Executive Summary

Climate change is already affecting the American people. Certain types of weather events have become more frequent and/or intense, including heat waves, heavy downpours, and, in some regions, floods and droughts. Sea level is rising, oceans are becoming more acidic, and glaciers and arctic sea ice are melting. These changes are part of the pattern of global climate change, which is primarily driven by human activity.

Many impacts associated with these changes are important to Americans' health and livelihoods and the ecosystems that sustain us. These impacts are the subject of this report. The impacts are often most significant for communities that already face economic or health-related challenges, and for species and habitats that are already facing other pressures. While some changes will bring potential benefits, such as longer growing seasons, many will be disruptive to society because our institutions and infrastructure have been designed for the relatively stable climate of the past, not the changing one of the present and future. Similarly, the natural ecosystems that sustain us will be challenged by changing conditions. Using scientific information to prepare for these changes in advance provides economic opportunities, and proactively managing the risks will reduce costs over time.

Evidence for climate change abounds, from the top of the atmosphere to the depths of the oceans. This evidence has been compiled by scientists and engineers from around the world, using satellites, weather balloons, thermometers, buoys, and other observing systems. The sum total of this evidence tells an unambiguous story: the planet is warming.

U.S. average temperature has increased by about 1.5°F since 1895; more than 80% of this increase has occurred since 1980. The most recent decade was the nation's hottest on record. Though most regions of the U.S. are experiencing warming, the changes in temperature are not uniform. In general, temperatures are rising more quickly at higher latitudes, but there is considerable observed variability across the regions of the U.S.

U.S. temperatures will continue to rise, with the next few decades projected to see another 2°F to 4°F of warming in most areas. The amount of warming by the end of the century is projected to correspond closely to the cumulative global emissions of greenhouse gases up to that time: roughly 3°F to 5°F under a lower emissions scenario involving substantial reductions in emissions after 2050 (referred to as the "B1 scenario"), and 5°F to 10°F for a higher emissions scenario assuming continued increases in emissions (referred to as the "A2 scenario") (Ch. 2).

The chances of record-breaking high temperature extremes will continue to increase as the climate continues to change. There has been an increasing trend in persistently high nighttime temperatures, which have widespread impacts because people and livestock get no respite from the heat. In other places, prolonged periods of record high temperatures associated with droughts contribute to conditions that are driving larger and more frequent wildfires. There is strong evidence to indicate that human influence on the climate has already roughly doubled the probability of extreme heat events like the record-breaking summer of 2011 in Texas and Oklahoma (Ch. 2,3,6,9,20).

Human-induced climate change means much more than just hotter weather. Increases in ocean and freshwater temperatures, frost-free days, and heavy downpours have all been documented. Sea level has risen, and there have been large reductions in snow-cover extent, glaciers, permafrost, and sea ice. Winter storms along the west coast and the coast of New England have increased slightly in frequency and intensity. These changes and other climatic changes have affected and will continue to affect human health, water supply, agriculture, transportation, energy, and many other aspects of society (Ch. 2,3,4,5,6,10,12,16,20,24,25).

Some of the changes discussed in this report are common to many regions. For example, very heavy precipitation has increased over the past century in many parts of the country. The largest increases have occurred in the Northeast, Midwest, and Great Plains, where heavy downpours have exceeded the capacity of infrastructure such as storm drains, and have led to flooding events and accelerated erosion. Other impacts, such as those associated with the rapid thawing of permafrost in Alaska, are unique to one U.S. region (Ch. 2,16,18,19,20,21,22,23).

Some impacts that occur in one region have more wide-ranging effects. For example, the dramatic decline of summer sea ice in the Arctic – a loss of ice cover roughly equal to half of the continental U.S. – exacerbates global warming by reducing the reflectivity of Earth's surface and increasing the amount of heat the Arctic absorbs. There is some evidence that this affects weather patterns farther south in the United States. Similarly, wildfires in one region can trigger poor air quality in far-away regions, and new evidence suggests the particulate matter in the atmosphere affects global circulation, leading to more persistent periods of anomalous weather. Major storms that hit the Gulf Coast affect the entire country through their cascading effects on oil and gas production and distribution (Ch. 2,4,16,17,18,19,20,22).

Sea level rise, combined with coastal storms, has increased the risk of erosion, storm-surge damage, and flooding for coastal communities, especially along the Gulf of Mexico, the Atlantic seaboard, and Alaska. In the Southeast, coastal infrastructure including roads, rail lines, energy infrastructure, and port facilities including naval bases, are at risk from storm surge that is exacerbated by rising sea level. Over the past century, global sea level has risen by about 8 inches. Since 1992, the rate of global sea level rise measured by satellites has been roughly twice the rate observed over the last century. Sea level is projected to rise by another 1 to 4 feet in this century. A wider range of scenarios, ranging from 8 inches to 6.6 feet of rise by 2100, has been suggested for use in risk-based analyses. In general, higher emissions scenarios that lead to more warming would be expected to lead to sea level rise toward the upper end of the projected range. The stakes are high, as nearly five million Americans live within four feet of the local high-tide level (Ch. 2,4,10,16,17,20, 22,25).

In addition to changing climate, carbon dioxide from fossil fuel burning has a direct effect on the world's oceans. Carbon dioxide interacts with ocean water to form carbonic acid, lowering the ocean's pH. Ocean surface waters have become 30% more acidic as they have absorbed large amounts of carbon dioxide from the atmosphere. This ocean acidification reduces the capacity of marine organisms with shells or skeletons made of calcium carbonate (such as corals, krill, oysters, clams, and crabs) to survive, grow, and reproduce, which in turn will affect the entire marine food chain (Ch. 2,8,23,24,25).

