U.S. Global Change Research Program

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Volume II

Impacts, Risks, and Adaptation in the United States

Report-in-Brief

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Image credit

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: 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. 14: Tribal, 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).

Introduction

Earth's climate is now changing faster than at any point in the history of modern civilization, primarily as a result of human activities. The impacts of global climate change are already being felt in the United States and are projected to intensify in the future—but the severity of future impacts will depend largely on actions taken to reduce greenhouse gas emissions and to adapt to the changes that will occur. Americans increasingly recognize the risks climate change poses to their everyday lives and livelihoods and are beginning to respond (Figure 1.1). Water managers in the Colorado River Basin have mobilized users to conserve water in response to ongoing drought intensified by higher temperatures, and an extension program in Nebraska is helping ranchers reduce drought and heat risks to their operations. The state of Hawai'i is developing management options to promote coral reef recovery from widespread bleaching events caused by warmer waters that threaten tourism, fisheries, and coastal protection from wind and waves. To address higher risks of flooding from heavy rainfall, local governments in southern Louisiana are pooling hazard reduction funds, and cities and states in the Northeast are investing in more resilient water, energy, and transportation infrastructure. In Alaska, a tribal health organization is developing adaptation strategies to address physical and mental health challenges driven by climate change and other environmental changes. As Midwestern farmers adopt new management strategies to reduce erosion and nutrient losses caused by heavier rains, forest managers in the Northwest are developing adaptation strategies in response to wildfire increases that affect human health, water resources, timber production, fish and wildlife, and recreation. After extensive hurricane damage fueled in part by a warmer atmosphere and warmer, higher seas, communities in Texas are considering ways to rebuild more resilient infrastructure. In the U.S. Caribbean, governments are developing new frameworks for storm recovery based on lessons learned from the 2017 hurricane season.

Climate-related risks will continue to grow without additional action. Decisions made today determine risk exposure for current and future generations and will either broaden or limit options to reduce the negative consequences of climate change. While Americans are responding in ways that can bolster resilience and improve livelihoods, neither global efforts to mitigate the causes of climate change nor regional efforts to adapt to the impacts currently approach the scales needed to avoid substantial damages to the U.S. economy, environment, and human health and well-being over the coming decades.

