

ship, or other vehicle uses the satellite signals to calculate its own location. Hikers and other people on foot may use small, portable receivers. The United States Air Force operates the satellites, but the system has both military and civilian users.

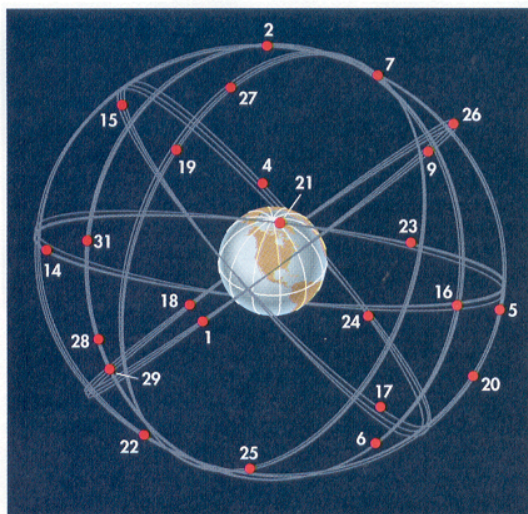
The GPS has 24 satellites, called Navstars, in six orbits with a height of about 12,500 miles (20,200 kilometers). As many as eight satellites may be above the horizon when viewed from any point on earth.

A GPS receiver uses signals from at least four, and often more, satellites. Each signal indicates the location of the satellite that sent the signal, and the broadcast time. The receiver can determine its latitude and longitude using only three satellites if its altitude is known.

GPS users can normally determine their location within 10 meters (33 feet). A technique called *carrier phase GPS* can be accurate to within 1 centimeter (0.4 inch). The U.S. armed forces began developing the GPS in the early 1970's. It became fully operational in 1995.

Alison K. Brown

See also Navigation.



WORLD BOOK illustration by Precision Graphics

**Global Positioning System** satellites, each identified by a number, shown here, broadcast radio signals. Aircraft and surface vehicles can use these signals to determine their own locations.

**Global warming** is an increase in the average temperature of Earth's surface. Since the late 1800's, the global average temperature has increased about 0.7 to 1.4 °F (0.4 to 0.8 °C). Many experts estimate that the average temperature will rise an additional 2.5 to 10.4 °F (1.4 to 5.8 °C) by 2100. That rate of increase would be much larger than most rates of past increases.

Scientists worry that human societies and natural *ecosystems* might not adapt to rapid climate changes. An ecosystem consists of the living organisms and physical environment in a particular area. Global warming could cause much harm, so countries throughout the world have drafted an agreement to limit it. However, that agreement, known as the Kyoto Protocol, has not yet been *ratified* (formally approved).

### Causes of global warming

*Climatologists* (scientists who study climate) have analyzed the global warming that has occurred since the late 1800's. A majority of climatologists have concluded that human activities are responsible for most of the warming. Human activities contribute to global warming by enhancing Earth's natural *greenhouse effect*. The greenhouse effect warms Earth's surface through a complex process involving sunlight, gases, and particles in the atmosphere. Gases that trap heat in the atmosphere are known as *greenhouse gases*.

The main human activities that contribute to global warming are the burning of *fossil fuels* (coal, oil, and natural gas) and the clearing of land. Most of the burning occurs in automobiles, in factories, and in electric power plants that provide energy for houses and office buildings. The burning of fossil fuels creates carbon dioxide, whose chemical formula is CO<sub>2</sub>. CO<sub>2</sub> is a greenhouse gas that slows the escape of heat into space. Trees and other plants remove CO<sub>2</sub> from the air during *photosynthesis*, the process they use to produce food. The clearing of land contributes to the buildup of CO<sub>2</sub> by reducing the rate at which the gas is removed from the atmosphere or by decomposition of dead vegetation.

