Executive Summary

Observations show that warming of the climate is unequivocal. The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping gases. These emissions come mainly from the burning of fossil fuels (coal, oil, and gas), with important contributions from the clearing of forests, agricultural practices, and other activities.

Warming over this century is projected to be considerably greater than over the last century. The global average temperature since 1900 has risen by about 1.5ºF. By 2100, it is projected to rise another 2 to 11.5ºF. The U.S. average temperature has risen by a comparable amount and is very likely to rise more than the global average over this century, with some variation from place to place. Several factors will determine future temperature increases. Increases at the lower end of this range are more likely if global heat-trapping gas emissions are cut substantially. If emissions continue to rise at or near current rates, temperature increases are more likely to be near the upper end of the range. Volcanic eruptions or other natural variations could temporarily counteract some of the human-induced warming, slowing the rise in global temperature, but these effects would only last a few years.

Reducing emissions of carbon dioxide would lessen warming over this century and beyond. Sizable early cuts in emissions would significantly reduce the pace and the overall amount of climate change. Earlier cuts in emissions would have a greater effect in reducing climate change than comparable reductions made later. In addition, reducing emissions of some shorter-lived heat-trapping gases, such as methane, and some types of particles, such as soot, would begin to reduce warming within weeks to decades.

Climate-related changes have already been observed globally and in the United States. These include increases in air and water temperatures, reduced frost days, increased frequency and intensity of heavy downpours, a rise in sea level, and reduced snow cover, glaciers, permafrost, and sea ice. A longer ice-free period on lakes and rivers, lengthening of the growing season, and increased water vapor in the atmosphere have also been observed. Over the past 30 years, temperatures have risen faster in winter than in any other season, with average winter temperatures in the Midwest and northern Great Plains increasing more than 7ºF. Some of the changes have been faster than previous assessments had suggested.

These climate-related changes are expected to continue while new ones develop. Likely future changes for the United States and surrounding coastal waters include more intense hurricanes with related increases in wind, rain, and storm surges (but not necessarily an increase in the number of these storms that make landfall), as well as drier conditions in the Southwest and Caribbean. These changes will affect human health, water supply, agriculture, coastal areas, and many other aspects of society and the natural environment.

This report synthesizes information from a wide variety of scientific assessments (see page 7) and recently published research to summarize what is known about the observed and projected consequences of climate change on the United States. It combines analysis of impacts on various sectors

such as energy, water, and transportation at the national level with an assessment of key impacts on specific regions of the United States. For example, sea-level rise will increase risks of erosion, storm surge damage, and flooding for coastal communities, especially in the Southeast and parts of Alaska. Reduced snowpack and earlier snow melt will alter the timing and amount of water supplies, posing significant challenges for water resource management in the West.

Society and ecosystems can adjust to some climatic changes, but this takes time. The projected rapid rate and large amount of climate change over this century will challenge the ability of society and natural systems to adapt. For example, it is difficult and expensive to alter or replace infrastructure designed to last for decades (such as buildings, bridges, roads, airports, reservoirs, and ports) in response to continuous and/or abrupt climate change.

Impacts are expected to become increasingly severe for more people and places as the amount of warming increases. Rapid rates of warming would lead to particularly large impacts on natural ecosystems and the benefits they provide to humanity. Some of the impacts of climate change will be irreversible, such as species extinctions and coastal land lost to rising seas.

Unanticipated impacts of increasing carbon dioxide and climate change have already occurred and more are possible in the future. For example, it has recently been observed that the increase in atmospheric carbon dioxide concentration is causing an increase in ocean acidity. This reduces the ability of corals and other sea life to build shells and skeletons out of calcium carbonate. Additional impacts in the future might stem from unforeseen changes in the climate system, such as major alterations in oceans, ice, or storms; and unexpected consequences of ecological changes, such as massive dislocations of species or pest outbreaks. Unexpected social or economic changes, including major shifts in wealth, technology, or societal priorities would also affect our ability to respond to climate change. Both anticipated and unanticipated impacts become more challenging with increased warming.

