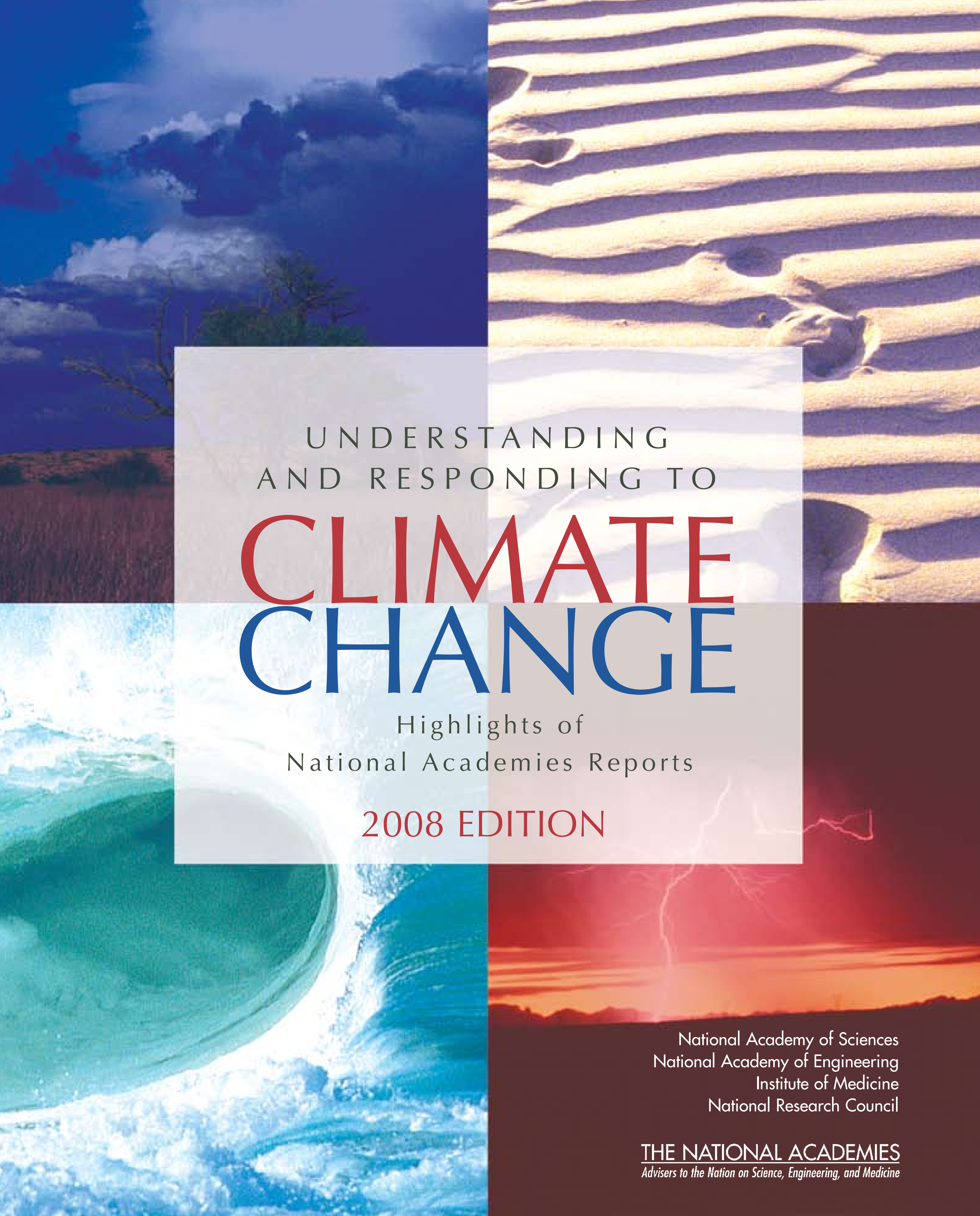


UNDERSTANDING AND RESPONDING TO CLIMATE CHANGE

Highlights of National Academies Reports

2008 EDITION

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

UNDERSTANDING AND RESPONDING TO CLIMATE CHANGE

2008 EDITION

UNDERSTANDING AND RESPONDING TO CLIMATE CHANGE

There is a growing concern about global warming and the impact it will have on people and the ecosystems on which they depend. Temperatures have already risen 1.4°F since the start of the 20th century—with much of this warming occurring in just the last 30 years—and temperatures will likely rise at least another 2°F, and possibly more than 11°F, over the next 100 years. This warming will cause significant changes in sea level, ecosystems, and ice cover, among other impacts. In the Arctic, where temperatures have increased almost twice as much as the global average, the landscape and ecosystems are already changing rapidly.

Most scientists agree that the warming in recent decades has been caused primarily by human activities that have increased the amount of greenhouse gases in the atmosphere (see Figure 1). Greenhouse gases, such as carbon dioxide, have increased significantly since the Industrial Revolution, mostly from the burning of fossil fuels for energy, industrial processes, and transportation. Carbon dioxide levels are at their highest in at least 650,000 years and continue to rise.

There is no doubt that climate will continue to change throughout the 21st century and beyond, but there are still important questions regarding how large and how fast these changes will be, and what effects they will have in different regions. In some parts of the world, global warming could bring positive effects such as longer growing seasons and milder winters. Unfortunately, it is likely to bring harmful effects to a much higher percentage of the world's people. For example, people in coastal communities will likely experience increased flooding due to rising sea levels.

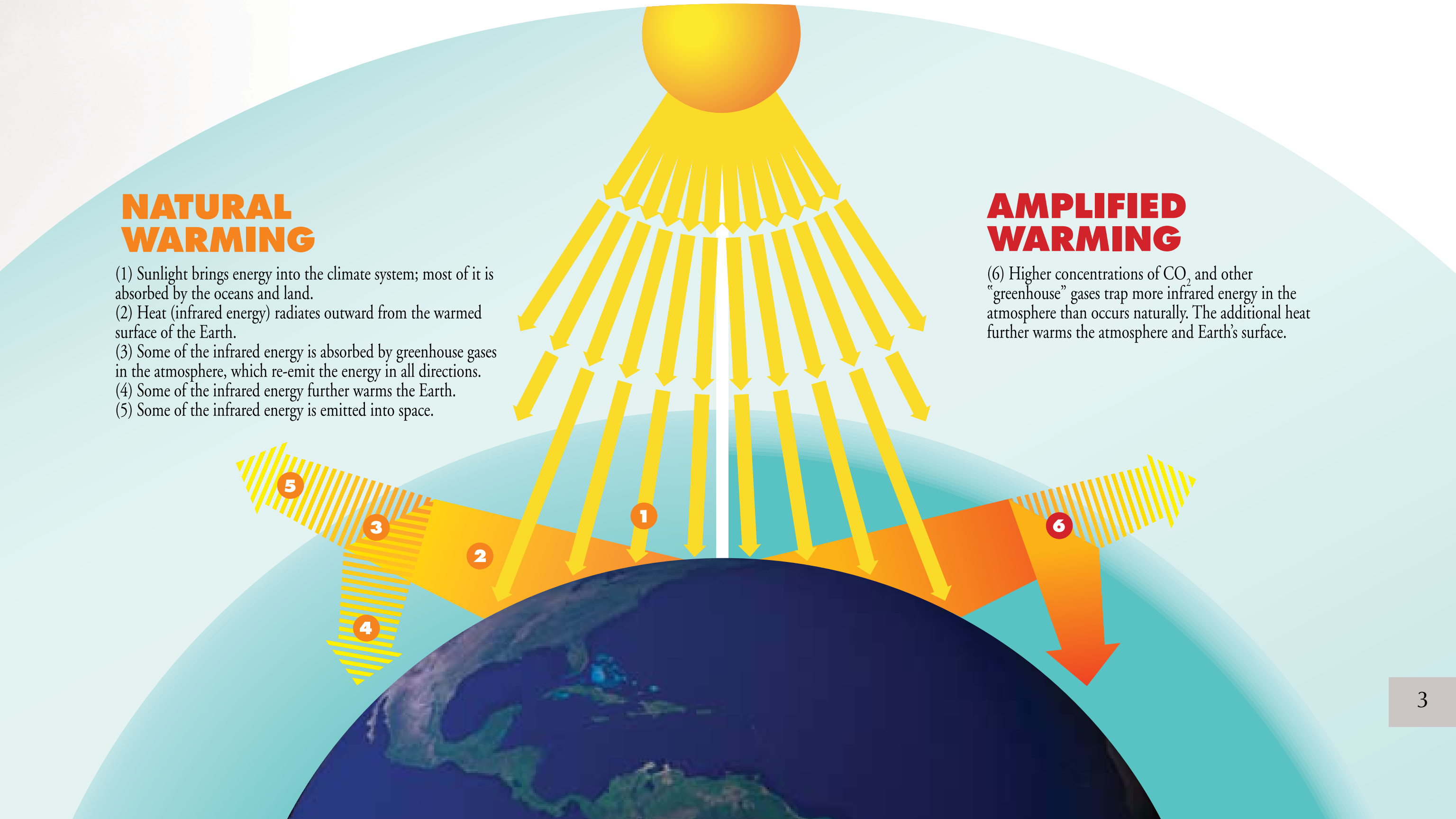
The scientific understanding of climate change is now sufficiently clear to begin taking steps to prepare for climate change and to slow it. Human actions over the next few decades will have a major influence on the magnitude and rate of future warming. Large, disruptive changes are much more likely if greenhouse gases are allowed to continue building up in the atmosphere at their present rate. However, reducing greenhouse gas emissions will require strong national and international commitments, technological innovation, and human willpower.

GLOBAL WARMING OR CLIMATE CHANGE?

The phrase "climate change" is growing in preferred use to "global warming" because it helps convey that there are changes in addition to rising temperatures.

