CHAPTER THREE

A New Era of Climate Change Research

As the preceding chapter makes clear, scientific research has steadily increased our understanding of climate change, as well as our appreciation of the complexity of the climate system and related, interacting human and environmental systems. The research summarized in Chapter 2, and described in further detail in Part II of the report, has also identified some of the challenges and risks associated with climate change, including some special characteristics and complexities that distinguish it from many other problems faced by society. In this chapter, we summarize some of these characteristics and discuss their implications in terms of the risks and choices faced by decision makers both in the United States and around the world. The chapter also briefly describes some of the actions that decision makers are taking to respond to climate risks, including actions to limit the magnitude of climate change and adapt to its impacts. These emerging responses call for a new era of climate change research, one that not only continues to improve understanding of climate change and the risks associated with it, but that also supports, facilitates, and improves actions taken to respond.

COMPLEXITIES OF CLIMATE CHANGE

Future climate will be unlike the climate of the recent past. Based on available records of atmospheric composition, sea level, and other sources (see Chapter 6), Earth's climate appears to have been relatively stable for roughly the past 10,000 years. Exceptional years, decades, and even centuries have occurred, of course, occasionally creating havoc for civilizations in some regions of the world (see, e.g., Diamond, 2005; Zhang et al., 2007b). However, human societies have generally been well served by assuming that the climate fluctuates around a relatively constant average state, with no long-term trends toward warmer or cooler temperatures, more or less precipitation, or more or fewer extreme events. This is changing, as Earth's climate system—from greenhouse gas (GHG) concentrations to ice cover, precipitation, and a host of other interrelated changes—moves outside the range within which it has fluctuated throughout the 10,000 years of recorded human history. As a result, many of our conventional practices for including climate and climate-related uncertainty in decision making—such as using historical records to plan for the "100-year flood" or the "100-year drought"—will need to be revisited, and new ways of thinking about preparing and adapting to change will need to emerge. Conventional practices may even heighten risks by encouraging us to continue planting vulnerable crop varieties, harvesting threatened resources at unsustainable levels, or building homes and communities in areas at growing risk from fires, floods, or rising sea levels.

Projections of future climate depend strongly on current and future human actions. The magnitude of future climate change and the severity of its impacts are strongly dependent on how human societies produce and use energy, manage natural resources, and take other actions to respond to climate risks and vulnerabilities in the decades ahead. Not only is it impossible to anticipate all of the actions that humans might take, but the consequences of these actions for both the climate system and related human and environmental systems are subject to a large number of uncertainties and unknowns.

Climate change processes have considerable inertia and long time lags. Until GHG emissions are brought below the rate of their removal from the atmosphere, atmospheric concentrations will continue to rise. The most important GHGs remain in the atmosphere for years to centuries and continue to affect Earth's heat balance throughout their atmospheric lifetimes. Other climate change processes also exhibit considerable inertia, which results in delays between GHG emissions and the impacts of climate change. The oceans, for example, warm much more slowly than the atmosphere in response to the buildup of heat-trapping gases. Additionally, many of the sources of GHG emissions, such as power plants and automobiles, have lifetimes of years to decades. Thus, decisions made now will shape the world for generations to come. Research has shown that individuals and organizations have trouble perceiving risks and taking action on problems with such long lead-times.

The sensitivity of the climate system is somewhat uncertain. As discussed in Chapters 2 and 6, scientists have learned a great deal about the response of the climate system to GHGs and other climate forcing agents through a combination of direct observations of recent climate change, indirect evidence of historical climate variations, and climate modeling studies. However, Earth's climate sensitivity—which dictates how much warming would be expected if future emissions were known exactly—remains somewhat uncertain. Thus, it is possible that future temperature changes will lie below the range of current climate model projections. However, it is also possible that realized temperature changes will lie above the projected range. Additionally, climate models cannot currently simulate certain feedback processes in the Earth system, such as those related to changes in ecosystems on land or in the oceans, that could potentially amplify (or reduce) the response to a given climate forcing. Uncertainty in the sensitivity of Earth's climate system also makes it difficult to precisely quantify the effectiveness of actions or strategies that might be taken to limit the magnitude of future climate change.

There may be tipping points or thresholds that, once crossed, lead to irreversible events. Some of the physical and biological feedbacks triggered by climate change can become irreversible when they pass a certain threshold or tipping point. For example, there is general scientific consensus that the Arctic, which is systematically losing summer sea ice thickness and extent on an annual basis, is expected to become permanently ice-free during summers by the middle of the 21st century, regardless of how future emissions change. This change to an ice-free summer Arctic is expected, in part, because of the positive feedback between warming and sea ice melting (see Chapter 6). A number of other possible tipping points and irreversible changes have been identified in the Earth system, and human systems can also experience tipping points, such as the collapse of an economy or political system. Because of the possibility of crossing such thresholds, simple extrapolations of recent trends may underestimate future climate change impacts. Given the complexity of coupled human-environment systems, it is difficult to forecast when a tipping point might be approaching, but the probability of crossing one increases as the climate system moves outside the range of natural variability.

