U.S. Global Change Research Program

Fourth National Climate Assessment

Volume II

Impacts, Risks, and Adaptation in the United States

Full report available online at: nca2018.globalchange.gov

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Front cover: *National Park Service*; **back cover:** *NASA Earth Observatory image by Joshua Stevens, using Landsat data from the U.S. Geological Survey.*

In August 2018, temperatures soared across the northwestern United States. The heat, combined with dry conditions, contributed to wildfire activity in several states and Canada. The cover shows the Howe Ridge Fire from across Lake McDonald in Montana's Glacier National Park on the night of August 12, roughly 24 hours after it was ignited by lightning. The fire spread rapidly, fueled by record-high temperatures and high winds, leading to evacuations and closures of parts of the park. The satellite image on the back cover, acquired on August 15, shows plumes of smoke from wildfires on the northwestern edge of Lake McDonald.

Wildfires impact communities throughout the United States each year. In addition to threatening individual safety and property, wildfire can worsen air quality locally and, in many cases, throughout the surrounding region, with substantial public health impacts including increased incidence of respiratory illness (Ch. 13: Air Quality, KM 2; Ch. 14: Human Health, KM 1; Ch. 26: Alaska, KM 3). As the climate warms, projected increases in wildfire frequency and area burned are expected to drive up costs associated with health effects, loss of homes and infrastructure, and fire suppression (Ch. 6: Forests, KM 1; Ch. 17: Complex Systems, Box 17.4). Increased wildfire activity is also expected to reduce the opportunity for and enjoyment of outdoor recreation activities, affecting quality of life as well as tourist economies (Ch. 7: Ecosystems, KM 3; Ch. 13: Air Quality, KM 2; Ch. 15 Tribes, KM 1; Ch. 19: Southeast, KM 3; Ch. 24: Northwest, KM 4).

Human-caused climate change, land use, and forest management influence wildfires in complex ways (Ch. 17: Complex Systems, KM 2). Over the last century, fire exclusion policies have resulted in higher fuel availability in most U.S. forests (CSSR, Ch. 8.3, KF 6). Warmer and drier conditions have contributed to an increase in the incidence of large forest fires in the western United States and Interior Alaska since the early 1980s, a trend that is expected to continue as the climate warms and the fire season lengthens (Ch. 1: Overview, Figure 1.2k; CSSR, Ch. 8.3, KF 6). The expansion of human activity into forests and other wildland areas has also increased over the past few decades. As the footprint of human settlement expands, fire risk exposure to people and property is expected to increase further (Ch. 5: Land Changes, KM 2).

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NCA4

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About This Report

The National Climate Assessment

The Global Change Research Act of 1990 mandates that the U.S. Global Change Research Program (USGCRP) deliver a report to Congress and the President no less than every four years that "1) integrates, evaluates, and interprets the findings of the Program . . .; 2) analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and 3) analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years."[1]

The Fourth National Climate Assessment (NCA4) fulfills that mandate in two volumes. This report, Volume II, draws on the foundational science described in Volume I, the *Climate Science Special Report* (CSSR).[2] Volume II focuses on the human welfare, societal, and environmental elements of climate change and variability for 10 regions and 18 national topics, with particular attention paid to observed and projected risks, impacts, consideration of risk reduction, and implications under different mitigation pathways. Where possible, NCA4 Volume II provides examples of actions underway in communities across the United States to reduce the risks associated with climate change, increase resilience, and improve livelihoods.

This assessment was written to help inform decision-makers, utility and natural resource managers, public health officials, emergency planners, and other stakeholders by providing a thorough examination of the effects of climate change on the United States.

Climate Science Special Report: NCA4 Volume I

The *Climate Science Special Report* (CSSR), published in 2017, serves as the first volume of NCA4. It provides a detailed analysis of how climate change is affecting the physical earth system across the United States and provides the foundational physical science upon which much of the assessment of impacts in this report is based. The CSSR integrates and evaluates current findings on climate science and discusses the uncertainties associated with these findings. It analyzes trends in climate change, both human-induced and natural, and projects major trends to the end of this century. Projected changes in temperature, precipitation patterns, sea level rise, and other climate outcomes are based on a range of scenarios widely used in the climate research community, referred to as Representative Concentration Pathways (RCPs). As an assessment and analysis of the physical science, the CSSR provides important input to the development of other parts of NCA4 and their primary focus on the human welfare, societal, economic, and environmental elements of climate change. A summary of the CSSR is provided in Chapter 2 (Our Changing Climate) of this report; the full report can be accessed at science2017.globalchange.gov.