Americans Respond to the Impacts of Climate Change

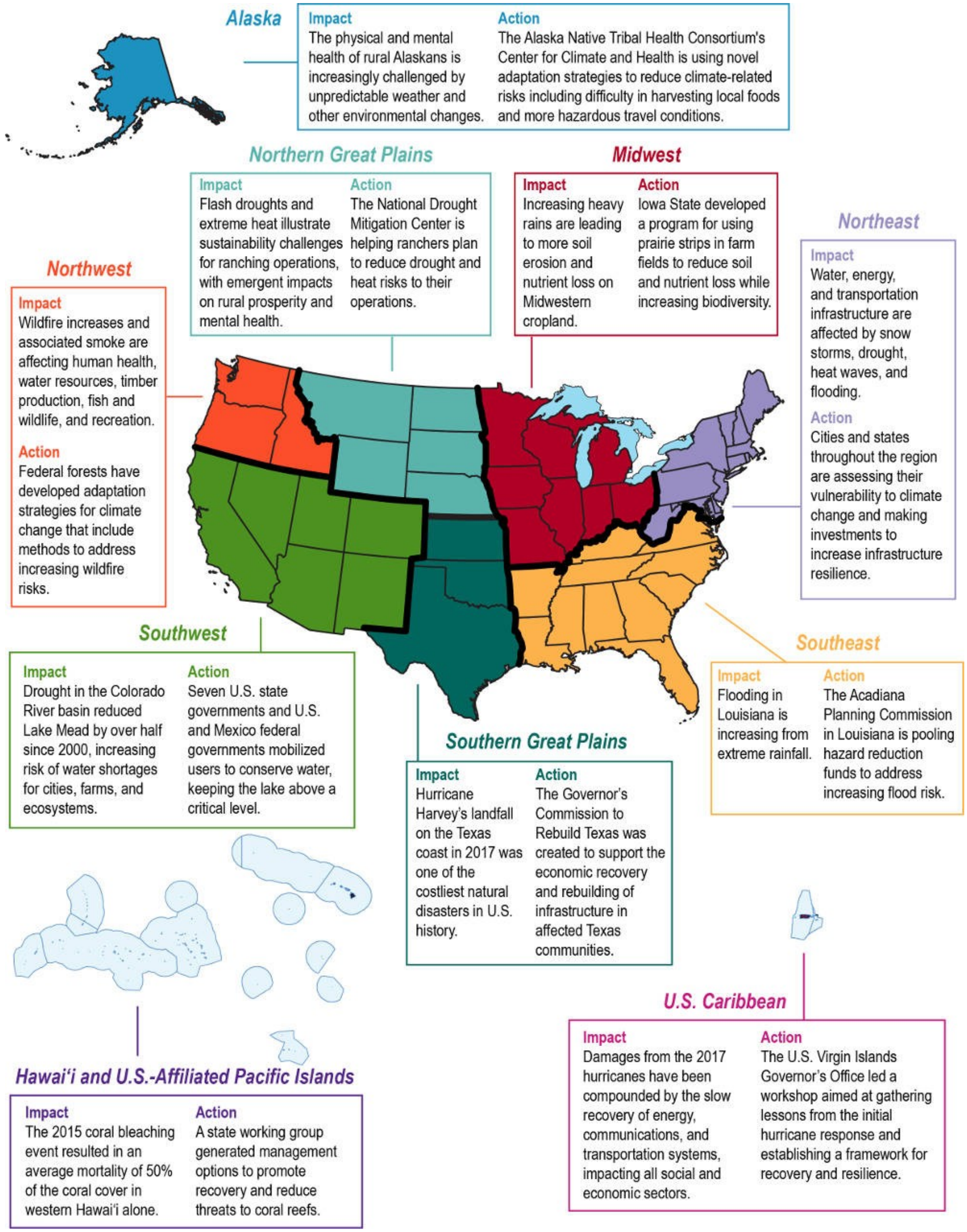

Figure 1.1: This map shows climate-related impacts that have occurred in each region since the Third National Climate Assessment in 2014 and response actions that are helping the region address related risks and costs. These examples are illustrative; they are not indicative of which impact is most significant in each region or which response action might be most effective. *Source: NCA4 Regional Chapters.*

Climate shapes where and how we live and the environment around us. Natural ecosystems, agricultural systems, water resources, and the benefits they provide to society are adapted to past climate conditions and their natural range of variability. A water manager may use past or current streamflow records to design a dam, a city could issue permits for coastal development based on current flood maps, and an electric utility or a farmer may invest in equipment suited to the current climate, all with the expectation that their investments and management practices will meet future needs.

However, the assumption that current and future climate conditions will resemble the recent past is no longer valid (Ch. 28: Adaptation, KM 2). Observations collected around the world provide significant, clear, and compelling evidence that global average temperature is much higher, and is rising more rapidly, than anything modern civilization has experienced, with widespread and growing impacts (Figure 1.2) (CSSR, Ch. 1.9). The warming trend observed over the past century can only be explained by the effects that human activities, especially emissions of greenhouse gases, have had on the climate (Ch. 2: Climate, KM 1 and Figure 2.1).

Climate change is transforming where and how we live and presents growing challenges to human health and quality of life, the economy, and the natural systems that support us. Risks posed by climate variability and change vary by region and sector and by the vulnerability of people experiencing impacts. Social, economic, and geographic factors shape the exposure of people and communities to climate-related impacts and their capacity to respond. Risks are often highest for those that are already vulnerable, including low-income communities, some communities of color, children, and the elderly (Ch. 14: Human Health, KM 2; Ch. 15: Tribes, KM 1–3; Ch. 28: Adaptation, Introduction). Climate change threatens to exacerbate existing social and economic inequalities that result in higher exposure and sensitivity to extreme weather and climate-related events and other changes (Ch. 11: Urban, KM 1). Marginalized populations may also be affected disproportionately by actions to address the underlying causes and impacts of climate change, if they are not implemented under policies that consider existing inequalities (Ch. 11: Urban, KM 4; Ch. 28: Adaptation, KM 4).

This report draws a direct connection between the warming atmosphere and the resulting changes that affect Americans' lives, communities, and livelihoods, now and in the future. It documents vulnerabilities, risks, and impacts associated with natural climate variability and human-caused climate change across the United States and provides examples of response actions underway in many communities. It concludes that *the evidence of human-caused climate change is overwhelming and continues to strengthen, that the impacts of climate change are intensifying across the country, and that climate-related threats to Americans' physical, social, and economic well-being are rising*. These impacts are projected to intensify—but how much they intensify will depend on actions taken to reduce global greenhouse gas emissions and to adapt to the risks from climate change now and in the coming decades (Ch. 28: Adaptation, Introduction; Ch. 29: Mitigation, KM 3 and 4).

