The impacts of climate change
An appraisal for the future

EMBARGOED FOR 00:00
9 NOVEMBER 2004

The impacts of climate change

An appraisal for the future

About International Policy Network

International Policy Network (IPN) is a charity based in the UK, and a non-profit (501c3) organization in the US. It is a non-governmental, educational and non-partisan organization which relies on charitable donations from individuals, foundations and businesses to carry out its work. It accepts no money from government.

IPN aims to empower individuals and promote respect for people and property in order to eliminate poverty, improve human health and protect the environment. IPN promotes public awareness of the importance of this vision for all people, both rich and poor.

IPN seeks to achieve its vision by promoting the role of market institutions in certain key international policy debates: sustainable development, health, and globalisation and trade. IPN works with academics, think tanks, journalists and policymakers on every continent.

Specifically IPN

- Supports like-minded individuals and groups around the world with websites, small grants and advice
- Sponsors and co-ordinates conferences, workshops and seminars
- Works with experts to produce books, monographs and opinion articles for the media
- Co-ordinates the participation of experts at key international conferences
- Engages with and promotes our partners to the news media

The impacts of climate change

An appraisal for the future

First published by International Policy Press
a division of International Policy Network.

Third Floor, Bedford Chambers
The Piazza
London WC2E 8HA UK
t : +4420 7836 0750
f: +4420 7836 0756
e: info@policynetwork.net
w : www.policynetwork.net

ISBN 1-905041-01-2

Designed and typeset in Latin 725 by MacGuru Ltd
info@macguru.org.uk

Cover design by Sarah Hyndman

Printed in Great Britain by Hanway Print Centre
102–106 Essex Road
Islington N1 8LU

Contents

Introduction

This report addresses the potential impacts of climate change in the next century. The contributors – economists and scientists – ask whether climate change will create circumstances that are different in the future to those which have been experienced in the recent past, especially those which already result from weather and climate *per se*.

Models versus observations

Models are intended to help us understand how the world works. When an aircraft engineer wants to know how a particular aircraft design might work, she builds a model and tests it in a variety of circumstances. This helps her to predict how the full-size craft might work under similar conditions, and helps ensure that the design is robust. Increasingly, models of all kinds have moved from physical representations to computational representations. The latest Boeing Aircraft, for example, the 7E7 'Dreamliner' was entirely designed using computer-based models.

For models to be useful, however, they must accurately represent the world. A scale model of an aircraft made with materials twice as heavy as those used to manufacture the real machine would lead to spurious interpretations and a poorly-designed aircraft. Unfortunately, this is similar to what has been done in the case of climate change. First of all, models have been used that do not accurately represent the past climate. Second, inappropriate assumptions about the future have been fed into these models, generating misleading projections concerning changes to the earth's climate over the course of the next century or so.

Contributors to this report have become increasingly concerned that the public is being fed a series of exaggerated claims regarding likely future climate change, based on these inaccurate models. At its most innocent, this is a result of widespread ignorance regarding the limitations of models. But it is implausible to assume that all those engaged in this discussion are ignorant of the limitations of the models; some people are clearly using these implausible predictions as a scare tactic to encourage more aggressive policies.

The test of a good model is that it works in the real world. An engineer often faces a real-world test of his or her design within a few months or years. If their design fails, it has a direct impact on their credibility and consequently their employability. This provides a strong incentive to 'get it right'. By contrast, many of those developing climate models will have retired by the time their predictions face such a reality test – in 2020 or 2050 or even 2100.

Climate modellers differ from aircraft engineers in another way: whereas most aircraft engineers are employed by the private sector and are rewarded according to the usefulness of their designs to the travelling public, climate modellers are funded primarily by governments, and are rewarded according to the extent to which their models are useful to politicians and their entourage. Since politicians seem more willing to fund research when the outcome might give them an excuse to impose regulations and/or taxes, we cannot be surprised that the modellers have responded to these incentives by generating models that exaggerate the impact of humanity's impact on the climate.

Section 1 discusses the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC), which has developed scenarios that underpin the IPCC's forecasts of climate change. These scenarios are based on assumptions about the world's future population, economic growth, energy sources and energy efficiency, which are fed into scientific climate models.

Many of the SRES scenarios over the next century are extremely implausible, yet the most extreme scenarios are "implicitly given more importance": after they are fed into the most sensitive climate models, these scenarios extend the IPCC's temperature projections for human-induced climate change. In fact, it is two implausible scenarios have been used to inflate the IPCC's central projection that global temperatures will increase by '1.5 to 5.8°C'. A more realistic approach would adjust this projection downwards by at least 2°C, even assuming that the climate models are accurate.

Despite its misuse in the SRES process, economics can help to clarify the tradeoffs that policymakers face in pursuing climate policy. Should we undertake actions today to prevent changes in the distant future – and would this benefit people who are alive today?

Section 2 sheds light on these questions, using a set of impact studies sponsored by the UK Department of Environment, Food and Rural Affairs (DEFRA), many of which were integrated into the IPCC's Third Assessment Report (TAR).

With one exception (coastal flooding), the Kyoto Protocol – the most prominent mitigation policy to date – 'would leave untouched the major share of the total risk burden' from a variety of environment and health impacts. Even a mitigation regime which stabilises greenhouse gases would leave these risks undiminished.

In contrast, a set of adaptation measures to specifically address those impacts 'would cumulatively cost much less, and deliver greater benefits than either the Kyoto Protocol or other more ambitious mitigation schemes'. With this course of action, we could potentially wait 25 years or more 'before initiating control actions to produce change beyond that which would be obtained automatically through continuous, long-term improvements in technologies'.

Sea level change, malaria, extreme weather, human health, and fisheries

Section 3 analyses the prospect of sea-level rise with particular reference to two low-lying areas, the Maldives and Tuvalu. The IPCC first estimated, from all of the variables which could contribute to sea level rise, a mean value of 0.9 mm per year – a value that coincides with historical and present observations. For reasons that remain unclear, 'the IPCC discarded their own estimate [of 0.9 mm/year] and replaced this observational value with a model value of 1.8 mm/year'.

It is disturbing that this 'model' value starkly conflicts with observation and evidence obtained in a major recent initiative on the part of the INQUA Commission on Sea Level Changes and Coastal Evolution. This expert group predicted a future sea level rise of 10cm, with a maximum of 20cm, over the next century.

Could a warmer climate lead to the spread of vector-borne diseases? **Section 4** shows that 'rudimentary mathematical models of transmission dynamics' are not reliable 'for assessing the impact of long-term climate change on disease transmission'. Such models are unable to predict the presence or absence of the disease, nor its prevalence, because they do not account for the parasite rate in humans or mosquitoes. These models also leave out the many ecological and behavioural factors, such as human behaviour and cultural traits, which affect the interaction of mosquitoes and humans.

In reality, malaria and other diseases are subject to a complex interplay of factors 'which defy simple analysis'. On the other hand, we know that malaria has been eliminated in many parts of the world – including Europe – by economic, environmental and medical interventions. With or without climate change, continued interventions and new technologies will remain a primary tool in the battle against malaria and other vector-borne diseases.

Section 5 suggests that there is a mismatch between the popular perception about the impact of global warming on extreme weather, and observations.

An analysis of observational data around the world reveals a lack of trends in extreme weather events which can be attributed to global warming. Many weather events such as tropical cyclones and rainfall in Asia and Africa are interrelated to with phenomena such as the El Niño/Southern Oscillation which themselves are not entirely understood, much less their relation to anthropogenic climate change.

Extreme weather events are intimately tied to their economic impacts. In the USA, studies indicate that increasing losses from floods and hurricanes are a result of societal change in wealth, population and other demographic factors, rather than evidence of global warming. Outside of the USA, very few studies have been reported so far to make a meaningful analysis of their economic impact.

The effects of climate change on human health are assessed in **Section 6**. It may come as a surprise that 'throughout Europe, and also in most of the world, cold-related deaths are far more numerous than heat-related deaths'. In absolute terms, a warmer climate would mean that 'the additional deaths due to heat would be much smaller than the reduction in deaths due to cold'.

This is not a form of reassurance to those people who might die as a result of heat. However, deaths of this kind are largely avoidable with adaptive measures, including air conditioning, proper attention to vulnerable groups such as the elderly and people in institutions, warnings to the public, and simple measures to keep people cool.

Some have argued that climate change may have a negative economic impact. **Section 7** uses an economic analysis of the effects of climate change on North Atlantic fisheries, which are especially important to the economies of Iceland, Norway and Greenland.

The Arctic Climate Impact Assessment working group on Arctic fisheries realised that 'there simply wasn't enough hydrographical, biological and ecosystem knowledge to translate predictions of global warming – uncertain as they are – into predictions for fish stocks and fisheries with a reasonable degree of confidence.' However, given existing knowledge, they concluded that for the main commercial fish stocks of the North Atlantic, 'a warming of the magnitude predicted is more likely than not to be beneficial.'

In the worst case of a set of three scenarios, the short-term consequences of sudden changes from warming could be economically harmful, especially to Greenland, but not over the long run (25 years or more). However, even this scenario depends on the extent and magnitude of warming, and seems unlikely.

The debate about climate impacts

The views of pundits and politically motivated activists from myriad disciplines are often aired in the debate about climate impacts. Raising fears of future harms, these people promote proposals which, if implemented by policymakers, would often be more detrimental to humanity than the alleged harms they seek to prevent.

The information presented in this report is not intended to be all-encompassing. Nevertheless, a notable synergy emerges from disciplines that are otherwise unrelated. It has been observed that forecasting is difficult, especially when one is trying to forecast the future. But climate modellers can't even forecast the past, let alone what might happen to economic growth, fisheries, storms, sea level or malaria in the future. Panic is not warranted; constructive measures are needed to help people today and in the future.

Unfortunately, science is uncertain. But pundits and activists are able to offer a moral certainty to policymakers that scientists cannot likewise offer. Undoubtedly, some of the former will cast aspersions on the motives of those who contributed to this document. In their minds, those who choose to challenge the 'conventional wisdom' of human-induced climate apocalypse are either the mouthpieces of big corporations, or they are deluded, or both.

Other critics will regurgitate the old chestnut that 2500 scientists of the IPCC have reached a consensus. Or, more absurd, 'most scientists' say this or that. Science does not proceed on the basis of consensus. When it does, the results can be tragic, as Paul Reiter observes in *Nature* (Volume 431, 14 October 2004):

> *'It is 40 years since the end of Trofim Lysenko's dictatorship over Soviet biology. A poorly educated agronomist, Lysenko gained political support during the agricultural crisis of the 1930s by denouncing conventional genetics as a "bourgeois deception" and promising improved crop yields on the basis of crude and unsubstantiated "experiments". He became the autocrat of Stalinist science, with catastrophic results that linger today.*
>
> *'Lysenkoism was a tragic example of illusion that became accepted as reality, despite all contrary evidence, because it was continually affirmed at meetings and by the media'.*

To those who choose the *ad hominem* approach to criticism: read this report and investigate the scientific literature. The contributors are pre-eminent in their fields and have published these views in peer-reviewed journals, demonstrating that the 'consensus' alleged by the IPCC and its supporters is illusory. The contributors share a spirit of goodwill to help humanity deal with problems in the future, whether or not they are caused by climate change.

The motivation of this report is to redress the balance in this debate, and to inspire policymakers and others to take a more balanced approach.

London
November 2004

Section 1

The scenarios underlying climate change 'predictions'

Martin Ågerup

Scientists are in broad agreement that human activities have some influence on global mean temperatures and climate, but they disagree about the extent of this influence. Absent the influence of humanity, the earth's climate would not be stable – it experiences extreme natural changes, and small manmade temperature increases are likely not to be a huge problem.

It is almost as uncontroversial that uncontrolled human emissions of greenhouse gases (GHGs) will result in an increase in global mean temperatures – all other things being equal. This does not in itself justify political action in general or climate mitigation in particular. The earth's climate would not be stable without human influence. In fact climate has always changed and will always change. Therefore, small manmade temperature increases are not a problem.

Some greenhouse gases are more effective per molecule when it comes to trapping infrared radiation than others. In order to simplify a matter slightly, the concentrations of the different GHGs in the atmosphere are converted into CO_2-equivalents on the basis of their relative radiative potency. The CO_2-equivalent atmospheric concentration is now about 32 percent higher than the pre-industrial level. The concentration is measured in parts per million (ppm) air molecules. The pre-industrial concentration of CO_2-equivalent was approximately 280 ppm while the current level is approximately 370 ppm. The Intergovernmental Panel on Climate Change (IPCC) projects a concentration in the year 2100 that ranges from 540 to 970 ppm.

Other things being equal this development will enhance the natural greenhouse effect and cause the global mean temperature to rise. Most scientists agree on this. What is unresolved is the question of *how much* temperatures will rise. That is not just an academic issue. If human emissions of GHGs have a small effect on climate, it may prove too costly to curb these emissions compared to the benefits. The issue is further complicated by the fact that small increases in temperatures may in fact be an advantage.

It is important to establish by how much temperatures can be expected to rise over a relevant time scale because of the influence of human activities. The IPCC has attempted this exercise for the past 15 years. The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The role of the IPCC is to assess

> *the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. The IPCC does not carry out research nor does it monitor climate related data or other relevant parameters. It bases its assessment mainly on peer reviewed and published scientific/technical literature.*[1]

In its third assessment report (2001), the IPCC predicted that the global mean surface temperature would rise by 1.4 to 5.8°C[2] and came to the widely-quoted conclusion that

> *There is new and strong evidence that most of the*

> *warming observed over the last 50 years is attributable to human activities.*[3]

However, the IPCC's conclusions are highly controversial. The predictions depend on two sets of computer models. One set predicts how much CO_2 and other greenhouse gasses (GHGs) that humanity will emit into the atmosphere. The other set of models predict how the climate system will react to such increases in GHGs.

In other words, the quality of the predictions depends completely on the ability of the models to produce reliable results. In fact, there are problems with both sets of computer models. These are the two main uncertainties with these models:

1. We don't know how sensitive the Earth's climate system is to increased levels of CO_2.
2. We don't know how much CO_2 we will emit – the subject of this section.

The IPCC's emissions scenarios

The IPCC's climate models calculate the consequences of increasing atmospheric GHG concentrations – typically at a level equivalent of a doubling of atmospheric carbon dioxide compared to the pre-industrial level. However, in order to predict expected warming, modellers need estimates of the rate of CO_2 increase in order to forecast how long it will take for concentration to double. In other words, they need forecasts of human emissions of CO_2 through the 21st century.

The IPCC has made such long range forecasting exercises for all of their three assessment reports since 1992. The latest results were published in 2000 in the Special Report on Emissions Scenarios (SRES)[4]. The SRES working group produced 40 scenarios out of which six were chosen as "marker scenarios" and fed into the climate models. In other words the emissions scenario exercise is a crucial step in creating the above mentioned temperature growth range for 2100 of 1.3 to 5.8°C. In fact, most of the span in this temperature range is produced by the huge difference in emissions across the marker scenarios.

The scenarios are based on parameters influencing emissions such as:

- GDP per capita growth on a country, regional and global level
- Population growth
- Energy efficiency (how much GDP does one unit of energy produce)
- Composition of fossil fuel consumption (coal, oil, gas)
- Non-carbon fuel share of total energy production (nuclear, wind, solar etc.)

Evaluation of the emissions scenarios

Obviously the quality of the emissions forecasts depends completely on the way these parameters are treated and the values given to them in the different scenarios. Over a time span of a century the degree of uncertainty for each parameter is enormous and as explained below, some of these uncertainties compound. However, this does not mean that anything should be considered plausible. Unfortunately the SRES scenario group does a very poor job of creating plausible scenarios.

For those who use scenario methods in their professions, the SRES scenario effort is problematic. There are three basic reasons for concern:

- Sloppiness
- Bad methods
- Scenarios being used as forecasts – the most important criticism.

The criticism concerning sloppiness includes treating the period 1990–2000 as part of the forecast period without taking into consideration that we now have data for that period. Apparently the SRES has been reusing data from previous scenario exercises. The problem is that time and real world observations have proven these projections wrong. For instance the scenario figures used for the increase in world GDP between 1990 and 2000 vary between 20.6 percent and 35.4 percent. However, IMF data for most of that period was available in 1999 and showed growth of 36.5 percent.[5] Probably this error doesn't have a substantial impact on model results by 2100. Nevertheless, it's amazing that such sloppy practices are allowed as part of an input to a modelling exercise that involves the use of supercomputers and costs millions of Euros.

The IPCC also suffers from poor methodology. One leading economic modeller, John Reilly of the MIT Joint Program on the Science and Policy of Global Change calls the SRES approach to scenario building an "insult to science."[6] According to Reilly, the scenario teams have worked backward from a desired end result in terms of emissions and temperature increases. In other words, the IPCC has allegedly started with an emission projection then made an estimate of the relationship between emissions and growth and finally calculated the growth rate needed to achieve the desired emissions projection.[7]

Another criticism of methods has been advanced by Ian Castles, former President of the International Association of Official Statistics, and David Henderson, former Chief Economist of the OECD. They accuse the SRES team of using inappropriate exchange rates which exaggerate current global economic inequality. Since the scenarios assume that income equality will improve over the course of the century, models overestimate growth rates in low income countries.[8]

While the SRES methods concerning growth projections are technically unsound, the scenario models will have to be modified before we can conclude if the exchange rate error should lead to substantial reductions in total global growth rate projections. However, the "end result" in terms of world GNP/GDP does seem very high. Many of the scenarios give us a world economy which by 2100 is up to approx. 25 times larger than it is today.[9]

In order to achieve that multiplication the world economy would have to grow 3 percent a year. This does not seem to be a realistic assumption, even for a high end scenario, given the historical performance of the world economy. But then, the SRES does not seem to take historic trends much into consideration. As David Henderson points out:

> *It is a surprising feature of the SRES that in a document surveying the long term future, which contains over 300 pages of main text and presents 40 different scenarios prepared by six different modelling groups, there is no chapter which systematically reviews the evidence of the past. The starting point for any such quantitative future-oriented inquiry should be a clear and careful survey of earlier developments and trends, going right up to the present.*[10]

What such a survey could have considered is the fact that since 1975, world GDP per capita has grown at an average 1.2 percent per annum.[11] Extending this growth rate for 110 years would give us a world per capita income which was 3.7 times larger than the present. If we assume that population doubles over the same period (and that would be a high estimate) we get a global economy which is 7.4 times bigger than the present. That's quite far from a 25-fold increase.

The only economy which has produced average annual growth rates comparable to the IPCC assumption over a sustained period is Japan. Between 1913 and 1996 Japan grew at an annual rate of 3.36 percent.[12] But it seems doubtful that the entire world economy would be able to do the same for as long as a century.

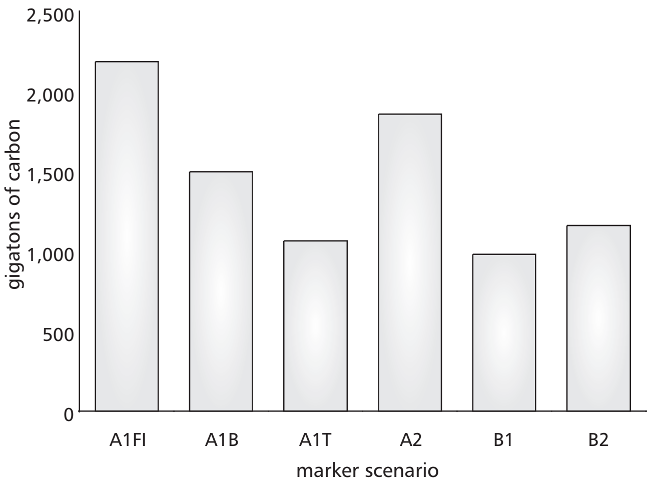
The use and abuse of scenarios

The most serious objection is the IPCC's use of scenarios. The scenarios are presented as an exercise in "free thinking" about the future. The SRES states that they are "images of the future or alternative futures" and should not be seen as predictions or forecasts. They are in fact "computer aided storylines". But at the end of the day the scenarios end up presenting a very concrete result in terms of numbers (emissions). These numbers are fed into a computer, which in turn produces a temperature. The SRES tries to have it both ways: a non-committal scenario process and a clear result in terms of a number.

The SRES claims that the scenarios "are not assigned probabilities of occurrence, neither must they be interpreted as policy recommendations."[13] But since each scenario gives a result which translates into a number there is in fact an implicit bias in favour of extreme scenarios. An extreme scenario extends the temperature range. A less extreme scenario doesn't. Therefore, an extreme scenario is implicitly given more importance. In the real world we would normally treat an extreme outcome as less likely and therefore assign less importance to it.

But the SRES scenarios are not assigned probabilities. That's normal when working with scenarios. The whole point of a scenario exercise is to cover the full range of possible futures. But this also implies that scenarios should not be used as forecasts, because a forecast doesn't make sense without a discussion of probability. Meteorologists only make weather forecasts extending 3–5 days into the future. The reason why they don't make longer forecasts is that the probability of being right gets too small. The SRES scenarios are used to make forecasts. In other words, the SRES team abuses the scenario method.

Figure 1 **Cumulative carbon dioxide total (1990–2100)**



Improbable high end scenarios

The following section shows that the high end temperature projection (which is being used as a forecast) is based on two scenarios which again are based on assumptions that have a very low probability, especially combined.

The six marker scenarios were based on very different assumptions about the parameters listed above. It is therefore not surprising that they produce very different result in terms of carbon emissions as shown in Figure 1.[14]

At the low end, the B1 scenario produces cumulative emissions by 2100 of 983 gigatons. At the high end the A1FI scenario produces emissions of 2.189 gigatons, more than twice as much.

How do those results compare with historic emissions? Figure 2 shows emissions per capita over the past half century.[15]

Until the beginning of the seventies carbon emissions per capita grew, but since then they have stabilised and even declined slightly. This has happened despite considerable economic growth.

Figure 2 **Per capita global emissions of carbon (1950–1999)**

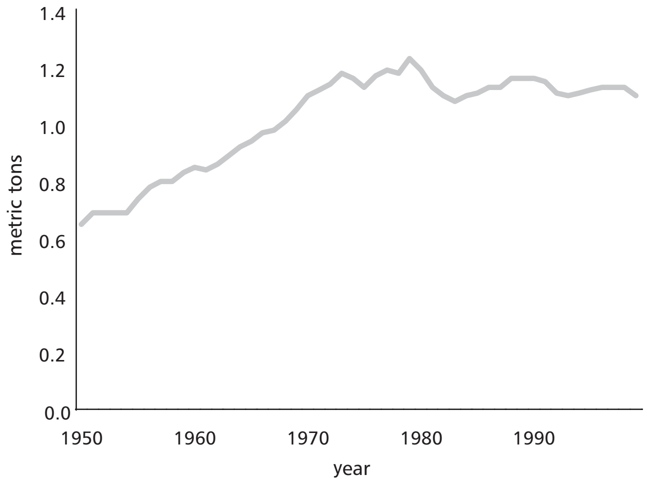
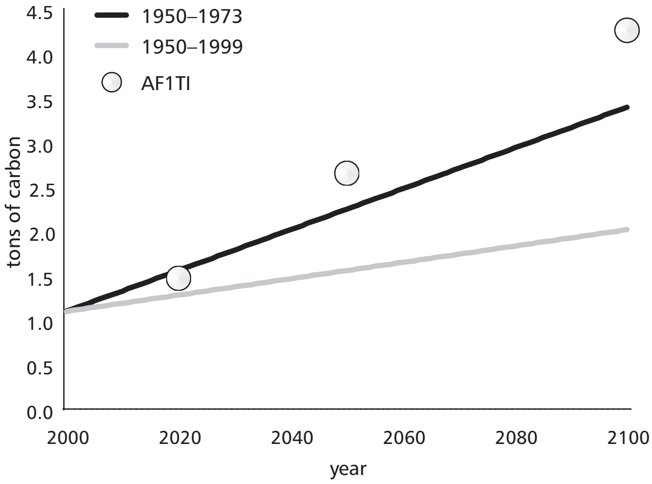


Figure 3 **Carbon emissions per capita based on historic trends**



Ross McKitrick, Associate Professor at the University of Guelph, concludes that:

> *…there is reason to believe that per capita CO_2 emissions are somewhat invariant to economic growth, at least at a globally averaged level.*[16]

It would therefore seem reasonable that per capita carbon consumption in at least some scenarios was near the current level of 1.1 tonnes of carbon. Nevertheless, the SRES scenarios are all *above* 1.2Ct per capita by 2020. Not one scenario follows the current trend of no growth!

The high end scenarios produce some results which are improbable. Figure 3 is based on two historic trend lines of carbon consumption per capita. One is a projection of the high growth trend from 1950–73. It's certain that no time period in human history has had a higher growth rate in carbon consumption per capita than this period. The other line shows the lower growth trend for the whole period from 1950 to 1999.

The figure shows how the A1FI scenario[17] overtakes even the fast growth trend by 2050. By 2100 , per capita emissions in the A1FI scenario are more than four times the current level, and 25 percent above the high growth historic trend which was only sustained for a couple of decades in reality.

Not surprisingly the scenario also arrives at very high estimates of atmospheric concentration of CO_2. Currently, CO_2-levels are increasing by approximately 0.4 percent a year.[18] Figure 4 shows how, by 2100, atmospheric CO_2 concentrations at the high end of the A1FI scenario reach a level 2.27 times what the current trend would imply.[19] The fact that the 1990s had both high global economic growth and probably the highest nominal population growth ever (including all of the 21st century[20]) suggests that annual CO_2-growth may not increase much above the current 0.4 percent.

The current trend for the second most important GHG, methane, is that the rate of growth has been decreasing and the actual concentration is currently falling. Yet none of the scenarios follow that trend. Figure 5 shows how the A1FI scenario predicts a concentration more than double the current trend.[21]

It is reasonable to conclude that the A1FI scenario depicts an extremely unlikely future. Nevertheless, it

Figure 4 **Atmospheric CO_2 concentration – alternate scenarios (1990–2100)**

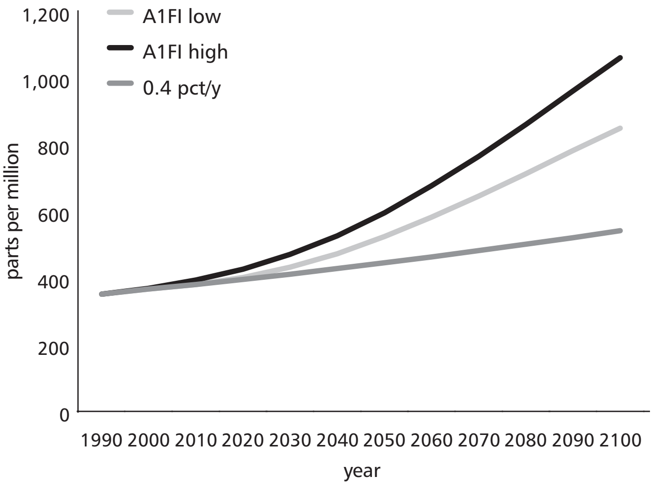
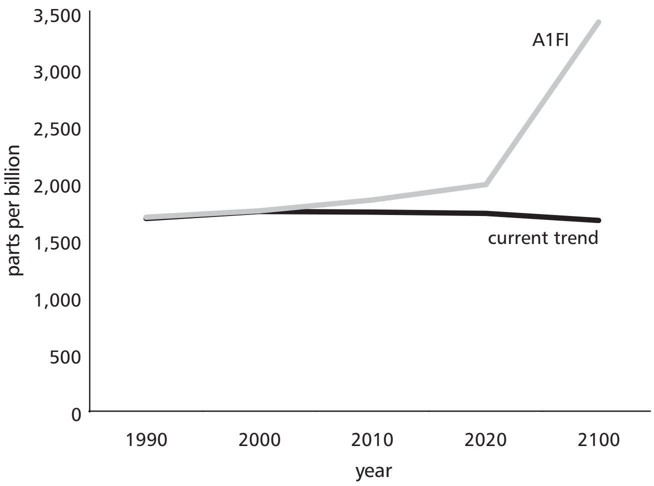


Figure 5 **Atmospheric methane concentration (1990–2100)**



is this scenario – and this scenario alone – which is responsible for the high end of the IPCC's Third Assessment Report temperature range of 1.3 to 5.8°C for the year 2100. The 5.8° forecast is arrived at by running the GHG concentration figures of the A1FI scenario through the climate model with the highest sensitivity to increased CO_2. If it wasn't for this scenario, the top temperature would be 1°C lower.[22]

If we ignore the 1°C which is produced by the A1FI scenario, we get a high temperature estimate of approx. 4.8°C. This is generated by running the A2 scenario through the most GHG-sensitive climate model. The A2 scenario predicts yearly CO_2 emissions by 2100 which are almost as exorbitant as the A1FI figures. But this scenario gets there in a different way. One of the tricks of the A2 scenario is a very high population projection.