Report Development, Review, and Approval Process

The National Oceanic and Atmospheric Administration (NOAA) served as the administrative lead agency for the preparation of this report. A Federal Steering Committee, composed of representatives from USGCRP agencies, oversaw the report's development.

A team of more than 300 federal and non-federal experts—including individuals from federal, state, and local governments, tribes and Indigenous communities, national laboratories, universities, and the private sector—volunteered their time to produce the assessment, with input from external stakeholders at each stage of the process. A series of regional engagement workshops reached more than 1,000 individuals in over 40 cities, while listening sessions, webinars, and public comment periods provided valuable input to the authors. Participants included decision-makers from the public and private sectors, resource and environmental managers, scientists, educators, representatives from businesses and nongovernmental organizations, and the interested public.

NCA4 Volume II was thoroughly reviewed by external experts and the general public, as well as the Federal Government (that is, the NCA4 Federal Steering Committee and several rounds of technical and policy review by the 13 federal agencies of the USGCRP). An expert external peer review of the whole report was performed by an ad hoc committee of the National Academies of Sciences, Engineering, and Medicine (NASEM).[3] Additional information on the development of this assessment can be found in Appendix 1: Report Development Process.

Sources Used in This Report

The findings in this report are based on an assessment of the peer-reviewed scientific literature, complemented by other sources (such as gray literature) where appropriate. In addition, authors used well-established and carefully evaluated observational and modeling datasets, technical input reports, USGCRP's sustained assessment products, and a suite of scenario products. Each source was determined to meet the standards of the Information Quality Act (see Appendix 2: Information in the Fourth National Climate Assessment).

Sustained Assessment Products

The USGCRP's sustained assessment process facilitates and draws upon the ongoing participation of scientists and stakeholders, enabling the assessment of new information and insights as they emerge. The USGCRP led the development of two major sustained assessment products as inputs to NCA4: *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*[4] and the *Second State of the Carbon Cycle Report*.[5] In addition, USGCRP agencies contributed products that improve the thoroughness of this assessment, including the U.S. Department of Agriculture's scientific assessment *Climate Change, Global Food Security, and the U.S. Food System*;[6] NOAA's Climate Resilience Tool Kit, Climate Explorer, and State Climate Summaries; the U.S. Environmental Protection Agency's updated economic impacts of climate change report;[7] and a variety of USGCRP indicators and scenario products that support the evaluation of climate-related risks (see Appendix 3: Data Tools and Scenario Products).

USGCRP Scenario Products

As part of the sustained assessment process, federal interagency groups developed a suite of high-resolution scenario products that span a range of plausible future changes (through at least 2100) in key environmental parameters. This new generation of USGCRP scenario products (hosted at https://scenarios.globalchange.gov) includes

- changes in average and extreme statistics of key climate variables (for example, temperature and precipitation),
- changes in local sea level rise along the entire U.S. coastline,
- changes in population as a function of demographic shifts and migration, and
- changes in land use driven by population changes.

USGCRP scenario products help ensure consistency in underlying assumptions across the report and therefore improve the ability to compare and synthesize results across chapters. Where possible, authors have used the range of these scenario products to frame uncertainty in future climate and associated effects as it relates to the risks that are the focus of their chapters. As discussed briefly elsewhere in this Front Matter and in more detail in Appendix 3 (Data Tools and Scenario Products), future scenarios referred to as RCPs provide the global framing for NCA4 Volumes I and II. RCPs focus on outputs (such as emissions and concentrations of greenhouse gases and particulate matter) that are in turn fed into climate models. As such, a wide range of future socioeconomic assumptions, at the global and national scale (such as population growth, technological innovation, and carbon intensity of energy mix), could be consistent with the RCPs used throughout NCA4. For this reason, further guidance on U.S. population and land-use assumptions was provided to authors. See Appendix 3: Data Tools and Scenario Products, including Table A3.1, for additional detail on these scenario products.

Guide to the Report

Summary Findings

The 12 Summary Findings represent a very high-level synthesis of the material in the underlying report. They consolidate Key Messages and supporting evidence from 16 underlying national-level topic chapters, 10 regional chapters, and 2 response chapters.

Overview

The Overview presents the major findings alongside selected highlights from NCA4 Volume II, providing a synthesis of material from the underlying report chapters.

