**Climate Change**
Full Committee Hearing
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The Testimony of
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Good morning. Thank you very much for this opportunity to testify. I am Richard Alley, a professor of geosciences at the Pennsylvania State University, and I served as chair of a recent committee of the National Academies that produced the report, "Abrupt Climate Change: Inevitable Surprises." Most of the other testimony this morning focuses on climate change in the broad sense and how we as a nation can improve our understanding of change and our resiliency in responding to its impacts. My role is to focus on a piece of this puzzle: abrupt climate change.

## WHAT IS ABRUPT CLIMATE CHANGE?

Just what do I mean by abrupt climate change? If you read the evidence hidden in ice cores and other records of what the climate was in the past, you will learn that the Earth has at times undergone large, abrupt, widespread and persistent changes in climate (see Figure 1, page 4). I'm talking about a change of as much as 10oC during just 10 years in some places. to a new climate state that persisted for centuries. For example, roughly half the north Atlantic warming since the last ice age was achieved in only a decade, and it was accompanied by significant climatic changes across most of the globe. Paleo-records show that local warmings as large as 16°C occurred repeatedly during the slide into and climb out of the last ice age. Think about what that kind of change might mean to farmers. Or to water managers. Evidence suggests that abrupt climate changes are not only possible but may be likely in the future, and regardless of timing such changes would bring large impacts on ecosystems and societies.

Our report, which was published in 2002, was an attempt to describe what is known about abrupt climate changes and their impacts, based on paleoclimate proxies, historical observations, and modeling. The report does not focus on large, abrupt causes—nuclear wars or giant meteorite impacts—but rather on the surprising new findings that abrupt climate change can occur when gradual causes push the earth system across a threshold. Just as the slowly increasing pressure of a finger eventually flips a switch and turns on a light, the slow effects of drifting continents or wobbling orbits or changing atmospheric composition may "switch" the climate to a new state. And, just as a moving hand is more likely than a stationary one to encounter and flip a switch, faster earth-system changes—whether natural or human-caused—are likely to increase the probability of encountering a threshold that triggers a still-faster climate shift.

## CAN WE PREDICT ABRUPT CLIMATE CHANGE?

We do not yet understand abrupt climate changes well enough to predict them. The models used to project future climate changes and their impacts are not especially good at simulating the size, speed, and extent of the past changes, casting uncertainties on assessments of potential future changes. Thus, it is likely that climate surprises await us.

When orbital wiggles and rising greenhouse gases warmed the earth from the last ice age, proxy records show that smooth changes were interspersed with abrupt coolings and warmings, wettings and dryings. By analogy, the expected future warming may come smoothly, but may come with jumps, short-lived or local coolings, floods or droughts, and other unexpected changes. Societies and ecosystems have an easier time dealing with slower or better-anticipated changes, so the abruptness and unpredictability of the possible changes may be disquieting.

Abrupt climate changes were especially common when the climate system was being forced to change most rapidly. Thus, greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events.

Our committee, which was composed of 11 of the most knowledgeable experts and which benefited from input from dozens of other scientists who participated in our workshops, considered patterns, magnitudes, mechanisms, and impacts of abrupt climate changes, possible implications for the future, and critical knowledge gaps. The potentially large impacts and prediction difficulties pose special challenges – how can we increase the adaptability and resiliency of societies and ecosystems?

## WHAT CAN SOCIETY DO TO PREPARE FOR ABRUPT CLIMATE CHANGE?

There is no need to be fatalistic about the threats posed by abrupt climate change. Societies have faced both gradual and abrupt climate changes for millennia and have learned to adapt through various mechanisms, such as moving indoors, developing irrigation for crops, and migrating away from inhospitable regions. Nevertheless, because climate change will likely continue in the coming decades, denying the likelihood or downplaying the relevance of past abrupt events could be costly. Societies can take steps to face the potential for abrupt climate change. The committee believes that increased knowledge is the best way to improve the effectiveness of response, and thus that research into the causes, patterns, and likelihood of abrupt climate change can help reduce vulnerabilities and increase our adaptive capabilities. The committee's report provides detailed recommendations in two broad categories:

(1) targeted research necessary to expand instrumental and paleoclimatic observations, and (2) modeling and associated analysis needed to understand abrupt climate change and its potential ecological, economic, and social impacts.

