Testimony of
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Chairman Markey, Ranking Member Sensenbrenner, Members of the Committee: I thank you for inviting me to testify today at this important and timely hearing. In what follows I will address all four of the questions posed in the Chairman's letter of invitation, although for convenience of exposition I will combine current and projected impacts of climate change (questions 1 and 2) into one section and research activities and products (questions 3 and 4) into another. Additional information on all four questions will be provided in the testimony that follows by my distinguished colleague, Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator Dr. Jane Lubchenco.

Current & Projected Climate Change Impacts in the United States and the World (questions 1 & 2)[1]

It is well established that climate is changing in the United States and all across the globe. The air and the oceans are warming, mountain glaciers are disappearing, sea ice is shrinking, permafrost is thawing, the great land ice sheets on Greenland and Antarctica are losing mass, and sea level is rising. We know the primary cause of these changes beyond any reasonable doubt. It is the emission of carbon dioxide (CO_2) and other heat-trapping pollutants from our factories, our buildings, our vehicles, and our power plants; from farming, cement manufacture, and waste disposal; and from deforestation and other forms of land-use change that move carbon out of soils and vegetation and into the atmosphere.

Impacts resulting from these changes are being felt today in this country and around the world. Over the past 50 years, the year-round, national average air temperature in the United

[1] The best compendium of observed and projected indicators of climate change and its impacts in the United States is the report on "Global Climate Change Impacts in the United States" released earlier this year by the U.S. Global Change Research Program (Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, eds. Cambridge University Press, 2009). The most authoritative global assessment, albeit limited to scientific findings through the end of calendar 2005, is the Fourth Assessment Report of the Intergovernmental Panel on Climate change, from which see especially "Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change" (M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds., Cambridge University Press, 2007). An excellent update of scientific findings since 2005 about climate change and its global impacts was recently released by the UN Environment Program: "Climate Change Science Compendium", C.P. McMullen and J. Jabbour, eds., UNEP, 2009. Impacts on developing countries are especially well documented in the 2009 report, "The Anatomy of a Silent Crisis" by the Geneva-based Global Humanitarian Forum and in the 2010 World Development Report of the World Bank, "Development and Climate Change", issued last month.

States has risen by more than 2ºF (1.1ºC), and this increase has been accompanied by a 5% rise in average rainfall with an increasing fraction of the total occurring in heavy downpours. This means more of the precipitation is lost to storm runoff. In addition, the average interval between rainfall episodes is increasing in some regions, which leads to increases in the frequency and severity of droughts as well as floods.

The United States has, in fact, been experiencing an increase in the severity of floods, droughts, and heat waves, with consequences for human life and health, property, and agriculture. Wildfires in the Western United States have increased over sixfold in average annual area burned over the past 30 years, and vast areas of pines and spruce in the western United States have been decimated by pest outbreaks associated with longer breeding seasons for the pests and trees weakened by drought and heat stress. The strongest hurricanes appear to be increasing in number and power in a pattern correlated with rising sea-surface temperatures in the regions that spawn these storms. And global-average sea level has risen about 8 inches over the last century (experienced as more in some places and less in others because of sinking or uplifting of the land, as well as other factors); the consequence for the heavily populated coastal zones of the United States has been increased losses to beach erosion and damage from winter storms as well as hurricanes.

The global effects documented by the Intergovernmental Panel on Climate Change (IPCC), the UN Environment Program, the Global Environment Forum, and the World Bank are similar in character, although in many respects worse in degree because of the greater vulnerability and smaller adaptive capacity of countries in the developing world. Tropical forests in regions once too consistently wet to burn now suffer periodic devastating wildfires (significantly augmenting CO_2 emissions to the atmosphere in dry years). China and India both report increasing damage to agriculture from changing monsoons (in patterns attributable to global climate change). The rapid shrinkage of mountain glaciers threatens the reliability of water supply for hundreds of millions of people, as well as puts inhabitants of mountain regions at risk from lake-outburst floods that are a further consequence of glacial melting. And the geographic range of a number of tropical diseases appears to spreading poleward.

