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Climate Science and Policy:

MAKING THE CONNECTION

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Washington, D. C.

Contents

Executive Summary

This report is intended to clarify the state of climate science and contribute to a stronger foundation for public policy. It is based on the belief that sound public policy on climate change should be based on a solid scientific foundation.

This report's starting point is the scientific assessment reports of the United Nations Intergovernmental Panel on Climate Change (IPCC). The Marshall Institute consulted with a distinguished workgroup of scientists and policy experts that was chaired by James Schlesinger, former Secretary of Defense 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 who was a Lead Author for the IPCC Third Assessment Report.

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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 how they may contribute to warming that may occur during 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 been controversial as well.

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.

A key finding of the IPCC's recent Third Assessment Report (TAR) is that temperature rose by 0.6 ± 0.2 °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 wide range of projected temperature rise to 2100 is the result of uncertainties in both future levels of greenhouse gas and aerosol emissions, the human activities that can affect climate, and how changes in greenhouse gas and aerosol concentrations might affect the climate system.

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The IPCC findings have been presented with a degree of certitude 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-troposphere[1] and at the surface over the past 20 years. The 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 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:

(1) uneven geographic coverage,

(2) deficiencies in the historical data base for sea surface temperature, and

(3) 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:

(1) well-documented deficiencies in climate models, including poor characterization of clouds, aerosols, ocean currents, the transfer of radiation in the atmosphere and their relationship to global climate change;

(2) the implicit assumption that the models adequately account for natural variability; and

(3) 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 projections 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 presupposes 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:

(1) that changes in the intensity of solar and cosmic radiation could affect cloud cover and thus climate, and

(2) a negative feedback due to the behavior of high level tropical clouds could counterbalance all of 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 vapor. 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 U. S. 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 vapor, 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 U.S. Global Change Research Program provides the umbrella for federally-funded research on climate change. But the effort is not a "program" in the usual sense of the word, since, according to the National Research Council, it lacks a comprehensive strategy, a mechanism for prioritization, and adequate funding. A more cost-effective approach requires:

- focused research programs 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 programs.

In addition, a focused research program will require:

- prioritizing scientific uncertainties in terms of their ability to reduce policy uncertainty;
- research programs with quantifiable measures of progress and estimates of the time and funding required to achieve specific milestones; and
- a stewardship and oversight procedure that (1) evaluates the merits of the research, (2) revises scientific priorities as necessary, (3) terminates projects that have reduced priority or appear unlikely to achieve their desired results, and (4) takes actions to keep the program from being politicized 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 analyzed as an operational responsibility of a specific agency. However, other data (such as solar variability) is collected and analyzed as part of research projects with other objectives. Collecting and analyzing 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 priorities. While climate data from the U.S. are important, the data must be global. Commitments from many other nations are needed as well.

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 national and international level. The U.S. 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 politicized 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 U.S. government addresses climate change. While additional funding may be warranted, the recommended changes are independent of funding considerations. A large amount of money is already available for climate related activities. It is a question of using these funds as effectively and productively as possible.

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No climate research program, no matter how well designed and how well funded, will provide all of 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 suggest 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 characterized 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.

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 plan to introduce climate change legislation. Some proposed actions could have significant economic and social impacts and 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.

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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 organization charged with assessing the state of knowledge on climate change, and a report from the 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 addresses the IPCC findings on past and future temperature rise. It uses information from IPCC publications, the NAS, and the scientific literature The goal is to distinguish among 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 for improving scientific assessments.

What Is the IPCC and How Does It Work?

The IPCC is often portrayed as a purely scientific and technical body. 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. 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.

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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 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.

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

Once the chapters have been drafted, the summarizing 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]

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.

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. 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* (emphasis added). ... 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 mention the IPCC as one of the exceptions 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 organization. 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 endeavors 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 senior scientist at the National Center for Atmospheric Research. a university consortium, 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 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 ± 0.2 °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

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

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 modeling study cited by IPCC are components of natural variability, but do not account for all of natural variability. Since the IPCC used a qualitative approach to attribute the climate change of the last 50 years to human activities, the modelers 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.

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 characterizes it as *likely*, which is defined as a 66-90% judgmental estimate of confidence that the statement is true. This represents the collective judgment of the authors, typically the 10 - 20 Lead Authors responsible for the Chapter in which the conclusion appears, using the observational evidence, modeling results and theory they examined. Such judgmental 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.

