29. Research Agenda for Climate Change Science

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Overview

Investments in science-based assessments and policy-relevant research advance basic scientific understanding, as well as supporting, improving, and expanding response options (Clark et al. 2006). These investments also result in a range of opportunities for private sector interests who can develop more tailored decision-support products for customers. The research needs and gaps discussed in this chapter were identified during the development of the regional and sectoral technical input reports and through the contributions of the over 240 authors of the National Climate Assessment (NCA) chapters.

The U.S. Global Change Research Program's 2012-2021 Strategic Plan (USGCRP 2012) and the National Research Council's (NRC) study of America's Climate Choices offer important research goals that will provide information for decision makers to support developing, evaluating and executing plans to prepare for and respond to climate change. The USGCRP Sustained Assessment process is designed to provide a foundation for these efforts and for timely access to advances in scientific understanding. This chapter identifies important gaps in knowledge, synthesized into seven research goals with recommendations of high priority research needs to support the national assessment process and a range of international assessments, including the Intergovernmental Panel on Climate Change (IPCC) AR5, Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), regional assessments (for example, the Arctic Assessment), and topical assessments such as the International Assessment of Agricultural Knowledge, Science, and Technology for Development.

Since the focus of this chapter is on research needs identified through the national assessment process, it is not intended to cover the full range of goals of the USGCRP. There are many additional USGCRP priorities for climate change and global change science more broadly that are not reflected here.

Research Goal 1

Deepen understanding of the climate system, feedbacks, and impacts.

Fundamental climate science investments across a broad range of disciplines are critically important to understanding, and in some cases reducing, uncertainties about some of the physical processes of the climate system and the impacts of these changes. These investments also develop information at multiple temporal and spatial scales that can help decision-makers manage risk and take advantage of opportunities (the observations component of this issue is addressed in Research Goal 4). Assessing the potential consequences of a changing climate requires understanding the role of feedbacks, thresholds, extreme events, and abrupt changes that may disrupt natural and socioeconomic systems, as well as the implications of more gradual changes and also the degree and effectiveness of response actions.

Future assessments, particularly the sustained assessments of the USGCRP, will increasingly require improved projections of near- and long-term risks and opportunities for the nation. Integrated assessment and modeling tools can, if well designed, implemented, and communicated: a) enhance capacity to address economic, physical, and social impacts and ecosystems processes; b) support identification of efficient adaptation and mitigation policies and measures, including evaluation of policy alternatives, such as risk assessment and scenario development; and c) implement adaptation and mitigation policies and measures across many scales, but particularly at local and regional scales.

High priority research needs include:

- Better **understanding of important sources of uncertainty and feedbacks in the climate system** such as clouds, changes in land and sea ice, aerosols, land use and land cover, thresholds and feedbacks, and the means by which ocean dynamics affect changes in the climate system;

- Advancing capacity to project **biogeophysical changes in the nation's ecosystems and associated services** (such as food availability and security, protection of biodiversity, healthy wetlands, and abundant fresh water) or the nature, timing, and location of terrestrial permafrost and methane release processes;

- Improved understanding of the **interactions of climate change and natural variability** at multiple time scales, including seasonal to decadal changes (and consideration of the El Niño Southern Oscillation, Pacific Decadal Oscillation, North Atlantic Oscillation, etc.), extreme events (hurricanes, droughts, and floods), potential changes in ocean circulation related to climate change, and the global transfer of heat laterally and toward the poles;

- Improved, and more detailed, projections of the **rate of change in oceanic pH, carbonate saturation, and attendant acidification** and its consequences for the marine biosphere and food chain;

- Research to improve our nation's ability to understand **the cumulative and synergistic relationships between climate change and numerous human-caused stressors** at appropriate scales, including multiple stresses affecting the climate system (including concentrations of heat-trapping gases and particulates in the atmosphere, changes in land use and land cover, shifts in human cultural behavior or demographics, or changes in economic factors).

- Experiments on the effects of multiple stressors within and between social, physical, and ecological systems in the context of global change;

- Better understanding of the **potential for crossing thresholds** and tipping points in affected climate systems, along with development of indicators that allow for anticipation of abrupt changes and extreme events in the context of a changing climate.

- Assessing the **relative importance of different types of uncertainty** that affect various decision-making contexts, including uncertainties regarding vulnerability, different impacts models, future socioeconomic factors, possible changes in governance structures, decision-making protocols, and regional climate change.

