Testimony of

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Chairman Rockefeller, Ranking Member Hutchison, and Members of the Committee, I am honored to speak with you today on the state of climate change science.

My name is Tim Killeen, and I am the National Science Foundation's Assistant Director for Geosciences. I am also the former director of the National Center for Atmospheric Research, and the Past President of the American Geophysical Union (AGU). My academic background includes a professorship at the University of Michigan, where I taught and conducted research programs in atmospheric, space, and Earth system sciences for many years.

The topic of this hearing is of tremendous importance to our understanding of the planet on which we live and to the stewardship of our world. I wish to make three simple but fundamental points: 1) the science of Earth's climate and climate change has advanced to the point where we now understand the basic drivers of the natural and man-made changes in the Earth's climate system – this is a supreme accomplishment of modern science and the scientific method; 2) we stand poised to expand that understanding and to begin to develop the detailed knowledge policy makers require for effective decisions that will surely shape our world for generations to come; and 3) the U.S. scientific and engineering, community can and must retain world leadership through our intellectual and technological capabilities to continuously improve predictions of climate changes on the temporal and spatial scales relevant to human endeavors.

WHAT WE KNOW

The many hundreds of climate scientists involved in the Intergovernmental Panel on Climate Change (IPCC) summarized the situation in their famous phrase: “Global warming is unequivocal” (IPCC AR4). We know that:

- the Earth is warming (more than 1 degree Celsius since 1860)
- the strength and pace of this warming is unprecedented in at least the past 1000 years
- this warming is linked to human activities, especially the release of carbon dioxide and other “greenhouse gases”
- significant continued warming is unavoidable
- changing climates have already significantly impacted people, infrastructure, and ecosystems throughout the globe, and these impacts will increase in extent and severity as climate changes continue.

While global warming represents a profound challenge to Earth’s people, its investigation is a story of scientific accomplishment. Global warming was forecast by simple theories and models well back into the previous century. Our current models capture the evolution and global patterns of climate change over the past century remarkably well, and they make credible and reproducible projections for the long-term climate outcomes of greenhouse warming. At the same time our observing systems, although incomplete, monitor changes in the global environment with unprecedented accuracy and precision.

Our knowledge is expanding. Driven by intense research efforts that are interdisciplinary, inter-governmental, and international, scientific understanding of global climate change is growing rapidly. Recent advances build on the understanding contained in the IPCC 4th Assessment (AR4, 2007), which is based on research conducted more than five years ago. We now know more about how the Earth functions as a system – the role of ice, carbon, rainfall and nitrogen cycles; ecosystem responses; the likelihood of extreme event occurrence (e.g., wildfires and heat waves) and more. A body of recent research compiled in the U.S. Climate Change Science Program’s Synthesis and Assessment Products (SAP) has been very helpful in expanding our regional knowledge in these areas.

Because of the accumulation of surplus heat energy in the ocean, atmospheric warming will continue long into the future, but the rate of this warming and any possibility for ultimate stabilization of this system will be dependent on how humans adjust concentrations of atmospheric greenhouse gases over the next years and decades.

WHAT WE NEED TO KNOW

As the pace of global change has accelerated, so has the demand from the public, business leaders, resource managers, and decision makers for climate predictions, not just a century ahead but over the next five, ten, or fifteen years, and not just globally, but regionally and locally. Led by U.S. researchers, the scientific enterprise can meet this demand, but must first fill fundamental gaps in our understanding of the Earth system and build new technologies for Earth-system prediction. Traditional research in fields like meteorology, oceanography, geology, glaciology, biology, and the social sciences must be linked to construct an understanding of the Earth-system including the impact of, and on, its human inhabitants. Underpinning all of this is the need for a comprehensive, high accuracy, high-spatial and high temporal resolution, stable, continuous, sustained global climate observing system that includes physical, biological, and social observations not only to monitor climate change but for use in research and modeling.

Results of interdisciplinary research efforts must then be used in developing computational models with verifiable predictive skill. These next-generation predictive models will need to be run on our most powerful computers that can store, display, and analyze, and similarly handle the ever-growing volumes of observational data used to further refine the models. New computational methods are needed to make the best possible use of our computing power. Finally, new knowledge and techniques in mathematics, statistics, information sciences and cyber-infrastructure are crucial in converting model results to quantifiable statements about the various impacts and risks posed by climate change.