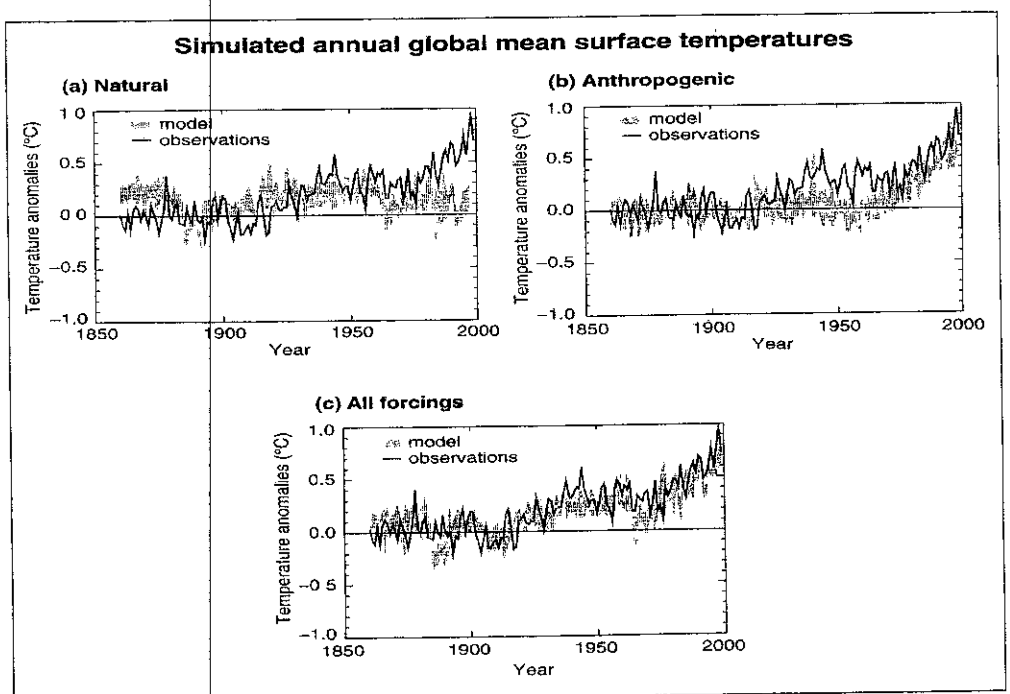

Figure 1 - Model Simulations of the Earth's Temperature Variations Using Different Forcings[11]

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

(1) the lack of a greenhouse "fingerprint" in the temperature record;

(2) the quality of the surface temperature data used to determine the global average surface temperature; and

(3) 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 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 warming.[14] This significant discrepancy between theory and observation has received less attention than it deserves.

The surface temperature data base has several limitations, including:

(1) uneven geographic coverage - most of the data are for industrialized nations, with sparse coverage over much of the developing world;[15]

(2) sea surface temperature measurements that are more scattered and require more adjustment that the land-based measurements;[16] and

(3) 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 modeling 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 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:

(1) the inputs of data on natural and man-made forcings; and

(2) 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 modelers to make assumptions about the emissions of greenhouse gases and aerosols between 1860 and 2000. The data to support these assumptions are limited.

The way climate models simulate the behavior of clouds, aerosols, water vapor, ocean currents, and other critical features of the climate system also involves significant uncertainties.

The way climate models simulate the behavior of clouds, aerosols, water vapor, ocean currents, and other critical features of the climate system also involves significant uncertainties. These issues were documented by the NAS.[18] However, there is one more that needs to be added, the incorrect characterization 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 well known 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, and they do not take into account the absorption of radiation measured in the atmosphere which is many times larger than the effect of doubling carbon dioxide concentration.[22]

uncertainties in their formulation, the limited size of their calculations, and the difficulty in interpreting their answers that exhibit almost as much complexity as in nature.[23]

But perhaps an equally good assessment of the state of climate modeling comes from Dr. Syukuro Manabe, who helped create for 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 fortunetellers.[24]

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.

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 we know!

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 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 of 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 paper[27] indicates that one of these forcings, black soot, may play a much larger role in the climate system than previously thought.

When all of 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.

When all of 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.

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 modeling study used 35 separate scenarios of future greenhouse gas and sulfate emissions developed by 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.

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, differences 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 important two—carbon dioxide and sulfates—will be considered. Because CO_2 is long-lived in the atmosphere (a century or more), cumulative emissions of CO_2 are more important than emissions for any given year.

> *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 range of cumulative CO_2 emissions between 1990 and 2100 in the SRES scenarios is 794 billion to 2498 billion metric tonnes carbon, a range of more than a factor of three. Sulfate aerosols are short-lived in the atmosphere (a few weeks), so it is their annual emissions that are important. The range of sulfate emission in 2100 in the SRES scenarios is 11 million to 93 million metric tonnes sulfur, a range of more than a factor of eight.[30]

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 CO_2 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 scenario. 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. 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. 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 estimates or projections, but "images of the future".[33] However, this caveat about images tends to get lost when the output of scenarios are used as input 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 modeling 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 sulfate 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.