Figure 6 shows the 2002 UN Population projection.[23] The medium population projection for 2050 is 8.9 billion. The high estimate is 10.6 billion. Nevertheless, the A2 scenario has 11.3 billion people in 2050, a figure above the UN's high estimate.

Unfortunately, the latest UN projection doesn't go beyond 2050. But the 2000 median projection estimated that world population would be 10.4 billion in 2100. In the new projection, the median figure for 2050 is revised downward from 9.3 to 8.9 billion[24] which implies that the forecast for 2001 would also be lower today. The A2 scenario assumes a world population in 2100 of 15.1 billion[25] – 50 percent above the median estimate. The A2 population is below the UN high projection of 18 billion, but few people consider that to be a likely outcome. It's not really a projection but a kind of "business-as-usual" scenario.

Secondly, and much more importantly, as figure 7 illustrates, the A2 scenario has a much higher share of coal than any of the other scenarios. This is significant since coal emits more carbon per unit of energy than oil and especially gas. On top of that A2 has a much lower share of zero carbon energy (renewable sources, nuclear etc.).[26] In short, the A2 scenario assumes virtually no advances in energy technology over the next century. In fact, the scenario assumes that a trend towards less carbon intensive energy sources – a trend which has persisted for over a century – is actually reversed.

Figure 6 **World population projections (2000–2050)**

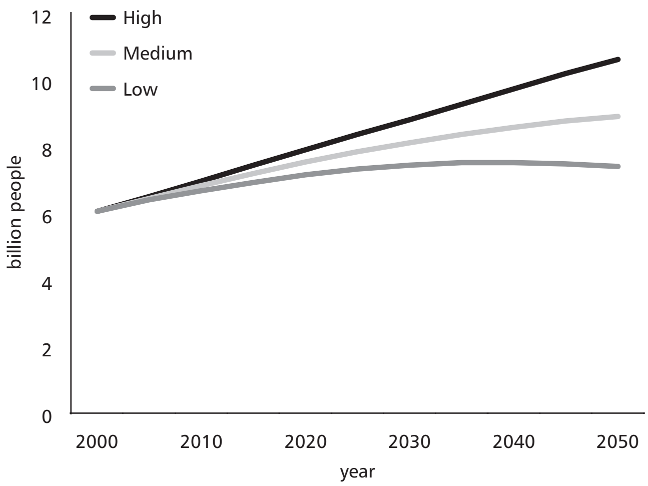
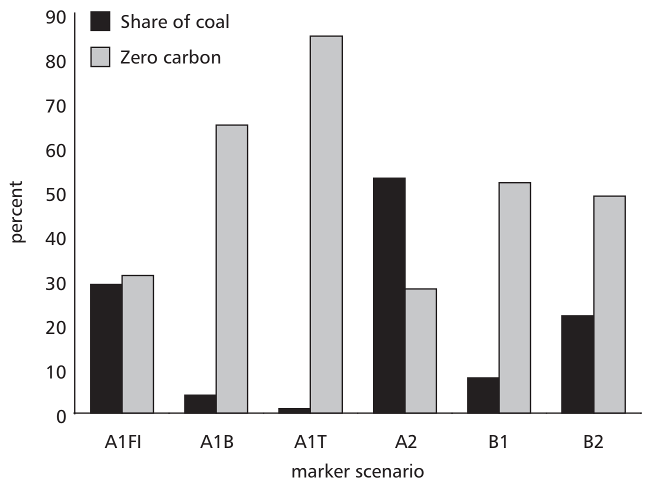


Figure 7 **Share of primary energy (2100)**



It is interesting to compare the A2 scenario with the A1T scenario. By 2100, the A2 has the second lowest world GDP of all six marker scenarios: 243.000 billion (measured in USD at 1990). In comparison the A1T scenario forecasts a world economy of 550.000 billion (1990 USD) – more than twice that size.[27] Still, the A2 world emits 28.9 Gt of carbon per year, which is 6.7 times more than the 4.3 Gt emissions that the A1T world produces. In other words, the carbon intensity of the A2 economy is 15 times higher – this world needs fifteen times more carbon per unit of GDP.

This difference illustrates the importance of expectations about future energy technology. The A2 and the A1T scenarios represent two extremes in this respect. In A2 there is very little technological development, so the world returns to coal as the primary source of energy. In A1T there is rapid technological development, and non-carbon energy technologies begin to replace fossil fuels by the middle of the century. Are both scenarios likely? The answer is probably no. The A1T scenario is likely, whereas the A2 scenario is not. The reason for this is that the A2 scenario reverses a very long term trend whereas the A1T scenario merely continues (and maybe accelerates) an existing long term trend.

Despite the fact that the share of coal in world energy supply has been decreasing over the whole of the 20th century[28] and no reversal of that trend seems in sight, the share of coal increases in the A2 scenario from the current level of 23.5 percent[29] to 53 percent.

For more than a hundred years the global carbon dioxide intensity of energy has been decreasing steadily, by almost a third[30]. The A2 scenario inexplicably reverses this trend of decarbonisation.

Most of the literature on the subject of energy technology expects that one or more non-carbon technologies will become competitive in the course of the 21st century. Both photovoltaic sources (solar energy) and windmills show historic learning curves with a learning rate of approximately 20 percent. In other words, a doubling of cumulative installed capacity gives a 20 percent reduction in costs. At that rate, wind energy will be competitive within a decade or two and photovoltaic energy around 2050. Even models which are less optimistic about the learning curve have alternative non-carbon energy

Table 1

Forecast exercise	*Principal uncertainties*
Create scenarios for future emissions of CO_2	■ World GDP growth per capita and its distribution among Low, Middle and High income countries. ■ Population growth ■ Composition of different fossil fuels in total consumption ■ Technological change, including shifts to non-carbon or low-carbon energy sources, energy efficiency, carbon sinks etc.
Convert emissions to atmospheric concentrations	■ The life time of different GHGs in the atmosphere
Model radiative forcing and convert this forcing to a projected temperature	■ The sensitivity of the climate system to increased CO_2 (feedback effects of clouds, aerosols etc). ■ Natural climate effects enhancing or counterbalancing manmade effect

sources overtaking fossil fuels before the end of the 21st century.[31]

For the time being, gas is becoming an increasingly attractive alternative in much of the world and the price of gas-generated electricity is falling. This is another trend which is reversed in the A2 scenario.

While nuclear energy has stumbled in Europe for political reasons, other parts of the world are expanding their nuclear energy base rapidly, particularly Asia. Nuclear energy's percentage share of global energy supply has expanded from 0.9 percent in 1973 to 6.8 percent in 2000. There is also a learning curve for nuclear energy, so the expansion of this energy source results in it becoming ever cheaper, so nuclear energy could be expected to play a much larger role in the future.[32]

To summarise, while both the A1FI and the A2 scenarios are possible scenarios and maybe even "good" scenarios within a framework of six very different marker scenarios, they are not suitable for the forecast exercise that the emissions output constitutes. Both scenarios have a very low probability since they are based on a number of assumptions which seem unlikely given historical trends.

Conclusion: How much warmer will the climate be by 2100?

Table 1 summarises the basic steps that the IPCC needs to undertake in order to achieve the expected warming interval (left hand column). For each step it lists what are widely considered to be the principal uncertainties given current scientific understanding (right hand column).

Through the forecast exercise, total uncertainty compounds as each new uncertainty is added.

Each of the parameters has a factor 2 uncertainty. The highest estimate is double the lowest estimate. But the result has a factor 4 uncertainty. The highest estimate is four times higher than the lowest. Adding a third parameter with a factor 2 uncertainty would gives us a high estimate which was 8 times higher than the low estimate. Uncertainty compounds.

The short answer is that we simply do not know how much warmer climate will be in 2100. In fact, the degree of (compound) uncertainty is so large that merely by providing temperature intervals, the IPCC is extremely misleading. For many of the parameters even the degree of uncertainty is controversial, despite the IPCC's phoney confidence intervals. Climate science is not at a stage where it is capable of providing confidence intervals, especially not for the earth's climate almost one hundred years into the future. In fact even the term "uncertain" is often misleading when it comes to climate science. A lot of things are not uncertain but simply *unknown*.

The NAS report concludes:

> *Because there is considerable uncertainty in current understanding of how the climate system varies naturally and reacts to emissions of greenhouse gases and aerosols, current estimates of the magnitude of future warming should be regarded as tentative and subject to future adjustments (either upward or downward).*[33]

Given current knowledge, downward adjustments seem to be by far the best bet. There are strong indications that the IPCC has a systematic bias in favour of exaggerated temperature increases. The climate sensitivity of the models is largely based on a number of positive feedbacks, whereas negative feedbacks are probably underestimated or completely ignored.

On top of that, the emissions scenarios produce growth rates of carbon emissions which are not in line with recent history. Especially the high end scenarios, such as the A1F-scenario, seem completely unrealistic. Nevertheless, the A1F-scenario provides the basis for the high end of the IPCC temperature range. According to the guidelines for scenario use that most forecasters and futurists refer and adhere to, a scenario must be both *possible* and *probable*. While the A1F-scenario is theoretically possible (and even that is debatable), it simply isn't probable.

As mentioned, temperature intervals do not make sense given current knowledge about the climate system. However, since this is the game that the IPCC has forced upon us, we should examine the interval of 1.5 – 5.8°C temperature increase which is the central IPCC projection. This interval is almost certainly way too high. The upper estimate should be decreased by about 1°C because it is based on the unrealistic emissions of the A1F-scenario, and by a further 1°C which results from the unrealistic A2 scenario.

Section 2

Understanding climate impacts

Indur M. Goklany

It has been suggested that climate change will overwhelm human and natural systems by increasing the prevalence of climate-sensitive diseases, reducing agricultural productivity in developing countries, raising sea levels, and altering ecosystems, forests and biodiversity worldwide.[1]

Will the impacts of global warming – on top of myriad other global public health and environmental threats – prove to be the proverbial 'straw that breaks the camel's back'?

This section examines whether analyses of the impacts of global warming into the foreseeable future support this claim and, if they do, whether it is more effective to rely on mitigation strategies, or on adaptation to their impacts. In this chapter, adaptation implies measures, approaches or strategies that would help cope with, take advantage of, or reduce vulnerability to the impacts of global warming.

Table 1 allows us to assess the importance of global warming, relative to other factors that might affect public health and the environment into the 'foreseeable future'. This table is based, for the most part, on a set of impact studies sponsored by the UK Department of Environment, Food and Rural Affairs (DEFRA), many of which have been incorporated into the IPCC's 2001 Third Assessment Report (TAR). Because the DEFRA-sponsored assessments did not provide an estimate of the future forest cover in the absence of climate change, it was necessary to rely on other studies reported by the IPCC for that estimate.

Notably, analysts involved in the DEFRA studies recognise that socioeconomic projections are 'not credible' beyond the 2080s[2], hence the selection of the 2080s in the table as the outside limit to the 'foreseeable future'. Although the TAR states that between 1990 and 2100, global temperature might increase from 1.4 to 5.8°C, it also notes that 'on time scales of a few decades, the current observed rate of warming … suggests that anthropogenic warming is likely to lie in the range of 0.1 to 0.2°C per decade over the next few decades.'[3] However, the scenarios employed in the DEFRA-sponsored impact assessments are based on globally averaged temperature increases of slightly more than 0.3°C per decade;[4] therefore, they may overestimate likely impacts to the 2080s.

In Table 1, column 3 provides estimates of various public health and environmental risks or factors related to those risks under baseline conditions in the 2080s (i.e., in the absence of global warming).

Column 4 provides the changes in risks or risk-related factors in the 2080s due to the imposition of global warming, above and beyond baseline conditions. Finally, column 5 provides estimates of reductions in total risks or risk-related factors due to full implementation of the Kyoto Protocol assuming that because the Protocol would reduce temperature change between 3–7% by 2100,[5] it would reduce the impacts of global warming by less than 7% for all risk categories except coastal flooding. For the latter, it is assumed that the Protocol will decrease the impact of climate change by thrice that amount.[6]

Table 1 **Projected climate change impacts in the 2080s, compared to other environmental and public health problems**

Climate-sensitive sector/indicator	*Year*	*Impact/effect* *Baseline (B) in the 2080s , includes impacts of environmental problems other than climate change*	*Impacts of climate change (ΔCC) in the 2080s, on top of the baseline*	*Impacts of Kyoto Protocol in 2080s, relative to baseline+ΔCC**
Global agricultural (cereal) production	2080s	4,012 million metric tons (MMT), vs 1,800 MMT in 1990	production would drop 2% to 4%; and could be substantially redistributed from developing to developed countries	increase net global production by 0.1% to 0.3%
Falciparum malaria (population at risk, PAR)	2080s	8.82 billion at risk by the 2080s, vs 4.41 billion in 1990	increase PAR by 0.26 to 0.32 billion (or 2.9% to 3.7%)	reduce total PAR by 0.2% to 0.3%
Water resources (population in countries where available resources use > 20%)	2085	6.46 billion, vs 1.75 billion in 1990	increase PAR from 0.04 to 0.11 billion (or 0.6% to 1.6%)	reduce total PAR by about 0.1% or less
Global forest area	2050s 2080s	decrease 25–30(+)% by 2050, relative to 1990	increase by 5%, relative to 1990	reduce the increase in global forest area by 0.4%
Sea-level rise (SLR)	2080s	varies	~41 cm (or 20 in), relative to 1990	reduce SLR by <1.4 in
Coastal flooding (PAR)	2080s	0.013 billion	increase PAR by 0.081 billion (or 623%)	reduce total PAR by 18.1%
Coastal wetlands (area)	2080s	decline of 40% relative to 1990	decline of 12% relative to 1990	reduce the decline by 0.8%, relative to 1990 level
Storms	2080s	unknown	unknown whether magnitudes or frequencies of occurrence will increase or decrease in any specific area	unknown

Sources: Parry *et al*. (1999) and IPCC (2001b) for agriculture; Arnell *et al*. (2002), and Goklany (2000), based on Solomon *et al*. (1996), for forest cover; Arnel *et al*. (2002) and IPCC (2001b) for *Falciparum* malaria; Arnell *et al*. (2002) for coastal flooding; Arnell (1999) for water resources; Arnell *et al*. (2002) for sea level rise, and coastal wetlands; IPCC (2001a), Henderson-Sellers (1998) and Henderson-Sellers *et al*.

* Assumes that the Kyoto Protocol, if implemented, would reduce climate change and its impacts by 7% by the late 21st century. See text.

Table 1 indicates that:

- In the absence of warming, (that is, in the 'baseline' case), *global cereal production* would increase by 123% from 1,800 megatons in 1990 to 4,012 megatons in the 2080s in order to meet additional food demand of a larger and wealthier global population.[7] Such an increase is plausible provided agricultural technology continues to enhance productivity, sufficient investments are made in the agricultural sector and related infrastructure, and trade continues to move food from surplus areas to deficit areas.[8]

  Due to global warming, agricultural production may decline in poor countries, but may increase in wealthy countries, resulting in a net decline in global production of 100 megatons to 160 megatons (i.e., 2–4% of total production in the absence of warming) in 2080. Thus, downturns in economic growth (which would inhibit investments in the agriculture and infrastructure), slower technological change, or less voluntary trade of food supplies are more likely to create a future food crisis than any potential global warming.[9] Notably, the Kyoto Protocol would result in a marginal improvement in production of less than 0.3% in the 2080s.

- The *population at risk (PAR) of malaria*, one of the most common and dreaded climate-sensitive infectious diseases, might essentially double in the absence of global warming, from 4.41 billion in 1990 to 8.82 billion in 2080.[10] With global warming, the numbers at risk of contracting malaria might increase by 0.26 billion to 0.32 billion in the 2080s (equivalent to an increase of between 2.9% and 3.7% over the 2080 baseline).[11] However, an increase in the numbers at risk does not necessarily translate into increased number of cases of malaria, or its prevalence.[12] The Kyoto Protocol would reduce the total numbers at risk of contracting malaria by less than 0.3% in the 2080s, as well.

- The number of people living in countries who experience *water stress* (defined as countries using more than 20% of their available water resources) would increase from 1.750 billion in 1990 to 6.464 billion under the baseline (no-climate-change) case in the 2080s.[13] Because of global warming, the latter number would increase by between 0.042 billion and 0.105 billion, depending on the precise climate model employed to estimate future climate change.[14] The impact of the Kyoto Protocol for this risk category will also be minimal into the 2080s.

- If all else remains the same (i.e., ignoring changes in land use after 1990), then by the 2080s, *global forest area* may *increase* 5% over 1990 levels due to global warming alone.[15] But if greater agricultural and other human needs increase the demand on land, as they well might (since the world's population will be larger and probably wealthier), forest cover may decline by 25–30%, putting enormous pressure on global biodiversity.[16]

- *Sea level* may rise about 40 cm from 1990 to 2080.[17] As a result, the population at risk of *coastal flooding* is expected to increase by 623% from 0.013 billion under the baseline to 0.094 billion. The Kyoto Protocol could reduce the total PAR from coastal flooding by about 18%. Sea-level rise could also lead to a loss of *coastal wetlands*, but such losses due to other human activities are expected to dominate at least into the 2080s.

- It is unclear whether the frequencies and magnitudes of *storms*, such as tornadoes, hurricanes and cyclones, will increase or decrease.[18] Thus, with the exception of coastal flooding, the impacts of climate change into the foreseeable future are secondary to the impacts of other agents of change built into the baseline case. Moreover, for the most part, the impacts of global warming would seem to be within the noise level of these baseline problems.

Consequently, stabilising GHG concentrations immediately – even if feasible – would, unfortunately, do little over the next several decades to solve the bulk of the problems frequently invoked to justify actions to reduce humanity's role in warming. Land and water conversion will continue almost unabated, with little or no reduction in the threats to forests, biodiversity, and carbon stores and sinks. Food production would not be markedly increased or decreased. Populations at risk of malaria would not be affected much, nor would the numbers of people at risk of water stress.

The reductions in risks due to the Kyoto Protocol would be relatively trivial, at least until the 2080s, with respect to all risk categories – again with the exception of coastal flooding. Nevertheless, climate change could be the proverbial last straw. Moreover, the relatively large reductions in the PAR from coastal flooding might arguably, by itself or in conjunction with reductions in other risk categories, justify the Kyoto Protocol (or other mitigation schemes).

Dealing with the last straw

There are several approaches to solving the problem of the straw that might break the camel's back; none of them needs to be mutually exclusive.[19]

Focusing on the last straw

The most common approach is to focus almost exclusively on the last straw, especially on reducing or eliminating it. This is equivalent to reducing or eliminating climate change, i.e., by reducing or eliminating GHG emissions. However, as Table 1 shows, this would accomplish little except in the case of coastal flooding, because it would leave untouched the major share of the total risk burden.

Reducing the cumulative burden

Another approach would be to lighten the total burden on the camel's back before it breaks. This is tantamount to reducing the cumulative environmental burden before global warming causes significant and irreparable damage. Consider malaria, for instance. Under the first approach, mitigation, one would, at most, eliminate the 0.26–0.32 billion increase in the PAR from malaria in the 2080s by eliminating climate change – which is impossible. By contrast, under the second approach, one would attempt to reduce the total PAR from malaria, whether it was 4.41 billion in 1990 or 9.14 billion in the 2080s. This approach has several advantages.

1. Even a small reduction in the baseline (or non-climate change- related) PAR could provide greater aggregate public-health benefits than would a large reduction in the relatively minor increase in PAR due to climate change. Assuming that annual cases and deaths due to malaria vary with the PAR, reducing the base rate for malaria by an additional 0.3% per year between 1990 and 2085 would compensate for any increases due to climate change.

2. Resources employed to reduce the base rate would provide substantial benefits to humanity decades before any significant benefits are realised from limiting climate change. Considering that 1 million Africans currently die from malaria every year, and that its death toll can be cut in half at a cost of between US$0.38 billion to US$1.25 billion,[20] humanity would be better served if such sums were spent now to reduce malaria in the near future, rather than on limiting climate change only to curb a relatively minor share of the potential in crease in malaria decades from now. Moreover, the benefits of reducing malaria in Africa today with the second approach are real and far more certain, and Africans would experience these benefits

decades sooner than any benefits resulting from eliminating climate change.

3 The technologies developed and public-health measures implemented to reduce the base rate would themselves serve to limit additional cases due to climate change when, and if, they occur.

4 Reducing the baseline rate would serve as an insurance policy against adverse impacts of climate change, whether that change is due to anthropogenic or natural causes or if the changes occur more rapidly than currently projected. In effect, by reducing the baseline today, one would also help solve the cumulative malaria problem of tomorrow, regardless of its cause.

5 Because of the inertia of the climate system, it is unrealistic to think that future climate change could be completely eliminated. Moreover, the Kyoto Protocol experience indicates that because of its socioeconomic impacts, even a freeze in emissions is likewise unrealistic, despite the inability of such a freeze to actually halt further climate change.

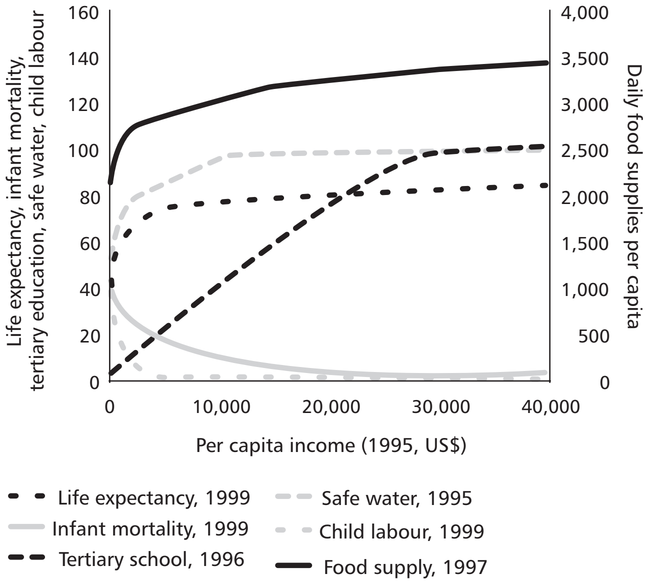
The logic of reducing the cumulative burden applies to other climate-sensitive problems and sectors where factors unrelated to climate change are expected to dominate for the next several decades. As Table 1 indicates, these problems and sectors include agriculture, food security, water, forests, ecosystems, and biodiversity.

Increasing resilience and reducing vulnerability

Yet another approach to dealing with the last straw is to strengthen the camel's ability to carry a heavier load. This calls for improving resilience and reducing vulnerability.

It is generally acknowledged that poorer countries have the greatest vulnerability to climate change, not because their climates are expected to change

Figure 1 **Human well-being vs economic development, 1990s**



Source: Goklany, 'Affluence, Technology and Well-being', *Case Western Reserve Law Review* 53: 369–390 (2002)

the most, but because they lack the resources to adapt adequately to any change. But their expected difficulty of coping with climate change is only one manifestation of a deeper overarching problem, namely poverty.

If we look around at the world today, we find that almost every indicator of human or environmental well-being improves with wealth (see Figure 1).[21] This is true whether or not the indicator is climate-sensitive.

Poorer countries have less food available per capita; they are hungrier and more malnourished; their air and water are more polluted; they have poorer access to education, sanitation and safe water; and they are more prone to death and disease from malaria and other infectious and parasitic diseases. Consequently, they have higher mortality rates and lower life expectancies.[22]

These populations are more vulnerable to any adversity because they are short on the fiscal and human-capital resources needed to create, acquire and use new and existing technologies to cope with that adversity. As a consequence, economic growth, by enhancing technological change, would make society more resilient and less vulnerable to adversity in general, and to climate change in particular.

Focusing on enhancing economic growth should be complemented by efforts to bolster the institutions that underpin society's ability and desire to develop, improve and utilise newer and cleaner technologies. These institutions include providing greater protections for property rights and contracts, enforcing the rule of law, providing honest and accountable government and bureaucracies, and supporting freer and open trade.[23]

Sharing the burden

Climate change might create regional winners and losers. In particular, it could redistribute agricultural production, with developing countries producing less and developed countries producing more.

That would aggravate the problem of hunger in the former. However, imbalances in production are not a new problem. Nor is a new solution needed. Currently, poor countries consume about 10% more grain than they produce.[24] Their future dependence on food imports might increase because their demand for food is expected to grow faster than their agricultural productivity. Such imbalances have traditionally been solved, by and large, through trade. Freer trade would work just as well in the future whether the imbalance is caused by climate change or another factor. In effect, trade is akin to helping solve the problem of the last straw by sharing the burden amongst more camels. However, developing countries would need the wherewithal to purchase food surpluses produced elsewhere. This is yet another reason for increasing economic growth, particularly in the non-food sectors of poor countries.[25]

Mitigation or adaptation?

The cost of the Kyoto Protocol to Annex B countries in 2010 is estimated at between 0.1% and 2.0% of their GDP.[26] Let us assume that their costs in 2010 would be 0.5% of GDP. In 2000, that would have amounted to $125 billion in 1995 US dollars.[27] Due to these expenditures, the benefits, currently at zero or less (see below), would rise over time. By the 2080s, net benefits would include a reduction of 18% in the PAR from coastal flooding, but for the other climate-sensitive risk categories listed in Table 1, the Protocol's benefits would be trivial compared to the baseline.

By contrast, the cost of stabilising GHG concentrations would be greater, but so would the benefits. Stabilisation at 450 ppm (parts per million), for instance, is estimated to cost a few trillion dollars between 1990 and 2100. However, despite the considerable costs, and regardless of which mitigation regime is imposed, the formidable baseline problems indicated in Table 1 would be virtually undiminished for all risk categories except coastal flooding. Moreover, one should expect that some residual impacts of global warming would persist.

Notably, some studies suggest that temperature increases of the order of 1–2°C might, in fact, result in net benefits for agricultural and timber production.[28] Consistent with these assessments, the IPCC report also suggests that a small (~1–2°C) increase might possibly be a net economic benefit to the world but an increase in excess of 2°C could be negative.[29] Therefore, the costs of any mitigation may have to be shouldered for several decades before one can be confident that they would create net benefits.

This problem is magnified because of the inertia of the climate system, which magnifies the lag time between when emission reductions are initiated, and when a noticeable effect on the impacts of global warming is observed. On the other hand, instead of mitigation-based approaches, we could employ a set of adaptation strategies based upon the principles outlined above for dealing with the last straw, and targeted to each of the risk categories in Table 1. These strategies would enhance adaptability and/or reduce vulnerability to both the impacts of warming and the other global changes included in the baseline. They would also have the added advantage that the benefits would be observed sooner after the costs were experienced. Examples follow.

