DANGEROUS CLIMATE CHANGE

HEARING

BEFORE THE

SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

FIRST SESSION

APRIL 26, 2007

Serial No. 110–2

Printed for the use of the Select Committee on
Energy Independence and Global Warming

globalwarming.house.gov

U.S. GOVERNMENT PRINTING OFFICE

57–965 WASHINGTON : 2010

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2104 Mail: Stop IDCC, Washington, DC 20402–0001

SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING

EDWARD J. MARKEY, Massachusetts, *Chairman*

EARL BLUMENAUER, Oregon
JAY INSLEE, Washington
JOHN B. LARSON, Connecticut
HILDA L. SOLIS, California
STEPHANIE HERSETH SANDLIN, South Dakota
EMANUEL CLEAVER, Missouri
JOHN J. HALL, New York
JERRY MCNERNEY, California

F. JAMES SENSENBRENNER, JR., Wisconsin, *Ranking Member*
JOHN B. SHADEGG, Arizona
GREG WALDEN, Oregon
CANDICE S. MILLER, Michigan
JOHN SULLIVAN, Oklahoma
MARSHA BLACKBURN, Tennessee

PROFESSIONAL STAFF

DAVID MOULTON, *Staff Director*
ALIYA BRODSKY, *Chief Clerk*
THOMAS WEIMER, *Minority Staff Director*

CONTENTS

WITNESSES

SUBMITTED MATERIAL

DANGEROUS CLIMATE CHANGE

THURSDAY, APRIL 26, 2007

HOUSE OF REPRESENTATIVES,
SELECT COMMITTEE ON ENERGY INDEPENDENCE
AND GLOBAL WARMING,
Washington, D.C.

The committee met, pursuant to call, at 10 a.m. in Room 2172, Rayburn House Office Building, Hon. Edward J. Markey (chairman of the committee) presiding.

Present: Representatives Markey, Inslee, Solis, Herseth Sandlin, Cleaver, Hall, McNerney, Sensenbrenner, Shadegg, Walden, Sullivan, Blackburn and Miller.

The CHAIRMAN. This hearing is called to order, and we thank you for joining us today as we examine the critical issues surrounding dangerous climate change.

Members of the Select Committee have been entasked by the Speaker to become experts on global warming. But a congressional expert is an oxymoron like jumbo shrimp or McLean night life. There is no such thing when compared to real experts who can come to help illuminate these issues.

In 1992, President George Herbert Walker Bush signed and the Senate ratified the U.N. Framework Convention on Climate Change. By signing it, the United States, along with 188 other countries, committed to stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous and trophogenic interference with the climate system.

But what is dangerous climate change and what are its consequences? How closer are we to it? What can we do to avoid it? The answers to these questions are critical as this Congress develops legislation to enhance our energy independence and to combat global warming. But let us start with what we already know.

Two hundred years ago, America's industrial revolution changed the economy, society of our country and the world; and it also began to change the air around us, powered by the burning of fossil fuels, first coal and now oil and natural gas. The energy we have used since that time has caused an increase in heat, trapping carbon dioxide in the atmosphere; and it turns out that when it comes to global warming, small changes make a big difference.

Since the industrial revolution, carbon dioxide concentrations have risen from 280 parts per million to 380 parts per million. It doesn't sound like much, but neither does a degree or two in your body temperature. On a normal day, when you are feeling fine, your temperature is 98.6. But when your temperature is raised a very small amount, to 101.6, for example, just three degrees, you feel lousy. You would stay home in bed and not go to work. But raise it yet another degree or two, and you would be in the hospital.

Right now, our planet has a temperature; and we are seeing the symptoms on every continent and in the oceans. Glaciers are melting, sea level is rising, hurricanes are stronger, heat waves are more deadly, forest fires are more intense, entire species are disappearing. Absent strong national leadership, we are heading for 480 parts per million and beyond; and, as you know, there is no hospital for sick planets.

If we continue to spew global warming pollution from our smokestacks and tailpipes, we will alter the very face of the earth and its inhabitants. For example, the Greenland ice sheet, which is larger than the State of Alaska and two miles thick in places, is increasingly in jeopardy. During the melt season, in one day enough ice breaks off in one large glacier in Greenland to supply water to New York City for a year. If the ice cap were to fully melt, sea level would rise 21 feet.

In the southern hemisphere, parts of Antarctica which contain similar amounts of water locked away as ice also appear vulnerable. Higher sea levels, rising storms from rising ocean temperatures will render many of the world's coastal areas, home to over a billion people today, uninhabitable. Rising temperatures will disrupt water supplies, agriculture and forestry, confounding public health gains in the poorest parts of the world; and creatures and cultures that thrive in the coldest parts of the earth may be unable to adapt and simply cease to exist.

Today's witnesses will make clear the urgent need to adopt policies that prevent the concentration of global warming pollution from rising to catastrophic levels and the necessity to prepare for those impacts that we can no longer avoid. If we are to avoid the worst impacts, we must act now; and that will be the intention of the Chair.

So let us at this point turn, and I will recognize the gentleman from Wisconsin, Mr. Sensenbrenner, the ranking member of the committee.

[The statement of Mr. Markey follows:]

Opening Statement for Edward J. Markey (D-MA)
"Dangerous Climate Change"
Select Committee on Energy Independence and Global Warming
April 26, 2007

This hearing is called to order.

Thank you all for joining us today as we examine the critical issues surrounding "Dangerous Climate Change." Members of the Select Committee have been tasked by the Speaker to become "Congressional Experts" on global warming. But congressional expert is an oxymoron like "jumbo shrimp" or "Chevy Chase nightlife." We are only experts compared to other Members of Congress. Our witnesses today are the real experts. They have devoted their scientific careers to understanding Earth's climate and our interaction with it. We appreciate you being here to share your expertise with us today.

In 1992, President George H. W. Bush signed, and the Senate ratified, the UN Framework Convention on Climate Change (UNFCCC). By signing it, the United States -- along with 188 other countries -- committed to stabilizing "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

But what is dangerous climate change and what are its consequences? How close are we to it? What can we do to avoid it? The answers to these questions are critical as this Congress develops legislation to enhance our energy independence and to combat global warming.

But let's start with what we already know. Two hundred years ago, America's Industrial Revolution began, dramatically changing the economy and society of our country and the world. But it also began to change the air around us. Powered by the burning of fossil fuels – first coal and now also oil and natural gas – the energy we've used since that time has caused an increase in heat-trapping carbon dioxide in the atmosphere.

And it turns out that when it comes to global warming, small changes make a big difference. Since the Industrial Revolution, carbon dioxide concentrations have risen from 280 parts-per-million to 380. It doesn't sound like much, but neither does a degree or two in your body temperature. On a normal day when you are feeling fine, your temperature is 98.6. But if your temperature is raised a very small amount -- to 101.6 for example - just 3 degrees – you feel lousy. You would stay home in bed and not go to work. Raise it another degree or two, and you would be in the hospital.

Right now, our planet has a temperature, and we are seeing the symptoms on every continent and in the oceans. Glaciers are melting. Sea level is rising. Hurricanes are stronger. Heat waves are more deadly. Forest fires are more intense. Entire species are disappearing.

Absent strong national leadership, we're headed for 480 parts-per-million and beyond, and, as you know, there is no hospital for sick planets. If we continue to spew global warming pollution from our smokestacks and tailpipes, we will alter the very face of the Earth and its inhabitants.

For example, the Greenland ice sheet – which is larger than the state of Alaska and two miles thick in places – is increasingly in jeopardy. During the melt season, in one day enough ice breaks off of one large glacier in Greenland to supply water to New York City for a year. If the ice cap were to fully melt, sea level would rise 21 feet. In the southern hemisphere, parts of Antarctica, which contain similar amounts of water locked away as ice, also appear vulnerable.

Higher sea levels and stronger storms from rising ocean temperatures will render many of the world's coastal areas – home to over a billion people today – uninhabitable.

Rising temperatures will disrupt water supplies, agriculture and forestry, confounding public health gains in the poorest parts of the world.

And creatures and cultures that thrive in the coldest parts of this Earth may be unable to adapt and simply cease to exist.

Today's witnesses will make clear the urgent need to adopt policies that prevent the concentration of global warming pollution from rising to catastrophic levels and the necessity to prepare for those impacts that we can no longer avoid.

If we are to avoid the worst impacts of dangerous climate change, we must use our nation's unparalleled, ingenuity, technology, and experience to address global warming with the urgency required. If we enact real solutions that limit global warming pollution, the world will become more prosperous, cleaner, safer and more sustainable home for all of us. In the end, we are either going to meet this challenge together, or suffer the consequences together. We are either going to solve this problem, or we are going to destroy the planet. The time to act is now.

And now I would like to recognize the Ranking Member of the Committee, the gentleman from Wisconsin, Mr. Sensenbrenner.

Mr. SENSENBRENNER. Thank you very much, Mr. Chairman.

The title of today's hearing sounds a little like a scary movie: Dangerous Climate Change. We have seen this film before; and it stars industrialized society, a character who improves the livelihood of billions of humans by providing them with vital jobs and services. But in this movie industry is actually the villain, with an evil plan to destroy the Earth with invisible, odorless gasses.

Our hero, Al Gore, sounds like an intrepid detective who has dug through the science and uncovered this nefarious plot. Naturally, our protagonist has a heroic way to defeat the villain: raise taxes.

Yes, the climate is changing; and human behavior bears some responsibility. But scientific predictions on whether these changes will be on the margin or the extremes or somewhere in between remains a question. Without predicting catastrophe, it is hard to advocate a tax hike.

As I said at least week's hearing, I firmly believe that many of these gloom-and-doom scenarios are Hollywood-style sketches of scientific data that, when studied closely, presents a much more sober and thoughtful picture; and while extremist scenarios haven't helped us make much progress in more than a decade of climate change to be, they made for one scary script.

I am pleased that one of our witnesses today, Dr. John Helms, offers climate change solutions that will not only protect American jobs but also give us healthier forests. I would like to thank Congressman Walden for bringing Dr. Helms to the Congress' attention; and I look forward to his testimony, even as a Stanford grad, hearing some wisdom from someone who has taught at Berkeley.

As a member of the House Science and Technology Committee for nearly three decades and as chairman of that committee for 4 years, I have developed a healthy respect for scientists when they are presenting the facts and answering specific questions posed by decision makers.

Scientists are also entitled to step beyond that role and advocate policy. But when they do so, they are stepping out of the scientific debate and into the political debate, where jobs and the economy have to be considered along with scientific data. And once scientists step into the political debate by advocating policy, then their legitimacy and motives are open for questioning, just like we politicians.

One of our witnesses today, Dr. James Hansen, has chosen to wade into the political debate by making these sort of policy proposals, and I welcome him. I also welcome realistic proposals that will help us with energy and independence and global warming, but any proposal must contain four key principles:

First, it must bring tangible environmental benefits to the American people; second, it must support advancing technology, including technologies across the energy spectrum from nuclear to clean coal to renewable to improved energy efficiencies; third, any climate change policy must protect U.S. jobs; and, fourth, it must require global participation.

This year, China will pass the United States of America as the largest emitter of CO_2. In creating global warming hysteria, the authors of that scary screenplay have stuck to a structurally very simple script. But we in Congress know that the story is much more complex than that. The title of our movie, Protect the Economy and the Environment, may not sell as many tickets or win an Oscar, but it is a common-sense plot that most Americans can understand and support.

I yield back the balance of my time.

Mr. Sensenbrenner's Opening Statement for Select Committee on Energy Independence and Global Warming hearing: "Dangerous Climate Change."

April 26, 2007

The title of today's hearing sounds a little like a scary movie: Dangerous Climate Change!

We've seen this film before. It stars industrialized society, a character who improves the livelihood of billions of humans by providing them with vital jobs and services. But in this movie, industry is actually the villain, with an evil plan to destroy the Earth with invisible, odorless gases.

The hero, Al Gore, like an intrepid detective, has dug through the science and uncovered this nefarious plot. Naturally, our protagonist has a heroic way to defeat the villain: raise taxes.

Yes, the climate is changing and human behavior bears some responsibility. But scientific predictions on whether these changes will be on the margin, or the extremes, or somewhere in between, remains a question.

Without predicting catastrophe, it's hard to advocate a tax hike.

As I said last week, I firmly believe that many of these gloom-and-doom scenarios are Hollywood-style stretches of scientific data that, when studied closely, presents a much more sober and thoughtful picture. And while extremist scenarios haven't helped us make much progress in more than a decade of climate change debate, they've made for one scary script.

I am pleased that one of our witnesses today, Dr. John Helms, offers climate change solutions that will not only protect American jobs, but also give us healthier forests. I would like to thank Congressman Walden for bringing Dr. Helms to the committee's attention and I look forward to his testimony.

As a member of the House Science and Technology Committee for nearly three decades, and as chairman of that committee for four years, I have developed a healthy respect for scientists when they are presenting the facts and answering specific questions posed by decision makers.

Scientists are also entitled to step beyond that role and advocate policy. But when they do so, they are stepping out of the scientific debate and into the political debate, where jobs and the economy have to be considered along with the scientific data. And once scientists step into the political debate by advocating policy, their legitimacy and motives are open to questioning, just as they are for politicians.

One of our witnesses today, Dr. James Hansen, has chosen to wade into the political debate by making these sorts of policy proposals, and I welcome him.

I also welcome realistic proposals that will help us with energy independence and global warming, but any proposal must contain four key principles:

First, it must bring tangible environmental benefits to the American people.

Second, it must support advancing technology, including technologies across the energy spectrum, from nuclear to clean coal to renewables to improved energy efficiencies.

Third, any climate change policy must protect U.S. jobs.

And fourth, it must require global participation. China will pass us this year as the largest emitter of CO_2.

In creating global warming hysteria, the authors of that scary screenplay have stuck to a very simple script. But we in Congress know the story is more complex than that. The title of our movie – Protect the Economy and the Environment – may not sell as many tickets or win an Oscar, but it is a common-sense plot that most Americans can understand and support.

####

The CHAIRMAN. The Chair will now recognize members for 2 minutes for opening statements or, if they wish, they can reserve their 2 minutes and it would be added to the 5 minutes that they have for questioning of the witnesses.

The Chair recognizes the gentlelady from California, Ms. Solis.

Ms. SOLIS. Thank you, Mr. Chairman; and I welcome this discussion today on the dangers of climate change because, you know, the attitude in my district right now and when we survey people is they are extremely concerned about what is happening globally to the temperature changes in my district.

I represent Los Angeles County, a large number of underrepresented communities, Hispanic, Asian American, part African American. Many are extremely concerned with the trends we are seeing: Heat waves that we have experienced in the last few years in Los Angeles, what we think is coming is a drought. There is a shortage of rainfall.

We see also our at-risk populations at a higher level of asthma, respiratory diseases. We also see more people having fewer abilities to go outdoors and recreate, to have open space. So, yes, there is a need to look at what is happening in our communities and especially communities of color. Urban centers as well as rural areas, they are also experiencing drought.

And I say that because agriculture is very important to our community and our economy. Many of the people that work in that industry happen to be three-quarters Latino. They are the ones that pick your fruits and vegetables. But if there isn't ample protection for them to work in the fields, if there is no water irrigation, the temperatures are too hot, you are going to see those failed policies of having people out there getting our fruit, our vegetables to us. So, yes, indeed there are some very pressing issues for us to look at.

You know, last year in one of our committees—we tried to offer in the Energy and Commerce Committee through the Energy Policy Act in 2005—I offered an amendment to talk about climate change in the wake of major heat waves in California, Nevada, and Arizona. My amendment would have required that any use of public funds would develop greenhouse gas technologies in the U.S. or developing countries. Unfortunately, my amendment failed at that time; and I wish that we would have begun to present the health impacts to our most vulnerable communities, including the elderly and young children.

I hope that you will hear and glean some great information from our witnesses.

Thank you very much, Mr. Chairman.

Opening Remarks of Congresswoman Hilda L. Solis
Select Committee Hearing on Energy Independence and Global Warming
Hearing on Dangerous Climate
April 26, 2007

Chairman Markey, thank you for holding this hearing to address the dangers of climate change.

As a Member who represents a diverse urban area, I am extremely concerned about the threat to health of Latinos and other communities of color posed by global warming.

Projected climate change will increase the risks of climate-sensitive health outcomes, particularly in low-income populations and communities of color.

As Dr. Ebi comments in her written testimony, developed countries may not be prepared to cope with the projected increase in intensity and frequency of extreme weather events.

The length of the heatwave season in California could increase from 5 to 13 weeks.

By 2080, the number of heatwave days in Los Angeles could increase between 4-fold and 6-8 fold.

Annual heat-related deaths in Los Angeles could increase by a factor of seven, to as many as 1,182!

Heatwaves can also increase respiratory problems.

This could be disastrous for the 44 million Americans, including 14 million Latinos, who are uninsured.

Heat wave deaths occur not only in urban communities, but also in the agricultural workforce which is comprised 3/4 of by Latinos – many of whom already face economic insecurity.

During consideration of the Energy Policy Act of 2005, I offered an amendment to address climate change in the wake of a major wave of heat-related deaths in California, Nevada, and Arizona.

My amendment would have required that any use of public funds to develop greenhouse technologies in the U.S. or developing countries be used to reduce GHG emissions.

Unfortunately my amendment failed and Congress continued its policy of inaction.

I wish that we would have begun to prevent the health impacts our vulnerable communities will experience then.

Without action to protect our vulnerable populations, these events could spell disaster for major urban and agricultural communities; I am hopeful we will take action now.

I yield back the balance of my time.

Mr. CHAIRMAN. The Chair recognizes Mr. Shadegg.

Mr. SHADEGG. I will reserve.

The CHAIRMAN. The Chair recognizes the chairman from Oregon, Mr. Walden.

Mr. WALDEN. Thank you, Mr. Chairman. I, too, will reserve my time.

The CHAIRMAN. The time will be reserved.

The Chair recognizes the gentleman from Oklahoma.

Mr. SULLIVAN. I, too, will reserve.

The CHAIRMAN. The gentleman's time is reserved.

The Chair recognizes the gentlelady from Michigan.

Mrs. MILLER. Thank you. I will reserve my time as well.

The CHAIRMAN. And the Chair recognizes the gentlelady from Tennessee.

Mrs. BLACKBURN. I will reserve my time.

OPENING STATEMENT OF HON. MARSHA BLACKBURN (7, Tennessee)

Mr. Chairman:

I appreciate the opportunity to serve on this committee and look forward to a healthy and judicious debate over the issue of climate change.

I also appreciate our witnesses for taking time out of their schedules to testify before our committee.

Today, this committee will be hearing testimony on present and future events that may be caused by climate change.

Yet, what I find is that many who advocate for drastic actions to reduce greenhouse gas emissions have failed to include the human element into their policy solutions.

Hurricanes, diseases, and other disasters will happen with or without global warming. But to follow some of the most radical policies such as shutting down power plants will make no one safer but only poorer and with less ability to adapt or deal with present threats. Some of these measures actually seem to be counterproductive.

If people do not have access to energy such as electricity, they will not be able to improve their health, incomes, or their environmental quality and become more productive.

In effect, we will starve the world's poor.

Mr. Chairman, I believe it is our responsibility to take reasonable actions to help poor and developing countries. But closing coal plants and imposing massive energy costs on consumers and developing nations is not the way to do it.

This is especially true when these policies are based on uncertain events and unreliable data.

Instead, we should devote our time through short term actions and mid-term strategies that lead us to long-term solutions to real, immediate threats and problems we can address now.

The CHAIRMAN. The Chair recognizes the gentlelady from South Dakota, Ms. Herseth Sandlin.

Ms. HERSETH SANDLIN. I will reserve my time.

The CHAIRMAN. The Chair recognizes the gentleman from Texas, Mr. Hall.

Mr. HALL. I will reserve my time.

The CHAIRMAN. And the Chair recognizes the gentleman from California, Mr. McNerney.

Mr. MCNERNEY. I will reserve.

The CHAIRMAN. Great.

The gentleman's time is reserved, and it will be added to his question time.

Rep. McNerney Opening Statement – Select Committee on Energy Independence and Global Warming – 4/26/07

Thank you Mr. Chairman.

I have spent a significant portion of my life developing and implementing clean energy sources, and like the majority of the world, I see the pressing need to address global warming.

As a mathematician, I appreciate the need for data to back up assertions and claims about environmental and political problems.

That is why today's hearing is so important.

As we move forward with our recommendations for energy independence and global warming, we should use the best available information to come to conclusions and find facts.

Likewise, we need to find ways to improve and expand scientific data so that future policies can be adjusted as we accumulate better information.

I'm hopeful that today's panel will provide insight into how we can best assess the difficulties we're facing.

Scientists and governments are still fine tuning the process by which we define certain - smaller - climate affects, but there are some forthcoming changes that will be devastating.

Working Group II of the IPCC identified specific impending problems for North America, and many of them affect my State of California.

The Sacramento/San Joaquin Delta in northern California - which is fed by a slowly melting mountain snowpack - provides water to more than 20 million people in the state.

In their report, the IPCC predicted that warming will cause increased snowpack melting, which will inevitably lead to less water for the majority of Californians who are already struggling to find new water resources.

I can only hope that the work we undertake in this Committee will eventually lead to solutions for the problems we will face as a result of global warming.

I'm interested in hearing the insights of today's panel and I'm hopeful that we can use their testimony to establish accurate benchmarks for assessing climate change.

Thank you again Mr. Chairman.

All time for opening statements from members has concluded.

[Prepared statement of Representative Cleaver is as follows:]

U.S. Representative Emanuel Cleaver, II
5th District, Missouri
Opening Statement
House Select Committee on Energy Independence and Global Warming Hearing
"Dangerous Climate Change"
Thursday, April 26, 2007

Chairman Markey, Ranking Member Sensenbrenner, other Members of the Select Committee, good morning.

To our distinguished panel of experts, I would like to join my colleagues in welcoming you to the Select Committee on Energy Independence and Global Warming. I anticipate listening to your testimony today and hearing your insights on the impacts human activities have on climate system and their predicted global effects.

Many of my colleagues are already familiar with this year's Intergovernmental Panel on Climate Change report. This report illustrates in precise scientific detail the effects global warming has already had on our planet. The consequences of increased concentrations of greenhouse gases in the atmosphere and higher global temperatures are alarming. It has been projected that warmer temperatures will lead to higher disease rates, rising sea levels, and greater storm intensity. The lasting results of climate change are even more serious, and there are likely more of which we are not already aware. This is perhaps the most distressing truth we must face as we continue our work on the Committee.

Our environment has already suffered significant damage because of certain human activity, and the effects on the most vulnerable communities are already evident. Many scientists already predict a possible "war over water" in Africa and Asia in the coming decades because of warmer temperatures. Because of this potential for conflict, global warming has the capability even to affect foreign relations and intervention, and this could potentially include the United States. Often the populations most vulnerable to the effects of climate change are least responsible for its consequences. It is difficult to not question the justice in this scenario, especially when considering the poverty and violence communities already suffer in areas of Africa.

My relatives in Tanzania have told me of the changes they have seen in Mount Kilimanjaro, which is near their home. Several years ago, the variation in temperature from the base to the peak of the mountain was immense. What began for climbers as a journey in wearing shorts ended as one in heavy winter clothing. Today, however, there is little temperature change, and most of the snow is gone from the mountain. Not only has the geological landscape been altered by global warming, but the area's economy has also suffered from a decrease in the water supply.

It is our responsibility as public servants to exercise our authority to work to mitigate these effects of climate change, both for communities in here in the United States, and those in other parts of the globe. Although it is too late to reverse some of the harmful effects of global warming, we have the opportunity to prevent future environmental costs. Today our panel of scientific experts will give us recommendations as to how the consequences of global warming may be mitigated, and I thank them for their insight.

Thank you.

We will now turn to our distinguished panel.

The CHAIRMAN. Our first witness is Dr. Judith Curry, who is a Professor and Chair of the School of Earth and Atmospheric Science at the Georgia Institute of Technology. She is an expert in various aspects of climate science. Her work has most recently focused on the variability of hurricanes in the North Atlantic and around the world. She has published over 140 referee journal articles and is a Fellow of both the American Meteorologic Society and the American Geophysical Union.

We welcome you, Dr. Curry. You have 5 minutes to make an opening statement.

STATEMENT OF JUDITH A. CURRY, GEORGIA INSTITUTE OF TECHNOLOGY

Ms. CURRY. I thank the chairman of the committee for the opportunity to offer testimony this morning.

The devastating 2004 and 2005 hurricane seasons, and particularly Hurricane Katrina, for the first time made the public realize that one degree of warming could potentially have dangerous consequences if this warming made future hurricanes like Katrina more likely.

Next.

In the last several months, two important assessments have been issued. Statements made by the World Meteorological Organization and the Intergovernmental Panel for Climate Change have assessed and clarified what we do know about hurricanes and global warming and also the associated uncertainties.

I would like to begin by presenting some of the data on North Atlantic hurricanes that support these two statements from the ICCP's report.

This diagram shows the historical data record of the number of North Atlantic tropical cyclones back to 1851, which is indicated by the dark blue curve. Also shown in this diagram is the average tropical sea surface temperature in the North Atlantic in red. This diagram shows a remarkable coherence in variations in the number of storms with sea surface temperature. In particular, the period 1910 to 1920 with low storm activity is associated with anomalously cool sea temperatures, while the largest number of tropical cyclones is seen during the past decade when the sea surface temperatures have been the warmest.

This figure illustrates the change in the intensity distribution for the North Atlantic since 1970. The data has been divided into three different periods, including the active period since 1995. Each bar represents the frequency occurrence of a different category of storm intensity. The most striking aspect of the histogram is the substantial increase in the frequency of Category 4 hurricanes during the period since 1995.

The highest resolution climate model simulations capable of resolving individual hurricanes have been made using the Japanese earth simulator computer and also by a European group. The results of these simulations for a climate that is warmer by about 2.5 degrees centigrade or 5 degrees Fahrenheit show a 30 percent increase in the number of North Atlantic tropical cyclones, a 10 percent increase in average tropical cyclone intensity and a 30 percent increase in the number of major hurricanes.

In the North Atlantic, there is a prospect of substantially elevated hurricane activity in the next few decades owing to the combination of global warming and the active phase of the North Atlantic multi-decadal oscillation. To estimate the combined impacts of global warming and the natural variabilities, I have constructed a simple statistical model that projects an average number of 15 to 20 tropical cyclones per year, with three to four of them reaching the strength of Category 4 to 5.

The combination of greenhouse warming and natural variability will produce tropical cyclone activity in the coming decades that is unprecedented. The impact of such elevated hurricane activity includes an increased number of intense storms striking the gulf coast with increased level of storm surges plus inland flooding and tornadoes.

The combination of coastal demographics with increased hurricane activity will continue to escalate the socioeconomic impact of hurricanes.

How should policymakers react to this risk? As a scientist, I do not get involved in advocating for specific policies. I am limiting my comments here to a general assessment of how certain policies strategies might affect the risks associated with increased hurricane activity as global temperatures continue to rise.

Specifically, with regards to energy policy, any conceivable policy for reducing carbon emissions is unlikely to have a noticeable impact on sea surface temperatures and hurricane characteristics over the next few decades. Rather, carbon mitigation strategies will only impact the longer-term effects of global warming, including sea level rise and the associated storm surges.

Particularly in the U.S., we are facing a very serious risk in the next few decades, owing to the combination of global warming and the active phase of the Atlantic multi-decadal oscillation. Adaptation measures are urgently needed to confront the vulnerability, particularly of our coastal regions. Decreasing our vulnerability to damage from hurricanes will require a comprehensive evaluation of coastal engineering, building construction practices, insurance, land use, emergency management and disaster relief policies.

Thank you.

The CHAIRMAN. Thank you, Dr. Curry.

[The statement of Judith Curry follows:]

STATEMENT TO THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING OF THE UNITED STATES HOUSE OF REPRESENTATIVES

Hearing on "Dangerous Climate Change"
26 April 2007

Judith A. Curry
Georgia Institute of Technology
curryja@eas.gatech.edu

I thank the Chairman and the Committee for the opportunity to offer testimony this morning on "Dangerous Climate Change." As a climate scientist, I have devoted 25 years to conducting research on a variety of topics including climate feedback processes in the Arctic, the exchange of energy between the ocean and the atmosphere, the role of clouds in the climate system, and most recently the impact of climate change on the characteristics of tropical cyclones.

The devastating 2004 and 2005 hurricane seasons, combined with the publication of two papers linking increased hurricane intensity to climate change (Emanuel 2005; Webster et al. 2005), for the first time made the public realize that one degree warming could potentially have dangerous consequences if this warming made future hurricanes like Katrina more likely. Hurricane-induced economic losses have increased steadily in the U.S. during the past 50 years, with estimated total losses averaging $36 billion per year during the last 5 years (IPCC AR4 2007a). During 2004 and 2005, nearly 2000 lost lives were attributed to landfalling hurricanes. To place the U.S. vulnerability in perspective, 50% of the U.S. population lives within 50 miles of a coastline. The physical infrastructure along the Gulf and Atlantic coasts represents an investment of over $3 trillion; over the next several decades this investment is expected to double.

The risk of increased hurricane activity is arguably the issue of greatest concern to the U.S. public associated with the near term impacts of global warming. Risk is the product of consequences and likelihood: what can happen, and the odds of it happening. Managing the risks associated with increased hurricane activity requires an assessment of how our policy choices will affect those risks. Uncertainty is a critical factor in assessing the effectiveness of different policy strategies.

A summary of our current understanding of this issue and the levels of uncertainty is provided by the IPCC 4th Assessment Report Summary for Policy Makers (IPCC AR4 2007b):

> "There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures. There are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. . . Based on a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical SSTs. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period."

Research on the potential impacts of climate change on hurricane activity has increased dramatically in volume over the past two years in response to the high-impact tropical cyclone events around the globe and particularly in the U.S. (for summaries see WMO 2007; Curry et al. 2006). My testimony seeks to clarify the nature of the risk associated with increased hurricane activity as a result of global warming. I will assess the current understanding of the impact of global warming on hurricanes, including the uncertainties, and the challenges to assessing what we can expect in terms of future hurricane activity if global temperatures continue to rise. I will present a general assessment of how certain policy strategies might affect the risks associated with increased hurricane activity as global temperatures continue to rise.

Observations of increased hurricane activity

During the 2005 hurricane season two papers were published, Emanuel (2005) and Webster et al. (2005), that demonstrated an increase in hurricane intensity associated with an increase in tropical sea surface temperature. Webster et al. (2005) examined the global hurricane activity since 1970 (the advent of reliable satellite data). The most striking finding from this study is that while the total number of hurricanes has not increased globally, the number and percentage of category 4 + 5 hurricanes has nearly doubled since 1970 (Figure 1). This increase in the percentage of category 4 + 5 hurricanes is associated with an increase in tropical sea surface temperatures (SST) of 0.5°C (1°F) in each of the ocean basins that spawn tropical cyclones. The surface temperature trends over the last century has been extensively studied as summarized in the IPCC AR4 (2007b). The unanimous conclusion of climate model simulations is that the global surface temperature trend since 1970 (including the trend in tropical SSTs) cannot be reproduced in climate models without inclusion of anthropogenic greenhouse gases, and that most of this warming can be attributed to anthropogenic greenhouse gases. The climate model simulations are the basis for attributing the increase in tropical sea surface temperatures to anthropogenic greenhouse warming.

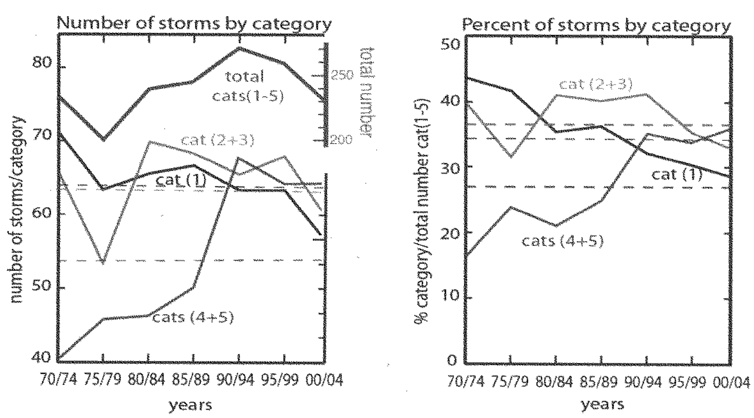


Figure 1: Intensity of global hurricanes according to the Saffir-Simpson scale (categories 1 to 5), in 5 year periods. (A) The total number of storms and (B) the percent of the total number of hurricanes in each category class. After Webster et al. (2005).

The quality of the hurricane intensity data used by Webster et al. has being questioned, particularly in the Pacific and Indian Oceans (e.g. WMO 2007). An additional issue of concern is that the magnitude of the intensity increase observed by Webster et al. substantially exceeds the intensity increase predicted by models and theory for a 1°F increase in tropical sea surface temperature. The Webster et al. (2005) observations scale to a 6% increase in maximum wind speeds for a 1°F SST increase. By contrast, high-resolution climate model simulations (Knutson and Tuleya 2004; Oouchi et al. 2006) have found a 2% increase in intensity when scaled for a 1°F SST increase, which is a factor of 3 times smaller than that determined from the observations. Two different theories of potential intensity indicate a 2.7 and 5.3% increase in hurricane intensity of a 1°F SST increase. Although these estimates differ in magnitude, the observations, models and theory all agree that average hurricane intensity will increase with increasing sea surface temperature. The disagreement is over the magnitude of the increase.

The most reliable data on hurricane intensity is for the North Atlantic. The quality of the intensity data since 1983 is generally accepted. Figure 2 shows histograms of the North Atlantic hurricane intensity during the periods 1970-1982, 1983-1994, 1995-2006. The most striking aspect of the histograms is the substantial increase of category 4 hurricanes during the period 1995-2006, consistent with the Webster et al. analysis. A key issue in the debate surrounding the intensity of the North Atlantic hurricanes is the intensity during the previous active period, ca. the 1950's. Unfortunately, the intensity data prior the reconnaissance flights beginning in 1944 are deemed to be unreliable, and during the period 1944-1970 the quality of the data and the appropriate corrections to the data are hotly debated.

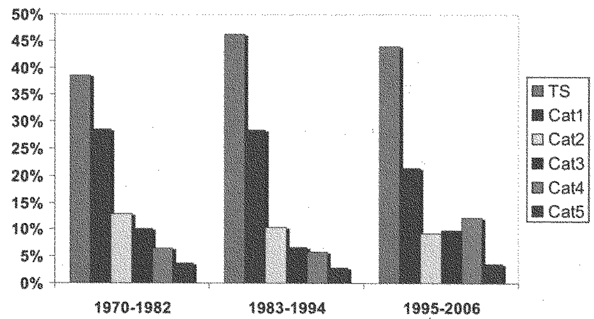


Figure 2. Histograms of the normalized distribution of hurricane intensities for 1970-1982, 1983-1994, and 1995-2006. Data are obtained from http://www.aoml.noaa.gov/hrd/hurdat/. Figure courtesy of M. Jelinek.

The increase in global hurricane intensity since 1970 has been associated directly with a global increase in tropical sea surface temperature. Figure 3 shows the variation of tropical sea surface temperature (SST) in each of the ocean regions where tropical cyclone storms form. It is seen that in each of these regions that the sea surface temperature has increased by approximately 0.5°C (or 1°F) since 1970. The causal link between SST and hurricane intensity was established over 50 years ago, when it was observed that tropical cyclones do not form unless the underlying SST exceeds 26.5°C (80°F) and that warm temperatures in the upper ocean are needed to supply the energy to support development of hurricane winds. The role of SST in determining hurricane intensity is generally understood and is supported by case studies of individual storms and by the theory of potential intensity. By contrast, no trend is seen in wind shear (Figure 4). Wind shear is the change of wind speed and direction with height in the atmosphere; small wind shear is conducive to tropical cyclone formation. While wind shear is an important determinant of the intensity of individual storms and even in the population of storms in an individual season, there is no trend in wind shear that can explain the observed increase in global hurricane intensity since 1970. Wind shear in the North Atlantic (dark blue curve) has shown some decrease during this period, contributing to the recent intensity increase in the North Atlantic.

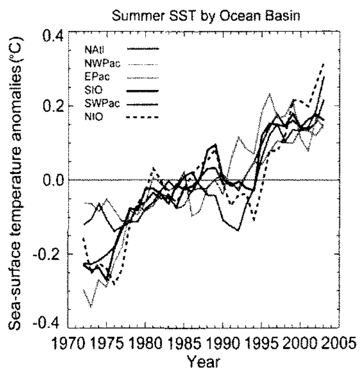


Figure 3. Evolution of the sea surface temperature anomalies relative to the 1970-2004 period for the North Atlantic, Western Pacific, East Pacific, South Indian Ocean, Southwest Pacific and North Indian Ocean Basins (Curry et al., 2006).

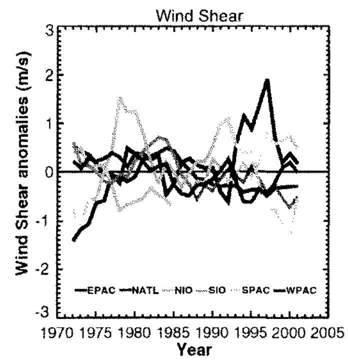


Figure 4. Evolution of the wind shear anomalies relative to the 1970-2004 period for the North Atlantic, Western Pacific, East Pacific, South Indian Ocean, Southwest Pacific and North Indian Ocean Basins (Hoyos et al., 2006).

In the North Atlantic, not only has the average sea surface temperature increased, but the area of the warm pool is expanding. Figure 5 shows the area in the North Atlantic with sea surface temperatures exceeding 28°C (82.4°F) during 1920, 1960, and 2000. The curve for 2000 shows that the warm pool has extended eastward to the coast of Africa. The expanding warm pool has resulted in the increased frequency of formation of tropical cyclones in the low latitudes of the east Atlantic. Further, the expanding warm pool has changed the temperature gradients in the North Atlantic, influencing atmospheric circulations and hence the wind shear and the currents that steer hurricanes. Hence, changes in wind shear are partially being influenced by changes in the patterns of sea surface temperature.

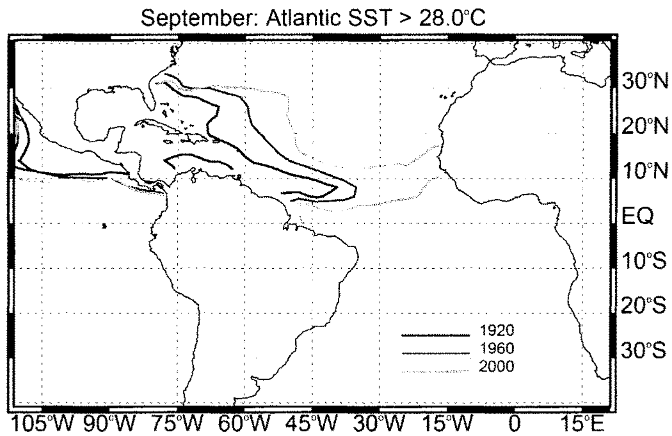


Figure 5. Map of the 28°C (82.4°F) isotherms during September in the North Atlantic for 1920, 1960, and 2000, showing the increased area and eastward extension of the warm pool. Figure courtesy of C. Hoyos and P. Webster

To look for signals of global warming in the hurricane database relative to natural variability, it is desirable to go back further in time. While the intensity data prior to 1950 is unreliable, a credible dataset on the number of the number of tropical cyclones (hurricanes plus tropical storms) in the North Atlantic exists back to 1851. Figure 6 shows the time series in the North Atlantic of the number of tropical cyclones where the data has been smoothed (11 year running mean) to eliminate the year-to-year variability and so to highlight the decadal and longer-term variability. A nominal 70-year cycle is evident from peaks ca. 1880 and 1950 and minima ca. 1915 and 1985. However, the most striking aspect of the time series is the overall increasing trend since 1970 and the high level of activity since 1995. Note, Figure 1 showed that the number of hurricanes has not increased globally since 1970; it is only in the North Atlantic that the numbers of tropical cyclones and hurricanes are increasing. How credible is this dataset, particularly during the early part of the period? There is almost certainly some undercounting of tropical storms prior to 1944, and particularly prior to 1900. Several estimates of undercounting have been made for the period prior to 1944, ranging from 1 to 2.5 storms. A further confounding factor is that some storms may have been counted twice, particularly prior to 1900. In any event, the inaccuracies in the tropical cyclone data set appear to be relatively small (with the effects of undercounting and double counting partially canceling), and we can state with confidence that the number of North Atlantic tropical cyclones in the last decade is unprecedented in the historical record. Also shown in Figure 6 is the time series of the average SST in the main development region of the tropical north Atlantic. Comparison of time series of SST and the number of topical cyclones shows generally coherent variations on the longer time scales. In particular, the period 1910-1920 with low storm activity is associated with anomalously cool sea surface temperatures, and the largest number of tropical cyclones is seen during the past decade, when SST values have been the warmest. The data set indicates that a 0.5°C (1°F) temperature increase has been associated with on average an additional 5 tropical storms.

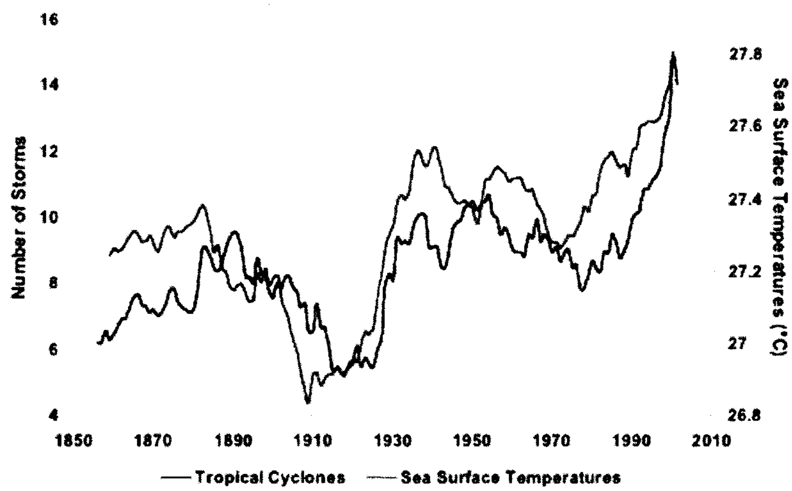


Figure 6: Number of total named storms in the North Atlantic and the average sea surface temperature in the main development region, filtered by an 11-year running mean. Data are obtained from http://www.aoml.noaa.gov/hrd/hurdat/. Figure courtesy of M. Jelinek.

A number of natural internal oscillations of the atmosphere/ocean system have a large impact on SST and tropical cyclone activity (e.g. El Nino, North Atlantic Oscillation), and some scientists have argued the increase in tropical cyclone activity can be explained by such natural variability. In particular, there have been repeated assertions from NOAA that the recent elevated hurricane activity is associated with natural variability, particularly the Atlantic Multidecadal Oscillation (AMO). Figure 7 shows the time series of the number of tropical cyclones and hurricanes since 1851, with arrows indicating the phases of the AMO. This figure suggests that the AMO (nominally a ~70 year cycle), does have an influence on North Atlantic hurricane activity. Separation of the AMO signal from the global warming signal has been the subject of recent debate. Assuming that the next peak of the AMO can be anticipated ca. 2020. The strength of the tropical cyclone activity during the period 1995-2005, which is at least a decade away from the expected peak of the current AMO cycle and already 50% greater than the previous peak period ca. 1950, suggests that the AMO alone cannot explain the elevated tropical cyclone activity observed during the last decade. The best available evidence supports the assertion that greenhouse warming is contributing to the increase in hurricane activity in the North Atlantic.

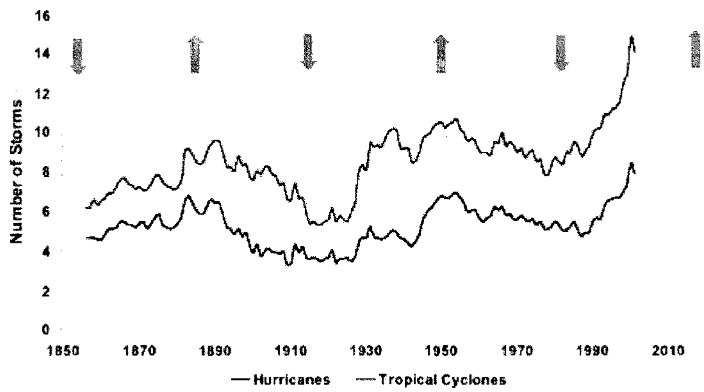


Figure 7: Number of tropical cyclones and hurricanes in the North Atlantic since 1851, filtered by an 11-year running mean. The up/down arrows indicate the positive/negative phases of the Atlantic Multidecadal Oscillation. Data are obtained from http://www.aoml.noaa.gov/hrd/hurdat/. Figure courtesy of M. Jelinek.

Examination of U.S. landfalling data (Figure 8) shows a strong signal of a 70-year cycle (nominally the AMO). Unlike Figure 7 which showed a showed an overall increase in the total number of North Atlantic tropical cyclones, no increase in the number of U.S. landfalling cyclones is seen. However there is a hint of an increase since the most recent number of landfalling tropical cyclone slightly exceeds the peak values observed ca. 1950 and 1880; since the next peak of the AMO is anticipated ca. 2020, it is plausible that we will see an increase in the coming decades exceeding anything in the historical data record.

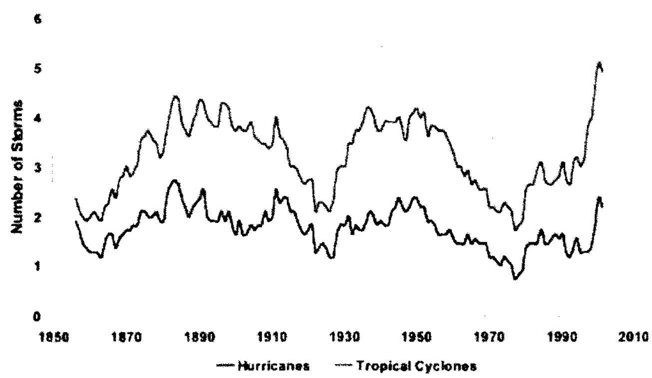


Figure 8: Number of tropical cyclones and hurricanes that have made landfall on the continental U.S. since 1851, filtered by an 11-year running mean. Data are obtained from http://www.aoml.noaa.gov/hrd/hurdat/. Figure courtesy of M. Jelinek.

What accounts for the fact that we are seeing an increase in the total number of North Atlantic tropical storms, but little or no increase in the number of U.S. landfalling storms? U.S. landfalling storms on average account for a fraction of the total North Atlantic storms. Storm tracks may take the storms north over the open ocean where they never strike land, or south where they may strike the Caribbean Islands or Central America. Unfortunately, prior to the satellite era, storm tracks are relatively unreliable, so it is difficult to sort out the influence of the AMO versus global warming on the long-term variations in tropical cyclone tracks. Some insight into variation in the tropical cyclone tracks can be gleaned from examining the time variations in the locations of the storms that strike the U.S. Figure 9 shows that the number of storms striking the Atlantic shows relatively little variation, whereas the number of storms striking the Gulf Coast shows a strong recent increase that is partly explained by the signal from the 70 year AMO cycle.

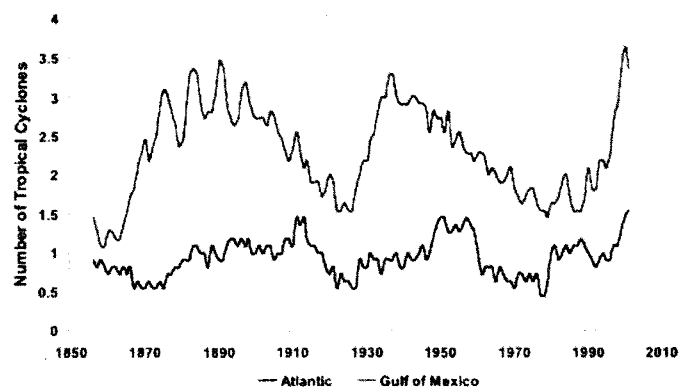


Figure 9: Number of tropical cyclones and hurricanes that have made landfall on the U.S. Atlantic coast and the Gulf coast since 1851, filtered by an 11-year running mean. Data are obtained from http://www.aoml.noaa.gov/hrd/hurdat/. Figure courtesy of M. Jelinek.

In summary, the Atlantic Multidecadal Oscillation appears to influence the number of North Atlantic tropical cyclones through wind shear and SST, and also the tropical cyclone tracks. However, the recent increase in the number of North Atlantic tropical cyclones, which is strongly correlated with sea surface temperature on multidecadal time scales, is unprecedented in the historical record. The intensity of the North Atlantic hurricanes has increased since 1970, this increase reflected most markedly by a doubling of the proportion of category 4 storms. Attribution of the increased hurricane intensity to global warming is complicated by the signal from the AMO and uncertainties in hurricane intensity prior to 1970, although an increase in intensity with increasing SST is expected from both theory and models.

Projections of future hurricane activity

Climate model projections of future hurricane activity in a warmer climate are hampered by the coarse resolution of the models that cannot adequately resolve the individual storms. Hence most climate model estimates of future hurricane activity rely on some sort of statistical relationship with the atmospheric circulation characteristics to infer hurricane activity. The most credible climate model projections of hurricane activity are made using high resolutions simulations. Using the Japanese Earth Simulator computer, Oouchi et al. (2006) conducted a ten year simulation of the current climate at 20 km resolution and a ten year simulation of a climate that is about 2.5°C (5°F) warmer. Oouchi et al. found that while the number of tropical cyclones decreased globally, the number increased in the North Atlantic by 30%. The simulated increase in intensity was 10%, in general agreement with previous high-resolution simulations using regional models. A recent high-resolution simulation (40 km resolution) by Bengtsson et al. (2007) also found a global decrease in the number of tropical cyclones, but not in the North Atlantic. Significantly they also found that the number of major hurricanes (categories 3, 4, 5) increased by 30% in the 21st century. While the Oouchi et al. and Bengtsson et al. simulations represent a considerable advance over previous simulations, significant uncertainties remain, especially with the treatment of convective clouds and the exchange of heat and moisture between the ocean and the lower atmosphere.

To infer what the hurricane activity might look like in the coming decades, a simple statistical model is formulated that accounts for both global warming and natural variability to estimate the average conditions in the year 2025, using results from both the observational record and climate model simulations. In the year 2025, we assume that the tropical sea surface temperatures have increased by 1°F owing to greenhouse warming. Figure 6 suggests that an increase of 1°F is associated with an increase of 5 tropical cyclones, while the increased number of North Atlantic tropical cyclones projected by Oouchi et al.'s high-resolution climate model simulation is slightly less than 1 when scaled for an increase of 1°F. Hence, we bound the range of the expected increase in tropical cyclones for a 1°F temperature increase by 1-5 storms. Further, we assume that 2025 is near the peak of the AMO cycle. Different interpretations of the relative importance of the AMO versus global forcing of the surface temperature yield estimates of the magnitude of the impact of the AMO on the total number of tropical cyclones per year range from 0 (no effect) to 4 (the AMO explains the entire magnitude of the trough to peak variability in Figure 7); since we are halfway up the positive phase of the AMO, we infer a maximum additional contribution of 1 cyclone from the AMO by 2025.

Based upon these assumptions of variability of the total number of North Atlantic tropical cyclones, consider the following simple statistical model for the projection of the average number of North Atlantic tropical cyclones in 2025. The average annual number for the past decade of North Atlantic tropical cyclones is 14 (Figure 7). We assume that the effects of greenhouse warming and the AMO are separable and additive. Adding the range of contributions from global warming plus the AMO to the base value of 14 tropical cyclones yields a range of projected average annual numbers of tropical cyclones in 2025 ranging from 15 to 20, the range accounting for the uncertainties in the impacts of both global warming and the AMO. Interannual influences, such as the El Nino-La Nina cycle will lead to some years being substantially lower, but others substantially higher, and future years similar to or exceeding 2005 must be expected. Thus, the combination of global warming and the elevated activity associated with the active phase of the AMO can be expected to result a level of tropical cyclone activity that is unprecedented in the historical record. In terms of the intensity of the storms, an increase in the number of category 4 and 5 hurricanes is expected, ranging from 3-4 per year.

What are the implications of the projected basin wide increase in total North Atlantic tropical cyclones for U.S. landfalls? We have seen from Figures 8 and 9 that the active phase of the AMO is associated with an increase in the proportion of U.S. landfalls, particularly those that strike the Gulf coast. As both the frequency and intensity of the hurricanes increases, we can expect increased damage from winds, storm surges, flooding, and tornadoes. Wind damage is estimated to vary with the cube of wind speed (Iman et al. 2005), so the 30% increase in major hurricanes projected by Bengtsson et al (2007) would be expected to lead to a more than doubling of the damage. Storm surge increases with increasing size and intensity of the hurricane. Climate models indicate that we can expect increased rainfall from hurricanes as a result of global warming. The increased frequency of Gulf landfalls combined with increased intensity increases the risk for inland flooding and tornadoes. The largest rainfall and tornadic activity are associated with the forward right quadrant of the storm, and hence an intense hurricane that makes landfall in the Gulf will be associated with intense rainfall and tornadic activity in the northeast part of the storm as the storm moves northward. A recent example of inland damage from an intense Gulf landfalling was Ivan, which caused much of its $13 billion damage inland. Ivan caused 100-year floods in the Chattahoochee River near Atlanta and many other rivers and streams and record flooding in the Delaware. Ivan also spawned an estimated 117 tornadoes including 26 in the DC and Maryland area (Franklin et al 2006).

What can we expect to happen after 2025? Once the AMO begins descending from its peak ca. 2020, continued warming makes it doubtful that we will ever again see the low levels of hurricane activity of the 1980's and we can expect a leveling off rather than significant decrease in activity until the next ascending phase of the AMO. Continued warming is likely to influence the AMO, and hence projections of the combined effects of global warming and the AMO beyond the next peak of the AMO are probably unjustified using the simple statistical model.

Theory and climate models provide only a rough guide to the longer-term future of hurricane activity. Theory and models both agree that with continued warming of the tropical oceans, we can expect continued increase in hurricane intensity. Projections regarding the number of tropical cyclones are less certain. There is some evidence supporting a decrease in the number of tropical cyclones outside the North Atlantic; it is only in the North Atlantic where the numbers are expected to increase. Our understanding is not sufficient to indicate whether the numbers in the North Atlantic will continue to increase, or whether they will saturate out at some point and what that point might be.

On longer time scales (order of a century), sea level rise will compound the impact of increased hurricane activity owing to increased storm surge vulnerability. By 2100, a sea level rise of 1 to 2 feet is plausible, and these figures do not account for any potential catastrophic melting of Greenland and Antarctica. Hurricane prone regions in the U.S. at greatest risk from storm surge enhancement associated with greenhouse warming are New Orleans, South Florida, and portions of the mid-Atlantic coast. Looking globally, Bangladesh is particularly vulnerable to the combination of increased hurricane activity and sea level rise; several hundred million people live in the southern part of the country where the elevation is only a few feet above sea level, and three tropical cyclones during the 20^{th} century each killed over 100,000 people. The vulnerability of the developing world to increased hurricane activity and sea level rise raises not only the obvious humanitarian and economic issues, but potential regional instabilities associated with mass migrations raise serious international security issues.

Policy responses

Based upon the arguments presented here, there is certainly a risk of further elevated hurricane activity with increased global warming, although the magnitude of this risk is uncertain. How should policy makers react to this risk in the face of the scientific uncertainties? The uncertainties in the hurricane data are sufficient that hurricanes cannot be used as any kind of "smoking gun" for global warming; however the risk of elevated hurricane activity arguably represents the most devastating short-term impact of global warming, at least for the U.S.

The combination of the coastal demographics with the increased hurricane activity will continue to escalate the socioeconomic impact of hurricanes. Any conceivable policy for reducing CO_2 emissions or sequestering CO_2 is unlikely to have a noticeable impact on sea surface temperatures and hurricane characteristics over the next few decades; rather, any such mitigation strategies would only have the potential to impact the longer term effects of global warming including sea level rise. Looking globally, Bangladesh is particularly vulnerable to the combination of increased hurricane activity and sea level rise; over a hundred million people live in the southern part of the country where the elevation is only a few feet above sea level, and three tropical cyclones during the 20^{th} century each killed over 100,000 people. The vulnerability of the developing world to increased hurricane activity and sea level rise raises not only the obvious humanitarian and economic issues, but potential regional instabilities associated with mass migrations raise serious national security issues.

