for time windows centered around 2050 and 2085. Weather generator time series based on observational reference data for the area (Meza *et al*., unpublished) were perturbed using this output (*change factor method*), generating new "stochastic" time series which could then in turn be used as input for the hydrological model. At this stage, preference was given to using a rather simple 'scaling' approach rather than on using more advanced and well-known downscaling techniques. This decision was based on the consideration that for an initial screening, the wider range of uncertainty associated with the different GCM models currently in use, should be assessed through the conduction of a sensitivity analysis of hydrological model output (mean monthly discharges) to a wide range of moderately plausible future climatic conditions over the Basin.

Time series from one of the first RCM applications for Southern South America (DGF-CONAMA, 2006) have also recently been obtained, and the impact of using coarse-scale (*change factor method*) versus downscaled climate change scenarios on hydrological model outcome is currently being analyzed. Preliminary available results relate to differences in total precipitation input into the basin water balance; these are documented in the present work.

2.3.2. Land use scenarios

Plausible future land use scenarios for input in the hydrological model were developed using expert judgment and logistic regression analysis. For the logistic regression approach (for a methodological description see e.g.: Pontius and Schneider, 2001), transition probabilities between specific land use types were established based on a historic (1979) and 'present-day' (2000) land use map for the study area, both derived from Landsat satellite imagery (transition matrix). Land use transitions observed between 1979 and 2000 mainly consisted of conversions to forestry plantations (from 0% in 1979 to > 40% by 2000). Results from the logistic regression approach are given further below.

2.3.3. Combined change scenarios

A first attempt was made at bringing plausible future climatic conditions into the logistic regression model for simulating future land use scenarios. At present, only predicted changes in minimum temperature have been taken into account, as these are known to constitute the main limiting climatic factors in the Biobío Basin for further extension of forestry plantations up into the Andes. Plausible ranges for future shifts in minimum temperature derived from MAGICC-SCENGEN were combined with a digital elevation model and locally established temperature lapse rates ($\Delta T/\Delta Z$), in order to generate a climate-change influenced plausible future land use map for the basin.

2.4. Scenario modeling

The calibrated & validated version of the hydrological model was run using the different perturbed stochastic precipitation time series generated under the step indicated before (the model was also run using the original, non-perturbed stochastic time series). Outcome from this process was used to calculate the effects of the different regionalized change scenarios on monthly discharge rates for return periods ranging from 1-30 years, as compared to the baseline scenario. In addition, scenarios for future total mean annual precipitation input into the Basin's water balance derived from output from both MAGICC-SCENGEN and an RCM were compared.

2.5. Economic analysis

Model results can now be coupled to the evaluation of the economic impact of recent or forthcoming developments in the Chilean legal framework. In the context of the TWINBAS project, the methodology for the evaluation of the economic impact of the Secondary Water Quality Standard for Biobío was extended to potential future conditions of river discharge (focus on impacts from climate change).

The Secondary Water Quality Standard for the Biobío Basin (to be implemented during 2007) establishes water quality criteria for a set of 28 parameters. Criteria are differentially set for the 25 different 'control' river reaches included in the Standard. The differential criteria themselves are based on a combination of *(i)* historical conditions of water quality in the reach; *(ii)* types of water uses for the reach; and *(iii)* input from a stakeholder consultation process. Criteria established under this Standard should be met by the 'current conditions' of water quality in the river network. From a legal perspective, 'current conditions' for a given parameter are established as the percentile 66 value of observational data obtained over a 2-year period, ranging from the moment of evaluation back into the past. Reach conditions that do not meet the criteria from the Standard lead to the declaration of a 'Saturated Zone' (parameter-dependent). Parameter conditions that approach a criterion up to a range of 20% of its actual value (i.e., on the compliance side) give rise to the declaration of a 'Latent Zone'. Under the Standard's implementation, and as a function of the former, remediation measures can or need to be defined.

In the "General Analysis of the Socio-Economic Impact of the Secondary Water Quality Standard for the Biobío Basin" (*Análisis General del Impacto Socio-económico de la Norma Secundaria de Calidad de Aguas en la Cuenca del Río Biobío;* EULA, 2006), current conditions of 'saturation' or 'latency' for the different [parameter, reach] combinations were identified. Existing water quality data from past monitoring programs were analyzed from a geographical and historical perspective, and then related to the corresponding locally observed river discharge. At present, a simple regression approach has been applied for establishing empirical relationships between contaminant levels and river flows, at 3 different reference sites along the river network.

From the established relationships between quality and discharge, elasticity functions of parameter concentrations versus river discharge could be determined. Distance between currently observed concentrations and the critical concentration from the Standard for the corresponding water quality parameter then allowed to predict the amount of percentual change in discharge that would be required (all other conditions remaining the same) in order to cause a shift in water quality status (e.g. 'compliance' status to 'latency' or 'saturation', or vice versa). The range of simulated changes in mean annual or monthly discharge rates from the climatic sensitivity analysis of the hydrological model (based on the output from MAGICC-SCENGEN) can then be used to determine direction and (range of) magnitude(s) of possible shifts in water quality. Outcome from this process can then be combined with a cost analysis of mitigation schedules and/or abatement technologies, in order to make an economic assessment of the net gain/loss caused by shifts in water quality status due to changed conditions of water availability under climate change. At this point, available results mainly relate to the methodological development, whereas specific outcome on the quantification of the economic impact itself is expected to become available in the near future.

2.6. Vulnerability assessment

Results from the previous analyses served as input for a set of preliminary evaluation rounds on the vulnerability and adaptive capacity of human society (and ecosystems) in and around the river basin. This preliminary exercise was conducted in the context of the TWINBAS public participation process. After an introduction on the basic concepts related to vulnerability and (mainly) climate change (incl. the concepts of exposure, sensitivity and adaptive capacity), stakeholder groups were asked to self-evaluate their sensitivity and capacity for adapting to changed conditions of water resources availability & quality, as well as to emit an opinion on strengths and weaknesses of different aspects of Chilean society considered determinant for adaptive capacity (sectoral analysis). This basic vulnerability assessment exercise was first applied prior to the dissemination of results from the previously illustrated modeling work. Stakeholders were then introduced into the results from this and other climate-change related research activities in Chile (e.g. general conclusions from the first national RCM runs; DGF-CONAMA, 2006), and the evaluation procedure was repeated. This approach allows for an assessment on how results from national and case-study specific research influence the perception of stakeholders with respect to their vulnerability to climate change. As such, it also contributes to the awareness building process around the need for an adaptive approach towards Integrated Water Resources Management, in a context of changing environmental conditions.

Table 1. Matrix for the evaluation of the impact of determinant on the adaptive capacity of different sectors of Society.

INQUIRY: EVALUATION OF ADAPTIVE CAPACITY												
	human society											
determinant ↓ sector →	IRRIGATION AGRICULTURE	NON-IRRIGATED AGRICULTURE	AGROINDUSTRIES	SANITARY SERVICES (DRINKING WATER)	SANITARY SERVICES (URBAN WASTE WATER)	SILVICULTURE	INDUSTRIAL SECTOR (PULP & PAPER MILLS)	INDUSTRIAL SECTOR (OTHERS)	ENERGETIC SECTOR (HYDROPOWER)	TOURISM	CIVIL SOCIETY	CONSERVATION - aquatic ecosystems/biodiversity
AVAILABILITY OF TECHNOLOGY												
COSTS OF TECHNOLOGY												
MARKET ALTERNATIVES												
INFRASTRUCTURE												
INSTITUTIONAL SETTINGS												
LEGAL SETTINGS												
AVAILABLE INFORMATION / KNOWLEDGE												
TRAINED PERSONNEL												
SOCIAL CONDITIONS / INEQUALITY / DISTR OF INCOME												
POLITICAL WILLNESS												
fill cell with score between 0 and 5												

The vulnerability assessment itself was based on input obtained from the stakeholders by means of the application of an n x m matrix. Columns in the matrix corresponded to the n main stakeholder groups ('sectors') identified for the Basin. Through the rows, the assumed adaptive capacity of each group, or individual belonging to the group, with respect to m specific societal aspects or determinants could be evaluated. The configuration of the matrix used in this process is given in Table 1. It is inspired on previous work by Mata (personal communication, 2005).

Each participant was asked to identify one or several columns corresponding to the stakeholder group(s) he/she represents. Subsequently, the participant was then asked to evaluate adaptive capacity in a semi-quantitative way, by assigning a value between 0 – 5 to the corresponding cell (1 meaning low, and 5 high adaptive capacity; with 0 representing the option of 'no adaptive capacity at all'). Mean, minimum and maximum scores, as well as standard deviation, were calculated for each determinant. The method gives both a global overview of the differential vulnerability of each sector (e.g. as evaluated by the members of the sector themselves), as well as of the societal determinants that most contribute to this perceived vulnerability.

3. Case study results

3.1. Results from the hydrological model application: calibration & validation phase

Model performance over the calibration period ranges from 'very good' to 'acceptable', based on the criteria given by Abu El-Nasr *et al*. (2005). General model performance remains good over the validation periods for both 'current' and historic land use (Stehr *et al*., in review), as can be seen from Table 2. Results from the calibration and first validation period are also shown in Figure 6.

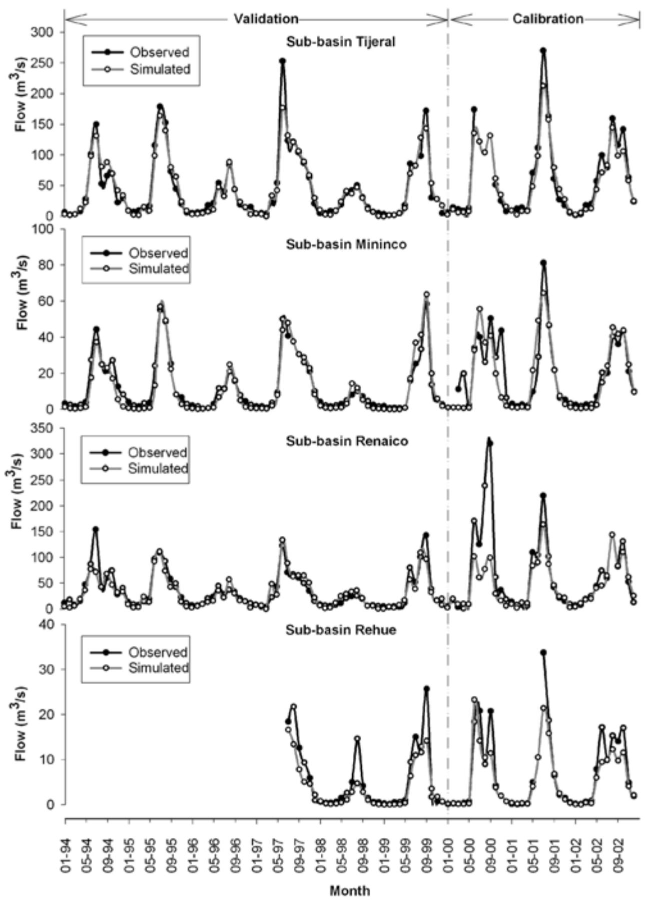


Figure 6. Example model results for the 1994-2002 calibration & validation period (mean monthly discharges; multiple internal control points shown).

Table 2. Model performance for the 2 validation periods (the first statistical indicator corresponds to the Nash-Sutcliffe modeling efficiency criterion EF, the second to percentual bias).

Period	Meteorological Stations	Tijeral	Mininco	Malleco
94-99	All available stations used	0.93 / 2.77	0.92 / 9.13	0.87 / 10.44
94-99	5 PP 3 T (2T extrapolated)	0.90 / 9.28	0.90 / 21.28	0.80 / 22.55
77-82	5 PP 3 T (2T extrapolated)	0.88 / 10.95	0.74 / 19.47	0.77 / 17.15

The former indicates that the model gives a good 'overall' representation of mean monthly discharge rates at the different control points, both for recently observed ('current') and historic conditions of land use & climate. Based on this calibration and double validation procedure, it can thus be reasonably assumed that the model, under its current form, is capable of reproducing 'realistic' mean monthly discharge rates under a scenario modeling exercise. The double validation exercise, however, does not provide direct information on how influential the different land use scenarios (i.e., historic versus 'current') are on the model outcome. For this purpose, additional model runs were applied, as described under Section 2.2. (see: *sensitivity of the model to land use changes*).

Performance indicators for modeled versus observed monthly mean discharge calculated from the 2 additional model runs –using a single observed meteorological time series (1992-2002) with a synchronized (1995-98) and non-synchronized (1979) land use map, respectively- were both high and at the same time very similar: the model, using the meteorological time series from 1992-2002, adequately reproduced the observed monthly discharge rates for that period, independent from the land use representation that was used.

This indicates that the model is capable of adequately representing the effect of meteorology on monthly discharge rates. However, for the current version of the model application for Vergara, the error (modeled – observed monthly discharge rates) caused by using the non-synchronized land use map falls within the acceptable error range for good model performance, as specified in Abu El-Nasr *et al*. (2005). Under these circumstances, no guarantees could be obtained yet with regard to the adequate representation by the model of the effects of land use changes on monthly discharge rates, and additional research will be required.

3.2. Results from the scenario generation process

In Figure 7, results obtained from the application of the MAGICC-SCENGEN tool are shown. Regionalized output from these model runs shows that under all 6 SRES marker scenarios, for all analyzed GCMs, for the area of interest (35º-40 º S, 70º-75º W) an increase in both temperature and precipitation is obtained for the time window centered around 2050, as compared to the reference period. Magnitudes of changes differ considerably between the scenarios. In the presented results, the effects of aerosols have not been included;

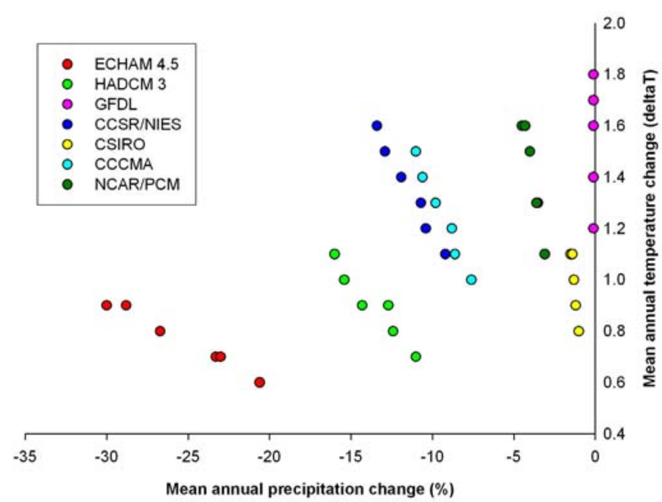


Figure 7. Regionalized output (annual mean temperature & precipitation; 35º-40 º S, 70º-75º W) from the 6 SRES marker scenarios for different GCMs (MAGICC-SCENGEN v4.1. – GreenHouse Gases only).

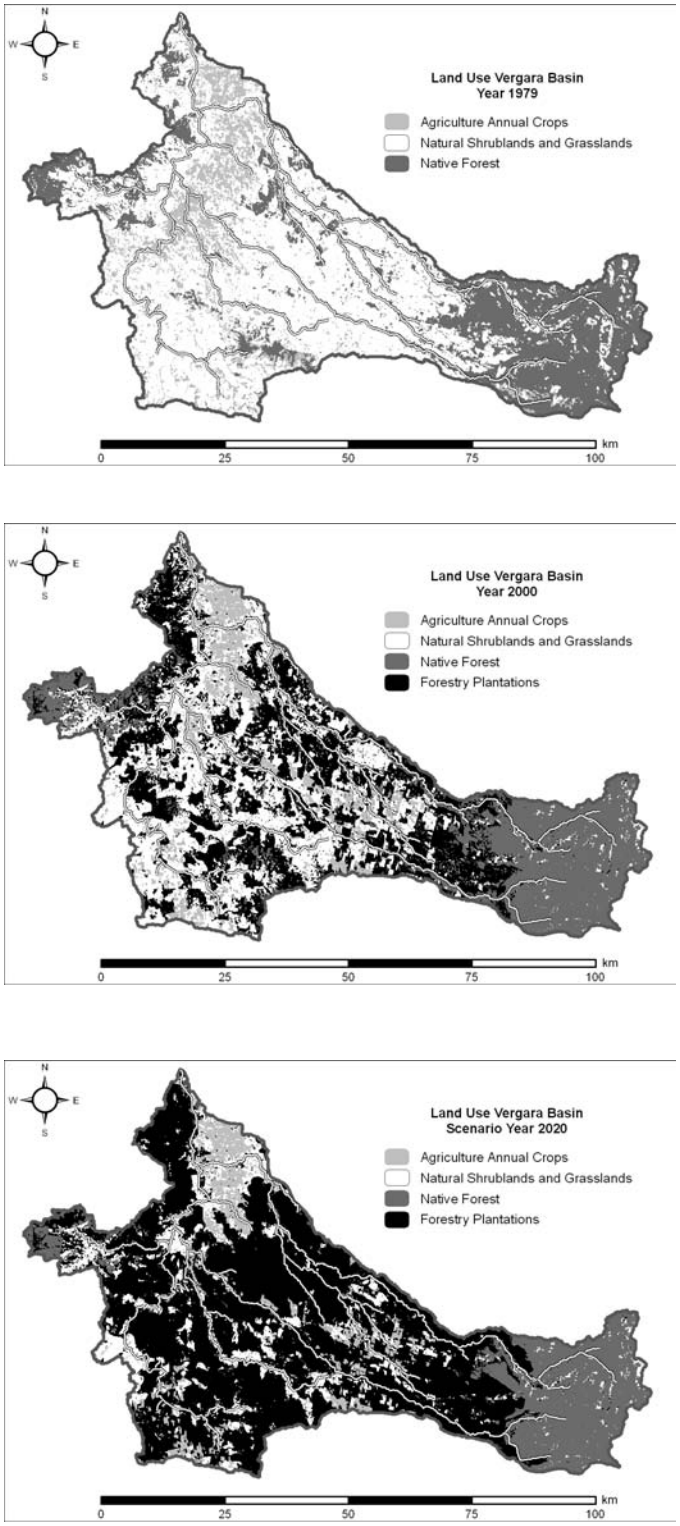


Figure 8. Historic, 'current' and logistic regression-based plausible future land use scenario for the Vergara Basin.

results from runs which include the effects of aerosols are somewhat different; however, general tendencies mostly remain the same.

Output from the first RCM runs for Chile were obtained from DGF-CONAMA (2006), and were used for calculating mean annual inputs to the basin water balance under 2 different scenarios of climate change (based on the A2 and B2 emission scenarios).

Generated plausible future land use scenarios will only briefly be discussed, as the available analysis of results from the hydrological model does not allow us yet to adequately evaluate model capacity with respect to the representation of land use change impacts on monthly discharges. A future land use scenario generated by means of the 'basic' logistic regression approach is shown in Figure 8. The 'extended' approach which consisted of the incorporation of a climate change signal (ΔT; see description under 2.3.3.) through one of the independent variables led to a minor, additional extension of forestry plantations, as compared to the 'basic' approach (results not shown). At this point, it was decided that additional research should go into evaluating the hydrological model's capacity for assessing impacts from land use changes (*e.g. on other, non-monthly components of the water balance*), before further land use scenario generation and impact modeling efforts are undertaken.

3.3. Results from the scenario modeling

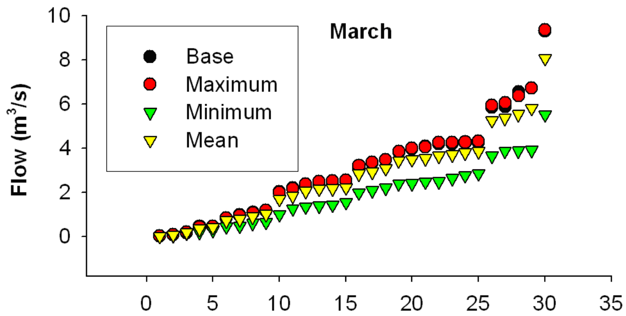
Figure 9 shows some results of the monthly discharge simulations for different return periods at Tijeral (nearest limnigraph to the outlet). These simulations have been made using both the reference precipitation time series (stochastic weather generator), as well as the perturbed versions of this time series (perturbations based on the climate change signals obtained under Section 3.2.). The figure shows both the baseline run, as well as the mean, minima and maxima obtained from the simulation of the different scenarios. As can be observed, for a given return period monthly discharges from the scenario analyses range from slightly inferior to considerably inferior, depending on the scenario used. For most months, differences tend to become more pronounced for the higher return periods.

Elasticity between percentual changes in mean annual precipitation and mean annual river discharge ranged from approx. 1,3 - 1,8. This indicates that, according to the model predictions, a given percentual reduction in total mean annual rainfall would lead to a proportionally higher reduction in mean annual discharge rate. This conclusion is highly relevant, as it indicates that impacts from climate change in the water resources sector of the Biobío Basin may be higher than what is initially deduced from the numbers given in Figure 7 (reduction of rainfall rates).

Additionally, a preliminary comparison was made of differences in mean annual precipitation input to the Vergara Basin water balance for future scenarios derived from both MAGICC-SCENGEN and an RCM. Percentual changes in mean annual precipitation input to the Basin with regard to the reference period, as derived from the regionalized change results from MAGICC-SCENGEN (GCM = HadCM3; options = both GreenHouse Gases and Aerosol + spatial drift), for a time window centered around 2085, are -20,31% and -17,36% for the A2 and B2 emission scenarios, respectively. Percentual changes for the 30-year time window centered around 2085 for the same two emission scenarios, calculated from the daily RCM results (DGF-CONAMA, 2006; used GCM = HadCM3/HadAM3) are -33,49% and -21,89%, respectively. These first results give a preliminary indication of the potential impact of using coarse-scale versus downscaled climate scenarios in hydrological assessment exercises. Ongoing research for Vergara includes the use of both types of scenario in the hydrological modelling exercise.

3.4. Results from the economic evaluation methodological development for Biobío

A methodology was developed to extend the evaluation of the economic impact of the Secondary Water Quality Standard for the Biobío Basin to future conditions of river discharge. At this stage,



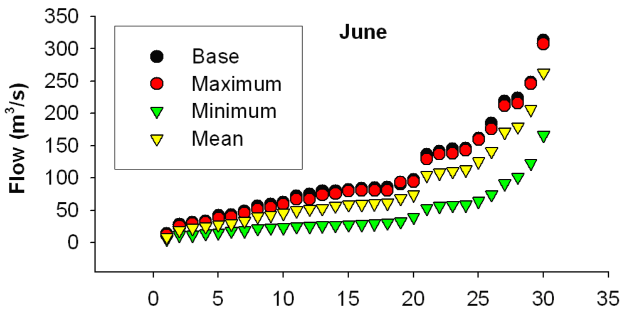


Figure 9. Example of mean monthly flow values for different return periods for March and June, for the baseline scenario and the change scenarios envelope (maximum, minimum and mean), Tijeral Station.

simple regression analyses were used for this purpose, based on simultaneous observations of river discharge and water quality (historical data sets).

For determining the elasticity of the quality-discharge relationship, the following equation was used:

$$\frac{\delta Ln(CP_{ij})}{\delta Ln(Q_n)} = \frac{\Delta CP_{ij} / CP_{ij}}{\Delta Q_n / Q_n} = \frac{\Delta\%CP_{ij}}{\Delta\%Q_n} = \eta$$

where:

CP_{ij} = value of water quality parameter i at monitoring station j

$Ln(CP_{ij})$ = natural logarithm of CP_{ij}

Q_n = flow rate in river reach n (reach where station j is located)

η = elasticity parameter-discharge

Strong positive elasticities (e.g. suspended solids, η-values of up to 3,97 in the mountainous upstream part of the Basin) were obtained for those water quality parameters that reflect contamination which is predominantly originated through runoff from diffuse sources. Strong negative elasticities are indicative of point-source contamination, where increased flow rates dilute contaminant concentrations in the river system (e.g. adsorbable organic halogens or AOX, with η-values of -1,96 in certain reaches). It becomes immediately clear that some limitations are inherent to the utilized approach (e.g. use of the established elasticities is based on the assumption that contaminant sources remain constant over time, etc.), and a more process-based approach is definitely recommended for future works. However, with the presented approach, a methodological development together with a preliminary assessment can already be made.

With the obtained elasticities, the critical percentages for flow changes can then be determined for the different parameters. These critical percentages indicate to what extent flow must be modified (e.g. due to climate change) in order for a parameter to change its conditions of compliance/no compliance under the new Water Quality Standard.

$$\Delta\%Q_c = \frac{\left(LC^{L,S}_{ij} - CP^{C,F}_{ij}\right) / CP^{C,F}_{ij}}{\eta}$$

where:

$\Delta\%Q_c$ = critical change in flow rate

$LC^{L,S}_{ij}$ = limiting value defining conditions of Latency/Saturation for a given parameter in the considered river reach

$CP^{C,F}_{ij}$ = current/future value of water quality parameter i at monitoring station j

Table 3. Discharge changes (%) required to cause a shift from saturated to normal conditions, or from normal to saturated conditions (white and grey cells, respectively) under the Secondary Water Quality Standard for the Biobío River Basin. Examples are given for 2 parameters in 2 river reaches of the Vergara Subbasin

River Reach	Suspended Solids	AOX
Vergara Station # 1 ("TR-10")	-32,2%	---
Vergara Station # 2 ("TR-20")	-14,6%	**-13,5%**

% change in discharge required for transition from normal to saturated conditions

% change in discharge required for transition from saturated to normal conditions

Table 3 shows how changing flow conditions can affect the compliance status for 2 parameters in 2 reaches from the Vergara Subbasin. Observed suspended solids concentrations in this part of the Basin were strongly positively correlated to river discharge (flow). Current conditions in these reaches are of no-compliance (water quality standard is violated; reaches are classified as saturated zone). Assuming that the obtained regression equations are valid for making projections on future status, it can be seen that a reduction in river flow of 14,6 – 32,2% (e.g. caused by climate change) would change the status of the reaches for this parameter to normal ("compliance"). However, for the parameter AOX, a reduction of river flow by 13,5% (all other factors remaining equal) would lead to saturated conditions in reach 2. These findings can now be compared with results from Figure 9, in order to evaluate how probable a transition from compliance to no-compliance (or vice versa) is, under a series of plausible future climatic conditions for the Basin.

For saturated reaches, actions have to be taken in order to remediate this situation of no-compliance with the Water Quality Standards (WQS). The costs of these actions will depend on the percentual reduction in the parameters' value required for achieving acceptable water quality conditions, and may thus be different for current and future flow conditions. The difference in costs of the mitigation actions required under both current and future flow conditions is an indication of how climate change may add up to, or reduce –depending on the case- the costs associated to achieving acceptable water quality conditions.

A simple theoretical example approach for calculating costs is given below:

$$C = W*(He*UC)$$

where:

C = cost associated to the implementation of the Secondary WQS

W = magnitude of the reduction in concentrations required for compliance with the WQS

He = number of hectares under erosion in the upstream drainage area of the considered reach

UC = mean cost per hectare for 1 unitary reduction in erosion (suspended solid concentrations)

For the case of Vergara reach # 1, a 60,55% reduction in Suspended Solids concentrations would be required under current flow conditions in order to achieve compliance. With the concentration-discharge elasticity value for the reach known, the required reduction in concentrations under plausible future river flow scenarios (climate change) can be deduced. If mitigation costs per hectare susceptible to erosion are known, the former equation can then be further used to evaluate the changing costs associated to achieving acceptable water quality due to climate change-induced future river discharge conditions in the Basin. A similar approach can be used for other parameters.

3.5. Results from the vulnerability assessment

At present, inquiries on sectoral adaptive capacity have been collected in the context of different TWINBAS public participation activities. Results for the sector "civil society" based on 35 received inquiries are shown in Fig. 10 b1 and b2. In addition to this, an example of individual evaluations from members of the "industry" sector is also given (Fig. 10 a). It is the intention of the authors to further extend this exercise in the future; however, some preliminary observations can already be made:

- Across almost all sectoral groups that have participated until now (mainly civil society and private & academic sector), political willingness is the determinant which consistently gets assigned (one of) the lowest score. This is however not perceived similarly when the inquiry is applied to the public institutions themselves: even when political willingness keeps getting a low score, it is no longer the worst evaluated factor (at present, only a very limited number of inquiries have been filled in by members of the public sector).
- Maximum scores tend to be only slightly lower for most factors after the information sessions (results from modeling) have been held. For the "civil society" adaptive capacity evaluation, only small changes in mean scores were obtained.
- As can also be seen from the example given in Figure 10, civil society typically estimates its adaptive capacity lower than the private sector (e.g. industries). The industrial sector in the basin mainly consists of powerful groups related to the paper and petrochemical industry. It must be indicated however, that at this stage only a few inquiries were obtained from industry, so care should be taken as not to generalize these results.

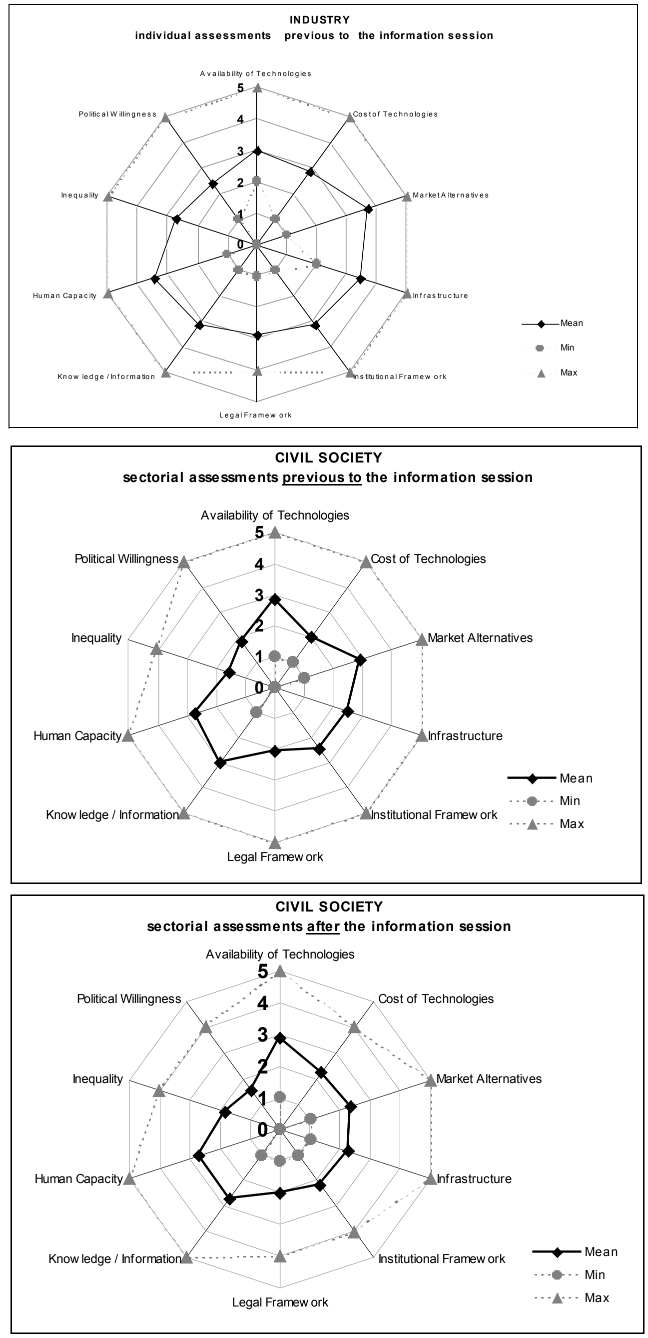


Figure 10. Determinant scores for adaptive capacity as perceived by members from (a) industrial sector and (b) civil society (in the last case, before and after knowing the results of the scenario analysis, fig. b1 and b2 respectively).

4. General discussion and conclusions

4.1. Discussion on the generic framework approach

The methodology and results presented in this manuscript were developed in the context of a '*twinned river basin*' integrated water resources management research project, "TWINBAS". Figure 1 indicates the efforts made in TWINBAS to establish a harmonized approach for the project's implementation. The present manuscript enters into an additional level of detail, by providing a more elaborated generic framework for the analysis of the hydrological impact of changing environmental conditions, combined with the evaluation of societal impacts associated to these changes, as well as for the building of awareness amongst stakeholders on the potential consequences arising from this. It is expected that through the provision of this generic framework and by documenting on the results from its implementation for a specific case study basin from the South, relevant information is made available that helps to steer others in the execution of similar initiatives. The generic framework presented here is open to further discussions, improvements, modification and adaptations that may be needed for enabling its application in other parts of the world. The framework will also be setting the basis for ongoing work under TWINLATIN (EC FP6), a sister project of TWINBAS in which 2 European and 5 Latin-American river basins are involved.

4.2. Discussion and conclusions from the case study application

Scenario modeling for the case study basin shows considerable potential impacts of climate change on regional water resources. However, it also shows the difficulties of providing unambiguous information with respect to the precise magnitude of climate change as well as of its hydrological impacts. This is mainly due to the currently existing uncertainties associated to emision scenarios, process representation/parameterization, as well as to issues of (spatial) simulation scales. Even so, the generated scenarios can be usefully applied to analyze the sensitivity ranges of the Vergara (and Biobio) hydrological systems to a wider range of plausible future scenarios of climate change.

Hydrological models that have been adequately validated for given case study basins can constitute valuable tools for assisting professionals from the water resources sector in their decision-making. Additionally, they may play an important role in societal awareness building around current and future opportunities and threats arising from different scenarios of water availability, management and use.

Most of the considerations (given under Section 2.1.) that led to the selection of the Vergara Subbasin for the case study application of TWINBAS's modelling component for Biobío have been established from a 'feasibility' point-of-view. From a research perspective, this is justified as it is indeed important to obtain insight in the capabilities of a model, as well as to gain trust in the validity of model results, before more complex modeling issues can be addressed. In this context, this manuscript documents on one of the first applications of its kind for meso-scale river basins in Chile, which are typically characterized by limited conditions of input data availability.

The use of results from the hydrological model application for assisting the evaluation process of the potential implications of changing environmental conditions on the newly established Chilean legal framework is promising indeed. However, also here, additional knowledge gaps need to be addressed, especially with regard to a better understanding and representation of the physical processes that drive the relation between water quality and discharge, and between changes in discharge and costs. The described approach (*the establishment of empirical relationships between water quality and discharge levels*) has some serious limitations, which are recognized by the implementing author, and which will need to be dealt with in the future. This is best to be done through the implementation of a more process-based modeling approach.

The former also indicates that major efforts still need to be conducted in these fields, in order to enable the scientific community to further expand on the 'feasibility'-side (*e.g. modeling or decision-making under limited conditions of data availability*), and, as such, become enabled to start implementing a primarily 'demand-driven' approach. This is especially relevant in countries with transition economies and in the developing world, as to provide society and governments, through both active and passive participation, with the information they need for reducing vulnerabilities, through sound-decision making with regard to the adaptive processes that will need to be undertaken over the decades to come.

5. Acknowledgements

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6. References

Abu El-Nasr A., Arnold J. G., Feyen J. and Berlamont J. (2005) Modelling the hydrology of a catchment using a distributed and a semi-distributed model. Hydrol. Processes 19: 573-587.

Arnold JG., Srinivasan R., Muttiah RS. and Williams JR. (1998) Large area hydrologic modeling and assessment – part I: model development. JAWRA 34(1): 73-89.

Campos H., Ruiz VH., Gavilán JF. and Alay F. (1993) Peces del Río Biobío. Concepción, Chile, Centro EULA-Chile, Universidad de Concepción.

DGF-CONAMA (2006). Estudio de la Variabilidad Climática en Chile para el Siglo XXI. Informe Final. Estudio realizado por Departamento de Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile. Comisión Nacional del Medio Ambiente, Santiago, Chile.

Di Luzio M., Srinivasan R., Arnold J. C. and Neitsch, S. L. (2002) ArcView Interface for SWAT2000 User's Guide. Texas, Texas Water Resources Institute, College Station

EULA (2006) Análisis General del Impacto Socio-económico de la Norma Secundaria de Calidad de Aguas en la Cuenca del Río Biobío. Universidad de Concepción, Concepción, Chile.

IPCC (2000) Special Report on Emission Scenarios. Intergovernmental Panel on Climate Change IPCC.

Marengo JA. and Ambrizzi T. (2006) Use of Regional Climate Models in Impact Assessments and Adaptation Studies from Continental to Regional and Local Scales. The CREAS (Regional Climate Change Scenarios for South-America) initiative in South America. Proceedings of the 8th ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 291-296.

Mata LJ. (2005) Personal Communication. Centre for Development Research ZEF, University of Bonn, Bonn, Germany.

Mata LJ. and Nobre C. (2006) Impacts, vulnerability and adaptation to climate change in Latin America. Background paper commissioned by the Secretariat of the United Nations Framework Convention on Climate Change. Lima, Peru, 67 pp.

Mearns LO. and Fu. C. (2001) Regional climate information — Evaluation and projections. In Climate Change 2001. The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, JT. Houghton, Y. Ding, DJ. Griggs, M. Noguer, PJ. van der Linden, X. Dai, K. Maskell and CA. Johnson (eds.). Cambridge University Press, Cambridge, UK, pp. 583-638.

Neitsch SL., Arnold JC., Kiniry JR., Sirinivasan R. and Williams JR. (2005a) Soil and Water Assessment Tool Theoretical Documentation. Version 2005. Texas, Grassland, Soil and Water Research Laboratory, Temple

Neitsch SL., Arnold JC., Kiniry JR., Sirinivasan R. and Williams JR. (2005b) Soil and Water Assessment Tool Input/Output File Documentation. Version 2005. Texas, Grassland, Soil and Water Research Laboratory, Temple

Nuñez MN., Solman S. and Cabré MF. (2006) Mean Climate and Annual Cycle in a Regional Climate Change Experiment over Southern South America. II. Climate Change Scenarios (2081-2090). Proceedings of the 8 ICSHMO, Foz do Iguacu, Brazil, April 2006, INPE, p. 325-331.

Pontius RG. and Schneider LC. (2001) Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA 85(1-3): 239-248.

Stehr A., Debels P., Romero F. and Alcayaga H. (2006) Hydrological modelling with SWAT under limited conditions of data availability: evaluation of results from a Chilean case study. Hydrological Sciences Journal (in review).

van Griensven A. and Bauwens W. (2003) Multiobjective autocalibration for semidistributed water quality models. Water Resources Research 39(12): 1348

van Griensven A., Meixner T., Grunwald S., Bishop T. and Sirinivasan R. (2006) A global sensitivity analysis tool for the parameters of multi-variable catchment models. Journal of. Hydrology 324: 10-23.

Wigley TML. and Raper MF. (1997) Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC Version 2.3.), The Climate Research Unit, University of East Anglia, UK.

Wigley TML. (2003) MAGICC/SCENGEN 4.1: Technical Manual, National Center for Atmospheric Research, Colorado, USA, October 2003.

New Approaches for Climate Change Impacts and Adaptation Regional Study – A Case in Ningxia China

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Abstract

The major regional study has taken place in Ningxia province in north-western China in 2006 and 2008. It includes finer resolution modeling of agriculture, water, climate and social and economic changes – but also incorporates a focus on stakeholder dialogue with government institutions, as well as a rural livelihoods approach to understanding vulnerability and decision-making. Scientists, policy makers and rural communities have all contributed to developing an appropriate framework for adaptation to climate change in Ningxia – an approach that is intended to inform future adaptation policies in other Chinese regions.

Introduction

Climate change has taken mix effects for agriculture in different regions of China. For future impacts, regional crop models were driven by PRECIS output, developed by the UK's Hadley Centre, to predict changes in yields of key Chinese food crops: rice, maize and wheat. Results from this project phase I suggest that, climate change without any responses could reduce the rice, maize, and wheat yields by up to 37% in the next 20 to 80 years. Recent results of this project has showed that meta-analyses of Free Air Carbon Enrichment (FACE) studies of carbon dioxide fertilization confirm conclusions from the TAR that crop yields at 550 ppm CO_2 concentration without other stress increase by an average of 10-20% for C3 crops. CERES Crop model estimates of CO_2 fertilization are in the range of FACE results. Elevated CO_2 of more than 450 ppm will likely cause some deleterious effects in grain quality. On average in cereal cropping systems adaptations such as changing varieties and planting times enable avoidance of a 10-15% reduction in yield This important Sino-UK cooperation climate change project combines cutting-edge scientific research with practical development policy advice.

In second phase, from 2006 until 2008, the major regional study takes place in Ningxia of north-western China with regional support from stakeholder organizations in the province. Due to the dry climate conditions throughout Ningxia water availability is limited to roughly 735m3 per capita, primarily from the region's allocation of Yellow River water. Crop production is most vulnerable.

This new study not only includes finer resolution modeling of agriculture, water, climate and social and economic changes – but also incorporates a focus on stakeholder dialogue with government institutions, as well as a sustainable likelihoods approach to working with rural communities. The aim is that scientists, policy makers and rural communities will all contribute to developing an appropriate framework for adaptation to climate change in Ningxia – an approach that is intended to lay the foundation for future adaptation policies in other Chinese regions.

Methodology

In order to engage effectively with planning and policy-making in Ningxia, we suggest that a number of steps are necessary to move towards developing a regional framework for adaptation to climate change – these are outlined below, comprised of five regional work packages and a stakeholder engagement strategy.

1) Climate change scenarios for Ningxia –

We use climate change scenarios interpolated to 25 X 25km from PRECIS for the 2020s and 2050s with IPCC SRES emissions scenarios A2 and B2 based on the regional planning.

The PRECIS, a regional climate model system developed at the UK Met Office Hadley Centre for Climate Prediction and Research, which is nested in one-way mode within the HadAM3P, a higher-resolution version of the atmospheric component of the Hadley Centre climate model HadCM3, is employed to simulate the baseline (1961—1990) climate for evaluation of model's capacity of simulating present climate and analyze the future climate change responses in the time-slice of 2071—2100 (2080s) under SRES A2 and B2 scenarios over China relative baseline average. It is indicated from the comparison of the simulated baseline climate with in situ observation that PRECIS can simulate the local distribution characteristics of surface air temperature over China, including Ningxia, quite well; generally speaking, the simulation for precipitation in the north of China and in winter is better than in the south of China and in summer, respectively; the simulation of precipitation in summer is sensitive to topography. It is shown from the pattern-scaling the simulated climate change responses in 2030s to 2050s under SRES A2 and B2 scenarios relative to baseline that there would be an obvious surface air temperature increase in the Ningxia and a little more increase in precipitation.

2) Socio-economic scenarios for Ningxia –

To use stakeholder consultation to derive a sub-set of socio-economic scenarios for Ningxia (consistent with national scenarios) based around plausible visions of regional development.

A downscaling method of Gaffin (2004) is used for developing Ningxia provincial socioeconomic scenarios based on the northwestern part of national scenarios, the national development planning scenario is the main benchmark of all socioeconomic scenarios. It is supposing the Ningxia GDP and population growth rate is consistent with the rate northwestern part of China. These scenarios provide agricultural land changes and water demand changes. But there are two different points used for the national A2 and B2 scenarios. Firstly, as for GDP, the price is based on US dollar market exchange rates in 1990. Secondly, the likelihood of population growth projected under A2 is more than China's current population policy results. Here the latter was used. Because there is no water resource data in SRES, the water demand scenarios under A2, B2 in China will be projected by own statistic model.

3) Modeling regional impacts on crop yields and water availability

In order to improve the ability of crop simulation, a cross-validation approach has been established and tested for the CERES-Rice model, and this will be extended to other crop models and crops. Crop simulation models are increasingly being used in assessing the impacts and adaptation of climate change on agricultural production, but there is a substantial mismatch between spatial and temporal scales of available data and crop simulation model input requirement. A cross calibration process based on limited experiment data, Agro-Meteorological Zones and 25 km×25 km grid scale geographical database was developed and tested on CERES-Rice model for climate impact studies in Ningxia, China. This approach was evaluated using either the experiment data, or the historical county yield data. The parameters which results in minimum bias between observed and simulated values of validation years were selected for individual sub-AEZ and season. After initialization of parameters through site calibration and validation, and cross calibration and validation through statistics RMSE, The performance of crossed calibrated model at site scale and source of bias and The performance of regional simulation and source of the bias have been analyzed so that the decreased simulation uncertainties

4) Rural livelihoods, vulnerability and adaptation in Ningxia

Effects of recent climate variability and responses to it were reviewed for the Agriculture and Livestock Department, the Science and Technology Department, the Poverty Relief Office, Water Resource Department and the Meteorological Administration of Ningxia, The results show that Agricultural livelihoods in Ningxia must cope with limited water availability, because recent decline in Yellow River flows and there have been negative and positive impacts of recent climate variability in agriculture.

A questionnaire was developed to provide a preliminary insight into rural livelihoods in Ningxia, as:

- Proximity to urban areas and access to irrigation water are important determinants of wealth and non-farming opportunities for local people.
- The most important factors influencing their family's agricultural income during the past 10 years are disasters, fertilizer price and cereal price.
- The climate factors perceived to have the greatest influence on agricultural production are drought, sandstorms and frost events (some differences exist in ranking between prefectures).

5) Integrated framework for assessing impacts and informing adaptation strategies

Technology progress will influence identification of baseline through influencing yield trends. Two approaches have been designed to explore the technology improvement in the study

- through genotype parameters adjustment or selection in crop modeling
- to project future increases based on analysis of historic average production trend.

Land use change provided by the projected socio-economic scenarios, could impact national agricultural production by either extending/shrinking the cultivation areas, or by altering the crop rotational systems. After analyzing the relationship between individual crop planting area via total grain planting area and annual mean temperature, we found that there is a good correlation between crop planting area rate for grain planting and annual mean temperature, especially the rice maximal planting area and annual mean temperature in each province. Other relative analysis have been carried out to demonstrate how the climate shaped the land use. Following a broad literature review and search for appropriate land use models, a state-of-the-art statistical approach is now constructing.

Water is the crucial determinant of China's food production. Both the demand for, and the supply of, water for irrigation will be affected by changing hydrological regimes. There will be concomitant increases in future competition for water with non-agricultural users, due to population and economic growth. A new method has been developed based on the hydrological model, crop model, and social-economic scenarios. The new method is an improvement over some previous approaches in three respects and be used in the improved simulation.

Cost benefit analysis has been carried out for maize, providing a useful overview of the country's crop production by region. The results could be used to simulate comprehensive food policy analysis for future scenarios.

Results

Climate scenarios produced by PRECIS shown that in the future Ningxia will be warmer and rainfall may decrease (although this is highly uncertain): From the regional climate modelling in Phase I of this project Ningxia becomes drier under our climate change scenarios. All the rainfed crops would suffer negative impacts, generally larger than in other provinces, whilst irrigated crops could maintain their present level of production, assuming no change in irrigation water availability.

Patterns of future potential crop yield modeled for Ningxia differ from national results. For rice, if agriculture management is held static, Ningxia shows the largest yield decrease when compared to other provinces. For wheat and maize, yield shows a smaller increase the than national increase. The CERES-Rice mode was able to simulated the rice production with good performance in most of the environment in China, with a RMSE=204 kg ha^{-1} and a relative RMSE=2.1% for yield in north-western China.

In order to adapt the changing climate, farmers have taken activities include:

- Retain soil moisture include using roller, plastic film and small stones. However, there is a significant variation in approaches to retaining soil moisture across the survey area.
- There is clear variability in the practice of rainwater harvesting. In irrigated areas the interviewees tended not to collect rainwater. Farmers have dug cellars and built rainwater harvesting sites to collect rainfall for domestic and livestock use.
- The main barriers that prevent farmers taking counter-measures in times of drought were identified as lack of money, infrastructure, technology and water.

The results show evidence of farmers diversifying and intensifying their production and adding value to their production. The livelihoods of many people in Ningxia, especially those dependent on farming activities, are to some degree exposed to climate variability and will be affected by future climate change. Many regional organisations are already actively supporting programmes that could act as potential adaptation strategies. The recent drought highlights vulnerable sectors (water resources) and people (rainfed farmers, remote communities) across the region. Livelihood diversification and agricultural intensification are shown to be important social processes occurring in Ningxia and throughout China and provide a rapidly changing situation against which climate change will occur. It is therefore important to integrate projections of regional trends with climate change impacts and adaptation.

Conclusion and Discussion

A crop study in China for food production shows that if we are able to adapt our practices; by warming of 3.2~3.8^{O}C dioxide fertilization effect of 560~720ppm will actually set off a decrease in levels of production due to the warming climate. These findings show that adaptation can delay the impacts of climate change on agriculture through practices such as: crop rotation; improved irrigation and water-saving technologies; selection of planted crops based on changed climate and prices; adoption of heat-resistant crops; and water-efficient cultivars.

Climate risk management, early warning, avoidance and tolerance, and risk mitigation are already being used to adapt the agricultural sector to the impacts of climate change. But we are still facing many challenges if the focus on quantifying future adaptation, an improvement of simulation will need.

Stakeholders are increasingly looking for practical advice on how to undertake adaptation, and this needs to draw on a suitable toolkit, the latest academic research, as well as experiences already engaged in adaptation. The advice needs to address the institutional or 'process' aspects of developing and implementing adaptation, so that it explains how climate risks can be mainstreamed within an organization. Where it is available, sector-specific information, e.g. on climate-proof technologies, is also invaluable.

Reference:

Fengmei Yao, Yinglong Xu, Erda Lin, Masayuki Yokozawa, Jiahua Zhang, 2007, Assessing the impacts of climate change on rice yields in the main rice areas of China, Climatic Change DOI 10.1007/s10584- 006- 9122-6

Ju Hui et al. (under revision) Simulating the impacts of climate change on wheat yield in China. Needs further work as part of Phase II. Climactic Change, re-submit 2007

L. Guo, P. Falloon, K. Coleman, B. Zhou, Y. Li, E. Lin1 & F. Zhang, 2007, Application of the RothC model to the results of long-term experiments on typical upland soils in northern China, Soil Use and Management doi: 10.1111/j.1475-2743.2006.00056.x

Lin Erda, Xiong Wei, Ju Hui et al., 2005, Climate change impacts on crop yield and quality with CO2 fertilization in China, Philosophical Transactions of the Royal Society B, 360, 214

Wei Xiong, Ian Holman, Erda Lin, 2007, A Cross Calibration of Crop Model for Use in Climate Impacts Studies,

Xiong Wei et al. (in press) The threshold of climate change and food security in China, Climatic Change, revised and accepted for publication

Xiong Wei et al. (submitted) The regional simulation of maize production in China under IPCC SRES scenarios, Climatic Change. Reviews suggest more crop model validation needed – under revision as part of Phase II work. Re-submit 2007?

Xu Yinlong , Huang Xiaoying , Zhang Yong , Lin Wantao , Lin Erda, 2006, Statistical Analyses of Climate Change Scenarios over China in the 21st Century, Advances in Climate Change Research , Suppl 1, 50-53Research

Xu Yinlong, ZHANG Yong, LIN Erda, LIN Wantao, DONG Wenjie, Richard Jones, David Hassell & Simon Wilson4, 2006, Analyses on the climate change responses over China under SRES B2 scenario using PRECIS, Chinese Science Bulletin, Vol. 51 No. 18 2260—2267

Yong Zhang, Yinlong Xu, Wenjie Dong, Lijuan Cao, and Michael Sparrow, 2006, A future climate scenario of regional changes in extreme climate events over China using the PRECIS climate model, GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L24702, 1-6

Aspects of Climate Change and Resource Conflicts in the Nigerian Savannah

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Abstract

This study analyses the pattern of rainfall anomalies and its relation with ecosystems changes and vulnerability of rural communities in the Nigeria Savannah. 60-year observed rainfall data for 22 stations over the Savannah was analyzed for spatial and temporal anomalies. Ecosystems change analysis was done using 19-year two-time landcover data. A simplified vulnerability index using multicriteria analysis was developed for about 750 communities using ecological zone, settlement status, administrative status, and the degree to which communities are tied to the land as candidate variables.

Results obtained showed that the 60-year long term annual mean and standard deviation for the Nigeria Savannah are 942mm and 270mm respectively. Correspondingly, the long term decadal mean and standard deviation are 976mm and 75mm respectively. The spatial pattern shows very high negative anomaly over the Sahel fringes and upper Sudan zones and high positive anomalies around the Guinea zones which reduce towards the lower Sudan zone. The influence of local perturbations is captured by the localized high positive anomaly around the highlands and very high negative anomalies around the inland basins. All the 4 stations in the Sahel zone and 6 in the upper Sudan zones recorded negative standardized rainfall. The temporal anomaly shows that the decades 1970s and 1980s are the driest in the Savannah over the last 60 years. Results from landcover and ecosystems changes indicate that general agricultural landuse increased by 20% between 1976 and 1995. In specifics, agricultural tree and crop production decreased by 30%, while rainfed arable crop production, extensive small holder rainfed agriculture with denuded areas, and extensive grazing areas increased by about 8000%, 129%, and 13% respectively. Water impoundments (reservoir and dams) increased by 115% and floodplain agriculture and irrigation agriculture increased by 110% and 572% respectively. Grassland increased by 121%, wood and shrublands decreased by about 37%, forest reduced by 17%, and aeolian sands and gullies increased about 428% and 15,000%. 231 of the sampled communities (23 in the Sahel zone and 208 in the Sudan zone) fall under the high vulnerability category. The spatial pattern of vulnerability of the communities to climate change and its effects clearly confirms that the trajectory of resource conflict in the Nigeria Savannah is towards the south of the Sudan zone. The paper also suggested necessary adaptation strategies to combat long-term implications of climate change in the Savannah.

1. INTRODUCTION AND STATEMENT OF PROBLEM

From the sophisticated megalopolis of the developed to the simple, poor, dotted villages and rural country sides of the less developed countries, the climate change story is becoming real by the day because of compelling evidences from its impacts. The risk of global climate change is associated with high probability of occurrence and well known damage potential, but with a time lag between trigger and consequence which often creates a fallacious impression of security (German Advisory Council on Global Change, 2000), and until recently, climate was generally taken for granted with little thought that the climate could be a problem with severe impacts (Ojo, 1987). The recently released summary for policy makers (SPM) of the Intergovernmental Panel of Climate Change Fourth Assessment Report (IPCC-AR4) by the Working Group 1 noted that "11 of the last 12 years (1995 -2006) rank among the 12 warmest years in the instrumental record of global surface temperature since 1850, the updated 100-year linear trend (1906–2005) of 0.74 [0.56 to0.92]°C is therefore larger than the corresponding trend of 0.6 [0.4 to 0.8]°C for 1901-2000 given in the Third Assessment Report(TAR). The linear warming trend over the last 50 years (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the last 100 years, and the total temperature increase from 1850 – 1899 to 2001 – 2005 is 0.76 [0.57 to 0.95]°C (www.ipcc.ch).

If these direct observation records and future projections from the various global and regional climate models are anything to go by, then more serious and focused attention must be paid to global climate and environmental change issues.

Africa is particularly vulnerable to the direct consequences of climate change because of poor preparedness for the effects of climate change poor and harsh socio-economic conditions on ground that have considerably diminished the resilience of the population. The Sahel region of Africa is highly vulnerable probably due to its proximity to the Sahara, large scale ocean changes and local desertification. Over the years, increased temperature and reduced rainfall has been the trend over the Sahel. A severe drought (which resulted in loss of many human lives, livelihoods, and livestock) was observed in the Sahel in the late 20th century (Ramaswamy, 2007; Adefolalu, 2006; Ojo, 1987). The Sahelian drought has not only created a difficult situation for the inhabitants of the region, but it has also thrown up new challenges in other ecological zones of Africa. The climatic-future appears very bleak because according to Ramaswamy (2007), results from the coupled models using estimates of historical forcings by scientists at Geophysical Fluid Dynamics Laboratory (GFDL) indicated that the Sahel gets drier in future scenarios.

Generally, rainfall is a prime factor of agriculture in Africa, and change in rainfall quantity and regime is a strong index of climate and climatic variability and a critical limiting factor to human survival in Africa. The effects of diminishing rainfall in the Sahel is leading to ecosystems perturbation, landuse pressure and land resource conflicts among social groups in the adjoining ecological zones such as currently being experienced in the Savannah region of Nigeria. In recent times, the certainty of climate change manifested in the different obvious ways in which both the urban and rural dwellers in the Savannah are being affected is making the people to exercise local adjustments and coping strategies. The herdsmen of the Sahel and upper Sudan zones appear to be moving permanently into the lower Sudan and Guinea Savannah zones (Fig1).

The rainforest zone of the south is increasingly being opened-up for tuber and cereal crop cultivation. The climatic limit of cultivation appears to be expanding for some crops and contracting for others. For example, the area of the southern rainforest zone devoted to cocoa cultivation (a major cash crop in Nigeria) appears to be

Fig 1: Herds roaming permanently in the Guinea Savannah.

shrinking as some of the lands that used to be cocoa plantations are now devoted to yam and cassava cultivation. These are some of the observed impacts and evidences of climate change at regional, local and communal levels in Nigeria which in turn have implications for natural resource management, food security, and long-term economic development of the nation.

2. AIM AND OBJECTIVES

Although the regional climate models have improved our understanding of the dynamics and effects of the climatic forcings better than the global climate models, they have not been able to provide insights into the vulnerability of people to the climatic variability and the struggle to cope with the effects at local levels. The global chain-effects of macro and regional climate variability may not give clue to how climate and environmental change affects human livelihoods, human well-being, and the struggle for diminishing resources among social groups at local and communal levels. The anomalies in climatic elements, especially rainfall and temperature, and their resultant strong ecological perturbations have increased the risk and vulnerability of rural communities in the Savannah. The aim of this study is to analyze the pattern of rainfall anomaly and correlate this with ecosystems changes to determine the degree of vulnerability of some rural communities in the Savannah region of Nigeria to the effects of climate change.

The specific objectives are:

§ To analyze the rainfall data over the Nigerian savannah and assess the rainfall anomaly over a 60-year period

§ To conduct ecosystems change analysis over a 19 year period and correlate the pattern and magnitude of observed changes with the pattern of rainfall anomaly

§ To conduct a simplified vulnerability assessment of some communities in the Savannah and correlate resulting vulnerability pattern with the pattern of rainfall anomaly and ecosystems change trajectory.

3. THE STUDY AREA

The Nigerian Savannah (roughly from Lat. $7^0 45^1$N to 14^0 N) straddles the entire longitudinal extent of Nigeria (Figure 2). The Savannah covers about 80% of Nigeria's landmass and is roughly divided into the Guinea, Sudan and Sahel ecologies with zonal transition following increasing latitude. The Guinea Savannah zone stretches from around Lat. $7^0 45^1$ N to 10^0N, the Sudan Savannah zone runs roughly between Lat. 10^0N to 12^0N, and the Sahel zone is found in areas above Lat. 12^0N.

Rainfall is perhaps the most important climatic characteristic which distinguishes the different zones of the Savannah. The onset and cessation of the rains in the Savannah, like in the other parts of Nigeria, is controlled by the movement of the inter-tropical convergence zone (ITCZ) over Nigeria. In the months April to September when the ITCZ moves across Nigeria into the Sahel (North of Lat. 15^0), the Savannah falls under the influence of the moist tropical maritime airmass (African monsoon wind) from the Atlantic and the region receives rainfall. As the ITCZ moves down south in October to February, the influence of the maritime air mass over the Savannah is replaced with that of the dry, dust-laden tropical continental air mass from the Sahara, and there is a progressive decrease in rainfall from the Sahel to the Guinea Savannah.

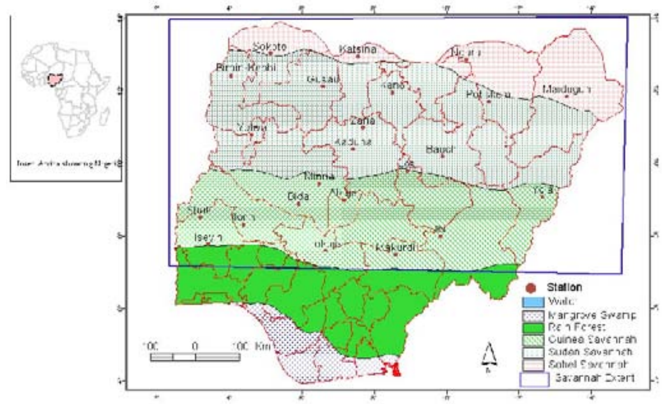

Figure 2: Generalized Ecological Regions of Nigeria.

Generally, mean annual rainfall in the Savannah is between 700mm and 1500mm and it decreases with increase in latitude with exceptions in few areas with local orographic perturbations. The mean annual rainfall is between 1200mm and 1500mm in the Guinea zone, 760mm-1020mm in the Sudan zone, and 380mm-700mm in the Sahel. Mean daily relative humidity and number of rainy days also decreased from the Guinea to the Sahel. Mean annual temperature is around 27^0c to 29^0c with a general rise with increasing latitudes. The only exceptions are in some small areas with strong orographic influences where the temperature is considerably lower than the surrounding areas.

The Savannah region of Nigeria is densely populated. It is dotted with many administrative, commercial and service urban centers. However, a large percentage of the population lives in scattered rural settlements and villages. Inhabitants of these rural communities depend entirely on land resources from the Savannah for livelihood, and agriculture is the main human activity. The Guinea and lower Sudan zones of the Savannah represent the crop cultivation zone. Tubers and cereals are the main crops and the inhabitants are sedentary cultivators. Animal rearing in these zones is intensive and localized. The Guinea Savannah zone (which is a transition from the southern rainforest) is regarded as the food basket of the Nigeria. It is a zone of rainfed agriculture and extensive small holder crop cultivation. A large percentage of the root and tuber food crops transported into cities and urban centers all over Nigeria originate from this zone. The lower part of the Sudan zone also produces cereals in large quantity which is distributed to urban centers across the nation.

The upper Sudan and the Sahel zones represent the zone of extensive grazing. Crop cultivation is restricted mainly to the river valleys, alluvial flood plains, inland wetlands and depressions (Fadamas) and irrigated lands. Because the time between the onset and cessation of the rains is very short in this zone, long range transhumance is practiced. Prior to the sahel drought of the 1980s, the nomadic herdsmen set out towards the lower Sudan and Guinea zones of the Savannah for greener pastures for their herds as soon as the dry period sets-in in the Sahel. This trans-humance is completed by a return journey to the upper-Sudan and Sahel zones at the on-set of the rainy season. Things appeared to have changed now as so many nomadic herdsmen have relocated their animals permanently into the southern guinea savannah and rain forest ecologies. This has increased the struggle and strife for diminishing resources among the northern invading herdsmen and the sedentary cultivators of the guinea and rainforest zones with its attendant effects on human security, livelihoods and ecological degradation.

4. METHODOLOGY

Data for this study consists of historical monthly rainfall records obtained from the Nigerian Meteorological Agency and multi-temporal landcover data obtained from the archive of the Department of Geography, University of Lagos. Digital spatial-administrative data and limited socio-economic attributes of about 750 communities in the Savannah were collated from different sources. The characteristics of the data utilized are shown on Table 1.

Table 1: Data and data sources.

S/n	Data	Year	Source
1	Monthly Rainfall data over 22 stations in the Savannah	1940-2000	Nigerian Meteoro-logical Agency
2	Multi-temporal Landuse/Landcover data for the Savannah region	1976 &1995	Archive of the Department of Geog-raphy, University of Lagos
3	Spatial data and attribute data on com-munities		Topographic base maps, Nigerian ab-stracts of statistics, Department of Geog-raphy, literatures

Historical Monthly rainfall data for 60 years (1940-2000) for 22 stations over the Savannah was collated and summarized for long-term mean, monthly and decadal means, and standard deviation. Rainfall index (standardized rainfall values) was calculated for each station. The spatial and temporal long term rainfall anomaly was computed for each station and for the 6 decades. Using GIS, the computed values for long-term mean and long-term rainfall anomaly (for each station) were converted into rainfall surfaces using the tools of geographic information systems (GIS).

Multi-temporal ecological/landcover data for the years 1976 and 1995 were accessed and analyzed and within GIS to generate landcover changes. The result of the change analysis was cross-tabulated to produce the perspectives, extent, rate and trajectory of change in the light of changing climate scenarios.

To present the climate change, ecological change, resource conflicts and vulnerability perspectives, about 750 settlements across the Nigeria Savannah were digitized from existing base maps. Limited attributes including names, settlement status (urban, semi-urban, rural), administrative status (Federal/State capital, Local Government Area headquarters, others), ecological zones where a community is located, and the major occupation of inhabitants (service/commercial/government, mixed, and peasant agriculture) were generated and digitally attached to each settlement. A simple multi-criteria analysis was used to allocate weights/scores to the different attributes of communities (Table 2) to create a simplified vulnerability index to climate change and its diminishing land resources impacts for each of the community.

The maximum obtainable score is 65 and the minimum is 20 (difference of 45). It is considered that a score of 45 (and above) is classified as low vulnerability (which indicates that the livelihoods of the inhabitants are not directly tied to primary production or land resources). Correspondingly, 30-44 is categorized as medium vulnerability (inhabitants depends on secondary and tertiary sectors as well as primary production from land resources for livelihoods), and less than 30 is categorized as high vulnerability (livelihoods of inhabitants completely tied to the land).

Table 2: Candidate variables for constructing simplified vulnerability index for communities.

Variables	Attributes	Total score	Score obtained
Ecology	Rainforest Guinea zone Sudan zone Sahel zone	50	20 15 10 5
Settle-ment status	Urban Semi-urban Rural	30	15 10 5
Admin-istrative status	Federal/State Capitals LGA Headquarters No status	30	15 10 5
Major occupa-tion	Tertiary and secondary - Gov-ernment/service/commerce Mixed – primary & secondary Primary – agric and natural resource based	30	15 10 5

5. RESULTS AND DISCUSSIONS

5.1 Rainfall pattern and rainfall anomaly over the Savannah

5.1.1 Spatial anomaly of rainfall

The long term mean and standard deviation of rainfall values for the 22 stations over the 60-year period is 942mm and 270mm respectively. The long term decadal mean and the standard deviation over the 6 decades are 976mm and 75mm respectively. Figure 3 presents rainfall isohyets constructed from the mean rainfall for each station over the 60 year period and Figure 4 presents the spatial anomaly of rainfall over the Savannah.

The average rainfall values decrease from Guinea zone to the Sahel zone. The highest value (1200mm) is recorded around Iseyin and Lokoja in the Guinea zone while the lowest value (450mm) is recorded around Nguru in the Sahel. The effect of local orographic perturbations is also very clear in the areas around Jos plateau (in the lower Sudan zone) where the average rainfall (1200mm-1250mm) is the highest in the Savannah region of Nigeria. The inland basins around Sokoto, Katsina, Maiduguri and Nguru displays lower aver-

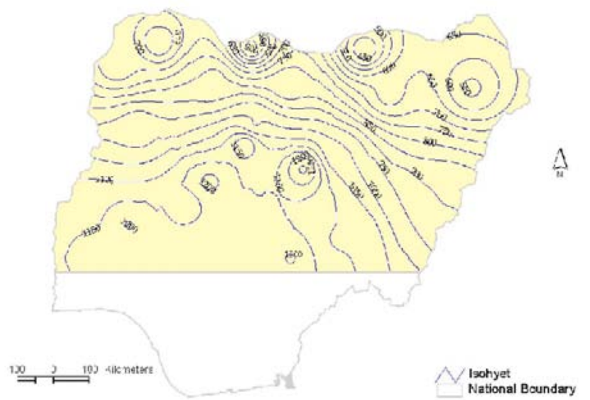

Fig 3: Rainfall isohyets.

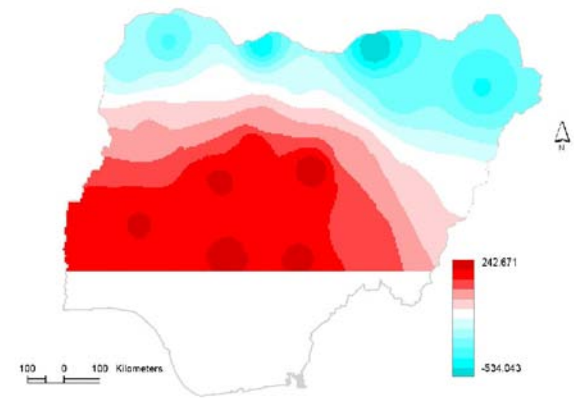

Fig 4: Spatial anomaly of rainfall over the Nigerian Savannah.

age rainfall than the surroundings. This is also consistent with the constructed spatial anomaly of rainfall. Very high negative rainfall anomaly is recorded over the Sahel and upper Sudan zones. Correspondingly, high positive anomaly is recorded over the Guinea zone. The influence of local perturbations (highlands and inland basins) is once again captured by the localized high positive anomaly around the highlands and very high negative anomaly around the inland basins.

An insight into the magnitude of diminishing rainfall over the Savannah is presented on Table 3 and Fig 5 which show the long-term standardized rainfall values for each station. 10 stations recorded negative long-term standardized rainfall values. These include all the 4 stations in the Sahel zone (Sokoto, Katsina, Nguru and Maiduguri) and 6 other stations (Birni-Kebbi, Gusau, Kano, Yola, Potiskum and Gusau) which are located within the upper part of the Sudan zone. Judging from the magnitude of negative anomaly of the stations in the Sahel zone, it is clear that this zone is facing severe rainfall deficiency. This has indeed impacted seriously on the ecosystems, water resources, agricultural activities and other human activities within the regions as will be discussed in the next section. In all, no station in the Guinea and lower Sudan zones of the Savannah recorded negative index value, while Nguru, Katsina and Maiduguri in that order recorded the highest negative rainfall anomaly.

This suggests serious decline in the carrying capacity of the Sahel and the lower Sudan ecologies which calls to question the ability of these ecological zones to continue to support human and animal populations without necessary intervention and adaptation strategies.

Table 3: Standardized rainfall index for the Nigeria Savannah.

S/n	Station	index value		S/n	Station	index value
1	Bauchi	0.22		12	Minna	1.01
2	Birnin-Kebbi	-0.84		13	Sokoto	-1.25
3	Gusau	-0.31		14	Yelwa	0.14
4	Ibi	0.57		15	Yola	-0.16
5	Ilorin	0.96		16	Nguru	-1.98
6	Jos	1.16		17	Potiskum	-1.15
7	Kaduna	0.90		18	Bida	0.70
8	Kano	-0.46		19	Katsina	-1.69
9	Lokoja	0.95		20	Iseyin	0.82
10	Maiduguri	-1.49		21	Zaria	0.21
11	Makurdi	0.96		22	Shaki	0.73

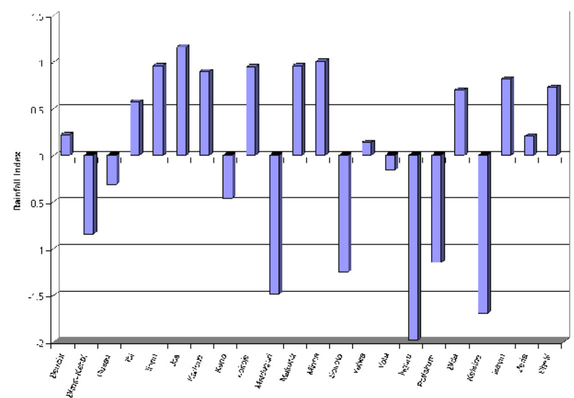

Fig 5: Standardized rainfall index for stations in the Nigeria Savannah.

There is high uncertainty about how successful the local response and coping strategies have been and for how long the local dwellers can tenaciously carry-on. It is however obvious that some forms of climatic adaptation strategies which are lacking, at present, need to be urgently considered and introduced.

5.1.2 Temporal anomaly of rainfall

Figure 6 shows the calculated long-term standardized rainfall index (temporal anomaly) for the 6 decades 1940-2000.

The decades 1970s and 1980s are the two driest decades in the Savannah over the last 60 years. This is consistent with what has been observed and reported over the Africa Sahel zone (Ramaswamy, 2007. Desiccation of water sources, loss of lives, livelihoods and livestock, and other effects of the droughts of 1970s and 1980s in the Nigeria Savannah have been reported in literatures (Adefolalu, 2006; Ojo, 1987). Incidentally, the decade 1980s is the beginning of a marked variation in the behavioral pattern of transhumance by the Fulani herdsmen of the Sahel and upper Sudan zones. It also marked a positive increase in resource conflicts and agrarian landuse change in the Savannah. Although, the rainfall situation improved in the 1990s as shown on Figure 6, the increased rainfall was accompanied by rising temperature perhaps more than in any previous decades. Realities on ground, therefore, suggest that the increased rainfall of the 1990s has not been significant enough to reverse the permanent down-south shift of activities by the Sahel and lower Sudan nomads to the lower Sudan and Guinea zones of the Savannah which was set in motion by the drought of the previous decade.

5.2 Ecosystems Perturbation and Change

Ecosystems are the most important resources of the Savannah on which the livelihoods of many of the rural inhabitants depend. Hence ecosystems change is perhaps the most visible effect of global climate change in the Nigeria Savannah. Its effects are all pervasive. Apart from the fact that ecosystems changes are central to global environmental change processes, they also significantly affect livelihoods of Savannah dwellers and thereby determine the spatial pattern of natural resources loss, trajectories of eco-migration, and land resource pressure and conflicts. The relationship between climate variability and human impacts, especially in the Savannah, is a vicious cycle. Decreased rainfall in the Savannah constrains human activities and thereby induces land degradation and loss of prime agricultural lands through synergistic effects of natural processes and human pressures on the land. This in turn exacerbates global climate change and its effects. Thus every year the intensity and effect of climate variability increases, pressure on available land resources increases, land degradation and resource loss increases, and the intensity of the forcings of climate variability also increases.

Table 4 summarizes the analysis of data on ecosystems change and ecological response to the impact of climate variability over the Savannah within a 19 year period (1976-1995).

The implications of climate change on ecosystems as well the implications of ecosystems changes on the environment and key human activities in the Savannah are summarized in the following discussions.

5.2.1 Agriculture

Agriculture is the major human activity in the Savannah, and it depends almost entirely on rainfall. Agriculture types and areas in the Savannah consist of agricultural tree and rainfed arable crop production of the Guinea Savannah, extensive small holder rainfed agriculture of the lower Sudan zone, intensive small holder rainfed agriculture with minor grazing of the upper Sudan zone, and extensive grazing with very little small-holder rainfed agriculture of the Sahel zone. Others include localized floodplain agriculture or Fadamas, irrigation projects or equipped wetlands and livestock projects.

Generally, between 1976 and 1995, the total area devoted to agriculture increased by about 20% which indicate about 1% annual growth. Specifically, while agricultural tree and crop production in the Guinea zone decreased by about 30%, rainfed arable crop production, extensive small holder rainfed agriculture with denuded areas, and extensive grazing areas increased by about 8000%, 129%, and 13% respectively. The decrease in the Guinea zone localized agriculture types which are balanced by the increase in Sudan and

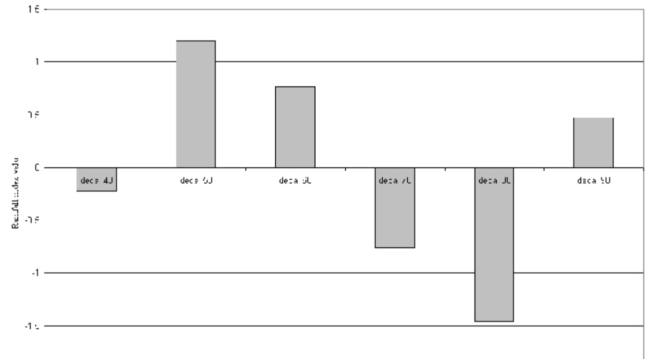

Fig 6: Temporal anomaly of rainfall.

Sahel agriculture types is a clear indication of extension of the Sahel and Sudan agriculture types to the Guinea zone. This clearly suggests effects of diminishing rainfall and by implication, effects of climate change and variability. The magnitude of influence exerted by population pressure on diminishing agricultural lands is indicated by the 117% increase in the area mapped as human settlements, which by extension led to 110% increase in floodplain agriculture (Fadamas) and 572% rise in irrigation agriculture.

5.2.2 Water resources and Wetlands

Water resource is a strong limiting factor of human habitation and livestock agriculture in the Savannah. Generally, within the period under review, areas mapped as water increased by about 47% over the 1976 extent. Specifically, the implication of climate change and human response to it is clear from the increase in the extent of water impoundments (reservoir and dams) which increased by 115% i.e. 6% per annum. This increase in water impoundment is also positively correlated with increase in Fadamas and irrigation agriculture. This shows human responses and adjustments to diminishing water resources in the Savannah. Increase in irrigation and floodplain agriculture as well as water impoundments is in turn leading to loss of natural wetlands. Within the period under review, natural wetlands decreased by about 52%. This is very significant because the biodiversity of these wetlands will be negatively impacted.

5.2.3 Grasslands and Woodlands

Green pastures and grasslands are important for livestock (animal) farming in the Savannah. Intensive fodders, feedlots and

Table 4: Ecosystems changes in the Savannah (1976-1995).

Sn	Ecological Classes	Coverage (km2) in 1976	Coverage (km2) in 1995	Change (km2) 1976-1995	Change (as % of 1976)	Change per annum (%)
1	Urban	1,250.03	2,724.40	1,474.37	117.95	6.21
2	Agriculture	403,870.26	483,739.62	79,869.36	19.78	1.04
3	Grassland	8,723.50	19,310.63	10,587.13	121.36	6.39
4	Woodlands/shrubs/tall grasses	277,635.71	175,212.50	-102,423.21	-36.89	-1.94
5	Forest/plantation	20,923.38	17,377.63	-3,545.75	-16.95	-0.89
6	Wetland	22,354.16	10,815.20	-11,538.96	-51.62	-2.72
7	Water	4,370.15	6,400.53	2,030.39	46.46	2.45
8	Sand/rock/gullies/mines	2,995.63	26,610.47	23,614.84	788.31	41.49

equipped grasslands are not available. Animals are moved from place to place in search of greener pastures virtually everyday. Generally, grassland increased by about 121% over the 19 year period. Although the increase in the area of grassland translates into increased grazing lands for animals, it also implies increased desiccation of former wood and shrub lands of the Guinea and lower Sudan zones of the Savannah. The implication is that the woodlands and shrublands of the southern Guinea forests are transiting to grassland at a rate of about 6% annually. This is a serious problem, because it is an indication of loss of resilience and stability by the Guinea zone ecosystems. This is also correlated with a 37% decrease in the extent of the wood and shrublands of the lower Sudan and Guinea zones. This strongly suggests that the lower zones of the savannah too are getting drier.

5.2.4 Forest and Plantation

Forests similar to those present in the southern rainforest zones are found in some parts of the lower Guinea zone of the Savannah. Galleria forests are found around wetlands and along river courses both in the Sudan and Sahel zones. Montane forests are also found in areas where local mountain perturbations produce orographic effects which significantly altered the vegetation. Forest plantations are mitigation responses to climate change effects. Trees are planted to act as shelter-belts and wind-breaks especially in the Sahel zone. In general, the area of forest reduced by about 17% (about 0.89% per annum) during the period under investigation. In specific terms, disturbed forests increased by 292%, undisturbed forests reduced by 90%, riparian and Montane forests reduced by 14% and 3% respectively, while forest plantation increased by about 213%.

5.2.5 Sand/rocks/gullies/mines

Another incontrovertible evidence of increased desiccation of the Sahel and by implication, the down-south march of the Sahara is the increase in areas covered by sand dunes. Reduced rainfall with its attendant pressure on land both for grazing and crop cultivation is also increasing the extent of exposed lands that are susceptible to soil degradation. In specific terms, area covered by Aeolian sand and gullies increased about 428% and 15,000% respectively, while fertile alluvial soils reduced by 41% during the period under review.

5.3 Climate change, human vulnerability and trajectory of resource conflicts

The discussions provided under rainfall anomaly have established strong signals of declining rainfall over the Savannah. Evidences from ecosystems change and diminishing natural resources have also established that the trajectory of landuse pressure and consequently, resource conflicts, is towards the lower Sudan and Guinea zones. If this trend of climatic variability and loss of natural resources is to be taken seriously, then existing adjustments and coping strategies of the rural communities in the Savannah may soon be outstripped. Hence, focused studies on climatic adaptation in the Savannah are urgently needed now to prevent future disaster.

However, for climatic adaptation studies, specifics such as the location and degree of vulnerability of each community are required in order to develop community (or group of communities) specific adaptation strategy. As noted in the methodology, a simplified vulnerability index, which is exploratory, is developed for a group of about 750 communities in the Nigerian Savannah. The index was based on the ecological zone of the Savannah where a community is located, the community status (rural, semi-urban, urban), administrative status, the degree to which the inhabitants are tied to the land (major occupation of inhabitants), and the availability of alternative livelihood sources in the face of climate change and diminishing land resources. Figure 7 presents the spatial perspectives of the degree of vulnerability of these communities.

The degree of vulnerability of communities in the different ecological zones of the Savannah is summarized on Table 5.

A total of 231 (of the 746) communities are categorized as highly vulnerable to the effects of climate change. Of these, 23 are located within the Sahel zone while 208 are located within the Sudan zone. These highly vulnerable communities appear to cluster around the northwest of the of Sudan zone. 351 communities fall under the medium vulnerability category and these consist of 38 in the Sahel, 158 in the Sudan, 134 in the Guinea and 21 in the upper rainforest zone. Low vulnerability communities are found mainly in the Guinea Savannah and there are 164 of these, with only 3 located in the Sahel, 8 in the Sudan, 104 in the Guinea and 49 in the forested area of the Guinea zone/lower rainforest. The spatial pattern of vulnerability of the communities clearly confirms that the trajectory of resource conflict in the Savannah is towards the south of the Sudan zone (i.e. the guinea zone). Clashes between communities and social groups on land resources is now a regular occurrence in these zones (Fasona and Omojola, 2005), and given the analyzed trends, conflicts over natural resources is likely to be intensified, except a drastic breaking solution is found soon.

Table 5: vulnerability of communities in different zones of the Savannah.

Vulnerability class	Sahel	Sudan	Guinea	Rainforest	Total
High	23	208	0	0	231
Medium	38	158	134	21	351
Low	3	8	104	49	164
Total	64	374	238	70	746

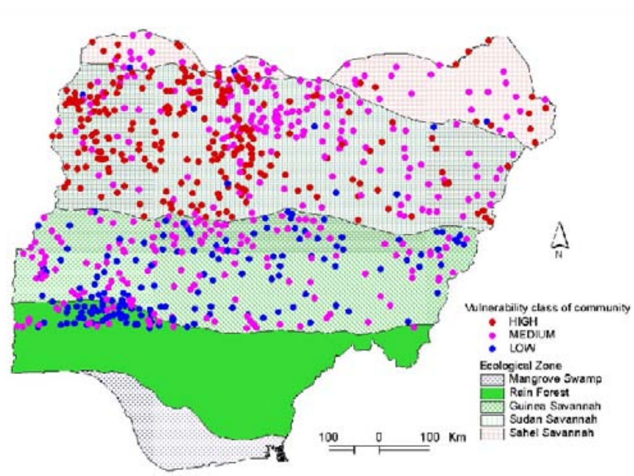

Figure 7: Vulnerability of communities to climate change in the Sahel.

6. CONCLUSIONS AND RECOMMENDATIONS

The results presented a classical case of the implications of climate change at sub-regional and local levels which may be very difficult for the global and regional climate models to capture. From the discussion under rainfall anomaly, it is clear that diminishing rainfall is a strong climatic forcing that has far reaching consequences for both natural ecosystems and human activities in the Savannah. The long term spatial anomaly of rainfall shows that the stations in the Sahel recorded strongly negative anomaly, while those in the Guinea recorded positive anomaly. The analysis on ecosystems changes and natural resources loss also indicate that critical ecologies including wetlands, forests, and arable lands are being lost, and degraded lands including Aeolian sands and gullies are increasing in extent. The results from the simplified vulnerability assessments also show the preponderance of highly vulnerable communities in the Sahel and Sudan zones, the loss of arable lands in the Sahel and Sudan and the opening up of forest lands and woodlands in the Guinea zone and upper rainforest are indication that the trajectory of landuse change, and, by implication, resource conflicts is towards the Guinea zone. Evidences on ground also suggest that these zones are fast becoming critical flash points of climate change induced human insecurity in Nigeria.

Apart from lack of consistent and focused government policy on agriculture, the most important trigger of agricultural decline in Nigeria is climate change and variability. Present adjustments and coping strategies by the rural communities in the Nigerian Savannah are multifarious. For cereals and other arable crop cultivation, Fadamas (wetland agriculture) have been intensified. Irrigation and equipped wetland farming is also on the increase. The government and some international organizations have also intensified planting of trees to serve as shelter breaks. For animal farming, the long range transhumance to the south for greener pasture has been intensified. There are more temporary and permanent Fulani herdsmen settlements in the Guinea Savannah and rainforest zones now than in the past. However, how sustainable these mitigation and coping strategies are in the face of obvious increased climatic variability is yet to be determined. However, it is clear that adaptation strategies to climate change will be more sustainable than the present coping strategies.

Any efforts at redeeming the present trend should aim first towards cooperation rather than competition among all actors and stakeholders – especially communities in the Guinea zone and the invading nomadic herdsmen from the Sahel and Sudan. Confidence building and tolerance among social groups are necessary for an enabling environment to introduce climatic adaptation strategies. Secondly, such efforts should also aim at making more arable and grazing lands available through restoration of already degraded and impoverished lands. Elements of such adaptation strategy will include sustainable all year round fodders and pastures for animals which will stem transhumance and the attendant conflicts in other ecological zones. This can be achieved through equipped grasslands and grazing areas to ensure all-year-round feed for animals. There is also the need to intensify research on animal fodder systems in Nigeria to sustain animals on hay and silage and feedlots which will reduce the search for greener pastures. Finally, there is need for adaptation research to improve local agriculture. Large scale afforestation projects can also create local perturbations that can positively alter the local climate and improve agriculture in both the Sudan and the Sahel zones.

The effects of climate change which are manifesting now are results of long and continuous neglect of the basic climatic signals of the past and gross under-investment in mitigation and adaptation strategies. Present remedy (coping mechanisms and adjustments) may be not be able to cope with future trends and effects of climate change. Therefore, the time is now for teamwork and cooperation among scientists, governments, policy makers and communities to develop friendly and robust adaptation strategies to future challenges of climate change in the Savannah.

References

German Advisory Council on Global Change (2000): World in Transition: Strategies for Managing Global Environmental Risks. Annual Report 1998. Springer-Verlag Berlin Heidelberg New York

Ojo, S.O (1987): The Climatic Drama. Inaugural Lecture Series, University of Lagos Press

Ramaswamy, V (2007): Lecture 5 on Radiation and Climate Change. Workshop on the Interdisciplinary Science of Global Climate Change: Basic Elements, University of Buenos Aires, Argentina, 12 March - 4 April, 2007. www.fcen.uba.ar/ictp1877

Adefolalu, D.O (2006): Weather events, Climate Variability and Change in relation to NEEDS and MDGS –'Problems and Prospects of the Nigerian Economy'. Inaugural Lecture series 9, Federal University of Technology, Minna, Nigeria

Fasona, M.J and Omojola, A.S (2005): Climate Change, Human Security and Communal Clashes in Nigeria. International Workshop on Human Security and Climate Change, Holmen Fjord Hotel, Asker, near Oslo, 22–23 June 2005, www.gechs.org/activities/holmen/Fasona_Omojola.pdf

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www.ipcc.ch

Climate Witness in Fiji: developing a generalizable method for assessing vulnerability andadaptation of mangroves and associated ecosystems

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ABSTRACT

Climate change (CC) and its impacts are gaining momentum which threatens the integrity and security of Pacific Island nations' natural ecosystems, economies and way of life that is intricately woven into the ocean, forests and the land. The key question for Pacific Island nations is then, how to proactively maintain or increase the resilience of its natural ecosystems to the impacts of climate change and hope for the best.

As a process to design an effective adaptive management strategy, WWF Fiji is working with local natural resource managers and other stakeholders to integrate CC adaptation strategies into their management philosophies and plans. Conservation of ecosystems and natural resources requires adaptive management, aggressive implementation or concede and accept that many natural ecosystems and biodiversity contained within them will be lost to climate change. A Global Environment Facility (GEF) funded global project is looking at developing a general approach for assessing vulnerability and adaptation of mangroves and associated ecosystems for which Fiji is one of 3 countries (including Tanzania & Cameroon) that will coordinate the testing of adaptation methods in geographically diverse locations within a common habitat type.

1.0 Project to build coastal resilience

The project goal is to ensure the long-term integrity of globally significant ecosystems by increasing resistance and resilience to climate change. Within this goal, the objective is to build and strengthen the capacity of conservation practitioners to promote effective vulnerability assessment and climate change adaptation projects and policies. A key activity to achieve this objective is the creation of a generalizable method and process to develop an effective adaptation strategy that could be applied in different sites within common ecosystems. The project will focus its activities on a single ecosystem type: mangroves and their associated systems, including near shore coral reefs in two project countries. The effectiveness of this approach and adaptation strategies for the ecosystems and communities involved will be tested via pilot initiatives in each of three project countries.

2.0 The need for a generalized method

Low-lying coastal areas, particularly those in tropical Africa and the South Pacific, are predicted to experience among the most dire consequences of global climate change (IPCC WGII TAR 2001). Despite the serious consequences of climate change impacts to these ecosystems, it is obvious that there is no mechanism by which the direct atmospheric effects (altered temperature regimes, precipitation patterns, extreme weather events, etc.) of climate change can be ameliorated in the short term. The current state of the science indicates that these changes are already occurring, are impacting ecosystems, will have profoundly more adverse impacts on ecosystems, and will continue to occur even after atmospheric CO_2 emissions are decreased during the long period of time to stabilization. Conservation of ecosystems and biological resources requires that we develop adaptive resource management strategies or accept that many natural systems may be lost to climate change.

There has been little development of methodologies for vulnerability assessments and strategies that are specifically useful across ecosystem type, or even between sites with common habitat type. Rather, most vulnerability assessments have focused on particular sectors or individual ecosystem types. In order for methodologies to be employable by resource managers and economically feasible, such a methodology needs to be advanced. By examining similar systems in multiple locations, the project aims to assist in the development of a generalizable method and replicable results between sites in mangrove, seagrass, and coral reef ecosystems.

This will also allow for development of regional scale planning, as well as to potentially promote ideas such as protected area networks and linkages between threatened systems (mangroves to seagrasses, coral reefs

3.0 Assessing vulnerability in Fiji

The project will first demonstrate a vulnerability assessment methodology to understand what aspects of the system are already experiencing climate change impacts or what aspects are most vulnerable to future impacts.

As a process to design an effective adaptive management strategy, the project will first demonstrate a vulnerability assessment methodology to understand what aspects of the system are already experiencing climate change impacts or what aspects are most vulnerable to future impacts given existing, non-climate stresses which could exacerbate problems cause by climate change or limit a system's ability to respond to environmental changes. The project will utilize and modify methods that have been developed by the IPCC and others to assess impacts on various ecosystems. Project proponents will build on the following general approach to assessing ecosystem vulnerability (Biringer et al. 2004):

1. Assess stresses to the system by modeling climate;
2. Analyze species distribution and conservation coverage;
3. Gather data on the extent of harvesting and/or resource use;
4. Understand the socioeconomic baseline; and
5. Analyze the adaptive capacity of the system in question by rating against the following factors: redundancy, complementarity, spatial heterogeneity, and memory.

The project will utilize and modify methods that have been developed by the IPCC and others to assess impacts on various ecosystems. The process for making these determinations is fairly standard, generally including three approaches: on-site experimental research, gathering information from the literature on studies already conducted, and scenarios based upon climate change model projections.

The best method is to have on-site experimental research to determine changes. Additionally and alternatively, information on impacts will be gleaned by reviewing the existing literature on nearby and similar regions, as well as consulting climate change model predictions. In the case of the latter two approaches, it is critical to consult multiple sources (several models, studies in several similar systems) in order to be inclusive of the potential variability of responses between different systems. The proposed project will involve a single ecosystem type (mangroves, and in two instances these will have associated near-shore coral reefs). This will allow for testing adaptation methods on geographically diverse locations of a common habitat type with the hope of increasing the effectiveness and replicability, i.e. develop generalizable methods and strategies.

During the process, the project will also attempt to assess what systems or aspects of the systems have greater resilience and resistance to climate change impacts. Coral reefs will serve as one variable to compare and contrast different mangroves systems by specifically analyzing whether their presence contributes to increased resilience and resistance. Many other system components that lead to increased resilience and resistance will also be studied. This type of information will assist in identifying sites that have greater long-term potential as ecosystem "refugia" from climate change impacts.

The project will also look into both proximal and confounding factors causing climate change impacts. For example, the proximal cause of coral bleaching is increased sea surface temperature, however there are many confounding variables that are suspected to exacerbate the rate of bleaching or hinder recovery from bleaching. These confounding factors include ultraviolet radiation, nutrients from terrestrial systems and resource extraction. By combining mangrove restoration with coral reef protection, the mutual benefits for surviving climate change can be assessed.

Based on the vulnerability assessment, the project will employ a participatory process to develop an adaptive management strategy. A response measure will be followed by actual implementation of pilot scale projects to examine and compare the effectiveness and feasibility of the strategy. These response measures will be unique for each selected site, not generalized, considering their ecological, economical, political, and cultural conditions.

3.1 Regional and national baselines

Fiji has the third largest mangrove area in the Pacific Island region, with eight true mangrove species and one hybrid (Ellision, 2004, and refs therein). The largest areas are on the SE and NW Viti Levu shorelines, and the northern shore of Vanua Levu, however, on many coastlines smaller mangrove areas exist that are significant to coastal stability and community usage. Climatic variation across the larger islands in Fiji influences mangrove distribution and ecology; this variation may serve as an indicator for how future changes in climate may affect Fiji's mangroves. The climatic variation also creates areas with opposing predicted changes in precipitation: dry areas are predicted to become even drier, and wet areas even wetter. Increasing temperatures will adversely affect mangroves; even more important may be the devastating effects of sea-level rise and increases in severe storms.

3.2 Project sites

Climatic variation across the larger islands in Fiji influences mangrove distribution and ecology, and different locations are expected to experience distinct effects of climate change. There will also be differences in the rate of sea level rise within Fiji, as certain areas are experiencing tectonic uplift or subsidence, while others are tectonically stable. Project activities will take place across sites in three areas, including Verata, Viti Levu and Vanua Levu.

From stakeholder consultation, sites were prioritized based on a list of criteria including being chosen on the context of existing programs; each site containing both degraded and intact mangrove habitat, to allow for comparison of reef health in relationship to mangrove health; identified as priority areas by NGOs or academics for mangroves, corals, or biodiversity in general. Sites included areas in both wet and dry areas, subsiding and tectonically stable areas.

Figure 1. Fiji map illustrating pre-selected sites of the Climate Change Coastal Resilience Project. Three of the five pre-selected sites have been confirmed as Fiji country level demonstration sites for developing a generalizable method for assessing vulnerability and adaptation of mangroves and associated ecosystems.

4.0 Climate Witness Program

As a complimenting tool for linking the science to community adaptation, WWF-Fiji has developed a Climate Witness Toolkit specifically to gauge community awareness on CC and to proactively develop community CC " no regrets" Adaptation Plans and implement them. The toolkit targets two key outputs, which are to collect and document stories from target communities to highlight the multifarious impacts climate change has and is having on these communities, to draw out and enhance the human face of the whole climate change phenomenon and debate on a global platform and getting developed nations such as the United States and Australia to ratify the Kyoto Protocol and more aggressive mitigation of Greenhouse Gases internationally. The second overarching purpose of is to raise climate change awareness within these Pacific Island communities and empower them to take assertive steps and actions to increase their resilience to the adverse impacts of Climate Change, through developing and implementing adaptation action plans.

Improved land/marine use planning is a key aspect of adaptation strategies to build resilience and resistance. For example, protected areas can be designed to better allow for species, population and ecosystem preservation in light of mounting climate change related pressures. This can include altering reserve design to include habitat refugia, adding robust corridors, linking reserves of different habitat types (such as marine and mangrove), or changing use allowances during periods of added stress.

In the case of mangroves, a central strategy is restoration of degraded systems, along with protection of intact systems. Restoration is applied in a strategic way, where the re-establishment of degraded sites in order to restore water quality and soil stabilization may be the only option to assist species' survival as tides move in at rates that may be higher than natural rates of migration for key mangrove species. Viewed in this way, restoration of mangrove systems can be seen as a low-cost preventative , and also 'no regrets' strategy for ensuring the health of the wider coastal and marine system on which many species and communities depend.

5.0 References

Alusa, A. L. and L. J. Ogallo, 1992. Implications of expected climate change in the Eastern African coastal region: An overview. UNEP Regional Seas Program Reports and Studies No. 149. 28pp

Anderson, S., R.G. Zepp, J. Machula, D. Santavy, L. Hansen and E. Mueller. 2001. Indicators of UV Exposure in Corals and Their Relevance to Global Climate Change and Coral Bleaching. Human and Ecological Risk Assessment. 7(5):1271-1282

Benioff, R., S. Guill, and J. Lee (eds). 1996. Vulnerability and Adaptation Assessments: An International Guidebook. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Carter, T.R., M.L. Parry, H. Harasawa, and S. Nishioka. 1994. IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations. Department of Geography, University College, London.

Dahdouh-Guebas, F., C. Mathenge, J.G. Kairo & N. Koedam. 2000. Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. Economic Botany 54(4): 513-527.

Ellison, A.M. 2000. Mangrove Restoration: Do We Know Enough? Restoration Ecology 8(3):219-229

Ellison, A.M. and E. J. Farnsworth. 1997. Simulated sea level change alters anatomy, physiology, growth, and reproduction of red mangrove (Thizophora mangle L.). Oecologia 112:435-446.

Ellison, J.C. 2004. Vulnerability of Fiji's Mangroves and associated Coral Reefs to Climate Change. Unpub. review for World Wildlife Fund.

Farnsworth, E. J. and A. M. Ellison. 1997. The global conservation status of mangroves. Ambio 26(6):328•334.

Feenstra, J.F., I. Burton, J. Smith, and R.S.J. Tol (eds.). 1998. Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies. UNEP and Institute for Environmental Studies, Vrije Univrsiteit, Amsterdam, The Netherlands. Available at http://130.37.129.100/english/o_o/instituten/IVM/research/climatechange/Handbook.htm

Fiji Government. 2002. Fiji's National Assessment Report 2002. Country Report to the World Summit on Sustainable Development, Johannesburg.

Hansen, L.J., Biringer, J., and Hoffman, J.R. (Editors) 2003 Buying Time: A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems. World Wildlife Fund, Gland.

IPCC. 1998. The Regional Impacts of Climate Change: An Assessment of Vulnerability. Cambridge University Press.

IPCC. 2001. Third Assessment Report: Working Group II: Impacts, Adaptation, and Vulnerability. Cambridge University Press.

Kairo, J. G. 2001. Ecology and restoration of mangrove systems in Kenya. Unpl. PhD Dissertation, Department of Biology, University of Brussels, Belgium.

Kaly, U.L., and G. P. Jonnes, 1998. Mangrove restoration: a potential tool for coastal management in tropical developing countries. Ambio 27: 656 - 661.

Kates, R.W., J. Ausubel, and M. Berberian (eds). 1985. Climate Impact Assessment. Studies of the Interaction of Climate and Society. Scientific Committee on Problems of the Environment. SCOPE Report No. 27. John Wiley and Sons, Chichester, United Kingdom.

Macintosh, D.J. and E.C. Ashton. 2002. A Review of Mangrove Biodiversity Conservation and Management. Centre for Tropical Ecosystems Research. University of Aarhus, Denmark.

Mazda, Y., Y. Sato, Sawamoto, S. Yokochi, H. Wolanski, E. 1990. "Links between physical, chemical and biological processes in Bashita-minato, a mangrove swamp in Japan." Estuarine Coastal and Shelf Science 31(6): 817-834.

McLusky, D.S., V.Bryant and R. Campbell. 1986. The effects of temperature and salinity on the toxicity of heavy metals to marine and estuarine invertebrates. Oceanography & Marine Biology: An Annual Review 24:481-520.

Ministere De l'Environnement et des Forets (MINEF). 1998. Final report on GEF project 2200-96-09, "Cameroon country case studies on climate change impacts and adaptation assessments"

Mumby, P.J., A.J. Edwards, J.E. Arias-Gonzalez, K.C. Lindeman, P.G. Blackwell, A. Gall, M.I. Gorczynska,

A.R. Har borne, C.L. Pescod, H. Renken, C.C.C. Wabnitz, and G. Llewellyn. 2004. Mangroves enhance the biomass of coral reef fish communities in the Carribean. Nature 427:533-536

Nganje, Martin. 1999. Potential of Mangroves and Mangrove Resources in Cameroon: With Elements on Sensitisation and Restoration. Ministry of the Environment and Forestry, Department of Forestry Studies and Planning Unit, Republic of Cameroon.

Parmesan, C., and G. Yohe, 2003: A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42

Pernetta, J.C. 1995. Mangrove Forests, Climate Change, and Sea-level Rise. IUCN

Richmond, T.D.A & J.M. Ackerman. 1975. Flora and Fauna of Mangrove formations in Viti Levu and Vanua Levu - Fiji.

Rubens, J and S. Kazimoto. 2003. Mafia Island: a demonstration case: application of the WCPA-Marine/WWF Guidebook on Evaluating Effective Management in MPAs. Online at http://effectivempa.noaa.gov/cases/MafiaIsland.pdf

Salm, R. V. 1995. Marine Biodiversity of the Western Indian Ocean: Status and conservation framework. P. 101 - 130. In: O. Linden, ed. Workshop and policy conference on integrated coastal management in Eastern Africa including the Island states. Coastal Management Centre (CMC) Conference Proceedings 1. 371pp. Metro Manila, Philippine

Salvat, B. 1992. Coral Reefs- a challenging ecosystem for human societies. Global Environmental Change 2:12-18.

Scott, D.A.(ed). 1993. A Directory of Wetlands in Oceania IWRB, Slimbridge, UK and AWB, Kuala Lumpur, Malaysia.

Smith, S.V. and Buddemeier, R.W. 1992. Global change and coral reef ecosystems. Annual Review Ecology Systematics 23:89-118.

Watling, D. 1985. A Mangrove Management Plan for Fiji Phase 1, Fiji Government Press, Suva.

West, J.M. and R.V. Salm. 2003. Resistance and Resilience to Coral Bleaching: Implications for Coral Reef Conservation and Management. Conservation Biology 17:956-967

World Bank, International Society for Mangrove Ecosystems, and Centre for Tropical Ecosystems Research. 2003. Draft Code of Conduct for the Sustainable Management of Mangrove Ecosystems. www.mangroverestoration.com/ MBC_Code_AAA_WB070803_TN.pdf

WWF. 2001. The World's Top Ten Most Vulnerable Forest Ecoregions

Vulnerability and the social economy: adaptation to climate change in the Upper Zambezi Valley floodplain

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Fieldwork for this paper was carried out in Western Zambia in 2001-2, 2004, 2005 and again from January to April 2007 with the assistance of the Zambian NGO, Barotseland.com, and the Zambia Meteorological Department's officers in Lusaka and Mongu. Statistical climate information was supplied by AWhere Inc., a commercial organisation based in the USA.

Abstract

This paper examines a floodplain ecosystem that, like all ecosystems, has physical and human inputs, processes and outputs. It narrates and analyses the interaction of social and physical processes working in tandem to influence environmental change and render socio-ecological networks and balances vulnerable to breakdown or failure and examines the potential for adaptation to these outcomes. Climate change and variability are fundamental mediators of environmental change impacting on ecosystems and their stability. However they are crosscut by socio-economic, political and cultural dynamics that distort, exacerbate or dilute the impacts of climate change. Meanwhile, the impacts of climate change are enacted in an arena of subjective human dynamics that impact materially on the production of environmental change and structural frameworks in which adaptive measures can be taken.

The geographical focus of this study is the Bulozi floodplain in the Upper Zambezi Valley region of western Zambia.[1] The valley has experienced several phases of climate change and intense human activity (the floodplain maintains a population today of around 225,000 people with a further 200,000 or so scattered around its edges) that have impacted on the local hydrological system and the occurrence, variety and scale of flora and fauna upon which local people depend.

The study summarises potential social adaptation to the negative impacts of climate aggravated dynamics in the case-study region, concomitantly suggesting unrealised potential among existing resources as well as potential for adaptation. The study argues that vulnerability in the case study region is being exacerbated by inadequate or inappropriate institutional capacity and policy-making, poor communications and other infrastructure, historical socio-economic processes such as regional conflict, low technology and skills, poor economic performance and lack of resources. However, adaptation is a positive process of creating choices and alternatives that reduce vulnerability and envisions climate change as a definable set of threats and opportunities.

Abbreviations

BRE – Barotse Royal Establishment
FAO – Food and Agricultural Organisation
ITCZ – Inter-Tropical Convergence Zone
JICA – Japanese International Cooperation Agency
NAPA – National Adaptation Plan of Action
NGO – Non-Governmental Organisation
PRSP - Poverty Reduction Strategy Paper

1. Introduction: contextualisation

The floodplain of the upper Zambezi Valley, known locally as Bulozi, comprises an ecosystem potentially capable of sustaining the human population not just of the plain (approximately 225 000 people) but also of those along the plain margins and surrounding areas (making around 425 000 in total). This situation has pertained throughout recorded human habitation of the area. David Livingstone was one of the first to realise the potential of the valley and was astonished to note that 'the people are never in want of grain,' and that local people claim, 'Here hunger is not known' (Livingstone, 1857: 215). He recorded that, 'Here the Banyeti have fine gardens, and raise great quantities of maize, millet and native corn (sorghum), of large grain and beautifully white. They grow also yams, sugar-cane, the Egyptian arum, sweet potato, two kinds of manioc or cassava…, besides pumpkin, melons, beans, and ground nuts.' These, '…with fine large herds of cattle quietly grazing on the succulent green herbage,' and '…with plenty of fish in the river, its branches and lagoons, wild fruits and water fowl, always make the people refer to the Barotse as a land of plenty' (Livingstone, 1857: 220).

Writers on the region including Gluckman (1941) Maclean (1965), Van Horn (1977), Van Gils (1988) and Kajoba (1993) have appreciated the food producing potential of the plain and surrounding margin areas for food production to assuage local needs and provide surplus. It is difficult to assess local population dynamics but early travellers such as Livingstone and missionaries such as Coillard described densely populated village clusters. Some outmigration took place in the colonial era and considerable rural-urban migration since independence in 1964 and while numbers are on the rise again more recently due to refugee influx from Angola and natural increase, the actual numbers of people in the region have probably not fluctuated that much in the last 150years or so.

Since the early decades of the twentieth century however, the ability of the Bulozi plain to provide enough food to meet local needs has gradually diminished. In reviewing food production dynamics in the region, Peters (1960), Gluckman (1968) and Van Horn (1977) were alarmed to record increasing food shortages and the appearance of an import economy. Since independence in 1965, the Western Province of Zambia has attained the unfortunate sobriquet of poorest in the country with levels of human development lagging behind those obtained in other regions. Moreover, while nearby Angola languished in civil war, Caprivi to the south (part of Namibia), enjoyed correspondingly higher standards of living from the 1960s, thanks to its geopolitical significance to the former colonial South African regime and to the independent Republic of Namibia. As Caprivi used to be a southern component of Lozi influence, its comparative well-being became a source of humiliation to a people whose cultural identity was premised on being the most powerful and wealthy in the region.

Explanations for this changed state of affairs, from resilience to vulnerability, are varied and range across human (specifically political and socio-economic) and physical processes that have combined to constrain and reduce the productive output of the region. By far the most acute of these processes have been human, consisting of: an invasion and occupation in the nineteenth century by the Sotho-led Makololo, followed by decades of internal conflict that disrupted productive activity; British colonial policy that saw the only value in the region in terms of migrant labour to the mines of South Africa and plantations of Southern Rhodesia; and, the perceptions held by the First and Second Republics of Zambia from 1964 to 1990 of the region as a hot-bed of potential insurrection and secessionism. This led to the withholding of development aid and assistance, particularly for projects that sought to improve basic infrastructure such as roads and telecommunications.

A further constraint has been on the provision of modern forms of energy to underpin socio-economic development. Markets in the region have remained underdeveloped as little processing is carried out locally, money has always been scarce and the ability to move raw and processed produce to developed markets and cities such as Lusaka and the Copperbelt have been hampered by poorly maintained arteries of communication.

Added to this, in recent decades, climate change has started to produce noticeable changes in weather regimes both in the plain and in the highland regions of Angola that supply rainwater to the Zambezi upstream of the plain, that are having impacts not only on traditional modes of production but also on people's ability to survive in the plain. Here I refer to increasing severe drought, devastating winds and scorching sun accompanied by intense daytime heat and colder nights in winter, interspersed with rainy seasons comprising heavy torrential downpours, electric storms and floods that arrive unexpectedly and with greater velocity (across the floodplain) than before, inundating to a greater depth.[2] The combined effect of these changing dynamics has been loss of crops, washing away of homesteads and villages, damage to infrastructure and, in dry years, desiccation of previously fertile land, famine and increased rural-urban migration.

Exacerbating the purely objective material results of these processes of change has been the impact on culture, morale and people's identification of self, society and others. The effect of changes to these subjective, metaphysical properties have far reaching potentialities In a rapidly globalising world, peripheralising tendencies inherent to the capitalist world economy have served to create social and economic relations of dependence and inequalities that have proven practically impossible to diminish in spite of more than fifty years of 'development' activity and paradigmatic rhetoric.

In terms of Africa and its location in the debate on climate change and variability, the continent is often cited as the most vulnerable to negative impacts. This is ascribed to lack of knowledge and information, a shortage of skills and technologies, lack of infrastructure, and most crushing of all, lack of resources to correct this lack of adaptive capacity. The impacts on society and culture have led to a peculiar mentality prevailing across much of the continent that is 'postcolonial' in nature. This mentality suggests that positive change and the resources to underpin such change only come from outside sources and bodies and that if such input fails to arrive, there are insufficient or inadequate resources to address domestic impoverishment and visible imbalances of power and wealth. There are a number of repercussions resulting from this, one of which is the intensification of migration to the cities of Africa and to developed countries in Europe and North America where the most adept African skills and knowledge are invested.

That this should be the case derives partly from the lack of progress made in reducing poverty and eliminating the vast differentials in wealth, living standards and opportunities (choice) between the north and south and between the narrow urban elites (*comprador* class)and the rest of the population of developing countries. Perhaps the single biggest barrier to defeating poverty is food insecurity and self sufficiency; overcoming which enabled Europe to undergo an industrial revolution. Meanwhile, the pervading feeling of unchangeability that endures across much of Sub-Saharan Africa represents one of the biggest constraints to effective and sustainable adaptation. And herein lies a big irony because the continent has the potential to be self-sufficient in food and produce surpluses using existing resources and without overstepping the balance between utilisation and regeneration capability of biocapacity (ecological footprint). Nevertheless, food, energy and water insecurity are just some of the related factors affecting overall human security.

Added to these and integral to all aspects of human security is socio-cultural security. Here I refer to the meanings and values that local communities attach to the symbiotic relationship with their physical and metaphysical environments. Nowhere is this better demonstrated than in western Zambia where images of homeland are emblazoned by visions of a flat expanse of land (the floodplain), green in one season, blue with water in another and yellowish brown in the third in which the climate plays a crucial role in the historical construction of social and cultural identity that has bound the Lozi peoples together as an ethnie, according to Smith's description (Smith, 1998), since earliest known times. These images exist in the minds even of those who have never visited Bulozi and become part of an imagined homeland in the same way that many English think of green rolling fields and village cricket greens even though these same people have rarely if ever been exposed to such images in reality (Short, 2005). In the Bulozi floodplain of western Zambia meanwhile, water has always been key to notions of homeland, security from enemies, production of food and, as important as all these, reproduction of culture. Lozis the world over dream of their homeland through imagined images of water, grass, canoes and cattle.

Meanwhile, as much of Africa appears to languish in water, food and energy shortages, and while populations continue to increase and become more dense, particularly in urban and peri-urban areas, putting extra pressure on environmental resources, the continent continues to enjoy considerable, if diminishing, resources to address these shortages. The problem lies in effectively harnessing them. In western Zambia, the continent's fourth largest river flows majestically through a region beset by increasing water scarcity during much of the year. Of course, it is true that, like other semi-arid tropical regions on both sides of the equator, Western Zambia is affected by more erratic movements of the Inter-Tropical Convergence Zone (ITCZ), and it seems likely that precipitation will decline, (although there is not much evidence of this overall to date), the diurnal range will increase and biophysical changes will occur and impact on local ecosystems.

Clearly, climate variability is having a serious impact, not least because there is so little advance warning of unusual or extreme weather available. That said, there should be no water shortage in the floodplain. In addition, with such a vast quantity of water flowing along perennial streams such as the Zambezi, Lungwebungu, Luanginga and Kafue, there should be considerably more locally produced energy availability. As a country, Zambia possesses abundant water resources, therefore, does not rely on other countries for its water resources despite its dependency ratio of 24% (FAO, 2005).

The focus on western Zambia is not a random choice. Herein lies a region capable of growing and grazing enough food for itself and for the wider region thereby providing wealth for its inhabitants beyond subsistence. This potential was taken cognisance in both the colonial and postcolonial eras as mentioned already. In 1951, the colonial Department of Agriculture for Northern Rhodesia stated as its policy for Barotseland, '…first to increase the production of food so that the Province becomes self-sufficient…, second to replace existing woodland cassava with crops of more nutritious value and three, to increase agricultural production to... provide an exportable surplus' (Maclean, 1965: 23). In 1986, the Government of Zambia noted the need to rehabilitate the indigenous agronomic systems of the floodplain which, it said, clearly still have the capacity to reduce or eliminate food insecurity in the region. This should be achieved, it said, through a combination of old and new drainage techniques, a reappraisal of agricultural and transhumance interrelationships and diversification of food crops (Kajoba, 1993).

The challenge today is similar to that articulated previously: to re-enable, through adaptation, latent indigenous capacity with a combination of traditional knowledge systems, and new technologies for cultivation, livestock, energy production, climate understanding and prediction and the need for enabling resources such as labour, skills, finance and access to markets. Further requirements are sensible use of land in the context of cultural norms regarding land ownership and tenure.

The objective is to create small sustainable adaptation projects that enhance existing production, create new production and help to strengthen social and cultural bonds that tie people to their land and the wider diaspora where emigrants are disseminated. From these small projects, research into the relative success and failure can establish which can go forward to larger implementation elsewhere.

Finally, it is argued that, in spite of human induced vulnerability, climate change, population increase and labour migration, the floodplain region of Western Zambia could still become a breadbasket region of Zambia and the sub-region on the basis of existing soil, predicted climate conditions and sensible adaptation strategies that take account of pre-existing indigenous knowledge networks and new technologies and choice and alternatives.

In fact, climate change itself may catalyse research into indigenous systems that have worked well in the past and, in seeking adaptation strategies to deal with current climate changes can intensify and increase opportunities for production from existing resources. This paper will investigate some of the issues relevant to this argument, specifically in the realm of water, in terms of supply, efficiency and the relationship between a people and water in terms of identity, culture and value.

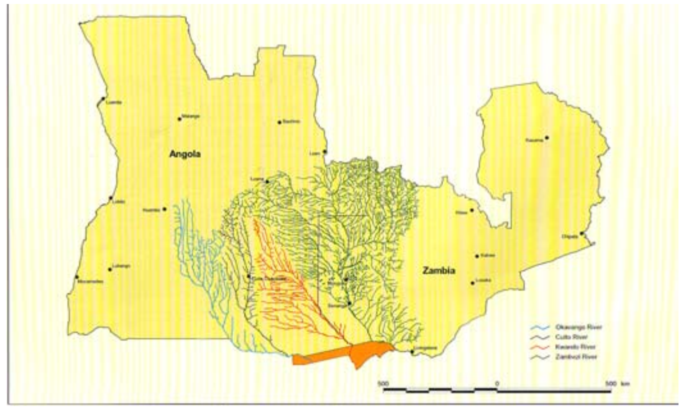

Figure 1. Dendritic map of Upper Zambezi Valley Basin also showing Okavango (in blue) and Kwando (in red) with the Zambezi proper in green and the Bulozi floodplain outlined in maroon.

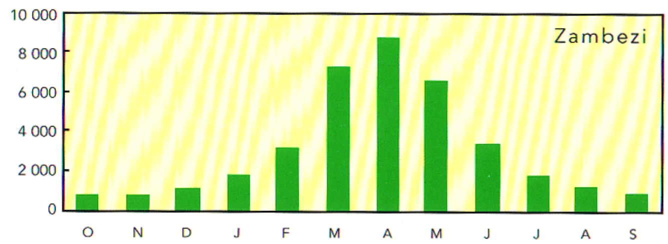

Figure 2. Chart showing flow over the Victoria Falls of the Zambezi River in m³/s by month.

2. Climate change, variability and the production of vulnerability

At 2,600 km from source to ocean, the Zambezi is the fourth longest river in Africa whilst the area of its basin at 136 million hectares, is populated by roughly 25.5 million people (Hoekstra et al, 2000). Meanwhile, the Upper Zambezi Basin has been described as one of the world's most complex due to the many intermittent feeder rivers and streams and the flood regulating effects of the Bulozi floodplain, which is the focus of this study, and the Chobe swamps (see Figure 1). Annual discharge at the confluence of the Chobe and Zambezi is estimated at 33.5 km^3 while that of the Chobe alone amounts to some 4.1 km^3 (Mendelsohn and Roberts 1997). However, this flow is very unevenly distributed throughout the year as can be seen in Figure 2, which demonstrates very graphically why water is, in normal years in plenty at one end of the year and serious scarcity in the middle of the dry season.

The Upper Zambezi River may be regarded as 'free flow' as there are no artificial dams to regulate the flow, which is subject to substantial seasonal variation. In the middle of the wet season, water discharge over the Victoria Falls can amount to 9,100 m^3/s while at the height of the dry season it can diminish to as little as 350 m^3/s (see Figure 2). Throughout the year, new channels open and close with the rise and fall in water levels, particularly in the floodplain where ox-bow lakes are a frequent occurrence as the main stream migrates and divides. Between the Bulozi and Chobe floodplains, the river contains numerous heavily wooded islands that are dissected by channels that may be several kilometres in length and vary in width from one to twenty metres.

The Bulozi floodplain is a verdant grassland during the rainy season and up to the point when all moisture has subsided from the surface strata. During the remainder of the year, the plain becomes a sun-scorched thirstland, scoured by desiccating winds. During this time the grass turns yellow and dies back, to be burnt in October in extensive man-made fires ahead of the next rainy season. Traditionally, this burning was carried out to leave behind ash which to fertilised the soil. In contemporary times, however, this burning has become so extensive that substantial pollution of the local atmosphere is caused by heavy concentrations of particulates which cause health problems, obscure visibility and contribute to greenhouse gas emissions. Vegetation on the sand-covered surrounding uplands on both sides of the plain comprise low canopy woodland sprinkled with rapidly disappearing hardwoods such as Rhodesian teak and rosewood. To the west, woodland gives way in some areas to extensive savannah grassland plains such as those that exist in the Liuwa National Park. These arid upland areas are interspersed with dambos and pans on and around which cultivation takes place on clay outcrops.

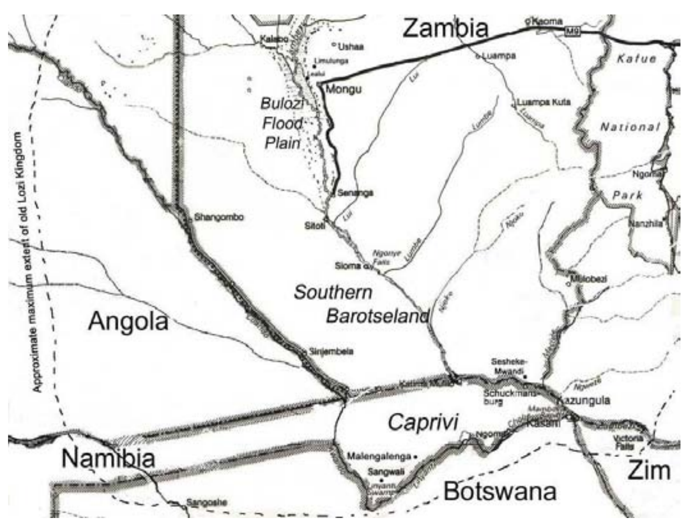

Figure 3.Geopolitical map of region (adapted From Fisch 1999).

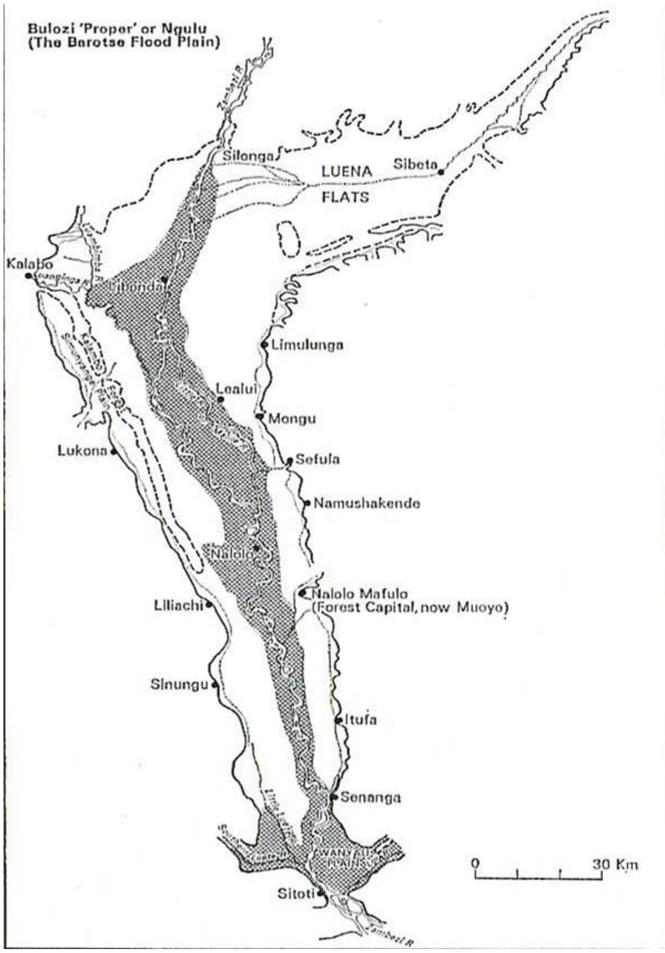

Figure 4. Map showing approximate shape of Floodplain and extent of inundation (from Bull 1973).

Meanwhile, the Upper Zambezi Valley and the Bulozi floodplain, in particular, comprise the productive and socio-cultural lifeblood for close to one million people living in western Zambia, southeastern Angola, northeastern Namibia and Northern Botswana (see Figures 3 and 4 for maps of the region). This lifeblood should be understood in terms of water for life support, agriculture and the reproduction of culture and heritage, which also impact on human security.

The floodplain is an integral and unique component of the Upper Zambezi Valley, situated wholly in western Zambia, measuring roughly 200 km in length and 70 km at its widest point (see Figure 1 above). The water and swamp area therein covers approximately 7,500 km^2 at the height of inundation. The peoples of the plain, who are collectively known as the Lozi peoples, number approximately 225,000 while a further 200,000 or so live along the plain margins (the total population of Western Province is around 650,000). These figures are very approximate due to the unreliability of census data and are subject to seasonal fluctuation as well as short-term migrancy flows to and from nearby Angola which is still recovering from a 30-year civil war.

The plain, together with the Chobe swamps further downstream in northeastern Namibia and northern Botswana, acts as a filter to water flowing from Angola and northwestern Zambia so that the water flowing over the Victoria Falls actually carries very little sediment load (Du Toit, 1983). This has been left as a fertile layer in the aforementioned floodplains overlying the Kalahari sands typical of the region, supporting the flora and fauna as well as the human security of the local population. In short, the river is central to the life support system of the region.

The Zambezi basin overall, like the Nile Basin, has low 'run-off efficiency' and a high dryness index, increasing its vulnerability to climate change (Riebsame et al., 1995). The climate of the Upper Zambezi Valley comprises three seasons, the boundaries of which, increasingly overlap. These are: warm and dry days with cool nights and desiccating winds from April to August; hot and dry from August to December; and warm and rainy from November/December to April. Rainfall averages around 1000mm per annum decreasing from north to south (Zambia Meteorological Department, 1987). The valley is especially sensitive to climate warming as it receives considerable sunshine and high daytime air temperatures (Riebsame et al., 1995), making it the subject of high rates of evapotranspiration (see Figure 8 below). Indeed, the rate of evaporation in the upper basin of the Zambezi is already so great that an estimated two-thirds of the region's precipitation is lost in this way (Pinay, 1988). Thus, even when precipitation increases, related run-off decreases due to the enhanced hydrological role played by evaporation.

A significant factor in the quantity and quality of water entering the plain is that most of the precipitation that mediates the level of inundation takes place in the central highlands of Angola and in the Congo-Zambezi watershed region. Precipitation in the plain and surrounding area do make a contribution to run-off but do not impact heavily on flood levels which are mediated by the Zambezi and its major affluents, the Kabompo, Lungwe-bungu, Luena and Luanginga. Therefore any interference with the flow of water upstream that might be associated with deforestation on the slopes of the Angolan highlands or by creating a barrage or just from climate change occurring in the watershed regions has an immediate knock-on effect in the Bulozi floodplain contributing to the extreme sensitivity of the system there.

Nevertheless, local climate does have a substantial impact on the floodplain ecosystem and on associated lives and livelihoods. Local people presented evidence during field surveys in January and June 2007 of increasing occurrence of weather extremes that were impacting on social and ecological systems. These consisted of very heavy storms (heavy storms are normal in the Bulozi rainy season) at unusual times of the year causing havoc and damage to infrastructure and livelihood activities. It was also reported that the plain dries out much quicker after the flood has receded due to desiccating dry, dust-laden winds that choke animals, humans and crops, and quickly put an end to the green grass that grows during the inundation. This has resulted in the failure of a previously mostly rain and flood fed system of agriculture to produce harvests during the dry season. Irrigation is still a novelty in the floodplain and even around the margins which traditionally rely on seepage zones from the surrounding higher land.

People continually speak of extremes of temperature, more intense daytime heat during the hot dry season and, ironically, warmer days with colder nights during the winter season after the flood goes down. Thus the diurnal range is increasing. Both of these are having impacts, not only on productive activity but also on health indicators both in terms of heat and cold stress and, in the hot season, on death from vector-borne diseases, particularly malaria. Seasoned commentators of the region will naturally refer to the fact that Bulozi has always experienced some extremes of climate but this should not be allowed to mask the very real variations that are occurring and research into recent climate activity compared with the past bears out what local people are stating.

The graph in Figure 5 shows precipitation levels recorded at Mongu over the last century and the pattern that appears suggests intradecadal cycles of more intense years interspersed by drier spells. Overall, there is little evidence to date of a big decrease in rainfall. However, if we examine the amount of rain that falls per day (unfortunately no graphical evidence of this can be presented yet), one discovers similar quantities of rain falling in the first decade of the twenty-first century as throughout the twentieth but in more intense events with vastly increased run-off and at unexpected times.

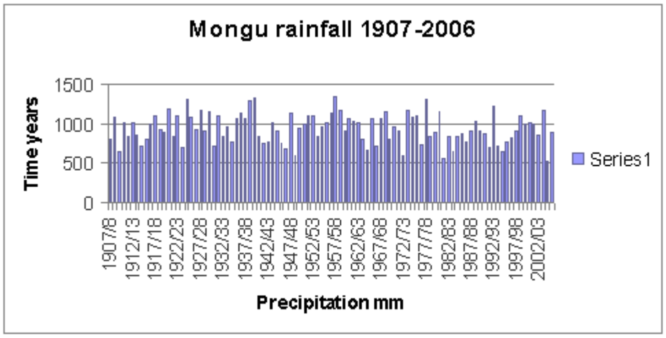

Figure 5. Precipitation recorded at Mongu Airport, Western Zambia between 1906 and 2005 in mm per year.

With temperature, the position is clearer. Figure 6 clearly shows that maximum and minimum temperatures have been increasing in the dry hot season, while minimum temperatures in the cold season have indeed, been decreasing. Meanwhile, Figures 7 and 8 demonstrate the trend even more graphically showing a discernible increase in the number of days when the temperature exceeded 26 and 33 degrees C respectively and that the hot season is shifting forward in time, simultaneously becoming prolonged. Even more significant is the fact that the comparison made here is between the present and a relatively recent past.

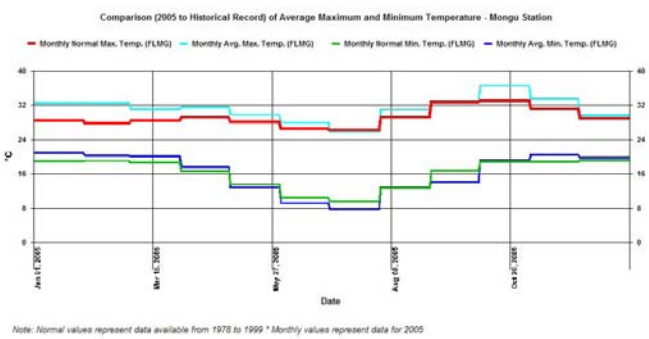

Figure 6. Shows the trend towards increased diurnal range between the period 1978- 1999 (in red and green) and 2000-2006 (light blue and dark blue) (Supplied by AWhere Inc.).

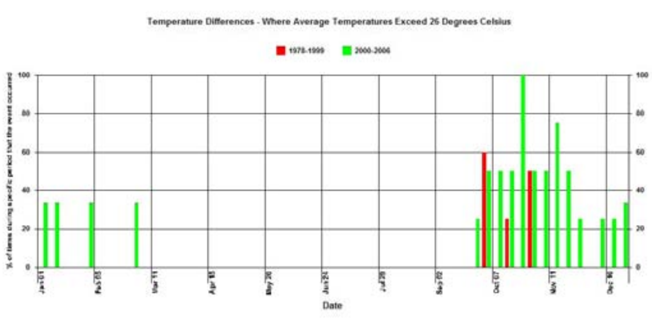

Figure 7. Shows the number of days when average temperatures exceeded 26ºC comparing the period 1978-199 (in red) and 2000-2006 (in green). Here it is also easy to see the the hot season is becoming prolonged (Supplied by AWhere Inc.).

Thus it becomes possible to begin assessing vulnerability according to the sensitivity of the system. These studies are still in the early stage and are hampered by the lack of recording stations that supply information to climate modelling and recording organisations and institutions (see Figure 9). The Zambian Meteorological Department does have more recording stations and, although the data is inconsistent, these show marked differences in climate statistics between the northern and southern extremities of the floodplain. What information exists will have to examined in considerable detail together with experiential evidence collected from across the region in order to produce a reliable map of climate vulnerability for the region.

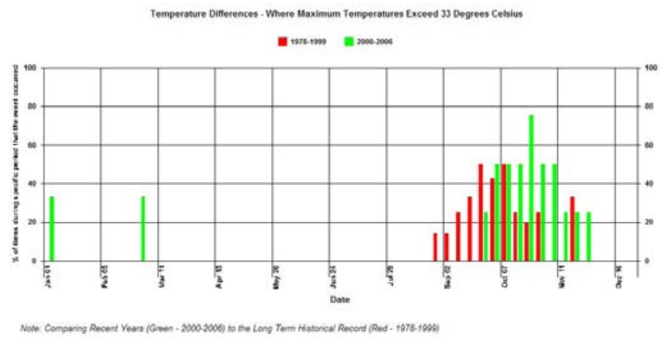

Figure 8. Shows the number of days when average temperatures exceeded 33ºC comparing the period 1978-1999 (in red) and 2000-2006 (in green). Here it is also easy to see the hot season is becoming prolonged (supplied by AWhere Inc.).

Figure 9. A map showing the lack of weather stations in Western Zambia and the approximate location of the Bulozi floodplain (maroon outline) (adapted from diagram supplied by AWhere Inc.).

The information in these graphics can be overlaid with information on evaporation (see Figure 10) which shows the west and south of Zambia as particularly vulnerable to this process which, with increasing temperatures, adds to the volume of water lost as demonstrated in the graph in Figure 11 which shows declining flows over the Victoria Falls between the middle of the last century and the present day.

As a secondary indicator of sensitivity and vulnerability impacting on socio-economic processes, one should examine the quantity of water arriving in the plain, particularly between December and April and the speed of its arrival. This determines subsequent outflow from the plain south to Caprivi in the northeastern panhandle of Namibia where flooding also occurs in the Chobe swamps (although later than in Bulozi), over the Victoria Falls contributing also to the flow arriving at the Kariba and Cabora Bassa dams. The latter three are all associated with electricity production.

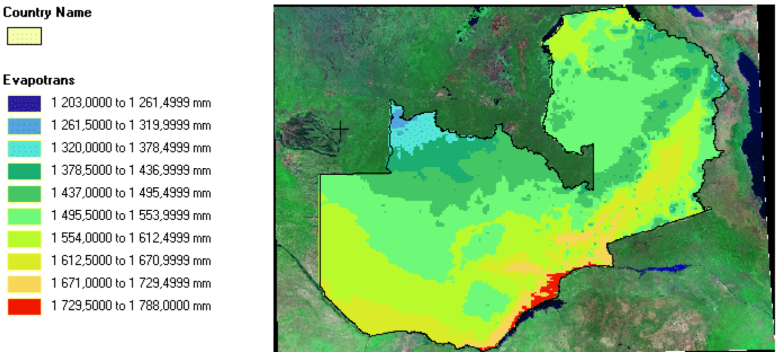

Figure 10. A layer map showing zones of different rates of evapotranspiration for Zambia. The south west and south (particularly close to Kariba where desertification has set in) are seen as particularly vulnerable as is the Luangwa Valley. Considerable quantities of water are lost this way in the floodplain (courtesy AWhere Inc).

Figure 11. Image showing average flow of water over Victoria Falls over the twentieth century in m³/s (from Mendelsohn and Roberts 1997).

Water, then, is the key commodity in the production and reproduction of lives, livelihoods, culture and environment in western Zambia as in many other riverine areas in the developing world. Water, or lack of it is a mediating factor in social dynamics such as out-migration, crime and culture although other factors also involved.

Maclean (1965) noted that 'In the absence of any major artificial water supplies, little settlement is found outwith (sic) walking distance of the river system or inland "pans"'. Maclean also noted that few permanent village wells existed and that reliance was thus placed on perennial surface water supplies, constraining the chance of irrigated agriculture outside of the traditionally drained system around the plain margins.

The real irony of water shortage in Bulozi is that, even at the driest times of year, water exists only a short depth (usually less than m) below the surface but that there are few working wells and little in the way of systematic irrigation. There are exceptions such as canals that were constructed during the early missionary years near to the eastern margin of the plain close to Mongu and the network of newly constructed concrete drainage dykes near to Sefula, built by the Japanese development cooperation. The former is slowly falling into disuse and is silted and overgrown in places while the latter enjoys little success due to a misunderstanding of traditional land tenure and inadequate communication with the Barotse Royal Establishment (BRE).

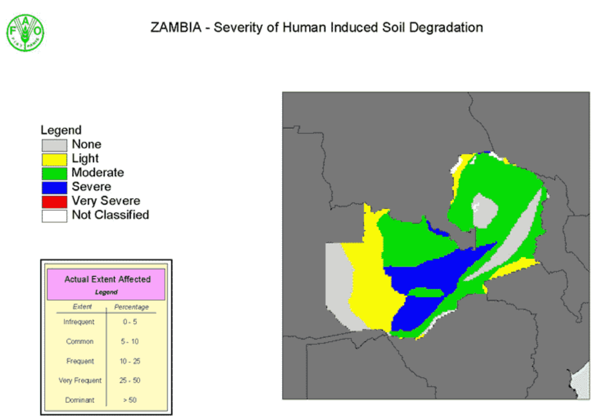

Figure 12. Diagram showing incidence of soil degradation in Zambia suggesting that while western Zambia is highly sensitive to any variations in climate and manifests high rates of social and ecological vulnerability, there are strong reasons to suggest a dynamic locally supported programme of sensible adaptation actions related to local social and ecological conditions could bear considerable fruit (from http://www.fao.org).

In the urban areas, a similar irony applies. During the Kuomboka festival (end Mar. 2007), the writer stayed in the local capital Mongu where there were torrential rainstorms every afternoon and waterlogged land in many areas. Meanwhile, the supply of piped water was limited to one hour in the morning and similar in the evenings with some days missed altogether. This was as a result of broken pumps and other infrastructural and financial difficulties but it reinforces the point that areas suffering underdevelopment that climate is impacting on, rarely suffer real water scarcity but simply the means to access and exploit water, which is where adaptation comes into play. A similar argument is made for soil as illustrated in Figure 12 below.

3. The objective and subjective significance of water: Meanings and values

The Lozi word for water is *mezi*, a word with enormous significance in the Lozi language and for anybody who comes from or lives close to the plain. Mezi is proffered to any traveller or stranger arriving in the villages of the floodplain as is food even though both of these may be in short supply. *Mezi* is concomitant with life and the most vivid manifestation of *mezi* is the majestic yet powerful and unpredictable *Lyambai* – the great Zambezi River without which the floodplain and its characteristics, together with a hefty chunk of Lozi identity would cease to exist. The *Lyambai* is the central environmental feature of the region running north-south through the middle of the plain. It is responsible for the life-giving waters that bring silt and nutrients to the many garden sites of the plain, encourages verdant grass to grow on which large herd of cattle (*Likomu*) graze and provides a home for the once-teaming fish (*Litapi*) of Bulozi, including several varieties of Bream, popular on meal tables throughout Zambia.

The digging of ditches and canals (*malomba*) on the margins of the Bulozi floodplain has been practised since the reign of the renowned Lozi King (*Litunga*) Lewanika (1878-1916) and this encouraged settlement on the plain margins utilising traditional agricultural production systems. These areas were previously waterlogged as a result of water from the annual inundation of the plain supplemented by year round seepage from below the Kalahari sandbelt covering the wooded uplands.

Many dykes and canals have fallen into disuse since colonial times when the workforce for such travail was drained away by migrant labour (see Figures 13 and 14). Now a high proportion of previously tilled land has fallen into disuse due to stagnant water and occurrence of swamp, which is also very unhealthy and contributes towards an increasing malaria incidence. In addition, partly as a result of population increase and partly because many landholders have stopped working their lands over recent generations, those gardens that have continued to be exploited over the generations, have lost much of the fertile humic soil layer, in some cases reducing from as much as 3.5m measured at the turn of the twentieth century to just a few inches. Occasionally, the humic layer has disappeared altogether leaving Kalahari sand once again exposed at the surface.

New dyke-building projects have been undertaken by the Japanese Co-operation Agency (JICA) but this has not resulted in widespread uptake by farmers, largely because of misunderstandings about traditional land tenure and ownership. Considerable indigenous knowledge exists here on the used and design of a network of dykes that could be shared in wetland regions of West Africa and put to good use with outside assistance.

During field research it was also reported that there are dams built during the colonial era that have never been brought into use but that could very easily be utilised for crocodile farming which is carried out on a large scale elsewhere in the country (the Zambezi floodplain has a high population of crocodiles that have been a serious menace to humans across the generations. When this idea was mentioned to farmers in Senegal who have access to river or seawater (it is quite feasible to imagine saltwater crocodiles being farmed), the idea received an enthusiastic response as it was immediately realised that the crocodile has strong earning potential both as a source of meat (though only to outsiders) and for the skin!

Figure 13: Example of hand-dug dyke, constructed originally at the start of the twentieth century, now fallen into disuse (Libonda district, Western Zambia, November 2003).

Figure 14: Hand-dug dyke, built at turn of twentieth century, recently renovated but not yet put to good use in cultivation (Old Limulunga district, Western Zambia, April 2005).

3.1 Cultural dimensions: Kuomboka

Culture rarely features as an impact of climate change and variability but in the Upper Zambezi Valley and to members of the Lozi diaspora scattered around the world, climate has an immediate and enduring impact on the production of identity and sense of self and otherness. In this case one can say that climate is a mediating factor in the construction of cultural citizenship.

The annual Kuomboka festival is held in the heart of the Upper Zambezi Valley. It is an event hosted by the Lozi peoples of western Zambia whose history and heritage is utilised as a strong symbol of identification not only by themselves but also, on a more global scale, by Zambians in general and other Africans across the sub-continent. It features the exodus from the floodplain of the Litunga leading his nation from danger to higher ground at the plain margins in his state barge, known as Nalikwanda (see Figure 15). He is followed by the Moyo (Queen or first wife), concubines, household baggage and then the ordinary people who follow in a clamouring flotilla. The entire procession is like that of a family, led by the father as inspirational leader and ending with the young children who must follow at a respectable distance.

Kuomboka was originally a response to environmental crisis. The flat floodplain became inundated each year to such a depth that even the extended mounds built up from termite mounds, on which clusters of clans and their followers lived, became either submerged or unliveable. In the midst of this inundation, the King or 'Litunga' of the nation would lead his people out of the flooded plain to the safer margins where the people would remain until the King signalled a return three or four months later. From being a response to crisis, the event today is more in the form of a pageant, of which the Kuomboka forms the central plank. It is a ceremonial festival, attended by more people than any other cultural event in Zambia or the sub-region.

When Lozis are asked what they think of in order of priority when they consider their sense of identity, which is very passionate in this region, it is Kingship, Kuomboka and floodplain in that order. Thus, two out of three of the core components of the Lozi consciousness are concerned with the environment and are impacted directly by climate change and variability. What Kuomboka represents is a reaffirmation of 'Loziness' and a confirmation that all is well in the Lozi cosmos. When Kuomboka fails to take place as it did in 2005 due to lack of sufficient water in the plain, there is a diaspora-wide outpouring of grief that a central pillar of Lozi identity and 'national' pride has somehow fallen away or dematerialised and something or someone (usually the latter) is sought on whom to place blame for this sense of failure.

If Kuomboka fails to take place it is also an economic disaster as more money enters the region at this time than at any other time of the year. Storekeepers, restaurateurs, hotels, hostels, boat and bus operators all benefit from the inflow of money at the festival which takes place over a week although most visitors just stay for a weekend at most. Nevertheless, an increase in the number of dry years when Kuomboka could not take place would be a national catastrophe on cultural and economic scales.

There are several adaptation strategies that have been suggested to ensure that Kuomboka is not affected by climate change, including using the main channel of the Zambezi for the voyage or digging a special channel so that the voyage can still take place in dry years but neither of these escapes the very real need for the plain to be flooded in order for the Kuomboka to have authentic significance. Kuomboka and the Nayuma Museum and Heritage Centre located at Limulunga, the terminus and flood season home of the Litunga will remain an icon of Lozi culture that has enormous cultural meaning and influence not just for Lozis but Africans and those interested in Africa for as long as it can endure. Thus a very special kind of adaptation is required here that responds to cultural as well as productive needs, realising the two are closely intertwined and share acute vulnerability to climate change and variability.

Figure 15. The Nalikwanda state barge carrying Litunga Imwiko II on route from Lealui in the heart of the floodplain to Limulunga on the plain margins, April, 2004.