Chapter Text

Key Messages and Traceable Accounts

Chapters are centered around Key Messages, which are based on the authors' expert judgment of the synthesis of the assessed literature. With a view to presenting technical information in a manner more accessible to a broad audience, this report aims to present findings in the context of risks to natural and/or human systems. Assessing the risks to the Nation posed by climate change and the measures that can be taken to minimize those risks helps users weigh the consequences of complex decisions.

Since risk can most meaningfully be defined in relation to objectives or societal values, Key Messages in each chapter of this report aim to provide answers to specific questions about what is at risk in a particular region or sector and in what way. The text supporting each Key Message provides evidence, discusses implications, identifies intersections between systems or cascading hazards, and points out paths to greater resilience. Where a Key Message focuses on managing risk, authors considered the following questions:

- What do we value? What is at risk?
- What outcomes do we wish to avoid with respect to these valued things?
- What do we expect to happen in the absence of adaptive action and/or mitigation?
- How bad could things plausibly get? Are there important thresholds or tipping points in the unique context of a given region, sector, and so on?

These considerations are encapsulated in a single question: What keeps you up at night? Importantly, climate is only one of many drivers of change and risk. Where possible, chapters provide information about the dominant sources of uncertainty (such as scientific uncertainty or socioeconomic factors), as well as information regarding other relevant non-climate stressors.

Each Key Message is accompanied by a Traceable Account that restates the Key Message found in the chapter text with calibrated confidence and likelihood language (see Table 1). These Traceable Accounts also document the supporting evidence and rationale the authors used in reaching their conclusions, while also providing information on sources of uncertainty. More information on Traceable Accounts is provided below.

Our Changing Climate

USGCRP oversaw the production of the *Climate Science Special Report* (CSSR): NCA4 Volume I,[2] which assesses the current state of science relating to climate change and its physical impacts. The CSSR is a detailed analysis of how climate change affects the physical earth system across the United States. It presents foundational information and projections for climate change that improve consistency across

analyses in NCA4 Volume II. The CSSR is the basis for the physical climate science summary presented in Chapter 2 (Our Changing Climate) of this report.

National Topic Chapters

The national topic chapters summarize current and future climate change related risks and what can be done to reduce those risks. These national chapters also synthesize relevant content from the regional chapters. New national topic chapters for NCA4 include Chapter 13: Air Quality; Chapter 16: Climate Effects on U.S. International Interests; and Chapter 17: Sector Interactions, Multiple Stressors, and Complex Systems.

Regional Chapters

Responding to public demand for more localized information—and because impacts and adaptation tend to be realized at a more local level—NCA4 provides greater detail in the regional chapters compared to the national topic chapters. The regional chapters assess current and future risks posed by climate change to each of NCA4's 10 regions (see Figure 1) and what can be done to minimize risk. Challenges, opportunities, and success stories for managing risk are illustrated through case studies.

