CEQ 10

Critical Issues in the

Intergovernmental Panel on Climate Change

Third Assessment Report

Prepared for the American Petroleum Institute
By
Lenny Bernstein
L. S. Bernstein & Associates, L.L.C.
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Critical Issues in the IPCC *Third Assessment Report*

Summary and IPCC Background

The Intergovernmental Panel on Climate Change (IPCC), founded in 1989, is the UN body charged with providing governments with scientific and technical assessments of the state of knowledge on climate change. At its April 2001 Plenary, the IPCC gave final approval to the three underlying reports that will form the body of its *Third Assessment Report*. While the full texts of these reports, each many hundred pages long, will not be available until late Summer, their 10 – 20 page individual Summaries for Pol...makers (SPMs) have been posted on the web and widely quoted.

The following short papers first discuss how the IPCC works (Papers 1 and 2), then identify and explain a number of key conclusions stated in the SPMs of the three underlying sections in IPCC's *Third Assessment Report* (Papers 3-20). When issues of uncertainty are raised regarding the IPCC's conclusions, scientific information is introduced to illustrate the issues involved. Highly technical details are avoided, but can be found in the references cited.

Some of the key issues raised in these papers are:

- The model studies IPCC cites as the basis for its conclusion that most of the warming of the last 50 years can be attributed to human activities (1) do not include some of the factors known to influence climate, e.g. soot, which recent studies indicate may play a larger role in climate than previously thought; (2) match the temperature profile of the surface, but not that of the lower atmosphere; and (3) depend on proxy data for solar variability, which the IPCC itself characterizes as questionable (Paper 4).

- IPCC's temperature projections for 2100 are highly uncertain since they include the uncertainties inherent both in climate models and in projections of future greenhouse gas emissions. The models assume no efforts to reduce greenhouse gas emissions (Paper 7).

- Even though the climate change could potentially affect the lifecycle of many disease pathogens and vectors, as IPCC points out:

  > In all cases, however, actual disease occurrence is strongly influenced by local environmental conditions, socioeconomic conditions, and public health infrastructure. ... For each anticipated adverse health impact there is a range of social, institutional, technological and behavioral adaptations to lessen the impact.[1] (Paper 13).

- The combination of changes IPCC projects for the next century - higher CO2 concentrations, higher temperatures and somewhat higher precipitation – should,

[1] IPCC Working Group II Summary for Policymakers.

within limits, be beneficial for food crops and help feed a growing world population (Paper 14).

- IPCC has overstated technology's potential to reduce greenhouse gas emissions through 2020. More realistic assessments of the market potential of technology are needed to guide policymakers (Paper 17).

- IPCC recognizes the important role of adaptation to climate change but raises concern over those with the least resources. Rational analysis would conclude that investment in development would bring a far greater reduction in the vulnerability of these people than an equivalent investment in climate change mitigation (Paper 19).

- The debate on the selection of policies to address climate change should proceed both at the national and international level, recognizing the sequential nature of the decision making process, the important accompanying uncertainties, and the reality that each country must retain the flexibility to balance its selection of policies to meet its own set of needs and priorities (Paper 20).

IPCC's *Third Assessment Report* is a compilation of the work of numerous small teams of climate change experts. While the total number of experts involved in the assessment totals thousands, most are involved in only one narrow aspect of the work and have little or no knowledge of many of the other issues covered in the assessment. Typically each chapter of an IPCC report represents the consensus of a team of 20 or fewer experts whose work is commented on by a similar number of reviewers.

The IPCC is often portrayed as a purely scientific and technical body and its work involves many leading scientific and technical experts. However, the IPCC itself is made up of government representatives -- often the same individuals who represent their countries at the Kyoto Protocol negotiations.

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 climate change. The Summary for Policymakers, which are the most widely read and quoted portions of IPCC reports, are the subject of intergovernmental negotiations and have a much more political flavor. Also, as the National Academy of Sciences (NAS) pointed out: "The [IPCC] Summary for Policymakers reflects less emphasis on communicating the basis for uncertainty ..."[2] 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." [3]

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[2] National Academy of Sciences, *Climate Change Science: An Analysis of Some Key Questions*, June 2001, Pg. 5.
[3] *Ibid.*, Pg. 23.

The IPCC is a consensus organization. Consensus-building is a necessary requirement for international politics, but it is not necessarily the best way to characterize the state of climate science or to inform policymakers. Science advances when new information or theory challenges the consensus. But simply because a new piece of information or theory challenges the consensus does not automatically make it right. Scientists who disagree with the IPCC's findings may be wrong. However, their theories should be tested and either supported or refuted with data, not dismissed because they do not agree with the consensus.

It is often argued that building a consensus among scientists reduces uncertainty. However, as Roger Pielke, Jr., a respected senior scientist at the National Center for Atmospheric Research, has pointed out:

> ... 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.[4]

[4] Pielke, Roger A., Jr. (2001): "Room for doubt." *Nature*, Volume 410, Pg. 151.

1 - How the IPCC Operates

The Intergovernmental Panel on Climate Change (IPCC) is often portrayed as a purely scientific and technical body. While the work of the IPCC involves many leading scientific and technical 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.

The SPMs are the most widely read and widely quoted portions of IPCC reports, and their text is usually changed significantly by governments during the line-by-line review process. This process gives the SPMs a much more political flavor. As the National Academy of Sciences (NAS) pointed out: "The Summary for Policymakers reflects less emphasis on communicating the basis for uncertainty ..."[1] 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." [2]

The on-going work of the IPCC between Plenary meetings is the responsibility of its Bureau (Executive Committee). The Bureau is chosen to "reflect balanced geographic representation (across the five UN geographic regions) with due consideration for scientific and technical requirements."[3] Whenever possible, each IPCC committee or writing team has at least two co-chairs, including one from a developed country and one from a developing country. While this procedure meets political needs, it does not guarantee that the IPCC will draw on the most qualified experts.

The IPCC is an independent body, but it maintains close links with the Kyoto Protocol negotiations under the UN Framework Convention on Climate Change (UNFCCC). The Bureaus of the two organizations meet on a regular basis and most of the work 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 UNFCCC - Kyoto Protocol negotiations, and usually several hours are spent discussing the implications for the climate negotiations.

Once the IPCC has decided to carry out an assessment, it is assigned to one of the IPCC's three Working Groups. Working Group I is responsible for assessments of the science of

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[1] National Academy of Sciences, *Climate Change Science: An Analysis of Some Key Questions*, June 2001, Pg. 5.

[2] *Ibid.*, Pg. 23.

[3] "Principles Governing IPCC Work" Approved at the Fourteenth Session (Vienna, 1-3 October 1998) on 1 October 1998

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 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 then, with the approval of the Bureau, selects writing teams for each chapter in the assessment. Typically a writing team is led by two Coordinating 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 experts for both Coordinating Lead Author and Lead Author positions, and most nominees are either government employees or academics who are able to dedicate a substantial portion of their time to IPCC work.

The writing teams are responsible for developing a draft that is a comprehensive assessment of the information available in the peer-reviewed literature on the subjects covered by their chapter. To assist in this effort, writing teams will often ask other experts to be contributing authors who draft text covering their specific area of expertise. The IPCC also has procedures for accepting non-peer-reviewed input.

Draft chapters undergo two rounds of review. The first review is by individual experts which generally includes experts employed by governments as well as other interested parties. The second review is by governments, with each government submitting one set of comments. Some governments, e.g., the U.S., ask for comments from experts within their country as they compile their comments. The writing teams are required to respond to all comments received during the two rounds of review; to either accept the comment and modify their draft accordingly, or give a valid reason for rejecting the comment. A written record is kept of the response to all comments and Review Editors ensure that all comments are treated fairly.

Once the chapters have been drafted, the process of summarizing the information begins. Coordinating Lead Authors prepare Executive Summaries for their Chapters. A team chosen from the Coordinating 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 chapter Executive Summaries are usually available for expert review, but the Technical Summary and SPM are usually only available for government review. As mentioned above, the SPM is subject to a line-by-line review by governments that usually results in extensive changes in wording.

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 climate change. The summaries, particularly the SPMs, which are the subject of intergovernmental negotiations, have a much more political flavor.

The claim 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 narrow 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 IPCC report.