To address the short-term (decadal) impacts of elevated hurricane activity, the increasing concentration of population, industry and wealth in vulnerable coastal regions must be confronted. Rapidly escalating hurricane damage in recent decades owes much to government policies that serve to subsidize risk and hence promote risky behavior. Decreasing our vulnerability to damage from hurricanes will require a comprehensive evaluation of coastal engineering, building construction practices, insurance, land use, emergency management, and disaster relief policies in vulnerable regions. Political will at levels from local to the federal government is needed to develop the appropriate policy and technological options that are practically feasible, cost effective, and politically viable. Adaptation strategies will vary regionally, based upon the local geographic risks and nature of the economic dependence on coastal development and activities; Florida's economic and geographic vulnerabilities are different from those of North Carolina and Louisiana.

The urgent need for adaptation strategies to deal with increased hurricane activity was emphasized in a statement made last year by 10 scientists involved in both sides of the sometimes acrimonious debate over hurricanes and global warming. The statement can be found at http://wind.mit.edu/~emanuel/Hurricane_threat.htm and is reproduced in its entirety in Attachment I to this testimony. Recently a group of concerned scientists wrote a letter to the Honorable Bart Gordon, Chairman of the House Science and Technology Committee, on the need for the Federal Government to undertake prompt action to institute a comprehensive interagency research program aimed at reducing the impacts of hurricanes for the U.S.A and our neighbors (this letter is appended to the testimony as Attachment II).

Summary. As the climate continues to warm, models and observations agree that it is likely that global hurricane intensity will increase and that the number of North Atlantic hurricanes will increase, although the magnitude of the increase is uncertain. The increasing hurricane activity coupled with existing (and increasing) coastal vulnerabilities indicates an urgent need for adaptation in vulnerable coastal regions, particularly in the North Atlantic where the combination of global warming with the active mode of the Atlantic Multidecadal Oscillation indicates substantially elevated hurricane activity in the next few decades. Reducing carbon dioxide emissions will help avoid the longer term risks associated with sea level rise and storm surge expected from increasingly intense hurricanes.

References

Bengtsson, L., K.I. Hodges, M. Esch, N. Keenlyside, L. Cornblueh, J.J. Luo, T. Yamagata, 2007: How may tropical cyclones change in a warmer climate? *Tellus,* conditionally accepted.

Curry, J.A. P.J. Webster, G.J. Holland, 2006: Mixing politics and science in testing the hypothesis that greenhouse warming is causing a global increase in hurricane intensity. *Bull. Amer. Meteorol. Soc.*, 87, 1025-1037.

Emanuel, K., 2005: Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, 436, 686-688.

Franklin, J.L, R.J. Pasch, L.A. Avila, J.L. Beven II, M.B. Lawrence, S.R. Stewart, and E.S. Blake, 2006: Atlantic Hurricane Season of 2004, *Mon. Wea. Rev., 134*, 981–1025.

Hoyos, C.D., P.A. Agudelo, P.J. Webster, J.A. Curry, 2006: Deconvolution of the factors contributing to the increase in global hurricane intensity. *Science* 312 (5770): 94-97.

Iman, R. L., M. E. Johnson, and C. E. Watson. 2005. Sensitivity Analysis for Computer Model Projections of Hurricane Losses, *Risk Analysis*, **25,** 1277-1297.

IPCC AR4, 2007a: *Climate Change 2007: Climate Change Impacts, Adaptation, and Vulnerability Summary for Policymakers.* http://www.ipcc.ch/SPM6avr07.pdf

IPCC AR4, 2007b: *Climate Change 2007: The Physical Science Basis Summary for Policymakers.* http://ipcc-wg1.ucar.edu/wg1/docs/WG1AR4_SPM_Approved_05Feb.pdf

Knutson, T.R., and R.E. Tuleya, 2004: Impact of CO2-induced warming on simulated hurricane intensity and precipitation: Sensitivity to the choice of climate model and convective parameterization. *J. Climate*, **17**, 3477-3495.

Oouchi, K., J. Yoshimura, H. Yoshimura, R. Mizuta, S. Kusunoki, A. Noda, 2006: Tropical Cyclone Climatology in a Global-Warming Climate as Simulated in a 20 km-Mesh Global Atmospheric Model: Frequency and Wind Intensity Analyses. *J. Meteorol. Soc. Japan*, **84**(2): 259.

Webster, P.J., G.J. Holland, J.A. Curry, and H.-R. Chang, 2005: Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*, **309**, 1844-1846.

WMO, 2007: *Statement on Tropical Cyclones and Climate Change.* http://www.wmo.ch/web/arep/press_releases/2006/iwtc_statement.pdf

Attachment I

Statement on the U.S. Hurricane Problem
July 25th 2006

As the Atlantic hurricane season gets underway, the possible influence of climate change on hurricane activity is receiving renewed attention. While the debate on this issue is of considerable scientific and societal interest and concern, it should in no event detract from the main hurricane problem facing the United States: the ever-growing concentration of population and wealth in vulnerable coastal regions. These demographic trends are setting us up for rapidly increasing human and economic losses from hurricane disasters, especially in this era of heightened activity. Scores of scientists and engineers had warned of the threat to New Orleans long before climate change was seriously considered, and a Katrina-like storm or worse was (and is) inevitable even in a stable climate.

Rapidly escalating hurricane damage in recent decades owes much to government policies that serve to subsidize risk. State regulation of insurance is captive to political pressures that hold down premiums in risky coastal areas at the expense of higher premiums in less risky places. Federal flood insurance programs likewise undercharge property owners in vulnerable areas. Federal disaster policies, while providing obvious humanitarian benefits, also serve to promote risky behavior in the long run.

We are optimistic that continued research will eventually resolve much of the current controversy over the effect of climate change on hurricanes. But the more urgent problem of our lemming-like march to the sea requires immediate and sustained attention. We call upon leaders of government and industry to undertake a comprehensive evaluation of building practices, and insurance, land use, and disaster relief policies that currently serve to promote an ever-increasing vulnerability to hurricanes.

Kerry Emanuel
Richard Anthes
Judith Curry
James Elsner
Greg Holland
Phil Klotzbach
Tom Knutson
Chris Landsea
Max Mayfield
Peter Webster

Attachment II

February 26, 2007

The Honorable Bart Gordon
Chairman Committee on Science and Technology
U.S. House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

We, the under listed group of concerned scientists, believe the Federal Government should undertake prompt action to institute a comprehensive interagency research program aimed at reducing the impacts of hurricanes for the U.S.A and our neighbors. We hope that your Committee might be persuaded to take the lead on legislation authorizing the establishment of such a program.

The severe hurricane impacts on Florida in 2004, along with the record number and intensities of hurricanes with severe impacts around the Gulf of Mexico and the devastating flooding of New Orleans in 2005, have provided a "wake-up" call that cannot be neglected. A combination of sustained development in vulnerable coastal areas and high levels of hurricane activity has brought us to a critical stage where major action is required to address critical gaps in our capacity to handle growing hurricane impacts that pose both immediate and very real long-term threats to the safety of US citizens and their property, and to local and regional economic activity.

These gaps have been identified by several distinguished scientific entities, including:

- The National Science Board, who has recommended that the relevant Federal agencies commit to a major hurricane research program to reduce the impacts of hurricanes and encompassing all aspects of the problem: physical sciences, engineering, social, behavioral, economic and ecological[1];
- The NOAA Science Advisory Board, who established an expert Hurricane Intensity Research Working Group that recommended specific action on hurricane intensity and rainfall prediction[2];
- The American Geophysical Union, who convened a meeting of scientific experts to produce a white paper recommending action across all science-engineering and community levels[3]; and,
- A group of leading hurricane experts have convened several workshops to develop priorities and strategies for addressing the most critical hurricane issues[4].

These separate investigations are entirely consistent in advising that we have a major and worsening situation that requires urgent action in the following priority areas:

---

[1] **Hurricane Warning: The Critical Need for a National Hurricane Research Initiative** www.nsf.gov/nsb/committees/hurricane/prc_publication.pdf
[2] **HIRWG Final Report** www.sab.noaa.gov/Reports/HIRWG_final73.pdf
[3] **Hurricanes and the U.S. Gulf Coast: Science and Sustainable Rebuilding** www.agu.org/report/hurricanes/
[4] **HiFi Science Strategy** www.nova.edu/ocean/hifi/hifi_science_strategy.pdf

- **0 to 5 Day Hurricane Forecast Improvements**
  - In particular, skill in forecasting hurricane intensity in terms of expected wind speed and the extent of damaging winds and flood rains is at an unacceptably low level;
  - Understanding the important processes and development of new hurricane forecasting tools will require development of innovative oceanic and atmospheric observing systems combined with the next generation of research and operational hurricane forecast models to enable observations and prediction of the critical internal hurricane processes.

- **Long Range Projections of hurricane activity from Weeks to Decades**
  - Climate projections out to 20, 40 and 60 years of the expected variations in the number of Atlantic hurricanes, their intensities and geographical regions affected are critical to sound planning and engineering design, yet these are presently largely unknown;
  - Developing a capacity to predict these longer-term variations and trends requires improved understanding of the complex interactions between hurricanes and the global climate, together with a commitment to development of the next generation of regional climate models.

- **Impacts Projections**
  - Hurricane damage arises from the effects of high winds, ocean waves, coastal storm surge, rainfall and associated flooding, land slippage and environmental deterioration;
  - Reducing these impacts will require multidisciplinary collaborations amongst physical scientists, engineers, social scientists, ecologists and community leaders.

Further details on these priorities are provided in the original documents as referenced on the previous page.

We were encouraged by, and supportive of the efforts by Senators Martinez and Nelson who introduced legislation in the last Congress (S. 2004) that proposed the authorization of a national initiative to address these priority areas. We hope that your Committee will consider enactment of legislation along the lines of the legislation introduced last year as part of the agenda for the 110th Congress.

Considerable planning discussions within the scientific community have convinced us that a visionary and comprehensive national hurricane initiative is required. To be successful this program needs to be sustained for at least a decade to ensure that the critical combination of fundamental research and system development can be accomplished. Further, several federal agencies and laboratories and the academic community should be involved in the initiative in a highly collaborative and cooperative manner to ensure the needed depth and diversity of multi-disciplinary expertise and institutional capabilities and to address the many dimensions of federal and state responsibility related to hurricanes.

We stand ready to assist your Committee and the Congress to address the Nation's need for improved understanding and prediction of hurricanes and their impacts.

Sincerely,

Dr. Greg Holland
National Center for
Atmospheric Research,
Boulder, Colorado.
gholland@ucar.edu
Ph: 303-497-8949

Professor Roger Lukas
University of Hawaii at Manoa
Hawaii
rlukas@hawaii.edu
Ph: 808-956-7896

Co-Chairs of the HiFi initiative

Supported by the following leading scientists:

Name	Name	State	Institution	E-mail	Phone
Holland	Dr. Greg	CO	NCAR	gholland@ucar.edu	303/497-8949
Lukas	Prof. Roger	HI	U. Hawaii	rlukas@hawaii.edu	808/956-7896
Agee	Prof. Ernie	IN	Purdue U.	eagee@purdue.edu	765/494-3282
Aneja	Dr. Viney	NC	NC State U	vpaneja@ncsu.edu	919/515-7808
Anthes	Dr. Richard	CO	UCAR	anthes@ucar.edu	303/497-1652
Betterton	Prof. Eric	AZ	U. Arizona	betterton@atmo.arizona.edu	520/621-2050
Bosart	Prof. Lance	NY	SUNY	Bosart@atmos.albany.edu	518/442-4564
Boss	Prof. Emmanuel	WA	U. Maine	emmanuel.boss@maine.edu	207-581-4378
Chen	Prof. Shuyi	FL	RSMAS	schen@rsmas.miami.edu	305/361-4048
Clark	Dr. Richard	PA	Millersville U.	Richard.Clark@millersville.edu	717/872-3930
Cook	Dr. Kerry	NY	Cornell U.	cook@metvax.cit.cornell.edu	607/255-5123
Cooper	Dr. Cort	TX	Chevron	CortCooper@chevron.com	925/842-9119
Curry	Prof. Judy	GA	GA Tech.	curryja@eas.gatech.edu	404/894-3955
Dewey	Dr. Ken	NE	U. of NE	kdewey1@unlnotes.unl.edu	402/472-2908
Donelan	Prof. Mark	FL	RSMAS	mdonelan@rsmas.miami.edu	305/421-4717
Drennan	Will	FL	U. Miami	wdrennan@rsmas.miami.edu	305/421-4701
Edson	Dr. Jim	CT	U. Connecticut	james.edson@uconn.edu	860/405-9165
Elsberry	Prof. Russ	CA	Naval Postgrad. S.	elsberry@nps.edu	408/646-2373
Elsner	Jim	FL	Fl. State U.	elsner@garnet.fsu.edu	850/644-6205
Few	Arthur	TX	Rice U.	few@rice.edu	713/527-8101 x3601
Fitzpatrick	Prof. Pat	MI	Miss. State U.	fitz@ERC.Ms.State.Edu	228/688-1157
Foufoula-Georgiou	Prof. Efi	MN	U. Minnesota	efi@tc.umn.edu	612-626-0369
Geernaert	Dr. Gary	NM	LANL	geernaert@lanl.gov	505/667-6020
Gillies	Dr. Robert	UT	Utah State U.	rgillies@gis.usu.edu	435/797-2190
Ginis	Dr. Isaac	RI	Private	iginis@gso.uri.edu	401/874-6484
Glenn	Dr. Scott	NJ	Rutgers U.	glenn@imcs.marine.rutgers.edu	732/932-6555 x506
Hakim	Prof. Gregory	WA	U. Washington	hakim@atmos.washington.edu	206/685-2439
Halliwell	Prof. George	FL	RSMAS	ghalliwell@rsmas.miami.edu	305/421-4621
Huebert	Prof. Barry	Hi	U. Hawaii	huebert@hawaii.edu	808-956-6896
Hurrell	Dr. James	CO	NCAR	jhurrell@ucar.edu	303/497-1383
Jenkins	Prof. Gregory	DC	Howard U.	gjenkins@howard.edu	202-806-5172
Kahl	Dr. Jonathan	WI	U. Wisc-Madison	kahl@uwm.edu	414/229-3949
Knupp	Prof. Kevin	AL	U. Alab-Huntsv.	kevin@nsstc.uah.edu	256-961-7762
Krishnamurti	Prof. T.	FL	Fl. State U.	tnk@io.met.fsu.edu	904/644-2210
Larson	Prof. Vincent	WI	U. Wisc-Milwaukee	vlarson@uvm.edu	414/229-5490

Leslie	Prof. Lance	OK	Oklahoma U.	lmleslie@ou.edu	405/325-0596
Luettich	Prof. Rick	NC	U. North Carolina	rick_luettich@unc.edu	252/726-2426
Lupo	Prof. Anthony	MO	U. M-Columbia	lupoa@missouri.edu	573/884-1638
Magnusdottir	Prof. Gudrun	CA	UC Irvine	gudrun@uci.edu	949/824 3520
Majumdar	Dr. Sharanya	FL	RSMAS	smajumdar@rsmas.miami.edu	305/421-4779
Melville	Prof. Ken	CA	SCRIPPS	melville@mpl.ucsd.edu	858/534-0478
Molinari	Prof. John	NY	SUNY	molinari@atmos.albany.edu	518/442-4562
Nowlin	Dr. Worth	TX	Texas A&M U.	wnowlin@tamu.edu	979/845-3900
Olson	Dr. Don	FL	RSMAS	dolson@rsmas.miami.edu	305/361-4074
Pietrafesa	Prof. Len	SC	U. South Carolina	len_pietrafesa@NCSU.edu	919/515-7777
Polvani	Prof. Lorenzo	NY	Columbia U.	lmp@columbia.edu	212/854-7331
Price	Dr. Jim	MA	WHOI	jprice@whoi.edu	508/289-2526
Rauber	Dr. Bob	IL	U. I-Urbana-Champaign	rauber@atmos.uiuc.edu	217/333-2835
Richardson	Prof. Mary Jo	TX	Texas A&M U.	mrichardson@ocean.tamu.edu	979/845-7966
Ritchie	Prof. Liz	NM	UNM	ritchie@ece.unm.edu	505/277-8325
Rosendahl	Dr. Bruce	MD	RSMAS (retired)	brucerr@earthlink.net	410/990-1151
Rusher	Prof. Paul	FL	Fl State U.	ruscher@met.fsu.edu	850/644-2752
Rutledge	Dr. Steven	CO	Co. State U.	rutledge@atmos.colostate.edu	970/491-8283
Sanford	Prof. Tom	WA	U. Washington	sanford@apl.washington.ed	206/543-1365
Sass	Prof. Ron	TX	Rice U.	sass@fuf.rice.edu	713/348-4066
Schroeder	Dr. John	TX	Texas Tech.	john.schroeder@ttu.edu	806/742-2813
Schroeder	Prof. Tom	HI	U. Hawaii	tas@hawaii.edu	808/956-7476
Shay	Dr. Nick	FL	RSMAS	nshay@rsmas.miami.edu	305/421-4075
Sheng	Dr. Peter	Fl	U. Florida	pete@coastal.ufl.edu	352/392-9537 x1521
Snow	Prof. John	OK	Oklahoma U.	jsnow@ou.edu	405/325-3101
Soloviev	Prof. Alex	FL	Nova Southern U.	soloviev@nova.edu	854/262-3659
Stafford	Dr. Fred	IL	U. of Chicago	fstaffor@uchicago.edu	773/207-9120
Trenberth	Dr. Kevin	CO	NCAR	trenbert@ucar.edu	303/497-1318
Velden	Prof. Chris	WI	U. Wisc-Madison	chris.velden@ssec.wisc.edu	608/263-6750
Wang	Dr. Yuqing	HI	U. Hawaii	yuqing@hawaii.edu	808/956-5609
Webster	Prof. Peter	GA	GA Tech.	pjw@eas.gatech.edu	404/894-1748
Weller	Dr. Robert	MA	WHOI	rweller@whoi.edu	508/289-2508
Wuebbles	Prof. Donald	IL	U. I-Urbana-Champaign	wuebbles@uiuc.edu	217/244-1568
Zehnder	Dr. Joseph	AZ	A. State U.	jzehnde@exchange.asu.edu	480/965-5163
Zhang	Dr. Chidong	FL	RSMAS	czhang@rsmas.miami.edu	305/421-4042

Biosketch

Dr. Judith Curry is Professor and Chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. Dr. Curry received a Ph.D. in atmospheric science from the University of Chicago in 1982. Prior to joining the faculty at Georgia Tech, she has held faculty positions at the University of Colorado, Penn State University and Purdue University. Dr. Curry's research interests span a variety of topics in climate; current interests include air/sea interactions, climate feedback processes associated with clouds and sea ice, and applications of satellite data to interpreting recent variations in the climate data record. Most recently she has been investigating the variability of hurricanes on global scales, in the North Atlantic, and landfalling hurricanes striking the U.S. and Latin America. Dr. Curry has recently served on the National Academies Climate Research Committee and the Space Studies Board, and the NOAA Climate Working Group. Dr. Curry is coauthor of the book *Thermodynamics of Atmospheres and Oceans* and is editor for the *Encyclopedia of Atmospheric Sciences.* She has published over 140 refereed journal articles. Dr. Curry is a Fellow of the American Meteorological Society and the American Geophysical Union, and her research has been recognized by receiving the Henry Houghton Award from the American Meteorological Society.

The CHAIRMAN. Our second witness, Dr. Camille Parmesan, is an Associate Professor of Biology at the University of Texas in Austin. Her landmark paper on nature and the impact of climate change on natural systems around the world established her as one of the foremost experts on the response of wildlife to global warming.

She is currently Chair of the International Conservation Unions Task Force on Climate Change and Conservation, and she has served as author and reviewer of reports by the Intergovernmental Panel on Climate Change and as an expert adviser for the National Assessment of the Potential Consequences of Climate Variability for Change of the United States.

Welcome, Dr. Parmesan. Whenever you feel comfortable, please begin.

STATEMENT OF CAMILLE PARMESAN, ASSOCIATE PROFESSOR IN INTEGRATIVE BIOLOGY, UNIVERSITY OF TEXAS AT AUSTIN

Ms. PARMESAN. Thank you.

This is working good.

Well, I think to address the question of dangerous climate change, it is—we can learn a lot by examining what has already happened with the amount of warming that we have currently had.

We don't have a huge number of biological studies for the U.S.A., but if you look globally, there are hundreds of studies, literally, reviewed. I just finished looking at 866 papers, and this is a minimum estimate because I only looked at major English journals. This represents thousands of species. We have seen impacts in every single continent in every single ocean, and when you look at analyses that have estimated what percentage of species have already been impacted we see that 50 percent of all species studied with long-term data have shown some sort of response to recent climate change. And by "recent" I mean of the past 100 years. This is a huge number, considering the amount of warming has only been 0.7 degrees centigrade, about a degree Fahrenheit.

It is a—these changes have been in every major biological group that has been studied, from herbs to trees, plankton in the ocean, lakes, fish, insects, mammals. Pretty much every type of organism that you have got long-term data on has shown a response; and, again, it has been about 50 percent in each of those groups.

This and several synthetic global analyses that have been published in the scientific literature have led to a very strong consensus amongst biologists that recent warming, this 0.07 degree centigrade, has indeed impacted natural systems. It has been the cause of the changes that we have been seeing.

And in the IPCC reports what you see is that the level of confidence of that now mirrors the level of confidence that climate scientists have that the warming is caused by humans, and both of those are put at more than 90 percent sure. But I can tell you if you look into the individual biological literature you will see that several analyses indicate that the kinds of patterns that we are seeing globally in wild species, there is less than 0.1 percent of a chance that those changes are due to something other than climate change.

These are very, very strong numbers.

Okay. Now I would like to show you, if you could go to the next slide, just very quickly a few of the examples. A lot of them are more detailed in the written testimony.

So this is again what we have already seen. This is showing shifts in phenology, shifts in changes in spring timing. Everything above that vertical line are later breeding or emergence or arrival. Everything below it is earlier emergence or breeding or arrival in the spring.

And the first thing I want to point out is, when you look at the average—so where there has been an advancement of spring events by 2 point days by decade on average, several studies have estimated this. But what I want to show you is this is a subset of studies that looked at whole communities, and you can see that there is large variability. In some species—those individual bars, each a different species—some species are showing very strong advancement. In butterflies and birds, you are seeing advances—that is the blue and the yellow—of 10 to 20 days per decade advancement in spring breeding. And if you look at the purple—those are frogs—summer breeding as early as 35 days earlier per decade. So if you look over the past 30 years we have had warming, that is an enormous advancement in spring events.

We are also seeing massive rain shifts, and so two of the consistent patterns are these earlier spring timing.

The other very consistent pattern globally is massive northward shifts of species ranges and upward shifts in mountainous ranges. And this is starting to actually affect whole biums. So we are seeing tropical species moving up from Mexico and Africa into Europe and into the U.S.A. We are seeing tempered species of the U.S.A. And Europe moving up into boreal zones of Canada, Alaska and Lapland; and we are seeing those boreal species actually contracting towards basically no man's land as the warming has continued.

This—you would think that tropical species might be resistant, so perhaps the whole earth is just going to be tropical, but coral reefs are actually already at their high temperature limits, and 30 percent have been killed off by recent high sea surface temperature events.

This is just showing that when you go to the cold adaptive species is where you see the other drastic declines. You don't see the graphics, but this is polar bears in the Arctic and green seals, things that are sea ice dependent. You go down to Antarctica, you see the same things in sea ice dependent species, massive declines and contractions towards the poles.

You don't get to see all of the pretty pictures of pikas, but what this is meant to show you is that the other type of cold-adapted species are mountaintop species; and we are seeing contractions of range as species are forced up mountains. Literally, it is getting too hot at the lower elevations, and we are starting to see the first whole-species extinctions.

So these are tropical highland frogs. Seventy-four species have gone extinct in the Cloud Forest of Central America. These are remote areas, undisturbed areas. These distinctions have been directly related to warming trends in those regions. And I do want to remind people that these brightly colored tropical frogs have provided us with a huge number of medicines, and particularly heart medicines.

The CHAIRMAN. Doctor, could you try to summarize it?

Ms. PARMESAN. All of these changes I have been talking about are with 0.7 degrees centigrade warming.

So what happens with 1 or 2 degrees centigrade or 4 to 5 degrees centigrade?

What this shows you is a time line going back 65 million years. The blue colors are colder than now. The red colors are hotter than now. And what you see is if you—I don't know if you can read this—but humans first appeared during that middle part of the graph during this cold earth period. So the entire time humans, homo sapiens, our species, have been around, the earth has primarily been colder than now.

Modern civilization, agriculture, the arts, et cetera, appeared when climate stabilized about 10,000 years ago. The little blips in the middle with the stars are 1 to 2 degrees higher temperature. There have been tiny blips where you have had human-like species around. But if you go back to where it has been 4 or 5 degrees centigrade warmer—that is all the way to the last third of the graph, that red arrow there—what you are getting to is a time when a lot of modern species did not exist. There was a completely different bium; and when the earth shifted from that hotter to the colder, you did have massive loss of species, about 20 to 30 percent.

And I think I will leave it at that.

The CHAIRMAN. I thank you very much.

[The statement of Ms. Parmesan follows:]

United States House of Representatives, Select Committee on Energy Independence and Global Warming

Hearing on "Dangerous Climate Change"
April 26, 2007

written testimony from Dr. Camille Parmesan,
Associate Professor in Integrative Biology
University of Texas at Austin
email: parmesan@mail.utexas.edu
wk ph: (512) 232-1860

My expertise on climate change and its impacts stems from my core research program and multiple scientific publications on the biological impacts of recent climate change, from participating for the past 10 years as author and reviewer of reports by the Intergovernmental Panel on Climate Change (formed by the United Nations and the World Meteorological Organization), and from teaching a graduate-level course at the University of Texas in Global Environmental Change which covers relevant materials from atmospheric science, meteorology, climate modeling and carbon emissions scenarios as well as the biological impacts and projections of climate change on wild species.

I. Summary of the current state of climate science

1) global warming is unequivocal
2) > 90% certainty that humans are the main drivers of global warming

Greenhouse gases that have increased due to human activities include carbon-dioxide, methane, and nitrous oxide. Direct quotes from the recent Intergovernmental Panel on Climate Change (IPCC), 2007[1]:

"Warming of the climate system is **unequivocal**, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level."

"Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* [**>90% certain**] due to the observed increase in anthropogenic greenhouse gas concentrations. "

II. Summary of current, observed impacts on natural systems and human health

1) We don't have a lot of biological studies in the southern USA, but global analyses can help us to understand what is likely to be happening more regionally It's clear that everywhere there's been measurable climate change, it has impacted wild species. With relatively small changes in

[1] IPCC 2007. Climate Change 2007: The Physical Science Basis, Summary for Policy Makers. The Intergovernmental Panel on Climate Change Fourth Assessment Report. IPCC Secretariat, Geneva, Switzerland. Download pdf file available at: www.ipcc.ch

recent temperatures (a rise of 0.7 ° C over the 20th century), we've documented that half (50%) of all wild species for which we have long-term data have shown a response to local, regional or continental warming[2].

Global warming has affected every major biological group that has been studied (*e.g.* from herbs to trees, from plankton to fish, and from insects to mammals) and responses have been seen on all continents and in all major oceans[3,4]. In my most recent review, I surveyed biological impacts studies from major international English-language journals only and found an astonishing 866 papers representing data from thousands of species worldwide (Figure 1). There are hundreds of additional studies which were not included in this review because the journal were in a non-English language or not available at a U.S. university library. This and several other synthetic, global analyses published in the scientific literature have concluded that these observed changes in biological systems are indeed caused by climate warming. The consensus among biologists that climate change has impacted a large part of the natural world now mirrors the level of consensus among climate scientists that the warming is caused by humans (in IPCC terms, we're more than 90% sure on both fronts)[1,2,3,4,5,6].

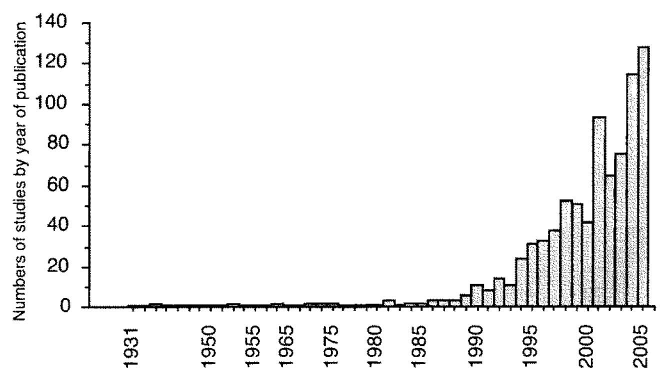


Figure 1. Numbers of papers by year of publication documenting a response of wild plants or animals to long-term changes in average temperature (from Parmesan 2006[4]).

---

[2] Parmesan C, Yohe G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. ***Nature*** 421:37—42. pdf file available on request from author

[3] Parmesan, C. and H. Galbraith. 2004 *Observed Ecological Impacts of Climate Change in North America,* Pew Center on Global Climate Change. Download of pdf file available from: www.pewclimate.org

[4] Parmesan, C. 2006. Observed ecological and evolutionary impacts of contemporary climate change. ***Annual Reviews of Ecology and Systematics*** 37:637-669. pdf file available on request from author

[5] Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C, Pounds JA. 2003. Fingerprints of global warming on wild animals and plants. ***Nature*** 421:57--60

[6] IPCC 2007b. Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability, Summary for Policy Makers. ***The Intergovernmental Panel on Climate Change Fourth Assessment Report.*** IPCC Secretariat, Geneva, Switzerland. Download pdf file available at: www.ipcc.ch

2) Globally, we're seeing a strong consistent pattern of northward movements of species ranges as well as upward movement in mountainous areas. Tropical species from Central America and Africa are moving into historically temperate zones of the USA and Europe, temperate species are moving into boreal zones of Alaska, Canada and Lapland, and true boreal species are losing total habitable area as woody shrubs invade the tundra, and sea ice disappears.

3) Some species that are adapted to a wide array of environments - globally common, or what we call weedy or urban species - will be most likely to persist. Rare species that live in fragile or extreme habitats are already being affected, and we expect that to continue. We are seeing stronger responses in areas with very cold-adapted species that have also had strong warming trends, such as in Antarctica and in the Artic. Species whose habitat is sea ice are showing drastic declines. This includes the polar bear and the ringed seal in the Arctic, and the Adelie and Emperor penguins in the Antarctic. Mountain-top species, like the pika, are dying off at their lower range boundaries, becoming more and more restricted to the highest elevations.

4) Tropical coral reefs world-wide have been killed off by recent high sea surface temperatures – often associated with El Niño – with nearly 30% of tropical coral reefs dead from multiple high temperature events. Caribbean reefs have suffered significantly. A coming danger is the increased acidity of the ocean due to increased absorption of carbon-dioxide. Ocean pH has already lowered from 8.2 to 8.1 in the tropics. At a only slightly lower pH (combined with warm temperatures) under lab conditions, animals such as corals and shellfish cannot build a hard shell. These conditions could be reached as early as 2050[7]. Massive loss of coral reefs is likely to hurt the economies of U.S. Caribbean islands that depend on reefs for fisheries and tourism.

5) Spring is earlier (by about two weeks) and fall is later (by about one week) throughout the northern hemisphere. Where sufficient precipitation exists, this has extended the growing season. While this effects is projected to increase agricultural production in Canada, Sweden and Finland, prime areas of U.S. agriculture – particularly the corn belt – are expected to experience continued drying conditions, which will negatively impact production as these areas currently do not irrigate but rely on natural rainfall.

6) Forestry has already seen large increases in pest outbreaks throughout the USA, Canada, Europe and Russia. This is both because of pest species moving northward and invading new territory (such as the white pine beetle in the western USA), and because warmer winters and extended growing seasons are allowing many populations to increase their generation time (such as for the mountain pine beetle in Colorado and the spruce bark beetle in Alaska).

7) We're seeing many tropical species moving into the Gulf Coast states – former migrants like the rufous hummingbird and the Mexican green jay have become year-around residents in Alabama and Texas, respectively. Florida has five new species of tropical dragonfly. Many tropical butterflies that are normally confined to Mexico are starting to breed as far north as Austin, Texas.

---

[7] Hoegh-Guldberg, O. (2005), Low coral cover in a high-CO2 world, ***J. Geophysical Research***, 110-121.

8) Human health is already being affected. In a recent yearly report, the World Health Organization estimated that 6% of malaria infections, 7% of dengue fever cases and 2.4% of diarrhea could be attributed to climate change (principally increased frequency and intensity of flood events). The observed northward movements of tropical species has implications for human health. The parasites that cause people to get sick when the vacation in Mexico are just wild animals and microbes – just as we're seeing birds & butterflies coming up from Mexico, human parasites and their wild animal vectors are likely to be shifting northward as well.

9) Where are we going? It's clear climate is going to continue to show a major shift. From recent deep ice-cores, we know that current carbon-dioxide levels are way out of bounds from natural fluctuations over the past 800,000 years. We're currently at 380 ppm CO_2, which is about 30% higher than peak levels during any of the warm periods during the recent Pleistocene climate changes. Over the many glacial/interglacial cycles which has characterized Earth for the past million years, peak CO_2 levels – which match peak warm temperatures – have stayed in the range of 270-300 ppm (Figure 2). There is a long lag time in the climate system – it takes hundreds of years for global temperature to stabilize after greenhouse gases have increased, and it takes thousands of years for sea level to stabilize, so we know we haven't yet felt the full effect of what we've already put out[4].

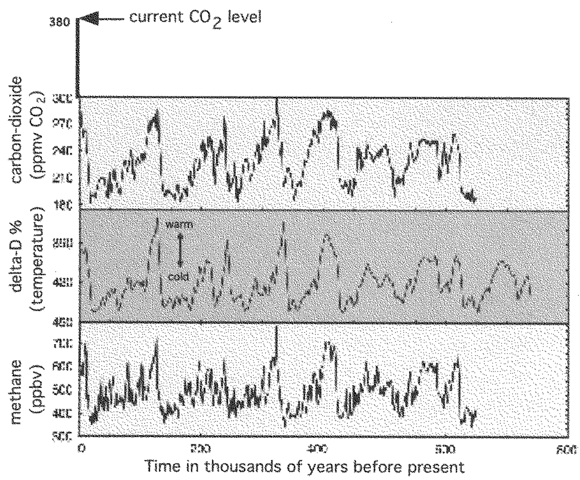


Figure 2: The ice core records from Antarctica. Top panel, carbon dioxide levels going back 600,000 years+. Heavy black line added to show current level of 380 ppmv CO_2. Middle panel, air temperatures going back 700,000 years+ (estimated from hydrogen/deuterium ratios). Bottom panel, methane levels going back 600,000 years+. Source: modified from EPICA

10) What are the implications of this for biodiversity and human health? All of the changes in natural systems that have been documented have occurred with only 0.7° C global average warming. This small amount of warming has already driven 74 species of frog extinct, has killed large areas of coral reef worldwide, has placed many boreal animals at high risk of extinction, and has begun to increase water borne diseases in humans[3,4,5]. Even the most optimistic minimum projections – of 1.8° C more warming - are more than twice what we've already seen (Figure 3). Under this "best case" scenario, projections of impacts on wild life have a large range depending on the species group, degree of habitat restriction, and geographic region. Examples on the low end are projected extinctions of 4% of birds and 7% of mammals in Mexico, to 6% of plants in Europe. On the upper end, projected extinctions with 2°C warming range from extinction of 70% of butterflies, 40% of birds and 40% of Proteacea plants in South Africa, to 79% of plants in the Amazon. (Table 1)

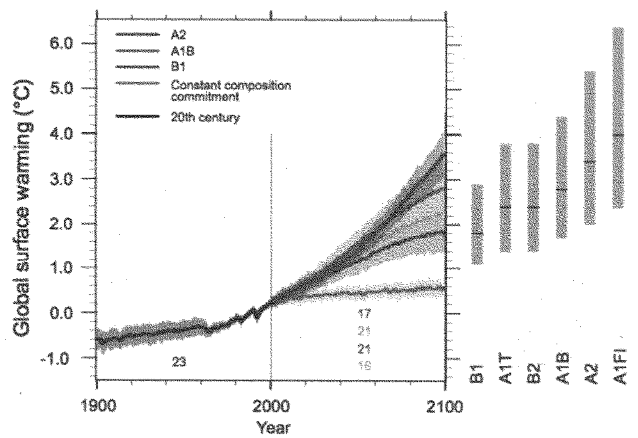


Figure 3: Temperature projections under different emission scenarios. Source: IPCC 2007

11) Business as usual projections lead to a 4°-5° C rise, with some models projecting as much as 6.8° C rise. This represents a climate the Earth hasn't seen in several million years – and an Earth humans, as a species, have never seen. The past million years or so has been a "cold Earth". Much of this time Earth has been heavily dominated by glaciers and sea ice. It is during this time that humans first appeared. For much of human history, we have lived as savage hunter/gathers in very small familial groups. It was only when we came out of these times of strong climate change – and no longer had to cope with repeated glacial/interglacial cycles – that we developed the modern trappings of humanity. Only when climate became relatively stable did we invent agriculture, the written language, art – everything we now associate with

"society". *(See figure in powerpoint presentation for timeline of climate over the past 65 million years)*

Under this "worst-case" scenario, projected impacts are severe for nearly every system studied. Worldwide mass extinctions are highly likely. Most cold-adapted species are expected to go extinct – those living in the Arctic and Antarctic and on mountaintops. Many tundra species, such as the caribou, are likely to go extinct. Large areas of boreal forest will die off, with obvious repercussions for the timber industry. Tropical diseases and parasites, along with their insect and mammalian vectors, will have shifted into the USA and Europe, with associated increased risk of human infection. (Table 1) Details of likely economic impacts can be found in the recent Stern Review[8].

III. Immediate strong action is required to prevent "dangerous anthropogenic interference with the climate system."

- The importance of acting now is because CO_2 is very stable in the atmosphere, and continues to have a strong effect on global climate for hundreds of years after it goes up into the atmosphere. 1/4 of the CO_2 we emit today will still be in the atmosphere 350 years from now

- We can't afford the worst case scenario – "business as usual" - either in terms of conservation of biodiversity, human health, or our economic stability[8]. We will see an enormous difference in life over the next 50 years regardless of which path we take (Table 1). Whether the impacts are ones for which we have some hope of devising adaptation strategies (*e.g.* physical movement of most sensitive species, industries and population centers, building barriers to sea level rise and higher intensity flooding), or whether we enter a climate era for which neither humans nor wild life have adaptation capacity, depends on what steps are taken now reduce emissions. It's only by implementing aggressive cuts in greenhouse gas emission immediately that we keep future global warming down to those lower projections we have some hopes of coping with – down to "just" another 1.8° C.

Table 1 *(next page)*: Observed and projected impacts on natural and human systems of different levels of global warming. Sources: 30+ studies published in scientific literature and IPCC 2007 report (bibliography available upon request).

---

[8] The Stern Review on the Economics of Climate Change, 2006. Her Majesties Treasury, United Kingdom. Pdf file downloadable from: www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm

Observed impacts of 0.7° warming over the past century
• 50% of species studied worldwide show measurable response • Every major group studied has been affected, and impacts have occurred on every major continent and in every major ocean • Northward range shifts from 30 - 600 miles, and upward shifts of 300 - 2,000 feet have occurred • Parasites and their vectors have also shifted northward, some of these affect human health as well as wildlife. • Spring events (breeding, migratory arrival, emergence from hibernation) are earlier by 2 weeks on average since 1970, with some frogs breeding a month earlier per decade. • Warmer winters, northward ranges shifts of moths and beetles, and extended growing seasons have resulted in increased pest outbreaks, tree deaths, and associated loss of productivity in forests across the lower USA, Alaska, Canada and Russia. • 74 species of highland cloud forest frogs have been driven extinct by climate change • ~ 30% of tropical coral reefs have been killed by rising sea temperatures • Cold-adapted and severely range-restricted species have lost habitat and are reaching "endangered" status because of loss of climatically-suitable space. Examples come from sea-ice habitats (polar bears & penguins) and from montane habitats (mountain-restricted frogs, mammals and butterflies)
Projected impacts of another 2°C warming
• Extinctions of most sensitive species – estimated species losses range from 4% for common, widespread trees and birds to 40% for sensitive species with small ranges. • Large contractions of tundra and sea ice habitats, likely extinctions of associated species (*e.g.* caribou, polar bear, ringed seal) • Major bleaching of most tropical coral reefs • Overall projected extinction of 20% of species worldwide • Increased incidences of tropical diseases in USA and Europe • Lower agricultural productivity at lower latitudes (incl. some of USA), but increases at higher latitudes (Canada).
Projected impacts of > 4°C warming
• Complete loss of suitable climate space for a large number of species (*e.g.* from polar bears to montane tree possums in Australia) and whole ecosystems (*e.g.* the fynbos in South Africa) • Mass extinction of wild species worldwide (on the order of >70%) • High ocean temperatures combined with increased acidity lead to complete loss of tropical coral reefs with associated loss of fisheries and tourism • Loss of much of boreal forests and associated lumber industries • Lowered agricultural production at all latitudes

IV. Emission reductions options compatible with biodiversity preservation goals

- There is no single action that can bring greenhouse gas emissions down to levels which would prevent dangerous consequences. While increased production and use of renewable energy is admirable in theory, in practice many "green" energy schemes are counter-productive. For example, use of existing agricultural lands in the USA to grow crops for biodiesal is a good idea, but cutting down pristine rainforest in Indonesia to plant oil palms for biodiesal export (as is currently happening) is not a good idea. Likewise, schemes to plant forests over native grassland not only destroy an entire biome, but the benefits are short-lived – once the forest matures it ceases to take up large amounts of carbon from the atmosphere. This can happen in as little as 30 years. Wind power is fine in some areas, but in others has led to high bird mortality, often of endangered species, both from directly being killed when hitting the blades in-flight, and from creating fright behavior in open-meadow species (ground-nesting meadow birds appear to mistake the large moving blades for hawk and eagle predators).

- Solar panels are perhaps the single renewable energy source with no negative biodiversity consequences. Requiring roof solar panels on all new homes in appropriate areas (*i.e.* most of the western USA) would add little to overall housing costs (from $5,000 - $10,000 total upfront cost), which pays for itself in just a few years by money saved from reduced consumption from the grid.

- The policy options which would have the most direct and immediate effect on greenhouse gas emissions involve incentives for industry as well as individuals to produce less emissions. These could range from higher electricity prices which would provide incentive for improved energy conservation by homes and businesses (*e.g.* turning off heat or air-conditioning when the building is not occupied) to gasoline taxes which would encourage buying lower fuel-consumption cars. In Britain, yearly car registration fees are based entirely on absolute CO_2 emissions, with current fees ranging from $0 for the smallest cars to $400 /year for large family cars. Recent government announcements are to increase the maximum to $800/year. This is easy to implement and would have immediate impacts on individual car purchases.

The CHAIRMAN. Our next witness is Dr. Kristie Ebi. She is an independent consultant working with the World Health Organization, the United Nations Development Program and USAID. She has been working on global climate change and public health issues for years. She is the author of three books. She is the lead author for the Human Health Chapter of the Intergovernmental Panel on Climate Change's recent Fourth Assessment Report.

We welcome you.

STATEMENT OF KRISTIE L. EBI, ESS, LLC

Ms. EBI. Mr. Chairman and members of the select committee, I really appreciate the opportunity to talk with you today.

The determination of when a risk becomes dangerous, such as anthropogenic climate change, is a social choice. It is my role as a scientist to inform that decision by describing the state of scientific knowledge.

People, plants, and animals are exposed to climate change through changing weather patterns such as more frequent and intense heat waves and floods and through climatic changes facilitating the geographic spread and increase our number of cases of a variety of infectious diseases as well as diseases associated with air pollutants and air allergens.

Population health integrates climate change impacts across all other sectors, such as changes in water availability, crop yields, and ecosystem changes and thus is a key sector for assessing the risk of climate change.

Human injuries, illnesses and deaths are already occurring due to climate change right now. Currently, approximately 150,000 deaths worldwide are attributed to climate change annually, with most of these deaths occurring in low- and middle-income countries.

Although 150,000 worldwide may not seem like a very large number, the number of life years lost is already about half of what we are seeing due to urban air pollution. The 150,000 is about 0.4 percent of all life years lost every year. This means that, together, between climate change and urban air pollution, approximately 1.2 percent of all life years lost are due to the combustion of fossil fuels.

As noted, I am an author of the Human Health Chapter of the Intergovernmental Panel on Climate Change for its assessment report, and we concluded that projected trends in climate-change-related exposures will have predominantly negative impacts, with injuries, illnesses and deaths occurring within all continents. These include increasing undernutrition and consequent disorders, including those related to child growth and development; increasing injuries, illnesses and death due to heat waves, floods, droughts, storms and fires; increasing numbers of cases of diarrheal diseases; increasing cardiorespiratory diseases where ozone exposure concentrations increase; and increase in the geographic range and length of transmission season of malaria in some regions and a decrease in the range of others.

Climate change has projected to bring some benefits to health, including fewer deaths due to exposure to cold, but these will not offset increased heat-related deaths.

Most of the impacts will occur in low- and middle-income countries, with the extent of the impacts increasing with increasing climate change.

Critically important to an assessment of what constitutes dangerous climate change is that the inherent inertia in the climate system means that weather and climate will continue to change, and health impacts will continue to occur for decades after stabilization of atmospheric concentration of greenhouse gasses. This is the commitment that we are already facing.

The health impacts of climate change will stress over-stretched public health programs and health care systems. It will not be possible to avoid all health impacts due to climate change, even with immediate implementation with effective adaptation, policy measures and aggressive reduction in greenhouse gas emissions. Adaptation and mitigation are urgently needed to manage the risk of current and projected climate change impacts.

Recent experiences such as the 2003 heat wave in Europe have shown the ability to plan for and cope with climate change needs to be improved everywhere.

Most impacts will not be as dramatic as these events. For example, we can expect more periods of heavy rain such as the storm in D.C. last fall that closed several government buildings for a few days. Because adaptation will be a continual process and will be required at every level, one policy response would be to mandate U.S. agencies, such as the Environmental Protection Agency, the Centers for Disease Control and Prevention and Fisheries and Wildlife to incorporate climate change risks into the programs and activities that are or could be affected by climate change and to provide them with the human and financial resources to do so. This mandate should include developing a more complete understanding of the risks that Americans may face over the coming decades.

In addition, I believe that the U.S. should have a central agency responsible for working with other agencies, States, communities, businesses and others to understand climate change risks and responses. This agency could provide expertise and decision with support tools to understand local and regional climate change projections as well as adaptation and mitigation options. One model is the U.K. Climate Impact Program, which is now in its tenth year.

Thank you very much.

The CHAIRMAN. I thank you. And, again, I think you are going to have plenty of opportunity to elaborate during the question and answer period.

[The statement of Ms. Ebi follows:]

Testimony of

Kristie L. Ebi

ESS, LLC

Mailing Address:

5249 Tancreti Lane

Alexandria, VA 22034

Before the

U.S. House of Representatives Select Committee on Energy Independence and Global Warming, Hearing on

"Dangerous Climate Change"

10:00 a.m., April 26, 2007

Room 2172, Rayburn House Office Building

Weather and climate are among the factors that determine the geographic range and incidence of several major causes of ill health, including undernutrition, which affects 17% of the world's population in developing countries [FAO 2005]; diarrheal diseases and other conditions due to unsafe water and lack of basic sanitation, which cause 2 million deaths annually, mostly in young children [Kosek et al. 2003]; and malaria, which causes more than a million childhood deaths annually [WHO 2004]. The Human Health chapter in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, for which I was a Lead Author, concluded that climate change has begun to negatively affect human health, and that projected climate change will increase the risks of climate-sensitive health outcomes, particularly in lower-income populations, predominantly within tropical/subtropical countries [IPCC WGII SPM 2007].

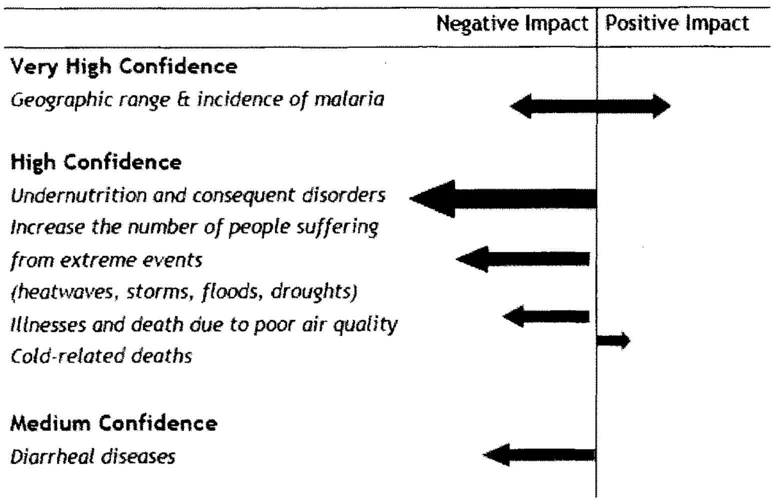
Weather, climate variability, and climate change can affect health directly and indirectly. Directly, heatwaves, floods, droughts, windstorms and fires annually affect millions of people and cause billions of dollars of damage. In 2003 in Europe, Canada, and the United States, floods and storms resulted in 101 people dead or missing and caused $9.73 billion in insured damages [Swiss Re 2004]. More than 35,000 excess deaths were attributed to the extended heatwave in Europe the same year [Kostasky 2005]. The health impacts of extreme events in developing countries are substantially larger. There is a growing body of scientific research projecting that the frequency and intensity of extreme weather events will likely increase over the coming decades as a consequence of climate change [Easterling et al. 2000; Meehl and Trebaldi 2004], suggesting that the associated health impacts also could increase.

Indirectly, climate can affect health through alterations in the geographic range and intensity of transmission of vector-, tick-, and rodent-borne diseases and food- and waterborne diseases, as well as through changes in the prevalence of diseases associated with air pollutants and aeroallergens. Climate change could alter or disrupt natural systems, making it possible for diseases to spread or emerge in areas where they had been limited or had not existed, or for diseases to disappear by making areas less hospitable to the vector or the pathogen [NRC 2001]. Climate-induced economic dislocation and environmental decline also can affect population health.

The cause-and-effect chain from climate change to changing patterns of health determinants and outcomes is often complex and includes factors such as wealth, distribution of income, status of the public health infrastructure, provision of medical care, and access to adequate nutrition, safe water, and sanitation [Woodward et al. 1998]. Therefore, the severity of future impacts will be determined by changes in climate as well as by concurrent changes in nonclimatic factors and by the adaptation measures implemented to reduce negative impacts. It is important to note that even if future trends decrease burdens of some climate-sensitive health outcomes, the attributable burden due to climate change could increase.

Figure 1 summarizes the relative direction, magnitude, and certainty of climate change-related health impacts as concluded by the Human Health chapter of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Figure 1: Summary of the Relative Direction, Magnitude, and Certainty of Climate Change-Related Health Impacts



Source: Confalonieri, Menne, et al. IPCC 2007.

Heatwaves, Floods, and Droughts

The impact of an extreme weather event is determined by the physical characteristics of the event, attributes of the location affected, and interactions of these with human actions and social, economic, institutional, and other systems. The health and social burden of extreme weather events can be quite large, causing loss of life and livelihood, infrastructure damage, population displacement, and economic disruption (such as in Honduras and Nicaragua following hurricane Mitch in 1998, and hurricane Katrina). Climate change is projected to increase the intensity and frequency of extreme weather events in many regions [IPCC SPM WGI 2007].

Heatwaves affect human health via heat stress, heatstroke, and death [Kilbourne 1997], as well as exacerbations of underlying conditions that can lead to an increase in all-cause mortality [Kovats and Koppe 2005]. The frequency and intensity of heatwaves [Meehl and Tebaldi 2004] and heat-related deaths are projected to increase with climate change [Keatinge et al. 2002; Dessai 2003; McMichael et al. 2003; Hayhoe et al. 2004]. For example, the annual number of heatwave days, the length of the heatwave season, and heat-related mortality were projected for four cities in California [Hayhoe et al. 2004]. By the 2080s, under two climate scenarios, the number of heatwave days in Los Angeles were projected to increase from 4-fold to 6-8 fold over the 1961-90 baseline. Annual heat-related deaths in Los Angeles were projected to increase from about 165 in the 1990s to 319 to 1,182 under different scenarios. The length of the heatwave season in California was projected to increase from 5-13 weeks. Projections have not considered changes in the frequency or intensity of severe heatwaves, such as occurred in 2003 in

Europe, nor have they estimated impacts in developing countries where increasing temperatures could affect human and agricultural productivity.

The adverse health consequences of flooding and windstorms can be complex and far-reaching [Ahern et al. 2005; Hajat et al. 2003]. Adverse health impacts include the physical health effects experienced during the event or clean-up process, or from effects brought about by damage to infrastructure, including population displacement. The physical effects largely manifest themselves within weeks or months following the event, and can be direct (such as injuries) and indirect (such as water and food shortages and increased rates of vector-borne and other diseases). Extreme weather events are also associated with mental health effects resulting from the experience of the event or from the recovery process. These psychological effects tend to be much longer lasting and can be worse than the direct physical effects [Ahern et al. 2005; Hajat et al. 2003].

The effects of drought on health include malnutrition (protein-energy malnutrition and/or micronutrient deficiencies), infectious diseases, and respiratory diseases [Menne and Bertollini 2000]. In addition, malnutrition increases the risk of dying from an infectious disease. The loss of livelihoods due to drought is a major trigger for population movements, which can cause additional disease burdens.

Parry et al. [2004] projected that the world will have sufficient food to feed everyone up to the end of the 21st century; however, this assumed that people in low-income countries, where climate change impacts are predominantly negative, would have access to food produced in temperate countries.

Attribution of the some portion of the burden of injuries, illnesses, and deaths due to floods, windstorms, and droughts to climate change is complex because of the multiple determinants of disease. Although data are limited, malnutrition associated with drought and flooding may be one of the most important consequences of climate change due to the large number of people that may be affected. For example, one study projected that climate change could increase the percentage of the Malian population at risk of hunger from 34% to 64 - 72% by the 2050s, although this could be reduced by implementation of a range of adaptive strategies [Butt et al. 2005].

Malaria and Other Infectious Diseases

Climate is a primary determinant of whether a particular location has environmental conditions suitable for the transmission of several vector-, rodent-, and tick-borne diseases, including malaria, dengue, cholera, meningitis, Japanese encephalitis, St. Louis encephalitis, West Nile virus, tick-borne encephalitis, Rift Valley Fever, schistosomiasis, and leishmaniasis. A change in temperature may hinder or enhance vector and parasite development and survival, thus lengthening or shortening the season during which vectors and parasites can survive. Small changes in temperature or precipitation may cause previously inhospitable altitudes or ecosystems to become conducive to disease transmission (or cause currently hospitable conditions to become inhospitable).

While climate is an important driver of malaria and other diseases, it is not the only one. The many determinants of infectious diseases often form an interconnected web with feedbacks between transmission dynamics and other factors [Chan et al. 1999]. For example, the socioeconomic and biological drivers of malaria include drug and pesticide resistance, deterioration of health care, deterioration of public health infrastructure (including vector control efforts), demographic change, and changes in land use.

Malaria is a complex disease to model, and current models have not completely parameterized the key factors that influence transmission. Given this limitation, models suggest that, in Africa, climate change may be associated with both expansions and contractions of the geographic area suitable for transmission of stable *Plasmodium falciparum* malaria, with expansion projected to be larger than contraction [Ebi et al. 2005; Tanser et al. 2003; Thomas et al. 2004; van Leishout et al. 2004]. These projections are consistent with experiences with malaria control officers in the field. Some projections suggest that the season of transmission may be extended, which may be as important as geographical expansion.

Several food- and waterborne diseases are climate sensitive, suggesting that climate change could affect their incidence and distribution. For example, studies report an approximately linear association between temperature and salmonellosis, a common form of food-poisoning [e.g. D'Souza et al. 2004; Kovats et al. 2004; Fleury et al. 2006].