4. A strategy for adaptation

4.1 Conceptualising adaptation

Sen (1999) defines development as the creation of choice and lack of development as having no choice or no say in what happens. According to this theory, underdevelopment is a condition in which a mode of economic production has ceased, due to changed local or external conditions that render the process valueless, and where no alternative strategy is in place and available to pursue. Vulnerability, therefore, is produced as conditions change. Africa has been 'underdeveloped' due the agendas of external agencies. One might include here the Atlantic Slave Trade, formal colonialism and post-colonial neo-liberal paradigms that encouraged Africa to reduce food self-sufficiency and rely on export earnings from a single crop or raw mineral. In this way, for centuries past, Africa was sucked into a vortex of increasing vulnerability by reducing its choices and making it dependent on economic processes articulated and controlled from outside. Community adaptation is partly a response to this dependency because it encourages inspirational, self motivational thinking 'from the inside' along the lines of 'what can we and what do we want to do for ourselves to increase our choices and make us less reliant.'

Adaptation is a social response to human and environmental vulnerability. Most vulnerability has not been caused by climate change, but climate variability and uncertainty have become added factors exacerbating vulnerability. Smit et al (2000) assert that there are two distinct modes of adaptation to be considered in relation to climate change impacts, those aimed primarily at the physical environment and those aimed at human processes, primarily socio-economic. However, in most cases the two are interdependent; they cannot operate independently.

Climate adaptation actions are rarely innovative; they are largely composed of actions that were already known about. What is innovative is the thinking that lies behind the planning i.e. thinking about climate, and the way in which we communicate information on climate (such as early warning systems), communicating climate risk, assessing adaptation capacity and delivering alternative strategies for consideration and possible implementation by stakeholder groups.

Adaptation must be seen as a positive response to a set of changes that has produces threats but, concomitantly, like all change, produces sets of opportunities. It is this aspect that injects positivity into the adaptation process. Adaptation to vulnerability, whether impacted by climate change or other processes, can lead to innovation in a multiplicity of ways not necessarily connected to the prime cause of vulnerability. This translates what would otherwise be a discreet process into one which can and must be integrated into sustainable development strategies.

Adaptation is a positive social process. It's about creating an insurance policy against loss of lives and livelihoods in the form of increased choices and alternatives. Its methodology pivots around communicative dynamics such as social learning, participative workshops, consultation. Adaptation requires stakeholder communities to remember and to valorise cognitive discourse concerning past practices, indigenous knowledge and skills. It is also about realising that even after remembering and adding up all the skills and knowledge to date, that cumulatively, it is not enough to deal with current exigencies or to achieve community aspirations in the context of sustainable development. And on that basis, community adaptation can more easily be addressed with policy and decision makers.

4.2 The vital role of policy and decision makers in the adaptation process

By pivoting adaptation around the idea of integrating responses to climate into strategies devised primarily by vulnerable communities themselves to maintain and enhance self-sufficiency and sustainable development, policy and decision makers can feel a sense that adaptation responds to their own agendas. This makes the idea of mainstreaming adaptation less of an intrusive and alien concept, imported from outside by agencies from the advanced economies whose responsibility for the dynamic they are trying to address is highly suspect.

Politicians and policy/decision makers across the world in both the developed and developing world are taking climate change more seriously. This is because it is on the lips of every major discussion of the world economy and because governments are having to engage with processes such as production of national communications on climate change to show just what they are doing in their respective countries and how they are mainstreaming climate into their national development plans. NAPA's and even PRSPs are just one example of this.

However, there are two further intervening barriers between policy makers knowing that adaptation requires to be mainstreamed and obtaining their support for enabling policies and help to eliminating bad practices. The first is to do with the fact that most decision makers have little knowledge of climate and even less time to spend on gaining such knowledge. The second has more to do with decision makers' sets of priorities that have more to do with economic development or poverty reduction and self-preservation than with the efficacy of adaptation.

It is important to engage both national and local decision and policy makers at the outset of an adaptation project in order to gain legitimacy and to cement into place a node of communication that will need to be returned to during and certainly at the end of the process. However, for this engagement to be successful requires research into the agenda and pressures facing the relevant policy maker, and renewed focus on positive, sustainable community development.

But as in the arena of community adaptation itself, failure or perceived failure to achieve stated objectives of adaptation can be fatal to the credibility of project and practitioner. Policy makers like to be associated with measures that are popular. So, at the outset it is important to agree objectives and realistic projected outcomes. The emphasis is on gaining legitimacy while stressing the vitality of the report-back function, possibly with a policy makers workshop, saying what has worked well and what has not and to show how it will be possible for local people, through their own enhanced capacity, to adjust, replicate and upscale those actions that have worked. This is to show that, for adaptation practitioners, the intention is only to inspire, drive and build capacity and not to create territory.

Thus, the emphasis at policy maker level is to inform, be positive, obtain approval legitimacy and promise to come back with results that can be projected in a policy makers workshop. This way, policy makers benefit in a useful and constructive way from the work that has taken place, get a better idea of local realities and are able to utilise the information better in their policy reviews. Climate, in effect has been integrated into policy and decision-making.

4.3 Metaphysical dimensions of adaptation

What the above narrative demonstrates is the very real affiliation that local people feel with their physical environment in the Upper Zambezi Valley, for survival, economic livelihood, societal cohesion and culture. The central pivot around which an adaptation strategy should pivot, it is argued here, is ownership by the group whose vulnerability is being addressed by the adaptation action. Local ownership is a much embraced term in contemporary development projects but, in reality, few address the issue seriously.

Ownership is not something that can be imbued by a person or community in a purely material, objective manner; rather, ownership lies in the metaphysical, subjective realm. This is to say that one may own a building in the legal, material, objective sense with title deeds. However, because of a high mortgage, or because the building was inherited or due to the nature of social relationships with those who live in or occupy the building or conduct a range of socio-economic activities from it, one may actually experience little true sense of subjective ownership or control.

Thus if an adaptation project is serious about local or community ownership then it must adopt a deliberate strategy aimed at making this a reality both in an objective and subjective sense. For the Upper Zambezi Valley project, the entry point is talking, listening to and valuing the evidence which is termed here as 'real world stories of climate, lives and livelihoods' presented by that community by way of a 'local decision makers workshop' held in the heart of the home region of the target affected community and not in a distant capital. This, together with the pilot survey mentioned in the text above are the first steps towards creating a sense of local ownership and the belief that 'this is something by us, for us.'

The objective here is for local people and their representatives from livelihood activities, belief systems, traditional authorities, and other civil society to come together to paint a picture of life in the region concerned that, by its very nature, will talk to the theme of climate and weather that are staple components of the cosmos of a community that depends on the natural environment for its very existence. It is important for the forum to be widely marketed and reported by local radio, in particular, in special programmes for a region where newspapers and television broadcasts are mostly not yet accessible.

With such a close interrelationship between social and ecological dynamics it becomes incumbent on development practitioners to develop adaptation strategies that place local people and their authentic leaders in a position of priority ownership and value. In so doing the forum will also address the overall theme of economic and social development within the context of sustainable environments and suggest themed areas for adaptation that relate partly to climate variability and change but within the overall context of vulnerability that is, in essence, a social production.

The evidence from this forum shouuld be collected, wherever possible, in the vernacular (in this case Silozi), as the ability of people to express themselves is coloured by the medium they use and the worldview in which that medium has been constructed. A language rooted in local history and culture used by all local groups as their lingua franca may be imbued by but not prescribed by global processes originating in the west. The vernacular can then be translated, preferably by speakers of the language of transmission, into the world language of its intended audience. This audience may consist of researchers, climate scientists, adaptation and other development practitioners and representatives of government who can be present at the workshop in but must keep a mostly silent profile and low level of participation and not dominate the proceedings.

The agenda of the workshop must be led and driven by resource persons from within the target community (in this case members of a local NGO whose capacity is intended to be built in the adaptation process), and although climate impacts are the underlying topic, with minimal overt direction except in terms of the module themes. Such a practice allows better opportunities for local people to express themselves freely using a worldview that is strictly their own, using a medium that may be imbued but not prescribed by global processes originating in the west.

It is argued that an understanding of the social causes of vulnerability, which are often hidden by cultural reserve and mystique, can only be obtained by free expression in a forum with minimal control. An example of this is the fact that in the Upper Zambezi Valley, where most people manifest a strong enthusiasm for Christianity, belief in witchcraft is also a strong force to be reckoned with. Such expression would have no place in a forum dominated by developed world NGOs and layers of governance and even in those dominated by national institutions and organisations of a similar nature. This is not just because such expression might not be taken seriously in forums that include people from countries where witchcraft is poorly understood and even outlawed (Reynolds 1963). It is also because local people who share such beliefs are aware of the cynicism of others who they view as handicapped by their inability to perceive the full spiritual realm, and have no wish to be ridiculed.

All belief systems can be argued to lie in the metaphysical and subjective realm. Nevertheless, if they have local credibility and belief, then they have value, relevance and, most importantly, power and influence over the acceptance as well as participation in any proposed adaptation strategy. Therefore they demand to be taken into consideration. This is to say that if you believe that a sudden and devastating storm that destroyed a house and crops came about at the instigation of God or some malign force in the occult, then your choice and/or enthusiasm for an adaptation action will be impacted and may be diminished by this. And if neither you nor your representatives have expressed this spiritual aspect of cause and effect, then any choice of adaptation actions will lack an important discursive aspect.

Thus, one of the focussed outcomes from the workshop will be that local people and their representative leaders will feel an initial surge of ownership of the project by the very project process at its inception that must be nurtured and protected throughout. It is essential they are able to express their feelings and aspirations in an experiential and participative way without any sense of prior agenda.

This imbuing of ownership is pursued in ensuing stages of the adaptation project consisting of the application of climate science that specifically addresses and explains the evidence presented by local people and offers predictive scenarios. These are then translated into locally usable data, articulated by local radio and other media as well as by word of mouth via existing mediums of communication such as local resource experts and networks of traditional authority.

Once a shortlist of adaptation actions has been prepared, these are then offered, through the newly-strengthened local organisation but with the support of external backers of new technologies, to the affected communities. This can take place through a series of smaller workshops held around the affected area and attended by local people with their legitimate representatives. Suggested actions are then accepted or rejected using local knowledge of acceptability and prioritised according to their perceived value and through the use of risk communication tools specially designed for community scale adaptation that screen potential adaptation actions for their efficaciousness and applicability to the local situation and provide a risk analysis.

5. Conclusion

This has not been an exhaustive tour of adaptation theory and practice nor of the full range of current thinking. What has been attempted here is to put across some thoughts on community level adaptation priorities as seen through the lens of an African NGO whose main purpose is to develop African capacity.

The methodology chosen to present these thoughts has been a partial presentation of a case study project that is currently underway in Zambia launched in early 2007 and expected to continue for some three to five years. The priorities that have been laid out surround issues of effective communication and knowledge of socio-economic, cultural and political dimensions of vulnerability that are receiving added impact from climate change and variability.

It has been argued that, without proper social science research, the main objective of climate adaptation strategies, to reduce vulnerability to climate affected processes and improve sustainable development can not be achieved. This is not to denigrate in any way the value of scientific research into climate and the important technologies that are becoming available for uptake by local communities. It is just to say that without first putting in place effective communication and management strategies, that allow the adaptation practitioner to listen and value local evidence of climate and its impacts, it is difficult to see how an effective vulnerability assessment can be carried out.

It is argued that if these essential cornerstones of communications are installed from the start, then ownership and participation will follow much more easily, and a cooperative community, even if the adaptation strategy is not particularly successful is one that will be prepared to try again and will appeal to policy and decision makers who respond to legitimacy and local credibility.

The Upper Zambezi Valley is one of a number of regions in Africa where abundant natural resources exist in a physical environment that is made difficult not only by biophysical processes but also by social and economic underdevelopment, a culture that is premised on the very biophysical processes that are currently under threat and a lack of skills, technology and information. These factors are exacerbated by severe exposure to climate change impacts, lost negative. The project described attempts to address some of these very issues on its way to successful adaptation strategies as improved information and communications are an adaptation strategy in themselves.

A sense of well-being among local communities, it is argued finally, can not be imposed or even imbued from outside, it can only come from within the subjective metaphysical being and it is to that aspect of social adaptation that this paper has given some added emphasis.

Bibliography and References

Du Toit, R.F. (1983) ‘Hydrological changes in the Middle-Zambezi system’, Zimbabwe Science News 17, 7/8, 121-6.

FAO [Food and Agriculture Organisation of the United Nations] (2005) Aquastat Information System on Water and Agriculture: Online Database, FAO, Rome online at http://fao.org/waicent/faoinfo/agricult/agl/aglw/aquastat/dbase/index.stm

Fisch, M. (1999) The Caprivi Strip during the German Colonial Period 1890 to 1914, Out of Africa Publishers, Windhoek.

Flint, L.S. (2003) ‘State-building in central southern Africa: Citizenship and subjectivity in Barotseland and Caprivi’, International Journal of African Historical Studies, 36, 2, 393-428.

______(2005) Historical constructions of postcolonial citizenship and subjectivity: the case of the Lozi peoples of southern central Africa’, unpublished PhD thesis, University of Birmingham, UK.

______(2006) ‘Contradictions and challenges in representing the past: the Kuomboka festival of Western Zambia’ Journal of Southern African Studies, 32, 4, 701-717.

______(2006) ‘Towards a strategy for environmental change: vulnerability and adaptation in the Upper Zambezi Valley region of Western Zambia’ in Junko, M. et al (eds.) Crossing Disciplinary Boundaries and Re-visioning Area Studies: Perspectives from Asia and Africa, Proceedings of Symposium, Kyoto University, Kyoto, Japan [195-207]

Gluckman, M. (1942) ‘Economy of the Central Barotse Plain’, Rhodes-Livingstone Papers, 11, Rhodes-Livingstone Institute, Livingstone.

Hoekstra, A.Y., Savenije, H.H.G. and Chapagain, A.K. (2001) ‘An integrated approach towards assessing the value of water: a case study of the Zambezi Basin’, Integrated Assessment 2, 199-208.

Kajoba, G. (1993) Food Crisis in Zambia, ZPC Publications Lusaka.

Livingstone, D. (1857) Missionary Travels and Researches in South Africa, John Murray, London.

Maclean, H.A.M. (1965) An Agricultural Stocktaking of Barotseland, Government Printer, Republic of Zambia, Lusaka.

Mendelsohn, J. And Roberts, P. (1997) An environmental profile and atlas of Caprivi. Windhoek, Ministry of Environment and Tourism, Windhoek, Ministry of
Environment and Tourism, Windhoek.

Peters, D.U. (1960) Land Usage in Barotseland, Rhodes-Livingstone Institute, Lusaka.

Pinay, G. (1988) ’Hydrobiological assessment of the Zambezi river system: a review’ IIASA Working Paper WP-88-089, Laxenburg, Austria.

Prins, G. (1980) The Hidden Hippopotamus, Reappraisal in African History: the Early Colonial Experience in Western Zambia, Cambridge University Press, Cambridge.

Reynolds, B. (1963) Magic, Divination and Witchcraft among the Barotse of Northern Rhodesia, Chatto and Windus, London.

Riebsame, W.E. et al, (1995) ‘Complex river basins’ in Strzepek, K.M. and J.B. Smith (eds.) As Climate Changes, International Impacts and Implications , Cambridge University Press, Cambridge.

Sen, A. (1999) Development as Freedom, Oxford University Pres, Oxford.

Short (2005) Imagined Country: Environment, Culture, and Society, Syracuse University Press, New York.

Smit, B. et al (2000) ‘An anatomy of adaptation to climate change and variability’, Climatic Change, 45, 1, 223-251.

Smith A.D. (1998) Nationalism and Modernism: A Critical Survey of Recent Theories of Nations and Nationalism, Routledge, London.

Timberlake, J. (2000) ‘Biodiversity of the Zambezi Basin Wetlands’, Consultancy Report for IUCN, The Zambezi Society, Harare, and Biodiversity Foundation for Africa, Bulawayo, Zimbabwe [particularly Volume III which deals with land use change in Barotseland].

Timberlake, J. Bailey, M. and Mundy, P. (2004) ‘Biodiversity of the Four Corners Area: bibliography’, Biodiversity Foundation for Africa, Bulawayo and the Zambezi Society, Harare.

Trapnell, C.G. and Clothier, J.N. (1957) The Soils, Vegetation and Agricultural Systems of North-Western Rhodesia: Report of the Ecological Survey, Government Printer, Lusaka

Van Gils, H. (1988) Environmental Profile: Western Province Zambia, International Institute for Aerospace Survey and Earth Sciences and Provincial Planning Unit, Mongu, Zambia.

Van Horn, L. (1977) ‘The agricultural history of Barotseland, 1840-1964’ in Palmer, R. and Parsons, N. (eds.) The Roots of Rural Poverty in Central and Southern Africa, Heinemann, London, 144-169.

Verboom W.C. and Brunt, M.A. (1970) An Ecological Survey of Western Province, Zambia, with Special Reference to the Fodder Resources [2 volumes I – ‘The environment’, II – The grasslands and their development’], Foreign and Commonwealth Office, Land resources Division, Tolworth, UK.

Zambian Meteorological Department (1987) Totals of Monthly and Annual Rainfall for Selected Stations: Western Province. Meteorological Department, Mongu, Zambia.

Endnotes

1 The region considered in this case study is part f the old Lozi kingdom of Barotseland that now lies split across the postcolonial republics of Angola, Zambia, Namibia and Botswana. After Zambian independence in 1965, the name for the main portion of the old Lozi Empire, which lies in modern-day Zambia became Barotse Province. Today, the region is Western Province. Some of these terms may appear interchangeably but they refer to the same region. Lozi is the name given to the peoples of this region and their language.

2 This information supplied during a pilot survey of local perceptions of climate carried out by a local organisation in the three villages of Sefula, Lealui and Limulunga during January 2007.

Developing future land use scenarios as effected by climate change and socio-economic scenarios in China, a case study of Ningxia Hui autonomous region

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Abstract

Land use reflects economic causes, policy measures and shows a wide range of impacts, including climate change, demographic and socio-economic changes and feedbacks between land use and its drivers (Busch, 2006). Future land use change is an especially vital aspect of the development of coupled socio-ecosystems at a range of scales from the local to the global, so many institutes and groups have studied and developed land use scenarios at different levels by multiple methods.

We have established land use change scenarios for 2020, 2030, 2050 in Ningxia Hui Autonomous Region (Ningxia), based on future climate change scenarios and socio-economic scenarios. In this study, climate change scenarios are derived from the PRCIS (Providing Regional Climates for Impacts Studies) regional climate modelling system. Socio-economic scenarios are downscaled from the special report on emissions scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC) and socio-economic scenarios from China national planning by a simple linear downscaling method.

Ningxia is an arid and semi-arid region which located in the middle reaches of the Yellow River in northwest China, with a total area of 51 800 sq. km and a population of 5.95 million. We obtained future land use demand (i.e. total area requirement of each land use types) according to socio-economic scenarios (e.g. GDP, population, and others) and potential crop yields under climate change scenarios at first. Secondly, we located the land use quantities in geographic space by spatial allocation rules.

1 Introduction

Land use reflects economic causes, policy measures and shows a wide range of impacts, including climate change, demographic and socio-economic changes and feedbacks between land use and its drivers (Busch, 2006). Future land use change is an especially vital aspect of the development of coupled socio-ecosystems at a range of scales from the local to the global, so many institutes and groups have studied and developed land use scenarios at different levels by multiple methods. CLUE model (Verburg et al, 1999, 2000) based on an empirical analysis of the spatial distribution of land use types, but CLUE may be have some problem, it is difficult to link with climate change scenarios and socio-economic scenarios directly. ATEAM land use scenarios (Rounsevell et al., 2005, 2006) based on a qualitative interpretation of the SRES storylines, an estimation of the aggregate totals of land use change and the allocation of these aggregate quantities in space using spatially explicit rules; In this work, climate change only impact on crop yield, but climate change also effect to distributions of land use and cover in future. In China, He et al (2006) developed a Land Use Scenario Dynamics (LUSD) model by the integration of System Dynamics (SD) model and Cellular Automata (CA) model and analysis future land use scenarios in Northern China. In this model, land use scenarios didn't concern future climate change, only socio-economic factors. Fan et al (2006) has simulated land cover scenarios in future by HLZ (Holdridge life zone) based on climate change scenarios, but only land cover not land use, didn't use socio-economic scenarios. Gao et al (2005) using multi-objective programming method obtained the rational proportion of land use and through computer-aided adjustment with GIS software to get land use security pattern.

Methodology on developing Land use scenarios is very complex, but all scenarios must answer two questions, HOW and WHERE? HOW Means the overall changes in land use are estimated on the basis of driving force assumptions. WHERE Stands for model simulations where these future land use changes are likely to occur. So we would obtain future land use demand (i.e. total area requirement of each land use types) according to socio-economic scenarios (e.g. GDP, population, and others) and potential crop yields under climate change scenarios at first. Secondly, we would locate the land use quantities in geographic space by spatial allocation rules.

2 Methods and data sources

2.1 Study area

Ningxia is one Autonomous Region for the Hui People who are a minority in China, located in the middle reaches of the Yellow River in northwest China, and lies between north latitude 34°14'-39°23' and east longitude 104°17'-107°39', with a total area of 51 800 sq. km and a population of 5.95 million. Ningxia is an arid and semi-arid region. The annual precipitation ranges from 78 to 295mm and annual average temperature from 8.2°C to 9.6°C. The climate in Ningxia has been getting dryer and warmer in recent decades and the natural conditions more and more difficult.

2.2 Data sources

- Land use data: Two period land use maps in 1980 and 2000 were provided by CAS, with resolutions of 1km×1km.
- Historic climate data is the observation data of all 22 meteorological stations in Ningxia from 1980 to 2004, including the monthly precipitation, mean temperature, maximum and minimum temperature, sunlight times, evaporation and relative humidity.
- Future climate change scenarios, Come from PRECIS, including the monthly precipitation, mean temperature, maximum and minimum temperature, sunlight times, evaporation and relative humidity in the 2020s, 2030s and 2050s.
- Socio-economic data: Includes historic statistical data and future scenarios, covered demographic data, agricultural production and economy, and others

2.3 Methodology of future land use scenarios development

2.3.1 Downscaling socio-economic scenarios

Socio-economic scenarios included A2 and B2 storyline of the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC), and National Development

Programming (NP). The main factors of these three scenarios are GDP, Population and others.

The downscaling method was based on SRES Downscaling method (Gaffin S. R., et al, 2004). This method is sometimes employed by demographers needing state and local population projections that are consistent with larger regional or national projections (Gaffin S. R., et al, 2004). Local regional annual growth rate for population or GDP, at any year, was set equal to the larger regional or national growth rate. In mathematics it is equivalent to keeping the fractional share of each region's population or GDP, relative to the larger regional or national population or GDP, constant, at the base year value, for the duration of the forecast period (Gaffin S. R., et al, 2004).

2.3.2 Developing of future land use scenarios

The methodology of future land use scenarios development, includes two steps: firstly, to obtain future land use demand (i.e. total area requirement of each land use types) according to socio-economic scenarios (e.g. GDP, population, and others) and climate change scenarios (e.g. precipitation, temperature); secondly, to locate the land use quantities in geographic space by spatial allocation rules (specific to each scenario). So we would obtain future land use demand using empirical–statistical models based on land use driving force, and would spatially distribute future land use by decision-making methods.

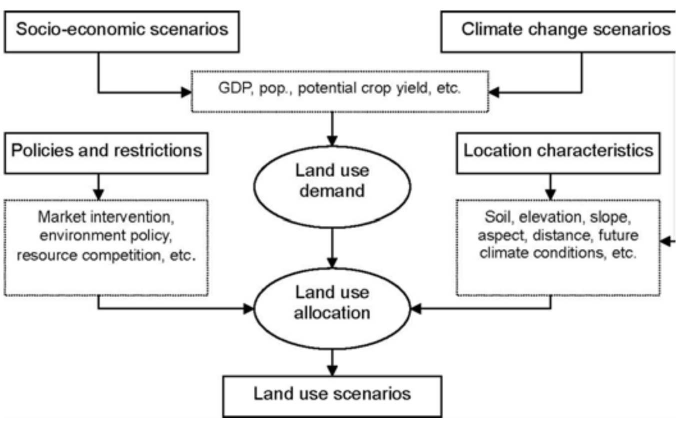

Fig. 1 Flow chart of future land use scenarios

2.3.3 Some principles on future land use scenarios development

- Competition between land uses

  Urban > cropland (rice paddy and upland)> water > forest land > grassland > unused land

- Environment policy

  (1) Current water and forest land are protected by local environment policy;

  (2) Grain for green: if precipitation ≥ 400mm, upland on slope gradients > 25o would be converted to forests; If precipitation < 400mm, upland on slope gradients > 25o would be converted to grassland;

- Climate restrictions

  (1) In areas where annual precipitation ≥ 400 mm and the aridity index is 1.3-1.6, the land is suitable to afforest;

  (2) Need some climatic indices of agricultural regionalization in Ningxia, especially for rice and upland crops.

3 Results and discussion

3.1 Land use change in Ningxia from 1980 to 2000

Tab. 1 and Fig. 2 show that the land use structure and its change in Ningxia from 1980 to 2000. In Ningxia, grasslands and croplands are the main land use types which account for about 50% and 30% of the total area respectively. From 1980 to 2000, cropland, forest land and urban lands have increased while grassland and unused land decreased.

Tab.1 Land use structure and its changes in Ningxia.

types	Area (km^2)		percentage (%)		Change rate (%)
	1980	2000	1980	2000	
Cropland	16080.4	18427.3	31.04	35.58	14.59
Forest land	2061.3	2231	3.97	4.31	8.23
grassland	26623.9	24199	51.4	46.72	-9.11
Water body	908.6	939.2	1.75	1.82	3.37
Urban land	914.9	990.1	1.77	1.91	8.22
Unused land	5210.7	5013.6	10.06	9.67	-3.78
Total	51800.0	51800.0	100.00	100.00	0.00

note: change rate (%) = $[(A_{i2000} - A_{i1980})/A_{i1980}] \times 100\%$; A_i is area of land use type i_o

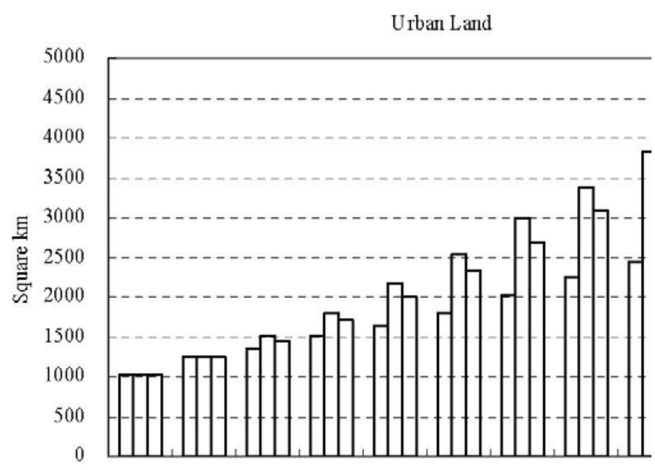

Fig.2 Land use maps of Ningxia Hui Autonomous Region.

The land use transition matrix result show that some grassland has changed to cropland, urban and forestland and degraded to unused land from 1980 to 2000 (see Tab.2). And a part of the uplands has improved to rice paddies while some cropland has been urbanized.

Tab.2 Transition matrix of land use in Ningxia during 1980 to 2000 .

1995 / 1980	Rice paddy	Up-land	Forest land	Grass-land	Water body	Urban land	Un-used land
Rice paddy	98.2	0.3	0.3	1.8	11.8	0.6	4.4
Upland	0.2	98.2	1.3	7.2	4.4	1.1	0.9
Forest land	0.1	0.2	94.1	0.5	0.7	0.0	0.3
Grassland	0.3	1.0	1.9	89.1	5.9	0.0	2.4
Water body	0.2	0.0	0.1	0.5	77.0	0.0	0.4
Urban land	0.8	0.1	0.1	0.1	0.0	98.4	0.4
Unused land	0.2	0.1	2.2	1.0	0.2	0.0	91.4

3.2 Downscaling socio-economic scenarios

The downscaling both the aggregated population and GDP data from country to Ningxia province level for the A2, B2 and national planning (NP) scenarios used a simple linear downscaling method. Fig.3 show that population is continues to increase in Ningxia from 2000 to 2050. According to A2 scenarios, the Ningxia population in 2020 will be 6.84 millions, whereas the B2 and NP scenario gives the population of 6.54 and 6.74 millions in 2020. In 2050, the Ningxia population will reach 8.66 millions for the A2 scenarios while 6.84 and 6.99 millions under the B2 and NP scenarios respectively. From 2005 to 2015, the population of NP scenarios is higher than the A2 and B2 scenarios; however the population of NP scenarios is very close to the B2 scenarios and lower than A2 scenarios from 2020 to 2050 (see Fig. 3).

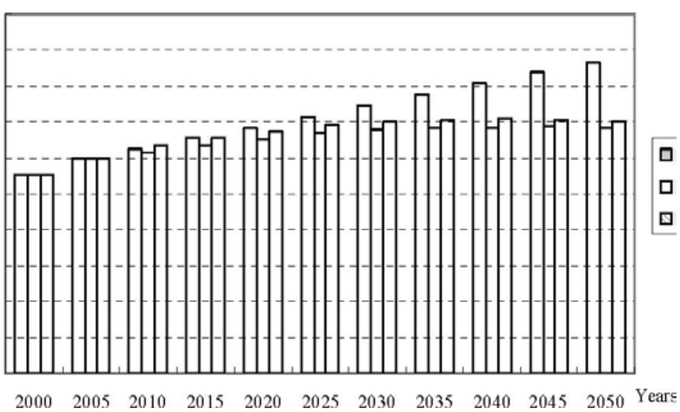

Fig. 3 Future population totals in Ningxia under A2, B2 and NP scenarios

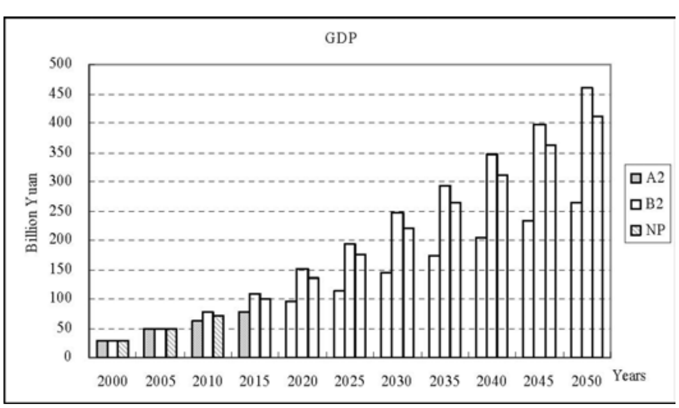

Fig. 4 Future GDP change in Ningxia under A2, B2 and NP scenarios

The downscaling result of GDP presented that GDP will be increase in Ningxia from 2000 to 2050 under the A2, B2 and NP scenarios(see Fig.4). The Ningxia GDP will reach 264.4 - 459.3 billion Yuan RMB in 2050. According to the A2, B2 and NP scenarios, the average growth rates of GDP are 6.2%, 13.8% and 11.6% for 2005-2020, and 4.2%, 4.3% and 4.4% for 2025-2050 respectively.

3.3 Future land use scenarios

3.3.1 Urban land

The theoretical principles of urban economy were formulated into an urban land use model and this was used for the development of the urban land use scenarios (Rounsevell, et al., 2006). The model included a demand module and a spatial allocation module (Rounsevell, et al., 2006). Urban demand estimates were calculated using an empirical–statistical model with population and GDP as the independent variables. The future scenarios were based on the population and GDP data of the A2, B2 and NP scenarios. The spatial allocation rules of future urban land: (a) Accessibility of the transport network and cities; (b) different urbanization processes; (c) land use planning and location constraints; (f) competition with other land uses (Rounsevell, et al., 2006).

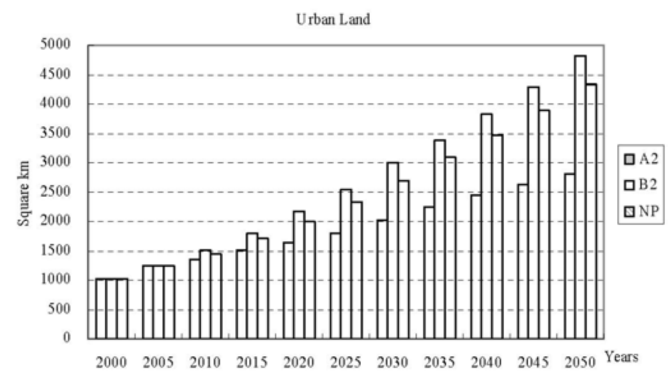

Fig. 5 Future changes in urban areas for Ningxia (km2) for the A2, B2 and NP scenarios.

The trends of urban land demand are summarized in Fig. 5 for the A2, B2 and NP scenarios from 2000 to 2050. These trends show large increases in Ningxia urban areas, According to B2 scenarios, the urban area in 2050 will be 4825.9 sq km (increase 371.5% from 2000), whereas the A2 and NP scenario gives the urban area of 4342.2 sq km (increase 324.2%) and 2801.1 sq km (increase 173.7%) in 2050.

3.3.2 Cropland (included rice paddies and upland)

Fig.6 shows that cropland areas decline substantially (to as much as 50% of current areas) by 2050 for the A2 and B2 and NP scenarios. Declines for the NP scenario are less severe, and the smallest declines are for the B2 scenario.

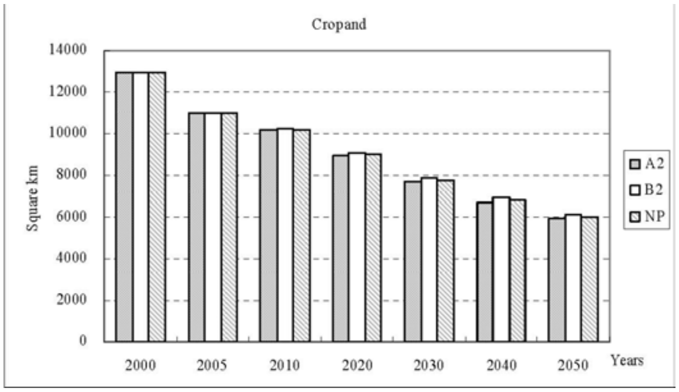

Fig. 6 Future demand of the cropland areas for Ningxia (km2) for the A2, B2 and NP scenarios.

3.3.3 Other land

The future changes of other land (included forest land, grassland, water body and unused land) in Ningxia for the A2, B2 and NP scenarios are shown as Fig.7. The other land area of Ningxia will increase in future. But the future land use demand and spatial allocation of each land use types (included forest land, grassland, water body and unused land) will be studied in our future work.

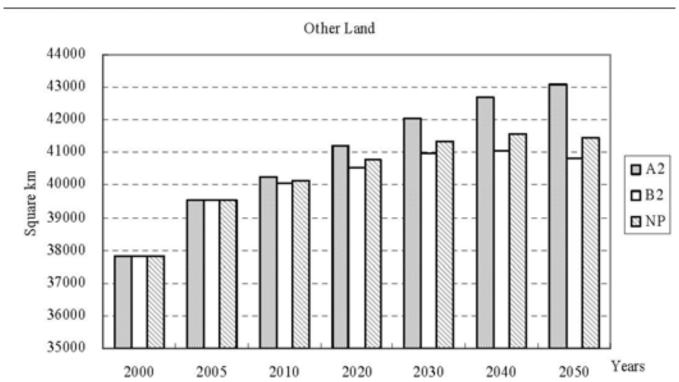

Fig. 7 Future changes of other land in Ningxia (km2) for the A2, B2 and NP scenarios.

3.4 Discussion

This extended abstract is more idea than results (for example, the spatial allocation will be finished before the meeting) at present, so we especially need to discuss more about future works. (1) Can we use the current land use driving force to extrapolate the future land use demand? (2) Can we use a simple linear downscaling method based on the current distribution of socio-economic factors? (3) In ATEAM land use scenarios, climate change scenarios only impact on crop yield, but climate change also effects the distributions of land use and cover in future. Which important climate changes impact on land use changes in future? (4) How did we do the calibration and validation of future land use scenarios?

4 Conclusions

(1) In Ningxia, grasslands and uplands are the main land use types which account for about 50% and 25% of the total area respectively. From 1980 to 2000, rice paddy, upland, urban lands have increased while grassland and unused land decreased.

(2) Total population is continues to increase in Ningxia. In 2050, the population will reach 8.66 millions for the A2 scenarios while 6.84 and 6.99 millions under the B2 and NP scenarios respectively. The Ningxia GDP will reach 264.4 - 459.3 billion Yuan for the A2, B2 and NP scenarios in 2050.

(3) Future urban land demand in Ningxia will increase 173.7%-371.5% from 2000 to 2050 under the different scenarios. According to B2 scenarios, the urban area in 2050 will be 4825.9 sq km, whereas the A2 and NP scenario gives the urban area of 4342.2 sq km and 2801.1 sq km in 2050.

(4) The cropland areas decline substantially by 2050 for the A2 and B2 and NP scenarios. Declines for the NP scenario are less severe, and the smallest declines are for the B2 scenario.

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References

Busch G. 2006. Future European agricultural landscapes—What can we learn from existing quantitative land use scenario studies? Agriculture, Ecosystems & Environment, 114:121-140.

Fan Z., Yue T. Liu J., et al. 2005. Spatial and temporal distribution of land cover scenarios in China. Acta Geographica Sinica.60(6): 941-952.

Gaffin, S.R., Rosenzweig, C., Xiaoshi, X., et al, 2004. Downscaling and geospatial gridding of socio-economic projections from the IPCC special report on emissions scenarios (SRES). Glob. Environ. Change, 14, 105–123.

Gao Q., XU H., Li Y., et al., 2005. Analysis on Ecological Security in the Soft Rock Area of Middle Yellow River□ A Case Study of Changchuan Watershed, Inner Mongolia, China, Proceedings of SPIE, Valume5884□497□508.

He C., P. Shi, J. Chen et al. 2006. Developing land use scenario dynamics model by the integration of system dynamics model and cellular automata model, Science in China. Series D, 48(11):1979-1989.

Rounsevell, M.D.A., I. Reginster, M.B. Araujo, et al. 2006. A coherent set of future land use change scenarios for Europe. Agriculture, Ecosystems and Environment, 114: 57–68

Rounsevell,M.D.A., Ewert, F., Reginster, I., et al, 2005. Future scenarios of European agricultural land use. II. Projecting changes in cropland and grassland. Agric. Ecosyst. Environ. 107, 117–135.

Verburg P. H., Youqi Chen, T. Veldkamp. 2000. Spatial explorations of land use change and grain production in China, Agriculture, Ecosystems and Environment, 82: 333–354.

Verburg P.H., A. Veldkamp, L.O. Fresco. 1999. Simulation of changes in the spatial pattern of land use in China. Applied Geography, 19: 211–233.

Adaptation in Rain-fed Agriculture Practices: policies and measures for water use efficiency in India

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Abstract

Recent scientific assessments of the impacts of climate change on patterns of monsoon rainfall on the Indian subcontinent indicate that major changes will be required in agriculture and related professions, on which the livelihoods of a large number of people in the region are based.

The paper to be presented at the Conference on "Integrating Analysis of Regional Climate Change and Response Options" reviews some of the recent assessments of future changes in monsoon patterns and the implications for management for water resource use in India, as well as projections for future water demand, demarcating sub regions in the country where a high level of vulnerability can be identified for rain-fed agriculture. These possibilities would require the institution of measures targeted at efficient water usage in agriculture and the adoption of technological and policy based solutions that would ensure higher efficiency of water use that is discussed in detail in the paper.

1. Recent Assessment of Indian Monsoon Patterns and Climate Change:

In recent literature published in Science, Goswami et al. have documented significant trends within Indian monsoon rainfall patterns. Scrutiny of the interannual variability of the daily rainfall data reveal that there has been a significant decreasing trend in frequency of moderate events over central India during the monsoon seasons from 1951 to 2000. Additionally, there are both significant rising trends in frequency and magnitude of extreme rain events over Central India. The observed trends thus suggest both a substantial increase in hazards related to heavy rain and a decrease in water availability (due to the greater number of droughts) over Central India in the coming decades (Goswami et al., 2006).

The Atmospheric Brown Cloud (ABC) formed from pollutants and aerosols emitted in the dry season, have been linked to influencing monsoon patterns. Recent studies using general circulation models (GCM) have shown that the global and regional water cycles can be profoundly affected by the presence of aerosols in the atmosphere (Rosenfeld, 2000; Ramanathan et al., 2001).

Ramanathan has suggested that the solar dimming due to ABCs has depressed the North Indian Ocean (Arabian Sea and Bay of Bengal) surface temperatures, whereas, the Indian Ocean south of equator has warmed by as much 0.7 C due to greenhouse gases (Meehl et al., 2003). This decrease in SST north south gradient (which was also observed in SSTs) was shown to be the major cause for the decrease in monsoon rainfall since the 1950s (Meehl et al., 2003).

Additionally, K.M. Lau et al. investigated the relative roles of solar dimming (SDM) with atmospheric heating effects by utilizing an atmospheric GCM coupled to a mixed layer ocean and forced by prescribed global aerosol forcing. Lau found that SDM can lead to surface cooling that results in overall increased stability of the lower atmosphere, reduced surface evaporation, suppressed convection, and hence a weakened global water cycle (K.M. Lau et al., 2007). Thus, during July and August, when the aerosol loading is substantially diminished, rainfall over all the Asian monsoon regions, except over and in the vicinity of the Tibetan Plateau, is reduced (K.M. Lau, 2007). The work of Meehl et al. running a similar GCM model at NCAR also attributed black carbon to the reduction of North Indian SST, act to reduce the Indian monsoon (Meehl et al., 2006).

The inclusion of the ABC component adds a new dimension to the dynamical effects of climate change influence on the Indian Monsoon. The dimming due to ABCs decreased the SST gradient (North-South) and thus decreased monsoon rainfall. Therefore the study suggests that both climatic change due to local ABCs and global warming from an increase in greenhouse gases, have led to a deceleration of the monsoon (Ramanathan et al., 2005; Lau et al., 2007).

While broad aspects of Asian climate change show consistency between AOGCM simulations, there remain a number of sources of uncertainty. There are substantial inter-model differences in representing monsoon processes and a lack of clarity over changes in ENSO, which further contributes to uncertainty about future regional monsoon and tropical cyclone behavior (Kripalani et al., 2007). However, new science has now progressed from vague statements linking climate change and the Indian monsoon to specific physical, chemical and dynamical mechanisms of impact. These future changes in monsoon patterns will intensify the pre-existing water crisis and have implications in India, particularly among rain-fed agriculture, necessitating immediate action in management for water resource use to increase water efficiency.

2. Review of IPCC Fourth Assessment Report: Assessment of water in South and South East Asia

According to the IPCC WGI Fourth Assessment Report, rainfall during the Indian monsoon season, accounts for about 70% of annual rainfall (IPCC WGI, 2007). In addition to depressed monsoons, factors such as glacier melt in the Himalayas and reduced river flow due to climate change will affect freshwater availability throughout Central, South, East and Southeast Asia. The effect of climate change, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by the 2050s. (IPCC WGII SPM, 2007).

2.1 Droughts:

Currently, in India, Pakistan, Nepal and Bangladesh, water shortages have been attributed to rapid urbanization and industrialization, population growth and inefficient water use that are aggravated by changing climate and its adverse impacts on demand, supply and water quality (Siddiqui, 2005). According to the Climate Change 2007: Impacts, Adaptation and Vulnerability, there has already been several observed changes in drought events over South East Asia and ~50% of the droughts have been associated with El Nino (IPCC WGII Asia, 2007). The increase in frequency and intensity of droughts in many parts of Asia are attributed largely to rise in temperature particularly during the summer and normally drier months, and during ENSO events (IPCC WGII Asia, 2007). The documented droughts that have occurred throughout South and South East Asia and have resulted in major impacts on water availability and human damages due to the low capacity. For example, a series of consecutive droughts in 1999 and 2000 in Pakistan and NW-India have led to sharp decline in water tables. Between 2000 and 2002 consecutive droughts caused crop failures, which resulted in mass starvation and affected ~11 million people in Orissa (IPCC WGII Asia, 2007).

2.2 Extreme Events Observed:

Throughout the last decade, India has experienced changes in precipitation. General trends have begun to emerge in recent decades, including an increase in extreme rains in the northwest during summer monsoon and lower number of rainy days along east coast (IPCC WGII Asia, 2007). Additionally, Southeast Asia extreme weather events associated with El-Niño were reported to be more frequent and intense in the past twenty years (Trenberth and Hoar 1997; Aldhous, 2004). Intense rainfall events are associated with severe floods, landslides, debris and mudflows. Past events documented by the Indian Meteorological Department Reports (from 2002 to 2006) include serious and recurrent floods in the Northeast states of India during 2002, 2003 and 2004.

Projections, according to the Fourth Assessment report, for South Asia include an increase in occurrence of extreme weather events including heat waves. Intense precipitation events are also projected in Southeast Asia along with increase in the interannual variability of daily precipitation in the Asian summer monsoon (IPCC WGII Asia, 2007).

3. Projections of demand for water for agriculture in India

According to the IPCC WGII report, agricultural productivity in Asia is likely to suffer severe losses because of high temperature, severe drought, flood conditions, soil degradation and water (IPCC WGII SPM, 2007). It is projected that both agriculture and water sectors are likely to be most sensitive to climate change-induced impacts.

When quantifying the water demand for India there are several factors that influence water supply and demand. This largely has to do with India's spatial heterogeneity, associated development, income, dietary preferences, crop yield, cropping intensity and groundwater use. Other factors include contribution to production from rain-fed agriculture, on the crop-production side; and future growth in domestic, industrial and environmental water demand, and internal and international trade (Amarasinghe et al., 2005).

Due to India's diverse geography, it is more reliable to categorize India based on its water catchment and socioeconomic areas. India's catchments can be divided into 19 major river basins, each representing largely varying per-capita water resource availability and per-capita water withdrawals. Irrigation is by far the largest user of water in all the basins. The basins of the westerly flowing rivers are classified as physically water-scarce and food-dependent. The second group of basins, the Indus and Pennar river basins are classified as physically water-scarce, but these basins have significant food surpluses. The water-scarcity problems of the third group of 11 river basins are mixed, but almost all have significant deficits in crop production. The fourth and fifth groups of river basins are classified as "non-water-scarce and food-sufficient" and "non-water-scarce and food-surplus," respectively. Figure 1 details the various water regions that have distinguished by the International Water Institute, based upon their varying water sources and environmental conditions (Amarasinghe et al., 2005).

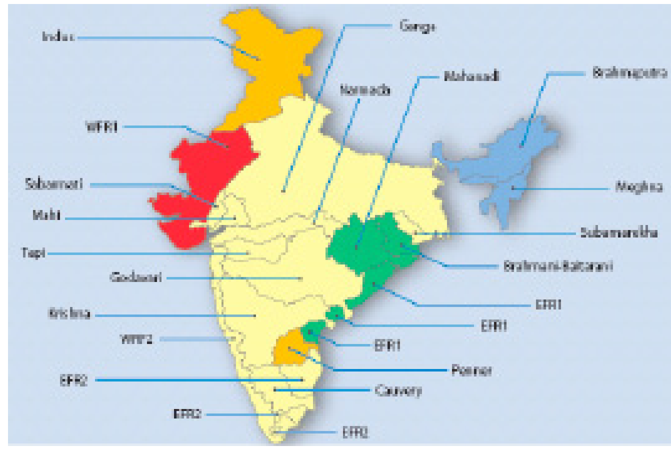

Figure 1: 19 water catchments in India. Source: International Water Institute, 2004.

Table 1: Irrigation Withdrawals of river basins.

Basin:	Crop Water Requirement (net evaporation) mm	Groundwater irrigated Area (% of Net Irrigated Area)
Indus	288	74
Mahi	417	47
Narmada	362	67
Sabarmati	443	38
Tapi	452	47
WFR1	429	41
WFR2	296	50
Brahmani & Baitarani	233	88
Cauvery	321	53
EFR1	431	81
EFR2	425	58
Ganga	318	76
Godavari	395	65
Krishna	426	59
Mahanadi	289	76
Pennar	582	78
Subarnarekha	232	88
Brahmaputra	95	79
Meghna	145	39
Total	373	69

India's aggregate water withdrawal in 1995 was estimated at about 650 km^3. Of this, 91 percent was withdrawn for agriculture, 4 percent for the domestic sector, and 5 percent for the industrial sector (Amarasinghe et al., 2005). Estimates of irrigation withdrawals in India vary, but several studies indicate that Indian withdraws more than 80 percent of total water resources (Seckler et al. 1998; IWMI 2000; Gleick 2000; WRI et al. 2000; FAO 2002a; Rosegrant et al. 2002).

Table 1 details the current water demand/withdrawals for the 17 separate catchments/zones in India as estimated by the International Water Institute. In total, are river basins represent approximately 373 mm/year and overall, 69% of the net irrigated area is a groundwater-irrigated area.

3.1 Changes in Water Demand:

In 1980, the contribution of agriculture to GDP was 38 percent. In 2001, it declined to 22.7 percent (Reserve Bank of India, 2006). While agriculture GDP growth has decreased, the contributions from both domestic and industrial sectors to the GDP have increased. The growth rate of the industrial sector has been booming at 5.2 and the service sector has grown to 6.6 percent (including a 11.0 percent growth in the fourth quarter of the 2005-2006 fiscal year) (Reserve Bank of India, 2006). While the GDP contribution of agriculture has declined in relative terms, the absolute demand for water will increase. With increasing urbanization and per-capita demand, the water demands of the domestic, industrial and other sectors are expected to increase rapidly (Seckler et al. 1998). According to Ministry of Water Resources, the overall water requirement will increase to approximately 970-1450 km^3/yr in the year 2050 (MOWR 2004).

4. Projections for supply of water in India in the future

According to the "Water for India in 2050" report, by the year 2050 when the population is expected to stabilize at 1640 million, India will be on the verge of becoming water-scarce (Gupta et al., 2004) (see figure 1 and table 2). The projected per capita water availability, not including the effects of climate change, will decline from ~1820 m^3/yr (2001) to ~1140 m^3/yr in 2050.

Most of the rainfall occurs in a relatively short period of three to four months during the monsoon period in India. The average rainfall in the four months from June to September during the southwest monsoon is about 903 mm, during the remaining eight months, an average of only about 294 mm of rainfall is received (CWC, 1993). Rainfall is accounted for approximately 4000 km^3.

In a 1993 study completed by the CWC, the estimated utilizable surface water (EUSW) in each river basin constitutes approximately 690 km^3/yr, which is dependent upon the water utilizable through conventional schemes, storage reservoirs, dams and diversion structures (CWC, 1993). Consequently, given that the assumption of historical rainfall data is to remain similar (not impacted by climate change) it is estimated that a bare minimum of 385 km^3 of live storage was needed to balance seasonal flows for irrigation of 76 mha (CWC, 1993).

The hydo-geologic data given by the Central Ground Water Board of India, and other existing State groundwater organizations, estimated there was 432 $km^3$of replenishable ground water (RGW) for one year (CCWB, 1996). This includes both natural recharge from rainfall plus the potential due to augmentation from canal irrigation systems (89.5 km^3). The average annual potential river flow, is approximated at 1869 km^3.

Overall, the amount of water available is dependent upon both the surface and ground water available in India. According to the 2050 water assessment, it is estimated that only 690 km^3/yr will be available via surface water and 432 km^3/yr will be available in ground water. Thereby leaving a total of 1122 km^3/yr of water available. Currently, the overall demand for water is approximately 500 km^3/yr. However, with an increase of population of around 1640 million and an increase in the standard of living, the demand for water in India may be as high as 1450 km^3/yr. With this estimate, India, without taking into effect climate change impacts, will be in a water shortage of 328 km^3/yr. Without other water infastructure in place or an increased effort to increase water efficiency, India could transition from a water stressed nation at <1700 m^3/person/yr to a water scarce nation at 1000 m^3/person/yr (Gupta et al., 2004)

Table 2: National water resources of India: Gross Annual Assessment.

Resource	Quantity (km^3)	Precipitation (%)
Annual Precipitation (including snowfall)	4000	100
Evaporation + groundwater	2131	53.3
Average annual potential flow in rivers	1869	46.7
Estimated utilizable water resources	1122	28.1
Surface water (EUSW)	690	17.3
Replenishable groundwater (RGW)	432*	10.8

**Natural recharge from rainfall (~342.4 km^3) + potential due to augmentation from canal irrigation system (~89.5 km^3).*
Source: Ministry of Water Resources (MOWR)

Table 3: A Summary of Water Availability in India.

	km^3/yr	Water Condition
Water Available: Surface Water (SW)	690	
Water Available: Ground Water	432	
Total Water Available:	1122	
Demand for Water in India now	500	Water Stressed or <1700 m^3/person/yr
Demand for Water in 2050	973-1450*	Water Scarce or <1000 m^3/person/yr

**Low and high estimates depending upon high estimated projected by UN high and low variant (1346-1640 million)*

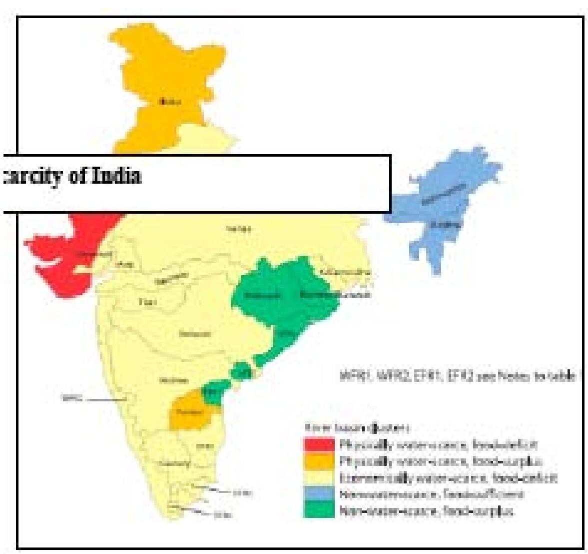

Figure 2: Water scarcity in India.

5. Assessment of Potential for Efficiency gains for water use in India

Sub regions in India where a high level of vulnerability can be identified for rain-fed agriculture would require the institution of measures targeted at efficient water usage in agriculture and the adoption of technological and policy based solutions that would ensure higher efficiency of water use. There are substantial gains that could be implemented in efficient water use. A simple institution of measures promoting efficiency gains can bring about substantial savings. For example, the city of Indore, was able to save 1.6 million rupees (US$35,000) within the first three months of action with no investment cost just by improving the way existing pumps worked together (Watergy, 2006). The combination of mechanical efficiency and policies such as effective water pricing can gain substantial benefits to water efficiency.

5.1 Improved irrigation techniques:

Enormous efficiency gains can be brought about in agriculture irrigation, which represents a 91 percent aggregate water withdrawal in India (Gupta et al., 2004). Water efficiency of traditional gravity irrigation systems is only about 40%. Sprinkler irrigation systems are around 70% efficient, however the upfront cost of investment and energy use, deter small farmers from investing in this technology. The drip irrigation system is a preexisting technology that with the correct fiscal and tax incentives would remain a viable alternative to farmers and substantially increase water efficiency. Drip irrigation systems provide an optimal solution because it utilizes cheap plastic tubing, and is up to 90 percent water use efficient (Wichelns, 1999).

Promoting drip irrigation would necessarily entail changing subsidies that unrealistically reflect the cost of water. Currently, the price of electricity for pumping groundwater is heavily subsidized, and in a few states has made electricity for farmers completely free (Ahluwalia, 2005). Under pricing the cost of ground water with electricity creates unfair distribution benefits to the upper end farmers. Those farmers that are able to afford larger pumps, are able to lower the water table, thus denying water to farmers who can only afford shallow wells.

While the cost of drip irrigation is not abhorrently expensive, start up costs remain a barrier for small-scale farmers to implement. Another initiatives promoting technology to improve efficiency involve providing farmers with low interest loans for drip irrigation with public sector commercial banks. Currently, there are existing barriers in the cooperative credit system by the politicization of cooperative institutions by state government interference. The cooperative credit system would have to undergo changes in capitalization to ensure professional management of banks (Ahluwalia, 2005).

5.2 Reformed Price Incentives:

A variety of reformed price incentives also provide an effective means to drive greater efficiency gains in water use. These include the privatization and regulation of urban water sources, reduced subsidies or increases tariffs, and direct ownership of water rights.

Necessarily, water remains a public good and is controlled by the government. However, increasing the private sector investment in water can help bolster efficiency. Development of privatization and regulation of urban water sources provide a driving market force to increase water efficiencies. When incremental water can be obtained at a low cost due to subsidies, little incentives exist to promote both physical efficiency through the investment of pipes or metering or economic efficiency (Wichelns, 1999). Private sector ownership of water places a price on water, and encourages those to invest in greater water efficiency measures.

In India the price of water for urban and agricultural uses is kept artificially low. Reducing subsidies on water as part of comprehensive water policy reform provides another incentive to increase water efficiency. For example, in Chile the removal of general water subsidies has allowed the government to increase the level of subsidies targeted directly to the rates paid for urban water by the poor. Subsidies also go to small farmers to allow them to acquire water rights from new infrastructure. Such reforms have been completed in Chile and increased aggregate irrigation efficiency by 22 to 26 percent from 1975 to 1992 (Rosegrant, 1999). According to the study, "using the lowest estimate, and taking into account Chile's total irrigated area of 1,200,000 hectares, this is equivalent to freeing up enough water to irrigate an additional 264,000 hectares of crops of average water-use intensity." (Rosegrant, 1999). In the industrial sector, increased water prices will lead to investment in water recycling and conservation technology. Increased water tariffs in Goa, India, induced a 50 percent reduction in water use over a five-year period by a fertilizer factory (Rosegrant, 1999). In São Paulo, three industries reduced water consumption by 40 to 60 percent in response to effluent charges. Removing subsidies on urban water use can also have dramatic effects. An increase in the water tariff in Bogor, Indonesia, from US$0.15 to US$0.42 per cubic meter resulted in a 30 percent decrease in household demand for water (PANOS, 1999).

Secure water rights held by the urban companies and an active market have encouraged the construction and operation of improved treatment plants that sell water for agricultural or urban use and established a viable water market. Outside India, effective water markets have dramatically increased in Chile. With the pricing or virtual market of water, a Chilean farmer can typically save 30 percent of his or her irrigation water on a 40-hectare grape farm and can sell his or her water rights for the saved water for $7,000-$10,000, without reducing yields (Rosegrant, 1999).

6. Conclusion:

Amongst the unprecedented economic growth of the Indian economy, there lies a grim reality of water scarcity and limited natural resources. Agriculture, representing the largest consumer of water, remains a key component that through some effort can produce substantial gains in efficiency and long-term sustainability of India. However, adapting to the prospect of changing rainfall patterns and expanding demand for water remains difficult. A large number of people have limited ability to adopt technological change, particularly where upfront investments are required. Thus, investments by government based on policies and fiscal measures that provide incentives for increasing water efficiency and promote technology as described in this paper are no longer an option, but a necessity. A nexus between scientific assessment and policy formulation are necessitated for adaptation measures to be carried to a reasonable measure of practical success against the prospect of changes in rainfall patterns in the Indian monsoon.

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References:

Ahluwalia, M. S., 2005: Reducing Poverty and Hunger in India: The Role of Agriculture, The Planning Commission.

Aldhous, P., 2004: Borneo is burning. Nature 432: 144-146.

Alliance to Save Energy, 2006: Watergy Water Efficiency: A Resource for Utility Managers, Community Planners, and Other Decision Makers. Washington DC.

Amarasinghe, U.A., B.R. Sharma, N. Aloysius, C. Scott, V. Smaktin, C. de iture, A.K.

Sinha, A.K. Shukla, 2005, Spatial Variation in Water Supply and Demand across River Basins of India. IWMI (International Water Management Institute), Research Report 83. Colombo, Sri Lanka: IWMI.

Annamalai H., K. Hamilton, and K. R. Sperber, 2007: The South Asian Summer Monsoon and Its Relationship with ENSO in the IPCC AR4 Simulations, Journal of Climate, Volume 20, Issue 6 pp. 1071–1092.

CCWB, National perspective plan for recharge to groundwater by utilizing surplus monsoon runoff. Unpublished report, Central Ground Water Board, Ministry of Water Resources, GOI, 1996.

CWC, Pricing of water in public systems in India. Report of the Central Water Commission, Govt. of India, 1993.

FAO (Food and Agriculture Organization of the United Nations). 2002. AQUASTAT statistical database. www.fao.org. Rome: FAO.

Gleick, P. H. 2000. The world's water 2000–2001. The biennial report on freshwater resources. Oxford, UK: Oxford University Press.

Goswami, B. N., V. Venugopal, D. Sengupta, M. S. Madhusoodanan, and Prince K. Xavier, 2006: Increasing Trend of Extreme Rain Events Over India in a Warming Environment, Science, 314 1442-1444.

Gupta, S.K. and R.D. Deshpande, 2004, Water for India in 2050: first-order assessment of available options, Current Science, 86(9)

WGII SPM IPCC, 2007: Summary for Poicymakers. In: Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

WGII IPCC, 2007: Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Asia Chapter Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

WGI IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IWMI (International Water Management Institute). 2000. World water supply and demand 1995 to 2025. Draft report prepared for World Water Vision. Colombo, Sri Lanka: IWMI.

Kripalani, R. H., J. H. Oh, A. Kulkarni, S. S. Sabade and H. S. Chaudhari 28 February 2007: South Asian summer monsoon precipitation variability: Coupled climate model simulations and projections under IPCC AR4, Theoretical and Applied Climatology, published online.

Lau K.M. and K.M. Kim, 2007: Does aerosol weaken or strengthen the Asian monsoon water cycle? In: Mountains: Witnesses of Global Changes – Research in the Himalaya and Karakoram [Baudo, R., G. Tartari, and E. Vuillermoz (eds.)]. Elsevier Science; 1 edition (Jul 31 2007). pp.11-20.

Meehl, G. A. & J. M. Arblaster, 2003: Mechanisms for projected future changes in south Asian monsoon precipitation, Climate Dynamics 21, 659–675.

Meehl, Gerald A., Julie M. Arblaster, and William D. Collins, 2006: Effects of black carbon aerosols on the Indian monsoon, J. Climate, in publication.

MOWR, Integrated water resource development- a plan for action. Report of the National Commission for Integrated Water Resources Development Plan, Ministry of Water Resources, Govt of India. 1999, vol. 1, p. 515.

PANOS July/August 1998: LIQUID ASSETS: Is water privatization the answer to access?. Media Briefing No. 29

Ramanathan V., C. Chung , D. Kim , T. Bettge , L. Buja , J. T. Kiehl , W. M. Washington , Q. Fu , D. R. Sikka, and M. Wild, 2005: Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle, PNAS (2005) paper.

Reserve Bank of India Report Macroeconomic and Monetary Developments: First Quarter Review 2006-07. Report of the Reserve Bank of India, Govt of India. 2007.

Rosegrant, M. W.; Cai, X.; Cline, S. A. 2002. World water and food to 2025: Dealing with scarcity. Washington, DC: International Food Policy Research Institute.

Rosegrant, Mark. 1995. Dealing with Water Scarcity in the Next Century. International Food Policy Research Institute Policy. 2020 Brief 21.

Rosenfeld, D., 2000: Suppression of Rain and Snow by Urban and Industrial Air Pollution, Science 287, 1793–1796.

Seckler, D.; Amarasinghe, U. A.; Molden, D.; de Silva, R.; Barker, R. 1998. World water supply and demand, 1995–2025. Research Report 19. Colombo, Sri Lanka: International Water Management Institute.

Siddiqui, K.M., Iqbal Mohammad and Mohammad Ayaz, 1999: Forest ecosystem climate change impact assessment and adaptation strategies for Pakistan, Climate Research, Vol. 12: 195–203.

Trenberth K.E and T.J. Hoar. 1997. El Niño and climate change. Geophysics Research Letter 24, 3057-3060.

Trenberth, K.E., J. Fasulla, and L. Smith, 2005: Trends and variability in column-integrated atmospheric water vapor, Climate Dynamics, 24, 741-758.

Wichelns, Dennis. 1999: Economic Efficiency and Irrigation Water Policy with an Example from Egypt. International Journal of Water Resources Development, Volume 15, Issue 4 December 1999, pages 543 – 560.

WRI (World Resources Institute); UNDP (United Nations Development Programme); UNEP (United Nations Environment Programme); World Bank. 2000. World resources 2000–2001. People and ecosystems: The fraying web of life. Oxford, UK: Elsevier Science.

Climate Change/Variability and Vulnerability of Livelihoods in the Offin River Basin, Ghana

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ABSTRACT

The effects of climate change and variability on water availability in Ghana is already being felt throughout the country. Coping with water scarcity thus becomes a major issue.

Most communities in the River Offin basin are rural with no pipe-borne water, and predominantly farmers who depend on irrigation for their crops. The basin provides the communities with water for drinking, and for other economic activities. Livelihood resources are heavily affected by prolonged rainfall shortages, droughts and extreme heat, leading to crop damages/losses, water shortage, diseases and income loss. This makes the basin very vulnerable to effects of climate change and variability.

With high dependence on rainfall and rivers for water needs, and the climate situation expected to worsen in the coming years, livelihoods in Ghana's Offin river basin are seriously at risk.

This paper examines rainfall and temperature patterns in the River Offin basin and assesses the vulnerability livelihoods in the River Offin basin to climate change and variability.

1. INTRODUCTION

Severe effects of climate change and variability have manifested in Sub-Saharan Africa and West Africa in particular, over the last 30 years. It is recorded that mean annual rainfall decreased by 10% in the Wet Tropical Zone to more than 30% in the Sahelian Zone while the average discharge of the region's major river systems dropped by 40 to 60%, in the 1970s (Niasse, 2005). Since then extreme effects of climate change and variability have been very prominent on the water resources of the sub region.

Although Ghana is fairly well endowed with water resources, there is a high variability in the amount of available water within the year and over several years. From the Ghana National Communication to the UNFCCC, by the year 2020 and 2050, all water basins will be marginally vulnerable and the country will face water management problems. The communication predicts resulting secondary impacts on health, nutrition and energy-based industrial activities, if proper adaptation options are not embarked upon.

Ghana experienced acute energy crises in 1998 and though several reasons were ascribed for the reduction in water volume at the Hydro Electric Power generation station on the Volta Lake, Andah (2003) concludes that the reduction was an effect of climate change/variability. Ten(10) years later, the crisis has recurred with greater intensity resulting in electricity rationing throughout the country. This has affected the country socially and economically, with the closure of many major industries including the VALCO Aluminium Smelting Factory.

In the general context of contributing to the processes of adaptation to climate change through the assessment of vulnerability derived from the impacts of climate change/variability on watersheds and watershed dependent communities, this paper examines rainfall and temperature patterns in the River Offin basin and assesses the vulnerability of the River Offin basin and its dependent communities to climate change and variability.

2. METHODOLOGY

Study Area

The River Offin is an easterly-flowing waterway in Ghana. The river takes its source from the Ashanti Region in middle Ghana, and flows southwards to join the River Pra before entering the Gulf of Guinea. Most communities in the River Offin basin are rural with no pipe-borne water, and predominantly farmers who depend on the river and rainfall for irrigation. The basin provides the communities with water for drinking, and for other economic activities.

The River Offin basin has a semi humid tropical climate with two main: a dry season (November to March) and a rainy season (April to October). The rainfall distribution of the basin is weakly bimodal with a main peak between May and June and a secondary peak in September to October.

Data Collection and Analysis

Since the study is relatively new in the area, a pre-assessment phase involved defining and clarifying concepts of vulnerability, gathering relevant information, and adapting and adopting concepts to suit the study.

The annual maximum and minimum temperatures and precipitation over the period of 1961-2006 are analysed to establish a trend, with the technique of linear regression. The seasonal and interannual variability was also assessed. This will be used for the assessment of climate change and variability and also serve as the baseline for future climate prediction and/or scenario simulation. This analysis will also present the baseline climate for future studies of the River Offin basin.

Interviews, questionnaires and literature search were used to set the climate-livelihoods contexts of the communities in the Offin basin. The data gathered was synthesized in two ways. First is to set the climate context by identifying the impacts of current climate hazards and climate change in the project area, particularly on local livelihoods. Secondly, the livelihood context was set by identifying the resources needed to help people conduct their livelihoods and cope with these impacts. This forms the baseline for analysis of the vulnerability of the communities to potential climate change and variability.

3. RESULTS AND DISCUSSION

Climatic Characteristics of the River Offin basin

The wettest year in the last forty-six years was 1968, with a mean annual precipitation of 2343.7mm and the driest year was 1982, with 891.5mm mean annual rainfall. There were significantly low precipitation recorded from 1977 to 1983 and high rainfall was also recorded between 1962 and 1965.

The mean maximum air temperatures show a weak seasonality (2.0^{o}C range). The highest mean maximum temperature recorded for a year was 31.8 ^{o}C in 1998 and the lowest was 29.8 ^{o}C in 1964. Similarly, 1998 recorded the highest mean minimum air temperature of 22.8 ºC and the lowest mean minimum temperature recorded was 21.0 ºC in 1964 (1.8ºC range). This makes 1998 and 1964 the warmest and coldest years, respectively, in the last forty-six (46) years. It also gives an indication of the consistent temperature rise over the last forty-six years.

On the other hand, from a mean minimum air temperature of 21.1 ºC in 1961, it rises to an average of 22.1 ºC in 2006. This is a 1.0 ºC rise in temperature over the entire period, compared to the 1.3 ºC rise in average maximum temperatures. This indicates a 4.7% rise in temperature compared to the 4.3% rise in average maximum temperatures.

3.1 Climate Trends

Indigenous people in the Offin River basin claim to have observed climatic changes in the basin. Such knowledge though very useful, was mainly based on what has happened within the last few years. The study therefore set out to scientifically validate this claim or otherwise by subjecting temperature and precipitation (the main parameters of climate change) to linear regression to establish the linear rate of change in these two parameters.

3.1.1 Precipitation

The seasonal precipitation trend did not change much over the years; a main peak in May to June and a secondary peak in September to October. However, the beginning and intensity of the peak and secondary rainy seasons showed some variability. There was also a marked reduction in the mean annual precipitation recorded over the period of 1961 to 2006. Mean annual precipitation has decreased by 22.2% from 1960 to 2006 and this agrees with Niasse, (2005) observation that there has been a significant decline of 15% to 30% in rainfall since the 1968-1972 periods, in West Africa, depending on the area.

Total mean annual rainfall of 1367.5mm was recorded from 1961 to 2006. June recorded the highest amount of rainfall over the period under study with 205.6 mm of rainfall whilst the least amount of rainfall was recorded in the month of January with 21.2 mm of rainfall.

There has been a gradual but consistent reduction of rainfall/precipitation from 1961 to 2006. Assessment of rainfall pattern for every ten (10) years showed that the decade of 1981-1990 recorded the least precipitation (105.9 mm) in the period under study. This decade falls within the era when Ghana experienced prolonged rainfall shortages and severe droughts. The highest rainfall (144.8 mm) was recorded for 1961-1970. There was, however, a sharp drop in precipitation from the 1961-1970 to 111.8 mm for 1971-1980, increased slightly to 107.6 mm in 1991-2000 and further up to 112.7 mm for 2001-2006. Generally, there is still a significant reduction in precipitation.

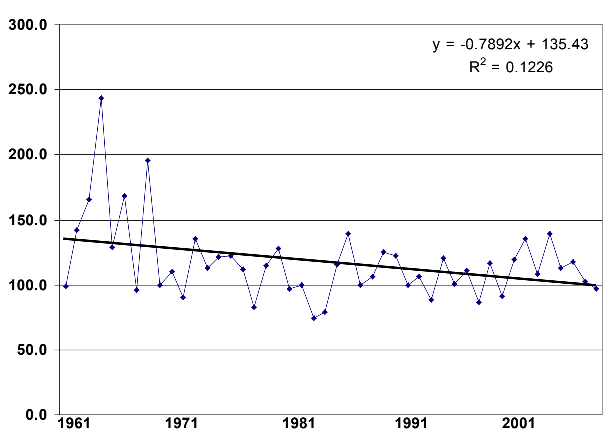

Figure 1. Trend in annual rainfall in River Offin Basin from 1961.

3.1.2 Mean Maximum Air Temperatures

The general trend of mean maximum temperature readings recorded over the period 1961 to 2006 has been presented in Figure 2. There is a gradual rise in average maximum temperatures over the stated period from 30.2 ºC in 1961 to 31.5 ºC in 2006. This shows a rise in temperature of 1.3ºC, representing a 4.3% rise, although there were periods within these two years that the mean maximum temperature fell below the 1961 initial value of 30.2 ºC and the 31.5 ºC in 2006. Though there was little variation in recorded temperature readings over the period, effects on the basin may be very significant.

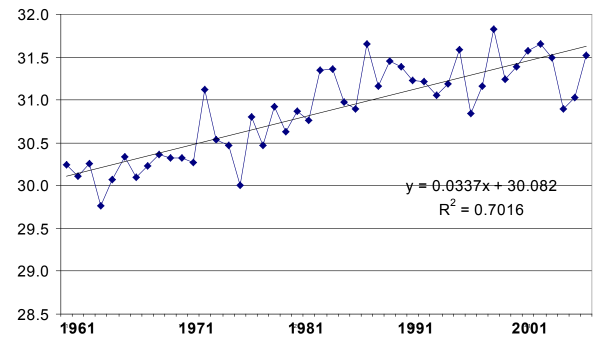

Figure 2. Trend in mean maximum air temperature in River Offin Basin.

3.2 Vulnerability of the River Offin Basin to Potential Climate Change/Variability

3.2.1 The Climate Context

Africa is highly vulnerable to climate change, with water resources, food production, human health, desertification, and coastal zones, as the main areas of vulnerability. Those with the least resources have the least capacity to adapt and are the most vulnerable (IPCC, 2001). The potential climate change impacts in the River Offin basin, the current climate hazards, the impacts of these climate hazards, and strategies people are using to cope with these impacts were established with the participation of the community through interviews and questionnaire administration as well as desk study. The communities identified the three main climate-related hazards, affecting them currently, as prolonged rainfall shortages, drought and extreme heat.

I. Prolonged Rainfall Shortages: Impacts and Coping Strategies

Prolonged rainfall shortages cause water shortage, crop damage/loss and loss of income to the people in the community. Community in the Offin basin mainly depends on the River Offin system and rainfall for their water needs although there are a few wells and boreholes fitted with hand pumps. Most of these wells completely dry out during the dry season and the boreholes often break down. The communities also prefer water from the rivers because, according to them, the river water tastes better than that of the wells.

The people are mainly crop farmers and depend on the rains to irrigate their crops. During periods of prolonged rainfall shortages, the crops get damaged and this leads to a great loss to the farmers. Due to lack of a holistic management policy that together looks at water and forests and their interactions, the typical African farmer is achieving low crop yields (Rockstrom & Falkenmark 2000). There is food shortage and also loss of income since produce from their farms provides food for the family as well as income from sale of the food.

To cope with water shortages, the communities have resorted to water rationing and rain water harvesting. They also prevent water waste and store as much water as possible during rains. Use of "waste water" for other activities such as backyard gardening is becoming popular in some communities. Some communities have initiated tree replanting projects to protect water courses in their towns. The traditional and local authorities have started realizing the impacts of felling of trees along the river banks on the streams/rivers and are making attempts to remedy the situation.

The only option left for the people to cope with loss of income from their farming activities is to do petty trading and casual labour. The communities are mostly rural with high poverty level and trading is not beneficial. There are also no industries or major construction works in the communities for casual labour work so many of the youth have migrated to Kumasi to find jobs. This has created a situation where most of the people left in the communities are the old, women and children.

II. Droughts: Impacts and Coping Strategies

As climate changes, there is reason to believe that drought hazards will increase (Downing and Ludeke, 2002). The impacts of droughts on the community are similar to that of the prolonged rainfall shortages. In addition, it results in food insecurity and reduced water quality. During drought situations there is severe food loss and wild fires that destroy farms. Worst affected families have to ration food.

In the late seventies and early eighties, severe droughts and the accompanying bush fires destroyed forests and farms, resulting in crop failure, livestock losses, malnutrition, increased health risks and famine. The water quality reduces during droughts because the river stagnates in pockets gathered along the river course, the water gets turbid and insect larvae are at times found in the water. The wells get dry and those who can not afford to buy water from sachet water producers have no option but to struggle for the little unwholesome water left for the community. Water shortage has become a national crisis especially during the dry season and as a result, bringing with it water related diseases such as malaria, diarrhoea and cholera (Nsiah-Gyabaah, 2001).

III. Extreme Heat: Impacts and Coping Strategies

The main impact of extreme heat on the communities is disease. Some of the people, especially children, suffer skin problems such as shingles during periods of extreme heat. Extreme heat also makes some people sleep in open compounds or in their rooms with windows open, exposing them to mosquitoes and eventually, malaria. This brings an extra cost in terms of medication on the relatively poor communities. There are no coping strategies and affected people are almost helpless. The communities believe it is God who controls the weather. The only option is to seek medical attention but there are no health facilities in most communities so they rely on herbal medicine.

3.2.2 The Livelihoods Context

Setting the livelihood context involved answering questions such as; which resources are important to people's livelihoods? To what extent are these resources negatively affected by current climate hazards identified? And to what extent do these resources influence current coping strategies?

The important livelihood resources identified by the communities are:

Natural Resources - Forest products, River Offin and Land

Human Resources - Indigenous knowledge, agricultural skills/training, water management skills/training

Financial Resources - Remittances, Savings

Physical Resources - Wells, bridges, roads

Social Resources - Local Community based organizations, Local Governance Institutions, Religious groups.

3.2.3 Influence of Climate Hazards on Important Livelihood Resources

"Given the potentially dramatic effects on local climate, natural resources, infrastructure and economic activities, Africa may be particularly physically vulnerable to and at risk from climate change (Eriksen, 2001)".

Prolonged rainfall shortages have a negative influence on the sources of water in the communities in the River Offin basin. This hazard causes a reduction in the volume of water available to the community, both for domestic use and irrigation of crops. Wells in the communities looses water after prolonged period of no rain and many rivers and streams cease flowing at the inception of the dry harmattan season. Opoku-Ankomah and Amisigo (1998), after evaluating the last 40 years of rainfall and runoff records, concluded that there has been a statistically significant reduction in rainfall and runoff in South-western Ghana, and links this to the influence of climate change.

Households that are affected by crop damage/loss have to use their savings to replant their failed farms.

On the other hand, prolonged rainfall shortages have enhanced the water management and agricultural skills/training of the communities. The people are now cautious on water use and are taking initiatives to protect their water bodies. They are improving on their farming practices to avoid crop damage/loss, in case of less/no rainfall.

Drought has similar influence on the livelihood resources as the prolonged rainfall shortages. However the intensity of the influence of the droughts on the water resources is more intense compared to the former. Most wells completely dry up. Droughts affect the effectiveness of schools. Pupils spend several hours looking for water for their families and get to school late whilst others can not make it to school at all. Pupils, and teachers alike, have to wake up at dawn to go and fetch water from the river since they by then the suspended particles would have settled over night and the quality of water would be better.

There are a lot of wild fires during droughts and prolonged rainfall shortages. Bushfires occur annually in the dry season (November to March) when land is prepared in anticipation of the first rains, for planting. Records indicate that only 20% of the forest zone in Ghana is currently covered by forest which has not burnt regularly (Hawthorne, 1994). Most farmers use the slash and burn method to prepare their lands for the planting season and carelessness on their part results in bush fires, destroying farms and forest resources and leads to heavy losses to people affected. Crops do not grow well and the farmers experience heavy crop damage/loss. Money spent on the preparation of land and planting, as well as expected income from the produce is lost.

Extreme Heat has very significant influence on the financial resources of the communities. During very hot nights, some people sleep outdoors or leave their windows open whilst sleeping, exposing them to mosquitoes and malaria attack. Financial resources are spent on the treatment of malaria and other heat-related disease such as shingles. Extreme heat affects human resource because income earners get sick, people can not go to their farms, and schools are also affected.

3.2.4. Influence of Livelihood Resources on Coping Strategies

In coping with prolonged rainfall shortage and droughts, the communities resort to rationing water and harvesting rain water. Their water management skills influence their ability to store water for the future. Those with good financial resources are better placed to cope with prolonged rainfall shortages and droughts.

The financial resources help the people to cope with the impacts of drought. In coping with non-availability and reduced quality of water during droughts, the people resort to purchasing sachet water for drinking. This, however, depends on the household's ability to pay for such services. Not many people are able to afford this coping strategy and those who can not afford are left to look for other options to cope with the impacts of drought and bad water quality.

The schools educate the children on the need to use water wisely. This is helping in bringing up a generation that will have good water management skills and training. The children also get enlightened on the impact of poor water quality on their health. Over the years, the people have coped with water shortage and droughts quite well with the help of their indigenous knowledge in water management.

Social resources have over the years helped the people to mobilise resources to provide good drinking water in times of crisis. Wells have been constructed to ease the problems of water shortage and poor water quality. However, wells that were dug to provide good quality water have not been very reliable since they often break down. Residents also claim water from the wells does not taste well and they prefer water from the rivers and streams. Local governance institutions and traditional authorities have started initiatives to protect the water resources in their communities. Some tree planting programmes are put in place to protect the rivers and streams whilst some authorities have made by-laws to protect the water resources from deforestation and pollution.

The financial and human resources influence the people's ability to cope with crop damage/loss. Households with strong financial resources are able to replant their failed farms, leaving those without the capacity to their fate. Remittances from relatives outside the community particularly help farmers to replant their farms after crop damage/loss.

The indigenous knowledge and agricultural skills of the people acquired over many years of practice help the people to cope with their crop damage and losses.

Good road network (physical resources) and the proximity of the communities to Kumasi, makes it possible for the people to travel to Kumasi to find casual work to cope with income loss due to climate hazards. There are no industries for casual labour and the roads make transportation easy. Accessibility to big market centres is also made easy by the roads. Farm produce is easily transported from the communities to outside markets such as Kumasi where they get better prices for their goods. A few community based organizations and religious groups occasionally organize training programmes in alternative livelihoods to give the people options to cope with impacts of climate hazards on their main source of livelihood, which is agriculture.

5. CONCLUSION

There has been a significant change in the climate pattern in the Offin river basin. Whilst mean temperatures are rising, rainfall is on a significant decline. Rainfall patterns are also showing increasing variability and this is affecting the livelihood resources of communities in the Offin basin, who are predominantly crop farmers. Their livelihood resources are heavily affected by prolonged rainfall shortages, droughts and extreme heat, leading to crop damages and great losses. With majority of the communities without pipe water and depending on the Offin River and other smaller streams for their water needs, they are highly vulnerable to the effects of climate change, more so when the climate situation is expected to worsen. Extreme heat and water-related diseases such as malaria, cholera, diarrhea and several skin diseases are expected to rise, with major impact on the human and financial resources of the communities.

REFERENCES

Adger, W. N., Huq, S., Brown, K., Conway, D., and Hulme, M., (2002). Adaptation to Climate Change: Setting the Agenda for Development Policy and Research. Tyndall Working Paper 16. Tyndall Centre for Climate Change Research.

Andah, W.E.I. (2003). Climate Variability/Change and the Energy Crisis in Ghana. Input to the West Africa Adaptation Strategy on Water and Climate. IUCN-BRAO.

CRISTAL Version 3.0 (2006). (Community-based Risk Screening Tool - Adaptation & Livelihoods). A decision support tool for assessing and enhancing project impacts on local adaptive capacity to climate variability and climate change. Developed by IISD, IUCN, SEI-B and Intercooperation)

Downing, T. and Lüdeke, M. (2002). Chapter 14, International Desertification. Social Geographies of Vulnerability and Adaptation In: Dahlem Workshop Report on Global Desertification: Do Humans Cause Deserts? ISBN 3-934504-10-8. Website: Dahlem Konferenzen der FREIEN UNIVERSITÄT

Eriksen, S. (2001). 'Linkages between climate change and desertification in East Africa'. Arid Lands Newsletter No. 49, May/June 2001.

Hawthorne W .D. (1994) Fire Damage and Forest Regeneration in Ghana. ODA Forest Series 4. Natural Resources Institute, Chatham, 53 pp.

IPCC. 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Technical Summary. Geneva: IPCC.

Niasse, M. (2005). Climate-Induced Water Conflict Risks in West Africa: Recognizing and Coping with Increasing Climate Impacts on Shared Watercourses. Paper Presented at Human Security and Climate Change workshop, Asker, Norway, 21–23 June 2005.

Nsiah-Gyabaah, K (2001). The Looming National Dilemma of Water Crisis in Peri-Urban Areas in Ghana. A Paper Presented at the Second Workshop on Peri-Urban Natural Resources Management Project at the Watershed Level. (DFID Project Funded Project R 7330)

Opoku-Ankomah, Y. and Amisigo B.A, (1998). Rainfall and Runoff Variability in the South Western River system of Ghana. A paper presented at an international Conference on water resources variability in Africa during the 20th century, at Abidjan, Cote d'Ivoire, 16-19th November, 1998.

Rockstrom, J. & Falkenmark, M. (2000) Semi-arid crop production from a hydrological perspective. Gap between potential and actual yields. Crit.Rev. Pl. Sci. 19, 319–346.

Developments in downscaling climate change scenarios

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The challenge for developing regional scale climate change projections has long been a limiting factor to implementing effective and defensible climate change policy and adaptation measures. Conventionally generating regional scenarios has been approached through the catch all phrase of downscaling, with the different methods sharing a common dependency on the low resolution global simulations with GCMs of the evolution of the future climate. Even though GCMs continue to improve in skill, and their resolution is steadily increasing, there remains a significant gap between the skillful scales of GCMs and the stakeholder needs at the regional scale. Hence there remains a continued and growing need for downscaling.

The methodologies have traditionally fallen into two streams; empirical/statistical downscaling techniques (SD), and high resolution dynamical modeling with either Regional Climate Models (RCMs) or variable resolution GCMs. Variants of these exist, such as statistical-dynamical downscaling, but all are based around the same conceptual elements. The dynamical and empirical approaches are not so much competitors but rather complementary, with each having relative strengths and weaknesses.

At the time of IPCC third assessment report (TAR) downscaling was still very much a developmental area with most energy focused on understanding the methodological issues. In the subsequent years leading up to the IPCC fourth assessment (AR4) the methodological approaches have become better understood, and more broadly applied to provide regional scale scenarios for impacts and adaptation. Nonetheless, in the AR4 downscaling results still played the smaller role, due to somewhat limited results as a consequence of the computational and/or experiential skill required to pragmatically implement a robust and credible downscaling, be it a dynamical or statistical approach. Consequently the AR4 chapter on regional projections still draws heavily on the raw GCM output with all its associated caveats and limitations. The AR4 does, however, couple the GCM output with a broader base of information, developing robust statements of regional change, where possible, based on the multi-model GCM output along with consideration of historical change, results from the (limited) downscaling output, and process-based understanding of the changes in large scale features driving the climate system.

There are a growing number of downscaling outputs now available that either explicitly addresses a user community need beyond that of a specific project, or else which may be leveraged as such. Examples include the PRUDENCE project in Europe, or all Africa scenarios developed under the AIACC project. Forthcoming developments include such examples as the high resolution scenarios to be used in the next UK CIP report and based on dynamical downscaling, or the empirical based downscaling for all continents in the ACCCA project. The expansion of downscaling activities reflects two factors. Firstly, the growing demand for actionable information from the policy and adaptation communities, ranging from national, regional and local government to specific sectors of society such as agriculture or water resources, and even to the man in the street asking "what about my back yard". Secondly, the growing confidence in understanding the strengths and weaknesses of the different downscaling approaches.

At present downscaling remains the only tractable solution to meet the user regional information need and, at the same time, give due consideration to assessing uncertainty and envelope range beyond that which would be possible with, for example, a single very high resolution GCM run. The growth and mainstreaming of downscaling does, however, bring a new set of challenges and difficulties, not least of which are issues of appropriate dissemination, the danger of over-interpreting data, or implementing single model solutions and building a fragile edifice of societal response on limited information.

In the sections following a brief consideration of the status of downscaling is presented, following which some of the leading issues in pragmatic downscaling are explored, along with the underlying conceptual challenges faced by these approaches. In addition, the possible frontiers in need of further research are examined, as well as the question of pragmatic implementation; who downscales, evaluation of skill, and how information is disseminated.

Status of downscaling methods

Downscaling as a basic concept is generally well comprehended by the potential user community. In its approach one recognizes that the Global Climate Models (GCMs) have a coarse grid cell resolution, and that the grid cell scale is not the skillful scale of the GCM (especially for precipitation) due to GCMs poorly resolving local forcing features. At the same time it is recognized that the GCMs are realistically skillful at the process scale of synoptic circulation features such as the primary high and low pressure systems of the atmosphere, etc. Recognizing that the local and regional scales of climate are largely a function of the larger scale processes, this opens the possibility of using the large scale circulation of the GCMs to condition a local scale response.

In RCM-based[1] downscaling one uses a GCM to establish the boundary fields of the RCM – essentially a model like a GCM but at higher resolution and over a smaller finite domain – and allow the RCM to derive a dynamic solution at higher resolution, and which is physically consistent with the larger scale circulation of the forcing GCM. Conceptually this is a satisfying solution, in that is based on fundamental dynamics and physics while it encompasses (some) feedbacks as well as resolving higher resolution features such as local topography. Nonetheless there are notable practical problems, which include:

- The skill scale of the RCM is, like the GCM, not its grid scale resolution.
- The choice of paramterizations for sub-grid scale processes can significantly alter the solution.
- The high computational demand for running one RCM with even just one forcing GCM places this solution out of reach for many, especially in developing nations.
- Similarly the computational demand often limits users to one or two RCMs, and usually only one driving GCM.
- Different RCM's can produce widely different solutions even when driven by the same GCM.
- Understanding the physical basis of the derived climate change response is not always readily transparent given the complexity of the RCM models.

1 In this discussion variable resolution and high resolution GCMs are, perhaps unfairly, lumped with RCMs under the dynamical downscaling umbrella. While there are clear specific issues related to each, they nonetheless share much in common as to the basis of the derived downscaled product.

RCM solutions for downscaling have a growing presence in the community, but are still somewhat limited in use by the adaptation community for the above and other reasons. Some large coordinated projects such as the European PRUDENCE program have made significant strides, but at substantial investments of time, money, and requiring large team collaboration. In other areas there are cases of RCMs used in climate adaptation project work, but more often than not it is only one RCM being forced by one GCM, which limits the possibility of exploring the range of the future climate envelope.

With empirical/statistical downscaling (SD) methods, the capacity to achieve a multi-GCM based downscaling is computationally readily achievable. The SD approach is conceptually simple, readily understood, and within reach of most scientists with a modicum of IT and statistical capacity. The solutions may readily be of equal skill to that achieved by RCMs, and the computational demands are far fewer. In addition SD may be used to downscale to point resolutions and for parameters not readily obtainable from RCMs.

However, the very simplicity of the approach opens it up to users potentially achieving a result that on the face of it appears valid, but which may be fundamentally flawed. For example, one may choose predictors which in themselves do not carry the inherent signal of climate change, and thus result in a misrepresentation of future change. Other difficulties include:

- A greater vulnerability than RCMs to issues of stationarity and feedbacks
- Dependence on predictor choice
- Difficulty in achieving spatial-temporal cohesion in multi-site downscaling
- A necessity for observational data (in some methodological approaches, requiring length records) in order to develop the cross scale relationships.

Recognizing the caveats of each method, and the pragmatics of implementing a downscaling, it is arguable that at present the SD approach has many pragmatic advantages for the bulk of the impact and adaptation community – at least insofar as achieving a credible and defensible downscaled solution of the first order regional response, and to do so across multiple GCMs. This is possibly what is most needed at present given the current foci of the adaptation community.

Questions that need answers in applied downscaling

With the growing emphasis on adaptation in many communities, there is the natural commensurate growth in demand for regional scale information. This is leading more and more to implementations of downscaling driven by the time-imperative of need. For the most part this is likely to focus on SD techniques, but also includes dynamical downscaling. In each case there are key issues and concepts that need to be carefully considered by both those implementing the downscaling, and also understood by the recipient community. In a limited way we list here some of the leading issues that should at least be recognized as providing a context for the downscaled product, even if each may only be partially answerable.

1. Variance: Optimally one desires for the variance structure of the downscaled product to be realistic in all frequency bands; that is correctly capturing the variability of both long and short time scales. Different methodologies have variable ability to accomplish this. At a minimum one needs to ask the question of to what degree the method captures the deterministic component (that is, the forcing arising from the large scale as represented by the GCM fields), as well as the locally forced component. GCMs are generally a constrained lower dimensional representation of the observed climate system, and with consequent lower variance. There is an important question of to what degree a downscaling technique can recover realistic high resolution variance.

2. Feedbacks: In reality the local scale processes inevitably introduce feedbacks. In some geographic locales this may be more important than others and affect the degree to which the downscaled product may be impacted. For example, a coastal location whose precipitation is dependent on large scale frontal systems is unlikely to be highly dependent on local scale feedbacks. In contrast, a region very dependant on convective processes may well be vulnerable to feedbacks modulating the precipitation. A less obvious aspect is that the feedback may also not have spatially coincident impacts, but may be manifest through some local tele-connection. An understanding of the regional climate process dynamics is thus important.

3. Related to the above point is the degree to which the downscaling methodology is dependent on teleconnection stability, such as the ElNino coupling to Africa. However, in general there appears to be a move away from downscaling that inherently uses teleconnections as predictors. In this case the issue is not negated, but the onus is passed to the GCM community to capture the dynamics of the large scale linkages.

4. Stationarity: Long touted as an Achilles heel of downscaling, this is the question of to what degree a downscaling function is able to capture the cross scale relationships of the future climate system. While it remains an issue there is emerging evidence and reason to argue that, on the medium term time horizon, this is perhaps not an insurmountable problem. Nonetheless it is an issue to be considered, and applies to both to SD and RCM approaches.

5. Envelopes and convergence: While discussed in more depth further on, it bears noting here that while there will be only one time evolution of this worlds climate, in projecting the future there are a range of physical plausible pathways which are not separable in advance. On the flip side, some of divergence in the GCM data may be an overstatement of the uncertainty, in-as-much it is predicated on grid cell values of the data from the GCM. There is evidence to suggest that in terms of the larger scale processes that drive the regional change, there may greater convergence between GCMs than is generally credited.

6. Single versus multi-model solutions: It is tempting, especially with computationally demanding approaches to downscaling, to take a single plausible and credible numerical projection and to build a response strategy around this. The danger here is highlighted in figure 1, where either one of the downscaling solutions from different RCMs for the future climate change could, in isolation, be credibly interpreted. Yet seen together they demonstrate the significant differences that may arise in the possible range of the downscaled output. As such, the current state of the science is that the skill of specific projections in terms of the projected *magnitude* of change remains open to question, and it is the pattern and direction of change that is at present more robust. This necessitates a consideration of the possible responses beyond that derived from forcing by one particular GCM.

7. Practical issues: There remain many pragmatic elements to be considered, not least of which are the computational requirements (both infrastructural as scientific capacity), and accessibility of observational data.

8. Spatial-temporal homogeneity/cohesion in multi-site downscaling: If the downscaled product is to be used in an activity that is sensitive to autocorrelation in space and time, then this attribute needs careful consideration. For example, modeling the response of catchment basins requires realistic spatial relationships of precipitation events. This is not necessarily a given attribute from the downscaling procedure.

Envelopes: range, agreement, and probability

The issue of the range, or envelope, of projected change goes to the heart of the issue of what exactly a particular downscaled solution means. There have, in recent years, been tentative moves to develop probabilistic scenarios of climate change, including weighted summations of models, developing probability distribution functions

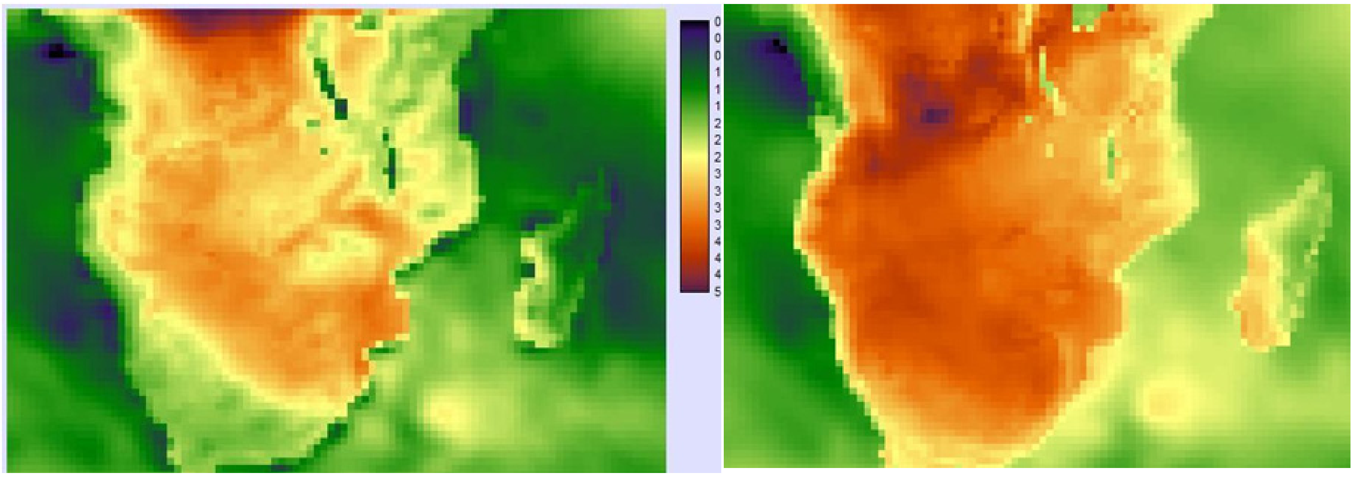

Figure 1: comparison of two downscaled simulations from different RCMs of the projected climate change anomaly, but forced by the same GCM (Tadross, Archer & Hewitson).

(for example, see the AR4 for a comparison of three techniques), or presenting percentiles of the range. In each case such an action infers three assumptions that are often ignored, and commonly not satisfied:

a) That the shape of the distribution has been realistically characterized – a problematic assumption in a case where, for example, one uses only some finite set of driving GCMs. Even in the case of efforts such as the climateprediction.net experiment, where many thousands of simulations are conducted to characterize some attributes of possible PDF shape, it remains only one model (albeit with variants through perturbed physics).

b) That the criteria used to characterize the envelope of possibilities, typically a mean annual temperature range, or perhaps a scatter plot of annual temperature versus precipitation anomalies, are representative criteria for identifying the bounds and range of projections.

c) That the question has been asked and answered as to what possible future change is excluded. That is, turning the question on its head by not asking what does the envelope encompass as characterized by the limited model runs, but what possible futures may justifiably be excluded.

One example of how this works out in the communication to stakeholders is shown in Figure 2. This figure from a recent case study communicates information that the stakeholders explicitly requested about the expected range and median climate change. However, the figure conveys the inference that the median is the most likely. In this specific situation there happens to be ancillary information which lends credibility to such an inference, but in isolation it is not a valid inference, and the key questions outlined above remain largely unanswered.

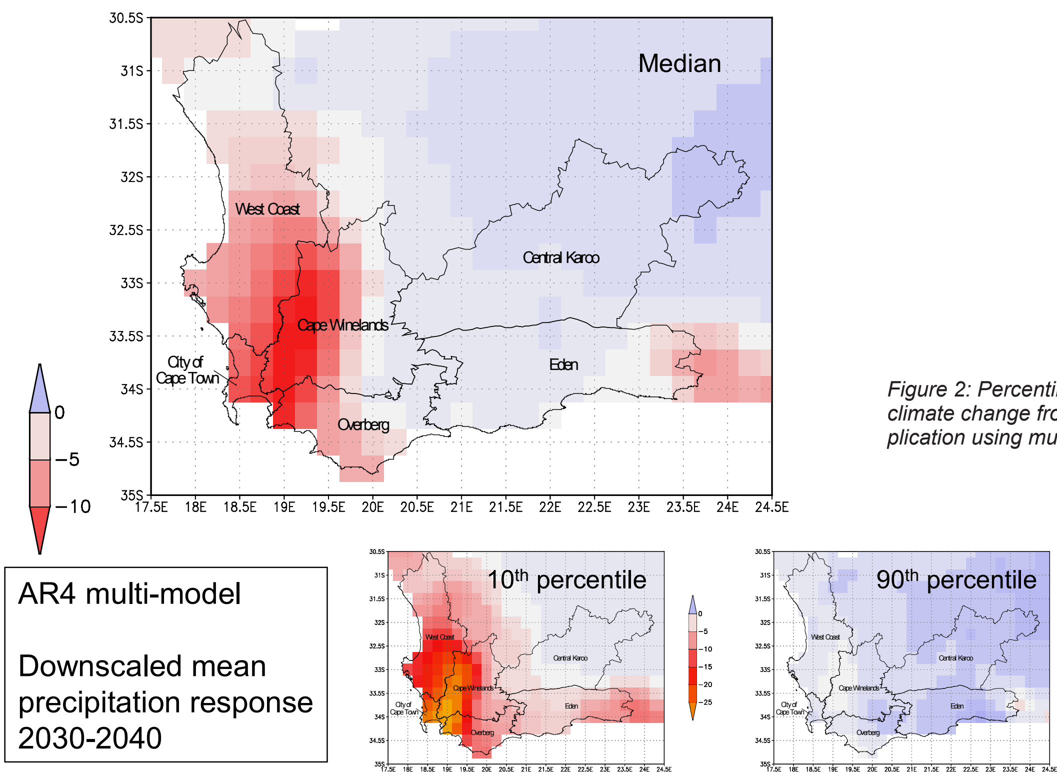

Figure 2: Percentile and median projected climate change from a downscaling application using multiple GCMs.

There is a thus a danger that downscaling results will be disseminated and the users, more likely than not, will make such inferences whether justified or not. The potential is then that significant and costly adaptation may be embarked on while there remains much uncertainty as to the likelihood, and while the limits of the bounding range (possibly equally likely) go largely ignored. From a risk assessment perspective and intent to enhance resilience, an emphasis on simple probabilistic products is cause for concern while the fundamentals as to the distribution remain uncertain. This especially so in the light of possible non-linearity, thresholds, and tipping points in both the climate system and the impact sector.

Taking this one step further, one may consider asking the question about the envelope in another way; that is, not simply asking what the range and limits of some simple quantity may be, nor even what such a criteria may legitimately exclude. Rather, one can consider how a specific impact sector could be used to define the criteria for defining the range. For example, consider an agricultural sector that may be relatively resilient to change in annual total precipitation and temperature, but is particularly vulnerable to dry spell duration and seasonal length. This dependency on sub-annual information and derivative attributes of the primary variable could readily be used as the criteria to define the envelope of projections, and do so in a far more relevant manner than simple annual change factors, and may disclose a distinctly different nature to the projected range of changes.

Communication

To date the application of downscaling has commonly placed significant onus on the recipient to either undertake the development of the downscaling themselves with some appropriate tutelage, or actual data is disseminated, more often than not in formats and specific variables not tailored to the end users needs. Compounding this is that the relevant contextual information that informs on the limits and strengths of the scenarios is often minimal or embedded in scientific literature and jargon. This is not unexpected in that aside from a few exceptions such as the UK CIP programme, the users commonly are engaging directly with the scientists, who in turn are arguably not the best or appropriate community to work across the interface with the breadth of stakeholder communities.

One current initiative that stands to advance this approach is led by SEI in partnership with other institutions to develop an end-to-end communication channel for climate change envelope analysis. In this initiative the core downscaling is undertaken using multiple GCMs and provides all the attendant derivative parameters (such as dry spell duration, or number of frost days, etc.). This is then packaged with an analysis tool that guides users in their exploration of the relevance of climate change to their particular activity, while allowing the user to formulate and guide the analysis according to their own expert knowledge. Such activities to facilitate access to tailored and contextualized downscaled scenarios, while lowering barriers between the climate downscaling community and end users, is possibly one of the most beneficial activities for the broader community at this time.

Frontiers of development in downscaling

It may be said that downscaling techniques have matured to the point of valid implementation for a broad range of adaptation activities. Nonetheless, there remain some challenging theoretical frontiers. It is suggested that the following comprise some of the leading issues:

a) Downscaling for high temporal resolution and low frequency events. Climate change is most readily seen initially by changes in the tails of the distribution of weather, and relates to initial impacts that are either event-based (e.g. changes in frequency or intensity of extremes), or from incremental change resulting in crossing thresholds (e.g. enough chill units for agriculture). The understanding of downscaling skill for such attributes is currently weak, yet probably of greater importance than downscaling small changes in the mean.

b) Greater understanding of the consequences of choices made in the implementation of a downscaling. For example, consider two different SD downscaling methods (Wilby et al., and Hewitson et al.) that are currently generating scenarios for a broad user community, and which approach the issue from fundamentally different starting points. One begins with a stochastic characterization (weather generator) subsequently conditioned by the deterministic signal from the GCMs, while the other begins with a deterministic cross scale relationship and then includes a stochastic element. A comparison of these two techniques for a point-scale downscaling for Casablanca (a target location with very specific challenges), produces results such as Figure 3. In this figure the downscaling ensemble mean from the one methodology is compared to downscaling with a different methodology from three GCMs. At one level it is encouraging to see that for the most part the direction of change is agreed on, but in terms of the envelope of change it is unclear how much of the differences are due to choices of method, choices of GCM, lack of skill, or many other choices made in the process of implementing the downscaling.

c) Probability. One might argue that at present, placing probabilities on the specific magnitudes of projected change is difficult to rigorously defend. Yet some groups are beginning to do just that, while users are asking for it and will inevitably use only a limited choice, if not just one, out of the possible spread of the projections. This places an imperative to advance this avenue of understanding, to improve credibility and defensibility of statements indicating probability.

d) Thresholds and feedbacks. At present these are poorly included in the global models and in the downscaling. At one level one might argue that there is a clear first order response of the global climate system to anthropogenically forced climate change, and the feedbacks will likely be modulators of this first order response. However, in the light of non-linearities in the system and the significant gaps in knowledge it is hard to discount the possibility that feedbacks and thresholds may substantially alter a downscaled climate projection for a given geographical region.

e) The climate change signal is embedded in a data representation that includes true stochastic noise, bias and systematic error, limited representation of fine resolution forcing factors, unrelated punctuated swings of a chaotic system, natural variability on multiple time scales, etc. Moreover, a given climate change projection may be entirely plausible, even likely, yet not be the actual single time line that evolves in the decades to come simply because of an excluded forcing factor or other limitation of the science and tools. There is a need to take the multiplicity of evidence and develop ways to draw out the robust and actionable regional scale information. The AR4 has made a start in this respect, but this is only one limited attempt based on finite and, for some regions, sparse data.

There is much more that can be said. Suffice at this point to note that the dialogue continues within an active community of scientists, while significant strides are being made to create downscaled scenarios of relevance and contextualized understanding for end users in the policy, vulnerability and adaptation arena.

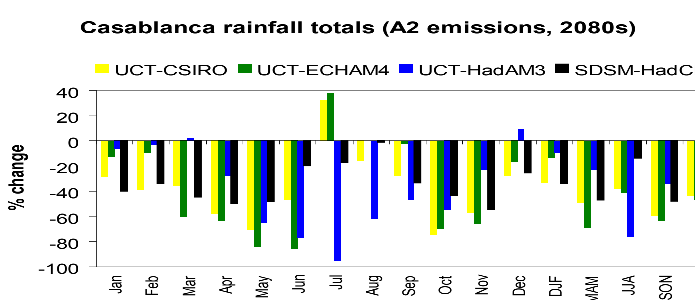

Figure 3: Downsca;ling fro Casablanca with different techniques and different GCMs (Wilby & Hewitson).

Scenarios to aid regional environmental change/food security policy formulation

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Identifying viable technological and policy options to improve food security in the face of climate and other environmental changes (collectively termed global environmental change, GEC) requires improved dialogue between researchers, policy makers and resource managers. A wide range of national and international projects are involved in food security research, although links to, and dialogue with, the policy process is often sub-optimal. In the GEC arena, most food security research has related to the impacts of climate change on food production – certainly an important issue – but the wider implications of GEC for food security (as opposed to on food production *per se*) are insufficiently addressed. Further, most research is conducted at local scale, and is not well coupled to the policy process; a better science-policy dialogue is needed at larger scales.

Scenario development and analysis has already been successfully used at a global scale to help reveal and address knowledge gaps about the plausible future interactions between GEC and a number of ecosystem goods and services, e.g. food production or water availability or climate regulation. Scenario analyses conducted at regional level help to systematically explore policy and technical options at the appropriate scale by providing a suitable framework for (i) raising awareness of key environmental and policy concerns; (ii) discussing viable adaptation options; and (iii) analysing the possible consequences of different adoption options for food security and environmental goals. These can be based on scenarios developed at the global scale e.g. the Millennium Ecosystems Assessment (MA, 2005) and the Global Environment Outlook (UNEP, 2002), but such analyses do not necessarily feature issues that are of particular relevance at the given regional level (Zurek & Henrichs, 2007). Also, they do not necessarily address all the issues related to food security (Zurek, 2006).

Attempts to "down-scale" global scenarios (such as those provided by the Intergovernmental Panel on Climate Change, IPCC, 2000) have proven to be difficult due to the relatively coarse scale of many global scenario exercises with respect to particular regions or specific driving forces important for food systems analysis. Furthermore, scenarios specifically designed to investigate the wider issues that underpin food security are lacking. Creating regional scenarios is not just a matter of "downscaling" the information available in global scenarios (e.g. climate change projections) for regional use; some information (such as trends in trade) will have been built up from smaller scale. Other information will be new and will need to come directly from the region in question (Zurek & Henrichs, 2007).

Research within the international research project "Global Environmental Change and Food Systems" (GECAFS[1]) includes a set of regionally-based (sub-continental scale) food systems analyses. These are underpinned by research of a more theoretical nature on concepts of food systems, their vulnerability to GEC and decision support for adaptation. To discuss uncertainty associated with GEC in the regional context, GECAFS also includes a specific topic on scenario construction related to medium- to long-term prospects for food security. These need to involve regionally-relevant components of the *socioeconomic conditions* (e.g. population, economic performance, technology, institutional arrangements and cultural variables) and *climate and other biogeophysical conditions* (e.g. natural resources such as land, and water quality and availability) which effect the *food system* (e.g. activities related to producing, processing, trading and consuming food, and the food security outcome of these activities related to food availability, access and utilisation). By including the range of biophysical and socioeconomic factors which underpin food security, such scenarios frame a set of manageable exploratory futures in which to undertake analyses and which also assist with developing better links between the GEC research community and regional/national policy makers (GECAFS, 2005).

In 2005, with funding from the International Council for Science (ICSU) and the United Nations Education, Science and Cultural Organisation (UNESCO), GECAFS, in collaboration with the UN Food and Agriculture Organization (FAO), the Millennium Ecosystem Assessment (MA), the European Environment Agency (EEA) and the United Nations Environment Programme (UNEP), developed the conceptual frameworks and methods necessary to formulate a set of prototype scenarios for researching the interactions between food security and environmental change at the Caribbean regional level. These scenarios were specifically designed to assist analyses of possible policy and technical interventions for adapting food systems to environmental change so as to explore the medium- and long-term prospects for given adaptation options for food security. The innovative operational framework was based on theoretical advances in the notion of food systems and their vulnerability to GEC, and downscaling global scenarios to regional level.

The Caribbean scenarios exercise involved about 30 people including social and natural scientists from regional research institutions, e.g. the University of the West Indies (UWI), the Caribbean Institute for Meteorology and Hydrology (CIMH); social and natural scientists from national research institutions, e.g. universities and national laboratories; policy-makers from regional agencies, e.g. the Caribbean Community Secretariat (CARICOM), Inter-American Institute for Cooperation on Agriculture (IICA); policy-makers from national agencies, e.g. Ministries of Agriculture; international agencies, e.g. FAO, UNEP; and was facilitated by the GECAFS scenarios group. A number of key steps were involved:

(i) Identifying key regional GEC and policy issues, based on an initial stakeholder consultation workshop involving regional scientists and policymakers.

(ii) Drafting a set of four prototype regional scenarios (Global Caribbean, Caribbean Order from Strength, Caribbean TechnoGarden and Caribbean Adapting Mosaic) in a first regional workshop, which were then elaborated upon in a follow-up writing exercise by regional authors. These were based on the broad rationale, assumptions and outcomes of the MA scenarios exercise, but allowing for regional

1 *"Global Environmental Change and Food Systems" (GECAFS: www.gecafs.org) is an international, interdisciplinary research project focussed on understanding the links between Global Environmental Change and food security. GECAFS was launched in 2001 as a Joint Project of the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP). In addition to setting a comprehensive, interdisciplinary GEC research agenda on the links between environment and food security, GECAFS established, from the outset, formal research partnerships with the CGIAR, FAO and WMO.*

deviation where needed.

(iii) Describing developments per scenario for key aspects of the food system, the focus of a follow-up regional workshop involving most of the first regional workshop participants.

(iv) Systematically assessing food system developments per scenario, and presenting outputs graphically as part of a second regional workshop. This involved describing the main developments per scenario for each Food Security element; systematically assessing each development per scenario for each food security element, and finally plotting each assessment (Figure 1).

The scenario exercise delivered a number of related outputs: it integrated improved holistic understanding of food systems (axes on graphs) with vulnerability (change of position along axes) with policy interpretation of future conditions (comparing four graphs) with adaptation insights for improving overall food security (where to concentrate effort on enlarging the polygon areas of each graph).

The GECAFS approach to scenario analysis helped integrate social and natural science in scenario design (climate, natural resource management, regional governance and policy dimensions; down-scale global scenarios to regional level, and enriched them with regionally-relevant features related to both policy and science; and helped established effective dialogue between GEC researchers and policy process (policy makers constituted about half of team) which raised mutual awareness in science and policy communities of each others interests, possibilities and limitations.

References

Ericksen, P. J. 2007. Conceptualizing food systems for global environmental change (GEC) research. Submitted to *Global Environmental Change*.

GECAFS. 2005. GECAFS Science Plan and Implementation Strategy. GECAFS Report No.1; Wallingford. (www.gecafs.org/publications/index.html)

GECAFS. 2006. A Set of Prototype Caribbean Scenarios for Research on Global EnvironmentalChange and Regional Food Systems. GECAFS Report No. 2; 62pp, Wallingford. (www.gecafs.org/publications/index.html)

IPCC - Intergovernmental Panel on Climate Change, 2000. Special Report on Emission Scenarios. Oxford University Press, Oxford, 2000.

MA - Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: Scenarios - Findings of the Scenarios Working Group, Millennium Ecosystem Assessment. Island Press. Washington DC.

UNEP - United Nations Environment Programme, 2002. Global Environment Outlook 3: Past, present, and future perspectives. (http://www.unep.org/geo/geo3)

Zurek, M., 2006. A Short Review of Global Scenarios for Food Systems Analysis. GECAFS Working Paper 1. Available at www.gecafs.org/Publications/Publications.htm

Zurek, M., Henrichs, T., 2007. Linking scenarios across geographical scales in international environmental assessments. *Technological Forecasting and Social* Change. (in print)

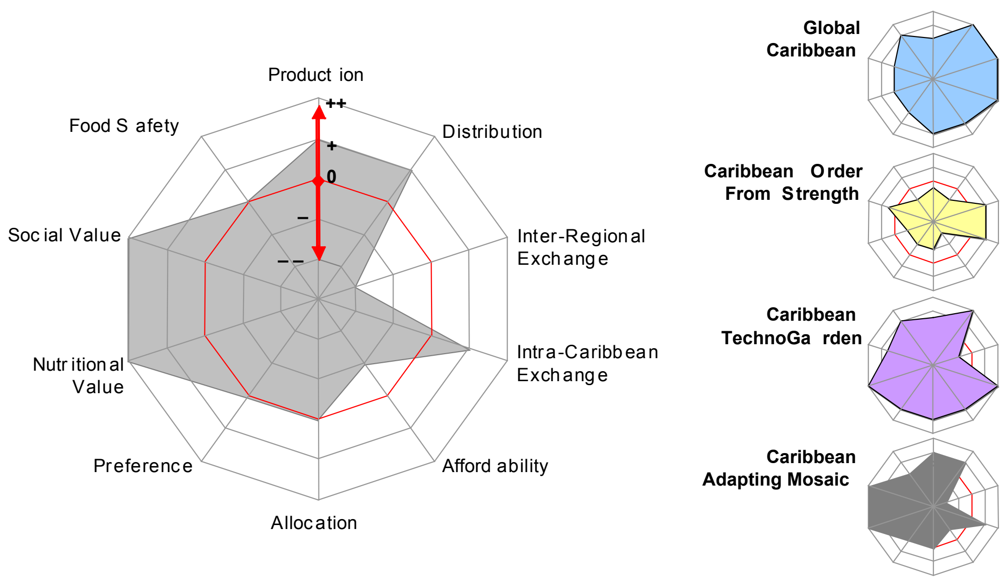

Figure 1. Food security outcomes plotted on the major food security elements (Ericksen, 2007) for each of the four Caribbean prototype scenarios. + and ++ respectively indicate slight and strong increase in the given food security element; - and --, weak and strong decrease (Source: GECAFS, 2006).

Spatial and Temporal Scales and Levels in Human Systems: Some examples in the context of food security

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Food security is a fundamental human goal. The pursuit of food security has been one of the main drivers of human systems for millennia and has given rise to a highly complex ensemble of cultural, institutional and technological developments over the ages. Agriculture has been intimately interwoven with the evolution of many societal structures including laws and regulations, customs and ceremonies, and trade and commerce. Food security is arguably of most interest for individuals in the near future. However, as population increases and globalisation proceeds, society is increasingly concerned with food security over decades ahead, and we need to be able to look across spatial and temporal scales and levels as never before. This is particularly important in relation to identifying adaptation options for food systems in response to global environmental change (GEC).

Human-ecosystem interactions operate at many levels along complex spatial and temporal scales[1]. This paper aims to:

i) discuss the significant of scales and levels in human systems;

ii) show how regional research helps to integrate between global and local levels;

iii) show how a "food systems" framework helps identify key aspects of human systems in the context of food security; and

iv) give some examples of how the human dimension of food systems can enhance or hinder alleviation of food insecurity.

There are numerous interactions between different scales and different levels in human systems, e.g. the links between institutions such as credit or land tenure arrangements which operate differently at different spatial and temporal levels. It is particularly important to understand these multi-level interactions for food security, especially in the context to GEC. A further research approach (as developed by Young et al, 1999/2005) asks whether it is possible to scale up or down propositions regarding the role of institutions in causing and confronting environmental problems. Of particular interest is the extent to which propositions about arrangements at the local level are applicable to similar concerns at the international level and *vice versa*.

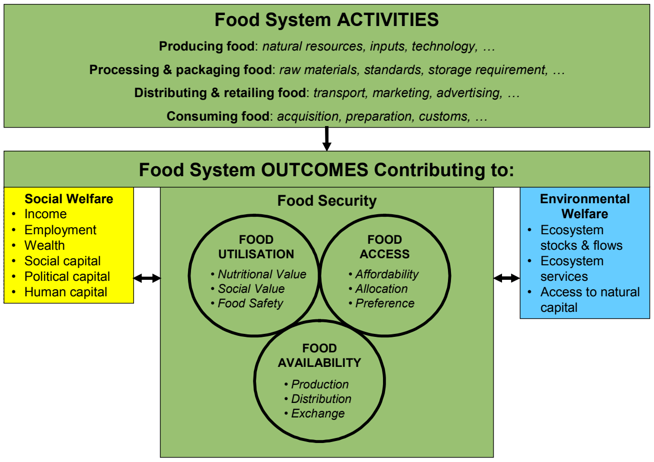
While new research approaches are emerging to help the interactions across human systems, the majority of food security/GEC studies are still conducted at either global or local levels. Work to link these via research at the intermediate, or "regional" level (i.e. sub-continental/supra-national), and how it relates to phenomena at both lower and higher levels, is particularly important for a number of reasons. First, given that climate and weather-related perturbations are often experienced at the regional level (Tyson *et al*, 2002) adaptation strategies may be applicable across more than one district or nation. Second, as climate projections become increasingly available at regional level, adaptation strategies focussed on human systems which operate at a concomitant level may prove more effective if managed regionally, e.g. in terms of improved intra-regional trade or food storage and transport facilities. Some (e.g. trade) need particular consideration in the context of both higher (global) and lower (local) levels. Third, some environmental management issues related to food security may manifest strongly at this spatial level (e.g. water resource depletion, as a region's major basins may be shared between nations) and solutions to such problems may often require supra-national policy considerations (e.g. agreements on inter-basin transfers of water). Fourth, regional governance structures have been established in many parts of the world (e.g. EU in Europe, SADC in southern Africa, CARICOM in the Caribbean) which aim to provide a mechanism for both regional and sub-regional development planning and discussions related to international agreements; regional governance structures offer a clear 'client' for regional-level research outputs.

While there is an argument for more research at the regional level, and particularly to help integrate issues from global to local levels, a host of jurisdictional issues emerge which need consideration over many spatial and temporal levels. This considerably increases the complexity of discussions of food security/adaptation to GEC and a clear conceptual framework within which to structure the debate is needed. If appropriately designed, such a framework would also help to consider multi-level issues, linking village/community through national/regional to global. It should also help with the multi-temporal discussions which are especially important given on one hand the long-term nature of climate change, while on the other the near- to mid-term need for mitigation and adaptation.

The "food systems" concept developed as part of the international research project "Global Environmental Change and Food Systems" (GECAFS[2]) and documented by Ericksen (2007) helps integrate food security issues across space and time. Specifically, it provides a structure within which to discuss interactions within the human systems related to food security and how they interact with environmental and other societal goals. It explicitly deals with the suite of *human activities* dealing with producing food; processing and packaging food; distributing and retailing food; and consuming food; and links these to the *outcomes of these activities* which contribute to food security: (*food availability*, with elements related to production, distribution and exchange; *food access*, with elements related to affordability, allocation and preference; and *food use*, with elements related to nutritional value, social value and food safety) (see figure, from Ericksen, 2007). The outcomes also contribute to environmental and other securities (e.g. income). Interactions between and within biogeophysical and human environments and systems influence both the activities and the outcomes. "Food systems" have often only been thought of as the activities, but including the outcomes as an integral part of the food system concept provides an explicit analytical lens for understanding food security, the principal objective of the food system.

1 "Scale" is the spatial, temporal, quantitative or analytical dimension used to measure and study any phenomenon, and "level" is the unit of analysis that is located at different positions on a scale (Gibson et al, 2000; Cash et al, 2006).

2 "Global Environmental Change and Food Systems" (GECAFS: www.gecafs.org) is an international, interdisciplinary research project focussed on understanding the links between Global Environmental Change and food security. GECAFS was launched in 2001 as a Joint Project of the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP). In addition to setting a comprehensive, interdisciplinary GEC research agenda on the links between environment and food security, GECAFS established, from the outset, formal research partnerships with the CGIAR, FAO and WMO.



Food security is a highly human-orientated concept, further underlined by the definition stemming from the World Food Summit in 1996: food security is met when "*all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO, 1996). Food security is underpinned by food systems and is diminished when food systems are stressed.

The food system framework developed by GECAFS draws attention to the many human activities and systems that collectively give rise to food security. Examples related to human systems of trade, distribution, storage agreements and marketing from GECAFS work in southern Africa offer an insight into the complexity of how some of these human systems operate across space and time, and where options for adaptation may lie.

To supplement *in situ* food production, food imports at both regional and national levels in southern Africa contribute significantly to food availability. Formal trading systems operate across many levels and are often nested and/or overlapping. The degree of connectivity of different countries with the global food trading system varies considerably. At national and sub-national level, informal cross-border trade continues to play an important role in filling some of the import requirements. Trade barriers and lack of harmonisation of trading systems are a serious constraint to food movements across borders which could have affects on local-level availability and prices. These, and other non-physical constraints including a lack of a cohesive and harmonised set of trade policies, exacerbate problems of food distribution.

While problems with physical infrastructure certainly complicate food distribution in the region, and especially in emergencies such as times of drought, many of the impediments to offering speedy and effective drought relief are related to institutional and other human systems constraints. In the 1990/91 drought, for instance, a massive international food aid programme was launched with food to be delivered via a number of rail 'corridors' from the region's major ports to the hinterland. Many problems arose in the human systems across a range of levels: from local security problems and theft, and poor labour management systems in ports (where there were no incentives to work more than necessary), to regional problems related to regulatory constraints for cargo destined for third countries, and conflicts between humanitarian requirements and commercial concerns. Food availability for the region was severely constrained not by lack of food *per se* (there were ships queuing at anchor to unload), but by lack of investment in distribution systems and institutional constraints at a range of spatial and temporal levels. Although a regional food crisis might be "solved" by institutions working at the global level, an effective regional food distribution system both in terms of physical and institutional infrastructure is critical for alleviating food insecurity whenever local production cannot meet demand.

Alleviation of the institutional impediments mentioned above would help not only in times of crisis but integrating across human systems would help more generally in the longer-term. This is particularly important given the growing concerns about how GEC will affect the region; longer-term visioning is needed to help alleviate food insecurity. One particular issue is the development of a regional food grain reserve. This has been under discussion since the 1980s, with early proposals based on considerations of enough physical maize stock for 12 months consumption. Despite this, most government reserves were at record low stocks at the 2002/2003 marketing year (Mano et al., 2003). The issue is one of political will at the regional – not national – level and the short-term vs longer-term benefits; the spatial and temporal dimensions interact.

The rapid rise of supermarkets, proliferating beyond middle-class big-city markets into smaller towns and poorer areas (Weatherspoon and Reardon, 2003), is another aspect of the human system affecting food access at a range of spatial levels and time-frames. This is driven by the marketing strategies of the big companies which are transforming the food retail sector; in South Africa, for example, supermarkets already account for more than 55 percent of national food retail (FAO, 2003). Supermarkets are affecting the food system in two main ways. First, supplying supermarkets presents both potentially large opportunities and big challenges for producers as supermarkets' procurement systems involve purchase consolidation, a shift to specialised wholesalers, and tough quality and safety standards. Making the necessary investments and adopting new practices is hardest for small producers, who risk exclusion from dynamic urban markets increasingly dominated by supermarkets. Second, supermarkets are bringing about a change in consumption patterns in the region, with more choice being made available and strong marketing campaigns usually promoting more processed foodstuffs.

Research on humans systems needs to be undertaken at a wide range of spatial and temporal levels, with research specifically targeted at cross-level and cross-scale issues. This is particularly important where there are issues of, for instance, common property studies, where aerial extent, resource access rights and tenure arrangements may be poorly defined. Of particular interest is how policies and plans devised at large spatial level and/or long-time horizons will affect implementation at smaller levels and/or in the short-term. Example questions are:

- How will interactions among regional-level and local-level food system adaptation policies affect conditions and decision-making at local level?
- How would long-term changes in donor philosophy for food- and seed-aid as applied at the local level affect regional self-reliance?
- How would implementing different short-term adaptation policies across the region help achieve SADC's long term food security goal?

If integrated effectively across space and time, answers to questions like these would deliver valuable information of high policy-relevance.

References

Cash, D. W., W. Adger, F. Berkes, P. Garden, L. Lebel, P. Olsson, L. Pritchard, and O. Young. 2006. Scale and cross-scale dynamics: governance and information in a multilevel world. Ecology and Society 11(2): 8. [online]

Ericksen, P. J. 2007. Conceptualizing food systems for global environmental change (GEC) research. Submitted to Global Environmental Change.

FAO, 1996. Report of the World Food Summit. FAO, Rome.

FAO, 2003. http://www.fao.org/english/newsroom/news/2003/23060-en.html.

Gibson, C.C, Ostrom, E. and Ahn T.K. 2000. The concept of scale and the human dimensions of global change: a survey. Ecological Economics 32, 217–239.

Mano, R., Isaacson, B., Dardel, P., 2003. Identifying Policy Determinants of Food Security Response and Recovery in the SADC Region: The case of the 2002 Food Emergency. FANRPAN Policy Paper.

Tyson, P., Odada, E., Schulze, R., Vogel, C.I., 2002. Regional-global change linkages: Southern Africa. In: Tyson, P., Fuchs, R., Fu, C., Lebel, L., Mitra, A.P., Odada, E., Perry, J., Steffen, W., Virji, H. (Eds.), Global-regional linkages in the earth system. START/IHDP/IGBP/WCRP. Springer, Berlin, London.

Weatherspoon, D.D., Reardon, T., 2003. The Rise of Supermarkets in Africa: Implications for Agrifood Systems and the Rural Poor. Development Policy Review 21, 333 - 355.

Young, O.R. with contributions by others 1999/2005. Institutional Dimensions of Global Environmental Change (IDGEC) Science Plan. 3rd ed. Bonn: IHDP.

Risk assessment and decision support

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The completion of the Intergovernmental Panel on Climate Change's Fourth Assessment Report (IPCC AR4) provides the opportunity to use the latest assessment of climate change science in supporting the integration of regional climate change and response options. However, quite a bit of work needs to be done to adapt these findings to support decision-making.

The full paper and presentation will address the following question: "How much climate change do we need to adapt to by when?" This question needs to be addressed separately for each activity that is sensitive to a specific set of climate variables. It also needs to account for planning horizons and the likely set of adaptations; largely whether they are incremental and can be implemented in a learning-by-doing environment, or whether they are designed for the long-term and require significant foresight.

I will show how five major sources of climate change uncertainty can be managed to assess impact risks, relevant to the above question. They are:

1. climate sensitivity,
2. greenhouse gas emission scenarios and radiative forcing,
3. climate variability and ongoing rate of change,
4. past and future commitments to climate change,
5. regional climate change projections.

The following points will be covered:

- The IPCC AR4 has produced well-communicated scientific information but it is inadequate to support decision-making needs.
- Several further steps need to be undertaken to frame the climate information in appropriate contexts (the specific context is relevant to particular projects but an overall approach can be described).
- Is the process of adaptation likely to be incremental (ongoing) or does it need to anticipate future change because it addresses long-term planning horizons and is not feasible to update or retrofit?
- Methods to manage climate change uncertainties range from probabilistic and sophisticated to qualitative and general, but should be framed to assess risk.
- Together the following uncertainties comprise a whole-of-climate approach: climate sensitivity, emissions, regional climate projections, and current rates of change and ongoing fluctuations in climate variability.
- These uncertainties are weighted differently over time: short-term needs will be far more dependent on ongoing climate variability and current rates of change; long-term needs much more dependent on climate sensitivity and emission futures.
- Assessments need good information on historical and current variability to take a whole of climate approach (including stakeholder experience).
- Probability distribution functions (PDFs, prediction of central tendencies) are inadequate to assess risk. Cumulative distribution functions (CDFs, likelihood of exceeding specific magnitudes of change) are far more useful.
- Current rates of global warming are 0.2°C per decade and not likely to be less than this – rates may peak 2030–2060 and could be more than double what they are now. Local rates can be calculated from records >50 years in length – except where variability is high. Sea level rise is also towards the high end of the projected range but has very different timescales of commitment and is current dominated by variability.
- Climate sensitivity has a best estimate of 3°C, is likely to be between 2°C and 4.5°C, is highly unlikely to be <1.5°C and values above 4.5 °C cannot be excluded. The best estimate contrasts with the Third Assessment Report estimate of ~2.6°C and the entire distribution is higher than earlier anticipated.
- Short term reference emission projections (at least to 2030 and probably 2050) are at the high end of the SRES envelope and produce changes as large as or larger than those previously estimated.
- The above three factors suggest that a heavy demand will be placed on adaptation over the coming decades, and that it is important not to under-estimate the eventual rate and magnitude of climate change.
- Adaptation will build on current perceptions of change (climatic and non-climatic). Near-term adaptation needs can be projected from an assessment of "committed" climate change based on the above factors, taking the recent rate of change into account.
- The question of how much climate risk should be hedged against, relies on a range of factors. These include whether risk should be tied to the likelihood of a given level of climate change, its direct impact, or the socio-economic outcomes of that impact. Consideration should be given to how dependent outcomes are on climatic stresses, or whether a range of other (non-climatic) factors, such as socio-economic conditions, other environmental hazards, influencing either risk or adaptive capacity, should be accounted for.
- Framing an issue correctly is more important than developing technical capacity without clear reference as to how it will be used. Ideally, scenarios should be constructed using the simplest information required to make the decision under consideration.

Interactions between ocean climate and tuna fisheries in the western & central Pacific ocean: understanding variability and predicting change

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ABSTRACT

The distribution and abundance of the principal market species of tuna caught in oceanic fisheries of the western & central Pacific Ocean (WCPO; in order of catch: skipjack Katsuwonus pelamis, yellowfin Thunnus albacares, bigeye Thunnus obesus, albacore Thunnus alalunga) respond to environmental variability at all scales thus far observed i.e. seasonal, interannual & decadal. This, in turn, leads to spatio-temporal variation in catches and catch rates across the Pacific, favouring some islands in some years and others in other years. This variation is broadly related to the El Niño Southern Oscillation (ENSO), with skipjack and yellowfin tuna being displaced eastward during the El Niño phase, and concentrated westward during La Niña. In addition to these distributional changes, there is variability in 'recruitment' for all species, which is directly, if not clearly, related to environmental variability. ('Recruitment' in this context refers to the appearance of the youngest age class of the species concerned within any particular fishery; the growth and survival of pre-recruits is intimately linked to environmental conditions, e.g. temperature & primary production, as well as to trophic interactions and cannibalism.) In recent work, SPC-OFP has developed robust statistical models relating recruitment to oceanographic varibility for both yellowfin and bigeye tuna, which will help reduce uncertainty in stock assessments and projections for these species. Ecosystem models have also been developed to relate ocean variability to primary production, and the production of tuna prey, through to the spatial population dynamics of tunas. As the results of these models converge with those of stock assessment models so it will become possible to provide estimates of tuna biomass at smaller scales than those resolved in the assessments. This kind of modelling can also explore the effects of spatially defined marine protected areas (MPAs) based on ecological and/or jurisdictional boundaries. Although not presently studied to the same level of detail as the tunas, it may also be possible to map changes in distribution and abundance of other species caught in association with tunas, i.e. sharks, seabirds and sea turtles. Long-term climate change has the potential to affect all these aspects of WCPO tuna fisheries in ways that are not presently well understood. Increased frequency of El Niño type conditions may enhance recruitment and biomass of at least skipjack and yellowfin tuna, but this advantage will fall to those fleets that are best able to exploit the associated changes in distribution. South Pacific fisheries for albacore are likely to be affected differently, with warming not thought to be favourable to this species, and with a possible southward shift in the species' range. Enhanced understanding of these potential changes is the subject of past, present and planned research at SPC-OFP, with the aim of providing policy-relevant scientific advice to SPC member countries and territories and to the Western & Central Pacific Fisheries Commission, and contributing to research under the GLOBEC Climate Impacts on Oceanic TOp Predators (CLIOTOP) project.

Integrating Global and Regional Model Results into Local Climate Change Scenarios for the Netherlands

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ABSTRACT

Strategies for adaptation to future climate conditions are needed for many sectors of society. It is unavoidable that such strategies are associated with large uncertainty given our incomplete understanding of climate change, in particular at the local scale. One means of dealing with this uncertainty is by constructing a suite of different climate change scenarios based on a careful assessment of climate model projections. The present paper describes how a new set of four scenarios for the Netherlands has recently been developed. Together, these scenarios are representative for the local climate conditions around the year 2050. The method combines an ensemble of global and regional climate model simulations (from the IPCC-PCMDI-GCM archive and the EU-PRUDENCE-RCM archive) and weights the outcomes. With this new analysis the relation between global warming, changes in atmospheric circulation above Western Europe and climate change in the Netherlands has been mapped systematically. Consultation of stakeholders (mainly in the areas of water management and coastal engineering) led to a selection of the most relevant scenario variables. These are often local quantities at high time resolution, which have a direct relation with the climatic extremes causing the impacts. Although no likelihood has been assigned to each individual scenario, the set of four scenarios enables a meaningful assessment of the future impacts of climate change and therefore contributes to informed decision making. The scenarios include all recent model projections and are developed in close cooperation with the Dutch impact community. They will serve as the national standard in adaptation policies for the coming years. We believe that our approach of dealing with multi-scale issues (from global to regional to finer spatial scales and from multi decadal to seasonal to daily time scales) sets a good example for use in other regions. For details, visit: www.knmi.nl/climatescenarios.

Introduction

Based on recent climate model simulations, we have constructed four different climate change scenarios for the Netherlands. Together, they reflect the uncertainty that is inherent to future climate projections at the local scale. The scenarios provide information on the characteristics of the average weather, as well as the likelihood of extreme events.

The starting point for the new scenarios has been the global temperature rise, as calculated by the most important GCMs. Subsequently, we analysed how the atmospheric circulation patterns above Western Europe will change according to the same climate model simulations. How the climate of the Netherlands (Western Europe) will change in response to global warming depends largely on the associated changes in the atmospheric circulation. The large-scale projections of temperature rise and circulation change have been downscaled to local changes in air temperature, precipitation, wind, and sea level in the Netherlands. For downscaling the air temperature and precipitation changes (Lenderink et al., 2007a), we used an ensemble of RCM simulations for Europe from the EU-PRUDENCE project (Christensen et al., 2007). In addition, statistical downscaling techniques have been applied employing long-term observational series from Dutch weather stations. The quality of the GCMs and RCMs used in this work has been evaluated by comparing the simulations for the present-day climate of Western Europe against observations (van Ulden and van Oldenborgh, 2006; Jacob et al., 2007). A comprehensive description of the scenarios including references to the scientific literature can be found in Van den Hurk et al. (2006).

For the new scenarios, we have used global temperature increases in 2100 of +2°C and +4°C (with associated temperature increases in 2050 of +1°C and +2°C, respectively). These choices lie within the likely range for global temperature rise around 2100 as projected by recent GCMs (between +1.1°C and +6.4°C for 2090-2099 relative to 1980-1999, according to the IPCC Fourth Assessment Report, AR4). The GCMs selected for this study (on the basis of a good representation of the present-day atmospheric circulation patterns above Europe; Van Ulden and van Oldenborgh, 2006), show either hardly any change in the atmospheric circulation patterns in summer and winter, or a clear change in both seasons. On the basis of this finding, a choice has been made for two scenarios with a change in the atmospheric circulation and two scenarios without a change. Together the 2×2=4 scenarios draw a consistent and plausible picture of possible future climate conditions in the Netherlands that can be used to formulate adaptation strategies.

The new scenarios present pictures of the local changes in air temperature, precipitation, wind, and sea level for a climatological period of 30 years. The scenarios for 2050 in Table 1 are representative for the climate around 2050 (between 2036 and 2065). Likewise, the climate in the baseline year 1990 is described with observational data from 1976 to 2005. The numbers per climate scenario do not include information on changes in natural year-to-year variability and decadal scale fluctuations. For all variables we assume that these variations remain the same as in the observational records. In particular for wind, these natural fluctuations are relatively large compared with the changes in the scenarios. Each of the four scenarios gives only one number for the change per variable, except for sea level rise where a range is presented. With our current knowledge it is not possible to indicate which of the four scenarios is most likely, but we argue that the spread between the scenarios gives a plausible description of the uncertainty in predictions of the local climate. Together, they enable a meaningful impact assessment for most applications.

Common changes across the four climate change scenarios

A number of key characteristics of climate change in the Netherlands and surrounding areas are common across all four scenarios:

Table 1. Climate change in the Netherlands around 2050[1] compared to the baseline year 1990[2], according to the four new climate change scenarios. The letters G (moderate) and W (warm) indicate 1°C, respectively, 2°C temperature rise on Earth in 2050 compared to 1990. The symbol + indicates the scenarios with significant change in atmospheric circulation patterns above Western Europe.

		G	G+	W	W+
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		no	yes	no	yes
Winter[3]	average temperature	+0.9°C	+1.1°C	+1.8°C	+2.3°C
	coldest winter day per year	+1.0°C	+1.5°C	+2.1°C	+2.9°C
	average precipitation amount	+4%	+7%	+7%	+14%
	number of wet days (>= 0.1 mm)	0%	+1%	0%	+2%
	10-day precipitation sum exceeded once in 10 years	+4%	+6%	+8%	+12%
	maximum average daily wind speed per year	0%	+2%	-1%	+4%
Summer[3]	average temperature	+0.9°C	+1.4°C	+1.7°C	+2.8°C
	warmest summer day per year	+1.0°C	+1.9°C	+2.1°C	+3.8°C
	average precipitation amount	+3%	-10%	+6%	-19%
	number of wet days (>= 0.1 mm)	-2%	-10%	-3%	-19%
	daily precipitation sum exceeded once in 10 years	+13%	+5%	+27%	+10%
	potential evaporation	+3%	+8%	+7%	+15%
Sea level	absolute increase	15-25 cm	15-25 cm	20-35 cm	20-35 cm

1 data on changes in 2100 can be found at www.knmi.nl/climatescenarios

2 the climate in the baseline year 1990 is deescribed with data from the period 1976 to 2005

3 'winter' stnds for December, January and February, and 'summer' stands for June, July and August

1. air temperature will continue to rise: mild winters and hot summers will become more common;
2. winters will become wetter and extreme precipitation amounts will increase;
3. the intensity of extreme rain showers in summer will increase, however the number of rainy days in summer will decrease;
4. calculated changes in wind are small compared to the natural fluctuations;
5. sea level will continue to rise.

Air temperature

The temperature increase in the Netherlands does not equal global temperature rise. The Netherlands is located at the edge of a continent, which warms faster than the global average. At the same time, it is located close to the north eastern part of the Atlantic Ocean, for which most climate models calculate a relatively slow temperature increase (Van Ulden and Van Oldenborgh, 2006). The four scenarios show a warming by 2050 of 0.9°C up to 2.3°C in winter and 0.9°C up to 2.8°C in summer. The scenarios with changes in atmospheric circulation show a faster warming than the scenarios that do not include such changes.

Precipitation

For southern Europe nearly all climate models calculate a decrease in summer precipitation and an increased chance for drought. For northern Europe the change in summer precipitation is less consistent. The Netherlands is situated in the transition zone. In the downscaled scenarios without significant change in atmospheric circulation, precipitation increases both in summer and winter with approximately 3% per degree global temperature rise. In the scenarios with significant change in atmospheric circulation, precipitation increases more in winter (about +7% per °C) and decreases in summer (about –10% per °C). The decrease in summer precipitation can be attributed mainly to the decrease in the number of rainy days during blocking situations. In all four scenarios, the average amounts in short and intense rain showers increase (e.g. see Figure 1), due to the increase in moisture holding capacity of warmer air, and possibly the intensification of cloud dynamics due to the stronger latent heating (Trenberth et al, 2003).

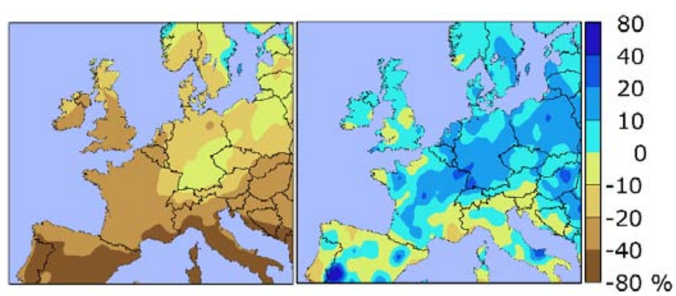

Figure 1: Illustration of the typical change in spatial precipitation patterns in the scenarios with significant change in atmospheric circulation for summers around 2050 compared to 1990. The maps are constructed using results of the RCM developed at KNMI. Left shows the change in average summer precipitation, and at right the change of the intense showers (daily precipitation sum exceeded once every 10 years). The average precipitation is decreasing almost everywhere, whereas the precipitation amount in heavy showers is increasing.

