BEFORE THE SOUTH DAKOTA PUBLIC UTILITIES COMMISSION

**In the Matter of the Application by Otter Tail )**
**Power Company on behalf of the Big Stone II Co- )**
**owners for an Energy Conversion Facility Siting ) Case No EL05-022**
**Permit for the Construction of the Big Stone II )**
**Project**

# Direct Testimony of
# Ezra D. Hausman, Ph.D.
# Synapse Energy Economics, Inc.

## On Behalf of
## Minnesotans for An Energy-Efficient Economy
## Izaak Walton League of America – Midwest Office
## Union of Concerned Scientists
## Minnesota Center for Environmental Advocacy

**May 19, 2006**

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EXHIBIT NO. 2
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## I. PROFESSIONAL QUALIFICATIONS AND SUMMARY

**Q. Please state your name for the record.**

A. My name is Ezra D. Hausman

**Q. Where are you employed?**

A. I am a Senior Associate with Synapse Energy Economics of Cambridge, Massachusetts

**Q. Please describe your formal education.**

A. I hold a PhD. in Atmospheric Science from Harvard University, a master's degree in applied physics from Harvard University, a master's degree in water resource engineering from Tufts University, and a Bachelor of Arts degree from Wesleyan University.

**Q. Please describe "atmospheric science."**

A. Briefly, atmospheric science is the study of the chemistry, circulation and heat transfer processes of the atmosphere. It encompasses the study of how the atmosphere interacts with the ocean and land surface through processes of chemistry, moisture exchange, and energy transfers. These processes are central to what we think of as the "climate" of the Earth and, in concert with oceanic processes, they control the distribution of surface temperature and patterns of precipitation on the planet.

Another way to look at this is as follows: A certain amount of energy reaches the surface of the Earth, as sunlight, every day. At equilibrium, the same amount of energy must be vented back to space, on average. Atmospheric science is the science of all of those chemical, physical and dynamical processes which work together to move that energy to the top of the atmosphere and release it back into space.

**Q. Please describe your experience in the field of atmospheric science.**

A. For my doctoral research at Harvard University, I built a dynamic computer model of the ocean-atmosphere system to explore how a number of observed changes in atmospheric chemistry, ocean circulation and ocean surface temperature at the end of the last glaciation ("ice age") can be used to explain certain aspects of the warming of the planet at that time. I demonstrated, among other things, that the increase in atmospheric Carbon Dioxide ($CO_2$) at that time was both a result of and a strong positive feedback for the concurrent warming of the planet.

After graduation, I worked with researchers at Columbia University to develop private sector applications of climate forecast science. This led to an initiative called the Global Risk Prediction Network, Inc. for which I served as Vice President in 1997-1998. Specific projects included serving as Principal Investigator for a statistical assessment of grain yield predictability in several crop regions around the world based on global climate indicators and for a statistical assessment of road salt demand predictability in the United States based on global climate indicators. I also prepared a preliminary design of a climate and climate forecast information website tailored to the interests of the business community.

**Q. Please describe your work since 1998.**

A. Since 1998 I have been primarily focused on electricity market issues, turning my numerical modeling and analysis skills to issues of electricity market structure, electric industry restructuring, asset valuation and price forecasting, and environmental regulations in the electric industry. In July of 2005, I joined Synapse Energy Economics of Cambridge, Massachusetts, to continue this work but with more of a focus on the environmental, long-term planning and consumer protection aspects of the industry. This has given me an opportunity to apply my combined expertise, in atmospheric science and in the electric industry, to some of the most important issues facing the industry and, indeed, our society.

**Q. Have you attached a copy of your current resume to this testimony?**

A. Yes, I have, as Exhibit JI-2-A

**Q. Please provide a summary of the main points of your testimony.**

A. Human induced climate change is a grave and increasing threat to the environment and to human societies around the globe. Its early effects, which are already observable and documented in the scientific literature, are consistent with those predicted by computer models of the global climate, and these same models predict much more severe effects to come. Indeed, we are on a path that, if unchanged, is likely to bring about a climate well outside the range of anything ever experienced by our species, with the potential for severe and irreversible changes that will forever alter our environment, our economies and our way of life.

While some level of climate change is already a fact, computer models tell us that we can still avoid the most dangerous impacts by limiting the further buildup of $CO_2$ in the atmosphere. Perhaps the most important way to achieve this is by limiting the burning of fossil fuels in the decades ahead. In contrast, if the Big Stone Unit II is built, it would inject enormous amounts of $CO_2$ into the atmosphere for decades to come and would contribute to the dangerous atmospheric buildup of this gas. Thus, the proposed unit would exacerbate a problem that is likely to cause dramatic environmental and economic harm to societies around the globe, including to the communities in South Dakota.

**Q. What issues in particular will your testimony cover?**

A. My testimony will:

- discuss the scientific basics of global climate change (Part II)
- describe some of the authoritative scientific literature on the subject, including that which is written specifically for the use of policymakers, and the state of the scientific consensus on the subject (Part III)

- describe the rise of atmospheric CO2 globally and in the context of the long-term history of atmospheric CO2 (Part IV)
- discuss climate changes that have occurred already (Part V)
- describe what is predicted for the future (Part VI)
- discuss some of the global impacts of climate change (Part VII)
- discuss some likely impacts of climate change on South Dakota (Part VIII)
- put Big Stone II's CO2 emissions in the context of overall emissions (Part IX)
- express my scientific conclusions as they relate to legal standards applicable to this proceeding (Part X)

## II. THE SCIENTIFIC BASICS OF GLOBAL CLIMATE CHANGE

**Q. Would you explain the "greenhouse effect"?**

A. The planet's climate is a function of how much energy it receives from the sun, how much of that energy it retains, and how that energy is distributed throughout the planet (by wind and ocean currents, evaporation, condensation, and other mechanisms). Solar radiation arrives on earth, mainly in the form of visible light. That radiation is absorbed by the surface of the planet, which in turn radiates heat energy upward. Some of that heat is trapped in the lower atmosphere by naturally-occurring gases, analogous to how heat is trapped in a greenhouse by the glass. This is the natural "greenhouse effect" and the heat trapping gases are commonly called "greenhouse gases."

Without the greenhouse effect, the earth would be far too cold to support liquid water, or probably any kind of life. Similarly with too strong of a greenhouse effect, the earth would be considerably warmer and might have no polar ice caps, as has happened in the geologic past. With an even stronger greenhouse effect the earth could become extremely hot and uninhabitable, like the planet Venus. For all of recorded human history, the greenhouse effect has remained within a fairly narrow range that we know today, allowing complex human civilizations to form and develop. During periods of geologic history that had different abundances of greenhouse gases such as $CO_2$, the earth had a very different climate.

**Q. How have humans enhanced the natural greenhouse effect?**

A. Human activities have increased the atmospheric concentration of many greenhouse gases, most notably the concentration of $CO_2$. This increase has come primarily from the burning of fossil fuels (coal, oil, and natural gas), and also from changes in land use such as deforestation. Of the fossil fuels, coal emits the most $CO_2$ per unit of energy obtained. Today the primary reason for burning coal is for generation of electricity.

Because of the continuous and accelerating recovery and combustion of fossil fuels, the background level of $CO_2$ in the air has increased by roughly one third since preindustrial times. This means that the planet as a whole does not lose heat to space as efficiently as it otherwise would, so the system as a whole is warming up. This is the phenomenon commonly referred to as “global warming.”

Global warming will affect different areas differently, changing the distribution of rainfall, warming many areas but cooling some others, changing the length of growing seasons, and so forth. To emphasize the planet’s complex *response* to global warming, scientists have coined the term “global climate change.” I personally prefer to use the term “global climate change” in contexts such as this one to emphasize that the impact of the increased atmospheric $CO_2$ burden will not just be measured in a few warm days, but in disruptions in the very characteristics of climate that define our lives and our livelihoods.

## III. SCIENTIFIC LITERATURE ON GLOBAL CLIMATE CHANGE

**Q. In your opinion, what is the most comprehensive, reliable, authoritative, and scientifically credible account, relied upon by you and other experts in your field of climate science, regarding global warming, including the causes of global warming and the potential impacts on people and on the natural world?**

A. There are a great number of studies published in distinguished, peer-reviewed scientific journals that are relied upon by scientists in developing a full understanding of the many aspects of climate science and climate change. However, perhaps unique to this area of science, there is a single source that has been carefully assembled by the leading researchers in the field to provide a comprehensive, reliable, authoritative, and scientifically credible digest of this body of research. This source is the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC).

**Q. What is the IPCC?**

A. The IPCC was formed in 1988 by the World Meteorological Organization and the U.N. Environment Programme in response to rising concerns about global climate change. It provides an organizational structure for the work of hundreds of the world's leading researchers in climate science and related sciences. The IPCC does not do scientific research as an organization; rather, it assesses the scientific literature in an extremely methodical and transparent way, publishing consensus reports that reflect the work of scientists from around the world.

**Q. Does the IPCC have any official role in advising policymakers?**

A. Yes. In 1988 the United Nations General Assembly formally requested that the IPCC provide a comprehensive review and recommendations with respect to "the state of knowledge of the science of climate and climatic change."[1] In 1992, after receiving the IPCC's first assessment of the science, nearly every nation in the world, including the U.S., entered into the United Nations Framework Convention on Climate Change. The signers of the Framework Convention have asked the IPCC to provide full assessments of the state of climate science every 4 to 5 years, and to prepare various technical papers related to specific aspects of climate science, technology, and the social and economic impacts of climate change. The IPCC's assessments are therefore written with policy making in mind; they do not advocate for particular policies, but they do strive to provide policy-relevant information.

**Q. Do the periodic assessments by the IPPC address the science of climate change?**

A. Yes. The most recent Assessment Report released by the IPCC is the Third Assessment Report (TAR), released in 2001. The Report of Working Group I of the IPCC, entitled "Climate Change 2001: The Scientific Basis," is the part of the TAR that addresses the science of climate change. (Hereinafter "Working Group I Report".)

**Q. How and by whom was the Working Group I Report prepared?**

A. The Working Group I report describes in its preface how it was prepared, stating: "This report was compiled between July 1998 and January 2001, by 122 Lead Authors. In addition, 515 Contributing Authors submitted draft text and information to the Lead Authors. The draft report was circulated for review by experts, with 420 reviewers submitting valuable suggestions for improvement. This was followed by review by governments and experts, through which several hundred more reviewers participated. All the comments received were carefully analyzed and assimilated into a revised document for consideration at the session of Working Group I held in Shanghai, 17 to 20 January 2001. There the

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[1] IPCC 2004 document, "Sixteen Years of Scientific Assessment in Support of the Climate Convention."

Summary for Policymakers was approved in detail and the underlying report accepted."

The lead and contributing authors of this report were, like the IPCC itself, drawn from the ranks of the world's leading researchers. It is my opinion that the IPCC Working Group I report represents a thorough, fully informed, and authoritative assessment of scientific knowledge related to climate change as of the time it was written.

**Q. Is there a summary of the report?**

A. Yes. The Summary for Policymakers was adopted as part of the Working Group I Report. A copy of the Working Group I Summary for Policymakers is attached as Exhibit JI-2-B to my testimony.

**Q. Does the IPCC Third Assessment Report include an analysis of the potential impacts of global warming?**

A. Yes. The IPCC Third Assessment Report (TAR) includes the report of Working Group II of the IPCC, entitled "Climate Change 2001: Impacts, Adaptation, and Vulnerability," hereinafter referred to as "Working Group II Report".

**Q. How was the Working Group II Report prepared?**

A. The preface of the Working Group II Report describes how it was prepared, stating: "The WGII report was compiled by 183 Lead Authors between July 1998 and February 2001. In addition, 243 Contributing Authors submitted draft text and information to the Lead Author teams. Drafts of the report were circulated twice for review, first to experts and a second time to both experts and governments. Comments received from 440 reviewers were carefully analyzed and assimilated to revise the document with guidance provided by 33 Review Editors. The revised report was presented for consideration at a session of the Working Group II panel held in Geneva from 13 to 16 February 2001, in which delegates from 100 countries participated. There, the Summary for Policymakers was approved in detail and the full report accepted."

As with Working Group I, the authors of the Working Group II report were among the leading researchers in their fields, and their findings are based on a thorough consideration of the science. The Working Group II's Summary for Policymakers is attached as Exhibit JI-2-C.

**Q.** **Can you identify any other documents for a nontechnical, policymaking audience which you consider to be authoritative on the subject of global warming?**

A. Yes. A good example is a statement issued in 2005 by the U.S. National Academy of Sciences along with national science academies of Brazil, Canada, China, France, Germany, India, Italy, Japan, Russia, and the United Kingdom entitled "Joint Science Academies' Statement: Global Response to Climate Change," which I will refer to as the "Joint Science Academies Statement". The Joint Science Academies Statement is attached to my testimony as Exhibit JI-2-D.

**Q.** **What is the US National Academy of Sciences?**

A. The National Academy of Sciences (NAS) was formed by legislation signed in 1863, and as mandated in its Act of Incorporation it has since then served to "investigate, examine, experiment, and report upon any subject of science or art" whenever called upon to do so by any department of the government. The National Academy of Sciences is comprised of approximately 2,000 members and 350 foreign associates, of whom more than 200 have won Nobel Prizes. Although chartered by the federal government, the NAS is a private, non-profit and independent scientific organization. It is currently headed by Dr. Ralph J. Cicerone, himself an atmospheric scientist with research interests in atmospheric chemistry and climate change. Election to the NAS is considered by many to be one of the highest honors an American scientist can receive.

**Joint Intervenors**
**Exhibit 2**

**Q. In addition to expressing its views in the Joint Science Academies Statement, has the NAS released any reports on climate change?**

A. The NAS has issued a number of publications and reports on this subject, reflecting the importance with which the scientific community views this issue. In 2001, at the request of the Bush Administration, it released a study entitled "Climate Change Science: An Analysis of Some Key Questions," which endorsed the essential findings and predictions of the IPCC.

**Q. In your opinion is the National Academy of Sciences qualified to assess and report on the scientific data related to the increased concentration of $CO_2$ and the effects of that increase on air, water, and natural resources?**

A. Yes. The National Academy of Sciences is eminently qualified to address and produce authoritative reports on these issues.

**Q. Would you say that there is a scientific consensus on the issue of global climate change?**

A. There is an unequivocal scientific consensus on many aspects of the issue of global climate change. These aspects include:

- The fact that the $CO_2$ content of the atmosphere is increasing rapidly;
- The fact that this rate of increase, and the resulting abundance of $CO_2$ in the atmosphere, is unprecedented in at least the past 200,000 years, and probably much longer;
- The fact that the primary source of the increase is combustion of fossil fuels by human industrialized societies, i.e., that it is anthropogenic $CO_2$;
- The fact that the increased abundance of atmospheric $CO_2$ has a direct radiative forcing effect on climate by altering the heat transfer characteristics of the atmosphere;
- The fact that this change in the heat transfer properties of the atmosphere will have an impact on the climate of the planet;
- The fact that the climate of the earth is currently changing in ways that are consistent with model predictions based on the increased radiative forcing due to the anthropogenic increase in atmospheric

$CO_2$, and that these changes include increased sea surface temperatures, increased sea level, loss of arctic permafrost, loss of mountain and polar glacier mass, and destruction of arctic habitat;

- The fact that these observed changes cannot be ascribed to any known natural phenomenon;
- The fact that the magnitude of climate impacts will increase with increasing atmospheric $CO_2$ content; and
- The fact that once the atmospheric abundance of $CO_2$ has been increased, it will only return to equilibrium levels through natural processes on a timescale of several centuries.

In addition, there is a strong scientific consensus that natural feedbacks in the climate system would, on balance, tend to reinforce warming rather than mitigate it; that one effect of global warming will be migration of climate zones so that human societies and natural ecosystems will find themselves poorly adapted to their local climate; and that this will result in disruption and dislocation of ecosystems, migration of pest species and disease vectors, and disruptions in agriculture. There is general agreement, if not yet consensus, that global climate change will lead to generally more extreme weather patterns across most of the globe, including more intense storms and rainfall events and more extreme dry spells.

**Q. Do the documents identified in this testimony, including the IPCC Working Group reports and the Joint Science Academies Statement, support these conclusions regarding scientific consensus?**

A. Yes.

## IV. THE RISE OF ATMOSPHERIC $CO_2$ LEVELS

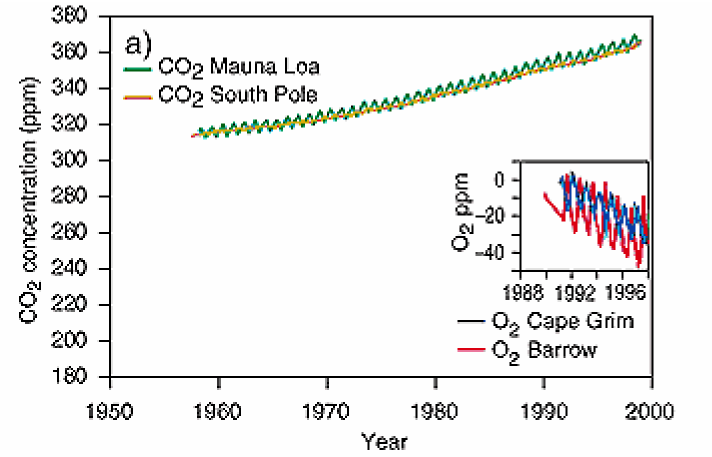
**Q. Since the last IPCC report in 2001, what has been observed by climate scientists about global levels of $CO_2$?**

A. The level of $CO_2$ is still increasing. For example, the U.S. National Oceanic and Atmospheric Administration (NOAA) reported on May 1, 2006, that the average atmospheric carbon dioxide level increased from an average of 376.8 parts per million in 2004 to 378.9 parts per million last year.[2]

**Q. Could you put this increase in $CO_2$ levels in perspective?**

A. Yes. I will put this in context with reference to a few figures from the Working Group I Report, which will show some of the key evidence demonstrating the nature of the modern rise in atmospheric $CO_2$.

The first graph shows the direct, instrumental measurements of $CO_2$ from Mauna Loa, in Hawaii, taken since the late 1950s. This graph shows both the seasonal variations in $CO_2$ associated with the growing season in the northern hemisphere, and the year-to-year increase in atmospheric $CO_2$ during this period:



In this period alone, essentially my lifetime, atmospheric $CO_2$ has risen from under 320 parts per million to almost 380 parts per million, and the rate of increase itself is also increasing.

This next graph shows the history of atmospheric $CO_2$ for the last thousand years or so. This is measured in ancient air samples recovered from bubbles trapped in polar ice, in this case from various sites in Antarctica. The vertical scale is the same as in the previous graph, and in fact it also shows the Mauna Loa data for comparison:

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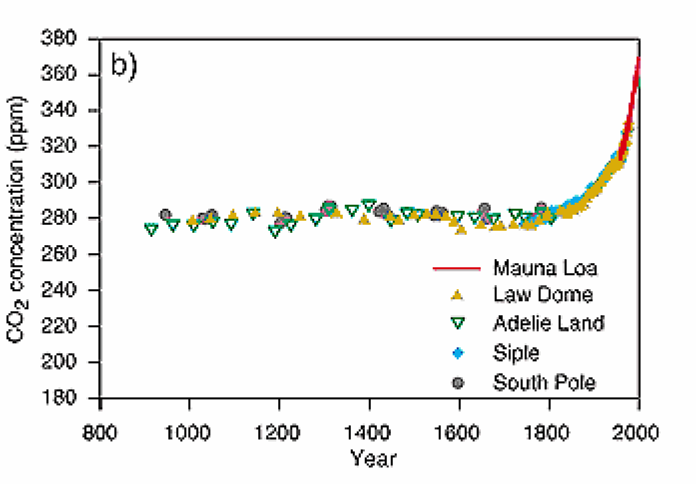
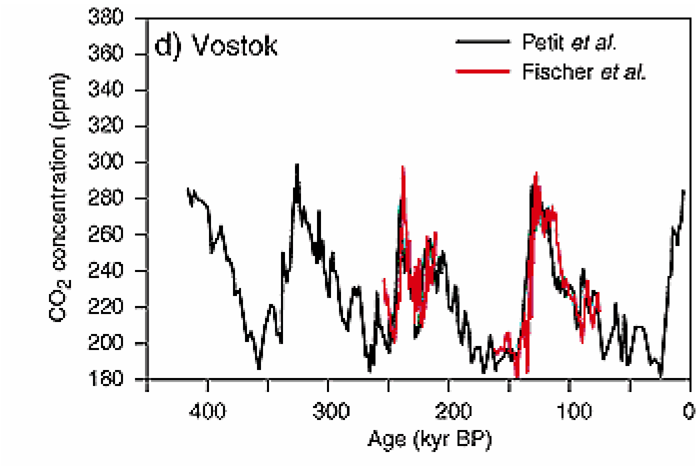
[2] *http://www.cmdl.noaa.gov/aggi*

**Joint Intervenors**
**Exhibit 2**



These data demonstrate that $CO_2$ levels have been relatively steady in the atmosphere for over 1,000 years, a time of remarkably quiescent climate by geological standards, during which modern human civilization and culture have flourished around the world.

Finally, this last graph shows the variations in atmospheric $CO_2$ over the last four glacial cycles, also recovered from Antarctic ice cores. The vertical scale is the same as for the two previous graphs, while the horizontal scale is in thousand years before the present:



Remember that the Mauna Loa data begin just below 320 ppm, and increase rapidly from there. This is already higher than has been measured for any time in the last 400,000 years, although the variations during this period were considerable. These variations were accompanied by enormous changes in climate, including the enormous advances of glaciers to cover much of the North American continent and Eurasia.

We have excellent computer models to predict some of the effects of elevated $CO_2$ levels, and some of these are the topic of my testimony. In addition to this, however, is the extraordinary risk associated with pushing the climate system to where it has never gone in over 400,000 years, and probably in tens of millions of years. This is, in my opinion, a dangerous game to play with the only planet we have.

**Q. How high are $CO_2$ levels projected to go in the century ahead?**

A. The IPCC predicts that $CO_2$ levels in the coming century will continue to steadily rise if the earth follows the "business as usual" path of fossil fuel consumption. These projections, based on various scenarios covering a range of assumptions regarding population growth, economic growth, globalization, etc., suggest that atmospheric $CO_2$ concentrations could reach from 490 to 1260 parts per million (an increase of 75% to 350% above 1750 concentrations). The higher the concentration, the more likely it is the earth will face dangerous or even catastrophic warming. Even concentrations above 550 or even 500 parts per million have the potential to cause dramatic and irreversible changes to our planet.

**Q. How long will these increased $CO_2$ levels persist in the atmosphere?**

A. The IPCC Working Group I Summary for Policymakers states that "several centuries after $CO_2$ emissions occur, about a quarter of the increase in $CO_2$ concentration caused by these emissions is still present in the atmosphere." [p. 17]. Thus, $CO_2$ that we put in the atmosphere today will affect the climate of the planet for many centuries to come.

## V. CLIMATE CHANGE TO DATE

**Q. Please describe, in general, changes in global temperatures in the last century, and the likely causes of those changes.**

A. The IPCC Working Group I Summary for Policymakers states that "[t]he global average surface temperature has increased over the 20th century by about 0.6 °C." [p.2] This is the conclusion drawn both from the more recent instrumental record, and from a number of so-called paleothermometers—the collected evidence from a large number of temperature proxies that all point the same direction.

We know that there is a causal relationship between atmospheric $CO_2$ levels and rising average surface temperatures. This relationship was originally postulated by the great mathematician and scientist Joseph Fourier as early as 1824, and was first quantified by Svante Arrhenius in 1896. As the quality of both measurement technology and numerical analysis have improved, these ideas have been strengthened and refined, and shown to be observable and measurable.

**Q. How do we know that this warming is not part of a natural trend?**

A. The IPCC Working Group I Summary for Policymakers concludes that "[t]here is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities….There is a longer and more closely scrutinized temperature record and new model estimates of variability. The warming over the past 100 years is very unlikely to be due to internal variability alone, as estimated by current models." [p.10]. [footnote omitted]

It goes on to state that "[i]n the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." [p.10]

Based on what I have seen in the scientific literature in the last few years I would expect the fourth annual report, due next year, to express even more certainty on this point in particular.