A small number of scientists argue that the increase in greenhouse gases has not made a measurable difference in the temperature. They say that natural processes could have caused global warming. Those processes include increases in the energy *emitted* (given off) by the sun. But the vast majority of climatologists believe that increases in the sun's energy have contributed only slightly to recent warming.

### The impact of global warming

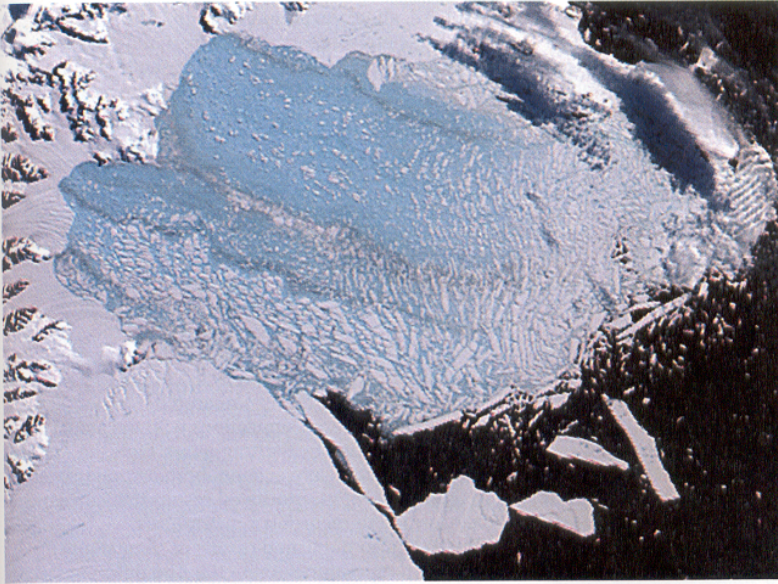
Continued global warming could have many damaging effects. It might harm plants and animals that live in the sea. It could also force animals and plants on land to move to new habitats. Weather patterns could change, causing flooding, drought, and an increase in damaging storms. Global warming could melt enough polar ice to raise the sea level. In certain parts of the world, human disease could spread, and crop yields could decline.

**Harm to ocean life.** Through global warming, the surface waters of the oceans could become warmer, increasing the stress on ocean ecosystems, such as coral reefs. High water temperatures can cause a damaging process called *coral bleaching*. When corals bleach, they expel the algae that give them their color and nourishment. The corals turn white and, unless the water temperature cools, they die. Added warmth also helps spread diseases that affect sea creatures.

**Changes of habitat.** Widespread shifts might occur in the natural habitats of animals and plants. Many species would have difficulty surviving in the regions they now inhabit. For example, many flowering plants will not bloom without a sufficient period of winter cold. And human occupation has altered the landscape in ways that would make new habitats hard to reach or unavailable altogether.

**Weather damage.** Extreme weather conditions might become more frequent and therefore more damaging. Changes in rainfall patterns could increase both





NASA/Earth Observatory

**Thousands of icebergs** float off the coast of the Antarctic Peninsula after 1,250 square miles (3,240 square kilometers) of the Larsen B ice shelf disintegrated in 2002. The area of the ice was larger than the state of Rhode Island or the nation of Luxembourg. Antarctic ice shelves have been shrinking since the early 1970's because of climate warming in the region.

flooding and drought in some areas. More hurricanes and other tropical storms might occur, and they could become more powerful.

**Rising sea level.** Continued global warming might, over centuries, melt large amounts of ice from a vast sheet that covers most of West Antarctica. As a result, the sea level would rise throughout the world. Many coastal areas would experience flooding, erosion, a loss of wetlands, and an entry of seawater into freshwater areas. High sea levels would submerge some coastal cities, small island nations, and other inhabited regions.

**Threats to human health.** Tropical diseases, such as malaria and dengue, might spread to larger regions. Longer-lasting and more intense heat waves could cause more deaths and illnesses. Floods and droughts could increase hunger and malnutrition.

