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THE IMPACTS OF CLIMATE CHANGE AND STATES' ACTIONS

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED EIGHTH CONGRESS

SECOND SESSION

MAY 6, 2004

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED EIGHTH CONGRESS

SECOND SESSION

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THE IMPACTS OF CLIMATE CHANGE AND STATES' ACTIONS

THURSDAY, MAY 6, 2004

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 9:31 a.m. in room SR–253, Russell Senate Office Building, Hon. John McCain, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. JOHN MCCAIN, U.S. SENATOR FROM ARIZONA

The CHAIRMAN. Good morning. Today, we continue with our series of hearings on the very critical topic of the impacts of global climate change, an issue of worldwide importance.

During the four previous hearings on this issue, the Committee has heard testimony regarding climate change and the impact it's having on the environment and various species around the globe. We've learned that climate change is contributing to the changes in the migration and destruction of many species, causing the destruction of sensitive ecosystems, such as coral reefs, despite our best management efforts, forcing the relocation of villages in the Arctic region to escape rising sea levels from polar ice-melt, and affecting the ocean's circulation. Climate change is real, and presents a clear danger to public health.

Arizona, my home state, is facing record droughts again this year. Two of the reservoirs on the Colorado River that supply water to much of the Southwest are only half full, due to the below-normal March snowfalls in the Rocky Mountains, and warming temperatures, which are consistent with climate change. This will only add to the ongoing drought, and exacerbate the wildfire concerns in my state. I'm looking forward to the testimony of Dr. Philip Mote, who will discuss the impacts of smaller snow packs on downstream water flows.

While I'm concerned about what's occurring in Arizona and across the United States, we must realize that what happens in one part of the world affects the weather in another part. Last year, I had discussions with Brazilian scientists about how the destruction of the rain forest in Brazil is affecting the weather in the Southwestern United States. The Australian Minister for the Environment and Heritage recently discussed with me the impact of Antarctica's changing conditions on the weather in Australia. There are myriad examples of the interconnection of the weather in various parts of the world, and we need to wake up and take

action now to address the growing impact of climate change. We must do more to reduce the greenhouse gas emissions here at home, and reach out internationally to educate others on the effects of climate change.

We will also hear from those who must deal with the climate-change-related public health issues firsthand—the states. The states have consistently taken the lead in addressing major environmental problems in the United States. It appears that, for climate change, the same is true. Although many countries are already taking action to require mandatory reductions in the emission of greenhouse gases, the United States is not.

In an effort to make the reduction of greenhouse gases a priority in the United States, Senator Lieberman and I introduced S. 139, the Climate Stewardship Act of 2003, in January of last year. S. 139 would require mandatory reductions in the U.S. greenhouse gas emissions, and would provide a trading system as a means for industry to meet these mandatory reductions. While the bill was voted on last fall by the Senate, and failed by a vote of 55 to 43, I believe the time has come for another vote. It's my hope that the evidence presented here today, along with the information from other hearings on the issue, will serve to educate not only the Members of this Committee, but all Members, that climate change and its impact on the environment is real.

I welcome our witnesses today, and look forward to their testimony.

Senator Lautenberg?

STATEMENT OF HON. FRANK R. LAUTENBERG, U.S. SENATOR FROM NEW JERSEY

Senator LAUTENBERG. Thanks, Mr. Chairman. And I commend you for holding this, the third, hearing in the last year on the impacts of global warming. And I very much appreciate your directing us to focus on the very real threats of global climate change.

We already see the impacts of global warming, and they'll continue to mount, harming our health, our economy, and the Earth's ecology if we fail to act. And I hope that the time to act has not totally passed us by.

New reports and scientific updates on the impacts of climate change continue to provide fresh evidence that our world is undergoing a dramatic shift in its temperature, and that human activities are mainly responsible. The Pentagon's report on climate change, which was disclosed last February, described some of the very frightening potential scenarios. These could play out in the event of an abrupt climate change, kind of going over the cliff, which scientists tell us could happen. Over the next 20 years, for instance, we could experience unprecedented droughts, famine, riots, and wars of survival. Last summer, 35,000 people died during the heat wave that enveloped Europe. It was the hottest summer there in five centuries.

But such deterioration of society does not have to happen. With America's capacity to innovate, our wealth, our technological expertise, we could be leading the world effort to reduce greenhouse gas emissions, instead of lagging behind.

Frankly, our unwillingness to take action is an international embarrassment. Striking events are occurring that cannot be ignored, events such as last October's breakup of the Artic's largest ice shelf, the Ward Hunt Ice Shelf. It had been unchanged for 3,000 years, and then broke into two pieces after having lost 90 percent of its mass in less than a century. Since 1950, the average thickness of Arctic ice has decreased by a staggering 40 percent. No doubt, more ice shelf breakups can be expected.

Ocean levels around the globe have risen four to eight inches in the 20th century, and are expected to rise another four to 35 inches this century. For my home state of New Jersey, with its 127 mile shoreline, that could be catastrophic. And according to the Environmental Protection Agency, the sea level along the New Jersey shoreline has been rising at 15 inches a century, at least twice the global average. And understand this, it is likely to rise another 27 inches by the end of the 21st century. I hate to imagine what would happen to my state's population and our economy if that rise in sea level continues as expected. This vulnerability is clearly compounded by the heavy concentration of population in coastal areas here and around the world. And, again, I believe that the message here is simple, that time has come when we must act.

Global warming is a serious business. The consequences are very serious. And Congress must be equally serious in addressing it.

Mr. Chairman, thank you. I look forward to our witnesses' testimony.

[The prepared statement of Senator Lautenberg follows:]

PREPARED STATEMENT OF HON. FRANK R. LAUTENBERG,
U.S. SENATOR FROM NEW JERSEY

Mr. Chairman:

I want to commend you for holding this hearing, the third hearing in the last year just on the impacts of global warming. Thank you for helping us to focus on the very real threats of global climate change.

We can already observe the impacts of global warming, and they will continue to mount, harming our health, our economy, and the earth's ecology—if we fail to act.

New reports and scientific updates on the impacts of climate change continue to provide fresh evidence that our world is undergoing a dramatic shift in its temperature, and that human activities are mainly responsible.

The Pentagon's report on climate change, which was disclosed last February, described some of the frightening potential scenarios that could play out in the event of "abrupt climate change," which the scientists tell us could happen. Over the next 20 years, for instance, we could experience unprecedented droughts, famines, riots, and wars of survival.

Last summer, 35,000 people died during the heat wave that blanketed Europe; it was the hottest summer there in five centuries.

But such deterioration of society does not have to happen. With America's capacity to innovate, our wealth, and technological expertise, we could be leading the world effort to reduce greenhouse gas emissions, instead of lagging behind. Frankly, our unwillingness to take action is an international embarrassment.

Striking events are occurring that cannot be ignored: events such as last October's break-up of the Arctic's largest ice shelf—the Ward Hunt Ice Shelf which had been unchanged for 3,000 years and then broke into two pieces after having lost 90 percent of its mass in less than a century.

Since 1950, the average thickness of Arctic ice has decreased by a staggering 40 percent. No doubt, more ice shelf break-ups can be expected.

Ocean levels around the globe have risen 4 to 8 inches in the 20th Century, and are expected to rise another 4 to 35 inches this century.

For my home State of New Jersey, with a 127 mile shoreline, that could be catastrophic.

According to the Environmental Protection Agency, the sea level along the Jersey shoreline has been rising at 15 inches per century, at least twice the global average. And—get this—it is likely to rise another 27 inches by the end of the 21st Century.

Mr. Chairman, I hate to imagine what that would do to my State's population and our economy.

This vulnerability is clearly compounded by the heavy concentration of population in coastal areas here and around the world.

Again, I believe the message here is simple: the time has come to act.

Global warming is serious business. Its consequences are very serious. And Congress must be equally serious in addressing it.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you very much.

Our panel is Mr. Ken Colburn, the Executive Director of the Northeast States for Coordinated Air Use Management; Dr. William Curry—Will the witnesses please come forward?—Dr. William Curry, Department of Geology and Geophysics, Woods Hole Oceanographic Institute; Dr. Paul Epstein, the Associate Director of the Center for Health and Global Environment, at Harvard Medical School; Dr. William Fraser, President of Polar Oceans Research Group; and Dr. Philip Mote, a Research Scientist at the University of Washington.

And I welcome our panelists.

And, Mr. Colburn, we will begin with you. And I want to welcome all of you for being here this morning.

STATEMENT OF KENNETH A. COLBURN, EXECUTIVE DIRECTOR, NORTHEAST STATES FOR COORDINATED AIR USE MANAGEMENT (NESCAUM)

Mr. COLBURN. Thank you, Mr. Chairman. It's a delight to be here.

My name's Ken Colburn. I'm the Executive Director of the Northeast States for Coordinated Air Use Management. We are an association of the air pollution control agencies of the eight northeast states, the six New England states, plus New York and New Jersey. Thank you for the opportunity to address the Committee regarding states' actions to address climate change.

The biggest concern I have, Senator, is staying within 5 minutes, because so much is going on. Your timing's particularly opportune. Regional, state, municipal, civic and private sector progress is advancing so rapidly that we may be close to a tipping point.

This week is a good example. On Monday, the northeast states met in New York with a high-level British delegation about climate activities and international trading. Yesterday, the Connecticut General Assembly passed legislation establishing economywide emission reductions, and authorizing a greenhouse gas registry, and requiring mandatory reporting of greenhouse gas emissions.

The CHAIRMAN. Was the Connecticut law along the lines of the California law?

Mr. COLBURN. Senator, I'm not sure if California has those provisions. California has many provisions, so it's probably——

The CHAIRMAN. On emissions?

Mr. COLBURN. California's is largely, at this point, on vehicles, if I recall correctly. And I do cover that later in testimony, Senator.

The CHAIRMAN. OK, thank you. I'm sorry to interrupt.

Mr. COLBURN. Also yesterday, Governor Don Carcieri, of Rhode Island, indicated that his state would adopt California clean car re-

quirements. And today in Boston, Governor Mitt Romney is announcing Massachusetts' new comprehensive climate protection plan.

Absent concerted Federal action to address climate change, states have stepped up to fill this policy void, as much out of economic self interest as fear of devastating climate impacts. Historically, the states have led by example, serving as a catalyst for Federal action by showing that the disaster scenarios predicted by special interests don't, in fact, come to pass.

In terms of context, the states recognize that economic well-being and environmental quality are cornerstones to quality of life, and there is strong scientific consensus that human activity is interfering with the climate. If we continue down the path we're on, the climate of Boston will relocate to somewhere between Richmond and Atlanta in the next hundred years.

The states also see that jobs producing mitigation measures, like developing and installing energy efficiency and renewable technologies, are in their own best interests. Such steps enhance energy security and reliability, keep our energy dollars closer to home, provide greater business certainty, boost our technology sector, assuage financial-sector concerns, provide significant public health benefits, and secure competitive advantage for the future. Not surprisingly, then, state efforts are strongly bipartisan and enjoy solid constituent support.

The climate actions being taken by individual states are so numerous that I can only cover a handful of them in order to also discuss regional climate actions. Many of the states are encouraging penetration of renewable energy—solar, wind, biomass—in the marketplace, and a number of states have committed to substantial renewable-power purchases themselves. These include, for example, New York, under Governor Pataki's Executive Order 111—insists that 20 percent of the power purchased by the state come from renewable sources. Connecticut Governor John Rowland's Executive Order 32 seeks 20 percent in state purchases by 2010, and a hundred percent by 2050. Over half the northeast states have adopted a renewable portfolio standard. And nationwide, at least 13 states have done so.

The states are also working to reduce motor vehicle greenhouse gas emissions. In 2002, the California State Assembly adopted legislation requiring maximum feasible reductions of greenhouses gases from cars and trucks starting in 2009. New technologies, even ones less expensive than the hybrids that are already enjoying success in the marketplace, can reduce greenhouse gases from vehicles by 25 percent and still save money for consumers over the life of the vehicle. Massachusetts, New York, Vermont, and Maine adopted clean car California regulations years ago. And this very year, New Jersey, Connecticut, and Rhode Island have joined them.

In the power sector, for pollutant emission reduction requirements for power plants have already been adopted in Massachusetts and New Hampshire. Oregon and Massachusetts also require newly built power plants to offset some of their carbon dioxide emissions.

The list doesn't stop there. There are state climate registries being built. State actions plans, on the order of 27 states are work-

ing on plans. In June 2003, Maine's legislature ordered economy-wide greenhouse gas reductions, and joined New Jersey in requiring reporting of greenhouse gas emissions from sources. States are investing, annually, about half a billion dollars in energy efficiency and renewable energy, just in the Northeast. New York alone is $300 million a year.

Last, the states are acting through their attorneys general, where necessary. Twelve states have challenged EPA's assertion that it does not have the authority to regulate greenhouse gases under the Clean Air Act.

States have also come together regionally to act on climate change. Uniform regional approaches often prove more cost effective and efficient in meeting reduction targets. In 2001, for instance, the six New England Governors and five Eastern Canadian premiers adopted a joint climate action plan calling for reductions in greenhouse gases to 1990 levels by 2010; a mid-term goal, an interim goal, of 10 percent below that by 2020; and then a long-term target of 75 to 85 percent reductions. And they've started with several initiatives, including an adaptation conference, the first time a major adaptation symposium's been held in pursuit of that climate action plan.

A regional greenhouse gas registry is also being developed in the Northeast. The registry is a system for organizing, reporting, recording greenhouse gas emissions information in support of current and future climate programs. Participants in this include the eight northeast states, but also Delaware and Pennsylvania, and it's open to other states, as well. This effort will be consistent with international protocols established by the World Resources Institute and the World Business Council for Sustainable Development, and it'll be compatible with the World Economic Forum's Climate Register and the California Climate Action Registry.

State interest in climate has advanced so rapidly, however, that, a year ago, New York Governor George Pataki invited the Governors of ten northeast states and mid-Atlantic states to join in developing a regional cap-and-trade program for CO_2 from the power sector. Dubbed the Regional Greenhouse Gas Initiative, or RGGI, this multi-state effort crosses the threshold from voluntary climate initiatives to a regulatory program. As such, it arguably represents the most significant effort to address climate change now underway in the United States. Nine states have signed on as full participants, and several others are observing, including international observers, Canadians and the Australians. Australians are looking at how a similar effort might be accomplished "down under," or coordinated with the RGGI. While RGGI's first focusing on CO_2 emissions from power plants, it's likely to expand to other sources, other gases, and into offset opportunities, like sequestration.

And then, finally, the West Coast is also getting in on this act. The Governors of the three West Coast states have begun to discuss regional climate mitigation strategies, have launched some initial steps, including procurement, reducing diesel use in ports, incentives for renewables, and energy efficiency standards, and they're coming in with a more comprehensive plan, I understand, this September.

In conclusion, Senator, this testimony represents just a humble sampling of the climate efforts underway at the state and regional scale. But bottom-up state, local, and regional action, while heartening, cannot substitute for collective national action. The United States' greenhouse gas emissions are rising rapidly, and only concerted action at the Federal level will put us on a path to ultimately reverse this trend. The national policies reduce uncertainty for the business community, and reduction targets can be reached in a more efficient and cost effective manner if tackled at the national scale.

There are many lessons to be learned from the states, and we hope that Federal policymakers will regard the states' innovative climate mitigation and adaptation strategies as models, and will quickly take action. Climate change has already begun to take its toll on our states' economies and natural resources. We need to act while the window to avert dangerous climate interference and to maximize economic opportunity is still open.

Thank you very much, Senator.

[The prepared statement of Mr. Colburn follows:]

PREPARED STATEMENT OF KENNETH A. COLBURN, EXECUTIVE DIRECTOR, NORTHEAST STATES FOR COORDINATED AIR USE MANAGEMENT (NESCAUM)

Thank you, Mr. Chairman. My name is Ken Colburn. I am the Executive Director of the Northeast States for Coordinated Air Use Management (NESCAUM). NESCAUM is an association of the state air pollution control agencies of Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont. We provide technical assistance and policy analysis to our member states on regional air pollution issues of concern to the Northeast. On behalf of the states, I would like to express our appreciation for this opportunity to address the Committee regarding the impacts of climate change and states' actions to address climate change. The timing is particularly opportune: regional, state, municipal, civic, and private sector progress on climate change is paving the way for future U.S. action, and may be rapidly approaching a tipping point.

This very week is illustrative: One Monday, the Northeast States met in New York with a British delegation headed by Margaret Beckett, Secretary of State for Environment, Food, and Rural Affairs concerning climate change activities and trading. Yesterday, the Connecticut General Assembly passed SB 595, establishing concrete emission reduction targets, requiring mandatory reporting of greenhouse gas emissions, and authorizing a voluntary greenhouse gas (GHG) registry. Also yesterday, Rhode Island Governor Donald Carcieri indicated that his state would adopt California's cleaner vehicle requirements. And today in Boston, Massachusetts Governor Mitt Romney is announcing his administration's comprehensive new Climate Protection Plan.

In the absence of concerted Federal action to address climate change, many states have stepped up to fill this policy void, as much out of economic self-interest as fear of devastating climate impacts or a sense of obligation due to culpability or ability-to-pay. In the process, they have become a testing ground for some of the most progressive climate change efforts around the globe.

In particular, the Northeast, Mid-Atlantic, and Western coastal states, as well as a handful of others, have undertaken an abundance of climate initiatives: renewable electricity mandates, state and regional GHG registries, mandatory GHG reporting, statewide caps on GHG emissions, GHG reductions from motor vehicles, and now, a power sector cap-and-trade program. The states are not just a laboratory to experiment with U.S. climate change policy; their own GHG emissions are significant. Taken collectively, the eight Northeast states and California would rank among the sixth largest GHG emitters in the world. Even without California, the eight Northeast states would rank among the top ten, in a league with Canada, Australia, and France. Historically, our states have led by example, and this environmental leadership has served as a catalyst for Federal action, once the disaster scenarios predicted by opponents do not, in fact, come to pass.

In this testimony, I will: (1) briefly describe the context and rationale which has spurred state and regional action on climate change; (2) outline a number of *re-*

gional climate actions, such as the development of a regional greenhouse gas cap-and-trade program and regional greenhouse gas registry; and (3) highlight a few of the countless *state* climate initiatives underway.

Context and Rationale for Regional and State Action on Climate Change

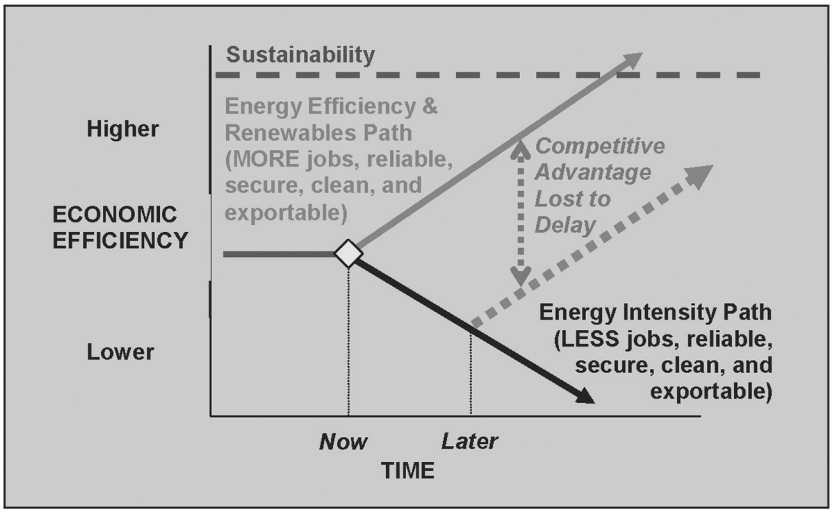
Perhaps counter-intuitive at first glance, it is actually not surprising that the states are shouldering the daunting task of addressing climate change. The states increasingly recognize that economic well-being and environmental quality are positively correlated; both are cornerstones to quality of life. The states are also acting within a strong scientific consensus confirming that increasing concentrations of atmospheric greenhouse gases are largely the result of human activity. If we continue down the path we're on, scientists estimate that the climate of Boston could "relocate" to somewhere between that of Richmond and Atlanta over the next hundred years—drastically altering the economies, ecosystems, and quality of life our citizens enjoy today.

States and regions are already experiencing the impacts of global warming and have little choice but to act. Climate change has already begun to take its toll on a number of industries—tourism and recreation (*e.g.,* skiing and snowmobiling), agriculture (*e.g.,* maple sugaring), pulp and paper, lumber and wood products, and hunting and fishing. These effects directly impact state budgets, reducing revenues and increasing expenditures.

The states have the foresight to see that jobs-producing GHG mitigation measures—like developing and installing energy efficiency and renewable technologies of the future—are in their own best interests. Such steps enhance energy security and reliability, keep our energy dollars closer to home, boost our technology sector, provide greater business certainty, assuage the financial and investment community, provide significant health co-benefits, and secure competitive advantage for the future. (See Figure 1.) Not surprisingly, then, such efforts are strongly bi-partisan and enjoy solid constituent support.

In short, the states are responding to climate change by positioning themselves *defensively* to protect their existing economies and reduce their vulnerability to climate risks; *offensively* to get ahead on the learning curve and secure the economic advantages accruing to early actors; and *aggressively* to protect public health, ecosystems, and overall quality of life.

Figure 1. Old or New Energy Path?



State Climate Actions

The states' responses have resulted in diverse strategies and a range of policy opportunities to move forward in addressing climate change. The climate action measures taken by individual states are virtually innumerable, so I will only be able to highlight a handful of them.

Renewable Energy Requirements

Many states are implementing steps to encourage the penetration of renewable energy (RE) such as solar, wind, and biomass in the marketplace. Several states have committed to purchasing significant amounts of renewable power themselves. New York Governor George Pataki's Executive Order 111, for example, insists that 20 percent of all power purchased by the state come from renewable sources. Connecticut Governor John Rowland's Executive Order 32, announced last month, seeks 20 percent RE in state purchases by 2010 and 100 percent by 2050. Others have adopted renewable portfolio standards (RPS)—market mechanisms that ensure a percentage of electricity sold is generated by RE sources. Over half of the Northeast states have implemented renewable energy portfolio standards, ranging from 4 percent to 30 percent. Nationwide, at least thirteen states (Arizona, California, Connecticut, Iowa, Maine, Massachusetts, Minnesota, Nevada, New Jersey, New Mexico, Pennsylvania, Texas, and Wisconsin) have established RPSs and more states (*e.g.,* New York) are joining them.

Reducing Motor Vehicle GHG Emissions

In 2002, the California State Assembly adopted legislation (AB 1493) requiring maximum feasible reductions in GHG emissions from light duty cars and trucks starting in 2009. Initial assessments have shown that new vehicle technologies—even less expensive than the hybrids already enjoying success in the marketplace—can reduce vehicle GHGs by at least 25 percent and save owners money over the life of the vehicle. Many other states already have or intend to adopt these California requirements. Massachusetts, New York, Vermont, and Maine have done so, joined this year by New Jersey and Connecticut following successful legislation. Rhode Island Governor Donald Carcieri announced yesterday that his state would follow suit.

States are also reducing emissions from their own fleets through vehicle procurement and use policies. Maine has an executive order insisting that state employees work to reduce Vehicle Miles Traveled (VMT) through videoconferencing, telecommuting, and carpooling, and requiring the purchase of hybrid electric vehicles where cars are necessary. Massachusetts requires state vehicles to be ULEV or better and to get at least 20 miles per gallon. It, along with Rhode Island, also limits the purchase and use of SUVs in state fleets. Last year in New York, 89 percent of vehicles purchased were hybrid or alternate fueled, en route to 100 percent by 2010. In addition, the NY Metropolitan Transit Authority is installing particulate traps three years ahead of schedule and purchasing 300 hybrid buses.

Reducing Power Sector GHG Emissions

A handful of states have moved forward by "four-pollutant" emission reduction requirements on power plants, covering sulfur dioxide, nitrogen oxides, mercury and carbon dioxide. Massachusetts adopted the first such regulations limiting power plant emissions in 2001. New Hampshire followed suit in legislation the next year, the first time that elected officials had voted to regulate carbon dioxide emissions from power plants. In addition, Oregon passed pioneering legislation in 1997, requiring newly built power plants to offset roughly 17 percent of their carbon dioxide emissions. Facilities can propose offset projects that they or a third party manage or can provide funding to the independent Climate Trust, an organization which has been granted authority to obtain qualifying offsets for the facilities.[1] Massachusetts has similar requirements regarding new power plants constructed there.

In April of 2004, New Mexico Governor Bill Richardson and California Governor Arnold Schwarzenegger recommended to the Western Governors' Association that it set a goal of developing at least 30,000 megawatts of clean energy in the West by 2015 and increase energy efficiency by 20 percent by 2020. The Governors have proposed to create a clean energy working group to develop a set of policy proposals for official presentation to the Western Governors within the next two years.[2]

Climate Action Plans

Many states have developed energy and climate action plans, which lay out strategies to curb greenhouse gas emissions and list action items to achieve targets. New Jersey set one of the first reduction targets at a 3.5 percent reduction from 1990 levels by 2005. New York's Energy Plan includes an economy-wide GHG reduction of 10 percent below 1990 levels by 2010. Governor Rowland of Connecticut accepted in March a plan with 38 recommendations, such as requiring energy efficiency measures in new state buildings. Rhode Island recently completed, and is now im-

[1] *http://www.energy.state.or.us/siting/co2std.htm*
[2] *http://www.westgov.org/wga/initiatives/energy/summit/clean-energy.pdf*

plementing a state-of-the-art climate change plan, and Maine is soon to finalize one. The Northeast is not unique in this respect. According to the Environmental Protection Agency, as of September 2003, 27 states were working on climate action plans, and the large majority of those states have already released their plans publicly at this point in time.[3] Not surprisingly, a broad diversity of GHG mitigation strategies are employed in these plans, such as tax incentives for fuel switching, recycling programs, methane reclamation programs, energy efficiency audits, and more.

State Climate Registries

A number of individual states have developed their own greenhouse gas registries. Several have done so at least in part due to the perceived shortcomings of the Federal program for voluntary reporting of greenhouse gases under Section 1605(b) of the Energy Policy Act of 1992 and to encourage credible voluntary emission reductions from the private sector by providing them—to the extent possible—with "baseline protection."

New Hampshire was the first state to create a greenhouse gas registry in 1999. Building on this lead, Wisconsin's Voluntary Emissions Reduction Registry was adopted in 2000 and allows for the registration of mercury, fine particulate matter, and other contaminants in addition to greenhouse gases. The most advanced state registry, California's Climate Action Registry, is widely considered the most credible and respected registry in the world. Over the past year, the California Registry and its partners have dedicated substantial resources to developing industry "best practices" and quantification and reporting protocols—as well as an online reporting tool (the California Action Registry Reporting Online Tool, or CARROT)—for use by participants, the media, and the public.

Other State Climate Actions

The list doesn't stop there. In June of 2003, Maine's legislature ordered economywide GHG reductions, and joined New Jersey in requiring mandatory reporting of GHG emissions. Connecticut's legislature passed SB 595 this week which includes both these initiatives. Through the use of "system benefits charge" funds, approximately half a billion dollars annually are being dedicated to clean energy and energy efficiency initiatives in the Northeast. New York State alone invests $300 million annually.

In a recent enforcement settlement with a utility, New Jersey included carbon dioxide reduction requirements. New York has introduced a "green building" tax credit. Several states have adopted new energy efficiency standards for appliances. Connecticut expects its bill, passed this session, to save consumers $380 million in energy costs by 2020.

Governor Arnold Schwarzenegger last month initiated California's "Hydrogen Highway Network" to accelerate progress toward (and his state's lead in) the hydrogen economy. California is also studying how it can reduce its dependence on petroleum fuels by 15 percent from 2003 levels by 2020. New York Governor Pataki suggested on April 23, 2004 that we work on the scale of the Manhattan Project or man's lunar landing to wean the U.S. from imported oil.

Litigation

Lastly, states are also acting through their state attorneys general. States concerned about climate change will turn to the courts, when necessary, regarding the Federal government's interpretation of its ability to regulate climate-altering gases. In one lawsuit, filed in October 2003, twelve states (California, Connecticut, Illinois, Maine, Massachusetts, New Jersey, New Mexico, New York, Oregon, Rhode Island, Vermont, and Washington) and several cities challenged EPA's assertion that it does not have the authority to regulate greenhouse gases under the Clean Air Act.

