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Statement of Rep. Henry A. Waxman
Chairman, Health and the Environment Subcommittee
February 21, 1991

This is our first environmental hearing of the 102nd Congress. It addresses an issue of first importance to the nation and the world -- global warming.

Since the industrial revolution began, we have steadily polluted the atmosphere with greenhouse gases. This pollution has changed the earth's atmosphere. Global warming is now a certainty.

For the last two years, I have waited to learn what our "environmental President" plans to do to reverse global warming. I did not join those who accused him of stalling. I did not question his sincerity. Instead, I gave President Bush the benefit of every doubt.

I remembered his promise in 1988 to fight the greenhouse effect with "the White House effect" and his promise in 1989 to take "decisive action" to limit emissions of carbon dioxide. I remembered Secretary Baker's pledge "not to wait until all the uncertainties have been resolved." I remembered that just last month EPA Administrator Bill Reilly called global warming the "greatest" environmental threat facing the country.

And I hoped and expected to see these commitments reflected in the President's global warming policy.

But now it seems that the hopeful promises have been broken.

This month, President Bush has taken three actions that define his response to global warming. He has announced a global warming "action plan." He has given marching orders to his negotiators in the United Nations' negotiations on climate change. And he has sent Congress a national energy strategy. We will concentrate on the details of these three actions in this hearing.

Unfortunately, these three actions do essentially nothing that is not already mandated by law to alleviate global warming.

Global warming cannot be controlled without limiting emissions of the principal greenhouse gas -- carbon dioxide. Carbon dioxide causes over half of the predicted global warming, and it is currently totally unregulated. That is why the rest of the industrialized world has pledged to stabilize or reduce emissions of carbon dioxide.

But what is the President's policy on carbon dioxide emissions? By the Administration's own reckoning, the policies that we will hear described today allow carbon dioxide emissions to rise by 15% by 2000. In other words, we are moving in exactly the wrong direction -- we are increasing, not decreasing, carbon dioxide emissions.

We will also hear today about the impacts of global warming from two panels of scientific experts. Their testimony is sobering.

As our expert witnesses will explain, we now know that the continued release of carbon dioxide, and other greenhouse gases such as methane and nitrous oxide, will change our planet's climate. Like the glass panes in a greenhouse, these gases allow the sun's warming rays to reach the earth, but then absorb the radiative heat that the earth releases. Higher temperatures inevitably follow.

The experts will also explain that there is scientific consensus that by the end of next century will see warming of 1.5 to 4.5 degrees Centigrade. This is an unprecedented rate of warming -- and it will occur thousands of times faster than any previous global temperature changes. While we cannot yet be certain of how we will be affected by such a rapid warming, the range of likely impacts is quite broad and quite dramatic. It includes: drought; rising sea levels and coastal flooding; loss of drinking water supplies; disruption of agriculture; direct health problems, such as heat strokes and heart attacks; increases in infectious diseases transmitted by insects; and potentially devastating impacts on ecosystems.

Perhaps most alarming, the testimony summarizes new research that raises new issues -- and new fears -- concerning the consequences of global warming.

We will hear new testimony from Dr. Oppenheimer of the Environmental Defense Fund and Dr. Woodwell of the Woods Hole Research Center, who predict that global warming will increase biological respiration and decay. This is likely to cause natural carbon dioxide emissions to accelerate -- and "swamp human capacities at control in a short time."

We will hear new testimony from Dr. Shope of Yale University, who warns that we may "confidently expect" global warming to cause large epidemics of dengue disease in the U.S. This disease is transmitted by tropical mosquitoes and is a major killer of children in cities like Manila, Bangkok, and Jakarta. It has no known vaccine.

We will hear new testimony from Dr. Kalkstein of the University of Delaware, who estimates that heat-related deaths are likely to increase threefold by the middle of the next century. He predicts that in my district in Los Angeles, heat-related death rates will probably increase from 84 to 824. In New York, he predicts, global warming will cause 880 deaths each year; in Philadelphia, 700; in Chicago, 622.

And we will hear new testimony from Dr. Park of the Holcomb Research Institute, who provides new estimates of the economic costs to the U.S. of rising sea levels. These costs are now calculated to be \$275 to \$400 billion -- three times higher than previously thought. The shrimp fisheries in Texas, Louisiana, and Florida will be particularly hard-hit, suffering "catastrophic decreases."

Our final panel will explore policy options for reversing climate change. We are fortunate to have with us today the lead author of the Congressional Office of Technology Assessment to discuss OTA's recent report on policies for control of climate change, as well as key witnesses for the Alliance to Save Energy, the World Resources Institute, and the Natural Resources Defense Council.

These policy experts tell us that there is a lot we could do to reduce carbon dioxide emissions. Many of the most important measures increase energy conservation and would actually reduce economic costs. One measure -- increasing the energy efficiency of buildings -- can cut carbon dioxide emissions by over 5% and save \$25 to \$50 billion dollars a year in energy costs. The cost savings from this measure alone are sufficient to more than offset the entire costs of last year's Clean Air Act.

I want to thank all of our witnesses for joining us here this morning.

NEWS FROM

U.S. Senator Al Gore



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ADMINISTRATION CONSISTENT: MISGUIDED IN ENERGY, GLOBAL ENVIRONMENT
Critical Opportunities Missed in Nat'l Strategy, Int'l Talks

WASHINGTON -- Misguided Bush Administration policies slowing action on an international agreement to confront global warming and backstepping on efforts to increase energy efficiency represent critical opportunities missed, said Sen. Al Gore, D-TN.

"There's a consistency to their policy; they are consistently moving in the wrong direction. It doesn't make sense. When the Bush Administration ought to be providing leadership, they're scrambling to take up the rear. When they ought to be thinking about the future, they're living in the past," said Gore, in testimony to the House Energy and Commerce Committee's Subcommittee on Health and the Environment.

Gore said the Bush Administration's footdragging prevented real progress on substantive issues at the first round of international negotiations to craft an agreement aimed at preventing global climate change. Those negotiations were conducted February 4 - 14 in Chantilly, VA.

"The United States could have made a big difference. Instead, our representatives encouraged little more than procedural discussions. We shouldn't have been talking about the shape of the negotiating table, we should have been talking about substantive steps that could reduce the pollution that creates the greenhouse effect," said Gore, chairman of the Senate Commerce Committee Subcommittee on Science, Technology, and Space.

Gore said it was ironic that while representatives of more than 100 nations were meeting in Chantilly to discuss policies that would reduce the burning of fossil fuels and the greenhouse gas emissions they produce, the Bush Administration's National Energy Strategy was revealed, proposing increased reliance on these fuels.

"We should instead be focusing on how we can make more efficient use of our energy. How we can save money and save our

(MORE)

environment from pollution. We should be focusing on development of new, renewable sources of energy and on conservation," said Gore. "The Administration's thinking is backwards."

"For example, instead of improving the energy efficiency of lighting and appliances, the Bush Energy Strategy would simply label the energy efficiency of certain appliances and lights -- something that's already done," said Gore.

"At the Chantilly talks, they wanted the world to believe they were committing to real reductions in greenhouse gases. In fact, they were relying on an existing policy targeted at another problem to take credit for one year of stabilized emissions. It was a sham," said Gore.

"Clearly, we need to move forward. It will be Congress that will provide the energy policy we need. And, in the international negotiations, it is my hope that the U.S. will change course and pick up the pace," said Gore.

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**Testimony of
ROBERT A. REINSTEIN
Deputy Assistant Secretary of State for
Environment, Health and Natural Resources
United States Department of State**

**Representing the Administration
before the**

**Subcommittee on Health and the Environment,
Committee on Energy and Commerce,
United States House of Representatives
February 21, 1991**

Thank you, Mr. Chairman. I am Robert A. Reinstein, the Deputy Assistant Secretary of State for Environment, Health and Natural Resources. I am also the United States negotiator for the proposed Framework Convention on Climate Change. On behalf of the Administration, I am presenting testimony that has been developed in consultation with all relevant agencies. Appearing with me are Mark L. Kerrigan, Associate Deputy Under Secretary for Policy, Planning and Analysis at the Department of Energy, and Richard D. Morgenstern, Director of Policy Analysis at the Environmental Protection Agency.

It is a pleasure to appear before this subcommittee to discuss the negotiations on a framework convention on climate change. I would like to discuss briefly with you the results of the negotiating session that just ended, the timetable for future sessions and the overall U.S. position in these negotiations. In so doing, I will also touch on the National Energy Strategy (NES) and the contribution that it can make to addressing climate change.

Results of the First Session

At President Bush's invitation, the United States hosted the first session of these negotiations on February 4-14 just outside of Washington, DC. One hundred and one countries from

every region of the world and representatives from over 20 international organizations, representing both developing and industrialized nations, participated in this session. Consistent with the open process that we sought, 68 non-governmental organizations (NGOs) also participated and will be able to provide input throughout the negotiations.

Not content with merely hosting the first session, we entered these negotiations eager to move the discussion forward substantively. We had hoped to develop a draft negotiating text during this session, although we expected that such a draft text would have numerous brackets reflecting the differences in positions to be expected at the start of any negotiations. Compiling a bracketed text would have clarified the initial negotiating positions of the various parties, thus facilitating the negotiations in subsequent sessions. Towards this end, we distributed a number of documents explaining the U.S. perspective on the contents of a framework convention. Unfortunately, however, resolution of procedural matters left no time for consideration of substantive proposals at the first session. The difficulty in resolving even procedural issues indicates the complexity of this subject and the importance many countries, including the United States, attach to it.

We are confident, nonetheless, that the organization and procedures on which we agreed in this session will pave the way for steady, substantive progress in the sessions to follow:

- We agreed to organize two working groups, one which will consider all sources and sinks of all greenhouse gases, and one which will consider mechanisms of implementation of the convention. This structure will provide for a comprehensive discussion of the issues and will provide for full consideration of the concerns common to the negotiating parties.
- We adopted on Rules of Procedure which emphasize decision making by consensus and which will, as I have mentioned, allow NGOs to play a viable role in the negotiations. The United States was a forceful advocate of NGO participation.
- We also discussed ways to increase the participation of developing countries. These negotiations, and any long-term response to climate change, will be effective only if the broadest spectrum of nations participates. The United States was the first country to contribute to a voluntary trust fund established to support the participation of developing countries. The number of developing countries participating should increase in later sessions and they should now be able to send experts from their capitals.
- Working with other nations, the United States helped to

produce an informal paper outlining the scientific, technical and economic research needs which the convention should address. This exchange of views should make it easier to conclude these sections of the convention at a later stage in the negotiations.

- We also reached agreement on the important role the Intergovernmental Panel on Climate Change (IPCC) will play in responding to the technical needs of the negotiations. With this mandate, the IPCC will be in a position to provide information and resolve questions of a technical nature during the negotiations.

Perhaps most importantly, we have laid the foundation for a cooperative relationship with other national delegations which will help to move the process along and will facilitate positive consideration of our position.

Next Sessions

This session was the first of four or five sessions of the negotiations established under the auspices of the United Nations General Assembly by Resolution 45/212 on the "Protection of Global Climate for Present and Future Generations." The next session is tentatively scheduled for the first two weeks of June in Nairobi. Following that

session, we will meet in September, again in December, and in 1992, as necessary. The goal, as articulated in 45/212, is to complete the negotiations so that the framework convention will be opened for signature during the UN Conference on Environment and Development in June 1992 in Brazil.

The U.S. View on the Negotiations

The United States is approaching these negotiations with several principles in mind -- principles which are key to an effective convention and global response to climate change:

- First, we believe we must take a comprehensive approach to climate change, one which considers all aspects of this complex issue and which addresses all greenhouse gases and their sources and sinks;
- Second, we must not wait for all uncertainties to be resolved, but must pursue economically efficient and cost-effective actions - already justified on other grounds - which will limit net greenhouse gas emissions;
- Third, we must continue to pursue aggressively scientific and economic research; systematic observation; collection, archiving and distribution of information; and technology development in order to resolve uncertainties and build a solid foundation for innovative responses;
- Fourth, we must recognize the special needs of the

developing countries and design mechanisms for assisting them in securing the scientific and technical tools necessary for their fullest participation in a truly global effort.

- Fifth, any response must be global. Emissions from developing countries are growing rapidly. Action by industrialized nations alone would be ineffective at restraining emissions. We must also be sensitive to the ways in which different commitments could affect the competitive position of both developing and industrialized nations. An effective response will require that all nations participate and meet obligations that are appropriate to their circumstances.

The United States will seek to translate these principles into an innovative and effective framework convention that will engage all nations in a concerted international response to climate change.

A Comprehensive Approach to Climate Change

The United States strongly supports a comprehensive approach, one which considers all sources and sinks of all greenhouse gases, for a number of reasons. This approach provides the flexibility needed for each nation to address

climate change in the context of its unique circumstances. A comprehensive approach also ensures that research and technology development address all facets of the problem. Further, a comprehensive approach will ensure that we take advantage of the most cost-effective opportunities to address climate change across the range of sources and sinks of all greenhouse gases. The comprehensive approach accounts for all activities that emit or absorb greenhouse gases and avoids creating incentives that shift emissions from one type of gas or sector to another, as we know from experience can happen with narrowly focussed approaches. A comprehensive approach would allow each nation the flexibility to choose its best mix of response measures. Accordingly, the framework convention, and any subsequent legal instruments, must be comprehensive and deal with the full array of greenhouse gases and their sources and sinks. In addition, the IPCC First Assessment Report notes that both limitation and adaptation must be considered as part of an integrated response.

During the first session, the United States distributed a booklet and led an informal discussion on the comprehensive approach. We will continue this effort to engage in open dialogue with the international community about the rationale and implications of this approach.

Actions that are Justified in Their Own Right

The United States is already taking concrete measures that are justified in their own right, but that also have climate change benefits. As outlined in the brochure "America's Climate Change Strategy: An Action Agenda" which we distributed at the first session, this strategy will result in net U.S. greenhouse gas emissions in the year 2000 being equal to or below the 1987 level. These actions include:

- Phasing out chlorofluorocarbons (CFCs) and other ozone depleting compounds that are also greenhouse gases faster than required by the Montreal Protocol;
- Encouraging energy efficiency and reducing greenhouse gas emissions by capping sulfur dioxide emissions at substantially reduced levels while allowing utilities the flexibility to meet this cap in the most economically efficient manner possible;
- Reducing air pollutants which are greenhouse gases or greenhouse gas precursors, such as volatile organic compounds and methane;
- Initiating a program to plant a billion trees a year;
- Speeding the adoption of energy efficient technologies and practices in homes and businesses; and
- Promoting the use of, and research into, non-fossil fuel energy sources.

Role of the National Energy Strategy

The National Energy Strategy, echoing the recommendations of the IPCC, includes a number of actions that, although taken principally for other energy related reasons, will have significant environmental benefits, including curbing the buildup of future U.S. emissions of greenhouse gases. The strategy includes actions that provide cost-effective alternatives to burning fossil fuels for generating electricity and more efficient and alternative-fuel vehicles that will reduce greenhouse gases produced from transportation emissions.

Many of these NES actions are in addition to those described initially in the brochure "America's Climate Change Strategy: An Action Agenda." We believe that the United States climate change strategy must be flexible and capable of being modified as scientific and economic knowledge about climate change and potential responses is improved.

If no actions were taken, emissions in the United States, from one important greenhouse gas, CO₂, are projected to grow by 80 percent by the year 2030, according to one part of the NES scenario. Likewise, emissions of other greenhouse gases, such as methane, nitrous oxides and carbon monoxide, projected

to grow as well. This growth would occur for the most part due to increased coal use for electricity generation and due to growth in auto emissions. While there is always uncertainty regarding future projections, without the NES, greenhouse gas emissions, as measured in terms of global warming potential, are likely to increase by over 2.82 billion tons of CO₂ equivalents. This would be a 38.4 percent increase over the 1990 levels by 2030.

Collectively, the NES actions will not only reduce our oil vulnerability, make the United States more energy efficient and increase our electricity supply options, but will also reduce the emissions of major greenhouse gases from what would otherwise occur:

- Based on the NES scenario, actions as a result of the strategy and current Administration programs will reduce the rate of growth of carbon dioxide and carbon monoxide emissions. These are key greenhouse gases related to energy use, in particular to combustion of fossil fuels. After 2015, increased use of alternative fuels, energy efficiency, renewable and nuclear energy will result in these emissions leveling off and remaining stable through 2030.
- NES actions, as well as EPA's regulations controlling methane from landfills, will reduce methane emissions

below current levels through 2015. Further, after 2015 annual methane emissions from energy sources will continue to decline.

- Nitrogen oxide and volatile organic compounds, precursors to tropospheric ozone that could lead to potential warming, are held to levels that are about the same or below the 1990 levels and decline from 2015 to 2030.

When all greenhouse gases are considered in terms of global warming potential, the National Energy Strategy, coupled with the existing Administration programs described in "America's Climate Change Strategy," will substantially curb the growth in these gases beyond the year 2000. The NES will allow us to hold emission levels within a range that is close to current levels well into the foreseeable future.

Consistent with our Climate Change Strategy and the NES, the framework convention could commit all nations to develop similar national strategies, emphasizing attention to actions that are warranted for other reasons and that also limit net greenhouse gas emissions. In light of the remaining uncertainties on global climate change and its effects, a global response of this nature will provide a realistic, prudent and cost-effective framework under which all countries can begin to implement measures with climate change benefits.

At the same time, it recognizes that the appropriate measures available to different countries will vary depending on their social, environmental, and economic circumstances.

Research and Systematic Observation

Research and systematic observation are essential to improving our understanding of climate change and helping us to tailor responses that are appropriate, efficient, effective, and sustainable over the long term. Research can also provide the needed energy-efficient technologies that are both economic and environmentally beneficial. For our part, we are pursuing a \$2 billion program of global change research and energy technology development that will provide the tools for devising innovative, long-term responses. Consistent with our own actions, the United States put forward an informal paper at the outset of the first session outlining a strong program of scientific and economic research and systematic observation that the framework convention could provide.

Implementation Issues

There are many other specific issues that must be addressed prominently in the framework convention. With regard to the developing countries, we recognize their desires

and aspirations for economic growth. It is essential for developing countries to participate in any response to climate change in a manner that recognizes both their development needs and the greenhouse gas implications of such development. Thus, the framework convention should include a general commitment to promote financial assistance to developing countries to study and address climate change. Existing bilateral and multilateral financial-assistance mechanisms and, in particular, the newly established Global Environmental Facility in the World Bank are the appropriate mechanisms for providing such assistance.

Technology transfer is essential to any effective global response and there are many existing low-cost, effective technologies that can be transferred now. We stated in the first session our willingness to explore such ideas as energy efficiency centers and agricultural and forestry demonstration projects, as well as facilitating industry joint ventures with other countries to promote available technologies. Implementation of these concepts will need to be considered, of course, in the context of specific commitments to action. Special efforts will need to be made to match appropriate technologies to needs.

Over the long term, new technologies will play an

increasingly important role in the response to climate change. Many of these technologies are still only ideas, or must undergo further development to become technologically and economically feasible. Therefore, the framework convention must provide the right incentives for continual research, development, and dissemination of relevant technologies. Since the private sector researches, develops and disseminates new technology most effectively, the framework convention should seek to remove barriers to effective commercial development and transfer of technology and should ensure that intellectual property rights are fully protected so as to provide the incentives necessary for continual development of new technology.

We should also discuss ways to transfer the knowledge necessary to understand, plan for and address climate change. The United States has traditionally provided a great deal of technical assistance in dealing with specific environmental problems, developing environmental institutions, and conducting country studies. During the first session, therefore, we stated that we are prepared to undertake, in cooperation with other nations, specific country studies to define appropriate technologies to reduce greenhouse gases. The NGO community, including the business community, also has an important role to play in this regard.

Conclusion

Mr. Chairman, procedural matters prevented us from developing a draft negotiating text during this first session, as we had hoped. Nonetheless, we agreed on a negotiating process which will promote an expeditious, open and unbiased discussion of the issues surrounding climate change. In the sessions that follow, the United States will continue to seek a framework agreement that is comprehensive, that recognizes the value of actions which help to address climate change and are justified on other grounds, that provides for a strong scientific and economic research program, and that recognizes the special needs of the developing countries. Rest assured that the United States will make every effort to conclude such an agreement before the June 1992 target date that we have endorsed. Such a convention is the crucial first step in what the United States realizes must be a sustained and long-term effort to address climate change.

Mr. Chairman, let me thank you again for the opportunity to appear before this subcommittee. My colleagues and I would be happy to answer any questions that you might have.



National Aeronautics and
Space Administration

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Presented by Witness

February 21, 1991

Subcommittee on Health and the Environment

Committee on Energy and Commerce

U.S. House of Representatives



Statement by:

Dr. Robert T. Watson
Earth Science and
Applications Division

Statement of
Dr. Robert T. Watson
Earth Science and Applications Division
Office of Space Science and Applications
National Aeronautics and Space Administration
before the
Subcommittee on Health and the Environment
of the
Committee on Energy and Commerce
U.S. House of Representatives

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss the international Scientific Assessment of Climate Change and the Assessment of the Potential Impacts of Climate Change, conducted under the auspices of Working Groups I and II, respectively, of the Intergovernmental Panel on Climate Change (IPCC), which was sponsored by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP).

This testimony will briefly present the background, participation, scope, review process, assessment outline, relation to policy, and executive summaries of the IPCC scientific and impacts assessments (the executive summaries presented in the Appendix to this testimony are verbatim from the IPCC assessments).

The dramatic rise in world population and industrial activities during the last century have produced the concern that human activities are affecting the global environment. In particular, one global environment change that may effect both human well being and the quality of life is global warming caused by increasing atmospheric concentrations of radiatively active trace gases such as carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and tropospheric ozone. This environmental issue is no longer the sole concern of the scientific community and environmental groups, and its importance has now been recognized by governments around the world. The current interest in the global warming issue has resulted in the endorsement, at the highest levels of governments, for comprehensive scientific, technical and economic assessments to be performed. The IPCC assessments were conducted in response to the need for such assessments.

Background

The World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) sponsored the Intergovernmental Panel on Climate Change (IPCC) to produce an international, state-of-the-knowledge review of climate change. There are three companion IPCC assessments: (i) scientific assessment of climate change, (ii) potential impacts of climate change, and (iii) formulation of response strategies. These three assessments were accompanied by a report of the IPCC special committee on the participation of developing

countries. The IPCC assigned lead responsibilities for the preparation of the three assessment reports as follows: (i) Science - United Kingdom; (ii) Impacts - USSR; and (iii) Response Strategies - USA. Each assessment is accompanied by a Policymakers Summary and an Executive Summary directed to government officials.

The first assessment report of the IPCC consists of: (i) an overview document, which brings together material from the four Policymakers Summaries; (ii) the Policymakers Summaries of the three assessments (Science, Impacts, and Response Strategies) and the Special Committee on the Participation of Developing Countries; and (iii) the reports of the working groups.

The scientific and impacts assessments of climate change are peer-reviewed scientific documents written by the best scientists available throughout the world. The scientific and impact assessments were completed, and their executive summaries released to the public, during May and June, 1990, respectively. The policymakers summaries and the main assessments were delivered to the IPCC secretariat during June, 1990.

Participants

The science assessment was chaired by Dr. J. Houghton, of the British Meteorological Office, and prepared and by about 250 of the leading scientists from around the world with an additional, comparable number responsible for the peer review. The assessment was coordinated, and initial drafts of the policymakers summary and its executive summary prepared, by a small core team of scientists at Bracknell, UK (I was a member of this team). The lead authors were selected by the IPCC Science Working Group (Working Group 1), and were responsible for the preparation of their sections. Daniel Albritton (NOAA) and I were the U. S. representatives on the IPCC Science Working Group on behalf of the Committee on Earth and Environmental Sciences (CEES).

The impacts assessment was chaired by Prof. Y. Izrael of the USSR State Committee for Hydrometeorology, co-chaired by Dr's M. Hashimoto (Japan) and W. Tegart (Australia), prepared by about 175 scientists from around the world, and peer-reviewed by an additional, comparable number of scientists. The chairmen and lead authors of each chapter were selected by the IPCC Impacts Working Group (Working Group 2), and were responsible for the preparation of their chapters. Alan Hecht (EPA) was the U. S. representative on the IPCC Impacts Working Group.

Scope of the Scientific and Impacts Assessments

The main features of the Scientific and Impacts Assessment of Climate Change are the following:

- o A special emphasis throughout both assessments on the identification of gaps in the knowledge and an attempt to better quantify uncertainties.
- o *Scientific Assessment:* Its scope encompassed the full climate change phenomenon, namely: climate forcing agents; processes involved in climate change; climate model formulation; tests of climate models; simulation of past climate changes; predictions of future climate; past climate record; and physical (sea level) and biological responses to climate change.
- o *Impacts Assessment:* Its scope encompassed the full range of potential impacts of climate change, namely: natural and managed (agriculture and forestry) terrestrial ecosystems;

hydrology and water resources; oceans, including coastal zones; cryosphere; industrial sectors; human settlements; and human health.

Review Process

The scientific and impacts assessments were subjected to several levels of peer review. The assessments (the main assessments, their policymakers summaries and their executive summaries) were peer reviewed both formally and informally by the international scientific community. These reviews were followed by an intergovernmental review of the policymakers summaries and their executive summaries to ensure consistency between the main assessments and the summaries.

Outline of Assessments

Scientific Assessment (Working Group I).

Section 1. Greenhouse Gases and Aerosols

Lead Authors: Watson (USA), Siegenthaler (Switzerland), Oeschger (Switzerland), and Rodhe (Sweden).

Section 2. Relative Importance of Climate Forcing Agencies

Lead Authors: Shine (UK), Morcrette (France), Derwent (UK), and Wuebbles (USA).

Section 3. Processes and Modelling

Lead Authors: Cubasch (FRG) and Cess (USA).

Section 4. Validation of Climate Models

Lead Authors: Gates (USA), Rowntree (UK), and Zeng (PRC).

Section 5. Equilibrium Climate Change

Lead Authors: Mitchell (UK), Tokioka (Japan), Manabe (USA), and Meleshko (USSR).

Section 6. Time-Dependent Greenhouse-Gas-induced Climate Change

Lead Authors: Bretherton (USA), Bryan (USA) and Woods (UK).

Section 7. Observed Climate Variations and Change

Lead Authors: Folland (USA), Karl (USA), and Vinnikov (USSR).

Section 8. Detection of the Greenhouse Effect in the Observations

Lead Authors: Wigley (UK) and Barnett (USA).

Section 9. Sea Level Rise

Lead Authors: Warrick (UK) and Oerlemans (Netherlands).

Section 10. Effects on Ecosystems

Lead Authors: Melillo (USA), Salati (Brazil), Sinha (India), and Woodward (UK).

Section 11. Narrowing the Uncertainties

Lead Authors: McBean (Canada) and McCarthy (USA)

Annex Climatic Consequences of Emissions

Coordinators Jenkins(UK) and Derwent (UK)

Impacts Assessment (Working Group II).

Chapter 1. Scenarios used in the Report

Chapter 2. Agriculture and Forestry

Chairmen: Parry (UK), Mendzhulin (USSR), and Sinha (India)

Chapter 3. Natural Terrestrial Ecosystems

Chairmen. Street (Canada) and Semenov (USSR)

Chapter 4. Hydrology and Water Resources

Chairmen. Shiklomanov (USSR), Lins (USA), Stakhiv (USA), and Mostefa-Kara (Morocco)

Chapter 5. Human Settlement; the Energy, Transport, and Industrial Sectors; Human Health; Air Quality; and Changes in Ultraviolet-B Radiation

Chairmen: Hashimoto (Japan), Styrikovich (USSR), and Nishioka (Japan)

Chapter 6. World Oceans and Coastal Zones

Chairmen: Tysban (USSR), Everett (USA), and Titus (USA)

Chapter 7. Seasonal Snow Cover, Ice and Permafrost

Chairmen: Street (Canada) and Melnikov (USSR)

Relation to Policy

While the assessments are scientific documents, their value to decisionmakers will be considerable. The reasons for this are severalfold:

- o They are strong single concise statements from the scientific community.

In the assessments, major representatives of the scientific community spoke at one time and one place regarding the knowns and unknowns of climate change, including global warming, and the potential impacts of climate change. The assessments can, therefore, be a common reference point for decisionmakers, in contrast to sporadic and separate statements reflecting the opinions of individuals.

- o They are international assessments.

All nations now have a common basis of scientific input for their decision making, as opposed to only several national statements.

- o The scope of the assessments was comprehensive.

The assessments provide decisionmakers with homogeneous summaries of the current scientific understanding of the whole climate change phenomenon and potential impacts, ranging from the causes of change to the physical and biological responses to that change. This is likely to be more useful than separate reviews of components of the phenomenon done at different times and perhaps for different purposes.

- o Both natural and human-induced climate change were considered.

In contrast to considering only the potential perturbation of climate by human activities, the assessments placed predicted change, and potential impacts, in the context of the observed and predicted changes that are a natural part of the climate system. The comparison of the two affords immediate and straightforward insight into the significance of any predicted human-induced perturbations.

- o The focus on identifying gaps in the knowledge and quantifying uncertainties will aid risk analysis.

The difference between (a) "The predicted range of possibilities is from X to Z, with a best estimate of Y" and (b) "The prediction is Y" is, with regard to decision making, a highly relevant difference, since the first statement explicitly reflects the existence of uncertainties in the prediction.

Conclusions and Response to Specific Questions

I believe that the IPCC scientific and impacts assessments represent strong, concise statements from the majority of the international scientific community, and that they will provide the required scientific basis for both national and international policy formulation.

The scientific assessment recognizes that while there are many uncertainties in our scientific knowledge, particularly with respect to our ability to predict the magnitude, timing, and regional patterns of climate change, human activities are causing the atmospheric concentrations of greenhouse gases to increase, particularly carbon dioxide, methane, the chlorofluorocarbons, and nitrous oxide; that these increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface; that current models predict that with the IPCC "business as usual" scenario (scenario A) of future trace gas emissions that the Earth's global mean temperature is likely to increase at a rate of between 0.2 to 0.5 degrees centigrade per decade; and that a warmer world will act to increase, rather than decrease, greenhouse gas concentrations (however, it should be noted that the feedback processes between climate and greenhouse gas concentrations are poorly understood). The assessment also noted that while the Earth's global mean temperature has increased between 0.3 and 0.6 degrees centigrade over the last 100 years, that this observed increase cannot be used to either validate or invalidate the "global warming" hypothesis, because while the magnitude of the observed warming is broadly consistent with the predicted global warming due to the increased concentrations of greenhouse gases, it is also comparable to natural variability.

The scientific assessment noted that atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for decades to centuries. The longer emissions continue to increase at present rates, the greater the reductions would have to be in order for concentrations to stabilize at a given level. The long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilize their concentrations at today's levels; methane would require a 15 - 20% reduction.

The key scientific uncertainties are associated with the sources and sinks of greenhouse gases, clouds, oceans, polar ice sheets, land-surface hydrology, and ecological systems. The President's FY 1992 U.S. Global Change Research Program (USGCRP) responds to these uncertainties identified by the IPCC by adopting four high priority Integrating Themes for FY 1992: (i) Climate Modeling and Prediction; (ii) Global Water and Energy Cycles; (iii) Global Carbon Cycle; and (iv) Ecological Systems and Population Dynamics. The Integrating Themes allow the USGCRP to focus the collective efforts of government and academic scientists, in collaboration with scientists from other countries, on high priority multi-disciplinary investigations in order to:

- Develop an improved predictive capability of the Earth as a coupled system with enhanced regional resolution;
- Improve the understanding of the water and energy cycles by focussing on the role of clouds, oceans, terrestrial ecosystems, and changes in sea level;
- Improve the understanding of the carbon cycle by quantifying sources and sinks, the processes that control them, and how the processes may influence and be influenced by global change;
- Improve the capacity to assess the effects of global change at regional scales on intensively managed and unmanaged terrestrial and oceanic ecosystems.

APPENDIX

PART I:

Executive Summary from Working Group I (verbatim from the IPCC assessment).

We are certain of the following:

- o there is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be.
- o emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, the chlorofluorocarbons and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface. The greenhouse gas, water vapor, will increase in response to global warming and further enhance it.

We calculate with confidence that:

- o some gases are potentially more effective than others at changing climate, and their relative effectiveness can be estimated. Carbon dioxide has been responsible for over half the enhanced greenhouse effect in the past and is likely to remain so in the future.
- o atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for decades to centuries. The longer emissions continue to increase at present day rates, the greater reductions would have to be for concentrations to stabilize at a given level.
- o the long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilize their concentrations at today's levels; methane would require a 15 - 20% reduction.

Based on current models, we predict:

- o under the IPCC Business-as-Usual (scenario A) emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0.3 degrees C per decade (with an uncertainty range of 0.2 to 0.5 degrees C per decade); this is greater than that seen over the past 10,000 years. This will result in a likely increase in global mean temperatures of about 1 degree C above the present value by 2025 and 3 degrees C before the end of the next century. The rise will not be steady because of the influence of other factors.
- o under the other IPCC emission scenarios which assume progressively increasing levels of controls, rates of increase in global mean temperature of about 0.2 degrees C per decade (scenario B), just above 0.1 degree C per decade (scenario C) and about 0.1 degree per decade (scenario D).
- o that land surfaces warm more rapidly than the ocean, and high northern latitudes warm more than the global mean in winter.

- o regional climate changes different from the global mean, although our confidence in the prediction of the detail of regional changes is low. For example, temperature increases in Southern Europe and central North America are predicted to be higher than the global mean, accompanied on average by reduced summer precipitation and soil moisture. There are less consistent predictions for the tropics and southern hemisphere.
- o under the IPCC Business-as-Usual emissions scenario, an average rate of global mean sea level rise of about 6 cm per decade over the next century (with an uncertainty range of 3 - 10 cm per decade), mainly due to thermal expansion of the oceans and the melting of some land ice. This amounts to a rise of about 20 cm in global mean sea level by 2030 and 65 cm by the end of the next century. There will be significant regional variations.

There are many uncertainties in our predictions, particularly with regard to the timing, magnitude, and regional patterns of climate change:

- o sources and sinks of greenhouse gases, which affect predictions of future concentrations.
- o clouds, which strongly influence the magnitude of climatic change,
- o oceans, which influence the timing and patterns of climate change, and
- o polar ice sheets, which affect predictions of sea level rise.

These processes are already partially understood, and we are confident that the uncertainties can be reduced by further research. However, the complexity of the system means that we cannot rule out surprises.

Our judgement is that:

- o global-mean surface air temperature has increased by 0.3 to 0.6 degrees C over the last 100 years, with five global-average warmest years being in the 1980s. Over the same period, global sea level has increased by 10 - 20 cm. These increases have not been smooth with time, nor uniform over the globe.
- o the size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus, the observed increase could be largely due to this natural variability; alternately, this variability and other human factors could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.
- o there is no firm evidence that climate has become more variable over the last few decades. However, with an increase in the mean temperature, episodes of high temperatures will most likely become more frequent in the future and cold episodes less frequent.
- o ecosystems affect climate and will be affected by a changing climate and by increasing carbon dioxide concentrations. Rapid changes in climate will change the composition of ecosystems; some systems will benefit, while others will be unable to migrate or adapt fast enough and may become extinct. Enhanced levels of carbon dioxide may increase productivity and efficiency of water use of vegetation. The effect of warming on biological processes, although poorly understood, may increase the atmospheric concentrations of natural greenhouse gases.

To improve our predictive capability, we need:

- o to understand better the various climate-related processes, particularly those associated with clouds, oceans and the carbon cycle.
- o to improve the systematic observations of climate-related variables on a global basis, and further investigate changes which took place in the past.
- o to develop improved models of the Earth's climate system.
- o to increase support for national and international research activities, especially in developing countries.
- o to facilitate international exchange of climate data.

PART II:

Executive Summary from Working Group II (verbatim from the IPCC assessment).

The IPCC Working Groups on scientific analysis (Working Group I), impacts (Working Group II) and response strategies (Working Group III) were established in November 1988 and proceeded to work in parallel under instructions from IPCC. The responsibility of Working Group II is to describe the environmental and socioeconomic implications of possible climate changes over the next decades caused by increasing concentrations of greenhouse gases.

The report of Working Group II is based on the work of a number of subgroups, using independent studies which have used different methodologies. Based on the existing literature, the studies have used several scenarios to assess the potential impacts of climate change. These have the features of:

- o an effective doubling of CO₂ in the atmosphere between now and 2025 to 2050 for a "business-as-usual" scenario;
- o a consequent increase of global mean temperature in the range of 1.5°C to 4°- 5°C;
- o an unequal global distribution of this temperature increase, namely a smaller increase of half the global mean in the tropical regions and a larger increase of twice the global mean in the polar regions; and
- o a sea-level rise of about 0.3-0.5 m by 2050 and about 1 m by 2100, together with a rise in the temperature of the surface ocean layer of between 0.2° and 2.5°C .