Climate change produces a variety of stresses on society, affecting human health, natural ecosystems, built environments, and existing social, institutional, and legal agreements. These stresses interact with each other and with other non-climate stresses, such as habitat fragmentation, pollution, increased consumption patterns, and biodiversity loss. Addressing these multiple stresses requires the assessment of composite threats as well as tradeoffs among the costs, benefits, and risks of available response options (Ch. 3,5,8,9,10,11,14,16,19,20,25,26,27,28).

Climate change will influence human health in many ways; some existing health threats will intensify, and new health threats will emerge. Some of the key drivers of health impacts include: increasingly frequent and intense extreme heat, which causes heat-related illnesses and deaths and over time, worsens drought and wildfire risks, and intensifies air pollution; increasingly frequent extreme precipitation and associated flooding that can lead to injuries and increases in marine and freshwater-borne disease; and rising sea levels that intensify coastal flooding and storm surge. Certain groups of people are more vulnerable to the range of climate change-related health impacts, including the elderly, children, the poor, and the sick. Others are vulnerable because of where they live, including those in floodplains, coastal zones, and some urban areas. In fact, U.S. population growth has been greatest in coastal zones and in the arid Southwest, areas that already have been affected by increased risks from climate change. Just as some choices can make us more vulnerable, other choices can make us more resilient. Maintaining a robust public health infrastructure will be critical to managing the potential health impacts of climate change (Ch. 2,7,9,11,12,13,16,18,20,25).

Climate change affects the entire living world, including people, through changes in ecosystems and biodiversity. Ecosystems provide a rich array of benefits to humanity, including fisheries, drinking water, fertile soils for growing crops, buffering from climate impacts, and aesthetic and cultural values. These benefits are not always easy to quantify, but they translate into jobs, economic growth, health, and human well-being. Climate change-driven perturbations to ecosystems that have direct human impacts include reduced water supply and quality, the loss of iconic species and landscapes, distorted rhythms of nature, and the potential for extreme events to eliminate the capacity of ecosystems to provide benefits (Ch. 3, 6, 8, 12, 14, 23, 24).

Climate change and other human modifications of ecosystems and landscapes often increase their vulnerability to damage from extreme events while at the same time reducing their natural capacity to modulate the impacts of such events. Salt marshes, reefs, mangrove forests, and barrier islands defend coastal ecosystems and infrastructure, including roads and buildings, against storm surges; their losses from coastal development, erosion, and sea level rise increase the risk of catastrophic damage during or after extreme weather events. Floodplain wetlands, although greatly reduced from their historical extent, absorb floodwaters and reduce the effects of high flows on river-margin lands. Extreme weather events that produce sudden increases in water flow, often carrying debris and pollutants, can decrease the natural capacity of ecosystems to process pollutants (Ch. 3, 7, 8, 25).

As climate change and its impacts are becoming more prevalent, Americans face choices. As a result of past emissions of heat-trapping gases, some amount of additional climate change and related impacts is now unavoidable. This is due to the long-lived nature of many of these gases, the amount of heat absorbed and retained by the oceans, and other responses within the climate system. However, beyond the next few decades, the amount of climate change will still largely be determined by choices society makes about emissions. Lower emissions mean less future warming and less severe impacts; higher emissions would mean more warming and more severe impacts. The choices about emissions pathway fall into a category of response options usually referred to as "mitigation" – ways to reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases (Ch. 2, 26, 27).

The other major category of response options is known as "adaptation" and refers to changes made to better respond to new conditions, thereby reducing harm or taking advantage of opportunity. Mitigation and adaptation are linked, in that effective mitigation reduces the need for adaptation. Both are essential parts of a comprehensive response strategy. The threat of irreversible impacts makes the timing of mitigation efforts particularly critical. This report includes chapters on Mitigation, Adaptation, and Decision Support that offer an overview of the kinds of options and activities being planned or implemented around the country as governments at local, state, federal, and tribal levels, businesses, other organizations, and individuals begin to respond to climate change (Ch. 26, 27, 28).

Large reductions in global emissions, similar to the lower emissions scenario (B1) analyzed in this assessment, would be necessary to avoid some of the worst impacts and risks of climate change. The targets called for in international agreements would require even larger reductions than those outlined in scenario B1 (Figure 1). Meanwhile, global emissions are still rising, and are on track to be even higher than the high emissions scenario (A2) analyzed in this report. The current U.S. contribution to global emissions is about 20%. Voluntary efforts, the recent shift from coal to natural gas for electricity generation, and governmental actions in city, state, regional, and federal programs under way and have contributed to reducing U.S. emissions in the last few years. Some of these actions are motivated by climate concerns, sometimes with non-climate co-benefits, while others are motivated primarily by non-climate objectives. These U.S. actions and others that might be undertaken in the future are described in the Mitigation chapter of this report; at present they are not sufficient to reduce total U.S. emissions to a level that would be consistent with scenario B1 or the targets in international agreements (Ch. 2, 4, 27).

With regard to adaptation, the pace and magnitude of observed and projected changes emphasize the need for being prepared for a wide variety and intensity of climate impacts. Because of the influence of human activities, the past climate is no longer a sufficient indicator of future conditions. Planning and managing based on the climate of the last century means that tolerances of some infrastructure and species will be exceeded. For example, building codes and landscaping ordinances will likely need to be updated not only for energy efficiency, but also to conserve water supplies, protect against insects that spread disease, reduce susceptibility to heat stress, and improve protection against extreme events. The knowledge that climate change is real and accelerating points to the need to develop and refine approaches that enable decision-making and increase flexibility, robustness, and resilience in the face of ongoing and future impacts. Being prepared for such events paves the way for economic opportunities (Ch. 2, 3, 5, 9, 11, 13, 26, 27, 28).