- The global cost estimate for protecting against a 50 cm *sea level rise* in 2100 is about US$1 billion per year,[30] or less than 0.005% of the overall global economic product.[31] Compared to the Protocol and any other mitigation approach, this is orders of magnitude cheaper, and would also provide greater reductions in the PAR from *coastal flooding* into the 2080s and beyond.
- A 20% increase, for example, in global agricultural research funding, which in the mid-1990s stood at US$33 billion per year (including US$12 billion in developing countries)[32] ought to, over 95 years, more than erase the entire 4% reduction in *agricultural production* due to global warming (this would be substantially more than the trivial portion that the Protocol would restore).
- No less important, to the extent the additional research funding increases sustainable agricultural productivity beyond the quantity needed to replace the shortfall, it would reduce the human demand for land. Accordingly increasing agricultural productivity would not only reduce conversion of wild land to new cropland, but it could return existing cropland back to nature. Increasing agricultural productivity is the single most effective method of preventing habitat loss and fragmentation, and conserving *global forests*, terrestrial *biodiversity* and *carbon stocks and sinks*.[33]
- Similarly, the above increases in agricultural research, if targeted appropriately, would also help to increase the amount of food that can be produced by one unit of water. Since agriculture is responsible for 85% of the fresh water consumed globally, each 1% reduction in agricultural water consumption allows consumption for other sectors to increase by 5.7%. This would not only reduce the PAR from *water stress* but also would decrease pressures on *freshwater species*.
- Annual expenditures of between US$0.38 billion and US$1.25 billion could reduce the current death toll from *malaria*, about 1 million people per year according to the World Health Organization. This too would be far more effective in reducing death and disease from malaria than either full implementation of the Kyoto Protocol or even halting climate change altogether. As previously noted, methods developed to prevent or treat baseline malaria problems (that is, the problems in the absence of global warming) can be used to address similar problems resulting from climate change.

Thus, until the 2080s, the above set of adaptation measures would cumulatively cost much less, and deliver greater benefits, than either the Kyoto Protocol or other more ambitious mitigation schemes. Advocates of immediate GHG controls, however, might argue that regardless of the urgency of climate change during the next several decades, unless GHG emission reductions commence now those reductions may come too late to do any good. The reason, they claim, is the inertia of the climate and energy systems.

But as Table 1 indicates, even if 50 years are required to replace human energy systems from start to finish,[34] we could nevertheless wait an additional 25 years or more before initiating control actions to produce change beyond that which would be obtained automatically through continuous, long-term improvements in technologies.

Meanwhile, we could implement the strategies outlined above, which would deliver benefits for people living today, while enhancing our ability to address future problems that climate change may exacerbate or cause. These strategies could be complemented by developing more cost-effective mitigation and adaptation technologies that could be implemented when they are needed.

Assessments of present-day and future impacts of human-induced climate change indicate that it is not now, nor is it likely to be in the foreseeable future (i.e., into the 2080s), as significant as other environmental and public health problems facing the globe.

Nevertheless, global warming could be the proverbial straw that breaks the camel's back, particularly for natural ecosystems and biodiversity. But instead of merely focusing on lightening or eliminating the last straw – analogous to reducing or halting climate change – the camel's back may also be saved in other ways. Also, reducing or eliminating the last straw does little good if the camel's back bends or breaks in the meantime.

Instead of concentrating on the last straw to reduce the cumulative burden of possible problems, we should reduce today's urgent public health and environmental threats (such as malaria, water stress, hunger and habitat loss) that might be exacerbated by climate change. As we have seen, this would provide greater, more cost-effective and quicker benefits to both humanity and the rest of nature. We should also strengthen the camel's back so that it can withstand a heavier load, regardless of how or why the load was generated. The basic reasons as to why some societies are less resilient and more vulnerable to climate change are precisely the same reasons why they are also less resilient and more vulnerable to adversity in general, namely, they have insufficient economic development and a lower propensity towards technological change.

Not surprisingly, poorer countries with less ability to develop, afford and use new technologies have higher rates of hunger; poorer public health services; greater incidence of infectious and parasitic diseases; less access to education, safe water or sanitation; and, therefore, greater mortality rates and lower life expectancies.

Accordingly, we should strengthen the institutions that drive both economic growth and technological change. Not coincidentally, many of these institutions nurture and foster each other. This approach would enhance societies' abilities to cope not only with climate change, but adversity in general, regardless of its cause, or whether it is man-made or not.

Thirdly, we should make it possible to share the burden among numerous camels. Since climate change would create regional winners and losers, the burden could be spread more evenly through trade. Thus shortfalls in agricultural production induced by climate change in some countries could be addressed through trade with others that would experience gains in agricultural production. Trade, moreover, has the added benefits of stimulating both economic growth and technological change. It particular, it allows societies everywhere to gain from innovations and inventions made elsewhere in the world, without having to reinvent wheels.

Policies based on these alternative approaches, all of which rely on improving adaptability and reducing vulnerability, are superior to the single-minded pursuit of reductions in climate change, at least into the foreseeable future. Into the 2080s, they would provide greater benefits, far sooner and far more economically than would be achieved by efforts which focus on mitigation.

Indeed, by reducing vulnerability and increasing adaptability, we might – consistent with the stated ultimate goal of the UN Framework Convention on

Climate Change – raise the level at which GHG concentrations might need to be stabilised to avoid dangers to humanity and nature, which would further reduce the costs of addressing climate change.[35]

Despite the inertia inherent in both the climate and energy systems, we have at least two to three decades before we need to embark on socially and economically costly efforts to reduce GHG emissions that would go beyond 'no-regrets' actions.[36]

In the interim, we should focus on: (a) solving today's urgent problems while creating the means to address future potential problems due to climate change; (b) improving our understanding of the impacts of climate change so that we can distinguish between the possible and the probable; (c) increasing information regarding the trade-offs and synergies between adaptation and mitigation; (d) reducing barriers to implementing no-regret technologies, whether they are related to mitigation or adaptation (such as eliminating needless subsidies for energy and natural resource uses); and (e) undertaking efforts to expand the portfolio of no-regret actions through greater R&D into more cost-effective mitigation and adaptation technologies.

Such a multifaceted and holistic approach would help solve today's problems to improve the lives of people living today, without compromising our ability to address future challenges, whether caused by human-induced climate change, another agent of global change, or something else entirely.

Section 3

Sea level change: Are low-lying islands and coastal areas under threat?

Nils Axel-Mörner, Stockholm University

> *'Rising sea levels spell disaster for [the Maldives]… "It will be the death of a nation", says the Maldivian President, Maumoon Abdul Gayoom.'*[1]

> *'Rising sea levels could be a further problem: The governments of small island nations, such as the Maldives in the Indian Ocean and Kiribati and Tuvalu in the Pacific have been calling for international action to slow climate change. Their nations are based entirely on coral atolls no more than two meters above sea level; therefore, rising water levels could have serious impacts.'*[2]

As these quotations demonstrate, the prospect of sea level change has frequently been discussed as an outcome of climate change. Sea level rise is often implicated as the cause of coastal erosion. But the reality is much more complicated.

This section presents an analysis of claims made concerning sea level rise, both in general and specifically with regard to one major low-lying area – the Maldives – which has been used as a paradigmatic case by those who claim that dramatic sea-level rise is occurring.

Numerous factors control the stability of the shoreline

Coastal dynamics
- Erosion
- Silting up
- Sediment transport
- Continental runoff
- Air pressure changes
- Long term trends
- Storms, hurricanes, tsunamis

Changes in land level
- Compaction
- Geoid deformation
- Seismotectonics
- Hydro-isostasy
- Glacial-isostasy

Changes in sea level
- Sterics effects (temperature, salinity)
- Basin volume changes (long term tectonics, glacial rebound)
- Geoid deformation
- Glacial eustasy

Historical sea level changes

The recording and understanding of past changes in sea level, and its relation to other changes (climate, glacial volume, gravity potential variations, rotational changes, ocean current variability, evaporation/precipitation changes, etc.) is the key to sound estimates of future changes in sea level.

After the last Ice Age, the earth experienced a general rise in sea level – a response to the melting of continental ice caps. In the last 5000 years, global mean sea level has been dominated by the redistribution of water masses over the globe. In the last 300 years, sea level oscillated close to the present level, with peak rates in the period 1890–1930.

Table 1 **Recent, present and possible future changes in sea level as recorded or calculated from different observational records**

Time period	*Rates (mm/yr)*	*Source of information*	*Reference*
1682–1940	1.1	mean of tide gauges	1
1860–1960	1.2	mean of tide gauges	2
1830–1930	1.1	NW Europe tide guage data	3
1830–1930	1.1	past uplift vs. present uplift and eustasy	3
1830–1930	max. 1.1	Earth's rotation vs. tide guage	4
Last 100 years	1	UK–North Sea tide guages	5
Last 100 years	1.1	Fennoscandian tide guages	6
1910–1990	0.9	estimates of all water sources	7
1992–1996	0	Satellite altimetry	8
1997–1998	ENSO*	Satellite altimetry	8
1999–2000	< 0.5	Satellite altimetry	8

References: (1) Gutenberg (1941), (2) Fairbridge and Krebs (1962), (3) Morner (1973), (4) Morner (1992), (5) Shennan and Woodworth (1992), (6) Lambeck et al. (1998), (7) IPCC (2001) (TAR-3), (8) Fig. 2.
*El Niño/Southern Oscillation

However, Peltier and Tushinghan (1989) claimed that the global average rise in sea level is currently 2.4 mm/year. If realistic, this rate would imply a complete reversal of observational records. It suggests, for example, that sea levels in the North Sea region and the Dutch coasts – known for their long-term subsidence – would be rising at a rate of about 1.2 mm/year. However, Mörner (1992) showed that the global rise is unlikely to exceed 1.1 mm/year.

Observational records indicate that mean global rise in sea level for the period 1850–1930 was in the order of 1.0–1.1 mm/year (see Table 1). After 1930–1940, this rise seems to have stopped,[3] at least until the mid-1960s. During the 1970s and 1980s, the data are not clear enough for a proper evaluation of any general trend in sea level.

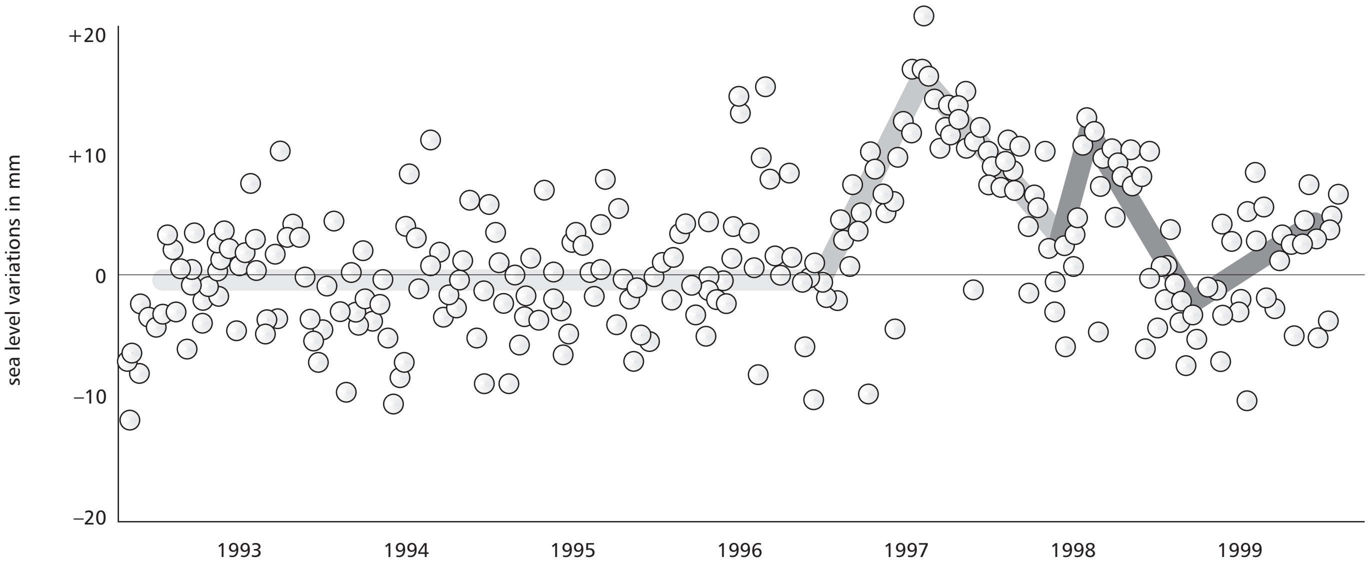
The first satellite altimetry recording (Geosat) were taken during 1986–1988. These measurements do not demonstrate a recognisable trend, but at the same time their technical precision was not sufficiently accurate.

With the TOPEX/POSEIDON mission, the situation changed. We now have a very good cover of the global mean sea level changes over the areas covered by satellite. These measurements indicate practically no changes in the last decade.

The record – displayed in Figure 1 – can be divided into three parts: (1) 1993–1996 with a clear trend of total stability (and noise of ±0.5 cm), (2) 1997–1998 with a high-amplitude rise and fall recording the ENSO event of these years and (3) 1998–2000 with an irregular record of no clear tendency (but possibly with a small rise of < 0.5 cm/year in years 1999–2000).[4] But most important, there is a total absence of any recent "acceleration in sea level rise" as often claimed by the Intergovernmental Panel on Climate Change and related groups.

The IPCC (2001) made an estimate of all variables and their possible contribution to sea level rise. They

Figure 1 **Sea level changes in mm as recorded by TOPEX/POSEIDON between October 1992 and April 2000: raw data before any filtering or sliding mean average[4]**



arrived at a mean value of 0.9 mm/year. This value coincides with the records of the present and near past presented in Table 1.

The mean value 0.9 mm/year is close to the truly observed value of 1.0–1.1mm/year for 1850–1930 and consequently is quite reasonable. Remarkably, the IPCC discarded their own estimate, replacing this observational value with a model value of 1.8 mm/year (cf. above).

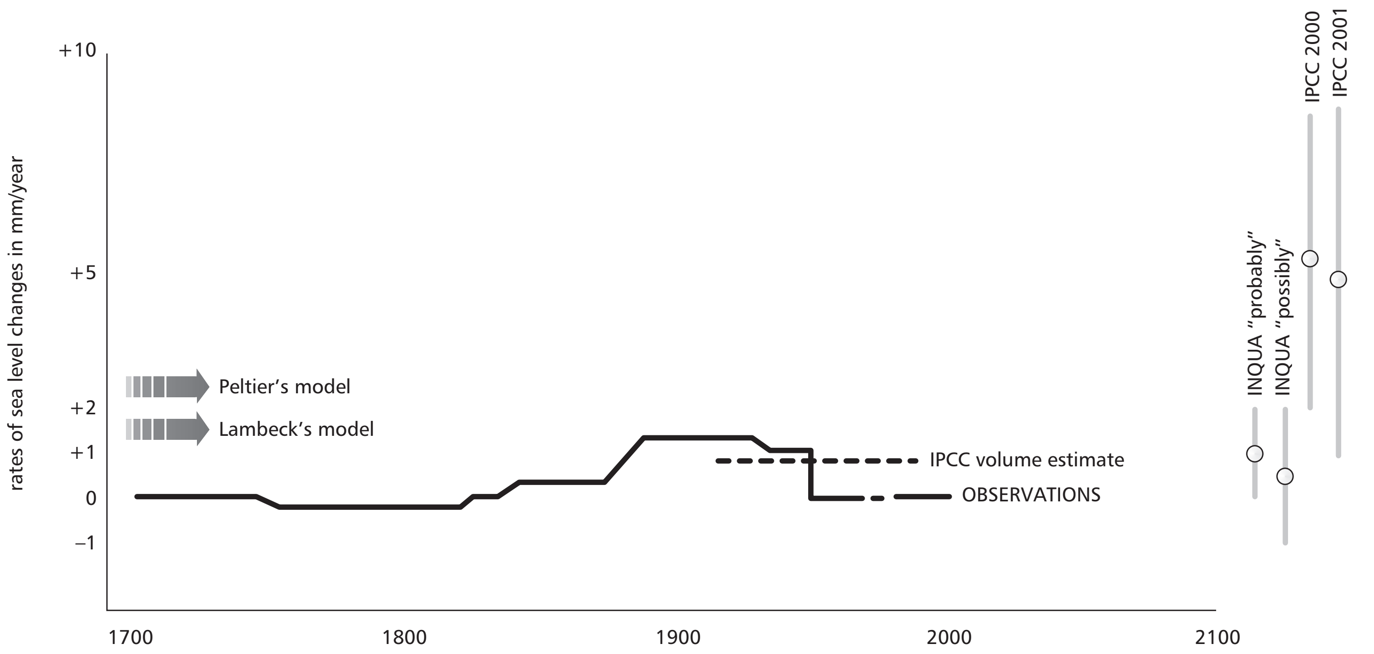
Figure 2 shows a summary of available data for the last 300 years: the 0.9 mm/year volume-estimate (discarded by the IPCC as "unrealistic"), the long-term trends as given by the geophysical models of Peltier and Lambeck (2.4 and 1.8 mm/year), and, to the right, the future estimated by the INQUA Commission on Sea Level Changes and Coastal Evolution (INQUA, 2000) and the scenario output values of IPCC (2001).

The scenarios for 2100 produced by the INQUA Commission on Sea Level Changes and Coastal Evolution and by the International Geoscience Programme (IGCP) are observation-based estimates of expected future changes. They yield a completely different evaluation for possible-to-probable future sea level changes by considering all available data, making qualified estimates, and regional and global syntheses. The output of this analysis is a likely future sea level rise in the order of 10 cm, with a maximum of 20 cm, in the next century.[5]

These observation-based estimates are in stark contrast to model-based 'global' trends and the IPCC's scenario-based predictions – which yield estimates for sea level change which are far above those obtained with observational data.

By discarding the IPCC's model outputs as well as global loading models, in favour of observation-based predictions of sea level, we see that sea level in the year 2100 will be + 10 ± 10 cm (or +5±15 cm). This implies that our fears are unjustified: we have no reason to believe, as suggested by most global warming scenarios, that massive flooding will occur due to an increase in sea levels.

Figure 2 **Rates of sea level changes from 1700 to 2100 AD as given by (1) observed records (solid line), (2) volume estimates by IPCC (dashed line) and (3) predictions (vertical bars) by INQUA and IPCC, respectively (arrows to the right refer to loading model outputs)**



Case study: Will the Maldives be inundated? What about Tuvalu?

The Maldives

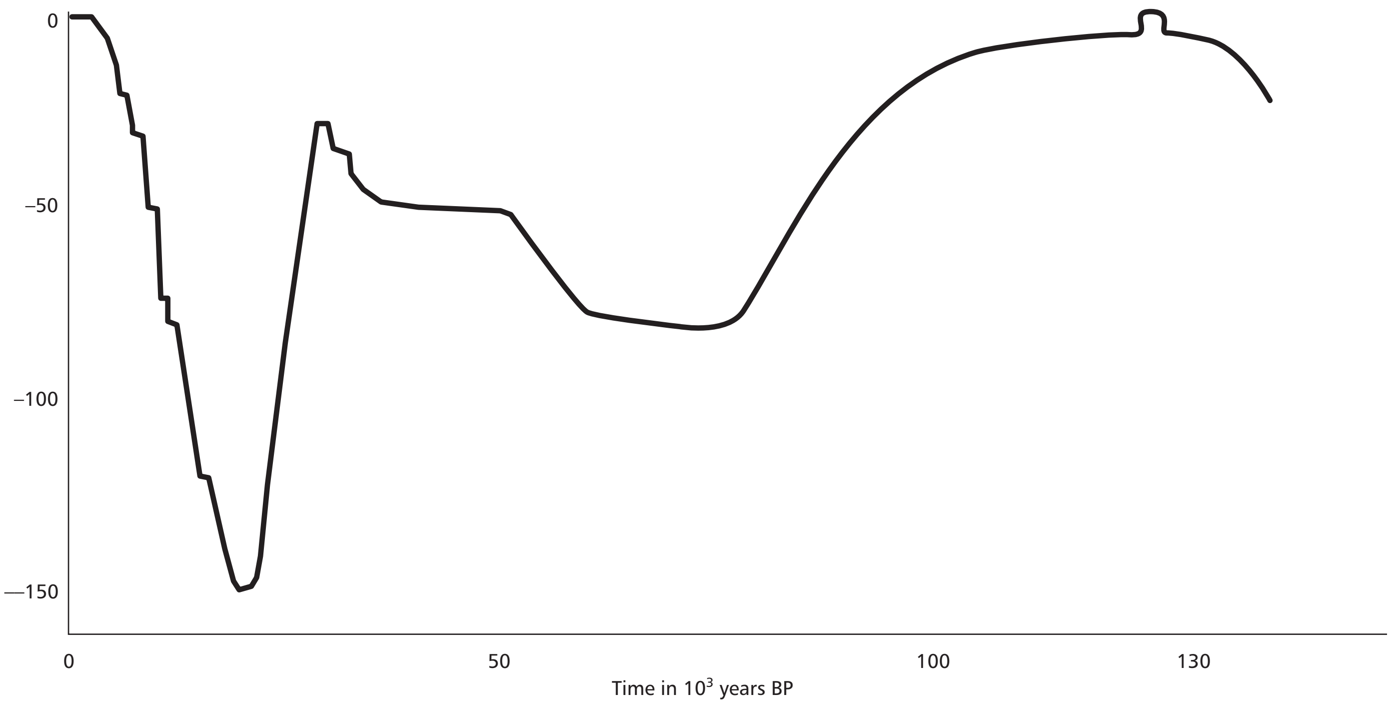
The Maldives in the central Indian Ocean consist of some 1200 individual islands grouped in about 20 larger atolls. They rise as steep pinnacles from a depth of about 2500 m[6] and consist of coral reefs, coral reef debris and coral sand. Their elevation is only of the order of 1–2 m. Hence, they have been portrayed as an area which will be extremely vulnerable to flooding in the near future, possibly within 50–100 years.[7] One NASA website suggests 'Even a moderate rise in sea level could threaten the coastlines of low-lying islands such as the Maldives.'[8] At 1000–800 BP, the people of the Maldives survived a higher sea level by about 50–60 cm.

The first studies of the Maldives are nearly a century old.[9] More recently, Woodroffe (1992) presented the first sea level curve for the Maldives. He claimed that the islands were predominantly formed by catch-up coral reef growth. In contrast to this, Anderson (1998) recorded the last glaciation maximum (LGM) sea level at several places, indicating that much of the Maldives existed as land during this sea level low-stand.

In 1999, the INQUA Commission on Sea Level Changes and Coastal Evolution initiated a special research project in order to decipher the history of the Maldives, record the past sea level changes and understand the present-to-future prospect of the islands.[10]

In this study of the coastal dynamics and the geomorphology of the shores, INQUA was unable to detect any traces of a recent sea level rise. On the contrary, we found quite clear morphological indications of a recent fall in sea level. Our information was obtained from numerous islands in the Baa–Raa–Guidhoo Atolls, from Viligili island in the North Male Atoll, from Lhosfushi–Garaidhoo–

Figure 3 **Maldives sea level changes in the past 130,000 years**



Kodoomaafushi islands in the South Male Atoll, and from Hithadhoo island in the Addo Atoll.

Many islands are affected by erosion. Erosion may be caused by sea level rise, sea level declines, change in wind direction and change in wind intensity. Hence, erosion itself is not a measure of sea level rise (as often claimed). The level of re-deposition of the sand and shingle set in motion by erosion is a much better indication of actual sea level changes – it will move over former land if the sea level is rising, and add lower levels seawards if the sea level is falling.

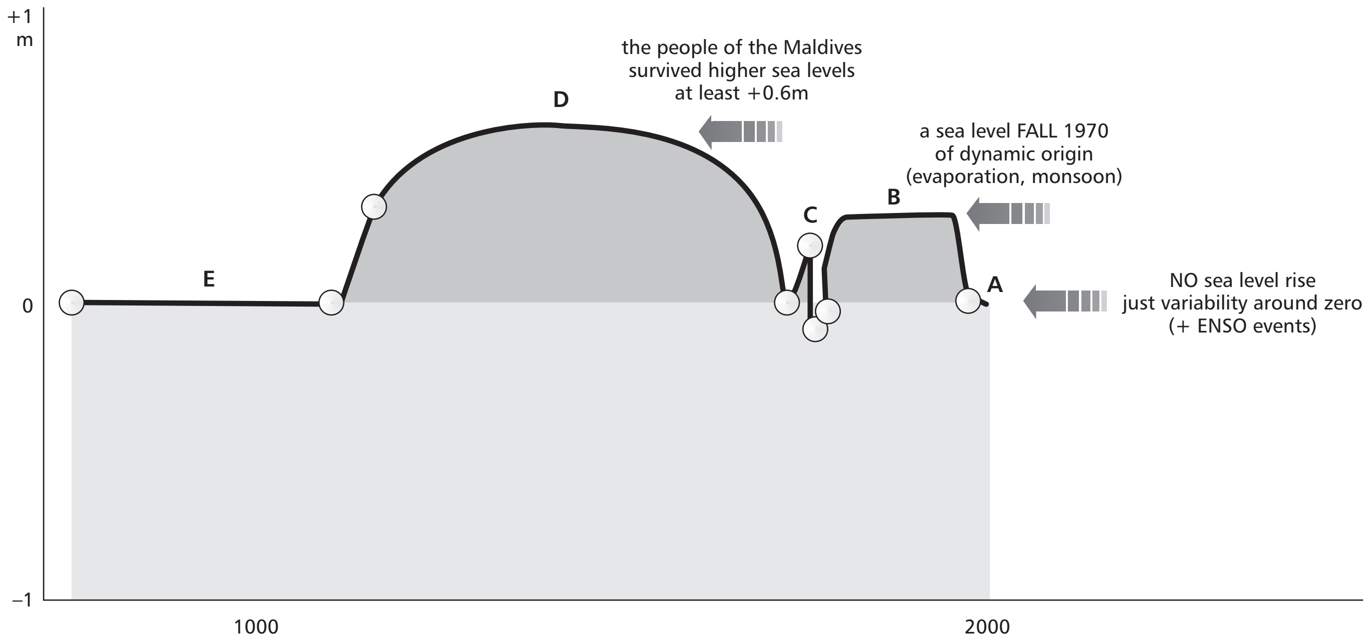
Of course, erosion may also be caused by human interference with the coastal dynamics and sediment supply. In the Maldives there are many examples of severe erosion due to the construction of causeways between islands, dredging, harbour works and sea defences. In most cases, however, those effects are easily understood in terms of actual human coastal activity.

Tide gauge data have been cited in support of an ongoing rise of mean sea level.[11] Tide gauge records, however, do not provide simple and straight-forward measures of regional eustatic sea level. They are often (and usually) dominated by the effects of local compaction and local loading subsidence. With this perspective, multiple morphological and sedimentological records appear more reliable and conclusive. Satellite altimetry observations support these conclusions, as they do not record any significant rise in global sea level in the last decades.[12]

In order fully to investigate the situation, however, available tide gauge records, now extending from 1990 to 2002, were re-examined. This too reveals a total absence of any rising secular trend.[13]

In the Maldives region, a general decline in sea level – about 20 to 30 cm – occurred some 30 years ago. Both the rate of decline (>10 mm/year) and the amplitude of the decline (20 to 30 cm) are much higher than expected.

Figure 4 **Sea level curve of the Maldives (past 1,250 years)**



The origin of this decline in sea level is likely to be an increased evaporation over the central Indian Ocean linked to an intensification of the NE-monsoon. In this region, eustatic sea level lies well below the geoid surface because of an exceptionally high rate of evaporation.[14] If this evaporation increases further, sea level will fall regionally.