Atmosphere (a–c): (a) Annual average temperatures have increased by 1.8°F across the contiguous United States since the beginning of the 20th century; this figure shows observed change for 1986–2016 (relative to 1901–1960 for the contiguous United States and 1925–1960 for Alaska, Hawai‘i, Puerto Rico, and the U.S. Virgin Islands). Alaska is warming faster than any other state and has warmed twice as fast as the global average since the mid-20th century (Ch. 2: Climate, KM 5; Ch. 26: Alaska, Background). (b) The season length of heat waves in many U.S. cities has increased by over 40 days since the 1960s. Hatched bars indicate partially complete decadal data. (c) The relative amount of annual rainfall that comes from large, single-day precipitation events has changed over the past century; since 1910, a larger percentage of land area in the contiguous United States receives precipitation in the form of these intense single-day events.

Ice, snow, and water (d–f): (d) Large declines in snowpack in the western United States occurred from 1955 to 2016. (e) While there are a number of ways to measure drought, there is currently no detectable change in long-term U.S. drought statistics using the Palmer Drought Severity Index. (f) Since the early 1980s, the annual minimum sea ice extent (observed in September each year) in the Arctic Ocean has decreased at a rate of 11%–16% per decade (Ch. 2: Climate, KM 7).

Oceans and coasts (g–i): (g) Annual median sea level along the U.S. coast (with land motion removed) has increased by about 9 inches since the early 20th century as oceans have warmed and land ice has melted (Ch. 2: Climate, KM 4). (h) Fish, shellfish, and other marine species along the Northeast coast and in the eastern Bering Sea have, on average, moved northward and to greater depths toward cooler waters since the early 1980s (records start in 1982). (i) Oceans are also currently absorbing more than a quarter of the carbon dioxide emitted to the atmosphere annually by human activities, increasing their acidity (measured by lower pH values; Ch. 2: Climate, KM 3).

Land and ecosystems (j–l): (j) The average length of the growing season has increased across the contiguous United States since the early 20th century, meaning that, on average, the last spring frost occurs earlier and the first fall frost arrives later; this map shows changes in growing season length at the state level from 1895 to 2016. (k) Warmer and drier conditions have contributed to an increase in large forest fires in the western United States and Interior Alaska over the past several decades (CSSR, Ch. 8.3). (l) Degree days are defined as the number of degrees by which the average daily temperature is higher than 65°F (cooling degree days) or lower than 65°F (heating degree days) and are used as a proxy for energy demands for cooling or heating buildings. Changes in temperatures indicate that heating needs have decreased and cooling needs have increased in the contiguous United States over the past century.

Sources: (a) adapted from Vose et al. 2017, (b) EPA, (c–f and h–l) adapted from EPA 2016, (g and center infographic) EPA and NOAA.

Causes of Change

Scientists have understood the fundamental physics of climate change for almost 200 years. In the 1850s, researchers demonstrated that carbon dioxide and other naturally occurring greenhouse gases in the atmosphere prevent some of the heat radiating from Earth's surface from escaping to space: this is known as the greenhouse effect. This natural greenhouse effect warms the planet's surface about 60°F above what it would be otherwise, creating a habitat suitable for life. Since the late 19th century, however, humans have released an increasing amount of greenhouse gases into the atmosphere through burning fossil fuels and, to a lesser extent, deforestation and land-use change. As a result, the atmospheric concentration of carbon dioxide, the largest contributor to human-caused warming, has increased by about 40% over the industrial era. This change has intensified the natural greenhouse effect, driving an increase in global surface temperatures and other widespread changes in Earth's climate that are unprecedented in the history of modern civilization.

Global climate is also influenced by natural factors that determine how much of the sun's energy enters and leaves Earth's atmosphere and by natural climate cycles that affect temperatures and weather patterns in the short term, especially regionally (see Ch. 2: Climate, Box 2.1). However, the unambiguous long-term warming trend in global average temperature over the last century cannot be explained by natural factors alone. Greenhouse gas emissions from human activities are the only factors that can account for the observed warming over the last century; there are no credible alternative human or natural explanations supported by the observational evidence. Without human activities, the influence of natural factors alone would actually have had a slight cooling effect on global climate over the last 50 years (Ch. 2: Climate, KM 1, Figure 2.1).

Future Change

Greenhouse gas emissions from human activities will continue to affect Earth's climate for decades and even centuries. Humans are adding carbon dioxide to the atmosphere at a rate far greater than it is removed by natural processes, creating a long-lived reservoir of the gas in the atmosphere and oceans that is driving the climate to a warmer and warmer state. Some of the other greenhouse gases released by human activities, such as methane, are removed from the atmosphere by natural processes more quickly than carbon dioxide; as a result, efforts to cut emissions of these gases could help reduce the rate of global temperature increases over the next few decades. However, longer-term changes in climate will largely be determined by emissions and atmospheric concentrations of carbon dioxide and other longer-lived greenhouse gases (Ch. 2: Climate, KM 2).

