Testimony of

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Thank you, Chairman Markey, for the invitation to appear before you and Ranking Minority Member Sensenbrenner and other members of your Select Committee today. With your permission I will read from my prepared testimony but I will not read all of it due to time limitations.

As most of you know, the National Academy of Sciences was created by Congress under President Lincoln in 1863 with a mission to respond to requests from the federal government for analysis and recommendations on all matters of science. Thus, we are not part of the federal government but we were created by the federal government. We elect our members annually based on their original contributions to research in their fields of science. Today we operate largely through the National Research Council which serves us and our partner, the National Academy of Engineering. Our reports to the government are developed by committees whom we appoint to study the topic at hand. Our members participate in this work along with other experts drawn from across the United States from academia, business, and other entities as well as occasionally people from other countries. We work very hard to be objective, non-partisan, and up- to-date in our analysis. We are very proud of our history of independence and objective analysis and we work hard to maintain it. The individuals who serve on our study committees do so without compensation except for their direct expenses incurred such as travel and subsistence costs.

I became President of the National Academy of Sciences in 2005 for a six-year term. My own scientific research has been mostly in atmospheric chemistry and how the changing chemical composition of the air forces climate change. My academic background began in electrical engineering and physics and moved more into chemistry over time. In the early 1980s, I worked on the so-called radiative forcing of climate change caused by the enhanced greenhouse effect due to the rising worldwide concentrations of carbon dioxide, methane, chlorofluorocarbons, nitrous oxide and other gases. As President of NAS, I also chair the National Research Council.

I want to present a brief summary of what scientists have learned about contemporary climate change, then go on to briefly describe our new NAS/NRC report "America's Climate Choices" and conclude with some remarks about how to protect and improve the ability of scientists in the conduct of their research and in their communications with policymakers.

Measurements of Climate Change

Temperatures of Air and Water. The most striking feature of these data is the rise in temperatures all over the world since the late 1970's or 1980. The warming is strongest in the Arctic and over world land areas, with smaller warmings over oceans. When one averages over the entire planet and over day and night one finds an overall warming of 1.0 degree F (0.55deg C) since 1979. These data come from thermometers at many land stations, island and ship operations. Temperature data are very important and maintaining a record of global patterns and averages is a large job. There are several groups around the world who do this work: the Goddard Institute for Space Studies of NASA, the National Climatic Data Center of NOAA also in the U.S. and the University of East Anglia Climate Research Unit in the U. K. to name three of them. Each of these centers uses different methods of examining and analyzing the data, they have somewhat different sources of data and means of presenting them but they find closely the same results.

To see clearly the patterns of temperature change requires continuous, sustained efforts. When we look at small regions and short periods of time we can get fooled easily by the ups and downs of local weather or by changes that do not persist. For example, during this past winter New York and Washington were relatively cold while Montreal was relatively hot. The year 2009 was the warmest on record for the entire world south of the Equator. So even with a variable as simple and familiar as temperature, we need sustained measurements from many places as opposed to simply relying completely on our own senses where we live.

Ocean surface temperatures are also on the rise. Records from shipboard measurements and from recent satellite observations show a global warming. Temperatures vary with water depth and it is most meaningful to keep track of the total heat content of the upper oceans (above 700 meters depth), the waters that are in closest contact with the air. Oceanic heat content has increased significantly since 1980. The fact that oceans are warming more slowly than air is likely due to the retarding influence of the large heat capacity of water.

Arctic sea ice. Most of us are aware that the horizontal extent of ice covering the Arctic Ocean has shrunk with especially rapid increases in the amount of open water in the summertime Arctic in the past decade. The decreasing extent has been visible (literally) from satellite images and from reports of marine navigators. A measure that has not been known as widely and is more difficult to measure is the <u>thickness</u> of the Arctic sea ice. It is now known that the thickness has decreased by over 50% in the past 50 years. The extensive measurement record comes to us from recently declassified U.S. Navy data and from recent satellite data

Ice on the Greenland and Antarctic Continents.

