

Climate Science and Policy: Making the Connection



The European Science and Environment Forum

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Cover photo:

Lightning striking the Eiffel Tower, June 3, 1902 at 9.20pm.

This is one of the earliest photographs of lightning in an urban setting. In: 'Thunder and Lightning' by Camille Flammarion, translated by Walter Mostyn and published in 1906.

Courtesy of National Oceanographic and Atmospheric Administration and the US Department of Commerce. Ref [www//photolib.noaa.gov/historic/nws/images/big/weaoo602.jpg](http://photolib.noaa.gov/historic/nws/images/big/weaoo602.jpg)

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Preface

The re-issue in the United Kingdom of this recently published booklet on climate change science and related public policy is to be warmly and widely welcomed.

In the UK, to date, critical discussion of climate change science and public policy has been far from adult, having been largely driven by European political agendas at both the governmental and the non-governmental levels. The problem has been further exacerbated by many of the more *bien pensant* media, such as *The Guardian* newspaper and Channel 4 TV 'News', which have frequently ignored science and economics critical of the Intergovernmental Panel on Climate Change (IPCC) and of the Kyoto Protocol. Indeed, there have sometimes been most unworthy attempts either to rubbish outright the scientific qualifications of those critical of the IPCC and of the Protocol or to claim that these represent a very tiny minority of contrarian and rather idiosyncratic scholars.

The George C. Marshall Institute is therefore to be congratulated for producing a new and most accessible booklet. It was written by the Marshall Institute (and is MI's opinion) after consultation with 11 major scholars all international authorities in their field of expertise, be it climate change science, environmental economics, or public policy. The universities represented are some of the world's finest, such as the Massachusetts Institute of Technology (MIT), Johns Hopkins, Harvard, Princeton, Delaware and Rochester, while other contributors include the President of the New York Academy of Sciences and Roger Sedjo from 'Resources for the Future'. The final 'Report' was put together by Dr Lenny Bernstein, a chemical engineer and himself a Lead Author for the IPCC's latest 'Third Assessment Report'. The academic legitimacy of the working group is thus beyond reproach, so much so that this particular booklet cannot be lightly dismissed or ignored in the manner that has all too readily characterised the behaviour in Europe of those unwilling to countenance any serious criticism of the concept of 'global warming' and of the Kyoto Protocol.

Europeans would therefore do well to heed the lessons of this booklet, for in countries such as the USA, Australia, Canada, and India, there is a much more open and critical approach to questioning the science of climate change and the proposed policy outcomes. And, perhaps even more significantly, it is surely this booklet, among others, that will inform policy making in President Bush's administration. To ignore the arguments presented here would be to fail to grasp the genuine reasons why many scientists and

scholars continue to reject the approach adopted by the IPCC and the Kyoto Protocol.

The aims of the booklet

The fundamental aim of the booklet is to help to clarify our current understanding of the highly complex science of climate change, thereby providing a stronger and more reliable basis for public policy debate. The authors correctly believe that sensible public policy can only rest on an honest, open, critical, and sound scientific foundation.

The booklet also aims to demystify the Intergovernmental Panel on Climate Change (IPCC), which, in the media, is often presented as a purely scientific and technical body. In reality, while the work of the IPCC involves many leading experts in the science of climate change, the IPCC itself is made up of governmental representatives, often the very same individuals who represent their countries at the ongoing Kyoto Protocol negotiations. The IPCC procedures are accordingly much more a cross between an element of scientific peer-review and intergovernmental wrangling.

The working party argues that there are two major concerns about the IPCC, namely the process that results in the production of the 'Summary for Policymakers' (SPMs) and the overriding emphasis on reaching consensus, a requirement that misleadingly reduces 'uncertainty' in the science. It will come as a big surprise to many to learn that the SPMs are concocted, line-by-line, at an IPCC Plenary Session during which the only scientists present are the so-called Convening Lead Authors. These can prevent governments from making changes that are factual nonsense, but they have much less influence over tone or political emphasis. The final Summary statement that reaches the world's media is thus very much a *political* document, a fact often overlooked by eager reporters awaiting the final 'scientific' proof of apocalyptic 'global warming'.

The science

Proponents of the general myth of 'global warming', as distinct from the complex science of climate change, assert without question that:–

- Recent temperature change is primarily caused by the human production of greenhouse gases, such as carbon dioxide and methane;
- Climate models clearly show that the Earth will suffer a large increase in temperature by as much as 6°C by the year 2100; and that

- We can only produce a ‘sustainable’ climate by controlling the human emissions of greenhouse gases.

In stark contrast, the authors of this booklet observe that:–

- While there is general agreement that increasing greenhouse gas concentrations may contribute to warming, there is no agreement that they have been or are the dominant factor;
- The relative rates of temperature rise at the surface and in the lower- to mid-troposphere do not exhibit a pattern consistent with the greenhouse warming theory;
- Our current climate models fail lamentably to cope with the behaviour of water vapour (the most important greenhouse gas of all), clouds, aerosols (atmospheric particles), ocean currents, and many other key factors, thus creating significant uncertainties;
- Models which strive to incorporate everything from dust to vegetation may look great, but the error range associated with each new additional factor results in near total uncertainty;
- The overarching assumption claiming that the models accurately simulate ‘natural’ variability, including volcanic eruptions and solar cycles and irradiance, is questionable because ‘natural’ variability *sensu lato* is a major unknown;
- When all the known information is taken into account, the IPCC simulation of surface temperature appears to be little more than a fortuitous bit of curve fitting rather than any genuine demonstration of human influence on global climate and climate change;
- The idea that feedbacks in the system generated by warming will always be positive – thus leading to more warming – is likely to be false; recent work on clouds and moisture, for example, clearly indicating the precise opposite, namely a negative feedback. If this latter finding were to be verified by further research, then any temperature rise associated with increased concentrations of greenhouse gases would be much smaller than currently predicted.

In terms of the basic science, therefore, there is very good reason to doubt the underlying conceptual models underpinning the approach of the IPCC and, by extension, of the Kyoto Protocol. Moreover, there still appears to be too much uncertainty in the estimates of both future gas emissions and

climate models to provide a sound and confident basis for projecting future climates.

A call for action on climate science

While admitting that a perfect understanding of climate change is probably beyond our reach, because parts of the climate system appear to be ‘chaotic’, the working party go on to call for further action in both science and public policy.

In terms of the science, we require a much better knowledge of the key climate processes, especially of clouds, solar cycles, and ocean currents. We also need a much fuller understanding of the role of humans with regard to gas emissions and to landscape alterations. Both of these, in turn, require better climate data to test and calibrate the climate models and improved computer capacity to represent climate processes at the necessary levels of spatial and temporal complexity.

It is thus vital to reverse, as soon as possible, the current deterioration in our existing global observational capacity, to identify critical factors not currently measured, and to build climate-observing requirements into all relevant national and international operational programmes.

This means that countries around the world will actually have to put their money where their mouth is and back their seeming concerns over climate change with ‘tangible commitments to collecting the data needed to address’ the uncertainties in climate change science.

The Kyoto Protocol is not the way forward

In the light of the above, it is clear that the mandatory, command-and-control, economics and politics of the Kyoto Protocol are not justified. Indeed, as the authors rightly conclude, ‘...actions must not be predicated on speculative images of an apocalyptic vision of life by 2100.’

This does not mean, however, that cost-effective and voluntary reductions in greenhouse gas emissions should not go forward. There are many sound economic and political reasons for diversifying energy technology that have absolutely nothing to do with climate change. Indeed, over-hyping the theoretical link with climate could ultimately prove counterproductive, especially if climate unhelpfully fails to live up to the expectations of an apocalyptic vision. The baby of sensible energy development could be thrown out with the dirty bath water of exaggeration and ecohype.

Above all, then, this booklet exposes the dangers of expressing certainty in science when uncertainty remains pervasive throughout. It challenges the antinomy that lies at the very heart of both the IPCC and the Kyoto Protocol, namely that climate is the most complex chaotic coupled non-linear system and we can control it by trying to manipulate just one small set of factors.

Scientifically, this is not mere uncertainty: it is a lie.

Philip Stott

Emeritus Professor of Biogeography in the University of London

11th January, 2002

Publisher's note

ESEF is pleased to reproduce this report of the George C. Marshall Institute in Europe.

We see it as an essential contribution to the debate on climate change policy. We thank the International Policy Network for providing sponsorship for this project.