2 - Does the IPCC Know Enough to Make Assessments of Climate Change?

The IPCC defines its role as follows:

> The role of the IPCC 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.[1]

This is an ambitious goal, and it is reasonable to ask whether the scientific and technical community has the proper tools to achieve it.

At least one knowledge group, the Committee on Global Change Research of the National Research Council of the U.S. National Academy of Sciene (NAS), questions the IPCC's ability to carry out assessments. In their 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 that the rule* (emphasis added). At the same time, assessment activities are consuming an ever-increasing portion of the limited time and money resources of the scientific community. 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* (emphasis in original) scientific credibility and political legitimacy.[2]

In reporting this finding, the NAS Committee clearly was aware of the IPCC's on-going assessment efforts, but chose not to cite them as one of the exceptions to its criticism.

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."[3]

Consensus-building is a necessary requirement for international politics, but it is not the necessarily the best way to characterize the state of climate science or to inform policymakers.

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[1] "Principles Governing IPCC Work" Approved at the Fourteenth Session (Vienna, 1-3 October 1998) on 1 October 1998

[2] Committee on Global Change Research, National Research Council, National Academy of Science (2000): "The Science of Regional and Global Change: Putting Knowledge to Work", pp. 9-10.

[3] "Principles Governing IPCC Work" Approved at the Fourteenth Session (Vienna, 1-3 October 1998) on 1 October 1998

Science advances when new information or theory challenges the consensus. Had the world's physicists been polled in 1905 as to whether they agreed with Einstein's view of the universe or Newton's, the overwhelming majority would probably have asked, "Who's Einstein?" and voted for Newton. Einstein himself doubted the validity of quantum mechanics for many years. Ultimately both the Theory of Relativity and quantum physics proved to be correct. But simply because a new piece of information or theory challenges the consensus does not automatically make it right. Scientists who disagree with the IPCC's findings may be wrong. However, their theories should be tested and either supported or refuted with data, not dismissed because they do not agree with the consensus.

It is often argued that building a consensus among scientists reduces uncertainty. Many such as Roger Pielke, Jr., a respected senior scientist at the National Center for Atmospheric Research, question this argument:

> ... 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.[4]

Nowhere is the "illusion of certainty" more apparent than in the IPCC's projections of the potential impacts of climate change. In its assessments the IPCC often uses scenarios of the greenhouse gas emissions that would result if various economic and social trends developed over the next 100 years. These scenarios are described as alternate views of the future, not forecasts, but their projected greenhouse gas emissions are routinely used to make estimates of future temperature and precipitation changes. Generally, the most severe of these projected climate changes are then used to estimate potential impacts on human health, the economy, natural ecosystems, etc. Despite the high level of uncertainty associated with each step in this calculation chain, the most extreme potential impacts are then presented as a scientific consensus of what the world can expect as a result of climate change, without an assessment of the probability of these events occurring.

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[4] Pielke, Roger A., Jr. (2001): "Room for doubt." *Nature*, Volume 410, Pg. 151.

3 - Has Temperature Risen During the 20th Century?

Earlier this year the IPCC approved the following finding:

> The global-average surface temperature (the average of near surface air temperature over land, and sea surface temperature) has increase since 1861. Over the 20th century the increase has been 0.6 ± 0.2 °C. (1.08 ± 0.36 °F) ... The record shows a great deal of variability; for example, most of the warming occurred during the 20th century, during two periods, 1910 to 1945 and 1976 to 2000. [1]

In the past, similar conclusions from the IPCC have been debated for two reasons:

1) acknowledged problems with the temperature data base, including:

   - the urban heat island effect, i.e., the fact that cities retain heat raising their temperature more than the increase in temperature of nearby rural areas; and

   - the lack of adequate temperature measurements over large areas of the developing world and over the oceans.

2) the differences in trends between temperature measurements at the surface and satellite measurements of the temperature of the lower troposphere (the atmosphere from the surface of the earth to five miles above the surface).

IPCC acknowledges all of these problems. It discusses the potential impacts of the urban heat island effect and calls for improved observations of temperature and other climate phenomena around the world. It quantifies the differences between surface and satellite temperature measurements and states that the reasons for these differences are not fully understood.

Given the concerns about the temperature data base, can we use other information to decide whether it has gotten warmer during the 20th century? If it has gotten warmer, the effects of that warming should be visible in physical systems, such as glaciers, and biological systems, such as the ranges of migratory animals. IPCC offers an array of information on the retreat of glaciers and ice caps, changes in the ranges of plants and animals, and increases in growing seasons, the large majority of which indicate that parts of the world have gotten warmer during the 20th century. However, the available information is ad hoc and not comprehensive or systematic. So the often cited physical and biological changes only indicate local warming and they cannot be used as a direct check of the estimated rise in global average temperature.

Even accepting that the available evidence supports the conclusion that the world has gotten warmer during the 20th century, this evidence still does not address the question, why has the warming occurred? As the IPCC carefully states:

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[1] IPCC Working Group I Summary for Policymakers.

> *Climate change* (italics in original) in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity.[2]

The next paper in this series address the question of what caused the warming of the 20th century.

[2] *Ibid.*

4 - Is Some/All of the Temperature Rise of the 20th Century Due to Human Activities?

In its recently approved *Third Assessment Report*, the IPCC concludes: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." [1] This finding is based on climate modeling studies that attempt to match the observed global average surface temperature since 1860.

Climate models are highly complex computer models that attempt to simulate the operation of the climate system with mathematical descriptions of the various physical and chemical processes that occur in the atmosphere and oceans. While much progress has been made in the development of more realistic models, they are still subject to many limitations. These have been fully described in many places such as the 1999 report titled "Global Environmental Change: Research Pathways for the Next Decade" issued by the Committee on Global Change Research of the National Research Council of the National Academy of Science.

Climate models use changes in the factors that affect climate -- solar variability, volcanic eruptions, greenhouse gas emissions, etc. -- to estimate the resulting changes in temperature and precipitation. The most complex models estimate the temperature profile in three dimensions; not only at the surface, but at various levels of the atmosphere into the stratosphere and at various depths in the oceans.

The modeling studies used by the IPCC first estimated the changes since 1860 in natural climate variables -- solar variability and volcanic eruptions -- and in man-made climate variables -- greenhouse gas and aerosol emissions. Greenhouse gases, such as carbon dioxide and methane, have a warming effect, while aerosols, such as sulfates, usually have a cooling effect. The climate models were run three times, first using only natural climate variables, then using only man-made climate variables, and finally using both natural and man-made climate variables.

Model calculations for global average surface temperature were compared with observed global average surface temperature. Using only natural climate variables, the models calculated a reasonable match for observed temperature up to about 1950, but a very poor match between 1950 and 2000. Using made-made variables, the match was poor from 1900 to 1950, but much better from 1950 to 2000. Using both natural and man-made variables resulted in the best fit over the full time scale. Since the changes in man-made variables during the 1950 to 2000 period were much larger than the changes in natural variables, the climate modelers concluded that human activities had caused most of the warming observed since 1950.

While the modeling studies used by the IPCC are an impressive piece of scientific work, they fall short of proof for at least three reasons.

[1] IPCC Working Group I Summary for Policymakers.

1) The modelers matched only one measure of temperature -- global average surface temperature. Their models calculated, but did not match, the pattern of temperature change of the lower troposphere - the first five miles above the surface. Is the match for surface temperature *alone* sufficient to constitute proof?

2) The models ignored a number of known man-made and natural climate variables, including soot, mineral dust, and the effects that aircraft have on clouds. They argued that each of these effects is small and therefore could be ignored. However, recent evidence suggests that soot may play a much larger role in the climate system than previously thought.[2] Additionally, while each of the ignored effects individually may be small, their combined effect is larger and possibly significant. Is a model that ignores important parts of the climate system a valid basis for evaluating the extent of human impacts?

3) Solar variability is an important natural climate variable, but direct satellite measurements of solar intensity have been available only since the late 1970s. For estimates of solar activity prior to the 1970s, climate modelers have to use a variety of proxy measurements These include the number of sunspots and changes in the concentrations in tree rings of isotopes created by cosmic rays. The IPCC assessment report concludes that there is only a very low level of scientific understanding about the changes in solar intensity prior to the last two decades. Are calculations based on a "very low level of scientific understanding" a valid basis for evaluating human impacts?