Adaptation considerations include local, state, regional, national, and international jurisdictional issues. For example, in managing water supplies to adapt to a changing climate, the implications of international treaties should be considered in the context of managing the Great Lakes, the Columbia River, and the Colorado River to deal with increased drought risk. Both "bottom up" community planning and "top down" national strategies may help regions deal with impacts such as increases in electrical brownouts, heat stress, floods, and wildfires. Such a mix of approaches will require cross-boundary coordination at multiple levels as operational agencies integrate adaptation planning into their programs (Ch. 3, 7, 9, 10, 18, 20, 21, 26, 28).

Proactively preparing for climate change can reduce impacts, while also facilitating a more rapid and efficient response to changes as they happen. The Adaptation chapter in this report highlights efforts at the federal, regional, state, tribal, and local levels, as well as initiatives in the corporate and non-governmental sectors to build adaptive capacity and resilience towards climate change (Ch. 28).

This report identifies a number of areas for which improved scientific information or understanding would enhance the capacity to estimate future climate change impacts. For example, knowledge of the mechanisms controlling the rate of ice loss in Greenland and Antarctica is limited, making it difficult for scientists to narrow the range of future sea level rise. Research on ecological responses to climate change is limited, as is understanding of social responses and how ecological and social responses will interact (Ch. 29).

There is also a section on creating a sustained climate assessment process to more efficiently collect and synthesize the rapidly evolving science and to help supply timely and relevant information to decision-makers. Results from all of these efforts will continue to build our understanding of the interactions of human and natural systems in the context of a changing climate (Ch. 30).

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Report Findings

1. **Global climate is changing, and this is apparent across the U.S. in a wide range of observations. The climate change of the past 50 years is due primarily to human activities, predominantly the burning of fossil fuels.**
U.S. average temperature has increased by about 1.5°F since 1895, with more than 80% of this increase occurring since 1980. The most recent decade was the nation's warmest on record. Because human-induced warming is superimposed on a naturally varying climate, rising temperatures are not evenly distributed across the country or over time (Ch. 2).

2. **Some extreme weather and climate events have increased in recent decades, and there is new and stronger evidence that many of these increases are related to human activities.**
Changes in extreme events are the primary way in which most people experience climate change. Human-induced climate change has already increased the frequency and intensity of some extremes. Over the last 50 years, much of the U.S. has seen an increase in prolonged stretches of excessively high temperatures, more heavy downpours, and in some regions more severe droughts (Ch. 2, 16, 17, 18, 19, 20, 23).

3. **Human-induced climate change is projected to continue and accelerate significantly if emissions of heat-trapping gases continue to increase.**
Heat-trapping gases already in the atmosphere have committed us to a hotter future with more climate-related impacts over the next few decades. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, now and in the future (Ch. 2, 27).

4. **Impacts related to climate change are already evident in many sectors and are expected to become increasingly challenging across the nation throughout this century and beyond.**
Climate change is already affecting human health, infrastructure, water resources, agriculture, energy, the natural environment, and other factors – locally, nationally, and internationally. Climate change interacts with other environmental and societal factors in a variety of ways that either moderate or exacerbate the ultimate impacts. The types and magnitudes of these effects vary across the nation and through time. Several populations – including children, the elderly, the sick, the poor, tribes and other indigenous people – are especially vulnerable to one or more aspects of climate change. There is mounting evidence that the costs to the nation are already high and will increase very substantially in the future, unless global emissions of heat-trapping gases are strongly reduced (Ch. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25).

5. **Climate change threatens human health and well-being in many ways, including impacts from increased extreme weather events, wildfire, decreased air quality, diseases transmitted by insects, food, and water, and threats to mental health.**
Climate change is increasing the risks of heat stress, respiratory stress from poor air quality, and the spread of waterborne diseases. Food security is emerging as an issue of concern, both within the U.S. and across the globe, and is affected by climate change. Large-scale changes in the environment due to climate change and extreme weather events are also increasing the risk of the emergence or reemergence of unfamiliar health threats (Ch. 2, 6 , 9, 11, 12, 16, 19,

20, 22, 23).

6. **Infrastructure across the U.S. is being adversely affected by phenomena associated with climate change, including sea level rise, storm surge, heavy downpours, and extreme heat.**
Sea level rise and storm surges, in combination with the pattern of heavy development in coastal areas, are already resulting in damage to infrastructure such as roads, buildings, ports, and energy facilities. Infrastructure associated with military installations is also at risk from climate change impacts. Floods along the nation's rivers, inside cities, and on lakes following heavy downpours, prolonged rains, and rapid melting of snowpack are damaging infrastructure in towns and cities, farmlands, and a variety of other places across the nation. Extreme heat is damaging transportation infrastructure such as roads, rail lines, and airport runways. Rapid warming in Alaska has resulted in infrastructure impacts due to thawing of permafrost and the loss of coastal sea ice that once protected shorelines from storms and wave-driven coastal erosion (Ch. 2, 3, 5, 6, 11, 16, 17, 18, 19, 20, 21, 22, 23, 25).

7. **Reliability of water supplies is being reduced by climate change in a variety of ways that affect ecosystems and livelihoods in many regions, particularly the Southwest, the Great Plains, the Southeast, and the islands of the Caribbean and the Pacific, including the state of Hawai`i.**
Surface and groundwater supplies in many regions are already stressed by increasing demand for water as well as declining runoff and groundwater recharge. In many regions, climate change increases the likelihood of water shortages and competition for water among agricultural, municipal, and environmental uses. The western U.S. relies heavily on mountain snowpack for water storage, and spring snowpack is declining in most of the West. There is an increasing risk of seasonal water shortages in many parts of the U.S., even where total precipitation is projected to increase. Water quality challenges are also increasing, particularly sediment and contaminant concentrations after heavy downpours (Ch. 2, 3, 12, 16, 17, 18, 19, 20, 21, 23).