WHAT ARE SOME OF THE LEADING SCIENTIFIC CHALLENGES?

Regional Climate Change

While our understanding of average global climate change and the large-scale factors driving it are fairly well understood we have yet to develop the capability to predict accurately how climate will change on a regional basis. Some parts of the globe, such as the Antarctic Peninsula, are warming much faster than others and the factors driving these local variations are not well understood. A key challenge to the research community is to identify and understand these smaller scale factors and to incorporate them into models that will predict reliably how communities and specific parts of the globe will be impacted by climate change.

Ice Sheet Changes and Rising Sea Levels

Rising sea levels are a major consequence of global warming. As the oceans warm, their waters expand. This effect is comparatively well understood and predictable. What is less understood and less predictable is the behavior of ice sheets and the possibility of great and rapid rises in sea level due to melting ice caps. The ice sheets of Greenland and Antarctica hold vast volumes of water. Because of uncertainties surrounding the behavior of ice sheets, their impact on sea level rise was not adequately addressed in the last IPCC assessment. Recent observations including increasing areas of summer melt on the surface of the Greenland icecap and space-based observations of decreasing ice-sheet mass suggest the potential for a 0.6 - 1.9 feet rise in sea level this century (SAP 3.4). Low lying regions, vital coastal wetlands and, in the developing world, densely populated agricultural regions could be inundated as a result of rapid sea level rise.

In the U.S. alone, protecting coastal infrastructure against such a rise could require continuing investments of billions of dollars. At present, however, we cannot make reliable statements on the likelihood of a disastrous rise in sea level because of our limited knowledge of how ice sheets work. Recent research suggests that some previously unknown or neglected processes, such as the lubrication of ice flow by surface meltwater which reaches the base of the ice sheet through crevasses, are important, but we are not yet at the point of incorporating these effects into predictive models (SAP 3.4). Other recent results suggest the importance of increasing ocean temperatures on the retreat of Greenland outlet glaciers and the diminishment of the ice sheet. Finally, the impact of sea level rise on coastal ecosystem may be significant and likely will have far reaching consequences to inland-oceanic processes, including freshwater quality and availability.

Water Scarcity

Three decades ago, climate modeling pioneer, Sukyuro Manabe, predicted that global warming would lead to reductions in rainfall in some of the Earth's most productive agricultural regions. The increased frequency of drought in places such as the southwest U.S. suggests that this trend may be underway (SAP 3.4). While models generally agree that the planet's subtropical dry zones are expanding, there is great disagreement among them in regard to the pace and severity. Within the tropics, the uncertainty is greater. For example, there is nearly perfect ***dis***agreement among models as to whether the Sahel region of Africa will become wetter or drier in this century. In the monsoon regions of South Asia a layer of haze, air pollution from industry and household fires, causes more sunlight to be absorbed within the atmosphere and less at Earth's surface. Some models predict that this change could result in a weakening of the Asian monsoon and more frequent failures of monsoon rains, but once again, the pace and strength of this effect is highly uncertain.

While our current models can address the global scale, they have not yet been fully adapted to regional and local scales. The water used by people, however, comes from local sources (e.g., wells, lakes and rivers recharged by rain and snow). At this stage, our models provide little information on these scales, which are small when viewed globally but critically important to a farmer or a water manager. Models that can provide information on the scales that users need are coming, but they are still in their infancy.

Ocean Acidification

Roughly one third of the carbon dioxide humankind has released from burning fossil fuels has gone into Earth's oceans (IPCC AR4). While ocean uptake has slowed the pace of global warming, it has been harmful to living things in the ocean. When carbon dioxide dissolves in the ocean, it makes seawater more acidic. Observations verify that the ocean has become more acidic, and, as this trend continues, it will make the ocean environment less and less hospitable for many key organisms, especially those that build hard shells, such as corals. While the basic chemistry of this problem is well understood, there are many questions we cannot yet answer: How will ocean ecosystems respond to increased acidity? How does ocean circulation, and its potential changes in a changing climate, affect how much carbon dioxide is absorbed and how rapidly the ocean acidifies? What are the implications of ocean acidification on marine ecology and the sustainability of fisheries and how might it affect the capacity of the ocean to continue to absorb carbon-dioxide? Ocean acidification is but one example of how questions about climate change extend beyond traditional climate science into other parts of the Earth system. In this case, a complete and coupled understanding of marine ecology along with climate physics is needed.