An obvious question is, if most of the warming of the last 50 years is not due to human activities, what caused it? Our current level of scientific understanding does not provide an answer for this question, but this should not be a reason for accepting questionable conclusions about the role of human activities.

[2] Andreae, M. O. (2001): "The dark side of aerosols." *Nature*, Vol. 409, pp. 671-2. and Jacobson, M. Z. (2001): "Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols." *Nature*, Vol. 409, pp. 695-7.

5 - Has Sea Level Risen During the 20th Century?

The IPCC concludes:

- "Tide-gauge data show that global-average sea level rose between 0.1 and 0.2 metres (4 - 8 inches) during the 20th century."[1]

- "... it is very likely that the 20th century warming has contributed significantly to the observed sea level rise, through thermal expansion of sea water and widespread loss of land ice."[2]

However, the IPCC also concludes that:

- "No significant acceleration in the rate of sea level rise during the 20th century has been detected...."[3]

Tide gauges, the basis for estimating 20th century sea level rise, measure the relative position of the sea surface to the land on which they sit. But the land under the oceans and along the coasts is not stationary. Its height changes as a result of geological forces and the on-going rebound since the last Ice Age. Attempts are made to correct tide-gauge data for these changes, but the IPCC report expresses concern about the accuracy of these methods. The IPCC report also expresses concern about the limited amount of high quality, long term tide-gauge data, and the fact that almost all of it is from the Northern Hemisphere -- even though more of the world's oceans are in the Southern Hemisphere. Data from the Southern Hemisphere, or more importantly the lack of it, is important because neither sea level nor sea level rise are constant around the world. A good global estimate requires data from all parts of the world.

The IPCC report attempts to estimate the amount of sea level rise due to the warming observed over the 20th century. This is a difficult calculation, since the relationships between atmospheric warming and either the thermal expansion of the oceans or the melting of land ice are not simple.

It is relatively easy to measure the thermal expansion of sea water as a function of temperature in a laboratory. However, to calculate the thermal expansion of the oceans, we also need to know the rate at which the oceans warm. While there is some historical data on the temperature of the ocean's surface, the earliest comprehensive data on temperatures below the surface dates from the 1950s. To deal with this lack of data, models are used to estimate the rate of heat transfer from the atmosphere to the oceans. Typically, estimates of heat transfer rate vary by a factor of more than two among the models used, creating a large range for estimates of the contribution of thermal expansion to sea level rise.

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[1] IPCC Working Group I Summary for Policymakers.
[2] *Ibid.*
[3] IPCC Working Group I Technical Summary.

The situation is similar with melting ice caps and glaciers. Much as been made of the on-going retreat of glaciers, and reasonably good records exist for the decrease in length of a number of glaciers. However, the change in a glacier's length is not enough to calculate its contribution to sea level rise. We need to know the change in its volume, i.e., the amount of ice that melted. We need the same type of data for ice caps, but limited data are available and models have been used to estimate the contribution of glaciers and ice caps to sea level rise over the 20th century.

The IPCC summed the contributions of model estimates of thermal expansion and melting glacier and ice caps and arrived at a range of - 0.08 to + 0.22 metres (- 3 to +9 inches) sea level rise for the 20th century. (A negative sea level rise is a fall in sea level.) The central value for this range was 0.07 metres (3 inches), less than the lower range of tide gauge estimates. This difference could be explained by changes in the height of the land along the coast and under the ocean, but a more likely explanation is incomplete understanding of the factors contributing to sea level rise.

At least one scientific group argues that the IPCC has overstated our understanding of the relationship between temperature and sea level rise. Prof. Nils-Emil Morner, a geologist at the University of Stockholm and President of the International Association of Quaternary Research's commission on sea level change (in geology, the Quaternary Era refers to the last million years), stated:

> The connection between heat and rising sea level is not as simple as the IPCC claims. ... Just because temperatures are rising does not necessarily mean that sea level will rise.[4]

He went on to point out that in the 1200s the temperature was 1 °C (1.8 °F) warmer than now but that sea level did not rise.

Sea level has been rising since the end of the last Ice Age, but despite some IPCC statements implying otherwise, it is unclear even within the *Third Assessment Report* whether the sea level rise of the 20th century was unusual.

[4] Quoted by Reuters New Service, May 15, 2001.

6 - Have Extreme Weather Events Become More Common During the 20th Century?

The IPCC assessment examined data on the frequency of extreme weather events and concluded that some had become more common during the 20th century, but that there was insufficient information to make judgements about others. Most of the extreme weather events that became more frequent during the 20th century are temperature related and can be attributed to the increase in average temperature that occurred during the century. As noted in Paper 3, there is strong evidence that global average surface temperature increased during the 20th century, but that the reasons for this increase are still debatable. The IPCC could not make judgements about whether there had been increases in the frequency of storms.

The definition of extreme weather changes with locality; 90 °F is a hot day in the Northeast, but unremarkable in the desert Southwest. If average temperature rises, maximum temperatures and the number of days crossing the local threshold for hot days would be expected to increase. By the same token, if average temperature rises, minimum temperatures would also be expected to increase and the number of days crossing the threshold for cold days or frost days would be expected to decrease. Also, if average temperature rises, the amount of evaporation, and therefore the humidity, would also be expected to increase. The combination of higher temperature and higher humidity would lead to a higher Heat Index. It could also lead to more intense precipitation -- thunder storms and other intense rainfall are more likely in warm weather than in cold weather.

The IPCC analyses detected all of the above changes. During the 20th century:

- maximum temperature and number of hot days increased over nearly all land areas;
- minimum temperatures increased and the number of cold or frost days decreased over nearly all land areas;
- Heat Index increased over many land areas; and
- more intense precipitation events were noted over many mid- to high-latitude Northern Hemisphere areas.

It has often been argued that climate change will bring an increase in storminess. Despite the observed increase in temperature and a small increase in precipitation in many parts of the world, the IPCC could not find any measurable increase in the frequency or intensity of storminess. There was no observed increase in top wind speed or amount of rainfall in hurricanes, nor could the IPCC make any judgement about smaller storms such as tornadoes, thunder and hail storms.

7 - Will Temperature Continue to Rise During the 21^{st} Century?

The IPCC states: "The globally averaged surface temperature is projected to increase by 1.4 to 5.8 °C (2.5 to 10.4 °F) over the period 1990 to 2100." [1]

Even a simple description of how this temperature range was derived indicates the complexity and uncertainties of developing century-long temperature projections.

- This temperature range is derived from a set of calculations using a simple climate model.
- 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 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.
- For each scenario the simple climate model was run seven times with different calibrations to simulate the performance of different complex climate models.
- Each of the emission scenario - model calibration combinations 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 (2.5 to 10.4 °F).

The IPCC has been careful not to designate any of the SRES scenarios as a more likely case. The SRES states: "There are six scenario groups that should be considered equally sound that span a wide range of uncertainty ... " [2] Similarly, none of the seven models are designated as better or more accurate than the others. As a result, the IPCC does not state whether the high end or the low end of their estimated range of temperature rise during the entire 21^{st} century is more likely. However, this has not stopped many advocates from implying that the high end of the temperature range is more likely than the low end.

But is the high end of the IPCC's range of temperature rise for the 21^{st} century really more likely? Climate modelers at the Massachusetts Institute of Technology's (MIT's) Joint Program on the Science and Policy of Global Change don't think so. In a recent report they conclude:

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[1] IPCC Working Group I Summary for Policymakers.

[2] Nakicenovic, N., *et al.* (2000): IPCC Special Report on Emission Scenarios. Pg. 5.

> … we find that, absent mitigation policies, our median projection shows a global mean surface temperature rise from 1990 to 2100 of 2.5 °C (4.5 °F), with a 95% confidence interval of 0.9 °C to 4.8 °C (1.6 °F to 8.6 °F). [3]

Both the IPCC and MIT's Joint Program assume no efforts to mitigate greenhouse gas emissions during the 21st century. This assumption is clearly overly pessimistic. The debate on the Kyoto Protocol aside, countries and industry groups within those countries are taking voluntary steps to reduce greenhouse gas emissions. These voluntary actions are likely to increase in the future, making even MIT's median projection of temperature rise unlikely.