Water and foodborne diseases continue to cause significant morbidity in the U.S. Annually, there are approximately 1,330 food-related disease outbreaks [Lynch et al. 2006], 34 outbreaks from recreational water (2004), and 30 outbreaks from drinking water (2004) [Dziuban et al. 2006, Liang et al. 2006]. For outbreaks of foodborne disease with known causes, *Salmonella* accounted for 55% and viruses accounted for 33% [Lynch et al. 2006]. Water- and foodborne disease are highly underreported; using a combination of underreporting estimates, passive and active surveillance data, and hospital discharge data, Mead et al. (1999) estimated that over 210 million cases of gastroenteritis annually in the U.S., including over 900,000 hospitalizations and over 6,000 deaths. Approximately 39 million of the cases can be attributed to a specific pathogen and about 14 million are transmitted by food. The causes differ somewhat from those reported for outbreaks, with the highest frequency of illness caused by viruses (67%; primarily noroviruses), followed by bacteria (30%; primarily *Campylobacter* and *Salmonella*) and parasites (3%; primarily *Giardia* and *Cryptosporidium*). Children ages 1-4 and older adults (>80 years) each make up more than 25% of hospitalizations involving gastroenteritis, but older adults contributed to 85% of the associated deaths [Gangarosa et al. 1992]. Clearly, as the U.S. population ages, the economic and public health burden of diarrheal disease will increase proportionally without appropriate interventions.

Air Pollutants

There is extensive literature documenting the adverse health impacts of exposure to elevated concentrations of air pollution, especially particulates with aerodynamic diameters under 10 and 2.5 μm, ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide, and lead. In 2000, there were 0.8 million deaths from respiratory problems, lung disease, and cancer that were attributed to urban air pollution, with the largest burden in developing countries in the Western Pacific region and South East Asia [WHO 2002]. In addition, there were 1.6 million deaths attributed to indoor air pollution caused by burning biomass fuels.

Air pollution concentrations are the result of interactions among local weather patterns, atmospheric circulation features, wind, topography, human responses to weather changes (i.e. the onset of cold or warm spells may increase heating and cooling needs, and, therefore, an increase in electricity generation), and other factors. Climate change could affect local to regional air quality directly through changes in chemical reaction rates, boundary layer heights that affect vertical mixing of pollutants, and changes in synoptic airflow patterns that govern pollutant transport. Indirect effects could result from increasing or decreasing anthropogenic emissions via changes in human behavior, or from altering the levels of biogenic emissions because of higher temperatures and land cover change. Establishing the scale (local, regional, global) and direction of change (improvements or deterioration) of air quality is challenging [Bernard et al. 2001].

More is known about the potential impact of climate change on ground-level ozone than on other air pollutants. Changes in concentrations of ground-level ozone driven by scenarios of future emissions and /or weather patterns have been projected for Europe and North America [Stevenson et al. 2000; Derwent et al. 2001; Johnson et al. 2001; Taha 2001; Hogrefe et al. 2004]. Future emissions are, of course, uncertain, and depend on assumptions of population growth, economic development, and energy use [Syri et al. 2002; Webster et al. 2002]. Based on projections of county-level pollutant concentrations, summer ozone-related mortality was projected to increase by 4% in the New York area by the 2050s based on climatic changes alone [Knowlton et al. 2004]. Increases in background ozone levels could affect the ability of regions to achieve air quality targets.

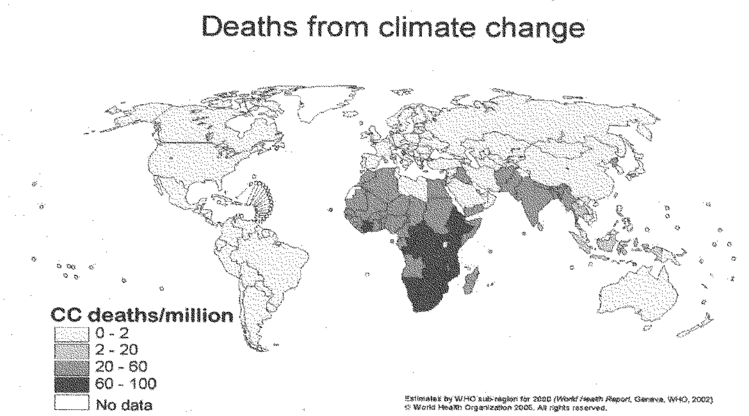
Global Assessments of the Health Impacts of Climate Change

Hitz and Smith [2004] reviewed the literature on the projected health impacts of climate change and concluded that health risks are more likely to increase than decrease with increasing global mean surface temperature, particularly in low latitude countries. In addition to greater vulnerability to climate, these countries have some of the highest populations, tend to be less developed, and generally have poorer public health infrastructure, likely leading to greater damages.

In the most comprehensive evaluation of the burden of disease due to climate change, McMichael et al. [2004] used a comparative risk assessment approach as part of the Global Burden of Disease study to project the total health burden attributed to climate change between 2000 and 2030 and to project how much of this burden could be avoided by stabilizing greenhouse gas emissions. Health outcomes were analyzed by region to better understand where current and projected future disease burdens are highest and to identify the outcomes that contribute to the largest share of the total burden. Limitations of the approach include the limited number of quantitative models that estimate the likely impacts of climate change on health and the limited geographic range of many of the models.

The health outcomes included in the analysis were chosen based on sensitivity to climate variation, predicted future importance, and availability of quantitative global models (or feasibility of constructing them) [McMichael et al., 2004]. Specific health outcomes included were episodes of diarrheal disease, cases of *Plasmodium falciparum* malaria, fatal unintentional injuries in coastal floods and inland floods/landslides, and nonavailability of recommended daily calorie intake (as an indicator for the prevalence of malnutrition). Inclusion of a limited number of health outcomes suggests that the estimated impacts are likely to be an underestimate of the true health impacts. In the year 2000, climate change was estimated to have caused the loss of more than 150,000 lives (0.3% of worldwide deaths) and 5,500,000 Disability Adjusted Life Years (DALYs) (0.4% worldwide), with malnutrition accounting for approximately 50% of these deaths and DALYs [Ezzati et al. 2002; McMichael et al. 2004; Patz et al. 2005]; see Figure 2. These estimates relate to a period when limited climate change had occurred, suggesting that future studies are likely to estimate larger health burdens due to climate change.

Figure 2: Current Health Burden due to Climate Change



The projected relative risks attributable to climate change in 2030 vary by health outcome and region, and are largely negative, with the majority of the projected disease burden due to increases in diarrheal disease and malnutrition, primarily in low-income populations already experiencing a large burden of disease [McMichael et al. 2004]. Absolute disease burdens depend on assumptions of population growth, future baseline disease incidence, and the extent of adaptation.

Particularly Vulnerable Populations

Vulnerability to climate change will vary between and within populations. Vulnerability to the health impacts of climate change depends on the region of interest, the health outcome, and population characteristics, including human, institutional, social, and economic capacity, distribution of income, provision of medical care, and access to adequate nutrition, safe water, and sanitation. In general, the most vulnerable include slum dwellers and homeless people in large urban areas, particularly in low-income countries, those living in water-stressed regions, settlements in coastal and low-lying areas, and populations highly dependent on natural resources. However, as shown during the 2003 heat event in Europe, developed countries may not be prepared to cope with the projected increase in the intensity and frequency of extreme weather events.

Adaptation and Mitigation

Climate change will make more difficult the control of climate-sensitive health determinants and outcomes. Therefore, health policies need to explicitly incorporate climate-related risks in order to maintain current levels of control [Ebi et al. 2006]. In most cases, the primary response will be to enhance current health risk management activities. Nearly all of the health determinants and outcomes that are projected to increase with climate change are problems today. In some cases, programs will need to be implemented in new regions; in others, climate change may reduce current infectious disease burdens. The degree to which programs and measures will need to be augmented to address the additional pressures due to climate change will depend on factors such as the current burden of climate-sensitive diseases, the effectiveness of current interventions, projections of where, when, and how the burden of disease could change with changes in climate and climate variability, the feasibility of implementing additional cost-effective interventions, other stressors that could increase or decrease resilience to impacts, and the social, economic, and political context within which interventions are implemented [Ebi et al. 2006]. Although there are uncertainties about future climate change, failure to invest in adaptation may leave communities and nations poorly prepared and increase the probability of severe adverse consequences [Haines et al. 2006]. Adaptation policies and measures need to consider how to effectively reduce climate-related risks in the context of sustainable development, considering projected demographic, economic, institutional, technologic, and other changes.

Because fossil fuel combustion is a source of urban air pollutants and greenhouse gases, policies to reduce GHG emissions can have health benefits in the near- and long-term. There are potentially synergies in reducing GHG and improving population health via sustainable transport systems that make more use of public transport, walking, and cycling, especially in rapidly developing countries such as China and India [Haines et al. 2006]. For other energy sources, health impact assessments should be conducted to evaluate positive and negative health impacts.

The current burden of climate-sensitive diseases suggests that adaptation and mitigation policies and measures need to be implemented soon to reduce the projected risks due to climate change.

References:

Ahern MJ, Kovats RS, Wilkinson P, Few R, Matthies F. 2005. Global health impacts of floods: epidemiological evidence. Epidemiol Rev 27:36-45.

Bernard SM, Ebi KL. 2001. Comments on the process and product of the Health Impacts Assessment component of the United States National Assessment of the potential consequences of climate variability and change. Environ Health Perspect 109(Suppl 2):177–184.

Butt T, McCarl B, Angerer J, Dyke P, Stuth J. 2005. The economic and flood security implications of climate change in Mali. Climatic Change 68:355-78.

Chan NY, Smith F, Wilson TF, Ebi KL, Smith AE. 1999. An integrated assessment framework for climate change and infectious diseases. Environ Health Perspect 107:329–337.

Confalonieri U, Menne B, Akhtar R, Ebi KL, Hauengue M, Kovats RS, Revich B, Woodward A. 2007. Human Health. Intergovernmental Panel on Climate Change Fourth Assessment Report: Climate Change Impacts, Adaptation, and Vulnerability.

Derwent RG, Collins WJ, Johnson CE, Stevenson DS. 2001. Transient behaviour of tropospheric ozone precursors in a global 3-D CTM and their indirect greenhouse effects. Climatic Change 49:463-487.

Dessai S. 2003. Heat stress and mortality in Lisbon Part II. An assessment of the potential impacts of climate change. Int J Biometeorol 48:37-44.

D'Souza RM, Becker NG, Hall G, Moodie KB. 2004. Does ambient temperature affect foodborne disease? Epidemiology 15:86-92.

Dzuiban EJ, Liang JL, Craun GF, Hill V, Yu PA, Painter J, Moore MR, Calderon RL, Roy SL, Beach MJ. 2006. Surveillance for waterborne disease and outbreaks associated with recreational water – United States, 2003 – 2004. Morbidity and Mortality Weekly Reports 55(SS-12): 1-31.

Easterling DR, Evans JL, Groisman PY, Karl TR, Kunkel KE, Ambenje P. 2000. Observed variability and trends in extreme climate events. Bulletin of the American Meteorological Society:81:417-425.

Ebi KL, Hartman J, McConnell JK, Chan N, Weyant J. 2005. Climate suitability for stable malaria transmission in Zimbabwe under different climate change scenarios. Climatic Change 73.

Ebi KL, Smith J, Burton I, Scheraga J. 2006. Some lessons learned from public health on the process of adaptation. Mitigation and Adaptation Strategies for Global Change 11:601-620.

Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S, Murray CJL, and Comparative Risk Assessment Collaborating Group. 2002. Selected major risk factors and global and regional burden of disease. Lancet 360:1347-1360.

Fleury M, Charron D, Holt J, Allen O, Maarouf A. 2006. A time series analysis of the relationship of ambient temperature and common bacterial enteric infections in to Canadian provinces. Int J Biometeorol 50:385-91.

Food and Agricultural Organisation. 2005. *The state of food insecurity around the world.*

Gangarosa RE, Glass RI, Lew JF, Boring JR. 1992. Hospitalizations involving gastroenteritis in the United States, 1985: The special burden of the disease among the elderly. American Journal of Epidemiology 135(3), 281-290.

Haines A, Kovats RS, Campbell-Lendrum D, Corvalan. 2006. Climate change and human health: impacts, vulnerability, and public health. Lancet 367:1-9.

Hajat S, Ebi K, Kovats S, Menne B, Edwards S, Haines A. 2003. The human health consequences of flooding in Europe and the implications for public health: A review of the evidence. Applied Environmental Science and Public Health 1:13–21.

Hayhoe K, Cayan D, Field CB, Frumhoff PC, Maurer EP, Miller NL, Moser SC, Schneider SH, Nicholas Cahill K, Cleland EE, Dale L, Drapek R, Hanemann RM, Kalkstein LS, Lenihan J, Lunch CK, Neilson RP, Sheridan SC, Verville JH. 2004. Emission pathways, climate change, and impacts on California. PNAS 101:12422-427.

Hitz S, Smith J. 2004. Estimating global impacts from climate change. Global Environmental Change 14:201-218.

Hogrefe C, Biswas J, Lynn B, Civerolo K, Ku JY, Rosenthal J, Rosenzweig C, Goldberg R, Kinney PL. 2004. Simulating regional-scale ozone climatology over the eastern United States: model evaluation results. Atmos Environ 38:2627.

Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report.

Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Summary for Policymakers. Contribution of Working Group II to the Fourth Assessment Report.

Johnson CS, Stevenson DS, Collins W, Derwent R. 2001. Role of climate feedback on methane and ozone studied with a coupled ocean-atmosphere-chemistry model. Geophys Res Lett 28:1723-1726.

Keatinge WR, Donaldson GC, Kovats RS, McMichael A. 2002. Heat and cold related mortality morbidity and climate change. In: Health Effects of Climate Change in the UK. Department of Health, London.

Kilbourne EM. 1997. Heat waves and hot environments. In: Noji EK, editor. *The public health consequences of disasters.* New York, Oxford University Press, p. 245-269

Kosek M, Bern C, Guerrent RL. 2003. The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. Bull World Health Organ 81: 197-204

Kovats RS, Edwards SJ, Hajat S, Armstrong BG, Ebi KL, Menne B. 2004. The effect of temperature on food poisoning: a time-series analysis of salmonellosis in ten European countries. Epidemiol Infect 132, 443-453.

Kovats RS, Koppe C. 2005. Heat waves: past and future impacts. In: Ebi KL, Smith JB, Burton I, eds. *Integration of Public Health with Adaptation to Climate Change: Lessons Learned and New Directions*. London, Taylor & Francis, pp 136-160.

Knowlton K, Rosenthal JE, Hogrefe C, Lynn B, Gaffin S, Goldberg R, Rosenzweig C, Civerolo K, Ku JY, Kinney PL. 2004. Assessing ozone-related health impacts under a changing climate. Environ Health Perspect 112, 1557-1563.

Kosatsky T. 2005. The 2003 European heat waves. Euro Surveill 10:148-9.

Liang JI, Dziuban EJ, Craun CF, Hill V, Moore MR, Gelting RJ, Calderon RL, Beach MJ, Roy SL. 2006. Surveillance for waterborne disease and outbreaks associated with drinking water and water not intended for drinking – United States, 2003 – 2004. Morbidity and Mortality Weekly Report 55(SS-12), 32-65.

Lynch M, Painter J, Woodruff R, Braden C. 2006: Surveillance for foodborne-disease outbreaks – United States, 1998-2002. Morbidity and Mortality Weekly Reports 55(SS-10), 1-42.

Mead PS, Slutsker L, Dietz V, McCaig LF, Bresee JS, Shapiro C, Griffin PM, Tauxe RV. 1999. Food-related illness and death in the United States. Emerging Infectious Diseases 5(5), 607-625.

McMichael AJ, Campbell-Lendrum D, Kovats S, Edwards S, Wilkinson P, Wilson T, Nicholls R, Hales S, Tanser F, LeSueur D, Schlesinger M, Andronova N. 2004. Global Climate Change. In: *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors*. Eds. Ezzati M, Lopez A, Rodgers A, Murray C. World Health Organization, Geneva, pp 1543-1649.

McMichael AJ, Woodruff RE, Hales S. 2006. Climate change and human health: present and future risks. Lancet 367:859-69.

McMichael A, Woodruff R, Whetton P, Hennessy K, Nicholls N, Hales S, Woodward A, Kjellstrom T. 2003. Human Health and Climate Change in Oceania: Risk Assessment 2002. Canberra, Commonwealth of Australia.

Meehl G, Tebaldi C. 2004. More intense, more frequent and longer lasting heat waves in the 21st century. Nature 305:994-997.

Menne B, Bertollini R. 2000. The health impacts of desertification and drought. Down to Earth 14: 4-6.

National Research Council. 2001. *Under the Weather: Climate, Ecosystems, and Infectious Disease.* National Academy of Sciences, Division on Earth and Life

Sciences Studies Board on Atmospheric Sciences and Climate Committee on Climate, Ecosystems, Infectious Disease, and Human Health. National Academy Press, Washington, DC.

Parry ML, Rosenzweig C, Iglesias A, Livermore M, Fischer G. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environmental Change 14:53-67.

Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. 2005. Impact of regional climate change on human health. Nature 438:310-317.

Stevenson DS, Johnson CE, Collins WJ, Derwent RG, Edwards JM. 2000. Future estimates of tropospheric ozone radiative forcing and methane turnover - the impact of climate change. Geophys Res Lett 27:2073-2076.

Swiss Re. 2004. Natural catastrophes and man-made disasters in 2003. Sigma 1/2004.

Syri S, Karvosenoja N, Lehtila A, Laurila T, Lindfors V, Tuovinen JP. 2002: Modeling the impacts of the Finnish Climate Strategy on air pollution. Atmos Environ 36: 3059-3069.

Taha H. 2001. Potential impacts of climate change on tropospherеic ozone in California: a preliminary episodic modeling assessment of the Los Angeles Basin and the Sacramento Valley. Lawrence Berkeley National Laboratories, Berkeley, California.

Tanser FC, Sharp B, le Sueur D. 2003. Potential effect of climate change on malaria transmission in Africa. Lancet 362:1792-1798.

Thomas CJ, Davies G, Dunn CE. 2004. Mixed picture for changes in stable malaria distribution with future climate in Africa. Trends in Parasitology 20:216-220.

Van Lieshout M, Kovats RS, Livermore MTJ, Martens P. 2004. Climate change and malaria: analysis of the SRES climate and socio-economic scenarios. Global Environmental Change 14:87-99.

Webster M, Babiker M, Mayer M, Reilly J, Harnisch J, Hyman R, Sarofim M, Wang C. 2002. Uncertainty in emissions projections for climate models. Atmos Environ 36:3659-3670.

WHO. 2002. *World Health Report 2002: reducing risks, promoting healthy life*. World Health Organization, Geneva.

WHO. 2004. *World Health Report 2004 – changing history*. World Health Organization, Geneva.

Woodward A, Hales S, Weinstein, P. 1998. Climate change and human health in the Asia Pacific region: who will be the most vulnerable? Climate Research 11:31-7.

Dr. Kristie L. Ebi is an epidemiologist and small business owner based in Alexandria, VA, who has been working on global climate change issues for more than 10 years. Her research focuses on the potential impacts of climate variability and change, including the impacts associated with extreme events, thermal stress, foodborne diseases, and vectorborne diseases. She is working with WHO, UNDP, USAID, and others on designing adaptation measures to reduce current and projected impacts in health and other sectors. She is a Lead Author for the Human Health chapter of the Intergovernmental Panel on Climate Change Fourth Assessment Report, and for the U.S. Climate Change Science Program Synthesis and Assessment Product 4.6 (Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems). She was a Convening Lead Author on the WHO publication: Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change, and was a Lead Author in the Millennium Ecosystem Assessment and the U.S. National Assessment of the Potential Consequences of Climate Variability and Change. Dr. Ebi has more than 25 years of multidisciplinary experience in environmental issues. She has edited three books on climate change and health, and has more than 75 publications. Dr. Ebi's scientific training includes a M.S. in toxicology and a Ph.D. and MPH in epidemiology, and two years of postgraduate research in epidemiology at the London School of Hygiene and Tropical Medicine.

The CHAIRMAN. Our next witness is Dr. John Helms, who is a Professor Emeritus at the University of California, Berkeley; and he is an expert in forestry and resource management. He has published numerous technical papers; and, in addition to the United States, he has worked on forestry issues in Sweden, Germany, Switzerland, Australia, Siberia and China. In 2005, he served as President of the Society of the American Foresters and is currently a member of the Board of Directors of the California Forest Products Commission.

We welcome you, Doctor, whenever you feel comfortable, please begin.

STATEMENT OF JOHN A. HELMS, PROFESSOR EMERITUS OF FORESTRY, UNIVERSITY OF CALIFORNIA, BERKELEY, AND 2005 PRESIDENT OF THE SOCIETY OF AMERICAN FORESTERS

Mr. HELMS. Thank you, Chairman Markey; and I thank Ranking Member Sensenbrenner and members of the subcommittee for this opportunity.

I would like to summarize my comments in five areas.

The first one deals with are forests important in this issue. I would like to comment that forests store about 50 percent more carbon than is in the atmosphere; and, secondly, U.S. forests sequester about 10 to 20 percent of the total U.S. greenhouse gas emissions. So it is important that we have policies to stabilize and preferably increase the amount of forest land base.

Secondly, what is the impact of climate change on forests? Well, obviously, forests have evolved over the past 30 or 40 million years and have adapted to change. Relative to the human life span, however, it seems that the forests are static, but, actually, their distributions are quite transitory. But the forests will tend to move up in elevation. They will tend to move northward in latitude.

And there are three issues here that I would like to emphasize. One is water. What is the impact of global climate on the water that is needed by populations and agriculture when most of the precipitation comes on forest watershed in the form of smur? Secondly, what is the impact on insects and diseases which will lead to mortality in the forests? And then, thirdly, the probability that there will be increased wildfire.

As you know, in 2006, we burned about 10 million acres of forest. The suppression costs were at $1.9 billion. And so the likelihood is that this situation is going to be increased.

The amount of carbon or greenhouse gasses that come from wildfires is difficult to estimate, perhaps a hundred tons per acre. And so it is a significant issue.

Now what is the role of forests in stabilizing greenhouse gasses? Why do we want to spend time on elaborating on sequestration and storage? But I would like to comment on the importance of recognizing wood as a renewable natural resource and to emphasize the importance of getting involved in life-cycle analysis to look at what is the fate of carbon in wood products and as they are recycled and to recognize that not only is wood preferable to using alternative materials, such as steel and aluminum, in terms of the carbon footprint, but it is important to look at wood from the standpoint of bio-fuels, wood pellets and with cellulosic ethanol.

The fourth point I would like to comment on is the question is often asked why should we manage forests rather than just leaving them to sequester carbon in a natural condition?

Well, there are two issues here: one, that if you look at current modeling, it shows you that a sequence of harvests is preferable and will store more carbon for two reasons. One is that young forests have a far higher efficiency and rate of net CO drop rates than older forests, and the second issue is you must take into account what happens to the carbon that is in the harvests which goes into products which are fundamentally important to the standard of living of the country.

So if you include the carbon stored in products, plus the carbon that—or the energy offsets that would have to be accounted for in the use of alternative products, it becomes clear that, in the long run, it is better to manage these forests.

In considering the role of forests, what should be the efforts that we should be considering?

First, we enhance the observation and monitoring, developing incentives for landowners to sequester carbon, and to get knowledge on what is the impact of emphasizing carbon on forests relative to the outputs of other products such as wood and water wildlife diversity. My expectation is that if you try and rise the output of any one thing like carbon, it will probably be at the expense of some of these important goods and services.

So, in conclusion, I would like to comment that history tells us that the health and welfare of nations is very closely associated with the health and welfare of its forests; and, therefore, it is important that we develop sound, prudent policies regarding how our forests are maintained in a healthy, sustainable condition. And I would trust that this issue would be so over-arching that it would bring together society, industry and conservation groups in order to move ahead on this issue.

Thank you very much.

The CHAIRMAN. Thank you, Dr. Helms, very much.

[The statement of Mr. Helms follows:]

Testimony of
Dr. John A. Helms
Professor Emeritus of Forestry
University of California, Berkeley,
And 2005 President of the Society of American Foresters
Before the House of Representatives Select Committee on
Energy Independence and Global Warming
April 26, 2007

Chairman Markey, Ranking Member Sensenbrenner and members of the Select Committee, thank you for the opportunity to give testimony on this important topic covering forests and climate change. My name is John A. Helms, Professor Emeritus of Forestry at the University of California Berkeley where I served as Head of the Department of Forestry and Resource Management. I am here today representing the Society of American Foresters for which I served as President in 2005. The Society has 15,000 members who are forest managers, consultants, academics, and researchers and promotes sustainable forest management for balanced and diverse values.

Importance of Forests in Sequestering Carbon

The role of the world's forests is critical when considering ways to address the rise in atmospheric carbon dioxide levels and potential climate change. Globally forests, both above ground and in the soil, store fifty percent more carbon than is in the atmosphere. Forests are better at storing carbon than any other land cover. US forests sequester about 200-280 million tons of carbon per year, which offsets about 12-20% of US greenhouse gas emissions and is equivalent to the amount of greenhouse gases emitted by about 235 million cars annually. It is therefore critically important to stabilize, or preferably increase, the world's forestland base. However, to the contrary, the world has a net loss of about 45 million acres of forest per year. Even in the US we lose about 1 million acres per year to development, although some of this loss is offset by reforestation.

In particular, deforestation, especially in the tropics, is a primary source of carbon emissions – second only to emissions from burning fossil fuels – which is why deforestation is such a central issue.

Forests won't solve the greenhouse gas problem, but should play an essential role in any strategy or policy and provide time to allow for other mechanisms to be developed such as alternative energy sources.

Impact of Global Warming on Forests

Forests have evolved over millions of years in association with many past changes in climate. Though forest makeup and distribution seem static relative to human life spans, their natural ranges are transient and temporary in geological time. Of particular concern is that ice core evidence suggests that past climate changes have often been remarkably quick – in some cases in the order of a couple of decades. Consequently there is some immediacy in considering the need to take action regarding increasing carbon dioxide levels. However, effects of climate change can be both beneficial and detrimental depending on the particular species and time frame being considered. Warmer temperatures will cause range of species to move up in elevation and northward in latitude, thus the US may lose forests in southern latitudes. Ecosystems in cooler and alpine areas are probably the most threatened. Details of the effects of potential climate change on species mix and timing of growing season are currently quite unpredictable. But broadly speaking the distribution of forests, shrubs, and grasslands will change as they have in the past. The effects will be most pronounced in areas of little topographic diversity. In particular, increased soil temperature will likely release a proportion of the large amounts of carbon stored below ground.

The likely effects of climate change on forest insect and disease populations is largely unknown, however it is believed that many of these populations are held in check by cold winters. To the extent that climate change causes a hotter drier climate it will likely stress forests, making them more vulnerable to insect and disease outbreaks. Similarly, warming trends are likely to adversely affect freshwater fish, especially salmon, that require cool streams.

Of critical concern is the effect of warming conditions on the nation's water supplies, a large proportion of which comes from forested watersheds. Precipitation in the form of rain will increase and snowpacks will decrease and it is not clear how this will affect supplies of water to population centers and agriculture areas.

Another major issue is wildfire. Although already at catastrophic levels, if the climate becomes warmer wildfires will become more frequent and intense. In 2006 wildfires in the US burned nearly 10 million acres, cost $1.9 billion to suppress, and were 166% greater in extent than the previous 10-yr average. It is estimated that, depending on forest type and intensity, and in addition to destroying a priceless natural resource, a wildfire emits up to about 100 tons of greenhouse gases, aerosols, and particulates per acre. Future fires are likely to be more severe, cost more to suppress, and have greater impacts on air and water quality, wildlife habitat and infrastructure. Current estimates show that 180 million acres of federal land in the US are at an unnaturally high risk of catastrophic wildfire. At present, harvest levels on national forests are about one-eighth of the growth resulting in forests that are overly dense and fire prone. In Oregon, tree mortality on federal lands from insects, disease, and fire is reported to be six times the level of harvest. Though there is some debate, it is generally agreed that continuation of this situation will not lead to healthy, sustainable forests that store carbon and serve the national interests.

Role of Forests in Stabilizing Green House Gases

The highest priority national issues are to reduce wildfire, stabilize forestland base, and limit forest conversion, development, and parcelization. The current divestment of huge areas of industrial forestlands to investment and real estate firms introduces considerable uncertainty regarding the long-term stability of the forestland base. Any forest carbon strategy must seek to maintain forest ecosystems with a balance of age classes at the landscape level from regeneration to old growth. Emphasis must be placed on maintaining forest health using thinning to avoid overstocking that increases mortality from drought, insects, disease, and wildfire. When catastrophes occur, these areas, unless in parks or reserves, should be promptly regenerated to ensure rapid restoration of forest cover.

Forests have added value in providing a renewable source of wood products upon which our standard of living depends. Use of wood should be enhanced because life cycle assessments show that using wood for construction and housing uses far less energy and has a much lower "carbon footprint" than structures built with steel, plastic, or aluminum. These alternatives require as much as 250 percent more energy to produce than an equivalent amount of wood product, and they are not renewable.

In addition, there are new opportunities to use sustainably produced woody biomass for power generation and biofuels. It is also evident that woody biomass obtained by reducing wildfire hazards, through thinnings, could be used to produce cellulosic ethanol which is preferable to growing corn that requires considerably greater energy inputs and land area. Developing woody biomass to its potential will require establishing an even playing field with other renewables such as wind and geothermal, both of which receive twice the Section 45 Production Tax Credit than does biomass. Providing tax parity for biomass will greatly help to increase investment in renewable energy while providing new revenues for treating hazardous fuels and reducing the fire hazard on our forests.

Much of the nation's forestlands are already managed sustainably by a diverse mix of owners that include state, industrial, non-industrial family, and Tribes as indicated by their meeting certification standards or state forest practice regulations. Thus forest management is already contributing significantly to sustainable carbon sequestration.

However, to stimulate the sequestering of carbon into forest management scenarios there needs to be stable, market-based mechanisms and incentives. Nation-wide cap-and-trade or carbon tax programs are being debated and considered and would likely influence the role of forests in carbon markets. In the absence of federal programs, several states and regions such as the 10-state Regional Greenhouse Gas Initiative and the California Climate Action Registry have instituted voluntary regional programs. In addition, programs have been developed both in the US and in other countries that use forests to sequester and store carbon to offset losses to development.

As these programs develop there is need to provide technical assistance and incentives for landowners to incorporate carbon-sequestration and storage in their management strategies. On national forest lands there is an urgent need to overcome the so-called federal "analysis paralysis" where land management decisions are made by litigation and layers of regulation rather than through decisions by resource professionals in a timely manner with public input.

Importance of Forest Management Rather than Leaving Forests to Nature

Currently the US imports thirty six percent of its wood consumption from other countries, some of which have far lower environmental standards and often may incorporate illegal logging. At issue is whether excessive restriction of harvesting on national forests is promoting excessive harvesting elsewhere. The basic need is to enhance forest health, which can be done by prudent thinnings that remove hazardous fuels while both effectively storing carbon and providing wood products that the nation needs.

Although there is debate on this issue, it seems clear from modeling studies that, in the long run, managed forests that incorporate a sequence of harvests result in more carbon sequestered than a forest left unmanaged. This is because young forests are more efficient in carbon sequestration. Old forests store more carbon, but as they age the net uptake of carbon dioxide can diminish to zero as carbon lost in respiration and decomposition becomes similar to the rates of carbon uptake. Harvesting, of course, results in an immediate decline in carbon storage, but the significance of this depends on considering spatial and temporal scales, the fate of carbon in the various harvested products, and the environmental and carbon costs of using alternative products, as noted above, that require far higher amounts of energy for manufacture.

There is no "best" approach to managing forests for carbon sequestration as the type of management used depends on ownership objectives, tree species, and site productivity. But over-arching principles include maintaining canopy cover, prompt regeneration, thinning, and longer time between harvests. It should be remembered, however, that managing to promote carbon storage in forests is likely to be associated with lower outputs of some other desired values such as wood, water, wildlife diversity, and other ecosystem services. Decisions on mix of outputs and values from forests will depend largely on economic values and incentives.

What's Needed

In considering the relation of forests to possible warming trends and to promote the use of forests for carbon sequestration, storage, carbon offsets, and mitigation banking, there is need for revised thinking on the development of public policies that encourage these new activities.

First, we need to enhance observation and monitoring of changes in ecosystem dynamics in relation to potential climate change. We need improved models that can test the likely effects of management for carbon sequestration on other forest values and uses needed by society.

We need to provide incentives to landowners who already manage forests sustainably to add carbon sequestration as a management goal. We need uniform and equitable forest policies and protocols that provide the means of determining additionality, inventory, permanence, verification, leakage, and adequately account for the role of forest products in meeting societal needs from paper to long-term structures and recycling.

Conclusion

Forests are unique in that no other means of sequestering or offsetting carbon has the added benefits of providing clean water, biodiversity, clean air, wildlife habitat, aesthetics, and needed products. Thus it is essential to include forests in any strategy to combat global climate change.

Prime focus must be placed on developing balanced and sound national land use policies and market incentives that enhance forest management and conservation and adequately address both domestic and global issues.

Sequestering carbon and sustaining healthy forests capable of adapting to possible climate change should be common cause of society, forest industry, and conservation groups.

The CHAIRMAN. Our final witness is Dr. James Hansen, who is the Director of NASA's Goddard Institute for Space Studies. He has been conducting groundbreaking climate research for over two decades. He has published numerous peer-reviewed publications. He is a Fellow of the American Geophysical Society and was named one of the 100 Most Influential People by Time Magazine in 2006. He is appearing today in his personal capacity and not as a NASA official.

Dr. Hansen, welcome. Whenever you feel comfortable, please begin.

STATEMENT OF JAMES E. HANSEN

Mr. HANSEN. Thank you, Chairman Markey, for inviting me to discuss dangerous human-made climate change.

In just the past year or two, scientific information has crystallized showing that we are closer to dangerous climate change than has been realized. The basis for my conclusions is provided primarily by four scientific papers listed in my written testimony as publications A, B, C, and D. These are peer-reviewed papers in the press in leading scientific journals.

Mr. Chairman, greenhouse gasses humans have added to the atmosphere have brought the climate close to critical tipping points with the potential for irreversible deleterious effects. This conclusion is revealed by improving data on how the earth would have responded to changes of atmospheric composition during its long history and by changes in the climate system we see in satellite and field observations.

There is new information about positive feedbacks which amplify climate change. Forest cover is expanding poleward as climate warms. Forests are dark and increase absorption of sunlight. Summer melt on ice sheets is starting earlier, lasting longer and moving higher up the ice sheets, making the ice sheets darker, absorbing more sunlight and melting more ice. Methane, a strong greenhouse gas, is beginning to bubble from melting tundra. The upshot is that very little additional forcing is needed to cause dangerous effects.

You asked me for advice on metrics, what constitutes dangerous. I suggest criteria based on critical tipping points that we must avoid.

Specifically, number one, the stability of the west Antarctic ice sheet, which is being attacked from below by a warming ocean and from above by summer surface melt. If it disintegrates, west Antarctic air can raise sea levels several meters, causing a world-wide retreat of shorelines and affecting hundreds of millions of people.

Number two is extermination of animal and plant species. Because, as with ice sheet disintegration, extinction is irreversible. Large climate change, because of species interdependencies, can cause the extinction of a large fraction of animal and plant species.

And, number three, regional climate change. If we stay on business as usual, we will cause intensification of subtropical conditions, exacerbating water shortages in the American West and other parts of the world and rendering the semi-arid States from west and central Texas through Oklahoma, Kansas, Nebraska, and the Dakotas increasingly drought prone and unsuitable for agriculture.

These criteria and the earth's history imply a limit on additional global warming of no more than 1 degree Celsius at most. The sharpest limitation comes from west Antarctica and sea level. The staggering conclusion is that the dangerous level of atmospheric CO_2 is no more than about 450 parts per million, and it probably is less. Humans have already caused CO_2 to increase from the preindustrial 280 parts per million to 383. It is continuing to increase by two PPM per year. If we continue business as usual for even another decade without taking decisive steps to move on to a different path, it will be impractical to avoid disastrous climate effects.

However, there is a bright side to the difficult imperative that we must stabilize atmospheric CO_2 at 450 PPM or less. It means that we must move on to the next phase of the industrial revolution, and the steps that I will outline serve not only to help stabilize global shorelines but also avoid problems that many people were beginning to consider inevitable.

We can still avoid loss of all Arctic ice. We can prevent the West from becoming intolerably hot and dry, and we can prevent acidification of the ocean. We can avoid exterminating the plants and animals of the world.

Science provides a clear outline for what must be done. A four point strategy: First, we must phase out use of coal except where the CO_2 is captured and sequestered. The reason is simple. We cannot prevent use of readily available oil in mobile sources where the CO_2 cannot be captured. That oil will take us close to the dangerous level. A substantial fraction of the CO_2 from old-technology coal-fired power plants will remain in the air for an eternity, for more than 500 years. If we do not capture and sequester it, we will guarantee creation of a different planet.

Second, there must be a rising price on carbon emissions, as well as effective energy efficiency standards and removal of barriers to efficiency. These actions are needed to spur innovation in energy efficiency and renewable energies and thus to stretch oil and gas supplies to cover the need for mobile fluid fuels, during the transition to the next phase of the industrial revolution beyond the petroleum, thus avoiding use of the hulking unconventional fossil fuels such as tar shield, which could destroy the planet.

Third, there should be focused efforts to reduce the non-CO_2 human-made climate force change, especially methane, ozone and black carbon.

Fourth, steps probably will be needed to be taken to draw down atmospheric CO_2 via improved farming and forestry practices. We also should consider burning biofuels in power plants with CO_2 sequestration, thus drawing down atmospheric CO_2. And as a native Iowan, I like the idea of the Midwest coming to the rescue of our coastal States.

By means of these steps, we not only avoid the climate tipping points, we will also have a cleaner, healthier atmosphere.

The actions serve our interest in many ways. They contribute to our energy independence and national security. We will benefit economically from extensive technology development with many good high-tech, high-paid jobs.

Of course, moving to the next phase of the industrial revolution surely will require changes, sacrifices and hard work, but these provide no basis for inaction.

Thank you.

The CHAIRMAN. Thank you, Dr. Hansen.

[The statement of Dr. Hansen follows:]

Dangerous Human-Made Interference with Climate

Testimony of

James E. Hansen
4273 Durham Road, Kintnersville, PA

to

Select Committee on Energy Independence and Global Warming
United States House of Representatives

26 April 2007

Dangerous Human-Made Interference with Climate

Contents

1. Summary

Crystallizing scientific data and analysis reveal that the Earth is close to dangerous climate change, to tipping points of the system with the potential for irreversible deleterious effects. The information derives in part from paleoclimate data, the record of how climate changed in the past, as well as from measurements being made now by satellites and in the field.

The Earth's history shows that climate is remarkably sensitive to global forcings. Positive feedbacks predominate. This has allowed the entire planet to be whipsawed between climate states. Huge natural climate changes, from glacial to interglacial states, have been driven by very weak, very slow forcings, and positive feedbacks.

Now humans are applying a much stronger, much faster forcing as we put back into the atmosphere, in a geologic heartbeat, fossil fuels that accumulated over millions of years. Positive feedbacks are beginning to occur, on a range of time scales.

The climate system has inertia. Nearly full response to a climate forcing requires decades to centuries. But that inertia is not our friend. It means that there is additional climate change in the pipeline that will occur in coming decades even without additional greenhouse gases.

The upshot is that very little additional forcing is needed to cause dramatic effects. To cause the loss of all summer Arctic ice with devastating effects on wildlife and indigenous people. To cause an intensification of subtropical conditions that would greatly exacerbate water shortages in the American West and many other parts of the world, and likely render the semi-arid states from west and central Texas through Oklahoma, Kansas, Nebraska and the Dakotas increasingly drought prone and unsuitable for agriculture. To cause the extermination of a large fraction of plant and animal species, an indictment of humanity's failure to preserve creation.

For humanity itself, the greatest threat is the likely demise of the West Antarctic ice sheet as it is attacked from below by a warming ocean and above by increased surface melt. There is increasing realization that sea level rise this century may be measured in meters if we follow business-as-usual fossil fuel emissions.

There is a bright side to this planetary emergency. We can successfully address the emergency only by stabilizing climate close to its present state; there is no viable option. Adaptation to a continually rising sea level is not possible. Therefore, if we address the problem, there will be no need to adapt to the highly deleterious regional climate changes mentioned above. In the process we can preserve creation and restore a cleaner, healthier atmosphere.

The dangerous level of CO_2 is at most 450 ppm, and it is probably less. The low limit on CO_2 forces us to move promptly to the next phase of the industrial revolution. Changing light bulbs and making ethanol from corn will not solve the problem, although the former act is useful. Science provides a clear outline for what must be done, a four point strategy:

First, we must phase out the use of coal and unconventional fossil fuels except where the CO_2 is captured and sequestered. There should be a moratorium on construction of old-technology coal-fired power plants.

Second, there must be a rising price (tax) on carbon emissions, as well as effective energy efficiency standards, and removal of barriers to efficiency. These actions are needed to spur innovation in energy efficiency and renewable energies, and thus to stretch oil and gas supplies to cover the need for mobile fuels during the transition to the next phase of the industrial revolution 'beyond petroleum'.

Third, there should be focused efforts to reduce non-CO_2 human-made climate forcings, especially methane, ozone and black carbon.

Fourth, steps must be taken to 'draw down' atmospheric CO_2 via improved farming and forestry practices, including burning of biofuels in power plants with CO_2 sequestration.

Note that I do not specify an exact fraction by which CO_2 emissions must be reduced by 2050 or any other date. Indeed, science is not able to specify an exact requirement now, but we can say that emissions must be reduced to a fraction of their current values. Given the fact that readily available oil will surely be employed for mobile sources, and given the magnitudes of the different fossil fuel reservoirs, it seems best to frame the problem as I have in this four-point strategy, and adjust specific targets and policies as knowledge improves.

Responsibility of the United States for global climate change exceeds that of any other nation by more than a factor of three, even though China is passing the United States in current emissions. The United States will continue to be primarily responsible for climate change for decades to come.

The above conclusions follow from the science. In part because of resistance that the scientific conclusions have met among special interests, and because of misinformation about the science that has been spread, I believe that it is not inappropriate for me to discuss my opinions about implications of this research for citizens in our democratic system. My opinions carry no more weight than those of any other citizen, but conceivably my experience in presenting this research in different circles allows some insight. In any case, I have as much right to express my opinion as do the special interests.

In my opinion, the United States should recognize openly its leading role in causing human-made climate change and promptly take a leadership role in addressing the matter. We have a moral responsibility to do so.

Moreover, it is in our interest to take actions now. We can benefit economically from extensive technology development, with many good high-tech high-pay jobs. Of course, moving to the next phase of the industrial revolution will require changes, dislocations, sacrifices and hard work. But these provide no reason for inaction.

We cannot let the pleadings and misinformation of special interests determine our actions, special interests driven by motives of short-term profit. And we cannot shrink from our personal responsibilities. We are now, through our government, standing alongside the polluters, officially as a hulking 'friend of the court', arguing against limitations on emissions.

Is this the picture of our generation we will leave for our children, a picture of ignorance and greed? We live in a democracy. Policies represent our collective will. We cannot blame others. If we allow the planet to pass tipping points, to set in motion irreversible changes to the detriment of nature and humanity, it will be hard to explain our role to our children and grandchildren.

We cannot claim, with legitimacy, that 'we did not know'. In my opinion, it is time for the public to demand, from government and industry, priority for actions needed to preserve the planet for future generations.

2. Basis for Testimony

My testimony is derived primarily from the six publications listed below. It is based on a much broader body of knowledge of the scientific community, which is not practical to document in the brief hours available to prepare this testimony.

The first three publications below are now 'in press' and will appear in coming weeks. These three papers are in regular peer-reviewed scientific journals, each having been reviewed by either two or three scientific peers. The fourth publication also has been reviewed and recommended for publication by both anonymous referees; I will make some slight edits to that paper before returning it to the journal within the next few weeks. The fifth article is my attempt to describe conclusions from this research in a language intended for a broader audience. The sixth article is the draft of an article, available as a referenceable preprint in the physics electronic ***ArXiv***, which we will soon be submitting to a regular print journal.

A. Dangerous human-made interference with climate: a GISS modelE study
(Hansen, J. and 46 co-authors, *Atomos. Chem. Phys.*, in press, 2007, available at
http://pubs.giss.nasa.gov/abstracts/inpress/Hansen_etal_3.html

B. Climate change and trace gases
(in press: Phil. Trans. Royal Soc.)
http://pubs.giss.nasa.gov/abstracts/inpress/Hansen_etal_2.html

C. Climate simulations for 1880-2003 with GISS modelE
(in press: Climate Dynamics) http://arxiv.org/abs/physics/0610115

D. Scientific reticence and sea level rise
(accepted for publication: Environ. Res. Lett.) http://arxiv.org/abs/physics/0703220

E. State of the Wild: Perspective of a Climatologist
(accepted, to be edited) http://www.giss.nasa.gov/~jhansen/preprints/Wild.070410.pdf

F. Implications of "peak oil" for atmospheric CO_2 and climate
(first draft available in ArXiv) http://arxiv.org/abs/0704.2782

3. Crystallizing Science

In the past few years it has become clear that the Earth is close to dangerous climate change, to tipping points of the system with the potential for irreversible deleterious effects. Paleoclimate data show that climate is remarkably sensitive to global forcings. Positive feedbacks have caused the entire planet to be whipsawed between climate states, driven by very weak climate forcings.

The time scale for full glacial-to-interglacial climate changes is millennia. However, this millennial time scale reflects the time scale of the slow weak climate forcing due to Earth orbital changes, not an inherent climate response time. Indeed, the response time of the climate system to rapid forcings, such as human-made greenhouse gases, will be decades to centuries, a function of ocean mixing time and climate feedbacks.

This decade-century climate response time is unfortunate for humanity. It is long enough to prevent people from seeing immediate consequences of human-made climate forcings, as much of the climate change is still 'in the pipeline'. Yet it is short enough for large climate impacts to occur this century.

The concept of additional global warming 'in the pipeline' is not new, but it has become more ominous through the realization that several nominally 'slow' climate feedbacks are likely to have significant effect on decadal time scales. These include poleward movement of vegetation, darkening and disintegration of ice sheets, and greenhouse gas feedbacks. These 'slow' feedbacks, which are not included in their entirety in standard IPCC simulations, are positive and thus they amplify expected anthropogenic climate change.

The implication of the crystallizing scientific understanding is that the planet is on the verge of dramatic climate change. It is still possible to avoid the most deleterious effects, but only if prompt actions are taken to stabilize global temperature close to its present value. Because of the profound implications, it is appropriate to clarify the basis of these conclusions.

We first discuss fundamental aspects of the climate system: climate forcings, feedbacks and response times. We then make note of how the Earth's climate responded to forcings in the past few million years. Finally, we summarize the basis for the conclusion that present climate is on the verge of critical tipping points.

A. Climate System

Climate is an average of weather over some period, including the variability and extremes within that period. Because day-to-day weather fluctuations are so large, it is not easy to notice small changes of the average weather or climate. However, moderate changes of climate can have significant effects, for example, on the ability of plants and animals to survive in a given region and on the stability of large ice masses and thus sea level.

Climate varies a lot without any help from humans. In part the variations are simply chaotic fluctuations of a complex dynamical system, as the atmosphere and ocean are always sloshing about. The climate also responds to natural forcings, such as changes of the brightness of the sun or eruptions of large volcanoes, which discharge small particles into the upper atmosphere where they reflect sunlight and cool the Earth.

Climate forcing. A climate forcing is a perturbation of the Earth's energy balance that tends to alter the Earth's temperature. For example, if the brightness of the sun increases 2% that is a positive forcing of about 4.5 W/m^2 (watts per square meter), because it results in an increase of that amount in the energy absorbed by the Earth. Such a forcing would upset the normal balance that exists between the amount of solar energy absorbed by the Earth and the amount of heat radiation emitted to space by the Earth. So the Earth responds to this forcing by warming up until its thermal radiation to space equals the energy absorbed from the sun.

Doubling the amount of carbon dioxide (CO_2) in the atmosphere causes a global climate forcing similar in magnitude to that for a 2% increase of solar irradiance. The CO_2 forcing works by making the atmosphere more opaque to infrared radiation, the wavelengths of the Earth's heat radiation. As a result of this increased opacity the heat radiation to space arises from greater heights in the atmosphere. Because the temperature falls off with height in the lower atmosphere, energy radiated to space with doubled CO_2 is reduced by an amount that is readily calculated from radiation physics to be approximately 4 W/m^2. So the planet's energy imbalance is about the same as for a 2% increase of solar irradiance. In either case, the Earth responds by warming up enough to restore energy balance.

Climate models show that, as might be expected, two forcings of similar magnitude yield similar global temperature change, although variations in the "efficacy" of specific forcings of the order of 20% are not uncommon, and a few more extreme cases have been found. Variations in efficacy are primarily a result of the differences in the physical locations (latitude or altitude) of the forcings, which affects the degree to which the forcings can bring climate feedbacks into play, as discussed below.

Climate sensitivity and climate feedbacks. Global climate sensitivity is usually defined as the global temperature change that occurs at 'equilibrium', i.e., after the climate system has had a long time to adjust, in response to a specified forcing. The specified forcing is commonly taken to be doubled CO_2, thus a forcing of about 4 W/m^2.

Climate sensitivity can be evaluated either theoretically, with the help of climate models, or empirically, from the Earth's climate history. In either case, it must be recognized that the climate sensitivity so inferred depends upon what climate variables are fixed as opposed to being allowed to change in response to the climate forcing.

The now famous 1979 National Academy of Sciences study of climate sensitivity chaired by Jules Charney focused on a case in which atmospheric water vapor, clouds and sea ice are allowed to vary with the climate, but other factors such as ice sheets and the global distribution of vegetation are kept fixed as unchanging boundary conditions. Also long-lived greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are taken as specified boundary conditions or forcings.

In reality all of these boundary conditions can change in response to climate change, in which case they become climate feedbacks that can be either positive feedbacks (magnifying the climate change) or negative feedbacks (diminishing the climate change). The choice of feedbacks that were allowed to operate in the Charney study (water vapor, clouds, sea ice) was in part based on realization that these variables change rapidly, i.e., they are 'fast feedbacks'. Thus if one is interested in climate change on the time scale of decades or longer, these feedbacks must be allowed to operate. Ice sheets and forest cover, on the other hand, might be considered 'slow feedbacks', not expected to change much on decadal time scales. In addition, climate models were not yet capable of modeling these slower processes.

The Charney study suggested that equilibrium climate sensitivity was ~3°C (5.4°F) for doubled CO_2, with uncertainty at least 50% (1.5°C). Improving climate models continue to yield global climate sensitivity ~3°C for doubled CO_2, but uncertainty remains because of the difficulty of accurately simulating clouds.

A more definitive evaluation of climate sensitivity is provided by the Earth's history. With the same choices for the variables specified as forcings, empirical data for climate change over the past 700,000 years yield a climate sensitivity of ¾°C for each W/m^2 of forcing, or 3°C for a 4 W/m^2 forcing. (see Figure 2 of Reference B). This empirical evaluation of climate sensitivity eliminates the concern with climate models, that they may inadvertently exclude important processes. The real world climate change included any cloud feedbacks that exist.

Climate response time. A practical difficulty with climate change arises from the fact that the climate system does not respond immediately to climate forcings. Figure 1 shows the climate response to a forcing introduced at time t = 0. It requires about 30 years for 50% of the eventual (equilibrium) global warming to be achieved, about 250 years for 75% of the response, and perhaps a millennium for 90% of the surface response.

The exact shape of this response function depends upon the rate of mixing in the ocean, thus upon the realism of the ocean model that is used for its calculation. The response time also depends upon climate sensitivity, the response being slower for higher sensitivity. The reason for this is that climate feedbacks come into play in response to climate change, not in response to the forcing per se, and thus with stronger feedbacks and higher climate sensitivity the response time is longer. The curve in Figure 1 was calculated for sensitivity 3°C for doubled CO_2.

This long response time means that even when GHGs stop increasing, there will be additional warming "in the pipeline". Thus we have not yet felt the full climate impact of the gases that have already been added to the atmosphere. This lag effect makes mitigation strategies more arduous.

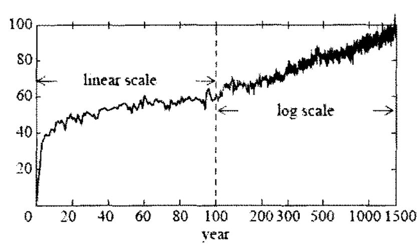


Figure 1. Climate response function (percent of equilibrium response) based on global surface air warming of GISS modelE coupled to Russell ocean model (Reference B).

Slow climate feedbacks. The 'Charney', or fast feedback, climate sensitivity is intended to be relevant to decadal time scales. But it is becoming clear that other feedbacks, omitted because they are 'slow' and difficult to deal with, may also be important.

One 'slow' feedback is the poleward movement of forests with global warming. If evergreen forests replace tundra and scrubland vegetation, it makes the surface much darker. Trees are 'designed' to capture photosynthetic radiation efficiently, and thus they can provide a strong positive climate feedback. Forest cover is a powerful positive feedback at Northern Hemisphere high latitudes, and significant changes are already beginning.

Another 'slow' feedback is associated with ice sheets. An ice sheet does not need to disappear for significant feedback to occur: just the change of ice surface albedo (reflectivity) that occurs with increased area and melt season duration contributes a large local climate feedback. This feedback occurs in a region where warming is especially important, because of the effect of warming on ice sheet disintegration and sea level rise. Increased areas of surface melt, and lengthening melt season, are observed on both Greenland and West Antarctica.

Still another 'slow' feedback is the effect of warming on emissions of long-lived GHGs from the land or ocean. Melting of tundra in North America and Eurasia is observed to be causing increased ebullition of methane from methane hydrates.

It is apparent that these 'slow' feedbacks, which are primary causes of the extremely high climate sensitivity on paleoclimate time scales, as discussed below, are beginning to operate already in response to the clear global warming trend of the past three decades.

B. Earth's History

Civilization developed during the present interglacial period, the Holocene, a period of relatively stable climate, now almost 12,000 years in duration. In this period the Earth has been warm enough to prevent formation of ice sheets in North America or Eurasia, but cool enough to keep ice sheets on Greenland and Antarctica. Sea level rose by more than 100 meters between the peak of the last ice age, 20,000 years ago and the Holocene. After sea level finally stabilized, about 7,000 years ago, the first urban centers developed at many points around the globe, perhaps because of the increase in coastal margin productivity that occurred with sea level stabilization and thus the increased availability of high quality food necessary for urban development (Day et al., Emergence of complex societies after sea level stabilized, *EOS Trans. Amer. Geophys. Union* **88**, 10 April, 2007).

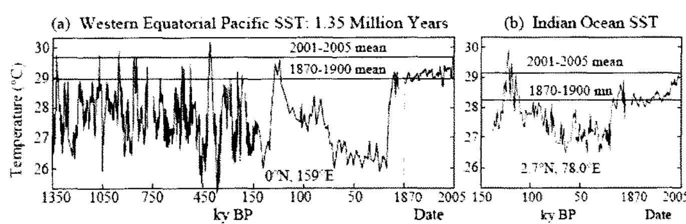


Figure 2. Western Equatorial Pacific (Medina-Elizade and Lea, The mid-:Pleistocene transition in the tropical Pacific, *Science* **310**, 1009-1012, 2005.

How much warmer does the Earth need to be to destabilize ice sheets and initiate eventual sea level rise of several meters or more? Figures 2 and 3 provide useful indications.

With the warming of the past 30 years, key tropical regions are now within 1°C or less of the warmest interglacial periods of the past million years (Figure 2). In the warmest of these interglacial periods, when global mean temperature was not more than about 1°C warmer than today, sea level is estimated to have been 4 ± 2 m higher than today (specifically during the previous interglacial period, about 130,000 years ago).

It is important to note that the large global climate changes illustrated in Figure 2 are entirely accounted for by two mechanisms: changes in the surface albedo of the planet (due to ice sheet area, vegetation distribution, and exposure of continental shelves) and changes in the amount of long-lived greenhouse gases (CO_2, CH_4, N_2O) in the atmosphere. Both the albedo and GHG changes occurred as feedbacks on these long time scales, the principal instigator of the climate changes being changes of the Earth's orbital elements (the tilt of the Earth's spin axis to the orbital plane, the eccentricity of the orbit, and the season of Earth's closest approach to the sun) due to gravitational pull of Jupiter, Saturn and Venus on Earth.

As feedbacks, the albedo and GHG changes tended to lag the climate change by several hundred years. It is probably not coincidental that the lag time is comparable to the ~500 year time scale for ocean turnover. It is important to note that the response time for the 'slow' feedbacks is much faster than the time scale of the orbital forcing changes.