Regional Climate Actions

While bottom-up, state-by-state climate action can lead to significant reductions in greenhouse gases and also to diverse policy initiatives, there are limitations to a decentralized approach to addressing climate change. The regulated community can be stymied by a patchwork of state policies, and insufficient state resources can retard action. As a result, states have begun to come together to act regionally on climate change. Uniform policies under a regional approach have often proven to be more cost effective and efficient in meeting reduction targets.[4]

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[3] *http://yosemite.epa.gov/oar/globalwarming.nsf/content/ActionsStateActionPlans.html#actionplans*

[4] Rabe, Barry G. "Greenhouse & Statehouse: The Evolving State Government Role in Climate Change." Washington, D.C.: Pew Center on Global Climate Change, 2002.

I would like to outline a few of the regional activities taking place in the United States today to curb greenhouse gas emissions. These efforts have brought about an unprecedented level of cooperation and are testament to the idea that bottom-up state action can lead to a more centralized form of climate change governance. Just as state action has paved the way for regional action, a flurry of regional activities might very well compel national action.

The NEG/ECP Climate Action Plan

Based on prior successes implementing regional agreements to address acid rain and mercury contamination, the New England Governors and Eastern Canadian Premiers (NEG/ECP) adopted a joint *Climate Change Action Plan* in August 2001. This Plan established a short-term goal to reduce GHG economy-wide emissions to 1990 levels by 2010, a mid-term goal to reduce to 10 percent below 1990 levels by 2020, and a long-term future target 75–85 percent below current levels. The Plan's nine action items include:

1. Establishing a standardized regional GHG emissions inventory;
2. Establishing a plan for reducing GHG emissions and conserving energy;
3. Promoting public awareness;
4. Leading by example by reducing public sector GHG emissions by 25 percent by 2012;
5. Reducing electricity sector GHG emissions by reducing carbon dioxide emissions per megawatt-hour by 20 percent by 2025;
6. Reducing total energy demand by 20 percent by 2025 through conservation and increased energy savings;
7. Mitigating and adapting to negative social, economic, and environmental impacts of climate change;
8. Reducing growth in transportation sector GHG emissions; and
9. Establishing a regional GHG emissions registry and exploring future GHG trading.

A climate change steering committee has been created to develop and evaluate mitigation programs. Initiatives developed so far include regional green procurement, clean vehicle programs, college and university partnerships, inventory and registry development, jurisdictional "lead by example" programs, and a major symposium on adaptation to our changing climate. These programs have been far reaching in helping governors and premiers meet climate targets. For example, the adaptation symposium, held in March 2004, was an unprecedented event, assembling policy-makers, scientists, and environmentalists for the first time to discuss and share strategies to address climate impacts on natural resources and civic infrastructure in the Northeast.

Regional Greenhouse Gas Registry (RGGR)

As noted above, the NEG/ECP Climate Action Plan's ninth action item called for the establishment of a regional greenhouse gas registry. Such a registry provides a system for organizing, reporting, and recording of information on GHG emissions in order to facilitate current and future climate programs.

A regional greenhouse gas registry for the Northeast is now under development at the Northeast States for Coordinated Air Use Management (NESCAUM). Beyond the NESCAUM states, regional registry participants also include Delaware and Pennsylvania, with several other states outside of the Northeast observing the process. This effort expects to quantify and report GHG emissions in a manner that is consistent with the *GHG Protocol* established by the World Resources Institute and the World Business Council for Sustainable Development, and it will be compatible with the World Economic Forum's climate register and the respected California Climate Action Registry. Expected to be completed in mid-2005, the registry development process is open to states outside of the region that are considering—but have not yet made—GHG reduction commitments. When finished, it will serve a sizeable region and encompass a number of functions, including potential baseline protection for proactive companies, improving the quality of GHG inventories, supporting mandatory reporting of GHG emissions, and serving as the emissions tracking system for a future regional GHG cap-and-trade program.

Regional Greenhouse Gas Initiative (RGGI)

In 2001, the latter function of the regional registry, supporting a future cap-and-trade program, was but a placeholder for eventual consideration. However, state interest in climate action has advanced so rapidly that in April 2003, New York Governor George Pataki publicly invited the Governors of ten Northeast and Mid-Atlan-

tic states to join together to develop a regional cap-and-trade program for the power sector. Dubbed the Regional Greenhouse Gas Initiative (RGGI), this multi-state effort elevates climate mitigation strategies from *voluntary* initiatives to a *regulatory* program. As such, it arguably represents the most significant effort to address climate change now underway in the United States.

To date, nine states (Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont) have signed on as full participants in RGGI. In addition, several other jurisdictions are participating as observers (Maryland, Pennsylvania, the District of Columbia, the Eastern Canadian Provinces, and New Brunswick). The Australian states of Victoria and New South Wales, also leaders in state-level climate action, are also staying abreast of RGGI and how a similar or complementary effort might be initiated "down under." While RGGI is initially focusing on CO_2 emissions from power plants, in later phases it may be expanded to other sources of emissions, as well as other greenhouse gases and offset opportunities.[5]

In July 2003, the participating states designated state representatives—from both state environmental agencies and energy offices—to the "RGGI Staff Working Group (SWG)." The SWG developed an action plan, which was endorsed by environmental commissioners and energy regulatory agency executives in September 2003. In its early meetings, the Staff Working Group determined RGGI's program goals, principles guiding its design, organization, and short-term tasks. The ambitious RGGI work plan has set April 2005 as its target date for completing model cap-and-trade regulations.

West Coast Governors Challenge

The Governors of the three West Coast states have similarly begun to develop regional climate mitigation strategies. Individually, these states have crafted progressive state climate policies. However, the Governors agreed that a uniform approach would be more efficient and could spur further progress. Thus, in September of 2003, the Governors of California, Oregon and Washington launched a collective strategy to address climate impacts, a series of joint policy measures to curb greenhouse gas emissions. The list of recommendations includes: group procurement of fuel-efficient vehicles; reducing the use of diesel fuel in ships; removing market barriers and creating incentives for renewables; upgrading efficiency standards; and improving emissions measurement and inventory practices. The Governors have extended the invitation to Canadian provinces, Mexican states, and other states throughout the Nation to join in this collaborative.

Conclusion

This testimony reflects only a humble sampling of the climate efforts underway at the state and regional scale. Climate change mitigation efforts in the Northeast and elsewhere extend well beyond state and regional activities. Counties, municipalities, and civic institutions have joined in, as the success of the Cities for Climate Protection program of the International Council of Local Environmental Initiatives (ICLEI) shows. Universities, hospitals and institutions are providing leadership in protecting the global climate. And businesses are acting without mandate, voluntarily curbing their GHG emissions. Many are saving money as a result. Insurers and the financial markets are starting to critically assess the climate risks and opportunities individual companies may face—and how they are responding. Shareholders are even making climate change a top priority, gaining unusually large votes on shareholder resolutions at corporate annual meetings.

This said, bottom-up, decentralized action—while heartening—cannot be a substitute for collective national action. The United States' greenhouse gas emissions are rising rapidly and only concerted action on the Federal level will place us on a path towards significantly curbing and eventually reversing this GHG emission trend. The diverse nature of state policies heightens uncertainty for the regulated community, and reduction targets can be reached in a more efficient and cost-effective manner if tackled on a national level.

However, there are many lessons to be learned from the states, which, in the absence of Federal action, have served as laboratories for climate policy development. We hope that Federal policymakers will regard the states' innovative climate mitigation and adaptation strategies as models and quickly take action. Climate change has already begun to take its toll on our states' economies and natural resources. We need to act while the window to avert dangerous interference with natural climate systems may be still open.

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[5] *http://www.rggi.org*

The CHAIRMAN. Thank you.
Dr. Curry, welcome.

STATEMENT OF WILLIAM B. CURRY, DIRECTOR, OCEAN AND CLIMATE CHANGE INSTITUTE, WOODS HOLE OCEANOGRAPHIC INSTITUTION

Dr. CURRY. Thank you, Mr. Chairman. Thank you, Members of the Committee.

My name is William Curry. I'm a scientist at the Woods Hole Oceanographic Institution. I'm the Director of the Ocean and Climate Change Institute at that institution. And my background as a scientist is that I study the history of ocean circulation on a variety of time scales, trying to understand how the ocean works with the atmosphere to produce the climate that we experience on Earth.

Today, I'd like to speak to you about some intriguing changes in the ocean that have been detected by researchers only in the last several years, but they involve changes in the ocean that have been happening for the last 40 years.

The CHAIRMAN. How long have you been doing this, Dr. Curry?

Dr. CURRY. Since 1980, Senator.

About 2 years ago, a paper was published that showed that, for the last 40 years, the subpolar and polar regions of the North Atlantic Ocean were getting fresher, meaning that fresh water was being added to the ocean's salty water at those high latitude locations. And then, just this past year, another paper was published showing that the tropical Atlantic has been getting saltier. The way the ocean gets saltier is that heat evaporates water from the surface of the ocean, taking fresh water away and leaving the salts behind, and concentrating them. So for the last 40 years, the tropical Atlantic has been getting saltier, while the subpolar region has been getting fresher.

The increase in salinity is actually global. It can be seen in the Pacific, the Indian Ocean, as well as in the Mediterranean Sea. Every tropical location in the oceans now has been getting saltier in recent decades. And then the subpolar Atlantic has been getting fresher.

Now, this is a consequence of a warmer atmosphere and a warmer ocean. It also has climatic consequences, or climatic possible consequences, because salinity controls one of the ways that the ocean circulates, and the ocean moves heat around the planet in ways that affects our climate.

So if I can just describe it quickly, salty water is denser than fresh water, and cold salty water is the densest water in the oceans, and it sinks, and it sinks to the deepest depths of the ocean. And in today's ocean, that water sinks in the North Atlantic, flows as a deep current, and, about a thousand years later, comes up in the Pacific and Indian Oceans. It's a long-term large scale circulation system.

The climatic consequence of that is that warm waters, part of which we would think of as the Gulf Stream off of our eastern coast, is delivering a large amount of heat to the North Atlantic region, particularly each winter, where the waters are actually warmer than the overlying atmosphere. And it's the process of giv-

ing up that heat that is the major climatic impact in the North Atlantic region, due to ocean circulation.

Now, the freshening that's been observed at high latitudes of the North Atlantic threaten this circulation system, because if you——

The CHAIRMAN. Could I stop you there?

Dr. CURRY. Yes, sir.

The CHAIRMAN. The Gulf Stream gives up the heat, and then that warms the atmosphere.

Dr. CURRY. Yup.

The CHAIRMAN. And then that does what?

Dr. CURRY. The water becomes colder and denser, and sinks, and flows out as a deep current.

The CHAIRMAN. I see. Thank you.

Dr. CURRY. You're welcome.

So by adding fresh water to the high latitude regions of the North Atlantic, you can be decreasing the density of those waters, making it such that they could not sink, and, furthermore, putting a layer of fresh water on the surface that insulates the warmer ocean waters from the colder atmosphere.

Now, this is a circulation system that has a long time-scale. Oceanographers have been studying the ocean seriously for, you know, 50 years or so, and it has never been seen to change drastically. But in the history of the Earth over centuries and millennia, it has been shown to have changed, and it's changed when fresh water was added to the North Atlantic region.

So my point to you today is that—you asked me to talk about the climate impacts on the ocean, and one of the major climate impacts on the ocean is changing the way fresh water is being distributed. The reasons for it are a warmer atmosphere and oceans, which is increasing evaporation at low latitudes, greater precipitation at high latitudes, and melting of ice at high latitudes because of warmer temperatures there. And those sorts of things have the potential of altering the Atlantic circulation in ways that could have climatic consequences down the line.

So this is a body of knowledge that's really only 20 years old, all together; and we're only just beginning to see the possibilities. And, at this point in time, the models—the ocean components of climate models are not up to the task of making a prediction about what will happen in the future on the basis of these salinity changes. They lack certain elements of ocean processes in the models, and, frankly, oceanographers themselves don't fully understand all the processes going on in the ocean, and how it mixes, today.

So there are ways that we can address this issue through research. It's still a research question. It's not a question of saying that this is not part of global warming. It is part of global warming. And this type of thing could cause regional changes in what people feel, in terms of their climate. It could be a little bit colder in winters at time because of this. It certainly would affect where places are experiencing drought or excess rainfall. It did in the geological records, and it's likely that, if changes in Atlantic circulation happen in the future, that that would be one of the consequences.

Thank you very much.

[The prepared statement of Dr. Curry follows:]

PREPARED STATEMENT OF WILLIAM B. CURRY, DIRECTOR, OCEAN AND CLIMATE CHANGE INSTITUTE, WOODS HOLE OCEANOGRAPHIC INSTITUTION

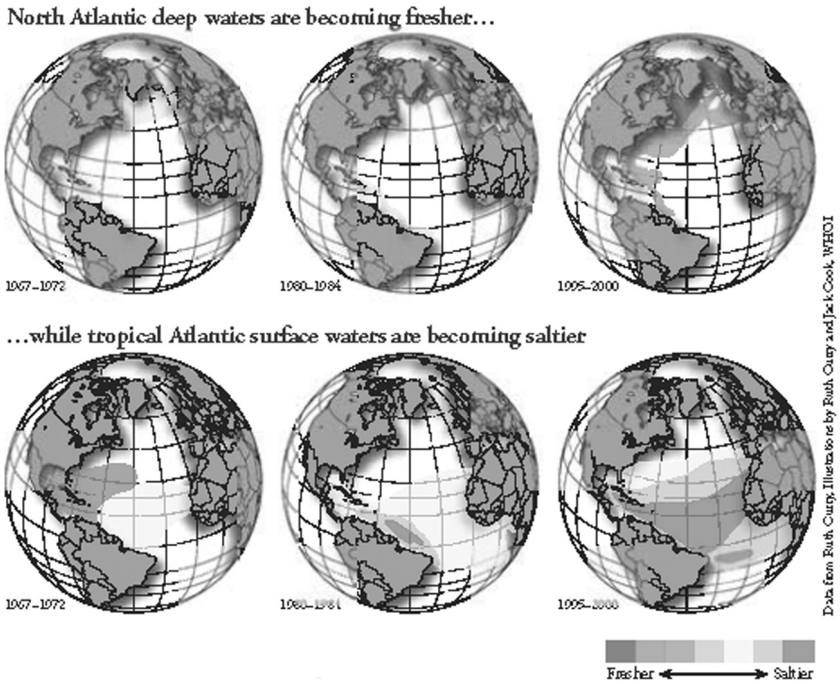
My name is William Curry. I am Director of the Ocean and Climate Change Institute of the Woods Hole Oceanographic Institution (WHOI) and a Senior Scientist in the Geology and Geophysics Department. I have served on the Ocean Studies Board of the National Research Council and on numerous advisory panels for the National Science Foundation and the National Oceanic and Atmospheric Administration.

I study the role of the ocean in climate change on a variety of time scales, trying to understanding how the ocean and atmosphere interact to produce the climate we experience on Earth. My background in geology provides me with a broad perspective on the full range of what Earth's climate system is capable of producing.

In my comments today, I will describe intriguing changes in the ocean that we have detected in only the last two years. I will discuss possible ocean and climate changes we may see in the future if the planet continues to warm. And I will explain what we can do to strengthen our position to predict climate changes, so that we can make the wisest decisions and the best preparations.

In brief, I'd like to make these points:

- The atmosphere and the ocean are inextricably linked in creating Earth's climate. Atmospheric changes tell only half the story.
- The geological record demonstrates that Earth's long-term history is punctuated by climate shifts that happened rapidly—on the scale of decades—and caused very large impacts that lasted for centuries to millennia. These are not blanket changes, but regionally diverse: Different regions will get warmer or colder, wetter or drier.
- These rapid climate shifts are linked to changes in ocean circulation—in particular, to changes in the North Atlantic that make waters there less salty.
- Evidence that has emerged in the last two years shows that over the past four decades, the subpolar North Atlantic has become dramatically less salty, while the tropical oceans around the globe have become saltier.
- We don't know if these changes indicate that we are approaching a threshold that could trigger abrupt ocean circulation and climate changes. Why? Because the models that simulate the workings of our climate system lack essential information. We don't understand ocean dynamics with nearly the same precision that we understand atmospheric dynamics. Which leads to my last point, and a call to action:
- We are scientifically and technologically poised to fill in that critical gap. If we are truly dedicated to understanding and predicting climate change in time to prepare for it, a relatively modest investment in ocean research has large potential payoffs.



During the last four decades, surface waters of the tropical Atlantic have increased in salinity while deep waters in the subpolar Atlantic have decreased in salinity. hTe changes in salinity result from increased evaporation at low latitudes and increased precipitation and ice melting at high latitudes.

Recent Changes in the Ocean

The ocean contains 97 percent of the water on the planet and plays a large role in the earth's hydrological cycle, which is the movement of water on Earth. In the warm tropical regions, water is evaporated from the oceans, leaving behind and concentrating the salts dissolved in the seawater. The water vapor is transported by the atmosphere toward higher latitudes, where it falls as rain and snow, adding freshwater back into the oceans and diluting salt concentrations at higher latitudes. As a result, the salinity of seawater is higher in the tropics and lower at higher latitudes. hT is is noticeable if you have ever experienced the saltiness of Caribbean waters compared to those in Ocean City, Maryland, or Cape Cod. Movement (circulation) of salty ocean water from high to low latitudes balances the movements of the water in the atmosphere, offsetting some of the salinity differences between high and low latitudes.

During the last four decades, oceanographers have observed large changes in the distribution of salinity, which appear to be related to the gradual warming of the atmosphere (see figure above). In the tropical regions of the Atlantic, Mediterranean, Indian, and Pacific Oceans, surface waters have increased in salinity, reflecting an increasing rate of evaporation in those locations caused by warmer ocean and air temperatures. At the same time, salinities have been decreasing in the subpolar and polar regions of both hemispheres: The high-latitude ocean is gaining freshwater because of higher precipitation, increased runoff from rivers, and increased melting of glacier ice and sea ice. These salinity changes are unprecedented in the relatively short history of the science of oceanography.

This pattern of salinity change—increasing salinity at low latitudes and decreasing salinity at high latitudes—may be a fingerprint of the warming atmosphere and ocean. The rising concentration of greenhouse gases in the atmosphere is trapping more energy from the sun and affecting the ocean, atmosphere and cryosphere (ice) systems in a variety of ways.

For instance, the atmosphere has been warming for the last century, with about one half of the warming the result of rising greenhouse gas concentrations. During

the last four decades, the oceans have warmed over a very large depth range. That indicates that the ocean has mitigated some of the warming expected from greenhouse gas increases because even a small temperature change in the ocean requires an enormous amount of heat energy to be absorbed by the ocean.

The warmer atmosphere and ocean have also accelerated the rate at which ice is melting. As a result, many mountain glaciers are melting, the Greenland ice sheet appears to be melting at an accelerated rate, and there has been a significant reduction in the amount of sea ice cover in the Arctic Ocean. Each of these factors is affecting the way water is distributed on the planet.

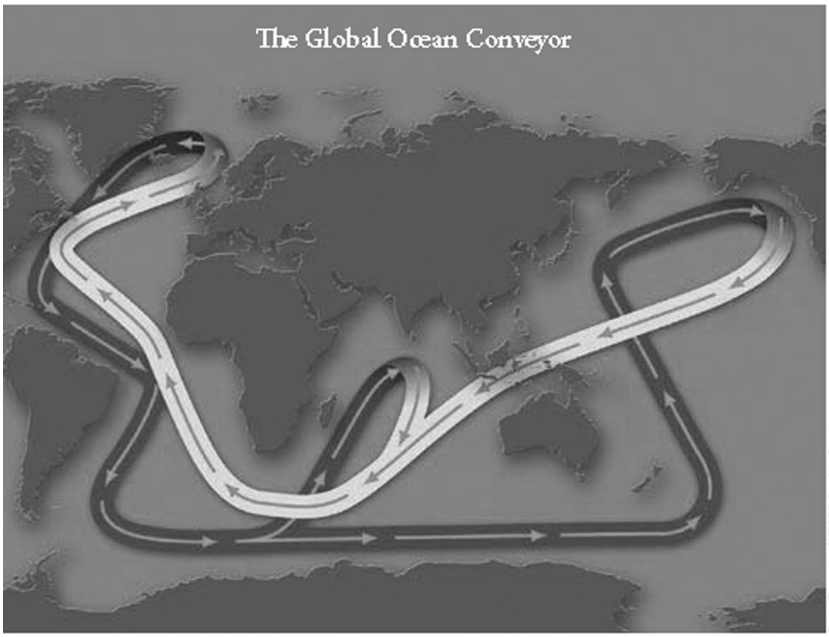
The warming of the atmosphere and ocean has a great impact on the patterns and intensity of evaporation and precipitation on the planet. A warmer atmosphere can accelerate the rate of evaporation from the ocean, and it can hold more water vapor (a wetter atmosphere). Thus, a wetter atmosphere delivers much more precipitation to high-latitude regions. These changes in evaporation and precipitation, as well as increased melting of ice, can cause changes in ocean salinity, which affects how the ocean circulates.

Possible Effects on Ocean Circulation and Climate

The circulation of the oceans exists in part because of density differences in seawater. Seawater density is controlled by its temperature and salinity: Warm water is less dense than cold water; low-salinity water is less dense than high-salinity water.

Today the Atlantic Ocean is saltier than the Pacific Ocean. Only in the Atlantic Ocean does surface water becomes dense enough to sink to the deepest parts of the oceans. As a result, the large-scale circulation of the oceans is dominated by the sinking of cold salty water in the North Atlantic Ocean, and the subsequent flow of these deep waters is from the Atlantic Ocean to the Pacific Ocean. This conveyor-like system is balanced by a return flow of warm and less dense water on the surface of the oceans from the Pacific to the Atlantic (see figure on page 17).

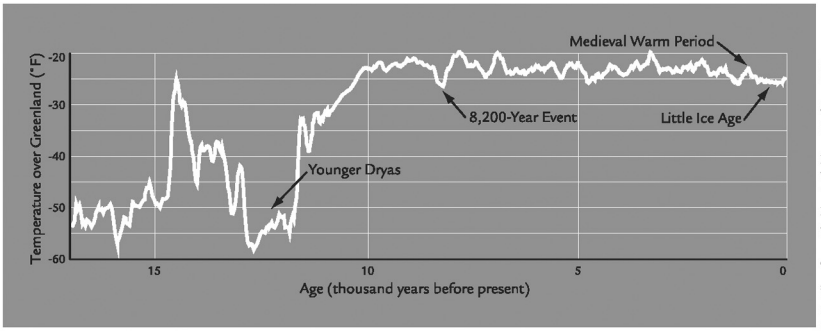
A climate consequence of this circulation is the delivery of large amounts of warm water to the high-latitude regions of the North Atlantic Ocean. Each winter in the subpolar North Atlantic, the ocean surface is warmer than the air above it. That warmth is transferred from the ocean to the atmosphere. As the salty water gives up its heat, its density increases and it sinks to the abyss.



The ocean circulation system known as the "Conveyor." The large-scale circulation of the oceans begins with sinking of water to the abyss of the Atlantic Ocean and the flow of this water at great depth from the Atlantic to the Pacific Ocean. This deep flow is compensated by a shallow return flow of warm salty water that brings heat to the high latitudes of the North Atlantic.

The amount of heat released by this process is large, warming the region by as much as 5°C, with greatest impact during winters when the temperature gradients between air and sea are greatest. This heat delivery system is dependent on the salinity of the seawater being high enough for the water to sink when it cools. The significant addition of freshwater, from enhanced precipitation or increased melting of ice back into freshwater, would make the water too light to sink. That would cut off the source of heat for the atmosphere and insulate the atmosphere from the warmer waters of the ocean beneath. The atmosphere would then cool.

For the last forty years, the waters in the subpolar North Atlantic region have been decreasing in salinity, but there is no evidence yet for a significant change in ocean circulation or heat delivery to this region. We have not yet reached a critical point at which salinity has decreased sufficiently to trigger circulation changes. The last time such changes occurred was hundreds of years ago—before the modern era of oceanographic measurements. But historical and geologic records show that changes in salinity have caused changes in ocean circulation and climate.



The history of air temperature over Greenland during the last 20,000 years. Several abrupt climate events occurred during this interval, including an abrupt cooling 13,000 years ago known as the Younger Dryas event and another cooling event 8,200 years ago. Each of these events was associated with an increase in freshwater delivery to the North Atlantic and with widespread cooling and drying throughout the northern hemisphere. A smaller event several hundred years ago, called the "Little Ice Age," was also associated with freshening of the North Atlantic Ocean.

Historical Changes in Circulation and Climate

As recently as two hundred years ago a fresher North Atlantic occurred during a period of cold climate conditions known by historians as The Little Ice Age. This was a five-hundred-year-long period of cold conditions affecting Europe and eastern North America. Contrary to what the name suggests, it did not involve ice-covered continents, as in a "real" ice age. But it did cause enough cooling to disrupt human activities. The changes may have been initiated by changes in the intensity of the sun's energy output, but they are linked to a freshening of the subpolar North Atlantic by increases in the delivery of icebergs (freshwater) to the region (see figure above).

The cooling associated with the Little Ice Age was small, yet it was large enough to force the Vikings to abandon settlements in Greenland, to advance mountain glaciers in Europe, and to cause severe winters on both sides of the Atlantic. An historic record of the end of the Little Ice Age comes from accounts of George Washington's brutally cold winter at Valley Forge, and his crossing of the ice-bound Delaware River to surprise the Hessians at Trenton. Today, the Delaware rarely freezes.

Much earlier in Earth history, larger climatic events occurred following the rapid freshening of the North Atlantic. The rapid release of freshwater from a large lake near Hudson Bay into the subpolar North Atlantic 8,200 years ago caused a century-long interval of colder and drier conditions over much of the northern hemisphere (see figure on page 7).

Earth's long-term climate history is punctuated with rapid changes in climate, which were associated with changes in ocean and atmospheric circulation that were usually linked to abrupt freshening of the North Atlantic. Often the climate impacts were very large, persisted for centuries or millennia, and were characterized by rapid shifts occurring over time spans as short as a few decades.

What does this mean for future climate?

Our understanding of abrupt climate changes like these is still in its infancy, but growing. Much of what I have described about Earth's climate history was discovered by researchers only in the last 20 years. The changes in ocean salinity were

detected only in the last two years. Thus, we are just beginning to experience and evaluate the potential effects of changing ocean salinity.

In 2002, the National Research Council published a report called *Abrupt Climate Change: Inevitable Surprises,* which summarizes the state of knowledge of these types of climate events. The report's authors pointed out that the likelihood of an abrupt climate event in the future was unknown, but was not zero.

Models of future climate disagree over the likelihood of an abrupt climate event. The models that do predict disruptions to the Atlantic circulation say they will occur far in the future. The NRC report also noted that many of the models used to study changes in ocean circulation have inadequate representations of ocean processes. The models may also be less sensitive to salinity perturbations than the actual ocean is. As a result, we are not yet in a position to predict these types of ocean circulation changes.

The climate history of the earth shows that adding freshwater to the North Atlantic disrupts the ocean circulation in ways that cause regional cooling and alter patterns of rainfall and drought. In the future, however, the effects of changing ocean circulation may not be the same—because it makes a difference if a disruption happens sooner rather than later.

Since human activity continues to raise the greenhouse gas concentration of the atmosphere, Earth will continue to experience rising air temperatures. A disruption to Atlantic circulation, if it were to occur in the next several decades, might be felt as colder winters in the Atlantic region. Should it be many decades before a circulation change occurs, the earth's average temperature will rise to the point that the disruption may mitigate the greenhouse warming experienced in the North Atlantic region.

Following the freshening of the North Atlantic 8,200 years ago, the North Atlantic region became colder and drier for about a century. Climate impacts extended beyond the North Atlantic region. The Asian monsoon system also appeared to be affected, causing drier conditions in Asian and Africa.

Winters would not be colder than today. But the ocean heat that would have been released into the atmosphere in the North Atlantic region remains in the climate system. If the North Atlantic does not receive the heat, some other location will, and that location would warm. The heat is not lost; it is moved to another location.

As greenhouse gases in the atmosphere continue to rise, the average Earth temperature will continue to rise. Yet most humans won't experience the *average* climate. There will be large regional differences in the climate: Some places will warm much more than others; some places will become wetter; and some places will become drier. The regional differences in climate change will be greatly affected by how the ocean is circulating and how it interacts with the atmosphere.

To better predict these changes, we will require better understanding of ocean circulation processes; more detailed reconstructions of the history of ocean circulation and climate; better simulations of ocean processes in climate models; and a more complete system to observe the state of ocean circulation.

Over the past half-century, satellites and a worldwide network of meteorological stations have been observing and monitoring atmospheric changes over time and space. These have given atmospheric scientists the data they need to make huge inroads into understanding the complexities of atmospheric dynamics.