[3] Webster, M. D., *et al.* (2001): Uncertainty Analysis of Global Climate Change Projections. MIT Joint Program on the Science and Policy of Global Change Report No. 73.

8 - Will Sea Level Rise During the 21st Century?

In its *Third Assessment Report*, the IPCC projects:

> Global mean sea level is projected to rise by 0.09 to 0.88 metres (4 - 35 inches) between 1990 and 2100, for the full range of SRES (Special Report on Emissions Scenarios) scenarios. [1]

This estimate is only slightly different from the projection of 0.13 to 0.94 meters (5 - 37 inches) sea level rise between 1990 and 2100 contained in the IPCC's Second Assessment Report issued in 1996.

However, this apparent agreement hides a significant change is estimating techniques. The sea level rise projection in the Second Assessment Report was based on a temperature rise projection of 1 to 3.5 °C (1.8 to 6.3 °F) between 1990 and 2100. The current sea level rise projection is based on a temperature rise projection of 1.4 to 5.8 °C (2.5 to 10.4 °F). A greater temperature rise should result in a greater sea level rise, but as the IPCC explains:

> Despite the higher temperature change projections in this assessment, the sea level rise projections are slightly lower, primarily due to the use of improved models, which give a smaller contribution from glaciers and ice sheets. [2]

The large range in the IPCC's estimate of sea level rise during the 21st century is indicative of the high level of uncertainty in these calculations. The lower end of the range is lower than the 0.1 to 0.2 metres which is IPCC's best estimate for sea level rise during the 20th century, while the higher end of the range is 4 - 8 times 20th century sea level rise.

This high level of uncertainty should be expected given the difficulty of estimating sea level rise. Changes in sea level are due to three factors:

1. change in the relative height of the land and sea as the result of geological changes;

2. thermal expansion (or contraction) of sea water as a result of changes in the temperature of the ocean due to atmospheric warming or cooling; and

3. growth or shrinkage of ice caps and glaciers; again as the result of atmospheric warming or cooling.

The IPCC's estimate of sea level rise in the 21st century only considers the last two of these factors.

Estimating future sea level changes is difficult for two reasons.

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[1] IPCC Working Group I Summary for Policymakers.
[2] *Ibid.*

First, the relationship between the temperature of the atmosphere and thermal expansion of the oceans is not simple. It is relatively easy to measure the thermal expansion of sea water as a function of temperature in a laboratory. However, to calculate the thermal expansion of the oceans, we also need to know the rate at which the oceans warm. Models are used to estimate the rate of heat transfer from the atmosphere to the oceans. Typically, estimates of heat transfer rate vary by a factor of more than two among the various models used, creating a large range for estimates of the contribution of thermal expansion to sea level rise.

Second, to calculate the contribution of glaciers and ice caps to the future sea level we need to know future temperature on a regional basis, not just as a global average. Regional temperature trends for the 21st century are even more uncertain than global average trends. Most models project that different parts of the world will warm at different rates, but there are often large differences between regional projections from different models. Differences in projected temperature translate into even larger differences in the rate of melting of glaciers and ice caps. As indicated by the significant change in the IPCC's estimates of this rate between its Second and *Third Assessment Reports*, there is still considerable uncertainty on this topic.

Sea level has been rising since the end of the last Ice Age, there was no significant acceleration of the raise of sea level rise during the 20th century, and it is virtually certain that it will continue to rise during the 21st century. However, projections of the amount of sea level rise during the 21st century should be treated with caution because of the many uncertainties in estimating techniques currently available.

9 - Will Climate Become More Extreme in the 21st Century?

Except at the upper end of the range, the global average climate changes the IPCC projects for the 21st century do not appear dramatic. A few degrees change in temperature is unlikely to have a significant effect on most people. What could have an effect are changes in extremes that could accompany the changes in average conditions.

As indicated in the discussion of weather extremes of the 20th century, there are two types of climate extremes, those which are directly related to the projected increase in average temperature, and those which are related to changes in either precipitation or storminess. Also, as indicated in the Paper 6, the definition of extreme weather varies with locality; 90 °F is a hot day in the Northeast, but unremarkable in the desert Southwest. If average temperature rises, maximum temperatures and the number of days crossing the local threshold for hot days would be expected to increase. By the same token, if average temperature rises, minimum temperatures would also be expected to increase and the number of days crossing the threshold for cold days or frost days would be expected to decrease. Also, if average temperature rises, the amount of evaporation and therefore the humidity would also be expected to increase. The combination of higher temperature and higher humidity would lead to a higher Heat Index.

The IPCC projects all of the above changes for the 21st century:

- maximum temperature and number of hot days are very likely to increase over nearly all land areas;
- minimum temperatures are very likely to increase and the number of cold or frost days decrease over nearly all land areas; and
- Heat Index is very likely to increased over most land areas.[1 2]

Higher temperatures result in more evaporation and therefore both more total rainfall and more of the rain falling in intense events. IPCC Working Group I projects that more intense precipitation events, which during the 20th century were observed over mid- and high-latitude portions of the Northern Hemisphere, are very likely over many areas of the world. [1,2]

The underlying assumption in all of the above projections is that the world will get significantly warmer. As noted in Paper 7, the amount of temperature rise during the 21st century is uncertain, and may be considerably less than the upper end of the IPCC's range of predictions.

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[1] IPCC Working Group I Summary for Policymakers

[2] Confidence levels are assigned on the basis of the judgement of the IPCC authors, not as the result of statistical analysis. Very likely indicates that they judge the probability of the statement being true as 90 - 99%; likely, 66 - 90%.

Consistent with past IPCC assessments, the *Third Assessment Report* does not project an increase in the frequency of tropical cyclones (hurricanes, typhoons, etc), but unlike these previous assessments it does project that increases in both the peak wind speed and precipitation intensities of these storms are likely over some areas. [1,2] This projection is based entirely on a limited number of model projections and the areas of the world where this might happen are not defined. Not all models come to this conclusion, nor is it supported by the 20th century data, which provides no indication of increase in tropical storm intensity despite the warming which has occurred.

For other types of storms (thunderstorms, tornadoes, hail and lightening), there is insufficient data or modeling capability to make projections.

Another climate phenomenon which is of some concern is the El Nino cycle. IPCC is cautious about projections in this area. It states:

> Confidence in projections of changes in future frequency, amplitude, and spatial pattern of El Nino events in the tropical Pacific is tempered by some shortcoming in how well El Nino is simulated in complex models. Current projections show little change or small increase in amplitude for El Nino events over the next 100 years. [1]

The IPCC does express concern that even without a change in the actual nature of El Nino, the effects of these events would be worse because of other changes in climate due to warming. Here again, the questions are how much warming is likely to occur and how small amounts of warming would interact with El Nino?

10 - What Have Been the Impacts of 20^{th} Century Warming?

Climate changed during the 20^{th} century, as it has changed in every previous century. And since human and natural systems are impacted by climate, there have been both positive and negative impacts.

The IPCC documents two types of climate changes during the 20^{th} century.

- As discussed in Paper 3, global average temperature has increased. The increases in temperature do not seem to have had negative impacts on human societies, but changes have been noted in both physical systems -- such as changes in the size of glaciers and ice caps -- and in biological systems -- such as changes in the ranges of some plants and animals. Some of these changes, such as longer growing seasons in Europe, have probably been beneficial.

- There also have been changes in precipitation patterns which have resulted in floods and droughts in some parts of the world. The IPCC summarizes the situation as follows:

> There is emerging evidence that some social and economic systems have been affected by the recent increasing frequency of floods and droughts in some areas. However, such systems are also affected by changes in socioeconomic factors such as demographic shifts and land-use change. The relative impact of climatic and socioeconomic factors are generally difficult to quantify. [1]

At least for the United States, studies have shown that changes in demographics, i.e., changes in the number of people living in flood- or hurricane-prone areas and in the value of their property, are the largest factors explaining the growth in weather-related losses. [2]

The IPCC did not link changes in precipitation patterns during the 20^{th} century to human activities. It merely notes that changes in precipitation have occurred. Climate models do a poor job of simulating precipitation patterns and cannot be used as a basis for exploring why precipitation patterns have changed. The inability of climate models to simulate observed precipitation patterns is one of their shortcomings.