These scenarios pre-date, but are in line with, the recent assessment of Working Group I which, for a "business-as-usual" scenario (scenario A in Working Group I Report) has estimated the magnitude of sea-level rise at about 20 cm by 2030 and about 65 cm by the end of the next century. Working Group I has also predicted the increase in global mean temperatures to be about 1°C above the present value by 2025 and 3°C before the end of the next century.

Any predicted effects of climate change must be viewed in the context of our present dynamic and changing world. Large-scale natural events such as El Nino can cause significant impacts on agriculture and human settlement. The predicted population explosion will produce severe impacts on land use and on the demands for energy, fresh water, food and housing, which will vary from region according to national incomes and rates of development. In many cases, the impacts will be felt most severely in regions already under stress, mainly the developing countries. Human-induced climate change due to continued uncontrolled emissions will accentuate these impacts. For instance, climate change, pollution and ultraviolet-B radiation from ozone depletion can interact, reinforcing their damaging effects on materials and organisms. Increases in atmospheric concentrations of greenhouse gases may lead to irreversible change in the climate which could be detectable by the end of this century.

Comprehensive estimates of the physical and biological effects of climate change at the regional level are difficult. Confidence in regional estimates of critical climatic factors is low. This is particularly true of precipitation and soil moisture, where there is considerable disagreement between various general circulation model and palaeoanalog results. Moreover, there are several

scientific uncertainties regarding the relationship between climate change and biological effects and between these effects and socioeconomic consequences.

This report does not attempt to anticipate any adaptation, technological innovation or any other measures to diminish the adverse effects of climate change that will take place in the same time frame. This is especially important for heavily managed sectors, e.g. agriculture, forestry and public health. This is one of the responsibilities of Working Group III.

Finally, the issue of timing and rates of change need to be considered; there will be lags between:

- o emissions of greenhouse gases and doubling of concentrations;
- o doubling of greenhouse gas concentrations and changes in climate;
- o changes in climate and resultant physical and biological effects; and
- o changes in physical and ecological effects and resultant socioeconomic (including ecological) consequences. The shorter the lags, the less the ability to cope and the greater the socioeconomic impacts.

There is certainty related to these time lags. The changes will not be steady and surprises cannot be ruled out. The severity of the impacts will depend to a large degree on the rate of climate change.

Despite these uncertainties, Working Group II has been able to reach some major conclusions, which are:

Agriculture and Forestry

Sufficient evidence is now available from a variety of different studies to indicate that changes of climate would have an important effect on agriculture and livestock. Studies have not yet conclusively determined whether, on average, global agricultural potential will increase or decrease. Negative impacts could be felt at the regional level as a result of changes in weather and pests associated with climate change, and changes in ground-level ozone associated with pollutants, necessitating innovations in technology and agricultural management practices. There may be severe effects in some regions, particularly decline in production in regions of high present-day vulnerability that are least able to adjust. These include Brazil, Peru, the Sahel Region of Africa, Southeast Asia, the Asian region of the USSR and China. There is a possibility that potential productivity of high and mid latitudes may increase because of a prolonged growing season, but it is not likely to open up large new areas for production and it will be mainly confined to the Northern Hemisphere.

Patterns of agricultural trade could be altered by decreased cereal production in some of the currently high-production areas, such as Western Europe, southern US, parts of South America and Western Australia. Horticultural production in mid-latitude regions may be reduced. On the other hand, cereal production could increase in northern Europe. Policy responses directed to breeding new plant cultivars, and agricultural management designed to cope with changed climate conditions, could lessen the severity of regional impacts. On balance, the evidence suggests that in the face of estimated changes of climate, food production at the global level can be maintained at essentially the same level as would have occurred without climate change; however, the cost of achieving this is unclear. Nonetheless, climate change may intensify difficulties in coping with rapid population growth. An increase or change in UV-B radiation at ground level resulting from the depletion of stratospheric ozone will have a negative impact on crops and livestock.

The rotation period of forests is long and current forests will mature and decline during a climate in which they are increasingly more poorly adapted. Actual impacts depend on the physiological adaptability of trees and the host parasite relationship. Large losses from both factors in the form of forest declines can occur. Losses from wildfire will be increasingly extensive. The climate zones which control species distribution will move poleward and to higher elevations. Managed forests require large inputs in terms of choice of seedlot and spacing, thinning and protection. They provide a variety of products from fuel to food. The degree of dependency on products varies among countries, as does the ability to cope with and to withstand loss. The most sensitive areas will be where species are close to their biological limits in terms of temperature and moisture. This is likely to be, for example, in semi-arid areas. Social stresses can be expected to increase and consequent anthropogenic damage to forests may occur. These increased and non-sustainable uses will place more pressure on forest investments, forest conservation and sound forest management.

Natural Terrestrial Ecosystems

Natural terrestrial ecosystems could face significant consequences as a result of the global increases in the atmospheric concentrations of greenhouse gases and the associated climatic changes. Projected changes in temperature and precipitation suggest that climate zones could shift several hundred kilometers towards the poles over the next fifty years. Flora and fauna would lag behind these climatic shifts, surviving in their present location and, therefore, could find themselves in a different climatic regime. These regimes may be more or less hospitable and, therefore, could increase productivity for some species and decrease that of others. Ecosystems are not expected to move as a single unit, but would have a new structure as a consequence of alterations in distribution and abundance of species.

The rate of projected climate changes is the major factor determining the type and degree of climatic impacts on natural terrestrial ecosystems. These rates are likely to be faster than the ability of some species to respond and responses may be sudden or gradual.

Some species could be lost owing to increased stress leading to a reduction in global biological diversity. Increased incidence of disturbances such as pest outbreaks and fire are likely to occur in some areas and these could enhance projected ecosystem changes.

Consequences of CO₂ enrichment and climate change for natural terrestrial ecosystems could be modified by other environmental factors, both natural and man-induced (e.g. by air pollution).

Most at risk are those communities in which the options for adaptability are limited (e.g. montane, alpine, polar, island and coastal communities, remnant vegetation, and heritage sites and reserves) and those communities where climatic changes add to existing stresses.

The socioeconomic consequences of these impacts will be significant, especially for those regions of the globe where societies and related economies are dependent on natural terrestrial ecosystems for their welfare. Changes in the availability of food, fuel, medicine, construction materials and income are possible as these ecosystems are changed. Important fibre products could also be affected in some regions.

Hydrology and Water Resources

Relatively small climate changes can cause large water resource problems in many areas, especially arid and semi-arid regions and those humid areas where demand or pollution has led to

water scarcity. Little is known about regional details of greenhouse-gas-induced hydrometeorological change. It appears that many areas will have increased precipitation, soil moisture and water storage, thus altering patterns of agricultural, ecosystem and other water use. Water availability will decrease in other areas, a most important factor for already marginal situations, such as the Sahelian zone in Africa. This has significant implications for agriculture, for water storage and distribution, and for generation of hydroelectric power. In some limited areas, for example, under the assumed scenario of a 1°C to 2°C temperature increase, coupled with a 10% reduction in precipitation, a 40-70% reduction in annual runoff could occur. Regions such as Southeast Asia, that are dependent on unregulated river systems, are particularly vulnerable to hydrometeorological change. On the other hand, regions such as the western USSR and western United States that have large regulated water resource systems are less sensitive to the range of hydrometeorological changes in the assumed greenhouse scenario. In addition to the changes in water supply, water demand may also change through human efforts to conserve, and through improved growth efficiency of plants in a higher CO₂ environment. Net socioeconomic consequences must consider both supply and demand for water. Future design in water resource engineering will need to take possible impacts into account when considering structures with a life span to the end of the next century. Where precipitation increases, water management practices, such as urban storm drainage systems, may require upgrading in capacity. Change in drought risk represents potentially the most serious impact of climate change on agriculture at both regional and global levels.

Human Settlements, Energy, Transport, and Industrial sectors, Human Health and Air Quality

The most vulnerable human settlements are those especially exposed to natural hazards, e.g. coastal or river flooding, severe drought, landslides, severe wind storms and tropical cyclones. The most vulnerable populations are in developing countries, in the lower income groups, residents of coastal lowlands and islands, populations in semi-arid grasslands, and the urban poor in squatter settlements, slums and shanty towns, especially in megacities. In coastal low lands such as in Bangladesh, China and Egypt, as well as in small island nations, inundation due to sea-level rise and storm surges could lead to significant movements of people. Major health impacts are possible, especially in large urban areas, owing to changes in availability of water and food and increased health problems due to heat stress spreading of infections. Changes in precipitation and temperature could radically alter the patterns of vector-borne and viral diseases by shifting them to higher latitudes, thus putting large populations at risk. As similar events have in the past, these changes could initiate large migrations of people, leading over a number of years to severe disruptions of settlement patterns and social instability in some areas.

Global warming can be expected to affect the availability of water resources and biomass, both major sources of energy in many developing countries. These effects are likely to differ between and within regions with some areas losing and others gaining water and biomass. Such changes in areas which lose water may jeopardize energy supply and materials essential for human habitation and energy. Moreover, climate change itself is also likely to have different effects between regions on the availability of other forms of renewable energy such as wind and solar power. In developed countries some of the greatest impacts on the energy, transport and industrial sectors may be determined by policy responses to climate change such as fuel regulations, emission fees or policies promoting greater use of mass transit. In developing countries, climate-related changes in the availability and price of production resources such as energy, water, food and fibre may affect the competitive position of many industries.

Global warming and increased ultraviolet radiation resulting from depletion of stratosphere ozone may produce adverse impacts on air quality such as increases in ground-level ozone in some

polluted urban areas. An increase of UV-B radiation intensity at the Earth's surface would increase the risk of damage to the eye and skin and may disrupt the marine food chain.

Oceans and Coastal Zones

Global warming will accelerate sea-level rise, modify ocean circulation and change marine ecosystems, with considerable socioeconomic consequences. These effects will be added to present trends of rising sea-level, and other effects that have already stressed coastal resources, such as pollution and overharvesting. A 30-50 cm sea-level rise (projected by 2050) will threaten low islands and coastal zones. A 1 m rise by 2100 would render some island countries uninhabitable, displace tens of millions of people, seriously threaten low-lying urban areas, flood productive land, contaminate fresh water supplies and change coastlines. All of these impacts would be exacerbated if droughts and storms become more severe. Coastal protection would involve very significant costs. Rapid sea-level rise would change coastal ecology and threaten many important fisheries. Reductions in sea ice will benefit shipping, but seriously impact on ice-dependent marine mammals and birds.

Impacts on the global oceans will include changes in the heat balance, shifts in ocean circulation which will affect the capacity of the ocean to absorb heat and CO₂ and changes in upwelling zones associated with fisheries. Effects will vary by geographic zones, with changes in habitats, a decrease in biological diversity and shifts in marine organisms and productive zones, including commercially important species. Such regional shifts in fisheries will have major socioeconomic impacts.

Seasonal Snow Cover, Ice and Permafrost

The global areal extent and volume of elements of the terrestrial cryosphere (seasonal snow cover, near-surface layers of permafrost and some masses of ice) will be substantially reduced. These reductions, when reflected regionally, could have significant impacts on related ecosystems and social and economic activities. Compounding these impacts in some regions is that, as a result of the associated climatic warming positive feedbacks, the reductions could be sudden rather than gradual.

The areal coverage of seasonal snow and its duration are projected to decrease in most regions, particularly at midlatitudes possibly experiencing increases in seasonal snow cover. Changes in the volume of snow cover, or the length of the snow cover season, will have both positive and negative impacts on regional water resources (as a result of changes in the volume and the timing of runoff from snowmelt); on regional transportation (road, marine, air and rail); and on recreation sectors.

Globally, the ice contained in glaciers and ice sheets is projected to decrease, with regional responses complicated by the effect of increased snowfall in some areas which could lead to accumulation of ice. Glacial recession will have significant implications for local and regional water resources, and thus impact on water availability and on hydroelectric power potential. Glacial recession and loss of ice from ice sheets will also contribute to sea-level rise.

Permafrost, which currently underlies 20-25% of the land mass of the Northern Hemisphere, could experience significant degradation within the next 40-50 years. Projected increases in the thickness of the freeze-thaw (active) layer above the permafrost and a recession of permafrost to higher latitudes and altitudes could lead to increases in terrain instability, erosion and landslides in those areas which currently contain permafrost. As a result, overlying ecosystems could be significantly altered and the integrity of man-made structures and facilities reduced, thereby influencing existing human settlements and development opportunities.

Future Action

The results of the Working Group II studies highlight our lack of knowledge, particularly at the regional level and in areas most vulnerable to climate change. Further national and international research is needed on:

- o regional effects of climate change on crop yields, livestock productivity and production costs;
- o identification of agricultural management practices and technology appropriate for changed climate;
- o factors influencing distribution of species and their sensitivity to climate change;
- o initiation and maintenance of integrated monitoring systems for terrestrial and marine ecosystems;
- o intensive assessment of water resources and water quality, especially in arid and semi-arid developing countries and their sensitivity to climate change;
- o regional predictions of changes in soil moisture, precipitation, surface and subsurface runoff regimes and their interannual distributions as a result of climate change;
- o assessment of vulnerability of countries to gain or loss of energy resources, particularly biomass and hydroelectric power in developing countries;
- o adaptability of vulnerable human populations to heat stress and vectorborne and viral diseases;
- o global monitoring of sea-level changes, particularly for island countries;
- o identification of populations and agricultural and industrial production at risk in coastal areas and islands;
- o better understanding of the nature and dynamics of ice masses and their sensitivity to climate change;
- o integration of climate change impact information into the general planning process, particularly in developing countries; and
- o development of methodology to assess sensitivity of environments and socioeconomic systems to climate change.
- o Some of these topics are already being covered by existing and proposed programs and these will need continuing support. In particular, there are three core projects of the International Geosphere-Biosphere Program that will provide valuable data in the coming years, namely:
 - Land-Ocean Interactions in the Coastal Zone
 - Biosphere Aspects of the Hydrological Cycle
 - Global Change Impact on Agriculture and Society

that will provide valuable data in the coming years.

GLOBAL CLIMATE CHANGE: EFFECTS AND IMPACTS

Testimony of

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before

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GREENHOUSE EFFECT DEBATE RAGES ON

Debate has raged since the intense heat waves in the summer of 1988 over whether a "signal" of global warming has finally been detected against the background "noise" of natural climatic variations. At times this debate has been acerbic and occasionally polemical (e.g., see the Epilogue in Schneider, 1990a--reproduced here as Appendix I). Irrelevant facts such as the non-warming trend in the lower forty-eight United States (e.g. Brookes, 1989) or postulated physical mechanisms that might mitigate any substantial global warming (for example Marshall Institute, 1989, Ellsaesser, 1984, Lindzen, 1990) have been offered by some to prove global warming a non-problem. These views have been challenged or debated by various others (e.g. Raval and Ramanathan, 1989, Hansen and Lacis, 1990 or Schneider, 1990b). 1990 proved to be (for the lower atmosphere) the warmest year on record in the global instrumental period of the past century; at the same time the stratosphere was the coldest in 1990. Both of these go together and are consistent with a greenhouse effect signal that might be anticipated from the greenhouse gas injections over the past 150 years, which saw a 25% increase in carbon dioxide, a 100% increase in methane, and the introduction of man-made heat trapping chemicals such as chlorofluorocarbons and halons. But most scientists still argue that although the approximately 0.5⁰C surface warming in the 20th century is "consistent" with the greenhouse gas buildup, it is not yet possible to state that the observed warming was unambiguously caused by that greenhouse gas forcing. It is possible (although at a relatively low probability of perhaps some 10%) that the 0.5⁰C 20th century warming trend

was wholly natural and that there were little or no contribution from the buildup of greenhouse gases. Of course, since one cannot tell whether an unforecastable internal fluctuation in climate in the 20th century could have created the bulk of the observed warming, one equally can not tell whether there was a negative fluctuation taking place naturally during the 20th century. If so, then the world would have warmed up perhaps twice as much as was observed had we not had a fortuitous natural cooling trend. One could even speculate that the dramatic temperature rise in the 1980's and all the new global warming records set in the 1980's reflect a terminated natural cooling trend combined with the rapid establishment of the expected global warming signal. Current observations are, depending upon various assumptions of non-greenhouse gas forcings, consistent with a CO₂-doubling equilibrium sensitivity of anywhere from 0.5 to 5.0°C (for instance, see Wigley and Raper, 1990).

Other possibilities that could have intervened to help create the 20th century temperature record seen in Figure 1 include the creation of man-made or natural sulfur dioxide-induced aerosol particles which could either directly reflect sunlight in cloudless regions of the atmosphere or indirectly reflect sunlight through incorporation into clouds, thereby increasing the number of cloud droplets thus making the average cloud brighter. Measurements and theory are not adequate to pin this mechanism down quantitatively, although some attempts are underway (for instance, Charlson et al., 1991), who suggest that industrial activities in the 1950's, 60's, and 70's held back the 2 W/m² of greenhouse warming by countering it with some 1.5 W/m² of cooling in the Northern Hemisphere. Such an SO₂-induced cooling may have opposed any global warming signal by at least several tenths of a degree. In short, no clear physical

objection or direct empirical evidence has contradicted the wide-scale consensus that the world is warming, nor has such evidence contradicted the substantial probability that temperatures will go up because of increases in greenhouse gases (e.g. IPCC, 1990). But certainly any quantitative connection between the 20th century warming trend and greenhouse gas buildup to date cannot be proved yet beyond a reasonable doubt--even though I believe these are very likely to be connected. It will probably take 10-20 more years to prove this connection beyond a doubt, but then this whole affair is not an academic experiment in the microchips of supercomputers, but rather a test being performed on "Laboratory Earth".

Despite detailed arguments over specifics, scientific consensus remains widespread that anywhere from 1 to 5 degrees C additional warming is likely in the next century (a strong restatement of which was recently offered by the Intergovernmental Panel on Climate Change, 1990). The IPCC used a five star rating system to describe various possibilities for global warming, one star being unlikely and five stars very likely. They gave global average temperature changes in the 1.5 to 4.5 degree range three stars--equivalent presumably to a 60% chance (see Table 1 from IPCC).

REGIONAL CHANGES STILL VERY SPECULATIVE

However, neither the IPCC, nor other assessments (for example, NAS, 1987, or my own views, Schneider, 1990a) have suggested we have anything approaching a strong consensus with regard to what climatic changes might evolve regionally. For example, the real world is not undergoing a dramatic and instantaneous doubling of carbon dioxide, as is the case in

most standard computer model experiments, but instead the world is undergoing a steady increase in greenhouse gas forcing. Since that increase is heating the earth reasonably uniformly, one might superficially expect uniform global response; but this is far from likely. For example, the centers of continents have relatively low heat-retaining capacity, and thus would move toward whatever their new equilibrium climate would be relatively rapidly compared to the centers of oceans, which are very massive thermally. However, tropical oceans have a thin (on the order of 50 meters) mixed layer which primarily interacts with the atmosphere. It takes on the order of ten years for that mixed layer to substantially change its temperature, which is much slower than the response time of the middle of continents, but again much faster than the time rate at which the ocean surface temperatures would change at high latitudes where waters can mix right down to the bottom of the ocean in places like the Wedell or Norwegian Seas.

Therefore, during the transient phase of climate change one would expect middle of continents, middle of oceans and high latitude oceans all to be evolving toward their new equilibrium temperatures at different rates. This means the temperature differences from land to sea and equator to pole will evolve over time, which suggests that regional climatic anomalies associated with global warming will not necessarily be uniformly increasing over time, but could have a transient character very different from the long-term equilibrium character (as originally suggested by Schneider and Thompson, 1981 and now verified by Stouffer et al., 1989 or Washington and Meehl, 1989).

The lack of clear regional predictive skill has implications, for example, for the adaptability of agricultural ecosystems. That is, any experience the farmers of say, the 2020's get with anomalous weather may not help them to adapt to the evolving climate change in the 2030's, since a transient climate change could be of different character over time. This would inhibit "learning by doing", creating a potential lack of adaptability associated with the difficulty of reliability predicting regional climatic consequences. Rapid and evolving climate changes would be especially difficult for natural ecosystems, since habitats do not have the luxury of choosing to plant new seeds, changing irrigation systems, soil tillage practices, and so forth.

ECOSYSTEMS RESPONSE TO RAPID CHANGE IS PROBLEMATIC

A. Forests

One of the Office of Management and Budget officials recently said it would be no more difficult to adapt to a few degrees' climate warming than to get off a Boston flight in Washington. Of course what this view, ignorant of ecology, neglects, is that the forests of Virginia can't call the neighborhood van lines to transplant millions of trees up to Massachusetts. Quite simply, many species of trees take hundreds, even thousands of years for substantial migration. Moreover, while individual species may migrate with slowly changing climate, whole habitats usually do not, as species composition is dramatically altered (e.g. see COHMAP, 1988). That is indeed what occurred when the ice ages waned about 12,000 years ago and in the next six thousand years were replaced by the relatively warm interglacial period we are now experiencing. At that time

a 5⁰C (9⁰F) temperature increase accompanied 100 meter (330 feet) sea level rises and dramatic habitat changes such as those seen in Figure 2. The ice age to interglacial transition quite literally revamped the ecological face of the earth. The time it took for nature to make this adjustment was on the order of thousands of years, driven by sustained global average temperature changes on the order of 5⁰C. We are facing the prospect of temperature changes of this magnitude on the time frame of a century, a rate that most ecologists who study forest ecosystems suggest is simply too fast for the trees--let alone habitats--to keep up.

In this connection, University of Minnesota ecologist Margaret Davis (1990) noted: "The fossil record shows that most forest trees were able to disperse rapidly enough to keep up with most of the climatic changes that took place in recent millennia. These changes were much more gradual than the climatic changes projected for the future. Even so, there were occasional periods of disequilibrium between plant distributions or abundances, soils, and climate that lasted a century or more. The most rapid dispersal rates known from the fossil record, however, are an order of magnitude too slow to keep up with the temperature rise expected in the coming century."

For example, Figure 3 shows the result of calculations (Davis and Zabinski, 1991) which suggests that certain species (Sugar Maple in this case) would be largely marooned out of their ranges should the climate change as projected by most modern generation climate models (GISS in panel A and GFDL in panel B of Figure 3). Habitats would change unpredictably and some species would quite literally be stranded in ecologically unsuitable territory.

B. Birds

Trees are not the only potential "victims" of rapid climate change, as various animals depend on complicated habitats for their livelihood, even survival. One symbolic case which has been described by (Botkin et al., 1991) is that of the Kirtland's Warbler in Northern Michigan, which lives in a narrow area of Jack Pine trees that survive on sandy soils in that climate. Ecological models of Jack Pine forests growth and decline suggest that even a small climate change would be enough to devastate that habitat, almost certainly dooming that bird to extinction in 30-60 years. Even without the issue of extinction, whose already high rates could be substantially exacerbated by climate changes occurring more rapidly than ecosystems could adapt (e.g. Wilson, 1989 or Peters, 1991), or having adaptation and migration blocked by highways, urban development, seawalls, agriculture, and so forth is the altered habitat that is associated with climate change. Ecologist Terry Root (1988a) of the University of Michigan has shown a very high degree of statistical correlation between the distribution and abundance of many bird species and large scale environmental factors such as temperature. Figure 4 shows the clear association between the January mean temperature and the northern range limit of the Eastern Phoebe. What this kind of analysis implies is that as climate changes, the physiological tolerance of some birds would cause them--habitat permitting--to change their ranges as well (Root, 1988b).

IMPLICATIONS FOR POLICY

While climate change is not necessarily a threat to the existence of each climate-sensitive species, given the transient nature of the climate change, which nonetheless would be occurring on scales of decades, and the transient nature of forest and other vegetation ecosystems, which could change on the timescale of decades to centuries, it is quite clear that plausible climatic changes could create substantial disequilibrium within ecosystems, where about the only outcome that can be predicted with certainty is major surprises. Substantial change to plant and animal populations, habitat types, and even some extinctions would seem inevitable from most climate change scenarios, and about the only forecast that seems clearly justifiable is the more rapidly the climate changes the higher the probability of substantial disruption and surprise.

These possibilities have led to a debate as to whether humans need to intervene as "ecological engineers" deliberately replanting or transplanting presently maladapted species in what might be their new habitats of the future. Given our relative ignorance of the full implications of these potential ecological impacts, some conservationists feel that such human intervention (or eco-engineering) would be unethical at best, whereas others argue that species extinctions that might take place if stranding occurs are even worse risks than habitat alteration that might take place from ecological engineering (e.g. Roberts, 1988). Unfortunately, all of these wrenching debates are created by the prospect of rapid global warming, which in turn is created by the increasing use of energy and materials demanded by growing populations insisting on using the cheapest available technology to increase their standards of living.

It is unlikely that societies will radically alter these plans. Thus, the capacity of ecosystems to respond to rapid change demands urgent study to help us figure out how to help nature adapt more effectively, although in the final analysis it is my personal belief that slowing down the rate of warming through the application of the so-called "tie-in" principal is the best immediate strategy. Although how to act is always a value choice about whether it is appropriate to invest present resources as a hedge against potential change, it is my view that those actions which are already cost effective (using and producing energy more efficiently, for example), should be vigorously pursued now and all political obstacles slowing the penetration of such already cost-effective actions be removed and incentives created. Moreover, additional policy actions that would seem sensible now should include those that not only help to slow the rate of global warming but help solve other problems as well--for example, banning CFC's not only reduces about 20% of potential global warming forcing, but also eliminates the emission of chemicals that reduce stratospheric ozone. Fuel switching from coal to natural gas not only cuts roughly in half the CO₂ released per unit energy produced, but substantially reduces the sulfur dioxide emissions that contribute to acid rain. Energy efficiency and conservation planning not only reduces environmental impacts, but helps reduce the dependency of countries such as the United States or Japan on imported energy supplies, thereby reducing our balance of payments deficits, military budgets, and even threats to world security.

These high leverage or tie-in strategies are, in my value system, long overdue with or without global warming, and because of the added urgency of slowing down global warming, thereby buying time for us and nature to adapt to whatever changes will take place, such actions seem to me self-evidently the most appropriate immediate policy response , (which I have discussed extensively in other forums; for example Schneider, 1990a).

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TABLE 1 (IPCC, 1990)

EXECUTIVE SUMMARY

1. All models show substantial changes in climate when CO₂ concentrations are doubled, even though the changes vary from model to model on a sub-continental scale.

2. The main equilibrium changes in climate due to doubling CO₂ deduced from models are given below. The number of *'s indicates the degree of confidence determined subjectively from the amount of agreement between models, our understanding of the model results and our confidence in the representation of the relevant process in the model. Five *'s indicate virtual certainties, one * indicates low confidence.

Temperature:

- ***** the lower atmosphere and Earth's surface warm;
- ***** the stratosphere cools;
- *** near the Earth's surface, the global average warming lies between +1.5°C and +4.5°C, with a "best guess" of 2.5°C;
- *** the surface warming at high latitudes is greater than the global average in winter but smaller than in summer. (In time dependent simulations with a deep ocean, there is little warming over the high latitude southern ocean);
- *** the surface warming and its seasonal variation are least in the tropics.

Precipitation:

- ***** the global average increases (as does that of evaporation), the larger the warming, the larger the increase;
- *** increases at high latitudes throughout the year;
- *** increases globally by 3 to 15% (as does evaporation);
- ** increases at mid-latitudes in winter;
- ** the zonal mean value increases in the tropics although there are areas of decrease. Shifts in the main tropical rain bands differ from model to model, so there is little consistency between models in simulated regional changes;
- ** changes little in subtropical arid areas.

Soil moisture:

- *** increases in high latitudes in winter;
- ** decreases over northern mid-latitude continents in summer.

Snow and sea-ice:

- **** the area of sea-ice and seasonal snow-cover diminish.

The results from models become less reliable at smaller scales, so predictions for smaller than continental regions should be treated with great caution. The continents warm more than the ocean. Temperature increases in southern Europe and central North America are greater than the global mean and are accompanied by reduced precipitation and soil moisture in summer. The Asian summer monsoon intensifies.

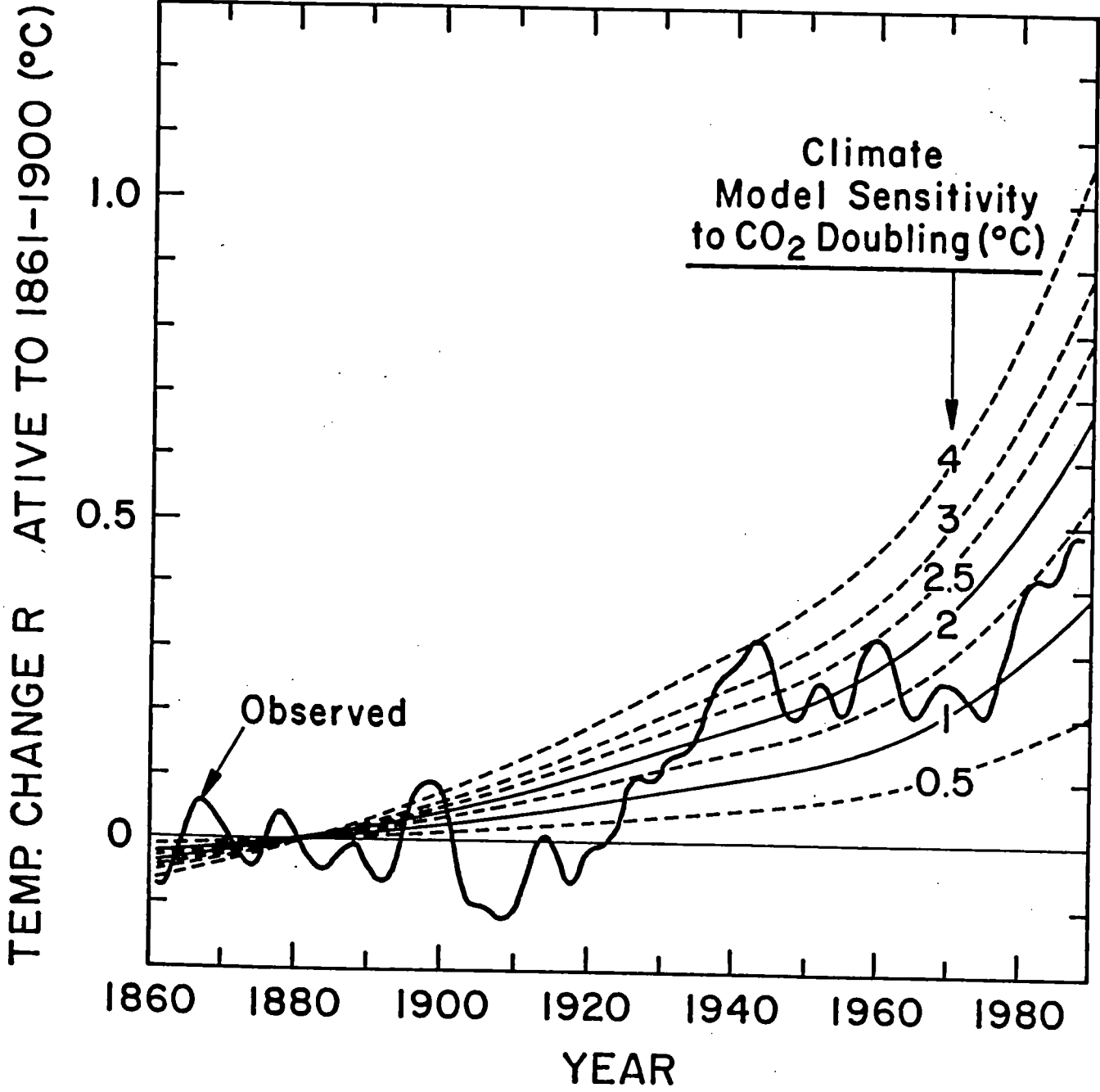
3. Changes in the day-to-day variability of weather are uncertain. However, episodes of high temperature will become more frequent in the future simply due to an increase in the mean temperature. There is some evidence of a general increase in convective precipitation.

4. The direct effect of deforestation on global mean climate is small. The indirect effects (through changes in the CO₂ sink) may be more important. However, tropical deforestation may lead to substantial local effects, including a reduction of about 20% in precipitation.

5. Improved predictions of global climate change require better treatment of processes affecting the distribution and properties of cloud, ocean-atmosphere interaction, convection, sea-ice and transfer of heat and moisture from the land surface. Increased model resolution will allow more realistic predictions of global-scale changes, and some improvement in the prediction of regional climate change.

FIGURE CAPTIONS

- Figure 1: Observed global-mean temperature changes (1861-1989) compared with predicted values. The observed changes are given in Section 7 of the IPCC (1990). The data have been smoothed to show the decadal and longer time scale trends more clearly. Predictions are based on observed concentration changes and concentration/forcing relationships as given in Section 2 of the IPCC (1990) and have been calculated using the upwelling-diffusion climate model of Wigley and Raper (1990). Source: Wigley and Raper, 1990.
- Figure 2: The relative fraction (in percent) of fossil pollen from various species of trees is shown on the maps. These pollen patterns can be correlated to climatic conditions. These maps show, for example, that at the end of the last Pleistocene Ice Age 11,000 years ago much of the northeastern United States was covered with spruce forests, which are found today in central Canada near Hudson Bay. As climatic conditions ameliorated the spruce "chased" the retreating ice sheet northward into Canada, whereas more temperate-climate trees like oak moved outward from their refuge in the Carolinas into the middle Atlantic states and the midwest. Around 4000 years ago the distribution of these temperate-climate trees stabilized in what is roughly their present configuration. Source: J. C. Bernabo and T. Webb III, 1977, Changing patterns in the Holocene pollen record of northeastern North America: A mapped summary, *Quaternary Research* 8:64-96.
- Figure 3: Present geographical range of sugar maple (horizontal lines) and potentially suitable range under doubled CO₂ (vertical lines). Cross-hatching indicates the region of overlap. A: predictions using climate scenario derived from the GISS general circulation model. B: predictions using climate scenario derived from the GFDL model. Gridpoints are sites of climatic data output for each model. Source: Davis and Zabinski, 1991.
- Figure 4: The distribution and abundance of the winter range of the Eastern Phoebe. The northern boundary lies very close to the -4 degree C isotherm of January minimum temperature (heavy solid line). Source: T. Root, 1988a.