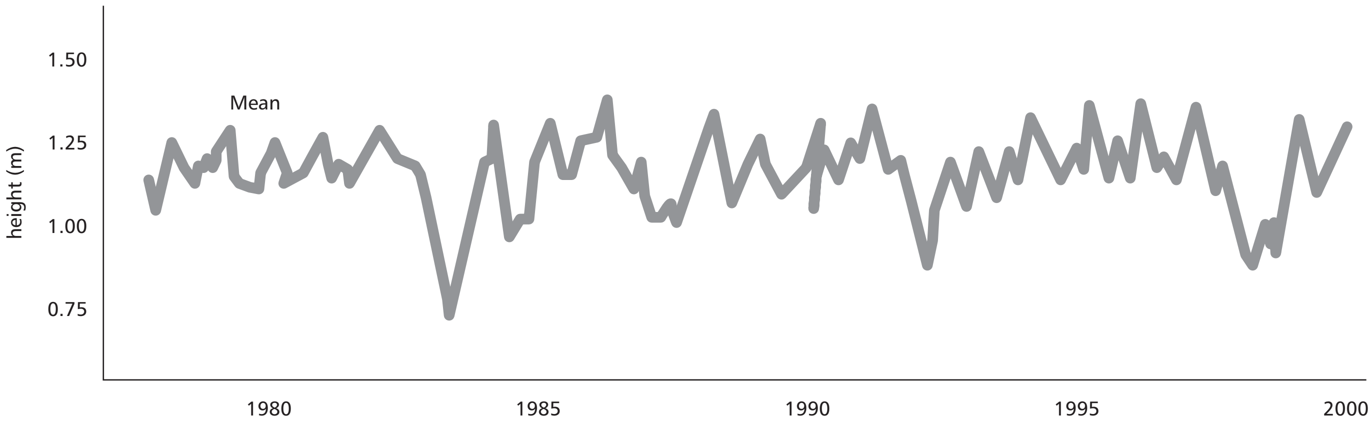
INQUA proposed that the sea level regression recorded in our observational data is the effect of increased evaporation. This fits with an increase of the NE-monsoon in the last decades as recorded in so many islands; not least in Addu Atoll. It seems significant that Pfeiffer *et al*. (2001) recorded a marked environmental change at about 1970 in the stable isotopes of corals from the Chagos Islands (south of the Maldives). They interpreted this in terms of decreased precipitation linked to the monsoonal circulation.

This explanation is duplicated from island to island, measured by different means. We also listened to what the local people had to say, which always produced the same results: sea level is not rising, and it fell in the 1970s.

Our findings reveal that there is no reality behind the scenario of a future flooding. The sea level has not been rising in the Maldives in the last centuries and at around 1970 it even experienced a significant decline. The models of IPCC are simply over-ruled by the theory and observation by sea level specialists within INQUA.

We should all be happy about this, one would assume. For the people of the Maldives it is a great relief not to live under a constant threat that all will be gone in one or two generations. Field observations – not absurd models which do not reflect those observations – are the basis by which scientists record the true story.

Figure 5 **Monthly sea levels at Tuvalu**



no traces of any long-term rise in sea level

Sadly, this is not the case. The government of the Maldives has invested much effort in the fear of a future flooding, accusing wealthier countries of having caused this situation and demanding that they pay for it. The government fears that if flooding scenarios are called off, it will lose the possibility of gaining foreign aid attached to this particular problem.

Tuvalu

The island of Tuvalu in the Pacific is well-known for its threat to sue the United States as the culprit of its on-going 'flooding'. However, tide guage records for the past 25 years (featured in Figure 5) illustrates that there is no rising trend – there is only variability around a zero level and some ENSO events (the lows).

Conclusion

Observations both globally and locally, in two low-lying areas, show that sea-level is not rising rapidly. These results contradict the claims made by many, including the IPCC, and suggest that future changes in sea level will be moderate, even with a rise in global mean temperature of 2°C or so. The proportion of the world covered in water will not rise any time soon.

Section 4

Would malaria spread to Europe in a warmer climate?

Paul Reiter, Director, Insects and Infectious Disease Unit, Pasteur Institute, Paris

Human health – and mosquito-borne disease in particular – is a prominent topic in the debate about climate change.[1] Claims have been made that malaria and dengue are moving to temperate zones, and moving to higher altitudes, because of human-induced global warming.

In 1995, the Intergovernmental Panel on Climate Change (IPCC) confidently forecast that malaria and other mosquito-borne diseases would move from the tropics into temperate regions.[2] Similarly, in 1997, the Environmental Protection Agency (EPA) of the United States stated that in the 21st century there would be "an increase from approximately 45 percent to 60 percent in the proportion of the world's population living within the potential zone for malaria transmission." In their estimate, this could result in 50–80 million additional cases annually.[3] Several other publications included maps that showed the future range of the disease extending into southern Europe.

Intuitive assumptions and predictions of the "spread" of malaria from the tropics into temperate regions still persist. Thus, in its *Third Assessment Report*, the IPCC repeated the assertion that "the geographic range of malaria is limited to the tropics and subtropics"[4], and the EPA continues to state:

> *global warming may also increase the risk of … infectious diseases … that only appear in warm areas. Diseases such as malaria could become more prevalent if warmer temperatures enabled (mosquitoes) to become established farther north.*[5]

Environmental activists quote these official statements and add warnings that are even more graphic. For example, the WWF quotes the IPCC, followed by a statement that "malaria generally extends only to places where the minimum winter temperatures reach no lower than 16°C." They even assert that "small outbreaks now occurring north and south of tropical regions are consistent with model projections" and support this with claims of local transmission of malaria in the United States and Canada "during particularly hot, humid periods."[6] In truth, malaria is limited by minimum *summer* temperatures of 16–18°C and the outbreaks they refer to are all associated with imported cases and occurred in regions where malaria was once common.

The discussion contained here is limited to malaria, specifically in Europe, but similar concepts apply to the disease in other parts of the world.

Change is a fundamental feature of climate

Climate is commonly understood to mean the "average weather" in a given region or zone. This definition is unsatisfactory, as it implies that unlike the obvious year-to-year variations of daily weather, long-term climate is a constant. Modern climatology recognizes that change is an inherent and fundamental feature of climate.[7] Just as the yearly averages of climatic elements – e.g. temperature, humidity, rainfall, wind and airborne particles – differ from one another, so too do the averages for decades, centuries, millennia, and millions of years.

Therefore, climatic values cannot be referred to without specifying the time span to which they refer.

Climate is a major parameter in all ecosystems, and has always been a fundamental factor in human settlement, economy and culture. For nearly three centuries the earth's climate has been in warming phase, punctuated by several periods of cooling. This was preceded by a particularly cold period, the Little Ice Age, which was itself preceded by a several centuries known as the Medieval Warm Period or Little Climatic Optimum. Such changes are entirely natural, but it is widely held that, in recent years, a portion of the current warming may be attributable to human activities, particularly the burning of fossil fuels.[8]

Climate and mosquito-borne disease

In nearly all mosquito species, the female obtains the protein she needs for the development of her eggs by feeding on vertebrate blood. A complex salivary secretion facilitates feeding. It is the direct injection of this fluid into the host's tissues that enables several life forms – viruses, protozoa and nematode worms – to exploit mosquitoes as a means of transfer between vertebrates. They do this by infecting the mosquito after they have been ingested in a blood meal, and eventually multiplying in the salivary glands, from which they can be inoculated into a new host during a later blood meal. The majority of such organisms do not appear to affect either the mosquitoes or their vertebrate hosts, but a small number are pathogens of important human and animal diseases.

The ecology, development, behavior and survival of mosquitoes, and the transmission dynamics of the diseases they transmit, are strongly influenced by climatic factors. Temperature, rainfall and humidity are especially important, but others, such as wind and the duration of daylight, can also be significant. The same factors also play a crucial role in the survival and transmission rate of mosquito-borne pathogens.

In particular, temperature affects the pathogens' rate of multiplication in the insect. In turn, this affects the rate at which the salivary secretions become infected, and thus the likelihood of successful transmission to another host. Of course, if the development time of the pathogen exceeds the life span of the insect, transmission cannot occur. The complex interplay of all these factors determines the overall affect of climate on the local prevalence of mosquito-borne diseases[9].

Seasonality is a key component of climate. Summer temperatures in many temperate regions are at least as high as in the warmest seasons of much of the tropics. The crucial difference is that the tropics do not have cold winters. If tropical mosquito-borne pathogens are introduced to temperate regions in the right season they can be transmitted if suitable vectors are present; in most cases they are eliminated when winter sets in.

Mosquitoes native to temperate regions have evolved strategies to survive the winter, as have the pathogens that they transmit. In the tropics, comparable adaptations are necessary for surviving in unfavorable dry periods, which can last for several years. In both cases, such adaptations impose a seasonality on transmission. For example, before eradication, the transmission season for *P. falciparum* in Italy was July to September.[10] The same three months constitute the malaria season in Mali, where the disease is still endemic.[11]

Disease models

Much of the speculation on the possible impacts of climate change on mosquito-borne disease is derived from rudimentary mathematical models of transmission dynamics.[12] However, these models have a limited value for assessing the impact of long-term climate change on disease transmission.[13] They cannot predict the presence or absence of the disease, nor its prevalence in any situation, because they do not account for the parasite-rate in humans or mosquitoes, nor any of the many ecological and behavioral factors that affect the interaction of mosquitoes and humans. For example, human behavior and cultural traits can be crucial to the transmission of the parasite. Daily activity patterns – work, rest and recreation – the location of homes in relation to mosquito breeding sites, the design of buildings, the materials used to build them, the use of screens and bed-nets, the presence of cattle as alternate hosts for the mosquitoes, and many other factors are all highly significant.

Malaria in Europe

The history of mosquito-borne diseases at different latitudes and in different climatic eras can help us to assess how climate variables relate to many other factors that affect transmission.

The introduction of agriculture in Europe led to increased populations of settled people, and increasingly favorable conditions for malaria transmission.[14] Extensive deforestation may also have contributed to prevalence, by creating additional habitat for malaria-carrying mosquitoes. Many literary references from that era, such as Homer's Iliad include references to killing fevers at harvest time.[15] We cannot be certain that this was malaria, but later texts confirm that the disease was a significant feature in Greek life. Indeed, there is evidence that a major wave of malaria began with the flowering of Greek civilization and transmission rates continued its increase throughout the period of the Roman Empire.[16]

Hippocrates (460–377 BC) gave exquisitely detailed descriptions of the course and relative severity of tertian vs. quartan infections.[17] He also noted their association with wetlands, and even observed that enlarged spleen, often a symptom of chronic malaria infection) was particularly prevalent in people living in marshy areas.

There is a wealth of evidence that malaria was common in imperial Rome.[18] Horace, Lucretius, Martial and Tacitus were among many Latin authors who mentioned the disease. The Pontine Marshes, close to the city, were notorious as a source of infection. The detailed writings of Galen and Celsus on the symptoms and treatment of 'intermittent fevers' give clear evidence that three species of parasite – *P. falciparum, P. ovale* and *P. vivax* – were commonly present.[19]

Though relatively little is known of climate during the 'Dark Ages', there seems to have been a cooling trend from the 5th century onwards, with some severely cold winters. Malaria continued to affect Europeans, including the armies of Visigoths, Vandals, Ostrogoths and other 'barbarians' that swept the continent. Several popes and churchmen, including St Augustine, the first Archbishop of Canterbury, died of malaria during their journeys to Rome. Around the turn of the millennium, the armies of Otto the Great, Otto II and Henry II suffered severely from the 'Roman Fever' during their sieges of the Holy City.

The Medieval Warm Period reached its peak in the 13th century, coinciding with major advances in technology and agriculture, and a significant population increase in Europe. The explosion of economies and culture that occurred during this warming period has been attributed, at least in part, to the beneficial impact of the warming climate. At the same time, from caliphate Spain to Christian Russia, numerous medieval writers, including Dante and Chaucer, mentioned 'agues', 'intermittent fevers' 'tertians', 'quartans' and the like.[20]

In the early decades of the 15th century, Europe experienced a cooling trend culminating in a series of severely cold winters.[21] Much of the earlier agricultural expansion was reversed. There were many years of famine, and a large-scale abandonment of farms. Despite this cooling, malaria persisted, even in northern regions.[22]

The first half of the 16th century was warm again. Temperatures were probably quite similar to those of the period 1900 to 1950. However, after a decade or so of particularly warm years, warm enough for young people to bathe in the Rhine in January, the winter of 1564–65 was bitterly cold[23]. The next 150–200 years, dubbed the 'Little Ice Age', were probably the coldest era of any time since the end of the last major ice age some 10,000 years ago[24] . Despite this spectacular cooling, malaria persisted throughout Europe.[25] In England, hardly known for its tropical climate even today, the 'ague' was familiar to many physicians and writers of the period – William Shakespeare (1564 – 1616) mentioned it several of his plays.

Temperatures were probably at their lowest in the period 1670 to 1700, yet it was during this period that Robert Talbor (c.1642 – 1681) persuaded the aristocracy of England and Europe to buy prescriptions for curing malaria (based on cinchona bark) that he had developed in the marshlands of Essex[26]. Data from burial records show mortality rates in "marsh parishes" were much higher than those in upland areas, and were comparable to those in areas of stable malaria transmission in sub-Saharan Africa today.[27]

During the Little Ice Age, there was a marked variability of temperatures, and this variability continued well into the 19th century. In the 1770s, much as is happening today, there was alarm that the climate was becoming increasingly erratic, and this prompted a new emphasis on the recording of weather variables. Some of the cold periods, particularly those between 1752 and the 1840s, were probably due to major volcanic eruptions. Whatever their causation, such episodes – accompanied by major advances of the Alpine glaciers from 1820 to 1850 – persisted until a more lasting warmth was established in the late 19th century.[28]

Nevertheless, numerous records from the 18th and 19th centuries give evidence of persistent malaria transmission. In the British Isles, the disease was common in most of England and in many parts of Scotland, with occasional transmission as far north as Inverness. It was endemic throughout Denmark, coastal areas of southern Norway, and much of southern Sweden[29] and Finland.[30] In Russia it was common in the Baltic provinces and eastward at similar latitudes throughout Siberia. The current average January temperature in some of these regions is less than -20°C (-4° F). Clearly, the distribution of the disease was determined by the warmth of the summers, not the coldness of the winters. Indeed, the northern limit of transmission[31] was roughly defined by the present 15°C July isotherm – not the 15°C *winter* isotherm, as stated in several widely-cited articles on climate change.[32]

After the mid-19th century, malaria began to decline in much of northern Europe. Denmark suffered devastating epidemics until the 1860s, but thereafter transmission diminished and essentially disappeared around 1900.[33] The picture was similar in Sweden, although isolated cases were still being reported until 1939.[34] In England, there was a gradual decrease in transmission until the 1880s, after which it diminished rapidly and became relatively rare except during a short period following World War I.[35] In Germany, transmission also declined after the 1880s; after World War I it was mainly confined to a few marshy localities.[36] The last outbreak of locally transmitted malaria in Paris was in 1865 during the construction of the Grandes Boulevards, and the disease largely disappeared from the rest of France by 1900[37]. In Switzerland, the majority of foci disappeared by the 1890s.[38]

The decline of malaria in all these countries cannot be attributed to climate change, for it occurred during a warming phase, when temperatures were already much higher than in the Little Ice Age. However, a host of other factors can be identified:

- Ecology of the landscape: In much of Europe, improved drainage, reclamation of swampy land for cultivation and the adoption of new farming methods served to eliminate mosquito habitat.
- New farm crops: New root crops, such as turnips and mangel-wurzels were adopted as winter fodder, enabling farmers to maintain larger numbers of animals throughout the year, thus diverting mosquitoes from feeding on humans.
- New rearing practices: Selective breeding of cattle, and new introductions (e.g. the Chinese domestic pig), in combination with the new fodder crops, enabled farmers to keep large populations of stock in farm buildings rather than in open fields and woodland. These buildings provided attractive sites for adult mosquitoes to rest and feed, diverting them from human habitation.
- Mechanization: Rural populations declined as manual labor was replaced by machinery. This further reduced the availability of humans versus animals as hosts for the mosquitoes, and of humans as hosts for the parasite.
- Human living conditions: New building materials and improvements in construction methods made houses more mosquito-proof, especially in winter, reducing human contact with the vector.
- Medical care: Greater access to medical care, and wider use of quinine reduced the survival rate of the malaria parasite in its human host.

Much of the decline in malaria came before recognition of the role of mosquitoes in its transmission. Thus, for most of the region, deliberate mosquito control played little or no role in its eventual elimination. In contrast, in countries where profound changes in crop production and stock rearing were absent, malaria did not decline.

In Russia, from the Black Sea to Siberia, major epidemics occurred throughout the 19th century, and the disease remained one of the principal public health problems for the entire first half of the 20th century. Annual incidence in military garrisons was 6.6 per 1,000 in St Petersburg, 31.0 per 1,000 in Moscow, and several hundred per 1,000 in the more southerly provinces. Mean annual incidence from 1900 to 1904 was 3,285,820, but by the period 1933 to 1937, it had risen to 7,567,348. Some of this increase can be attributed to more effective reporting, but there is no doubt that the disease became much more prevalent after the Bolshevik Revolution and the civil war that followed. Indeed, in the wake of massive social and economic disruption, two years of severe drought, and a year of widespread flooding, a pandemic swept through the entire Soviet Union.[39] Official figures for 1923–25 listed 16.5 million cases, of which not less than 600,000 were fatal. Tens of thousands of infections, many caused by *P. falciparum*, occurred as far north as the Arctic seaport of Archangel (61° 30′N).

The Soviet government appeared to make some headway against the disease in the 1930s, with drainage schemes, afforestation, and naturalistic methods such as the use of mosquito-eating fish. World War II interrupted these efforts, and transmission soared, particularly in the Ukraine, Byelorussia and other occupied areas. Finally, in 1951, a huge multi-faceted anti-malaria campaign was initiated in Russia, involving widespread use of DDT and other residual insecticides, antimalarial therapy, land reclamation, water management, public health education and many other approaches. This mammoth effort finally brought about a dramatic reduction of transmission, so that by the mid-1950s the national annual incidence was below 1 per 10,000.[40]

The contrast between the devastation caused by malaria in the Soviet Union until the 1950s, and its quiet withdrawal from other countries at similar latitudes in the previous century is a lucid illustration of the importance of non-climatic factors in transmission. In other parts of Europe, particularly the Mediterranean region, malaria was stubbornly persistent in economically backward areas.

The advent of DDT revolutionized the situation[41], for it enabled cheap, safe, effective treatments to be targeted at the site where most infections occur – in the home. Spectacular results in southern Italy, Cyprus and Greece led to a pan-European decision to eradicate the disease from the continent. A massive campaign, orchestrated by several international agencies, particularly the World Health Organization (WHO) and the United Nations Childrens Fund, as well as numerous national bodies including the U.S. Public Health Service, and the International Health Division of the Rockefeller Foundation provided generous financial and technical support. By 1961, eradication had already been achieved in many countries, and the entire continent was finally declared free of endemic malaria in 1975. One of the last countries affected was The Netherlands.

Could malaria return to Europe?

In much of Europe, changes in lifestyles and living conditions were the most important factor in the elimination of malaria. Even in countries where these factors were less dominant, eradication of the disease did not require total elimination of the vector. Residual treatments were effective because they reduced the life span of the adult insect, reducing the probability of transmission and eventually leading to the elimination of the parasite. Thus, the malaria-carrying mosquitoes are still present in the brackish waters of England, the rice fields of Italy, the ponds of Poland, the forest pools of Finland, and the riverine swamps of Russia.

Advances in agriculture and improvements in living standards have limited the mosquito populations and reduced their contact with humans in many regions, but this is not always the case. For example, recent surveys show that in large areas of Italy, *Anopheles* mosquito populations have returned to levels not seen since before the DDT era. The infestations are comparable to those in areas of Africa that have extremely high transmission rates. Nevertheless, the malariogenic potential of Italy is considered to be very low, and re-establishment of malaria is judged unlikely unless living standards deteriorate drastically.[42] Moreover, if the present warming trend continues, human strategies to avoid these temperatures – particularly indoor living and air conditioning – are likely to become more widespread.

Of course, this does not mean the disease will be entirely absent. International travel and population movement will facilitate introductions from other parts of the world. For example, in 2000 WHO recorded more than 15,000 cases of imported malaria in the European Region. Such cases occasionally lead to summertime transmission,[43] recently reported as far north as Berlin. In wealthier countries, such outbreaks are likely to be small, easily contained, and confined to a limited geographic area.

The same may not be true of less affluent regions. Rapid economic decline, combined with political instability, has already brought back epidemic typhus, diphtheria and other infectious diseases to several countries of the former Soviet Union. In the 1990s, malaria made a dramatic reappearance in Armenia, Azerbaijan, Tajikistan, Turkmenistan. Cases were also reported from Dagestan (Russian Federation), Georgia, Kazakhstan, Kyrgizstan and Uzbekistan.[44]

From 1991 to 1997, the number of malaria cases reported annually in the Newly Independent States of the former USSR rose from about 400 to more than 40,000. The overall situation began to improve in most countries towards the end of the 1990s; in Georgia and Kyrgyszstan, however, the number of autochthonous cases is increasing, and Tajikistan now faces the resumption and spread of *P. falciparum*. In Turkey, more than 15 million people live in areas where malaria is endemic.[45] The United States Centers for Disease Control and Prevention (CDC) now advises all travellers to Armenia, Azerbaijan, Georgia, Kyrgyzstan, Tajikistan, Turkey, Turkmenistan and Uzbekistan take prophylactic antimalarial drugs when visiting these countries.[46]

It is quite conceivable that the disease will spread northward from these regions into Russia and westward around the Black Sea. The 1999 conflict in the Balkans states was in the same region where hundreds of thousands were infected with malaria during World War I. Endemic transmission in such areas could be significant if the parasite were to be reintroduced. Climate change might augment this possibility, particularly at high latitudes (e.g. in Siberia) although low stability should facilitate control.

Conclusions

The history of malaria in Europe, especially during periods when the climate was much colder than it is today, contradicts the popular notion that the disease is restricted to the tropics.

The natural history of malaria is complex, and the interplay of climate, ecology, vector biology, and many other factors defies simplistic analysis. No scientist denies that temperature *is* a factor in the transmission of mosquito-borne diseases, and that transmission *may* be affected if the world's climate continues to warm. But it is immoral for political activists to mislead the public with erroneous concepts of mosquito-borne disease to justify colossal amounts of scarce resources to "halt" global warming, even as climate experts confess that the true contribution of human activities to the present warming trend is uncertain.

The true reasons are far more complex, and the principal determinants are politics, economics, and human activities. A creative and organized application of resources to correct the situation is urgently needed, regardless of future climate.

Will the world experience an increase in catastrophic weather events?

Madhav Khandekar
Research scientist, Environment Canada (Retired)

Pundits, activists, journalists and others have alleged a positive relationship between increasing atmospheric greenhouse gases, the present Earth surface warming, and extreme weather phenomena. In particular, it is claimed that warming will manifest itself in the form of extreme weather events – droughts, storms, hurricanes, tornadoes, floods, heat waves, snowstorms, etc – and that we are currently experiencing these events because of climate change.

This section examines recent studies on trends and changes in extreme weather events in Canada and other parts of the world, and assesses these studies in the context of global warming and remaining uncertainties about the link between warming and extreme weather.

Global warming and extreme weather: media and public perception

Climate change and extreme weather have arguably become the most important environmental issues at present and are often referred to in news media and in environmental policy discussions.

Worldwide incidences of severe weather events are more often reported in the news media at present than they were reported ten or twenty years ago. According to Unger[1], television viewers in the USA are three times more likely to see a story on severe weather today than they were only 30 years ago. In Canada, news items regarding release of regional or national Government reports, as well as release of reports by the Intergovernmental Panel on Climate Change, have received front page news coverage and bold headlines in the past five years.

These headlines and warnings about more frequent occurrences of severe weather events have created a perception amongst many people that with increasing mean surface temperature there will be increasing incidences of severe weather events like winter blizzards, droughts/floods, thunderstorms/tornadoes and heat waves.

Recent studies using observational data over various regions of Canada, the United States and elsewhere do not appear to support the generally held perception that severe weather events have increased. The IPCC's recent Third Assessment Report[2] categorically states that no systematic changes in the frequency of tornadoes, thunder days or hail events are evident in the limited areas analysed.

Thus, there is a mismatch between the popular perception about the impact of global warming on extreme weather and observation.

Extreme weather and IPCC projections: present and future

The IPCC's Third Assessment Report (TAR) was recently published.[3] The report of IPCC Working Group I analyses the current understanding of the basic science of climate change and reinforces the earlier findings regarding increasing concentrations of greenhouse gases and most of the observed warming of the last fifty years being attributed to human activities.

Table 1 **Estimates of confidence in observed and projected changes in extreme weather and climate events (IPCC)**

Confidence In observed changes (latter half of the 20th century)	*Changes in phenomenon*	*Confidence in project changes (during the 21st century)*
Likely (66–90% chance)	Higher maximum temperatures and more hot days over nearly all land areas	Very likely
Very Likely (90–99% chance)	Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely
Very Likely	Reduced diurnal temperature range over most land areas	Very likely
Likely over many areas	Increase of heat index over land areas	Very likely over most areas
Likely over many Northern Hemisphere mid-to high latitude land areas	More intense precipitation events	Very likely over many areas
Likely in a few areas	Increased summer continental drying and associated risk of drought	Likely over most mid-latitude continental interiors. (Lack of consistent projections in other areas)
Not observed in the few analyses available	Increase in tropical cyclone peak wind intensities	Likely, over some areas
Insufficient data for assessment	Increase in tropical cyclone mean and peak precipitation intensities	Likely, over some areas

The report further identifies certain changes that have occurred in important aspects of climate, with specific reference to 'more frequent warm episodes of the ENSO (El Niño/Southern Oscillation) phenomenon since mid-1970s and frequency and intensity of droughts increasing in parts of Asia and Africa'. The TAR also identifies certain extreme weather and climate events, and obtains estimates of confidence in observing these changes in the latter half of the 20th century and in the 21st century. These estimates of confidence for various weather and climate events are provided in Table 1.

The TAR has made estimates of confidence in observed and projected changes in extreme weather events and climate events. According to these estimates (see Table 1), some of the extreme weather events (e.g. higher maximum temperature and more hot days; higher minimum temperature and fewer cold days; more intense precipitation events; increased summer continental drying and associated risk of drought) are likely to be observed in the latter half of the 20th century and very likely to be observed during the 21st century.

According to a recent study of extreme weather phenomena in Canada,[4] it appears that many of the IPCC's general projections are not reflected in data and observations. Other studies indicate that this is true for the rest of the world.

Some of the changes in extreme weather events discussed in Table 1 are 'very likely' to be observed during the 21st century, although the precise timing of occurrence of these changes remains highly uncertain at this time. An oft-quoted study by Kharin and Zwiers[5] obtains estimates of changes in extreme events for the period 2040–60 and beyond.

For climate change assessment over the next two decades, Kharin and Zwiers' study is of little utility. Based on an assessment of recent studies on trends and changes, it appears that for Canada and the rest of the world, the likelihood of increasing incidences of extreme weather events in the next twenty years is rather small.

Canadian trends

The link between global warming and extreme weather is more perception than reality. A careful analysis of the 20th-century data reveals that extreme weather events such as thunderstorms, tornadoes, droughts, floods, heat waves, etc. are not increasing anywhere in Canada.

- The dust bowl years (1910–1940) were in general hotter during summer months than the decade of the 1990s.
- The deadliest heat wave in Canada occurred in July 1936, when the temperature in Toronto hit 41°C three days in a row, killing more than 1,000 people in the prairies and Southern Ontario.
- The worst flood in Canadian history was due to Hurricane Hazel (October 1954) and killed more than 75 people in the western suburbs of Toronto. No meteorologist or climatologist has blamed this on global warming.

Summer months in Canada in general and over the prairies in particular have not become hotter during the 1990s. It is the higher minimum temperature over most regions that has boosted the mean temperature over Canada as a whole and not the summer maximum temperature as has been suggested.