Lorraine Mooney

Director, European Science and Environment Forum

Executive Summary

This report is intended to clarify the state of climate science. The philosophy of the Marshall Institute is that public policy on climate change should be based on a solid scientific foundation; it is hoped that this report will have a beneficial influence on the policymaking process.

The primary reference source of this report are the scientific assessment reports of the United Nations Intergovernmental Panel on Climate Change (IPCC). The Marshall Institute consulted a distinguished workgroup of scientists and policy experts, chaired by James Schlesinger, former US Secretary of Defence and Energy, and Robert Sproull, President Emeritus of the University of Rochester. Information on the IPCC assessment of science was reviewed by them and discussions were held about the state of climate science, our understanding of the climate system, the relationship of science to policy, and actions to address gaps in the state of scientific knowledge. Dr Lenny Bernstein, of L. S. Bernstein and Associates used the information obtained through this process to prepare this report. Dr Bernstein is a chemical engineer and was a Lead Author for the IPCC Third Assessment Report.

The individuals who participated in this process were:

Professor Albert Arking	Johns Hopkins University
Dr Rodney Nichols	President, New York Academy of Sciences
Professor Will Happer	Princeton University
Mr William O'Keefe	Senior Vice President, JSC, Inc. and President, Marshall Institute
Professor David Legates	University of Delaware
Dr James Schlesinger	former Secretary of Defence and Energy
Professor Richard Lindzen	Massachusetts Institute of Technology
Dr Roger Sedjo	Resources for the Future
Dr Robert Sproull	President Emeritus, University of Rochester

Although these individuals were consulted during the report preparation, the views expressed are those of the Marshall Institute.

For about a decade, there has been an ongoing debate about the contribution of human activities to the global warming of the past century and the possible contribution to the climate of the 21st century. Too often, this debate has been contentious. International efforts to reach agreement on inferences about human influence on the climate system that can be drawn from

science, and on policy prescriptions for addressing the climate change risk, have also been controversial.

Wise, effective climate policy flows from a sound scientific foundation and a clear understanding of what science does and does not tell us about human influence and about courses of action to manage risk.

The wide range of this projection is the result of uncertainties in future levels of greenhouse gas and aerosol emissions, human activities that can affect climate, and how changes in greenhouse gas and aerosol concentrations might affect the climate system.

A key finding of the IPCC's recent Third Assessment Report (TAR) is that temperature rose by $0.6 \pm 0.2^{\circ}\text{C}$ over the 20th century. This warming occurred during two periods: 1910 to 1945 and 1975 to 2000. There was little or no change from 1945 to 1975. That increasing greenhouse gas concentrations *contributed* to this warming is not in serious dispute. What is subject to debate is whether those increases in greenhouse gas concentrations were the dominant factor, specifically whether 'most of the temperature rise over the last 50 years is attributable to human activities'. That assumption is the basis of the TAR projections of 1.4 to 5.8°C temperature rise between 1990 and 2100. The IPCC findings have been presented with a degree of certainty that is not justified by the underlying science. The IPCC concludes that human activities were responsible for most of the temperature rise of the last 50 years. Their conclusion is based on a comparison of observed global average surface temperature since 1861 with model simulations of surface temperatures. However, these model simulations fail to reproduce the difference in temperature trends in the lower to mid-troposphere¹ and at the surface over the past 20 years. The United States National Academy of Sciences finds this difference to be real but inconsistent with the prevailing global warming theory. Some experts explain the difference between surface and tropospheric temperature trends as a delayed response in surface temperature to earlier warming in the troposphere. However, the tropospheric warming that occurred rather

¹ The lower troposphere extends from the surface to approximately 30,000 feet.

abruptly around 1976 is not consistent with the gradual change in tropospheric temperature that would be expected from greenhouse gas warming. And since 1979, satellite measurements have not recorded any significant increase in tropospheric temperature.

The data for surface temperature are uncertain because of:

- uneven geographic coverage;
- deficiencies in the historical data base for sea surface temperature; and
- the urban heat island effect, which the IPCC indicates may account for as much as one-fifth of the observed temperature rise.

The model simulations are uncertain because of:

- well-documented deficiencies in climate models, including poor characterization of clouds, aerosols (airborne particles), ocean currents, the transfer of radiation in the atmosphere and their relationship to global climate change;
- the implicit assumption that the models adequately account for natural variability; and
- omission of known influences on the climate systems, such as black soot.

The projections of temperature rise to 2100 are uncertain because they depend on model simulations and are subject to the acknowledged limitations on those models. In addition, projections depend on estimates of greenhouse gas and aerosol emissions to 2100, which in turn depend on assumptions about changes in global population, income, energy efficiency, and sources of energy in the 21st century. The levels of these parameters in 2100 are not only unknown, but unknowable within ranges that are relevant for policy making.

The IPCC projections are based on a conceptual model of the climate system that presumes that greenhouse gas emissions from human activities will be the primary driver of climate change during the next century. This conceptual model also assumes positive feedbacks in the climate system, which means that any warming due to increased atmospheric concentration of greenhouse gases will be amplified. This model fails to acknowledge recent studies indicating:

- that changes in the intensity of solar and cosmic radiation could affect cloud cover and thus climate; and

- a negative feedback due to the behaviour of high level tropical clouds, which could counterbalance all the positive feedbacks present in the most sensitive climate models. The positive feedbacks present in current models emerge automatically from the model treatments of clouds and water vapour. Given the acknowledged uncertainties in these treatments, the model positive feedbacks are by no means certain to be real.

Reducing these many uncertainties requires a significant shift in the way climate change research is carried out in the US and elsewhere. Climate models are one tool in advancing understanding of the climate system; they can also be useful in evaluating policy options, but they should be used with great caution.

Better climate models will require improved:

- knowledge of key climate processes, e.g., the roles of clouds, water vapour, aerosols, ocean currents and radiative transfer;
- understanding of the influences that determine future rates of greenhouse gas and aerosol emissions;
- climate data to calibrate and validate improved climate models; and
- computer capacity to represent climate processes at the necessary level of complexity and spatial and temporal resolution.

Currently the US Global Change Research Programme provides the umbrella for federally-funded research on climate change. But the effort is not a 'programme' in the usual sense of the word, since, according to the US National Research Council, it lacks a comprehensive strategy, a mechanism for prioritisation, and adequate funding. A more cost-effective approach requires:

- focused research programmes with tangible deliverables that address significant, policy-relevant scientific uncertainties;
- consistent, long-term commitment to climate observation and data collection;
- improved scientific assessments; and
- a process for integrating the information provided by these programme.

In addition, a focused research programme will require:

- prioritising scientific uncertainties in terms of their ability to reduce policy uncertainty;
- research programmes with quantifiable measures of progress and estimates of the time and funding required to achieve specific milestones; and
- a stewardship and oversight procedure that (a) evaluates the merits of the research, (b) revises scientific priorities as necessary, (c) terminates projects that have reduced priority or appear unlikely to achieve their desired results, and (d) takes actions to prevent the programme becoming politicised or a basis for perennial budget growth.

Building better models also requires a better understanding of climate processes which, in turn, requires a long-term commitment to climate observations and data collection. Some of the required data (such as weather information) is collected and analysed as an operational responsibility of a specific agency. However, other data (such as solar variability) is collected and analysed as part of research projects with other objectives. Collecting and analysing all critical data needs to be an operational responsibility for the appropriate agency, not a research effort subject to short-term changes in direction and procedures. While climate data from the US are important, the data must be global. Commitments from many other nations are also needed.

Scientific assessment is the critical step in turning scientific information into useful input for public policy decisions. It needs to be carried out at both the

A large amount of money is already available for climate-related activities; the trick is to use these funds as effectively and productively as possible.

national and international level. The US does not have a credible, ongoing assessment process and needs to establish one. The IPCC provides the international assessment of climate change, but its conclusions have become politicised and fail to convey the underlying uncertainties that are important in policy considerations. One way of improving IPCC assessments would be to include a listing of robust findings and key uncertainties in every IPCC

summary. Research, climate data, and assessment efforts need to be brought together in a process that is not distorted by political pressures.