Analyses of impacts resulting from higher levels of climate change are limited. Most scientific analyses of climate change have focused on the impacts associated with a global temperature change of between 3.6°F to 5.4°F (2°C to 3°C) by the end of the 21st century, relative to preindustrial conditions. Yet model-based projections of future global temperature change range from 2°F to more than 11°F, and even larger changes are possible. For comparison, the higher end of the expected range of future temperature change is comparable to the estimated temperature difference between the present climate and the climate at the height of the last ice age, when glaciers covered the sites presently occupied by New York, Chicago, and Seattle and ecosystems around the world were radically different. Although there have been some recent efforts to estimate the impacts that might be associated with global temperature changes of greater than 9°F or 10°F (5°C or 6°C) over the next century (see, for example, University of Oxford, Tyndall Centre, and Hadley Centre Met Office, 2009), relatively little scientific information is available regarding the potential risks posed by such extreme changes in global climate.

Climate change does not act in isolation. As noted in several parts of Chapter 2 and in many of the chapters in Part II, climate change is just one of many stressors affecting human and environmental systems. For example, estuaries and coral reefs are being affected by warming ocean temperatures, ocean acidification, sea level rise, and changes in runoff from precipitation, and these climate-driven impacts interact with other ongoing threats such as pollution, invasive species, coastal development, and overfishing. The impacts of these multiple stresses and interacting environmental changes on food production, water management, energy production, and other critical human activities are associated with important risks in terms of meeting human needs. The prevalence of multiple stresses and the interconnected nature of many climate-related processes also raise significant scientific and management challenges.

Vulnerabilities to climate change vary across regions, societies, and groups. Climate change will unfold in different ways across the United States and across the globe, and different sectors, populations, and regions will be differentially exposed and sensitive to the impacts of these changes. Different groups will also differ in their ability to cope with and adapt to environmental changes. In general, research suggests that the impacts of climate change will more harshly affect poorer nations and communities. Actions taken to limit future climate change and adapt to its impacts also have the potential to cause differential benefits or harm. For example, different communities or regions may experience differential exposure to the unintended side effects of alternative energy production strategies. However, our understanding and ability to predict vulnerability, adaptive capacity, and the side effects of different response strategies are less well established than our understanding of the basic causes and mechanisms of climate change.

Individually and collectively, the complexities described in the paragraphs above make it challenging to analyze the risks posed by climate change. Nonetheless, as described in Chapter 2 and discussed in detail in Part II of the report, the scientific community has high confidence in projections of a number of future climate changes and impacts. For example, (1) water availability will decrease in many areas that are already drought-prone and in areas where freshwater systems are fed by glaciers and snowpack; (2) a higher fraction of rainfall will fall in the form of heavy precipitation events, increasing the risk of flooding; (3) people and ecosystems in coastal zones will be exposed to higher storm surges, saltwater intrusion, and other risks as sea levels rise; and (4) coral reefs will experience widespread bleaching and mortality as a result of increasing temperatures, rising sea levels, and ocean acidification. There is less certainty in other projections, such as the combined impact of CO_2 increases, temperature increases, precipitation changes, and other climate and climate-related changes on agricultural crops and natural ecosystems in different regions of the world, although negative impacts are expected to increase with higher temperatures. Projections of the future—in any sphere—always entail some amount of uncertainty. Nevertheless, as described in the next two sections, decision makers are already starting to take actions to respond to these and other risks associated with climate change, and scientific research can help in a number of ways.

RESPONDING TO CLIMATE RISKS

Based on current scientific understanding of ongoing and projected future changes in climate, and the risks associated with these changes, many decisions makers are now taking or planning actions to limit the magnitude of climate change, to adapt to ongoing and anticipated changes, and to include climate considerations in their decision-making processes. These actions are detailed in the three companion reports to this study (NRC, 2010a-c). For example, in *Informing an Effective Response to Climate Change* (NRC, 2010b), it is noted that 34 states have created climate change action plans, 20 have established emissions-reduction targets, and 15 have developed adaptation plans. Many U.S. cities and counties have also begun to respond to the challenges of climate change, and there is substantial activity at the federal level as well—for example, at least 10 of the 15 cabinet-level agencies and departments have made climate-related decisions. Many private firms are also taking action. At least 475 major companies have provided information on emissions to the Carbon Disclosure Project, over 60 major companies have set emissions-reduction targets, and climate change concerns are affecting the investment decisions of many. Finally, individuals in the United States and around the world are supporting government actions or taking actions themselves. For example, in 2009 one in three Americans rewarded companies that are taking steps to reduce GHG emissions by buying their products, while more than one in four avoided buying products from companies they perceived to be recalcitrant on the issue (Leiserowitz, 2010).