Wind storms

In the scenarios without change in atmospheric circulation the maximum daily wind speed per year hardly shows any change (≤ 1%), whereas in the scenarios with a significant change in atmospheric circulation a slight increase in the maximum daily wind speed per year is seen. The strength of the heaviest storms, that currently occur less than once per year, also shows a slight increase above northwest Europe (Leckebusch et al., 2006). However, these projected changes are small compared to the natural year-to-year and decadal scale fluctuations (Figure 2). In none of the four scenarios, the decreasing trend in the total number of storms in the Netherlands which has been observed in recent decades (Smits et al., 2005) continues to the same degree.

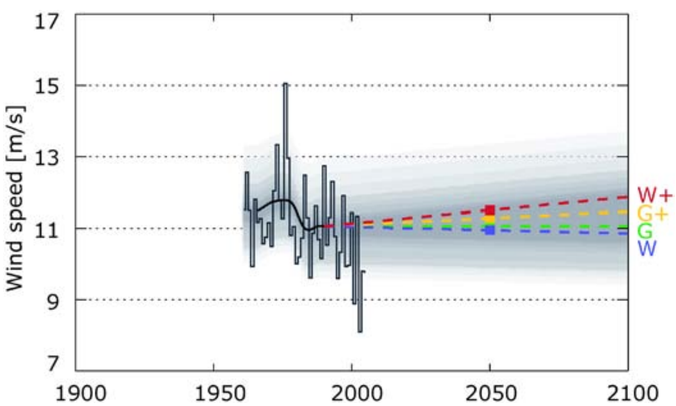

Figure 2: Maximum daily wind speed measured at station De Bilt between 1962 and 2005 (black line), and the four climate change scenarios for 2050 (coloured squares). The thick black line represents the 30-year moving average of the observations. The thick coloured and dashed lines connect each climate scenario with the baseline year 1990. The grey band represents the year-to-year variations, derived from the observations. The four scenarios are indicated by the same symbols as in Table 1.

Sea level rise

Oceans react slowly to air temperature rise. Therefore, the sea level rise in the next few decades is rather insensitive to the rate of air temperature increase. Only after 2050 the rate of global warming becomes more important. Due to the slow reaction of the oceans, the sea level will continue to rise long after 2100, even if greenhouse gas concentrations stabilise. Climate models show large mutual differences with regard to the sensitivity of sea level rise to increased air temperature. In order to represent this uncertainty, a range of sea level rise is given for each scenario, instead of only one number. The sea level rise along the Dutch coast varies in the scenarios between 15 and 35 cm around 2050 and between 35 and 85 cm around 2100.

Example applications

The scenarios above are intended for studies exploring the impacts of climate change. Based on the results of such impact studies, adaptation strategies will be formulated. Some examples of relevant impacts for the Netherlands are provided below.

Discharge of rivers Rhine and Meuse

In the river basins of Rhine and Meuse, the increase in winter precipitation in the scenarios will lead to increased peak discharges (Lenderink et al., 2007b). On the other hand, for the scenarios with more blocked air flow (G+ and W+), the average summer precipitation clearly decreases and evaporation increases. The resulting low water levels during summer (De Wit et al., 2006) may lead to navigation problems, water quality problems, shortage of cooling water, and salt water intrusion from the rising sea. To aid the application of the new scenarios in hydrology, a stochastic weather generator has been developed that makes use of resampling techniques (Leander and Buishand, 2007).

Energy use for heating

Due to the temperature increase in all four scenarios the energy need for heating of houses, factories and offices will decrease. The energy need for heating shows a clear relation with the number of heating degree-days (the sum of the deviations from 17°C for all days with an average temperature < 17°C). Compared to 1990, the number of heating degree-days will decrease by 9% up to 20% in a representative time series for 2050, which has been derived by transforming the mean and variance of an observational record according to the changes in each scenario (for details see: Van den Hurk et al., 2006).

Agricultural production

In the Netherlands, an increase of temperature and CO_2-concentration in the air may have a favourable impact on agricultural production. However, in the scenarios with a change in the atmospheric circulation leading to more summer blocking situations, the favourable effect may be cancelled out by the larger chance of drought and water shortage. The same scenarios also have wetter winters, as a result of which grasslands may become swampier in spring, hindering grazing and mowing.

Growing season

Due to the higher temperatures in winter and spring, the growing season of many plants will start earlier, a trend that has already been observed over the past decades. The first day in the year after which the daily average temperature remains above 5°C until the first of July can be used as an indicator for the start of the growing season. According to this definition, the growing season will start between 6 and 19 days earlier in 2050 compared with 1990, depending on the chosen climate change scenario. Again, a simple transformation of the mean and variance of an observed record has been used to obtain these results for each scenario.

Wind energy

The observed decrease in wind speed in the past decades in the Netherlands has had serious consequences for the energy production of wind turbines. The scenarios do not give reason to believe that wind energy production will continue to decrease in the future. However, the relatively small changes for wind in the scenarios (associated with the pole ward movement of extra-tropical storm tracks) imply that for the wind energy sector, the natural year-to-year and decadal scale climate fluctuations are of much greater importance than the longer term anthropogenic change.

Air quality

Weather conditions, such as wind direction and solar radiation intensity highly affect air pollution. Periods of summer smog (high ozone concentrations) frequently coincide with heat waves (Vautard et al., 2005). In case emissions remain unchanged, the chance of smog will increase during summer, when temperatures are higher. In winter, the chance of smog decreases in the scenarios in which increased westerly winds bring relatively clean air from the sea.

'Eleven city marathon' speed skating event

The chance of long periods with frost will decrease due to the expected temperature rise. As a consequence, in all four scenarios the expected number of times that the famous 'Eleven city marathon' can be skated on frozen lakes and rivers will decrease. In the scenarios with changes in atmospheric circulation, the decrease is much stronger than expected on the basis of the average temperature rise alone, since the coldest days will warm more than the average.

Discussion

Within this new analysis, the relation between global warming, changes in atmospheric circulation above Western Europe and local climate change in the Netherlands has been mapped systematically. For the first time the results from a large ensemble of global and regional climate models and observational series have been combined (Van den Hurk et al., 2006; Lenderink et al., 2007a).

Climate models differ considerably in their projection of global temperature rise. This is partly caused by uncertainty regarding future emissions of greenhouse gasses and aerosols. Climate models use emission scenarios which are connected to 'story lines' on how the world population, economy, and technology will develop. In general, the low temperature increase scenarios both match better to the story lines B1 (strong Europe) and B2 (regional communities), whereas the high temperature increase scenarios both match better to the story lines A1 (global economy) and A2 (transatlantic market).

However, uncertainty concerning future emissions of greenhouse gases and dust particles causes only a relatively small part of the differences between the four scenarios for 2050. Most of the uncertainty is caused by differences in model projections due to our limited knowledge of the complex processes in the climate system. For example, the representation of the influence of water vapour, clouds, snow and ice on the Earth's solar and thermal radiation balance and hence on temperature still requires improvement. Some processes are not included at all. None of the climate models used in this study has an active carbon cycle. Besides, there are limits to the predictability of complex systems, such as the climate system. After 2050, differences in the emission scenarios start to become distinguishable in the temperature projections (see IPCC AR4 figure SPM-5).

The uncertainty further increases going from the global scale to the regional scale of Western Europe and the local scale of the Netherlands. At these scales, the atmospheric circulation and wind direction play an important role. Most climate models calculate a clear change in the atmospheric circulation patterns above Western Europe. However, the magnitude and direction of change differ between the models. We selected four climate change scenarios to deal with the uncertainty in both the global temperature rise and regional circulation change. These scenarios span a plausible range in the possible future climate of the Netherlands and, therefore, they are relevant for Dutch adaptation policies. After consultation of the main stakeholder communities, a complete picture of future climate is presented for each scenario.

The new climate change scenarios for the Netherlands do not account for any possible occurrences associated with abrupt climate change, for example as a result of a complete collapse of the 'Gulf Stream' or as a result of the unexpectedly fast melting of large ice sheets in Greenland and West Antarctica. The simulation of these types of events is relatively poor in climate models due to incomplete scientific knowledge about these phenomena (Overpeck et al., 2006; Stouffer et al., 2006). Moreover, the indications for abrupt changes in the observations are also very uncertain. The new climate change scenarios for the Netherlands do not include phenomena for which it is unclear if they are physically realistic, such as 'super' storms that are much heavier than ever occurred in Europe (Van den Brink et al., 2004). Changes in year-to-year and decadal scale fluctuations are not included explicitly in the scenarios either. For the time being, we assume that the variations at these time scales in the past will remain the same in the future. Whenever new insights become available on this topic, they will be included in the next update of the scenarios.

The choice for a limited number of relevant scenarios forms an intermediate step on the long way to future probabilistic climate forecasts. Selecting a limited number of discrete scenarios was preferred above a probabilistic approach that combines the uncertainties at all time and space scales. At present, it is not well understood how to combine different uncertainty sources on a global and regional scale in a fully probabilistic framework, or the information to do so (e.g. model runs) is lacking. We note, however, that this is a hot scientific subject and that work towards this goal is presently carried out in the EU-funded project ENSEMBLES (www.ensembles-eu.org).

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References

Christensen, J.H., T.R. Carter, M. Rummukainen and G. Amanatidis, 2007. Evaluating the performance and utility of regional climate models: the PRUDENCE project. Climatic Change, DOI 10.1007/s10584-006-9211-6.

De Wit, M.J.M., P.M.M. Warmerdam, P.J.J.F. Torfs, B. van den Hurk, E. Roulin and W.P.A. van Deursen, 2006. Impact of climate change on low flows in the river Meuse. Climatic Change, DOI 10.1007/s10584-006-9195-2

Jacob, D., L. Bärring, O.B. Christensen, J.H. Christensen., M. de Castro, M. Déqué, F. Giorgi, S. Hagemann., M. Hirschi, R. Jones, E. Kjellström, G. Lenderink, B. Rockel, E. Sánchez Sánchez, C. Schär, S.I. Seneviratne, S. Somot, A. van Ulden and B. van den Hurk, 2007. An inter-comparison of regional climate models for Europe: model performance in present-day climate. Climatic Change, DOI 10.1007/s10584-006-9213-4

Leander, R. and T.A. Buishand, 2007. Resampling of regional climate model output for the simulation of extreme river flows. J. Hydrology, 332, 487-496.

Leckebusch, G.C., B.U. Ulbrich, J.G. Pinto, T. Spangehl and S. Zacharias, 2006. Analysis of frequency and intensity of winter storm events in Europe on synoptic and regional scales from a multi-model perspective. Climate Research, 31, 59-74.

Lenderink, G., A. van Ulden and B. van den Hurk, F. Keller, 2007a. A study on combining global and regional climate model results for generating climate scenarios of temperature and precipitation for the Netherlands. Clim. Dyn., DOI 10.1007/s00382-007-0227-z

Lenderink, G., A. Buishand and W. van Deursen, 2007b. Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach. Hydrol. Earth Syst. Sci., 11, 1145-1159.

Overpeck, J.T., B.L. Otto-Bliesner, G.H. Miller, D.R. Muhs, R.B. Alley, and J.T. Kiehl, 2006. Paleoclimatic Evidence for Future Ice-Sheet Instability and Rapid Sea-Level Rise. Science 311, 1747-1750.

Smits, A., A.M.G. Klein Tank and G.P. Können, 2005. Trends in storminess over the Netherlands, 1962-2002. Int. J. Climatol., 25, 1331-1344.

Stouffer, R.J., J. Yin, J.M. Gregory, K.W. Dixon, M.J. Spelman, W. Hurlin, A.J. Weaver, M. Eby, G.M. Flato, H. Hasumi, 2006. Investigating the causes of the response of the thermohaline circulation to past and future climate changes. J. Climate, 19, 1365-1387.

Trenberth, K.E., A. Dai, R.M. Rasmussen, and D.B. Parsons, 2003. The changing character of precipitation. Bull. Am. Met. Soc., 84, 1205-1217.

Van den Brink, H.W., G.P. Können and J.D. Opsteegh, 2004. Statistics of extreme synoptic-scale wind speeds in ensemble simulations of current and future climate. J. Climate, 17, 4564-4574.

Van den Hurk, B.J.J.M., A.M.G. Klein Tank, G. Lenderink, A.P. van Ulden, G.J. van Oldenborgh, C.A. Katsman, H.W. van den Brink, F. Keller, J.J.F. Bessembinder, G. Burgers, G.J. Komen, W. Hazeleger and S.S. Drijfhout, 2006. KNMI Climate Change Scenarios 2006 for the Netherlands. KNMI scientific report WR2006-01, pp.82. Available from www.knmi.nl/climatescenarios

Van Ulden, A., G. Lenderink, B. van den Hurk and E. van Meijgaard, 2007. Circulation statistics and climate change in Central Europe: PRUDENCE simulations and observations. Climatic Change, DOI 10.1007/s10584-006-9212-5

Van Ulden, A.P. and G.J. van Oldenborgh, 2006. Large-scale atmospheric circulation biases and changes in global climate model simulations and their importance for climate change in Central Europe. Atmos. Chem. Phys., 6, 863-881.

Vautard R., C. Honore, M. Beekmann, and L. Rouil, 2005. Simulation of ozone during the August 2003 heat wave and emission control scenarios. Atmos. Environ., 39, 3291-3303.

River floods and their impacts in the changing climate – integrated view

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Abstract

Flood damages, worldwide, have dramatically increased in the last few decades. Flooding is a complex phenomenon which can be caused by several mechanisms, coupled to physical, terrestrial, climate and socio-economic systems. The climate track in the observed changes is likely, even if human encroaching into the harm's way and increase in the damage potential in floodplains are often the dominating factors. Increase in intense precipitation has been observed, with consequences to increasing risk of flooding. Projections for the future, based on regional climate models, indicate increase of flood risks in many areas.

The present contribution addresses the climate track in the flooding phenomenon in an integrated way, tackling issues related to multiple factors, databases, detection and attribution, projections, methodological constraints, and scale problems.

Problems related to integration of datasets are demonstrated. Data on an individual flood event range from physical variables related to the generation mechanism (e.g. precipitation, snowmelt), and the flood itself (river stage and discharge, inundated area) to damage metrics (e.g. total damage, insured damage, damage to cultural heritage, number of destroyed / damaged houses, and human losses – numbers of fatalities, evacuees, people affected). Serious problems are related to availability and dissemination of hydroclimatical observations, and even more so – socioeconomic data. Trend detection and attribution are not trivial, because it is difficult to disentangle the climatic change component from strong natural variability and direct human impacts.

Methodological constraints are manifold. Flood frequency analysis, addressing rare events and based on short (often non-homogeneous) records, involves high uncertainty, extrapolation (e.g. of the stage-discharge relation) and subjectivity even in the stationary case. It is much more complex in the non-stationary case, since a discharge corresponding to an old 100-year flood may become a new 10-year flood.

Interpretation of projections is not straightforward, since models cannot perfectly cope with reconstruction of past events. Analysis of flooding has to resolve multiple scale issues. The scale of concern can range from local (e.g. flood protection in settlements on a small creek) up to global (re-insurance industry perspective). Large river flooding may jeopardize towns on the river, along thousands of kilometers of its course, hence rendering the problem regional, national, or even continental. Moreover, decisions on risk assessment and selection of strategy (e.g. whether to protect, or to accommodate, or to retreat) may be taken at a higher administrative level (e.g. central government), or even internationally (e.g. international river basin commissions). Impacts and adaptations are studied locally, being most interesting to people living there. This scale is very much different from the large scale of climate models, and even regional models, hence disaggregation is necessary.

Information on the Floods Directive, issued by the European Union (27 countries) and examples of impacts of climate change on national flood protection design codes is provided.

1 Introduction

Over several decades, floods have become more destructive worldwide, causing average material damage of tens of billions of dollars per year in both developed and developing countries, and thousands of fatalities, mostly in developing countries.

Several catastrophic floods have occurred in the last ten years. The costliest floods were recorded in China in summer 1998 when material losses exceeded 30 billion dollars. In the European continent, material flood damages in 2002 exceeded 20 billion Euro, being higher than in any single year before. In 1998, during a large river flooding in Bangladesh, over two thirds of the country's area were under water.

Flooding is a serious problem in many countries of the world. Adverse impacts of floods can be found in many sectors: agriculture, ecosystems, water supply, health, transport, settlements, insurance and financial services.

The present contribution addresses the climate track in the flooding phenomenon in an integrated way, reviewing issues related to multiple factors, databases, detection and attribution, projections, methodological constraints, and scale problems.

2 Climate track and the multi-factor context

Flooding is a complex phenomenon that can be caused by several mechanisms, such as intense and / or long-lasting precipitation, snowmelt, dike or dam break, ice jam / land slide, outburst of glacial lake. One can identify three groups of factors which control high river flows and floods: changes in climate, changes in terrestrial systems, and changes in socio-economic systems. Changes in flood hazard and vulnerability are generally due to a range of factors, whose relative order of importance is site-specific.

Changes in climate and atmospheric systems of relevance to floods embrace: total precipitation, intense precipitation events, temperature (controlling snowmelt and ice-jam), seasonality and climate variability (e.g. ENSO, NAO, PDO). Changes in the frequency of heavy precipitation events can arise from several causes, e.g., changes in atmospheric moisture or circulation. As the atmosphere's water holding capacity, and thus its absolute potential water content, increase with temperature according to the Clausius-Clapeyron law, the potential for intensive precipitation also increases in the warming world. Increased atmospheric moisture contents favours heavy precipitation events and this is a sufficient condition, caeteris paribus, for an increase in risk of rain-caused floods. Yet there are also other, non-climatic, factors exacerbating flood hazard. Land-use changes, which induce land-cover changes, induce changes of hydrological systems and control the rainfall–runoff relations, hence impacting on flood risk. Deforestation, reduction of wetlands, and rising urbanization have adversely influenced flood hazard in many watersheds by reduction of the available water storage capacity, increase in the portion of impervious area (roofs, yards, roads, pavements, parking lots, etc.) and in the runoff coefficient. This leads to growth in the amplitude and reduction in the time-to-peak of a flood.

Economic development of flood-prone areas, with a general increase in population and wealth, has led to increasing exposure to flood and exacerbated flood losses. Humans occupy unsafe areas (e. g., many informal settlements on flood plains around mega-cities in the developing world), thereby increasing the loss potential. Growing wealth has been accumulated in flood-endangered areas. For instance, in Japan half the total population and about 70% of the total assets are located on flood plains, which cover only about 10% of the land surface. An important factor influencing the flood hazard is an unjustified belief in the absolute security of structural defenses. However, even an over-dimensioned and perfectly maintained dike (e.g. designed to withstand a 100-year flood) does not guarantee complete protection—it can be overtopped by an extreme flood (e.g. whose return period exceeds 1000 years). When a dike breaks, the damage may be greater than it would have been in a levee-free case. Further, a short memory syndrome can be observed. During a flood-free interval, nations and decision makers gradually decrease the investments necessary for flood-preparedness systems.

3 Data problems

In order to quantify flood events, their generating mechanism and impacts, one has to collect a wealth of information on past flood events, referring to many variables and characteristics, which contribute to a holistic perspective on flooding:

Key variables referring to climate and atmospheric systems include precipitation characteristics (total and heavy precipitation, seasonality, and climate variability, e. g., related to ENSO) and snowmelt. Key variables referring to terrestrial systems (hydrological systems and ecosystems) include river discharge and stage (amplitude, frequency statistics, seasonality); water storage capacity (e. g., decrease caused by land-use change, e. g. deforestation, urbanization, elimination of flood plains and wetlands); runoff coefficient and infiltration capacity, portion of impervious area (e. g., changes caused by urbanization). Key variables referring to economic and social systems include anthropogenic pressure (population growth, urbanization, deforestation, drainage, and human occupation of unsafe areas); adaptive capacity; vulnerability; and measures of flood losses (number of fatalities; number of evacuees; total material damage; insured losses; losses in cultural heritage; further specification of losses, e. g., destroyed infrastructure, buildings, industrial plants, railways, bridges, roads, dikes, etc.; inundated area; therein agricultural land, crop loss).

It would be enlightening to study longer time series of records pertaining to the variables above. But this is possible only to a limited extent. Serious problems are related to availability and dissemination of hydroclimatical observations, and even more so – socioeconomic data. Long time series are available only for a few of the variables from the list given above, and then only for a limited numbers of locations (Kundzewicz & Schellnhuber, 2004). Hence results a prominent role of such initiatives as the Dartmouth Floods Observatory and its open-access database.

There are further problems related to the data, one of which is the non-homogeneity. Baseline conditions are rare, and human influence is typically strong (river regulation, deforestation, urbanization, dams and reservoirs). In order to detect a weak, if any, climate change component in the process of river flow, it is necessary to eliminate other influences and use data from pristine (baseline) river basins. Possible further sources of heterogeneity (e.g., due to changes in instruments, observation techniques, and rating curves, i. e., stage-discharge relationships) should also be identified and dealt with. A great deal of uncertainty results from the need for extrapolation of rating curves to high values, where no direct flow measurements exist. Missing values and gaps are further complicating factors.

But, even if the data are perfect, it is worthwhile to re-state a tautology: extreme events are rare (Kundzewicz & Schellnhuber, 2004). They do not happen frequently, so even where a very long time series of instrumental records exists, one still deals with a small sample of truly extreme and destructive floods (cf. Kundzewicz & Robson, 2000). This dilemma may only be resolved by deriving the correct probability density functions for disastrous events from first geophysical principles.

Further data-related problems are discussed in the section 6, dealing with methodological constraints.

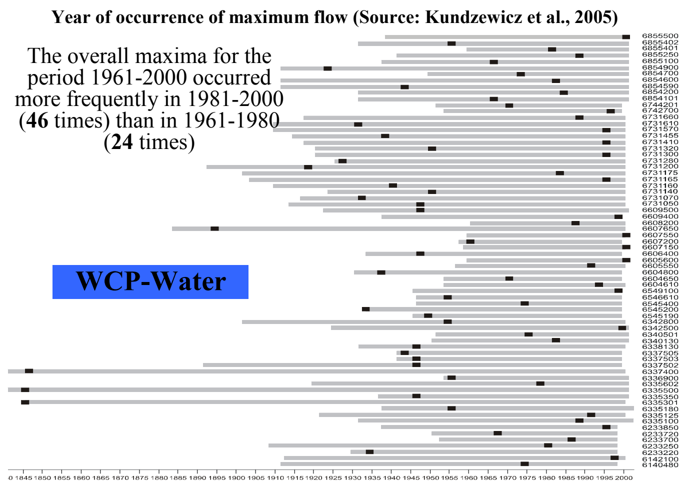

Figure. 1 Results of a change detection study of 70 long time series of annual maximum daily river flows in Europe. Source: Kundzewicz et al. (2005).

4 Trend detection in flood data

Berz (2001) examined inter-decadal variability of great flood disasters (understood as such events where the ability of the region to help itself is distinctly overtaxed, making international or inter-regional assistance necessary) in the period 1950-1998. The number of great flood disasters in the nine years 1990-1998 was higher than in the three-and-half decades 1950-1985, together (Kundzewicz, 2002).

The frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has likely increased over most land areas, consistent with warming and observed increases of atmospheric water vapour (IPCC, 2007), with consequences to increasing risk of flooding.

However, despite observation of the increase in frequency of heavy precipitation, no ubiquitous, uniform, and coherent increase in high river flows has been detected. The conclusive and general statement that severe floods are becoming more frequent is supported by a portion of the available studies, while other publications report contradictory evidence. There have been a number of trend detection studies for European flood data, mostly at the national level, and even more studies of time series at a single stream gauge. However, spatial patterns are problematic (cf. Kundzewicz et al., 2005). Only some series show a significant trend and only some of those with significant trend feature an upward tendency. It is not uncommon that neighbouring gauges behave in a different way, possibly due to non-climatic factors, which are not necessarily in tune with gross climate-related drivers.

Kundzewicz et al. (2005) carried out a change detection study of 70 long time series of annual maximum daily river flows in Europe. The results do not support the hypothesis of a general significant increase of annual maximum river flows. Out of 70 time series, only 20 show statistically significant changes (11 increases and 9 decreases), while most (50) time series do not show any significant changes. However, it was found (cf. Fig. 1) that the overall maxima (for the whole 1961–2000 period) occurred more frequently (46 times) in the later sub-period, 1981–2000, than in the earlier sub-period, 1961–1980 (24 times).

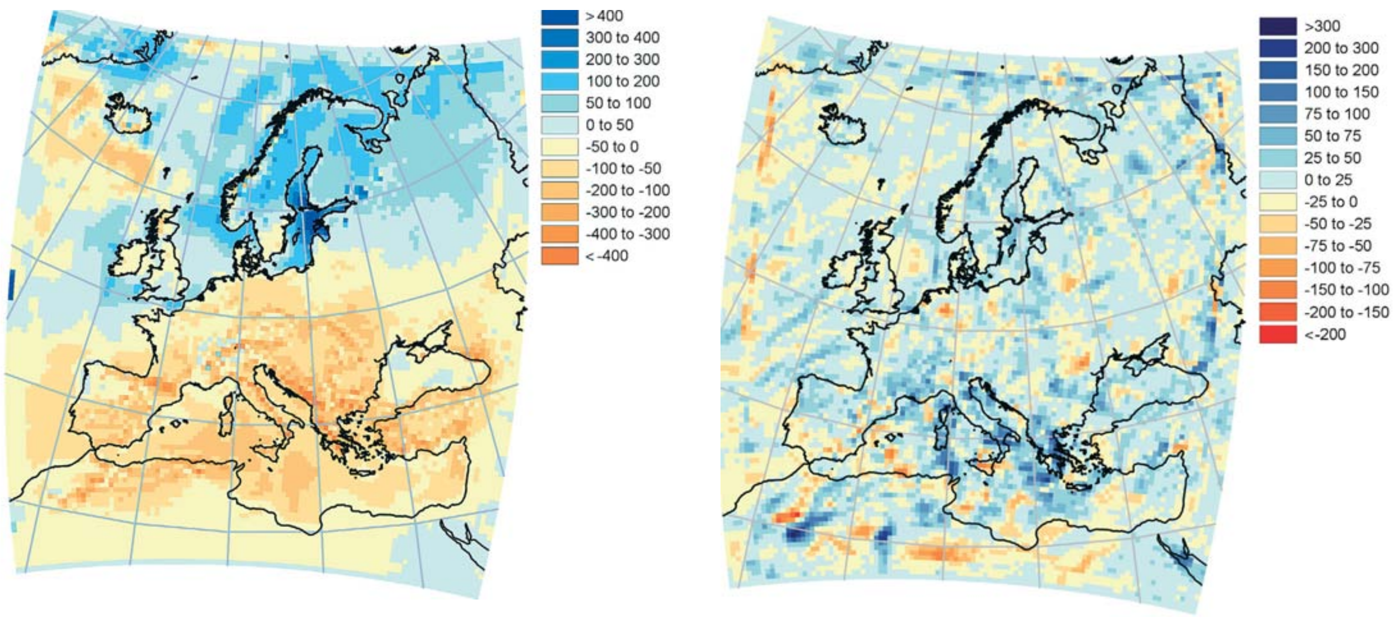

Figure 2 Difference in (a) annual mean precipitation and (b) annual maximum daily precipitation (mm) over Europe between the control period (1961–1990) and future projection (2070–2099) (HadRM3-P, SRES A2 scenario). Source: Kundzewicz et al. (2006).

Milly et al. (2002) demonstrated an increase in the frequency of severe floods (exceeding 100-year levels) in 16 extra-tropical basins worldwide during the 20th century. They examined long series of monthly river flow data and concluded that seven out of eight 100-year floods (on a monthly scale) occurred in the second (more recent) half of the records.

Climate-related changes in flood frequency are complex, depending on the flood-generating mechanism (rainfall vs snowmelt). Regional changes in the timing of floods have been observed in many areas of Europe, with increasing incidence of late autumn and winter floods (caused by rain) and fewer spring snowmelt floods. High flows come earlier in the year due to earlier snowmelt (sometimes in winter rather than spring) and less snow cover may reduce the severity of spring snowmelt floods. The number of inundations caused by ice jams has gone down as a result of warming (more rivers do not freeze at all) and better human capacity to cope with ice-based obstructions of flow.

5 Projections for the future

Based on global model simulations and for a wide range of scenarios, one can make projections of extreme events for future climate: the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) will very likely increase over most land area (IPCC, 2007). More frequent heavy precipitation events would lead to multiple adverse consequences, such as; increased flood, landslide, avalanche, and mudslide damage; increased soil erosion; increased pressure on government and private flood insurance systems and disaster relief.

As demonstrated by Kundzewicz et al. (2006), according to HadRM3-P results, mean summer precipitation over much of Europe is likely to decrease from the control period (1961–1990) to the period of interest in the 21st century (2070–2099). This is not necessarily so for the highest quantiles of precipitation amounts or for annual maximum precipitation, which are likely to increase over many areas (Fig. 2). This result is in agreement with the findings of Christensen & Christensen (2003), who used another climate model.

A significant portion of the increase of flood hazard will continue to be caused by human factors, including land-use changes and the increase in population and wealth accumulated in endangered areas.

Changes in future flood frequency are complex, depending on the generating mechanism, e.g., increasing flood magnitudes where floods result of heavy rainfall and decreasing magnitudes where floods are generated by spring snowmelt. In some areas, where snowmelt is the principal flood-generating mechanism, the time of greatest flood risk would shift from spring to winter. Winter flood hazard is likely to rise for many catchments under many scenarios. However, global warming may not necessarily reduce snowmelt flooding everywhere. Since an increase in winter precipitation is expected, snow cover may increase in areas where the temperature is still below 0°C. In some places, "[r]apid snowmelt from rain-on-snow events or warm periods in the middle of winter is a potential threat in a warmer world" (IPCC, 2001a, p. 395).

Palmer & Räisänen (2002) analyzed the modelled differences between the control run with 20th century levels of carbon dioxide and an ensemble with transient increase in CO_2 and calculated around the time of CO_2 doubling (61-80 years from present). They found a considerable increase of the risk of a very wet winter in Europe and a very wet monsoon season in Asia. The modelling results indicate that the probability of total boreal winter precipitation exceeding two standard deviations above normal will considerably increase over large areas of Europe. For example, an over five-fold increase is projected over Scotland and the island of Ireland and much of the Baltic Sea basin, and even over seven-fold increase for parts of Russia.

Milly et al. (2002) demonstrated adverse changes in the risk of great floods (exceeding 100-year levels). For all (but one) large basins (over 200 000 km^2) analyzed, the control 100-year flood is exceeded more frequently as a result of CO_2 quadrupling. In some areas (beyond Europe), what is given as a 100-year flood in the control run, is projected to become much more frequent, even occurring as often as every 2 to 5 years. Milly et al. (2002) found that the likelihood that these changes are due to natural climate variability is small.

Floods have been identified in the IPCC TAR (2001) and IPCC AR4 (2007) among regional reasons of concern. As noted in (IPCC, 2007), in the Himalaya, glacier melt will lead to increasing numbers and severity of melt-related floods (including glacial lake outburst floods), ice and rock avalanches from destabilized slopes and disruption of water resources. Flooded area in Bangladesh is projected to increase at least by 23-29% with a global temperature rise of 2°C (Mirza et al., 2003). In Australia and New Zealand, higher risks to major infrastructure such as floodplain protection and urban drainage/sewerage are very likely. Flash floods are likely to increase in all of

Europe, while snowmelt-related floods in Central and Eastern Europe are expected to decline. In Andean countries, melting glaciers are leading to flooding and changes in the seasonal pattern and amount of runoff.

As noted by Kundzewicz & Mata (2007), increase in floodings will have adverse impacts on sustainable development. Up to 20% of the world population live in river basins that are likely to be affected by increased flood hazard by 2080s in the course of global warming (Kleinen and Petschel-Held, 2006).

6 Methodological constraints

Published results of change detection in flood flows do not give a conclusive and general proof as to how climate change affects the flood behaviour, in the light of the data observed so far. It may well be that strong natural variability overshadows weak, if any, greenhouse signature. It is generally difficult to find a gradual, low-frequency change (e.g. related to climatic impacts) in the behaviour of the extremes of river flow, amidst overwhelming natural variability. In order to detect a weak, if any, climate change component, it is necessary to eliminate other influences, e.g. by using data from baseline river basins.

Highly skewed distributions render change detection in annual maxima of daily river flows difficult. Kundzewicz et al. (2005) showed that it is not uncommon that the highest recorded annual maximum daily flow at a given station is considerably (e.g., four or more times) higher than the second highest value in the long time series of records. As noted by Radziejewski & Kundzewicz (2004), tests are not able to detect a weak trend or change that has not lasted sufficiently long, but this cannot be interpreted as a demonstration of the absence of change. With the enhanced climate change, the changes of hydrological processes may be stronger and last longer, so that the likelihood of change detection may grow. However, methodological developments are needed, including tools to study weak trends.

Apart from the inherent complexity of the issue of detecting a greenhouse component in flow records, there are serious problems with the data with which to work, and also with the methodology to detect changes. Data should consist of long time series of good quality records. They are not available in many areas. Due to financial constraints, several countries have been reducing their observation networks. Even if data are collected, they may not be readily available for international research studies, or only available at (often prohibitively high) cost. Because of strong climate variability, records of less than 30 years are almost certainly too short for detection of climate change. It is suggested that at least 50 years of records are necessary for climate change detection (Kundzewicz & Robson, 2000), but in the case of strong natural variability even this may not be sufficient.

The immediate question that attracts increasing interest is the following: to what extent a sensible rise in various flood-related indices (e. g. flood hazard and vulnerability) can be linked to climate variability and change?

In many places, flood risk is likely to grow, due to a combination of anthropogenic and climatic factors; strong natural variability and influenced by man-made environmental changes: urbanization, deforestation, human occupation of hazardous areas, reduction in storage capacity and increase in runoff coefficient. A part of detected trend is linked to socio-economic factors, such as population increase and accumulation of wealth in vulnerable areas. However, these factors alone cannot explain the whole observed growth, and a portion of it is linked to climate. Trend detection and attribution are not trivial, because it is difficult to disentangle the climatic change component from strong natural variability and direct human impacts.

Methodological constraints are manifold. Quantification of flood statistics is subject to high uncertainty. Flood frequency analysis, addressing rare events and based on short (often non-homogeneous) records, involves high uncertainty, extrapolation (e.g. of the stage-discharge relation) and subjectivity even in the stationary case. It is much more complex in the non-stationary case, since a discharge corresponding to an old 100-year flood may become a new 10-year flood.

When planning for the future (e.g., flood infrastructure of long lifetime) and assessing future vulnerability, one has to deal with strong, and manifold, uncertainties. Interpretation of projections for the future is not straightforward, since models cannot perfectly cope with reconstruction of past events. There are many sources of uncertainty in future projections, starting from impossibility to foresee the future human behaviour (population change, social and economic development, mitigation policies at the global and national scales, controlling the future emission and sequestration. Uncertainties are also introduced by the transfer functions: to atmospheric concentration of greenhouse gases, further to climate change (including feedbacks) and to climate change impacts. Every transfer function in the above chain bears large uncertainty. For example, climate model uncertainty (converting greenhouse gas concentrations into climatic variables, such as temperature and precipitation) is large. Precipitation is poorly represented in GCMs, which do not perform well in the validation process, in some regions, using global observations. There is a large difference between results obtained by using different scenarios and different models, while difference between models for the same emission scenario is often larger than for the same model and different emission scenarios.

Neither a single simulation nor an ensemble (consensus) average of model results are appropriate in extreme event studies, since they may lead to underestimation of extreme precipitation and flooding. Studying frequency distributions of extreme events among a large multi-model ensembles is likely to produce more trustworthy results (e.g., Palmer & Räissänen, 2002).

7 Scale issues

When undertaking flood studies, one has to resolve multiple scale problems. The scale of concern can range from local (e.g. flood protection in settlements on a small creek) up to global (re-insurance industry perspective). Large river flooding may jeopardize towns on a large river, along thousands of kilometers of its course, hence rendering the problem regional, national, or even continental. Moreover, decisions on risk assessment and selection of strategy (e.g. whether to protect, or to accommodate, or to retreat) may be taken at a higher administrative level (e.g. central government), or even internationally (e.g. international river basin commissions).

The general conclusion drawn from the science of the climate change is as follows: the hydrological cycles are likely to accelerate in the warmer climate. However, in general, today's climate models are not good at producing local climate extremes due to, inter alia, inadequate (coarse) resolution. Only in some, but not all, areas, the projected direction of change of hydrological processes is consistent across different scenarios (emissions of greenhouse gases, which drive climate models) and across different models. There is hope that, with improving resolution and parameterization of land-surface processes, models will be able to grasp details of extreme events in a more accurate and reliable way. With a well-designed research programme we are in a position to drastically reduce uncertainties in assessments.

However, there is a great deal of uncertainty in findings about future climate change impacts on water resources, and this refers particularly to extreme events. Part of the problems is due to a spatial and temporal scale mismatch between coarse-resolution climate models and the smaller-grid scale (hydrological scale of a drainage basin, which is relevant to impact studies), for which the much finer information is necessary. Adaptations are undertaken locally, being most interesting to people living there. Further, time scale of interest (e.g. for heavy precipitation resulting in flash flood, the dynamics of flood routing is in the temporal scale of minutes to hours) differs from the available climate model results (given at monthly/daily intervals). Both spatial and temporal scale mismatch requires disaggregation, which is another source of uncertainty.

8 Adaptation to floods – EU Floods Directive

In response to destructive floods in Europe since 1990, water managers in a few European countries, including the Netherlands, the UK, and Germany have begun to consider the implications of climate change explicitly in flood management and national flood protection design codes. In the UK, for example, design flood magnitudes are increased by 20% to reflect the possible effects of climate change, based on early impact assessments. Measures to cope with the increase of the design discharge for the Rhine in the Netherlands from 15 000 to 16 000 m3/s must be implemented by 2015 and it is planned to increase the design discharge to 18 000 m3/s in the longer term due to climate change. In the German State of Bavaria, the design values have increased by 15%.

On the European Union (27 countries) level, the Floods Directive (Directive..., 2006) has now been approved. The term ”flood” is interpreted in the Directive as temporary covering by water of land not normally covered by water and ”flood risk” means the likelihood of a flood event of a certain severity together with the estimated damage to human health, the environment and economic activity associated with a flood event of that severity. The Directive embraces river floods, flash floods, urban floods, sewer floods and coastal floods.

The Directive foresees that EU Member States shall, for each river basin district or the portion of an international river basin district lying within their territory, undertake a preliminary flood risk assessment, which shall include at least the following:

(a) a map of the river basin district including the borders of the river basins, sub-basins and where appropriate associated coastal zones, showing topography and land use;

(b) a description of the floods which have occurred in the past;

(c) a description of flooding processes and their sensitivity to change, including the role of flood plain areas as a natural retention/ buffer of floods and flood conveyance routes now or in the future;

(d) a description of development plans that would entail a change of land use or of allocation of the population and distribution of economic activities resulting in an increase of flood risks in the area itself or in upstream or downstream regions;

(e) an assessment of the likelihood of future floods based on hydrological data, types of floods and the projected impact of climate change and land use trends;

(f) a forecast of the estimated consequences of future floods to human health, the environment and economic activity taking into account long-term developments including climate change.

Further, EU Member States shall prepare flood maps and indicative flood damage maps, for the river basins, sub-basins and stretches of coastline, which shall cover the geographical areas which could be flooded with a high probability (likely return period, on average once in every 10 years); with a medium probability (likely return period, once in every 100 years), and with a low probability (extreme events). The map should illustrate projected water depths; flow velocities; and areas which could be subject to bank erosion and debris flow deposition. The indicative flood damage maps shall show the potential damage associated with floods and expressed in terms of the number of inhabitants potentially affected; potential economic damage in the area; and potential damage to the environment.

Finally, EU Member States shall prepare and implement flood risk management plans at the level of the river basin district for the river basins, sub-basins and stretches of coastline, focusing on the reduction of the probability of flooding and of potential adverse consequences of flooding, and taking into account relevant aspects: water management, soil management, spatial planning, land use and nature conservation. The flood risk management plans shall include measures that aim at achieving the required levels of protection, addressing all phases of the flood risk management cycle focusing on prevention, protection, preparedness, and taking into account the characteristics of the particular river basin or sub-basin. Flood risk management measures taken in one EU Member State must not increase flood risks in neighbouring countries.

The Directive (2006) identifies the timelines for completion of the activities specified above, with the ultimate goal to complete and publish flood risk management plans by 22 December 2015.

9 Concluding remarks

Studies of changes in flood records are of considerable theoretical and practical importance. Flood protection systems have been designed and are operated on the basis of the assumption of stationarity. Since this assumption is incorrect, the existing design procedures for flood protection systems (including structural measures - embankments, dams, reservoirs, relief channels, polders, etc.) have to be revised. Otherwise, they would be under- or over-designed and are either not serving their purpose adequately or are overly costly (e. g., with large safety margin).

There is no doubt that the future changes of flood hazard due to climate forcing will be complex, depending on the flood-generating mechanism (rainfall vs snowmelt). Increase in frequency of heavy precipitation has likely been observed and is very likely to occur in the future, leading to increase in the risk of rain-caused floods. In many places flood risk is likely to grow, due to a combination of anthropogenic and climatic factors..

The climatic impact on flood preparedness depends, in general, not only on changes in the characteristics of streamflow, but also on such system properties, as: pressure (stress) on the system, its management (also organizational and institutional aspects), and adaptive capacity. Climate change may challenge existing practices by contributing additional uncertainty.

The IPCC TAR statement that „the analysis of extreme events in both observations and coupled models is underdeveloped.”remains broadly valid to-date, despite the progress achieved.

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REFERENCES

Berz, G. (2001) Climatic change: effects on and possible responses by the insurance industry. In: Climate of the 21st Century: Changes and Risks :(ed. by J. L. Lozan, H. Graßl & P. Hupfer), Wissenschaftliche Auswertungen, Hamburg, Germany, 392–399.

Christensen, J. H. & Christensen, O. B. (2003) Severe summertime flooding in Europe, Nature, 421, 805.

Directive of the European Parliament and of the Council on the assessment and management of floods (2006) {SEC(2006) 66} (draft).

IPCC (Intergovernmental Panel on Climate Change) (2001) Climate Change 2001: The Scientific Basis (edited by Houghton, J. T., Ding, Y., Griggs, D. J., Nouger; M., van der Linden, P. J., Dai, X., Maskell, K. & Johnson, C. A.). Contribution of the Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K.

IPCC (Intergovernmental Panel on Climate Change) (2001a) Climate Change 2001: Impacts, Adaptation and Vulnerability (edited by Mc Carthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J. & White, K. S.). Contribution of the Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K.

IPCC (Intergovernmental Panel on Climate Change) (2007) Climate Change 2007: The Physical Science Basis. Summary for Policymakers. Contribution of the Working Group I to the Fourth Assessment Report of the

Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K.

IPCC (Intergovernmental Panel on Climate Change) (2007a) Climate Change 2007: Impacts, Adaptation, and Vulnerability. Summary for Policymakers. Contribution of the Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K.

Kleinen, T. & Petschel-Held, G. (2006) Integrated assessment of changes in flooding probabilities due to climate change. Climatic Change.

Kundzewicz, Z. W. (2002) Non-structural flood protection and sustainability, Water International, 27(1), 3-13.

Kundzewicz, Z. W., Graczyk, D., Maurer, T., Pinskwar, I., Radziejewski, M., Svensson, C. & Szwed, M. (2005) Trend detection in river flow series: 1. Annual maximum flow. Hydrol. Sci. J. 50(5), 797–810.

Kundzewicz, Z. W. & Mata, L. (Coordinating Lead Authors) (2007) Freshwater resources and their management. Chapter 3 in: IPCC (Intergovernmental Panel on Climate Change) (2007a) Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of the Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K.

Kundzewicz, Z. W., Radziejewski, M., Pinskwar, I. (2006) Precipitation extremes in the changing climate of Europe. Clim. Res. 31: 51–58.

Kundzewicz, Z. W. & Robson, A. J. (2004) Change detection in river flow records – review of methodology. Hydrol. Sci. J. 49(1): 7-19.

Kundzewicz, Z. W. & Schellnhuber, H.-J. (2004) Floods in the IPCC TAR perspective. Natural Hazards 31: 111-128.

Milly, P. C. D., Wetherald, R. T., Dunne, K. A. & Delworth, T. L. (2002) Increasing risk of great floods in a changing climate. Nature 415, 514–517.

Mirza, M. M. Q., Warrick, R. A. & Ericksen, N. J. (2003) The implications of climate change on floods of the Ganges, Brahmaputra and Meghna Rrivers in Bangladesh. Climatic Change, 57, 287-318.

Palmer, T. N. & Räisänen, J. (2002) Quantifying the risk of extreme seasonal precipitation events in a changing climate, Nature, 415, 512-514.

Radziejewski, M. & Kundzewicz, Z. W. (2004) Detectability of changes in hydrological records. Hydrol. Sci. J. 49(1), 39–51.

Methodological issues on linking integrated assessment with life cycle impact assessment

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ABSTRACT

Various kinds of integrated assessment models (IAMs) have been developed to analyze climate change mitigation and adaptation strategies. On the other hand, life cycle impact assessment (LCIA) methodology has been made from different views. It aims at making comprehensive analysis of environmental effects of product life cycle such as production, utilization and disposition. These two approaches can provide common and consistent framework basis for bottom-up and top-down integration in climate change impact assessment, although they are different in primary focuses. It is important to establish the methodology on comprehensive economic evaluation of environmental impacts to design mitigation/adaptation and global/regional/local environmental policy portfolio. The authors have developed preliminary framework of climate change mitigation and adaptation, by linking the integrated assessment model GRAPE (Global Relationship Assessment to Protect the Environment) and the endpoint type life cycle impact assessment methodology LIME (Lifecycle Impact assessment Method based on Endpoint modeling). The assessment methodology is summarized and methodological issues on linking climate change mitigation and adaptation assessment are discussed.

1. Introduction

Environment problems are categorized into local and global issues. Historically, the former deals with air, water and soil pollutant emissions and local impacts. Cumulative knowledge from natural and social science in climate change research area has an impact on global policy agenda. Therefore, attentions also have to be paid to the latter 'global issue' including climate change.

Integrated assessment models (IAMs) have been developed to evaluate climate change impacts and mitigation measures and are used as research and policy tools for decision making. On the other hand, life cycle impact assessment (LCIA) has been used to make comprehensive product evaluations of products life-cycle from production, utilization and disposal. In other words, IAM should initially focus on top-down environmental assessment from global and dynamic views, while LCIA primary concern is bottom-up comprehensive assessment of products/services environmental impacts from cradle-to-grave perspective. Lack of practical dynamic data makes dynamic LCIA realization difficult. Under these circumstances, LCIA static bottom-up data and IAM dynamic top-down framework are not fully linked in global and local environmental assessment since these tools have been developed independently.

The purpose of this paper is to provide the issues in linkage of IAM and LCIA through the preliminary assessment example, and to discuss the applicability of IAM-LCIA as mitigation/adaptation portfolio design tools.

2. Integrated Assessment of Climate Change

After 1990s, many researchers developed IAMs to make comprehensive assessment of global issues arising from climate change. These models deal with interdisciplinary knowledge from climate change, energy system and landuse etc.

Characteristics of integrated assessment of climate change can be summarized by interdisciplinary characteristics and long-term aspects. Global atmosphere, technologies and economics should be assessed in one framework with regional-global integration.

GRAPE (Global Relationship Assessment to Protect the Environment) model has been developed and used to evaluate the flexibility embedded in the Kyoto Protocol and to discuss long term climate targets such as CO_2 concentration, radiative forcing and atmospheric temperature. The flexibility of climate change mitigation policy is composed of three categories; space, time and gas species. Emission certificate trade, joint implementation and clean development mechanism (i.e. Kyoto mechanism) depend on spatial flexibility (Kurosawa et.al, 1999). Intertemporal flexibility could mitigate drastic shock if banking/borrowing of Greehnouse Gas (GHG) quota would be available (Kurosawa 2000). In addition, the diversity of target GHGs will enhance the choices of climate change mitigation measures and enable more flexible policy options (Kurosawa 2006).

3. Life Cycle Impact Assessment

Life cycle assessment provides scientific and objective basis of environmental improvement decision-making by quantitative information of resource and energy requirement as well as environmental burden. These informations are compiled from analyses of resource extraction, design, production, transport, utilization and recycle/disposal in various kinds of products or services. International Organization for Standardization (ISO) established 14040 series of Life Cycle Assessment (LCA) guidelines and prepared four documents from 1997 to 2000. They were 'Principles and framework (14040)', 'Goal and scope definition of inventory analysis (14041)', 'Life cycle impact assessment (14042)' and 'Life cycle interpretation (14043)'. These documents have been reorganized as new 14040 and 'Requirements and guidelines (14044)' guidelines to enhance readability in 2006.

We used LIME (Lifecycle Impact assessment Method based on Endpoint modeling) version 1 for the LCIA tool. LIME is originally developed to make comprehensive environmental assessment of Japanese products life cycle. The schematic design of LIME1 is shown in Figure 1. The LIME assessment procedure is divided into five steps. In the first 'fate analysis', environmental toxic concentration change is evaluated by various kinds of environmental burden. The second step 'exposure analysis' deals with relationship among toxic concentrations and receptor impact categories. The third step 'damage assessment' treats changes of potential damage by category endpoints. Fourth step 'quality analysis' summarizes damages of each safeguard subjects. Final step 'weighting' integrates environmental economic impacts by weighting method.

Recently developed LIME 2 modified assessment scheme to evaluate uncertainties of emissions inventories, cause-and-effect chains and weighting, and to include noise and indoor pollutions as impact categories.

LCIA has been developed and used in developed regions. Its application to developing regions is underway.

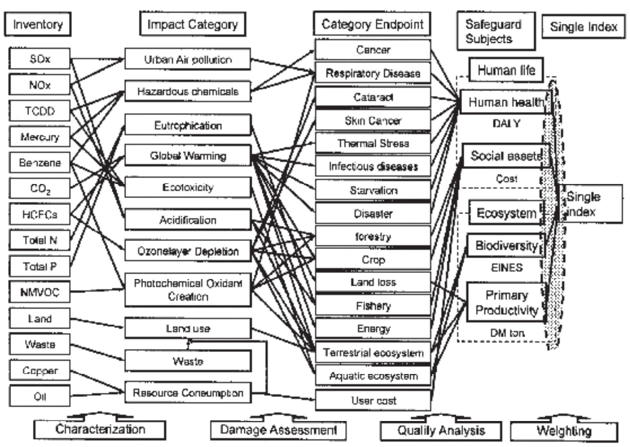

Figure 1. Conceptual figure of LIME (Life-cycle Impact assessment Method based on Endpoint modeling) version 1 (partly modified from Itsubo et.al, 2004).

4. Issues on Linkage IAM with LCIA

In general, we can obtain detail information by LCIA of specific time point depending on local environmental data availability. On the contrary, global and dynamic perspectives of climate change are treated as main agenda in IAMs. The framework is needed to match the interface between IAM and LCIA. Pennington (2004) stated that LCIA could be considered as in the framework of IAM, and introduced regional acidifying impact assessment example of RAINS (Regional Air Pollution Information and Simulation) model. The resolution of issues below is required for the global scale integration of two methodologies.

4.1 Dynamics

LCIA is originally developed to evaluate static product lifecycle impacts and it assumes that cause-and-effect relationship formula is constant and that there is no linkage generation/vanishment. If we need dynamic aspects of policy and project evaluations using LCIA, the impact pathways of the LCIA method shown in Figure 1 should be modified to adapt it to dynamic assessment. Meanwhile, mitigation assessment using IAM with energy resource and/or atmospheric CO_2 constraint has dynamics in its initial assessment design.

4.2 Boundary and cause-and-effect scheme design

LCIA methodology tries to capture various environmental impacts as possible. Thresholds information of dose-response functions and screening of impact categories etc. are required to apply LCIA to the developing regions. Regional or local data are essential to select influential inventories, impact categories, category endpoints and safeguards subjects.

In general, LCIA assumes linear relationship between causes and effects for the pursuit of user friendliness. If the relationship is known as non-linear, marginal value of local linearization is adopted as proxy. Impacts are evaluated by 'safe side principle' since this simplified approach could result undervaluation or overvaluation of impacts.

4.3 Economic Valuation

Economic valuation of environmental impacts remains matter of debate. There are two kinds of approaches in environmental economics. One is 'revealed preference method', which evaluates environmental value indirectly based on consumption behavior etc. Another is 'stated preference method', which is based on direct query of environmental values. LIME adopted conjoint analysis, one of the stated preference methods. It can assess multi-attribute environmental value, and assessment results can be expressed in monetary terms as marginal willingness to pay (MWTP).

When linking with the IAM, internalization of external cost using MWTP value can be regarded as a feedback to the macroeconomy balance equation of IAM. According to the strict definition, adaptation cost is not equal to willingness to pay. However, prior evaluation of environmental impacts requires existence/nonexistence of environmental impacts and their order estimates. In this sense, these evaluation results can be the useful information to decision making. Attentions have to be paid to benefit transfer function application to periods or regions other than original estimation was made.

4.4 Uncertainty Management

There is no explicit consideration of uncertainty in LIME 1. Monte Carlo simulation assuming probabilistic distribution function was conducted to assess variation of inventory, cause-and-effect and economic valuation in the development of LIME 2. But trueness of cause-and-effect relationship should be assessed by expert judgements from existing researches or literatures.

5. Preliminary Approach of Linking LCIA with IAM

GRAPE model took simple approach by assessing macroeconomic impact using a damage formulation as a function of atmospheric temperature rise from base year.

In the GRAPE/LIME framework, we include environmental external cost from LCIA in the GRAPE macroeconomy balance formula to express local and global environmental impacts other than global warming (Tokimatsu, et.al 2006 and Kosugi, et.al 2006). External cost is calculated by GHGs and SOx emissions, mineral mining activities, landuse and landuse change simulation data to assess biodiversity and NPP change effects, etc. (Figure 2). We assume that current Japanese MWTP by detail assessment can be extended to future and to other global regions using benefit transfer function parameterized per capita GDPs and income elasticities. We have to admit that this is ad hoc approach, because we lack definite information on inventory, cause-and-effect, and MWTP information in other global regions based on the detailed and consistent analysis. In this preliminary analysis with feedback of external cost, gross world products reduces a few per cent from the baseline. Forest preservation

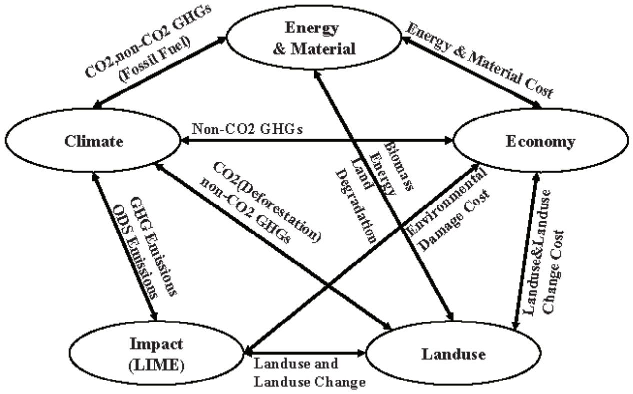

Figure 2. GRAPE/LIME framework (partly modified from Kosugi (2006).

and shift from fossil fuel is observed in the simulation to decrease external cost.

6. Portfolio of Adaptation/Mitigation and Global/ Regional/Local Countermeasures

6.1 Co-Benefit of Mitigation Efforts to Local Environment

Declining the dependency on fossil fuel in global energy system is effective to reduce greenhouse gas effects from CO_2 as well as other local air pollutants such as SOx and NOx. LIME can capture these effects endogenously in its assessment framework. If we collect and compile inventory data and dose-response relationship formula in developing regions, ancillary local health benefit can be assessed. Other local environmental co-benefit can be assessed in a similar way.

6.2 Mitigation/Adaptation portfolio design

Working Group II of Intergovernmental Panel on Climate Change stated the importance of mitigation and adaptation portfolio in the summary for the policymakers of fourth assessment report (IPCC, 2007). It stresses that the value of a portfolio or mix of strategies that includes mitigation, adaptation, technological development and research, and that such portfolios could combine policies with incentive-based approaches, and actions at all levels from the individual citizen through to national governments and international organizations.

Comprehensive portfolio design should be based on mitigation/ adaptation balance as well as global/regional/local balance. Design requirements from climate impacts and adaptation should include the degree of regional dependence of vulnerability and adaptation cost, critical adaptation measure dependent on income level (e.g., vaccine for malaria, etc.), impact thresholds, and climate variability shorter than annual variation.

LCIA is the consequences of intensive national scale bottom-up assessment by its nature. Future LCIA assessment in developing regions needs inventory data collections, estimations of dose-response and other cause-and-effect relationship analyses, and flexible impact category formulations dependent on regional environmental vulnerabilities such as sea level rise.

From the mitigation side, GHG reduction technologies have versatility. But developing regions' acceptance of these technologies should overcome the technology transfer and diffusion barriers by infrastructure development and capacity building.

7. Conclusion

Current LCIA is utilized mainly in developed regions and is established as local and bottom-up assessment method. But the bottom-up data compilation in developing regions is not enough to conduct LCIA in these regions. We should start data collection and integration of inventory and cause-and-effect relationship with uncertainty information.

We need methodology on comprehensive economic evaluation of environmental impacts to design mitigation/adaptation and global/ regional/local environmental policy portfolios. Coupling of IAM and LCIA is powerful tool to manage this important task although the future is uncertain.

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References

IPCC (2007), Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, pp.7-22.

Itsubo, N., Sakagami, M., Washida T., Kokubu, K., and Inaba, A. (2004), Weighting Across Safegurd Subjects for LCIA through the Application of Conjoint Analysis, The International Journal of Life Cycle Assessment, vol.3, pp.196-205

Kosugi, T., Tokimatu, K, Kurosawa, A., Itsubo, N., Ii, R., Yagita, H., and Sakagami, M., (2006), Global Sustainable Development Indices for the Future: A Simulation Study Linked IAM and LCIA, Proceedings of the 7th International Conference on Ecobalance, Tsukuba, Japan.

Kurosawa, A., Yagita, H., Zhou W., Tokimatsu, K. and Yanagisawa, Y. (1999), Analysis of Carbon Emission Stabilization Targets and Adaptation by Integrated Assessment Model, Special Issue on the Cost of the Kyoto Protocol: A Multi-Model Evaluation, pp.157-176, Energy Journal, International Association for Energy Economics.

Kurosawa, A. (2000), When Flexibility in Carbon Certificate Trade under Kyoto Mechanism, Proceedings of the 23rd Annual IAEE International Conference, International Association for Energy Economics, Sydney, Australia.

Kurosawa A. (2006), Multigas Mitigation: An Economic Analysis Using GRAPE Model, Special Issue on Multi-Greehnouse Gas Mitigation and Climate Policy, pp.275-288, Energy Journal, International Association for Energy Economics.

Pennington, D.W., Potting. J., Finnveden. G., Lindeijer, E., Jolliet, O., Rydberg, T. and Rebitzer, G. (2004), Life Cycle Assessment Part 2: Current impact assessment practice, Environment International, vol. 30, pp721-739.

Tokimatsu, K., Itsubo, N., Kurosawa, A., Kosugi, T., Yagita, H. and Sakagami, M. (2006), A simulation study of merging a lifecycle impact assessment (LCIA) with integrated assessment model (IAM) – an optimal economic growth via interlizing external costs by environmental impacts – (in Japanese), Kankyo Kagaku Kaishi, vol.19 no.1, pp25-36.

Production of vegetable oils and biodiesel in Northeastern Brazil: a case study on Mitigation & Adaptation synergy

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Abstract

This paper discusses the possibility of addressing concerns about climate change through an integrated adaptation and mitigation strategy. This "Ad-Mit" or "Mit-Ad" approach is illustrated through the case of crop diversification by family farmers for vegetable oil and biodiesel production from cultivation of different raw materials in the Northeast semi-arid region of Brazil. Regional and rural development, improved national energy security, local and global environment protection are the main benefits from biodiesel production as a sustainable energy source. Potential barriers to biodiesel production development in the Northeast semi-arid region are identified, including capacity building and logistics requirements. Follows a discussion of policies and measures to overcome these barriers and meet the challenge of tapping the potential benefits of applying a Mit-Ad approach in this case.

1. Introduction

Impact assessments of some climate change scenarios have identified the Northeast region of Brazil as one of the most vulnerable in the country (IPCC, 2001b). This region has a dry climate and irregular rainfall distribution. The area has been chronically affected by droughts. Moreover, El Niño South Oscillation (ENSO) has been responsible for aggravating the severity and increasing the frequency of these droughts.

Small farmers from the Northeast semi-arid region are among the social groups most vulnerable to climate change. The strengthening of the social and economic conditions of these rural communities through the growing of vegetable oil crops is an important adaptation strategy vis-à-vis future climate change, constituting an income generation activity in the biodiesel production chain. The use of vegetable oils and biodiesel as a fuel prevents CO_2 emissions due to the displacement of diesel oil, thus it also contributes to a mitigation strategy.

Recently, the Brazilian government started the National Program for the Production and Use of Biodiesel (PNPB) as a substitute for imported diesel oil, acknowledging that public policies and significant investments are essential to promote economies of scale and allow for the introduction of this innovation (La Rovere et al, 2006). In the first stage of the program, diesel oil will be blended with two percent biodiesel, for its use in diesel vehicles. The PNPB explicitly targets the sustainable production of biodiesel in Brazil, promoting social inclusion. The requirement of a Social Fuel Certificate (SCS) to benefit from tax reductions was established by the Federal Government as a mechanism for fostering job generation and the insertion of small farmers in the biodiesel production chain.

Castor bean (*Ricinus communis*) is indicated as a crop that is suitable for small farmers in the Brazilian Northeast since it is already grown in the region and is adapted to the semi-arid climate. Castor bean can be associated with subsistence crops, such as beans, in a manual production system. However, current production of castor beans far from meets the demand for biodiesel created by the Brazilian government. In this initial stage, lack of raw materials may lead biodiesel producers to use soybean oil for biodiesel production. As soybean is produced in large agribusiness plantations, social benefits would be severely limited in this case. Several initial attempts to implement biodiesel production involving family farmers have failed in Brazil. Many barriers must be overcome to obtain the social development goals of the program, including logistical complexity throughout the small family farm[1] raw material supply chain, vegetable oil extraction in decentralized units and its transformation into biodiesel (through the transestherification, in larger plants).

This regional case study discusses the requirements for the successful implementation of vegetable oil and biodiesel production in the Northeast semi-arid region of Brazil. Results highlight the gap between governmental goals and the current status of small farmer involvement in the PNPB.

2. Current Socio-Climatic Vulnerability of the Northeast Semi-Arid Region

The Northeast of Brazil covers an area of 1.5 million km^2, equivalent to 18.3% of the country, and includes nine of the 26 states. In all of Brazil's regions average monthly incomes are lower in rural households than in urban, though in the Northeast this situation is aggravated, since rural incomes only amount to 46.1% of urban ones, while it is the only region where they are lower than the Brazilian average of 47.5% (DIEESE, 2006). The problem is heightened in the semi-arid region that covers 56.6% of the Northeast and which is inhabited by approximately 25 million people (IBGE, 2004). 40% of the semi-arid population lives in poverty, approximately 8 million people in 2003 (Carvalho and Santos, 2003).

In 2005 the Northeast region had the lowest life expectancy at birth, 65.5 years for men and 72.7 for women, and the highest infant mortality rate, 38.2%, for the same period, in comparison with the other four Brazilian regions (Oliveira et al., 2006). The Northeast is responsible for approximately 14% of Brazilian GDP and holds 27.6% of the total population; in addition, the region has the lowest average per capita GDP, approximately R$4,000 per inhabitant, and the highest GDP per capita concentration of the country (IBGE, 2006). Approximately 75% of children and teenagers in the semi-arid region are supported by families whose per capita income is less than half a minimum wage (Gomes Filho, 2003). In 2003 the Human Development Index (IDH) of the Northeast varied from 0.56 to 0.65, whereas the Brazilian average was 0.75 (IBGE, 2004). Most Northeast states include a significant amount of poor municipalities, with municipal IDH levels of between 0.46 and 0.58 (UNDP, 2002). Concentrations of land, knowledge and productive assets cause difficulties in improving the quality of life and create obstacles for the regional work force (MI, 2003). Measured by Gini Index, land concentration reaches 0.670 in Alagoas (UNDP, 2002).

Climate change impact scenarios identify the Northeast as one of the most vulnerable regions in the country (Marengo, in NAE, 2005). Temperatures in the region are high with annual average varying between 20° and 28°C. Moreover, rainfall is unequally distributed, occurring in just three months and with annual totals varying between 300 and 2000 mm. In the Northeast semi-arid region, annual average temperature is within the range of 23 to 27˚C, with annual rainfall below 800 mm. It repeatedly undergoes chronic water shortages (UNDP, 2006). The volume of water evaporated is around three times higher than that the volume that falls in precipitation, resulting in an unfavorable hydric balance. Semi-arid low soil fertility is associated with the scarcity of water, impacting negatively not only on human water consumption, but also on the use of water for agriculture and livestock raising (MI, 2003). Figure 1 shows the semi-arid areas with water deficits. The most critical area with respect to irregular rainfall is within the semi-arid region. During the four years of analysis (1999-2003), large areas in this region presented a high number of days with water deficit in one or more years, even during the rainy season, due to insufficient rain in a critical period, when it is particularly needed to avoid the loss of subsistence crops that provide staple food. Figure 1 demonstrates the high social and environmental vulnerability of small farmers the semi-arid region of Northeastern Brazil.

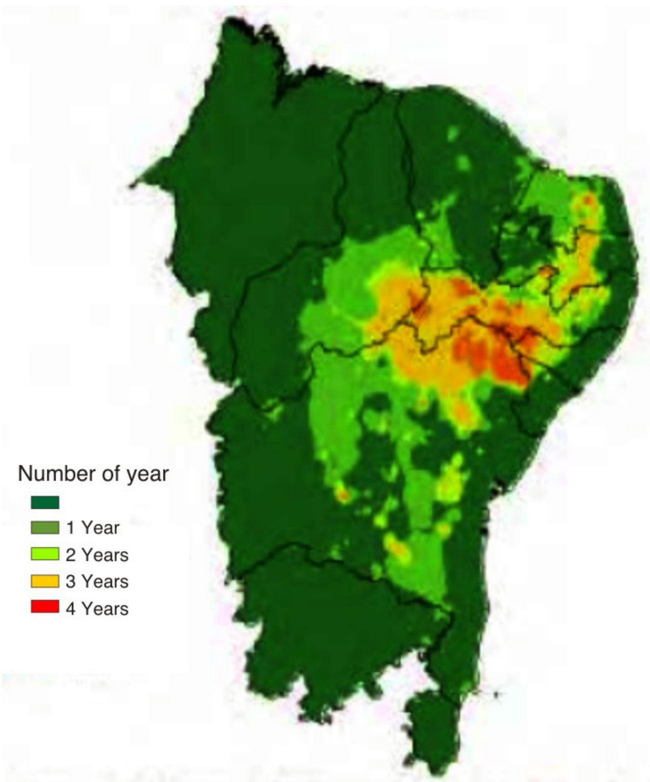

Figure 1- Geographical scope of the areas with severe water deficit periods (up to 30 days) during the rainy season in the period from 1999 to 2003.

Poor communities that depend on climate-sensitive resources, such as water supply, are particularly more vulnerable and are likely to have more restricted adaptive capacities (IPCC, 2007b). Almost half of the children and teenagers living in the semi-arid in 2003 had no access to a water supply network, well or water spring (Gomes Filho, 2003). During the dry season, women and children are obliged to walk long distances in search of water (Diaconia, 1999).

In a large part of the *sertão* (semi-arid area in Northeast region), dryland agriculture is the main economic activity. Relying on a fragile technical base, traditional techniques are used to take advantage of unfavorable natural conditions. Approximately 90% of agricultural establishments in the Northeast region are family farms and cover around 40 million hectares (Mha) (INCRA, 2000). Family agriculture in the Northeast consists mostly of subsistence farming marked by low technological input.

3. Future Climate Change Impacts on the Northeast Region

According to ANA (2006) around 41 million inhabitants of the semi-arid region and adjacent areas could be faced with water supply problems by 2025. Global warming may further aggravate the lack of water in this region, while this will be one of the main impacts of climate change on the region.

The release of the Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC) highlights the progress that has been made in understanding uncertainties related to global climate change, mainly due to the improvement of models and the expansion of datasets and data analyses (IPCC, 2007a). Although there has been an improvement in understanding projected rainfall patterns at a regional scale, uncertainties remain at the local scale (IPCC, 2007a). Five different models[2] simulated two scenarios of high and low emissions in the Third Assessment Report (TAR) suggesting a tendency of warming for the Northeast region of Brazil, but no consensus regarding precipitation trends has yet been reached (IPCC, 2001b). The HadCM3 model presents a considerable interannual variability and simulates severe El Niño events, suggesting a decrease in precipitation for the Northeast region, while the GFDL model indicates a positive anomaly for rainfall in the same area (Marengo, 2007). It has still not been possible to establish reliable scenarios for hydrological regimes at local scale, promoting public policies that mitigate vulnerabilities and seek for adaptation measures to climate change (Marengo, in NAE, 2005).

Recent studies have been developed aimed at recognizing observational climate trends and characterizing the climate of the twentieth century, its variability and tendencies (Marengo, 2007). Observational analyses indicate interdecadal variability for periods of approximately 25 to 30 years in the region, but neither an increase nor a decrease in rainfall trends has yet been identified (Marengo et al., 2007). Some evidence points to a possible increase in average and extreme temperatures in Brazil, in relation to both annual and seasonal values (Marengo et al., 2007). A slight increase in long term rainfall has been observed in the Northeast, but the trend is not statistically significant (Marengo, 2007).

In relation to continental scale rainfall projections for 2071 – 2100, the figures from the Northeast region are the most reliable, and it can be stated with medium or high confidence that there will be a rainfall reduction in this region. The annual hydric deficiency of the Northeast, which occurs during the months of drought, may last for almost the whole year according to studies carried out using hydric balance simulations for all Brazilian regions. As a result there will be a substantial worsening of Figure 1, indicating a tendency towards the 'aridization' of the semi-arid region at the end of the twenty-first century. The possible impact of climate change will be felt by regional subsistence agriculture, causing the population to migrate to larger cities (Marengo et al., 2007).

El Niño impacts have also been observed in the country, especially in the Northeast region where dry conditions are strengthened during the event (Freitas, 1999). El Niño is characterized by the increase in the sea surface temperature (SST) of the west and central Tropical Pacific Ocean (Marengo, 2007). Changes in SST have been linked to droughts. Interannual variability of SST and wind over the Tropical Atlantic immensely affect climate variability over South America at a global level, including the Amazon, and the South, Southeast and Northeast regions of Brazil (Marengo, 2007). If the frequency or intensity of El Niño increases in the future, the country may be exposed more frequently to droughts and floods (Marengo, 2007), which might affect local production negatively, mainly in subsistence sectors (IPCC, 2007b).

Poor farmers, such as those involved in subsistence farming in the Northeast semi-arid region, will be the group most vulnerable to climate change if a combination of projections of increased temperatures, a reduction in rainfall and an increase in evaporation rates are proved correct (Marengo et al., 2007).

All global climate models indicate warming at the regional level, while the rate of heating varies according to the model used. The average warming rate in 2100, calculated using six IPCC TAR models, points to an increase of temperature in the Northeast between 2.2 and 4ºC, depending on the emission scenario used (Marengo et al., 2007). Increases in temperature of this magnitude are worrying, irrespective of what happens in relation to rainfall, since it favors the evaporation of lakes, dams and reservoirs (Marengo, in NAE, 2005). A pessimistic temperature scenario that considers a 4ºC increase for the Northeast, even when combined with a 15% increase in rainfall, will result in hydric deficits throughout the year, due to evaporation, making the region inappropriate for dryland agriculture (Marengo, in NAE, 2005).

4. Biodiesel Production and Use as an Adaptation and Mitigation (Ad-Mit) Strategy

In the semi-arid Northeast, marked by the low level of socio-economic development, agricultural activities represent the means of survival for a large part of the population. The agricultural sector plays a strategic role in the social, economic and political universe of the Northeast. This sector is dynamic and very heterogeneous, with the process of technological modernization having taking place very rapidly in some regions. Nonetheless, traditional family agriculture still predominates, mostly practiced by low-income farmers (Leite et al., 2006).

The planting of vegetable oils crops by family farmers in the semi-arid region for the production of biodiesel may reduce the vulnerability of this population to climate change, as an income and job generation activity. Vegetable oils crops that are potentially suited to planting by family farmers in dry areas include peanuts (*Arachis hypogaea*), sesame (*Sesamum indicum*), sunflower (*Helianthus annuus*), cotton (*Gossypium hirsutum*), castor oil (*Ricinus communis) and* purging nut (*Jatropha curcas)*. All these crops with the exception of sunflower can be planted alongside subsistence crops such as beans and corn. All these crops have available genetic material (seeds), adapted to temperature and precipitation comditions in the semi-arid region, both the current ones and those projected due to future climate change. They have good oil content (around 50%), with appropriate physical-chemical conditions for biodiesel production, and can be manually cultivated. Therefore, they meet pre-feasibility requirements to be adopted by family farmers in teh semi-arid region, as an option for diversifying their crops, increasing their resilience and income generation prospects (see Table 1). Peanuts, cotton and castor oil have a climatic risk zoning, with an indication of the best time for planting. Table 2 gives an estimate of crop productivity, oil content, oil productivity and the area required to produce a ton of oil for the selected crops. The minimum productivity considered for cotton, castor oil and sunflower is the average crop return obtained in the Northeast in 2005 (IBGE/PAM, 2005). For palm oil the average crop productivity in Bahia for the 2004 harvest (IBGE, 2004) was used. The maximum productivity refers to the genetic potential of the varieties developed by the Brazilian Agricultural Research Company (EMBRAPA) for Northeast climatic and soil conditions, with a minimum water availability of 600 mm/year. The choice of vegetable oil species suitable to dry land cultivation is fundamental taking into account the climatic vulnerability of this region, climate change projections, and the socio-economic vulnerability of family farmers.

Cotton and sesame have the lowest oil productivity amongst the crops evaluated. The potential return of oil in relation to area serves to illustrate the amount of land that needs to be used to produce a ton of oil. The oil obtained from cotton, castor oil, sunflower and sesame requires a greater area of production per ton of oil, while palm oil and peanuts require a maximum of two hectares.

Large production areas are generally associated with a higher degree of agricultural mechanization, greater transformation of land and degradation of the soil through the use of heavy equipment and a lower possibility for family farming. Temporary crops such as peanuts, sunflower, castor oil and sesame allow shared cultivation, crop rotation and a greater use of land, which is indicated for the large majority of family properties in the semi-arid region. Subsistence production is fundamental and monoculture is not a viable option for the regional family based agricultural system. The growing of staple food such as beans, corn and fruits is associated with the raising of a small number of animals. According to INCRA/FAO (2000), the number of farmers with access to technical assistance is very low in the Northeast, while more than 80% of family farms use either animal (20.6%) or manual labor (61.1%).

Table 1. Range of Temperature)(oC), Range of precipitation (mm/year) and Oil Productivity (ton/ha) for peanuts, cotton, castor oil, sumflower and seasame in the conditions of the semi-arid Northeast.

	Crop Productivity		Oil Content	Oil Productivity	Use of land
	(Kg/ha)	(%)	(Kg/ha)	(ha/ton)	
	Minimum	Maximum			
Peanuts	1337	1700	40- 43	535- 731	1.9
Cotton	400	2200	15	60 - 330	17
Castor oil	700	1500	45- 50	315- 750	3.2
Sunflower	800	1500	30 -50	240- 750	4.2
Palm oil	4000	6000	16 -22	640-1320	1.6
Sesame	300	1500	48- 58	144- 870	6.9

Source: Brasil, 2005.

In 2003, the Brazilian government created the National Program for Biodiesel Production and Use (PNPB), which set the minimum percentages for the biodiesel blend used in the diesel oil. It stated that between 2005 and 2007 the use of B2 (2% biodiesel and 98% diesel) would be optional. From 2008 to 2012 the addition of 2% of biodiesel to diesel will become mandatory and from 2013 on, B5 (5% biodiesel and 95% diesel) must be used.

The PNPB encourages the sustainable production of biodiesel in Brazil, trying to promote social development. The use of the Social Fuel Certificate launched by the Federal Government is an attempt to encourage the creation of employment and to include family agriculture in the biodiesel production chain. Companies that produce biodiesel and meet specified social conditions can have access to better funding conditions from the Brazilian Social and Economic Development Bank (BNDES) and other financial institutions, and may also take part in biodiesel auctions organized by the Federal Regulatory Agency for Oil and Biofuels (ANP). Production industries that acquire raw materials from family farmers and guarantee pre-established prices will also be entitled to a waiver of some taxes.

The demand for vegetable oils increased considerably in Brazil after 2003 due to the launch of PNPB, and will reach around 840 million liters of biodiesel from 2008 on. The government expects that part of this demand will be met through the supply of raw material by family farmers in the North and Northeast of the country. This goal is supported by the state governments in the Northeast region, which try to encourage social and regional development

Biodiesel is a renewable fuel, since the emission of carbon dioxide from the burning of the fuel is reabsorbed in the new harvest planted, and it can replace diesel oil in all its uses, reducing the emission of Greenhouse Gases (GHG). Biodiesel is the methyl or ethyl esther obtained through the reaction of vegetable oils, with an alcohol and a catalyst, a process known as transestherification. In Brazil, methanol (methyl alcohol) is used as reagent, since the reaction with methanol is a well known technology, while the use of ethanol is a innovative process still being tested. In the use of biodiesel, the GHG emissions caused by the use of methanol must be accounted for, as it is produced from natural gas. Besides reducing 78% of CO_2 emissions, the use of biodiesel reduces sulphur and particle material emissions between 98% and 50%, respectively, when compared to those of diesel oil (Brasil, 2003).

As part of PNPB, tax incentives stimulate the production of vegetable oils by family agriculture, especially in the North and Northeast regions. Production companies will have the right to exemptions from the PIS and COFINS levies[3] by guaranteeing the purchase of raw material from family farmers at pre-established prices. The reduction of these taxes reaches 100% if the biodiesel produced uses castor oil planted by family farmers in the Northeast region. Another form of support for the generation of employment and the insertion of family farming in the biodiesel productive chain is the concession of the SCS label. This is given to biodiesel producers who include commercial conditions in contracts that guarantee income and payment periods compatible with family farmers, as well as providing technical assistance and training. Biodiesel companies that obtain the SCS label will be granted access to better financing conditions from other financial institutions, as well as being able to participate in biodiesel auctions held by the National Agency for Oil, Gas and Bio-Fuels (ANP). These auctions are aimed at stimulating investments in the production chain and securing a market for the sale of biodiesel. This tool is helping the start-up of the program and tries to promote the insertion of family farms in the supply of raw materials (Gomide, 2006). The volume of biodiesel acquired in the five auctions already held by the government has surpassed 840 million liters.

The production of biodiesel allows the prospect of the organization of a local productive chain capable of stimulating economic and social development. Vegetable oil can be considered to be a cash crop, since it is a product that can be sold, with liquidity in the market. Furthermore, the planting of vegetable oils is associated to the encouragement of new productive systems to be adopted by small farmers. The producers may also have access to agricultural raw materials, soft loans and family consumption goods. The strengthening of the regional economy through the increase of the income of family farmers, combined with the diversification of agricultural production, illustrates the potential of biodiesel production as a strategy for climate change adaptation.

On the mitigation side, climate change renews the urgency for stimulating viable options for energy production from biomass and sustainable land use policies (Beg et al., 2002). Biodiesel production from renewable vegetable oils allows for 78% reduction of CO_2 emissions from replaced diesel oil, and is thus a promising strategy for climate change mitigation.

5. Barriers to the implementation of biodiesel production and use as an Ad-Mit strategy

The biodiesel production chain needs to be well structured starting from the first stages of production in order to guarantee that this market can be consolidated in Brazil. Recently the SCS of Soyminas, which participated in the first auction and which has an authorized production capacity of 12 million liters of biodiesel, was cancelled by the Ministry of Agrarian Development. Based in Minas Gerais, the company was the first biodiesel plant to receive the SCS, but it lost this label since it did not use raw materials produced by family farming and also for using a percentage lower than required by the legislation. The volume negotiated in ANP auctions provides a false impression that the demand created by the government will be easily met by production based on family farming. In fact, the PNPB biodiesel production targets are being met thanks to the low price of soybean oil in the international market. In 2006, 90% of biodiesel production in Brazil was based on soybean oil, which is based on soybean crop, produced in large plantation schemes.

Economic limitations of small family farmers are evidenced by restricted access to machinery and work equipment, capital constraints and high environment liability, such as soil depletion. Small farmers play a subordinate role in the production chain, providing raw material, but with no possibilities of aggregating value. In addition, institutional isolation characterized by low institutional density and inadequate functioning requires the organization of a solid support program to overcome these barriers.

Petrobras – the state-owned corporation operating in the oil, gas and energy industries, and the largest company in the country – is being used by the government as a tool to overcome these barriers. Petrobras has been developing technological research in biodiesel production at a pilot plant in Guamaré (Rio Grande do Norte state) and will set up three commercial scale biodiesel production plants in Candeias (Bahia), Montes Claros (Minas Gerais) and Quixadá (Ceará). Petrobras will thus enter the biodiesel market in Brazil and, at the same time, contribute to the sustainable development of family farming in the municipalities surrounding these three localities. Field research carried out by the project has confirmed the existence of institutional vulnerability in these areas. Encouragement of cooperatives is crucial, since very few family farming establishments are organized in associations and cooperatives. Productive process organization and the insertion of small farmers in the biodiesel market are both related to meeting the needs of these families, and therefore are dependent on established social relations. Agriculture represents not only an economic activity, but also an essential element that delineates the social identity of the farmer and his family. The child labor issue clearly illustrates it.

Different local stakeholders have diverse opinions regarding child labor, which raises a complicated issue to be addressed in vegetable oil supply contracts. Sometimes, small farmers' children have a negative view of farming and prefer to move to larger centres, creating social identity problems and putting at risk family farming sustainability. Research carried out in 2001 revealed that 34.8% of children and adolescents in the Northeast aged between 5 and 17 did not attend school, either because of their own choice, or that of their parents or guardians, while 78.7% of those working in agriculture are satisfied with the work (IBGE, 2007). In 2001, approximately 221,000 children and adolescents between 5 and 17 were working and did not attend school in the rural Northeast (IBGE, 2007). In the project carried out by Petrobras, the contracts signed included a clause prohibiting the inclusion of children in agricultural labor, emphasizing the need for them to frequent school. Nonetheless, this measure by itself is not enough to guarantee that child labor will be eradicated, since huge monitoring and inspection difficulties remain.

A fundamental aspect that needs to be addressed is the reluctance of farmers to plant vegetable oil crops due to unsuccessful past experiences. If farmers do not believe that they will be able to sell their crop at a reasonable price, they will not agree to plant and the whole biodiesel production process will be compromised. In the castor bean case, difficulties in identifying potential buyers and ascertaining the level at which prices will be set contribute to diminish farmers expectations. Seeds planted by family farmers ought to be of good quality and adequate agricultural practices must be adopted, assuring oil seed supply.

The productivity obtained varies substantially within the semi-arid region. Differences are mainly due to soil quality, agricultural practices, seed quality and, above all, the scheduling of planting. The best time for planting in the semi-arid region is at the beginning of the rainy season, which can vary from November to January because of climatic micro-regions. Delays in seed delivery postpone planting, causing productivity to decline severely. Although most recent studies indicate productivity varying between 1,000 kg/ha and 1,500 kg/ha, average historical Brazilian productivity, calculated since 1976, does not reach even 600 kg/ha (CONAB, 2007). Increased productivity may be obtained through technological advances, which are hardly ever implemented in rural areas. Soil restoration is also crucial for the ecological equilibrium of production. If there is no improvement in soil quality, low productivity will stimulate farmers to plant elsewhere, expanding the total area utilized. Environmental impacts caused by vegetable oil crops are still not fully understood, but the excessive use of new areas might rapidly reduce productivity, leading to deforestation.

Brazilian castor bean production estimates from CONAB (2007) for the harvest of 2005/2006 suggest a decrease of approximately 50%, to 103,9 thousand ton, compared to the previous year, because of commercialization difficulties and lack of access to credit. Cotton and peanuts forecasts also indicate a production decline for the same period (CONAB, 2007). The expansion of credit programs and increase in volume of resources allocated to these programs have still not resulted in adequate access to credit. Not only do poorer farmers have fewer financial agents to deal with, but a lack of valid guarantees and systematic delays regarding announced government resources for programs have imposed limits on finance (Bittencourt and Abramovay, 2003). Although federal public banks are still significantly involved in providing rural credit, their contribution has decreased approximately 50% over the last few years (Bittencourt, 2003).

Furthermore, the social conduct of some companies that have already obtained the SCS label can be questioned. Agricultural production systems have been implemented by companies with the objective of guaranteeing independence of the vegetable oil commodities market. Brasil Ecodiesel, for instance, has created community production centres, aiming to foster small family farmers' development, offering them school, medical assistance and commercial centres. The Santa Clara Community Production Centre, located in Canto do Buriti (Piauí), is an example of the company's strategy. It is responsible for castor bean seed supply for biodiesel production, but it has been constantly accused of mistreating workers. Press statements have attributed several irregularities to this centre concerning work conditions offered to farmers (Brasil Ecodiesel, 2007).

Biodiesel produced from castor bean oil has to overcome economic and technological obstacles, such as oil viscosity. Costs associated with raw materials and biodiesel production represent one of the main barriers to the commercialization of biodiesel, since they are responsible for making final prices extremely high (Lima, 2004). High castor bean opportunity costs have led some biodiesel companies to export castor oil and produce biodiesel using soy oil. Brazil Ecodiesel, which has already obtained the SCS label and which has actively participated in the biodiesel auctions, is said to be producing biodiesel from soybean oil and selling castor oil for non-energy uses (the international market for castor oil as a lubricant offers very attractive prices). The export price of castor oil has been historically higher than soy oil prices, establishing comparative advantages for biodiesel produced from soy (Das Neves et al, 2006). In addition, transportation costs are lower in the soybean production chain (La Rovere et al, forthcoming). SCS is still obtained, since castor beans are purchased from small family farmers in the Northeast. However, extracted castor oil is worth much more as an export commodity than a raw material for biodiesel production. Farmers who have planted castor bean to sell to biodiesel producers and have no access to alternative commercialization mechanisms can face difficulties in the future.

6. Policy tools to overcome the barriers to biodiesel production as an Ad-Mit strategy

The insertion of small family farmers in the biodiesel production chain is characterized by a productive pattern of low productivity, deficient environment sustainability and low financial return. Barriers have been identified throughout the whole production chain, from crop to biofuel, showing that a strong governmental policy is needed to structure the biodiesel chain so that PNPB social development targets can be met. Small semi-arid farmers lack basic technical conditions crucial to production development, such as work equipment, electric energy and access to water. Credit programs aimed at promoting vegetable oil production that actually reach small farmers, could provide a starting point for fostering investment to facilitate the sustainable development of the biodiesel production from small farmers in Brazil.

Despite the efforts made so far, in most parts of the semi-arid region small farmers are continuing with their regular activities and acting conservatively, as they are still not convinced about the effectiveness of the PNPB. If the uncertainties related to commercialization are not dealt with, lack of confidence will make supply for biodiesel production one of the most important obstacles to deal with. The organization of small family farmers through associations and cooperatives could help structure agricultural production, reducing risks faced by farmers and encouraging them to actively participate in the PNPB. Diversified production and alternative income sources could allow farmers to take the risks of planting a new crop, but subsistence farmers tend to behave as risk-adverse individuals (FACT Foundation, 2006). Furthermore, small farmers need to adequately organize themselves through new associations and cooperatives in order to fill institutional gaps and meet biodiesel producers' demands. Besides that, the articulation of the institutions already created is highly important. According to DIEESE (2006), approximately 43% of rural workers unions are located in the Northeast, the highest regional percentage, which suggests that the creation of new associations in the Northeast is not enough in itself, but that the absence of articulation also needs to be dealt with. Farmers may experience solid economic growth once they learn about the market they are engaged in, playing a much important role than mere producers in the biodiesel chain (Abramovay, 1999). Therefore, technical assistance and capacity building should be provided so that the insertion of small farmers can be self-sustained.

The usually observed productive schemes consisted of commitments between farmers and biodiesel producers. Small farmers guaranteed to sell their entire crop, reaching productivity targets by hectare, for pre-set prices in exchange for goods and services such as certified seeds, technical assistance, capacity building and basic tools for planting. This type of contract tends to cause conflicts instead of establishing partnerships between stakeholders. Growing indebtedness is likely to be followed by unilateral disruption once other purchasers offer small farmers higher prices. Similar schemes have been implemented in other parts of the country, in the pig and poultry sectors in the south and milk and fruit production in the Northeast. Leader companies that commit themselves to purchase oil seeds from small farmers act as a guarantee for the governmental Empowerment Family Farming National Program (PRONAF) soft loan.

PRONAF promotes rural development through two main approaches, one for infra-structure and services and another for family farming. The first focuses on municipalities and provides financial resources that must be used in accordance with the municipal rural development plan, but the results observed have been extremely diverse. Farmers that benefited from the second approach belong to the family farming category, but the resources are particularly concentrated in the south of Brazil and especially among farmers connected to agribusiness. Although PRONAF has produced an institutional environment that amplifies the social basis of the national credit policy, the outcome is still timid (Abramovay and Veiga, 1999). PRONAF has permitted many family farmers to gain access to credit, but both the Federal Government and social organizations agree that the banking system is an obstacle to the enlargement of the social basis of the Program since farmers have no guarantees to offer (Bittencourt and Abramovay, 2003).

Contracts set up between farmers and potential vegetable oil seed purchasers are based on the use of large capacity presses. Pressing oil concentration in centralized industrial units will benefit large purchasers of the oil *in natura* instead of the small farmers, who will become vulnerable to market price ups and downs. In the medium term, indebted small farmers will be obliged to sell their property and move to large urban centres, as happened under the Brazilian program of alcohol production used to fuel vehicles. Moreover, decentralized and small capacity crushing units could facilitate the usage of by-products as fertilizers and animal food. Buying and price guarantees can be given once there is an economically viable pressing facility operating. This can only be possible if the necessary production volume is supplied.

In contrast, soybean production chain in Brazil is already structured, logistics are implemented and large volumes are produced. Market forces imply that biodiesel production supported by soy agribusiness would be economically advantageous; nevertheless, the social benefits would be severely compromised. Brazil is the second world major soybean producer and increasing biodiesel demand could induce soy plantations expansion in the country. In this case, the PNPB incentives to include small farmers in the biodiesel market could be insufficient to guarantee social benefits to the semi-arid rural population. Furthermore, environmental benefits of the use of biodiesel as a fuel may be balanced by the expansion of soy plantations towards the Amazon region with the risk of inducing deforestation.

On the other hand, the recent decision by the U.S. administration of supporting U.S. production of ethanol from corn has led to an increase of corn and soybean prices in the international market. In the future, if soybean prices go up again, biodiesel production from soy oil may loose its cost effectiveness, depending on the evolution of oil prices. The economic prospects for alternative vegetable oil crops, such as the purging nut, may be more promising as feedstocks for biodiesel production in the medium and long term. A lot of agronomical research is still needed in this field, as there is very little experience of cultivating this crop in Brazil. Preliminary results from Petrobras technological research also suggests that there is room for many improvements in biodiesel production technology, including the use of alternative feedstocks such as the direct production from seeds, as well the use of byproducts, which may lead to lower production costs.

7. Conclusion

In summary, biodiesel production from vegetable oils by small farmers in the semi-arid region of Brazilian Northeast certainly presents a great potential for simultaneously promoting climate change adaptation and mitigation, and illustrates a good case for the Ad-Mit approach. However, overcoming the barriers to tap this potential is a challenge that cannot be underestimated, and will require not only technological research efforts but also additional policies and measures designed to this end.

8. Notes

1. INCRA/FAO's (2000) definition of family farming is based on the management of the productive unit, which must be carried out by individuals with marital or blood ties between them. In addition, most labor must also be supplied by family members and the ownership of the means of production, though not always the land, should belong to the family. The classification of family farmers on the basis of their social relations of production seeks to overcome the tendency to stipulate a maximum area of land or a production value for the family establishment, in order to avoid a mistaken association with low production levels.

2. Further details regarding the AOGCMs (Atmosphere-Ocean General Circulation Models) utilized by TAR can be found in IPCC (2001a).

3. PIS (the Social Integration Program - Programa de Integração Social) - is a social contribution paid by companies with the aim of financing the payment of unemployment insurance and bonuses for workers who earn up to two minimum salaries. COFINS (the Social Security Financing Contribution - Contribuição para o Financiamento da Seguridade Social) is a federal levy incurred on the gross revenue of companies in general, aimed at financing social security. These taxes correspond to R$217.97 per cubic meter of biodiesel produced.

9. References

Abramovay R (1999) Agricultura familiar e desenvolvimento territorial. Revista da Associação Brasileira de Reforma Agrária, vols.28, nos. 1,2,3 e 29, no. 1. Jan/Dez 1998 e Jan/Ago 1999.

Abramovay R, Veiga J E da (1999) Novas Instituições para o Desenvolvimento Rural: o caso do Programa Nacional de Fortalecimento da Agricultura Familiar (PRONAF). Texto para discussão no 641. Convênio FIPE/IPEA. Brasília.

ANA – Agência Nacional de águas (2004) Projeto PróÁgua Semi-Árido: Elaboração do Atlas de Obras Prioritárias para a Região Semi-Árida: RP – 03 – Balanço Oferta – Demanda nos Horizontes Considerados. Parte A – Estudos de Demandas. Superintendência de Recursos Hídricos. Brasília, DF. 111pp.

ANA – Agência Nacional de águas (2006) Atlas Nordeste: Abastecimento Urbano de Água. Superintendência de Recursos Hídricos. Brasília, DF, 83pp.

Beg N, Morlot J C, Davidson O, Afrane-Okesse Y, Tyani L, Denton F, Sokona Y, Thomas J P, La Rovere E L, Parikh J K, Parikh K, Rahman A A (2002) Linkages between climate change and sustainable development. Global Environmental Change 12: 25–40

BiodieselBR (2007). http://www.biodieselbr.com. Cited 08 May 2007

Bittencourt G A (2003) Abrindo a Caixa Preta: O Financiamento da Agricultura Familiar no Brasil. Master's Thesis. Universidade Estadual de Campinas. Campinas, São Paulo. 243 pag.

Bittencourt G A, Abramovay R (2003) Inovações Institucionais no financiamento à agricultura familiar: o Cresol. Revista Economia Ensaios, vol.16, no 1: at press.

BRASIL. Casa Civil da Presidência da República. Grupo de Trabalho Interministerial – GTI (2003) Relatório Final – Anexo III. Brasília: imprensa oficial. 32 p.

BRASIL. Presidência da República (2005) Biocombustíveis. Núcleo de Assuntos Estratégicos da Presidência da República. Cadernos NAE, Brasília, n. 2.

http://www.planalto.gov.br/secom/nae.

Brasil Ecodiesel (2007). http://www.brasilecodiesel.com.br/en/quemsomos/divaagricola. Cited April 2007

De Carvalho O, dos Santos A J (2003) Contribuição da "Nova Sudene" para o Desenvolvimento da Região Semi-Árida do Nordeste. Relatório Final, Recife, PE

CONAB – Companhia Nacional de Abastecimento (2007). http://www.conab.gov.br/conabweb/index.php?PAG=131. Cited April 2007

Diaconia (1999) Articulação no Semi-Árido Brasileiro: Programa de Formação e Mobilização Social para a Convivência com o Semi-Árido: Um milhão de Cisternas Rurais (P1MC). Anexo II do Acordo de Cooperação Técnica e Financeira celebrado entre FEBRABAN e APIMC.

DIEESE – Departamento Intersindical de Estatística e Estudos Socioeconômicos; Núcleo de Estudos Agrários e Desenvolvimento Rural (2006) Estatísticas do Meio Rural. MDA. São Paulo.

FACT Foundation – Fuels from Agriculture in Communal Technology (2006). Jatropha Handbook – First Draft. 45 pag. Available at: www.fact-fuels.org. Accessed in April, 2007.

FAO - INCRA (1996) Perfil da agricultura familiar no Brasil: dossiê estatístico. FAO - INCRA, Brasília.

Freitas M A V (1999) O Estado das Águas no Brasil. Perspectivas de gestão e informação de recursos hídricos. Agência Nacional de Energia Elétrica – ANEEL. Sindicato Nacional do editores de Livros. Rio de Janeiro. 334 p.

Gomes Filho, J F (2003) Crianças e Adolescentes no Semi-Árido Brasileiro 2003. Recife: Unicef. 80 pg. Available at: www.unicef.org/brazil/SA2003_parte1.pdf.

Gomide, R B (2006) Programa Nacional de Produção e Uso do Biodiesel. Ministério de Minas e Energia – Departamento de Combustíveis Renováveis. Brasília, Distrito Federal.

IBGE - Instituto Brasileiro de Geografia e Estatística (2000). Indicadores Sociais Mínimos (2000). Aspectos Demográficos. Fonte: IBGE/DPE/Departamento de Populações e Indicadores Sociais. Divisão de Estatutos e Análises da Dinâmica Demográfica. Projeto UNFPA/BRASIL (BRA/98/P08). Sistema Integrado de Projeções e Estimativas Populacionais e Indicadores Sócio Demográficos. Instituto Brasileiro de Geografia e Estatística, Rio de

Janeiro, RJ, Brazil.

IBGE - Instituto Brasileiro de Geografia e Estatística (2004) Síntese de Indicadores Sociais Available via http://www.ibge.gov.br/home/estatistica/populacao/condicaodevida/indicadoresmi nimos/sinteseindicsociais2004/

IBGE – Instituto Brasileiro de Geografia e Estatística (2006) Contas Nacionais: Produto Interno Bruto dos Municípios 2004. no 18. Diretoria de Pesquisas, Coordenação de Contas Nacionais. Ministério do Planejamento, Orçamento e Gestão. Rio de Janeiro.

IBGE - Instituto Brasileiro de Geografia e Estatística / PAM - Pesquisa Agrícola Municipal (2006) Cereais, Leguminosas e Oleaginosas 2005. Rio de Janeiro.

IBGE – Instituto Brasileiro de Geografia e Estatística (2007) Diretoria de Pesquisas, Departamento de Emprego e Rendimento. Pesquisa Nacional por Amostra de Domicílios 2001. Rio de Janeiro. Available via

http://www.ibge.gov.br/home/estatistica/populacao/condicaodevida/trabalho_infantil/default.shtm. Cited 08 May 2007.

INCRA/FAO – Instituto Nacional de Colonização e Reforma Agrária (2000) Novo Retrato da Agricultura familiar. O Brasil redescoberto. Brasília – DF: Ministério do Desenvolvimento Agrário/INCRA. 76p

IPCC - Intergovernmental Panel on Climate Change (2001a) Climate Change 2001: The Science Basis. Working Group I. TAR. Cambridge Univ. Press.

IPCC - Intergovernmental Panel on Climate Change (2001b) Climate Change 2001: Impacts, Adaptation and Vulnerability. Working Group II. TAR.

IPCC - Intergovernmental Panel on Climate Change (2007a) Climate Change 2007: The Physical Science Basis. Working Group I. AR: Summary for Policymakers.

IPCC - Intergovernmental Panel on Climate Change (2007b) Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Working Group II. AR4: Summary for Policymakers.

Moteiro, JMG (2007). Planting of Vegetable Oil Crops by Family Farmers in the Semi-Arid Northeast for the Production of Bio-Diesel as a Strategy for Adaptation and Mitigation on Climatic change. Thesis Doctor of Science (DSc). Advisor: Emilio Lebre La Rovere. PPE/COPPE/UFRJ. Rio de Janeiro. RJ. 302p.

La Rovere E L, Monteiro J, Avzaradel, A C. (forthcoming) Development and Climate Change Adaptation and Mitigation Impacts of Bioenergy Plantations in Brazil. Climate Policy.

La Rovere E L, Pereira A S, Simões A F (2006) Biofuels and Sustainable Energy Development in Brazil. World Development, (forthcoming).

Leite S P, Cintrão R, Lasa C (2006) O Meio Rural Baiano como Espaço Privilegiado de Políticas Públicas: uma análise do contexto institucional e do financiamento das políticas rurais. Convênio SEPLAN – BA e REDES/CPDA-UFRRJ.

Marengo J (2005) Vulnerabilidade da agricultura do semi-árido à variabilidade natural e a mudanças climáticas. In: NAE/Núcleo de Assuntos Estratégicos da Presidência da República – nº 3, Fevereiro – Brasília: Núcleo de Assuntos Estratégicos da Presidência da República. Secretaria de Comunicação de Governo e Gestão Estratégica.

Marengo J A (2007) Caracterização do Clima no Século XX e Cenários no Brasil e na América do Sul para o Século XXI derivados dos Modelos de Clima do IPCC – Relatório no1. MMA/SBF/DCBio.

Marengo J A (2001) Impactos das Condições Climáticas e da Variabilidade e Mudanças do Clima sobre a Produção e os Preços Agrícolas: Ondas de Frio e seu Impacto sobre a cafeicultura nas Regiões Sul e Sudeste do Brasil. In: Lima M A de, Cabral O M R, Miguez J D G (Eds.). Mudanças Climáticas Globais e a Agropecuária Brasileira. Embrapa Meio Ambiente, Jaguariúna, SP. pp. 97-123.

Marengo J A, Nobre C A, Salati E et al (2007) Mudanças Climáticas Globais e Efeitos sobre a Biodiversidade: Caracterização do Clima Atual e Definição das Alterações Climáticas para o Território Brasileiro ao longo do Século XXI – Sumário Técnico. MMA/SBF/DCBio.

MI - Ministério da Integração Nacional (2003) Bases para a Recriação da Sudene por uma Política de Desenvolvimento Sustentável para o Nordeste. Secretaria de Políticas de Desenvolvimento Regional, Grupo de Trabalho Interministerial para a Recriação da Sudene. http://www.integração.gov.br. Cited April 2007

Obregón G, Marengo J A (2007) Mudanças Climáticas Globais e Efeitos sobre a Biodiversidade: Caracterização do Clima no Século XX no Brasil: Tendências de Chuvas e Temperaturas Médias e Extremas – Relatório no 2. MMA/SBF/DCBio.

Oliveira J de C, Albuquerque F R P de C, Senna J R X (2006) Breves notas sobre a mortalidade no Brasil no período 2000-2005. Diretoria de Pesquisas, Coordenação de População e Indicadores Sociais. IBGE – Instituto Brasileiro de Geografia e Estatística. Rio de Janeiro.

UNDP- United Nations Development Program (2002) Atlas do Desenvolvimento Humano no Brasil (IDH-M) 1991 – 2000. http://www.pnud.org.br/atlas/oque/index.php. Cited April 2007

UNDP – United Nations Development Program (2006) Relatório do Desenvolvimento Humano 2006: A água pra lá da escassez: poder, pobreza e a crise mundial da água.

PROCLIMA – Programa de Monitoramento Climático em Tempo Real da Região Nordeste (2007). http://www.cptec.inpe.br/proclima. Cited April 2007

Rebouças A C (2003) A Sede Zero. Revista Ciência e Cultura out/dez.2003, vol. 55, no 4, p. 33-35. http://www.cienciaecultura.bvs.pdf/cic/v55n4.pdf. Cited April 2007.

Application of an Integrated Assessment & Action Methodology for Sustainable Development to Addressing Climate Change: a Fiji Perspective

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Abstract

Climate change [1](CC) is already affecting the economic and livelihood sources of Pacific Islanders. The interaction of climatic factors with those attributed by economic and basic livelihood induced activities often complicate the assessment of climate change impacts. Therefore it is imperative that vulnerability assessments and adaptation initiatives for rural communities on the outset should take on an integrated approach to capture these interactions.

The paper discusses the application of an integrated assessment and action methodology for sustainable development, developed by the Pacific Centre for Environment & Sustainable Development (PACE-SD) in collaboration with the Institute of Applied Sciences (IAS) of the University of the South Pacific (USP). It uses a simplified integrated vulnerability and adaptation assessment methodology, piloted for six rural communities in Fiji. The method assesses the vulnerability of communities from three types of stresses, viz. environmental, social and economic induced stresses.

The use of the methodology is prompted by three underlying principles. The first one is that climate change induced stress is interlinked to social, environmental and economic induced stresses. The second principle is that meaningful adaptation measures to address both current and future vulnerabilities of communities should be carried out in the context of sustainable development. The third is that in advocating adaptation to climate change for rural communities, it is important to note that the success and sustainability of projects will greatly depend on the understanding, participation and commitment of rural communities. The crucial element in this is their understanding and acceptance of the perceived flow-on benefit of any proposed projects to the improvement of their basic livelihood both in the short and long term. Therefore, their involvement and participation, through proper guidance, within an integrated assessment framework, in identifying problems and opportunities and prioritizing adaptive measures are of utmost importance.

It is envisaged that the method can be modified and tailored to other issues besides climate change requiring integrated assessment before action, and could be transferable to other Pacific Island Countries (PICs), and beyond.

1.0 Introduction

The stress induced by present climate variations and future climate change on rural communities and their key livelihood sectors such as agriculture and ecosystems, such as watershed and coastal zone is additional to the stresses caused by non-climatic factors such as rapid coastal developments, land-based pollution, haphazard farming practices and deforestation. The interactions between the biophysical, social and economic systems coupled with local climate variations are rather complex. Therefore it is imperative that vulnerability assessments and adaptation initiatives for rural communities on the outset should take on an integrated approach to capture these complex interactions.

In 2006, USP and the Fiji Department of Environment secured funding from the Australian Agency for International Development (AusAID) to implement a pilot project on CC adaptation in six rural communities focusing on the coastal zone and its ecosystems and water resources. The expected outcomes of this pilot project are (i) enhanced understanding of CC impacts and adaptation through community level planning and capacity building; and (ii) the improved resilience of the six communities to CC and climate variability (CV). In pursuit of the above outcomes, it became apparent that these rural communities must be provided with a tool/method for V&A assessment based on an integrated approach (considering both climatic and non-climatic factors) to adaptation planning and implementation. In addition, the method should be simple, but skillful in its ability to precisely elucidate the vulnerability of the sector in consideration to CC, ascertain the level of impacts, and point to the adaptation options that could be implemented.

2.0 Background

The intertwining of the physical aspects of CC with natural, socioeconomic and political systems, adds to the complexity of assessing the impacts of CC and the pertinent responses, even though there are established methods for vulnerability and adaptation (V&A) assessments. This challenge is underpinned by the specificity of adaptation, which are the actions or activities taken to accommodate, cope with, or benefit from, the impacts of climate change [1]. CC Adaptation is place-based and sector specific, for example, sea walls are commonly recommended to curb further coastal erosion; however, it has been shown that in some places, that the erection of seawalls accelerated erosion on adjacent beaches [2]. Furthermore, the lack of consideration given to the wave dynamics and storm surge characteristics often result in sea walls being overwhelmed. Often, the decision taken to construct the seawall is largely driven by copying what nearby villages may have done. Consequently, a V&A assessment must trigger specific considerations of the site under investigation, and this can only be done with the application of suitable V&A assessment methodology. Moreover, the outputs of the V&A assessment should be a guide for the identification of interventions and where necessary identify areas where extra assessments, data and information are required.

3.0 Rationale for the development of an applicable methodology

A number of V&A methodologies have been implemented in the Pacific Islands. There have been two approaches used thus far. The old approach (standard approach) is 'scenario driven', guided by such methodologies as the IPCC [3] and UNEP [4]. The new approach is 'development driven', such as the UNDP Adaptation Policy Frame-

1 The Intergovernmental Panel on Climate Change (IPCC) defined CC as any change in climate over time, whether due to natural variability or as result of human activity. CC is evidenced by the changes and rates of change in temperature, global, regional, and local patterns of temperature, precipitation, and sea level rise and changes in extreme climate events.

work [5]. This approach concentrates on current vulnerability in preparation for future possible impacts.

Within the "old approach" of V&A, a number of methods, tools and frameworks have been developed to assess climate variability and change. While some have been abandoned such as the US country studies methodology [6], some are still in use today. Some are still being refined to address some of their deficiencies whilst others have further evolved as off shoots of earlier versions. Two of the major concerns regarding these approaches and methodologies are their applicability and complexities in regards to community based assessments. Two of the probable underlying factors for these are: (i) the inability of the methods to properly elucidate the complexity of the climate change problem itself; and (ii) lack of or improper framework upon which these assessment methodologies have been based.

A number of these "old V&A" assessment methods have been applied in several PICs under regional projects such as PICCAP (Pacific Islands Climate Change Adaptation Project) and during the preparation of the first national communications of PICs under their obligations to the United Nations Framework Convention on Climate Change (UNFCCC). More recently, the Secretariat of the Pacific Regional Environment Programme (SPREP) and the WWF (South Pacific Programme) developed and piloted the Community Vulnerability and Adaptation Assessment and Action (CV&A) [7] and the WWF Climate Witness Toolkit [8] in a few communities with in the Pacific region respectively. Both methods share a commonality where emphasis was on community participation in the assessment and decision-making processes (using standard participatory rural appraisal/participatory learning and action methods) pertinent to climate change and other stressors. However, upon close examination, there are inherent "deficiencies" in the two methods. The CV&A methodology portray an inclination towards participatory approach in conducting V&A assessment and the overall V&A assessment, including hazard risk assessments and assessing adaptation options are treated in a relatively simplistic way. The WWF Climate Witness Toolkit lacked in-depth technical assessments of key climate change impacts and adaptation options pertinent to the sectors or communities in consideration.

.The third IPCC assessment report (2001) also highlighted that there were methodological gaps that remain concerning scales, data, validation, and integration. It stated that procedures for assessing regional and local vulnerability and long-term adaptation strategies require high resolution assessments, methodologies to link scales, and dynamic modeling that uses corresponding and new data sets. It acknowledged that adaptation models and vulnerability indices to prioritize adaptation options were at early stages of development in many fields and highlighted the need to improve methods that enable stakeholder participation in assessments.

The current trend now is that methods change as new ideas or research findings come to light, or paradigm shifts, such as the incorporation of sustainable development. Against the above developments in climate change V&A methods and their draw backs, this proposed integrated assessment and action methodology for sustainable development has been developed and applied to six rural communities in Fiji. The major thrusts of this work are: (i) to develop and pilot an integrated methodology of vulnerability and adaptation (development) assessment keeping in mind the sustainable development implications of the process and actions taken, (ii) ensure that local communities and project facilitators are equal partners in the V&A assessment process and (iii) the methodology remain simple and generic for application in climate change and other related areas.

4.0 The Integrated Assessment and Action Methodology

By definition, an integrated assessment is an interdisciplinary process that combines, interprets, and communicates knowledge from diverse scientific disciplines in an effort to investigate and understand causal relationships within and between complicated systems [1]. The method is called an Integrated Assessment & Action Methodology for Sustainable Development, with the acronym "I AAM for SD" or PACE-SD Methodology. This methodology has three inter-linked components, (i) integrated project cycle (see figure 1), (ii) procedural framework (see figure 2) and (iii) strategic adaptation framework (see figure 3). Imbedded within component 2 are various methods and tools which can be employed to assess the vulnerability and perform adaptation option analysis. The choice of methods and tools will depend on the available expertise, the socio-economic condition of the project community and prevailing physical status of the environment.

4.1 Integrated Project Cycle

Component 1 (see Figure 1) depict the 7 steps project cycle, which forms the basis of developing and implementing a project. Steps 1 and 2 are pre-project steps usually done in the development of the project. Table 1 summarizes the objectives and outputs of each step.

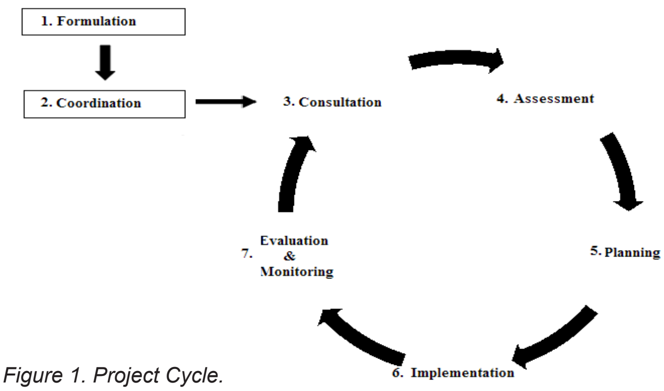

Figure 1. Project Cycle.

Table 1. Objectives of each of the seven steps of the integrated methodology

Steps	Objectives/Outputs
1. Formulation	Defines project objectives, policy context, scope & design.
2. Coordination	Management, coordination, facilitator team & advisory team set-up
3. Consultation	Initial community consultation, stakeholder involvement & participation
4. Assessment	Identification and characterization of hazards. Identification & characterization of exposure units with respect to vulnerability and resilience; Adaptation assessment (Assessment of adaptations options through risk assessment and other assessment tools)
5. Planning	Formulation of adaptation plans, stakeholder consultation & community endorsement of adaptation measures or projects
6. Implementation	Implementation of endorsed adaptation measures
7. Evaluation & Monitoring	Evaluation of the effectiveness & efficiency of the execution of the overall project and monitoring of the effectiveness of the implemented adaptation measures

4.2 Procedural Framework

The procedural framework is the most critical component of this methodology as it ties components 1 and 3 and more importantly represents a departure from typical V&A methods applied so far in PICs. The premise of departure is the strong and equal emphasis it places on (i) community-based approaches to assessing vulnerability and adaptation options using participatory tools and (ii) facilitator-based approaches to assessing vulnerability and adaptation options using rigorous scientific tools and methods. The procedural framework is linked to the project cycle at step 3 (consultation). The project cycle begins with Consultation 1, which involves initial discussions and meetings with various stakeholders and the project communities.

Hereafter, the method is divided into two separate but interconnected streams of activities. As depicted in the procedural framework, refer to Figure 2, the left portion of activities denotes community based activities whilst the right portion denotes facilitator based activities. These activities are linked by two main consultation forums, namely consultation 2 and consultation 3. The main purpose of the consultations is for presentation of findings, discussions, mainstreaming and endorsements of adaptation plans. It should be noted that depending on the circumstances on the ground, the activities of both streams may be merged onwards from consultation 2.

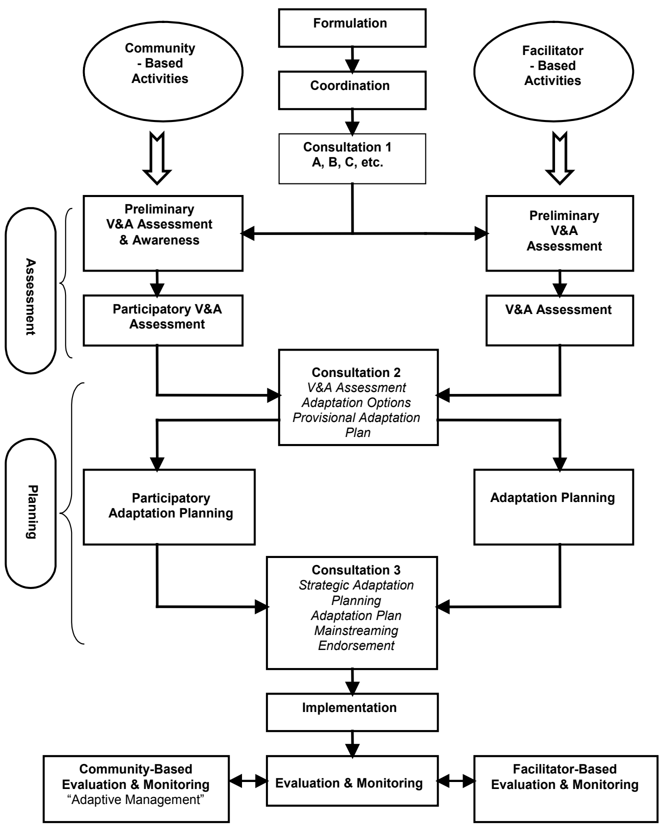

Figure 2. Procedural Framework.

4.3 Strategic Adaptation Framework

As there are scarce resources available for adaptation work in developing countries, it is therefore critical that adaptation plans need to be strategic. The adaptation framework (see Figure 3) is strategic in three ways. Firstly the assessment and plans are based on a firm understanding of the current socio-economic, cultural and environmental problems currently faced by the community. Secondly, it firstly addresses critical problem/s related to climate change currently faced by the community, before sequentially addressing other aspects of climate change within the time frame of short, medium and long term. In the context of climate change, the three time frames neatly correspond to climate extremes, climate variability, and climate change. Thirdly, it sets in motion a process that would initiate and catalyse community actions that would enable them to develop in a sustainable manner.

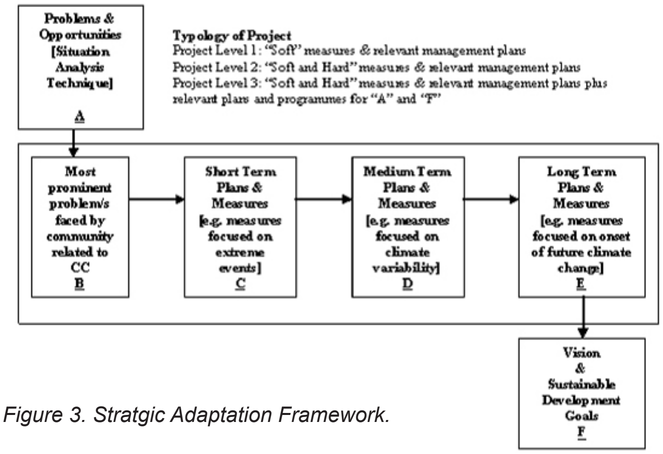

Figure 3. Stratgic Adaptation Framework.

In addition to sequentially addressing the various aspects of climate change, projects are also categorized into a three tier project classification system, viz. project level 1, 2 and 3. The category upon which a project is classified under is dependant upon the amount of resources available to undertake relevant adaptation measures. Within the strategic adaptation framework, project level one would mainly focus on soft measures for communities to follow to address issues under A to F, (see figure 3). Project level two would focus on soft measures related to issues under A to F and discrete measures related to issues under B to E. Project level three would focus on both soft and discrete measures related to issues under A to F. Under this proposed classification, project level 1 involves projects dealing mainly with process-based and soft adaptation measures, most of which the communities themselves can address with minimal external input. Project level 2 involves projects dealing with process-based and soft adaptation measures together with discrete measures but restricted to one or two specific sectors. Project Level 3 involves projects dealing with both process-based and soft adaptation measures together with discrete adaptation measures covering more than two sectors plus initiatives and programmes that addresses and facilitates sustainable development of project communities.

The USP project, under this proposed classification, is classified as project level 2, as it is limited to processed based adaptation measures and discrete measures limited to two sectors, coastal and water. The ensuing methodology description is limited to this type of project category.

4.4 Generalized application guide

The following serves as a generalized guide which one should consider when implementing adaptation projects within the PICs region, particularly in Fiji.

- Community participation and consultation in adaptation projects is critical, as the majority of the natural resources are community-owned and their endorsement is vital before any implementation can be carried out.
- Engaging communities both at the outset and throughout the project will also ensure optimal capacity building for the community, facilitates community input and ownership and ensures sustainability of the adaptation initiatives.

• The science of climate change and its impacts are relatively complex issues therefore will require external input by way of assessment and advice to the local communities. Therefore the selection of relevant technical advisors is of critical importance.

• The facilitating team should always try to access, evaluate and apply the project community's traditional adaptation methods wherever applicable, in conjunction with modern methods.

• Awareness raising of climate change should be strategic in content and focus. That is, it should be addressed succinctly in the context that it is an additional external stress to current social, economic and environmental stresses faced by communities. The objectives are (i) to provide a holistic perception of global, regional and national issues and challenges, (ii) to inspire communities to increase their resilience and adaptive capacity by effectively and efficiently addressing socio-economic and environmental problems currently faced, and (iii) minimizes the risk of portraying climate change as a "scape goat' for all socio-economic and environmental ills faced by the community.

• Strategic adaptation planning is necessary to ensure that communities are not unnecessarily overwhelmed with adaptation to all possible impacts of climate change at once and at the same time. In essence, by assisting the communities to address and prepare for climate extreme and variability will enhance their resilience and adaptive capacity to address future climate change.

• Facilitating the communities to assess other currently faced socio-economic and environmental problems and guiding them to opportunities to deal with them will improve their resilience and adaptive capacity to the impacts of climate change.

• Addressing the impacts of current and future climate change in the absence of sustainable development initiatives and programmes for communities will virtually be impossible to sustain. The progress of humanity throughout the past centuries has been of unsustainable development which brought climate change into existence in the first place. Therefore trying to address climate change in the long term in any other way may simply prove futile.

5.0 Field Application of the Methodology

5.1 Flexibility of the methodology

The method is flexible and is dependent upon the circumstances and the level of preparedness and experience of the facilitating team. For instances if the community has had previous awareness training on climate change or have a resource management plan already drawn up from other programmes, then the number of days of interaction would be shortened accordingly.

To minimize on costs when dealing with communities residing in remote locations, with proper prior planning by the facilitators, some or possibly all of the activities can be combined into one extended workshop and assessment programme.

5.2 Assessment tools and techniques

Within the methodology, various participatory tools and field assessment techniques can be used to elucidate the specific vulnerabilities and possible adaptation measures. In the community stream of activities, it is anticipated that participatory tools such as seasonal calendars, historical time lines, resource mapping, face-to-face dialogue and the use of simple analysis and prioritization schemes shall be the dominant tools. These tools have been used extensively in natural resource management projects in the Pacific and a number of local communities are familiar with these tools. In addition, the WWF Climate Witness Toolkit also stipulated the use of these tools.

The facilitator's team may use expert judgment, qualitative and quantitative assessments, and interviews of key informants within and outside of the community. More scientifically rigorous technical assessments using standard techniques pertinent to the sector(s) in consideration should be utilized including the use of climate change modeling outputs. The methodology by design allows for flexibility in the tools to be used based on the availability and the type of information required. It will also be useful to engage technical experts outside of the facilitating team for internal validation purposes and to compliment the assessment carried out by the facilitating team.

5.3 Community-based activities

5.3.1 Focus of community-based activities

Three of the key outcomes of the community-based activities are: (i) capacity building, (ii) development of process based adaptation measures and (iii) sustainable socio-economic and natural resources management plans.

Therefore adequate resources and time should be given to community based activities, especially funding of community workshops. This is also important for the following additional reasons, (i) avenues for engaging the communities, (ii) facilitates confidence building and trust, (iii) facilitates the transfer of informal (traditional) knowledge, and (iv) ensures the sustainability of proposed programmes.

5.3.2 Preliminary V&A Assessment and Awareness

This can either be a one day workshop or a planned meeting with the community. After the workshop introduction, as an 'ice breaker' the community is divided into two groups to work on the following topics, historical time line, and current socio-economic and environmental problems. After group presentations, a strategic climate change awareness presentation is conducted. The presentation is to be guided by the level of understanding the community have on climate change issues, average level of education and the mode of communication including the language the community can best communicate in and appreciate.

5.3.3 Participatory V&A Assessment

This is a one to two day workshop depending on the circumstances and the level of preparedness and experience of the facilitating team. The presentations, working groups and field activities and assessment are to be guided by the strategic adaptation plan framework. That is, it starts of with assessing current socio-economic and environmental problems faced by the community and then proceeds to the issue of the impacts of future climate change. Facilitation of their thought process is achieved through intermittent presentation of relevant topics. Such topics may include the following, hydrological cycle; carbon cycle; soil formation, fertility and management; coral reef health and morphology; importance of mangrove system to fisheries, coastal protection and reef system. Furthermore, it is important to have a balanced and fair representation by the different gender groups within the community as well as include participants from surrounding settlements as they play a vital role on the implementation of the adaptation measures.

In all these activities, the objective is for communities to participate actively in thinking through the issues and coming up with solutions. The process itself is vital for capacity building and sustainability.

5.3.4 Participatory Adaptation Planning

Likewise, the participatory adaptation planning workshop is a one to two day workshop depending on the circumstances of the community and the facilitating team. The objective of the workshop is to formulate an adaptation plan by which the community will adopt and implement. The outcomes of the workshop are (i) to formulate process based adaptation measures; and (ii) to formulate sustainable socio-economic and natural resources management plans.

5.4 Facilitator-based activities

The facilitating team is entrusted to assess the community's vulnerability, identify adaptation options and assess identified adaptation options for feasibility, applicability and sustainability. The findings from their assessment will compliment the community-produced V&A assessment findings. These complementary assessment reports will help facilitate the formulation of suitable community adaptation projects. In this regard the findings must be communicated and discussed with the community so that the process is kept as transparent as possible. An added benefit of such an approach is that it will invariably contribute to capacity building as the community discusses and articulate on the facilitating team's findings.

5.5 Presentation of Results

It is of vital importance that the results of the V & A assessment is properly set out in an orderly fashion so that it clearly points to final adaptation plan that is to be implemented. This will not only help in the standardisation of reporting, especially if several sites are being assessed, but will also facilitate in validating and auditing of the assessment procedures and results against the method used. Using this methodology together with the strategic adaptation framework, the following format is recommended.

- Results – Vulnerability and Adaptation Assessment
- Vulnerability to Climate Change
  - Current opportunities & constraints
  - Most prominent problem/s currently faced related to Climate Change
    - Extreme Events
    - Climate Variability
    - Climate Change
- Adaptive capacity and resilience
  - Current opportunities & constraints
  - Most prominent problem/s currently faced related to Climate Change
    - Extreme Events
    - Climate Variability
    - Climate Change
- Adaptation Assessment
  - Identification of adaptation options
  - Assessment of the identified adaptation options
- Adaptation Plan
  - Adaptation Strategy
  - Adaptation Implementation Plan

In addition to a detailed assessment report, a summary report should be compiled, which we have referred to as "Discussion Document". This report is for cirtculation to the relevant stakeholders and relevant government agencies, and one for the community elder. Apart from its use as a basis for discussions among the relevant stakeholders, it also facilitates mainstreaming of adaptation activities. In addition to these two reports, an information sheet of not more than three pages should be compiled, and preferably translated to the local vernacular. This will ensure that important issues, findings and plans are communicated effectively to the communities.

6.0 Discussion

6.1 Tier approach as a mechanism for follow up activities

As mentioned earlier, the method encompasses three project level type activities. Project level 1 are projects that are merely involved in facilitating the formulation of process based adaptation measures. The funding level is such that minimal external input is provided to the community to actually implement the identified adaptation measures. Project level 2 are those involved in facilitating both process based and discrete adaptation measures but limited to two sectors. Project level 3 are those involved in facilitating both process based and discrete measures, as well as implementing mitigation and sustainable development initiatives.

There are many benefits to having a three tier approach. For instance, follow up activities can be better coordinated, minimizing duplication of activities, particularly from similar and across different implementing and financing agencies. Another advantage is that it will encourage communities to embrace the drawing up of their adaptation plans in anticipation of receiving discrete adaptation funding under levels 2 and 3 type projects.

6.2 Current knowledge about responding to climate change

We have included the relevant findings of the IPCC WG11 Fourth Assessment Report (Summary for Policy Makers) [9], as it supports some of the guiding principles as well as the approach of this methodology.

- Some adaptation is occurring now to observed and projected future climate change, but on a limited basis.
- Adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions.
- A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to future climate change. There are barriers, limits and costs, but these are not fully understood.
- Vulnerability to climate change can be exacerbated by the presence of other stresses.
- Future vulnerability depends not only on climate change but also on development pathway.
- Sustainable development can reduce vulnerability to climate change, and climate change would impede nation's abilities to achieve sustainable development pathways.
- Many impacts can be avoided, reduced, or delayed by mitigation.
- A portfolio of adaptation and mitigation measures can diminish the risks associated with climate change.
- Impacts of climate change will vary regionally but, aggregated and disconnected to the present, they are very likely to impose net annual costs, which will increase over time as global temperature increases.

7.0 Conclusion

In conclusion, presented here is a *methodology*, together with a *procedural framework* and a *strategic adaptation framework* that will ensure that communities will adequately assess and address the impacts of current and future climate change.

The methodology on the one hand embraces the notion that community consultation and participation in any adaptation programme is critical in the Fiji sociological and cultural context, as the majority of natural resources are community-owned and their endorsement is vital before any implementation can be carried out. On the other hand, the methodology acknowledges that the science of climate change and its impacts are relatively complex issues therefore will require external input by way of assessment and advice to the local communities by technical experts. Therefore to archive an acceptable balance, a truly integrated approach in assessment, planning and action is required.

Raising the awareness of communities on climate change should be strategic in content and focus. That is, it should be addressed succinctly in the context that it is an additional external stress to current socio-economic and environmental stresses faced by communities. Strategic adaptation planning is necessary to ensure that communities are not overwhelmed with adaptation to all possible impacts of climate change. Facilitating the communities to assess other currently faced socio-economic and environmental problems and guiding them to opportunities to deal with them will improve their resilience and adaptive capacity to the impacts of climate change. Assisting the communities to address and prepare for climate extreme and variability will enhance their resilience and adaptive capacity to addressing future climate change.

The methodology embraces a three tier approach. The benefits are many including, enhancement of project transparency thereby minimizing duplication particularly across various organizations and institutions, inspires follow-up activities, and catalyses community-based resource management and socio-economic focused development planning and initiatives

Addressing the impacts of current and future climate change in the absence of sustainable development initiatives and programmes for communities stands to threaten the sustainability of the adaptation measures and process. The progress of humanity throughout the past centuries has been one of unsustainable development, which brought climate change into existence in the first place. Thus trying to address climate change in the long term in any other way may simply prove futile. Therefore it is imperative that communities are facilitated to draw up sustainable development plans as part of their process based adaptation measures and hopefully be assisted in there implementation under level 2 and 3 type projects.

References

IPCC 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate (IPCC). Cambridge University Press, Cambridge, UK. 1032 pp.

World Bank, *Cities, Seas and Storms: Managing Pacific Island Economies: Volume IV: Adapting to Climate Change (November, 2000 draft)*, East Asia and Pacific region, Papua New Guinea and Pacific Islands Countries Management Unit: 2000, World Bank, Washington D.C.

IPCC 1994. *Technical Guidelines for Assessing Climate Change Impacts and Adaptations,* Carter, T.R., M.L. Parry, H. Harasawa, and S. Nishioka, University College, London, United Kingdom, and Centre for Global Environmental Research, Tsukuba, Japan, 59 pp.

UNEP 1988. *Handbook on Methods for Climate Change Impact Assessment & Adaptation Strategies* J.F. Freenstra, I. Burton, J.B. Smith, and R.J.S. Tol (eds). United Nations Environment Programme (UNEP), Nairobi, 448 pp.

UNDP 2004. *Adaptation Policy Framework for Climate Change: Developing Strategies, Policies & Measures, B.Lim, E. Spanger-Siegfried, E. Malone, and I. Burton (eds).*

USCSP 1996. *Steps in Preparing Climate Change Action Plans: A Handbook*, R. Benioff, J. Warren (eds), Washington DC: US Country Studies Program, 300 pp.

SPREP 2006. CV&A: a guide to community vulnerability and adaptation assessment and action.

WWF South Pacific Programme Publication 2007. Climate Witness: Community Toolkit

IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

Past and Future Changes in Climate and their Impacts on Annual Crops Yield in South East South America

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INTRODUCTION

South-eastern South America (SESA) constitutes one of the major food producing regions of the world. In this zone most agricultural activities are carried out under rainfed conditions and therefore, crop production is dependent on rainfall during the growth season and they are strongly affected by climatic variability. Furthermore, against the very unfavourable economic scenarios of the last decades, farmers have been struggling to maintain their income by continuously trying to increase yields by intensifying their production systems, which have often become more vulnerable to climate variability and potential climate change.

SESA is one of the world's zones were significant changes in climate have been evidenced. During the last few years several studies reported a positive trend in annual precipitation as well as in extreme events (Barros et al., 2000; Penalba and Vargas, 2004; Bidegain et al., 2005; Haylock et al., 2006). Increases in minimum and maximum temperature in southeast Brazil (Marengo & Camargo, 2007), and increases in minimum and decreases in maximum temperature in central Argentina (Rusticucci & Barrucand, 2004), have also been reported.

These changes in climate contributed to increase crop yields in the Argentinean Pampas region, mainly in summer crops and in the semiarid zone mostly due to increases in precipitation. Comparing the period 1950-70 with 1970-2000 increases in rainfed yields attributable to changes in climate were 38% in soybean, 18% in maize, 13% in wheat and 12% in sunflower (Magrin et al., 2005).

Regarding to potential impacts of climate change on crop production, several studies were carried out in SESA using GCM (Global Circulation Models) and crop simulation models, with contrasting results according to the climatic scenario considered (Magrin and Travasso, 2002; de Siqueira et al., 2000; Baethgen, 1997). Uncertainties are mainly related with the climatic scenarios and precipitation projections as results from different sources are usually diverse and even contradicting. An alternative method to the GCMs for generating climate change scenarios is to study the changes in the last few decades and then project those changes into the near future. Furthermore this method has the advantage that it is based in observed changes.

The aim of the present work is to quantify the changes occurred in seasonal climate between the first (1930-1960) and the last part (1970-2000) of the 20th century in SESA and their impacts on crop yields, and to assess the potential impact of climate change arising from projections of past climatic trends on crops yield.

MATERIALES and METHODS

The study area, extended from 25.4° up to 38.7° lat S. and from 48.5° up to 65° long W, includes 6 sites located in Brazil (Passo Fundo), Uruguay (La Estanzuela) and Argentina (Pergamino, Tres Arroyos, Azul and Santa Rosa). The annual precipitation ranges from near 1850 mm in Brazil to 750 mm in Santa Rosa, while maximum and minimum temperature ranges between 23.6 and 20.5ºC, and 13.3 and 8.0ºC respectively (Table 1).

Table 1: Sites location and mean (1970-2000) climatic data.

Site	Lat. (S)	Long. (W)	Annual Rainfall (mm)	TMax (ºC)	TMin (ºC)
Passo Fundo (Br-PFU)	-28.26	-52.41	1854	23.6	13.3
La Estanzuela (Uy-EST)	-34.33	-57.68	1152	21.7	11.8
Pergamino (Ar-PER)	-33.90	-60.58	1013	22.8	10.7
Azul (Ar-AZU)	-36.78	-59.85	954	20.8	8.0
Tres Arroyos (Ar-TAR)	-38.37	-60.27	798	20.5	8.6
Santa Rosa (Ar-SRO)	-36.62	-64.28	750	22.6	9.0

Climatic data: Daily values of precipitation and temperature corresponding to de period 1930-2000 were analyzed for the 6 sites. The analysis was conducted for two thirty-year periods (1930-1960 and 1970-2000) comparing the behaviour of precipitations, number of rainy days, duration of wet and dry spells and maximum and minimum temperature in each one. Differences between periods were analyzed by trimester and the Wilcoxon test (Wilcoxon, 1945) was used for identifying significant differences. Changes occurred in precipitation and its associated variables as well as in temperature between the periods 1930-1960 and 1970-2000 were used to develop a future climatic scenario by means of LARS-WG model (Semenov et al. 1998) for each site.

Yield simulations: Crop models included in DSSAT (Tsuji et al, 1994) were used to assess climate impacts on crops yields (CERES for wheat and maize and CROPGRO for soybean). These models allow isolating climatic impacts on crops productivity if all the other inputs are left unchanged. Inputs, including initial conditions characterizing water and nitrogen in the soil profile, date of planting, plant density, depth of planting, date and amount of fertilizers applications and cultivars, were defined according to the current typical conditions in each site. Current climate was defined with observed daily data (maximum and minimum temperature, precipitation and solar radiation) corresponding to the periods 1931-1960 and 1971-2000. Future climate scenarios were produced with a synthetic thirty-year period generated by the LARS-WG. Observed trends were lineally projected into the future, maintaining the same variability, to generate the 30-year period of "Climate Change". Models runs were done with and without considering the biological effects of CO2 on crop production.

RESULTS:

Changes observed in climate:

Seasonal changes in precipitation and temperature observed between the periods 1930-1960 and 1970-2000 are presented in Table 2. During 1970-2000 the annual rainfall amounts were significantly higher than during 1930 -1960 in all the sites. Increases in rainfall between the two periods were concentrated in the spring and summer months and attained up to 42% in the driest zone (Ar-SRO). Inversely, a negative non significant trend was observed for winter precipitation in the sites located in the Buenos Aires province of Argentina (Ar-PER, Ar-AZU and Ar-TAR), and for autumn precipitation in Uruguay (Uy-EST).

The number of wet days significantly increased (up to 20%) during spring and summer in almost all the sites, and during autumn also in Brazil and Uruguay. However wet spells only had significant increases during spring, summer and autumn in Uruguay and during summer in Brazil. On the other hand, dry spells decreased significantly during spring, summer and autumn in Brazil (up to 21%) and during spring in Uruguay.

Minimum temperatures significantly increased in all sites during spring and summer (up to 1.5ºC) while in Ar-SRO and Ar-PER significant increases were evidenced all over the year. Inversely, maximum temperature decreased significantly during the summer in Argentina and Uruguay. Only in one site (Ar-AZU) TMax significantly increased during cold months.

Changes in crops yield:

Between 1931-1960 and 1971-2000, wheat yields variations ranged between increases of 13% and 24% in the south-western part of the study region (Ar-SRO, Ar-AZU and Ar-TAR), 3% in Uy-EST, and decreases of 3% in Ar-PER and 6% in Br-PFU (Figure 1, Table 3). Positive changes could be mostly attributed to the increase in spring precipitations, while the negative ones could be related to the warmer conditions observed in the two sites.

For summer crops the behaviour was more consistent, with increases in all sites. Maize yield increases ranged between 12% and 49% (Figure 1, Table 3), while for soybean figures were 9% (Br-PFU)

Table 2: Changes in three monthly median values of precipitation related variables (%) and temperature (ºC) between the periods 1930-1960 and 1970-2000. In bold significant values (p<0.05)

		Changes in precipitation related variables (%)				Changes in temperature(ºC)	
Trimester	Site	Rain	Wet days	Wet Spell	Dry Spell	Minimum	Maximum
Summer (J-F-M)	Br-PFU	10	**19**	**8**	**-9**	**0.4**	0.3
	Uy-EST	0	**13**	**11**	5	**0.3**	**-0.7**
	Ar-PER	8	**14**	-6	-3	**1.1**	**-0.9**
	Ar-AZU	**33**	6	-4	-4	**0.3**	**-0.6**
	Ar-TAR	6	**16**	1	2	**0.4**	**-1.7**
	Ar-SRO	**42**	**20**	-3	1	**1.0**	**-0.9**
Autumn (A-M-J)	Br-PFU	12	**19**	9	**-21**	0.0	0.3
	Uy-EST	-9	**17**	**18**	-9	-0.1	0.0
	Ar-PER	6	8	2	7	**0.8**	0.0
	Ar-AZU	4	-10	-5	6	0.1	**0.7**
	Ar-TAR	22	13	12	6	-0.1	**-0.7**
	Ar-SRO	29	18	-2	-12	**0.7**	-0.3
Winter (J-A-S)	Br-PFU	14	8	1	-3	0.4	-0.5
	Uy-EST	3	0	**7**	-4	0.1	0.6
	Ar-PER	-29	7	0	7	**0.7**	0.3
	Ar-AZU	-6	-3	-9	0	0.1	**0.7**
	Ar-TAR	-8	-2	12	-2	0.1	0.0
	Ar-SRO	19	-4	3	-12	**1.1**	-0.3
Spring (O-N-D)	Br-PFU	**15**	**17**	5	**-15**	**0.2**	0.2
	Uy-EST	29	13	**12**	**-15**	**0.4**	**-0.4**
	Ar-PER	18	**13**	-10	-1	**1.5**	0.3
	Ar-AZU	**17**	10	-2	-13	**0.5**	0.1
	Ar-TAR	**16**	**20**	-1	11	**0.4**	**-1.0**
	Ar-SRO	**25**	**11**	9	-14	**0.7**	-0.7

and 92% (Ar-TAR) (Figure 1, Table 3). Certainly the greater spring-summer rainfall benefited both crops, although increases in minimum temperatures were especially favourable for soybeans.

It is interesting to remark that the mean increases in maize and soybean yields found in this work are significantly greater than those previously reported for the Pampas region (Magrin et al., 2005) when comparing the periods 1950/1970 and 1970/2000: 18% for maize and 38% for soybean. These differences could be attributed to the higher precipitations during spring-summer months in 1950/1970 as compared to those of 1930-1960.

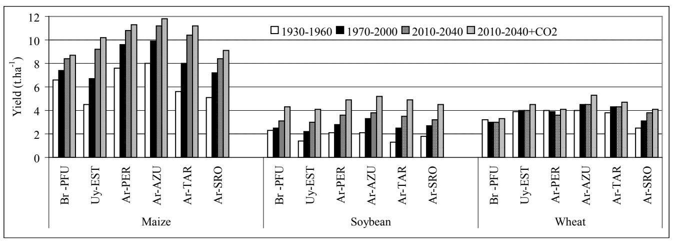

Figure 1. Maize, soybean and wheat yields for the six sites under climatic conditions corresponding to 1930-1960, 1970-2000, 2010-2040 and 2010-2040 considering CO_2 increase.

Assuming that climatic trends will continue, in the near future (2020-2030) wheat yields would continue to increase only in Ar-SRO (23%), would decrease in Ar-PER (-8%) and would remain constant in the other sites if CO_2 potential effects are not taken into account (Figure 1, Table 3). Maize and soybean yields could increase between 13% and 37% and 15% and 40% respectively all over the region (Figure 1, Table 3).

If the biological effects of CO2 increases are considered (Figures 1, Table 3), a generalized augment in crop yields is likely to happen in all sites, with increases ranging between 5% to 32% in wheat, 18% to 52% in maize and 58% to 96% in soybean.

CONCLUDING REMARKS

The obtained results confirm that in South-eastern South America important changes in climate have occurred during the last century. Between two 30–year-periods centred in 1945 (1930-1960) and 1985 (1970-2000) rainfall increased up to 42% and the number of wet days up to 20%. Significant increases in wet spells and decreases in dry spells were observed in Brazil and Uruguay. During the warm semester increases of up to 1.5ºC in minimum temperature and decreases of up to 1.7ºC in maximum temperature were registered.

These changes in climate led to important increases in summer crops yields (maize and soybean) and in wheat planted in the centre-south part of SESA. Between 1930-1960 and 1970-2000 yield increase due to climate change attained a mean of 33% in maize and 50% in soybean, while the increase for wheat sown in the centre and south of the region attained 13%. Inversely, wheat yields slightly decreased in lower latitudes like Br-PFU (-6%) and Ar-PER (-3%), two of the warmest sites where both minimum and maximum temperature increased during the spring months.