The principal orbital forcing is change of the tilt of the Earth's spin axis, which varies from about 22½° to 24½° at a frequency of about 41,000 years (41 kyr). When the tilt is large it exposes both poles (at 6 month intervals) to increased summer insolation that tends to melt ice sheets, while small tilt allows polar ice sheets to grow. This is the most important orbital forcing, because it has the same sign in the two hemispheres. And this forcing is always present, independent of the eccentricity of the Earth's orbit.

The eccentricity (non-circularity) of the Earth's orbit varies irregularly from about zero (circular orbit) to about 0.06. The time scale of the changes, as the Earth is tugged by several planets, is not so regular as for tilt, but the largest changes are on ~100 kyr time scales. When the eccentricity is significantly different than zero the third orbital parameter comes into play: the season when the Earth is closest to the sun, or, stated differently, the precession of the equinoxes. This precession is the most rapid of the orbital forcings, going through a complete cycle in about 23 kyr.

Eccentricity and precession, working together, cause climate change on ~23 kyr and ~100 kyr periodicities, but the forcing has opposite sign in the two hemispheres, so the net global effect tends to be small, except in special cases as noted below. The eccentricity/precession forcing functions via its effect on seasonal insolation. Today, for example, the Earth is closest to the sun in January and furthest away in July. This situation favors growth of ice sheets at high latitudes in the Northern Hemisphere, as the relatively warm winters increase atmospheric moisture and snowfall, while the cool summers allow a budding ice sheet to survive.

Thus the natural tendency today, absent humans, would be toward the next ice age, albeit the tendency would not be very strong because the eccentricity of the Earth's orbit is rather small (~0.017). However, another ice age will never occur, unless humans go extinct. Although orbital changes are the 'pacemaker' of the ice ages, the two mechanisms by which the Earth becomes colder in an ice age are reduction of the long-lived GHGs and increase of ice sheet area. But these natural mechanisms are now overwhelmed by human-made emissions, so GHGs are skyrocketing and ice is melting all over the planet. Humans are now in control of global climate, for better or worse. An ice age will never be allowed to occur if humans exist, because it can be prevented by even a 'thimbleful' of CFCs (chlorofluorocarbons), which are easily produced.

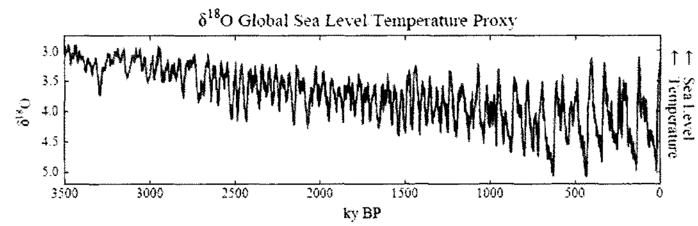


Figure 3. Proxy record of Plio-Pleistocene (3.5 million years) temperature and ice volume. Based on oxygen isotope preserved in shells of benthic (deep ocean dwelling) foraminifera. (Lisieki and Raymo, A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records, *Paleoceanogr.* **20**, PA1003, doi:10.1029/2004PA001071).

But back to the natural world: why did the principal periodicity of ice ages change about one million years ago from 41 kyr to 100 kyr? Figure 3 illustrates this change. H_2O molecules that contain the oxygen isotope ^{18}O are heavier and thus move more slowly than H_2O molecules containing the more abundant ^{16}O. Therefore H_2O molecules with ^{18}O evaporate from the ocean less readily. As a result, ice sheets are depleted in ^{18}O, and as ice sheets grow the proportion of ^{18}O in ocean water increases. These changes are recorded in the ^{18}O of shells of microscopic marine animals preserved now in oceans sediments.

Figure 3 shows a record of ^{18}O in ocean sediments around the world (from Lisieki and Raymo, A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records, *Paleoceanogr.* **20**, PA1003, doi:10.1029/2004PA001071). $\delta^{18}O$ (δ means 'the change of' relative to a standard case) in Figure 3 shows the 41 kyr frequency of global temperature that existed up until about one million years ago when it changed to a frequency of about 100 kyr. Before noting the explanation for this transition, which may be very simple, I need to first note that there are two factors that influence $\delta^{18}O$ significantly: one, already mentioned, is the amount of ice locked in ice sheets (i.e., sea level), and the other is the ocean temperature at the location where the microscopic creatures (benthic, i.e., deep ocean dwelling, foraminifera, whose shells carry the $\delta^{18}O$ record) lived.

The long-term trend in Figure 3 is a consequence of both the ocean becoming colder over that period and more (isotopically light) water being locked in ice sheets on the continents. At the beginning of this period (3.5 million years ago, the middle of the Pliocene epoch) the world was 2-3°C warmer than today and sea level was 25 ± 10 m (80 ± 30 feet) higher.

Figure 3 also shows that the amplitude of the glacial-interglacial climate fluctuations increased as the world became colder. This is because the ice/snow albedo feedback becomes larger as the planet becomes colder and has larger area of ice and snow.

The period of the glacial-interglacial swings was ~41 kyr up until one million years ago, because the areas of ice and snow in the two hemispheres were comparable, and thus the effects of eccentricity and precession, opposite in the two hemispheres, tended to largely offset each other in global effect. However, by one million years ago the Earth had become cold enough for a huge ice sheet (called the Laurentide ice sheet) to cover most of Canada, reaching into parts of the United States. A comparable area of ice/snow could not form in the Southern Hemisphere, because at those latitudes (~60°) there is no land in the Southern Hemisphere, but rather roaring east-west ocean currents. This huge asymmetry between the hemispheres allowed the eccentricity/ precession effects to become important, so thereafter the global temperature contains signature of all of the ~23, ~41 and ~100 kyr periodicities.

The astute reader is probably asking: why was the Earth gradually getting colder, ice area growing, and sea level falling, overall, during the past several million years. The reason, almost surely, was the strong orogeny (mountain building) during the past 10-20 million years. The South American continent has been hitting a rough spot, pushing up the Andes rapidly. It is hard to determine the exact rate, but available evidence indicates, for example, that between 11 and 7 kyr BP (before present) the Andes were rising at a rate of about 1 mm per year, i.e., 1 km per million years (Ghosh et al., Rapid uplift of the Altiplano revealed through ^{13}C-^{18}O bonds in paleosol carbonates, *Science*, **311**, 511-515, 2006). The Himalayas have also been rising rapidly during the past 40 million years (Raymo and Ruddiman, Tectonic forcing of the late Cenozoic climate, *Nature*, **359**, 117-122, 1992), as the Indian plate is crashing into Asia.

Rising mountains increase the rate of weathering of the rocks, and thus the deposition of carbonates on the ocean floor, thus drawing down atmospheric CO_2 amount. The precise ice core records of atmospheric CO_2 amount go back only about 700,000 years, so we must use much more crude estimates of the atmospheric CO_2 content, for example, the stomata of leaves change as atmospheric CO_2 changes. From such evidence, it is estimated that the CO_2 amount 3½ million years ago was probably in the range 350-450 ppm.

It is apparent that the Earth's history has much to tell us about what degree of atmospheric change will constitute "danger". I have described some of the empirical information about climate sensitivity and climate feedbacks. There is another vital piece of information in the paleoclimate data that warrants special attention, because it is relevant to what may be the greatest danger that humanity faces with climate change: sea level rise.

One thing that the paleoclimate record shows us is that ice sheet disintegration and sea level rise are usually much more rapid than the opposite process of ice sheet growth and sea level fall. This is reasonable because ice sheet disintegration is a wet process with many positive feedbacks, so it can proceed more rapidly than ice sheet growth, which is limited by the snowfall rate in cold, usually dry, places. At the end of the last ice age sea level rose more than 100 m in less than 10,000 years, thus more than 1 m per century on average. At times during this deglaciation, sea level rose as fast as 4-5 m per century.

If we follow "business-as-usual" GHG emissions, yielding global warming this century of a few degrees Celsius, how long will it take for West Antarctica and Greenland to begin to disintegrate? In the past, an answer to this question has been given based on ice sheet models that were built to try to match paleoclimate records of sea level change. These models tend to require millennia for ice sheets to change by large amounts. It is now reasonably clear that those models were based on a false premise and incomplete physics.

The large sea level changes between glacial and interglacial times typically require several thousand years. However, this corresponds to the time scale of the changing forcing, not an inherent response time of the ice sheets. On the contrary, there is no evidence of any substantial lag between the forcing and the ice sheet response (references B and D above). The most rapidly changing paleoclimate forcing has a time scale of 11-12 ky from minimum forcing to maximum forcing, and the changes of sea level are practically coincident with the changes of forcing, suggesting that ice sheets can respond to forcings within centuries.

C. Current Situation

People are just beginning to notice that climate is changing. Global warming, 1°F in the past 30 years, is much smaller than day to day weather fluctuations or even monthly mean local temperature anomalies. However, the warming is larger over land than over ocean, and the astute observer can note changes that have occurred over the past several decades. A typical isotherm (line of a given average temperature) is now moving poleward, in typical land areas, by about 50 km per decade. As this warming continues, or accelerates with "business-as-usual" GHG emissions, it will begin to have dramatic effects, as discussed in the next section.

To understand the urgency of addressing the global warming problem, it is necessary to recognize a critical distinction that exists among pollution problems arising in the fossil-fuel-driven industrial revolution. When the industrial revolution began in Britain it was powered first by coal, the most abundant of the fossil fuels. Later discoveries of oil and gas, which are more mobile and convenient fossil fuels, provided energy sources that helped power the developed world to ever greater productivity and living standards.

We did not face up to the dark side of the industrial revolution until it was thrust in our face. London choked on smog. A river in the United States burned. Forests were damaged by acid rain. Fish died in many lakes. These problems were traced to pollutants from fossil fuels.

We have solved or are solving those pollution problems, at least in developed countries. But we did not address them until they hit us with full force. That approach, to wait and see and fix the problems post facto, unfortunately, will not work in the case of global climate change. On the contrary, because of the inertia of the climate system, the fact that much of the climate change due to gases already in the air is still 'in the pipeline', and the time required for economically-sensible phase-out of existing technologies, ignoring the climate problem at this time, for even another decade, would serve to lock in future catastrophic climatic change and impacts that will unfold during the remainder of this century and beyond (references A and B).

But there is no reason for gloom and doom. On the contrary, there are many bright sides to the conclusion that the 'dangerous' level of CO_2 is no more than 450 ppm, and likely much less than that. It means that we, humanity, are forced to find a way to limit atmospheric CO_2 more stringently than has generally been assumed. In so doing, many consequences of high CO_2 that were considered inevitable can be avoided. We will be able to avoid acidification of the ocean with its destruction of coral reefs and other ocean life, retain Arctic ice, prevent the West from become intolerably hot with desertification of presently semi-arid regions, and the other undesirable consequences of large global warming.

It is becoming clear that we must make a choice. We can resolve to move rapidly to the next phase of the industrial revolution, and in so doing help restore wonders of the natural world, of creation, while maintaining and expanding benefits of advanced technology. Or we can continue to ignore the problem, creating a different planet, with eventual chaos for much of humanity as well as the other creatures on the planet.

4. Metrics for Dangerous Climate Change

I have argued elsewhere (Hansen, *New York Review of Books*, LIII no. 12, July 13, 2006) that ice sheet disintegration and extermination of species deserve high priority as metrics for dangerous climate change, because, for all practical purposes, these consequences are irreversible. Regional climate change also has great impacts on humanity.

A. Sea Level Rise

The sharpest criterion for defining dangerous climate change is probably maintenance of long-term sea level close to the present level (reference A), as about one billion people live within 25 m elevation of today's sea level. These areas (Figure 4) include many East Coast U.S. cities, almost all of Bangladesh, and areas occupied by more than 250 million people in China.

The Earth's history suggests that a CO_2 level exceeding 450 ppm is almost surely dangerous, in the sense of risking sea level rise of several meters or more. Indeed, the Earth's history suggests that the CO_2 limit may be significantly lower than that. Reduction of non-CO_2 forcings provides some, but only moderate, flexibility in the CO_2 ceiling.

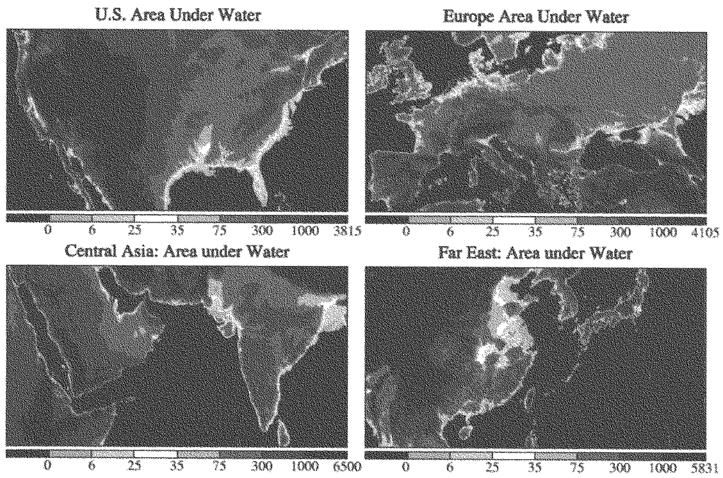


Figure 4. Areas under water for specified sea level increases. Blue regions would be expected to eventually be under water with global warming as great as that of the middle Pliocene (2-3°C).

Sea level change has received less attention in the past than it warrants, because of a common presumption that ice sheets had an inertia preventing substantial changes on time scales shorter than millennia. Closer inspection of paleoclimate data calls that assumption into question, and increasingly rapid changes on West Antarctica and Greenland, observed by satellite and in the field during the past few years, are truly alarming. West Antarctica is of particular concern, because, as a marine based ice sheet, global warming attacks it from both below and above.

Sea level is already raising at a rate of 3.5 cm per decade (more than one foot per century) and the rate is accelerating. It is impossible to say at exactly what level of global warming cold accelerate to meters per century, because ice sheet disintegration is a very non-linear process in which changes can occur suddenly. But paleoclimate data suggests that we are not far from such a level of global warming.

B. Extermination of Species

Climate change is emerging while the state of the wild is stressed by other forces. Pressures include destruction of habitat, hunting and resource use, pollution, and introduction of exotic competing species. Climate effects are magnified by these stresses, including human-caused fragmentation of ecosystems. As a result, continued business-as-usual greenhouse gas emissions threaten many ecosystems and their species, which together form the fabric of life on Earth and provide a wide range of services to humanity.

Animals and plants migrate as climate changes, but their potential escape routes may be limited by geography or human-made obstacles. Polar species can be pushed off the planet, as they have no place else to go. In Antarctica, Adelie and emperor penguins are in decline, as shrinking sea ice has reduced the abundance of krill, the penguins shrimp-like food source (Gross, As the Antarctic ice pack recedes, a fragile ecosystem hangs in the balance, *PLoS Biol.* 3(4):e127).

Arctic polar bears are also feeling the pressure of melting sea ice. Polar bears hunt seals on the sea ice and fast in the summer, when the ice retreats from shore. As ice is receding earlier, populations of bears in Canada have declined about 20%, with the weight of females and the number of surviving cubs decreasing a similar amount.

Figure 5. Polar bear numbers are in decline. In some populations the weight of females and the number of cubs have decreased about 20 percent. (Image Credit: Paul Burke, First People)

The apparent good news is that the U.S. Fish and Wildlife Service is considering whether it will protect polar bears under the Endangered Species Act (Pennisi, U.S. weighs protection for polar bears, *Science* **315**, 25, 2007). I say apparent, because the announcement was made only after the Fish and Wildlife Service was taken to court for failure to act. And connection of polar bear plight to greenhouse gas emissions has been drawn only by those bringing suit, not by the government.

Life in alpine regions, including the biologically diverse slopes leading to the mountains, is similarly in danger of being pushed off the planet. As a given temperature range moves up the mountain the area with those climatic conditions becomes smaller and rockier, and the air thinner. The resulting struggle for life is already becoming apparent in the southwest United States, where the effects are hastened by intensifying drought and fire.

The Mount Graham red squirrel survives now on a single Arizona mountain, one of the 'islands in the sky' in the American Southwest. These 'islands' are green regions scattered on mountains in the desert. Stresses on this species include introduction of a grey squirrel that raids the food middens built by the red squirrel. Classified as endangered, the Graham red squirrel population rebounded to over 500 by 1999 (Jordan, Computers may help save Mount Graham red squirrel, *Univ. Arizona News*, April 27, 2006), but has since declined to between 100 and 200 (Egan, Heat invades cool heights over Arizona desert, *New York Times*, 27 March 2007). Loss of the red squirrel will alter the forest, as its middens are a source of food and habitat for chipmunks, voles and mice.

Figure 6. Mount Graham Red Squirrel survives on a single mountain in Arizona, one of dozens of 'islands in the sky', green regions surrounded by desert. Green islands and squirrels are pushed higher as temperature rises and will be pushed off the planet if global warming continues. (Credits: PHOTOSMITH, 2004, Claire Zugmeyer and Bruce Walsh, University of Arizona.)

The new stress driving down Graham red squirrel numbers, perhaps toward extinction, is climatic: increased heat, drought and fires. Heat-stressed forests are vulnerable to prolonged beetle infestation and catastrophic fires. Rainfall still occurs, and when it does it can be substantial because warmer air holds more water. But dry periods are more intense and resulting forest fires burn hotter, thus leaving an almost-lifeless 'scorched earth' so devastated that lower reaches of the forest cannot recover, becoming part of the desert below.

Might the Graham red squirrel be 'saved' by transplantation to a higher mountain, where it could compete for a niche? One difficulty would be the 'tangled bank' of interactions that has evolved among species (Montoya et al., Ecological networks and their fragility, *Nature* **442**, 259-264, 2006). What is the prospect that humans can understand, let alone reproduce, all the complex interactions that create ecological stability? 'Assisted migration' thus poses threats to other species (Zimmer, A radical step to preserve a species: assisted migration, *New York Times*, 23 January 2007), as well as uncertain prospects for those that are transported.

The underlying cause of the climatic threat to the Graham Red Squirrel, and millions of other species, is continued 'business-as-usual' increase of fossil fuel use. The best chance for all species, including humans, is a conscious choice by the latter species to pursue an alternative energy scenario, one leading to stabilization of climate.

C. Regional Climate Change

Regional climate changes due to global warming may have the greatest impact on humans in the near-term. Changes of the hydrologic cycle are of special concern. An expansion and intensification of subtropical dry conditions occurs consistently in climate model simulations of global warming. Practical impacts include increased drought and forest fires in regions such as the Western United States, Mediterranean, Australia, and parts of Africa. Paleoclimate data provide further evidence of increased drought in the Western United States accompanying warmer climate.

It is difficult to specify a precise threshold for 'dangerous' based on regional effects, but there is already evidence that some of these impacts are beginning to be detectable. Thus regional climate change, as well as sea level and species, would be protected by stabilizing global warming near its current level.

5. Four-Point Strategy to Stabilize Climate

The evidence we have presented is no reason for gloom and doom. Instead, we must resolve to move rapidly to the next phase of the industrial revolution. In doing so, we can help restore wonders of the natural world, of creation, while maintaining and expanding benefits of advanced technology.

Actions that are needed become apparent upon review of basic fossil fuel facts. Figure 7a shows estimated amounts of CO_2 in each fossil fuel reservoir: oil, gas, coal and unconventional fossil fuels (tar sands, tar shale, heavy oil, methane hydrates). A significant fraction of oil and gas has already been used (dark portion of bar graph). Proven and anticipated reserves are based on Energy Information Administration estimates. Other experts estimate higher or lower reserves, but the uncertainties do not alter our conclusions.

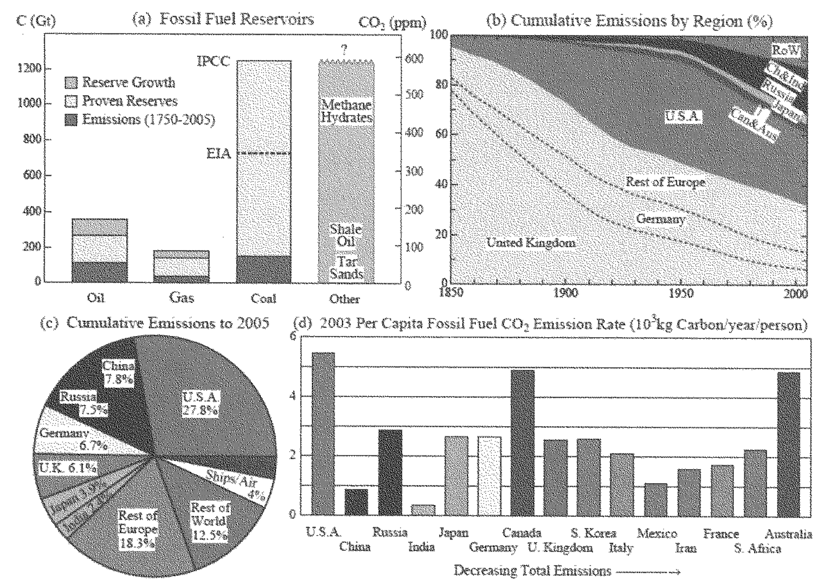


Figure 7. (a) Carbon dioxide contained in fossil fuel reservoirs, the dark areas being the portion already used, (b, c) Cumulative fossil fuel CO_2 emissions by different countries as a percent of global total, (d) Per capita emissions for the ten largest emitters of fossil fuel CO_2 (Marland, *A Compendium of Data on Global Change*, Oak Ridge Natl. Lab., 2006).

Data on fossil fuel reservoirs must be combined with knowledge about the 'carbon cycle'. The ocean quickly takes up a fraction of fossil fuel CO_2 emissions, but uptake slows as CO_2 added to the ocean exerts a 'back pressure' on the atmosphere. Further uptake then depends upon mixing of CO_2 into the deep ocean and ultimately upon removal of CO_2 from the ocean via formation of carbonate sediments. As a result, one-third of fossil fuel CO_2 emission remains in the air after 100 years and one-quarter still remains after 500 years.

One conclusion from these fossil fuel facts is that readily available oil and gas resources alone will take atmospheric CO_2 to the neighborhood of 450 ppm. Coal and unconventional fossil fuels could take atmospheric CO_2 to far greater levels. These carbon reservoirs are an important boundary condition in framing solutions to the climate crisis.

A second boundary condition is the Earth's energy imbalance, which defines the 'momentum' of the climate system. Creation of 'a different planet', with an ice-free Arctic and eventual disintegration of ice sheets, can be averted only if planetary energy balance is restored at an acceptable global temperature, i.e., one that avoids these catastrophic changes. Estimates of permissible additional warming must be refined as knowledge advances and technology improves, but the upshot of crystallizing science is that the 'safe' global temperature level is, at most, about 1°C greater than year 2000 temperature. It may be less, indeed, I suspect that it is less, but that does not alter our conclusions.

A 1°C limit on added global warming implies a CO_2 ceiling of about 450 ppm (reference A). There is some 'play' in the CO_2 ceiling due to other human-made climate forcings that cause warming, especially methane, nitrous oxide, and 'black soot'. The 'alternative scenario' (Hanse et al., Proc. Natl. Acad. Sci., 97, 9875-9880, 2000), designed to keep additional warming under 1°C, has CO_2 peaking at 475 ppm via an assumed large reduction of CH_4. However, human-made sulfate aerosols, which have a cooling effect, are likely to decrease and tend to offset reductions of positive non-CO_2 forcings. Therefore 450 ppm is a good first estimate of the maximum allowable CO_2. Indeed, if recent mass loss in Antarctica is the beginning of a growing trend, it is likely that even 450 ppm is excessive and dangerous.

The low limit on allowable carbon dioxide has a bright side. Such a limit requires changes to our energy systems that would do more than solve the sea level problem. They would leave ice in the Arctic and avoid dramatic climate changes in other parts of the world. Air pollutants produced by fossil fuels, especially soot and low level ozone, also would be reduced, thus restoring a more pristine, healthy planet. Most species on the planet could survive.

An outline of the strategy that humanity must follow to avoid dangerous climate change emerges from the above boundary conditions. It is a four-point strategy (following tables).

Outline of Solution

1. Coal only in Powerplants w Sequestration
   Phase-out old technology. Timetable TBD
2. Stretch Conventional Oil & Gas
   Via Incentives (Carbon tax) & Standards
   Avoid Unconventional Fossil Fuels
3. Reduce non-CO_2 Climate Forcings
   Methane, Black Soot, Nitrous Oxide
4. Draw Down Atmospheric CO_2
   Improved Agricultural & Forestry Practices
   Perhaps Biofuel-Powered Power-Plants

Methods to Reduce CO_2 Emissions

1. Energy Efficiency & Conservation
   More Efficient Technology
   Life Style Changes
2. Renewable & CO_2-Free Energy
   Hydro
   Solar, Wind, Geothermal
   Nuclear
3. CO_2 Capture & Sequestration

→ No Silver Bullet
→ All Three are Essential

A. Coal and Unconventional Fossil Fuels

First, coal and unconventional fossil fuels must be used only with carbon capture and sequestration. Existing coal-fired power plants must be phased out over the next few decades. This is the primary requirement for avoiding 'a different planet'.

It is probably impractical to prevent use of most of the easily extractable oil and its use in small mobile sources. This makes it essential to use the huge coal resource in a way cuach that the CO_2 can be captured, and, indeed, the logical use of coal is in power plants. It is important to recognize that a substantial fraction of the CO_2 emitted, if it is not captured, will remain in the air for an eternity.

Thus the most critical action for saving the planet at this time, I believe, is to prevent construction of additional coal-fired power plants without CO_2 capture capability. As governments around the world, not only in the United States, China and India, fail to appreciate this situation, it is important that citizens draw attention to the issue.

B. Stretching Oil and Gas with a Carbon Tax

Oil and gas must be 'stretched' so as to cover needs for mobile fuels during the transition period to the next phase of the industrial era 'beyond petroleum'. This 'stretching', almost surely, can only be achieved if there is a continually rising price on carbon emissions. Innovations will be unleashed if industry realizes that this rising price is certain. Efficiency standards, for vehicles, buildings, appliances, and lighting are needed, as well as a carbon price. The carbon tax will also avert the threat of emissions from unconventional fossil fuels, such as tar shale.

C. Drawing Down Atmospheric CO_2

Because CO_2 is already near the dangerous level, steps must be taken to 'draw down' atmospheric CO_2. Farming and forestry practices that enhance carbon retention and storage in the soil and biosphere should be supported.

In addition, burning biofuels in power plants with carbon capture and sequestration could draw down atmospheric CO_2 (Hansen, *Political interference with government climate change science*, 19 March 2007 testimony to Committee on Oversight and Government kReform of the U.S. House of Representatives, <http://www.columbia.edu/~jeh1) in effect putting anthropogenic CO_2 back underground where it came from. CO_2 sequestered beneath ocean sediments is inherently stable (House et al., Permanent carbon dioxide storage in deep-sea sediments, *Proc. Natl. Acad. Sci.*, **103**, 12291-12295), and other safe geologic sites may also be available.

This use of biofuels in a power plant, which would draw down atmospheric CO_2, should be contrasted with use of corn-based ethanol to power vehicles. The latter process still results in large increases of atmospheric CO_2, increases food prices worldwide, and results in deforestation and poor agricultural practices as greater land area is pressed into service. In the use of biofuels for power plants, mentioned above, we would envisage use of cellulosic fibers and native grasses harvested with non-till practices. Limited land availability may make it difficult for biofuels to be the long-term solution for vehicle propulsion.

D. Non-CO_2 Climate Forcings

A reduction of non-CO_2 forcings can be a significant help in achieving the climate forcings needed to keep climate change within given bounds. Reduction of non-CO_2 forcings has benefits for human health and agriculture [*West et al.*, 2005; *Air Pollution Workshop*, www.giss.nasa.gov/meetings/pollution2005], as well as for climate. Reduction of non-CO_2 forcings is especially effective in limiting Arctic climate change (reference A).

The CHAIRMAN. We thank all of the panelists for their testimony.

I will now turn to recognize members of the committee for questions for the panel, and the Chair will recognize himself now for 5 minutes.

Dr. Hansen, you identified the melting of the west Antarctica ice sheet as the greatest threat from global warming and suggest that we could see many feet of level in the rise of the level of water in this century. The IPCC's report released in February predicts less sea level rise than you suggest. Can you explain the discrepancy between your conclusion and the IPCC?

Mr. HANSEN. Yes. IPCC declined to put a number on the disintegration of the west Antarctic or Greenland ice sheets. The number that they gave represents only thermal expansion of the ocean and the effect of mountain glaciers. So those are relatively small effects.

By far, the largest issue is the stability of the west Antarctic ice sheet and the Greenland, but especially west Antarctica, because it is an ice sheet that is sitting below sea level. Its base is below sea level. So it is being attacked by both a warming ocean and by a warming atmosphere. And we know that it, in just the last few years, has been losing ice at a rate of about 150 cubic kilometers per year. So it is already beginning to respond to the warming.

The CHAIRMAN. Let me ask the other witnesses if they could quickly respond to how close they each believe we are to dangerous interference with climate systems as a result of human activities.

Dr. Curry.

Ms. CURRY. Well, I would agree with Dr. Hansen that the most likely catastrophic thing that could happen in the next century would be the collapse of the west Antarctica ice sheet. I mean, that is sort of beyond dangerous. I would call that catastrophic. I would say that is the single most catastrophic thing that we might see in the next century.

Ms. PARMESAN. From a biodiversity standpoint and also how that impacts human health, I would say that if we get up to between 1 and 2 degrees, we will lose species but that most people think that is manageable. So species will go extinct, but can we manage reserves? Can we tolerate the amount of increase in disease that that is going to have? Probably we can. But everyone that I have talked to in publications is in agreement that if you go to up to 4 degrees centigrade, that is catastrophic.

Ms. EBI. It is a very good and very difficult question. As I said, human health is already being affected; and danger is a social choice. As a scientist, I can tell you we don't have the studies that will tell you what might happen with human health with a 2-degree, 3-degree or 4-degree increase. We know what is already going on will become worse. We know the diseases will change their range. We know the heat waves will be a bigger problem.

At some point we have to decide when enough people are suffering and dying and we need to start making changes. The changes have to be both adaptation and mitigation. We have to start helping today, and we have to help future generations.

The CHAIRMAN. Dr. Helms.

Mr. HELMS. I have two responses: One, at a global level, looking at the effect of warming climate on global forests, tremendous danger relative to those northern boreal forests in particular.

The CHAIRMAN. How close are we to the danger?

Mr. HELMS. I would hesitate to put an actual number on that, but currently the reports are that the permafrost is melting.

The second response would be relative to the U.S., and I would point to the likely increase in wildfire, particularly in the western forests. If this becomes more prevalent, it is going to be a very dangerous situation.

The CHAIRMAN. Okay. Thank you.

Let me ask—Dr. Hansen, let me ask you one final question. Has the United States, in your opinion, lived up to its commitment thus far under the United Nation's Framework Convention on Climate Change to prevent dangerous climate change?

Mr. HANSEN. Well, I think that we have not done what we need to do. Because the United States has contributed more than three times the carbon dioxide—the increase in carbon dioxide that is in the atmosphere. And it is said that China is now about to pass us in current emissions. But what counts is the integrated emissions, the cumulative emissions, because a large fraction of the CO_2 stays in the air forever, more than 500 years. So we should be—given our moral responsibility for what we have put up there, we should be taking a leadership role in addressing the problem, and we are not doing that.

The CHAIRMAN. Thank you, Dr. Hansen.

My time has expired.

The Chair recognizes the gentleman from Wisconsin.

Mr. SENSENBRENNER. Thank you.

Dr. Hansen, are greenhouse gasses pollutants?

Mr. HANSEN. I don't understand that word.

Mr. SENSENBRENNER. Do they pollute the atmosphere?

Mr. HANSEN. Absolutely. In my opinion, given the impacts that they will have and on the climate——

Mr. SENSENBRENNER. How can you say they are pollutants when they occur naturally? The largest progenitor of CO_2 are the oceans.

Mr. HANSEN. That is true for many things which are nutritious are pollutants or poisonous if you have them in excessive amounts. And I can tell you what the excessive amounts of CO_2 will do. In fact, I have already described some of the potential factors and——

Mr. SENSENBRENNER. I have read your full testimony here, and you talk a lot about CO_2. Which causes more damage to the climate, CO_2 or methane?

Mr. HANSEN. Per molecule, methane has a stronger greenhouse effect, but because of the overwhelming number of CO_2 molecules, it is causing a larger effect.

The other thing is that CO_2 has a much longer lifetime. As I have said, more than a quarter of it stays there more than 500 years. But methane has a lifetime of 10 years.

Mr. SENSENBRENNER. Why don't we talk more about the sequestration of methane or the reduction of methane?

Mr. HANSEN. We should.

Mr. SENSENBRENNER. Because molecule per molecule, methane is much more dangerous than CO_2.

Mr. HANSEN. It is an opportunity to reduce the overall problem, and that is one of the four points that I mentioned, and that is one of the things which the United States should be given credit for.

We have taken steps—our present government has taken steps to reduce methane emissions, and that is helpful, but it is not enough.

Mr. SENSENBRENNER. Well, do you know what I can say is that almost all the debate on this subject has been relative to CO_2. And in the Kyoto Protocol, you and I have talked about that at some length in the past, there are six greenhouse gases that are under the Kyoto Protocol, but CO_2 ends up being the biggest culprit. How do we change the debate on this so that we deal with the other five greenhouse gases, particularly methane.

Mr. HANSEN. Well, we need to talk about that. We need to put more emphasis on that. But the critical thing, because of its long lifetime, is indeed carbon dioxide. And that is where we have got to bring the sources of that under control within the next several years, or we are in big trouble.

Mr. SENSENBRENNER. In your written testimony you talked about a carbon tax. In your oral testimony you didn't really emphasize the T word. How high a tax would be necessary to achieve the reductions that you think are necessary?

Mr. HANSEN. That is a difficult thing to say. What I have said about that is we should have a nonpolitical czar the way we do in economics. You don't want to damage the economy, you want to push this up, and you don't want it to be political. You want to push it up fast enough that you influence the development of technology, but you have to give the consumer options so that he can purchase things that reduce his requirements for fuel.

Mr. SENSENBRENNER. There is a small problem in that called the United States Constitution, which gives the House of Representatives the exclusive authority to initiate tax legislation. As I said in my opening statement, when scientists weighed into policy discussions, as you have done very eloquently, you are advising us what we ought to do. You are advocating a carbon tax. How high does it need to be to reduce the amount of CO_2 you want to see us reduce?

Mr. HANSEN. It has to be high enough to drive the innovations in the technology and to drive energy efficiency. It has got to be high enough that people feel that they will be better off if they use energy more efficiently.

Mr. SENSENBRENNER. How much per ton of carbon or how much per pound of carbon?

Mr. HANSEN. That would be a function of time. Actually it can start out relatively small, because you notice people do complain about increases in prices of energy, so they will notice. But you have got to do it in a way that allows the introduction of technologies.

Mr. SENSENBRENNER. I guess I would say that if you increase the gas tax or increase taxes on other types of energy like natural gas, every economist says it is a progressive taxation, and I don't think that is very popular.

My time is up. Thank you.

Mr. HANSEN. There are things that you can do to relieve the burden on the people who are affected the most.

The CHAIRMAN. The gentleman's time is expired.

The Chair recognizes the gentlelady from North Dakota Ms. Herseth.

Ms. HERSETH SANDLIN. Thank you, Mr. Chairman. I want to thank our witnesses for their testimony today.

I represent the entire seat of South Dakota, and agriculture is our largest industry, and we have been plagued by a multiyear drought. And so I am very interested in the testimony that a number of you offered as it relates to rainfall location changes, where that has happened predominantly in each continent and the impact on agriculture.

Just by way of some description of what is happening in South Dakota, last summer, midsummer, central South Dakota reached record high temperatures, as high as 117 degrees in a community right along the Missouri River. The reservoirs along the Missouri River in the Upper Basin States are experiencing record low levels of water in those reservoirs linked directly to what has been happening with snowmelt and snow levels in the mountains in Montana. As I mentioned, we are experiencing this drought and the impact that it is having predominantly on agriculture as it relates to livestock producers, but also some of our grain producers, and how the drought is affecting forest health in the Black Hills National Forest in western South Dakota. So I offer that by way of description, not to be parochial, but to provide the context of my question.

If you could address the issues of rainfall changes, perhaps Dr. Parmesan and perhaps Dr. Helms. If you could answer the question of we know when forests are overstocked, they present a risk of forest fire. But the impact that they have on the water resources and the watershed is also significant. I was wondering, as you described, the carbon storage potential of our forest, does overstocking of the forest also affect the potential for carbon storage? And if you could describe that.

And then just to clarify my question to you, Dr. Parmesan, if you could say where in North America you have seen the most significant rainfall location changes and how that affects drought, and perhaps where you have seen that in other continents, and if it is different from previous cycles of drought that we have always experienced in some arid States.

Ms. PARMESAN. I am not a climate scientist, I am a biologist, but I can talk about the impacts of changes in rainfall that we have seen. And certainly large areas of the Southwestern U.S.A. have become much drier, and we are seeing species going extinct and changes in vegetation structure. Other areas have become wetter, and again we are seeing changes in vegetation structure and species distributions within the U.S.A. that go along with that.

Now, when I have looked at the projections for the U.S.A., one thing that has concerned me is I am actually a farmer also. I have got farms in the Corn Belt in Illinois, and they rely on normal rain, natural rainfall, without irrigation. And it has become more and more difficult to actually grow crops there with natural rainfall they have had, not quite as strong a drying trend as you have had, but a slight drying trend. And fairly quickly, I think 11 of the 12 models believe that section of the country will continue to become drier. So it is a concern to me actually personally that agriculture areas in that section will not be able to sustain crops anymore.

Ms. HERSETH SANDLIN. Let me just ask a quick follow-up, if you don't mind, Dr. Helms. When you say "can't sustain those crops," we know American agriculture and agriculture around the world is not a stagnant industry. We have seen technology going into drought-resistant crops, et cetera. But your projections, when you say 11 of the 12 models, is that based on just the current types of crops in sea technology that they are using, or do you think it is actually going to reach levels that won't sustain row crops or other types of grain production?

Ms. PARMESAN. Again, this is not quite my area of expertise. But the agriculture models that do this both globally and within the U.S.A. and within Europe project that with a little more warming, you are going to have increased production in more northern latitudes, meaning Canada, Sweden and Finland, not in the lower latitudes, the U.S.A. and the lower part of Europe, and that when you get up to 4 degrees warming, production goes down globally.

Mr. HELMS. The importance of forest, forested watersheds, is the forests enable the water to get down into the soil, which is where you want it to be, because a watershed, the water that is stored in the soil, is the critically important thing both from the storage capacity and also in terms of slow release into the streams. If the forest becomes overly dense and overly stressed, and you have mortality in the forest, then the forest is not able to serve that function. And particularly if it induces fire, you are likely to have more surface flow. And so if you have surface flow, you have not high-quality water, and you have very rapid water getting into the watersheds.

So as we look at global climate change, we get concerned about trying to do whatever we can to maintain forest health. And then we have to distinguish between whether the precipitation is in the form of rain or in the form of snow. And then the actual management of that watershed would differ a little, because, again, the idea would be to get the moisture into the soil and, in the case of snow, delayed snowmelt.

Ms. HERSETH SANDLIN. And so in the case of overstocking that leads to tree mortality, for example, knowing that overstocking exacerbates the problem of beetle infestations, that does affect the carbon storage potential of that forest?

Mr. HELMS. Yes. And also the water. Obviously if you are going to grow trees, they will consume water. But the important—and the most important issue on watershed is to maintain that forest in a healthy condition and not allow it to get overstocked, because as we have seen in a lot of forests in the Southwest, it tends to enhance the probability of insect disease populations that leads to mortality that leads to increased fire risk.

Ms. HERSETH SANDLIN. Thank you, Dr. Helms.

One final comment before my time is up. I do want to agree with you, Dr. Hansen, that I do think there is great potential for the Great Plains in the Midwest to assist our Coastal States as it relates to the impacts of global warming and climate change. And I think the questions I am posing to agriculture not only address the issue of the grains that are grown or the livestock that are raised for food and for the nutrition of our populations, but increasingly the potential to meet our energy needs through the form of cellulosic ethanol, other renewable sources.

So I thank you, Mr. Chairman.

The CHAIRMAN. The gentlelady's time is expired.

The Chair recognizes the gentleman from Arizona for 7 minutes.

Mr. SHADEGG. Thank you, Mr. Chairman. And I want to thank all of our witnesses. I appreciate your testimony. I think it has been a great contribution to this discussion.

Dr. Hansen, I was very encouraged, both by your written testimony and by your oral testimony, in the kind of optimism that you bring to the topic; that is, the things you say that we can do that are positive. It is kind of nice to hear it is not too late, recognizing that you call for some pretty strong medicine, but I appreciate that optimism.

I have lots of questions. I want to start by saying in your testimony you make the point that we could see dramatically greater sea level rise than the IPCC. The IPCC said 23 inches. You said it could be much more, and you explained that in response to the Chairman's question. That is driven largely by the issue of the demise of the West Atlantic Ice Sheet; is that correct?

Mr. HANSEN. Yes.

Mr. SHADEGG. I want to commend you for disagreeing. I am a little troubled by scientific consensus, and I am glad that some scientists can say, no, I disagree with other scientists, even with a consensus scientist, and say, no, I just happen to have a different opinion, because IPCC says 23 inches, you say it could be worse. I am glad somebody out there is willing to disagree even when everybody is on one side.

Mr. HANSEN. Well, you know, I perhaps should point out that, in fact, if you ask the several top glaciologists, they agree that IPCC has not addressed the real issue, and they are all very worried about the stability of these ice sheets.

Mr. SHADEGG. I appreciate that very much. And I am—just because there is a consensus doesn't mean a group of you can't say, do you know what, I just think different. As a matter of fact, years ago there was an advertising bulletin put out I think by United Technologies that I used to have on the wall in my office that said, if 10,000 people believe in a dumb idea, it is still a dumb idea. And we can be wrong about things.

You all have different views, and at some point in your paper you say, look, science can't predict these things with absolute certainty. And I notice everybody—at least several others agreed with you, that the most catastrophic thing that could happen would be the demise of the West Atlantic Ice Sheet. Obviously, you don't believe the likelihood of that is at zero, and you don't think the likelihood of that is at 100. Are you willing to try to put a number on it, or is that something you are not comfortable doing?

Mr. HANSEN. No, I am willing to talk about that, but it depends which scenario we follow. And our best guide for that is the Earth's history. We know that when the Earth was 2 to 3 degrees warmer, sea level was a lot higher, and the West Antarctica Ice Sheet was not there. So if we follow business as usual, then it is a lead pipe cinch, in my opinion, that West Antarctica will go. The only issue is how long does it take for it to happen.

Again, the Earth's history is our best guide, and it shows there is not much lag. The lag is of the order of centuries at most. And given that the sea level rise associated with 2 to 3 degrees warming was 30 meters——

Mr. SHADEGG. I want to follow not following business as usual, because you make a number of recommendations on that; stop using coal without sequestration. I have some trouble with the idea of long-term sequestration. Perhaps that is the right way to go. I would rather figure out a use for that CO_2 than lock it away, but maybe we can figure that out.

I am encouraged by your belief that we can, in fact, reduce the current level of CO_2 by farming and on forestation. I take it then that you agree largely with many of the comments of Dr. Helms with regard to the importance of managing our forest and doing other things?

Mr. HANSEN. Yes, that is right, managing the forest and also the agricultural practices, because the soil can store a lot of carbon.

Mr. SHADEGG. And, for example, I have a number of constituents in Arizona who are working aggressively, for example, to build biofuel plants that would produce electricity for biofuels, another way we can help in this process, correct?

Mr. HANSEN. It depends on how we do it. We have to do it in an effective way. Some of the plans for corn-based ethanol would put quite a bit of CO_2 in the atmosphere.

Mr. SHADEGG. I am not a big fan of corn-based ethanol. What they are talking about in Arizona is actually related to Dr. Helms' testimony.

Mr. HANSEN. Those programs are okay to give us a start, but we shouldn't have a huge program at the beginning because there are many disadvantages of that in terms of increasing the cost of food worldwide.

Mr. SHADEGG. This is actually forest biomass. We have lots of forests in Arizona.

Mr. HANSEN. That is a very good thing to do.

Mr. SHADEGG. And Dr. Helms probably knows the work of Dr. Wally Covington, who has talked about the overgrowth of our forests. They become too dense. It was talked about in Ms. Herseth's questioning. They are talking about moving that overgrowth to allow the forest to be more productive and then burning that biomass, another positive thing we can do for both greenhouse gas emissions and also to produce a new source of fuel as long as we sequester any CO_2 that is produced in that process.

Methane, the Ranking Member talked a little bit about methane and the fact that it is by multiples worse than carbon dioxide. You mentioned methane in your testimony, I have read, 21 times to 23 times. I heard you say that carbon is a more serious problem because it lasts longer, but I did not hear in your testimony suggestions for how we deal with methane. I think about that occasionally, okay, what do we do with animal-caused methane. But then the other big question is the one alluded to in your testimony, which is increasing amounts of methane escaping from the tundra. And I just wanted to ask if you have suggestions for what we can do about methane.

Mr. HANSEN. There are a number of things that can be done: capturing methane at coal mines, for example, and at landfills and reducing leakage in the whole fossil fuel process. We have actually made some progress in that. That is why the growth rate of methane has slowed down a bit.

Mr. SHADEGG. I would like to see us pursue that, but I am running out of time.

Dr. Curry, I want to ask you one question. In your testimony at page 1, if you would look at it, your written testimony, you quote a long paragraph from IPCC number 4, or IPCC 4th. And about halfway down that paragraph, there is an ellipsis and an omitted sentence. Do you know what that omitted sentence says?

Ms. CURRY. It wasn't the omitted sentence. That text appeared in two different subsections of the report. There was one on detection of climate change, which is the part before the ellipsis appeared, and then maybe four or five subsections later there was one about projections of future climate change and impact. So those two little paragraphs appeared in two different subsections of the report. That is the entire mention of hurricanes in the IPCC summary for policymakers.

Mr. SHADEGG. If you look at page 8 of 18 of the testimony, there is, in fact, an omitted sentence.

Ms. CURRY. There is an omitted sentence?

Mr. SHADEGG. There is an omitted sentence.

Ms. CURRY. Oh, okay. My apologies.

Mr. SHADEGG. At the end of the first paragraph. And that omitted sentence says: There is no clear trend in the annual numbers of tropical cyclones.

It might be better if that sentence appeared.

Ms. CURRY. My apologies.

The CHAIRMAN. The gentleman's time has expired. We can clarify that.

The gentleman from New York Mr. Hall is recognized for 7 minutes.

Mr. HALL. Thank you, Mr. Chairman. And thank you, too, everybody on our panel, for your enlightening testimony.

Just a couple quick comments. One is that the price of fuel is going to rise no matter what we do. Those of us who talk about peak oil, for instance, know by the laws of supply and demand, whether it is oil companies charging more and making more profit even as they are making record profits already, or whether it is the countries that control the oil charging more by cartel manipulation and raising prices that way, we are going to hit higher gas prices whether we tax it or not. In fact, I have been reading that some expect gasoline prices this summer to go over $4. I don't know whether that will happen or not. I suppose as a consumer I hope it doesn't.

I personally bought an American-made hybrid. I decided to vote with my dollars to try to boost the American automobile industry in the right direction. And we are talking about this since jobs have been mentioned. I am as concerned as anybody about jobs. There are two things. One is these new technologies will create jobs. In fact, unfortunately, they are creating more of them—unfortunately for us, I think, in the United States, they are creating more of them in Japan right now as evidenced by Toyota just passing GM as the number one volume auto maker. But I had to sacrifice approximately 20 miles per gallon to buy an American hybrid, because the American companies didn't, they wouldn't, they made a decision at the corporate level not to build fuel-efficient cars 20 years ago when the research and development was going on in other countries.

So some of these things can be absolutely job-creating if we do the right thing. In fact, the Clean Water Act, the Clean Air Act, other pollution control, scrubbers that we required, industry always screams or in the past has screamed that it is going to cost jobs, and, in fact, it usually winds up creating jobs to solve these problems and give us cleaner and cleaner water. So I for one believe addressing climate change will do the same thing.

I wanted to ask, using the median projection of sea level rise, would it be correct—Dr. Hansen, I will start with you—to say that such places as Hilton Head, Ocracoke, Hatteras, South Padre Island, Nantucket, Manhattan, many of the landmark resorts and famous golf courses and vacation spots that we have become quite fond of will be at risk?

Mr. HANSEN. The entire eastern United States seaboard is at risk; in Florida almost the entire State. So we have a lot at risk, but so do China, Bangladesh, India and many other places. It is something that we should be able to cooperate with the rest of the world on.

Mr. HALL. I hope in terms of the adaptation versus mitigation that we lean sooner on the mitigation and don't have to adapt as much later.

Mr. HANSEN. Mitigation is absolutely essential. We could not—it is not practical to adapt to our rapidly rising sea level. New Orleans is a village in comparison to the cities around the coastlines all around the world. The disasters would be far greater than we saw in New Orleans. So we just can't adapt to that. We have got to mitigate.

Mr. HALL. Thank you.

Dr. Ebi, perhaps this would be good for you. A number of you have testified about dramatic climate change and increase in droughts and heat waves. Are we looking at possibly the creation of a migratory America as people from coastal population centers or elsewhere are forced to move or migrate to more tolerable locations, or are we looking at migrations from the countries who are south even more than is already happening into the United States looking for a more temperate climate?

Ms. EBI. I don't think that is an "or," it is an "and"; that as we see changes, and we are seeing changes already in temperature and precipitation, we heard about the drought in South Dakota, people do make choices about where to live. And they will make choices based on a range of things, one of which is the current weather and climate. We also have a large number of migratory workers that come from Mexico and further south into the U.S. to pick our crops.

These are complex systematic changes. It is likely that as we see drought in some regions of the world—and to be honest, most of us are much more worried about places like Africa and Southeast Asia, where you have very high populations at risk. Dr. Hansen mentioned Bangladesh. About a third of Bangladesh is at risk for sea level rise. Bangladesh is the most populated country in the world. We are looking at sub-Sahara Africa where another degree or two in temperature and you may have very severe problems with rain throughout agriculture. Those people have to go somewhere. Yes, we will see migrations.

Mr. HALL. Our last panel was about national security implications of climate change, and they talked a lot about the instability of countries, especially in the developing world, relative to this. But we are living in the experiment, as I understand it. If you do the scientific method, you ordinarily will have one group of mice or frogs or whatever it is that you are testing, and then you will have a controlled group that you don't do the experiment on, and then you have a separate population that you do do the experiment on, and then you can tell the difference between the controlled group.

We don't have a control planet; we don't have another Earth that this change is not happening to that we can compare it to. So given the fact that we have not much to gain in terms of our balance of trade deficit being improved if we change our energy mix and develop more renewables here at home, and that we can perhaps lessen asthma, emphysema in the inner city, and we can have fewer oil spills and less mercury pollution and less acid rain, and many fewer wars in the other parts of the world where they happen to have oil, it seems that even if climate change turns out to be a fiction, nonetheless we help ourselves by starting to deal with it. And my time is yielded.

The CHAIRMAN. The gentleman's time has expired.

The Chair recognizes the gentleman from Oregon Mr. Walden.

Mr. WALDEN. Thank you, Mr. Chairman. I appreciate it. And I appreciate the testimony of our witnesses. Obviously we are going to get called for some votes here, so I will try and make my questions quick, and I hope you will give us the full answers.

Dr. Helms, Dr. Hansen mentioned just briefly in part of his testimony the notion the forests are moving to the north, and you are seeing more and more dark cover over the Earth as a result of that. Are you seeing that kind of migration, if you will?

Mr. HELMS. I haven't personal experience. I have seen references to it in literature.

Mr. WALDEN. I have, too. I read a report recently about some people say, well, if that is the case, then those forests become more heat sinks because they are darker, which could actually elevate the temperature. And then the same author went on to say, don't for a minute think you want to have more snow on the ground thereby clear-cutting those forests. That wouldn't be good behavior either.

Mr. HELMS. It is my understanding the study you are referring to was dealing with issues that albedo is high. Obviously if you replace that with a darker forest, that will absorb more heat. But I think the issue that we are more interested in is the more temperate area from the tropics up to the boreal where one gets concerned about making sure that the forests are stable and increasing because they are indeed storing carbon.

Mr. WALDEN. As you know, I chaired the Forests and Forest Health Subcommittee on the Resources Committee until this Congress, and we worked very hard to try to change America's forest policy to get at some of the things that you have testified today about. First, are forests a carbon sink if managed properly?

Mr. HELMS. Of course.

Mr. WALDEN. And managed properly means trying to keep them in balance with what would have naturally occurred pre-fire suppression time?

Mr. HELMS. That is right.

Mr. WALDEN. And that deals then with stand density, correct?

Mr. HELMS. Yes.

Mr. WALDEN. As the temperature rises on the planet, won't there be more pressure on these forests? If they are not managed at the right density levels, they will be more stressed, therefore more susceptible to insect infestation?

Mr. HELMS. I think you are quite correct in that statement.

Mr. WALDEN. At the end of the day, that then leads to higher incidence of fire, correct?

Mr. HELMS. Correct.

Mr. WALDEN. And if that happens, then—talk to me again about the release of carbon into the atmosphere, as well as other greenhouse gases. Aren't there other pollutants that are released into the atmosphere as a result of these catastrophic fires we are seeing?

Mr. HELMS. There are a variety of greenhouse gases, in aerosols in particular, that are important. Carbon is just one of these. But when we are dealing with forest, the fundamental basic tenet of forest management is to ensure the maintenance of forest health. The way that is done is to be concerned about stand density. Now, nature takes care of this over time through mortality. The problem for human society is that we can't tolerate commonly the consequences of mortality because of the infrastructure and the fact that we have urban development in forests.

Mr. WALDEN. To get back to one of your points, doesn't it also affect wildlife habitat and water and watersheds? If you wipe out a forest through catastrophic fire that can otherwise have been better managed to be more in balance, you lose it.

Mr. HELMS. You lose the whole suite of ecosystem services that the forests provide. Now, these will come back in time as they have historically.

Mr. WALDEN. But the issue here is one of time, as we hear today from every panel that is here. We may not have as much time as we thought we had to address this issue, correct? Aren't you all telling us this could happen exponentially, and it could be rapid, in a matter of decades as opposed to centuries? So does it make sense then to ignore forest policy as a small but important part of this equation dealing with carbon?

Mr. HELMS. Well, forests——

Mr. WALDEN. Can I get an answer from each of you? Do you agree with what Dr. Helms is suggesting? And I won't have much time here, so you can give me a yes or no, and I hate to do that to you.

Dr. Hansen.

Mr. HANSEN. I agree it is an urgent issue, yes.

Mr. WALDEN. But the forests need to be managed.

Mr. HANSEN. And the forests are a significant part of the solution.

Mr. WALDEN. Dr. Curry.

Ms. CURRY. Yes.

Mr. WALDEN. Dr. Parmesan.

Ms. PARMESAN. Yes. And I would like to add that he is absolutely right. When you properly manage a forest, the fires are small, they are much less hot. It is when you don't manage it they get really dense, and you get these huge catastrophic fires.

Mr. WALDEN. Thank you.

Dr. Ebi.

Ms. EBI. Yes.

Mr. WALDEN. Thank you.

Now, the other issue is the replacement potential for using wood or woody biomass for products. The dais we are on here is made of wood. This is a natural carbon sink.

Mr. HELMS. Correct.

Mr. WALDEN. So that versus the concrete. And I am not against concrete manufacturers or anything like that, but when we look at these issues, there are trade-offs here, aren't there?

Mr. HELMS. And this is the important part of the discussion is to make sure that we have a balanced evaluation of alternatives.

Mr. WALDEN. Then consumers could make choices, couldn't they?

Mr. HELMS. Yes. And part of the discussion is to look at what is called the life cycle assessment of the alternative products that we use in building and construction in daily use. And if you look at that, it is very clear that wood has by far the lowest carbon footprint of alternative materials.

Mr. WALDEN. And so would it be to our benefit and that in the environment to try to encourage the use of woody biomass, for example, for alternative fuels or production of energy?

Mr. HELMS. That is absolutely correct. And in addition to that, while you are doing this, you are improving the health of the forest and reducing a fire hazard. So it is a win-win situation.

Mr. WALDEN. The final point is after a catastrophic fire, do you remove more carbon by quickly replanting and getting a healthy forest growing sooner, or by letting it sit there and let nature regenerate it over a much longer period of time?

