

## Advancing the Science of Climate Change

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

**A**s a result of the growing recognition that climate change is underway and poses serious risks for both human societies and natural systems, the question that decision makers are asking has expanded from “what is happening” to “what is happening and what can we do to respond?” Scientific research can help answer both of these important questions.

This report, part of the *America's Climate Choices* suite of studies requested by Congress, examines the status of the nation's climate change research efforts and recommends steps to improve and expand current understanding. The report reviews what the scientific community has learned about climate change and its interactions with human and natural systems in 12 areas of interest to decision makers (Box 1). It identifies advances needed to improve the effectiveness of actions taken to respond to climate change—including actions to limit its magnitude and adapt to its impacts—as well as understanding of the causes, mechanisms, and consequences of climate change.

### What is Known about Climate Change

Science has made enormous progress toward understanding climate change. As a result, there is a strong, credible body of evidence, based on multiple lines of research, documenting that Earth is warming. Strong evidence also indicates that recent warming is largely caused by human activities, especially the release of greenhouse gases through the burning of fossil fuels. Global warming is closely associated with other climate changes and impacts, including rising sea levels, increases in intense rainfall events,



SOURCE: NASA

### Box 1. Areas of Interest to Decision Makers Examined in this Report

- changes in the climate system
- sea level rise and the coastal environment
- freshwater resources
- ecosystems, ecosystem services, and biodiversity
- agriculture and fisheries
- public health
- cities and the built environment
- transportation systems
- energy systems
- solar radiation management
- national and human security
- climate policy

## Box 2. What Is Known about Changes in the Climate System

- Thermometer measurements show that Earth's average surface temperature has risen substantially over the past century, and especially over the last three decades.
- These data are corroborated by a variety of independent observations showing warming in other parts of the Earth system, including the oceans, the lower atmosphere, and ice-covered regions.
- Most of the recent warming can be attributed to fossil fuel burning and other human activities that release carbon dioxide and other heat-trapping greenhouse gases into the atmosphere.
- Human activities have also resulted in an increase in small particles in the atmosphere, which on average tend to have a cooling effect, but this cooling is not strong enough to offset the warming associated with greenhouse gas increases.
- Changes in solar radiation and volcanic activity can also influence climate, but observations show that they cannot explain the recent warming trend.
- Natural climate variability leads to year-to-year and decade-to-decade fluctuations in temperature and other climate variables as well as significant regional differences.
- Human-caused climate changes and impacts will continue for many decades and in some cases for many centuries. The magnitude of climate change and the severity of its impacts will depend on the actions that human societies take to respond to these risks.

decreases in snow cover and sea ice, more frequent and intense heat waves, increases in wildfires, longer growing seasons, and ocean acidification. Individually and collectively, these changes pose risks for a wide range of human and environmental systems. While much remains to be learned, the core phenomenon, scientific questions, and hypotheses have been examined thoroughly and have stood firm in the face of serious scientific debate and careful evaluation of alternative explanations.

Projections of future climate change anticipate an additional warming of 2.0 to 11.5 °F (1.1 to 6.4 °C) over the 21st century, on top of the 1.4 °F already observed over the past 100 years. Warming is and will be greatest over land areas and higher latitudes. Projected impacts of future climate change include:

- Water availability will decrease in many areas that are already drought-prone and in areas where rivers are fed by glaciers or snowpack;
- A higher fraction of rainfall will fall in the form of heavy precipitation, increasing the risk of flooding and, in some regions, the spread of water-borne illness;
- People and ecosystems in coastal zones will be exposed to higher storm surges, intrusion of salt water into freshwater aquifers, and other risks as sea levels rise;
- Coral reefs will experience widespread bleaching as a result of increasing temperatures, rising sea levels, and ocean acidification.



Johns Hopkins Glacier. SOURCE: NOAA. Photo by John Bortniak

There is less certainty in other projections, such as how the combination of greenhouse gas increases, temperature increases, precipitation changes, and other climate and climate-related changes will affect agricultural crops and natural ecosystems in different regions. Furthermore, different sectors, populations, and regions will vary in their exposure and sensitivity to the impacts of these changes; in general, research suggests that the impacts of climate change will more harshly affect poorer nations and communities.

Finally, scientific research has revealed a great deal about responses to climate change. There is a growing body of knowledge about technologies and policies that can be used to limit the magnitude of future climate change, a smaller but expanding understanding of the steps that can be taken to adapt to climate change, and a growing recognition that climate change will need to be considered in decisions across a wide range of sectors and interests.

## Complexities of Climate Change

As with all projections of the future, there will always be some uncertainty regarding the details of future climate change. For example, there are uncertainties in how human societies will decide to produce and use energy and other resources in the decades ahead, making it difficult to project future greenhouse gas emissions. Certain Earth system processes—such as ice

sheet dynamics, cloud processes, and regional climate effects—are either incompletely understood or not fully resolved in current climate models, leading to uncertainties in the magnitude and rate of global climate change and its manifestations at local and regional scales.

