Executive Summary

Observations show that warming of the climate system is now unequivocal. The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping gases. These emissions come primarily from the burning of fossil fuels (coal, oil, and gas), with additional major contributions from the clearing of forests and agricultural 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 1.5°F. By 2100, it is projected to rise another 2 to 10°F. Temperatures in the United States have risen by a comparable amount and are very likely to rise more than the global average over this century. 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, and at the upper end if emissions continue to rise at or near current rates. Other important factors that affect the range are related to the strength of the response of the climate system to human influences.

Reducing emissions of carbon dioxide would reduce warming over this century and beyond. Reducing emissions of some shorter-lived greenhouse gases, such as methane, and some types of particles, such as soot, would begin to reduce warming within decades. Volcanic eruptions or other natural variations could temporarily mask human-induced warming, but these effects would be short-lived.

Climate-related changes already have 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, and sea ice. A longer ice-free period on lakes and rivers, lengthening of the growing season, and increased water vapor in the atmosphere has also been observed.

These changes are expected to increase and will impact human health, water supply, agriculture, coastal areas, and many other aspects of society and the natural environment. Some changes are likely for the United States and surrounding coastal waters including more intense hurricanes and related increases in wind, rain, and storm surges (but not necessarily an increase in the number of storms that make landfall), as well as drier conditions in the Southwest and Caribbean.

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 and flooding for coastal communities, especially in the Southeast and parts of Alaska. Reduced snowpack will alter the timing and amount of water supplies, exacerbating water shortages in the West.

Society and ecosystems today are generally adapted to recent climate. For this reason, the projected rapid rate and large amount of climate change over this century will challenge the ability of society and natural systems to adjust. For example, it is difficult and expensive to alter or replace long-lived infrastructure, such as 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. And some of the impacts of climate change will be irreversible, such as species extinctions and coastal land lost to rising seas.

Unanticipated impacts of climate change have already occurred and more are likely in the future. These future impacts might stem from unforeseen changes in the climate system, such as major alterations in oceans, ice, or storms; and unpredicted 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 affect our ability to respond to climate change. Both anticipated and unanticipated impacts become more likely 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 lead generally to further increases in heat-trapping emissions. None of the scenarios used in this Report assume any policies explicitly designed to address climate change. However, the level of emissions varies from one scenario to the next because of differences in population, economic activity, and energy technologies. Scenarios cover a range of emissions of heat-trapping gases, illustrating that lower emissions result in less climate change and thus reduced impacts over this century. 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 under higher emission scenarios.

In projecting future conditions, there is always some level of uncertainty. For example, there is a high degree of confidence in projections of future temperature increases that are greatest nearer the poles and in the middle of continents. For precipitation, there is high confidence in continued increases in the Arctic and sub-Arctic (including Alaska) and decreases in the tropical regions, but the precise location of the transition zone between these is less certain. On smaller time and space scales, 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 smaller 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 first major category of action is "mitigation," or options for reducing heat-trapping emissions such as carbon dioxide, methane, nitrous oxide, and halocarbons. With respect to carbon dioxide, mitigation options include improving energy efficiency, using energy sources that don't produce carbon dioxide or produce less of it, capturing and storing carbon dioxide from fossil fuel use, and so on.

While mitigation is not directly addressed in this Report, it is a critical component of a comprehensive strategy to address climate change. Mitigation options have been the subject of previous assessments and are being actively considered in current research (see page 8).

The second category is "adaptation," which refers to changes made to better respond to present or future climate and other environmental conditions. Mitigation and adaptation are both essential parts of a climate change response strategy. Effective mitigation measures reduce the need for adaptation.

No matter how aggressively heat-trapping emissions are reduced, the world will still experience some continued climate change and resulting impacts. This is true for several reasons. First, because some

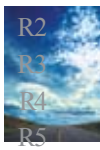
of these gases are long-lived, they lead to elevated levels of atmospheric heat-trapping gases for hundreds of years. Second, Earth's vast oceans have absorbed much of the heat added to the climate system due to the increase in heat-trapping gases, and they will retain the heat and sustain global warming for many decades, even after human-induced emissions are substantially reduced. And third, the factors that determine emissions, such as energy-supply systems, cannot be changed overnight. Consequently, there also is a need for adaptation.