8. **Adverse impacts to crops and livestock over the next 100 years are expected. Over the next 25 years or so, the agriculture sector is projected to be relatively resilient, even though there will be increasing disruptions from extreme heat, drought, and heavy downpours. U.S. food security and farm incomes will also depend on how agricultural systems adapt to climate changes in other regions of the world.**
Near-term resilience of U.S. agriculture is enhanced by adaptive actions, including expansion of irrigated acreage in response to drought, regional shifts in crops and cropped acreage, continued technological advancements, and other adjustments. By mid-century, however, when temperature increases and precipitation extremes are further intensified, yields of major U.S. crops are expected to decline, threatening both U.S. and international food security. The U.S. food system also depends on imports, so food security and commodity pricing will be affected by agricultural adaptation to climate changes and other conditions around the world (Ch. 2, 6, 12, 13, 14, 18, 19).

9. Natural ecosystems are being directly affected by climate change, including changes in biodiversity and location of species. As a result, the capacity of ecosystems to moderate the consequences of disturbances such as droughts, floods, and severe storms is being diminished.

In addition to climate changes that directly affect habitats, events such as droughts, floods, wildfires, and pest outbreaks associated with climate change are already disrupting ecosystem structures and functions in a variety of direct and indirect ways. These changes limit the capacity of ecosystems such as forests, barrier beaches, and coastal- and freshwater-wetlands to adapt and continue to play important roles in reducing the impacts of these extreme events on infrastructure, human communities, and other valued resources (Ch. 2, 3, 6, 7, 8, 10, 11, 14, 15, 19, 25).

10. Life in the oceans is changing as ocean waters become warmer and more acidic.

Warming ocean waters and ocean acidification across the globe and within U.S. marine territories are broadly affecting marine life. Warmer and more acidic waters are changing the distribution of fish and other mobile sea life, and stressing those, such as corals, that cannot move. Warmer and more acidic ocean waters combine with other stresses, such as overfishing and coastal and marine pollution, to negatively affect marine-based food production and fishing communities (Ch. 2, 23, 24, 25).

11. Planning for adaptation (to address and prepare for impacts) and mitigation (to reduce emissions) is increasing, but progress with implementation is limited.

In recent years, climate adaptation and mitigation activities have begun to emerge in many sectors and at all levels of government; however barriers to implementation of these activities are significant. The level of current efforts is insufficient to avoid increasingly serious impacts of climate change that have large social, environmental, and economic consequences. Well-planned and implemented actions to limit emissions and increase resilience to impacts that are unavoidable can improve public health, economic development opportunities, natural system protection, and overall quality of life (Ch. 6, 7, 8, 9, 10, 13, 15, 26, 27, 28).

Table 1.1: Regional Observations of Climate Change

Regional Observations of Climate Change	
Northeast	Heat waves, coastal flooding due to sea level rise and storm surge, and river flooding due to more extreme precipitation events are affecting communities in the region.
Southeast	Decreased water availability, exacerbated by population growth and land-use change, is causing increased competition for water; risks associated with extreme events like hurricanes are increasing.
Midwest	Longer growing seasons and rising carbon dioxide levels are increasing yields of some crops, although these benefits have already been offset in some instances by occurrence of extreme events such as heat waves, droughts, and floods.
Great Plains	Rising temperatures are leading to increased demand for water and energy and impacts on agricultural practices.
Southwest	Drought and increased warming have fostered wildfires and increased competition for scarce water resources for people and ecosystems.
Northwest	Changes in the timing of streamflow related to earlier snowmelt have already been observed and are reducing the supply of water in summer, causing far-reaching ecological and socioeconomic consequences.
Alaska	Summer sea ice is receding rapidly, glaciers are shrinking, and permafrost is thawing, causing damage to infrastructure and major changes to ecosystems; impacts to Alaska native communities are increasing.
Hawaii	Increasingly constrained freshwater supplies, coupled with increased temperatures, are stressing both people and ecosystems, and decreasing food and water security.
Coasts	Coastal lifelines, such as water supply infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, and other climate-related changes.
Oceans	The oceans are currently absorbing about a quarter of human-caused carbon dioxide emissions to the atmosphere and over 90% of the heat associated with global warming, leading to ocean acidification and the alteration of marine ecosystems.

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Crosscutting Themes and Issues

There are several themes that run throughout the assessment. These include: the "multiple stresses context" in which climate change impacts must be interpreted; the effects of socioeconomic and cultural decisions on vulnerabilities to climate change; and the importance of considering climate-change impacts on the U.S. in an international context.

1. Climate change should be considered in the context of multiple factors

Climate change and its impacts cannot be adequately assessed in isolation. Rather, they are part of a broader context including many other factors such as: land-use change, local economies, air and water pollution, and rates of consumption of resources. This perspective has implications for assessments of climate change impacts and the design of research questions at the national, regional, and local scales. This assessment begins to explore the consequences of interacting factors by focusing on sets of crosscutting issues in a series of six chapters: Water, Energy, and Land Use; Biogeochemical Cycles; Impacts of Climate Change on Tribal Lands and Resources; Urban Infrastructure and Vulnerability; Land Use and Land Cover Change; and Impacts on Rural Communities. This Assessment also includes discussions of cascading impacts in several chapters (particularly in the Urban Infrastructure and Vulnerability Chapter and the Water, Energy, and Land Use Chapter), and emphasizes that many of the impacts identified in the Assessment will occur in parallel, not in isolation from one another. As illustrated by recent events, this greatly stresses the capacity to respond to a series of climate-related crises that occur simultaneously or soon after one another.