Projections of future climate change come from careful analyses of outputs from global climate models run on the world's most advanced computers. The model simulations analyzed in this report used plausible scenarios of human activity that generally lead to further increases in heat-trapping emissions. None of the scenarios used in this report assumes adoption of policies explicitly designed to address climate change. However, the level of emissions varies among scenarios because of differences in assumptions about population, economic activity, choice of energy technologies, and other factors. Scenarios cover a range of emissions of heat-trapping gases, and the associated climate projections illustrate that lower emissions result in less climate change and thus reduced impacts over this century and beyond. Under all scenarios considered in this report, however, relatively large and sustained changes in many aspects of climate are projected by the middle of this century, with even larger changes by the end of this century, especially under higher emissions scenarios.

In projecting future conditions, there is always some level of uncertainty. For example, there is a high degree of confidence in projections that future temperature increases will be greatest in the Arctic and in the middle of continents. For precipitation, there is high confidence in projections of continued increases in the Arctic and sub-Arctic (including Alaska) and decreases in the regions just outside the tropics, but the precise location of the transition between these is less certain. At local to regional scales and on time frames up to a few years, natural climate variations can be relatively large and can temporarily mask the progressive nature of global climate change. However, the science of making skillful projections at these scales has progressed considerably, allowing useful information to be drawn from regional climate studies such as those highlighted in this report.

This report focuses on observed and projected climate change and its impacts on the United States. However, a discussion of these issues would be incomplete without mentioning some of the actions society can take to respond to the climate challenge. The two major categories are "mitigation" and "adaptation." Mitigation refers to options for limiting climate change by, for example, reducing

heat-trapping emissions such as carbon dioxide, methane, nitrous oxide, and halocarbons, or removing some of the heat-trapping gases from the atmosphere. Adaptation refers to changes made to better respond to present or future climatic and other environmental conditions, thereby reducing harm or taking advantage of opportunity. Effective mitigation measures reduce the need for adaptation. Mitigation and adaptation are both essential parts of a comprehensive climate change response strategy.

Carbon dioxide emissions are a primary focus of mitigation strategies. These include improving energy efficiency, using energy sources that do not produce carbon dioxide or produce less of it, capturing and storing carbon dioxide from fossil fuel use, and so on. Choices made about emissions reductions now and over the next few decades will have far-reaching consequences for climate-change impacts. The importance of mitigation is clear in comparisons of impacts resulting from higher versus lower emissions scenarios considered in this report. Over the long term, lower emissions will lessen both the magnitude of climate-change impacts and the rate at which they appear. Smaller climate changes that come more slowly make the adaptation challenge more tractable.

However, no matter how aggressively heat-trapping emissions are reduced, some amount of climate change and resulting impacts will continue due to the effects of gases that have already been released. This is true for several reasons. First, some of these gases are very long-lived and the levels of atmospheric heat-trapping gases will remain elevated for hundreds of years or more. Second, the Earth's vast oceans have absorbed much of the heat added to the climate system due to the increase in heat-trapping gases, and will retain that heat for many decades. In addition, the factors that determine emissions, such as energy-supply systems, cannot be changed overnight. Consequently, there is also a need for adaptation.

Adaptation can include a wide range of activities. Examples include a farmer switching to growing a different crop variety better suited to warmer or drier conditions; a company relocating key business centers away from coastal areas vulnerable to sea-level rise and hurricanes; and a community altering its zoning and building codes to place fewer structures in harm's way and making buildings less vulnerable to damage from floods, fires, and other extreme events. Some adaptation options that are currently being pursued in various regions and sectors to deal with climate change and/or other environmental issues are identified in this report. However, it is clear that there are limits to how much adaptation can achieve.

Humans have adapted to changing climatic conditions in the past, but in the future, adaptations will be particularly challenging because society won't be adapting to a new steady state but rather to a rapidly moving target. Climate will be continually changing, moving at a relatively rapid rate, outside the range to which society has adapted in the past. The precise amounts and timing of these changes will not be known with certainty.