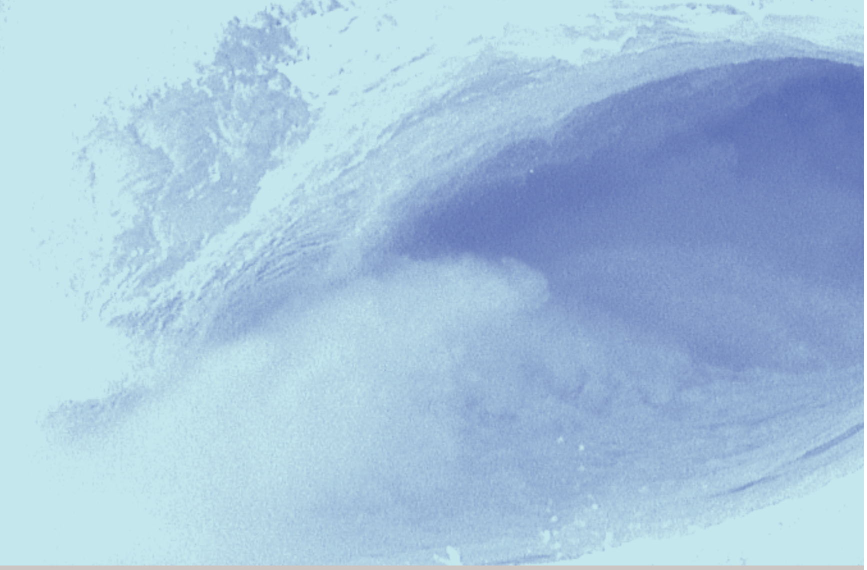
This brochure highlights findings and recommendations from National Academies' reports on climate change. These reports are the products of the National Academies' consensus study process, which brings together leading scientists, engineers, public health officials, and other experts to address specific scientific and technical questions. Such reports have evaluated climate change science, identified new avenues of inquiry and critical needs in the research infrastructure, and explored opportunities to use scientific knowledge to more effectively respond to climate change.

Figure 1. The greenhouse effect is a natural phenomenon that is essential to keeping the Earth's surface warm. Like a greenhouse window, greenhouse gases allow sunlight to enter and then prevent heat from leaving the atmosphere. Water vapor (H_2O) is the most important greenhouse gas, followed by carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halocarbons, and ozone (O_3). Human activities—primarily burning fossil fuels—are increasing the concentrations of these gases, amplifying the natural greenhouse effect. Image courtesy of the Marion Koshland Science Museum of the National Academy of Sciences.



(1) Sunlight brings energy into the climate system; most of it is absorbed by the oceans and land.
(2) Heat (infrared energy) radiates outward from the warmed surface of the Earth.
(3) Some of the infrared energy is absorbed by greenhouse gases in the atmosphere, which re-emit the energy in all directions.
(4) Some of the infrared energy further warms the Earth.
(5) Some of the infrared energy is emitted into space.

(6) Higher concentrations of CO_2 and other "greenhouse" gases trap more infrared energy in the atmosphere than occurs naturally. The additional heat further warms the atmosphere and Earth's surface.



ABOUT THE SCIENCE

> *Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.*
>
> ***—Climate Change 2007:***
> ***The Physical Basis*, Intergovernmental**
> **Panel on Climate Change**

The Earth is warming.

Temperature readings from around the globe show a relatively rapid increase in surface temperature during the past century (see Figure 2). These data, which have been closely scrutinized and carefully calibrated to remove potential problems such as the "urban heat island" effect, show an especially pronounced warming trend during the past 30 years—in fact, 9 of the 10 warmest years on record have occurred during the past decade. Furthermore, the surface temperature data are consistent with other evidence of warming, such as increasing ocean temperatures, shrinking mountain glaciers, and decreasing polar ice cover.

One inevitable question people ask is whether the current warming trend is unusual compared to temperature shifts on Earth prior to the 20th century—that is, before the buildup of excess greenhouse gases in the atmosphere. To help answer this question, scientists analyze tree rings, ice cores, ocean sediments, and a number of other "proxy" indicators to estimate past climatic conditions. These studies are important for understanding many aspects of Earth's climate, including the natural variability of surface temperature over many centuries. *Surface Temperature Reconstructions for the Last 2,000 Years* (2006), produced in

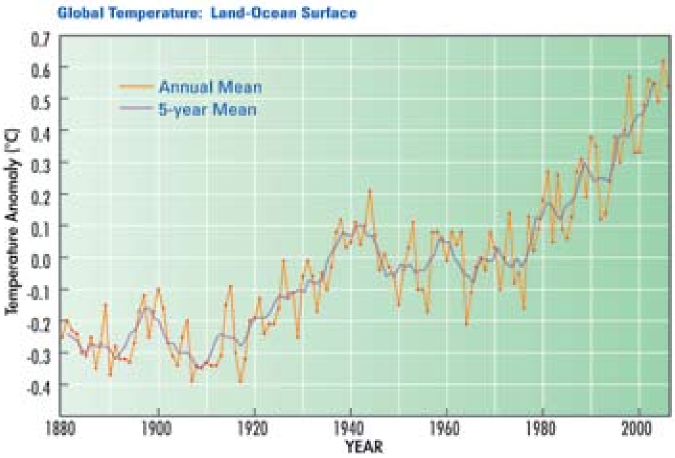


Figure 2. Global surface temperature, based on surface air temperature measurements at meteorological stations and on sea surface temperature measurements from ships and satellites, shows a temperature increase of 1.4°F (0.78°C) since the beginning of the 20th century, with about 1.1°F (0.61°C) of the increase occurring in the past 30 years. Data courtesy of NASA Goddard Institute for Space Studies.

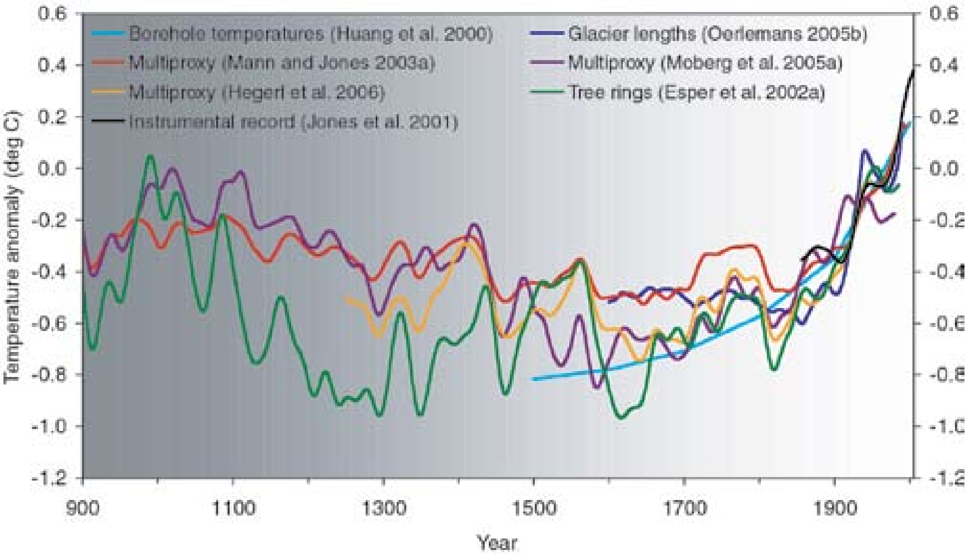


Figure 3. Surface temperature reconstructions made by six different research teams (colored lines) are shown along with the instrumental record of global surface temperature (black line). Each team used a different method and different set of "proxy" data to produce its temperature estimate. The uncertainty in each reconstruction generally increases going backward in time (as indicated by the gray shading). All the curves indicate that the last few decades of the 20th century were warmer than any comparable period during at least the past four centuries, and probably longer. Source: *Surface Temperature Reconstructions for the Last 2000 Years* (National Research Council, 2006)

response to a request from Congress, assesses the scientific evidence used to estimate global temperature variations during the past two millennia, as well as how these estimates contribute to our understanding of global climate change. The report concludes, with a high level of confidence, that global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period since at least A.D. 1600 (see Figure 3). Estimating the Earth's global-average temperature becomes increasingly difficult going further back in time due to the decreasing availability of reliable proxy evidence, but the available evidence indicates that most regions are warmer now than at any other time since at least A.D. 900.

Human activities are changing climate.

In May 2001, the White House asked the National Academy of Sciences to assess our current understanding of climate change by answering some key questions related to the causes of climate change, projections of future change, and critical research directions to improve understanding of climate change. *Climate Change Science: An Analysis of Some Key Question*s (2001) concluded that "changes observed over the last several decades are likely mostly due to human activities." Additional evidence collected over the past several years has increased confidence in this conclusion.

How do we know that human activities are changing the Earth's climate? The concurrent increase in surface temperature with carbon dioxide and other greenhouse gases during the past century is one of the main indications. Prior to the Industrial Revolution, the amount of carbon dioxide released to the atmosphere by natural processes was almost exactly in balance with the amount absorbed by plants and other "sinks" on the Earth's surface. The burning of fossil fuels (oil, natural gas, and coal) releases additional carbon dioxide to the atmosphere. About half of this excess carbon dioxide is absorbed by the ocean, plants, and trees, but the rest accumulates in the atmosphere,

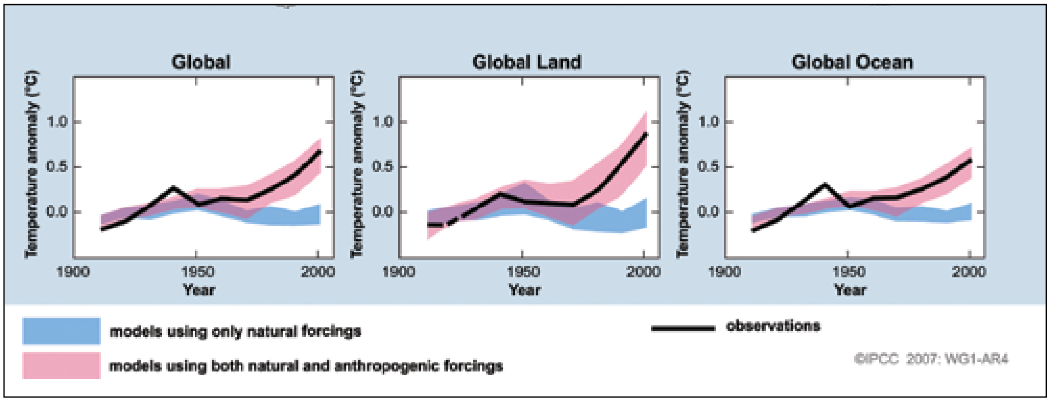


Figure 4. Model simulations of 20th century climate variations more closely match observed temperature when both natural and human influences are included. Black line shows observed temperatures. Blue-shaded regions show projections from models that only included natural forcings (solar activity and volcanos). Red-shaded regions show projections from models that include both natural and human forcings. Source: *Climate Change 2007: The Physical Science Basis*, Intergovernmental Panel on Climate Change 2007.

amplifying the natural greenhouse effect. There is also considerable evidence that human activities are causing the increases in other greenhouse gases such as methane and nitrous oxide.