If observed climatic trends persist in the future, summer crops yield would continue to increase to about 20% in maize (14% in Brazil, 37% in Uruguay and 18% Argentina) and to about 30% in soybean (24% in Brazil, 36% in Uruguay and 26% in Argentina). However, wheat yields would remain the same or slightly decrease in most of the area, with the exception of the semiarid part of the Argentinean Pampas, where it would continue to increase.

Table 3. Changes in crops yields (%) between different periods for the six sites and mean values for Argentina.

	Periods	Br-PFU	Uy-EST	**Ar-PER**	**Ar-AZU**	**Ar-TAR**	**Ar-SRO**	**Ar-Mean**
Maize	1970-2000/ 1930-1960	**12**	**49**	26	24	43	41	**34**
	2010-2040/ 1970-2000	**14**	**37**	13	13	30	17	**18**
	2010-2040/ 1970-2000 +CO_2	**18**	**52**	18	19	40	26	**26**
Soybean	1970-2000/ 1930-1960	**9**	**57**	33	57	92	50	58
	2010-2040/ 1970-2000	**24**	**36**	29	15	40	19	**26**
	2010-2040/ 1970-2000 +CO_2	**72**	**86**	75	58	96	67	**74**
Wheat	1970-2000/ 1930-1960	**-6**	**3**	-3	13	13	24	**12**
	2010-2040/ 1970-2000	**0**	**0**	-8	0	0	23	**4**
	2010-2040/ 1970-2000 +CO_2	**10**	**13**	5	18	9	32	**16**

References:

Baethgen,W.E., 1997. Vulnerability of the agricultural sector of Latin America to climate change. Climate Research 9, 1-7.

Barros, V. M.E. Castañeda and M, Doyle 2000: Recent precipitation trends in Southern South America to the East of the Andes: an indication of a mode of climatic variability. In: "Southern Hemisphere Paleo and Neoclimates. Concepts, Methods, Problems". Springer.

Bidegain M, RM Caffera, F Blixen, V Pshennikov, LL Lagomarsino, EA Forbes, GJ Nagy, 2005. Tendencias Climáticas, Hidrológicas y Oceanográficas en el Río de la Plata y costa uruguaya. Cap. 14:137-143. (Eds. Barros V, A Menéndez, GJ Nagy).

de Siquiera, O., S. Steinmetz, M. Ferreira, A.Castro Costa and M.A.Wozniak 2000. Climate changes projected by GISS models and implications on brazilian agriculture. Revista Brasileira de Agrometeorologia, Santa Maria, v. 8, n. 2, p. 311-320

Haylock, M. R., T. Peterson, L. M. Alves, T. Ambrizzi, Y. M. T. Anunciação, J. Baez, V. R. Barros, M. A. Berlato, M. Bidegain, G. Coronel, V. Corradi, V. J. Garcia, A. M. Grimm, D. Karoly, J. A. Marengo, M. B. Marino, D. F. Moncunill, D. Nechet, J. Quintana, E. Rebello, M. Rusticucci, J. L. Santos, I. Trebejo, and L. Vincent, 2006: Trends in total and extreme South American rainfall 1960-2000 and links with sea surface temperature. Journal of Climate, 19, 1490-1512.

Magrin, G. O., M. I. Travasso. 2002. An Integrated Climate Change Assessment from Argentina (Chapter 10) In: Effects of Climate Change and Variability on Agricultural Production Systems. Otto Doering III; J.C.Randolph; J.Southworth and R.A.Pfeifer (Eds). Kluwer Academic Publishers, Boston. pp193-219.

Magrin, G. O., M. I. Travasso, G. R. Rodríguez. 2005. Changes in climate and crops production during the 20th century in Argentina. Climatic Change 72:229-249

Marengo J., and C. Camargo. 2007. Surface air temperature trends in Southern Brazil for 1960-2002. Int. J. Climatology (in press)

Penalba O.C., Vargas W.M. 2004. Interdecadal and interannual variations of annual and extreme precipitation over central-northeastern Argentina. International Journal of Climatology 24(12): 1565-1580

Rusticucci, M, M. Barrucand. 2004. Observed trends and changes in Temperature Extremes over Argentina. J. Climate vol 17, No. 20, 4099-4107

Semenov M.A., Brooks R.J., Barrow E.M. & Richardson C.W (1998): Comparison of the WGEN and LARS-WG stochastic weather generators in diverse climates. Climate Research 10, 95-107.

Tsuji, G. Y., G. Uehara, and S. Balas. 1994. Decision Support System for Agrotechnology Transfer (DSSAT v3.0). IBSNAT. Department of Agronomy and Soils. University of Hawaii. Honolulu, HI.

Wilcoxon, F. 1945. Individual Comparisons by Ranking Methods. Biometrics 1, 80-83.

Integrating across Spatial and Temporal Scales in Climate Projections: Challenges for using RCM projections to develop plausible scenarios for future extreme events in South America for vulnerability and impact studies

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Abstract

Using the PRECIS climate model system, this study analyzes distribution of extremes of temperature and precipitation in South America to simulate the distribution of the present (1961-1990) and to simulate future (2071-2100) extreme climate events changes under the IPCC SRES A2 and B2 scenarios. The results show that for the present climate the model simulates well the spatial distribution of extreme temperature and rainfall events when compared with observations, being the temperature comparisons more realistic. In the future the occurrence of warm nights is projected to be more frequent in the entire tropical South America, while the occurrence of cold night events is likely to decrease. A warm climate would also affect trends in rainfall extremes and dry spells. There would be an overall increasing trend in extreme precipitation events over most of Southeastern South America and western Amazonia consistent with projected increasing trends in total rainfall in the future in that region. In Northeast Brazil and eastern Amazonia, the projected negative trends in rainfall from previous studies are due to a positive trend in the frequency of consecutive dry days in 2071-2100 as compared to present. In all scenarios the future climate would be characterized for an irregular distribution in rainfall and temperature extremes. These changes would have impacts in biodiversity, human health, water resources and may have to be considered in the implementation of adaptation measures to cope with climate change.

1. Introduction

The models used to evaluate future climate changes have evolved over time. Global models have allowed for a better scientific understanding of anthropogenic global climate change and this led to commensurate developments of mitigation strategies. However, at the regional scale there remains an urgent need for relevant, targeted projections of the regional climate change. Furthermore, adaptation, as opposed to mitigation, is inherently a local and regional scale issue, and limited by the measure of confidence in the projected changes at these scales.

Therefore, it is at regional scales that credible information of probable climate change is most urgently needed to facilitate the development of appropriate adaptation strategies. Within the impacts and adaptation community there is a growing move toward integrated assessment, wherein regional climate change projections form a principal factor for decision support systems aimed at reducing vulnerability. At present the regional projections are perhaps the weakest link in this process, and the bulk of information readily available for policy and resource managers is largely derivatives of Global Climate Models (GCMs), the data of which have limited skill in accurately simulating local scale climates, especially as regards the key parameter of precipitation. GCM data are commonly mapped as continuous fields, and with different model skill and climate predictability.

In view of the pressing need for regional projections, much effort has been expended in recent years on developing regional projections through diverse methodologies, and significant advances made to downscale the GCM skilful scale to the regional and local scales, either through high resolution dynamical modelling, or via empirical cross scale functions.

In this paper, we look at the problem of developing climate scenarios for climate extremes in the future. Extremes are important for impacts for things like hydrologic impacts, crop yield changes. This paper focuses on the analyses of two 30-year simulations: the present climate that examines the time period 1961–1990 and the future climate that covers the time slice of 2071–2100 under the IPCC SRES (Special Report on Emissions Scenarios) A2-high emission and B2-low emission scenarios using the HadRM3P model under the PRECIS (Providing REgional Climates for Impacts Studies) (Jones et al., 2004). On this study it is investigated the performance of the HadRM3P model in simulating present extreme climate events and to make comparisons with observations, and also for future climate change projections.

2. Literature review

The recent study by Tebaldi et al. (2006) has documented changes in extremes worldwide using the mean of 16 IPCC AR4 global models for the A1B SRES scenario for 2080-2099. In South America the projections show tendencies for increasing extremes in temperatures in the entire continent, while rainfall extremes show a more regional variability, with increase in the frequency and intensity of extremes on subtropical South America and negative trends in some sections of tropical and subtropical South America.

Regional Climate Models (RCMs) can represent the local land-surface variables affecting regional climate as well as internal climate variability, and they represent an effective method of downscaling to add fine-scale detail to simulated patterns of climate variability and change. The "added value" provided by the regionalization techniques depend on the spatial and temporal scales of interest, as well as on the variables concerned and on the climate statistics required. A review of the different downscaling methods can be found in Wilby and Wigley (1997), and Giorgi et al. (2004).

The issue of the spatial resolution in scenarios must be put in the context of other uncertainties of climate change. Studies and analyses of climate change impact and adaptation assessments recognize that there are a number of sources of uncertainty in such studies which contribute to uncertainty in the final assessment. The importance of high resolution climate scenarios for impacts and adaptation studies remains to be thoroughly explored in South America. High resolution scenarios developed from regional climate model results have been obtained in various parts of the world.

Various international projects are already working with regional climate scenarios for studies of detection, and assessments of impacts and vulnerability. In Europe, the PRUDENCE-*Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects* (Christensen et al. 2006) and its successor ENSEMBLES project and in North America, by the NARCCAP-*North American Regional Climate Change for Assessment Program* (Mearns et al. 2004). Both PRUDENCE/ENSEMBLES and NARCCAP use the HAdAM3P as global model that forces various regional models from meteorological services and research institutions in the regions. Typically, a present day (e.g. 1960-1990) and a future climate (2070-2100) time slices are simulated to calculate changes in relevant climatic variables, and can be up-scaled to other time slices.

In South America, an initiative has been the implementation of CREAS (*Regional Climate Change Scenarios for South America* – Marengo and Ambrizzi 2006, Marengo et al. 2007). This project aims to provide high resolution climate change scenarios in South America for raising awareness among government and policy makers in assessing climate change impact, vulnerability and in designing adaptation measures, and also uses the HadAM3P model. The CREAS project runs three regional models nested in the HadAM3P: Eta CCS, RegCM3 and HadRM3P. On this study the focus on the HadRM3P.

We explore issues such as: the challenges for using regional climate projections to develop plausible scenarios for future changes at daily time scales for extreme events; the way in which this currently being done; an assessment on how good/bad are these methods for some regions where data is available.

3. Methodology

PRECIS (Providing Regional Climates for Impacts Studies), a regional climate model system developed by the Hadley Centre that can be run over any area of the globe (Jones et al. 2004), and has been applied, for instance in studies of climate change in China for impact studies (Zhang et al. 2006, Gao et al. 2006, Xu et al. 2006a, b). The lateral boundary conditions for the HadRM3P are obtained from a global atmosphere general circulation model, HadAM3P. The current version of the HadRM3P has a resolution of 50 km and 19 vertical levels, and the evolution of concentration of greenhouse gases and sulphur for the present and the future (A2 and B2 scenarios) is the same as the HadCM3. Therefore, the HadRM3P provides climate change projections consistent with the global model.

The HadAM3P provides the forcing for the HadRM3P. This global model shows a spatial resolution of 1.25 latitude by 1.875 longitude (Gordon et al. 2000). The HadAM3P model constitutes the atmospheric component of the Hadley Centre HadCM3 forced with the SST anomalies derived from observations for the recent past and by combining these observations with changes from the global coupled ocean-atmosphere GCM HadCM3 (see Jones et al., 2004 for details). The global and regional runs are available for the periods 1961-90 (present climate) and 2071-2100 for the IPCC TAR SRES A2 and B2 scenarios.

The validation of the simulated extremes for the present (1961-90) was made using temperature and precipitation records of 104 stations in South America, mostly concentrated in subtropical South America south of 6 ^{0}S. For details on the stations location, quality control and the time series and the interpolation at regular 1/2º x 1/2º grid using ordinary krigging the reader is referred to Haylock et al. (2006), Alexander et al. (2006) and Vincent et al. (2005). Given the lack of stations in tropical South America, we focus our study South of 10º South were stations are more concentrated. Once the grids are obtained, trends have computed the over the 40 years at every grid box following Alexander et al. (2006).

The indices used to calculate short term extreme climate events were defined by Frich et al (2002). These indices sample the extreme end of a reference period distribution and have been calculated for 1961-90 present and 2071-2100 future, for both scenarios A2 and B2. From a total of 27 indices we calculated:

-*Very cold nights* (TN10): The percentage of time in a year when daily minimum temperature is below the 10th percentile of the 1961–90 daily temperature distribution,

-*Very warm nights* (TN90): The percentage of time in a year when daily minimum temperature is above the 90th percentile of the 1961–90 daily temperature distribution,

-*Consecutive dry days* (CDD): The annual maximum number of consecutive days when daily precipitation was less than 1 mm.

- *Wet days* (R10): The number of days in a year with precipitation above 10 mm.

The statistical significance of such a trend is determined by conducting a Student's t-test.

4. Validation of trends extreme climate indices for present climate

Considering the observations and PRECIS simulations for the present climate (1961-90), Figure 1 shows the observed and simulated spatial distribution of trends for the indices TN10, TN90, CDD, and R10, respectively. Generally, the temperature-based indicator

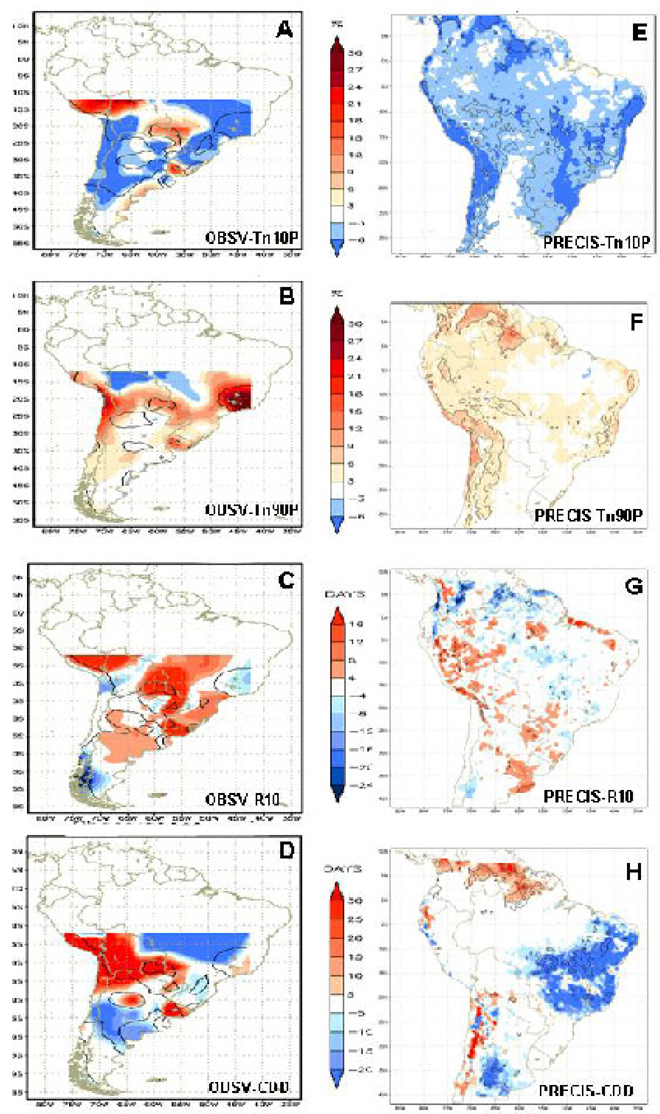

Figure 1. Observed and simulated trends of extreme climate indices for 1961-90. The trend is assumed as linear and represents the values of 1990 minus 1961. Left panel represents observations and right panel represents HadRM3 (PRECIS) simulations. (A, E) TN10 in %/30 years; (B, F) TN90 in %/30 years; (C, G) R10 days/30 years; (D, H) CDD in days/30 years. Color scale is shown on the lower side of the simulated indices maps, and the black line delimitates areas where the linear trend is statistically significant at 5% level using the Student t-test.

figures show similar spatial patterns between the simulated and the observed, at least for the regions with observational coverage. Over southeastern South America the TN10 (cold nights) and TN90 (warm nights) indices suggest positive trends in the warm nights and negative trends in the cold nights, indicators of regional warming during the present.

The precipitation based indices for present climate are also shown in Figure 1. The Figure shows the observed and simulated spatial distribution of the occurrence of R10mm and CDD, respectively, during the present in South America. The broad spatial pattern of observed R10mm is well simulated by the model, with positive trends in large regions of Southeastern South America and negative trends around 20 oS in south eastern Brazil. The simulated result tends to be somewhat lower and shows a reduction from South to North in the region east of the Andes.

The CDD maps shows that the model captures well the negative trends in central Argentina and west central Brazil south of 15 oS, and in the model the negative trends extend to Northeast Brazil. The observations show positive trends in Uruguay and in the boundary region between Argentina-Paraguay-Brazil while the model does not show any trend. Extreme northern Amazonia and Venezuela show positive trends in simulated CDD that are consistent with positive CDD trends observed in that region by Alexander et al. (2006).

5. PRECIS derived future changes on extremes

In general the temperature-based indicator maps (Figure 2) are changes consistent with the expected warmer future climate, with negative trends in cold nights and positive trends in warm nights. The trends are larger for A2 especially in tropical South America and the Andean regions while the trends are smaller South of 25 oS. These projected trends seem to be a continuation of the observed trends in the XX Century for Northern South America, Northeast Brazil, and in central South America extending from Bolivia do central Brazil and in southern Brazil. The projected positive trends in the TN90 trends from the PRECIS simulations are also consistent with the positive and statistically significant TN90 trends detected in the global IPCC AR4 multimodel simulation, especially in the region extending from Bolivia to Central Brazil in the A1B scenario from Tebaldi et al. (2006).

About the extreme rainfall indices trends, it is expected that as a consequence of global warming due to an increase on the Greenhouse Gases Concentration, an intensification of the hydrological cycle would be expected and that will increase the frequency and intensity of extreme rainfall events and also dry spells (IPCC 2007a, b). As the climate responds to global warming, the changes in occurrence of R10mm (Figure 2) show a positive trend in western Amazonia, the northern coast of Peru and Ecuador and in southeastern South America in the B2 scenario, while in the A2 scenario the changes are more accentuated in western Amazonia and southern Brazil. These regions would experience more extreme precipitation events in the future than at present. Negative trends are detected in northern South America and the eastern Amazonia- Northeast Brazil region, being the trends larger in the A2 scenario. The R10 index show positive trends for both B2 and A2 scenario suggesting increases in extremes in western Amazonia and Southeastern South America.

The projected trends in Southeastern South America show basically a continuation and intensification of the positive rainfall extreme trends detected during the second half of the XX Century, particularly in southeastern South America. On the other hand, the CDD index shows an increasing trend in the region extending from eastern Amazonia to Northeast Brazil in the B2 scenario and extending into the northern South American coast and into southeastern Brazil in the B2 scenario until the end of the XXI Century.

Regional climate model runs for South America for 2071-2100 (Marengo et al. 2007, Ambrizzi et al. 2007) have shown reductions of rainfall in eastern Amazonia and Northeast Brazil regions between on the order of 5-20%, as well to increases of rainfall in southeastern South America that can reach 10%, relative to the 1961-90 for both the A2 and B2 scenarios. The results of this paper shows that the rainfall reductions in eastern Amazonia would be accompanied by changes in the frequency of extremes, with positive trends in consecutive dry days (and consequently dry spells) in eastern Amazonia and northeast Brazil in the future. The increase of rainfall in southeastern South America would be due an increase in the frequency of intense rainfall more irregular in the future, and this would be even more intense in western Amazonia, where the risk of floods will be higher in the future.

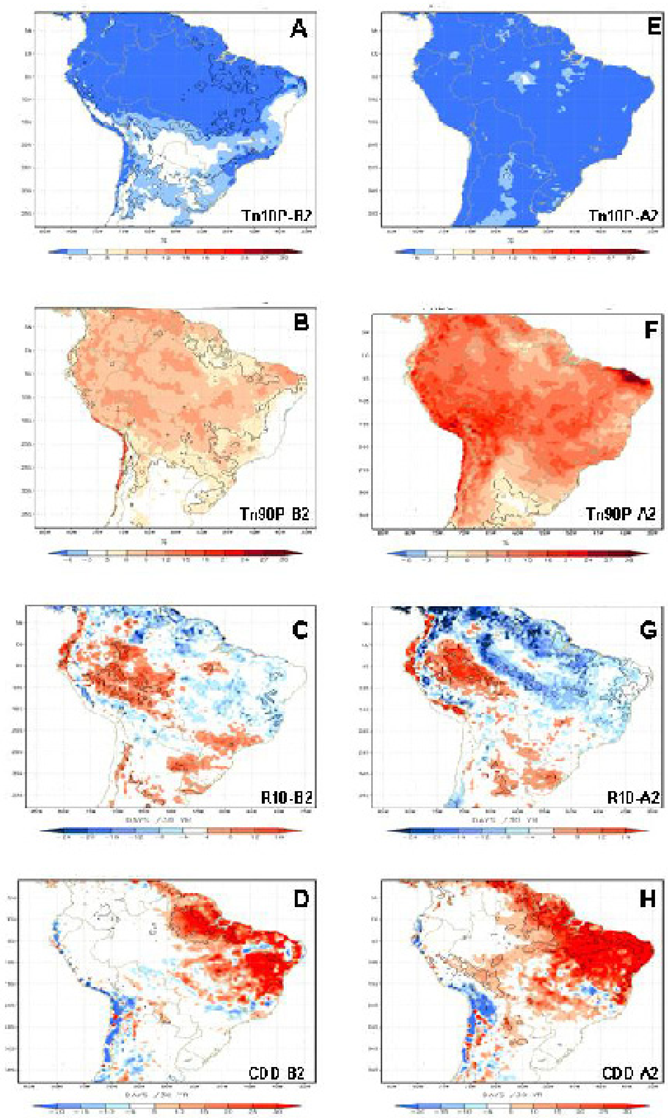

Figure 2. Projected trends of extreme climate indices for 2071-2100 relative do 1961-90. Left panel represents projections for the B2 scenario and right panel represents projections for the A2 scenario. (A, E) TN10 in %/30 years; (B, F) TN90 in %/30 years; (C, G) R10 in days/30 years; (D, H) CDD in day/30 years. Color scale is shown on the lower side of each panel, and the black line delimitates areas where the linear trend is statistically significant at 5% level using the Student t-test.

Limitations and data gaps especially in tropical South America prevent more complete attribution of the causes of observed changes in climate extremes and therefore, and also the assessment of climate extreme responses to anthropogenic warming. Nevertheless, there is consistency between observed and projected changes in this and several studies and the spatial agreement between significant regional warming.

Acknowldegements:

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References

Alexander, L. V., et al. (2006) Global observed changes in daily climate extremes of temperature and precipitation, J. Geophys. Res., 111, D05109, doi:10.1029/2005JD006290.

Ambrizzi, T., R. Rocha, J. A., Marengo, I. Pisnitchenko, L. and Alves, (2007) Cenários regionalizados de clima no Brasil para o Século XXI: Projeções de clima usando três modelos regionais. Relatório 3, MINISTÉRIO DO MEIO AMBIENTE - MMA, SECRETARIA DE BIODIVERSIDADE E FLORESTAS –SBF, DIRETORIA DE CONSERVAÇÃO DA BIODIVERSIDADE – DCBio Mudanças Climáticas Globais e Efeitos sobre a Biodiversidade - Sub projeto: Caracterização do clima atual e definição das alterações climáticas para o território brasileiro ao longo do Século XXI. Brasília, Fevereiro 2007.

Christensen, J. H., T. R. Carter, and M. Rummukainen (2006) Evaluating the performance and utility of regional climate models: The PRUDENCE project, Clim. Change, in press.

Frei, C., R, Scholl, S. Fukutome, J. Schmidli and P. L. Vidal, (2006) Future change of precipitation extremes in Europe: Intercomparison of scenarios from regional climate models, Journal of Geophysical Research, 111, D06105, doi:10.1029/2005JD005965, 2006

Frich, P., L. V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A. M. G. Klein Tank, and T. Peterson, (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century, Clim. Res., 19, 193– 212.

Gao, X., J. S. Pal, and F. Giorgi, (2006) Projected changes in mean and extreme precipitation over the Mediterranean region from a high resolution double nested RCM simulation, Geophys. Res. Lett., 33, L03706, doi:10.1029/2005GL024954.

Giorgi, F., Bi X, J.S. Pal, (2004) Mean, interannual variability and trends in a regional climate change experiment over Europe. I: present day climate (1961-1990). Clim. Dyn. 22:7333-756.

Gordon, C., C. Cooper, C. A. Senior, H. Banks, H. M. Gregory, T. C. Johns, J. F. B. Mitchell, and R. A. Wood (2000) The simulation of SST, sea ice extent and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments, Clim. Dyn., 16, 147– 168.

Haylock M. R., Peterson T., Abreu de Sousa J. R., Alves L. M., Ambrizzi T., Baez J, Barbosa de Brito J. I., Barros V. R., Berlato M. A., Bidegain M., Coronel G., Corradi V., Garcia V. J., Grimm A. M., Jaildo dos Anjos R., Karoly D., Marengo J. A., Marino M. B., Meira P. R., Miranda G. C., Molion L., Muncunil D. F., Nechet D., Ontaneda G., Quintana J., Ramirez E., Rebello E., Rusticucci M., Santos J. L., Varillas I. T., Vincent L., and Yumiko M. (2006) Trends in total and extreme South American rainfall 1960-2000 and links with sea surface temperature. Journal of Climate, 19, 1490-1512..

Intergovernmental Panel on Climate Change IPCC (2007a) Climate Change 2007: The Physical Science Basis Summary for Policymakers Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 18 pp.

Intergovernmental Panel on Climate Change IPCC (2007b) Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerabilit,y Summary for Policymakers, 23 pp.

Jones, R. G., M. Noguer, D. Hassell, D. Hudson, S. Wilson, G. Jenkins, and J. Mitchell (2004) Generating high resolution climate change scenarios using PRECIS, report, Met Off. Hadley Centre, Exeter, UK.

Marengo, J. A., L. Alves, M., Valverde, R., Rocha, and R., Laborbe, (2007) Eventos extremos em cenários regionalizados de clima no Brasil e América do Sul para o Século XXI: Projeções de clima futuro usando três modelos regionais. Relatório 5, Ministério do Meio Ambiente - MMA, Secretaria de Biodiversidade e Florestas – SBF, Diretoria de Conservação da Biodiversidade – DCBio Mudanças Climáticas Globais e Efeitos sobre a Biodiversidade - Sub projeto: Caracterização do clima atual e definição das alterações climáticas para o território brasileiro ao longo do Século XXI. Brasília, Fevereiro 2007

Mearns, L. (2004) NARCCAP North American Regional Climate Change Assessment Program A Multiple AOGCM and RCM Climate Scenario Project over North America. 12/17/2004. AGU Fall Meeting, San Francisco, USA.

Pope, V. D., M. L. Gallani, P. R. Rowntree, and R. A. Stratton (1999) The impact of new physical parametrizations in the Hadley Centre climate model: HadAM3, Clim. Dyn., 16, 123–146.

Tebaldi, C., K. Hayhoe, J. Arblaster, G. Meehl, (2006) Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. In Press, Climatic Change.

Vincent, L.A., T.C. Peterson, V.R. Barros, M.B. Marino, M. Rusticucci, G. Carrasco, E. Ramirez, L.M. Alves, T. Ambrizzi, M.A. Berlato, A.M. Grimm, J.A. Marengo, L. Molion, D.F. Moncunill, E. Rebello, Y.M.T. Anunciação, J. Quintana, J.L. Santos, J. Baez, G. Coronel, J. Garcia, I. Trebejo, M. Bidegain, M.R. Haylock, D. Karoly, (2005) Observed trends in indices of daily temperature extremes in South America 1960-2000. Journal of Climate, 18, 5011-5023.

Wilby, R. L., and T. M. L. Wigley, (1997) Downscaling general circulation model output: A review of methods and limitations. Prog. Phys. Geogr., 21, 530-548, 1997.

Xu, Y. L., X. Y. Huang, Y. Zhang, W. T. Lin, and E. D. Lin, (2006a) Statistical analyses of climate change scenarios over China in the 21st century, Adv. Clim. Change Res., 2, Suppl. 1, 50– 53.

Xu, Y. L., Y. Zhang, E. D. Lin, W. T. Lin, W. J. Dong, R. Jones, D. Hassell, and S. Wilson, (2006b) Analyses on the climate change responses over China under SRES B2 scenario using PRECIS, Chin. Sci. Bull., 51(18), 2260– 2267.

Zhang, Y., X. Yinlong, D. Wenjie, C. Lijuan and M. Sparrow (2006) A future climate scenario of regional changes in extreme climate events over China using the PRECIS climate model, Geophys. Res. Lett., 33, L24702, doi:10.1029/2006GL027229

Interactions Between Climate Change and Other Environmental Stresses on North American Forest and Rangeland Health

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Abstract

Forests and rangelands are socially, ecologically and economically important to the countries of North America. Timber, grazing, sources of clean water, carbon capture, landscape beauty, and wildlife habitats are a few of the services provided by these ecosystems. However, since 1850 atmospheric concentrations of carbon dioxide and other greenhouse gases associated with global warming have changed the climate of North America, and that rate of change is increasing. Forests and rangeland have slowly evolved over thousands of years, and the impacts of rapid climate change on ecosystem health and natural resource supply is uncertain. However, there is sufficient evidence to indicate the general direction if not magnitude of change. Climate variability (i.e., daily to inter-annual scale) is likely to increase, bringing more intense precipitation events, droughts, and heat waves. These changes, in turn, will likely increase soil erosion, stream sedimentation, and wildfire occurrence. Increases in insect and disease outbreaks will likely be worsened by a synergism with other pollutant stresses (e.g., ozone, acid rain). Long-term climate change (i.e., decadal and beyond) associated with increasing temperature and shifts in precipitation patterns and seasonality will likely lead to changes in ecosystem composition, fisheries, and wildlife habitat, forest and range land productivity, and stream flow. The severity of climate change may shift some forest areas into rangelands, and rangelands into chaparral or desert ecosystems. Forest and rangeland managers to have a role in mitigating climate change. Land managers will also need to develop and apply adaptation tools and strategies to minimize the negative impacts of climate variability and change on these ecosystems. Interactions between climate change and other environmental stresses on North American forest and rangeland health are examined in this paper.

Introduction

Atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases have been increasing since the beginning of the industrial revolution in the 1850s. Since 1860, the average Earth surface temperature has risen over 1°C. Over the next century, increasing gas concentrations could cause the temperature to rise another 2-3°C (IPCC, 2001).

North America experienced one indication of climate change in 1988: that summer was one of the hottest, driest ever recorded. Barges were stranded on the Mississippi River, and forest fires burned millions of acres in the West. In the eastern United States, temperatures were so high that many factory assembly lines had to be shut down. During that same year, the former Soviet Union states and China experienced severe drought, while Africa, India, and Bangladesh witnessed torrential rains and flooding. Since 1988, the planet has continued to warm (Figure 1) with nine of the ten hottest years ever recorded occurring after 1995 (NCAR).

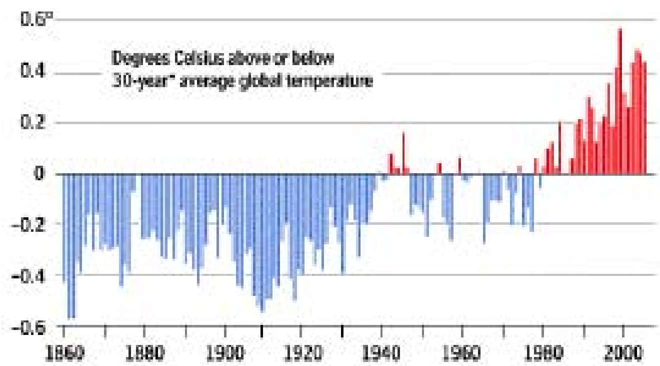

Figure 1. Derivation from global mean temperatures.

The interaction of climate with other forms of environmental stress (e.g., fire, insects, air pollution) is of particular concern (Aber et al., 2001). Ecosystems may be able to withstand individual stresses, but multiple, co-occurring stresses could seriously impact forest and rangeland health and sustainability. In this paper, we will examine the impact of the interactions of climate change and other environmental stress on North American forests and rangelands.

Climate change and climate variability

For the purposes of this paper we define climate change as a long-term progression to a different climate regime through the accretion of small changes. In contrast, climate variability is the daily to inter-annual fluctuation in weather which has always been part of the climate record, but the amplification of which has increased over the past century.

Although there is debate regarding the proportion of climate change that can be attributed to natural variability and cycles, there is an overwhelming consensus that human atmospheric inputs of CO_2 and other gases are increasing global surface air temperatures (Figure 1). These increases in air temperature are projected to continue well into the next century, as predicted by recent general circulation models (GCM). The Hadley Centre's Second Generation Coupled Ocean-Atmosphere GCM, version 2 (HadCM2Sul), predicts an approximate increase of 3.0°C in mean global annual air temperature by 2100 (Climate Impacts LINK Project, 1999).

We have seen increases in variability resulting in weather changes that range from local to continental scales. Precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid- and high-latitudes of the Northern Hemisphere continents, and rainfall has increased by 0.2 to 0.3% per decade over tropical (10°N to 10°S) land areas. Rainfall has decreased over much of the Northern Hemisphere sub-tropical (10°N to 30°N) land areas during the 20th century by about 0.3% per decade (Holland, 1997).

Across the mid- and high-latitudes of the Northern Hemisphere and over the latter half of the 20th century, there has been a 4% increase in the frequency of heavy precipitation events across the US. Increases in heavy precipitation events can arise from a number of causes, including changes in atmospheric moisture and increased atmospheric convectivity that lead to increased thunderstorm activity and large-scale storms (Emanuel, 2005).

In total, these alterations in climate variability and change have begun to alter North American forests and rangelands. These changes will continue and will likely accelerate in the coming years and decades (IPCC, 2002).

Interactions between climate change and other environmental stresses

Climate change is not the only environmental stress impacting forests and rangelands. Insects and disease, wildfire, ozone, and acid rain are additional stresses that can impact ecosystem health and sustainability. Climate change is likely to interact with each of these stresses as global warming continues.

The impacts of these disturbances are highly variable over time and space. Some disturbances, such as hurricanes and ice storms, may be infrequent (i.e., one major event every few years) but have extreme (i.e., near-complete ecosystem destruction) impacts on large areas of forest (e.g., more than 1,000km^2). Other disturbances such as windstorms may be more frequent (i.e., hundreds per year), but individually affect a smaller area (e.g., less than 100 km^2). North American forests and rangelands are increasingly seeing more frequent and severe disturbances such as wildfires and insect outbreaks.

Although much has been learned about the impacts of individual disturbances on forest structure and function, there is little research on the interactions of climate and disturbance (Dale et al., 2000). From our current understanding, some disturbances will very likely increase in severity (e.g., insect and pathogen outbreaks), shift in geographic region (e.g., ice storms), or shift in frequency (e.g., major hurricanes). The combination of climate change and variability will now be examined in conjunction with other environmental stresses

Climate change and ozone interactions on ecosystem stress

Expanding urbanization in North America means that more of our landscape can be considered urban forests. Data suggest that atmospheric CO_2 concentrations in many of our cities are significantly above those in rural areas. Concentrations of ground-level ozone (O_3), have also been increasing recently in most Canadian cities (16% since 1990) (Stats. Can., 2005), meaning that urban forests are already experiencing levels of these gasses predicted for the future. The increased smog days have negatively impacted the already declining urban forest in the larger cities.

Long-range transport of ozone precursors (such as nitrous oxides) and its formation downwind lead to the exposure of large tracts of North American forests to toxic levels of the gas. Effects of this exposure can worsen effects of drought and winter thaw on trees by decreasing their root to shoot growth ratio, and also reduce root energy resources and water use efficiency. This could increase the severity and incidence of large scale tree decline (Cox and Zhu, 2003) and drought interaction (McLaughlin and Percy, 1999). The toxic effects of ozone exposure also offset the positive gains in productivity due to increased atmospheric CO_2 (Karnosky et al., 1999). In combination, higher temperatures and increased O_3 will further stress forests, thus leaving these ecosystems more vulnerable to secondary pathogens such as insects.

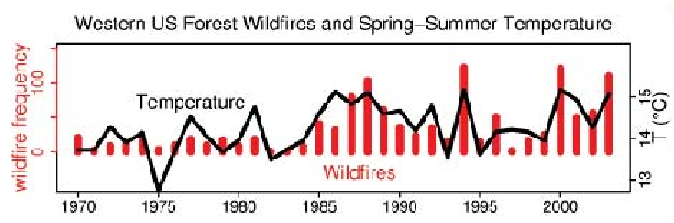

Figure 2. Annual frequency of large (> 400 ha) western U.S. forest wildfires (bars) and mean March through August temperature for the western US.

Climate and wildfire interactions on ecosystem stress

Higher temperatures in western North America from March through August coupled with earlier snowmelt are extending the wildfire season and increasing the intensity of wildfires (Westerling et al., 2006; Running, 2006). Westerling et al. (2006) illustrates the correlation between warming temperatures and the occurrence of large wildfires (Figure 2).

Running (2006) suggested that the trends in larger fires correlate well with reduced moisture availability in forest areas. Flannigan et al. (2005) have projected between 74 and 118% increases in wildfire burn areas in Canada. Also, the 1998 record air temperature year corresponded to the a record year for wildfires in Mexico.

Land managers have done an excellent job of suppressing wildfires since the 1950's. The recent increase in wildfires has been blamed on the accumulated increase of wildfire fuel loads over this time period. However, considering the correlations presented between temperature, snow melt and available moisture, and fire activity, it is likely that climate, more specifically changing climate variability, may play a larger role than previously thought in western fire issues.

Westerling et al. (2006) concluded that

> "land use history is an important risk factor in specific forest types (e.g., some ponderosa pine and mixed conifer forests), but that broad-scale increases in wildfire frequency across the western United States has been driven primarily by sensitivity of fire regimes to recent changes in climate over a relatively large area. The overall importance of climate in wildfire activity underscores the urgency of ecological restoration and fuels management to reduce wildfire hazards to human communities and to mitigate ecological impacts of climate change in forests that have undergone substantial alterations due to past land uses. At the same time, however, large increases in wildfire driven by increased temperatures and earlier spring snowmelts in forests where land use history had little impact on fire risks indicate that ecological restoration and fuels management alone will not be sufficient to reverse current wildfire trends."

The amount of funding to battle wildfires has doubled in the past decade and now represents 40% of the total USDA Forest Service budget. Managers need to work with researchers regarding current and future impacts of climate change on forest and rangelands to avoid unexpected costs and ecosystem consequences.

Winter warming and forest mortality interactions on ecosystem stress

Warmer winters are likely across northern latitudes as global temperatures increase, with increased maximum temperatures, interannual variation, and longer, more intense winter thaws. The number of damaging winter thaws in the northern forests has increased since 1930 (Bourque et al., 2005). In the sub-boreal mixed woods, tree adaptation to harsh winter conditions is paramount to their survivorship. Sudden changes in winter conditions, in relation to the speed of genetic adaptation of these populations, may push some tree species beyond their ability to adapt. An example of this lack of adaptation is the wide spread (i.e., sub-continental) decline of yellow birch (Betula alleghaniensis) since the 1930s. Investigators have determined biophysical and physiological thresholds to winter thaw duration in yellow birch (Cox and Zhu, 2003); since the 1930s, 82% of the birch decline occurred in areas with damaging thaws (Figure 3).

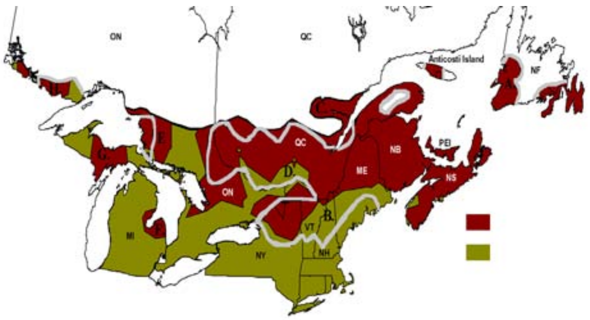

Figure 3. Overlay of projected biologically significant thaw/freeze areas with the observed accumulated areas of birch decline from 1930 to 1960.

Schaberg et al. (2002) also observed that red spruce (Picea rubens) was more susceptible to foliar damage due to winter thaws in areas with high nitrogen deposition rates. The trees with foliar damage had a much higher likelihood of dying when compared to undamaged trees. This combination of climate variability and nitrogen deposition could compromise several tree species across New England and southeastern Canada.

Climate and insect interactions on ecosystem stress

Researchers have long known about the tight linkage between insect outbreaks and climate (Uvarov, 1931). The length and severity of winter freeze, length of the growing season, droughts, and cycles in predator/prey relationship all impact the severity of insects and diseases for which insects are often the vector. Insect outbreaks have been recorded across North America since the early 20th century (Swaine and Craighead, 1924).

Since the mid-1990s, there is evidence that the amount of insect-caused forest mortality has dramatically increased due to a single insect. Approximately 240 million m^3 of lodge pole pine on 11.3 million ha of British Columbian forestland have been killed by mountain pine beetle (Dendroctonus ponderosae, MPB) since 1994, when the first colonies were found (Wilent, 2005). The Canadian Ministry of Forests projects that a total of 500 million m^3 of timber will be killed by 2007 (BC Ministry of Forests, 2004). Approximately 300 million m^3 will be harvested and 200 million m^3 will not be harvested; this converts to 119 Tg of lost wood carbon that will decompose as CO_2 back into the atmosphere (McNulty et al., in review).

The potential for additional MPB range expansion appears likely. Cold temperatures at the upper elevations of the Rocky Mountains have historically posed a barrier to the MPB (Logan et al., 2003). Since the mid-1990s, a series of mild winters greatly increased MPB populations, and in 2002 the MPB established a population on the east side of the Rockies at an elevation of 874 m. The MPB is now only 50 to 100 km from the nearest jack pine (Pinus banksiana) stands, which could potentially be a host species for the beetles (Carroll, 2003; Logan and Powell, 2005). If the MPB were to become established in the jack pine forest, there would be a contiguous host species across all of Canada (approximately 400 million ha), and down the eastern U.S. as far as Texas (Logan and Powell, 2005). If MPB were to move into eastern North America, forest carbon loss could easily exceed a Petagram (i.e., 100 million metric tons). To put this into perspective, this amount of wood loss, is equal to 2159 times the weight of the doomed cruise ship Titanic!

Also, between 2002 and 2003 a drought and bark beetle infestation induced regional-scale die-off of pinon pine (Pinus edulis) across 12,000 km^2 of southwestern North America. This example highlights the potential for such sub-continental die-offs to be more severe and extensive in future global-change-type drought under warmer conditions (Breshears et al., 2005).

Climate and air pollution interactions on ecosystem stress

Since the passage of the US 1990 Clean Air Act Amendments, sulfur (S) deposition has been significantly reduced across much of North America, but little progress has been made in reducing nitrogen (N) emissions or deposition. Concern regarding the impacts of continued S and N (commonly termed "acid") deposition on forest health prompted the development of critical acid loads assessments for forest soils. A critical acid load (CAL) is a quantitative estimate of exposure to one or more pollutants above which harmful effects on sensitive elements of the environment occur. A pollutant load in excess of CAL is termed exceedance.

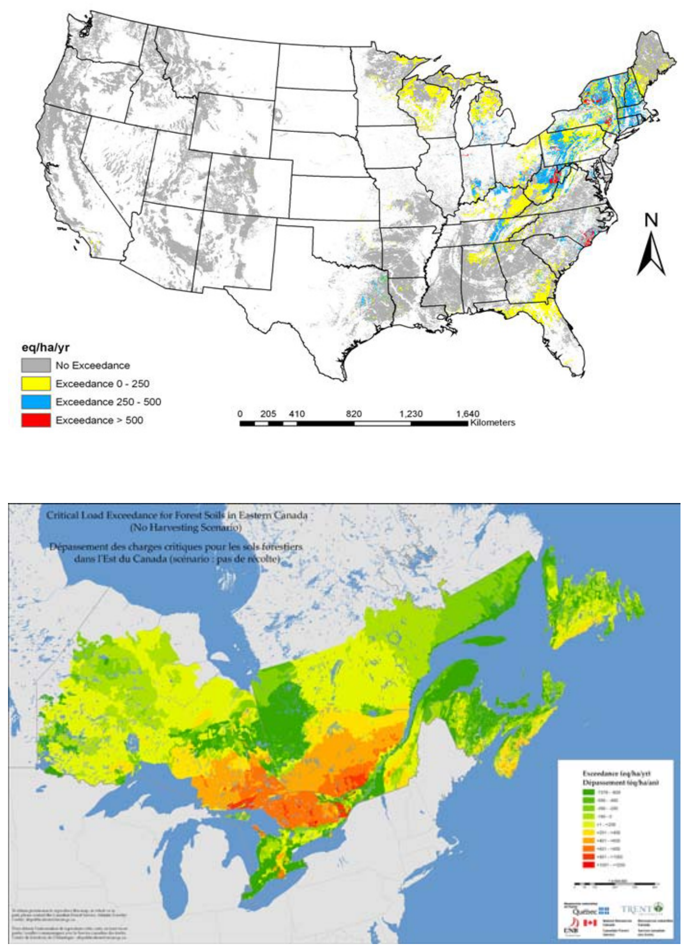

Figure 4. Exceedance of critical loads in the United States (top) and eastern Canada (bottom) based on the average 1994–1998 atmospheric total S+N depositions (from Ouimet et al., 2005; McNulty et al., in review).

Over 50% of the mapped areas between Ontario and the Atlantic Provinces were in exceedance of the CAL, with highest exceedances in southern Ontario and Quebec and the southern Maritimes (Figure 4b, Ouimet et al., 2005). Approximately 3% of US forest soils are in exceedance of their CAL by more than 250 eg ha^{-1} yr^{-1} (McNulty et al., in review). The CAL estimates and steady-state exceedance values for S+N deposition did not include the effects of forest fire or forest harvesting, which could have considerable impacts on critical loads.

Although these results are interesting, model predictions do not account for the synergistic impacts of climate change and other environmental stress on an ecosystem's critical load capacity. Drought, insects, disease, and ozone can all individually or simultaneously occur as additional ecosystem stress. The combined impacts of these stresses can greatly impact an ecosystem's response to climate change and variability (Figure 5).

For example, the interactions of drought, ozone, and insect stresses could reduce a soil's critical acid load by more than half. Land managers need to consider the interactions of climate and other stresses as CAL limits are set. Also, CAL limits will need to be revaluated as the atmosphere continues to warm and interactions between climate change and other ecosystem stress continue to shift.

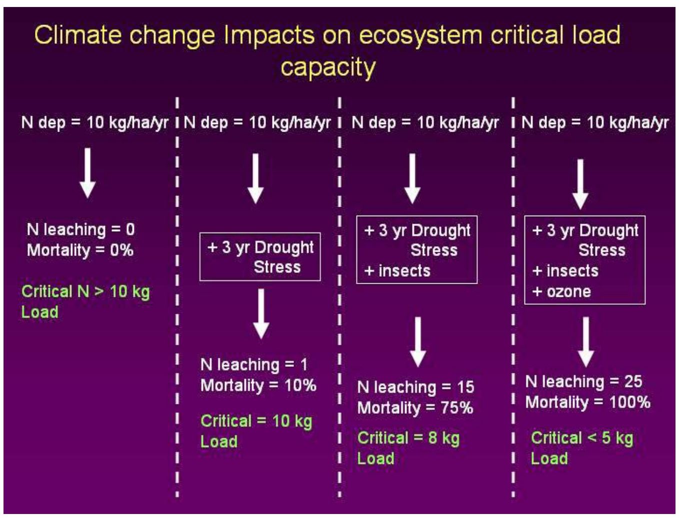

Figure 5. The impact of multiple stresses on soil CAL.

Conclusions

Carbon dioxide remains in the atmosphere for up to a century after it is released. Therefore, it will be many decades before even the most aggressive greenhouse gas mitigation strategies reverse global warming. During this time, the forests and rangelands of North America will be subjected to more intense and often new combinations of environmental stress. The rate of climate change will be much faster than the thousands of years required for trees and grasses to adapt to change conditions. Forest and rangeland managers will need to intervene through the application of existing (e.g., controlled burns, forest thinning, insect control) and new management activities. Good progress is being made by scientists in understanding the complex interactions between climate change and other ecosystem stresses. However, little research is currently occurring on mitigation strategies for coping with expected interactive stress. Significant increases in adaptation studies are now required to prevent unforeseen and potentially catastrophic ecosystem disturbances caused by a changing climate.

References

Aber John, R.P. Neilson, S.G. McNulty, J.M. Lenihan, D. Bachelet, and R.J. Drapek. 2001. Forest Processes and Global Change: Predicting the Effects of Individual and Multiple Stressors. Bioscience 51:735 -751.

Bourque C. P.and R.M. Cox, R. 2005. Spatial extent of winter thaw events in eastern North America : historical weather records in relation to yellow birch decline. Global Change Biology 11:1477-1492.

Breshears, D. D. and N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B.Myers, and C.W. Meyer. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences of the United States of America 102: 15144-15148

Cox, R. M. and X.B.Zhu. 2003. Effects of simulated thaw on xylem cavitation, residual embolism, spring dieback and shoot growth in yellow birch: Tree Physiology 23:615-624.

Dale, Virginia H., L.A. Joyce, S.G. McNulty, R.P. Neilson. 2000, The interplay between climate change, forests, and disturbances. Science and the Total Environment 262: 201-204.

Emanuel, K. A. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436:686-688.

Flannigan M.D., K. A. Logan, B. D. Amiro, W. R. Skinner and B. J. Stocks. 2005. Future Area Burned in Canada. Climate Change 72:1-16.

Holland, G.T., 1997: The maximum potential intensity of tropical cyclones. Journal of Atmospheric Science 54:2519-2541.

Intergovernmental Panel on Climate Change (IPCC). Climate Change 2001: Impacts, Adaptation and Vulnerability. 1005 pgs.

Intergovernmental Panel on Climate Change (IPCC). IPCC Workshop on Changes in Extreme Weather and Climate Events. IPCC Working Group II. Meeting Report. 2002. 107 pgs.

Karnosky, D.F., B. Mankovska, K. Percy, R.E. Dickson, G.K. Podila, J. Sober, A. Noormets, G. Hendrey, M.D. Coleman, M. Kubiske, K.S. Pregitzer and J.G. Isebrands. 1999. Effects of tropospheric O3 on trembling aspen and interaction with CO2: Results from an O3-gradient and a FACE experiment. J. Water, Air and Soil Pollut. 116:311-322.

Logan Jesse, Jacques Regniere and James A. Powell, 2003. ``Assessing the Impacts of Global Warming on Forest Pest Dynamics. Frontiers in Ecology and the Environment. 1: 130-137.

McLaughlin, S. and K. Percy. 1999. Forest Health in North America: Some Perspectives on Actual and Potential Roles of Climate and Air Pollution. Water, Air, and Soil Pollution 116: 151-197

McNulty, S.G., E.C. Cohen, H. Li, and J. Moore Myers. 2007. Estimates of critical acid loads and exceedances for forest soils across the conterminous United States. Environmental Pollution: In press.

Ouimet R., P.A. Arp, S.A. Watmough, J.Aherne, J. and I. Demerchant. 2006. Determination and Mapping Critical Loads of Acidity and Exceedances for Upland forest soils in Eastern Canada. Water Air and Soil Pollution 172: 57–66

Running S.W. 2006. Is global Warming Causing more, Larger Wildfires? Science:6 July 2006 (10.1126/Science.1130370).

Schaberg P.G., D.H. DeHayes, G.J. Hawley, P.F. Murakami, G.R. Strimbeck, and S.G. McNulty. 2002. Effects of chronic N fertilization on foliar membranes, cold tolerance, and carbon storage in montane red spruce. Can. J. For. Res. 32:1351-1359.

Statistics Canada- Catalogue no. 16-125 Executive summary pp iv.

Swaine, J.M. and F.C. Craighead. 1924. Studies on the spruce budworm (Cacoecia fumiferana Clem.). Part I. A general account of the outbreaks, injury and associated insects. Can. Dep. Agric. Tech. Bull. No. 37:3-27.

Uvarov, B.P. 1931. Insects and climate. Royal Entomology Society of London79:174-186.

Wilent, S. 2005. Mountain Pine Beetles Threaten Canadian, US Forests Invasive, Native Species May Cross Canada and Enter United States. The Forestry Source. Society of American Foresters. Vol. 10, No. 5, Pgs. 1 and 4.

Westerling, A. I. H. G. Hidalgo, D. R. Cayan, T. W. Swetnam. 2006 Warming and Earlier Spring Increases Western U.S. Forest Wildfire Activity. Science 6 July 2006 (10.1126/Science.1128834).

Simulating soil-precipitation feedbacks in South America

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Abstract

We resume the recent progress in regional climate modeling in South America using the Rossby Centre regional atmospheric climate model (RCA3-E) with emphasis on soil moisture processes. A series of climatological integrations using a continental scale domain nested in reanalysis data were carried out. The role of including a spatially varying and deeper soil depth in the model, the influence of anomalous soil moisture initial conditions on the intraseasonal development of the South American Monsoon System, and the land-atmosphere coupling strength were analyzed. In these simulations the austral winter soil moisture initial condition has a strong influence on wet season rainfall over the continental convective monsoon regions and subtropical South America appears as a region with relatively high coupling strength during the mature phase of monsoon development.

1 Introduction

South America extends across the equator from about 10°N to 55°S and has unique surface features from the world's largest rain forest in Amazonia to the driest desert in northern Chile and a high desert in the Altiplano. The South American Monsoon System (SAMS, Nogués-Paegle et al., 2002) dominates the mean seasonal cycle of precipitation in the region. Climate variability associated with the SAMS significantly affects people and ecosystems due to altered precipitation patterns. The timing of its onset and duration and the frequency and intensity of daily rainfall have important implications for agriculture, hydroelectric power generation, and local ecosystems throughout large regions of tropical and subtropical South America. The large-scale land cover changes and the shift in population to high density urban areas have put supplementary worry on water resources. The correct simulation of the SAMS and the understanding of the associated surface processes are keys for seasonal climate forecasting, for studying the interannual variability and the long-term changes of the regional precipitation and for determining the climatic impact of land use.

Regional Climate Models (RCMs) are crucial tools to investigate climate variability, in principle, adding value over coarse resolution global models and reanalyzes. However, there is relatively little experience in the use and development of RCMs for this region. At present much of the work on regional climate modelling in South America remains at the level of methodological development and preliminary testing. Important processes affecting South America are poorly represented or not included in current climate models. In particular, the deficient representation of the underlying land surface adds to the uncertainty in the simulation of fundamental aspects of the SAMS.

The simulation of soil moisture–precipitation feedback processes is an issue that has not been fully addressed in South America yet. The purpose of this study is to resume the recent progress in regional climate modeling in South America using the Rossby Centre regional atmospheric climate model (RCA3, Kjellström et al., 2005; Samuelsson et al., 2006), with emphasis on the simulated surface feedbacks in the region. Our objectives are threefold: (a) To isolate the role of including a spatially varying and deeper soil depth; (b) To examine the influence of soil moisture initial conditions on SAMS development; and (c) To explore the land-atmosphere coupling strength (defined as the degree to which prescribed soil moisture conditions affect precipitation).

2 Model description and assessment of the simulated rainfall

The Rossby Centre Regional Atmosphere Model, RCA, is a hydrostatic, primitive equation grid-point limited area model. In this work we use the most recent version of RCA, called RCA3 (Kjellström et al. 2005), modified by including the surface database Ecoclimap (Masson et al., 2003) as well as adjustments of the atmospheric physics due to limitations in the transferability (RCA3-E). Details on the physical parameterizations, including changes in the radiation, turbulence and cloud parameterizations in RCA3 compared to earlier versions, as well as recent updates regarding technical aspects, are described in http://www.smhi.se/sgn0106/if/rc/rca.htm. All simulations were carried out using a continental scale domain and were forced by large-scale boundary conditions from the European Centre for Medium-Range Weather Forecasts (ECMWF) 40-year Reanalysis (ERA-40). This domain is based on a rotated grid system with a horizontal resolution of 0.5º and 24 unevenly spaced vertical levels.

We performed a 5-yr simulation of the present climate (1995-2000) with 2 years of spin-up for soil moisture and one month of spin-up for the atmosphere. In comparison to high-resolution (0.5ºx0.5º) precipitation data compiled by the Climatic Research Unit (CRU) of the University of East Anglia, RCA3-E captures many aspects of the observed climate, but underestimates the annual mean rainfall over parts of northern Amazonia and central Brazil, and over some areas of south-eastern South America (southern Brazil, Uruguay, north-eastern Argentina). The precipitation is overestimated in parts of northern Brazil (around 5ºS), western Amazonia and along the Andes (figure 1). The model has also been compared with other similar models in the framework of the CLARIS project (http://www.claris-eu.org). RCA3-E exhibits a reasonably good agreement with observations, although some deficiencies (often also found in other state-of-the-art global and regional models) are evidenced in the simulation of the regional precipitation. The biases over regions with relatively flat terrain, common to many models, remain for the most part unexplained and the search for their responsible physical mechanisms will be challenging. However, as South America and surrounding oceans is a data-poor region, the actual model skill is masked by existing uncertainties in the lateral boundary conditions used to drive the model and in the observational-based datasets used in its evaluation.

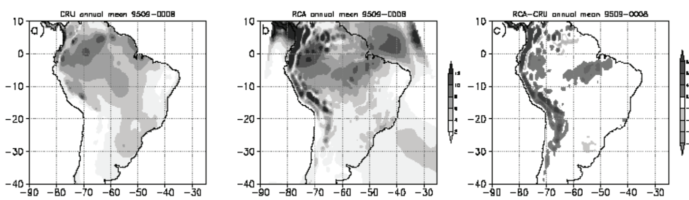

Figure 1: Annual-mean precipitation 1995-09-01 – 2000-08-31. a) CRU, b) RCA3-E, c) RCA3-E minus CRU.

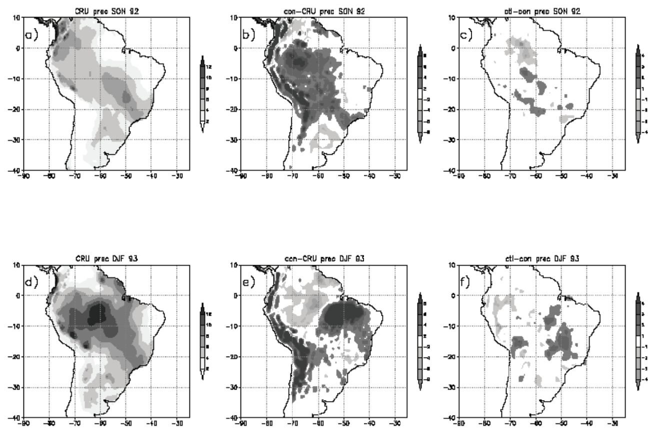

Figure 2: Mean rainfall (mm/d) for a) – c) the spring (SON) 1992 and d) – f) summer (DJF) 1992-93: a) and d) CRU climatology, b) and e) bias with respect to the ensemble with constant soil depth (CON), and c) and f) difference between both ensembles (CTL-CON: variable soil depth minus constant soil depth).

3 Sensitivity to a spatially varying soil depth

The depth of the hydrological soil reservoir, usually too small in RCMs, is a key factor for determining the strength of the hydrological cycle (van den Hurk et al., 2005). A need for a proper specification of this depth and for improvement in the modelling of surface processes is implied. In general, land surface parameterizations in both global and regional models generally use values of about 2 m for rooting depth (e.g. the current version of RCA3 used over Europe employs a constant soil depth of 2.2 m for all regions but mountain regions where it is set to 1.0m). This is in contrast to the observational-based data: deep roots of up to several meters could exist in the Amazon basin (Nepstad et al., 1994).

The interest in focusing on this parameter is motivated by two factors: (i) the fact that over large areas of northern South America, the forest soil depths are significantly increased with the incorporation of Ecoclimap in the model, and (ii) previous works suggest the importance of soil depth and deep rooted vegetation on the climate system (e.g. Kleidon and Heimann, 2000). In order to estimate the impact on the development of the SAMS of introducing a spatially varying soil depth or rooting depth in the model (both parameters are coincident in this land surface model), we performed two ensembles of five members each of the period September 1st 1992 through March 31 1993 (with 2 years of spin-up for soil moisture and one month of spin-up for the atmosphere). Ensemble CTL was run with soil depth from the new Ecoclimap database while ensemble CON with the usual constant soil depth (2.2 m).

Figure 2 compares the CRU climatology for the spring and summer 1992-93 with the simulated ensemble means for the simulations performed with constant soil depth (CON) and with variable soil depth (CTL). The inclusion of a spatially varying soil depth tends to reduce the bias in spring and to enhance it in summer over Amazonia. Further south, over tropical regions, the positive precipitation bias in spring was increased in CTL, likely due to an enhanced southward transport of atmospheric moisture associated with the low level jet. During summer the difference between both ensembles is the largest over Brazil and tends to increase the precipitation over large areas affected by the SACZ (a south eastward extension of cloudiness and precipitation from the southern Amazon towards southeast Brazil and the neighbouring Atlantic Ocean).

4 SAMS sensitivity to soil moisture initial conditions

In this section we explore the influence of anomalous soil moisture initial conditions in late austral winter on the intraseasonal development of the SAMS. The soil moisture memory potentially contributes to atmospheric variability and seasonal predictability. In a study using ERA15 data, Fu and Li (2004) and Li and Fu (2004) found that the continental surface conditions seem to control the onset date of the monsoon, and in particular that an anomalously dry land surface during the dry season could delay the onset of SAMS with as much as two months. Two recent sensitivity studies performed with regional models have explored the effects of initial soil moisture on precipitation, focusing on particular years and areas (Ferreira et al., 2006; Collini et al.; 2006).

We performed two simulations of the period 1 September 1990–31 April 1991 with modified initial soil moisture. These simulations, with anomalously dry and wet land surface conditions over the whole domain, will in the following be called "D" and "W", i.e. too dry and too wet initial soil moisture, respectively. The initial soil water availability (SWA) was taken from the driving reanalysis (ERA40). The SWAERA40 was multiplied by a factor 0.2 to generate dry conditions, and we used the formula SWAWET=SWAERA40 + (1- SWAERA40)*0.8 to generate wet conditions.

To outline the premonsoon and monsoon evolution during the rainy season, we illustrate in figure 3 the monthly mean precipitation, zonally averaged between 60°W and 40°W, from September through May. The development phase of SAMS during austral spring of 1990 was characterized by the presence of the ITCZ in the northern part of the domain; with a tendency toward moving southward especially in experiment D. A strong precipitation band between 15°S and 25°S appears from October in experiment D and one month later in experiment W. Meanwhile, the rapid southward shift of the region of intense convection from the equator toward the southern Amazon Basin is manifested earlier in experiment W (in November). During the mature phase (December-January), rainfall intensity is heavier in case W over the SAMS core region, but case D simulates stronger precipitation further south over eastern Brazil and the nearby Atlantic. The decay phase continues through austral summer as convection gradually retreats northward toward the equator merging with the ITCZ. The band with intense precipitation is stronger in experiment W, but tends to be wider (more meridionally extended) in experiment D.

In order to provide a more detailed picture of the model's sensitivity than the monthly mean values, figure 4 displays the histograms of daily rainfall on different intensity classes over three continental areas where January sensitivity is particularly strong: Amazonia, central-eastern Brazil and northern Argentina (monthly mean rainfall decreases in Amazonia and increases in the other two regions in experiment D). The methodology is to count for each grid point, the total number of days within each interval representing dry days (0-0.5 mm/day) and light (0.5–6 mm/day), moderate (6–15 mm/day), strong (15–30 mm/day) and heavy (> 30 mm/day) precipitation days.

The effect of soil moisture late winter initial conditions on the frequency distribution of the daily rainfall rates in January shows a considerable spread among the different regions. Over Amazonia, dry surface initial conditions strongly decrease the number of intense convective rainstorms (i.e. strong and heavy rainfall days) and the number of wet days, consistently with a monthly mean decrease in the rainfall amount. However, experiment D generates larger frequencies for light intensities (0.5 to 6 mm/d). Over central-eastern Brazil

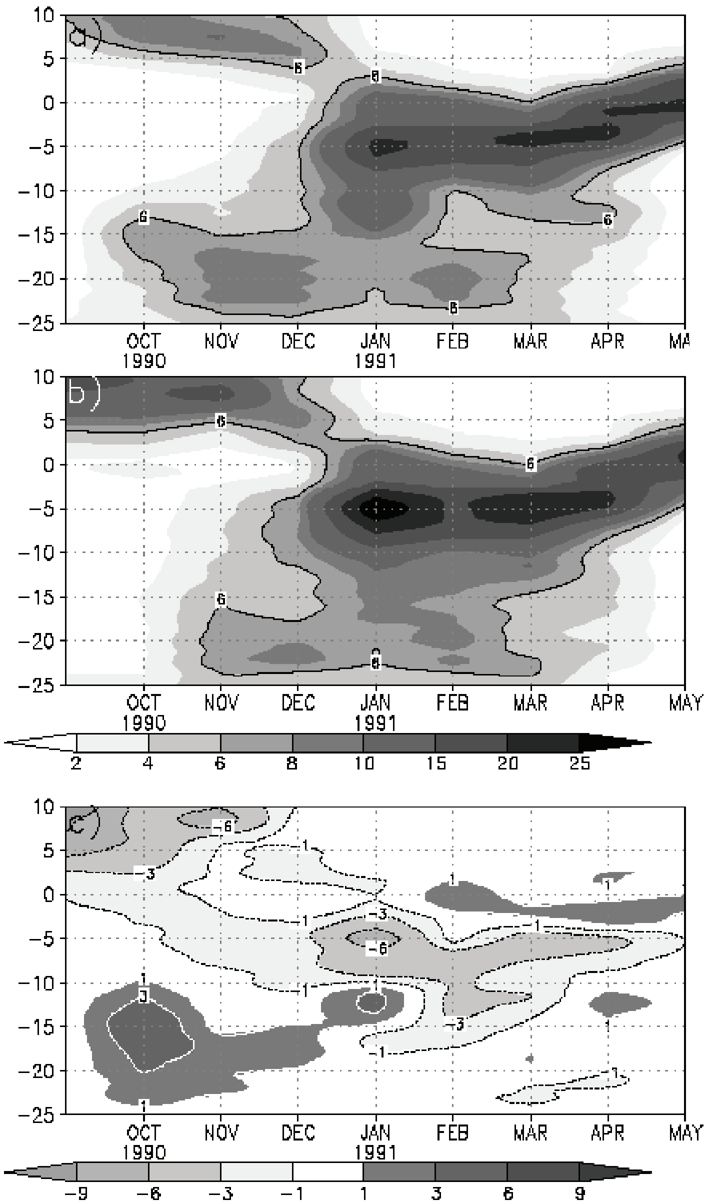

Figure 3: Temporal evolution of the monthly mean precipitation (mm/day) averaged over 40°–60°W from September through May: a) dry, b) wet, and c) dry minus wet. Vertical axis shows latitudes.

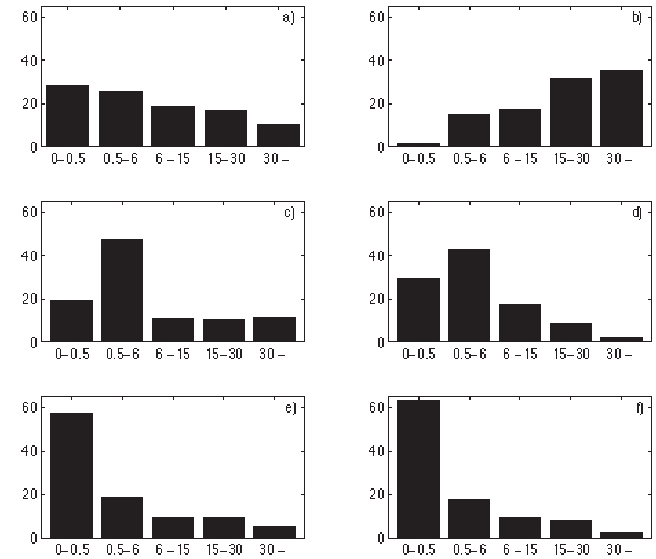

Figure 4: Histograms of daily January precipitation rates (mm/day) over a), b) Amazonia (3°S–8°S, 63°W-53°W), c), d) central-eastern Brazil (14°S-20°S, 44°W-40°W) and e), f) northern Argentina (24°S-28°S, 62°W-58°W) for the dry (left panels) and wet (right panels) experiments (ordinate in percentage).

dry days are less frequent and the number of events in the highest intensity regime is considerably augmented in experiment D. Changes in northern Argentina are weaker, but we still notice a decreased number of dry days and an increased number of strong and heavy rainfall days as a response to decreased initial soil moisture, consistently with the increase in monthly mean precipitation in experiment D.

5 Land-atmosphere coupling strength

We explore another way of determining soil moisture influence on the South American climate. Coupling strength is defined as the degree to which all prescribed boundary conditions affect some atmospheric quantity. In our case, we are interested in documenting the degree to which the precipitation responds to soil moisture anomalies during the mature phase of SAMS. Coupling strength is still largely unknown for South America and is a very uncertain aspect of regional modelling.

The methodology has been adapted to regional modeling following Koster et al. (2003, 2004) who made an estimate of the soil moisture coupling to precipitation using atmospheric GCMs. Two ensembles (called W and S) of ten members each were created, starting from different initial dates. Each member includes the 120-days-period November 1st 1992 through March 31 1993 (with 2 years of spin-up for soil moisture and one month of spin-up for the atmosphere). In the first ensemble (W) the only difference between members is the initialization date and the model predicts soil moisture. The second ensemble (S) is similar, but the ensemble members are forced to maintain the same space-time series of top and deep soil moisture. The initial dates are the same for the two ensembles so the only difference between ensemble W and S is that soil moisture is equal among members in ensemble S while it differs among members of ensemble W. By comparing the variance among the members of W with the variance among the members of S, we will be able to isolate the space varying impact of the soil moisture on precipitation.

We can quantify coupling strength by examining measures of the agreement in the weather generated amongst the ensemble members. Figure 5 shows the coupling strength, as measured by the variance ratio, across South America for December and January (i.e. the rainfall variance across the 10 members of ensemble S divided by the corresponding variance for ensemble W for the 31 days of December and the 31 days of January). Following Koster et al. (2003), the idea is that if rainfall is strongly controlled by subsurface soil moisture state, then the rainfall variance for ensemble S, which uses identical soil moisture time series in each member simulation, should be smaller than that for ensemble W, which allows soil moisture to differ across the simulations. In other words, the variance ratio should be less than one in regions where precipitation responds to soil moisture. The regions in which the variance for ensemble W is at least twice the variance for ensemble S are shown in dark shaded areas in the figure. The few regions with strong coupling strength between soil

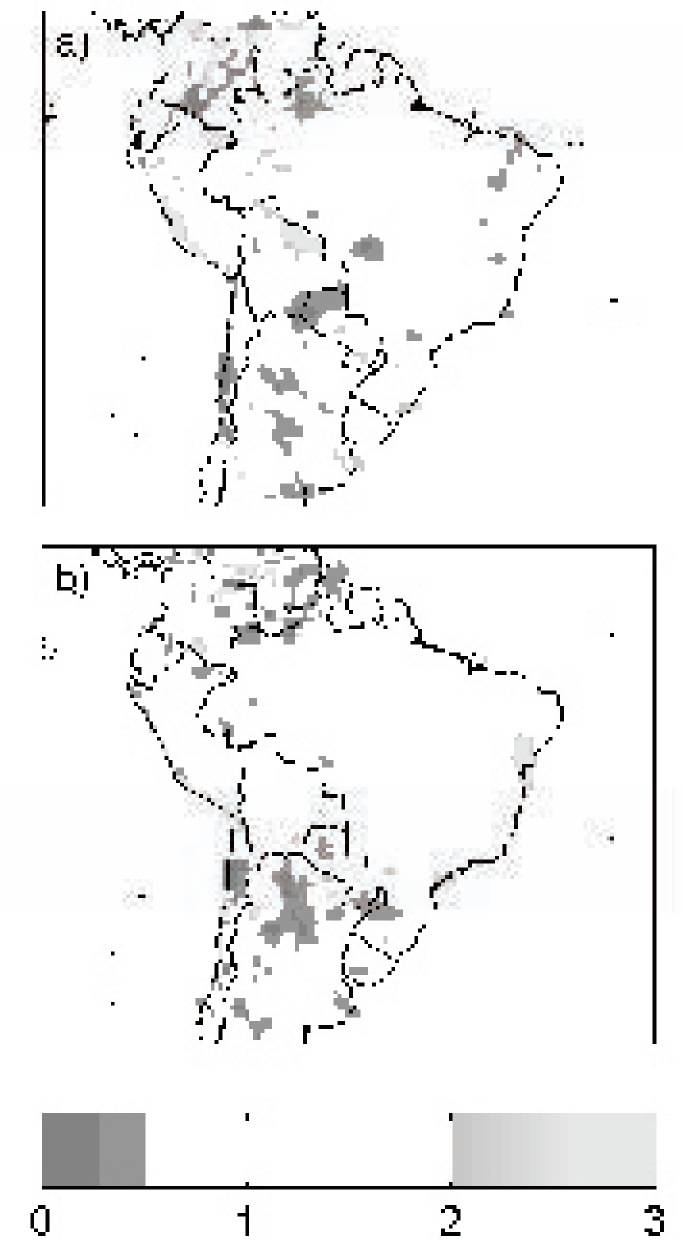

Figure 5: The "variance ratio" as a measure of the coupling strength between soil moisture and precipitation (the rainfall variance across the 10 members of ensemble S divided by the corresponding variance for ensemble W) for a) December and b) January. The areas with strong coupling strength are shaded in dark grey.

moisture and precipitation tend to be found in northern Argentina and Paraguay. Thus, these results suggest that subtropical South America is a region with relatively high coupling strength during the mature phase of monsoon development.

6 Final remarks

We have described ongoing research using RCA3-E in South America with emphasis on soil moisture processes. Obtaining a better understanding of the effect of land surface conditions on the SAMS development and the associated daily rainfall characterization is useful for various research areas, including seasonal forecasting and climate change studies. The evolution of the SAMS has important consequences for agriculture, hydroelectric power generation and local ecosystems. Various experiments, initialized with the new Ecoclimap database and driven with ERA-40 reanalysis, were carried out using a continental scale domain.

An objective of this work was to isolate the role on SAMS development of including a soil depth that extends as deep as 8 m in some areas of Amazonia. We have compared an ensemble of simulations which includes spatially varying soil depth to another with the standard constant soil depth. The role of the soil depth depiction was relatively less critical than expected, with both beneficial and detrimental effects on the simulation of the seasonal mean rainfall. However, it should be considered that the simulations were initialized in late winter, extending only throughout spring and summer. Kleidon and Heimann (2000) suggest that the incorporation of deep roots into a climate model would be important especially during the dry season (i.e. austral winter in South America). The ever-green forest would be capable of transpiring considerable amounts of water throughout the dry season if deep soil depth and deep roots are included in the model. According to Kleidon and Heimann (2000), in that case, evapotranspiration and the associated latent heat flux are considerably increased and the enhanced atmospheric moisture is transported towards the main convection areas in the inner tropical convergence zone where it supplies more energy to convection thus intensifying the tropical circulation patterns. This effect still needs to be verified with RCA3-E and will be the subject of future research.

Another objective was to examine the influence of soil moisture initial conditions on the SAMS development. In this case, we have compared two simulations of the period 09/1990 to 04/1991 with modified initial soil moisture. Of course, studying the impact of soil moisture initial conditions constitutes a limited approach as part of the difficulty for understanding and simulating the hydrologic cycle in this region. In this simple and qualitative assessment of the soil–precipitation feedback, we have analyzed simulations with opposite soil moisture initial conditions in order to represent two highly idealized and extreme anomalous surface conditions during the late austral winter. Our results suggest that the initial springtime soil moisture conditions feed back upon the SAMS during the warm months, not only over Amazonia but in subtropical South America as well. This could be related with two mechanisms: (i) Anomalies in the Bowen ratio in the tropics could propagate southward through an enhanced (or poorer) transport of atmospheric moisture associated with the low level jet; and (ii) Changes in convection patterns can affect the Hadley Circulation and thus propagate climate perturbations into the mid-latitudes. The fact that tropical regions have the potential to affect climates beyond their neighbouring area has been discussed in the recent literature (e.g. Voldoire and Royer, 2004; Avissar and Werth, 2005; Feddema et al., 2005).

In Koster et al. (2003, 2004) the coupling strength simulated by a dozen atmospheric GCMs was evaluated for the Northern Hemisphere summer. The results differ widely from model to model. This model dependency suggests that the physical processes occurring at the continental land surface are not properly represented in current climate models. These processes are indeed very numerous and intricately linked, being a function of the parameterizations controlling e.g. the land surface energy balance, the development of the boundary layer and the precipitation generation. Based on the analysis of two ensembles of simulations of the austral summer, our results indicate that the degree to which the atmosphere responds to soil moisture conditions is relatively large in northern Argentina, southern Bolivia and Paraguay. The reasons for the geographical variations in the coupling strength are not sufficiently clear and require additional analysis. Koster et al. (2004) suggest that in continental transition zones between wet and dry climates during summer, where boundary layer moisture can trigger moist convection and where evaporation is suitably high but still sensitive to soil moisture, can we expect soil moisture to influence precipitation. The regions of maximum coupling strength simulated by RCA3-E indeed tend to be located in transition zones in South America and are qualitatively compatible with Koster et al. (2004) thoughts. In order to address the realism of

RCA3-E's coupling strength and sensitivity to soil moisture conditions more diagnostics and simulations are needed and, in particular, it would be useful to determine how it compares with other RCMs in this region.

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References

Avissar R, Werth D (2005) Global hydroclimatological teleconnections resulting from tropical deforestation. J Hydrometeorol 6: 134–145

Collini EA, Berbery EH, Barros V (2006) Seasonal dependence of surface-atmosphere interactions for subtropical South America. Proceedings of the 8th ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 999-1004

Feddema JJ, et al. (2005) A comparison of a GCM response to historical anthropogenic land cover change and model sensitivity to uncertainty in present-day land cover representations. Clim Dyn 25:581–609

Ferreira LJ, Saulo C, Ruiz J, Seluchi M (2006) The impact of land use changes over the low level circulation related to the Northwestern Argentinean Low. Proceedings of the 8th ICSHMO, Foz do Iguaçu, Brazil, Apr.24-28, 1029-1035

Fu R, Li W (2004) The influence of the land surface on the transition from the dry to wet season in Amazonia. Theoretical and Applied Climatology 78:97-110

Kjellström E, Bärring L, Gollvik S, Hansson U, Jones C, Samuelsson P, Rummukainen M, Ullerstig A, Willén U, Wyser K (2005) A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3). Reports Meteorology and Climatology No. 108, SMHI, SE-60176 Norrköping, Sweden, 54pp

Kleidon A, Heimann M (2000) Assessing the role of deep rooted vegetation in the climate system with model simulations: mechanism, comparison to observations and implications for Amazonian deforestation. Clim. Dyn. 16:183-199

Koster RD, PA. Dirmeyer, Z Guo, G Bonan, E Chan, P Cox, CT Gordon, S Kanae, E Kowalczyk, D Lawrence, P Liu, C-H Lu, S Malyshev, B McAvaney, K Mitchell, D Mocko, T Oki, K Oleson, A Pitman, Y C Sud, C M Taylor, D Verseghy, R Vasic, Y Xue, T Yamada (2004) Regions of Strong Coupling Between Soil Moisture and Precipitation. Science 305:1138-1140

Koster R, Guo Z, Dirmeyer P (2003) GLACE: Quantifying Land-Atmosphere Coupling Strength Across a Broad Range of Climate Models. CLIVAR Exchanges 28:1-3

Li W, Fu R (2004) Transition of the Large-Scale Atmospheric and Land Surface Conditions from the Dry to the Wet Season over Amazonia as Diagnosed by the ECMWF Re-Analysis. J Clim 17: 2637–2651.

Masson V, Champeaux J-L, Chauvin F, Meriguet C, Lacaze R (2003) A Global Database of Land Surface Parameters at 1-km Resolution in Meteorological and Climate Models. J Clim 16: 1261–1282

Nepstad DC, de Carvalho CR, Davidson EA, Jipp PH, Lefebvre PA, Negreiros HG, da Silva ED, Stone TA, Trumbore SE, Vieira S (1994) The role of deep roots in the hydrological and carbon cycles of Amazonian forests and pastures. Nature 372:666-669

Nogués-Paegle J, and co-authors (2002) Progress in Pan American CLIVAR research: understanding the South American monsoon. Meteorologica 27:1-30

Samuelsson P, Gollvik S, Ullerstig A (2006) The land-surface scheme of the Rossby Centre regional atmospheric climate model (RCA3). Report in Meteorology 122, SMHI. SE-601 76 Norrköping, Sweden

van den Hurk B, et al (2005) Soil control on runoff response to climate change in regional climate model simulations. J Clim 18:3536–3551

Voldoire A, Royer JF (2004) Tropical deforestation and climate variability. Clim Dyn 22:857–874

Regional climate effects of land cover changes in the Mato Grosso do Sul State, Brazil

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ABSTRACT

In this study are presented results from a land surface model, the National Center for Atmospheric Research Community Land Model, version 3 (CLM3), driving by the high resolution model of the Weather Forecast Study Center CPTEC, Atmosphere General Circulation Model (AGCM). The land-surface model is used to estimate the variability over land surface atmosphere, water and energy flux exchanges. Little is known regarding vegetation-climate equilibrium and the interactions of land cover dynamics with precipitation patterns and variability. In this preliminary study, the land surface of the Mato Grosso do Sul State, Brazil (24° S to 17° S; 59° W to 50° W) is characterized by an intense field campaign and remote sensing techniques. The land cover is characterized through remote sensing by a multitemporal analyzes and the topographic data is obtained from a digital elevation model, where the flow directions were determined to the most important Basins (Miranda and Guariroba Basins). The leaf area index (LAI), gathered from MODIS remote sensing data and a dynamic phenology scheme allow leaf biomass and fractional area respond to environmental variation. This dynamic phenology scheme is calibrated by field experiments. In this study two types of the land surface are used. The first land surface has used a current vegetation distribution and a hydrological net based on the main basins flow direction. The second one has used a natural vegetation distribution, this land surface data do not include any land cover changes or rivers in details. The preliminary results indicate that the conversion process from natural vegetation to the current land cover and the presence of rivers, lakes and wetlands in the model, produced discernable effects over land surface, atmosphere, water and energy flux exchanges, but the magnitude of the effects are dependent upon the preexisting vegetation type. The land use change impacts are most pronounced during the dry season months (March to September) when surface heating is strongest and differences in surface moisture between irrigated land and natural vegetation are largest. In spite of correctly represent the Basins in the simulation can account for a best agreement between model and observed near surface temperature values.

1. INTRODUCTION

The land surface processes exchanges water, energy, momentum and also CO_2 with the atmosphere, and play an important role in the climate system, Gulden and Yang [2006].

Given the potential importance of land surface process in the climate system, efforts have been made to develop process-based on biophysical models of land-atmosphere exchange processes looking for to couple them to general circulation models, Tao Z. N. and A. K. Jain [2005].

Nowadays, a considerable number of land surface models, that differ greatly in the processes considered and in the degree of complexity, are been used by the scientific communities, de Rosnay, P., A. Boone, A. Beljaars, and J. Polcher [2006]. The majority of these models simulate the land surface process by considering a prescribed geographical distribution of the vegetation and soils. A small number of land surface models also represent the dynamics of the vegetation and the carbon cycling in vegetation and soil.

In order to increase realism in the climate impact modeling, the primary purpose of the present paper is scrutinize CLM3 scientifically, when it is driven by high resolution CPTEC/AGCM and emphasizes a description of the CLM3´s contribution to climate simulations of the Mato Grosso do Sul State. This study may subside other environmental and climatic models on tropical areas.

2. THE STUDY CASE AREA

The Mato Grosso do Sul State, with 358000 km^2, is located into a climatic transition area suffering with different air masses, resulting in a high spatial and temporal thermal variability. This State has a large hydrographic net, with two important hydrographic Basin of Brazil: Paraguay and Paraná River Basins.

The Paraguay Hydrographic region (Figure 1) includes one of the most humid continuum extensions of the planet, the Pantanal, considered National Patrimony by the 1988 Brazilian Federal Constitution and Biosphere Reserve by UNESCO in 2000 year. In these regions two important biomes could be observed: Cerrado and Pantanal, with transitions zones. The predominant vegetation was savanna trees (Cerrado) and forested savanna (Cerradão). Since 70's decade, the cattle breeding expansion, soy bean and sugarcane extensive productivity in plan areas have lead to land cover changes, with increasing deforestation and soil erosion. Actually, this region is intensely cultivated and features rapid landscape changes.

3. MODELS AND METHODS

The NCAR CLM3 model was developed to represent the spatial heterogeneity of land surface and hydrological processes; Oleson et al. [2004] and Dai et al. [2003], provided a thorough description of the standard CLM, which can be integrated either as part of a fully coupled model of the climate system, or using preexisting high-resolution meteorological forcing data, in off line mode, but with prescribed sea surface temperatures (SSTs) and sea ice concentrations (fractional coverage).

The processes considered by CLM3 include: vegetation composition, structure and phenology; absorption, reflection and transmittance of solar radiation; absorption and emission of longwaves radiation; momentum, fluxes of sensible heat (ground and canopy) and

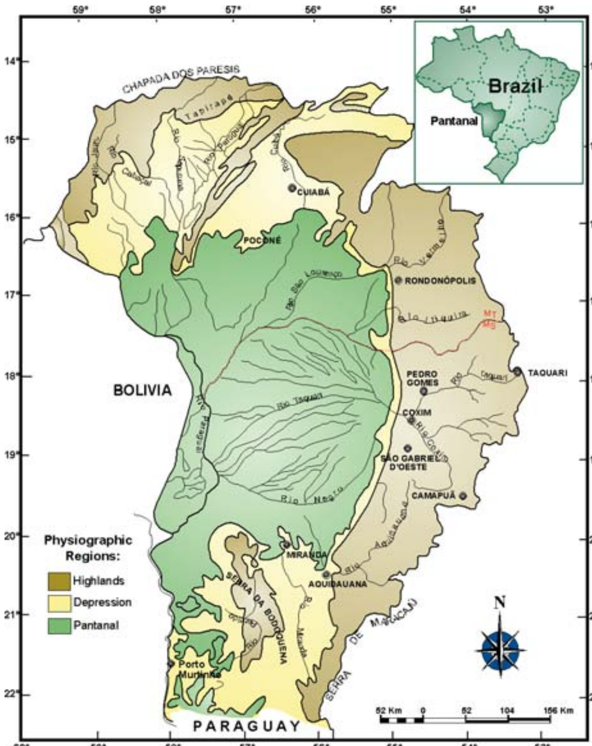

Figure 1: the High Paraguay Hydrographic Basin in Brazil, showing the main Physiographic Regions.

latent heat (ground evaporation, canopy evaporation, plant transpiration); heat transfer in soil and snow, including phase changes.

The terrestrial hydrological processes in the model include interception of precipitation by the vegetation canopy, canopy hydrology; snow hydrology; soil hydrology (surface runoff, infiltration, sub-surface drainage, redistribution of water within the column which has 10 layers and a fixed depth of 3.43 m); stomatal physiology and photosynthesis, lake temperatures and fluxes; routing of surface runoff to streams and rivers and to oceans. Although water storage in lakes and rivers is not explicitly represented in the model, a lake model is included in the NCAR CLM to compute its water storage variations through the variations of precipitation and evaporation. The emissions of biogenic volatile organic compounds (BVOCs) are considered as a function of plant species, photosintetically radiation PAR, canopy temperature, and leaf biomass density, Gulden et al. [2006].

In order to simulate the distribution and structure of natural vegetation dynamically, the DGVM was considered coupled to CLM, referenced by CLM-DGVM. Such coupling enables the simulation of two-way biogeophysical and biogeochemical feedbacks between climate and vegetation, ensuring conservation of energy and mass in the modeled system.

3.1 Construction of atmospheric forcing data: The CPTEC AGCM

The atmospheric forcing data for driving CLM3 include 3-hourly precipitation, temperature, specific humidity and wind speed, surface air pressure and downward solar radiation at T062L28 (200x200km) and T213L42 (63x63 km) resolutions of the high resolution CPTEC Atmosphere General Circulation Model (AGCM). The atmospheric forcing data to T062L28 resolution has covered the period from 1984 to 2004. With this aim, a preprocessor was constructed to prepare the CPTEC AGCM output to drive CLM3, with one year's worth of atmospheric forcing variables, in monthly netCDF format suitable for running the model in offline mode (uncoupled from the atmospheric model).

3.2 Surface Data Set

The structure of CLM consists of local process rules together with rules for scaling from the plot scale to the grid scale. Data are included in the model as tables correlated with the land cover description. In order to simulate the interactions of land with the atmosphere, on the grid scale, assuring accuracy on describing Mato Grosso do Sul State land cover as thoroughly as possible, two surface data sets are generated for running CLM3.

In order to consider the water storage variations inside of the study area, the main basin flow directions are considered into account. The study area, Miranda river hydrographic basin (Figure 2), has had its limits determined using the NASA SRTM (Shuttle Radar Topographic Mission) digital elevation data, which has also been used as topographic data source, as slope, aspect and flow direction. A smaller Basin, Guariroba Stream, responsible for human water supply in the biggest city of the State, has also been modeled.

3.3 Multitemporal Analysis

In order to quantify the extensive land cover changes in the study area, a multitemporal analysis has been carried out. The entire 224/074 (path/row) Landsat TM images of 1989 and 2004 (LANDSAT, 1989 e LANDSAT, 2004) have been classified, using the maxver algorithm and all visible channels.

The classified area represents a square of 185 x 185 km, between latitudes 19°16'52,45''S and 21°10'20,15''S e longitudes 54°43'47,31''W e 52°25'09,25''W, comprising two important cities: Ribas do Rio Pardo e Água Clara.

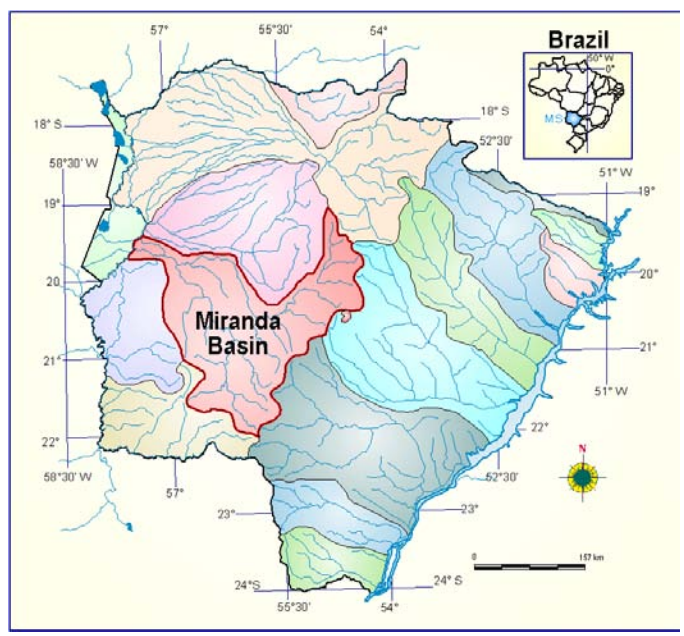

Figure 2: Miranda River hydrographic basin localization.

The Figure 3 shows the 1989 classified image. The table 1 presents the quantification of the different land cover based on their spectral signatures (Paranhos Filho 2004; Paranhos Filho et al., 2006).

The Figure 4 shows the 2004 classified image. The Table 2 presents the quantification of the different land cover based on their spectral signatures.

In order to improve land surface climate and energy balance simulations in the CLM3, a new land surface data set was created from the latest MODIS high quality products of LAI, vegetation con-

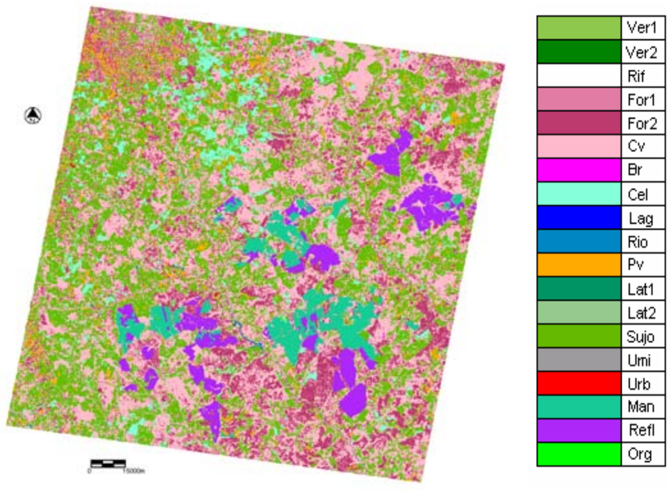

Figure 3: 224/074 (path/row) Landsat TM image of 05/13/1989 showing the land cover based on the spectral signatures (see also table 1 for the interpretation of the legend).

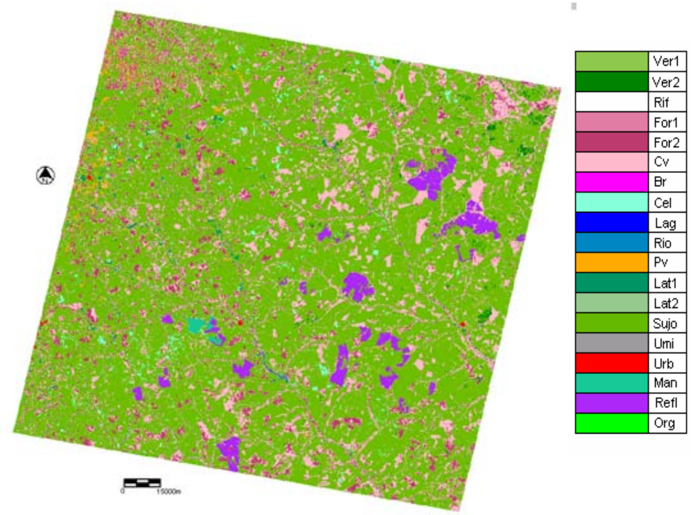

Figure 4: 224/074 (path/row) Landsat TM image of 10/29/2004 showing the land cover based on the spectral signatures (see also table 2 for the interpretation of the legend).

Table 1: 1989's land cover percent of each spectral signature.

1989's land cover types obtained from the image classification	Percent of Total Area (%)
Ver1 (open pasture)	0,60459
Ver2 (higher and dry pastures)	0,00025
Rif (uncovered areas)	0,00077
For1 (forest)	3,34014
For2 (cerradão - arboreous dense savanic formation)	14,06749
Cv (cerrado - savanic formation)	35,59426
Br (burnt areas)	0,02593
Cel (low pasture)	4,65808
Lag (lakes/water bodies)	0,04639
Rio (rivers)	0,07676
Pv ('green' pastures)	3,35484
Lat1 (arable soils 1)	0,07714
Lat2 (arable soils 2)	0,31859
Sujo (pasture in evolution)	29,07378
Umi (humid areas)	0,27023
Urb (urban areas)	0,02116
Man (pastures in management)	3,87122
Refl (Reflorestamentos)	4,59836
Org (dark arable soils)	0,00000
Total	100,00000

Table 2: 2004's land cover percent of each spectral signature.

2004's land cover types obtained from the image classification	Percent of Total Area (%)
Ver1 (open pasture)	0,06366
Ver2 (higher and dry pastures)	0,60968
Rif (uncovered areas)	0,01345
For1 (forest)	1,05434
For2 (cerradão - arboreous dense savanic formation)	5,74092
Cv (cerrado - savanic formation)	15,69014
Br (burnt areas)	0,00000
Cel (low pasture)	1,11733
Lag (lakes/water bodies)	0,11058
Rio (rivers)	0,04144
Pv ('green' pastures)	0,69343
Lat1 (arable soils 1)	0,51054
Lat2 (arable soils 2)	0,02463
Sujo (pasture in evolution)	70,43915
Umi (humid areas)	1,12714
Urb (urban areas)	0,05605
Man (pastures in management)	0,16383
Refl (Reflorestamentos)	2,46211
Org (dark arable soils)	0,08157
Total	100,00000

5. RESULTS

A time series of simulated biogenic emissions is shown in Figure 5. The average absolute percent departure from the mean BVOC flux provides a measure of variability that is not directly tied to the magnitude of the simulated flux. Detailed results are presented for each month. Biogenic emissions peak during dry season and BVOC flux increases; however other BVOC-related climatic processes may be most sensitive to relative variability during wet season. Model results are consistent with the expectations: biogenic emissions peak in May, where biomass density is highest. Its important observed that the principal economic activity in the State is agriculture. Besides of this, MODIS LAI product could not classify all the variability of land use types. The consequence of this fact is the large quantity of undetermined values to LAI indices. The agricultural areas of the State are are priority localized at south and north. The biogenic module within CLM establishes that biogenic emissions are a linear function of leaf biomass density. In this preliminary study we assumed that leaf biomass density is a linear function of satellite-observed spectral reflectance. This assumption implies that BVOC flux and leaf pigmentation are directly proportional. For a father study, MODIS LAI products should be calibrated for the State thought field campaign where the LAI should be measured by non destructive methods. In addition, CLM should be implemented in order to consider an agricultural model.

Figure 5 shows modeled average values to 2 m air temperature. By comparing with observed values, there is a disagreement of around 1 K. But the seasonality is observed.

The gradient in mean annual precipitation is shown in Figure 6. The rain season (October to February) is well characterized considering that 2004 year was a no typical in spite of rain pattern. The rain season starts at September after a long period of dry.

6. CONCLUSIONS

One of the objectives of this study was evaluate the performance of the high resolution CPTEC AGCM in driving CLM3 surface model considering dynamical vegetation, DGVM and rivers and lakes in to account. The Mato Grosso do Sul State was chosen in order to test some principal parameterizations, like 2 m air temperature.

The preliminary results indicate that Mato Grosso do Sul State is a great plain area with a multi land use patern. In spide of this The CLM3 surface model should be calibrated in order to increase the model´s realism. Our stimates of BVOC and energy fluxes have implications for policymakers and air quality modelers, who, for the sake of simplicity, often assume that the magnitude of biogenic emissions is constant between years. Like a preliminary results, can be conclude that land use change impacts are most pronounced during the dry season months (March to September) when surface heating is strongest and differences in surface moisture between irrigated land and natural vegetation are largest.

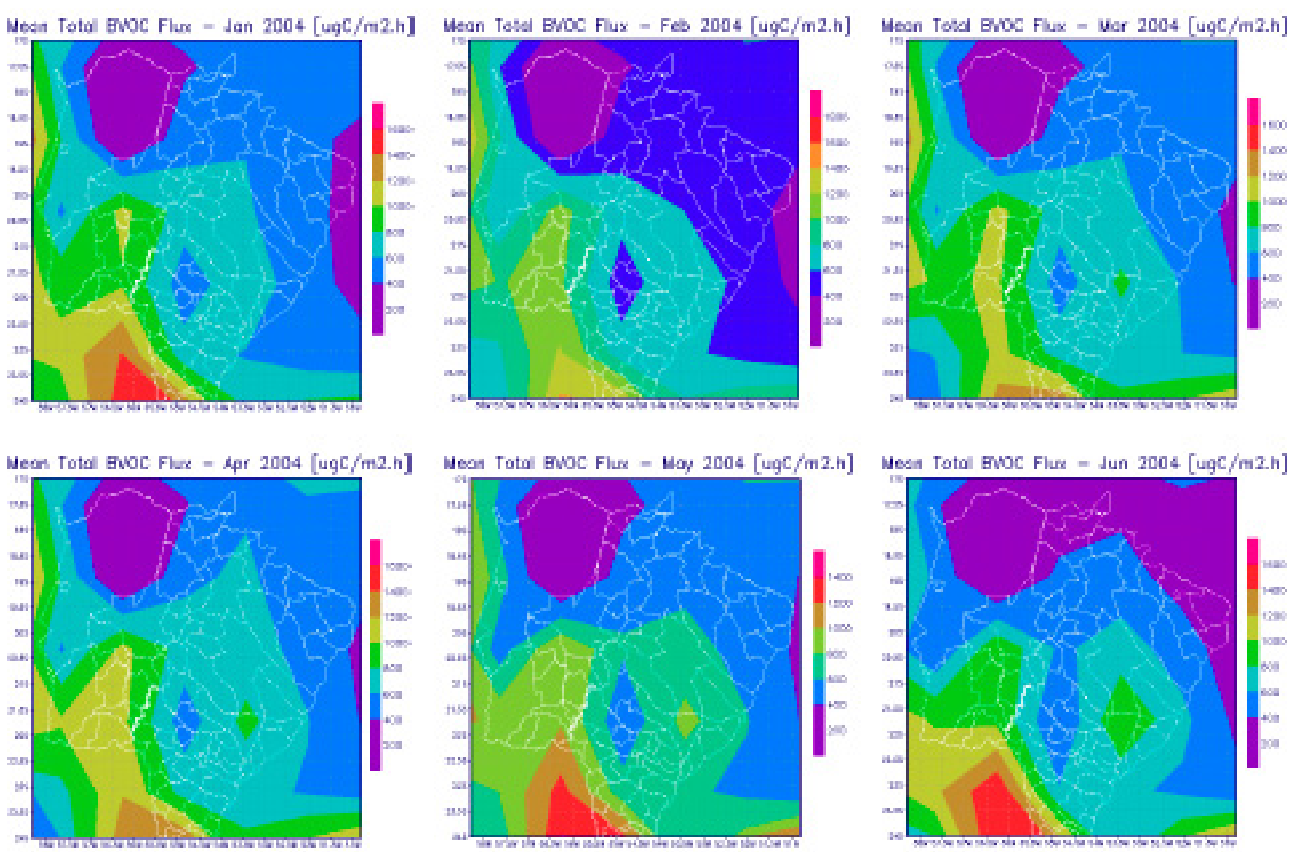

Figure 5: Mean total BVOC plots from January to December of 2004.

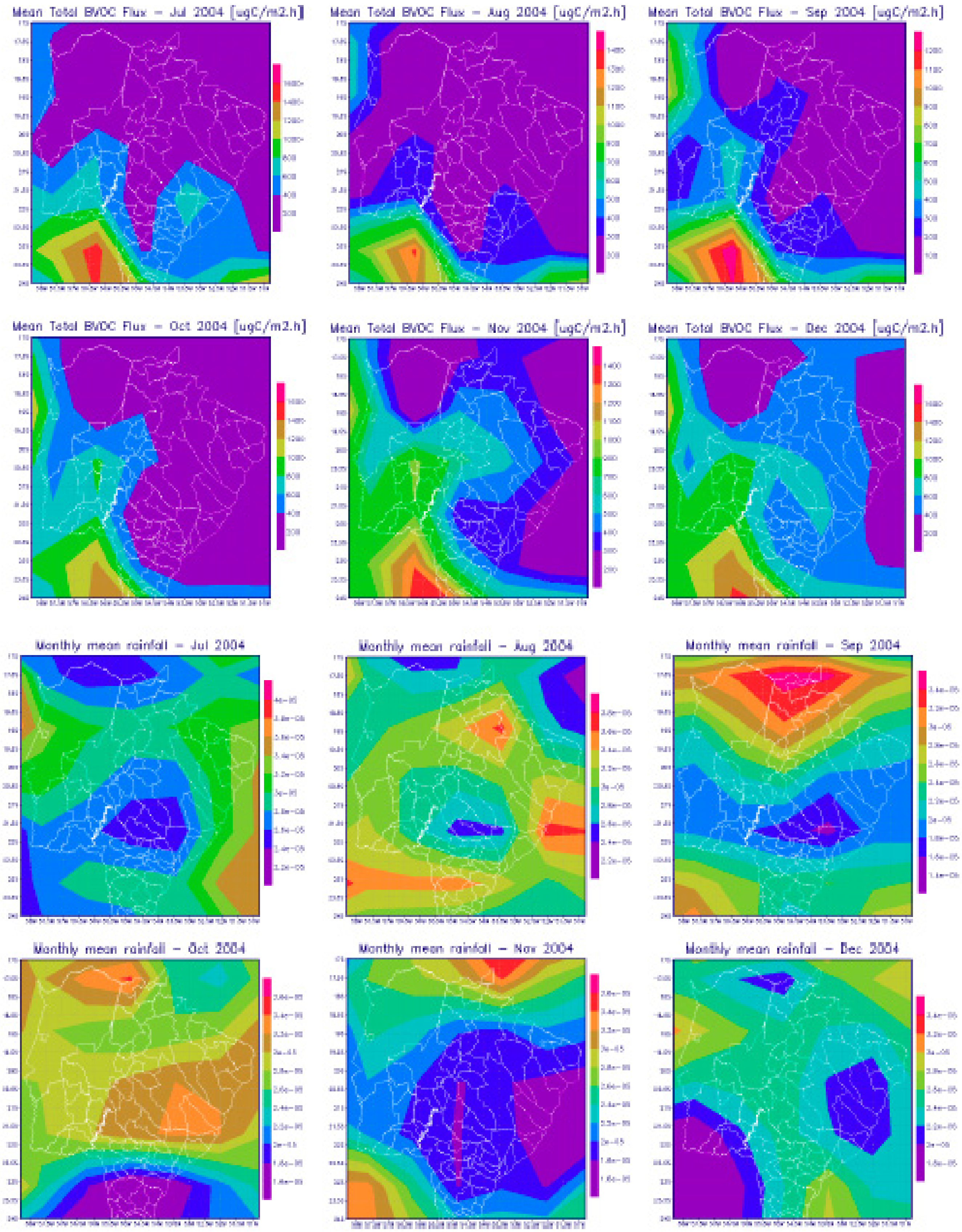

Figure 6: Annual rain fall characteristics.

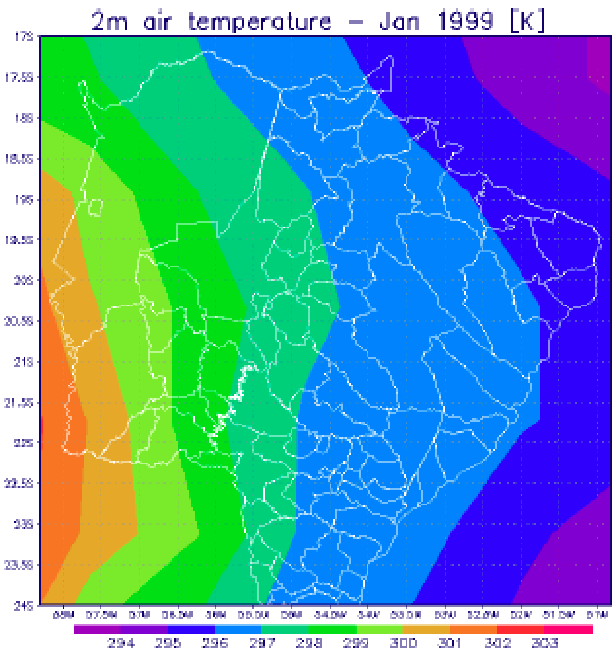

Figure 7: 2m average air temperature.

7. REFERENCES

Bonan, G. B., S. Levis, L. Kergoat, and K. W. Oleson (2002a), Landscapes as patches of plant functional types: An integrating concept for climate and ecosystem models. Global Biogeochem. Cycles, 16, doi:10.1029/2000GB001360.

Bonan, G. B., K. W. Oleson, M. Vertenstein, S. Levis, X. B. Zeng, Y. J. Dai, R. E. Dickinson, and Z. L. Yang (2002b), The land surface climatology of the community land model coupled to the NCAR community climate model. J. Clim., 15, 3123-3149.

Bonan, G. B., and S. Levis (2006), Evaluating aspects of the community land and atmosphere models (CLM3 and CAM3) using a Dynamic Global Vegetation Model, Journal of Climate, 19, 2290-2301.

Cavalcanti, I.F.A.; et al. Global Climatological Features in a Simulation Using the CPTEC-COLA AGCM. J. Climate , v.15, p.2965-2988, 2002.

de Rosnay, P., A. Boone, A. Beljaars, and J. Polcher, 2006: AMMA Land-Surface modeling and intercomparison projects. GEWEX News, February, 16 (1), 10-11.

Gulden, L.E., and Yang, Z.-L. (2006), Development of species-based, regional emission capacities for simulation of biogenic volatile organic compound emissions in land-surface models. Atmospheric Environment, v. 40, no. 8, p. 1464-1479.

LANDSAT TM. Imagem de Satélite. Canais 1, 2, 3, 4, 5, 7. Curitiba: Engesat. Órbita 224 Ponto 074. CD-ROM. 1989.

LANDSAT TM. Imagem de Satélite. Canais 1, 2, 3, 4, 5, 7. Curitiba: Engesat. Órbita 224 Ponto 074. CD-ROM. 2004.

PARANHOS Fº., A. C.; FIORI, P.A; LASTORIA, G.; DISPERATI, L.; TORRES, T.G.; IDE, C.N.; Uso de imagens de satélite na avaliação das variações na cobertura do solo da região de Coxim. Revista de estudos ambientais. V. 6, N. 1, Universidade de Blumenau. Instituto de Pesquisas Ambientais. Janeiro/Abril. 2004.

PARANHOS F°., A. C.; PAGOTTO, T.C.S.; FERREIRA, T. S.; TORRES, T. G.; MATOS F°., H.J.S. Sensoriamento Remoto do Complexo Aporé-Sucuriú. In: Biodiversidade do Complexo Aporé-Sucuriú: subsídios à conservação e ao manejo do Cerrado: Área prioritária 316-Jauru - Organizadores: PAGOTTO, T.C.S. e Souza, P.R. de. Probio - Mnistério do Meio Ambiente. Editora da UFMS. 2006. 309p.

Tao, Z. N. and Jain, A. K.: Geophys. Res. - Atmos., 110, D21, doi:10.1029/2005JD005874.

Probabilistic regional and local climate projections: false dawn for impacts assessment and adaptation?

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Introduction

The uncertainties involved in assessing climate change impacts – the so-called "uncertainty cascade" – are well documented (Mearns et al. 2001), but less well quantified. These uncertainties relate to future emissions, estimating climate response to these future emissions, and in evaluating the impacts of the climate response on any particular system. It has been argued (e.g., Pittock et al. 2001) that a probabilistic treatment of these uncertainties should be the basis for rational decision making; without probabilities, adaptation decisions will have to be delayed or based on gambles. Others (e.g., Dessai & Hulme 2004) argue that in many instances probabilities for climate change are not necessary to making an adaptation decision. Considerable effort has been now invested in developing methods that can provide probability estimates for future climate change projections. In this paper, I summarise some of these developments, and discuss some emerging issues for impacts assessment and adaptation assessments.

The probabilistic approach

Current efforts in producing probabilistic projections of climate change concentrate on quantifying the uncertainty in simulating climate response to a given emissions scenario. Future emissions are dependent on societal choice. For climate policy, this is need not be an issue, as climate change projections based on a given emissions scenario may allow an informed choice on emissions policy (Stainforth et al. 2007a). For impacts and adaptation, decisions have to be made in the face of uncertainty about future emissions policy choices; so current probabilistic projections based on one or a few emissions scenarios do not, at the outset, cover the full uncertainty in forecast process. This aspect of uncertainty becomes increasingly significant about 25 years from the present day (Meehl et al. 2007). We return to this issue later.

For a given emission future, much of the remaining uncertainty relates to two aspects of climate models: initial condition uncertainty and climate model imperfections (see Stainforth et al. 2007b for a detailed discussion). Given a perfect climate model, quantification of initial condition (IC) uncertainty through a large enough IC ensemble would allow us to define the attractor for the chaotic climate system of the future. However, models are imperfect, so an IC ensemble simply quantifies the IC uncertainty in the model system, which we hope relates to the real climate system to some extent. Climate model imperfections fall into two main categories – model inadequacy and process/parameter uncertainty. As models are invariably a simplification of the real system, they cannot exactly represent the system; we hope (and test models to make sure) that they represent aspects of the system considered important to some degree of adequacy. Process uncertainty relates to the way the models are simplified. Discretisation of fluid dynamical equations introduces one form of uncertainty. Another is the use of parameterisations to represent processes that cannot be resolved by fundamental equations at the scale of discretisation. The importance of these uncertainties can be explored using multi-model ensembles (MMEs) and perturbed-physics ensembles (PPEs).

The aim of a probabilistic projection is usually to estimate, for a given set of climate change simulations, both the range of future climate changes that are possible and the probabilities across that range. This requires interpolation between available model data and, most likely, extrapolation beyond the data. Various approaches to creating probability distribution functions (PDFs) for global and regional climate metrics are summarised by Meehl et al. (2007) and Christensen et al. (2007). In all cases it is crucial to realise that any resulting probability distribution is conditional upon the data available. For example, the underlying data may be derived from an MME (Furrer et al. 2007; Tebaldi et al. 2005), a PPE (Harris et al. 2006), or a combination of the two (Murphy et al. 2007).

The approach used to interpolate and/or extrapolate the data may also be different. In the case of a MME, some method of interpolating from the available data to that expected from a suitably large population of possible models is required. The simplest approach, used for illustrative purposes by the IPCC, involves fitting a normal distribution to the available data; other distributions could also be fitted. In reality, the models all share characteristics to a greater lesser extent, so any fitted distribution should take this into account. For a PPE, there are many more combinations of parameter values than model runs. The first step to producing a probability distribution therefore involves interpolating between model data to estimate the full response surface in parameter space. Note that this estimated response is only for the parameters that have been perturbed; many other parameters are not perturbed.

Most approaches (for both for MMEs and PPEs) acknowledge that some models may be better (or at least less inadequate) representations of the real climate system than others. They then use some criteria of similarity to the real climate system to weight models and/or model version. For example, after estimating the global temperature response in parameter space of a PPE, Murphy et al. (2004) use a multivariate index of similarity to spatial patterns of observed climate variables to produce an adjusted probability distribution. Similarly, Piani et al. (2005) adopt a fingerprinting method (Stott & Kettleborough 2002) to produce a weighted distribution across one of the climateprediction.net ensembles.

To date, most regional probabilistic projections have been based on global climate model data, and are thus limited by the skill resolution of the GCM, typically much lower than the native GCM grid resolution. To get to the spatial resolution required for most impacts assessments requires downscaling within a probabilistic framework. Early attempts at this are beginning to emerge. For example New et al. (2007) use an PPE of 450 GCMs from the climateprediction.net experiment with a simple change factor approach to downscale to the Thames river basin in the UK. Fowler et al. (2007) present an example using a Bayesian approach to a MME comprising several RCMs driven by two parent GCMs.

The latest release, in 2008, of UK Climate Impacts Program scenarios (UKCIP08) will be expressed in terms of probabilities at 25km spatial resolution (Murphy et al. 2007). These PDFs are based on a combination of (i) a 17 member PPE of transient simulations using an AOGCM (HadCM3); (ii) a 17 member RCM PPE, where each RCM is driven by an equivalent AOGCM perturbed physics model version; (iii) a larger PPE of 2xCO_2 simulations with a AGCM coupled to a slab ocean model (HadSM3) which enables better interpolation between the 17 member AOGCM PPE; (iv) use of a GCM MME to place the HadCM3 PPE into a wider multi-model context. The combined PPE-MME GCM ensemble is also constrained by observations so that any resulting PDF has higher likelihoods in areas of parameter space that produce GCM outputs with a better match to observations (as defined by Murphy et al. 2007 - other definitions of "match" are possible). The UKCIP08 dataset will be the most comprehensive set of regional probabilistic climate data available to the impacts and adaptation community, and represents the culmination of some six years of work at the Hadley Centre.

Probabilities and impacts/adaptation assessment

What does all this mean for climate impacts and/or adaptation assessment? First, if probabilistic climate information, with its implicit quantification of uncertainty in the projection methodology, is used, a similar approach is required from impacts modellers. Models used to assess impacts are themselves subject to uncertainties similar to those inherent in climate model projections (e.g., Araujo & New 2007), and should be treated in a similar manner. Methods for uncertainty assessment are well developed in some sciences, such as hydrology (Beven & Freer 2001), yet have only rarely been used in climate impacts assessments (Figure 1, see also New et al. 2007; Wilby 2005; Wilby & Harris 2006). For example, in building design models are used to design the thermal and ventilation characteristics of the building; these have typically been used deterministically, but a similar uncertainty assessment would be required.

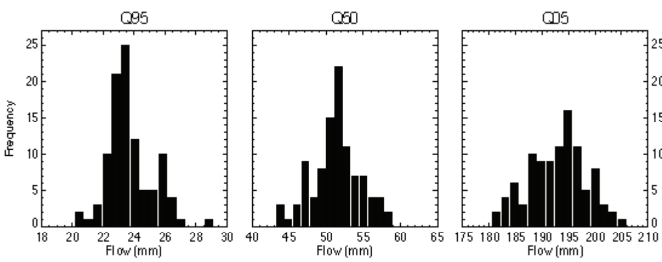

Figure 1. Frequency distributions for present-day flow statistics for the River Thames from an uncertainty analysis of the CATCHMOD rainfall runoff model used by the UK Environment Agency for water resource planning (New et al. 2007). Statistics are derived from 100 perturbed-parameter versions of CATCHMOD, all of which satisfy specified goodness of against observed river flow. CATCHMOD is driven by observed rainfall and potential evaporation data from 1961-1990 for the Thames catchment.

Second, a probabilistic (or uncertainty analysis) approach to climate impacts assessment raises difficult questions about how decisions should be made about adaptation options. In the simple case of an engineering design for a new structure, the traditional approach may be adequate, albeit more complicated. Instead of designing against a return period derived from extreme value analysis of historical data, one can design against a PDF for a given return period in the future. A decision has to be made about the degree of certainty against which to design, but this is qualitatively no different to standard engineering design. An additional issue may be cost; the cost of building to withstand different magnitude events increases with event magnitude, usually non-linearly. However, even if the build-cost increase is linear against magnitude, the cost against probability may be non-linear (Figure 2). Thus cost considerations may be the deciding factor rather than avoiding a given probability of failure. An approach is needed that considers the interaction between cost and safety, allowing for differing capacity or willingness of various end-users to pay for adaptation.

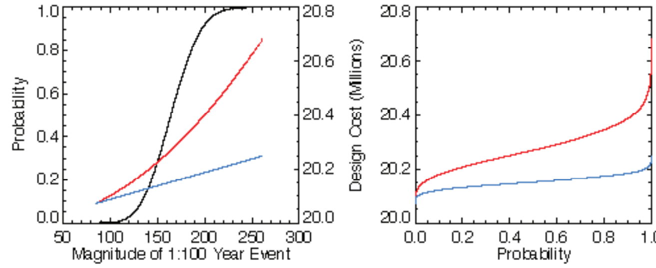

Figure 2. A probabilistic approach to engineering design. (a) The cumulative probability of a hypothetical 1:100 year event (black), as might be derived from a probabilistic climate change analysis. Also shown are two possible curves for the cost of building to a design for different magnitude events, where the cost in either linear (yellow) or non-linear (red). (b) The increase in cost of building as a function of probability of safety against a 1:100 year event, for both linear and non-linear cost-magnitude relationships.

In many instances, however, the issues are more complex than this. For example, in a water resource planning situation, there may be multiple options to augment supply and multiple options to manage demand, all with differing costs. In addition, future drivers of demand (e.g. population, housing, wealth, regulation) are also highly uncertain, and need to be incorporated into a probabilistic analysis. One strategy might be optimal (according to one or more criteria) over one part of the range of projected climate and socioeconomic changes; a second strategy might be optimal over another part of the range; a third strategy might not be the most optimal over any part of climate change space, but the least sub-optimal across the entire range. This is illustrated with a simple example in Figure 3, which shows a PDF of change in some climate variable (e.g. rainfall) or climate-dependent variable (e.g. water supply capacity) and the damage due to different levels of climate change for different adaptation strategies. "No Adaptation" is one strategy, which has zero damage (is optimal) for no climate change, but has increasing damage cost as climate moves away from the current conditions. Adaptation 1 minimises damage for extreme decreases in the climate variable, but

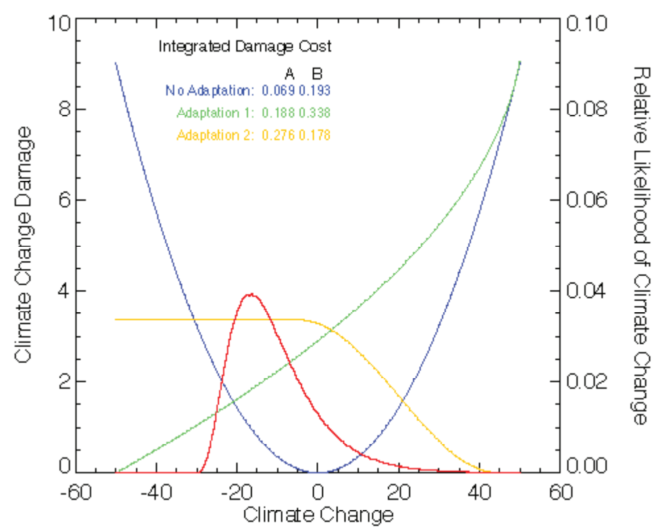

Figure 3. Implications of multiple adaptation options within a probabilistic assessment framework. A probabilistic projection of climate change is produced (red). Several adaptation options are considered, including a "do not adapt" response; each option has an associated damage cost for a given climate change. The damage cost can be integrated over the probability of climate change (A) or assuming equal probability across the range of projected changes (B).

damage increases monotonically from this minimum. Adaptation 2 minimises cost for extreme positive climate change, but has constant, relatively high damage for negative climate change. If one integrates the damage for each strategy across the PDF of climate change, the do nothing option has the lowest average cost in the face of the uncertainty (the climate change PDF). This is because the projected changes have highest probability over climate changes close (but more negative) to the present where the damage is close to minimum. However, if one is more interested in robustness across the range of possible changes without consideration of probability, "Adaptation 2" would be considered optimal; this is an approach suggested by some authors (Stainforth et al. 2007b). Alternatively, a decision might be taken to do nothing for several years until more information is available, as the difference between doing nothing and a more robust adaptation is small, given the current information.

Third, users of probabilistic information need to be aware that any distribution is one of many possible distributions, dependent on source data and analysis methods (Rougier 2007). Even for large-scale metrics such as global mean temperature, distributions can be different, most notably at the high end of the range (Meehl et al. 2007). At regional and smaller scales, different approaches will provide even more different distributions, because the underlying model data are less convergent and the observational constraints are less effective (that is, models are all equally inadequate and/or the observed data have no real signal that can be used for constraining the models).

This is illustrated in Figure 4, which shows the relationship between a measure of relative adequacy (tested against observed data) at global and regional scales, for a subsection of the climateprediction.net transient PPE (Frame et al. submitted). Here models that agree best with the observed changes in global temperature from 1950 to 2006 are not necessarily those that agree best with observed regional changes. Different choices regarding how to weight models (e.g. global versus regional adequacy, a combination of global or regional, or some other criteria) will therefore produce different PDFs from the same dataset. New model data (new models or more runs from existing models), new observations and new analysis methods will likewise yield new distributions; these will in turn yield new distributions of impacts.

If the probabilistic information misrepresents the uncertainties, use of such information within an cost-minimisation framework outlined above may lead to bad adaptation decisions (Hall 2007). Analysis methods that identify adaptation options that are robust across a wide range of possibilities may be more appropriate than those that are optimal to the current probability estimates (Lempert et al. 2006). Indeed, such an approach may fit in with a decision-maker's instinctive response, as it will enable greater resilience against low-probability high-impact outcomes that are discounted by the probability distribution. This is particularly pertinent for climate model diagnostics for which we have little confidence, such as intense rainfall or wind extremes: an optimal response to the derived PDF is no use if the PDF is based on data that have limited relation to reality.

Fourth, for assessment periods out beyond about 25 years, any probabilistic assessment becomes increasingly limited, as emissions uncertainties become an important component of the total uncertainty. Given the inherent uncertainty in projecting future emissions, any probabilistic treatment of emissions will be largely belief-based, and highly conditional on the prior distribution for emissions assumed by the analyst. There seems to be little utility is a probabilistic representation of climate response, when the forcing cannot usefully be treated probabilistically. For shorter-term projections, ocean IC uncertainty can be significant, but recent efforts to initialise climate models using current observations show some promise in reducing this aspect of the uncertainty issue (Smith et al. 2007).

A final consideration relates to the resources required for a probabilistic assessment. Generating such large amounts of coupled GCM-RCM PPE and/or MME data are beyond the resources of many institutions. A potential solution is the public computing approach taken by climateprediciton.net project. Indeed, a new sub-project within climateprediction.net aims to nest a RCM within the GCM, and should yield RCM-GCM PPEs for particular regions. Yet even if such data are available, significant post-processing is required, which will also be difficult for many end-users. Typically, terabytes of data need to downloaded, stored and processed. More importantly, use of the data within a probabilistic framework requires careful assessment of model adequacy over the region of interest, and especially for the variables of relevance to the impacts assessment. Simpler sensitivity studies that identify robustness over ranges of possible climate change, informed by easily available data, may be more appropriate for many cases (Stainforth et al. 2007b).

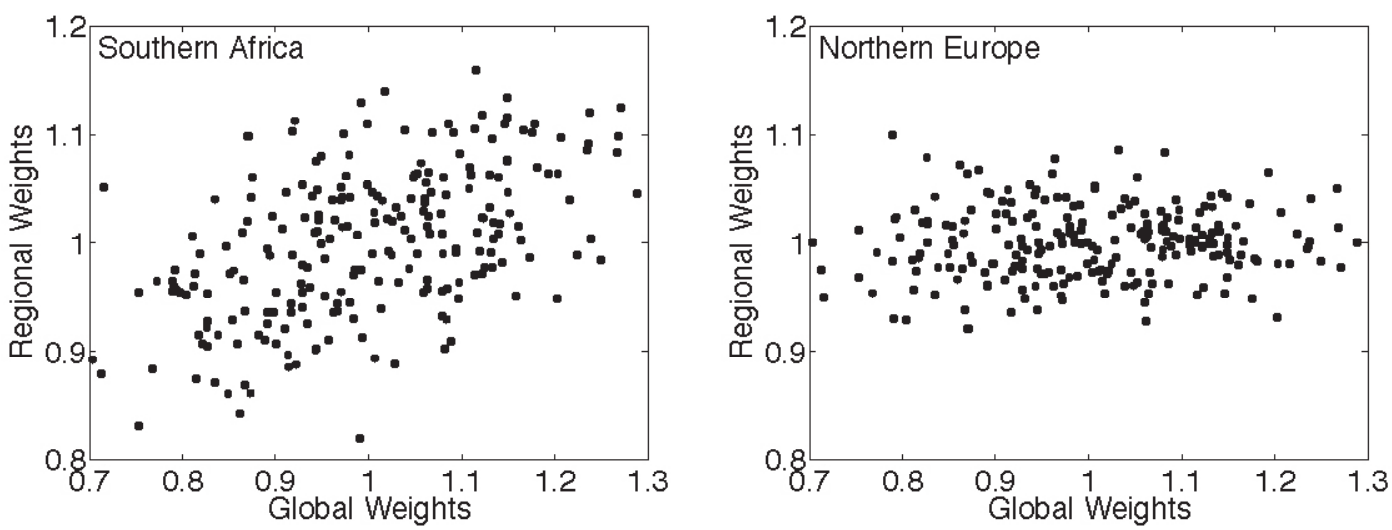

Figure 4. Relationship between a measure of relative model adequacy, at global and regional scales, in some of the first climateprediction.net transient simulations. Both sets of weights are calculated by assessing model skill against observations, where the observations (in this example) are transient temperature change from 1950-2006, either for global mean temperature, or for regional mean temperature.

Concluding thoughts

MME and, more recently, PPE analyses have been very useful in identifying the range of possible projections of climate change that are possible from the current generation of GCMs and RCMs. Estimating the probability of any change within (or indeed outside) this range is far more problematic, and dependent on availability of model data, model experimental design and post-simulation statistical treatment. Different data and approaches will yield different probabilities. Further, probabilities for some variables may have little real-world meaning if they arise out of processes that are inherently inadequate in climate models. This means that traditional engineering approaches to dealing with uncertainties will generally be inappropriate. Further, the fundamental inability to provide objective probabilities for future emissions negate most of the potential of probabilistic projections of climate change at longer (>25 year) timescales. However, MMEs and PPEs do provide more information than use of one or a few GCM scenarios; the challenge is to use this information to make more robust adaptation decisions, rather than to search for the optimum decision for a current probabilistic projection.

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References

Araujo, M. B. & New, M. 2007 Ensemble forecasting of species distributions. Trends in Ecology & Evolution 22, 42-47.

Beven, K. & Freer, J. 2001 Equifinality, data assimilation, and uncertainty estimation in mechanistic modelling of complex environmental systems using the GLUE methodology. Journal of Hydrology 249, 11-29.

Christensen, J. H., et al. 2007 Regional Climate Projections. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (ed. S. Solomon, et al.), pp. 847-. Cambridge, UK and New York, USA: Cambridge University Press.

Dessai, S. & Hulme, M. 2004 Does climate adaptation policy need probabilities? Climate Policy 4, 107-128.

Fowler, H. J., et al. 2007 Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling. International Journal of Climatology, in press.

Frame, D. J., et al. submitted Transient climate change likelihoods from the climateprediction.net transient experiment. Nature.

Furrer, R., et al. 2007 Spatial patterns of probabilistic temperature change projections from a multivariate Bayesian analysis. Geophysical Research Letters 34.

Hall, J. 2007 Probabilistic climate scenarios may misrepresent uncertainty and lead to bad adaptation decisions. Hydrological Processes 21, 1127-1129.

Harris, G. R., et al. 2006 Frequency distributions of transient regional climate change from perturbed physics ensembles of general circulation model simulations. Climate Dynamics 27, 357-375.

Lempert, R. J., et al. 2006 A general, analytic method for generating robust strategies and narrative scenarios. Management Science 52, 514-528.

Mearns, L. O., et al. 2001 Climate Scenario Development. In Climate Change 2001: The Scientific Basi (ed. J. T. Houghton, et al.), pp. 739-768. Cambridge: Cambridge University Press.

Meehl, G. A., et al. 2007 Global Climate Projections. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (ed. S. Solomon, et al.), pp. 747-. Cambridge, UK and New York, USA: Cambridge University Press.

Murphy, J. M., et al. 2007 A methodology for probabilistic predictions of regional climate change from perturbed physics ensembles. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 365, 1993-2028.

Murphy, J. M., et al. 2004 Quantification of modelling uncertainties in a large ensemble of climate change simulations. Nature 430, 768 - 772.

New, M., et al. 2007 Challenges in using probabilistic climate change information for climate change impact assessments: an example from the water sector. Philosophical Transactions of the Royal Society - A, in press.

Piani, C., et al. 2005 Constraints on climate change from a multi-thousand member ensemble of simulations. Geophysical Research Letters 32.

Pittock, A. B., et al. 2001 Probabilities will help us plan for climate change - Without estimates, engineers and planners will have to delay decisions or take a gamble. Nature 413, 249-249.

Rougier, J. 2007 Probabilistic inference for future climate using an ensemble of climate model evaluations. Climatic Change 81, 247-264.

Smith, D. M., et al. 2007 Improved Surface Temperature Prediction for the Coming Decade from a Global Climate Model. Science 317, 796-799.

Stainforth, D. A., et al. 2007a Confidence, uncertainty and decision-support relevance in climate predictions. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 365, 2145-2161.

Stainforth, D. A., et al. 2007b Issues in the interpretation of climate model ensembles to inform decisions. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 365, 2163-2177.

Stott, P. A. & Kettleborough, J. A. 2002 Origins and estimates of uncertainty in predictions of twenty- first century temperature rise. Nature 416, 723-726.

Tebaldi, C., et al. 2005 Quantifying uncertainty in projections of regional climate change: A Bayesian approach to the analysis of multimodel ensembles. Journal of Climate 18, 1524-1540.

Wilby, R. L. 2005 Uncertainty in water resource model parameters used for climate change impact assessment. Hydrological Processes 19, 3201-3219.

Wilby, R. L. & Harris, I. 2006 A framework for assessing uncertainties in climate change impacts: Low-flow scenarios for the River Thames, UK. Water Resources Research 42.

Responding to the Challenges of Climate Change in the Pacific Islands: Management and Technological Imperatives

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Abstract

The challenges posed by climate change to Pacific Island nations are many and varied, similar to the challenges faced by developing nations elsewhere in the world yet exacerbated by the comparative smallness, remoteness, and archipelagic character of most island nations. It is also clear that solutions proposed to manifestations of climate change in the Pacific Islands have often been uncritically imposed from elsewhere and have proved unsuited to both the environmental and cultural contexts.

Effective solutions to the challenges of climate change in the Pacific Islands must acknowledge their environmental character, particularly their high insularity (coastal length to land area) ratios, their topographic and geological diversity, and the raw materials that are readily available to support adaptation.

In terms of the cultural context, the pathways of current environmental decision-making in the Pacific Islands are important to understand, as are the ways in which adaptation can be sustained. The effectiveness of the past emphasis on aid funding of policy development (top-down) rather than empowering community-level decision-makers (bottom-up) is questioned.

Understandably, the principal focus of most Pacific Island governments is on economic growth with little tangible investment in non-profit environmental conservation. Yet Pacific Island countries need to take ownership of the climate-change adaptation process to a greater degree than they do at present, with external assistance becoming focused on special cases and trialling of novel solutions rather than on routine adaptation.

In the global context, there should be a reduced emphasis on the perception of sea-level rise as the principal challenge posed by climate change to Pacific Island nations and a better appreciation of the other challenges, particularly inundation and salinization of economically-critical lowland and the increasingly widespread degradation of coral reefs.

In many respects, the Pacific Islands are unique among the Earth's inhabited environments. They are located in the world's largest ocean, they are collectively large enough to have their own identity – both environmental and cultural – and yet they are small enough in the implicitly pejorative view of many to form an unremarkable adjunct to most of the rest of the world's landmasses in global issues of climate change.

There are dangers in both underestimating the global importance of the Pacific Islands region and in oversimplifying the nature of the threats posed to it by climate change. The Pacific Islands region may be considered as a sensitive indicator of projected 21st-century climate change, from the dynamics of ENSO variations, the changing intensity and reach of tropical cyclones, sea-level rise and shoreline erosion. In addition, owing to the enhanced vulnerability that many Pacific islands have to climate change primarily as a result of their insularity, the responses of their governments and communities to climate change may presage what will become increasingly common – particularly in the "developing world"[1] – over the next few decades.

The principal reason for writing this paper is to explain the state of preparedness for future climate change in the Pacific Islands as it is perceived by the author, on the basis of more than 20 years of intimate observation. There are other reasons, not least of which is the incomplete and often somewhat simplistic understanding of the Pacific Islands region by some of those concerned with global climate change and its likely impacts. There is also the desire to show the way forward for Pacific Island nations and those who collaborate with them on climate-change issues.

This paper begins with a discussion of the climate-change challenges in the Pacific Islands, both those for decision-makers within island nations and for the international community that interacts with them (section 1). There follows a review section that describes and evaluates the current responses to climate-change challenges, divided into technological and management responses (section 2). One of the points that comes out of these two sections is the widespread lack of understanding of both the environmental and cultural contexts of climate change in the Pacific Islands, something that is subsequently described in sections 3 and 4. Sections 5 and 6 deal with the technological and management imperatives for the future of the Pacific Islands, acknowledging both the unsustainability of many current developmental trends and the ways in which they will be exacerbated by future climate change. The concluding section outlines the recommended way forward (section 7).

It should be noted that throughout this paper, the "Pacific Islands" are intended to refer to the sovereign nations of the region, not to those (such as the Hawaii group) that are fully integrated parts of a "developed" continental nation and can therefore access solutions to the challenges of climate change that are neither readily available nor often especially suited to the independent island nations of the Pacific.

1. Challenges from climate change in the Pacific Islands

The challenges to Pacific Island inhabitants from future projected climate change represent – as elsewhere in the world - processes of global forcing modulated by local environmental and cultural contexts. Yet at the outset, we in the Pacific Islands should ask the questions "what is it exactly that challenges us, and what outcome do we seek to achieve" or else risk having these questions both posed and answered from outside our region by those unaware of its special circumstances. The lack of clarity regarding the answers to such questions by Pacific Island decision-makers is one reason why there has been so little adaptive response from within island countries. In the introduction to this section, I will attempt to provide plausible answers to these two questions in the context of the Pacific Islands region.

What is it exactly that challenges us? We are confronted by a series of likely climate (or climate-driven) changes that threaten the sustainability of the way of life of people in the Pacific Islands, largely through

- increased climate variability, both the continuation of the present ENSO pattern that sees El Niño occurring every 3-5 years, and the likelihood that there will be less rain (seasonally) in the future,

- changes in climate extremes, particularly that the recent high incidence of intense tropical cyclones will continue as will El Niño associated droughts,
- temperature rise, which will have impacts on terrestrial ecosystem productivity (particularly crop yields) and on nearshore ecosystems (particularly coral reefs) on which many Pacific Island people depend, and
- sea-level rise, which will inundate coasts, cause shoreline erosion and groundwater salinization of low-lying areas, and allow larger-amplitude waves to cross offshore reef barriers than at present.

It is however legitimate to compare likely future scenarios with what happened in the past, for it is clear that Pacific Island societies within the past 1200 years at least have proved highly vulnerable to various climate changes, particularly drought and sea-level fall, that have in some cases seen societies fundamentally transformed (Nunn, 2007; Nunn et al., 2007). Yet in many cases, the increased vulnerability in the past was matched by equally high resilience, which allowed Pacific Island societies to recover comparatively quickly (Figure 1). The difference today is that Pacific Island societies have become completely sedentary in ways that they were not even 200 years ago, and – in common with most other parts of the inhabited world – they have become part of the global family, an increasingly homogenous society of which its tangible building blocks (for example, buildings, infrastructure, farms, fishing grounds) have become fixed (not transitory or mobile) and in which its intangible qualities (like financial investment, income generation, education) have become inexorably tied to these fixed elements. What challenges today's Pacific Island societies is therefore the disruption of their present developmental trajectories in ways that will confound their efforts to "develop" to the "level" of the "developed world".

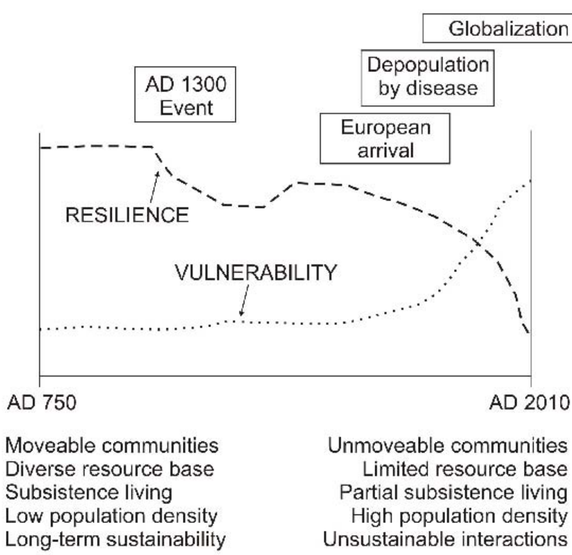

Figure 1. Generalized view of the changing levels of resilience and vulnerability of humans to climate change in the Pacific Islands since AD 750. The AD 1300 Event was a period of regional cooling and sea-level fall that impacted Pacific Island societies profoundly, temporarily reducing their resilience yet hardly altering their vulnerability because they adapted largely by relocation to less vulnerable locations (Nunn, 2007; Nunn et al., 2007). In recent times, the arrival of Europeans and the imposition of alien systems of human-environment interaction, followed by the depopulation of Pacific Island indigenous populations associated with the introduction of unfamiliar diseases, and the processes of globalization, particularly the establishment of networks of dependency within and beyond the region (McNeill, 1994, 1999).

What outcome do we seek to achieve? This depends on who you talk to. Most politicians are concerned ultimately that nothing should disrupt "progress" – the perceived climb up the ladder of economic development – for in such progress lies the best chance of re-election. Most educated people in the Pacific Islands would feel otherwise, noting the widespread environmental cost of such apparent progress, from the cavalier disposal of toxic mine waste (Brown, 1974; Heffler et al., 1997) to deforestation (Hviding and Bayliss-Smith, 2000; Lomo, 2001), and wishing for truly sustainable development. Many less formally educated people, particularly in more rural areas of the Pacific Islands, may typically be less concerned about their islands' long-term future and more concerned about having sufficient cash for immediate needs. So maybe the question should be rephrased to the insensitive "what is best for the Pacific Islands to ensure that they will continue to sustain their inhabitants in future"? Maybe no-one from outside the Pacific Islands, who cannot be readily identified as part of this region, should ask such a bold question but if it is not answered properly soon – and the answer acted upon effectively – many of the bleak prognoses for Pacific Island environmental futures may prove correct (Nunn, 2004a, 2006; Nunn et al., 1999; Pelling and Uitto, 2001; Zurick, 1995).

In terms of what is needed to effectively confront the challenges of projected climate change in the Pacific Islands, it is helpful to separate the needs of in-country (national) decision-makers (section 1.1) and intra-regional advisory bodies (section 1.2) from the needs of extra-regional (international) decision-makers (section 1.3). It is no shame to acknowledge that such needs exist – every climate-change "expert" has had to bring together their knowledge of disparate fields of learning to reach that state – but denial of them will lead to inaction (or at least ill-informed action) that will unduly exacerbate the impacts of future climate change.

1.1. Challenges for in-country decision-makers

An important challenge for national decision-makers in Pacific Island countries is to understand the challenges posed by climate change to the extent that their responses are significantly informed by both the science of climate change and its projected impacts within the country in question. It is simplest to identify three levels of in-country decision-making in the Pacific Islands - governmental decision-making, community-based decision-making, and decision-making by non-governmental organizations.

In looking at governmental decision-making in Pacific Island countries, one of the first issues that stands out is the comparatively small number of trained people who are able to influence national climate-change policy (Nunn et al., 2006). Most of these people are University graduates, under 40, who, upon joining governments quickly realize the near-impossibility of actually influencing policy. In such democratic "developing" countries of typically fewer than one million citizens, few politicians are brave enough to follow through policies that will visibly hinder economic development. Most citizens want their income increased between elections, and few politicians will find jobs outside parliament that pay as well as within, so, although there are many examples of bold-sounding statements about "sustainable development" made by Pacific Island politicians, the underlying reality is that sustainable development – in any sense of the term – is not a real policy goal of any Pacific Island government.

Many efforts have focused on building capacity within governments to understand and confront the challenges of climate change. Most of these efforts, while worthy, have failed in the sense that no Pacific Island government has developed a country-specific climate-change action plan significantly independently of international agendas. In this way, international priorities have become national priorities; international solutions have been uncritically imposed on island nations. The clearest manifestation of this has been in the policy arena, with most Pacific Island nations having an impressive body of environmental legislation pertinent to climate change ... but absolutely no way of enforcing it.