2. Societal choices affect vulnerability to climate change impacts.

Because environmental, cultural and socioeconomic systems are tightly coupled, climate change impacts can either be amplified or reduced by cultural and/or socioeconomic decisions. In the context of the "risk-based framing" for their chapters, the authors of this report were asked to focus on attributes of regions and sectors most likely to experience significant impacts. In many chapters, it is clear that societal decisions have the greatest impact on valued resources. For example, rapid population growth and development in areas that are particularly susceptible to climate change impacts can amplify those impacts. Recognition of these couplings, together with recognition of the multiple-stresses perspective, helps identify the information needs of decision-makers as they manage risk.

3. Importance of the international context

Climate change is a global phenomenon; the causes and the impacts involve energy-use and risk-management decisions across the globe. Impacts, vulnerabilities, and opportunities in the U.S. are related in complex and interactive ways with changes outside the U.S., and vice versa. In order for U.S. concerns related to climate change to be addressed comprehensively, the international context must be considered. U.S. security, foreign assistance, and economic interests are affected by climate changes experienced in other parts of the world. Although there is significantly more work to be done in this area, this report does identify some initial implications of global and international trends that can be more fully investigated in future assessments.

4. Thresholds, Tipping Points, and Surprises

A significant issue in studying and preparing for global climate change is the fact that changes in human, social, and physical systems do not always occur gradually. Same changes may occur in a relatively predictable way, while others involve unexpected break-points or thresholds beyond which there are irreversible changes or changes of higher magnitudes than expected based on previous experience. These "tipping points" are very hard to predict, as there are many uncertainties associated with understanding future conditions. These uncertainties come from a number of sources, including insufficient data associated with low probability/high consequence events, models that are not yet able to represent the interactions of multiple stresses, incomplete understanding of physical climate mechanisms related to tipping points, and a multitude of issues associated with human behavior, risk management, and decision-making.

5. Weather and Climate Extremes

Understanding how climate is changing requires consideration of changes in the average climate as well as changes in "extremes" – weather and climate events like hot spells, heavy rains, periods of drought and flooding, and severe storms. The climate change impacts expected to have the greatest consequences are those involving extremes: changes in the frequency, intensity, timing, duration, and spatial extent of such extremes, as well as through the occurrence of unprecedented extremes.

Terms like "weather-extremes," "climate extremes," "heat waves," and "heavy downpours" need to be defined when used in a scientific context. Researchers use different definitions depending on which characteristics of extremes they are choosing to explore at any one time, in the context of the particular issue they are studying. Nevertheless, most of the scientific literature on extremes uses definitions that fall roughly into two categories (IPCC 2012): those related to the probability of occurrence of a certain type of event, and those related to exceeding a particular threshold.

For example, common measures of extremes include the number, percentage, or fraction of days in a month, season, or year with maximum (or minimum) temperature above the 90th, 95th, or 99th percentile compared to a reference time period (for example, 1961-1990) – or alternatively, how often a threshold temperature (for example, 32°F or 90°F) is exceeded during a given decade. Alternative definitions refer to how often, on average, an event of a specific magnitude occurs (sometimes called the "return period") – for example, how frequently we might expect to see daily rainfall exceeding two inches in a given region.

In addition, extremes occur over different time periods, ranging from events lasting a few days to a few weeks, like a heat wave or cold snap, to those that happen over longer timescales, such as a period of drought or an unusually hot summer.

Changes in extremes are often more difficult to study than changes in the average climate because of the smaller data sample for particularly rare events. This is less of an issue for so-called "moderate extremes," such as those occurring as often as 5% to 10% of the time. For more "extreme extremes," statistical methods are often used to overcome these sampling issues.

For any given aspect of climate, such as temperature or precipitation, it is important to look at a variety of measures to get an overall picture of the changes in extremes. For the several types of

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extremes discussed in Chapter 2: Our Changing Climate under Key Messages 6, 7, and 8, for example, the cited studies address different, complementary aspects of each of these phenomena. In the impact studies cited in other chapters, the word "extreme" is often defined differently within different sectors, such as water or health. However, collectively, these studies paint a consistent picture of changes in average climate as well as changes across a range of weather and climate extremes in the United States.

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About This Report

The development of this draft National Climate Assessment (NCA) report was overseen by the 60-member National Climate Assessment and Development Advisory Committee (NCADAC), a Federal Advisory Committee (FAC) appointed by the Secretary of Commerce at the request of the National Science and Technology Council (NSTC). The NSTC is required, under the 1990 Global Change Research Act (GCRA, Title 15 USC Sec 2921 2012), to provide such reports periodically to the President and the Congress. The report, which assesses current scientific findings about the observed and projected impacts of climate change on the United States, relies heavily on the findings of the U.S. Global Change Research Program (USGCRP) (USGCRP 2012). USGCRP activities include observations, monitoring, modeling, process research, and data management focused on discerning global change impacts and informing response options such as adaptation and mitigation. After government review, this report is expected to become the third National Climate Assessment (Karl et al. 2009; USGCRP 2000).

As required by Section 106 of the GCRA, the NCA integrates, evaluates, and synthesizes the science of climate and global change and the observed and projected impacts of climate change on the U.S. The assessment integrates the findings of USGCRP with climate-change research and scientific observations from around the world. Major topics in the assessment include evaluating current understanding of climate change science as well as related impacts on various societal and environmental sectors and regions across the nation. The goal of this assessment report is to establish a scientific and credible foundation of information that is useful for a variety of science and policy applications related to managing risk and maximizing opportunities in a changing climate. The report also documents some societal responses to climate changes, and gives public and private decision-makers a better understanding of how climate change is affecting us now and what is in store for the future.