Source: Wigley & Raper, 1990

Figure 1

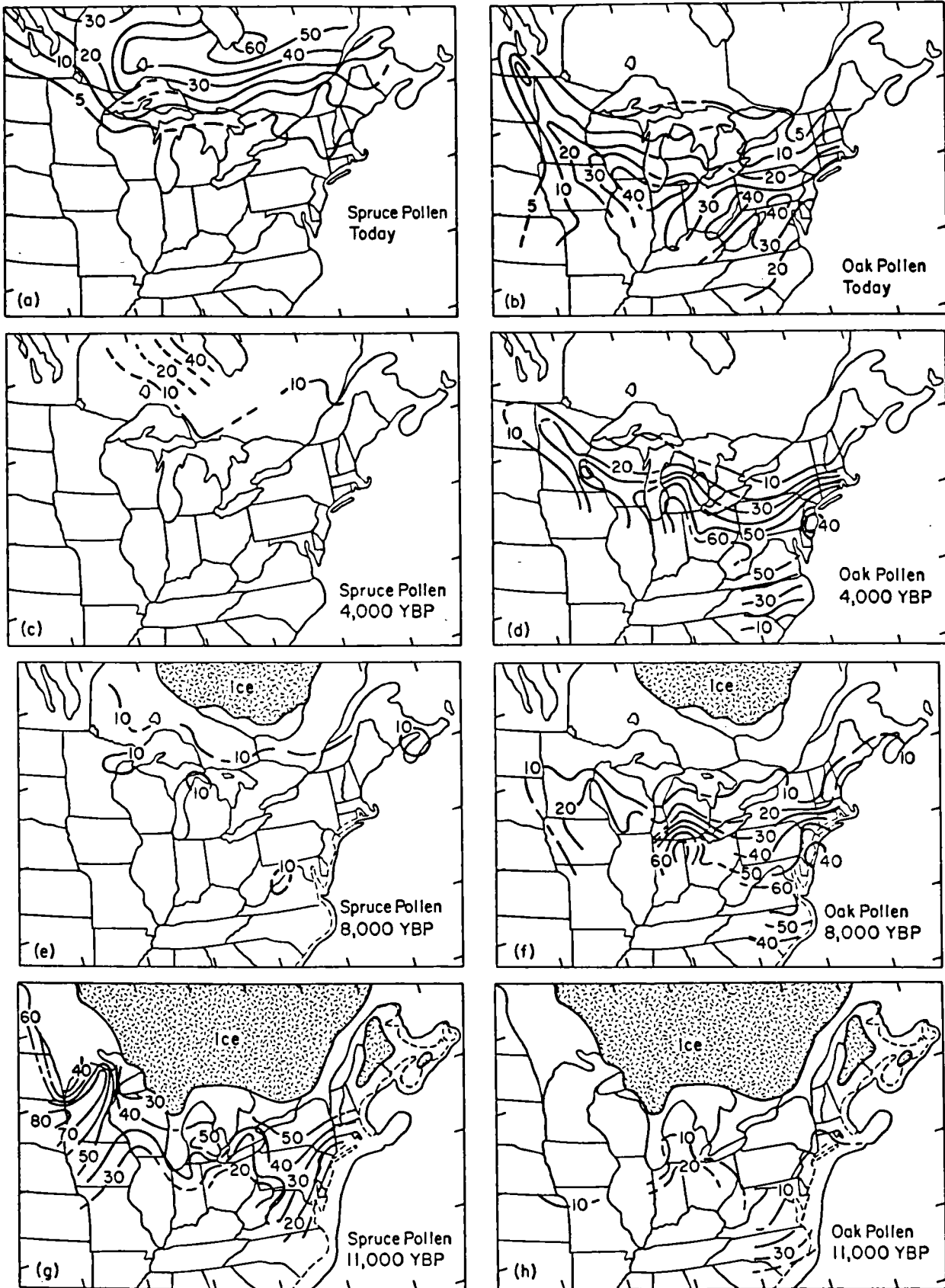
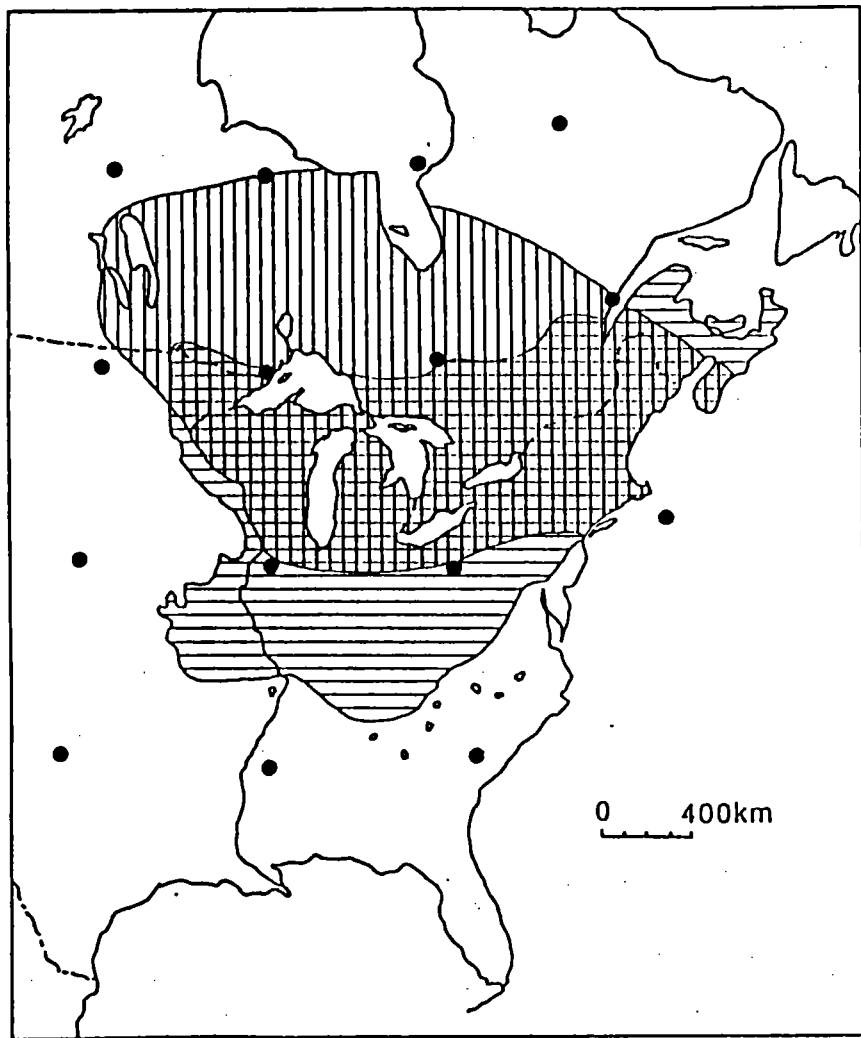
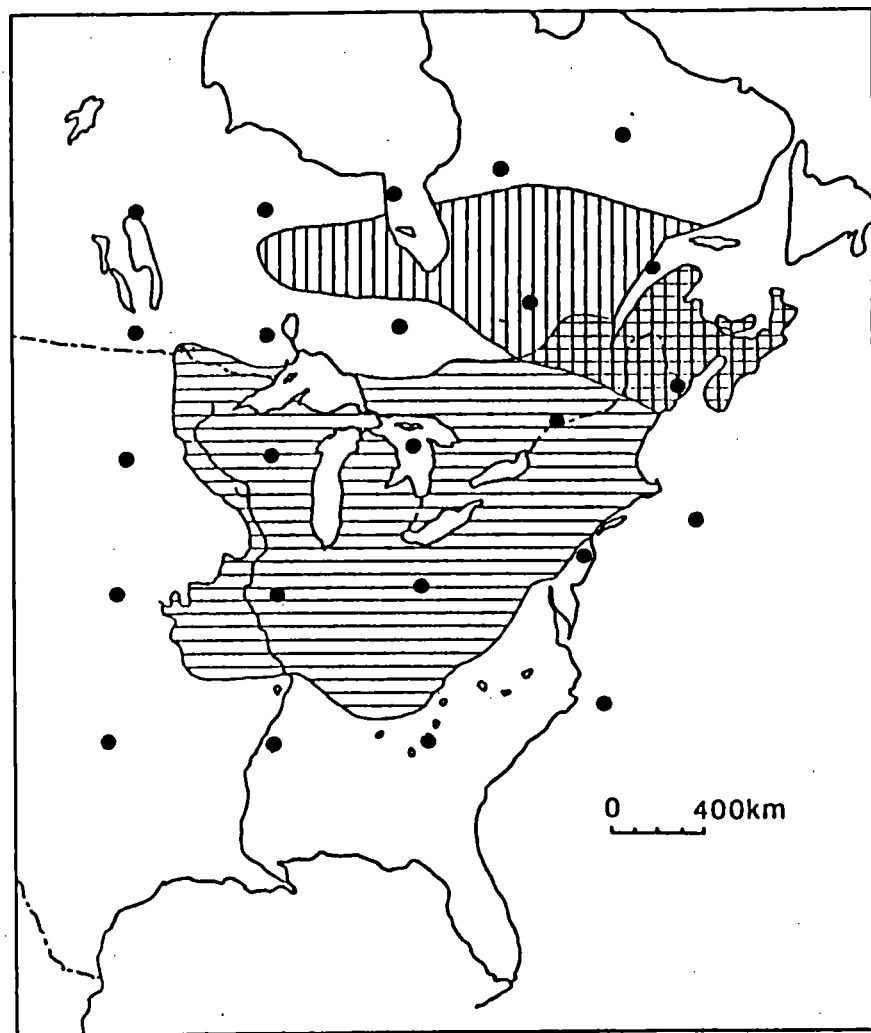


Figure 2

SUGAR MAPLE



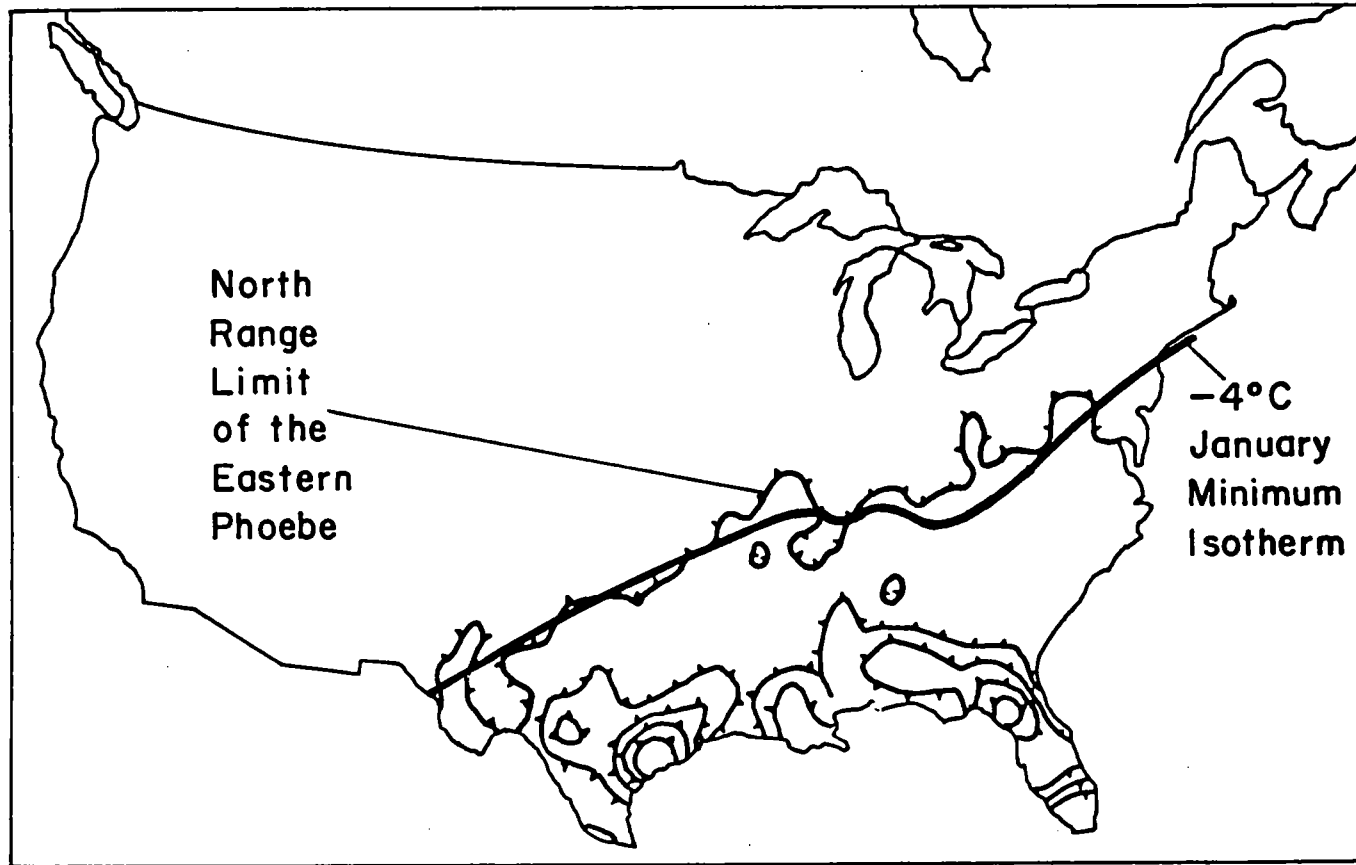
A



B

Figure 3

DISTRIBUTION AND ABUNDANCE OF EASTERN PHOEBE



Source: T. Root (1988)

Figure 4

Appendix I

Stephen H. Schneider

Global Warming

*Are We Entering
the Greenhouse Century?*



Vintage Books

A Division of Random House, Inc.

New York

1990

Epilogue

The Global Warming Debate Heats Up

Since the first appearance of *Global Warming* in September 1989 there has been vociferous debate among scientists, economists, industrialists, and environmentalists about how serious the global warming issue is. This sometimes acrimonious exchange has spread confusion among the public and politicians alike about the credibility of greenhouse effect warnings and has, at least temporarily, delayed action on the problem. Therefore, I think it is worthwhile to summarize briefly what has happened since the initial publication of *Global Warming*, and why the ensuing debate hasn't changed the fundamental conclusions of the original edition. Indeed, while many scientific questions remain open to dispute, some of the bitter criticisms denying the immediacy of the problem are becoming recognized for what they are: attempts by special interest groups or ideologues to delay global actions that might adversely affect them.

Eighteen years ago, when I first began to address the public policy implications of still uncertain climatic forecasts, a controversial and well-known scientist took me aside: "You'll be able to judge the magnitude of your impact on society," he warned, "by the position and vehemence of your critics." Getting people's attention is one thing, however; getting action on public policy is another.

Critics maintain four principal objections to the likelihood of global warming. First, the scientific basis for projecting future climate change is so uncertain that no responsible scientists would dare propose immediate policy responses. Second, those who suggest that a hundred years or more of unprecedented climate change (what I have called the Greenhouse Century) is being built into the future are just "environmental activists" whose ideological agenda aims to destroy the free market system. On the other hand, those who argue that there are unlikely to be any significant effects are, by contrast, thoughtful senior scientists protecting the public's interests. Third, decade-to-decade temperature changes over the past 100 years aren't consistent with climate model predictions of the effects of increasing greenhouse gases; thus the model projections are probably exaggerated. And fourth, it's too expensive to do anything about global warming anyway. The only thing to do now is wait and see what happens—after all, the changes probably won't be great and may be beneficial even if they occur. So say the most strident critics.

The debate became so intense that in 1990 the U.S. National Academy of Sciences invited the principal scientific opponents of activism on global warming to debate the scientific "establishment" that has consistently reaffirmed its confidence in its own 1.5°C to 4.5°C warming estimates for the middle of the next century. President Bush's Chief of Staff, John Sununu, cited these oppositionist critics to justify a go-slow approach to joining international efforts to regulate emissions of atmospheric pollutants that have the potential to cause unprecedented climate change in the twenty-first century. As long as the U.S. refuses to limit its emissions, Great Britain, France, Canada, Japan, and other nations are also unlikely to act. Thus, the U.S. refusal to agree to specific curbs on some of its emissions is having a major impact on the shape of the Greenhouse Century.

The debate has strayed far from reason and civility on occasion. *Forbes* magazine, for example, placed an ad on the back page of the *New York Times* (February 7, 1990), praising itself for courageous journalism in debunking global warming as "Hype Not Heat" and belittling the issue with the headline, "No Guts, No Story." "Global warming effects," *Forbes* said, "would be at worst minimal." Editorial cartoons in support of warming controls

advocates escalated the media circus. One showed Sununu as a devil whispering in the President's right ear, "To hell with the future, let's go for short-term profit." Bush is flicking an angel, William Reilly, the Environmental Protection Agency administrator, off his left ear as Reilly reminds him of his campaign promise to be the "Environmental President." When debate degenerates to such inanity, it's no wonder the public and most politicians are confused about what the real problem is, let alone what to do about it.

The irony is that very little has changed scientifically during the past several years. Nevertheless, when new technical data surfaces that apparently reduces the magnitude of the problem, it is welcomed by global warming opponents as a major finding. New data that reinforces global warming concerns is ignored by the critics, but promoted by environmentalists. Sides are taken without putting new information in perspective, with the result that confusion grows. Unfortunately, while such a polarized debate makes entertaining op-ed page reading and grabs ratings on TV, it clarifies little of the real scientific controversy or of the broad consensus on basic issues within the scientific community.

Typical projections of global warming possibilities (see Figure 7, page 105) into the twenty-first century have been drawn by a group of scientists convened by the International Council of Scientific Unions. They show warming from a moderate half degree Celsius (.9°F) up to a catastrophic 5°C (9°F) or greater before the end of the next century. I do not hesitate to call the latter figure catastrophic because it is the magnitude of warming that occurred between about 15,000 and 5,000 years ago: from the end of the last ice age to our present interglacial epoch. It took nature some 5,000 to 10,000 years to accomplish that warming, which was accompanied by an approximately 100-meter (330-foot) rise in sea level, long distance migration of forest species, radically altered habitats, extinction and evolution of species, and other major environmental changes.

Critics of immediate policy responses to global warming are quick to point out the uncertainties that could reduce the average projections of climate models (such as the middle line on Figure 7). Indeed, most climate modelers include similar caveats in their papers. Many critics, including the authors of a report

for the Marshall Institute¹ (a Washington-based think tank best known for its advocacy of President Reagan's "Star Wars" Strategic Defense Initiative), hardly mention that the sword of uncertainty has two edges: that is, the same inexactitude in physical or biological processes that makes it possible for the present generation of models to overestimate future warming effects is just as likely to cause the models to underestimate change. [I wrote a letter putting this Marshall Institute report in perspective at the request of Alan Hecht, a deputy administrator in the U.S. Environmental Protection Agency. Since that letter has already been widely circulated (after someone obtained it under the U.S. Freedom of Information Act), I reproduce it here in the notes.]²

The public policy dilemma is how to respond in the absence of conclusive evidence of the effects of global warming. It is my opinion that the scientific community will not be able to provide definitive information over the next decade or so about the precise timing and magnitude of century-long climate changes, especially if research efforts remain at current levels. Policy makers must decide how much information is "enough" to act on and what measures to take to deal with the plausible range of environmental changes. Unfortunately, the probability of such changes cannot be precisely estimated by analytical methods. Rather, we must rely on the intuition of experts, which is why obfuscating media debate impedes policy development.

Fortunately, making intuitive scientific judgments is the purpose of such deliberative bodies as the National Research Council of the U.S. National Academy of Sciences (NAS) and the International Council of Scientific Unions. NAS, for example, regularly convenes a range of experts to estimate the probabilities of various scenarios of change. The deliberations of these panels are removed from the cacophony of media debates that typically highlight only the extreme opposite positions. Half a dozen such assessments³ over the past ten years have all reaffirmed the plausibility of unprecedented climate change building into the next fifty to a hundred years. In 1990 a United Nations-sponsored group of several hundred international scientists, the Intergovernmental Panel on Climate Change (IPCC), also reaffirmed that plausibility.⁴

I've mentioned that the National Academy of Sciences has regularly produced studies from a broad cross-section of the scien-

tific community of possible climate changes from greenhouse gas build-up. Since these assessments have been used by both politicians and conservationists to justify serious consideration of policy actions, some critics have tried to discredit the National Research Council (NRC), which compiles such assessments for NAS.

One such critic, Richard Lindzen, a meteorologist at the Massachusetts Institute of Technology, is himself a member of the National Academy. Nearly 20 years ago Lindzen criticized the Department of Transportation's Climatic Impact Assessment Program to evaluate the environmental impact of high-flying supersonic transports (SSTs). In 1989 he went so far as to try to discredit the Academy consensus on global warming by impugning the credentials of its committees:

The National Academy consists of about 1,500 members who are elected on the basis of their scientific accomplishments. Election to the Academy is considered a high honor. When, however, the Academy responds to inquiry, it does so through committees of the National Research Council. Oddly enough, there's only a minuscule representation of Academy members on these committees (approximately 6%). Thus, the connection of so-called National Academy Reports to the Academy is itself tenuous and uncertain. In principle, these reports are reviewed by academicians, but the selection of these reviewers is fairly arbitrarily handled by the NRC staff and the presidents of the Academies of Science and Engineering and the Institute of Medicine.⁸

In other words, to Lindzen the Academy committees are suspect because many of their members have not met the standards for election to the Academy—high academic standards to be sure. But Academy membership is largely based on disciplinary specialization and outstanding contributions in a narrow field, rather than on an individual's capacity for multidisciplinary synthesis. But the latter quality is also essential for integrative assessments of complex subjects such as climate change. That is one reason why the Academy casts its net widely in selecting committee members.

Lindzen went on to suggest that his intuitive understanding of how the atmosphere worked led him to believe that its "response to doubling of carbon dioxide may readily be 1/2 to 1/4—or even less—of what is suggested" by the National Research

Council consensus of 1.5°C to 4.5°C warming if CO₂ doubled. Lindzen based this "1/2 to 1/4" statement upon his intuitive scientific judgment and offered no calculations in the peer-reviewed literature to back it up. Nevertheless, opinion page articles proliferated following Lindzen's statements, and my telephone was busy with reporters and others seeking my response to his assertions that global warming was a vastly overblown environmental scare.

Finally, the December 25, 1989 issue of *Forbes* magazine featured an article whose scientific objectivity was emblazoned colorfully on the cover: "Global Warming Panic: A Classical Case of Overreaction."⁹ Excerpts appeared in newspaper opinion pages for weeks following. The piece was by Warren Brookes, an economic journalist who combines sharply worded anti-global warming scientific and policy opinions with *ad hominem* attacks. It's not surprising that such stuff is written, but it is surprising to me that it appears on the opinion pages of respectable newspapers without any attempt to put this nonscientist's scientific arguments in the perspective of the broad consensus. What newspapers tend to do for "balance" is print the contrary views of comparably extreme advocates of radical environmental policies or *laissez-faire* economics. The result is increased confusion and further loss of objectivity and perspective, as I observed in Chapter 7 on "Mediarology."

What Brookes does is to cite the many uncertainties surrounding global warming projections—usually attributing the caveats to the critics, whose impeccable credentials he flaunts. Then he selectively quotes from "environmental activists" (like Jim Hansen or me). But more important than its *ad hominem* attacks, the *Forbes* article does not indicate that most of the scientific uncertainties mentioned are as likely to make our estimates for the future worse as they are to make it better. Unknown phenomena are as likely to cause increases as decreases in current estimates of future changes. Furthermore, Brookes does not refer to the substantial amount of information that validates climate models, including their capacity to reproduce the large seasonal cycle of surface temperature and to reproduce many significantly different climates from glaciological history. He overlooks the fact that ice ages and interglacial warm periods have seen 5°C (9°F) temperature changes marked by 25% increases in CO₂ at the warm times

and 25% decreases in the cold times (see Figure 2, page 40). These strong circumstantial pieces of evidence are what motivate me, and most other scientists involved in National Research Council or IPCC studies, to believe there is a substantial probability of unprecedented warming building into the next century.

Brookes, along with other critics, also points out the lack of significant warming in the lower forty-eight United States during the past century. "That news alone," Brookes asserts, "should have cooled off the global warming movement." What he and others who raise this issue ignore is that while the U.S. warmed in the west and cooled in the east, if Alaska were included in their estimates (which it was not), the U.S. as a whole would have warmed up more than 0.3°C , close to the global average. What the data actually shows is that natural climate variability is significant on a regional basis. For example, had one chosen to observe north central Asia, one would have noticed a 40-year warming trend vastly in excess of the rest of the globe. It is as deceptive to suggest that the Asian trend proves the world is warming up faster than the models project, as it is to allege that the absence of an appreciable temperature trend in the lower forty-eight United States proves that the greenhouse effect does not apply to the world—or even to the U.S. This kind of scientific silliness couldn't survive in serious debate, yet it is reprinted in news stories and opinion pieces.

As mentioned before, because of public doubt aroused by the *Forbes* story and other commentaries, the National Academy of Sciences and National Academy of Engineering organized debates to inform their most recently convened panel of the critics' views. Lindzen and others were present at the first debate, along with the "establishment scientists": James Hansen, Director of NASA's Goddard Institute for Space Studies; V. Ramanathan, a climate expert from the University of Chicago; and Jerry Mahlman, Director of the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory in Princeton. Also attending was my NCAR colleague, Kevin Trenberth, frequently cited as a critic of global temperature trend data.

Trenberth started the discussion, showing how difficult it is to estimate the world's average surface temperature. He noted that ocean temperatures inferred from ships' records in the pre-1900s period were problematic, since they were obtained from

thermometers placed in buckets dropped over the side of the boat. Some buckets were made of leather, some of wood; some measurements were taken on the windward side, some to the leeward side of the ship, all of which would affect the readings. He also showed that the fraction of the oceans covered by ship tracks before 1900 was 10% to 20% at best. One of the Academy panel members asked him if he felt there was any utility at all in the ocean temperature data before 1900 for the purpose of global trend analysis. "Not much," he said. In fact, he commented, the corrections due to faulty measurement techniques are typically larger than the inferred climatic trends, which is why no one pays serious attention to them.

Nevertheless, Brookes, Lindzen and other critics have prominently cited M.I.T. meteorologist Reginald Newell's study suggesting that ocean temperatures were as warm in the 1850s as in the 1950s; thus they argue that no global warming has taken place over the past 150 years. But as noted by Trenberth, pre-1890 thermometer data are not usually regarded as credible in scientific assessments of global trends; coverage is not global and the measurements themselves are unreliable. These reservations did not stand out in the critics' citation of Newell's analysis.

I asked all the assembled scientists at this Academy debate my favorite polling question: "What is your estimate of the probability that the next century will see a global warming of 2°C (3.6°F) or more?" All the atmospheric scientists present, including Lindzen, agreed that there would be warming. He, however, felt the most likely extent of warming was between 0.5°C to 1°C rather than 2°C to 4°C as in typical Academy assessments—and the IPCC estimate. Atmospheric scientists Hansen, Mahlman, Trenberth and Ramanathan all agreed that 2°C was certainly a reasonable number for the twenty-first century. They assigned the occurrence of a 2°C warming a probability between 60% and 90%–95%. Lindzen was the only exception; his probability for 2°C warming was 25%—the lowest estimate I've yet heard from any knowledgeable atmospheric scientist. Indeed, several people in the audience—aware of his assertions that global warming is likely to be "1/2 to 1/4" of what the Academy presently estimates—expressed surprise to hear that his estimate of the probability of unprecedented warming in the next century differs from mine by less than a factor of 2.5 (25% for him versus 60% for me). One science

writer observing the Academy debate for a major newspaper said to me later, "This 'great debate' is a phony; you guys really disagree scientifically much less fundamentally than most people think." I was glad he discovered it.

Perhaps the strangest aspect of the National Academy debate occurred the morning before the debate itself. Warren Brookes, writing an editorial in the *Washington Times* entitled "Greenhouse Showdown or Show Trial?"⁹ blasted the upcoming session by challenging the roster of debaters and the credentials of the Academy committee members who called for the debate. "Only one of the three panelists asked to prepare papers is from the dissenting side," said Brookes. That, of course, was not true; in addition to Lindzen there was Trenberth, and retired Yale University forester William Reifsnyder, all of whom had been mentioned as critics. Moreover, Robert Jastrow of Dartmouth and William Nierenberg of Scripps Institute of Oceanography, co-authors of the Marshall Institute critique of global warming, refused to attend the meeting, though invited. Nierenberg, however, apologized for his absence by letter and said he was certain that his views would be adequately represented by the three critics present.

Nevertheless Brookes went on: "The most serious 'offenders' to be tried at today's meeting are three of the nation's most prominent senior scientists who won't even be there, Robert Jastrow of Dartmouth, founder of the Goddard Institute for Space Studies at NASA, Frederick Seitz, past president of NAS and William Nierenberg, former director of Scripps Institution (*sic*) of Oceanography." Brookes accused the Academy of being "eager to trash" Jastrow, Seitz and Nierenberg, authors of the Marshall Institute report that many believe was used by White House Chief of Staff John Sununu to prevent E.P.A. Administrator William Reilly from convincing President Bush to join in an international commitment to reduce greenhouse gas pollution. Brookes concluded by accusing some in the Academy of coming "dangerously close to using Lysenkoist tactics to anyone who dares to dissent from the prevailing political/scientific wisdom." (Lysenko was the Soviet biologist who faked genetic research results to match Stalinist ideology.)

Interestingly these personal attacks were not reciprocated by those accused of Lysenkoism. Perhaps they did not feel the ideological antagonism expressed by Brookes in *Forbes*: "As Marxism

is giving way to markets, the political 'Greens' seem determined to put the world economy back into the red, using the greenhouse effect to stop unfettered market-based economic expansion." To me, this says that *Forbes* wasn't publishing a courageous exposé about science, as its newspaper ads boast ("No Guts, No Story"), but rather a defense of its ideology in the guise of science journalism. Everyone is entitled to an ideology, and, to his credit, Brookes admits his in this one sentence, even if he buries it in the middle of a six-page article. What does bother me is his cavalier way of taking selected bits of science out of context to cut and paste them into a slick-sounding article in support of a blatantly ideological viewpoint—a criticism that applies to the writings of some environmental activists as well.

Scientists share responsibility with the media for often failing to communicate complex issues clearly to the public. What the general public, as well as politicians and bureaucrats, do not recognize is that most scientists spend their time arguing about what they don't know. Scientists generally consider discussions of accepted ideas boring and a waste of time. This is because the scientific method operates by constant questioning, particularly of issues not yet well substantiated. But if the public and its representatives do not understand the process of scientific inquiry, then they will have difficulty interpreting the "dueling scientists" debates, let alone deciding whether debaters are honest or ideologically driven.

We scientists simply have to spend more time differentiating accepted information from what is reliably believed to be true and, most important, from what is highly speculative. The public version of the global warming debate rarely separates those components clearly, thereby leaving the false impression that the scientific community overall is in intellectual disarray, when, in fact, the IPCC and the National Research Council's consensus of 1.5° to 4.5°C warming in the next century still reflects the best estimate of a wide range of knowledgeable scientists. This estimate includes recent United Kingdom studies that halved the "best guess" from over 5°C to around 2.5°C.⁹ Perhaps some new discovery will push the best guess higher again next week, but meanwhile the 1.5° to 4.5°C consensus warming range endures. Unless we communicate what we do know along with what we don't know the public policy process is subverted in confusing debate that

inadequately represents the true nature of informed opinion.

It is difficult for the media to do what I sometimes wish they would: back off the concept of "balance" in favor of the concept of "perspective." If an issue is complicated, it simply is not enough to play off "all sides," particularly if the opinions of the majority of the experts—the people who create the consensus—are left out. Moreover, that consensus information must be expressed in terms of its probability. Very few scientists would say they believe the future climate will warm up from 1.5°C to 4.5°C; rather, most believe that to be reasonably probable. Conveying issues in probabilistic terms with the range of views in perspective is necessary if scientific opinion is to be communicated accurately, rather than as a misleading debate among feuding scientists, or occasionally as a travesty perpetrated by polemicists and ideologues.

Let's return to the details of the debate. Another criticism of global warming projections has been the imperfect match between the warming of the earth and the smooth increase in greenhouse gases over the past hundred years (see Figure 4, page 85). It has been alleged that since most warming in the twentieth century took place up to the 1940s, followed by a cooling at the time the global greenhouse gases were increasing at their fastest, the decade-by-decade temperature trends in the twentieth century cannot therefore be attributed to greenhouse gas build-up.

At first reading that sounds like a valid criticism; but there are several flaws in the argument. First, nature always fluctuates. Several tenths of a degree Celsius warmings and coolings over decades are part of the natural record and, indeed, are normal. Scientists call these fluctuations "climatic noise." These are not predictable as far as anyone can tell, since they appear to be caused largely by the internal redistribution of energy among the principal reservoirs: the atmosphere, oceans, ice, and land surfaces. Therefore, natural fluctuations could partially explain the sharp warming up to the 1940s, the Northern Hemisphere's cooling to 1975, and possibly even the spectacularly rapid rewarming of the 1980s—the warmest decade in the 100-year instrumental record. Secondly, we do not know precisely what other potential climatic forcings (that is, processes that could force the climate to change) have been doing over the past 100 years. These include energy output from the sun, atmospheric particles from

volcanic eruptions, or particles generated by human activities—or as University of Wisconsin climatologist Reid Bryson likes to put it, the "human volcano."

This "forcings" problem is akin to a criminal investigation in which the whereabouts of only one suspect is known and the activities of the other possible suspects were not carefully observed. In this case, the "crime" is the 100-year 0.5°C (0.9°F) warming trend and the leading "suspect" is the known greenhouse gas increase. Unfortunately, since we do not have quantitatively accurate ways of knowing precisely what the other potential forcings may have been (that is, the unwatched "other suspects"), we can't rule out some possible role for them. Some scientists, such as James Hansen and myself, have led efforts to estimate what volcanic or solar forcings may have contributed to twentieth-century temperature trends.¹⁰ Indeed, such estimates improve the match of our computer model simulations to observed twentieth-century temperature trends. However, as all of us have admitted, without more quantitatively reliable information these exercises can do nothing more than sketch out plausible rather than definitive results.

Incidentally, my own simulation result, which used temperature trend data up to the early 1980s, suggested the best fit to the data was such that a CO₂ doubling would cause only about 1.5°C to 2°C global warming—the lower end of the 1.5°C to 4.5°C range cited in most U.S. National Academy of Science reports or by the ICPP. However, it was noted at the time that this could not be taken as strong evidence that CO₂ doubling would result in such a moderate climate warming because we know that the twentieth century record is marked by natural noise, unmeasured alternative forcings and uncertainties in how much temperature change actually occurred. Most scientists still agree that without ten to twenty more years of thermometer, solar, air pollution, and volcanic observations it's difficult to pin down anything quantitatively to very high reliability, say 99% confidence.

Arguing that climate models have been unable to predict a detailed sequence of decade-by-decade temperature fluctuations has been a favorite tactic of some global warming critics.¹¹ But this is akin to arguing that because we can't predict the individual rolls of a pair of dice, we also can't predict the odds of getting any two faces on any roll. All gamblers know better. Though we

know the statistics for rolling a particular number, we certainly wouldn't be expected to know the sequence of numbers on successive rolls, even for slightly loaded dice. In short, those who argue that an absence of an exact match on a decade-by-decade basis between observed temperature fluctuations and greenhouse gas build-up demonstrates that greenhouse effect sensitivity of models is wrong are simply off in their logic. Such agreement should not be expected in detail as long as a large degree of climatic noise continues to make up much of the decade-by-decade temperature record and as long as we lack precise data on other non-greenhouse gas forcings.

Fortunately, we are now measuring the sun, volcanos and pollution-generated particles, and can thus account better for their effects. In other words, we finally are checking up on the "other suspects." Thus, as greenhouse gases continue to build up in the future, if greenhouse warming does not take place at roughly the predicted rate during the 1990s and into the twenty-first century, then indeed it will be possible to argue on the basis of some direct evidence that the effect predicted by today's models is off base. Personally, I'll be surprised if there is a major error that overrides the 1.5°C to 4.5°C warming projections.

Let me next address the final, and perhaps the most important, criticism made against action to slow global warming; that immediate policy steps to cut CO₂ emissions are too expensive. The *Forbes* newspaper ad suggests, for example, that if we cut CO₂ emissions the U.S. will be bankrupt and the Third World impoverished. Indeed, as I discuss frequently in *Global Warming*, there is substantial Third World opposition to the prospect that they may be deprived of their own industrial revolutions, and of the economic growth experienced in the Victorian period by the then-developing countries using cheap and dirty coal. Since developing Third World countries such as India and China have abundant coal supplies, they would like to use them as low-cost means to industrialization. In 1990, however, these countries have between them some two billion people, whereas in the nineteenth century the entire world didn't have two billion people. The global impact of the developing countries' use of coal to produce even a quarter of our current industrial standard of living would be greater than was ours. Needless to say, such arguments are not met sympathetically in China or India.

It is sensible, I believe, to argue that developing countries need not repeat the western experience of industrialization with smog-choked cities, acid rain, and inefficient power production, given that modern technology has many better solutions. Unfortunately, developing countries typically respond that high-tech, efficient machinery is more expensive than the traditional options available to them. This dilemma makes obvious the need for a bargain. Countries with technology and capital must provide resources to developing countries, which in return must keep population growth under control and work toward industrial development with the lowest polluting, most efficient technologies, even if they cost more initially.

There have been international efforts afoot to draft an agreement requiring the developed nations to decrease their carbon dioxide emissions by, say, 20% by the year 2000, and to cut the projected emissions growth rates in developing countries. This has been strongly opposed by the United States, echoed by Japan, the U.K., the U.S.S.R., and some other countries. The Japanese are unhappy since they're already twice as energy efficient as the U.S. They claim it would cost them much more to cut carbon dioxide by 20% than the U.S., since our very inefficiency gives us more opportunity to cut cheaply.

Still less efficient developing countries could produce far less growth in carbon dioxide pollution by using efficient, modern technologies instead of older, cheaper ones. This sets up a possibility for creative international management that might not only eliminate Third World opposition to global emissions limitations, but also could encourage competition among these nations to be the venue for future emissions cuts funded by developed countries; cuts that in turn could buy the developed nation out of its reduction requirement by funding even larger CO₂ reductions in now-energy inefficient developing countries.

I recently discussed this idea with a Japanese economist, Yoichi Kaya, an energy analyst from the University of Tokyo. He tried to assess what a significant cut in CO₂ emissions might imply for world and Japanese economic growth. Kaya concluded that for energy-efficient countries (like Japan) substantial cuts could severely lower economic growth—unless ways were found to increase the rate at which the economy becomes less dependent on energy growth. (This is what environmentally oriented energy

analysts already argue is essential for environmentally sustainable development; see discussion in Chapter 8.) He also showed that developing countries' economic growth would require efficient energy or else they would pollute severely.