Notwithstanding the claims of some climate-change “skeptics” that climate change came to a halt over the past decade, the reality is that both the drivers and the symptoms of climate change have been growing more rapidly since 1997 than before. CO_2 emissions from fossil fuels (including gas flaring) and cement manufacture grew at an average of 1.4% per year from 1987 to 1997 and at an average of 2.2% per year from 1997 to 2007. Growth of the CO_2 concentration in the atmosphere averaged 1.45 parts per million volume (ppmv) per year from 1987 to 1997 and 2.0 ppmv per year from 1997 to 2007. The 11 hottest years in the global instrumental record maintained by the National Oceanic and Atmospheric Administration (NOAA) all occurred from 1997 onwards. The average temperature anomaly in the 11 years from 1998 through 2008 was 0.95°F (0.53°C) above the 20th century average, compared to 0.56°F (0.31°C) above the 20th century average in the 11 years from 1987 through 1997. The rate of sea level rise in the past decade has been twice the average rate during the 20th century. All of these increases have been near or above the high end of the projections for this period made by the IPCC in the mid-1990s.

The changes and impacts described in the foregoing are not projections. They are what have been observed to date, in a world that has warmed, on the average, only about 1.5°F (0.8°C) since 1900. If global emissions of heat-trapping gases continue to grow on what is often termed a "business as usual" trajectory, mid-range estimates indicate that the global average surface temperature increase compared to 1900 will be around 3.6°F (2°C) by 2050 and 5.4 to 7.2°F (3-4°C) by 2100. Moreover, considerably greater increases in average temperature in this century cannot be ruled out because of uncertainties about the strengths of "positive feedbacks" in the climate system (such as CO_2 releases from warming seas and soils). And whatever the global-average increases turn out to be, we know on solid scientific grounds that the increases in mid-continent will be typically 40% more, and that those at high latitudes in the Northern Hemisphere larger still.

The 2009 report of the U.S. Global Change Research Program (USGCRP) on "Global Climate Change Impacts in the United States" found that in a "business as usual" global emissions scenario (the scenario labeled A2 in the 2007 report of the IPCC, entailing about a tripling of global greenhouse-gas emissions over the 21st century), the average-annual temperature increase in the United States would reach 4-6°F (2.2-3.3°C) by 2050 and 7-11°F (3.9-6.1°C) by 2090. In a different "business as usual" scenario assuming different economic, technological, and demographic predictions which lead to significantly lower emissions (IPCC B1, in which global emissions peak around 2050 at 30% above the 2000 level and fall by 2100 to about half the 2000 level), the average-annual temperature increase in the United States is projected to be 3-5°F (1.7-2.8°C) in 2050 and 4-7°F (2.2-3.9°C) in 2100. (The lower of these trajectories is still much higher than would be associated with trying to limit the global annual-average temperature increase to 3.6°F (2°C), the goal embraced by G-20 leaders in July.)

The least that can be expected in the way of impacts along either the A2 or B1 trajectory of increasing average surface temperatures is a worsening of the kinds of effects already being experienced – that is, further increases in floods, droughts, heat waves, and wildfires; changes in the frequency and intensity of weather extremes; continuing rise in sea level, most probably at an accelerating rate; increasing stress on water supplies in many regions already short of water; new and larger pest outbreaks afflicting crops and forests; still further stresses on agriculture and forestry arising from more frequent occurrence of ever higher temperature extremes; declines in coral reefs under the combined stress of higher water temperatures and continuing acidification of the surface layer of the ocean from absorption of part of the excess atmospheric CO_2; expanded geographic range of tropical pathogens and their vectors; and further changes in the geographic distribution of many other species of plants, animals, and micro-organisms accompanied, in all likelihood, by an increase in the rate of extinctions.

For the United States, the regional impacts projected by the 2009 USGCRP report under the IPCC's A2 and B1 scenarios included declining snowpack and associated stress on water resources in the Northwest; increased drought and water-availability problems in the Southwest and Great Plains; more heat waves, air-quality problems, and floods in the Midwest; shifts in marine species affecting fisheries in Alaska and the Northeast; increased damage from hurricanes and increased heat stress impacts on health in the Southeast; and increased coastal erosion and storm damage on all of the coasts. The higher the emissions, the worse these problems are expected to be.