Creating more relevant scientific information requires major changes in the way the US government addresses climate change. While additional funding may be warranted, the recommended changes are independent of funding considerations. No climate research programme, no matter how well designed and how well funded, will provide all the answers policymakers need in the short-term. Uncertainty about greenhouse gas emission rates, the effect of changes in greenhouse gas concentrations on climate, and the impact of climate changes on humans and the environment is unavoidable. However, it is possible to identify economically defensible short and mid-range strategies in the face of long-term uncertainties. As the IPCC points out:

Climate change decision-making is essentially a sequential process under general uncertainty. The literature suggests that a prudent risk management strategy requires careful consideration of the consequences (both environmental and economic), their likelihood, and society's attitude towards risk. ...The relevant question is not 'what is the best course of action for the next 100 years', but rather 'what is the best course for the near term given the expected long-term climate change and accompanying uncertainties'.²

This counsel has been ignored in the apocalyptic scenarios that all too often have characterised climate change policy debates and media reports. An effective risk management strategy involves an iterative planning and decision making process. It would more closely link changes in knowledge, policy actions, adjustments in objectives and strategy with their economic and social implication.

² Metz, B. *et al.* (2001): Climate Change 2001: Mitigation – Contribution of Working Group III to the Third Assessment Report of the IPCC. Cambridge University Press, p. 12.

Introduction

President Bush's announcement in March 2001 that he would not seek ratification of the Kyoto Protocol led to increased discussion and debate about the risks that human activities may pose to the climate system and the policy proposals for addressing those risks. Several members of Congress from both the House and Senate plan to introduce climate change legislation. Some actions to address potential climate change could have significant economic and social impacts. Some proposed actions are based on both a presumed understanding of how the climate system operates and projections of human activities over the course of a century or more.

It is important to better understand the scientific basis for legislative proposals and the policy choices associated with them.

In preparing this report, the George C. Marshall Institute consulted a distinguished group of scientists and policy experts to examine the scientific basis for the public policy proposals being considered by the Bush Administration, the Congress and at international negotiations held under the auspices of the United Nations.

The most up-to-date reviews of the state of climate science come from two sources: the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), a United Nations organisation charged with assessing the state of knowledge on climate change; and a report from the United States National Academy of Sciences (NAS) that was undertaken at the request of President Bush. The Institute also considered recently published scientific literature, which may not have been included in either the IPCC or NAS reports.

In August 2001, the IPCC published the reports from its three Working Groups that form the body of its Third Assessment Report (TAR). These three reports, which are more than 2500 pages long, are summarized in a recently published Synthesis Report. More than 100 governments reviewed the Synthesis Report, which provides the IPCC's answers to policy-relevant questions about climate change.

The IPCC Working Group reports contain many conclusions. The major ones attribute most of the warming observed over the past 50 years to human

activities and predict significant warming over the next century. These are the key findings, since all other findings about sea level rise and impacts on natural and human systems derive from past or future temperature rise. These conclusions have been widely, if selectively, disseminated and have entered the political debate as accepted facts by some. However, they are not as certain as they have been portrayed.

Following a short description of the IPCC and its procedures, this report examines the IPCC findings on past and future temperature rise, using information from IPCC publications, the NAS, and the scientific literature. The goal is to distinguish between facts, hypotheses, assumptions, simulation, and speculation: any work on policy options must confront the major uncertainties on inputs. Next, the report addresses the uncertainties in the conceptual model on which IPCC conclusions are based. Finally, the report makes recommendations for reducing the uncertainties in order to improve scientific assessments.

What is the IPCC and how does it work?

The IPCC is often portrayed as a purely scientific and technical body. It is government representatives who decide which assessments the IPCC will undertake and ultimately approve the final reports of those assessments after a line-by-line review of their Summaries for Policymakers (SPMs). These decisions, and all other major decisions about the IPCC's operations, are made at Plenary meetings held once or twice a year and typically attended by 100 or more countries.

While the work of the IPCC involves many leading experts in the science and technology of climate change, the IPCC itself is made up of government representatives – often the same individuals who represent their countries at the Kyoto Protocol negotiations.

The IPCC maintains close links with the Kyoto Protocol negotiations, and most of the work currently carried out by the IPCC is in response to requests from the Kyoto Protocol negotiators. Each IPCC report is formally released at a meeting of the Kyoto Protocol negotiations.

Once the IPCC decides to respond to a request from the negotiators, it is assigned to one of the IPCC's three Working Groups. Working Group I is responsible for assessments of the science of climate change; Working Group II, for assessments of the impacts of, and vulnerability and adaptation to, climate change; and Working Group III, for assessments of the technology for and economics of climate change mitigation. Each Working Group has its own Bureau and is supported by a Technical Support Unit.

The Technical Support Unit develops an outline for the assessment and, with the approval of the Bureau, selects writing teams for each chapter in the assessment. Typically, a writing team is led by two Convening Lead Authors, one from a developed country and one from a developing country, and contains up to 20 Lead Authors. As with all IPCC activities, an effort is made to maintain geographic distribution among the Lead Authors. Governments are responsible for nominating both Convening Lead Authors and Lead Authors; most nominees are either government employees or academics who are willing to dedicate a substantial portion of their time to IPCC work. While this procedure meets political needs, it does not ensure the highest quality scientific input. Some scientists are unwilling to participate in the IPCC because of the time it requires. Industry and environmental groups limit their participation for the same reason.

The writing teams are responsible for developing a draft that is a comprehensive assessment of the information available in the published literature on the subjects covered by their chapter. Draft chapters undergo two rounds of review; first by individual experts from government, academia, industry and environmental groups, and then by governments.

Once the chapters have been drafted, the summarising process begins. Convening Lead Authors prepare Executive Summaries for their Chapters. A team, chosen from the Convening Lead Authors and members of the Working Group Bureau, prepare a Technical Summary and, most critically, a short Summary for Policymakers (SPM) for the report.

The IPCC procedures are a cross between a scientific peer-review and an intergovernmental negotiation.

The underlying chapters of IPCC reports are scientific or technical documents that provide reasonably comprehensive summaries of the available information on some aspect of climate change. The SPMs, the

most widely read and widely quoted portions of IPCC reports, are approved only after a line-by-line review by governments at an IPCC Plenary, during which the text of the SPM is usually changed significantly. Typically, the only scientists present during the line-by-line review are the Convening Lead Authors. They can prevent governments from making changes that are factually incorrect, but have less influence in matters of tone or emphasis.

The line-by-line review process makes SPMs political documents, and as the National Academy of Sciences (NAS) pointed out: ‘The Summary for Policymakers reflects less emphasis on communicating the basis for uncertainty ...’³ leading the NAS to express concern that ‘without an understanding of the sources and degree of uncertainty, decision-makers could fail to define the best ways to deal with the serious issue of global warming’.⁴

The assertion is often made that IPCC reports represent the consensus of hundreds, or even thousands, of climate change experts. While it is true that large numbers of experts are involved in the IPCC process, the overwhelming majority are involved in only one aspect of the work, for example, estimating potential sea level rise. The experts involved on each issue usually reach consensus on their issue, but typically have limited knowledge of most of the other issues covered by the report.

The IPCC says that its role is to:

... assess on a comprehensive, objective, open and transparent basis 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.⁵

This is an ambitious goal, and it is not at all clear that the scientific and technical community has the proper tools to achieve it.

At least one knowledgeable group, the Committee on Global Change Research of the National Research Council of the NAS, questions the IPCC's ability to carry out assessments.

³ NAS (2001): *Climate Change Science: An Analysis of Some Key Questions*. p. 5.

⁴ *Ibid.*, p. 23.

In a recent report they stated:

Effective assessment aims to integrate the concepts, methods, and results of the physical, biological, and social sciences into a decision support framework. Unfortunately, our ability to create effective and efficient assessments is limited. Assessments that provide useful, credible scientific information to decision makers in a timely and politically acceptable manner remain the exception rather than the rule... Research on how to do more effective, credible, and helpful scientific assessments is badly needed. Of particular importance is the development of assessment processes that link knowledge producers and users in a dialogue that builds a mutual understanding of what is needed, what can be credibly said, and how it can be said in a way that maintains both scientific credibility and political legitimacy.⁶

In reaching this finding, the NAS did not cite the IPCC as an exception to its critique.

A second concern about the IPCC's approach to climate change assessments is its emphasis on consensus. The IPCC is a consensus organisation. The first sentence of its Procedures reads: 'In taking decisions, and approving, adopting and accepting reports, the Panel and its Working Groups shall use all best endeavours to reach consensus.'⁷

It is often argued that building a consensus among scientists reduces uncertainty. Many question this guidance. For example, Roger Pelke, Jr., a university consortium senior scientist at the National Center for Atmospheric Research, has observed:

... efforts to reduce uncertainty via 'consensus science' – such as scientific assessments – are misplaced. Consensus science can provide only an illusion of certainty. When consensus is substituted for a diversity of perspectives, it may in fact unnecessarily constrain decision-makers' options. ... As a general principle, science and technology will contribute more effectively to society's needs when decision-makers base their expectations on a full distribution of

⁵ "Principles Governing IPCC Work" Approved at the Fourteenth Session (Vienna, 1–3 October 1998) on 1 October 1998

⁶ NAS (2000a): "The Science of Regional and Global Change: Putting Knowledge to Work", pp. 9–10.