Oceanographers require similar tools to comprehend ocean dynamics. It's more difficult to understand what you can't see, or monitor, or measure. After all, as ter-

restrial creatures, we live in the atmosphere, but for most of us, the ocean remains a foreign place. Yet the ocean has significant impact on our lives.

We now have the technological capability to put "eyes" in the oceans that can reveal how the oceans work. A substantial commitment to an ocean-observing system would make a huge difference. It would give us the measurements we need to fill in that big gap in our climate models and make them more representative of the real world.

The ability to accomplish this is within reach. The cost is relatively modest—especially compared to the huge potential economic and societal payoffs—including, for example, improved predictions of energy demands, water resources, crop planting and harvesting decisions, and natural hazards. Perhaps most importantly, they will provide the foundation for making the wisest possible decisions concerning the future habitability of our planet.

The CHAIRMAN. Thank you.

Dr. Epstein?

STATEMENT OF PAUL R. EPSTEIN M.D., M.P.H., ASSOCIATE DIRECTOR, CENTER FOR HEALTH AND THE GLOBAL ENVIRONMENT, HARVARD MEDICAL SCHOOL

Dr. EPSTEIN. Thank you, Senator McCain and Senators Snowe and Lautenberg.

In January of this year, the Pentagon released a report that repositioned climate change as a security issue. My job today is to explain how global warming has come to our backyards. And, given the audience, I hope to arm you in our common struggle to change awareness about the connections between the changes you've just heard and our own health.

I'm a physician trained in tropical public health. I'm at the Center for Health and Global Environment, at Harvard Medical School.

I want to begin with findings from Senator McCain's state, New Mexico, Biosphere II, in Tucson.

The CHAIRMAN. That's Arizona.

Dr. EPSTEIN. Arizona. Forgive me.

[Laughter.]

Dr. EPSTEIN. I'm getting ahead of myself.

Arizona—Tucson, Arizona—outside of Tucson is an experiment, an enclosed farm—animals, humans, plants, a small ocean. After several years, carbon dioxide rose. And when I visited that with a team of scientists several years ago, the weeds were flourishing, the ants were everywhere. Biosphere 2 is fast becoming our new reality.

Carbon dioxide levels are now 379 parts per million. It had gone up three parts per million last year. Before, it was a rate of 1.8. I say that to point out we're accelerating our rate of carbon dioxide, and maybe we're saturating some of the ocean and plant sinks. It's gone up, and it's higher than it's been for 420,000 years, probably two million years, when the Isthmus of Panama closed off, and the Gulf Stream that Dr. Curry described started going north, and then sunk in this "pump" that you've just heard described that drives the ocean circulation.

So for two million years, we've been oscillating between large caps and medium caps. We're on our way to small caps. We're in uncharted, heated waters. This is a state that we've not seen on this planet for several million years, at least.

Weedy species are the ones that thrive in disturbances, so what I saw at Biosphere 2 is what's happening in the cities and what's

happening in countryside. Ragweed, poison ivy, some of the flowering trees that flower early—the birches, the poplars, the lovely ones, maples on the corner—these are flowering early because of climate change, but they're also getting boosted just by carbon dioxide. And we've heard, for several years, that carbon dioxide might be good for agriculture, good for plants. We now have discovered an unexpected side effect for our public health.

We've seen this——

The CHAIRMAN. Which are?

Dr. EPSTEIN. Which are—first, asthma has increased two and a half to three times since 1984. This includes children, 6.8 million children—that's 11–12 percent of their population; overall, it's 7.5 percent. In Harlem, one out of four children suffer from asthma. This causes work absences, school absences, and costs the American taxpayers $18 billion.

Several new factors—pollen count—let me run down a number of related issues.

In the cities, pollen counts are rising. Counts of 150, 100 parts per cubic meter, are cause for alert. We're seeing counts of 6,000 parts per cubic meter. We've seen this in Atlanta, Boston. You're seeing it here in the Nation's capital. These are going off the charts. What is responsible for this?

We took ragweed, put it under double CO_2. In fact, it was started—these experiments were started by a woman who's a legislative aid now for Congressman Boehlert. Under double CO_2, the stalks rose 10 percent, pollen rose 61 percent. Ragweed, weeds, like this extra CO_2. They seize upon it, they shovel it into their reproductive power to spread their wings and spread to new areas. This is a particular area in inner city, urban abandoned lots, railways. So it's a problem in the inner cities. Heat also stimulates ragweed growth. Carbon dioxide and humidity also stimulate molds.

Carbon dioxide levels have reached very high levels in the inner city. This has been surprising for me to discover in the recent months, looking at this data. There's a CO_2 dome in the cities. It parallels a "heat island" effect. "Heat island" effect is about seven degrees Fahrenheit greater than surrounding areas. Carbon dioxide levels have been shown, by the Center for Carbon Dioxide and Climate Change, to be four-, five-, six-hundred parts per million. Now, you remember it was 379 globally, average. This was found in Baltimore, it was found in Phoenix. And I don't mean to be picking on you, Senator, but arming you. And in New York City, a count of 611. This is a trapping of inversions.

There's more. Diesel particles, a result of trucks and buses, glob onto this pollen and mold and help deliver it deep into lung sacs, and present it to the immune cells. They sensitize them, irritate them, so they're contributing to this allergy assault.

Finally, smog or—photochemical smog or ozone, which is a product of tail-pipe emissions, volatile organic compounds, noxes, is increased with heat. And the kind of heat wave we saw last week in L.A., April 27, 102 degrees, this speeds up the reaction of these chemicals to form smog, and those, we know from a study last year, published, cause asthma—not just trigger asthma, but cause it, in children especially.

So we have this concoction of pollen, molds, particles, unhealthy air mass and smog, and this is compounded by more intense heat waves. And CO_2 is not something that's going to be let up, we don't know if it could go through different changes, but CO_2 is going up. This change, through the plants, on our health is something that is going to continue.

Now, we comfort ourselves that we can deal with these public health related issues of climate in this country. But these issues I'm describing to you finesse this, supersede this.

We're also seeing some other issues I want to touch on quickly. Plants themselves are being attacked by pests and pathogens. New Mexico, that I had mentioned erroneously in the beginning—from New Mexico into Arizona to Alaska, we see beetles. Drought dries out the resin that drowns the bark beetles, so it weakens the trees. The beetles are getting emboldened—two generations a year up in Alaska, high altitudes, high latitudes, over-wintering—so the pests are emboldened, the host is weakened, and we're seeing a compounding of issues with the drought that is now emerging in its fifth year, and the fires, and the beetles.

Parenthetically, the Pacific Ocean is also in a very anomalous state. And I quote an article from *Science* that it was called "the perfect ocean for drought." It's in a state of cold in the East, warm in the West, that's driving much of the climate and the drought in the West, as well as in Europe, in addition to what is happening in the Atlantic. And, also, the Indian Ocean is in an anomalous state. It's hotter than it has been since the 1800s. All of the oceans are changed. It's the heat in the ocean, the oceans are warming, the ice is melting, and water vapor is rising. It's this change in atmospheric chemistry, changing the heat budget, affecting the water cycle. That's what affects our health through extreme weather events, heat waves, and floods.

Let me try to wind up here and mention there are other plant issues that are important in California, with a fungus that's spreading, perhaps through nursery plants. In the Northeast, we have woolly adelgid, which is threatening the hemlock trees. These, in addition to all the issues that you've heard about, of Malaria and Denghi fever, and so on, which, frankly, has been put to bed by the Intergovernmental Panel on Climate Change as being related to range affected by warming, and the timing and intensity of outbreaks affected by extreme weather events.

To conclude, we are looking at heat waves, we are looking at a number of problems. Are we ready for this summer in this country, with our nation's grid for a blackout like we had on August 14? Scenarios that we must envision involve a heat wave that hits Greece in the middle of the Olympics. We are looking at the earliest heat waves, the earliest fires that we've seen in decades. This is what is coming to us through our lungs, through the animals, through a pulse of carbon.

So just as we underestimated the rate at which climate change—and we are looking at ourselves, scientists, bewildered at the rate at which it's changing, the rate of biological responses to that change, and the rising costs of that, in terms of the re-insurance and insurance industry—and just as we underestimated these responses, we've underestimated, perhaps, the solutions. For the good

news is that we may have vastly underestimated the benefits of making this clean energy transition. And this is, I hope, the message that we can get together to the American people. A properly financed clean energy transition with green buildings, public transport, bike paths, pedestrian walkways, a "smart" grid and "smart" technologies, alternative technologies, solar and fuel cells, and so on. This can provide the engine for growth for this 21st century. We need a new engine. We need a clean one.

I conclude with that. My full report will be entered into the congressional record. Thank you. And welcome, any questions.

[The prepared statement of Dr. Epstein follows:]

PREPARED STATEMENT OF PAUL R. EPSTEIN M.D., M.P.H., ASSOCIATE DIRECTOR, CENTER FOR HEALTH AND THE GLOBAL ENVIRONMENT, HARVARD MEDICAL SCHOOL

Global warming has entered our backyards.

I begin with findings from the home state of the honorable Senator John McCain. In Biosphere II, Just outside Tucson, humans and animals lived on farms, with small forests and oceans. After several years carbon dioxide levels rose. The Weeds flourished and ants blanketed the plants, soils and rocks.

Biosphere II is fast becoming our new reality. CO_2 levels today are 379 parts per million—100 ppm above where they have been for over 420,000 years. Since then we have been cycling between medium and large ice caps, while today we are moving into a world with small polar caps—a third state. We are truly entering uncharted waters.

Weedy species—ragweed, poison ivy and insects—thrive on disturbance and, for plants, CO_2 provides new opportunities for the opportunists to flourish. Weeds and pioneering trees, whose seeds and pollen line our streets and enter our airways, increase with CO_2 as do molds.

What are the new concerns for public health?

First, Asthma and associated childhood mortality has increased 2½—3 times since 1984. 7.5 percent of the U.S. population has asthma; 11–12 percent of children; and ¼ of the children in Harlem suffer from this affliction.

This causes school and work absences and costs the health care system $18 billion per year.

There are several new factors.

Pollen counts are rising. Levels like 100 to 150 grains per cubic meter generate alerts. Recently levels of up to 6,000 grains per M^3 have been reported in many U.S. cities. We see it on sidewalks and ponds and feel it in our lungs.

Note that mosquito larvae eat pollen, adding food for the carriers of West Nile virus, a mosquito-borne disease in cities. We know how to control mosquitoes in rural areas. This is a new problem—how to safely use chemicals in urban centers.

One of our star students—now a legislative aide in Congressman Boehlert's office—placed ragweed under double the average CO_2 levels. The stalks grew 10 percent. The pollen increased 61 percent.

Heat also stimulates ragweed growth.

CO_2 and humidity also stimulate molds.

CO_2 levels in cities have reached surprisingly high levels. Under "CO_2 domes"—accompanying the "heat island effect"—inversions and unhealthy air masses levels in the 4, 5 and 6 hundreds have been found in Phoenix—I don't mean to be picking on you, Senator—Baltimore, and New York City!

There's more.

Diesel particles—that work their way deep into lung sacs—provide excellent delivery systems for pollen and molds. They attach to one another, helping them penetrate and inflame immune cells.

Finally, smog or ground-level ozone causes asthma. Heatwave—like the very early one that in L.A. last week—accelerates the reactions between tailpipe emissions that form ozone.

The concoction of pollen, molds, particles, unhealthy air masses, photochemical smog and more intense heatwaves is assaulting our lungs, especially for our young ones, and all these factors are related to the emissions from fossil fuels.

While we comfort ourselves that public health authorities can control emerging threats to our health, the ones I describe can only be prevented.

Meanwhile plants, themselves, are under attack from insects and fungi. From New Mexico to Alaska—and the states and Canadian Provinces in between—bark beetles, emboldened by warming, are overwintering and slipping in an extra generation each year, then climbing to new heights and high latitudes—to bore through the bark of vast stands of pines weakened by drought, now in its fifth consecutive year in the west. The trees die in a year—setting the stage for further wildfires, burns, respiratory disease, property and timber losses.

In California a fungus—akin to the one that caused the Irish potato famine—is afflicting trees and could spread across the country via the trade in nursery pants. In the Northeast, an aphid-like bug is killing hemlock pines that shelter animals in the winter, and it moved north in lockstep with each warm winter.

Returning to immediate threats—heatwaves have already begun. During the Boston marathon on April 19 140 people were felled from heat exhaustion and dehydration. The August 14, 2003 blackout during Last summer's heatwave could easily be repeated and the grid is still vulnerable. Temperatures in New Delhi have been over 107 for weeks and a heatwave in Greece during the Olympics—like that in Europe last summer—could be devastating.

Just as we underestimated the rate that the climate would change, we have underestimated the responses of biological systems—especially the opportunistic weeds, microorganisms and insects—to the warming and the wide swings in weather. The oceans are warming, ice is melting and water vapor is rising, as are the costs from extreme weather events. Large reinsurers are increasingly concerned by projections that damages will rise to $150 billion a year within this decade, if current trends continue. Add to that business interruptions, plus restrictions on trade, travel and tourism. The full figures are in my affidavit.

The good news is that we may have vastly underestimated the benefits from making the transition to clean energy. A properly financed clean energy transition—with incentives for greater efficiency, alternative sources, "green buildings," smart technologies to secure the grid, distributed generation, streamlined transport, more livable cities with pedestrian and biking pathways, hybrid cars, solar panels and fuel cells—can provide the sorely needed engine of growth for the 21st century.

AFFIDAVIT

Summary

Rising levels of carbon dioxide (CO_2)—in addition to trapping more infrared (heat) radiation leaving the earth—promote plant pollen production, soil bacteria and fungi, and alter species composition by favoring opportunistic weeds (like ragweed and poison ivy). Other emissions from burning fossil fuels in cars, trucks and buses—nitrogen compounds (NO_Xs) and volatile organic compounds—form photochemical smog that causes and exacerbates asthma, while diesel particulates help deliver pollen and molds deep into lung sacs. The combination of air pollutants, aeroallergens, heatwaves and unhealthy air masses—increasingly associated with a changing climate—causes damage to the respiratory systems, particularly for growing children, and these impacts disproportionately affect poor and minority groups in the inner cities.

The estimated cost in the U.S. of treating asthma in those younger than 18 years of age is $3.2 billion per year. The health impacts include asthma and other respiratory illnesses, infectious diseases, heat stress, heart disease. Meanwhile the preventative strategies include measures that could simultaneously improve air quality and enhance the livability of urban communities.

Combustion of fossil fuels—oil, coal and natural gas—is responsible for air pollution and climate change, and air quality is a particular problem for urban centers worldwide. Traffic patterns and automotive exhaust, power plants, airports and industrial emissions are the primary sources, while wind patterns can bring in pollution and unhealthy air masses originating in other regions. Allergens (molds and pollen) originating in rural urban areas can reach high levels in highly populated cities.

The impacts of air pollution can be compounded by extreme weather events, whose intensity and frequency is increasing as climate changes. These include more heatwaves, drought-driven fires, floods and the impacts of warming are exacerbated by "the heat island effect" generated in cement cities with inadequate green space.

Today, atmospheric concentrations of CO_2 are 379 parts per million. The earth has not experienced levels of CO_2 above 280 ppm for at least 420,000 years. This report examines the direct impacts of CO_2 combined with the climate change the rise generates, focusing on urban centers; examining synergies between air pollution and climate change and connections between climate change and emerging infectious diseases—in particular, West Nile virus, a disease carried by urban-dwelling mosquitoes that presents new problems for public health and mosquito control authorities.

Key Points

1. *Ragweed* (in vacant lots and other disturbed areas) pollen and tree pollens (*e.g.,* maples, birches, poplars) are stimulated by increased carbon dioxide (CO_2), and by warmer winters and early arrival of spring.
2. *Molds* are also stimulated by higher levels of CO_2. In addition, humidity, heavy rain and floods associated with climate change foster fungal growth in houses.
3. *Diesel* particles combine with aeroallergens (pollen and mold) to deliver them deep into lung sacs.
4. Fungal growth inside houses can affect respiratory *health and insurance coverage.*
5. Floods can drive *rodents* from their natural burrows into developed areas.
6. *Photochemical smog* (ground-level ozone) is a product of reactions between tailpipe emissions—oxides of nitrogen (NO_Xs) and volatile organic compounds (VOCs)—and the chemical reaction is accelerated during heatwaves—intensified with climate change.
7. *Heatwaves,* unhealthy air masses, high heat indices (a function of temperature and humidity), plus lack of nighttime relief all affect cardio-respiratory illness and mortality.
8. Increased *humidity* and *nighttime temperatures* (daily minimums) are associated with a changing climate.
9. The *Heat Island Effect* can raise ambient temperatures in urban centers as much as 7ºF over those in rural areas.
10. *Particulates,* carbon monoxide (*CO*), ground-level ozone and carcinogenic polycyclic aromatic hydrocarbons (*PAHs*) from drought-driven wildfires can affect populations living far from the fires.
11. *West Nile virus* in the U.S. is a new phenomenon—a mosquito-borne disease in urban areas; one not previously faced by public health and mosquito control agencies.
12. The avian-mosquito cycle of West Nile virus (WNV) is amplified by *warm winters, spring droughts and summer heatwaves.* Bird-biting, urban-dwelling mosquitoes (*Culex pipiens*) breed in shallow pools in city drains with organically-rich litter (*e.g.,* leaves and pollen). The disease threatens humans, birds and other wildlife.
13. *Severe and erratic weather*—early and late snowstorms, ice storms and dense fog—present hazards for automotive drivers and pedestrians.
14. *Severe storms* in coastal cities (intensified by sea level rise) can damage infrastructure, such as water and sanitation systems, with wide-ranging implications for public health.
15. *Early warning systems* of conditions conducive to large outbreaks of WNV can facilitate environmentally-friendly public health interventions.
16. *Roof gardens, urban parks, tree–lined streets,* "smart growth," and improved pedestrian, bicycle and public *transport* can reduce the "Heat Island Effect."
17. Developing *alternatives to fossil fuels* is fundamental for the protection of public health and for maintaining environmental and economic stability.

AFFIDAVIT

Global warming has entered our backyards.

I begin with findings from the home state of this committee's chair—the honorable Senator John McCain. Just outside Tucson, Arizona Biosphere II was erected to examine the way Earth functions. After several years of humans and animals living with plants and small oceans, carbon dioxide (CO_2) levels rose. Weeds flourished and, when I visited with a team of scientists, the ants were crawling everywhere.

Biosphere II is becoming our new reality. CO_2 levels are today 379 parts per million—having risen 3 ppm last year, up from the average 1.8 ppm throughout the 1990s—100 ppm above where they have been for over 420,000 years, and, probably,

for 2 million years when earth began cycling between medium and large size ice caps. Today we are speeding head-long into a third state—with small polar caps. We are in truly in uncharted, overheated waters.

Weedy species—ragweed, poison ivy and insects—thrive on disturbance and, for plants, CO_2 provides new opportunities for the opportunists to flourish. Weeds and pioneering trees, whose seeds and pollen line our streets and enter our airways, increase with CO_2 as do molds, mosquitoes, bark beetles and aphids that threaten our Nation's forests.

CO_2, released in our breath attracts mosquitoes and we use CO_2 in mosquito traps to catch and sample them. Whether rising CO_2 stimulates mosquito activity, in general, requires further study.

Then we come to what we know from elemental chemistry: CO_2 stimulates plant growth through photosynthesis, combining with water to generate carbohydrates and oxygen—plants being the primary producers of our food and air. But some plants respond to higher levels of CO_2 by producing excessive amounts of pollen, enabling them to spread. And those most stimulated are the weedy, opportunistic species. Ragweed, and some pioneering trees that colonize field edges, seize upon increased levels of CO_2 to grow in new, often disturbed, territory. Poison ivy also thrives in higher CO_2 levels. Abandoned lots in urban centers are ideal places for the spread of ragweed, as are old railway lines and fields following fires.

What are the new concerns for public health?

Let's look at urban centers first.

1. Asthma and associated childhood mortality has increased 2½—3 times since 1984. 7.5 percent of the U.S. population has asthma; 11–12 percent of children; and ¼ of the children in Harlem suffer from this sometimes frightening and life-threatening affliction.

Asthma affects patients and parents, causes school and work absences, and costs the health care system $18 billion per year.

2. Pollen counts are rising exponentially. Levels of 100 to 150 grains per cubic meter often generate alerts. In the past few springs levels of up to 6,000 grains per M^3 have been reported in many U.S. cities and we see it on ponds and roadways and feel it in our lungs.

Of note, mosquito larvae eat pollen. This is an added stimulus for the carriers of West Nile virus, a mosquito-borne disease in cities. Public health authorities know well how to control mosquitoes in rural areas; but this new problem poses new challenges as to how safely to use chemicals in the cities. Horses and birds are affected and the disease is now spreading in the Americas.

3. 3. CO_2 also stimulates molds.
4. Warm temperatures stimulate ragweed pollen (Wan *et al., 2000)* and humidity and floods foster fungal growth.
5. Another surprise is that CO_2 levels in cities have reached extraordinary levels.

Under CO_2 domes—paralleling the "heat island effect," inversions and unhealthy air masses—researchers (Idso *et al.,* 1998, 2001; Ziska *et al.,* 2000, 2003) have found levels in the four and five hundreds in Phoenix, Baltimore, and a reading of 611 ppm in New York City.

6. Diesel particles –themselves damaging to the lungs—provide an excellent delivery system for pollen and molds. They attach to the particles, helping them penetrate deep into lung sacs and sensitizing immune (defense) cells to the allergens.
7. Photochemical smog—ground-level ozone (O_3)—also causes asthma. This was demonstrated in Los Angeles, and the heatwaves—like the spring heatwave that occurred last week accelerates the reaction of the tailpipe emissions that combine to form ozone.
8. In another recent surprise, CO_2—that traps heat and is swelling the inner atmosphere (out to six or eight miles)—is contracting the outer atmosphere (stratosphere, mesosphere and thermosphere) out to hundreds of miles. This new finding—that our activities are affecting the atmosphere so far out, in addition to slowing repair of the 'ozone hole'—could cause the numerous satellites we have up to change their trajectories.

The concoction of pollen, molds, particles, unhealthy air masses, photochemical smog and more intense heatwaves is assaulting our lungs, especially for our young ones, and all these factors are related to the emissions from fossil fuels—indirectly,

through their impact on plants and directly via heatwaves and the trapping of heat by CO_2 and other greenhouse gases.

While we comfort ourselves that public health authorities can control emerging threats to our health, the ones I describe can only be prevented.

Forest health

Meanwhile plants, themselves, are under attack from insects and fungi. From New Mexico to Alaska—and the states and Canadian Provinces in between—bark beetles, emboldened by warming, are overwintering and slipping in an extra generation each year, then climbing to new heights and high latitudes—to bore through the bark of vast stands of pines weakened by drought, now in its fifth consecutive year in the west. (The resin that drowns the beetles dries out in drought.) The trees die in a year—setting the stage for further wildfires, burns, respiratory disease, property and timber losses.

United States' forests are unhealthy; but thinning them will not cure them. Pest infestations, climate extremes and poor management are together increasing vulnerability to fire, and a sustainable "Healthy Forest Initiative" will require an integrated set of policies aimed at nurturing forest defenses and stabilizing the climate.

In the past five years over 90 percent of Southern California's pines have been killed by bark beetles, and denuded stands from Arizona to Alaska contributed substantially to this summer's conflagrations. When weakened by drought and wilted by heat, trees become susceptible to pests. Drought dries the resin that drowns the invaders, while the galleries of eggs left by penetrating beetles pave the way for tree death within one year.

While droughts weaken the hosts (trees), warming emboldens the pests. Since 1994, mild winters have cut winter mortality of the larvae in Wyoming, for example, from 80 percent per annum to under 10 percent. In Alaska, spruce bark beetles are sneaking in an extra generation a year due to warming and have stripped four million acres in the Kenai Peninsula. In British Columbia, nearly 22 million acres of lodgepole pine have become infested—enough timber to build 3.3 million homes or supply the entire U.S. housing market for two years (*The Economist* 9 Aug).

The battle between insects and plants began several hundred million years ago, when forests spread across the land. Trees fought back the leaf-eaters and bark-borers with chemicals; then garnered support from birds, spiders and ladybugs. Woodpeckers and nuthatches keep beetle numbers in check. But with warmer winters, beetle populations outpace their pursuers and their populations can quadruple in a year.

"This is another example of global climate change that has deadly implications for my state," declared Senator Ted Stevens (U.S. Congressional Record, 24 July 2002). (The tundra is also melting, undermining pipelines, and thinning of North Polar ice in the past 20 years occurred at 8 times the rate it did in the previous 100.)

Warming is also expanding the range of beetles. Lodgepole pines are the preferred target, but ". . . in the past four or five years, the bugs [are] attacking whitebark pine stands [that] grow at about 8,000 feet elevation or higher" (M. Stark, *Billings Gazette,* 8 Aug 2003).

Other forest pests are challenging forest health. In California several tree species have been attacked by an opportunistic fungus (*Phytophthora*) akin to that of the Irish Potato Famine. On the East Coast, aphid-like bugs—the Wooly adelgid—threaten the dark green hemlock pines that line rivers in Connecticut and Massachusetts, and they are migrating towards Vermont with each warm winter.

Wildfires are hazardous for wildlife, property and people. They pose immediate threats to courageous firefighters and homeowners, while particles and chemicals from blazes and wind-carried hazes cause heart and lung disease.

Not all forest fires should be suppressed; periodic fires can be rejuvenating. But the drought-and beetle-driven wildfires today are not self-limiting, and the underlying conditions need to be addressed.

Unfortunately, little can be done to directly control the pests. Pesticides, which enter ground water, are minimally effective and must be applied widely long before beetles awaken in spring.

Forest "thinning" has two meanings: the preferred method entails cutting small trees (<6" in diameter). But this approach is not profitable and will not be employed without public financing. The extensive logging and clear-cutting form of "thinning" under the resident's initiative is a thinly disguised gift to the timber industry and these practices damage soils, increase sedimentation, reduce water-holding capacity and dry up rivers and streams—all increasing vulnerability to pests and fires.

Even the best forest practices, however, will be insufficient to stem the ravages of drought and the onslaught of beetles. The forests need moisture. Climate-induced

changes in Earth's water cycle pose threats to the health of forests, crops and humans.

Climate instability

In January 2004, the Pentagon released one scenario based on the growing signs of climate instability: an abrupt deep-freeze in northern North America and Europe. "Global warming, rather than causing gradual, centuries-spanning change, may be pushing the climate to a tipping point," states an article in Fortune Magazine based on the Pentagon document." The ocean-atmosphere system that controls the world's climate can suddenly change its path.

The report 2002 report by the National Academy of Sciences, entitled *Abrupt Climate Change: Inevitable Surprises,* reveals how an accelerating pace of climate change and erratic weather patterns—the very changes we are experiencing today—can be precursors to abrupt climate change.

Climate records show that warming trends can become quite variable and can lead to "cold reversals"—affecting North America and Europe in ways vastly different from the tropics. How might this work?

First, weather patterns have become more variable and extreme. Droughts are drier and more prolonged while—with increased water vapor—more precipitation falls in downpours. Last August—while Europe was suffering a sweltering heatwave—the World Meteorological Organization reported that increased heat in the climate system accounted for the severe and erratic weather patterns being observed worldwide.

Such erratic weather is not good for our health and it certainly confuses the birds. But it also tells us that our climate is not stable.

In the past 50 years the top two miles of the world's oceans have warmed—that's half way down—and ocean warming is melting sea ice. In just several decades the floating North Polar ice cap has shrunk from ten to five feet thick during the summers and Greenland is losing 9 percent each decade.

Fresh water from the melting ice and rain landing on the northern ocean just layers out, instead of sinking. Cold, *salty* water sinks—the deep water pump that pulls the warm Gulf Stream north and drives the ocean conveyor belt that stabilizes climate over millennia.

The impacts of freshening are already apparent. The accompanying North Atlantic "high" pressure system accelerates transatlantic winds and pushes the Jet Stream south. And these changes may be driving frigid fronts down the eastern U.S. seaboard and across to Europe.

Ice core records demonstrate that the North Atlantic Ocean can freshen to a point where the deep water pump fails and since the 1950s the deep overflow between Iceland and Scotland has slowed by 20 percent.

Since cold reversals have occurred naturally, what is the contribution of human activity today?

Cycles of the earth around the sun—the tilts and orbits—change over time. Recent calculations of these cycles indicate that our hospitable climate was not likely to have ended any time soon. But due to the buildup of carbon dioxide (CO_2)—to levels greater than in half a million years—the equations have changed, and we have entered uncharted waters.