The impotence of national policy in effecting appropriate decisions in Pacific Island nations means that everyday decisions about particular environments are generally taken solely by the leaders of the people that occupy these environments. Such community-level decision-makers are generally more concerned than their national counterparts with sustainable interactions between people and the environment, even to the point of sometimes resisting proposals for its development that may entail a loss of sustainability (Kuijper, 2003; Hviding, 2006). Yet in general, community-level decision-makers are often less well educated in the science of climate change and the nature of appropriate responses. The challenge is therefore to find ways to empower such people to make appropriate decisions.

Finally, there is a role for non-government organizations (NGOs) in in-country decision-making for climate change in the Pacific Islands. Yet there is considerable diversity in the nature, membership, and mandates of such NGOs in this region. International NGOs like Greenpeace and the World Wide Fund for Nature (WWF) pursue largely international agendas which may be important in a global context but sometimes make little sense in a community context. For example, many NGOs place a huge emphasis on biodiversity conservation, often to the point of underrating the daily needs of locally dependent communities. Many regional and national NGOs have picked up on parts of these agendas but typically also merge these with priorities identified in-country. Some NGOs, particularly those linked to particular religions, have considerable unrealized potential to influence environmental decision-making (Takesy, 2004).

Understanding and enforcement (implementation) are the two biggest challenges for in-country decision-makers in the Pacific Islands. There is a comprehensive lack of understanding about climate change amongst most influential government decision-makers who typically allow action on climate change to be subordinated to decisions that will lead to short-term economic growth. There is hardly any effective enforcement of legislation concerned with climate-change adaptation and mitigation.

1.2. Challenges for intra-regional advisory bodies

The comparative smallness of Pacific Island countries and their economies combined with the broad similarities of the challenges they face in a number of areas (not just from climate change) make it understandable that these countries have developed regional approaches to many of these. These regional approaches are served through a number of organizations headed by the Pacific Islands Forum. Their mandates are set by representatives of member countries and, since none of these are "developed" countries, it is understandable that these mandates are preoccupied with economic development. Two of these organizations (SPREP and SOPAC) have climate change as one of their specialist areas.

SPREP (South Pacific Regional Environment Programme) is the appointed interface between most Pacific Island nations and the international climate-change community, representing island nations' views in particular fora, adapting international agendas to the Pacific Islands context, and advising Pacific Island governments on priority areas for combating climate change. Among the latter are improvement of meteorological services, enhanced awareness raising of climate change throughout the region, policy development, and action on ozone-depleting substances.

For a long time implacably opposed to the idea that temperatures and sea level were rising and would rise this century, SOPAC (South Pacific Applied Geoscience Commission) has changed its stance within the last ten years, now advising island governments quite the opposite of what they advised them a decade ago. The role of SOPAC in climate-change studies in the Pacific Islands was formerly to gather and process environmental data that demonstrated the facts of climate change, but this role has now extended into more awareness raising and appropriate policy formulation.

The role of intra-regional advisory bodies is determined by their member countries, but it could be argued that this role should extend to advising member countries about the unsustainability of the paths currently being pursued with respect to the environment of the Pacific Island countries by governments, particularly with reference to its exploitation for short-term economic gain. To date, the writer is not aware of any of these bodies having made such a statement in unequivocal terms.

1.3. Challenges for the international community

The international community is also challenged to effectively communicate the challenges of climate change to Pacific Island decision-makers. This may sound like a straightforward process but it is not.

For most Pacific Island people, English is at least a second language and not the one that most are comfortable speaking, reading, or listening to at length. Yet there seems a widespread expectation among the international community that because English is the one common language of most Pacific Island nations, it should be possible to communicate even high-level science effectively in it to high-level decision-makers (in government, for example) as well as to convey apparently simple ideas to comparatively well-educated people (at the community level, for example).

None of these expectations are valid, not because Pacific Island people are unintelligent, not because they lack interest or commitment in confronting the challenges posed by climate change, but in many cases because of cross-cultural problems that inhibit communication. Climate-change issues are viewed quite differently across cultures; one of the most extreme examples may be the competitions for the best climate-change jokes that have been sponsored at some US-based meetings[2], something that may be considered appropriate in the cocooned environments of Washington DC but is repellent to anyone living amongst vulnerable people in the Pacific Islands.

So the challenge for the international community outside the Pacific Islands is not simply to communicate in the way that they are accustomed to doing with each other, but to communicate in ways that will ensure their message is clearly apprehended by those for whom it is intended. Anything less is largely a waste of time and resources.

Cross-cultural problems associated with communications about climate change between the international community and Pacific Island peoples also extend to conceptualization (Hviding, 2003; Wood, 2003). Science may be taught in much the same manner everywhere in the world, but the language used around the interface of science and society is often more obscure and often region-specific. For example, to explain adaptation to climate change, and talk of more specific concepts such as anticipatory adaptation and no-regrets adaptation, may often make them appear as alien concepts to Pacific Islanders whereas in fact they have been doing all these things for decades, even centuries. The point is that for people who interact daily with the natural environment, the dialectics of modern climate-change science simply obscure familiar ideas and responses. The most best way to effect changes in people's attitudes and responses in such situations is to cut through the language and conceptual barriers and explain things in familiar terms using familiar examples.

This brings me on to my last point in this section, which is the use of strategies – perhaps for climate-change adaptation – that have been tried and successfully tested elsewhere in the world and which are imposed unthinkingly on the environments of smaller islands where such strategies may be inappropriate (Nunn, 2004a, 2004b). Hard-fix solutions to problems of shoreline erosion are appropriate to richer countries having comparatively short coastlines along which there has been considerable investment (private and public). There is a glaring need to protect this investment, and the money is available to do so in the most appropriate way. Given the degree to which humans have generally already interfered with such coasts, the usual solution is to construct artificial structures, the appropriateness of which has been decided by modelling coastal dynamics. But poorer countries such as those in the Pacific Islands, in which perhaps every part can be classified as coastal, cannot entertain such solutions. Firstly, there are insufficient data available or being acquired in such countries to enable a sufficient understanding of coastal dynamics to know what structures are most appropriate. Secondly, such structures are prohibitively expensive to construct, although aid funding is one possible way in which this can be done. Finally, the cost of maintaining such structures is often beyond the means of such countries, so they often fall into disrepair and their original function is thereby negated.

An attendant problem with the display of hard-fix solutions, often aid-funded, in showcase locations in the Pacific Islands – typically in the centres of capital cities – is the spread of what has been called the "seawall mindset" (Nunn, 2004b). This refers to the uninformed emulation of such solutions by rural communities throughout the Pacific Islands which, anxious about their eroding shorelines and unable to access advice about appropriate solutions, simply build seawalls because this is what appears to work in the showcase locations (Figure 2a). These seawalls, often part-funded by governments keen on realizing short-term development goals, are typically opened with great fanfare – something that also accounts for the spread of the seawall mindset – but collapse 12-18 months later as a result of scour along their fronts and ponding along their backs. These seawalls may be repaired or rebuilt if funds are available, but many of the communities that they enclose are only partly within the cash economy, and the common result is such seawalls – unless they also fortuitously protect some national infrastructure like a road – remain in a state of collapse a few years after they were first erected (Figure 2b).

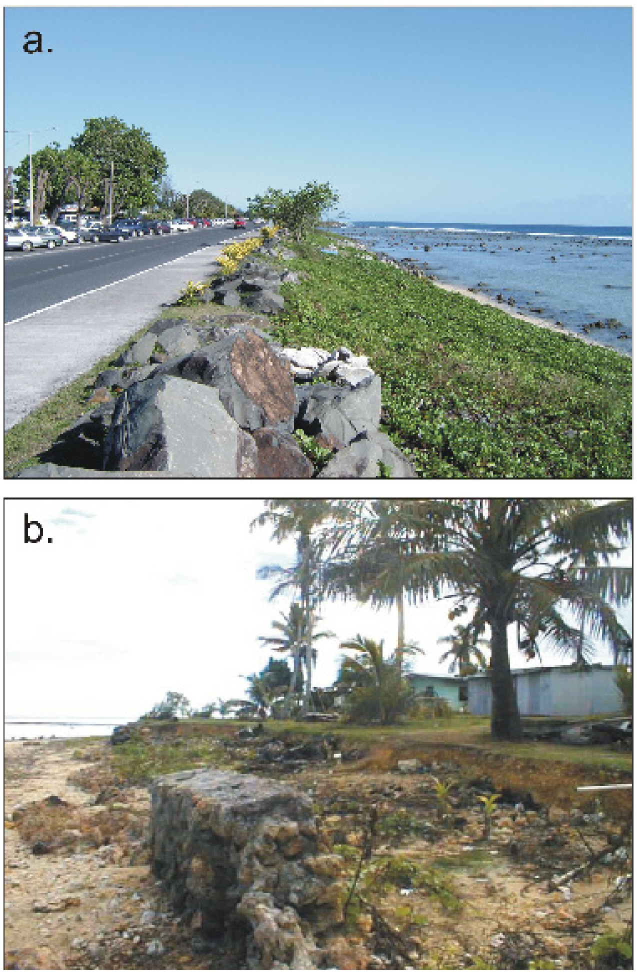

Figure 2. Artificial structures along Pacific Island coasts.

a. Aid-funded artificial shoreline along the front of Avarua, the capital city of the Cook Islands. Large boulders have been piled up along the shoreline, covered by mesh in places, and vegetated.

b. Remains of a typical rural seawall in the Pacific Islands, at Yadua Village, Viti Levu island, Fiji. The original seawall remained intact for 18 months, was partially rebuilt, then collapsed again. Note how wave scour has begun eroding the area behind the original seawall, cutting into the coastal plain and threatening the nearby houses.

In summary, there seems in the Pacific Islands region to have been little thought given by the international community to how their messages about climate change are received and permeate through the people of the region. These messages are manifestly not bringing about the desired results because of problems associated with language, communication, with conceptualization, and with the dissemination of climate-change know-how throughout the people of the Pacific Islands.

2. Current responses to climate-change challenges in the Pacific Islands

In countries of the "developing world" such as those of the Pacific Islands, governments often have very little money to invest in things that will not yield a short-term financial gain. Funds are therefore ploughed into tourism, mining and forestry schemes while issues such as environmental conservation and ecosystem sustainability are marginalized, generally only receiving enough funding to satisfy international watchdogs. Often that funding comes solely from external sources, governments realizing that by both actively subscribing to the rhetoric of "sustainable development" and ratifying all the relevant international agreements will ensure a steady flow of external assistance. There have been many instances of where such assistance, earmarked for sustainable development, has been diverted into other areas, particularly those supporting revenue generation (Turnbull, 2004; Huffer, 2005; Barclay and Cartwright, 2007).

This generally means that the responses of most Pacific Island countries to climate-change challenges has been less than satisfactory to date, both in terms of the types of responses – technological and management – and in terms of their distribution within countries. The latter point is so important and so under-recognized that it is worth developing briefly.

All nations have a core (or cores) in which most development is concentrated and a periphery where development tends to be less. Other core-periphery contrasts that are apparent in most countries are differences in the ways of life, the cores usually being at the forefront of progress, the peripheries tending to be more traditional. In most Pacific Island countries, the differences between the core(s) and the periphery are amplified by the archipelagic nature of these countries. Most of the peripheries in continental countries are accessible by road but in archipelagic countries they are far more difficult to access, inter-island boats generally being sporadic and often unsafe. Young adults have left outer-island (peripheral) communities in many parts of the Pacific Islands in search of waged employment, so that traditional lifestyles are reinforced on the periphery by the interaction between children and elderly people.

These kinds of environmental and cultural disparities in most Pacific Island countries between cores and peripheries also affect the ways in which climate-change solutions are understood and implemented (Kumar, 2007). In core areas, there is generally better understanding and more appropriate solutions adopted. In the often vast peripheries, hardly ever visited by government environmental officers or by representatives of international climate-change agencies, there is widespread misinformation (even ignorance) about climate

Table 1. Recent and current adaptation responses to climate change in the Pacific Islands.

Climate Change	Recent and current adaptation responses
TECHNOLOGICAL RESPONSES	
Increased climate variability	None. Improvements of water management practices are in response to unsatisfactory water management under current conditions.
Climate extremes	None
Temperature rise	None
Sea level rise	Some. Construction of artificial structures in city centres to poorly planned seawalls in peripheral areas
MANAGEMENT RESPONSES	
Increased climate variability	None. Extra-regional preduictions of forthcoming El Nino events are not acted
Climate extremes	Little. Upgrading meteorological services for improved weather prediction, especially early warning of tropical cyclones, is a response to the perceived climate of recent years. Disaster-management strategies are all reactive not proactive. Community-based response plans to disasters have developed after particular events.
Temperature rise	Little. Trialling of new crop strains, but most of this is in response to demands for increased production.
Sea level rise	Some. Government and aid schemes to protect key (or pilot) areas. Governments have received reports on likely effects of future climate change. Some new infrastructure being built inland of vulnerable areas.

change, and environmental decision-making is conditioned largely by instinctive responses.

This section describes and evaluates the existing (and recently tried) responses to climate change in the Pacific Islands, separating technological from management responses (Table 1). This section focuses on adaptation responses not on mitigation responses, the latter being largely the same throughout the Pacific Islands region.

2.1. Technological responses and their effectiveness

In the past, appropriate human responses to climate change in the Pacific Islands were far simpler to both identify and implement than they are today. People moved from vulnerable to less vulnerable areas. The disruption was comparatively slight because communities were not sedentary to the degree that they are today. Comparative ease of movement was helped by the absence of any formal system of land ownership (such as exists today), by low population densities on particular islands, and almost certainly by the communal memory of communities having moved in the past as a result of particular climate forcing. the latter point should not be underestimated. Today the idea of relocation of settlements is almost inconceivable (see section 6.5).

A good example comes from the societal crisis around AD 1300 in the tropical Pacific Islands that was driven by climate change, principally cooling (Nunn, 2007; Nunn et al., 2007). Climate change appears to have led to sea-level fall which caused a food crisis along many island coasts. People responded by abandoning coastal settlements in every part of the tropical Pacific Islands region (from Solomon Islands in the west to French Polynesia in the east) in favour of inland hilltop settlements where they could also be safe from the associated conflict.

Understandably there is far more resistance to relocation as an adaptation option in the modern Pacific Islands region, but the essential vulnerability of island environments that led to wholesale population relocation during the "AD 1300 Event" has not changed. Part of the reason for this is that there are no obvious, widely-available technological fixes to the challenges of climate change in this part of the world. Coastlines – the most vulnerable terrestrial environments – are extraordinarily lengthy in the Pacific Islands compared to total land areas[3] and most Pacific Island nations are comparatively poor, and therefore doubly handicapped when it comes to technological fixes to the challenges of climate change.

Some work has focused on traditional knowledge concerning coastal protection in the Pacific Islands, work that has been driven by the broader agenda that traditional solutions to environmental problems are the key to sustainable human-environment interactions in such societies (Johnson, 1992; Morrison et al., 1994). yet it seems that human memories concerned with shoreline protection in the Pacific Islands, which might be expected to have 200-300 year recollection spans, consistently fail to report anything that could be helpful in the modern context (Mimura and Nunn, 1998). Named solutions included piling up of sand barriers, held in place by wooden structures (palisades), or piles of stones. No such strategies were reported to have been especially helpful, and Mimura and Nunn (1998) concluded that relocation was the preferred adaptation option until the 20th century in most parts of the Pacific Islands.

Archaeological investigations in parts of the Pacific Islands (reinterpreted by Nunn, 2007) suggest that in especially vulnerable locations, climate change led to significant human modifications of refuge environments. For example, on remote Kapingamarangi Atoll in the Federated States of Micronesia, there is evidence that a natural sand accumulation was manipulated by people around AD 1400 to make it habitable, it eventually becoming Touhou Islet[4]. Equivalent evidence for the extension of the lowland area of Lelu Island in Kosrae (Federated States of Micronesia) also suggests increased occupation about AD 1400[5]. Artificial islands in many parts of Pacific Island countries may have been constructed in response to the need for refuges from conflict arising from climate-driven resource depletion (Nunn, 2007).

Modern technological responses to climate change are generally non-indigenous, and therefore less environmentally and culturally appropriate than we can reasonably assume earlier (indigenous) solutions to have been. These include various forms of shoreline protection, usually involving a vertical impermeable seawall or a structure (typically made from fallen trees, stone piles, and domestic waste) that is intended to stop shoreline erosion. Such measures are short-term remedies and may not even weather the next significant storm surge. Most seawalls of the kind described collapse within 18 months of their construction. As discussed in section 5.2, soft solutions are generally more effective, they last longer, and are more easily managed by rural communities in the Pacific Islands.

2.2. Management responses and their effectiveness

Most Pacific Island governments have units of government that are responsible for national environmental management. Within a few of these units, there may be a person with special responsibility for climate change. Typically that person (like others within the unit) may be funded on short-term contracts funded by aid/project funds from external sources.

Many more people in Pacific Island governments may have attended courses intended to build their government's capacity to deal with the challenges of climate change. By and large, most of these people are ineffective in bringing about changes in government policies concerning climate change, even to the extent of working in areas of government with hardly any involvement with climate-change activities.

To understand the ineffectiveness of the responses of many Pacific Island governments to the challenges of climate change, it is also necessary to focus on the comparative smallness and poverty of these countries.

Smallness means small numbers of government employees, few in areas like environment that are not essentially self-funding. Many of the government employees in the Pacific Islands charged with environmental management are so overstretched (and attend so many international meetings) that they are simply unable to develop or effectively implement appropriate strategies for climate change.

Then there is the issue of poverty which means in this case that while government income may be used to showcase the nation globally, it is rarely used for anything else that does not itself generate revenue. Thus skyscrapers cluster along the ocean fronts of many Pacific Island cities, while governments invest heavily in infrastructure that services economic activities. Funding for non-revenue-generating activities like natural-disaster prevention, individual poverty alleviation (inequality of wealth distribution), and cultural-heritage preservation are commonly sought from non-government sources.

It is clear that many international aid donors to the Pacific Island countries accept this situation, many donors actively supporting it by targeted programs that include many aspects of climate change adaptation and mitigation. It may seem self-defeating to criticize such a situation but it is continuing to encourage the subordination of climate change (and environmental issues more generally) by Pacific Island governments. It is sending a message to these governments to continue their preoccupation with revenue-generating activities because aid will always be on hand to cope with many of their other responsibilities.

Added to this situation is the emphasis by many international aid donors to Pacific Island countries on policy development. Millions of dollars have been poured into developing policies for sustainable development in the Pacific Islands, but in none of the recipient nations is there effective enforcement of these policies. To international donors, policy development is an attractive area for funding support because it is clearly nations supporting nations at a national level. Yet few donors have paused to ask how effective this is in the Pacific Islands, and it certainly seems that, while a few selected communities have benefited from being the objects of pilot studies, there is no widespread improvement in knowledge about climate change or responses to its many manifestations in any Pacific Island countries.

3. The environmental context of current and future climate change in the Pacific Islands

The diversity in Pacific Island environments confounds generalizations about the ways in which they will respond to particular aspects of climate change. The obvious distinction between higher islands and lower islands (atolls) is helpful but also disguises many details that environmental managers need to consider.

The inhabitants of high islands, like those in Solomon Islands, Vanuatu, Fiji and other countries, clearly have the potential to weather many effects of climate change in ways that countries with fewer high islands have not. Yet such observations can mislead, for almost all the people in such countries live along island coasts, dependent on their bounty – terrestrial and marine – for their daily sustenance. Not only do few coastal communities own inland areas to which they can readily move, but also they are accustomed to coastal life and cannot readily sustain themselves elsewhere[6]. In many high-island nations, not only do most people live along the coast but also most economic activity is concentrated there. Sea-level rise therefore has a great potential to disrupt life on high islands.

Low (atoll) islands are inherently vulnerable to sea-level changes, and it is likely that some such islands will need to be abandoned within the next 20-30 years. While sediment movements in atoll lagoons may allow some islands to endure longer than generally expected (Cowell and Kench, 2001; Kench and Cowell, 2001), there exist thresholds within the structures of most atolls that, once surpassed, will see existing atoll islands rapidly eroded (Dickinson, 1999).

Yet clearly people living on any type of Pacific Island who interact daily with the environment to acquire food (rather than buy it from a shop) are vulnerable to the vagaries of changing climate. Increased climate variability and the impact of extreme events (droughts and tropical cyclones) will see many long-held methods of food acquisition strained, particularly as temperature rise affects crop yields and coral-reef health.

Two ecosystems are of especial concern in the tropical Pacific Islands – mangroves and coral reefs. Both play vital roles in physically protecting island coasts from erosion and inundation, and both are critical in the maintenance of nearshore ecosystems on which most people living in the Pacific Islands depend.

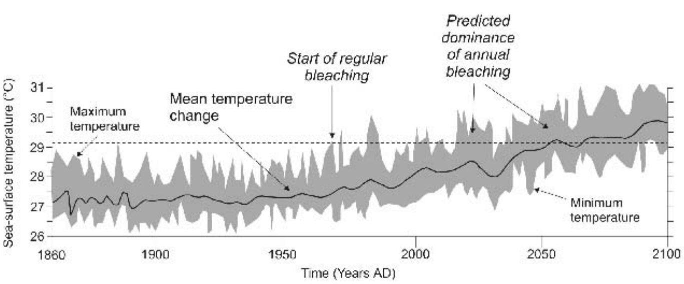

Figure 3. Sea-surface temperatures AD 1860-2100 for Tahiti incorporating ENSO effects compared to the thermal tolerance of corals (dashed line) (after Hoegh-Guldberg, 1999a). Note how for the first 100 years of record, sea-surface temperatures in Tahiti never rose above the coral tolerance limit, so there was no bleaching. Yet beginning around 1970 when mean sea-surface temperature had begun rising, temperature maxima during El Niño events reached above the coral tolerance limit and resulted in bleaching. By around 2050, it is expected that mean sea-surface temperature around Tahiti will have reached close to the coral tolerance limit, so that bleaching episodes will become annual occurrences; "most evidence suggests that coral reefs will not be able to sustain this stress and a phase shift to algal dominated benthic communities will result" (Hoegh-Guldberg, 1999a: 15). A more recent assessment is that bleaching will become an annual or biannual event in the next 30-50 years, and that coral reefs in Micronesia and western Polynesia will be especially vulnerable (Donner et al., 2005).

Mangroves were common as coastal fringes along tropical Pacific Island coasts until 150 years or so ago, when they began to be cleared by coastal peoples, something that opened the door for accelerated shoreline erosion in many places (Nunn, 2000, 2003). Mangroves are a recommended part of future shoreline-protection strategies in the region (see section 5.2) and are being replanted with this in mind in a few showcase sites. But it is unclear how mangroves will respond to projected climate change over the next few decades (Gilman et al., 2006).

It is far less easy for people to manage coral reefs than mangroves yet coral reefs are the most enduring form of natural shoreline protection along Pacific Islands and are currently in a more degraded state than they have probably ever been (Hoegh-Guldberg, 1999b). The principal causes of current degradation are mostly human-associated, ranging from their unsustainable exploitation to their pollution. Mining and dynamiting of reefs are comparatively widespread. Coral-reef conservation is not just a "green" issue but should be viewed as part of a package for climate-change adaptation; a healthy reef is intrinsically better able to respond to climate change than a degraded one. That said, there is compelling evidence that coral-reef degradation has progressed to a point where its continuation, at least in the next few decades, seems unavoidable. Figure 3 shows how changes in ocean-surface temperatures have forced bleaching episodes increasingly frequently since the 1970s and how, more worryingly, these episodes are destined to become more frequent and more enduring as these temperatures continue to rise. The effects will be widely felt, not just in physical and ecological terms, but also in societal terms, for coral-reef degradation will remove food sources that remain as important to humans as ever in the Pacific Islands.

Outside the region, the ignorance about Pacific Islands geography and the nature of the region's terrestrial environments is legion. A widespread popular belief is that all the islands are atolls, and that sea-level rise is therefore the most profound problem that confronts the region (Nunn, 2004b). Such ignorance clearly does not worry many climate-change players on the world stage but it is unhelpful at a regional scale (Nunn, 2004a).

4. The cultural context of current and future climate change in the Pacific Islands

To the disinterested observer, it may seem that climate change transcends culture much as it transcends boundaries between nations. Climate change, after all, is one of the few global challenges that is forcing all the world's nations to begin to act with a common purpose. So surely, the recommended solutions to climate change can be couched in language that is universally understood. Not so.

In the Pacific Islands, it is often the fate of new ideas to be explained, absorbed, apparently accepted, and then ignored thereafter. Climate change is widely regarded in the Pacific Islands as a foreign construct, a preoccupation of "developed" nations, something that has made victims of Pacific Islands people, and therefore something that those responsible should and will do something about.

In the modern era, in which all Pacific Island nations are subject to the pressures associated with globalization, there has developed therein a culture of dependence (Sofer, 1985; Ravuvu, 1988) that reinforces the view of climate change as an alien problem that should be solved by outsiders. That this view has apparently become established among many political leaders is proving unhelpful to long-term planning.

It needs also to be mentioned that, while the fervent Christianity present in every part of the Pacific Islands is undeniably a characteristic that defines the region for many people, it is also sometimes a hindrance to rising to the challenges of climate change[7]. From outright denial of climate change to the lesser belief that Divine Providence will be a significant part of any solution to climate-change associated problems, it is clear that Christianity is used both as an excuse for inaction and as a reason for sidelining climate change in national plans.

In this section, I discuss the processes of environmental decision-making in the Pacific Islands, explaining the important ways in which it differs from those in many other countries (section 4.1). Then I talk about how best appropriate adaptation, once it is implemented, can be sustained (section 4.2).

4.1. Understanding processes of environmental decision-making

There are of course parts of the Pacific Islands where decisions about environmental management, particularly coastal management, are appropriately informed by government advice. There are also economic concerns – typically involving tourism or mining – where economic (cost-saving) constraints apparently justify overriding environmental imperatives[8]. But this section is not explicitly concerned with either such situation.

In most parts of most Pacific Island nations, decisions about the environment are made by the community that owns the part in question. A coastal community that experiences shoreline erosion will generally discuss and decide what to do about it. The hierarchical nature of most Pacific Island communities means that it is the experiences of the acknowledged leaders of these communities that dictate what will happen. And those experiences are most likely to be informed by traditional human-environment interactions – often quite different to what is happening today – and a lack of scientific understanding of either the local environment or the wider context of climate change.

Government policy or even government-sponsored advice rarely plays any role in local-area community decision-making of this kind. This is largely because of the lack of enforcement of policies, the lack of sufficient dissemination of relevant policies and advice, and – conversely – the determination of local communities to have final say (and resist outside "interference") over their land. It is this kind of situation that ensures that top-down solutions do not work well in the area of environmental decision-making in the Pacific Islands.

These processes are amplified in archipelagic countries (like many Pacific Island nations) where "development gradients" between cores and periphery are far steeper than in countries of no or perhaps just a few islands. Work on this issue in Fiji highlighted the situation on Moturiki, an island belonging to the development periphery (Kumar, 2007). Most coastal communities on densely-populated Moturiki had made a series of what appeared at the time to be appropriate decisions but which proved calamitous. Commonest among these was the construction of seawalls, but many villages on the island also continued to remove the mangrove fringe as soon as it showed signs of regrowth (Nunn, 2000).

Most people in the Pacific Islands are religious, and are guided in many aspects of life by church leaders. Such people also have inputs into environmental decision-making but these sometimes tend to emphasize the power of piety and prayer rather than practical solutions. This is not to undervalue the sincere effort by many churches in the Pacific Islands to understand climate change, but there is a problem with disseminating that understanding top-down (Takesy, 2004).

Finally, in understanding environmental decision-making in most parts of the Pacific Islands, it is important to acknowledge the inputs of people within the community perceived as learned, but whose learning may be inappropriate to the situation at hand. Schoolteachers' opinions are often solicited in this context, even though their training has not necessarily given them the answers required. Yet, in this cultural context, it is inappropriate to refuse advice outright even though you may know you are not qualified to give it.

4.2. Implementing and sustaining appropriate adaptation

There is a challenge in identifying appropriate adaptation to climate change in the Pacific Islands, discussed in section 5 below.

But under the heading of the cultural context, it is also important to understand how this affects both the implementation of appropriate adaptation and its sustainability.

Any kind of top-down solution seems doomed to failure in the Pacific Islands context, not just because of the ineffectiveness of the pathways of knowledge transfer but also, as noted in the previous section, the resistance from landowning communities to anything that could be interpreted as interfering with their right to manage their own land as they see fit. For such reasons, it is considered that the most effective way for outsiders to inform environmental decision-making in the Pacific Islands is by having a direct input at a community level. Pacific Island governments are naturally ambivalent about such a strategy, seeing in it on the one hand an admission of the ineffectiveness of their preferred top-down approaches but on the other hand acknowledging its efficacy.

Governments are best placed within the Pacific Islands to undertake such programs of community outreach but few do systematically, at least in the field of environmental decision-making. To date, it is non-government organizations (NGOs) that have been most effective in advising communities on how best to respond to the challenges of environmental management, including climate change. Such NGOs are often religious-based, sometimes exclusively in-country (not regional), although some global NGOs like WWF have adopted this approach in the Pacific Islands region.

NGOs are perceived differently from governments by local-area communities, often able to spend more time engaging the community, often bringing in volunteers for prolonged attachments, thereby displaying the kind of commitment that governments cannot afford to display. Further, NGOs often come with some funding attached, a powerful incentive for communities to hear their message and act on it. Finally, NGOs often exhibit the kind of long-term interest in projects within particular communities that governments are unable to do.

In this analysis, it seems better for appropriate climate-change adaptation strategies to be directed to local communities in the Pacific Islands through NGOs but, as seen above, they all have different agendas, even on the issue of climate change, which may prove unhelpful in the long term. One reason for this is that, because there are simply too many communities troubled by climate-change linked problems in the Pacific Islands for each one to be visited individually, strategies need to be developed whereby experiences of one community can be shared amongst similar communities. The Internet is an obvious tool for sharing experiences in the future but for now, given that most rural communities have no Internet access, there need to be developed more practical ways of sharing experiences. These are discussed in section 6.

Sharing experiences is also a way of helping ensure that appropriate adaptation solutions are sustained in the Pacific Islands. The problem of sustainability, so alien to people in "developed countries" (who expect their governments to do it), is profound in the Pacific Islands, especially when the solutions to be sustained are dependent on external factors as well as on continued management inputs by the local community. Let me illustrate the point.

In Japan or coastal USA, artificial shoreline protection structures are commonly designed appropriately for particular coasts, they are built with government (or state) funds and, should they collapse or fall into disrepair, the same sources of funding are available for their immediate restoration. Thus the artificial adaptation solution is sustained. The role of the local community is usually confined to drawing government's attention to the needs of adaptation.

In the Pacific Islands, an environmental management strategy involving an artificial shoreline structure may be built with locally-raised funds, perhaps with some support (money or material) from the government. But should the structure need repair, the costs of that would generally be borne entirely by the local community. Many local communities are only partly within the cash economy and find fundraising difficult, especially for maintenance costs, so eventually such structures may be abandoned.

5. Technological imperatives

There seems no doubt that Pacific Island nations need appropriate technological solutions for adaptation to climate change, present and projected. To date, as described above, technological solutions have – unless aid-funded and constructed – largely been uninformed emulations of solutions employed in metropolitan countries (to which they may be well suited) but which do not provide sustainable solutions in most parts of the Pacific Islands.

In the Pacific Islands context, appropriate solutions would not only be ones that are part of a package of adaptation to future climate change but are also those that acknowledge the special character of island nations per se, as well as that of the environments and cultures of the Pacific Islands. It is worth reiterating the key climate-change issues in the region that require technological solutions, both in the present and the future (Table 2).

In Table 2, it can be seen that the key (not all the) effects of increased climate variability will be in the agricultural and water supply sectors. The associated technological imperatives involve conserving and better managing existing resources, besides looking into how to reduce these sectors' exposure to climate change by changing crop types, improving food preservation and water-storage capacity.

Changes in the frequency and magnitude of climate extremes are also likely to affect the agriculture and water sectors. In addition, an increased tropical-cyclone frequency and intensity is likely to have an increased impact on the built environment of Pacific Island nations (Table 2). The most obvious way to reduce the exposure of vulnerable units is to relocate them to places where that exposure is less. Exposure can also be reduced by changing the nature of the unit to as to make it less vulnerable to climate extremes; for example, some crops are better able to withstand droughts and strong winds than others[9]. Agricultural techniques that maximize the use of the available water should be encouraged. In this context, the revival of traditional knowledge concerning water-conservatory techniques and food preservation should be encouraged.

Temperature rise is also likely to impact the agricultural sector (Table 2), but not nearly as much as mean annual precipitation changes for which there are still no reliable projections for the Pacific Islands in the rest of this century. Research into crops and crop strains that are more tolerant of higher temperatures is recommended. The issue of coral-reef bleaching and degradation and its impacts on coral-reef ecosystem productivity is one for which there is no readily apparent technological solution. Certainly the conservation of existing reefs and, where appropriate, the restoration of degraded reefs is encouraged.

Along many Pacific Island coasts, sea-level rise is already an issue, and one that it is projected to become an even greater one in the future. There are four major effects of sea-level rise that are relevant to Pacific Island coasts (Table 2).

- Coastal inundation (sustained flooding of coastal lowlands) can only be solved in most parts of the Pacific Islands by relocation of the affected people, agriculture and built environment (Figure 4a). Expensive technological fixes are likely to provide only a temporary solution.
- Shoreline erosion can be countered by the construction of appropriate artificial structures but these are commonly expensive to both build and maintain and often have unanticipated deleterious effects on the environment (Figure 4b). Far better to implement natural solutions, such as the planting of mangrove forest and/or the restoration of coral reefs.
- Groundwater salinization in coastal lowlands cannot be effectively reversed for affected agriculture. The only viable solution in the Pacific Islands context is its relocation.
- Sea-level rise will also allow larger-amplitude waves to cross protective offshore reef barriers and reach island shorelines where

they may have an unprecedented erosive effect. Conserving coral reefs so that they are optimally able to respond to sea-level rise is helpful, but the only long-term solution is relocation.

There are many possible technological solutions to the issues associated with sea-level rise described above (and listed in Table 2) and it is stressed that local environmental (and to a lesser extent, cultural) conditions should dictate the precise nature of these. That said, it does seem appropriate to discuss a few of what are perhaps the most common technological solutions. The discussion below is divided into "hard" solutions – typically engineered solutions to specific problems – and "soft" solutions – those which typically adapt or restore the natural environment to a condition where its effectiveness in reducing the impacts of climate change is maximized. Note that relocation, which is not a technological imperative in the sense of the others discussed here, is considered below in section 6.5.

5.1. Hard solutions for sea-level rise

The problem with most seawalls built along Pacific Island coasts with a view to preventing their continued erosion is that they are vertical and impermeable. In other words, they replace a shoreline that was gently sloping and allowed wave energy to be dissipated, particularly seawards, with a shoreline that focuses wave energy, typi-

Table 2. Technological and management imperatives for adaptation to key climate-change issues in the Pacific Islands region.

Climate change	***Issue***	***Technological imperatives***	***Management imperatives***
Increased climate variability	Variable agricultural productivity	Reduction of vulnerability by soil/water conservation; Changed crop types/strains; Improved food preservation	Appropriate long-term planning
	Variable water supply	Improved storage capacity	Appropriate water management
More climate extremes			
- tropical cyclones	Increased infrastructure/building damage	Relocation of exposed units; Improved design/materials for new units	Hazard mapping; Enforced zoning, building laws
	Increased damage to subsistence food sources	Relocation of exposed sources; Use of less vulnerable locations; Use of less vulnerable food sources	Subsistence food supply mapping and planning
- drought	Decreased/variable food supply	Changed crop types/strains; Improved food preservation; Water-conservatory agricultural techniques	Appropriate contingency planning
	Decreased water supply	Improved storage capacity	
Temperature rise	Decreased productivity of key crops	Research into new crops/strains	Sponsorship of research
	Increasing coral-reef bleaching	Conservation/restoration of coral reefs	Enforce appropriate legislation; Declare marine protected areas
Sea-level rise	Coastal inundation	Relocate vulnerable people and units	National strategy plans required
	Shoreline erosion (and consequent nearshore sediment mobilization)	Appropriate artificial structures; Mangrove reafforestation; Coral-reef conservation	Appropriate advice needed
	Groundwater salinization in coastal lowlands	Relocate affected agriculture	National strategy plans required
	Larger waves able to cross reefs and reach island shorelines	Relocate vulnerable people and units; Conserve/restore coral reefs	National strategy plans required.

Figure 4. Views of coastal settlements on Moturiki Island, Fiji, part of this nation's developmental periphery.

a. Low tide at Naicabecabe Village. The mean high-water mark can be clearly seen. During high spring tides, the village is underwater.

b. The people of Navuti Village stand on their seawall close to high tide. A 10-cm sea-level rise will see Navuti almost permanently inundated.

cally at the foot of the seawall (contributing to its undermining) and at either end of it. Further, it replaces a shoreline that was permeable, and therefore reduced wave impact and backwash, with one that is impermeable, which also focuses wave energy causing scour along the base of the seawall. In some parts of the Pacific Islands, offshore coral reefs have been mined to provide the building blocks for seawalls, something that increases their exposure to wave attack.

If artificial structures are to be constructed (and there are alternatives), then as far as possible they should mimic the form and the composition of the natural shoreline they are replacing. Thus seawalls should slope seawards much as beaches do, and they should be permeable, perhaps comprising large boulders or smaller-sized particles held in place by artificial webbing. But all such solutions are expensive to design, construct and maintain and are therefore realistically beyond the capacity of many local-area communities in the Pacific Islands.

5.2. Soft solutions for sea-level rise

A more appropriate long-term strategy is to use natural coastal protection, commonly the (re-) planting of mangrove forests within the intertidal zone. The main advantages of mangrove reafforestation is that it is cheap, low-maintenance, and effective. A mangrove fringe 30 m broad is a effective barrier to shoreline erosion, as many studies have shown, as well as being able to shield the coast behind it from at least small amounts of sea-level rise (Gilman et al., 2006). The disadvantage of mangrove reafforestation for many coastal communities in the Pacific Islands is that it takes a long time for a forest to grow from seedlings – as much as 25 years.

It is also worth mentioning the practicality of conserving coral reefs and looking at ways to restore those that have been degraded.

Coral-reef conservation is widely perceived in the Pacific Islands as a "green" preoccupation of western countries rather than a practical solution to existing and future problems. There are signs that this view is changing, as the benefits of local marine managed areas become widely known (Cinner et al., 2006). Yet the bottom line is that a healthy coral reef has a better chance of responding to sea-level rise (by growing upwards) and weathering periods of prolonged stress (associated with warming or increased sedimentation following heavy rain) than one which is significantly degraded, as many Pacific Island reefs have become (Hoffmann, 2002).

The issue of the restoration of degraded coral reefs, particularly with a view to restoring their diversity and ecosystem productivity, has hardly been explored in the Pacific Islands region, but may contribute in the future to adaptation packages for climate change.

6. Management imperatives

One of the issues that is not mentioned much in this paper is that of management for mitigation of climate change. This is a manifestly important area at a regional and a global level, with many smaller island countries being able to pressure larger ones to follow international standards intended to reduce carbon emissions and increase global forest cover. But this section, as with most of this paper, looks specifically at adaptation.

This section looks first at the management imperatives associated with particular climate-change issues, as listed in Table 2, before continuing to examine five cross-cutting management imperatives for adaptation to climate change in the Pacific Islands.

As shown in Table 2, management imperatives associated with increased climate variability require appropriate planning to ensure – as far as possible – no serious disruption to food supply, and appropriate water management. The latter ranges from the continued upkeep of communal water tanks in rural areas to a reduced dependency on large sources of open water (in reservoirs).

In order to reduce the impacts of more climate extremes, there should be better identification of vulnerable areas through hazard mapping, and the enforcement of zoning laws and building standards. The whole question of national food and water supply should become the object of national plans, with climate change factored in, and viable contingency plans emplaced.

The effects of temperature rise on agriculture can be countered to some extent by research into more appropriate crops and crop strains, which could be sponsored by governments and intra-regional advisory bodies. The conservation of coral reefs could be assisted by the enforcement of appropriate legislation as well as the declaration of marine protected areas.

Responding to the many effects of sea-level rise is something that is best done through effective national planning. Aside from identifying needs and opportunities for relocation, national plans can also help in the revitalization of over-exposed units in the agricultural and coastal sectors.

All such factors have been discussed before (Hay et al., 2003; Nunn and Mimura, 2006). The remainder of this section is devoted to a discussion of what are considered to be the region-wide management imperatives for coping with climate change. The first section deals with the question of ownership of climate-change issues by Pacific Island nations, which seems to be the critical step needed to confront the associated challenges effectively (section 6.1). The second section (6.2) deals with the need for long-term planning, something that is often problematic in smaller poorer democratic nations where new mandates may be given to governments with radically different agendas every few years. The third section (6.3) explains the imperative of mainstreaming climate-change awareness, not only to dispel alarmism, but also to set the stage for considered country-wide responses to particular issues. The fourth section (6.4) follows on from this by considering the specific need to empower community-level decision-makers to make appropriate decisions about the future of the environments under their stewardship. Finally, there is a section that considers relocation, arguing that, while much resisted, it remains the most appropriate response to many issues of climate change in the Pacific Islands (section 6.5).

6.1. Taking ownership of climate-change responses in the Pacific Islands

For as long as Pacific Island nations (and other "developing" countries) depend on external sources of funding to help understand and adapt to the effects of climate change within their countries, it will continue to be a marginalized issue. The point is not restricted to climate change, but to almost every initiative concerned with sustainable environmental development, an often-quoted phrase that has become oxymoronic in the Pacific Islands context (Nunn, 2004a).

The problem is specifically that, unless Pacific Island governments begin to commit sizeable portions of their earned revenue towards climate-change adaptation (and other environmental issues), this issue will never be appropriately addressed within that country. Most of its inhabitants will continue to be uninformed about what to do about climate change, and how it is likely to affect their lives in the future. External financial assistance is adequate for a degree of national capacity building but, as seen above, this is not having the beneficial effects that sponsors of such initiatives have long hoped for. External financial assistance is also adequate for trialling particular adaptation options or for running limited-term pilot studies, but is not intended for nation-wide adaptation, which is what is needed now and will be increasingly in the next few decades.

The other side of the coin is that most Pacific Island governments would claim that they have insufficient funds to commit to climate-change adaptation (and more broadly, sustainable environmental development) because of competing priorities. Yet these competing priorities are often those that involve exploitation of the environment for short-term profits, which is the principal raison d'etre for most such governments. The time is likely to come within the next 10-20 years when the problems associated with climate change become so acute in the Pacific that island governments will finally be forced to divert substantial amounts of their earned revenues to adaptation. But this will be far more expensive and probably less effective than starting the process of self-funded national adaptation now.

International donors should acknowledge the dangers of long-term dependency of such nations on external funding assistance for the challenges of climate change, and encourage these nations to take increasing ownership of climate-change adaptation.

6.2. The imperative of long-range planning

Five-year democracies are commendable in many ways but, especially in smaller poorer countries, electorates tend to reward governments that put more money into individual pockets between elections than those – if there are any in such countries – that embrace long-term plans that restrict resource use and environmental exploitation in the name of sustainable development. This is a real dilemma of democracy in smaller poorer countries (Clague et al., 2001) and one that manifestly contributes to the difficulties of getting global action on combating climate change (Sarewitz, 2004).

Minimizing the undesirable impacts of climate change in larger wealthier countries involves long-range planning that almost all competing political alliances would agree is above their individual agendas. But in smaller poorer countries like those in the Pacific Islands, while long-range development plans are issued, invariably it becomes more important to attain short-term development goals. Yet there is no escaping the imperative of long-range planning if the impacts of climate change on Pacific Island peoples are to be minimized in the future. Many government decision-makers recognize this clearly, but their political masters typically overrule such decisions when the short-term consequences are clearly likely to be unpopular.

No obvious solution comes to mind. Yet if long-term plans are not put in place and rigidly adhered to, then again the situation will likely become exigent 10-20 years from now, and rapid action will be taken to save particular communities and particular resources.

6.3. Mainstreaming awareness of climate change

One important way forward involves the mainstreaming of awareness of climate change. Of course, this (education) is merely frustrating unless you also give opportunities and, where appropriate, the tools to adapt to climate change, but it is a necessary preliminary. The people of the Pacific Islands should become more aware of what future climate change is likely to involve, precisely how it will affect present-day lifeways, and what the best options are for adaptation.

There is a huge amount of misinformation about climate change in the Pacific Islands, much of it engendered by a disingenuous media who focus on disastrous situations, and on extreme predictions of what might happen. The media could well use their considerable power in the Pacific Islands region to raise awareness about mainstream views of climate change and help spread awareness about successful solutions to various aspects of climate change, but they hardly do[10].

Yet there are other ways of raising awareness, ways that are generally better respected among Pacific Island communities than many media sources. These could be either information sheets or personalized verbal communication.

Many Pacific Island communities are truly communal in the sense that they share many tasks and activities, and that individuals within those communities cooperate and communicate regularly with one another. These attributes provide excellent opportunities for mainstreaming awareness of climate change. For example, information sheets written in vernacular languages, well illustrated, culturally apt, and using familiar examples would be studied and exchanged at length among rural communities. It is also appropriate, as discussed more in the following section, to empower community leaders – be they hereditary chiefs, elected spokespeople, school teachers, or church leaders – to communicate mainstream views about climate change to the people that commonly listen to them.

As a last point in this section, it is appropriate to discuss awareness raising amongst school children through the incorporation of climate-change issues in school curricula. It is important that this is done in ways that are culturally appropriate so that school children do not feel that this is an alien issue of no immediate relevance to them. But it is also important not to place too much faith in this type of awareness raising as a way of changing the attitude of Pacific Island societies towards climate change. Most such societies remain rigidly hierarchical and children are at the bottom of the pile, generally not encouraged to speak for themselves but to listen to and receive the wisdom of their elders. In the Pacific Islands, creating a young generation that is far more aware of climate-change issues than their parents' and grandparents' generations will not bring about change in the position of societies on these issues as quickly as might be expected in other, less communally-focused societies.

6.4. Empowering community-level decision-makers

It was seen above that most national policies, expressed through legislation, concerning environmental management in Pacific Island countries are ineffectual, both because of a lack of enforcement and because of the conviction of landowners that they should be permitted to arrive at decisions regarding their land independently of what is perceived as outside interference. This situation is unlikely to change significantly in the next few decades, so it follows that an important way to bring about appropriate adaptation to the various manifestations of climate change is to give landowners (community-level decision-makers) the information they need to make appropriate decisions about their environments.

This information involves giving enough explanation of the science of climate change, supplemented by Pacific Island examples, to convince decision-makers of the need for action. Additional information should concentrate on the likely nature of present and future changes to environments, again supported by examples from similar situations. Finally, and most importantly, there should be a systematic explanation of the options available to communities for combating the undesired effects of climate change and what is involved in sustaining each option into the foreseeable future.

While community-level decision-makers could be targeted specifically, perhaps through short courses in regional centres, it is also important to embed information about climate-change decision-making within communities. To localize and emphasize the importance of the climate-change issue, it seems essential to deliver the message in vernacular languages, those which are most commonly used and best understood not only by community-level decision-makers but also by members of the communities in particular places. The best medium would be in print, in the form of specially-designed pamphlets that could be circulated within communities and mulled over at length. Printed information could be supplemented by radio and television where appropriate.

To ensure that this approach to empowering community-level decision-makers is sustained, it needs to be regularly reinforced. There are two principal ways in which such reinforcement could come about in the Pacific Islands context: reinforcement by government, and reinforcement through shared experiences.

Reinforcement by government might involve refresher courses for community-level decision-makers in which they are encouraged to explain the actions that their community had taken with respect to particular problems and how effective these actions appear to have been. Reinforcement by government might also be through regular slots on radio and television, as appropriate, that would demonstrate that climate-change issues remained high on national agendas.

Reinforcement through shared experiences would involve communities talking to other communities, both within a particular country and between countries. This approach acknowledges the similarities, not only in environments that particular communities occupy, but also the nature of competing interests to climate-change adaptation, and the tools available within communities for adaptation. Reinforcement of this kind would seem very important to communities debating various adaptation strategies, but also in demonstrating that action can bring about improvements.

6.5. Relocation: the unthinkable option?

From a geological perspective, the alternate submergence and emergence of coastal lands – even entire islands – is something that is expected and unavoidable in the course of history. But being so sanguine about this issue is little practical help to Pacific Island people whose homes are being submerged, now and in the next few decades. But such a view should serve to make the task of decision-makers in the Pacific Islands simpler in this regard. For whatever resistance there will inevitably be to relocation, there is simply no alternative in most cases where coastal/lowland settlements are threatened by sea-level rise. Far-sighted decision-makers should act now to minimize future disruption.

Much has been written about the vulnerability of the lowest and most insular (measured by the insularity ratio – Nunn and Kumar, 2006) islands in the Pacific. Such atoll islands (or motu) comprise all (or most) of entire nations like Kiribati, the Marshall Islands, Tokelau, and Tuvalu. While armoured by beachrock and other types of naturally-forming conglomerate in places, most atoll islands are formed from unconsolidated gravel and sand. Life on atolls is generally more challenging and involves fewer options than on larger Pacific islands. Sea-level rise this century has been predicted to render some such atolls uninhabitable, both because of inundation, contracted water tables, and erosion (Roy and Connell, 1991; Barnett and Adger, 2003). There is no doubt that atoll dwellers face serious and impending problems involved in their continued occupation of such vulnerable environments. The lack of high ground on atoll islands means that off-island relocation is the only long-term adaptation option.

The focus on atolls and the attendant media hype has reduced the attention paid to the probable impact of sea-level rise on other types of Pacific island (Nunn, 2004b, 2007). But the future of many high-island countries is threatened to an equally serious extent by sea-level rise because most of the cash-generating (as opposed to subsistence) activities of these countries are situated on coastal plains often rising only a few metres above sea level. Sea-level rise threatens the existence of these coastal plains, and the fact that there is higher ground in their hinterlands to which coastal dwellers could relocate fails to acknowledge the economic effects of such a scenario.

For example, many coastal towns (and cities) in the (non-atoll) Pacific Island countries are experiencing increasing regular flooding during heavy rain. So unthinkable is the idea of relocation – and all the disruption and cost that would entail – that the affected people are clamouring for more dredging of nearby rivers, more upstream dams, and better seawalls. But none of these are any more than cosmetic solutions, unable to solve the problem. For such towns were originally built – typically 100-150 years ago - on lowlands for the convenience of building, in coastal locations to facilitate ship transport, and close to rivers for freshwater and access to the hinterland. But in the time since these towns were established, much of the hinterland has been denuded of its natural vegetation cover thereby increasing river sediment loads (Figure 5a). These sediment loads are carried downstream and, where stream gradients are reduced, as they are on coastal lowlands, the sediment is deposited in river channels and around their mouths. This reduces river-channel capacity, making flooding more frequent. More frequent floods are also caused by rain falling on the now-denuded catchments where there is no longer as much vegetation as there once was to slow the movement of rainwater into river channels. Added to this is sea-level rise, which not only causes shoreline erosion of such delta fronts and coastal plains, but also causes base-level rise forcing river channels to aggrade thereby reducing their capacity further. Finally, there is human impact. The weight of a coastal town compresses the unconsolidated sediments below causing it to sink slowly, a process that is occasionally in the Pacific Islands exacerbated by groundwater extraction. The concretization of urban landscapes – the construction of roads and pavements (sidewalks) also reduces the amount of rainwater (or floodwater) that can be absorbed into the ground, so much runs straight into the rivers. As sea level rises in the future, so the functions of such locations will become increasingly difficult to sustain (Figure 5b).

In such a situation, in countries where the funds for "big-fix" engineering solutions will never be found everywhere it is needed, the only long-term adaptation option is relocation.

It is apt to end this section with a brief discussion of why we in the Pacific Islands – and of course elsewhere in the world – so strongly resist the idea of relocation. For it is not only along coasts threatened by sea-level rise where people resist the idea of moving but also on the slopes of active volcanoes or in the subsiding centres of deltaic cities. Principally we resist relocation because we have become fully sedentary in the way that our ancestors a few hundred years ago were not. We have built ourselves permanent dwellings, surrounded ourselves with permanent infrastructure and have convinced ourselves of humanity's dominion over Nature. But it is a false belief, as periodic natural disasters remind us. The Indian Ocean Tsunami on 24th December 2004 was a shock to coastal peoples throughout that part of the world, as was the 1994 Northridge Earthquake (California, USA) and the 1995 Kobe Earthquake (Japan). After the latter event, urban

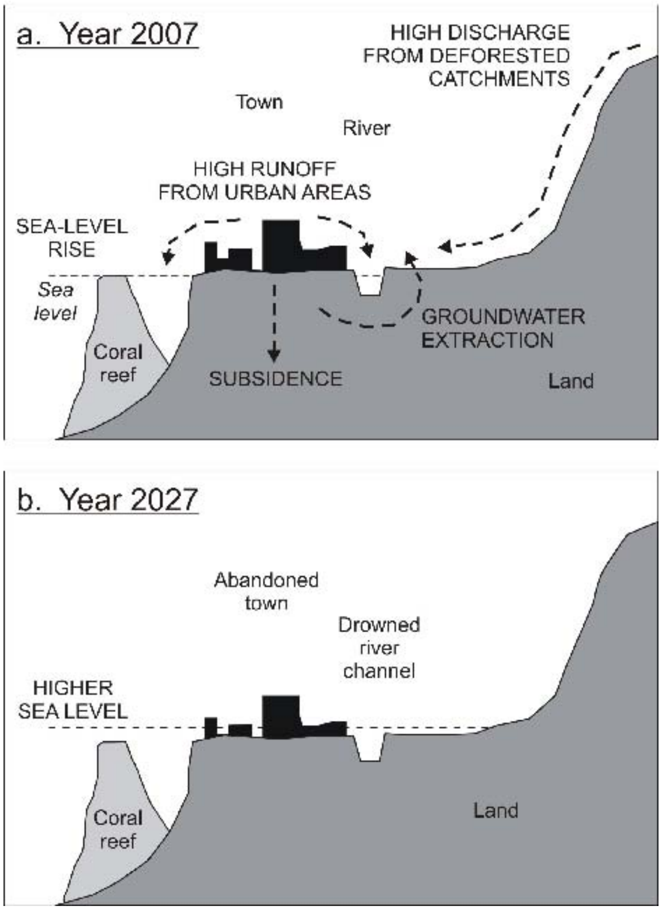

Figure 5. Many coastal towns and cities in the Pacific Islands will not be readily inhabitable in 20 years time. This shows a typical situation.

a. In the year 2007, many coastal towns are being affected by both sea-level rise and subsidence, the combination of which is causing their levels to drop relative to the sea surface, something that is manifested in the short term by increased flood frequency and magnitude. Flooding is exacerbated in such locations by upland deforestation and unhelpful agricultural practices, and by high runoff from urban areas, the combination of which is to reduce river-channel capacity.

b. In the year 2027, the higher sea level will combine with other factors to submerge many such coastal towns and cities. For poorer countries, the best long-term adaptation option is to begin relocating such towns and cities to less vulnerable areas.

planners acknowledged that they had allowed inappropriate development driven by economic growth without fully acknowledging or even understanding the seismic hazards of the area. In a similar way, coastal dwellers in the Pacific Islands have allowed themselves to be lulled into a false sense of security about the permanence of the environments they occupy. As Amata Kabua, former President of the Marshall Islands, said in 1988 at the first meeting of Pacific Island countries specifically devoted to climate change and sea-level rise,

> "It is truly frightening to think that our ocean will turn against us. We have been sustained by the ocean for two millennia. It has been bountiful and continues to yield to us its bounty. We have learned that this harmony may be interrupted by the action of nations very distant from our shores. I hope that the appeal of the peoples of the Pacific can help convince the industrialized nations to discontinue their profligate contamination of the atmosphere."

And as Tamari'i Tutangata, the Director of SPREP in 2000, reflected

> "As a ten-year-old, I used to look at the sea with awe, at the seemingly endless supply of fish that I could harvest … now when I look at it, I wonder how far into the new millennium we will be before it overwhelms our coasts. What is there to celebrate about a new millennium if the northern group of the Cook Islands, or the many islands of Kiribati, Tokelau, Tuvalu, the Federated States of Micronesia and the Marshall Islands are about to disappear beneath the ocean?"

Unpalatable as it may be, the only possible adaptive response to climate change in many parts of the Pacific Islands region is relocation.

7. Conclusions: the way forward

The mindset of Pacific Islands decision-makers – a microcosm of the entire globe – needs to be fundamentally changed if the Pacific Islands region is not to be badly affected by climate change this century. This is the message of the 2007 IPCC Report, that if something is not done urgently then human societies on the Earth will be severely impacted in a number of ways. Some large rich countries – long opposed to the science as well as the socio-economic imperatives – are finally showing signs of acknowledging projected climate changes while others are not.

Within the greater global scheme of things, one might legitimately ask whether it matters at all what smaller poorer nations like those in the Pacific Islands do or don't do with regards to climate change. This is largely a rhetorical question at one level, but at another it clearly matters profoundly to the people living in Pacific Island nations how effectively their leaders both seek to mitigate the causes of deleterious climate change on the world stage and implement appropriate adaptation measures throughout their island nations.

The achievement of the latter requires a sea change in thinking about climate change and planning for future climate change in the Pacific Islands. In particular, it requires that Pacific Island nations

- take ownership of the climate-change issue as it applies to their countries,
- ensure that viable and appropriate long-range plans are followed,
- ensure that climate-change awareness is mainstreamed within the knowledge pools of these countries, and
- ensure that community-level decision-makers are given the knowledge and the right tools to make informed decisions about environmental management in a world where the climate is changing at an unprecedented rate.

20 years ago, Stephen Schneider admonished those governments that refused to credit predictions of 21st-century climate change and its implications for global wellbeing with the memorable phrase, "not to decide [to act on climate change] is to decide" – on other words that nations which decide not to do something about adapting to climate change are nonetheless making a decision. For several reasons, discussed above, most Pacific Island nations then chose to do nothing. In 2007, most Pacific Island nations have stuck implicitly with that decision, paying lip-service to global climate-change agendas but declining to commit their own resources to the challenge. Should they continue to stay with this course of action – as seems highly likely – then the future of the Pacific Islands region will be more difficult than it need be. It is likely that, 20-30 years from now, the impacts of climate change on the Pacific Islands will be so severe that there will be innumerable calls for external assistance. What must be realized is that the traditional benefactors of the region may then be combating the effects of climate change in their own countries, and will be unable or unwilling to commit what is needed to help the Pacific Islands.

References

Athens JS (1995) Landscape Archaeology: prehistoric settlement, subsistence, and environment of Kosrae, eastern Caroline Islands, Micronesia. International Archaeological Research Institute, Honolulu.

Barclay K, Cartwright I (2007) Governance of tuna industries: the key to economic viability and sustainability in the Western and Central Pacific Ocean. Marine Policy 31: 348-358.

Barnett J, Adger WN (2003) Climate dangers and atoll countries. Climatic Change 61: 321-337.

Brown MJF (1974) A development consequence: disposal of mining waste on Bougainville, Papua New Guinea. Geoforum 18: 19-27.

Cinner J, Marnane MJ, McClanahan TR, Almany GR (2006) Periodic closures as adaptive coral reef management in the Indo-Pacific. Ecology and Society, 11: 31 (online at http://www.ecologyandsociety.org/vol11/iss1/art31).

Clague C, Gleason S, Knack S (2001) Determinants of lasting democracy in poor countries: culture, development, and institutions. Annals of the American Academy of Political and Social Science 573: 16-41.

Cowell PJ, Kench PS (2001) The morphological response of atoll islands to sea-level rise. Part 1: modifications to the shoreface translation model. Journal of Coastal Research 34: 633–644.

Dickinson WR (1999) Holocene sea-level record on Funafuti and potential impact of global warming on central Pacific atolls. Quaternary Research 51: 124-132.

Donner SD, Skirving WJ, Little CM, Oppenheimer M, Hoegh-Guldberg O (2005) Global assessment of coral bleaching and required rates of adaptation under climate change. Global Change Biology 11: 2251-2265.

Gilman E, Ellison JC, Jungblut V, Van Lavieren H, Wilson L, Areki F, Brighouse G, Bungitak J, Dus E, Henry M, Kilman M, Matthews E, Sauni Jr I, Teariki-Ruatu N, Tukia S, Yuknavage K (2006) Adapting to Pacific Island mangrove responses to sea level rise and climate change. Climate Research 32: 161-176.

Hay JE, Mimura N, Campbell J, Fifita S, Koshy K, McLean RF, Nakalevu T, Nunn P, de Wet N (2003) Climate Variability and Change and Sea-Level Rise in the Pacific Islands Region. South Pacific Regional Environment Programme, Apia, Samoa.

Heffler J, Irion G, Lehmann B (1997) Environmental impact of mining waste disposal on a tropical lowland river system: A case study on the Ok Tedi Mine, Papua New Guinea. Mineralium Deposita 32: 280-291.

Hoegh-Guldberg O (1999a) Climate Change, Coral Bleaching, and the Future of the World's Coral Reefs. Greenpeace, Amsterdam.

Hoegh-Guldberg O (1999b) Coral bleaching, climate change and the future of the world's coral reefs. Review of Marine and Freshwater Research 50: 839-866.

Hoffmann TC (2002) Coral reef health and effects of socio-economic factors in Fiji and Cook Islands. Marine Pollution Bulletin 44: 1281-1293.

Huffer E (2005) Governance, corruption, and ethics in the Pacific. The Contemporary Pacific 17: 118-140.

Hviding E (2003) Between knowledges: Pacific studies and academic disciplines. The Contemporary Pacific 15: 43-73.

Hviding E (2006) Knowing and managing biodiversity in the Pacific Islands: challenges of environmentalism in Marovo Lagoon. International Social Science Journal 58: 69-85.

Hviding E, Bayliss-Smith TP (2000) Islands of Rainforest: agroforestry, logging and eco-tourism in Solomon Islands. Ashgate, Aldershot.

IPCC WGI (2001) Climate Change 2001, Scientific Basis. Cambridge University Press, Cambridge.

Johnson M (ed) (1992) Lore: capturing traditional environmental knowledge. IDRC, Ottawa.

Kench PS., Cowell PJ (2001) The morphological response of atoll islands to sea-level rise. Part 2: application of the modified shoreface translation model. Journal of Coastal Research 34: 645–56.

Kuijper MWM (2003) Marine and coastal environmental awareness building within the context of UNESCO's activities in Asia and the Pacific. Marine Pollution Bulletin 47: 265-272.

Kumar R (2007) Problems and prospects for islands at the margins: a case study of Moturiki Island, central Fiji. Kagoshima University Research Center for the Pacific Islands, Occasional Paper (Proceedings of the Conference on Global Warming in the Pacific).

Leach BF, Ward G (1981) Archaeology on Kapingamarangi Atoll: a Polynesian outlier in the eastern Caroline Islands. Manuscript, Pacific Collection, The University of the South Pacific Library, Suva, Fiji.

Lomo FF (2001) Commercial logging, subsistence livelihoods and rural development: a case study of Rufoki Village, Malaita Province, Solomon Islands. Unpublished MA thesis, Department of Geography, The University of the South Pacific.

McNeill JR (1994) Of rats and men: a synoptic environmental history of the island Pacific. Journal of World History 5: 299-349.

McNeill JR (1999) Islands in the Rim: Ecology and History In and Around the Pacific, 1521-1996. In: Flynn DO, Frost L, Latham AJH (eds) Pacific Centuries: Pacific and Pacific Rim History since the Sixteenth Century. Routledge, London, pp70-84.

Mimura N, Nunn PD (1998) Trends of beach erosion and shoreline protection in rural Fiji. Journal of Coastal Research 14: 37-46.

Morrison RJ, Geraghty PA, Crowl L (eds) (1994) Science of Pacific Island Peoples. Institute of Pacific Studies, The University of the South Pacific, Suva, Fiji, 4 volumes.

Nunn PD (2000) Coastal changes over the past two hundred years around Ovalau and Moturiki Islands, Fiji: implications for coastal-zone management. Australian Geographer 31: 21-39.

Nunn PD (2003) Nature-society interactions in the Pacific Islands. Geografiska Annaler 85 B: 219-229.

Nunn PD (2004a) Through a mist on the ocean: human understanding of island environments. Tijdschrift voor Economische en Sociale Geografie 95: 311-325.

Nunn PD (2004b) Understanding and adapting to sea-level change. In: Harris F (ed) Global Environmental Issues. Wiley, Chichester, pp45-64.

Nunn PD (2006) Island origins and environments. In: Baldacchino G (ed) A World of Islands: A Physical and Human Approach. Agenda, Malta, pp5-37.

Nunn PD (2007) Climate, Environment, and Society in the Pacific during the Last Millennium. Elsevier, Amsterdam.

Nunn PD, Kumar R (2006) Coastal history in the Asia-Pacific region. In: Harvey N (ed) Global Change and Integrated Coastal Management: The Asia-Pacific Region. Springer, Berlin pp93-116.

Nunn PD, Mimura N (2006) Promoting sustainability on vulnerable island coasts: a case study of the smaller Pacific Islands. In: McFadden L, Nicholls RJ, Penning-Rowsell E (eds) Managing Coastal Vulnerability. Elsevier, Amsterdam, pp193-221.

Nunn PD, Hunter-Anderson R, Carson MT, Thomas F, Ulm S, Rowland M (2007) Times of plenty, times of less: chronologies of last-millennium societal disruption in the Pacific Basin. Human Ecology: An Interdisciplinary Journal. doi 10.1007/s10745-006-9090-5.

Nunn PD. Keally CT, King C, Wijaya J, Cruz R (2006) Human responses to coastal change in the Asia-Pacific region. In: Harvey N (ed) Global Change and Integrated Coastal Management: The Asia-Pacific Region. Springer, Berlin, pp117-161.

Nunn PD, Veitayaki J, Ram-Bidesi V, Vunisea A (1999) Coastal issues for oceanic islands: implications for human futures. Natural Resources Forum 23: 195-207.

Pelling M, Uitto JI (2001) Small island developing states: natural disaster vulnerability and global change. Environmental Hazards 3: 49-62.

Ravuvu AD (1988) Development or Dependence. Institute of Pacific Studies, The University of the South Pacific, Suva, Fiji.

Roy P, Connell J (1991) Climatic change and the future of atoll states. Journal of Coastal Research 7: 1057-1075.

Sarewitz D (2004) How science makes environmental controversies worse. Environmental Science and Policy 7: 385-403.

Slimak MW, Dietz T (2006) Personal values, beliefs, and ecological risk perception. Risk Analysis 26: 1689-1705.

Sofer M (1985) The dependency paradigm applied to the Fijian periphery. Singapore Journal of Tropical Geography 6: 127-139.

Takesy A (2004) Using the churches to spread the gospel: earth's stewards of the Pacific. Islands Business 30: 46.

Thaman RR (1982) Deterioration of traditional food systems, increasing malnutrition and food dependency in the Pacific Islands. Journal of Food and Nutrition 39:109-121.

Thaman RR (1990) Coastal reforestation and agroforestry as immediate ameliorative measures to address global warming and to promote sustainable habitation of lowlying islands and coastal areas. In: Streets DG, Siddiqi TA (eds) Responding to the Threat of Global Warming: Options for the Pacific and Asia. Proceedings of a Workshop Sponsored by Argonne National Laboratory and Environment and Policy Institute, East-West Center, Honolulu, Hawaii 21-27 June 1989. Argonne National Laboratory, Illinois. pp4.33-4.57.

Turnbull J (2004) Explaining complexities of environmental management in developing countries: lessons from the Fiji Islands. The Geographical Journal 170: 64-77.

Ulijaszek SJ (2002) Modernization and the diet of adults on Rarotonga, the Cook Islands. Ecology of Food and Nutrition 41: 203-228.

Wood H (2003) Cultural studies for Oceania. The Contemporary Pacific 15: 340-374.

Zurick DN (1995) Preserving paradise. Geographical Review 85: 157-173.

ENDNOTES

1 These deprecatory terms are intentionally placed in parentheses.
2 The author attended one such meeting in Charleston.
3 The coastline length to land area is known as the insularity index, and has been used as a crude comparative measure of national vulnerability to climate change in the Asia-Pacific region (Nunn and Kumar, 2006). For example, the island nation of Palau has an insularity index of 332, making it evidently far more vulnerable than even Japan which has an insularity index of 8.
4 The original archaeological work was by Leach and Ward (1981).
5 The original work on Lelu was undertaken by Athens (1995).
6 The diets of urban-dwelling Pacific Islanders compared to their rural counterparts is an illustration of this (Thaman, 1982; Ulijaszek, 2002).
7 The author has been told by the Director of Meteorology for one of the island nations that he advises his government not to act on climate change because God will not allow any of these terrible things to befall their god-fearing nation. Similar providential beliefs are common for other natural phenomena in the Pacific Islands – the tsunami that destroyed the town of Gizo in Solomon Islands in April 2007 was believed by at least one commentator to be punishment for its inhabitants' lack of piety (Sydney Morning Herald, 4 April 2007). Such distasteful judgements should not be overlooked in any evaluation of environmental management in the Pacific Islands or indeed elsewhere in the world (Slimak and Dietz, 2006).
8 In the past 12 months, the government of a South Pacific island nation approved development plans submitted by two new tourist resorts that unashamedly stated that their domestic waste would be dumped on the coral reef edge, 100 m offshore. This is a clear example of how environmental laws are flouted for short-term economic benefits.
9 Agroforestry is an important technique in this regard (Thaman, 1990).
10 As a former Editor of the Fiji Times newspaper told the author, "mainstream does not sell papers", "our readers spend their dollars to read about people worse off than themselves". The bottom line, unsurprisingly, is profit. In defence of the Fiji Times, it is now perhaps the most responsible of all Pacific Islands print media in dealing with issues of climate change.

"Cross-System Interactions of Ecosystems and Human Systems" or "Dealing with Climate Change: A Coupled System Response"

Dennis Ojima

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The current changes in the earth system are affecting climate, biophysical, and socio-economic systems concurrently. The transition the earth system is undergoing is unprecedented in terms of the magnitude of the rate of change in the human-environmental system and the effects this has on local to global system dynamics. The world's population has more than doubled in the past 50 years, and it will most likely increase by at least half again before stabilizing toward the end of this century. The biogeochemical cycles have been greatly accelerated with resulting loading of GHG in the atmosphere, C and N utilized at increasing rates for energy and food production, and ecosystem services damaged due increased pollutant levels affecting air and water quality. There is more crowding and consumption of resources on our planet than at any time in history. The development of industrial activities and technological advances has provided great enhancements to our quality of life; however, the tremendous rate of consumptive use around the world has over-ridden the natural cycles of air, water, and nutrients. These activities affect key ecosystem services that regulate clean water and air, provide adequate food, forage, fuel, and fiber, regulate risk to infectious diseases, and maintain soil fertility. Providing food, energy, water, and other goods into the future presents a huge challenge in itself, but it also exacts an enormous cost on the life support systems of the planet - the atmosphere, climate, water, and ecosystems that provide so many of the goods and services that make our planet habitable. Achieving a sustainable world under the current pressures on the earth system represents the greatest challenge faced by humanity.

An environmental science paradigm is emerging; the coupled human-environmental framework that explicitly recognizes the impacts of human activities on the environment, ecosystem dynamics, and ecosystem services and the effects these impacts have on society. Development of pathways toward coping and adapting to climate change will take a concerted effort that is interdisciplinary and integrated across the social, physical, biological, and engineering disciplines; international in scope, and accessible to the decision makers and business sectors.

In order to develop appropriate strategies to mitigate, cope, and adapt to potential climate change effects it will be necessary to fundamentally change the way we conduct research and sound decision making. The challenges threatening our environments are too complex to solve by traditional sectoral or disciplinary approaches alone. Future actions for mitigation or adaptation will require the integration of the best science into real-world decision-making, public policy dialogue, and development of appropriate applications; with the ultimate goal the management of our planet's natural resources upon which all life depends — air, water, land, and biological diversity.

The human-environment characteristics provide a context to better understand the cultural landscape in which changes in the land environment is taking place and the manner in which regional differences in social structures at multiple scales affect biogeochemical cycles, biodiversity, and biophysical processes. The development of the research activities will require the joint efforts of scientists from various communities, including the social, economic, ecological, soil, biogeochemical, hydrological, atmospheric chemistry, and atmospheric dynamic sciences.

The analysis of complex interactive systems have revealed the roles of emergent and path-dependent properties related to coupled human-environmental systems, and the thresholds in these systems that change their structure and function. The non-linear dynamics of transitional systems challenges the society and the management of ecosystem services. The disruption of biotic interactions due to differential responses to climate thresholds altering phonological patterns; outbreaks of pests and diseases altering ecosystem structure and functions; or ocean acidification which alter marine food web relationships can have dramatic effects on ecosystem services society has come to rely on. In addition, socio-economic actions are concurrently disrupting ecosystem services in dramatic ways, such as production of reactive N compounds; harvesting of keystone species; biotic substitutions for commodity production; and geological and hydrological restructuring of whole landscapes or river basins.

The current rate of change in the earth systems associated with the socio-economic and the biophysical systems demands that a more integrated approach is need for assessing the decision of resource use and energy production and use. The integrated science approach associated with the study of vulnerability, resilience, and ecosystem services have demonstrated the usefulness of the coupled system approach. Studies of social learning and decision making have improved understanding of how coupled human-environmental systems, including land systems, are sustained or cope with forces of change. Advances in agent-based and other integrated modelling techniques permit these complex factors to be treated systematically and holistically, providing land-based outcomes and near-term projections.

The complexity of land systems, the variability in the forcing functions acting on them and the synergy of the human and environmental subsystems enhance the need for place-based analysis (e.g., production unit, ecosystem, landscape) to address vulnerability, resilience, and sustainability. Yet, profound scalar dynamics in land systems and the multiple needs of science and society regarding these systems also require that integrative analysis and assessment address multiple spatio-temporal resolutions to the problem.

New analytical tools and monitoring systems are being developed to better investigate and assess the dynamics of the coupled system. Agent-based modeling approaches that incorporate the interaction between ecosystem services and decision making provide an additional tool for assessing strategies for mitigation, coping and adaptation. An example of this development for semi-arid pastoral systems will be presented.

Using Bayesian networks to model the impact of climate change scenarios on biofuels production from irrigated agriculture - analysing water, energy and food sector interdependencies

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Abstract

Both socio-economic and ecological systems exhibit complex behaviours which are often difficult to model and understand. This is due to the complex re-organisation of non-linear, cross-scale feedbacks and other interactions between key sub-system processes for adaptation purposes. The re-organisation of these systems in real time limits our understanding from historical observations and results in the inherent uncertainty associated with predictive ability of models. Climate change adaptation research involves exploring the interdependencies (or linkages) between the socio-economic and ecological variables spanning inter-dependent human development sectors. These are usually evaluated using differing methodologies, analytical techniques and epistemologies which are constrained by their respective disciplinary perspectives. We propose an approach for evaluating adaptation responses that integrates the food, water and energy sectors using Bayesian networks. Interdisciplinary consideration of variables may be enhanced through the sensitivity analysis enabled by Bayesian networks, which is used to conceptualise the causal dependencies between sub-system variables. The approach is intended for facilitating inter-disciplinary consideration of cross-scale and inter-sector dependencies. We formulate and run a national scale South African model which links the impacts of projected climate change effects in southern Africa to irrigated agriculture, water storage planning and biofuels production. We demonstrate how the evaluation of climate change adaptation responses to projected climate change scenarios for southern Africa may be enabled through the approach - and how conflicting demands between water, food and biofuel energy sources may be preliminarily identified and assessed in an integrated probabilistic framework. Evaluating this problem in the context of water availability and the threat posed by climate change provides a way of enabling research to support integrated development analysis and planning.

1 Biofuels for South Africa: A Complex Social- Ecological System Problem

1.1 Using Biofuels as Adaptation Strategies to Mitigate Climate Change Effects

Both climate change effects and regional human development may threaten water supply and agricultural food production activities in southern Africa (Mukheibir and Sparks, 2003; Mendelsohn, 2000; Midgeley, 2005). Biofuels are currently being considered as a viable supplementary source of low emission, renewable energy as a liquid fuel supplement in agriculture intensive economies in transitional and first world countries (e.g. Brazil, USA) - especially as the pressure to lower emissions has grown with the increased global awareness of climate change effects. However, the impact of the agricultural sector entering an energy market with rising demands and the threat of lower fossil fuel reserves in the future poses inter-sectoral development challenges. This is due to the interdependency being created between the energy and food production sectors by the introduction and use of biofuels as a viable source of alternative energy which helps reduce emissions from liquid petroleum (Lemmer, 2006).

In America, rising energy demands are placing pressure on agricultural production practises. The production of maize in the American midwest for ethanol production has already exceeded 50 percent of total maize produced (MIT Technology Review, 2007) and has led to an increase in maize prices. It has been claimed that this has had remote effects on distant economies like South Africa where food prices have risen sharply in recent years. For example, a recent press report presented the view that perceptions amongst dairy farmers was that the increased cost of maize feed grown in the American Midwest - due to the demand from the US biofuels industry - is having a significant impact on milk production costs in South Africa (Independent Online, 2007). In the southern African region, climate change models (Mendelsohn *et al*., 2000) predict an increase in water-scarcity due to temperature increases. For agricultural production this suggests an increase in plant evapotranspiration rates, surface runoff and dam evaporation rates. At the national scale this implies that sector-driven competition will also increase. Avoiding unintended effects of diverting existing agriculture for food and animal feed to biofuel production requires prescribing an appropriate *balance* between food and biofuel production agricultural activities.

The South African government's stated aim is to grow the national biofuel production capability to account for 40 percent of national renewable energy production by 2013. This is estimated to be 10 000 GWh of renewable energy. However a full biofuels strategy is still being developed and is being formulated using the International Energy Agency's (IEA) recommendations for developing national biofuels strategies' (Department of Minerals and Energy, South Africa (DME), 2006). The government has established a joint implementation committee (JIC) to oversee the national biodiesel industry consisting of trade unions, oil companies, agricultural lobbies and the South African Petroleum Industry Association (SAPI). So far, the committee has established a biodiesel standard for South Africa, and plans to produce a pricing model for the local biodiesel industry in the near future.

The aim of the JIC is to help grow the biodiesel industry to supply 2 percent of the total diesel consumption (eight billion litres) in South Africa in the short term - which suggests that a production capability of 160 million litres would have to be established in the current economy and be able to grow with the economy. The total national biofuel target (Lemmer, 2006) for 2013 is 4.5 % of national petroleum production (NPP: 10.985E6 l) i.e. 494 325 000 l. Biofuel production from maize, soya-beans, sunflowers and sugar-cane on this scale from irrigated agriculture alone would require a large amount of new arable land to be made available for cultivation. This strategy may require the conversion of significant areas of land on which food producing agriculture is being practised to fuel producing agriculture. This may create the conditions for conflicting sectoral interests to play out in response to the biofuels strategy being proposed.

An approach is required which provides a framework in which subtle changes - resulting from different strategic responses to different scenarios - in various sectors may be evaluated against each other. Various perspectives are held and debated on the national biofuel development strategy between disciplines, sectors, civil society and governance bodies. Moreover climate change adaptation strategies for the development of the biofuels sector, requires that production limits and inter-sectoral dependencies are taken into account.

1.2 A Complexity-Based Approach for Modelling Social-Ecological Systems

The aim of this study is to show how multi-participatory cooperation can be enhanced by using a Bayesian model to assess adaptation strategies against multiple scenarios i.e. to establish an understanding of multi-sector, social-ecological system in an analytical framework which could support a multi-participatory approach. It is important that an approach of this kind emerges from an understanding of social-ecological systems theory. Social-ecological systems theory draws heavily on ideas in complexity theory – which is in its simplest definition 'the theory of complex, adaptive systems' (Heylighen *et al*., 2007). Complexity theory provides a conceptual framework for dealing with the self-organisation of systems (Holland, 1995) from an analysis of relationships (e.g. cross-scale, linear and non-linear feedbacks between long and short term variables of change). Resilience theory (Gunderson, 2000) takes a complexity-based approach towards social-ecological systems in an attempt to provide a more inclusive adaptive governance and management approach towards social-ecological system development than traditionally used (Gunderson and Holling, 2002).

The sub-optimisation principle is a systems theory concept which is useful when considering the self-organisation and optimisation of sub-systems (Skyttner, 2001); optimisation at the system scale requires that some sub-system components may have to function at sub-optimal levels (Richardson, 2002). The 'resilience' of a social-ecological system (Gunderson, 2000) may therefore arise from changes in cross-scale and cross-sector interdependencies, and sub-system process optimisation. Self- organisation brings about resilience or vulnerability to external drivers. Self-organisation (for system resilience) is a subjective measure of system performance (Gershenson, 2003). Resilience may also be considered as a subjectively assessed 'purpose' of the system, which can change with different 'grainings' or level of description used to describe the system. By visualising the interdependencies of multi-scale and cross-sector variables we evaluate the effectiveness of the approach in assessing the different levels of description which may be explored using a Bayesian framework.

Studies of the suitability of Bayesian nets for modelling social-ecological system challenges have recently emerged in the literature dealing with the applications of Bayesian nets. Bayesian nets have been used to model environmental decision support (Baran and Jantunen, 2004), biophysical systems (e.g. integrating estuarine eutrophication models - Borsuk *et al*., 2004) and integrated water resource planning (Bromley *et al*., 2005). In the approach used in this study, long and short scale spatio-temporal system interdependencies may be considered within an integrated framework for considering adaptation response strategies to climate change effects. The approach helps formulate a Bayesian model which provides a probabilistic framework of driver-response mechanisms acting across scales and sectors. In particular, the food, water and energy sectors are considered in an integrated framework in which biofuel development strategies being considered in South Africa may be evaluated against its cross-sector impacts in other industries. The framework is formulated using a graphical causal maps in such a way that interdisciplinary and multi-sector concerns and diverse 'mental models' of the system may be formulated and tested in a Bayesian network modelling framework.

We evaluate adaptation responses in a Bayesian modelling framework and assess the relative trade-offs of increased biofuel production in terms of food crop production and impacts on water supply. Through the sensitivity analysis provided by Bayesian nets, an enhanced understanding of cross-scale and cross-sector activities is obtained. In this way, interdisciplinary cooperation may be enabled. The approach provides a probabilistic framework for exhaustive sensitivity analysis of cross-scale and cross-sector interdependencies. This framework merges quantitative data sources and qualitatively (or subjectively) assessed variables with varying levels of confidence and uncertainty. System interdependencies and sensitivities may be manually changed within this framework to reflect unfolding contextual changes and improved understanding of system features. Expert opinion and information obtained from published literature and available data is used to constrain the probabilities in the Bayesian model.

This case study extends a model formulated in previous research which assessed the impact of climate change on irrigated agriculture in South Africa using Bayesian networks (Musango and Peter, 2007). We formulate and run a national scale South African model which links the impacts of predicted climate change effects (e.g. changes in temperature and rainfall) to irrigated agricultural activities, water storage planning and biofuel production. Using the model, we show how the resilience of a possible biofuels strategy (adaptation response) to various climate change scenarios may be assessed. The scenarios are drawn from regional climate change predictions for the African continent and Southern Africa in particular (Mendehlson *et al*., 2000; Midgeley *et al*., 2005). These regional climate change models predict a general increase in temperatures over the southern African region. More detailed predictions indicate that rainfall may decrease in the west (Midgeley, 2005) while increase in the Eastern part of the country. The model that was formulated and tested in this study does not provide a spatial account of activities in South Africa. Instead, activities are aggregated at the national scale i.e. each activity is assessed independently of its local spatial context. The flexibility provided by the Bayesian modelling framework enables different scenarios and adaptation responses to be appropriately formulated and tested at this scale. We use the model to evaluate the threat that rising energy needs may place on food and water security due to rising demand for biofuel crop production. Assessing biofuel production in the context of food security, water availability and the threat posed by climate change is shown to be a valuable way of supporting research for integrated development analysis and planning.

The conceptual framework of Total Economic Value (TEV) (Blignaut and de Wit, 2004) goes beyond the utility-based approach of neoclassical economics by considering a wide range of ecological services provided by ecosystems, ranging from ecosystems as sources or sinks to ecosystems as providers of human development services (e.g. recreation, spiritual and cultural value). We use the conceptual framework of TEV to define and formulate the linkages between the various sectoral socio-economic and biophysical domains of concern in this study. Furthermore, in a recent study of agricultural services in the Crocodile Basin of the Incomati catchment, Hassan (2003) used Direct and Total Value Add (VAD) to assess the value of sugar cane, subtropical fruit and forestry activities. We use the economic multipliers derived in this study to evaluate both Direct and Total VAD derived from water use in human activities as proxies to help compare the micro and macroeconomic impacts of adaptation strategies, within the broader TEV framework.

Using a Bayesian modelling approach, we show how key sensitivities between sub-system components and with the external system environment may be elucidated and assessed (and verified) and how sensitivities change depending on the scenario under which the social-ecological system is being assessed. The approach may be used to enable interdisciplinary consideration and scrutiny of adaptation responses under a variety of proposed scenarios - and integrates top-down and bottom-up learning in a traceable process. This may also used to stimulate dialogue and debate between various decision-makers and help create a shared understanding of cross-sector and cross-scale dependencies which have a significant impact at the system scale.

2 Method

2.1 Formulating the model

A graphical causal model of the various sub-models formulated in an integrated Bayesian framework is shown in Figure 1. The model is formulated to evaluate the economic value add of water to agricultural production and water use:

a. In relation to water storage and climate driven changes in annual temperature and rainfall, and,

b. Without considering climate driven changes and water losses from water storage in dams.

The energy balance for biofuel production is not explicitly considered in the model, but may be deduced using the outputs of the model e.g. from total biofuel production and by considering the inputs to agricultural production. Emission reductions due to the inclusion of biofuel in petroleum may be similarly deduced i.e. using estimated conversion rates for emission reductions from the percentage of biofuels added to the national petroleum supply. For example, the carbon dioxide extracted from wheat amounts to roughly a third of the wheat ground (Lemmer, 2006). Other indicators of interest which are not explicitly calculated in the model may be inferred from the models outputs. For example, there are estimates available for the value added through the use of agricultural produce for biofuels - a tonne of ground wheat is estimated to yield a value add of 243 South African rands (Lemmer, 2006).

2.1.1 Populating the model

The best available information and expert opinion was used to populate and verify the model - which is based on a model formulated in a previous study on irrigated agriculture in South Africa conducted by Musango and Peter (2007). The use of economic multipliers for water intensive activites derived by Hassan (2003) are used to assess and compare the *relative changes* in micro and macroeconomic impacts of water adaptation strategies, even though the actual values of multipliers may be contentious. Information regarding the national biofuels strategy (DME, 2006) and the bio-ethanol production feasibility of a plant in the Western Cape (Lemmer, 2006) was used to obtain an idea of the national and provincial considerations made in formulating a biofuels development strategy. Dam evaporation rates were obtained from the South African Council for Scientific and Industrial Research (CSIR) records and reports. Information about current levels of irrigated agricultural activities was obtained from several local and international sources (e.g. AQUASTAT, 2005). All sources were compared and verified before use. Trace-ability of model parameters and the reasoning behind using them is captured in the software used to formulate Bayesian nets and may therefore be shared and scrutinised amongst researchers.

2.1.2 Sensitivity Analysis and Running the Model

When running the Bayesian model using the Hugin software interface, the probability distribution of each selected variable may be viewed. This is shown in Figure 2, which illustrates the parameters of states (or intervals) chosen for each variable. The probability of the variable being in any state is also shown; as a discrete probability distribution over the range of states for each variable. Before the model is run, variables are set to 'default' or current value settings (e.g. the 'Area: Grain (ha)' variable in Figure 2 has a 69.36 % chance of being in the interval (or state) 103 040 – 115 920. Sensitivity analysis is conducted by varying the values of driver variable states (Figure 3)

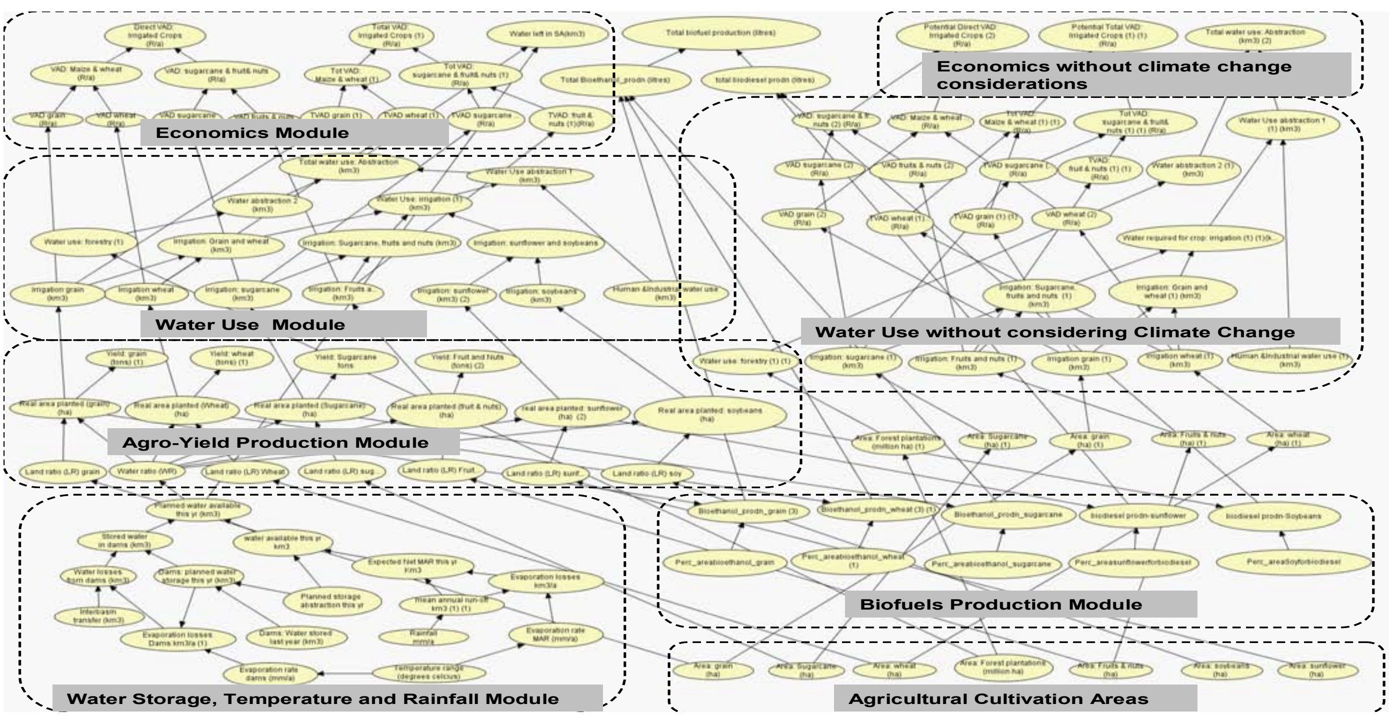

Figure 1: Sub-models of Bayesian agro-water-bio-fuels model for South Africa.

and observing response variable distributions. For each scenario, the response variables are verified for the full range of driver variables. Some response variable values are verified using calculations, while others using information available online.

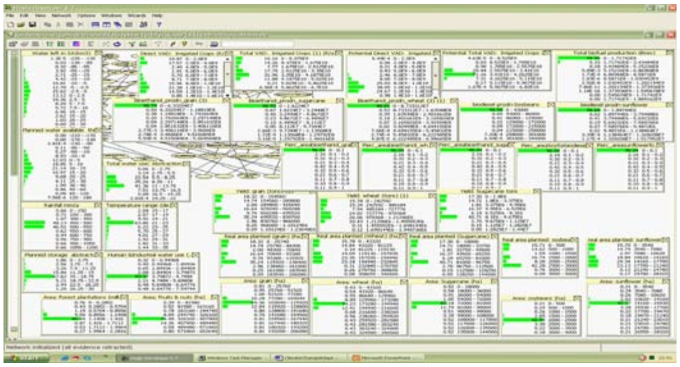

Figure 2: Probability distributions for selected variables in Bayesian model in the initial system state.

2.2 Proposed Strategy for Scenario Testing

Several scenarios were chosen to illustrate how sector interdependencies created by a national biofuel production strategy which relies on agricultural production for biodiesel and ethanol feedstock, may be assessed in response to climate change effects within an integrated modelling framework. One possible multi-sector growth strategy to reach the South African biofuels production target i.e. 4.5% of national petroleum production (DME, 2006) is proposed in Figure 3. This strategy is tested under different scenarios to illustrate how Bayesian nets may be used to estimate *the* robustness of the proposed strategy to possible climate change effects (Mendelsohn *et al*., 2000). The agricultural expansion strategy considered in Figure 3, was identified from sensitivity analyses conducted on the model – on the basis that it provides the necessary agricultural expansion needed to achieve the national biofuels target. The scenario may be understood by comparing the driver and response variables in Figure 3 with their current values in Figure 2. Driver variables are changed to reflect the scenario as outlined below:

- Grain area (see ‘Area: Grain (ha)’) under cultivation is increased by approximately 24 percent from 109 480 to 135 240 hectares.
- Wheat cultivation area is increased by 47 percent from 184 110 to 270 750 hectares.
- Sugar cane cultivation area is increased by 25 percent from 76 500 to 94 500 hectares.
- Soybean cultivation area is increased by 44 percent from 2250 to 3250 hectares.
- Sunflower cultivation area is increased by 47 percent from 15 045 to 22 125 hectares.

The yields obtained from cultivating these areas are sensitive to water availability, and are calculated from the ‘real area planted’ variables shown Figure 3, which are used to indicate the reduction or increase in yields of selected crops. The relationships which characterise yield variations with water availability are assumed to be equivalent for all crop-types and are denoted by a gradient one linear relationship in all cases. Lastly, percentages of the yields generated from the ‘real area’ of each crop are dedicated to bio-ethanol and biodiesel production in this scenario in Figure 3. For each hectare of grain, wheat, sugar cane, soybeans and sunflower seeds cultivated, biofuel production of 542 *l*, 2016 *l*, 1014 *l*, 86 *l* and 536 *l* (litres) respectively is assumed feasible and is consistent with that in online and published literature and discussions on the subject (e.g. Lemmer, 2006). Under these circumstances it is feasible that the national bio-

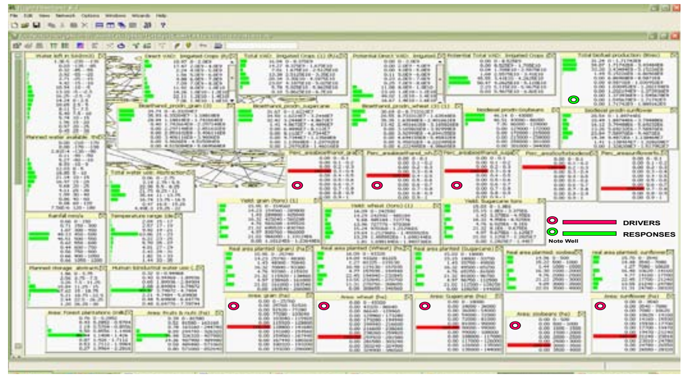

Figure 3: Agricultural growth strategy with current distributions for annual water storage, rainfall and temperature.

fuel production target of 494 325 000 *l* can be reached. This requires an expansion of area under agricultural cultivation by 137 580 ha, roughly 8 percent of the total area of land currently under irrigated agricultural cultivation.

3 Results

In Group 1 scenarios the availability of water in the national system for irrigation is considered. Water storage and rainfall sensitivities are illustrated. In Group 2 scenarios the robustness of the strategy against annual temperature increases is evaluated.

3.1 Group 1 Scenarios: Water Storage and Rainfall

The annual average rainfall is increased to 525 mm per annum and the ‘planned storage abstractions’ is significantly reduced. The ‘real area planted’ variables are very sensitive to water availability. By reducing the ‘planned storage abstractions’ variables for dams and other water storage methods to half its current value in Figure 4, the probability of obtaining more ‘total biofuel production’ is increased. Water losses due to evaporation in dams are high, and result in large water losses. Keeping water ‘in the system’ should be the goal of coordinated water management programmes. The integrated management of water resources (e.g. coordinated dam releases) is necessary to mitigate evaporation losses from the large volumes of water stored in dams.

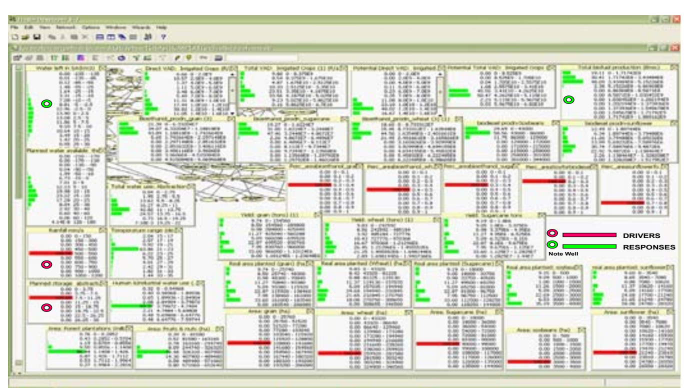

Figure 4: Scenario 1a - reducing planned storage abstractions. The strategy being evaluated is shown to be more feasible in high rainfall years (Figure 5). The ‘real area planted’ for each crop increases in response to the additional available water, yielding more agricultural produce overall.

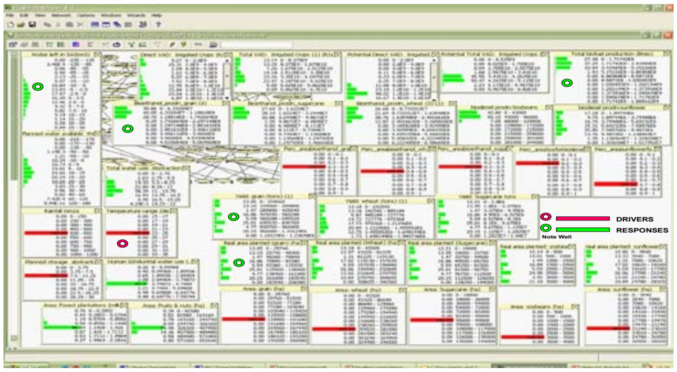

Figure 5: Scenario 1b - increased annual rainfall improves chances of achieving national biofuels production target.

3.2 Group 2 Scenarios: Increase in Temperature

The sensitivity of the proposed agricultural growth strategy to rises in temperature is assessed in Figure 6 and Figure 7. The average annual temperature is raised by 2 degrees - from 22 to 24 degrees Celsius in Figure 6, and by 4 degrees in Figure 7. The 'total biofuels production' decreased, but not drastically. The general shape of the curve is still located at a desirable level of production i.e. between 171 and 343 million litres of biofuel production, but at a lower probability (37.25 %) than under more favourable conditions.

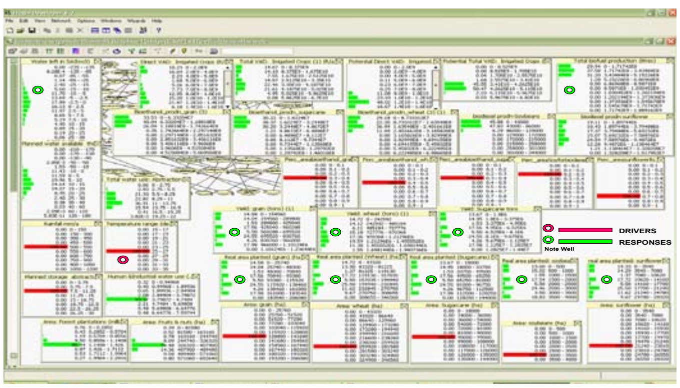

Figure 6: Scenario 2a - increasing average annual temperature by 2 degrees to assess sensitivity to climate change conditions

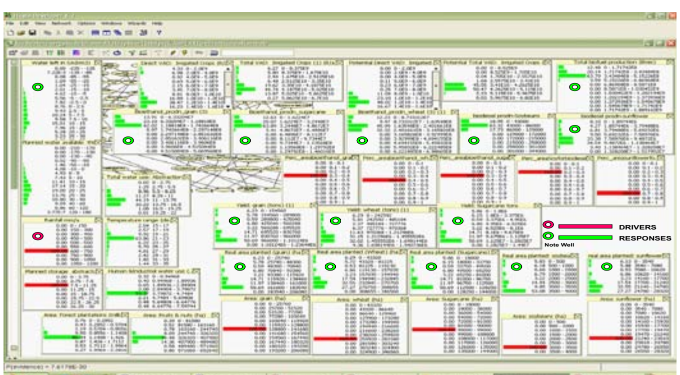

Figure 7: Scenario 2b: increasing annual average temperature by 4 degrees.

Figure 8: Legend to Figures

4 Discussion

Socio-economic development strategies have historically focussed narrowly on local development concerns and have not emphasized cross-sector interactions and dependencies; especially over long spatial and temporal scales (Gunderson and Holling, 2002; Starzomski, 2004; Levin, 2006). The consideration of long-term and remote effects of ecological exploitation for human development purposes has not historically been a major consideration. The idea of sustainable development is a concept which enables a discussion around the long *and* short-term implications of human development trajectories into the future. The global and local sustainability of social-ecological systems is increasingly being confronted with a variety of challenges, and diverse solutions are proposed by stakeholders. Realising sustainable development requires the consideration of multiple human and biophysical drivers of change, which are driven by mechanisms which lie within and beyond the control of society to manage. Therefore, society will have to adapt through available mechanisms of control and innovative self-organisation of internal system dependencies to respond to drivers of change - such as climate change, energy crises and water shortages. Self-organisation in a system that is already bounded by existing sub-system interdependencies requires the consideration of all existing interdependencies in order to obtain the required behaviour at the 'whole' systems level.

Social-ecological systems are therefore 'most fundamentally … complex, adaptive systems' (Levin, 2006) which exhibit emergent behaviours due to evolving interactions (self-organisation) between sub-system components (including entities, processes and agents). Self-organisation of human systems to respond or 'adapt' to unforeseen or uncontrollable changes requires the consideration of short and long scale spatio-temporal consequences of development and adaptation strategies. The implications for social-ecological systems are that optimising human development activities at a local scale for short-term, microeconomic gain don't necessarily translate into benefits at the whole system scale. In particular the effects of local development optimisation efforts have often had significant remote effects in other social-ecological system sectors or ecosystem components. These sectors are traditionally viewed as distinct parts of a system and only *local* dependencies and interactions with other sectors are considered in strategic planning and implementation.

This approach helps envisage cross-sector interdependencies, and to compare system level trade-offs in an integrated analytical framework. Bayesian belief networks are as certain as the information used to characterise it, and reflects real-world uncertainties over cross-system and multi-scale interdependencies. We showed how the national biofuel strategy of South Africa (and other countries) may be tested at the national scale before key sub-system dependencies may be investigated more deeply. This requires research into sub-systems using empirical and modelling techniques as inputs to the Bayesian framework. The model enables various strategies may be assessed against one another, which may be used to facilitate more focussed discussion around system interdependencies and cross-sector linkages at policy making and implementation level. The model is interdisciplinary and allows for a broad variety of variables to be linked, irrespective of scale or whether the variables are formulated using empirical data or subjective judgement. The sensitivities and uncertainties associated with all variables may be visualised and used to enhance decision-making processes through a broader consideration of system linkages.

In particular, the threat that rising energy needs and the need for lower emissions may place on food security through rising demand for biofuel crop production is considered in the results of the proposed strategy under different scenarios. A large amount of new arable land is needed to meet the national biofuels target, and it is more likely that biofuels production will have a negative effect on the food sector if unregulated through appropriate policies. The rising demands for energy and low emissions may cause food prices to rise as agricultural farming for biofuels becomes more lucrative and dedicate larger tracts of land to crop strains suited for fuel production.

5 Conclusion

The model presented in this study is multi-scale and consists of various sub-system modules which relate cross-sector interactions. The Bayesian software interface enables the model to be easily adapted with changes in understanding of sub-system inter-dependencies and sensitivities and may be used to facilitate and enable interdisciplinary consideration and scrutiny of adaptation responses under a variety of proposed scenarios. In this way, the approach taken in this study integrates top-down and bottom-up learning in a traceable process. Key parameters, thresholds and functional relationships defining the system are encoded into a Bayesian network using a software enabled knowledge engineering language to manage model development. Best available information from current literature and available data is used to constrain the probabilities in the Bayesian model, which is then verified through sensitivity analysis. The approach elucidates key sensitivities in the system, which depends on the scenario under which the system is being assessed. Sensitivity to scale and the exact nature of the causal interdependencies in the system may be iteratively probed and compared with observation and empirical data. Using this approach understanding may be shared and obtained in the consideration of policy-making for biofuels development programmes which have consequences in other related sectors.

6 References

AQUASTAT, 2005, http://www.fao.org/ag/agl/aglw/aquastat/countries/south_africa/print1.stm

Baran, E. and Jantunen, T., 2004, "Stakeholder consultation for Bayesian decision support systems in environmental management," *Proceedings of the Regional Conference on Ecological and Environmental Modeling (ECOMOD)*, ISSN 0304-3800, Universiti Sains Malaysia, 15-16 September.

Blignaut, J., de Wit, M.P., 2004 *Sustainable Options: Development Lessons from Applied Environmental Economics*, University of Cape Town Press, ISBN 1919713433.

Borsuk, M. E, Stow, C. A., Reckhow, K., H., 2004, "A Bayesian network of eutrophication models for synthesis, prediction and uncertainty analysis", *Ecological Modelling*, v. 173, pp. 219-239.

Bromley J., Jackson N.A., Clymer O.J., Giacomello A.M., Jensen F.V., 2005, "The use of Hugin to develop Bayesian networks as an aid to integrated water resource planning", *Environmental Modelling and Software*, v. 20, pp. 231-242.

Department of Minerals and Energy (DME), 2006, Draft Biofuels Industrial Strategy of the Republic of South Africa.

Gershenson, C. and Heylighen, F., 2003, "When Can we Call a System Self-organizing?" in Banzhaf, W, T. Christaller, P. Dittrich, J. T. Kim, and J. Ziegler (ed.), Advances in Artificial Life, 7th European Conference, ECAL 2003, Dortmund, Germany, pp. 606-614. LNAI 2801. Springer.

Gunderson, L. H., 2000, "Ecological resilience – In theory and application," *Annual Review of Ecology and Systematics*, ISSN 0066-4162, v. 31, pp. 425-39.

Gunderson, L. H. and Holling, C.S. (2002) (eds.), *Panarchy: Understanding transformations in human and natural systems*, ISBN 1559638575.

Hassan, R.M., 2003, "Economy-wide benefits from water intensive industries in South Africa: quasi-input-output analysis of the contribution of irrigation agriculture and cultivated plantations in the Crocodile river catchment ", *Development Southern Africa*, v. 20, pp. 2.

Heylighen, F., Cilliers, P. and Gershenson, C., forthcoming 2007, "Complexity and Philosophy," in J. Bogg and R. Geyer (eds.) *Complexity, Science and Society*, ISBN 0415152877.

Holland, J. H., 1995, *Hidden Order: How Adaptation Builds Complexity*, ISBN 0201442302.

Independent Online (Gosling, M.), 2007, Costly maize milks SA dairy industry, Mar 21 http://www.thecattlesite.com/news/16041/costly-maize-milks-sas-dairy-industry

Lemmer, W., 2006, Bio-ethanol production in the Western Cape: Value Adding to Winter Cereal through Ethanol-, DDGS-, and CO2- production, Department of Agriculture (Western Cape/ South Africa), wessell@elsenberg.com.

Levin, S. A., 2006, "Learning to live in a global commons: socio-economic challenges for a sustainable environment," *Ecological Research, Special Feature*, ISSN 09123814, v. 21, pp. 328-333.

Mendelsohn, R., Dinar A. and Dalfelt A., 2000, Climate change impacts on African agriculture, Centre for Environmental Economics and Policy in Africa.

Midgley, G.F., Chapman, R.A., Hewitson, B., Johnston, P., de Wit M., Ziervogel, G., Mukheibir, P., van Niekerk, L., Tadross, M., van Wilgen, B.W., Kgope, B., Morant, P.D., Theron, A., Scholes, R.J., Forsyth, G.G., 2005. A Status Quo, Vulnerability and Adaptation Assessment of the Physical and Socio-economic Effects of Climate Change in the Western Cape. Report to the Western Cape Government, Cape Town, South Africa. CSIR Report No. ENV-S-C 2005-073, Stellenbosch.

MIT Technology Review, 2007, Ethanol Demand Threatens Food Prices, Feb 13, http://www.technologyreview.com/Energy/18173/

Mukheibir P., Sparks, D., 2003, Water resource management and climate change in South Africa: Visions, driving factors and sustainable development indicators, April 2003, Report for Phase I of the Sustainable Development and Climate Change project, Energy and Development Research Centre (EDRC), University of Cape Town.

Musango, J.M., Peter, C., 2007, "A Bayesian approach towards facilitating climate change adaptation research on the South African agricultural sector", *AGREKON: South African Journal of Agricultural Economics*, 46(2), 245-259

Richardson, K. A. (2002). "On the limits of bottom-up computer simulation: Towards a nonlinear modelling culture," *Proceedings of the 36th Hawaii International Conference on System Sciences*.

Starzomski, B. M., Cardinale, B.J., Dunne, J.A., Hillery, M.J., Holt, C.A., Krawchuk, M.A, Lage, M., McMahon, S. and Melnychuk, M.C., 2004, "Contemporary visions of progress in ecology and thoughts for the future," *Ecology and Society,* ISSN 17083087, v. 9, no. 1, art. 14.

Skyttner, L., 2001, *General systems theory: Ideas and applications*, River Edge, NJ: World Scientific, ISBN 9810241755.

Climate and Complexity in Agricultural Production Systems of the Argentine Pampas

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1. Introduction

Agriculture plays a central role in world food production and food security (Falcon & Naylor 2005). As agricultural production also is one of the sectors of society most vulnerable to climate variability and change (Parry & Carter 1989; Meinke et al. 2006), it is important to explore linkages between complex agroecosystems, uncertain decadal climate trajectories, and land use changes over periods of a few decades, a scale relevant to sustainable resource management.

Our focus is on crop production systems in the region of central eastern Argentina known as the Pampas, one of the most important cereal and oilseed producing regions in the world (Hall et al. 1992; Morello & Solbrig 1997; Satorre 2005). This region has shown some of the most significant trends in precipitation during the 20th century (Giorgi 2002). A steady increase in annual rainfall has been observed in the Pampas since the 1960s (Castañeda & Barros 1994; Rusticucci & Penalba 2000; Boulanger et al. 2005; Mauget 2007). The rainfall changes have been distributed unevenly through the seasonal cycle: concentrated in late spring-summer, whereas winter has seen little or no change. Furthermore, the increase has been particularly marked near the western margin of the Pampas, displacing westward the transition to semi-arid regions that represent the boundary of rainfed agriculture (Berbery et al. 2006).

The rainfall increase has partly contributed to major changes in land use patterns in the Pampas (Viglizzo et al. 1995, 1997; Magrín et al. 2005; Satorre 2005). Obviously, the impacts of climate variability and change also must be assessed within the economic, institutional, land tenure, and technological contexts in which they take place. Structural economic changes since the early 1990s fostered investment in agricultural technology (larger farming machinery, increased use of fertilizers and biocides). Creation and expansion of governmental and stakeholder institutions for agricultural research and extension enhanced technology diffusion. Evolving land tenure regimes also played a role. As in the U.S. (Carolan 2005), about half of the area cropped in the Pampas is not owned by farmers cultivating it. As land becomes more commodified, competition among farmers for rental land increases. Short leases (usually one year) and cash-rent arrangements prevail. Such contracts provide strong incentives to maximize short-term returns via agriculture (in recent years, significantly more profitable than other types of production) and may discourage sustainable practices (Carolan 2005; Lichtenberg 2007; Myyrä et al. 2007). Finally, technological innovations such as a wheat/soybean double crop, no-tillage planting, and genetically-modified, herbicide-tolerant soybeans (Trigo & Cap 2003; Kesan & Gallo 2005; Martínez-Ghersa & Ghersa 2005; Qaim & Traxler 2005; Traxler 2006) played a major role in land-use changes.

The dynamic interaction of climate variability and economic, social and technological drivers has resulted in a significant expansion of the area dedicated to agriculture in the Pampas, particularly in marginal regions (Schnepf et al. 2001; Satorre 2005). In places where agriculture was previously established, continuous cropping has widely replaced agriculture-pasture rotations. One remarkable process has been the impressive expansion of soybean in the Pampas and the rest of Argentina: introduced in the early 1970s, soybean area (production) reached 5.1 Mha (11 Mtons) in 1990 and exploded to 15.0 Mha (40+ Mtons) in 2006, displacing other crops, pastures, and forests.

Nevertheless, potential conflicts and concerns about the sustainability of current systems already are arising. While Argentina enjoys the economic benefits of soybean exports (≈$4.5 B in the first half of 2006; 20% of all exports), worries are growing about "soybean monoculture," i.e., the abandonment of ecologically-sound crop rotations (Leteinturier et al. 2006). Clearly, a system in which over half of the agricultural area is dedicated to a single crop is highly brittle to shocks or surprises such as commodity price fluctuations or climate anomalies.

Recent awareness of the impacts of precipitation changes on land use and production systems in the Pampas has heightened stakeholders' concerns about a possible return to drier conditions. Agricultural production systems that evolved in recent decades partly in response to increased rainfall may not be viable if (as is entirely possible) climate reverts to a drier epoch. Unfortunately, there is much uncertainty about projected paths of future climate, particularly on regional scales and time horizons (25-30 years hence). Despite the uncertainty, the agricultural sector increasingly demands actionable information for these horizons, as 25-30 years is a highly relevant scale to investment and infrastructure planning. Such societal demands motivate this paper, which describes a preliminary exploration of plausible climate scenarios in the Pampas and their potential impacts on the economic sustainability of agricultural systems.

2. The study region

We selected two locations in the Pampas with different climatic and ecological characteristics: Pergamino (Buenos Aires province, 33º56'S, 60º33'W) and Pilar (Córdoba province, 31º41'S, 63º53'W) respectively represent near-optimal and relatively marginal agricultural conditions. Pergamino is in the most productive subregion of the Pampas, whereas Pilar is in the northern, semi-arid margin of the region (Paruelo & Sala 1993, Dardanelli et al. 1997). Characteristic crop rotations in both sites include maize, soybean, and a wheat-soybean doublecrop (wheat followed by short-cycle soybean). Precipitation in both sites has varied significantly over past decades. Median rainfall for Oct-Mar (spring-summer) in Pergamino increased about 12% between 1931-50 and 1975-94; Pilar rainfall showed a much higher increase of 33% between the same periods. The two regions also have different agricultural history and traditions. Contrasting ecological and cultural conditions between sites let us explore differences in vulnerability to climate, risk perceptions, and scope for adaptive management.

3. Approach

To assess how current agricultural systems might respond to inter-decadal climate variability, we followed four main steps. First, we used historical climate data to define a set of plausible and relevant climate scenarios 25 years into the future. Second, we used a semi-parametric weather generator to downscale regional scenarios into multiple realizations of daily weather consistent with the proposed decadal scenarios. Third, we used the synthetic daily weather series and crop growth models to simulate trajectories of agricultural outcomes (yields, economic returns) and monitor risk metrics in current production systems given a plausible precipitation decrease. Finally, we investigated optimal adaptive responses based on decision-makers' perceptions of explored rainfall trends. In the following sections we present a brief description and preliminary results for each of these steps.

3.1 Definition of plausible climate trajectories

Substantial progress in global and regional modeling at medium to high spatial resolution provides the opportunity of using atmospheric-ocean global general circulation models (AOGCMs) to generate regional projections of temperature and precipitation (Tebaldi et al. 2006). There are concerns, however, that such models still are not capable of simulating regional climate for short time horizons (25-30 years into the future) to levels of accuracy desirable to support effective and defensible policies or actions (Rosenzweig et al. 2004; Tebaldi et al. 2006). Temperature and precipitation trajectories at the end of the 21st century have been studied for South America by Boulanger et al. (2006, 2007): whereas they found consistency in predicted temperature changes, there was considerable divergence among models in precipitation projections. Lack of consistency in AOGCM projections requires that we explore alternative approaches to the definition of plausible climate scenarios for the 25-30 years timeframe on which we focus.

The definition of plausible climate scenarios—the first step—was based on exploration of historical climate records for each location. The underlying assumption was that patterns that had occurred in the past might be observed again in the near future, as in short time horizons natural variability might dominate.

We computed total annual precipitation for Pergamino (1931-2004) and Pilar (1931-2005). Then, linear trends were fitted to precipitation totals over a series of overlapping 25-year windows shifted by one year. For example, the first window for Pilar encompassed the period 1931-1955, the second one corresponded to 1932-1956, and so forth. Trends were fitted using ordinary least squares regression, a robust regression that minimized the impact of outliers, non-parametric methods for trend detection; we also tested 20- and 30-year window widths. All approaches yielded fairly robust results; for brevity we show results only for the ordinary regression. Figure 1 shows annual precipitation totals and the trends fitted for each window at both locations. Various patterns are apparent: (a) a precipitation decrease in Pergamino between the 1930s and the 1950s (although in Pilar this decrease is not as consistent), (b) a marked increase between the end of the 1950's and the early 1990's at both locations and, (c) a considerable decreasing trend in Pilar over the last 15 years (this second decrease in Pergamino also was not as consistent as in Pilar).

The trends estimated from historical records (i.e., the slopes of fitted lines in Figure 1) were used to project plausible trajectories of annual precipitation 25 years from the end of existing data (i.e., 2005-2029 and 2006-2030 for Pergamino and Pilar respectively; Figure 2). Here we focus only on one specific pattern: a decrease in annual precipitation. Two reasons justify this choice. First, agriculture in the Argentine Pampas is largely rainfed, so production is highly sensitive to precipitation deficits. Second, stakeholders' concerns about a possible return to a drier epoch are growing, particularly for marginal regions where changes may be felt earlier. Nevertheless, we stress that by focusing on decreasing rainfall we do not suggest that such trajectory is the likeliest. Indeed, the spread of fitted trends (Figure 2) suggests a wide range of plausible scenarios,

To select a plausible decrease for Pilar future precipitation, we averaged the slopes estimated for the ten most recent 25-yr windows: this mean trend (indicated on Figure 2, lower panel) was -6.3 mm yr^{-1}. In Pergamino, in contrast, the recent evolution of precipitation

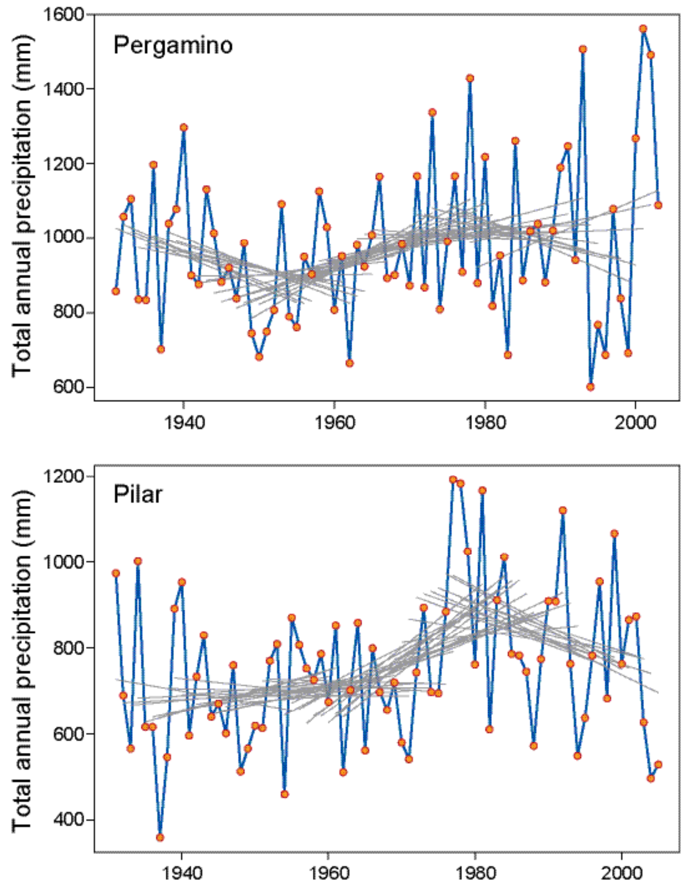

Figure 1. Total annual precipitation for Pergamino (1931-2004) and Pilar (1931-2005). The light grey lines indicate the trends (fitted by ordinary least squares regression) to overlapping 25-year windows.

is less consistent: both positive and negative slopes are observed. For this reason, we estimated the average magnitude of increasing trends for Pergamino between the 1950s and 1990s and then reversed its sign. That is, we assumed that precipitation could decrease at a rate comparable to previously observed increases. The resulting trend was -5.5 mm yr^{-1} (Figure 2, upper panel). The start for projected rainfall trajectories was the median annual precipitation for the five most recent years on record: 980 mm (Pergamino) and 775 mm Pilar).

3.2 Temporal downscaling of selected rainfall trajectories

The second stage involved the temporal disaggregation of the selected climate trajectories (specified as changes in annual precipitation totals) into daily synthetic (simulated) series of weather variables required by crop simulation models (maximum and minimum temperature, total daily precipitation and solar radiation). We coupled a semi-parametric (or hybrid) method for the generation of daily weather sequences (Apipattanavis et al. in press) and a biased re-sampling algorithm that replicates an observed low-frequency trend or simulates a hypothetical climate trajectory.

The semi-parametric approach to stochastic weather generation proposed by Apipattanavis et al. (in press) has two main components: (a) a Markov chain for generating the precipitation state (i.e., no rain, rain, or heavy rain), and (b) a k-Nearest Neighbor (k-NN) bootstrap re-sampler (Rajagopalan & Lall 1999) for generating remaining weather variables. The Markov chain correctly describes rainfall spell statistics, whereas the k-NN bootstrap captures the distributional and lag-dependence statistics of other weather variables. Plausible climate scenarios can be easily incorporated into the weather genera-

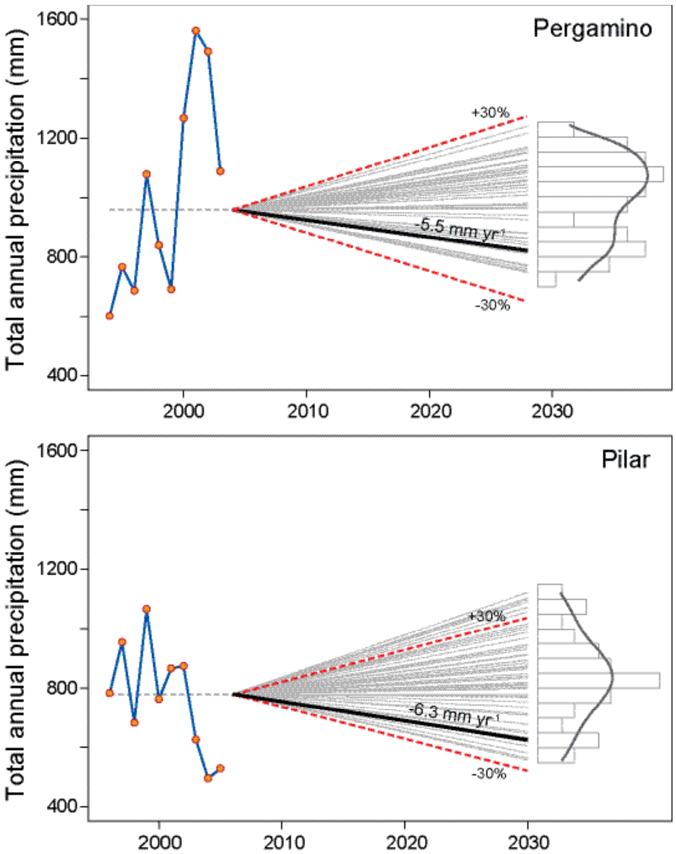

Figure 2. The grey lines indicate all linear trends (fitted by ordinary least squares regression) to overlapping 25-year windows of historical annual precipitation totals. The left sides of the figures show precipitation totals for the 10 most recent years of available data (1995-2004 for Pergamino; 1996-2005 for Pilar). The median totals for these periods (980 mm for Pergamino, 775 mm for Pilar) were used as the point of departure for projections based on estimated trends. The two decreasing trends selected for further analysis are indicated by a thick black line. Histograms of projected precipitation totals 25 years into the future are shown on the right side of each panel. An empirical density was fit to the histogram to facilitate visualization of the distribution of trends. However, the histograms and densities should not be interpreted as a rigorous statement about the probability of each trend.

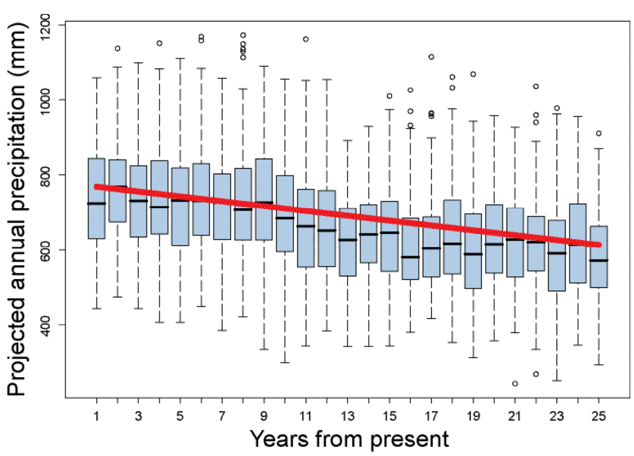

Figure 3. Boxplots of projected annual precipitation totals in Pilar. Each box-and-whiskers plot shows the distribution of precipitation totals for the 100 realizations corresponding to each year in the sequence. The line in the center of the box represents the median of the 100 realizations, the box encloses the central 50% of the distribution, and the whiskers indicate the range of the data. The thick line overlaid to the boxplots indicates the proposed decreasing trend (-6.6 mm yr^{-1}).

tor framework (Yates et al. 2003; Clark et al. 2004). Resampling of the historical record is biased according to the trend one wishes to reproduce or simulate. Each historical year is weighted according to its "closeness" (in terms of the conditioning variables) to the scenario for which weather sequences are to be generated. This step produced an ensemble of 100 equally-likely sequences (each 25 years long) of simulated daily weather at each location, each ensemble being consistent with the decadal trends considered. Figure 3 displays boxplots of simulated annual precipitation totals for Pilar.

3.3 Simulation of crop yields and economic returns

Dynamic, process-level crop models simulate crop growth and development as a function of daily weather, soil type, and crop genetic characteristics (Boote et al. 1996). We used models in the Decision Support System for Agrotechnology Transfer (DSSAT, Jones et al. 1998, 2003) to simulate yields for the three main crops in the region: Generic-CERES (Ritchie et al., 1998) for maize and wheat, and CROPGRO (Boote et al. 1998) for soybean. DSSAT models have been calibrated and validated in many production environments, including the Pampas (Guevara et al 1999; Meira et al. 1999; Mercau et al. 2007). As these models simulate realistic outcomes of management practices (e.g., genotypes, planting date, fertilization amount), they allow exploration of a large portion of the potential adaptation space. In consultation with local experts we chose, for each crop and location, a management most representative of current practices (Table 1).

A constant economic context (crop prices and input costs) was assumed for all analyses, providing an "all else being equal" situation which helps isolate the effects of changing climate from impacts that may result from quite different factors that are sometimes closely interconnected (Parry 1985). We computed net economic returns per hectare as the difference between income and costs. Gross income per hectare was the product of simulated yields and the 2000-2005 median of crop prices during the month when most of the harvest is marketed. Cost calculations were based on a representative 600-ha farm and included fixed, variable, and structural expenses, and income tax; details are available elsewhere (Messina et al. 1999; Ferreyra et al. 2001; Letson et al. 2005). The probability of negative economic returns (PNER) was used to quantify economic risks to production associated with climate trends. Using the 100 realizations for each year in the 25-yr simulated sequences, we computed PNER as the proportion of realizations for each year in which economic returns were negative.

Table 1. Agronomic managements typical or representative of current production systems for each crop and region considered.

	Pergamino			Pilar		
Crop	Fertilizer	Planting date	Fertilizer (kg N ha-1)	Cultivar	Planting date	Fertilizer (kg N ha-1)
Full-cycle soybean	DM-4800	1 Nov	0	DM-4800	1 Nov	0
Maize	DK-682	15 Sept	40	DK-682	20 Oct	80
Wheat	Escorpion	10 Jun	30	Escorpion	20 May	40
Short-cycle soybean	DM-4800	After wheat harvest	0	DM-4800	After wheat harvest	0

4. Results

4.1 Impacts of decadal climate trends on current production systems

A first group of simulations involved the assumption of a naïve farmer who does not adapt to changing conditions. That is, the current representative management for each crop was used throughout the simulated sequences.

The proposed decreasing precipitation trends had quite different impacts on crop yields at each location: simulated yields for all crops increased slightly in Pergamino, whereas they markedly decreased in Pilar (Table 2). At the end of the 25-yr projected sequences, Pergamino yields of summer crops (full-cycle soybean, maize, and soybean after wheat) increased on average 7, 5, and 1 % respectively, while wheat yields (a winter crop) decreased slightly (-6 %). The moderate yield increases for summer crops may be related to higher radiation levels and decreases in minimum temperatures associated with a progressive decrease in the number of rain days along the simulated sequence. In Pilar, in contrast, simulated yields for summer crops showed a much larger drop: average decreases after 25 years were 28, 25, and 39 % for full-cycle soybean, maize, and short-cycle soybean.

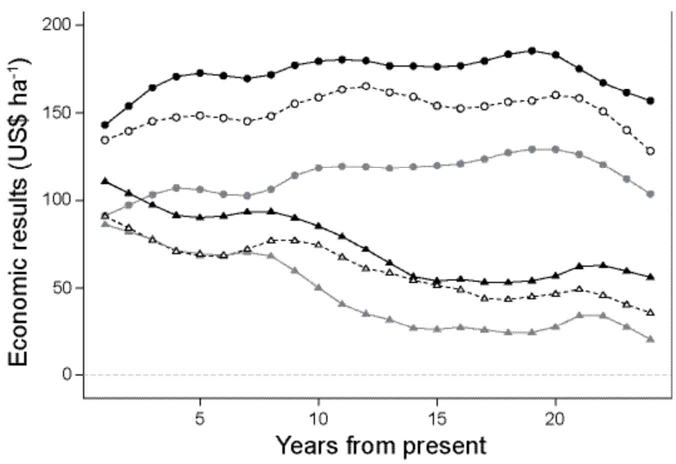

Figure 4. Temporal evolution of economic returns (averaged over the 100 realizations for each year in the sequence) for summer crops in Pergamino (circles) and Pilar (triangles). The dark line corresponds to full-cycle soybean, the dashed line indicates the wheat-soybean double crop, and the grey line is for maize. The lines have been smoothed to facilitate visualization of trends.

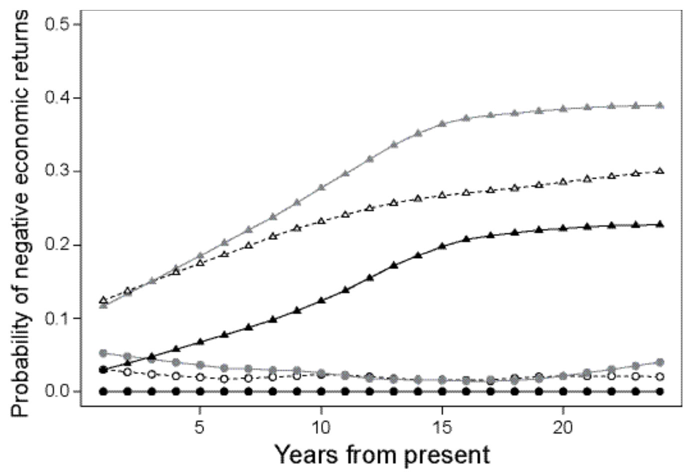

Figure 5. Temporal evolution of the probability of negative economic returns (a metric of production risk) in Pergamino (circles) and Pilar (triangles). The dark line corresponds to full-cycle soybean, the dashed line indicates the wheat-soybean double crop, and the grey line is for maize. The lines have been smoothed to facilitate visualization of trends.

In contrast, simulated yields for wheat declined much less—about 7 %— than for summer crops, as projected precipitation decreases occur mostly during the wet period in late spring-summer.

Patterns for simulated economic returns were similar to those for yields (Figure 4). In Pergamino, economic returns for summer crops increased moderately, whereas Pilar returns showed a marked decrease. Starting from values fairly close to those in Pergamino, Pilar economic returns decreased to about 50 % by the end of the 25-yr sequences. The most dramatic decrease was for maize, which reached average profits close to zero (i.e., as many losses as gains). Given the economic context for which returns were calculated (typical of conditions in the last few years), full-cycle soybean showed the highest economic profit in both locations, and maize was the least profitable crop.

For Pergamino, PNER (i.e., the risk of economic losses) for all crops was always close to 0 and did not change noticeably with decreasing precipitation (Figure 5). Conversely, increases in PNER were much higher in Pilar: PNER for maize grew almost fourfold throughout the 25-yr sequence, from 0.11 to 0.40. The risk increase also was very high for full-cycle soybean: PNER rose from 0.05 to 0.23. The chance of negative profits for the double-wheat-soybean double crop increased from 0.12 to 0.30.

Table 2. Crop yields (averaged over the 100 realizations in each year) on years 1 and 25 (i.e., at the beginning and the end) of the simulated sequence and yield trends. The average yield trends are calculated from trends fitted to each of the 100 realizations of 25-year yield sequences.

Crop	Pergamino			Pilar		
	Avg. Yield Yr 1 (kg ha^{-1})	Avg. Yield Yr 25 (kg ha^{-1})	Avg. Yield trend (kg ha^{-1} yr^{-1})	Avg. Yield Yr 1 (kg ha^{-1})	Avg. Yield Yr 25 (kg ha^{-1})	Avg. Yield trend (kg ha^{-1} yr^{-1})
Full-cycle soybean	3270	3488	+ 6.1	2853	2070	- 31.7
Maize	7463	7799	+ 35.1	6485	4858	- 76.4
Wheat	3170	2969	- 9.9	1597	1575	- 4.6
Short-cycle soybean	1294	1307	+ 9.1	1491	917	- 19.8

4.2 Adaptation of crop management to decadal climate trends

A second group of simulations assumed a "clairvoyant" farmer who is perfectly aware of fluctuating climate and adapts her crop management using currently available technology or know-how to mitigate impacts of a precipitation decrease. This case represents the complete opposite of the "no management change" situation explored in the previous section.

To explore outcomes of adapting to a varying climate, we defined a suite of viable alternative managements for each crop and location. Two full-cycle-soybean managements were defined by early (1 November) and late (10 December) planting dates. Three alternative maize managements were based on fertilization rates (0, 40, and 80 kg N ha^{-1}). Two management schemes for wheat also were defined by differences in fertilization (40 and 80 kg N ha^{-1} in Pergamino; 0 and 30 kg N ha^{-1} in Pilar). Yields and economic returns for all managements and locations were simulated as before, using the 100 realizations of daily weather in the 25-yr sequences. Then, the "optimal actions" (the proportion of land allocated to each crop and management) in response to perceived precipitation decreases were selected.

"Best" or "optimal" agricultural practices adopted as part of adaptation to a changing context often involve strong assumptions about decision-makers: that they are fully rational, know the outcomes of all alternative actions, and seek to maximize their expected utility (EU, von Neumann and Morgenstern 1944) of their actions. Despite its obvious strengths, EU maximization as the (sole) objective of risky choice has encountered some opposition in recent years (Gintis 2000; Jannsen & Jager 2000; Camerer 2005). Prospect theory (PT, Kahneman and Tversky 1979) and its successor cumulative prospect theory (Tversky and Kahneman 1992; Fennema and Wakker 1997) currently have become the most prominent alternatives to EU theory. Two major characteristics of PT include: (a) the utility of decision outcomes is defined in terms of relative gains or losses, that is, positive or negative deviations from a reference point such as the status quo, and (b) individuals exhibit strong "loss aversion" (the psychological impact of economic losses is larger than the perceived benefit of gains of comparable magnitude).

"Optimal" actions to adapt to the proposed climate trend were selected by maximization of PT's value function. Details on the objective function and the optimization procedure for a similar case can be found in Podestá et al. (in press). Optimal management was determined for a series of overlapping two-year windows along the 25-year sequence of decreasing rainfall. This assumes the farmer is aware of the likely range of expected climate conditions, defined on one hand by a window's position in the sequence (i.e., windows towards the end of the sequence are drier) and, on the other hand, by the natural variability contained in the 200 realizations of simulated weather in each 2-yr window.

For both locations, the optimal action was to allocate 100% of land to full-cycle soybean throughout the entire 25 years of decreasing rainfall (i.e., no adaptation was necessary). None of the other crops appeared in the optimal solutions. That is, if relative commodity prices and input costs remain similar to recent levels (as assumed for simplicity) soybean may continue to have higher economic profitability than other crops, even in a context of decreasing rainfall. In Pergamino, optimal management of full-cycle soybean (early planting) was the same for the entire simulated sequence. In Pilar, in contrast, about ten years into the simulated sequence, the optimal management switched from early to late planting. This shift may reflect the fact that Pilar has much drier winters and thus crop success is highly dependent on spring and summer rainfall. As overall precipitation decreases, a delay in planting may be necessary to accumulate water in the soil.

5. Discussion

This paper describes an exploration of plausible climate scenarios 25 years into the future and their potential impacts on agricultural systems in the Argentine Pampas. Inter-decadal climate variability, together with changes in the economic, institutional, land tenure, and technological contexts, has contributed to major recent changes in land use patterns in the Pampas. Although there is considerable uncertainty about projected paths of future climate, particularly on regional scales and short time horizons, there is growing concern among stakeholders in the Pampas that agricultural production systems that evolved partly in response to increased rainfall may not be viable if (as is entirely possible) climate reverts to a drier epoch.

Two locations in the Pampas, Pergamino and Pilar, representing respectively climatically optimal and marginal conditions, were selected for detailed analyses. Two decreasing linear trends consistent with previously experienced fluctuations, -5.5 and -6.3 mm yr^{-1} for Pergamino and Pilar respectively, were chosen for detailed analysis. Nevertheless, subsequent studies also might consider other plausible trends.

There have been two equally unrealistic extremes in modeling farmers' adaptation to climate variability and change: a naïve farmer who does not notice a changing context and makes decisions as always, and a "clairvoyant" farmer who tracks fluctuating climate precisely and follows the best adaptation strategies (Schneider et al. 2000). In reality, farmers are neither naïve nor clairvoyant (Risbey et al. 1999; Smit & Skinner 2002), but these two extreme situations help bracket possible responses.

In the case of no adaptation, our results show impacts of plausible decadal precipitation variability that are quite different between optimal and marginal locations: whereas in Pergamino crop yields and economic returns do not change noticeably (or even increase slightly) with decreasing precipitation, the more marginal Pilar experiences a clear decrease of yields and profits. If precipitations decrease as projected, Pilar also might experience much higher probabilities of negative economic results. Pilar farmers growing maize, who currently experience economic losses once every nine or ten years, might in the future lose money in four out of ten years. The increased rate of economic failure may endanger the future viability of continuous agriculture in climatically marginal regions of the Pampas such as Pilar, where farmers already may operate near the limits of profitability and have a slender buffer against hardship.

In a second step, we allowed farmers to adapt their agronomic management in response to fluctuating climate using currently available technology or know-how. In both locations, optimal adaptive actions involved allocating 100% of land to full-cycle soybean, regardless of decreasing precipitation. This finding probably reflects the strong effect of current relative commodity prices and input costs on soybean profitability. At present, soybean not only yields higher economic profits, but also requires lower initial investments and less management effort (e.g., genetically modified varieties tolerant to herbicides simplify considerably weed controls) than other crops. This result is consistent with the recent expansion of soybean in Argentina at the expense of other crops and cattle. Nevertheless, it may be useful to explore the robustness of our results to changes in relative prices and input costs for different crops. For example, higher global demand for bioethanol in the near future might increase prices of maize (a source of this biofuel), possibly changing the optimal adaptation strategies found here.

Forthcoming advances in agricultural technology may affect not only the sector's productivity, but also its vulnerability to changes in climate (McKenney et al. 1992). Future studies should consider realistic adaptation options that involve not only changes in currently available genotypes or management actions, but also technological innovations. For instance, it is relevant to ask whether crop breeding can keep pace with projected yield decreases associated with the rainfall trends considered. For Pilar, average yield decreases for maize are ≈76 kg ha^{-1} yr^{-1}. Crop breeding, in contrast, has produced recent average yield increases 100-250 kg ha^{-1} yr^{-1} (Eyhérabide et al.

1992; Eyhérabide et al. 2001; Luque et al. 2006). Projected decreases in full-cycle soybean yields in Pilar are ≈32 kg ha^{-1} yr^{-1}. Unlike maize, projected drops in soybean yields compare unfavorably with recent breeding increases of 12-16 kg ha^{-1} yr^{-1} (Santos et al. 2006). In any case, it would be critical to assess whether recent rates of yield enhancements could be maintained in drier environments.

To plan for adaptation, it is important to anticipate the technological changes that may shape agriculture over the next decades. One of the most anticipated developments in agricultural biotechnology is the introduction of genes to enhance drought tolerance in plants (Babu et al. 2003; Masle et al. 2005). In the next decade, seed companies expect to introduce transgenic solutions to improve drought tolerance in maize. Maize is the main alternative to soybean in the Pampas, and its yields are very sensitive to drought-related stresses. Availability of drought-tolerant maize may allow cropping in a marginal area that becomes even drier. Further, rotations including drought-tolerant maize would be more attractive in a drier climate and partially alleviate concerns about soybean mono-cropping.

In the next few decades, complex interactions between decadal climate variability, technological innovations and other drivers will force agricultural stakeholders and policy-makers to face unavoidable tradeoffs between productivity, stability, and sustainability in agroecosystems of the Pampas (Viglizzo & Roberto 1998). The growing tension between multiple and conflicting objectives, coupled with incomplete and uncertain information about expected climate trajectories and other valid societal concerns offer opportunities for salient scientific knowledge to inform decision-making and policy.

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7. Literature Cited

Apipattanavis, S., G.P. Podestá, B. Rajagopalan and R. Katz. A semiparametric multivariate and multisite weather generator. In press, Water Resources Research.

Babu, R.C., B.D. Nguyen, V. Chamarerk, P. Shanmugasundaram, P. Chezhian, P. Jeyaprakash, S.K. Ganesh, A. Palchamy, S. Sadasivam, S. Sarkarung, L.J. Wade and H. T. Nguyen. 2003. Genetic analysis of drought resistance in rice by molecular markers: association between secondary traits and field performance. Crop Science 43: 1457-1469.

Berbery, H., M. Doyle and V. Barros. 2006. Tendencias regionales de la precipitación. In: Barros, V., R. Clarke and P. Silva Dias (eds). El cambio climático en la Cuenca del Plata. CONICET, Buenos Aires.