The charge to the committee asked us to think about what kinds of research are necessary to improve our understanding of abrupt climate change, so we give a lot of attention to research needs. A few of the most important areas are: · Understanding abrupt climate

change and its potential impacts requires that we study both human impacts on climate and also natural causes of climate change; · Abrupt climate changes of the past especially involved shifts in ocean circulation, in land-surface processes affecting drought, in snow and ice, and in the preferred patterns of the climate system such as El Nino, so these topics are prominent in the committee's recommendations. · Climate histories from ice and sediment cores, tree rings and more have been very important in the study of abrupt climate changes—events that actually occurred must be possible—so continued study of the history of climate remains important.

The committee emphasized the opportunity for research to identify "no regrets" measures to reduce vulnerabilities and increase adaptive capacity at little or no cost. Climate histories show that change is almost certain, and that abrupt and surprising changes are likely in at least some regions. Many current policies and practices are likely to be inadequate in a world of rapid and unforeseen climatic changes. Identifying ways to improve these policies will be beneficial even if abrupt climate change turns out to fit a best-case, rather than a worst-case, scenario. Societies will have "no regrets" about the new policies, because they will be good policies regardless of the magnitude of environmental change. For example, the phase-out of chloroflourocarbons and replacement by gases with shorter atmospheric lifetimes have reduced the U.S. contribution to global warming while at the same time reducing future health risks posed by ozone. History shows that in response to climatic challenges, some groups have "broken" while others have "bent", so the committee deemed it wise to study ways to promote "bendability".

Thank you for this opportunity to talk about abrupt climate change so you can consider this as you think about the new Climate Change Strategic Plan. More details from our report appear in my written testimony and I'd be happy to answer questions.

RECOMMENDATIONS FROM THE REPORT, "ABRUPT CLIMATE CHANGE: INEVITABLE SURPRISES"

Improve The Fundamental Knowledge Base Related To Abrupt Climate Change

Recommendation 1. Research programs should be initiated to collect data to improve understanding of thresholds and nonlinearities in geophysical, ecological, and economic systems. Geophysical efforts should focus especially on modes of coupled atmosphere-ocean behavior, oceanic deepwater processes, hydrology, and ice. Economic and ecological research should focus on understanding nonmarket and environmental issues, initiation of a comprehensive land-use census, and development of integrated economic and ecological data sets. These data will enhance understanding of abrupt climate change impacts and will aid development of adaptation strategies.

Physical, ecological, and human systems are imperfectly understood, complex, nonlinear, and dynamic. Current changes in climate are producing conditions in these systems that are outside the range of recent historical experience and observation, and it is unclear how the systems will interact with and react to the coming climatic changes. Our ability

to adapt to or mitigate the effects of climate change will be improved if we can recognize climate-related changes quickly. This will require improved monitoring of climatic, ecological, and socioeconomic systems. Many of the needed data sets overlap with those used to study gradual climate change.

To increase understanding of abrupt climate change, research should be directed toward aspects of the climate system that are believed to have participated in past abrupt changes or that are likely to exhibit abrupt and persistent changes when thresholds in the climate system are crossed. Key research areas for increasing our understanding of abrupt climate change include: · oceanic circulation, especially related to deepwater formation; · sea-ice transport and processes, particularly where they interact with deepwater formation; · land-ice behavior, including conditions beneath ice sheets; · the hydrological cycle, including storage, runoff, and permafrost changes; and · modes of atmospheric behavior and how they change over time. In the ecological and human sphere, data collection should target sectors where the impacts of abrupt climate change are likely to be largest or where knowledge of ongoing changes will be especially useful in understanding impacts and developing response alternatives. Data collection should include a comprehensive land-use census that monitors fragmentation of ecosystems, tracking of wildlife diseases, and conditions related to forest fires, as well as improved seasonal and long-term climate forecasts, and sustained study of oceanic regimes of intense biological activity, particularly near the coasts. In the social arena, priority should be given to development of environmental and nonmarket accounts, and analyses of possible threshold crossings.