In an increasingly interdependent world, U.S. vulnerability to climate change is linked to the fates of other nations. For example, conflicts or mass migrations of people resulting from food scarcity and other resource limits, health impacts, or environmental stresses in other parts of the world could threaten U.S. national security. It is thus difficult to fully evaluate the impacts of climate change on the United States without considering the consequences of climate change elsewhere. However, such analysis is beyond the scope of this report.

Finally, this report identifies a number of areas in which inadequate information or understanding hampers our ability to estimate future climate change and its impacts. For example, our knowledge of changes in tornadoes, hail, and ice storms is quite limited, making it difficult to know if and how such events have changed as climate has warmed, and how they might change in the future. Research on ecological responses to climate change is also limited, as is our understanding of social responses. The section titled *An Agenda for Climate Impacts Science* at the end of this report offers some thoughts on the most important ways to improve our knowledge. Results from such efforts would inform future assessments that continue building our understanding of humanity's impacts on climate, and climate's impacts on us.

Key Findings

1. Global warming is unequivocal and primarily human-induced.
Global temperature has increased over the past 50 years. This observed increase is due primarily to human-induced emissions of heat-trapping gases. (p. 13)

2. Climate changes are underway in the United States and are projected to grow.
Climate-related changes are already observed in the United States and its coastal waters. These include increases in heavy downpours, rising temperature and sea level, rapidly retreating glaciers, thawing permafrost, lengthening growing seasons, lengthening ice-free seasons in the ocean and on lakes and rivers, earlier snowmelt, and alterations in river flows. These changes are projected to grow. (p. 27)

3. Widespread climate-related impacts are occurring now and are expected to increase.
Climate changes are already affecting water, energy, transportation, agriculture, ecosystems, and health. These impacts are different from region to region and will grow under projected climate change. (p. 41-106, 107-152)

4. Climate change will stress water resources.
Water is an issue in every region, but the nature of the potential impacts varies. Drought, related to reduced precipitation, increased evaporation, and increased water loss from plants, is an important issue in many regions, especially in the West. Floods and water quality problems are likely to be amplified by climate change in most regions. Declines in mountain snowpack are important in the West and Alaska where snowpack provides vital natural water storage. (p. 41, 129, 135, 139)

5. Crop and livestock production will be increasingly challenged.
Many crops show positive responses to elevated carbon dioxide and low levels of warming, but higher levels of warming often negatively affect growth and yields. Increased pests, water stress, diseases, and weather extremes will pose adaptation challenges for crop and livestock production. (p. 71)

6. Coastal areas are at increasing risk from sea-level rise and storm surge.
Sea-level rise and storm surge place many U.S. coastal areas at increasing risk of erosion and flooding, especially along the Atlantic and Gulf Coasts, Pacific Islands, and parts of Alaska. Energy and transportation infrastructure and other property in coastal areas are very likely to be adversely affected. (p. 111, 139, 145, 149)

7. Risks to human health will increase.
Harmful health impacts of climate change are related to increasing heat stress, waterborne diseases, poor air quality, extreme weather events, and diseases transmitted by insects and rodents. Reduced cold stress provides some benefits. Robust public health infrastructure can reduce the potential for negative impacts. (p. 89)

8. Climate change will interact with many social and environmental stresses.
Climate change will combine with pollution, population growth, overuse of resources, urbanization, and other social, economic, and environmental stresses to create larger impacts than from any of these factors alone. (p. 99)

9. Thresholds will be crossed, leading to large changes in climate and ecosystems.
There are a variety of thresholds in the climate system and ecosystems. These thresholds determine, for example, the presence of sea ice and permafrost, and the survival of species, from fish to insect pests, with implications for society. With further climate change, the crossing of additional thresholds is expected. (p. 76, 82, 115, 137, 142)

10. Future climate change and its impacts depend on choices made today.
The amount and rate of future climate change depend primarily on current and future human-caused emissions of heat-trapping gases and airborne particles. Responses involve reducing emissions to limit future warming, and adapting to the changes that are unavoidable. (p. 25, 29)