Also, precipitation events are not getting more intense anywhere in Canada. The estimates of confidence provided in Table 1 for the observed changes in extreme events during the latter half of the 20th century are based on a limited number of studies so far[6] and do not specifically refer to any Canadian regions. Nevertheless, it is of interest to note that the projections of some extreme events are so far not observed in data from recent decades in Canada.

On the Canadian prairies, extreme cold spells and winter blizzards have declined during the past 40 years. In fact, in eastern Canadian provinces (Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland) have been getting colder in the past 50 years. Total precipitation has increased everywhere in Canada but this increase is mainly due to increase in low- to moderate-intensity events.

There is a considerable variability (and uncertainty) in many of the climate model projections of extreme weather occurrences, particularly in regard to the timing of the occurrences. Based on the careful evaluation of available studies, it appears that the likelihood of increased incidences of extreme weather events during the next ten to twenty years over any region of Canada is very small at this time.

Extreme weather trends in other parts of the world

Available studies indicate no increasing trend in extreme weather events in other parts of the world.

Figure 1 **US death rates due to various extreme weather events (1900–97), deaths per million population, 9-year moving averages (MA)[8]**

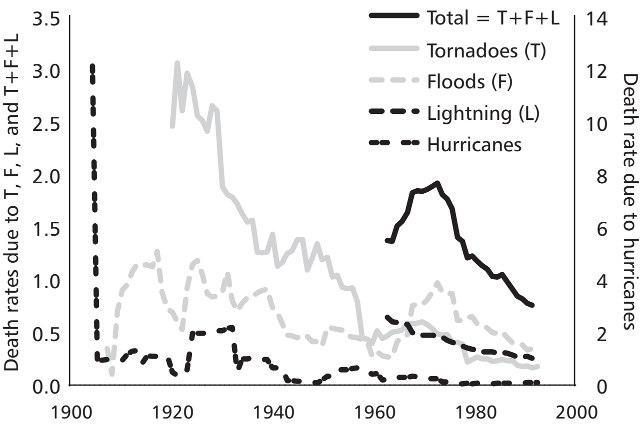
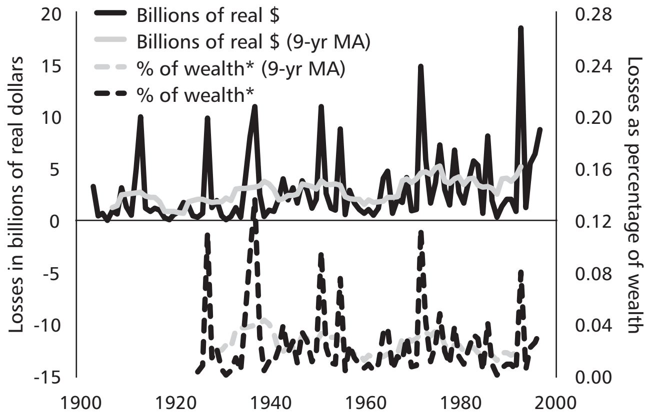


Figure 2 **US property losses due to floods (1903–97)[10]**



*Wealth measured as fixed reproducible tangible assets.

Human deaths from extreme weather (USA)

'Loss of life due to weather extremes exhibits mixed outcomes over time. Little change is found in deaths due to lightning and extremely cold temperatures. Loss of life related to tornadoes and hurricanes has decreased with time, whereas loss of life due to extreme heat may have increased. The analysis supports the hypothesis that the downward shifts and the flat trends of lives lost (in the context of a growing population) are a result of improved warnings and other responses, whereas the possible increase in heat deaths is a function of societal conditions in larger cities.'[7] (see Figure 1)

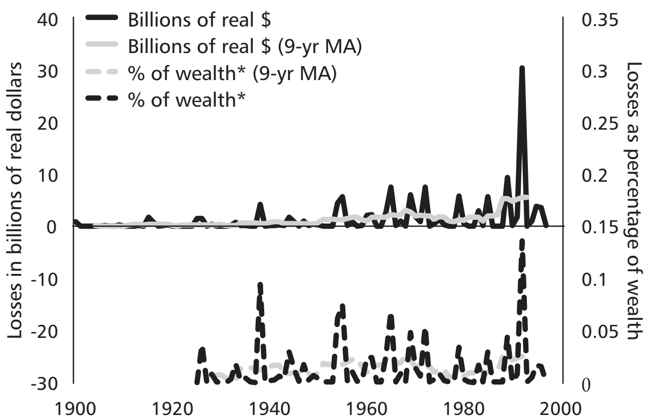
Flooding

'In inflation-adjusted terms, average annual flood damage has increased in the United States over the past few decades. This increasing trend in damages appears to be related to increases in population and the value of developed property in floodplains, as well as changes in precipitation characteristics, with perhaps as much as 80% of the trend attributable to population and wealth changes. Measured as a proportion of real tangible wealth, average annual flood damages have been roughly constant over time. This ongoing vulnerability comes despite the fact that various federal, state, and local governments and private entities have built approximately 40,000 km of levees along the rivers and streams of the United States—a combined total distance that is long enough to encircle the Earth at the equator.'[9] (see Figure 2)

Hurricanes (USA)

'The increase in hurricane damages over recent decades has almost entirely taken place during an extended period of no upward trend in hurricane frequencies and intensities. This means that fewer storms are responsible for the increased damages, and these storms are no stronger than those of past years. Clearly, rather than the number of and strength of storms being the primary factor responsible for the increase in damages, it is the rapid population growth and development in vulnerable coastal locations.'[11] (see Figure 3)

Figure 3 **US property losses due to hurricanes (1900–97)[12]**



*Wealth measured as fixed reproducible tangible assets.

Rainfall: Southern Africa and other regions

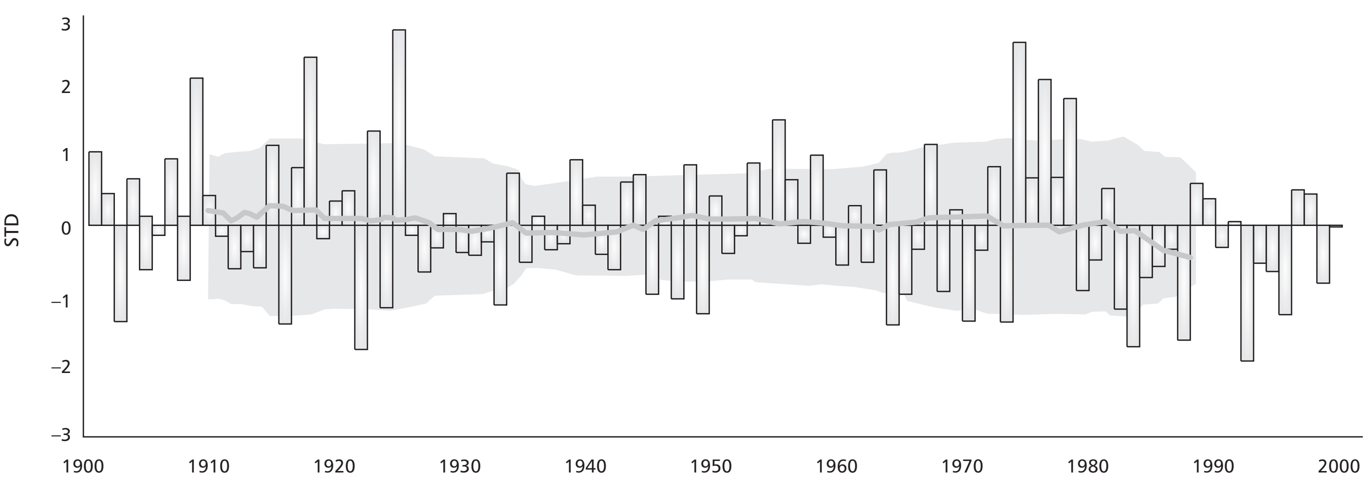
A recent study[13] concludes that some regions in Southern Africa have experienced a shift toward more extreme rainfall events in recent decades; however this increasing trend appears to be due to a closer link to ENSO phase in recent years (Figure 4).

According to the authors, "No significant trend is evident from SARI [Southern Africa Rainfall Index] along the century [1901–1998], in agreement with many previous studies of long term rainfall variations over the region."[14]

On a seasonal time-scale, say the authors, "Southern Africa as a whole does not experience a definitive trend toward desiccation or more moist conditions. As far as variations of seasonal rainfall amounts are concerned, modelling studies indicate that no significant shifts are expected as a consequence of enhanced greenhouse gases."

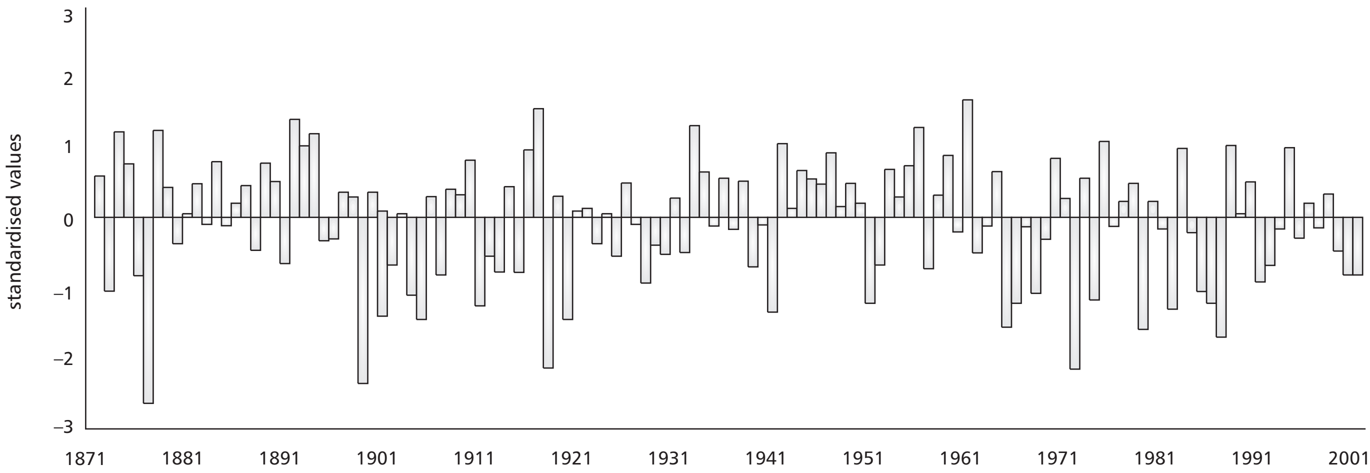
A recent paper[16] analyses extreme precipitation trends over North America, and concludes that there is a definite increase in extreme precipitation trends in some regions of USA (e.g., Great Lakes and northeast) but not over Canada. A subsequent paper[17] analyses newly available data on rainstorms and concludes that the recent increase in extreme precipitation events in USA may be similar to what

Figure 4 **Changes in rainfall amounts and variance for SARI from 1901 to 1998 bars: standardised December to April (DJFMA) rainfall amounts for SARI[15]**



Central curve: 20-year running mean.
External envelopes and shading: 20-year running standard deviation.

Figure 5 **Indian monsoon rainfall standardised values, 1871–2001**



was observed more than 100 years ago and could thus be related to natural variability and not necessarily due to anthropogenic influence.

For southeast Asia, interannual rainfall variability is primarily governed by the ENSO phase and does not reveal an increasing or decreasing tendency in recent years.[18]

A comprehensive analysis[19] finds a 20% increase in the probability of summer daily precipitation amount of over 25.4 mm (1 inch) in a few northern European countries such as Norway and Poland, but such increasing trend has not been reported elsewhere in Europe. Over Australia, heavy rainfall events have increased in some areas, but this increase is not significant.

Indian monsoon rainfall

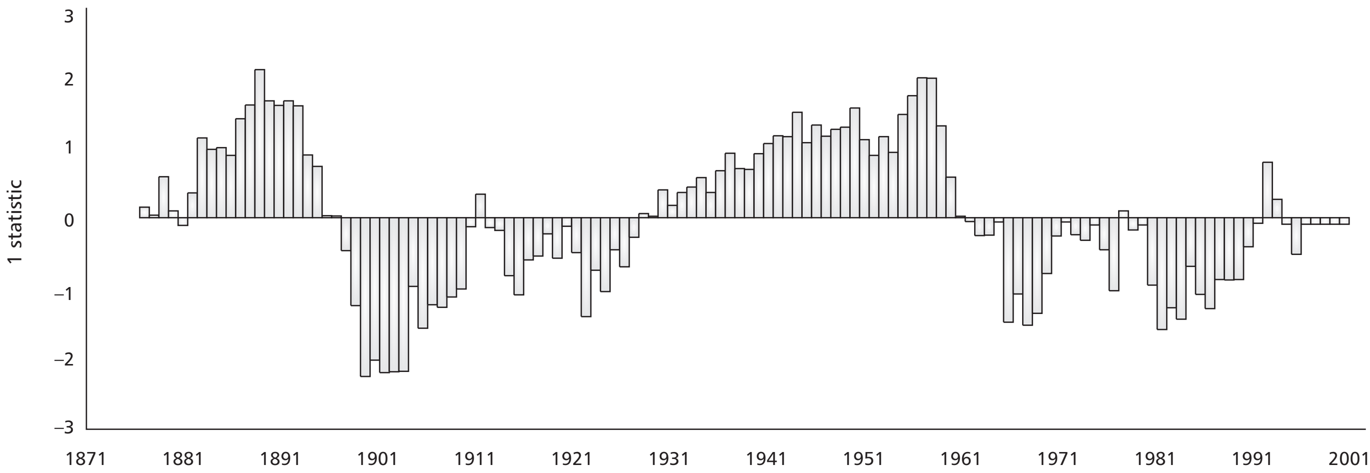
CAPTION, Figures 5 and 6 : (Top) Indian Monsoon Rainfall standardised values, 1871–2001 (Bottom) Cramer's t-statistic for 11-year running mean depicting decadal variability and epochs[20]

Analysis of extreme rainfall has been carried out for China[21] and for summer monsoon rains over India.[22] Both of theses studies conclude no significant increasing trend in extreme rainfall events of 1 to 3 day duration. For southeast Asia, interannual rainfall variability is primarily governed by the ENSO (El Niño-Southern Oscillation) phase and does not reveal an increasing or decreasing tendency in recent years.[23]

While the IPCC's Second Assessment Report[24] on climate model projections of Asian/Indian monsoon stated 'Most climate models produce more rainfall over South Asia in a warmer climate with increasing CO_2', the recent Third Assessment Report states 'It is likely that the warming associated with increasing greenhouse gas concentrations will cause an increase in Asian summer monsoon variability and changes in monsoon strength.'

Climate model projections[25] also suggest more El Niño-like events in the tropical Pacific, an increase in surface temperatures and a decrease in the northern hemisphere snow cover. The Indian Monsoon is an important component of the Asian monsoon. Its linkages with large scale patterns – the ENSO, northern hemisphere surface temperature and Eurasian snow cover (in the previous winter) – are well documented.

Figure 6 **Cramer's t-statistic for 11-year running mean depicting decadal variability and epochs**[20]



In the light of the IPCC's projections for the Asian monsoon, the interannual and decadal variability in summer monsoon rainfall over India and its teleconnections have been examined by using observed data for the 1871–2001 period – 131 years (Figures 5 and 6). While the interannual variations show year-to-year random fluctuations, the decadal variations reveal distinct alternate epochs of above normal and below normal rainfall. The epochs tend to last for about three decades.

There is no clear evidence to suggest that the strength and variability of the Indian Monsoon Rainfall (IMR) nor the epochal changes are affected by global warming, including that of the last five decades. The 1990s have been the warmest decade of the millennium,[26] yet the IMR variability has decreased drastically. Thus, claims that monsoon variability will increase in a warmer world are not supported by available evidence.

Connections between IMR and the ENSO phenomenon, northern hemisphere surface temperature and Eurasian snow reveal that the correlations are not only weak but have changed signs in the early 1990s, suggesting that the IMR has delinked not only with the Pacific but also with the northern hemisphere/Eurasian continent. Temperature and snow relationships with IMR are also weak, further suggesting that global warming need not be a cause of the recent ENSO-monsoon weakening.

Tropical cyclones (Australia and West North Pacific)

'"Tropical cyclone" is the generic term for a non-frontal, synoptic scale, "warm-core" low-pressure system that develops over tropical or sub-tropical waters with organized convection and a well-defined closed cyclonic surface wind circulation. It derives its energy primarily from latent and sensible heat flux from the ocean which is enhanced by strong winds and lowered surface pressure. These energy sources are tapped through condensation in convective clouds concentrated near the cyclone's centre'.[27]

A recent paper[30] analysed some of the unresolved issues with tropical cyclones, concluding that 'there is yet no convincing evidence in the observed record of changes in tropical cyclone behaviour that can be ascribed to global warming.'

Figure 7 **Tropical cyclones in the western North Pacific, 1959–1994**[28]

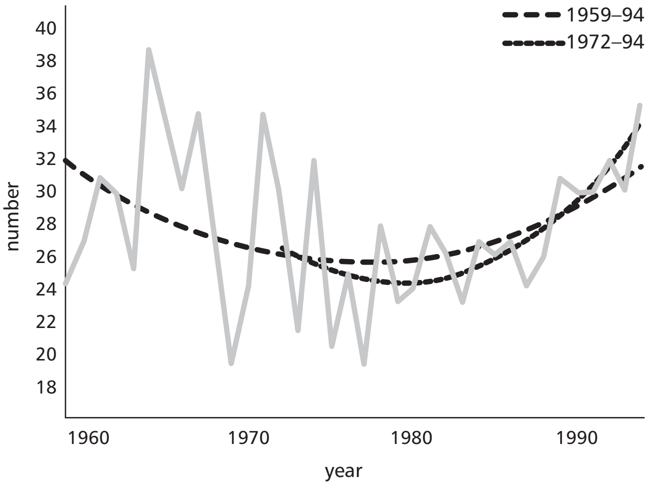
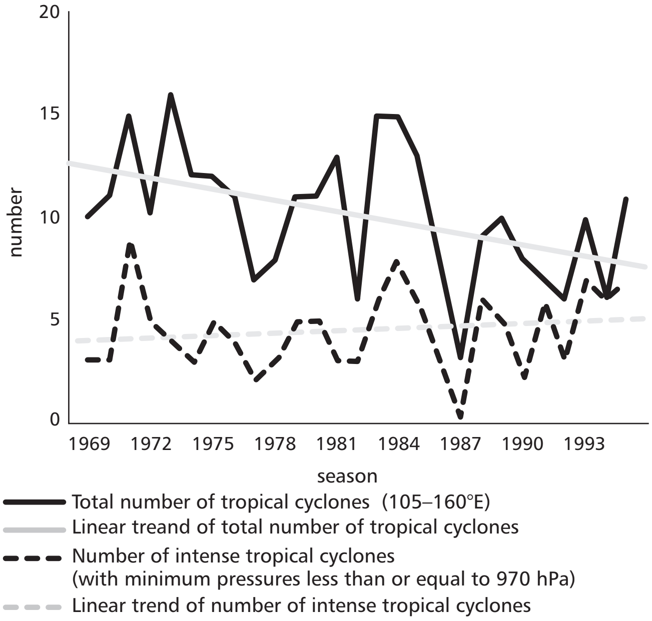


Figure 8 **Tropical cyclones: Australian region**[29]



Walsh suggests that numerous uncertainties remain, with regard to the formation rates, the region of formation, and poleward movement of cyclones after they leave their region of formation.

Formation rates: 'There may be substantial regional changes in formation rates, but in a number of basins these are strongly influenced by ENSO, whose behaviour in a warmer world remains substantially uncertain. Model projections give little consensus on changes in formation rates.'

Region of formation: 'In contrast to the general issue of numbers of tropical cyclones in a warmer world, there does appear to be some consensus on the issue of whether tropical cyclones would form in regions much outside their current formation basins. There is little theoretical or modelling evidence for changes in formation regions, unless they are associated with possible large-scale changes in ENSO.'

Poleward movement: 'There is little evidence yet of substantial changes in a warmer world in the typical poleward extent of active tropical cyclones, once they leave their tropical regions of formation.'

Figures 7 and 8 show recent data for tropical cylones in the western North Pacific and Australia. Figure 7 shows an increasing number of tropical cyclones for the western North Pacific. However, there are numerous complexities involved in this analysis, and Figure 8, which comes from a paper by Nicholls, Landsea and Gill, displays the total incidence of cyclones versus the number of intense cyclones.

Nicholls *et al.* state that 'The number of tropical cyclones observed in the Australian region (south of equator; 105–160° E) has apparently declined since the start of reliable (satellite) observations in the 1969/70 season. However, the number of more intense cyclones (with minimum pressures dropping to 970 hPa or lower) has increased slightly. The numbers of weak (minimum pressures not dropping below 990 hPa) and moderate systems (minimum pressures between 970 and 990 hPa) have declined.' The relationship between cyclones and the Southern Oscillation Index (SOI) appears to be strongest for moderate cyclones, and 'only weakly related to intense or weak cyclones'.[31]

Moreover, the authors point out that great care is needed 'in the analysis of "derived" variables such as tropical cyclone numbers, especially if trends in the variables are to be examined': 'If only total cyclone numbers are examined, one might conclude that the Australian region cyclone numbers have exhibited a significant trend similar to that in the Atlantic. The difference between the two basins, however, is that in the Atlantic it is the intense cyclones which have exhibited a downward trend in numbers. In the Australian region, the intense cyclones have shown a weak upward trend. This trend does not appear to be attributable to the improved discrimination between tropical cyclones and other systems, nor to trends in the SOI. In fact, the observed increase in intense cyclones may have been larger, but for the downward trend in the SOI.'[32]

Conclusions

There appears to be no intimate link between global warming and world-wide extreme weather events at this point in time. Increasing economic impacts due to extreme weather events in the conterminous USA appear to be a result of societal change in wealth and population and not due to global warming. Outside of the USA, very few studies have been reported so far to make a meaningful analysis of economic impact of extreme weather events.

The following broad conclusions can be drawn:

- Heat waves and summer maximum temperatures are not increasing in Canada, USA or elsewhere at present.
- Intense precipitation events show increasing trends over USA but not over Canada. Elsewhere, trends are mixed. Natural climate variability, increased sea surface temperatures and local/regional influences are considered as possible causes.
- Thunderstorms/tornadoes have declined over North America in recent years, compared to the Dust Bowl years of the 1920s and 1930s.
- The Indian/Asian Monsoon is governed primarily by large-scale features and not influenced by global warming at present.
- Tropical cyclone variability and intensity does not appear to be influenced by global warming at this time.
- Extreme weather events as identified by the IPCC are not increasing anywhere in North America.
- Based on available studies, there appears no increasing trend in extreme weather events elsewhere, eg. Europe, Africa, Australia.
- The likelihood of increased incidences of extreme weather events in the next ten to twenty-five years remains very small at this time.

However, uncertainties and gaps in existing knowledge do not justify complaisance. Quite the contrary – we need to address our inadequate knowledge of severe weather phenomena and their implications for society at large.

For Canada as a whole, several aspects of extreme weather events have not been fully assessed as yet due to unavailability of long period of data and an analysis of their inter-annual variability. These severe weather phenomena, being much more common in the USA, have been extensively studied using a much larger (and a longer) database that is readily available over many regions the USA.

Two recent studies[33] provide a comprehensive analysis of thunderstorms and associated rainfall, hail and wind damage and their inter-annual variability over the conterminous USA based on one hundred years of data. In Canada, data on thunderstorms and related severe weather activity (tornado, hail, wind) are available on a much shorter time frame, about 20 to 30 years. Further, very few comprehensive studies on interannual variability of these severe weather events on regional to smaller spatial scales are available.

The perception that global warming and climate change would lead to an increase in extreme weather events appears to be inconsistent with observations across the world. There is a need to continue monitoring trends of extreme events, particularly for assessing inter-annual variability of such events on the regional and smaller spatial scales. A recent study of the United States[34] shows that economic loss values due to weather extremes, when adjusted to societal changes, do not indicate a shift due to global warming. A similar conclusion has been drawn by[35] while assessing US flood damage against societal wealth. The economic impacts of weather extremes and the linkages to global warming and/or societal changes need to be more accurately assessed.

When carefully analysed, the link between global warming and extreme weather is more a perception than reality; there is absolutely no evidence of an escalation of such events worldwide. It is unfortunate that, rather than focusing on narrowing our knowledge gap, the IPCC has tended to use papers that rely more on speculation than data analysis to generate claims that extreme weather is on the rise. In fact, whether it will increase in 2025 or beyond is anyone's guess.

Section 6

Illness and mortality from heat and cold: will global warming matter?[1]

William Keatinge, Emeritus Professor, Queen Mary School of Medicine and Dentistry, London

How does cold and hot weather affect health and mortality?

In the first book produced in the European continent, Herodotus wrote, 'Change is the great cause of men falling sick, more particularly change of seasons'. Today, death rates still increase in winter, and they also increase during heat waves in summer. These increases still represent the principal adverse effect of environment on mortality, and they are largely avoidable. Mortality in European countries is at its lowest when mean daily temperature is around 17°C [2, 3] and it rises as temperature either falls or rises from that level. The numbers of these excess deaths per year give the best measures respectively of cold related and heat related mortality.

An older measure used to measure winter mortality was the number of deaths per million during the December to March period as an excess over the mean mortality rate during the rest of the year. That is simple to calculate, and often provides a rough comparison of winter mortalities at different times and in different regions, but this measure has major drawbacks. Its worst drawback is that it is determined by mortality due to hot weather as well as to cold. If there were more deaths due to hot weather in summer than to cold weather in winter, the calculation could suggest no winter mortality due to cold, although cold did in fact produce high mortality during the winter.

Throughout Europe, and also in most of the world, cold-related deaths are far more numerous than heat-related deaths. This is particularly true of Britain, which has around 40,000 cold related deaths per year compared to 1,000 heat related deaths per year.[4] About half of the cold related deaths are due to coronary and cerebral thrombosis (heart attacks and strokes), and about half of the remaining deaths are due to respiratory disease.[5]

The main reasons for these deaths are straightforward. Coronary and cerebral thrombosis in cold weather is caused by the blood becoming more concentrated, and thus more liable to clot when people are exposed to cold. That concentration is part of the body's adjustment after blood flow to the skin is shut down in cold conditions to conserve body heat.[6, 7, 8] The shift of blood from the skin produces an excess of blood in central parts of the body. In order to correct for the excess blood, salt and water are moved out from the blood into tissue spaces, and eventually excreted. This leads to increased levels of a variety of blood components that promote clotting. The blood also contains a substance called Protein C which hinders clotting, but this molecule is small enough to diffuse through the walls of blood vessels. As a result, it can redistribute through most of the tissue spaces of the body, and shows little increase in the cold. This selective concentration of clot-promoting factors in the blood causes little harm in young people, whose arteries are generally in good condition. However, it greatly increases the chance of a clot forming on rough patches of atheroma, which are common in the arteries of elderly people. Respiratory infections in winter also increase blood levels of fibrinogen, which further promote clotting.[9]

The increase in respiratory deaths in winter is due partly to respiratory infections, which spread more readily in cold weather. There are several reasons for this. People crowd together in poorly ventilated spaces when it is cold. Breathing of cold air stimulates coughing and running of the nose. Other reasons for the respiratory deaths are that cold stress tends to suppress immune responses to infections, and the mucosa (lining) of the airways seems to resist infection better if surrounding temperatures are warm. The old remedy of inhaling steam for approximately 30 minutes not only immediately reduces the symptoms of a cold, but moderates the entire subsequent course of the illness.[10, 11]

Severe influenza can cause fatal pneumonia directly, as well as through secondary infection. Epidemics of influenza used to kill many tens of thousands of people every two or three years. Since the 1970s, these epidemics have been much less common and less severe. The decline mostly occurred before the start of immunisation against influenza.[5, 12] It probably resulted from better hygiene, which reduced spread to man of new strains of avian influenza. Such spread is still limited to a degree, but new strains of influenza developing among chickens raised in large numbers in crowded conditions have recently caused large epidemics among these birds. There is a risk of these new strains developing the capacity for rapid transmission in man, and triggering human illness on the scale of the influenza pandemic of 1918.