I met with Professor Kaya in Tokyo in November 1989, while the Noordwijk Conference, an international environmental meeting in the Netherlands, was producing daily headlines about how the U.S., Japan, and the United Kingdom were balking at specific emissions cuts. Professor Kaya and I agreed that equal percentage emissions limitations for each nation may make international politics simpler, but that from a global point of view, reducing emissions by a fixed fraction for all nations may be neither the most cost effective plan, nor the fairest. Unequal fractional cuts may sound unfair to some nations, but what determines fairness, we felt, is not how much CO₂ emission each cuts at home, but *who pays* for all the cuts. To be sure, the rich nations should pay a disproportionate share of the costs since they have been responsible for over half of the CO₂ pollution to date. But energy-efficient countries like Japan, Germany, and Italy may not be the logical first places to look for big CO₂ emissions savings. However, we agreed it would not be politically easy to negotiate a system where some nations pay and other nations cut their emissions (or limit emissions growth rates in the case of Third World nations) by greater amounts. But from the point of view of the minimum global investment for the maximum amount of global pollution reduction, such a strategy probably is most efficient and consideration of the issue should be part of the international negotiating process.

In other words, supposing each developed country had to reduce its CO₂ impact on the world by something equivalent to 20% of its present production. Let's say, continuing the Japanese example, that their quota is to cut 100 million tons of CO₂ annually. Why not structure an international agreement so that the Japanese need to be responsible either for reducing 100 million tons of CO₂ from their own industries, or else paying to cut 150 million tons in another country (or some combination of both)? The obvious candidate is China, since Japanese investment in China for efficient energy production would both reduce acid rain over Japan as well as global CO₂ build-up. It is likely to be much cheaper per unit of CO₂ saved for the Japanese to improve

Chinese energy efficiency, since China is starting out so inefficient, than for Japan to improve its own efficiency. At the same time the Chinese would receive extra development assistance, the Japanese would get less acid rain and could buy out of their emissions reduction quota without having to cut emissions at home. Moreover, the Japanese would be creating friendship and markets for their products in the future, whereas the Chinese would be getting more efficient machines with lower long-term operating costs, thereby improving their economy and competitive posture into the twenty-first century. In other words, everybody wins. But first, we need a world emissions agreement that provides incentives for such bargaining and trading to take place. That agreement is what the U.S., the U.K., the U.S.S.R., and Japan were balking at in 1989.

Other similar ideas include issuing "tradeable (or leaseable) permits," giving everyone in the world the right to emit a certain amount of CO₂ or some other greenhouse gas.¹² These permits could be traded for cash, food, energy efficient products, etc. As of the signing of the global agreement, all nations would have equal per capita CO₂ emissions rights. That implies a certain amount of total national emissions. In the future a country could sell or trade these rights or exercise them for development, or increase their population and thereby limit their future emissions per capita. In other words, a fixed per capita emissions right that goes into effect at the signing date would dramatically reduce Third World suspicions that they were being singled out to bear the immediate burden of emission controls.

Critics of emissions reductions cite the supposed annual costs of global warming reduction at tens of billions of dollars—too much to be worth the benefits of climate change abatement. But they often neglect the additional non-greenhouse-effect benefits of emissions reductions: reduced acid rain; reduced air pollution; reduced balance of payments deficits; and lower long-term operating costs of efficient equipment, which reduces the energy costs of manufactured products and enhances competitiveness. Critics who simply cite the potential capital costs of CO₂ reduction write newspaper stories about how many billions or trillions it will cost and scare people away from action. But they often present a very unbalanced view of the distribution of benefits that come with greenhouse gas abatement. Unfortunately, it is

very difficult to communicate these benefits in bumper sticker length headlines or in sound bites on the evening news, which is often all the time this complicated story gets.

For example, John Sununu, defending his role in persuading President Bush not to agree to specific CO₂ emissions reductions at Noordwijk, said on TV in 1990: "There's a little tendency by some of the faceless bureaucrats on the environmental side to try and create a policy in this country that cuts off our use of coal, oil and natural gas. I don't think America wants not to be able to use their automobiles."¹³ I agree we don't want to cut "off our use of coal, oil and natural gas"; nor do we want to abandon our cars. But, Mr. Sununu, who does? Not one proposal from any bureaucrat, National Academy of Sciences committee or even environmental group I know of ever proposed such an absurd policy. Rather, most talk about giving up (or heavily taxing) gas-guzzling cars and switching to less polluting, more energy-efficient equipment, regardless of the fuel used. But some studies have suggested that switching to less polluting energy systems could cost "\$800 billion, under optimistic scenarios of available fuel substitutes and increasing energy efficiency, to \$3.6 trillion under pessimistic scenarios . . . between now and 2100." This quote from the February 1990 "Economic Report of the President" to Congress was based on the initial results of the first wave of economic model simulations.

Because of the controversy over the reliability of such models, the National Academy of Sciences ran a debate (following the climate debate mentioned earlier) among some economic forecasters and their critics. What emerged was very revealing. First, over 110 years (1990 to 2100) even a trillion dollars in CO₂ reduction costs, which sounds very expensive, is less than \$10 billion each year—only a few percent of the current annual defense budget. Moreover, Robert Williams, an energy technology specialist from Princeton University, pointed out that the so-called "optimistic scenario" of \$800 billion in costs to cut CO₂ emissions was based on very *pessimistic* assumptions about the rapidly decreasing costs of renewable energy systems such as solar, wind, or biomass power. Furthermore, with the exception of one effort by Yale University economist William Nordhaus, none of the other modeling simulations attempted to estimate the direct environmental benefits of our supposed trillion dollar investment

in CO₂ emission controls. It is unconscionable that some critics of global warming action would cite these dubious cost estimates without so much as mentioning the potential benefits of slowing CO₂ emissions. Nordhaus, though, by balancing costs and benefits in his model runs, argued that cutting annual CO₂ emissions by as little as 10% or as much as 47% would actually produce benefits greater than the costs.¹⁴ His model, however, was admittedly crude, laden with unprovable assumptions, and unable by itself to provide quantitatively reliable information for making policy choices.

Cross-examination of the economists by Academy committee members also revealed that their economic models had not been tested to see how they performed in predicting the economic consequences of historical events such as the 1973 OPEC oil price hike. I was shocked that such tests had not been done, and dismayed that some administration officials were actually citing these premature, unvalidated economic model results for costs of emissions controls as an alleged rational basis for making national policy.¹⁵

In summary, then, the greenhouse effect, the heat trapping properties of the atmosphere and its gases and particles, is well understood and well validated as a scientific principle. Indeed, it is as good a theory as there is in the atmospheric sciences. Moreover, in late 1989, A. Raval and V. Ramanathan at the University of Chicago, used satellite observations to study the important water vapor greenhouse feedback mechanism, a process that is central to most models' estimates of some 3°C plus or minus 1.5°C equilibrium warming from a doubling of CO₂. They conclude, "The greenhouse effect is found to increase significantly with sea surface temperature. The rate of increase gives compelling evidence for the positive feedback between surface temperature, water vapour and the greenhouse effect; the magnitude of the feedback is consistent with that predicted by climate models."¹⁶ *In other words, the heat-trapping capacity of the atmosphere is well understood and well measured on earth, and much of the sometimes polemical debate in the media over the greenhouse effect has little basis in reality.* This empirical confirmation of the natural greenhouse effect, which is consistent with the greenhouse effect of climate models, stands in stark contrast to the theoretical arguments of some critics. They believe that their untested conceptions

of temperature–water vapor processes in parts of the tropics will reduce present model estimates of global warming by a factor of four or so.

It is well known that the 25% increase in CO₂ documented since the industrial revolution, the 100% increase in methane since the industrial revolution, and the introduction of man-made chemicals such as chlorofluorocarbons (also responsible for stratospheric ozone depletion) since the 1950s should have trapped about two extra watts of radiant energy over every square meter of earth. That much is accepted by most climatological specialists. Less well accepted, however, is how to translate those two watts of heat into “x” degrees of surface temperature change, since this involves assumptions about how that heat will be distributed among surface temperature rises, evaporation increases, cloudiness changes, ice changes, and so forth. The factor of two to three uncertainty in global temperature rise projections cited in the National Research Council’s reports reflects a legitimate estimate of uncertainty held by most in the scientific community. Indeed, recent attempts by a British group to mimic the effects of cloud droplets halved their model’s sensitivity to doubled CO₂, but the results remained well within the often-cited 1.5°C to 4.5°C range. However, the authors of the study wisely pointed out that “although the revised cloud scheme is more detailed, it is not necessarily more accurate than the less sophisticated scheme.”¹⁷ I have never seen this forthright and important reservation quoted by global warming critics who cite the British work as a reason to lower our concern by 50%. Nor, in the spring of 1990, was a NASA group’s satellite estimate of global temperature change for the 1980s properly cited in the media as confirming, rather than questioning, instrumental records of global warming.¹⁸ Finally, as explained in the original edition of *Global Warming*, predicting detailed regional distribution of climatic anomalies—that is, where and when it will be wetter and drier, whether floods will occur in the spring in California or forest fires in Siberia in August—is highly speculative, although plausible scenarios can be given.

While climatic models are far from fully verified for future simulations, the present seasonal and ancient climatic simulations, along with satellite observations of atmospheric heat trapping, are strong evidence that state-of-the-art climatic models already

have considerable predictive skills. An awareness of what models are and what they can and can’t do is probably the best we can ask of the public and its representatives. Then the tough policy problem is how to apply society’s values about risk taking in choosing to face the future, given the possible outcomes that climatic models foretell.

The global warming debate takes in both science and politics. But it is essential for the public to understand that disagreements over what to do about the prospect of global warming (a political value issue) are far greater than over the approximate probability that unprecedented climate change is being built into a Greenhouse Century (a scientific debate). Nothing that has happened since the first publication of *Global Warming* has changed the strong consensus among scientists that climatic changes unprecedented in the 10,000-year era of human civilization are a good bet to happen. The more we debate and the longer we delay slowing down the greenhouse gas emissions, the greater the magnitude of climatic change that we and the rest of life on Earth will have to cope with. We are still marching relentlessly into the Greenhouse Century.

Market Forces to Protect Our Environment: Initiatives for the New President (Washington, D.C.: December 1988; copies can be obtained by writing to either senator).

27. T. C. Schelling, "Climatic Change: Implications for Welfare and Policy," chap. 9 in *Changing Climate*, National Research Council, 449-82. Quotation from p. 481.

EPILOGUE

1. George C. Marshall Institute, *Scientific Perspectives on the Greenhouse Problem* (Washington D.C.: George C. Marshall Institute, 1989): 37 pp.
2. S. H. Schneider, 1989 personal correspondence to Alan Hecht as follows:

September 1, 1989

Dr. Alan Hecht
Office of International Activities
Environmental Protection Agency

Dear Alan:

Congratulations on your new job. I predict it will be stimulating both for you and the people you interact with. As you requested, here is my brief analysis of the recent Marshall Institute report (*Scientific Perspectives on the Greenhouse Problem*, 1989, George C. Marshall Institute, Washington, D.C.)

The Marshall Institute report is really three reports in one. The first part is a fairly standard review of the greenhouse science problem. It is typical of that in most National Academy of Science reports, and reflects the caveats normally given in the presentations of most of the climatic modelers that talk or write on this issue. There is an impression in the Marshall report that somehow these caveats have been under-represented by some members of the community, but this is not strongly argued. In any case, up to page 14, I have few disputes with the narrative, other than its constant focus on uncertainty and its omission of the primary reasons that climate modelers are concerned for the future: validation of the models' performance against actual climatic changes. There is insufficient mention of model validation in the Marshall report. For example, the authors do not mention the excellent performance of most General Circulation Models in simulating the very large seasonal cycle of surface temperature, or the successes in simulation of neighboring planets, Mars and Venus, each of which has radically different greenhouse properties than earth, nor is there mention of the daily variability validation studies that have recently been published. While these validations do not remove the uncertainties focused on in the first 14 pages, the absence of the mention of the substantial degree of model validation of climate sensitivity suggests a bias.

On page 15 begin what I believe to be the major problems with this report. First of all, the authors note, citing my *Science* article (S. H. Schneider, *Science* 243, 771, 1989), that the global temperature response to CO₂ doubling is in the range of 1° to 5°C. They correctly point out that a temperature drop of roughly 1°C relative to today's temperatures occurred in the Little Ice Age. That episode occurred between about 1400 and 1850 in various parts of the world at various times and differing degrees. Thus, a natural cooling of 1°C would, the Marshall authors argue, completely compensate for the lower end of any greenhouse warming if such a Little Ice Age-like event recurred in the next century. Indeed, this is correct, but it fails to mention that the upper range of the CO₂ warming limit, (i.e., 5°C), would totally swamp any natural fluctuations of the type that have occurred in the past 10,000 years, the time since the end of the last ice age. Moreover, natural centuries-long fluctuations on the order of 1° warming (e.g., the so-called Medieval Optimum around 1,000 years ago) are just as likely to occur, and could add to any anthropogenic greenhouse warming in the next century. Indeed, what is absent in the remainder of the Marshall document is any statement, even intuitive ones, about the relative probabilities of the greenhouse warming being at the low end of the range and comparable natural cooling occurring relative to the probabilities that more middle or upper severity warming scenarios could occur. (e.g., see *Current Issues in Atmospheric Change*, National Acad-

my of Sciences, 1987 for statements of the high probability of warming greater than 1°C in the 21st century.)

In section four the authors delve into the very complicated and long debated controversial issues of potential solar effects on climate. They cite the fact that sunspots have been relatively absent for certain century long periods, which have typical recurrence intervals of hundreds of years. The coincidence between the last such minimum, the "Maunder Minimum" between 1650 and 1700, and the "Little Ice Age" is cited. But what is not cited by the Marshall authors is the fact that before and after this 50 year long minimum the so-called Little Ice Age was in full force in many parts of the world. Furthermore, the coolest periods during this time did not necessarily occur in all places at the same time nor was it fully coincident with Maunder Minimum. In addition, a 10,000 year look at tree ring evidence shows many other such minima, but does not reveal consistent correlation of these sunspots minima with glacial advance periods, and therefore, no firm correlation can be established. This is why this area of research is still controversial, a point not adequately stressed in the Marshall document. Finally, the magnitude of natural, several century long global climate fluctuations during the past 10,000 year inter-glacial period is on the order of 1°C, which is at the low end of the 1° to 5°C range the Marshall authors concede as the consensus estimate for the next century.

Therefore, the higher probabilities are that whatever nature does on the sun or earth to cause natural fluctuations is likely to be swamped by manmade influence of greenhouse gases sometime between now and the first few decades of the 21st century. These relative probabilities get no prominent attention. Rather the lower probability scenarios are what the Marshall Institute authors focus on. Moreover, they cite recent evidence that some stars have been observed to have energy output changes on the order of a few tenths of a percent to explain recent global warming trends. By no means can this be cited to explain with high confidence the observed approximately 0.5°C warming trend of the past century. It is equally likely, as not mentioned by the Marshall Institution report, that a solar constant decrease from our sun could have been in progress during the past 100 years, and therefore, any greenhouse warming that has taken place could have been masked by such an event. Since the solar constant has not been well observed, except in the past decade, both scenarios are equally likely. Furthermore, if only a few tenths of a percent change in solar energy were responsible for the 0.5°C century long trend in climate over the past century, then this would suggest a planet that is relatively sensitive to small energy inputs. The Marshall Institute simply can't have it both ways: they can't argue on the one hand that small changes in solar energy output can cause large temperature changes, but that comparable changes in the energy input from greenhouse gases will not also produce comparable large signals. Either the system is sensitive to large scale radiative forcing or it is not, another factor not mentioned by the Marshall authors. Although they argue that a 33-year running average of sunspot numbers superficially resembles the temperature record of the past 100 years, they do wisely admit that this could well be a coincidence.

The Marshall authors go on to claim that "scientists' concerns for offering sound advice on the greenhouse problem have tended to rely on the observed temperature increase of 0.5°C since 1880 as their best evidence that the greenhouse effect is already here and that steps should be taken now to cope with its full development in the next century." (Marshall Institute, page 28.)

However, only very few people have made such a claim. Most scientists I know argue that it is not the performance of the planet in the past century, which only in the last decade is at the margin of the noise level of natural climate fluctuations, that motivates their concerns for the next century. Rather, our concerns are grounded in the very well-validated understanding of how radiative trapping by important trace gases like carbon dioxide, methane and chlorofluorocarbons can heat the surface. Further concern is based on the (less well) validated modeling sensitivity studies which suggest that something between 1° and 5°C warming is the most probable prediction for the next century, (e.g., NAS, 1987). Indeed, it will take another decade or two of observations, with a presumed continuing of the record heat of the 1980s, to establish to a high degree of confidence that the greenhouse forcing of the past cen-

tury is finally unambiguously detected. But, if we follow the Marshall Institute's advice and wait for such certainty before implementing actions we will then have to adapt to a much larger dose of change than if we attempt to slow it down now. That decision, of course, is a *value judgement*, not a decision that can be made based solely on any scientific method.

Herein is my principal objection to the Marshall report, and in fact, an objection so serious as to make me doubt the capability of the authors to provide a balanced scientific view. They claim "current forecasts of the manmade greenhouse effect do not appear to be sufficiently accurate to be used as a basis for sound national policy decisions." (Marshall Institute, page 23.) Furthermore, they argue that "it is our judgement that if a prudent investment is made in computing power, observing programs and added manpower, answers that have a usable degree of reliability can be provided to policy makers within three to five years." Thus, they recommend no current policy response to the present debate, other than more research. What I find so objectionable in these statements, particularly the former one, is that it is not a scientific judgement, but their value judgement, which they do not explicitly claim as their personal views of how to respond to the range of uncertainties. The second statement is technically inaccurate, I believe, in that virtually all knowledgeable scientists would never claim that we will have a strong consensus of atmospheric researchers as to the reliability of the regional distribution of time evolving climate changes in three to five years, regardless of the level of research effort. If left to its own devices, the climate community is likely to take twenty-five years to provide such information. If the kinds of "prudent investments" that the Marshall Institute authors do wisely call for were implemented, then it is my opinion, and one I believe is widely shared in the scientific community, that we could *accelerate* substantially the rate of building such consensus. But, a decade or so would still be needed before which high resolution, coupled with models of atmosphere, ocean, sea ice, land hydrology, ecosystems, and chemistry could be adequately run, tested and validated to provide credible regional forecasts. Of course, it is better to produce such forecasts in ten years than in twenty-five and the costs are small relative to the potential risks. Thus, I agree with the advice to invest in such research. But to claim answers will be clear within three to five years and therefore, policy should wait for them, is in my opinion a scientifically erroneous judgment as well as a value judgment with which I personally disagree strongly. People may legitimately disagree about values, but scientists must always make this explicit, and the absence of this is what has me so disturbed about the Marshall Report.

Finally, the authors provide no cost/benefit analysis of the risks or benefits of alternative actions now versus the risks and benefits of delay. In the absence of such studies, or even the citation to the few such studies that exist, the Marshall report's primary conclusion to delay policy actions has little merit.

Alan, I hope this is useful to you and that you can use it to good purpose.
Warm regards and best wishes in your new position.

Sincerely,
Stephen H. Schneider
Head

Interdisciplinary Climate Systems

3. National Research Council, *Carbon Dioxide and Climate: A Scientific Assessment* (Washington, D.C.: National Academy Press, 1979): 11 pp; National Research Council, *Changing Climate: Report of the Carbon Dioxide Assessment Committee* (Washington D.C.: National Academy Press, 1983): 496 pp; National Academy of Sciences, *Current Issues in Atmospheric Change*, (Washington D.C.: National Academy Press, 1987): 39 pp., are examples of National Academy reports in which the well-traveled 1.5°C-4.5°C warming range is cited. A current study by the National Research Council's Committee on Science, Engineering and Public Policy is likely to reaffirm that range, in full awareness of the current debate.
4. Intergovernmental Panel on Climate Change (IPCC), *Scientific Assessment of Climate Change*, 2nd Draft, March 1990 (Geneva: World Meteorological Organization).
5. R. S. Lindzen, "Greenhouse Warming: Science Versus Consensus" (unpublished—but widely circulated—manuscript, dated October 10, 1989). A less *ad hominem* ver-

sion was published as: R. S. Lindzen, "Some Coolness Concerning Global Warming," *Bulletin of the American Meteorological Society* 77 (1990): 188-199. In the first version Lindzen asserted that the NAS consensus overestimated global warming by a factor of four to eight. The published version some months later suggested a more moderate factor of two to five overestimation.

6. W. T. Brookes, "The Global Warming Panic," *Forbes*, (25 December 1989): 96-102.
7. W. T. Brookes, *op. cit.*
8. W. T. Brookes, "Greenhouse Showdown or Show Trial?," *Washington Times* (January 24, 1990): Fr.
9. J. F. B. Mitchell, C. A. Senior and W. J. Ingram, "CO₂ and Climate: A Missing Feedback?" *Nature* 341 (1989): 132-134.
10. J. Hansen, D. Jolinson, A. Lacis, S. Lebedeff, P. Lee, D. Rind and G. Russell, "Climate Impact of Increasing Atmospheric Carbon Dioxide," *Science* 213 (1981): 957-966; R. L. Gilliland and S. H. Schneider, "Volcanic, CO₂ and Solar Forcing of Northern and Southern Hemisphere Surface Air Temperatures," *Nature* 310 (1984): 38-41. See also, T. M. L. Wigley and S. C. B. Raper, "Natural variability of the Climate System and Detection of the Greenhouse Effect," *Nature* 344 (1990): 324-327.
11. H. W. Ellsaesser, "The Climatic Effect of CO₂: A Different View," *Atmospheric Environment* 18 (1984): 431-434.
12. M. Grubb, "The Greenhouse Effect: Negotiating Targets," *Energy and Environmental Program* (London: Royal Institute of International Affairs, 1989): 56 pp.
13. S. Engelberg, "Sununu Says He Revised Speech on Warming," *New York Times* (February 5, 1990): A15.
14. W. D. Nordhaus, "To Slow or Not To Slow: The Economics of the Greenhouse Effect," manuscript submitted to the Panel on Policy Implications of Greenhouse Warming: Committee on Science, Engineering and Public Policy (Washington D.C.: National Research Council, 1990).
15. To understand why one prominent economic model is very questionable in projecting economic costs of CO₂ emissions cuts (usually stated as a loss of gross national product) we need to explain briefly how it works. In essence, the econometric model used to project future GNP performance as a function of energy prices is calibrated by statistical methods (called regression equations) that match GNP change over time with energy prices over time. For example, following the OPEC oil price rise of 1973, GNP responded by decreasing for several years. Then, as economies adjusted to the higher prices and energy efficiency was encouraged by the price shock, GNP grew once again even though total energy consumption changed very little for the next half dozen years. Clearly, the immediate transient response of the GNP to energy price changes will be different from the medium term adjustment, which should again be different over the very long term. Yet, an econometric model used to project GNP response to CO₂ controls (which were dealt with as an equivalent energy tax) was run over 100 years into the future based on curve matching that included data on short term, transient conditions. Seen in this light it is not surprising that such models would predict large GNP losses 100 years into the future when energy prices go up—it is built into the model by regression equations that include transient situations and then apply them over the very long term. It is also no wonder such models were severely criticized at the U.S. National Academy of Sciences debate. More on this debate can be found in Williams, R. H., 1990 (Draft). "Will Constraining Fossil Fuel Carbon Dioxide Emissions Really Cost So Much?" A Critique of: Manne, A. S. and R. Richels, 1990 (Draft). "Global CO₂ Emissions Reduction—the Impacts of Rising Energy Costs," February 1990.
16. A. Raval and V. Ramanathan, "Observational Determination of the Greenhouse Effect," *Nature* 341 (1989): 758.
17. J. F. B. Mitchell et al., *Nature*.
18. In 1990 two NASA satellite experts [Spencer, R. W. and J. R. Christy, "Precise Monitoring of Global Temperature Trends from Satellites," *Science* 247 (1990): 1558-1562] stated the following:

Passive microwave radiometry from satellites provides more precise atmospheric temperature information than that obtained from the relatively sparse

distribution of thermometers over the earth's surface. Accurate global atmospheric temperature estimates are needed for detection of possible greenhouse warming, evaluation of computer models of climate change, and for understanding important factors in the climate system. Analysis of the first ten years (1979 to 1988) of satellite measurements of lower atmospheric temperature changes reveals a monthly precision of 0.01°C, large temperature variability on time scales from weeks to several years, but no obvious trend for the ten-year period. The warmest years, in descending order, were 1987, 1988, 1983, and 1980. The years 1984, 1985, and 1986 were the coolest.

The usually warm early 1980s were followed by a few cooler years that were coincident with the explosive volcanic eruption of El Chichon. This was followed a few years later by the warmest years in the instrumental record, 1987 and 1988 (see Fig. 4, p. 85). Whether the cool year-volcano correlation was coincidence or cause and effect is not certain. What is important is that the instrumental record for the 1980s correlated well with the satellite remote-sensing technique for mid-tropospheric temperature of Spencer and Christy. Yet, most of the media stories following the publication of this paper ignored the correlation between the thermometer and satellite records, and instead extrapolated out of context a sentence of the authors to the effect that no global warming trend was evident in the ten years of their analysis. Of course, no responsible scientist would ever claim that a global warming signal could be detected above background noise from ten years of data! Nevertheless, a frequent media interpretation of this study was that there was "no global warming trend"—clearly a serious misinterpretation of the facts given the one-hundred-year record (on Fig. 4).

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Testimony to the House Subcommittee on Health and the Environment

February 22, 1991

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Two years ago I testified that evidence was beginning to accrue indicating that the popular vision of a climate changed by doubling carbon dioxide--a global temperature rise of 4°C, disastrous sea level rise, and civil strife resulting from ecological chaos--may have been flawed. In the succeeding two years there had been mounting and compelling evidence that the likelihood of this ecological disaster is becoming more remote.

The fact that this is counter to a politically popular vision is a result of the premature politicization of the global warming problem. The normal process in the science of complex issues--in which there is a creative and dynamic tension between the empirical and the dynamic, between the inductive and deductive processes, has characterized the global warming issue. Put in more pedestrian terms, the observed data seemed at variance with climate model calculations, and the normal process of science is an attempt to reconcile the two. Unfortunately, this normal process is now refracted by the prism of politics, which endangers science itself.

It is often stated, for example, that there is a monolithic consensus of scientists that the popular vision is in fact correct. Nothing could be further from the truth, and nothing could hurt the normal process of research more. (Remainder not read) There are in fact two prevailing views, and the second is that the climate change issue is potentially neutral or perhaps even beneficial. Both of these views are based upon a voluminous scientific literature, and it is my opinion that the observed data support the latter, which is at variance to the climate models of the mid-1980's that established the politically popular vision.

(Not read) This more empirical view of climate change tends to be championed by those who are intimately familiar with the various records of climate over the last 120 years. In terms of actual numbers, I suspect that this labor pool is in fact smaller than the pool of dynamic modellers, but this is a result of the fact that climate modelling is a very labor intensive operation, while data analysis is not. Thus, if a vote were taken, there might be larger numbers favoring the politically popular view, but only because there are fewer people directly involved in analysis of the data stream that seems at variance with that view. Nonetheless, nature does not poll scientists and act accordingly.

The scientific community recently witnessed a rather striking example of the diversity of opinion that exists among the active researchers in this area. While Richard Lindzen of the National Academy of Sciences and the Massachusetts Institute of Technology recently wrote that the active research community in this area is very small (I would estimate a

hundred or so), thirty of these scientists recently met at Arizona State University for a research symposium built around a central hypothesis: *The politically popular vision of climatic change is wrong*. Their findings were recently transmitted in a letter to President George Bush, dated February 1, 1991. I am including copies of the letter and the associated research document as a part of this testimony.

These scientists produced a research agenda titled "Global Climatic Change: A New Vision for the 1990's". While all of these scientists agree that the Earth will undergo some warming, their concern that the politically popular vision is distorted is heightened as calls for economically significant remedies become more strident.

Why would such a significant fraction of the research community develop this hypothesis? The lines of evidence include:

- The Magnitude of Observed Warming.** The historical record of ground based temperature suggests global warming for a doubling of carbon dioxide will be far below the 4.2°C that fuels the popular vision. The satellite record further indicates that even these historical records are overestimating what small warming has occurred. Evidence strengthens daily that economic activity is also producing emissions that have prevented warming.
- The Timing of Observed and Projected Warming.** New generation climate models project most of their warming in high latitude winter, which partitions most warming into the night. This mitigates most of the deleterious effects that fuel the popular vision and in fact lengthens growing seasons. The warmth of 1990 was consistent with the projection as were last year's world-averaged record crop yields.
- The Growth Enhancement Caused by Carbon Dioxide.** Carbon dioxide is currently a limiting nutrient for plants, and a voluminous scientific literature demonstrates enhanced plant growth and water use efficiency as its concentration increases.

It is truly ironic that the highly politicized nature of the global warming problem tends to suppress support for the position that gives a more balanced view of the future, and that those espousing this view are somehow labelled as politically motivated. They are only interpreting a complicated problem in the light of their considerable experience.

On Monday, I was asked to speak to the American Association for the Advancement of Science on whether or not policy on global warming was based on science. My answer was yes--and no. A policy to explore the profound discrepancy that exists between theory and observation, prior to any expensive remediation seemed, to me to be based on sound science and an intimate knowledge of the history of environmental science. A policy to take drastic action now, such as profound limits on carbon emissions, is, in my opinion, similarly *not* based upon defensible and internally consistent science.

ENVIRONMENTAL DEFENSE FUND

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Testimony of Dr. Michael Oppenheimer
before the
Subcommittee on Health and the Environment
U.S. House of Representatives

21 February 1991

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My name is Dr. Michael Oppenheimer. I am an atmospheric physicist and a senior scientist with the Environmental Defense Fund (EDF) in New York. EDF is a private, non-profit organization with 200,000 members, dedicated to the preservation of the natural environment and the protection of human health.

I currently serve as chairman of EDF's Global Atmosphere Program. In this capacity, I lead a small group of scientists involved in research on various aspects of atmospheric change. In addition, I have participated in steering committees for two recent assessments of climate change issues sponsored by the World Meteorological Organization, the so-called Villach-Bellagio process in 1987 and the Second World Climate Conference in 1990. I am a member of NASA's advisory committee on the Atmospheric Effects of Stratospheric Aircraft, and I served as a reviewer for the scientific assessment of the Intergovernmental Panel on Climate Change (IPCC).

I would like to thank the committee for this opportunity to testify on the nature and severity of anticipated global climate change, and on the importance of international action to address this problem. I shall focus on the general characteristics of anticipated global warming and on the uncertainties in the projections of future climate, in order to provide a scientific framework for assessing appropriate responses. I shall also discuss the findings of recent research by scientists at EDF and other institutions which suggest that processes (called "temperature feedbacks in the carbon cycle") not currently considered in climate models may accelerate the projected warming.

It is my overall view that global warming due to anthropogenic emissions of the greenhouse gases presents humanity with singular risks and opportunities: if we act now to reduce the risk of rapid climate change, we can simultaneously prevail in our struggles against air pollution, oil spills, and dependence on imported energy. On the other hand, if we demur and climate should change rapidly, society may face a future of economic disruption and political instability, while many natural ecosystems may have no future at all.

The Scientific Picture

The IPCC report provides a timely assessment of our scientific understanding of greenhouse gas emissions, their effect on the atmosphere, and the projected climatic consequences of their increase. I will highlight only a few issues which are particularly relevant to the formulation of a response strategy.

OVERVIEW

We are entering an era of inadvertent human control of global climate. Earth's natural greenhouse effect is being augmented by the increasing emissions of anthropogenic greenhouse gases, particularly carbon dioxide, various halocarbon compounds (e.g. CFC's), methane, nitrous oxide, and tropospheric ozone. Although a variety of industrial and agricultural activities contribute to these emissions, the lions share of future greenhouse gas growth will result from fossil fuel combustion. In spite of the complexity of the climate system, we can predict with near certainty that increased atmospheric concentrations of these gases will lead to global warming.

The reasons for such confidence derive from over one hundred and fifty years of research on the physical basis of the greenhouse effect, and the observation of the radically different climates of our neighboring planets. Venus, with an atmosphere dense in carbon dioxide, has a surface temperature near 900 Fahrenheit; Mars, with a relatively weak greenhouse effect compared to Earth, has a temperature of less than -50 Fahrenheit.

Considerable uncertainty attaches to the crucial issue of how much and how fast the earth will warm, given a particular trajectory of future emissions. Nevertheless, several independent lines of evidence suggest that the rate of growth projected for emissions over the next century will produce a historically significant warming. These include the results of computer simulations of global climate and paleoclimatic evidence of the relation between greenhouse gas levels and temperatures in the distant past. A primary source of this evidence is provided by studies of ancient air bubbles included in ice cores. Temperature, carbon dioxide, and methane levels have tracked closely over 160,000 years. Changes in the levels of these greenhouse gases were sufficient to account for a considerable portion of the warming and cooling which has accompanied the periodic beginning and end of ice ages.

A range of computer climate simulations (explored by the IPCC) indicates that during the first quarter of the 21st century, global average temperature is predicted to exceed levels attained during the entire history of human civilization. By the end of the 21st century, earth may warm by 4 to 9 degrees Fahrenheit above today's level, a warming nearly equivalent (at the upper end of the range) to that which ended the last ice age, bringing about temperatures not attained during the previous history of the modern human

species. The anticipated rates of warming are unprecedented, on a sustained basis, during the entire history of civilization and, also surpass the adaptation abilities of many natural ecosystems.

Global average sea level will rise as earth warms. The temperature changes above imply a 30-110 centimeter increase over the next century, approximately 3 to 6 times the rate over the last century. With more than one-half of humanity now resident within 50 miles of the coast, and with many people living in densely-populated deltaic regions, sea level rise of this magnitude could spell disaster for some of us, costly adaptation for most of us, and an unprecedented global refugee problem affecting all of us.

Other regional consequences of warming are harder to predict. Changes in storm patterns, precipitation, and evapotranspiration will alter water availability for human and agricultural consumption. A general trend to mid-continent drying, which would cause significant agricultural shifts in the U.S., is predicted in several computer simulations. The net consequences for agriculture of increases in carbon dioxide and changes in soil moisture will change from place to place, but many areas with already-marginal food supplies may periodical come under stress. Global supplies could decrease, even with advances in technology, in years of widespread drying. In a world where food does not always get to those who need it, the additional stress of global warming can be expected, periodically, to wreck considerable havoc.

CRITICAL ASPECTS OF THE WARMING

Several characteristics of projected global warming are unique, and bear special implications for policy. I shall briefly elaborate on those aspects here.

Continuity

No known processes, except the exhaustion of the sources of the gases, are expected to limit the warming in the foreseeable future. The warming is expected to be continuous as long as greenhouse gas concentrations increase. In order to halt the increase in carbon dioxide immediately, a reduction in emissions of greater than 60% would be required.

Irreversibility

Carbon dioxide has a very long lifetime in the atmosphere. Once carbon dioxide levels are enhanced by human activity, they will not return to natural levels for centuries. Intentional means of removing carbon dioxide, such as reforestation, may be capable of speeding this process, but only modestly. Thus, the carbon dioxide buildup must be regarded as irreversible on a human timescale. CFC's and nitrous oxide exhibit similar behavior.

Lag

The large mass of water in the oceans is slow to warm, and this thermal inertia retards the warming of the atmosphere. Consequently, the warming resulting from today's emissions will not be fully manifest for decades. This

lag between emissions and realized warming means that at any time, including now, more warming is "in the pipeline" than is evident from global temperature measurement. Current commitment to warming is reckoned at more than two degrees Fahrenheit (in the best estimate IPCC scenario).

The Surprise Factor

The climate system is highly non-linear. These non-linearities, or feedbacks, limit our ability to comfortably extrapolate into a climate regime which earth has not visited for millions of years. Some feedbacks, like the increase in heat-trapping water vapor which follows from warming, are fairly well characterized by theory and measurement. Others, like the changes in cloudiness which both trap heat and reflect sunlight, are the source of most of the considerable uncertainty in the projected range of warming for the next century.

Some feedbacks not even considered in computer simulations, could cause considerable amplification of the projected warming. For example, several researchers have recently investigated the potential acceleration of carbon dioxide growth by the warming itself. This feedback could occur as follows. Much more carbon is naturally transferred annually from the land and ocean into the atmosphere, and visa versa, than is emitted by human activity, including fossil fuel combustion. But these transfers are so closely balanced that, over centuries, they generally cause little long term change in atmospheric carbon dioxide.

Several investigators, among them George Woodwell, have suggested that a secular temperature increase could upset this balance and cause the atmospheric buildup of carbon dioxide to accelerate. Two recent studies, including one at the Environmental Defense Fund which I supervised (see attached article) have noted a statistical relationship between natural temperature fluctuations and the rate of buildup of carbon dioxide a few months later (see attached figure). These findings are consistent with, but do not prove, the hypothesis that that temperature fluctuations with durations of up to several years affect natural carbon transfers for an equivalent duration. Should this effect extend for many decades, a significant global warming-carbon dioxide feedback could occur.