Authorship and Review and Approval Process

A team of more than 240 experts operating under the authority of the NCADAC wrote this document. The NCADAC was assisted by the staff of the USGCRP National Coordination Office, a Technical Support Unit located at the NOAA National Climatic Data Center, and communication specialists in development of this draft report. The report will be extensively reviewed and revised based on comments from the National Research Council of the National Academies of Science and the public. It will then be submitted for review and approval by the National Oceanic and Atmospheric Administration, other agencies of the Subcommittee on Global Change Research, the Committee on the Environment and Natural Resources of the NSTC, and the NSTC itself. Upon approval, the report will be transmitted to Congress and the President. The entire process is designed to ensure that the report meets all federal requirements associated with the Information Quality Act, including those pertaining to public comment and transparency (OMB 2012).

Stakeholder Engagement

This third National Climate Assessment effort has included extensive involvement of stakeholders in providing inputs to the structure and substance of the report. Teams of regional and sectoral experts, decision-makers, and stakeholders were formed to provide technical input and data to the Assessment process. Stakeholder and expert groups participated in more than 70 workshops and listening sessions. Participants included public and private decision-makers, resource and environmental managers, researchers, non-governmental organizations, and the general public (USCGCRP 2012). Stakeholders from various regions and sectors identified climate-change issues and information they asked to be considered in the assessment. In addition, a number of stakeholder groups submitted data and written reports related to their knowledge about specific climate change issues in response to a request for such input through the Federal Register. A communications and engagement workgroup of the FAC provided oversight and advice regarding the events and engagement processes that led to this report.

Sources of Information

The report draws from a large body of scientific peer-reviewed research published or in press by July 31, 2012. This new work was carefully reviewed by the author teams to ensure a reliable assessment of the state of scientific understanding. Another important source of information for this report was a set of technical input reports produced by federal agencies and other interested parties in response to a request for information by the Assessment's federal advisory committee (USGCRP 2012). In addition, other peer-reviewed scientific assessments were used, including those of the Intergovernmental Panel on Climate Change, the U.S. National Assessment's 2009 report, *Global Climate Change Impacts in the United States* (Karl et al. 2009), the National Academy of Science's *America's Climate Choices* reports (NRC 2011), and a variety of regional climate impact assessments. These assessments were augmented with government statistics as necessary (such as population census and energy usage) as well as publicly available observations. The final version of this report will be deployed electronically as an "e-book," allowing for linkages across and within topics and chapters as well as transparent, clickable access to the data and references behind each of the conclusions.

Responding to Climate Change

While the primary focus of this report is on the impacts of climate change in the U.S., it also documents some of the actions society is already taking or can take to respond to the climate challenge. Responses to climate change fall into two broad categories. The first involves "mitigation" measures to reduce climate change by reducing emissions of heat-trapping gases and particles, or increasing removal of carbon dioxide from the atmosphere. The second involves "adaptation" measures to improve society's ability to cope with or avoid harmful impacts and take advantage of beneficial ones, now and in the future. At this point, both of these response activities are necessary to limit the magnitude and impact of global climate change on the United States. More effective mitigation measures can reduce the amount of climate change, and therefore the need for adaptation in the future.

This report underscores the effect of mitigation by comparing impacts resulting from higher versus lower emissions scenarios. This shows that choices made about emissions in the next few decades will have far-reaching consequences for climate change impacts in the middle to latter part of this century. Over the long term, lower emissions will lessen both the magnitude of climate change impacts and the rate at which they appear.

While the report underscores the importance of mitigation as an essential part of the nation's climate change strategy, it does not evaluate mitigation technologies or undertake an analysis of the effectiveness of various approaches. These issues are the subject of ongoing studies by the

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U.S. Government's Climate Change Technology Program and several federal agencies including the Department of Energy, Environmental Protection Agency, Department of Transportation, and Department of Agriculture. The range of mitigation responses being studied by these agencies includes, but is not limited to, more efficient production and use of energy, increased use of non-carbon-emitting energy sources, and carbon capture and storage.

Adaptation actions are complementary to mitigation options. They are focused on moderating harmful impacts of current and future climate variability and change, and taking advantage of possible beneficial opportunities arising from climate change. While this report does assess the current state of adaptation actions and planning across the country, the implementation of adaptive actions is still nascent, and a comprehensive assessment of actions taken, and of their effectiveness, is not yet possible. This report documents actions currently being pursued to address impacts such as increased urban heat extremes and air pollution, and describes the challenges decision makers face in planning for and implementing adaptation responses.

Risk-Based Framing

Authors of this assessment were asked to approach it from the perspective of a decision-maker trying to limit risk to valued systems, resources, and communities (and to consider opportunities as well). For each chapter, they were asked to frame a number of key questions or issues that address the most important information needs of stakeholders, and consider the decisions stakeholders are facing. The criteria provided for identifying key vulnerabilities in their sector or region included: magnitude, timing, persistence/reversibility, distributional aspects, likelihood, and importance of impacts (based on the perceptions of relevant parties) as well as the potential for adaptation. For the purposes of this assessment, risk was defined as the product of likelihood and consequence, and authors were encouraged to think about these topics from both a quantitative and qualitative perspective, and to consider the influence of multiple stresses if possible.

Assessing Confidence

The level of confidence the chapter authors have in the key findings they report is given in "traceable accounts" that accompany each chapter. A traceable account is intended to: 1) document the process the authors used to come to the conclusions in their key messages; 2) provide additional information to reviewers about the quality of the information used; and 3) allow traceability to data and resources. The authors have assessed a wide range of information in the scientific literature and previous technical reports. In assessing confidence, they have considered the strength and consistency of the observed evidence, the skill, range, and consistency of model projections, and insights about processes and climate from peer-reviewed sources.