Rising temperatures and greenhouse gas concentrations observed since 1978 are particularly noteworthy because the rates of increase are so high and because, during the same period, the energy reaching the Earth from the Sun has been measured precisely by satellites. These measurements indicate that the Sun's output has not increased since 1978, so the warming during the past 30 years cannot be attributed to an increase in solar energy reaching the Earth. The frequency of volcanic eruptions, which tend to cool the Earth by reflecting sunlight back to space, also has not increased or decreased significantly. Thus, there are no known natural factors that could explain the warming during this time period.

Additional evidence for a human influence on climate can be seen in the geographical pattern of observed warming, with greater temperature increases over land and in polar regions than over the oceans. This pattern is strongly indicative of warming caused by increasing greenhouse gas concentrations, as is the vertical profile of warming in the atmosphere and oceans. Further, model simulations of temperature change during the past century only match the observed temperature increase when greenhouse gas increases and other human causes are included (see Figure 4).

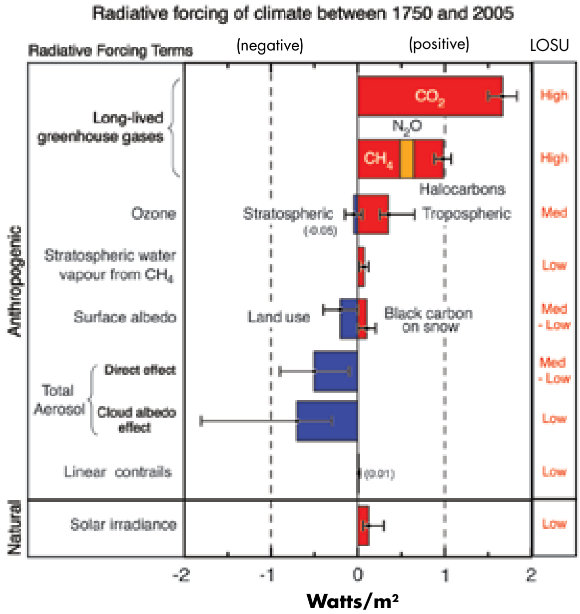


Figure 5. Various climate drivers, or radiative forcings, act to either warm or cool the Earth. Positive forcings, such as those due to greenhouse gases, warm the Earth, while negative forcings, such as aerosols, have a cooling effect. If positive and negative forcings remained in balance, there would be no warming or cooling. The column on the right indicates the level of scientific understanding (LOSU) for each forcing. Source: *Climate Change 2007: The Physical Science Basis*, Intergovernmental Panel on Climate Change 2007.

The Earth's temperature is influenced by many factors.

Many different factors play a role in controlling Earth's surface temperature. Scientists classify these factors as either *climate forcings* or *climate feedbacks* depending on how they operate. A forcing is something that is imposed externally on the climate system by either human activities or natural processes (e.g., burning fossil fuels or volcanic eruptions). Positive climate forcings, such as excess greenhouse gases, warm the Earth, while negative forcings, such as most aerosols produced by industrial processes and volcanic eruptions, cool the Earth (see Figure 5). In general, the cooling caused by aerosols is not as well understood as the warming caused by greenhouse gases.

Climate feedbacks, on the other hand, either amplify or dampen the response to a given forcing. A feedback is an energy change that is produced within the climate system itself in response to a climate forcing. During a feedback loop, a change in one factor, such as temperature, leads to a change in another factor, such as water vapor, which either reinforces or offsets the change in the first factor (see Figure 6a and 6b).

Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties (2005) takes a close look at a range of different climate forcings. The report concludes that it is important to quantify how forcings cause changes in climate variables other than temperature. For example, regional changes in precipitation could have significant impacts on water availability for agricultural, residential, industrial, and recreational use.

WHAT WARMS AND COOLS THE EARTH?

"Forcings" are things imposed externally on the climate system that can warm or cool the Earth. If positive and negative forcings remained in balance, there would be no warming or cooling.

Greenhouse gases warm the planet:

Carbon dioxide (CO_2) has both natural and human sources, but CO_2 levels are increasing primarily because of the use of fossil fuels, with deforestation and other land use changes also making a contribution. Increases in carbon dioxide are the single largest climate forcing contributing to global warming (see Figure 5).

Methane (CH_4) has both human and natural sources, and levels have risen significantly since pre-industrial times due to human activities such as raising livestock, growing rice, filling landfills, and using natural gas (which releases methane when it is extracted and transported).

Nitrous oxide (N_2O) concentrations have risen primarily because of agricultural activities and land use changes.

Ozone (O_3) forms naturally in the upper atmosphere, where it creates a protective shield that intercepts damaging ultraviolet radiation from the Sun. However, ozone produced near the Earth's surface via reactions involving carbon monoxide, hydrocarbons, nitrogen oxide, and other pollutants is harmful to both animals and plants and has a warming effect. The concentration of O_3 in the lower atmosphere is increasing as a result of human activities.

Halocarbons, including chlorofluorocarbons (CFCs), are chemicals that have been used for a variety of applications, such as refrigerants and fire retardants. In addition to being potent greenhouse gases, CFCs also damage the ozone layer. The production of most CFCs is now banned, so their concentrations are starting to decline.

Other human activities can also force temperature changes:

Most aerosols (airborne particles and droplets), such as sulfate (SO_4), cool the planet by reflecting sunlight back to space. Some aerosols also cool the Earth indirectly by increasing the amount of sunlight reflected by clouds. Human activities, such as industrial processes, produce many different kinds of aerosols. The total cooling that these aerosols produce is one of the greatest remaining uncertainties in understanding present and future climate change.

Black carbon particles or "soot," produced when fossil fuels or vegetation are burned, generally have a warming effect because they absorb incoming solar radiation. Black carbon particles settling on snow or ice are a particularly potent warmer.

Deforestation and other changes in land use modify the amount of sunlight reflected back to space from the Earth's surface. Changes in land use can lead to positive and negative climate forcing locally, but the net global effect is a slight cooling.

Natural processes also affect the Earth's temperature:

The Sun is Earth's main energy source.The Sun's output is nearly constant, but small changes over an extended period of time can lead to climate changes. In addition, slow changes in the Earth's orbit affect how the Sun's energy is distributed across the planet, giving rise to ice ages and other long-term climate fluctuations over many thousands of years. The Sun's output has not increased over the past 30 years, so it cannot be responsible for recent warming.

Volcanic eruptions emit many gases. One of the most important of these is sulfur dioxide (SO_2), which, once in the atmosphere, forms sulfate aerosol (SO_4). Large volcanic eruptions can cool the Earth slightly for several years, until the sulfate particles settle out of the atmosphere.

FEEDBACKS CAN AMPLIFY WARMING AND COOLING

A feedback is an energy change within the climate system in response to a climate forcing. For example:

Water vapor (H_2O) is the most potent and abundant greenhouse gas in Earth's atmosphere. However, its concentration is controlled primarily by the rate of evaporation from the oceans and transpiration from plants, rather than by human activities, and water vapor molecules only remain in the atmosphere for a few days on average. Thus, changes in water vapor are considered a feedback that amplifies the warming induced by other climate forcings (see Figure 6a).

Sea ice reflects sunlight back to space. Changes in sea ice are a positive climate feedback because warming causes a reduction in sea ice extent, which allows more sunlight to be absorbed by the dark ocean, causing further warming.

Clouds reflect sunlight back to space, but also act like a greenhouse gas by absorbing heat leaving the Earth's surface. Low clouds tend to cool (reflect more energy than they trap) while high clouds tend to warm (trap more energy than they reflect). The net effect of cloudiness changes on surface temperature depends on how and where the cloud cover changes, and this is one of the largest uncertainties in projections of future climate change (see Figure 6b).

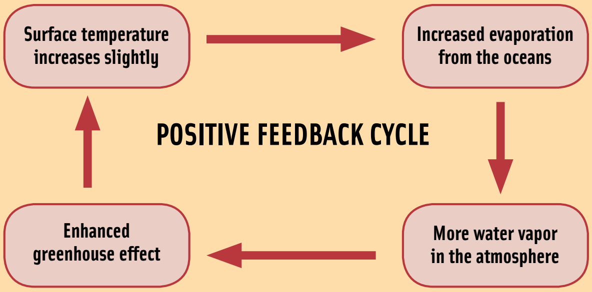


Figure 6a: This schematic illustrates just one of the dozens of climate feedbacks identified by scientists. The warming created by greenhouse gases leads to additional evaporation of water from the oceans into the atmosphere. But water vapor itself is a greenhouse gas and can cause even more warming. Scientists call this the "positive water-vapor feedback."

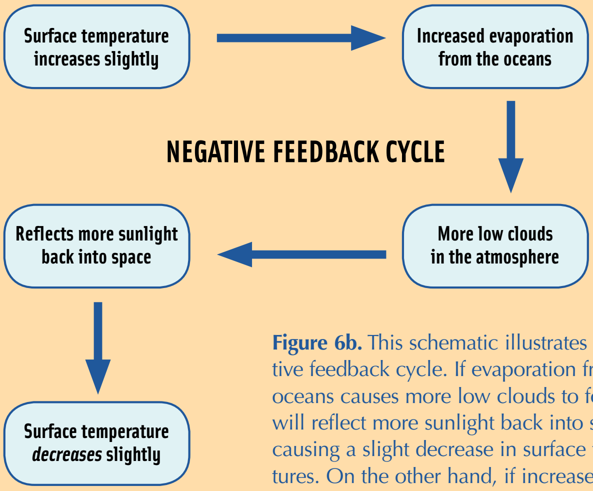


Figure 6b. This schematic illustrates a negative feedback cycle. If evaporation from the oceans causes more low clouds to form, they will reflect more sunlight back into space, causing a slight decrease in surface temperatures. On the other hand, if increased ocean evaporation leads to the formation of more high clouds, the result would be a positive feedback cycle similar to the water-vapor feedback shown in Figure 6a.

Another report, *Understanding Climate Change Feedbacks* (2003) examines what is known and not known about climate change feedbacks and identifies important research avenues for improving our understanding. A substantial part of the uncertainty in projections of future climate change can be attributed to an incomplete understanding of climate feedback processes. Enhanced research in the areas of climate monitoring and climate modeling are needed to improve understanding of how the Earth's climate will respond to future climate forcings.

The magnitude of future climate change is difficult to project.

The Intergovernmental Panel on Climate Change (IPCC), which involves hundreds of scientists from the United States and other nations in assessing the state of climate change, concluded in a 2007 report that average global surface temperatures will likely rise by an additional 2.0–11.5°F (1.1–6.4°C) by 2100. This temperature increase will be accompanied by a host of other environmental changes, such as an increase in global sea level of between 0.59 and 1.94 feet (0.18 and 0.59 meters).