⁷ "Principles Governing IPCC Work" Approved at the Fourteenth Session (Vienna, 1–3 October 1998) on 1 October 1998

outcomes, and then make choices in the face of the resulting – perhaps considerable – uncertainty.⁸

The key findings in the IPCC TAR on past and future temperature rise: How certain are they?

Proposition: human activities are responsible for most of the warming of the last 50 years

The IPCC concludes that global average surface temperature rose $0.6 \pm 0.2^{\circ}\text{C}$ during the 20th century.⁹ This warming occurred during two periods: 1910 to 1945 and 1975 to 2000. There was little or no change from 1945 to 1975.

While there is general agreement that increasing greenhouse gas concentrations contributed to this warming, there is no agreement that they were the dominant factor.

The IPCC conclusion that ‘most of the warming observed over the last 50 years is attributable to human activities’¹⁰ is based on a comparison of observed global average surface temperature since 1861 with model simulations of the global climate over the same period. These model simulations (Figure 1) tried to match the temperature record since 1861 with:

1. only natural variables, solar variability and the effects of volcanic eruptions;
2. only man-made variables, greenhouse gases and aerosols; and
3. both natural and man-made variables.

These variables, both natural and man-made, are referred to as ‘forcings’. The natural variables, solar variability and the effects of volcanic eruptions, considered in modelling studies cited by the IPCC, are components of natural variability, but do not account for all natural variability. Since the IPCC used a qualitative approach to attribute the climate change of the last

⁸ Pielke, Roger A., Jr. (2001): "Room for doubt." *Nature*, Volume 410, p. 151.

⁹ Houghton, J. T., *et al.* (2001): *Climate Change 2001: The Scientific Basis -Contribution of Working Group I to the Third Assessment Report of the IPCC*. Cambridge University Press, p. 2.

¹⁰ *Ibid.*, p. 10.

50 years to human activities, the modellers did not make a numerical estimate of natural variability.

Use of only natural forcings, Figure 1(a), gave a moderately good fit of the surface temperature curve until the middle of the 20th century and a poor fit thereafter; observed temperature rose while the model projected a decline in temperature. Use of only man-made forcings, Figure 1(b), gave a poorer fit during the first half of the 20th century and a better fit during the second half; while use of both natural and man-made forcings, Figure 1(c), gave the best fit over the whole time frame. Since the model run with only natural forcings projected a decrease in temperature for the past 50 years, and the model run with both natural and man-made forcings provided a reasonable simulation of the observed temperature rise, IPCC concluded that human activities were responsible for most of the observed temperature rise of the last 50 years.

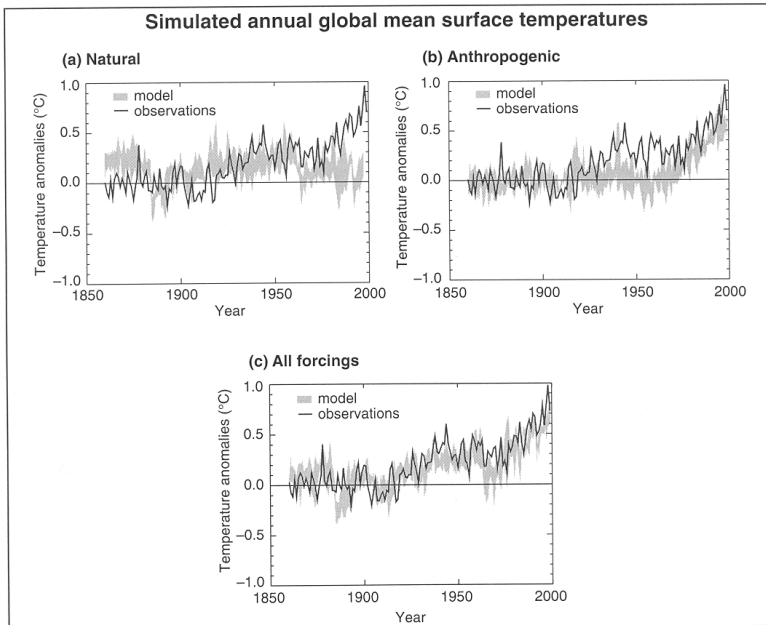


Figure 1 – Model simulations of the Earth’s temperature using different forcings ¹¹

¹¹ *Ibid.*, p. 11.

While the conclusion attributing the temperature rise of the 20th century to human activities is stated as a fact, elsewhere in its report the IPCC characterises it as ‘likely’, which is defined as a 66–90% judgemental estimate of confidence that the statement is true. This represents the collective judgement of the authors, typically the 10–20 Lead Authors responsible for the Chapter in which the conclusion appears, using the observational evidence, modelling results and theory they examined. Such judgemental estimates do not constitute proof, nor do they provide policymakers with the information about the sources and degree of uncertainty which the NAS believes they need.

The significant uncertainties in the IPCC’s conclusion arise from:

- the lack of a greenhouse ‘fingerprint’ in the temperature record;
- the quality of the surface temperature data used to determine the global average surface temperature; and
- the models used to simulate that surface temperature.

The natural greenhouse effect is real and plays an important role in determining the Earth’s climate. Greenhouse gases in the lower- to mid-troposphere absorb heat radiated from the Earth’s surface, warming the atmosphere, which in turn further warms the surface.

If the troposphere and the surface of the Earth were the only parts of the climate system of concern, and the increase in greenhouse gas concentration the only determinant of temperature increase, the lower to mid-troposphere should warm at least as quickly as the surface. This would constitute the ‘greenhouse fingerprint’. However, from 1979–1998, the lower- to mid-troposphere warmed less than the Earth’s surface. The NAS estimates that during that 20-year period, global average surface temperature rose 0.25 to 0.4°C, while temperature of the lower- to mid-troposphere rose 0.0 to 0.2°C.¹² The NAS concluded that while there were uncertainties in estimates of temperature rise at both the surface and in the troposphere, the differences were real.¹³

However, the climate system is more complex than simple heat transfer from the troposphere to the surface. Heat transfer to the oceans can cause a time lag in surface temperature increase. The difference between troposphere and surface temperature increases could represent a delayed response in surface

¹² NAS (2000b): Reconciling Observations of Global Temperature Change, p. 21.

¹³ *Ibid.*, p. 22.

temperature to earlier warming of the troposphere. However, the troposphere warming recorded by weather balloons occurred rather abruptly around 1976. The recorded pattern is unlike the gradual change in tropospheric temperature that would be expected from greenhouse gas warming¹⁴. This significant discrepancy between theory and observation has received less attention than it deserves.

The surface temperature data base has several limitations, including:

- uneven geographic coverage – most of the data are for industrialised nations, with sparse coverage over much of the developing world;¹⁵
- sea surface temperature measurements that are more scattered and require more adjustment than the land-based measurements;¹⁶ and
- the urban heat island effect that IPCC indicates could account for up to 0.12 °C, temperature rise during the 20th century, one-fifth of the total observed.¹⁷

The most complex climate models are called General Circulation Models (GCMs). GCMs attempt to simulate global climate by mathematically modelling the physical processes in the atmosphere and oceans that are known to affect climate, e.g. the way heat is transferred in the atmosphere, from the atmosphere to the oceans, and through the oceans. GCMs were developed as research tools to allow scientists to study relationships among the various components of the climate system. They were not meant to be used as the IPCC has used them, to simulate the climate of the last 140 years and to predict the climate of the next century.

Using GCMs as the IPCC has used them requires confidence that their output is based on a complete scientific description of the climate system. A GCM's output depends on two factors:

- the inputs of data on natural and man-made forcings; and
- the mathematical description of the processes in the climate system.

Both factors are uncertain. The climate simulations supporting the conclusion that human activities were responsible for most of the warming of the last 50 years required climate modellers to make assumptions about

¹⁴ Lindzen, R. S. and C. Giannitsis (2001): "Reconciling observations of global temperature change." Submitted to *Geophysical Research Letters*.

¹⁵ *Ibid.*, p. 18.

¹⁶ Houghton, J. T., *et. al.*, (2001), pp. 110–112.

¹⁷ *Ibid.*, p. 106.

the emissions of greenhouse gases and aerosols between 1860 and 2000. The data to support these assumptions are limited.