The Pentagon planners argue strongly that the climate system is exhibiting greater turbulence and instability—as evidenced by the hastening build-up of atmospheric carbon dioxide and heat, and wide swings in weather, and the examination of surprise shifts by the scientific community has generated a new sense of urgency.

The Pentagon report reclassifies climate change as a national security, rather than an environmental, issue. The reason: the mounting extremes and a sudden, abrupt change could well trigger conflicts globally for shrinking resources.

Changes in the chemical composition of the atmosphere are changing the heat balance in the air, land, oceans and ice. The inner atmosphere is actually swelling from the heat and, as Earth's surfaces warm, evaporation dries out soils and forests. Paradoxically, rising evaporation from warming oceans and melting ice also generate more tropical–like outbursts when it does rain.

While engineers are turning their attention to technologies to clean the air and bury the carbon, we are faltering on prevention.

Heatwaves

Returning to immediate threats—heatwaves have already begun. The heatwave in Los Angeles in the third week of April was unusually early and ozone levels were high. During the Boston marathon on April 19 140 people were felled from heat exhaustion and dehydration. The August 14, 2003 blackout during Last summer's heatwave could easily be repeated and the grid is still vulnerable. Temperatures in

New Delhi have been over 107 for weeks and a heatwave in Greece during the Olympics—like that in Europe last summer that killed some 30,000 people in five countries, and led to crop failure and wildfires—could be devastating.

Just as we underestimated the rate that the climate would change, we have underestimated the responses of biological systems—especially the opportunistic weeds, microorganisms and insects—to the warming and the wide swings in weather. The oceans are warming, ice is melting and water vapor is rising, as are the costs from extreme weather events.

All these impacts come with costs. Homes in Texas are no longer insured for floods and mold. Insurance companies are pulling costs back from houses on Cape Cod. Costs have risen from $4 billion per year in the 1980s a year to $40 billion in the 1990s, were $55 billion in 2002, $60 billion in 2003 and the United Nations Environment Programme projects the losses to rise to $150 billion a year—and business interruptions, plus restrictions on trade, travel and tourism—within this decade if current trends continue. This has generated collaborative work through our Center with the Swiss Reinsurance company and the UNDP to project the health, ecological, and economic dimensions of possible climate futures.

The costs of weather extremes and spreading diseases involving humans, crops, trees, birds, chickens, cows, pigs, cats, rodents, bats and marine life are affecting international trade, causing business interruptions and restricting tourism. The diseases involving insects, rodents, migrating birds and marine organisms all reflect warming and climatic extremes. And as climate becomes more unstable, it is playing an ever-expending role in the emergence, resurgence and spread of infectious diseases.

The good news is that we may have vastly underestimated the benefits from making the transition to clean energy. A properly financed clean energy transition—with incentives for greater efficiency, alternative sources, "green buildings," smart technologies to secure the grid, distributed generation, streamlined transport, more livable cities with pedestrian and biking pathways, hybrid cars, solar panels and fuel cells—can provide the sorely needed engine of growth for the 21st century.

Solving the "triple-E" equation—energy, environment and the economy—is the job of all, and means determining the public role to enable market mechanisms that can drive the transition in a way that stabilizes the climate, while initiating a cleaner, healthier and more equitable form of economic growth.

Former U.K. Prime Minister Margaret Thatcher was one of the first world leaders to address global warming and William F. Buckley has warned of the dangers. As the climate becomes more unstable maintaining this global threat as a partisan issue based in vested interests, will not meet the needs of this generation and the increasingly troubled generations to come.

See *http://www.med.harvard.edu/chge/green.pdf* for full report and references for material in this affidavit.

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The CHAIRMAN. Thank you very much.

Dr. Fraser?

STATEMENT OF DR. WILLIAM R. FRASER, PRESIDENT, POLAR OCEANS RESEARCH GROUP

Dr. FRASER. Mr. Chairman, Members of the Committee, I thank you for the invitation to participate in today's Full Committee hearing on climate change impacts and states' actions.

I am Dr. William R. Fraser, President of Polar Oceans Research Group, a nonprofit organization based in Sheridan, Montana. I am

ecologist with a long-term interest in understanding the mechanisms that regulate the populations of Antarctica's top marine predators, particularly penguins and other sea birds.

This Committee has asked me to focus my testimony on my research activities in Antarctica, and specifically on the impacts of climate change. It is an honor to provide you with this testimony, which I would like to begin by providing three points of reference to place this work in context.

First, it is important to establish that the information I present here is based only on the findings from the Western Antarctic Peninsula region. Second, this information is not based on models, but, rather, on nearly 25 years of continuing field research that began in 1974, at Palmer Station, a regional U.S. research facility. And, third, the life histories of indicator species, such as penguins and other predators, offer a window through which to detect and monitor climate-change effects in Antarctica. These species provided some of the first evidence of the changes I will discuss today, our findings.

A 51-year instrument record of surface air temperatures indicates that significant warming has occurred since at least the mid-1950s, and especially in the two decades following 1980. This trend exhibits strong seasonality, and it is midwinter warming, in particular—June in the Southern Hemisphere—that shows the largest statistically significant increase. Midwinter temperatures have increased by more than one-tenth of a degree Centigrade per year, representing a six-degree Centigrade increase in June temperatures over the 51-year record. This winter warming is unequaled on the Earth, both in terms of its magnitude and rate of increase.

Coincident with this winter warming, three complementary patterns of sea-ice loss have been documented. The first, based on a relationship between temperature and sea-ice formation, indicates the number of cold years with extensive sea-ice development have trended downward from an average of four out of five during the mid-1950s to only one every four-and-a-half years to date.

The second pattern, based on the beginning of the satellite record, shows that in the two decades following 1973, sea-ice extent decreased by approximately 20 percent as a recession that encompassed both winter and summer sea ice.

The third pattern, based on the timing of annual sea-ice advance and retreat, indicates that sea ice is now forming later and retreating earlier, resulting in a sea-ice season that is shortened by 2 weeks. This pattern became more prevalent after 1990.

Warming has also affected glacial ice. Near Palmer Station, glaciers are retreating at a rate of approximately ten meters per year. Evidence of glacial thinning is also apparent as mountain ranges flanking the southeastern perimeter of Anvers Island, not visible 30 years ago, are now emerging into full view. The amount of new ice-free land along the entire southwest coast of Anvers Island is being redefined by glacial retreat, including exposure of four new islands that were unrecognized on local charts prior to 1995.

Ecological responses to this warming have been widespread, and indicate that the cold, dry, polar marine ecosystem of the Western Antarctic Peninsula region is being replaced by a warm, moist, maritime regime. This change is progressing along the peninsula

gradient from north to south as rising surface air temperatures affect sea ice and snow cover, which are among the most important drivers of ecological processes in polar, marine, and terrestrial ecosystems. Snow is increasing because the loss of sea ice improves the exchange of water vapor from the open ocean to the atmosphere, which then falls as precipitation.

All major components of the marine food web are responding to these changes. The trends in Antarctic krill populations and in the populations of penguin species with different affinities to sea ice present two best examples.

Adelie penguins are an ice-dependent species that breeds early in the spring. Since 1975, their populations have decreased by 60 percent. The factors responsible are a decrease in sea ice, which represent critical and essential winter habitat, and an increase in snowfall, which floods nests and drowns eggs and chicks when it melts, in spring.

Chinstrap and Gentoo penguins are two ice-avoiding species that that breed 3 weeks later than Adelies. Their populations have increased dramatically, 3500 and 4500 percent respectively, from founder populations that established in 1974 and 1993. The factors favoring population increase in these species are greater availability of open water and a late breeding schedule that circumvents spring snow-melt and flooding. Both species have core ranges that encompass the Northern Antarctic Peninsula; hence, their presence in our study area represents recent range expansion. This is confirmed by a 700-year-old paleoecological record indicating that the environmental conditions promoting the success of these two species today are unprecedented within the temporal limits of this record.

Antarctic krill are the foundation of the Western Antarctic Peninsula food web, a key component in the diets of most wildlife. Krill are also an ice-dependent species. Young krill cannot survive their first year of life without winter sea ice, which provides shelter and food. Sea ice is thus a key variable determining recruitment or the number of young krill that survive to become the next generation of reproductive adults.

Since 1975, krill abundance has been cycling in boom-and- bust fashion with a periodicity of four-and-a-half years, the same periodicity with which years of extensive sea ice are cycling in this marine system. Since sea ice is key to the survival of young krill, this population cycling means that krill recruitment is tracking these ice cycles. The "boom" part of this krill population cycle occurs when abundance peaks following these extensive ice years, and the surviving young krill move into the population; while the "bust" part results as these krill decrease in abundance over the next four or 5 years, in the absence of extensive ice and new recruitment.

This coupled cycling of sea ice and krill abundance presents a very troubling scenario. Krill live only five to 6 years, meaning their life span is already at the threshold of capacity to bridge the four- to five-year gap that is, on average, separating the favorable sea-ice conditions required for successful recruitment.

This marine ecosystem depends on the predictable availability of sea ice, yet the trend during the last five decades have been toward less predictability. If continued warming forces sea ice into a range

of periodicities that exceeds 4 and 5 years, krill's life span will no longer be capable of bridging the gap. This will severely compromise krill reproductive success, with possibly catastrophic consequences to the integrity of this marine system.

Concluding statements. Climate change in the Western Antarctic Peninsula region is unquestionably forcing a shift in the core ranges of wildlife populations. Many wildlife species on Earth, however, occupy habitats that are compromised by human activity. Relocation in the face of climate change for these species is not an option, suggesting that extinctions will inevitably accelerate in the decades ahead.

The Arctic and the Western Antarctic Peninsular region are exhibiting similar changes, but of different magnitudes and several environmental and ecological variables, including trends in summer and winter temperatures, sea ice, and the redistribution and abundance of wildlife populations. These coherences at opposite ends of the Earth argue strongly in favor of the climate change signature that is evolving over global scales.

And, finally, the findings presented in this testimony do not address the cause of climate change, but they do indicate, unequivocally, that Western Antarctic Peninsular warming is occurring, and the effects are having significant and measurable impacts on the marine ecosystem. Antarctica has no indigenous population; hence, the effects of local human activity are negligible, for all practical purposes. This is not the case for the rest of the Earth, suggesting one of the great challenges facing scientists and policymakers will be to understand how the collective activities of six-and-a-half billion people will influence ecological thresholds on which climate change is impinging.

Thank you.

[The prepared statement of Dr. Fraser follows:]

PREPARED STATEMENT OF DR. WILLIAM R. FRASER, PRESIDENT, POLAR OCEANS RESEARCH GROUP

Introduction and Terms of Reference

Mr. Chairman, Members of the Committee, I thank you for your invitation to participate in today's Full Committee hearing on Climate Change Impacts and States' Actions. I am Dr. William R. Fraser, President of Polar Oceans Research Group, a small non-profit organization based in Sheridan, Montana, whose principal activities center on conducting long-term ecological research in Antarctica and facilitating the education and training of future ecosystems scientists. I am an ecologist by profession, with a long-term interest in identifying and understanding the mechanisms that regulate the populations of Antarctica's top marine predators, including, in particular, penguins and other seabirds. Our research has demonstrated that some seabird species are extremely sensitive indicators of climate change effects in Antarctica, a finding now also supported by many other studies. Indeed, it is worth pointing out that trends in penguin populations provided some of the first evidence that sea ice conditions in some regions of Antarctica were deteriorating in response to climate warming. We published these results in 1992, five years before a publication in 1997 based on satellite remote sensing confirmed our suspicions regarding these regional trends in temperature and sea ice.

This Committee has asked me to focus my testimony on my research activities in Antarctica, and specifically on the impacts of climate change in this most southern of the Earth's continents. It is both a pleasure and honor to provide you with this testimony, which I would like to begin by discussing 3 points of reference to place this work in context, and provide this Committee with a gauge of its significance and limitations. First and foremost, it is important to establish that the information I present here is based only on findings from the western Antarctic Peninsula region (Figure 1). I make this distinction because the word "Antarctica" is on

occasion used somewhat generically when questions about the evidence backing climate change on this continent arise. Antarctica is vast, equal in surface area to the United States and Mexico combined, and while it is true that climate change signatures have been less pronounced at more southern latitudes, this is most definitely not the case in the western Antarctic Peninsula region. The IPCC's Third Assessment Report (2001) recognizes this distinction and is quite correct in its prediction that the Antarctic Peninsula will be one of the areas experiencing the largest and most rapid climate change on the Earth. I will say more about this later in this testimony.

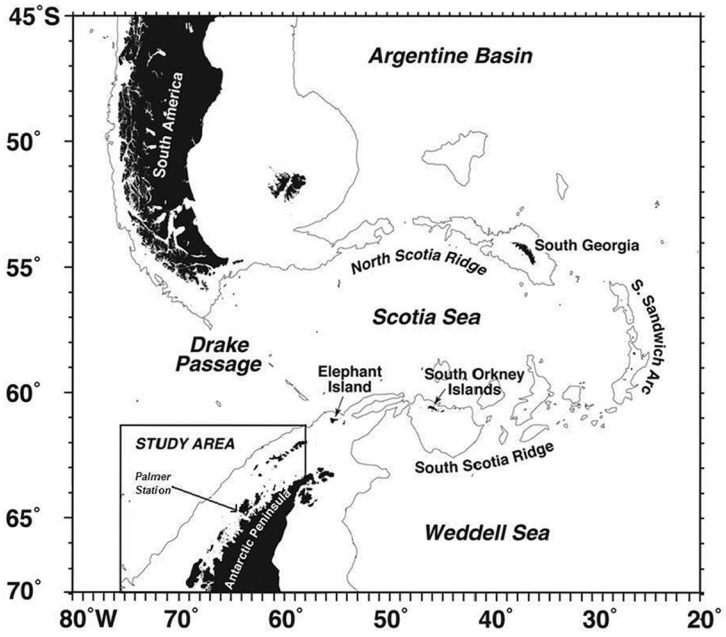

Figure 1. Palmer Station and the western Antarctic Peninsula PAL LTER study area.

The second point I wish to bring to the attention of this Committee is that the observations and conclusions I present here are not based on models. This comment is not in any way meant to diminish the value of models as tools to investigate climate change dynamics, but simply to point out that what I report is, in effect, an account of climate change impacts based on nearly 25 years of field research in the western Antarctic Peninsula region. I began this work in 1974 and have continued to the present. Today this research is coupled to the Palmer Long-Term Ecological Research program (PAL LTER), which since its inception in 1990 has been based at Palmer Station, a U.S. research facility operated by the National Science Foundation on Anvers Island (Figure 1). This program brings together an interdisciplinary group of core investigators and collaborators from both domestic and foreign institutions whose objectives focus on documenting and understanding the effects of regional climate change on the marine ecosystem. These objectives drive an intense terrestrial and oceanographic program that annually samples over approximately 80,000 km^2 (the PAL LTER study region), operates for up to six months each season and has included many years of winter studies. As a result, our record of climate-induced changes in this region now spans 3 decades and incorporates an ecosystem-scale perspective that is now beginning to reveal the often subtle relationships between cause and effect.

As the third and final point in these terms of reference, I would like to expand briefly on the concept of indicator species, which I introduced earlier in this testimony when I alluded to the important role played by penguins and other seabirds in advancing our understanding of the interactions between climate change and marine ecosystem response in the western Antarctic Peninsula region. All ecosystems are populated by species that are particularly sensitive to some component of the

environment that is key to the successful completion of their life cycles. Salmon in the Pacific Northwest, for example, do not reproduce successfully in waters where temperatures and/or silt loading rise above some critical threshold. For this reason, and because negative changes in salmon populations can signal deteriorating habitat conditions in a stream or river, salmon are regarded a key indicator species of water quality in the region. An analog to this example is observed in the western Antarctic Peninsula among three species of penguins whose life histories exhibit very different affinities to sea ice. For Adélie penguins (*Pygoscelis adeliae*), the presence of sea ice is essential to their survival. By contrast, it is the absence of sea ice that is essential to the survival of the otherwise ecologically similar Gentoo (*P. papua*) and Chinstrap (*P. Antarctica*) penguins. Although these relationships were not fully described until 1992, they now define a role for these species as indicators of environmental change in Antarctica that has been incorporated into the long-term monitoring and research programs of more than 15 countries working throughout coastal Antarctica.

Climate Change Effects in the Western Antarctic Peninsula Region

Temperatures, Sea Ice and Glacial Ice

On March 3, 2004, this Committee heard the distinguished testimony of Dr. Robert Corell, Chairman of the Arctic Climate Impact Assessment, who reviewed climate change effects in the Arctic. Many of the changes reported for the Arctic closely track trends in the western Antarctic Peninsula region, especially with respect to the seasonal timing and magnitude of warming and its effects on sea ice conditions. Several current and significant studies addressing these trends on a regional scale were published in 2003. One of these studies, based on a 51-year (1951–2001) instrument record of surface air temperatures in our focal PAL LTER study region, indicates that significant warming has occurred since at least the mid-1950s, especially in the two decades following 1980. This trend, moreover, exhibits a strong seasonality, and it is mid-winter warming in particular, June in the Southern Hemisphere, that shows the largest, statistically significant increase. Mid-winter temperatures have increased by 0.11 C° per year, representing a 6 C° increase in June temperatures over the 51-year record. This winter warming is unequaled on the Earth, both in terms of its magnitude and rate of increase.

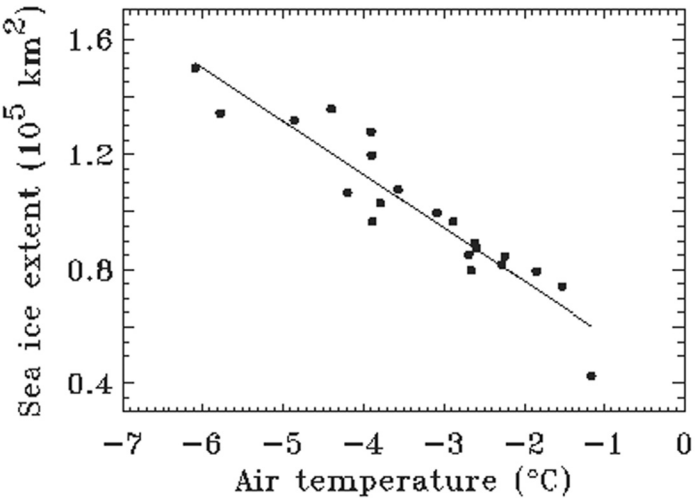

Figure 2. Relationship between temperature and sea ice extent

Because sea ice forms primarily during winter, and there is a significant anti-correlation between surface air temperatures and sea ice extent (Figure 2), several complementary patterns of sea ice loss have been documented in the western Antarctic Peninsula region. The first, based strictly on the relationship between temperature and sea ice formation, indicates that the number of cold years producing heavy sea ice conditions, or ice covering the ocean's surface to at least 61° south latitude, has decreased from an average of 4 out of 5 during the mid-1950s to 1–2 out of 5 today. Indeed, since the mid-1970s, these heavy sea ice years have oc-

curred, on average, only once every 4.5 years. The second pattern is based on remote sensing since the beginning of the satellite imaging record, and shows that in the two decades following 1973, sea ice extent decreased by 20 percent as a recession that encompassed both winter and summer sea ice. The third and final pattern concerns changes in the length of the sea ice season, or the number of days between the time ice begins to advance in autumn and retreat in spring. This record indicates that sea ice is now forming later and retreating earlier, resulting in a sea ice season that has shortened by 2 weeks. This pattern became more prevalent after 1990 if the decades prior to 1990 are compared.

When compared to the sea ice time series, the record of change in glacial ice over the same time period is unfortunately less robust. This is not to say that such a record does not exist, as certainly the data needed to develop it must be available in the form of archived images based on remote sensing. Rather, and with the exception of some studies that lie outside the regional scope of our work, it appears that little effort has been directed at compiling, comparing and publishing the data that may be available. Nevertheless, 2 trends evident in the immediate vicinity of Palmer Station bear further comment because they track patterns observed elsewhere on the Antarctic Peninsula. For example, mapping of the boundary region separating the station from the nearby Anvers Island glacier (Figure 1) using GPS (Global Positioning System), has revealed that the glacier's face is retreating at a rate of approximately 10 meters per year. Evidence of glacial thinning is also apparent as mountain ranges flanking the southeastern boundary of this glacier, not visible 30 years ago from Palmer Station, are now emerging into full view. These local-scale patterns are also confirmed by larger-scale events. The amount of new ice-free land along the entire southwest coast of Anvers Island, for example, has been redefined by glacial retreat, including exposure of 4 new islands that were unrecognized on local maps and charts prior to 1995.

Ecological Responses

The western Antarctic Peninsula region is experiencing a gradual replacement of a cold, dry polar marine ecosystem with a warm, moist maritime regime. This change is progressing along a Peninsular gradient from north to south as rising surface air temperatures affect sea ice and snow cover, which are among the most important drivers of ecological processes in polar marine and terrestrial ecosystems. Although, we have evidence that all the major components of the food web are responding to these changes, two particularly clear examples are the contrasting, long-term population responses of penguin species with different affinities to sea ice (Figure 3) and the patterns of variability now evident in Antarctic krill (*Euphausia superba*) populations.

Since 1975, focal study colonies of the ice-dependent Adélie penguin have decreased by 60 percent, representing a loss of approximately 10,000 breeding pairs. The factors responsible are a decrease in sea ice, which represents critical and essential winter habitat, and an increase in snowfall, which melts in the spring and drowns eggs and chicks. Evidence from glacial cores suggests that snow deposition has been increasing in the region for perhaps 100 years as the loss of sea ice improves exchanges of water vapor from the open ocean to the atmosphere. This is supported by our observations, as the rate at which Adélie penguin populations have decreased is significantly greater (70 percent vs. 40 percent) in colonies located on south-facing terrain where snow deposition is enhanced due to prevailing northerly winds. The contrasting population trends shown by the ice-avoiding Chinstrap and Gentoo penguins substantiate these dynamics (Figure 3). Although the core range of both these species encompasses the northern Antarctic Peninsula and sub-Antarctic islands, their range during the last 3 decades has been expanding to the south, with founder populations establishing locally in 1974 and 1993, respectively. Two factors have favored their very substantial population increases (Figure 3), greater availability of open water, and a late breeding schedule that circumvents spring snow melt and flooding. Of special relevance, however, is that a 700-year old paleoecological record shows no evidence that these species occurred in this region in the past. This suggests that the environmental conditions that are promoting their success today are unprecedented within the temporal limits of this record.

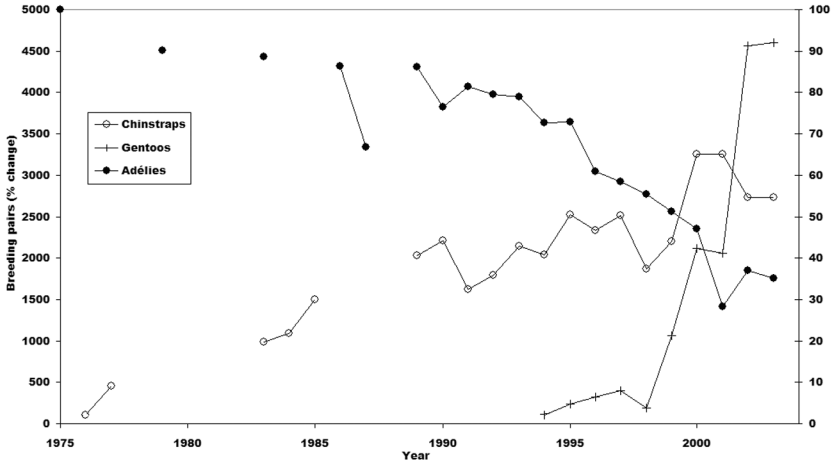

Figure 3. Changes in penguin populations in the Palmer Station vicinity, 1975–2003.

The Antarctic krill, a shrimp-like crustacean that is fished commercially, is the foundation of the western Antarctic Peninsula food web, and is a key component of the diets of many species from squid and fish to seabirds, seals and whales. Krill is also a species whose life-history is critically tied to sea ice. Adult krill feed in spring and summer on the vast phytoplankton blooms that are produced along ice edges as the melt season progresses. Female krill in particular need these blooms to stimulate and enhance reproductive condition and spawn. However, although adult krill can survive sub-optimal feeding conditions from year to year, this is not the case for larval krill, which are produced after eggs hatch prior to winter. These young krill cannot survive their first year of life without winter sea ice, which both shelters them from predators and provides them with food in the form of algae and diatoms. Sea ice is thus an indispensable nursery for krill because without it there is little or no recruitment; that is, no contribution by one population to the next generation of reproductive adults.

Our data show that since 1975, krill abundance has been cycling in a boom and bust fashion with a periodicity of 4–5 years, which as noted previously in this testimony, is also the frequency with which years of heavy sea ice are cycling in this marine system. This is not surprising. Given the critical role played by sea ice in larval krill survival, it indicates that krill recruitment is tracking these ice cycles. The boom part of the cycle occurs when krill abundance peaks following these heavy ice years as the surviving age-class recruits into the population, while the bust part of the cycle develops as this age-class decreases in abundance over the next 4–5 years in the absence of optimal ice conditions and new recruitment. This cycling in krill population abundance currently presents a troubling scenario insofar as possible future consequences of climate warming to the marine ecosystem in this region. The reason is that krill live to be only 5–6 years of age, meaning their life span is already at the very limits of their capability to bridge the 4–5 year periodicity in the occurrence of the favorable sea ice conditions they need for successful reproduction and recruitment. This marine ecosystem depends on the predictable availability of sea ice, yet the trend during the last 5 decades has been towards less predictability. If current thresholds are breached any further by future climate warming, that is, if sea ice periodicities begin to exceed krill life span by manifesting at intervals that are longer than 4–5 years, krill life span will no longer bridge the gap and severely compromise reproductive success. This will have catastrophic consequences to the integrity of this marine ecosystem.

Concluding Statements

1. Climate change in the western Antarctic Peninsula region is forcing a shift in the core ranges of wildlife populations, but suitable habitats available to absorb these changes remain. Many wildlife species on the Earth, however, occupy habitats that are already compromised by human activities. Relocation in the face of climate change for these species is not an option, suggesting that extinctions will inevitably accelerate in the decades ahead.

2. The Arctic and the western Antarctic Peninsula region are exhibiting similar changes but of different magnitudes in several environmental and ecological variables, including trends in summer and winter temperatures, sea ice and the redistribution and abundance of wildlife populations. These coherences at opposite ends of the Earth argue strongly in favor of a climate change signature that is evolving over global scales.

3. The findings presented in this testimony do not address the cause of climate change, but they do indicate unequivocally that western Antarctic Peninsula warming is occurring and the effects are having significant and measurable impacts on the marine ecosystem. Antarctica has no indigenous population and the footprint of human activity is for all practical purposes negligible. This is not the case for the rest of the Earth, suggesting one of the great challenges facing scientists and policy makers will be to understand how the collective activities of 6.5 billion people will influence the ecological thresholds on which climate change is impinging.

The findings presented in this testimony were taken in part from the following sources:

Emslie SD, Fraser WR, Smith RC, Walker W (1998) Abandoned penguin colonies and environmental change in the Palmer Station area, Anvers Island, Antarctic Peninsula. Antarctic Science 10: 257–268.

Fraser WR, Hofmann EE (2003) A predator's perspective on causal links between climate change, physical forcing and ecosystem response. Marine Ecology Progress Series 265: 1–15.

Fraser WR, Trivelpiece WZ, Ainley DG, Trivelpiece SG (1992) Increases in Antarctic penguin populations: reduced competition with whales or a loss of sea ice due to global warming? Polar Biology 11:525–531.

Jacobs SJ, Comiso JC (1997) Climate variability in the Amundsen and Bellingshausen seas. J Climate 10:697–709.

Smith RC, Fraser WR, Stammerjohn SE, Vernet M (2003) Palmer Long-term ecological research on the Antarctic marine ecosystem. In: Domack E, Leventer A, Burnett A, Bindschadler R, Convey P, Kirby M (eds) Antarctic Peninsula Climate Variability: Historical and Paleoenvironmental Perspectives. AGU Vol. 79, pp. 131–144.

The CHAIRMAN. Dr. Fraser, are there any individuals or organizations who disagree with your findings?

Dr. FRASER. There's always those organizations, Senator.

The CHAIRMAN. Yes.

Dr. Mote?

STATEMENT OF PHILIP W. MOTE, PH.D., JOINT INSTITUTE FOR THE STUDY OF THE ATMOSPHERE AND OCEAN, CLIMATE IMPACTS GROUP, UNIVERSITY OF WASHINGTON

Dr. MOTE. Thank you, Senator McCain, for continuing to draw attention to this issue.