Boote, K., J.W. Jones, and N.B. Pickering. 1996. Potential Uses and Limitations of Crop Models. Agronomy Journal 88: 704–16.

Boote, K., J.W. Jones, and G. Hoogenboom. 1998. Simulation of crop growth: CROPGRO model. In: Peart RM, Curry RB, (Eds). Agricultural systems modeling and simulation. Marcel Dekker, New York.

Boulanger, J.-P., J. Leloup, O. Penalba, M. Rusticucci, F. Lafon and W. Vargas. 2005. Observed precipitation in the Paraná-Plata hydrological basin: long-term trends, extreme conditions and ENSO teleconnections. Climate Dynamics 24: 393–413.

Boulanger, J.P, F. Martinez and E.C. Segura. 2006. Projection of future climate change conditions using IPCC simulations, neural networks and Bayesian statistics. Part 1: Temperature mean state and seasonal cycle in South America. Climate Dynamics 27: 233–259.

Boulanger, J.P., F. Martinez and E.C. Segura. 2007. Projection of future climate change conditions using IPCC simulations, neural networks and Bayesian statistics. Part 2: Precipitation mean state and seasonal cycle in South America. Climate Dynamics 28: 255–271.

Camerer, C. 2005. Three cheers–psychological, theoretical, empirical–for loss aversion. Journal of Marketing Research 42: 129-133.

Carolan, M.S. 2005. Barriers to the adoption of sustainable agriculture on rented land: an examination of contesting social fields. Rural Sociology 70: 387-413.

Castañeda, M.E. and V. Barros. 1994. Las tendencias de la precipitación en el Cono Sur de América al este de los Andes. Meteorológica 19: 23-32.

Clark, M.P., S. Gangopadhyay, D. Brandon, K. Werner, L. Hay, B. Rajagopalan, and D. Yates. 2004. A resampling procedure for generating conditioned daily weather sequence. Water Resources Research 40, doi:10.1029/2003WR002747.

Dardanelli, J.L., O.A. Bachmeier, R. Sereno, and R. Gil. 1997. Rooting depth and soil water extraction patterns of different crops in a silty loam Haplustoll. Field Crops Research 54: 29-38.

Eyhérabide, G.H., and A.L. Damilano. 2001. Evolución de la ganancia genética en rendimiento de grano de maíz en Argentina entre 1979 y 1998. In: Asoc. Ing. Agr. del Norte de la Prov. de Buenos Aires (Eds), Proceedings of: VII Congreso Nacional de Maíz, Pergamino, Argentina, pp. 45.

Eyhérabide, G.H., A. Damilano, J. Colazo, A.F. Van Becelaere, R. Sans. 1992. Ganancia genética en rendimiento de grano de maíz en Argentina desde 1979 hasta 1991. In: Asoc. Ing. Agr. del Norte de la Prov. de Buenos Aires (Eds), V Congreso Nacional de Maíz, Pergamino, Argentina, pp 70–78.

Falcon, W.P. and R. Naylor. 2005. Rethinking food security for the twenty-first century. American Journal of Agricultural Economics 87: 1113-1127.

Fennema, H.P. and P.P. Wakker. 1997. Original and cumulative prospect theory: A discussion of empirical differences. Journal of Behavioral Decision Making 10: 53-64.

Ferreyra, R.A., G.P. Podestá, C.D. Messina, D. Letson, J. Dardanelli, E. Guevara, and S. Meira. 2001. A linked-modeling framework to estimate maize production risk associated with ENSO related climate variability in Argentina. Agricultural and Forest Meteorology 107: 177- 192.

Gintis, H. 2000. Beyond Homo economicus: evidence from experimental economics. Ecological Economics 35: 311-322.

Giorgi, F. 2002. Variability and trends of sub-continental scale surface climate in the twentieth century. Part I: Observations. Climate Dynamics 18: 675-691.

Guevara, E., Meira, S., Maturano, M., and Coco, G., 1999. Maize simulation for different environments in Argentina. Pp 193 - 194. In: International Symposium: Modelling cropping systems. European Society of Agronomy University of Lleida, Catalonia, Spain.

Hall, C.M. Rebella, C.M. Ghersa, and J.Ph. Culot. 1992. Field-crop systems of the Pampas. In: C.J. Pearson (Ed.), Ecosystems of the World. Field crop ecosystems, Elsevier, pp. 413- 449.

Janssen, M.A. and W. Jager. 2000. The human actor in ecological-economic models. Ecological Economics 35: 307-310.

Jones, J., G. Tsuji, G. Hoogenboom, L. Hunt, P. Thornton, P. Wilkens, D. Imamura, W. Bowen, and U. Singh. 1998. Decision support system for agrotechnology transfer. In: Tsuji, G, G. Hoogenboom, and P. Thornton (Eds.), Understanding Options for Agricultural Production, Kluwer, pp. 157–77.

Jones, J.W., G. Hoogenboom, C.H. Porter, K.J. Boote, W.D. Batchelor, L.A. Hunt, P.W. Wilkens, U. Singh, A.J. Gijsman, J.T. Ritchie. 2003. The DSSAT cropping system model. European Journal of Agronomy 18: 235-265.

Kahneman, D., and A. Tversky. 1979. Prospect theory: an analysis of decision under risk. Econometrica 47: 263–291.

Kesan, J.P. and A.A. Gallo. 2005. Property rights and incentives to invest in seed varieties: governmental regulations in Argentina. AgBioForum 8(2-3): 118-126.

Leteinturier, B., J.L. Herman, F. Longueville, L. Quintin, and R. Oger. 2006. Adaptation of a crop sequence indicator based on a land parcel management system. Agriculture, Ecosystems and Environment 112: 324-334.

Letson, D., G. Podestá, C. Messina, and R.A. Ferreyra. 2005. The uncertain value of perfect ENSO phase forecasts: stochastic agricultural prices and intra-phase climatic variations. Climatic Change 69(2-3): 163-196.

Lichtenberg, E. 2007. Tenants, landlords, and soil conservation. American Journal of Agricultural Economics 89: 294-307.

Luque, S.F., A.G. Cirilo, and M.E. Otegui. 2006. Genetic gains in grain yield and related physiological attributes in Argentine maize hybrids. Field Crops Research 95: 383-397.

Magrín, G.O., M.I. Travasso and G.R. Rodríguez. 2005. Changes in climate and crop production during the 20th century in Argentina. Climatic Change 72: 229-249.

Martínez-Ghersa, M.A. and C.M. Ghersa. 2005. Consecuencias de los recientes cambios agrícolas. Ciencia Hoy 15(87): 37-45.

Masle, J., S.R. Gilmore and G.D. Farquhar. 2005. The ERECTA gene regulates plant transpiration efficiency in Arabidopsis. Nature 436: 866-870.

Mauget, S.A. 2006. Intra- to multidecadal terrestrial precipitation regimes at the end of the 20th century. Climatic Change 78: 317-340.

McKenney, M.S., W.E. Easterling, and N.J. Rosenberg. 1992. Simulation of crop productivity and responses to climate change in the year 2030: the role of future technologies, adjustments and adaptations. Agricultural and Forest Meteorology 59(1-2): 103-127.

Meinke, H., R. Nelson, P. Kokic, R. Stone, R. Selvaraju and W. Baethgen. 2006. Actionable knowledge: from analysis to synthesis. Climate Research 33: 101-110.

Meira, S., Baigorri, E., Guevara, E., and Maturano, M., 1999. Calibration of soybean cultivars for two environments in Argentina. Global Soy Forum. Chicago, August 4–7 1999.

Mercau, J.L., J.L. Dardanelli, D.J. Collino, J.M. Andriani, A. Irigoyen and E.H. Satorre. 2007. Predicting on-farm soybean yields in the pampas using CROPGRO-soybean. Field Crops Research 100, 200–209.

Messina, C.D., J.W. Hansen, and A.J. Hall. 1999. Land allocation conditioned on ENSO phases in the Pampas of Argentina. Agricultural Systems 60: 197-212.

Morello, J. and O.T. Solbrig (eds.). 1997. Argentina granero del mundo: hasta cuándo? Orientación Gráfica Editora. Buenos Aires, Argentina.

Myyrä, S., K. Pietola and M. Yli-Halla. 2007. Exploring long-term land improvements under land tenure insecurity. Agricultural Systems 92: 63-75.

von Neumann, J. and O. Morgenstern. 1944. Theory of Games and Economic Behavior. Princeton University Press, Princeton.

Parry M.L. 1985. The Impact of Climatic Variations on Agricultural Margins. In: Kates, R.W., J.H. Ausubel, and M. Berberian (eds). Climate Impact Assessment Studies of the Interaction of Climate and Society. Scientific Committee on Problems of the Environment (SCOPE) 27. Wiley, U.K., 625 pp.

Parry M.L. and T.R. Carter. 1989. The impact of climate change on agriculture. In: Topping I.C., (ed.). Coping with Climate Change: Proceedings of the Second North American Conference on Preparing for Climate Change. Washington, D.C., Climate Institute, pp. 180-184.

Paruelo, J.M. and O.E. Sala. 1993. Effect of global change on maize production in the Argentinean Pampas. Climate Research. 3: 161-167.

Podestá, G.P., E. Weber, C. Laciana, F.E. Bert, and D. Letson. In press. Agricultural Decision- Making in the Argentine Pampas: Modeling the Interaction between Uncertain and Complex Environments and Heterogeneous and Complex Decision Makers. In: Decision Modeling and Behavior in Uncertain and Complex Environments. Springer Publishing.

Qaim, M. and G. Traxler. 2005. Roundup ready soybeans in Argentina: farm level and aggregate welfare effects. Agricultural Economics 32: 73- 86.

Rajagopalan, B. and U. Lall. 1999. A k–nearest-neighbor simulator for daily precipitation and other weather variables. Water Resources Research 35(10), 3089–3101.

Risbey, J., M. Kandlikar, H. Dowlatabadi, and D. Graetz. 1999. Scale, context, and decision making in agricultural adaptation to climate variability and change. Mitigation and Adaptation Strategies for Global Change 4: 137-165.

Ritchie, J.T. 1998. Soil water balance and plant water stress. p. 41-54. In: Tsuji, G.Y. et al. (ed.) Understanding options for agricultural production. Kluwer Academic Publishers, Dordrecht.

Rosenzweig, C., K.M. Strzepek, D.C. Major, A. Iglesias, D.N. Yates, A. McCluskey and D. Hillel. 2004. Water resources for agriculture in a changing climate: international case studies. Global Environmental Change 14: 345-360.

Rusticucci, M. and O. Penalba. 2000. Interdecadal changes in the precipitation seasonal cycle over Southern South America and their relationships with surface temperature. Climate Research 16: 1-15.

Santos, D., D. Fresoli, P. Beret, R. Benavidez, R. Vicentini, and A.J. de la Vega. 2006. Ganancia genética en soja en Argentina entre 1980 y 2000. Available online in: http://www.inta.gov.ar/PARANA/info/documentos/produccion_vegetal/soja/evaluacion_manejo/20220_060524_gan.htm.

Satorre, E.H. 2005. Cambios tecnológicos en la agricultura actual. Ciencia Hoy 15: 24 -31.

Schneider, S.H., W.E. Easterling, and L.O. Mearns, 2000. Adaptation, sensitivity to natural variability, agent assumptions and dynamic climate changes. Climatic Change 45: 203-221.

Schnepf, R.D., E. Dohlman, and C. Bolling. 2001. Agriculture in Brazil and Argentina: Developments and prospects for major field crops. Washington, D.C., U.S. Department of Agriculture. Economic Research Service Agriculture and Trade Report WRS-01-3.

Smit, B., and M.W. Skinner. 2002. Adaptation options in agriculture to climate change: a typology. Mitigation and Adaptation Strategies for Global Change 7 (1): 85-114.

Tebaldi, C., K. Hayhoe, J.M. Arblaster and G. Meehl. 2006. Going to the extremes: an intercomparison of model-simulated historical and future changes in extreme events. Climatic Change 79: 185-211.

Traxler, G. 2006. The GMO experience in North and South America. International Journal of Technology and Globalisation 2: 46-64.

Trigo, E.J. and E.J. Cap. 2003. The impact of the introduction of transgenic crops in Argentinean agriculture. AgBioForum, 6(3): 87-94.

Tversky, A. and D. Kahneman. 1992. Cumulative prospect theory: An analysis of decision under uncertainty, Journal of Risk and Uncertainty 5: 297-323.

Viglizzo, E.F., Z.E. Roberto, M.C. Filippin and A.J. Pordomingo. 1995. Climate variability and agroecological change in the Central Pampas of Argentina. Agriculture, Ecosystems and Environment 55: 7-16.

Viglizzo, E.F., Z.E. Roberto, F. Lértora, E. Lopez Gay and J. Bernardos. 1997. Climate and land use change in field crop ecosystems of Argentina. Agriculture, Ecosystems and Environment 66: 61-70.

Viglizzo, E.F. and Z.E. Roberto. 1998. On tradeoffs in low input agroecosystems. Agricultural Systems 56: 253-264.

Yates, D., S. Gangopadhyay, B. Rajagopalan, and K. Strzepek. 2003. A technique for generating regional climate scenarios using a nearest neighbor algorithm. Water Resources Research 39(7): 1119-1134.

Impacts, Vulnerability and Adaptation of the Pantabangan-Carranglan Watershed, Philippines to Climate Change: Perspective of the Stakeholders

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Introduction

Climate change is considered as one of the most pressing environmental issues of our day because experts believe that it carries along harmful effects both on environment and human population. The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) states that there will be a shift in the timing of streamflow, changes in the amount of rainfall to be received by the different regions of the world, decrease in water quality in areas that will be receiving less rainfall, increase in occurrence of floods in many regions, decrease in biodiversity, change in species distribution and dominance, movement of species in higher elevation, etc. In the Philippines, projected impacts of climate change according to Cruz (1998) include: (1) likely expansion of rainforests as a result of increased temperature and rainfall; (2) increase in the frequency of droughts and floods which would likely render many areas currently under cultivation unfit for agricultural crop production resulting to opening of more forested areas for cultivation; (3) increased in precipitation during the wettest months which will cause occurrence of severe soil erosion, floods and landslides; (4) occurrence of prolonged dry spells that will increase vulnerability of the grasslands to occurrence of fire; (5) loss of biodiversity; (6) outbreak of pests and diseases; and (7) highly probable damage to mangrove areas because of siltation.

In the issue of climate change, watersheds are among the areas that are believed to be badly affected. In a country such as the Philippines where watersheds comprise large portion of the country's land area, careful planning should be undertaken to decrease the probable impacts of climate change. Representing at least 70% of the total area of the country, watershed areas cover around 21 million hectares. Size of these watersheds can range from as small as 4,000 ha to as large as 2,500,000 ha.

The benefits derived from the watersheds are undeniably important. They provide whole range of goods and services such as water, timber, food, fiber, minerals, medicine, biodiversity, carbon storage and sequestration, oxygen generation, microclimate condition, landscape beauty etc. In addition, it is a home to more than 20 million people who are highly vulnerable to climate related risks. Most of them cultivate marginal hilly areas and rely heavily on rain as source of water for farming and domestic use.

To minimize loss of benefits derived from the watersheds, impacts and vulnerability of the watershed areas to climate change need to be identified. Likewise, existing adaptation strategies should be determined as such strategies could form a strong foundation for exploring viable options for adaptation of Philippine watersheds to climate change.

Objectives

1. To assess the impacts of and vulnerability to climate variability and extremes of the different ecosystems in the Pantabangan-Carranglan watershed;
2. To explore the adaptation strategies developed by the various institutions and local communities in the Pantabangan-Carranglan Watershed to cope with the impacts of climate variability and extremes;
3. To promote a multi-stakeholder approach in formulating climate risk adaptation strategies; and
4. To promote the participatory approach in the research process

Methodology

The study used a combination of primary and secondary data. Primary data was gathered through conduct of focus group discussions, workshops, consultation meetings and direct field observation. Secondary data was gathered from the local government units, National Power Corporation (NPC), National Irrigation Administration (NIA), Department of Environment and Natural Resources (DENR) and other relevant agencies. Secondary data collected include the biophysical aspect of the watershed such as land use, climate, soil and topography.

To assess the impacts, vulnerability and adaptation strategies to climate change of the different ecosystems in the watershed, views of the different stakeholders in PCW were elicited during focus group discussions (FGDs), workshops and consultation meetings. The participants were asked to evaluate the impacts of the 'early and late onset of rainy season', 'La Nina', 'El Nino', 'high temperature/summer season', and 'rainy season' on the different land uses present in PCW. Vulnerability of each land use as well as the adaptation strategies being undertaken to cope with the impacts of the mentioned climate variability and extremes were also solicited. Participants of the FGDs, workshops and consultation meetings include the Provincial and Community Environment and Natural Resources Officers of the DENR, planning officers of the five municipalities, barangay officials, farmers or members of the local community, area managers of the NPC and the NIA and representatives of the non-government organizations operating in the area.

The Study Site

The study was conducted in the Pantabangan-Carranglan Watershed (PCW). Located in the island of Luzon, PCW is approximately 175 km away from Manila. It is found within the provinces of Nueva Ecija, Nueva Vizcaya and Aurora. PCW covers 36 barangays and five municipalities namely Pantabangan and Carranglan of the province of Nueva Ecija, Alfonso Castaneda and Dupax del Sur of the province of Nueva Vizcaya and Ma. Aurora of Aurora province. However, large portion of the watershed is located in Pantabangan and Carranglan (Figure 1).

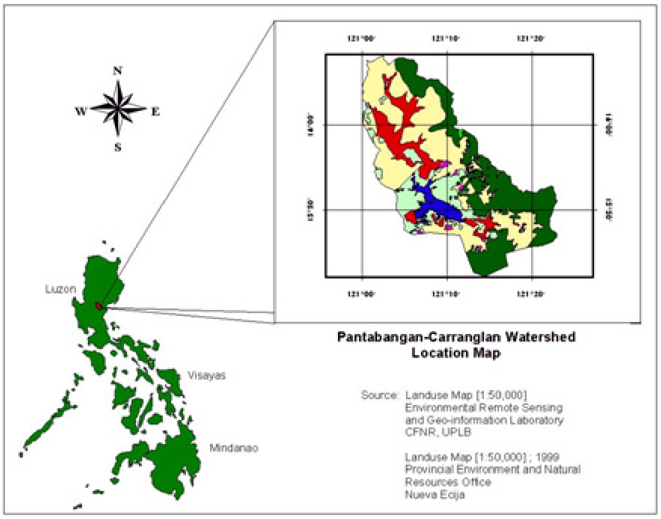

Figure 1. Location of the study site.

Based on the 1999 land use map, PCW covers a total area of 97,318 ha of which 4023 ha consist of the water reservoir. Land uses include forestlands, open grasslands and cultivated lands.

PCW falls under two kinds of climate: Type 1 and Type II. Large portion of the watershed falls under the Climatic Type I of the Corona Classification System. This area has pronounced dry and wet seasons where dry period is from November to April while wet season is from May to October. Small portion of PCW however, falls under Climatic Type II. This area has very pronounced wet season from November to January and evenly wet the rest of the year. Annual rainfall in the watershed ranges from 1776.5 to 2270.9 mm. The mean monthly temperature ranges from 25.7º C to 29.5º C. The lowest and highest temperature in the watershed occurred in January 1963 at 23.8º C and May 1970 at 30.6º C, respectively.

Results and Discussion

Impacts and vulnerability assessment

'Early onset of rain' has in general, positive impacts on all land uses. For instance in lowland farms, this period allows the farmers especially in Pantabangan where farms are rainfed to plant palay and other agricultural crops ahead of the usual schedule. This is done to take advantage of the rain, an important component in growing crops.

Similarly, 'early onset of rain' results to early cultivation of the upland farms. Likewise, the farmers noted that such climate variability results to higher agricultural production and higher income derived from upland farming. One negative impact though of this climate variability is the expansion of kaingin areas in Pantabangan because of the favorable condition that rain creates for growing crops.

In natural forests, 'early onset of rain' causes the flowers of the trees to bloom ahead of its usual schedule. Also, this season promotes decomposition of the litter layer in the forest soils as decomposition is faster when there is enough moisture available. As a result, soils in the natural forests become more fertile.

Growth of trees in plantation areas is enhanced during the 'early onset of rain'. According to the participants, this is manifested by the fast growth of the trees observed when rain falls at an earlier schedule.

Grasslands are more protected from fire during the 'early onset of rain'. This is due to the availability of moisture that keeps the grasses fresh. During this climate variability, occurrence of fire in grassland areas is less likely to happen as grasses are not too dry. Also, grassland areas according to the participants have early regeneration when there is 'early onset of rain'. However, one negative effect of this climate variability is the occurrence of soil erosion in grassland areas as soil particles in grassland areas are not very much bonded together compared with the soils of tree plantation and natural forests.

'Late onset of rain' negatively affects the different ecosystems in the watershed. In lowland and upland farms, this climate variability results to a decrease in the production of agricultural crops. As a consequence, income derived from farming of the upland and lowland farmers are low and not at all sufficient to meet the needs of their families. Thus, they have to look for other sources of livelihood that will provide them additional income.

In tree plantation, 'late onset of rain' results to death of seedlings planted. It should be noted that outplanted seedlings need regular watering to ensure high probability of survival. Thus, when rain comes later than its schedule, it is very likely that outplanted seedlings would die and result to very low rate of survival of the established tree plantations. For bigger trees, 'late onset of rainy season' results to drying up of their leaves.

Among the land uses, grassland areas are the most vulnerable to 'late onset of rain'. The participants mentioned that such climate variability results to drying up of grasses and accumulation of fuel in the grassland areas. As a consequence, grassland areas in PCW become more prone to fire.

The impact of 'late onset of rain' on trees in natural forests is similar to its impact on plantation areas where trees dry up due to insufficient moisture that is available. Moreover, this climate variability results to migration of wildlife to other thickly forested areas or areas that have higher moisture.

One of the noted impacts of the La Nina event that has been observed to occur in all the ecosystems of the watershed is the occurrence of soil erosion. Excessive rain characterizing La Nina results to disintegration of the soil particles across ecosystems. As a consequence, soil nutrients are washed out reducing the fertility of the soils.

Aside from soil erosion, La Nina according to the participants causes floods in lowland and upland farms. As a consequence, the crops are badly damaged resulting to loss of income for the farmers.

In tree plantation, La Nina enhance occurrence of pests and diseases. This results to decay or at worst death of trees in the area. In grassland areas, the participants mentioned that the birds, rats, and other predator species present die during La Nina event while in natural forests, cross pollination of trees is affected.

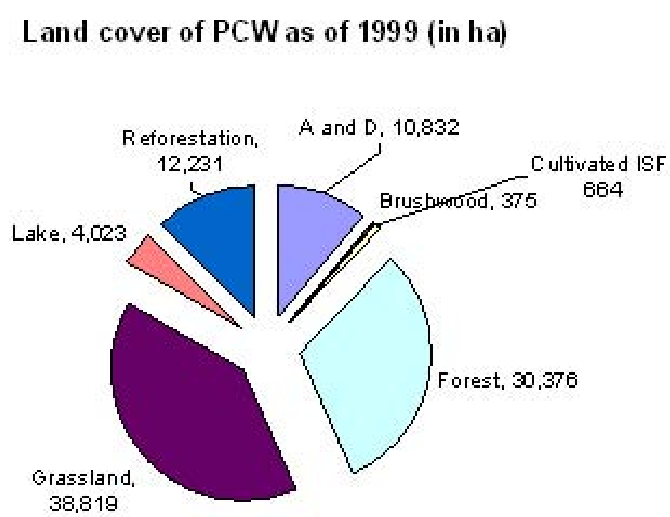

Figure 2. Land uses of the Pantabangan-Carranglan watershed.

The absence of rainfall during El Nino events results to decreased productivity of all the ecosystems present in the watershed. The participants mentioned that El Nino causes stagnation of the growth of the crops in lowland and upland farms and that of seedlings in tree plantation areas. Most often, the unavailability of sufficient moisture causes the plants to experience severe water stress which leads to death. As a result, farmers derive very low income from upland/lowland farming. While big trees present in tree plantations and natural forests survive the extreme dryness brought about by El Nino, the participants mentioned that such trees have very slow growth during such phenomenon.

Aside from reduction of the land productivity of all the ecosystems in the watershed, El Nino also results to increased risk of such areas to occurrence of fire. The extreme dryness due to absence of rainfall during El Nino results to build up of combustible materials which could burn easily when ignited.

In tree plantations, the participants noted that there is a decrease in the number of soil organisms in the area during El Nino which results to decreased fertility of the soil. In natural forests on the other hand, the participants mentioned that such ecosystem is at greater risk during El Nino because climate is very dry. Access roads to the natural forests are passable and safe hence they are very conducive to transporting harvested forest products.

Impacts of high temperature/summer season on the watershed are milder versions of the observed effects of El Nino. In fact most portions of the natural forests of PCW according to the participants are not significantly affected by high temperature/summer season.

In general, rainy season provides favorable condition to all the ecosystems in the watershed. During this climate event, growth of crops is enhanced resulting to higher land productivity. Also, the participants mentioned that it is during this time when cost incurred of maintaining the farms are low.

Rainy season according to the participants increases the risk of fungal infestation in upland farms due to too much moisture available. Also, expansion of kaingin farms is likely to happen as climate condition is favorable to cultivation. This impact results to decrease of forest cover in the watershed. Since upland farms are located in sloping areas, occurrence of soil erosion is highly probable during rainy season resulting to decreased soil fertility.

Aside from the ecosystems, the stakeholders mentioned that water supply both for domestic and commercial purposes are reduced due to 'El Nino', 'late onset of rain' and 'high temperature/summer season' It should be noted however that impact of 'El Nino' on water supply is more severe than the impact of 'late onset of rain' and 'high temperature/summer season'. Since rainfall is abundant during 'rainy season' or 'La Nina' or 'early onset of rain', water supply for domestic use, irrigation and power purposes is replenished. In terms of water quality, climate variability and extremes will likely lead to deterioration of its quality.

Adaptation measures

As regards adaptation measures being undertaken, the participants mentioned that in lowland and upland farms, tree plantations and grassland areas, a shift in the type of species to be planted is being undertaken. For instance, in seasons when there is insufficient moisture that is available due to 'El Nino' or 'late onset of rain', the farmers/tree farmers choose the drought tolerant species.

Other adaptation strategies being carried out in lowland and upland farms include: installation of firelines to reduce occurrence of fires, adoption of sustainable farming practices and delay of planting activity in cases when there is 'late onset of rain'.

In tree plantations, adaptation strategies being undertaken include implementation of proper silvicultural practices, shift in the type of species of trees to be planted and construction of firelines.

In grassland areas, adaptation measures being undertaken are: (1) dependence on forest resources for livelihood; (2) intensive information campaign on environmental protection; and (3) application of controlled burning.

While natural forests are barely hit by climate variability and extremes, the stakeholders suggested several adaptation strategies that should be undertaken to minimize impact of climate change in the area. These include: reforestation of the area using lesser used species, fruit trees, and agroforestry crops; enrichment planting through the assisted natural regeneration; control of settlement areas; effective land use management; co-management between and among stakeholders; strict implementation of forestry laws/rules; and provision of sustainable alternative livelihood development.

For water resources, adaptation strategies noted are effective watershed management planning, reforestation of the watershed areas with suitable species, use of shallow tube wells, rotation in receiving irrigation crops and use of water impounding technology. To address the problem on water quality, application of erosion control measures and periodic monitoring of water quality can be undertaken.

Conclusion

In sum, forest ecosystems are vulnerable to climate change although they vary in their degree of vulnerability. The degree of impacts of climate change varies depending on the type and location of the forest ecosystems being affected. Also, water, one of the most important environmental services provided by the watersheds is highly vulnerable to climate variability and extremes. To minimize its impacts, appropriate adaptation strategies must be put in place. An overall adaptation strategy should probably focus on identifying which forest ecosystem in the watershed is more at risk. Specific adaptation strategy could be helping the local communities to find alternative livelihood to reduce pressure on ecosystems that are at risk.

References

Bantayan, N. C., S. R. saplaco and R. V. O. Cruz. 2001. GIS-Based Atlas of Selected Watersheds in the Philippines. DOST-PCARRD and UPLB-CFNR-ERSG.

Cruz, R. V. O. 1998. Adaptation and Mitigation Measures for Climate Change Impacts on the Forestry Sector. In Proc F. B. Pulhin and R. D. Lasco (eds) Climate Change: Status, Issues and Challenges. Environmental Forestry Programme, College of Forestry, University (eds) Consultation Meeting for the International Conference on Tropical Forests and of the Philippines Los Banos, College, Laguna. pp 27-52.

IPCC. 2001. Climate change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, U.K. Cambridge University Press. pp 235-342.

Coupling population dynamics to carbon emissions

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Abstract

Since the beginning of the last century the world is experiencing an important demographic transition, which will probably impact on economic growth. Many demographers and social scientists are trying to understand the key drivers of such transition as well as its profound implications. A correct understanding will help to predict other important trends such as the world primary energy demand and the carbon emission to the atmosphere, which may be leading to an important climate change. This paper proposes a set of coupled differential equations to describe the changes of population, gross domestic product, primary energy consumption and carbon emissions, modeled as competing species. The predator–prey model is well known in the biological, ecological and environmental literature and has also been applied successfully in other fields. This model proposes a new and simple conceptual explanation of the interactions and feedbacks among the principal driving forces leading to the present transition. The estimated results for the temporal evolution of world population, gross domestic product, primary energy consumption and carbon emissions are calculated from year 1900 to year 2100. The calculated scenarios are in good agreement with common world data and projections for the next 100 years.

1. Introduction

Since the last century, the world has experienced important changes in demographic parameters. Better health care and social improvements have decreased infant mortality and have expanded longevity. As a consequence, world population had increased constantly since 1800 up to approximate 1970, but more recently that annual growth rate has been declining at a high pace, showing a visible demographic transition. This demographic transition will most probably have a real impact on economic growth, and therefore, the development of sound models will be increasingly relevant. Moreover, these changes will also impact on energy primary consumption and carbon emissions, a very sensitive aspect in dealing with global climatic change.

The economic theory debate on whether population growth is detrimental or beneficial to the welfare of humanity essentially comes down to the opposing schemes of exogenous technical progress (see, e.g., Ramsey, 1928; Cass, 1965) versus endogenous growth models (Romer, 1986; Lucas, 1988), or in another words, diminishing returns versus creation of technology to overcome them.

In this paper, the population dynamics and economic growth are treated as a dynamic system described by a set of ordinary differential equations in a general form of competing species. The use of these equations, based in the Lotka–Volterra relation (Lokta, 1925 and Volterra, 1926), is justified and detailed in a paper by the authors to be published shortly (Puliafito et. al, 2007). The resulting model is a typical prey-predator model, well known in the biological, ecological and environmental literature (Jost and Arditi, 2000; Shertzer et al., 2002; Song and Xiang, 2006, and others).

Additionally, in this paper it is intended to board another central topic, being the establishment of a theoretical basis on the possible pathways of world carbon emissions and primary energy consumption. The environmental economics literature on this issue has two distinct lines of research: a theoretical one, including pollution in mathematical growth models and an empirical one, based mostly on different equations specifications relating mainly carbon emissions to GDP per capita. More on the side of ecological economics literature, the IPAT identity was proposed in the early 1970s as a first guess to analyze the driving forces of environmental change (Commoner et al.,1971; Ehrlich and Holdren, 1972). The IPAT calculations establish that environmental impacts are the product or combination of three main driving forces: population, affluence (per capita consumption or production) and technology (impact per unit of consumption or production). Here, following that same idea, carbon emissions and energy demand are modeled as dependent on socio-economic variables.

Sections 2 and 3 will briefly introduce the employed models, while Section 4 presents sample simulation for world values. Section 5 discusses the modeled processes emphasizing the modeling of pathways of CO_2 emissions and energy demand. Finally Section 6 concludes the presented work.

2. Model for Population and GDP Dynamics

Lokta and Volterra (Lokta, 1925; Volterra, 1926) first proposed a relation to explain the dynamics of two (or more species), known as prey-predator equations. Lokta Volterra relations (LVR) might be seen as a particularization of more general system dynamics equations. In fact, the LVR can be found in the literature in many different forms and variations, but it may be written as a set of two (or more) ordinary differential equations (ODE). The LVR, in essence, describes the interaction of two species, where the growth rate of the first specie is dependent on the growth rate of the other specie. Some authors explicitly incorporate a logistic growth function for one of the species, some others, especially in ecology, explicitly specify a functional response to describe the interaction between the two species, including the concept of carrying capacity of the environment. Social scientists and demographers have used the concept of logistic growth to describe population dynamics, but uncoupled from other variables (or species). Here, the proposed set of equations is a generalization in the form of an open-system dynamic model, which includes a functional response *f*, to capture the influence of the variation of the substrate on the growth rates of the considered species:

$$\frac{dp}{dt} = (\alpha_1 + \alpha_3 f)\, p + \alpha_2 gp \qquad (1)$$
$$\frac{dg}{dt} = \beta_1 g + \beta_2 pg$$

where *p* is the population of one specie (i.e. world population), *g* the population of the second specie (i.e. world gross domestic product – GDP), dp/dt and dg/dt are their respective annual changes. The coefficients α_1 and β_1 represent the growing rates for population and GDP; α_2 and β_2 are the main control mechanism in the LVR, which moderates the growth in p and g, and $\alpha_3 f$ is used to modulate the growth rate α_1. The experience shows that most positive culture and technology changes arise in scenarios with an increasing g/p rate. Therefore, the function $f(g,p,t)$ could be expressed in terms of GDP per capita. If $f = g/p$ is replaced in (1), equation (2) follows:

$$\frac{dp}{dt} = \alpha_1 p + \alpha_3 k_1 g + \alpha_2 gp$$

(2)

$$\frac{dg}{dt} = \beta_1 g + \beta_2 pg$$

Since g/p has a near exponential growth, the first term in Equation (2), for example, with α_3 positive, will induce to produce a higher growth rate for p. Since α_2 is negative it will produce a reduction in the growth rate, specially for higher values of g. The combination of both coefficients allows a great flexibility in the dynamic of the variables.

3. Model for Energy Consumption and Carbon Emissions

The identification and understanding of key driving forces leading to carbon emission into the atmosphere confronts the researcher to deal with socio-economic variables that lie far beyond the atmospheric sciences, such as population growth, gross domestic product, and energy consumption, among others (see e.g. IPCC, 2000). In this paper, we estimate the annual changes in (world primary) energy consumption e and (world total) carbon emission c assuming a similar behaviour in the changes in GDP and population. Since de/dt and dc/dt are strongly coupled to dp/dt and dg/dt, we propose a similar set of differential equations as (2) to estimate the annual changes in both variables:

$$\frac{de}{dt} = \varepsilon_1 e + \varepsilon_2 pe$$

(3)

$$\frac{dc}{dt} = \sigma_1 c + \sigma_2 pc$$

Where ε_1 is the rate of increase in energy consumption in absence of any other limiting factor, ε_3 is the energy growth by an increasing per capita wealth led by a growing economy; and ε_2 is the control mechanism, associated to the energy reduction through new technology and spare behaviors. Similar considerations can be said for changes in the carbon emissions, i.e, σ_1 and σ_3 are the increase rates in carbon emissions for a growing economy; σ_2 is the carbon emissions control or reduction through increasing environmental awareness in the population and more efficient technology. It must be noted that to solve equation (3) it is necessary to run simultaneously equations (2), thus, obtaining four differential equations. This interrelation may be understood in the following way: a better efficiency induced by higher purchase possibilities and more investments in technology may produce a reduction in consumption; but also a rise of it due to higher purchase possibilities, as seen in developed countries.

4. Simulations

As sources of data, for years 1960 to 2006; and projections to 2015, we consulted several international agencies databases, such us the International Energy Outlook (EIA, 2005), United Nations Demographic Yearbook (UN, 2004), the US Census Bureau (2006), The World Bank (2005), International Monetary Fund (2004). For historical data (prior to 1960) we consulted estimations from United Nations (1973, 1999), McEvedy and Jones (1978), Biraben (1980), Durand (1974, 1977), Maddison (1995), Klein Goldewijk (2005), and Marland (2007).

Fig. 1 shows the predicted values of world population and world gross domestic product from year 1900 to 2100 as calculated by equations (2). The values used in Figure 1 are as follow: initial values $T_0 = 1880$, final year $T_F = 2100$; step size $D_T = 1.0$; $P_0 = 1.40$ Billions inhabitants; $G_0 = 0.75$ Trillions U$S. The annual rates are $\alpha_1 = 0.25\%$, $\alpha_2 = -5.8 / (10^{20}$ U$S); $\alpha_3 = 5.5$ Hab. / U$S, $\beta_1 = 2.55\%$, $\beta_2 = -5.8 /(10^{20}$ Hab.). According to the proposed coefficients, the population will have a slow growth of about 0.25% per year (typical value for population growth by 1900), and it is boosted through the per capita growth rate increase present in the functional response $\alpha_3 f$. But the same GDP growth will limit the population growth expressed by negative sign of α_2. On the other side, the mean growth of GDP at a high rate of 2.55 % is controlled by the population growth β_2. The function f is then used as a proxy function to represent the technological and cultural changes.

The inset in Fig. 1 exhibits the world annual population growth rates. Dots represent data and projections estimated in the UN Demographic Yearbook, while the solid line indicates the present

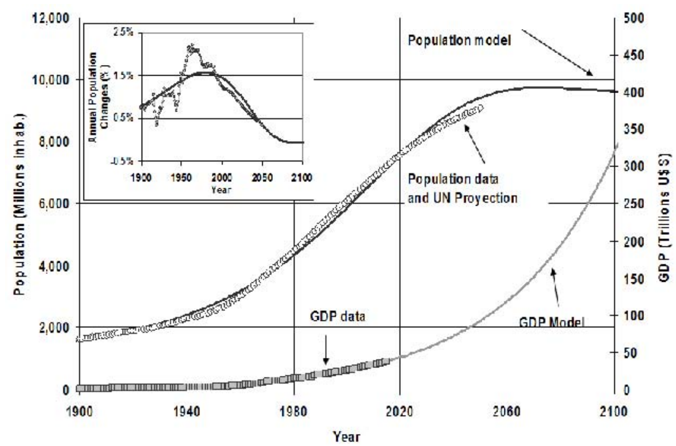

Figure 1: World Population (Millions inhabitants) and world Gross Domestic Product (Trillions U$S) evolution. Dots represent data from international agencies; solid black line population model; solid gray line GDP model. Inset represents world population annual changes (%).

model results. This trajectory clearly shows the ongoing demographic transition, showing a bell shaped curve, associated to the derivative of a logistic function.

Fig. 2 shows a representation of world primary energy consumption (EJ) and carbon emissions (GTn), using the proposed model compared to international agencies data. The coefficients of Equation (3) are: $E_0 = 4.20$ EJ, $C_0 = 0.85$ GTn C, $\varepsilon_1 = 1.1\%$, $\varepsilon_2 = -4.2/(10^{10}$ U$S.); $\varepsilon_3 = 3.8 \times 10^2$ Hab. / U$S.; $\sigma_1 = 1.1\%$, $\sigma_2 = -4.6 /(10^{10}$ U$S), $\sigma_3 = -3.7 \times 10^2$ Hab/ U$S.

The modeled values presented one possible trajectory of world development, consistent with stabilization in lower rate for g and p. The choice of other values for the control parameters will produce a shift in the maximum values, producing an early decay or a delay. In this way, all the variability suggested by IPCC-SRES projected scenarios of energy consumption and carbon emissions (IPCC 2000, Pepper et al, 1992) can be modeled by modifying the parameters of the equations presented in Sections 2 and 3.

The inset at the top-left of Fig. 2 displays the world pathway of energy consumption vs. carbon emissions. Dots represent data provided in the International Energy Outlook, while the solid line indicates the present model results. This trajectory shows a higher slope at the initial values, tending to stabilize and reduce emission rates by 2100. Further analysis of pathways is presented in the following Section.

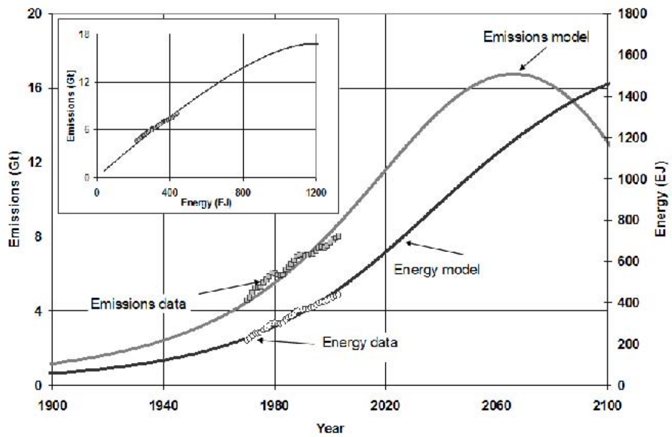

Figure 2: World Primary Energy consumption (Exa Joule) and world carbon dioxide emissions (Gt = 10^3 Tg) evolution. Dots represent data from international agencies; solid black line energy model; solid gray line emissions model. Inset represents world emissions vs. primary energy consumption trajectory.

5. Discussion of the described process

Advances in technology and knowledge boosted economic growth, reduced mortality rates and increased life expectancy, increasing the population, which began its transition from a labor-intensive agro-rural economy to a more urban industrial one. This effect was reinforced by the introduction of computation and automation, which reduced the need for manual activities, replacing human labor activity for fewer but highly educated/trained personnel, leading to a steady decline both in p and g. If this tendency continues, the model predicts a stabilization (or even a decline) level for g and p for the end of this century and beginning of the next one. But in the same way we had in the past an important boost due to knowledge accumulation, it is very likely that at some point in the next decades a new excitation may boost again the economy leading to a new phase of population growth; but probably before that the fossil fuel energy-based economy should shift to a new form of energy availability. It is therefore likely that carbon emissions will be reduced in the next decades, as more investments in cleaner technology are performed and fossil energy shifts towards other sources of energy generation followed by a growing environmental awareness.

The application of the same set of equations to individual countries allows the distinction of three well-defined groups which yield similar patterns of energy demand vs. carbon emissions and energy demand vs. GDP. These three groups are characterized by having alike slopes, agreeing with the following classification scheme: one group corresponds to developing countries whose economy is based on agriculture, livestock and natural resources exploit (e. g., Argentina, Mexico); a second group tallies developing countries based on "heavy" industry (e. g., China, India); and a last group agreeing with developed countries based on services (e.g., UK, Germany). Each scenario can be captured and modeled by properly modifying each of the coefficients in the presented equations. In the latter case, developed countries exhibit by now low slopes of carbon emissions and energy consumption as a function of their GDP, achieving a high increase of GDP but maintaining energy demand and carbon emissions roughly constant. This behavior may be explained by the adoption of more efficient technology, but also because international corporations have shifted their main heavy production to developing countries, remaining in the original countries the managing and financial divisions, which are less energy demanding. A deeper understanding of these pathways will allow an enormous improvement in the predictions of energy consumption and carbon dioxide emissions.

6. Conclusions

In this paper, we propose a set of ordinary differential equations for competing (or prey-predator) species to explain population dynamics, economic growth, energy consumption and carbon emissions. In this model, the inclusion of an additional function to the simplest LVR relations represents the influence that technological and cultural changes have on the population dynamics and economic growth.

The results of the model not only fit reasonably well population and GDP data or projections of international agencies (UN, EIA), but also explain in a simple mathematical way the transitional changes in both variables. Our application of the model to world energy demand and carbon emissions to the atmosphere was performed by adding two differential equations to those representing population and economy annual changes. The comparison of the model calculations to several agencies projections (IPCC, EIA) leads to similar output scenarios. Thus, the value of the present model is not only the ability to reproduce wide ranges of current projections, but also to capture conceptually in a simple mathematically formalism the present transitional trends in population, economy, energy-demand and carbon emissions.

Finally, it is important to note that world mean values hide big differences among regions and groups of countries. However, the application of the model on a group of countries or regions, i.e. North America, Europe, Asia, Latin America, and individual countries give also similar good fits as presented for the world mean values, which can be obtained by selecting the proper coefficients as described in Eqs. (2) and (3). These regional studies are oriented to establish common pathways of developments for the key drivers such as GDP, population, energy consumption, and carbon emissions.

References

Biraben, Jean-Noel, 1980. An Essay Concerning Mankind's Evolution, Population, Selected Papers, December, table 2.

Cass, D., 1965. Optimum Growth in an Aggregative Model of Capital Accumulation. Review of Economic Studies, 32, pp. 233-240.

Commoner, B., Corr, M. and Stamler, P.J., 1971. The causes of pollution. Environment, Vol. 13(3), pp. 2 -19.

Durand, J.D., 1974. Historical Estimates of World Population: An Evaluation. University of Pennsylvania, Population Center, Analytical and Technical Reports, No. 10.

Durand, J.D., 1977. Historical estimates of world population. Population and Development Review, 3(3): 253-296.

Ehrlich, P. and Holdren, P., 1971. Impact of Population Growth. Science, 171: 1212-17.

EIA, 2005. Energy Information Administration: International Energy Outlook 2005, www.eia.doe.gov/oiaf/ieo/index.html.

IMF, 2004. International Monetary Fund: World Economic and Financial Survey, World Economic Outlook, The Global Demographic Transition, Sept

ember 2004. http://www.imf.org/external/index.htm.

Jost, C. and Arditi, R., 2000. Identifying predator–prey processes from time-series. Theoretical Population Biology, 57, pp. 325–337.

Klein Goldewijk, K., 2005. Three centuries of global population growth: A spatial referenced population density database for 1700 – 2000, Population and Environment, 26(5): 343-367.

Lotka, A. J., 1925. Elements of physical biology. Baltimore: Williams & Wilkins Co.

Lucas, R., 1988. On the Mechanics of Economic Development. Journal of Monetary Economics, 22:1, pp. 3-42.

Maddison, A., 1995. Monitoring the world economy 1820 - 1992, OECD, Paris.

Marland, G., T.A. Boden, and R. J. Andres. 2007. Global, Regional, and National CO2 Emissions. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

McEvedy, C. and Jones, R., 1978. Atlas of World Population History, Middlesex, England: Viking Penguin. pp. 342-351. January 1978, ISBN: 0871964023.

Puliafito, S. E., Puliafito, J. L., Conte Grand, M., 2007. Modeling population dynamics and economic growth as competing species: An application to CO2 global emissions. Ecological Economics, accepted.

Ramsey, F., 1928. A Mathematical Theory of Saving. Economic Journal, Vol. 38, December, pp. 543-559.

Romer, P., 1986. Increasing Returns and Long-Run Growth. Journal of Political Economy, 94:5, pp. 1002-1037.

Shertzer, K.W., Ellner, S.P., Fussman, G.F. and Hairston, N.G., 2002. Predator–prey cycles in an aquatic microcosm: testing hypotheses of mechanism. Journal of Animal Ecology, 71, pp. 802–815.

Song, X. and Xiang, Z., 2006. The prey-dependent consumption two-prey one-predator models with stage structure for the predator and impulsive effects. Journal of Theoretical Biology, 242 , pp. 683–698.

U.S. Census Bureau, 2006. Total Midyear Population for the World: 1950-2050. http://www.census.gov/ipc/www/worldpop.html.

United Nations, 1973. The Determinants and Consequences of Population Trends, Population Studies, No. 50.

United Nations, 1999. The World at Six Billion, http://www.un.org/esa/population/publications/sixbillion/sixbilpart1.pdf.

United Nations, 2004. World Population Prospects: The 2004 Revision: http://www.un.org/esa/population/unpop.htm.

Volterra, V., 1926. Variazioni e fluttuazioni del numero d'individui in specie animali conviventi. Mem. R. Accad. Naz. dei Lincei. Ser. VI, vol. 2.

World Bank, 2005. World Development Indicators, Washington D.C, http://www.worldbank.org/data/wdi2000/index.htm.

Integrating data for the Assessment of National Vulnerabilities to the Health Impacts of Climate Change: A Novel Methodological Approach and a Case Study from Brazil

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ABSTRACT

A national quantitative assessment of the current regional vulnerability of the Brazilian population to the health impacts of climate change was undertaken with the support of the Brazilian Ministry of Science and Technology. A conceptual framework of vulnerability in the health sector with a modified general "Exposure-Response" model was adopted (Confalonieri, 2003). For the quantification of the vulnerability, a new methodology was used to develop a synthetic (composite) General Vulnerability Index (IVG), from averages of specific indices of vulnerability in three areas: Socio-economic, Epidemiological and Climatic.The socio-economic vulnerability Index has had the greatest relative importance in influencing the General Vunerability Index of the states found to be the most vulnerable. The approach used has shown that the Brazilian northeastern region is the most vulnerable to the health impacts of a changing climate.

1 INTRODUCTION

Future scenarios of global climate change project a greater instability of the climate system, especially in relation to climate extremes, meaning an increased risk of disease and injury to the population, particularly to the most vulnerable groups (IPCC, 2001; 2007).

Vulnerability to the impacts of weather and other natural disasters has been defined as "the characteristics of a group or a person related to their capacity to anticipate, to cope with, resist and recover from the impacts of natural hazards" (Blaikie et al, 1994). It is recognized that the most vulnerable social groups are those that experience the most exposure to a hazard, that are the most sensitive to it, and have the weakest capacity to respond and ability to recover.Vulnerability to global environmental changes is also distinguished as both a biophysical condition (geographic space) and defined by political, social and economic conditions (Liverman, 1990).

Brazil, because of its geographical characteristics, the continental size of its territory, its climatic profile, a large population and structural social problems, may be considered a vulnerable area to the different impacts of a changing climate upon human population health. One of the most important aspects that contribute to the vulnerability of the population to the health impacts of climate is the persistence of endemic infections diseases sensitive to climate variability such as malaria, dengue fever, leishmaniasis and leptospirosis, among others.

In this article we propose a new methodology for the quantitative assessment of the population vulnerability to the health impacts of climate, using Brazil as a case study.

1.1 Conceptual Frameworks

The principal objective of the study was to characterize the vulnerability of the country, for the period of study 1996-2001), using as health outcomes climate-sensitive infectious diseases of public health importance. The historical health situation (time series of data) was used to show the trends in incidence and impacts of the diseases in the recent past. It was assumed that the changes in the climatic hazards for health, brought about global climate change, will manifest as alterations in the patterns of extreme climatic events and as average values for temperature and precipitation; in short, by changes in the patterns of climatic variability. The need for the characterization of the vulnerability is to subsidize the policy making process, with the objective of adaptation to a changing climate. The importance of addressing current vulnerabilities is that they not only may be projected, in part, to the future, but mostly because they can presently be reduced by specific policies.

For the framing of the vulnerability a methodological-theoretical framework was adopted from a previous work (Confalonieri, 2003). It was developed based on a general "exposure-response" model (Watts & Bohle, 1993). A set of proximate drivers of vulnerability was identified, affecting both the exposures and the responses of the population to the climate-generated hazards. These range from individual characteristics such as age, gender and physical capacity to geographical aspects (eg. place of residence), and institutions and general infrastructure. These immediate determinants are conditioned by structural characteristics such as education, income, governance and political power, which were called "primary" or "ultimate" drivers of vulnerability (Figure 1).

Other vulnerability concepts and frameworks are based on other elements such as perturbation stresses and coupled socioecological systems (Kasperson & Dow, 2005). Another component frequently included is the resilience of exposed people, places and ecosystems, in terms of their capacity to absorb shocks and perturbations while maintaining function. A recent review of the concept of social vulnerability called for an interdisciplinary conceptualisation of vulnerability, based on the themes of poverty/exclusion and social-environmental interactions (Hogan & Marandola, 2006).

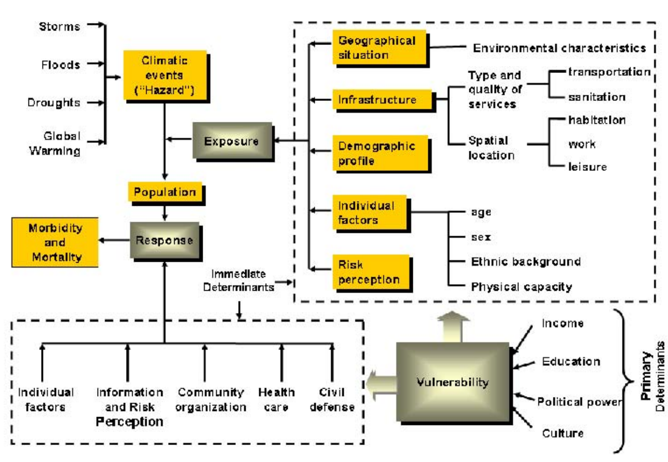

Figure 1: Conceptual model for social vulnerability to health impacts of climate.

2 - PROPOSED APPROACH

An index was developed for each of the dimensions - socio-economic; epidemiological and climatic - analysed in this research. The Socio-economic Vulnerability Index (IVSE) was developed for the quantification of social and economic factors, originally collected as primary data by the Brazilian National Population Census. An Epidemiological Vulnerability Index (IVE) was constructed from morbidity, mortality and health costs data, related to seven endemic infectious diseases occurring in the Brazilian territory. These diseases are sensitive to climate variability. The Climatic Vulnerability Index (IVC) was developed from historical precipitation data, as a proxy of the population exposure to weather extremes. In the next section the methods used for the development of these indices are presented.

2.1 Synthetic Indicators

The synthetic indicators have, as their main function, the concentration of information in just one variable. This allows for comparisons of elements, individuals and units, both at cross-sectional as well as temporal levels. For the development of the synthetic indicators we have followed the methodology used by the United Nations Development Program, with some modifications, for the construction of the "Human Development Index" (HDI). This Index was created to measure the level of human development of the countries, using indicators of education, income and life expectancy. Their values range from 0 (no development) to 1 (complete human development). The indices developed in this paper were meant to represent the state of the as-yet-unmeasured vulnerability of the 26 Brazilian states, plus the Federal District (DF), to the impacts of a changing climate, from a public health perspective.

These indices were elaborated from a comprehensive set of simple indicators related to the vulnerability concept adopted as a framework in our research. These were classified into three major dimensions: socio-economic; epidemiological and climatic.

All indicators were transformed (standardized) to indices with values ranging from 0 to 1, with the higher values indicating a greater vulnerability. To achieve this we have determined the relationship between the value of each indicator and the magnitude of the vulnerability. Thus, they were classified either as of Type I, if a high value of an indicator represented a situation of less vulnerability or, alternatively, of Type II, if the low value of the indicator was associated to a situation of less vulnerability.

The following formulae were used for the standardization of the selected indicators:

Type I:

$$SI_s = \frac{I_s - \min(I)}{\max(I) - \min(I)}, s = 1,...,S$$

Type II:

$$SI_s = \frac{I_s - \min(I)}{\max(I) - \min(I)}, s = 1,...,S$$

where: *Is* is the observed value the indicator *I* for the "n" state and S is the total number of states compared. *SIs* is the standardized indicator; min(I) is the smaller value observed, among all states, of the indicator I and max(I) is the highest observed value of the indicator I, among all brazilian states.

After all standardized indicators were obtained, arithmetic means were calculated for the values of the indicators in the same dimension. Therefore, the indices for each dimension were obtained using the following formula:

$$dimension_s = \frac{1}{n}\sum_{i=1}^{n} SI_{i,s}, s = 1,...S.$$

The vulnerability indices were defined as linear combinations (arithmetic or weighted means) of the synthetic indicators of different dimensions. Thus, each dimension of the vulnerability had the same relative importance (weight) for the quantitative assessment of the overall vulnerability. All indices range from zero to one; if a given index is equal to zero (0) this means that the corresponding area (state) has the better situation, when compared to the other states, for the same period of time. However, it should be stressed that if an index is zero, it does not mean that there is no vulnerability. In other words, the values of zero and one for the indices represent the best and the worse relative situation. The indices developed do not measure the degree of vulnerability of ideal or theoretical situations.

2.2 The Socio-Economic Vulnerability Index

The Socio-Economic Vulnerability Index (IVSE) was developed to measure the degree of vulnerability of each state, on a comparative basis. Its main objective is to rank the states, from the lowest to the highest level of relative vulnerability, using the primary data. The IVSE was elaborated using 11 simple indicators, classified into 5 different dimensions: (1) Demography: demographic density (inhabitants/ km2) and degree or urbanization (%); (2) Income: households with more than 2 persons / room (%) and poverty level (%); (3) Education: degree of schooling (%); (4) Sanitation: piped water supply (%); sewage treatment (%) and garbage disposal (%) and (5) Health: infant mortality rates (per 1000 live births); life expectancy at birth (in years) and health insurance coverage (%). Table A.1 (ANNEX) shows the definition of each of the indicators used to elaborate the IVSE. Among the eleven basic indicators, six were classified as belonging to Type I (higher values associated to smaller vulnerability) and the remaining were of Type II. The IVSE is the result of the arithmetic mean of the indices calculated for each of the five dimensions included:

$$IVSE_s = \frac{1}{5}(demog_s + income_s + education_s + sanit_s + health_s), s = 1,...S,$$

where: demog, income, education, sanit and health represent the indices obtained with the standardized indicators of the dimensions "demography", "income", "education", "sanitation" and "health", respectively.

2.3 The Epidemiological Vulnerability Index

The Epidemiological Vulnerability Index (IVE) was developed with the objective of synthesizing, in just one composite index, the information contained in a group of indicators related to seven endemic diseases sensitive to climate variability. The data referred to the period 1996 – 2001, for each Brazilian state. The diseases were: cholera; dengue fever; malaria; leptospirosis, visceral leishmaniases; cutaneous leishmaniases and hantavirus pulmonary syndrome. The selected indicators were: (i) incidence rate; (ii) number of hospital admissions in the state/number of hospital admissions in the country: (iii) cause-specific mortality in the state/ cause-specific mortality in the country; (iv) total cost (R$) of hospital admission in the state/ total cost of hospital admission in the country (R$). In the case of malaria we have used the "Annual Parasite Rate" (IPA). For all the endemic diseases - except for hantavirus pulmonary syndrome – we decided not to use the absolute observed number of hospital admissions, hospital deaths and the costs, but rather the proportion of these variables for each state, in relation to the national totals. In the case of the hantavirus infections, since it is a recently emerged disease in the country, there are records only for the number of cases and incidence rates. As a consequence, since the indicators were calculated using six years of data, overall, 24 indices were developed for cholera, dengue fever, malaria and leptospirosis; 30 for the leishmaniases and 6 for hantavirus infections.

In the case of the epidemiological vulnerability, we have considered each endemic disease as one dimension per se. The index for each disease is the simple mean of the averaged indicators. In this research, standardization was made in a way that the values close to 1 represent high incidences and proportions, and the used formula corresponds to the Type II indicator. As a consequence, we have calculated one synthetic index for each disease, varying from 0 to one. The worse relative situation correspond to the indices close to 1.

The IVE has been calculated from the individual indices for each disease. Since each disease has its own characteristics, which differ from those of the other diseases, we have decided to give a weight to each, based on five features: (1) Possibility of reduction of involuntary exposures, (ii) Efficiency of environmental control, (iii) Occurrence of drug resistance, (iv) Possibility of etiological treatment, and (v) Fatality Rates. For the calculation of the weight for the diseases, it has been attributed to each, one the following values: 1 (better situation), 2 (intermediate) and 3 (worse situation), according to the known natural history and control strategies of the disease, in regard to the characteristics analysed.

In Table 1 the values attributed to each disease are shown, for each characteristic, as well as the final weight (last column), used for the calculation of the IVE. We can observe that the highest weights were attributed to malaria (11) and hantavirus pulmonary syndrome (12); this means that these are the diseases presenting the greatest risk for the population and/or have the smaller probability of effective control. The calculation of the IVE used the followings formula:

$$IVE_s = \frac{1}{51}(7 \times coler_s + 7 \times deng_s + 11 \times malar_s + 5 \times leptos_s + 9 \times leishm_s + 12 \times hanta_s), s = 1,...S,$$

where: colers, dengs, malars, leptoss, leishs and hantas refer to the indices obtained from the standardized indices for each disease.

Table 1. Structure of the weights attributed to each disease

Diseases	Reduction of the Involuntary Exposition	Efficiency of environmental control	Existence of drug resistance	Possibility of Etiological Treatment	Fatality Rates	Final Weight
Cholera	1	1	1	3	1	7
Dengue	1	1	1	3	1	7
Malaria	3	3	3	1	1	11
Leptospirosis	1	1	1	1	1	5
Leish. Cutaneous	2	2	1	1	1	7
Leish. Visceral	2	2	3	1	1	9
Hantavirus	3	2	1	3	3	12

Codes (except fatality rates): 1 = better situation, 2 = medium situation, 3 = worse situation.

Codes for fatality Rates: 1 = up to 10%, 2 = from 11% to 39%, and 3 = over 40%

2.4 - The Climatological Vulnerability

The main objective of this assessment of climatological vulnerability was to classify the states according to the number of months of extreme precipitation, either higher or lower than the historical means. The aim was not to assess the total precipitation but rather the number of months showing anomalous precipitation levels.

An extreme precipitation value was defined as the value much higher or much lower than those from a historical series. Box Plots were used to identify these values due to their simplicity. They are easy to develop and interpret and constitute a common tool for the identification of "outliers", taking into account the asymmetry and variability of a given data set. Monthly precipitation records were used for each state, and the indicator developed was the percentage of months with extreme precipitation (Type II indicator). The IVC was developed to vary from the greatest vulnerability, that is, with the largest number of months with extreme precipitation levels, to the smallest.

In this paper, extremely low precipitation values did not mean drought (no rain). A state with a pattern of high annual precipitation may have extremely low relative values. This is the case of Amazonas, in the northern region, which has precipitation averages over 100 mm per month but, in June 1997, the observed precipitation of 66.8 mm was very low, when compared to the historical mean of 158.2 mm for that month.

On the other hand a state with a pattern of low precipitation and long drought periods, such as Piauí, did not show low relative values, since the low precipitation mean observed for August (10.0 mm) is not atypical for that area and period.

By analogy, an extremely high precipitation value does not mean flooding. As an example, the state of Pará had 200 mm as a March mean for the period of study, which is not an uncommon level. On the other hand, Piauí, which is affected by droughts in July and August, has had a precipitation level, in August 1983, of 70.6 mm, a value over ten times the historical mean for that month.

2.5 - General Vulnerability Index

The general Vulnerability Index (IVG) is the arithmetic mean of he three other vulnerability indices calculated: IVSE; IVE and IVC.

The IVG for the state s is given by the formula:

$$IVG_s = \frac{1}{3}(IVSE_s + IVE_s + IVC_s), s = 1,...S.$$

This formula can be used since all component indices have values ranging from 0 to 1 and, at same time, the value 0 (zero) indicates the less vulnerable situation and the value 1 means the greater vulnerability. As a consequence the IVG, also ranging from 0 to 1, represent the relative vulnerabilities, by the same way.

3 - DATA FROM THE BRAZILIAN STATES

The secondary data analyzed corresponded to the Brazilian states plus the Federal District (Figure 3). The socio-economic data were obtainded from the National 2001 census available at web site of the Brazilian Institute for Geography and Statistics – IBGE (www.ibge.gov.br) as well as from the 2002 "Indicadores e Dados Básicos para a Saude "(IDB, 2002). The epidemiological data and indicators were obtained from the Ministry of Health, State Departments of Health the National Health Foundation – FUNASA.

Precipitation data used in this study were obtained at the Center for Weather Prediction and Climate Studies (CPTEC/INPE), and the time series corresponded to 42 years of data. These data resulted from an interpolation made with data from the National Institute of Meteorology (INMET) and State Departments of Meteorology. Data were interpolated for the 0.25º x 0.25º grid (around 25 km x 25 km) for the visualization and development of the time series of the accumulated value for each state. Time series of the total monthly precipitation for each state were used; the data period ranged from January 1961 to December 2003 (total of 504 observations – 42 for each month).

4 - RESULTS

Figure 3 depicts the synthetic indices calculated for the three components studied: socio-economic, epidemiological and climatological (Table A.2 in appendix shows the individual values for each state).

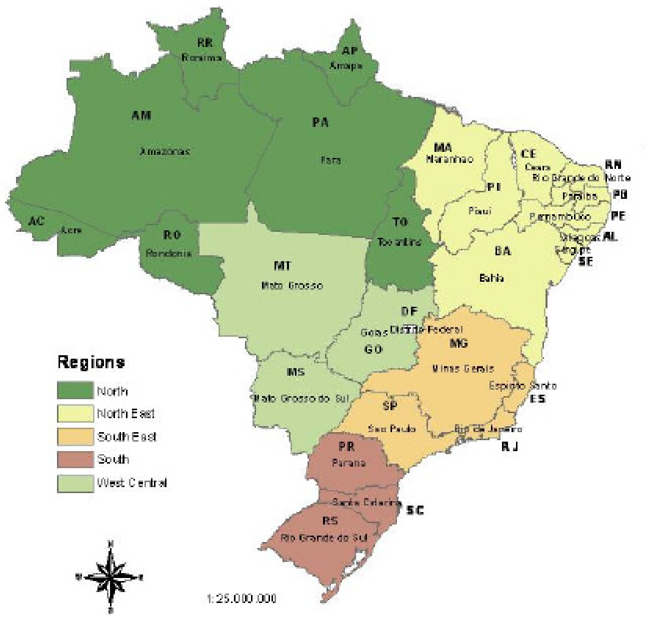

Figure 2: Brazil – States and Regions

This section begins with the individual analyses of the indices, as well as with the classification of the States, according to their respective indices. In the last sub-section we present the values of the General Vulnerability Index and the classification of the Brazilian states obtained from the calculated IVGs.

4.1 Socio-economic Vulnerability

The states with the highest demographic densities were Rio de Janeiro (328.6 inhab/km^2); Distrito Federal (353.5 inhab/km^2) and São Paulo (149 inhab/km^2) while the states with the lower population densities were in the northern part of the country: Roraima (1.4 inhab/km^2) and Amazonas (1.8 inhab/km^2). All states have more than 60% of its population living in urban areas and Rio de Janeiro had the highest urbanization rate (97%). In regard to the percentage of households with two or more persons per room, four northern states (Acre, Amazonas, Pará e Amapá) had more that 10% of the households in this situation.

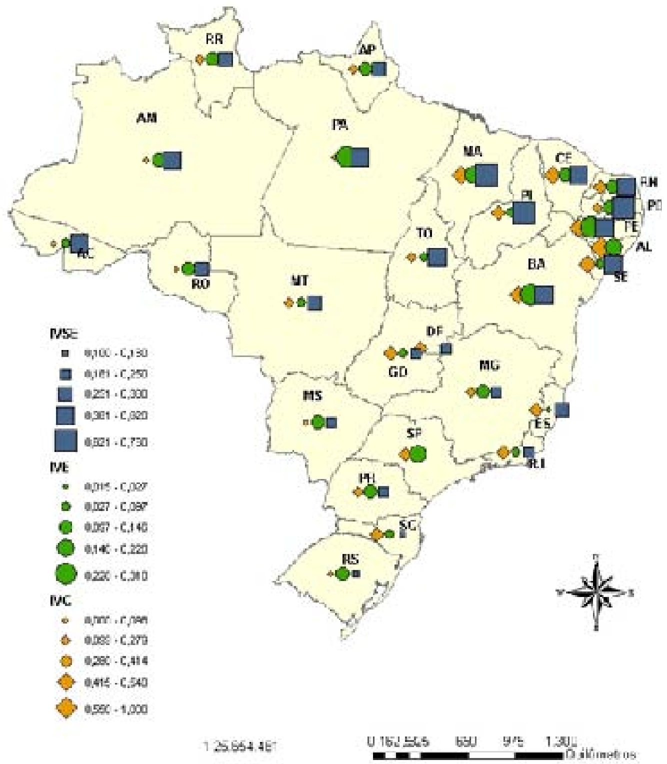

Figure 3: IVSE, IVE and IVC by state.

The highest poverty rates were found in the northeastern region: Alagoas (57%), Maranhão (57%); Pernambuco (55%); Piauí (53%) and Ceará (52%). São Paulo and Santa Catarina were the states with the lower percentages of poor people: 12% and 13%, respectively. The percentage of the population over 15 years of age, with less than four years of school attendance, ranged from 15% to 50% in the different states, with the lower degrees of formal schooling being found in the northeastern region.

All states in the southern, southeastern and central-western regions had more than 95% of their households supplied with piped water; only the states of Amazonas (northern region) and Piauí, Pernambuco and Alagoas (northeastern region) had less than 80% of the housed supplied by this service. In relation effluent disposal, the states of Maranhão (55.5 % of the houselds) and Piauí (56.0 %) had de poorest situation, while in the southern region more than 90% of the households had some type of sewage collection system. In the southern, southeastern and central-western regions more than 93% of the households had garbage collection services; this percentage varies from 67.5% to 87.6% in the northeastern region and from 80.6% to 93.7% in the states of the northern region.

In regard to infant mortality rates the states of Rio Grande do Sul and Santa Catarina have the lowest rates in the country: 15.1 and 15.9 per 1000 live births, respectively. On the other hand, the highest rates were observed in the northeastern states and Alagoas, with a rate of 62.5/1000 live births, it was much higher than that of the second higher rate of 49.0/1000, corresponding to Maranhão. Life expectancy at birth ranged from 63.2 years in Alagoas to 71.6 years in Rio Grande do Sul.

The southeastern States like São Paulo (35.8% of coverage) and Rio de Janeiro (24.9%) had the higher coverage rates of private health insurance, as well as the Federal District (25.1%). Most of the northern states (except Amazonas) had less than 5% of their population with private health insurance.

Table 2 shows the classification of the Brazilian states according to the IVSE obtained from the data described above. The lowest socio-economic vulnerability rates were found in São Paulo (0.10) and Santa Catarina (0.15). The low rate for São Paulo is explained by its high rate of urbanization (94%) and the low poverty rate (12%). It has also a high rate of formal schooling, when compared to the other states (18% with less than four years of school attendance). São Paulo had also the best rates of sanitation (99.1% of water supply; 98.6% of sewage disposal and 99.1% with garbage disposal), the third lowest infant mortality rate (17.3/1000) and the best health insurance coverage in the country (35.8%).On the other hand, Alagoas (0.76); Maranhão (0.75) and Piauí (0.73) were the states with the highest socio-economic vulnerability indices. In the case of Alagoas this poor ranking is explained by its high demographic density (101.47), the lowest urbanization rate of the country (68%); the highest proportion of poverty (57%), a high percentage of poor schooling (50% with

Table 2: Classification of the Brazilian states according to the IVSE

		IVC VALUES	STATES
Greater Vulnerability	I	0.0 < IVSE<= 0.2	SP, SC, RS, DF
	II	0.1 < IVSE<= 0.3	MG, ES, RJ, PR, MS
	III	0.2 < IVSE<= 0.4	RO, RR, AP, MT
	IV	0.3 < IVSE<= 0.5	AM, PA, TO
	V	0.4 < IVSE<= 0.6	AC, RN, PE, SE
	VI	0.5 < IVSE<= 0.7	CE, PB, BA
	VII	0.6 < IVSE<= 1.0	MA, PI, AL

less than four years of study) and the fact that it is poorly serviced by sanitation. Furthermore it has the lowest life expectancy in Brazil (63.2 years), one of the lowest health insurance coverage (4%) and the highest infant mortality rate in the country (62.5).

4.2 Epidemiological Vulnerability

The incidence rates for the diseases studied had a discernible pattern of evolution in the six years period of this study. In the case of dengue fever the highest incidence rates in the years from 1996 to 1998 have been observed in the northeastern region; from 1999 through 2001 the highest rates were observed in the northern region. This evolution is depicted in Figure 4. The other health indicators analyzed (deaths and hospital admissions) have had also changes associated to the incidence rates of the diseases; however, the hospital costs were always higher in the southeastern region, particularly in the state of São Paulo.

Table 3 shows the indices obtained for each disease and for each state. We can note, as an example, that the cholera rate for Roraima and Amapá was 0.00; this was because from 1996 to 2001 no cholera cases were reported in these areas. The highest rates were observed in Alagoas (0.732) and Pernambuco (0.437) and Alagoas has had also the highest disease cost in four of the six years of study.

In the case of leptospirosis, the highest indices were in Bahia (0.434), Rio de Janeiro (0.467), Pernambuco (0.478) and São Paulo (0.662). These states have a high demographic density and urbanization rate, factors that can facilitate outbreaks of this disease. As for the hantavirus pulmonary syndrome only nine states have had cases of this disease during the study period, since this disease has emerged in Brazil in 1993. The highest indices were observed in São Paulo (0.270); Rio Grande do Sul (0.361), Paraná (0.399) and Mato Grosso do Sul (0.463). In the southern region hantavirus cases increased from 4 in 1998 to 52 in 2001, while in the southeastern region cases have risen from 2 in 1996 to 12 in 2001 and, in the central-western part of the country, 3 cases were observed in 1999 and 11 in 2001.

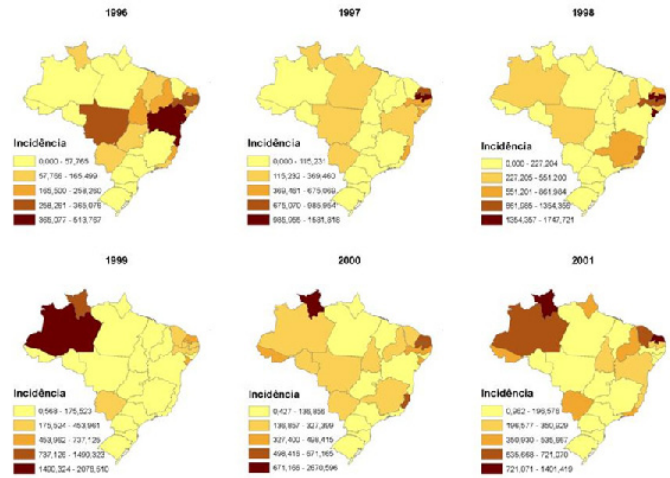

Figure 4: Incidence Rates for Dengue Fever in the Brazilian States, 1996 - 2001.

Table 3. Synthetic Indicators for each diseaseThe values in boldface correspond to the worse values

States	Cholera	Dengue Fever	Malaria	Leptospirosis	Leishmaniasis	Hantavirus
AC	0.017	0.024	0.144	0.092	0.109	0.000
AL	**0.732**	0.059	0.002	0.098	0.259	0.000
AM	0.018	0.097	0.306	0.051	0.088	0.000
AP	0.000	0.018	0.222	0.269	0.133	0.000
BA	0.213	**0.439**	0.002	**0.434**	**0.688**	0.200
CE	0.155	0.194	0.003	0.079	0.346	0.000
DF	0.005	0.012	0.001	0.043	0.049	0.000
ES	0.002	0.118	0.002	0.047	0.030	0.000
GO	0.006	0.046	0.015	0.010	0.073	0.015
MA	0.010	0.262	0.151	0.055	**0.403**	0.000
MG	0.090	0.198	0.007	0.092	0.259	0.164
MS	0.004	0.065	0.001	0.007	0.103	**0.463**
MT	0.007	0.124	0.113	0.068	0.199	0.000
PA	0.041	**0.395**	**0.824**	0.316	0.220	0.013
PB	0.196	**0.356**	0.000	0.051	0.190	0.000
PE	**0.437**	**0.447**	0.001	**0.478**	**0.341**	0.000
PI	0.007	0.137	0.031	0.001	0.245	0.000
PR	0.039	0.013	0.003	0.202	0.031	**0.399**
RJ	0.076	0.153	0.005	**0.467**	0.053	0.000
RN	0.030	**0.453**	0.001	0.037	0.240	0.000
RO	0.001	0.024	**0.399**	0.007	0.118	0.000
RR	0.000	0.134	0.251	0.004	0.181	0.000
RS	0.068	0.000	0.001	0.349	0.001	**0.361**
SC	0.008	0.001	0.004	0.276	0.003	0.228
SE	0.108	0.254	0.000	0.097	0.215	0.000
SP	0.172	0.071	0.015	**0.662**	0.216	0.270
TO	0.005	0.144	0.041	0.004	0.272	0.000

The values in boldface correspond to the worse values for each Brazilian state.

In Table 4 are depicted the ranking of the Brazilian states according to the IVEs. States with the highest IVEs were Bahia and Pará; in the former the indices for four the six diseases were high (dengue fever; cholera; leptospirosis and leishmaniases) while in the case of Pará, the high indices for dengue and malaria were responsible for the high IVE of this state. It should be noted that, in the calculation of the IVE, malaria has a high weight, which contributes to a high IVE. States with the lowest IVEs were Distrito Federal, Espírito Santo and Goiás.

Table 4: Classification of the Brazilian States according to the IVE.

Greater Vulnerability		IVE VALUES	STATES
	I	0.00 < IVE<= 0. 03	DF, ES, GO
	II	0.03 < IVE<= 0.09	AC, PI, TO, SC, MT, RJ
	III	0.09 < IVE<= 0.12	SE, AP, AM, RR, RO, RN, PB, CE
	IV	0.12 < IVE<= 0.20	PR, RS, MG, MS, MA, AL
	V	0.20 < IVE<= 0.30	SP, PE
	VI	0.30 < IVE<= 0.40	BA, PA

In the case of the DF the IVE can be explained because it has very low indices for the six diseases (in no case the individual index was higher than 0.01). For Espírito Santo the epidemiological index for the state has been influenced by the absence of hantavirus infection; by very low rates of malaria and cholera (0.002); a leptospirosis index of 0.047 and a leishmaniasis index of 0.030. In the case of Goiás, the highest disease index was for leishmaniasis (0.073), followed by dengue fever (0.046); malaria and hantavirus pulmonary syndrome (0.015); leptospirosis (0.010) and cholera (0.006). All these indices were very low.

4.3 Climatological Vulnerability

The greatest precipitation levels in the central-western region correspond to the period from November to March, while in the northeastern region most of its states have the highest precipitation values between March and July. In the southern and southeastern regions the lowest precipitation levels are observed between the months of May and September. The state of Amapá (northern region) had the highest monthly accumulated precipitation intensity in the country: in the months of March and April monthly rainfall intensity was over 400 mm (averages: 453.2 in March and 418.9 in April).

Another important aspect is that in the northern and central-western regions the highest precipitation levels are up to ten times higher than the lowest precipitations: in Amapá, the mean value for February was 350.6 mm, as compared to only 32.4 mm for October. Another example is the state of Goiás, which had a mean value for January of 253.4 mm as opposed to just 14.2 mm in June. However, this situation is completely different in the southern region, where there is much less variability in precipitation along the year.In the state of Santa Catarina, for example, the highest mean precipitation level was observed in January (179.6 mm) and the lowest (113.4 mm) in April. The difference between the precipitation in the driest and the wettest month was 58%.

The number of extreme values calculated for each state corresponds to the sum of all extreme values identified for each month of the year (42 per month). The state of Alagoas has shown the largest number of high values (5.16 % of 504 observations), followed by Sergipe, Ceará and Maranhão. The states of Acre, Amazonas and Pará, even having high monthly precipitation means, have had the smallest number of high extreme precipitation events (less than 0.8% of the observations). This means that these states have shown precipitation levels within a regular and expected pattern.

Table 5 shows the classification of the Brazilian states according to the Climatic Vulnerability Index (IVC). Since this index has been constructed based on the percentage of months with extreme precipitation levels, the interpretation of the results is similar. Therefore, Alagoas is the state with the highest climatic vulnerabilty index in comparison with the other states (IVC = 1.0), since it has had the highest number of extreme precipitation episodes in the study period. The states of Acre, Amazonas, Pará, Mato Grosso do Sul, Rondônia e Rio Grande do Sul have the lowest climatic vulnerability indices due to the smaller percentages of extreme values of precipitation, for that period.

Table 5: Classification of the Brazilian States according to the IVC.

Greater Vulnerability		IVC VALUES	STATES
	I	0.0 < IVC<= 0.1	AC, AM, PA, MS, RO, RS
	II	0.1 < IVC<= 0.2	PR
	III	0.2 < IVC<= 0.3	AP, MG, PB, RR, MT, TO
	IV	0.3 < IVC<= 0.4	GO, RN, SC, SP, RJ
	V	0.4 < IVC<= 0.5	ES, PI, BA
	VI	0.5 < IVC<= 0.6	PE, CE, MA, SE
	VII	0.6 < IVC<= 1.0	AL

4.4 General Vulnerability

As has been explained before, the General Vulnerability Index is the simple mean of the other three indices developed in this research. As a consequence, it can be interpreted as a measure of the average level of vulnerability of the states. Table 6 shows the classification of the states according to their IVGs. It should be noted that Alagoas is the state with the higher IVG Index (0.64); this can be explained since it has the worst situation in two of the three components of this study: the largest IVSE (0.76) and IVC (1.0) among all states. Furthermore, its IVE value (0.16) is close to the national average.

The second group of states with high general vulnerability is formed by five states of the northeastern region: Piauí, Ceará, Pernambuco, Bahia and Maranhão. This result was expected since these states had high values for at least two of the three indices.The high vulnerability of this group of states plus Alagoas, also located in the northeastern region, indicate that this is the most vulnerable region in the country. In the other spectrum of the classification we have the three southern states (Rio Grande do Sul, Santa Catarina and Paraná) as well as the states of Mato Grosso do Sul and Rondônia. The good ranking of these states is explained by the good individual indices for the southern region as well as by the low epidemiological and climatological vulnerability of the other two states. An IVG of 0.20 was obtained for the states of Amazonas, Acre and Goiás. By grouping the latter with those states with the lowest IVGs, we have an homogeneous group of states in the central and southern parts of the country (Figure 5).

Table 6: Classification of the Brazilian States according to the IVG

Greater Vulnerability		IVG VALUES	STATES
	I	0.1 < IVG<= 0. 2	RS, MS, DF, PR, RO, SC, AM, GO, AC
	II	0.2 < IVG<= 0.3	MG, SP, AP, RJ, MT, ES, RR, PA, TO
	III	0.3 < IVG<= 0.4	RN, PB, SE
	IV	0.4 < IVG<= 0.5	PI, CE, PE, BA, MA
	V	0.5 < IVG<= 0.7	AL

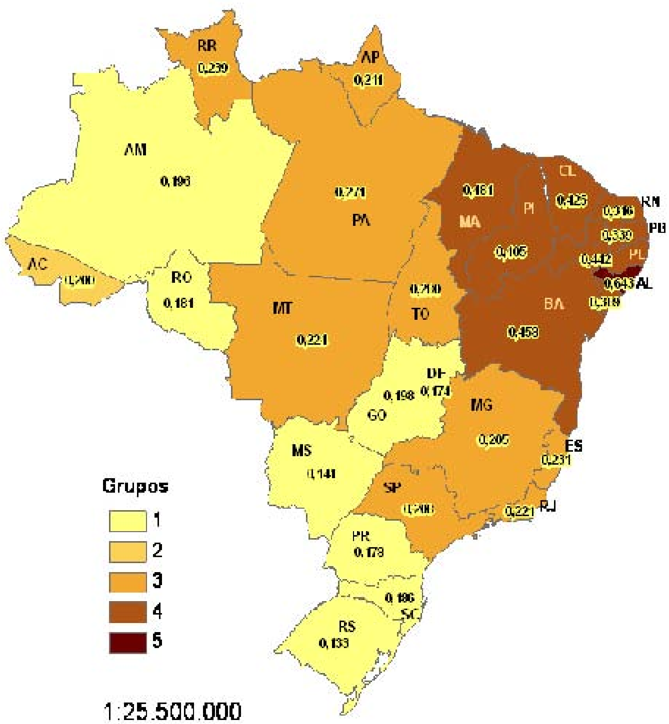

Figure 5: General Vulnerability Index (IVG), Brazil

5 - DISCUSSION AND CONCLUSIONS

Most of the national assessments of vulnerability and impacts of climate change conducted so far did include some data on the health impacts, but these are usually a minor component, and were never adequately quantified for comparisons among states, provinces or municipalities of the respective countries. The same is true for the specific health risk assessments associated to climate change. (Bhutan, 2006; Bolivia, 2000; Bresser, 2006; Kaumov & Muchmadeliev, 2002; Koike, 2006; Kovats et al., 2003; McMichael, et al, 2003 ; Moreno, 2005; Panama, 2000; Thommen Dombois & . Braun-Fahrlaender, 2004; United Kingdom, 2001; Zebisch et al., 2005).

The indices presented here do not measure the degree of vulnerability in relation to ideal situations and, therefore, an index equal to zero does not mean the absence of vulnerability; the results must be understood in a comparative way, considering all Brazilian states. We did not include in this vulnerability study health outcomes related to the direct effects of climate extremes, such as storms and floods, because Brazil does not have a reliable national data base on morbidity and mortality related to these events.

The approach used was an operational one, allowing for quantitative comparisons of different geographical units (states) and should be considered as a starting point for further vulnerability assessments. These could be developed and expanded by either including other components or geographical scales. As an example, for a given country or region, data on malnutrition/food security; water quality/availability; urban atmospheric pollution and morbidity and mortality associated to weather disasters could be included as components of vulnerability. These are aspects that are expected to be affected by climate change and are important detrminants of human population health.

The methods used in this study could also be applied in the analysis of vulnerabilities for cities or municipalities, provided that adequate data series exist. The analysis of vulnerabilities in finer spatial scales could allow the use of more qualitative information, such as livelihood strategies and particular environmental characteristics, which are important aspects of the social-environmental vulnerability. Socio-economic indicators do not provide enough information on these differential determinants of risks: the population in a urban squatter settlement in a developing country is vulnerable to the effects of climate due to reasons different from those that make the subsistence small-holders in the rural area of the same country also vulnerable.

From the results obtained with the proposed methodology the general conclusions that can be drawn are:

1- the northeastern region is the most vulnerable one, in terms of the possible impacts of a changing climate in tropical infectious diseases. This is the result of a combination of poor socio-economic indicators; a semi-arid type of climate prone to extreme variations and the persistence of important endemic infectious diseases in the region.

2- the higher level of socio-economic development of the southern and southeastern regions make them less vulnerable to the effects of climate.

3- Although the three major components of vulnerability have had the same weight in the calculation of the General Vulnerability Index, most of the states with high IVGs have had their indices strongly influenced by their IVSE values and, to a lesser extent, by the IVCs and IVEs.

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REFERENCES

Bhutan, 2006. National Environment Commission, Royal Government of Bhutan, UNDP, and GEF, National Adaptation Programme of Action. National Environment Commission, Royal Government of Bhutan, Thimphu, 95 pp.

Blaikie, P. et al., 1994. At Risk. Natural hazards, people's vulnerability and disasters. Routledge, London, XIV, 284 pp.

Bolivia, 2000.[Vulnerability and adaptation to protect human health from effects of climate change in Bolivia]. Programa Nacional de Cambios Climaticos Componente Salud, Viceministerio de Medio Ambiente, Recursos Naturales y Desarrollo Forestal, 111 pp.

Bresser, A., 2006: The Effect of Climate Change in the Netherlands. Netherlands Environmental Assessment Agency, MNP Bilthoven, 112 pp.

Confalonieri, U. 2003. Variabilidade climática, vulnerabilidade e saúde no Brasil. Terra Livre, S.Paulo, 19-1(20):193-204.

Hogan, D. & Marandola, E, 2006. Towards an interdisciplinary characterization of vulnerability. Popul., Space & Place, 11:455-471.

IPCC, 2001. Climate Change. Impacts, Adaptation, and Vulnerability. Summary for Policymakers and Technical Summary of the Working Group II Report. WMO/UNEP, 89 pp.

IPCC, 2007. Working Group II, Fourth Asessment Report - Summary for Policy Makers, 23 pp (http://www.ipcc-wg2.org/authors/).

Kasperson, R.E.; Dow, K. et al., 2005. Vulnerable Peoples and Places, pp 143-164, chapter 6, W.Reid; H. Mooney; A.Crooper. (Org.). In Millennium Ecosystem Assessment, Conditions and Trends., vol 14, Island Press.

Kaumov, A. and B. Muchmadeliev, 2002: Climate Change and its Impacts to the Human Health. Dushanbe, Avesto, 172 pp.

Koike, I., 2006, State of the art findings of global warming. Contributions of the Japanese researchers and perspective in 2006. The second report of the global warming initiative, climate change study group. Ministry of Environment, Japan, Tokyo, 165-173 pp.

Kovats, S.; Menne, B; Ahern, M.J & Patz, J.A, 2003. National assessments of health impacts of climate change: a review, pp 181-203, Chapter 9, IN: McMichael, A.J.; Campbell-Lendrum, D.H.; Corvalan, C.F.; Ebi, K. L. ; Githeko, A.; Scheraga, J.D. & Woodward, A. (Eds.) Climate Change and Human Health. Risks and Responses. WHO/WMO/UNEP, Geneva, 322 pp.

Liverman, D., 1990. Vulnerability to Global Environmental Change, pp 27-44, In Kasperson, R.E. et al (eds) – Understanding Global Environmental Change: the Contributions of Risk Analysis and management. CLAK University, The Earth Transformed Program, Worcester, MA.

McMichael, A., R. Woodruff, P. Whetton, K. Hennessy, N. Nicholls, S. Hales, A. Woodward, and T. Kjellstrom, 2003, Human Health and Climate Change in Oceania: Risk Assessment 2002. Department of Health and Ageing, Canberra, Commonwealth of Australia, 128 pp.

Moreno, J., 2005: A preliminary assessment of the impacts in Spain due to the effects of climate change. ECCE project final report. Universidad de Castilla-La Mancha, Ministry of the Environment, Madrid, 741 pp.

Panamá, Autoridad Nacional del Ambiente, 2006: [Primera comunicacion nacional sobre cambio climático, 2000] . ANAM, http://unfccc.int/resource/docs/natc/pannc1/index.html, 136 pp.

Thommen Dombois, O. and C. Braun-Fahrlaender, 2004, Health impacts of climate change with relevance for Switzerland. Insititut fuer Sozial- und Preventivmedizin der Universitaet Basel, Bundesamt fuer Gesundheit, Bundesamt fuer Umwelt, Wald und Landschaft, Basel, 85 pp.

United Kingdom, 2001.Department of Health and Expert Group on Climate Change and Health in the UK, Health Effects of Climate Change in the UK. Department of Health, London, 238 pp.

Watts, M.J. & Bohle, H.G., 1993. The space of vulnerability: The causal structure of hunger and famine. Progr Human Geogr, 17: 43-67.

Zebisch, M., T. Grothmann, D. Schroeter, C. Hasse, U. Fritsch, and W. Cramer, 2005: Climate change in Germany. Vulnerability and adaptation of climate sensitive sectors.Federal Environmental Agency (Umweltbundesamt), Dessau, 205 pp.

ANNEX I

Table A.1. Socio-economic Indicators

Demography	Definition	Source*
Demographic density	Inhabitants/km^2	IBGE, 2000
Degree of urbanization	%	IDB, 2002
Income		
Households with more than 2 persons/room	%	IBGE, 2000
Poverty	%	IDB, 2002
Education		
Years of school attendance	%	IDB, 2002
Sanitation		
Piped water supply	%	IBGE, 2000
Sewage treatment	%	IBGE, 2000
Garbage disposal	%	IBGE, 2000
Health		
Infant mortality rate	per 1000 live births	IDB, 2002
Life expectancy at birth	In years	IDB, 2002
Health insurance coverage	%	IBGE, 2000

** IBGE: Furdacao Instituto Brasileiro de Geografia e Estatistica*
IDB: Indicadores e Dados Basicos para a Saude (Ministerio de Saude)

Table A.2. Vulnerability Indices by states: IVSE, IVE, IVC and IVG

	Socio-economic Vulnerability Index	Epidemiological Vulnerability Index	Climatological Vulnerability Index	General Vulnerability Index
UF	**IVSE**	**IVE**	**IVC**	**IVG**
AC	0.53	0.06	0.00	0.20
AL	0.76	0.16	1.00	0.64
AM	0.48	0.10	0.01	0.20
AP	0.30	0.10	0.23	0.21
BA	0.62	0.30	0.46	0.46
CE	0.61	0.12	0.55	0.43
DF	0.18	0.02	0.32	0.17
ES	0.25	0.03	0.41	0.23
GO	0.24	0.03	0.32	0.20
MA	0.75	0.15	0.55	0.48
MG	0.25	0.13	0.23	0.21
MS	0.23	0.14	0.05	0.14
MT	0.31	0.08	0.28	0.22
PA	0.49	0.31	0.01	0.27
PB	0.67	0.11	0.23	0.34
PE	0.59	0.23	0.50	0.44
PI	0.73	0.07	0.41	0.41
PR	0.22	0.13	0.19	0.18
RJ	0.21	0.09	0.37	0.22
RN	0.51	0.11	0.32	0.32
RO	0.38	0.11	0.05	0.18
RR	0.38	0.10	0.23	0.24
RS	0.17	0.13	0.10	0.13
SC	0.15	0.08	0.32	0.19
SE	0.52	0.10	0.55	0.39
SP	0.10	0.20	0.32	0.21
TO	0.48	0.08	0.28	0.28

Energy Development Paths and Corresponding Carbon Emissions for Brazil up to 2025

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The work presented in this paper is based on studies conducted under a partnership initiative led by the International Atomic Energy Agency (IAEA) in cooperation with the Graduate School of Engineering of the Federal University of Rio de Janeiro (COPPE), the Brazilian Reference Centre on Biomass of the University of São Paulo (CENBIO), and the United Nations Department of Economic and Social Affairs (UNDESA). This effort culminated with the 2006 publication of a joint report on "Brazil: A Country Profile on Sustainable Energy Development" (IAEA et al, 2006)

Abstract

This paper aims at assessing possible paths towards sustainable energy development for Brazil with a special emphasis on Greenhouse Gas (GHG) emissions and GHG emission reduction potentials associated with these paths. The framework, systematic approach and guidelines proposed in this paper represent an attempt to move forward with the discussion of effective mechanisms that permit the incorporation of sustainable development concepts to one of the most important sectors affecting economic and social development, and key to GHG emissions and climate change – energy.

Building on a comprehensive database on domestic energy resources; indigenous and adapted energy technologies and energy efficiency potentials; energy and economic development alternatives; energy, the environment and health issues; energy and social issues; energy security; and policy options for future sustainable energy development; the future is explored by developing and using two alternative scenarios for Brazil for the period 2000-2025: a 'Reference' (REF) and a 'Shift' (SHIFT) scenario. In general, the analysis conducted shows that, in both scenarios, Brazil moves towards fulfilling sustainable energy development criteria, but a scenario that creates more value added while uses factors of production more wisely and efficiently (SHIFT) has the potential to generate substantially lower GHG emissions than a business-as-usual (REF) scenario.

1. Introduction

Increasingly, climate change is perceived as being the most critical, yet probably the most intractable, of all environmental challenges ever faced by humankind. However, given the gravity of the situation, as recently portrayed by the Stern review (Stern, 2006) and as being portrayed by the latest Intergovernmental Panel on Climate Change reports (IPCC, 2007a; b), mitigation and adaptation strategies have to be increasingly pursued, with climate policies alone not being enough to solve the problem. Sustainable development practices, of which climate change concerns ought to be an integral part, are increasingly understood as the only possible way out of the climate change challenge. Sustainable development requires integrated economic development based on social responsibility and respect for the environment while keeping in mind the impact on future generations. Energy supply and demand has a significant bearing on all the dimension of sustainability: social, economic, environmental and institutional. Proper management of the energy sector in developing countries is indispensable to reducing poverty and advancing sustainability, as these countries are the ones that already suffer, and will increasingly suffer, the most the impacts or wrong choices. Greenhouse gas (GHG) emissions from developing countries are both growing much faster than GHG emissions from developed nations and the impacts of climate change will hurt these countries more seriously.

This paper aims at assessing possible paths towards sustainable energy development for Brazil with a special emphasis on GHG emissions and GHG emission reduction potentials associated with these paths. The framework, systematic approach and guidelines proposed in this paper represent an attempt to move forward with the discussion of effective mechanisms that permit the incorporation of sustainable development concepts to one of the most important sectors affecting economic and social development, and key to GHG emissions and climate change – energy.

Building on a comprehensive database on domestic energy resources; indigenous and adapted energy technologies and energy efficiency potentials; energy and economic development alternatives; energy, the environment and health issues; energy and social issues; energy security; and policy options for future sustainable energy development; the future is explored by developing and using scenarios in two main steps and by producing two types of output. In the first step, overall socioeconomic scenarios are constructed on the basis of recent dynamics, existing assets and generally agreed objectives and directions for medium term strategic development. In the second step, energy modeling, the energy demand associated with the macro level scenarios is calculated using MAED (Model for Analysis of Energy Demand) and other tools. Several options to satisfy the energy requirements are explored using MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts), resulting in several variants of energy strategies under the different socioeconomic scenarios, which result in different GHG emissions and GHG emission reduction potentials.

The region of interest is Brazil and alternative paths are developed for the period ending in 2025.

2. Methodology

The comprehensive assessment of different energy development paths in Brazil follows and integrated approach based on assumptions derived from criteria for sustainable energy development. In this integrated approach, top-down assumptions about the country's economy, population and life-styles are combined with bottom-up disaggregated specifications and constraints about resources, fuels and technologies to develop scenarios of energy demand and optimal energy supply. The integrated, computer aided approach is illustrated in Figure 1. The assessment includes two major modeling components:

· Energy demand: This component provides detailed sectoral energy demand projections by applying the International Atomic Energy Agency (IAEA) Model for Analysis of Energy Demand (MAED) based on numerous scenario assumptions concerning demographic developments, technological progress, behavioural changes, economic structural change and economic growth. These scenarios assumptions are taken from IAEA (2006) and are key drivers of future energy demand, which serves as input to the energy supply system optimization.

· Energy supply optimization: This component allows the formulation of optimal scenarios of energy and electricity supply mixes using the IAEA Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE), taking into consideration available resources, present energy infrastructures, current and future conversion technologies, and socioeconomic, technical and environmental (policy) constraints.

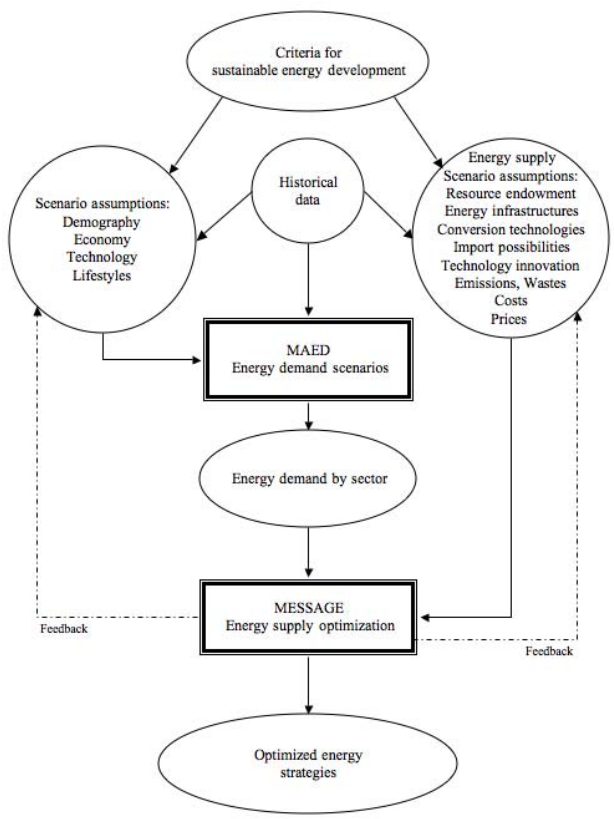

Figure 1. Conceptual modeling framework.

2.1. Methodology of MAED

MAED was used to project energy demand for the two scenarios. MAED evaluates future energy demand scenarios based on medium to long term socioeconomic, technological and demographic development assumptions. The model systematically relates the specific energy demand for producing various goods and services to the corresponding social, economic and technological factors that affect this demand. Energy demand is disaggregated into a number of end use categories, each corresponding to a given service or to the production of a certain good. The main inputs and outputs of MAED are depicted in Figure 2.

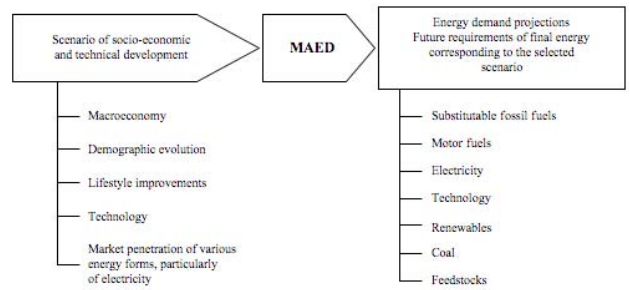

Figure 2. Major inputs and outputs of MAED.

2.2. Methodology of MESSAGE

MESSAGE is designed to formulate and evaluated alternative energy supply strategies consonant with user defined constraints on new investment limits, market penetration rates for new technologies, fuel availability and trade, environmental emissions, etc. The underlying principle of the model is the optimization of an objective function (e.g. least cost, lowest environmental impact, maximum self-sufficiency) under a set of constraints. The backbone of MESSAGE is the techno-economic description of the modeled energy system. This includes the definition of the categories of energy forms considered (e.g. primary energy, final energy, useful energy), the fuels (commodities) and associated technologies actually used (e.g. electricity, gasoline, ethanol, coal or district heat), as well as energy services (e.g. useful space heat provided by type of energy/technology). Technologies are defined by their inputs and outputs (main and by-products), their efficiency and the degree of variability if more than one input or output exists (e.g. the possible production patterns of a refinery or a pass-out turbine). Economic characteristics include, among other things, investment costs, fixed and variable operation and maintenance (O&M) costs, imported and domestic fuel costs and estimates of levellized costs and shadow prices.

Fuels and technologies are combined to construct so-called energy chains, where the energy flows from supply to demand. The definitional limitations on supplying fuels are that they can belong to any category except useful energy, they have to be chosen in the light of the actual problem, and limits on availability inside the region/area and on import possibilities have to be specified. The technical system provides the basic set of constraints to the model, together with demand, which is exogenous to the model. Demand must be met by the energy flowing from domestic resources and from imports through the modeled energy chain(s).

The model takes into account existing installations, their age and their retirement at the end of their useful lives. During the optimization process, this determines the need to construct new capacity of various technologies. Knowing new capacity requirements permits the user to assess the effects of system growth on the economy.

MESSAGE uses the projections of useful energy demand from MAED to generate the energy supply system. MESSAGE formulates and evaluates alternative energy supply strategies consonant with the criteria and constraints specified. The main inputs and outputs of MESSAGE are presented in Figure 3.

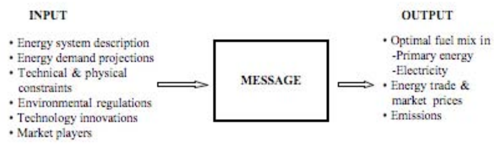

Figure 3. Major inputs and outputs of MESSAGE

3. Study Approach

For energy demand analysis, the economy is disaggregated into agriculture, construction, manufacturing, mining, households, services and transport. The manufacturing sector is further disaggregated into four subsectors: basic materials, machinery, equipment and miscellaneous, and chemicals. Transport activities include freight and passenger transport.

The supply and demand analyses are performed at the national level. However, for electricity, MESSAGE categorizes electricity demand separately for three regions: North and Northeast (NNE), South and Southeast (SSE) and Remote Areas (RA). The regional division is based on demographic and industrial concentrations and transmission capacities for flow of electricity among various geographic regions. Of these three regions, only the NNE and SSE regions are interconnected.

The year 2000 has been selected as the base year for the study because of the comprehensive quality of the data set for that particular year. However, the available data for more recent years were also used to guide projections for those years, making projections closer to reality. A study horizon of 25 years, from 2000 to 2025 subdivided into five-year interval, was chosen.

4. General Assumptions and Criteria

4.1. General assumptions

- Demography: population will grow at a declining rate and the level of urbanization will continue to increase.
- Economic situation: economic recovery will continue, with annual gross domestic product (GDP) growth rates of about 4 % in the long term.
- Economic development: no major structural changes in the economy are assumed in the REF scenario but structural changes in the economy are assumed in the SHIFT scenario, and income per capita will continue to grow at rates slightly above recent rates.
- Lifestyle: housing situation will improve with respect to household size and number of occupants per dwelling, number of electrical appliances per average household will increase as a result of higher incomes, number of passenger vehicles will increase, and mobility will increase within the country.
- Transport: more modern roads will be constructed to satisfy increasing intercity and urban travel, and the share of public transport and the share of freight transport by internal navigation and rail will increase from current levels.
- Technological improvements: process efficiencies will increase above historically observed rates, non-commercial fuels will continue to be replaced by commercial fuels, and indigenous technology use will increase substantially.

4.2. Sustainable energy criteria

- Energy options and technologies are progressively less environmentally damaging and minimize the transfer of intergenerational environmental costs.
- Renewable energy options are increasingly used.
- Supply options secure long term sustainable energy supply.
- Natural resources are used more efficiently.
- Energy supply chains create jobs and income.
- Energy options promote indigenous technology development.
- Energy options minimize energy vulnerability (enhance diversity in energy supply markets).
- Energy options permit optimal universal energy services (optimal national availability of energy services).

5. Energy Demand Analysis

After calibrating and reproducing the values of energy demand for the base year, a reference (REF) scenario and an alternate (SHIFT) scenario were developed. These two scenarios were developed representing consistent sets of four groups of scenario parameters: demographic evolution, economic development, lifestyle change, and technology change. Both scenarios are based on the same demographic and economic growth but have different assumptions about the future structure of the economy. The scenarios also differ in their assumptions about improvements in technology, processes, efficiencies, and changes in the preferences and behaviour of people.

5.1. Quantitative scenario specification

5.1.1. Demography and economy

The assumptions about population and GDP projections are common to both scenarios, and are depicted in Table 1. The population growth rates are based on the latest demographic census conducted in Brazil (IBGE, 2001). GDP growth assumptions are based on assumptions by the Ministry of Planning (MPOG, 2004) that define long term economic growth in Brazil. These assumptions are in line with those of other recent macroeeconomic studies (Giambiagi, 2003a; b; Mantega, 2003; Meirelles, 2003).

5.1.2. Economic structure

In the REF scenario, the evolution of the structure of the economy is characterized by the growth of the GDP share of the industrial sector at the expense of the services sector. The most recent dynamics include a gradual increase in aggregated investment, a gradual decrease in government expenses (as a percentage of GDP), some gains in labour productivity and continued export of energy intensive products.

The SHIFT scenario presents a particular image of how the future could unfold based on different assumptions related to the structure of the economy. In this scenario, a gradual change in the current dynamics is assumed, so that the increase in the industrial share and the corresponding decrease in the services share of GDP in the REF scenario are avoided. A substitution process takes place, particularly in industries and subsectors of the manufacturing sector. It assumes that efforts will be made to shift away from energy intensive industries and to emphasize high value added industries. A major change in the type of exports is assumed, from the current emphasis on raw materials to an increased share of finished goods. The REF and SHIFT scenarios for the structure of the Brazilian economy are presented in Table 2. The sectoral annual growth rates for both scenarios are presented in Table 3. The historical evolution and the projections for the two major economic sectors (industry and services) for both scenarios are presented in Figure 4.

Table 1. Population and GDP growth.

	Unit	2000		2005		2010		2015		2020		2025
Population	Million	171.3		185.7		198.5		210.2		220.9		230.8
Annual growth ratea	%		1.63		1.34		1.16		1.00		0.85	
GDP	Bill US $ppp-2000	1151		1365		1682		2057		2509		3060
Annual growth ratea	%		3.47		4.26		4.11		4.05		4.05	
GDP/capb	US $ppp-2000/cap	6719		7351		8475		9788		11 360		13 261

a Annual growth rate for five-year periods.

b The per capita GDP for the year 2000 based on exchange rates was US $3513.

Table 2. Economic structure: sectoral shares of GDP (%).

Sector	2000	2005	2010	2015	2020	2025
	REF					
Agriculture	7.7	7.7	7.4	7.2	6.9	6.6
Construction	9.6	9.6	10.7	12.0	13.2	14.5
Mining	0.4	0.5	0.6	0.6	0.7	0.7
Manufacturing	18.6	18.9	19.7	20.3	20.7	21.1
Energy	7.2	8.0	8.1	8.1	8.1	8.0
Services	56.6	55.2	53.5	51.8	50.4	49.0
	SHIFT					
Agriculture	7.7	8.4	8.5	8.2	7.6	6.8
Construction	9.6	8.6	9.3	10.5	10.4	9.7
Mining	0.4	0.5	0.5	0.4	0.4	0.3
Manufacturing	18.6	18.1	18.4	18.6	18.5	18.3
Energy	7.2	8.1	8.3	8.4	7.9	7.0
Services	56.6	56.3	55.1	53.9	55.2	57.9
Total GDP (Bill US $ppp-2000)	1151	1365	1682	2057	2509	3060

Table 3. Sectoral annual growth rates (%).

Sector	2000–2005	2005–2010	2010–2015	2015–2020	2020–2025
	REF				
Agriculture	3.59	3.51	3.47	3.27	3.10
Construction	3.52	6.52	6.44	6.19	6.02
Mining	11.24	6.63	6.09	5.91	5.74
Manufacturing	3.83	5.10	4.68	4.51	4.42
Energy	5.90	4.41	4.14	3.99	3.88
Services	2.95	3.61	3.47	3.44	3.49
	SHIFT				
Agriculture	5.51	4.41	3.25	2.45	2.00
Construction	1.27	5.74	6.78	3.92	2.53
Mining	9.08	4.15	2.77	1.31	0.47
Manufacturing	2.88	4.60	4.36	3.95	3.78
Energy	5.99	4.93	4.39	2.59	1.57
Services	3.37	3.80	3.65	4.58	5.03

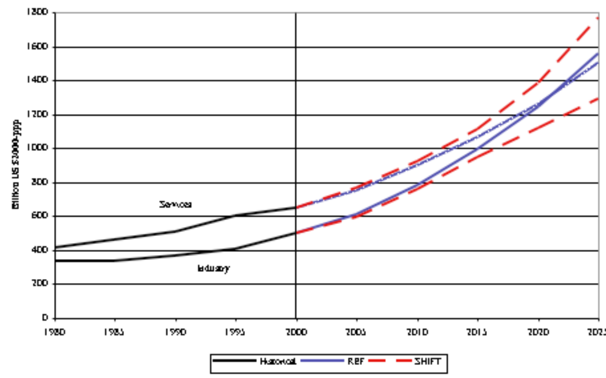

Figure 4. Value added of major economic sectors, historical values and projections. Note: Historical data from Schaeffer et al (2003).

MAED considers the evolution of the economy at a sectoral level and only for an aggregated selection of subsectors of the manufacturing sector. Further changes are assumed within subsectors and in specific industries of the manufacturing sector, which are major factors determining energy use, and GHG emissions, in the REF and SHIFT scenarios. Table 4 presents the assumed changes for the different scenarios and Table 5 shows the expected evolution of value added by the subsectors of the manufacturing sectors.

Table 4. Manufacturing subsectors, shares of value added (%).

Sub-sector	2000	2005	2010	2015	2020	2025
	REF					
Basic materials	16.8	16.8	17.2	17.8	18.4	18.9
Machinery, equipment & misc.	37.3	38.9	40.2	41.3	42.3	43.2
Non-durables	25.3	23.8	22.1	20.4	18.9	17.4
Chemicals	20.6	20.6	20.5	20.5	20.5	20.5
	SHIFT					
Basic materials	16.8	15.9	15.9	15.6	15.3	14.9
Machinery, equipment & misc.	37.3	38.4	38.2	37.9	37.8	37.6
Non-durables	25.3	25.6	26.6	27.5	28.0	28.5
Chemicals	20.6	20.0	19.3	19.0	18.9	18.9

Table 5. Value added by manufacturing subsectors (109 US $ 2000-PPP).

Sub-sector	2000	2005	2010	2015	2020	2025
	REF					
Basic materials	36.0	43.4	56.9	74.0	95.4	122.2
Machinery, equipment & misc.	80.0	100.6	133.4	172.2	219.8	278.8
Non-durables	54.3	61.4	73.3	85.2	98.0	112.1
Chemicals	44.1	53.2	68.1	85.5	106.5	132.1
Total	214.3	258.6	331.7	416.9	519.7	645.2
	SHIFT					
Basic materials	36.0	39.2	49.2	59.8	71.2	83.4
Machinery, equipment & misc.	80.0	95.0	118.1	145.2	175.5	210.5
Non-durables	54.3	63.3	82.4	105.3	130.3	159.7
Chemicals	44.1	49.5	59.7	72.8	87.9	106.0
Total	214.3	247.0	309.4	383.0	464.9	559.6

5.1.3. Lifestyle parameters

Scenario data for selected lifestyle parameters are presented in Table 6. The selected parameters are for the household, transport and services sectors.

Table 6. Selected lifestyle parameters in the REF and SHIFT scenarios.

Parameter		Unit	2000	2005	2010	2015	2020	2025
Household size		Persons/ dwelling	3.8	3.5	3.4	3.3	3.2	3.1
Electrified dwellingsa		%	94.5	95.6	96.7	97.8	98.9	100
		Specific electricity use per dwelling						
	REF	kWh/dw	1488	1235	1510	1783	2076	2140
	SHIFT	kWh/dw	1488	1201	1430	1709	1953	1917
Auto ownershipa		Autos/1000 persons	93	105	111	121	135	155
		Mobility - Intercity travel (average distance travelled)						
	REF	km/auto/ year	2716	2740	3146	3748	4552	6779
	SHIFT	km/auto/ year	2716	2740	3116	3692	4470	6634
Total service floor areaa		million m2	264	292	315	336	356	373

a Same for both scenarios.

5.1.4. Technology

Technology is also a major factor that determines energy intensities. While energy intensities in Brazil have not been improving recently, annual average improvements of 1 % per year have been observed at the global level over extended periods of time. The SHIFT scenario therefore assumes a considerable reduction in energy intensities, especially in the manufacturing sector, as shown in Table 7.

Table 7. Energy intensity assumptions for the manufacturing sector (2000 = 1.00).

	2000	2005	2010	2015	2020	2025
	Motor fuel					
REF	1.00	1.00	1.01	1.02	1.03	1.04
SHIFT	1.00	0.99	0.98	0.97	0.97	0.96
	Electricity					
REF	1.00	1.00	1.00	1.01	1.02	1.03
SHIFT	1.00	0.98	0.96	0.94	0.92	0.90
	Thermal use					
REF	1.00	0.98	0.96	0.95	0.94	0.93
SHIFT	1.00	0.98	0.96	0.92	0.88	0.84

5.2. Results – Final energy demand

The projections of total final energy demand by sector in the REF and SHIFT scenarios are presented in Figure 5. The total final energy demand grows 2.5 fold in the REF scenario and 2.1-fold in the SHIFT scenario over the 25-year period. The low demand in the SHIFT scenario is due to the fact that this scenario assumes an economy based on less energy intensive industries and larger reductions in energy intensities.

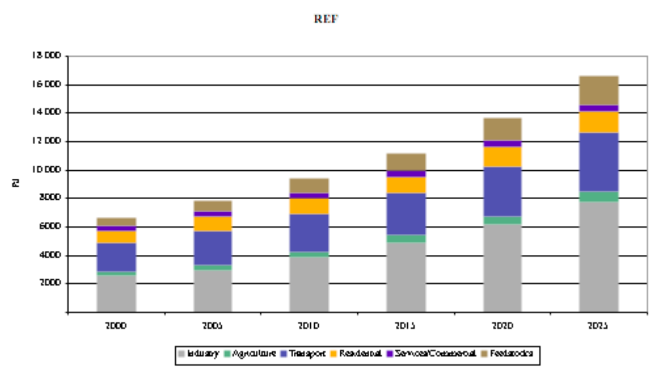

Figure 5. Final energy demand (PJ) by sector.

6. Energy Supply Analysis

6.1. Energy supply system and scenario assumptions

The specific assumptions, constraints and other conditions stipulated for the definition of the two scenarios are listed in Table 8.

Table 8. Scenario assumptions, constraints and other conditions.

Item	Scenario	Conditions
Coal	REF	· No restrictions on imports of coal · Domestic coal production kept at the current levels
	SHIFT	· Domestic coal production kept at the current levels · Charcoal replaces 90% of coal requirements for metallurgical industry by 2025
Natural gas	REF and SHIFT	· GASBOL (Bolivia) pipeline expanded from 30 to 60 million m3/day · MERCOSUR (Argentina) pipeline fully operating at 15 million m3/day by 2015 · Domestic production of associated gas linked to oil production and of non-associated gas based on resource depletion
Oil/oil products	REF	· No restrictions
	SHIFT	· No net oil imports (trading of crude and products) · Upper limit 30% of oil derivatives imports (today only LPG is 30%) · Maximum 15% of imports (LPG and diesel)
Hydro	REF	· Minimum power density of 64 kW/ha · 10% above today's average costs for large plants (US $1110/kW in Amazonia; US $800/kW in other regions)
	SHIFT	· Minimum power density of 64 kW/ha · 10% above today's average costs for large plants (US $1110/kW in Amazonia; US $800/kW in other regions) · Maximum 20% exploitation of remaining resources in Amazonia
Nuclear	REF	· No new plants except Angra III
	SHIFT	· No new plants, not even Angra III
Wind, small hydro and biomass for electricity (PROFINA)	REF and SHIFT	· A minimum of 10% share in national electricity matrix in 2025
Sugarcane	REF	· Starting in 2010, 40% of new light vehicles to be flex-fuel, using pure ethanol 70% and gasohol 30% of the time
	SHIFT	· Starting in 2010, 70% of new light vehicles to be flex-fuel, using pure ethanol 70% and gasohol 30% of the time
Coal-fired thermal plants	REF	· New plants with minimum technology requirements: pulverized coal firing + scrubbers, precipitators, filters (particulates and SOx controls)
	SHIFT	· All plants required to have fluidized bed combustion technology and particulates, SOx and NOx controls or IGCC (integrated gasification combined cycle)
Natural-gas-fired plants	REF and SHIFT	· Dry cooling

6.1.1. Oil and natural gas

Future production of oil and gas from indigenous resources is expected to increase considerably as a result of continued efforts in exploration, resulting in new discoveries. Most of the undiscovered oil and gas resources are located offshore. Assumptions about the maximum oil production profile were developed following the trend of an adjusted Hubbert curve (Szklo et al, 2007).

Gas production assumptions take into account both associated and non-associated gas. Future associated gas production is linked to the corresponding oil production levels. Assumptions about production of non-associated gas consider recent discoveries in the country.

6.1.2. Coal

In view of the poor quality of domestic coal, no increase beyond the present production levels is assumed for the future. Imports of coal are assumed to continue and may increase, but strict environmental standards will be imposed on its use, particularly for power plants. In the SHIFT scenario, coal imports are not allowed for electricity generation. In the REF scenario, coal power plants with flue gas desulphurization equipment are allowed, whereas in the SHIFT scenario only fluidized bed combustion technology is allowed.

6.1.3. Renewables

In addition to hydropower, the model includes fuelwood, sugar cane, energy crops for biodiesel, wind and solar. Sugar cane is considered for ethanol production and its by-product, bagasse, is considered for both industrial thermal uses and electricity production. Likewise, fuelwood is considered for charcoal conversion and direct burning in households and in the commercial and industrial sectors, as well as for power generation. In the SHIFT case, charcoal replaces 90 % of coal requirements in the metallurgical industry by 2025. Wind power technology is assumed to be introduced both for grid and non-grid supply. Photovoltaics are also considered for electricity supply, but for remote areas only.

6.1.4. Hydropower system

There is a large potential for additional hydropower development in Brazil. In the Amazon region alone, over 1000 000 MW of unexploited hydropower potential exists.

Hydropower plants are grouped into several categories based on size and geographic location. On the basis of size, the plants are classified as small (up to 30 MW), medium sized (from 30 to 600 MW) or large (more than 600 MW). The small and medium sized categories are grouped into three regions – North and Northeast (NNE), South and Southeast (SSE) and Remote Areas (RA) – whereas the large hydropower plants are grouped into four regions – South, Southeast, North and Northeast. This representation of hydropower allows supply and demand to be matched on a regional basis and, more importantly, allows the use of water to be optimized within a year and over a number of years for large hydropower plants.

6.1.5. Import-export

Trade in all main fuels, primary as well as refined, is allowed in the REF scenario and with some restrictions in the SHIFT case.

6.1.6. Electricity supply system

Based on demographic and industrial concentrations and transmission capacities for flow of electricity among various geographical regions, the model categorizes electricity demand separately for the NNE, SSE and RA regions. The model considers all available options for electricity generation, including hydropower, coal, gas, oil, nuclear and a number of renewable technologies. An important feature for electricity supply is transmission lines for exchange of power between the NNE and SSE regions. As the peak occurs at different times in the two regions, the flow could be in both directions. Also, as most of the new hydropower sites are in the North, if economically justified, larger amounts of power are expected to flow from North to South. The cost and performance data for the various power technologies considered for future expansion of the electricity systems in Brazil are presented in Table 9.

Table 9. Cost and performance data for various electricity generation technologies.

Technology	Efficiency (%)	Capacity factor (%)	O&M costsa ($/MWh)	Investment[a,b] ($/kW)	Construction time (years)
Hydro-small	n.a.c	64	4.4	1570	2
Hydro-medium	n.a.c	55	1.5	1230	4
Hydro-large	n.a.c	53.5	2.3	1110 or 800d	7
Coal	35	80	15	1300	4
Gas combined-cycle	50	85	7	495–420e	3
Gas open-cycle	35	85	8.7	350	2
Oil	30	85	7	1070	3
Biomass	25	70	2.7	900	3
Nuclear	33	80	10.5f	1535–1228e	5
Wind	n.a.c	25	10	1000–800e	2

a All costs are in 2000 US $; O&M = operation and maintenance costs.

b Investments do not include interest during construction.

c Not applicable

d US $1110/kW for Amazonia and US $800/kW for large hydro plants in other regions.

e Investment costs decrease over time.

f Includes fuel costs.

6.2. Scenario results

6.2.1. Primary energy supply and final energy demand

The resulting scenarios of primary energy supply are presented in Tables 10 and 11, and Figure 6. The total primary energy supply (TPES) grows at a faster pace in the REF scenario (4.2 % per year) than in the SHIFT scenario (3.7 % per year). By 2025, the TPES in the SHIFT scenario is about 13 % below that of the REF scenario. The main differences in the evolution of the energy supply structures are the level of imports and the share of renewables.

Table 10. Total primary energy supply, REF scenario (PJ).

Domestic	2000	2005	2010	2015	2020	2025
Coal	109	110	110	110	110	110
Gas	348	482	931	1304	1389	1255
Oil	2668	3311	4983	6528	7092	6875
Hydro	1096	1246	1396	1517	1763	1955
Nuclear	84	150	250	199	199	199
Renewables	1984	3184	4049	4927	6156	7584
Total domestic	6289	8484	11 719	14 585	16 710	17 979
	Net imports					
Coal	456	568	680	878	1129	1501
Gas	81	309	543	941	1461	1955
Oil	1042	561	–539	–1486	–1041	998
Electricity	160	113	70	66	112	225
Total imports	1739	1551	755	399	1662	4679
	Domestic + Imports					
Coal	566	678	791	988	1239	1612
Gas	429	791	1474	2245	2850	3210
Oil	3710	3872	4443	5042	6052	7873
Hydro	1096	1246	1396	1517	1763	1955
Nuclear	84	150	250	199	199	199
Renewables	1984	3184	4049	4927	6156	7584
Elec (imports)	160	113	70	66	112	225
Total	8028	10 036	12 473	14 984	18 372	22 659
	Fuel shares (%)					
Coal	7.05	6.76	6.34	6.59	6.74	7.11
Gas	5.35	7.88	11.82	14.98	15.51	14.17
Oil	46.21	38.59	35.62	33.65	32.94	34.75
Hydro	13.65	12.42	11.19	10.12	9.59	8.63
Nuclear	1.04	1.50	2.00	1.33	1.09	0.88
Renewables	24.71	31.73	32.46	32.88	33.51	33.47
Elec (imports)	1.99	1.13	0.56	0.44	0.61	0.99
Total	100	100	100	100	100	100

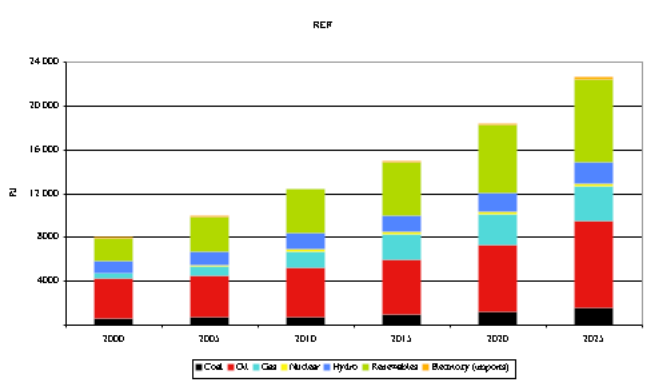

Figure 6. Total primary energy supply (PJ).

Table 11. Total primary energy supply, SHIFT scenario (PJ).

Domestic	2000	2005	2010	2015	2020	2025
Coal	109	110	110	110	110	110
Gas	348	482	931	1304	1389	1255
Oil	2668	3311	4983	6528	7092	6875
Hydro	1096	1244	1401	1602	1796	1950
Nuclear	84	150	150	100	100	100
Renewables	1984	3178	4041	5087	6234	7645
Total domestic	6289	8476	11 616	14 731	16 722	17 935
	Net imports					
Coal	456	578	663	656	723	971
Gas	81	243	250	415	529	1102
Oil	1042	593	–500	–1526	–1380	–389
Electricity	160	76	82	63	122	126
Total imports	1739	1490	495	–392	–5	1810
	Domestic + Imports					
Coal	566	688	773	766	834	1082
Gas	429	724	1181	1718	1918	2357
Oil	3710	3905	4483	5002	5713	6486
Hydro	1096	1244	1401	1602	1796	1950
Nuclear	84	150	150	100	100	100
Renewables	1984	3178	4041	5087	6234	7645
Elec (imports)	160	76	82	63	122	126
Total	8028	9966	12 111	14 339	16 716	19 745
	Fuel shares (%)					
Coal	7.0	6.9	6.4	5.3	5.0	5.5
Gas	5.3	7.3	9.8	12.0	11.5	11.9
Oil	46.2	39.2	37.0	34.9	34.2	32.8
Hydro	13.6	12.5	11.6	11.2	10.7	9.9
Nuclear	1.0	1.5	1.2	0.7	0.6	0.5
Renewables	24.7	31.9	33.4	35.5	37.3	38.7
Elec (imports)	2.0	0.8	0.7	0.4	0.7	0.6
Total	100	100	100	100	100	100

The final energy demand by fuel is presented in Tables 12 and 13. The evolution of the final energy demand is very similar in the two scenarios. The main difference is the relatively higher demand for ethanol and other renewables in the SHIFT scenario balanced by the relatively lower demand for fossil fuels. Other renewables include fuelwood, biodiesel, charcoal, bagasse and other vegetable residues.

Table 12. Final energy demand by fuel, REF scenario (PJ).

	2000	2005	2010	2015	2020	2025
Oil	3354	3397	3957	4763	5687	6726
Coal	443	563	702	889	1 148	1501
Gas	211	420	549	644	904	1288
Electricity	1156	1331	1650	2014	2496	3057
Alcohol	270	307	529	712	909	1198
Other renewables	1227	1535	1828	2150	2522	2979
Total	6661	7554	9215	11 172	13 667	16 750

Table 13. Final energy demand by fuel, SHIFT scenario (PJ).

	2000	2005	2010	2015	2020	2025
Oil	3354	3434	3893	4455	5092	5865
Coal	443	573	685	680	767	1002
Gas	211	355	467	609	629	686
Electricity	1156	1294	1559	1863	2233	2605
Alcohol	270	307	529	712	909	1314
Other renewables	1227	1538	1821	2225	2612	2967
Total	6661	7501	8955	10 545	12 242	14 439

6.2.2. Electricity generation

Electricity generation and imports for the REF and SHIFT scenarios are presented in Tables 14 and 15. Total electricity generation grows at a slower pace in the SHIFT scenario (3.3 %) than in the REF scenario (4.0 %). By 2025, electricity generation in the SHIFT scenario is about 14 % lower than in the REF scenario.

Table 14.Electricity generation and imports, REF scenario (TW-h).

	2000	2005	2010	2015	2020	2025
Hydro	304.4	346.2	387.8	421.3	489.6	543.2
Coal	8.3	8.1	4.8	4.8	2.5	2.5
Oil	15.2	6.5	6.3	4.1	4.2	64.8
Gas	4.1	38.3	105.3	189.8	235.6	235.6
Nuclear	6.0	13.8	22.9	18.3	18.3	18.3
Renewables	10.9	14.4	19.2	28.0	56.1	79.7
Wind	0.0	0.1	1.6	6.5	17.0	36.3
Imports	44.2	31.5	19.4	18.2	31.2	62.5
Total	393.1	458.8	567.2	690.9	854.6	1043.0
	Shares (%)					
Hydro	77.44	75.46	68.37	60.98	57.30	52.08
Coal	2.10	1.76	0.84	0.69	0.30	0.24
Oil	3.88	1.42	1.10	0.60	0.50	6.22
Gas	1.03	8.34	18.56	27.46	27.57	22.59
Nuclear	1.54	3.00	4.04	2.65	2.14	1.75
Renewables	2.77	3.13	3.39	4.05	6.56	7.64
Wind	0.00	0.02	0.28	0.94	1.99	3.48
Imports	11.24	6.86	3.43	2.64	3.66	5.99
Total	100	100	100	100	100	100

Table 15. Electricity Generation and imports, SHIFT scenario (TW-h).

	2000	2005	2010	2015	2020	2025
Hydro	304.4	345.7	389.2	445.0	498.8	541.5
Coal	8.3	8.1	4.8	4.8	2.5	2.5
Oil	15.2	6.1	10.1	4.7	7.3	1.1
Gas	4.1	38.0	75.9	121.5	144.3	200.7
Nuclear	6.0	13.8	13.8	9.2	9.2	9.2
Renewables	10.9	13.7	19.2	34.0	56.3	79.7
Wind	0.0	0.2	1.3	5.3	13.9	22.3
Imports	44.2	21.2	22.7	17.6	34.0	35.1
Total	393.1	446.6	536.8	642.0	766.2	892.2
	Shares (%)					
Hydro	77.44	77.39	72.50	69.31	65.10	60.70
Coal	2.10	1.81	0.89	0.74	0.33	0.28
Oil	3.88	1.37	1.87	0.74	0.95	0.13
Gas	1.03	8.50	14.13	18.92	18.84	22.49
Nuclear	1.54	3.09	2.57	1.43	1.20	1.03
Renewables	2.77	3.06	3.57	5.30	7.34	8.94
Wind	0.00	0.05	0.24	0.82	1.81	2.50
Imports	11.24	4.74	4.22	2.74	4.43	3.93
Total	100	100	100	100	100	100

In both scenarios, hydropower continues to be the largest contributor to electricity generation throughout the period considered. Its share, however, decreases from 77 % in 2000 to 52 % in the REF scenario and 61 % in the SHIFT scenario by 2025 (see Figure 7). This reduction is mainly balanced by share increases in gas, renewables and wind.

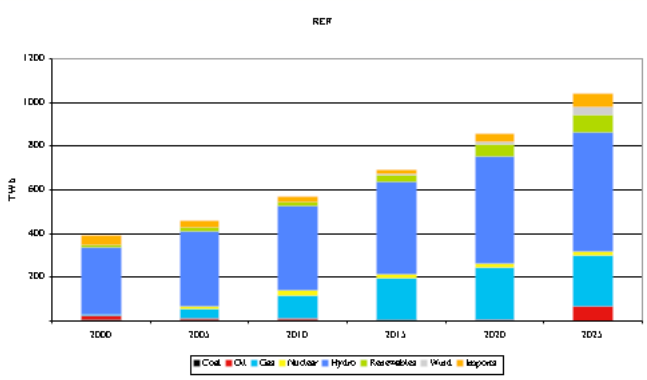

Figure 7. Electricity generation (TW-h) by fuel.

6.2.3. Electric generating capacity

The evolution of electric generating capacity is shown in Tables 16 and 17, and Figure 8. The overall capacity grows at an annual rate of 4.0 % in the REF scenario and 3.6 % in the SHIFT scenario. By 2025, the capacity in the SHIFT scenario is about 9 % lower than that in the REF case. The hydropower capacity almost double by 2025, growing at an annual rate of 2.6% in both scenarios; however, the hydropower capacity share decreases from 85 % in 2000 to 61 % in the REF case and to 68 % in the SHIFT case by 2025.

Table 16. Electric generating capacity, REF scenario (GW).

	2000	2005	2010	2015	2020	2025
Hydro	60.8	75.9	83.7	90.5	104.6	116.0
Coal	1.6	1.2	0.7	0.7	0.4	0.4
Oil	4.6	4.3	3.5	2.3	2.2	8.2
Gas	1.1	6.2	15.6	26.8	32.9	33.0
Nuclear	0.7	2.0	3.3	2.6	2.6	2.6
Renewables	2.5	2.5	3.3	4.8	9.8	14.4
Wind	0.0	0.1	0.7	3.0	7.8	16.6
Total	71.3	92.0	110.7	130.6	160.2	191.1
	Shares (%)					
Hydro	85.31	82.46	75.59	69.26	65.29	60.68
Coal	2.27	1.25	0.61	0.52	0.22	0.19
Oil	6.45	4.67	3.16	1.74	1.35	4.30
Gas	1.49	6.71	14.04	20.51	20.57	17.26
Nuclear	0.93	2.14	2.95	2.00	1.63	1.37
Renewables	3.52	2.72	2.99	3.71	6.10	7.52
Wind	0.03	0.05	0.65	2.27	4.84	8.68
Total	100	100	100	100	100	100

Table 17. Electric generating capacity, SHIFT scenario (GW).

	2000	2005	2010	2015	2020	2025
Hydro	60.8	75.8	84.0	95.5	106.5	115.7
Coal	1.6	1.2	0.7	0.7	0.4	0.4
Oil	4.6	4.3	3.5	2.3	2.2	1.0
Gas	1.1	5.9	11.7	17.7	20.7	28.3
Nuclear	0.7	2.0	2.0	1.3	1.3	1.3
Renewables	2.5	2.4	3.3	5.9	9.8	14.4
Wind	0.0	0.1	0.6	2.4	6.3	10.2
Total	71.3	91.5	105.7	125.8	147.2	171.1
	Shares (%)					
Hydro	85.31	82.76	79.44	75.94	72.38	67.60
Coal	2.27	1.26	0.64	0.54	0.24	0.21
Oil	6.45	4.70	3.31	1.80	1.47	0.56
Gas	1.49	6.42	11.05	14.06	14.05	16.51
Nuclear	0.93	2.15	1.86	1.04	0.89	0.77
Renewables	3.52	2.60	3.12	4.70	6.66	8.40
Wind	0.03	0.11	0.57	1.92	4.30	5.95
Total	100	100	100	100	100	100

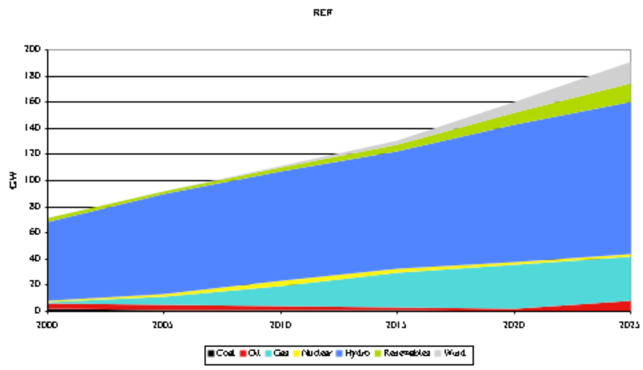

Figure 8. Electric generating capacity (GW) by fuel.

6.2.4. Carbon emissions

Table 18 shows estimates of carbon emissions associated with the projected energy and electricity supplies in the REF and SHIFT scenarios. In the REF case, carbon emissions from the overall energy system grow at an annual rate of 3.0 %, and those from electricity at about 7.8 % (see Figure 9). In the SHIFT case, carbon emissions from the energy system increase at an annual rate of 2.0 %, and those from electricity at about 5.4 %. The increasing trend in carbon emissions is due to the projected higher level of fuel diversification in both energy and electricity, and in particular to the substitution of gas for hydropower. These emissions are higher for the REF case than for the SHIFT case because of the higher amount of fossil fuels used to satisfy the additional demand projected in this scenario.

Table 18. Estimated carbon emissions (Mt).

	2000	2005	2010	2015	2020	2025	Annual growth rate (%)
	Energy						
REF	97.1	97.8	117.2	137.6	162.2	204.4	3.0
SHIFT		97.4	111.6	120.2	131.4	157.4	2.0
	Electricity						
REF	6.1	7.4	14.2	23.9	27.1	39.8	7.8
SHIFT		7.5	11.1	15.5	17.3	22.7	5.4

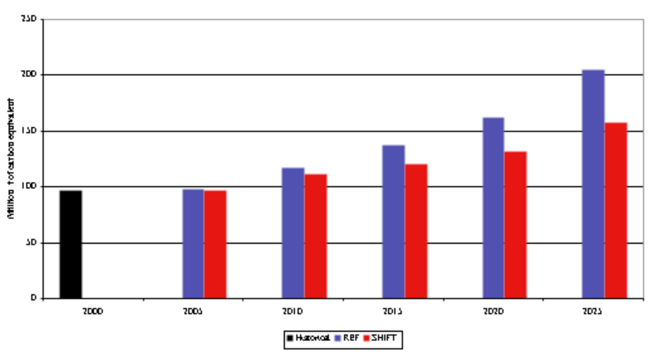

Figure 9. Carbon emissions from the energy system.

6.2.5. Economic aspects

Figure 10 shows average annual energy investments in the REF and SHIFT scenarios. There is a need to increase investments in the energy sector. This increase is lower in the SHIFT case, since the energy requirements are lower in this scenario.

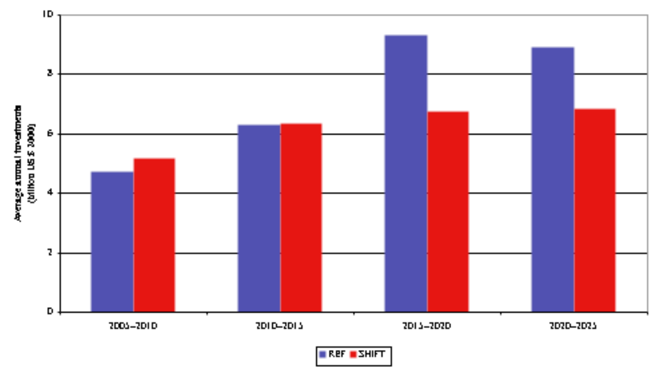

Figure 10. Average annual energy investments.

7. Concluding Remarks

The scenarios developed in this study can be evaluated with respect to their sustainability in terms, among other things, of their GHG emissions. Figure 11 shows GHG emissions from the energy sector per capita (bars) and per unit of energy supplied (lines). Although the carbon emissions per capita follow an increasing trend, the corresponding emissions per unit of energy supplied show a decreasing trend in both scenarios. The higher values on a per capita basis result from a higher per capita use of energy compared with per capita carbon dioxide emissions. The decreasing trend for carbon emissions per unit of energy supplied indicates an increasing dependence on non-carbon fuel in the future in both scenarios, with the dependence being higher in the SHIFT case.

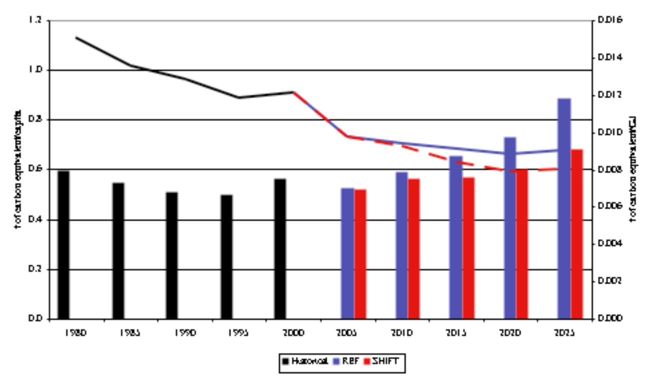

Figure 11. GHG emissions from the energy sector per capita (bars) and per unit of energy supplied (lines).

Figure 12 shows carbon emissions from electricity generation in terms of kilowatt-hours. The emissions increase in both scenarios owing to a projected rapid growth in electricity generation that hydropower and renewables cannot fully satisfy; therefore, the share of gas in electricity generation increases, resulting in higher carbon emissions on a per kilowatt-hour basis. Nevertheless, compared with other countries, Brazil will still be in a very favourable position with respect to GHG emissions from energy use. In fact, in 2025, carbon emissions are projected be around 40 g/kW-h in the REF case and only about 25 g/kW-h in the SHIFT case. There is basically no parallel to that in the World.

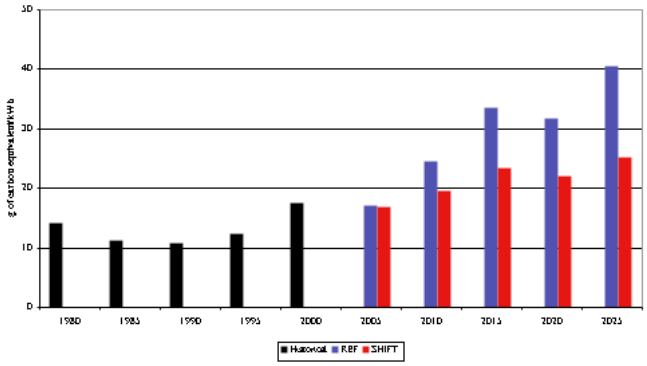

Figure 12. Carbon emissions from electricity generation per kilowatt-hourTables.

In general, the analysis conducted here shows that, in both scenarios, Brazil moves towards fulfilling sustainable energy development criteria, but a scenario that creates more value added while uses factors of production more wisely and efficiently (SHIFT) has the potential to generate substantially lower GHG emissions than a business-as-usual (REF) scenario.