Mr. HELMS. If your goal is to sequester carbon, you have got to get leaf area growing on that burned area as quickly as possible. What I think is important, however, after a forest fire, the most important first thing to do is a very quick prompt assessment of the issue, because the watershed is not a single kind. You don't do things. You probably leave wilderness and natural areas alone; otherwise you have to have prompt regeneration.

Mr. WALDEN. Thank you. Thank you all.

The CHAIRMAN. Let me just tell everyone they have about 8½ minutes left to go before this roll call on the House floor. My intention is to recognize Mr. McNerney for 7 minutes, if he would like at this time, or I can recognize Mr. Larson for 5 minutes. It would be up to you, Mr. McNerney. But I will announce that my intention is for the Chair to go over and make this first vote; then there will be a 10-minute recommittal debate, and then obviously a 15-minute vote, which will give us about another 20-minute gap. So

I intend on returning and reconvening the hearing after this first vote.

So, Mr. McNerney, it will be your choice right now. You would have to adjourn the hearing with 1 minute left to go and run and make the vote, or I can recognize Mr. Larson at this time.

Mr. MCNERNEY. I will make it 1 minute.

The CHAIRMAN. The gentleman is recognized for 7 minutes.

Mr. MCNERNEY. Thank you, Mr. Chairman. And I do want to thank the board. I know it is a big commitment for you to come here and sit in front of this committee. A mounting evidence on global warming has caused concern of climate change and become a significant part of our national consciousness. In fact, just last week I was meeting with religious leaders, national religious leaders, who were talking about what they can do to save God's creation. So it is very impressive what that has done.

We have an opportunity, I think, to use the national consensus to develop a new national purpose, to energize and to inspire our population, especially the coming generation, to become engaged in education and innovation necessary to end global warming, to give our country a national leadership position in energy and economic and environmental issues in the coming decades. And I think I better leave it with that. Thank you again for coming, and we will probably see you in another half hour.

[Recess.]

The CHAIRMAN. We thank you, and we will reconvene the hearing. And I need to recognize the Members that have arrived. Is there anyone who would want to take on the issue of the acidification briefly?

Dr. Parmesan.

Ms. PARMESAN. In the tropical regions the ocean has become more acidic, and this is partly because the ocean has been absorbing a huge amount of the carbon dioxide that we have been putting out. I think the estimate is 40 or 50 percent. And it is starting to become saturated, which means it is starting to get more and more acidic, and at some point it is not going to be able to absorb the CO_2.

So there are two problems. One is we have been sort of not recognizing that we are not feeling the full strength of what we put out because the ocean has been this wonderful thing, and that is gradually going away; and also that as the oceans become more acidic, they are starting to get near the tipping point for hard-shelled organisms to be able to make their shells. And it is a combination of temperature and acidity that in the tropical regions some estimates, the sort of business as usual estimates, is that by 2050 a lot of organisms such as corals and shellfish will not be able to create hard shells.

The CHAIRMAN. And this additional emission of CO_2 is what leads directly to the acidification of the ocean?

Ms. PARMESAN. Yes, absolutely, as far as making Coca-Cola.

The CHAIRMAN. Meaning?

Ms. PARMESAN. You add more carbon to the atmosphere, more of it gets absorbed by the ocean, and that makes propionic acid, so gradually it becomes more amorphic.

The CHAIRMAN. So it is like making Coca-Cola is not too far off the point either?

Ms. PARMESAN. No, I was serious.

The CHAIRMAN. It is serious, but it also an easy way to understand the point for ordinary people, because everyone knows when you are shaking up something with too much carbon in it.

Let me now recognize the gentleman from California Mr. McNerney for 6 minutes.

Mr. MCNERNEY. Thank you.

I just finished a diatribe on how global warming can energize us and give us a national purpose. Dr. Parmesan, many of the changes we are seeing just in biodiversity and species reduction, just on a .7-degree change, that is Centigrade, right.

Ms. PARMESAN. Centigrade.

Mr. MCNERNEY. Well, it seems that this is a proverbial canary in the mine. Do you see that we are approaching a major breakdown in international health because of global warming?

Ms. PARMESAN. On the health issue what really worries me, as I said, all the diseases, the parasites that cause humans to become sick are generally not monitored in the wild. So we know when we go to Mexico, we have a really high risk of getting diarrhea. Well, part of the reason is that they have lot more parasites there, a lot more harmful bacteria than we get in the temperate zone. So as we are seeing birds and butterflies moving northward, it is very, very likely that those parasites and the vectors of human parasites are also moving northward even if we don't have the data, because butterfly collectors don't go out and collect worms and protozoa.

Mr. MCNERNEY. We hear a lot about biodiversity. We have heard about it for 20 years or so now. It seems like as we eliminate more species, we are getting closer to a point where systems are going to be breaking down. Is that your vision of where we are headed with all this?

Ms. PARMESAN. That is a very active side of research, at what point—we know that ecosystems are interrelated sets of species. How many species can an ecosystem lose and stop being able to function in terms of human services, in terms of watershed capability, in terms of filtering the air, et cetera? That is a big debate. There isn't a number on that.

But what I can say is we are actually seeing whole ecosystems being destroyed. So coral coral reefs are an ecosystem, and we have lost 30 percent in the area globally already with .7-degree Centigrade warming. Arctic ecosystems are declining in general. I cannot give you like a number, if we lose 20 percent of the species, we are going to lose our ecosystem services, but what I can tell you is we are literally losing whole ecosystems that we do rely on. Coral reefs provide tourism. There are fisheries. There is a huge amount of economic gain from coral reefs that is being lost.

Mr. MCNERNEY. I am going to direct my next question to Dr. Ebi. You noted that the U.K. has a global warming agency that could be a model for us. How do they deal with business integration into the solutions that might be found for this problem?

Ms. EBI. The U.K. Climate Impacts Program, U.K. CIP, is funded by the U.K. Government, as I noted, for 10 years now, and it focuses on adaptation. And it works directly with the government; it works with communities, schools, businesses, the insurance industry on what kinds of changes they can see at their local level. They have got downscaling to a very fine scale in the U.K., and then work with the people, the schools, the businesses, the regional centers on what that would mean then for what kinds of things do they need to adjust to. Do they need to change their flood risk policies? Do they need to look at their housing infrastructure? How are they going to deal with heat waves? How can they start making changes so that they can deal with the change in temperature and precipitation that already occurred, what is built into the system and what is projected, then flows into the mitigation policies to make sure that adaptation and mitigation work together so that we can make all our communities as resilient as possible?

Mr. MCNERNEY. Well, is there like a venture element to this or a venture fund element or some way to encourage businesses to move in that direction that would mitigate the problem or adapt, whichever the case is?

Ms. EBI. I don't specifically know if they got venture capital funding. I do know they have been working with business and industry. I know that the British insurance industry has put out a whole very detailed book on how they are going to be adjusted. So they are working to make sure that innovation does take place.

Mr. MCNERNEY. Thank you.

Mr. Chairman, I yield back.

The CHAIRMAN. The gentleman's time has expired. The Chair recognizes the gentleman from Washington State Mr. Inslee for 5 minutes.

Mr. INSLEE. Thank you.

I would like to ask you for some professional advice for free if I can. One of the mysteries to me is we have this enormous consensus in the scientific community about the human contribution to climate change; I mean, enormous consensus across the international spectrum, multiple fields, multiple studies. It really is quite compelling. It is also combined with now our visual observation of being able to see these things with our naked eye, with melting glaciers and ice caps and changes in vegetation and biological patterns, which I thought the testimony was interesting on.

So the question I would like to ask you about is with all of that enormous scientific consensus and even visual impacts that we can see with our own eyes, we still have people who are basically ignoring the signs, blinding themselves to it, still saying that scientists don't know what they are talking about, or it is the sunspots, or how can humans possibly change the climate of the Earth because we are well less than 10 percent of the total CO_2 going into the atmosphere, so how could we possibly influence the climate? And it is really surprising to me because these are people who depend on science in their life. They use a microwave oven, they use a cell phone, they depend on quantum mechanics, they ride in airplanes, they trust science, their lives are dependent on science, but when it comes to this issue, they want to ignore it.

And I guess just the question is do any of you have any advice on what helps people understand the degree of consensus and get over some of these hurdles? Now, my theory has been it is fear. People are afraid that we can't deal with it. People tend to ignore what they fear. So I am doing some things to try to get people to have a little confidence so we can skin this cat. But I just ask your advice in that general realm how to help people come to terms with this issue.

Ms. EBI. I have two different responses. I think you are right, people need to know that there are a whole range of things that they can do, and that they are fairly simple. And there is a number of people working very hard to get that message out.

Another thing that we really haven't talked about explicitly here is, as I like to say, the weather is going to win. If you look at Europe in the last 5 years, they have had more than eight 1-in-500-year weather events. They have been inundated with very severe weather events, and we have been very fortunate in the States that we have not. And I personally don't see why our luck will hold for a long period of time. And so ultimately the weather has been convincing people around the planet.

I have been working with eight developing countries on adapting to climate change. And people on the ground are seeing changes. They are seeing them faster than what we are seeing in the scientific literature. And you go out on the ground, and people know what is going on.

Mr. INSLEE. Anyone else want to take a stab at that?

Dr. Hansen.

Mr. HANSEN. I would like to comment that we need to educate the public about the fundamental difference between this climate problem and prior global problems such as air pollution when we are talking about particles in the atmosphere, because in that case we could see the effects, and we could take actions, and the effect of our actions would be immediate because particles fall out within 5 days.

In the case of the climate problem, what is very clear to the scientists is that there is a long time constant, so we have only felt part of the impact of the gases that are already in the atmosphere. And the physics is straightforward. So it makes it a much more dangerous problem because of this lag effect. And the proof of that is in the fact that we can prove that the planet is out of energy balance. There is more energy coming in than is going out, and it is going into the ocean, and that means that we have got almost as much warming in the pipeline as we have already seen. And as we have heard this morning, even the 7/10 of a degree that we have seen is noticeable. So we need to make these sort of simple facts clearer to the public.

Mr. INSLEE. I want to ask you about the economics of this issue. We heard some people argue that we should just do nothing about this because it might have some impact on our economy. And that strikes me it would be an interesting academic exercise except they always forget the economic losses we will have from inaction.

Now, the most comprehensive review I have seen is the Stearn's report that suggests we will have I think it almost a 5 percent reduction in global GDP ultimately if we remain on this course of inaction. Could any of you comment on that and how we should think of that?

The CHAIRMAN. The gentleman's time has expired. I would like to be able to recognize the other panels who have come back, but the panel, please, very quickly answer that question, anyone who would like to take it.

Ms. PARMESAN. Well, as I have said earlier, we are already seeing economic impacts as small islands and States' coastal areas that rely on coral reefs are already seeing huge economic losses.

The CHAIRMAN. Anyone else?

The gentleman's time is expired.

The Chair recognizes the gentleman from Oklahoma, Mr. Sullivan, for 7 minutes.

Mr. SULLIVAN. Thank you, Mr. Chairman. I just have a few questions I would like to ask the entire panel, and I do appreciate you being here today, and I appreciate your testimony.

What action should the Federal Government undertake to reduce CO_2 emissions?

Dr. Hansen.

Mr. HANSEN. I mentioned several things in my testimony. I think the most critical thing concerns coal, because coal has far more CO_2 than oil and gas. And oil and gas are very convenient mobile fuels, but coal can be used for power plants. And in that application it is practical to capture the CO_2 and sequester it, and we are talking about doing that, but until we have that technology, we shouldn't be building any more coal-fired power plants with the old technology because it is going to become very clear within, I would say, less than 10 years that these old power plants are going to have to be bulldozed. So it is economically stupid to build them.

Mr. SULLIVAN. What kind of time frame do you think these technologies of sequestration can be competitive with other fossil fuels?

Mr. HANSEN. It is expected it is still going to take another 6 or 8 years to have full-scale carbon sequestration for power plants. You could speed that up maybe a couple of years. But in the interim there is plenty of potential in energy efficiency that we can avoid the need for new coal-fired power plants if we would encourage energy efficiency. The building engineers and builders realize that they can make the new buildings 50 percent more efficient right now. The technology is available for that, and we need to encourage that and see that it happens.

Mr. SULLIVAN. So you think coal, did you say, would eventually be out of the equation totally?

Mr. HANSEN. I think coal is very likely to be a major energy source, but it should be used in a way that doesn't put the CO_2 into the atmosphere.

Mr. SULLIVAN. By using technologies and things like that, right?

Mr. HANSEN. With the sequestration technology, yeah.

Mr. SULLIVAN. What other technologies do you think we could use?

Mr. HANSEN. I think that we should let the market decide what are the most effective technologies. That is why I say we need to have—the market needs to understand that there is going to be a gradually rising price on the emissions, and if that were the case, then the different renewable energies and energy efficiency itself could compete very effectively. There is tremendous potential in energy efficiency and in renewable energies, so that is why I say the best way to do it is to put a rising price on the emissions and then let them compete.

Mr. SULLIVAN. Dr. Curry.

Ms. CURRY. In the past two decades we have spent so much time saying is it really warming, are we really causing it? And we are just now coming to the, well, what are we going to do about it?

I believe that what we need to spend some time—not delay, but spend some time—to really assess the policy options and what their implications are for the economy, what their feasibility are, and what their political viability are. And I think without recommending specific policies, I think we need to fundamentally change the incentive system in terms of how we do things so that we can promote effective dealing with this issue.

Mr. SULLIVAN. Sounds good.

Ms. PARMESAN. I couldn't agree more with both people who came before me. There are a couple things I wanted to add. One is that we have an enormous amount of technology that we are not using. Carbon sequestration is actually doable right now in certain areas. For instance, the Texas coast, where you have a huge number of coal-fired plants, is right next to an enormous salt dome. The technology exists for doing it, but they need the infrastructure, and no money is being put forward to do this. Better more fuel-efficient cars, we have the technology; again, there is not the incentive for people to buy them.

In terms of renewable energy, it is very nice in theory, but a lot of the renewable energy alternatives do have negative biodiversity consequences. Sometimes they are fine, as you will see in my written testimony; in other cases they are not. So those need to be looked at carefully before just sort of jumping on the bandwagon and saying we should put up windmills everywhere and we should convert everything to biodiesel.

Solar panels. Solar energy is perhaps the single one that has absolutely no negative consequences in terms of biodiversity as far as I know. The technology again is there. It is not being implemented as much as it could be.

Ms. EBI. In addition to looking at technologies, you have an opportunity here to take a look at other policies. I have worked quite a lot in Europe, and Europe is redoing its transport policies, in part in response to reducing emissions from cars, but also to try and address problems with growing obesity and trying to create communities where people can walk to work.

So you can look at a broad range of things that ultimately come under the rubric of energy efficiency, but if you look more broadly, you will find places where you can make a change that will help in areas more than just emissions.

Mr. SULLIVAN. Dr. Helms.

Mr. HELMS. I would like to comment in terms of renewables. I think there needs to be a level playing field relative to the tax incentives that are used to encourage wind and geothermal, which happen to be about twice the incentive that is for woody biomass. So I think it would be helpful to take a look at that and see whether these incentives for renewables could be made a little more equitable.

Mr. SULLIVAN. Another question I have. Do you feel strongly that nuclear energy could be part of a climate change solution which should be a big part of the mix?

Dr. Hansen.

Mr. HANSEN. I think it needs to be looked at. As you know, there are still some disadvantages with nuclear power, but the next-generation nuclear power, the current potential for nuclear power can solve some of the problems that are associated with potential accidents, for example. Nuclear power does not produce CO_2, so it is—if consumers are willing to have nuclear power plants, then it certainly should be part of the mix.

The CHAIRMAN. The gentleman's time is expired. I apologize to the gentleman, but I just have time to let the gentleman from Connecticut be recognized for 5 minutes before we all have to run over for the roll call. The gentleman is recognized.

Mr. LARSON. Thank you, Mr. Chairman. I want to thank the panelists as well, and I want to commend all of you.

And, Dr. Hansen, let me say to you that I agree with you about the establishment of a czar. I recommend that the czar be Alan Greenspan. I think that it would make an awful lot of sense. And as Shakespeare would say, more truth is said in jest than not. But when we sort all through this, and you have been questioned by everyone not necessarily in your field, but on the economics and legislation of this, and I do think that it has been noted through a number of the testimony that we have heard to date since the committee's inception about the need for financial platforms and the need to make sure that we have the wherewithal to deal with this issue, and having someone like Alan Greenspan in the position of a czar who could oversee ultimately monies that would have to be granted or the benefits of a cap in trade policy.

So I want to cut to the chase, given that it doesn't seem as though anyone on the panel doesn't agree that climate change is imminent and that it could be disastrous if we don't act now and too late, but that means outside from all the good policy issues, et cetera, making sure that we have the financial capability to do so.

And so in your testimony, Dr. Hansen, but we didn't get a chance to hear from the rest of the panelists as well, you talk about a form of carbon tax. I would call it more an antiterrorist tax, inasmuch as we heard testimony on national security that this is really a national security issue, et cetera. But there is a tendency for these things to be talked about in a way that avoids the issue, much like the issue has been avoided of addressing global warming and climate change itself as to how we are going to pay for it. And if you followed Representative Sensenbrenner's questioning, he was asking you to come up with the pricing of what that would be. I think that might be best left up to another body.

But would you all readily agree—or at least I would like to hear your opinion on whether or not you think that this kind of a tax or front, shall we say, is something that if we don't do, I just don't think we can continue to kid ourselves that we won't have the monies available to do the various things that you want to do with forestation from a biological standpoint or from the standpoint of making sure that we are able to preserve the West Antarctic Ice Sheets.

We will start with Dr. Hansen.

Mr. HANSEN. There is no reason that a tax has to be a reason for the government to get deeper into your pockets overall. You can have some compensation elsewhere. But I do think there has to be a price on these emissions. They are not paying for the costs that they are incurring. And so I think it is essential. To solve the problem we are going to have to put a price on the emissions. It is just too easy. Some of these fuels are so easy, so cheap to mine.

Mr. LARSON. So what you are saying is to do that further up the line, so to speak, than actually in the consumer. Some would argue that they will pass that along to the consumer, but I assume that is what you are talking about.

Mr. HANSEN. Frankly, I am not a person to say where that price should be imposed, but it has got to be there so that the person who is using the energy will feel a difference if he conserves the energy.

Mr. LARSON. Thank you, Dr. Hansen.

Dr. Curry.

Ms. CURRY. Right now carbon emissions are an externality. We basically do it for free. The key issue is to put a value on the carbon.

Mr. LARSON. Who would you recommend place that value?

Ms. CURRY. I don't know.

Mr. LARSON. A combination of scientists and, say, economists?

Ms. CURRY. I would guess so. But the key issue is to change the incentive structure relative to that value.

Mr. LARSON. Dr. Parmesan.

Ms. PARMESAN. I agree. I think we need to do things that will change individual behaviors. And I just want to bring up one example that Britain has done that brought in a lot of taxes, but it allows the consumers to actually choose how much tax they are going to pay. So, for instance, the yearly car registration there is based on the amount of carbon dioxide emissions, nothing else. And it goes from zero up to $400, and that top end is about to go up to $800. So as a consumer you can choose to buy a car where you have zero tax.

The CHAIRMAN. We have 1 minute to make the roll call on the House floor. We thank the panel. We are going to take a brief recess, and then other Members will come back, and I will recognize them at that time. The committee will reconvene. While we are waiting for the members to come back out, I will ask some questions.

You have noted that our increasing hurricane risk is a combination of changes from global warming and societal changes. We noted in the Gulf of Mexico we have lost area highlands and wetlands over the last few decades.

Is restoring these natural barriers one of the ways we can prepare for stronger hurricanes? What are some of the other policies that you would suggest?

Ms. CURRY. Well, I think the issue with hurricanes is an issue where adaptation policies do make sense. Restoring the wetlands, I think, is something that makes very much sense in New Orleans.

How this is going to do it—how to do this most effectively and have it help, effectively limit our damage on a time scale that is going to get us through these next few decades, I am not an expert on this. But I will emphasize that I think that adaptation, particularly on the gulf coast, is something that will help the issue address the threat that we see, particularly in the coming—the threat is upon us, and it is going to be increasing fairly rapidly in the next few decades.

The CHAIRMAN. Dr. Hansen, you mentioned that the entire East Coast could be at risk and especially Florida. Could you elaborate a little bit on that? And what is the cause of the most likely threat that you can see to the East Coast of the United States and to Florida, and what is the time frame you are talking about?

Mr. HANSEN. Well, the—we know that if you go back a few million years ago, that sea level was 25, plus or minus 10 meters higher. We know there are actually so-called "Orangeburg scarp" which show where the shoreline was. We would lose cities from Boston, New York, Philadelphia, Washington, if we were to get a comparable sea level rise.

Now, the question of how long does it take ice sheets to respond to a forcing is the big question, and that is practically impossible. You can't make a precise prediction on when a nonlinear process is going to go unstable, but we know that the time constant from looking at the Earth's history is not longer than centuries.

The CHAIRMAN. Is the threat to the East Coast of the United States more from Greenland or from the west Antarctic; or does it make a difference, in other words?

Mr. HANSEN. It is from both, but west Antarctica is the one that can respond more quickly because it is a marine ice sheet which, as I say, has been attacked from both below and above. So, frankly, I think that the experts that I—in glaciology that I respect the most are very concerned that there could be sea level rise this century measured in meters; and no one wants to speculate on a number or when you start getting a very large effect, but just at what is already happening. Over just the last 100s of years, the rate of sea level rises increased from 12 centimeters per century to, now, 35 centimeters per century. So it is already more than a foot per century, and it is getting higher all the time.

The CHAIRMAN. Let me turn to recognize the gentlelady from Tennessee, Ms. Blackburn, for 7 minutes.

Mrs. BLACKBURN. Thank you, Mr. Chairman, and I truly want to express my appreciation to you all for enduring with us as we go through votes and running back and forth to the floor. As you can see, we get plenty of exercise around here.

I have questions for Dr. Hansen, Dr. Curry and Dr. Ebi, and I think I will start with you, Dr. Ebi, if I may.

With the IPCC report—and, Mr. Chairman, I have a summary I want to submit for our record. It is an independent summary for policymakers of the IPCC report; and I would like, with your permission, sir, to submit this for our record.

The CHAIRMAN. I apologize.

Mrs. BLACKBURN. That is okay. I just want to submit—I have got an independent summary for policymakers.

The CHAIRMAN. Without objection, it will be included.

[The information follows on page 143.]

Mrs. BLACKBURN. Thank you, sir. I appreciate that.

But, Dr. Ebi, some of the disasters, many of the disasters from—the IPCC report, which is helpful in going through this and being able to look at different things is very helpful to us—these are going to occur from time to time and have seemed to occur throughout history regardless of global warming and whether or not that plays a role.

And when you are looking at this, shouldn't they be faced directly? Hurricanes, droughts, diseases, things of that nature be faced directly, irrespective of global warming, just as stand-alone causes, rather than having to wait or address it via the global warming filter?

And my second question to you is, as you look at your report and then as you read about economists and scientists who talk about prioritizing health, water, education, famine, the things that we see, hunger, things that we are seeing happening in some of our developing nations, prioritizing that first before those countries address global warming?

So how do you stack that up in your thought matrix?

Ms. EBI. The two questions are related. The things that we are worried about with climate change, most of them are risks to health right now; and there are very large programs to try to reduce those risks, because we do like to save human lives. We don't like to see people suffer and die needlessly when we can prevent that.

What we do see with the projections on climate change—with what has already happened since 1961 to 1990, what is happening today and what is projected for the future—is that these risks are going to increase. And we know that these are putting a strain on resources, and that when you get at the country level, countries have to make choices of where they are going to spend their very scarce dollars.

Basically what you are asking, in some way, is—one of the phrases we use in the States—is robbing Peter to pay Paul, saying, why don't you use the resources you already have to address increased heat waves, address increased malarial deaths? And that money, if it is dealing with those kinds of issues, is not going to deal with other issues. It is not going to deal with HIV/AIDS, it is not going the deal with obesity, it is not going to deal with child malnutrition.

There is a responsibility here because of the emission of greenhouse gasses, and traditionally when we looked at large environmental issues, we have looked at where the sources of those emissions have been, whether it is an occupational exposure, an environmental exposure; and so we need to deal with those.

Mrs. BLACKBURN. Okay. And I ask that simply because, as you read your report and look at your things—and you don't have to respond back to this—it seems that you prioritize the global warming issue above the others. And I find—think that would be a very difficult position for many of these developing nations.

Dr. Curry, I wanted to ask you, in your report, you use hurricane intensity data, 1950 on. And do you consider that data, prior to 1950, unreliable?

Ms. CURRY. I have discussed the issue of data reliability extensively in my written testimony. I do not believe the intensity data prior to 1970. However, the counts, I believe, aren't too bad, even back to 1851. There have been some estimates of the uncertainty.

Mrs. BLACKBURN. Just the counts? Not the intensity?

Ms. CURRY. The intensity I do not believe prior to 1970, frankly.

Mrs. BLACKBURN. How much research funding have you received to examine the effects of the hurricanes with regards to climate change?

Ms. CURRY. None. Subsidized by Georgia Tech specifically.

Mrs. BLACKBURN. By Georgia Tech.

And, Dr. Hansen, I wanted to talk with you a minute about the hockey stick theory. We had a hearing on that last year on the paper that was published by Dr. Mann. And we had independent statistical analysis by Professor Wegman and the NRC, and they showed some fatal flaws in that paper. And all of that was really very interesting to me, because I remember growing up in the 1950s and 1960s and being in high school and through the early 1970s when we were in an ice age, an ice age was coming and we were warned about this ice age.

So then you turn around and before too long, you have children who are in school and it is all about warming, which at one point we were told we were supposed to have. But I asked Dr. Mann about some of these problems with his paper, and he didn't want to answer questions dealing with independent statisticians and independent reviews.

So, to you, what is your opinion on the use of the independent statisticians reviewing science papers such as Dr. Mann's and others who analyze large amounts of data that are used for temperature reconstructions?

Mr. HANSEN. Well, I think that data that scientists use for their analyses should be made available.

But, you know, this is kind of a red herring; and I think if you look in my testimony, I have found other data that we can look at to see how the current temperature compares with earlier temperatures on the Earth. What we see is that, especially in the most important regions, tropical oceans, that the recent warming is indeed rapid and is putting us back two levels that are at least comparable to the warmest in the current interglacial period and within less than 1 degree Celsius of the warmest interglacial period in the past million years.

So the basic conclusion of Mike Mann that the recent warming is sudden and is taking us into new territory is a valid conclusion, even though you might question some of the mathematical methods.

The CHAIRMAN. The gentlelady's time has expired.

The Chair recognizes the gentleman from Missouri, Mr. Cleaver.

Mr. CLEAVER. Thank you, Mr. Chairman.

I will move quickly, and I apologize again, as the chairman has, that we had to leave you here while we went to vote.

I have—my family is in Tanzania. They live in Arusha, in and around Arusha. I haven't been there since 1995, but I flew into the airport; it is called the Kilimanjaro Airport. I landed at the Kilimanjaro Airport which is in the shadow of the mountain. Flying in or flying out in 1995, I saw what my ancestors saw 2,000 years ago which—what they called the "whitecap" worn by the mountain.

It takes 3 days to climb Kilimanjaro, and I have a cousin who does it once a year. You start out at the bottom with shorts, warm—you have to deal with the warmth—but by the time you get to the top, you have to have a jacket because it gets cold.

Now you can go from the bottom to the top with virtually no temperature change, and most of the snow is gone, which the Masai tribe in the area in which—my relative is one of the elders. They said that they attribute demonic causes because it has always been there.

They have in Arusha, there is one little source of water and people wash their cars in it and then boil it and then do all kinds of things with it. But not far from the downtown area are sprinklers going 24 hours a day just watering exotic flowers so that people in the Western world can have fresh flowers each day.

This is not an industrialized country. The average income is below $1,500 a year. They didn't—they didn't do anything to contribute to this problem. And so what—you can stand out in an open field in the Serengeti at night and see the craters on the moon. You know, the sky is clear. There is no factories anywhere in the country.

What can we do in a country like Tanzania? Any of you? Dr. Ebi?

Ms. EBI. I had the privilege last year to work on a project funded by USAID in Mali, working with farmers in the southern part of Mali to try and adapt to climate change. During the year in which I worked there, the Mali Mission reported that their budget had been cut 50 percent.

USAID is doing marvelous work around the world, helping people right now adapt to current climate variability; and I have to say, in that region, the farmers reported the temperatures have gone up several degrees, water availability has gone down.

No one has mentioned here that when it is warmer, you get more evaporate transformation from the soil, the soil gets drier. We have had a decrease in rainfall in sub-Saharan Africa, and these farmers have done everything their ancestors have taught them to do, and they are turning to any external source that will help them to figure out how they can increase their crop yields. They are changing their seed varieties; they are changing the way they are planting. They are innovating in ways that their ancestors never did, and they still need more help.

There is a lot that we can do. There are organizations such as the Global Environment Facility that is funding adaptation work around the world. I am working with the World Health Organization in seven other countries on this very issue. There is USAID. We have got a lot of different mechanisms whereby we can get money to different organizations and different donors to help the people that are working right now to reduce vulnerability.

Mr. CLEAVER. You mentioned earlier that this is a social decision. This is a choice, social choice, that we are contributing in the Western world by supporting what I think is a sinful use of water in those countries so that we can have exotic plants in the hotels in downtown Washington.

Ms. EBI. And you didn't mention my personal favorite soapbox. Look at how many golf courses go into regions that don't have enough water; they use an awful lot of water.

Mr. HELMS. I had the pleasure of being in Tanzania a month ago and was impressed to see the amount of woody biomass that women had to carry; and so it reinforces the point that in the world at large, most of the wood in the world at large is used for fuel, fuel for heating in developing countries.

And so one issue that would be of concern is, what ways and means can there be in Tanzania to assist in developing reforestation projects that take the burden off the women who are having to carry fuel for such a long distance to make woody biomass a little more readily available?

Mr. CLEAVER. Thank you.

Let us assume that the world experiences an epiphany, and everyone decides today at 1 o'clock that we are going to do the right thing ecologically and environmentally.

Based on something that Dr. Helms said, it is still a bit chilling to me that if CO_2 has the shelf life of 500 years. If we stopped everything today, what are the problems that would continue?

Ms. EBI. Several people have mentioned we are committed to at least another 1 degree Fahrenheit of warming.

Mr. CLEAVER. No matter what?

Ms. EBI. We are committed to more warming no matter what.

There was on the back table something from the National Environmental Trust; I am sorry they have run out. It is a temperature chart showing what has happened—based on the IPCC, what has happened with current warming and what is projected with each degree of temperature.

And I can give you the Web address to download that. It is a nice summary.

The CHAIRMAN. The gentleman's time has expired.

Mr. HANSEN. Could I make a quick comment, an optimistic comment?

Currently, of the CO_2 that we put into the atmosphere, 42 percent is taken up by the ocean or biosphere. If we reduce our emissions sufficiently, it is possible to actually decrease atmospheric CO_2 and avoid a lot of problems that people are beginning to argue—are beginning to feel are inevitable.

I don't think they are inevitable. It is going to take major actions. People haven't yet realized how serious the problem is and what actions are required. But it is possible to deal with these things.

The CHAIRMAN. You are saying they could actually come back from the parts per million, from 380 parts per million back down?

Mr. HANSEN. Absolutely. That is when I am talking about drawing it down with biofuel power plants. You actually draw down the amount of CO_2 in the atmosphere.

The CHAIRMAN. So it is not irreversible?

Mr. HANSEN. It is not irreversible. But, of course, if you go too far and the ice sheet collapses, that is irreversible on time scales of less than tens of thousands of years. So you have got to start taking your actions soon enough.

The CHAIRMAN. What is the number one action that you would say——

Mr. HANSEN. The number one action is a moratorium on new coal-fired power plants.

The CHAIRMAN. And then what would happen if there was a moratorium in terms of the reversing and reducing. What is the phenomenon that would unfold that would—that would remove the carbon from the——

Mr. HANSEN. Right now, as I mentioned, you know, 40 percent of the emissions are taken up. So if you reduced your emissions tomorrow to 50 percent, you would get a slight uptake for at least some years.

But if you really want to draw it down, then start sequestering the CO_2. If you burn biofuels in a power plant, for example, and sequester the CO_2, the biofuels are drawing the CO_2 out of the atmosphere and you are putting it back where it came from, in the ground.

The CHAIRMAN. Thank you, sir.

Well, you know, we can adjourn this.

What I am going to ask each one of you is to give us a 1-minute summation of what it is that you want us to remember.

We will come back from you, Dr. Helms. But I am just wondering if Mr. Cleaver or Mr. Hall, do you have any final question you would like to ask?

Mr. HALL. Thank you, Mr. Chairman. I have just a couple of them.

One is too elementary probably for all of your degrees. You are overqualified, in other words. But methane was talked about before, and I was curious if by capturing methane from landfills or from farm waste or from wherever and burning it, which produces, among other things, CO_2, would that not be an improvement over just allowing the methane to escape into the atmosphere?

Mr. HANSEN. Yes. That is—that helps. You do produce CO_2, but it has much less of a greenhouse effect than the methane.

Ms. EBI. This is certainly outside of my expertise.

I have listened to many economists and climatologists debate this, and they are viewing these kinds of technologies essentially as a safety valve; if climate change starts going even more rapidly than it has been, the question is, when do you want to deploy that technology. Do you want to deploy it today, or if you are concerned about the rate of warming in 10 years, do you want to do it in 10 years?

So, again, it comes down to choices of when you play that card, of when it would be most effective to try to reduce the most impacts.

Mr. HALL. Thank you.

And in my county, the five counties that I represent, which are all currently under a disaster declaration because we have had three 50-year floods in the last 18 months, can I tell people where there is no proof of cause, it nonetheless is consistent with what models show of extremes of weather phenomena as the climate changes?

Anybody can take that.

Mr. HANSEN. I mean, we know that the extremes do increase as the globe gets warmer; the extreme events and, in particular, the hydrologic cycle do get greater. And it is reasonable to expect that the 100-year floods are going to be more frequent, especially in the eastern U.S., I think.

Mr. HALL. Thank you, Mr. Chairman. That is all I have.

The CHAIRMAN. I thank the gentleman.

Mr. Hansen, you have a new paper coming out?

Mr. HANSEN. Yeah. I have four new papers coming out, which I listed in my written testimony; part of my testimony today is based on those papers, yes.

The CHAIRMAN. If there was a headline over what you were adding to what you have said in the past, what would that headline be?

Mr. HANSEN. I think the headline which has become clear in the last year or two is that the level of dangerous human-made interference is a lot lower than we thought a few years ago. We had thought, well, a couple of degrees, maybe we can deal with that. But I don't think the west Antarctic ice sheet has a prayer even if we go 1 degree Celsius warmer than now.

But in a sense that is good news, because it means we are going to have to figure out how to solve—how to meet that cap, and it is going to solve a lot of these other problems that we were beginning to think we are going to have to adapt to. Maybe we can mitigate them.

The CHAIRMAN. Let us turn, and we will ask each one of you to give us your 1-minute summation.

Dr. Helms, please, whenever you are ready.

Mr. HELMS. I would like to leave the message that forests, although they won't solve the issue, they are a terribly important component.

The first thing that needs to be done is to make sure we stabilize the forestland base and look at why it is that we are losing 1 million acres a year to development, why are there so many disincentives to small, private landowners to sell our land.

The second thing that we have really got to come to grips with is wildfire and enhancing forest health, particularly on public lands. We have got to do something about this because it is going to get worse.

And the third thing I would leave is to take a realistic look at renewable wood from the standpoint of its carbon footprint, life cycle assessment, comparison with alternative products and its use for biofuels and wood pellets.

There is every reason why we should be using more wood, not less.

The CHAIRMAN. Okay. Thank you, Doctor, very much.

Dr. Ebi.

Ms. EBI. I would like to leave just a couple of messages. We are seeing climate change already. The people who are working on this issue are very concerned because we are seeing it more rapidly and much sooner than had been expected. We do need to mitigate and we do need to adapt and we do need to do both of those urgently. Your leadership is required in order to do so.

I urge everyone not only to focus on what we need to do about mitigation. Adaptations are a win-win which should be something that you should be able to create a policy around, You have got agencies that are working on that issue right now; have them be responsible for responding, taking the risks and responses of climate change into account in the policies that they create.

The CHAIRMAN. Thank you, Doctor.

Dr. Parmesan.

Ms. PARMESAN. Yes. I would like to say that "business as usual" leads to the worst case scenario, which is this 4 or 5 Centigrade rise that we cannot afford in terms of biodiversity laws, in terms of human health, or in terms of our economic systems. And the only way to keep down to the best case scenario, which is still more than twice what we have already seen, is by immediate implementation of whatever use you can come up with that would reduce CO_2 and other greenhouse gas emissions.

The CHAIRMAN. Dr. Curry.

Ms. CURRY. I am relieved to see that the U.S. Federal policymakers are beginning to accept that dangerous climate change is upon us if we continue with business as usual and are now asking the question, what are we going to do about it. Again, I urge you to consider both adaptation and mitigation strategies.

And I would also like to add that there is—as we deal with this complex and urgent problem, there is much room for mischief in policy-making that would not—that would have unintended consequences and not meet the objectives, all sorts of opportunities for pork and all sorts of problems. I urge careful consideration, complex, you know, analysis of the policy options so we get something that will be effective, economically feasible and politically viable.

The CHAIRMAN. Thank you very much.

Dr. Hansen.

Mr. HANSEN. I would like you to have in your mind the chart that is in my testimony, a bar graph showing that oil and gas are relatively small bars, coal is huge and the unconventional fossil fuels are huge.

Now, the oil and gas are very valuable fuels, and we need to stretch them until we can get to the next—beyond petroleum. But because any of these fossil fuels, you put the carbon in the atmosphere, it is going to stay there a long time, so we can't afford to put the coal and the unconventional fossil fuels in the atmosphere.

So if we are going to use those, we are going to have to capture the CO_2 and sequester it.

The CHAIRMAN. You said unconventional fossil fuels.

Mr. HANSEN. I mean tar shale, tar sands, methane hydrates. There is a tremendous amount of those, and we just—and there are companies that are making plans to cook the Rocky Mountains and drip oil out of them. It is very energy intensive, and the planet is sunk if we allow that to happen.

The CHAIRMAN. Thank you very much.

Mr. CLEAVER. I have a suggestion on a paper for you. Thank you for agreeing.

China signed the Kyoto Protocol, and they are starting a new coal-fired power plant every 3 days. Could you write a paper on what you think they would be doing had they not signed?

The CHAIRMAN. I thank the gentleman very much.

I want to, first of all, thank you, each of you. You brought a lot of expertise to this committee.

Speaker Pelosi has only been in office now for 4 months. She is only creating one select committee for her first 2 years as Speaker; it is the Select Committee on Energy Independence and Global Warming. And so I think you can actually feel the whole system responding to this intense interest which the Speaker has in this issue and her public announcement that she intends on passing legislation with a mandatory cap and trade system within this 2-year period.

So this testimony helps us a lot. It actually helps to build the momentum. It helps us to understand the issue better and to take a smart action that not only won't harm our economy but in the long run, help our economy, which is, I think, the surprise ending as long as we work smarter, not harder, and deal with this in a wise way.

And so your testimony has been very helpful. We look forward to any other advice that you might want to give the select committee in the months ahead, because we intend to be putting together a very intensive work schedule.

With that, this hearing is adjourned.

Thank you.

[Whereupon, at 1:10 p.m., the select committee was adjourned.]

Questions for Dr. Curry

1) *You say that there is a scientific consensus that hurricanes are getting more powerful. Yet, the latest World Meteorological Organization consensus statement from December says no such thing: "no firm conclusion can be made at this point." "1. Though there is evidence both for and against the existence of a detectable anthropogenic [human-caused] signal in the tropical cyclone climate record to date, no firm conclusion can be made at this point. Mr. Emanuel whose paper you quote in your testimony is part of World Meteorological Organization consensus. Are you wrong about the scientific consensus?*

A point of clarification: I did not use the word "consensus" in my written or oral testimony. It is a word that I deliberately try to avoid using. In my testimony, I attempted to assess the state of the understanding, including the uncertainties, as they related to the issue of hurricanes and dangerous climate change. There is very obviously no "consensus" on this topic as evidenced by the very public statements by Bill Gray stating that there is no connection between global warming and increased hurricane activity adding, in fact, that there is no such thing as global warming anyhow.

The WMO International Working Group on Tropical Cyclones is comprised of a mixture of operational tropical cyclone forecasters and tropical cyclone research scientists. The WMO statement is a fair representation of the community it represents, which is a rather narrow community and includes very few people that can be considered as climate researchers. In my opinion, the summary statement is a misleading representation of the complete WMO statement, which can be found at the following link:
http://www.wmo.ch/pages/themes/wmoprod/documents/iwtc_statement.pdf
Consider the following points from the complete statement:

13. The scientific debate concerning the Webster et al and Emanuel papers is not as to whether global warming can cause a trend in tropical cyclone intensities. The more relevant question is how large a change: a relatively small one several decades into the future or large changes occurring today? Currently published theory and numerical modeling results suggest the former, which is inconsistent with the observational studies of Emanuel (2005) and Webster et al. (2005) by a factor of 5 to 8 (for the Emanuel study). The debate is on this important quantification as to whether such a signal can be detected in the historical database, and whether it is possible to isolate the forced response of the climate system in the presence of substantial decadal and multi-decadal natural variability. This is still hotly debated area for which we can provide no definitive conclusion.

18. Given the consistency between high resolution global models, regional hurricane models and MPI (maximum potential intensity) theories, it is likely that some increase in tropical cyclone intensity will occur if the climate continues to warm.

21. There is general agreement that no individual events in those years can be attributed directly to the recent warming of the global oceans. A more appropriate question is whether the probability of an event happening in a particular basin has been increased by the ocean warming, as for example the probability of cyclone development can change according to the phase of ENSO or of the Madden Julian Oscillation. It is well established that global atmospheric structure responds to the tropical sea surface temperature, and that such a response will affect the potential intensity (MPI) as well as other environmental factors such as vertical shear and relative vorticity. Thus it is possible that global warming may have affected the 2004-2005 group of events as a whole. The possibility that greenhouse gas induced global warming may have already caused a substantial increase in some tropical cyclone indices has been raised (e.g. Mann and Emanuel, 2006), but no consensus has been reached on this issue.

The statements 13, 18, and 21 are not inconsistent with the substance of my testimony, although the nuances of the wording. The one substantive disagreement is in #13, where my careful analysis gives a factor 2-3 discrepancy between the observations and models/theory, compared with the WMO statement that the discrepancy is a factor of 5-8. I provide references supporting my analysis; the WMO statement does not. In comparing the WMO statement to the IPCC statements regarding tropical cyclones and global warming, it is worth considering several things. The IPCC report is an assessment report, worked on by a very large number of scientists, vetted by an extremely comprehensive external peer review process. The extensive external review of the IPCC report acts to filter out any technical errors in an analysis. The summary statements are very carefully vetted in collaboration with decision makers to insure that decision makers would not be mislead.

In contrast to the IPCC, the WMO statement was not submitted for external review (I identified one significant scientific error in the WMO statement regarding the magnitude of the discrepancy between observed intensity increase and that predicted by theory/models). The WMO statement is more properly regarded as a "consensus statement" rather than as an assessment report. The statement "for which we can provide no definitive conclusion" or "for which there is no consensus" are not statements that would appear in a scientific assessment report. Assessments attempt to report the level of certainty of the scientific research, using words like

virtually certain > 99%
very likely > 80-99%
likely > 50 - 80%
about an even chance 40-60%
unlikely 20- <50%
very unlikely 1-20%
virtually impossible < 1%

In this context, the phrases "no definitive conclusion" implies nothing beyond a certainty of less than 99% (which is a rare level of certainty in any scientific endeavor). The phrase "no definitive conclusion" simply is not a useful statement in assessing scientific research, and reflects the thinking of operational meteorologists rather than research scientists. In spite of the misleading wording of some their conclusion statements, I do not view the WMO consensus statement as disagreeing with the assessment given by the IPCC.

2) *Dr. Curry, you state in your testimony, "any conceivable policy for reducing CO2 emissions or sequestering CO2, is unlikely to have a noticeable impact*

on sea surface temperatures and hurricane characteristics over the next few decades; rather, any such mitigation strategies would only have the potential to impact the longer term effects of global warming including sea level rise. Therefore, are you suggesting that the U.S. and the world should first look at developing strategies to adapt to global warming and put a secondary importance on trying to stop Global Warming?

I am suggesting that adaptation to the threat facing coastal regions associated with elevated hurricane activity is an issue of considerable urgency, and that adaptation will be more effective in the short term in addressing the hurricane threat than reducing greenhouse gases. However, hurricanes are not the only threat facing the U.S. and world associated with global warming. Effective strategies to address global warming should combine adaptation and mitigation strategies. Because of the elevated threat in the North Atlantic in the coming decades, we need to act now to develop and implement adaptation strategies for vulnerable U.S. coastal cities and also in the Caribbean and Central America. Adaptation strategies are regional, and hence simpler to implement (both economically and politically) than strategies to reduce CO2 emissions, the latter being necessarily a global endeavor. We need to begin now to develop strategies to address the issue of reducing CO2 emissions that are technologically feasible, economically palatable, and politically viable.

3) *The summary of your testimony states that reducing CO2 emissions will help avoid the longer term risk associated with global warming. What actions should the federal government undertake to reduce CO2 emissions?*

Recommending specific policies regarding reducing CO2 emissions is outside of my area of expertise. The person that I look to as my primary source of information on strategies to reduce CO2 emissions is Dr. Joseph Romm. Dr. Romm was Acting Assistant Secretary at DOE's Office of Energy Efficiency and Renewable Energy during 1997 and Principal Deputy Assistant Secretary from 1995 though 1998. In 2006 he published a book, *Hell and High Water*, which addresses solutions to global warming using available technology. He has also published a number of books on energy efficiency and reducing carbon emissions and pollution with green technologies, including *The Hype about Hydrogen*, *Cool Companies: How the Best Businesses Boost Profits and Productivity by Cutting Greenhouse Gas Emissions* (the first book to benchmark corporate best practices for using advanced energy technologies, including fuel cells, to reduce greenhouse gas emissions), *Lean and Clean Management*, and *The Once and Future Superpower*, and other topics. He also wrote the National Commission on Energy Policy's report, "The Car and Fuel of the Future," (July 2004).

4) *What percentage of China and India's population are within 50 miles of a coastline? What policies should the US pursue to encourage dialogue regarding reducing CO2 emissions and refugees with these nations? Have you worked with your peers in the scientific community in China and India on this issue?*

There is a very considerable concentration of population along the coasts of India and China. The following paper provides an excellent analysis of this issue:

McGranahan, G., D. Balk and B. Anderson. 2007. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment & Urbanization* 19(1): 17-37 (2007). International Institute for Environment and Development (IIED). http://eau.sagepub.com/cgi/content/abstract/19/1/17

China and India rank #1 and #2 globally with the largest populations in low elevation coastal zones. In terms of percentage of total population, this corresponds to 11% (China) and 6% (India) in terms of the percentage of total population of these countries.

The coast of China sees the most landfalling tropical cyclones worldwide. The North Indian Ocean sees relatively little activity, with the majority of the tropical cyclones on the Bay of Bengal side (this is why Cyclone Gonu in the Arabian Sea was so unusual). While landfalls in India are relatively rare, they can be very deadly: the deadliest recorded tropical cyclone was the 1970 Bhola cyclone that killed over 300,000 people and possibly as many as 1 million, mainly in Bangladesh and India. Is the issue of tropical cyclones likely to be effective as a "hook" to raise the level of concern in India and China about global warming? Possibly, but probably not. It is only in the North Atlantic that the total number of tropical cyclones is increasing; in other regions the numbers seem to be steady or even slightly decreasing. Climate models project a slight decrease in the number of tropical cyclones in these regions (although the intensity of the storms is projected to increase on average). In the U.S., hurricanes are such a big issue since both the number and intensity of hurricanes have been increasing and are projected by climate models to continue to increase.

My colleague Peter Webster is working with the Asian Disaster Preparedness Center and the governments of south and southeast Asia (particularly Bangladesh) to address the issue of adaptation to the tropical cyclone threat.

Questions for Dr. Parmesan

1. **Global Warming is a Global Problem that requires Global Solutions. How do you suggest we go about getting China and India to actively participate in reducing carbon emissions? Along that same line, as a scientist, what kind of work have you done with scientists from developing nations, such as China and India to discuss the potentially harmful impacts of climate change? And what is the best way for us to engage them in this issue? Are they pushing their own governments to take actions in reducing CO2 emissions?**

Response (Parmesan):
The most powerful persuasion the USA could use is by example. The USA cannot expect to motivate other countries to reduce carbon emission until we have done so ourselves. As part of the many international panels and processes I've been involved with, I've worked with scientists from many developing nations, such as India, Nepal, South Africa, Peru, Chile, Argentina, Columbia, Mexico and Costa Rica. While there are differences in interpretations and conclusions among scientists, these differences have more to do with variance in the viewpoints of individuals than of country of origin or geographic placement of a person's job. Health and biodiversity impacts have been documented in both industrial and in developing nations, with many actual and potential negative consequences. Most scientists that are working in these fields participate in writing or editing educational documents for non-scientists (policy reports, lay articles and media interviews), regardless of where they are from and where they are working. In other words, scientists from all nations are active to some extent in disseminating scientific finding to their governments and the general public. Whether that information is being acted on is up to the policy-makers in those governments.

However, there is a dearth of trained ecologists, physiologists, and epidemiologists in a large number of developing nations, many of which are being heavily negatively impacted by climate change. Therefore, for many nations that are experiencing strong climatic changes, we lack long-term data that is necessary to document impacts. This may hamper the process for local action, as it may appear that climate change is not a local problem, whether or not it actually is, simply because the appropriate analyses cannot be conducted.

2. **If we cannot afford "business as usual" regarding climate change. Then every option should be on the table including nuclear energy. However, you never mentioned nuclear energy. If we want to decrease the amount of CO2 emissions without hurting the economy, then nuclear energy would seem like a logical choice. What actions should the federal government undertake, if any, to encourage increasing the use of nuclear energy?**

Response (Parmesan)

Generating more power from nuclear (fission) reactors should be one of the many options under consideration, but it certainly is not the magic bullet solution. This is not my primary field, and I strongly recommend that you consult qualified physicists with expertise in fission for detailed advice. The following statements come from my own readings on this topic, as well as conversations with experts in fusion and fission research.

First, the raw fuel for fission reactors is quite limited world-wide, and there simply isn't enough appropriate uranium to provide enough fuel for a global conversion of power supply to fission reactors. The world's top uranium producers are Canada (28% of world production) and Australia (23%). Other major producers include Kazakhstan, Russia, Namibia and Niger. Known uranium ore resources which can be mined at about current costs are estimated to be sufficient to produce fuel for about 85 years, based on the 2004 nuclear electricity generation rate. However, if there were a large increase in electricity generation from nuclear plants, then, barring new finds, known uranium deposits would be depleted considerably sooner. Therefore, this option is of limited feasibility unless a large investment in new breeder reactors were to parallel an increase in nuclear power plants. Breeder reactors coupled with new nuclear plants would extend this time considerably. This could be an effective short-term stop-gap measure until energy technology evolves to use new fuels and new systems (both nuclear and non-nuclear).

Second, High level long lived nuclear waste is an intrinsic end product of fission (and breeder) technology. Suitable burial sites for large amounts of long-half-life radioactive waste is already are already in short supply. The quantity of waste can possibly be reduced with breeder technology by transmuting the high level long lived waste to lower level and shorter life time elements in breeder reactors, either as dedicated reactors for waste reduction or as a by-product of power generating breeder reactors. One partial solution to the waste problem is breeder reactors, which result in more energy produced per unit of raw fuel, and much reduced half-life (radioactivity) of the final waste product. But, breeder reactors have two of their own problems: (1) there is an increased risk of weapons-grade material becoming available and (2) they are most efficient when they are running at near-criticality, which means they either have to be run well below peak efficiency, or carry high risk of melt-down. It may be that new research into fission could come up with alternate raw fuels (hence effectively increasing supply) and design alternate reactors that would produce waste with little radioactivity and/or short a half-life. It's my understanding that little R&D money has gone toward radically new fission designs, but that reactors designs with these traits are not theoretically impossible.

Finally, fusion energy appears to be the only long term solution for an energy source to supplement the so called alternative and renewable energy program. Fusion energy is still in the experimental stage, a demonstration plant is yet to be built although the physics and engineering looks both difficult and possible. The US program in particular has suffered from capricious and inadequate funding and this has resulted in some over-optimistic expectations. A large international experimental program, ITER, which is expected to provide the main answers to the feasibility of magnetic fusion is in construction in France, at present the US has dropped support of this program. Fusion might eventually be the answer, but large-scale fusion reactors are at least 100 years away, and that will be too late in terms of mitigating global warming over the next 200 years.

Therefore, if nuclear power is under consideration, then it would have to be fission reactors. If the goal is to convert a very large proportion of global energy production over to fission, then current reactor designs (using uranium fuel), even barring safety considerations, are inadequate to meet long-term energy demands. For nuclear power to substantially fill the coming energy gap on a time scale of the next hundred years between the phasing out of fossil fuelled power plants towards some, as yet undefined and perhaps even unknown form of power generation, a new generation of fission and breeder reactors would need to be designed and built. Such a program would need to be strongly supported by the US government, both for funding and also for monitoring to ensure the safety of the program.

3. **In addition you did not mention carbon sequestration technologies, the US will be using coal for electric generation for the foreseeable future. Therefore, in the real world, the U.S. must develop carbons sequester technology in order to decrease CO2 emissions. However, this technology is not available today on the commercial side. Do you support carbon sequestration technology?**

The term "carbon sequestration" has two meanings. There is biological sequestration: promoting plant communities that will take up more carbon (through photosynthesis and tissue storage) than they emit (through respiration and decomposition). And there is geological sequestration: liquefying carbon dioxide emissions and pumping them underground for long-term storage.

Biological sequestration doesn't require new technology - it's simply a matter of reducing forest clearing (deforestation is a sizeable proportion of greenhouse gas emissions globally), and to some extent planting high-carbon sink communities (certain forests and grasslands). The catch with the latter is that these systems are often only carbon sinks while they are in their initial growth stage. E.g., a typical temperate forest in the eastern USA will likely be a carbon sink for only 30-50 years while young trees are experiencing rapid growth. Once the forest is in a climax state (mostly large, mature trees), carbon-in tends to more or less equal carbon-out.

Geological sequestration technology already exists (from the oil industry, which uses high--pressure CO_2 pumped into wells to force out additional oil), and practical application is not long off. There is a large project underway in Texas, involving (among others) researchers from the Bureau of Economic Geology at the University of Texas. The field testing phase has already begun, and I believe that implementation will occur in a matter of a few years (<5?).

Success in geological sequestration relies on having a very stable, sealed geological formation in which to place the liquid CO_2 for long term storage. If the underground system is leaky (as most are), then pumping down the CO_2 merely delays its release in the atmosphere by a few years, thus merely delaying the problem. One relatively leak-proof formation is a large salt dome. Such a salt formation would also need to be in an area with seismic stability (low probability of earthquakes). In addition, because of the cost of transporting liquid CO_2, the scheme may not be cost-effective unless the CO_2 sources - e.g. the power plants - are geographically close to the storage formation. An appropriate, extensive underground salt dome exists off the Texas Gulf Coast, very close to several coal-powered electricity plants. There are few equivalent sites globally, but its my understanding that most regions simply don't have the appropriate geological formations, or are in earthquake-prone zones. It would behoove the globally community to identify other geologically appropriate sites, and focus new coal-powered electrical plants in those regions for which sequestration is a viable option.

4. **In your testimony, you state there is a long lag time in the climate system – it takes hundreds of years for global temperature to stabilize after greenhouse gases have increased, and it takes thousands of years for sea level to stabilize. Therefore, are you suggesting that the U.S. and the world should first look at**

developing strategies to adapt to global warming and put a secondary importance on trying to stop Global Warming?