Massive amounts of ice are perched on the land of Greenland and Antarctica and they are important to Earth's climate in several ways. One way is that water added to Greenland (as snow) or Antarctica ice lowers sea level and ice moved from Greenland and Antarctica, either as ice or liquid water, to the oceans raises sea level. Just in the past few years, it has become possible to measure changes in the masses of ice in these two places. The data show that ice is being lost, and at accelerating rates. Of course, snow is added during the respective wintertimes and lost in the following summers but rather than being in balance, the net annual change is negative, and increasingly so. The key measurements are from NASA satellites using ultra-sensitive gravity sensors and sophisticated radars. Such data were simply not available until approximately 2000-2005.

Sea Level. Measurements show that sea levels are rising worldwide. The measurements are being made by specialized radar-ranging instruments on Earth-orbiting satellites. Prior to 1992, such devices were unknown and data were gathered carefully but with more primitive instruments along coastlines. Prior to 1992, the best estimate of global-averaged sea-level rise was about 1.6 mm/year (17 cm in 110 years) and there were significant differences from continent to continent. Now the observed rate of rise is 3.2 mm/year, approximately double the earlier rise, and the worldwide average is known more clearly. This newer, larger rate of rise can be explained well by adding the rates due to ice losses from Greenland, Antarctica, and inland glaciers to the contribution from thermal expansion of (warming) ocean water. Current estimates of future rates of sea-level rise are larger than those of five years ago but they are still not viewed with confidence.

Other Climate Indicators.

Climate is a big word and many variables go into defining it. Some of them are very meaningful for human, animal and plant life. I will mention just a few. Growing seasons are becoming longer in many places and areas with snow cover in the early spring are decreasing. Dates of snow melt are coming earlier. The total snowpack mass is decreasing especially in the Pacific northwest and California. More new record maximum temperatures are being recorded than new record low temperatures. Precipitation amounts are increasing on average. More high-intensity precipitation events are being recorded. Observing these trends and defining them better requires a large commitment to measurements and to data analysis.

Explaining and Predicting Climate Change.

The Greenhouse Effect. For over 100 years, scientists have known the physics of the greenhouse effect, how certain gaseous chemicals in air absorb and re-radiate planetary infrared radiation, thus trapping more energy near the surface than would happen without these gases. The most important wavelengths of radiation and the chemicals that interact at these wavelengths are well known from laboratory and field measurements. The fact that the concentrations of such chemicals like carbon dioxide, methane, nitrous oxide and a number of synthetic fluorine-containing organic compounds have increased worldwide is well-established from direct measurements. In turn, it is well-established that human activities have caused these increases, for example, approximately 85 % of the current carbon dioxide increase is due to fossil-fuel burning and perhaps 15% from deforestation. Not only is there this "bottoms-up" information but there is also the predictive power of calculations using it; we can calculate how much global warming should have been expected from these changes to the atmospheric and we get very reasonable answers.

Not only does the well-understood greenhouse effect serve to explain the altered planetary energy balance that we are seeing, there is no alternative explanation which anyone has identified. Scientists continue to look for alternative explanations but no good ideas have come forward.

Similarly, scientists are performing increasingly detailed calculations of Earth's climate changes that are based on the greenhouse effect and trying to pin down more detailed manifestations of the changes in temperatures, precipitation, ice amounts and sea level, for example. These calculations use the equations of conservation of mass, energy, momentum, etc. and they solve the equations with differing geographical resolution on computers. Through these calculations, scientists are evaluating the various forces at play as the Earth system adjusts and moves further from the original balance. Some of these forces constitute stabilizing feedbacks and some of them are destabilizing.

America's Climate Choices.

America's Climate Choices is a National Research Council project in response to a request from Congress from over two years ago. America's Climate Choices is a fairly comprehensive and up-to-date report about major climate change topics. The first three topical reports were released on May 19. One is called *Advancing the Science of Climate Change*, the second is *Limiting the Magnitude of Future Climate Change*, and the third is *Adapting to the Impacts of Climate Change*. A fourth panel report will be released in several months on issues of communication involving the general public and policy makers and an overall general report from the parent committee will be released in the fall.