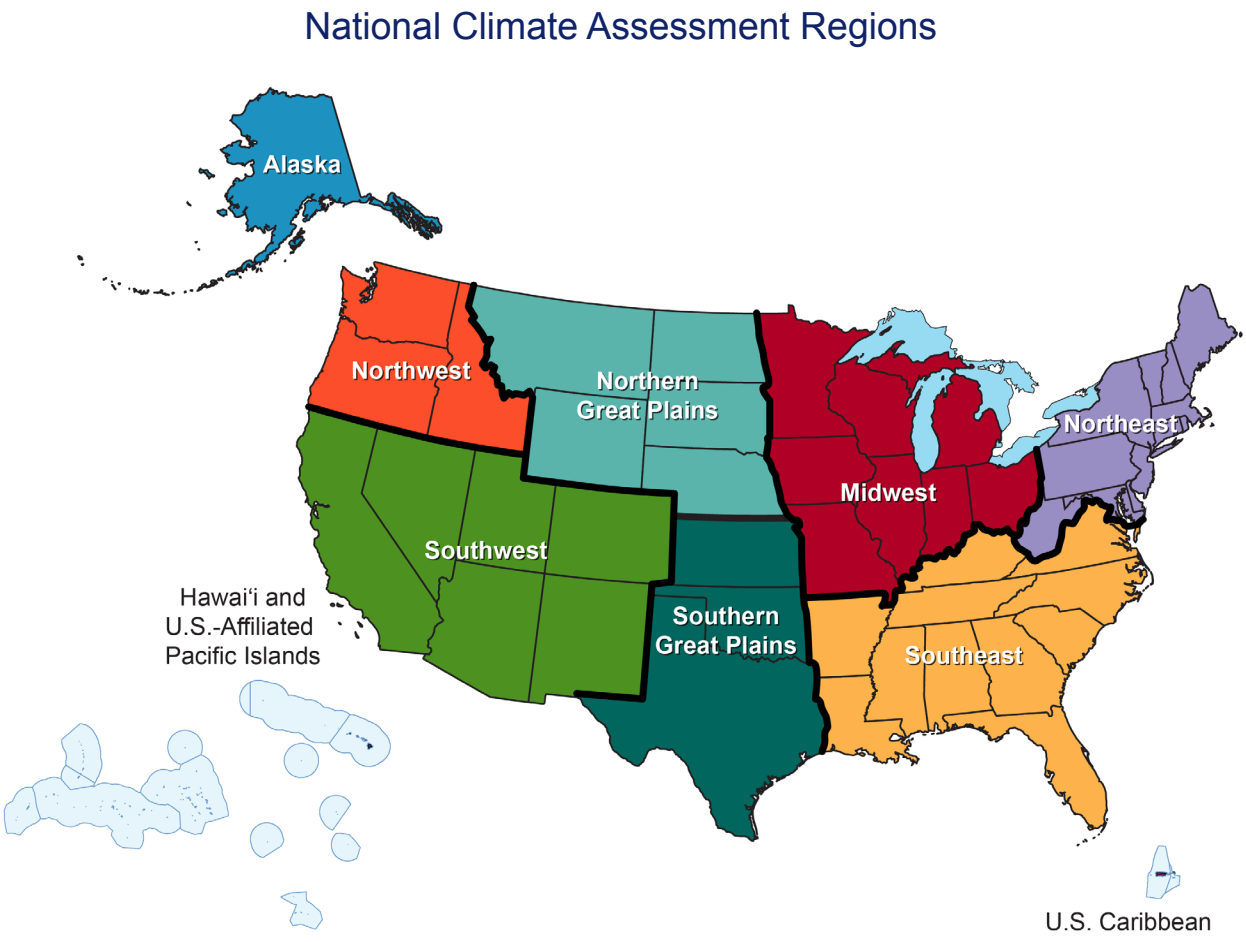

Figure 1: Map of the ten regions used throughout NCA4.

The regions defined in NCA4 are similar to those used in the Third National Climate Assessment (NCA3),[8] with these exceptions: the Great Plains region, formerly stretching from the border of Canada to the border of Mexico, is now divided into the Northern Great Plains and Southern Great Plains along the Nebraska–Kansas border; and content related to the U.S. Caribbean islands is now found in its own chapter, distinct from the Southeast region.

Response Chapters

The response chapters assess the science of adaptation and mitigation, including benefits, tradeoffs, and best practices of ongoing adaptation measures and quantification of economic damages that can be avoided by reducing greenhouse gas emissions. The National Climate Assessment does not evaluate or recommend specific policies.

Economic Estimates

To the extent possible, economic estimates in this report have been converted to 2015 dollars using the U.S. Bureau of Economic Affairs' Implicit Price Deflators for Gross Domestic Product, Table 1.1.9. For more information, please visit: https://bea.gov/national/index.htm. Where documented in the underlying literature, discount rates in specific estimates in this assessment are noted next to those projections.

Use of Scenarios

Climate modeling experts develop climate projections for a range of plausible futures. These projections capture variables such as the relationship between human choices, greenhouse gas (GHG) and particulate matter emissions, GHG concentrations in our atmosphere, and the resulting impacts, including temperature change and sea level rise. Some projections are consistent with continued dependence on fossil fuels, while others are achieved by reducing GHG emissions. The resulting range of projections reflects, in part, the uncertainty that comes with quantifying future human activities and their influence on climate.

The most recent set of climate projections developed by the international scientific community is classified under four Representative Concentration Pathways, or RCPs.[9] A wide range of future socioeconomic assumptions could be consistent with the RCPs used throughout NCA4.