**Q. Since the IPCC report was issued in 2001, what has been observed by climate scientists about global temperatures?**

A. The highest annual average global surface temperature ever measured occurred during the 2005 calendar year, based upon an ongoing NASA analysis. The NASA scientific team noted that 2005 was slightly warmer than 1998, the warmest previous year known. However, in 1998, there was an "El Niño" event,[3] which was not the case in 2005. This event has a strong effect on the equatorial Pacific surface ocean and would have affected the temperature record in that year.[4]

Below I have reproduced one of the graphs from this study, showing the mean surface temperature "anomaly" from 1880 through the present. By anomaly the authors mean the difference between the annual average surface temperature for a given year and the long-term average surface temperature, which they define as the overall average for the period 1951 through 1980. If a year is exactly average in terms of temperature, the anomaly would be zero. The graph also shows the "smoothed" 5-year mean temperature anomaly over this period:

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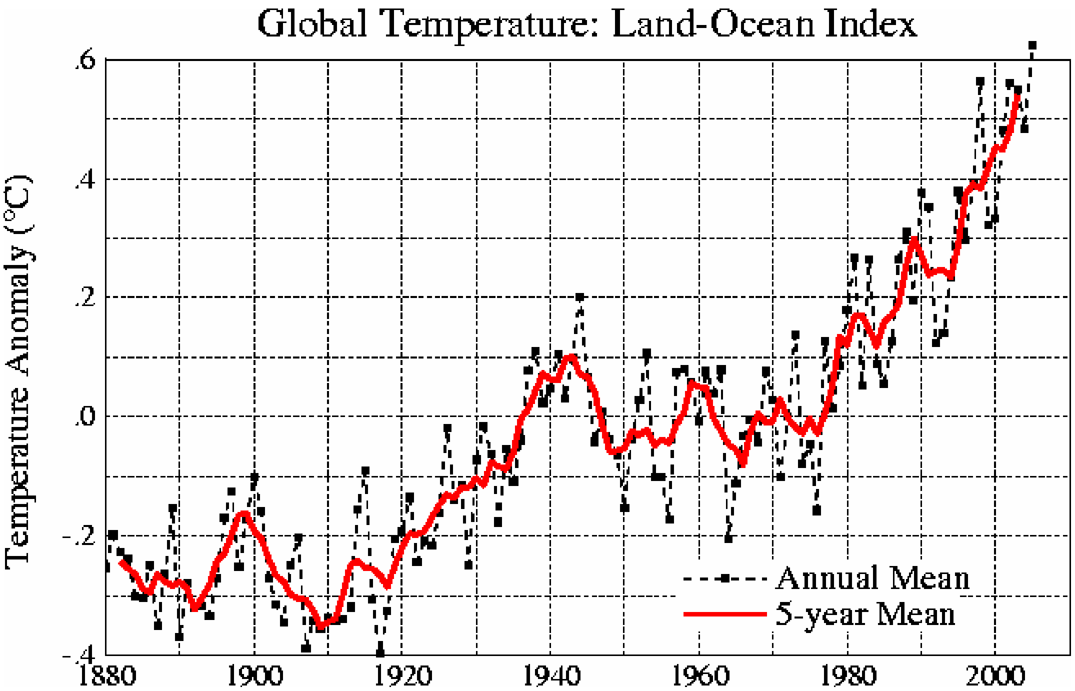
[3] El Niño is an occasional disruption of the ocean-atmosphere system in the tropical Pacific, in which the trade winds weaken and warm water from the western boundary floods much of the surface equatorial Pacific. Thus this large warm anomaly would tend to elevate average global surface temperatures, independent of any other effects.

[4] The GISS Surface Temperature Analysis is produced by Dr. James Hansen, director of NASA's Goddard Institute for Space Studies (GISS) at Columbia University in New York, along with Dr. Reto Ruedy and Dr. Ken Lo, also with the Goddard Institute, and Dr. Makiko Sato of the Columbia University Center for Climate Systems Research.

**Joint Intervenors**
**Exhibit 2**



There are a number of ways to look at this. Four of the five warmest years on record have occurred since 2000. The ten hottest years on record have all occurred since 1990. Nineteen of the twenty warmest years on record have occurred since 1980, and so on. The evidence is consistent, statistically significant, and convincing. In addition, it is consistent with what is and has been predicted by computer models of the climate in response to today's elevated concentrations of atmospheric $CO_2$.

## VI. PROJECTED WARMING

**Q. What additional warming is predicted for the century ahead?**

A. The IPCC predicts that the average surface temperature of the earth will increase by 1.5 to 5.8 degrees Celsius by 2100. The range reflects uncertainty about future emission levels and about precisely how the earth will respond to those emissions.

**Q. Can you provide any perspective on the significance of the projected changes in global temperatures in this century?**

A. These may sound like small figures, but the average surface temperature differential between the last ice age and the present was only about 5 degrees Celsius. During the last ice age, earth was a profoundly different place, with much of North America covered by an ice sheet a mile or more thick. At the upper range of the IPCC's 2001 warming prediction, earth would experience a warming equivalent to the one that melted that ice sheet. The recovery from the last major glacial period took 5,000 to 10,000 years. The warming we are discussing here will occur within a single century.

## VII. IMPACTS OF CLIMATE CHANGE GLOBALLY

**Q. What kinds of impacts are associated with warming projections in this range?**

A. The IPCC Working Groups I and II Reports predict a large number of very serious negative impacts associated with this warming, including:

- rising sea levels, exposing coastal areas to increased risk of inundation and storm damage;
- Damage to or loss of natural ecosystems, such as prairie wetlands and alpine;
- Migration of habitats, leading to species extinctions and expansion of disease vectors and pests;
- heat waves leading to higher morbidity and mortality from heat stress;
- more intense precipitation events resulting in increased floods, mudslides, and soil erosion; and
- increased summer drying in most continental interiors resulting in more droughts; reduced crop yields, reduced water availability and quality.

The higher the atmospheric abundance of $CO_2$ rises, the more severe we can expect these impacts to be; to some extent they are expected even at the lower warming projections. Indeed, there is evidence that the 0.6 °C warming we have experienced to date has already initiated some of these impacts.

**Q. Are the impacts of future warming likely to unfold gradually?**

A. Many scientists believe that this is unlikely. While the computer models are unable to predict specific abrupt climate changes, we know from the geologic history that when the planet is changing from one type of climate to another, such as from an ice age to an interglacial, it often makes those changes in an abrupt, lurching fashion. The well-dated ice core records, in particular, show several abrupt and sudden climate swings of a magnitude that would be extremely disruptive were they to occur today. Unfortunately, we cannot predict with certainty at what level of atmospheric $CO_2$ such abrupt climate events would be likely to occur.

## VIII. IMPACTS OF CLIMATE CHANGE ON SOUTH DAKOTA

**Q. Turning now to the regional impacts of climate change, can you identify any credible sources that forecast the impacts of increased atmospheric $CO_2$ on the geographic region around South Dakota?**

A. First let me note that it is much more difficult to predict climate change impacts for specific areas than it is for the planet as a whole, because of the significant complexities associated with changes in atmospheric circulation and cycling of moisture. Further, even the most highly resolved climate models still treat the Earth in large chunks compared to human scales—the most recent GISS model,[5] for example, has a grid size of $4^o$ longitude by $3^o$ latitude—an area about 2/3 the size of South Dakota in a single grid square.

Nonetheless, certain forecasts can be made for mid-continental areas such as South Dakota, which appear to be a robust feature of climate models. Furthermore, a team of leading university and government scientists in the Great Lakes region conducted an extensive study in 2003 of the likely

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[5] A climate model produced by NASA's Goddard Institute for Space Studies at Columbia University in New York.

impacts of climate change in the Great Lakes area, including Minnesota, which provides valuable guidance. The report, entitled “Confronting Climate Change in the Great Lakes Region: Impacts on Our Communities and Ecosystems” (“Great Lakes Study”), was co-sponsored by the Ecological Society of America and the Union of Concerned Scientists. I consider this report to present scientifically sound, credible projections of the likely impacts of climate change in the nearby region.

**Q. What approach did the Great Lakes Study use in forecasting local impacts of increased atmospheric $CO_2$?**

A. The Great Lakes Study based its analysis upon global climate simulations using two of the world’s leading climate models. In addition, they analyzed historical climate and weather data to establish relationships between climate trends (predictable by the models) and local temperature and weather characteristics.

**Q. What did the Great Lakes Study team conclude about the likely impacts of climate change on the region?**

A. I will quote from the subreport, which deals specifically with impacts on Minnesota, which is likely to be the closest proxy in this study for impacts in Eastern South Dakota:

> **Climate Projections**
> In general, Minnesota’s climate will grow considerably warmer and probably drier during this century, especially in summer.
>
> • *Temperature:* By the end of the 21st century, temperatures are projected to rise 6–10 °F in winter and 7–16 °F in summer. This dramatic warming is roughly the same as the warming since the last ice age. Overall, extreme heat will be more common and the growing season could be 3–6 weeks longer.
>
> • *Precipitation:* While annual average precipitation may not change much, the state may grow drier overall because rainfall cannot compensate for the drying effects of a warmer climate, especially in the summer. Seasonal precipitation in the state is likely to change, increasing in winter by 15–40% and decreasing in summer by up to 15%. Minnesota, then, may well see drier soils and perhaps more

> droughts.
>
> • *Extreme events:* The frequency of heavy rainstorms, both 24-hour and multiday, will continue to increase, and could be 50–100% higher than today.
>
> • *Ice cover:* Declines in ice cover on the Great Lakes and inland lakes have been recorded during the past 100–150 years and are expected to continue.
>
> **How the Climate Will Feel**
>
> These changes will dramatically affect how the climate feels to us. By the end of the century, the Minnesota summer climate will generally resemble that of current-day Kansas, and winters may be like those in current-day Wisconsin.

The report goes on to project specific impacts on the region, including impacts on water resources, agriculture, human health, wetlands and shorebirds, recreation and tourism, and forests and terrestrial wildlife. Some of these impacts will be similar in South Dakota and some will not. What is a consistent theme for all regions studied in this manner, however, is that the seasonal temperatures, seasonal pattern of rainfall, growing season, and other climate variables will be affected.

**Q. Understanding that you cannot predict impacts on South Dakota itself with great specificity, what can you predict in more general terms?**

A. I can make a number of general predictions with fairly high level of confidence. South Dakota is likely to experience increased heating for more of the year, which will lead to increased evaporation and transpiration and ultimately to decreased soil moisture. This is likely to harm both agriculture and natural vegetation. There will be an increase in heat stress as the number of extremely hot days increases, and an increase of heat-related morbidity and mortality. Although total rainfall may not change appreciably or may even increase, the region can expect an increased probability of severe drying and drought in the summer months and resulting ecological and economic damage.

As a result, plant and animal species that reside in South Dakota today will be displaced, and others will encroach the state's habitats as conditions change within the state and in the surrounding regions. Many species of plants and animals will not be able to adapt to change and will become extinct. Agricultural pests and diseases are likely to spread as a result of the disruption of ecosystems. As a result of increased storm intensity, flooding and pollution of streams from soil erosion can be expected to increase.

In addition, a large percentage of prairie wetlands will be damaged or dry up, particularly the ephemeral seasonal wetlands that are so important to waterfowl production, likely resulting in a loss of waterfowl population. The impact on Prairie Pothole Region, wetlands and waterfowl will be discussed more fully below.

**Q. Is it likely that most of the changes in the South Dakota climate will be detrimental?**

A. Yes. It is an unfortunate fact that most of the climate changes described in the Great Lakes Study are likely to be detrimental to the environment of South Dakota. In fact, *any* rapid change in hydrology, temperature, seasonality, and habitat is likely to be economically and socially disruptive. The ecosystem and agriculture of the state exist in a balance, which is adapted to a certain set of climatic conditions, including a long-term range of variability. Once this system is changed that balance is disturbed, invariably resulting in damage to the natural system as it exists and is valued today.

**Q. Is your testimony on these climate change trends supported by specific findings and conclusions in the IPCC report, Working Group I?**

A. Yes.

**Joint Intervenors**
**Exhibit 2**

**Q. What are the key findings and conclusions from that Report on which you rely?**

A. The IPCC Working Group I Summary for Policymakers contains the following statements and forecasts which support the conclusions I have presented:

1. "Increase of heat index over land areas" is projected to be "very likely, over most areas" during the 21st century. [p. 15, Table 1] [footnotes omitted].

2. "More intense precipitation events" are projected to be "very likely, over many areas" during the 21st century. [p. 15, Table 1] [footnotes omitted].

3. "Increased summer continental drying and associated risk of drought" is projected to be "likely, over most mid-latitude continental interiors" in the 21st century. [p. 15, Table 1] [footnote omitted].

**Q. Are you familiar with and have you reviewed a recent publication by W. Carter Johnson and coauthors, entitled "Vulnerability of Northern Prairie Wetlands to Climate Change", appearing in the October, 2005 issue of the journal Bioscience?**[6]

A. Yes.

**Q. Can you summarize the approach taken by the researchers as reported in this article?**

A. The researchers base their analysis on global circulation models predictions of future climate, with increased atmospheric $CO_2$, in the Prairie Pothole Region (PPR). The PPR extends from northern Iowa and Nebraska, across most of the eastern Dakotas and up into Canada.

The authors then apply these climate conditions to a calibrated model of the PPR wetlands to determine how the wetlands will respond and what the

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[6] Johnson, W.C., B.V. Millett, T. Gilmanov, R.A. Voldseth, G.R. Guntenspergen and D.E. Naugle, "Vulnerability of Northern Prairie Wetlands to Climate Change", *Bioscience 55(10),* pp.863-872, October, 2005.

implications will be for migrating waterfowl, in what they refer to as the "heart of the PPR's 'duck factory' during the 20th century." [p. 869]

**Q. What do the authors conclude regarding expected future changes in climate in this region?**

A. Johnson and coauthors summarize the climate model results as follows:

> Increased drought conditions in the PPR are forecast to occur under nearly all global circulation model scenarios. Regional climate assessments suggest that the central and northern Great Plains of the United States may experience a 3.6 °C to 6.1 °C increase in mean air temperature over the next 100 years. Longer growing seasons, milder winters in the north, hotter summers in the south, and extreme drought are projected to be a more common occurrence over the PPR. Trends in mean annual precipitation are more difficult to predict, and range from no change to an increase of 10% to 20% concentrated in the fall, winter, and spring, accompanied by decreased summer precipitation and a higher frequency of extreme spring and fall precipitation events. [pp. 864-865. References removed.]

**Q. Can you comment on the conclusions reached in that article regarding the impact of these changes on the ecology of the Prairie Pothole Region?**

A. The authors find that global climate change is likely to have a significant negative effect on this region, and ultimately on the population of waterfowl that use this region as a breeding ground:

> The observed sensitivity of the model to climate variability suggests that wetlands in the drier portions of the PPR, such as the US and Canadian High Plains, would be especially vulnerable to climate warming, even if precipitation were to continue at historic levels. Only a substantial increase in precipitation would counterbalance the effects of a warmer climate. Additionally, the most productive wetlands, currently centrally located in the PPR, may become marginally productive in a warmer, drier future climate. Historically a mainstay for waterfowl, the region including the Dakotas and southeastern Saskatchewan would become a more episodic and less reliable region for waterfowl production, much as areas farther west have been during the past century. [p. 871]

Interestingly, the authors find this to be the case even though some regions will become wetter and others will become dryer:

> A logical question is whether the favorable water and cover conditions in the eastern PPR that we simulated can compensate for habitat losses in the western and central PPR. Historically, the eastern PPR and northern parklands served as a safe haven for waterfowl during periodic droughts. Today, however, options are limited, because more than 90% of eastern PPR wetlands have been drained for agricultural production. Although wetland restoration programs have been under way since the mid-1980s, less than 1% of basins drained in Minnesota and Iowa have been restored. Restoration efforts in the east have developed slowly, largely because of the high cost of farmland easements. [pp.871-872, references removed]

**Q. Does this finding support your assertion, stated earlier, that *"any* rapid change in hydrology, temperature, seasonality, and habitat is likely to be economically and socially disruptive"?**

**A.** Yes.

## IX. BIG STONE UNIT II's $CO_2$ EMISSIONS

**Q. Are fossil-fired electric generation plants in the United States, such as the proposed Big Stone Project. a significant contributor to the production and build-up of these gases?**

A. Yes**.** The United States contributes more than any other nation, by far, to global greenhouse gas emissions on both a total and a per capita basis, contributing 24 percent of the world $CO_2$ emissions from fossil fuel consumption.

Coal-fired power plants in the United States already emit almost one-third of U.S. emissions, or 8% of all the world's anthropogenic $CO_2$ into the atmosphere, a staggering contribution to the global buildup of greenhouse gases. Further, recent analysis has shown that in 2004, power plant $CO_2$

emissions were 27 percent higher than they were in 1990.[7] Coal fired power plants are unquestionably a major and growing source of greenhouse gases, and thus a significant cause of global climate change.

**Q. Other than their relative contribution to increasing atmospheric $CO_2$ each year, are there any other characteristics of coal-fired power plants like the proposed Big Stone Unit II that raise particular concerns regarding climate change?**

A. Yes. Large, base load coal plants in the United States are built to produce electricity for decades, as long as 70 years in the case of some of the older plants still operating today. The evidence I have presented and discussed in my testimony shows that climate change is a serious threat to the environment and to human societies, including that of South Dakota, and that that threat is becoming increasingly obvious and severe. Today, the United States is almost alone among industrialized nations in failing to impose any cost on our electric sector or our industries for producing the greenhouse gases that cause this problem. As a result, utilities around the nation are making plans to invest in infrastructure that will emit $CO_2$ by the millions of tons into the indefinite future. The Big Stone II proposal is a good example of this shortsighted and distorted investment strategy.

**Q. What would the lifetime emissions of $CO_2$ from the Big Stone II Unit be?**

A. If built and operated as proposed, the Big Stone II Unit would add over 4.5 million tons of $CO_2$ to the atmosphere every year of its operational life, inexorably and significantly contributing to the buildup of greenhouse gases in the atmosphere. Assuming it operates for fifty years, that amounts to lifetime emissions of over 225 million tons of $CO_2$. For perspective, this lifetime production is roughly equal to the total amount of $CO_2$ produced by the entire country of Spain in one year.

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[7] EIA, "Emissions of Greenhouse Gases in the United Sates, 2004;" Energy Information Administration; December 2005, xiii

**Q. Could you compare the projected $CO_2$ emissions from the Big Stone II Unit to South Dakota emissions today?**

A. The Big Stone II Unit's annual emissions would represent an enormous increase in South Dakota's emission levels. According to the EPA,[8] South Dakota's $CO_2$ emissions in 2001 (the last year for which these figures are available) was 13.23 million tons. The Big Stone II Unit's emissions of over 4.5 million tons per year of $CO_2$ would therefore represent approximately a 34% increase in the state's 2001 $CO_2$ emissions. It would more than double the current rate of emissions from the state's electric sector (3.79 million tons).

The EPA states that the average annual $CO_2$ emissions for an American automobile is about 6.75 tons.[9] At 4.5 million tons per year, emissions from the Big Stone Unit II would be equivalent to emissions from almost 670,000 cars. According to the federal Department of Transportation, there were fewer than 400,000 cars registered in South Dakota in 2004.[10] This means that the Big Stone Unit II is very likely to emit over two-thirds more $CO_2$ than all of the cars currently registered in South Dakota, combined.

**Q. What is the significance of the Midwestern United States to the Global Warming phenomenon?**

A. The Midwest is America's heartland and responsible for 20% of the $CO_2$ emissions in the United States, and 5% of the world's total emissions. The Midwest alone is responsible for more global warming gas pollutants than any country in the world other than the U.S. itself, China, the former Soviet Union, India and Japan.

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[8] U.S. EPA, "Carbon Dioxide Emissions from Fossil Fuel Combustion (Million Metric Tons CO2)," Prepared by the U.S. EPA using DOE/EIA State Energy Consumption Data (2001) and EIIP emission factors.

[9] U.S. EPA, "EPA's Personal Greenhouse Gas Calculator," states that 13,500 lbs/year of CO2 emissions is "about average per vehicle."

[10] Federal Highway Administration (Department of Transportation), "State Motor-Vehicle Registrations – 2004."

Joint Intervenors
Exhibit 2

## X. SCIENTIFIC CONCLUSIONS RELATED TO LEGAL STANDARDS

**Q. Based upon your background, education, training and experience, your reading of the Governmental and non-governmental documents and treatises, including those that you have described, and assuming that the emissions from the proposed plant will operate as described in the record, including emissions of over 4.5 million tons of $CO_2$ annually, do you have an opinion to a reasonable level of scientific certainty, as to whether the proposed Big Stone II facility will cause irreversible changes anticipated to remain beyond the life of the facility?**

A. Yes. My opinion is that the emissions of over 4.5 million tons of $CO_2$ per year from this proposed facility would cause irreversible damage to the environment, especially considering its expected lifetime of 50 years or more and the slow recovery time for atmospheric $CO_2$. These emissions will contribute to elevated levels of $CO_2$ in the atmosphere, to increased radiative forcing of climate and to accelerated global climate change for several centuries to come. I consider this to be a significant and irreversible impact on the environment, both globally and in South Dakota.

**Q. Based upon your background, education, training and experience, your reading of the Governmental and non-governmental documents and treatises, including those that you have described, do you have an opinion, to a reasonable level of scientific certainty, as to whether the proposed Big Stone II facility will have cumulative or synergistic adverse consequences in combination with other operating energy conversion facilities, existing or under construction?**

A. Yes. My opinion is that this facility will have a cumulative effect, in combination with other operating energy conversion facilities, both existing and under construction, of causing the level of atmospheric carbon dioxide to be significantly elevated relative to what it would be without this plant. The cumulative impact of coal-fired electrical generation plants in the

United States alone contributes about 8% of all anthropogenic $CO_2$ emissions today. This represents a substantial and growing contribution to global warming and global climate change, and a considerable threat to the environment globally and in South Dakota.

In dealing with a global problem such as warming, it is appropriate to look at the cumulative impact of like facilities. This is particularly true of coal fired electrical plants, since the number of plants is relatively small, but the cumulative impact is great.

**Q.** **Are you aware that the Administrative Rules of South Dakota provide the following guidance in identifying the environmental, health and welfare effects of a proposed electrical generation facility:**

> **The environmental effects shall be calculated to reveal and assess demonstrated or suspected hazards to the health and welfare of human, plant and animal communities which may be cumulative or synergistic consequences of siting the proposed facility in combination with any operating energy conversion facilities, existing or under construction. ASDR 20:10:22:13.**

A. Yes.

**Q.** **Considering that definition of environmental effects, and based upon those same assumptions and factors as in the previous two questions, do you have an opinion as to whether this facility, considering the cumulative effect which you have described in your previous answer, will or will not pose a threat of serious injury to the environment or to the social and economic condition of inhabitants or expected inhabitants in the siting area?**

A. Yes. In my opinion, the environmental effects of this facility will pose a threat of serious injury to the environment in South Dakota and in the broader region.

As noted in my earlier testimony, the continued growth of carbon dioxide emissions from coal fired power plants as well as from other sources is extremely likely to trigger dangerous and irreversible global climate change. Any increase in emissions will increase the ultimate environmental damage and social costs, as well as the likelihood of abrupt and potentially catastrophic climate shifts. South Dakota, specifically, would expect severe drying and droughts in the summer months, disruptive changes in precipitation patterns in the winter, more intense storms, and adverse impacts on local ecosystems and on agriculture. We can expect harmful migration of pests, loss of a number of species of plants and animals due to habitat destruction and migration and invasive species, and a severe impact on the prairie pothole resource and its breeding waterfowl populations.

**Q, Based upon your background, education, training and experience, your reading of the Governmental and non-governmental documents and treatises, including those that you have described do you have opinion as to whether the facility will or will not substantially impair the health, safety or welfare of the inhabitants in South Dakota?**

A. Yes. My opinion is that the environmental effects of the facility as discussed above will substantially impair the health and welfare of the inhabitants of South Dakota, along with those of the rest of the world.

**Q. Please explain your opinion.**

A. The expected health impacts of climate change include morbidity and mortality due to increased heat in the region, and expanded habitat for disease vectors. Welfare impacts include the economic impacts expected to agriculture, as well as the loss of recreational hunting grounds and loss of the economic benefits of hunting, tourism and recreation in the region.

**Q. Based upon your background, education, training and experience, your reading of the Governmental and non-governmental documents and treatises, including those that you have described, do you have an opinion as to whether the facility will result in any pollution, impairment, or destruction of the air, water, or other natural resources or the public trust therein?**

A. Yes. My opinion is that this facility will result in impairment of the air, by increasing the carbon dioxide levels in the atmosphere. I state this based both on the volume of carbon dioxide emissions that it will cause over its lifetime, over 225 million tons, and on the fact that this will elevate the carbon dioxide load of the atmosphere for several centuries. This facility, by itself and cumulatively with other electrical generation plants, will exacerbate the effects of global warming and global climate change. The levels of carbon dioxide in the atmosphere will determine how much global warming, and hence how much environmental damage, ultimately occurs. Reducing carbon emissions now will have a definite impact on the ultimate severity of climate impacts and on the ultimate costs of remediation. Likewise, investments in infrastructure which materially increase those emissions, will surely increase the severity of future impacts and costs.