But these more or less steadily increasing impacts are not the only possible outcome. Climate scientists worry about "tipping points" in the climate system, including ecosystems, meaning thresholds beyond which a small additional increase in average temperature or some associated climate variable results in major changes to the affected system. Examples of tipping points of potential concern include the complete disappearance of Arctic sea ice in summer, leading to drastic changes in ocean circulation and climate patterns across the whole Northern Hemisphere; drastic acceleration of the rate of ice loss from the Greenland and Antarctic ice sheets, driving rates of sea-level increase that could reach 6 feet per century or more; ocean acidification from CO_2 absorption reaching a level that causes massive disruption in ocean food webs; and a flood of carbon dioxide and methane from warming tundra and thawing permafrost, accelerating the onset of all of the other impacts of concern.

While our understanding of the global climate system and our ability to project its future behavior have grown enormously over the past couple of decades, we cannot yet predict with confidence exactly where on a rising temperature trajectory these or other thresholds would be crossed. It seems clear, however, that the probability of crossing one or more of them goes up sharply as the global-average surface temperature increase compared to 1900 goes above 3.6°F (2°C). That is a major reason for the growing global consensus that worldwide efforts should limit heat-trapping emissions sufficiently to hold the average temperature increase to 3.6°F (2°C) or less.

Climate-Science Research Activities, Needs, and Products (questions 3 and 4)[2]

Investments in climate science over the past several decades have contributed to an improved understanding of global climate. To continue to assist the government and society as a whole with understanding, predicting, projecting, mitigating, and adapting to climate change, the agencies of the federal government deploy a wide range of powerful science and technology resources. Each agency has different sets of key specialists and capabilities, different networks and relationships with the external research community, and separate program and budget authorities. The USGCRP brings the essential capacities for research and observations together into a single interagency program. A fundamental component of success in delivering the information necessary for decision-making is coordination of the programmatic and budgetary decisions of the 13 agencies that make up the USGCRP.

The USGCRP was mandated by Congress in the Global Change Research Act of 1990 (P.L. 101-606) to improve understanding of uncertainties in climate science, expand global observing systems, develop science-based resources to support policymaking and resource management, and communicate findings broadly among scientific and stakeholder communities. Thirteen departments and agencies participate in the USGCRP. The Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) work closely with

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[2] This section of my testimony draws heavily from my previous testimony before the Committee on Commerce, Science, and Transportation on the topic of "Climate Services: Solutions from Commerce to Communities", July 30, 2009. Primary references on the structure and research priorities for the US Global Change Research Program are "Restructuring Federal Climate Research to Meet the Challenges of Climate Change," National Research Council, 2009; and "Informing Decisions in Changing Climate," National Research Council, 2009. Further elaboration of the science elements of the USGCRP can be found in the recent publication "Our Changing Planet: The U.S. Global Change Research Program for Fiscal Year 2010," a supplement to the President's Budget for FY 2010. The National Research Council report, "Satellite Observations to Benefit Science and Society: Recommended Missions for the Next Decade," 2008, is germane to my treatment of Earth observations and is mentioned there.

the USGCRP to establish research priorities and funding plans to ensure the program is aligned with the administration's priorities and reflects agency planning.

The 2010 Budget provides $2.0 billion for the USGCRP Climate Change Science Program (CCSP), an increase of $46 million or 2.3 percent over the 2009 level (excluding Recovery Act funds). USGCRP programs also received over $461 million in Recovery Act funding based on preliminary agency allocations, including $237 million for NASA climate activities. In addition to these sums, the Recovery Act included $170 million for two NOAA climate supercomputers. The 2010 Budget supports research activities including the development of an integrated Earth system analysis capability; a focus toward creating a high-quality record of the state of the atmosphere and ocean since 1979; development of an end-to-end hydrologic projection and application capability; enhanced carbon cycle research on high latitude systems; quantification of climate forcing and feedbacks by aerosols, non-carbon dioxide greenhouse gases, water vapor, and clouds; an improved understanding of the non-CO_2 climate impacts of aviation; assessment of abrupt change in a warming climate; development and use of climate models on regional and decadal scales; examination of the feasibility of development of an abrupt change early warning system; understanding climate change impacts on ecosystem functions; and refining ecological forecasting.