- Better **long-term and regional scale projections of sea level changes**

- More specific regional information about the **role of soil moisture, groundwater recharge, and evapotranspiration in the hydrologic cycle** and water supply availability.

Research Goal 2

Develop local, regional, national, and international options to adapt to climate change.

Effectively and efficiently managing the risks and opportunities of current and projected climate change through adaptation requires understanding the risks posed by changing weather and climate patterns at local and regional scales, and who or what is exposed to those risks. This assessment and others, including the America's Climate Choices *Adapting to the Impacts of Climate Change* report (NRC 2010a) and Chapter 4 (on adaptation and mitigation options and responses) of the IPCC's AR4 Synthesis Report (IPCC 2007b), identified a broad set of research needs for understanding and implementing adaptation. These include research on adaptation processes, adaptive capacity, adaptation option identification and evaluation, and adaptive management of risks and opportunities. Important needs are geospatial assessments of vulnerability, research on the limits to, timing of, and tradeoffs in adaptation, and understanding of how adaptation interacts with mitigation activities, other stresses, and broader sustainability issues. Examples of high priority research needs include:

- Research on **best practices for adaptation planning and implementation** for federal, state, and local agencies, private firms, non-governmental organizations and local communities, including plans and actions to effectively manage risks due to climate

change, and institutional frameworks to sustain adaptation efforts and enhance resilience over the long term;

- Evaluation of **alternative approaches to designing federally enabled clearinghouse(s)** with the capability to link decision-makers to adaptation tools, data, and expertise that support adaptation decision-making;

- Research that focuses on **adaptation processes and strategies** to better facilitate, evaluate (including evaluations of the effectiveness of adaptation), and coordinate adaptation within and across federal to local scales, across sectors and regions, and across public and private enterprises, recognizing the broad diversity of knowledge and research gaps that need to be addressed;

- Guidance on **appropriate use of information from global models as well as on various downscaling approaches** (statistical and dynamical), to assist decision-makers at local and regional scales with appropriate approaches to developing a range of projected future conditions for planning purposes;

- Research on **alternative institutional strategies to support adaptation,** including revisions to legal codes and policy practices;

- Enhancements of **understanding of synergies, trade-offs, and path dependencies between adaptation and mitigation** at local to national scales, over short- to longer-term time scales; and

- Better documentation of the rich history of adaptation activities over many centuries within Native American communities, leading to the potential for **integrating traditional knowledge and western science** in new and useful understanding of impacts, vulnerabilities, and adaptation strategies.

Research Goal 3

Explore options and actions that reduce the rate and magnitude of climate change.

Enhanced understanding of the interconnectedness of Earth and energy/economic systems will require research on the ways global-scale climate change is connected to energy strategies and global economic conditions. The NAS/NRC report on *Limiting the Magnitude of Climate Change* (NRC 2010c), in its America's Climate Choices study, recommended that the U.S. promptly develop and implement appropriate strategies that reduce GHG emissions. Examples of high priority research needs that build on this foundation include:

- Deepen understanding of the relationship between the fate of human-induced and natural carbon emissions, uptake by the terrestrial biosphere and oceans, and atmospheric concentrations, in order to **better understand the effectiveness and timescales of mitigation measures**;

- **Support socioeconomic analyses related to decision-making about land use, land management, water resources, associated ecological processes and services,** and how these sectors respond to changes in the climate system;

- **Test and expand understanding of the effects of different climate and integrated assessment model structures** and ways to categorize uncertainties in the supporting data;

- **Understand social, cultural, and behavioral processes that influence public understanding and motivations for individual and corporate mitigation actions**, including strategies and that increase resilience and flexibility in energy systems; and

- Understand the relationship between climate change, energy development, and water-dependent socioeconomic sectors to **inform national and state-level energy policies, aquifer utilization, and river agreements.**

Research Goal 4

Maintain, extend, expand, and improve the observations and data systems essential to understanding climate change and responding to it.