These issues were documented by the NAS.¹⁸ However, there is one more that needs to be added and that is the incorrect characterisation of the ‘thermohaline’ circulation.¹⁹

Carl Wunsch, an oceanographer at MIT, points out that as early as 1970 it was clear that the representation of ocean circulation in most climate models was incorrect. Density differences, which are supposed to be the basis of thermohaline circulation, are not strong enough to derive major ocean currents like the Gulf Stream.²⁰

Wunsch cites the work of Egbert and Ray,²¹ which shows that the Moon is slowly moving away from the Earth, creating the tidal energy necessary to drive ocean circulation. If Wunsch is correct, then climate models have the wrong basis for ocean circulation. And, concern about climate change leading to a shut down of this circulation, one of the fears often raised about the human impact on climate, is misplaced.

The way climate models simulate the behaviour of clouds, aerosols, water vapour, ocean currents and other critical features of the climate system, is hampered by significant uncertainties.

Renowned physicist, Freeman J. Dyson, added other concerns, such as the fact that most climate models fail to predict El Niño, one of the major characteristics of the Earth’s climate. They also fail to predict the marine stratus clouds that cover large areas of the ocean; neither they do not take

¹⁸ NAS (1999a): Global Environmental Change: Research Pathways for the Next Decade, Chapter 10.

¹⁹ This is the global ocean circulation that is driven by density of sea water which is controlled by temperature and salinity. See also information on the Argo Programme (www.argo.ucsd.edu) an international ocean research programme involving institutions such as Woods Hole Oceanographic Institute, Scripps Institute of Oceanography and NOAA among others. This programme will provide a means to gather long-term observations needed to reveal the ocean’s role in newly identified climate oscillations and to incorporate their effects into climate forecasts.

²⁰ Wunsch, C. (2000): “Moon, Tide and Climate,” *Nature*, 405:743-4.

²¹ Egbert, G. D. and R. D. Ray (2000): “Significant dissipation of tidal energy in the deep ocean inferred from Satellite Altimeter Data,” *Nature*, 405: 775-8.

into account the absorption of radiation measured in the atmosphere, which is many times larger than the effect of doubling carbon dioxide concentration.²²

These concerns led the NAS to conclude:

... climate models are imperfect. Their simulation skill is limited by uncertainties in their formulation, the limited size of their calculations and the difficulty in interpreting their answers, that exhibit almost as much complexity as nature itself.²³

But perhaps an equally good assessment of the state of climate modelling comes from Dr Syukuro Manabe, who helped create for National Oceanographic and Atmospheric Administration (NOAA) the first climate model that coupled the atmosphere and oceans:

The best we can do is to see how global climate and the environment are changing, keep comparing that with predictions, adjust the models and gradually increase our confidence. Only that will distinguish our predictions from those of fortune-tellers.²⁴

Dr Manabe also made another important observation:

'Models that incorporate everything from dust to vegetation may look like the real world, but the error range associated with the addition of each new variable could result in nearly total uncertainty'.

This would certainly represent a paradox: The more complex the models, the less they tell us!

The IPCC conclusion raises two additional concerns:

- Implicit in the IPCC's finding is the assumption that climate models adequately account for the natural variability of climate. The NAS questions this assumption;
- Because of the large and still uncertain level of natural variability inherent in the climate record and the uncertainties in the time

²² Dyson, F. J. (1999) "The Science and Politics of Climate." Talk given at the American Physical Society Centennial Meeting, Atlanta, Georgia, March 25, 1999.

²³ NAS (2001), p. 15.

²⁴ Quotation in article by Revkin, A. C., "The devil is in the details," *The New York Times*, July 3, 2001, p. D2.

histories of the various forcing agents (and particularly aerosols), a causal linkage between the buildup of greenhouse gases in the atmosphere and the observed climate change of the 20th century cannot be unequivocally established. The fact that the magnitude of observed warming is large in comparison to natural variability as simulated in climate models is suggestive of such a linkage, but it does not constitute proof of one because the model calculations could be deficient in natural variability on the decadal-to-century time scale.²⁵

The models used to support the IPCC's conclusions do not include all the known influences on the climate system. They ignore the role of black soot, mineral dust, albedo changes due to land-use change and the effects of aircraft contrails. The IPCC justifies this exclusion by saying '...the forcings included are sufficient to explain the observed changes, but do not exclude the possibility that other forcings may also have contributed.'²⁶ This approach could be justified if the total impact of these other forcings were small, but a recently published paper²⁷ indicates that one of these forcings, black soot, may play a much larger role in the climate system than previously thought.

*When all the available information is considered,
the IPCC simulation of surface temperature
appears to be more a fortuitous case of curve
fitting than a demonstration of human
influence on the global climate.*

²⁵ NAS (2001), p. 17.

²⁶ Houghton, J. T., *et al.* (2001), p. 10.

²⁷ Jacobson, M.Z., 2001: "Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols," *Nature* 409: 695-7.

Proposition: human activities will lead to an average temperature rise of 1.4 to 5.8°C between 1990 and 2100

A second widely quoted IPCC finding states:

The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100. These results are for the full range of 35 SRES (IPCC Special Report on Emissions Scenarios) scenarios, based on a number of climate models.²⁸

The IPCC derived this using the following procedure:

- A simple climate model was used to simulate the performance of more complex climate models.²⁹
- As input, the modelling study used 35 separate scenarios of future greenhouse gas and sulphate emissions developed by the IPCC in its Special Report on Emissions Scenarios (SRES). These emission scenarios are baseline scenarios; they assume that no explicit actions will be taken during the next 100 years to limit future greenhouse emissions. The emission scenarios cover a wide range of possible economic and environmental futures, from a world that uses very little fossil fuel in 2100, to a world that uses many times current levels of fossil fuel consumption in 2100. But because there are no useable projections of future changes in natural climate forcings, only man-made forcings were used in the study.
- For each scenario the simple climate model was run seven times with different adjustments to simulate the performance of different complex climate models. Each emission scenario – model calibration combination produced an estimate of temperature rise in 2100.
- The IPCC took the highest and lowest of these estimates as the boundaries for its estimate of temperature rise to 2100, i.e., the temperature range of 1.4 to 5.8°C.

This wide range of projected temperature rise to 2100 is due to two factors: difference in projected emissions; and differences in climate models. The SRES scenarios encompass a wide range of future greenhouse gas and aerosol emission rates, but for purposes of this discussion, only the most

²⁸ Houghton, J. T., *et al.* (2001), p. 13.

²⁹ Complex models are three-dimensional representations of the atmosphere and oceans. Simple models typically are two-dimensional and average over latitude.

important two – carbon dioxide and sulphates – will be considered. Because CO₂ is long-lived in the atmosphere (a century or more), cumulative emissions of CO₂ are more important than emissions for any given year. The range of cumulative CO₂ emissions between 1990 and 2100 in the SRES scenarios is 794 to 2498 billion metric tonnes carbon, a range of more than a factor of three. Sulphate aerosols are short-lived in the atmosphere (a few weeks), so it is their annual emissions that are important. The range of sulphate emission in 2100 in the SRES scenarios is 11 to 93 million metric tonnes sulphur, a range of more than a factor of eight.³⁰

The year 2100 is likely to be at least as different from the present as the present is from 1900. Emissions rates in 2100 are not only unknown, but unknowable because we do not know what the future holds for global population, income, energy efficiency and sources of energy.

The differences in climate models are as large. One way of comparing climate models is by their climate sensitivity, i.e., the equilibrium temperature rise they project for a doubling of atmospheric CO₂ concentration. The typical range of climate sensitivity is usually stated as 1.5 to 4.5°C, a factor of three.³¹

The differences in models lead to as large a range of uncertainty as the differences in emission scenarios. As the IPCC concluded:

By 2100, the range in surface temperature response across the group of climate models run with a given scenario is comparable to the range obtained from a single model run with different SRES scenarios.³²

The emissions scenarios themselves, as well as the climate models, have limitations. Yet assumptions on these inputs are used to estimate greenhouse gas and aerosol emissions. We do not know the technology that will be in use in 2100. So we cannot project the effect of technology choices on energy efficiency and source. The IPCC is careful to point out that scenarios are not

³⁰ Nakicenovic, N., *et al.* (2000): IPCC Special Report on Emissions Scenarios, p. 17.

³¹ Houghton, J. T., *et al.* (2001), p. 527.

³² *Ibid.*, p. 13.

estimates or projections, but ‘images of the future’.³³ However, this caveat about images tends to get lost when the outputs of scenarios are used as inputs to climate models to develop projections of future temperature rise.