Improve Modeling Focused On Abrupt Climate Change

Recommendation 2. New modeling efforts that integrate geophysical, ecological, and social-science analyses should be developed to focus on investigating abrupt climate changes. In addition, new mechanisms that can cause abrupt climate change should be investigated, especially those operating during warm climatic intervals. Understanding of such mechanisms should be improved by developing and applying a hierarchy of models, from theory and conceptual models through models of intermediate complexity, to high-resolution models of components of the climate system, to fully coupled earth-system models. Model-data comparisons should be enhanced by improving the ability of models to simulate changes in quantities such as isotopic ratios that record past climatic conditions. Modeling should be used to generate scenarios of abrupt climate change with high spatial and temporal resolution for assessing impacts and testing possible adaptations. Enhanced, dedicated computational resources will be required for such modeling.

Developing theoretical and empirical models to understand abrupt climate changes and the interaction of such changes with ecological and economic systems is a high priority. Modeling is essential for collaborative research between physical, ecological, and social scientists, and much more effort is needed to develop accurate models that produce a useful understanding of abrupt climate processes. Model analyses help to focus research on possible causes of abrupt climate change, such as human activities; on key areas

where climatic thresholds might be crossed; and on fundamental uncertainties in climate-system dynamics. To date, most analyses have considered only gradual climate change; given the accumulating evidence of past abrupt climate change and of its capacity to affect human societies, more attention should be focused on scenarios involving abrupt change.

Climate models that are used to test leading hypotheses for abrupt climate change, such as altered deep-ocean circulation, can only partially simulate the size, speed, and extent of the large climatic changes that have occurred. The failure to explain the climate record fully suggests either that the proposed mechanisms being used to drive these models are incomplete or that the models are not as sensitive to abrupt climate change as is the natural environment. It is also of concern that existing models do not accurately simulate warm climates of the past.

A comprehensive modeling strategy designed to address abrupt climate change should include vigorous use of a hierarchy of models, from theory and conceptual models through models of intermediate complexity, to high-resolution models of components of the climate system, to fully coupled earth-system models. The simpler models are well suited for use in developing new hypotheses for abrupt climate change and should focus on warmer climate, because warming is likely. Because reorganizations of the thermohaline circulation have never been demonstrated in climate models employing high-resolution ocean components, improving the spatial resolution in climate models assumes high priority. Complex models should be used to produce geographically resolved (to about 1° of latitude by 1° of longitude), short-time (annual or seasonal) sensitivity experiments and scenarios of possible abrupt climatic changes.

Long integrations of fully coupled models under various forcings for the past, present, and future are needed to evaluate the models, assess possibilities of future abrupt changes, and provide scenarios of those future changes. The scenarios can be combined with integrated-assessment economic models to improve understanding of the costs for alternative adaptive approaches to climate change with attention to the effects of rising greenhouse-gas concentrations and nonclimatic factors, such as land use changes and urbanization. Model-data comparisons are needed to assess the quality of model predictions. It is important to note that the multiple long integrations of enhanced, fully coupled earth-system models required for this research are not possible with the computer resources available today, and thus these resources should be enhanced.

Improve Paleoclimatic Data Related To Abrupt Climate Change

Recommendation 3. The quantity of paleoclimatic data on abrupt change and ecological responses should be enhanced, with special emphasis on:

· Selected coordinated projects to produce especially robust, multi-parameter, high-resolution histories of climate change and ecological response. · Better geographic coverage and higher temporal resolution. · Additional proxies, including those that focus

on water (e.g., droughts, floods, etc.). · Multidisciplinary studies of selected abrupt climate changes.

The current scientific emphasis on abrupt climate change was motivated by strong evidence in proxy records that showed extreme climatic changes in the past, sometimes occurring within periods of fewer than 10 years. Paleoclimatic records provide important information related to changes in many environmental variables. However, not all proxy archives provide equally high confidence for estimating past climatic conditions, such as temperature and precipitation, and for determining when and how rapidly changes occurred.