This plant's emissions of carbon dioxide, by itself and cumulatively with other electrical coal fired generation plants, will also impair the water resources of South Dakota. This is because the adverse environmental impacts of global warming, including changes in the patterns of precipitation to which our ecosystems, our society and our agriculture are adapted, will be made more severe than they would be without this plant or without the cumulative effect of this and other electrical generation plants. As noted elsewhere in my testimony, such water impairment will likely include increasingly severe summer droughts, more intense storms and extreme rainfall events, increased soil erosion and silting, and the loss of much of the prairie pothole wetland resource and its associated waterfowl populations.

**Q. In summary, what would you say is the significance of the Big Stone II plant to the problem of Global Warming, assuming that it will emit over 4.5 million tons of $CO_2$ each year for approximately the next 50 years, or longer?**

A. The significance of the proposed plant is this: This plant, alone and in combination with other energy conversion facilities, will contribute materially and significantly to the environmental, social and economic destruction associated with global climate change. We cannot pretend to be protecting the environment of either South Dakota or the world at large from this overwhelming threat while we continue to build long-lived infrastructure that has exactly the opposite effect. In this respect, I conclude that Big Stone Unit II will have a significant, long-term, and costly adverse impact on the environment both in South Dakota and throughout the region, the continent and the planet.

**Q. Does this conclude your testimony?**

A. Yes.

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## SUMMARY

I have worked since 1998 as an electricity market analyst with a focus on market design and market restructuring, as well as pricing of energy, capacity, transmission, losses and other electricity-related services. I have recently performed market analysis, prepared testimony and/or provided other expert support to clients in a number of areas, including:

- Electricity and capacity price forcasting and asset valuation
- Efficient and cost-effective pricing of generating capacity
- The impact of environmental and other regulations, including future $CO_2$ regulations, on electricity markets
- The role of the electric sector in addressing global climate change
- The impact of increased Liquefied Natural Gas (LNG) imports in the U.S. natural gas and electricity markets.

I hold a Ph.D. in atmospheric science from Harvard University, a Master's degree in applied physics from Harvard University, a Master's degree in water resource engineering from Tufts University, and a Bachelor of Arts degree from Wesleyan University.

## PROFESSIONAL EXPERIENCE

**Synapse Energy Economics Inc.**, Cambridge, MA. Research Associate, 2005-present. Conducting research, writing reports, and presenting expert testimony pertaining to consumer, environmental, and public policy implications of electricity industry regulation. Focus of work includes:

- Electricity industry regulation and restructuring
- Efficient and cost-effective pricing of generating and transmission capacity
- Long-term electric power system planning and market design
- Electricity market analysis and price forecasting
- Impact of air quality and environmental regulations on electricity markets and pricing
- Natural gas and Liquified Natural Gas (LNG) market dynamics
- Energy efficiency and renewable energy programs and policies, and their role in the electricity market .
- Power plant performance and economics
- Market power and market concentration analysis in electricity markets
- Consumer and environmental protection.

**Joint Intervenors**
**Exhibit 2 – A**

**Charles River Associates (CRA).** Cambridge, MA. Senior Associate, 2004-2005.
CRA acquired Tabors Caramanis & Associates in October, 2004.

**Tabors Caramanis & Associates.** Cambridge, MA. Senior Associate, 1998-2004.
Modeling and analysis of electricity markets, generation and transmission systems. Projects included:

- Several market transition cost-benefit studies for development of Locational Marginal Price (LMP) based markets in US electricity markets
- Long-term market forecasting studies for valuation of generation and transmission assets,
- Valuation of financial instruments relating to transmission system congestion and losses
- Natural gas market analysis and price forecasting studies
- Co-developed an innovative approach to hedging financial risk associated with transmission system losses of electricity
- Designed, developed and ran training seminars using a computer-based electricity market simulation game, to help familiarize market participants and students in the operation of LMP-based electricity markets.
- Developed and implemented analytical tools for assessment of market concentration in interconnected electricity markets, based on the "delivered price test" for assessing market accessibility in such a network
- Performed regional market power and market power mitigation studies
- Performed transmission feasibility studies for proposed new generation and transmission projects in various locations in the US
- Provided analytical support for expert testimony in a variety of regulatory and litigation proceedings, including breach of contract, bankruptcy, and antitrust cases, among others.

**Global Risk Prediction Network, Inc.** Greenland, NH. Vice President, 1997-1998.
Developed private sector applications of climate forecast science in partnership with researchers at Columbia University. Specific projects included a statistical assessment of grain yield predictability in several crop regions around the world based on global climate indicators (Principal Investigator); a statistical assessment of road salt demand predictability in the United States based on global climate indicators (Principal Investigator); a preliminary design of a climate and climate forecast information website tailored to the interests of the business community; and the development of client base.

**Hub Data, Inc.** Cambridge, MA. Financial Software Consultant, 1986-1987, 1993-1997.
Responsible for design, implementation and support of analytic and communications modules for bond portfolio management software; and developed software tools such as dynamic data compression technique to facilitate product delivery, Windows interface for securities data products.

**Abt Associates, Inc.,** Cambridge, MA. Environmental Policy Analyst, 1990-1991.
Quantitative risk analysis to support federal environmental policy-making. Specific areas of research included risk assessment for federal regulations concerning sewage sludge disposal and pesticide use; statistical alternatives to Most-Exposed-Individual risk assessment paradigm; and research on non-point sources of water pollution.

**Massachusetts Water Resources Authority,** Charlestown, MA. Analyst, 1988-1990. Applied and evaluated demand forecasting techniques for the Eastern Massachusetts service area. Assessed applicability of various techniques to the system and to regional planning needs; and assessed yield/reliability relationship for the eastern Massachusetts water supply system, based on Monte-Carlo analysis of historical hydrology.

**Somerville High School.** Somerville, MA. Math Teacher, 1986-1987.
Courses included trigonometry, computer programming, and basic math courses.

## EDUCATION

**Ph.D.,** Earth and Planetary Sciences. Harvard University, Cambridge, MA, 1997.

**S.M.,** Applied Physics. Harvard University, Cambridge, MA, 1993.

**M.S.,** Civil Engineering. Tufts University, Medford, MA, 1990.

**B.A.,** Wesleyan University, Psychology. Middletown, MA, 1985.

## FELLOWSHIPS AND AWARDS

**UCAR Visiting Scientist Postdoctoral Fellowship,** 1997.

**Postdoctoral Research Fellowship,** Harvard University, 1997.

**Certificate of Distinction in Teaching,** Harvard University, 1997.

**Graduate Research Fellowship,** Harvard University, 1991-1997.

**Invited Participant,** UCAR Global Change Institute, 1993.

**House Tutor,** Leverett House, Harvard University, 1991-1993.

**Graduate Research Fellowship,** Massachusetts Water Resources Authority, 1989-1990.

*Teaching Fellowships:*

> **Harvard University:** *Principles of Measurement and Modeling in Atmospheric Chemistry; Hydrology; Introduction to Environmental Science and Public Policy; The Atmosphere.*
>
> **Wesleyan University:** *Introduction to Computer Programming; Psychological Statistics; Playwriting and Production.*

## PUBLICATIONS AND REPORTS

**Hausman, E.D., K. Takahashi, D. Schlissel and B. Biewald,** "The Proposed Broadwater LNG Import Terminal: An Analysis and Assessment of Alternatives" Synapse Energy report on behalf of the Connecticut Fund for the Environment and Save The Sound, March 2, 2006.

**Hausman, E.D., P. Peterson, D. White and B. Biewald,** "RPM 2006: Windfall Profits for Existing Base Load Units in PJM: An Update of Two Case Studies" Synapse Energy report prepared on behalf of Pennsylvania Office of Consumer Advocate and the Illinois Citizens Utility Board, February, 2006.

**Hausman, E.D., K. Takahashi, and B. Biewald,** "The Glebe Mountain Wind Energy Project: Assessment of Project Benefits for Vermont and the New England Region" Report prepared on behalf of Glebe Mountain Wind Energy, LLC., February, 2006.

**Hausman, E.D., K. Takahashi, and B. Biewald,** "The Deerfield Wind Project: Assessment of the Need for Power and the Economic and Environmental Attributes of the Project" Report prepared on behalf of Deerfield Wind, LLC., January, 2006.

**Hausman, E.D., P. Peterson, D. White and B. Biewald,** "An RPM Case Study: Higher Costs for Consumers, Windfall Profits for Exelon" Synapse Energy report to the Illinois Citizens Utility Board, October, 2005.

**Hausman, E.D. and G. Keith,** "Calculating Displaced Emissions from Energy Efficiency and Renewable Energy Initiatives" Content for EPA website, 2005 (in prep.)

**Rudkevich, A., E.D. Hausman, R.D. Tabors, J. Bagnal and C Kopel,** "Loss Hedging Rights: A Final Piece in the LMP Puzzle" *Hawaii International Conference on System Sciences, Hawaii,* January, 2005 *(accepted).*

**Hausman, E.D. and R.D. Tabors,** "The Role of Demand Underscheduling in the California Energy Crisis" *Hawaii International Conference on System Sciences, Hawaii,* January, 2004.

**Hausman, E.D. and M.B. McElroy,** The reorganization of the global carbon cycle at the last glacial termination, *Global Biogeochemical Cycles, 13*(2), 371-381, 1999.

**Norton, F.L., E.D. Hausman and M.B. McElroy,** "Hydrospheric transports, the oxygen isotope record, and tropical sea surface temperatures during the last glacial maximum" *Paleoceanography, 12,* 15-22, 1997.

**Hausman, E.D. and M.B. McElroy,** "Variations in the oceanic carbon cycle over glacial transitions: a time-dependent box model simulation" presented at the spring meeting of the American Geophysical Union, San Francisco, 1996.

## PRESENTATIONS AND WORKSHOPS

***Energy Modeling Forum:*** Participant in coordinated academic exercise focused on modeling US and world natural gas markets, December, 2004.

***Massachusetts Institute of Technology (MIT):*** Guest lecturer in Technology and Policy Program on electricity market structure, the LMP pricing system and risk hedging with FTRs, 2002-2005.

***LMP: The Ultimate Hands-On Seminar.*** Two-day seminar held at various sites to explore concepts of LMP pricing and congestion risk hedging, including lecture and market simulation exercises, July-December, 2003.

*Learning to Live with Locational Marginal Pricing: Fundamentals and Hands-On Simulation.* Day-long seminar including on-line mock electricity market and congestion rights auction, December 2002.

*LMP in California.* Series of seminars on the introduction of LMP in the California electricity market, including on-line market simulation exercise. 2002.

## EXPERT TESTIMONY

**Illinois Pollution Control Board (Docket No. R2006-025) – April 2006**
Prefile testimony on behalf of the Illinois EPA regarding the costs and benefits of proposed mercury emissions rule for Illinois power plants.

**Federal Energy Regulatory Commission (Docket Nos. ER055-1410-000 and EL05-148-000) - February 2006**
Affidavit filed on setting of model parameters for PJM's proposed RPM capacity market model.

**State of Vermont Public Service Board – February 2006**
Prefile testimony in support of Certificate of Public Good pursuant to 30 V.S.A. §248 for proposed Catamount Wind Project.

**State of Vermont Public Service Board – February 2006**
Prefile testimony in support of Certificate of Public Good pursuant to 30 V.S.A. §248 for proposed Deerfield Wind Project.

**Long Island Sound LNG Task Force – January 2006**
Presentation of study on the need for and alternatives to the proposed Broadwater LNG storage and regasification facility in Long Island Sound.

**Iowa Utilities Board (Docket No. SPU-05-15) – November 2005**
Whether Interstate Power and Light's should be permitted to sell the Duane Arnold Energy Center nuclear facility to FPLE Duane Arnold, Inc., a subsidiary of Florida Power and Light.

# Summary for Policymakers

## A Report of Working Group I of the Intergovernmental Panel on Climate Change

*Based on a draft prepared by:*
Daniel L. Albritton, Myles R. Allen, Alfons P. M. Baede, John A. Church, Ulrich Cubasch, Dai Xiaosu, Ding Yihui, Dieter H. Ehhalt, Christopher K. Folland, Filippo Giorgi, Jonathan M. Gregory, David J. Griggs, Jim M. Haywood, Bruce Hewitson, John T. Houghton, Joanna I. House, Michael Hulme, Ivar Isaksen, Victor J. Jaramillo, Achuthan Jayaraman, Catherine A. Johnson, Fortunat Joos, Sylvie Joussaume, Thomas Karl, David J. Karoly, Haroon S. Kheshgi, Corrine Le Quéré, Kathy Maskell, Luis J. Mata, Bryant J. McAvaney, Mack McFarland, Linda O. Mearns, Gerald A. Meehl, L. Gylvan Meira-Filho, Valentin P. Meleshko, John F. B. Mitchell, Berrien Moore, Richard K. Mugara, Maria Noguer, Buruhani S. Nyenzi, Michael Oppenheimer, Joyce E. Penner, Steven Pollonais, Michael Prather, I. Colin Prentice, Venkatchalam Ramaswamy, Armando Ramirez-Rojas, Sarah C. B. Raper, M. Jim Salinger, Robert J. Scholes, Susan Solomon, Thomas F. Stocker, John M. R. Stone, Ronald J. Stouffer, Kevin E. Trenberth, Ming-Xing Wang, Robert T. Watson, Kok S. Yap, John Zillman

with contributions from many authors and reviewers.

**Joint Intervenors**
**Exhibit 2 – B**

# Summary for Policymakers

The Third Assessment Report of Working Group I of the Intergovernmental Panel on Climate Change (IPCC) builds upon past assessments and incorporates new results from the past five years of research on climate change[1]. Many hundreds of scientists[2] from many countries participated in its preparation and review.

This Summary for Policymakers (SPM), which was approved by IPCC member governments in Shanghai in January 2001[3], describes the current state of understanding of the climate system and provides estimates of its projected future evolution and their uncertainties. Further details can be found in the underlying report, and the appended Source Information provides cross references to the report's chapters.

## An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.

Since the release of the Second Assessment Report (SAR[4]), additional data from new studies of current and palaeoclimates, improved analysis of data sets, more rigorous evaluation of their quality, and comparisons among data from different sources have led to greater understanding of climate change.

### *The global average surface temperature has increased over the 20th century by about 0.6°C.*

- The global average surface temperature (the average of near surface air temperature over land, and sea surface temperature) has increased since 1861. Over the 20th century the increase has been 0.6 ± 0.2°C[5,6] (Figure 1a). This value is about 0.15°C larger than that estimated by the SAR for the period up to 1994, owing to the relatively high temperatures of the additional years (1995 to 2000) and improved methods of processing the data. These numbers take into account various adjustments, including urban heat island effects. 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.
- Globally, it is very likely[7] that the 1990s was the warmest decade and 1998 the warmest year in the instrumental record, since 1861 (see Figure 1a).
- New analyses of proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely[7] to have been the largest of any century during the past 1,000 years. It is also likely[7] that, in the Northern Hemisphere, the 1990s was the warmest decade and 1998 the warmest year (Figure 1b). Because less data are available, less is known about annual averages prior to 1,000 years before present and for conditions prevailing in most of the Southern Hemisphere prior to 1861.
- On average, between 1950 and 1993, night-time daily minimum air temperatures over land increased by about 0.2°C per decade. This is about twice the rate of increase in daytime daily maximum air temperatures (0.1°C per decade). This has lengthened the freeze-free season in many mid- and high latitude regions. The increase in sea surface temperature over this period is about half that of the mean land surface air temperature.

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[1] *Climate change* in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where *climate change* refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

[2] In total 122 Co-ordinating Lead Authors and Lead Authors, 515 Contributing Authors, 21 Review Editors and 420 Expert Reviewers.

[3] Delegations of 99 IPCC member countries participated in the Eighth Session of Working Group I in Shanghai on 17 to 20 January 2001.

[4] The IPCC Second Assessment Report is referred to in this Summary for Policymakers as the SAR.

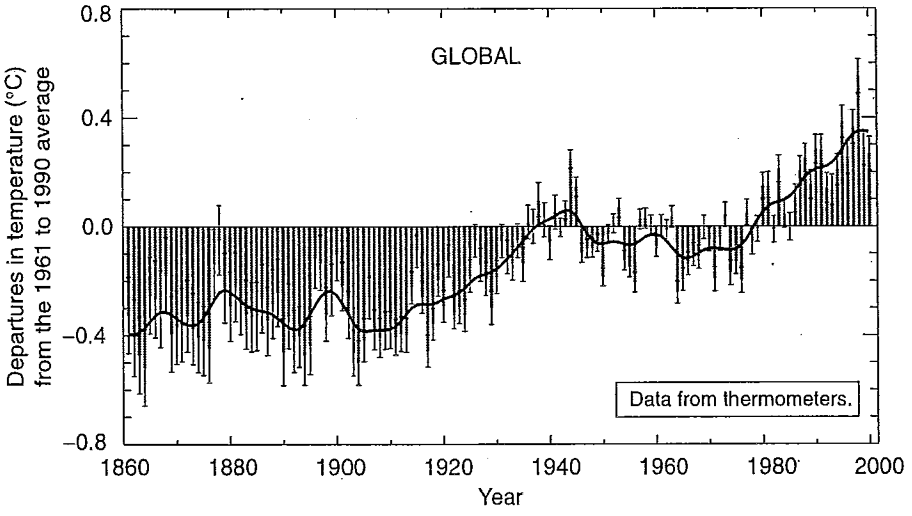
[5] Generally temperature trends are rounded to the nearest 0.05°C per unit time, the periods often being limited by data availability.

[6] In general, a 5% statistical significance level is used, and a 95% confidence level.

[7] In this Summary for Policymakers and in the Technical Summary, the following words have been used where appropriate to indicate judgmental estimates of confidence: *virtually certain* (greater than 99% chance that a result is true); *very likely* (90–99% chance); *likely* (66–90% chance); *medium likelihood* (33–66% chance); *unlikely* (10–33% chance); *very unlikely* (1–10% chance); *exceptionally unlikely* (less than 1% chance). The reader is referred to individual chapters for more details.

## Variations of the Earth's surface temperature for:

### (a) the past 140 years



### (b) the past 1,000 years

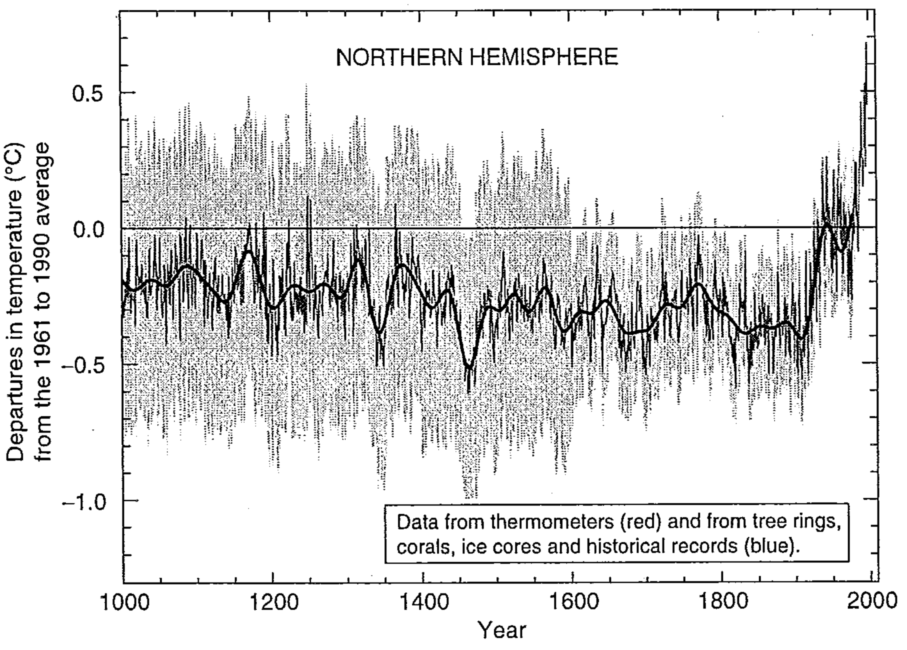


**Figure 1: Variations of the Earth's surface temperature over the last 140 years and the last millennium.**

(a) The Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (black line, a filtered annual curve suppressing fluctuations below near decadal time-scales). There are uncertainties in the annual data (thin black whisker bars represent the 95% confidence range) due to data gaps, random instrumental errors and uncertainties, uncertainties in bias corrections in the ocean surface temperature data and also in adjustments for urbanisation over the land. Over both the last 140 years and 100 years, the best estimate is that the global average surface temperature has increased by 0.6 ± 0.2°C.

(b) Additionally, the year by year (blue curve) and 50 year average (black curve) variations of the average surface temperature of the Northern Hemisphere for the past 1000 years have been reconstructed from "proxy" data calibrated against thermometer data (see list of the main proxy data in the diagram). The 95% confidence range in the annual data is represented by the grey region. These uncertainties increase in more distant times and are always much larger than in the instrumental record due to the use of relatively sparse proxy data. Nevertheless the rate and duration of warming of the 20th century has been much greater than in any of the previous nine centuries. Similarly, it is likely[7] that the 1990s have been the warmest decade and 1998 the warmest year of the millennium.

[Based upon (a) Chapter 2, Figure 2.7c and (b) Chapter 2, Figure 2.20]

### *Temperatures have risen during the past four decades in the lowest 8 kilometres of the atmosphere.*

- Since the late 1950s (the period of adequate observations from weather balloons), the overall global temperature increases in the lowest 8 kilometres of the atmosphere and in surface temperature have been similar at 0.1°C per decade.
- Since the start of the satellite record in 1979, both satellite and weather balloon measurements show that the global average temperature of the lowest 8 kilometres of the atmosphere has changed by +0.05 ± 0.10°C per decade, but the global average surface temperature has increased significantly by +0.15 ± 0.05°C per decade. The difference in the warming rates is statistically significant. This difference occurs primarily over the tropical and sub-tropical regions.
- The lowest 8 kilometres of the atmosphere and the surface are influenced differently by factors such as stratospheric ozone depletion, atmospheric aerosols, and the El Niño phenomenon. Hence, it is physically plausible to expect that over a short time period (e.g., 20 years) there may be differences in temperature trends. In addition, spatial sampling techniques can also explain some of the differences in trends, but these differences are not fully resolved.

### *Snow cover and ice extent have decreased.*

- Satellite data show that there are very likely[7] to have been decreases of about 10% in the extent of snow cover since the late 1960s, and ground-based observations show that there is very likely[7] to have been a reduction of about two weeks in the annual duration of lake and river ice cover in the mid- and high latitudes of the Northern Hemisphere, over the 20th century.
- There has been a widespread retreat of mountain glaciers in non-polar regions during the 20th century.
- Northern Hemisphere spring and summer sea-ice extent has decreased by about 10 to 15% since the 1950s. It is likely[7] that there has been about a 40% decline in Arctic sea-ice thickness during late summer to early autumn in recent decades and a considerably slower decline in winter sea-ice thickness.

### *Global average sea level has risen and ocean heat content has increased.*

- Tide gauge data show that global average sea level rose between 0.1 and 0.2 metres during the 20th century.
- Global ocean heat content has increased since the late 1950s, the period for which adequate observations of sub-surface ocean temperatures have been available.

### *Changes have also occurred in other important aspects of climate.*

- It is very likely[7] that precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid- and high latitudes of the Northern Hemisphere continents, and it is likely[7] that rainfall has increased by 0.2 to 0.3% per decade over the tropical (10°N to 10°S) land areas. Increases in the tropics are not evident over the past few decades. It is also likely[7] that rainfall has decreased over much of the Northern Hemisphere sub-tropical (10°N to 30°N) land areas during the 20th century by about 0.3% per decade. In contrast to the Northern Hemisphere, no comparable systematic changes have been detected in broad latitudinal averages over the Southern Hemisphere. There are insufficient data to establish trends in precipitation over the oceans.
- In the mid- and high latitudes of the Northern Hemisphere over the latter half of the 20th century, it is likely[7] that there has been a 2 to 4% increase in the frequency of heavy precipitation events. Increases in heavy precipitation events can arise from a number of causes, e.g., changes in atmospheric moisture, thunderstorm activity and large-scale storm activity.
- It is likely[7] that there has been a 2% increase in cloud cover over mid- to high latitude land areas during the 20th century. In most areas the trends relate well to the observed decrease in daily temperature range.
- Since 1950 it is very likely[7] that there has been a reduction in the frequency of extreme low temperatures, with a smaller increase in the frequency of extreme high temperatures.

- Warm episodes of the El Niño-Southern Oscillation (ENSO) phenomenon (which consistently affects regional variations of precipitation and temperature over much of the tropics, sub-tropics and some mid-latitude areas) have been more frequent, persistent and intense since the mid-1970s, compared with the previous 100 years.
- Over the 20th century (1900 to 1995), there were relatively small increases in global land areas experiencing severe drought or severe wetness. In many regions, these changes are dominated by inter-decadal and multi-decadal climate variability, such as the shift in ENSO towards more warm events.
- In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades.