For my testimony, I am drawing on the work of several people, not just myself; most of it conducted quite recently, and much of it conducted at various regional centers in NOAA's Regional Integrated Sciences and Assessments Program, RISA Program, which your acquaintance, Brad Udall, is a participant in.

RISA efforts seek to translate climate information—and, specifically, seasonal forecasts—into better natural-resource management. And along the way, we have had to understand climate variability and change on a wide range of time scales. It was pretty clear that snow is a key resource in the Western U.S., and so we've begun to focus on variability and trends in mountain snowpack.

Warming trends in the Western U.S. have already produced significant changes in snow-driven hydrology. In the past 50 years, dates of peak snow accumulation and of peak snowmelt-derived stream flow have shifted earlier, typically by ten to forty days, and spring snowpack has decreased in most of the West. Although a di-

rect causal connection between the observed changes and rising concentrations of greenhouse gases cannot firmly be established, it is likely that the declines do reflect human influence.

In many important respects, these observed changes are consistent with projections of future change in a warming world, and point toward further reductions in summer water supply and increased demand.

If you have, in front of you, my written testimony, I'd like to draw your attention to a couple of figures. Firstly, Figure 1, which shows maps of trends in April 1st snowpack, both taken from snow-course observations, on the left, and from our hydrologic model, shown on the right. Both model and observations agree that spring snowpack has declined in about 75 percent of the West during the last 50 years, except where large——

The CHAIRMAN. During the last how long?

Dr. MOTE. Fifty years, roughly. And the same is true if we look back over 80 years, but there are very few observations that go back more than 50 years, so we kind of have to rely on the model, before 1940.

The magnitude of trends are similar in observations and in our hydrologic model. Losses, averaged over the entire West, are about 10 to 20 percent in the last 50 years, but they are larger where winter temperatures are relatively mild; namely, the mountains of Washington, Oregon, and Northern California. In most mountain ranges—and you can see this particularly in the panel on the right—trends are small at ridge-top, indicated by the white shading, and grow to be substantial at the snow line, indicated by the deep-red shading—in some cases, exceeding 100 percent loss in the last 50 years. These variations in trends, both regionally and locally, point to a dominant role for temperature trends, not for other factors. And temperature trends play a bigger role the closer the site is to freezing temperatures.

If I could turn your attention to Figure 3, spring snowmelt timing has advanced by 10 to 40 days in most of the West, which has led to increasing flow in March in most of the West, as indicated by the blue circles, and decreasing flow in June, the bottom panel, red circles, especially in the Pacific Northwest, which, again, is a region of fairly mild temperatures, so a little bit of warming goes a long way.

And, finally, if I could turn your attention to Figure 6, which looks at the future, we've used a mild scenario of climate change from the NCAR parallel climate model. This is a model that is among the least sensitive to greenhouse gas increases, so it probably represents a lower bound of what would happen, barring efforts like yours to curb greenhouse gas increases.

Using this model, our hydrologic model projects that losses in West-wide April 1 snowpack will reach approximately 40 percent by the 2050s and 50 percent by the 2090s. Note that most other climate models would give larger decreases because they produce more warming. And, again, for perspective, note that in the last 50 years the model simulated about an 11 percent decline, and observations indicate about a 20 percent decline.

Clearly, agencies that manage water resources must begin to come to grips with the reductions in summer flow and earlier

snowmelt, which are key aspects of how global warming is already affecting the West.

Thank you.

[The prepared statement of Dr. Mote follows:]

PREPARED STATEMENT OF PHILIP W. MOTE, PH.D.*, JOINT INSTITUTE FOR THE STUDY OF THE ATMOSPHERE AND OCEAN, CLIMATE IMPACTS GROUP, UNIVERSITY OF WASHINGTON

Summary

Warming trends in the western U.S. have already produced significant changes in snow-driven hydrology. In the past 50 years, dates of peak snow accumulation and of peak snowmelt-derived streamflow have shifted earlier, typically by 10–40 days, and spring snowpack has decreased in most of the West (total decrease of 11 percent since 1950). Although a direct causal connection between the observed changes and rising concentrations of greenhouse gases cannot yet be established, it is likely that the declines reflect human influence. In many important respects, these observed changes are consistent with projections of future change in a warming world, where losses in the West's total April 1 snowpack are likely to exceed 40 percent by the 2050s. These observed changes point toward further reductions in summer water supply and increased demand.

Snow Resources

> "Snowpack is the lifeblood of the West and provides about 75 percent of the water supply in the West."—*Natural Resources Conservation Service, U.S. Department of Agriculture*

In much of western North America, snow provides the primary means for storage of winter precipitation, effectively transferring water from the relatively wet winter season to the typically dry summers. Built storage (dams and reservoirs) and snow storage play varying roles in different parts of the West: built storage is largest—several times the annual flow—in the middle and lower Colorado River basin, and helps buffer California against large year-to-year variations in precipitation. Conversely, reliance on snow storage is substantial in the Northwest, where reservoirs on the Columbia River can store only about 30 percent of the annual flow and reservoirs in the Cascade Mountains store only about 10 percent of the annual flow.

Since the 1970s (*e.g.,* ref. 5) scientists have pointed out that mountain snowpack would be reduced in a warming world. Recent research, summarized in this document, indicates that warming in much of the West during winter and spring has already produced declines in mountain snowpack (–11 percent averaged over the West), earlier snowmelt runoff, and lower summer streamflow. These changes have taken place in most of the mountainous West, except in places where large increases in precipitation have offset the warming-induced decline. The observed declines in snowpack and summer streamflow, and shifts toward earlier streamflow timing, have been largest in the mountains of Washington, Oregon, and northern California.[6-9]

Trends in Snow and Snowmelt During the 20th Century and the Role of Temperature

In order to provide water supply forecasts for summer water users, the USDA Natural Resources Conservation Service (NRCS), California Department of Water Resources, and partner agencies collect measurements of snowpack each spring, most commonly around April 1. Analysis of these snowpack data indicate that much of the mountain West has experienced declines in spring snowpack (Figure 1), especially since mid-century, despite increases in winter precipitation in many places.[3,6-8] Analysis and modeling also shows that climatic trends are the dominant factor in the declines, not changes in land use, forest canopy, or other factors.[7]

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* This document was prepared by Philip Mote with contributions from Alan Hamlet (UW), Iris Stewart (Scripps Institution of Oceanography (SIO), UC San Diego), Andrew Wood (UW), Tom Pagano (Water and Climate Center, USDA Natural Resources Conservation Service), Dan Cayan (SIO/UCSD), Lara Whitely Binder (UW), Dennis Lettenmaier (UW), and Martyn Clark (Univ. of Colorado).

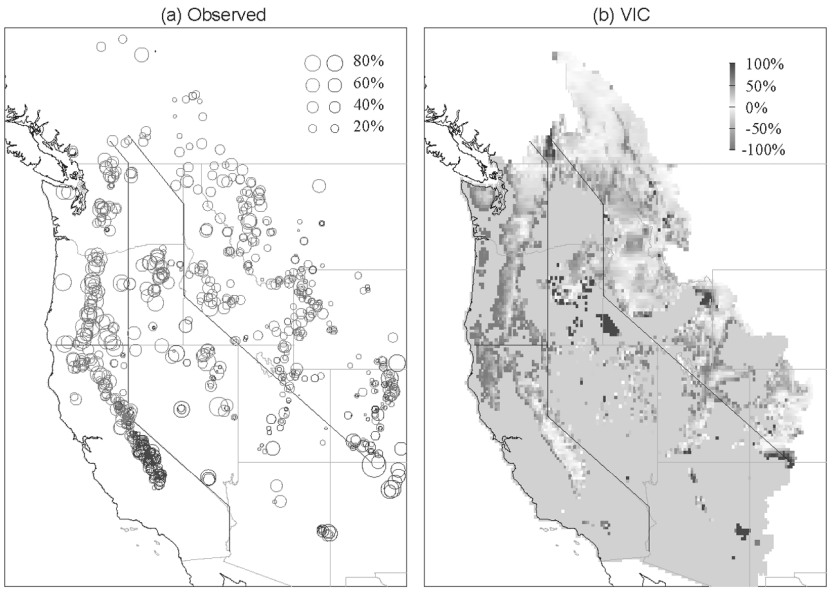

Figure 1. Linear trends (1950–1997) in April 1 snow water equivalent (SWE) relative to the starting value for the linear fit, (a) at 824 snow course locations in the western U.S. and Canada, with negative trends shown by red circles and positive by blue circles; (b) from a simulation by a hydrologic model (domain shown in gray).

Accompanying these declines in April 1 snowpack are trends toward earlier peak snowpack[6] (Figure 2) and earlier spring snowmelt, as measured by streamflow timing.[1,8,9] As a result, March flows have tended to increase and June flows have tended to decrease[9] (Figure 3), a pattern that is consistent with trends toward earlier peak snowmelt.

The largest decreases in snowpack and largest advances in snowmelt timing have occurred where winter temperatures are relatively mild (Figure 4), especially in the Cascade Mountains and Northern California, while cold high-elevation basins remain well below freezing even under considerable warming. In most mountain ranges, trends are minimal at ridgetop and grow to be substantial at snowline.[7] These local and regional patterns of trends point to a dominant role of temperature trends: snow accumulation and melt at locations with winter temperatures near freezing are most sensitive to temperature.

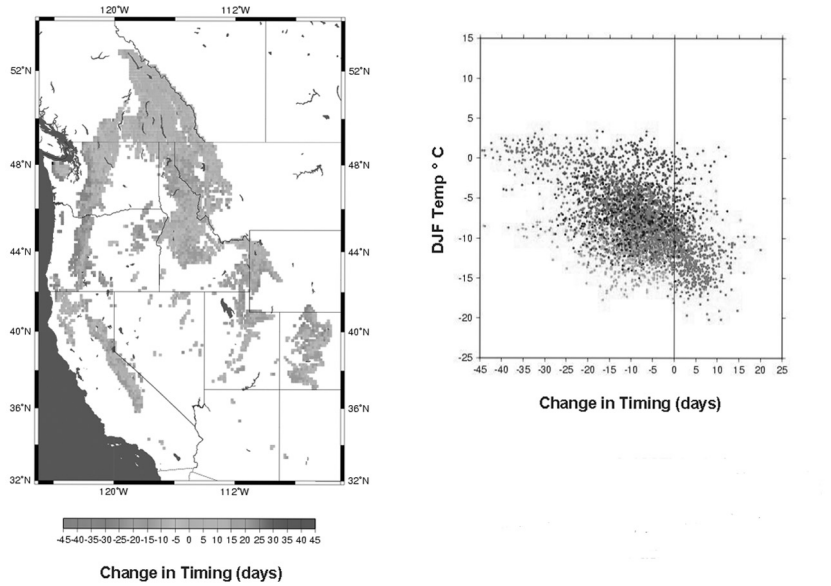

Figure 2. Trends (1916–1997) in timing of peak snow accumulation (left), in days, and (top) plotted against December-February temperature (°C). Red dots for points in the Northwest, blue for California, green for Colorado River basin, black for Great Basin.

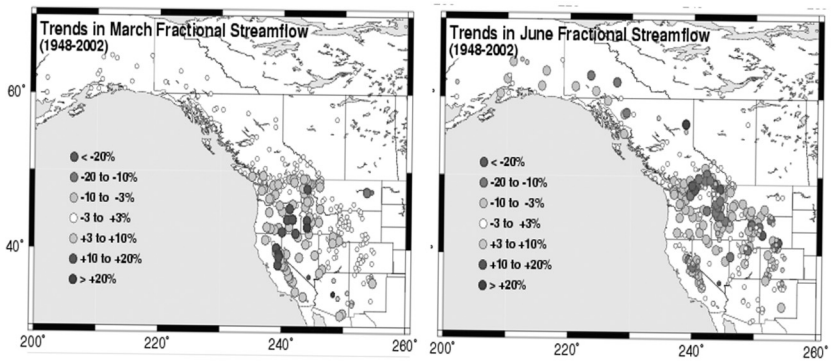

Figure 3. Trends in March (left) and June (right) snowmelt-derived streamflow as a fraction of annual total flow. The colored dots represent the percentage of change for a given monthly flow over the 1948–2002 period. Generally, March flows have been increasing and June flows decreasing, consistent with trends toward earlier peak spring flow. From Stewart, I.T., D.R. Cayan, and M.D. Dettinger (2004). Changes toward earlier streamflow timing across western North America, submitted to *Journal of Climate.*

2004 Record Losses

Between March 1, 2004 and April 1, 2004, many snow observation sites in the western U.S. posted record or near-record losses of snowpack (Figure 5). Unusually warm and dry weather, not necessarily long-term climate change, were responsible. These large drops in springtime snowpack exacerbate a drought that is in its seventh year in much of the West, and underscore the necessity of preparing to manage water in a warmer world with reduced snow storage.

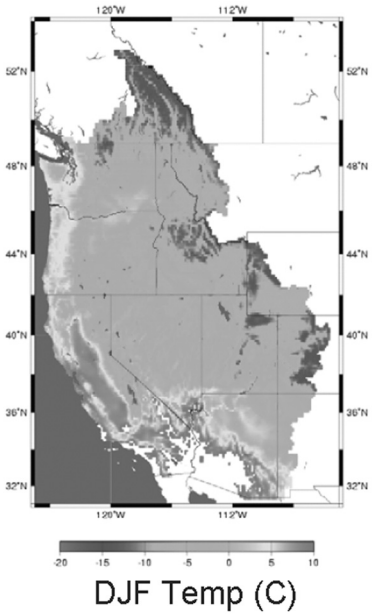

Figure 4 (above). Average December–February temperature. In addition to the Rockies, the southern Sierra Nevada mountains are quite cold and the Cascades and the mountains of northern California are milder and more susceptible to warm years or warming trends.

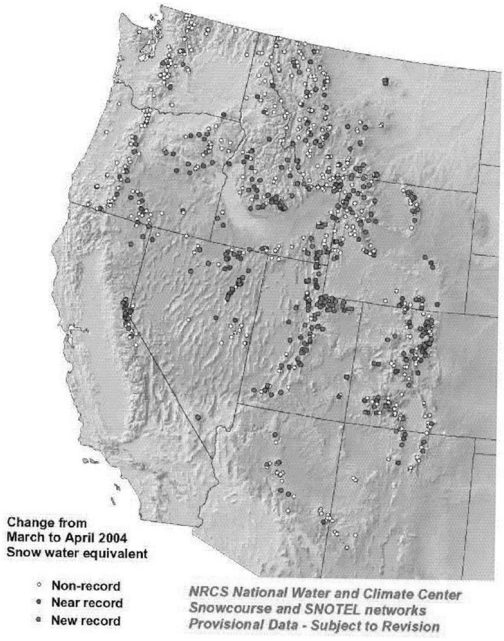

Figure 5 (left). March 2004 saw record (red) or near-record (blue) losses in snow at most snow observation sites in the West, owing to unusually warm and dry weather.

Snow and Streamflow in the 21st Century

Researchers have quantified the effects of higher temperatures on snowpack and streamflow using statistical techniques or numerical modeling (*e.g.,* refs. 2 and 4). Warming inevitably produces declines in snowpack at moderate and lower elevations with earlier peak streamflow and reduced summer flows in a prolonged summer drought period.[2,4] Under projected temperature increases from a global model that is relatively insensitive to greenhouse gas forcing, hydrologic simulations indicate that spring snowpack in much of the West would be substantially diminished by mid-century[4] (Figure 6). Models having greater response to climate warming produce substantially larger losses of snowpack. In areas where snowpack increased during the 20th century owing to large increases in precipitation, it is unlikely that precipitation will continue to increase fast enough to offset further warming at the pace expected for the western U.S. Even if the overall yearly precipitation did not change in the future, spring runoff that arrives earlier cannot necessarily be captured for summer water supply because of requirements to maintain flood control.

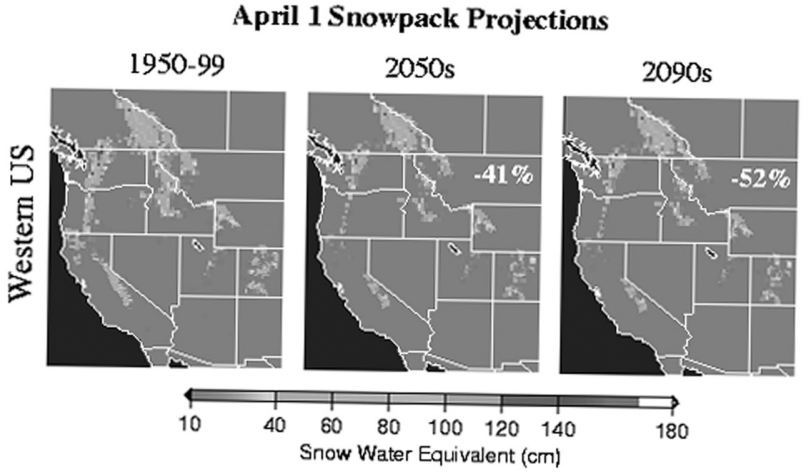

Figure 6. Simulated April 1 snowpack for a baseline (1950–99) climate, and for climate scenarios for the 2050s and 2090s provided by the NCAR Parallel Climate Model, a model with a low rate of warming. Percentage declines in total snowpack are shown.

The pattern of these simulated future changes is broadly similar to the observed trends in the 20th century, indicating that the stresses on western water resources experienced in recent years are foreshadowing much larger stresses to come. Even without the very likely increases in demand for water driven both by population growth and by the higher evaporative needs of plants, declines in summer water supply and shifts toward earlier peak snow will affect irrigated agriculture, instream flows for fish and wildlife, hydropower production, flood control, navigation, recreation, forest growth, severity of forest fires, and many other aspects of western economic and environmental health.[2,4]

Adaptation

Agencies that manage water resources must begin to come to grips with the implications of warming, especially the likely reductions in summer flow.[4] New Federal legislation may be needed to enable or require agencies to adapt to the changing flow regime: for example, to revise rule curves that govern the management of dams to aim for earlier reservoir refill, or to make decisions about water availability in the process of relicensing dams, to name just two examples. Consistent and widespread monitoring of climatic and hydrologic conditions is also critical.

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The CHAIRMAN. Dr. Mote, before I turn to Senator Snowe, who would like to make an opening comment, there are those who allege that the last 70 or 80 years in the West is an aberration, that there was much increased moisture, and that historically there was less, and we're just sort of going back to the historic trends. They say that tree rings and other indicators indicate that. What do you say?

Dr. MOTE. Well, that's certainly a fair question, and we have striven pretty hard to place these changes in context. For example, in the Northwest, where we've used the hydrologic model and what observations there are, we know that the 1930s was a very dry decade, considerably drier than the 1990s, yet the snow amounts in the 1990s are comparable to those in the 1930s. And the only explanation is the warming.

Going back much farther, clearly there have been severe droughts, but these deprivations of snowpack in the distant past have occurred because of precipitation. What we're seeing now is that, in addition to those precipitation fluctuations, there is a very persistent warming trend, consistent with rising greenhouse gases, which is shrinking the area of the mountains that actually stores snow.

So precipitation and temperature are two different effects.

The CHAIRMAN. Senator Snowe, you wanted to make an opening——

Senator SNOWE. I'll be very brief——

The CHAIRMAN.—statement?

Senator SNOWE.—Mr. Chairman. I don't want to interrupt your hearing. I will ask unanimous consent to include my entire statement in the record.

The CHAIRMAN. Without objection.

STATEMENT OF HON. OLYMPIA J. SNOWE, U.S. SENATOR FROM MAINE

Senator SNOWE. Mr. Chairman, I just want to thank you for the amount of attention that you have given this issue consistently, not only through this Congress, but in previous Congresses. I think it's regrettable, in fact, that not enough colleagues are here to hear your testimony this morning. You're preaching to the choir.

And I think that the fact is that Chairman McCain's leadership on this issue stands in stark contrast with the failure of Congress to address this issue and address one of the most significant environmental issues that we're facing in the 21st century, without question.

And I've just become Co-chair of an independent worldwide task force with scientists and other elected officials from other countries, and we plan to issue a recommendation next February on what we can do to address solutions on a global basis.

I'm pleased that my state has taken the leadership, as you mentioned, Mr. Colburn, in passing the first greenhouse reduction legislation—last June, in fact. And states are taking the leadership. I think that's the other irony in all of this, that more than 26 states, I understand, have assumed the mantle of environmental leadership, which again stands in stark contrast to the failure of Congress—not for the lack of trying on the part of the Chairman and some of the Members of this Committee, and otherwise in the Senate and in the House. But the fact is, the Chairman's legislation received a vote of 43 Senators last fall, and that was viewed as the high-water mark, and it was the first vote on this issue in 6 years in the U.S. Senate. Isn't that a sad commentary?

Again, it stands in contrast to the sobering and staggering testimony that you are presenting here today. And I have an entire statement, but I want to thank you, Mr. Chairman.

[The prepared statement of Senator Snowe follows:]

PREPARED STATEMENT OF HON. OLYMPIA J. SNOWE, U.S. SENATOR FROM MAINE

Thank you, Mr. Chairman. I want to commend you for your attention to this issue through this hearing and the other you've held since the 106th Congress, which have given us a greater understanding of what I believe is one of the most significant environmental issues of the 21st century. The message we have heard from renowned scientists clearly tells us that the time has come to adaptation and mitigation solutions to this problem to ensure that we do not leave an even graver situation for future generations to solve.

In fact, I feel so strongly about the need to act on a worldwide basis that I have accepted an invitation to be Co-chair of an independent international taskforce of scientists and politicians from around the world. The taskforce, developed respected think tanks from the U.K., Australia and the U.S., is looking at scenarios to move forward to reduce greenhouse gas emissions on a global scale, and we expect to come out with recommendations next February.

Mr. Chairman, the main finding of a 2001 National Academies' report, "Climate Change Science: Analysis of Some Key Questions"—was that, *"Greenhouse gases are accumulating in the Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise."* This is alarming considering that the carbon dioxide emitted today will linger in the atmosphere on average of at least a century.

Scientists note an extreme jump in temperatures in the last decade when compared to the *last 1,000* years, according to tree rings, corals, historical records, and from thermometers. Evidence shows that the snows of Kilimanjaro could vanish in 15 years, that glaciers in the Bolivian Andes may disappear in another 10 years. In Alaska, the average temperature has risen almost five and a half degrees over

the past 30 years, and there is evidence of melting permafrost, sagging roads, and dying forests. A 150 square mile, 100 foot thick mass of ice that has existed on the coast of Canada for 3,000 years is disintegrating—and the melting has been accelerating over the past two years. Coral reefs, a large and integral part of the coastal oceans around the world, are under huge stresses as coral bleaching is induced by high water temperatures.

I have heard from scientists in past hearings, that warming trends are real, and that they are affecting both the public's health in my State of Maine and others, and imperiling the safety of the people who live in the Western U.S. through continued drought and forest fires. And we will hear the effects of warming on wildlife species that live in narrow ecosystems around the globe. The science tells us that the time for mitigation actions against further warming is now—the health of the planet cannot be ignored.

I look forward to hearing from Ken Colburn of NESCAUM in particular on what states across the U.S. are doing to reduce their CO2 emissions. The *New York Times* reported last fall that, *"In the last three years, state legislators have passed at least 24 bills, usually with bipartisan support"* that address global warming.

Last June 26, the state of Maine signed into law the first greenhouse gas emissions reduction bill passed by any state that mandates reductions in CO2 emissions to below 1990 levels by 2020.

Grassroots efforts in states around the country are sending Congress a clear message—and we should listen, as our atmosphere knows no boundaries. What is really needed is a national, not just a patchwork approach as a first step to emissions reductions for solutions that are environmentally and economically sound. Your bill, Mr. Chairman, the Climate Stewardship Act is that first step, and I look forward to working with you for a positive outcome for the bill. I thank the Chair.

The CHAIRMAN. Well, thank you, Senator Snowe, and thank you for your leadership and involvement in this issue. And I know we have a lot of important things going on in the world, and we're in critical situation, but I find this testimony today, from highly credible individuals to be, again, very chilling and very concerning.

Dr. Curry, we had a witness in the last hearing that said that the coral reef is dying—the Great Barrier Reef is dying. Have you information about that?

Dr. CURRY. Mr. Chairman, that's not my specialty, but I do keep up with the reading on that literature. And, you know, as the tropical oceans get warmer, there appear to be more frequent bleachings of the corals and—you know, I don't know the specifics about the Great Barrier Reef, but it's fairly widespread in the Caribbean and other locations.

The CHAIRMAN. I keep bringing that up because if the coral reefs die, it's obvious that that's the beginning of the food chain, and I don't know what percentage of the world is dependent upon the oceans for their subsistence, but I would imagine it's pretty large.

Dr. Fraser, is the plight of the penguin "the miner's canary" of global warming?

Dr. FRASER. Senator, that is the perfect analog. For the southern oceans and Antarctica, they are the ultimate "canary in the coal mine," because—and I'm talking specifically about Adelie penguins, because of their strict and complete dependence on sea ice.

The CHAIRMAN. Dr. Mote, I would appreciate a written statement from you about this issue of whether we had just been in a period of unusual wet period in our history or whether there—or this statement that you made, that there is this marked difference in this period that we're in now.

Dr. MOTE. I'll submit that.

The CHAIRMAN. I don't know of an issue that's gotten more attention in the West, and particularly in my state, as well as Cali-

fornia, about—et cetera—on the issue of water, as we see our magnificent Lake Powell now well below 50 percent of capacity, and apparently no end in sight here, which can have dramatic effects. As we lower the depth of the lake, there are certain toxic materials down there that—if that starts flowing downstream, it can have also interesting impacts. There's so many ramifications of this that they're hard to encompass.

I'd like to ask the witnesses, beginning with Dr. Epstein, what actions should be taken by the United States to address the impacts of climate change? And maybe you don't have to give me all of those actions, but maybe you could give me, in priority, What actions do you think—policy changes and actions—should be taken by the United States of America? Beginning with Dr. Epstein.

Dr. EPSTEIN. I thank you for the opportunity for that. Can I respond to the coral question?

The CHAIRMAN. Yes, sir.

Dr. EPSTEIN. Because we are seeing this issue of bleaching when the oceans go over a certain temperature, 29 degrees Centigrade, bleaching, but we're also seeing diseases of coral reefs, and they seize upon these bleached coral that are lacking their defenses. And so that the combination of warming and diseases now is playing havoc with our habitat—and, as you say, our oldest food chain habitat.

Climate is changing. Every weather event has to be interpreted in that light. That is another—that is a statement you don't hear, usually. But that is the way we have to look at the dynamics of all of these surprises, like the heat waves and droughts now evolving, the heat waves in Europe in the summer in 2003, what can be done about all this.

Our inner cities can be protected. This "heat island" effect, CO_2 dome, this stuff that's in there that's all about fossil-fuel emissions, can be controlled if we have roof gardens, if we have more trees. You have parks here. We need more of these parks. We need better transport. These things can protect the inner cities; as well, make them less vulnerable to this intensified effect.

But we do need a new energy policy, and from a public—if I take off my clinician hat, put on my public health hat—we have to look at the upstream primary prevention. This is about our energy policies, which are also about security. But this is about clean energy driving this, I would suggest, not only with new regulations and rules and caps, but with the proper incentives. That's how we bring up our children. That's how we're going to have to move this economy, I believe. This is the way we can provide the carrots and sticks that help this become a win-win solution between energy, environment, and the economy. This is our triple-E problem we've got to solve. That's our problem: as a public sector, how to enable the private sector through the proper incentives to make this transition.

The CHAIRMAN. Dr. Curry?

Dr. EPSTEIN. Thank you.

Dr. CURRY. Well, first of all, the rising CO_2 is the added stress on the system, so the rate of growth has to be decreased, and eventually the amount of CO_2 in the atmosphere has to be brought down.

For the oceans—well, let me address this. The biggest weaknesses in our predictions of future climate are not whether or not the Earth will warm, on average; it's going to warm. And the problems with the way we talk about it is that nobody lives in an average climate. Some places will warm more than others. Some will get wetter. Others will get drier. The West might get a lot drier.

The predictability of climate, on the regional scale, given the perturbation of rising CO_2 in the atmosphere, is one of the biggest weaknesses we have right now, knowing what places will get drier, and how much drier, and what places will get wetter, what will get warmer, and what ones that won't get so warm.

Now, in order to do that, there are improvements that need to be made in understanding of how the ocean circulates, and how the ocean and the atmosphere are coupled together to create the climate systems that we experience. Both of those parts of the climate system—the ocean and the atmosphere—are partners in this, and they work together. And, in fact, you know, the atmosphere on certain longer time scales is driven by the surface conditions on the ocean. How warm it is in the Western Pacific affects how much rainfall you get in Arizona.