As noted in Paper 6, there is no evidence of an increase in storminess, either hurricanes or smaller storms such as thunderstorms and tornadoes, during the 20^{th} century.

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[1] IPCC Working Group II Summary for Policymakers.

[2] See, for example, Changnon, S. and D. Changnon (1999): Record-high losses for weather disasters in the United States during the 1990: how excessive and why. *Natural Disasters*, Vol. 18, Pg. 287-300.

11 - Would the Climate Change Projected for the 21st Century Threaten Endangered Species?

The IPCC concludes:

> Many species and populations (of plants and animals) are already at high risk, and are expected to be placed at greater risk by the synergy between climate change rendering portions of current habitat unsuitable for many species, and land-use change fragmenting habitats and raising obstacles to species migration. *Without appropriate management* (emphasis added), these pressures will cause some species currently classified as "critically endangered" to become extinct and the majority of those labeled "endangered or vulnerable" to become rarer, and thereby closer to extinction, in the 21st century. [1]

As a qualitative statement, the IPCC's conclusion is logical. Plants and animals are sensitive to climate, and if climate changes, they will be subject to more stress. If they are already vulnerable, their risk of extinction will increase. However, the IPCC does not provide any quantitative measures of the relative risks to endangered species of climate change and other factors, such as habitat fragmentation and destruction, improper use of toxic substances, and in the case of some animals, uncontrolled hunting. Since species extinction is viewed by many as a serious problem today, it appears reasonable to assume that these other factors have been more important than climate change.

The IPCC conclusion also provides a response strategy for the risks humans pose to biodiversity. Proper management is necessary, with or without climate change, and should include consideration of potential climate change.

[1] IPCC Working Group II Summary for Policymakers.

12 - Would the Climate Change Projected for the 21st Century Create Risks to Ecosystems?

The IPCC paints a gloomy picture of the potential impacts of climate change on ecosystems:

- Vegetation modeling studies continue to show the potential for significant disruption of ecosystems under climate change.
- Distributions, population sizes, population density and behavior of wildlife have been, and will continue to be, affected directly by changes in global or regional climate and indirectly through changes in vegetation.
- Future sea surface warming would increase stress on coral reefs and result in increased frequency of marine diseases.[1]

But is this gloom justified? The evidence suggests that it is not.

First, looking at vegetation changes: The usual scenario for the impact of climate change is that the optimum habitat for many plants would move, causing large changes in the typical vegetation cover, and as a result, the potential for ecosystem disruption. However, recent studies have shown that increasing carbon dioxide levels from 350 parts per million (ppm), approximately the current level, to 650 ppm increases the optimum temperature for plant growth by up to 5 °C (9 °F). This temperature rise is more than the temperature rise typically projected by climate models for that increase in atmospheric carbon dioxide concentrations.[2] With these two simultaneous changes, plant habitats would stay much the same as they are today, minimizing disruption. Also, natural ecosystems enjoy the benefits of higher carbon dioxide concentrations, which are discussed in relation to food crops in Paper 14.

Second, animal species are sensitive to climate, but, at least in theory, have the capability to migrate as climate changes. The argument is often made that because of other human impacts, the habitats of these animals are highly fragmented and they do not have the flexibility to adapt to potential climate change. If this is true, the more serious issue would appear to be habitat fragmentation, not climate change. Many organizations are addressing biodiversity concerns, and if they are successful, the solutions they develop should also address concerns about the impacts of climate change on animal species.

Coral bleaching, loss of the algae which are part of the coral community and critical to its nutrition, occurs when coral are exposed to any stress -- warmer water, colder water, excessive solar radiation, reduced salinity, bacterial infections, etc. Repeated bleaching can lead to the death of the coral and disruption of the ecosystems they support. Higher

[1] IPCC Working Group II Summary for Policymakers.

[2] Cowling, S. A. and Sykes, M. T. (1999): Physiological significance of low CO_2 for plant-climate interactions. *Quaternary Research*, Vol 52, pp. 237-42.

sea water temperatures have often been cited as the primary cause of coral bleaching, but the causes of this phenomenon appear to be more complex. A recent review of the scientific literature on coral bleaching concluded:

> ...attributing cause and effect has not been straightforward, with an apparent lack of correlation between coral reef bleaching and sea surface temperature anomalies (deviations from average) in the tropical Western Atlantic. [3]

As with the explanations of coral bleaching, many aspects of climate change science are more complex than they appear at first.

[3] Brown, B. E. (1997): Coral bleaching: causes and consequences. *Coral Reefs*, Vol. 16, pp. S129 -S138.

13 - Would the Climate Change Projected for the 21st Century Threaten Human Health?

The potential impacts of climate change on human health fall into two categories: infectious diseases and the affects of extreme weather events. On infectious diseases, the IPCC concludes:

> Many vector-borne, food-borne and water borne infectious diseases are known to be sensitive to changes in climatic conditions. ... there is *medium to high confidence*[1] that, under climate change scenarios that there would be a net increase in the geographic range of potential transmission of malaria and dengue -- two vector-borne infections, each of which currently impinge on 40 - 50% of the world's population. ... In all cases, however, actual disease occurrence is strongly influenced by local environmental conditions, socioeconomic conditions, and public health infrastructure. ... For each anticipated adverse health impact there is a range of social, institutional, technological and behavioral adaptations to lessen the impact.[2]

The National Academy of Science came to much the same conclusion in a recent report:

> Studies have shown that factors such as temperature, precipitation, and humidity affect the lifecycle of many disease pathogens and vectors (both directly and indirectly through ecological changes) and thus can potentially affect the timing and intensity of disease outbreaks. However, disease incidence is also affected by factors such as sanitation and public health services, population density and demographics, land use changes, and travel patterns. The importance of climate relative to these other variables must be evaluated in each situation. [3]

These are well-balanced statements that recognize the realities of disease transmission; how do they apply to the U.S.?

Much of the U.S. already has a climate which is conducive to the transmission of both malaria and dengue. As Paul Reiter of the Centers for Disease Control and Prevention points out, malaria was common in the U.S. east of the Mississippi until the 1930s, when it was eliminated by eradicating enough of the mosquito population to break the chain of disease transmission.[4] Reiter's analysis that climate is a relatively unimportant factor in the transmission of malaria is not unique. For example, David Rogers and Sarah Randolph of Oxford University, in a recently published article in the journal *Science*,

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[1] Confidence levels are assigned on the basis of the judgement of the IPCC authors, not as the result of statistical analysis. Medium confidence indicates that they judge the probability of the statement being true as 33 - 67%; high confidence, 67 - 95%.

[2] IPCC Working Group II Summary for Policymakers.

[3] Committee on Climate, Ecosystems, Infectious Disease, and Human Health of the National research Council of the National Academy of Science (2001): *Under the Weather: Climate, Ecosystems, and Infectious Disease*, pp. 2-3.

[4] Reiter, P. (2000): "From Shakespeare to Defoe: Malaria in England in the Little Ice Age." *Perspectives*, Vol. 6, No. 1.

concluded that even under the most extreme climate change scenarios there would be "remarkably few changes" in the distribution of malaria in a warmer world.[5]

Dengue is another example of the importance of factors other than climate. Dengue is relatively common in northern Mexico, but rare in southern Texas, just across the border, because appropriate public health measures have been taken. It is these public health measures, not climate, that determine the occurrence of the disease.

The second potential impact of climate change on public health concern is death and injury as the result of extreme weather events. Paper 16 notes that despite concerns about increased deaths from heat waves, more people die in winter (which might become less cold with climate change) than in the summer. Paper 6 concluded that many of the statements being made about increases in extreme weather events could not be supported by the available information. This question aside, we know that hurricanes, floods, heat waves, etc. kill and injure people. This is a serious concern independent of climate change.

However, consider the differences in the impacts of two of the major hurricanes of the past decade. Hurricane Andrew in 1992 is remembered because it was the first storm to cause over $1 billion in property damage. However, it killed only a handful of people. Hurricane Mitch in 1999 is remembered because it killed at least 10,000 people in Central America, but probably caused much less property damage than Hurricane Andrew. The difference was in the vulnerability of the populations involved. Hurricane Andrew hit South Florida, where, despite numerous building code violations, people had early warning and lived in solid housing or moved to shelters that could withstand the hurricanes, which are a normal part of their climate. Hurricane Mitch hit Central America where many people were living in flimsy housing perched on the sides of hills which were vulnerable to floods and landslides. They could not withstand the hurricanes which are a normal part of their climate.