Methane Gas

Even when we look to the past, we are confronted by questions about the interrelationships between greenhouse gases and other environmental phenomena. For example, from ice cores drilled in Greenland and Antarctica, we know that in Earth's recent geologic past (hundreds of thousands of years) the concentrations of two greenhouse gases, carbon dioxide and methane, have varied nearly in lockstep with Earth's temperature (IPCC AR4). The changes in greenhouse gases must have played a significant role in the temperature changes, while, at the same time, and by mechanisms we still do not fully understand, changes in temperature caused changes in levels of greenhouse gases. We do not know if the processes that caused carbon dioxide and methane to change naturally in the past could still function today in a warmer climate. If they do, the implications for global warming are profound, as they would function as a positive feedback loop, increasing the rate of global warming. Great quantities of methane are sequestered in Arctic permafrost. This methane may be released to the atmosphere as Earth warms and the permafrost melts, but we do not know how much or how fast (SAP3.4).

Extreme Events

Researchers have already observed that an increasing portion of the rainfall comes in intense events. Two general implications of this trend are that the risk of flooding is increasing and that the fraction of rainfall that runs off may be greater. Recent modeling results suggest that as the Earth warms severe local storms and the damages from flash floods and high winds will increase (SAP 3.3). Further, the time between rainstorms may increase (SAP 3.3), which could lead to greater fire risk and water-stress to crops. Currently, our ability to make quantitative and precise statements about these risks that would be useful to emergency planners, farmers, and flood-control engineers is limited. Once again, the limitation comes from the scales of our models. The present generation of global climate models is far from being able to represent a locally severe thunderstorm or the time between storms.

Biodiversity and Ecosystem Function

The Earth's climate and related life support systems are changing today at highly accelerated rates that are markedly different from those experienced by living systems in the recent geological history. The processes associated with climate change, as well as the mechanisms available to mitigate it, are largely biological - every part of the Earth is affected by the seemingly endless ability of living organisms to transform the world around them. The relationship between the Earth's ability to function as a set of interconnected ecosystems and the biodiversity within and among those interacting systems is an area of incomplete knowledge and critical importance. Research that builds a mechanistic understanding of carbon, nutrient and water cycles and the connections with living systems; that connects carbon and nutrient cycles to land use changes; and that identifies likely continental sinks of CO_2 is necessary to fill gaps in the climate change picture and directly relevant to human well being. Finally, achieving an understanding of the linkages between the biological and physical Earth systems and social systems is needed. Maintaining a healthy planetary ecosystem depends on both the maintenance of the Earth's biodiversity and its ability to respond to changing conditions.

Human Health

In the summer of 1995 a heat wave in Chicago caused 521 deaths; the European heat wave of 2003 killed 35,000 people. Careful statistical and modeling studies indicate that the European heat wave was probably related to global warming (IPCC AR4). As the global temperature rises, the risk of severe heat waves is expected to increase. Yet we are limited in our ability to predict future heat waves and their impacts on people. Our models are not yet able to represent the complex urban environment where heat waves are most severe. Further, the impacts of heat waves depend on the vulnerability of urban populations and how they and community leaders respond when the thermometer spikes.

Heat waves are but one example of how global climate change can influence human health. Others include the spread of disease agents and vectors into new areas, such as from tropical to temperate regions and to higher latitudes and altitudes. Other examples include key findings from SAP 4.6 which include: (1) Hurricanes, extreme precipitation resulting in floods, and wildfires also have the potential to affect public health through direct and indirect health risks; (2) The impacts of higher temperatures in urban areas and likely associated increases in tropospheric ozone concentrations can contribute to or exacerbate cardiovascular and pulmonary illness if current regulatory standards are not attained; and (3) There will likely be an increase in the spread of several food and water-borne pathogens among susceptible populations depending on the pathogens' survival, persistence, habitat range and transmission under changing climate and environmental conditions.