Although this study has its limitations -- for example it does not take into consideration the changes in climate, the impacts on physical and biological systems and the vulnerability of ecological and human systems that can affect the Brazilian territory, which even in the time horizon of this study may impact the energy sector by affecting the availability of water resources for hydroelectric generation, biomass-based fuels production, thermal power plants cooling, or the productivity of agriculture for biomass production, or wind patterns for wind power production --, it does call the attention to the fact that, increasingly, climate policies have to be part of sustainable development strategies and not seen as barriers to development itself. And for that, there is an urgent need for the development of further studies that integrate socio-economic, environmental and climate datasets, both observational and projected, exploring feedbacks and couplings among different systems.Acknowledgements

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References

Giambiagi F (2003a) Um cenário para a economia brasileira com permanência da austeridade fiscal e redução da vulnerabilidade externa. Banco Nacional de Desenvolvimento Econômico e Social – BNDES, Rio de Janeiro, Brazil

Giambiagi (2003b) Bases para uma estratégia gradualista de expansão. Banco Nacional de Desenvolvimento Econômico e Social – BNDES, Rio de Janeiro, Brazil

IAEA, COPPE, CENBIO, UNDESA (International Atomic Energy Agency, Graduate School of Engineering of the Federal University of Rio de Janeiro, Brazilian Reference Centre on Biomass of the University of São Paulo, and United Nations Department of Economic and Social Affairs) (2006) Brazil: a country profile on sustainable energy development, Vienna

IBGE (Brazilian Institute of Geography and Statistics) (2001) Anuário estatístico do Brasil - 2000. Ministério de Planejamento e Orçamento, Rio de Janeiro, Brazil

IPCC (Intergovernmental Panel on Climate Change) (2007a) Working group I contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report: climate change 2007 - The physical science basis – Summary for policy makers, Paris

IPCC (Intergovernmental Panel on Climate Change) (2007b) Working group II contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report: climate change 2007: Climate change impacts, adaptation and vulnerability – Summary for policy makers, Brussels

Mantega G (2003) A nova estratégia de crescimento sustentado. In: Velloso J P (ed) Governo Lula: novas prioridades e desenvolvimento sustentado, 1st edn. José Olympio, Rio de Janeiro, Brazil

Meirelles H (2003) O controle da inflação como condição do desenvolvimento. In: Velloso J P (ed) Governo Lula: novas prioridades e desenvolvimento sustentado, 1st edn. José Olympio, Rio de Janeiro, Brazil

MPOG (Ministry of Planning of Brazil) (2004) Impactos econômicos do portfolio de investimentos dos eixos nacionais de desenvolvimento: cenário tendencial 2001-2020, Brasília, Brazil

Schaeffer R, Szklo A, Machado G, Nunes L (2003 ISED Project – Brazil Team's Second Year Report, COPPE/UFRJ, Rio de Janeiro, Brazil

Stern, N The economics of climate change: the Stern review. Cambridge University Press, Cambridge

Szklo A, Machado G, Schaeffer R (2007) Future oil production in Brazil – Estimates made on a Hubbert model. Energy Policy 34 (4) 2360-2367

Sustainable Development and Resilience to Climate Stress

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1. Good morning Ladies and Gentlemen. I am delighted to be here and I wish to thank the Organizers for inviting me to participate in this important event. It seems to me that the timing of this expert meeting is quite critical: A tide of concern about the impacts of climate change is rising in scientific, political, and financial circles. This bodes very well for our endeavors. Release of the latest IPCCC assessment report focuses world attention on the urgency of responding to this critical problem. The recommendations of the G8-Gleneagles Summit highlight the necessity of building resilience in developing countries for coping with climate stress and for managing the risks of climate change. And the adoption of the Clean Energy Investment Framework by the World Bank's Board of Executive Directors at its mid-April 2007 annual meetings in Washington, D.C. offers formal guidance for "climate proofing" World Bank and IMF Investment Projects as well as for mainstreaming adaptation into national development strategies. I can say, therefore, that this is indeed an exciting time to be addressing such a distinguished audience on a subject matter that has come through a period of significant neglect following the Rio Earth Summit in the early 1990s.

2. We are here today in this session to think collectively about achieving "Sustainable Development and Resilience to Climate Stress." We do so with an eye towards sketching out a roadmap that will inform the key players and decision-makers in both industrialized and developing countries alike. For the sake of clarity, I shall begin by sharing my basic understanding of climate stress and focusing our attention on several key questions:

- "What do we mean by climate stress?"
- "How can we recognize the early warning signs?" and
- "How best might we be able to deal with climate stress and manage the risks of climate change?"

Then I should like to draw your attention to a few critical challenges that, in my personal view, must be overcome, if the international community is to make further progress on the issue of development in a world confronting increasing climate stress. I will close my remarks by engaging all of you in thinking about an additional series of questions that I hope will spark a lively debate. I should indicate at the outset that the illustrations I will use in this talk are drawn principally from the experience of Africa. I choose to focus on Africa, not because it is the only continent whose societies and ecosystems are at risk from future climate change, but rather because of the particularly compelling situation and the unique vulnerability of this region to the impacts of climate change.

What do we mean by climate stress? How can we recognize the early warning signs?

3.Sustainable development refers to the process of balancing out the needs of today's human populations for economic and social development with the need to protect the natural and built environment in order to meet the needs of future generations. The critical components in the process of sustainable development are economic growth, social equity, and environmental integrity.

4. Climate stress is defined as the perturbations (and resulting dislocations) in natural ecosystems, in Earth's geophysical systems, and in human societies that are caused by alteration in climatic conditions. These perturbations and dislocations result in increased variability in weather patterns, including storms, droughts, hurricanes, floods, and larger El Nino events, among other environmental impacts. The human consequences of these environmental stresses often reach catastrophic proportions. They are beamed into our living rooms on a daily basis through television, radio, and the Internet. I think that it is fair to suggest that responding to such extreme events not only involves a measure of immediate disaster relief management, but also requires communities to prepare for long-term climate trends that may have even larger consequences for human life and natural ecosystems in the future.

Historical modes of coping with climate stress (1960-present)

5. From an historical perspective, it is especially informative to study the example of the Sahel. Traditional farmers in the Sahel have shifted their crops over the past several decades to shorter cycle varieties of millet and maize, gradually abandoning crops like groundnuts that require higher and more consistent rainfall. The use of fallow periods has been introduced into traditional agriculture to improve soil management and to stabilize yields from agricultural lands. During the mid-1990s, livestock were herded further south, away from the desert margins and into settled and cultivated areas, necessitating -- in the mid 1990s -- a new accommodation between animals and crops. Wells have been dug and small dams built to provide water for gardens of onions, tomatoes and mangoes that can be sold as cash crops. Many farmers have also moved southward, looking for land in better-watered areas. In general, donor assistance was characterized by a few projects such as National Land Management Program in Burkina Faso and by a number of technical assistance projects from the Inter State Committee to Combat Drought in the Sahel.

Since the late 1960s, five million people from Burkina Faso and Mali have migrated south to neighbouring Côte d'Ivoire. Much of the recent civil strife in Côte d'Ivoire stems from the uneasy relations between these immigrants and local indigenous people. The presence of these immigrants has caused a growing shortage of land in a region where land was formerly considered to be in unlimited supply. In the face of increasing pressure on the land, traditional ways of building resilience to climate stress have confronted new limits.

More modern approaches to coping with climate stress

6. Alongside the traditional and naturally intuitive ways of coping with climate stress that are described above, relatively modern solutions have gradually made in-roads in Sahelian societies. These new approaches have helped rural communities to increase their resilience to climate variability and to manage long-term climate risks. These new approaches include cloning of plants (crops) and animal species, increased use of fertilizers, the adoption of innovative irrigation systems, and the application of biological control mechanisms in lieu of

industrial pesticides. Construction materials and building techniques have also been adapted to increase the resilience of local communities to climate stress. These modern approaches to coping with climate stress result in much greater agricultural yields and allow for achieving economies of scale that are necessary to support well-functioning markets. The application of these modern coping strategies allows the developers of infrastructure investment projects to account for climate risks if the proponents and project participants can afford the additional cost of more expensive purchased inputs.

Community responses to climate stress

7. As seen in the foregoing discussion, to be resilient to climate stress, many communities have developed strategies for coping with climate disturbances and for increasing their resilience to climate stress. They have learned from recent observations of our changing weather and have devised forward-looking strategies to strengthen their adaptive capacities. New social and institutional arrangements have been established with varying levels of flexibility. Some of these new institutional arrangements have been developed on an ad-hoc basis and others have emerged in a more systematic and structural form. In both cases, the new strategies build on traditional knowledge and local cultural practices. Much of the observed progress can largely be attributed to a spontaneous process of trial and error, made possible by the availability of critical financial support from donor countries. Donor country support, though critical, is ad hoc and project based, and does not often address developing resilience to climate stress in a systematic, structural, and sustainable (long-term) way. Perceptive observers of the African scene realize that sustainable and orderly transitions are possible in many ecosystems affected by climate stress (including semi-arid rangelands, lakes, coral reefs and forests) only if careful and consistent attention is also given to these systematic, sustainable, structural responses. A number of these necessary structural responses will be discussed below.

Why has this issue of climate stress and resilience to climate risk only recently gained more currency in the international development debate, fifteen years after the Rio Earth Summit?

8. Although the notion of linkage among sustainable development strategies, climate stress, and the need to increase the resilience of communities, ecosystems and institutions is reflected in the text of the UN Framework Convention on Climate Change, negotiations on emissions reductions have dominated much of the international community's debate on climate change since the Earth Summit in Rio de Janeiro, Brazil (June 1992). The emphasis in these debates on mitigation measures has left the developing world, in general, and Sub-Saharan Africa, in particular, losing ground in the struggle for sustainable development. In the face of a singular emphasis on mitigation by the international development community, Sub-Saharan Africa has little to show as success stories and nothing to show as a measure of concrete achievements on the path towards a more resilient and sustainable future. In the same period, colleagues at the World Bank tell me that much ground has been gained in South Asia and in the CARICOM (Caribbean Community) Countries.

I am hopeful that the combination of the Stern Report, the report of the Blair Commission for Africa – and to a certain extent – the recent expressions of urgent concern by a few African policy-makers, may create a new and favorable theme in the international development community. These new voices cry out for increased attention to the harsh reality that Africa is losing out on the pledge of a double dividend for development and environmental sustainability.

How can we best deal with climate stress and manage climate change risks?

9. The next question to which we should turn our attention is how best to deal with climate stress and to manage climate change risks. I expect that this meeting will provide some clues on how to address – and hopefully --- to meet these challenges.

Let me simply suggest that one fruitful approach might be to begin by recognizing that an appropriate strategy must, at a minimum, consider the following three elements:

(i) the need to improve short-term (disaster relief) responses to extreme events while simultaneously reinforcing the adaptive capacity of communities to deal with long-term change in climate;

(ii) the observed fact that maladaptation and low levels of adaptive capacity for responding to climate stresses has historically been associated with significant economic losses in many regions as well as with irreversible damages to our one and only earth; and

(iii) the challenge of removing barriers and constraints to strengthening the resilience of communities to short term climate variability and climate change risks while promoting an integrated and balanced development strategy during a period of increasingly scarce government resources.

Discussion:

A Dual Problem: Dealing simultaneously with current and imminent weather-related emergencies while strengthening long-term adaptive capacity for coping with climate change risks

10. Typically, developing nations do not have well-equipped disaster relief agencies. Responsibilities for planning and coordination of emergency programs are likely to be fragmented and incompletely specified. Opportunities to strengthen local adaptive capacities for dealing with climate stresses are not discussed in the context of planning for more immediate risks. Little attention is given to possible synergies that could result from linking such efforts with disaster relief strategies.

Little understanding of the impacts of maladaption and poor adaptive capacity to climate risks

11. A point of critical importance in connection with the impacts of climate stress, is the notion that maladaption is costly to both the economy and to local societies. Maladaptation leads to:

- reduced access to clean water;
- lower agricultural yields and reduced productivity;
- increased vulnerability for local infrastructure to damage from weather events;
- increased likelihood of the spread of infectious diseases (e.g., malaria, meningitis, and cholera); and
- loss of revenues from tourism because of significant biodiversity losses.

These very real economic and social costs can no longer be ignored. The latest IPCC report on impacts of climate change (IPCC Working Group 2, 2007) suggests that there will be a 10% drop in rainfall in many African sub-regions where shortages of water are already painfully real. Recognizing that 75% of the African landmass is in dryland areas, a decline by 2050 of 5 - 40% in run-off and available surface water could be devastating. Combining this prospect with the possibilities for Sea Level Rise in the range of 1 to 5 meters suggests that the need for increased adaptive capacity in Africa will soon be extreme.

What can we reasonably expect to happen if the Niger River in West Africa loses 5 to 40% of it flow as it crosses the land mass of ten countries and leaves a parched watershed area of some 2 million square kilometres? What can we expect to happen in Egypt when the upper Nile dries out and the delta of the lower Nile is flooded by a rising global sea level? How will the Middle East cope with the likely increase in tensions between upstream and downstream watershed users? In this increasingly urgent context, our expectations for this Conference are necessarily quite high!

Clear understanding is needed of the barriers and constraints to strengthening community resilience to climate variability and climate risk

12. During the past 4 to 5 years, many of us have come to realize that the availability of adequate information is a key and critical constraint to the work that we are doing. In our countries, policymakers have few ties and little interaction with research centres or universities. Potential solution strategies arising from local research are shelved for too long and almost never enter into national policy debates. Technological advances like global positioning systems (GPS), remote sensing analysis, and geographic information systems (GIS) that could be used to create an accurate inventory of natural resources are largely ignored in many developing countries.

The fragmentation of climate policies across many poorly-equipped Ministries, with no systematic coordination from the senior political leadership of the country can only lead to piecemeal solutions that miss many opportunities for cooperation and synergy. The situation is only worsened by the loss of key local champions through the high turn-over rates in many Ministerial posts. The exclusion of key grass-root actors and advocates (including leaders of non-governmental organizations (NGOs) and community-based associations) has meant that there is little effective input from those who are at risk from changes in climate. Finally, the lack of formal insurance and relief mechanisms to cover the damages that result from extreme weather events (which periodically recur at the scale of national catastrophes) further underscores the desperate situation in many developing countries.

Linking resilience to climate variability and climate risks to the Millennium Development Goals

13. In the last several years, international development assistance efforts have focused on achieving the Millennium Development Goals (MDGs). These goals, formally adopted at the World Summit on Sustainable Development in Johannesburg, RSA (December 2002) outline eight major areas in which the international community has pledged to make major advances by the year 2015. The target areas include: reducing poverty, increasing access to potable water, improving public health, providing better schooling -- especially for girls, and lowering the rates of infection for HIV/AIDS. As discussions at the 2005 summit in New York made clear, many African countries are not on track to achieve many of these goals, despite very substantial amounts of international development assistance. The impacts of global climate change will only increase the difficulty of reaching these important targets.

A few critical challenges to overcome

14. It was not my intention to try to capture the thrust of the entire debate that we expect to hear during this meeting but rather to try to set the tone for our discussions together! Given the wealth of experience that is represented among the participants in this meeting, it seems to me that the following questions merit further attention:

(i) How can this meeting best support the articulation of a sharper vision for sustainable development and for strengthening the resilience of developing countries in the face of climate stress? How can we together evolve a new strategic perspective on these issues? And, more specifically, how can we move from where we are today in our countries to where we want to be so that we link unequivocally the process of responding to climate stress with our countries' struggle for national survival and cultural identity. In considering these issues, it is important to recall that much of the civil unrest in Cote-d'Ivoire is tied to the difficult accommodations of migrants fleeing the Sahel towards wetter coastal areas. They are in search of arable lands, and these will become increasingly difficult to find as climate change dries out this region of sub-Saharan Africa. Furthermore, I believe that the civil war in the Darfur is, in fact, linked with the impacts of competition for access to the already scarce water resources of the Sudan.

(ii) Considering that hopeful signs of progress are visible in terms of overall national and international sensitization to the risks of climate change, how best can developing countries mobilize much-needed investment resources to meet the expectations being raised? Typically, Developing Countries politicians do not raise issues that they do not claim to have the answer for! Is ODA a good target? That is, can we expect multilateral and bi-lateral donor agencies to incorporate our concerns about climate stress and climate risks into their mainstream development grants, lending procedures, and technical assistance activities?

(iii) What kind of new international partnerships among donors and public-private partnerships in developing countries are likely to bear fruit before the next crisis occurs? Are there useful lessons that we can draw upon from the insolvency of insurance companies in the USA after Hurricane Katrina?

(iv) Is there a need to develop new types of financial instruments in order to leverage more resources with existing instruments and institutions? And, finally,

(v) How do we break through the chicken-and-egg dilemma? We know that many of the questions raised above will require strengthened institutions and sizable investment resources. But these are precisely what we is lacking in many of the countries represented here at this Conference. Many developing country governments believe that they simply cannot afford to strengthen institutions confronted with long-term risks because they are saddled with the legacy of international debt and over-stretched budgets. Where then, do we start?

(vi) How can we best shift scale from local to country, from country to region, and from region to subcontinent, where governance at those scales, where perhaps some or even much of the solutions to resilience and adaptation could be found, is not existent or not efficient?

Concluding Remarks

15. By way of conclusion, let me emphasize that although addressing the challenges evoked above could appear to be a daunting task, I am quite positive and hopeful that innovative approaches and shared principles will emerge from the collective brainstorming at this Conference. Yes, linking development with a strengthened resilience to climate stress is important. We see this illustrated by the Poverty Reduction Strategy Papers of many developing countries attending this meeting. We must face the challenge of how to ensure that nationally-oriented, climate-resilient policies are put in place despite possible conflicts with the traditional institutional, regulatory and operational requirements of donors (or of some governments)!

16. Perhaps, partly as a result of recent institutional and organizational developments, and partly as a result of the sector reforms implemented during the 1990s, a reconfigured institutional landscape is emerging in many developing countries. This new landscape could create a new setting within which it is possible to listen to the needs of the communities that are the intended beneficiary of development projects and to the proponents of real development in the climate change focal area. This may be easiest when it comes to dealing with high probability, high impact climate events. The intended gradual shifting of power from central Ministries to decentralized local governments and municipalities is another hopeful sign. Governments and international agencies can no longer ignore the increasing array of national autonomous agencies supplemented by a host of cred-

ible, local, private participants, that are acting in different – though complementary—ways and who wish to be accepted as informed and legitimate stakeholders in the national development debate.

17. Ladies and Gentlemen, please, let me suggest in closing that I believe that this profound decentralization represents a transformation of both power sharing and accountability. It is occurring concurrently with a major split of administrative and technical responsibilities among collaborating and competing national agencies and has resulted from earlier reforms in the infrastructure and environment sectors. It continues to evolve with an increasing emphasis on local private sector participation in national development policy. These changes have had and will continue to have a dual impact on the governance structure of the infrastructure and environment sectors and on the strategies available for responding to the risks of future climate change.

18. This process has created a greatly strengthened local capacity to formulate multi-sectoral strategies that are climate resilient. Projects to improve energy supply, access to clean water and public sanitation can and should be integrated with measures to strengthen the capacity of local communities to respond to climate change. These types of integrated development projects are central to achieving the national development priorities of many countries represented at this meeting.

19. I very much hope that this conference will probe the extent to which the adverse, donor-driven selection criteria for development projects may be contributing to the environmental crisis that has been growing in developing countries since the heady days of the Earth Summit in Rio. I look forward to discussing these issues further with you throughout this Conference.

Changes in growing-season rainfall characteristics and downscaled scenarios of change over southern Africa: implications for growing maize

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Abstract:

Global climate change is a detectable and attributable phenomenon, yet its manifestation at the regional scale, especially within the rainfall record, can be difficult to characterize due to the high degree of variability. At the same time, an understanding of historical change is essential in order to provide context for climate change projections, as well as a credible basis for adaptation. Over southern Africa this task is complicated by particularly erratic rainfall, the presence of multidecadal trends, and limited data with sparse spatial coverage. Furthermore, climate models suggest that competing responses (such as increasing numbers of dry days, coupled with increases in rainfall intensity), working at different timescales, will serve to additionally mask any signals in the time-averaged total rainfall.

Ideally, the changes in the secondary attributes can then be compared with equivalent attributes from downscaled climate scenarios to assess agreement and contribute to confidence in projected downscaled data. However, downscaled scenarios may suffer from varied biases and limitations due to their methodological approach, e.g. rainfall parameterisations within RCMs and neglected land-climate interactions within empirically derived scenarios. These limitations may lead to inconsistencies between different sources of information. The comparisons described earlier, based on secondary attributes and sub-seasonal timescales, facilitate highlighting areas of weakness in each downscaling, which may not be readily manifest in the more commonly used time-averaged products.

These issues are explored using data from southern Africa; station observations of daily rainfall, dynamical scenarios from 2 regional climate models and empirical scenarios from 6 general circulation models. The observations are analysed for detectable trends in the start, end, and duration of the rainfall season, as well as number of dry days, length of dry spells and measures of rainfall intensity during critical periods for agriculture. Correlations with the Southern Oscillation Index (SOI) and Antarctic Oscillation (AAO) are used to infer how large-scale climate variability affects these attributes of rainfall and highlight where (and when) trends may contribute to more frequent crossings of critical thresholds. Trends are also compared with and discussed in relation to changes projected in the downscaled scenarios, highlighting inconsistencies, which may be due to systematic biases in each methodology. The implications for agricultural adaptation are examined and discussed. The paper suggests that when building scenarios of climate change, a wide range of models and methodologies should be interrogated and their interpretation relies heavily on understanding the methods and underlying physical processes. Furthermore, such processes act across political boundaries and collaboration across institutions, as highlighted here, is needed to confidently make regional assessments.

1. Introduction

Africa is considered highly vulnerable to climate change (FAO, 2004), largely because many socio-economic activities in Africa, particularly agriculture, depend on climate and especially rainfall. Consequently, climatic variations and change have an impact on the productivity of many socio-economic activities (Obasi, 2005). Within the agriculture sector drought is arguably the most important climatic challenge and has major impacts on rural livelihoods (Buckland *et al*., 2000). In the 1991/92 drought alone, cereal output in the Southern African Development Community (SADC) region (excluding South Africa) fell from an average of 11.3 million to 6.2 million tonnes, necessitating extensive food imports (FAO, 2004). Furthermore, projections of future change place southern Africa's agriculture sector at the forefront of climate change vulnerability with potential negative impacts on revenue from dryland farming (Kurukulasuriya *et al*., 2006). There is therefore a pressing need to assess the capacity of southern African countries to cope with, and adapt to, the impact of climate change.

A major problem for any adaptation initiative, particularly at the local level is insufficient information about what to adapt to. This often results from a lack of awareness of how the climate has changed in the past (and how social systems have responded), how it is expected to change in the future and if observed changes are consistent with projected changes based on models of the climate system (e.g. Hewitson and Crane, 2006; Jones *et al*., 2004; Tadross *et al*., 2005). This is further complicated by the need to interpret changes from meteorological analyses (typically expressed as monthly or seasonal averages) in terms of an impact on a particular sector. For the agricultural sector, which is the main source of livelihood for the majority of the region's population, it is crucial to understand how rainfall characteristics are changing, particularly those affecting planting dates and the crop growth cycle e.g. the start of the rains or frequency and intensity of dry spells and daily rainfall, that can destroy crops if they occur at critical stages of plant growth (Dennet, 1987; Ati *et al*., 2002; Usman *et al*., 2005).

Besides long-term change, year-to-year variability and its effect on farm management practices is also crucial. The supposition of this shorter-term climate variability on longer term change, within a region that operates close to critical thresholds, is key to formulating adequate adaptation options. Whilst aspects of year-to-year climate variability, such as the El-Nino Southern Oscillation (ENSO) and Antarctic Oscillation (AAO), have a well documented relationship with seasonal climate anomalies in the region (e.g. Reason and Rouault, 2002; Richard *et al*., 2000; Lindesay, 1988; Mason, 1995; Hulme *et al*., 2001; Reason and Rouault, 2005), relatively fewer studies have investigated relationships with rainfall characteristics that are closely tied to management decisions and the crop growth cycle (e.g. Usman and Reason, 2004; Tadross *et al*., 2005; Reason *et al*., 2005). Certainly, within southern Africa little is currently known regarding how climate change and trends may be affecting daily rainfall characteristics at the local level and for particular times in the seasonal cycle (see New *et al*., 2006 for a comprehensive assessment of changes in extremes). Such knowledge can help raise awareness about the climate; support sectoral and integrated impact assessments of climate change, lead to improved seasonal forecasting capabilities, and improve the effectiveness of adaptation options in the agriculture sector.

This paper explores observed changes in daily rainfall records and evaluates the agricultural implications of these changes. Indices were developed to represent planting dates, rainfall cessation, dry spell length, frequency of dry days, rainfall intensity and total rainfall during critical stages of the crop growth cycle. As maize is the main SADC food/nutrition source (Smale and Jayne, 2003) we focus on indices relevant to maize cropping. To understand how variations in seasonal rainfall patterns are linked to large-scale climate modes, we relate variability in these indices to ENSO and AAO and calculate trends in these indices using daily rainfall data from 104 stations across Malawi, Mozambique, Zambia and Zimbabwe. Downscaled climate scenarios for the late 21st century from both Regional Climate Models (RCMs) and empirical approaches are used to suggest where and when the scenarios may be consistent with each other and with the observed trends. Section 3 presents the observations, rainfall indices and the methodological approach. The observed trends and variability of the indices are presented in section 4, downscaled projections under anthropogenic climate change are presented in section 5, with a summary of the implications for growing maize and adapting within a changing climate presented in section 6.

2. Study region

Figure 1 presents the study region and the geographical distribution of the 104 stations used in this study. The background map is a NASA blue marble false colour composite image and indicates the distribution of green vegetation typically found in January. The rainfall season over this region is unimodal (lasting 3-6 months depending on location), with the start of the rains typically occurring during September-October in the far north/south and arriving later (November-December) in the central regions (Tadross *et al*., 2005). Towards the south and east early rains are associated with high pressure anomalies driving warm moist air onshore (Tadross *et al*., 2005; Reason *et al*., 2005). During the rainy season rainfall variability is dominated by the Inter-tropical Convergence Zone (ITCZ) in the north, whereas further south Tropical Temperate Troughs (TTTs) bring rain, oriented in a northwest-southeast direction, to large swathes of the subcontinent. Variability in these TTTs are critical to rainfall variability over southern Zambia, Zimbabwe and most of the central semi-arid regions (Washington and Todd, 1999). Generally the rainy season ends in March-April following the retreat of the ITCZ northwards and the reduced heating of the continent as winter approaches. By mid-season this results in the average vegetation distribution indicated in Figure 1; greater vegetation densities towards the north and over Mozambique, with lower densities towards the westerly arid regions.

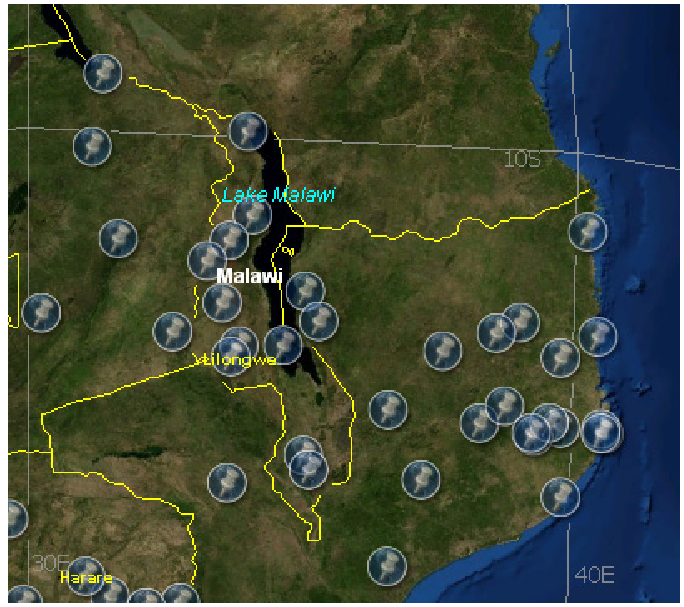

Figure 1: The study area indicating the geographical spread of stations (indicated by tack symbol). Figure background image courtesy of NASA earth observatory.

3. Data and methods

3.1 Rainfall data

The metadata for the observed daily station rainfall datasets available to this study are given in Appendix 1. Altogether the 104 stations span a range of geographical locations, ranging widely in latitude, longitude and altitude. As far as we are aware this is the most comprehensive set of daily station rainfall records yet assembled for an analysis of this kind within these countries. All the station data were quality controlled using the Rclimdex software[1] which tested for negative precipitation and long periods of zero precipitation (see Peterson *et al*., 2002; New *et al*., 2006). Additionally all daily precipitation > 450 mm were set to missing. Missing data is important for this type of analysis within Africa and this is especially true for the later decades and over war torn regions such as Mozambique. If not sufficiently accounted for, increasing levels of missing data can lead to false trends. We calculated the number of missing days for each month throughout the timeseries and whilst some stations indicated missing data later in the timeseries, this mostly resulted from blocks of missing data, usually for a single month. To prevent missing data from introducing false trends in the derived indices (see below), rigorous checks for missing data included:

1. Planting and cessation indices set to undefined if any missing data were encountered before they were defined;
2. All other indices only calculated if planting and cessation dates are defined;
3. All indices set to undefined if any missing data is encountered in the calculation.

3.2 Agricultural rainfall indices

Of the many aspects of intra-seasonal rainfall that affect maize cropping, indices presented here capture some of the most important aspects. These include the onset (which is when a farmer may choose to plant and is here assumed to be the planting date) and the cessation of rainfall, which together measure the effective duration of the rainy season, which then affects the choice of maize cultivar e.g. whether to choose a 130 or 90 day maturing cultivar. Once a farmer has chosen

1 Expert Team on Climate Change detection Monitoring and Indices; http://cccma.seos.uvic.ca/ETCCDMI/index.shtml

the cultivar and decided to plant the success of the rain-fed maize crop is then largely dependent on characteristics of the climate, and in particular rainfall, during the following 90-130 days. Here we assume a 130-day maturing crop with the following cycle: days 1-40 (germination phase), days 41-110 (growth phase), days 111-130 (ripening phase). Rainfall characteristics that may particularly impact maize growth during these phases are: (1) long dry spells during the germination and growth phases (limiting water availability), (2) high intensity rainfall during the germination (resulting in water logging) and ripening (resulting in rotting and fungal infections) phases. We therefore also design indices that measure aspects of rainfall frequency and intensity during these phases after planting.

The naming convention for the indices reflects three different definitions of planting date (see Table 1). Indices ending with the suffix "A" refer to a definition of planting based on minimal moisture required to sow and seeds to grow: 25 mm of cumulative rainfall in 10 consecutive days. The suffix "B" reflects a definition we adopted to take into account a common problem associated with planting early: the risk of a long dry spell soon after planting. To address this, we define a criteria for planting which is based on the earlier definition: 25 mm in 10 days, but not followed by a period of ten consecutive dry days (we define "dry day" as one when observed rainfall does not exceed 2mm) in the following 20 days. If "Planting_A" and "Planting_B" are different, we consider the season has a "false start". Indices ending with the suffix "C" are based on a definition of planting from Raes *et al*., 2004: 45 mm of cumulative rainfall in 4 consecutive days. All planting indices are set to the first day their respective criteria occur after August 1 (before the rainy season starts).

Table 1: Naming convention for indices based on different planting dates.

Suffix	Criteria used to define planting date
A	25 mm of accumulated rainfall in 10 days
B	25 mm of accumulated rainfall in 10 days, not followed by a period of 10 consecutive days with observed rainfall < 2 mm in the following 20 days
C	45 mm of accumulated rainfall in 4 days

A single definition of seasonal cessation - 3 consecutive dekads (10 day periods) of less than 20mm each, occurring after February 1st (approximately middle of rainfall season) - together with the three planting criteria defines three indices of rainy season duration; Duration_(A, B, C). Within each of the three rainy periods defined by planting and cessation days, we calculated the mean and maximum dry spell duration (number of consecutive dry days), the fraction of days with rain and the total rainfall within the rainy season. All indices assume a dry day < 2 mm day^{-1}, and a wet day > 2 mm day^{-1} and are presented in Table 2.

The final sets of indices are crop specific and assume a 130-day maturing maize varietal, based on the germination, growth and ripening phases described earlier. For each of these phases we calculate the total rainfall, rain day frequency and mean rainfall intensity on rainy days to understand the potential implications of changes in rainfall intensity and frequency. Furthermore an aggregate maize index, which is closely tied to maize yield, is calculated as a weighted sum of total rainfall during each of the three growing phases (Doorenbos and Pruitt, 1977); germination (8%), growth (90%), ripening (2%).

Table 2: Description of indices used to analyze rainy season. These indices are based on an Aug-Aug year. Suffixes "A", "B" and "C" represent different criteria for definition of planting (see Table 1).

Index	Definition
Planting_(A, B, C)	Time of planting (days after 1 August). See table 1 for definition of each planting critera)
Cessation	Time of cessation: 3 consecutive dekads each < 20mm (days after 1 February)
Duration_(A, B, C)	Duration of rainy season (days)
DrySpellMax_(A, B, C)	Maximum dry spell duration (days)
DrySpellMean_(A, B, C)	Mean dry spell duration (days)
RainDayFr_(A, B, C)	Fraction of rainy days within the season
TotRain_(A, B, C)	Total rainfall: planting-cessation (mm)
GermTotRain_(A, B, C)	Total rainfall during germination phase (from planting to planting + 40 days)
GermRainDayFr_(A, B, C)	Fraction of rainy days during germination phase (from planting to planting + 40 days)
GermRainInt_(A, B, C)	Mean rainfall intensity on a rainy day during germination phase (from planting to planting + 40 days)
GrowTotRain_(A, B, C)	Total rainfall during growth phase (from planting + 40 days to planting + 110 days)
GrowRainDayFr_(A, B, C)	Fraction of rainy days during growth phase (from planting + 40 days to planting + 110 days)
GrowRainInt_(A, B, C)	Mean rainfall intensity on a rainy day during growth phase (from planting + 40 days to planting + 110 days)
RipeTotRain_(A, B, C)	Total rainfall during growth phase (from planting + 110 days to planting + 130 days)
RipeRainDayFr_(A, B, C)	Fraction of rainy days during growth phase (from planting + 110 days to planting + 130 days)
RipeRainInt_(A, B, C)	Mean rainfall intensity on a rainy day during growth phase (from planting + 110 days to planting + 130 days)
MaizeIndex_(A, B, C)	A weighted maize index for rainfall after planting: days 1-40 (8%), days 40-110 (90%), days 110-130 (2%)

3.3 Tests for long-term trends and correlations with large-scale climate anomalies

To determine trends in observed rainfall characteristics accurately, data must be for a continuous record and for the longest possible period. However, given that a primary focus of this project is the detection of trends that may be due to anthropogenic climate change, and that the anthropogenic signal in global temperature is only distinguishable from natural variability during the latter half of the 20th century (Stott *et al*., 2003), we determine trends for the period from 1960 onwards.

The time series of all the indices given in table 2 were tested for trends using robust regression with significance (probability that the null hypothesis is true i.e. that the trend is zero) indicated using the non-parametric Mann-Kendall test. Several studies have suggested that there may be links between ENSO and/or the Antarctic Oscillation[2] (AAO) and intra-seasonal rainfall characteristics over parts of southern Africa (Tadross *et al*., 2005; Usman and Reason, 2004; Reason *et al*., 2005). As a simple test of potential links with these large-scale climate anomalies, index time series were tested for significant correlations with the Southern Oscillation index[3] (SOI) and the AAO[4] during September, October and November – months which straddling the start of the rainfall season. Correlations were calculated using Kendall's tau, which is a rank-based measure of association recommended when variables are not necessarily normally distributed. As indices were potentially not defined for all years because of missing data, trends and correlations were only calculated when indices were available for 30 years or more. All defined trends were mapped to station locations and kriged to spatially interpolate the trends to a regular 0.5° × 0.5° grid (maximum distance of a station's influence set to 1°).

3.4 Climate change projections

The climate change projections which are compared with the observational data were taken from both empirical and RCM downscalings. The empirical downscaling used the method of Hewitson and Crane, 2006 and was applied to the control and future periods of the 6 GCMs described in table 3 (forced using the SRES A2 emissions scenario). This downscaling was trained on observed daily rainfall records from stations reporting on the General Telecommunications System (GTS) and is presented in Christensen *et al*., 2007. The GTS station data was not available for the same stations as used in the observational analysis but provides a wide coverage of the study region. Summarising, the downscaling associates a probability density function (pdf) of rainfall with typical large-scale atmospheric circulations and uses the GCM projected changes in atmospheric circulation (under an A2 emissions scenario) to project changes in the rainfall pdf. Because the training is performed using observations, GCM biases will be reflected in both the control and future simulations. We therefore present the future anomaly or change between the control and future climate.

Table 3: GCM data used in empirical downscaling

GCM	Control period	Future period (A2 scenario)
HadAM3P	1960-1990	2070-2100
CSIRO MK II	1961-1990	2070-2100
ECHAM4.5	1971-2000	2070-2100
GFDL	1961-1991	2081-2099
MIROC	1961-1991	2081-2099
MRI CGCM	1961-1991	2081-2099

An alternative to empirical downscaling is to use a Regional Climate Model (RCM) – similar to a GCM except used to simulate a limited area of the globe at a higher spatial resolution. However, the output from RCMs may also suffer from similar problems as GCMs regarding rainfall parameterisations (Tadross *et al*., 2006). Furthermore, over southern Africa such differences can lead to different projections of change (Tadross *et al*., 2005). Here we compare projections of change in total rainfall and number of rain days in two RCMs; the Mesoscale Model 5 (MM5, Grell *et al*., 1994) and PRECIS (Jones *et al*., 2004), both forced with a single GCM (HadAM3P, A2 emissions scenario). The periods available from each RCM are: PRECIS control period 1960-1979, future period 2070-2089; MM5 control period 1975-1984, future period (2070-2079). Data from each RCM was projected to a 0.5° × 0.5° grid. For the purpose of the discussion below it is important to recognise that each RCM simulates a hydrological cycle of different intensity; PRECIS rains more often and with a lower than observed intensity, whereas MM5 rains less often and with a higher than observed intensity. Because of this and that RCM downscalings are only available for one GCM, we concentrate on the rainfall projected using the empirical downscaling. Recognising that there may be processes which the empirical downscaling fails to capture we do, however, use the RCM rainfall as a check to see if this technique would likely produce different results, i.e. as a cautionary note against placing too much emphasis on the empirical projections.

2 *http://jisao.washington.edu/data/aao/slp/index2.html*
3 *http://www.cgd.ucar.edu/cas/catalog/climind/soi.html*
4 *http://jisao.washington.edu/data/aao/slp/index2.html*

4. Observed variability and trends

4.1 Planting dates and duration of rainy season

Mean planting dates (days after 1st August) for the three planting criteria Planting_(A,B,C) (as described in table 1) are shown in Figure 2. Planting_A implies planting on average within 40 to 80 days from the beginning of August across central and southern Mozambique, parts of Zimbabwe and in the northwest of Zambia (Fig. 2a). The introduction of the test for a false start to the season (Planting_B) shifts the mean planting date to 80 to 140 days after 1st August across all four countries (Fig. 2b), indicating this is a frequently important consideration over the whole region. Planting_C shifts the mean planting date to 100 to 140 days after 1st August across much of the subregion (Fig 2c) and in general can be considered the planting criteria that occurs the latest. The geographical distribution of mean planting dates can be partly explained by the different rainfall producing systems bringing early rains. Over southern Mozambique highly variable mid-latitude ridging systems advect moisture onshore from the southeast as early as September (Tadross *et al*., 2005), whereas inland tropical regions are dependent on convective rainfall and the proximity of the ITCZ which arrives later (this results in early greenup over Mozambique and is reflected in Figure 1). Figures 2b & 2c emphasise this point; the greatest differences are found mostly over the tropical regions with little change over Mozambique. Mean cessation dates (Figure 2d) indicate that the rainfall season ends first in southern Mozambique, Zimbabwe and southern Zambia, with northern tropical regions receiving consistent rain on average 2 months longer.

Figure 3 indicates the robust trends (1960-2005) of the three planting dates and cessation shown in figure 2. All three planting dates indicate trends for a later start to the season in the northern regions over Zambia and Malawi, though with the exception of Planting_B these trends are mostly not significant. Elsewhere, trends are also not significant, except over northwest Zambia where there has been a tendency for earlier planting dates. Cessation dates (figure 3d) have been tending to arrive earlier over the northern regions and where trends are significant they are negative. In general the pattern of seasonal duration reflects that of Cessation with mean duration decreasing through Planting_A, Planting_B and Planting_C for any particular location. Figure 4a indicates the mean seasonal duration for Planting_B (Duration_B), demonstrating that the shortest mean seasonal duration (90-120 days) occurs towards the southwest with longer seasons further north and east. Whilst 90-120 days is sufficient for growing short season maize cultivars (approx 90 days) it is borderline for the 130-day cultivar on which we base our maize index in table 2 (which needs approximately 110 days if we ignore the 20-day ripening period at the end of the season). This region, which is on average close to these critical thresholds, expands further north and east if Planting_C is considered (not shown). Under these circumstances it is quite clear that a farmer using a longer maturing cultivar in these regions would want to plant as early as possible to minimise their risk of crop failure due to early cessation of rainfall.

Figure 4b shows the trend (1960-2005) in Duration_B, which indicates decreases in seasonal duration over many northern regions (except northwest Zambia), extending through southern Zambia. Whilst most stations indicate insignificant trends, over southern Zambia this generally negative trend coincides with the region indicated

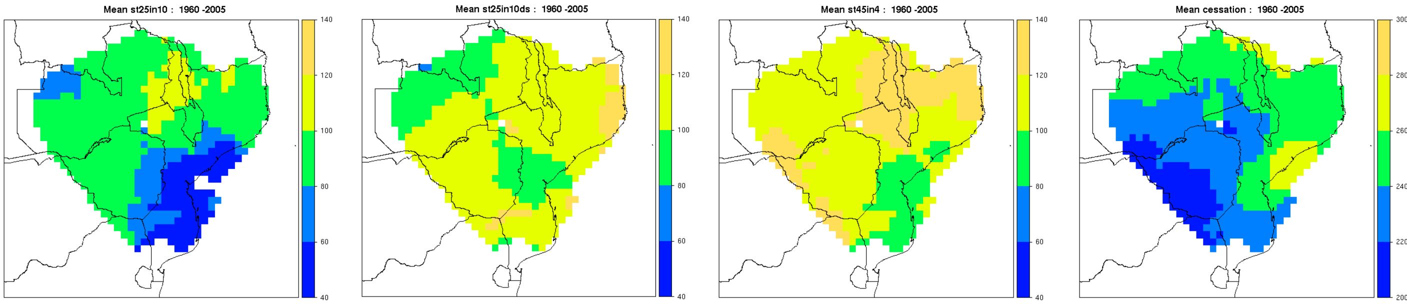

Figure 2: Mean planting and cessation dates (days after 1st August) assuming planting when rainfall is a) 25mm in 10 days (Planting_A), b) 25mm in 10 days not followed by a dry spell of 10 days or longer (Planting_B), c) 45mm in 4 days (Planting_C). (d) rainfall cessation when 3 consecutive dekads of < 20mm each (Cessation).

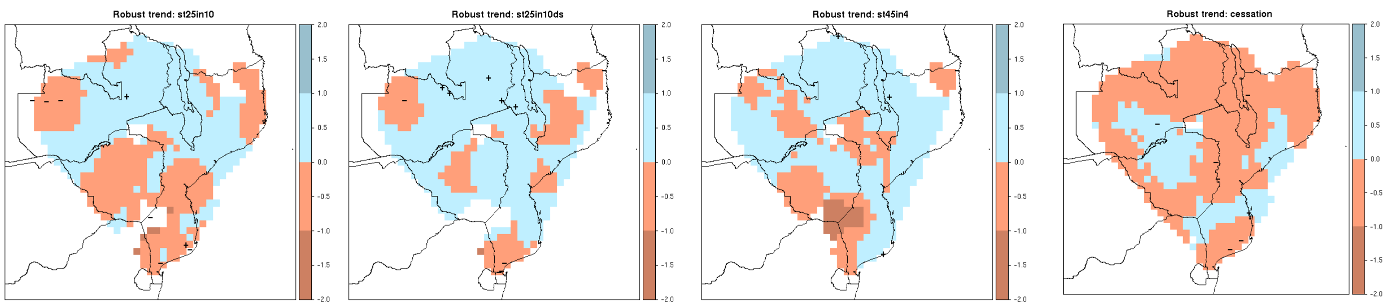

Figure 3: Robust trends (1960-2005) of planting and cessation dates presented in Figure 1: a) Planting_A, b) Planting_B, c) Planting_C, d) Cessation. Significant trends marked with "+"/"-".

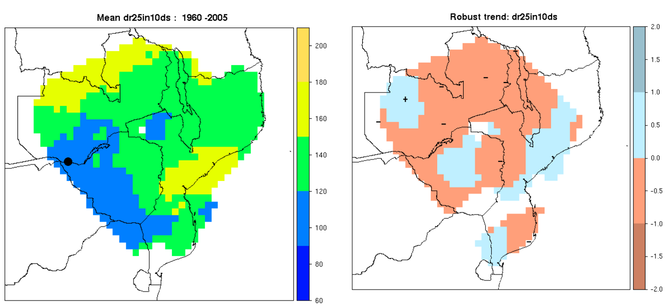

Figure 4: (a) Mean Duration_B (days after 1st August). (b) Trends in Duration_B (days year-1) since 1960. Significant trends marked with "+"/"-". Dark circle marks location of Livingstone.

in figure 4a as being close to the critical threshold of seasonal duration needed to grow maize. This is clearly demonstrated in figure 5, which shows the timeseries of seasonal duration for the three planting criteria (Duration_A-C). It can be seen that Duration_A is on average the longer season, remaining above the critical threshold of 110 days (indicated by the red line) for many years, despite the negative trend. However Duration-B, whilst remaining above the critical threshold in the earlier period, is more often than not below the threshold post 1980. Duration_C has often been below the threshold throughout the period and has rarely offered greater than a 50% probability of sufficient seasonal duration for the 130 day cultivar. Whilst figure 5 clearly demonstrates the importance of interannual variability, it is clear from this example that if regions are close to critical thresholds, even non-significant trends in rainfall can have significant impacts on the risk of a crop failure.

Interannual variability is clearly important in figure 5 and indices were correlated with SOI to test for potential relationships. Spatially extensive positive correlations are found between September SOI and Planting_A (Figure 6a), though not with Planting_B (figure 6b), suggesting that El-Nino (negative SOI) brings early rains, though with long dry spells so that Planting_B is not satisfied. Indeed negative correlations over the southern regions suggest El-Nino is associated with a delayed start to the rains if a false start is to be avoided. Correlations between October SOI and Cessation (Figure 6c) indicate that El-Nino is also associated with an early cessation. This suggests that generally La Nina events are associated with later Planting_A/ Cessation and El Nino with an earlier Planting_A/Cessation (i.e. a shift in the seasonal boundaries). However, infrequent rainfall at the start of the season during an El Nino leads to a later start of consistent rainfall for Planting_B, which when combined with earlier Cessation leads to a shorter season, as indicated by the positive correlations with seasonal duration in figure 6d. Whilst further work is needed to elucidate the links between planting/cessation dates and ENSO, any reliable prediction of either would have immediate benefits for water management; planting dates can suggest appropriate starts to the cropping season and cessation dates the required storing and scheduling of irrigation water at the end of the cropping season.

4.2 Within season rainfall distribution

Figure 7 (a & b) show the correlations of September SOI with within-season (Planting_A to Cessation) mean dry spell duration (DrySpellMean_A) and rain day frequency (RainDayFr_A) respectively. Clear significant correlations across the region indicate that El-Nino is associated with a reduced frequency of rain days and an increase in mean dry spell length, and vice versa when a La Nina is present. Figure 7 (c & d) presents the robust trends of DrySpellMean_A and RainDayFr_A respectively, indicating that dry spell lengths have been increasing and the frequency of rain days reducing through time, most significantly over Zambia though extending into Zimbabwe and Malawi. This may be related to the increased frequency of El-Nino during more recent periods, though Figure 5 would suggest

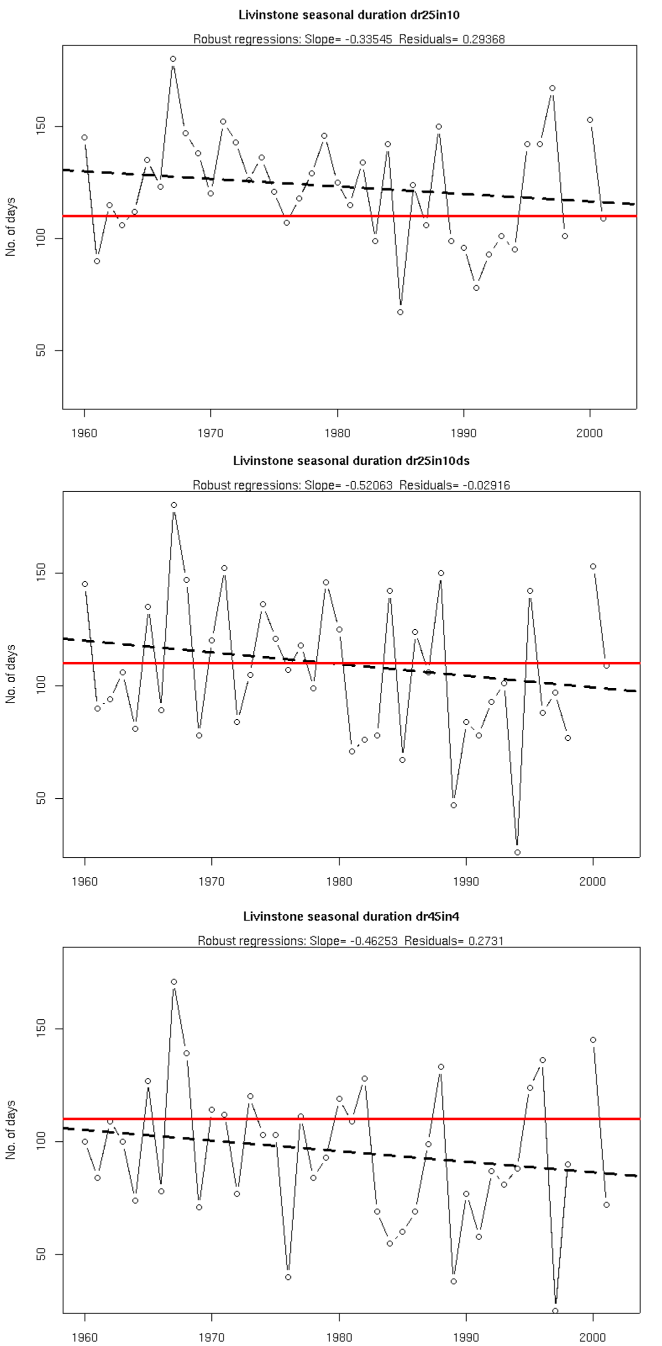

Figure 5: Seasonal duration at Livingstone, Zambia 1960-2001. (a) Duration_A, (b) Duration_B, (c) Duration_C. Dashed line indicates robust trend. Red line indicates 110 days required for growing 130-day maize varietal.

this is not the whole story for Livingstone. Indeed this shift to more sporadic rainfall is consistent with trends for an increasing frequency of high pressure anomalies found over the subcontinent, particulary the western parts, during the 1979-2001 December-February period (Hewitson *et al*., 2006). Those indices characterising intensity during the rainfall season indicated less spatially consistent and few significant changes, though this may change when using annual indices averaged over a wider region (e.g. New *et al*., 2006). It is therefore not surprising that the dominant patterns of change in total rainfall indices reflect those seen for indices related to rain days and are not shown here.

The association between El-Nino and early, though erratic rains, suggested earlier is clearly demonstrated in figure 8a which shows the correlation of September SOI and the number of rain days during the first 40 days after Planting_A (GermRainDayFr_A). The positive correlations mean that during an El Nino the number of rain days are reduced immediately after Planting_A, though it occurs earlier on average. Correlations between SOI and most within season rainfall indices related to rain days and total rainfall yielded extensive significant correlations (see figure 7b), whilst correlations between the Antarctic Oscillation (AAO) and indices reported so far remained mostly insignificant. However, correlations between November AAO and the number of rain days during the maize ripening phase (RipeRainDayFr_B, Figure 8b) are significant over regions of Zimbabwe, southern Zambia and Malawi. This is not surprising as the AAO describes fluctuations of high/low pressure anomalies further south, which are known to affect winter rainfall (Reason and Rouault, 2005). The negative correlations in this case suggest that when the AAO has a positive polarity (which it has tended towards over the last few decades, Marshall *et al*., 2004) and assuming Planting_B criteria is adhered to, the number of rain days is reduced during the maize ripening phase. This may be advantageous as dry conditions are often preferred to enhance the ripening process, though if the AAO has a negative polarity more rain days may prove detrimental to crop development. Given the relatively short duration of the ripening phase (20 days) and the trends noted for later planting times, the AAO may become an important factor during the growth phase.

4.3 Maize index

Given the dependency of total rainfall on the frequency of rain days, the significant correlations demonstrated with SOI and previous work (e.g. Cane *et al*., 1994), it is not surprising that the maize indices MaizeIndex_(A,B,C) (which are weighted averages of total rainfall) calculated for the three planting dates all show significant positive correlations with SOI (example of MaizeIndex_A given in figure 9a). We also found significant negative correlations over Zimbabwe between maize indices based on later planting (MaizeIndex_B and MaizeIndex_C) and November AAO (example shown in Figure 9b), emphasising that the correlations in Figure 8b may affect end of season rainfall sufficiently to also affect the maize index for the two later planting dates. Therefore both SOI, through changes in the frequency of rain days during the season, and AAO, through changes in rain days towards the end of the season, can affect the amount of

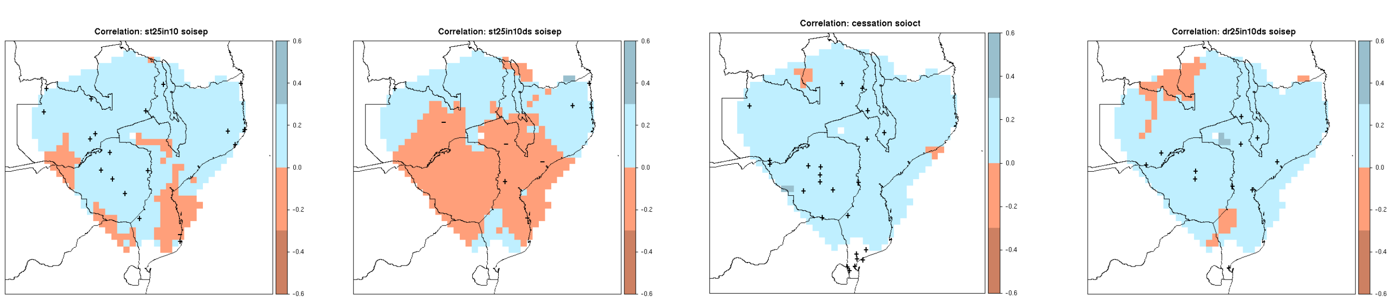

Figure 6: Correlations between a) September SOI and Planting_A, b) September SOI and Planting_B, c) October SOI and Cessation, d) September SOI and Duration_B. Significant correlations marked with "+"/"-".

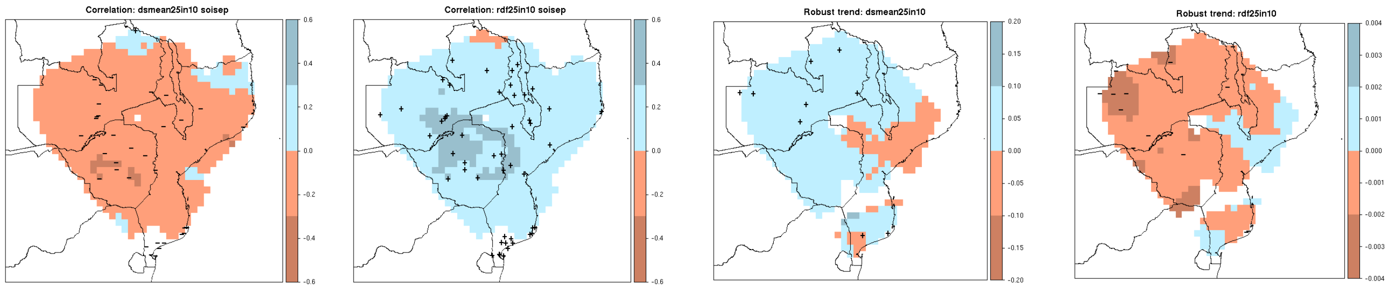

Figure 7: Correlations of within-season a) mean dry spell length (DrySpellMean_A) and b) rain day frequency (RainDayFr_A) with September SOI. Trends of c) DrySpellMean_A (days year-1) and d) RainDayFr_A (year-1) 1960-2005. Significant correlations/trends marked with "+"/"-".

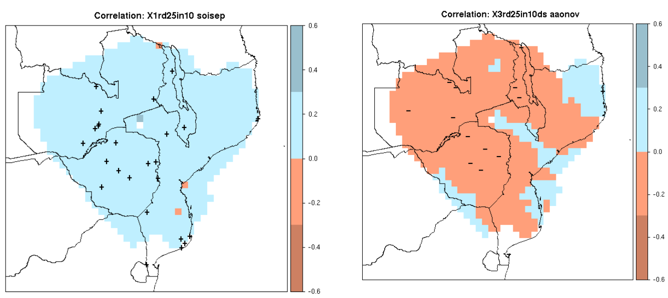

Figure 8: Correlations between a) September SOI and GermRainDayFr_A, b) November AAO and RipeRainDayFr_B. Significant correlations marked with "+"/"-".

useful rainfall for growing maize. As with all other rainfall indices, the strength of these relationships depends on location and planting date.

5. Projected changes under anthropogenic climate change

Noting the previously observed changes, we now seek to compare them with rainfall projections for the late 21st century, projected using both the empirical and RCM downscalings detailed earlier. The locations of available empirically downscaled stations are presented in Figure 10. Monthly anomalies (change between modelled future and control periods) of total rainfall and number of raindays for six stations, which span the region, and which are indicated by their WMO codes in Figure 10, were calculated and are presented in Figures 10 and 11. The empirical downscalings of the 6 GCMs are shown as boxplots for each month, whereas the two RCM downscalings are presented as blue and red dots. The purpose of presenting both datasets and their comparison is the following: 1) All downscalings agree on the sign of change indicating significant confidence in the sign of change; 2) Collectively the RCMs disagree on the sign of the change compared to the range of empirical downscalings (i.e. the two RCMs agree on a –ve/+ve change which is the opposite to that indicated by the range of the empirical downscalings). This implies that the downscaling method (empirical vs. RCM) has a bearing on the result and suggests significant caution in the interpretation; 3) One RCM disagrees on the sign of the change compared to the other RCM and all empirical downscalings. This implies reasonable confidence as it shows that an RCM can be reasonably configured to give the same sign change as the empirical downscalings; 4) There is no consensus between the empirical downscalings, suggesting that no confidence can be attached to either a +ve or –ve change.

Figure 10 presents the downscalings for the three most northern selected stations, representing an approximately west to east transect. For the northwestern-most station (67475), the empirical downscalings indicate an increase in late summer (April-May) total rainfall and number of rain days. During the early summer period (September – December) the sign of the projected change is less clear with 2-4 models projecting both positive and negative changes. The projections from the RCMs generally fall within the bounds of the empirical projections, though they indicate significantly smaller increases in rainfall during April-May. Further east over Malawi (station 67586) increased rainfall (both total and number of rain days) is also simulated during the January-May period, with early summer changes being less consistent - October (the beginning of the rainfall season)

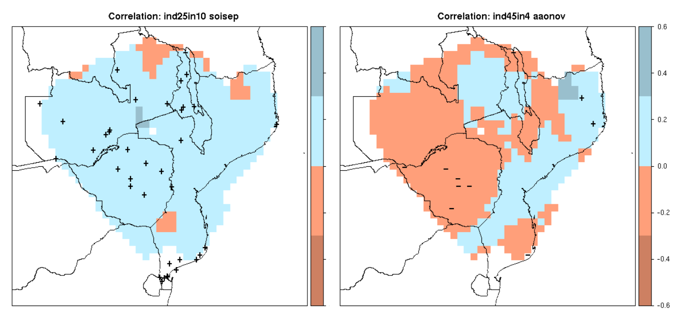

Figure 9: Correlations between a) September SOI and MaizeIndex_A, b) November AAO and MaizeIndex_C. Significant correlations marked with "+"/"-".

Figure 10: The study area indicating stations for which empirically downscaled precipitation data is available (indicated by tack symbol). Identification number indicates those for which data presented in figure 10. Figure background image courtesy of NASA earth observatory.

indicates a decrease in rainfall, with one RCM consistently projecting a decrease in rainfall. Further east over northern Mozambique (station 67223) an increase in rainfall is projected for all months by all empirical downscalings and at least one RCM, indicating a wetter early rainfall season than further west.

The three stations further south (67633, 67867 and 67315) are presented in Figure 11 and all three stations indicate similar late summer wetting during the March-May period (especially in number of rain days) in the empirical downscalings. Again projected change during early summer is relatively inconsistent in the empirical downscaling. During this period there is a tendency to project negative changes in rain days, except for the easterly station, which indicates increases in rainfall during all months, much like the station in northern Mozambique. However this is clearly at odds with the changes projected from both RCMs which cautions against these increases. The most westerly station (67633) projects an undetermined change in the empirical downscalings but the RCMs indicate a decrease for several months during September to December – this station by being further towards the west is closer to the region influenced by projected increases in high-pressure anomalies within the GCM forcing data (Hewitson *et al*., 2006), which will increase the likelihood of dry days.

The empirical downscalings indicate some consistent changes across all locations (increases in late summer rainfall, of greater magnitude towards the north) and some that are less consistent in particular locations and times e.g. mostly undetermined changes during early summer towards the east. It is also apparent that the timing of greatest increases in rainfall during summer tend to come earlier for stations located further east. Each RCM often responds quite differently to the same GCM forcing and, as mentioned earlier, this is at least partly because they both simulate different hydrological cycles. There is, however, some consistency during the early summer period (September–December) where both RCMs suggest a reduction in the number of rain days over most regions. This suggests a later onset of consistent rainfall. Whilst it is not possible to directly connect these results with the observed changes presented earlier, they are reasonably consistent with the observed trends for later planting dates. Importantly the RCM downscalings do not contradict the projected

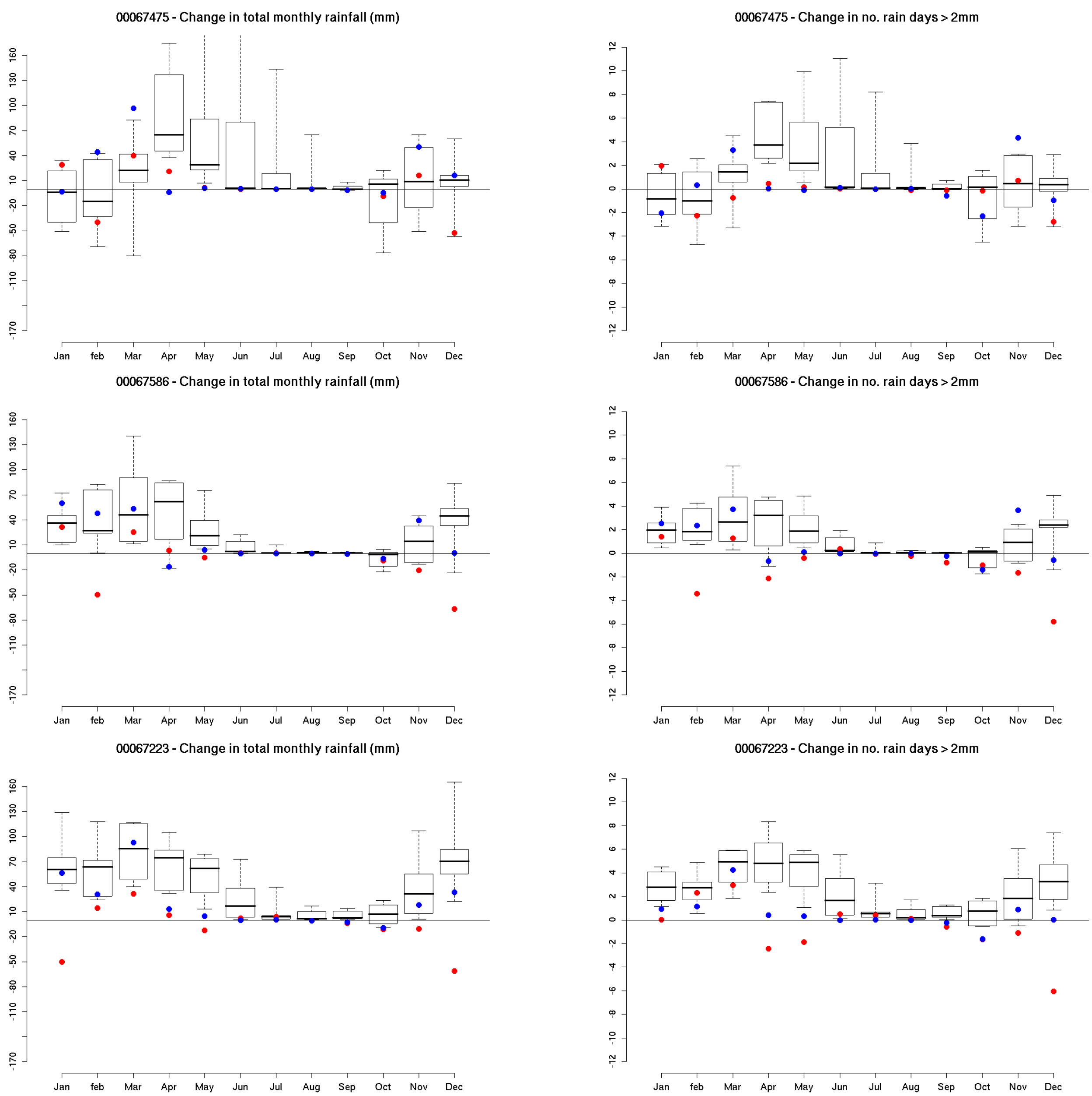

Figure 11: Projected change (Future - Control) in rainfall at selected northern stations (going from west to east) for empirical downscaling of 6 GCMs (boxplots) and two RCM downscaling of one GCM (blue/red dots); a) total monthly rainfall, b) monthly number of rain days >2mm.

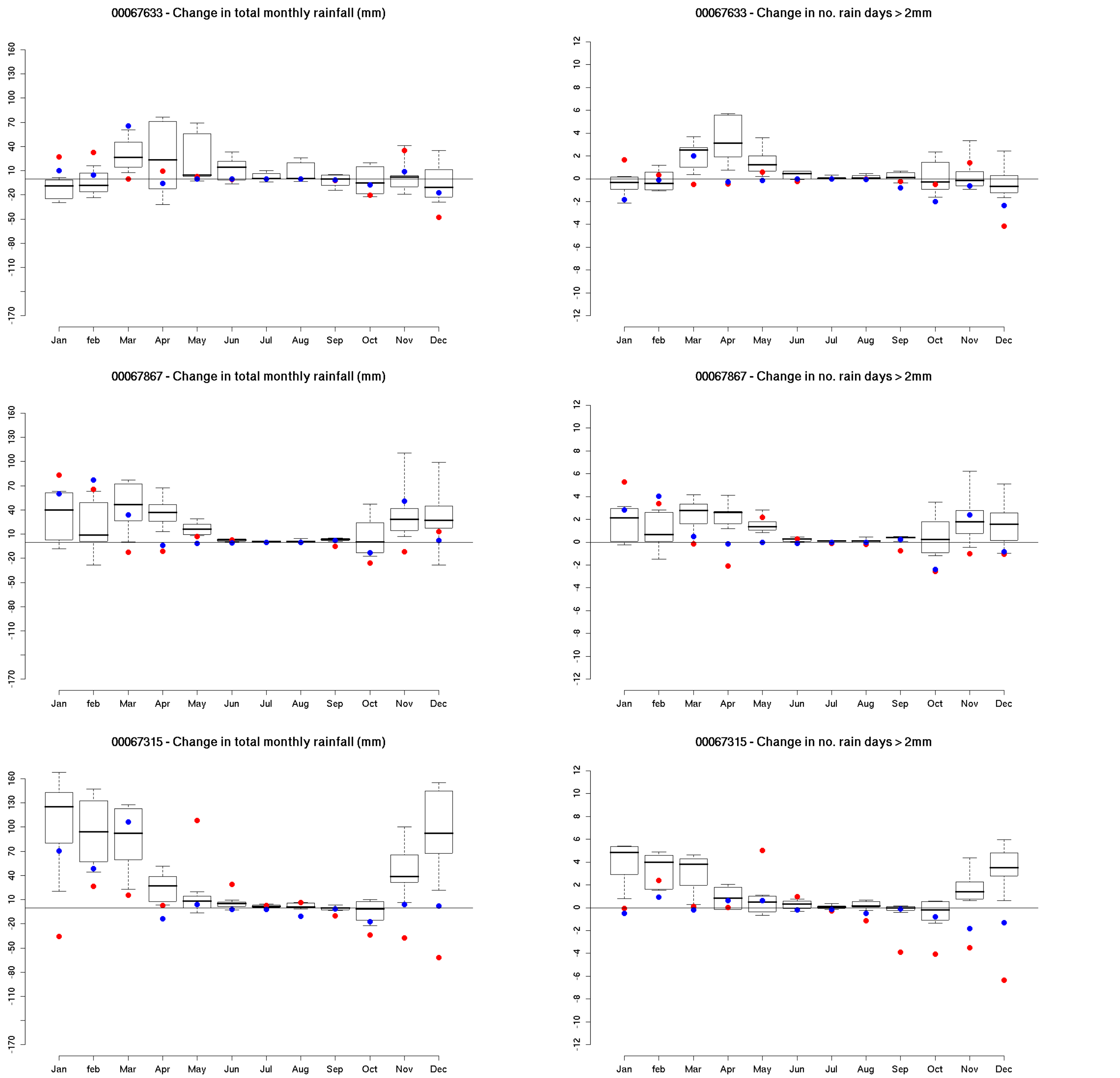

Figure 12: Projected change (Future - Control) in rainfall at selected southern stations (going from west to east) for empirical downscaling of 6 GCMs (boxplots) and two RCM downscaling of one GCM (blue/red dots); a) total monthly rainfall, b) monthly number of rain days >2mm.

increases in late summer rainfall indicated in the empirical downscalings. During early summer the comparison is less clear - potentially dynamical downscalings may capture processes and feedbacks not present in the empirical downscaling e.g. land surface – boundary layer interactions.

6. Summary

We have calculated indices designed to measure aspects of intra-seasonal rainfall variability related to maize cropping over southeastern southern Africa. This analysis has proceeded from three definitions of planting dates and a single definition of rainfall cessation. It has been demonstrated that there have been weak trends for later planting and earlier cessation dates in the north, which has generally led to shorter rainfall seasons This is especially significant over southern Zambia as the duration of the rainfall season is close to critical thresholds (for planting 130-day maize cultivars), which is an incentive for farmers to plant as early possible. Trends between 1960 and 2005 for shortened rainfall seasons at Livingstone station show that although trends are insignificant they lead to more frequent failure to cross critical thresholds of seasonal duration required for maize cultivation.

Climate variability, through both the AAO and ENSO (SOI), is also demonstrated to be an important additional pressure, altering the character of the cropping season in fundamental ways. Over much of the region a negative SOI (El-Nino) is associated with an early start to the season (using Planting criteria A), though not necessarily with consistent rain – a direct result of an increase in the number of dry days and mean dry spell length. Generally, there is also an early Cessation, which places added strain on farmers who are now faced with a shorter season of less consistent rain, which the temptation to plant early. Under these circumstances it is easy to see how crop failure is a regular occurrence during El-Nino. With the thresholds in seasonal duration and trends for later planting dates noted above making it increasingly more difficult – essentially the window of useful rainfall for maize cropping appears to be shrinking in the north where climate variability may then impact cropping more frequently. An additional rainfall factor that may also be important when planting late, and the cropping season extends into late summer/early autumn, is the mode of the AAO. If it promotes more rainfall during the ripening phase this may have negative consequences for crop development, though the phase of the AAO has been tending towards conditions that reduce rainfall. Whilst this is now beneficial, continued trends for later planting may eventually result in reduced rainfall during the growth phase, which will have a negative impact on crop yield.

Increases in mean dry spell length and reductions in rain day frequency are also demonstrated over Zambia, Malawi and Zimbabwe during the rainfall season (as defined from planting date to rainfall cessation). That this is true particularly when the planting date is taken at its earliest (ignoring false starts) suggests that changes are occurring at the beginning of the season, reinforcing the evidence that the start of consistent rainfall for planting has been getting later over these regions. These observations are also consistent with regional trends (noted within the literature) for later onset, an increase in the frequency of high pressures over the continent and increased length of the dry season.

Empirically downscaled climate change scenarios, for six representative stations spanning the region, suggest that increases in late summer rainfall (total and number of rain days) can be expected over widespread areas. However, empirical downscalings for early summer are relatively uncertain, depending on location; some GCMs suggest positive changes in rainfall and others negative changes. There is an indication that further north and east these changes tend to be mostly positive, tending to be more negative further west. The RCM downscalings of a single GCM mostly depend on the choice of RCM and the characteristics of the hydrological cycle each simulates. However, both RCMs tend to agree on increases in late summer rainfall, consistent with the results from the empirical downscaling, though changes during early summer are often less certain.

Allowing for the large uncertainty in changes simulated under CO_2 induced anthropogenic climate change, the projected changes are not at odds with those changes noted in the observational record, though statements of attribution are not possible. Indeed rainfall changes under climate change may not be apparent for 70+ years (Christensen *et al*., 2007). However, observed changes are significant and important, especially to those involved in agriculture. In this regard it should be noted that there have been documented increases in temperature (which are expected to continually increase in the future) over these same regions, which will place additional water-related stresses on agriculture even without any change in rainfall. Changes in factors such as land-use and multidecadal climate factors can all have a bearing on observed trends, and even CO_2 induced climate change alone may be nonlinear – reductions in raindays may be counteracted by increases in rainfall intensity and it is the relative strength of competing processes, at different timescales moving into the future, that will determine changes found in the observational record. Understanding which of these changes may occur in tandem with each other, at different locations, is key to the implementation of successful adaptation strategies.

Acknowledgements

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Bibliography

Ati, F. O., C. J. Stitger and E. O. Oladipo (2002). A comparison of methods to determine the onset of the growing season in northern Nigeria. International Journal of Climatology 22: 731-742.

Buckland, R., G. Eele and R. Mugwara (2000). Humanitarian crises and natural disasters: a SADC perspective. Food and Human Security. E. Clay and O. Stokke. London, Frank Cass Publishers.

Cane, M. A., G. Eshel and R. W. Buckland (1994). Forecasting Zimbabwean maize yield using eastern equatorial Pacific sea-surface temperature. Nature 370(6486): 204-205.

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R. K. Kolli, W.-T. Kwon, R. Laprise, V. M. Rueda, L. Mearns, C. G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton (2007). Regional Climate Projections. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manninget al. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

Dennet, M. D. (1987). Variation in rainfall - the background to soil and water management in dryland regions. Soil Use and Management 3(2): 47-57.

Doorenbos, J. and W. O. Pruitt (1977). Crop Water Requirements. Irrigation and drainage paper No. 24. Rome, Food and Agricultural Organization of the United Nations: 144.

FAO (2004). Drought impact mitigation and prevention in the Limpopo River Basin: A situation analysis. Land and Water Discussion Paper 4. Rome, Food and Agricultural Organisation of the United Nations.

Grell, G. A., J. Dudhia and D. R. Stauffer (1994). A description of the fifth-generation Penn State-NCAR mesoscale model (MM5). NCAR Technical Note NCAR/TN-398+STR. pp 117

Hewitson, B. C. and R. G. Crane (2006). Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. International Journal of Climatology 26(10): 1315-1337.

Hewitson, B. C., M. A. Tadross, A. Sarr, S. Jain, M. Mdoka, C. Jack, N. McKellar, R. Walawege, J. Intsiful, W. J. J. Gutowski, R. G. Crane and M. Stendel (2006). The development of regional climate change scenarios for sub-sahara Africa. Assessment of Impacts and Adaptation to Climate Change project AF07 (http://www.aiaccproject.org/Final%20Reports/final_reports.html). START secretariat, Washington DC, US. pp 115

Hulme, M., R. Doherty, T. Ngara, M. New and D. Lister (2001). African Climate Change: 1900-2100. Climate Research 17(2): 145-168.

Jones, R. G., M. Noguer, D. C. Hassell, D. Hudson, S. S. Wilson, G. J. Jenkins and J. F. B. Mitchell (2004). Generating high resolution climate change scenarios using PRECIS. Met Office, Hadley Centre, Exeter, UK. pp 40

Kurukulasuriya, P., R. Mendelsohn, R. Hassan, J. Benhin, T. Deressa, M. Diop, H. M. Eid, K. Y. Fosu, G. Gbetibouo, S. Jain, A. Mahamadou, R. Mano, J. Kabubo-Mariara, S. El-Marsafawy, E. Molua, S. Ouda, M. Ouedraogo, I. Se´ne, D. Maddison, S. N. Seo and A. Dinar (2006). Will African agriculture survive climate change? World Bank Economic Review.

Lindesay, J. A. (1988). South African rainfall, the Southern Oscillation and a Southern Hemisphere semiannual cycle. Journal of climatology 8: 17-30.

Marshall, G. J., P. A. Stott, J. Turner, W. M. Connolley, J. C. King and T. A. Lachlan-Cope (2004). Causes of exceptional atmospheric circulation changes in the Southern Hemisphere. Geophysical Research Letters 31. L14205, doi:10.1029/2004GL019952

Mason, S. J. (1995). Sea surface temperature - South African rainfall associations, 1910-1989. International Journal of Climatology 15: 119-135.

New, M., B. Hewitson, D. B. Stephenson, A.Tsiga, A. Kruger, A. Manhique, B. Gomez, C. A. S. Coelho, D. N. Masisi, E. Kululanga, E. Mbambalala, F. Adesina, H. Saleh, J. Kanyanga, J. Adosi, L. Bulane, L. Fortunata, M. L. Mdoka and R. Lajoie (2006). Evidence of trends in daily climate extremes over southern and west Africa. Journal of Geophysical Research 111. D14102, doi:10.1029/2005JD006289

Obasi, G. O. P. (2005). The impacts of ENSO in Africa. Climate Change and Africa. P. S. Low. Cambridge, UK, Cambridge University Press.

Peterson, T. C., M. A. Taylor, R. Demeritte, D. L. Duncombe, S. Burton, F. Thompson, A. Porter, M. Mercedes, E. Villegas, R. S. Fils, A. K. Tank, A. Martis, R. Warner, A. Joyette, W. Mills, L. Alexander and B. Gleason (2002). Recent changes in climate extremes in the Caribbean region. Journal of Geophysical research 107(D21): 161-169. 4601, doi:10.1029/2002JD002251

Raes, D., A. Sithole, A. Makarau and J. Milford (2004). Evaluation of first planting dates recommended by criteria currently used in Zimbabwe. Agricultural and Forest Meteorology 125: 177-185.

Reason, C. J. C., S. Hachigonta and R. F. Phaladi (2005). Interannual variability of rainy season characteristics over the Limpopo region of southern Africa. International Journal of Climatology 25: 1835-1853.

Reason, C. J. C. and M. Rouault (2002). ENSO-like decadal patterns and South African rainfall. Geophysical Research Letters 29(13). doi: 10.1029/2002GL014663

Reason, C. J. C. and M. Rouault (2005). Links between the Antarctic Oscillation and winter rainfall over western South Africa. Geophysical Research Letters 32. L07705, doi:10.1029/2005GL022419

Richard, Y., S. Trzaska, P. Roucou and M. Rouault (2000). Modification of the southern African rainfall variability/ENSO relationship since the late 1960s. Climate Dynamics 16: 883-895.

Smale, M. and T. S. Jayne (2003). Maize in Eastern and Southern Africa: “Seeds” of success in retrospect. Conf. “Successes in African Agriculture”, Pretoria, South Africa, InWEnt, IFPRI, NEPAD, CTA.

Stott, P. A., G. S. Jones and J. F. B. Mitchell (2003). Do models underestimate the solar contribution to recent climate change? Journal of climate 16(24): 4079-4093.

Tadross, M. A., W. J. J. Gutowski, B. C. Hewitson, C. J. Jack and M. New (2006). MM5 simulations of interannual change and the diurnal cycle of southern African regional climate. Theoretical and Applied Climatology 86: 63-80. doi 10.1007/s00704-005-0208-2

Tadross, M. A., B. C. Hewitson and M. T. Usman (2005). The interannual variability of the onset of the maize growing season over South Africa and Zimbabwe. Journal of climate 18(16): 3356-3372.

Tadross, M. A., C. Jack and B. C. Hewitson (2005). On RCM-based projections of change in southern African summer climate. Geophysical Research Letters 32(23). L23713, doi 10.1029/2005GL024460

Usman, M. T., E. Archer, P. Johnston and M. Tadross (2005). A conceptual framework for enhancing the utility of rainfall hazard forecasts for agriculture in marginal environments. Natural Hazards 34: 111-129.

Usman, M. T. and C. J. C. Reason (2004). Dry spell frequencies and their variability over southern Africa. Climate Research 26: 199-211.

Washington, R. and M. Todd (1999). Tropical-temperate links in southern African and southwest Indian Ocean satellite-derived daily rainfall. International Journal of Climatology 19: 1601-1616.

Appendix 1

Station name, location, country and available period of daily rainfall data.

Station name	Latitude	Longitude	Altitude	Period	Country
Karonga	-9.88	33.95	529	1961-2005	Malawi
Mzuzu	-11.43	34.02	1254	1961-2005	Malawi
Mzimba	-11.9	33.6	1349	1933-2005	Malawi
Kasungu	-13.02	33.47	1058	1961-2005	Malawi
Salima	-13.75	34.58	512	1954-2005	Malawi
Kamuzu	-13.78	33.78	1229	1961-2005	Malawi
Chitedze	-13.97	33.63	1149	1961-2005	Malawi
Chileka	-15.67	34.97	767	1949-2005	Malawi
Bvumbwe	-15.92	35.07	1146	1961-2005	Malawi
Chipata	-13.55	32.58	1140	1945-2002	Zambia
Choma	-16.85	27.07	1200	1951-2002	Zambia
Kabompo	-13.6	24.2	1100	1961-2002	Zambia
Kabwe	-14.45	28.47	1140	1951-2002	Zambia
Kafiro	-12.6	28.12	1243	1967-2002	Zambia
Kafue	-15.75	28	1140	1957-2002	Zambia
Kaoma	-14.8	24.8	1120	1961-2002	Zambia
Kasama	-10.22	31.13	1300	1933-2002	Zambia
Kasempa	-13.53	25.25	1160	1938-2002	Zambia
Livingstone	-17.82	25.82	960	1932-2002	Zambia
Lundazi	-12.28	33.2	1280	1956-2002	Zambia
Lusaka02	-15.33	28.43	1200	1967-2002	Zambia
Lusaka01	-15.41	28.31	1252	1950-2002	Zambia
Mansa	-11.1	28.85	1140	1960-1998	Zambia
Mbala	-8.85	31.33	1660	1961-2002	Zambia
Mongu	-15.25	23.15	1060	1935-2002	Zambia
Mt_Makulu	-15.55	28.25	1160	1961-2002	Zambia
Mpika	-11.9	31.6	1180	1932-2000	Zambia
Mwinilunga	-11.75	24.43	1340	1950-2002	Zambia
Ndola	-13	28.65	1280	1942-2002	Zambia
Serenje	-13.23	30.22	1384	1957-2001	Zambia
Sesheke	-17.47	24.3	960	1950-2002	Zambia
Solwezi	-12.18	26.38	1400	1961-2002	Zambia
Zambezi	-13.53	23.12	1080	1953-2002	Zambia
Mocimboa_da_Praia	-11.35	40.37	27	1951-2005	Mozambique
Montepuez	-13.13	39.03	534	1951-2001	Mozambique
Mecufi	-13.28	40.57	10	1951-1991	Mozambique
Namara_Balama	-13.35	38.57	597	1955-1991	Mozambique
Manjacaze	-24.72	33.88	65	1951-2001	Mozambique
Chibuto	-24.68	33.53	90	1951-2000	Mozambique
Macia	-25.03	33.1	56	1951-2002	Mozambique
Xai_Xai	-25.05	33.63	4	1951-2004	Mozambique
Maniquenique	-24.73	33.53	13	1951-2003	Mozambique
Praia_do_Bilene	-25.45	33.25	20	1958-1999	Mozambique
Chokwe	-24.55	33	33	1961-2004	Mozambique
Inhambane	-23.86	35.38	14	1951-2003	Mozambique
Inharrime	-24.38	35.02	43	1951-2004	Mozambique
Morrumbene	-23.67	35.37	22	1951-1996	Mozambique
Nhacoongo	-24.3	35.18	30	1951-1998	Mozambique
Panda	-24.05	34.72	150	1951-1999	Mozambique
Quissico_Zavala	-24.72	34.75	147	1951-1996	Mozambique
Vilanculos	-22	35.32	20	1951-2001	Mozambique
Massinga	-23.32	35.4	109	1951-2004	Mozambique
Inhamussua	-23.9	35.23	37	1951-1996	Mozambique
Chimoio	-19.12	33.47	731	1951-2003	Mozambique
Messambuzi	-19.5	32.92	966	1951-1999	Mozambique
Sussundenga	-19	33.23	620	1969-1999	Mozambique
Maputo_Observatorio	-25.97	32.6	60	1927-2004	Mozambique
Namaacha	-25.98	32.02	523	1911-1990	Mozambique
Umbeluzi_Agricola	-26.05	32.38	12	1924-2005	Mozambique
Manhica	-25.37	32.8	35	1951-2000	Mozambique
Inhaca	-26.03	32.93	27	1954-2000	Mozambique
Chobela	-25	32.73	15	1941-2000	Mozambique
Maputo_Mavalane	-25.92	32.57	39	1956-2004	Mozambique
Changalane	-26.3	32.18	100	1962-2004	Mozambique
Benfica	-25.92	32.57	37	1970-2000	Mozambique
Sabie	-25.32	32.23	80	1951-1991	Mozambique
Ilha_de_Mocambique	-15.03	40.73	9	1955-1991	Mozambique
Namapa	-13.72	39.83	200	1961-1998	Mozambique
Ribaue_Agricola	-14.98	38.27	535	1955-1999	Mozambique
Angoche	-16.22	39.9	61	1951-2001	Mozambique
Meconta	-14.98	39.85	235	1951-1997	Mozambique
Nampula_Agricola	-15.15	39.33	432	1951-1998	Mozambique
Muecate	-14.9	39.63	280	1951-2001	Mozambique
Mossuril	-14.95	40.67	15	1951-1999	Mozambique
Mecuburi	-14.65	38.75	468	1951-2000	Mozambique
Lumbo	-15.03	40.67	10	1956-2001	Mozambique
Nampula	-15.1	39.28	438	1956-2003	Mozambique
Maniamba	-12.77	34.98	1	1951-2000	Mozambique
Cuamba	-14.82	36.53	606	1951-2001	Mozambique
Lichinga	-13.3	35.23	1364	1951-2003	Mozambique
Marrupa	-13.73	37.55	836	1951-1996	Mozambique
Beira_Observatorio	-19.83	34.85	7	1955-1999	Mozambique
Tete	-16.18	33.58	149	1952-2005	Mozambique
Quelimane	-17.58	36.58	6	1951-2004	Mozambique
Errego_Ile	-16.03	37.18	533	1951-1990	Mozambique
Mapai	-22.06	32.05	254	1956-1999	Mozambique
Beira_Aeroporto	-19.8	34.54	8	1972-2003	Mozambique
Inhassune	-24.23	32.7	48	1971-1999	Mozambique
Manhica_Maragra	-25.45	32.8	100	1970-1997	Mozambique
Harare	-17.83	31.02	1471	1900-2003	Zimbabwe
Bulawayo	-20.15	28.51	1343	1920-2003	Zimbabwe
Kadoma	-18.32	29.88	1149	1951-1993	Zimbabwe
Karoi	-16.83	29.62	1343	1951-1990	Zimbabwe
Kwekwe	-18.93	29.83	1213	1951-2003	Zimbabwe
Masvingo	-20.07	30.87	1094	1951-2003	Zimbabwe
Nyanga	-18.28	32.75	1878	1951-2003	Zimbabwe
Rusape	-18.37	32.13	1430	1962-1998	Zimbabwe
Beitbridge	-22.22	30	456	1922-2003	Zimbabwe
Gweru	-19.45	29.85	1428	1944-2003	Zimbabwe

Analysis of Potential Coastal Zone Climate Change Impacts and Possible Response Options in the Southern African Region

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Abstract

The aim of this paper is to estimate realistically physical coastal zone impacts due to expected climate change and provide some mitigating response options. The Namibia, South Africa and Mozambique coastal region is considered.

The primary effects of climate change (CC) in the coastal zone are discussed, e.g. potential modification in storminess and sea level rise (SLR). The latest SLR projections, accelerated SLR, and applicability to southern Africa are reviewed. Estimates are presented of present and future extreme inshore sea water levels. Potential changes in local wave conditions and sediment transports are explored.
Some issues associated with thresholds and complexities of coastal processes and effects are identified. How impacts will vary depending on diversity of the coastline is discussed. This is also linked to the resilience afforded by certain natural features and processes. Some of the most vulnerable areas and local issues are identified in Namibia, South Africa and Mozambique. Possible responses and guidelines to mitigate CC impacts are presented, including coastal vulnerability indicators and some coastal management and development guidelines.

1. Background

The threat posed by global warming (Stern, 2006) is at present finally being generally recognised at many levels of society (public and private). (The recent awarding of 2 Oscars to the "Global Warming documentary" film made by Al Gore, is another case in point.) Since the 1970s the "greenhouse effect" and sea-level rise have continued to generate interest and concern. Coupled with this have often been dramatic predictions of massive coastal impacts (e.g. Hughes and Brundrit, 1990). The potential impacts of sea-level rise (in terms of shoreline recession) have also been considered (e.g. Bruun, 1983, 1988). Climate change (CC) and sea level rise (SLR) potentially have far-reaching consequences for southern Africa's coastal provinces where the great majority of the population live and work in, or near, the coastal zone (Midgley, et al 2005). More than 37 % of the global population live within 100 km of the coast (Syvitski, et al 2005). Similarly, more than thirty percent of South Africa's population currently lives near the coast, with an even higher proportion in Mozambique (about 60%). More than eighty percent of the southern African coastline comprises of sandy shores susceptible to large variability and erosion. Due to the expected impacts and the uncertainty of sea-level rise predictions, more comprehensive studies into the potential effects/impacts are required (IPCC, 2001). In the UK, for example, CC scenarios looked 30-80 years ahead; even in that timescale, damage due to coastal erosion is set to increase by 3 to 9 times (Allsop, 2005).

The focus area of this paper is the southern African coastline of Namibia, South Africa and Mozambique (Figure 1 below).

Figure 1: Study area - coastline of Namibia, South Africa and Mozambique

2. Sea level rise (SLR) and potential modification in storminess

2.1 Main causes of SLR

One of the observed impacts of Global Warming is sea level rise. The main causes of eustatic sea level rise are (IPCC, 2007):

- Thermal expansion of the oceans.
- Melting of glaciers and ice caps.
- Increased ice discharge from Greenland and Antarctic ice sheets.

2.2 Latest SLR projections

The observed sea level rise in the period 1950 to 2000 was 1.8 +/- 0.3 mm/y (Church et al, 2004). Recent observations from satellites, very carefully calibrated, are that sea level rise 1993-2003 is 3.1+/- 0.7 mm/y (Cazenave and Neren, 2004), while the latest data give sea level rise of 3.3+/- 0.4 mm/y in 1993-2006 (Rahmstorf et al, 2007). About 85% of this rise can be explained by known mechanisms, mainly thermal expansion and ice melting (the latter is responsible for 0.76 +/- 0.14 mm/y). Figure 2 below depicts measured and predicted SLR for the 1800 - 2100 period (relative to 1990), according to the just released IPCC WGI Fourth Assessment Report (AR4 -IPCC, 2007).

The IPCC AR4 Report (IPCC, 2007) predicts that the rise of global average sea level by 2100 will be in the range from 0.18 to 0.59 m depending on the emissions scenario. This report also concludes that anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized.

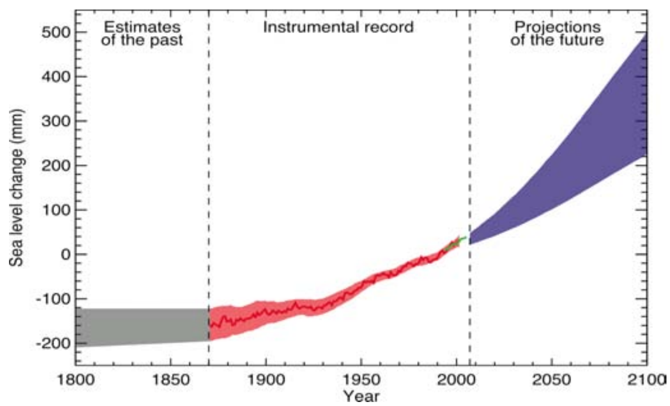

Figure 2: Measured and predicted SLR for 1800 - 2100 (IPCC, 2007)

Rahmstorf (2006) presented a semi-empirical relationship that connects global sea-level rise to global mean surface temperature. His relationship results in a projected sea-level rise in the order of twice the IPCC recommended range. Rahmstorf also concluded that the uncertainty in future sea-level rise is probably larger than previously estimated.

2.3 Regional estimates of SLR for southern Africa

Church et al, (2004), identified a regional pattern of sea level rise: the maximum sea level rise is in the eastern off-equatorial Pacific and there is a minimum along the equator, in the western Pacific, and in the eastern Indian Ocean. Also, the trends are lower in the east Atlantic than in the west (as suggested by various other authors). According to Church et al, (2004), the regional distribution of sea level rise between 1950 and 2000 from reconstructed sea level fields using tide gauge data, shows SLR of about 1 to 2.5 mm/y for the Namibia-South Africa-Mozambique region.

Park (2006), found that the Atlantic Ocean shows the most homogeneous field of sea level trends and is associated with weak positive trends in general, while in the Indian Ocean negative trends are dominant. The Southern Ocean south of 40°S shows noticeable positive trends in most places: over the 1993-2000 period, the mean sea level trend is estimated at 2.34 ± 0.34 mm/yr.

Comparisons between about 30 years of South African tide gauge records and the longer term records elsewhere, show substantial agreement. This means that the global records from tectonically stable areas can be used with confidence to extend the trends to southern Africa (Hughes et al 1991). Brundrit (1995), also concluded that estimates of future rise in sea level attributable to global warming can be extrapolated to the coasts of Namibia and South Africa (SA). A recent analysis of sea water levels recorded at Durban confirms that the local rate of sea level rise falls within the range of global trends (Mather pers com, 2007).

Eustatic sea level rise is a very slow process that is difficult to discern (at this stage) due relatively much greater shorter term variability (e.g due to weather events or ENSO/La Nina ocean dynamics) and other changes (e.g. land subsidence or tectonic uplift). Thus, it is recommended that the general trend for southern Africa (based on the water level recordings of the major regional ports and/or satellite altimetry data) be evaluated every 15 to 20 years by scientists competent in the field. A review should therefore be conducted by 2010.

2.4 Accelerated SLR

The IPCC WGI Fourth Assessment Report (2007) states that it is unclear whether the faster rate for 1993 to 2003 (compared to 1961 to 2003) reflects decadal variability or an increase in the longer-term trend. This IPCC report also found that there is high confidence that the rate of observed sea level rise increased from the 19th to the 20th century. The probability of sudden large rises in sea level (several metres) due to catastrophic failure of large ice-shelves (e.g. Church and White, 2006) is still considered unlikely this century, but events in Greenland (e.g. Gregory, 2004) and Antarctica (e.g., Bentley, 1997; Thomas et al, 2004) may soon force a re-evaluation of that assessment. The projections into the 21st century must be at least 3 mm/y, and probably more, given the acceleration observed. In the longer term the large-scale melting of large ice masses is inevitable.

2.5 Components of extreme inshore sea water levels

South Africa

Tides in South Africa are semi-diurnal with a total mean spring tide range of about 1.5 m (Saldanha) to 1.8 m (Durban; SAN, 2005). Spring tides occur approximately every 14 days. Highest astronomical tide (HAT) is predicted to be about 1.2 to 1.4 m above mean sea level (MSL). HAT is the highest predicted astronomical tide under average meteorological conditions over a full 19-year nodal cycle, and will not be reached every year.

Weather conditions and waves often cause set-up resulting in the actual water-level exceeding the tidal water-level (e.g. Jury et al., 1986). This can be further exacerbated by the extra high spring tides during equinox, as well as by the locally raised water levels due to a low-pressure weather system. Wind set-up at the coast due to onshore or alongshore winds is mainly a function of the slope of the sea-floor and the wind speed (e.g. Battjes, 1974). This phenomenon is amplified if the wind blows into a semi-enclosed bay such as False Bay, which is a large bay of about 35 km by 35 km in size, situated near Cape Town. For an onshore wind of 25 m/s (which is likely to occur a few times every year in the Western Cape), a wind set-up of 0.5 m was predicted at the shore of False Bay (CSIR, 1987a). For the 1 in 50 year wave height the wave set-up (super elevation of the water surface over normal water elevation due to onshore mass transport of the water by wave action alone) was calculated to be 1 m in False Bay (CSIR, 1987). Wave set-up (S) near the shoreline can be approximated by:

S = 0.15 to 0.2 x Hb (significant breaking wave height).

A summary of the different parameters and estimated effects is given in the table below.

Table 1: Parameters and estimated maximum effects on still-water levels for SA coast.

Parameters and effects	Elevations (m to MSL) and set-ups (+ m)
Mean high water spring tide	1
Highest Astronomical Tide (19 yr HAT)	1.4
Severe wind set-up	+0.5
Maximum hydrostatic set-up	+0.35
Wave set-up	+1
100 year sea-level rise (IPCC, 2007)	+0.2 to +0.6 (say 0.4)

Note, that the (as yet undetermined) potential other additional impacts of climate change (e.g. more extreme weather events) on wind- and hydrostatic set-up are not included in the above.

Adding all of these set-up effects (with possible values for wind set-up = 0.5 m) and sea-level rise of 0.4 m, to the highest astronomical tide, gives a probable maximum seawater level of 3.65 m MSL. However, the joint probability of all of these events occurring simultaneously would be extremely low. To accurately determine the elevations for different return periods and account for joint probabilities would require an in depth investigation beyond the scope of the present study. A very probable scenario would be to add the three set-up effects (which are not independent and do sometimes occur simultaneously to some degree) to the mean high water spring tide. If sea-level rise of 0.4 m is then added, a probable maximum seawater level of about 3.25 m MSL is predicted. (Similar results are obtained if HAT is combined with only two of the three set-up effects and sea-level rise is added.)

The above elevations all relate to the still-water level at the shoreline. This should not be confused with the additional effect of wave run-up, which can reach even higher elevations. Wave run-up is the rush of water in the swash zone up the beach slope above the still-water level. The wave run-up is mainly a function of parameters such as wave height and period, the surf zone width, type of wave breaking, the roughness, slope and permeability of the near and inshore profile (i.e. the rocks or beach), and the wave height distribution. A steeper beach slope, for example, leads to more severe wave run-up. The wave run-up exceeded for 2% of the time during a typical storm was calculated to be about 1.7 m in False Bay (CSIR, 1983a). The above effects are demonstrated by the fact that parts of the coastal road in the vicinity that have an elevation of +3.7 m to MSL are inundated on a few occasions every year.

Maximum run-up levels on the open Kwazulu-Natal (KZN) coast near Durban on the SA east coast during the March 2007 storm, which coincided with HAT, reached up to about + 10 m MSL (according to surveyed elevations - A Mather, pers com), or 9 m above mean spring tide. (Note that wave set-up and run-up are both accounted for in these levels.) The wave height recurrence period was found to be about 1-in-35 years, while the joint probability of recurrence of the wave height and tidal level (HAT) is estimated at more than 1-in-500 years (M Rossouw, pers com). Direct infrastructure damages alone resulting from this storm is estimated to be over R 400 million (see example in Figures 3 below). This storm is particularly significant, not just in terms of its severity, but also in that the joint probability of the events is extremely low at present. However, due to SLR, the tidal levels reached during this storm (19 yr HAT level) will effectively be reached during ordinary spring tides every 2 weeks by about 2100. This factor alone means that the potential return period of a similar event will be much reduced (i.e. occur more frequently). In addition, due to potentially increased sea storminess (through CC), similar storm wave heights could occur more often in future. The joint probability of such a future less extreme wave height with ordinary spring tides would be much higher relative to the extreme rarity of the same conditions occurring at present. In other words, the same conditions could potentially occur much more frequently in future

Figure 3: Example of impact of March 2007 Kwazulu-Natal storm. (Photo: D. Phelp)

due to SLR and increased sea storminess. The recent storm should perhaps serve as a timely warning of the potential impacts that could be incurred much more frequently in future due to CC effects.

Namibia and Mozambique

Tides at Walvis Bay and Luderitz In Namibia are semi-diurnal with spring tidal range of about 1.4 m and HAT of about 1 m above MSL; thus similar to, but slightly less (about 0.2 m) than those in SA.

Information from Oranjemund, at the southern border of Namibia indicates that run-up elevations of 4.1 m MSL are often reached, while run-up elevations of 4.7 m MSL are reached more occasionally. The average beach slope in this area is 1 in 17 with some slopes as steep as 1 in 9. (Note that wave set-up and run-up are both accounted for in these levels.) Based on this information, present extreme run-up levels are at least 5 m above MSL. This could increase by about 0.5 m by 2100 due to SLR alone (based on the IPCC (2007) recommended values of SLR). (Note, that climate change is expected to increase sea storminess, which would then also probably result in slightly higher maximum wave run-up levels. This has not been included.)

Extreme wave heights along the Namibian coast are in the same order, but slightly less than along the KZN coast of SA. The effect of the slightly lower maximum tidal levels and slightly lower extreme wave heights, means that in general, maximum run-up levels in Namibia will also be slightly lower than along the KZN coast. The fact that run-up levels of 10 m above MSL were recorded during the recent storm along the KZN coast, indicates that although this was a very exceptional event, a level of 5.5 m above MSL as determined above for Oranjemund, is perhaps not sufficiently conservative. As a general and very rough guideline for Namibian beach areas, it is suggested that an extreme run-up level of 6 to 8.5 m above MSL be considered in future planning.

Tides at Maputo in Mozambique are also semi-diurnal with a mean spring tide range of about 3 m. The maximum sea level at Maputo is reported to be about 2 m above MSL. The tidal range in Maputo Bay is greater than at locations to the south (e.g. Richards Bay on the north-eastern SA coast), and less than those to the north of Maputo, e.g. Beira, where the mean spring tidal range is about 5.6 m. Tidal variations in Mozambique are therefore much greater than in SA (double and more, partially due to the continental shelf and coastal configuration).

Meteorological data for the Maputo area indicates that the strongest winds are from the south, including gale-force winds, which may occur in any month of the year. Two cyclones of significance have come ashore near Maputo since 1950. Wind speeds well in excess of 30 m/s are to be expected when such rare events occur. Although cyclones rarely approach close to the coast, they could potentially result in extreme wind conditions with relatively large wind waves and significant elevation of the local water level.

It appears that while extreme wave heights along the Mozambican coast may be slightly lower than along the SA east coast, wind conditions off the Mozambican coast may be more extreme (due to cyclones). Thus, it is suggested that as a general and very rough guideline for Mozambican beach areas, an extreme run-up level in the order of 6 to 9 m above mean spring tide be considered in future planning. While this may appear too conservative for present planning of developments with relatively short design lifetimes (< 30 years), in the long run it should pay off, especially for more permanent developments with long design lifetimes (> 50 years).

2.6 Potential changes in local wave regime

The problem with sea level rise is not just the mean, which is now a relatively modest 3.1+/- 0.7 mm/y (e.g. Cazenave and Neren, 2004), but its interaction with changing storm intensities and wind fields to produce sea conditions which overwhelm existing infrastructure (e.g. Battjes, 2003; Houghton, 2005). This is a particularly important risk in the case of the highly exposed South African coastline, and a subject that up to now has been virtually unexplored, even internationally. Although a good general knowledge basis has been laid, there is thus a need for improved understanding of, and especially predictive capabilities regarding the interaction of sea level rise and increased storminess on coastal erosion.

The available information indicates that despite some possible trends in certain parts of the world, potential changes in oceanic wave regimes resulting from global warming are still very uncertain in all parts of the globe. Although various authors refer to a possible increase in sea storms or storminess (e.g. Hughes et al, 1991b) no quantification or estimated values are given for the southern African region. However, more information appears to be available regarding potential changes in regional wind regimes (albeit mostly qualitative). This enables an exploratory assessment of potential changes in regional wave regime, as the mechanisms for wave generation by oceanic wind fields are fairly well understood.

According to the IPCC WGI Fourth Assessment Report (February 2007), mid-latitude westerly winds have strengthened in both hemispheres since the 1960s. The IPCC report finds that it is likely that future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures (SSTs). Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation, and temperature patterns, continuing the broad pattern of observed trends over the last half-century.

According to Hewitson (2006), predicted changes in SA wind regime due to Global Warming are as follows: average wind velocity is expected to increase in all seasons. This does not mean all days will be windier, but that the prevailing wind will likely be stronger. This is associated with a stronger and more dominant south Atlantic high pressure system. The increases are most notable in coastal regions. While seemingly modest, these are changes in the average, and reflect a significant change for coastal areas.

Thus, despite the likelihood of stronger winds, predicted values for potential changes in wind regimes in the southern African region are lacking. In view of this shortcoming and to enable an assessment of the potential impacts of stronger winds, a relatively modest increase of 10% will be assumed.

Wave height (in the fully developed state) is proportional to the square of the wind stress factor (UA). UA is related to the wind speed (U) according to the following expression (US Army, Corps of Engineers, 1984):

$$UA = 0.71xU^{1.23}$$

Similarly, the wave period and duration are both directly proportional to the wind stress factor (US Army, Corps of Engineers, 1984).

Thus, a modest 10% increase in wind speed, means a 12% increase in wind stress and a 26% increase in wave height.

2.7 Potential changes in sediment transport

Based on the above, the effect of an increase in wind speed can also be calculated in terms of sediment transport rates. The effects on surf zone wave conditions of an increase in oceanic winds is much more complex than considered above, but these potential changes can never-the-less be used to obtain preliminary estimates of potential effects on sediment transport.

Application of one of the best alongshore sediment transport rate formulas, namely the Kamphuis formula (Schoonees and Theron, 1996), shows that the transport rate potentially increases by 60% due solely to the wave height increase predicted above, resulting from a 10% increase in wind speed. However, a 10% increase in wind speed also means a 12% increase in wave period, resulting in a total potential increase of 90% in the transport rate (based on the above formulations). If alternatively, one of the best known and most widely used formulas is similarly applied, namely the CERC formula (US Army, Corps of Engineers, 1984), the total potential increase in the alongshore sediment transport rate is calculated to be 80%, resulting from a 10% increase in wind speed.

Various well known cross-shore sediment transport formulas are based on wave energy or wave power concepts (for examples, see Schoonees and Theron, 1995).

The formula for wave energy (E) is as follows (US Army, Corps of Engineers, 1984):

$$E = 1/8 \rho g H^2$$

with:

ρ = water density in kg/m^3
g = acceleration due to gravity (9,81 m/s^2)
H = wave height in m

In other words, wave energy is proportional to the square of the wave height (which in itself, in the fully developed state, is proportional to the square of the wind stress factor). Thus, a modest 10% increase in wind speed, means a 60% increase in wave energy.

The wave power (or wave energy flux) per unit width along the wave crest is defined as the wave energy per unit water surface area, multiplied by the propagation speed of the energy, which is the so-called wave group velocity. The wave power per unit wave crest length (in deep water) is computed using the following equation:

$$Pw = 1/2E\ Cg$$

where :

Pw = wave power (W/m)
Cg = group velocity of the waves (m/s)

The group velocity is defined by the local water depth (d) and the wave period (T). In deep water, the group velocity reduces to $Cg = (g/4\pi)T$.

Therefore, with the wave period directly proportional to the wind stress factor, an increase of only 10% in wind speed means as much as an 80% increase in wave power. This means that a modest 10% increase in wind speed could also result in a potential increase in the order of 40% to 100% in the cross-shore transport rate.

The actual changes in both the alongshore and cross-shore sediment transport rates will also depend on other local factors, such as the effects of CC on each wave generating wind field, the availability of sediment to be transported and the 3-dimentional changes in the surf zone currents and beyond. The above scenario should be seen as a much simplified indication of potential effects of climate change on wave conditions and coastal sediment transports. The impacts on the overall wind, wave, current and transport regimes are much more complex. Other external, but linked systems will also be affected resulting in significant impacts on coastal dynamics. For example, climate change will affect rainfall and thus river runoff, in turn affecting catchment sediment yields and supply to the coast, which in the long-term will impact coastal sediment budgets and therefore also affect shoreline evolution.

3. Effects and impacts of climate change in the coastal zone

3.1 Effects on diverse types of coastlines

In assessing the erosion potential of the coastline for various areas and types of coastline, coastal areas must first be defined in terms of two main shoreline geographical characteristics, i.e. hard erosion-resistant shores, or sandy erodeable beaches. Hard, erosion-resistant shores are usually rocky or have been "artificially" armoured, e.g. revetments, seawalls, breakwaters, etc.

Hard shores will generally respond to sea level rise as follows: In most cases, there will be no noticeable erosion as such. However, the high-water line will still move landward according to the slope above the present high-water line. (This approach is based upon a rudimentary upward transferal of the existing profile.) For example, if the present slope is 1 in 10, then a rise of 0.2 m or 0.4 m (average values for 2050 and 2100 from IPCC, 2007) means a landward movement of 2 m or 4 m respectively. Slopes above the high-water line are often much steeper than those of the sub-aerial beach or nearshore profile. In most instances, the landward movement of the high-water line will only be in the order of a few metres. However, in a few unusual situations, where the slope above the high-water line is very flat, the landward movement could be in the order of 10s of metres. For example, if the slope is 1 in 100, then a rise of 0.2 m or 0.4 m means a landward movement of 20 m or 40 m respectively.

Cliffed coasts, consisting of hard (weather and wave resistant) rock, will tend to be impacted in the same manner as described above. Cliffed coasts consisting of softer material (prone to weather and wave erosion), are often already undergoing a slow long-term erosional tend. Although the high-water line would tend to respond in the same manner as for hard cliffs, sea level rise and especially increased storminess, may increase the rate of cliff retreat. A possible local example, is Swartklip (Northern False Bay coast), which has been reported as subject to slow long-term erosion.

The southern African coastline includes many sandy areas, which have no or very little hard protection and where the wave regime is regarded as high energy. This leads to a high potential for erosion of these sandy coastlines. The most widely known (and applied) formula for estimating recession as a result of sea-level rise was proposed by Bruun (1983, 1988). The main parameters that are taken into account in Bruun's unsophisticated rule are the amount of sea level rise and the slope of the nearshore. The implications for sandy coastlines of two scenarios of sea level rise of 20 and 40 cm are investigated using Bruun's erosion rule. Thus, sandy areas along the coastline with a steep nearshore slope are predicted to erode between about 5 m to 20 m for the given scenarios, while areas with relatively mild or flat nearshore slopes are predicted to erode between about 20 m to 80 m. (Stive, 2004 and Davidson-Arnott, 2003, present some of the few alternative and potentially better (although more involved) ways of assessing shoreline response to SLR.)

In some cases, broad dunes and wide beaches could mitigate such predicted erosion. In other situations narrower beaches backed by hardened dunes will resist erosion, resulting in less erosion than predicted by the Bruun rule. In fact, there are many types of coastal conditions where application of the Bruun rule is inappropriate (Cooper and Pilkey, 2004; Theron, 1994). Hands (1977) found that in areas having broad active profiles or low back shore, offshore or longshore sediments sinks, as well as in areas where the eroding backshore contains a large percentage of material that would be unstable as a nearshore deposit, the ratio of retreat to submergence would be even larger. Narrow active profiles, higher back shore sediment deposits, coarse grain sediments and increased supplies of sediment from outside the area considered will all tend to diminish the ratio of shore retreat to submergence.

In fact, a rise in eustatic sea level cannot be simply related to local coastal erosion. The sediment availability and the overall sediment budget are important. With an adequate supply of sediments having appropriate sizes for the littoral zone, beach accretion can prevail over modest rates of sea level rise. The retreat of the shore owing to a long-term increase in sea level is episodic rather than continuous, as it depends on sediment movement produced by storm waves and on associated processes such as storm surges. Thus, the shoreline response is sensitive to sediment supply and budgets. Many areas of the southern African coast are considered to be in a state of dynamic equilibrium, but with some known areas of progressive erosion (e.g. Langebaan Point in the Western Cape, SA), while very few areas are subject to accretion/progradation. The sediment supply and budget of the equilibrium areas are expected to be relatively sensitive to Global Change (climate, anthropogenic, etc) without substantial "reserves" and could easily be upset by progressive change.

Climate change impacts on the coast are also linked to the resilience afforded by certain natural features and processes, e.g. dunes, abundant/depleted sediment sources, etc. Encroachment by historical development has threatened and destroyed many dunes along our coastline. This is problematic as the dunes serve not only as a natural asset for biodiversity but also form an important coastal defence system. During high seas the dunes is eroded and the sand moves into an offshore bar. This causes storm waves to break on the bar and therefore reduces the energy and erosion potential of each breaking wave. Local and regional authorities need to initiate programmes to maintain this asset through scientific management.

3.2 Complexities, thresholds, discontinuities and non-linearities

One spatial threshold is determined by the width/elevation between present development and the high-water line; i.e. space for sea-level transgression up the coastal slope is fixed and has already run out in specific instances. Similarly, at present the surplus (or balance) in the sediment budget in certain coastal cells will probably be upset by a rise in sea-level exacerbated by an increase in wave energy, resulting in coastal erosion. However, there is also a spatial teleconnection between the marine/coastal system and the river catchments, where in some catchments more extreme weather events could lead to increased soil erosion (Schulze, 2005) and yield to the coast.

An example of the repercussions of cascading effects is that, while there may be a very slow increase in global sea levels, coastal areas presently protected by low-lying reefs may become more exposed much sooner due to the combined effects of increased water depth (SLR) and more extreme wave-climate.

While shoreline response to wave conditions usually occurs on time scales of hours to days, shoreline evolution due to SLR is expected to be significant on decadal time scales. Such multi-scale issues thus add to the complexities of coastal processes and effects.

Sediment transport and thus erosion is exponentially related to wave height, which in itself is not linearly related to wind conditions (as affected by CC, Section 2.6). Some impacts of slightly increased winds (10 % stronger) resulting in significant sediment transport increases (Section 2.6), can be readily foreseen, especially for extreme events. This will also be particularly noticeable where there are disruptions in alongshore transport or discontinuities. For example, harbour entrance channels which trap alongshore transport are likely to trap much more sediment in future, requiring increased dredging (potentially in the order of 50% to 100% more – Section 2.6). On the downdrift side of such harbours, the potential transport is also likely to be increased significantly, requiring increased sand bypassing and/ or beach nourishment to maintain the downdrift beaches.

Another example relates to short-term shoreline erosion resulting from sea storms. It has been shown (Section 2.6) that a possible 10% increase in storm wind velocity could result in a significant increase in wave height (and to a lesser extent in wave period), leading to a potential increase in cross-shore transport perhaps in the order of 50%. Assuming then also a 50% increase in erosional volume, this can be very roughly translated to a potential 50% increase in horizontal shoreline erosion distance (assuming a simplified profile response and, for example, that the effect of the increase in active profile depth will be approximately cancelled out by the effect of the increase in storm duration). Thus, the shoreline variability and maximum excursion distance are likely to increase significantly (or, in other words, the profile envelope will expand). An implication of this scenario, is that besides potential long-term erosional trends from a Bruun-like response to sea level rise, new coastal development setback lines will in addition also have to allow for significantly greater short-term shoreline erosion (perhaps in the order of 50% more). This factor alone (i.e. expanded profile envelope) suggests that an additional setback distance typically in the order of 15 m to 30 m would potentially be required for exposed beach areas along the southern African coastline, to account for the effects of an increase in wave attack due to slightly stronger storm winds.

3.3 General coastal impacts

The National Committee on Coastal and Ocean Engineering of Australia (NCCOE, 2004) identified a number of potential major impacts for the coastal zone resulting from climate change, such as:

- inundation and displacement of wetlands and lowlands
- eroded shorelines
- increased coastal flooding by storms
- salinity intrusion of estuaries and aquifers
- altered tidal ranges, prisms and circulation in estuarine systems
- changed sedimentation patterns
- decreased light penetration
- changed storm patterns, windiness, wave energy or direction impacting coastal stability and alignments

Although we are not able to reliably estimate at this time changes in storm patterns, windiness, wave energy or direction, the increase in storm activity and severity will probably be the most visible impact and the first to be noticed. For example, higher sea levels will require smaller storm events to overtop existing storm protection measures (see Figure 4 below - example of an existing problem area).

Figure 4: An existing overtopping & flooding problem (Table Bay, SA), likely to worsen due to climate change. (Photo: M. van der Merwe)

Examples of adverse implications related to critical protective coastal infrastructure include:

- Breakwaters which provide shelter to boats/ships/vessels at fishing harbours or commercial Ports. The safety provided by such structures will be slightly reduced due to the combined impacts of sea level rise and increased sea storms. More importantly, however, the longevity of such structures and facilities will be reduced, and more maintenance will be required due to the growing intensity of extreme events and the progressive onslaught of the sea.
- Revetments and sea walls, which protect infrastructure such as housing, promenades, pavements, parking areas, etc from direct wave action and under scouring. In most instances the infrastructure was originally unwisely located (in hindsight). In other instances originally safe infrastructure has become endangered and required protection through progressive coastal erosion. All such adverse situations will worsen considerably and in some instances beyond critical limits due to the combined impacts of sea level rise and increased sea storms.
- Road and rail embankments. In some instances, roads and railway lines have been located too close to the sea. Their embankments and foundations thus have to be protected by for example rock armouring. The foundations of such structure could be under scoured due to the combined impacts of sea level rise and increased sea storms, resulting in structural damage and potentially fatal accidents.
- Managed dunes. In some instances, it is only the maintenance /management of the primary dune which provides ongoing protection to coastal infrastructure against wave attack and erosion. Coastal erosion and changed sediment budgets resulting from climate change, will reduce the dune volume and associated natural coastal protection. Another very important function of such vegetated dunes is to prevent or reduce wind blown sand problems. There are many examples of where anthropogenic impacts have resulted in severe wind blown sand problems.
- Any structure providing or allowing public access onto the sea (e.g. harbour walls, jetties, etc.). This leads to people (sometimes unwary/uninformed) being swept off such structures into the sea during high wave events. Due to the combined impacts of sea level rise and increased sea storms, such incidents will occur more often. In the worst cases the whole structure may be in danger of collapse during extreme events, including potentially some marine outfalls/pipelines.
- Tidal pools and structures which promote bathing, have an inherent danger of people drowning (which may be exacerbated by factors such as lack of lifeguards or alcohol abuse). The safety provided by such structures will be reduced due to the combined impacts of sea level rise and increased sea storms. In addition, the longevity of such structures and coastal recreational facilities will be reduced, and more maintenance will be required due to the growing intensity of extreme events and the progressive onslaught of the sea.

Other adverse implications related to coastal impacts due to climate change include:

- Sandy erodeable beaches: 20 to 80 m of erosion could result on mild/flat slopes due to SLR alone. In addition, short term erosion due to more extreme wave events may reslut in the order of another 15 m to 30 m of erosion on top of the "normal" erosion due to intense sea storms.
- Inundation and flooding of low-lying areas adjacent to some estuaries, tidal inlets, coastal wetlands and marinas - mainly residential and holiday homes (some commercial). Mostly due to river floods combined with closed estuary mouths resulting in high water levels within the estuary, but sometimes also due to high sea water levels (including wind and wave setup).
- Degradation/narrowing of beaches due to coastal erosion makes tourism areas less attractive.
- Reduced fair weather fishing time and increased safety risks due to increased occurrence, duration and magnitude of seastorms. Also increased cost of maintenance to equipment (e.g. boats).
- Altered freshwater inflows and sea conditions (waves, water-levels, sediment) will (further) reduce environmental function of some estuaries – also impacts fisheries (e.g. nursing grounds).
- Increased saltwater intrusion and raised groundwater tables in farming areas directly adjacent to estuaries and shoreline.
- A rise in the sea level is likely to also have a significant impact on the coastal ecology. In many areas anthropogenic development has encroached too close to the high-water line. In some instances there is now not sufficient space available for biota/ echosystems to migrate upwards with sea-level rise. Thus, in such areas the ability of biota to adapt have been diminished and they have indirectly become more sensitive to the effects of climate change. In relation to the total coastal zone, the impacted areas may be minute, but they could impact critical habitat areas.

3.4 Estuaries

Many of southern Africa's estuaries are ranked as being highly important for biodiversity conservation (e.g. the Knysna, Olifants and Berg River estuaries in SA; Turpie, 2004, Turpie et al, 2002). Estuaries constitute a unique habitat type that supports many species of fauna and flora found nowhere else. Ecologically, they serve as vital nursery areas for a number of marine fish and shellfish. In addition to their ecological functions, estuaries also fulfill important economic and cultural functions. Their contribution to national economies in southern Africa in terms of fisheries alone is considered to be highly significant. Lamberth and Turpie (2003) estimated that the total value of South African estuarine and estuarine dependent fisheries was in the order of R950 million in 1997.

A high percentage of southern Africa's estuaries (70% in SA) are temporary open/closed. Key determinants of estuarine goods and services are access (by biota) to/from the sea and specific salinity ranges resulting from fresh/sea water exchanges. Progressive changes in estuarine hydro- and sediment dynamics, driven by the predicted changes in river runoff and by the sea level rise and increased sea storminess described before, have not yet been quantified. A second direct risk related to these drivers is progressive changes in salinity penetration. In terms of changes in salinity regime, the largest risk is expected to be exceedance of a given threshold for ecological function of an estuary. Therefore, due to climate change, most of our estuaries are exposed to changes in salinity regime, and changed mouth dynamics resulting in regime changes regarding mouth status (open/closed).

3.5 Potential impacts on livelihoods

Examples of potential impacts on livelihoods within various socio-economic sectors is as follows:

- Industrial: hindered shipping access to port, reduced navigability and increased cost of maintenance to infrastructure due to increased storminess leading to loss of jobs in the long term. Increased down time for shipping and trade would have a huge impact.
- Commercial: reduced fair weather fishing time and increased safety risks due to increased occurrence, duration and magnitude of sea-storms, leading to less appealing and adverse working conditions.
- Farming areas adjacent to the shoreline may suffer from salt water intrusion, resulting in lower earning potential.
- Residential: coastal suburbs may lose properties including houses, hotels, guesthouses, etc, and their associated employment opportunities.
- Recreational areas: loss of area/space and/or appeal (both through erosion) and therefore fewer visitors leading to reduced economic activity.

3.6 Potential benefits to the coast arising from climate change

Coastal and marine areas appear to have virtually no potential benefits arising from climate change. A few potential exceptions are as follows:

- In areas where marine water quality is problematic (e.g. associated with outfall pipelines, tidal pools or polluted low energy embayments), the sea level rise and increased sea storms could enhance water circulation, mixing and dispersal of matter. On the other hand, for example, presently acceptable dredge dumpsites, may become less suitable and require relocation (deeper, further away).
- Certain water sport activities may be enhanced, at least in some locations, e.g. surfing (more, larger waves), sailboarding and kiting (more windy), etc. In general, this cannot be seen as a major benefit.
- The overall response of estuaries to the combined effects of climate change (reduced/increased river inflows, sea level rise, increased sea storms, changed sediment budgets, etc.) is very complex. Some estuaries are perceived/believed to be detrimentally progressively silting up due to anthropogenic and/or natural processes. Simply put, an increase in water depth could potentially "restore" such estuaries (although ecological functioning may still be perceived to be adversely affected). In specific instances, the increased tidal prism may be beneficial. However, this could easily be more than offset by, e.g. reduced river inflows, or increased mouth closures due to increased marine sediment intrusion. The overall response remains uncertain, and needs to be investigated in more detail.

4. Identification of some of southern Africa's most vulnerable areas and local issues

The most vulnerable areas along the coast will almost invariably be located where problems are already being experienced at present. In most cases these are the areas where development has encroached too close to the high-water line, or at a too low elevation above mean sea level.

4.1 Namibia

The coastline of Namibia is 1 500 km long, and consists of 78% sandy beaches, 16% rocky shores and 4% mixed sand and rock shores, while only 2% of the shore is backed by lagoons UNFCCC (2002). In terms of coastal real estate, the Namibian coast is largely undeveloped, and there are only four significant towns on the coast: Lüderitz, Walvis Bay, Swakopmund and Henties Bay. However, the coastline is an important tourism and recreation asset, and coastal diamond mining areas stretch along significant portions of the coast. Marine diamond mining, tourism and commercial fishing are amongst the leading foreign currency earners. The main harbour and only dee-water port, located at Walvis Bay, is an important national economic hub and regional import/export freight access point for landlocked countries such as Botswana.

Much of the town of Walvis Bay lies below 2 m elevation (Hughes and Bundrit, 1992). Thus, even a small amount of sea level rise combined with a moderate sea storm could already have severe impacts. Walvis Bay's mean annual rainfall is only 20 mm, and the town relies on coastal aquifers which are already susceptible to salt intrusion (UNFCCC, 2002). This intrusion would be further exacerbated by sea level rise. A desalination plant is planned which would assist the town to adapt to a more saline water supply by reducing the demand for groundwater thus making the aquifers less susceptible to salt water ingress.

During seasonal storms, waves wash over the major peninsular sand spit protecting the Port of Walvis Bay. The 10 km long Walvis Peninsula is low-lying with an average height of only about 1 m above mean sea level (Schoonees et al, 1998). Major sandspits are found around the world and are common features along the Angolan and Namibian (Walvis Bay and Sandwich Harbour – see Figure 5 below) coasts. In Angola, the Mussulo Peninsula apparently breached before 1768, while Ilha de Luanda has been breached twice in recorded history. At Baia dos Tigres in southern Angola, natural breaching of a 41 km long sand spit occurred, leaving an 11 km wide gap in the spit, thereby forming an island, destroying safe anchorage and preventing easy access to the spit (Schoonees et al, 1998). The Walvis Peninsula did in fact partially breach in 1999. It is concluded that breaching of the Walvis Peninsula by the sea poses a real threat because the peninsula is so low-lying. Both SLR and increased sea storminess have the distinct possibility of greatly increasing this risk. A large breach of the Walvis peninsula would have similar disastrous consequences as occurred at Baia dos Tigres. Measures which could be employed to prevent breaching include: sand nourishment, groynes, rock revetments, and sand-filled geotextile shore protection.

Figure 5: Namibian sandspits at Walvis Bay (vulnerable) and Sandwich Harbour. (Image Science and Analysis Laboratory, NASA-Johnson Space Center. Astronaut Photography of Earth.)

Swakopmund and Henties Bay are generally less vulnerable to rising sea levels, but localized erosion problems have occurred and some development seems to be located too close to the sea. Lüderitz is located on a steep, rocky shore, and is relatively invulnerable to SLR.

The time scales on which coastal diamond mining operates is so much shorter than that of SLR, that impacts relating to SLR are not considered significant. (Figure 6 above shows an example of beach diamond mining operations.) However, increased storminess due to CC may well impact costs (e.g. requiring increased beach-wall maintenance and protection, etc.) and increase the difficulty of mining in certain areas.

Figure 6: Example of beach diamond mining operations in Namibia

Natural areas, such as the Skeleton Coast Park, are expected to be more resilient to SLR, as there should be sufficient space for coastal features and biota to migrate landward.

It appears that apart from some important potential impacts in the Walvis Bay area, the Namibian coastline is relatively invulnerable to CC impacts (compared to many other countries).

2.2 South Africa

In South Africa, limited research has been done on sea level rise and physical coastal impacts, with only a few studies by local researchers, mainly Brundrit (1984, 1995), Cooper (1991, 1995a, 1995b), Hughes et al (1991), Hughes and Brundrit (1992), Theron (1994) and Midgley et al (2005).

Fortunately, due to the relief of much of the SA coast and the location of existing developments, relatively few developed areas are sensitive to flooding and inundation resulting from projected SLR (to 2100). Midgley et al, (2005) have identified a number of vulnerable coastal areas (resulting from climate change impacts) within the Western Cape Province. The ongoing migration of people to coastal areas will worsen the impacts.

The most vulnerable SA coastal areas (resulting from predicted climate change impacts) that have been identified are:

- Northern False Bay
- Table Bay
- Saldanha Bay Area
- The south Cape coast, Mossel Bay to Nature's Valley
- Port Elizabeth
- Developed areas of the Kwazulu-Natal Coast

According to Tol (2004), by 2100 South Africa would lose some 11% of its wetlands due to full coastal protection measures and structures erected to mitigate SLR impacts, making SA potentially the 5th most vulnerable country worldwide i.t.o wetland losses resulting from SLR (in 2100).

2.3 Mozambique

Mozambique is a maritime country: most of its citizens live in small, traditional fishing villages, tucked away in dune forests along its vast 2 500 km long coastline; while fishing is a major sector of the workforce and fish an important source of protein (Slater, 1997). Tourists are flocking to the tropical beaches and coral reefs of especially the Inhambane province, while many lodges dot the southern coastline. Many low lying hotels and houses are found on the Bazaruto Archipelago, islands north of Pemba and Qurimbas Archipelago. Food processing, petroleum refining and commercial fishing are probably still the leading foreign currency earners. Main harbours are located at Maputo (a major source of income for the government) and Beira (where the entrance to the terminal is limited by the tides and some large vessels have to time their transits accordingly). Smaller harbours are located at Inhambane, Quelimane, Nacala and Pemba. Although parts of the lush tropical coastline and islands, with their beaches, have been exploited by developers, other areas remain untouched. Mozambique's coral reefs rank with the world's richest and most extensive, and are usually found at depths varying from a few meters at low tide to around 15 m at high tide (Slater, 1997). Dune thickets occur along long stretches of the coast, and mangrove swamps occur extensively on the edge of shallow coastal bays and between some islands. In Sofala Province, deltas are found along the coast at the mouths of the Save, Buzi, Pungoe and Zambezi Rivers.

Deep-sea swells approaching the Mozambique Coast are usually generated in the westerly gale belt of the roaring forties. On the south Mozambique Coast these swells are refracted to approach from between south-south-east and south-east. The coast on this side of the Mozambique Channel has been classified as a low-energy environment despite its meso-tidal (2 to 4 m) regime. The indications are, however, that this coast is not much less energetic than the north-east coast of SA, which is still a relatively energetic coast. In the Mozambique Channel an additional factor that could be very significant is the occurrence of cyclones. Cyclones rarely approach close to the coast, but strong cyclones, even while far away, generate large waves

Figure 7: Mozambican example of the kind of problem likely to worsen due to climate change

that could potentially impact the local coastline. Such waves are more likely to have an easterly component.

Given the nature of the Mozambique coast and economic dependency thereon as described above, it is not surprising that the IPCC (2001) found it likely that SLR will affect coastal settlements, flooding and coastal erosion, especially along the southeastern coast of Africa. The IPCC (2001) also noted that adaptive capacity in the region is low, that the largest cities are along the coast, and that the region is vulnerable to extreme events, coastal erosion and SLR. (A local example of the kind of problem likely to worsen due to CC is shown in Figure 7.) Stern (2006) reported that the total measurable costs of flood disasters in 2000 were approximately $550 million or as much as 12% of Mozambique GDP. A Third World country such as Mozambique can certainly not afford traditional engineering solutions to wide scale coastal erosion or flooding.

Tol (2004) predicts that by 2100 Mozambique will have lost 1.3 % of its "dryland" area due to SLR, making it potentially the 5th most vulnerable country worldwide to SLR (in 2100).

The impact of CC through coral bleaching on coral reefs of the Western Indian Ocean has been well documented. Obura (2005), reported on high coral bleaching in both southern and northern Mozambique resulting from SST increases during 1998, with highly varying mortality rates ranging from 20 to 80%. The coral reef areas of Mozambique (e.g. Figure 8, below) are thus very vulnerable to CC impacts, i.t.o. direct effect on the biota as well as on the important linked socio-economic sectors (e.g. tourism). In addition, the coral reefs serve other important functions, such as sheltering the coast from wave action and by providing beach building materials. Thus, loss of coral due to CC will also negatively impact these functions with detrimental impacts on the coast (e.g. erosion).

Figure 8: Example of Mozambique coast - vulnerable corals and mangroves. (Photo: D. Phelp)

Fringing reefs are found along many parts of the East African Coast, including some areas in Mozambique. These reefs comprise tough, algal-clad intertidal bars composed largely of coral rubble derived from their ocean front, and provide protection from wave attack to the inshore areas with their sediment veneers and beach sands that are susceptible to erosion (Arthurton 2003). If the eastern African coasts are subjected to the rise of sea-level that is predicted at the global scale during the coming century, the protective role of the reef bars will be diminished if their upward growth fails to keep pace. Favourable ocean temperatures and restraint in the destructive human pressures impacting the reef ecosystems will facilitate such growth (Arthurton 2003).

The Maputo shoreline has a history of coastal erosion problems as evidenced by the old groynes found along part of the coast. In addition, parts of the city are low-lying and prone to flooding (both from river floods and high sea water levels). These problems will be exacerbated by both SLR and increased sea storminess through coastal erosion, higher wave run-up levels and higher water levels. This is besides the potential impacts of CC on river floods and on cyclones. (IPCC (2007) states that it is likely that future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation.) In all, Maputo is likely to be one of the most problematic areas in Mozambique from a climate change perspective and appropriate local planning and adaptation measures should be instigated in the short-term.

5 Possible responses and guidelines to mitigate CC impacts

New coastal developments, structures or protection can be designed specifically to compensate for the effects of climate change (e.g., a new Mozambican hotel was built on stilts). This, however, requires a good understanding of the short-term coastal processes, as well as coastal evolution on the longer time and larger space scales.

All forms of coastal land use should allow flexibility for adjustment to possible futures sea levels. Stive et al (1991) argue that shore nourishment is an effective mechanism to prevent shore retreat owing to long-term sea level rise because of the uncertainties and the flexibility that shore nourishment provides. Provided that sufficient sources of suitable sand are available, this is a good "soft" adaptive strategy, often better than "hard" (e.g. structural) approaches in the long-term. However, sand nourishment is expensive (like "hard" solutions) and the need for eventual re-nourishment, although foreseen and planned for, is sometimes publicly perceived as "failure". Saizar (1997) estimated that the cost of adaptation responses to SLR in Montevideo (Uruguay) would be slightly higher for artificial beach nourishment compared to seawalls. However, this only considered the direct implementation costs and not the total costs over the long-term (including e.g. mitigation of environmental and other detrimental impacts), which experience has shown (in retrospect) should often favour the "softer" approach. In southern Africa, it would not be practical or economical just to heighten much of the existing man-made coastal protection; existing infrastructure will eventually have to be replaced at great expense.

In general, regarding developed areas and existing infrastructure, southern African states have very little adaptive capacity, other than relatively expensive upgrades or replacements. Where this is deemed acceptable and space permits, the best policy in the long-term is probably not to combat coastal erosion and allow the natural progression of coastal processes. In any case, our ability to halt the coastal impacts of climate change on a large scale is virtually non-existent and may well lead to other detrimental impacts.

Structural interventions should be complemented by environmental management strategies, including managed dunes. In some instances, it is only the maintenance/management of the primary dune which provides ongoing protection to coastal infrastructure against wave attack and erosion. Similarly, the coral reef areas of Mozambique are very vulnerable to CC impacts, i.t.o. direct effect on the biota as well as on the important linked socio-economic sectors (e.g. tourism), and impact on the coast (e.g. erosion). Restraint in the destructive human pressures impacting reef ecosystems will facilitate the important protective role of corals and reef bars.

Another indirect but important response to mitigate potential CC impacts that should be implemented urgently is not to worsen CC impacts by unsustainable practices such as anthropogenic impacts in river catchments that reduce the sediment supply to the coast. A crucial factor that co-determines how severely CC will impact the coast is the amount of available sediment. In water scarce developing countries such as Namibia and SA this requires particularly frugal and wise management of the water resources (e.g., large river impoundments can trap sediment that would otherwise feed the coast).

Tol (2004), predicts that adaptation would reduce impacts by a factor of 10 to 100 (globally), and that adaptation would come at a minor cost compared to the damage avoided. This strongly emphasizes the need for setting and implementing adaptation measures sooner rather than later.

Each vulnerable stretch of coastline should be studied in terms of aspects such as wave energy, sand budgets, future sea levels and potential storm erosion setback lines, including accounting for at least a Bruun-type erosional response, as well as expanded profile envelopes. At the very least coastal zone managers, coastal engineers and planners need to remain informed on the probable future impacts of global weather changes (Theron, 1994).

It is recommended that when provincial state of coasts reports are initiated, SEAs, strategic development planning is conducted, etc. that coastal development set-back lines are accurately determined for the particular stretch of coastline under study. There are many publications that provide information on some aspects of coastal development setback lines (e.g. Cambers 1997, Collier et al 1977, FEMA 2000, Nichol 2003). However, it is important to point out that new development setback lines should start to take account of various factors, which include:

- the probable increase in duration and magnitude of sea storms due to climate change (or any other such impacts, in addition to just sea-level rise);
- the probable increase in maximum natural short-term shoreline variability (due to predicted higher storm waves resulting from climate change.);
- the probable increase in progressive shoreline retreat rates (due to climate change, e.g. resulting in a greater gradient in alongshore transport) where this phenomenon is occurring.

The IPCC (1991) provides guidelines for case studies, outlining "7 steps to the vulnerability assessment of coastal areas to SLR", which contains most of the basic principles required. More recently, the US Geological Survey (USGS) has devised a physically based coastal vulnerability index (CVI) based on 6 physical variables to assess the vulnerability of the coastline to climate change (Theiler and Hammar-Klose, 2000). Boruff et al (2005) developed a coastal social vulnerability index (CoSVI) to determine the socio-economic vulnerability of coastal areas to SLR. These indexes can also be combined to give an overall vulnerability index, which appears to be a good approach.

In southern Africa, we need to develop decision-support tools such as maps, a geographic information system (GIS) database, and reports for use by the coastal management community. This will lead to a coastal vulnerability classification scheme, whereby realistic scenarios of future coastal conditions can be used to support adaptive management and the development of coastal policy. Sufficient physical environmental data should be available for most locations along the southern African coast to draw up a point rating system whereby the vulnerability of sites can be evaluated objectively on a relative scale in terms of the main potential impacts. The Coastal Sensitivity Atlas of southern Africa, by Jackson and Lipschitz (1984) provides useful preliminary information on some aspects.

Our best "adaptive capacity" appears to lie in planning and research related initiatives, such as:

- Instigate and maintain a measurement program (high resolution aerial photographic/satellite mapping, hydraulic conditions, coastal erosion/evolution (including surveys if possible), sediment transports/budgets).
- Identify important thresholds of dangerous change and include sensitivity analyses.
- Development of vulnerability atlas/GIS i.t.o. potential impacts listed, and identify hotspots/ hazardous areas of change.
- Determine coastal erosion and development setback lines (allowing for at least a Bruun-type erosional response, as well as expanded profile envelopes).
- Draw up Shoreline Management Plans. (The main options relate to: do nothing, hold the existing line, advance the existing line or retreat).

  In terms of developments and infrastructure, this will provide the strategic framework in which all coastal structures and sea defenses are evaluated. This plan should provide the layperson and the authorities with a clear framework to work within. Specialist studies and monitoring of the shoreline is an essential ongoing element of the SMP (Midgley et al, 2005).
- Design coastal protection /developments /structures specifically to compensate for effects of climate change. Vrijling and Van Beurden (1990) have, for example, developed an economic model to calculate the optimal height of sea defences in the case of a sea level rise as well as the optimal strategy for heightening of sea defences in the case of an uncertain sea level rise.

6. Final conclusions

Appropriate coastal development needs to take into account proper planning, knowledge of coastal processes including CC effects and impacts, and environmental assessments. This is particularly relevant considering that about 90 % of the world's coastline is already affected by erosion, which is likely to be exacerbated significantly by SLR and increased sea storminess. Coastal real estate, tourism and recreation along our coasts have enormous socio-economic value, which assets should be protected and wisely governed. The importance of sustainable development of these resources has been recognized by national governments as reflected in, e.g. the new SA National Environmental Management: Coastal Zone Bill (2006) which inter alia calls for coastal management plans, which include CC effects and impacts. The White Paper for Sustainable Coastal Development in South Africa aims to "achieve sustainable coastal development through a dedicated and integrated management approach" (DEAT, 2000). If the current fast tracked development of the coast is to occur in a communally beneficial and sustainable manner, it is vital that planning takes place based on scientific knowledge of present and expected future conditions.

Locally applicable methods have to be developed urgently to quantify realistically the impacts along the southern African coast. To mitigate the detrimental impacts of climate change, we have to understand the adaptation options available to southern African society, which is considerably different from 1st world approaches, and still largely undefined.

Quantitative information remains largely unavailable and the resulting somewhat speculative predictions presented here are uncertain. Some important potential consequences of Global Warming on the southern African coast are highlighted, and there is a clear and urgent need for improved understanding of, and especially predictive capabilities regarding these issues. It is recommended that more focus be given to the southern African region as present efforts appear to be almost exclusively aimed at other parts of the globe.

This will eventually enable us to achieve wider goals such as:

- To integrate physical processes at different spatial and temporal scales into regional models to improve predictions of regional responses to global change.
- To understand the increased vulnerabilities of coastal biodiversity and ecosystem services to the cumulative effects of climate change (rainfall, temperature, sea conditions, ocean water levels), human agency (water allocation, water quality, development in the coastal zone and catchments) and natural processes (hydrology, wind regime, sea currents, wave regime, coastal processes, underlying geology, sediment transport).
- To understand, identify thresholds and risks and predict system state transitions.
- To inform, aid and promote wise policy, management and governance of the southern African coastal zone from a holistic and integrative perspective.

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REFERENCES

Allsop, W, pers. com, November 2005, Technical Director, Maritime Structures, HR Wallingford, UK.

Arthurton, R (2003). The Fringing Reef Coasts of Eastern Africa - Present Processes in Their Long-term Context. Western Indian Ocean J. Mar. Sci. Vol. 2, No. 1, pp. 1–13, WIOMSA.

Battjes, J A (2003) Developments in Coastal Engineering Research (Delft University of Technology, Delft, The Netherlands). Keynote lecture presented at the Special Symposium for the 50Th Anniversary of Japanese Conference on Coastal Engineering, Tokyo, Japan. Published in the Proceedings of this Symposium, pp. 25-39

Battjes, J A (1974). Computation of set-up, longshore currents, run-up and overtopping due to wind generated waves. Doctoral thesis, Delft, 1974.

Bentley, CR (1997). Rapid sea-level rise soon from West Antarctic Ice Sheet collapse? Science (Washington). Vol. 275, no. 5303, pp. 1077-1079.

Boruff, B J, Emrich, C and Cutter, S L (2005). Erosion hazard vulnerability of US Coastal Counties. Journal of Coastal Research, 21(5); 932-942.

Brundrit, G.B. (1984). Monthly mean sea level variability along the west coast of Southern Africa. S. Afr. J. Mar. Sci., 2, pg 195□203.

Brundrit, G.B. (1995). Trends of Southern African sea level: Statistical analysis and interpretation. S. Afr. J. Mar. Sci., 16, pg 9□17.

Bruun, P. (1983). Review of conditions for uses of the Bruun rule of erosion. Coastal Engineering, 7: 77-89.

Bruun, P (1988). The Bruun rule of erosion by sea-level rise: a discussion on large-scale two and three-dimensional usages. Journal of Coastal Research, Vol. 4, No. 4, 627-648. Charlottesville (Virginia), USA.

Cambers, G. (1997). 'Planning for coastal change: Guidelines for construction setbacks in the Eastern Caribbean Islands', CSI info No. 4.