### *Some important aspects of climate appear not to have changed.*

- A few areas of the globe have not warmed in recent decades, mainly over some parts of the Southern Hemisphere oceans and parts of Antarctica.
- No significant trends of Antarctic sea-ice extent are apparent since 1978, the period of reliable satellite measurements.
- Changes globally in tropical and extra-tropical storm intensity and frequency are dominated by inter-decadal to multi-decadal variations, with no significant trends evident over the 20th century. Conflicting analyses make it difficult to draw definitive conclusions about changes in storm activity, especially in the extra-tropics.
- No systematic changes in the frequency of tornadoes, thunder days, or hail events are evident in the limited areas analysed.

## Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate.

Changes in climate occur as a result of both internal variability within the climate system and external factors (both natural and anthropogenic). The influence of external factors on climate can be broadly compared using the concept of radiative forcing[8]. A positive radiative forcing, such as that produced by increasing concentrations of greenhouse gases, tends to warm the surface. A negative radiative forcing, which can arise from an increase in some types of aerosols (microscopic airborne particles) tends to cool the surface. Natural factors, such as changes in solar output or explosive volcanic activity, can also cause radiative forcing. Characterisation of these climate forcing agents and their changes over time (see Figure 2) is required to understand past climate changes in the context of natural variations and to project what climate changes could lie ahead. Figure 3 shows current estimates of the radiative forcing due to increased concentrations of atmospheric constituents and other mechanisms.

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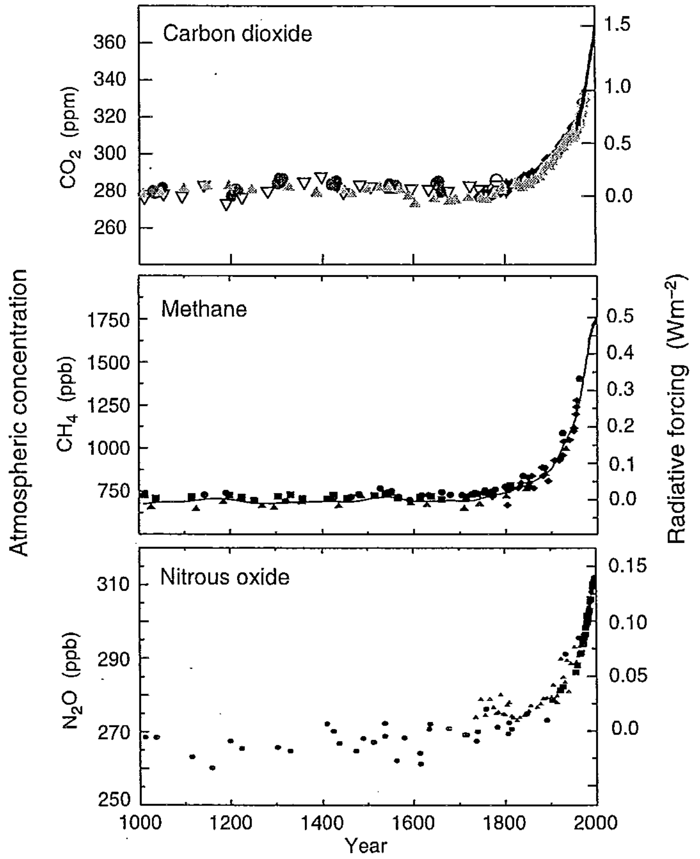
[8] *Radiative forcing* is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism. It is expressed in Watts per square metre ($Wm^{-2}$).

**Indicators of the human influence on the atmosphere during the Industrial Era**

**(a) Global atmospheric concentrations of three well mixed greenhouse gases**



**(b) Sulphate aerosols deposited in Greenland ice**

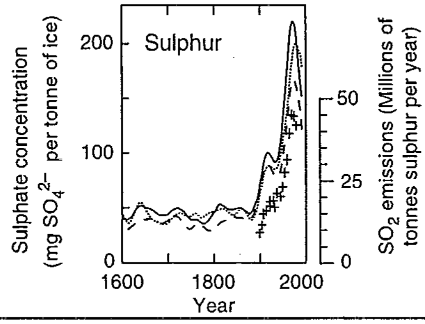


**Figure 2: Long records of past changes in atmospheric composition provide the context for the influence of anthropogenic emissions.**

(a) shows changes in the atmospheric concentrations of carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) over the past 1000 years. The ice core and firn data for several sites in Antarctica and Greenland (shown by different symbols) are supplemented with the data from direct atmospheric samples over the past few decades (shown by the line for $CO_2$ and incorporated in the curve representing the global average of $CH_4$). The estimated positive radiative forcing of the climate system from these gases is indicated on the right-hand scale. Since these gases have atmospheric lifetimes of a decade or more, they are well mixed, and their concentrations reflect emissions from sources throughout the globe. All three records show effects of the large and increasing growth in anthropogenic emissions during the Industrial Era.

(b) illustrates the influence of industrial emissions on atmospheric sulphate concentrations, which produce negative radiative forcing. Shown is the time history of the concentrations of sulphate, not in the atmosphere but in ice cores in Greenland (shown by lines; from which the episodic effects of volcanic eruptions have been removed). Such data indicate the local deposition of sulphate aerosols at the site, reflecting sulphur dioxide ($SO_2$) emissions at mid-latitudes in the Northern Hemisphere. This record, albeit more regional than that of the globally-mixed greenhouse gases, demonstrates the large growth in anthropogenic $SO_2$ emissions during the Industrial Era. The pluses denote the relevant regional estimated $SO_2$ emissions (right-hand scale).

[Based upon (a) Chapter 3, Figure 3.2b ($CO_2$); Chapter 4, Figure 4.1a and b ($CH_4$) and Chapter 4, Figure 4.2 ($N_2O$) and (b) Chapter 5, Figure 5.4a]

**Concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities.**

- The atmospheric concentration of carbon dioxide ($CO_2$) has increased by 31% since 1750. The present $CO_2$ concentration has not been exceeded during the past 420,000 years and likely[7] not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20,000 years.
- About three-quarters of the anthropogenic emissions of $CO_2$ to the atmosphere during the past 20 years is due to fossil fuel burning. The rest is predominantly due to land-use change, especially deforestation.
- Currently the ocean and the land together are taking up about half of the anthropogenic $CO_2$ emissions. On land, the uptake of anthropogenic $CO_2$ very likely[7] exceeded the release of $CO_2$ by deforestation during the 1990s.
- The rate of increase of atmospheric $CO_2$ concentration has been about 1.5 ppm[9] (0.4%) per year over the past two decades. During the 1990s the year to year increase varied from 0.9 ppm (0.2%) to 2.8 ppm (0.8%). A large part of this variability is due to the effect of climate variability (e.g., El Niño events) on $CO_2$ uptake and release by land and oceans.
- The atmospheric concentration of methane ($CH_4$) has increased by 1060 ppb[9] (151%) since 1750 and continues to increase. The present $CH_4$ concentration has not been exceeded during the past 420,000 years. The annual growth in $CH_4$ concentration slowed and became more variable in the 1990s, compared with the 1980s. Slightly more than half of current $CH_4$ emissions are anthropogenic (e.g., use of fossil fuels, cattle, rice agriculture and landfills). In addition, carbon monoxide (CO) emissions have recently been identified as a cause of increasing $CH_4$ concentration.
- The atmospheric concentration of nitrous oxide ($N_2O$) has increased by 46 ppb (17%) since 1750 and continues to increase. The present $N_2O$ concentration has not been exceeded during at least the past thousand years. About a third of current $N_2O$ emissions are anthropogenic (e.g., agricultural soils, cattle feed lots and chemical industry).
- Since 1995, the atmospheric concentrations of many of those halocarbon gases that are both ozone-depleting and greenhouse gases (e.g., $CFCl_3$ and $CF_2Cl_2$), are either increasing more slowly or decreasing, both in response to reduced emissions under the regulations of the Montreal Protocol and its Amendments. Their substitute compounds (e.g., $CHF_2Cl$ and $CF_3CH_2F$) and some other synthetic compounds (e.g., perfluorocarbons (PFCs) and sulphur hexafluoride ($SF_6$)) are also greenhouse gases, and their concentrations are currently increasing.
- The radiative forcing due to increases of the well-mixed greenhouse gases from 1750 to 2000 is estimated to be 2.43 $Wm^{-2}$: 1.46 $Wm^{-2}$ from $CO_2$; 0.48 $Wm^{-2}$ from $CH_4$; 0.34 $Wm^{-2}$ from the halocarbons; and 0.15 $Wm^{-2}$ from $N_2O$. (See Figure 3, where the uncertainties are also illustrated.)
- The observed depletion of the stratospheric ozone ($O_3$) layer from 1979 to 2000 is estimated to have caused a negative radiative forcing (–0.15 $Wm^{-2}$). Assuming full compliance with current halocarbon regulations, the positive forcing of the halocarbons will be reduced as will the magnitude of the negative forcing from stratospheric ozone depletion as the ozone layer recovers over the 21st century.
- The total amount of $O_3$ in the troposphere is estimated to have increased by 36% since 1750, due primarily to anthropogenic emissions of several $O_3$-forming gases. This corresponds to a positive radiative forcing of 0.35 $Wm^{-2}$. $O_3$ forcing varies considerably by region and responds much more quickly to changes in emissions than the long-lived greenhouse gases, such as $CO_2$.

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[9] ppm (parts per million) or ppb (parts per billion, 1 billion = 1,000 million) is the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air. For example: 300 ppm means 300 molecules of a greenhouse gas per million molecules of dry air.

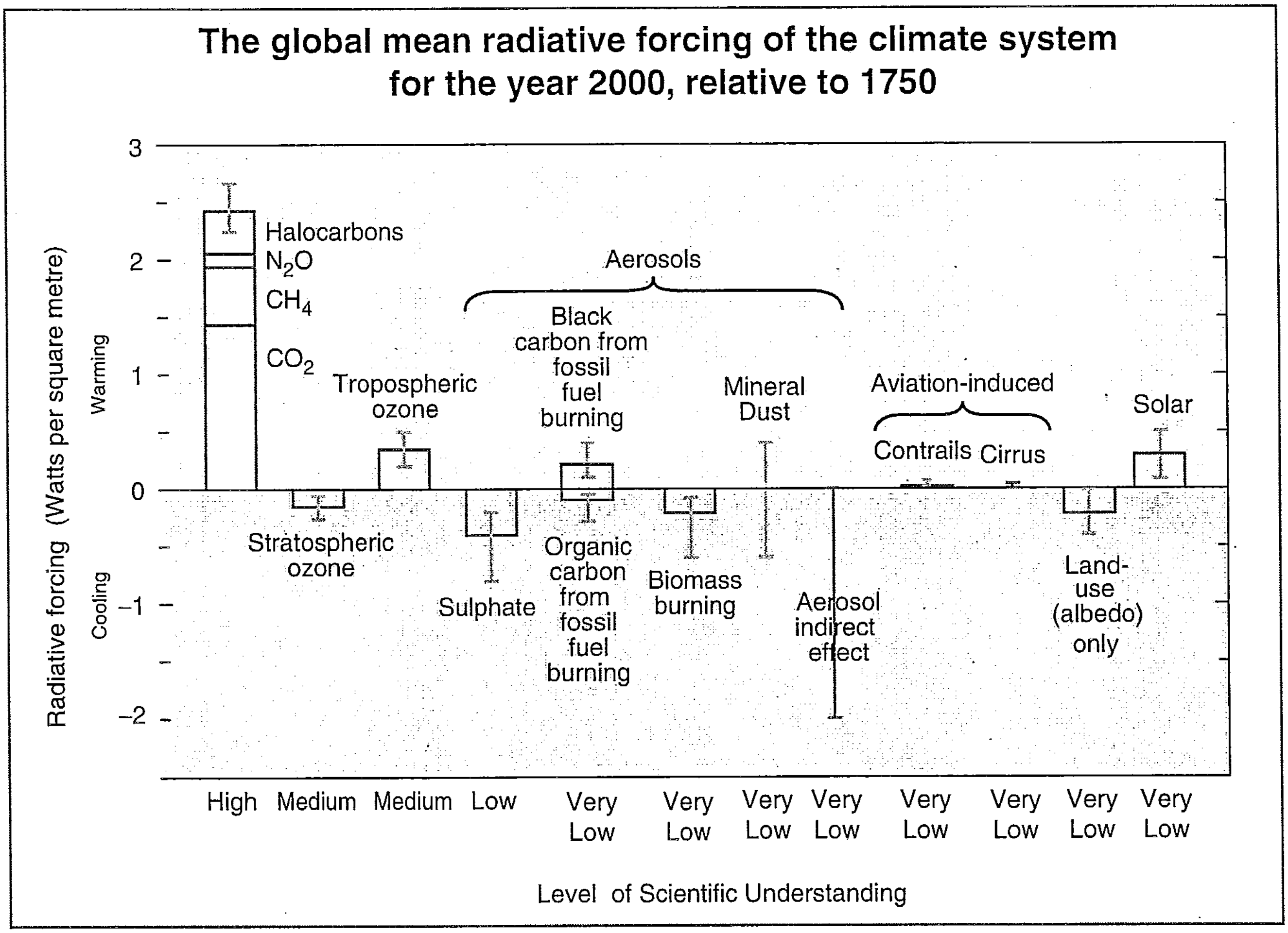

**Figure 3: Many external factors force climate change.**

These radiative forcings arise from changes in the atmospheric composition, alteration of surface reflectance by land use, and variation in the output of the sun. Except for solar variation, some form of human activity is linked to each. The rectangular bars represent estimates of the contributions of these forcings – some of which yield warming, and some cooling. Forcing due to episodic volcanic events, which lead to a negative forcing lasting only for a few years, is not shown. The indirect effect of aerosols shown is their effect on the size and number of cloud droplets. A second indirect effect of aerosols on clouds, namely their effect on cloud lifetime, which would also lead to a negative forcing, is not shown. Effects of aviation on greenhouse gases are included in the individual bars. The vertical line about the rectangular bars indicates a range of estimates, guided by the spread in the published values of the forcings and physical understanding. Some of the forcings possess a much greater degree of certainty than others. A vertical line without a rectangular bar denotes a forcing for which no best estimate can be given owing to large uncertainties. The overall level of scientific understanding for each forcing varies considerably, as noted. Some of the radiative forcing agents are well mixed over the globe, such as $CO_2$, thereby perturbing the global heat balance. Others represent perturbations with stronger regional signatures because of their spatial distribution, such as aerosols. For this and other reasons, a simple sum of the positive and negative bars cannot be expected to yield the net effect on the climate system. The simulations of this assessment report (for example, Figure 5) indicate that the estimated net effect of these perturbations is to have warmed the global climate since 1750. [Based upon Chapter 6, Figure 6.6]

### *Anthropogenic aerosols are short-lived and mostly produce negative radiative forcing.*

- The major sources of anthropogenic aerosols are fossil fuel and biomass burning. These sources are also linked to degradation of air quality and acid deposition.
- Since the SAR, significant progress has been achieved in better characterising the direct radiative roles of different types of aerosols. Direct radiative forcing is estimated to be $-0.4$ Wm$^{-2}$ for sulphate, $-0.2$ Wm$^{-2}$ for biomass burning aerosols, $-0.1$ Wm$^{-2}$ for fossil fuel organic carbon and $+0.2$ Wm$^{-2}$ for fossil fuel black carbon aerosols. There is much less confidence in the ability to quantify the total aerosol direct effect, and its evolution over time, than that for the gases listed above. Aerosols also vary considerably by region and respond quickly to changes in emissions.
- In addition to their direct radiative forcing, aerosols have an indirect radiative forcing through their effects on clouds. There is now more evidence for this indirect effect, which is negative, although of very uncertain magnitude.

### *Natural factors have made small contributions to radiative forcing over the past century.*

- The radiative forcing due to changes in solar irradiance for the period since 1750 is estimated to be about $+0.3$ Wm$^{-2}$, most of which occurred during the first half of the 20th century. Since the late 1970s, satellite instruments have observed small oscillations due to the 11-year solar cycle. Mechanisms for the amplification of solar effects on climate have been proposed, but currently lack a rigorous theoretical or observational basis.
- Stratospheric aerosols from explosive volcanic eruptions lead to negative forcing, which lasts a few years. Several major eruptions occurred in the periods 1880 to 1920 and 1960 to 1991.
- The combined change in radiative forcing of the two major natural factors (solar variation and volcanic aerosols) is estimated to be negative for the past two, and possibly the past four, decades.

## Confidence in the ability of models to project future climate has increased.

Complex physically-based climate models are required to provide detailed estimates of feedbacks and of regional features. Such models cannot yet simulate all aspects of climate (e.g., they still cannot account fully for the observed trend in the surface-troposphere temperature difference since 1979) and there are particular uncertainties associated with clouds and their interaction with radiation and aerosols. Nevertheless, confidence in the ability of these models to provide useful projections of future climate has improved due to their demonstrated performance on a range of space and time-scales.

- Understanding of climate processes and their incorporation in climate models have improved, including water vapour, sea-ice dynamics, and ocean heat transport.
- Some recent models produce satisfactory simulations of current climate without the need for non-physical adjustments of heat and water fluxes at the ocean-atmosphere interface used in earlier models.
- Simulations that include estimates of natural and anthropogenic forcing reproduce the observed large-scale changes in surface temperature over the 20th century (Figure 4). However, contributions from some additional processes and forcings may not have been included in the models. Nevertheless, the large-scale consistency between models and observations can be used to provide an independent check on projected warming rates over the next few decades under a given emissions scenario.
- Some aspects of model simulations of ENSO, monsoons and the North Atlantic Oscillation, as well as selected periods of past climate, have improved.

## There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.

The SAR concluded: "The balance of evidence suggests a discernible human influence on global climate". That report also noted that the anthropogenic signal was still emerging from the background of natural climate variability. Since the SAR, progress has been made in reducing uncertainty, particularly with respect to distinguishing and quantifying the magnitude of responses to different external influences. Although many of the sources of uncertainty identified in the SAR still remain to some degree, new evidence and improved understanding support an updated conclusion.

- There is a longer and more closely scrutinised temperature record and new model estimates of variability. The warming over the past 100 years is very unlikely[7] to be due to internal variability alone, as estimated by current models. Reconstructions of climate data for the past 1,000 years (Figure 1b) also indicate that this warming was unusual and is unlikely[7] to be entirely natural in origin.
- There are new estimates of the climate response to natural and anthropogenic forcing, and new detection techniques have been applied. Detection and attribution studies consistently find evidence for an anthropogenic signal in the climate record of the last 35 to 50 years.
- Simulations of the response to natural forcings alone (i.e., the response to variability in solar irradiance and volcanic eruptions) do not explain the warming in the second half of the 20th century (see for example Figure 4a). However, they indicate that natural forcings may have contributed to the observed warming in the first half of the 20th century.
- The warming over the last 50 years due to anthropogenic greenhouse gases can be identified despite uncertainties in forcing due to anthropogenic sulphate aerosol and natural factors (volcanoes and solar irradiance). The anthropogenic sulphate aerosol forcing, while uncertain, is negative over this period and therefore cannot explain the warming. Changes in natural forcing during most of this period are also estimated to be negative and are unlikely[7] to explain the warming.
- Detection and attribution studies comparing model simulated changes with the observed record can now take into account uncertainty in the magnitude of modelled response to external forcing, in particular that due to uncertainty in climate sensitivity.
- Most of these studies find that, over the last 50 years, the estimated rate and magnitude of warming due to increasing concentrations of greenhouse gases alone are comparable with, or larger than, the observed warming. Furthermore, most model estimates that take into account both greenhouse gases and sulphate aerosols are consistent with observations over this period.
- The best agreement between model simulations and observations over the last 140 years has been found when all the above anthropogenic and natural forcing factors are combined, as shown in Figure 4c. These results show that the forcings included are sufficient to explain the observed changes, but do not exclude the possibility that other forcings may also have contributed.

In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely[7] to have been due to the increase in greenhouse gas concentrations.

Furthermore, it is very likely[7] 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. Within present uncertainties, observations and models are both consistent with a lack of significant acceleration of sea level rise during the 20th century.

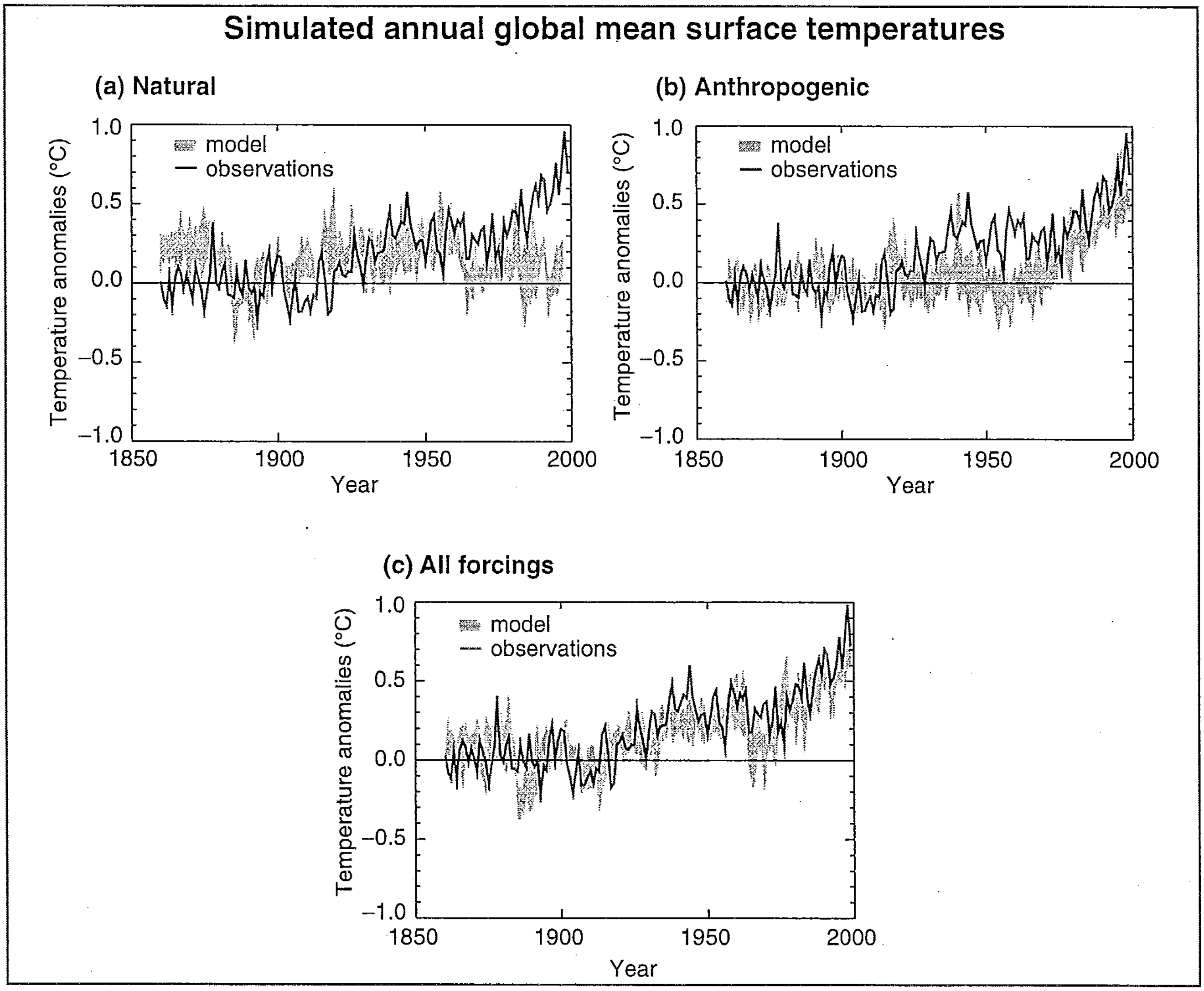

**Figure 4: Simulating the Earth's temperature variations, and comparing the results to measured changes, can provide insight into the underlying causes of the major changes.**

A climate model can be used to simulate the temperature changes that occur both from natural and anthropogenic causes. The simulations represented by the band in (a) were done with only natural forcings: solar variation and volcanic activity. Those encompassed by the band in (b) were done with anthropogenic forcings: greenhouse gases and an estimate of sulphate aerosols, and those encompassed by the band in (c) were done with both natural and anthropogenic forcings included. From (b), it can be seen that inclusion of anthropogenic forcings provides a plausible explanation for a substantial part of the observed temperature changes over the past century, but the best match with observations is obtained in (c) when both natural and anthropogenic factors are included. These results show that the forcings included are sufficient to explain the observed changes, but do not exclude the possibility that other forcings may also have contributed. The bands of model results presented here are for four runs from the same model. Similar results to those in (b) are obtained with other models with anthropogenic forcing. [Based upon Chapter 12, Figure 12.7]

## Human influences will continue to change atmospheric composition throughout the 21st century.

Models have been used to make projections of atmospheric concentrations of greenhouse gases and aerosols, and hence of future climate, based upon emissions scenarios from the IPCC Special Report on Emission Scenarios (SRES) (Figure 5). These scenarios were developed to update the IS92 series, which were used in the SAR and are shown for comparison here in some cases.