Confidence can be improved by encouraging coordinated, multi-parameter, multi-investigator study of selected archives that have seasonal to decadal time accuracy and resolution, substantial duplication of measurements to demonstrate reproducibility, and extensive calibration of the relation between climate and sedimentary characteristics. As one example, in the ice-core projects from central Greenland, duplication of the measurements by independent, international teams provides exceptional confidence in most data and reveals which datasets do not warrant confidence. Sampling at very high time resolution to produce datasets complementary to those of other investigators gives an exceptionally clear picture of past climate. Such projects require more funding and effort than are typical of paleoclimatic research, but they provide an essential reference standard of abrupt climate change to which other records can be compared. A difficulty is that this reference standard is from one place in high northern latitudes and is inappropriate for study of much of the climate system.

Not all paleoclimatic records can be studied in the same detail as those from Greenland, but generation of at least a few similar highly resolved (preferably annually or subannually) reference standards including a North Atlantic marine record comparable with Greenland records, would be of great value. The ultimate goal is to develop a global network of records with at least decadal resolution. Terrestrial and marine records of climate change and ecological response from the regions of the western Pacific warm pool (the warmest part of the global climate system) and the Southern Ocean and Antarctic continent (the southern cold pole of the climate system) are among the most critical targets for future paleoclimate research, including generation of reference standards.

Abrupt climate change is likely to influence water availability and therefore is of great concern for economic and ecological systems. Focus on measures of precipitation, evaporation, and the quantitative difference between them is particularly important. Freshwater balance is also important in controlling water density and thus the thermohaline circulation of the oceans; reconstructions of water-mass density in polar and subpolar regions are central. New methods for investigating past changes in the hydrological cycle are important, as are additional studies of the relation between a range of climatic changes and the signals they leave in sedimentary archives.

Global maps of past climates, with high resolution in time and space and spanning long intervals, would be of great use to the climate community. However, such maps are unlikely to be available soon. The traditional alternative of reconstructing climate for selected moments, or "time-slices," fails to capture the short-lived anomalies of abrupt climate changes. Instead, mapping efforts are needed and should focus on the patterns of selected abrupt climatic changes in time and space and on their resulting effects. Additional emphasis on annually resolved records of the last 2000 years will help to place the warming and associated changes of the last 100 years in context.

## Improve Statistical Approaches

Recommendation 4. Current practices in the development and use of statistics related to climate and climate-related variables generally assume a simple, unchanging distribution of outcomes. This assumption leads to serious underestimation of the likelihood of extreme events. The conceptual basis and the application of climatic statistics should be re-examined with an eye to providing realistic estimates of the likelihood of extreme events.

Many societal decisions are based on assumptions about the distribution of extreme weather-related events. Large capital projects, for instance, often have embedded safety margins that are derived from data and assumptions about the frequency distribution of extreme events. Many major decisions are based on statistical calculations that are appropriate for stationary climates, such as in the use of "30-year normals," for deriving climate data for individual locations.

On the whole, those assumptions are reasonable, if imperfect, rules of thumb to use when the variability of weather is small and climate is stationary. If climate follows normal distributions with known and constant means and standard deviations, businesses and governments can use current practices. However, in light of recent findings related to nonstationary and often highly skewed climate-related variables, current practices can be misleading and result in costly errors.

The potential for abrupt climate change and the existence of thresholds for its effects require revisions of our statistical estimates and practices.

## Investigate "No-Regrets" Strategies To Reduce Vulnerability

Recommendation 5. Research should be undertaken to identify "no-regrets" measures to reduce vulnerabilities and increase adaptive capacity at little or no cost. No-regrets measures may include low-cost steps to: slow climate change; improve climate forecasting; slow biodiversity loss; improve water, land, and air quality; and develop institutions that are more robust to major disruptions. Technological changes may increase the adaptability and resiliency of market and ecological systems faced by the prospect of damaging abrupt climate change. Research is particularly needed to assist poor countries, which lack both scientific resources and economic infrastructure to reduce their vulnerabilities to potential abrupt climate changes.