Our understanding and ability to assess changes in climate and other global processes is based on a comprehensive and sustained system of observations, monitoring, and data systems that document the history of climate and related changes on spatial scales relevant to regional and sectoral understanding and over many timescales. Additional effort is needed to ensure that the large data systems that bring together these observations are integrated and accessible in ways that increase utility of data for stakeholders. These observations include critical geophysical variables such as temperature, precipitation, and sea level rise, but also data on the processes that drive feedbacks (including social systems), mechanisms of abrupt change, atmospheric chemistry, solar radiation, and land use/land cover impacts. The data systems that bring together these observations need to be easily accessible to stakeholders, with clear communication of metadata, data quality, and uncertainties. High priority data needs include observations, monitoring, and indicator capabilities focused on data-poor regions, poorly documented socioeconomic and health-related factors, and under-observed regional and sectoral data; important measurements of system resilience; and data for sensitive systems, including social systems, that currently do not have adequate temporal or spatial resolution for vulnerability analysis and decision support.

Examples of high priority research needs include:

- **Evaluation of the data needs, potential components, and structure of a national indicator system**. Indicators can support understanding of changes in the rate of global change, progress in adaptation/response efforts, and communication of climate change risks and opportunities. Indicators could include trends and changes in land use, air and water pollution, water supply and demand, vector borne disease, coastal and ocean conditions (acidification, sea level, ocean stratification, temperatures, salinity, and

ecosystem health), snow, sea ice conditions, ice sheets and glacier melt rates, public health, and agronomic data, for example; indicators are critically needed to assess progress in adaptation and response efforts, a "grand challenge" for integrated physical and social science; and

- **Prioritizing investments in observations and data systems** that are designed to support responses to climate change, including, for example, efforts to limit emissions, monitor public health, sequester carbon, and implement adaptation strategies. This requires establishing baseline conditions, specifying spatial detail and temporal frequency of observations, and setting standards for metadata, interoperability, and regulatory and voluntary reporting, such as those outlined in the Informing Effective Responses Report of the NRC/NAS Americas Climate Choices series (NRC 2010b).

Research Goal 5

Inform and enable decision-makers to address the challenges of climate change and its consequences.

There is a growing demand from leaders in both the public and private sectors for better dissemination of climate-relevant information and more effective ways to support climate-related decisions. Critical gaps in knowledge relative to decision support include the variety of socioeconomic issues that affect the capacity of individuals and communities to use the best available scientific information in support of decision-making, including the need to understand risk perception as a motivator for taking actions that reduce risk.

There are also numerous instances where policy barriers, institutional capacity or structure, or conflicting laws and regulations are noted. For instance, Chapter 12 (Impacts of Climate Change on Tribal/Indigenous and Native Lands and Resources) notes that there is no institutional framework for addressing responses of the magnitude of village relocation in Alaska, and Chapter 3 (Water Resources) points out that existing water management institutions may be inadequate in the context of rapidly changing conditions. These instances point to a need to evaluate whether the existing legal and regulatory structures, largely developed to address specific issues in isolation, can adequately respond to the highly interconnected issues associated with climate change. There will be a growing need to more thoroughly consider problems that are different in kind rather than magnitude. The extent to which our existing structures and expertise are capable of responding effectively is unclear and represents a significant gap in our knowledge.

High priority research needs include:

- Research to support **risk-based decision processes, including more effective means to communicate interactions of multiple stresses and levels of scientific confidence and uncertainty.** High priority research on social processes includes transferable vulnerability assessment techniques, evaluation methodologies, improved understanding of consumption patterns and environmental consequences, effective resource management institutions, iterative risk management, and social learning and adaptive processes;

- Research into and assessment of **decision-maker information needs** within regions and sectors and the methods and tools to meet those needs;

- Research on how to increase the **effectiveness of processes and practices designed to inform decisions across regions and sectors**, including strategies for managing carbon, early warning systems, climate and drought information services, and the analyses of legal, regulatory, and policy approaches that support adaptation and mitigation efforts in the context of a non-stationary climate;

- Improved and expanded efforts **at characterizing the costs and benefits of mitigation and adaptation actions,** including economic and non-economic metrics that evaluate the costs of action versus the costs of inaction;

- Development of **methodologies and baseline information to support evaluation of completed and ongoing adaptation, mitigation, and assessment efforts**; and

- Studies of the **capacity of existing institutions and regulatory strategies to function in the context of a changing climate,** and ways to develop more flexible and integrated management approaches**.**

Research Goal 6

Capacity Building, Education, and Workforce Development

Building human capacity to respond to the emerging challenges described in this Assessment requires expansion of skills within the existing public and private sectors and developing a new workforce that excels at critical and interdisciplinary thinking. Useful capacities include facilitation and communications skills, integration of new technologies and data sources into existing programs and practices, management of collaborative processes to allow for imaginative solutions, development and use of sustainable technologies to reduce climate risks, and building frameworks for decision-making in an internationally interdependent world. A deeper understanding of such matters as evaluations of processes and impacts of climate change, disaster risk reduction, energy policy impacts, ecosystem services and biodiversity, poverty reduction, food security, and sustainable consumption require new approaches to training and curriculum, as well as research to evaluate the effectiveness of different approaches to research and teaching.