### Greenhouse gases

- Emissions of $CO_2$ due to fossil fuel burning are virtually certain[7] to be the dominant influence on the trends in atmospheric $CO_2$ concentration during the 21st century.
- As the $CO_2$ concentration of the atmosphere increases, ocean and land will take up a decreasing fraction of anthropogenic $CO_2$ emissions. The net effect of land and ocean climate feedbacks as indicated by models is to further increase projected atmospheric $CO_2$ concentrations, by reducing both the ocean and land uptake of $CO_2$.
- By 2100, carbon cycle models project atmospheric $CO_2$ concentrations of 540 to 970 ppm for the illustrative SRES scenarios (90 to 250% above the concentration of 280 ppm in the year 1750), Figure 5b. These projections include the land and ocean climate feedbacks. Uncertainties, especially about the magnitude of the climate feedback from the terrestrial biosphere, cause a variation of about −10 to +30% around each scenario. The total range is 490 to 1260 ppm (75 to 350% above the 1750 concentration).
- Changing land use could influence atmospheric $CO_2$ concentration. Hypothetically, if all of the carbon released by historical land-use changes could be restored to the terrestrial biosphere over the course of the century (e.g., by reforestation), $CO_2$ concentration would be reduced by 40 to 70 ppm.
- Model calculations of the concentrations of the non-$CO_2$ greenhouse gases by 2100 vary considerably across the SRES illustrative scenarios, with $CH_4$ changing by −190 to +1,970 ppb (present concentration 1,760 ppb), $N_2O$ changing by +38 to +144 ppb (present concentration 316 ppb), total tropospheric $O_3$ changing by −12 to +62%, and a wide range of changes in concentrations of HFCs, PFCs and $SF_6$, all relative to the year 2000. In some scenarios, total tropospheric $O_3$ would become as important a radiative forcing agent as $CH_4$ and, over much of the Northern Hemisphere, would threaten the attainment of current air quality targets.
- Reductions in greenhouse gas emissions and the gases that control their concentration would be necessary to stabilise radiative forcing. For example, for the most important anthropogenic greenhouse gas, carbon cycle models indicate that stabilisation of atmospheric $CO_2$ concentrations at 450, 650 or 1,000 ppm would require global anthropogenic $CO_2$ emissions to drop below 1990 levels, within a few decades, about a century, or about two centuries, respectively, and continue to decrease steadily thereafter. Eventually $CO_2$ emissions would need to decline to a very small fraction of current emissions.

### Aerosols

- The SRES scenarios include the possibility of either increases or decreases in anthropogenic aerosols (e.g., sulphate aerosols (Figure 5c), biomass aerosols, black and organic carbon aerosols) depending on the extent of fossil fuel use and policies to abate polluting emissions. In addition, natural aerosols (e.g., sea salt, dust and emissions leading to the production of sulphate and carbon aerosols) are projected to increase as a result of changes in climate.

### Radiative forcing over the 21st century

- For the SRES illustrative scenarios, relative to the year 2000, the global mean radiative forcing due to greenhouse gases continues to increase through the 21st century, with the fraction due to $CO_2$ projected to increase from slightly more than half to about three quarters. The change in the direct plus indirect aerosol radiative forcing is projected to be smaller in magnitude than that of $CO_2$.

## Global average temperature and sea level are projected to rise under all IPCC SRES scenarios.

In order to make projections of future climate, models incorporate past, as well as future emissions of greenhouse gases and aerosols. Hence, they include estimates of warming to date and the commitment to future warming from past emissions.

### *Temperature*

- The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C (Figure 5d) over the period 1990 to 2100. These results are for the full range of 35 SRES scenarios, based on a number of climate models[10,11].
- Temperature increases are projected to be greater than those in the SAR, which were about 1.0 to 3.5°C based on the six IS92 scenarios. The higher projected temperatures and the wider range are due primarily to the lower projected sulphur dioxide emissions in the SRES scenarios relative to the IS92 scenarios.
- The projected rate of warming is much larger than the observed changes during the 20th century and is very likely[7] to be without precedent during at least the last 10,000 years, based on palaeoclimate data.
- By 2100, the range in the 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 the different SRES scenarios.
- On timescales of a few decades, the current observed rate of warming can be used to constrain the projected response to a given emissions scenario despite uncertainty in climate sensitivity. This approach suggests that anthropogenic warming is likely[7] to lie in the range of 0.1 to 0.2°C per decade over the next few decades under the IS92a scenario, similar to the corresponding range of projections of the simple model used in Figure 5d.
- Based on recent global model simulations, it is very likely[7] that nearly all land areas will warm more rapidly than the global average, particularly those at northern high latitudes in the cold season. Most notable of these is the warming in the northern regions of North America, and northern and central Asia, which exceeds global mean warming in each model by more than 40%. In contrast, the warming is less than the global mean change in south and southeast Asia in summer and in southern South America in winter.
- Recent trends for surface temperature to become more El Niño-like in the tropical Pacific, with the eastern tropical Pacific warming more than the western tropical Pacific, with a corresponding eastward shift of precipitation, are projected to continue in many models.

### *Precipitation*

- Based on global model simulations and for a wide range of scenarios, global average water vapour concentration and precipitation are projected to increase during the 21st century. By the second half of the 21st century, it is likely[7] that precipitation will have increased over northern mid- to high latitudes and Antarctica in winter. At low latitudes there are both regional increases and decreases over land areas. Larger year to year variations in precipitation are very likely[7] over most areas where an increase in mean precipitation is projected.

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[10] Complex physically based climate models are the main tool for projecting future climate change. In order to explore the full range of scenarios, these are complemented by simple climate models calibrated to yield an equivalent response in temperature and sea level to complex climate models. These projections are obtained using a simple climate model whose climate sensitivity and ocean heat uptake are calibrated to each of seven complex climate models. The climate sensitivity used in the simple model ranges from 1.7 to 4.2°C, which is comparable to the commonly accepted range of 1.5 to 4.5°C.

[11] This range does not include uncertainties in the modelling of radiative forcing, e.g. aerosol forcing uncertainties. A small carbon-cycle climate feedback is included.

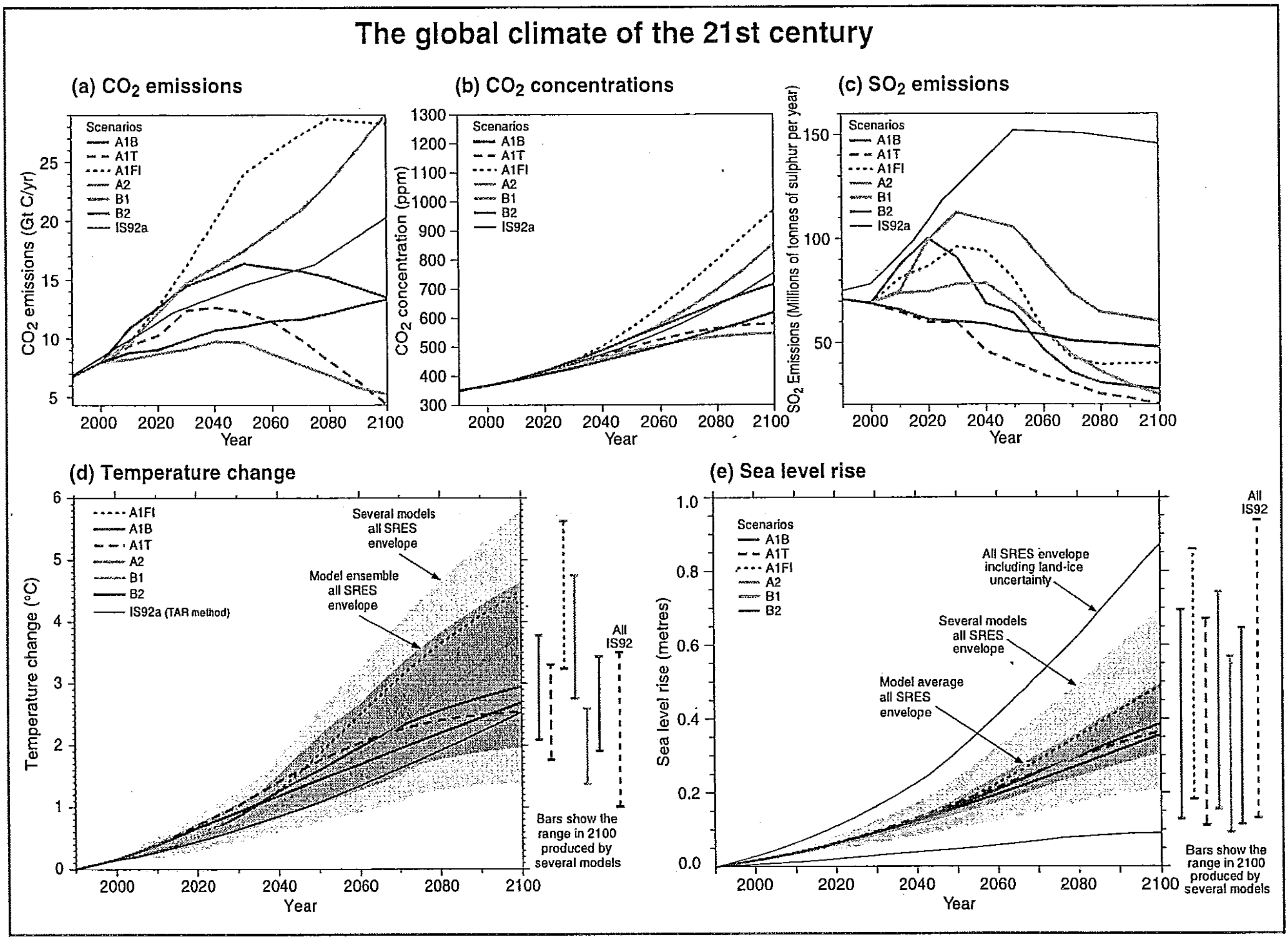

**Figure 5: The global climate of the 21st century will depend on natural changes and the response of the climate system to human activities.**

Climate models project the response of many climate variables – such as increases in global surface temperature and sea level – to various scenarios of greenhouse gas and other human-related emissions. (a) shows the $CO_2$ emissions of the six illustrative SRES scenarios, which are summarised in the box on page 18, along with IS92a for comparison purposes with the SAR. (b) shows projected $CO_2$ concentrations. (c) shows anthropogenic $SO_2$ emissions. Emissions of other gases and other aerosols were included in the model but are not shown in the figure. (d) and (e) show the projected temperature and sea level responses, respectively. The "several models all SRES envelope" in (d) and (e) shows the temperature and sea level rise, respectively, for the simple model when tuned to a number of complex models with a range of climate sensitivities. All SRES envelopes refer to the full range of 35 SRES scenarios. The "model average all SRES envelope" shows the average from these models for the range of scenarios. Note that the warming and sea level rise from these emissions would continue well beyond 2100. Also note that this range does not allow for uncertainty relating to ice dynamical changes in the West Antarctic ice sheet, nor does it account for uncertainties in projecting non-sulphate aerosols and greenhouse gas concentrations. [Based upon (a) Chapter 3, Figure 3.12, (b) Chapter 3, Figure 3.12, (c) Chapter 5, Figure 5.13, (d) Chapter 9, Figure 9.14, (e) Chapter 11, Figure 11.12, Appendix II]

### *Extreme Events*

Table 1 depicts an assessment of confidence in observed changes in extremes of weather and climate during the latter half of the 20th century (left column) and in projected changes during the 21st century (right column)[a]. This assessment relies on observational and modelling studies, as well as the physical plausibility of future projections across all commonly-used scenarios and is based on expert judgement[7].

- For some other extreme phenomena, many of which may have important impacts on the environment and society, there is currently insufficient information to assess recent trends, and climate models currently lack the spatial detail required to make confident projections. For example, very small-scale phenomena, such as thunderstorms, tornadoes, hail and lightning, are not simulated in climate models.

**Table 1:** Estimates of confidence in observed and projected changes in extreme weather and climate events.

| Confidence in observed changes (latter half of the 20th century) | Changes in Phenomenon | Confidence in projected changes (during the 21st century) |
|---|---|---|
| Likely[7] | **Higher maximum temperatures and more hot days over nearly all land areas** | Very likely[7] |
| Very likely[7] | **Higher minimum temperatures, fewer cold days and frost days over nearly all land areas** | Very likely[7] |
| Very likely[7] | **Reduced diurnal temperature range over most land areas** | Very likely[7] |
| Likely[7], over many areas | **Increase of heat index[12] over land areas** | Very likely[7], over most areas |
| Likely[7], over many Northern Hemisphere mid- to high latitude land areas | **More intense precipitation events[b]** | Very likely[7], over many areas |
| Likely[7], in a few areas | **Increased summer continental drying and associated risk of drought** | Likely[7], over most mid-latitude continental interiors. (Lack of consistent projections in other areas) |
| Not observed in the few analyses available | **Increase in tropical cyclone peak wind intensities[c]** | Likely[7], over some areas |
| Insufficient data for assessment | **Increase in tropical cyclone mean and peak precipitation intensities[c]** | Likely[7], over some areas |

[a] For more details see Chapter 2 (observations) and Chapter 9, 10 (projections).

[b] For other areas, there are either insufficient data or conflicting analyses.

[c] Past and future changes in tropical cyclone location and frequency are uncertain.

---

[12] Heat index: A combination of temperature and humidity that measures effects on human comfort.

### *El Niño*

- Confidence in projections of changes in future frequency, amplitude, and spatial pattern of El Niño events in the tropical Pacific is tempered by some shortcomings in how well El Niño is simulated in complex models. Current projections show little change or a small increase in amplitude for El Niño events over the next 100 years.

- Even with little or no change in El Niño amplitude, global warming is likely[7] to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño events in many different regions.

### *Monsoons*

- It is likely[7] that warming associated with increasing greenhouse gas concentrations will cause an increase of Asian summer monsoon precipitation variability. Changes in monsoon mean duration and strength depend on the details of the emission scenario. The confidence in such projections is also limited by how well the climate models simulate the detailed seasonal evolution of the monsoons.

### *Thermohaline circulation*

- Most models show weakening of the ocean thermohaline circulation which leads to a reduction of the heat transport into high latitudes of the Northern Hemisphere. However, even in models where the thermohaline circulation weakens, there is still a warming over Europe due to increased greenhouse gases. The current projections using climate models do not exhibit a complete shut-down of the thermohaline circulation by 2100. Beyond 2100, the thermohaline circulation could completely, and possibly irreversibly, shut-down in either hemisphere if the change in radiative forcing is large enough and applied long enough.

### *Snow and ice*

- Northern Hemisphere snow cover and sea-ice extent are projected to decrease further.

- Glaciers and ice caps are projected to continue their widespread retreat during the 21st century.

- The Antarctic ice sheet is likely[7] to gain mass because of greater precipitation, while the Greenland ice sheet is likely[7] to lose mass because the increase in runoff will exceed the precipitation increase.

- Concerns have been expressed about the stability of the West Antarctic ice sheet because it is grounded below sea level. However, loss of grounded ice leading to substantial sea level rise from this source is now widely agreed to be very unlikely[7] during the 21st century, although its dynamics are still inadequately understood, especially for projections on longer time-scales.

### *Sea level*

- Global mean sea level is projected to rise by 0.09 to 0.88 metres between 1990 and 2100, for the full range of SRES scenarios. This is due primarily to thermal expansion and loss of mass from glaciers and ice caps (Figure 5e). The range of sea level rise presented in the SAR was 0.13 to 0.94 metres based on the IS92 scenarios. Despite the higher temperature change projections in this assessment, the sea level projections are slightly lower, primarily due to the use of improved models, which give a smaller contribution from glaciers and ice sheets.

## Anthropogenic climate change will persist for many centuries.

- Emissions of long-lived greenhouse gases (i.e., $CO_2$, $N_2O$, PFCs, $SF_6$) have a lasting effect on atmospheric composition, radiative forcing and climate. For example, several centuries after $CO_2$ emissions occur, about a quarter of the increase in $CO_2$ concentration caused by these emissions is still present in the atmosphere.
- After greenhouse gas concentrations have stabilised, global average surface temperatures would rise at a rate of only a few tenths of a degree per century rather than several degrees per century as projected for the 21st century without stabilisation. The lower the level at which concentrations are stabilised, the smaller the total temperature change.
- Global mean surface temperature increases and rising sea level from thermal expansion of the ocean are projected to continue for hundreds of years after stabilisation of greenhouse gas concentrations (even at present levels), owing to the long timescales on which the deep ocean adjusts to climate change.
- Ice sheets will continue to react to climate warming and contribute to sea level rise for thousands of years after climate has been stabilised. Climate models indicate that the local warming over Greenland is likely[7] to be one to three times the global average. Ice sheet models project that a local warming of larger than 3°C, if sustained for millennia, would lead to virtually a complete melting of the Greenland ice sheet with a resulting sea level rise of about 7 metres. A local warming of 5.5°C, if sustained for 1,000 years, would be likely[7] to result in a contribution from Greenland of about 3 metres to sea level rise.
- Current ice dynamic models suggest that the West Antarctic ice sheet could contribute up to 3 metres to sea level rise over the next 1,000 years, but such results are strongly dependent on model assumptions regarding climate change scenarios, ice dynamics and other factors.

## Further action is required to address remaining gaps in information and understanding.

Further research is required to improve the ability to detect, attribute and understand climate change, to reduce uncertainties and to project future climate changes. In particular, there is a need for additional systematic and sustained observations, modelling and process studies. A serious concern is the decline of observational networks. The following are high priority areas for action.

- Systematic observations and reconstructions:
  - Reverse the decline of observational networks in many parts of the world.
  - Sustain and expand the observational foundation for climate studies by providing accurate, long-term, consistent data including implementation of a strategy for integrated global observations.
  - Enhance the development of reconstructions of past climate periods.
  - Improve the observations of the spatial distribution of greenhouse gases and aerosols.
- Modelling and process studies:
  - Improve understanding of the mechanisms and factors leading to changes in radiative forcing.
  - Understand and characterise the important unresolved processes and feedbacks, both physical and biogeochemical, in the climate system.
  - Improve methods to quantify uncertainties of climate projections and scenarios, including long-term ensemble simulations using complex models.
  - Improve the integrated hierarchy of global and regional climate models with a focus on the simulation of climate variability, regional climate changes and extreme events.
  - Link more effectively models of the physical climate and the biogeochemical system, and in turn improve coupling with descriptions of human activities.

Cutting across these foci are crucial needs associated with strengthening international co-operation and co-ordination in order to better utilise scientific, computational and observational resources. This should also promote the free exchange of data among scientists. A special need is to increase the observational and research capacities in many regions, particularly in developing countries. Finally, as is the goal of this assessment, there is a continuing imperative to communicate research advances in terms that are relevant to decision making.

## The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

## Source Information: Summary for Policymakers

This appendix provides the cross-reference of the topics in the Summary for Policymakers (page and bullet point topic) to the sections of the chapters of the full report that contain expanded information about the topic.

### *An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.*

| SPM Page | Cross-Reference: SPM Topic – Chapter Section |
|---|---|
| 2 | *The global average surface temperature has increased over the 20th century by about 0.6°C.* ● Chapter 2.2.2 ● Chapter 2.2.2 ● Chapter 2.3 ● Chapter 2.2.2 |
| 4 | *Temperatures have risen during the past four decades in the lowest 8 kilometres of the atmosphere.* ● Chapter 2.2.3 and 2.2.4 ● Chapter 2.2.3 and 2.2.4 ● Chapter 2.2.3, 2.2.4 and Chapter 12.3.2 |
| 4 | *Snow cover and ice extent have decreased.* All three bullet points: Chapter 2.2.5 and 2.2.6 |
| 4 | *Global average sea level has risen and ocean heat content has increased.* ● Chapter 11.3.2 ● Chapter 2.2.2 and Chapter 11.2.1 |
| 4 – 5 | *Changes have also occurred in other important aspects of climate.* ● Chapter 2.5.2 ● Chapter 2.7.2 ● Chapter 2.2.2 and 2.5.5 ● Chapter 2.7.2 ● Chapter 2.6.2 and 2.6.3 ● Chapter 2.7.3 ● Chapter 2.7.3 |
| 5 | *Some important aspects of climate appear not to have changed.* ● Chapter 2.2.2 ● Chapter 2.2.5 ● Chapter 2.7.3 ● Chapter 2.7.3 |

### *Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate system.*

| SPM Page | Cross-Reference: SPM Topic – Chapter Section |
|---|---|
| 5 | Chapeau: "Changes in climate occur …" Chapter 1, Chapter 3.1, Chapter 4.1, Chapter 5.1, Chapter 6.1, 6.2, 6.9, 6.11 and 6.13 |
| 7 | *Concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities.*<br>Carbon dioxide: ● Chapter 3.3.1, 3.3.2, 3.3.3 and 3.5.1 ● Chapter 3.5.1 ● Chapter 3.2.2, 3.2.3, 3.5.1 and Table 3.1 ● Chapter 3.5.1 and 3.5.2<br>Methane: ● Chapter 4.2.1<br>Nitrous oxide: ● Chapter 4.2.1<br>Halocarbons: ● Chapter 4.2.2<br>Radiative forcing of well-mixed gases: ● Chapter 4.2.1 and Chapter 6.3<br>Stratospheric ozone: ● Chapter 4.2.2 and Chapter 6.4<br>Tropospheric ozone: ● Chapter 4.2.4 and Chapter 6.5 |
| 9 | *Anthropogenic aerosols are short-lived and mostly produce negative radiative forcing.* ● Chapter 5.2 and 5.5.4 ● Chapter 5.1, 5.2 and Chapter 6.7 ● Chapter 5.3.2, 5.4.3 and Chapter 6.8 |
| 9 | *Natural factors have made small contributions to radiative forcing over the past century.* ● Chapter 6.11 and 6.15.1 ● Chapter 6.9 and 6.15.1 ● Chapter 6.15.1 |

### Confidence in the ability of models to project future climate has increased.

| SPM Page | Cross-Reference: SPM Topic – Chapter Section |
|---|---|
| 9 | Chapeau: "Complex physically-based ..." Chapter 8.3.2, 8.5.1, 8.6.1, 8.10.3 and Chapter 12.3.2 |
| 9 | ● Chapter 7.2.1, 7.5.2 and 7.6.1 ● Chapter 8.4.2<br>● Chapter 8.6.3 and Chapter 12.3.2<br>● Chapter 8.5.5, 8.7.1 and 8.7.5 |

### There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.

| SPM Page | Cross-Reference: SPM Topic – Chapter Section |
|---|---|
| 10 | Chapeau: "The SAR concluded: The balance of evidence suggests ..." Chapter 12.1.2 and 12.6 |
| 10 | ● Chapter 12.2.2, 12.4.3 and 12.6<br>● Chapter 12.4.1, 12.4.2, 12.4.3 and 12.6<br>● Chapter 12.2.3, 12.4.1, 12.4.2, 12.4.3 and 12.6<br>● Chapter 12.4.3 and 12.6. ● Chapter 12.6<br>● Chapter 12.4.3 ● Chapter 12.4.3 and 12.6 |
| 10 | "In the light of new evidence and taking into account the ..." Chapter 12.4 and 12.6 |
| 10 | "Furthermore, it is very likely that the 20th century warming has ..." Chapter 11.4 |

### Human influences will continue to change atmospheric composition throughout the 21st century.

| SPM Page | Cross-Reference: SPM Topic – Chapter Section |
|---|---|
| 12 | Chapeau: "Models have been used to make projections ..." Chapter 4.4.5 and Appendix II |
| 12 | *Greenhouse gases* ● Chapter 3.7.3 and Appendix II<br>● Chapter 3.7.1, 3.7.2, 3.7.3 and Appendix II<br>● Chapter 3.7.3 and Appendix II<br>● Chapter 3.2.2 and Appendix II<br>● Chapter 4.4.5, 4.5, 4.6 and Appendix II<br>● Chapter 3.7.3 |
| 12 | *Aerosols* ● Chapter 5.5.2, 5.5.3 and Appendix II |
| 12 | *Radiative forcing over the 21st century*<br>● Chapter 6.15.2 and Appendix II |

### Global average temperature and sea level are projected to rise under all IPCC SRES scenarios.

| SPM Page | Cross-Reference: SPM Topic – Chapter Section |
|---|---|
| 13 | *Temperature* ● Chapter 9.3.3 ● Chapter 9.3.3<br>● Chapter 2.2.2, 2.3.2 and 2.4 ● Chapter 9.3.3 and Chapter 10.3.2 ● Chapter 8.6.1, Chapter 12.4.3, Chapter 13.5.1 and 13.5.2<br>● Chapter 10.3.2 and Box 10.1 ● Chapter 9.3.2 |
| 13 | *Precipitation* ● Chapter 9.3.1, 9.3.6, Chapter 10.3.2 and Box 10.1 |
| 15 | *Extreme events* Table 1: Chapter 2.1, 2.2, 2.5, 2.7.2, 2.7.3, Chapter 9.3.6 and Chapter 10.3.2<br>● Chapter 2.7.3 and Chapter 9.3.6 |
| 16 | *El Niño* ● Chapter 9.3.5 ● Chapter 9.3.5 |
| 16 | *Monsoons* ● Chapter 9.3.5 |
| 16 | *Thermohaline circulation* ● Chapter 9.3.4 |
| 16 | *Snow and ice* ● Chapter 9.3.2 ● Chapter 11.5.1<br>● Chapter 11.5.1 ● Chapter 11.5.4 |
| 16 | *Sea level* ● Chapter 11.5.1 |

### Anthropogenic climate change will persist for many centuries.

| SPM Page | Cross-Reference: SPM Topic – Chapter Section |
|---|---|
| 17 | ● Chapter 3.2.3, Chapter 4.4 and Chapter 6.15<br>● Chapter 9.3.3 and 9.3.4 ● Chapter 11.5.4<br>● Chapter 11.5.4 ● Chapter 11.5.4 |

### Further work is required to address remaining gaps in information and understanding.

| SPM Page | Cross-Reference: SPM Topic – Chapter Section |
|---|---|
| 17 – 18 | All bullet points: Chapter 14, Executive Summary |

# SUMMARY FOR POLICYMAKERS

# CLIMATE CHANGE 2001:
# IMPACTS, ADAPTATION, AND VULNERABILITY

## *A Report of Working Group II of the Intergovernmental Panel on Climate Change*

*This summary, approved in detail at the Sixth Session of IPCC Working Group II (Geneva, Switzerland • 13-16 February 2001), represents the formally agreed statement of the IPCC concerning the sensitivity, adaptive capacity, and vulnerability of natural and human systems to climate change, and the potential consequences of climate change.*

Based on a draft prepared by:

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**Joint Intervenors**
**Exhibit 2 – C**

## CONTENTS

## 1. Introduction

The sensitivity, adaptive capacity, and vulnerability of natural and human systems to climate change, and the potential consequences of climate change, are assessed in the report of Working Group II of the Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2001: Impacts, Adaptation, and Vulnerability*.[1] This report builds upon the past assessment reports of the IPCC, reexamining key conclusions of the earlier assessments and incorporating results from more recent research.[2,3]

Observed changes in climate, their causes, and potential future changes are assessed in the report of Working Group I of the IPCC, *Climate Change 2001: The Scientific Basis*. The Working Group I report concludes, *inter alia*, that the globally averaged surface temperatures have increased by 0.6 ± 0.2°C over the 20th century; and that, for the range of scenarios developed in the IPCC *Special Report on Emission Scenarios* (SRES), the globally averaged surface air temperature is projected by models to warm 1.4 to 5.8°C by 2100 relative to 1990, and globally averaged sea level is projected by models to rise 0.09 to 0.88 m by 2100. These projections indicate that the warming would vary by region, and be accompanied by increases and decreases in precipitation. In addition, there would be changes in the variability of climate, and changes in the frequency and intensity of some extreme climate phenomena. These general features of climate change act on natural and human systems and they set the context for the Working Group II assessment. The available literature has not yet investigated climate change impacts, adaptation, and vulnerability associated with the upper end of the projected range of warming.