C. D. Keeling of Scripps Oceanographic Institute has shown that the rate of carbon dioxide buildup has indeed accelerated over the last 15 years, a period of overall warming. Other factors, like changes in the rate of deforestation by humans, also came in play during that time, but temperature-carbon dioxide feedback may well have played a role in the accelerated buildup. Unfortunately, sufficient data to confirm the latter speculation may not be in hand until the earth is already significantly warmer than today.

But the possibility that such processes may cause warming projections to be underestimates needs to be taken into account in assessing the risk of allowing emissions to continue to increase. We have other recent---and unfortunate--- experience with such surprise processes not accounted for in

models: those which cause the ozone hole in Antarctica, and the similar depletion in the Arctic. Together, these phenomena appear to have drawn down global ozone levels, and with them, our protection from ultraviolet radiation.

SUMMARY

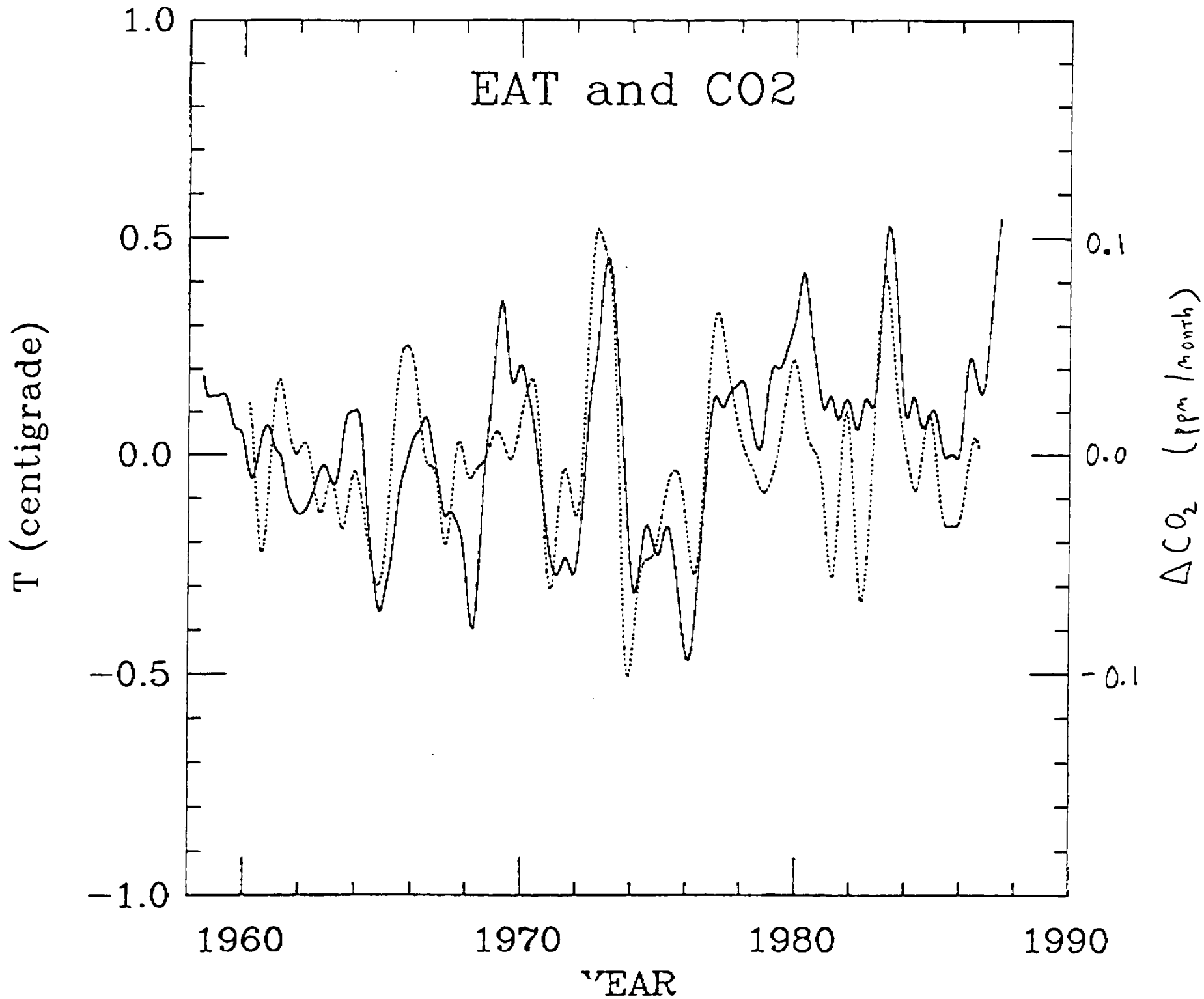
Consider these four properties: continuity, irreversibility, lag, and surprise. Taken together, they translate into a compelling need to reduce the emissions of greenhouse gases, particularly carbon dioxide, now. Continuity means the problem will only intensify until we act. And largescale action, indeed, is required to stabilize greenhouse gas concentrations. Irreversibility and lag, taken together, mean that we will never have direct evidence of the consequences of our actions until it is too late to repeal them. Furthermore, if we decide at any one time that we cannot tolerate the warmer world we have created, we are still in for more trouble, no matter what action we might realistically take, before the warming ceases. Additional, irreversible warming is always in the pipeline.

Consider these properties in the context of the projected record rate of warming, a warming which, at the low end of estimates, would strain the ability of many societies to adapt, which at the upper end, may spell havoc for all societies, and which, at either end of the spectrum, spells doom for many natural ecosystems. Consider that global temperature has remained stable within a narrow range of about 2 degrees Fahrenheit in either direction for 10,000 years. Consider that, as a result, there is much we do not know about a warmer world, and many of these questions will only be resolved by the (ill-advised) experiment of watching the warming proceed. The only prudent course is to begin to reduce emissions, now.

Attachments:

The figure illustrates equatorial air temperature deviations (EAT) and monthly carbon dioxide increment in the atmosphere over a thirty-year period. Seasonal variations have been removed from both series, and carbon dioxide has been further adjusted to remove the fossil fuel component.

The article is a galley proof of a Scientific Correspondence to appear in 14 February 1991 issue of Nature.



HIV Infectivity

SIR—It has been thought that infection by the human immunodeficiency virus (HIV) occurs only with exposure to intact virions or infected cells. We assessed the validity of this assumption by attempting to infect the monkey *Macaca fascicularis* with simian immunodeficiency virus of macaques (SIV_{MAC}) proviral DNA.

Recombinant bacteriophage lambda DNA containing SIV_{MAC} was prepared as described in refs 1 and 2. The starting phage stock was expanded in *Escherichia coli*; the resulting higher-titre suspensions were used to infect aliquots of bacterial host at an m.o.i. of 0.05. Each infection was cultured in LB medium, bacterial debris removed by low-speed centrifugation and phage sedimented by treating the supernatant with 10% polyethylene glycol and 1 M NaCl. Particles were precipitated, further purified, and digested with RNase A/Proteinase K as described in refs 2, 3. DNA was resuspended in distilled water and adjusted to 0.5–1 mg ml⁻¹. The yield was about 1 mg l⁻¹ of culture. (Further details of the method available on request from N.L.L.)

Four healthy adult *M. fascicularis* each received a single intramuscular inoculation of 200 µg DNA. Heparinized blood was taken from these animals once a month following inoculation. Two of these animals had seroconverted by 1 month following DNA inoculation, as determined by indirect immunofluorescence on SIV_{MAC}-infected H9 cells. A third monkey seroconverted within 2 months of inoculation. Peripheral blood lymphocytes obtained from the four monkeys at each bleeding were CD8⁺ lymphocyte-depleted, concanavalin A-activated, and expanded in interleukin-2-containing medium. Supernatants of the cultured lymphocytes from the three animals that seroconverted contained reverse transcriptase activity and had gag antigen (p28) detected in an antigen capture assay. We used electron microscopy to demonstrate intact viral particles in the cells of one of these cultures. These culture supernatants also transmitted SIV_{MAC} infection *in vitro* to lymphocytes of normal *M. fascicularis*. Thus, intact SIV_{MAC} could be isolated from peripheral blood lymphocytes of three of the four monkeys inoculated with phage DNA.

The phage DNA did not infect *M. fascicularis* lymphocytes *in vitro*. Aliquots of 10⁷ concanavalin A-activated, interleukin-2-expanded, CD8⁺ cell-depleted *M. fascicularis* lymphocytes, despite supporting the replication of intact SIV_{MAC} virus, did not yield replicating virus after seeding with phage DNA, implying that there was no contamination of the phage DNA preparation with intact virus.

Our observations will facilitate work

being done on genetic determinants of AIDS virus pathogenesis in nonhuman primates. Perhaps more important, these findings raise the possibility that AIDS virus DNA by itself may be infectious for laboratory investigators, suggesting that viral DNA handling practices may require re-evaluation.

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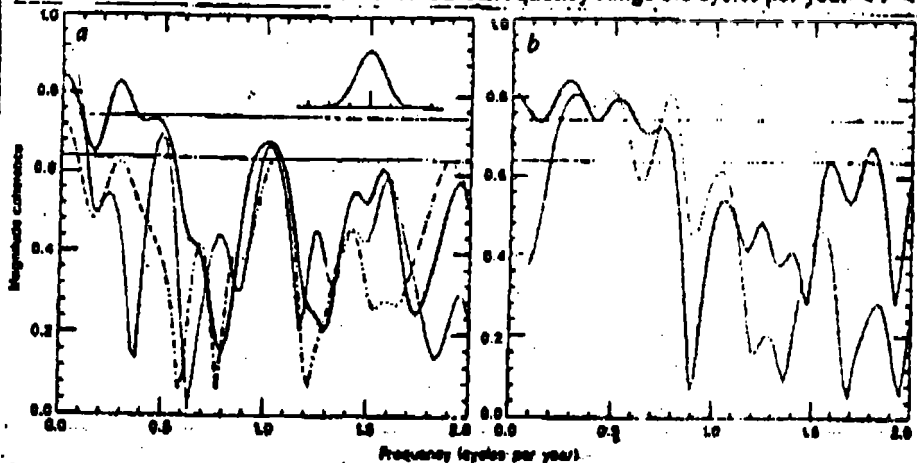
CO₂ and temperature *we*

SIR—Kuo *et al.* have shown¹ that the monthly concentration of atmospheric carbon dioxide at Mauna Loa, Hawaii exhibits statistically significant coherence over a range of frequencies with monthly surface air temperatures averaged over the entire globe. The CO₂ record lags behind the temperature record; this lag is consistent with the hypothesis that temperature fluctuations or associated meteorological changes² cause the short-term CO₂ anomalies rather than vice versa. In any event, fluctuations in CO₂ concentration at frequencies ≥ 0.2 per year are too small to cause the observed

temperature variations by the greenhouse effect. We have analysed air and sea surface temperatures averaged over different regions of the Earth, and find that air temperatures averaged over equatorial regions and sea temperatures averaged over the equatorial Pacific are more highly correlated with the CO₂ anomalies than air temperatures averaged over non-equatorial northern (90° to 23.6° N) or southern (90° to 23.6° S) regions. This result suggests that the sources and sinks of atmospheric CO₂ in question lie in the equatorial regions.

We have used the Goddard Institute for Space Studies (GISS) monthly air temperature record from land stations³, monthly sea surface temperature (SST) data from the Comprehensive Ocean-Atmospheric Data Set (COADS)⁴ and the monthly atmospheric CO₂ record at Mauna Loa⁵ to search for coherences between the temperature and the month to month change in the CO₂ concentration. The seasonal cycle in both the CO₂ and temperature time series is removed by calculating the departures from the mean values for each month of the year. Spectral analysis allows us to ascertain directly the degree of coherency between the monthly temperatures and the monthly rate of change in CO₂ at different frequencies. We use a gaussian spectral window of half-width $\sigma = 0.07$ per year and apply a smooth cutoff to each end of the time series to reduce leakage.

Part *a* of the figure shows the coherency between the monthly rate of change of CO₂ and surface air temperatures averaged over the entire globe, over non-equatorial northern regions and over non-equatorial southern regions during March 1958 to December 1987. The probability that the observed coherences between the global air temperature and the month to month change in CO₂ in the frequency range 0.0 cycles per year $< \nu <$



Coherence between the monthly rate of change of CO₂ and temperatures averaged over different regions. Upper and lower horizontal lines, 99% and 95% confidence limits, respectively. The spectral window appears in the inset of *a*. *a*, Solid line, global air temperatures; dashed line, air temperatures in the northern region (90° to 23.6° N); dotted line, air temperatures in the southern region (90° to 23.6° S). *b*, Solid line, equatorial air temperature; dotted line, SST in the equatorial Pacific.

0.55 per year occurred by chance is less than 5%. The rise in the coherence at frequencies < 0.15 per year is due to long-term increasing trends in both series'. As the non-equatorial northern and southern regions show much weaker coherence for $\nu > 0.1$ cycles per year, we conclude that most of the short-term correlations present in the global temperature record originate in the equatorial region. Indeed, equatorial air temperatures from 23.6° S to 23.6° N are coherent with CO₂ over a broader range of frequencies than temperatures averaged over the entire globe (h in the figure). Coherences in the equatorial record at frequencies higher than roughly 0.5 cycles per year are apparently washed out in the global average. Sea surface temperatures averaged over the equatorial Pacific region (20° S to 20° N and 80° W to 180°) show coherences comparable to those in the equatorial air temperature record at frequencies greater than about 0.25 per year. Both the equatorial air and the sea surface temperature show three peaks in the coherence at frequencies of approximately 0.3, 0.5 and 0.8 cycles per year, but we do not know if they represent physically distinct processes.

Phase analysis shows that the SST fluctuations lead the CO₂ anomalies by about 4 months but equatorial air temperature leads CO₂ by only 1 month. This difference is not surprising as the air temperature is strongly correlated with the SST but lags behind by about 3 months. The relative time lags are consistent with the hypothesis that fluctuations in SST set off changes in the equatorial air temperature and the CO₂ concentration. If SST variations directly affect equatorial

sources and sinks then the lag is consistent with the atmospheric transport time for a parcel of CO₂-enriched or CO₂-depleted air to reach Mauna Loa.

The flux of CO₂ between the atmosphere and the equatorial regions can be affected by fluctuations in the temperature through changes in CO₂ solubility, upwelling of CO₂-enriched deep water and availability of nutrients for the organic carbon pump. Associated changes in wind and precipitation also affect terrestrial biota. The coherence between temperature and CO₂ is significant over a range of frequencies in addition to those that characterize ENSO². It is important to consider whether these mechanisms could lead to a significant positive temperature-CO₂ feedback on the longer timescales for which global warming is projected to occur.

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Whale carcasses

Six—Communities of benthic marine invertebrates, including clams and other animals supported by chemosynthetic processes, are associated with whale skeletons on the deep-sea floor'. Such animals, apparently dependent upon sulphide-rich reducing microenvironments created by the decomposing carcasses, are closely related to taxa found at hydrothermal vents, cold seeps and on sunken wood'. We have found clams associated with three early Tertiary fossil whales from northwestern Washington State, and our results indicate that molluscs may have been utilizing this trophic resource for approximately the past 35 million years.

The fossil whales, in the collections of the Natural History Museum of Los Angeles County, are probably previously unknown taxa. They were collected at three separate localities along the north shore of the Olympic Peninsula, from concretions within hemipelagic siltstones of the Makah Formation, deposited at lower to middle-bathyal depths' and are

early Oligocene (about 35 million years) in age'. These basin-plain and outer-fan fringe deposits' are otherwise nearly barren of macrofossils, and only a few widely scattered deep-water gastropods (such as *Aforia* spp. and *Bathyhembis* spp.) and large isopods' have been found in them.

Two of the fossil whales are small (less than 4 m body length) primitive mysticetes (baleen whales). Small clams (*Modiolus* sp.) are found in the immediately surrounding matrix. There are external moulds of clams (*Thyasira*) in the matrix on the outside of one skull and within the cranial cavity. The third whale is a smaller (less than 2 m), primitive odontocete (toothed whale). A single clam (*Lucinoma hannibali*) was found nestled among its ribs and vertebrae.

Both valves of all these clams are still articulated in the living position, and the *Thyasira* inside the skull seems to be too large to have entered accidentally through the foramen magnum, so it probably matured within the cranium. The clams, therefore, seem to have been preserved where they lived and grew rather than

having been transported. Fossils of *Lucinoma hannibali* and *Modiolus* sp. were also found associated with a single 15-cm-long piece of fossil wood from the same stratigraphic horizon of the Makah Formation where the whales were found.

The association of fossil whales and clams in the Makah Formation is, in our opinion, not coincidental. Extant species of clams in the same genera (*Modiolus*, *Thyasira* and *Lucinoma*) have been reported from modern' and ancient reducing environments'. Their *in situ* relationship with the Oligocene whales in otherwise essentially fossil-barren deposits strongly suggests that they were part of a chemosynthetic community supported by whale bone-oil seepage.

Smith *et al.*' suggested that whale carcasses could be 'stepping stones' for dispersal of such benthic invertebrates, especially vent faunas, that depend on chemosynthesis. But, as pointed out by Tunnicliffe and Juniper', whale carcasses are not good vent analogues. Another problem for dispersal of vent faunas via whale carcasses is the timing. There is no record of whales in the Pacific Basin before the latest Eocene (about 39 million years ago)^{1,2}; however, cold methane-seep communities' and (probably) hydrothermal-vent communities existed in deep-ocean basins in the northeast Pacific as early as the middle Eocene. The carcasses of Oligocene whales that lived in the North Pacific, as exemplified by those from the Makah Formation, were apparently not large enough to sustain many organisms. Because whales of sizes comparable to some of the larger (15 m body length) recent mysticetes are unknown in the Pacific Basin before the late Miocene', carcasses large enough to sustain many chemosynthetic animals were unavailable until about 11 million years ago. It is, therefore, very unlikely that whales were significant in the early dispersal of vent faunas.

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**TESTIMONY OF
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**BEFORE THE
SUBCOMMITTEE ON HEALTH AND THE ENVIRONMENT
U.S. HOUSE OF REPRESENTATIVES**

FEBRUARY 21, 1991

POTENTIAL HEALTH IMPACTS OF GLOBAL WARMING

POTENTIAL HEALTH IMPACTS OF GLOBAL WARMING

The impact of variable climate on human health and well-being is becoming a topic of increasingly intensive study, partially because of the potential threat of an anthropogenic-induced global warming. The majority of the climate/human health evaluations in the U.S. concentrate on mortality, as these data are not difficult to obtain, and they are much easier to interpret than most sources of general morbidity data, such as hospital admissions tallies or visits to the doctor. This testimony will concentrate specifically on weather-related mortality, and how it might change in a warmer world.

There has been considerable research on present-day climate/mortality relationships. For example, studies at the Centers for Disease Control have identified a number of factors that may inhibit the onset of heat stroke, such as consumption of fluids, availability of air conditioning, and living in well-shaded residences. Other researchers have noted that mortality attributed to weather seems to vary considerably with age, sex, and race, although there is disagreement in defining the most susceptible population group. Evaluations have been performed for winter weather impacts as well, and mortality increases have been noted during extreme cold waves.

Our research is unique in two ways. First, it represents the first attempt to evaluate the impact of weather upon mortality on a national scale, which allows for a detailed spatial analysis. Second, we are the first to develop estimates of mortality for the mid-21st century assuming that a global warming takes place. Thus, this testimony will comprise these two important facets: (1) a present-day spatial evaluation of weather-related mortality, and (2) estimates of what might happen to weather-related mortality in a warmer world, using weather scenarios developed by NASA's Goddard Institute for Space Studies (GISS).

Historical Weather/Mortality Relationships

Many studies have shown that oppressively hot weather imposes a great stress on the physiological responses of the human body, and this is manifested in the form of increased mortality during these conditions. However, the degree of inter-regional response was vastly underestimated until recently, when a U.S. EPA-funded study of weather-related mortality for 50 U.S. cities indicated a systematic disparity across climatic regions.

The EPA study demonstrated that many cities in the northeastern and midwestern United States show a sharp rise in total mortality during unusually hot weather conditions, and in some cases, daily mortality can be more than double baseline levels when the weather is oppressive. Interestingly, mortality rates rise only after a "threshold maximum temperature" is surpassed, and this threshold varies regionally based on the frequency of very hot weather. For example, the five cities which demonstrate the greatest rise in mortality during very hot conditions are New York, Chicago, Philadelphia, Detroit, and St. Louis, respectively. The threshold temperatures for these cities are: New York: 92°F; Chicago: 91°F; Philadelphia: 92°F; Detroit: 90°F; and St. Louis: 96°F.

The magnitude of the threshold temperature appears to be related to its frequency across these cities; for example, a maximum temperature of 96°F in St. Louis occurs with approximately the same frequency as a maximum temperature of 90°F in Detroit. This strongly suggests that the notion of a "heat wave" is relative on an inter-regional scale, and is dependent upon the frequency of a given maximum temperature.

However, there is also evidence to refute this notion. Mortality rates in the southern and southwestern United States do not seem to be affected by weather in the summer, no matter how high the temperature. For example, the cities of Dallas, Atlanta, New Orleans, Oklahoma City, and even Phoenix show little change in mortality even during the hottest weather. In fact, threshold temperatures for these cities are virtually impossible to define. One possible explanation may involve the variance in summer temperatures between the two regions. In the northern and midwestern cities, the very hot days or episodes are imbedded within periods of cooler weather. Thus, the physiological and behavioral "shock value" of a very high temperature episode is quite high. This point is further substantiated by the fact that most of the high mortality days occur during hot weather early in the summer season. Thus the first or second heat episodes of June or early July are much more critical than a comparative episode in August. For example, during an average summer, 31 people die of heat-related causes in Chicago in June, while only 13 die in August. This is in spite of the fact that August is traditionally much hotter in Chicago than June. In the southern cities, the hottest periods are less unique, as they do not vary as much from the average temperature. This seems to play a role in diminishing the impact of a very hot episode on human mortality.

The relationships between weather and mortality appear to be much weaker in winter. While it is true that daily winter mortality averages about 10 percent higher than summer, there is no apparent temperature threshold below which mortality totals increase dramatically. In addition, the regionality in mortality which was apparent in the summer data is not evident in winter, although death rates are slightly higher in the Northeast and the Midwest than in other parts of the country. Finally, the generally higher winter mortality totals appear to be related to a seasonal increase in infectious diseases, such as influenza. It is probable that inclement weather forces people indoors and in closer contact, creating an environment which increases the probability of microbial or viral infection.

Weather-Mortality Predictions in a Warmer World

What do these mortality/weather responses imply for the warmer earth that many believe will exist in the 21st century? The answer depends primarily on how the population acclimatizes to this change in conditions. People might react to increased warmth in several ways. First, they might physiologically acclimatize, implying that changes in the physical make-up of humans might occur (such as an increased sweat rate) to account for the warmer weather. Second, there may be behavioral acclimatization, which might involve increased adeptness in avoiding stressful conditions by changing lifestyles. Third, acclimatization might take the form of a changing urban

environment, in which dwellings are constructed which are more efficient in dispersing heat during very hot weather.

Assuming that people react to weather in a warmer world much as they do today (implying little or no acclimatization), it is quite likely that deaths from heat stress-related causes will increase dramatically. Thus, our research indicates that regional climate changes, created by a doubling of CO₂ levels as estimated by the GISS model, could induce a sevenfold increase in heat-related deaths by the middle of the 21st century if acclimatization does not occur. This would render heat-related deaths as a major killer, rivaling the present number of deaths from leukemia. The greatest brunt of this increase would be borne in the northeastern and midwestern U.S., and it is estimated that the number of heat-related deaths in New York City would rise from the present 320 during a typical summer today to 1,743 during a typical summer in the mid 21st century. Under such circumstances, the number of days exceeding the threshold temperature would show at least a twofold increase, contributing to this dramatic rise.

Of course, a more likely scenario is that some degree of acclimatization will occur, as the gradual increase in warmth over the next 60 years would permit time for certain behavioral and physiological adjustments. A satisfactory means to account for this acclimatization has alluded the scientific community, although an attempt was made in the EPA Report to Congress on the potential effects of global climate change. Analog cities, which possess present day weather most duplicative of predicted mid-21st century weather for each evaluated city, were established to account for full acclimatization. For example, the use of the GISS doubled CO₂ climate change scenario to estimate weather in Atlanta in the mid-21st century will produce a regime which approximates the present weather in New Orleans. Since New Orleans residents are fully acclimatized to this regime, the weather/mortality relationships that exist today for New Orleans can be utilized for the mid-21st century estimated climate in Atlanta to account for full acclimatization.

Employing this acclimatization procedure, new estimates were developed for the number of heat stress-related deaths in the mid-21st century, yielding very different results from the unacclimatized estimates. Rather than the sevenfold increase developed for the unacclimatized model, less than a twofold increase results when accounting for acclimatization. In fact, some cities actually show a decrease in heat-related mortality if the population fully acclimatizes to a climate change. For example, the number of heat-related deaths which occur in an average summer today in Los Angeles is 84. If residents in Los Angeles fully acclimatize to the increased warmth expected in the mid-21st century, the number of heat-related deaths is estimated to drop to virtually zero. Astoundingly, if residents of Los Angeles don't acclimatize at all, the number of heat-related deaths estimated for an average summer in the mid-21st century rises to 1570! Similar disparities between acclimatized and unacclimatized estimates are noted for some northern and midwestern cities such as Detroit, New York, and St. Louis.

This wide variation has much to do with the technique used in this evaluation to account for acclimatization. Since the climate analogs for the northern cities are other cities located further south, and considering that southern populations respond much less dramatically to heat, it is not surprising that the fully acclimatized mortality estimates are so low. This points to some

shortcomings within our acclimatization procedure. First, the only similarities drawn between the target and analog cities relate to climate alone, with no consideration of possible urban structural or architectural disparities. For example, many of the low income population in the South, who are especially vulnerable to heat stress due to a lack of air conditioning or other amenities, reside in small frame houses which, although far from luxurious, are well-adapted to the rigors of a southern summer. They are often light colored with metal (reflective) roofs and well-ventilated with windows or doors on four sides. In contrast, most northern urban poor live in tenement dwellings constructed of dark-colored brick, black tar roofs, and windows often on two sides associated with a row house motif. During very hot conditions, these northern dwellings suffer from poor ventilation and absorb considerably more radiation than their southern counterparts. These regional architectural factors might partially explain the differential mortality response between northern and southern populations.

Assuming that people can physiologically adapt to the predicted increasing warmth, we can expect only a partial acclimatization to occur as it is highly unlikely that the architectural makeup of the urban area will change significantly over the next 50 to 75 years to account for warmer conditions. This is particularly true for dwellings of the poor, and it is unlikely that the tenements of northern cities will be leveled and replaced by other forms of housing which are more amenable to hotter conditions.

An added shortcoming of the acclimatization procedure is underscored by the fact that the analog and target cities are also very different in their demographic composition, as the differential proportion of elderly (who are particularly vulnerable to heat-related mortality) and minorities has not been accounted for. Furthermore, no attempt has been made to determine what these proportions might be in the target city in the mid-21st century. The expected increase in the percentage of elderly people (greater than 65 years old) over the next 75 years might partially counter the dampening in heat-related mortality attributed to physiological acclimatization.

Thus, the Report to Congress also includes an estimate of mid-21st century mortality assuming partial acclimatization, which is probably more realistic than the previous two estimates. The assumption here is that the apparent full acclimatization which presently exists in the South will not occur in a warmer North for two reasons: (1) any architectural changes in dwellings will lag considerably behind the warming itself, rendering many residences unsuitable for the increasing warmth, and (2) the demographic composition of these cities will be comprised of a larger proportion of people more vulnerable to heat-related stresses.

The partial acclimatization estimates for heat-related mortality represent a substantial increase over present-day mortality estimates, with over a three-fold increase predicted for the U.S. in the Report to Congress. Cities with the greatest number of projected deaths in an average summer using the doubled CO₂ climate scenarios are New York (880 heat-induced deaths compared to 320 today), Los Angeles (824 compared to 84 today), Philadelphia (700 compared to 145 today), and Chicago (622 compared to 173 today). Consistent with previous findings, southern cities will probably be less susceptible to heat-related mortality assuming partial acclimatization. For New Orleans, no heat-related deaths are estimated, and very few are expected for Oklahoma City (23 compared to 0 today) and Atlanta (79 compared to 18 today) as well.

As an added consideration, it is possible that the expected 1.5°C to 4.5°C warming by the mid-21 century might actually increase temperatures in many southern and southwestern cities to levels which might be beyond the tolerances of our society. For example, the average annual number of days in Atlanta which exceed 90°F today is 17. This number is expected to reach 53 by the mid-21st century using the GISS doubled CO2 scenario. Even more troubling is the number of days with temperatures exceeding 100°F. Presently, cities such as Memphis, Jackson, and Birmingham experience three such days during an average summer. This will increase to about 20 days with the expected temperature increase. Considering similar increases in the number of very hot days in Phoenix and other southwestern cities, it is possible that certain areas might simply become uninhabitable in the warmer world of the mid-21st century. Of course, this is highly speculative, as no examples presently exist to support this notion.

Finally, any changes in winter mortality which might occur due to global warming are expected to be much too small to compensate for the sizable increases expected in the summer if the population partially acclimatizes. Assuming that indoor contact is responsible for much of the weather-related mortality in winter, there is no reason to expect that people's activities will change dramatically by the mid-21st century, as the temperature increases expected will be too small to change living habits to a significant degree.

There is much speculation which exists in research of this type. Beyond the uncertainties of acclimatization, this evaluation assumes that estimates from global circulation models, which assume that the world will be considerably warmer, are reasonably accurate. This leap of faith has prodded some skeptics to consider climate impact research of this type virtually useless. However, there is certainly the possibility that humans in a warmer world will respond in a fashion somewhat similar to what has been described here, and global warming/impact research should be considered an "insurance policy" to be drawn upon if signs of a large-scale warming begin to appear. At present, we are making decisions on greenhouse gas emissions which may commit our children and grandchildren to an environment with an altered climate. It is imperative, therefore, to appraise the range of potential lifestyle changes which they might be obliged to make in a warmer world, and to consider the negative implications which we might be imposing upon them in the process.

Testimony of Robert E. Shope, M.D. to the House Subcommittee on Health and the Environment, February 21, 1991.

Thankyou Mr. Chairman. My name is Robert E. Shope, and I am Professor of Epidemiology, Yale University School of Medicine. I am past president of the American Society of Tropical Medicine and Hygiene and I do research on infectious diseases carried by mosquitoes, ticks and sand flies. Thankyou for inviting me to testify on the possible effects of global climate change on the spread of these diseases. I request that my written statement be placed in the record.

Temperature and rainfall determine the distribution and frequency of a number of infectious diseases. Those diseases most likely to be affected are often focally distributed. Their localization depends on a reservoir such as an insect or wild animal, and they need rainfall or water, and warm temperatures for the insect or animal to thrive. Not only does temperature limit the range of the vector, but also the larvae develop more rapidly in warm temperatures, and the infectious agent multiplies faster so the vector can transmit earlier in the season.

The expected climate change must not come too quickly, or else the reservoir arthropod may be abruptly killed; the vector and wild animal must also be able to move into the new territory that has become warmer. Some examples of diseases are malaria, dengue and St. Louis encephalitis transmitted by mosquitoes, and Lyme disease carried by ticks.

Dengue exemplifies the problem. This virus disease causes hemorrhagic fever in children. The virus is carried by Aedes aegypti mosquitoes. Since 1953 it has been a major killer of children in cities like Manila, Bangkok, and Jakarta. Hemorrhagic dengue spread to Havana in 1981 and has since caused large epidemics in Venezuela and Brazil; as we speak, it is killing people in Rio de Janeiro. Aedes aegypti thrives in tropical cities. It does not survive freezing, and has not yet established itself north of Memphis, Tennessee. The mosquito is common in Houston, Miami, and other southern U.S. cities. According to the CDC, tourists and business people infected with dengue virus enter the country regularly, but fortunately have not yet established epidemic dengue in our South. This disease is on the increase throughout the Tropics, the mosquito vector moves into warm areas with humans, and we can confidently expect warming of North America to set the stage for large epidemics of dengue in the southern United States.

St. Louis encephalitis could also become more prevalent. It was the fear of this mosquito-borne encephalitis that kept tourists away from Disney World in Orlando last year and it has been a serious health problem in California for years. The St. Louis encephalitis virus is transmitted in California by Culex tarsalis. These mosquitoes are most abundant in irrigated areas. Studies have shown that the risk of St. Louis encephalitis was greater with warmer temperatures, and risk peaked with average summer temperatures of 86 degrees F. (1) The explanation is straightforward. The virus is found in wild birds; mosquitoes feed on the blood of birds, then the virus must incubate in the mosquito before she can transmit to people. This incubation occurs most efficiently at warm temperatures. Therefore with the warming of climate change, the mosquito will be ready to transmit earlier in the season, and more efficiently, thus

causing more human encephalitis.

I and others have written about additional possible examples such as yellow fever, malaria, Lyme disease, vampire bat rabies, cholera, viral diarrhea, and leishmaniasis. (2,3,4,5,6,7) These infectious diseases have the potential to move into newly warmed areas. Each of these could be out of control if we do nothing. In every case, with adequate resources, we can do something.

How can we meet the microbial threats associated with climate change? Congress can support links between medical and natural scientists; we can give priority in our research programs to studies of the ecology of infectious diseases associated with climate. Studies of the fringes of the distribution of the arthropod vectors and animal reservoirs are especially important, because that is where changes are likely to occur. Vectors are developing genetic resistance to chemical pesticides. This is well-documented in California where local mosquito control districts are faced with the problem of killing the vectors of St. Louis encephalitis virus. Improved control of vectors, especially mosquitoes and ticks, should become emphasis areas of our Environmental Protection Agency and National Institutes of Health research programs.

In the case of dengue, the World Health Organization and federal government agencies are developing vaccines in a coordinated program. We can support the WHO, both through our normal assessment and through extrabudgetary means. We can support the outstanding dengue vaccine program of the Walter Reed Army Institute of Research. We can support the tropical infectious disease research funded by the National Institute of Allergy and Infectious Diseases. In addition, the Centers for Disease Control and U.S. AID have the capacity to control vectors. They can be encouraged to work with the Pan American Health Organization to organize control of Aedes aegypti in Latin America, both to help the Latin nations, and to delay the introduction of dengue to the U.S. It takes years to develop new vaccines, but with tactics to delay introduction, and with adequate resources to support development, the vaccines should be available to the U.S. by the time gradual climate change has created favorable conditions here for dengue.

Finally, we need to study infectious agents that have potential to emerge, especially in areas such as Alaska where U.S. populations may migrate to cope with warming.

The measures I have suggested are actions needed with or without warming; the threat of climate change now lends them immediacy. This concludes my formal statement. I would be pleased to answer questions that the Subcommittee may have.

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**STATEMENT OF
DR. RICHARD A. PARK**

Thank you Mr. Chairman. I would like to summarize briefly the causes of sea level rise due to global warming, the potential impacts that it will have on coastal areas, including communities, wetlands, and fisheries, and appropriate responses to the threat.

For the past six years I have been part of a team of scientists, including Steve Leatherman, Rich Weggel, and Gary Yohe, working with Jim Titus at EPA to assess the damages and costs of sea level rise during the next century. In 1989 we contributed to the Report to Congress entitled *The Potential Effects of Global Climate Change on the United States*; part of my purpose today is to update our earlier estimates of impacts. Since 1987 the National Research Council and others have generally accepted a 1-m rise by the year 2100 as a best estimate. If you will turn to Exhibit 1 you will see that the estimates have varied greatly. The Intergovernmental Panel on Climate Change estimates of 30 to 110 cm with a best estimate of 66 cm, or 2 ft, are somewhat lower; but, as you can see from Exhibit 2, they did not include an estimate of Antarctic ice discharge or groundwater loss due to drought conditions. I will confine my remarks today to the 1-m scenario.

We can consider both ecological and economic impacts. In the Report to Congress we estimated that a 1-m rise could result in a 46 to 66% loss in wetlands, depending on whether or not adjacent dry land is protected by bulkheads and dikes. Salt marshes are valuable because they provide flood control, water purification, and nursery grounds for coastal fisheries. Brown shrimp, in particular, depend heavily on saltmarshes. In Exhibit 3 you can see that the fishery zone including Galveston Bay, Texas, and the area east to the Louisiana state line could experience an increase in saltmarsh conditions suitable for brown shrimp over the next three decades, as wetlands migrate onto adjacent dry land; then, however, a catastrophic decrease could occur as inundation proceeds, with the catch going from 15% above present levels to 40% below. The brown shrimp fishery offshore of Port Richey, Florida, which is already marginal, would gradually deteriorate as saltmarshes are inundated and then replaced by mangrove swamps due to global warming. Overall, we estimate that the brown shrimp fishery in the Gulf of Mexico may experience a slight increase in catch during the next decade, but that with a 1-m scenario, the catch could suffer at least a 35% decline by the year 2040.