Social and ecological systems have long dealt with climate variability by taking steps to reduce vulnerability to its effects. The rapidity of abrupt climate change makes adaptation more difficult. By moving research and policy in directions that will increase the adaptability of economic and ecological systems, it might be possible to reduce vulnerability and increase adaptation at little or no cost. Many current policies and practices are likely to be inadequate in a world of rapid and unforeseen climatic changes. Improving these policies will be beneficial even if abrupt climate change turns out to fit a best-case, rather than a worst-case, scenario. Societies will have "no regrets" about the new policies, because they will be good policies regardless of the magnitude of environmental change. For example, the phaseout of chloroflourocarbons and replacement by gases with shorter atmospheric lifetimes have reduced the US contribution to global warming while at the same time reducing future health risks posed by ozone depletion.

In land-use and coastal planning, managers should consider the effects on ecosystem services that could result from interaction of abrupt climate changes with changes caused by people. Scientists and government organizations at various levels may be used to develop and implement regulations and policies that reduce environmental degradation of water, air, and biota. Conservation measures related to land and watersheds might be put into place to reduce the rate of biotic invasions, with management strategies used to limit the spread of invasions. The potential economic and ecological costs of disease emerging from abrupt climate change should be assessed.

A promising option is to improve institutions to allow societies to withstand the greater risks associated with abrupt changes in climate. For example, water systems are likely to be stressed by abrupt climate change; to manage scarce water, it might prove beneficial to seek more flexible ways to allocate water, such as through use of water markets. Another example of a "no-regrets" strategy is insurance against the financial impacts of fires, floods, storms, and hurricanes. Through the development of new instruments, such as weather derivatives and catastrophe bonds, markets might better accommodate extreme events such as the effects of abrupt climate change. It will be important to investigate the development of better instruments to spread large losses that result from extreme events, priced realistically to reflect the risks but not to encourage excessive risk taking.

Because of the strength of existing infrastructure and institutions, the United States and other wealthy nations are likely to cope with the effects of abrupt climate change more easily than poorer countries. That does not mean that developed countries can remain isolated from the rest of the world, however. With growing globalization, adverse impacts – although likely to vary from region to region because exposure and sensitivity will vary – are likely to spill across national boundaries, through human and biotic migration, economic shocks, and political aftershocks. Thus, even though this report focuses primarily on the United States, the issues are global and it will be important to give attention to the issues faced by poorer countries that are likely to be especially vulnerable to the social and economic impacts of abrupt climate change.

The United States is uniquely positioned to provide both scientific and financial leadership, and to work collaboratively with scientists around the world, to gain better understanding of the global impacts of abrupt climate change as well as reducing the vulnerability and increasing the adaptation in countries that are particularly vulnerable to these changes. Many of the recommendations in this report, although currently aimed at US institutions, would apply throughout the world.

The Testimony of
**Dr. Thomas E. Graedel**
Professor of Industrial Ecology, Yale University, Department of Industrial Ecology

Good morning, Mr. Chairman, Senator Hollings, and members of the Committee: My name is Thomas Graedel. I am professor of industrial engineering at Yale University and serve as chairman of the Committee to Review the U.S. Climate Change Science Program Strategic Plan of the National Research Council. The Research Council is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, chartered by Congress in 1863 to advise the government on matters of science and technology. I appreciate the opportunity to appear before the Committee today to discuss a recent report of the National Research Council entitled Planning Climate and Global Change Research: A Review of the Draft U.S. Climate Change Science Program Strategic Plan. I am pleased to share this panel with three members of the committee who wrote this report: Tony Janetos from the H. John Heinz III Center for Science, Economics, and the Environment; Diana Liverman from the University of Arizona; and Andrew Solow from the Woods Hole Oceanographic Institute. Research to understand how the climate system might be changing, and in turn affecting other natural systems and human society, has been underway for more than a decade. Significant advancement in understanding has resulted from this research, but there are still many unanswered questions, necessitating a continuance of this effort. The U.S. Climate Change Science Program, or CCSP, was formed in 2002 to coordinate and direct U.S. efforts in climate change and global change research. The CCSP builds upon the decade-old U.S. Global Change Research Program. Since its inception the Global Change Research Program, or GCRP, has reported hundreds of scientific accomplishments and, together with other major international partners and programs, has been responsible for improving the understanding of climate change and associated global changes. The CCSP incorporates the GCRP and adds a new component—the Climate Change Research Initiative, or CCRI—whose primary goal is to "measurably improve the integration of scientific knowledge, including measures of uncertainty, into effective decision support systems and resources." Thus, this overall activity combines an existing program, the Global Change Research Program, with a new component, the Climate Change Research Initiative. On September 17, 2002, Assistant Secretary of Commerce for Oceans and Atmosphere James R. Mahoney requested that the National Academies undertake a fast-track review of the U.S. Climate Change Science Program's draft strategic plan for climate and global change studies. He asked the National Academies to form a committee to review both the discussion draft of the strategic plan, which was released on November 11, 2002, and the final strategic plan after it has been revised. In response the 17-member Committee to Review the U.S. Climate Change