So I would say that, in terms of a research for better predictability and better understanding of how to mitigate the affects of global warming, we need to understand and do a better job with regional predictions in our global models. And there are aspects of ocean research that can make strides in that direction.

Thank you.

The CHAIRMAN. Dr. Mote?

Dr. MOTE. There are two aspects of your question that I think really need to be addressed. The first is mitigation, reducing greenhouse gas emissions. And there are a number of examples around the world. BP and the UK have both reduced net greenhouse gas emissions over the last five to 10 years, at no apparent economic harm. I'm not an economist or a policymaker, but, as an interested observer, it seems to me that these examples show that greenhouse gas reductions can be accomplished while still providing a growing economy.

The area that's really more my bailiwick is the issue of adaptation. That is, learning to live with climate change. It's pretty clear that carbon dioxide is continuing to rise, and will continue to rise for some time, until ultimate stabilization. And we are already seeing, as I described, effect on our water resources.

Clearly, every Federal and state agency that manages water resources, whether it's the Bureau of Reclamation, the U.S. Army Corps of Engineers, and so on, need to take account of these changes that have already occurred, and will occur over the next 20 to 40 years.

For example, the U.S. Army Corps of Engineers, which, in the Columbia Basin and the Colorado, has to manage for flood control, needs to change these flood control rule-curves to reflect the fact that the peak flow is coming earlier. It's no longer appropriate to aim for a July 1 refill date for the reservoirs in the Columbia, for example. When dams come up for relicensing through the Federal Energy Regulatory Commission, FERC, these estimates of how

much flow can be provided for various uses in the next 20 to 40 years clearly have to take account of climate change.

I could go on and on, but you get the picture, that there are many things that should be done now to recognize what science is pointing out about the way that our water resources and snow resources are changing in response to warming climate.

The CHAIRMAN. Thank you.

Dr. Fraser?

Dr. FRASER. Senator, I'd like to reference your earlier question with respect to whether anyone disputes my observations. And I think the answer is that the observations are not disputed, but the mechanistic process that explain the trends is disputed.

The issue is that climate change operates by impinging on ecosystem thresholds. These thresholds are already being altered by human activity, such as massive deforestation or over-fishing. And so we are really looking at cumulative converging impacts on Earth's systems. And it is these impacts, human activity and environmental variability—when the two converge, these are what historically has led to rapid negative changes to the earth's systems.

What I see as one of the key issues here is that we simply do not have enough baseline data to be able to say, "Is this an unusual trend? Is this a unique trend, or is this something the planet has seen in the past?"

So what I would encourage, coming from strictly a research standpoint, is that data bases be mined for information that will at least allow us to gauge whether these trends are unique or not. Because as soon as we can identify those parameters, we can probably better address mitigation procedures.

The CHAIRMAN. Do you agree with Dr. Curry, that these significant changes are taking place in the ocean?

Dr. FRASER. Yes. We see—we don't see those changes in our region of operation, on the Western Antarctic Peninsula. The reason we don't see them is that we do not have the baseline data that I just mentioned. But, for example, in the southern Ross Sea, a region about 1,600 miles south of where we work, there is absolute evidence that the ocean is becoming fresher, and it's also warming.

The CHAIRMAN. Well, I guess my question—how much research data do we need? How long is it before the naked eye indicates that we'd better act?

Dr. FRASER. I think what I'm getting at, Senator, is that before we can act on issues, we need to understand the mechanisms by which they are occurring. So that's what I mean by there being a need to—the better informed we are, from a long-term perspective, the better that we can target the mechanisms that may be involved in producing essentially ecosystem chaos through climate change.

The CHAIRMAN. Mr. Colburn?

Mr. COLBURN. Thank you, Senator. If I could just comment on the last reflection, I would caution about mechanisms. You'll recall that, in 1964, the Surgeon General issued a caution about smoking, and the mechanisms weren't understood, toxicologically, until 1997. The mechanisms I think my colleague is talking about is the 1964 epidemiological type of mechanisms in pursuit of the toxicological mechanisms. More knowledge is surely good, but enough knowledge, at some point, is enough to act on.

Senator, I would offer two major veins of thoughts in response to your question. One is in terms of understanding, and one is in terms of action.

In terms of understanding, I'll recollect that, in December 1992, a multi-agency convocation was held, assembling the world's best climate scientists to helped develop the Federal Climate Change Strategic Plan. What I heard at that convocation was regional climate modeling, over and over again, as fine detail as we could get it to help understand what will happen in our specific regions, because they differ around, not only the globe, but around our country. A good example of that is that the EU is undertaking such efforts. The UK is undertaking such efforts. Even the province of Quebec is undertaking such efforts—in part, so that they can understand the world that they will be entering, and tune their economies toward it.

In our case, in the Northeast, in Senator Snowe's state, for example, if the habitat of forest is going to change from maple, beech, and birch, in our foliage season, to oak and hickory, perhaps our paper industry should start changing to a furniture industry. This kind of level of understanding and detail is available; however, it hasn't been made available to the states, and hasn't been a priority.

In the resulting Climate Change Strategic Plan, if you look at it, regional climate modeling is in there, but it's not in the executive summary, it's not in the goals and objectives; it's buried in there as a sub-header.

Senator, in terms of action, it's basically, "It's the fossil, dummy." That might be our—I guess the line was, "It's the fossil fuel, stupid," to copy it more precisely. And that, of course, is oil and coal.

Governor Schwarzenegger, in California, has an effort underway to see if his state can reduce, by 15 percent, his dependence on petroleum fuels by 2020. Two weeks ago, Governor Pataki, in New York, suggested that the Nation needed an effort on the scale of the Manhattan Project or the lunar landing to wean our nation off imported oil. I think those types of efforts would go a long way, and, basically, are necessary.

In terms of coal, that's the other chief culprit. And what we need there, of course, is the kind of capital stock turnover in our generation industry that Congress anticipated when it passed the Clean Air Act amendments of 1977 and its New Source Review provisions. They have not come to pass, and the technology is increasingly available to have that opportunity that you described of cleaning up our air. Specifically, by stripping the solids out of coal, we can continue to use coal—it's a process called integrated gasification—then run through a combined cycle power plant. The additional benefit is that stripping the CO_2 out of that stream is among the most readily available CO_2 capture technologies that we're aware of. That technology should be mandatory for moving ahead.

There is an energy penalty associated with it. Currently, we're paying a health penalty and a climate penalty, instead of an energy penalty. I'd suggest to you that we need to pay the energy penalty.

Further, that technology is going to be developed. China is very interested in it. The question is, who will own the patents? Who will export that technology? And I would suggest it should be us.

Senator, R&D is not the mother of invention. Commercial availability is not the mother of invention. Necessity is the mother of invention. We need to make these technologies, these clean technologies, necessities.

The CHAIRMAN. Thank you.

Senator Lautenberg?

Senator LAUTENBERG. Thanks, Mr. Chairman. I thank our friends at the witnesses table for that illuminating data.

The thing that concerns me is that, as I look at the depth of the problem, I fail to see that the alarm has gone out. And you're in the watchtowers in many places, in some of the most beautiful places in the world, whether you've spent time in Antarctica and down to the South Pole, or whether it's in the Arctic or Woods Hole or Montana, all these places that immediately connote environment and nature at its best. Then we find out that we see nature at its worst, in many instances.

And I've lived long enough to have some memories of different climates in the state of New Jersey, when we used to have a lot more snow, and now we hardly see it, and, when we do, it's rather severe, a lot of ice and gone in a hurry.

And when I look at the data that you've provided, I see something different. I see the faces of ten wonderful children that I'm privileged to have as grandchildren. The oldest is ten, the youngest is 3 months. And I wonder what kind of a world they're going to live in. We have been a family fortunate enough to be able to go to the mountains and go to the sea, and we do it regularly. And we've watched the whales touch our boat off the coast of Cape Cod, and I've been to Antarctica and listened as the glaciers groaned. It was almost a death knell that you could hear, because they were straining to stay together. And the family of ice was being separated into lots of little parts. And I've watched the penguins, with admiration, at their industriousness in their capacity to walk long distances until they get to an opening in the ice to be able to provide—to gather sustenance for their young.

And as you talk about these things, each one of you has a rather ominous message, but we're not getting it through to the public. Because if the public understood the seriousness and the imminence of this better, then folks like our distinguished Chairman, who are concerned about it, who will talk about it, would be able to gather even more than the 43 votes that you gathered, Mr. Chairman, in the last vote that we had. I think people would be rushing to register their opinion.

If there's no other way to sound the alarm, one need only look at the Pentagon report. And I don't know why more hasn't been made of this, because when we talk—when our universe is deluged with information about security, and we see what the Pentagon report—have all of you looked at this report? Is there a question about its reliability or——

Dr. Curry: Senator, it's not a prediction, as far as I can tell. It appears to be a thought process of—like a worst-case scenario. There's no prediction at all like that in——

Senator LAUTENBERG. Well, but when they talk about, "The borders will be strengthened around the country to hold back [inaudible] starving immigrants from Caribbean islands—Mexico, South

America—energy supply will be shored up—too expensive—alternative nuclear renewables—hydrogen—Middle East contracts."

We, the United States—not to make—trivialize such serious discussion, but we're apparently the major exporter of carbon dioxide. We always look to the countries that export minerals or fuel or oil or what have you, but now we have the dubious distinction of being the largest exporter of carbon dioxide. Four percent of the population, 25 percent of the carbon dioxide, and yet we haven't reached the point at which people understand it. It's a little bit of a mystery—a lot of a mystery, because it doesn't affect people on the short term.

I see it—lots of kids that I meet, who are asthmatic. I've got two children, of my ten grandchildren, who have asthma. Their parents are pretty healthy people, but yet we see these things—intense allergies, things of that nature—that result from the changes that we're witnessing.

And I never quite understood, after my trip to the South Pole, how it got to be the repository for 70 percent of the world's fresh water, which was, in the vernacular, down there. But as we've gotten into this, I've begun to understand that the lift up into the atmosphere takes the fresh water, and it's built up as a result of the reduction in salinity, which, I guess, bottoms it out.

And I wonder how quickly we can turn this around. The notion of the carrot and the stick is one that's common throughout this place, and very often it's used to challenge the logic of simple decisions. We don't want to be punitive. But the punishment that comes from this is going to be more in the future generations.

This report says—the Pentagon report says that, in the year 2007, the Netherlands can expect severe and disruptive flooding. They talk about countries that can be deluged by rising sea levels. And we've already seen it, but the effects are not quite as clear. I know that New Jersey, my beloved home state, has always had these generous beaches. Well, now we have to work like the devil to replenish the sand that's being taken away. It's not a coincidence; it's a constant.

So whether—how important is it that we, for instance, join in the Kyoto treaty? Does it matter at this juncture, in your judgment?

Dr. EPSTEIN. Thank you. And this is a fabulous discussion.

Clearly, that's a toe in the door, but it's a door that has to be opened. And I applaud Senator Snowe's involvement in this international effort.

A couple of comments on where you've been going. We're looking—I believe that reality is going to ratchet up this debate, because what we're asking about is, when do we reach the tipping point, not only in the reality, but the awareness about it? And hopefully the latter will accelerate as we see changes and the kinds of surprises that we're beginning to see in physical and biological systems. And we're talking about parts of Greenland that are melting down to the base, through the crevasses, that could slip. Hopefully, this will wake us, and not swamp us.

The Pentagon scenario is one of three major scenarios. And I applaud what you've ended up with, these predictions about the Netherlands. And buried in that scenario is the reality that's evolving now of this warming and greater volatility.

We have to ask ourselves, is this climate more stable, more—is it stable or unstable? What are the characteristics that could lead to these abrupt changes? The rate of change is increasing. It may not be a threshold of CO_2; it maybe a derivative, the rate at which we could go up. The volatility is increasing, and the gradients across the ocean are increasing.

The North Atlantic is one scenario. Thawing tundra and release of methane is another. A third is the Antarctic Peninsula, which has now lost some of its ice shelves, which, like the dunes on Cape Cod and elsewhere, when you take the beach sand away, you get the dunes flowing down. We're afraid now that there's an acceleration of the ice sheets on land. That's what could change sea levels, et cetera. So we see unstable conditions in the North Pole, South Pole, and now in the tundra regions.

I want to just touch on one other indicator that we haven't really stressed—the economic. Because the extreme weather events have cost the insurance industry—FEMA quadrupled in the 1990s. We're looking at $4 billion in the 1980s, average a year; $40 billion in the 1990s; it went up to $55 billion losses in 2002, $60 billion in 2003, and a quarter of that is insured. The United Nations Environmental Program, along with several consultants—Munich Reinsurance, Swiss Reinsurance Company—have now—estimating $150 billion losses per year within this decade if the current trends continue. So I think you're going to hear much more from Swiss Reinsurance and other reinsurers as to whether they can reinsure and insure our future.

Finally, if we're looking at these costs, we have to look—these big problems must incite bold solutions, and we've got to, as our international efforts, look at how funds can be put together that create new markets for Honduras and Mozambique for our projects, for our solar panels that create—stimulate their economies. We've got to trade, beyond Kyoto, in air and carbon; we've got to trade products that are efficient, that are alternative, that change markets. We've got to create the conditions and enabling architecture that allows companies to move lockstep into this new clean energy transition.

The CHAIRMAN. Senator Snowe?

Senator SNOWE. Thank you, Mr. Chairman. And I want to thank all of you again for your sobering testimony here this morning.

I know the Chairman asked you all exactly what could we do with respect to enacting Federal policies here, but what can we do to maximize the change, sooner rather than later? I mean, anything, any implementation of Federal policy is going take some time to trigger and to have an effect of any kind on these warming trends and climate changes, and particularly those that are abrupt. I mean, what can we do? I mean, we invest in research. Should we do a lot more in that regard? Or do you think we have sufficient, you know, information and data that we can proceed with specific initiatives that can make all the difference in beginning to turn the clock back on some of these issues?

Dr. Epstein?

Dr. EPSTEIN. I'll start, and be very brief. I agree, we are at a point where we can make decisions. Tax incentives, subsidies—we're subsidizing coal and oil in this country right now, to the tune

of tens of billions; $20 billion, just for starters. If we talk about protecting the oil lines across the globe, it's another hundred. We're talking about subsidies that could be switched, and this is, internally, the way in which we could begin this process.

Globally, again, we're going to need to figure out, collectively, how we provide the international incentives to drive this. But there's a lot that we can do internally.

Senator SNOWE. Dr. Curry?

Dr. CURRY. In two parts. The first part is about the rising CO_2 emissions and the concentration in the atmosphere. You should do everything you can to reduce the rate of growth of that CO_2, stabilize it, and help to reduce it at some point in the future, because the rate at which that changes in the future will affect the likelihood of abrupt climate events, will affect the magnitude of the changes that you experience in the future.

Senator SNOWE. And so mandatory reductions in emissions, for example, or, like the Chairman's legislation, a cap-and-trade system?

Dr. CURRY. I'm not sure that I can choose, you know, intelligently between those two, but something that——

Senator SNOWE. But the idea is that——

Dr. CURRY. But the idea is to bring it down. Bring down CO_2 growth rates, bring down the level in the atmosphere. That's the one part.

The other part is that there still are research elements, in terms of our predictability of what next decade will be like, what 2050 will be like, and what 2100 will be like. And that is not about whether or not the earth will be warmer; it's how much warmer where, how much wetter where, how much drier where. And there are things that the Congress could do to help improve that. There are aspects of it that involve basic scientific problems in ocean sciences and atmospheric sciences. There's the development of larger-scale observation system, so that you can actually see what's going on in the very remote place on earth, particularly in many spots in the ocean, and then working to improve the model, numerical simulations, of those processes, so that you could actually make a credible guess as to whether or not it will be wetter or drier out West.

Senator SNOWE. We have a Gulf of Maine observation system, and we hope to apply that nationally, and that's something I've been urging Admiral Lautenbacher to endorse. I think he certainly does support a national system. And it's actually proposed by the U.S. Commission on Ocean Policy, as well. And I think, you know, it's obviously going to require some investments, but I think that really that would be a major milestone.

Dr. CURRY. There's a global aspect of it that you shouldn't overlook, though—working with other nations, as well, to make sure that the entire globe is being measured, because, as I said earlier, the temperatures in the Pacific can determine how much rainfall you get out West.

Senator SNOWE. And all oceans are warming. Is that——

Dr. CURRY. All the oceans in the tropical locations appear to be warming, yes. Most high latitude locations, as well.

Dr. EPSTEIN.—that's four miles each—all the oceans. That's the work of NOAA,——

Dr. CURRY. Yes.

Senator SNOWE. OK.

Dr. EPSTEIN.—and the Department of Commerce,——

Dr. CURRY. Yup.

Dr. EPSTEIN.—where of the heat from essentially global warming over past century.

Senator SNOWE. That's amazing.

Dr. EPSTEIN. Yes.

Senator SNOWE. Thank you.

Dr. Mote?

Dr. MOTE. You asked what can be done, sort of, immediately, and we know that different greenhouse gases have different lifetimes in the atmosphere; and methane, in particular, has a much shorter lifetime than carbon dioxide. So immediate reductions in methane will have a more immediate effect. Clearly, over the long term we will have to address CO_2 in a major way, because it's responsible for most of the greenhouse effect. But if we additionally tackle black carbon soot, which causes human health problems, as Dr. Epstein was saying, we get a "two-fer," in that we're attacking the climate problem, but also a local air quality problem. There are a lot of other, sort of, intermediate steps that we can take on the way to stopping the freight train that is CO_2 emissions.

If I could say just something about—in response to Senator Lautenberg's question about the Kyoto Protocol, as I understand that policy instrument, it is primarily a weight loss goal. It is a group of nations getting together and agreeing on a weight loss goal. But you cannot meet any goals without specific actions. And whether or not we signed and ratified the Kyoto Protocol, it would still be left to Congress and states and companies to find ways to meet that goal, whatever it is. And so if the Climate Stewardship Act passes, and it's successful, it almost wouldn't matter—again, as a nonpolicy expert, but it seems to me that having an actual action is more important than having a goal and not meeting it.

Senator SNOWE. Dr. Fraser?

Dr. FRASER. As an ecologist, I continue to consider what it is that we can do for ecosystems that are basically facing a bottleneck if climate change is allowed to continue. And I agree with the comments of my colleagues, but I also think that some of the things we can do immediately—for example, in the case of the oceans' fish stocks, there's no question that most of them are being over-fished, and they're collapsing.

The CHAIRMAN. We had testimony from the Oceans Commission, week before last, on that very issue. Their conclusions were, indeed, disturbing.

Dr. FRASER. Thank you, Senator.

And so over the immediate future, the question, for me, is, How can policy and management converge to at least preserve the biodiversity that was at one time inherent in these systems? How can we affect policy that will prevent over-fishing? What policy will affect deforestation on a global scale? Those things, we can implement immediately.

The comment that we have a freight train heading toward us, I think, is absolutely correct. And we need to basically prevent ecosystems from going over the threshold. And I think management is perhaps one of the best options.

Senator SNOWE. Mr. Colburn?

Mr. COLBURN. Thank you, Senator.

This is literally a sooner rather than later problem. The quicker we can get started, the less problem that we'll have to deal with ultimately. And as you know, the old saying about, "There's never time to do it right, but always time to do it over," may have a parallel here that we all always rush in with FEMA or whatever to pay for destruction, but we are reluctant to avoid that destruction in the first place.

There are a couple of substantial things that can be done. A few, I mentioned already. The carrot of requiring IGCC and subsidizing that coal technology would be very effective. The stick of emissions controls, and the co-benefits that Dr. Epstein and Dr. Mote mentioned, in terms of human health effects from sulphur and mercury and so forth, could also be done reasonably quickly. Almost immediately, Congress could bring some stability to the wind energy tax credit, so that that industry doesn't feel like a ping pong ball and could similarly retain, for the long term, a hybrid vehicle tax credit that currently exists.

Ultimately, of course, I hope that you'll all be encouraged to bring back S. 139, or something like it, over and over again until it succeeds, because this has to be dealt with.

Senator SNOWE. Yes.

The CHAIRMAN. You can count on that.

Senator SNOWE. I appreciate it. As you mentioned the stellar performance on the part of states, compared to the lackluster federal response, frankly, other than what Chairman McCain has been doing to advance his legislation—I think that there are still a number of people who simply don't get it. I mean, they ought to be doing a catalog and a tally of the costs of this and the implications of this climate change and what it is doing to our health—Dr. Epstein you cataloged that in very compelling terms. In my state, we have the highest rate of asthma per capita. We're victimized by the transported polluted wind from the industrial states. And so that's having enormous health implications. And then the economic implications, the environmental—and it goes down the list. We ought to have a catalog in every direction. People need to understand how perilous this problem is to our futures and to the future of the world. And so this isn't just going to happen sometime down the road. It is happening, and it's in our backyard, Dr. Epstein, as you said.

And so I hopefully—that we can give a sense or urgency to this issue, rather than—as I look at the budget, even, on some of these issues—and I mentioned this to Admiral Lautenbacher the other day in the hearing—you know, with zeroing out, you know, different programs for paleoclimate, you know, research, for example, the oceans consortiums, research. I mean, this is not the direction we ought to be taking. The fact is, it's quite the opposite.

Thank you, Mr. Chairman.

The CHAIRMAN. Admiral Lautenbacher, I believe, is the one who testified before this Committee on climate change, he said we'd have to go to sleep for 30 years before we'd know anything about climate change. So it's not surprising that they would be cutting the budget for these very vital and important programs. It's disgraceful.

I thank the witnesses. It has not been a very pleasant hearing. And I appreciate your candor, and I appreciate the expertise you bring here. And I'm very grateful.

Mr. Colburn, I especially want to express my appreciation to the leadership of the Northeast, as we are also seeing in the West, to begin attempting to address these issues. We all know that it has to be done nationally, but perhaps we would be motivated to emulate some of your activities.

I thank the witnesses. The hearing is adjourned.

[Whereupon, at 11:05 a.m., the hearing was adjourned.]

A P P E N D I X

The Washington Post—Sunday, September 7, 2003; Page B05

"Climate Change Is Really Bugging Our Forests"

By Paul R. Epstein and Gary M. Tabor

As lightning continues to ignite wildfires across the parched North American West, an unseen armada of beetles, encouraged by warming, burrows beneath the bark of drought-weakened trees, killing vast stands rapidly and transforming them into kindling. Together, climatic extremes and the pests they foster are stalking our Nation's forests, threatening habitat, wildlife and even human health.

President Bush has proposed a Healthy Forests Initiative to combat the danger of wildfires. But no effort at restoring the soundness of our forests can succeed in the face of global warming and the accompanying intensification of weather extremes, which encourage the infestations and conflagrations, unless it includes a clean energy policy aimed at stabilizing the climate.

In July, the U.N. World Meteorological Organization affirmed that warming of the atmosphere and deep oceans is intensifying droughts, along with heat waves and floods, worldwide. The prolonged droughts in the U.S. West are part of this phenomenon and are directly attributable to anomalous sea surface temperatures in the Pacific Ocean.

As the earth's surfaces warm, evaporation is drying out forests and soils, increasing susceptibility to fire. Last summer, more than 7.3 million acres of U.S. forests burned during an intense drought. This year, there have been more than 800 separate fires in British Columbia; Oregon has seen fires lay waste to pristine areas; and wildfires have sent haze billowing from Arizona to Montana. Most alarmingly, as an intergovernmental panel concluded in 2001, earth's biological systems are already responding to climate change. The current epidemic of bark beetles adds a new dimension to the risk of fires. In just the past few years, bark beetles have damaged forests in Arizona, New Mexico, southern California, Wyoming, Montana, Idaho, Washington, Oregon, Alaska and British Columbia. In British Columbia, nearly 22 million acres of lodgepole pine have become infested—enough timber to supply the entire U.S. housing market for two years.

Mountain bark beetles (Dendroctonus ponderosae) attack lodgepole, ponderosa, Douglass fir, sugar and western white pines, destroying them by injecting a fungus. The galleries of eggs they lay inside the bark pave the way for the trees' death within a year. Healthy trees secrete pitch to drown the invaders and plug the holes they bore, but drought dries out the pitch. Woodpeckers and nuthatches keep adult numbers in check, but with warmer winters, beetle populations can quadruple in a year, outpacing their pursuers. Warming is increasing the reproduction, abundance and geographic range of beetles, destabilizing the age-old, hard-won truce between insects and vegetation. Since 1994, mild winters in Wyoming have helped the beetle larvae survive the season. Usually, 80 percent die, but the mortality rate has dropped to less than 10 percent. In Alaska, spruce bark beetles are sneaking in an extra generation a year due to warming, and have denuded 4 million acres in the Kenai Peninsula in the past five years. "This is another example of global climate change that has deadly implications for my state," declared Alaska's Republican Sen. Ted Stevens last year.

Warming is also expanding the beetles' range into higher altitudes. In the past four or five years, they have begun to attack whitebark pines at an elevation of 8,000 feet or higher. Jesse Logan of the Utah Forest Service told the Billings (Mont.) Gazette last month that this development coincides with an overall warming trend that began in the 1980s. "Beetles are cold-blooded, so their metabolism is related to the environment they're in," said Logan, adding that the beetles seem to be a reliable indicator of global climate change. "Taken all together, it becomes a pretty compelling story, and a scary story to me."

Wildfires are hazardous to people, wildlife and property. Beyond the immediate danger of the fire itself, particles and chemicals from blazes cause heart and lung disease, and the hazes can carry thousands of miles. Last summer's Hayman fire in Colorado left lingering respiratory illnesses, and after the 1998 fires in Florida, complaints of asthma increased by 91 percent, bronchitis by 132 percent and chest pain by 37 percent.

Not all forest fires, of course, should be suppressed. Periodic fires help rejuvenate forests. But the drought-and beetle-driven wildfires today are not self-limiting, and the underlying causes must be addressed. Unfortunately, little can be done directly to control bark beetles. Pesticides, which enter ground water, are only somewhat effective and must be applied widely long before the beetles awaken in spring. The president proposes thinning forests to reduce the threat of fire. But the extensive logging and clear-cutting that would be allowed under the Bush administration's initiative is a practice that damages soils, increases sedimentation, reduces water-holding capacity and dries up rivers and streams—all increasing susceptibility to pests and fires.

Even the best forest practices, however, will be insufficient to stem the ravages of drought and the onslaught of beetles. Forests plagued by wildfire and beetles need moisture.

Just as we underestimated the rate at which the climate would change, we have underestimated the biological responses to warming and the costs associated with the accompanying weather extremes. Climate change is weakening the hosts and emboldening the pests. If we are serious about protecting the world's forests, we must embark upon a comprehensive program to stabilize the climate by burning far less fossil fuel, adopting energy efficiencies and smart technology, and felling far fewer trees, which absorb heat-trapping carbon dioxide. And the sooner we do it, the better.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO KENNETH A. COLBURN

Question 1. In your written statement you point out that the governor of Rhode Island has announced that his state would adopt California's cleaner vehicle requirements. You also mention that the Northeast States for Coordinated Air Use Management are working to develop a registry system that would be compatible with the California registry system. Do you believe other Northeast states will begin to adopt California's clean air policies?

Answer. Under the Federal Clean Air Act, states other than California are preempted from regulating certain sources of air pollution such as vehicle emissions and fuel constituents. These states may choose to adopt Federal standards or California's standards for controlling such sources. Where states have specific air pollution concerns and California has adopted pollution controls more stringent than Federal requirements, states have often opted to adopt pollution control requirements consistent with California's policies.

This structure has now existed for decades, and states including the Northeast states have adopted many of California's programs, including those associated with vehicle emission standards, so the states are already well on their way to adopting California's clean air policies. Using the example cited above, for instance, Rhode Island joins Connecticut and New Jersey as states adopting California's cleaner vehicle requirements in 2004. These three states join Maine, Massachusetts, New York, and Vermont, which have had similar requirements in place for several years. Since seven of the eight Northeast states, have now adopted California's cleaner vehicle requirements, this trend is nearly complete rather than just beginning.

As the market for cleaner California cars expands and concerns about air pollution increase, it is likely that additional states -both within and outside of the Northeast-will also consider adopting California's clean vehicle standards.

Question 1a. Do you believe that the Federal Government should act to adopt tougher clean air standards?

Answer. Yes, both for environmental reasons and economic competitiveness reasons. Light duty vehicle manufacturers have achieved extraordinary progress in reducing emissions from automobiles. However, greater numbers of vehicles and

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longer driving distances have caused vehicular emissions to remain a major health concern. Moreover, further progress is eminently achievable.

Manufacturers that push the envelope in developing and introducing cleaner car technologies will ultimately enjoy a long term competitive advantage in the global marketplace. If U.S. manufacturers are required by Federal regulation to develop and introduce such technologies, their long term future -and the U.S. jobs associated with them-will be more secure.