The panel report on *Advancing the Science of Climate Change* reviews the scientific evidence for climate change in more detail than I did today and it examines the status of the nation's current scientific research efforts. The report says "A strong, credible body of scientific evidence shows that climate change is occurring, is caused largely by human activities, and poses significant risks for a broad range of human and natural systems. As decision makers respond to these risks, the nation's scientific enterprise can contribute both by continuing to improve understanding of the causes and consequences of climate change, and by improving and expanding the options available to limit the magnitude of climate change and to adapt to its impacts. To do so, the nation needs a comprehensive, integrated, and flexible climate change research enterprise that is closely linked with action-oriented programs at all levels. Also needed are a comprehensive climate observing system, improved climate models and other analytical tools, investments in human capital, and better linkages between research and decision making."

The report on *Limiting the Magnitude of Future Climate Change* points out that for us to meet internationally discussed targets for limiting greenhouse gas emissions and the associated global climate changes will require a major departure from business as usual in how the world uses and produces energy from fossil fuels, for example. The report recommends that U.S. policy be based in terms of a budget for the cumulative greenhouse gas emissions over the period from 2012 to 2050. It identifies opportunities in the near term through energy efficiency and low carbon energy sources and longer-term opportunities through more basic research and development while it also describes a national policy framework that can assist progress towards this common goal and the development of policy mechanisms that are durable enough to persist for decades, but flexible enough to adapt to new information and understanding.

The report on adaptation calls for a new realization that considers a range of possible future climate conditions and associated impacts, some of which are outside the realm of past experience. It outlines the need for much more targeted information and the role of the federal government and other sectors in providing that information base and helping efforts which will be locally and regionally based to identify appropriate information as they make decisions. In short, it states the need for a national adaptation strategy to support and coordinate decentralized efforts.

In sum, there is a broad challenge before us. We must continue our efforts to observe climate changes and to understand them and to gain predictive capability while we also try to minimize the size of these changes by limiting our emissions of greenhouse gases and at the same time prepare thoughtfully for needed adaptation in response to climate changes which are not avoided.

Finally, Chairman Markey, you asked me what policies are necessary to protect and improve scientists' ability to conduct research and to share scientific information with policymakers. First, on the conduct of climate research, the good news is that we have one of the essential ingredients, smart and motivated scientists, many of whom are young. They are ready to go and many of them are already involved. To do their work, they need not only advanced graduate education, which they have, but access to modern instruments and computers and access to data from all over the world. I know that some scientists have been harassed and threatened but so far I do not see the need for protections aside from our normal civil laws. An atmosphere of encouraging scientists to seek the truth and to share their findings with others is always needed, as is a return to civility.

Climate research today is an increasingly international activity, an activity to which the U.S. wants to contribute and also to lead. We want to be at least advanced enough so that we can recognize and evaluate claims and breakthroughs that are made elsewhere. It is also important to have a climate research effort that is based on scientists in academia as well as in government labs and elsewhere pursuing as many independent techniques and independent lines of investigation as possible. Altogether, I think that our current effort is thin in this regard.

The sharing of information and communication with the general public and with policymakers is an increasingly difficult task. Part of the reason for this difficulty is that science itself has become so specialized and climate science is no exception. Climate science stretches over many fields of meteorology, oceanography, atmospheric physics, various kinds of biology and chemistry, geology, paleorecords and so forth. These pursuits are very specialized and it is increasingly difficult to communicate with generalists. Scientists have developed their own terminology, their own vocabularies, methods, and so forth, so the sharing of information is largely a communications problem. An essential ingredient to this sharing of information with policymakers is the conduct and maintenance of assessments which are high-level, peer-reviewed evaluations of the state of the science that are written intentionally in more general terms, more understandable to non-specialists. These assessments serve the dual role of periodically defining the state of the art and what is understood and accepted by all as well as communicating that state more widely. Examples of such assessments are those of the United States Global Change Research Program and the Intergovernmental Panel on Climate Change (IPCC) and, of course, a number of NAS-NRC reports. Through these more general assessments, the scientific results which appear in top-flight peer-reviewed specialized scientific journals internationally are made available to the general public and to policymakers.

Once again, Chairman Markey, thank you for the invitation to appear before you today and for all that you are doing on this very important issue for our nation and the world.