Assessing Likelihood

When it is considered scientifically justified to report the likelihood of particular impacts within the range of possible outcomes, this report takes a plain-language approach to expressing the expert judgment of the author team based on the best available evidence. For example, an outcome termed "likely" has at least a two-thirds chance of occurring; an outcome termed "very likely," at least a 90% chance. Key sources of information used to develop these characterizations of uncertainty are referenced.

Addressing Incomplete Scientific Understanding

Within each traceable account, the authors identify areas where a lack of information and/or scientific uncertainty limits their ability to estimate future climate change and its impacts. The section on "An Agenda for Climate Impacts Science" at the end of this report highlights some of the areas suggested for additional research.

Scenarios

Scenarios are ways to help understand what future conditions might be, with each scenario an example of what might happen under particular assumptions. Scenarios are not predictions or forecasts. Instead, scenarios provide a starting point for examining questions about an uncertain future and help us to visualize alternative futures in concrete and human terms. The military and businesses frequently use these powerful tools for future planning in high-stakes situations. We use scenarios to help identify future vulnerabilities as well as to support decision-makers who are focused on limiting risk and maximizing opportunities. Three types of scenarios are used in this assessment – emissions scenarios (including population and land use components), climate scenarios, and sea level rise scenarios.

Emissions Scenarios

Emissions scenarios quantitatively illustrate potential additions to the atmosphere of substances that alter natural climate patterns. Emissions result from essential human activities, including energy production and use, agriculture, and other activities that change land use. These scenarios are developed using a wide range of assumptions about population growth, economic development, the evolution of technology, and decisions about environmental protection, among other factors. A wide range of assumptions is used because future trends are uncertain and depend on unpredictable human choices. These assumptions about the future include a wide array of considerations – not only emissions, but also the extent to which changes in climate will have impacts on society and natural resources, and capacity for adaptation.

Perspectives on "plausible" emissions scenarios evolve over time. The Intergovernmental Panel on Climate Change (IPCC) has been a leader in developing scenarios and has released three different sets since 1990. In 2000, the IPCC released a Special Report on Emission Scenarios (Nakicenovic et al. 2000) that provided its most recent set of scenarios (known as SRES) that described a wide range of socioeconomic futures and resulting emissions. In the higher end of the range, the SRES A2 scenario represents a divided world with high population growth, low economic growth, slower technology improvements and diffusion, and other factors that contribute to high emissions and lower adaptive capacity (for example, low per capita wealth). At the lower end of the range, the B1 scenario represents a world with lower population growth, higher economic development, a shift to low-emitting efficient energy technologies that are diffused rapidly around the world through free trade, and other conditions that reduce the rate and magnitude of changes in climate averages and extremes as well as increased capacity for adaptation. Recently, a new set of scenarios (Representative Concentration Pathways – RCPs) has been prepared and released by scientists who study emissions, climate, and potential impacts (Moss et al. 2010). This new set incorporates recent observations and research and includes a wider range of future conditions and emissions. Because climate model results are just now being prepared using the new scenarios, and there are few impacts studies that employ them, when scenarios are needed, the report uses the SRES B1 and A2 to span a range of potential futures.

Scientists cannot predict which of these scenarios is most likely because the future emissions pathway is a function of human choices. A wide range of societal decisions and policy choices will ultimately influence how the world's emissions evolve, and ultimately, the composition of the atmosphere and the state of the climate system.

Climate Scenarios

Global models that simulate the Earth's climate system are used, among other things, to evaluate the effects of human activities on climate. Since the second U.S. National Climate Assessment report in 2009, a new set of model simulations has been introduced that include more Earth system physics and chemistry and have higher resolution.

These models use emissions scenarios to project expected climate change given different assumptions about how human activities and/or associated emissions levels might change.

The range of potential increases in global average temperature in the newest climate model simulations is wider because a wider range of options for future human behavior is considered. For example, one of the new RCP scenarios assumes rapid emission reductions that would limit the global temperature increase to about 3.7°F, a much lower level than in previous scenarios. However, it is noteworthy that the emissions trajectory in RCP 8.5 is similar to SRES A2 and RCP 4.5 is roughly comparable to SRES B1 (see figure comparing SRES and RCP scenarios below).

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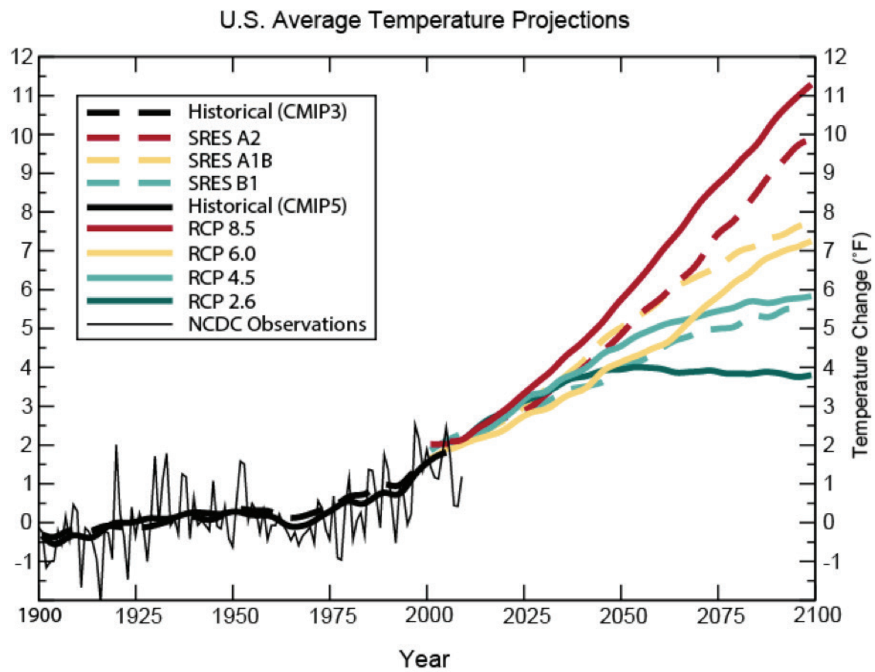

Figure 1.1: U.S. Average Temperature Projections

Caption: Projected average annual temperature changes (°F) over the contiguous U.S. for multiple future emissions scenarios, relative to the 1901-1960 average temperature. The dashed lines are results from the SRES scenarios and the previous simulations. The solid lines are results from RCPs and the most recent simulations. (Figure source: Michael Wehner, LBNL. Data from CMIP3, CMIP5, and NOAA.)