Question 2. What has been the reaction of industry to the climate change policies that are being implemented on a state by state basis?

Answer. Reaction has been mixed with respect to specific policies applicable to specific industries in specific states, but on the whole it has been remarkably positive. In many cases, in fact, industry support has been essential to the successful adoption of state climate change policies. In the case of New Hampshire's greenhouse gas registry legislation, the support of the state's business community enabled its passage. Passage of this state's "4–P" power plant legislation (covering emissions of sulfur dioxide, nitrogen oxides, mercury, and carbon dioxide) would have been impossible without the active support of the affected utility. California's greenhouse gas registry legislation was conceived, initiated, and executed by that state's business community. Climate legislation has been adopted in Connecticut and Maine with little opposition from industry. The most aggressive action contemplated to date, the Regional Greenhouse Gas Initiative (a power sector carbon dioxide cap and trade system being developed by nine Northeast states), has thus far been met with cautious support by industry stakeholders.

Generally speaking, the industrial community appears to recognize that the time has come for concerted action to address climate change. This is not surprising given that most of today's companies operate internationally and are likely to be subject to greenhouse gas (GHG) control requirements in other nations. There is little doubt that industry would prefer a coherent national program over potentially differing programs in multiple states or regions, but the business community evidently regards the risks associated with inaction as greater than the risks inherent in fragmented implementation.

Question 3. Your written statement notes that states are acting to correct the effect of climate change based on a strong scientific consensus that increasing concentrations of atmospheric greenhouse gases are largely the result of human activity. Is the scientific data that states are considering any different from the data that we have at the Federal level?

Answer. No. The states' scientific data is publicly-available, peer-reviewed information from the world's foremost academic and research institutions and such entities as the International Panel on Climate Change (IPCC).

Question 3a. If the data being considered is the same, what do you believe needs to be done to get better action at the Federal level to address the growing problems associated with climate change?

Answer. Federal action must originate with Congress or the Administration, and can take either of two paths (or both). One approach would be to cease the prevailing denial regarding the causes and impacts of climate change and search for solutions rather than excuses for inaction (*e.g.,* scientific uncertainty). Climate science, like any scientific or economic endeavor, has attendant uncertainties. But such uncertainties do not exceed those inherent in economic forecasts used to project Federal deficit and debt levels nor constrain either our ability or need to reach other key policy decisions (like federal budgets).

A second approach would be to recognize the cost saving, technological development, and global competitiveness opportunities associated with constructive climate action. With the current environment in Washington hostile to climate change action, companies are reluctant to broadcast their achievements, but those acting on climate change are, in fact, saving substantial sums and enjoying enhanced global competitiveness.

Congress and the Administration need to recall how capable America's ability to lead really is. We have a long record of technological achievement, much (perhaps most) of it mandated (*e.g.,* by war in the case of the Manhattan Project; by Presidential commitment in the case of the moon landing; and by environmental regulation in the case of cleaner vehicles, fuels, and factories). Columnist Tom Friedman, in fact, has suggested that we initiate a "Manhattan Project" for national energy independence, and one can only imagine (1) the economic benefits of keeping our current energy dollars at home instead of sending them to the Middle East (particularly as China begins to meaningfully compete for the same resources), and (2) the national security and defense benefits of doing so.

The combination of the costly, harmful climate impacts likely to result from inaction and the economic opportunities likely to result from concerted action are, in short, what underlie states' willingness to adopt policies to address climate change. America's greatness derived from generations of individuals who accepted difficult challenges in order to build a better future for their children and grandchildren. In their current focus on the short term, Congress and the Administration has departed from this fundamental precept, putting America's continued greatness-and its citizens' well being-at risk.

Question 4. The Administration has indicated that we are spending more than $4 billion per year on climate change. Do you believe that is an adequate level of funding to halt the impact of man-made climate change? Do states agree with the Administration on the level of Federal spending?

Answer. To my knowledge, the states have taken no specific position on the adequacy of Federal spending on climate change. Given the magnitude of the task, however, there is little doubt that the current level of funding is insufficient. One might subdivide the climate issue into three levels of attention: researching, addressing, and solving. Federal support for climate research is substantial and laudable, as the U.S. government's efforts targeting technology development. U.S. efforts to address climate change, however, are relatively weak. Research is not an adequate response to a threat already underway, action is required. Similarly, technology development is a necessary, but not sufficient, condition for technological penetration in the marketplace.

Unlike research, the task of dramatically increasing energy efficiency and renewable energy penetration is not well funded, and will require substantially greater Federal expenditures and/or the imposition of regulatory requirements to accomplish. The comparison to the Manhattan Project above is appropriate not only relative the scope of the threat of climate change, but the magnitude of the effort and expenditure necessary to address it.

In terms of actually halting the impacts of anthropogenically induced climate change, we may be already too late. Climate systems can take hundreds to thousands of years to reach equilibrium, so we may not be able to judge success for generations. This fact suggests that we need to focus not only on mitigating greenhouse gas emissions, but also on adapting to an altered climate. This area is too substantially underfunded, with little Federal effort currently underway to identify and share regionally specific climate impacts and to plan and implement adaptive responses to such impacts.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO PAUL EPSTEIN, M.D., M.P.H.

Question 1. You note in your written statement that we have the ability to control mosquitoes in the rural areas of the country, but not in the urban areas. How urgent is it that we address this problem in light of the growing spread of the West Nile virus?

Answer. This is an urgent issue, as West Nile Virus is just the first of such urban-related mosquito-borne diseases. Another called Usutu, left Africa recently and has decimated the crow population of Vienna.

Furthermore, while these mosquito-borne diseases are bred in the city (in corner drains, catch basins, abandoned swimming pools and other containers), they spread to wildlife (WNV is in 230 species of animals; though not all get ill), and especially birds (138 species). The latter poses risks for species on the margin—endangered or threatened—with population declines or even extinctions, and threaten to affect biological diversity throughout the Americas. Horses have been greatly affected, with over 14,000 cases in 2002, 1/3 mortality; until equine vaccination was employed (in this country).

The difficulties with mosquito control in the cities are the following:

1. Some insecticides are toxic to humans, birds, and friendly insects (like spiders and dragon flies) that consume mosquitoes.
2. Other insecticides, like the pyrethrins (synthesized from chrysanthemums), are less toxic; but
3. All the insecticides are relatively ineffective in urban settings, as they settle out and do not reach backyards where mosquitoes can persist.
4. The best approach is to place larvicides in drains early in the spring. This is especially important when droughts are developing or persisting (as they are in the west), as the foul, nutrient-rich water remaining in shallow pools during

droughts (here's the climate connection) breed the *Culex pipiens* that bite birds and maintain high levels of virus circulating.

5. Chemical larvicides, however, may be toxic (*e.g.,* to lobsters when they enter bays and estuaries). Methoprine works by disrupting hormones.
6. Initial studies indicate that bacterial larvicides are equally effective. *Bacillus sphaericus* is nontoxic (it is like *Bacillus Thuringiensis Israeliensis,* or *BTI,* used for other mosquitoes and gypsy moths. *Bacillus sphaericus* needs to be more widely employed.
7. Finally, early warning systems of drought, with improved climate and weather predictions can help facilitate timely, environmentally friendly public health intentions.

Question 2. Asthma and its associated illnesses cost the health care system about $18 billion per year. Can you tell us how much of this cost is associated with the treatment of asthma brought on by the increase in carbon dioxide levels?

Answer. I'm afraid it is too early in the study of these expected impacts of CO_2 to assess the attributable fraction. But, given the 2½ fold rise in asthma since the 1980s, and no appreciable change in indoor pollutants (or, of course, genetic predisposition), one might speculate that well over half the costs are due to outdoor pollutants—diesel articles, photochemical smog compounded by heatwaves, and the increase in aeroallergens (pollen and mold). Note all these factors are related to the combustion of fossil fuels.

Question 3. Based upon your previous research, you have concluded that the rise in malaria rates in Latin America, Central Africa, and Asia can be linked to climate change. However, your findings have been challenged by some who claim these increases are attributable to the influx of people from malarious lowlands, major man-made ecological disturbances, such as deforestation, and road and dam construction, which have opened up the areas to malaria transmitting insects. How do you respond to these challenges?

Answer. Changes in the distribution of malaria are multifactoral. Local influences—deforestation, movement of population, susceptibility, drug resistance—all play a role. But the changes in altitude are attributable to climate change for the following reasons:

1. The pattern is global, involving mountain ranges in the Americas, Africa, and Asia. It is a particularly severe problem for populations living in the highlands of Africa.
2. Plant communities are migrating upward in the same areas, as well as in the U.S. Sierra Nevada and the Swiss Alps, *i.e.,* wherever studies are ongoing.
3. Alpine glaciers are retreating at accelerating rates, in the very same mountain ranges.
4. Finally, the freezing isotherm—the level at which the ground is frozen all year round—has moved up 450 feet, equivalent to 2 °F warming, since 1970. This, by definition, means that the *conditions conducive to* ongoing transmission of malaria has shifted upwards in mountain ranges worldwide.

Furthermore, the temperature must exceed a certain level (*e.g.,* 16 °C or 60.8 °F) to sustain transmission of *Plasmodium falciparum,* the most lethal type of malaria.

Question 4. In your written statement you point out that unhealthy air mass with CO_2 levels in the 4, 5, and 6 hundreds [parts per billion] have been found in Phoenix. Can you elaborate on that finding?

Answer. Idso *et al.* (2002) describe these findings, similar to findings in Baltimore, New York City, and Sydney, Australia. Idso *et al.* found daily maximum CO_2 concentrations (at night) peaking at 490.6 parts per million (ppm) during the coldest part of the year (December–January) and 424.3 ppm just before sunrise during the warmest part of the year (July–August). Remarkably, the found a mean-cold season maximum of 619.3 ppm, which is 67.4 percent greater than the rural background value.

- Idso, S, B., C. D. Idso and R. C. Balling, Seasonal and diurnal variations of near-surface atmospheric CO_2 concentrations within residential sectors of the urban CO_2 of Phoenix, AZ, USA, *Atmospheric Environment,* v:36:2002, p1655–1660.

Paper appended.

Question 5. In your written statement you note that bark beetles, brought on by warming, are surviving through the winter and slipping into an extra generation each year. I assume this means there will be more beetles leading to more damaged

and dead trees that will eventually lead to more forest fires. Can you elaborate on this connection and the impact of increased forest fires on the public's health?

Answer. Yes, this is a growing problem for western pines, especially spruce, and is now appearing in the southwest. Drought weakens trees by drying out the resin that drowns bark beetles as they try to penetrate the bark. Warming compounds the problem by (1) increasing the overwintering of beetles, (2) accelerating their reproductive rates, and (3) providing the conditions allowing beetles to migrate to higher latitudes and altitudes.

The wildfires associated with drought are worsened by the dead stands (infested trees die within one year). The public health problem include burns and injuries for firefighters, respiratory disease from the smoke (that can carry long distances), and the carcinogens generated when buildings are burned. There is also property loss, timber loss, damage to habitat, injuries for wildlife and the pulse of carbon that from the fires. Wildfires are, of course, an issue for the insurance and reinsurance industry. Please find the *Washington Post Outlook* piece with more on these issues.

I do want to thank you for your deep concern for our environment, our security and the economy, and for the opportunity to address these issues. I certainly hope that greater attention to the growing biological and economic consequences of an increasingly unstable climate can propel energy policies that jump-start and sustain a transition to clean energy—and, in the process, stimulate the economy. I applaud you for your work in initiating this process in the U.S. and would be pleased to provide any further assistance in the months and years to come.

"Seasonal and diurnal variations of near-surface atmospheric CO_2 concentration within a residential sector of the urban CO_2 dome of Phoenix, AZ, USA

by Sherwood B. Idso, Craig D. Idso, and Robert C. Balling Jr.

was submitted by Dr. Epstein as part of his answer to Question 4. on p. 63. The article was published in *Atmospheric Environment* 36 (2002) 1655–1660.

The abstract of the article follows:

Abstract

Over most of an entire year (315 days), we obtained 1-min averages of near-surface (2-m height) atmospheric CO_2 concentration, temperature and wind speed in a residential area of a suburb of Phoenix, AZ. Daily minimum CO_2 concentrations, which occurred during the afternoon, were nearly invariant over the year, averaging 390.2±0.2 ppm. Daily maximum CO_2 concentrations, however, which occurred at night, varied seasonally with the air temperature, exhibiting a mean peak of 490.6 ppm about 2 h before midnight during the coldest part of the year (December–January) and 424.3 ppm just before sunrise during the warmest part of the year (July–August). Reevaluating prior assessments of the strength of the urban CO_2 dome at the center of Phoenix, our results suggest a mean cold-season maximum there of 619.3 ppm, which is 67.4 percent greater than the rural background value. At our residential site, however, the mean cold-season maximum was only 32.6 percent greater than the surrounding rural mean. Averaged over the entire night, this enhancement dropped to 25.4 percent in the cold season and 10.9 percent in the warm season, while over the daylight period it averaged 10.5 percent and 10.1 percent in the cold and warm seasons, respectively. CO_2 concentrations were greater on weekdays than on weekends from 0415 to 0830 in the warm season and from 0445 to 1045 in the cold season. During peak morning traffic, the maximum weekday–weekend CO_2 differential was 35.9 ppm in the cold season and 22.0 ppm in the warm season.

Keywords: Automobiles; Boundary layer; Carbon dioxide; City climate; Urban environment

Instructions for obtaining this article can be found at *http://www.sciencedirect.com/science/article/pii/S1352231002001590*

Response to Written Questions Submitted by Hon. John McCain to Dr. William R. Fraser

Question 1. In your written statement, you state that your conclusions on impacts of climate change are based upon 25 years of field observations and research in the western Antarctic Peninsula region. What are the most significant observations you have made during your years of field research in Antarctica? What conclusions have you drawn from those observations?

Answer. As I indicated in my written statement, I am an ecologist with a long-term interest in identifying and understanding the mechanisms that regulate the populations of Antarctica's top marine predators, including, in particular, penguins and other seabirds. Because aspects of this question are discussed also as part of my answer to question #4, I will be purposely brief with my answer here, distilling out to the extent possible the key findings and conclusions.

The effects of climate change on wildlife have now been observed throughout much of the world, but identifying and understanding the mechanisms by which climate is inducing these changes has been more problematic. This has been the focus of much of my work, especially with Adelie penguins during the last 15 years. One of the most significant findings in this regard, is the observation that the long-term population trends of AdOlie penguins in the western Antarctic Peninsula region are driven by interactions between the marine habitat in which they feed and the terrestrial habitat on which they breed. Both these habitats are changing in response to rapid climate warming. A gradual decrease in the availability of winter sea ice is denying Addle penguins access to critical winter feeding areas, while an increase in snow accumulation is flooding nesting areas and drowning eggs and chicks. The impacts of these processes are cumulative, negatively affecting penguin survival, and ultimately driving local populations into extinction.

These findings currently guide much of our current research, experimental design and interpretation of our data. The key conclusion regarding the question of how climate warming might induce ecological changes, is that it specifically seems to disrupt the availability of critical resources that species need to survive and reproduce. Addie penguin life history, for example, is critically dependent on winter sea ice, which is decreasing due to warming and negatively affecting populations of this species. Population changes are usually the precursors to changes in the composition of plant and animal communities, and ultimately in the structure and nature of both terrestrial and marine ecosystems. That analogs to our findings are now being observed throughout much of the world, is indicative of a similar, fundamental mechanism through which climate warming is affecting species and ecosystems. It is this finding that in part suggests that preserving biodiversity, as I discuss in my answers to question #4, should be one of the imperative strategies for mitigating climate change effects.

Question 2. I note that you are from Montana and that much of your research has focused on the impact of climate change on glaciers. Would you care to comment on the situation in Glacier National Park?

Answer. In my answer to question 3 below, and also in my testimony, I point out that the glaciers in our long-term study area show evidence of significant melting and retreat during the last five decades. Our interest in these processes are not due so much to the fact that this is a focal point of our work, but rather that glacial retreat makes available new, ice-free land that can potentially be colonized by seabirds such as penguins. This has implications to understanding how the western Antarctic Peninsula marine ecosystem is responding to rapid warming and affecting the populations of top predators that have been the focus of much of my research for nearly three decades. Now directly answering the topic addressed by this question, it is worth pointing out that the very substantial melting and retreat of glaciers that we have observed in our region of Antarctica is actually not a unique situation. Rather, it seems to be part of a large-scale pattern now evident in most of the ice fields of North and South America from Alaska to Patagonia, including Glacier National Park.

Based on research (*http://www.nrmsc.usqs.qov/research/qIaciers.htm*) by the USGS, only 50 small glaciers remain in Glacier National Park. Although these glaciers have been receding since they were first described in 1901, tree-ring studies indicate that this recession actually began in about 1850. It is estimated that at that time there were more than 150 glaciers within the boundaries of the area now encompassed by the park. Change in these glaciers, moreover, is consistent with an increase since 1900 of approximately 1 °C in average summer temperatures. Many smaller glaciers originally present in the park have disappeared completely and some of the remaining larger glaciers are now approximately ⅓ the size they were in 1850. There has also been a 73 percent reduction in the area of Glacier National Park covered by glaciers, from 99 km^2 in 1850 to only 27 km^2 in 1993 when the last major surveys were undertaken. Computer models now predict that if present rates of warming continue, the remaining glaciers in Glacier National Park will disappear by 2030. The situation in Glacier National Park is thus another example of a climate warming signature that is in fact coherent over global scales.

Question 3. In your written testimony, you state that the amount of ice-free land which has been redefined by glacial retreat in Antarctica includes the exposure of

four new islands that were unrecognized on maps and charts prior to 1995. Can you elaborate on this finding and its implications?

Answer. The charts and maps to which I refer in this testimony encompass the southwest coast of Anvers Island, and were compiled over the course of about 20 years beginning in 1950 by British, Chilean, Argentine and American cartographers. If one compares these older maps and charts with more recent ones, one can see that the original margins of the glacier that covers much of

Anvers Island have retreated inland away from the sea. As a result, land that was originally covered by glacial ice, and characterized as either not exposed or only partially exposed in the older charts and maps, is now ice-free. The four islands discussed in my testimony represent such land areas. In the older documents these appear as small peninsulas along the coast that, based on naming conventions, were clearly regarded as land areas that were physically connected to the Anvers Island mainland. Subsequent glacial retreat, however, has revealed that these peninsulas are actually islands that are physically separated from the mainland by the ocean. Because of these changes, many of these older charts and maps no longer portray the coastlines in this region accurately. A more serious implication, however, stems from the fact that our local observations of glacial recession are in agreement with similar observations in many other regions of the world, and which bear directly on the issue of potential changes in sea level. Much of the western Antarctic Peninsula is glaciated, meaning that inputs of melt water into the ocean could as a result of continued regional warming contribute directly to a rise in global sea levels.

Question 4. Your written testimony presents concrete examples of the effects of global warming on the animals that live in Western Antarctica. How is this significant to human beings, and what should we be doing to address this problem?

Answer. Researchers from many different disciplines have generally agreed that the effects of climate warming, if and when it occurred, would be observed first and most directly in the polar regions, the Arctic and the Antarctic. This prediction was advanced long before climate warming became the prominent issue that it is today, and encompassed many corollaries on the impacts this warming would have on a range of variables and processes, from changes in sea levels to the responses of plant and wildlife populations. Within the context of these predictions, the significance and implications of our research in the western Antarctic Peninsula region to human beings can be summarized by highlighting two main points.

The first is that most of the early predictions about climate warming and its possible effects in polar regions strongly concur with our observations during the last three decades, a point that becomes even more significant if the results of Arctic research are also considered. The relevance of these findings are clear. There is no longer a valid reason to be skeptical about the reality of climate warming, nor about its potential to negatively alter the marine and terrestrial ecosystems on which the globe's 6.5 billion people are currently dependent. The Arctic and Antarctic are not only proving to be extremely sensitive barometers of climate change impacts, but the fact that current trends in these regions show no evidence of abatement certainly portends of a much warmer future for the earth as a whole.

The second point, and perhaps one of the most critical to consider for our times, was not completely anticipated, and thus emerged as somewhat of a surprise. This is the rapidity with which changes are actually occurring at the poles, both in terms of their respective warming trends and the response times of various ecosystem components. If there is a take-home message to consider based on our work in the western Antarctic Peninsula region, it is that the timelines for virtually all the changes we have observed have been remarkably short, in fact, far shorter in most cases than the span of a human lifetime. Also important, is that even within the scope of these relatively short timelines, the pace of change of many physical and biological ecosystem components has neither been gradual nor consistent. A case in point is illustrated in Figure 3 of my testimony, which shows that the post-1990 collapse of Adelie penguin populations was nothing short of catastrophic compared to population changes during the entire pre-1990 period. Consistent with this pattern, and notable because it encompassed a very different event, is the recent collapse of part of the Larsen Ice Shelf, which was widely reported by the media and documented in part by Argentine researchers as eye-witnesses. This shelf is located approximately 90 km due east and slightly north of our focal study area. In 2002, over the course of only 46 days, the Larsen Ice Shelf shed 3320 km^2 of ice, with the last 2500 km^2 falling away as a catastrophic disintegration. Geological evidence suggests this ice shelf had been stable for thousands of years prior to this event. Thus, to the extent that our research shows that the western Antarctic Peninsula region is a sensitive barometer of climate warming, it is the pattern or blueprint of change we have documented that presents the most troubling scenario from a global perspective. The implications are clear. Major environmental changes due to climate

warming could occur very rapidly, not unrealistically in the next 30–50 years, and encompass catastrophic events from which recovery to pre-event conditions may be difficult or impossible.

Turning now to the question of what we should be doing to address global warming, refocusing energy policies and preserving biodiversity should in my opinion be at the forefront of possible mitigating actions. A recent paper in the 10 June issue of the journal *Nature* based on a 740,000 year old Antarctic ice core concludes that the greenhouse gas carbon dioxide today exceeds by 30 percent the previous concentrations of this gas over the past 400,000 years. Through their activities, particularly the use of fossil fuels, human beings are having a significant impact on the earth's climate, and this ice core is a most remarkable record supporting this conclusion. In agreement with the observations of others, it seems essential to me that conservation rather than exploration, combined with increasing investments and research on renewable energy and emission control technologies, become the immediate focus of any new national energy policy. Coupled to this effort, we need to dramatically increase and enforce measures that promote and protect global biodiversity, including, especially, remaining, reasonably intact and pristine marine and terrestrial ecosystems. Apart from the societal benefits that can be derived from these ecosystems, biodiversity protection can potentially buffer key natural processes from the impacts of climate changes. These processes range from the genetic diversity of populations to the integrity and composition of species reservoirs that will form the raw materials of future ecosystems. Finally, and based on what we have documented in Antarctica, it seems clear that our response horizon to address climate change issues is probably much shorter than we realize, probably no more than 10–15 years, if we consider the lag times that mitigating measures will require before they begin offsetting the stresses converging on the earth's ecosystems due to the combined effects of climate warming and the demand for resources by growing human populations. In this light, the two mitigating measures discussed are particularly appealing because much of the groundwork with respect to implementation and cost-benefit ratios is already available, for example, in the core studies associated with the Kyoto Protocol and the most recent reports of the Intergovernmental Panel on Climate Change. What seems to be missing at the moment in terms of going forward with these crucial actions, is the right political environment.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO PHILIP W. MOTE, PH.D.

Question 1. You state that it is unlikely that precipitation will increase fast enough to offset further warming in the West. What does this mean for the future survivability of the region?

Answer. Future climate-driven reductions in water supply will add to the population-driven increases in demand. Increasing conflicts over water are likely, but will not threaten the "survivability" of the region. Rapid population growth in arid areas like Phoenix and Las Vegas could continue, but at some point in the near future (even without climatic change) available sources of water will be insufficient and demand will have to be met by reductions in per capita consumption, for example by eliminating the use of landscaping that requires large amounts of water. Irrigated acreage is likely to continue to decrease in areas with chronic water shortages, with a permanent (or drought-contingent) transfer of some existing water rights to municipal and industrial (or other) uses. Such transfers are already taking place in many areas of the West.

Question 2. Much of the Western U.S. is heading into its sixth year of drought. How does this past year's decreased snowfall affect this continuing drought situation?

Answer. In much of the West, snowfall from October 2003 through February 2004 was near-normal, but a very warm dry spring caused record-fast decreases in snowpack during March and April. By May 1 most of the West had less than 50 percent of normal snowpack, greatly reducing water storage. The rapid loss of snow did not translate into greater runoff, because soils were unusually dry and absorbed much of the snowmelt.

Question 3. With much of the snowpack melting and heading downstream earlier and earlier each year, the risk of floods is increased. Can you elaborate on how we could go from flooding in the spring to droughts in the summer? What type of stresses does this put on the environment?

Answer. The risk of floods does not necessarily increase with warming. In basins where flooding is caused by rapid spring snowmelt, *i.e.,* most of the rivers in the West except coastal basins and smaller basins in the Southwest, a reduction in snow

accumulation means on average less flood risk. Changes in spring precipitation regimes could offset these effects, but there is little conclusive evidence that such changes will be large enough to increase flood risks. In mixed rain-snow basins, like many in the Northwest and parts of California, warming means that precipitation that might have fallen as snow and melted later falls as rain, melting snow already on the ground. Thus a substantial fraction of the basin has simultaneous runoff, at the same time as infiltratration is limited wet (or frozen) soils, hence increasing the risk of flooding. In effect the basin area becomes larger in winter in a warmer climate—meaning that the same amount of precipitation would produce more outflow. Variability of winter flows would also increase in general. The earlier snowmelt runoff pulse results in an earlier start of the annual summer drought period with no precipitation and lower flows, effectively requiring to stretch stored water supplies over a longer interval. Lower (and warmer) flows can have important consequences for ecosystems. For example, lower and warmer freshwater inflows to the San Francisco Bay, can increase salinity and disturb ecosystems, lower and warmer streams are detrimental to salmon runs.

Question 4. Where are the areas of the West where precipitation has increased and can they offset the areas with declining precipitation?

Answer. There have been widespread, modest increases in precipitation over much of the West since 1916, but the changes are generally not very big compared with year-to-year and decade-to-decade variations, unlike the changes in temperature in most places. Considering only the period since 1950, widespread and substantial increases in precipitation are limited to the Southwest, and these increases are with respect to the 1950s drought in the Southwest region. In addition, natural variability of annual precipitation is higher in the Southwest than in the rest of the West, thus it is unlikely that these patterns of variability can be relied on to stay the same over time, and designing infrastructure to capitalize on existing trends is probably a bad idea unless such systems can also be shown to function well in other circumstances. Furthermore, reductions in precipitation in one area can only be offset by increases in precipitation in another where conduits (rivers, canals, or pipelines) exist to move the water. Another problem is that there is frequently very strong social and political resistance to moving water between basins, even if the water is not currently needed in one area and is badly needed in another.

Question 5a. Should we expect to see continued dwindling amounts of snowpack in the future?

Answer. Yes. Warming by itself, which has been observed and is virtually certain to continue owing to the accumulation of greenhouse gases, will reduce snowpack in most places where winter temperatures are at least—10 °C (+14 °F). Rates of decline have been and will continue to be greatest in places with mildest climate: the Oregon Cascades and the mountains of northern California. Precipitation variability will change over time, and there will be dry and wet periods in different regions with higher and lower spring snowpacks, but snowpack will be lowered in each case because of warmer temperatures.

Question 5b. What do you think will happen to the West's ecosystems if we continue to see greatly reduced snowpack?

Answer. The answers are very place-specific. We know from examining records of the last 50–100 years that high-elevation productivity increases (trees grow more, and over the long term forests invade alpine meadows) when snowpack is reduced, while at moderate and low elevation, lower snowpack and earlier snowmelt dries out soils, reduces forest productivity, raises likelihood of forest fires, increases forest susceptibility to insect infestations, and over the course of decades to centuries can transform the dominant forest types as well.

Changes in snowpack have many consequences beyond simply ground cover: it is a dominant factor for ecosystem changes, in some cases suppressing activity and in other cases protecting or enhancing plants and animals. Change in reflectivity of the surface affect soil temperature; changes in timing and quantity of snowmelt affect soil microbes, which help determine soil nutrients and hence plant productivity. Meadows have more biodiversity (variety of species, including insects and large grazing mammals) than forests, so a conversion from meadow to forest reduces biodiversity.