This Summary for Policymakers, which was approved by IPCC member governments in Geneva in February 2001, describes the current state of understanding of the impacts, adaptation, and vulnerability to climate change and their uncertainties. Further details can be found in the underlying report.[4] Section 2 of the Summary presents a number of general findings that emerge from integration of information across the full report. Each of these findings addresses a different dimension of climate change impacts, adaptation, and vulnerability, and no one dimension is paramount. Section 3 presents findings regarding individual natural and human systems, and Section 4 highlights some of the issues of concern for different regions of the world. Section 5 identifies priority research areas to further advance understanding of the potential consequences of and adaptation to climate change.

## 2. Emergent Findings

### 2.1. *Recent Regional Climate Changes, particularly Temperature Increases, have Already Affected Many Physical and Biological Systems*

Available observational evidence indicates that regional changes in climate, particularly increases in temperature, have already affected a diverse set of physical and biological systems in many parts of the world. Examples of observed changes include shrinkage of glaciers, thawing of permafrost, later freezing and earlier break-up of ice on rivers and lakes, lengthening of mid- to high-latitude growing seasons, poleward and altitudinal shifts of plant and animal ranges, declines of some plant and animal populations, and earlier flowering of trees, emergence of insects, and egg-laying in birds (see Figure SPM-1). Associations between changes in regional temperatures and observed changes in physical and biological systems have been documented in many aquatic, terrestrial, and marine environments. [2.1, 4.3, 4.4, 5.7, and 7.1]

The studies mentioned above and illustrated in Figure SPM-1 were drawn from a literature survey, which identified long-term studies, typically 20 years or more, of changes in biological and physical systems that could be correlated with regional changes in temperature.[5] In most cases where changes in biological and physical systems were detected, the direction of change was that expected on the basis of known mechanisms. The probability that the observed changes in the expected direction (with no reference to magnitude) could occur by chance alone is negligible. In many parts of the world, precipitation-related impacts may be important. At present, there is a lack of systematic concurrent climatic and biophysical data of sufficient length (2 or more decades) that are considered necessary for assessment of precipitation impacts.

Factors such as land-use change and pollution also act on these physical and biological systems, making it difficult to attribute changes to particular causes in some specific cases. However, taken together, the observed changes in these systems are consistent in direction and coherent across diverse localities

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[1] *Climate change* in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where *climate change* refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. Attribution of climate change to natural forcing and human activities has been addressed by Working Group I.

[2] The report has been written by 183 Coordinating Lead Authors and Lead Authors, and 243 Contributing Authors. It was reviewed by 440 government and expert reviewers, and 33 Review Editors oversaw the review process.

[3] Delegations from 100 IPCC member countries participated in the Sixth Session of Working Group II in Geneva on 13-16 February 2001.

[4] A more comprehensive summary of the report is provided in the Technical Summary, and relevant sections of that volume are referenced in brackets at the end of paragraphs of the Summary for Policymakers for readers who need more information.

[5] There are 44 regional studies of over 400 plants and animals, which varied in length from about 20 to 50 years, mainly from North America, Europe, and the southern polar region. There are 16 regional studies covering about 100 physical processes over most regions of the world, which varied in length from about 20 to 150 years. See Section 7.1 of the Technical Summary for more detail.

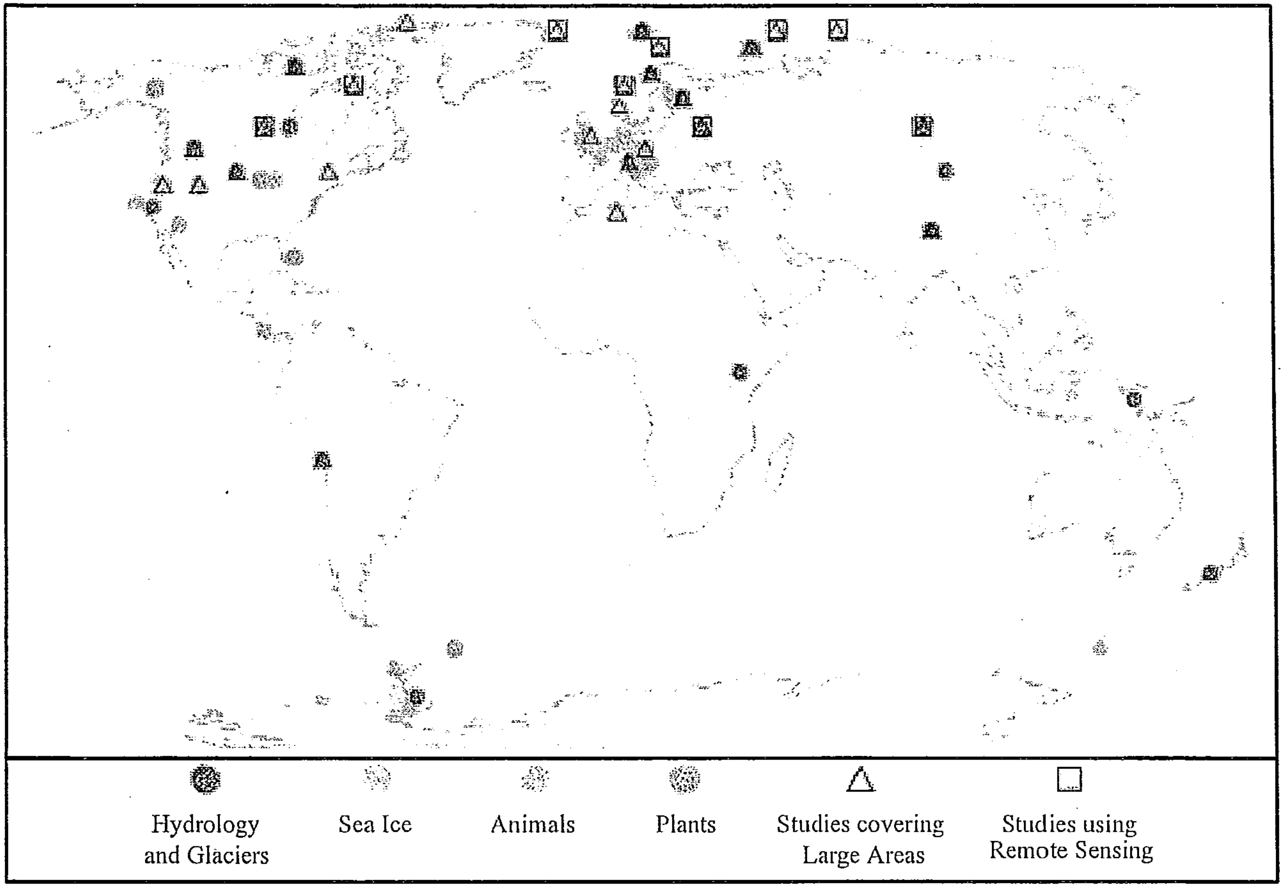

**Figure SPM-1:** Locations at which systematic long-term studies meet stringent criteria documenting recent temperature-related regional climate change impacts on physical and biological systems. Hydrology, glacial retreat, and sea-ice data represent decadal to century trends. Terrestrial and marine ecosystem data represent trends of at least 2 decades. Remote-sensing studies cover large areas. Data are for single or multiple impacts that are consistent with known mechanisms of physical/biological system responses to observed regional temperature-related changes. For reported impacts spanning large areas, a representative location on the map was selected.

and/or regions (see Figure SPM-1) with the expected effects of regional changes in temperature. Thus, from the collective evidence, there is *high confidence*[6] that recent regional changes in temperature have had discernible impacts on many physical and biological systems.

### 2.2. *There are Preliminary Indications that Some Human Systems have been Affected by Recent Increases in Floods and Droughts*

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 changes. The relative impact of climatic and socioeconomic factors are generally difficult to quantify. [4.6 and 7.1]

### 2.3. *Natural Systems are Vulnerable to Climate Change, and Some will be Irreversibly Damaged*

Natural systems can be especially vulnerable to climate change because of limited adaptive capacity (see Box SPM-1), and some of these systems may undergo significant and irreversible damage. Natural systems at risk include glaciers, coral reefs and

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[6] In this Summary for Policymakers, the following words have been used where appropriate to indicate judgmental estimates of confidence (based upon the collective judgment of the authors using the observational evidence, modeling results, and theory that they have examined): *very high* (95% or greater), *high* (67-95%), *medium* (33-67%), *low* (5-33%), and *very low* (5% or less). In other instances, a qualitative scale to gauge the level of scientific understanding is used: *well established, established-but-incomplete, competing explanations*, and *speculative*. The approaches used to assess confidence levels and the level of scientific understanding, and the definitions of these terms, are presented in Section 1.4 of the Technical Summary. Each time these terms are used in the Summary for Policymakers, they are footnoted and in *italics*.

atolls, mangroves, boreal and tropical forests, polar and alpine ecosystems, prairie wetlands, and remnant native grasslands. While some species may increase in abundance or range, climate change will increase existing risks of extinction of some more vulnerable species and loss of biodiversity. It is *well-established*[6] that the geographical extent of the damage or loss, and the number of systems affected, will increase with the magnitude and rate of climate change (see Figure SPM-2). [4.3 and 7.2.1]

### 2.4. *Many Human Systems are Sensitive to Climate Change, and Some are Vulnerable*

Human systems that are sensitive to climate change include mainly water resources; agriculture (especially food security) and forestry; coastal zones and marine systems (fisheries); human settlements, energy, and industry; insurance and other financial services; and human health. The vulnerability of these systems varies with geographic location, time, and social, economic, and environmental conditions. [4.1, 4.2, 4.3, 4.4, 4.5, 4.6, and 4.7]

Projected adverse impacts based on models and other studies include:

- A general reduction in potential crop yields in most tropical and sub-tropical regions for most projected increases in temperature [4.2]
- A general reduction, with some variation, in potential crop yields in most regions in mid-latitudes for increases in annual-average temperature of more than a few °C [4.2]
- Decreased water availability for populations in many water-scarce regions, particularly in the sub-tropics [4.1]
- An increase in the number of people exposed to vector-borne (e.g., malaria) and water-borne diseases (e.g., cholera), and an increase in heat stress mortality [4.7]
- A widespread increase in the risk of flooding for many human settlements (tens of millions of inhabitants in settlements studied) from both increased heavy precipitation events and sea-level rise [4.5]
- Increased energy demand for space cooling due to higher summer temperatures. [4.5]

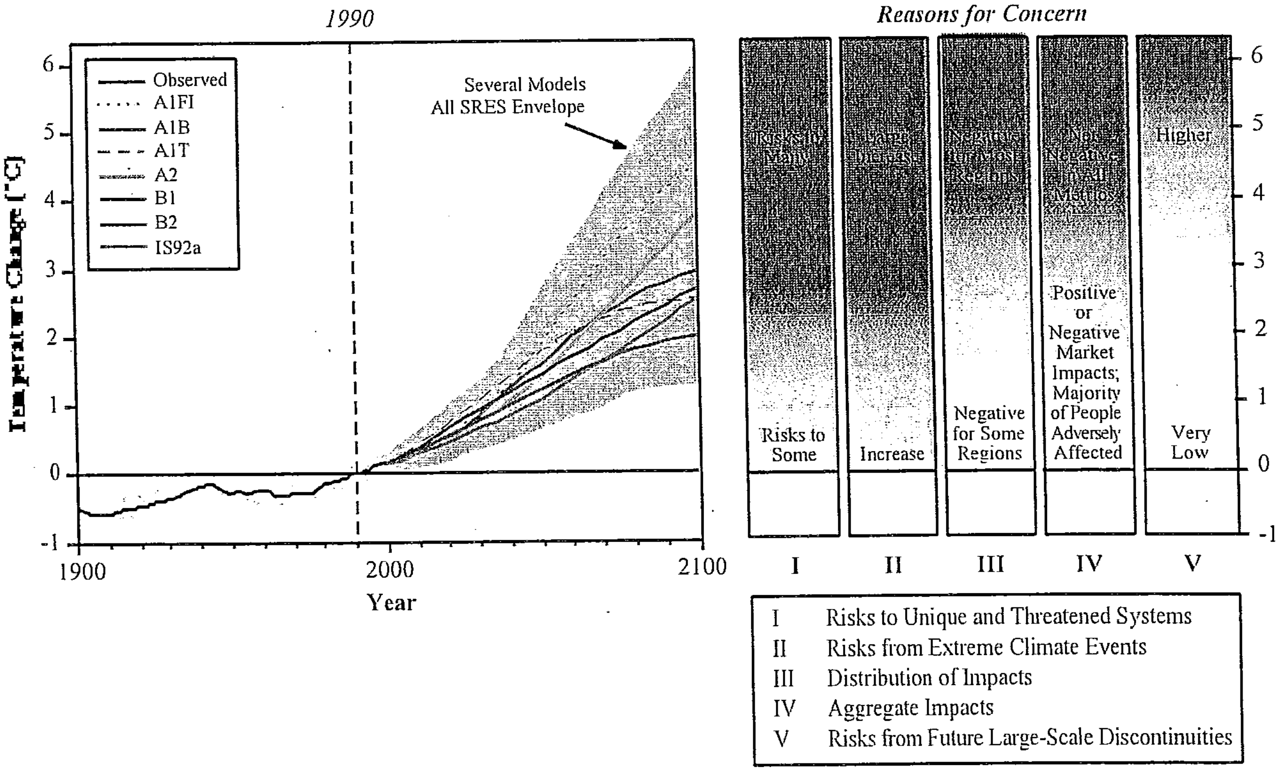

**Figure SPM-2:** Reasons for concern about projected climate change impacts. The risks of adverse impacts from climate change increase with the magnitude of climate change. The left part of the figure displays the observed temperature increase relative to 1990 and the range of projected temperature increase after 1990 as estimated by Working Group I of the IPCC for scenarios from the *Special Report on Emissions Scenarios*. The right panel displays conceptualizations of five reasons for concern regarding climate change risks evolving through 2100. White indicates neutral or small negative or positive impacts or risks, yellow indicates negative impacts for some systems or low risks, and red means negative impacts or risks that are more widespread and/or greater in magnitude. The assessment of impacts or risks takes into account only the magnitude of change and not the rate of change. Global mean annual temperature change is used in the figure as a proxy for the magnitude of climate change, but projected impacts will be a function of, among other factors, the magnitude and rate of global and regional changes in mean climate, climate variability and extreme climate phenomena, social and economic conditions, and adaptation.

### Box SPM-1. Climate Change Sensitivity, Adaptive Capacity, and Vulnerability

*Sensitivity* is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

*Adaptive capacity* is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

*Vulnerability* is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Projected beneficial impacts based on models and other studies include:

- Increased potential crop yields in some regions at mid-latitudes for increases in temperature of less than a few °C [4.2]
- A potential increase in global timber supply from appropriately managed forests [4.3]
- Increased water availability for populations in some water-scarce regions—for example, in parts of southeast Asia [4.1]
- Reduced winter mortality in mid- and high-latitudes [4.7]
- Reduced energy demand for space heating due to higher winter temperatures. [4.5]

### 2.5. *Projected Changes in Climate Extremes could have Major Consequences*

The vulnerability of human societies and natural systems to climate extremes is demonstrated by the damage, hardship, and death caused by events such as droughts, floods, heat waves, avalanches, and windstorms. While there are uncertainties attached to estimates of such changes, some extreme events are projected to increase in frequency and/or severity during the 21st century due to changes in the mean and/or variability of climate, so it can be expected that the severity of their impacts will also increase in concert with global warming (see Figure SPM-2). Conversely, the frequency and magnitude of extreme low temperature events, such as cold spells, is projected to decrease in the future, with both positive and negative impacts. The impacts of future changes in climate extremes are expected to fall disproportionately on the poor. Some representative examples of impacts of these projected changes in climate variability and climate extremes are presented in Table SPM-1. [3.5, 4.6, 6, and 7.2.4]

### 2.6. *The Potential for Large-Scale and Possibly Irreversible Impacts Poses Risks that have yet to be Reliably Quantified*

Projected climate changes[7] 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. These possibilities are very climate scenario-dependent and a full range of plausible scenarios has not yet been evaluated. Examples include significant slowing of the ocean circulation that transports warm water to the North Atlantic, large reductions in the Greenland and West Antarctic Ice Sheets, accelerated global warming due to carbon cycle feedbacks in the terrestrial biosphere, and releases of terrestrial carbon from permafrost regions and methane from hydrates in coastal sediments. 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 (see Figure SPM-2). [3.5, 5.7, and 7.2.5]

If these changes in Earth systems were to occur, their impacts would be widespread and sustained. For example, significant slowing of the oceanic thermohaline circulation would impact deep-water oxygen levels and carbon uptake by oceans and marine ecosystems, and would reduce warming over parts of Europe. Disintegration of the West Antarctic Ice Sheet or melting of the Greenland Ice Sheet could raise global sea level up to 3 m each over the next 1,000 years[8], submerge many islands, and inundate extensive coastal areas. Depending on the rate of ice loss, the rate and magnitude of sea-level rise could greatly exceed the capacity of human and natural systems to adapt without substantial impacts. Releases of terrestrial carbon from permafrost regions and methane from hydrates in coastal sediments, induced by warming, would further increase greenhouse gas concentrations in the atmosphere and amplify climate change. [3.5, 5.7, and 7.2.5]

### 2.7. *Adaptation is a Necessary Strategy at All Scales to Complement Climate Change Mitigation Efforts*

Adaptation has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs

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[7] Details of projected climate changes, illustrated in Figure SPM-2, are provided in the Working Group I Summary for Policymakers.

[8] Details of projected contributions to sea-level rise from the West Anarctic Ice Sheet and Greenland Ice Sheet are provided in the Working Group I Summary for Policymakers.

*Table SPM-1: Examples of impacts resulting from projected changes in extreme climate events.*

| Projected Changes during the 21st Century in Extreme Climate Phenomena and their Likelihood[a] | Representative Examples of Projected Impacts[b] *(all high confidence of occurrence in some areas[c])* |
|---|---|
| *Simple Extremes* | |
| Higher maximum temperatures; more hot days and heat waves[d] over nearly all land areas (*very likely*[a]) | • Increased incidence of death and serious illness in older age groups and urban poor [4.7]<br>• Increased heat stress in livestock and wildlife [4.2 and 4.3]<br>• Shift in tourist destinations [Table TS-4 and 5.8]<br>• Increased risk of damage to a number of crops [4.2]<br>• Increased electric cooling demand and reduced energy supply reliability [Table TS-4 and 4.5] |
| Higher (increasing) minimum temperatures; fewer cold days, frost days, and cold waves[d] over nearly all land areas (*very likely*[a]) | • Decreased cold-related human morbidity and mortality [4.7]<br>• Decreased risk of damage to a number of crops, and increased risk to others [4.2]<br>• Extended range and activity of some pest and disease vectors [4.2 and 4.3]<br>• Reduced heating energy demand [4.5] |
| More intense precipitation events (*very likely*[a] over many areas) | • Increased flood, landslide, avalanche, and mudslide damage [4.5]<br>• Increased soil erosion [5.2.4]<br>• Increased flood runoff could increase recharge of some floodplain aquifers [4.1]<br>• Increased pressure on government and private flood insurance systems and disaster relief [Table TS-4 and 4.6] |
| *Complex Extremes* | |
| Increased summer drying over most mid-latitude continental interiors and associated risk of drought (*likely*[a]) | • Decreased crop yields [4.2]<br>• Increased damage to building foundations caused by ground shrinkage [Table TS-4]<br>• Decreased water resource quantity and quality [4.1 and 4.5]<br>• Increased risk of forest fire [5.4.2] |
| Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities (*likely*[a] over some areas)[e] | • Increased risks to human life, risk of infectious disease epidemics, and many other risks [4.7]<br>• Increased coastal erosion and damage to coastal buildings and infrastructure [4.5 and 7.2.4]<br>• Increased damage to coastal ecosystems such as coral reefs and mangroves [4.4] |
| Intensified droughts and floods associated with El Niño events in many different regions (*likely*[a]) (see also under droughts and intense precipitation events) | • Decreased agricultural and rangeland productivity in drought- and flood-prone regions [4.3]<br>• Decreased hydro-power potential in drought-prone regions [5.1.1 and Figure TS-7] |
| Increased Asian summer monsoon precipitation variability (*likely*[a]) | • Increased flood and drought magnitude and damages in temperate and tropical Asia [5.2.4] |
| Increased intensity of mid-latitude storms (little agreement between current models)[d] | • Increased risks to human life and health [4.7]<br>• Increased property and infrastructure losses [Table TS-4]<br>• Increased damage to coastal ecosystems [4.4] |

[a] Likelihood refers to judgmental estimates of confidence used by TAR WGI: *very likely* (90-99% chance); *likely* (66-90% chance). Unless otherwise stated, information on climate phenomena is taken from the Summary for Policymakers, TAR WGI.

[b] These impacts can be lessened by appropriate response measures.

[c] High confidence refers to probabilities between 67 and 95% as described in Footnote 6.

[d] Information from TAR WGI, Technical Summary, Section F.5.

[e] Changes in regional distribution of tropical cyclones are possible but have not been established.