That is not at all what I am suggesting. The interpretation you place on this fact is the exact opposite of my own (please note that the basic information is taken from the IPCC 2007 report). A long lag time means that by the time we have impacts of the magnitudes and frequencies which would cause even the most reluctant segment of the general public to perceive global warming as a threat to the lifestyle, health and economy of US citizens, we will have already passed the point of being able to do anything about it. The signs we are already seeing are quite alarming: *e.g.* massive movements of species both poleward and upward, earlier spring breeding, flowering, migration, etc. (by 1-5 weeks), later fall ice-up, and extended growing seasons, and melting of glaciers. These signs represent only a fraction of what we can expect from emissions that have already entered the atmosphere. The long lag time means that we should be taking these early signs much more seriously than their apparent immediate impact might suggest. They are telling us that what greenhouse gases already in the air are likely to do severe damage to many natural and human systems. Knowledge of a lag time in climate response to greenhouse gas emissions means that action we take now must be much more drastic than current, observed impacts would appear to dictate.

Questions for Dr. Ebi

1. As a scientist, what kind of work have you done with scientists from developing nations, such as China and/or India to discuss the potentially harmful impacts of climate change? And what is the best way for us to engage them in this issue?

Response: I have been engaged with scientists from developing nations through workshops, projects, and scientific collaboration.

Workshops: I am working with the World Health Organization (WHO) on a series of workshops on human health vulnerabilities and public health adaptations to climate variability and change. By early 2008, 10 workshops will have been held, covering all WHO regions. These workshops have typically focused on three main areas: awareness-raising of government and non-government organizations and other relevant stakeholders about the human health impacts of climate variability and long-term climate change; identification of specific human health risks linked to climate variability and change, and identification of vulnerable populations; and development of a framework for the design and implementation of adaptations to reduce climate change-related vulnerability.

In addition, I have worked with countries through UNDP-funded workshops designed to help Non-Annex I countries as they begin their Second National Communications under the UNFCCC. I trained participants at workshops conducted in Mozambique, Georgia, and Indonesia.

Projects: Projects in which I have been engaged include the following. I am happy to provide more details.

WHO/UNDP-GEF*:* Piloting Climate Change Adaptation to Protect Human Health (Barbados, Bhutan, China, Fiji, Jordan, Kenya, and Uzbekistan). In particular, I have been working closely with scientists from Barbados, Bhutan, China, Jordan, and Kenya on developing adaptation projects to reduce the projected impacts of climate change on human health. The project should be funded by the end of 2007, with research continuing for 3-4 years.

UNDP-GEF*:* Ghana Country Programme on Climate Change and Human Health. I am facilitating preparation of the project proposal.

USAID*:* Pilot Project for Assessing Climate Change-Related Vulnerability in Agriculture in Mali. I managed this pilot project on agricultural adaptation to reduced soil moisture.

Scientific Collaboration: Through the above activities, presentations at international conferences, and other venues, I work with a wide-range of scientists from developing countries.

There are many opportunities to engage with scientists from developing countries, including:

- Directly fund projects (for example, research in developing countries was funded under the now defunct NOAA/NASA/NSF/EPA/EPRI Joint Announcement on Climate Variability and Human Health);
- Engage scientists through projects run by USAID, NOAA, CDC, and others (for example, the USAID-funded project in Mali engaged scientists from several sectors);
- Support international activities related to climate change and human health, such as supporting the activities undertaken by the WHO; and
- Providing research and training opportunities through the above and other relevant programs. In every workshop in which I have participated, scientists from developing countries have requested additional training. This could be facilitated through a one- to two-week climate change and health training course conducted at country and regional levels. Another possible option is to develop regional institutes on climate change and health developed in conjunction with WHO and other organizations.

2. What actions should the U.S. and rest of the world pursue to assist low-medium income nations to cope with increase illness and death from climate change?

Ministries of Health and other actors responsible for public health infrastructure and health care delivery are over-stretched with current problems. Projections suggest that, in many low- and middle-income countries, additional financial, human, and technical resources will be needed just to maintain current levels of disease control. In other cases, current programs and activities could be modified to increase coping capacity. Those with decision-making authority need to be aware of the potential risks and the range of appropriate responses, and, in many cases, will need additional funding to address the risks of and responses to climate change.

3. You have helping eight developing nations develop adaptation programs and activities through projects with the World Health Organization, the United Nations Development Programme, and US AID. What is your most significant success so far? What metrics do you use to quantify success? What is the primary limiting factor for these programs?

The main factors limiting adaptation in these eight nations are financial and human resources. Seven of the countries are part of a project to be funded by the Global Environment Facility on Piloting Climate Change Adaptation to Protect Human Health (Barbados, Bhutan, China, Fiji, Jordan, Kenya, and Uzbekistan). This project identified key climate change and health risks and responses in each country through working with WHO country and regional offices, Ministries of Health, and other key stakeholders (such as water authorities). The project is scheduled to be funded by the GEF later this year. Each country will implement a 3- to 4-year adaptation program. The focus on the programs includes heatwaves, water stress, flooding/storm surges, and vectorborne diseases changing their geographic range. The other country with which I have worked (Ghana) is developing responses to projected increases in the risk of malaria.

Each project will have different measures of success; all will be a measure of reduced vulnerability to climate change-related health impacts. In some countries, the metrics of success will be qualitative and in others the metrics will be quantitative.

4. In your testimony you stated that adaptation will be a continual process and will be required at every level, one policy response is to mandate U.S. agencies (such as the Environmental Protection Agency, Centers for Disease Control and Prevention, and Fisheries and Wildlife) to incorporate climate change risks into programs and activities that are — or could be — affected by climate change, and to provide them with the human and financial resources to do so. Do you know how much these recommendations will cost?

Increasing the human and financial resources for U.S. agencies to incorporate climate change risks and responses into their program and activities requires that agencies have access to downscaled climate information (at the scale needed for decision-making); this could be provided by a central adaptation agency (see next question). Then each agency would need methods and tools to evaluate ongoing and planned activities to determine the climate risks and opportunities. Screening tools could be developed by a central adaptation agency, or could be developed jointly across agencies (with necessary modifications for the relevant issues for each agency). Most agencies would then likely need no more than a few people to work with others across the agency to ensure that climate change is appropriately taken into consideration.

However, it is important to note that during the week preceding my testimony, there were several hearings on the results from Working Group II (Impacts, Adaptation, and Vulnerability) of the Intergovernmental Panel on Climate Change's Fourth Assessment Report. During these hearings, many of the questions basically asked the climate change-related impacts in a particular district. In general, such information is not available because the research has not been funded. There was considerable interest in knowing more about projected local impacts and possible options to reduce the identified risks.

5. You state in your testimony that the U.S. should create a central agency responsible for working with other agencies, states, communities, businesses, and others to understand climate change risks and responses. This agency could provide expertise and decision support tools to understand local and regional climate change projections, as well as adaptation and mitigation options. Do you know how much setting up a new governmental agency costs?

The costs of a new governmental agency will depend on the specific mandate for the agency and the planned staffing. The costs need not be large. One model for such an agency is the UK Climate Impacts Programme (UKCIP), which was set up in April 1997. UKCIP works with stakeholders and co-ordinates research on how climate change could have an impact at regional and national levels. Their stakeholders or partners commission the research and determine the research agenda, ensuring that it meets their needs. UKCIP offers expertise on impacts assessment and independent advice on the most appropriate methods and research approaches, and communicates the results to a wide audience to inform decision-making. UKCIP provides a bridge between researchers and decision-makers in government organizations and business.

UKCIP has 16 employees, including a climate scientist to provide information to stakeholders on local and regional climate projections, and less than a dozen technical experts on facilitating adaptation. The population of the U.S. is about 5 times that of the UK and the land area is much larger, suggesting that less than 100 employees could be sufficient for an adaptation agency.

Responses by John A. Helms to Follow-Up Questions asked by The House Select Committee on Energy Independence and Global Warming
September 20, 2007

1) I commend the inclusion of forestry in the California Climate initiative. This is a common-sense approach. You mentioned a 10 state regional program that includes forestry – can you expand on that? And what other states are actively working to improve their forest management to increase carbon sequestration?

The Regional Greenhouse Gas Initiative (RGGI) is a 10-state cooperative of Northeast and Mid-Atlantic States aimed at reducing carbon dioxide emissions. The cooperative is developing a cap-and-trade mechanism with an emissions trading system aimed primarily at electric power generation. RGGI rules allow afforestation to be used as an offset, however, sustainably managed forests, reforestation, forest conservation (avoided deforestation), and harvested wood products do not currently qualify. (http://www.rggi.org/. http://www.rggi.org/docs/model_rule_corrected_1_5_07.pdf)

The California Climate Action Registry includes a forestry protocol that because of its particular requirements for additionality, baseline, and permanence through conservation easements is currently appealing to only a limited number of landowners. Washington and Oregon have initiatives for forest carbon and Wisconsin has established a task force to examine carbon sequestration (http://dnr.wi.gov/environmentprotect/gtfgw/WG_fa.html). Georgia has established a forest registry (http://www.gfc.state.ga.us/ForestMarketing/CarbonRegistryDocs.cfm). The Climate Registry (http://www.theclimateregistry.org/) is a multi-state registry that includes about 38 states, all Canadian Provinces, and at least one Mexican State that will be developing offset rules sometime toward the end of this year.

All this interest in forests as sinks for carbon is encouraging. However, the development of many state protocols is resulting in multiple eligibility and program rules and definitions that create cost and institutional barriers that limit participation in carbon markets and investment in sustainable forestry as a credible climate change mitigation measure. A national policy is needed having clearly defined rules under which forest carbon offset projects can be registered and traded or marketed together with coordination and technical transfer assistance. All forestry practices that provide credible climate change mitigation benefits should be promoted.

2) As we all know, Global Warming is a Global problem that will require Global solutions. What is the state of forestry management in other countries? Are developing nations like China and India making any attempt to manage their forest resources? Are there any countries that have turned around the loss of forest resources by doing management techniques such as the ones you mention?

China has a long history of forest exploitation and is now rebuilding its forest estate. China has the world's largest extent of forest plantation (a total of 71 m ha, FAO 2007) and leads in annual rate of reforestation.

India has a long history of forest management -- a legacy of the English colonial days. India is 19 percent forested and the forest area is reported to be increasing somewhat due to reforestation projects. However, forest losses are continuing due to shifting cultivation and exploitation and inventory data are limited. (India: State of Forest Report. http://envfor.nic.in/fsi/sfr99/sfr.html).

In 1992, Australia initiated an ambitious program aimed at resolving controversies between forest industry and conservation concerns by framing eleven Regional Forest Agreements. Australia has 1.7 million ha of softwood plantations and aims to be self-sufficient in wood needs by 2020 with a plantation area of 3 million ha. Australia has begun aggressive program of carbon trading using plantations to offset GHG emissions.

In the early 1900s New Zealand developed a major softwood plantation program now comprising 1.7 million ha (same as Australia) and is now is a significant exporter of softwood logs and fiber. All native hardwood forests are now in reserves. As a signatory to the Kyoto Protocols, New Zealand is using its plantations established since 1990 to offset carbon emission in other sectors. The national government has retained initial rights to plantation carbon credits, which has resulted in controversy and a marked slowdown in reforestation.

The European Union encourages the use of afforestation and reforestation practices within its member states. An estimated carbon sequestration potential for these efforts within the EU-15 by 2010 is 33 Mt CO_2eq. They also encourage the use of renewable energy, including those from biomass. By 2010 the European Union hopes to have 21 percent of its total energy consumption being produced with renewable energy sources.

3) Do you think it is fair to say that a forest fire can constitute a global warming emergency based on the amount of carbon that it releases into the atmosphere? And the follow on question – would it require any new technology development for us to work on this problem *right now* as a preventative measure?

Depending on forest type and fire intensity a single forest fire emits from 10-100 tons of CO2 equivalent per acre into the atmosphere. Across the US in 2006 almost 10 million acres were burned. Thus wildfires annually contribute enormous amounts of greenhouse gases into the atmosphere.

However, wildfires have always been part of many natural forest ecosystems. Native American people commonly used fire to manage game, encourage desirable plants, deny hiding places for enemies, etc. In California prior to 1800 it is estimated that fires burned between 1.8 and 4.8 million hectares annually (Stephens et al. 2007). The difference between presettlement fires and modern wildfires is not so much in acres burned but in the intensity of fires due to current high stand densities on national forests.

Since carbon from forest fires have always been part of the carbon cycle and will continue to be in the future, I am reluctant to describe a forest fire, or even the total amount of area burned annually as constituting a "global warming emergency", even though the total amount of greenhouse gases emitted from forest forests undoubtedly constitute a significant fraction of total anthropogenic emissions. We should, however work towards developing healthy forests that limit the amount of these emissions, especially on national forest lands. Of particular concern is the growing human population that is urbanizing forested areas and the fact that in 2006, of the 96,380 forest fires that occurred, 83% were human-caused (Natl. Interagency Fire Center, 2007).

Regarding the follow-question, greenhouse gas emissions from wildfires could be limited by a program, especially on national forest lands, aimed at restoring the forests to a healthy state by fuel treatments and thinning. Current knowledge and technology are adequate for this program. Because the area needing treatment is so large, there is no possibility of the costs being covered by appropriations of public funds. The task of fuel reduction could be accomplished by partly recouping costs from the value of the biomass. Unfortunately, the current value of biomass is at the borderline of being economically feasible. This could be alleviated by ensuring long-term contracts that make investment of private funds feasible, and by incorporating within the fuel reduction and density-control treatments mid-sized trees that have economic value. According to the 2005 report by the USDA and US Dept. of Energy, "an annual supply of 1.3 million dry tons can be accomplished by relatively modest changes in land use and agricultural and forestry practices."
(http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf)

4) In 1990, the IPCC said that deforestation is responsible for about 20% of global CO2 emissions. Do you think that this figure has increased or declined?

According to FAO's most recent "Global Forest Resources Assessment, 2005", deforestation, mainly the conversion of forest to agricultural land, continues at the rate of about 13 million hectares per year. At the same time, forest planting and the natural expansion of forests particularly in Europe and North America are expanding such that the net loss of forests globally is about 7.3 million hectares per year. Although deforestation continues to be a major problem, especially in the tropics, the annual rate of forest loss is declining -- down from an estimated 8.9 million hectares per year over the period 1990 - 2000.

5) Is it true that forests in the United States are net carbon sinks because the annual growth exceeds the annual harvest? Would you recommend that we actively increase the growth as well?

Yes, the statement is true -- nationwide forest growth (20 billion board feet) exceeds harvest (3 billion board feet), especially on national forests. However, it must also be recognized that annual mortality (10 billion board feet) due to natural processes of death and decay accompanied by attacks by insects and disease as suppressed trees in dense stands die also contributes substantial amounts of carbon into the atmosphere. Loss of trees to mortality on national forests greatly exceeds the volume of wood removed in timber harvest.

6) Turning to the use of biomass energy, is it safe to say that forest management can provide biomass for energy production – so basically serve two purposes in reducing carbon emissions as a fuel and also reducing the risk of wildfires?

Yes, forest management can provide biomass for energy production. In fact this is already common on private industrial lands where for many years "waste" products from wood processing is used for production of energy that satisfies mill requirements and excess energy production is used by the community or fed into the power grid.

According to a USDA/US Dept. Energy report 2005, there is enough biomass nationwide to produce a sustainable supply of energy sufficient to displace 30% or more of the country's present petroleum consumption. The report finds that residues from logging and fuel treatment thinnings could provide 120 million dry tons of biomass annually. (http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf)

A major issue to be addressed is that long-term supply contracts would be needed to attract investment funds needed to build biomass utilization facilities.

7) After a forest fire, what actions need to be taken to make sure that we accelerate the return of a healthy forest to that area? Are we doing enough to make sure that this happens?

Immediately after a forest fire, an assessment is needed to determine what portions of the burned area are prone to soil erosion and need treatment, what areas need prompt regeneration and restoration if adequate natural regeneration is unlikely, what proportion of dead and dying trees should be salvaged, and what areas should be left alone for ecological or other reasons.

This assessment enables an analysis of the effects and risks of both doing nothing and prescribing treatments on the rate at which the forest is restored to its previous mix of stand conditions and values.

Areas where it is determined that shrubs and grasses will rapidly dominate the site should be promptly planted to trees -- either single or multiple species as needed -- to ensure that the area does not revert to a brushfield. Dead and dying trees designated for salvage should be utilized promptly to avoid the rapid loss of value from insects and decay and to limit carbon emissions to the atmosphere.

8) You mention that it is important to provide technical assistance and incentives for landowners to incorporate carbon-sequestration and storage in their management strategies. Any suggestions on what form those should take?

About a dozen states have forest practice legislation, varying in level of restrictions, which prescribe management on private forest land. Some require timber harvest plans and at least one state require these plans to be prepared by a registered professional forester. However, regulations can be so strict, and cost of complying so expensive, that they deter small private landowners from actively managing their lands. Non-industrial forest lands currently supply about 60% of the nation's wood, yet only a small proportion of these utilize the services of professional foresters in developing forest management plans. Industrial forests are commonly managed by professional foresters, however this is uncommon on small family forests. The productivity of non-industrial forest lands could be markedly enhanced if professional services were made more readily available, outreach programs from universities were better funded, and if incentives such as taxation relief or subsidized programs were more readily available.

Obtaining value from carbon sequestration is particularly complex because it requires accurate inventories to quantify and document baseline levels of management, additionality that can be attributed to treatments that exceed business as usual, procedures that ensure permanence, and documentation that there is no "leakage" of carbon due to change of practices on neighboring lands. The necessity for this documentation incurs considerable transaction costs, thus incentives and services are needed to enable forest landowners, particularly the small non-industrial, family landowners, to understand the management costs and benefits, comply with documentation, and to consider including sequestration of carbon as a desirable management goal. There is ample precedence in the U.S. for assisting family landowners in meeting conservation-related goals. Examples of such incentive or cost-share programs include the Forest Stewardship Program (FSP), Conservation Reserve Program (CRP) Environmental Quality Incentive Program (EQIP), Wildlife Habitat Incentive Program (WHIP), and the Forest Land Enhancement Program (FLEP).

9) Let's talk for a minute about "Green Buildings" – Do you think that the use of wood as a valuable carbon storage vessel should be addressed when we look at green design standards?

Yes. In choosing among alternative materials for design and construction it is essential to include comparisons of efficiency of use of energy in manufacture, reduction in environmental impact, relative "carbon footprint" (emissions linked to production and use), life cycle analysis, and certification. Green building systems should evaluate all building materials equally without bias against all these criteria. If this is done wood, a renewable natural resource, will be shown to be a highly desirable environmental choice.

Georgia Institute of Technology

School of Earth & Atmospheric Sciences
Atlanta, Georgia 30332-0340 U.S.A.
PHONE: 404•894•0231
FAX: 404•894•5638

9 May 2007

Dear Chairman Markey:

I would like to correct for the record an inadvertent omission in my written testimony for the hearing on "Dangerous Climate Change" held by the Select Committee on Energy Independence and Global Warming on April 26, 2007. During the hearing it was pointed out that in a quotation taken from the Intergovernmental Panel on Climate Change's Summary for Policymakers of the report "The Physical Science Basis," I omitted the sentence, "There is no clear trend in the annual numbers of tropical cyclones." This omission was unintentional, and I apologize for having left it out, as I did during the hearing. The bottom of the first page of my testimony should be corrected to the following:

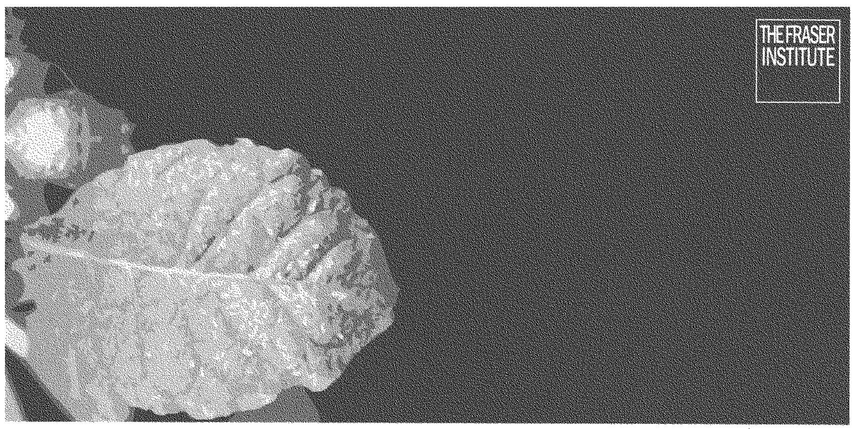
> A summary of our current understanding of this issue and the levels of uncertainty is provided by the IPCC 4th Assessment Report Summary for Policy Makers (IPCC AR4 2007b):
>
> "There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures. There are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and th quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. There is no clear trend in the annual numbers of tropical cyclones... Based on a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical SSTs. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period."

Thank you again for this opportunity to correct my testimony for the record.

Sincerely,

Judith A. Curry
Professor and Chair

SUBMITTED MATERIALS AS REQUESTED BY REPRESENTATIVE MARSHA BLACKBURN



Independent Summary for Policymakers IPCC Fourth Assessment Report

Coordinator: Ross McKitrick, Ph.D.

Writing Team:
Joseph D'Aleo, M.Sc.,
Madhav Khandekar, Ph.D.,
William Kininmonth, M.Sc., M.Admin.,
Christopher Essex, Ph.D.,
Wibjörn Karlén, Ph.D.,
Olavi Kärner, Ph.D.,
Ian Clark, Ph.D.,
Tad Murty, Ph.D., and
James J. O'Brien, Ph.D.

About the Fraser Institute

Our vision is a free and prosperous world where individuals benefit from greater choice, competitive markets, and personal responsibility. Our mission is to measure, study, and communicate the impact of competitive markets and government interventions on the welfare of individuals.

Founded in 1974, we are an independent research and educational organization with offices in Vancouver, Calgary, and Toronto, and international partners in over 70 countries. Our work is financed by tax-deductible contributions from thousands of individuals, organizations, and foundations. In order to protect its independence, the Institute does not accept grants from government or contracts for research.

For media information, please contact our Communications department via telephone: 604.714.4582; via e-mail: communications@fraserinstitute.ca

To learn more about the Institute and to read our publications on line, please visit our web site at www.fraserinstitute.ca.

The authors of this study have worked independently and opinions expressed by them are, therefore, their own, and do not necessarily reflect the opinions of the supporters, trustees, or staff of The Fraser Institute.

Editing: Serena Howlett. Cover design: Kim Forrest. Design and typesetting: Irma Rodriguez
Date of issue: February 2007

For information about **how to support The Fraser Institute**, please write to:
Development Department, The Fraser Institute,
Fourth Floor, 1770 Burrard Street,
Vancouver, BC, V6J 3G7.;
or contact the Development Department:
via telephone, toll free: 1.800.665.3558, ext. 586
via e-mail: development@fraserinstitute.ca
Vancouver via telephone: 604.688.0221, ext. 586
via fax: 604.688.8539
Calgary via telephone: 403.216.7175, ext. 227
via fax: 403.234.9010
Toronto via telephone: 416.363.6575, ext. 232
via fax: 416.934.1639.

Contents

List of Authors

Coordinator

Ross McKitrick, Ph.D. Associate Professor, Department of Economics, University of Guelph and Senior Fellow, Fraser Institute, Vancouver BC.

Writing Team

Joseph D'Aleo, M.Sc. Chief Meteorologist (Ret'd) WSI Corporation. Past Chairman, American Meteorological Society Committee on Weather Analysis and Forecasting. Member, American Meteorological Society Council. Fellow, American Meteorological Society. Certified Consulting Meteorologist.

Madhav Khandekar, Ph.D. Research Scientist (ret'd), Environment Canada. Editor, *Climate Research* 2003-2005. Member, Editorial Board, *Natural Hazards* since 1999. Previously, Lecturer in Meteorology, Barbados (West Indies); International Civil Aviation Organization Expert in Aeronautical Meteorology, Qatar.

William Kininmonth, M.Sc. M.Admin. Head (ret'd) National Climate Centre, Australian Bureau of Meteorology. Previously: Consultant to the World Meteorological Organization Commission for Climatology; Scientific and Technical Review Coordinator, United Nations Task Force on El Niño.

Christopher Essex, Ph.D. Professor of Applied Mathematics, University of Western Ontario, and Associate Director, Program in Theoretical Physics. Formerly, NSERC Postdoctoral Fellow, Canadian Climate Centre.

Wibjörn Karlén, Ph.D. Professor emeritus, Dept. of Physical Geography and Quaternary Geology, Stockholm University, Sweden

Olavi Kärner, Ph.D. Senior Research Associate, Atmospheric Sensing Group, Tartu Astrophysical Observatory, Tõravere, Estonia.

Ian Clark, Ph.D. Professor of Arctic Paleohydrology and Geology, University of Ottawa.

Tad Murty, Ph.D. Adjunct Professor, Departments of Earth Sciences and Civil Engineering, University of Ottawa; Editor, *Natural Hazards*; Associate Editor *Marine Geodesy*; Leader, World Meteorological Organization group to prepare a manual on storm surges from hurricanes and extra-tropical cyclones. Formerly: Senior Research Scientist, Canadian Department of Fisheries and Oceans; Professor of Earth Sciences, Flinders University, Adelaide, Australia; Director of Australia's National Tidal Facility.

James J. O'Brien, Ph.D. Robert O. Lawton Distinguished Professor, Meteorology & Oceanography and Director Emeritus of the Center for Ocean-Atmospheric Prediction Studies, Florida State University. Florida State Climatologist. Fellow of the American Meteorological Society, Fellow of the American Geophysical Union, Fellow of the Royal Meteorological Society, Fellow of the American Association for the Advancement of Science.

Preface

This is an *Independent Summary for Policymakers* (ISPM) of the Fourth Assessment Report (AR4), Working Group 1, of the Intergovernmental Panel on Climate Change (IPCC). In producing this Summary we have worked independently of the IPCC, using the Second Order Draft of the IPCC report, as circulated after revisions were made in response to the first expert review period in the winter and spring of 2006. Section references will be checked against the final IPCC version, as soon as copies are available following the release later in 2007. If, in preparing the final draft of the Fourth Assessment Report, the IPCC substantially rewrites the Assessment text, such that the key summary materials presented herein need to be re-worded, we will do so and publish an Appendix to that effect.

The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to assess the risk of human induced climate change. The IPCC is open to all members of the WMO and UNEP. The IPCC has three working groups. Working Group 1 assesses the scientific aspects of climate change; Working Group 2 assesses the positive and negative impacts of climate change and the options for adaptation; and Working Group 3 assesses policy options to mitigate climate change.

The Fraser Institute's Rationale for the ISPM

The IPCC involves numerous experts in the preparation of its reports. However, chapter authors are frequently asked to summarize current controversies and disputes in which they themselves are professionally involved, which invites bias. Related to this is the problem that chapter authors may tend to favor their own published work by presenting it in a prominent or flattering light. Nonetheless the resulting reports tend to be reasonably comprehensive and informative. Some research that contradicts the hypothesis of greenhouse gas-induced warming is under-represented, and some controversies are treated in a one-sided way, but the reports still merit close attention.

A more compelling problem is that the *Summary for Policymakers*, attached to the IPCC Report, is produced, not by the scientific writers and reviewers, but by a process of negotiation among unnamed bureaucratic delegates from sponsoring governments. Their selection of material need not and may not reflect the priorities and intentions of the scientific community itself. Consequently it is useful to have independent experts read the underlying report and produce a summary of the most pertinent elements of the report.

Finally, while the IPCC enlists many expert reviewers, no indication is given as to whether they disagreed with some or all of the material they reviewed. In previous IPCC reports many expert reviewers have lodged serious objections only to find that, while their objections are ignored, they are acknowledged in the final document, giving the impression that they endorsed the views expressed therein.

The ISPM addresses these concerns as follows.

- The ISPM was prepared by experts who are fully qualified and experienced in their fields, but who are not themselves IPCC chapter authors, nor are they authors of the IPCC *Summary for Policymakers*.
- The ISPM summarizes the most important elements of the science, regardless of whether it is given the same level of focus in the IPCC's Summary documents. There is no attempt to downplay or re-word uncertainties and limitations in the underlying science, hence the summary paragraphs in the ISPM may not be identical to those of the Summary produced by the IPCC.
- If a chapter of the Fourth Assessment Report introduces its topic by briefly elaborating on deep uncertainties, then presents results at length as if the uncertainties were not there, the ISPM may devote proportionally more attention to understanding the uncertainties than summarizing all the results, where this is deemed a more pertinent way to characterize the underlying state of knowledge.

- In a number of places the writing team felt the treatment of a topic was inadequate in the Fourth Assessment Report, or some additional comments were needed for perspective. These are noted in separate sidebars. Also, the Fraser Institute will publish a series of short supplementary papers to provide more detailed critical discussion of some technical subjects. These are noted at various points in the ISPM as well.
- The ISPM was subject to expert review by the reviewers listed at the end. Their responses to review questions are tabulated so readers can see to what extent the reviewers agree with the contents of this Summary.

Format Notes

- *Third Assessment Report* refers to the Third Assessment Report (TAR) of the IPCC, Working Group I, published in 2001
- *Fourth Assessment Report* refers to the Fourth Assessment Report (AR4) of the IPCC, Second Order Draft, Working Group 1
- Section references in brackets, e.g., [3.4.3.1], refer to the Fourth Assessment Report of the IPCC, Second Order Draft, Working Group 1. Some references are to Summation Questions included in the Fourth Assessment Report chapters, e.g., [Question 5.1].

Acknowledgments

Stephen McIntyre assisted in collation of data, preparation of many graphs and technical editing of some sections. Nicholas Schneider was involved in this project from inception and acted as the key Fraser Institute staff person. Their contributions are gratefully acknowledged.

Disclaimer

The text presented herein uses our best estimate of the wording of the final version of the Working Group I contribution to the Fourth Assessment Report. Much of the text herein follows wording as set by IPCC Lead and Contributing Authors in the Second Order Draft as of the close of the scientific review period on June 2, 2006, on the assumption that this will also be the wording in the final draft. However a check against the final wording will take place after the IPCC releases the underlying report. The IPCC has indicated that, although they are publishing the Summary for Policymakers on February 2, 2007, they will not release the underlying report until some time in May 2007. Until that time, readers should note that the IPCC has not officially accepted the wording of the underlying report or of drafts on which it is based.

Executive Summary

Observed Changes in Factors That May Influence the Climate

The climate is subject to potential influence by both natural and human forces, including greenhouse gas concentrations, aerosols, solar activity, land surface processes, ocean circulations and water vapor. Carbon dioxide is a greenhouse gas, and its atmospheric concentration is increasing due mainly to human emissions.

The IPCC gives limited consideration to aerosols, solar activity and land-use change for explaining 20th century climate changes. Aerosols have a large potential impact on climate but their influence is poorly understood. Some evidence suggests that solar activity has increased over the 20th century to historically high levels. Land use changes are assumed by the IPCC to have only a minor role in explaining observed climate change.

Observed Changes in Weather and Climate

Globally-averaged measurements of lower atmospheric temperatures from satellite data since 1979 show an increase of 0.12°C to 0.19°C per decade over this period, at the low end of the IPCC estimate of future warming. Globally-averaged temperature data collected at the surface show an increase from 1900 to 1940 and again from 1979 to the present.

There is no globally-consistent pattern in long-term precipitation trends, snow-covered area, or snow depth. Many places have observed a slight increase in rain and/or snow cover. There is insufficient data to draw conclusions about increases in extreme temperature and precipitation. Current data suggest a global mean sea-level rise of 2 mm to 3 mm per year over the past several decades. In the tropics, there is evidence of increased cyclone intensity but a decrease in total tropical storms, and no clear global pattern since 1970.

Arctic sea ice showed an abrupt loss in thickness prior to the 1990s, and the loss stopped shortly thereafter. There is insufficient data to conclude that there are any trends in Antarctic sea ice thickness. Glaciers have retreated in most places and the loss accelerated in the 1990s.

Climatic Changes in a Paleoclimate Perspective

Paleoclimate refers to the Earth's climate prior to the start of modern instrumental data sets. There are historical examples of large, natural global warming and cooling in the distant past. The Earth is currently within a warm interglacial period, and temperatures during the last interglacial period were warmer than present.

Natural climate variability and the uncertainty associated with paleoclimate studies are now believed to be larger than previously estimated. In general, data are sparse and uncertain, and many records have been questioned for their ability to show historical temperature variability. These uncertainties matter for assessing the ability of climate models to simulate realistic climate changes over historical intervals.

Climate Models and Their Evaluation

Some broad modeling predictions made 30 years ago are consistent with recent data, but there remain fundamental limitations of climate models that have not improved since the Third Assessment Report. Many models are incapable of simulating important aspects of the current climate, and models differ substantially in their projections. It is not possible to say which, if any, of today's climate models are reliable for climate prediction and forecasting.

Global and Regional Climate Projections

Models project a range of forecasts, and uncertainty enters at many steps in the process. Forecasts for the 21st century are inherently uncertain, especially at the regional level.

Current models predict: an increase in average surface temperature; an increased risk of drought, heat waves, intense precipitation and flooding; longer growing seasons; and an average sea levels rise of about 20 cm over the next 100 years.

Glacier mass is projected to decrease. An abrupt change in ocean circulation is very unlikely. Tropical cyclone intensity may increase or decrease.

Attributing the Causes of Climate Change

Attributing an observed climate change to a specific cause like greenhouse gas emissions is not formally possible, and therefore relies on computer model simulations. As of yet, attribution studies do not take into account the basic uncertainty about climate models, or all potentially important influences.

Increased confidence that a human influence on the global climate can be identified is based the proliferation of attribution studies since the Third Assessment Report. Models used for attributing recent climate change estimate that natural causes alone would not result in the climate that is currently observable.

ISPM Overall Conclusions

The following concluding statement is not in the Fourth Assessment Report, but was agreed upon by the ISPM writing team based on their review of the current evidence.

The Earth's climate is an extremely complex system and we must not understate the difficulties involved in analyzing it. Despite the many data limitations and uncertainties, knowledge of the climate system continues to advance based on improved and expanding data sets and improved understanding of meteorological and oceanographic mechanisms.

The climate in most places has undergone minor changes over the past 200 years, and the land-based surface temperature record of the past 100 years exhibits warming trends in many places. Measurement problems, including uneven sampling, missing data and local land-use changes, make interpretation of these trends difficult. Other, more stable data sets, such as satellite, radiosonde and ocean temperatures yield smaller warming trends. The actual climate change in many locations has been relatively small and within the range of known natural variability. There is no compelling evidence that dangerous or unprecedented changes are underway.

The available data over the past century can be interpreted within the framework of a variety of hypotheses as to cause and mechanisms for the measured changes. The hypothesis that greenhouse gas emissions have produced or are capable of producing a significant warming of the Earth's climate since the start of the industrial era is credible, and merits continued attention. However, the hypothesis cannot be proven by formal theoretical arguments, and the available data allow the hypothesis to be credibly disputed.

Arguments for the hypothesis rely on computer simulations, which can never be decisive as supporting evidence. The computer models in use are not, by necessity, direct calculations of all basic physics but rely upon empirical approximations for many of the smaller scale processes of the oceans and atmosphere. They are tuned to produce a credible simulation of current global climate statistics, but this does not guarantee reliability in future climate regimes. And there are enough degrees of freedom in tunable models that simulations cannot serve as supporting evidence for any one tuning scheme, such as that associated with a strong effect from greenhouse gases.

There is no evidence provided by the IPCC in its Fourth Assessment Report that the uncertainty can be formally resolved from first principles, statistical hypothesis testing or modeling exercises. Consequently, there will remain an unavoidable element of uncertainty as to the extent that humans are contributing to future climate change, and indeed whether or not such change is a good or bad thing.

1 Observed changes in factors that may influence the climate

1.1 "Radiative Forcing" as a conceptual tool for comparing climatic effects

1.1a "Radiative Forcing" (RF) is a modeling concept that attempts to summarize the climatic effect of diverse changes in the environment. It is not directly measured, nor is it related to the "greenhouse effect," and overall remains poorly quantified.

- RF is a concept that arose from early climate studies using simple radiative-convective models. It is not directly measured. Instead it is calculated by simplified climate models under the assumption that a comparison can be made between equilibrium states of the climate. The climate does not reach equilibrium, but reflects transient responses to external and internal changes. The RF relationship to transient climate change is not straightforward. To evaluate the overall climate response associated with a forcing agent its time evolution and its spatial and vertical structure need to be taken into account. Further, RF alone cannot be used to assess the potential climate change associated with emissions, as it does not take into account the different atmospheric lifetimes of the forcing agents. [2.2]
- RF itself is not directly related to the "greenhouse" effect as associated with greenhouse gases. [2.3.8]
- Measurement of RF in Watts/square meter is a convention, but RF itself is not a measured physical quantity. Instead it is computed by assuming a linear relationship between certain climatic forcing agents and particular averages of temperature data. The various processes that it attempts to approximate are themselves poorly quantified. [2.2]
- An observed decrease in radiative flux at the characteristic radiation bands of CO_2 and methane between 1970 and 1997 has been associated with changing concentrations. This change is what is meant by the term "enhanced greenhouse effect", but it is not directly related to the "Radiative Forcing" concept. [2.3.8]

SUPPLEMENTARY INFORMATION

Greenhouses and 'Greenhouse Gases'

While use of the term 'greenhouse' is nowadays unavoidable, the term 'greenhouse effect' is an inappropriate metaphor since it suggests a parallel between the mechanism that causes warming in an actual greenhouse and the influence of infrared-active gases, like water vapour and carbon dioxide, on the Earth's climate system. The two mechanisms are quite distinct, and the metaphor is misleading. It leaves out the complexities arising from the nonlinear, dynamic processes of our climate system, namely evaporation, convection, turbulence and other forms of atmospheric fluid dynamics, by which energy is removed from the Earth's surface. Simplistic metaphors are no basis for projecting substantial surface warming due to increases of human-caused carbon dioxide concentration in the atmosphere.

This problem is explored in the forthcoming Fraser Institute Supplementary Analysis Series report, 'Why the 'Greenhouse' Metaphor is Misleading.'

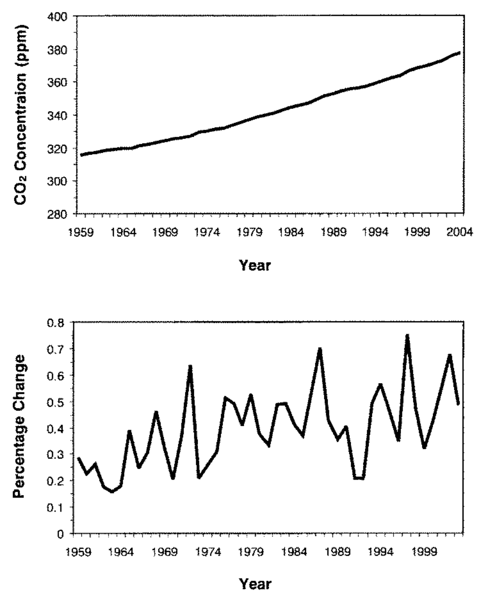


FIGURE ISPM-1: CARBON DIOXIDE CONCENTRATIONS

TOP: Annual average atmospheric carbon dioxide concentration since 1958.
BOTTOM: annual percentage rate of change of carbon dioxide concentration.
Source: Marland *et al*, 2006.

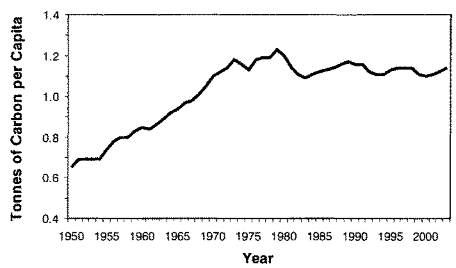
1.2a Carbon dioxide (CO_2) levels in the atmosphere are rising at approximately 0.5% per year.

- Figure ISPM-1(top) shows the atmospheric CO_2 concentration since the late 1950s. The rate has no overall trend but fluctuates around a mean of 0.5% since the early 1990s, up from 0.4% in the 1970s and 1980s (Figure ISPM-1(bottom)).
- The main causes of this accumulation are fossil fuel burning, cement production, gas flaring, and, to a lesser extent, land-use changes such as deforestation. [2.3.1]
- Human activities contribute about 7 Gigatonnes carbon equivalent to the atmosphere each year, up from around 6 Gigatonnes in 1990. [2.3.1]

SUPPLEMENTARY INFORMATION

Per capita carbon emissions have not increased for 30 years

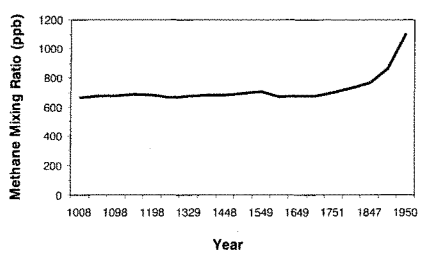
The growth rate of CO_2 emissions (in carbon equivalent) is equal to or slightly below the growth rate of world population (see Figure ISPM-2). Global per capita carbon emissions peaked at 1.23 tonnes per person in 1979 and the per-person average has declined slightly since then. As of 2003 the global average is 1.14 tonnes per capita, an average that has not changed since the early 1980s. If this trend continues, global emissions growth in the future will be constrained by total population growth.



ISPM-2: GLOBAL PER CAPITA CARBON EMISSIONS, 1950-2003
Source: Marland *et al.*, 2006.

1.2b Ice core records indicate that the atmospheric CO_2 levels were constant at about 280 parts per million (ppm) for at least several thousand years prior to the mid-1800s.

- This implies a post-industrial accumulation in the atmosphere of about 100 ppm, yielding the current level of nearly 380 ppm. [2.3.1]
- CO_2 variations over the last 420,000 years broadly followed Antarctic temperature, typically with a time lag of several centuries to a millennium (i.e., atmospheric carbon dioxide levels rise several centuries after the air temperature rises). [6.4.1]



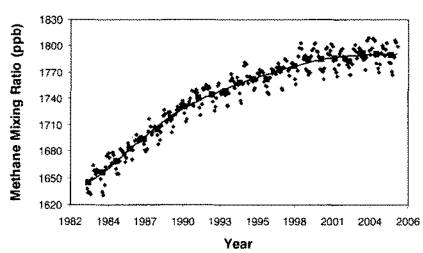


FIGURE ISPM-3: METHANE CONCENTRATIONS
LEFT: Long-term atmospheric methane levels, 1008 to 1950.
Source: Etheridge *et al.*, 2002.
RIGHT: Mauna Loa, Hawaii methane record, 1983-2005.
Source: World Data Center for Greenhouse Gases, 2006.

1.2c Atmospheric methane (CH_4) levels stopped growing in the late 1990s and have declined somewhat in recent years. Sources of methane emissions are poorly understood, but the total appears to be declining. It is not understood how this could be happening despite ongoing atmospheric temperature increases.

- Ice core records indicate pre-industrial methane levels were about 700 parts per billion (ppb), prior to the 18th century. The methane level increased over the next three centuries, and at the global level currently averages about 1,780 ppb (see Figure ISPM-3).
- Overall sources of methane emissions to the atmosphere are poorly known, but are thought to include wetlands, rice agriculture, biomass burning and ruminant animals.
- Emissions from anthropogenic sources remain the major contributor to atmospheric methane budgets. [7.4.1.2]
- Atmospheric methane concentrations peaked several years ago and have been flat or declining since then [Fig 2.5, see Figure ISPM-3, Bottom]. The reason for the recent decline is not understood. [2.3.2]
- The atmospheric concentration of methane is tied to atmospheric temperature, as total emissions increase with atmospheric warming. Total emissions from sources are suggested to have decreased since the time of the Third Assessment Report, as nearly zero growth rates in atmospheric methane concentrations have been observed with no change in the sink strengths. It is not well understood why emissions have decreased despite continued warming of the Earth's surface and the atmosphere. [7.4.1.2]

1.2d Hydrochlorofluorocarbons (HCFCs) and Chlorofluorocarbons (CFCs) are presently covered by other emission control legislation, and are declining.

- HCFCs and CFCs are covered by the Montreal Protocol on ozone-depleting substances. Global emissions have fallen radically since 1990 and their atmospheric levels are slowly declining. [2.3.4]

1.2e Other infrared active gases (Nitrous Oxide (N_2O) and Hydrofluorocarbons (HFCs)) are accumulating slowly in the atmosphere, or are at levels that imply very low climatic effects. [2.3.3; Table 2.1]

1.3 Aerosols

1.3a Aerosols play a key role in the Earth's climate, with a potential impact more than three times that of anthropogenic carbon dioxide emissions, but their influence remains subject to low or very low scientific understanding.

- Aerosols have a significant presence in the global atmosphere. The combined Direct Radiative Effect of natural and anthropogenic sources on climate, is estimated to be about -5.3 Watts/m^2, more than three times the magnitude of the estimated Radiative Forcing of anthropogenic CO_2 (1.63 Watts/m^2) [2.4.2.1.2]
- It is very challenging to distinguish natural and anthropogenic aerosols in satellite data. Validation programs for these advanced satellite-data products have yet to be developed and initial assessments indicate some systematic errors. [2.4.2.1]
- The climatic effect of each type of aerosol consists of both direct and indirect effects, the latter including influences on cloud formation. Overall direct and indirect effects are subject to wide uncertainties, and some important semi-direct effects were not included in the Third Assessment Report. [2.4]

- Effects on cloud formation are not well understood and the magnitude of the effects are not reliably estimated at this time, in part because of the lack of satellite data to support model development and testing. [2.4.6]
- Modelling the cloud albedo indirect effect from first principles has proven difficult because the representation of aerosol-cloud interactions and of clouds themselves in climate models are still crude. [2.4.6.5]
- Although there is agreement about the quality of the basic evidence (data), there is no consensus about the direct climatic (radiative forcing) effect of aerosols on climate, and the overall state of knowledge is categorized as *Low Scientific Understanding.* [Table 2.11]
- All categories of indirect aerosol effect on climate, are characterized by: no consensus; varying confidence in the basic empirical evidence, and *Low* or *Very Low Scientific Understanding.* [Table 2.11]

1.3b Aerosols can affect both cloud lifetime and cloud albedo (reflectivity), though models contradict one another on which effect is larger.

- Whereas some models show that the cloud albedo effect is four times as important as the cloud lifetime effect, other models simulate a cloud lifetime effect that is larger than the cloud albedo effect [7.5.2.4].

1.3c It is generally assumed that aerosols exert an overall cooling effect on the climate. Quantitative estimates of the overall effect vary by a factor of 10.

- The global mean total anthropogenic aerosol effect (direct, semi-direct and indirect cloud albedo and cloud lifetime effect) is defined as the change in net radiation at the top of the atmosphere from pre-industrial times to present-day, and ranges from -0.2 Wm^{-2} to -2.3 Wm^{-2}. This implies that aerosol emissions exert an overall cooling effect, but the magnitude of this effect is unknown. [7.5.2.4]

1.3d Studies that attribute observed global warming to greenhouse gases are based on models that assume that aerosols exert a large cooling effect.

- The models used for the Fourth Assessment Report assume a large cooling effect from aerosols. [Table 2.12]
- The effect is assumed to be strongest in the Northern Hemisphere. [Figure 9.2.1e]

1.4 Changes in the Sun and Solar-Climate connections

1.4a New studies since the Third Assessment Report have improved empirical knowledge of climate responses to forcing by solar variability on annual to decadal time scales.

- Overall the troposphere is warmer and moister during solar maxima, and thickens in response to solar variability with a distinct zonal signature. [2.7.1.1.2]

1.4b The Third Assessment Report reported that solar activity was exceptionally high in the 20th century in the context of the last 400 years. Since then, new reconstructions of solar activity have indicated modern solar output levels are high, and possibly exceptionally high, compared to the past 8,000 years.

- Solar activity is estimated by historical information on sunspot counts and, prior to that, by cosmogenic isotopes (residual C14 and Be-10). [2.7.1.2.1]
- One reconstruction shows modern solar levels to be exceptional within the past 8,000 years while another shows few comparable episodes. [2.7.1.2.1; see Figure ISPM-4]
- Several reconstructions of solar activity show a strong upward trend from 1700 to the present. [see Figure ISPM-4]
- The minimum in solar activity around 1700 AD (the Maunder Minimum) has been associated with contemporary cold temperatures. [see Figure ISPM-9]

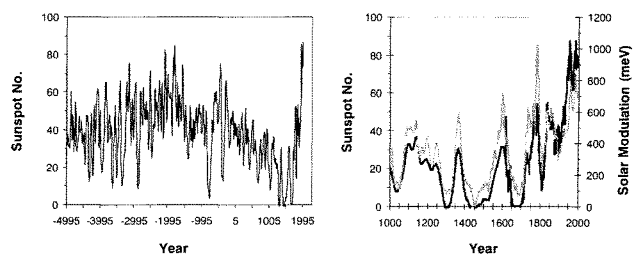


FIGURE ISPM-4: SOLAR ACTIVITY

LEFT: reconstruction for past 8,000 years (Usoskin *et al.* 2006); RIGHT: reconstructions for the past millennium; Blue – reconstruction of sunspot numbers from residual C14 (Usoskin *et al.*, 2006); Red – group sunspot number (Hoyt and Schatten, 1993); Green – reconstruction of solar modulation from residual C14 (meV) (Muscheler *et al.*, 2005).

1.4c Scientific understanding of solar variability remains low.

- Estimates of the change in solar forcing between the Maunder Minimum and the late 20th century range over almost an entire order of magnitude. [2.7, 2.7.1.2.1, Table 2.10; see Figure ISPM-5]
- A new estimate of solar irradiance increase since the Maunder Minimum (0.037% according to Wang *et al.*, 2005) is nearly an order of magnitude lower than another recent estimate of 0.3% by Fligge and Solanki, 2000. [2.71, Table 2.10]

157

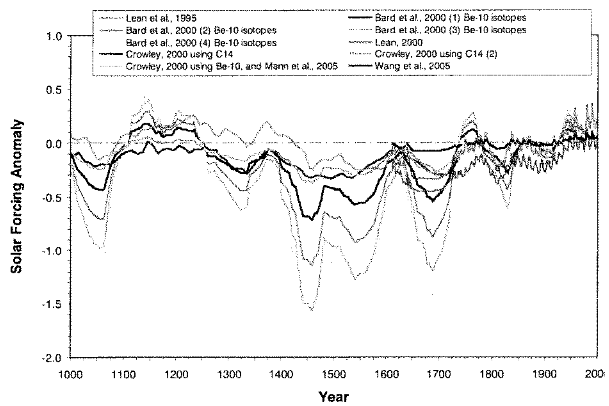


FIGURE ISPM-5: SOLAR FORCING ANOMALY (WATTS/ M²) FOR THE PAST MILLENNIUM

Forcing anomaly calculated as irradiance divided by 4 and multiplied by 0.7 (albedo) following Table 2.10 of the Fourth Assessment Report. Anomaly centered on 1850-1960.

NOTE: There are four variations from Bard et al., 2000 Be-10 isotopes, and two from Crowley, 2000 using C14.

1.4d Total solar irradiance measurements are subject to important uncertainties due to instrumentation.

- Total Solar Irradiance has been measured only since 1978 and even then only with different instruments, none of which cover the entire interval. ACRIM instruments show an increase in excess of 0.04% between 1989 and 1992. This apparent increase may merely be a result of instrumental changes. [2.7.1]
- A continuous record can be constructed only by combining records from different satellites with different instruments. If the measured change of 0.04% proves accurate, this increase is as large as the increase since the Maunder Minimum. [2.7.1.1.2, Figure 2.19]

1.4e New evidence has emerged of indirect solar effects on climate.

- Although solar UV radiation represents only a small fraction of the energy from total irradiance, UV radiation is more variable by at least an order of magnitude. Since the Third Assessment Report, new studies have confirmed and advanced the plausibility of indirect effects on the climate system involving the modification of the stratosphere by solar UV irradiance variations (and possibly by solar-induced variations in the overlying mesosphere and lower thermosphere), with subsequent dynamical and radiative coupling to the troposphere. [2.7.1.3]
- It is now well established from both empirical and model studies that solar cycle changes in UV radiation alter middle atmospheric ozone concentrations, temperatures and winds. [2.7.1.3]

- When solar activity is high, the more complex magnetic configuration of the heliosphere reduces the flux of galactic cosmic rays in the Earth's atmosphere. Various scenarios have been proposed whereby solar-induced galactic cosmic ray fluctuations might influence climate, possibly through low cloud formation. [2.7.1.3]
- An unequivocal determination of specific mechanisms - whether direct or indirect - that involve solar variability and climate has yet to be accomplished. [2.7.1.3]

SUPPLEMENTARY INFORMATION

The sun and climate change

Solar and greenhouse forcings have both increased through the 20th century, making it extremely difficult to conclusively identify the influence of the sun on the recent climate.

New IPCC estimates of solar forcing are much lower than those used in millennial simulations (e.g., Crowley, 2000; Gonzalez-Rauco *et al*, 2003; Mann *et al*, 2005). If the new estimates prove reliable, many explanations of past climate variations relying on former estimates of solar forcing will need to be re-considered.

If the sun does have a strong effect on climate, this adds importance to recent projections that solar output is likely to decline over the next several decades (e.g., Zhen-Shan, 2007).

This topic is explored in the forthcoming Fraser Institute Supplementary Analysis Series report, "Solar Changes and the Climate."

1.5 Changes to the land surface

1.5a Changes in the land surface over the 20th century have likely had large regional and possibly global effects on the climate, but the effects do not fit into the conceptual model used for assessing anthropogenic climate change.

- Changes to the land surface act as anthropogenic perturbations to the climate system and fall at least partly within the "forcing" component of the *forcing-feedback-response* conceptual model. But it is difficult to quantify the pure forcing component of such changes as distinct from feedbacks and responses. A quantitative metric separating forcing from feedback and response has not yet been implemented for climatic perturbation processes which do not act directly on the radiation budget. [2.5.1]
- Attempts to use climate models to convert land use changes into RF measures have produced a wide range of results. Some estimated magnitudes of the local RF effects of agricultural change in North America and Eurasia are considerably larger than that from CO_2 in the atmosphere [2.5.3]. However the data for parameterizing basic RF effects are not consistent and the uncertainties remain large. [2.5.3.1]

1.5b Many studies have found that urban areas are warmer than the surrounding country-side, introducing a "non-climatic" warm bias into local long term weather records. If true, this would imply IPCC climate data overstate the recent global warming trend. Some studies have asserted, however, that urbanisation is adequately corrected in the globally-averaged data. All IPCC analysis assumes the latter to be the case.

- The urban heat island effect is real, and causes temperature records from urban and suburban areas to have an upward trend unrelated to climatic changes. [3.2.2.2]

- Some studies argue that the global climate data sets, which compile urban, suburban and rural records into regional averages, are not contaminated by such upward biases. [3.2.2.2]
- All IPCC usage of climatic data operates on the assumption of no contamination. However many studies have shown that changes in land use and land cover can have large regional effects on the climate that are comparable in magnitude to temperature and precipitation changes observed over the last several decades, and the large numbers of such studies collectively demonstrate a potentially important impact of human activities on climate, especially local climate, through land use modification. [7.2.4.4]
- Detection and attribution studies do not account for urbanization, data quality problems or other non-climatic effects in the temperature data. All observed changes in the data are assumed to be due to climatic changes. [9.4.1.2]

SUPPLEMENTARY INFORMATION

Problems with the surface temperature record

Research on the nature of the surface thermometer network has cast some doubt on the claim of the IPCC that the surface temperature record is free of biases related to non-climatic effects, such as land-use change, urbanization and changes in the number of stations worldwide. For example, studies have shown that the spatial pattern of warming trends over land correlate strongly with the distribution of industrial activity, even though such a correlation is not predicted by climate models (e.g., de Laat and Maurellis 2004, 2006).

These and related issues are explored in the forthcoming Fraser Institute Supplementary Analysis Series report "Problems in the Surface Thermometer Network."

2.1 Large-scale temperature averages

2.1a Weather satellites collect daily data throughout the atmosphere and are used to measure average atmospheric temperatures. Different teams produce slightly different results based on different assumptions about the way to interpret the data.