Controlling human emissions of greenhouse gases will not eliminate hurricanes. Protecting vulnerable people, such as the poor of Central America, by providing them with adequate housing, is a far better way to reduce the loss of life associated with extreme weather events. And it has immediate payoff -- not only in protection from loss of life and property from hurricanes, but in terms of a better quality of life.

[5] Roger, D. J. and Randolph, S. E., (2000): "The Global Spread of Malaria in a Future, Warmer World." *Science*, Vol. 289, pp. 1763-6.

14 - Would the Climate Change Projected for the 21st Century Threaten Food Supplies?

The IPCC's conclusion on food supplies in the 21st century reads:

> Based in experimental research, crop yield responses to climate change vary widely, depending upon the species and cultivar (variety of plant); soil properties; pest and pathogens; the direct effects of CO_2 (carbon dioxide) on plants; the interactions between CO_2, air temperature, water stress. mineral nutrition, air quality, and adaptive responses. Even though increased CO_2 concentrations can stimulate plant growth and yield, that benefit may not always overcome the adverse effects of excessive heat and drought (medium confidence). [1 2]

The IPCC's assessment of the effects of the changes in atmospheric CO_2 concentration and climate projected for the 21st century on food supplies are arguably overly pessimistic. Plants grow via photosynthesis, the process that converts CO_2 and water into biomass. At the simplest level, CO_2 is plant food, and more CO_2 should lead to more biomass.

Idso and Idso [3] surveyed estimates of population growth and the effects of rising CO_2 concentration on plants which currently supply 95% of the world's grain, fruits and vegetables. They concluded that by 2050, the world's population will grow by 51%, and that without any benefits from increased CO_2 levels, food production would grow by only 37%. However, with the benefits of higher CO_2 concentrations food supply should be able to keep pace with the expected growth in population.

In addition to stimulating the growth of plants directly, higher CO_2 levels increase the efficiency with which plants use water, and a number of researchers have found that the relative enhancement of plant growth is greater under drought conditions than under well-watered conditions. [4] Other researchers have found that the interaction of increased CO_2 and temperature is also positive at moderate temperatures, but appears to be negative at very high temperatures. [5] Taking full advantage of the beneficial effects of higher CO_2 concentrations may require planting crops earlier in the year.

Overall, it appears that the combination of changes projected for the next century -- higher CO_2 concentrations, higher temperatures and somewhat higher precipitation -- should be beneficial to food crops and should help the world meet the food needs of a

[1] IPCC Working Group II Summary for Policymakers.

[2] Confidence levels are assigned on the basis of the judgement of the IPCC authors, not as the result of statistical analysis. Medium confidence indicates that they judge the probability of the statement being true as 33 - 67%.

[3] Idso, C. D. and Idso, K. E. (2000): Forecasting world food supplies: The impact of rising CO_2 concentration. *Technology* Vol. 7S, pp. 33-56.

[4] See, for example, Samarakoon, A. and Gifford, R. M. (1996): Elevated CO_2 effects on water use and growth of maize in wet and drying soil. *Australian Journal of Plant Physiology*, Vol. 23, Pg. 53-62.

[5] See, for example, Horie, T. (2000): Crop ecosystem responses to climate change: rice. In: *Climate Change and Global Crop Productivity*, CAB International Publication, pp. 81 - 106.

growing population. However, as with all such beneficial trends, there are limits. Plants still need water, even if higher CO_2 concentrations allow them to use water more efficiently. Similarly very high temperatures harm plants. In light of the complexities involved, IPCC concludes that more research is needed to understand the interactions between CO_2 concentration and the other factors affecting plant growth.

15 - Would the Climate Change Projected for the 21st Century Create Risks of Irreversible Changes in the Climate System?

One of the IPCC's more alarming conclusions is: "Projected climate changes during the 21st century have the potential to lead to future large-scale and possibly irreversible changes in Earth systems resulting in impacts at continental and global scales." [1] Having raised this specter with an appearance of certainty, the IPCC later cautions: "The likelihood of many of these changes in Earth systems is not well known but is probably very low; however, their likelihood is expected to increase with the rate, magnitude, and duration of climate change." [2]

Several possible changes are discussed including: shutdown of the thermohaline circulation that transfers heat through the oceans, large-scale melting of the West Antarctic Ice Sheets, and releases of methane from hydrates in coastal sediments.

Looking first at thermohaline circulation: The conventional picture of the oceans is that there are large patterns of circulation driven by differences in the density of sea water resulting from cooling and evaporation. For example, ocean circulation in the North Atlantic is assumed to proceed because less dense water from the subtropics becomes colder and saltier and therefore more dense as it moves north. Finally it becomes dense enough to sink in the vicinity of Iceland and Greenland, where deep ocean currents return it to the subtropics. This circulation is known as thermohaline circulation, and carries large amounts of heat to Western Europe, making that side of the Atlantic much warmer that the equivalent latitudes of North America. Without the thermohaline circulation, England would have the climate of Labrador.

Some climate models project that with sufficient warming, thermohaline circulation could be disrupted, resulting in changes in the distribution of heat through the oceans. At first it was thought that this would lead to colder temperatures in Europe, but the same models show that the amount of warming necessary to disrupt thermohaline circulation is greater than the amount of warming produced by the circulation. Under this scenario, Europe would warm, but not as much as previously predicted.

Are the models right? At least one respected oceanographer, Prof. Carl Wunsch of MIT, thinks not. In a recent article in *Science* [3] he points out that as early as about 1970 it was clear that the model of the oceans used in most climate models was incorrect. However, it wasn't until recently that the source of energy for ocean circulation was recognized. It turned out to be the Moon, the same source of energy that drives the tides. In the same issue of *Science*, an article by Egbert and Ray [4] uses satellite data to calculate the amount of energy available for deep ocean circulation as a result of the slow separation of the

[1] IPCC Working Group II Summary for Policymakers.
[2] *Ibid.*
[3] Wunsch, C. (2000): "Moon, tides and climate" *Science*, Vol. 405, pp. 743-4.
[4] Egbert, G. D. and R. D. Ray (2000): "Significant dissipation of tidal energy in the deep ocean inferred from satellite altimeter data." *Science*, Vol. 405, pp. 775-8.

Earth and Moon. Since the Moon appears to be the source for "thermohaline circulation", concerns about this circulation being disrupted by climate change are unfounded.

IPCC Working Group I which is responsible for assessments of the science of climate change, concludes that it is now widely agreed that substantial melting of the West Antarctic Ice Sheet is very unlikely during the 21st century, and that "... its dynamics are still inadequately understood, especially for projections on longer time scales."[5] Working Group I continues:

> Current ice dynamic models suggest that the West Antarctic ice sheet could contribute up to 3 metres to sea level rise over the next 1000 years, but such results are strongly dependent on model assumptions regarding climate change scenarios, ice dynamics and other factors. [6]

IPCC Working Group II, responsible for the assessment of the impacts of climate change, simply states that the West Antarctic ice sheet could contribute up to 3 metres to sea level rise over the next 1000 years, and via a footnote refers the reader to Working Group I for details and caveats.[7] Clearly concern about melting of the West Antarctic ice sheet is based on speculation, not strongly supported by either data or modeling studies.

Regarding methane, large amounts are stored in the sediments under the oceans and coastal waters in the form of methane hydrate. Since methane is a greenhouse gas, there is concern that these hydrates could be released to the atmosphere accelerating warming. Ice core studies indicate that there have been no large scale releases of methane from hydrates for at least the last 420,000 years.[8] However, despite a lack of either data or modeling studies indicating the circumstances under which methane could be released from hydrates, Working Group II lists it as one of the potential large-scale, irreversible changes that could affect the global climate. Such concerns are highly speculative, at best.

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[5] IPCC WG I Summary for Policymakers.
[6] *Ibid.*
[7] IPCC WG II Summary for Policymakers.
[8] Petit, J. R., *et al.* (1999): "Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica" *Nature*, Vol. 399, pp. 429-36.

16 - Would there be Benefits to the Climate Change Projected for the 21st Century?