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

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 greenhouse gases, accounts for most of the temperature rise of the 20th century. If so, then projections 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. Other researchers have identified much longer solar cycles which the IPCC has not included in its considerations and analysis.

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 modelers' "best guesses" as 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 vapor. As temperature rises, more water evaporates from the surface and the concentration of water vapor (absolute humidity) in the atmosphere increases. Water vapor is the dominant greenhouse gas in the atmosphere, so an increase in its concentration leads to more warming. More water vapor 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 vapor 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 Center[41] 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 analyzed, 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

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

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

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

For fiscal year 2002, about $1.6 billion will be allocated to the U. S. Global Change Research Program (USGCRP). About one-half of 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 program have been disappointing. As the National Research Council noted in a recent assessment,[43] the USGCRP lacks:

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

> 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.

A Rational Way Forward

To summarize, 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 to 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 uncertainties that now limit our understanding of the climate system must be reduced. 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.

The fundamental problem is that the USGCRP is not a "program" in the sense the term is typically used. There is no central funding, prioritization or management. Rather it is a loose coordination effort among 14 federal agencies,[44] not all of which could be expected to fund climate change research. Funding, and implicitly prioritization, 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 programs 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 programs

Focused Research Programs

Much work has already been done to identify key areas of scientific uncertainty,[45] but links between scientific questions and public policy needs are often unclear. The first step in the development of a focused research program should be to prioritize areas where clarity is most urgently needed in climate science in terms of their ability reduce policy uncertainty. For example, reducing the uncertainty in estimates of future climate change would have a higher priority than reducing the uncertainty in the impacts of such climate change.

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Once a prioritized list of uncertainties has been established, research programs should be developed to address them. These programs 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 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 program. 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 program with clearly defined goals will help overcome some of the problems with terminating projects. While the goals of this program are not likely to be as clear as those of the Manhattan or Apollo programs, they still will act as a standard against which results can be continually tested. Appointing a manager for the program, who is held politically accountable for program results and has the authority to change the program 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 U.S. climate observation effort are summarized 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 Program 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 programs as a high priority;
- revamp existing climate programs and some climate-critical parts of operational observing programs 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 programs.[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 fulfill 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 recognize 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.* (emphasis added) [47]

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

Climate change is a global concern. and the data base needed to address that concern has to be global. The NAS concerns about the deterioration of the U.S. climate observation system become even more urgent when one considers the state of the climate observation system world-wide, particularly in developing nations. Both money and trained personnel are in short supply. The U.S. currently funds a number of climate related programs in developing nations. These programs need to recognize that adequate climate observations are critical both to the recipient country and to the U.S. However, it is unrealistic to assume that U.S. funded programs 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 politicize 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 U.S. does not have a credible, ongoing assessment process. The one attempt at a U.S. scientific assessment[48] was a poorly designed, poorly funded exercise which fortunately has had little influence on policy debate in the U.S. This need should be addressed by a program that is separate from, but draws upon, the research and observation efforts 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.

> *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.*

The international process for scientific assessment is the IPCC. Its problems and limitations have been discussed in detail. A key concern is the politicization 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 findings and key uncertainties could help redress the current imbalance in the IPCC's approach.

Improved Coordination

The preceding recommendations outline three independent activities for the U.S.: a focused research program, 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 Program 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 programs.

The steps outlined above represent major changes in the way the U.S. government addresses climate change. Such changes are needed if the U.S is going to significantly increase the productivity of its climate change related programs. 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 Light of 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 endeavors, there is a need for balance. The dramatic reductions in greenhouse gas

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emissions called for in the Kyoto Protocol, which has been rejected by the Bush Administration and by others on the basis that it would have unacceptable economic consequences in the U.S. and many other countries. There is a 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-CO_2 gases. These emission reduction opportunities should be pursued. The success of voluntary programs, 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 programs 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.

years for the benefits of this new technology to be seen in greenhouse gas sions inventories. Once fuel cells become commercially viable that benefit will be eved, and in a fashion which helps rather than hurts the economy.

limate change research program described above will help reduce the uncertain- faced by policymakers. However, no climate research program, no matter how designed and how well funded, will provide the critical answers policymakers need years to come. Uncertainty—about greenhouse gas emission rates, the effect of nges in greenhouse gas concentrations on climate, and the impact of changes in ate on humans and the environment—is pervasive in any assessment of potential ate change. But it is possible to identify short-term strategies in the face of long- m uncertainties. As the IPCC itself has underscored:

> 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.

Are calls about uncertainty in the state of scientific knowledge a call for no action? Nothing could be further from the truth. The 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.

ENDNOTES

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

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