Climate models representing our understanding of historical and current climate conditions are often used to project how our world will change under future conditions (see Ch. 2: Climate, Box 2.7). "Climate" is defined as weather conditions over multiple decades, and climate model projections are generally not designed to capture annual or even decadal variation in climate conditions. Instead, projections are typically used to capture long-term changes, such as how the climate system will respond to changes in greenhouse gas levels over this century. Scientists test climate models by comparing them to current observations and historical changes. Confidence in these models is based, in part, on how well they reproduce these observed changes. Climate models have proven remarkably accurate in simulating the climate change we have experienced to date, particularly in the past 60 years or so when we have greater confidence in observations (see CSSR, Ch. 4.3.1). The observed signals of a changing climate continue to become stronger and clearer over time, giving scientists increased confidence in their findings even since the Third National Climate Assessment was released in 2014.

Today, the largest uncertainty in projecting future climate conditions is the level of greenhouse gas emissions going forward. Future global greenhouse gas emissions levels and resulting impacts depend on economic, political, and demographic factors that can be difficult to predict with confidence far into the future. Like previous climate assessments, NCA4 relies on a suite of possible scenarios to evaluate the implications of different climate outcomes and associated impacts throughout the 21st century. These "Representative Concentration Pathways" (RCPs) capture a range of potential greenhouse gas emissions pathways and associated atmospheric concentration levels through 2100.

RCPs drive climate model projections for temperature, precipitation, sea level, and other variables under futures that have either lower or higher greenhouse gas emissions. RCPs are numbered according to changes in radiative forcing by 2100 relative to preindustrial conditions: +2.6, +4.5, +6.0, or +8.5 watts per square meter (W/m^2). Each RCP leads to a different

22 Northern Great Plains

Cattle grazing in the plains of western Montana

Key Message 1

Water

Water is the lifeblood of the Northern Great Plains, and effective water management is critical to the region's people, crops and livestock, ecosystems, and energy industry. Even small changes in annual precipitation can have large effects downstream; when coupled with the variability from extreme events, these changes make managing these resources a challenge. Future changes in precipitation patterns, warmer temperatures, and the potential for more extreme rainfall events are very likely to exacerbate these challenges.

Key Message 2

Agriculture

Agriculture is an integral component of the economy, the history, and the culture of the Northern Great Plains. Recently, agriculture has benefited from longer growing seasons and other recent climatic changes. Some additional production and conservation benefits are expected in the next two to three decades as land managers employ innovative adaptation strategies, but rising temperatures and changes in extreme weather events are very likely to have negative impacts on parts of the region. Adaptation to extremes and to longer-term, persistent climate changes will likely require transformative changes in agricultural management, including regional shifts of agricultural practices and enterprises.

Key Message 3

Recreation and Tour

Ecosystems across the Northern Great Plains provide recreational opportunities and other valuable goods and services that are at risk in a changing climate. Rising temperatures have already resulted in shorter snow seasons, lower summer streamflows, and higher stream temperatures and have negatively affected high-elevation ecosystems and riparian areas, with important consequences for local economies that depend on winter or river-based recreational activities. Climate-induced land-use changes in agriculture can have cascading effects on closely entwined natural ecosystems, such as wetlands, and the diverse species and recreational amenities they support. Federal, tribal, state, and private organizations are undertaking preparedness and adaptation activities, such as scenario planning, transboundary collaboration, and development of market-based tools.

Key Message 4

Energy

Fossil fuel and renewable energy production and distribution infrastructure is expanding within the Northern Great Plains. Climate change and extreme weather events put this infrastructure at risk, as well as the supply of energy it contributes to support individuals, communities, and the U.S. economy as a whole. The energy sector is also a significant source of greenhouse gases and volatile organic compounds that contribute to climate change and ground-level ozone pollution.

Key Message 5

Indigenous Peop

Indigenous peoples of the Northern Great Plains are at high risk from a variety of climate change impacts, especially those resulting from hydrological changes, including changes in snowpack, seasonality and timing of precipitation events, and extreme flooding and droughts as well as melting glaciers and reduction in streamflows. These changes are already resulting in harmful impacts to tribal economies, livelihoods, and sacred waters and plants used for ceremonies, medicine, and subsistence. At the same time, many tribes have been very proactive in adaptation and strategic climate change planning.