On the economic side, my colleagues and I submitted our original analysis for the Report to Congress to the journal *Coastal Management*. By the time we had made all the revisions suggested by the reviewers the estimate of the costs of sea level rise for coastal areas had tripled from about \$100 billion to between \$275 and \$400 billion! Exhibit 4 shows the sources of our revisions. One of the largest components is the cost of pumping sand onto beaches and barrier islands to offset inundation and erosion; several reviewers found our original assumption of required sand quantities to be too conservative. We also included the additional costs for land for dike construction, undeveloped lands lost, and wetlands lost.

Even our new estimates are probably too low. For purposes of the preliminary analysis we have assumed that only existing developed areas will be protected. In fact, there is and will continue to be new development, which means that the area requiring protection and that wetland loss could be much greater, unless there is a serious Federal effort at long-term planning for sea level rise. An article in the current issue of *Environmental Management* systematically analyzes adaptation options, demonstrates that immediate policy action is warranted—even if one believes that there is only a 5% chance for global warming, and recommends that an interagency task force be created to develop a strategy for adapting to sea level rise.

Mr. Chairman, it is appropriate for you to focus your efforts on limiting emissions. Nevertheless, the IPCC has concluded that it is already too late to prevent a 16- to 59-cm rise in sea level by 2100, so we must also help the most vulnerable areas of our country adapt. There will be plenty of time to build dikes to protect our cities as the need arises, but land use decisions cannot be reversed as easily as we can build dikes. If we fail to prepare for sea level rise, our coastal ecosystems and fisheries will be the victims of our lack of foresight. Analogous to health care, we must couple prevention and treatment of the causes and effects of sea level rise. Over the last decade scientists and public officials have defined the options; we now need a policy decision at the Federal level in order to proceed. Thank you.

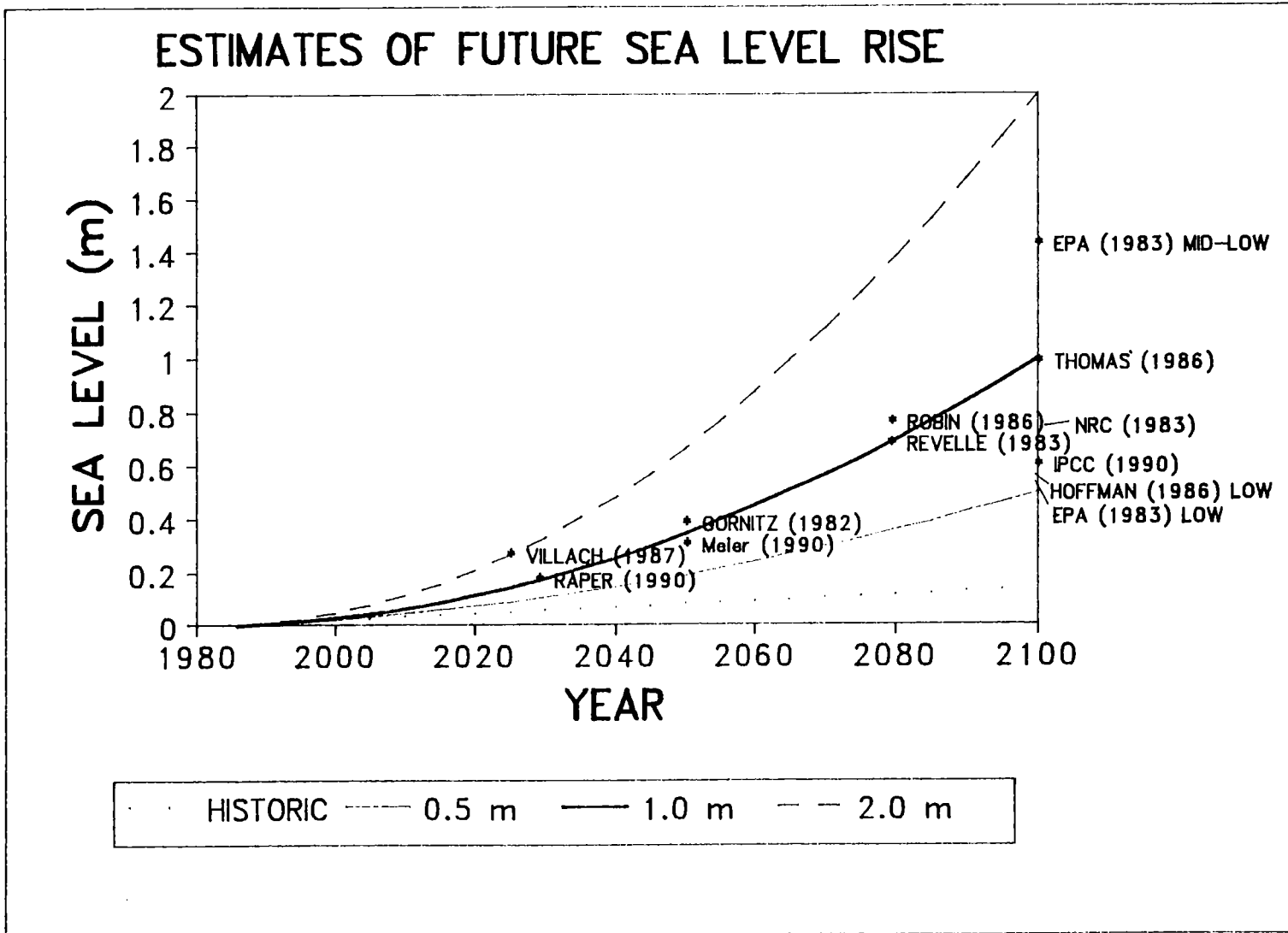


Exhibit 1

ESTIMATES OF SEA LEVEL RISE (cm)

Study	Thermal Expansion	Alpine	Greenland	Antarctica		Groundwater	Total	To Year
				Accumulation	Ice Discharge			
Revelle (1983)	30	12	12	—	—	—	70	2080
Hoffman (1983) (1986)	28 to 115 18 to 83	— 12 to 37	— 6 to 27	—	— 12 to 220	—	56 to 345 58 to 367	2100 2100
PRB (1985)	—	10 to 30	10 to 30	-10	0 to 110	—	10 to 160	2100
Robin (1986)	30 to 60	8 to 32	0 to 10	-10 to 0	—	—	80	2080
Thomas (1986)	28 to 83	14 to 35	9 to 45	—	13 to 80	—	60 to 230	2100
Meier (1990)	20 ± 10	16 ± 14	8 ± 12	-30 ± 20	0	20 ± 30	34 ± 42	2050
IPCC (1990)	6.8 to 14.9	2.3 to 3.7	0.5 to 3.7	-0.8 to 0	—	—	8.7 to 28.9	2030
IPCC ¹ (1990)	21 to 50	9 to 40	3 to 18	-3 to 0	—	—	30 to 110	2100

1 Extrapolated from above estimates for 2030 using ratio of estimates of 2100 to 2030, except for total which is IPCC's published estimate.

Exhibit 2

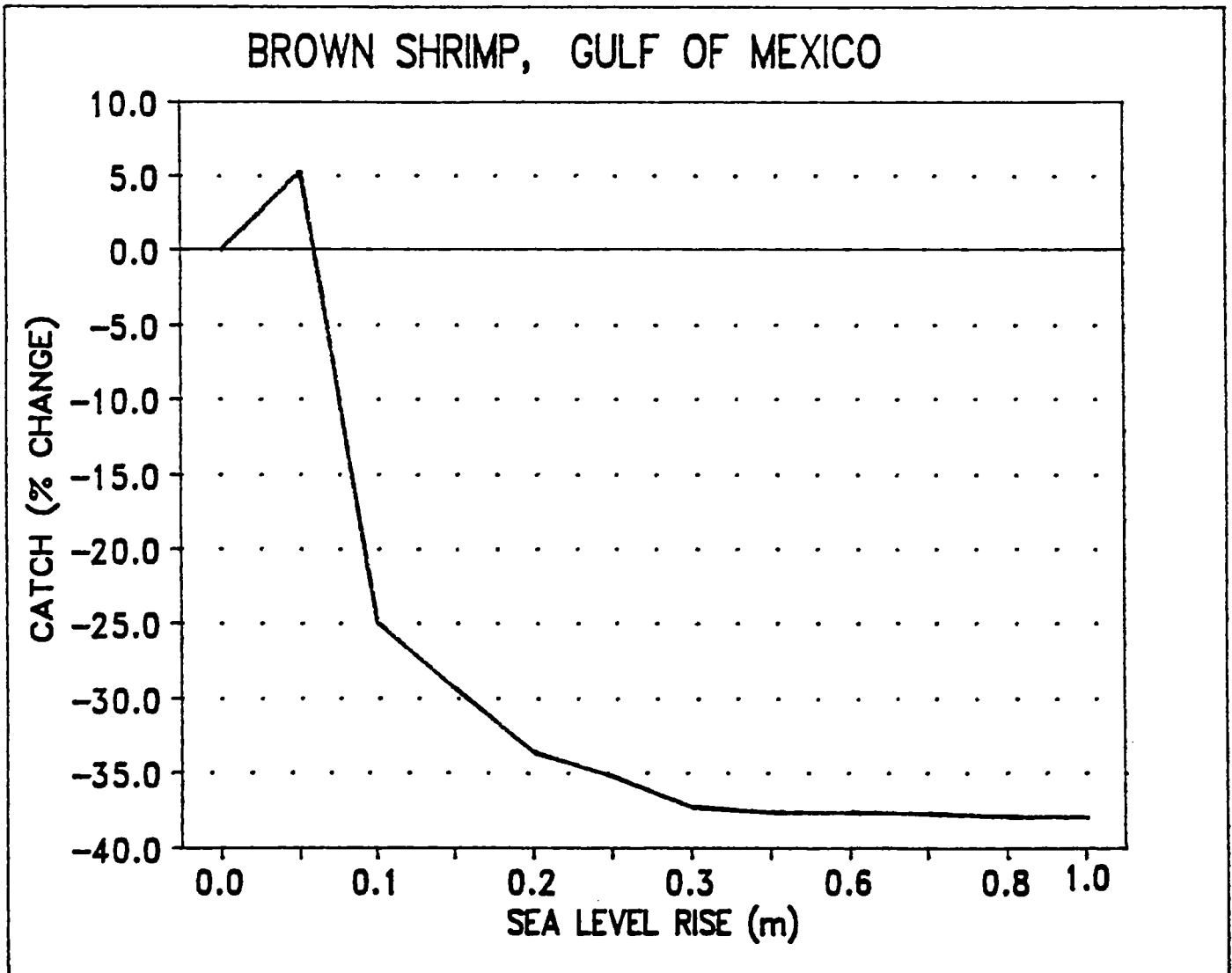
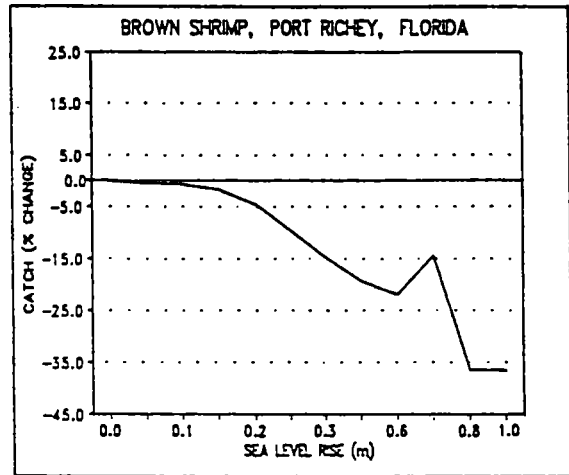
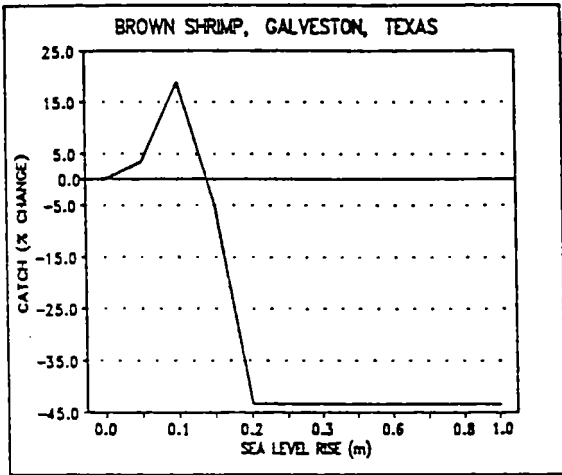
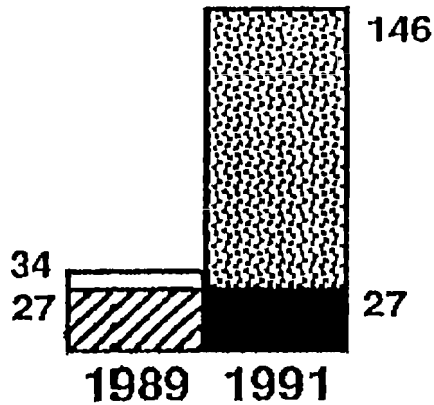


Exhibit 3

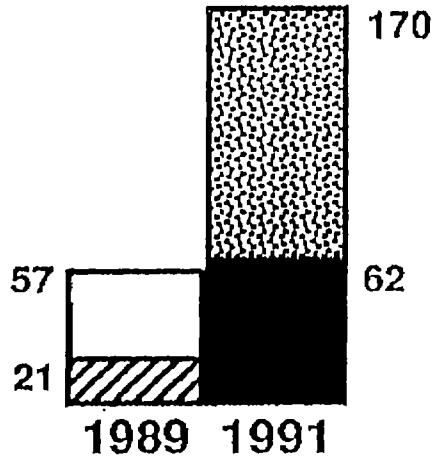
Cost of Sea Level Rise

Comparison between EPA (1989) and Titus et al. (1991)
one meter rise, \$ billions

Sand



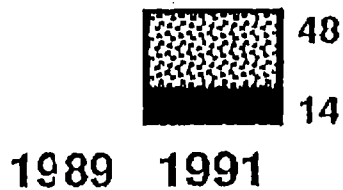
Elevate structures



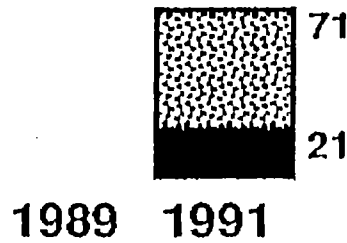
Dike construction



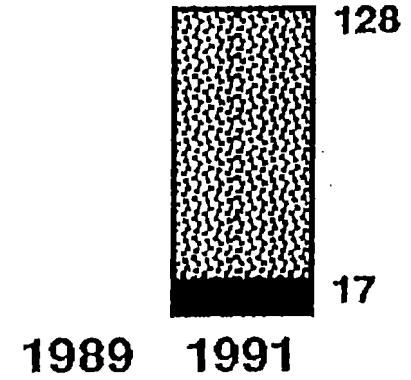
Land for dike



Undeveloped dry land



Wetlands lost



**WRITTEN TESTIMONY OF
DR. RICHARD A. PARK
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INDIANAPOLIS, INDIANA 46208**

**BEFORE THE
SUBCOMMITTEE ON HEALTH AND THE ENVIRONMENT
COMMITTEE ON ENERGY AND COMMERCE
U.S. HOUSE OF REPRESENTATIVES**

SEA LEVEL RISE PROJECTIONS

One of the consequences of global warming due to emissions of greenhouse gases will be a dramatic rise in sea level over the next century. Long-term sea level changes related to climatic changes are due to

- thermal expansion as oceanic water warms
- melting of small glaciers and ice caps
- accumulation of snow (causing a reduction in sea level) and increased discharge of ice to the sea in Antarctica
- melting and increased discharge of the Greenland ice sheet (and possibly accumulation of snow)
- loss of ground- and surface water due to drought conditions on land

Many uncertainties are associated with predictions based on these processes, and these uncertainties are reflected in the range of estimates of future sea level rise (Figure 1). One particular uncertainty, currently being debated, is the importance of increased snowfall on the Greenland and Antarctic ice sheets as opposed to increased discharge of those ice sheets into the oceans and melting of grounded ice shelves in Antarctica. The Intergovernmental Panel on Climate Change's estimate of 30-110 cm, with a best estimate of a 66-cm (2 ft) rise by the year 2100, assumes a net loss due to snow accumulation in Antarctica; even their high estimate assumes no net contribution from

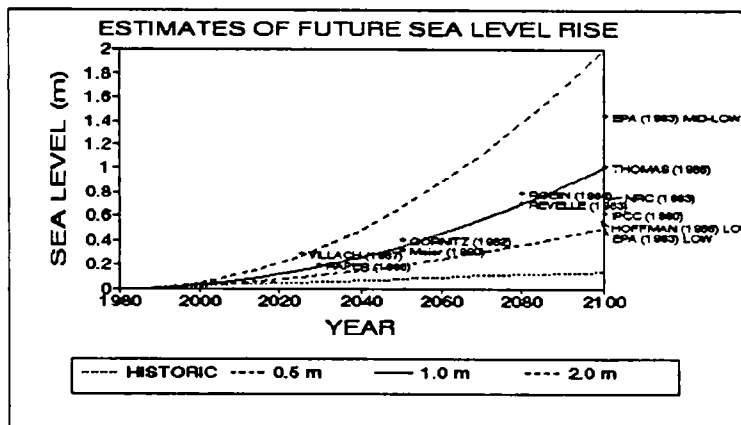


Figure 1. A comparison of various estimates of sea level rise, including the IPCC estimate of 66 cm by 2100 and the scenarios used by Smith and Tirpak (1989), Park et al. (1989), and Titus et al. (1991).

Antarctica or from groundwater loss due to drought conditions (Table 1). Given the uncertainties, it seems prudent to consider possible impacts from future sea level rise comparable to or greater than the IPCC estimate. In the Report to Congress (Smith and Tirpak 1989) we based our analyses on scenarios of 50, 100, and 200 cm; our current estimates emphasize the 50- and 100-cm scenarios (Titus et al. 1991).

Table 1. Estimates of Sea Level Rise (cm)

Study	Thermal Expansion	Alpine	Greenland	Antarctica Accu.	Ice Dischrg	Groundwater	Total	To Year
Revelle (1983)	30	12	12	-	-	-	70	2080
Hoffman (1983)	28 to 115	-	-	-	-	-	56 to 345	2100
(1986)	18 to 83	12 to 37	6 to 27	-	12 to 220	-	58 to 367	2100
PRB (1985)	-	10 to 30	10 to 30	-10	0 to 110	-	10 to 160	2100
Robin (1986)	30 to 60	8 to 32	0 to 10	-10 to 0	-	-	80	2080
Thomas (1986)	28 to 83	14 to 35	9 to 45	-	13 to 80	-	60 to 230	2100
Meier (1990)	20 ± 10	16 ± 14	8 ± 12	-30 ± 20	0	20 ± 30	34 ± 42	2050
IPCC (1990)	6.8 to 14.9	2.3 to 3.7	0.5 to 3.7	-0.8 to 0	-	-	8.7 to 28.9	2030
IPCC ¹ (1990)	21 to 50	9 to 40	3 to 18	-3 to 0	-	-	30 to 110	2100

¹ Extrapolated from above estimates for 2030 using ratio of estimates of 2100 to 2030, except for total which is IPCC's published estimate.

IMPACTS OF SEA LEVEL RISE

Sea level rise of 50 to 100 cm by 2100 will have profound effects on coastal areas. If we assume that all land developed by 1986 will be protected by dikes, then the land lost through inundation and erosion is estimated to be worth \$13 billion to \$71 billion in 1988 dollars (Figure 2). The value of vegetated wetlands lost is potentially even greater, given the services they perform, including nurseries for coastal fisheries, flood control, and water purification; we estimate the value lost will be between \$11 billion and \$128 billion (Figure 3).

One sector that will be hard hit is the shrimp fishery in the Gulf of Mexico. Brown shrimp, in particular, depend heavily on saltmarshes. Investigators at the National Marine Fisheries Service Galveston Laboratory have observed that shrimp production may increase temporarily with slightly accelerated sea level rise, but that it may decline sharply with higher rates of rise (Zimmerman et al. 1991). Using the NMFS historic shrimp data and our forecasts of changing marsh conditions, we estimate that the brown shrimp fishery in the Gulf of Mexico may experience a slight increase in catch during the next decade, but that with a 1-m scenario, the catch could suffer at least a 35% decline by the year 2040 (Figure 4).

It is instructive to examine the predicted responses of two quite different coastal areas (Figure 5). The fishery zone including Galveston Bay, Texas, and the area east to the Louisiana state line could experience

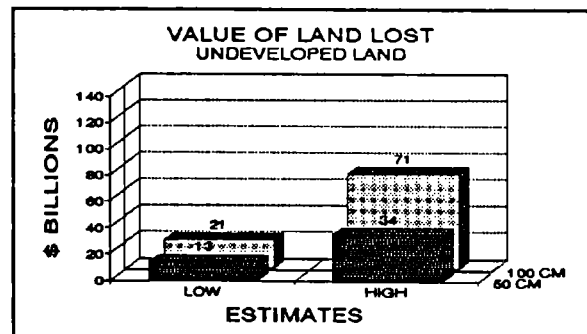


Figure 2. Value of undeveloped land inundated or eroded by sea level rise (based on Titus et al. 1991).

an increase in saltmarsh conditions suitable for brown shrimp over the next three decades, as wetlands migrate onto adjacent dry land; then, however, a catastrophic decrease could occur as inundation proceeds, with the catch going from 15% above present levels to 40% below. The brown shrimp fishery offshore of Port Richey, Florida, which is already marginal, would gradually deteriorate as saltmarshes are inundated and then replaced by mangrove swamps due to global warming.

The estimates of impacts of saltwater intrusion on freshwater supplies have been studied in the Delaware basin, Florida, and San Francisco Bay, but require additional study elsewhere. Measures for counteracting saltwater intrusion usually involve increased discharge of water, which could be in short supply if drought conditions prevail. Freshwater intake on estuaries is protected by controlled discharge of upstream water to force saltwater seaward (Hull 1986, Williams 1989). Coastal aquifers are often protected by regulating withdrawal of groundwater and by maintaining a freshwater head with recharge ponds and injection wells (Sorensen et al. 1984).

Using FEMA data, we are initiating a study of the coastal impacts of sea level rise coupled with flooding and storm surge. One cause for alarm is not only that sea level rise will greatly increase coastal areas subject to flooding from so-called 100-year storms, but that storms of such intensity may be more frequent in the next century. Emanuel (1987) has estimated that a 40-50% increase in the destructive potential of hurricanes could occur as a result of warming associated with doubling of CO₂.

COSTS OF HOLDING BACK THE SEA

In the 1989 Report to Congress preliminary estimates were given for the costs of protecting residential and commercial areas from sea level rise (Titus and Green 1989). The figures for the cost of bulkhead and dike construction have not changed; for 50- and 100-cm scenarios they vary between a low of \$5 billion to a high of \$33 billion (Figure 6). However, the value of the land that the dikes will occupy was not considered earlier, and that could be another \$9 billion to \$48 billion (Figure 7).

Barrier islands and spits are especially vulnerable to inundation and erosion from sea level rise. Leatherman (1989) has given low estimates of the sand required to maintain Florida Atlantic beaches and barrier islands (Figure 8). The costs for sand for that stretch of coast alone could be \$845 million for a 50-cm rise and \$1.9 billion for a 100-cm rise. Additional study and computations have yielded significantly higher figures for protecting barrier islands nationwide (Titus et al. 1991). The cost of supplying sand to nourish eroding beaches and to raise barrier islands in place would still be \$15 billion as a low estimate, but could go as high as \$146 billion to protect against a 100-cm rise (Figure 9). Furthermore, the cost of raising roads,

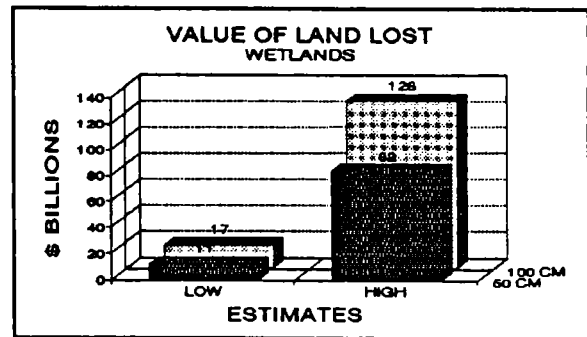


Figure 3. Value of vegetated wetlands lost due to sea level rise (based on Titus et al. 1991).

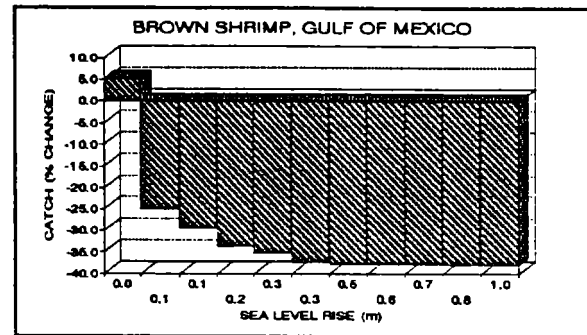


Figure 4. Percent change in catch of brown shrimp in the Gulf of Mexico with a 1-m sea level rise.

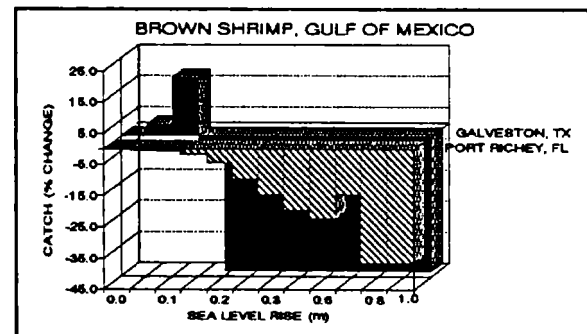


Figure 5. Percent change in catch of brown shrimp for fisheries near Galveston, Texas, and Port Richey, Florida.

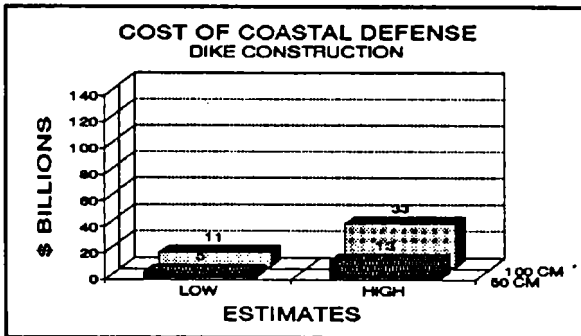


Figure 6. Cost of constructing bulkheads and dikes to protect developed coastal areas (based on Titus and Greene 1989).

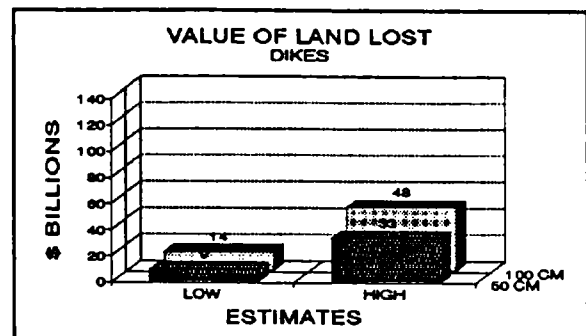


Figure 7. Value of land lost due to construction of dikes (based on Titus et al. 1991).

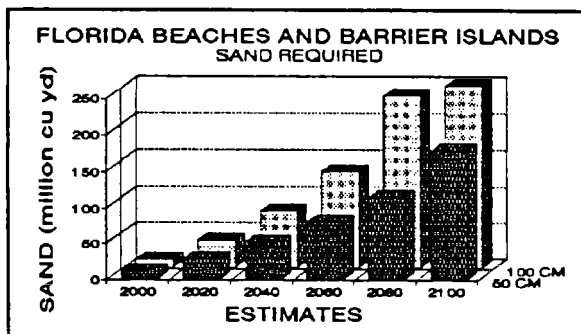


Figure 8. Sand required to maintain Florida Atlantic beaches and barrier islands (after Leatherman 1989).

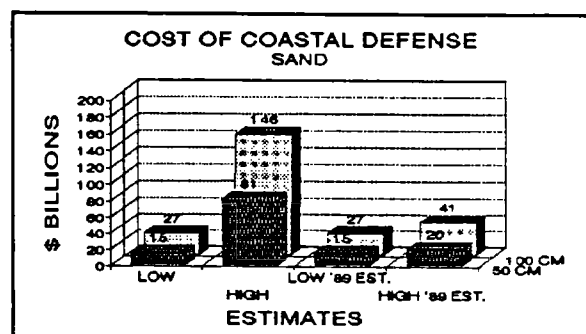


Figure 9. Cost of supplying sand to maintain beaches and barrier islands (based on Titus et al. 1991).

bridges, drainage lines, and other structures is now estimated to be between \$29 billion and \$170 billion (Figure 10).

THE CONFLICT BETWEEN COASTAL DEVELOPMENT AND COASTAL ECOSYSTEMS

As developed areas are protected, wetlands will be squeezed between the advancing sea and the land being protected. The costs of losing those wetlands will be even greater if further development results in additional bulkheads and dikes to impede the landward migration of these important ecosystems.

The estimated costs given for protecting residential and commercial developments and the value of wetlands lost are minimal because they assume no new development. However, coastal areas are under severe pressure for development in many regions. We are currently preparing estimates of future development and the costs involved in protection.

IMMEDIATE POLICY ACTION IS NEEDED

Governments lack the funds to purchase all undeveloped lowlands subject to inundation, and they lack the authority to prohibit their development. Titus (1991) has proposed that a legal mechanism be established to allow property owners to use coastal property, but prohibiting construction of bulkheads—thereby

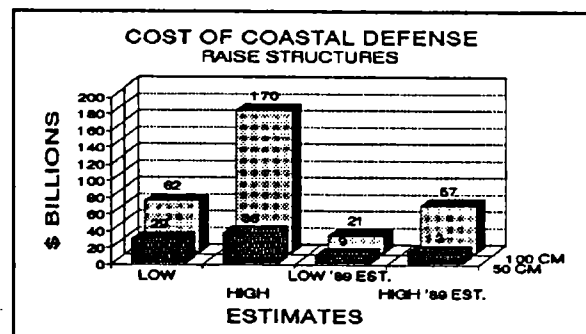


Figure 10. Cost of raising roads, bridges, and other structures (based on Titus et al. 1991).

ensuring that the land will be abandoned when it is threatened by the rising sea. An alternative could be to convert property rights of current owners (with compensation if necessary) to conditional leases that would expire whenever the property is inundated by sea level rise. The cost will be small if the policy is formulated now, but great if we delay until sea level rise projections are more precise.

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**RECENTLY OBSERVED ALTERATIONS IN MARINE ECOSYSTEMS
AND THEIR POSSIBLE RELATIONSHIP TO FLUCTUATIONS IN
GLOBAL CLIMATE.**

**TESTIMONY TO THE U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON ENERGY AND COMMERCE, SUBCOMMITTEE ON
HEALTH AND THE ENVIRONMENT**

21 February, 1991

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and

**Member of the Executive Boards:
Association of Marine Laboratories of the Caribbean
Global Coral Reef Alliance, Inc**

I thank you for the invitation to present to this congressional committee reports of recent massive disturbances within marine ecosystems which may be the consequence of global climate change. My colleague, Dr. Ernest H. Williams, Executive Director of the Association of Marine Laboratories of the Caribbean and Professor of Marine Science at the University of Puerto Rico, regrets that he is unable to appear before the committee today. I would like to summarize his testimony (Williams, 1991) and then to describe data from my own research on tropical coral reef bleaching events in the Caribbean region.

WILLIAMS TESTIMONY- SUMMARY

These disturbances have been observed over wide regions in many parts of our oceans. They are mounting in severity and are affecting increasingly more organisms and more species. The incidence of these mortalities, abnormal growths, and stress responses has risen dramatically since 1980. Moreover, they are occurring at a time when marine environmental temperatures are increasing and when other expressions of global climate change are being predicted. Should these climatic trends continue, we expect that the incidence of these marine events will rise, leading to widespread death of sensitive organisms, shifts in ecosystem composition, and the ultimate loss of entire species or even ecosystems.

The cause for many of these disturbances is unknown. The ranges and frequencies of these events are too extensive in space and time to ascribe them to a local insult or pollutant. These are large scale ecosystem perturbations which are interpreted to be the consequence of changes that operate over broad geographic areas and throughout multiple zones of depth in the marine environment. Global climate change would certainly be consistent with, if not directly responsible for, the scale of disturbances observed. Marine ecosystem effects which might be expected from global climate changes are those which alter the physical or chemical features of sea water, or which change the rate of proliferation and distribution of organisms in the marine environment.

One marine disturbance which appears to be linked to a physical change in sea water is the bleaching of sessile organisms of the tropical coral reef ecosystem. Coral reef bleaching, as it is commonly termed, is a general stress response which we know may

be elicited by increasing sea temperature, by decreasing salinity, or by decreasing water clarity. These physical changes in sea water impose stressful conditions which are incompatible with the maintenance of the symbiotic relationship between sessile marine organisms and their unicellular algae. Soft corals, hard corals, and sponges of the reef ecosystem all harbor these photosynthetic plant cells. When environmental changes are introduced abruptly, the symbiotic relationship uncouples, the algae are sloughed, a dramatic and visible color change occurs, and when prolonged the host organism is at risk for predation by opportunistic organisms and eventually for death.

In our research on the histological and metabolic changes in the stony coral during bleaching (Hayes and Bush, 1990), we have observed that the bleaching response of a coral colony appears gradually by the spread of localized bleached areas. The tissue changes during bleaching include a loss of algal cells, the death of many of these cells, the release of copious amounts of mucus, and the physical disruption of coral tissues. After bleaching for short durations, some coral colonies do recover; however, others bleached for longer periods or to a greater degree have died. We have reports from the most recent bleaching episode in the fall of 1990 that coral mortality was high. Many colonies have died, and some species have been eliminated from zones of the reef ecosystem.

The bleaching of the reef coral is not simply a cosmetic change in color. Although the observed color changes are most easily detected, there are several less obvious changes in these colonies which indicate the severity of the bleaching. In the bleached condition, the corals:

1. No longer secrete their skeleton
2. Are unable to nourish themselves
3. Do not reproduce
4. Have reduced resistance to opportunistic organisms, and
5. Can not defend themselves physically against parasites.

Therefore, the bleached coral is vitually starving, defenseless, and growthless. The skeletal frame of the reef is eroding, since there is no longer a mechanism for depositing the crystalline calcium carbonate of the reef. If these events occur over vast areas of the reef and for a protracted time, not only will species disappear from the reefs, but the reef frame will be destroyed and overgrown

with fleshy algae. The loss of the tropical reef ecosystem, especially in conjunction with sea level rises, would be unfortunate for seacoasts and islands which depend upon these natural barriers for physical protection.

Another aspect of our research has been to analyze satellite derived sea surface temperatures in the Caribbean region during periods when coral reef bleaching has been observed. In collaboration with Dr. Thomas Goreau of the Global Coral Reef Alliance and scientists with the National Ocean Service and Ocean Assessment divisions of NOAA, we have statistically analyzed sea temperatures in several locations over the past decade (Goreau et al, 1991, Roberts, 1990). We have found that when sea temperatures are elevated above seasonal norms, coral reef bleaching occurs. We conclude from these data that abnormal warming correlates precisely with coral reef bleaching, and is essential for, if not the triggering event behind, the bleaching events.

In testimony before a U.S. Senate Committee chaired by Senator Ernest Hollings (D, South Carolina) and Senator Albert Gore (D, Tennessee) in October, 1990, Dr. Williams, Dr. Goreau, myself, and other marine scientists, recommended a series of measures which might be undertaken to address the problem of coral reef bleaching (Hayes et al, 1990). These were:

- (1) to establish in-water and atmospheric monitoring stations throughout the coral reef ecosystem to allow long-term determination of environmental conditions which might account for these changes;
- (2) to enhance funding for research into the causes and mechanisms of coral reef bleaching;
- (3) to establish a network for alert scientific communication about events in the marine environment;
- (4) to educate the public about the sensitivity of the marine ecosystem to local and global insults; and
- (5) to encourage federal agencies such as NOAA to apply remote sensing technology systematically in the tropical marine ecosystem.