Estimates of future climate change are typically called projections and are expressed as a range of possible outcomes. One reason for this uncertainty is because it is difficult to predict how human populations will grow, use energy, and manage resources, all of which will have a strong influence on future greenhouse gas emissions. There are also uncertainties about how the climate system will respond to rising greenhouse gas concentrations. For example, the IPCC's estimate

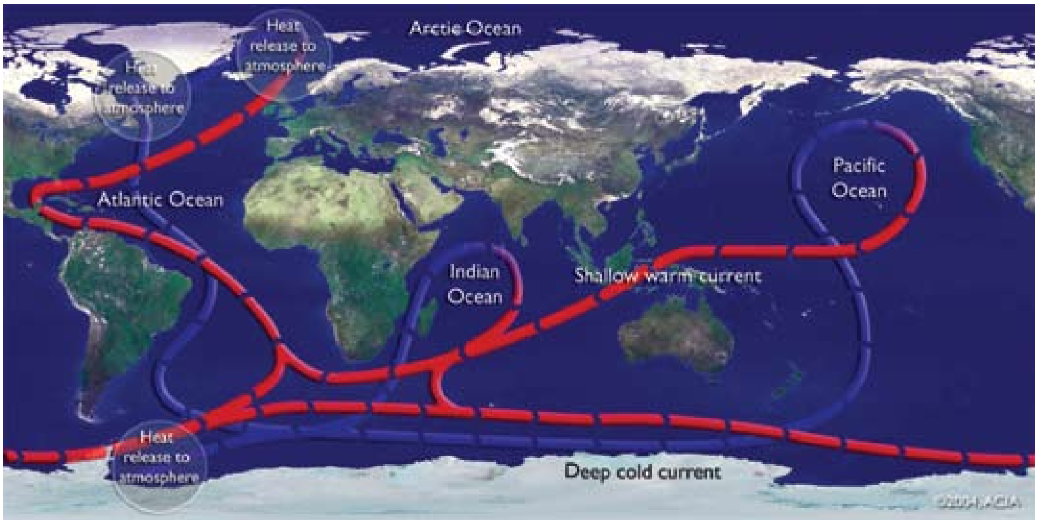


Figure 7. A key mechanism in the circulation of water through the world's oceans is the sinking of cold salty seawater. For example, in the Atlantic, oceanic currents transport warm, saline water to the North Atlantic where the water becomes denser as it is cooled by cold Arctic air. The chilled seawater sinks to the bottom, forming a southward-moving water mass. It has been hypothesized that large inputs of less dense fresh water from melting ice caps could disrupt ocean circulation by preventing the formation of chilled salty water. Such a disruption could trigger a host of climate changes such as cooling across much of northern Europe. Source: *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*, p. 32

of future sea level rise does not take into account the possibility that ice sheets or glaciers could start melting more rapidly as the temperature rises.

It is very likely that increasing global temperatures will lead to higher maximum temperatures, more heat waves, and fewer cold days over most land areas. Some scientists believe that hurricanes may also become more intense as ocean temperatures rise, but others have argued that this intensification could be moderated or offset by other changes, such as changes in tropical winds or El Niño events.

One of the most important areas of uncertainty being investigated is regional climate change. Although scientists are beginning to project how the climate will change in specific regions and what some of the impacts of these changes might be, their level of confidence in these projections is not as high as for global climate change projections. In general, global temperature is easier to project than regional changes such as rainfall, storm patterns, and ecosystem impacts.

Complicating things further is the fact that the climate has changed abruptly in the past—within a decade—and could do so again. Abrupt changes, such as the Dust Bowl drought of the 1930s which displaced hundreds of thousands of people in the American Great Plains, take place so rapidly that humans and ecosystems have difficulty adapting to them. *Abrupt Climate Change: Inevitable Surprises* (2002) outlines some of the evidence for and theories about abrupt change. One theory is that melting ice caps could "freshen" the water in the North Atlantic, slowing down the natural ocean circulation that brings warmer Gulf Stream waters to the north and cooler waters south again (see Figure 7). Such a slowdown would make it much cooler in northern Europe.

CARBON DIOXIDE: FORCING OR FEEDBACK?

The role of carbon dioxide in warming the Earth's surface via the natural greenhouse effect was first proposed by Swedish scientist Svante Arrhenius more than 100 years ago. Arrhenius suggested that changes in carbon dioxide might explain the large temperature variations over the past several hundred thousand years known as the ice ages (see Figure 8a). Carbon dioxide appears to have acted like a feedback during these cycles, reinforcing temperature changes initiated by natural variations in Earth's orbit. In contrast, carbon dioxide levels were nearly constant during the past several thousand years until human activities began emitting large amounts of carbon dioxide into the atmosphere, amplifying the natural greenhouse effect (see Figure 8b). Thus, while carbon dioxide may have acted as a feedback in the past, it is acting as a forcing in the current climate.

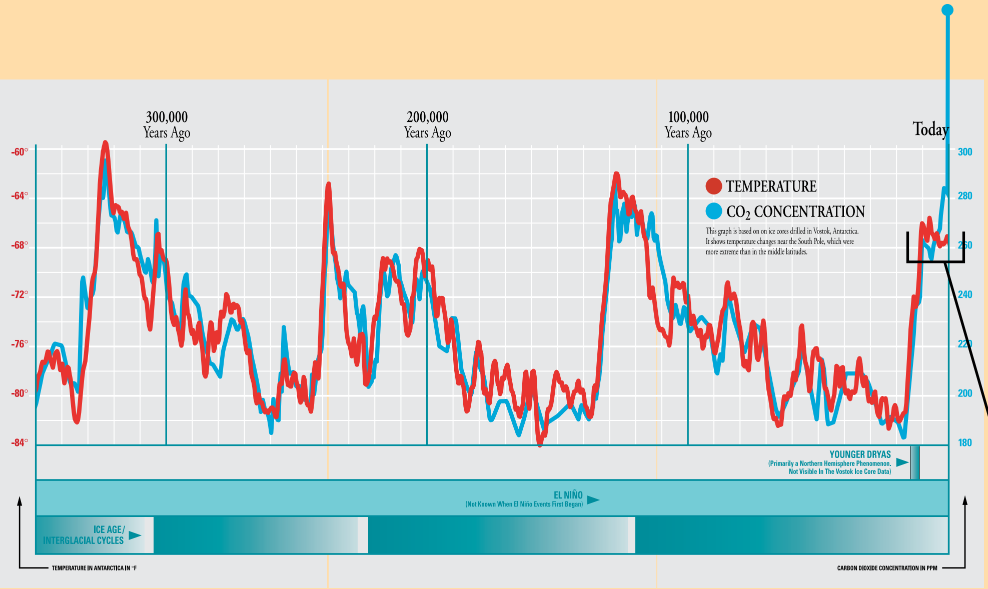
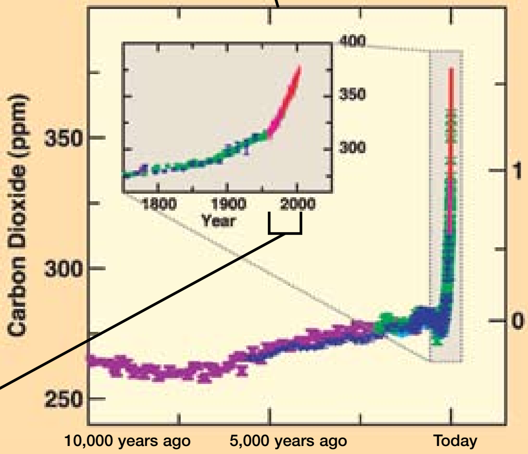


Figure 8a. (left) As ice core records from Vostok, Antarctica show, the temperature near the South Pole has varied by more than 20° F during the past 350,000 years in a regular pattern that constitutes the ice age/interglacial cycles. Changes in carbon dioxide concentrations (in blue) track closely with changes in temperature (in red) during these cycles, but carbon dioxide levels are now higher than at any time during the past 650,000 years. Image courtesy of the Marian Koshland Science Museum of the National Academy of Sciences.

Figure 8b. (right) Atmospheric concentrations of carbon dioxide during the past 10,000 years (large panel) and since 1750 (inset panel) show a rapid increase in carbon dioxide. Measurements are shown from ice cores (symbols with different colors for different studies) and atmospheric samples (the red line, which is data from the Keeling curve shown below). Source: *Climate Change 2007: The Physical Science Basis,* Intergovernmental Panel on Climate Change.



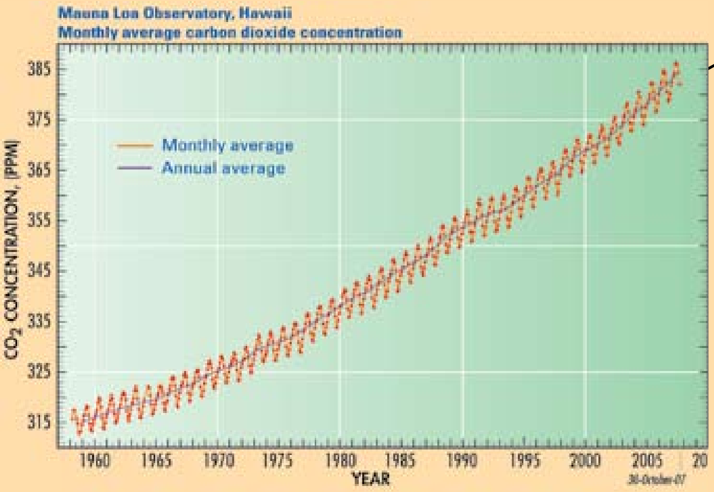
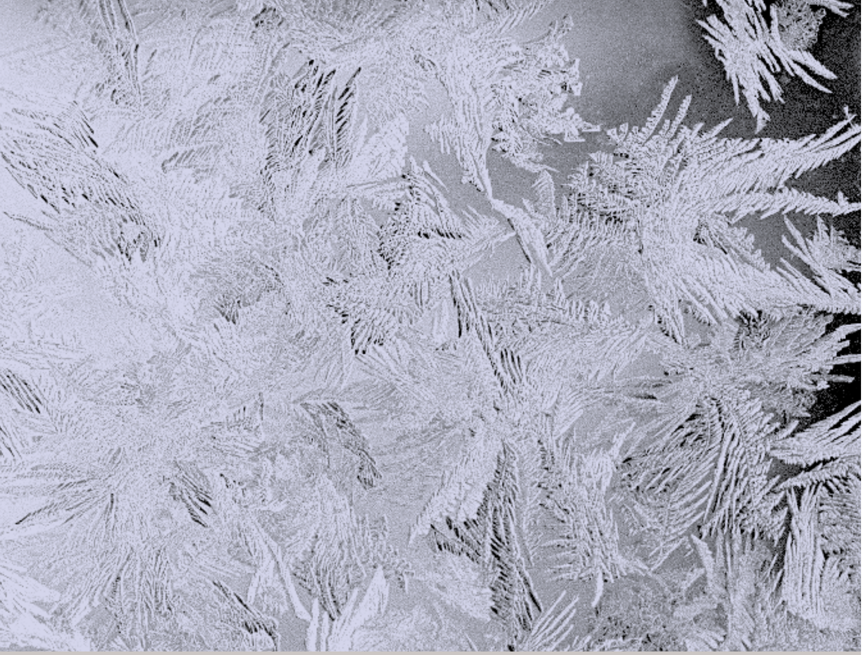


Figure 9. Charles Keeling's curve provides a precise record of atmospheric carbon dioxide (CO_2) concentrations, which he began measuring in 1958. The steady upward trend shows increases in annual average CO_2 concentrations. The sawtooth pattern seen in the Keeling curve is like the breathing of the planet. In the wintertime, carbon dioxide is released into the atmosphere by the decaying of vegetation from the previous growing season and by soil respiration. Then in the spring and summer of the following year, carbon dioxide is taken up by plants as they grow. Data source: Carbon Dioxide Information Analysis Center.