Science Program Strategic Plan was formed. The committee's first report, in which the draft strategic plan is reviewed, was released on February 25, 2003. My remaining comments reflect the findings and recommendations presented in this report. The committee commends the CCSP for undertaking the challenging task of developing a strategic plan. The current draft of the plan represents a good start to the process, particularly in that it identifies some exciting new directions for the program while building on the well-established foundation of the Global Change Research Program. The committee finds that the draft strategic plan identifies many of the cutting-edge scientific research activities that are necessary to improve understanding of the Earth system. The Climate Change Research Initiative portion of the plan introduces an admirable emphasis on the need for science to address national needs, including support for those in the public and private sectors whose decisions are affected by climate change and variability. Further, the CCSP has made genuine overtures to researchers and the broader stakeholder community to gain feedback on the draft strategic plan and how to improve it. These efforts indicate a strong interest on the part of the CCSP in developing a plan that is consistent with current scientific thinking and is responsive to the nation's needs for information on climate and associated global changes. In general, the draft strategic plan provides a solid foundation for the Climate Change Science Program. With suitable revisions, the plan could articulate an explicit and forward-looking vision for the CCSP and clearly identifiable pathways to successful implementation. To assist the CCSP in revising the strategic plan, the NRC review makes an extensive set of recommendations. These recommendations for revisions fall into five categories: (1) clarify the vision and goals of the CCSP and the CCRI, (2) improve the treatment of program management, (3) fill key information needs, (4) enhance efforts to support decision making, and (5) set the stage for implementation. I will comment briefly on some of the specific recommendations that address these five points. I refer you to the committee's full report for more details.

The first set of recommendations address revisions to the draft strategic plan that would clarify the vision and goals of the Climate Change Science Program and its subcomponent, the Climate Change Research Initiative. The committee finds that the draft strategic plan lacks the kind of clear and consistent guiding framework that would enable decision makers, the public, and scientists to clearly understand what this research program is intended to accomplish and how it will contribute to meeting the nation's needs. In particular, it lacks most of the common elements of a strategic plan: a guiding vision, executable goals, clear timetables and criteria for measuring progress, an assessment of whether existing programs are capable of meeting these goals, explicit prioritization, and a management plan. The draft plan lists a multitude of proposed activities, but does not identify which of these activities are higher priorities than others, nor does it provide an explicit process for establishing such priorities. A systematic and coherent strategic plan is especially necessary when, as in the CCSP, the institutional environment is diverse and fragmented and when the program involves new directions and collaborations. Such a plan would provide a common basis for planning, implementation, and evaluation and would protect against a continuation of the status quo. The committee recommends that the revised strategic plan articulate a clear, concise vision statement for the program in the context of national needs. The vision should be