**Changes in crop yields.** Canada and parts of Russia might benefit from an increase in crop yields. But any increases in yields could be more than offset by decreases caused by drought and higher temperatures—particularly if the amount of warming were more than a few degrees Celsius. Yields in the tropics might fall disastrously because temperatures there are already almost as high as many crop plants can tolerate.

#### Limiting global warming

Climatologists are studying ways to limit global warming. Two key methods would be (1) limiting CO<sub>2</sub> emissions and (2) *carbon sequestration*—either preventing carbon dioxide from entering the atmosphere or removing CO<sub>2</sub> already there.

**Limiting CO<sub>2</sub> emissions.** Two effective techniques for limiting CO<sub>2</sub> emissions would be (1) to replace fossil fuels with energy sources that do not emit CO<sub>2</sub>, and (2) to use fossil fuels more efficiently.

**Alternative energy sources** that do not emit CO<sub>2</sub> include the wind, sunlight, nuclear energy, and underground steam. Devices known as *wind turbines* can con-

vert wind energy to electric energy. *Solar cells* can convert sunlight to electric energy, and various devices can convert solar energy to useful heat. *Geothermal power plants* convert energy in underground steam to electric energy.

Alternative sources of energy are more expensive to use than fossil fuels. However, increased research into their use would almost certainly reduce their cost.

**Increased fuel efficiency.** CO<sub>2</sub> emissions could be greatly reduced if automobiles and trucks utilized fuel more efficiently. Some scientists and engineers are working on engines with improved fuel efficiency. Other inventors are developing devices to replace fuel-burning engines or to use with smaller engines. Cars known as *hybrids* have already entered the market. A hybrid has all the components of a battery-driven electric car plus another power source, usually a small gasoline engine. *Fuel cells*, devices that convert chemical energy to electric energy, may be used in future automobiles.

**Carbon sequestration** could take two forms: (1) underground or underwater storage and (2) storage in living plants.

**Underground or underwater storage** would involve injecting industrial emissions of CO<sub>2</sub> into underground geologic formations or the ocean. Suitable underground formations include natural reservoirs of oil and gas from which most of the oil or gas has been removed. Pumping CO<sub>2</sub> into a reservoir would have the added benefit of making it easier to remove the remaining oil or gas. The value of that product could offset the cost of sequestration. Deep deposits of salt or coal could also be suitable.

The oceans could store much CO<sub>2</sub>. However, scientists have not yet determined the environmental impacts of using the ocean for carbon sequestration.

**Storage in living plants.** Green plants absorb CO<sub>2</sub> from the atmosphere as they grow. They combine carbon from CO<sub>2</sub> with hydrogen to make simple sugars, which



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they store in their tissues. After plants die, their bodies decay and release CO<sub>2</sub>. Ecosystems with abundant plant life, such as forests and even cropland, could tie up much carbon. However, future generations of people would have to keep the ecosystems intact. Otherwise, the sequestered carbon would re-enter the atmosphere as CO<sub>2</sub>.

### Agreement on global warming

Delegates from more than 160 countries met in Kyoto, Japan, in 1997 to draft the agreement that became known as the Kyoto Protocol. That agreement calls for decreases in the emissions of greenhouse gases.

**Emissions targets.** Thirty-eight industrialized nations would have to restrict their emissions of CO<sub>2</sub> and five other greenhouse gases. The restrictions would occur from 2008 through 2012. Different countries would have different emissions targets. As a whole, the 38 countries would restrict their emissions to a yearly average of about 95 percent of their 1990 emissions. The agreement does not place restrictions on developing countries. But it encourages the industrialized nations to cooperate in helping developing countries limit emissions voluntarily.

Industrialized nations could also buy or sell *emission reduction units*. Suppose an industrialized nation cut its emissions more than was required by the agreement. That country could sell other industrialized nations emission reduction units allowing those nations to emit the amount equal to the excess it had cut.