HOW THE SCIENCE IS DONE

Our understanding of climate and how it has varied over time is advancing rapidly as new data are acquired and new investigative instruments and methods are employed.

—Ralph Cicerone, *foreword of Surface Temperature Reconstructions for the Last 2000 Years*, National Research Council, 2006

Observations and data are the foundation of climate science.

In the 1950s, long before the idea of human-induced climate change was prevalent, oceanographer Roger Revelle suggested that the sea could not absorb all the carbon dioxide being released from fossil fuel usage. Revelle made the first continual measurements of atmospheric carbon dioxide with the goal of better understanding the carbon cycle—how carbon is exchanged between plants, animals, the ocean, and the atmosphere. In 1958, Revelle's colleague Charles Keeling began collecting canisters of air once or twice each week at the Mauna Loa Observatory, 11,000 feet above sea level in Hawaii, far away from major industrial and population centers. This remarkable 50-year dataset, known as the Keeling curve (see Figure 9, left), is a cornerstone of climate change science. Similar observations are now routinely made at stations across the globe.

Most of the observing systems used to monitor climate today were established to provide data for other purposes, such as predicting daily weather; advising farmers; warning of hurricanes, tornadoes, and floods; managing water resources; aiding ocean and air transportation; and understanding the ocean. Data used for climate research, however, have unique requirements. Higher accuracy and precision are often needed to detect gradual climate trends, observing programs must be sustained over long periods of time, and observations are needed at both global scales and at local scales to serve a range of climate information users.

A key requirement for climate change science is the ability to generate, analyze, and archive long-term climate data records in order to make ongoing assessments of

Figure 10. **(top left)** The Landsat satellite series has provided continuous record of the Earth's continental surfaces since 1972, providing critical information for global change research. Image courtesy of the NASA Goddard Space Flight Center. **(bottom left)** Weather stations, both on land and floating on buoys moored at sea, provide regular measurements of temperature, humidity, winds, and other atmospheric properties. Image courtesy of TAO Project Office, NOAA Pacific Marine Environmental Laboratory. **(right)** Weather balloons, which carry instruments known as radiosondes, provide vertical profiles of some of these same properties throughout the lower atmosphere. Image © University Corporation for Atmospheric Research.

the state of the environment. *Climate Data Records from Environmental Satellites* (2004) defines a climate data record as a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. The report identifies several elements of successful climate data record generation programs that range from effective, expert leadership to a long-term commitment to sustaining observations and archives.

Climate science relies on a wide range of data sources.

Climate scientists rely on data collected using a wide array of observing systems, operated by various government agencies, universities, and other domestic and international groups (see Figure 10). For example, surface temperature measurements are taken by both humans and automated instruments at fixed stations on land and on buoys in the ocean, and also on ocean-going ships. Measurements of temperatures at different heights in the atmosphere are obtained primarily from weather balloons and satellites. All measurements go through rigorous quality control procedures and must be carefully calibrated to account for changes in measuring technology. Having multiple independent data sources is impor-

WHAT'S THE DIFFERENCE BETWEEN WEATHER AND CLIMATE?

Weather refers to hour-to-hour and day-to-day changes in temperature, cloudiness, precipitation, and other meteorological conditions. *Climate* is commonly thought of as the average weather conditions at a given location over time, but it also includes more complicated statistics such as the average daytime maximum temperature each month and the frequency of storms or droughts. *Climate change* refers to changes in these statistics over years, decades, and even centuries. The term *global change* is sometimes used to include these and other environmental changes, such as deforestation, ozone depletion, and the acidification of the world's oceans because of rising carbon dioxide levels.

The accuracy of weather forecasts can be confirmed by observing the actual weather. Climate models, on the other hand, produce projections many years into the future, making them difficult to verify. Further, climate models must take into account a much larger number of variables, such as changes in ocean circulation, vegetation, and greenhouse gas concentrations. Climate models have been shown to accurately simulate a number of past climate changes, including the cooling observed after major volcanic eruptions, global temperature change during the 20th century, and even the ice ages, so our confidence in these models is increasing.

tant for detecting and removing biases and other errors.

Space-based observations are especially important for monitoring present and future climate change because they offer a unique vantage point and can take measurements over the entire surface of the Earth. *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation* (2005) examines the current and planned system of U.S. environmental satellites, including the satellites needed to observe climate change, and concludes that the system is "at risk of collapse." A subsequent report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (2007), presents a prioritized list of space programs, missions, and supporting activities that would restore the satellite observations needed to address the most important environmental issues of the next decade and beyond, including climate change.

Scientists have also developed a variety of methods for estimating how the Earth's climate varied prior to the mid-19th century, when thermometer measurements first became widely available (see Figure 11). For example, ice cores are drilled in polar and mountain ice caps and analyzed to reconstruct past climate changes; in addition to analyzing the isotopes of hydrogen and oxygen atoms that make up the ice to infer past temperatures in the region, the bubbles trapped in the ice can be sampled to determine past concentrations of greenhouse gases. Tree rings, corals, ocean and lake sediments, cave deposits, and even animal nests have also been analyzed to estimate past variations in climate.

Various human records can also be used to reconstruct past climate conditions. Shipping records have been analyzed to estimate changes in the frequency of hurricanes in the Atlantic Ocean during the past 150 years. In Burgundy, France, monastery

Figure 11. Scientists infer past temperatures using several different methods: ice cores from polar ice caps and mountain glaciers (left) provide samples of past atmospheres frozen in the ice—the deeper you go, the further back in time. Temperature is inferred by examining characteristics of the hydrogen and oxygen atoms that make up the ice, among other data. Tree rings (right) can reveal past climate conditions based on the width of each annual ring and many other characteristics, such as density of the wood in each ring. Other types of samples used to infer past climate include marine sediments and soil samples. Ice core photo courtesy of the National Geophysical Data Center. Tree ring photo courtesy of Connie Woodhouse.

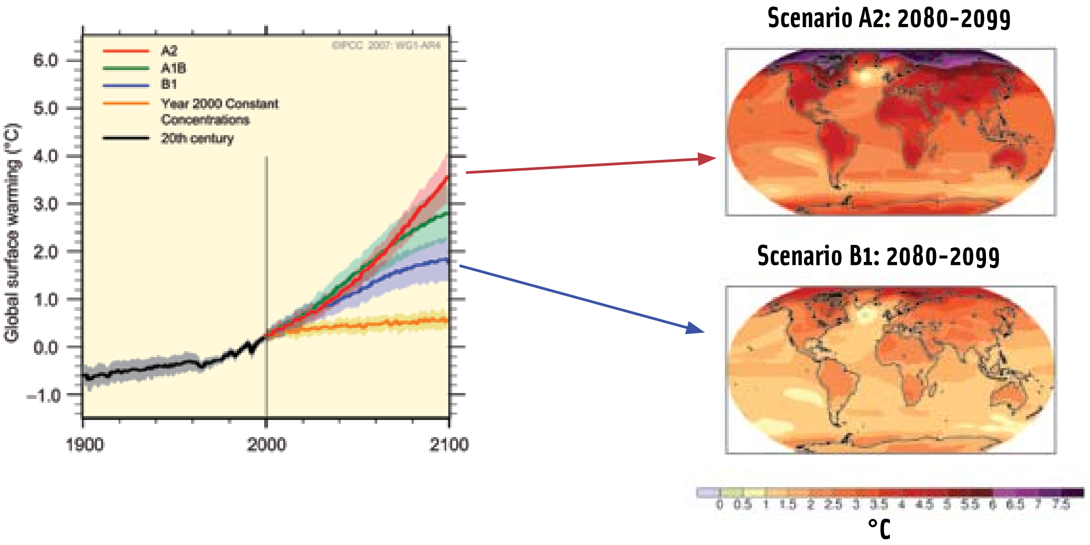


Figure 12. Climate models often are used to help inform policy decisions. The graph on the left shows the projected global mean temperature change for several different scenarios of future emissions based on assumptions of future population growth, economic development, life style choices, technological change, and availability of energy alternatives. Each line represents the average of many different models run using the same scenario. The images on the right show the projected geographical pattern of annual mean surface air temperature changes at the end of the century (relative to the average temperatures for the period 1980–1990) for the scenarios A2 and B1 (red and blue lines). The projected warming by the end of the 21st century is less extreme in the B1 scenario, which assumes significant reductions in greenhouse gas emissions, than in the A2 scenario, which assumes "business as usual." In both scenarios, land areas are expected to warm more than oceans, and the greatest warming is projected at high latitudes. Source: *Climate Change 2007: The Physical Science Basis*, Intergovernmental Panel on Climate Change 2007.

archives record the timing of the pinot noir harvest back to 1370, which provides information about climate, and similar records exist for the blossoming dates of cherry trees and other flowering plants in Japan and China. Records of Alpine glacier length, some derived from paintings and other documentary sources, have even been used to reconstruct surface temperature variations in south-central Europe for the past several centuries.

Models help illuminate the many dimensions of climate change.

Climate models are important tools for understanding how different components of the climate system operate today, how they may have functioned differently in the past, and how the climate might evolve in the future in response to forcings from both natural processes and human activities. Climate models use mathematical equations to represent the climate system, first modeling each system component separately and then linking them together to simulate the full Earth system. These models are run on advanced supercomputers.