specific, ambitious, and apply to the entire Climate Change Science Program. The plan should translate this vision into a set of tangible goals, apply an explicit process to establish priorities, and include an effective management plan. The revised strategic plan also must present clear and consistent goals for the Climate Change Research Initiative. The draft strategic plan states that to be included in the CCRI, a program must produce significant decision or policy-relevant deliverables within two to four years and contribute significantly to improving scientific understanding; optimizing observations, monitoring, and data management systems; or developing decision support resources. The committee considers the CCRI's emphasis on scientific support for decision makers one of the most promising and innovative features of the draft strategic plan. Further, the plan appropriately recognizes that there are some short-term products that can and should be delivered by the program. Unfortunately, the plan's descriptions of decision support as a two to four year activity give the false impression that decision support is needed only in the near-term. While short-term deliverables are possible in this arena, decision support also will be needed as an ongoing component of the program. In addition, many of the CCRI activities aimed at reducing uncertainty and improving observations are not consistent with the CCRI focus on decision support and are not likely to produce deliverables within four years. This is not to say that these activities are unimportant, but simply that they are not consistent with the goals for CCRI as given in the draft plan. The committee recommends that the revised strategic plan present clear goals for the Climate Change Research Initiative and ensure that its activities are consistent with these goals while maintaining the CCRI's strong emphasis on support for near-term decisions as an ongoing component. The revised strategic plan also needs to describe more clearly how the research activities included in the Global Change Research Program support the decision support needs of the Climate Change Research Initiative. Indeed, there should be a "rolling linkage" between the two programs, with CCRI objectives periodically redefined as a result of new scientific input from the GCRP. The committee believes it is essential for the Climate Change Science Program to move forward with the important new elements of CCRI while preserving crucial parts of existing GCRP programs. The committee recommends that the revised plan include an explicit mechanism to link Global Change Research Program and Climate Change Research Initiative activities.

The second overarching area for improvement in the draft plan is its treatment of program management. The management of an interagency program involving 13 agencies, each with a separate mission and a long history of independent research on climate and associated global changes, is a challenging task. The Global Change Research Program has been criticized in the past for being unable to do much beyond encouraging multi-agency cooperation and support because it lacked the authority to redirect long standing programs and mandates of individual agencies. The draft plan takes positive steps towards improved interdisciplinary research opportunities. The creation of a cabinet-level committee with the authority to shift resources among agencies to meet the goals of the Climate Change Science Program is an improvement over past approaches to managing the GCRP. However, the interagency approach to managing the program may not be enough to ensure that agencies cooperate toward the common goals of the CCSP because no individual is clearly identified in the draft plan as having responsibility for managing the program as a whole. The committee recommends that the revised strategic plan

describe the management processes to be used to foster agency cooperation toward common Climate Change Science Program goals. In particular, the responsibilities of the CCSP leadership and relevant agencies should be clearly outlined. The Climate Change Technology Program is an interagency program parallel to the CCSP and created to coordinate and develop technologies for stabilizing and reducing greenhouse gas levels in the atmosphere. The committee is concerned that the existing management and program links between the CCSP and the Climate Change Technology Program may not be extensive enough to take advantage of the synergies between these two programs. The committee recommends that the revised Climate Change Science Program strategic plan clearly describe mechanisms for coordinating and linking its activities with the technology development activities of the Climate Change Technology.

A third overarching set of recommendations for improving the draft strategic plan addresses better filling key information needs. In this regard, the Global Change Research Program's research of the last decade, which focused on national- to global-scale phenomena, should be augmented with research to develop an understanding of regional scale variability and change. Such information would be useful to international, federal, state, and local decision makers facing environmental problems, including drought, flooding, or other climate impacts. Insufficient detail is provided in the draft plan about how current work on large-scale climate will be adapted and combined with information to address regional issues and seasonal-to-interannual timeframes. The committee recommends that the revised strategic plan more fully describe how models and knowledge that support regional decision making will be developed. The next decade of research must also support an increase in understanding the potential impacts of climate change on human societies and ecosystems, and related options for adaptation and mitigation. The need for research and applications in these areas logically follows from the CCSP's new emphasis on decision support. The draft strategic plan's treatment of human dimensions and ecosystems, however, has several important gaps. The draft plan lacks research into consumption, institutions, and social aspects of technology as causes of climate and associated global changes. It does not propose any research into the costs and benefits of climate change and related response options. And, its treatment of ecosystems needs a more cohesive and strategic organizational framework that places a clear priority on predicting ecosystem impacts and on providing the scientific foundation for possible actions and policy choices. The committee recommends that the revised strategic plan strengthen its approach to the human, economic, and ecological dimensions of climate and associated global changes. The draft strategic plan's call for greatly improved observational capabilities reflects a well recognized priority for increasing understanding of climate and associated global changes. To date, the global climate observing system is only a patchwork of observational networks maintained by various agencies within the United States and by other nations. Careful planning and major investments are needed to maintain and expand an integrated climate observing system. A critical weakness in the draft plan is that it does not adequately explain how existing observation systems will be integrated and expanded. The committee recommends that the revised strategic plan better describe a strategic program for achieving an integrated observing system for detecting and understanding climate variability and change and associated global changes on scales from regional to global.