Events leading to respiratory deaths in winter often start with a cold or some other minor infection of the upper airways. This spreads to the bronchi (the airways in the lungs), and to the lungs. Secondary infection then causes pneumonia. Surprisingly, hypothermia, the most obvious cause of death from cold exposure, is rare in peacetime. After influenza deaths declined in the 1970s, it was widely assumed that most of the remaining rise in mortality in cold weather was due to hypothermia, which involves simple cooling of the body until vital organs such as the heart and brain cease to function. In reality, cases of hypothermia are rare in Britain[13, 14] and probably throughout Europe.

Although it is straightforward that exposure to cold weather causes illness and death, evidence is needed to prove that cold causes most of the excess deaths in winter. It would theoretically be possible that some altogether different factor, such as vitamin deficiency in the winter diet, was responsible for many deaths. This was plausible, since vitamin C does have a protective action against arterial thrombosis. It is found particularly in fresh fruit and vegetables, which are most plentiful in summer and autumn, and scarcer in winter. Cheap fruit and vegetables, and particularly orange juice, are now freely available even in winter. However, other possible factors that have been suggested to cause winter mortality are absence of sunshine, and seasonal changes in lifestyle.

Positive evidence that cold causes most of the excess mortality in winter is provided by analysis of short term relationships between cold weather and daily deaths.[15] The standard method for examining relationships of that kind is time series analysis, a branch of statistics designed to show changes in one factor after a change in the other. In this case, the usual procedures used for that analysis were complicated by the fact that a fall in temperature one day is on average preceded by a rise in temperature on previous days. Thus it is difficult to establish whether the fall in temperature, or the earlier rise in temperature, causes a subsequent change in daily mortality. The solution was to evaluate changes in mortality after a cold day for the time of year, rather than to evaluate this change after a fall in temperature.

To carry out this evaluation, first a low pass filter was used to remove slow seasonal changes. Regression coefficients were then calculated, at successive days lag and advance, for daily temperature on temperature and then for daily mortality on temperature. It showed that spells of cold weather were accompanied by increases in mortality which continued for many days after the cold spells ended. Analysis in the linear temperature/mortality range 0 to 15°C provided evidence that the size of this mortality from short term effects of cold was large enough to account for all of the excess mortality in winter.

The time relationships of these mortalities to cold weather differed between causes of death. Coronary deaths peaked within one to three days of peak cold, but respiratory deaths peaked twelve days after peak cold. This fitted with coronary deaths being produced by the changes in blood composition observed in the cold. It also fitted with the respiratory deaths being due to cold, which promotes the spread of respiratory infections and exacerbates existing infections, which then progressed to cause fatal pneumonia many days later.

Surprisingly, much of heat related mortality in hot weather is also due to coronary and cerebral thromboses. This also results from haemo-concentration, but in this case it is due to loss of salt and water in sweat.[16] Other heat-related deaths result from a range of other factors which are not well understood, but include hyperthermia, and probably the strain on failing hearts when additional blood flow to the skin is needed to increase loss of heat from the body. One mitigating factor in heat-related mortality is that these deaths occur within a day or two of hot weather, and are followed by a lower than normal mortality. The likely reason is that many of those who die in the heat are already very ill, and even without heat stress would have died within the following two or three weeks.

How will global warming affect mortality?

There is now strong evidence that global warming has been under way for at least thirty years, and that it is largely man made and is continuing.[17] A large part of the warming is due to emissions of carbon dioxide from the burning of fossil fuels. Since there are fewer heat-related deaths than cold-related deaths, the overall effect of global warming could be expected to be a beneficial one. When it was recognised in the 1990s that global warming was under way, public attention inevitably shifted from the hazards of cold weather to those of hot weather.

The main concern at first was that diseases transmitted by insects, such as malaria, would spread to cooler regions of the world, and would become a serious problem in these areas. Closer examination showed that this was unlikely to happen. Malaria, for example, was once endemic in most of Europe, and even in Russia, but had already been eliminated. The main reason was that modern farming methods and changes in human living conditions had reduced the number of the mosquitoes that spread the disease, and reduced their opportunities to bite people.[18] There is no reason to expect that global warming would bring a resurgence of malaria, even if summers became substantially warmer. For the same reasons, mosquitoes which carry *Falciparum* malaria, the most dangerous variety, are unlikely to spread from the tropics. If they did start to spread, spraying to kill mosquito larvae should control them.

Global warming could affect mortality through the more direct effects of temperature on people. If these are assessed on the assumption that particular degrees and patterns of heat or cold will continue to produce the same mortalities as they did previously, the additional deaths due to heat would be much smaller than the reduction in deaths due to cold. For Britain, on this assumption the rise in temperature of 2°C expected over the next fifty years would increase heat related deaths by about 2000, but would reduce cold related deaths by about 20,000.[4]

Of course, people who die as a result of heat would not be reassured by being told that fewer people would die next winter as a result of cold. Studies of populations that live in widely different climates showed that they had in fact adjusted to their own climates remarkably well. The Eurowinter study, with active surveys of 12,000 people in eight regions of Europe, showed that people in cold regions such as the north of Finland protected themselves so well from cold that they experienced no more winter mortality than people in regions with much milder winters such as London and Athens.[2] Heat-related mortality in Finland indicated similar adaptation – it was not significantly greater in the hot summers of Athens or London than in the north of Finland.[3]

Studies of actual changes in heat-related mortality since the advent of observed global warming show that as temperatures have risen, the increase in heat-related mortality produced by a particular level of high temperatures has fallen. Summer temperatures have risen at least 1°C both in London and in the subtropical region of North Carolina since 1971. However, heat-related mortality has not risen in London, and has virtually disappeared in North Carolina despite humidity also increasing there and wind decreasing.[19] Studies in Siberia have strengthened the evidence that people adjust effectively to cold climates. Remarkably, there is little excess winter mortality there; there is none at all in Yakutsk, in eastern Siberia, the coldest city in the world with temperatures averaging -30 to -40°C in winter.[20]

The explanations are straightforward. The surveys showed that at a given outdoor temperature in winter, people in cold parts of Europe not only kept their houses warmer than people in warm parts of Europe, they also dressed more warmly and were more likely to keep moving when outside. People in Yakutsk wore massive fur clothing outdoors. The comparisons were made for the same outdoor temperature, and for people of the same ages. People in cold countries were simply much more effective in keeping warm in cold weather. At the same time, people in countries with hot summers seem to be more effective in protecting themselves from heat. The siesta of southern Europe is an obvious example. In North Carolina, a large increase in air conditioning in the region seems to be responsible for the virtual disappearance of heat-related mortality.

The effect of warming on tropical countries close to the equator remains difficult to assess. These countries generally do not produce the daily mortality figures needed to estimate heat related mortality. Extraction of daily figures world wide will be needed for a full world wide assessment.

What should we do to protect health during European heat waves in the next decade?

It would be easy to look at these facts and say that we need do nothing, at least in Europe. Global warming is not likely to increase overall mortality, even in the short term. People will also make their own adjustments to hotter summers in time, and that will prevent increases in summer mortality in the long run.

In reality, there is much that we can and should do. Sudden heat waves can be expected to produce record high temperatures from time to time as the climate warms. These inevitably expose populations to higher environmental temperatures than they have ever encountered before. They are accordingly likely to cause high mortality for a few days, especially amongst people who are not prepared. Although deaths due to cold weather can be expected to fall by an amount which more than balances these deaths, people who might die in a heat wave will not be reassured with the knowledge that far fewer people are likely to die from cold in the winter.

Air conditioning can provide a comfortable indoor temperature in the most extreme heat waves, and it plays an important role in preventing heat related mortality in tropical and subtropical climates. It will be useful in buildings where elderly people reside in warm parts of Europe, at least as a reserve in heat waves if other methods fail. It is also helpful in maintaining efficient working conditions of temperate regions. Unfortunately, air conditioning also has drawbacks. The most important is high energy consumption, which requires increased generation of electricity, and this in turn is generally achieved by burning more fossil fuels. Air conditioning can also involve substantial capital cost in relation to the amount that it is used, particularly in temperate regions where severe heat waves are rare.

Alternative strategies are therefore important to supplement air conditioning in hot climates and to replace it in cool ones. Building regulations need to ensure that buildings are designed, or modified when necessary, to keep cool in hot weather. Suitable design can enable buildings to keep a more even temperature throughout the 24 hour cycle. Important elements in suitable building design are high thermal insulation in outer walls, high thermal mass internally, and protection against direct sunlight. It is particularly important to prevent sunlight from entering through windows, which causes greenhouse heating of houses. In Southern Europe, external slatted shutters are a traditional and effective way to prevent such overheating in houses. Windows are best kept closed after dawn for as long as the interior of a building remains cooler than the outside air, and so long as they do not cause heat stress to people inside. Cooking should be kept to a minimum wherever it will warm indoor living spaces and increase humidity. Crowding of people indoors will also increase temperature and humidity.

Warnings to the public are important when severe heat waves are forecast, together with advice on how their effects can be mitigated. Broadcasting such forecasts and advice together will give time for people to ensure that fans and water are available and that windows can be opened. Once the interior of a building does become uncomfortably hot, a combination of light clothing, air movement from a fan, open windows, and sprinkling water on the clothing, can be used to reduce heat stress. People should continue to eat regular meals with moderate salt content and to drink water, even if they do not feel hungry or thirsty.

These measures will normally be effective even for people who are elderly, vulnerable because of illnesses such as diabetes, or people who are taking drugs that suppress sweating. Sprinkling water on clothing can substitute for sweating, and will allow evaporative cooling even in these people. Evaporative cooling also requires that the air should not be saturated. When heat stress develops, ventilating with air from an open window, together with the other measures, ensures that it will not be saturated, since outdoor air is not saturated at hot times of the day in European heat waves.

Anyone who becomes seriously overheated, with a mouth temperature around or above 40.5°C, needs to be cooled immediately rather than transported to an institution. This should be started at once rather than waiting for help from the emergency services. Immersion in a cool bath can be used if other measures are difficult to implement effectively. Extremely cold water will cause vasoconstriction, which can retard cooling, thus mild cooling should be the aim. A high proportion of those people who died in France in the 2003 heat wave appear to have died in institutions. Institutions which are treating the elderly and other vulnerable people need to dedicate special attention to protective measures against extreme heat.

Important as these measures are, we should not lose sight of the fact that cold weather causes more deaths than hot weather. The importance of warm housing in winter is well recognised, but the large contribution of outdoor cold stress to winter mortality [2, 21] is generally not equally recognised. Without action to address cold-related mortality, it is unlikely that global warming will reduce such mortality in the long run. Since people in regions with mild winters protect themselves less effectively against cold and generally experience more winter mortality than people in colder regions[2], climatic warming cannot on its own be expected to cause long term reduction in winter mortality. Active measures to reduce exposure to cold both outdoors and indoors will remain important.

The wider implications of global warming

The general conclusion is that the effects of rising temperatures on health and mortality are manageable and generally beneficial, at least in the medium term and over much of the world. A broader assessment would of course need to take account of other effects of rising global temperatures. For example, one estimate suggests that melting of the icecaps and warming of the oceans could raise sea level by 34 cm by the year 2100.[22] Predictions of that kind are extremely controversial in detail, and need to be weighed against the cost in human and financial terms of reducing fossil fuel consumption or switching to nuclear energy. Even the Kyoto Protocol would only slightly reduce global warming.

Section 7

Will fisheries be altered by climate change, with corresponding economic consequences?[1]

Ragnar Arnason, Department of Economics, University of Iceland

Substantial global warming due to the accumulation of greenhouse gases in the Earth's atmosphere has been predicted for some time. These predictions are corroborated by several sophisticated meteorological models. By the year 2100, most of these models predict global temperature increases of between 2 and 4.5°C. It is clear that a temperature increase of this magnitude will have a major environmental impact, which might be most significant in Northern latitudes where temperature increases are predicted to be significantly higher than the global average.

This section examines the possible impact of global warming on the fish stocks in the North Atlantic and their contribution to the economy of Iceland, Greenland and Norway. It is found that the impact of global warming on the most valuable fish stocks is more likely to be positive than negative. Moreover, even if it turns out to be negative, the long-term impact on the Icelandic and Norwegian economies is unlikely to be significant. In the case of Greenland the economic impact is even more likely to be positive and might easily be quite significant.

Climate change and the Arctic

Climate models generally predict that the temperature rises in the Arctic will substantially exceed the global rise. This applies especially in the high Arctic where the ice cover is expected to diminish substantially with the effect that the surface absorption of solar radiation will greatly increase. Further to the south, partly because of the effects of melting ice and possible changes in ocean currents, the situation is much less clear. In some of the sub-Arctic ocean areas, it may be the case that ocean temperature will rise little or not at all. The following figure gives the predicted temperature rises for the various Arctic and sub-Arctic ocean regions.

The variability in predicted temperature increases from one region to another is quite substantial. The highest temperature rises are expected to occur in the Barents Sea, close to 6°C by 2100. Note that these predictions are basically averages of several models. Some predictions are even higher. The predicted temperature increases in the Bering Sea are substantially less or 4°C by the year 2100. In the Iceland – Greenland area, the predicted temperature increases by the end of this century are only 2–3°C.

Impact on fisheries

The impact of global warming on fish stocks and fisheries is hard to judge. There are several reasons for this.

First, as discussed above, there is a great uncertainty regarding the extent and speed of global warming.

Second, there is even more uncertainty regarding the warming in the North Atlantic. This holds not the least for those areas of the North Atlantic where most fishing currently takes place. These areas are often cold water- warm water frontiers where thermoclines are steep. Not surprisingly, it is precisely in these areas where global warming predictions are most uncertain.

Third, the state of fisheries depend heavily on local conditions; up-welling, mixing of water masses, water salinity, currents, ice formation and melting and so on. Temperature is only one of the factors which affect fish stocks. On the other hand, temperature changes influence all these other hydrographical factors. What these effects will be, however, is very hard to predict.

Fourth, it is clear that global warming will alter the configuration of ocean currents and, consequently, also the most favourable regions for fishing. This effect can be small or large. Some hydrological models suggest that global warming will have a major impact on the world's ocean current systems.[2] If that is the case, then there would be a corresponding major impact on fishing conditions in the North Atlantic.

Fifth, any changes in habitat conditions due to global warming will alter the conditions for the various species in the marine ecosystem in different ways. This will give rise to an almost certainly very complicated and possibly drawn-out process of species adjustments and readjustments. The outcome of that process for individual species is very hard to predict. It may for instance easily be the case that species that experience favourable environmental changes are reduced in stock size due to less supply of prey that is unfavourably affected by the environmental change.

It follows from this that there is great uncertainty about the impact of global warming on the commercial fish stocks and fisheries in the North Atlantic. In the Arctic Climate Impacts Assessment working group on Arctic fisheries[3], it was recognized that there simply wasn't enough hydrographical, biological and ecosystem knowledge to translate predictions of global warming, uncertain as they are, into predictions for fish stocks and fisheries with a reasonable degree of confidence.

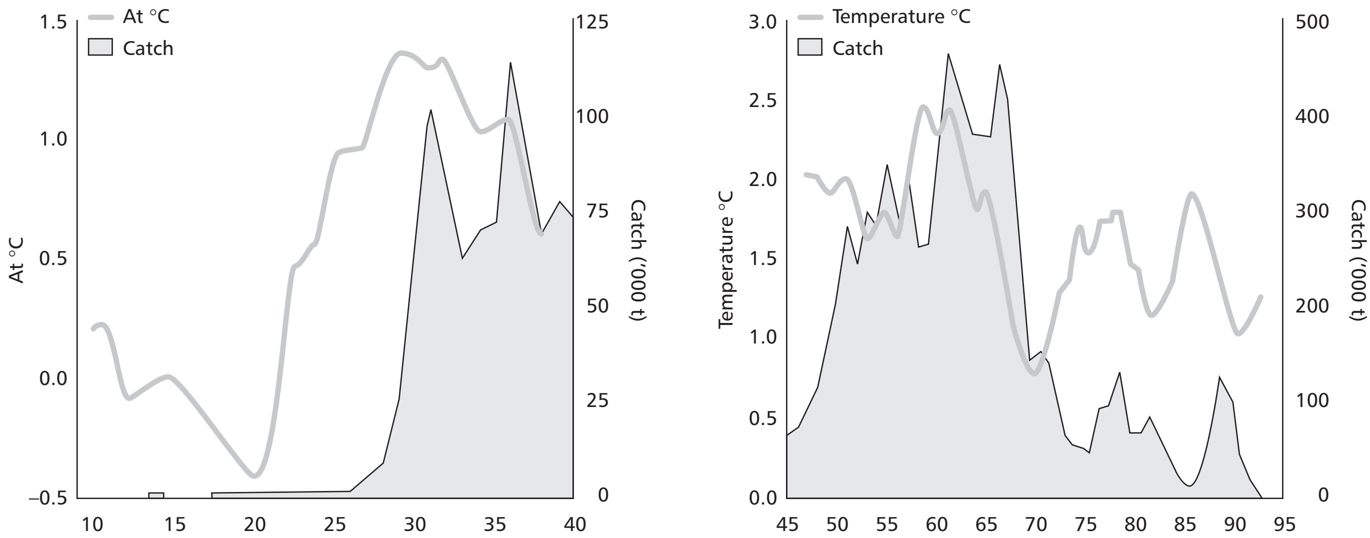
Nevertheless, faced with the need to make some sorts of predictions, the ACIA working group came to the following general conclusions regarding the main commercial fish stocks of the North Atlantic.

- A warming of the magnitude predicted is more likely than not to be beneficial to the fisheries of the North Atlantic
- Important species that would probably benefit are: Cod, haddock, saithe, herring, blue whiting, several species of flatfish and crustaceans (Norway lobster).
- Important species that would probably decline are: Shrimp, capelin, Greenland halibut and some species of flatfish.
- To a certain extent, especially in the Barents Sea, ocean warming will induce a northward shift in the range of some species.
- Less ice cover may offer more access to fish stocks.

The case of cod, the single most important commercial stock in the North Atlantic, is particularly interesting. Extensive areas of the North Atlantic are currently marginally habitable for cod due to low temperatures. This holds in particular for the Greenland area and to a lesser extent for the northern part of the Barents Sea. A slight warming would make these areas habitable again with the consequent expansion in the range of cod of a very substantial magnitude. For instance, during the warm period in the North Atlantic between 1930 and 1960, the range of cod in the Iceland-Greenland ecosystem expanded greatly. At the same time the Greenland-based cod stock became quite large, yielding catches similar to the Icelandic cod stock. The relationship between cod catches off Greenland and temperature changes in the 20th-century is illustrated in Figure 1.

Thus, both biological arguments and historical experience suggest that some warming of ocean temperatures in the Greenland area will substantially improve the environmental conditions

Figure 1 **Cod at Greenland: temperature (°C) and catch ('000 tonnes)**



for cod and therefore, in all likelihood, lead to a greatly increased size of the cod stock in the in the Iceland-Greenland ecosystem. Ocean warming may affect other species differently. However, due to the high commercial value of cod, this positive effect will probably dominate any negative effects on other species – i.e. shrimp and capelin – in the region.

We now turn our attention to the statistical estimation of the economic impact of a possible shift in the availability of fish to the fishing industries of the North Atlantic.

The statistical estimation is based on Icelandic data. However, due to the structural similarities of the economies in question, there are reasons to believe that the results for Iceland can be extrapolated to the economies of Greenland and North Norway as well.

Fisheries constitute an activity of major economic importance in the North Atlantic. In Greenland, the fishing industry is the main source of non-government employment and local economic activity with fish and fish products constituting over 90% of the total Greenland exports.[4] In Greenland, a major part of the national income consists of financial transfers from Denmark. Taking this into account and interpolating from the more complete Icelandic statistics, it may well be that about 50% of the Greenland GDP is generated in the Fisheries sector.

In Iceland, in spite of a considerable relative decline, the fishing industry still accounts for 8–9% of employment, 10% of the GDP and over 40% of total export earnings.

In Norway, the fishing industry does not amount to major part of the economy as a whole. However, in northern Norway, i.e. the area to the north of Trondheim, the fishing industry plays a similarly major role in economic life as it does in Iceland and Greenland.

It is important to realize that the national accounts statistics may well understate the real contribution of the fishing industry to the economies in these three countries. There are two fundamental reasons for this. First there are a number of economic activities closely linked with the fishing industry but not part of it. These activities consist of the production of inputs to the fishing industry, the so-called backward linkages, and the various secondary uses of fish products, the so-called forward linkages.[5]

The backward linkages include activities such as ship building and maintenance, fishing gear production, the production of fishing industry equipment and machinery, the fish packaging industry, fisheries research, educations and so on. The forward linkages comprise the transport of fish products, the production of animal feed from fish products, the marketing of fish products, retailing of fish products, part of the restaurant industry and so on. According to Arnason[6], these backward and forward linkages may easily add at least 25% to the GDP contribution of the fishing industry.

The other reason why the national accounts may underestimate the true contribution of the fishing industry to the GDP is the role of the fishing industry as a disproportionately strong exchange earner. To the extent that the availability of foreign currency constrains economic output, the economic contribution of a disproportionately strong export earner may be greater than is apparent from the national accounts. While the size of this "multiplier effect" is not easy to measure, some studies suggest it may be of a significant magnitude.[7] If that is true, the total contribution of the fishing industry to the GDP might easily be much higher than the above direct estimates suggest, in the sense that removal of the fishing industry would, *ceteris paribus*, lead to this reduction in the GDP.

It is equally important to realize that there are economic reasons why a change in the conditions of the fishing industry due e.g. to global warming, might have a lesser economic impact than suggested by the direct contribution of the fishing industry to GDP. This is especially true in the long run. Most economies exhibit certain resilience to exogenous shocks. This means that the initial impact of such shocks is at least partly counteracted by labour and capital moving to the economic activity made comparatively more productive by the shock. For instance, a negative shock in the fishing industry would to a certain extent be offset by labour and capital moving from the fishing industry to alternative industries and vice versa. As a result, the *long-term* impact of such a shock may be much less than the initial impact. The extent to which this type of substitution happens depends on the availability of alternative industries. However, with increased labour mobility, communication technology and human capital, this type of flexibility is probably significantly greater than in the past.

The role of fisheries in the Icelandic economy

For centuries, pasture farming and fishing were Iceland's most important economic activities. By the end of the 19th century, fishing overtook farming in terms of economic importance. In 1910 almost 25% of the working population was engaged in fishing and fish processing generating almost 80% of the country's merchandise exports.[8] Although the fraction of labour working in the fishing industry declined from this high in the following decades, the importance of fish products in merchandise exports actually increased to between 90–95% during the middle of the century. Since then, both the share of fish products in merchandise exports and the fraction of the total labour force engaged in fishing have declined significantly.

National accounts estimates of the contribution of fishing industry (fishing and fish processing) to the gross domestic product (GDP) are available since 1980. According to these figures, the direct contribution of the fishing industry to the GDP is currently (2000) just over 11%. In line with the trend in the fishing industry's labour and the export share, this represents a considerable decline compared to 1980 when the fishing industry contributed over 16% to the GDP.

In fact, the trend toward less economic dependence on fisheries has gained speed over time becoming particularly pronounced over the past 10–15 years. This declining trend in the relative importance of the fishing industry may be assumed to continue in the future.

In spite of the long-term decline in the macro-economic importance of the fishing industry, the Icelandic economy is still heavily dependent on fisheries. Thus, in the year 2000, the fishing industry accounted for some 8.2% of total labour, about 63% of merchandise exports and about 42% of total export earnings. In the same year the fishing industry contributed about 11% to the GDP.

Economic impacts of global warming: possible scenarios

From an economic point of view, climate change may impact fisheries in at least two different ways: first, by altering the availability of fish to the fishermen, and second, by changing the prices of fish products and fisheries inputs. The first impact is of primarily of a marine biological and ecological nature. The second is of an economic nature and must be investigated by the application of general equilibrium theory. Although both classes of impacts may be initiated by climate change, the first is a much more direct consequence of climate change than the second. The second is primarily a consequence of changed production conditions, often referred to by economists as a "supply shock", including but not limited to change in fish availability. It is generally promulgated by adjustments and readjustments throughout the economic system in very much the same way as exogenous impacts are promulgated through the ecosystem.

In this section we will calculate estimates of the possible GDP impact of changed fish stock availability as a result of climate change. These calculations are based on two key premises; (i) the impact of future climate change on the value of fish production in Iceland and (ii) the estimated relationship between economic growth and the value of fish production as discussed above.[9] Both of these premises, not least the impact of climate change on the value of fish production, are highly uncertain. Therefore, the following calculations should not be regarded as predictions. They are merely intended to serve as indications of likely magnitudes of the GDP impact in Iceland stemming from a certain stated premises regarding changes in fish stock availability.

Scenarios

Now, the available predictions suggest that the global warming during the next 50–100 years is first of all not going to have a great impact on fish stock availability in Icelandic waters. Second, it is more likely to benefit the most valuable fish stocks rather than the reverse. These expectations, however, are highly uncertain as already mentioned. Therefore, in this section, we will proceed on the basis of three examples or scenarios.

In the first scenario we will assume a 20% gradual increase in fish stock availability over a period of 50 years. This corresponds to a 0.4% increase in the value of fish production annually. We refer to this as the optimistic scenario.

In the second scenario we will assume a gradual reduction in fish stock availability of 10% over 50 years. This corresponds to an annual reduction in the value of fish production by some 0.2%. We refer to this as the pessimistic scenario.

In the third scenario we assume a 25% reduction in fish stock availability occurring over a relatively short period of 5 years. This would correspond to a collapse in the stock size of a major or a group of important commercial species. Indeed, there are some biological and ecological grounds to believe that the response of fish stocks to climatic change may indeed be sudden and discontinuous rather than gradual. Due to the magnitude and suddenness of this reduction we refer to it as the dramatic case.

Hopefully these scenarios will serve to illustrate the likely range of the economic impacts of global warming around Iceland. (Needless to say, other, better-founded, examples can be calculated).

The optimistic scenario

In the optimistic scenario, fish stock availability is assumed to increase in equal steps by 20% over the next 50 years. Perhaps the most noteworthy result is that this considerable increase in fish stock availability has a relatively minor impact on GDP.

The maximum impact occurs in year 50, when increased fish stock availability has fully materialized. At this point the GDP has increased (compared to the initial level) by less than 4%. The long term impact, when economic adjustment processes have occurred, is even less or some 2.5%.

The annual impact of this increase in fish availability is more easily gauged by analysing annual economic growth rates.

With this scenario, the largest increase in annual growth rates in any one year period is well under 0.2%. This occurs soon after the increase in fish stock availability and, hence, fish production commences. For most of the period, however, the impact on annual economic growth rates is much less. In the years following the end of the increase in fish production, growth rates actually decline because production factors which have moved to the fishing industry have reduced economic production elsewhere. It should be noted that all these deviations in annual GDP growth rates are well within GDP measurement errors. Long run GDP growth rates are, of course, unchanged.

The fundamental conclusions to be drawn from these calculations seem to be that a 20% increase in the output of the fishing industry equally spread over 50 years has a very small, indeed hardly noticeable, impact on the short-run economic growth rates in Iceland as well as the long-term GDP.

The pessimistic scenario

In the pessimistic case, fish stock availability is assumed to decrease in equal steps by 10% over the next 50 years.

As in the optimistic case, the most striking result is that this considerable decrease in fish stock availability has a relatively minor impact on long-term GDP. The maximum impact occurs in year 50, when the GDP has fallen by less than 2%. The long-term impact, when economic adjustment processes have occurred, is even less or just over 1%.