The USGCRP Climate Change Technology Program (CCTP) is the technology counterpart to CCSP. Its aim is to accelerate the development of new and advanced technologies to address climate change, focusing on energy-efficiency enhancements and technologies that can reduce, avoid, or capture and store greenhouse gas emissions. The 2010 Budget provides $5.3 billion for CCTP programs, an increase of $52 million over the 2009 level, excluding Recovery Act funds described below. The Budget funds a wide range of activities that support progress toward climate change goals including programs that focus on energy efficiency improvements, low-carbon fuels and power, enabling technologies, such as energy storage and improving the electric power grid, power distribution and controls, and efforts to promote reductions emissions of non-CO_2 greenhouse gases. CCTP programs received over $25 billion in Recovery Act funding allocations, with most of it supporting DOE programs, including $16.8 billion for energy efficiency and renewable energy, $4.2 billion for electricity delivery and energy reliability, $3.4 billion for efficiency and sequestration programs in fossil energy R&D, and $400 million for the Advanced Research Projects Agency-E (ARPA-E), augmenting the support for advanced research in the Department of Energy (DOE) science programs. Other agencies also received Recovery Act funding for CCTP-related technology development and deployment, including the Department of Defense (DoD, $139M), the Department of Transportation (DOT, $100M), the National Aeronautics and Space Administration (NASA, $31M), and the National Science Foundation (NSF, $2M).

Although the USGCRP supports a wide variety of research activities to gain more detailed predictive understanding of a changing climate, there remain significant gaps in going from an estimate of how much the climate may change to the effects these changes may have on ecosystem services, water resources, natural-resource utilization, human health, and societal well-being. It is important for the USGCRP to make a strong commitment to providing the information that society is seeking in order to reduce vulnerabilities and improve resilience to variability and change. For example, the recent National Research Council (NRC) reports referenced at the beginning of this section of my testimony recommend change to the research activities and structure of the USGCRP that would, in large part, support the policy needs of the approaching societal problems from climate change. They recommend "research on the end-to-end climate change problem, from understanding causes and processes to supporting actions needed to cope with the impending societal problems of climate change." This will require the USGCRP to support a balanced portfolio of fundamental and application-oriented research activities from expanded modeling efforts to studies of coupled human-natural systems and institutional resilience.

In addition, it would mean boosting adaptation research; bolstering the capacity to observe changes in climate, climate variability and impacts of climate change; producing the sorts of integrated assessment of the pace, patterns, and regional impacts of climate change that will be needed by decision-makers as input into their deliberations on the metrics and goals to be embraced for both mitigation and adaptation; and making climate data and information accessible to those who need it. Besides enhancing research and modeling of the physical climate system, four areas of particular need for more comprehensive and coordinated treatment from USGCRP are Earth observations, adaptation research, integrated assessment, and climate services. I take up each briefly in turn.

Earth observations

Observations are taken from space, within the Earth system (*in situ*), from the air and on and below the land and the oceans. Obtaining accurate climate data requires calibrated measurement systems that are traceable to national and international standards. Once the integrity of the data is validated, the data can then be interpreted, interpolated, and integrated into applications such as Earth System models. The myriad of observations taken today vary widely in purpose and scope and are appropriately distributed among hundreds of programs under the purview of Federal agencies and other institutions and individuals. To a large degree, these observations have been only loosely coupled, coordinated, and integrated. The critical leap forward can only be achieved with a synergy between remotely sensed and *in situ* observations supported by robust data systems.