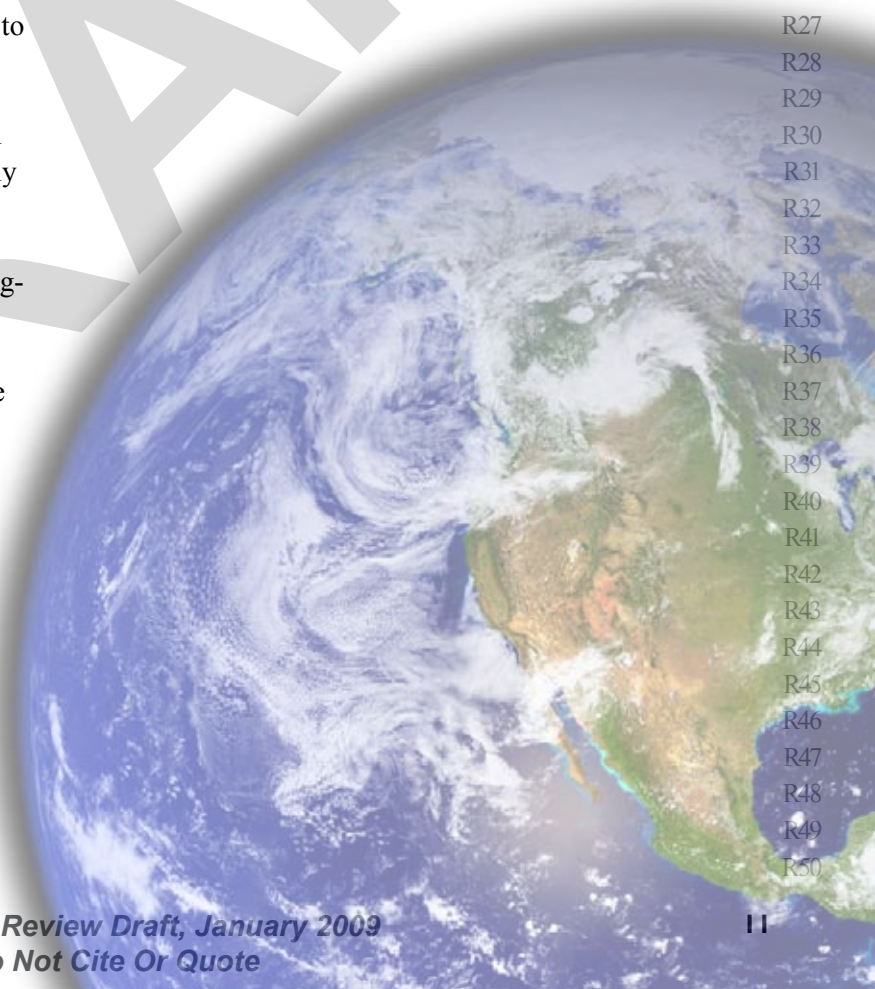
Adaptation involves deliberately adjusting to observed or anticipated changes to avoid or reduce detrimental impacts or to take advantage of beneficial ones. For example, a farmer might switch to growing a different crop variety better suited to warmer or drier conditions. A company might relocate key business centers away from coastal areas vulnerable to sea-level rise and hurricanes. A community might alter its zoning and building codes to place fewer structures in harm's way and make 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 are identified in this Report. However, it is clear that there are limits to how much adaptation can achieve.

Humans have adapted to changing conditions in the past. What will make adaptations particularly challenging in the future is that society won't be adapting to a new steady state but rather to a moving target. Climate will be continually changing, moving outside the range to which society is adapted, at a relatively rapid rate; 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 resource limits, health, or environmental stresses in other parts of the world could threaten 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 Assessment identifies a number of areas in which inadequate information or understanding hampers our ability to estimate likely 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 also is limited, as is our understanding of social responses. The section *Recommendations for Future Work* at the end of this Report identifies some of the most important gaps in knowledge and offers some thoughts on how to address those gaps. 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.

There is no question that 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 temperature, sea level, and heavy downpours, 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 larger. (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. 41-108, 109-156)

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 and increases in evapotranspiration, 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 Northwest, Southwest, and Alaska where snowpack provides vital natural water storage. (p. 41, 133, 139, 143)

5. Crop and livestock production will be increasingly challenged.

Agriculture is considered one of the sectors most able to adapt to climate change. However, increased heat, pests, 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 regions at increasing risk of erosion and flooding, especially along the Atlantic and Gulf Coasts, Pacific Islands, and parts of Alaska. Energy and transportation infrastructure in coastal cities is very likely to be adversely affected. (p. 153)

7. Threats to human health will increase.

Health impacts of climate change are related to heat stress, water-borne diseases, reduced air quality, extreme weather events, and diseases transmitted by insects and rodents. Robust public health infrastructure can reduce the potential for negative impacts. (p. 91)

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 any one of these alone. (p. 101)

9. Rapid, irreversible, and unanticipated changes are likely as a result of crossing key thresholds.

Some aspects of climate change and its impacts are likely to be unanticipated as complex systems respond to ongoing changes in unforeseen ways. Such changes have already been observed. Some changes in climate and associated ecological responses are likely to be rapid and irreversible as tipping points are reached. (p. 26, 159)

10. Future climate change and its impacts depend on choices made today.

The amount and rate of future climate change depends 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. Adaptation examples include water conservation and modified land-use planning in areas with high flood and fire risks. (p. 142, 151, 156)