In all of these cases, a useful estimate of the risk depends on more than predicting changes in the physical climate, even if we can do so at the small scales of a city neighborhood. Biology, ecology, and human physiology come into play, and, even more importantly, human responses. We must better understand the human and social dimensions of climate change if we are to address the wide range of climate change problems, but the scientific study of these human factors is in early stages.

Smart Adaptation and Smart Mitigation

It is imperative that society adapts to the impacts of continued warming of the climate. The extent to which we will need to adapt will depend substantially on future emissions and the success of mitigative efforts. Anticipating the magnitude of potential impacts is complicated by other factors such as population growth, urbanization, the availability and implementation of new technologies, the health and resilience of natural systems and human communities, and pollution, which can amplify or exacerbate the impacts due to changing climate. Current climate projections are based largely on scenarios that assume no particular climate polices with respect to greenhouse gases (IPCC AR4), however, policy choices will, in fact, affect how natural and human systems respond, perhaps in unexpected ways.

Society will need to pursue a mix of smart adaptation and mitigation strategies. Identifying the best sets of options requires tools that allow us to understand how the Earth's physical, biological and human systems will respond to various adaptation and mitigation strategies and the tradeoffs with respect to effectiveness and cost. Factors of politics, economic development, and human behavior and health must be taken into account. These requirements bring us into a new and very challenging realm where traditional natural science, social science, and policy sciences all intersect.

Potentially Disruptive Climate Change

Studies of ancient climate change have shown evidence of dramatic changes in the Earth's climate. Much new work focuses on possible "tipping points" or thresholds, at which a system undergoes rapid and dramatic change. Such events occur rarely, but carry high consequences when they do. For example, during the 1990s, Alaska experienced the largest outbreak of spruce bark beetles in the world. This outbreak was associated with a threshold response to milder winters and warmer temperatures that allowed more beetles to survive the winter (SAP 4.2) The concept also applies to social and economic systems. Identifying potential tipping points in our natural and social systems is challenging because many systems are nonlinear, but fully informed decision making by policymakers will need to take the possibility of tipping points into account.

Dealing with Uncertainty

No matter how sophisticated our models and predictive capabilities there will always be uncertainties in the projections and the risks of adopting particular strategies cannot be fully known. Scientists must find new ways to convey to non-specialists the uncertainties of their predictions and develop tools that allow decision-makers to incorporate the information into the decision process.

The Ultimate Goal

The goal of climate change science is to make verifiable quantitative predictions. We need this predictive capability for two reasons. First, and most importantly, societies need them to respond intelligently to the challenges posed by a changing climate. At the same time, as scientists, we know our understanding can be tested only by making predictions and comparing them with what actually happens – this is as true today for global climate change as it was for predicting the orbits of the planets in the days of Kepler and Newton. Getting to a useful predictive capacity requires scientific understanding of the myriad processes and interactions that comprise the Earth system. It requires constructing computational models that incorporate our understanding. It requires access to our best supercomputer hardware and the development of computational methods to implement these models. It requires observations of all aspects of the Earth system, including its human dimensions, that can be used as the starting points for model predictions and as data for testing the accuracy of models. And it requires the human and cyber infrastructure to deliver model results to people in forms and media that they can use.

As noted previously the scientific community has made remarkable progress in gaining an understanding of climate relevant processes and the ability to model these processes to give a realistic representation of the current climate system on a global scale and how human activities have begun to impact climate. There really is no longer a question of humankind's perturbation of the climate. The question now is the timing and the magnitude of climate change that will occur in the future.

CONCLUSION

Society cannot avoid the need to adapt to the impacts of continued warming of the climate due to past emissions of greenhouse gases, but policy and decision makers need a rational basis for deciding how to proceed and an understanding of the potential consequences of their choices. Climate Science has progressed to the point where the detailed predictions required are within reach, once a set of definable scientific challenges is overcome. The predictive knowledge base to inform sound and effective policy is perhaps the most important gift science will ever yield to humanity.

The U.S. leads the world in research in the natural and social sciences and engineering disciplines and in developing computing hardware and computational tools. The significance of the climate problem demands that the U.S. take the lead in its solution. The U.S. science community is poised to take on this challenge.

Mr. Chairman, I appreciate the opportunity to appear before the Committee to speak to you on this important topic. I would be pleased to answer any questions that you may have.