Increasingly this promise is being realized, and seemingly disparate observations are being combined in new ways to produce benefits across multiple societal areas. This recognition has led to the concept of an integrated Earth observing system as articulated by the Group on Earth Observations (GEO), whose Sixth Plenary Session was hosted by the United States here in Washington on November 17-18. To achieve the synergies and benefits of an integrated system of observations, the United States Group on Earth Observations (USGEO) was formed in 2005 as a standing subcommittee of the National Science and Technology Council (NSTC). That same year, the Global Earth Observation System of Systems (GEOSS), was formed to coordinate observations at the international level. By 2009, 79 countries, the European Commission and over 50 international organizations were engaged in this effort. The U.S. contribution to GEOSS is the Integrated Earth Observation System (IEOS). GEOSS and IEOS will facilitate the sharing and applied usage of global, regional, and local data from satellites, ocean buoys, weather stations, and other surface and airborne Earth observing instruments. The end result will be access to an unprecedented amount of environmental information, integrated into new data products benefiting societies and economies worldwide. With Recovery Act support in 2009, the National Science Foundation launched a new *in situ* observing system focused on ocean acidification and the role of the ocean in climate change and coastal ecosystem health.

The state of the U.S. space-based observational system in 2009 is largely unchanged from that of 2005, but the outlook has significantly worsened, according to the NRC's Decadal Survey Report. Continuity of the weather observing system is threatened by reductions and delays in the National Polar-orbiting Operational Environmental Satellite System (NPOESS) and plans for climate measurements on NPOESS have been scaled back. The likelihood of a gap in land imagery impacting multiple societal needs (e.g., agriculture, biodiversity, climate, ecosystems, water, etc.) is now almost a certainty. In addition, no plans have been developed to continue some of the valuable observations demonstrated by the NASA Earth Observing System (EOS) program that benefit the disaster preparedness, human health, climate, and water areas.

OSTP is playing an important role in coordinating interagency satellite observation policy. We must increase government oversight and improve the interagency partnerships central to the management of civilian satellite programs, which among other things are critical to the nation's climate and weather forecasting. We need to proactively manage our programs to avert future cost and schedule overruns. Agencies must work together to manage the contractors building these satellites and demand cost and schedule accountability. Improving the management of NPOESS in order to ensure continuity of weather and climate data is a high priority for the Administration's leadership team. A task force within the Executive Office of the President (including representatives from OMB as well as the National Security Council) has been meeting regularly with representatives from NOAA, NASA, and DoD, the three agencies partnering on the program, to identify the best way forward, and I will soon be making a recommendation based on the task force's findings.

In an overall sense, deployments of new and replacement satellites are not keeping pace with the termination of older systems, even though many existing satellites are operating well past their nominal lifetimes. A number of satellites built as research missions are now seen to have ongoing societal benefit, but there are currently no plans for continuity of many of these. Over the next eight years, 50% of the world's current and planned suite of Earth observing satellites will be past their useful life. Given the long development times associated with fielding new systems, particularly satellite systems, and absent a dramatically increased commitment to sensor system development, this declining census of instruments and missions could lead to a loss of observing capability in the next decade. This reality reinforces the need to address the recommendations in the NRC's Decadal Survey.

In addition to global observations made from space, *in situ* measurements provide critical data at fine spatial and temporal scales of parameters and in places not achievable from space. They also serve as necessary benchmarks to validate the remote measurements made by satellites. In general, our observational infrastructure for *in situ* measurements is aging and investment in monitoring programs has declined despite growing demand. And, there still remains the grand challenge and promise of using geospatial information to link the broad coverage and context of our top-down remote-sensing view with the comprehensive and detailed measurements made *in situ* in order to best characterize and understand environmental resources.