Since the late 1960s, when climate models were pioneered, their accuracy has increased as computing power and our understanding of the climate system have improved. *Improving Effectiveness of U.S. Climate Modeling* (2001) offered several recommendations for strengthening climate modeling capabilities in the United States. The report identified a shortfall in computing facilities and highly skilled technical workers devoted to climate modeling as two important problems. Several of the report's recommendations have been adopted since it was published, but concerns remain about whether the United States is training enough people to work on climate change issues.

Social science helps us understand how human choices affect climate.

Research on the social and behavioral sciences is essential for understanding and responding to climate change. Research on the human dimensions of global change focuses on four general areas: (1) human activities that alter the Earth's environment, (2) the forces that drive these activities, (3) the consequences of environmental changes for societies and economies, and (4) how humans respond to these changes. *Global Environmental Change: Understanding the Human Dimensions* (1992) develops a conceptual framework for combining the efforts of natural and social scientists to better understand how human actions influence global change.

Although fossil fuel burning is the most significant human activity contributing to climate change, other activities also have significant influences. For example, land-use changes, such as the conversion of forests and wetlands to agricultural or urban uses, have a strong influence on both local and global climate. *Population, Land Use, and Environment* (2005) looks at the many demographic factors—including population growth, density, fertility, mortality, and the age and sex composition of households—that are known to affect land use and land cover change. The report identifies the research needed to better understand these connections.

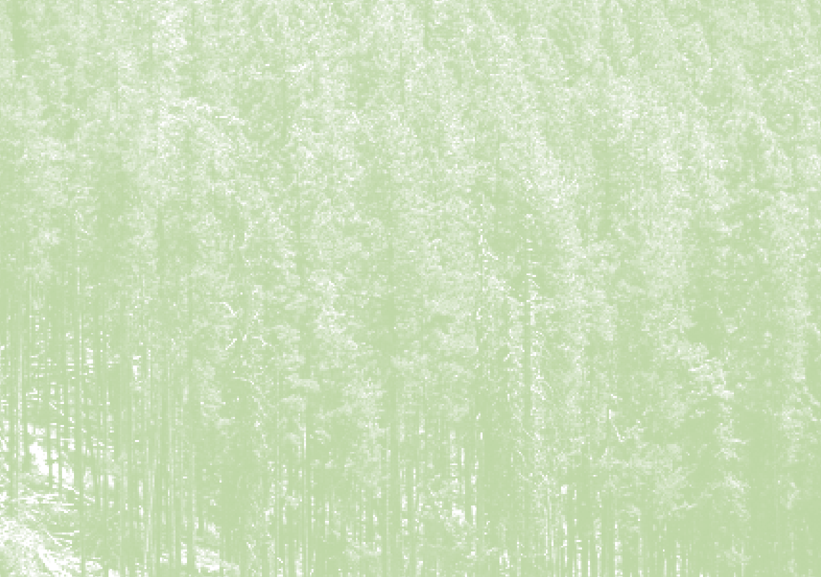
FEDERALLY COORDINATED RESEARCH ON CLIMATE CHANGE

More than a dozen federal agencies are involved in producing and using climate change data and research. The first efforts at a coordinated government research strategy culminated in the creation of the U.S. Global Change Research Program (USGCRP) in 1989. USGCRP made substantial investments in understanding the underlying processes of climate change, documenting past and ongoing global change, improving modeling, and enhancing knowledge of El Niño and the ability to forecast it.

The U.S. Climate Change Science Program (CCSP) was formed in February 2002 as a new management structure to coordinate government activities on climate. The CCSP has asked the National Academies to provide independent advice on numerous aspects of the program, including a two-stage review of its strategic plan, metrics for evaluating the progress of the program, scientific reviews of assessment reports, and ongoing strategic advice on the program as a whole.

Evaluating Progress of the U.S. Climate Change Science Program (2007) concluded that the program has made good progress in documenting and understanding temperature trends and related environmental changes, and the influence of human activities on these observed changes. The ability to predict future climate changes has improved, but efforts to understand the impacts of climate changes on society and analyze mitigation and adaptation strategies are still relatively immature. The program also had not yet met expectations in supporting decision making, studying regional impacts, and communicating with a wider group of stakeholders.

Much of the uncertainty about how the climate will change during the next 100 years is due to an inability to predict how population growth, economic development, energy and land use, and other human activities will evolve. To illustrate how various human choices affect future climate change, climate models are typically run using a number of different "scenarios," each of which is designed to represent a plausible and internally consistent prediction of future human activities (see Figure 12). Improving these scenarios depends on progress in understanding changes in human behavior and how these changes affect climate forcing.



IMPACTS OF CLIMATE CHANGE

Many of the world's poorest people, who lack the resources to respond to the impacts of climate change,are likely to suffer the most.

—Joint science academies' statement on sustainability, energy efficiency, and climate protection (May 2007)

Climate change will have many kinds of impacts.

Climate change will affect ecosystems and human systems—such as agricultural, transportation, and health infrastructure—in ways we are only beginning to understand (see Figure 13). There will be positive and negative impacts of climate change, even within a single region. For example, warmer temperatures may bring longer growing seasons in some regions, benefiting those farmers who can adapt to the new conditions but potentially harming native plant and animal species. In general, the larger and faster the changes in climate are, the more difficult it will be for human and natural systems to adapt.

Unfortunately, the regions that will be most severely affected are often the regions that are the least able to adapt. Bangladesh, one of the poorest nations in the world, is projected to lose 17.5 percent of its land if sea level rises about 1 meter (39 inches), displacing millions of people. Several

The Chinstrap penguin: a regional winner. Even within a single regional ecosystem, there will be winners and losers. For example, the population of Adélie penguins has decreased 22 percent during the past 25 years, while the Chinstrap penguin population increased by 400 percent. The two species depend on different habitats for survival: Adélies inhabit the winter ice pack, whereas Chinstraps remain in close association with open water. A 7-9° F rise in midwinter temperatures on the western Antarctic Peninsula during the past 50 years and associated receding sea-ice pack is reflected in their changing populations.

Global changes most keenly felt in polar regions
Recent years have brought a flurry of dramatic changes in the polar environment—changes that are happening faster than at other latitudes and faster than scientists had expected. Glaciers and sea ice are melting more and more quickly. Thawing permafrost can cause houses to sink, create forests of "drunken trees" that tilt at odd angles, and weaken roads, runways, and pipelines. Photo courtesy Larry Hinzman.

islands in the South Pacific and Indian oceans may disappear. Many other coastal regions will be at increased risk of flooding, especially during storm surges, threatening animals, plants, and human infrastructure such as roads, bridges, and water supplies.

Developed nations, including the United States, also will be affected. For example, most models indicate that snowpack is likely to decline on many mountain ranges in the West, which would bring adverse impacts on fish populations, hydropower, water recreation, and water availability for agricultural, industrial, and residential use. However, wealthy nations have a better chance of using science and technology to anticipate and adapt to sea level rise, threats to agriculture, and other climate impacts. Adaptations measures could include revising construction codes in coastal zones or the development of new agricultural technologies. Developing nations will need assistance in building their capacity to meet the challenges of adapting to climate change.

Polar regions are already experiencing major changes in climate.

Like the proverbial canary in the coal mine, changes in the polar regions can be an early warning of things to come for the rest of the planet, and the environmental changes now being witnessed at higher latitudes are alarming. For example, Arctic sea ice cover is decreasing rapidly and glaciers are retreating and thinning (see Figure 14, next page), NASA data show that Arctic sea ice shrunk to a new record low in 2007; 24 percent lower than the previous record (2005), and 40 percent lower than the long-term average.

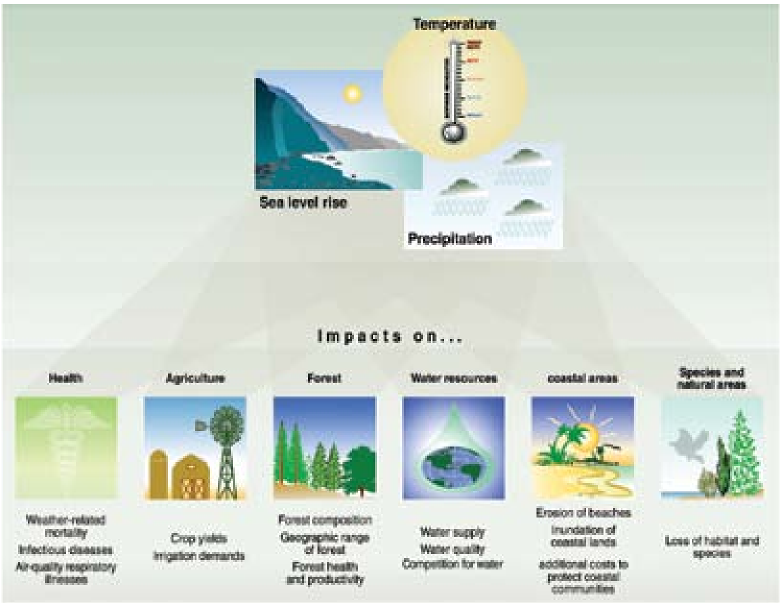
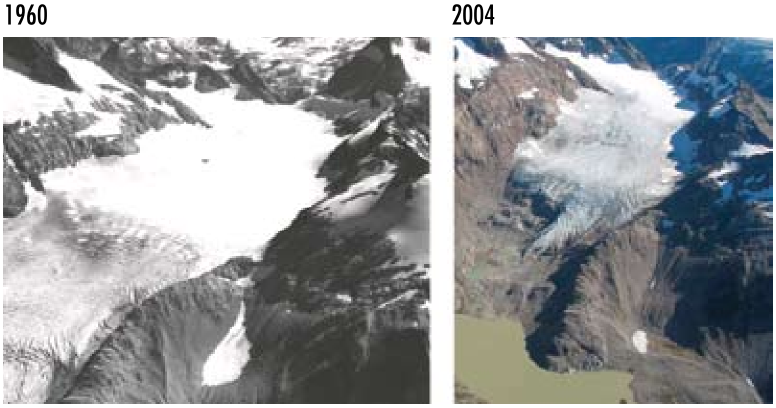


Figure 13. Climate changes could have potentially wide-ranging effects on both the natural environment and human activities and economies. Source: U.S. Environmental Protection Agency.


1960

2004

Figure 14. Warmer temperatures are causing glaciers to recede, as illustrated by theses photos of South Cascade Glacier in the state of Washington. Photo courtesy of Andrew Fountain.