- Satellites measure atmospheric radiation from two layers of the atmosphere, denoted T2 and T4.
- T2 radiation mostly comes from the surface and lower troposphere, whereas T4 mostly emanates from the stratosphere. From these radiation readings, temperature averages can be inferred based on an assumed set of weights. [3.4.1.2.2]
- The "true" weights cannot be known with certainty. The weights that yield results most closely matching data from weather balloons shows the least amount of tropospheric warming. [Figure 3.4.3]

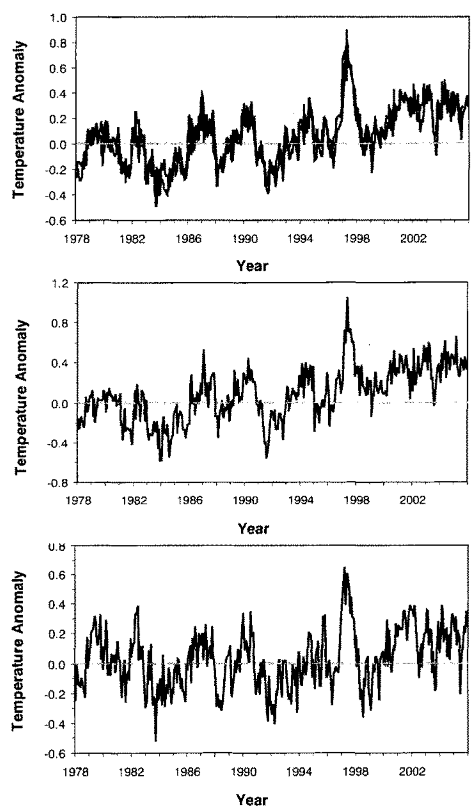


FIGURE ISPM-6: SATELLITE-MEASURED MEAN GLOBAL TEMPERATURE ANOMALIES SINCE 1979 (°C)
TOP: Global average; MIDDLE: Northern Hemisphere; BOTTOM: Southern Hemisphere.
Sources:
Top: Red -Mears and Wentz (2006); Blue - Global Hydrology and Climate Centre – University of Alabama in Huntsville (GHCC-UAH);
Middle and Bottom: GHCC-UAH.

2.1b Satellite data from the lower atmosphere (T2) yield trends of about 0.04 °C to 0.2 °C / decade over 1979-2004, implying estimated trend coefficients in averaged tropospheric temperatures of about 0.12 °C to 0.19 °C/decade.

- Three different teams of analysts have examined satellite-measured microwave radiation data spanning 1979 to the present. [3.4.1.2.2]
- The channel T2 data imply global warming of the troposphere of 0.04 to 0.20°C /decade for the period 1979-2004, depending on assumptions about instrument calibration, orbital drift and diurnal cycle corrections and merging across data sets. [3.4.1.2.2; Figure ISPM-6]
- Adjusting T2 data to remove an estimated contribution from the stratosphere yields tropospheric trend coefficients ranging from about 0.12 °C to 0.19 °C per decade, depending on the method. [3.4.1.2.2; Figure 3.4.3]
- Tropospheric trends computed from NRA (model-based) reanalysis data are lower and statistically insignificant, but may be unreliable. [3.4.1.5]
- Extrapolated to a century scale these trends compare to the low end of past IPCC warming projections (0.14 °C to 0.58 °C/decade) as presented in the TAR.

2.1c There is no significant warming in the tropical troposphere, which accounts for half the world's lower atmosphere. This is where models that assume a strong influence of greenhouse gases forecast some of the most rapid warming should occur.

- The tropics account for half the world's atmosphere. In none of the available data sets is significant warming observed in the tropical troposphere [Figure 3.4.3]. One of the available satellite data sets shows trends consistent with increased warming at higher altitude in the tropics [3.4.1.2.2], while others do not.
- Climate models based on the assumption that greenhouse gases drive climate change predict some of the strongest warming should be observed in the upper troposphere over the tropics [Figure 10.3.4]. This pattern is predicted to be evident early in the forecast period and the pattern is simulated consistently among the models. [10.3.2.1]

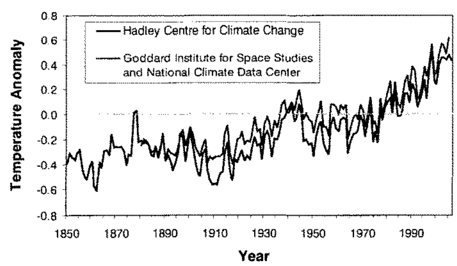


FIGURE ISPM-7: ANNUAL AVERAGE MEAN TEMPERATURE ANOMALIES MEASURED AT THE EARTH'S SURFACE OVER THE LAST 120-150 YEARS (°C)
Sources: Goddard Institute for Space Studies (GISS), National Climate Data Center (NCDC), and Hadley Centre for Climate Change.

2.1d A global average of temperature data collected over land, combined with ocean surface measurements from ships and buoys, with local means removed and some adjustments applied to control for uneven sampling, loss of half the land-based weather stations in the early 1990s, changes in measurement techniques and other potential problems, exhibits an upward trend from 1900 to 1940, and again from 1979 to the present.

- The statistic is commonly called the global mean temperature anomaly or "global temperature" for short.
- The global temperature statistic produced by the Goddard Institute for Space Studies (GISS) and the National Climate Data Center (NCDC) was slightly higher in 2005 than at any time since 1998, while that produced by the Hadley Center peaked in 1998 and has been slightly lower ever since. (see Figure ISPM-7) [3.2.2]
- See also Section 2.1e below.

	1850–2005	1901–2005	1910–1945	1946–1978	1979–2005
Land: Northern Hemisphere					
CRU (Brohan et al, 2006)	**0.063 ± 0.018**	**0.089 ± 0.030**	**0.142 ± 0.057**	−0.038 ± 0.064	**0.330 ± 0.108**
GHCN (Smith and Reynolds, 2005)		**0.072 ± 0.031**	**0.127 ± 0.065**	−0.040 ± 0.074	**0.344 ± 0.121**
GISS		**0.083 ± 0.030**	**0.166 ± 0.061**	−0.053 ± 0.062	**0.294 ± 0.090**
Lugina et al. (2005) up to 2004		**0.074 ± 0.032**	**0.144 ± 0.074**	−0.051 ± 0.061	**0.278 ± 0.096**
Land: Southern Hemisphere					
CRU (Brohan et al, 2006)	*0.034 ± 0.033*	**0.078 ± 0.054**	*0.091 ±0.076*	0.031 ±0.063	**0.135 ± 0.087**
GHCN (Smith and Reynolds, 2005)		**0.057 ± 0.020**	*0.091 ± 0.069*	0.054 ± 0.072	**0.220 ± 0.114**
GISS		**0.056 ± 0.015**	0.033 ± 0.042	*0.060 ± 0.052*	*0.085 ± 0.067*
Lugina et al. (2005) up to 2004		**0.056 ± 0.013**	**0.064 ± 0.046**	0.014 ± 0.052	*0.074 ± 0.062*
Land: Globe					
CRU (Brohan et al, 2006)	**0.054 ± 0.020**	**0.084 ± 0.026**	**0.125 ±0.042**	-0.016 ±0.055	**0.268 ± 0.084**
GHCN (Smith and Reynolds, 2005)		**0.068 ± 0.029**	**0.116 ±0.057**	−0.013 ±0.061	**0.315 ± 0.108**
GISS		**0.069 ± 0.020**	**0.102 ± 0.041**	0.003 ± 0.046	**0.188 ± 0.084**
Lugina et al. (2005) up to 2004		**0.065 ± 0.024**	**0.108 ± 0.043**	- 0.021 ± 0.059	**0.183 ± 0.075**

TABLE ISPM-1: LINEAR TRENDS OF TEMPERATURE (°C/DECADE)

Reproduction of Table 3.2 from the Fourth Assessment Report. Each cell shows the IPCC-estimated trend and 2-standard error confidence interval. 'CRU' denotes Climatic Research Unit; 'GHCN' denotes Global Historical Climatology Network; 'GISS' denotes Goddard Institute for Space Studies. Bold denotes a statistically significant (1%) trend in IPCC methodology; italics denotes significant (1-5%); but see Section 2.1g below.

2.1e Post-1979 trends in temperature data averaged over land areas in the Southern Hemisphere are small compared to those from the Northern Hemisphere, and statistically less significant.

- Temperature trends in land-based data for the Northern and Southern Hemispheres from 1979-2005 are shown in Table ISPM-1. In all cases the Southern Hemisphere trend is small compared to the Northern Hemisphere trend.
- In two of the four surface data sets the Southern Hemisphere trend is less than one-third as large as the Northern Hemisphere trend and is statistically less significant. [Table 3.2]
- Both data sets that merge land-based data with relatively sparse and uncertain sea surface temperature data show Southern Hemisphere trends less than half those in the Northern Hemisphere. [Table 3.2]

2.1f The Third Assessment Report drew attention to the declining Diurnal Temperature Range (DTR) as evidence of global warming (Working Group 1 Summary for Policymakers, page 1). The decline in the DTR has now ceased, and appears to be growing in most places.

- The DTR declined after 1950, but stabilized as of the mid-1990s. [3.2.2.7, Figure 3.2.2]
- From 1979 to 2004, data from many locations on all continents show an increasing DTR, especially in North America, Europe, Australia and South America. [Figure 3.2.11]

2.1g The significance of trends in temperature and precipitation data is likely to have been overstated in previous analyses.

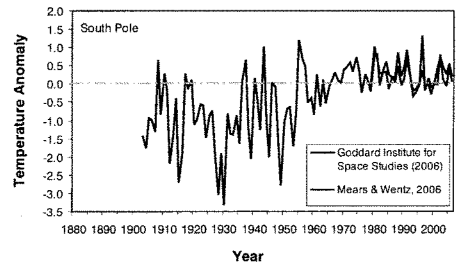
- The climate system responds to change slowly over time, and past changes accumulate through long term persistence to influence ongoing trends. As a result the trend estimation techniques used in recent IPCC Assessments likely overstate the statistical significance of observed changes, and the results of trend analysis often depend on the statistical model used. [3.2.2.1]

SUPPLEMENTARY INFORMATION

Long Term Persistence and Trend Analysis

Methods for estimating trends, and assessing their statistical significance, have undergone considerable advance in the past decade. Technical issues being raised include *nonstationarity* and *Long Term Persistence*. While the literature on these issues originated in hydrology, econometrics, finance and statistics, it has begun to be applied to climate data sets as well. The main findings are that proper treatment of long term processes in climate data often require a major reinterpretation of the significance of recent trends, as the new methods attribute more of the observed changes in climate data to natural variance.

This is explored in the forthcoming Fraser Institute Supplementary Analysis Series report, "Long Term Persistence in Geophysical Data."



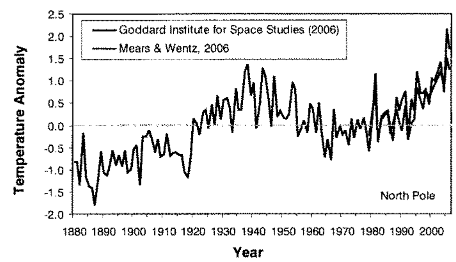


FIGURE ISPM-8. AVERAGE SURFACE TEMPERATURE ANOMALY POLEWARD OF 64 DEGREES LATITUDE (GRAY LINE) AND CORRESPONDING SATELLITE-MEASURED DATA (BLUE LINE)

TOP: South Pole; BOTTOM: North Pole.

Source: Gray-Goddard Institute for Space Studies (2006); Blue- Mears and Wentz (2006).

2.1h There are differences in linear trends of tropospheric temperatures between the high latitudes of the Northern and Southern Hemispheres that are not consistent with computer model projections.

- Geographical patterns of the linear trend in tropical temperature show coherent warming over the Northern Hemisphere but areas of cooling over the Southern Hemisphere. [3.4.1.2.2, Figure 3.4.4]
- The North Pole exhibits a sudden upward trend in mean temperature after 1990, but not the South Pole. (see Figure ISPM-8)
- Model projections suggest greenhouse gas-induced warming patterns at the north and south poles will be nearly symmetrical. [Figure 10.3.5]

2.11 The Earth's climate is characterized by many modes of variability, involving both the atmosphere and the oceans, and also by the cryosphere and the biosphere [1.4.6]. There is an increasing recognition that changes in the oceans may be playing a role in climate change.

- Our understanding of the variability and trends in different oceans is still developing, but it is already apparent they are quite different. The Pacific is dominated by the El-Niño/Southern Oscillation (ENSO) cycle and is modulated by the Pacific Decadal Oscillation (PDO), which may provide ways of transporting heat from the tropical oceans to higher latitudes and from the ocean to the atmosphere. [3.6.3]
- Since 1900, North Pacific Sea Surface Temperatures (SST) show warm mode phases from 1925-1946 and 1977 to 2005. [3.6.3]
- Since the 1850s, North Atlantic SSTs show a 65-75 year variation, with apparent warm phases at roughly 1860-1880 and 1930-1960 and cool phases during 1905-1925 and 1970-1990. This feature has been termed the Atlantic Multidecadal Oscillation (AMO). The cycle appears to have returned to a warm phase beginning in the mid-1990s and tropical Atlantic SSTs were at record high levels in 2005. [3.6.6.1]
- The AMO has been linked to multi-year precipitation anomalies over North America, as well as Atlantic hurricane formation, African drought frequency, winter temperatures in Europe, sea ice concentration in the Greenland Sea and sea level pressure over high northern latitudes. [3.6.6.1]
- The multidecadal variability in the Atlantic is much longer than the Pacific but it is noteworthy that all oceans exhibit a warm period around the early 1940s. [3.2.2.3]

SUPPLEMENTARY INFORMATION

Major Ocean-Atmosphere Climate Oscillations

An important theme in recent meteorological research is the identification of some large-scale atmospheric cycles that operate on time spans of 30 years or more. These oscillations arise from the interaction of the oceans and atmosphere, and are typically measured using pressure gradients across large regions of the Earth's surface. Representation of the oceans in climate models as truly dynamic systems (as opposed to the earlier "slab" ocean models) is only beginning. A comprehensive description of the atmospheric and ocean circulations has been delayed by lack of observations from the high atmosphere and deep oceans.

Major oscillation systems have been shown to have significant explanatory power for recent climatic changes, including trends in temperature and precipitation. The El Niño-Southern Oscillation (ENSO) is a coupled air-sea phenomenon that has its origins in the Pacific Ocean but affects climate globally. The mechanisms and predictive skill of ENSO are still under development. The North Atlantic Oscillation (NOA, first discovered by Sir Gilbert Walker in the 1930s) is a phenomenon that affects weather and climate and is associated with variability and latitudinal shifts of the westerly winds and jet streams. Despite a long history of observation and research the NAO and its low-frequency variability remains poorly understood.

The IPCC discusses some of these issues, but does not provide adequate detail about the connection between these systems and recent weather changes.

This topic is explored in the forthcoming Fraser Institute Supplementary Analysis Series report, "Major Climatic Oscillations and Recent Weather Changes."

2.2 Precipitation and snow cover

2.2a There is no globally-consistent pattern in long-term precipitation trends.

- At the global level, slight decline was observed in total precipitation from 1950 to the early 1990s, which has since reversed. [3.3.2.1; Figure 3.3.1]
- Precipitation in North and South America has risen slightly over the past century in many places, though in some regions it has fallen. [3.3.2.2]
- The drying trend noted in the 1980s in the Sahel (the coastal region in Africa bordering the Sahara desert) has since reversed considerably. [3.3.2.2]
- Rainfall in India increased from 1901 to 1979 then declined through to the present [3.3.2.2], and there is no overall trend. [3.3.2.2]
- Australian precipitation trends vary by region and are closely linked to the El Niño cycle. [3.3.2.2]

2.2b There is no globally-consistent pattern in snow-covered area or snow depth.

- In the Northern Hemisphere, mean observed snow cover in April declined somewhat from the 1950s to the 1970s, declined rapidly in the 1980s and has increased slightly since 1990. [Figure 4.2.1]
- Over the 1966 to 2004 interval, mean Northern Hemisphere snow cover in October showed a statistically insignificant decline. But over the entire span of available data (1922 to 2004) the mean Northern Hemisphere snow cover in October shows a statistically significant increase. [Table 4.2.1]
- Over the 1966 to 2004 interval, mean Northern Hemisphere snow cover trended downward in spring and summer, but not substantially in winter. [4.2.2.2; Table 4.2.1]
- In North America the trend in November-January snow-covered area over the 20th century is upward overall, with a recent downward trend especially in Western North America. [4.2.2.2.1]
- Snow-covered area in mountainous areas of Switzerland and Slovakia has declined since 1931, but not in Bulgaria. [4.2.2.2.2]
- Lowland areas of central Europe have exhibited decreased snow-covered area, while increased maximum snow depth has been recorded in the former Soviet Union, Tibet and China. [4.2.2.2.2]
- In South America a long term increasing trend in snow days has been observed in the eastern central Andes. [4.2.2.3.1]
- In Southeastern Australia, late-winter snow depth has declined considerably, though winter precipitation has decreased only slightly. [4.2.2.3.2]

2.2c In areas north of 55N latitude, snowfall has increased over the past 50 years. Trends in the frequency of heavy snowfall events vary by region.

- At high latitudes, winter precipitation has increased in the past 50 years [3.3.2.3] and there has been little change in the fraction falling as snow rather than rain. [3.3.2.3]
- In North America, the incidence of heavy snowfall events has increased in Northern Canada and in the lee of the Great Lakes, but decreased in the lower Missouri river basin. [3.3.2.3]
- In some areas, namely Southern Canada and western Russia, the earlier onset of the spring season over the past 50 years has meant an increasing fraction of precipitation falls as rainfall [3.3.2.3]. However other data have shown an overall increase in snowfall in parts of southern Canada. [3.3.2.3]

SUPPLEMENTARY INFORMATION

Recent North American snowfall records

"Record-breaking" local hot weather events are sometimes promoted as evidence of global warming. What can we infer if record-breaking cold weather events begin to accumulate in some local data?

New York City's Central Park has a January (their coldest month) average temperature of 0.1°C and winter average of 1.0°C. For the first time since records began in the 1860s, Central Park reported four successive years of 100 centimetres of snow or more ending in the winter of 2005/06. On February 11-12, 2006, Central Park broke the all-time single snowstorm record with 68.3 centimetres of snow. Also in 1995/96, Central Park and most other cities in the central and eastern US had all-time record seasonal snowfall. In Central Park, that winter brought 192 centimetres of snow.

Not far to the north in Boston, MA where the winter temperature averages -0.1°C, the 12 year average snowfall in the winter ending 2004/05 was 130.3 centimetres, the highest in their entire record dating back into the 1800s. A new all-time single snowstorm record was set on February 17-18, 2003 with 70 centimetres and a new all-time seasonal snowfall record of 273 centimetres was set in 1995/96. In the last dozen years, Boston has recorded their 1st, 3rd, 5th, 7th and 12th snowiest winters.

In the Canadian Atlantic provinces winter snow accumulation has increased in recent years. The city of St John's (Newfoundland) recorded its highest ever snow accumulation in one season, ~650 cm, from November 2000 through May 2001. This is the highest snow accumulation at a sea-level location anywhere in the world. In February 2004 the city of Halifax (Nova Scotia) received a record-breaking 100 cm of snow in a 24-hour period.

Data Source: US National Weather Service and Environment Canada

2.3 Storms and extreme weather

2.3a Perceptions of increased extreme weather events are potentially due to increased reporting. There is too little data to reliably confirm these perceptions.

- People tend to hear about extreme events more now because of technology. Pictures shot by camcorders on the news may foster a belief that weather-related extremes are increasing in frequency. [3.8.1]
- Global studies of temperature and precipitation extremes over land suffer from a scarcity of data. In various parts of the globe, there is a lack of homogeneous (i.e., subject to consistent quality control and constant sampling conditions) daily observational records. The lack of homogeneous data has been attributed to, among other things, changes in observing practices or urban heat island effects. [3.8.1]
- Identification of changes in extremes is also dependent on the statistical analysis technique employed. [3.8.1]
- Global studies of daily temperature and precipitation extremes over land suffer from both a scarcity of data and regions with missing data. [3.8.1]
- Analyses of trends in extremes are also sensitive to the analysis period; e.g., the inclusion of the exceptionally hot European summer of 2003 may have a marked influence on results if the period is short. [3.8.1]

2.3b Since 1970, there is some evidence of increased tropical cyclone intensity in both hemispheres, but a decrease in total tropical storm numbers, and no clear global pattern.

- A number of recent studies suggest that cyclone activity over both hemispheres has changed over the second half of the 20th century. General features include a poleward shift in storm track location and increased storm intensity, but a decrease in total storm numbers. [3.5.3]
- Station pressure data over the Atlantic-European sector (which has long and consistent records) show a decline of storminess from high levels during the late-19th century to a minimum around 1960 and then a quite rapid increase to a maximum around 1990, followed again by a slight decline. [3.5.3]
- Data suggest that cyclone activity in the Northern Hemisphere mid-latitudes has increased during the past 40 years, whereas there have been significant decreases in cyclone numbers, and increases in mean cyclone radius and depth, over the southern extratropics over the last two or three decades. [3.5.3]
- With respect to storm data generally, data uncertainties compromise evidence for trends. [3.8.1]
- The considerable inter-decadal variability reduces the significance of any long-term trends. Careful interpretation of observational records is therefore required. [3.8.3]
- The overall power of cyclones has been characterized using the Accumulated Cyclone Energy (ACE) index and the Power Dissipation Index (PDI). The ACE is proportional to the square of the wind speed and the PDI is proportional to the wind speed cubed. The PDI for the world as a whole shows an upward trend since the 1970s, but because of its cubic exponent it is very sensitive to data quality. Pre-1970 data are particularly uncertain [3.8.3]. The ACE index is available in some regions back to 1948 and shows no overall trend over the entire interval. The ACE shows an upward trend after 1980 only in the North Atlantic, but a downward trend post-1980 in the West North Pacific, East North Pacific, Australian-South Pacific, North Indian and South Indian regions [Figure 3.8.4]. At the global level, the ACE Index values for 2004 and 2005 are about average for the whole post-1980 interval. [3.8.3]

2.3c Data are too sparse, and trends inconsistent, to identify a pattern in extratropical cyclones.

- As with tropical cyclones, detection of long-term changes in extratropical cyclone measures is hampered by incomplete and changing observing systems. Some earlier results have been questioned because of changes in the observation system. [3.8.4.1]
- An increase in the number of deep cyclones is apparent over the North Pacific and North Atlantic, but only the North Pacific trend is statistically significant. Significant decreases have been noted in cyclone numbers over the southern extratropics over the last two or three decades, along with increases in mean cyclone radius and depth. [3.8.4.1]

2.3d Evidence for changes in temperature variability is sparse and insignificant.

- Evidence for changes in observed interannual variability is still sparse. Seasonal mean temperature in central Europe showed a weak increase in summer and decrease in winter, for the time period 1961 to 2004. These changes are not statistically significant at the 10% level. [3.8.2.1]

- Regional studies from several continents show patterns of changes in extremes consistent with a general warming, although the observed changes of the tails of the temperature distributions are not consistent with a simple increase in the entire temperature distribution. [3.8.2.1]
- For the period 1951–2003, three-quarters of the global land area sampled showed a significant decrease in the annual occurrence of cold nights; while a significant increase in the annual occurrence of warm nights took place over 72% of the area. This implies a positive shift in the distribution of daily minimum temperature throughout the globe. Changes in the occurrence of cold days and warm days show warming as well, but generally less marked. This is consistent with the increase in minimum as opposed to maximum temperature. [3.8.2.1]

2.4 Ocean temperatures and sea levels

2.4a Regarding the Gulf Stream and the global Meridional Overturning Circulation (MOC), it is very likely that the MOC has changed on annual and decadal time scales, but evidence for overall weakening is mixed and uncertain, and the connection to surface climate is not well understood.

- The global Meridional Overturning Circulation (MOC) consists primarily of dense waters that sink to the seafloor at high-latitudes in the North Atlantic Ocean and near Antarctica. This influences global ocean currents and may influence wind patterns, including the Gulf Stream. [Box 5.1]
- Only indirect estimates of the MOC strength and variability exist, and the best evidence for observational changes in the overturning circulation comes from the North Atlantic. [Box 5.1]
- There is evidence for a link between MOC and abrupt changes in surface climate during the past 120,000 years, although the exact mechanism is not clear. [Box 5.1]
- One recent study concluded that the MOC transport in the North Atlantic at 25°N has decreased by 30% between 1957 and 2004, indicating a stronger mid-ocean return flow in the upper kilometre, though not a decrease in Gulf Stream strength. Note however that this result is based on 5 snapshots in time, and it is not clear whether the trend estimate can be viewed as robust in the presence of considerable variability. [Box 5.1]
- Two other studies examined a model-based relation of MOC transport with interdecadal sea surface temperature patterns and concluded that the MOC has increased since the 1970s. [Box 5.1]
- There is only a low level of confidence that the strength of deep limb of the MOC in the North Atlantic MOC has actually decreased. [Box 5.1]

SUPPLEMENTARY INFORMATION

Questions about the MOC Mechanism

It has not been formally established that deep-water formation drives the MOC. Others have argued (e.g., Wunsch, 2002) that deep-water formation does not provide sufficient energy to drive the MOC, and that it is a largely wind-driven circulation, where the wind field provides the mechanical energy necessary to overcome the natural stratification of the ocean.

A recent paper (Latif et al, 2006) concludes that multi-decadal MOC variations can be understood as the lagged response to the multi-decadal variations in the NAO, and further does not provide any evidence for a sustained weakening of the MOC during the last few decades.

2.4b Regarding sea levels, a critical issue concerns how the records are adjusted for vertical movements of the land upon which the tide gauges are located. Current data suggest a global mean sea level rise of between 2 and 3 millimeters per year.

- Tide gauges provide data about sea level variations with respect to the land on which they lie. However, the Earth's crust is subject to various vertical motions due to geological factors such as tectonics and local subsidences. To extract an accurate sea level signal, tide gauge readings need to be adjusted to compensate for vertical motions. [5.5.1]
- Sea level change based on satellite altimetry measurements is measured with respect to the earth's center of mass, and thus is not distorted by land motions, except for a small component due to large scale deformation of ocean basins from Glacial Isostatic Adjustment (GIA). [5.5.1]
- Models are used to correct recent global tide gauge estimates for Glacial Isostatic Rebound (GIR), but not for other land motions. Adjusted rates could be underestimated by several tenths of millimeters per year in analyses which employ extrapolations of geological data obtained near the gauges. [5.5.2.1]
- Tide gauge data suggests a rise in mean sea level over 1961-2003 of about 1.8 mm/year, ±0.5 mm. [5.5.2.1]
- Satellite estimates of mean sea level yield an accuracy of ±5 mm. Satellite data show a rate of sea level rise of +3.1 ± 0.8 mm per year over 1993-2005. The accuracy of this estimate is partly dependent on the calibration against vertical land motions as measured by tide gauges. [5.5.2.1]
- By comparison, satellite observations show a 15 mm rise and fall of mean sea level and a 0.4°C rise and fall of global mean sea surface temperature accompanying the 1997-1998 El Niño-Southern Oscillation (ENSO) event. [5.5.2.1]

2.4c Regional trends in sea level are quite varied and some regions are experiencing declining sea levels. Changes in air pressure and wind account for some observed sea level increase.

- While global sea level rose by approximately 120 metres during the several millennia that followed the end of the last glacial maximum, the level stabilized between 3000 and 2000 years ago. Since then, paleo sea level indicators suggest that global sea level did not change significantly: the average rate of change from 2000 years ago to about 100 years ago is near zero. [Question 5.1]
- Although regional variability in coastal sea level change had been reported from tide gauge analyses, the global coverage of satellite altimetry provides unambiguous evidence of non-uniform sea level change in open oceans. [5.5.2.2]
- For the past decade, the western Pacific Ocean and eastern Indian Oceans show the highest magnitude of sea level rise, however, sea level has been dropping in the eastern Pacific and western Indian Oceans. [5.5.2.2]
- Except for the Gulf Stream region, most of the Atlantic Ocean shows sea level rise during the past decade. [5.5.2.2]
- Northeast Atlantic sea level records are notable for their 20th century trends that are lower than the global average. Explanations include Glacial Isostatic Adjustment, and air pressure and wind changes associated with North Atlantic Oscillation (NAO). [5.5.2.6.1]
- Arctic Ocean sea level time series have well pronounced decadal variability which corresponds to the variability of the North Atlantic Oscillation Index. In this particular region, wind stress and atmospheric pressure loading contribute to nearly half of the observed Arctic sea level rise. [5.5.2.6.2]

2.4d There is very little sea-level data from Pacific Ocean islands. The available series appear to indicate less than one millimeter sea level rise per year.

- There are only four Pacific island stations with more than 50 years of data. Data from these stations show an average rate of sea-level rise (relative to the Earth's crust) of 1.6 mm/year. Twenty-two Pacific island stations have more than 25 years of data and they indicate an average sea level rise less than half as great, at 0.7 mm/year. However, these data suffer from poorly quantified vertical land motions. [5.5.2.6.3]

2.4e Changes in extreme sea level are due to changes in sea level and storminess. 20th century trends differ by location.

- The annual maximum high water surge at Liverpool since 1768 was larger in the late-18th, late-19th and late-20th centuries than for most of the 20th century. [5.5.2.7]
- The tide gauge record at Brest from 1860 to 1994 shows an increasing trend in storm surges (as measured by maxima and top-1% groups), but shows a decreasing trend during the period 1953-1994. [5.5.2.7]
- Extreme winter surges at San Francisco have exhibited a significant increasing trend since about 1950. [5.5.2.7]
- The rise in extreme sea level along the US east coast is closely correlated to the rise in mean sea level. [5.5.2.7]
- A long term increase in the number and height of extreme daily sea level readings has been noted at Honolulu, but no evidence indicates an increase relative to the underlying upward mean sea level trend. [5.5.2.7]

2.4f Sea level increases over the past decade are not uniform, and it is presently unclear whether they are attributable to natural variability.

- The instrumentally-based estimates of modern sea level change provide evidence for an onset of acceleration at the end of the 19th century. Recent estimates for the last half of the 20th century (1950-2000) give approximately 2 mm/year global mean sea level rise. New satellite observations show that since 1993 sea level has been rising at a rate of 3.1 mm/year. [Question 5.1]
- Satellite data also confirm that sea level is not rising uniformly over the world. [Question 5.1]
- It is presently unclear whether the higher rate of sea level rise in the 1990's indicates an acceleration due to global warming, or a result of natural climate variability, or a combination of both effects. [Question 5.1]

SUPPLEMENTARY INFORMATION

Historical Storm Surges

The greatest storm surge in historical time was 13.6 meters and occurred in 1876 in the Bay of Bengal. The second highest on record was 13 meters in the Bathurst Bay in Australia in 1899. Since 1876, the maximum surge in the Bay of Bengal was about 9 meters in 1970 and 1999. By comparison, the maximum surge by Hurricane Katrina of August 2005 was 8.5 meters.

2.5 Glaciers, sea ice and ice caps

2.5a Glacier archives indicate that most of the Earth's alpine glaciers receded or disappeared between 9,000 and 6,000 years ago.

- Most archives from the Northern Hemisphere and the tropics show small or absent glaciers between 9,000 and 6,000 years ago. [Box 6.3]
- Glaciers began growing thereafter, up to the 1800s. [Box 6.3]
- This tendency is primarily related to changes in the Earth's orbit, however shorter, decadal-scale, regionally diverse glacier responses must have been driven by other factors which are complex and poorly understood. [Box 6.3]

2.5b Glaciers in most places have retreated since the 1800s

- General retreat of glacier termini started after 1800, with considerable mean retreat rates in all regions after 1850 lasting throughout the 20th century. A slowdown of retreats between about 1970 and 1990 is evident in the raw data. Retreats were again generally rapid in the 1990s; though advances of glaciers have been observed in western Scandinavia and New Zealand. [4.5.2]
- There are few records of directly measured glacier mass balances, and they stretch back only to the mid 20th century. [4.5.2] When areal weighting and spatial interpolation are used to estimate large-scale patterns from the available data, the 1990s trend towards glacier retreat appears to have leveled off or reversed after 1998. [Figure 4.5.2]

2.5c Over the last half century, global mean winter accumulation and summer melting of glacier ice have both increased.

- At least in the Northern Hemisphere, winter accumulation and summer melting of glacial ice correlates positively with hemispheric air temperature, whereas the net balance correlates negatively with hemispheric air temperature. An analysis of 21 Northern Hemisphere glaciers found a rather uniformly increased mass-turnover rate, qualitatively consistent with moderately increased precipitation and substantially increased low-altitude melting. [4.5.2]

2.5d While the loss of Northern Hemisphere glacier mass accelerated in the 1990s, loss of Arctic sea ice thickness slowed or stopped during the 1990s

- In the Northern Hemisphere, the rate of glacier mass loss was twice as rapid in the 1990s compared to the period from the 1960s to1990. [4.5.2]
- An early study of Arctic ice found that ice draft in the mid 1990s was less than that measured between 1958 and 1977 at every available location (including the North Pole). The decline averaged about 42% of the average 1958-1977 thickness. Subsequent studies indicate that the reduction in ice thickness was not gradual, but occurred abruptly before 1991, with no evidence of thinning along 150°W from six springtime cruises during 1991-1996. Springtime observations from 1976 to 1994 along the same meridian indicated a decrease in ice draft sometime between the mid 1980s and early 1990s, with little subsequent change. [4.4.3.2]

2.5e On a regional basis the pattern of glacier regimes remains complex. Precipitation and solar changes appear to be important factors, especially in the tropics, including Kilimanjaro.

- Although reports on individual glaciers or limited glacier areas support the global picture of ongoing strong ice shrinkage in almost all regions, some exceptional results indicate the complexity of both regional to local scale climate and respective glacier regimes. [4.5.3]
- Whereas Himalayan glaciers have generally shrunk at varying rates, several high glaciers in the central *Karakoram* are reported to have advanced and/or thickened at their tongues, probably due to enhanced transport of moisture to high altitudes. [4.5.3]
- Norwegian coastal glaciers advanced in the 1990s and started to shrink around 2000 as a result of almost simultaneous reduced winter accumulation and greater summer melting. Norwegian glacier termini farther inland have retreated continuously at a more moderate rate. [4.5.3]
- Glaciers in the New Zealand Alps advanced during the 1990s, possibly due to increased precipitation, but since 2000 they have started to shrink. [4.5.3]
- Tropical glaciers, being in principle very sensitive to changes in both temperature and atmospheric moisture, have shrunk mostly in response to regional changes in atmospheric moisture content and related energy and mass balance variables such as solar radiation, precipitation, albedo, and sublimation during the 20th century. Inter-annual variation in the seasonal pattern of moisture strongly dominates the behaviour of tropical glaciers. [4.5.3]
- Glaciers on Kilimanjaro behave exceptionally. Even though the thickness of the tabular ice on the summit plateau has not changed dramatically over the 20th century, the ice has shown an incessant retreat of the vertical ice walls at its margins, for which solar radiation is identified as the main driver. The mass balance on the horizontal top ice surfaces is governed by precipitation amount and frequency and associated albedo, and has sporadically reached positive annual values even in recent years. In contrast to the plateau ice, the shrinkage of the glaciers on Kilimanjaro's slopes is constantly decelerating. [4.5.3]

2.5f Sea ice thickness is one of the most difficult geophysical parameters to measure on large-scales.

- Because of the large variability inherent in the sea-ice-climate system, evaluation of ice thickness trends from the available observational data is difficult. [4.4.3.7]
- Recent changes have occurred within the context of longer term decadal variability due to both dynamic and thermodynamic forcing of the ice by circulation changes associated with low-frequency modes of atmospheric variability. [4.4.3.7]
- Ice thickness varies considerably from year to year at a given location and so the rather sparse temporal sampling provided by submarine data makes inferences regarding long-term change difficult. [4.4.3.2]
- There are insufficient data to draw any conclusions about trends in the thickness of Antarctic sea ice. [4.4.3.7]

2.5g It is not possible to attribute the abrupt decrease in sea ice thickness inferred from submarine observations entirely to the (rather slow) observed warming in the Arctic.

- Some of the dramatic decrease may be a consequence of wind-driven redistribution of ice volume over time. [4.4.3.4]
- Low-frequency, large-scale modes of atmospheric variability (such as interannual changes in circulation connected to the Northern Annular Mode) affect both wind-driving of sea ice and heat transport in the atmosphere, and therefore contribute to interannual variations in ice formation, growth and melt. [4.4.3.4]

2.5h Estimates of Greenland ice cap changes indicate near coastal thinning and inland thickening.

- Many recent studies have addressed Greenland mass balance. They yield a broad picture of slight inland thickening and strong near-coastal thinning, primarily in the south along fast-moving outlet glaciers. [4.6.2.2]
- Assessment of the data and techniques suggests overall mass balance of the Greenland Ice Sheet ranging between growth by 25 Gigatonnes per year (Gt/year) and shrinkage by 60 Gt/year for 1961-2003. [4.6.2.2]
- This range changes to shrinkage by 50 to 100 Gt/year for 1993-2003 (which translates to 0.1-0.2 mm per year sea level rise: [10.3.4]) and by even higher rates between 2003 and 2005. However, interannual variability is very large, driven mainly by variability in summer melting and sudden glacier accelerations. Consequently, the short time interval covered by instrumental data is of concern in separating fluctuations from trends. [4.6.2.2]

2.5i The ice sheet in Eastern Antarctica appears to have grown while that in Western Antarctica appears to have shrunk. The overall change may be positive or negative depending on assumptions about ice dynamics.

- Assessment of the data and techniques suggests overall Antarctic ice-sheet mass balance ranging from growth by 50 Gt/year to shrinkage by 200 Gt/year from 1993-2003. [4.6.2.2]
- There is no implication that the midpoint of this range provides the best estimate. Lack of older data complicates a similar estimate for the period 1961-2003. [4.6.2.2]
- A pattern of East Antarctic thickening and West Antarctic thinning was observed across several independent studies. [4.6.2.2]
- Considering the lack of estimated strong trends in accumulation rate, assessment of the possible acceleration and of the slow time scales affecting central regions of the ice sheets, it is reasonable to estimate that the behavior from 1961-2003 falls between ice-sheet growth by 100 Gt/year and shrinkage by 200 Gt/year. [4.6.2.2]

2.5j Summing changes in Greenland and Antarctic indicates either a gain or a loss of ice mass over the 1961-2003 interval.

- Simply summing the 1993-2003 contributions from Greenland and Antarctica produces a range from balance (0 Gt/year) to shrinkage by 300 Gt/year, or contribution to sea-level rise of 0 to 0.8 mm per year. [4.6.2.2]
- For 1961-2003, the same calculation spans growth by 125 Gt/year to shrinkage by 260 Gt/year. [4.6.2.2]

2.6 Humidity and radiation flux

2.6a Changes in mid and upper tropospheric water vapour are proposed as an important potential amplifier of climate change. There is evidence of increased specific humidity, but not relative humidity, over the past two decades.

- Water vapour in the mid and upper troposphere accounts for a large part of the atmospheric greenhouse effect and is believed to be an important amplifier of climate change. [3.4.2.2]
- Due to instrumental limitations, long-term changes of water vapour in the upper troposphere are difficult to assess. [3.4.2.2]
- Satellite data indicate that specific humidity in the upper troposphere increased over the period 1982-2004, but changes in relative humidity were negligible. [3.4.2.2]
- This signature is generally consistent with increased tropospheric temperatures, though the increase in specific humidity is strongest over the tropics [Figure 3.4.6] where temperature trends are insignificant. (see Section 2.1g)

2.6b Observed changes in radiation flux at the top of the atmosphere are small and equivocal, and may simply reflect natural variability.

- Although there is independent evidence for decadal changes in top-of-atmosphere (TOA) radiative fluxes over the last two decades, the evidence is equivocal. [3.4.4]
- Changes in the planetary and tropical TOA radiative fluxes are consistent with independent global ocean heat storage data, and are expected to be dominated by changes in cloud radiative forcing. To the extent that the evidence is valid, these changes may simply reflect natural low-frequency variability of the climate system. [3.4.4]

3 Climatic changes in paleoclimate perspective

3.1 Geological evidence of warming and cooling episodes

3.1a On a time scale of millions of years, current temperatures are not unprecedented. Through much, if not most, of the last 100 million years, temperatures were warmer than at present, including a super-warm interval approximately 50 million years ago.

- The earth was ice-free during most of its history [6.3.1]
- The Pliocene (about 3 million years ago) was the most recent time in Earth's history when mean global temperatures were substantially warmer (about 2°C to 3°C warmer) [6.3.2]
- The Paleocene-Eocene Thermal Maximum was several degrees warmer still. [6.3.3]

3.1b On the other hand, temperatures during most of the most recent 1 million years (the Pleistocene) have been colder than at present. Long glacial periods have alternated with short (10 to 30,000 year long) interglacials.

- Continental glaciers covered much of North America, Europe and Asia during the Pleistocene. [6.4.1]
- Ice cores and ocean sediment cores have enhanced our understanding of both glacial and interglacials. [6.4.1]
- Glacials and interglacials are attributed to changes in the earth's orbit: precession, obliquity and eccentricity. [Box 6,1]

3.1c The last interglacial (LIG, 129,000-116,000 years ago) was warmer than the present.

- Globally, there was less glacial ice and higher sea level on Earth during the Last Interglacial than now. This suggests significant meltback of the Greenland and possibly Antarctica ice sheets occurred. The climate of the LIG has been inferred to be warmer than present, although the evidence is regional and not neccessarily synchronous globally. Proxy data indicate warmer-than-present coastal waters in the Pacific, Atlantic, and Indian Oceans and in the Mediterranean Sea, greatly reduced sea ice in the coastal waters around Alaska, and extension of boreal forest into areas now occupied by tundra in interior Alaska and Siberia, during the early LIG. Ice core data indicate Greenland and Antarctic temperatures were 4-5°C warmer than present. [6.4.1.6]
- The length and amplitude of interglacials varied. The shortest lasted only a few thousand years, while the longest (Stage 11) lasted nearly 30,000 years. [6.4.1.5]

3.1d The current interglacial (the Holocene) began about 11,600 years ago and is already longer than some interglacials. Some features are comparable to the unusually long Stage 11 interglacial. [6.5, 6.4.1.5]

- The most recent ice age began about 116,000 years ago. Glaciation reached a maximum about 21,000 years ago. Deglaciation, or the transition to a warm interval, took place between 20,000 and 10,000 years ago. [6.4.1.2, 6.5]
- The present orbital configuration has been compared to the Stage 11 configuration (420,000-395,000 years ago), when there was a long interglacial. [6.4.1.5]

3.1e Large, widespread, abrupt climate changes have occurred repeatedly throughout the ice age/post-glacial interval.

- Abrupt climate change refers to events of large amplitude regionally, typically a few degrees Celsius, and that occur on time scales significantly shorter than 1,000 years. [1.4.2]
- Abrupt temperature events were larger and more widespread during the ice age then during the warm Holocene. The most dramatic of these abrupt climate changes are characterised by a warming in Greenland by 8 to 16°C within a few decades, followed by much slower cooling over centuries. Another type of abrupt change is the Heinrich event, involving sea surface cooling that lasts several thousands of years, followed by abrupt warming over several decades. At the end of the last ice age, as the climate warmed and ice sheets melted, climate went through a number of abrupt cold phases, notably the Younger Dryas and the 8.2 kyr event. [6.4.2.1]
- Abrupt temperature changes were first detected in deep ice cores from Greenland. By the end of the 1990s it became clear that abrupt climate changes, as found in the Greenland ice cores during the last ice age, were numerous, indeed abrupt, and of large amplitude. [1.4.2]
- The importance of internal variability and processes was reinforced in the early 1990s with the analysis of records with high temporal resolution: new ice cores, ocean cores with high sedimentation rate, lacustrine sediments, and also cave stalagmites. Reconstruction of the thermohaline circulation of deep and surface water shows the participation of the ocean in these abrupt changes. [1.4.2]
- There are many examples of abrupt changes that are regional rather than global in extent. [1.4.2]
- Abrupt climate change during both ice age and warm epochs alters the notion of relative climate stability, as previously suggested. Rather there is a coherent picture of an unstable ocean-atmosphere system of global extent. [1.4.2]

3.1f The causes of large-scale climate variations on the century and longer time scales are not well-understood.

- Based on the correlations between changes in climate proxy records and production of cosmogenic isotopes - assumed to relate to solar activity changes - some authors argue that solar activity, through cosmic radiation and cloud nucleation, may be the driver for centennial to millennial variability. Correlations between climate proxy records and geomagnetic field variations suggest further influence on climate by cosmic radiation on millennial and greater time scales. The possible importance of internal climate variability, for instance related to the deep ocean circulation, has also been highlighted. [6.5.1.6]
- However, in many records, there is no apparent consistent pacing at specific centennial to millennial frequencies through the Holocene period, but rather shifts between different frequencies. [6.5.1.6]
- The current lack of consistency between various data sets makes it difficult, based on current knowledge, to attribute the century and longer time scale large-scale climate variations solely to solar activity, episodes of intense volcanism, or variability internal to the climate system. [6.5.1.6]

3.2 Global climate reconstructions over the past 2,000 years

3.2a Natural climatic variability is now believed to be substantially larger than was estimated in the Third Assessment Report, as is the uncertainty associated with paleoclimate studies.

- The Third Assessment Report placed considerable emphasis on the "hockey stick" climate reconstruction, which suggested the late 20th century climate was unusual in the context of the past 1,000 years. This graph has subsequently been subject to considerable criticism [6.6.1.1]
- When viewed together (Fig ISPM-9), the currently available reconstructions indicate generally greater variability in centennial time scale trends over the last 1000 years than was apparent in the Third Assessment Report.
- Proxy evidence cannot characterize the mean Northern Hemisphere temperature to within at least ±0.5°C, and over significant stretches of time the available reconstructions differ by 0.7-1.0°C [Figure 6.10; Figure ISPM-9].

SUPPLEMENTARY INFORMATION

Recent refutations of hockey stick millennial paleoclimatic methods and conclusions.

Two recent, detailed reviews of the methodology of paleoclimatic reconstructions (National Research Council 2006, Wegman et al. 2006) both concluded that there were methodological errors in the "hockey stick" graph of Mann et al. which was prominently promoted in the Third Assessment Report (Summary for Policymakers Fig 1). Both reports concluded that the data and methods did not support the assertions that the 1990s were the "warmest decade of the millennium" and 1998 the "warmest year" of the millennium (NRC p. 109; Wegman et al. p.49). The National Research Council Report also concluded that uncertainties of published paleoclimate reconstructions have been generally underestimated (NRC p. 91).

The National Research Council recommended that proxies sensitive to precipitation be avoided in temperature reconstructions and, in particular, that strip-bark bristlecones and foxtails be avoided. However, none of the IPCC reconstructions for the past millennium observe the National Research Council recommendations.

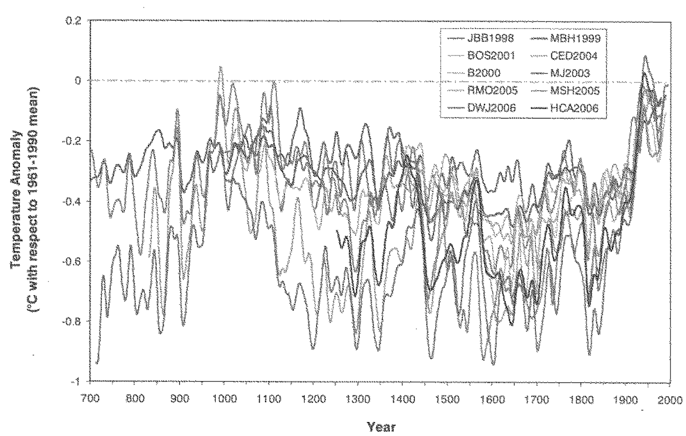


FIGURE ISPM-9: SOME RECENT PALEOCLIMATE TEMPERATURE RECONSTRUCTIONS OF PAST 1300 YEARS FOR THE NORTHERN HEMISPHERE, ALL CALIBRATED OVER THE 1902-1980 INTERVAL

NOTE: Instrumental splice post-1850 has been removed (see Supplementary Information Box below).

Source: Reproduction of Fourth Assessment Report Figure 6-10b. (JBB1998) = Jones et al., 1998 calibrated by Jones et al., 2001; (MBH1999) = Mann et al. 1999; (BOS2001) = Briffa et al., 2001; (CED2004) = Cook et al., 2004; (B2000) = Briffa, 2000 calibrated by Briffa et al., 2004; (MJ2003) = Mann and Jones, 2003; (RMO2005) = Rutherford et al., 2005; (MSH2005) = Moberg et al., 2005; (DWJ2006) = D'Arrigo et al., 2006; and (HCA2006) = Hegerl et al., in press.

SUPPLEMENTARY INFORMATION

The Divergence Problem

A number of recent studies (Briffa et al. 1998, Briffa et al. 2001, d'Arrigo et al 2006, National Research Council 2006) have observed that proxies, especially tree ring proxies, and reconstructions relying on them diverge from instrumental temperature series as temperatures increased in the 1980s and 1990s. This creates a fundamental uncertainty over whether such reconstructions could have detected warming trends in the past (the "Divergence Problem").

The Divergence Problem is a major unresolved problem in millennial reconstructions. Until it is resolved, it is statistically invalid to splice an instrumental series onto a proxy-based series as if the two are interchangeable.

For this reason, Figure ISPM-9 reproduces IPCC Figure 6-10b with the black instrumental series removed.

3.2b Paleoclimatic proxy data are sparse and uncertain, and many appear to be sensitive only to summer temperature, or to precipitation.

- In the Northern Hemisphere as a whole there are relatively few long and well-dated climate proxies, particularly for the period prior to the 17th century. Those that do exist are concentrated in extra-tropical, terrestrial locations, and many have greatest sensitivity to summer rather than winter (or annual) conditions or to precipitation. [6.6.1.1]
- There are markedly fewer well-dated proxy records for the Southern Hemisphere compared to the Northern Hemisphere, and consequently little evidence of how large-scale average surface temperatures have changed over the past few thousand years. [6.6.2]
- There are very few strongly temperature-sensitive proxies from tropical latitudes. Stable isotope data from high-elevation ice cores provide long records and have been interpreted in terms of past temperature variability, but recent studies indicate a dominant sensitivity to precipitation changes, at least on seasonal to decadal timescales, in these regions. [6.6.1.1]
- Melting of tropical glaciers has been observed in recent decades. [6.6.1.1; see Supplementary Information box below]

SUPPLEMENTARY INFORMATION

Regional paleoclimatic indicators

The Fourth Assessment Report provides a very small survey of regional paleoclimatic evidence from the Southern Hemisphere [6.6.2]. The available literature on location-specific paleoclimatology is very large, and in many locations in both the Northern and Southern Hemispheres indicates periods of anomalous warmth exceeding that in the late 20th century. Little of this information is surveyed in the IPCC Report.

There is evidence that several tropical glaciers (Quelccaya, Puruogangri, Dasuopu) formed after the Holocene Optimum. Radiocarbon dating on fossils disgorged from receding glaciers often yields evidence that tree lines and vegetation were higher in the past and were engulfed by past glacier advances during the past few thousand years and/or the Little Ice Age. This evidence shows that modern recession is not unprecedented even within the Holocene.

The literature is explored in the forthcoming Fraser Institute Supplementary Analysis Series report, "Paleoclimatic Indicators of Medieval Climate Conditions."

3.2c Uncertainties in paleoclimate reconstructions affect climate modeling work since models are tested against results from paleoclimate reconstructions.

- Testing models with paleoclimatic data is important, as not all aspects of climate models can be tested against modern instrumental climate data. Good performance for present climate is not a conclusive test for a realistic sensitivity to carbon dioxide. To test this, simulation of a climate with very different CO_2 levels can be used. [6.2.2]
- Also, many empirical parameterizations describing sub-grid scale processes (e.g., cloud parameters, turbulent mixing) have been developed using present-day observations; hence climate states not used in model development provide an independent benchmark for testing models. [6.2.2]
- Paleoclimate data are therefore key to evaluating the ability of climate models to simulate realistic climate change. [6.2.2]

4 Climate models and their evaluation

4.1 Fundamental limitations of climate models

4.1a Early climate models provided some qualitative conjectures at the global scale that are consistent with some observed changes.

- At the global scale, some broad predictions made 30 years ago about the possible response to increased CO_2 concentration in the atmosphere, namely increased average tropospheric temperature, decreased average stratospheric temperature and a more rapid hydrological cycle, are consistent with data that have emerged since then. [8.1.2]
- Even when specific predictions are shown to be correct, models should be viewed critically. [8.1.1]

4.1b The fundamental limitations of climate modeling have not changed since the Third Assessment Report.

- Climate models employ approximations to basic physical processes, some of which are controlled approximations (e.g., those based on large scaled Newtonian mechanics) and some of which are empirically based (e.g., fundamental convection processes). [8.1.3]
- "Parameterization" is the process of constructing empirically-based procedures that account for the significant large-scale effects of processes that cannot be resolved (i.e., represented within the computational scheme) because of basic limits in computational power. These limits are induced by the scope of the climate modeling problem. Empirical parameterizations are not unique. Because empirical parameterizations can be invented to force a model to match observations, the ability of a model to represent observed conditions cannot be cited as grounds for confidence in the model's physical realism. [8.1.3]

SUPPLEMENTARY INFORMATION

Basic Modeling uncertainties

The following observation, made in the Third Assessment Report, remains just as true today. The Fourth Assessment Report had nothing to add to it:

In climate research and modeling, we should recognize that we are dealing with a coupled non-linear chaotic system, and therefore that the long-term prediction of future climate states is not possible. The most we can expect to achieve is the prediction of the probability distribution of the system's future possible states by the generation of ensembles of model solutions. (Third Assessment Report, Section 14.2.2.2)

An extended discussion of this is provided in the forthcoming Fraser Institute Supplementary Analysis Series report "Fundamental Uncertainties in Climate Modeling."

4.1c A model's ability to accurately simulate the current mean climate state does not imply it is reliable for projecting future climate changes.

- Multimodel evaluations have shown that even though a group of climate models of intermediate complexity can all replicate observed mean ocean temperature and salinity, and mean atmospheric temperature and humidity, they are not strongly constrained in their future predictions [8.1.2].
- Figure 8.4.2 of the Fourth Assessment Report shows that different models can produce results spreading over more than a factor of 10 for long (climate) time scales exceeding 100 months.

- Models tuned to "perfectly" reproduce an observed mean climate state have nonetheless shown only a weak ability to predict subsequent climatic conditions. It is not possible to say which, if any, of today's climate models are reliable for climate prediction and forecasting. [8.3]

4.1d It is not formally known if today's climate models are a suitable basis for projecting climate.

- A model that has been "tuned" to give a good representation of certain key observations may have a greater likelihood of giving a better prediction than a similar model which is less closely tuned. If the number of tunable parameters of a General Circulation Model (GCM) exceeds the number of degrees of freedom in the observational testing scheme for the GCMs, then the use of GCMs to forecast climate change is not justifiable. There has been no formal evaluation of the extent to which current GCMs satisfy this requirement. [8.1.3.1]

4.1e Some climate models now obey the law of conservation of mass, but it is not known if this is an improvement.

- Numerical advection schemes have been introduced in some cases that do not violate conservation of mass–a fundamental law of nature. However there is no consensus on whether they are better than the alternatives. [8.2.1.1]
- In some cases new schemes do not permit negative concentrations of water vapor. [8.2.1.1]

4.2 Significant known model problems

4.2a The strength of the coupling between land processes and the atmosphere is not known.

- Models strongly disagree on this important feedback. There is insufficient data at the global level to evaluate this feature of GCMs. [8.2.3.2]

4.2b Cryosphere

- Simulation of high latitude processes in models is still enough of a problem that their projections of sea ice extent remain highly uncertain. Northern Hemisphere winter is the best-simulated case, and even here the range of simulated sea ice extent exceeds 50% of the mean, and ice thickness also varies considerably. This is particularly troubling because the model sea ice biases may influence estimated global climate sensitivity. [8.3.3]
- On the continental scale, the peak monthly amount of water in snow integrated over the North American continent in models varies within ±50% of the observed value of ~1500 km^3. The magnitude of these model errors is large enough to affect continental water balances. [8.3.4.1]
- Glaciers are not modeled. [8.2.4.1]

4.2c Clouds

- The relatively poor simulation of clouds in the present climate is a reason for some concern. Cloud feedbacks indicate that climate models exhibit different strengths and weaknesses, and it is not yet possible to determine which estimates of the climate change cloud feedbacks are the most reliable. Cloud feedbacks are a large source of uncertainty in climate sensitivity estimates. [8 Summary]

4.2d Monsoons

- Climate models do not capture the linkage between the equatorial Indian Ocean and the Indian summer monsoon, and a comparison of 15 GCMs found large errors in the simulated precipitation in the equatorial regions and in the Asian monsoon region. [8.4.10]
- The impact of time-varying direct and indirect effects of aerosols is not fully resolved. These effects will become increasingly significant in future due to increasing human activity over south Asia/India. [10.3.5.2]

5 Global and regional climate projections

5.1 Reproduction of the present climate

5.1a Quantitatively, individual climate models are typically unable to reproduce the observed mean surface temperature to better than +/- 3 kelvin, with worse performance near the poles. They are also unable to reproduce the onset of ice ages. The margin of present-day error is similar to the size of the projected global warming trend over a century.