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 climate 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. [6]

Experience with adaptation to climate variability and extremes can be drawn upon to develop appropriate strategies for adapting to anticipated climate change. Adaptation to current climate variability and extremes often produces benefits as well as forming a basis for coping with future climate change. However, experience also demonstrates that there are constraints to achieving the full measure of potential adaptation. In addition, maladaptation, such as promoting development in risk-prone locations, can occur due to decisions based on short-term considerations, neglect of known climatic variability, imperfect foresight, insufficient information, and over-reliance on insurance mechanisms. [6]

### *2.8 Those with the Least Resources have the Least Capacity to Adapt and are the Most Vulnerable*

The ability of human systems to adapt to and cope with climate change depends on such factors as wealth, technology, education, information, skills, infrastructure, access to resources, and management capabilities. There is potential for developed and developing countries to enhance and/or acquire adaptive capabilities. Populations and communities are highly variable in their endowments with these attributes, and the developing countries, particularly the least developed countries, are generally poorest in this regard. As a result, they have lesser capacity to adapt and are more vulnerable to climate change damages, just as they are more vulnerable to other stresses. This condition is most extreme among the poorest people. [6.1; see also 5.1.7, 5.2.7, 5.3.5, 5.4.6, 5.6.1, 5.6.2, 5.7, and 5.8.1 for regional-scale information]

Benefits and costs of climate change effects have been estimated in monetary units and aggregated to national, regional, and global scales. These estimates generally exclude the effects of changes in climate variability and extremes, do not account for the effects of different rates of change, and only partially account for impacts on goods and services that are not traded in markets. These omissions are likely to result in underestimates of economic losses and overestimates of economic gains. Estimates of aggregate impacts are controversial because they treat gains for some as canceling out losses for others and because the weights that are used to aggregate across individuals are necessarily subjective. [7.2.2 and 7.2.3]

Notwithstanding the limitations expressed above, based on a few published estimates, increases in global mean temperature[9] would produce net economic losses in many developing countries for all magnitudes of warming studied (*low confidence*[6]), and losses would be greater in magnitude the higher the level of warming (*medium confidence*[6]). In contrast, an increase in global mean temperature of up to a few °C would produce a mixture of economic gains and losses in developed countries (*low confidence*[6]), with economic losses for larger temperature increases (*medium confidence*[6]). The projected distribution of economic impacts is such that it would increase the disparity in well-being between developed countries and developing countries, with disparity growing for higher projected temperature increases (*medium confidence*[6]). The more damaging impacts estimated for developing countries reflects, in part, their lesser adaptive capacity relative to developed countries. [7.2.3]

Further, when aggregated to a global scale, world gross domestic product (GDP) would change by ± a few percent for global mean temperature increases of up to a few °C (*low confidence*[6]), and increasing net losses would result for larger increases in temperature (*medium confidence*[6]) (see Figure SPM-2). More people are projected to be harmed than benefited by climate change, even for global mean temperature increases of less than a few °C (*low confidence*[6]). These results are sensitive to assumptions about changes in regional climate, level of development, adaptive capacity, rate of change, the valuation of impacts, and the methods used for aggregating monetary losses and gains, including the choice of discount rate. [7.2.2]

The effects of climate change are expected to be greatest in developing countries in terms of loss of life and relative effects on investment and the economy. For example, the relative percentage damages to GDP from climate extremes have been substantially greater in developing countries than in developed countries. [4.6]

### *2.9. Adaptation, Sustainable Development, and Enhancement of Equity can be Mutually Reinforcing*

Many communities and regions that are vulnerable to climate change are also under pressure from forces such as population growth, resource depletion, and poverty. Policies that lessen pressures on resources, improve management of environmental risks, and increase the welfare of the poorest members of society can simultaneously advance sustainable development and equity, enhance adaptive capacity, and reduce vulnerability to climate and other stresses. Inclusion of climatic risks in the design and implementation of national and international development initiatives can promote equity and development that is more sustainable and that reduces vulnerability to climate change. [6.2]

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[9] Global mean temperature change is used as an indicator of the magnitude of climate change. Scenario-dependent exposures taken into account in these studies include regionally differentiated changes in temperature, precipitation, and other climatic variables.

## 3. Effects on and Vulnerability of Natural and Human Systems

### *3.1. Hydrology and Water Resources*

The effect of climate change on streamflow and groundwater recharge varies regionally and between climate scenarios, largely following projected changes in precipitation. A consistent projection across most climate change scenarios is for increases in annual mean streamflow in high latitudes and southeast Asia, and decreases in central Asia, the area around the Mediterranean, southern Africa, and Australia (*medium confidence*[6]) (see Figure SPM-3); the amount of change, however, varies between scenarios. For other areas, including mid-latitudes, there is no strong consistency in projections of streamflow, partly because of differences in projected rainfall and partly because of differences in projected evaporation, which can offset rainfall increases. The retreat of most glaciers is projected to accelerate, and many small glaciers may disappear (*high confidence*[6]). In general, the projected changes in average annual runoff are less robust than impacts based solely on temperature change because precipitation changes vary more between scenarios. At the catchment scale, the effect of a given change in climate varies with physical properties and vegetation of catchments, and may be in addition to land-cover changes. [4.1]

Approximately 1.7 billion people, one-third of the world's population, presently live in countries that are water-stressed (defined as using more than 20% of their renewable water supply, a commonly used indicator of water stress). This number is projected to increase to around 5 billion by 2025, depending on the rate of population growth. The projected climate change could further decrease the streamflow and groundwater recharge in many of these water-stressed countries—for example in central Asia, southern Africa, and countries around the Mediterranean Sea—but may increase it in some others. [4.1; see also 5.1.1, 5.2.3, 5.3.1, 5.4.1, 5.5.1, 5.6.2, and 5.8.4 for regional-scale information]

Demand for water is generally increasing due to population growth and economic development, but is falling in some countries because of increased efficiency of use. Climate change is unlikely to have a big effect on municipal and industrial water demands in general, but may substantially affect irrigation withdrawals, which depend on how increases in evaporation are offset or exaggerated by changes in precipitation. Higher temperatures, hence higher crop evaporative demand, mean that the general tendency would be towards an increase in irrigation demands. [4.1]

Flood magnitude and frequency could increase in many regions as a consequence of increased frequency of heavy precipitation events, which can increase runoff in most areas as well as groundwater recharge in some floodplains. Land-use change could exacerbate such events. Streamflow during seasonal low flow periods would decrease in many areas due to greater evaporation; changes in precipitation may exacerbate or offset the effects of increased evaporation. The projected climate change would degrade water quality through higher water temperatures and increased pollutant load from runoff and overflows of waste facilities. Quality would be degraded further where flows decrease, but increases in flows may mitigate to a certain extent some degradations in water quality by increasing dilution. Where snowfall is currently an important component of the water balance, a greater proportion of winter precipitation may fall as rain, and this can result in a more intense peak streamflow which in addition would move from spring to winter. [4.1]

The greatest vulnerabilities are likely to be in unmanaged water systems and systems that are currently stressed or poorly and unsustainably managed due to policies that discourage efficient water use and protection of water quality, inadequate watershed management, failure to manage variable water supply and demand, or lack of sound professional guidance. In unmanaged systems there are few or no structures in place to buffer the effects of hydrologic variability on water quality and supply. In unsustainably managed systems, water and land uses can add stresses that heighten vulnerability to climate change. [4.1]

Water resource management techniques, particularly those of integrated water resource management, can be applied to adapt to hydrologic effects of climate change, and to additional uncertainty, so as to lessen vulnerabilities. Currently, supply-side approaches (e.g., increasing flood defenses, building weirs, utilizing water storage areas, including natural systems, improving infrastructure for water collection and distribution) are more widely used than demand-side approaches (which alter the exposure to stress); the latter is the focus of increasing attention. However, the capacity to implement effective management responses is unevenly distributed around the world and is low in many transition and developing countries. [4.1]

### *3.2. Agriculture and Food Security*

Based on experimental research, crop yield responses to climate change vary widely, depending upon species and cultivar; soil properties; pests, and pathogens; the direct effects of carbon dioxide ($CO_2$) on plants; and interactions between $CO_2$, air temperature, water stress, mineral nutrition, air quality, and adaptive responses. Even though increased $CO_2$ concentration can stimulate crop growth and yield, that benefit may not always overcome the adverse effects of excessive heat and drought (*medium confidence*[6]). These advances, along with advances in research on agricultural adaptation, have been incorporated since the Second Assessment Report (SAR) into models used to assess the effects of climate change on crop yields, food supply, farm incomes, and prices. [4.2]

Costs will be involved in coping with climate-induced yield losses and adaptation of livestock production systems. These agronomic and husbandry adaptation options could include, for example, adjustments to planting dates, fertilization rates, irrigation applications, cultivar traits, and selection of animal species. [4.2]

When autonomous agronomic adaptation is included, crop modeling assessments indicate, with *medium* to *lowconfidence*[6], that climate change will lead to generally positive responses at less than a few °C warming and generally negative responses for more than a few °C in mid-latitude crop yields. Similar assessments indicate that yields of some crops in tropical locations would decrease generally with even minimal increases in temperature, because such crops are near their maximum temperature tolerance and dryland/rainfed agriculture predominates. Where there is also a large decrease in rainfall, tropical crop yields would be

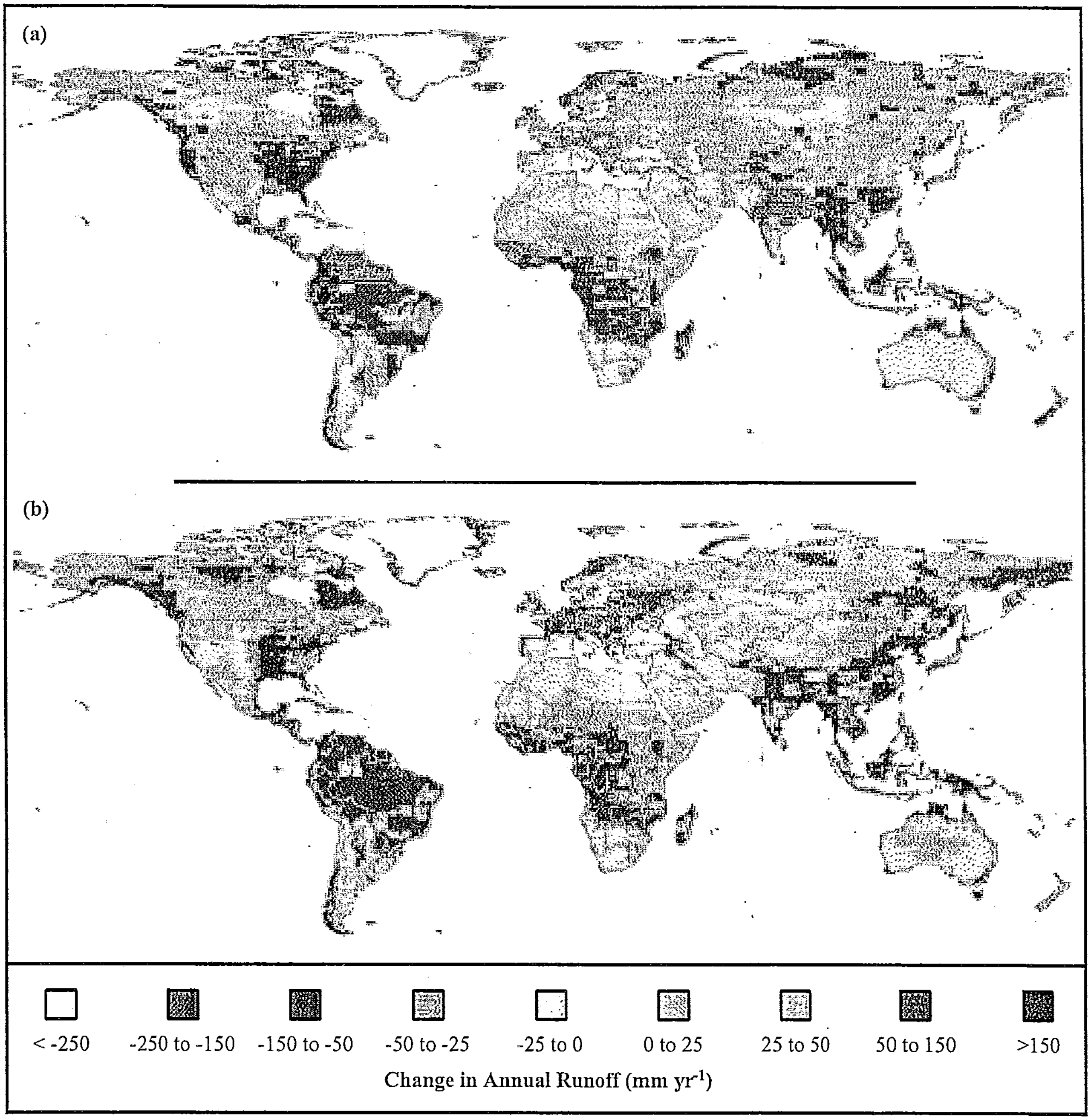

**Figure SPM-3:** Projected changes in average annual water runoff by 2050, relative to average runoff for 1961–1990, largely follow projected changes in precipitation. Changes in runoff are calculated with a hydrologic model using as inputs climate projections from two versions of the Hadley Centre atmosphere-ocean general circulation model (AOGCM) for a scenario of 1% per annum increase in effective carbon dioxide concentration in the atmosphere: (a) HadCM2 ensemble mean and (b) HadCM3. Projected increases in runoff in high latitudes and southeast Asia, and decreases in central Asia, the area around the Mediterranean, southern Africa, and Australia are broadly consistent across the Hadley Centre experiments, and with the precipitation projections of other AOGCM experiments. For other areas of the world, changes in precipitation and runoff are scenario- and model-dependent.

even more adversely affected. With autonomous agronomic adaptation, crop yields in the tropics tend to be less adversely affected by climate change than without adaptation, but they still tend to remain below levels estimated with current climate. [4.2]

Most global and regional economic studies not incorporating climate change indicate that the downward trend in global real commodity prices in the 20th century is likely to continue into the 21st, although confidence in these predictions decreases farther into the future. Economic modeling assessments indicate that impacts of climate change on agricultural production and prices are estimated to result in small percentage changes in global income (*lowconfidence*[6]), with larger increases in more developed regions and smaller increases or declines in developing regions. Improved confidence in this finding depends on further research into the sensitivity of economic modeling assessments to their base assumptions. [4.2 and Box 5-5]

Most studies indicate that global mean annual temperature increases of a few °C or greater would prompt food prices to increase due to a slowing in the expansion of global food supply relative to growth in global food demand (*established, but incomplete*[6]). At lesser amounts of warming than a few °C, economic models do not clearly distinguish the climate change signal from other sources of change based on those studies included in this assessment. Some recent aggregated studies have estimated economic impacts on vulnerable populations such as smallholder producers and poor urban consumers. These studies find that climate change would lower incomes of the vulnerable populations and increase the absolute number of people at risk of hunger, though this is uncertain and requires further research. It is established, though incompletely, that climate change, mainly through increased extremes and temporal/spatial shifts, will worsen food security in Africa. [4.2]

### 3.3. *Terrestrial and Freshwater Ecosystems*

Vegetation modeling studies continue to show the potential for significant disruption of ecosystems under climate change (*high confidence*[6]). Migration of ecosystems or biomes as discrete units is unlikely to occur; instead at a given site, species composition and dominance will change. The results of these changes will lag behind the changes in climate by years to decades to centuries (*high confidence*[6]). [4.3]

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. Climate change will lead to poleward movement of the boundaries of freshwater fish distributions along with loss of habitat for cold- and cool-water fishes and gain in habitat for warm-water fishes (*high confidence*[6]). Many species and populations 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, 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 (*high confidence*[6]). [4.3]

Possible adaptation methods to reduce risks to species could include: 1) establishment of refuges, parks, and reserves with corridors to allow migration of species, and 2) use of captive breeding and translocation. However, these options may have limitations due to costs. [4.3]

Terrestrial ecosystems appear to be storing increasing amounts of carbon. At the time of the SAR, this was largely attributed to increasing plant productivity because of the interaction between elevated $CO_2$ concentration, increasing temperatures, and soil moisture changes. Recent results confirm that productivity gains are occurring but suggest that they are smaller under field conditions than indicated by plant-pot experiments (*medium confidence*[6]). Hence, the terrestrial uptake may be due more to change in uses and management of land than to the direct effects of elevated $CO_2$ and climate. The degree to which terrestrial ecosystems continue to be net sinks for carbon is uncertain due to the complex interactions between the factors mentioned above (e.g., arctic terrestrial ecosystems and wetlands may act as both sources and sinks) (*medium confidence*[6]). [4.3]

Contrary to the SAR, global timber market studies that include adaptations through land and product management, even without forestry projects that increase the capture and storage of carbon, suggest that a small amount of climate change would increase global timber supply and enhance existing market trends towards rising market share in developing countries (*mediumconfidence*[6]). Consumers may benefit from lower timber prices while producers may gain or lose depending on regional changes in timber productivity and potential dieback effects. [4.3]

### 3.4. *Coastal Zones and Marine Ecosystems*

Large-scale impacts of climate change on oceans are expected to include increases in sea surface temperature and mean global sea level, decreases in sea-ice cover, and changes in salinity, wave conditions, and ocean circulation. The oceans are an integral and responsive component of the climate system with important physical and biogeochemical feedbacks to climate. Many marine ecosystems are sensitive to climate change. Climate trends and variability as reflected in multiyear climate-ocean regimes (e.g., Pacific Decadal Oscillation) and switches from one regime to another are now recognized to strongly affect fish abundance and population dynamics, with significant impacts on fish-dependent human societies. [4.4]

Many coastal areas will experience increased levels of flooding, accelerated erosion, loss of wetlands and mangroves, and seawater intrusion into freshwater sources as a result of climate change. The extent and severity of storm impacts, including storm-surge floods and shore erosion, will increase as a result of climate change including sea-level rise. High-latitude coasts will experience added impacts related to higher wave energy and permafrost degradation. Changes in relative sea level will vary locally due to uplift and subsidence caused by other factors. [4.4]

Impacts on highly diverse and productive coastal ecosystems such as coral reefs, atolls and reef islands, salt marshes and mangrove forests will depend upon the rate of sea-level rise relative to growth rates and sediment supply, space for and obstacles to horizontal migration, changes in the climate-ocean environment such as sea surface temperatures and storminess, and pressures from human activities in coastal zones. Episodes of coral bleaching over the past 20 years have been associated with several causes, including increased ocean temperatures. Future sea surface warming would increase stress on coral reefs and result in increased frequency of marine diseases (*high confidence*[6]). [4.4]

Assessments of adaptation strategies for coastal zones have shifted emphasis away from hard protection structures of shorelines (e.g., seawalls, groins) toward soft protection measures (e.g., beach nourishment), managed retreat, and enhanced resilience of biophysical and socioeconomic systems in coastal regions. Adaptation options for coastal and marine management are most effective when incorporated with policies in other areas, such as disaster mitigation plans and land-use plans. [4.4]

### 3.5. *Human Health*

The impacts of short-term weather events on human health have been further elucidated since the SAR, particularly in relation to periods of thermal stress, the modulation of air pollution impacts, the impacts of storms and floods, and the influences of seasonal and interannual climatic variability on infectious diseases. There has been increased understanding of the determinants of population vulnerability to adverse health impacts and the possibilities for adaptive responses. [4.7]

Many vector-, food-, and water-borne infectious diseases are known to be sensitive to changes in climatic conditions. From results of most predictive model studies, there is *medium* to *high confidence*[6] that, under climate change scenarios, 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 population.[10] Within their present ranges, these and many other infectious diseases would tend to increase in incidence and seasonality–although regional decreases would occur in some infectious diseases. In all cases, however, actual disease occurrence is strongly influenced by local environmental conditions, socioeconomic circumstances, and public health infrastructure. [4.7]

Projected climate change will be accompanied by an increase in heat waves, often exacerbated by increased humidity and urban air pollution, which would cause an increase in heat-related deaths and illness episodes. The evidence indicates that the impact would be greatest in urban populations, affecting particularly the elderly, sick, and those without access to air-conditioning (*high confidence*[6]). Limited evidence indicates that in some temperate countries reduced winter deaths would outnumber increased summer deaths (*medium confidence*[6]); yet, published research has been largely confined to populations in developed countries, thus precluding a generalized comparison of changes in summer and winter mortality. [3.5 and 4.7]

Extensive experience makes clear that any increase in flooding will increase the risk of drowning, diarrhoeal and respiratory diseases, and, in developing countries, hunger and malnutrition (*high confidence*[6]). If cyclones were to increase regionally, devastating impacts would often occur, particularly in densely settled populations with inadequate resources. A reduction in crop yields and food production because of climate change in some regions, particularly in the tropics, will predispose food-insecure populations to malnutrition, leading to impaired child development and decreased adult activity. Socioeconomic disruptions could occur in some regions, impairing both livelihoods and health. [3.5, 4.1, 4.2, 4.5, and 4.7]

For each anticipated adverse health impact there is a range of social, institutional, technological, and behavioral adaptation options to lessen that impact. Adaptations could, for example, encompass strengthening of the public health infrastructure, health-oriented management of the environment (including air and water quality, food safety, urban and housing design, and surface water management), and the provision of appropriate medical care facilities. Overall, the adverse health impacts of climate change will be greatest in vulnerable lower income populations, predominantly within tropical/subtropical countries. Adaptive policies would, in general, reduce these impacts. [4.7]

### 3.6. *Human Settlements, Energy, and Industry*

A growing and increasingly quantitative literature shows that human settlements are affected by climate change in one of three major ways:

1) The economic sectors that support the settlement are affected because of changes in resource productivity or changes in market demand for the goods and services produced there. [4.5]
2) Some aspects of physical infrastructure (including energy transmission and distribution systems), buildings, urban services (including transportation systems), and specific industries (such as agroindustry, tourism, and construction) may be directly affected. [4.5]
3) Populations may be directly affected through extreme weather, changes in health status, or migration. The problems are somewhat different in the largest (<1 million) and mid- to small-sized population centers. [4.5]

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[10] Eight studies have modeled the effects of climate change on these diseases, five on malaria and three on dengue. Seven use a biological, or process-based approach, and one uses an empirical, statistical approach.