A number of ecosystem changes, such as plants flowering earlier in the year and declines in animal species that depend on sea ice for habitat, have been attributed to the strong warming observed at northern latitudes. Changing climate is also having human impacts: some Alaskan villages have been moved to higher ground in response to increasing storm damage, and the thawing of permafrost is undermining infrastructure, affecting houses, roads, and pipelines in northern communities around the world.

Given the global significance of changes in the polar regions, it is vital to have observational records that are sufficiently complete to both understand what is happening and guide decision makers in responding to change. *A Vision for the International Polar Year 2007-2008* (2004) recommends that the IPY 2007-2008—an unprecedented multinational effort to better understand the polar regions—be used as an opportunity to design and implement multidisciplinary polar observing networks. The Arctic has an especially limited record of observations that are often few and far between, short-term, and not coordinated with related observations. *Toward an Integrated Arctic Observing Network* (2006) recommends building a network that delivers complete pan-arctic observations.

CLIMATE AND HUMAN HEALTH

There are many ways in which climate change might affect human health, including heat stress, increased air pollution, and food scarcities due to drought or other agricultural stresses. Because many disease pathogens and carriers are strongly influenced by temperature, humidity, and other climate variables, climate change may also influence the spread of infectious diseases or the intensity of disease outbreaks. For example, some studies have predicted that global climate change could lead to an increase in malaria transmission by expanding mosquito habitat.

Current strategies for controlling infectious disease epidemics rely primarily on surveillance and response. *Under the Weather: Climate, Ecosystems, and Infectious Disease* (2001) recommends a shift toward prediction and prevention, such as developing early warning systems. Overall vulnerability to infectious disease could be reduced through water treatment systems, vaccination programs, and enhanced efforts to control disease carriers. The report also recommends increasing interdisciplinary collaboration among climate modelers, meteorologists, ecologists, social scientists, and medical and health professionals to better understand the linkages between climate change and disease.

HOW SCIENCE INFORMS DECISION-MAKING

Policymakers look to climate change science to answer two big questions: what could we do to prepare for the impacts of climate change, and what steps might be taken to slow it?

—Richard Alley, Professor,
Pennsylvania State University

Steps can be taken to prepare for climate change.

Climate information is becoming increasingly important to public and private decision-making in various sectors, such as emergency management, water management, insurance, irrigation, power production, and construction. The emerging ability to forecast climate at seasonal-to-interannual time scales can be of tremendous value if the information is used well. *Making Climate Forecasts Matter* (1999) identifies research directions toward more useful seasonal-to-interannual climate forecasts and how to use forecasting to better manage the human consequences of climate change.

There is a wealth of climate data and information already collected that could be made useful to decision-makers in the form of "climate services." Such efforts are analogous to the efforts of the National Weather Service to provide useful weather information. *A Climate Services Vision: First Steps Towards the Future* (2001) outlines principles for improving climate services: for example, climate data should be made as user-friendly as weather information is today, and the government agencies, businesses, and universities involved in climate change data collection and research should establish active and well-defined connections to users and potential users.

Weather forecasts have benefited from a long and interactive history between providers and users, but this kind of communication is only beginning to develop in climate science. For example, western states have traditionally relied on January snowpack surveys to project annual streamflows. During the past several years, climate scientists have worked with water management agencies to develop streamflow projections based on increasingly reliable El Niño predictions, which are available several months ahead of the January surveys and thus allow greater management flexibility. *Research and Networks for Decision Support in the NOAA Sectoral Applications Research Program* (2007) identifies additional ways to build communications between producers and users of climate information.

Another way to prepare for climate change is to develop practical strategies for reducing the overall vulnerability of economic and ecological systems to weather and climate variations. Some of these are “no-regrets” strategies that will provide benefits regardless of whether a significant climate change ultimately occurs in a region. No-regrets measures could include improving climate forecasting based on decision-maker needs; slowing biodiversity loss; improving water, land, and air quality; and making our health care enterprise, financial markets, and energy and transportation systems more resilient to major disruptions.

Steps can be taken to mitigate climate change.

Despite remaining unanswered questions, the scientific understanding of climate change is now sufficiently clear to justify taking steps to reduce the amount of greenhouse gases in the atmosphere. Because carbon dioxide and other greenhouse gases can remain in the atmosphere for many decades, centuries, or longer, the climate change impacts from greenhouse gases emitted today will likely continue well beyond the 21st century. Failure to implement significant greenhouse gas emission reductions now will make it much more difficult to stabilize atmospheric concentrations at levels that avoid the most severe impacts.

CLIMATE DATA INFORM WATER MANAGEMENT DECISIONS IN COLORADO

Studies of past climate and streamflow conditions of the Colorado River Basin have shed new light on long-term water availability in the region. Water management decisions have been based on the past 100 years of recorded streamflows. However, studies reveal many periods in the past when streamflow was much lower than at any time in the past 100 years of recorded flows. *Colorado River Basin Water Management* (2007) concludes that managers are therefore basing decisions on an overly optimistic forecast of future water availability, particularly given regional warming trends. The report recommends that Colorado prepare for possible water shortages that can not be overcome through current technology and management practices. Photo of Lake Powell, courtesy of Brad Udall, University of Colorado.

Governments have proven they can work together to reduce or reverse negative human impacts on nature. A classic example is the successful international effort to phase out use of chlorofluorocarbons (CFCs) in aerosol sprays and refrigerants, which were destroying the Earth’s protective ozone layer. Although the success of controls on CFCs cannot be denied, the problem of controlling greenhouse gas emissions is much more difficult: alternative technologies are not readily available to offset many human activities that contribute to climate change, and, instead of the handful of companies responsible for producing CFCs, there are literally billions of individuals, as well as many businesses and governments, making decisions that affect carbon dioxide and other greenhouse gas emissions.

At the present time there is no single solution that can eliminate future warming. However, as early as 1992, *Policy Implications of Greenhouse Warming* (1992) concluded that there are many potentially cost-effective technological options that could help stabilize greenhouse gas concentrations. Personal, national, and international choices have an impact; for example driving less, regulating emissions, and sharing energy technologies would all help reduce emissions. The climate change problem is one of the most difficult problems of managing the "commons"—environmental goods that benefit everyone but that can be degraded by the individual actions of anyone. Social scientists are working to identify social institutions that are suitable for managing commons problems, such as greenhouse gas emissions.

The increasing need for energy is the single greatest challenge to slowing climate change.

Energy is essential for all sectors of the economy, including industry, commerce, transportation, and residential use. Worldwide energy use continues to grow with economic and population expansion. Fossil fuels supply most of today's energy needs. According to the Department of Energy, about 82 percent of all greenhouse gases produced in the United States by human activity comes from burning fossil fuels. Developing countries, China and India in particular, are rapidly increasing their use of energy, primarily from fossil fuels, and consequently their carbon dioxide emissions are rising sharply (see Figure 15, next page).

Carbon dioxide emissions can be reduced either by switching to alternative fuels that produce less or no carbon dioxide or by using energy more efficiently. Energy efficiency could be improved in all sectors of the U.S. economy. Many of these improvements are cost-effective, but constraints such as a lack of consumer awareness and higher initial costs hold them back. *Energy Research at DOE: Was It Worth It?* (2001) addresses the benefits of increasing the energy efficiency of lighting, refrigerators, and other appliances.

Oil is the main fuel in the transportation sector. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards* (2002) evaluates car and light truck fuel use and analyzes how fuel economy could be

INFORMING POLICY THROUGH ASSESSMENTS

Climate change assessments are collective, deliberative processes by which experts review, analyze, and synthesize scientific knowledge to provide information for decision-making or about remaining scientific uncertainties. One of the most influential set of assessments on climate change is produced by the Intergovernmental Panel on Climate Change (IPCC), which was established by the World Meteorological Organization and the United Nations Environment Programme to assess scientific, technical, and socioeconomic information relevant for the understanding of climate change. IPPC's fourth assessment report was issued in 2007. *Analysis of Global Change Assessments: Lessons Learned* (2007) identifies the key elements of effective assessments, such as the development of tools that make use of scientific analyses at the regional and local level where decisions are made.

Personal, national, and international choices have an impact. For example, driving less, regulating emissions, and sharing energy technologies would all help reduce emissions.

improved. Steps range from improved engine lubrication to hybrid vehicles.

There are many alternatives to producing energy from fossil fuels. Electricity can be produced without significant carbon emissions using nuclear power and renewable energy technologies, such as solar, wind, hydropower, and biomass (fuels made from plant matter). Biofuels can also be used to power vehicles. Interest in these technologies is growing, and research and development could make all of them more viable, but each renewable energy technology carries its own set of issues and challenges. For example, *Water Implications of Biofuels Production in the United States* (2008) concludes that although ethanol and other biofuels can help reduce our nation's dependence on fossil fuels, the increase in agriculture to grow biofuel crops, such as corn, could have serious impacts on water quality due to more intense use of fertilizers and increased soil erosion.

Another way to reduce emissions is to collect carbon dioxide from fossil-fuel-fired power plants and sequester it in the ground or the ocean. *Novel Approaches to Carbon Management: Separation, Capture, Sequestration, and Conversion to Useful Products* (2003) discusses the development of this technology. If successful, carbon sequestration could weaken the link between fossil fuel use and greenhouse gas emissions, but considerable work remains before this approach can be widely adopted.

Capturing carbon dioxide emissions from the tailpipes of vehicles is essentially impossible, which is one factor that has led to considerable interest in hydrogen as a fuel. However, as with electricity, hydrogen must be manufactured from primary energy sources. If hydrogen is produced from fossil fuels (currently the least expensive method), carbon capture and sequestration would be required to reduce net carbon dioxide emissions. Substantial technological and economic barriers in all phases of the hydrogen fuel cycle must also be surmounted. *The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs* (2004) presents a strategy that could lead eventually to production of hydrogen from a variety of domestic sources—such as coal with carbon sequestration, nuclear power, wind, or photo-biological processes—and its efficient use in fuel-cell vehicles.