In this scenario, the largest decrease in annual growth rates in any one year is well under 0.1%. This occurs a few years after the decline in fish stock availability. For most of the period, however, the impact on annual economic growth rates is much less. In the years following the end of the decrease in fish production, growth rates actually improve, as production factors moving from the fishing industry find productive employment elsewhere. The maximum annual decline is about 0.1%. It should be noted that all these deviations in annual GDP growth rates are well within GDP measurement errors. Long run GDP growth rates are, of course, unchanged.

As in the optimistic case, the fundamental conclusions to be drawn from these calculations seem to be that a 10% decrease in the output of the fishing industry equally spread over 50 years has hardly any noticeable impact on the short-run economic growth rates in Iceland as well as the long-term GDP.

The dramatic scenario

The dramatic scenario assumes a fairly substantial drop in fish stock availability and hence, a 25% decrease in fish production over the next 5 years. This sudden drop in fish stock production has a significant negative impact on GDP in the short run. At its lowest point, eight years later, GDP is reduced by over 9% compared to its initial level. However, the long term negative impact — when economic adjustment processes have occurred — is only about a 3% reduction in GDP.

The decrease in annual growth rates for the first seven years following the commencement of reduction in fish stock production are quite significant: -1 to -2%. The maximum decline occurs toward the end of the reduction process (four and five years later). However, already, in year nine (four years later), the contraction ends. The deviation in annual GDP growth rates is reversed as production factors released from the fishing industry find productive employment elsewhere in the economy. This adjustment process is fully worked out in year 25, according to these calculations, when growth rates have fully reverted to the basic underlying economic growth level.

Extrapolation to other North Atlantic economies

The above calculations are for Iceland. However, there is good reason to believe that apart from scale similar relationships apply to Greenland and Norway. In Greenland, the economic importance of the fishing industry is probably four times higher than in Iceland. Moreover, due to the importance of the cod stock, global warming is likely to have a substantially more positive effect than in Iceland.

Finally, the flexibility, i.e. substitution possibilities, in the Greenland economy is probably significantly smaller than in the Icelandic economy. Thus, in Greenland, the optimistic scenario might easily generate a 15–25% increase in GDP, more than half of which might be permanent. The pessimistic scenario for Greenland would be similarly more dramatic. However, as already noted, the likelihood of adverse changes in Greenland waters is probably not very high at all.

In Norway regarded as a whole, the fishing industry is much less important than in Iceland and the economy offers probably more alternative opportunities. Moreover, the likelihood of adverse changes is probably no greater than in Iceland. Hence, the effects of global warming on the Norwegian fisheries are bound to be even less economically noticeable than in Iceland. Focussing on northern Norway, rather than Norway as a whole, the situation is probably quite similar to Iceland. However, the difference is that adverse changes are likely to meet with financial compensations in the form of transfers from other parts of the Norwegian economy.

Impacts on fish markets

Reductions or increases in fish production in the North Atlantic of the magnitude envisaged above will probably not have a significant impact on global fish markets.

This holds especially if the changes are gradual. For certain species, however, especially demersals such as cod, there might be a temporary noticeable effect. If there is an overall decline in the global supply of species of species that the North Atlantic nations currently exploit, the impact on marketing of these species is uncertain. Most likely the marketing of the species in reduced supply will become easier. Thus, prices will tend to rise, counteracting the contraction in volume. However, it should be recognized that the marketing impact might actually be the opposite. For some species, a large and steady supply is required to maintain marketing channels. If this is threatened, these channels may close and alternative outlets have to be found.

Conclusions

The main conclusion to be drawn from the above is that the changes in fish stock availability that now seem most likely to be induced by global warming over the next 50–100 years are unlikely to have a significant long term impact on the Icelandic and Norwegian economies. In the case of Greenland, however, the impact may be quite strong and more long lasting.

If, on the other hand, global warming triggers sudden rather than gradual changes in fish stock availability, the short time impact on the Icelandic and Northern Norway GDPs, not to mention the Greenland one, and economic growth rates may be quite significant. It is unlikely, however, that the impact could be rated as dramatic (over 5% change in GDP between years) except possibly in the case of Greenland.

It is more important, however, that the impact of global warming on North Atlantic fisheries is more likely to be positive than negative. Most of the commercially important fish stocks, especially herring and cod, are much more likely to be favourably affected than the reverse. Hence, broadly speaking, global warming appears to be good news rather than bad – for the North Atlantic fisheries at least.

Obviously, both short term and especially long run impacts may lead to social and political adjustments. Larger and more permanent impacts will imply greater adjustments. In Iceland and Norway, these adjustments will almost certainly be very minor, except in certain particularly fish-dependent regions. In Greenland, the adjustments may be quite substantial.

Contributors

Section 1: Economic scenarios underlying climate models

Martin Ågerup is a Bachelor of Science in economics and economic history from the University of Bristol and MA in European economics from the University of Exeter. He has written a best-selling Danish book about environment issues, and writes a weekly column in a Danish newspaper. Martin is President of the Danish Academy for Futures Studies.

Section 2: Understanding climate impacts

Indur M. Goklany is an engineer and a visiting fellow at the American Enterprise Institute. He is the author of numerous books and peer-reviewed papers on climate change, biodiversity and the relationship between economic growth and the environment.

Section 3: Sea level rise and low-lying coastal areas

Prof. Nils-Axel Mörner holds a Ph.D. in geology and is head of Paleogeophysics & Geodynamics at Stockholm University in Sweden. He has spent 35 years as a leading international sea level researcher, and formerly was president of an international commission on Sea Level Changes and Coastal Evolution (1999–2003). He was leader of the Maldives Research Project, and author of hundreds of peer-reviewed research papers and several books.

Section 4: The spread of vector-borne disease

Dr Paul Reiter is a specialist in mosquitoes, the diseases they transmit and improved methods for mosquito control. He worked for 22 years as a medical entomologist for the Division of Vector-Borne Infectious Disease of the Centers for Disease Control and Prevention (CDC) and now heads a new unit of Insects and Infectious Disease at the Pasteur Institute in Paris.

Section 5: Extreme weather phenomena

Dr. Madhav L. Khandekar holds a B.Sc. in Mathematics and Physics, an M.Sc. in Statistics from India (Pune University) as well as M.Sc. and Ph.D. degrees in Meteorology from Florida State University, USA.. Khandekar has worked in the fields of climatology, meteorology and oceanography for close to 47 years and has published well over 100 papers, reports, book reviews and scientific commentaries as well as a book on Ocean Wave Analysis and Modeling, published by Springer-Verlag (1989). He has published numerous research papers on a range of subjects, including ocean surface waves, Arctic sea ice, ENSO/Monsoon and global weather, Numerical weather prediction, Boundary-layer meteorology, Tropical cyclones etc. He is presently on the editorial board of *Natural Hazards* (Kluwer, Netherlands) and *Climate Research* (Inter-research, Germany). Khandekar acted as a guest editor in 2002 for a special issue of the Journal Natural Hazards on Global warming and extreme weather, this Sp Issue published as Vol. 29, No.2, June 2003. His current research interests: global warming/climate change & extreme weather, El Niño/Southern Oscillation, Asian Monsoon & global weather anomalies.

Section 6: Human deaths from heat and cold

Prof. William Keatinge went to Cambridge University in 1949, where he earned a degree in physiology with natural sciences for medicine, followed by clinical training at St Thomas's Hospital. He qualified as a doctor in 1955 and worked at that hospital for a year as casualty officer and house officer to the medical unit.

William Keatinge worked from 1961 to 1968 for the Medical Research Council in the department of the Regius Professor of Medicine, Oxford University. Moving to London University in 1968, he became professor of physiology at the London Hospital Medical College in 1971. At the London Hospital Medical College he became heavily involved in administration, including the college's merger with Bart's and with Queen Mary and Westfield College in 1990. He became head of the joint department of physiology, dean of basic medical sciences from 1991 to 1994, and Emeritus professor in 1996.

He is author of more than 200 scientific papers, reviews, chapters and two books, and commentator on the media about effects of cold and heat on human health. During 1993–8, he was coordinator of the European Union Eurowinter Project, and related projects in Siberia.

Section 7: North Atlantic fisheries

Prof. Ragnar Arnason received his Ph.D in natural resource economics from the University of British Columbia in 1984. He became a professor of fisheries economics at the University of Iceland in 1989. He has published extensively in the area of fisheries economics and advises on fisheries policy and management around the world. He is a contributing author to the Arctic Climate Impact Assessment.

Notes

Section 1: The scenarios underlying climate change 'predictions'

1 http://www.ipcc.ch/about/about.htm

2 http://www.grida.no/climate/ipcc_tar/index.htm

3 IPCC (2001a), p. 5

4 IPCC (2000)

5 Henderson (2003)

6 Corcoran (2002). See Webster et.al. (2001) for a more in-depth analysis of projected emissions of carbon dioxide.

7 Ibid.

8 The Economist (2003)

9 A spreadsheet with the scenario data is available at: http://sres.ciesin.org/

10 Henderson (2003)

11 UNDP (2002), p. 193

12 Maddison (1991), David Landes (1999)

13 SRES (2000), p. 3

14 IPCC (2000), Special Report on Emissions Scenarios, Summary for Policymakers, Table SPM-3a, p. 17, Link: http://www.ipcc.ch/pub/sres-e.pdf

15 Gregg Marland, Tom Boden Carbon Dioxide Information Analysis Center, Link: http://cdiac.ornl.gov/ftp/ndp030/global99.ems

16 McKitrick (2003), p14

17 Own calculations based on tables SPM 1a and SPM 3a in the SRES Summary for Policymakers

18 McKitrick (2003)

19 Gray (2002)

20 Lomborg, Figure 13, p. 47

21 Gray (2002)

22 IPCC (2001), Technical Summary of Working Group I Report, Figure 22, p. 70

23 UNPP (2002)

24 http://www.un.org/News/Press/docs/2003/pop850.doc.htm

25 IPCC (2000) Table SPM 1a

26 Ibid., Table SPM 2a

27 Ibid., Table SPM 1a

28 IPCC (2000), SRES chapter 2.4.11 Carbon Intensity and Decarbonisation

29 IEA (2002b)

30 IPCC (2000), SRES chapter 2.4.11 Carbon Intensity and Decarbonisation, Figure 2–11

31 Nakicenovic and Riahi (2002); Chakravorty and Tse (no date)

32 Magné and Moreaux (2002)

33 National Academy of Sciences (2001).

Section 2: Understanding climate impacts

1 Trenberth (undated), Knowlton (2000). In fact, the Dutch government commissioned an IMAX movie by IRAS Films, *The Straw that Breaks the Camel's Back*, for screening at the World Climate Conference in The Hague, November 2000. See http://www/irasfilm.com/200101straw.htm

2 Arnell *et al.* (2002), p.418.

3 IPCC (2001a): p. 13.

4 Hulme *et al.* (1999), p. S8, S14.

5 Wigley (1998); Malakoff (1997).

6 Goklany (2003).

7 Parry *et al.* (1999), pp. S60, S62. *See also*, Gitay *et al.* (2001), p. 259.

8 Goklany (1998).

9 Goklany (1999a).

10 Arnell *et al.* (2002), p. 439.

11 *Ibid.*; McMichael *et al.* (2001), p. 466.

12 In 1990, about a tenth of the population estimated to be at risk contracted malaria, while fatalities were about 0.2% of that. *See* WHO (1999).

13 Arnell (1999), Table 5.

14 *Ibid.*: Table 6.

15 Arnell *et al.* (2002), p. 424.

16 Solomon *et al.* (1996), pp. 492–96.

17 Hulme *et al.* (1999), p.S14.

18 IPCC (2001a), p. 73; Henderson-Sellers, *et al.* (1998); Henderson-Sellers, (1998).

19 This section draws heavily upon: Goklany (2001b), pp. 465–74; and Goklany (2000).

20 WHO (1999), p. 56.

21 Goklany (2002a).

22 Goklany (2000); Goklany (2001a).

23 Goklany (1995); Goklany (2000).

24 FAOSTAT Database.

25 Goklany (1995); Goklany (1999b); Goklany (2000).

26 IPCC (2001b), p.10.

27 World Bank (2002).

28 IPCC (2001b), pp. 238, 240, 259, 295.

29 *Ibid*., pp. 957–58.

30 Pearce *et al.* (1996), p. 191.

31 Goklany (2000).

32 Byerlee and Echeverria (2002).

33 Goklany, (1998); Goklany (1999a).

34 Ha-Duong *et al.* (1997); Wigley *et al.* (1996); Wigley (1997).

35 Goklany (2000).

36 If they are not costly in a socioeconomic sense, they are, almost by definition, no-regret actions.

Section 3: Sea level changes

1 Joffe-Walt, Benjamin (2004). "Hope for the Maldives rises from the sea", *Sydney Morning Herald*, 28 August, http://www.smh.com.au/articles/2004/08/27/1093518095871.html?oneclick=true

2 WWF, "Threats to coral reefs : global warming", http://www.panda.org/about_wwf/what_we_do/marine/what_we_do/coral_reefs/threats/climatechange.cfm

3 Pirazzoli *et al.*, 1989; Mörner, 1973, 2000b.

4 Data obtained from TOPEX-POSEIDON website and publications; used in Mörner (2004). The graph shows a variability around zero level (blue) and a major ENSO event (yellow).

5 Mörner, 1995b, 1996b; INQUA, 2000.

6 Barbu, 1988

7 e.g. Hoffman *et al.*, 1983; IPCC, 2001.

8 http://earthobservatory.nasa.gov/Library/GlobalWarming/warming3.html

9 Gardiner, 1902; Agassiz, 1903; see also Davis *et al.*, 1971; Prudy, 1981).

10 INQUA, 2000; Tooley, 2000

11 Singh *et al.*, 2001

12 See Figure 1; Mörner, 2003a

13 Mörner, 2003b

14 Mörner, 2000a.

Section 4: Would malaria spread to Europe in a warmer climate?

1 See, for instance, McMichael *et al.* (1996); Patz *et al*. (1996); Hay (2001); Hay *et al*. (2002); Mouchet, J. *et al*. (1998); Epstein *et al*. (1998).; McMichael, Patz, and Kovats (1998); Martens (1998); Epstein (1999); Kovats *et al*. (1999); Reiter (2000)**;** Shanks *et al*. (2000); Reiter (2001).

2 Watson Zinyowera, and Moss (1996).

3 EPA (1997) p. 1–4.

4 Manning and Nobre (2001) p.74.

5 EPA (2002) pp.1–4.

6 Epstein (2002).

7 Wigley (1981); Lamb (1995); Chorley and Barry (1998).

8 Houghton *et. al* (1996); Tett (1999); Wigley and Schimel (2000).

9 Gilles and Warrell (1993); Cook (Ed.)(1996).

10 Bruce-Chwatt and de Zulueta (1980) p. 240

11 Craig, *et al*. (1999) pp. 105–11.

12 Martens (1998) p.176; Lindsay and Birley (1996) pp. 573–88; Jetten and Focks (1997) pp. 285–97; Patz (1998) pp. 147–53.

13 Rogers and Randolph (2000) pp. 1763–6; Dye and Reiter (2000) pp. 1697–1698.

14 Bruce-Chwatt and de Zulueta (1980) p. 240

15 Homer (1990). Book 22, lines 31–37.

16 Lamb (1995) p. 433; Jones (1909).

17 Langholf (1990).

18 Bruce-Chwatt and de Zulueta (1980) p. 240

19 Lamb (1995) p.433.; Jones (1907).

20 Dante (1949) Cantica I: Hell (L'inferno). Canto XVII, lines 85–8; Chaucer (1977). "The Nun's Priest's Tale", lines 134–140.

21 Campbell (1991) p. 232.

22 Bruce-Chwatt and de Zulueta (1980) p. 240

23 Lamb (1995) p. 433.

24 Grove (1988).

25 Bruce-Chwatt and de Zulueta (1980) p. 240.

26 Bruce-Chwatt and de Zulueta (1980) p.240; Dock (1927) pp. 241–247; Siegel and Poynter (1962) pp. 82–85; Dobson (1998) pp. 69–81.; Poser and Bruyn (1999) p.165.

27 Reiter (2000) pp. 1–11.

28 Lamb (1995) p.433.; Grove (1988).

29 Ekblom (1938) pp. 647–55.

30 Renkonen (1944) pp. 261–75.

31 Russell (1956) pp. 937–65.

32 Patz (1996) pp. 217–23.; Epstein (1998) pp. 409–417.

33 Wesenberg-Lund (1921) pp. 383–6.

34 Ekblom (1938) pp. 647–55.

35 Bruce-Chwatt and de Zulueta (1980) p.240); James (1920) pp. 71–85.

36 Bruce-Chwatt and de Zulueta (1980) p.240.

37 Crosnier (1953) pp. 1299–1388.; Laigret (1953) pp.1308–12.

38 Galli-Valerio (1917) pp. 440–54.

39 Hackett (1937) p. 336.

40 Bruce-Chwatt and de Zulueta (1980) p.240.

41 Brown, Haworth, and Zahar (1976) pp.1–25.

42 Guido Sabatinelli, W.H.O.W., Regional Office for Europe, Copenhagen, Denmark.

43 Zucker (1996).

44 Sabatinelli (1998).

45 WHO http://euro.who.int/malaria/ctryinfo/CtryInfoTop

46 http://www.cdc.gov/travel/regionalmalaria/easteurp.htm

Section 5: Will the world experience an increase in catastrophic weather events?

1 Unger (1999)

2 IPCC (2001)

3 IPCC (2001)

4 Khandekar (2001)

5 (2000).

6 IPCC (2001) Ch.9.

7 Changnon *et al.* (1999) p.1094.

8 Figure taken from Goklany (2003).

9 IPCC (2001), Impacts, Adaptation and Vulnerability, section 15.2.1.3

10 Figure taken from Goklany (2003).

11 Changnon *et al*. (1999) p.1084.

12 Figure taken from Goklany (2003).

13 Fauchereau *et al.* (2003)

14 *ibid.*

15 Figure taken from Faucherau *et al.* (2003)

16 Kunkel (2003a)

17 Kunkel (2003b)

18 Khandekar et al (2000); Kriplani and Kulkarni (1997).

19 Groisman *et al* (1999)

20 Kripalani *et al* (2003)

21 Zhai *et al.* (1999)

22 Rakhecha and Soman (1994)

23 Khandekar *et al*, (2000); Kriplani and Kulkarni (1997)

24 IPCC, 1996

25 IPCC, 2001

26 IPCC (2001)

27 Holland (1993) cited in Landsea *et al.* (1999)

28 Chan and Shi (1996).

29 Nicolls *et al.* (1998).

30 Walsh (2004).

31 Nicolls *et al.* (1998).

32 *Ibid.*

33 Changnon (2001a,b)

34 Changnon (2003)

35 Pielke Jr (2002)

Section 6: Illness and mortality from heat and cold

1 This section was first published in *Environment and Health: Myths and Realities* (London: International Policy Press, 2004).

2 Eurowinter Group (1997).

3 Keatinge WR et al (2000).

4 Donaldson *et al.* (2001).

5 Keatinge *et al.* (1989).

6 Keatinge *et al.* (1984).

7 Neild *et al.* (1993).

8 Neild *et al.* (1994).

9 Woodhouse *et al.* (1994).

10 Ophir and Elad (1987).

11 Tyrrell *et al.* (1989).

12 Donaldson and Keatinge (2002).

13 Coleshaw et al (1986).

14 Woodhouse *et al.* (1989).

15 Donaldson and Keatinge (1997).

16 Keatinge *et al.* (1986).

17 Hulme *et al.* (2001).

18 Reiter (2002).

19 Donaldson *et al.* (2003).

20 Donaldson *et al.* (1998).

21 Keatinge (1986).

22 Titus and Narayanan (1996).

Section 7: Will fisheries be altered by climate change?

1 This section is based on a longer paper, which is available at http://www.efnahagsmal.hi.is/solofile/1004158

2 Possibly weakening the Gulf-current substantially.

3 ACIA 2003

4 ACIA, 2003.

5 Arnason, 1994

6 1994

7 Arnason 1994; Agnarsson and Arnason 2003.

8 Note that merchandise exports do not represent total export earnings. Total export earnings include the exports of services in addition to merchandise exports. Over time the share of services in total exports has been increasing. Currently the export of services represents about 1/3 of total export earnings in Iceland.

9 see Agnarsson and Arnason 2003.

References

Section 1: The scenarios underlying climate change 'predictions'

Chakravorty, Ujiayant and Tse, Kin-Ping (no date). "Transition from Fossil Fuels to Renewable Energy", http://www.earthinstitute.columbia.edu/events/econSeminar/Chakravorty.pdf

Commission of the European Communities (2002), COM 702. Available at http://europa.eu.int/eurlex/en/com/rpt/2002/com2002_0702en01.pdf (last visited 13 July 2003).

Corcoran, Terence (2002). "An 'insult to science'", *National Post*, 14 December. Available at http://www.canada.com/national/nationalpost/financialpost/story.html?id=%7b54b082f6-100c-4ada-9012-edf7ec30dd03%7d

Den Elzen, M.G.J. and Both, S. (2002). "Modelling emissions trading and abatement costs in FAIR 1.1 – Case study: The Kyoto Protocol under the Bonn-Marrakech Agreement", RIVM (National Institute of Public Health and the Environment, Denmark) report 728001021, available at http://www.rivm.nl/bibliotheek/rapporten/728001021.html

The Economist (2003), "Hot Potato", 13 February.

Eurostat (2002), Yearbook, Brussels, European Commission.

Gray, Vincent (2002). *The Greenhouse Delusion*. Brentwood, Essex, UK: Multi-Science.

Grubb, Michael (forthcoming) "The Economics of the Kyoto Protocol" in Owen, Anthony D (Ed.) *The Economics of the Kyoto Protocol*.

Henderson, David (2003), "SRES and IPCC: Further Concerns", available at http://www.economist.com/displaygeneric.cfm?pageheadgif=FinanceandEconomics&key=efhp1 pp. 7–10. See also: Castles, Ian and Henderson, David (2003). Correspondence with the SRES http://www.economist.com/displaygeneric.cfm?pageheadgif=FinanceandEconomics&key=efhp1;

Castles, Ian and Henderson, David (2003). "The IPCC Emission Scenarios: An economic-statistical critique" in *Energy and the Environment*, Vol.14, Nos.2&3, pp.159–185.

International Energy Agency (IEA)(2002a), Beyond Kyoto: Energy Dynamics and Climate Stabilisation, Paris, OECD.

IEA (2002b), *Key World Energy Statistics*, http://www.iea.org/statist/keyworld2002/key2002/keystats.htm

Intergovernmental Panel on Climate Change (IPCC)(1996) *Climate Change 1995 – Scientific-Technical Analyses of Impacts, Adaptations and Mitigations of Climate Change*. Report of IPCC Working Group II. Cambridge, Cambridge University Press.

IPCC (1998), *The Regional Impacts of Climate Change: An Assessment of Vulnerability*

IPCC (2000), Special Report on Emissions Scenarios, Summary for Policymakers, http://www.ipcc.ch/pub/sres-e.pdf

IPCC (2001), *The Scientific Basis: Technical Summary*, Climate Change 2001, Working Group I, available at http://www.grida.no/climate/ipcc_tar/wg1/010.htm

Landes, David (1998), *The Wealth and Poverty of Nations*, London, Abacus.

Lomborg, Bjørn (2001), *The Skeptical Environmentalist*, Cambridge, Cambridge University Press.

Maddison, Angus (1991). *Dynamic Forces in Capitalist Development: A Long-Run Comparative View* (New York: Oxford University Press). See also Maddison, Angus (2002). *The World Economy: A Millennial Perspective* (Paris: OECD Development Centre)

Magné, Bertrand and Moreaux, Michel (2002) "Long Run Energy Trajectories: Assessing the Nuclear Option In Response To Global Warming" (Preliminary Draft). February. http://weber.ucsd.edu/~carsonvs/papers/617.pdf

Marland, Gregg (no date). Tom Boden Carbon Dioxide Information Analysis Center, Link: http://cdiac.ornl.gov/ftp/ndp030/global99.ems

McKitrick, Ross (2003). "Emission Scenarios & Recent Global Warming Projections", Fraser Forum, January.

Nakicenovic, N. and Riahi, K (2002) "An Assessment of Technology Change", International Institute for Applied Systems Analysis, 2002. Available at http://www.iiasa.ac.at/Publications/Documents/RR-02-005.pdf

National Academy of Sciences (NAS)(2001) *Climate Change Science: An analysis of some key questions*, Washington, DC, National Academy Press. Available at http://www.nap.edu/html/climatechange/

Nordhaus, William D. (2001) "Global Warming Economics", *Science*. 294, pp.1283–4. (9 November).

Nordhaus, William D. and Boyer, Joseph G. (1999). "Requiem for Kyoto: An Economic Analysis of the Kyoto Protocol", (February 8), available at http://www.econ.yale.edu/~nordhaus/homepage/Kyoto.pdf

Nordhaus, William D. and Boyer, Joseph G. (1999) "Roll the Dice Again: Economic Models of Global Warming", MIT Press (25 October), internet version: http://www.econ.yale.edu/%7Enordhaus/homepage/dice_section_I.html

UNDP (2002), Human Development Report, Oxford, Oxford University Press. http://hdr.undp.org/reports/global/2002/en/

UNPP (2002), *World Population Prospects: The 2002 Revision*. http://esa.un.org/unpp/

Webster, et. al (2001). "Uncertainty in Emissions Projections for Climate Models", MIT Joint Program on the Science and Policy of Global Change, Report No. 79 (August) Available at http://www.mit.edu/afs/athena.mit.edu/org/g/globalchange/www/MITJPSPGC_Rpt79.pdf

Section 2: Understanding climate impacts

Arnell, N. W. (1999), 'Climate Change and Water Resources,' *Global Environmental Change* 9: S31–49.

Arnell N.W. *et al.* (2002). 'The Consequences of CO2 Stabilization for the Impacts of Climate Change,' *Climatic Change* 53, pp. 413–46.

Byerlee, D. and Echeverria, R. G. (eds) (2002). *Agricultural Research Policy in an Era of Privatization* (CABI International). Chapters 1&2 online at http://www.cabi-publishing.org/Bookshop/ReadingRoom/0851996000.asp, visited 9 July 2003.

Gitay, H. *et al.* (2001), 'Ecosystems and their Goods and Services,' in IPCC, *Climate Change 2001: Impacts, Adaptation, and Vulnerability* (New York, Cambridge University Press, 2001).

Goklany, I. M. (1995), 'Strategies to Enhance Adaptability: Technological Change, Sustainable Growth and Free Trade', *Climatic Change* 30, pp. 427–49.

Goklany, I. M. (1998), 'Saving Habitat and Conserving Biodiversity on a Crowded Planet', *BioScience* 48, pp. 941–53.

Goklany, I. M. (1999a), 'Meeting Global Food Needs: the Environmental Tradeoffs

Between Increasing Land Conversion and Land Productivity', *Technology* 6, pp. 107–30.

Goklany I. M. (1999b), 'Richer Is More Resilient: Dealing with Climate Change and More Urgent Environmental Problems', in R. Bailey (ed.), *Earth Report 2000: The True State of the Planet Revisited* (New York, McGraw-Hill, 1999).

Goklany, I. M. (2000), 'Potential Consequences of Increasing Atmospheric CO2 Concentration Compared to Other Environmental Problems', *Technology* 7S, pp. 189–213.

Goklany, I. M. (2001a), *Economic Growth and the State of Humanity* (Bozeman, MT: Political Economy Research Center).

Goklany, I. M. (2001b), 'The Problem of the Last Straw: The Case of Global Warming', in Dorf, R. (ed.), *Technology, Humans, and Society: Toward a Sustainable World* (San Diego, Academic Press, 2001).

Goklany, I. M. (2002a), 'Affluence, Technology, and Well-Being', *Case Western Reserve Law Review* 53, pp. 369–90.

Goklany, I. M. (2003), 'Relative Contributions of Global Warming to Various Climate Sensitive Risks, and Their Implications,' (in review; paper submitted to journal for review).