In reviewing the IPCC’s projections of future temperature rise, the NAS concluded:

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).³⁴

How certain is the conceptual model on which IPCC conclusions are based?

The most fundamental question about the IPCC’s conclusions that needs to be considered is whether the IPCC’s conceptual model is appropriate to evaluate future climate change?

The IPCC does not present its conceptual model for future climate, but it can be inferred from the modelling studies and other information that are presented. It appears to have the following characteristics:

- While the climate system is complex, over the next century human activities will be the only significant driver for change. The effects of changes in solar irradiance, volcanic eruptions and the other components of natural variability will be small.
- Greenhouse gas emissions resulting from human activities will be the dominant component of human-induced climate change; the positive forcing (i.e., warming effect) they create will be significantly larger than the negative forcing (i.e., cooling effect) created by sulphate aerosol emissions, land-use changes, etc.
- The feedbacks created by this warming will be positive.³⁵ The direct effect of a doubling of atmospheric carbon dioxide concentration is 1.2°C warming, but with feedbacks, doubling carbon dioxide concentration will lead to 1.5 to 4.5°C warming.

³³ Nakicenovic, N. *et al.* (2000), p. 62

³⁴ NAS (2001), p. 1.

³⁵ Positive feedbacks enhance warming which enhance warming while negative ones reduce warming.

Each of the points in this conceptual model is subject to question.

The overarching assumption that these models accurately simulate natural variability is questionable because natural variability is in fact a major unknown.

Role of natural forcings

Since volcanic eruptions are random events, investigations of the potential effect of changes in natural forcings have focused on the role of solar irradiance in the climate system. The Sun is the source of all energy in the climate system and satellite measurements since the late 1970s have shown that its output has been remarkably constant, varying by only 0.08% annual average between the maximum and minimum of the 11-year solar cycle.³⁶ Changes in solar irradiance will explain a significant portion of the observed temperature rise of the past few decades only if they act through a feedback mechanism.

The feedback that may provide the link between changes in solar activity and global climate was first reported by Svensmark and Friis-Christensen,³⁷ two Danish researchers. They and others since then have observed that cosmic ray intensity varies on the 11-year solar cycle as a result of changes in the Sun's magnetic field. Based on satellite measurements, low cloud cover appears to change on the same 11-year cycle. Since low clouds tend to cool the Earth's surface, any factor that affects their coverage will also affect temperature. Cosmic rays affect the formation rate of the cloud nuclei that are necessary for cloud formation. Dr Paal Brekke, a solar physicist with the European Space Agency,³⁸ and Drs Sallie Baliunas and Willie Soon of the Harvard-Smithsonian Center for Astrophysics,³⁹ argue that this effect, not

³⁶ Houghton, J. T., *et al.* (2001), p. 380.

³⁷ Svensmark, H. and E. Friis-Christensen (1997): "Variation in cosmic ray flux and global cloud cover—A missing link in the solar-climate relationship," *Journal of Atmospheric Solar-terrestrial Physics* **59**: 1225-1232.

³⁸ Quoted by BBC News, "Viewpoint: The Sun and climate change," November 16, 2000.

³⁹ Baliunas, S. and Soon, W. (2000): Man vs. Milky Way revisited. *Environment & Climate News*, August 2000.

greenhouse gases, accounts for most of the temperature rise of the 20th century. If so, then projection for temperature rise in the 21st century based on greenhouse gas warming are overstated.

Scientific understanding of the role of solar variability in the global climate system is evolving. The IPCC's Second Assessment Report (1995) did not contain a discussion of possible feedbacks that would amplify small changes in solar variability,⁴⁰ but the IPCC's Third Assessment Report does. It indicates that some of the proposed mechanisms may have a small effect on the climate system. More data and analysis over the next few years should reduce this uncertainty.

Emissions of greenhouse gases and aerosols

The natural greenhouse effect is real and greenhouse gases play an important role in the climate system. Aerosols, which can either cool by reflecting solar energy or warm by absorbing it, are also important in determining climate. Therefore estimates of their future emission rates and the atmospheric concentrations that will result are key inputs to climate models. In 2000, the IPCC published a new set of emissions scenarios, which provides a wide range of potential future greenhouse gas and aerosol emissions rates. While these scenarios represent economic modellers' 'best guesses' to what the future holds, any projection of economic activity 100 years into the future is highly speculative. Better understanding of the human activities that determine greenhouse gas and aerosol emissions would reduce this uncertainty, but improved understanding will have policy relevance to estimates covering near term decades; not ones a century away.

Feedbacks

Feedbacks play a dominant role in the climate system. The climate system responds to both the direct effect of changes and to the indirect effects that these changes have on other system parameters. Climate models include both positive and negative feedbacks, but the net effect in all models is a positive feedback – more warming than the direct effect of increases in greenhouse gas concentration. Most of this positive feedback comes from the effect of water vapour. As temperature rises, more water evaporates from the surface and the concentration of water vapour (absolute humidity) in the atmosphere increases. Water vapour is the dominant greenhouse gas in the atmosphere, so an increase in its concentration leads to more warming. More

⁴⁰ Houghton, J. T., et al.(1996): *Climate Change 1995: The Science of Climate Change*, pp. 115-117.

water vapour also leads to the formation of more clouds. Low level clouds, which reflect sunlight before it can reach the surface, have a cooling effect; but high level cirrus clouds, which tend to absorb infrared radiation from sunlight and re-emit it downward, have a warming effect. The net effect of water vapour is generally assumed to be positive, but this may be a misrepresentation of the climate system. The observational data supporting this assumption are still inconclusive.

A recently published study by Prof. Richard S. Lindzen of MIT, and Ming-Dah Chou and Arthur Y. Hou of NASA Goddard Space Flight Center⁴¹ indicates that high level clouds may regulate the amount of heat retained by the lower atmosphere much in the same way that the iris regulates the amount of light entering the eye. Lindzen and his co-workers report:

...cloud data for the eastern part of the western Pacific ... have been analysed, and it has been found that the area of cirrus cloud coverage ... decreases by about 22% per degree Celsius increase in surface temperature of the cloudy region. A number of possible interpretations of this result are examined and a plausible one is found to be that cirrus detrainment from cumulus convection diminishes with increasing temperature. ... such a change in the Tropics could lead to a negative feedback in the global climate, with a feedback factor of about -1.1 , which if correct would more than cancel all the positive feedbacks in the more sensitive current climate models. ... This new mechanism would, in effect, constitute an adaptive infrared iris that opens and closes in order to control the Outgoing Longwave Radiation in response to surface temperature in a manner similar to the way in which the eye's iris opens and closes in response to changing light levels. ... Preliminary attempts to replicate observations with GCMs (complex climate models) suggest that models lack such a negative cloud/moisture areal feedback.

This evidence for a new negative feedback, if correct, would more than cancel any positive feedbacks in the climate models that project the largest increases from increased atmospheric concentrations of CO_2 . If this finding is verified by further research, then the temperature rise associated with increased atmospheric concentrations of greenhouse gases will be much smaller than currently projected by the IPCC.

⁴¹ Lindzen, R. S., M. D. Chou and A. Y. Hou (2001): "Does the Earth Have an Adaptive Infrared Iris?" *Bull. Am. Meteorological Soc.* 82: 417-432.

A rational way forward

To summarise, many significant observations undercut the certainty with which the IPCC presents its conclusions:

- Relative rates of temperature rise at the surface and in the lower- to mid-troposphere do not show the pattern that is consistent with the greenhouse warming theory.
- The climate models on which these conclusions are based have many well-documented limitations, and the climate data base with which model results are compared, has many shortcomings.
- There is reason to question the underlying conceptual model on which IPCC conclusions are based. Its assumption that human emissions of greenhouse gases will be the primary driver of climate change during the next century ignores potentially critical determinants of future climate including positive feedbacks that amplify changes in solar variability and negative feedbacks that moderate the effect of increased greenhouse gas concentrations.
- There is too much uncertainty both in estimates of future emissions and in climate models to provide a sound and confident basis for projections of future climate.

Accordingly, we need a better scientific basis for developing climate change policy. The goal is not perfect understanding, since parts of the climate system appear to be ‘chaotic’. However, actions will be taken and we can improve both our empirical and theoretical knowledge as a basis for societal choices.