The most widespread direct risk to human settlements from climate change is flooding and landslides, driven by projected increases in rainfall intensity and, in coastal areas, sea-level rise. Riverine and coastal settlements are particularly at risk (*high confidence*[6]), but urban flooding could be a problem anywhere that storm drains, water supply, and waste management systems have inadequate capacity. In such areas, squatter and other informal urban settlements with high population density, poor shelter, little or no access to resources such as safe water and public health services, and low adaptive capacity are highly vulnerable. Human settlements currently experience other significant environmental problems which could be exacerbated under higher temperature/increased precipitation regimes, including water and energy resources and infrastructure, waste treatment, and transportation [4.5]

Rapid urbanization in low-lying coastal areas of both the developing and developed world is greatly increasing population densities and the value of human-made assets exposed to coastal climatic extremes such as tropical cyclones. Model-based projections of the mean annual number of people who would be flooded by coastal storm surges increase several fold (by 75 to 200 million people depending on adaptive responses) for mid-range scenarios of a 40-cm sea-level rise by the 2080s relative to scenarios with no sea-level rise. Potential damages to infrastructure in coastal areas from sea-level rise have been projected to be tens of billions US$ for individual countries—for example, Egypt, Poland, and Vietnam. [4.5]

Settlements with little economic diversification and where a high percentage of incomes derive from climate-sensitive primary resource industries (agriculture, forestry, and fisheries) are more vulnerable than more diversified settlements (*high confidence*[6]). In developed areas of the Arctic, and where the permafrost is ice-rich, special attention will be required to mitigate the detrimental impacts of thawing, such as severe damage to buildings and transport infrastructure (*very high confidence*[6]). Industrial, transportation, and commercial infrastructure is generally vulnerable to the same hazards as settlement infrastructure. Energy demand is expected to increase for space cooling and decrease for space heating, but the net effect is scenario- and location-dependent. Some energy production and distribution systems may experience adverse impacts that would reduce supplies or system reliability while other energy systems may benefit. [4.5 and 5.7]

Possible adaptation options involve the planning of settlements and their infrastructure, placement of industrial facilities, and making similar long-lived decisions in a manner to reduce the adverse effects of events that are of low (but increasing) probability and high (and perhaps rising) consequences. [4.5]

### 3.7. *Insurance and Other Financial Services*

The costs of ordinary and extreme weather events have increased rapidly in recent decades. Global economic losses from catastrophic events increased 10.3-fold from 3.9 billion US$ $\mathrm{yr}^{-1}$ in the 1950s to 40 billion US$ $\mathrm{yr}^{-1}$ in the 1990s (all in 1999US$, unadjusted for purchasing power parity), with approximately one-quarter of the losses occurring in developing countries. The insured portion of these losses rose from a negligible level to 9.2 billion US$ $\mathrm{yr}^{-1}$ during the same period. Total costs are a factor of two larger when losses from smaller, non-catastrophic weather-related events are included. As a measure of increasing insurance industry vulnerability, the ratio of global property/casual insurance premiums to weather related losses fell by a factor of three between 1985 and 1999. [4.6]

The costs of weather events have risen rapidly despite significant and increasing efforts at fortifying infrastructure and enhancing disaster preparedness. Part of the observed upward trend in disaster losses over the past 50 years is linked to socioeconomic factors, such as population growth, increased wealth, and urbanization in vulnerable areas, and part is linked to climatic factors such as the observed changes in precipitation and flooding events. Precise attribution is complex and there are differences in the balance of these two causes by region and type of event. [4.6]

Climate change and anticipated changes in weather-related events perceived to be linked to climate change would increase actuarial uncertainty in risk assessment (*high confidence*[6]). Such developments would place upward pressure on insurance premiums and/or could lead to certain risks being reclassified as uninsurable with subsequent withdrawal of coverage. Such changes would trigger increased insurance costs, slow the expansion of financial services into developing countries, reduce the availability of insurance for spreading risk, and increase the demand for government-funded compensation following natural disasters. In the event of such changes, the relative roles of public and private entities in providing insurance and risk management resources can be expected to change. [4.6]

The financial services sector as a whole is expected to be able to cope with the impacts of climate change, although the historic record demonstrates that low-probability high-impact events or multiple closely spaced events severely affect parts of the sector, especially if adaptive capacity happens to be simultaneously depleted by non-climate factors (e.g., adverse financial market conditions). The property/casualty insurance and reinsurance segments and small specialized or undiversified companies have exhibited greater sensitivity, including reduced profitability and bankruptcy triggered by weather-related events. [4.6]

Adaptation to climate change presents complex challenges, but also opportunities, to the sector. Regulatory involvement in pricing, tax treatment of reserves, and the (in)ability of firms to withdraw from at-risk markets are examples of factors that influence the resilience of the sector. Public- and private-sector actors also support adaptation by promoting disaster preparedness, loss-prevention programs, building codes, and improved land-use planning. However, in some cases, public insurance and

*Table SPM-2: Regional adaptive capacity, vulnerability, and key concerns.*[a,b]

| Region | Adaptive Capacity, Vulnerability, and Key Concerns |
|---|---|
| Africa | • Adaptive capacity of human systems in Africa is low due to lack of economic resources and technology, and vulnerability high as a result of heavy reliance on rain-fed agriculture, frequent droughts and floods, and poverty. [5.1.7]<br>• Grain yields are projected to decrease for many scenarios, diminishing food security, particularly in small food-importing countries (*medium to high confidence*[6]). [5.1.2]<br>• Major rivers of Africa are highly sensitive to climate variation; average runoff and water availability would decrease in Mediterranean and southern countries of Africa (*medium confidence*[6]). [5.1.1]<br>• Extension of ranges of infectious disease vectors would adversely affect human health in Africa (*medium confidence*[6]). [5.1.4]<br>• Desertification would be exacerbated by reductions in average annual rainfall, runoff, and soil moisture, especially in southern, North, and West Africa (*medium confidence*[6]). [5.1.6]<br>• Increases in droughts, floods, and other extreme events would add to stresses on water resources, food security, human health, and infrastructures, and would constrain development in Africa (*high confidence*[6]). [5.1]<br>• Significant extinctions of plant and animal species are projected and would impact rural livelihoods, tourism, and genetic resources (*medium confidence*[6]). [5.1.3]<br>• Coastal settlements in, for example, the Gulf of Guinea, Senegal, Gambia, Egypt, and along the East–Southern African coast would be adversely impacted by sea-level rise through inundation and coastal erosion (*high confidence*[6]). [5.1.5] |
| Asia | • Adaptive capacity of human systems is low and vulnerability is high in the developing countries of Asia; the developed countries of Asia are more able to adapt and less vulnerable. [5.2.7]<br>• Extreme events have increased in temperate and tropical Asia, including floods, droughts, forest fires, and tropical cyclones (*high confidence*[6]). [5.2.4]<br>• Decreases in agricultural productivity and aquaculture due to thermal and water stress, sea-level rise, floods and droughts, and tropical cyclones would diminish food security in many countries of arid, tropical, and temperate Asia; agriculture would expand and increase in productivity in northern areas (*medium confidence*[6]). [5.2.1]<br>• Runoff and water availability may decrease in arid and semi-arid Asia but increase in northern Asia (*medium confidence*[6]). [5.2.3]<br>• Human health would be threatened by possible increased exposure to vector-borne infectious diseases and heat stress in parts of Asia (*medium confidence*[6]). [5.2.6]<br>• Sea-level rise and an increase in the intensity of tropical cyclones would displace tens of millions of people in low-lying coastal areas of temperate and tropical Asia; increased intensity of rainfall would increase flood risks in temperate and tropical Asia (*high confidence*[6]). [5.2.5 and Table TS-8]<br>• Climate change would increase energy demand, decrease tourism attraction, and influence transportation in some regions of Asia (*medium confidence*[6]). [5.2.4 and 5.2.7]<br>• Climate change would exacerbate threats to biodiversity due to land-use and land-cover change and population pressure in Asia (*medium confidence*[6]). Sea-level rise would put ecological security at risk, including mangroves and coral reefs (*high confidence*[6]). [5.2.2]<br>• Poleward movement of the southern boundary of the permafrost zones of Asia would result in a change of thermokarst and thermal erosion with negative impacts on social infrastructure and industries (*medium confidence*[6]). [5.2.2] |

relief programs have inadvertently fostered complacency and maladaptation by inducing development in at-risk areas such as U.S. flood plains and coastal zones. [4.6]

The effects of climate change are expected to be greatest in the developing world, especially in countries reliant on primary production as a major source of income. Some countries experience impacts on their GDP as a consequence of natural disasters, with damages as high as half of GDP in one case. Equity issues and development constraints would arise if weather-related risks become uninsurable, prices increase, or availability becomes limited. Conversely, more extensive access to insurance and more widespread introduction of micro-financing schemes and development banking would increase the ability of developing countries to adapt to climate change. [4.6]

## 4. Vulnerability Varies across Regions

The vulnerability of human populations and natural systems to climate change differs substantially across regions and across

*Table SPM-2 (continued)*

| Region | Adaptive Capacity, Vulnerability, and Key Concerns |
|---|---|
| Australia and New Zealand | • Adaptive capacity of human systems is generally high, but there are groups in Australia and New Zealand, such as indigenous peoples in some regions, with low capacity to adapt and consequently high vulnerability. [5.3 and 5.3.5]<br>• The net impact on some temperate crops of climate and $CO_2$ changes may initially be beneficial, but this balance is expected to become negative for some areas and crops with further climate change (*medium confidence*[6]). [5.3.3]<br>• Water is likely to be a key issue (*high confidence*[6]) due to projected drying trends over much of the region and change to a more El Niño-like average state. [5.3 and 5.3.1]<br>• Increases in the intensity of heavy rains and tropical cyclones (*medium confidence*[6]), and region-specific changes in the frequency of tropical cyclones, would alter the risks to life, property, and ecosystems from flooding, storm surges, and wind damage. [5.3.4]<br>• Some species with restricted climatic niches and which are unable to migrate due to fragmentation of the landscape, soil differences, or topography could become endangered or extinct (*high confidence*[6]). Australian ecosystems that are particularly vulnerable to climate change include coral reefs, arid and semi-arid habitats in southwest and inland Australia, and Australian alpine systems. Freshwater wetlands in coastal zones in both Australia and New Zealand are vulnerable, and some New Zealand ecosystems are vulnerable to accelerated invasion by weeds. [5.3.2] |
| Europe | • Adaptive capacity is generally high in Europe for human systems; southern Europe and the European Arctic are more vulnerable than other parts of Europe. [5.4 and 5.4.6]<br>• Summer runoff, water availability, and soil moisture are likely to decrease in southern Europe, and would widen the difference between the north and drought-prone south; increases are likely in winter in the north and south (*high confidence*[6]). [5.4.1]<br>• Half of alpine glaciers and large permafrost areas could disappear by end of the 21st century (*medium confidence*[6]). [5.4.1]<br>• River flood hazard will increase across much of Europe (*medium to high confidence*[6]); in coastal areas, the risk of flooding, erosion, and wetland loss will increase substantially with implications for human settlement, industry, tourism, agriculture, and coastal natural habitats. [5.4.1 and 5.4.4]<br>• There will be some broadly positive effects on agriculture in northern Europe (*medium confidence*[6]); productivity will decrease in southern and eastern Europe (*medium confidence*[6]). [5.4.3]<br>• Upward and northward shift of biotic zones will take place. Loss of important habitats (wetlands, tundra, isolated habitats) would threaten some species (*high confidence*[6]). [5.4.2]<br>• Higher temperatures and heat waves may change traditional summer tourist destinations, and less reliable snow conditions may impact adversely on winter tourism (*medium confidence*[6]). [5.4.4] |
| Latin America | • Adaptive capacity of human systems in Latin America is low, particularly with respect to extreme climate events, and vulnerability is high. [5.5]<br>• Loss and retreat of glaciers would adversely impact runoff and water supply in areas where glacier melt is an important water source (*high confidence*[6]). [5.5.1]<br>• Floods and droughts would become more frequent with floods increasing sediment loads and degrade water quality in some areas (*high confidence*[6]). [5.5]<br>• Increases in intensity of tropical cyclones would alter the risks to life, property, and ecosystems from heavy rain, flooding, storm surges, and wind damages (*high confidence*[6]). [5.5]<br>• Yields of important crops are projected to decrease in many locations in Latin America, even when the effects of $CO_2$ are taken into account; subsistence farming in some regions of Latin America could be threatened (*high confidence*[6]). [5.5.4]<br>• The geographical distribution of vector-borne infectious diseases would expand poleward and to higher elevations, and exposures to diseases such as malaria, dengue fever, and cholera will increase (*medium confidence*[6]). [5.5.5]<br>• Coastal human settlements, productive activities, infrastructure, and mangrove ecosystems would be negatively affected by sea-level rise (*medium confidence*[6]). [5.5.3]<br>• The rate of biodiversity loss would increase (*high confidence*[6]). [5.5.2] |

populations within regions. Regional differences in baseline climate and expected climate change give rise to different exposures to climate stimuli across regions. The natural and social systems of different regions have varied characteristics, resources, and institutions, and are subject to varied pressures that give rise to differences in sensitivity and adaptive capacity. From these differences emerge different key concerns for each of the major regions of the world. Even within regions however, impacts, adaptive capacity, and vulnerability will vary. [5]

*Table SPM-2 (continued)*

| Region | Adaptive Capacity, Vulnerability, and Key Concerns |
|---|---|
| North America | • Adaptive capacity of human systems is generally high and vulnerability low in North America, but some communities (e.g., indigenous peoples and those dependent on climate-sensitive resources) are more vulnerable; social, economic, and demographic trends are changing vulnerabilities in subregions. [5.6 and 5.6.1]<br>• Some crops would benefit from modest warming accompanied by increasing $CO_2$, but effects would vary among crops and regions (*high confidence*[6]), including declines due to drought in some areas of Canada's Prairies and the U.S. Great Plains, potential increased food production in areas of Canada north of current production areas, and increased warm-temperate mixed forest production (*medium confidence*[6]). However, benefits for crops would decline at an increasing rate and possibly become a net loss with further warming (*medium confidence*[6]). [5.6.4]<br>• Snowmelt-dominated watersheds in western North America will experience earlier spring peak flows (*high confidence*[6]), reductions in summer flows (*medium confidence*[6]), and reduced lake levels and outflows for the Great Lakes-St. Lawrence under most scenarios (*medium confidence*[6]); adaptive responses would offset some, but not all, of the impacts on water users and on aquatic ecosystems (*medium confidence*[6]). [5.6.2]<br>• Unique natural ecosystems such as prairie wetlands, alpine tundra, and cold-water ecosystems will be at risk and effective adaptation is unlikely (*medium confidence*[6]). [5.6.5]<br>• Sea-level rise would result in enhanced coastal erosion, coastal flooding, loss of coastal wetlands, and increased risk from storm surges, particularly in Florida and much of the U.S. Atlantic coast (*high confidence*[6]). [5.6.1]<br>• Weather-related insured losses and public sector disaster relief payments in North America have been increasing; insurance sector planning has not yet systematically included climate change information, so there is potential for surprise (*high confidence*[6]). [5.6.1]<br>• Vector-borne diseases—including malaria, dengue fever, and Lyme disease—may expand their ranges in North America; exacerbated air quality and heat stress morbidity and mortality would occur (*medium confidence*[6]); socioeconomic factors and public health measures would play a large role in determining the incidence and extent of health effects. [5.6.6] |
| Polar | • Natural systems in polar regions are highly vulnerable to climate change and current ecosystems have low adaptive capacity; technologically developed communities are likely to adapt readily to climate change, but some indigenous communities, in which traditional lifestyles are followed, have little capacity and few options for adaptation. [5.7]<br>• Climate change in polar regions is expected to be among the largest and most rapid of any region on the Earth, and will cause major physical, ecological, sociological, and economic impacts, especially in the Arctic, Antarctic Peninsula, and Southern Ocean (*high confidence*[6]). [5.7]<br>• Changes in climate that have already taken place are manifested in the decrease in extent and thickness of Arctic sea ice, permafrost thawing, coastal erosion, changes in ice sheets and ice shelves, and altered distribution and abundance of species in polar regions (*high confidence*[6]). [5.7]<br>• Some polar ecosystems may adapt through eventual replacement by migration of species and changing species composition, and possibly by eventual increases in overall productivity; ice edge systems that provide habitat for some species would be threatened (*medium confidence*[6]). [5.7]<br>• Polar regions contain important drivers of climate change. Once triggered, they may continue for centuries, long after greenhouse gas concentrations are stabilized, and cause irreversible impacts on ice sheets, global ocean circulation, and sea-level rise (*medium confidence*[6]). [5.7] |

In light of the above, all regions are likely to experience some adverse effects of climate change. Table SPM-2 presents in a highly summarized fashion some of the key concerns for the different regions. Some regions are particularly vulnerable because of their physical exposure to climate change hazards and/or their limited adaptive capacity. Most less-developed regions are especially vulnerable because a larger share of their economies are in climate-sensitive sectors and their adaptive capacity is low due to low levels of human, financial, and natural resources, as well as limited institutional and technological capability. For example, small island states and low-lying coastal areas are particularly vulnerable to increases in sea level and storms, and most of them have limited capabilities for adaptation. Climate change impacts in polar regions are expected to be large and rapid, including reduction in sea-ice extent and thickness and degradation of permafrost. Adverse changes in seasonal river flows, floods and droughts, food security, fisheries, health effects, and loss of biodiversity are among the major regional vulnerabilities and concerns of Africa, Latin America, and Asia where adaptation opportunities are generally low. Even in regions with higher adaptive capacity, such as North America and Australia and New Zealand, there are vulnerable communities, such as indigenous peoples, and the possibility of adaptation of ecosystems is very limited. In Europe, vulnerability is significantly greater in the south and in the Arctic than elsewhere in the region. [5]

*Table SPM-2 (continued)*

| Region | Adaptive Capacity, Vulnerability, and Key Concerns |
|---|---|
| Small Island States | • Adaptive capacity of human systems is generally low in small island states, and vulnerability high; small island states are likely to be among the countries most seriously impacted by climate change. [5.8]<br>• The projected sea-level rise of 5 mm $yr^{-1}$ for the next 100 years would cause enhanced coastal erosion, loss of land and property, dislocation of people, increased risk from storm surges, reduced resilience of coastal ecosystems, saltwater intrusion into freshwater resources, and high resource costs to respond to and adapt to these changes (*high confidence*[6]). [5.8.2 and 5.8.5]<br>• Islands with very limited water supplies are highly vulnerable to the impacts of climate change on the water balance (*high confidence*[6]). [5.8.4]<br>• Coral reefs would be negatively affected by bleaching and by reduced calcification rates due to higher $CO_2$ levels (*medium confidence*[6]); mangrove, sea grass bed, and other coastal ecosystems and the associated biodiversity would be adversely affected by rising temperatures and accelerated sea-level rise (*medium confidence*[6]). [4.4 and 5.8.3]<br>• Declines in coastal ecosystems would negatively impact reef fish and threaten reef fisheries, those who earn their livelihoods from reef fisheries, and those who rely on the fisheries as a significant food source (*medium confidence*[6]). [4.4 and 5.8.4]<br>• Limited arable land and soil salinization makes agriculture of small island states, both for domestic food production and cash crop exports, highly vulnerable to climate change (*high confidence*[6]). [5.8.4]<br>• Tourism, an important source of income and foreign exchange for many islands, would face severe disruption from climate change and sea-level rise (*high confidence*[6]). [5.8.5] |

[a] Because the available studies have not employed a common set of climate scenarios and methods, and because of uncertainties regarding the sensitivities and adaptability of natural and social systems, the assessment of regional vulnerabilities is necessarily qualitative.

[b] The regions listed in Table SPM-2 are graphically depicted in Figure TS-2 of the Technical Summary.

## 5. Improving Assessments of Impacts, Vulnerabilities, and Adaptation

Advances have been made since previous IPCC assessments in the detection of change in biotic and physical systems, and steps have been taken to improve the understanding of adaptive capacity, vulnerability to climate extremes, and other critical impact-related issues. These advances indicate a need for initiatives to begin designing adaptation strategies and building adaptive capacities. Further research is required, however, to strengthen future assessments and to reduce uncertainties in order to assure that sufficient information is available for policymaking about responses to possible consequences of climate change, including research in and by developing countries. [8]

The following are high priorities for narrowing gaps between current knowledge and policymaking needs:

- Quantitative assessment of the sensitivity, adaptive capacity, and vulnerability of natural and human systems to climate change, with particular emphasis on changes in the range of climatic variation and the frequency and severity of extreme climate events
- Assessment of possible thresholds at which strongly discontinuous responses to projected climate change and other stimuli would be triggered
- Understanding dynamic responses of ecosystems to multiple stresses, including climate change, at global, regional, and finer scales
- Development of approaches to adaptation responses, estimation of the effectiveness and costs of adaptation options, and identification of differences in opportunities for and obstacles to adaptation in different regions, nations, and populations
- Assessment of potential impacts of the full range of projected climate changes, particularly for non-market goods and services, in multiple metrics and with consistent treatment of uncertainties, including but not limited to numbers of people affected, land area affected, numbers of species at risk, monetary value of impact, and implications in these regards of different stabilization levels and other policy scenarios
- Improving tools for integrated assessment, including risk assessment, to investigate interactions between components of natural and human systems and the consequences of different policy decisions
- Assessment of opportunities to include scientific information on impacts, vulnerability, and adaptation in decisionmaking processes, risk management, and sustainable development initiatives
- Improvement of systems and methods for long-term monitoring and understanding the consequences of climate change and other stresses on human and natural systems.

Cutting across these foci are special needs associated with strengthening international cooperation and coordination for regional assessment of impacts, vulnerability, and adaptation, including capacity-building and training for monitoring, assessment, and data gathering, especially in and for developing countries (particularly in relation to the items identified above).

# Joint science academies' statement: Global response to climate change

## Climate change is real

There will always be uncertainty in understanding a system as complex as the world's climate. However there is now strong evidence that significant global warming is occurring[1]. The evidence comes from direct measurements of rising surface air temperatures and subsurface ocean temperatures and from phenomena such as increases in average global sea levels, retreating glaciers, and changes to many physical and biological systems. It is likely that most of the warming in recent decades can be attributed to human activities (IPCC 2001)[2]. This warming has already led to changes in the Earth's climate.

The existence of greenhouse gases in the atmosphere is vital to life on Earth – in their absence average temperatures would be about 30 centigrade degrees lower than they are today. But human activities are now causing atmospheric concentrations of greenhouse gases – including carbon dioxide, methane, tropospheric ozone, and nitrous oxide – to rise well above pre-industrial levels. Carbon dioxide levels have increased from 280 ppm in 1750 to over 375 ppm today – higher than any previous levels that can be reliably measured (i.e. in the last 420,000 years). Increasing greenhouse gases are causing temperatures to rise; the Earth's surface warmed by approximately 0.6 centigrade degrees over the twentieth century. The Intergovernmental Panel on Climate Change (IPCC) projected that the average global surface temperatures will continue to increase to between 1.4 centigrade degrees and 5.8 centigrade degrees above 1990 levels, by 2100.

## Reduce the causes of climate change

The scientific understanding of climate change is now sufficiently clear to justify nations taking prompt action. It is vital that all nations identify cost-effective steps that they can take now, to contribute to substantial and long-term reduction in net global greenhouse gas emissions.

Action taken now to reduce significantly the build-up of greenhouse gases in the atmosphere will lessen the magnitude and rate of climate change. As the United Nations Framework Convention on Climate Change (UNFCCC) recognises, a lack of full scientific certainty about some aspects of climate change is not a reason for delaying an immediate response that will, at a reasonable cost, prevent dangerous anthropogenic interference with the climate system.

As nations and economies develop over the next 25 years, world primary energy demand is estimated to increase by almost 60%. Fossil fuels, which are responsible for the majority of carbon dioxide emissions produced by human activities, provide valuable resources for many nations and are projected to provide 85% of this demand (IEA 2004)[3]. Minimising the amount of this carbon dioxide reaching the atmosphere presents a huge challenge. There are many potentially cost-effective technological options that could contribute to stabilising greenhouse gas concentrations. These are at various stages of research and development. However barriers to their broad deployment still need to be overcome.

Carbon dioxide can remain in the atmosphere for many decades. Even with possible lowered emission rates we will be experiencing the impacts of climate change throughout the 21st century and beyond. Failure to implement significant reductions in net greenhouse gas emissions now, will make the job much harder in the future.

## Prepare for the consequences of climate change

Major parts of the climate system respond slowly to changes in greenhouse gas concentrations. Even if greenhouse gas emissions were stabilised instantly at today's levels, the climate would still continue to change as it adapts to the increased emission of recent decades. Further changes in climate are therefore unavoidable. Nations must prepare for them.

The projected changes in climate will have both beneficial and adverse effects at the regional level, for example on water resources, agriculture, natural ecosystems and human health. The larger and faster the changes in climate, the more likely it is that adverse effects will dominate. Increasing temperatures are likely to increase the frequency and severity of weather events such as heat waves and heavy rainfall. Increasing temperatures could lead to large-scale effects such as melting of large ice sheets (with major impacts on low-lying regions throughout the world). The IPCC estimates that the combined effects of ice melting and sea water expansion from ocean warming are projected to cause the global mean sea-level to rise by between 0.1 and 0.9 metres between 1990 and 2100. In Bangladesh alone, a 0.5 metre sea-level rise would place about 6 million people at risk from flooding.

Developing nations that lack the infrastructure or resources to respond to the impacts of climate change will be particularly affected. It is clear that many of the world's poorest people are likely to suffer the most from climate change. Long-term global efforts to create a more healthy, prosperous and sustainable world may be severely hindered by changes in the climate.

The task of devising and implementing strategies to adapt to the consequences of climate change will require worldwide collaborative inputs from a wide range of experts, including physical and natural scientists, engineers, social scientists, medical scientists, those in the humanities, business leaders and economists.

**Joint Intervenors**
**Exhibit 2 – D**

## Conclusion

We urge all nations, in the line with the UNFCCC principles[4], to take prompt action to reduce the causes of climate change, adapt to its impacts and ensure that the issue is included in all relevant national and international strategies. As national science academies, we commit to working with governments to help develop and implement the national and international response to the challenge of climate change.

G8 nations have been responsible for much of the past greenhouse gas emissions. As parties to the UNFCCC, G8 nations are committed to showing leadership in addressing climate change and assisting developing nations to meet the challenges of adaptation and mitigation.

We call on world leaders, including those meeting at the Gleneagles G8 Summit in July 2005, to:

- Acknowledge that the threat of climate change is clear and increasing.
- Launch an international study[5] to explore scientifically-informed targets for atmospheric greenhouse gas concentrations, and their associated emissions scenarios, that will enable nations to avoid impacts deemed unacceptable.
- Identify cost-effective steps that can be taken now to contribute to substantial and long-term reduction in net global greenhouse gas emissions. Recognise that delayed action will increase the risk of adverse environmental effects and will likely incur a greater cost.
- Work with developing nations to build a scientific and technological capacity best suited to their circumstances, enabling them to develop innovative solutions to mitigate and adapt to the adverse effects of climate change, while explicitly recognising their legitimate development rights.
- Show leadership in developing and deploying clean energy technologies and approaches to energy efficiency, and share this knowledge with all other nations.
- Mobilise the science and technology community to enhance research and development efforts, which can better inform climate change decisions.

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*Notes and references*

1 This statement concentrates on climate change associated with global warming. We use the UNFCCC definition of climate change, which is 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'.

2 IPCC (2001). Third Assessment Report. We recognise the international scientific consensus of the Intergovernmental Panel on Climate Change (IPCC).

3 IEA (2004). World Energy Outlook 4. Although long-term projections of future world energy demand and supply are highly uncertain, the World Energy Outlook produced by the International Energy Agency (IEA) is a useful source of information about possible future energy scenarios.

4 With special emphasis on the first principle of the UNFCCC, which states: 'The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof'.

5 Recognising and building on the IPCC's ongoing work on emission scenarios.

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