Development of an integrated climate observing system stands as a large and urgent challenge. One part of the challenge is that the required observing system must deliver multi-decade data records with the accuracy and precision needed to distinguish long-term climate changes from natural variability and other environmental influences. To help ensure compatibility and consistency between various international monitoring organizations and laboratories, the National Institute of Standards and Technology (NIST), the Nation's national measurement institute, can provide traceable measurement techniques and standards based on the International System of Units. Indeed, NOAA, NASA, and NIST are currently discussing approaches to better ensure the accuracy of satellite-based climate measurements with a scope from satellite instrument design to on-orbit calibration and performance evaluation. In addition, the NASA Earth Observing System (EOS) demonstrated the ability to create long-term, high-precision climate data records. The experience of this program has revealed the difficulties in "transitioning" long-term, research-type measurements to an operational system. Owing to these challenges, the distinction between "research" and "operational" capabilities and assets must be considered in order to successfully deliver sustained climate-related measurements. Accordingly, we should work to overcome the limitations of the current "research to operations" construct with respect to climate observations, and instead recognize that climate observations require a sustained integrated "research **and** operations" approach. The institutional structures and capacity, and specific agency roles and responsibilities must be developed to deliver an integrated climate observing system.

Adaptation research

There currently exists limited knowledge about the ability of communities, regions, and sectors to adapt to a changing climate. To address this shortfall, research on climate variability and change impacts and adaptation must include complex human dimensions, such as economics, management, governance, behavior, and equity. Interdisciplinary research on adaptation that takes into account the interconnectedness of the Earth system and the complex nature of the social, political, and economic environment in which adaptation decisions must be made will be central to this effort. Given the relationships between climate variability and change and extreme events, the community of researchers, engineers and other experts who work on reducing risks from natural and human-caused disasters will have an important role to play in framing climate change adaptation strategies and in providing information to support decision-making during implementation. For example, assessments of emergency preparedness and response systems, insurance systems, and disaster-relief capabilities are an important component of a society's adaptive capacity.

Recently President Obama issued an Executive Order on Federal Leadership in Environmental, Energy, and Economic Performance that calls for an integrated strategy towards sustainability and enhanced engagement in adaptation. As part of this effort, an adaptation science workgroup is currently developing a government approach for linking adaptation planning with the science and technology needed by decision-makers. The emergence of adaptation planning driven by public awareness and policy processes has created a demand for adaptation research – including the organization, transfer, and communication of information – within decision settings. Adaptation plans have been inspiring science to be more directly relevant to social and policy outcomes. There is an emerging paradigm shift from a view that decision support is contingent only upon highly accurate predictions, to a risk management approach where uncertainty is always a factor, and planning moves ahead through identification of vulnerabilities and policy trade-offs across a set of possible future conditions. Science focused on questions about adaptation will improve local and regional predictions, informing decision-making and integrating knowledge from social, ecological and physical research that can help to identify thresholds and tipping points.

Integrated assessment

Preparing for and adapting and responding to the impacts of climate change must start locally and regionally, as each region is distinct, and different impacts are experienced in different ways in different places and for different sectors of the economy. Assessments serve a very important function in providing the scientific underpinnings of informed policy. They also serve as progress reports by identifying advances in the underlying science, providing critical analyses of issues, and highlighting key findings and key unknowns that can improve policy choices and guide decision-making related to climate change. Comprehensive assessments provide an opportunity to evaluate the social implications of climate change within the context of larger questions of how communities and the nation as a whole create sustainable and environmentally sound development paths.

Over the past decade, U.S. federal agencies, through the USGCRP, have undertaken two coordinated, national-scale assessment efforts to evaluate the impacts of global climate change on this country. Each effort produced a report to the nation: Climate Change Impacts on the United States, published in 2000; and Global Climate Change Impacts in the United States, published in 2009. A unique feature of the first report was that, in addition to reporting the current state of the science, it created a national discourse on climate change that involved hundreds of scientists and thousands of stakeholders to help the scientific community develop a problem-solving framework that integrates the information society wants and needs. A notable feature of the second report was the incorporation of information from the USGCRP's 21 topic-specific Synthesis and Assessment Products, many motivated by stakeholder interactions.

The next national assessment mandated by Section 106 of the 1990 Global Change Research Act is due in 2013. The vision for this climate change assessment is in a formative stage, but will include sustained, extensive stakeholder involvement to ensure full regional and sectoral coverage. It may also include targeted, scientifically rigorous reports that assess mitigation and adaptation strategies and their interactions. The best decisions about these strategies will emerge when there is widespread understanding of the complex issue of climate change—especially the science and its many implications for our nation.