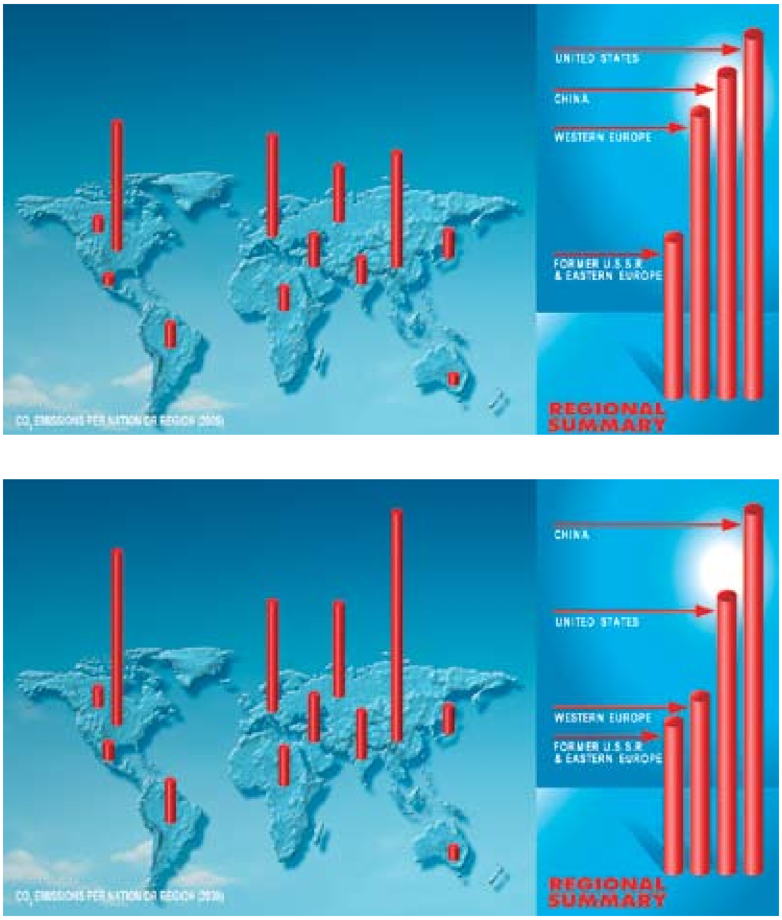


Figure 15. The two panels compare CO_2 emissions per nation in 2005 and projections for 2030. In 2005, the largest emitter of CO_2 was the United States, which is responsible for 25 percent of global emissions. By 2030, China and the developing world are expected to have significantly increased their CO_2 emissions relative to the United States. Image courtesy of the Marian Koshland Science Museum of the National Academy of Sciences, updated 2007.

Continued scientific efforts to address a changing climate

Although the understanding of climate change has advanced significantly during the past few decades, many questions remain unanswered. The task of mitigating and adapting to the impacts of climate change will require worldwide collaborative input from a wide range of experts, including physical scientists, engineers, social scientists, medical scientists, business leaders, economists, and decision-makers at all levels of government. It is important to continue to improve our understanding of climate change science, and to make sure that available climate information more fully addresses the needs of decision makers. Through its expert consensus reports, the National Academies will continue to provide analysis and direction to the policymakers and stakeholders involved in understanding and responding to climate change.

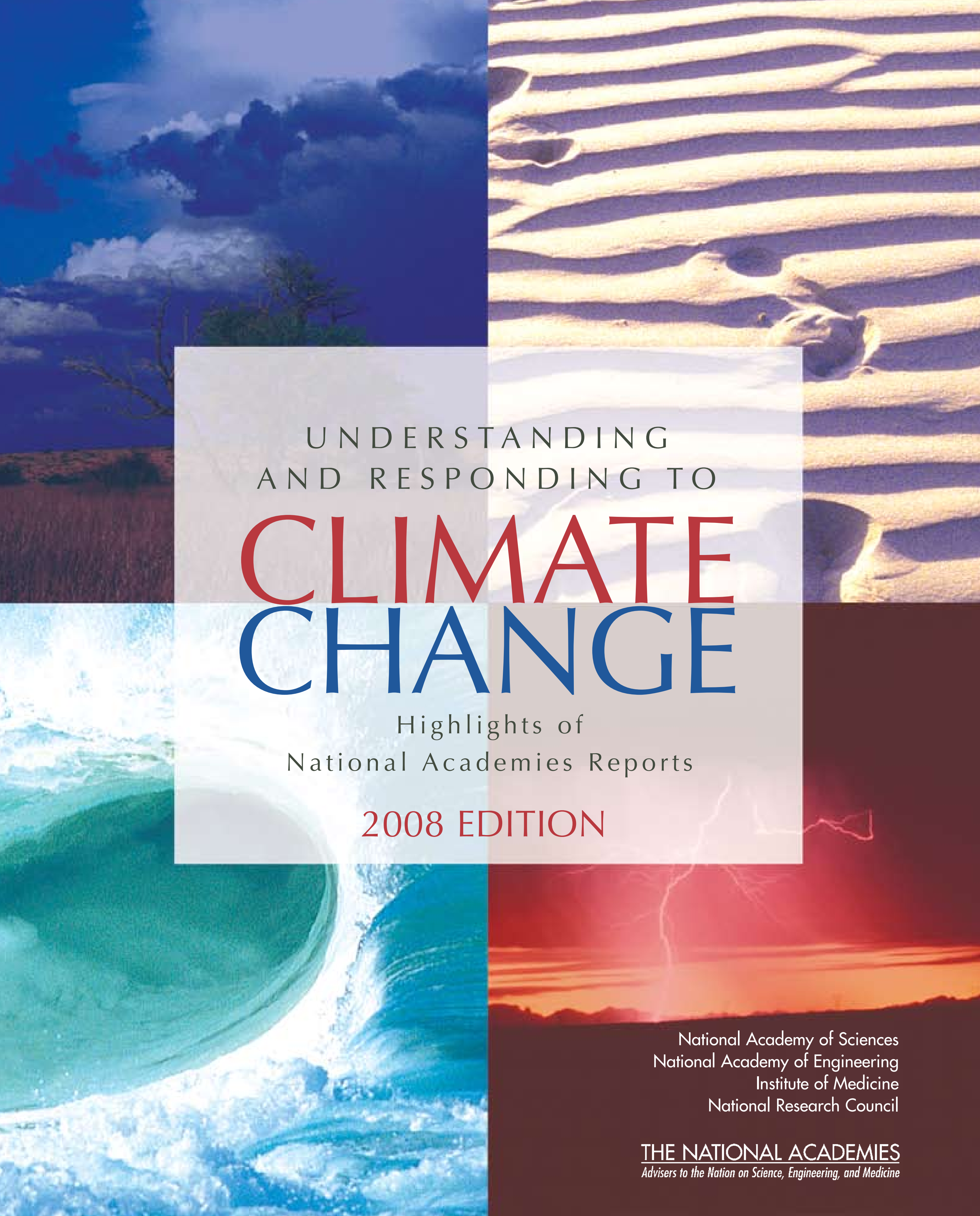
CLIMATE CHANGE AND RELATED REPORTS FROM THE NATIONAL ACADEMIES

Highlighted in this booklet

Water Implications of Biofuels Production in the United States (2008)
Analysis of Global Change Assessments: Lessons Learned (2007)
Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability (2007)
Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (2007)
Evaluating Progress of the U.S. Climate Change Science Program (2007)
Research and Networks for Decision Support in the NOAA Sectoral Applications Research Program (2007)
Surface Temperature Reconstructions for the Last 2000 Years (2006)
Toward an Integrated Arctic Observing Network (2006)
Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation (2005)
Population, Land Use, and the Environment (2005)
Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties (2005)
Thinking Strategically: The Appropriate Use of Metrics for the Climate Change Science Program (2005)
A Vision for the International Polar Year 2007-2008 (2004)
Climate Data Records from Environmental Satellites (2004)
The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs (2004)
Implementing Climate and Global Change Research: A Review of the Final U.S. Climate Change Science Program Strategic Plan (2004)
Novel Approaches to Carbon Management: Separation, Capture, Sequestration, and Conversion to Useful Products (2003)
Planning Climate and Global Change Research: A Review of the Draft U.S. Climate Change Science Program Strategic Plan (2003)
Understanding Climate Change Feedbacks (2003)
Abrupt Climate Change: Inevitable Surprises (2002)
Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (2002)
A Climate Services Vision: First Steps Towards the Future (2001)
Climate Change Science: An Analysis of Some Key Questions (2001)
Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research from 1978 to 2000 (2001)
Improving the Effectiveness of U.S. Climate Modeling (2001)
Under the Weather: Climate, Ecosystems, and Infectious Disease (2001)
Making Climate Forecasts Matter (1999)
Global Environmental Change: Understanding the Human Dimension (1992)
Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base (1992)

EXPERT
CONSENSUS
REPORTS

For more studies and related information see http://dels.nas.edu/globalchange and http://dels.nas.edu/basc.
National Academies reports are available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; 800-624-6242; http://www.nap.edu. Reports are available online in a fully searchable format.



UNDERSTANDING AND RESPONDING TO CLIMATE CHANGE

Highlights of National Academies Reports

2008 EDITION

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

About the National Academies

The National Academies are nongovernment, nonprofit organizations that were set up to provide independent scientific and technological advice to the U.S. government and nation. The National Academies include three honorary societies that elect new members to their ranks each year—the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine—and the National Research Council, the operating arm that conducts the bulk of the institution's science policy and technical work. The Academies enlist committees of the nation's top scientists, engineers, and other experts, all of whom volunteer their time to study specific issues and concerns.

The National Academies offer the following e-mail newsletters and notifications related to climate change:

Earth & Life Studies at the National Academies, http://dels.nas.edu
(immediate notification of new projects, committee postings, reports, and events)

Climate and Global Change at the National Academies e-update,
http://dels.nas.edu/globalchange (monthly)

The Board on Atmospheric Sciences and Climate Newsletter,
http://dels.nas.edu/basc (quarterly)

For more information, contact the Board on Atmospheric Sciences and Climate at 202-334-3512 or visit http://dels.nas.edu/basc. This brochure was prepared by the National Research Council based on National Academies' reports. It was written by Amanda Staudt, Nancy Huddleston, and Ian Kraucunas and was designed by Michele de la Menardiere. Support for this publication was provided by the Presidents' Circle Communications Initiative of the National Academies. Thanks to Antonio Busalacchi, Richard Alley, Sherry Rowland, Dennis Hartmann, Tom Vonder Haar, Tom Wilbanks, Taro Takahashi, Alan Crane, Art Charo, Chris Elfring, Paul Stern, and Gregory Symmes for their helpful contributions.

At a time when responding to our changing climate is one of the nation's most complex endeavors, reports from the National Academies provide thoughtful analysis and helpful direction to policymakers and stakeholders. These reports are produced by committees organized by the Board on Atmospheric Sciences and Climate, its Climate Research Committee, and numerous other entities within the National Academies. With support from sponsors, the National Academies will continue in its science advisory role to the agencies working on understanding changing climate, documenting its impacts, and developing effective response strategies.

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

The nation turns to the National Academies—National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council—for independent, objective advice on issues that affect people's lives worldwide.
www.national-academies.org