As a medical educator and as a bio-medical researcher, I would argue that global climate changes, including global warming of our atmosphere and our oceans, pose serious threats to the survival of individuals, species, and ecosystems. Not only is the marine ecosystem at risk (Richards and Bohnsack, 1990), but humanity itself may suffer adverse effects of global climate change (Leaf, 1989). Continued atmospheric and sea warming, sea level rising, and storms resulting from global climate changes will certainly lead to more frequent and more pervasive marine disturbances. We would be well advised to act promptly to offset further deterioration in our global environment.

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Oral Statement of
Dr. Rosina Bierbaum
before the Subcommittee on Health and the Environment
of the Committee on Energy and Commerce
February 21, 1991

(to accompany the submitted Summary of *Changing By Degrees*)

Good Morning. My name is Dr. Rosina Bierbaum and I am a Project Director at the Congressional Office of Technology Assessment, responsible for its work on climate change. We recently completed the report "Changing By Degrees: Steps to Reduce Greenhouse Gases." At the Subcommittee's request, I submit the Summary of that report for the record. Printed copies of the full report should arrive from the Government Printing Office later today; I will be pleased to make available copies to all interested Committee Members and staff.

This work was requested by six Full Committees of the Congress in 1988, two in the House and four in the Senate. The House requesters are: Committee on Science, Space and Technology, and Committee on Foreign Affairs. The Senate requesters are: Committee on Commerce, Science and Transportation; Committee on Energy and Natural Resources; Committee on the Environment and Public Works; and Committee on Governmental Affairs. Although the House Committee on Energy and Commerce was not a requesting Committee, you highlighted global warming as an area warranting future research 11 years ago in a letter to OTA requesting an acid rain assessment.

Our climate change study, as requested by the Committee letters, focused on carbon dioxide (CO₂) emission reductions achievable over the short-term-- that is, within the next 25 years. Unlike some other Congressionally-mandated studies, we did not have a preconceived target--such as 20 percent below current emission levels or a freeze on carbon dioxide emissions.

I would like to highlight three points today:

- o A mix of policies crossing all sectors will be needed to keep CO₂ emissions from rising significantly over the next 25 years.
- o With new aggressive initiatives, it is conceivable the United States could decrease CO₂ emissions to 35 percent below today's levels by 2015;
- o Even so, after 2015, emissions will rise again unless vigorous and sustained research, development and demonstration (RD&D) on non-fossil alternatives (such as solar and nuclear power) leads to their commercialization by that time.

OTA looked at the ability of different technical options to reduce emissions under two scenarios: "Moderate" (basically cheap and easy), and "Tough" (not so cheap or easy). The Tough scenario is designed to be technically feasible; it is not a hypothetical "technical potential" scenario involving untested prototypes, but one tempered with reality and driven by natural replacement times of equipment). Our results surprised us. To summarize (as displayed in the attached figure):

Without any new initiatives, CO₂ emissions in the United States are likely to increase by 50 percent between now and 2015.

Under our Moderate scenario, we can hold that growth to 15 percent over current levels. This scenario is low or no cost; the estimated \$145 billion saved in avoided fuel costs offsets initial costs for purchasing more efficient equipment.

OTA's Tough scenario drops CO₂ emissions 35 percent below 1987 levels-- that is, it eliminates the 50 percent growth that would occur without new initiatives plus decreases emissions by another 35 percent. Of the CO₂

reductions and offsets possible under our Tough scenario, about 30 percent would come from commercial and residential buildings; about 25 percent from manufacturing; between 15 and 20 percent each from transportation and electric utilities; and about 10 percent from forestry. This tough scenario may or may not be expensive: adding up the upper and lower cost bounds of the 100 technical options we modeled suggests the cost of our Tough scenario could be anywhere between making the country \$20 billion a year to costing up to \$150 billion dollars per year. The upper estimate is about equivalent to a recent EPA estimate of what we will be paying for all environmental protection by the year 2000.

Of course, many other scenarios are possible, as well. There is enough information in the report to specify a control program that can achieve targets between our Moderate and Tough scenarios, such as a freeze at 1990 levels or 20 percent below--targets being discussed by several other industrialized nations.

If the United States chose a goal between our Moderate and Tough scenarios, starting with the diverse measures in our Moderate scenario would be a reasonable, but not sufficient, first step. Congress would need to add some of the more cost-effective "Tough" measures, such as more energy-efficient new building construction, improved commercial lighting, more efficient industrial motors, and tighter appliance efficiency standards. Measures "halfway" between those specified for our Moderate and Tough scenarios are also possible.

Regardless of scenario, note that the timing of the reduction target is quite important. Some measures can be quickly implemented (for example, retrofits such as insulating homes, or replacing light bulbs). Others, such as retiring and replacing existing power plants, factories, buildings, and equipment may require decades. The 25-year time frame was too short to

include a scenario to supplant fossil fuels and have non-CO₂ emitting technologies supplying the major fraction of United States energy.

To be able to make the transition to non-CO₂ sources (such as solar technologies or a new generation of nuclear power) soon after the 25 year horizon of our assessment, a strong RD&D effort is needed starting today. Even under our Tough scenario, CO₂ emissions will begin to rise again shortly after 2015 unless new nonfossil supply can be brought on line. This is because economic growth--demand for new goods and services--begins to outstrip foreseeable prospects for further efficiency improvements.

While we believe both the Moderate and Tough cases are possible futures for the United States, neither will happen without policy intervention. A combination of regulatory 'push' and market 'pull', will be needed. These include performance standards, tax incentive programs, carbon-emission or energy taxes, labeling and efficiency ratings, and RD&D activities. We believe that to achieve lasting reductions in greenhouse gases, government signals (e.g., pricing and regulatory policies) need to be consistent and reinforcing. Moreover, no single sector of the economy can achieve sufficient emissions reductions alone.

Attached to my statement is a table outlining the most promising technical options to lower CO₂ emissions and the policy options for achieving them. These are organized by economic sector. For example, under residential buildings, promising technical options include better insulation, windows, and improved construction methods to lower heating and cooling needs. For new homes, these can be achieved through building energy codes for new construction. For existing homes, "demand-side management" programs implemented by electric and gas utilities may be more appropriate. Information programs, such as requiring home energy ratings for Federally-supported mortgages, would be helpful adjuncts.

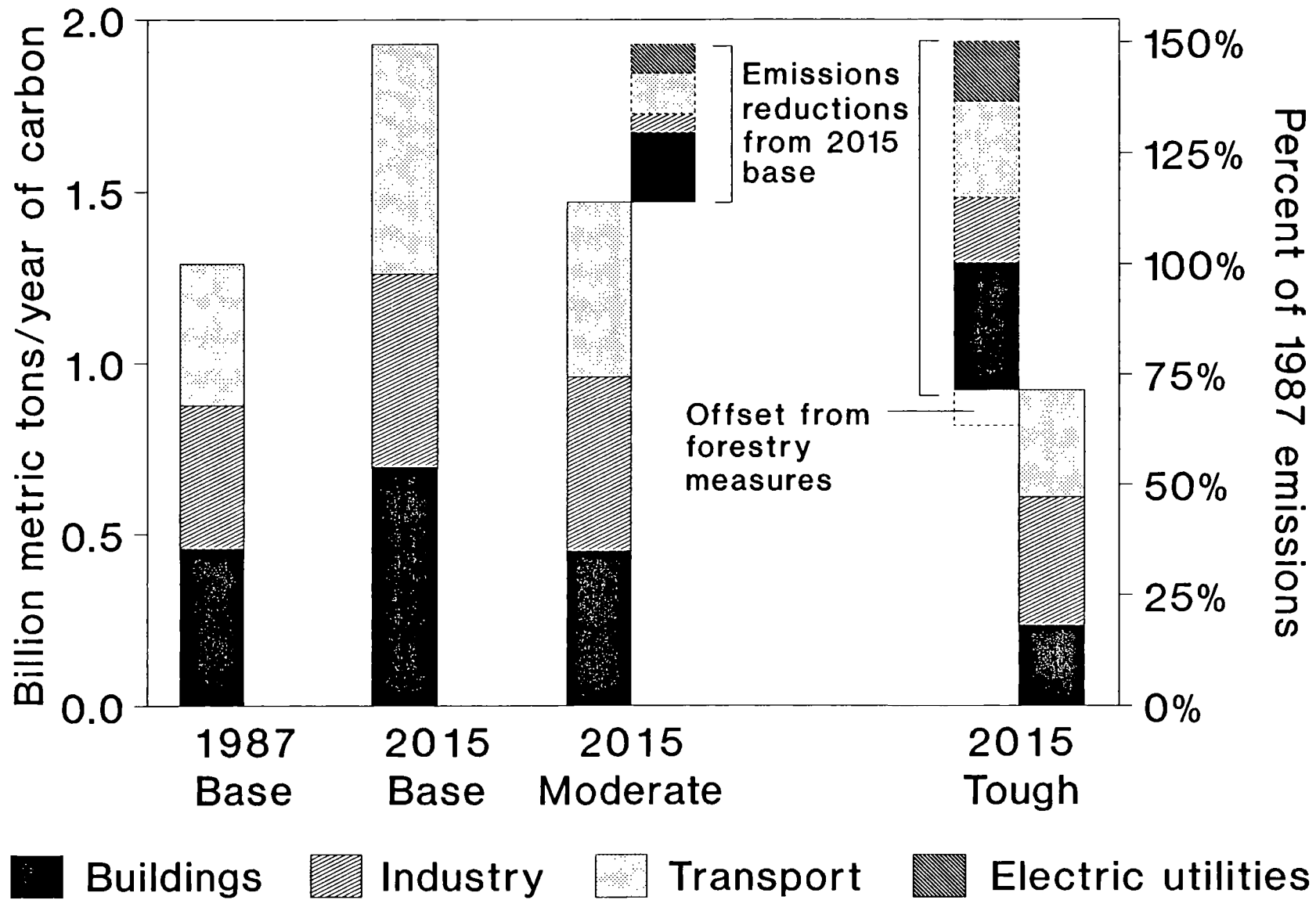
In the transportation sector, a combination of tighter fuel efficiency standards and financial measures such as a gasoline tax offer the greatest opportunities for reductions.

In both the utility and industrial sectors, we see opportunities both for efficiency improvements and for fuel switching from high carbon-emitting fuels (coal) to lower carbon-emitting fuels such as natural gas. In these sectors, with fewer -- and more financially savvy -- decisionmakers, so called "market based" approaches such as a carbon tax or marketable carbon permits are prime candidates.

For forestry, increased tree planting can provide some CO₂ offsets by storing carbon in plant tissue or replacing the use of fossil fuels. In this sector, expanding the Conservation Reserve Program, adding incentives for forest management, and increasing existing Federal forestry assistance programs would help. However, it is important to recognize that these offsets are only short-term; eventually the stored carbon will be released back to the atmosphere.

Our report also includes options available to the United States to help lower CO₂ emissions abroad and options to lower other greenhouse gases such as methane and nitrous oxide from the food sector.

In conclusion, the extent to which the United States can reduce emissions has been hotly debated. OTA's analyses show that we already have technical options that can significantly slow the rate of growth (our Moderate Scenario) or reduce emissions well below current levels (our Tough Scenario). I will be happy to answer questions.



Selected Options To Lower U.S. Carbon Dioxide Emissions

Measures that affect all sectors:

Promising policy options:

- carbon emission tax
- marketable permits for carbon emissions
- RD&D for noncarbon energy sources and energy-efficient technologies

Buildings:

Technical options:

- Better insulation, windows, and improved construction methods to lower heating and cooling needs
- more efficient furnaces, air conditioners, and appliances
- Improved lighting, especially in commercial buildings

Promising policy options:

- efficiency standards such as tighter appliance standards and building energy codes for new construction
- "demand-side management" programs by electric and gas utilities to facilitate improvements in existing buildings
- Information programs such as energy audits and home energy ratings as a requirement for mortgages

Transportation:

Technical options:

- fuel efficiency improvements
- increased use of mass transit, vanpools, and carpools
- more efficient vehicle operation through measures to reduce congestion, reinstate 55-mph speed limit

Promising policy options:

- tighter fuel efficiency standards for cars and trucks
- gasoline tax
- transportation control measures (e.g., high-occupancy vehicle lanes and parking management), better mass transit, and improved urban design

Manufacturing:

Technical options:

- continuing process improvements—especially for iron and steel, chemicals, paper, and petroleum
- increased cogeneration of electricity and heat
- Improved electric motors
- fuel switching from coal to gas

Promising policy options:

- carbon emission tax
- Joint Industry/utility programs for "demand-side management"
- marketable carbon emission permits

Electricity generation:

Technical options:

- increased use of nonfossil sources (e.g., hydro, wind, solar, nuclear)
- co-firing existing coal-fired plants with natural gas
- retiring existing fossil-fuel-fired plants after 40 years

Promising policy options:

- marketable carbon emission permits
- carbon emission tax

- efficiency standards, carbon emission limits, and/or moratorium on new coal-fired powerplants
- RD&D for noncarbon energy sources

Forestry:

Technical options:

- increasing productivity of forests
- planting trees on marginal croplands, other nonforested rural lands, and in urban areas
- growing short-rotation woody crops for use as biomass fuels

Promising policy options:

- increase existing Federal forestry assistance programs
- expand Conservation Reserve Program
- tax incentives for forest management, tree planting

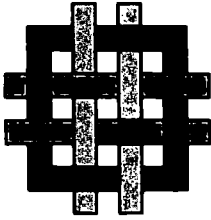
Food:

Technical options:

- decrease livestock methane emissions
- increase efficiency of nitrogen fertilizer use to reduce nitrous oxide emissions
- take marginal croplands out of production and rotate crops

Promising policy options:

- increase research funding to evaluate efficacy of methane-reducing practices
- require farmers to adopt environmentally sound agricultural practices as a prerequisite for receiving Federal price and income supports
- continue to remove disincentives to crop rotations



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GLOBAL CLIMATE CHANGE AND GREENHOUSE EMISSIONS
HEARING FOR THE SUBCOMMITTEE ON HEALTH AND ENVIRONMENT
COMMITTEE ON ENERGY AND COMMERCE
U.S. HOUSE OF REPRESENTATIVES

FEBRUARY 21, 1991

Testimony
by

Roger C. Dower

Director, Climate, Energy and Pollution Program

World Resources Institute
Washington, D.C.

We are faced with evidence that our global environment is threatened by our reliance of fossil fuels to power economic development. The potential changes to our global climate associated with emissions of carbon dioxide is one important example of the environmental risks posed by our current mix of energy sources. Indeed, we and a few other countries have created the model upon which many developing countries are now relying. This model equates large-scale fossil fuel exploitation with long-term economic development. Our global environment cannot sustain the projected levels of growth in fossil fuel emissions that will occur as developing nations seek their share of the world's wealth -- fueled the same way the rest of world received theirs.

This committee has established a strong track record of addressing the health and environmental risks associated with combustion of fossil fuels. Further, this committee has played important roles in dealing, directly and indirectly, with gases that contribute to global warming, such as CFC's and carbon monoxide. My comments today focus mainly on steps needed to reduce carbon dioxide emissions. Other speakers are better able help the committee focus on other greenhouse gases, such as methane, about which we know to learn much more.

I know the committee is aware that to focus on the role of carbon dioxide in increasing risks of climate change is to focus on our national energy consumption and production patterns. This does not mean, however, that a solution can only be devised through the perspective of a national energy strategy. For example, a

conventional air pollution perspective can also be adopted -- one could ask what national emission levels of carbon dioxide are protective of public health and welfare and then investigate the most effective strategies for achieving the chosen level. Many of these strategies will be ones I discuss here. Nevertheless, the advantages and disadvantages of alternative perspectives to the risks of climate change -- pollution, energy or tax policy -- have not been carefully documented and might offer a fruitful area for further investigation. I hope this committee does not shy away from careful investigation of these alternatives.

CHARACTERISTICS OF A RESPONSE TO CLIMATE CHANGE RISKS

The U.S. has a very special responsibility (that goes beyond our national borders) to help lead the world towards an energy future that can be sustained over the long run. We are the world's largest consumer of fossil fuel energy and, not surprisingly, the largest emitter of carbon dioxide. We are also the least efficient energy consumer, using more energy to produce a dollar of GNP than virtually any other industrialized country. We cannot ask the developing world to adopt a different development path unless we are prepared to help show the way -- financially, technologically, and institutionally.

While a complete picture of a sustainable energy future has yet to take form, the general contours are, I think, becoming clear. And while we may not know every twist and turn in the road

to this future, we do know the major intersections. Let me list just three of the major elements that should be part of any U.S. transition to a sustainable energy future. I pick these as three features that are generally agreed to be part of a climate change strategy no matter how the issue is ultimately addressed.

Energy Efficiency Investments

There is a growing consensus that the first step in reducing carbon dioxide emissions should be increasing the efficiency by which energy is transformed into energy services. The opportunities in our economy for reducing pollution by using less energy to produce any given level of energy services such as lighting or heating/cooling appear to be substantial. One energy efficient light bulb can result in 300 fewer pounds of carbon dioxide being emitted each year into the atmosphere.

There is a long running debate between energy economists and energy engineers as to the true economic cost of making energy efficiency improvements. The latter argue that many of these improvements can be made at negative costs -- that is, there would be a real savings from investing in energy efficiency. In response, many economists ask the reasonable question as to why these investments have not already occurred if they are so worthwhile. They tend to assume that efficiency must be more costly than the alternative or we would have more of the first and less of the second. The truth is between but probably much closer to the negative cost school. Investing in the new light fixture or

new electric motor does cost money and may cost more than the alternative low efficiency alternative. Over its lifetime, the same investment, however, may also reduce your energy bill. There may be many applications of efficiency improvements where these savings outweigh the initial up-front costs.

The literature is replete with evidence of the economic savings from efficiency investments. We are learning much more about why the opportunities for these savings exist. Regulatory barriers, first cost bias, and informational disparities all act to limit the economic incentive to invest in energy efficiency. Many creative programs are being developed to reduce the impact of these barriers on investment decisions. More and more states are allowing utilities to earn a rate of return on energy efficiency investments as compared to building new capacity. Energy service companies, or ESCOs, are creating a market niche for themselves by providing efficiency technology to potential users in exchange for some of the savings. As these programs, and others expand, we will learn much more about the true costs of energy efficiency. Federal facilities may offer a valuable testing ground for energy efficiency programs.

Investments in Renewable Energy Supplies

As important as they are, energy efficiency investments alone are unlikely to provide the basis for substantial, long term reductions in carbon dioxide emissions. We will also need new non-fossil sources of energy -- energy sources that do not emit carbon.

The most economically, technologically and politically viable alternatives, at least at this point, appear to be non-nuclear renewable technologies such as solar, wind, biomass, geothermal and hydropower. Several of these technologies with the largest long term potential to substitute for fossil fuels are not quite economically and technologically competitive on a broad scale, but progress is being made. The economic potential for these technologies, however, is hardly static. The cost per kilowatt hour for windpower is within striking distance of conventional base load cost and is already competitive with peak power cost. Solar thermal can compete for peaking purposes, but has some way to go as a stand alone source of energy. Photovoltaics make sense for many remote applications, but are several times more expensive than their fossil fuel alternative. Biomass generated energy makes sense for some industries although large scale production of alternative fuels, for example, is not yet competitive with gasoline.

Shifting the economy towards renewable energy sources before these technologies have matured will impose costs on the economy. There is considerable evidence that market barriers exist to the use of renewables at today's prices, there are probably fewer negative cost opportunities in the renewable sector than in the case of energy efficiency. The benefits of renewable energy resources in terms of reducing climate risks justify some level of federal research and development support beyond its importance as a backstop technology. Beyond this, however, the direction is

somewhat less clear - because market barriers to the use of renewables and their solution have been less well studied. Some market biases are fairly well understood. Since prices for renewables do not reflect fully their lower pollution levels, they are over priced relative to fossil fuel sources of energy. Thus, utilities have less incentive to invest in renewables, everything else being equal. It may also be the case that certain definitions and requirements used in the electric utility industry do not apply as well to renewables as they do to conventional fossil energy sources. For example, issues of system reliability may require different considerations for solar energy, which only produces energy during daylight hours, than for a coal-fired unit.

Getting the Prices Right

The consensus that exists over the role of energy efficiency and renewable energy investments in reducing risks of climate change does not spill over to the most appropriate mechanisms for encouraging those investments or to sustaining their benefits. The alternatives range from traditional command and control regulations specifying the amount and levels of carbon dioxide allowed for each economic activity to a tax on carbon emitting activities as a means of reflecting their environmental costs. In between these two options is a third -- a system of tradeable carbon dioxide emission permits -- that borrows some of the qualities of each of the two extremes. A permit trading system for carbon dioxide sets the quantity of carbon dioxide to be emitted, unlike the tax which sets

the price, but allows buying and selling of allowed emissions. Of course, there are endless variations and combinations of these three approaches.

I do not think there really is much choice between these mechanisms for reducing carbon dioxide emissions. If we ignore the importance of energy prices in guiding the millions and millions of transactions that define energy markets, we will almost certainly end up with a carbon dioxide reduction program that: (1) costs more than it should; and (2) produces less, in terms of benefits, than it should. For example, CAFE standards can play an important role in pushing the technological development of fuel efficient automobiles. We may not be able to reap the full benefits of these standards, however, if they serve to lower the cost of driving. As long as gasoline prices fail to reflect the environmental costs of combustion, artificially low costs of driving are likely to reduce the benefits from increases in individual car efficiencies.

Getting energy prices right through a carbon tax is the fundamental component of the transition from our current fossil fuel based economy to one that is sustainable over the long-run. Improved pricing of energy is not a cure-all; certain types of market failures in energy markets will require special legislative and regulatory treatment. It makes sense, however, to get the prices right first and then see which additional problems still need to be addressed. For example, a production tax credit for renewable energy sources may not be necessary if the price of

fossil fuels were raised to reflect their global warming risks.

There is relatively wide-spread agreement on an intellectual level that carbon taxes are the most effective and least expensive tool for lowering U.S. emission of fossil fuels. On a practical level, the support for better energy pricing is less secure. Industrial dislocations, regional economic impacts, regressive income impacts and other factors are commonly cited as undesirable characteristics of energy taxes in general and carbon taxes in particular. It is true that these effects are likely to be associated with carbon taxes and need to be addressed in the design of any carbon tax strategy, for example through tax offsets. These outcomes will also result from any attempt to lower carbon dioxide emissions -- they are not unique to carbon taxes but are a consequence of the transition away from fossil fuels.

CONCLUSIONS

The risks of climate change from the combustion of fossil fuels adds significantly to the pressure and necessity of beginning a transition to a sustainable energy future where energy services are created as efficiently as possible and where low or no-pollution renewable technologies are the major energy source. There is no easy way to make this move. Our reliance on artificially cheap fossil fuel sources of energy will not be simple to redress. The trick of the transition, however, is not in technological development -- we have the means and knowledge to

begin the required shift. Our real task will be to find the right pace and timing so as to minimize the economic costs of change. Correcting energy prices is the first step in this direction -- we must create the economic atmosphere in which sustainable energy investments can compete. The second step is to look for those utility decision making reforms that will remove existing biases towards more fossil fuel combustion over less damaging alternatives. Third, we should exploit those opportunities for federal (and state) governments to take the lead in showing what is doable. Large scale energy efficiency investments by the federal government could, if properly targeted, save federal dollars and provide a role model for other sectors of the economy.

The environmental returns from U.S. leadership in an energy transition are not limited to our national borders. We can be the template for action by other industrialized countries and the developing world and thus offer a role model for the rest of the world. We stand to gain more than global virtue and environmental improvements. The U.S. can place itself as the supplier of the technological and intellectual means for a global transition to a sustainable energy future.



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Testimony of William A. Nitze
President of the Alliance to Save Energy
Before the Subcommittee on Health and the Environment
Committee on Energy and Commerce
U.S. House of Representatives
February 21, 1991

Mr. Chairman, Members of the Subcommittee, Ladies and Gentlemen:

My name is William Nitze and I am President of the Alliance to Save Energy. I appreciate the invitation to testify before the Subcommittee regarding policies available to mitigate global climate change as well as the anticipated costs of these policies. The Alliance to Save Energy is a national nonprofit coalition of government, business, environmental and consumer leaders dedicated to increasing energy efficiency. We conduct research, pilot projects, educational programs and policy advocacy to achieve this goal.

1. The Current U.S. Position on CO₂ Emissions Reduction Targets

The United States is the only major industrialized country that has not committed to stabilize its manmade CO₂ emissions by 2000 or shortly thereafter, with reductions to follow. Germany in particular has made a commitment to reduce its CO₂ emissions by at least 25% from 1987 levels by 2005. The German Government has already announced a comprehensive reduction strategy that includes all energy supply sectors (e.g. power plants) and all energy consumption sectors (e.g. industry, transport and private households).

The Bush Administration, by comparison, has informally committed to the much less stringent goal of holding its overall greenhouse gas emissions, measured in terms of their relative global warming potential, at or below current levels in 2000. This commitment falls far short of CO₂ stabilization. While European nations are both eliminating CFCs and stabilizing carbon emissions, the Administration is using the phase-out of CFCs simply to offset a projected 15% increase in U.S. CO₂ emissions under current policies. Furthermore, the "stabilization" is illusory, representing only a temporary reduction in the rate of emissions increases due to the one-time benefit from previously-agreed to CFC reductions.

Under the Administration's plan, total U.S. greenhouse gas emissions would resume their rise after the year 2000. Administration spokesmen say that they will propose additional policy initiatives to reduce the projected increase in U.S. CO₂ emissions, but the White House has so far steadfastly refused to propose any energy policy initiatives that would significantly reduce either U.S. fossil fuel consumption or U.S. CO₂ emissions.

The White House claims that we do not yet know how to reach similar targets in the U.S. without imposing large costs on the U.S. economy. There are a number of factors that contribute to greater physical energy use per unit of output in the U.S. than in Europe, including greater extremes of climate, longer distances, and more dispersed residential patterns. But the most important factor is that low energy prices, particularly for fossil fuels, have encouraged relatively high levels of energy use and discouraged investment in energy conservation, efficiency and non-fossil energy sources.

This situation presents a tremendous opportunity to U.S. government at all levels to work with the private sector in improving energy efficiency, developing non-fossil energy sources and thereby reducing U.S. CO₂ emissions. The technologies for achieving significant low-cost efficiency improvements and developing non-fossil energy sources already exist.

The real challenge is to develop a set of policies that will cause those technologies to be deployed as rapidly as possible with minimum adjustment costs. My colleagues and I at the Alliance believe that, given the necessary political will, we can devise a combination of tax shifts, regulatory changes, financial incentives, education initiatives and research, development and demonstration (RD&D) programs that can stabilize U.S. CO₂ emissions at the 1990 level by 2000 and reduce those emissions 20% by 2010 at the latest with little or no net cost to the U.S. economy.

2. Benefits of Achieving CO₂ Emissions Reduction Targets

Before making my case for that belief, I would like to summarize the potential benefits the U.S. would gain from committing to these targets.

First, accelerating reductions in U.S. CO₂ emissions, which account for almost a quarter of the world total, would buy us valuable time to learn more about greenhouse warming and how to deal with it and valuable insurance against truly catastrophic climatic changes. The longer we wait to take serious steps to reduce U.S. CO₂ emissions, the greater the total cost of achieving any ultimate level of required reduction will be.

Only by committing to targets such as the ones proposed above will the U.S. be able to persuade key non-OECD countries to take the necessary steps to reduce their own CO₂ emissions. The countries from which a growing portion of future manmade emissions will come - the Soviet Union, China, India and Brazil - are looking to the United States to show that it is serious about reducing its own CO₂ emissions before they commit to reduce their own emissions. The participation of these and other non-OECD countries in the long run is essential to the success of any international effort to slow greenhouse warming. Therefore an early U.S. commitment to stabilize and subsequently reduce its CO₂ emissions has a potentially large multiplier effect abroad.

Second, the two most important steps necessary to reduce U.S. CO₂ emissions - using energy more efficiently and developing non-fossil energy sources - would bring important non-greenhouse benefits to our economy. These benefits include reduced vulnerability to international oil price shocks (with the associated improvement in national security), lowering the cost of most energy services, cutting energy-related pollution such as acid rain and urban smog, making housing more affordable, and improving the U.S. balance of payments by reducing energy imports and making U.S. goods and services more competitive in world markets.

The competitive advantage of energy efficiency improvements is critical as we enter the next century. Japan, Germany and other U.S. competitors have already announced long-term plans to improve their energy efficiency by developing and deploying new technologies, products and processes. Japanese auto makers, for example, are already developing 60 miles-per-gallon (mpg) cars to be produced early in the next century. Unless the U.S. keeps pace, we will lose ground in world markets.

3. Costs of Achieving CO₂ Emissions Reduction Targets

Against the benefits of achieving the CO₂ emissions reduction targets discussed above must be weighed the costs of achieving those targets. Estimates of those costs vary greatly depending upon the assumptions made about human responses to price changes, economic incentives and other policy initiatives. There is a growing consensus among economists and policy analysts, however, that substantial reductions in CO₂ emissions could be made over the next 25 years at little or no cost to the economy with a combination of tax shifts, regulatory changes, financial incentives, education initiatives and RD&D programs.

The Office of Technology Assessment, for example, concludes¹ that the U.S. could reduce its CO₂ emissions by 20 to 35% between now and 2015 at a cost ranging from a savings of 0.2% to a cost of 1.8% of GNP projected for 2015. In reviewing cost studies, Professor William Nordhaus found a common view that 10 or perhaps 20 percent reductions in CO₂ emissions can be made in the long run at modest costs.² Professor William Chandler and his colleagues at Battelle Research Institute estimate that U.S. CO₂ emissions could be reduced 20% from current levels by 2000 at a cost of less than 0.5 percent of GNP.³

4. Policy Options

The key to achieving a 20% carbon reduction by 2010 at no or little net cost to the U.S. economy is development of the right combination of policy measures. Each key energy producing and consuming sector must be included; no single policy, or even group of policies aimed at a single sector, will be sufficient. By implementing a comprehensive set of policies, moreover, tax shifts, regulatory changes and other policy initiatives that carry potential adjustment costs can be phased in ensuring that overall burdens and benefits are more fairly distributed. Policies must focus on opportunities to remove impediments to energy efficient investments; to reap ancillary economic gains from improved tax policy; and to incorporate external environmental and national security costs into private energy use decisions. In each case, economic efficiency and energy efficiency can be jointly served. The following is a policy package for achieving the targets described above broken down by sector.

4.1 Energy Production - Fossil Fuels

Natural gas. Natural gas deliverability should be improved to ensure that sufficient quantities are available to meet long term-requirements for electricity generation, transportation fuels and heating and cooling. The regulatory approval process for new gas pipelines should be streamlined, while preserving appropriate environmental safeguards. The lower carbon

¹Congress of the United States, Office of Technology Assessment, "Changing by Degrees: Steps to Reduce Greenhouse Gases," Summary, February, 1991, p.10.

²Economist, 7 July 1990, p. 22.

³Carbon Emissions Control Strategies, Executive Summary, William U. Chandler, Editor, 1990, pp.27-29.

content of natural gas should be gradually reflected in the price by phasing in a carbon fee or equivalent incentive.

Finally regulatory requirements and financial incentives to use natural gas as a transportation fuel should be strengthened. The resulting substitution of natural gas for more carbon intensive fuels could reduce the Department of Energy (DOE)'s projected CO₂ emissions of 1501 million tons in 2000 (hereinafter referred to as projected U.S. CO₂ emissions in 2000) by one percent or more.

Coal. The long-term future of the U.S. coal industry will substantially depend on its ability to reduce the amount of CO₂ emitted for each unit of coal fired energy produced. The Department of Energy (DOE)'s Clean Coal Technology Program should be redirected to give greater priority to combined cycle and other technologies that increase the conversion efficiencies of coal fired generating units. Incentives to use less carbon intensive fuels should be structured to apply to the carbon emissions from a given use rather than to the carbon content of the fuel itself. These steps are unlikely to have a substantial impact on U.S. CO₂ emissions before 2000, but could contribute to reducing emissions in the first decade of the new century.

4.2 Energy Production - Renewables.

Renewable energy sources - hydropower, solar thermal, photovoltaics, windpower - currently provide almost seven quads or about eight percent of the energy used in the U.S. The cost-effectiveness of certain non-hydropower renewable technologies such as solar thermal has improved to a point where they are competitive with conventional power sources in selected areas.

Growth in renewable energy production and the associated decline in unit costs need to be encouraged by incentives such as the two cents per kilowatt renewable production tax credit originally proposed by DOE and subsequently deleted from the President's National Energy Strategy (NES) proposal by the White House. A carbon fee or equivalent incentive to use less carbon intensive energy sources would also encourage use of renewables. The Federal government should itself use renewable energy as much as possible to support the industry's development. Finally, states should be encouraged to incorporate environmental externalities in utility regulation.

Increasing the renewable share of overall U.S. energy production from eight to 12% by 2000 could reduce projected U.S. CO₂ emissions in 2000 by more than two percent.

4.3 Energy Consumption - Industry

Industry should be able to achieve continuing improvements in energy efficiency under current policies. Between 1971 and 1986, the energy intensity of industrial processes in the United States - the amount of energy required to produce a ton of steel or a kilogram of polyethylene - declined between 1.5 and two percent per year. These efficiency improvements, combined with a change in the mix of products produced and consumed, have reduced total industrial energy use by one percent per year despite a two percent annual growth in manufactured output.

There is no reason to believe that these improvements will not continue as companies optimize the cost of existing processes, introduce process refinements, and make breakthroughs that lead to entirely different methods of manufacturing. Insulating the 29,000 miles (22% of total pipe) of uninsulated pipe in the United States would save about four percent of all industrial energy use and reduce projected U.S. CO₂ emissions in 2000 by five percent.

The outlook for industrial consumption of electricity is particularly promising. Electric motors consume 65 to 70% of industrial electricity. By combining currently available variable speed drives, superefficient motors and other system improvements, electricity consumption by motor systems can be reduced by 50% or more. Since electricity accounts for over 95% of the life cycle cost of a typical large industrial motor, industry has a substantial incentive to achieve this reduction.

If U.S. industrial energy use continues to decline at one percent per year, we will achieve an overall decline of over 10% in industrial energy use by 2000. If the rate of decline can be increased to 1.5% per year through policy initiatives, the overall decline would increase to 16%. Since industrial energy use accounts for over 30% of total U.S. energy use, the lower trend would result in an overall reduction in U.S. energy use of about three percent and the higher trend a reduction of about five percent. Absent a significant change in the mix of industrial energy sources, these reductions would produce roughly equivalent reductions in projected U.S. CO₂ emissions.

Industry is not subject to market imperfections to the same extent as the commercial, residential and transportation sectors, but there is nonetheless an important role for policy initiatives designed to stimulate industrial energy savings. Energy using firms, being generally smaller than energy-producing firms, tend to have higher capital costs and less ability to coordinate research and demonstration efforts.

The Federal government can help overcome these limitations and accelerate the trend towards greater efficiency in industrial energy use by providing research support and financial incentives for improvements in industrial process technology. Such joint R&D efforts would provide an impetus to technological development in energy using industries, much as EPRI and GRI does for the electric and gas industries, respectively, or U.S.G.S. does for oil and gas exploration. Significant expansion of an existing program of grants to university engineering departments would provide a cost-effective means of disseminating technological advances.

Gradual increases in fossil fuel prices to reflect environmental externalities would further strengthen the trend to greater efficiency. Encouragement of least cost planning by utilities could also lead to additional efficiency improvements by their industrial customers.

The payoff for an industrial efficiency program along these lines is increased competitiveness, both through reduced production costs and development of new, U.S. manufactured efficiency products to market abroad.

4.4 Energy Consumption - Residential and Commercial

The residential and commercial sector offers tremendous potential for energy savings, particularly in electricity use. The Alliance estimates that compact fluorescent lighting, "low-

emissivity" windows, and energy efficient oil burners alone could save approximately two quads or over two percent of projected U.S. energy use in 2000. Compact fluorescent lamps, for example, consume 75 percent less electricity than do incandescent ones. They typically last nine times longer than ordinary incandescent bulbs.

Similar efficiency gains can be obtained with appliances and home heating systems. Manufacturers have already developed refrigerators and freezers that consume 80 to 90 less electricity than conventional models. A field test organized by the Alliance in Buffalo, N.Y., has shown that cost-effective energy retrofits can save 25% of the heating energy used in single-family homes. The Buffalo field test realized measured space heating savings that demonstrated a significant improvement over earlier programs, which showed poor correlation between projected and actual energy savings.

Together with passive design improvements and automated controls, these additional savings have the potential to increase total energy savings in the residential and commercial sector to at least four percent of projected U.S. energy use in 2000. The challenge is to overcome market imperfections that inhibit rapid development and deployment of the available technologies. The three most promising policy options for overcoming those imperfections are integrated resource planning (IRP) programs by utilities, stricter codes and standards for building shells and equipment used therein, and a "feebate" system to encourage the purchase of more energy efficient appliances.