Building better climate models will require:

- better knowledge of key climate processes, e.g., improved descriptions of the roles of clouds, aerosols, solar cycles and irradiance, and ocean currents;
- better understanding of the human systems that determine future rates of greenhouse gas and aerosol emissions;
- better climate data to test and calibrate improved climate models; and
- improved computer capacity to represent climate processes at the necessary level of complexity and spatial and temporal resolution.

While much of the required research falls in the realm of physical sciences, economists, social scientists and technologists also have important roles to play.

The uncertainties that now limit our understanding of the climate system must be reduced.

For fiscal year 2002, about \$1.6 billion will be allocated to the US Global Change Research Programme (USGCRP), the bulk of which is devoted to climate change related projects. About half this amount is for NASA's space-based climate observations.⁴² These space-based measurements have provided insights into the climate system, e.g. direct measurement of solar irradiance, which would have been difficult or impossible to achieve from surface-based measurements.

Better climate models are an important key to improving both our understanding of the climate system and our ability to predict future climate.

The USGCRP budget is a large amount of money and builds on many years of similar rates of expenditure for climate change related research. However, the results of this programme have been disappointing. As the National Research Council noted in a recent assessment,⁴³ the USGCRP lacks:

- a comprehensive strategy,
- a mechanism for prioritisation, and
- adequate funding.

The fundamental problem is that the USGCRP is that it is not a 'programme' in the sense the term is typically used. There is no central funding, prioritisation or management. Rather it is a loose coordination effort among

⁴² USGCRP (2001): "Table 1: US Global Climate Research Programme FY 2000-2002 Budget by Agency" and "Table 2: US Global Climate Research Programme FY 2001 – FY 2002 Budget by Research Programme Element."

⁴³ NAS (1999a), pp. xi–xii.

14 federal agencies,⁴⁴ not all of which could be expected to fund climate change research. Funding, and implicitly prioritisation, comes from the individual agencies, and must compete with the other goals these agencies have.

What is needed, either through a revamped USGCRP or a new structure, is:

- focused research programmes with tangible deliverables that address significant, policy-relevant scientific uncertainties;
- consistent, long-term commitment to climate observation and data collection efforts;
- improved scientific assessments; and
- better coordination of the information provided by these programmes.

Focused research programmes

Much work has already been done to identify key areas of scientific uncertainty, but links between scientific questions and public policy making still need attention.

The first priority should be to focus research on those issues which are currently crucial to policy, but which are still uncertain⁴⁵. For example, improving estimates of future climate change should have a higher priority than reducing the uncertainty in the impacts of such climate change.

Once a prioritised list of uncertainties has been established, research programmes should be developed to address them. These programmes should include quantifiable measures of progress and estimates of the time and funding required to achieve specific milestones. By their very nature, research outcomes are unpredictable and any projection of the time it will take to reach a certain level of understanding is likely to be wrong. However, unless that projection is made, there is no way in which to judge whether the

⁴⁴ The federal agencies are: the NSF, NASA, EPA, DOE, Dept. of State, DOD, DOI, Dept. of Agriculture, DOT, OMB, OSTP, CEQ, and the National Institutes of Environmental Health Sciences of the National Institutes of Health.

⁴⁵ *Ibid.* Chapter 11.

research is likely to produce the desired results in a timeframe that will be useful for public policy.

Finally, a stewardship and oversight process needs to be developed which not only evaluates the merits of the research, but has mechanisms for revising scientific priorities and for terminating projects that either have lowered priorities or appear unlikely to achieve their desired results.

Terminating projects is likely to be the most difficult aspect of a focused research programme. Researchers must be optimists, who believe that they will accomplish their objectives despite negative results. Their optimism is often contagious and can convince review boards to stay on a research path long after a more critical review would have terminated the project. Projects also develop political constituencies, which will support them for a variety of reasons unrelated to their intrinsic merit.

The development of a focused programme with clearly defined goals will help overcome some of the problems with terminating projects. While the goals of this programme are not likely to be as clear as those of the Manhattan or Apollo programmes, they still will act as a standard against which results can be continually tested. Appointing a manager for the programme, who is held politically accountable for programme results and has the authority to change the programme to achieve those results, is essential.

Long-term commitment to climate observations and data analysis

Observations of the climate system are critical to advancing our knowledge. Climate models can only be tested against an observational data base. Empirical understanding, which can lead to the theoretical insights needed to improve climate models, often evolves from the analysis of observations.

The problems in the US climate observation effort are summarised in the following NAS finding and recommendation:

FINDING: There has been a lack of progress by the federal agencies responsible for climate observing systems, individually and collectively, towards developing and maintaining a credible integrated climate observing system, consequently limiting the ability to document adequately climate change.

RECOMMENDATION: These agencies should work through the US Global Change Research Programme process and at higher government levels to:

- reverse the deterioration of the existing global observational capacity;
- identify critical variables that are not adequately measured;
- build climate observing requirements into their operational programmes as a high priority;
- revamp existing climate programmes and some climate-critical parts of operational observing programmes through the implementation of the ten principles of climate monitoring proposed by the National Research Council; and
- establish a funded activity for the development, implementation and operation of climate-specific observational programmes.⁴⁶

The NAS elaborates on the type of system needed to provide adequate climate monitoring and how it should be funded and managed as follows:

A monitoring system is needed to detect secular changes in the global environment. Even for research purposes alone, the system must be in place long enough to see a few cycles of the change. ... from an operational point of view of tracking the environmental state of our planet, a system is needed essentially for the duration of the perturbations and response. Obviously, such a multipurpose system would fulfil important research needs; however, its cost is likely to be significant, particularly when integral costs are considered and not just annual costs. Therefore, it must satisfy operational purposes if it is to be sustained. An essential shift is needed within the federal government: the federal government must recognise that monitoring the changes in the global environment on significantly longer time scales than demanded by operational meteorology is in the forefront of the national interest.⁴⁷

Climate change is a global concern and the data base needed to address that concern has to be global.

The NAS's concerns about the deterioration of the US climate observation system become even more urgent when one considers the state of the climate

⁴⁶ NAS, (1999b): Adequacy of Climate Observing Systems, p. 5.

⁴⁷ NAS, (1999a): pp. 428–429.

observation system world-wide, particularly in developing nations. Both money and trained personnel are in short supply. The US currently funds a number of climate related programmes in developing nations. These programmes need to recognise that adequate climate observations are critical both to the recipient country and to the US. However, it is unrealistic to assume that US-funded programmes can make more than a limited contribution to the overall need for climate data.

Countries around the world will have to back their oft-stated concern about climate change with tangible commitments to collecting the data needed to address uncertainties in climate science.

Data collection is critical, but it must be accompanied with a reasonable level of analysis to provide objective, user-relevant summaries of the data to identify trends. The temptation to politicise such summaries will be great, but doing so will reduce the credibility and usefulness of the data base. Individual researchers will have to make their own analyses of the data base and every effort should be made to reduce barriers to such activities.

Improved scientific assessments

Scientific assessment is the critical step in turning scientific information into useful input for public policy decisions. However, current scientific assessments are not meeting the needs of policymakers. The problem exists at two levels.

At the national level, the US does not have a credible, ongoing assessment process. The one attempt at a US scientific assessment⁴⁸ was a poorly designed, poorly funded exercise which fortunately has had little influence on policy debate in the US. This need should be addressed by a programme that is separate from, but draws upon, the research and observation efforts

⁴⁸ An overview of this assessment was published in 2000 by the National Assessment Synthesis Team in a book titled *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*. The information supporting this overview has never been published.

described above. There should be sufficient funding to commission limited studies critical to the assessment, but the assessment process should not be an ongoing source of research funding. The National Academy of Sciences might be a reasonable place to house such an activity.

The international process for scientific assessment is the IPCC. Its problems and limitations have been discussed in detail. A key concern is the politicisation of the IPCC process. This may be unavoidable, given that the political negotiations on climate change are justified by the scientific findings developed in IPCC assessments. Governments will naturally try to ensure that IPCC findings support their political positions. They will also try to downplay scientific uncertainty in the presentation of these findings, again to make it easier to promote their political agendas.

The approach taken in the development of the Synthesis Report to the IPCC's Third Assessment Report is a step in the right direction. The last section of the Synthesis Report is a summary of robust findings and key uncertainties in the major policy relevant aspects of climate science. Building on this approach to require that all future IPCC summaries begin with a list both of robust finding and key uncertainties could help redress the current imbalance in the IPCC's approach.

Improved co-ordination

The preceding recommendations outline three independent activities for the US: a focused research programme; an ongoing climate data collection and analysis activity; and an ongoing assessment effort. While these efforts need to be independent, they also need to be tied together to produce policy-relevant results. The US Global Change Research Programme has neither the funding nor the staffing to provide the required co-ordination.