Climate change also poses special challenges that set it apart from risks with which people normally deal. For example, many climate change processes have long time lags, so future generations will have to deal with the consequences (both positive and negative) of decisions made today. There is also the potential that the Earth system could cross thresholds that result in abrupt changes or other “surprises.” The potential consequences of such events could be irreversible and highly challenging, but their likelihood is not very well understood.

Despite these uncertainties and complexities, it is clear that Earth’s future climate will be unlike the climate that ecosystems and human societies have become accustomed to during the last 10,000 years, leading to significant challenges across a broad range of human endeavors. It is likewise reasonable to expect that the magnitude of future climate change and the severity of its impacts will be larger if actions are not taken to limit its magnitude and adapt to its impacts.



SOURCE: USDA. Photo by Scott Bauer

## A New Era of Climate Change Research

As a result of the growing recognition that climate change is underway and poses serious risks for both natural systems and human well-being, decision makers of all types—including individuals, businesses, and governments at all levels—are now taking or planning actions to respond to climate change. These actions are explored in the other reports in the *America’s Climate Choices* series. Effective management of climate risks will require decision makers to take actions that are flexible and robust, to learn from new knowledge and experience, and to adjust future actions accordingly.

Because decisions always involve value judgments, scientific knowledge cannot tell decision makers what they *should* do to respond to climate change. Scientific research can, however, play a key role in the nation’s response to climate change by, for example:

- Projecting the beneficial and adverse effects of climate changes, and their likelihood.
- Identifying and evaluating the likely or possible consequences—including unintended consequences—of different actions taken to respond to climate change
- Expanding the portfolio of options available for responding to climate change, and improving the effectiveness of existing options
- Developing improved decision making processes.

## Recommendations

The report concludes that the nation needs a flexible, comprehensive, and integrative climate change science enterprise, one that not only contributes to our fundamental understanding of climate change but also informs and expands America’s climate choices (see Box 3). Meeting this expanded set of research requirements will require changes in the way climate change research is supported, organized, and conducted.

### Box 3. Cross-cutting Research Themes Identified in Report

#### Research to Improve Understanding of Human-Environment Systems

1. Climate Forcings, Responses, Feedbacks and Thresholds in the Earth System
2. Climate-Related Human Behaviors and Institutions

#### Research to Support Effective Responses to Climate Change

3. Vulnerability and Adaptation Analyses of Coupled Human-Environment Systems
4. Research to Support Strategies for Limiting Climate Change
5. Effective Information and Decision Support Systems

#### Tools and Approaches to Improve Both Understanding and Responses

6. Integrated Climate Observing Systems
7. Improved Projections, Analyses, and Assessments

**The nation's climate change research enterprise should be:**

- **Integrative and interdisciplinary**, including research across and among the physical, social, biological, health, and engineering sciences
- Focused on **fundamental, use-inspired** research that contributes to both improved understanding and more effective decision making
- **Linked with action-oriented programs** focused on limiting the magnitude of climate change, adapting to its impacts, and informing effective responses
- **Flexible**, able to respond to emerging needs and changing demands

A single federal interagency program or other entity should be given the authority and resources to coordinate and implement a comprehensive, integrated climate change research effort. The U.S. Global Change Research Program has a sufficiently broad mandate to serve this role, and could do so if the following modifications are made:

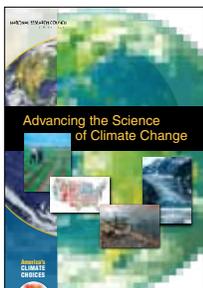
- An expanded mission that includes research for both understanding and supporting effective responses to climate change
- More and better mechanisms for stakeholder interactions
- Improved mechanisms for identifying and addressing weaknesses, gaps, and barriers
- High-level, forward-looking leadership with budgeting oversight and authority

The federal climate change research program, working in partnership with other relevant domestic and international bodies, should:

- Redouble efforts to develop, deploy, and maintain a **comprehensive climate observing system** that can support all aspects of understanding and responding to climate change
- Accelerate the development of **advanced models and other analytical tools**
- Expand and engage the **human capital** needed to carry out climate change research and response programs

**America's Climate Choices** is a congressionally requested suite of studies from the National Research Council designed to inform and guide the nation's response to climate change. Experts representing various levels of government, the private sector, nongovernmental organizations, and research and academic institutions were selected to provide advice in peer-reviewed reports on limiting the magnitude of climate change, adapting to the impacts of climate change, advancing the science of climate change, and informing effective decisions related to climate change.

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The National Academies appointed the above panel of experts to address the specific task, sponsored by the National Oceanic and Atmospheric Administration. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.

For more information, contact the Board on Atmospheric Sciences and Climate at (202) 334-3426 or visit <http://nationalacademies.org/basc> or America's Climate Choices at [americasclimatechoices.org](http://americasclimatechoices.org). Copies of *Advancing the Science of Climate Change* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; [www.nap.edu](http://www.nap.edu).



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