Much has been made of the risks posed by climate change, but moderate amounts of climate change would provide some very real benefits. The beneficial effects of warmer temperatures and increased atmospheric concentrations of carbon dioxide were discussed Paper 14. Warmer temperatures would also be beneficial for human health, at least in temperate areas such as the U.S.

While there have been concerns raised about increased deaths in the U.S. as the result of increased summer heat waves, the reality is that more people die in the winter than in the summer. One study projected 20,000 fewer wintertime deaths in the UK, a 25% decrease, by the 2050s.[1] Another study pointed out that the sensitivity to cold weather -- that is the increase in death rate per degree of cooling -- is greater in relatively warm areas, such as the southern U.S., than in cold areas, such as northern Europe.[2] These studies led IPCC to conclude with medium confidence[3] that "... in some temperate countries reduced winter deaths would outnumber increased summer deaths.[4]

In their book, *The Impact of Climate Change on the Unites States Economy*, Robert Mendelsohn of Yale University and James E. Neumann of Industrial Economics Inc., conclude: "The empirical studies, taken as a group, suggest that modest warming would have a small but beneficial impact on the U.S. economy..." [5]. Their numerical results indicate that the impact would be an 0.1 to 0.2% increase in GDP in the 2060s.

Three studies extended the work of Mendelsohn and Neumann globally. The first, by Mendelsohn and co-workers [6], found that 1.5 - 2.5 °C (2.7 - 4.5 °F) of warming would provide an 0.1% benefit to global GDP. Tol [7] found that 1 °C (1.8 °F) of warming would provide 2.3 $\pm$ 1% benefit, while Nordhaus and Boyer [8] found that 2.5 °C (4.5 °F) of warming would result in a 1.5% loss in global GDP. Based on this limited number of studies, the IPCC concluded that a moderate amount of warming would be beneficial on a global average basis. However, they cautioned that the benefits would be unevenly

[1] Donaldson, G. C., *et al.* (2000) "The potential impact of climate change on heat- and cold-related mortality and morbidity." in *Health Effects of Climate Change in the UK* (forthcoming).
[2] Eurowinter Group (1997): Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe." *Lancet*, Vol. 349, pp. 1341-6.
[3] Confidence levels are assigned on the basis of the judgement of the IPCC authors, not as the result of statistical analysis. Medium confidence indicates that they judge the probability of the statement being true as 33 - 67%.
[4] IPCC Working Group II Summary for Policymakers.
[5] Mendelsohn, R and J. E. Neumann, eds. (1999): *The Impacts of Climate Change on the United States Economy*. Cambridge University Press, Pg. 315.
[6] Mendelsohn, R. *et. al.* (2000): Country-specific market impacts of climate change. *Climate Change*, Vol, 45, pp. 553 - 69.
[7] Tol, R. S. J. (1999): "New estimates of Damage Costs of Climate Change, Part I: Benchmark Estimates", Working Paper D99-01, Institute for Environmental Studies, Vrije University, Amsterdam, The Netherlands.
[8] Nordhaus, W. and J. Boyer (2000): *Warming the World: Economic Models of Climate Change*, MIT Press.

distributed and that some parts of the world would experience negative economic impacts from any amount of warming.

In many cases some adaptation on the part of human society is required before the benefits of climate change can be achieved. But much of this adaptation would come naturally. For example, fewer frost days mean a longer growing season. To obtain the benefit of the longer growing season farmers would have to plant their crops earlier.

The IPCC points out that the poorest members of human society are both the most vulnerable to the impacts of climate change and the ones least able to adapt. While this statement is true, it ignores one important question. If we wish to improve conditions for these poorest members of society, will we be more effective spending money on development assistance that raises their standard of living, or spending money on greenhouse gas mitigation to avoid climate change? The answer is obviously that development assistance will be more effective.

17 - What is the Short Term Potential for Reducing Greenhouse Gas Emissions with Improved Technology?

IPCC Working Group III, which is responsible for assessing the mitigation of climate change, provides a long list of technologies that could reduce future greenhouse gas emissions. It then concludes that depending on the emission scenario, half of the projected rise in global emissions between 2000 and 2010 - 2020 could be reduced "with direct benefits (energy saved or greenhouse gas recovered) exceeding direct costs (net capital, operating, and maintenance costs), and the other half at net direct costs of up to $100/metric tonne carbon equivalent (at 1998 prices)". There are two caveats to this conclusion:

- These cost estimates are derived using discount rates in the range of 5 to 12 percent, consistent with public discount rates. Private internal rates of return vary greatly, and are often significantly higher, affecting the rate of adoption of these technologies.

- Realizing these reductions involve additional implementation costs, which in some cases may be substantial, the possible need for supporting policies, increased research and development, effective technology transfer and overcoming barriers. [1]

Technology has a large potential to significantly reduce greenhouse gas emissions, but, unfortunately, the IPCC has overstated its case for several reasons:

1) It includes in its analysis technologies, such as automotive fuel cells, which are still under development. While several automobile manufacturers have announced their intentions to introduce vehicles using fuel cell technology, similar announcements of new technology have been made in the past either without the technology actually appearing, e.g. gas turbines for passenger cars, or the technology failing to meet market demands, e.g. rotary engines. Automotive fuel cells have great promise, but until they succeed commercially, care should be taken in claiming their benefits for greenhouse gas emissions reduction. Similar examples exist in other sectors.

2) Much of the reduction in emissions IPCC claims comes from either the building or agricultural sectors. While there is a great deal of greenhouse gas emissions reduction technology that could be applied in these sectors, they are highly fragmented and individual operators often lack the capital resources or technical skills to take advantage of that technology.

3) The 5 - 12% discount rate that IPCC uses in its economic evaluation is far lower than the return required to create incentives for individuals and companies to invest in greenhouse gas emissions reduction technologies. Returns of 15 - 50% are usually required.

[1] IPCC Working Group III Summary for Policymakers.

4) The estimate of emissions reductions assumes that the greenhouse gas emissions reduction technology will be adopted world-wide. This is an optimistic assumption, given the barriers to technology diffusion that exist in many parts of the world.

The IPCC has provided a view of the greenhouse gas emissions reductions that could be achieved under the best possible circumstances, but more realistic assessments of the market potential of technology are needed to guide policymakers.

18 - What is the Potential to Stabilize Atmospheric Concentrations of Greenhouse Gases?

The objective of the UN Framework Convention on Climate Change reads, in part:

> The ultimate objective of this Convention and any related legal instruments that the Conference of Parties may adopt [a phrase which includes the Kyoto Protocol] is to achieve ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic [man-made] interference with the climate system. [1]

Neither the Convention nor IPCC assessments define the atmospheric concentration of greenhouse gases that would cause dangerous interference with the climate system. However, the IPCC does offer assessments of amount that greenhouse gas emissions would have to be reduced to achieve stabilization at a variety of concentration levels and how much such reductions might cost.

Studies of what would be required to stabilize atmospheric concentrations of greenhouse gases have focused on carbon dioxide for two reasons: (1) all scenarios show that it is likely to be the most important human greenhouse gas emission for the foreseeable future, and (2) it is likely to be the most difficult human greenhouse gas emission to control. Previous IPCC assessments have indicated that stabilization of atmospheric carbon dioxide concentration at any level up to 1000 parts per million (current concentration is about 370 parts per million) will eventually require that human emissions be reduced to a small fraction of current emissions. [2]

Currently human activities emit about 8 billion metric tonnes of carbon per year, about 6.3 billion metric tonnes from fossil fuel use and about 1.6 billion metric tonnes from land-use change, i.e. deforestation and loss of soil carbon. [3] (The IPCC measures carbon dioxide emissions in terms of the carbon they contain; 3 2/3 pounds of carbon dioxide contain one pound of carbon.) The acceptable amount of emissions under stabilized conditions is not well defined, but appears to be less than 2 billion metric tonnes of carbon per year, 25% or less the current emission rate. [4]

In its current assessment, the IPCC concludes:

> There is no single path to a low emission future and countries and regions will have to choose their own path. Most model results indicate that known technological options could achieve a broad range of atmospheric carbon dioxide stabilization levels, such as 550 ppmv (part per million by volume), 450 ppmv or

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[1] UN Framework Convention on Climate Change, Article 2.