A fourth opportunity for improvement to the draft strategic plan is to strengthen its treatment of decision support. The committee views the definition and development of decision support resources as a critical short-term goal of the CCSP. Although the draft strategic plan has incorporated general language about decision support in many places, it is vague about what this will actually mean. Indeed, the draft plan does not recognize the full diversity of decision makers and does not describe mechanisms for two-way communication with stakeholders. The committee recommends that the revised strategic plan identify which categories of decision makers the Climate Change Science Program serves and describe how the program will improve two-way communication with them. The revised plan also should better describe how decision support capabilities will be developed and how these efforts will link with and inform the program's research to improve understanding of climate and associated global changes. The draft strategic plan identifies the reduction of uncertainty as a top priority for the Climate Change Science Program and its subcomponent, the Climate Change Research Initiative. The draft plan recognizes three important points about uncertainty: (1) uncertainty is inherent in science and decision making and therefore not in itself a basis for inaction; (2) decision makers need to be well informed about uncertainty so that decisions can be made more knowledgeably; and (3) accelerated research should focus on those uncertainties that are important for informing policy and decision making. Unfortunately, the draft plan does not apply a systematic process to identify the key scientific uncertainties and to ascertain which of those are most important to decision makers. Thus, the plan's research objectives intended to address decision making under uncertainty are not necessarily those of optimum use to decision makers. The committee recommends that the revised strategic plan identify what sources and magnitudes of reductions in key climate change uncertainties are especially needed to benefit decision-making.

A fifth and final overarching area for improving in the draft strategic plan is to better set the stage for implementation. The draft strategic plan calls for a multitude of research and decision support advances. In this regard, the committee believes that the Climate Change Science Program faces major challenges in "capacity building": systematically developing institutional infrastructure; growing new multidisciplinary intellectual talent; nurturing "networking" of diverse perspectives and capabilities; and fostering successful transition from research to decision support applications. In addition, capacity building is necessary to acquire the computing, communication, and information management resources necessary both to conduct the extensive climate modeling called for in the draft strategic plan and to process and store the large amounts of data collected from a greatly expanded observation network. The committee recommends that the revised strategic plan explicitly address the major requirements in building capacity in human and computing resources necessary to achieve its goals. It is clear that the scope of activities described in the draft strategic plan is greatly enlarged over what has been supported in the past through the Global Change Research Program. Implementing this expanded suite of activities will require significant investments in infrastructure and human resources. This will necessitate either greatly increased funding for the Climate Change Science Program or a major reprioritization and cutback in existing programs. Even if program funding increases, CCSP management will continue to be faced with many funding decisions, such as which new programs should be initiated (and when), whether any

existing programs should be scaled back or discontinued, how to balance short-term and longer-term commitments, and how to balance support for international and U.S. programs. The committee recommends that the Climate Change Science Program use the clear goals and program priorities of the revised strategic plan and advice from an independent advisory body to guide future funding decisions.

To conclude, the committee finds that the draft plan addresses crucial issues facing our nation and the world in the twenty-first century. The committee has worked diligently to make this report as useful as possible to the Climate Change Science Program. We wish the CCSP leadership well as it takes on the challenging task of revising the draft strategic plan to enhance the usefulness of the program to the decision makers who need to better understand the potential impacts of climate change and make choices among possible responses. Thank you for this opportunity to address the committee. We would be pleased to answer any questions the committee might have.