As these decision makers continue to take actions in response to climate change, many issues emerge that science can address. For example, scientific research can

- Project the beneficial and adverse effects of climate change, and their likelihood;
- Identify and evaluate the likely or possible consequences—including unintended consequences—of different decisions and actions taken (or not taken) to respond to climate change;
- Monitor and evaluate the effectiveness and consequences of actions as they are taken;
- Improve the effectiveness of actions before or while they are taken;
- Expand the portfolio of possible actions that might be taken in the future; and

BOX 3.1
Adaptive Risk Management:
Iterative and Inclusive Management of Climate Risks

Because individuals and groups often have trouble making sound decisions in the face of uncertainty, many tools have been developed to enhance our ability to make decisions in the face of risk (Bernstein, 1998; Jaeger et al., 2001). This suite of tools and the logic of their application are often referred to as adaptive risk management or sometimes iterative risk management or risk governance (Arvai et al., 2006; Renn, 2005, 2008). Components of adaptive (or iterative) risk management are discussed in the following paragraphs and are developed in more detail in the companion report *Informing an Effective Response to Climate Change* (NRC, 2010b).

Risk identification, assessment, and evaluation. Risks need to be evaluated by a range of affected stakeholders (who typically have different values and preferences) and by considering a range of factors. These include the impacts of allowing risks to go unmitigated, the costs of different risk-management strategies, and public perceptions and acceptability of risks and/or responses to those risks, as well as broader societal values that tend to favor certain general approaches to managing risk over others (e.g., a precautionary approach versus a cost-benefit or risk-benefit approach).

Iterative decision making and deliberate learning. Because many climate-related decisions will have to be made with incomplete information, and new information can be expected to become available over time (including information about the effectiveness of actions taken), decisions should be revisited, reassessed, and improved over time. This will require deliberate planning and processes for "learning by doing," as well as ongoing monitoring and assessment to evaluate both evolving risks and the effectiveness of responses.

Maximizing flexibility. Whenever decisions with long-term implications can be made incrementally (i.e., in small steps rather than all at once), the risk of making the "wrong" decision now can be reduced by keeping as many future options open as possible.

- Develop, through research on human behavior and decision making itself, improved decision-making processes.

The discussion in the preceding section suggests that the climate is not a system that can be turned quickly and that responses to climate change may be necessary even as more information on risks is collected. Fundamentally, dealing with climate change requires making decisions without complete certainty. Under such conditions, adaptive risk management (Box 3.1) is a useful—and advisable—strategy for responding to climate-related risks as conditions change and we learn more about them.

Maximizing robustness. When decisions have to be made all at once (for example, whether to build a piece of infrastructure), the risk of making the "wrong" decision can be reduced by selecting robust options—options that maximize the probability of meeting identified goals and desirable outcomes while minimizing the probability of undesirable outcomes under a wide range of plausible future conditions.

Ensuring durability. Many climate-related policies will need to remain in place, albeit in modified form, for many decades in order to achieve their intended goals. This requires mechanisms that can ensure the long-term durability of policies and provide stability for investors and society, while allowing for adaptive adjustments over time to take advantage of new information—a significant challenge for policy and institutional design.

A portfolio of approaches. In the face of complex problems, where surprises are expected and much is at stake, it would be unwise to rely on only one or a small number of actions to "solve" the problem without major side effects. A more robust approach would be to employ a portfolio of actions to increase the chance that at least one will succeed in reducing risk and to provide more options for future decision makers.

Effective communication. An essential component of effective risk management is the communication of risks, including the risks associated with different responses, to all involved stakeholders, including public-, private-, and civic-sector stakeholders as well as expert and lay individuals familiar with, or potentially affected by, the risks at hand.

Inclusive process. Since climate-related risks affect different regions, communities, and stakeholders in different ways and to different degrees, stakeholders should be included in significant roles throughout the process of identifying risks and response options, determining and evaluating what risks and responses are "acceptable" and "unacceptable," as well as in the communication and management of the risks themselves (NRC, 2008h).

IMPLICATIONS FOR THE NATION'S CLIMATE RESEARCH ENTERPRISE

The past several decades of research have yielded a great deal of knowledge about climate change, but there is much still to be learned about both ongoing and future changes and the risks associated with them. Moreover, as decision makers respond to the risks posed by climate change, additional knowledge will be needed to assist them in making well-informed choices. For example, decision makers could use additional information about how the Earth system will respond to future GHG emissions, the range of impacts that could be encountered and the probabilities associated with them, the quantifiable and nonquantifiable risks posed by these changes, the options that can be taken to limit climate change and to reduce vulnerability and increase adaptive capacity of both human and environmental systems, and methods for making choices and managing risk in an environment that continues to change.

Because decisions always involve values, science cannot prescribe the decisions to be made, but scientific research can inform decisions and help to ensure and improve their effectiveness. As we enter a time when decision makers are responding to climate change, the nation's climate research enterprise can assist by including both science for understanding and science for supporting responses to climate change. The diverse and complex set of scientific issues to be addressed in this new era of climate change research span the physical, social, biological, health, and engineering sciences and require integration across them. In the next chapter, we discuss the research needs and themes for the nation's climate change science enterprise in this new era.