NCA4 focuses on RCP8.5 as a "higher" scenario, associated with more warming, and RCP4.5 as a "lower" scenario with less warming. Other RCP scenarios (e.g., RCP2.6, a "very low" scenario) are used where instructive, such as in analyses of mitigation science issues. To promote understanding while capturing the context of the RCPs, authors use the phrases "a higher scenario (RCP8.5)" and "a lower scenario (RCP4.5)." RCP8.5 is generally associated with higher population growth, less technological innovation, and higher carbon intensity of the global energy mix. RCP4.5 is generally associated with lower population growth, more technological innovation, and lower carbon intensity of the global energy mix. NCA4 does not evaluate the feasibility of the socioeconomic assumptions within the RCPs. Future socioeconomic conditions—and especially the relationship between economic growth, population growth, and innovation—will have a significant impact on which climate change scenario is realized. The use of RCP8.5 and RCP4.5 as core scenarios is broadly consistent with the range used in NCA3.[8] For additional detail on these scenarios and what they represent, please see Appendix 3 (Data Tools and Scenario Products), as well as Chapter 4 of the *Climate Science Special Report*.[10]

Treatment of Uncertainties: Risk Framing, Confidence, and Likelihood

Risk Framing

In March 2016, NASEM convened a workshop, Characterizing Risk in Climate Change Assessments, to assist NCA4 authors in their analyses of climate-related risks across the United States.[11] To help ensure consistency and readability across chapters, USGCRP developed guidance on communicating the risks and opportunities that climate change presents, including the treatment of scientific uncertainties. Where supported by the underlying literature, authors were encouraged to

- describe the full scope of potential climate change impacts, both negative and positive, including more extreme impacts that are less likely but would have severe consequences, and communicate the range of potential impacts and their probabilities of occurrence;
- describe the likelihood of the consequences associated with the range of potential impacts, the character and quality of the consequences, both negative and positive, and the strength of available evidence;
- communicate cascading effects among and within complex systems; and
- quantify risks that could be avoided by taking action.

Additional detail on how risk is defined for this report, as well as how risk-based framing was used, is available in Chapter 1: Overview (see Box 1.2: Evaluating Risks to Inform Decisions).

Traceable Accounts: Confidence and Likelihood

Throughout NCA4's assessment of climate-related risks and impacts, authors evaluated the range of information in the scientific literature to the fullest extent possible, arriving at a series of Key Messages for each chapter. Drawing on guidance developed by the Intergovernmental Panel on Climate Change (IPCC),[12] chapter authors further described the overall reliability in their conclusions using these metrics in their chapter's Traceable Accounts:

- **Confidence** in the validity of a finding based on the type, amount, quality, strength, and consistency of evidence (such as mechanistic understanding, theory, data, models, and expert judgment); the skill, range, and consistency of model projections; and the degree of agreement within the body of literature.
- **Likelihood**, which is based on measures of uncertainty expressed probabilistically (in other words, based on statistical analysis of observations or model results or on the authors' expert judgment).

The author team's expert assessment of confidence for each Key Message is presented in the chapter's Traceable Accounts. Where the authors consider it is scientifically justified to report the likelihood of a particular impact within the range of possible outcomes, Key Messages in the Traceable Accounts also include a likelihood designation. Traceable Accounts describe the process and rationale the authors used in reaching their conclusions, as well as their confidence in these conclusions. They provide additional information about the quality of information used and allow traceability to data and resources.

Confidence Level
Very High
Strong evidence (established theory, multiple sources, confident results, well-documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Likelihood				
Very Likely	**Likely**	**As Likely as Not**	**Unlikely**	**Very Unlikely**
≥ 9 in 10	≥ 2 in 3	= 1 in 2	≤ 1 in 3	≤ 1 in 10

Table 1: This table describes the meaning of the various categories of confidence level and likelihood assessment used in NCA4. The levels of confidence are the same as they appear in the CSSR (NCA4 Volume I). And while the likelihood scale is consistent with the CSSR, there are fewer categories, as that report relies more heavily on quantitative methods and statistics. This "binning" of likelihood is consistent with other USGCRP sustained assessment products, such as the Climate and Health Assessment[4] and NCA3.[8]

Glossary of Terms

NCA4 uses the glossary available on the USGCRP website (http://www.globalchange.gov/climate-change/glossary). It was developed for NCA3 and largely draws from the IPCC glossary of terms. Over time, it has been updated with selected new terms from more recent USGCRP assessments, including *The Impacts of Climate Change on Human Health in the United States* (https://health2016.globalchange.gov/glossary-and-acronyms) and the *Climate Science Special Report* (https://science2017.globalchange.gov/chapter/appendix-e/).

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