Several other programs could also help an industrialized nation earn credit toward its target. For example, the nation might help a developing country reduce emissions by replacing fossil fuels in some applications.

**Approving the agreement.** The protocol would take effect as a treaty if (1) at least 55 countries ratified it, and (2) the industrialized countries ratifying the protocol had CO<sub>2</sub> emissions in 1990 that equaled at least 55 percent of the emissions of all 38 industrialized countries in 1990. By early 2003, over 100 countries, including nearly all the countries classified as industrialized under the protocol, had ratified the agreement. Ratification by Russia or the United States would bring the protocol into force.

In 2001, the United States rejected the Kyoto Protocol. President George W. Bush said that the agreement could harm the U.S. economy. But he declared that the United States would work with other countries to limit global warming. Other countries, most notably the members of the European Union, agreed to continue with the agreement without United States participation.

### Analyzing global warming

Scientists use information from several sources to analyze global warming that occurred before people began to use thermometers. Those sources include tree rings, *cores* (cylindrical samples) of ice drilled from Antarctica and Greenland, and cores drilled out of sediments in oceans. Information from these sources indicates that the temperature increase of the 1900's was probably the largest in the last 1,000 years.

Computers help climatologists analyze past climate changes and predict future changes. First, a scientist programs a computer with a set of mathematical equations known as a *climate model*. The equations describe how various factors, such as the amount of CO<sub>2</sub> in the at-

mosphere, affect the temperature of Earth's surface. Next, the scientist enters data representing the values of those factors at a certain time. He or she then runs the program, and the computer describes how the temperature would vary. A computer's representation of changing climatic conditions is known as a *climate simulation*.

In 2001, the Intergovernmental Panel on Climate Change (IPCC), a group sponsored by the United Nations (UN), published results of climate simulations in a report on global warming. Climatologists used three simulations to determine whether natural variations in climate produced the warming of the past 100 years. The first simulation took into account both natural processes and human activities that affect the climate. The second simulation took into account only the natural processes, and the third only the human activities.

The climatologists then compared the temperatures predicted by the three simulations with the actual temperatures recorded by thermometers. Only the first simulation, which took into account both natural processes and human activities, produced results that corresponded closely to the recorded temperatures.

The IPCC also published results of simulations that predicted temperatures until 2100. The different simulations took into account the same natural processes but different patterns of human activity. For example, scenarios differed in the amounts of CO<sub>2</sub> that would enter the atmosphere due to human activities.

The simulations showed that there can be no "quick fix" to the problem of global warming. Even if all emissions of greenhouse gases were to cease immediately, the temperature would continue to increase after 2100 because of the greenhouse gases already in the atmosphere.

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#### Related articles in *World Book* include:

Air (Changes in the atmosphere)	Electric car	Greenhouse effect
Carbon dioxide	Energy supply (Environmental effects)	Ocean (Climate change)
Climate (Causes of climate change)	Fuel cell	Solar energy

#### Additional resources

- Christianson, Gale E. *Greenhouse: The 200-Year Story of Global Warming*. Walker, 1999.  
Godrej, Dinyar. *The No Nonsense Guide to Climate Change*. Verso, 2001.  
Johansen, Bruce E. *The Global Warming Desk Reference*. Greenwood, 2002.

**Globalization** is the trend toward increased economic, cultural, and social connectedness between individuals, businesses, and public organizations across international borders. The term is also used to describe a set of beliefs that promotes such a sense of connectedness. In more specific terms, economic globalization can be defined as an increasingly international approach to the production, distribution, and marketing of goods and services. Globalization involves an emphasis on international financial transactions, the removal of international trade restrictions, and the increase in worldwide communication. It affects numerous complex political, social, economic, and environmental issues.

Aspects of globalization have existed for thousands of years through travel, migration, trade, and the spread of culture. The trend accelerated in the late 1900's, largely as a result of technological developments. These developments included improvements in transportation,