The lessons learned from the previous assessment activities provide the main ingredients and structure for this next assessment. Understanding climate change impacts and adaptation requires a bottom-up approach—identifying impacts in a specific place or within an economic or industrial sector and aggregating information to larger scales. Therefore, the assessment, implemented through interagency efforts, will include workshops and studies that focus on regions and sectors, as well as a national synthesis component. OSTP is working with agencies and the USGCRP team to develop the scope and plan for the assessment due in early January.

In addition to the national assessment effort, individual agency programs further the development of assessment tools and models that help advance decision-making in particular sectors, as well as contribute to the national process. For example, DOE's Integrated Assessment Research Program is designed to evaluate the complex interactions of human and natural systems and to develop the integrated models and tools that will underpin future national and regional decision-making on options for mitigation and adaptation.

Climate services

Coordinated, timely and authoritative climate information and services are needed to assist decision-making across public and private sectors. Local planners may need information on likely changes in extreme events, such as floods and droughts, heat waves and freezes; farmers and farm cooperatives may need information on changes in season length and temperature, not just for their own farms, but for those of their local and distant competitors; coastal zone managers may need information on likely changes in sea level, storminess, and estuarine temperatures; water resource managers may need information on likely changes in snowpack and runoff, and changes in the frequency and intensity of floods and droughts; community health planners may need information on changes in locations of heat and cold waves and heavy precipitation events tied to disease outbreaks; industry may need information on changes in extremes that might affect their businesses and shipping; those preparing environmental impact statements may need information on how changes in a given location affect environmental outcomes; those doing economic analyses may need information across the region; and much more.

Just as the nation's climate research efforts require and benefit from interagency and academic partnerships, so too will the development and communication of climate change information to users. To be successful, the delivery of climate services will require sustained federal agency partnerships, comprehensive *in situ* and space-based observing assets, data handling and information generation capabilities, and effective means of delivering relevant information to end-users. No single agency has the ability to deliver full end-to-end climate services, but, with strategic investments, the federal agencies will collectively be able to do so.

Through the USGCRP, the Nation's science agencies have made significant investments in climate-related observations, research, modeling, and assessment programs that provide a strong foundation for a move toward effective services. For example, NOAA, NASA, NSF, and DOE currently have substantial, but incomplete, observing and data handling capabilities; these agencies currently take advantage of DOE's leadership class computing to improve climate models at global and regional scales; and agencies such as the Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA) have useful well-targeted information development and delivery capabilities. OSTP is developing an interagency process to assess our national capabilities for delivering climate services.

Concluding Remarks

As I have tried to indicated in this testimony, we know a great deal about global climate change – what its causes are, how it works, what its impacts are and are likely to become – but there is more to learn; and the Federal government is doing a lot in support of the research needed to learn more, and its translation into products our society can use to better cope with climate change, but we need to do more.

That said, I want to emphasize that in my judgment and that of the vast majority of other scientists who have seriously studied this matter, the current state of knowledge about it (even though incomplete, as science always is) is sufficient to make clear that failure to act promptly to reduce global emissions to the atmosphere of carbon dioxide and other heat-trapping substances is overwhelmingly likely to lead to changes in climate too extreme and too damaging to be adequately addressed by any adaptation measures that can be foreseen.

It goes almost without saying that the United States, as the largest contributor to the cumulative additions of anthropogenic greenhouse gases to the atmosphere since the beginning of the Industrial Revolution and still today the second-largest emitter after China, and as the world's largest economy and pre-eminent source of scientific and technological innovation, has both the obligation and the opportunity to lead the world in demonstrating that the needed emissions reductions can be achieved in ways that are affordable and consistent with continued economic growth, that create new jobs, and that bring further co-benefits in the form of reduced oil-import dependence and improved air quality.

President Obama is going to Copenhagen to underline that the United States is fully committed to assuming this leadership role. The Administration obviously will need the support of the Congress in delivering on this promise, and I'd like to thank you, Chairman Markey, and this Committee for your own leadership in this critically important matter. I thank you as well for your attention to this testimony.