What is needed is an information collection and analysis activity that can be relatively free of political pressures. It could act as an independent check on the outputs of the research, observation and assessment activities. To maintain this independence, it should not be involved in the management or funding decisions for any of these programmes.

The steps outlined above represent major changes in the way the US government addresses climate change. Such changes are needed if the US is going to significantly increase the productivity of its climate change related programmes. While additional funding may be warranted, the recommended changes are independent of funding considerations. A large amount of

money is already available for climate change related activities. It is a question of using these funds in a more effective and productive manner.

Policymaking in uncertainty

There is a justifiable concern about the potential for human activities to affect future climate. Action is appropriate. The question is what action?

As in all human endeavours, there is a need for balance. The dramatic reductions in greenhouse gas emissions called for in the Kyoto Protocol, which has been rejected by the Bush Administration, would have unacceptable economic consequences in the US and many other countries. This is clearly demonstrated by the growing body of economic analyses of the Kyoto Protocol impact.

However, cost-effective reductions in greenhouse gas emissions can be achieved through economically justified energy technology and capture of non-CO₂ gases. These emission reduction opportunities should be pursued, and the success of voluntary programmes in the US, such as the Energy Star and Natural Gas Star, indicates that they can be achieved, although some have questioned the efficacy of voluntary initiatives. The many voluntary programmes that have been created by the federal government should be subjected to periodic assessments to identify changes to increase their effectiveness and perhaps terminate those that are not producing useful results.

Significant progress has been made on the development of new, low greenhouse gas emissions technology, such as fuel cells, over the past few years. It will take several more years for the benefits of this new technology to be seen in greenhouse gas emissions inventories. Once fuel cells become commercially viable that benefit will be achieved, and in a fashion which helps rather than hurts the economy.

The climate change research programme described above will help reduce the uncertainties faced by policymakers. However, no climate research programme, no matter how well designed and how well funded, will provide the critical answers policymakers need for years to come.

But it is possible to identify short-term strategies in the face of long-term uncertainties. As the IPCC itself has emphasised:

Climate change decision-making is essentially a sequential process under general uncertainty. The literature suggests that a prudent risk management strategy requires careful consideration of the consequences (both environmental and economic), their likelihood, and society's attitude towards risk. ... The relevant question is not 'what is the best course of action for the next 100 years', but rather 'what is the best course for the near term given the expected long-term climate change and accompanying uncertainties'.⁴⁹

Uncertainty – about greenhouse gas emission rates, the effect of changes in greenhouse gas concentrations on climate, and the impact of changes in climate on humans and the environment – is pervasive in any assessment of potential climate change.

Calling attention to uncertainty in the state of scientific knowledge is not a call for no action. Our message to policy makers is not to delay action until uncertainties are reduced. Rather, actions should flow from the state of knowledge, should be related to a long term strategy and objectives and should be capable of being adjusted – one way or the other – as the understanding of human influence improves. There is a sufficient basis for action because the climate change risk is real. Yet, it is equally true that actions must not be predicated on speculative images of an apocalyptic vision of life by 2100.

⁴⁹ Metz, B. *et al.* (2001): Climate Change 2001: Mitigation – Contribution of Working Group III to the Third Assessment Report of the IPCC. Cambridge University Press, p. 12.

Biographies

Albert Arking is a Principal Research Scientist in Earth and Planetary Sciences at Johns Hopkins University. Previously, he was a Senior Scientist at NASA Goddard Space Center, where he headed the Climate and Radiation Branch. Dr Arking is Associate Editor of Theoretical and Applied Climatology and Chairman of the Review Committee for the Environmental Research Division at Argonne National University.

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James R. Schlesinger has served as Secretary of Defence and Energy, Director of the Central Intelligence Agency, Chairman of the Atomic Energy Commission and Assistant Director of the Bureau of the Budget (OMB). He is currently Senior Adviser to Lehman Brothers and Chairman of the MITRE Corporation.

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Robert L. Sproull is President Emeritus at the University of Rochester. An internationally-known physicist and former Director at the Advanced Research Projects Agency for the Defence Department, Dr Sproull was also vice president at Cornell University before coming to Rochester. Dr Sproull is also a life trustee at the University of Rochester and currently retains an emeritus faculty appointment in the Department of Physics.

Philip Stott is Emeritus Professor of Biogeography at the University of London, where he taught at the School of Oriental and African Studies (SOAS). He was Head of Department for some seven years and recently Dean of Student Admissions. Professor Stott has researched on the construction of 'environmental knowledge' for over twenty-five years, most recently in relation to 'global warming', tropical rain forests and biotechnology in agriculture. He is Editor of the internationally important *Journal of Biogeography* (Blackwell Science) and his latest books are *Global environmental change* with Dr Peter Moore and Professor Bill Chaloner, and *Political ecology: science, myth and power* with Dr Sian Sullivan. Professor Stott broadcasts regularly, being a panellist on BBC Radio 4's interactive environmental programme, 'Home Planet'; he also writes widely for the press. Professor Stott has a special interest in the developing world. He is married with two children, and he has a passionate interest in early music and master works on paper.

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- The linear no-threshold hypothesis is rubbish (i.e. the dose makes the poison)
- An entire industry has developed to scare us into stopping certain activities, or making us feel guilty for continuing them, or lobbying to have them banned by government
- The public are quite capable of making decisions that involve complex trade-offs if only we would let them; indeed, not letting them causes enormous problems as government bodies do not have the dispersed knowledge to do this, and are subject to interest group pressure
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- Global climate models are criticised for their inability to simulate normal or chaotic weather patterns. Predictions of increased frequency and intensity of hurricanes are not supported by theory or empirical evidence, which point to the opposite effect of fewer, less intense events. The question of properly interpreting measurements of global climate made by satellite is addressed, and a warning given of the dangers of extrapolating from incomplete and incompatible records of the past.
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It is therefore of great importance for everyone concerned with these decisions and their implications to understand the basis on which they are made and their reliability and legitimacy. The principle objective of this book is to highlight the uncertainties inherent in 'scientific' estimates of risk to humans and the environment resulting from exposure to certain hazards. Numerous examples of potential and real hazards are given. They all show that injury to health or the environment is a function not only of the toxicity but of the dose of the particular substance. The dose makes the poison.

Existing regulation is criticized by being based on a flawed application of a poor epidemiological methodology, where toxicity is the basis of regulation and dose tends to be ignored. Furthermore, some authors conclude that risk is a subjective phenomenon that cannot be eliminated through regulation.

Contents: Preface, Methodology, Indoor Air Quality and Epidemiology, Environmental Tobacco Smoke, Pesticides, Dioxin, Asbestos, Benzene, Ionizing Radiation, Science Policy, Risk Perception, Risk and the Media, Index.

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Climate Science and Policy: Making the Connection

The authors of this booklet argue:

- While there is general agreement that increasing greenhouse gas concentrations may contribute to warming, there is no agreement that they have been or are the dominant factor;
- The relative rates of temperature rise at the surface and in the lower- to mid-troposphere are inconsistent with the greenhouse warming theory;
- Our current climate models fail lamentably to cope with the behaviour of water vapour (the most important greenhouse gas of all), clouds, aerosols (atmospheric particles), ocean currents, and many other key factors, thus creating significant uncertainties;
- Models which strive to incorporate everything from dust to vegetation may look comprehensive, but the error range associated with each new additional factor results in near total uncertainty;
- The overarching assumption claiming that the models accurately simulate 'natural' variability, including volcanic eruptions, solar cycles and irradiance, is questionable because the range of 'natural' variability is a major unknown;
- When all the known information is taken into account, the IPCC simulation of surface temperature appears to be little more than a fortuitous bit of curve fitting rather than any genuine demonstration of human influence on global climate and climate change;
- The idea that feedbacks generated by warming will always be positive – thus leading to more warming – is likely to be false; recent work on clouds and moisture clearly indicates the precise opposite, namely a negative feedback. Verification of this finding by further research would make any temperature rise associated with increased concentrations of greenhouse gases much smaller than currently predicted.
- The projections of temperature rise to 2100 are uncertain because they depend on model simulations and are subject to the acknowledged limitations on those models. In addition, projections depend on estimates of greenhouse gas and aerosol emissions to 2100, which in turn depend on assumptions about changes in global population, income, energy efficiency and sources of energy in the 21st century. The levels of these parameters in 2100 are not only unknown, but unknowable within ranges that are relevant for policy making.



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