Cazenave, A and Nerem, R S (2004). Present-day sea level change: observations and causes. Reviews of Geophysics, 42(3), RG3001, doi:10.1029/2003RG000139.

Church J A, White N J, Coleman R, Lambeck, K and Mitrovica J X. (2004). Estimates of the Regional Distribution of Sea Level Rise over the 1950–2000 Period. Journal of Climate, American Meteorological Society. Vol 17: 2609 - 2624

Church, J. A. and White, N. J. (2006). A 20th century acceleration in global sea-level rise, Geophys. Res. Lett., 33, L01602.

Collier, C A, Eshaghi K, Cooper, G, Wolfe R S (1977). Guidelines for beachfront construction with special reference to the coast construction setback line. Florida State University System, Sea Grant Program, Report No 20, 75 p.

Cooper, J. A. G. (1995a). Sea Level Rise and its Potential Physical Impacts on the Shoreline of KwaZulu Natal. Town and Regional Planning Commission.

Cooper, J. A. G. (1995b). Sea Level Rise and its Potential Physical Impacts on the Shoreline of KwaZulu Natal. Tugela river mouth to Mtamvuna river mouth. Town and Regional Planning Commission.

Cooper, J.A.G.(1991). Shoreline changes on the Natal Coast. Mkomazi river mouth to Tugela river mouth. Natal Town and Regional Planning Report, Volume 77.

Cooper, J A G and Pilkey, O H (2004). Sea-level rise and shoreline retreat: time to abandon the Bruun Rule. Global and Planetary Change Volume 43, Issues 3-4, November 2004, Pages 157-171.

Cooper, J.A.G.(1991). Shoreline changes on the Natal Coast. Mkomazi river mouth to Tugela river mouth. Natal Town and Regional Planning Report, Volume 77.

CSIR (1983). Coastal Erosion Along Baden-Powell Drive, Strandfontein. CSIR Report C/SEA 8399, Stellenbosch.

CSIR (1987). St James Walkway. CSIR Report C/SEA 8764, Stellenbosch.

Davidson-Arnott, R (2003). Modelling the Response of Sandy Coasts to Sea-Level Rise. Proc. Canadian Coastal Conference 2003. pp 8Department of Environmental Affairs and Tourism (2000). 'White Paper for Sustainable Coastal Development in South Africa'

Dorst, C.J. and Wilde, D.P. (2003). 'Integrated coastal zone management, from policy to design', COPEDEC VI.

Douglas, B C (1997). Global Sea Rise: a Redetermination. Surveys in Geophysics, Volume 18, Issue 2/3, May 1997. pp. 279-292

FEMA (2000). Coastal Construction Manual: Principles and Practices of planning, Siting, Designing, Constructing, and Maintaining Buildings in Coastal Areas. Federal Emergency Management Agency, FEMA Manual 55. Jessup, MD.

Glavovic, B.C. (2000). 'Our Coast for Life: From policy to local action'. Department of Environmental Affairs and Tourism.

Gregory, JM. (2004). Threatened loss of the Greenland ice-sheet. Nature, vol. 428, issue 616, p 257.

Hands, E. B. (1977). Implications of submergence for coastal engineers. Coastal Sediment '77, Proceedings, Fifth Symposium of the Waterways, Port, Coastal and Ocean Division of the ASCE: 149-166.

Hewitson B (2006). Potential changes in Western Cape climate due to Global Warming. Presentation to the Western Cape Provincial Government, CSAG, UCT.

Houghton J (2005). Global warming. Rep. Prog. Phys. 68 (2005) 1343–1403

Hughes, P. and Brundrit, G. B. (1990). The Vulnerability of the Durban Coastline to the Projected Rise in Sea Level. Sea Level Research Group, Dept. of Oceanography, Univ. Cape Town. SLRG Report 9004/1.

Hughes, P. and Brundrit, G. B. (1992) An index to assess South Africa's vulnerability to sea level rise, S.A. J. Sci., 88, 308-311.

Hughes, P., Brundrit, G. B and Shillington, F. A. (1991a). South African Sea Level Measurements in the Global Context of Sea Level Rise. S. Afr. J. Science, 87, pg 447□453.

Hughes, P., S. Searson and MacArthur C I (1991). Stormy waters ahead: The missing link between storminess and sea level rise. Conserva, 6, 16-22.

IPCC (Intergovernmental Panel on Climate Change) (1991). The seven steps to the vulnerability assessment of coastal areas to Sea Level Rise, guidelines for case studies. Response Strategies Working Group; Steering Committee for IPCC Sea Level Rise Assessment – Coastal Zone Management.

IPCC (2001). Climate Change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report. Cambridge University Press.

IPCC (2007). Climate Change 2007: The Physical Science Basis, Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 21 pp, Geneva. Downloaded from http://www.ipcc.ch on February 21, 2007.

Jackson, L.F. and Lipschitz S (1984) Coastal Sensitivity Atlas of southern Africa, Department of Transport, South Africa.

Jury, M R, Shillington, F A, Prestedge, G and Maxwell, C D 1986. Meteorological and oceanographic aspects of a winter storm over the south-western Cape Province, South Africa. S A Journal of Science, Vol. 82, 315-319.

Lamberth, S.J. and Turpie, J.K. (2003) The role of estuaries in South African fisheries: Economic importance and management implications. African Journal of Marine Science, 25, 31-57.

Mather, A (2007). pers. com. Project Executive: Coastal and Catchment Policy, Management and Co-ordination, Engineering Unit, Ethekwini Municipality, SA.

Midgley, G.F., Chapman, R.A., Hewitson, B., Johnston, P., de Wit, M., Ziervogel, G., Mukheibir, P., van Niekerk, L., Tadross, M., van Wilgen, B.W., Kgope, B., Morant, P.D., Theron, A.K., Scholes, R.J., Forsyth, G.G. (2005). A Status Quo, Vulnerability and Adaptation Assessment of the Physical and Socio-economic Effects of Climate Change in the Western Cape. Report to the Western Cape Government, Cape Town, South Africa. CSIR Report No. ENV-S-C 2005-073, Stellenbosch.

Moller, J.P. and Swart, D.H., (1988). Extreme erosion event on an artificial beach. In: Proceedings, 21st International Conference on Coastal Engineering, Malaga. ASCE, New York, Vol. 2, pp. 1882-1896.

NCCOE (2004). Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering. The National Committee on Coastal and Ocean Engineering. Institution of Engineers Australia, Barton. Pp 12-13.

Nichol, M.D. (2003). 'Draft review of the Californian coastal erosion planning and resource response: a strategy for action'. Accessed: http://ceres.ca.gov/cra/ocean

Obura D O (2005). Resilience and climate change: lessons from coral reefs and bleaching in the Western Indian Ocean. Estuarine, Coastal and Shelf Science, Vol 63, Issue 3: 353-372.

Park Y H (2006). Interannual sea level variability in the Southern Ocean within the context of global climate change. 3 pp. Downloaded from http://topex-www.jpl.nasa.gov/ science/investigations.html (NASA - Jet Propulsion Laboratory) on November 6, 2006.

Rahmstorf S (2006). A Semi-Empirical Approach to Projecting Future Sea-Level Rise. SCIENCE, VOL 315: 368-370. Published online 14 December 2006; 10.1126/science.1135456. Downloaded from www.sciencemag.org on January 19, 2007.

Rahmstorf, S, Cazenave, A, Church, JA, Hansen, JE, Keeling, RF, Parker, DE, Somerville, RCJ (2007). Recent Climate Observations Compared to Projections. SCIENCE VOL 316 4 MAY 2007 p709. www.sciencemag.org Published online 1 February 2007; 10.1126/science.1136843

Rossouw, M (2007). pers. com. Senior Coastal Engineer, CSIR, Stellenbosch, SA.

Saizar A (1997). Assessment of impacts of potential sea level rise on the coast of Montevideo, Uruguay. Climate Research, Vol 9: 73-79.

SAN (2005). South African tide tables. SAN HO-2, The Hydrographer, South African Navy, Tokai.

Schoonees, J S and Theron, A K (1995). Evaluation of 10 cross-shore sediment transport/ morphological models. Coastal Eng., Vol. 25: 1-41.

Schoonees, J S and Theron, A K (1996). Improvement of the most accurate longshore transport formula. 25 Intn. Conf. On Coastal Eng., Orlando, Florida. ASCE, Volume 3, Chapter 282, page 3652-3665.

Schoonees, J S, Lenhoff, L, and Raw, A J (1998). Preventing natural breaching of the major spit protecting the Port of Walvis Bay. 26 International Conference on Coastal Engineering, ASCE, Copenhagen. Vol. 2: 1475-1488.

Schulze, R.E. (2005). Looking into the future: Why research impacts of possible climate change on hydrological responses in South Africa? In: Schulze, R.E. (Ed) Potential impacts and vulnerabilities of climate change on hydrological responses in southern Africa. Water Research Commission, Pretoria, Report 1430/1/05.

Slater, M (1997). Guide to Mozambique. Struik Publishers, Cape Town. 176 pp.

Stern, N (2006). Stern Review: the economics of climate change. UK treasury, London.

Stive M J F, Nicholls R J, De Vriend H J (1991). Sea-level rise and shore nourishment: a discussion. Coastal Engineering, Vol. 16, No.1:147-163.

Stive, M J F (2004). How Important Is Global Warming For Coastal Erosion? An Editorial Comment. Climatic Change 64: 27–39, 2004.

Sustainable Development Unit (2005). Guidance on Designing Developments for a Changing Climate. Consultation Document: Issued by the Three Regions Climate Change Group comprising representatives from the East of England Sustainable Development Roundtable, London Climate Change Partnership and South East Climate Change Partnership. London, UK.

Swart, D H (1974). Offshore sediment transport and equilibrium beach profiles, D.Sc Thesis, Delft University of Technology.

Syvitski, J P M, Vorosmarty, C J, Kettner, A J and Green, P (2005). Impact of Humans on the Flux of Terrestrial Sediment to the Global Coastal Ocean. Science [0036-8075], sciencemag.org, vol:308, iss:5720, p:376.

Theiler, E R and Hammar-Klose, E S (2000). National Assessment of Coastal Vulnerability to Future Sea-Level Rise: preliminary Results for the US Gulf of Mexico Coast. US Geological Survey, Open-File Report 00-179. Online at: http://pubs.usgs.gov/of/of00-179/

Theron, A K (1994). Sea level rise, impacts and the use of Bruun's erosion rule. J SA Inst Civ Eng, Vol 36, No 3, Fourth Quarter 1994: 6-10.

Theron, A K (2004). Sediment Transport Regime at East London. M.Eng Thesis. University of Stellenbosch. pp 192

Thomas,R, Rignot,E, Casassa,G, Kanagaratnam,P, Acuña,C, Akins,T, Brecher,H, Frederick,E, Gogineni,P, Krabill,W, Manizade,S, Ramamoorthy,H, Rivera,A, Russell,R, Sonntag,J, Swift,R, Yungel,Y and Zwally J. (2004). Accelerated Sea-Level Rise from West Antarctica. Science Magazine, 8 October 2004, pp. 255 – 258

Tol, R.S.J. (2004). The Double Trade-Off between Adaptation and Mitigation for Sea Level Rise: An Application of FUND. FNU-48 (submitted), Research Unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science.

Turpie, J.K., Adams, J.B., Joubert, A., Harrison, T.D., Colloty, B.M., Maree, R.C., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taljaard, S. and van Niekerk, L. (2002) Assessment of the conservation priority status of South African estuaries for use in management and water allocation. Water SA, 28, 191-206.

Turpie, JK (2004) Improving the biodiversity importance rating of estuaries. Water Research Commission Report. 126pp.

U S Army, Corps of Engineers (1984). Shore protection manual. Department of the Army, U S Army Corps of Engineers, CERC, Vicksburg, Mississippi. Vol. 1.

UNFCCC (2002). Initial National Communication (INC) of the Republic of Namibia to the United Nations Framework Convention on Climate Change (UNFCCC). 154pp.

Vrijling, J. K. and Van Beurden, I. J. C. A. (1990). Sea level rise: A probabilistic design problem. Proceedings, 22nd International Coastal Engineering Conference, ASCE, Delft. Volume 2: 1160-1171.

Do we recognize a climatic shift when we see one? Lessons from the Western Sahel

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Abstract

Recent rainfall and vegetation greenness data in the Western Sahel have prompted speculation that the region was undergoing not only a recovery from 30 years of very dry conditions but an actual shift to a wetter period. The rainy seasons in 2000, 2001, and 2005 in the west-central part of Senegal, the study area, showed precipitation levels clearly beyond the 1970-1999 mean. Despite the fact that the 2005 values were evenly distributed throughout the rainy season and total values approached the high levels from the 1960s, most crops, now adapted to a short (90-day) growing cycle, rotted in the fields and farmers complained about a poor harvest. At current time, it remains highly contested whether or not these recent observations in the region signify a climatic shift that will continue throughout the coming decades. Model predictions for the Western Sahel include both significantly drier conditions and clearly wetter monsoons with 20-50% more precipitation. Not knowing the climatic conditions to which to adapt makes planning and adaptive management an exceedingly difficult undertaking.

This paper addresses two challenges with respect to adaptation: 1) how do decision-makers on the ground - small-scale farmers and agricultural extension agents - identify the onset of an actual climatic shift that requires adaptive measures; and 2) how can we, as researchers, find appropriate means to mobilize local memory and awaken 'latent adaptive capacity' to facilitate adaptation. I use participatory conceptual mapping to explore local understandings of causes and consequences of climate variability and change.

Introduction: A Potential Climatic Shift in the Western Sahel

Since the late 1990s, rainfall data in the Western Sahel have prompted speculation that the region was undergoing not only a recovery (Nicholson 2005), but an actual shift to a wetter period (Ozer et al., 2002; Hubert et al., 2005). Also, recent findings from remote sensing studies suggest an increase in seasonal greenness over large parts of the Sahel since the mid 1980s (Rasmussen et al., 2001; Olsson et al., 2005; Hermann et al., 2006). This notion of a 'greener' Sahel substantiates earlier evidence for the response of semi-arid ecosystems to climatic variability and their ability to recover from droughts (Tucker and Nicholson, 1999; Eklundh and Olsson, 2003).

In 2003, summer rains in the Western Sahel caused flooding and landslides in some parts and even reached into usually dry areas in northern Mali and Mauritania (Brooks, 2004). The 2005 season produced generally good rains in July and August, again with localized flooding (GIEWS, 2005). In the centre of the Old Peanut Basin in Senegal, all precipitation records since 2000, with the exception of 2002, were above the 1970-1999 mean. High values at the ISRA/CNRA station in Bambey in 2001 and 2005 and in Ngoye 2000 and 2005 matched the average 35% increase in rainfall compared to the 1968-97 very dry period, as approximated after Nicholson (2005). Extreme off-season rain events in 2002 resulted in another flooding of St. Louis in the Northwest of the country (Fall et al., 2006), a January phenomenon not witnessed since 1933 when the French aviator Jean Mermoz had to postpone his transatlantic flight due to heavy rains (Graëff, 2002).

In 2005, August precipitation in Dakar amounted to 455 mm, the closest to the century high of 495 mm, recorded in 1959 (CSE, 2005). Continuous heavy rains into early September caused flooding in most of the city and a sharp increase in cholera cases with 46 deaths, which led the government to declare an emergency and evacuate 60,000 people (IRI, 2005a). The 2005 rainy season ended with 36-150% above average October rains in the center of the Old Peanut Basin (ISRA/CNRA, personal communication), confirming the IRI September-October-November prediction of 65% above normal rainfall probability (IRI, 2005b). Despite the fact that the 2005 precipitation values for Ngoye (west-central Senegal), for instance, were evenly distributed throughout the rainy season and total values approached the high levels from the 1960s, most crops (millet and groundnuts), now adapted to a short (90-day) growing cycle, rotted in the fields and farmers complained about a poor harvest. Farmers seemed utterly unprepared with no strategies to moderate damage or take advantage of the opportunity.

The 2006 rainy season in the Western Sahel produced satisfactory rainfall in most parts, despite irregular rainfall in June and July over Senegal and Mauritania. However, torrential rainfalls in August caused flooding in Niger and Burkina Faso. In Niger, over 15,000 people were affected, with most harm occurring in the region of Agadez, including >1,000 houses destroyed and roughly 3,000ha of fields and gardens damaged (ReliefWeb, UN, Sept. 5, 2006; see Figure 1). As of May 2007, the predictions for the 2007 rainy season (July-September) show slightly to substantially enhanced probabilities for above normal rainfall for the Western Sahel (IRI, 2007; ACMAD, 2007).

At current time, it remains highly contested whether or not these recent observations of wetter conditions in the region signify a climatic shift that will continue throughout the coming decades. Model predictions for the Western Sahel include both significantly drier conditions and clearly wetter monsoons with 20-50% more precipitation (Mitchell et al., 2000; Held et al., 2005; Haarsma et al., 2005; Hurrell and Hoerling, 2005; Zhang and Delworth, 2005; Knight et al., 2005; Kerr, 2005). Not knowing the climatic conditions to which to adapt makes planning and adaptive management an exceedingly difficult undertaking. While more scientific certainty is required with respect to increasing extreme events and changing climate patterns for the Sahel, adaptation to the expanding tails in rainfall distributions has become paramount. Flexible response mechanisms to both floods and droughts appear more opportune than attempted adaptation to changing long-term means. If the region was indeed experiencing a return to a wetter period, adaptive measures to dwindling rainfall, rising temperatures, and deteriorating natural resources, as presented in the NAPAs of Mauritania (2004) and Senegal (2006), would be utterly counterproductive.

This paper addresses two challenges with respect to adaptation:

1) how do decision-makers on the ground - small-scale farmers and agricultural extension agents - identify the onset of an actual climatic shift that requires adaptive measures;

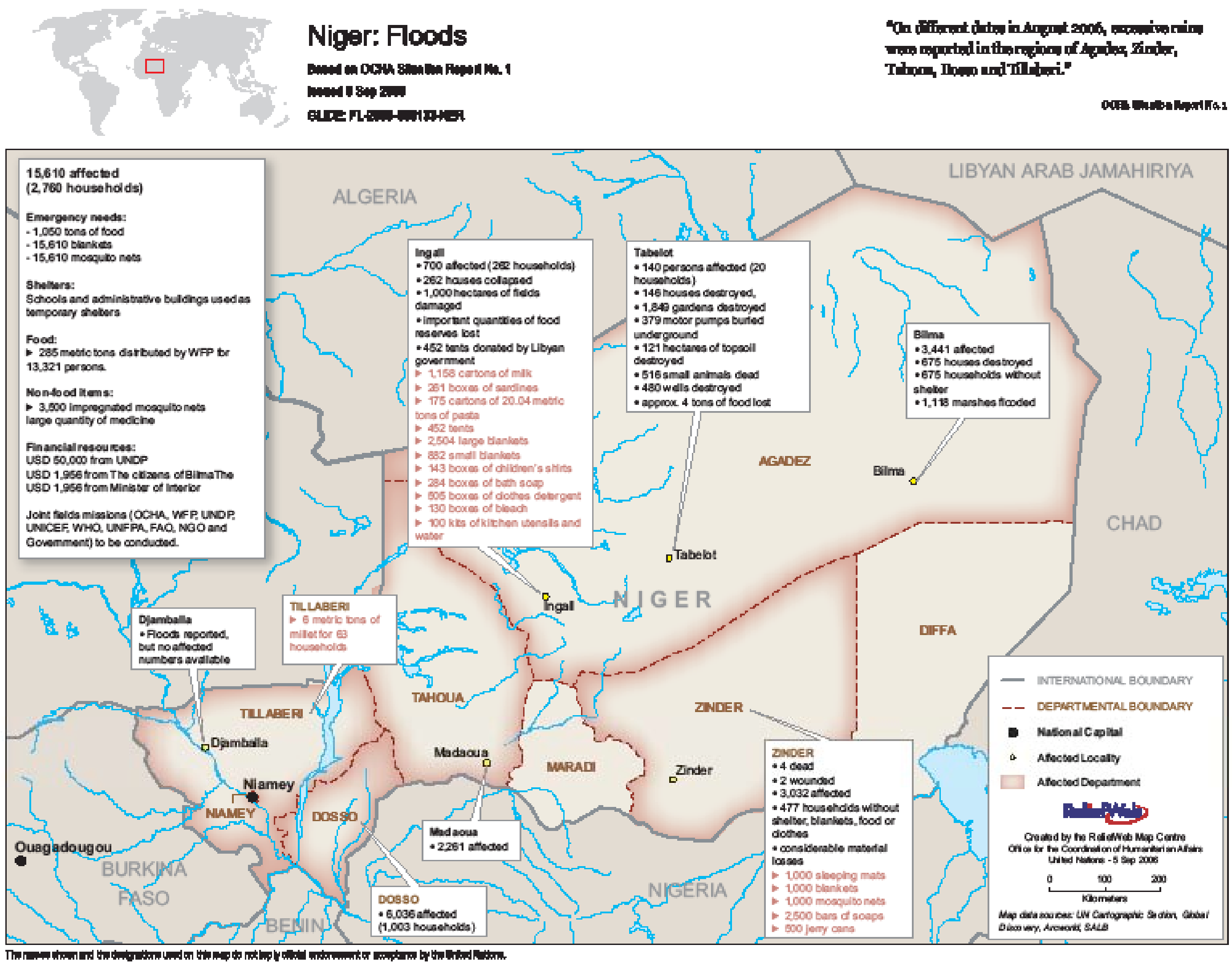

Figure 1: Floods in Niger, Sept. 5, 2006 (Source: ReliefWeb, UN)

2) how can we, as researchers, find appropriate means to mobilize local memory and awaken 'latent adaptive capacity' to facilitate adaptation.

Understanding of Climatic Changes and Climate-Related Decision-Making

Rural decision-makers in Senegal and other parts of the Sahel largely lack access to information that would allow them to judge whether the recent wet period is simply a series of anomalous years to be endured or indeed indicative of a climatic switch and a longer lasting change that would require adaptive responses. The vast majority of farmers are still entrenched in an overriding desertification discourse that has shaped the Sahelian countries since the 1980s. This discourse becomes apparent during participatory conceptual mapping activities where local understandings of causes and consequences of climate variability and change are explored, as described in Tschakert (2007). Small-scale farmers, agricultural extension agents, and district policy makers engaged in reflections on how seasonal patterns of rainfall and temperature had changed over time. Most rural populations still remembered the 'good' times around independence (1950s and early 1960s) when rains and yields were plentiful. Farmers also evoked the cooler periods that then came with the rains and the chilly nights during *noor* winter when it was too cold to hold a cigarette outside. The 1970s, 1980s, and also early 1990s were unanimously referred to as *bekkoor* (drought). As for the recent wet years, including the abundant rains in 2005, farmers made it clear that this period did not represent a return to the pre-drought era. To them, the recent rains were detrimental, 'parasitic', and 'not blessed'. This negative reaction reflects a lack of strategies to protect their crops from or take advantage of the rains to enhance agricultural yields. Several participants also stressed the unusually warm temperatures in December 2005 and January 2006. While participants were reluctant to see these recent changes as a shift in climate, they agreed that they were troublesome.

Causes for changes in climatic patterns were attributed to two main factors - resource (mis-) management and meteorological aspects (Figure 2). Most participants saw a direct link between drought, deforestation, agricultural overexploitation, and insufficient environmental protection. Repeatedly, farmers emphasized that cutting down trees brought droughts, whereas shady canopies attracted rains. At the same time, there was a general agreement that wind strength and direction had an influence on rainfall events. Exceedingly strong WE monsoons were believed to carry rain-bearing clouds into Mauritania while the NE harmattan in May was perceived to push clouds southwards, in each case preventing the rains from reaching farmers' fields. The most interesting and controversial factor discussed was the so-called 'radar', a cloud seeding device. Although none of the discus-

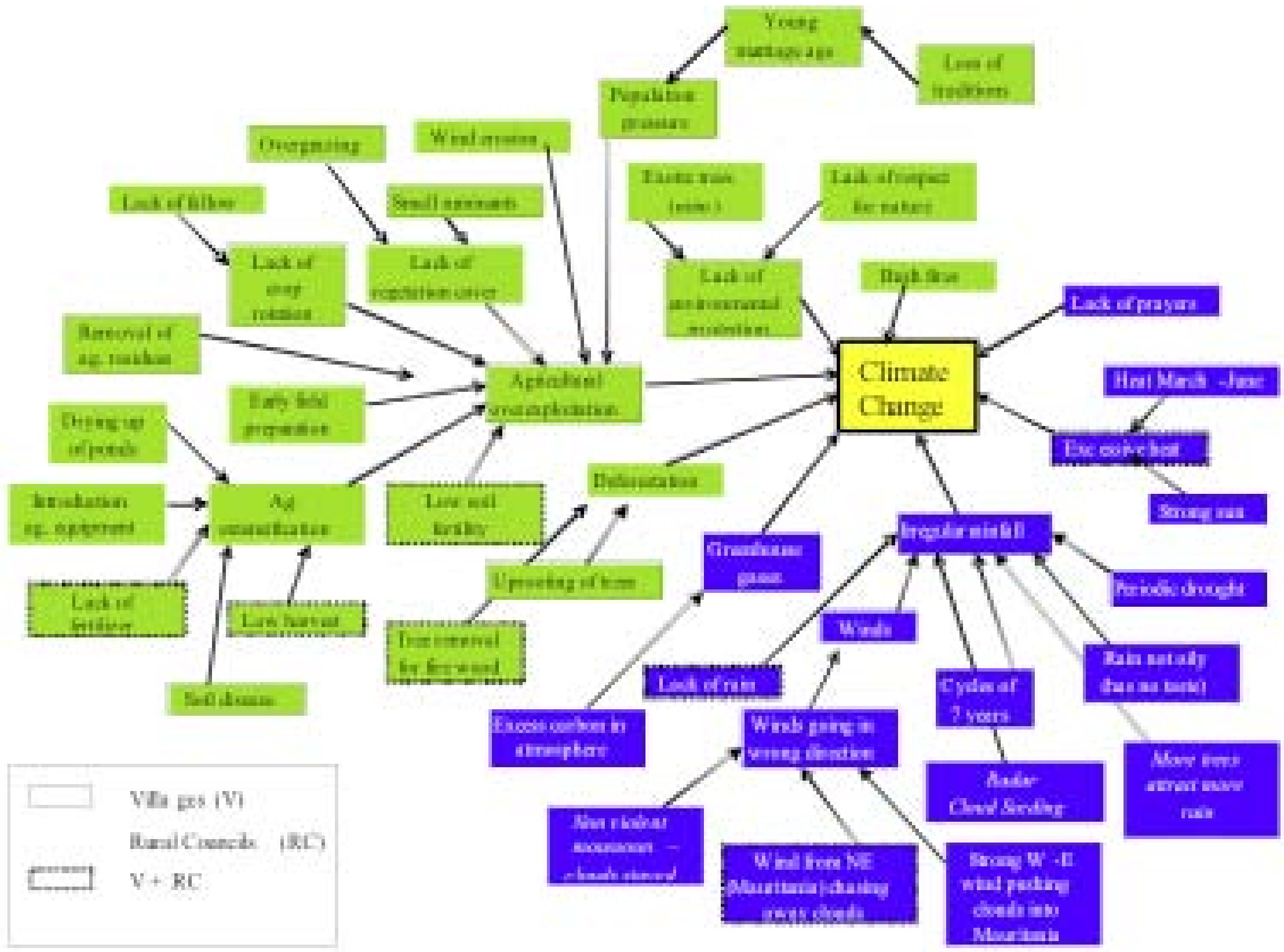

Figure 2: Causes of climatic changes, as understood by farmers, extension agents, and district-level policy makers in west-central Senegal, 2006 (Source: Tschakert, 2007).

sants had seen the device, 150 km away, the 'machine' was (wrongly) believed to be responsible for the 2005 rains throughout the entire country. The biblical seven-good-and-seven-bad-years cycle was also put forward as an explanation for changing climatic patterns.

Sadly, a more informed debate about anticipated climatic changes with both wetter and drier outlooks has been hampered by policy discourses that perpetuate the unwavering crisis narrative of dwindling rainfall, deteriorating natural resources, and the stereotypical notion of victimization. For instance, the Senegal NAPA portrays the country as highly vulnerable to droughts but neglects to address recent records and impacts of increases in rainfall.

The Role of Researchers in Awakening 'Latent' Adaptive Capacity

Shared knowledge and lessons learned from previous climatic stresses can mobilize local memory and provide vital entry points for social learning and enhanced adaptive capacity to both wetter and drier periods now and in the future. For instance, the same conceptual mapping exercises revealed a series of negative and positive impacts of climatic changes rural decision-makers had observed since independence. While the appearances of various diseases (malaria, bilharzias, cholera) are clearly linked to the recent high rainfall events, decline if food availability and diversity as well as outmigration indicate the depressing consequences of the drought years. On the positive front, many participants agreed that the lessons from the long drought years had spurred new research, knowledge and practices in natural resource and land management while promoting natural regeneration due to abandoned fields and longer fallow periods. Despite the suffering in the 1970s and 1980s, it was emphasized how the need for being adaptive, innovative, and resourceful had opened new income-generating activities, hade triggered learning opportunities that made people better prepared for new crises to come, and had ultimately contributed to a higher quality of life. This is not to suggest that crises are a necessary requirement for improved well-being. Rather, these examples show how disasters can hold the potential for successful renewal and reorganization, as suggested under the resilience concept (Carpenter et al., 2001).

Unfortunately, numbing discourses of climate vulnerability and victimization currently undermine local awareness raising, resourcefulness, and agency all of which had emerged as part of farmers' adaptive responses to the drought years. Mismatches between real climate dynamics and 'expert' and 'non-expert' perspectives delay exchange of information, undermine learning and understanding, and thwart the emergence of innovative institutions to monitor changes and experiment with response options.

Currently, farmers' adaptive capacity lays dormant, preventing them from taking advantage of the favorable rainfall conditions. Only few research participants had ever seen a seasonal climate forecast and agricultural extension agents were only marginally better informed than farmers themselves. We, as researchers and policy makers, should build more effectively on local memory, discuss past adaptive strategies and their effectiveness for different groups of people, and promote social learning around climate change to awaken this 'latent' adaptive capacity and support more effective responses to anticipated risks of future climate conditions.

References:

ACMAD, 2007. July-August-September Total Rainfall Forecast PRESAO-10. Updated May 30, 2007. African Centre of Meteorological Application for Development, http://www.acmad.ne/en/climat/PRESAO10-may07_en.pdf

Brooks, N., 2004. Drought in the African Sahel: long term perspectives and future prospects. Working Paper 61, Tyndall Centre for Climate Change Research, Norwich, UK.

Carpenter, S., Walker, B., Anderies, J.M., Abel, N., 2001. From metaphor to measurement: Resilience of what to what? Ecosystems 4, 765-781.

CSE, 2005. Contribution à la mise en œuvre du Plan Jaxaay. Evolution de la pluviométrie et de l'occupation des sols dans la Région de Dakar. Centre de Suivi Ecologique (CSE), Dakar, Senegal.

Eklundh, L., Olsson, L., 2003. Vegetation index trends for the African Sahel 1982-1999. Geophysical Research Letters 30, 1430, doi:10.1029/2002GL016772

Fall, S., Niyogi, D., Mohanty, U.C., Kumar, A., 2006. Application of weather prediction models for hazard mitigation planning: A case study of heavy off-season rains in Senegal. Natural Hazards (in press).

GIEWS, 2005. Sahel weather and crop situation report, Report No 4 - 15 September 2005.

Global Information and Early Warning System on Food and Agriculture. Food and Agriculture Organization (FAO), http://www.fao.org/docrep/008/J6124e/J6124e00.htm

Graëff, E., 2002. Inondations en janvier! Saint Louis du Senegal, http://www.saintlouisdusenegal.com/inondations.htm

Haarsma, R. J., Selten, F.M., Weber, S.L., Kliphuis, M., 2005. Sahel rainfall variability and response to greenhouse warming, Geophysical Research Letters 32: L17702, doi:10.1029/2005GL023232

Held, I. M., Delworth, T.L., Lu, J., Findell, K.L., Knutson, T.R., 2005. Simulation of Sahel drought in the 20th and 21st centuries, Proceedings of the National Academy of Sciences 102, 17891-17896.

Herrmann, S.M., Anyamba, A., Tucker, C.J., 2005. Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. Global Environmental Change 15, 394-404.

Hubert P., Bader J.C., Bendjoudi H., 2005 : Un siècle de débits annuels du fleuve Sénégal. Presented at the Montpellier HSM Seminar, "Impacts climatiques et anthropiques sur al variabilité en ressources d'eau", Montpellier, November 22-24, 2005.

Hurrell, J.W., Hoerling. M.P., 2005. A Continent Split by Climate Change: New Study Projects Stronger Drought in Southern Africa, More Rain in Sahel. News Releases, The National Center for Atmospheric Research and UCAR Office of Programs. May 24, 2005, http://www.ucar.edu/news/releases/2005/hurrell.shtml

IRI, 2005a. Flooding in Dakar, Senegal exacerbates cholera outbreak. The International Research Institute for Climate and Society, University of Columbia, Climate Digest Highlights 8 (10), 1.

IRI, 2005b. IRA multi model probability forecast for precipitation for September-October-November 2005, issued August 2005, The International Research Institute for Climate and Society, University of Columbia, http://iri.columbia.edu/climate/forecast/net_asmt/2005/aug2005/SON05_Afr_pcp.html

IRI, 2007. IRA multi model probability forecast for precipitation for July-August-September 2007, issued May 2007, The International Research Institute for Climate and Society, University of Columbia, http://iri.columbia.edu/climate/forecast/net_asmt/2007/may2007/ASO07_Afr_pcp.html

Kerr, R., 2005. Atlantic climate pacemaker for millennia past, decades hence? Science 309, 1 July, 41-42.

Knight, J.R., Allan, R.J., Folland, C.K., Vellinga, M., Mann, M.E., 2005. A signature of persistent natural thermohaline circulation cycles in observed climate. Geophysical Research Letters 32, L20708, doi:10.1029/2005GL024233.

Mitchell, J.F.B., Johns, T.C., Ingram, W., Lowe, J.A., 200. The effect of stabilizing the atmospheric carbon dioxide concentrations on global and regional climate change. Geophysical Research Letters 27 (18), 2977-2980.

NAPA, Islamic Republic of Mauritania, 2004, http://unfccc.int/resource/docs/napa/mau01e.pdf

Nicholson, S., 2005. On the question of "recovery" of the rains in the West African Sahel. Journal of Arid Environments 63, 615-641.

Olsson, L., Eklundh, L., Ardoe, J., 2005. A recent greening of the Sahel – trends, patterns, and potential causes. Journal of Arid Environments 63, 556-566.

Ozer, P., Erpicum, M,. Demarée, G., Vandiepenbeeck, M., 2002. The Sahelian drought may have ended the 1990's: Discussion of 'analysis of a sahelian annual rainfall index from 1896 to 2000; the drought continue' by L'Hôte et al., Hydrological Sciences Journal 48(3), 489-496.

PANA SENEGAL, 2006. Plan d'Action National pour l'Adaptation aux Changements Climatiques. Ministère de l'Environnement et de la Protection de la Nature du Sénégal, Dakar, Senegal (in press).

Rasmussen, K., Fog, B., Madsen, J.E., 2001. Desertification in reverse? Observations from northern Burkina Faso. Global Environmental Change 11, 271-282.

ReliefWeb, 2006: Niger: Floods – Situation map. Sept. 5, 2006. http://www.reliefweb.int/rw/rwb.nsf/db900SID/AHAA-6TCTEX?OpenDocument

Tschakert, P., 2007. Views from the vulnerable: Understanding climatic and other stressors in the Sahel. Global Environmental Change 17 (3-4: 381-396.

Tucker, C.J., Nicholson, S.E., 1999. Variations in the size of the Sahara desert from 1980 to 1997. Ambio 28, 587-591.

Zhang, R., Delworth, T.L., 2005. Impact of Atlantic multidecadal oscillations on India/Sahel rainfall and Atlantic hurricanes. Nature 11/15.

Climate change science knowledge transfer in support of vulnerability, impacts and adaptation activities on a North American regional scale: Ouranos as a case study

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Abstract

This paper provides an overview of how climate change science knowledge transfer is achieved at Ouranos in support of Vulnerability, Impacts assessments and Adaptation (V&I&A) activities. Ouranos is a Canadian consortium on regional climatology and adaptation to climate change, launched in 2002 by the Government of Québec, Hydro-Quebec and the Meteorological Service of Canada to coordinate climate change research in Québec. This paper presents, via Ouranos' ongoing V&I&A projects in coastal regions, the knowledge transfer environment in place. It also demonstrates how the development of climate indices and indicators of vulnerability, following a Pressure State Response (PSR) framework, form a useful knowledge transfer tool. Two specific case studies address the development of a set of temperature trend indices for southern Québec and climate-social indicators for the assessment of risks to public health due to extremely high temperature events. The first case study illustrates how a systematic analysis of climate variability and relevant extremes indices can be useful for decision-makers at regional scales (southern Quebec). The second case study examines the potential and the feasibility of a Risk Assessment Framework approach for regional impacts and adaptation climate change studies.

1. Introduction

Reducing the adverse impacts of climate change requires both mitigation and adaptation efforts. Indeed, even if CO_2 emissions stabilized at Kyoto levels, the planet would experience warming for the next 100 years (IPCC, 2007) and require the implementation of adaptive measures. Dessai et al. (2004) show how climate adaptation policy is at the confluent of an estimation of physical vulnerability, from data and scenarios at both global and local scales, and social vulnerability, from adaptive capacity based on socio-economic indicators.

Adaptation to climate change is a wide-ranging and complex issue involving numerous technical and scientific challenges, as well as the need for effective communication and knowledge transfer between researchers and decision-makers. This knowledge transfer is needed to address issues like compatibility of spatial and temporal scales, multidisciplinary and integrated approaches, language used by researchers and users of study results, treatment and integration of uncertainties, etc. Climate adaptation policy requires timescale and planning horizons to be put in place. Recently, according to the IPCC (2007) WGI Fourth Assessment Report, numerous long-term changes in climate statistics have been observed not only at continental but also at regional and ocean basin scales. These include changes in annual and seasonal Arctic temperatures and ice cover, widespread changes in precipitation amounts, level of ocean salinity, wind patterns and aspects of extreme weather events including droughts, heavy precipitation, heat waves as well as the intensity of tropical cyclones. Thus, regional and institutional adaptation actions should be anticipatory and planned so as to minimize costs and optimize opportunities. The question is how to tackle climate change issues to adequately address scientific and management challenges at the regional level, and define the required interface between theory and practice.

In Canada, in order to better address these multiple challenges, a consortium on regional climatology and adaptation to climate change was created in 2002 by a group of prominent stakeholders, namely eight Government of Québec ministries, Hydro-Québec, the Meteorological Service of Canada and Valorisation-Recherche Québec. Four universities, already involved at a scientific level, officially joined the non-profit organisation in 2004, namely the Université du Québec à Montréal (UQAM), McGill University, Université Laval, and the Institut national de la recherche scientifique (INRS). Seen as a critical mass of expertise on applied climate change science, Ouranos' mission is to develop knowledge and coordinate the required multidisciplinary initiatives that will help decision-makers integrate adaptation to climate change into decision making processes. This unavoidably involves developing structures for analysis of multidisciplinary problems, promoting synergetic work, developing or optimally applying tools like the Canadian Regional Climate Model (CRCM) or climate and socio-economic scenarios required to support vulnerability and impacts assessments and develop adaptation strategies (V&I&A). The first phase of Ouranos (2001-2005) concluded with the establishment of a flexible organisation with facilities, computer resources and basic infrastructure, financial and human resources contributions from its members (Ouranos, 2007), a scientific program (Figure 1) and a synthesis of current climate change adaptation knowledge (Ouranos, 2004).

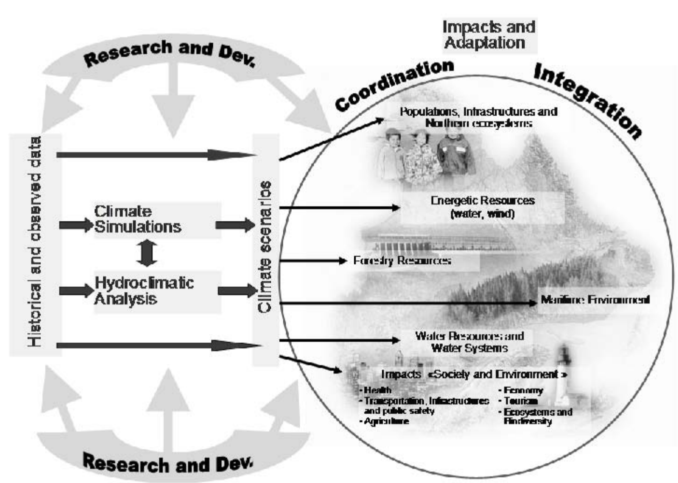


Figure 1. Ouranos: geographic coverage and scientific programs

By working at a regional scale and enabling direct links among experts developing V&I&A activities, Ouranos provides/creates opportunities for innovative dialogue and facilitates knowledge transfer. To illustrate this, below are presented (1) the structure of a coastal region V&I&A project as well as (2) two case studies discussing the use of indicators as a potential knowledge translation tool from science to environmental management practices.

2. Knowledge transfer from science to practice: the Ouranos approach

One of the greatest challenges regarding knowledge transfer is the issue of uncertainties. One approach to cope with the uncertainties regarding future impacts of climate change to human and natural systems is to use climate scenarios as one component within a combination of decision-support tools. These representations of plausible future climates can help the elaboration of climate adaptation policies by estimating potential consequences of anthropogenic climate change (Larrivée and Simonet, 2007, in press). This approach, often called the “top-down” approach, stems from R&D development in climate scenarios. Models are then typically used to evaluate impacts and extrapolated to eventually estimate physical vulnerabilities at local levels (Dessai, 2004). However, there are significant challenges associated with this approach, in particular regarding the accumulation of uncertainties, the possibility of non-linear responses to very high greenhouse gas concentrations (IPCC, 2007), the difficulty of estimating economic and social costs or vulnerabilities (Ambrosi, 2004) as well as the potential lack of participation of the user-groups. This is why several authors focus on user-driven research and non-climatic factors which can have great influence on regional scales when added to climate change effects (Kelly, 2000). Thus, climate adaptation policy development also needs data from indicators based on socio-economic components of the studied system to estimate or build local determinants of a strong adaptive capacity (Yohe, 2002). This “bottom-up” approach is based on short temporal and local scales and can be used to develop climate adaptation policies that enhance coping capacity for both human and natural environments (Adger, 2005). In its programs, Ouranos has several projects that combine top-down and bottom-up approaches. In all cases, the organisation’s structure and the projects it coordinates allow a two way transfer of information, data, results, priorities and research questions between climate specialists, impacts researchers and user-groups to ensure the evaluation of the most relevant potential impacts and to facilitate mainstreaming of adaptation solutions both during and after projects.

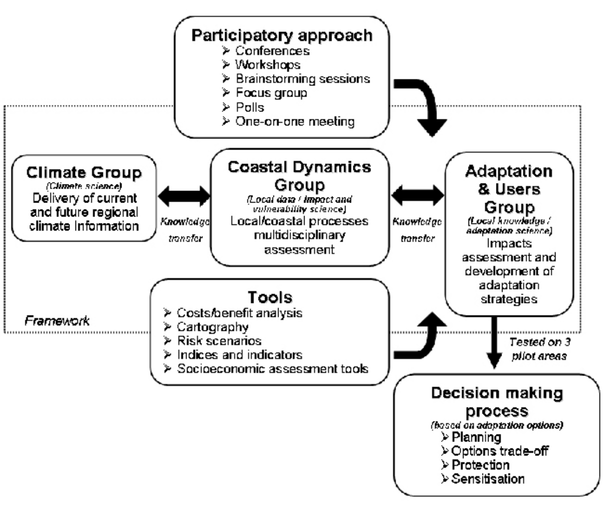


Figure 2. Coastal erosion project framework.

Of its various programs, the one concerning coastal erosion has created one of the organisation’s most successful project environments. Figure 2 illustrates the structure of this project located along the coastlines of the Gulf of St-Lawrence in eastern Quebec. The project is led by a public safety official well-known for his interests in integration, crisis situation management, participatory approaches, knowledge of local scale human and physical geography and for his communication skills. The project includes a “climate” group, a “vulnerability” group and an “adaptation and users” group working in parallel and who have agreed on the research questions to be addressed and on the added-value tools and information to be developed. A three-way communication is ensured through a variety of means like face-to-face meetings; brainstorming sessions; surveys; forums and symposiums that take place throughout the project stages (from the project definition to its conclusion).

The climate group develops or applies tools like the CRCM, climate scenarios and historical data trend analyses to assess past and future probabilistic evolutions of the four climatic indices identified by the coastal dynamics researchers and local experts as relevant for coastal erosion processes (e.g. ice cover, freeze-thaw cycles, storminess, water levels). The coastal dynamics group initially used historical trends in coastal erosion and used expert judgment to propose optimistic, average and pessimistic erosion scenarios for the next 30 years for three pilot areas (a few kilometres of coastline selected by 3 communities). This group then uses, for example, outputs from the climate group, from the adaptation and users groups and from their own sectorial research to better assess the probable evolution of the biophysical vulnerability of the selected coastline. The adaptation and users group reassesses potential impacts of the different proposed coastal erosion scenarios, discusses adaptive capacity or even mandate-specific adaptation option studies with the objective of revisiting current practices in coastal zone management. One of the many contributions of having this project structure is the conclusion that simple indices or indicators mapped at the request of interested users can add significant value and facilitate knowledge transfer.

3 Indicators as a knowledge translation tool

This section discusses the development and use of indicators as an interface and knowledge translation tool by Ouranos. This is illustrated by a more detailed look at two specific case studies addressing (1) the development of a set of temperature trend indices for southern Québec, and (2) climate and social indicators assessing public health risks due to extremely high temperature events. The two case studies serve to illustrate how indicators have been developed by Ouranos following a Pressure, State Response (PSR) framework and suggest what the future development for this could be. The PSR framework states that human activities exert pressures (e.g. pollution emissions) on the environment that can induce changes in the state of the environment (e.g. changes in ambient pollutant levels, climate characteristics, water flows, etc.). Society then responds to changes in pressure or state with environmental and economic policies and programs intended to adapt, prevent, reduce or mitigate these pressures and/or environmental damages.

3.1 Case study 1: Development of a set of climate indices in southern Québec

A recent study of Canada’s climate shows significant changes in temperature and precipitation occurring during the twentieth century (Vincent and Mekis, 2006). However, because the climate indices used reveal a high degree of spatial variability, Vincent and Mekis (2006) conclude that more detailed research is needed on a regional basis. In 2002, Ouranos, in collaboration with the Quebec Ministry of Sustainable Development, Environment and Parcs, launched a historical data study to examine regional temperature trends across southern Quebec. Consequently, 1960 to 2003 daily minimum and maximum recorded temperature series at 53 stations were analysed and homogenised. Homogeneity problems due to station relocations and changes in observation procedures were addressed using a technique based on regression models and surrounding stations (Vincent, 1998). The technique used to identify inconsistencies/incongruities was tailored to the regional Quebec data set used (Yagouti et al. 2007). Thus, 106 maximum and minimum temperature series were homogenized on various temporal scales (daily, monthly, seasonal and annual). The results of the homogenisation process show that only 36% of the 106 series were homogeneous. Amplitudes of the detected inconsistencies were estimated and corrections were made where necessary to the non homogeneous series. At the end of the process, 52 statistically homogeneous stations were retained. One station was eliminated because of the high percentage of missing values and the many relocations of this station during the time period.

Chosen mainly to provide a general portrait of the southern Quebec climate, the temperature indices computed from these homogenized series were selected in close collaboration with Ouranos' stakeholders. The results show that the surface air temperature has increased in southern Québec over the 1960-2005 period. A significant warming is evident in the west and south while the increasing trends are not as important towards the north and east. The warming is more pronounced during the winter, although many significant increasing trends are also detected during the summer months. The analysis of temperature extremes strongly indicates more nights with very high temperatures in all seasons. The temperature indices also

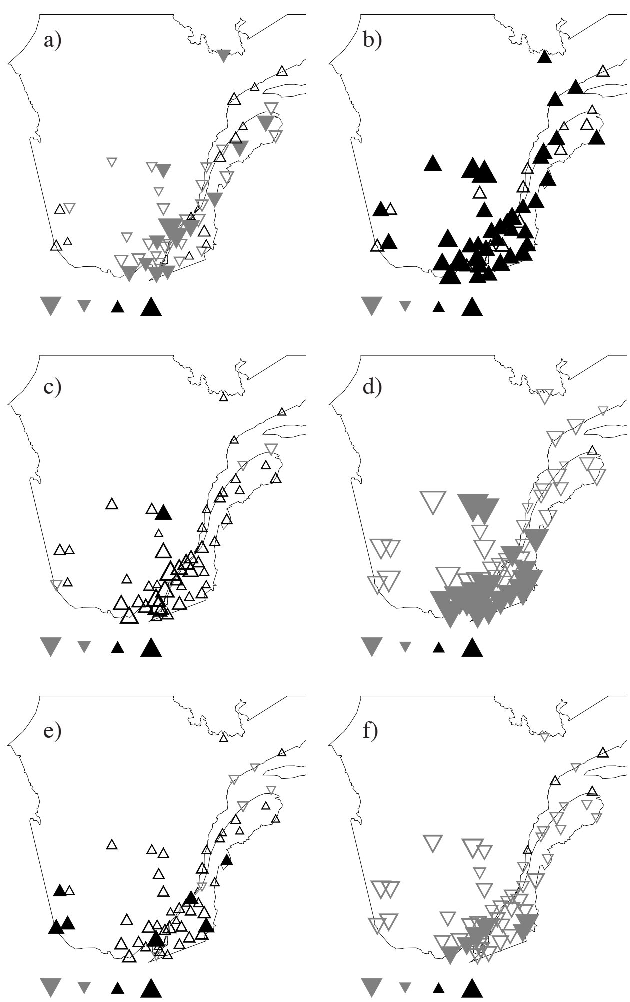


Figure 3. Trends in six temperature indices for 1960-2005. (a) Frost degree days-annual, (b) Growing degree days-annual, (c) Cooling degree days-annual, (d) Heating degree days, (e) Thaw/frost days-winter, (f) Thaw/frost days-spring.

suggest a decrease in the length of the frost season (Figure 3a) and an increase in the length of the growing season (Figure 3b), an increase in cooling degree days (Figure 3c) and a decrease in heating degree days (Figure 3d) as well as an increase in the number of freeze-thaw cycles during the winter (Figure3e) and a decrease in the number of freeze-thaw cycles during the spring (Figure 3f). This study improves our understanding of the trends and variations in temperature and precipitation indices in Southern Québec. The majority of the findings are consistent with those expected in a warmer climate. The observed warming appears to have some beneficial impacts for certain socio-economic activities in Québec, such as a longer growing season and a shorter frost season. However, the warming can also have adverse effects on various industries in Québec, including a shorter tourism season in the winter and increased energy demand for cooling buildings in the summer.

3.2 Case study 2: Climate vulnerability indicators for assessing public health risks due to extremely high temperature events

A study published in 2005 (Vescovi et al. 2005) demonstrates the feasibility and potential of a risk assessment approach and the development of public health risk indices for a regional impact and adaptation climate change study applied to heat waves in southern Québec. The methodology developed for this study was inspired by the NOAA (1999) vulnerability assessment tutorial, by the EPA (1998) guidelines for Ecological Risk Assessment, by Cutter et al. (1997), Schiegg (2000) and by the Tyndall Centre's research (Adger et al. 2004). Climate variables and socio-economic parameters were integrated via a geographic information system (GIS) tool to produce maps of estimated present and future public health risks.

To characterize current climate hazards, data from 310 Environment Canada stations in southern Quebec were used along with two indices:

1) Mean number of days with Tmax > 30°C, for weather stations with data for at least 16 years between 1971 and 2000 (272 stations). This index was interpolated using the natural neighbour method.

2) Mean number of episodes per year with at least three consecutive days with Tmax > 30°C and Tmin > 22°C. These were computed from daily temperature series within the period 1971 to 2000 for the stations with indexes (1) higher than 2.5 d y^{-1} (67 stations).

These are based on practical characterizations of extreme temperature events established by the Montreal Public Health Board (MPHB) which recently proposed an operational definition based on a daytime high of 30°C (Tmax) and night time low of 22°C (Tmin) for 3 consecutive days (Drouin et al. 2005).

To characterize future climate hazards related to potential impacts of extreme heat, climate projections for 2039 - 2063 were made using the Canadian Regional Climate Model (CRCM) V3.6.1, driven by the coupled ocean-atmosphere model CGCMII and following the IS92a (IPCC) emissions scenario for greenhouse gas emissions. The CRCM performs climatic simulations at a small-scale resolution (distance between each grid point about 45 km) and for timesteps of 15 minutes.

Social vulnerability was calculated through four social sub-indices determinant for Quebec's reality and considered relevant elsewhere for defining the vulnerablility of human populations to extreme high temperature events. These four sub-indices are:

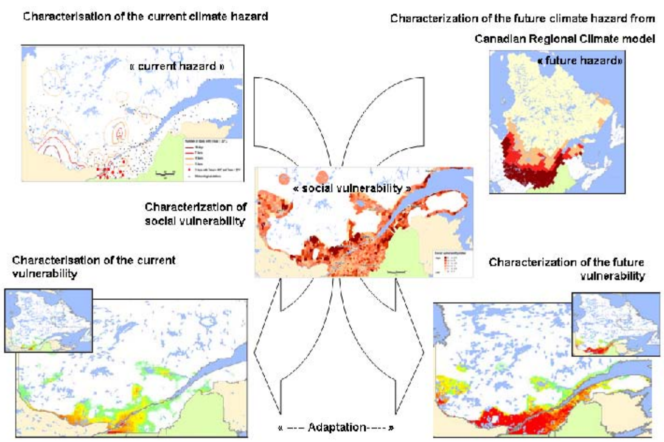
1) Age index: frequency of people aged 65 and over

2) Poverty index: frequency of low-income earners (LICO-base 2001) by Statistics Canada for rural zones, with the FGT (Foster-Greer-Thorbecke) index by classes of income in 2000 Canadian dollars

3) Social isolation index: frequency of single person households

4) Education index: frequency of people aged 20 and over with less than 13 years of education

Figure 4 Methodological principle applied to public health risk maps for current and future conditions (adapted from Vescovi et al. 2005)



A comparison of risk maps for present and future conditions (Figure 4) showed that the number of locations where populations would be at risk due to high temperature events would dramatically increase in Quebec over the next few decades. Based upon the assessment of biophysical vulnerability to climate change (which is a relatively new concept combining physical and human processes), this study gives preliminary input to the Quebec public health decision-makers currently developing a spatially explicit on-line analytical processing tool using Web-GIS technology to identify areas potentially vulnerable to climate change.

4. Discussion and conclusion

By creating Ouranos, Canadian decision makers at the national and provincial levels confirmed that V&I&A, in the context of climate change, is a priority. More than simply supporting an integrated scientific program, one additional objective is to develop a structure for analysis of multidisciplinary problems and to promote synergetic work in the search for solutions to climate change adaptation issues in a North American context. By working at a regional scale and enabling links between various researchers and decision-makers, Ouranos provides an opportunity for innovative multidisciplinary, multi-organisational dialogue and facilitates the mainstreaming of adaptation. Various methodologies are used by Ouranos' "scientific brokers" to accomplish this, including face to face meetings; brainstorming sessions; surveys; forums; symposiums and scientific projects which ideally include a climate, a vulnerability and an adaptation component working in parallel to achieve the project objectives. Also, Ouranos develops or tailors several tools to support V&I&A analyses such as the Canadian Regional Climate Model and climate change scenarios applied for priority issues. Using concrete examples taken from Ouranos' ongoing V&I&A projects in Coastal regions, this paper demonstrates how the science developed at Ouranos is used to facilitate knowledge transfer to practice.

Among the knowledge transfer tools available, the development of climate indices and indicators of vulnerability following a PSR framework (such as the one illustrated in Figure 5), is recognised as being very useful for assessing positive and negative impacts to global and regional climate change (OECD, 1993, 2006).

Also, this paper demonstrates how the development of climate indices and indicators of vulnerability (specific and relevant to each of the issues and regions of interest identified by Ouranos) following a PSR framework are useful knowledge transfer tools. This is illustrated by a more detailed look at two specific case studies addressing the development of a set of temperature trend indices for southern Québec, and climate and social indicators assessing public health risks due to extremely high temperature events. The first case study documents how various user-relevant climate variability and extremes indices ("State" of PSR if the climate system is considered and "Pressure" if the problem is examined from the human system point of view) was likely affected at regional scales (southern Quebec) by atmospheric increases in GHG concentrations ("Pressure" of PSR considering the climate system). The latter case study examines how a relatively new concept of biophysical vulnerability to climate change, which combines both physical and human processes, can also be used in the PSR framework.

Thus, assessing trends, processes and warning signals (e.g. extreme temperature events, precipitation events, sea level rise, etc…) or reporting the efficiency of adaptation (and mitigation) strategies are the major drivers pushing towards the development of indicators. In each case, the strength of the metric will be its high diagnostic value in attributing detectable changes to identifiable forcing factors. Indeed, one of the main challenges is to adequately address long term climate change trends with short term managerial commitments (Corfee-Morlot and Höhne, 2003). Thus, for decision-makers, addressing metrics (process and indicators) of diagnostic value, capable of attributing changes to identifiable forcing factors is of great interest to provide a reliable response in terms of adaptation strategies to implement (OECD, 2006).

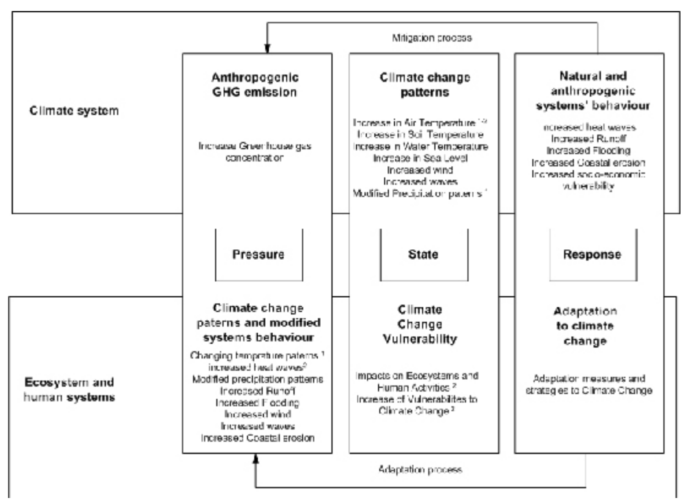


Figure 5 Matrix grouping indicators according to the PSR approach

References

Adger N. W., Kelly M., Bentham S., Eriksen S. (2004) New indicators of vulnerability and adaptive capacity. Report No. 7, Tyndall Center for Climate Change Research.

Adger N. W., Arnell N. W., Tompkins, E. L. (2005). «Successful adaptation to climate change across scales.» Global Environmental Change 15: 77-86.

Ambrosi, P. and Courtois, P., (2004). «Impacts du changement climatique et modélisation intégrée, la part de l'arbitraire.» Nature Sciences et Sociétés 12: 375-386.

Corfee-Morlot J. and Höhne N. (2003) Climate change: long term targets and short term commitments. Global Environmental Change: 13, 277-293.

Cutter S. and Scott S. M. (1997) Handbook for Conducting a GIS-based Hazard Assessment at the county level. University of South Carolina

Dessai, S. and Hulme M. (2004). «Does climate adaptation policy need probablities?» Climate Policy 4: 107-128.

Drouin L, King N., Jacques L., Fortier I., Roy L. A., Litvak E., Simard J.O., Kosatsky T. (2005) The Response of the Montreal Public Health Board to Climate Change: Preventing Excess Morbidity and Mortality due to Extreme Summer Temperatures in Vulnerable Human Populations. In Adapting to Climate Change in Canada 2005: Understanding Risks and Building Capacity, Montreal, Québec, 4 to 7 May 2005.

EPA (1998) Guidelines for Ecological Risk Assessment. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC.

IPCC (2007). Climate Change 2007: The Physical Science Basis. Summary for Policy makers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/SPM2feb07.pdf

Kelly P. M. and Adger, N. W. (2000). «Theory and Practice in Assessing Vulnerability to Climate Change and facilitating Adaptation.» Climatic Change 47: 325-352.

Larrivée, C. and Simonet G. (2007). The use of climate scenarios at the municipal level. In Climate Change : A Guide to Policy and Practice for Canadian Municipalities. In press.

NOAA Coastal Services Center (1999). Vulnerability Assessment Tutorial.

OECD (1993) OECD core set of indicators for environmental performance reviews. OECD Environment Monographs No. 83. OECD. Paris. http://lead.virtualcentre.org/en/dec/toolbox/Refer/gd93179.pdf

OECD (2006) Metrics for assessing the economic benefits of climate changes policies : sea level rise. ENV/EPOC/GSP(2006)3/FINAL. OECD. Paris

Ouranos (2004). S'adapter aux changements climatiques, Montréal. 91 p. Accessible le 16 mars 2006 à : http://www.ouranos.ca/doc/produit_f.html

Ouranos (2007) Site Internet consulté le 25 avril 2007 - http://www.ouranos.ca/intro/intro_e.html

Schiegg O. (2000) DRM Strategy, Tactics, Example. World Institutes for Disaster-Risk-Management.

Vescovi L., Rebetez M., and Rong F. (2005). Assessing public health risk due to extremely high temperature events: climate and social parameters. Climate Research, Vol 30 :71-78.

Vincent L. A. (1998) A technique for the identification of inhomogeneities in Canadian temperature series. J. Clim. 11: 1094–1104

Vincent L. A. and Mekis É. (2006) Changes in Daily and Extreme Temperature and Precipitation Indices for Canada over the Twentieth Century Atmosphere-Ocean 44 (2) 2006, 177–193

Yagouti A., Boulet G., Vincent L.A, Vescovi L. and Mekis É. (2007) Observed changes in temperature and precipitation indices in southern Québec, 1960-2005. Submitted to Atmosphere-Ocean.

Yohe G. (2000) «Assessing the Role of Adaptation in Evaluating Vulnerability to Climate Change.» Climatic Change 46: 371-390.

Coastal Vulnerability & Monitoring in Central Pacific Atolls

Arthur Webb

SOPAC- Secretariat of the Pacific Islands Applied Geoscience Commission, Ocean & Islands Programme

Accelerated sealevel rise is routinely cited as the reason behind coastal erosion in the SW Pacific region however, quantitative, empirical data which supports this premise is almost non-existent. SOPAC advocates accurate ongoing shoreline monitoring and assessment using multi-temporal image techniques as a valuable approach to the pressing issue of shoreline erosion in atolls and assessment of appropriate mitigation strategies.

Introduction

Given current IPCC 2007 advice and predictions, the premise that low-lying atolls and the cultures and communities they sustain are in an extremely vulnerable position can not be over emphasised. Predicted climate change impacts of shifting weather patterns, accelerating sea level rise and the distinct possibility of perturbation of tropical reef ecosystems through change in physiochemical parameters of surface water quality (e.g. temperature and CO2 concentration) provides a sobering vision of the future for atoll environments.

Significant progress has been achieved in efforts to understand and monitor weather patterns and sealevel across our region. Additionally, important parameters such as, sea surface temperature and oceanic currents are also being routinely monitored largely due to advances in remote sensing technology. (e.g. SEAFRAME, TOPEX / Poseidon-Jason, NOAA systems, etc.).

Whilst the information these systems supply has (and continues to) greatly advance understanding of Pacific and global oceanic and weather systems, its direct relevance to small communities of the developing Pacific Island nations may not be readily apparent. An issue of central importance to all Pacific coastal communities especially on atolls is how these changing processes are affecting their shorelines, scant land resources and vulnerable groundwater systems.

At this point in time there is no systematic or regional approach to monitoring shoreline change and erosion, and otherwise accepted predictive modelling approaches to erosion appear inappropriate, particularly in atoll situations. SOPAC advocates accurate ongoing shoreline monitoring and assessment using multi-temporal image techniques as the most beneficial and appropriate approach to the pressing issue of shoreline erosion in atolls (and other low-lying Pacific communities)

Established coastal erosion assessment

The UNESCO Methodology Handbook for assessment of coastal erosion outlines only one model when discussing the need to predict coastal response to sealevel rise (The Bruun Rule). This method whilst widely used is also widely understood to be an over simplification of coastal response and is known not to adequately describe shoreline possesses on atolls (Kench & Cowell, 2001; Cooper & Pilkey 2004).

The Bruun Rule states that an incremental increase in sealevel results in a predictable incremental loss of land. This method whilst widely used is also widely understood to be an over simplification of coastal response and is known not to adequately describe shoreline possess on atolls (Kench & Cowell, 2001).

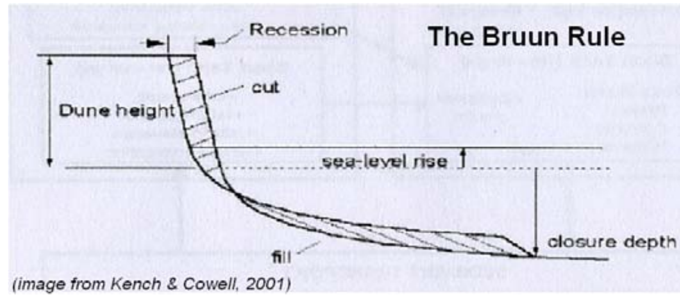


Figure 1.

Kench & Cowell (2001) propose that an alternative modelling approach "Shoreline Translation Modelling" (STM) better describes reef platform beach (atoll) response to sealevel rise. Certainly this modelling approach paints a significantly different picture of how atoll shores may respond and corresponds sharply with Bruun-style calculations which would suggest 0.9 m of sealevel rise would essentially result in complete erosion and disappearance of soft shore atolls.

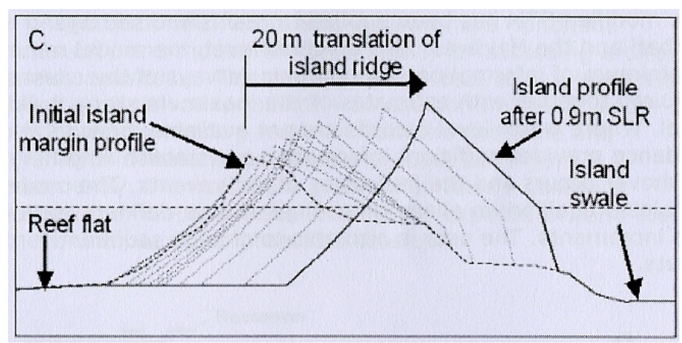


Figure 2.

The Bruun Rule, a simple mathematical rule, essentially indicates that there will be an incremental loss of land for every incremental rise in sealevel. Not only has the simplicity of this method been exhaustively debated but, in view of the results of SOPAC's work, it is obviously incorrect when applied in the context of reef flat perched, carbonate beaches commonly found on atolls and elsewhere in the Pacific.

Adherence to and widespread use of Bruun style predictive models may add to the popular perception that atolls are disappearing rapidly and that the principal culprit or causal factor is sealevel rise - this perception deserves greater attention.

SOPAC's approach to coastal processes & erosion

Like Pilkey (2004), advocates recognition and acceptance that we cannot actually predict shoreline retreat related to sea level rise at this time – "it's just too complex". And whilst it is recognised that modelling is the primary tool with the potential to eventually predict what shoreline response to sealevel rise may be, all models are necessarily a mathematical simplification of the real environment and can only be as good as our understanding of the function of any particular shoreline system.

Throughout the tropical Pacific many of our coasts are "living" features, as found on atolls, and are among the most complex shoreline systems on Earth. Composed entirely of material which is biogenic (the skeletal remains of once living reef organisms) they are therefore greatly influenced by any changes to reef productivity, biological composition and ecology.

Like all soft beaches, sediment is delivered to atoll shores by waves whose energy is dictated by weather and oceanic conditions (these alone are vastly difficult to predict and understand in terms of climate change). However, on atolls, the manner in which wave energy moves from the ocean, over reef crests and flats and ultimately to shorelines, is further controlled by the shape and elevation of living fringing reefs and associated algal ridges. The response of these living features to climate change is unknown but any change in terms of productivity, composition, shape or elevation, will in turn influence the manner in which wave energy travels from the ocean to the shoreline and thus also bares great influence over shoreline sedimentary processes.

Reliable prediction of changing weather or marine conditions at a resolution appropriate to a single island or atoll remains at this time beyond our reach. And the prediction of natural variation in shorelines let alone the additional broader implications of physical and chemical changes in surface waters to tropical reef function (i.e. increased sealevel, CO_2 concentration and sea surface temperatures) is also presumably some time away.

In the apparent absence of adequate modelling systems and understanding of even present existing variability in tropical Pacific shoreline processes, SOPAC advocates monitoring of these systems to clearly and dispassionately quantify how atoll shores are responding to sealevel rise and other possible climate change related stress as well as local human induced change. A deeper data based understanding of these processes will conclusively inform atoll Governments and communities of how their environment maybe changing and will provide an excellent ongoing tool for coastal vulnerability, management and mitigation responses. Further, data which empirically explains variability and change in these environments will ultimately allow more appropriate modelling approaches to be developed.

Coastal monitoring using multi-temporal image comparisons

Historical aerial photographs are available for many locations throughout the SW Pacific. For many locations the record begins in the early 1940's corresponding to the WWII Pacific campaign and the early widespread use of air photography for military reconnaissance purposes. For many locations through the region this early period corresponds to lower levels of environment disturbance since island populations and lifestyles were closer to their subsistence origins. Of additional interest, the early 1940's also allows a view back into a world where rates of temperature and sealevel change may have been lower than those of today and climate change related phenomena such as mass coral bleaching from heat stress were at that time unreported (Hoehh-Guldberg, 1999).

Access to high resolution satellite images and accurate portable GPS systems is changing the face of natural resource and environmental management approaches. The greater availability of powerful "off-the-shelf" computers and software have facilitated digitalisation and manipulation of historic and current satellite images and it has become comparatively easy to accurately detect environmental change - including shoreline position. SOPAC has successfully and accurately determined coastal change in atolls over several time periods which span a total of up to 60 years. This work can also be undertaken remotely, although ground truthing and a detailed knowledge and understanding of the target coastal environment is an indispensable necessary to ensure accuracy.

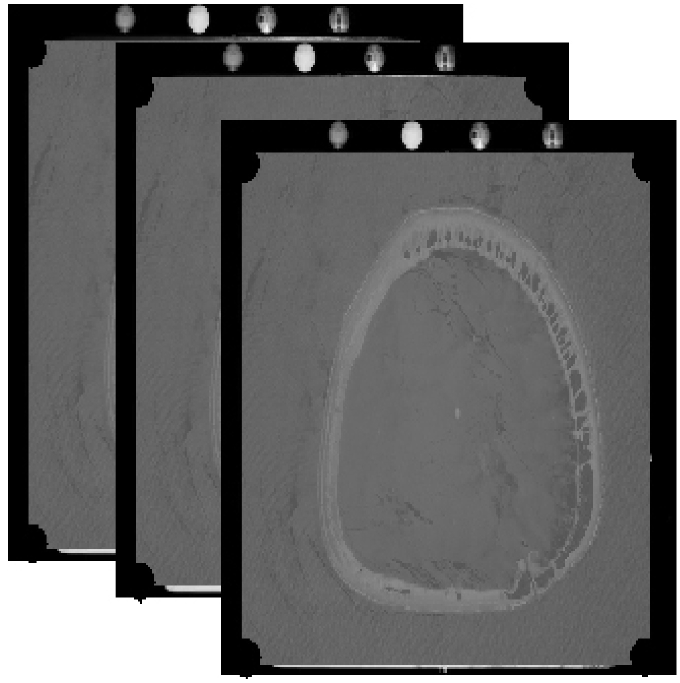


Figure 4.

Figure 5.

Once present and historic images have been accurately geo-rectified and identical geo-reference information has been embedded, they become a powerful archive and monitoring tool. These allow comparisons of shorelines (and other features) over time and can detect change of less than 1 m (depending on the resolution of the images used). The products of this system remain as part of a GIS (digital geographic information system) and are also ideally suited for local resource managers when printed as elegantly simple maps which accurately show trends and shoreline change over time (e.g. Webb, 2006).

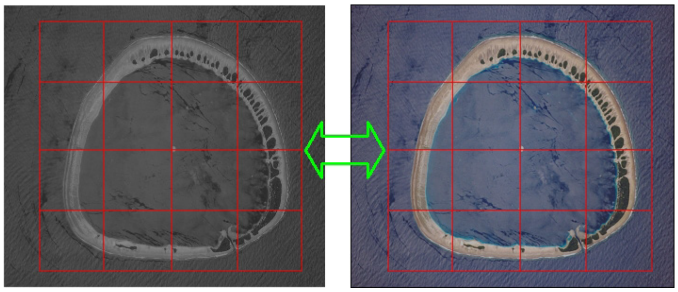


Figure 6.

CASE STUDY

Innate environmental sensitivity, swelling populations and resource scarcity are also contributing to the vulnerability of atoll coastal systems to climate change impacts. Betio Islet, Kiribati is one of South Tarawa atoll's larger land masses and hosts the main port of entry and is the National centre of trade and commerce;

- Betio has a land area of approximately 1.5km^2 giving an average population density of 1,430 people / km^2.
- The islet is on average between 1 and 1.5m above the average high water mark.
- Every year, 70,000m^3 of sand and gravel is mined from South Tarawa's sensitive and vulnerable beaches (Pelesikoti, 2007), this is approximately equivalent to the area of land above the low tide water mark, within the red circle.

Figure 3.

Whilst there can be little doubt that the community on Betio and other parts of South Tarawa are extremely vulnerable to climate change stress and associated sea level rise and they do already suffer greatly during adverse weather events and the reason for this can not be linked to climate change alone.

Intense over-crowding and competition for space has lead to settlement of extremely marginal and unstable shoreline areas and ad-hoc, poorly designed reclamation proliferates. Any form of property or dwelling built in such areas or protected by such 'engineering', are vulnerable to even mild weather shifts or events and even natural ongoing sediment transport processes can result in hardship and property loss under such conditions (Webb and Biribo, 2007).

SOPAC's coastal assessment work in Betio is a graphic example of this phenomena. Despite a long history of requests to assist on issues of coastal instability and erosion in Betio and South Tarawa our recent image comparison work shows a pattern of significant increases in land area rather than erosion. The first of the following images show Betio in 2004 (colour IKONOS satellite image) with a red line indicating the comparative historical 1943 shoreline). The second image alternatively shows an accurately geo-rectified 1943 aerial photograph (blank and white) with a yellow line showing the comparative 2004 shoreline.

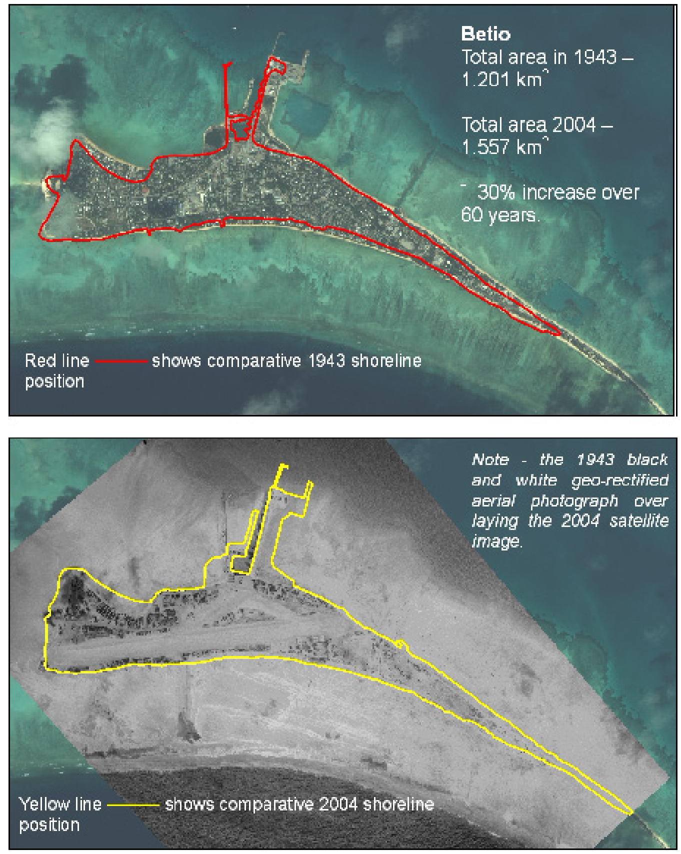


Figure 7.

Images from 1943, 1968, 1998 and 2004 were available of Betio Islet and once geo-rectified, these showed that despite the huge pressures on this tiny sand islet the land area has steadily increased over time - equivalent to about 30% growth over the last 60 years). Whilst a significant proportion of the increase is due to reclamation (note the wharf structure) a greater amount is due to on going sand accretion (Webb & Biribo, 2007).

According to models such as the Bruun Rule island area increase should not have occurred, as it is estimated than mean sealevel in neighbouring Funafuti has risen 10 ± 5cm over the last 50 years (Church et al, 2006) and it is assumed that similar rates have also acted on Betio's shores. The 2005, SEAFRAME report indicates a 12 year sealevel trend of +6.2mm yr^{-1} at Betio, however it is recognised that it is too early for the SEAFRAME trend to be considered reliable.

However, given that sealevel rise has and is occurring, such examples of net islet growth fly in the face of established thought and modelling. It is also instructive to note that additional assessments on other atolls including islets and locations where direct human disturbance does not artificially contribute to increases in land area, also show net gains in land area (Biribo, 2007, MSc thesis). These results suggest that shoreline response in these environments is complex and does not necessarily follow established thought with regards to soft shore erosion and sealevel rise.

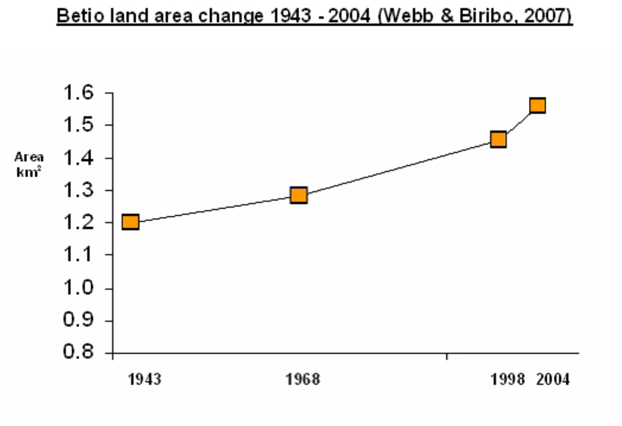


Figure 8.

It is not known when sealevel rise and / or other climate change related stresses will result in net land area reduction in these environments. However, in the absence of data or monitoring we have no way of knowing when or if such a threshold will be reached. As such, it is of crucial importance to atoll and other low-lying coastal communities that empirical shoreline assessment and monitoring approaches are promoted. And in particular, the use of accurate historical comparisons to develop an understanding of present coastal processes in the context of past ongoing trends is an invaluable tool to both researchers and on the ground decision makers. It is also suggested that identifying and developing past trends is the soundest manner in which to attempt to detect unusual change, analogous to long term sealevel or temperature measurement.

SOPAC is an intergovernmental organisation mandated to assist some 18 developing Pacific Island Nations. Through its Ocean & Islands Programme it offers - research, development and management of non-living resources in ocean, coastal and island systems addressing issues relating to seabed resources, hydrodynamics, monitoring of ocean and coastal processes and maritime boundary delimitation. (www.sopac.org)

Notes and references

Paper and poster compiled by Dr. Arthur Webb - Coastal Processes Adviser to SOPAC, however the invaluable editing, review and assistance of the Ocean & Islands team is gratefully acknowledged.

The examples and multi-temporal image comparison method explained was used successfully over the last 3 years and examples of this work are available via the SOPAC web site (www.sopac.org -Technical Reports 46, 53, 54).

References

- Church, J.A., White, N.J. & Hunter, J.R. 2006. Sea-level Rise at tropical Pacific and Indian Ocean islands. Global and Planetary Change, 53. 155-168.
- Cooper, J.A.G. & Pilkey, O.H. 2004. Sea-level rise & shoreline retreat: time to abandon the Bruun Rule. Global and Planetary Change, 43. 157-171.
- Hoehh-Guldberg, O. 1999. Climate change, coral bleaching & the future of the world's coral reefs. Marine & Freshwater Research, 50. 839-866.
- Kench, P.S. and Cowell, P.J. 2001. The Morphological Response of Atoll Islands to Sea-Level Rise. Part 2: Application of the Modified Shoreline Translation Model (STM). Challenges for the 21st Century in Coastal Sciences, Engineering and Environment, Journal of Coastal Research, Special Issue, 34: 645-656.
- Pelesikoti, N. 2007. Extent of household aggregate mining in South Tarawa. Kiribati Technical Report 72. SOPAC. Suva, Fiji.
- Webb, A.P. & Biribo, N. 2007. Coastal change analysis using remote sensing at selected sites on Tarawa Kiribati. Technical Report. SOPAC. Suva, Fiji.
- Webb, A.P. 2006. Coastal change analysis using multi-temporal image comparisons – Funafuti Atoll. Tuvalu Technical Report 54. SOPAC. Suva, Fiji.

Designing appropriate and effective climate change adaptation (CCA) responses: some lessons from the development phase of a first generation CCA pilot in Namibia

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Abstract

Namibia is said to be particularly vulnerable to forecasted climate changes over the coming decades. With an economy strongly dependent on natural resources such as agriculture, water, fisheries, wildlife, and nature-based tourism, predicted impacts can have severe repercussions for the country. The large percentage of people living on subsistence and small-holder ranching and in some areas agriculture (about seventy percent of the population) is at risk of impairing their livelihood base and exacerbating poverty if adaptive capacities cannot be improved. Relevant responses to climate change have to be designed and implemented at all levels, including local resource managers, regional and national service providers, and the policy making level. Based on a pilot assessment carried out in preparation of climate change adaptation activities in northern Namibia, the lessons learnt in the preparation of such activities, challenges identified and recommendations for an improved methodology, can be shared.

1. Background

1.1. Climate variability, climate change risk and need for adaptation in Namibia

Climatic variability is a common phenomenon in Namibia. Persistent droughts, as well as unpredictable and variable rainfall and temperatures, are considered normal climatic conditions. At the same time, climate change predictions for Namibia based on the IPCC's Third Assessment Report and other recent studies suggest that by 2050 temperatures and rainfall over southern Africa will be 2 – 4°C higher and 10 – 20% less than the 1961-90 baseline, respectively (Figure 1).

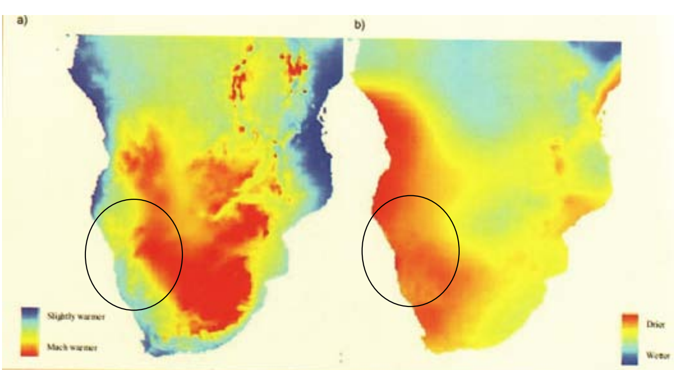

Figure 1: HADCM3 climate model projections of changes in temperature (a) and precipitation (b) for 2050 relative to mean conditions over the 1961 to 1990 period, under the IPCC SRES A2 (high emissions) Scenario (Scholes & Biggs, 2004). The approximate location of Namibia is indicated by the circles.

Namibia's Initial National Communication (INC) (MET, 2002) outlines projected climate change impacts and vulnerabilities. The water and agricultural sector are expected to suffer from the most significant negative impacts through increased temperatures and evaporation rates and reduced rainfall. Additionally the fisheries sector has been indicated to be vulnerable, as even relatively low temperature changes in the Benguela Current system may lead to significant changes in the nutrient status of the system. Changes in sea-level are predicted for Walvis Bay, the largest coastal town of Namibia, with the only deep sea harbour in the country. In-depth studies have been carried out on predicting ecosystem changes (Midgley et al., 2004) and certain plants, including the Namibian flahship species the Quiver Tree (*Aloe Dichotoma*) already suffer from changed CO_2 levels and other climate related factors (Midgley, 2007). Significant changes in vegetation structure and landscapes are forecast for a number of Namibia's characteristic ecosystems, notably the Oshana ephemeral drainage in the North. It is asserted that such changes may impact on the tourism sector, amongst others. Last but not least, the predicted climatic changes may worsen the health situation in Namibia. This is compounded in particular by the high prevalence of HIV amongst Namibians, with more severe climatic conditions believed to lead to accelerated and increased death rates. A recent paper by McGregor et al. (2006) draws attention to the need to quantify the financial and other economic impacts that will be induced by climate change on various sectors in Namibia, and the authors have since incepted a project to measure such effects.

In anticipation of worsening climatic conditions in the long-term for agricultural productivity, the Namibian Government identified that the adaptive capacities of farmers, pastoralists and natural resource managers needs to be strengthened as a matter of priority. However, there is a gap between identifying a general need for the strengthening of adaptive capacities and the design, planning and implementation of the most appropriate and effective responses. Drawing from a Namibian pilot Climate Change Adaptation response[i] (designed for subsistence farmers in northern Namibia) and at the same time geared to improve service delivery in terms of Early Warning Systems by regional and national government, the following sections (i) describe the link between the predicted impacts and worsening land degradation and poverty, (ii) illustrate how community level projects can be planned for, and (iii) outline the key lessons learnt in terms of information needs and interventions for the design of the most appropriate and effective response actions.

1.2 Prolonged and more frequent drought – link to land degradation and development

As the most arid country in sub-Saharan Africa, with a majority of the population and the key economic sector depending directly on natural resource-based sectors such as agriculture, and already challenged by water scarcity, climate change impacts need to be taken seriously. In this context it is realised that the inter-linkages between normal dry periods, drought and land degradation and gradual climate change are important to consider. Although drylands are naturally "drought-adapted/resilient", (Behnke et al. 1993, Scoones 1995; Illius & O'Connor 1999), the expected climate change impacts together with increasing population pressure, increased consumption expectations, and an increase in the number of rural poor are expected to worsen negative effects on water availability, food security, health, poverty and degradation (Figure 2). Analysing in some more detail the three bottom impact areas of prolonged drought, i.e. potential health impacts, less income, and potential land/resource degradation, highlights how both bio-physical and socio-economic impacts can lead to increased land degradation risk disturbances (Figure 3) of existing coping mechanisms and thus a reduction of adaptive capacity to climate change.

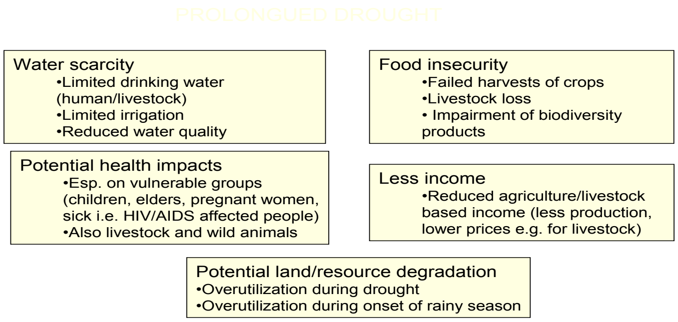

Figure 2: Impacts on the bio-physical and socio-economic environment induced by prolonged drought, predicted to be exacerbated through climate change (Zeidler & Chunga, 2007).

2. Assessing climate risks, vulnerability and adaptive capacities: a pilot assessment in northern Namibia

2.1. Background

In preparation of a first adaptation pilot project in Namibia, prioritised in the INC, local, regional and national assessment and analysis of (i) climate change vulnerability, (ii) current and past climatic conditions, and (iii) the current adaptive capacity of farmers in potential pilot areas was attempted. It was envisaged that the assessment results would help identify key issues pertaining to climate change adaptation and thus lead to the development of targeted priority interventions. Following a proposed standardised methodology (Lim & Spranger-Siegfried (eds.), 2005), a pilot field assessment was undertaken over a two week period during February 2005, a target of which was to identify and include project participants in the project design. It is essential that not just community-level interventions, but also those geared at regional and national institutions, are designed in close consultation with the stakeholders. This is particularly important in the context of climate change, as it is difficult to contextualise the theme, and interactive discussions of the issues can contribute significantly to awareness raising and the development of well accepted and integrated responses.

In preparation of and during the field visits, more detailed assessments were carried out, addressing the following:

Assessment of future climate risks: Involves developing scenarios of future climate, vulnerability, and socio economic and environmental trends as a basis for considering future climate risks.

Assessment of current vulnerability and existing coping strategies: "Where does society stand today with respect to vulnerability to climate risk?, "What factors determine its current vulnerability", and "How successful are its efforts to adapt to current climate risks?"

Assessment and enhancement of adaptive capacity: Involves the identification of responses that would contribute to empower communities and service provides (including Government) to better cope with climate change, including variability, through capacity strengthening efforts at all levels. It ought to be noted that adaptive capacities vary strongly between communities, regions and also service providers, thus targeted responses need to be designed and tailored to the specific capacity needs.

2.2. Short field study description

Field consultations were carried out in small-scale rural communities in three regions in northern Namibia, namely Omusati, Oshana and Oshikoto. A questionnaire was designed and semi-structured interviews and community meetings were conducted in eight villages. Further interviews with individuals from different government institutions, NGOs and other service providers were conducted on a regional level. The objectives of the consultations were to (i) better understand climate change-induced impacts in north-central Namibia, (ii) assess the effectiveness of current coping strategies and early warning systems, (iii) assess institutional capacity, community and household needs in terms of piloting specific adaptation activities, and (iv) identify and develop in a participatory manner relevant response activities and pilot sites for a first CCA pilot project in Namibia.

Eight villages, four in Oshana region and two each in Omusati and Oshikoto region, were selected for the assessment. Selection criteria included that two pairs of villages situated in eco-regions with similar features and similar land uses, leading to similar natural resource bases and climate change impact challenges being consulted. The two villages would differ, however, in their anticipated adaptive capacities, i.e. one community would have established community-based natural resources management (CBNRM) institutions, whilst the other had no such institutional support structures. A comparison of adaptive capacity and vulnerability to climate change should be possible and a wider range of response priorities and options be covered by the assessment.

3. Results from pilot assessment

3.1. Risk

Little information currently available in Namibia has been geared specifically towards the systematic analysis of climate change vulnerability, risk impacts and for the planning of adaptation interventions. Climate risk is described primarily by general models such as those published by IPCC. Only a few more in-depth studies have been undertaken e.g as part of the INC, several studies have recently been commissioned under the Second National Communication (SNC), and Midgley et al. (2004) prepared a study on expected ecosystem changes. A technology needs assessment is also currently being carried out.

3.2. Vulnerability and existing coping strategies

Based on available information, northern Namibia is characterised by generally more humid climates than those prevailing in other areas of the country, and drylands agriculture is widely practiced (other areas in Namibia are not fit for agricultural production; large and small stock ranching is widely practiced) . Population density is amongst the highest in these regions compared to other regions in Namibia. More than 70% of the population living in the north-central regions (Omusati, Ohangwena, Oshana and Oshikoto) depend directly on subsistence agriculture for their livelihood. Land degradation is a major threat to agricultural production, as are social and economic issues such as worsening health conditions including through a high rate of HIV/AIDS, little agricultural investments, and insecurity of land and resource tenure rights. Although climate risk assessments may not identify this area as the most severely affected, the socio-economic parameters characterising the three regions identify them as high priority areas to fostering climate change adaptation capacities in these areas.

A diversity of drought coping strategies are in place in Namibia (Sweet, 1998). Such strategies are applied on various levels. Farmers at the local level have over the years adopted mechanisms to cope with drought or low rainfall seasons. Common strategies at household level include: Storage of food to use in drier periods; buying food from shops/markets; moving animals to cattle posts; economic diversification; dependency on drought relief and relief programmes such as Food-for-Work Programme (FFW). All of these coping strategies are short-term and reactive in nature and may not address the impacts of longer-term, persistent change.

At the government/institutional level, responses include the formulation and partial implementation of a National Drought Policy (1997) prior to which ad hoc subsidies and relief measures were provided. Today, drought relief responses fall into 3 categories: those to alleviate nutritional stress of people and livestock, those to provide incentives for de-stocking, and those to facilitate post-drought recovery. Furthermore, significant investments into drought subsidies are being made. Since 2005, there has been a move to increase Namibian investments into sustainable land management (SLM), including response actions on the policy and implementation levels. These investments are geared towards laying the foundation for long-term responses to existing variability and environmental threats, thus providing an integrated approach to land management and climate change adaptation.

3.3 Adaptive capacity

An assessment of adaptive capacity to climate change was undertaken, measured in terms of

a. Set of resources available for adaptation (natural, financial, human and institutional resources) at the consulted sites

b. Ability of the system (community) to use the resources effectively (age, health, education, distance to markets and farm management practices)

c. Presence of external factors influencing adaptation (policies, laws, regulations)

The vulnerability assessment indicated strong variations in adaptive capacities amongst the various communities. Communities that were organised in different types of associations (natural resource management or agriculture) were generally more alerted to issues pertaining to sustainable land management and tapping into information that would assist them in developing options and alternative uses, where appropriate. The socio-economic characteristics amongst the surveyed farmers also pointed to the fact that challenges (i.e. induced by the severe impacts of HIV on households, including household composition and financial capacity) differed. It was notable that the issue of HIV was not widely acknowledged amongst the farmers.

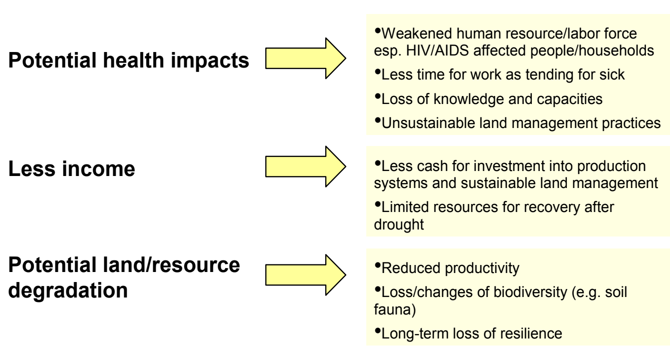

Figure 3: Drought impacts lead to increased land degradation risk. Indirect impacts, such as through-effects on human resource capacities and household economics, increase the vulnerability of farmers and farming systems, and consequently worsen the land degradation threat. Climate change adaptive capacities are equally reduced (Zeidler & Chunga, 2007).

Although it was anticipated that major investments had to be made at the local level, i.e. strengthening the capacities of the local resource manager and farmer, it became equally clear from the consultations that major shortcomings exist in the response capacity at the country-regional level, e.g. amongst key (agricultural and meteorological) service providers (agricultural or forestry extension, seed suppliers, land use planners, and communal land boards). Overall national-level decision making, information flow, policy and legal frameworks, and the level and success of decentralisation, had major impacts on response actions on the regional and local levels, and an effective Early Warning and Response System ought to be implemented.

4. Lessons learnt and key challenges

4.1 Data and information availability

Generally, Namibia has a better information base than most countries in Africa. However, still very limited research information on the potential and expected impacts of climate change on the natural resources base and the economy per se currently exist. The local research capacity in this regard is also relatively low (MET, 2005).

In order to plan the most relevant response actions on site, a different set of information is needed. The pilot assessment of existing adaptive capacities and existing coping strategies in north-central Namibia is revealing as it points to the type of information needed to design interventions that can improve adaptive capacities.

Questions need to be asked such as: What type of research information is needed? In what type of format? At what scale is information available and how to link socio-economic data with the bio-physical and climate information? How to best design the assessments, considering that the project preparation has to be pragmatic and not a scientific exercise in itself? What is the minimum information required to design a useful adaptation intervention? How to link information on local climate, trends, other environmental threats such as land degradation and desertification, and the socio-economic elements characterising adaptive capacities? What are the information needs at the various levels pertaining to adapting to climate change? Climatic variability per se? How can these be communicated in an effective manner, considering that currently there seems to be so little accessible? What is realistic?

4.2 Information sharing and knowledge management

A fair amount of information is available in the public domain and could potentially be accessed in-country. However, major investments are needed to support information channels and information flows both from the local to higher levels and in reverse. It has to be recognised that much information is written in scientific jargon which may not be readily accessible by practitioners or affected people. Communication specialists may have to be engaged in making knowledge accessible. Early warning systems and adaptive management options are two major thematic fields of interest. Information sharing and knowledge management linkages of flow of information and decisions to be made should be in the final output.

4.3 Local level institution building – a strong investment

Adaptive capacities, especially at the local resource user level, need to be enhanced. Developing countries often struggle with the challenges of empowering local communities and individuals to be able to better manage natural resources, build more sustainable livelihoods, be less vulnerable to impacts such as climate change but also poverty per se. Outreach to the local level can only become effective with the successful devolution of decision making to the local level. In southern Africa a great deal of approaches and some success stories can be told on institution building, esp. CBNRM. Such approaches, like in the case of Namibia, can be linked to United Nationas Convention to Combat Desertification (UNCCD) implementation at the country level, addressing SLM (which is one strong coping mechanism and enhances adaptive capacity).

4.4 Affected people have to be involved in response planning

It is important that response actions to climate change are planned together with the affected people – and the people who can support local resource managers such as extension services of ministries and information providers such as the meteorological services. This principle rings true for any community-level intervention, but is particularly important when addressing adaptation as climate change is usually difficult to contextualise by future affected populations. Establishing a meaningful dialogue and enabling local resource managers to take informed decisions now and in future is at the heart of any effective response intervention.

4.5 The impact of HIV/Aids on adaptive capacity

The impact of HIV/Aids on the adaptive capacity cannot be overestimated; impacts on households, communities, professionals and countries are huge and must be addressed and integrated as a matter of priority; relevant investments need to be leveraged that address building of adaptive capacity whilst preventing HIV/Aids and mitigating the impact thereof.

4.6 Risking Millenium Development Goals (MDG's) Attainment

If climate change adaptation responses are not mainstreamed into national planning frameworks, Namibia (like other vulnerable countries) risks losing any progress made towards achieving the Millenium Development Goals (MDGs). Climate change impacts will exacerbate poverty and already vulnerable communities are at extreme risk of loosing their livelihood basis. A global effort is needed to leverage meaningful investments to counteract and enhance adaptive capacities, especially in developing countries at risk.

5. Acknowledgements

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6. Endnotes

[i] The Ministry of Environment and Tourism (MET), with the support from the United Nations Development Programme (UNDP), has developed a first climate change adaptation (CCA) project for funding under the Special Adaptation Priority (SPA) of the Global Environment Facilities' (GEF) climate change adaptation window. The identified priority project is in line with country priorities identified in Namibia's Initial National Communication (INC), in partial fulfilment of Namibia's obligations under the United Nations Framework Convention on Climate Change (UNFCCC). Furthermore, the project is allocated under the Country Pilot Partnership for Sustainable Land Management (CPP for SLM), Namibia's national framework for action for country priorities - including those under the UN Convention to Combat Desertification (UNCCD). Clear linkages in the implementation of the two international instruments are made. The designed intervention is entitled "Adapting to Climate Change through the Improvement of Traditional Crops and Livestock Farming", and is designed as a pilot project in northern Omusati region with linkages to regional and national level interventions. The project will contribute to the goal of enhancing adaptive capacity to climate change in agricultural and pastoral systems in Namibia. To support progress towards this goal, the project objective is to develop and pilot a range of coping mechanisms for reducing the vulnerability of farmers and pastoralists to climate change, including variability. The objective will be achieved through activities that support three outcomes including (i) climate change adaptation measures of rural communities in piloted and tested agricultural production; (ii) improved information flows on climate change, including variability (such as drought) between providers and key users, and (iii) climate change issues integrated into planning processes. These outcomes should also facilitate effective replication and up-scaling of measures that promote adaptation to climate change through the Country Pilot Partnership (CPP) for Integrated Sustainable Land Management (ISLM) country programme or other means. The project will be implemented in several drought-prone constituencies in the North-Central region of Namibia. The region is selected based on assessments of vulnerability to climate change, adaptive capacity, national level priority and other relevant issues (e.g. accessibility, extent of ongoing activities to address climate change concerns in this area)

7. References

Behnke R, Scoones I and Kerven C (eds.) (1990) Range ecology at disequilibrium. ODI, London, UK, p. 248

IECN (2006) Strategic Assessment of the Relationship between HIV/AIDS and Environment in Namibia. Vol 1: Synthesis Report; Vol 2: Status Report; Vol 3: Elements for an Action Plan; Vol 4: Action Plan; Vol 5: Extended Bibliography. For the Ministry of Environment and Tourism, Namibia by Integrated Environmental Consultants Namibia, Windhoek, Namibia

Illius AW & O'Connor TG (1999) on the relevance of non-equilibrium concepts to arid and semi-arid grazing systems. Ecological Applications, 9(3): 798-813

IPCC, 2001. Climate change. Impacts, adaptation and vulnerability. Summary for policy makers. Intergovernmental Panel on Climate Change, Geneva

Lim, B. & Spranger-Siegfried, E., 2005. UNDP/GEF's Adaptations Policy Frameworks http://www.undp.org/gef/05/kmanagement/pub_practitioner.html

MacGregor, J., Reid, H. & Sahlen, L., 2006. An 'agenda for change': Quantifying climate change impacts on natural resource-based economies. Sustainable Development Opinion, IIED, UK

MET, 2005. National Capacity Self Assessment (NCSA) for Global Environmental Management. Ministry of Environment & Tourism, Windhoek, Namibia

MHSS, 2004.Health survey. Ministry of Health and Social Services, Windhoek, Namibia

Midgley, G., 2007. Presentation on climate change, ecosystems and floristic diversity: assessing potential impacts in Namibia. Presented at an CCA Roundtable Meeting, Ministry of Environment and Tourism (MET; Namibia) and International Institute for Environment and Development (IIED; UK); 6 February 2007, Windhoek, Namibia

Midgley, G., Hughes, G., Thuiller, W., Drew, G. and Foden, W., 2004. Assessment of potential climate change impacts on Namibia's plant species biodiversity and ecosystem structure and function. Namibia's National Biodiversity Programme, Ministry of Environment and Tourism, Windhoek Namibia

Reid, H. & MacGregor, J. (forthcoming). Paper based on a round table discussion on climate change, natural resources and economic growth in Namibia. Roundtable meeting, 6 February 2007, Ministry of Environment and Tourism, Windhoek, Namibia, a project of the International Institute for Environment and Development (IIED), UK

Scoones I (ed) (1995) Living with uncertainty: new directions in pastoral development in Africa. IIED, London, UK

Zeidler, J. & Chunga, R., (2007). Drought Hazard and Land Management in the Drylands of southern Africa. In Shivakumar, M. & Ndiang'ui N. (eds.), Climate and Land Degradation, Springer Verlag, Germany, ISBN 3540724370.

Adaptation and development futures: looking ahead

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Abstract

Adaptation to climate change has become a prominent focus within the climate change community and more recently is becoming part of development agendas. Adaptation is a complex process. It requires consideration of the climate science, understanding of existing and future climate and non-climate vulnerabilities and support from a range of stakeholders. At this critical point in time when adaptation is receiving large amounts of funding and attention, it is important that a number of issues are prioritised. Adaptation to climate change should be viewed as a process that facilitates social learning and can foster agency. This can add value to existing development interventions and promoting adaptive capacity. In order to achieve this, better communication between scientists, practitioners and those impacted by climate change is needed which requires improved methods for integrating climate science into development planning and policy. Given that developing counties are expected to suffer most from the negative impacts of climate change, it is of paramount important that the voice of developing countries is given more prominence in driving adaptation priorities and policies.

1. Introduction

Adaptation to climate change has become a prominent topic in the climate change community (Adger et al, 2005; Brooks et al, 2005; Fussel and Klein, 2006; Huq et al, 2003; IPCCb, 2007) and is gaining prominence as a topic within development agendas (AfDB, 2003; Christian Aid, 2006; Huq et al 2006; Klein et al, in press; Simms et al, 2004; Swart et al, 2003). This is not surprising, given that the evidence for human-induced warming and associated climate change is no longer questionable and the need to adapt is becoming more urgent as the climate-related impacts start to emerge more rapidly than before (IPCCb, 2007). Even with extreme mitigation measures, we are committed to increasing temperatures for the next century and have to support adaptation within a range of fields including biodiversity, agriculture, health, water and disasters to name a few (IPCCb, 2007). The links to development are clear, as evidence suggests that the negative impacts of climate change are greater and expected to grow more rapidly in the developing world (IPCCb, 2007; Pachauri, 2004; Tol et al, 2004).

The increased prominence of adaptation to climate change on the global agenda is good in the sense that the problem needs to be urgently addressed. However, the predicament in responding urgently to problems is that there is not always time to stop and reflect on the process. Ensuring that state-of-the-art methods are used and that intervention has maximum positive benefits and limited negative impacts have to be weighed up with supporting an urgent response. Although addressing adaptation to climate change is new in the way it is packaged, it is important to recognise that adaptation has occurred in the past (Mortimore and Adams, 2001; Huq et al, 2003). Systems and communities exposed to stresses continually respond, at times with negative outcomes and at times positive outcomes. The improvement in the ability to deal with the stresses currently and in future suggests that a process of adaptation is occurring. The term adaptation pathway is used to describe this process. It is used in the plural, adaptation pathways, to emphasise the potential for numerous alternative processes and outcomes.

Development can be viewed as social change, and capacity the ability to carry out this change. In this paper, development is seen as part of people and systems' endogenous response to stimuli as well exogenous intervention aimed at improving people's livelihoods. Development interventions aim to enable communities to cope better with existing stresses and hopefully adapt to future stress endogenously. Although development can have positive impacts it can worsen situations, create dependency and shift power relations. Often interventions are in response to a specific stress or threat, yet the reality is that there is a complex interplay of factors and stressors at various scales that determine vulnerability. Climate change is now seen as a stressor that poses a serious threat to these development and poverty alleviation interventions (Christian Aid, 2006; Eriksen et al, 2007; Huq et al, 2006; IPCCb, 2007). The rate of climate change also suggests that endogenous responses that may have been sufficient to deal with past climate stressors may not be sufficient in future. Finding ways of integrating development interventions with the emergent adaptation to climate change responses is therefore necessary in order not to duplicate efforts and to ensure an approach that addresses multiple stressors. However, caution should be exercised as evidence suggests that environmental issues have not been sufficiently integrated into development in the past and climate change may present a suite of issues that are challenging to address within existing poverty alleviation remits (DfID et al 2002; Newell, 2004).

At the nexus of development and climate change lies a number of equity issues which manifest at various scales (Paavola and Adger, 2006; Adger et al, 2006; Thomas and Twyman, 2005). Developed countries have contributed more to emissions than developing countries, yet it is developing countries that are expected to suffer most. At the same time, developing countries are expected to curb the emissions that supported the growth of developed countries. Developed countries are well aware of their responsibility in supporting adaptation (Simms and Reid, 2005). Yet, there is a fine balance between developed countries supporting adaptation, particularly in developing countries versus developed countries driving the adaptation agenda. It is time to ensure that despite limited adaptive capacity in developing countries, there is equal say and hopefully some degree of consensus, in what is needed in terms of adaptation and development pathways. This requires dialogues and opportunities that bring both parties to the table as equal partners, despite the funding often coming from developed countries.

This paper offers some adaptation principles, as well as highlighting some of the key issues linking development and adaptation that help to reflect on the current pathway we are on in linking adaptation to climate change with broader development issues. A new approach to supporting the adaptation process is suggested and linked to a case study example to highlight the innovation needed to address adaptation to climate change.

2. Adaptation principles

The process of adapting to climate change is expected to decrease the impact of actual and expected climate change on systems and communities of concern. At the Stockholm Environment Institute (SEI) and among its colleagues, a number of years have been spent exploring theoretical and empirical issues related to vulnerability and adaptation to climate change (Bharwani et al, 2005; Downing et al., 2006; Klein et al., 2005; Smith et al. 2006; Ziervogel et al, 2006a; Ziervogel et al, 2006b). Initial theoretical discussions viewed adaptation as an outcome that reduced vulnerability. More recent experience suggests that adaptation should be viewed as a process and adaptive capacity as a set of competencies necessary to respond to the current and future climatic changes. This conceptualisation helps to link adaptation to development as it promotes the use of a development-planning chain.

A number of principles on adaptation help to guide thinking about engaging in adaptation activities (SEI, 2007). Firstly, adaptation can be viewed as a process of social learning. This helps to accommodate goals and processes that vary between stakeholders rather than focusing on a fixed method for 'reducing vulnerability'. This allows the context of stakeholder decision making to be appreciated by acknowledging differences in local environments and exposure to a range of stresses, where climate is one of many (Reid and Vogel, 2006; O'Brien et al, 2005).

Secondly, adaptation strategies and actions should be robust against a wide variety of future conditions. In order to achieve this, robust conclusions and critical uncertainties should be effectively communicated to enable stakeholders to evaluate the climate envelope within which current actions can continue or the thresholds beyond which adaptation is needed.

Lastly, climate change information and climate change adaptation should be able to be integrated within existing risk management practises. The state is required to respond to this, as individuals and companies tend to respond when there in an immediate threat to themselves (Parnell et al., in press). At present, most government departments do not see it as their role to integrate climate change concerns within their development remit (Eriksen et al., 2007). Encouraging planning for long-term sustainable development and risk management is also challenging when incentives are often for short-term responses (Barnett, 2006).

These principles illustrate the complexity of adaptation as something than cannot be viewed as generic, operates differently at different scales (Adger et al, 2005) and in different contexts and requires us to find new ways to integrate climate information into existing operations where possible. Robust tools are needed in order to address these emerging needs. In addition, the rate of climate change requires a process that is highly responsive to external change whilst facilitating learning and development within the system of concern (Berkhout at al, in press).

3. Integrating adaptation and development

Mainstreaming adaptation to climate change into sustainable development and poverty reduction strategies has been widely supported (Eriksen et al, 2007; Huq et al, 2006). This is an important concept as by focusing too narrowly on adaptation to climate change, broader development issues might be excluded, in turn undermining adaptation and potentially resulting in mal-adaptation. And it is addressing these broader development issues at the same time that might enable actors to respond independently to climate change. Although, if sustainable development is seen to subsume adaptation to climate change, there might not be sufficient emphasis placed on factoring in and responding to significant climate change impacts. This highlights the necessity for building common goals between the climate change and development communities in order to support successful adaptation pathways. In addition there are numerous other communities, such as disaster management, urban development, planning, industry, social science and anthropology, that should be brought in to the discussions (Parnell et al., in press; Pelling et al., 2005; Thomalla et al, 2006). They bring with them experience in fields related to climate variability and change that could support future adaptation pathways.

A number of key areas should be addressed in supporting the integration of climate change adaptation and sustainable development. Although there is international support for adaptation to climate change, without high level national support, implementation becomes challenging (IIED, 2007). Often, it is catastrophic events that raise the profile of climate change amongst policy makers (Adger et al., 2005). This momentum needs to be built upon and supplemented by a richer understanding and appreciation of issues related to adaptation, particularly that involving slow onset events and longer term stresses. Adaptation to climate change is a complex concept, as it can take so many forms and is hard to separate from other activities at times (Reilly and Schimmelpfennig, 2000). Commitment is needed from scientists to work with national policy makers to ensure that adaptation issues are understood in order to gain support for implementing policies that ensure development that is climate-sensitive and adaptation that compliments developmental processes.

Once climate change is on the national agenda, it is important the process is consultative and inclusive. Traditional policy stakeholders are not used to working with other stakeholders such as communities at risk. Yet, including a wide range of stakeholders is necessary in order to understand what outcome adaptation will have in a multi-stressor environment. In many instances adaptation is aimed at supporting the most vulnerable groups. Including representatives from these groups is therefore critical in exploring adaptation pathways that are suited to beneficiaries as well as the policy makers and others who enable an adaptive environment. This process takes time, patience and resources, which are often hard to come by.

Sector-specific adaptation has been supported as a key means of gaining progress in adaptation to climate change (IISD, 2007a; Klein et al, in press). In places this is critical but in other instances, focusing on sectors isolates responses which might benefit from a more integrated approach. If climate is going to be placed in a development context, multiple goals need to be recognised which requires sector-specific approach to be undertaken in tandem with cross-cutting approaches. Livelihoods of certain vulnerable groups cannot be addressed by one sector (Midgley et al, 2005). For example, enabling pastoralists in east Africa to adapt might require addressing issues related to livestock, health, governance, environment and climate. An integrated approach would enable multiple goals to be addressed rather than different sectors promoting different approaches.

Although the policy environment is important, adaptation is often about change at the local scale (Simms and Reid, 2005). In this context, one of the most important aspects to consider when addressing climate change adaptation is how agency is promoted. Years of development intervention have shown that imposing external solutions fails time and time again. Understanding community and individual needs, building on existing strengths and ensuring that impacted groups are part of the response supports their agency, which is critical. Although it is critical, it is challenging. Some of the lessons in this area have emerged through the community-based adaptation approach, as illustrated in the rich output from the Second International Workshop on Community-based Adaptation to Climate Change, held in Bangladesh in February 2007 (IISD, 2007a).

4. Adaptation assessment methods

The challenge of integrating adaptation principles into a range of national and local policies and plans is crucial to address in order to ensure a response to climate change. Once there is support for adaptation, it is essential that methods for screening adaptation options are well established and appropriate to the complex environment of choosing adaptation options.

Screening adaptation options requires stakeholders to make decisions on which options are best to pursue depending on their chosen criteria. A range of information is needed for this process, from deciding on criteria to choosing appropriate adaptation options given the climate change scenarios, based on risk assessments and understanding of the uncertainties. In the process of putting forward adaptation options, the vulnerabilities of the sectors, systems and communities of concern should be well understood. Much work has been done on developing the concept of vulnerability yet there is not a consistency in approaches (Downing et al, 2005; O'Brien et al., 2004).

Although numerous adaptation options are being implemented around the world, particularly in response to specific climate variables in specific locations (IPCC, 2007b), there is the need to further develop existing methods for choosing among adaptation options. The NAPA process undertaken in Least-developed countries (LDCs) is an example of a country-level process for choosing adaptation options (UNFCCC, 2007). The outcomes of the first round suggest that whilst the process engaged the national level, the criteria for choosing options was often decided by a small group of stakeholders that tended to address their broader development needs. This is not surprising given that the countries are LDCs, often struggling to address poverty among their people. It is hard to argue that the injection of resources for climate change adaptation should not be used for climate-related development issues. However, the aim of climate change adaptation should be to prioritise options against a robust set of scenarios. Implementing the adaptation option should enable systems or communities to cope with the new climate envelope likely to be experienced due to climate change, that would otherwise have exceeded the coping capacity.

There are a number of methods and tools for vulnerability assessment and adaptation assessment in particular contexts (Benioff et al., 1996; Füssel and Klein, 2006; Downing et al., 2005). An example of a software tool that aims to maximize adaptation opportunities by supporting the assessment of climate risk management for planned or ongoing development projects is CRISTAL (Community-based RIsk Screening Tool - Adaptation & Livelihoods) (IISD, 2007a). The tool supports a bottom-up process by engaging local communities on the climate and livelihood context and then on project screening and adjustment for project managers. Although this tool has the strength of engaging local stakeholders it does not guide the user through detailed information about climate scenarios and it is project focused so not appropriate for evaluating adaptation options across different groups of stakeholders at the same time.

Screening adaptation options requires a methodology that brings together the different components mentioned in the previous sections. It is about engaging stakeholders at various levels for awareness raising and capacity strengthening as well as ensuring there is sufficient interaction with climate scientists in understanding the latest scenarios at the relevant scales in order to undertake vulnerability and adaptation assessments and implement selected adaptation options. At SEI, a climate adaptation platform called ClEAR (Climate Envelope/Adaptation Risk Screening Platform) is being developed that helps to bring these elements together (MudSprings, 2007). The platform supports social learning through the engagement of a range of stakeholders in the adaptation process. It prioritizes climate information as key to this process. This may sound obvious but often the current and future climate information is not well integrated in the adaptation process.

One component of ClEAR is an open object tool, using AWhere software, that provides a means for:

- Assembling spatial data on current vulnerability
- Analysing climate trends
- Calculating thresholds of exposure to climatic risks in a variety of sectors
- Charting envelopes of climate scenarios for critical thresholds
- Estimating sensitivity of adaptation options to future conditions (MudSprings, 2007)

In the software package, the integration of climate and non-climate information is critical, as it is this non-climate information that often determines adaptive capacity and exposure to other stressors. The iteration of the development of the software and outputs is another important aspect as it brings together a range of stakeholders. If the software is not built based on user needs and outcome, it loses its purpose. The case study below highlights why this more holistic adaptation platform is necessary.

5. Case study: the need for adaptation in Sekhukhune district, South Africa

Sekhukhune district in Limpopo Province is one of the poorest districts in South Africa, with high levels of food insecurity and unemployment (Rule et al, 2005). The district is located within the summer rainfall region of South Africa, receiving more than 80% of its mean annual rainfall (of between 500 and 800mm) between November and March (DWAF 2005). The rainfall patterns are highly variable over intra- and inter-annual time scales. Research undertaken at the village and municipal level sought to identify the range of key stressors that villagers and government stakeholders were experiencing as well as the existing and potential responses to these stressors (Ziervogel et al 2006b). Climate change was not perceived as a key threat by these stakeholders. Rather, people acknowledge that the climate has changed and that it has an impact on individual livelihoods and economic development. At the village level, climate variability impacts rainfall frequency and amount, which in turn impacts on agricultural production and domestic water availability, particularly in areas without reticulation. At the district level, bulk water is scarce and is currently limiting expansion in the mining sector, which in turn is compromising water availability for commercial agriculture and delivery of domestic water.

Although climate change is on the national agenda (DEAT 2004) it has not filtered down to remote areas. Adaptation has only begun to be addressed in large urban municipalities in South Africa (Midgley et al, 2005; Mukeibir and Ziervogel, 2007; Hounsome and Iyer, 2006). It is not surprising then, that climate change was not mentioned in discussions among municipal stakeholder about the future growth of the district or addressing poverty and livelihood vulnerability at the village level. It was also not a concept thought of at the village level, where concerns focus on food for tomorrow and someone in the household getting a job or a grant, hopefully in the next month. Yet a change in temperature and rainfall threatens development in this area, where water is already scare, livelihoods are highly vulnerable to climate and other stressors and proposed mines have the potential to bring increased revenue to the country and hopefully the municipality.

It is clear that adaptation to climate change should be urgently addressed in order not to compromise future development and poverty alleviation interventions. In order to plan adaptation options it is necessary that stakeholders in a range of sectors and at various levels, understand the nature of current climate variability and the potential future envelope of change. At present this information is not easily available. Yet, without understanding climate information, appropriate adaptation options cannot be discussed and so development proceeds, ignoring climate scenarios or climate-sensitive development.

Applying the ClEAR platform would support the adaptation process in this context. It would engage a range of stakeholders (at the local, municipal, district, provincial and national level), improve access to climate information, integrated with other socio-economic information, support the decision process of choosing adaptation options and ultimately lead to adaptation options to reduce vulnerability to climate change. Currently, this is a long way off.

6. Conclusion

Adaptation to climate change is supported at the global scale and resources are being channeled into it. Yet, the methods for ensuring integration of social and physical information into all stages of the process of adapting to climate change are in their infancy. This is a critical point in time for us to reflect on the trajectory we are on in response to the urgent emphasis on adaptation. We should use this opportunity to support the integration of state-of-the-art climate science, with years of experience in development planning, to ensure effective adaptation to climate change, particularly for the most vulnerable groups.

The process of adaptation to climate change requires commitment and action at many scales. Scientists and practitioners need to be clear about the climate science and other stakeholders need to be able to voice their needs and concerns and access the information and resources they require to respond to climate impacts. This process requires patience, resources, good communication, political will and support for social learning which speaks directly to development aims. If the process of adaptation to climate change can improve the ability of a wide range of stakeholders to respond more effectively to climate variability and climate change, perhaps it can promote a legacy of learning and applied science and in turn contribute to future development. Hopefully this development will be more sensitive to the dynamic nature of the human and earth systems' interactions.

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References

Adger, W.N., Arnell, N.W. and Tompkins, E.L. (2005). Successful adaptation to climate change across scales. Global Environmental Change 15, 77–86.

Adger, W. N., Paavola, J., Huq, S. and Mace, M.J. (eds) (2006) Fairness in Adaptation to Climate Change. MIT Press: Cambridge. 312pp.

African Development Bank (AfDB), Asian Development Bank, UK DFID, Netherlands DGIS, European Commission DG for Development, German BMZ, OECD, UNDP, UNEP, World Bank. (2003) 'Poverty and Climate Change. Reducing the Vulnerability of the Poor through Adaptation. Department for International Development.

Barnett, T. (2006). A Long-wave Event. HIV/AIDS, Politics, Governance and "Security": Sundering the intergenerational bond. International Affairs, 82, 2 (2006), pp. 302-4.

Benioff, R., S. Guill and J. Lee, 1996: Vulnerability and Adaptation Assessments: An International Handbook. Kluwer Academic Publishers, Dordrecht.

Berkhout, F. and Hertin, J. and Gann, D. M. (in press). Learning to adapt: organisational adaptation to climate change impacts. Climatic Change.

Bharwani, S., Bithell, M., Downing, T.E., New, M., Washington, R and Ziervogel, G. (2005) Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. Philosophical Transactions of the Royal Society B. 360. 2183-2194.

Brooks, N., Adger, W. N. and Kelly, P. M. (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global Environmental Change 15(2), 151-163.

Christian Aid. 2006. The climate of poverty: facts, fears and hopes. London. 48pp.

Department for International Development (DfID), EC, UNDP and The World Bank (2002). Linking Poverty Reduction and Environmental Management – Policy Challenges and Opportunities. Washington DC, World Bank.

Department of Environmental Affairs and Tourism (DEAT), (2004). A National Climate Change Response Strategy for South Africa, www.deat.gov.za (accessed 24 May 2006), 48pp.

Downing, T.E., Aerts, J., Soussan, J., Barthelemy, O., Bharwani, S., Ionescu, C., Hinkel, J., Klein, R.J.T., Mata, L., Martin, N., Moss, S., Purkey, D. and Ziervogel, G. (2006) Integrating social vulnerability into water management. SEI Working Paper and Newater Working Paper No. 4. Oxford: Stockholm Environment Institute.

Downing, T.E. and Patwardhan, A., with Klein, R.J.T., Mukhala, E., Stephen, L., Winograd, M. and Ziervogel, G. (2005). Assessing Vulnerability for Climate Adaptation. In Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures. Lim, B., Spanger-Siegfried, E., Burton, I., Malone, E. and Huq, S. (Eds). Cambridge University Press, Cambridge.

DWAF: Department of Water Affairs and Forestry (2005). Water Services Planning Reference Framework, Sekhukhune District Municipality. DWAF, Inviromap and GPM Consultants, Pretoria, 124pp.

Eriksen, S.E.H., R.J.T. Klein, K. Ulsrud, L.O. Næss and K.L. O'Brien. 2007. Climate Change Adaptation and Poverty Reduction: Key Interactions and Critical Measures. GECHS Report 2007:1, University of Oslo, Norway, 42 pp.

Füssel, H.-M. and R.J.T. Klein, 2006: Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change, 75(3), 301-329.

Hounsome, R. and Iyer, K. 2006. Headline climate change adaptation strategy for Durban. Prepared for Ethekwini municipality. CSIR. Durban. 45pp.

Huq, S., Rahman, A., Konate, M., Sokona, Y. and Reid, H. (2003). Mainstreaming Adaptation to Climate Change in Least Developed Countries. IIED, London. 40pp.

Huq, S., Reid, H. and Murray, L.A. 2006. Climate Change and Development Links. Gatekeeper 123. IIED. 24pp.

IIED. 2007. Media release. Climate policy should consider the needs of the poor. Accessed 2 May 2007. http://www.iied.org/mediaroom/releases/070410CCPolicy.html

IISD (International Institute for Sustainable Development) in collaboration with IIED. 2007a. Second International Workshop on Community-Based Adaptation to Climate Change. Vol. 135 No. 1.

IISD. 2007b. http://www.iisd.org/security/es/resilience/climate_phase2.asp. Accessed 2 May 2007. Climate and livelihoods: Phase II.

IPCC. 2007a: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2007b. Climate Change 2007: Climate Change Impacts, Adaptation, and Vulnerability - Summary for Policymakers. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). [Parry, M., Canziani, O. & Palutikof, J. (eds.)] Cambridge University Press, Cambridge, UK, 23pp.

Klein, R.J.T., E.L.F. Schipper and S. Dessai, 2005: Integrating mitigation and adaptation into climate and development policy: three research questions. Environmental Science and Policy, 8(6), 579-588.

Klein, R.J.T., S.E.H. Eriksen, L.O. Næss, A. Hammill, C. Robledo, K.L. O'Brien and T.M. Tanner, 2007. In Press. Portfolio screening to support the mainstreaming of adaptation to climate change into development assistance. Climatic Change.

Midgley, G., Chapman, R., Hewitson, B., Johnston, P., De Wit, M., Ziervogel, G., Mukheiber, P., Van Niekerk, L., Tadross, M., Van Wilgen, B.,Kgope, B., Morant, P., Theron, A., Scholes, R., Forsyth, G. (2005). Western Cape Report: A Status Quo, Vulnerability and Adaptation Assessment of the Physical and Socio-Economic Effects of Climate Change in the Western Cape. Report commissioned by the Provincial Government of the Western Cape: Department of Environmental Affairs and Development Planning.

Mortimore, M. J. and Adams, W. M. (2001) Farmer adaptation, change and 'crisis' in the Sahel. Global Environmental Change 11, 49-57.

MudSprings. 2007. http://www.mudsprings.com/contentpage.aspx?RequestID=227. UNEP/SEI CLEAR programme. Accessed 2 May 2007.

Mukheibir, P. and Ziervogel, G. (2007). Developing a Municipal Adaptation Plan (MAP) for climate change: the city of Cape Town. Environment & Urbanization. 19(1).

Newell, P. 2004. Climate change and development: A tale of two crises. IDS Bulletin-Institute of Development Studies, 35 (3): 120.

O'Brien, K., Eriksen, S., Schjolden, A., and Nygaard, L.P. (2004). What's in a word? Conflicting interpretations of vulnerability in climate change research. CICERO Working Paper 2004:04.

O'Brien, K., Leichenko, R., Kelkar, U. Venema, H. Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., and West, J. (2005) Mapping multiple stressors: Climate change and economic globalization in India. Global Environmental Change 14 (4). 303-313.

Paavola, J. and Adger, W. N. (2006) Fair adaptation to climate change. Ecological Economics 56(3), 594-609.

Pachauri, RK. 2004. Climate change and its implications for development: The role of IPCC assessments. IDS Bulletin-Institute of Development Studies, 35 (3): 11.

Parnell, S., Simon, D. and Vogel, C. In press. Global change and urban risk –the rising challenge in poor cities. Area.

Pelling, M. and High, C. (2005) Understanding adaptation: What can social capital offer assessments of adaptive capacity? Global Environmental Change. 15. 308–319.

Reid, P. and Vogel, C. (2006) Living and responding to multiple stressors in South Africa—Glimpses from KwaZulu-Natal. Global Environmental Change 16 (2), 195-206.

Reilly, J and Schimmelpfennig, D (2000). Irreversibility, uncertainty, and learning: Portraits of adaptation to long-term climate change. Climatic Change, 45 (1): 253-278.

Rule SR, Aird R, Drimie S, Faber M, Germishuyse T, Jordaan A, Kok P, Roberts B, Roefs M, Schonfeldt HC, Schwabe C, Van Lieshout M, Van Zyl J and Vermeulen H. (2005) Report on survey in Sekhukhune to pilot the development of a food insecurity and vulnerability modelling system (FIVIMS) for South Africa. Human Sciences Research Council.

Stockholm Environment Institute (SEI) 2007. Adaptation principles. Internal document.

Simms, A., Magrath, J. and Reid, H. (2004) Up in smoke? London: International Institute for Environment and Development New Economics Foundation and others. 38 pp (http://www.ewg.org/reports/upinsmoke/pr.html/).

Simms, A. and Reid, H. (2005) Africa - Up in smoke? London: International Institute for Environment. 40pp.

Smith, J.B., R.J.T. Klein and S. Huq. (2003) Climate Change, Adaptive Capacity and Development. Imperial College Press, London, England, p. 9-28.

Smit, B. and Pilifosova, O. (2003): From adaptation to adaptive capacity and vulnerability reduction; in Climate Change, Adaptive Capacity and Development, (ed.) J.B. Smith, R.J.T. Klein and S. Huq., Imperial College Press, London, England, p. 9-28.

Swart R, Robinson J and Cohen S, 2003 Climate change and sustainable development: expanding the options Climate Policy 3 19-40

Thomalla, F., T.E. Downing, E. Spanger-Siegfried, G. Han and J. Rockström. (2006). Reducing Hazard Vulnerability: Towards a Common Approach Between Disaster Risk Reduction and Climate Adaptation. Disasters, 30 (1), 39-48.

Thomas, D. S. G. and Twyman, C. (2005) Equity and justice in climate change adaptation amongst natural-resource dependant societies. Global Environmental Change 15(2), 115-124.

Tol, RSJ; Downing, TE; Kuik, OJ; Smith, JB. 2004. Distributional aspects of climate change impacts. Global Environmental Change-Human and Policy Dimensions, 14 (3): 259-272.

UNFCCC. National Adaptation Programmes of Action (NAPAs) website. http://unfccc.int/national_reports/napa/items/2719.php. Accessed 2 May 2007.

Ziervogel, G., Bharwani, S. and Downing, T.E. (2006a) Adapting to climate variability: pumpkins, people and policy. Natural Resource Forum. 30. 294–305.

Ziervogel, G., Taylor, A., Thomalla, F., Takama, T. and Quinn, C. (2006b) Adapting to climate, water and health stresses: insights from Sekhukhune, South Africa, Stockholm Environmental Institute Report, Oxford, UK.

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ANNEX II: SCOPING DOCUMENT

IPCC TGICA Expert Meeting
Integrating Analysis of Regional Climate Change and Response Options

An Expert Meeting on Regional Impacts, Adaptation, Vulnerability, and Mitigation

Sponsored by the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA), the Global Change System for Analysis, Research and Training (START) and the Pacific Center for Environment and Sustainable Development at the University of South Pacific (PACE/USP)

Nadi, Fiji, June 20-22, 2007

1. INTRODUCTION

Human-induced climate change is a reality. Energy use, land transformations and other activities are increasing the atmospheric concentrations of gases that are warming the Earth and causing other changes to the climate. The changes in climate, the impacts on physical and biological systems, the vulnerability of ecological and human systems, and the harmful and beneficial consequences for human well-being and sustainable development will be conditioned by exposures to other stresses and the capacity to cope, recover and adapt, all of which will vary across space and time. Planning appropriate responses to manage climate change risks requires scientific understanding of system processes from global to regional to finer spatial scales, at time steps ranging from the very near term to multi-century time scales, and interactions across the many systems affected by climate change, including physical, ecological, and socioeconomic processes. Developing this understanding will require further advances in regional research that better integrates connections and feedbacks across these system processes at variable temporal and spatial scales.

The IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) announces an international meeting to explore innovative research approaches for addressing the multi-scale and multi-disciplinary challenges associated with climate change impacts, adaptation, vulnerability and mitigation.

The regional climate change research to be highlighted by the conference will address multiple spatial scales, time scales, systems and/or stresses.

2. RATIONALE

Research on regional aspects of global climate change has advanced substantially since the Third Assessment Report (TAR) and these advances are reflected in the draft Fourth Assessment Report (AR4). These advances will improve decisions that depend on understanding regional patterns and differences in the projected changes in climate, capacities to adapt and mitigate, and vulnerability to adverse impacts. A remaining challenge for research is to better capture the complexity of interactions across systems and across spatial and temporal scales that will shape the consequences of different courses of action or inaction. If this challenge is to be met in time to allow advances in a future IPCC assessment, preparatory work needs to begin now to bring together members of the different research communities to identify problems that impede integration and to explore innovative approaches to overcome them. To make the emerging science more policy-relevant, and to facilitate responsible decision-making, a more holistic approach to understanding regional climate change is necessary. Key issues include improving access to needed scientific and technical data on climate, environmental, and socio-economic data and building capacity in the application of these data in integrative research.

The regional expert meeting “Integrating Analysis of Regional Climate Change and Response Options” will help catalyze progress and contribute to a more holistic approach in the next IPCC assessment. The meeting will establish a baseline of the state of integrative regional climate change research on cross-system and cross-scale problems, identify gaps and critical research needs, explore innovative methods that address critical research needs, facilitate communication among researchers working on these problems, and promote collaborative regional climate change research. These objectives are consistent with the missions and mandates of the sponsoring organizations, TGICA, START and PACE/USP, as well as those of the IPCC.

In anticipation of future climate assessments, this meeting will promote integrative approaches to addressing regional concerns.

Within the mandate of TGICA, a meeting was proposed and approved at the 24th IPCC Plenary to bring together scientists to explore innovative approaches to interdisciplinary research associated with climate change, impacts, adaptation, vulnerability and mitigation.

3. PROPOSED CONTENT

This regional expert meeting, "Integrating Analysis of Regional Climate Change and Response Options", has six primary objectives:

1. To identify and explore innovative research approaches for dealing with multi-scale issues and cross-system processes that are relevant to climate change impacts, adaptation, vulnerability and mitigation;
2. To continue to foster dialogue among researchers from different fields of climate change research (the climate system; biophysical and human system impacts, adaptation and vulnerability; and mitigation), as well as relevant stakeholder communities;
3. To explore the complexities arising from the combination of multiple climatic and non-climatic stressors;
4. To engage a growing community of scientists active in observation and modelling of global and regional scale changes in Earth and human systems; climate change and climate variability impacts, adaptation, and vulnerability; climate change mitigation; environment and sustainable development linkages; and related areas of research;
5. To identify the ways in which the TGICA can continue to facilitate research, including greater access to observational and model data; and
6. To recognize and prepare for future needs of the IPCC, the DDC and related avenues of data dissemination, and the community-at-large.

The meeting will help advance the state of the art of integrative regional research by providing a forum for discussion of innovative research on the following broad topics:

- Drivers of climate and environmental change;
- Responses of climate and biophysical systems;
- Vulnerability of ecological and human systems to adverse impacts;
- Managing the risks: climate change mitigation and adaptation;
- Integrated studies of climate change impacts, adaptation and vulnerability; and
- Sustainable development and climate change.

Abstracts should address these topics in the context of:

- Non-linear interactions, especially those between coupled systems;
- Consistency between global or large-scale scenarios and scenarios at higher resolutions;
- Transitioning between and/or integrating spatial and temporal scales; and
- Integrating emission forcings at different scales.

Sessions may include, but are not limited to, downscaling scenarios; complexities and non-linearities; integrating socio-economic, environmental, and climate datasets; feedbacks and thresholds; spatial teleconnections and cascading effects; and regional case studies. To be eligible for participation in the meeting, abstracts should address problems of integration, either across different spatial scales, different temporal scales, or different systems. Abstracts can focus on either methodological approaches or regional case studies that integrate challenges and/or multiple scales. We encourage scientists from any of the areas of climate systems, impacts and adaptation, or mitigation, as well as integrated assessment, to participate in this meeting. Abstracts should clearly include a description of the challenge(s), the specific issue under consideration, the method or approach that will be presented and/or the region of interest.

In addition to the invited papers, leading experts will be invited to present keynote talks on critical issues. Ample time will be included for discussion and informal interactions. Those who abstracts are accepted will be asked to prepare a paper in advance of the workshop, a poster for display at the workshop and a 3-minute presentation. The format will maximize the opportunity for reviewing the wide array of approaches, and for discussion amongst the participants. A meeting report synthesizing the presentations, and summarizing recommendations on future research avenues in support of IPCC objectives will be produced under the auspices of the TGICA.

Participation is especially encouraged from early career scientists from all regions of the world and varying areas of climate systems research (including impacts, adaptation, mitigation, integrated assessment).

Abstracts should focus on methodological approaches or regional case studies that use new innovative or integrative approaches.

4. PLANNING AND COSTS

A conference steering committee has been established by TGICA to plan the content and program for the NARCC meeting. Members of the committee are identified in Annex II. Co-chairs of the three IPCC Working Groups are being consulted on the meeting content. Planning for the meeting, including logistics, is to be supported by the Working Group I Technical Support Unit, assisted by the Working Group II Technical Support Unit.

The local host will be Dr. Koshy at the Pacific Center for Environment and Sustainable Development at the University of South Pacific (PACE/USP); he will also be the local organizer and convener.

A timetable of key milestones for planning the meeting, a description of planned deliverables, and an indicative budget are provided below.

4.1 Time table

August 21, 2006: Steering Committee members circulate their comments on the draft expert meeting Call for Papers & Scoping Document.
September 12, 2006: Call for Papers & Scoping Document forwarded to the IPCC Working Groups for comment; comments to be returned to the Scoping Committee by September 19th
September 22, 2006: Call for Papers completed and circulated broadly
September 29, 2006: Scoping Document sent to the IPCC Secretariat
November 30, 2006: Deadline for receipt of paper abstracts
December 15, 2006: Paper abstracts distributed to Steering Committee members for review
January 15, 2007: Scoping Committee completes decisions on abstract/paper acceptances.
May 1, 2007: Deadline for submission of papers by participants
June 20-22, 2007: Meeting to be held in Nadi, Fiji

4.2 Deliverables

Submitted abstracts that are accepted will require the invited participant to tender a full paper no later than 1 May 2007. Failure to submit a full paper by this date will result in the retraction of invitation to participate in the meeting. Accepted abstracts will be asked to prepare a poster for display at the workshop and a 3-minute presentation.

In addition, a Meeting Report will be produced that synthesizes presentations and summarizes recommendations for future research directions and proposed actions to facilitate the research.

The full papers presented at the meeting will be made available via the Technical Support Units of the IPCC Working Groups. Subject to availability of funding, a conference proceedings volume would be published. The conference steering committee will explore possibilities for publication as a special issue of a peer-reviewed journal or other format to make the papers widely available to scientific and policy communities. Because of the cutting edge nature of the issues to be addressed, no comparable publication exists and the conference proceedings volume is expected to be an important contribution to the published literature. It is anticipated and intended that the meeting would have value in stimulating new research and research collaborations to advance regional climate change science that would have value beyond the next IPCC report.

ANNEX I. CALL FOR ABSTRACTS

Integrating Analysis of Regional Climate Change and Response Options

An Expert Meeting on Regional Impacts, Adaptation, Vulnerability, and Mitigation

Sponsored by the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA), the Global Change System for Analysis, Research and Training (START) and the Pacific Center for Environment and Sustainable Development at the University of South Pacific (PACE/USP)

Nadi, Fiji, June 20-22, 2007

Human-induced climate change is a reality. Energy use, land transformations and other activities are increasing the atmospheric concentrations of gases that are warming the Earth and causing other changes to the climate. The changes in climate, the impacts on physical and biological systems, the vulnerability of ecological and human systems, and the harmful and beneficial consequences for human well-being and sustainable development will be conditioned by exposures to other stresses and the capacity to cope, recover and adapt, all of which will vary across space and time. Planning appropriate responses to manage climate change risks requires scientific understanding of system processes from global to regional to finer spatial scales, at time steps ranging from the very near term to multi-century time scales, and interactions across the many systems affected by climate change, including physical, ecological, and socioeconomic processes. Developing this understanding will require further advances in regional research that better integrates connections and feedbacks across these system processes at variable temporal and spatial scales.

The IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) announces an international meeting to explore innovative research approaches for addressing the multi-scale and multi-disciplinary challenges associated with climate change impacts, adaptation, vulnerability and mitigation.

This regional expert meeting, "Integrating Analysis of Regional Climate Change and Response Options", has six primary objectives:

1 To identify and explore innovative research approaches for dealing with multi-scale issues and cross-system processes that are relevant to climate change impacts, adaptation, vulnerability and mitigation;
2 To continue to foster dialogue among researchers from different fields of climate change research (the climate system; biophysical and human system impacts, adaptation and vulnerability; and mitigation), as well as relevant stakeholder communities;
3 To explore the complexities arising from the combination of multiple climatic and non-climatic stressors;
4 To engage a growing community of scientists active in observation and modelling of global and regional scale changes in Earth and human systems; climate change and climate variability impacts, adaptation, and vulnerability; climate change mitigation; environment and sustainable development linkages; and related areas of research;
5 To identify the ways in which the TGICA can continue to facilitate research, including greater access to observational and model data; and
6 To recognize and prepare for future needs of the IPCC, the DDC and related avenues of data dissemination, and the community-at-large.

Call for Abstracts

To meet the above-mentioned objectives, we invite abstracts that address the following challenges:

- Integrating socio-economic, environmental and climate datasets, both observational and projected, which address quantifying uncertainty across data sets and risk assessment, and/or resolving variable spatial scales, time steps and different sources of data;
- Exploring feedbacks and couplings among different systems, across spatial scales and across temporal scales;
- Assessing issues associated with rapid changes, thresholds and discontinuities;
- Addressing methodological constraints;
- Identifying spatial teleconnections among different systems; and
- Identifying repercussions and consequences of cascading effects.

Participation by established as well as early career scientists from all regions of the world and varying areas of climate systems research (including impacts, adaptation, mitigation, integrated assessment) is encouraged. Abstracts should focus on methodological approaches or regional case studies using new innovative or integrative approaches. Sessions may include, but are not limited to, downscaling scenarios; complexities and non-linearities; integrating socio-economic, environmental, and climate datasets; feedbacks and thresholds; spatial teleconnections and cascading effects; and regional case studies.

Leading experts will be invited to present keynote talks on critical issues. Ample time will be included for discussion and informal interactions. Authors of accepted abstracts will be asked to prepare a paper in advance of the workshop, a poster for display at the workshop, and a 3-minute presentation. The format will maximize the opportunity for reviewing the wide array of approaches, and for discussion amongst the participants. A meeting report synthesizing the presentations, and summarizing recommendations on future research avenues in support of IPCC objectives will be produced under the auspices of the TGICA.

Abstract Submission: Abstracts should clearly describe the challenge(s) to be addressed, the specific issue under consideration, the method or approach that will be presented and/or the region of interest. Abstracts must be submitted by e-mail to ipcc-wg1@al.noaa.gov no later than 30 November 2006 using the form provided at the end of this announcement. Submitted abstracts will be reviewed by the conference steering committee and invited papers will be announced by 15 January 2007. Authors must submit a full paper no later than 1 May 2007. Failure to do so will result in retraction of the invitation to participate in the meeting.

Financial Support: Financial support for travel, lodging and subsistence is available for invited participants from developing and transition economy countries. Invited participants from developed countries must acquire support for their expenses. Note that this is an IPCC sanctioned conference and that many developed countries have established funds to support the costs for participation in IPCC meetings by their scientists. Paper authors from developed countries should contact their IPCC national focal point to inquire about possible financial support.

For more information, please contact ipcc-wg1@al.noaa.gov.