By requiring utilities to invest in customer efficiency improvements (if they are cheaper than capacity additions) in meeting projected demands for energy services, and by making those investments profitable for utilities, IRP programs establish a level playing field for energy supply and efficiency improvements, leading utilities to implement efficiency improvements that customers might not pursue on their own. IRP programs have already eliminated the need for significant capacity additions in California and New England and greatly increased the demand for compact fluorescent lighting. The Federal government should encourage the spread of IRP programs to other states by requiring utilities to prepare such plans as a condition to receiving cheap power from Federal power marketing authorities or approval for interstate power sales.

Similarly stricter energy codes for building shells and efficiency standards for equipment used therein could remove the least efficient designs and products from new homes and commercial buildings. Although building codes are traditionally within state and local jurisdiction, the Federal government could require development of nationwide model energy codes for different climate zones and provide technical assistance and incentives for the adoption of such codes. Federal efficiency standards should be gradually increased and extended to new product areas such as lighting.

Finally the Federal government should consider a "feebate" system for major appliances subject to Federal efficiency standards. By imposing a fee on appliances that are below a benchmark level of energy efficiency and providing a rebate on appliances that are above the benchmark level, a feebate system would provide a market incentive for the purchase of more energy efficient products.

4.5. Energy Consumption - Transportation

The transportation sector presents the greatest challenge of all. The average fuel efficiency of U.S. automobiles improved from 15.3 mpg in 1975 to 25.8 mpg in 1988. As a result, CO₂ emissions per vehicle declined by approximately 1.5% per year over the same period. Unfortunately this improvement has been more than offset by continuing growth in the number of U.S. cars and light trucks and in vehicle miles travelled, resulting in an approximately 13% increase in CO₂ emissions from these vehicles over the same period.

To reverse the growth in CO₂ emissions from the transportation sector, we need to take five key steps. First, we should gradually shift Federal taxes from income and labor to gasoline and other fossil energy sources. Second, we should gradually increase fuel efficiency standards on automobiles and impose minimum standards on vans, trucks and buses. Third, we should institute a "feebate" system for all automobiles, vans and light trucks. Fourth, we should encourage the development of non-oil based transportation fuels. Fifth, we should build more public transportation.

Gradually shifting Federal taxes from income (by raising the threshold for paying Federal income taxes) and labor (by reducing social security taxes) to gasoline and other fossil energy sources serves a number of purposes. It provides an incentive for fuel conservation and the purchase of more efficient cars. It increases incentives to work and employer incentives to hire. It minimizes the regressive effects of higher energy taxes by reducing other Federal taxes on low income workers. Finally, if one phases these shifts in over the decade, it will enable vehicle manufacturers, vehicle owners and local governments to anticipate changes in demand and minimize adjustment costs.

Increasing corporate average fuel efficiency (CAFE) standards for automobiles and extending them to vans and light trucks is also necessary. The type of gradual shift in taxes proposed above will not provide a sufficient short-term incentive for fuel conservation since fuel costs represent such a small portion of the life-cycle costs of a vehicle. CAFE standards should also be extended to vans and light trucks, to slow the growth in the proportion of relatively fuel inefficient vans and light trucks in the total household fleet.

Existing technologies such as multiple valve engines, lightweight materials and aerodynamic styling already enable automobile manufacturers to increase the average fuel efficiency of new cars from the current 27.5 mpg to over 35 mpg by 2000 without increasing cost or sacrificing size or performance. If the full range of available technologies is exploited, it may be possible to achieve efficiencies of 40 mpg by 2000 even if customers retain their current preferences for car size and performance. Car prices might have to increase, but a recent poll conducted by the Alliance and the Union of Concerned Scientists found 89% of respondents willing to pay up to \$500 more per car to achieve the 40 mpg standard.

A "feebate" system for vehicles subject to CAFE would enhance the efficiency gains from increasing CAFE standards and higher gasoline taxes. The feebate system would impose a fee on each mpg by which a vehicle fell below an efficiency threshold (e.g. 90% of CAFE) and pay an offsetting rebate for each mpg by which a vehicle exceeded an efficiency ceiling (e.g. 110% of CAFE). By providing a significant point of purchase incentive to purchase more fuel

efficient vehicles, such a feebate system would accelerate improvements in overall fleet efficiency.

There are already several measures to encourage the use of non-oil based alternative fuels in the President's NES proposal, including extending the 10% fleet requirement to the whole country and lifting the CAFE exemption cap on dual fuel vehicles. Biomass fuels also receive a preferential Federal tax rate. These incentives could be made more effective by gradually increasing both the gasoline tax and CAFE and exempting all non-oil based fuels from both.

Finally, to the extent that the public is being asked to drive less, it must be given an alternative in the form of better public transportation. One way to support public transportation would be to provide for a portion of gasoline tax receipts to be dedicated to improving public transportation.

It is difficult to quantify the total impact of these measures on projected U.S. CO₂ emissions in 2000. The Alliance estimates that increasing CAFE to 40 mpg by 2000 would save 2.8 million barrels of oil per day in 2005. If one assumes that oil consumption for transportation would otherwise increase by approximately two percent per year from 10.9 million barrels a day to 14.7 million barrels a day in 2005, this would hold transportation oil consumption to 11.9 million barrels a day. If the combination of higher gasoline taxes and a feebate system with improved public transportation increased this reduction by 50%, transportation oil use would actually drop to 10.5 million barrels a day. If increased use of alternative fuels reduced transportation oil use another 5% by 2005, the total would drop to 10 million barrels, 4.7 million or 32% below the original 14.7 million barrel projection. Since transportation accounts for over 30% of total U.S. CO₂ emissions today, and only two percent of transportation is non-oil based, this reduction should reduce total projected U.S. CO₂ emissions in 2005 by almost 10%. Assuming half of this reduction takes place before 2000, there should be an approximately 5% reduction in projected U.S. emissions in 2000.

5. Conclusion

If one adds up the low-end reduction figures from each of the sectors discussed -- natural gas one percent, renewables two percent, industrial use three percent, residential and commercial four percent, and transportation five percent, the total comes to 15%, which just offsets DOE's projected increases in U.S. CO₂ emissions by 2000. If one takes the high-end and adds an additional five percent for transportation efficiency increases by 2005, one comes up with a further 10% reduction by 2005, which is consistent with achieving a 20% reduction by 2010.

The above numbers are of necessity inexact. But hopefully they demonstrate that we do have the potential of stabilizing U.S. CO₂ emissions at 1990 levels by 2000 and reducing them by approximately 20% during the first decade of the next century at little or no cost to the economy. Even if we were to take the high end of OTA's cost estimate for a 20-35% reduction in 2015 -- 1.8 percent of GNP -- it would in my opinion be a small price to pay for the environmental and other benefits of reducing CO₂ emissions.

The real obstacle to achieving the necessary reductions is not cost, but the difficulty in moving a comprehensive package of policy changes, some of which impact powerful constituencies,

through the U.S. political process. The Alliance looks forward to working with this Subcommittee, Mr. Chairman, and the Congress as a whole in overcoming this obstacle.



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Statement of

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before the

Subcommittee on Health and the Environment

Committee on Energy and Commerce

U.S. House of Representatives

February 21, 1991

Thank you Mr. Chairman and members of the Committee. I am Daniel Lashof, a senior scientist with the Natural Resources Defense Council (NRDC). Previously I was an Environmental Scientist at the Environmental Protection Agency, where I was the lead author of the Draft Report to Congress *Policy Options for Stabilizing Global Climate*. I hold a doctorate in Energy and Resources from the University of California, Berkeley, where I specialized in the global carbon cycle. I appreciate the opportunity to appear at this important hearing.

NRDC is a non-profit environmental protection organization, founded in 1970 and supported by 160,000 members. NRDC's Energy Program has more than ten years of experience in promoting energy efficiency and least-cost energy planning. In 1988 NRDC launched its Atmosphere Protection Initiative (API) to provide a coordinated response to the related threats to the integrity of the earth's atmosphere--global warming, ozone depletion, acid rain, and urban smog. This effort involves more than a dozen NRDC scientists, resource specialists, and attorneys expert in climate, energy efficiency, nuclear energy, forestry, agriculture, international environment, air pollution control, and coastal protection.

Mr. Chairman, the United States is the world's leading emitter of greenhouse gases and it should be the world's leader in action to reduce these emissions. However, the Bush Administration's continuing refusal to accept targets and timetables for reducing carbon dioxide, the most important global warming gas, remains the largest obstacle to progress. In fact, the U.S. *Climate Change Strategy* contemplates a substantial increase in CO₂ emissions in the decades ahead. Every other wealthy industrialized country is ready to stabilize or reduce emissions of carbon dioxide. Key developing countries, such as Brazil, are also ready to make commitments to protect forests provided that industrialized nations curb their fossil fuel CO₂ emissions. In my statement today I will summarize the scientific background that should guide the negotiation of a climate protection treaty, then I will review the policies adopted by the leading industrialized countries in contrast to those of the United States, and finally I will discuss the disappointing results of the first treaty negotiating session.

Scientific Basis for a Climate Protection Treaty

The Toronto Conference on the Changing Atmosphere, in June 1988, warned that "humanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war," and called on the world to cut CO₂ emissions from fossil fuel combustion 20% by 2005. In the last two years the declaration of this ad hoc group of scientists, environmentalists, and policy makers has been strongly reinforced by the Intergovernmental Panel on Climate Change (IPCC), the Second World Climate Conference, and the Stockholm Environment Institute.

The IPCC, which was established in the Fall of 1988, completed its First Assessment Report last summer. The first working group, chaired by Dr. John

Houghton, Chief Executive of the British Meteorological Office, has provided the most authoritative scientific assessment of global warming ever conducted. Preparation of the report involved most of the active scientists working in the field: 170 scientists from 25 countries contributed sections and 200 others served as reviewers.

Under a "business-as-usual" emissions scenario the IPCC predicts that the earth will be 5-10°F warmer than preindustrial times within a century. Conditions would be warmer than any encountered during the last 150,000 years by the middle of the next century. The IPCC also examined a scenario in which warming could be limited to 2-5°F, if CO₂ emissions were reduced by 50% by the middle of the next century and if other greenhouse gases were also controlled.

A great deal of public attention has focused on observed temperature changes over the last century. The IPCC concluded that the earth has warmed significantly, by 0.5-1.0°F, and that "[t]he size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to this natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more." This carefully worded statement underscores the danger of a wait-and-see policy. It makes no sense to wait for "unequivocal detection" while we see ourselves being committed to ever greater warming. The scientific consensus that this warming will occur is clear, regardless of uncertainty over what has caused the warming to date.

Fortunately, the consensus of world leaders is that we should not wait. Cabinet-level officials from 137 countries (including the United States) at the Second World Climate Conference last November declared that "[t]he potentially serious consequences of climate change, including the risk for survival in low-lying and other small island States and in some low-lying coastal and arid and semi-arid areas of the world, give sufficient reasons to begin by adopting response strategies even in the face of significant uncertainties." They called for negotiating an international convention on climate change by June 1992. The Ministers agreed "that the ultimate global objective should be to stabilize greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with climate."

The implications of this objective were spelled out by the Stockholm Environment Institute (SEI) in a recent report on Targets and Indicators of Climatic Change (the summary of this report is attached for the record). This report concludes that dangerous interference with climate can be avoided only if the rate of warming is kept to less than 0.2°F per decade, and the absolute warming is kept to less than 2-4°F compared with pre-industrial times. Warming greater than the lower limit of 2°F "may elicit rapid, unpredictable, and non-linear responses that could lead to extensive ecosystem damage," while beyond 4°F "the risks of grave damage to ecosystems, and of non-linear responses,

are expected to increase rapidly." To prevent warming of more than 2°F the SEI study estimates that the atmospheric concentration of greenhouse gases would have to be limited to the equivalent of 330-400 parts per million (ppm) of CO₂ (this is called the CO₂-equivalent concentration). The concentration of CO₂ in the atmosphere is already over 350 ppm, and the CO₂-equivalent concentration of all greenhouse gases exceeds 400 ppm, thus the world is most likely already committed to exceeding the 2°F limit. To avoid exceeding even the upper limit SEI estimates that greenhouse gas concentrations would have to be limited to 400-560 ppm CO₂-equivalent. To be prudent in the face of uncertainty we must adopt a goal in the lower half of this range. I propose a greenhouse gas concentration limit of 475 ppm CO₂-equivalent. Based on feasible limits for the concentrations of greenhouse gases other than CO₂ I calculate that this target requires holding CO₂ concentrations to about 400 ppm. Immediate action to reduce CO₂ emissions is essential if this limit is not to be exceeded.

Industrialized countries, with 25% of the world's population, are responsible for 75% of current global emissions of CO₂ from the energy sector. Reducing energy-related CO₂ emissions from industrialized countries is the most important action needed to combat global warming, and is essential to achieve the global targets just discussed.

In particular, OECD nations should have a binding obligation to reduce energy-related CO₂ emissions by at least 20% below 1988 levels by the year 2000. Other industrialized nations should achieve this target by the year 2005. Deeper cuts in CO₂ emissions from industrialized countries will be required after these dates in order to stabilize atmospheric greenhouse gas concentrations. Let me emphasize that stabilizing **emissions** of greenhouse gases at current levels will allow greenhouse gas **concentrations** to continue increasing at roughly current rates. The only way to stabilize atmospheric concentrations of CO₂ is to cut emissions by 60% or more, according to the IPCC.

Developing countries, with 75% of the world's population, are responsible for 25% of global energy-related CO₂ emissions. These emissions are expected to grow to meet legitimate development needs. In order to remain within the global CO₂ target of 400 ppm the aggregate increase in CO₂ emissions from developing countries would have to be limited to no more than 50% over 1988 levels by 2005. The incremental costs of achieving this target should be borne by the industrialized countries, in accordance with their responsibility for the preponderance of all past emissions that have elevated greenhouse gas concentrations to current levels.

Industrialized Country Policy Commitments

Every wealthy industrialized country other than the United States has already taken significant steps toward the required emission reductions. Eighteen countries are committed, individually or collectively, to stabilizing or reducing their CO₂ emissions by the year 2000. In addition, Germany, Denmark, Australia, and New Zealand are committed to emission reductions of 20% or more by 2005. Implementation of policies to achieve these commitments is at different stages in different countries. The most

detailed plans adopted to date are probably those of Germany, Denmark, and the Netherlands. The German plan, for example, is designed to achieve a 25% reduction in CO₂ emissions by 2005 compared to 1987. This plan was formally adopted by the German Federal Cabinet on November 7, 1990. The Environment Minister has publicly stated that this plan was based on analysis of former West Germany, and that a larger reduction of 30% should be achieved for Germany as a whole (but this target has not yet been formally adopted). Relevant ministries will draft legal instruments to implement this plan in each sector. These will include regulations to increase energy efficiency by amending Ordinances on insulation, heating installations, small incineration plants, and large combustion plants. The efficiency of automobiles is to increase by an average of 30% by 2005, and increased reliance on rail transport will be promoted.

Germany's plans will be coordinated with the European Community (EC) as a whole, which has adopted the aggregate target of stabilizing emissions of CO₂ at 1990 levels by 2000, with reductions thereafter. Increased energy taxes, for example, are being taken up very seriously at the European level. The EC Council of Ministers adopted a policy statement on December 21, 1990 calling for a carbon tax in combination with a general energy tax, although the levels of these taxes have not yet been agreed upon. It is instructive that the Council noted that there was a risk to the competitiveness of some industries, but that "if a reinforced policy of environmental protection leads European companies to an adaptation of their marketing and R&D efforts ahead of others, these companies will in the future be better placed on world markets." The Council concluded that the EC CO₂ stabilization policy will have a "...positive overall impact. The available evidence indicates that their macroeconomic effects could be small, even when abstracting from the expected environmental benefits."

The forward looking policies of the EC contrast sharply with the Bush Administration's "inaction agenda," as it was so aptly put by the Senate Majority Leader recently. The one welcome aspect of "America's Climate Change Strategy," which was distributed at the negotiations, is a clearer recognition by the Administration than we have seen before that action is needed to combat global warming. We welcome this significant change in tone from the White House, but unfortunately there have not been any corresponding policy commitments to real action.

The U.S. is still planning for large increases in CO₂ emissions while the European Community is planning decreases. Nothing in the White House's glossy brochure changes this black and white reality. Instead the Administration Strategy is to claim that the U.S. will stabilize total greenhouse gas emissions by offsetting the CO₂ increase with reductions in CFC emissions, which are already required to be phased out under the Montreal Protocol.

Every CFC producing country has already agreed to phase out these compounds because of their threat to the stratospheric ozone layer. No country other than the U.S., is proposing to take double credit for this action against CO₂ increases. If Germany did

its accounting the way the U.S. proposes, it would be able to claim about a 40% reduction in greenhouse gases by 2005. The kind of "stabilization" that the U.S. is planning for would lead to inexorable increases in CO₂ concentrations and a commitment to massive global warming at a rate of 4-9°F over the next 100 years.

Previously the U.S. has said that the National Energy Strategy (NES) would be the forum for addressing CO₂ emissions from fossil fuel use. But the claimed CO₂ reductions in the Climate Strategy amount to less than 40 million tonnes of carbon, or less than 3% of current emissions. Too little to significantly offset expected growth, let alone stabilize or reduce current emissions. Indeed, the National Energy Strategy released yesterday anticipates significant increases, rather than decreases, in CO₂ emissions, and contains neither targets nor significant policy initiatives to cut CO₂.

Slow Progress of the Negotiations

It is imperative that targets and timetables be elaborated in the climate convention to be signed at the United Nations Conference on Environment and Development in June, 1992. At the first negotiating session, which ended last week, it was clear that the United States stands virtually alone in supporting a framework convention that is merely an empty shell, with any specific commitments deferred to subsequent negotiations over protocols. Both European and developing countries called for an agreement in 1992 containing substantive commitments, including stabilization or reduction in CO₂ emissions from industrialized countries and provisions for funding and technology transfer so that poorer countries can develop without "achieving" the same level of pollution output as the richer nations.

The Administration's failure to commit the United States to these principles remains the largest obstacle to progress in the negotiations. Diplomats responsible for protecting the world's climate sparred for two weeks over the basic issue of whether they are going to negotiate real commitments to control CO₂ and other greenhouse gases, or merely an empty framework. The first negotiating session was consumed debating the instructions of two working groups set up to negotiate the specifics of the treaty. There was no time for these groups to meet, or even to choose their leaders. The meeting adjourned without adopting a draft text of a treaty, which most countries (including the United States) had hoped to have as the basis for future negotiations. As the next meeting will not be until June, real progress has been delayed by several months. With only 15 months until the treaty is to be signed, there is no more time to waste.

The continuing failure of the Bush Administration to come to grips with global warming is not only bad environmental policy, it is bad foreign policy, bad energy policy, and bad economic policy. We call upon the Congress to help lead the Administration out of the greenhouse wilderness.

**BIOTIC INFLUENCES AS THE EARTH WARMS:
WARNER AND WARNER, FASTER....and faster...and..?(1)**

George M. Woodwell

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9900

I as a biologist with more than thirty years' experience in ecology addressing various aspects of the global carbon cycle, especially the interactions between life and environment. I have specialized in research on units of landscape such as forests and estuaries. I believe that we know enough now to anticipate great difficulties with the capacity of the earth for supporting us over the next years unless we move rapidly to correct the series of trends outlined in the scientific presentations today. The failure of the current US leadership to acknowledge this problem and offer the leadership that the rest of the world expects of us has made the United States an international pariah. To emphasize the seriousness of that unflinching perspective I am enclosing a copy of a recent editorial in *The Guardian* (2). I would also call attention to the recent report of the Office of Technology Assessment that shows clearly that the nation could reduce its reliance on fossil fuels by as much as 20% almost immediately at a net saving in dollars and with many ancillary environmental, economic, international and military advantages (3).

The accumulation of carbon dioxide and methane in the atmosphere is causing, and will cause, more than three quarters of the warming anticipated from heat-trapping gasses over the next several decades. Both are products of the exploitation of fossil fuels and products of biotic activity. For brevity I shall

1. Testimony of G.M. Woodwell before the Subcommittee on Health and Environment, Committee on Energy and Commerce, U.S. House of Representatives, February 21, 1991.

2. Jeremy Leggett in *The Guardian*, Feb 1, 1991 (appended).

3. OTA, 1991. *Changing by Degrees: Steps to Reduce Greenhouse Gases*. Congress of the United States, Office of Technology Assessment. 42pp.

emphasize carbon dioxide.

My most important conclusion is that evidence is accumulating that we are observing and can expect a continuing acceleration of the rate of accumulation of carbon dioxide and methane as the earth warms, an acceleration that will probably speed the warming (4).

I shall also emphasize that the primary control of the concentration of carbon dioxide in the atmosphere over years to decades is on land, not the oceans. Forests are the most important vegetation type on land because they are large in area, contain about three times as much carbon as the atmosphere currently contains, and because their annual metabolism involves an exchange with the atmosphere of at least 100 billion tons of carbon (Fig 1). This exchange is highly vulnerable to changes in the environment.

The two most powerful factors that affect the influence of forests on the composition of the atmosphere are their areal extent and their metabolism.

The area of forested lands in the world is declining. The magnitude of the decline is in question, but the pattern and direction of change globally are not. The pattern is now almost classical, if over-simplified here: in this world that adds 90 million new people annually, forests, especially in the tropics, are displaced by agriculture. The agriculture survives for a time, may be replaced by low-density grazing, and the land gradually lapses into impoverishment. It falls out of the economy and the records. Such land is accumulating globally, but there is little attempt to measure it. One third of the land area of India is now recognized officially by Indian officials as impoverished to the point where it is outside agriculture and non-forested. Most is barren, salinized, or rock from which the soil has been lost through erosion by wind and monsoonal rains. The accumulation of impoverished land is the most important land-use change currently underway in the world. Most of that land was

4. Woodwell, G.M. 1983. Biotic effects on the concentration of atmospheric carbon dioxide: A review and projection. in Changing Climate, NAS Press, Washington, D.C., pp 215-241

----- 1986. Testimony of G.M. Woodwell in hearings before the U.S. Senate Subcommittee on Environmental Pollution, of the Committee on Environment and Public Works, June 10-11, 1986. Congressional Record Special Printing, pp 98-106

WMO/UNEP 1990. Climate Change: The IPCC Scientific Assessment. 365pp. Geneva.

once forested and its impoverishment constitutes a major transfer of carbon from forest and soil to the atmosphere. The transfer continues. It can and will be measured, but only by applications of satellite imagery whose use, although technically advanced, is not yet being applied to this purpose with sufficient vigor to produce progress in proportion to the growth of the problem. There is, of course, question as to how the warming of the earth will affect climates globally, but the first assumption must be that a warming in the range of tenths of a degree C to one degree or more C per decade will cause an acceleration of the trend toward impoverishment.

The implications are seen most clearly by considering a forest such as the eastern deciduous forest of North America. At its warmer and drier limit it yields to grassland; at its wetter and colder limit it is replaced by coniferous or mixed hardwoods and softwoods in a transition zone to the boreal forest. Throughout its broad range it is made up of populations of trees of several species, but each population has existed through several generations and been selected for a genetic constitution appropriate for that place and climate. As the earth warms and climates change, plants at the warmer and drier limits of their distribution first, fail to reproduce, then succumb to pests of disease or fire. The forest is replaced by shrubland, later, by grassland. The transition may be accelerated by fire or disease as the trees are weakened. At the wetter and colder margin a similar transition occurs except that while climates may be appropriate to support forest, mortality of trees will far outstrip the capacity of the trees to regenerate and the interim community will be shrubland or some other stage of impoverished forest. These are conspicuous changes at the margins of the distribution of a plant community. There are parallel changes throughout the community. Each population of plants has been selected through several generations for the particular site and climate of its place. As climate changes, each population becomes maladapted to that place and each organism becomes more vulnerable to disease, to competition, to parasites or other disturbance. The community as a whole is weakened and, ultimately, impoverished as longer lived species die and are replaced but slowly if at all. The impoverishment will be accompanied by accelerated decay of dead and dying plants, adding to the release of carbon as carbon dioxide and methane into the atmosphere.

The changes in the metabolism of forests as our earthly habitat is modified under the human care are also difficult to discern. A close acquaintance with the physiology of forests will lead in almost any direction; some have suggested that the increased precipitation and temperature in the higher latitudes associated with a warming of the earth and combined with the increased carbon dioxide in the atmosphere will cause a surge in the fixation and storage of carbon that will be a boon to life

and tend to check the accumulation of carbon dioxide in the atmosphere. Such an effect may occur, possibly in a lesser degree than some of the more optimistic have asserted (5). But others will argue that whatever advantages there may be to gross photosynthesis will be lost through the acceleration of respiration in response to warmer temperatures (6). The issue is vital, for it contains the potential for diminishing or greatly aggravating the warming of the earth far beyond the current calculations of the climatologists. The question hinges on whether the changes in climate can be expected to stimulate the removal of carbon from the atmosphere through photosynthesis or the release of carbon as carbon dioxide and methane through the stimulation of the respiration of decay.

I suggest that the evidence for a resolution of that question sufficient to provide a basis for governmental action is available. The evidence was alluded to in the recent report of the Intergovernmental Panel on Climate Change (see note 4 above) which provided an international consensus on the seriousness of the problem. The IPCC called attention to the probability that the warming would proceed more rapidly than estimations based on emissions from fossil fuels have suggested.

Three lines of evidence show that the dominant influence on forests will be the changes in temperature and that a warming will cause a net release of carbon from the land into the atmosphere.

One is first principles of physiology and ecology; rates of respiration, including the respiration of decay, are highly sensitive to temperature. A one degree C. increase in temperature will increase rates of respiration by 5-30%, sometimes more. Rates of photosynthesis are much less sensitive to temperature and can be increased by as much as 10% only with difficulty. Virtually any disturbance of a forest stimulates respiration over

5. The topic has been reviewed at length in Strain, B.R. and J.D. Cure. (eds) 1985. Direct Effects of Increasing Carbon Dioxide on Vegetation. U. S. Dept of Energy. National Technical Information Service, Springfield, Virginia 22161. 286 pp. and summarized in Woodwell, G.M. 1988. The warming of the industrialized middle latitudes 1985-2050: causes and consequences. Prepared for the Symposium: Developing Policies for Responding to Future Climatic Change held in Villach, Austria, September, 1987. Climatic Change, 15:31-50, 1989.

6. Houghton, R.A. and G.M. Woodwell, 1989. Global Climatic Change. Scientific American, April, pp36-44.

photosynthesis. Specific data addressing this issue are few and difficult to obtain.

But the most persuasive data we have are the observations of variations in temperature and carbon dioxide over time. We have the now well-known data from the Vostok Core that show concentrations of both carbon dioxide and methane varying with temperature over 160,000 years of recent glacial history (Fig 2). While these data offer little insight into cause and effect, they do show that there is no basis, at least in that record, for defending the hypothesis that as temperature and carbon dioxide rise photosynthesis will be stimulated enough to reduce the concentration of carbon dioxide in the atmosphere and cure the problem. The carbon dioxide record seems to suggest that, at least during declining temperatures, the carbon dioxide concentrations lagged the changes in temperature.

We also have a set of data from Mauna Loa accumulated and analyzed by David Keeling and his colleagues, who have shown that there is a correlation between the temperature and carbon dioxide concentrations when the upward trend and the pronounced annual oscillation are removed (Fig. 3). The carbon dioxide concentration lags the temperature, a relationship that suggests that the temperature changes cause the changes in carbon dioxide. The shorter term oscillations are ascribed by Keeling et al (7) to changes in the surface temperature of the oceans; the longer term oscillations to changes in the metabolism on land. A more recent analysis of these same data by Oppenheimer and others shows that there are longer-term cycles of temperature and carbon dioxide that follow the same pattern with the carbon dioxide lagging temperature.

The third line of evidence is what is happening at the moment. We have had since 1980 seven of the warmest years for the globe in 130 years of record. If the observations above hold, we should see the accumulation of additional carbon in the atmosphere as carbon dioxide as the large pools of carbon in forests warm and respiration is accelerated. Such a change appears to be underway. Keeling and his colleagues (6) again have provided us with a set of data on the accumulation of carbon dioxide in the atmosphere (Fig 4). Two aspects of this curve are important. Firstly, after 1973 there was a sharp drop in the rate of expansion of global use of fossil fuels. In fact the rate of use stabilized through the first half of the 1980's. There was,

7. Keeling, C.D., R.B. Bacastow, A.F. Carter, S.C. Piper, T. P. Whorf, M. Heimann, W.G. Mook, and H. Roeloffzen. 1989. A three dimensional model of atmospheric CO₂ transport based on observed winds: 1. Analysis of observational data. Geophysical Monograph 55. American Geophysical Union (pp165-236).

however, no obvious reduction in the rate of accumulation of carbon dioxide in the atmosphere. In subsequent years, in fact, with no appreciable increase in the use of fossil fuels globally, the rate of accumulation accelerated above the rate that had prevailed for more than 15 years. During the fifteen years prior to 1986 the rate of accumulation was about 1.5 ppm/yr, equivalent to about 3 billion tons of carbon. Since that year the rate of increase has varied up to 2.6 ppm or about 5 billion tons of carbon without any equivalent change in the use of fossil fuels. Keeling and colleagues examined this issue themselves in 1989 and prepared the graph shown here. Their conclusion was that the release is a biotic release. The conclusion was substantiated by considering the isotopic ratio of carbon in air. The rate of accumulation heat trapping gasses, especially carbon dioxide, has risen as might be expected from the experience summarized above.

The most important point here is that the warming of the earth can be expected to release additional carbon into the atmosphere and to speed the warming. The process appears to be underway. The seriousness of it becomes apparent only when one compares the magnitudes of the flows of carbon that contribute to the accumulation of 3-5 billion tons of carbon in the atmosphere as carbon dioxide.

The release from fossil fuels is about 5.6 billion tons of carbon. There is an additional release from deforestation currently estimated as between 0.5 and 3.0 billion tons, possibly more. Presumably these two fluxes are under human control and have been the major cause of the long-term accumulation of carbon in the atmosphere in heat-trapping gasses. A third net flux is appearing, if these analyses are correct. It is a shift in the formerly approximately balanced two-way flow of carbon through gross photosynthesis and total respiration in favor of respiration. The magnitude of such shift is potentially large, enough to swamp human capacities at control in a short time.

There is urgency in moving with deliberate and effective speed to stabilize the heat-trapping gas content of the atmosphere before we lose the capacity for affecting it and commit the earth to a cycle of warming of unknown severity, speed, duration and effects. While we may be able to anticipate with reasonable accuracy the effects of a warming of 1-2 degrees C, we are not able to anticipate the effects of a greater warming and the complex changes that will accompany it.

The steps to correct this circumstance are well known. The reasons for our failure to take them have nothing to do with science or knowledge or lack of insight as to the consequences.

Figure Captions:

Fig. 1. The global carbon cycle. Units are in billions of tons of carbon (10^{15} grams). The important point is the flux of carbon between the atmosphere and biotic pools on land. These flows are affected heavily by climate and by the management of vegetation, especially forests.

Fig. 2. Data on carbon dioxide and methane concentrations with estimations of temperature over 160,000 years of recent history of the earth. Adapted from IPCC, 1990.

Fig. 3. Temperature and carbon dioxide concentrations in air at Mauna Loa. The annual increase and the seasonal oscillation have been removed. (From Keeling et al. 1989)

Fig. 4. The accumulation of carbon dioxide in the atmosphere. During the late 1970's and early 1980's there was a levelling of the global use of fossil fuels. This levelling did not appear in the rate of accumulation of carbon dioxide in the atmosphere as shown in this graph. Later, during the late 1980's, the rate of accumulation has increased without any concomitant increase in the rate of consumption of fossil fuels. (From Keeling et al 1989)

Face the facts, George

Friday, February 1, 1990

Gulf war: as the oil slick widens, the rhetoric thickens. On the eve of a major conference on global warming, **Jeremy Leggett** asks who are the world's greatest carbon criminals

NO ONE can forgive the poisoning of the Gulf with more than 11 million barrels of oil. A criminal environmental act, right enough — a restricted, shallow sea, an already fragile ecosystem: a grotesque environmental tragedy. But as the rhetoric of war flows thick, parallel acts of carbon criminality are passing without comment.

● 22,000 million barrels: the amount of oil burnt each year worldwide, more than a quarter of it in the US. These 22 billion barrels contribute 60 per cent of all energy-related carbon dioxide which mankind puts into the atmosphere each year, there to contribute — along with the products of coal and gas burning — almost 60 per cent of the human-enhanced greenhouse effect.

Remaining addicted to fossil fuels in this way will, within decades, unleash rates of temperature and sea level rise unprecedented in human history. This is not doom-mongering: it is the prediction of every big climate-modelling centre in the world, and the opinion of hundreds of climate scientists who urged cuts in CO₂ emissions at last year's UN World Climate Conference. Yet, having located more than a million million barrels of oil under the ground (more than two thirds in the Gulf), oil companies are still looking for more.

● 7,000 million barrels: transport's share of oil consumption. Transport consumes around one third of all the energy used in the world each year. The 24 leading industrialised countries of the OECD (Organisation for Economic Co-operation and Development) consume more than half the world's oil, and transport consumes more than half of the

average car puts more than four times its body weight of CO₂ into the atmosphere.

● 2,600 million barrels: the amount of gasoline burnt in one year in the US. America's share of oil used in world transport is more than one third. Small wonder, of the 600 million cars on the planet, American cars drive one Oiled. Their fleet fuel efficiency average is one-fifth inefficiency unparalleled in the OECD: 20 mpg, at a time when Ford, General Motors, and Chrysler have the capability to mass-produce cars which do more than 100 mpg. Or to make battery- and hydrogen-powered cars charged by solar photovoltaic, so producing no direct greenhouse gas emissions.

● 1,000 million barrels: the amount of oil imported to the US each year from the Gulf. And this is only 24 per cent of all US oil imports. By how much would fuel efficiency of the US car fleet have to improve to remove the need for these 1,000 million barrels? One third would more than do the trick. Average fuel efficiency of new US cars decreased from 1985 to 1989 (from 27.5 to 26 mpg), when the Reagan Administration slackened auto industry efficiency requirements. In the UK, fuel efficiency — after improving in the early eighties — has stalled, the Government having refused to introduce mandatory standards.

● 800 million barrels: the approximate amount of oil aboard at any one time in super-tankers, each one running the gauntlet of an Amoco Cadiz disaster (approximately two million barrels spilled). Over the last 16 years, 100 accidents have spilled more than 10,000 barrels each.

● 8 million to 20 million barrels: the amount of oil spilled each year deliberately from

naval operations, dry docking, barge and fuel oil dumping. The "low" estimate is from the International Maritime Organisation. For a high estimate, try the US Department of the Interior Minerals Management Service's best guess of around 20 million.

● 5 million to 11 million barrels: Saddam's alleged act of environmental terrorism — as estimated so far. Five million barrels represents less than a tenth of 1 per cent of all oil into which Kuwait's oil wells tap.

● 1.8 million barrels: the average daily oil production in Kuwait in 1989 — less than 2 per cent of the world total. By how much would the average fuel efficiency of the American car have to increase to shed the need of the US share of this and of Iraq's production in a normal year? Just 2 mpg — from 20 to 22 mpg — according to the US Government's Lawrence Berkeley laboratory.

● 260,000 barrels: the amount split by the Exxon Valdez. That "clean-up" involved 11,000 people, cost over \$1 billion, and "cleared" only 20 per cent of the 1,000 miles-plus of beaches affected. The spill's short-term impacts on wildlife are well known. The scientific jury is still out on the long-term effects. It involved a finite source of oil (20 per cent of the capacity of a supertanker). And it

● 1 barrel: the amount of oil needed for an oil-fuelled US aircraft carrier to steam 238 yards, or an M-1 tank to chug 20 miles (over that distance each puts 600 kilograms of CO₂ into the atmosphere).

The Global Climate Convention negotiations start on Monday, with more than 100 governments round the table. The low-lying island countries queuing up to plead for their physical and cultural survival are likely to be disappointed with the response.

George Bush, hoping to deter Iraq (along with Turkey, this is the only OECD government to have promised stabilising or cutting greenhouse emissions in the years to come), offered to host the talks in Washington. Appropriately for the world's largest consumer and importer of oil, the world's largest producer of coal, and the world's largest emitter of CO₂ and total greenhouse gases (nearly a quarter of all world emissions), the US government has moved the talks to a Virginia backwater. As Bob Hall of the US Petroleum Institute said: "Burning hydrocarbons is a way of life."

The question is just who are the carbon criminals, George?

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