Box: Emissions Scenarios
In this report, the two SRES emissions scenarios recommended for use in impact studies are a higher emissions scenario (the A2 scenario from SRES) and a lower emissions scenario (the B1 scenario from SRES). These two scenarios do not encompass the full range of possible futures: emissions can change less than those scenarios imply, or they can change even more. Recent carbon dioxide emissions are, in fact, above the A2 scenario. Whether this will continue is unknown.

-- end box --

Sea Level Rise Scenarios
After at least two thousand years of little change, sea level rose by roughly 8 inches over the last century, and satellite data provide evidence that the rate of rise over the past 20 years has roughly doubled. In the U.S., millions of people and many of the nation’s assets related to military readiness, energy, transportation, commerce, and ecosystems are located in areas at risk of coastal flooding because of sea level rise and storm surge.

Sea level is rising because ocean water expands as it heats up and because water is added to the oceans from melting glaciers and ice sheets. Sea level is projected to rise an additional 1 to 4 feet

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in this century. Scientists are unable to narrow this range at present because the processes affecting the loss of ice mass from the large ice sheets are dynamic and still the subject of intense study. Some impact assessments in this report use a set of sea level rise scenarios within this range, while others consider sea level rise as high as 6.6 feet.

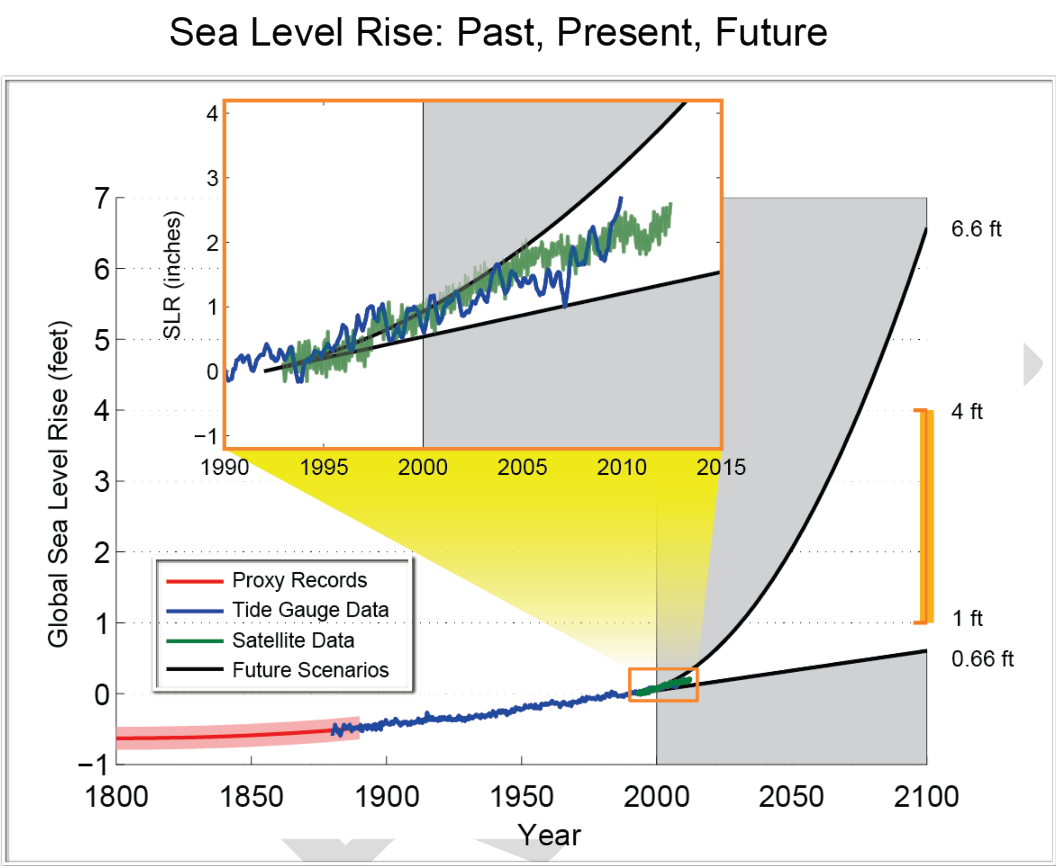

Figure 1.2: Sea Level Rise: Past, Present, and Future

Caption: Historical, observed, and possible future amounts of global sea level rise from 1800 to 2100. Historical estimates (Kemp et al. 2012) (based on sediment records and other proxies) are shown in red (pink band shows uncertainty range), tide gauge measurements in blue (Church and White 2011), and satellite observations are shown in green (Nerem et al. 2010). The future scenarios range from 0.66 feet to 6.6 feet in 2100 (Parris et al. 2012). Higher or lower amounts of sea level rise are considered implausible by 2100, as represented by the gray shading. The orange line at right shows the currently projected range of sea level rise of 1 to 4 feet by 2100, which falls within the larger risk-based scenario range. The large projected range of scenarios reflects uncertainty about how ice sheets will respond to the warming ocean and atmosphere, and to changing winds and currents. Figure source: Josh Willis, NASA Jet Propulsion Laboratory, based on cited data sources.

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