Higher air temperatures and lower summer streamflows, direct consequences of warming and reduced snowpack, will tend to increase water temperatures in rivers. These changes will have further consequences for aquatic ecosystems, particularly for heat-intolerant species like salmon and trout, with indirect but important consequences for other species. Chemical properties of water change with temperature as well, and some aquatic species are very sensitive to chemical composition and temperature. Water temperature and the timing of streamflow also directly affect

the lifecycle of various species—for instance, increased water temperatures or the timing of spring peak flow may cause eggs to hatch earlier and may cause juveniles to be flushed downstream earlier in the spring, with subsequent impacts in the estuaries or the coastal ocean (*e.g.,* adequate food supply missing earlier in the spring). Migration of adults in the fall may be delayed due to low streamflow and/or high water temperatures.

Prepared by Philip Mote with input from Dr Dan Fagre, Mr Alan Hamlet, Dr his Stewart, and Dr David L Peterson.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. GEORGE ALLEN TO PAUL EPSTEIN, M.D., M.P.H.

Question 1. Dr. Epstein, your views are based on the belief that global warming will make the world warmer and wetter. A wetter and warmer world, in your view, will increase the breeding grounds for mosquitoes and increase the incidence of vector borne diseases. Please furnish the Committee with copies of your original research and related data sources that lead to and support this conclusion?

Answer. Thank you for this opportunity. The relevant data are found in the following papers:

http://www.med.harvard.eduichge/BAMS.pdf
http://www.med.harvard.edu/chge/Climate.pdf

Question 2. Please provide the Committee with the evidence that changes in the transmission of vector borne diseases are due to climate?

Answer. I refer you to the Health Chapter from the Third Assessment of the Intergovernmental Panel on Climate Change, 2001

http://www.grida.no/climate/ipcc_tar/wg2/347.htm

and, especially, the work in that document by Pim Martens and Anthony J. McMichael, which reviews the relevant data and understanding.

I also refer you to the 1PCC 2001 Working Group II on Impacts chapter:

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

http://www.grida.no/climate/ipcc_tar/wg2/007.htm

for a comprehensive examination of how many species—including birds, butterflies, trees and marine life—are responding to warming (especially to warmer winters, occurring twice as fast as overall warming since 1970, as over wintering is key to these biological responses).

Question 3. It has been suggested that malaria and dengue and yellow fever are tropical diseases. Explain, therefore, dengue and yellow fever as far north as Boston and the prevalence of malaria in England during the Little Ice Age?

Answer. The conditions conducive to ongoing transmission of these mosquito-borne diseases have existed outside the tropics in many eras. There is a lower temperature threshold, however. If temperatures remain below 16 °C (60.8 °F) all year around, for example, this would prevent transmission of Plasmodium falciparum, the most lethal type of malaria.

Question 4. Please provide information on malaria outside of tropical climates and areas where temperature got colder, not warmer?

Answer. Please see the first paper mentioned above from the Bulletin of the Meteorological Society. Regarding the second part—when temperatures got colder—please see the publications of Paul Reiter.

Question 5. Do you agree that the widespread disappearance of malaria has been due to the loss of mosquito habitats, control techniques, a smaller rural population, better farming practices, medical care and improved living conditions? If not, how do you explain such large differences in the incidence of malaria between the Texas and Mexican sides of the Rio Grande?

Answer. Yes I do. Socioeconomic issues, screens, etc. would account for the difference. Climate conditions that allow transmission of dengue fever are present on both sides of the border, but these conditions are necessary for maintaining transmission, but are not sufficient for transmission: other factors also certainly contribute.

Thank you again for this opportunity to address these concerns.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN F. KERRY TO KENNETH A. COLBURN

Question 1. In July 2003, nine states, including Massachusetts, formally agreed to join New York in developing a regional strategy in the Northeast to reduce greenhouse gas emissions. The strategy entails a market-based emissions trading system that would apply to power generators emitting carbon dioxide into the atmosphere. Would the cap and trade program be limited to power generators in the Northeast, or would a Northeast plant, for instance, be able to sell some of its credits to a plant from another region?

Answer. The multi-state effort referenced is called the Regional Greenhouse Gas Initiative (RGGI). Nine states have joined in this initiative as full participants (CT, DE, ME, MA, NH, NJ, NY, RI, and VT), and other jurisdictions are participating as observers (DC, MD and PA). The Eastern Canadian Provinces are also observers, represented by the province of New Brunswick.

RGGI is in now the process of doing the technical and analytical work necessary to prepare a model rule for a cap-and-trade program limiting carbon dioxide emissions from the power sector. RGGI's initial effort is targeted for completion in April 2005. Individual jurisdictions will then proceed to implement the program through their existing legislative and/or regulatory processes. Although greenhouse gases other than carbon dioxide will not be included initially, other greenhouse gases are likely to be included in later phases of RGGI. Similarly, RGGI may expand to include sources outside the power sector in later phases. In addition, "offsets"—reductions elsewhere made by and/or paid for by power sector participants—may eventually be accepted as meeting compliance obligations under the program. The ultimate character of the final RGGI cap-and-trade system awaits several decisions to be taken between now and April 2005, so accurate characterizations of its future provisions are not possible at this time.

As a general response to this question concerning emission reduction credit sales outside the Northeast, allow me to offer the following. It is unlikely, in my view, that RGGI would constrain the ability of power sector participants to sell credits (representing emission reductions above and beyond those the participants themselves need to comply with RGGI's cap) to willing buyers outside the Northeast. What is significantly less clear, however, is what would motivate outside buyers to purchase such credits, since they are unlikely to be subject to RGGI's emission reduction obligations. As for allowing RGGI sources to *buy* credits from sources outside the Northeast, as noted above, the RGGI participants may decide to allow transactions involving "offsets" to count toward the compliance obligations sources face under the anticipated cap-and-trade program.

A larger question concerns whether the RGGI cap-and-trade program might be expanded to include other states, conceivably even states non-contiguous to the Northeast. My understanding is that every effort is being made to design the RGGI program in such a fashion that not only would this be possible, it could occur relatively simply. Since greenhouse gas emissions represent a global—rather than regional—risk in terms of their impact, the addition of other states to the RGGI program in the future should be enabled and encouraged.

Question 2. How precise are the measurements of greenhouse gas emissions from certain sources and regions of the country? For instance, does one region in the country generate a greater percentage of greenhouse gases than other regions, or is it fairly equal?

Answer. There is certainly ample room for improvement in the calculation of greenhouse gas emissions (known as "inventories") from regions, states, sources, and even natural processes (*e.g.,* decay). However, the vast majority of greenhouse gas emissions result from fuel combustion, and because fuel consumption is reasonably well tracked, emissions profiles are sufficiently accurate to support climate action.

Regional emissions and emissions per capita vary fairly significantly across the country. Several factors are responsible, including the fuels primarily used for power generation (*e.g.,* coal-burning areas typically have higher emissions) and transportation, economic character (*e.g.,* high tech vs. low tech, services vs. manufacturing, etc.), relative sector sizes (*e.g.,* transportation, power, etc.), age of vehicle fleet, etc. Per capita emissions in California—which has little coal combustion—are approximately one half of the national average. Emissions vary significantly within regions as well. In the Northeast, for instance, per capita emissions by state vary by ±30–50 percent.

Question 3. What measurements and monitoring systems are needed to further our understanding of the sources and impacts of greenhouse gases? It seems to me that if we are to effectively regulate emissions and control global warming in this

country, we need to build the science foundation upon which these regulations would be based.

Answer. There is no question that continued efforts to improve our scientific understanding of climate change, its impacts, to what extent it can be curtailed, and how we might most effectively adapt to changes that can't be avoided is vitally needed. Climate change is the greatest threat facing the sustainability of the planet as we know it and the species that have evolved on it (including homo sapiens). Therefore, dedicated efforts on the scale of the Manhattan Project or America's lunar landing are appropriate with regard to scientific understanding, mitigation, *and* adaptation).

That said, understanding is a dynamic, iterative process, not a static state. We have enough understanding now to warrant concerted action. Greater understanding in the future will help refine or adjust future action, but our quest for greater knowledge must not be used as an excuse to avoid concerted action at this time.

Redoubled research into atmospheric characteristics, processes, history, and changes (*e.g.,* through monitoring, satellite measurements and remote sensing, modeling, analysis of proxy indicators, and similar strategies) is vital for greater understanding of the nature, rate, and risks of climate change (*e.g.,* can we expect linearity from the Earth's systems, or should we expect the unexpected?). Because climate impacts are likely to vary substantially over geographical and temporal scales, regional climate simulation should be a particular priority for greater understanding, as difficult as it currently may be.

Many steps that would directly improve our practical knowledge are also readily available. Federal leadership in determining protocols to clearly and consistently quantify greenhouse gas emissions from various source categories and activities would help sources grasp (and perhaps reduce) their emissions profiles, leading to a clearer overall emissions inventory picture. Mandatory reporting of greenhouse gas emissions should be required of sources for the same reasons. Similarly, proposed transportation projects should be required to quantify and disclose their attendant greenhouse gas emissions consequences. Consistent with America's tradition of transparency, such information should be made publicly available, by source, sector, and state, along with appropriate trend information. Similar Federal efforts to quantify the emissions reductions (and cost savings) available from mitigation measures (*e.g.,* from energy efficiency steps) could also help significantly, not least in terms of consumer awareness and market penetration, particularly in the commercial and residential sector.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN F. KERRY TO WILLIAM CURRY, PH.D.

Ocean Circulation

Question 1. Dr. Curry, in your testimony you stated that the effects of abrupt climate change would be felt regionally as opposed to globally. Can you give some examples of what could theoretically occur in certain regions, specifically in the United States, in the event of an abrupt climate change?

Answer. The effects differ depending on when an abrupt change occurs since rising greenhouse gases in the atmosphere will continue to warm the planet. An abrupt climate change caused by a decrease in Atlantic Ocean overturning circulation, if it were to occur in the next several decades, would have its greatest impact in the circum-North Atlantic region. Colder winters would be felt in eastern North America and western Europe leading to possible societal impacts such as increased energy demand. If the overturning circulation were to shut down (an unlikely prospect according to current model predictions), there would be widespread drying in North America, Africa, and Asia, particularly in the monsoon regions with concomitant impacts on agriculture and water resources.

If an abrupt change caused by a decrease in Atlantic Ocean overturning circulation occurs in a century or more, the average temperature of the planet will be much higher. A change in circulation may mitigate the effects of this warming in the North Atlantic region, but winters would not cool to levels below those experienced today.

Other potential causes of abrupt climate change also exist which can have widespread climate impact. For instance a change in the frequency or amplitude of the El Niño-Southern Oscillation system would cause significant climate responses, including changes in precipitation and evaporation patterns over much of the United States with impacts on the frequency and intensity of droughts, floods, and wildfires.

Question 2. You mentioned that the salinity changes being observed in the tropics and the poles are unprecedented in the short history of oceanography. However, we know they have happened in past abrupt climate change events such as the "Younger-Dryas" and the "Little Ice Age". Do oceanographers have the data necessary from these past events to compare the rates of salinity change between the past and the present? If so, please explain how the rates compare and if not, what data are we lacking that would assist oceanographers in the comparison?

Answer. Quantitative estimates of the rates of past salinity change are difficult to produce in geological archives such as marine sediment cores because the resolution of short-term events is poor and because geological estimates of past salinity do not have the same level of accuracy as modern measurements. Some work is underway using very high resolution records and we may see progress in this research in the near future. Yet much remains to be done to understand how the ocean differed in the past. We still lack high resolution records of past salinity from the Arctic Ocean, from subpolar regions of the Atlantic and Pacific Oceans, from many tropical locations around the globe, and from most of the southern hemisphere. Development of records from these regions would greatly improve our understanding of past changes in salinity and ocean circulation.

There is a sound, qualitative understanding about past freshening events. The freshening events observed in the geological record were most often associated with the sudden release of freshwater caused by the collapse of glacial ice dams. As a result, very large amounts of fresh water were suddenly and abruptly released into key areas of the oceans, causing rapid changes in salinity and ocean circulation. In contrast, the freshening observed today is gradual—caused by gradual melting of sea ice, glacial ice and by a gradual increase in precipitation at higher latitudes. The added freshwater can be traced in the deep waters along the western boundary of the Atlantic nearly to the equator. So far there has been little effect on ocean circulation. It is not clear how the ocean and climate system will react to this gradual freshening.

In my opinion there is a clear need to increase the level of government support for geological reconstructions of past abrupt climate change to make significant progress in this area. Research supported by the National Science Foundation (NSF), particularly the Earth System History (ESH) program in the Geosciences Directorate, and research supported by the National Oceanic and Atmospheric Administration (NOAA) are directed toward this goal.

Question 3. You stated that oceanographers do not know if these salinity changes indicate that we are approaching a threshold that could trigger a change in ocean circulation. What is the current state of the research being done to figure out what this threshold may actually be? What, if any, technological advances are necessary to further this research?

Answer. Several approaches are being pursued to better understand the ocean circulation and how it might be perturbed. Overall we are still far from predicting the threshold behavior of the oceans, but research in three areas will improve understanding.

First, there is a nascent observational system in the ocean which is designed to study and monitor changes in ocean properties and circulation. The goal is a system with global coverage much like the weather system that monitors changes in the atmosphere. The ocean observation system is still inadequate in several ways: observational systems are missing from key areas (for instance, many polar and subpolar regions of the oceans in both hemispheres) and there are technological challenges that need to be overcome in order to study certain processes (for instance, the deployment of mooring systems and autonomous underwater vehicles beneath sea ice). Some of the important processes in ocean circulation occur in winter at high latitudes and in regions with significant ice cover, which prove to be significant challenges to monitor hydrographic changes.

Second, numerical model simulations of the oceans continue to improve, but certain ocean circulation processes are poorly simulated in the current models. The geographic distribution and rates of ocean mixing are unrealistic in current models. Some models have difficulty reproducing the modern salinity distributions, so it is unclear how reliable they are for predicting the future state of the oceans or if the oceans are approaching a circulation threshold. Improved understanding of ocean circulation processes and improved model parameterizations are both needed to make progress. These are challenges that will require research funds to better understand ocean circulation processes and collaborative research efforts among modelers and oceanographers to improve the simulation of the process in computer models.

Third, more geological reconstructions are needed to improve our understanding of the past behavior of the oceans. The modern history of oceanography is too short

to have experienced the full magnitude of change that the ocean is capable of. Geological studies will remain one of the best ways to "observe" ocean circulation behavior and improve understanding of threshold behavior in the ocean-climate system.

These are research challenges with great societal importance but the resources to address the challenges are inadequate. According to the report of the U.S. Commission on Ocean Policy, government funding in ocean sciences has lagged other R&D funding in the United States during the last several decades. To address this shortfall and to provide the science needed for sound ocean policy, the commission report recommends doubling ocean sciences funding over the next five years.

Question 4. If ocean circulation does begin to slow to a point where abrupt climate change becomes a serious threat, what will be the earliest observable indicators? How can the U.S. improve our ocean observation program so that we will be prepared to recognize these indicators if and when they occur?

Answer. The earliest indicators of slowing Atlantic overturning circulation are likely to be in the decreased rate of flow of deep, cold, salty water across the straits separating the North Atlantic from the Norwegian Greenland Sea, and along the western margin of the North Atlantic. There may also be changes in the distribution of hydrographic properties (temperature and salinity) and the vertical and horizontal density gradients seen in the North Atlantic and its adjacent subpolar seas. The extent of sea ice in the Arctic Ocean and the exchange of freshwater between the Arctic and North Atlantic Oceans may also prove important early indicators of changes in hydrography and circulation.

Because the ocean changes slowly, it will be difficult to separate natural variations in these observations from those caused by greenhouse warming of the earth. Thus a long-term commitment must be made to fully understand the changes in the oceans, with a commitment to observe the oceans with a global array of monitoring instruments. Deploying an integrated, global system to monitor and observe the oceans is one recommendation of the report of the U.S. Commission on Ocean Policy. Like the global system in place to observe changes in weather, the development of a large scale ocean monitoring system will provide significant new information about the changing state of the oceans and significantly improve forecasting of future changes in ocean circulation and climate.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN F. KERRY TO PHILIP W. MOTE, PH.D.

Question 1. In your testimony, you state that observed spring snowpack has decreased in Western states over the past 50 years, which has major ramifications for the region's water supply. You mention that Federal legislation may be needed to help agencies adapt to changing flows. Can you elaborate on what legislation would be needed?

(answers prepared by Alan F. Hamlet, Dept of Civil and Environmental Engineering, University of Washington: *hamleaf@u.washington.edu*)

Question 1a. Why should the Federal Government have a prominent role in this issue?

Answer. Water resources planning and management impacts everyone in the country, and climate affects water resources.

Poor planning has high costs down the line. Without the inclusion of climate change in long range water planning, the integrated and cumulative impacts of global warming have the potential to cost the Federal government and the U.S. populace a tremendous amount of money over time via unanticipated impacts of droughts and floods and other indirect effects to forests, lakes, and coastal areas.

Climate change will potentially disrupt important transboundary agreements between the U.S., Canada, and Mexico, and between states that share water resources. The Federal Government is probably in a better position to look towards effective and sustainable long term solutions than the individual partners in these agreements.

Adaptation to climate change will take time, and waiting for a series of crises to emerge on a case by case basis, while perhaps politically expedient, is unlikely to successfully avoid impacts. Proactive adaptation is needed. The Federal government is in a position to take a leadership role and to provide specific incentives to act.

Many water management agencies in the U.S. (perhaps most notably the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation) are Federal agencies. These agencies *implement* Federal policies, but cannot in general act on their own to *change* policy. Our experience in the Pacific Northwest suggests that these agencies will include global warming in their long range planning only when Federal guidelines and legislation unambiguously direct them to do so.

Question 1b. What might Federal legislation to encourage more effective long-range water planning for global warming look like?

Answer. Federal guidelines for water planning carried out by Federal water management agencies could include specific directives to:

- Assess the potential risks of climate variability and global warming as part of long range planning,
- Develop specific contingency plans to cope with climate uncertainty (*e.g.,* better drought plans, like the measure pushed by the Western Governors Association),
- Identify "no regrets" strategies that are likely to be effective in both resolving current problems and reducing future vulnerabilities to climate variability and global warming,
- Identify sustainable long-term management options and their costs,
- Develop tools and procedures and an a strategy for streamlining ongoing adaptations to avoid incurring planning "start up" costs over and over again as global warming progresses.

An Example from the Pacific Northwest

Planning Activity

At the request of various Federal agencies including the Bonneville Power Administration and the Northwest Power and Conservation Council, the U.S. Army Corps of Engineers is preparing to conduct a formal review of flood control policy in the Columbia River basin. Flood control is an important water resources objective in its own right and also has major implications for most other water management activities in the basin, including hydropower production and the protection and restoration of Columbia River salmon runs. Specific activities that have been proposed include remapping of flood plain areas (last done about 25 years ago), assessing the state of protective structures such as levies and dykes, reassessing flood risks based on more people and structures in the flood plain, evaluating alternative flood control management policies to improve efficiency of flood control in the attempt to reduce unintended impacts on other system objectives.

Climate Connection

Altered precipitation and snow accumulation and melt patterns in the Pacific Northwest, probably already underway as a consequence of global warming, have the potential to exacerbate winter flood risks in moderate elevation areas, whereas spring flooding may be systematically reduced over time. Peak flows may come earlier in the year, and current flood evacuation practices may jeopardize reservoir refill by failing to capture some of the (decreasing) spring freshet. Flood risks may be significantly altered by changing hydrologic regimes, and Federal insurance programs need better information upon which to set land use guidelines and flood insurance premiums.

What Role Could the Federal Government Play?

Given that Federal funding will be used to conduct this study, the Federal Government could stipulate that the potential effects of global warming should be evaluated as part of the study, and an ongoing adaptation strategy be specified as a deliverable component of the study. Such a strategy might include monitoring activities, research, contingency planning, development of more effective management and data collection systems, and streamlining of future system performance reviews.

Other Water Planning and Management Activities with Federal Oversight Likely to be Affected by Global Warming

FERC relicensing of hydropower projects

Long-range planning at Federal agencies such as the Bonneville Power Administration, U.S. Army Corps of Engineers, and U.S. Bureau of Reclamation

NMFS Endangered Species Act consultation

FEMA planning guidelines (both land use guidelines and actuarial issues)

Irrigation policies using Federal storage projects (*e.g.,* USBR projects)

International negotiations with Canada and Mexico (Columbia River Treaty, Great Lakes, Colorado River)

Other interstate or international compacts to maintain instream flow or water quality

In some cases quantitative guidance can be provided (*e.g.,* about ranges of future summer streamflows) to these planning processes.

Question 2. Last year, Washington and Oregon [we add: and California] announced plans to develop a coordinated strategy to reduce global warming. What are the specific goals and details of that strategy and what steps have been taken to begin implementing it?

(answer prepared by Philip Mote, Climate Impacts Group, University of Washington)

Answer. The answers to this question fall outside our expertise, but it is our understanding that the state task forces are still in the stage of generating and evaluating proposed steps, with a comprehensive plan to be drafted later this year. Each of the states, however, had already taken steps to reduce greenhouse gas emissions, for example by mandating lower vehicle emissions and higher fuel economy (California) or requiring mitigation of CO_2 emissions by new power plants (Oregon and Washington). For details, contact the office of each state's governor.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. FRANK R. LAUTENBERG TO WILLIAM B. CURRY, PH.D.

Question. Dr. Curry, my home State of New Jersey, with more than 127 miles of densely populated shoreline, has been rising at about 1.5 inches per year or about double the high estimate for the globe. Clearly, New Jersey is at risk of extensive coastal damage in the coming years. EPA predicts that by 2100, New Jersey's sea line will rise by 27 inches. That represents an enormous loss in terms of the human and economic costs. Is it known how such a major increase in sea level might impact New Jersey, its coastline and coastal towns?

Answer. This question is in an area well outside my expertise but I will make some general comments. Global warming causes sea level to rise in two ways. First, as the ocean warms, it expands in volume. To the extent that warming is gradual, this thermal effect on the oceans will be experienced as a gradual rise in sea level. Global warming also is increasing the rate at which glacier ice is melting. The meltwater is flowing to the oceans causing sea level to rise because the ocean is gaining water that was previously locked up as ice on land. The melting effect on glaciers may be experienced as gradual sea level rise, but may also occur in sudden, rapid increases in sea level if glaciers suddenly collapse.

It is clear that rising sea levels will have a great impact on coastal states like New Jersey. The effects will be felt in the gradual loss of coastal property as sea level rise increases beach erosion and causes beaches to retreat. More catastrophic impacts may result during severe storms and flooding as the shoreline encroaches on developed properties. The mitigations costs of sea level rise are likely to be very high. They will also be more easily addressed if sea level rise continues to be a gradual process. Sudden collapse of glacier ice would make mitigation strategies more problematic.

Because this is a research area well outside my own expertise, I am unfamiliar with specific reports that address the effects of sea level rise on New Jersey. Two local New Jersey researchers would be better able to address these issues: (1) Kenneth G. Miller of the Department of Geology, Rutgers University and (2) Norbert P. Psuty of the Institute of Marine and Coastal Science, Rutgers University. These individuals are measuring the current rates of sea level rise for New Jersey and are also familiar with any specific assessments of the impacts of such a rise.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. FRANK R. LAUTENBERG TO PAUL EPSTEIN, M.D., M.P.H.

Question 1. Dr. Epstein, I am astonished that 30,000 to 35,000 people died in Europe from the terrible heat wave which occurred there last summer—and apparently after all the data are reported that number is likely go up. The Earth Policy Institute warns that such deaths are likely to increase, as "even more extreme weather events lay ahead". Do you believe there is a likelihood of such a devastating heat wave occurring in the United States?

Answer. Yes the losses were enormous and the European heatwave, Summer 2003 was also associated with wildfires, with implications for air quality (ozone levels in Switzerland) and the timber industry; crop failures and food trade; glacier extent (est. 10 percent loss in Swiss Alps) and the hydrological balance (water availability and water quality, and sensitivity to future extreme precipitation events); for tourism; and subsequent monitoring and preparation for heatwaves (est. $500 million in France alone).

The costs (damages) from climate change published in the IPCC Third Assessment Report (2001) are primarily from property and casualty losses. The figures—

that rose from $4 billion annually in the 1980s to $40 bn/yr in the 1990s and are projected to rise to $150 bn/yr within this decade—do not include the costs associated with life and health losses and the impacts on natural systems from climate extremes and diseases.

Another event, also lying well outside two standard deviations of weather variability, occurred in Southeastern Haiti in May, 2004. There, flooding occurred after five feet of rain fell in 36 hours (!); >2 inches a day is the measure used for an extreme precipitation event. Hurricane Mitch in 1998 brought six feet of rain over three days. "Outlier" events appear to already be occurring more frequently.

The IPCC Third Assessment Report (2001) concluded that extreme weather events are becoming more extreme and many (*e.g.*, heatwaves, floods) are becoming more frequent. In 2003 the World Meteorological Organization reiterated the association of anomalous and severe weather with the heat building up in the atmosphere and deep oceans.

Question 2. Dr. Epstein, in your discussion of forests, you described the heat-induced proliferation of beetles and other insects that are devastating forests. In my home state of New Jersey, thousands of acres of forest have become infested and thousands of trees have died. Is it possible to know if these infestations are "natural" or the result of climate change?

Answer. Bark beetles are a natural part of the forest ecosystem, but climate change is encouraging the proliferation of the infestations in two ways:

1. Warming leads to their overwintering, migration to higher altitudes and latitudes, and more rapid and frequent reproduction; and
2. Drought dries out the resin (or pitch) that drowns the beetles as they bore trough bark; thus decreases the resistance of the trees.

Both warming and more prolonged droughts are part of climate change. Please see accompanying Outlook article from *The Washington Post*.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. FRANK R. LAUTENBERG TO DR. WILLIAM R. FRASER

Question. Dr. Fraser, we know that the Polar Regions are experiencing the greatest and most rapid impacts from climate change, in comparison to other regions of the planet. I've visited the Antarctic Peninsula, and the Arctic, and this deeply concerns me. The average temperatures across the Arctic have raised nearly twice as much as the global average—and indigenous communities are paying the price. Could you comment on the hardships this has already created for circumpolar communities?

Answer. Regions of the Arctic and Antarctic are experiencing similar changes in many environmental parameters. These include increasing surface and oceanic temperatures, decreases in sea ice extent and changes in the timing of sea ice formation, rapid glacial retreat, increasing precipitation and increasing fresh water flows into marine and terrestrial basins. The Arctic has also experienced thawing of the permafrost. Because these environmental parameters are important determinants of the structure and function of polar ecosystems generally, similar changes in Arctic and Antarctic biological communities and populations have also been recorded. For example, deteriorating sea ice conditions are forcing a decrease in populations of Adélie and emperor penguins in Antarctica, and of polar bears and some seal species in the Arctic. Evidence that has accumulated during the last 15 years in particular also indicates that the ranges and distributions of many species of both marine and terrestrial plants and animals are changing, with lower latitude species becoming more common at higher latitudes, and higher latitude species becoming more rare.

Although Antarctica does not have an indigenous population, this is not true of the Arctic, where eight countries host thousands of communities of Aleuts, Inuit, Athabascans, Dene and Saami. Although extraordinarily diverse in many respects, these indigenous peoples of the Arctic share cultures that are fundamentally and inextricably linked to the land, and economies that still depend on subsistence hunting, fishing and reindeer herding. To these peoples especially, climate change poses serious, if not immediate sociological and economic threats. This has been shown in a number of TEK (traditional environmental knowledge) studies, which not only confirm (and in some cases pre-date) the scientific record of climate change impacts briefly discussed above, but also reveal the emerging and potential economic consequences. In the Canadian Arctic, for example, the indigenous peoples of Banks Island and Hudson Bay have reported that hunting seals, polar bears and some migratory birds and mammals has become both more dangerous and less predictable

in the last few decades. They attribute this to changes in environmental factors that are affecting wildlife directly and/or the ability of hunters to reach wildlife, including changes in weather patterns, the extent to which permafrost is thawing and the formation and annual persistence of sea ice. Similar changes are being documented by indigenous peoples throughout the Arctic, even among the non-hunting societies of reindeer herders, who have indicated that changing patterns of wind and snow deposition are making it increasingly difficult to travel and move their herds to suitable seasonal grazing areas. The Arctic, in short, is becoming less predictable to a people whose TEK has developed over thousands of years and is at the core of their ability to survive both economically and culturally. Indeed, the loss of cultural identity due to loss of their traditional ways of life, looms as a facet of climate change with potentially devastating impacts on Arctic peoples. This is because cultures and belief systems, though varied between peoples, are all fundamentally based on a relationship with the land and its life. Given that changes in these factors are already evident, it seems highly probable that undesirable cultural consequences will follow. This certainly is at the forefront of concerns among the elders in many societies, with some suggesting that such negative cultural consequences may be no more than two generations away.