Examples of recommended research include:

- Research into new **approaches to education of the existing and future workforce** and training in the professions, including evaluation of the best ways to educate the next generation in the fields of science (natural, physical, and social), technology, engineering, and mathematics (STEM) and related fields of study (such as business, law, medicine, and other relevant professional schools). Ideally, such training would include a deeper understanding of the climate system, natural resources, energy policy options, and economic sustainability;

- Investigations of effective approaches to developing a more climate-informed civil society, including **alternative media and methods for communication**; and

- Research on improving **STEM education and training programs at Native American colleges and universities and other similar institutions** to increase capacity to carry out climate change impact and adaptation plans.

Research Goal 7

Enhance scenarios to include essential attributes of coupled human and natural systems.

Scenarios are important tools that help with analysis of climate drivers and the effects of management and policy decisions. They provide the scientific research and assessment communities with the capability to: a) evaluate the governing conditions (such as timing and rates of change in concentration of greenhouse gases and aerosols) in the atmosphere that might unfold under specific socioeconomic conditions and technological and environmental options; b) assess the natural response of the Earth system and the potential impacts and consequences of a range of future climates; and c) evaluate the implications of different approaches to mitigation and adaptation (Moss et al. 2010). Stakeholders and scientists identified a need for more fully developed scenario-building capabilities that better enable assessments at regional to more local scales on timeframes of relevance to policy and decision-making.

The IPCC has led in the development of scenarios to support international scientific work of the three IPCC Working Groups, and it made major progress with the release in 2000 of the Special Report on Emissions Scenarios (SRES)(IPCC 2000). Historically, scenarios have been used for analyzing global-scale trends (IPCC 2007a) that include a range of demographic changes, social and economic conditions, and technological options. These can be used to project emissions and other inputs to Global Climate Models/General Circulation Models (GCMs). A new scenario process is underway within IPCC that will facilitate more regional/local assessments through finer scale models.

Examples of research needs related to scenario development include:

- **Using components of the new scenarios to enhance** understanding of the implications of a changing climate at more regional scales and to support international climate negotiations, especially where a focus on smaller geographic scales and sectoral levels, such as coastal sea level, land use and land cover change, and socioeconomic conditions, will be important;

- **Developing new methods, tools, and skill to apply scenarios to policy development at local levels**, to broaden civil society's understanding of a changing climate, and provide ways and means to expand education and training capacities for the nation (for example, the Global Business Network's Four Quad Scenario planning methodology that has been used by the U.S. Park Service (GBN 2012));

- **Providing scenario-based guidance to stakeholders** who want to understand climate variability and change in the near- and longer-term in order to support them in their decisions and policies; and

- **Ensuring that socioeconomic, land use, water resource, and climate scenario information is available** in a timely way for future assessment processes.

Conclusions

This chapter includes research recommendations on a number of broad topics. Addressing the important research recommendations identified in this chapter will enhance knowledge of the intersection of human and natural systems in the context of climate change – knowledge that is needed for regional, national, and international policy development and decision-making. Expanding scientific understanding and responding to the needs of decision-makers at multiple scales will require integrated research activities across sectoral, regional, and temporal scales.

Traceable Accounts

Chapter 29: Research Agenda

Chapter Process:

The author team asked each of the other chapter author teams to identify important gaps in knowledge and key research needs that they identified in the course of writing their chapters. In addition to the lists provided by each chapter author team, the team also drew on analyses from over 40 technical inputs provided by the public, and a wide variety of technical and scholarly literature, especially the U.S. Global Change Research Program's Strategic Plan (USGCRP 2012) and the National Research Council's America's Climate Choices (NRC 2011), to compile a potential research agenda. Using expert deliberation, including a number of teleconference meetings and email conversations among author team members, the author team agreed on high-priority research needs, organized under seven synthetic research goals.

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