- Errors in polar regions average between 3 and 5 kelvin (K), and on average all climate models overestimate mean Antarctic temperatures by at least 5 K. [Figure 8.3.1]
- The extent to which these errors detract from the models' ability to accurately simulate climate change in response to external perturbation (e.g., GHG emissions) is unknown, but may be significant. [8.3.1]
- Climate models are not able to successfully simulate the onset of an ice age [6.4.1.7], although they are able to reproduce some features of the end of an ice age. [6.4.2.3]
- Models are used to evaluate greenhouse-induced changes that are about 0.3 K per decade, a tenth the size of the annual margin of error for estimates in most regions.

5.2 Forecasts for the coming century are inherently uncertain

5.2a The spread of model outcomes shown in the Fourth Assessment Report forecast ensembles does not span the full range of uncertainty.

- For future climate change in the 21st century, a subset of three scenario simulations have been selected from the six commonly used ones. This subset constitutes a "low", "medium", and "high" scenario among the marker scenarios, and this choice is solely made by the constraints of available computer resources that did not allow for the calculation of all six scenarios. This choice, therefore, does not imply a qualification of or preference over the six marker scenarios. By the same argument, it is not within the remit of this report to assess the realism and likelihood of emission scenarios. [10.1]
- Even though the ability to simulate present day mean climate and variability, as well as observed trends, differs across models, all submitted models are weighted equally in the mean. Since the ensemble is strictly an 'ensemble of opportunity', without sampling protocol, the spread of models is unable to span the full possible range of uncertainty, and a statistical interpretation of the model spread is therefore problematic. [10.1]

5.2b Uncertainties enter model projections at every step in the process.

- There are multiple emission scenarios for the 21st century, and even at this first stage there is uncertainty with regard to the evolution over time of emissions of various forcing agents, such as greenhouse gases. Then these emissions must be converted to concentrations of constituents in the atmosphere. Gas cycle models must be employed, and these models include their own set of parameterisations, assumptions and caveats. Then the concentrations in the atmospheric models produce radiative forcing that acts on the climate system within the atmospheric model components, each with their own radiation schemes and other formulations that affect radiative forcing. Finally, the modelled coupled climate system takes those radiative forcings and produces a future simulated climate. The components of the atmosphere, ocean, sea ice and land surface in each model interact with their sets of strengths and weaknesses to produce a spread of outcomes for future climate. [10.1]
- Thus at every step in this process there are uncertainties and assumptions that must be made to proceed from emissions, to concentrations, to radiative forcing, and eventually to simulated climate changes and impacts. [10.1]

5.2c Few of the climate models used for the Fourth Assessment Report forecasts account for solar changes, land-use changes and indirect aerosol effects.

- Only two out of 23 models account for the effects of time-varying solar changes. [Table 10.2.1]
- Only two out of 23 models account for effects of time-varying land-use changes. [Table 10.2.1]
- Only nine out of 23 models include the first indirect effect of aerosols, only six include the second indirect effect and only four include both. [Table 10.2.1]

SUPPLEMENTARY INFORMATION

Defining 'Climate Change'

The IPCC assumes that climate change can be defined as a change in the mean state of the climate. This assumes that means of climatic variables are stationary and well-defined, something recent research has put into question. If the climate is nonstationary, a change in the mean is consistent with an 'unchanged' climate since the observed mean is dependent on the time period over which the observations are collected. Also the concept of variability is problematic since the variance of a nonstationary process is, in some cases, mathematically undefined.

For more on this topic see the forthcoming Fraser Institute Supplementary Analysis Series report 'Long Term Persistence in Geophysical Data.'

5.3 Model-generated global warming forecasts

5.3a Climate models predict warming is occurring everywhere on Earth.

- The average across models implies a forecast that, over all land areas on Earth, a warming of 0.5 to 1°C will be noticeable in a comparison of the two decades beginning at 2011 relative to the 1980-1999 interval. [Figure 10.3.5]
- The North and South polar regions are forecast to warm relatively faster, and land areas are forecast to warm faster than adjacent ocean areas. [Figure 10.3.5]
- 1979-2005 trends as measured by weather satellites show temperature trends are 0-0.5°C/decade over land and are not systematically stronger than over adjacent ocean areas. [Figure 3.4.4]
- 1979-2005 trends as measured by weather satellites show Southern Hemisphere warming trends get weaker towards the South Pole, which exhibits zero or negative temperature trends in many surrounding areas.

5.3b On average, models that assume strong greenhouse warming project the tropical troposphere to warm faster than the surface. Current data do not support these forecasts.

- The tropical troposphere is forecast to warm faster than the surface. [Figure 10.3.4]
- This conflicts with current data. (see Section 2.1c)

5.3c All climate models used for the Fourth Assessment Report are tuned so that the average surface temperature will increase between about 2.0°C and 4.5°C in response to a doubling of the atmospheric carbon dioxide concentration.

- The "equilibrium climate sensitivity" refers to a model's assumed increase in global surface temperature following a doubling of the atmospheric equivalent CO_2 concentration. [10.5.2.1]
- The suite of models used for the Fourth Assessment Report simulations apply an equilibrium climate sensitivity between approximately 2.0°C and 4.5°C. [Figure 10.5.1]

5.3d Models generate many specific global forecasts based on assumptions of significant greenhouse warming.

- **Global Mean Temperature:** Climate models based on the assumption that atmospheric carbon dioxide levels will double over the next century predict that global average surface temperature will increase by between about 2.0°C and 4.5°C. [Figure 10.5.2]
- **Sea Ice:** Models show a range of responses in Northern Hemisphere sea ice areal extent ranging from very little change to a dramatic change, and accelerating reduction over the 21st century. Seasonal ice cover is rather robust and persists to some extent throughout the 21st century in most (if not all) models. In 20th and 21st century simulations, Antarctic sea ice cover decreases more slowly than in the Arctic. Overall models have poor agreement on the amount of thinning of sea ice and the overall climate change in the polar regions. [10.3.3.1; Figure 10.3.10a,b Figure 10.3.11]
- **Ocean Circulation:** Models initialized at the year 1850 have difficulty producing late 20th century values of the Meridional Overturning Circulation (MOC) in the observed range. Of the model simulations consistent with the late 20th century observational estimates, no simulation predicts an increase of MOC during the 21st century; reductions range from indistinguishable within the simulated natural variability to 60% relative to the 1960-1990 mean; none of the models projects an abrupt transition to an off state of the MOC [Figure 10.3.13]. The best estimate of sea level increase from 1993-2003, associated with the slight net negative mass balance from Greenland, is 0.1-0.2 mm per year. The corresponding amount of sea water, even when added directly and exclusively to the North Atlantic, has been suggested to be too small to affect the North Atlantic MOC. Taken together, it is likely that the MOC will reduce, but very unlikely that the MOC will undergo an abrupt transition during the course of the 21st century. [10.3.4, Figure 10.3.13]
- **Temperature Variability:** Climate models predict a decrease in temperature variability during the cold season in the extratropical Northern Hemisphere and a slight increase of temperature variability in low latitudes and in the warm season in northern mid latitudes. [10.3.5.1]
- **Monsoons:** Climate models runs predict that pronounced warming over the tropics in the middle-to-upper troposphere would result in a weakening of monsoon circulations. Also, atmospheric moisture buildup due to increased GHGs and consequent temperature increase is predicted to result in a larger moisture flux and more precipitation for the Indian monsoon. [10.3.5.2]
- **Precipitation:** Climate models predict an increased chance of summer drying in most parts of the northern subtropics and midlatitudes and an associated increased risk of drought. Associated with the risk of drying is also an increased chance of intense precipitation and flooding. Though somewhat counter-intuitive, this is because precipitation is

concentrated into more intense events, with longer periods of little precipitation in between. Increases in the frequency of dry days does not necessarily mean a decrease in the frequency of extreme high rainfall events depending on the threshold used to define such events. The change in the frequency of extreme precipitation at an individual location can be difficult to estimate definitively due to model parameterization uncertainty. Climate models continue to confirm the earlier predictions that in a future climate warmed by increasing GHGs, precipitation intensity would increase over most regions. [10.3.6.1]

- **Temperature Extremes:** The Third Assessment Report concluded that models project that there is very likely a risk of increased temperature extremes, with more extreme heat episodes in a future climate. This result has been confirmed in subsequent climate model simulations. Several recent studies have found that climate models predict that in a future climate there is an increased risk of more intense, longer-lasting and more frequent heat waves [10.3.6.2] though the change does not become strong until after 2020. [Figure 10.3.17]
- **Cyclones:** There have been a number of climate change experiments with global models that can begin to simulate some characteristics of individual tropical cyclones, though studies with classes of models with 100 km resolution or higher cannot simulate observed tropical cyclone intensities. Global climate models with 100 km resolution or higher predict a decrease in tropical cyclone frequency globally, and no change or slight decreases in intensity of cyclones, but some regions may differ. Studies performed with models that use a high resolution (down to 9 km) mesoscale hurricane model predict that future tropical cyclones will be more intense. [10.3.6.3]
- **Growing Season:** Globally, models project an increase in the average growing season length by three to five standard deviations by mid-century. [Figure 10.3.17]
- **Ocean Surface Acidity:** Increasing atmospheric CO_2 concentrations lowers oceanic pH and carbonate ion concentrations, thereby increasing acidity. Surface ocean pH today is already 0.1 unit lower than preindustrial values. By the end of the century, models predict it may decline by another 0.13 to 0.34 pH units. Experimental evidence suggests that if these trends continue, key marine organisms - such as corals and some plankton - will have difficulty maintaining their external calcium carbonate skeletons. [10.4.2, Figure 10.4.5]
- **Sea Levels:** Models project that a doubling of CO_2 levels in the atmosphere (A1B scenario), if accompanied by a warming of 2–4.5°C, will cause a sea level increase of about 20 centimeters, plus or minus 10 cm over the next 100 years [10.6.5; Fig 10.6.1]. However the spatial pattern in projections is not uniform. The geographical patterns of sea level change from different models are not generally similar in detail, but the differences are not as large as they were in the Third Assessment Report. Still, the largest spatial correlation coefficient between any pair is 0.76, and only 20% of correlation coefficients exceed 0.5. [10.6.2]
- **Glaciers:** Since their mass balance depends strongly on their altitude and aspect, use of data from climate models to make projections requires a method of downscaling, because individual glaciers are too small to be handled in typical GCMs. Statistical relations can be developed between GCM and local meteorology but they may not continue to hold in future climates [10.6.3]. Models predict overall loss of glacier volume, but there is uncertainty about how to estimate the dynamics. [10.6.3.3]

5.3e Models have also been used to generate regional forecasts, though the uncertainties are substantial.

- Important details about climate change pertain to geographical details too small to be resolved in global models. Hence regional models have been developed, which involve schemes for downscaling the information from a global model. [11.1.1]
- Downscaling can be done two ways. "Dynamical downscaling" involves feeding information from a global model into a regional climate model, using the data from the global model to impose boundary conditions on the regional model. However this does not necessarily yield a better match to observations. [11.2.1.1.1]
- "Statistical downscaling" involves applying empirical estimates between local variables and global variables to estimate changes in the local variables based on global model forecasts. This requires the assumption that the relationships are stationary – i.e., that the empirical relationship is steady over time and under different climatic conditions. Stationarity remains a concern with statistical downscaling. It is not know whether the cross scale relationships are valid under future climate regimes. This limitation is only weakly assessed through cross-validation tests. [11.2.1.1.2]
- Most sources of uncertainty on regional scales are similar to those on the global scale, but there are both changes in emphasis and new issues that arise in the regional context. Of the climate forcing agents, uncertainty in aerosol forcing adds especially to regional uncertainty because of the spatial inhomogeneity of the forcing and the response. Changes in land-use and cover have an inherently regional scope as well. When analyzing studies involving further layers of models to add local detail, the cascade of uncertainty through the chain of models used to generate regional or local information has to be considered. The degree to which these uncertainties influence the projections of different climate variables is not uniform. Also, the climate may itself be poorly known on regional scales in many data-sparse regions. Thus, evaluation of model performance as a component of an analysis of uncertainty can itself be problematic. [11.2.2.1]

6 Attributing the causes of climate change

6.1 Measuring and analyzing climate change

6.1a There is reliance on computer models both to identify what might be the scales of internal variability and the magnitude of natural forcing, as well as the form of the anthropogenic-forcing signal. It is against these basic shortcomings that attribution studies must be assessed [1.3.3].

- Detection and attribution of climate change are separate processes. [1.3.3]
- Detection of climate change is the process of demonstrating that climate has changed in some statistical sense, without providing a reason for that change. Attribution of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence. [1.3.3]
- Both detection and attribution rely on observational data as well as model output. [1.3.3]
- In practical terms, attribution of anthropogenic climate change is understood to mean:
  - detection;
  - demonstration that the detected change is consistent with computer model predictions of the climate change "signal" that is calculated to occur in response to anthropogenic forcing; and
  - demonstration that the detected change is not consistent with alternative physically plausible explanations that exclude anthropogenic forcing. [1.3.3]
- Estimates of century-scale natural climate fluctuations are difficult to obtain from the observations because of the relatively short length of records. [1.3.3]

6.1b The definition of climate change assumes stationarity of the climate system.

- *Climate change* "refers to a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer". [9.1.1]

6.1c The climate is subject to natural variability on all time scales, from days up to centuries.

- Natural climate variability results from internal climate processes and the climate's response to natural external forcing. Internal variability is present on all time scales from virtually instantaneous (e.g., the triggering of convection) up to years (e.g., tropospheric-stratospheric or inter-hemispheric exchange). Other components of the climate system, such as the ocean and the large ice-sheets tend to operate on longer time scales of decades to centuries. These components produce internal variability directly and by integrating variability from the rapidly varying atmosphere. In addition, internal variability is also produced by coupled interactions between components, such as is the case with the El-Niño Southern Oscillation. [9.1.1.]

6.1d Internal variability and climate change are inherently difficult to estimate, and usually require the use of climate models.

- The climate's internal variability is difficult to estimate because all climate observations are influenced, at least to some extent, by variations in external forcing. However estimates can be obtained from observations or models under certain conditions. [9.1.1.]
- The methods used to identify change in observations are based on the expected responses to external forcing, either from physical understanding or as simulated by climate models. An identified change is *detected* in observations if its likelihood of occurrence by random chance or by internal variability alone is determined to be small.

A failure to detect a particular response might occur for a number of reasons, including the possibility that the response is weak relative to internal variability, or that the metric used to measure change is insensitive to the expected change. [9.1.2]

- The detection of an effect of external forcing on the climate does not necessarily imply that it has an important impact on the environment, biota, or human society. [9.1.3]

6.2 Difficulties in attributing observed climate change to specific causes.

6.2a Detection of climate change relies on model-generated predictions of the response of the climate to external forcing, such as greenhouse gas emissions, and as such can never be absolutely certain.

- Many studies use climate models to predict the expected responses to external forcing, and these predictions are usually represented as patterns of variation in space, time, or both. Such patterns, which are commonly referred to as *fingerprints*, are usually derived from changes simulated by a climate model in response to forcing. [9.1.2]
- The spatial and temporal scales used to analyze climate change are carefully chosen so as filter out internal variability and enable the separation of the responses to different forcings. The choice of filter criteria is based on prior expectations about the time and spatial scales to be analyzed. [9.1.2]
- Because detection studies are necessarily statistical in nature, inferences about whether an external influence has been detected can never be absolutely certain. It is always possible that a significant result at, say, the 5% level, could simply reflect a rare event that would have occurred in any case with less than 1 chance in 20 in an unchanged climate. Corroborating lines of evidence providing a physically consistent view of the likely cause for the change reduces the risk of spurious detection. [9.1.2]

6.2b Investigation of the causes of observed individual climate events can be biased due to "self-selection" phenomena.

- For many decision-makers, the most pertinent detection questions involve a particular observed phenomenon, (for example, whether the drying in the Sahel region can be attributed to greenhouse gases). It is difficult to respond to such questions because of a statistical phenomenon known as "selection bias". Only large observed climate anomalies in a historical context would be likely to be the subject of such a question. Decision-makers are unlikely to ask about small or non-existent events. Hence the selection of events to analyze is biased towards large, anomalous observations. The fact that the questions are "self selected" from the observations makes it difficult to assess their statistical significance from the same observations. [9.1.2]

6.2c Attribution of the cause in climate change is not formally possible.

- Detection does not imply attribution of the detected change to the assumed cause. *Attribution* "of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence". As noted in the Second Assessment Report (published in 1996) and the Third Assessment Report (published in 2001), unequivocal attribution would require controlled experimentation with our climate system. That, of course, is not possible. [9.1.2]

6.2d The term "attribution" means consistency with a climate model-generated scenario, rather than formal proof of causality. The same data could be consistent with contradictory hypotheses, including large or small greenhouse warming.

- From a practical perspective, attribution of anthropogenic climate change is understood to mean the detected change is "consistent with the estimated responses to the given combination of anthropogenic and natural forcing". [9.1.2]
- Any assessment of observed climate change that compares simulated and observed responses will be affected by errors and uncertainties in the forcings prescribed to a climate model and its corresponding responses. [9.2.3]
- Assessment of the consistency between an observed change and the estimated response to a hypothesized forcing is often achieved by determining whether the amplitude of the hypothesized pattern of change estimated from observations is statistically consistent with expectations based on climate model predictions, as measured by statistical tests. [9.1.2]
- Attribution also requires evaluating the possibility that the observed change is consistent with alternative explanations that exclude important elements of a given combination of forcings that are hypothesized to have influenced the climate. Statistical analysis requires that the separate influences on climate are properly accounted for. For instance, the attribution of recent warming to greenhouse gas emissions becomes more reliable if the influences of other external forcings, for example solar forcing, are explicitly accounted for in the analysis. [9.1.2]
- This is an area of research with considerable challenges because different forcing factors may lead to similar large-scale spatial patterns of response. [9.1.2]
- If it is not possible to distinguish the spatial pattern of greenhouse warming from that of fossil-fuel related aerosol cooling, then the observed warming over the last century could be explained by large greenhouse warming balanced by large aerosol cooling or alternatively by small greenhouse warming with very little or no aerosol cooling. [9.2.3]

6.2e Attribution studies rely on the validity of model-generated estimates of the climatic response to forcing, and model-generated estimates of natural variability.

- All three aspects of attribution require knowledge of the internal climate variability on the timescales considered, usually decades or longer. The residual variability that remains in instrumental observations after the estimated effects of external forcing have been removed is sometimes used to estimate internal variability. However, these estimates are uncertain because the instrumental record is short relative to the timescales of interest, and because of uncertainties in the forcings and the estimated responses. Thus internal climate variability is also estimated from long control simulations from coupled climate models. [9.1.2]
- Subsequently, an assessment is usually made of the consistency between the residual variability referred to above and the model based estimates of internal variability. Confidence depends on the ability of models to simulate the various modes of observed variability, comparisons between variability in observations and climate model data and by comparison between proxy reconstructions and climate simulations of the last millennium. [9.1.2]

6.2f The reported uncertainties in attribution studies do not take into account basic uncertainty about climate model parameters. These uncertainties can be considerable.

- Model and forcing uncertainties are important considerations in attribution research. Ideally, the assessment of model uncertainty should include uncertainties in model parameters, and in the representation of physical processes in models (structural uncertainty). Such an assessment is not yet available, although research with that goal in mind is underway. [9.1.2]
- The effects of forcing uncertainties, which can be considerable for some forcing agents, such as solar and aerosol forcing, also remain difficult to evaluate, despite advances in research. [9.1.2]
- There are also very large uncertainties in the temporal forcing associated with solar radiation changes, particularly on timescales longer than the 11-year cycle. Previous estimates have used sun spot numbers to determine these slow changes in solar irradiance over the last few centuries, but are not necessarily supported by current understanding. In addition, the magnitude of radiative forcing associated with major volcanic eruptions is uncertain and differs between reconstructions. [9.2.2.3]
- Detection and attribution results that are based on several models or several forcing histories do provide information on the effects of model and forcing uncertainty that leads towards a more reliable attribution of climate change to a specific cause. Such results suggest that the attribution of a human influence on temperature change during the latter half of the 20th century is robust. [9.1.2]
- In addition to substantial uncertainty in the timing and amplitude of solar variations on timescales of several decades to centuries, uncertainty also arises because the spatial response of surface temperature to solar forcing resembles that due to anthropogenic forcing. These uncertainties in interpretation of the role of different forcings reflects substantial uncertainties in our knowledge about the size of past volcanic forcing and of the timing and size of long-term variations in solar forcing, as well as differences in the way these effects are taken into account in model simulations. [9.3.3.2]
- There remains considerable uncertainty in the forcings that are used in climate models. Estimates of the uncertainties in reconstructions of past solar forcing have increased since the Third Assessment Report, and chemical and dynamical processes associated with the atmosphere's response to solar irradiance are omitted or not adequately resolved in many climate models used in detection studies. Furthermore, some models include the indirect effects of sulphate aerosols on clouds, whereas others consider only the direct radiative effect. [9.4.1.8]

6.3 Assumptions needed to attribute climate change to anthropogenic causes.

6.3a Evidence for a human influence on climate relies on model-based detection studies.

- The evidence that was available at the time of the Third Assessment Report consisted of results from a range of detection studies of the instrumental record, relying on output from several climate models for fingerprints and estimates of internal climate variability. On this basis the Third Assessment Report stated that warming over the 20th century was "very unlikely to be due to internal variability alone as estimated by current models". [9.1.3]
- It is implicitly assumed in these studies that the surface observational record is not affected by nonclimatic trends such as land use change. [3.2.2.2]
- There are now a greater number of attribution studies than were available for the Third Assessment Report, and these have used more recent climate data than previous studies and a greater variety of model simulations. Increased confidence in detection of an anthropogenic signal in the instrumental record refers to this proliferation of studies. [9.4.1.4]

6.3b On average, models used for attributing recent climate change to human interference assume that natural forcings alone would have yielded virtually no change over the 20th century, and global cooling since 1979.

- Climate models that include only natural forcings estimate that over the 20th century there would have been no change or a slight cooling (up to 0.5C) everywhere on Earth. [Figure 9.4.2]
- When the same models are run over the post-1979 interval, they propose that natural forcings alone would have yielded no change, or cooling, everywhere except for a small portion of the Bering Strait and a few other locations. [Figure 9.4.2]

6.3c Attribution studies to date do not take into account all known sources of possible influence on the climate.

- Studies have concentrated on what are believed to be the most important forcings: greenhouse gases, direct solar effects, some aerosols and volcanism. Most analyses exclude some forcings that could potentially have significant effects, particularly on regional scales, but possibly on global scales as well. [9.4.18]
- Observational campaigns have demonstrated the importance of black carbon in the South Asia region and modeling studies have shown that the global forcing from black carbon could be large. Yet few detection studies have explicitly included the temperature response to black carbon aerosols because there are few transient coupled model simulations including this forcing due to large modeling uncertainties. [9.4.18]
- Land use changes are another forcing that could be potentially important, particularly on regional scale. [9.4.18]
- Attribution analyses that use recent model simulations which include carbonaceous aerosols and land use changes continue to detect a significant anthropogenic influence on 20th century temperature changes. [9.4.18]

6.3d Due to the uncertainties involved, attribution of climate change to human cause is ultimately a judgment call.

- The approaches used in detection and attribution research described above can not fully account for all uncertainties. [9.1.2]
- Ultimately expert judgment is used to estimate the likelihood that a specific factor is responsible for a given climate change. [9.1.2]

7 Overall conclusions

The following concluding statement is not in the Fourth Assessment Report, but was agreed upon by the ISPM writers based on their review of the current evidence.

The Earth's climate is an extremely complex system and we must not understate the difficulties involved in analyzing it. Despite the many data limitations and uncertainties, knowledge of the climate system continues to advance based on improved and expanding data sets and improved understanding of meteorological and oceanographic mechanisms.

The climate in most places has undergone minor changes over the past 200 years, and the land-based surface temperature record of the past 100 years exhibits warming trends in many places. Measurement problems, including uneven sampling, missing data and local land-use changes, make interpretation of these trends difficult. Other, more stable data sets, such as satellite, radiosonde and ocean temperatures yield smaller warming trends. The actual climate change in many locations has been relatively small and within the range of known natural variability. There is no compelling evidence that dangerous or unprecedented changes are underway.

The available data over the past century can be interpreted within the framework of a variety of hypotheses as to cause and mechanisms for the measured changes. The hypothesis that greenhouse gas emissions have produced or are capable of producing a significant warming of the Earth's climate since the start of the industrial era is credible, and merits continued attention. However, the hypothesis cannot be proven by formal theoretical arguments, and the available data allow the hypothesis to be credibly disputed.

Arguments for the hypothesis rely on computer simulations, which can never be decisive as supporting evidence. The computer models in use are not, by necessity, direct calculations of all basic physics but rely upon empirical approximations for many of the smaller scale processes of the oceans and atmosphere. They are tuned to produce a credible simulation of current global climate statistics, but this does not guarantee reliability in future climate regimes. And there are enough degrees of freedom in tunable models that simulations cannot serve as supporting evidence for any one tuning scheme, such as that associated with a strong effect from greenhouse gases.

There is no evidence provided by the IPCC in its Fourth Assessment Report that the uncertainty can be formally resolved from first principles, statistical hypothesis testing or modeling exercises. Consequently, there will remain an unavoidable element of uncertainty as to the extent that humans are contributing to future climate change, and indeed whether or not such change is a good or bad thing.

References

Bard, E., Raisbeck, G., Yiou, F. and Jouzel, J (2000). Solar irradiance during the last 1200 years based on cosmogenic nuclides. *Tellus* 52B: 985-992.

Briffa, K.R., F.H. Schweingruber, P.D. Jones, T.J. Osborn, S.G. Shiyatov, and E.A. Vaganov (1998). Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. *Nature* 391, 678-82.

Briffa, K.R., 2000: Annual climate variability in the Holocene: interpreting the message of ancient trees. *Quaternary Science Reviews* 19(1-5): 87-105.

Briffa, K.R., T.J. Osborn, and F.H. Schweingruber (2004). Large-scale temperature inferences from tree rings: a review. *Global and Planetary Change* 40(1-2): 11-26.

Briffa, K. R., T. J. Osborn, F. H. Schweingruber, I. C. Harris, P. D. Jones, S. G. Shiyatov, and E. A. Vaganov (2001). Low-frequency temperature variationsfrom a northern tree ring density network. *Journal of Geophysical Research* 106: 2929-2941.

Christy, J (2006). Atmospheric Science Department, University of Alabama in Huntsville. Data available online at http://vortex.nsstc.uah.edu/public/msu/t2lt/uahncdc.lt.

Cook, E.R., J. Esper, and R.D. D'Arrigo (2004). Extra-tropical Northern Hemisphere land temperature variability over the past 1000 years. *Quaternary Science Reviews* 23(20-22): 2063-2074.

Crowley, T. J. (2000). Causes of climate change over the past 1000 years. *Science* 289: 270-277.

D'Arrigo, R., R. Wilson, and G. Jacoby (2006). On the long-term context for late twentieth century warming. *Journal of Geophysical Research-Atmospheres* 111(D3) Doi: 10.1029/2005JD006352.

De Laat, A.T.J., and A.N. Maurellis (2004). Industrial CO2 Emissions as a Proxy for Anthropogenic Influence on Lower Tropospheric Temperature Trends. *Geophysical Research Letters* 31, L05204, doi:10.1029/2003GL019024.

De Laat, A.T.J., and A.N. Maurellis (2006). Evidence for Influence of Anthropogenic Surface Processes on Lower Tropospheric and Surface Temperature Trends. *International Journal of Climatology* 26: 897-913.

Etheridge, D.M., L.P. Steele, R.J. Francey, and R.L. Langenfelds (2002). Historical CH_4 Records Since About 1000 A.D. From Ice Core Data. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Fligge, M., and S.K. Solanki (2000). The solar spectral irradiance since 1700. *Geophysical Research Letters* 27: 2157-2160.

Goddard Institute for Space Studies (2006). Annual mean Land-Ocean Temperature Index in 0.1C selected zonal means. Data available online at http://data.giss.nasa.gov/gistemp/tabledata/ZonAnn.Ts+dSST.txt.

Gonzalez-Rouco, F., H. von Storch, and E. Zorita (2003). Deep soil temperature as proxy for surface air-temperature in a coupled model simulation of the last thousand years. *Geophysical Research Letters* 30, 2116, doi:10.1029/2003GL018264.

Hegerl, G.C., T.J. Crowley, W.T. Hyde, and D.J. Frame (in press). Constrains on climate sensitivity from temperature reconstructions of the last seven centuries. *Nature*, in press.

Hoyt, Douglas V. and Kenneth H. Schatten (1993). A discussion of plausible solar irradiance variations, 1700-1992. *Journal of Geophysical Research* 98(A11): 18,895-18,906.

Jones, P.D., K.R. Briffa, T.P. Barnett, and S.F.B. Tett (1998). High-resolution palaeoclimatic records for the last millennium: interpretation, integration and comparison with General Circulation Model control-run temperatures. *Holocene* 8(4): 455-471.

Jones, P.D., T.J. Osborn, and K.R. Briffa (2001). The evolution of climate over the last millennium. *Science* 292(5517): 662-667.

Latif, M., C. Böning, J. Willebrand, A. Biastoch, J. Dengg, N. Keenlyside, U. Schwecenkendiek, and G. Madec (2006). Is the Thermohaline Circulation changing?. *Journal of Climate* 19: 4631-4637.

Lean, J., J. Beer, and R. Bradley (1995). Reconstruction of solar irradiance since 1610: implications for climate change. *Geophysical Research Letters* 22: 3195-319.

Lean, J. (2000). Evolution of the sun's spectral irradiance since the Maunder Minimum. *Geophysical Research Letters* 27: 2425-2428.

Mann, M.E., R.S. Bradley, and M.K. Hughes (1999). Northern hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. *Geophysical Research Letters* 26(6): 759-762.

Mann, M.E., and P.D. Jones (2003). Global surface temperatures over the past two millennia. *Geophysical Research Letters* 30(15), art. no.-1820.

Mann, M.E., M.A. Cane, S.E. Zebiak, and A. Clement (2005). Volcanic and Solar Forcing of The Tropical Pacific Over the Past 1000 Years. *Journal of Climate* 18: 447-456.

Marland, G., T.A. Boden, and R. J. Andres (2006). Global, Regional, and National Fossil Fuel CO_2 Emissions. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. Available online at http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm.

Mears, C.A., and F.J. Wentz (2006). MSU Data, Remote Sensing Systems, Santa Rosa, California. Data available online at http://www.remss.com/data/msu/monthly_time_series/RSS_Monthly_MSU_AMSU_Channel_TLT_Anomalies_Land_and_Ocean_v03_0.txt.

Moberg, A., D.M. Sonechkin, K. Holmgren, N.M. Datsenko, and W. Karlen (2005). Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. *Nature* 433(7026): 613-617.

Muscheler, R., F. Joos, S.A. Mueller, and I. Snowball, (2005). How unusual is today's solar activity? *Nature* 436: E3-E4.

National Research Council (2006). Surface Temperature Reconstructions for the past 2,000 Years. National Academies Press, Washington, D.C., U.S.A. Available online at http://www.nationalacademies.org/morenews/20060622.html

Rutherford, S., M.E. Mann, T.J. Osborn, R.S. Bradley, K.R. Briffa, M.K. Hughes, and P.D. Jones (2005). Proxy-based Northern Hemisphere surface temperature reconstructions: Sensitivity to method, predictor network, target season, and target domain. *Journal of Climate* 18(13): 2308-2329.

Usoskin, I.G., S.K. Solanki, and M. Korte (2006). Solar activity reconstructed over the last 7000 years: The influence of geomagnetic field changes *Geophysical Research Letters* 33(8): L08103.

Wang, Y.M., J.L. Lean, and N.R. Sheeley (2005). Modeling the sun's magnetic field and irradiance since 1713. *Astrophysical Journal* 625: 522-538.

Wegman, E.J., D.W. Scott, and Y.H. Said (2006). Ad Hoc Committee Report on the 'Hockey Stick' Global Climate Reconstruction. Washington: mimeo. Available online at http://energycommerce.house.gov/108/home/07142006_Wegman_Report.pdf.

World Data Centre for Greenhouse Gasses (2006). Mauna Loa, Hawaii, USA, monthly methane record covering period of May 1983 to December 2005. Available at http://gaw.kishou.go.jp/wdcgg.html.

Wunsch, C. (2002). What is the thermohaline circulation?. *Science* 298: 1179-1181.

Zhen-Shan, Lin, and Sun Xian (2007). Multi-scale analysis of global temperature changes and trend of a drop in temperature in the next 20 years. *Meteorology and Atmospheric Physics* 95(1-2): 115-121.

Appendix 1– Expert Review

The ISPM was sent out to reviewers around the world. We hereby acknowledge with gratitude the extremely helpful feedback given, at short notice, by dozens of colleagues, whose suggestions substantially improved the final edition. The following individuals provided responses as of January 22, 2007.

Alberto Montanari	Hydrology	University of Bologna	Italy
Anastasios Tsonis	Mathematics	University of Wisconsin	USA
Anthony Lupo	Climatology	University of Missouri	USA
Arthur S. deVany	Mathematics	University of California-Irvine	USA
Barrie Jackson	Chemical Engineering	Queen's University	Canada
Bjarne Andersson	Thermodynamics	Niels Bohr Institute	Denmark
Boris Winterhalter	Oceanography	Geological Survey of Finland	Finland
Christopher deFreitas	Climatology	University of Auckland	New Zealand
David Deming	Paleoclimatology	University of Oklahoma	USA
David Legates	Climatology	University of Delaware	USA
Demetris Koutsoyiannis	Hydrology	University of Athens	Greece
Douglas Hoyt	Solar Physics	Raytheon Corp. (Retired)	USA
Eduardo Zorita	Paleoclimatology	GKSS Institute of Coastal Research	Germany
Einar Sletten	Chemistry	University of Bergen	Norway
Garth Paltridge	Atmospheric science	University of Tasmania	Australia
Gösta Walin	Oceanography	Goteborg University	Sweden
Harry Lins	Hydrology	United States Geological Survey	USA
John Maunder	Climatology	WMO Commission for Climatology (ret'd)	New Zealand
Keith Hage	Meteorology	University of Alberta	Canada
Larry Hulden	Biology	Finnish Museum of Natural History	Finland
Lena Hulden	Historical Biology	University of Helsinki	Finland
Marcel Leroux	Climatology	University of Lyon	France
Nicola Scaffeta	Solar Physics	Duke University	USA
Oddbjörn Engvold	Physics	University of Oslo	Norway
Olav Kvalheim	Physical Chemistry	University of Bergen	Norway
Ole Humlum	Physical Geography	University of Oslo	Norway
Olev Trass	Chemical Engineering	University of Toronto	Canada
Oliver Frauenfeld	Meteorology	University of Colorado	USA
Patrick Michaels	Climatology	Virginia Tech	USA
Peter Robinson	Meteorology	University of North Carolina-Chapel Hill	USA
Peter Stilbs	Physical Chemistry	Royal Institute of Technology, Sweden	Sweden
Piia Post	Meteorology	University of Tartu	Estonia
Richard Lindzen	Climatology	Massachusetts Institute of Technology	USA
Ramesh Kriplani	Meteorology	Indian Institute of Tropical Meteorology	India
Richard McNider	Meteorology	University of Alabama	USA
Robert Balling	Climatology	Arizona State University	USA
Robert Carter	Paleoclimatology	James Cook University	Australia
Robert S. Knox	Physics	University of Rochester	USA
Terence Mills	Statistics	Loughborough University	UK
Thomas N. Chase	Meteorology	University of Colorado	USA
Tim Patterson	Paleoclimatology	Carleton University	Canada
William Alexander	Biosystems Engineering	University of Pretoria	South Africa
William Gray	Meteorology	Colorado State University	USA

In addition, 11 reviewers asked to remain anonymous.

Reviewers were asked to respond to the following questions on the indicated scale from 1–5.
The scores given are based on 54 reviews received.

1. **To what extent does the ISPM cover the range of topics you consider important for policy makers and other general readers who want to understand climate change?**

   1 (Quite Inadequately)
   2 (Somewhat Inadequately)
   3 (Neutral)
   4 (Adequately) *Mean response = 4.2*
   5 (Quite Adequately)

2. **To what extent do you consider the ISPM to convey the current uncertainties associated with the science of climate change?**

   1 (Generally overstates the uncertainties)
   2 (In some cases overstates the uncertainties)
   3 (Is about right) *Mean response = 3.3*
   4 (In some cases understates the uncertainties)
   5 (Generally understates the uncertainties)

3. **To what extent to you agree with the Overall Conclusions?**

   1 (Strongly disagree)
   2 (Disagree)
   3 (Neutral)
   4 (Agree) *Mean response = 4.4*
   5 (Strongly Agree)

4. **Do you support the publication of the ISPM as a means of communicating the current state of climate science to policy makers and other general readers?**

   1 (No, strongly opposed)
   2 (No, somewhat opposed)
   3 (Neutral)
   4 (Yes, somewhat in support)
   5 (Yes, strongly in support) *Mean response = 4.7*

About the Authors

Coordinator

Dr. Ross McKitrick holds a BA in economics from Queen's University, and an MA and Ph.D. in economics from the University of British Columbia. He was appointed Assistant Professor in the Department of Economics at the University of Guelph in 1996 and Associate Professor in 2001. In the fall of 2002 he was appointed as a Senior Fellow of the Fraser Institute in Vancouver B.C. His research focuses on the relationship between economic growth and pollution; regulatory mechanism design; and various aspects of the climate change policy debate. He has published numerous scholarly articles in both economics and science journals. His coauthored book *Taken By Storm: The Troubled Science, Policy and Politics of Global Warming* was awarded a prestigious Donner Prize for Best Book on Canadian Public Policy. Professor McKitrick's research has been discussed in such places as *Nature, Science, The Economist, Natuurwetenschap&Techniek, The National Post, The Globe and Mail* and in a front page article in the *The Wall Street Journal* (Feb 14 2005). He has made invited academic presentations in Canada, the US and Europe, as well as professional briefings to the Canadian Parliamentary Finance and Environment Committees, to government staff at the US Congress and Senate and to the US National Research Council.

Writing Team

Joseph S. D'Aleo has over three decades of experience as a meteorologist and climatologist. He holds BS and MS degrees in Meteorology from The University of Wisconsin and was in the doctoral program at New York University. Mr. D'Aleo was a Professor of Meteorology at the college level for over 8 years (6 years at Lyndon State College in Vermont) and was a co-founder and the first Director of Meteorology at the cable TV Weather Channel. From 1989 to 2004, D'Aleo was Chief Meteorologist at WSI and Senior Editor for WSI's popular Intellicast.com web site. Mr. D'Aleo is a Certified Consultant Meteorologist and was elected a Fellow and Councilor of the American Meteorological Society. He has served as member and chairman of the American Meteorological Society's Committee on Weather Analysis and Forecasting. He has authored and/or presented numerous papers focused on advanced applications enabled by new technologies, and the role of natural solar and ocean cycles on weather and climate. His published works include a resource guide for Greenwood Publishing on El Niño and La Nina. He is currently Executive Director for ICECAP, an organization and international web site that will bring together the world's best climate scientists to shed light on the true complex nature of climate change.

Dr. Madhav L. Khandekar holds a B.Sc. in Mathematics and Physics, an M.Sc. in Statistics from Pune University, India, and both M.S. and Ph.D. degrees in Meteorology from Florida State University. Khandekar has worked in the fields of climatology, meteorology and oceanography for almost 49 years and has published well over 100 papers, reports, book reviews and scientific commentaries as well as a book on Ocean Surface Wave Analysis and Modeling, published by Springer-Verlag in 1989. Khandekar spent 25 years as a Research Scientist with Environment Canada (now retired) and has previously taught meteorology and related subjects at the University of Alberta in Edmonton (1971-74) and for two United Nations training programs: Barbados, West Indies (1975-77, World Meteorological Organization lecturer in meteorology) and Qatar, Arabian Gulf (1980-82, ICAO expert in aeronautical meteorology). He has published research on surface waves, arctic sea ice, ENSO/monsoon and global weather, numerical weather prediction, boundary-layer meteorology, and tropical cyclones. He presently serves on the editorial board of the international Journal, *Natural Hazards* (Kluwer, Netherlands) and was an editor of *Climate Research* (Germany) from 2003-2005. Khandekar acted as a guest editor for a special issue of the journal *Natural Hazards* on global warming and extreme weather, published in June 2003. Khandekar has been a member of the American Meteorological Society since 1966, the Canadian Meteorological and Oceanographic Society since 1970, and the American Geophysical Union since 1986.

Mr. William Kininmonth has a B.Sc. from the University of Western Australia, an M.Sc from Colorado State University, and an M.Admin from Monash University. He is a consulting climatologist, and worked with the Australian Bureau of Meteorology for 38 years in weather forecasting, research and applied studies. For 12 years until 1998 he was head of its National Climate Centre. William Kininmonth was Project Manager of an Australian Government project of assistance to the Meteorology and Environmental Protection Administration of Saudi Arabia, based in Jeddah (1982-85). Mr. Kininmonth was Australian delegate to the World Meteorological Organization's Commission for Climatology (1982-1998) and served two periods on its Advisory Working Group (1985-89 and 1993-97). He participated in Expert Working Groups of the Commission and carried out regional training activities in relation to climate data management and climate monitoring. Between 1998 and 2002 he consulted to the Commission, including coordinating an international review of the 1997-98 El Niño event and preparation of a WMO publication, *Climate into the 21st Century* (Cambridge). He was a member of Australia's delegations to the preparatory meetings for the Ministerial Declaration of the Second World Climate Conference (1990) and to the United Nations Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (1991-92). William Kininmonth is author of the book, *Climate Change: A Natural Hazard* (Multi-Science Publishing Co. UK - 2004)

Dr. Christopher Essex Christopher Essex is a full Professor of Applied Mathematics at the University of Western Ontario, where he is Director of the Program in Theoretical Physics. He holds a B.Sc (hon.), from the University of Western Ontario, an M.S. from Rice University and a Ph.D. from York University. He was an NSERC Postdoctoral Fellow at the Canadian Climate Centre and held a Humboldt Research Fellowship at the University of Frankfurt in Germany, and was recently a visiting scientist at the Niels Bohr Institute in Denmark. Dr. Essex specializes in the underlying mathematics, physics and computation of complex dynamical processes such as climate. His research, including discoveries in statistical physics, has been published in leading scientific journals, and he is a frequently invited speaker at professional international science symposia. He is a recipient of the $10,000 Donner Prize (2002) for his book on global warming and is a life member of the Canadian Industrial and Applied Mathematics Society. In 2006 he was appointed by the Governor General of Canada to the Natural Sciences and Engineering Research Council.

Dr. Wibjörn Karlén received a Masters degree at the University of Maine in 1972. The focus of his thesis was the pattern and possible cause of Holocene climatic variations. A few years later he defended a Ph.D. at the Department of Physical Geography at Stockholm University. He has during the following years maintained his interest in the climate of the Holocene. He has collected field data in a number of areas around the world, including Scandinavia, Svalbard, Alaska, Kenya and Antarctica. Between 1984 and 2004 he was appointed professor at Stockholm University, and between 1985 and 1995 was in charge of the Tarfala Research Station, where research focuses on glaciology. After retirement he is now the editor of an international scientific journal, *Geografiska Annaler*. Since 1992 he has been a member of the Royal Swedish Academy of Sciences.

Dr. Olavi Kärner studied mathematics at the University of Tartu, Estonia before receiving his Ph.D. in Atmospheric Physics from the Leningrad Hydrometeorological Institute in 1974. In 1966, Dr. Kärner joined the Tartu Observatory in Tõravere, Estonia, and since 1977 has held the position of Senior Research Associate, Atmospheric Sensing Group. His scientific interests include time series analysis for climate studies, and the development of satellite cloud classification methods for radiation budget calculations. In 1993, Dr. Kärner and co-author, Dr. Sirje Keevallik, published *Effective Cloud Cover Variations* (A. Deepak Publishing). He was born in 1942 in Tartu, Estonia, and is married with three children.

Dr. Ian Clark holds a B.Sc. and M.Sc. in Earth Sciences from the University of Waterloo, and a Ph.D. Sciences de la Terre from the Université de Paris-Sud. Dr. Clark is a Professor in the Department of Earth Sciences at the University of Ottawa. He conducts research on past climates and environmental change in the Arctic since the last ice age. Current programs involve field work with students in the Yukon Territory and on the Mars environment analogue site on Devon Island in Nunavut, which is supported by the Canadian Space Agency. He teaches courses on Quaternary Geology and Climate Change and on Groundwater Geochemistry. Dr. Clark is director of the G.G. Hatch Isotope Laboratory, an internationally-renown facility supporting research in Earth and environmental science.

Dr. Tad Murty completed his early education in India and later received an M.S. and Ph.D. in Meteorology and Oceanography from the University of Chicago. Dr. Murty was a Senior Research Scientist with the Canadian Department of Fisheries and Oceans for 27 years and a Professor of Earth Sciences at Flinders University, Adelaide, Australia. Murty has also served as the Director of Australia's National Tidal Facility, and as a Senior Scientist with Baird & Associates Coastal Engineers in Ottawa, Canada. Dr. Murty retired in 2004 and is now an Adjunct Professor in the Departments of Earth Sciences and Civil Engineering at the University of Ottawa. Dr. Murty has authored, co-authored and edited 18 books and monographs and more than 250 papers in peer reviewed scientific journals. He has served on various national and international committees, and received several awards for original and outstanding research on mathematical modelling of marine hazards. At present, he is the leader of a World Meteorological Organization group preparing a manual on storm surges from Hurricanes and extra-tropical cyclones. Dr. Murty is also the Editor of *Natural Hazards* published by Springer Associate, and the Editor of *Marine Geodesy* published by Taylor& Francis.

Dr. James J. O'Brien Dr. James J. O'Brien is the Robert O. Lawton Distinguished Professor, Meteorology & Oceanography, and the Director of the Center for Ocean-Atmospheric Prediction Studies at Florida State University. After receiving his Ph.D. in meteorology from Texas A&M University in 1966, O'Brien has published more than 115 scientific publications, and has significantly contributed to the advancement of the science of atmospheric and ocean modeling. O'Brien is a Fellow of the American Meteorological Society, the American Geophysical Union, the Royal Meteorological Society, and the American Association for the Advancement of Science. He is also a Member of the Norwegian Academy of Science and Letters, and a Foreign Fellow of the Russian Academy of Natural Science. He has been the Editor of the *Journal of Geophysical Research:Oceans*, and the Associate Editor of *Monthly Weather Review*, and *Continental Shelf Research*. He is currently an Associate Editor of the *International Journal of Math and Computer Modeling*. A member of Florida State University's Faculty for more than 35 years, he is perhaps best known for his early, basic research into El Niño. Since 1999, O'Brien has been the Florida State Climatologist, and in 2006 he received the prestigious Uda Prize from the Japanese Oceanographic Society.

Glossary

Accumulated Cyclone Energy (ACE)	a measure used by the National Oceanic and Atmospheric Administration (NOAA) to express the activity of Atlantic hurricane seasons
Acidity	the level of hydrogen ion concentration in a solution measured on the pH scale such that the majority of readings range from 1 (very high acidity) to 14 (very high alkalinity)
Aerosols	tiny solid particles or liquid droplets that remain suspended in the atmosphere for at least several hours. Aerosols include volcanic dust, sea spray and its particulate products, wind generated dust, smoke from natural forest fires, and particles emitted during combustion
Albedo	the extent to which an object reflects light; the ratio of scattered to incident electromagnetic radiation power. For example, snow covered surfaces have a high albedo, and dark bare ground has a low albedo.
Altimetry	the measurement of altitude
Altitude	the elevation of an object above a known level; commonly, the elevation of an object above mean sea level
Anthropogenic	resulting from or produced by human beings
Areal	the adjective of area; relating to or involving an area. For example, average rainfall over an area could be referred to as the areal average
Aspect	in geography, aspect refers to the direction a slope is facing
Atlantic Multidecadal Oscillation (AMO)	an ongoing series of long-duration changes in the sea surface temperature of the North Atlantic Ocean, with cool and warm phases that may last for 20-40 years at a time; these changes are natural and have been occurring for at least the last 1,000 years
Biosphere	the outer part of the Earth (including the land, air, and water) in which life occurs
Biota	the flora (plant) and fauna (animal) of a region or time period
Black carbon	a term describing a group of compounds consists mainly of soot, charcoal, and possible light-absorbing organic matter.
Carbonate concentration	the number of molecules of a carbonate (a compound containing carbon and oxygen such as calcium carbonate, which is limestone) in a given volume
Chlorofluorocarbons (CFC)	a family of chemical compounds composed of carbon, fluorine, chlorine and hydrogen that were used extensively as propellants, refrigerants, and solvents.
Conservation of mass	a law of physics that states that matter cannot be created or destroyed only changed in form.
Climate	The IPCC defines climate in a narrow sense as the "average weather", or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years
Carbon Dioxide (CO_2)	a molecule consisting of one carbon atom bonded to two oxygen atoms. At room temperature it is a colourless and odourless gas
Coral series	coral growth is influenced by temperature (but not temperature alone), and can be used much like tree-ring widths to make inferences about the climate in historical times. A coral series generally refers to a coral sample(s) that is used to estimate past climate changes

Cryosphere	refers to the portions of the Earth's surface where water is in solid (frozen) form, and includes snow, ice, and frozen ground (including permafrost)
Diurnal temperature range (DTR)	the difference between the maximum and minimum temperature in a day
Downscaling	a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution global climate models (GCMs). Typically, GCMs have a resolution of 150-300 km by 150-300 km, but many models require information at scales of 50 km or less, so some method is needed to estimate the smaller-scale information
Dynamical downscaling	a method for obtaining high-resolution climate data from relatively coarse-resolution global climate models which uses a limited-area, high-resolution model (a regional climate model, RCM) driven by boundary conditions from a GCM to derive smaller-scale information; used whenever models require small-scale data
El Niño	otherwise known as the El Niño-Southern Oscillation (ENSO) is a coupled air-sea phenomenon that has its origins in the Pacific Ocean but affects climate globally
Emissions	in the climate change context, emissions refers to the release of a greenhouse gas or its precursors into the atmosphere
ENSO	see El Niño
Equilibrium climate sensitivity	the change in surface air temperature following a unit change in radiative forcing
Extratropical	The extratropics refer to an area outside of the tropics. *Extratropical* is often used to describe storms or cyclones that originate outside of the tropics
Firn	A type of snow that has survived at least one season and has become granular and dense, almost an ice. It is often found under snow that accumulates at the head of glaciers
Fossil fuel	refers generally to fuels such as coal, oil, and natural gas that were formed from decayed plants and animals by exposure to heat and pressure over hundreds of millions of years in the Earth's crust
General Circulation Model (GCM)	a time-dependent, numerical, three-dimensional computer model of the climate system, representing the effects of such factors as reflective and absorptive properties of atmospheric water vapor, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries
Glacial Isostatic Adjustment (GIA)	the process whereby the earth's shape and gravitational field are modified in response to large scale changes in surface mass load related to glaciation and deglaciation
Greenhouse gas	any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs) , ozone (O_3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs)
Gulf Stream	a warm, swift, relatively narrow ocean current that flows along the east coast of the United States
Heat island	an urban area that is significantly warmer than the surrounding countryside; otherwise called an Urban Heat Island (UHI) or the 'urban heat island effect'.

Heinrich events	sudden intense cold and dry phases which are the most extreme of a spectrum of abrupt, brief cold events which seem to have occurred very frequently over the last 115,000 years
Holocene	the post-glacial period, between the present and 10,000 years before present
Ice cores	a cylinder of ice removed from an ice sheet containing layers of compacted ice useful for the reconstruction of past environments
Irradiance	a measure of the amount of light energy incident on a unit area per unit wavelength interval (Watts per meter square per nanometer, for example) from all directions
kelvin	the base unit of temperature in the International System of Units. Zero kelvin (0 K) is defined as absolute zero - the lowest possible temperature where no heat energy remains in a substance. A temperature change of one kelvin is equal to a temperature change of one degree Celsius.
Lacustrine	pertaining to or living in lakes or ponds
Last Interglacial (LIG)	the most recent time (115 000 to 125 000 years ago) during which global temperatures were as high as or higher than in the postglacial, when continental glaciers were limited to the Arctic and Antarctic, and sea levels were near current positions
Meltback	a periodic melting of a glacier
Meridional Overturning Circulation (MOC)	sinking and spreading of cold water; for instance, the Atlantic meridional overturning circulation carries warm upper waters into far-northern latitudes and returns cold deep waters southward across the Equator
Monsoon	a thermally driven wind arising from differential heating between a land mass and the adjacent ocean that reverses its direction seasonally
Nonstationarity	see Stationarity
Northern Annular Mode	large-scale modes of climate variability in the Northern Hemisphere also known as the Arctic Oscillation or the North Atlantic Oscillation.
Ozone	a molecule made up of three atoms of oxygen that occurs naturally in the stratosphere and filters out much of the sun's ultraviolet radiation; ozone builds up in the lower atmosphere as smog pollution
Pacific Decadal Oscillation	a pattern of climate and ocean conditions occurring in the north Pacific Ocean that results in shifts in sea surface temperatures and plankton abundance on a decades-long time scale
Paleohydrology	the study of hydrologic processes and events using proxy measures that occurred before the beginning of the systematic collection of hydrologic data
Paleolithic	the Old Stone Age; the archaeological period before c.10,000 BC, characterized by the earliest known stone tool manufacture
Parameterization	the representation of physical effects as simplified parameters in a dynamic model; for instance, cloud formation is calculated from quantities like water vapor, depending on the exact parameterization scheme employed
pH	a measure of the acidity or alkalinity of a solution; pH scale typically ranges from 0 to 14 such that 7 indicates neutral solutions, small numbers indicating greater acidity and large numbers indicating greater alkalinity

Power Dissipation Index (PDI)	for a tropical cyclone PDI is defined as the sum of the maximum one-minute sustained wind speed cubed, at six-hourly intervals, for all periods when the cyclone is at least tropical storm strength; The PDI takes into account the frequency, strength, and duration of tropical cyclones
Proxy record	a substitute measure when direct measurement is not possible
Radiation	energy that comes from a source and travels through some material or through space; light, heat and sound are types of radiation.
Radiation budget	the balance between incoming energy from the Sun and outgoing thermal (longwave) and reflected (shortwave) energy from the earth
Radiosonde	a measuring device attached to weather balloons that directly records various atmospheric parameters
Radiative Forcing (RF)	the net flux of radiation into or out of a system such that there must be some change to the non-radiative energy states of the system such as a change in its temperature
Sea level	the position of the boundary between the air and the sea; serves as the reference point from which all land elevations and water depths are measured. The sea level at any location changes constantly with tide, atmospheric pressure, and wind conditions and is therefore commonly defined as mean sea level (msl)
Sink strength	the degree to which a process capable of removing energy or a substance from the atmosphere; a sink provides storage for a substance; for example, plants act as sinks through photosynthesis, as they transform carbon dioxide in the air into organic matter which either stays in the plants or is stored in the soils
Stationarity	a condition of time series data in which both the mean and variance are finite and constant with respect to time, and the covariance across fixed intervals is constant across time.
Statistical downscaling	a method for obtaining high-resolution climate data from relatively coarse-resolution global climate models which derives statistical relationships between observed small-scale (often station level) variables and larger (GCM) scale variables, using regression analysis or neural network methods
Stratosphere	the atmosphere is categorized into layers; the stratosphere is the layer above the troposphere and below the mesosphere; it is generally defined as beginning at 10km above the earth's surface and ending at 50km above the earth's surface and is characterized by an increase in temperature with height
Sublimation	a phase change of a substance from solid directly to gas
Subsidence	the sinking or downward settling of the Earth's surface
Surface thermometer network	an interconnected system of temperature-measuring devices
Thermohaline Circulation	the flow of ocean water caused by changes in density, which depends on both temperature (thermo) and salinity (haline)
Top of the Atmosphere (TOA)	the upper limit of the atmosphere defined differently depending on the application; in climatology, TOA is the altitude at which air becomes so thin that atmospheric pressure or mass becomes negligible

Troposphere	the atmosphere is categorized into layers, the lowest of which is the troposphere that extends from the earth's surface to approximately 15km; all weather processes take place in the troposphere
Younger Dryas	an abrupt and brief (approximately 1300 ± 70 years) cold climate period at the end of the Pleistocene between approximately 12,700 to 11,500 years Before Present