[2] IPCC, *Climate Change 1995: The Science of Climate Change*, Cambridge University Press, (1996), Pg. 70.

[3] IPCC, *Special Report on Land-Use, Land-Use Change, and Forestry*, Cambridge University Press (2000), Pg. 5.

[4] IPCC, *Climate Change 1995: The Science of Climate Change*, Cambridge University Press, (1996), Pg. 85.

below over the next 100 years or more, but implementation would require associated socio-economic and institutional changes. [5]

Two of the terms in this statement require further definition:

- "known technological options" include technology which is either currently commercial or has been demonstrated at the pilot plant stage. This includes all renewable energy technologies, as well as geological sequestration of carbon dioxide, i.e., permanently burying carbon dioxide underground, a technology currently being demonstrated in the North Sea.

- "associated socio-economic and institutional changes" refers to changes of the type envisioned in some of the scenarios developed as part of IPCC's Special Report on Emission Scenarios (SRES). These were baseline scenarios, i.e., scenarios without policies to limit greenhouse gas emissions. Their carbon dioxide emissions in 2100 ranged from about 4 billion metric tonnes of carbon to more than 35 billion metric tonnes of carbon. Obviously it is easier to reduce carbon dioxide emissions to below 2 billion metric tonnes if you are starting from the 4 billion metric tonne level than if you are starting from the 35 billion metric tonne level.

But the world that leads to about 4 billion metric tonnes of carbon dioxide emissions in 2100 is a very different world than the one we live in today. It has a population that peaks in the middle of the 21st century and declines there after reaching about 7 billion in 2100. It is a world with a high degree of globalization which depends on a service and information technology economy and an emphasis on economic, social and environmental sustainability.[6] The IPCC does not define the social-economic or institutional changes necessary to evolve to this type of world, but they would be substantial.

As might be expected, the cost of achieving stabilization of atmospheric concentrations of carbon dioxide will increase as the stabilization level decreases. IPCC does not provide cost estimates but observes:

> While there is a moderate increase in costs when passing from 750 to 550 ppmv concentration stabilization level, there is a larger increase in costs passing from 550 ppmv to 450 ppmv unless the emissions in the baseline scenario are very low.[7]

IPCC's caution in not quoting costs is fully justified. Achieving stabilization would require reducing emissions by 75% or more from current levels at a time decades to

[5] IPCC Working Group III Summary for Policymakers, Para. 9.
[6] IPCC, *Special Report on Emissions Scenarios*, Cambridge University Press, (2000), Summary for Policymakers.
[7] IPCC Working Group III Summary for Policymakers, Para. 14.

centuries in the future. Economic models are not capable to making credible projections about changes in the economy which are either that large or that far in the future.

The IPCC has helped the discussion of climate change by introducing some of the complexities associated with thinking about the stabilization of the atmospheric concentrations of greenhouse gases, and by not trying to offer estimates of either the cost or the technical difficulty. This discussion needs to proceed so that the long term challenges raised by the objective of the UN Framework Convention on Climate Change are understood and factored into the discussion of shorter range goals.

19 - What is the Role of Adaptation in Responding to Climate Change?

The IPCC discusses adaptation in the following terms:

> *Adaptability* refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes in climate. Adaptation can be spontaneous or planned, and be carried out in response to or in anticipation of changes in conditions.[1]

In its current assessment, IPCC concludes:

> Adaptation has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damages. Extremes, variability and rates of change are all key features in addressing vulnerability and adaptation to climate change, not simply changes in average conditions. Human and natural systems will to some degree adapt autonomously to climate change. Planned adaptation can supplement autonomous adaptation, though options and incentives are greater for adaptation of human systems than for adaptation to protect natural systems. *Adaptation is a necessary strategy at all scales to complement climate change mitigation efforts.* (emphasis added)[2]

The IPCC's recognition of the importance of adaptation is a welcome departure from some of the past political debate where any mention of adaptation was seen as a lack of commitment to reducing greenhouse gas emissions.

Climate variability -- the El Nino cycle and other changes -- and climate extremes -- hurricanes, floods, droughts, etc. -- are facts of life, and cause significant property damage and human suffering. Many of the adaptation measures discussed by the IPCC, such as better long-range weather forecasting and more heat resistant agricultural crops, would bring immediate benefits in terms of improved resilience to current climate variability, as well as improving capability to respond to any future climate change.

The IPCC also warns against what it refers to as "maladaption":

> In addition, maladaption, such as promoting development in risk-prone locations, can occur when decisions are based on short term considerations, neglect of known climate variability, imperfect foresight, insufficient information, or over-reliance on insurance mechanisms.[3]

These problems are found all over the world, including here in the U.S., where building continues in flood plains despite repeated losses.

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[1] IPCC, *Climate Change 1995 - Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*, Cambridge University Press (1996), Pg. 5.
[2] IPCC Working Group II Summary for Policymakers.
[3] *Ibid.*

Finally, the IPCC raises the concern that "Those with the least resources have the least capacity to adapt and are the most vulnerable."[4] This is a legitimate concern, but begs a critical question: If we wish to improve the lot of the most vulnerable, is it better to invest in development that will raise their standard of living or in climate change mitigation which may reduce some of their risk?

Any rational analysis would conclude that investment in development will bring a far greater reduction in vulnerability by raising the standard of living of "those with the least resources" than could be achieved by an equivalent investment in climate change mitigation. Governments of developing nations agree, as witnessed by their continual statements that the alleviation of poverty is their highest priority. However, in designing programs to alleviate poverty, reducing the impacts of climate variability and extremes should be one of the considerations. This will help today, and help tomorrow, if climate changes substantially.

[4] *Ibid.*

20 - How Should Decisions Be Made in Light of the Uncertainties about Future Climate?

IPCC Working Group III offers some interesting advice to policymakers about how climate change policy should be developed. First:

> Climate change decision-making is essentially a sequential process under general uncertainty. The literature suggest that a prudent risk management strategy requires a 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 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." [1]

Also:

> The effectiveness of climate change mitigation can be enhanced when climate policies are integrated with non-climate objectives of national and sectoral policy development and be turned into broad transition strategies to achieve the long-term social and technological changes required by both sustainable development and climate change mitigation. Just as climate policies can yield ancillary benefits]ancillary benefits are benefits which were not objectives of the policy, but occur anyway, e.g., the reduction in local air pollution that could occur as a result of less fuel usage to meet climate policy objectives] that improve well being, non-climate policies may produce climate benefits. [2]

These statements are worthy of careful consideration by policymakers. And Working Group III's emphasis on the importance of uncertainties echoes the earlier commentary on the "illusion of certainty" that sometimes seems to characterize Working Group I's Summary for Policymakers description of climate science.

The need for a flexible approach in dealing with the potential risks of climate change should be evident from the many statements of uncertainty in previous papers. Unfortunately, this is not the way the world seems to be addressing this concern. For several years, the international political process has locked onto a rigid set of targets and timetables for the reduction of greenhouse gas emissions. Many saw these mandatory targets and timetables as the first step to an ever more stringent set of targets and timetables on the path toward stabilization of atmospheric concentrations of greenhouse gases. As was pointed out in Paper 18, stabilization requires the elimination of 75% or more of carbon dioxide emissions at some time in the future. Society does not know enough at this time to plan for that amount of change over the next 100 years. The IPCC's recognition that the development of climate policy needs to be a sequential process is a useful contribution to the formulation of an effective and realistic climate policy.

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[1] IPCC Working Group III, Summary for Policymakers, Para. 21.

[2] *Ibid.*, Para. 19.

It is also refreshing that the IPCC acknowledges that climate change is not the only problem that society has to deal with. In the underlying text, the IPCC authors observe that climate change is not a high priority issue for many countries. This is reinforced in the Kyoto Protocol negotiations when developing nations correctly point out that the alleviation of poverty is their most important priority. Developed nations, too, have other priorities, whether it is dealing with the social needs of their citizens or with local and regional environmental problems.

There is merit in the IPCC's conclusion that climate policies will be more effective if they are addressed in the broader context of national policymaking and that non-climate policies can help reduce greenhouse gas emissions. However, the debate on the selection of policies needs to proceed both at the national and international level, recognizing "the accompanying uncertainties" and the reality that each country must retain the flexibility to balance its selection of policies to meet its own set of needs and priorities.