Ha-Duong, M., Grubb, M. J. and Hourcade, J. C. (1997), 'Influence of Socioeconomic Inertia and Uncertainty on Optimal C02-Emission Abatement', *Nature* 390, pp. 270–73.

Henderson-Sellers, A. *et al.* (1998), 'Tropical Cyclones and Global Climate Change: a Post-IPCC Assessment', *Bulletin of the American Meteorological Society* 79, pp. 19–38.

Henderson-Sellers, A. (1998), 'Climate Whispers: Media Communication about Climate Change', *Climatic Change* 40, pp. 421–56.

Hulme, M., Mitchell, J., Ingram, W., Lowe, J., Johns, T., New, M. and Viner, D. (1999), 'Climate Change Scenarios for Global Impact Studies', *Global Environmental Change* 9, pp. S3–S19.

Intergovernmental Panel on Climate Change (IPCC) (2001a), *Climate Change 2001: The Scientific Basis* (New York, Cambridge University Press, 2001).

IPCC (2001b), *Climate Change 2001: Mitigation* (Cambridge [UK], Cambridge University Press, 2001).

McMichael A. *et al.* (2001), 'Human Health', in IPCC (2001b).

Parry, M. L., Rosenzweig, C., Iglesias, A. Fischer, G. and Livermore, M. (1999), 'Climate Change and World Food Security', *Global Environmental Change* 9, pp. S51–S67.

Pearce, D. W., *et al.* (1996), 'The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control', in IPCC, *Climate Change 1995: Economic and Social Dimensions of Climate Change* (New York, Cambridge University Press, 1995).

Solomon, A. F. *et al.* (1996), 'Wood Production under Changing Climate and Land Use', in IPCC, *Climate Change 1995: Impacts, Adaptations and Mitigation* (Cambridge, Cambridge University Press, 1996).

Trenberth, K. (undated), 'Does Climate Change Cause More Extreme Weather? Yes', in *Washington Post*, Issues from Global Climate Change, undated, online at www.washingtonpost.com/wp-adv/specialsales/nei/global/article9.htm, visited 4 December 2002 (no longer available).

Wigley, T. M. L. *et al.* (1996), 'Economic and Environmental Choices in the Stabilization of Atmospheric CO2 Concentrations', *Nature* 379, pp. 240–43.

Wigley, T. M. L. (1997), 'Implications of Recent CO2 Emission-Limitation Proposals for Stabilization of Atmospheric Concentrations', *Nature* 390, pp. 267–70.

World Bank, *World Development Indicators 2002*.

World Health Organization (1999), *World Health Report 1999* (Geneva: WHO).

Section 3: Sea level change

Agassiz, A., 1903. The coral reefs of the Maldives. *Mem. Mus. Comp. Zoology Harv. Coll.* 29, 1–168.

Anderson, R.C., 1998. Submarine topography of Maldivian atolls suggests a sea level of 130 metres below present at the last glaciation maximum. *Coral Reefs* 17, 339–341.

Barbu, E.M. (Ed.), 1988. Proc. ODP, Initial Reports, p. 115.

Davis, P.S., Stoddart, D.R., Sigeo, D.C., 1971. Reef forms of Addu Atoll, Maldive Islands. *Symp. Zool. Soc. Lond.* 28, 217–259.

Gardiner, J.S., 1902. The formation of the Maldives. *Geogr. J.* 19, 277–301.

Hoffman, J.S., Keyes, D., Titus, J.G., 1983. *Projecting future sea level rise.* US Environmental Protection Agency. Gov. Print. Office, Washington, DC. 266 pp.

IGBP (International Geosphere-Biosphere Programme), 1992. Global change. Reducing Uncertainties.

INQUA (International Union for Quaternary Research), 2000. Homepage of the commission on sea level changes and coastal evolution, http://www.pog.su.se/sea. Sea Level Changes, News and Views, The Maldives Project.

Mörner, N.-A., 1973. Eustatic changes during the last 300 years. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 9, 153–181.

Mörner, N.-A., 1992. Sea-level changes and earth's rate of rotation. *J. Coastal Res.* 8, 966–971.

Mörner, N.-A., 1995. Recorded sea level variability in the Holocene and expected future changes. In: Eisma, D. (Ed.), *Climate Change. Impact on Coastal Habitation*. CRC Press, Boca Raton, FL, pp. 17–28.

Mörner, N.-A., 1996. Sea level variability. *Z. Geomorphol*., N.F., Suppl-Bd. 102, 223–232.

Mörner, N.-A., 2000a. Sea level changes in the Indian Ocean. *Integrated Coastal Zone Management*, Launch Ed. IPC Publ., pp. 17–20.

Mörner, N.-A., 2000b. Sea level changes along Western Europe. *Integrated Coastal Zone Management*, 2nd ed. IPC Publ., London-Hong Kong, pp. 33–37.

Mörner, N.-A., Laborel, J., Tooley, M., Dawson, S., Allison, W., Islam, S., Laborel, F., Collina, J. & Rufin., C., 2003. Sea level changes: The Maldives Project. Freed from condemnation to become flooded. *GI2S Coast, Res. Publ.,* 4, p. 175–176.

Mörner, N.-A., 2004a. Estimating future sea level changes. *Global Planet. Change*, 40, 49–54.

Mörner, N.-A., Tooley, M. & Possnert, G., 2004b. New perspectives for the future of the Maldives. *Global Planet. Change*, 40, 177–182.

Mörner, N.-A., 2004c. Changing Sea Levels. In: *Encyclopedia of Coastal Science* (M. Schwartz, Ed.), p. 284–288.

Mörner, N.-A., 2004d. The Maldives Project: a future free from sea level flooding. *Contemprary South Asia*, 13 (2), p. 149–155.

Peltier, W.R., Tushinghan, A.M., 1989. Global sea level rise and the greenhouse effect. Might there be a connection? *Science* 244, 806–810.

Pfeiffer, M., Dullo, C., Eisenhauer, A., 2001. Indian Ocean reef corals: evidence for secular changes in monsoon circulation? In: Ruth, S., Rüggenberg, A. (Eds.), 2001 Margins Meeting *Schrift. Deutschen Geol. Gesellschaft*, vol. 14, pp. 151–152.

Pirazzoli, P.A., Grant, D.R., Woodworth, P., 1989. Trends of relative sea-level changes: past, present, future. *Quat. Int.* 2, 63– 71.

Prudy, E.G., 1981. Evolution of the Maldive atolls, Indian Ocean. *Proc 4th Int. Corral Reef Symp*. 1, 659.

Singh, O.P., Ali Khan, T.M., Aktar, F., Sarker, M.A., 2001. Recent sea level and sea surface temperature change along the Maldives coast. *Mar. Geod.* 24, 209–218.

Woodroffe, C.D., 1992. Morphology and evolution of reef islands in the Maldives. *Proc. 7th Int. Coral Reef Symp.*, Gaum 2, 1217–1226.

Section 4: Would malaria spread to Europe in a warmer climate?

Brown, A.W. Haworth, A.J., and Zahar, A.R (1976) "Malaria eradication and control from a global standpoint" *Journal of Medical Entomology,* vol.13, pp.1–25.

Bruce-Chwatt, L.J. and de Zulueta, J (1980). *The rise and fall of malaria in Europe, a historico-epidemiological study*. Oxford, Oxford University Press.

Campbell, B.M.S. (ed.)(1991) *Before the Black Death: studies in the 'crisis' of the early fourteenth century*. Manchester, Manchester University Press.

Calder, N. (1974) *The Weather Machine.* New York, Viking.

Chaucer, G. (1977) *The Canterbury Tales; translated into Modern English by Nevill Coghill.* London: Penguin.

Chorley, R.J. and Barry, R. G. (1998) *Atmosphere, Weather and Climate*. Routledge.

Cook, G. (ed.) (1996) *Manson's Tropical Diseases*. 20th ed. London, W. B. Saunders Co.

Craig, M.H., Snow, R.W. and D. le Sueur (1999), "A climate-based distribution model of malaria transmission in sub- Saharan Africa" *Parasitology Today* vol. 15, no. 3, pp. 105–11.

Crosnier, F. (1953) "De quelques considérations sur le paludisme métropolitain" *Revue Path.* hum. comp. 53, pp. 1299–1388.

Dante, A., *The Comedy of Dante Alighieri the Florentine.* London, Penguin (reprinted).

Dobson, M.J. (1998) "Bitter-sweet solutions for malaria: exploring natural remedies from the past." *Parassitologia*, vol. 40, nos.1&2, pp. 69–81.

Dock, G., (1927) *Robert Talbor, Madame de Sévigné, and the introduction of cinchona. An episode illustrating the influence of women in medicine.* Annals of Medical History vol. 4, pp. 241–247.

Dye, C. and Reiter, P. (2000) *Temperatures without fevers? Science* vol. 289, pp.1697–1698.

Ekblom, T. (1938) "Les races Suédoises de l'Anopheles maculipennis et leur role épidémiologique". *Bull Soc Pathol Exot* vol.31, pp. 647–55.

Epstein, P.R., *et al*. (1998) "Biological and physical signs of climate change: focus on mosquito-borne diseases." *Bulletin of the American Meteorological Society* vol. 79, pp. 409–417.

Epstein, P.R. (1999) "Climate and Health". *Science* vol. 285, pp. 347–348.

Epstein, P.R. (2002) *Global Warming: Health and Disease*. WWF.

Environmental Protection Agency (EPA)(1997) *Climate Change and Public Health*. Office of Policy, Planning and Evaluation (2171), Washington, D.C, EPA.

EPA (2002). *Global Warming – Impacts. Health.* Office of Policy, Planning and Evaluation. Washington, DC, EPA.

Galli-Valerio, B. (1917) *La distribution géographique des Anophèlines en Suisse au point du vue du danger de formation de foyers de malaria.* Bull. schweiz. Gesundheit Amt., vol. 40 pp. 440–54.

Gilles, H.M. and Warrell, D.A., (Eds.)(1993) *Bruce-Chwatt's essential malariology.* London, Edward Arnold.

Grove, J.M. (1988) *Little Ice Age*. London: Routledge, Keegan and Paul.

Hackett, L.W. (1937) *Malaria in Europe, an ecological study*. London, Oxford University Press.

Hay, S.I., (2001). "The world of smoke, mirrors and climate change". *Trends Parasitol*, vol. 17, no. 10, pp. 466.

Hay, S.I., *et al* (2002). " Climate change and the resurgence of malaria in the East African highlands." *Nature* vol. 415 pp. 905–9.

Homer (1990) *The Iliad*; translated by Robert Fagles. New York, Viking Penguin.

Houghton, J.T., *et al*. (Eds.) (1996) *The Science of Climate Change. Contribution of Working Group I to the Second Assessment of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge, Cambridge University Press.

James, S.P. (1920) "The disappearance of malaria from England". *Proc R. Soc. Med*. vol.23 pp. 71–85.

Jetten, T.H. and Focks, D.A (1997) "Potential changes in the distribution of dengue transmission under climate warming." American Journal of Tropical Medicine and Hygiene vol. 57, no.3, pp. 285–97.

Jones, W.H.S. (1909) *Malaria and Greek History*. Manchester, Manchester University Press.

Jones, W.H.S. (1907) *Malaria: a neglected factor in the history of Greece and Rome*. Cambridge, Macmillan and Bowes.

Kovats, R.S., *et al*. (1999). "Climate change and human health in Europe." *British Medical Journal* vol. 318 pp. 1682–5.

Laigret, M. (1953) *Remarques d'ordre général concernant la régression du paludisme dans nos pays. Revue Path*. hum. comp. vol. 53 pp.1308–12.

Lamb, H.H. (1995) *Climate, history and the modern world*. London, Routledge.

Langholf, V. (1990), *Medical theories in Hippocrates: early texts and the 'Epidemics' (Untersuchungen zur Antiken Literature und Geschichete, Band 34)*. Berlin, Walter de Gruyter.

Lindsay, S.W. and Birley, M.H. (1996) "Climate change and malaria transmission". *Ann Trop Med Parasitol* vol. 90 no.6 pp. 573–88.

Manning, M. and Nobre, C. (Eds.) (2001) *Technical Summary. Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge, Cambridge University Press.

Martens, P. (1998) *Health and climate change: modelling the impacts of global warming and ozone depletion*. London: Earthscan Publications.

McMichael, A.J., Patz, J and Kovats, R.S. (1998). "Impacts of global environmental change on future health and health care in tropical countries". *British Medical Bulletin* vol. 54 no.2 pp. 475–88.

McMichael, A.J., *et al*. (1996) *Climate change and human health*. Geneva, World Health Organisation.

Mouchet, J., *et al*. (1998) "Evolution of malaria in Africa for the past 40 years: impact of climatic and human factors". *Journal of the American Mosquito Control Association*, vol. 14 no.2 pp.121–30.

Patz, J.A., *et al*. (1996), "Global climate change and emerging infectious diseases" *Journal of the American Medical Association* vol. 275 no.3 pp. 217–23.

Patz, J.A. *et al*. (1998) "Dengue fever epidemic potential as projected by general circulation models of global climate change." *Environmental Health Perspectives vol* 106 no. 3 pp. 147–53.

Poser, C.M. and G.W. Bruyn (1999) *An illustrated history of malaria*. New York, Parthenon.

Reiter, P. (2000) "From Shakespeare to Defoe: Malaria in England in the Little Ice Age" *Emerging Infectious Diseases* vol. 6 no.1 pp. 1–11.

Reiter, P. (2001) Climate change and mosquito-borne disease. *Environmental Health Perspectives* vol 109 Suppl 1, pp. 141–61.

Renkonen, K.O. (1944) "Über das Vorkommen von Malaria in Finnland." *Acta Medica Scandinavica* vol.119 pp. 261–75.

Rogers, D.J. and Randolph, SE (2000) "The global spread of malaria in a future, warmer world". *Science* vol. 289 pp. 1763–6.

Russell, P.F. (1956) "World-wide malaria distribution, prevalence, and control." *American Journal of Tropical Medicine and Hygiene* vol. 5 pp. 937–65.

Sabatinelli, G. (1998) *Malaria situation and implementation of the global malaria control strategy in the WHO European region.* World Health Organisation Expert Committee on Malaria, 1998. MAL/EC20/98.9.

Shanks, G.D. *et al*. (2000) "Changing patterns of clinical malaria since 1965 among a tea estate population located in the Kenyan highlands" *Trans R Soc Trop Med Hyg* vol. 94 pp. 253–255.

Siegel, R.E. and Poynter, FNL (1962) "Robert Talbor, Charles II and Cinchona. A contemporary document." *Medical History* vol.6 pp. 82–85.

Tett, S.F.B. *et al* (1999). "Causes of twentieth-century temperature change near the Earth's surface" *Nature*. vol. 399 pp. 569–572.

Watson, R.T., M.C. Zinyowera, and R.H. Moss (Eds.)(1996) *Impacts, Adaptations and Mitigation of Climate change: Scientific-Technical analyses. Contribution of Working Group II to the Second Assessment of the Intergovernmental Panel on Climate Change* Cambridge, Cambridge University Press.

Wesenberg-Lund, C. (1921), "Sur les causes du changement intervenu dans le mode de nourriture de l'Anophèle maculipennis." *C. r. Séanc. Soc. Biol* vol.85 pp. 383–6.

Wigley, T.M.L., M.J. Ingram, and G. Farmer (Eds.)(1981) *Climate and History*. Cambridge, Cambridge University Press.

Wigley, T.M.L. and Schimel, D. (Eds.)(2000) *The Carbon Cycle*. 2000, Cambridge, Cambridge University Press.

Zucker, J.R. (1996) "Changing patterns of autochthonous malaria transmission in the United States: a review of recent outbreaks" Emerging Infectious Diseases vol. 2 no.1 pp. 37–89.

Section 5: Will the world experience an increase in catastrophic weather events?

Chan, J.C.L. and Shi, J. (1996). Long-term trends in interannual variability in tropical cyclone activity over the western Pacific. *Geophysical Research Letters* 23, pp. 2765–2767.

Changnon, S.A., K.E. Kunkel, and R.A. Pielke Jr., (1999). Temporal Fluctuations in Weather and Climate Extremes That Cause Economic and Human Health Impacts: A Review, *Bulletin of the American Meteorological Society*, Vol. 80, No. 6, Jun. 1999, pp 1077–1098.

Changnon, S.A., R.A.Pielke Jr., D. Changnon, R.T. Sylves and R. Pulwarty. (2000). Human Factors Explain the Increased Losses from Weather and Climate Extremes. *Bulletin of the American Meteorological Society*, Vol. 81, No. 3, March 2000, pp 437–442.

Changnon, S. A. (2001a). Thunderstorms across the nation: An atlas of storms, hail and their

damages in the 20th century. Mahomet Illinois, USA: Changnon Climatologist.

Changnon, S. A. (2001b). Damaging thunderstorm activity in the United States. *Bull. Amer. Meteor. Soc.* 82,597–608.

Changnon, S. A. (2003). Shifting economic impacts from extreme weather in the United States: A result of societal changes and not global warming. *Natural Hazards*, Sp Issue vol 29, no. 2, June.

Fauchereau N.; Trzaska S.; Rouault M.; Richard Y. (2003). Rainfall Variability and Changes in Southern Africa during the 20th Century in the Global Warming Context, *Natural Hazards*, June, vol. 29, no. 2, pp. 139–154(16)

Goklany, Indur. (2003). "Climate change: the 21st century's most urgent environmental problem or proverbial last straw?" in Okonski, K. (ed) *Adapt or Die: The science, politics and economics of climate change*. London: Profile Books.

Groisman, P.,Ya, Karl, Easterling, Knight, Jamason, Hennessy, Suppiah, Page, Wibig, Fortuniak, Razuvaev, Douglas, Forland and Zhai, (1999), Changes in the probability of heavy precipitation: important indicators of climate change, *Climatic Change*. 32, 243–283.

Intergovernmental Panel on Climate Change (IPCC)(1996), *Second Assessment Report*

IPCC (2001). *Third Assessment Report*. Impacts, Adaptation and Vulnerability, section 15.2.1.3. http://www.grida.no/climate/ipcc_tar/wg2/557.htm

Kharin, V.V. and F.W. Zwiers (2000). Changes in extremes in an ensemble of transient climate simulations with a coupled atmosphere-ocean GCM. *J of Climate*,13,3760–3780.

Khandekar, M.L., T.S. Murty, T.S., Scott, D., and Baird, W. (2000), The 1997 El Nino, Indonesian Forest Fires and the Malaysian smoke problem: A deadly combination of natural and man-made hazard. *Natural Hazards* 21*, 131–144.*

Khandekar, ML. (2002). *Trends and Changes in Extreme Weather Events: An assessment with focus on Alberta and Canadian Prairies.* Edmonton: Alberta Environment.

Kriplani, R.H. and Kulkarni, A. (1997), Rainfall variability over south-east Asia: Connection with Indian Monsoon and ENSO extremes: New perspectives. *Int. J. of Climatology*. 17, 1155–1168.

Kripalani, RH, Kulkarni, A, Sabade, SS, Khandekar, ML. (2003) Indian Monsoon Variability in a Global Warming Scenario; *Natural Hazards* 29 (2): 189–206, June.

Kunkel, E.K. (2003a), North American trends in extreme precipitation. *Natural Hazards*. *29*, 291–305.

Kunkel, E.K. (2003b), Temporal variation of extreme precipitation of USA. *Geophy. Research Letters. 30,* 1900–1903.

Landsea, C.W., R. Pielke Jr., A.M. Mestas-Nuñez, J.A. Knaff (1999). Atlantic basin hurricanes: indices of climate change. *Climatic Change*, 42:89–129.

Nicolls, N., Landsea, C., Gill, J. (1998). Recent trends in Australian region tropical cyclone activity. *Meteorol. Atmos. Phys.* 65, pp. 197–205.

Pielke, Jr. R. (2002). Chapter Channel, "Is extreme weather increasing?" *Bull. Am. Met. Soc.* 83, p.15.

Rakhecha, P.R. and Soman, M.K. (1994), Trends in the annual extreme rainfall events of 1 to 3 days duration over India, *Theor. and Applied Climatology. 48*, *227–237.*

Unger, S. (1999). Is strange weather in the air? A study of U.S. national network news coverage of extreme weather events. *Climatic Change*, 41, 133–150

Walsh, K. (2004). Tropical cyclones and climate change: Unresolved issues. *Climate Research*, August.

Zhai,P., Sun, Ren, Liu, Gao, and Zhang (1999), Changes of climate extremes in China, *Climatic Change*. *42,* 203–218.

Zhang, Xuebin, K.D. Harvey, W.D. Hogg and T.R. Yuzyk, (2001). Trends in Canadian streamflow. *Water Res.Research,*37, 987–998.

Section 6: Illness and mortality from heat and cold

Coleshaw, S. R. K., Easton, J. C., Keatinge, W. R., Floyer, M. A., Garrard, J. (1986). "Hypothermia in emergency admissions in cold weather." *Clinical Science* 70 (Suppl. 13), pp.93–94P.

Donaldson, G. C., Keatinge, W. R. (1997). "Early increases in ischaemic heart disease mortality dissociated from, and later changes associated with, respiratory mortality, after cold weather in south east England." *J. Epidemiol. Comm. Health* 51, pp. 643–8.

Donaldson, G. C., Ermakov, S. P., Komarov, YM, McDonald, C. P., Keatinge, W. R. (1998). "Cold-related mortalities and protection against cold in Yakutsk, eastern Siberia: observation and interview study." *British Medical Journal* 317, pp. 978–82.

Donaldson, G. C., Kovats, R. S., Keatinge, W. R., McMichael, R. J. (2001). "Heat- and cold-related mortality and morbidity and climate change." in Maynard, R. L., Ed. *Health effects of climate change in the UK*, pp.70–80. UK: Report to the Department of Health.

Donaldson, G. C., Keatinge, W. R. (2002). "Excess winter mortality: influenza or cold stress? Observational study." *British Medical Journal* 324, pp. 89–90.

Donaldson, G. C., Keatinge W. R., Nayha S. (2003). "Changes in summer temperature and heat related mortality since 1971 in North Carolina, South Finland and Southeast England." *Environmental Research*, 91, pp. 1–7.

Eurowinter Group: Keatinge, W. R., Donaldson, G. C., Bucher, K., Cordioli, E., Dardanoni, L., Jendritzky, G., Katsouyanni, K., Kunst, A. E., Mackenbach, J. P., Martinelli, M., McDonald, C., Näyhä, S., Vuori, I. (1997) "Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe." *The Lancet* 349, pp. 1341–1346.

Hulme, M., Jenkins, G., Brooks, D., Cresswell, R., Doherty, R., Durman, C., Gregory, J., Lowe, J., Osborn, T. (2001). "What is happening to global climate and why?" in Maynard, R. L., Ed. *Health effects of climate change in the UK*, pp.70–80. UK: Report to the Department of Health.

Keatinge, W. R., Coleshaw, S. R. K., Cotter, F., Mattock, M., Murphy, M., Chelliah, R. (1984). "Increases in platelet and red cell counts, blood viscosity, and arterial pressure during mild surface cooling: factors in mortality from coronary and cerebral thrombosis in winter." *British Medical. Journal* 289 pp. 1405–1408.

Keatinge, W. R. (1986). "Seasonal mortality among elderly people with unrestricted home heating." *British Medical Journal* 293, pp. 732–733.

Keatinge, W. R., Coleshaw, S. R. K., Easton, J. C., Cotter, F., Mattock, M. B., Chelliah R. (1986). "Increased platelet and red cell counts, blood viscosity and plasma cholesterol level during heat stress, and mortality from coronary and cerebral thromboses." *American Journal of Medicine* 81, pp. 795–800.

Keatinge, W. R., Coleshaw, S. R. K., and Holmes, J. (1989). "Changes in seasonal mortality with improvement in home heating in England and Wales 1964–1984" *International Journal of Biometeorology* 33, pp. 71–76.

Keatinge, W. R., Donaldson, G. C., Cordioli, E., Martinelli, M., Kunst, A. E., Mackenbach, J. P., Nayha, S., Vuori, I. (2000). "Heat related mortality in warm and cold regions of Europe, observational study." *British Medical Journal* 321, pp. 670–3.

Ophir, D., Elad, Y. (1987). "Effects of steam inhalation on nasal patency and nasal symptoms in patients with the common cold." *Amer J Otolaryngol* 3, pp. 149–153.

Neild, P. J., Syndercombe-Court, D., Keatinge, W. R., Donaldson, G. C., Caunce M. (1993). "Role of cold diuresis and natriuresis in the haemo-concentration caused by exposure to cold in man." p95 in Milton, A.S. Ed. *Thermal Physiology*. Aberdeen: International Union of Physiological Sciences Thermal Physiology Commission.

Neild, P. J., Syndercombe-Court, D., Keatinge, W. R., Donaldson, G. C., Mattock, M., Caunce, M. (1994). "Cold-induced increases in erythrocyte count, plasma cholesterol and plasma fibrinogen of elderly people without comparable rise in protein C or factor X." *Clin.Sci.* 86 pp.43–48.

Reiter, P. (2003) "Could global warming bring mosquito-borne disease to Europe?" in Okonski, K. Ed. *Adapt or Die: The Science, Politics and Economics of Climate Change.* London: Profile Books.

Titus, J. G., Narayanan, V. (1996). "The risk of sea level rise: a Delphic Monte Carlo analysis in which twenty researchers specify subjective probability distributions for model coefficients within their respective areas of expertise." *Climatic change* 33, pp.151–212.

Tyrrell, D., Barrow, I., Arthur, J. (1989). Local hypothermia benefits natural and experimental common colds. *British Medical Journal* 298, pp. 1280–1283.

Woodhouse, P., Coleshaw, S. R. K., Keatinge, W. R. (1989). "Factors associated with hypothermia in patients admitted to a group of inner city hospitals." *The Lancet* 2, pp.1201–1205.

Woodhouse, P. R., Khaw, K-T, Plummer, M., Foley, A., Meade, T. W. (1994). "Seasonal variations of plasma fibrinogen and factor VII in the elderly: winter infections and death from cardiovascular disease." *The Lancet* 343, pp. 435–439.

Section 7: Will fisheries be altered by climate change?

ACIA (2003). Draft Report. Forthcoming.

ACIA (2003). http://www.acia.uaf.edu.

Agnarsson, S. & Arnason, R. (2003). *The Role of the Fishing Industry in the Icelandic Economy. An Historical Examination*. Institute of Economic Studies. University of Iceland. (Forthcoming).

Arnason, R. (1994). *The Icelandic Fisheries*: *The Evolution of a Fishing Industry*. Oxford: Fishing News Books.

Other IPN publications

Environment and Health: Myths and Realities
Edited by Kendra Okonski and Julian Morris
International Policy Press, 2004, £12.99

Adapt or Die: The Science, Politics and Economics of Climate Change
Edited by Kendra Okonski
Profile Books, 2003, £14.99 (available from IPN)

Sustainable Development: Promoting Progress or Perpetuating Poverty?
Edited by Julian Morris
Profile Books, 2002, £14.99 (available from IPN)

The impacts of climate change
An appraisal for the future

The present and future impacts of climate change have sometimes been exaggerated to the public and invoked as a justification for policies to mitigate humanity's influence on the earth's climate.

What is the historical and current scientific evidence for these impacts, and their causes? Are we experiencing these impacts now and if so, is it due to human-induced climate change? What does the future really hold for humanity and the planet?

A critical evaluation of potential climate impacts by economists and scientists, *The impacts of climate change: An appraisal for the future* offers answers to these and other questions.

- Economic scenarios underlying climate models
- Understanding climate impacts
- Sea level rise and low-lying coastal areas
- The spread of vector-borne disease
- Extreme weather phenomena
- Human deaths from heat and cold
- North Atlantic fisheries

£10

ISBN 1-905041-01-2

9 781905 041015

International Policy Network

International Policy Press
A division of International Policy Network