Atmosphere and Climate Change

CHAPTER 13

1 Climate and Climate Change

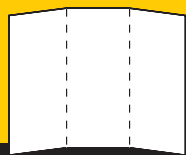
2 The Ozone Shield

3 Global Warming

PRE-READING ACTIVITY

FOLDNOTES

Tri-Fold Before you read this chapter, create the **FoldNote** entitled "Tri-Fold" described in the Reading and Study Skills section of the Appendix. Write what you know about climate change in the column labeled "Know." Then, write what you want to know in the column labeled "Want." As you read the chapter, write what you learn about climate change in the column labeled "Learn."



The climate on Earth can be very extreme. This satellite image of Hurricane Fran was taken before it struck the coastline of North Carolina in early September 1996.

SECTION 1
Climate and Climate Change

EARTH SCIENCE CONNECTION

Weather is the state of the atmosphere at a particular place at a particular moment. **Climate** is the long-term prevailing weather conditions at a particular place based upon records taken. To understand the difference between weather and climate, consider Seattle, Washington, and Phoenix, Arizona. These two cities may have the same weather on a particular day. For example, it may be raining, warm, or windy in both places. But their climates are quite different. Seattle's climate is cool and moist, whereas Phoenix's climate is hot and dry.

What Factors Determine Climate?

Climate is determined by a variety of factors. These factors include latitude, atmospheric circulation patterns, oceanic circulation patterns, the local geography of an area, solar activity, and volcanic activity. The most important of these factors is distance from the equator. For example, the two locations shown in **Figure 1** have different climates mostly because they are at different distances from the equator.

Objectives

- Explain the difference between weather and climate.
- Identify four factors that determine climate.
- Explain why different parts of the Earth have different climates.
- Explain what causes the seasons.

Key Terms

climate
latitude
El Niño
La Niña

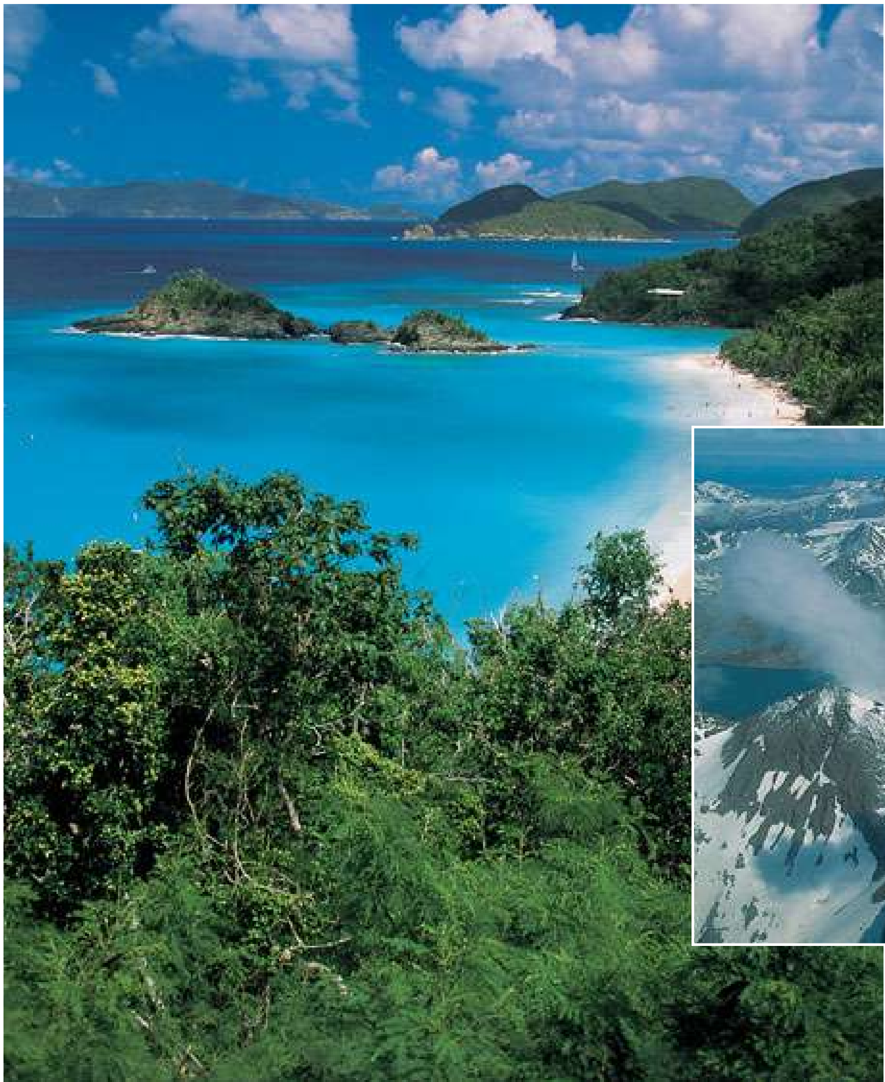


Figure 1 ▶ At left is Trunk Bay on the island of St. John in the U.S. Virgin Islands, which is located near the equator. Below is a photograph of the Antarctic Peninsula.

Latitude

The distance from the equator measured in degrees north or south of the equator is called **latitude.** The equator is located at 0° latitude. The most northerly latitude is the North Pole, at 90° north, whereas the most southerly latitude is the South Pole, at 90° south.

Low Latitudes Latitude influences climate because the amount of solar energy an area of Earth receives depends on its latitude. More solar energy falls on areas that are near the equator than on areas that are closer to the poles, as shown in **Figure 2.** The incoming solar energy is concentrated on a relatively small surface area at the equator.

In regions near the equator, night and day are both about 12 hours long throughout the year. In addition, temperatures are high year-round, and there are no summers or winters.

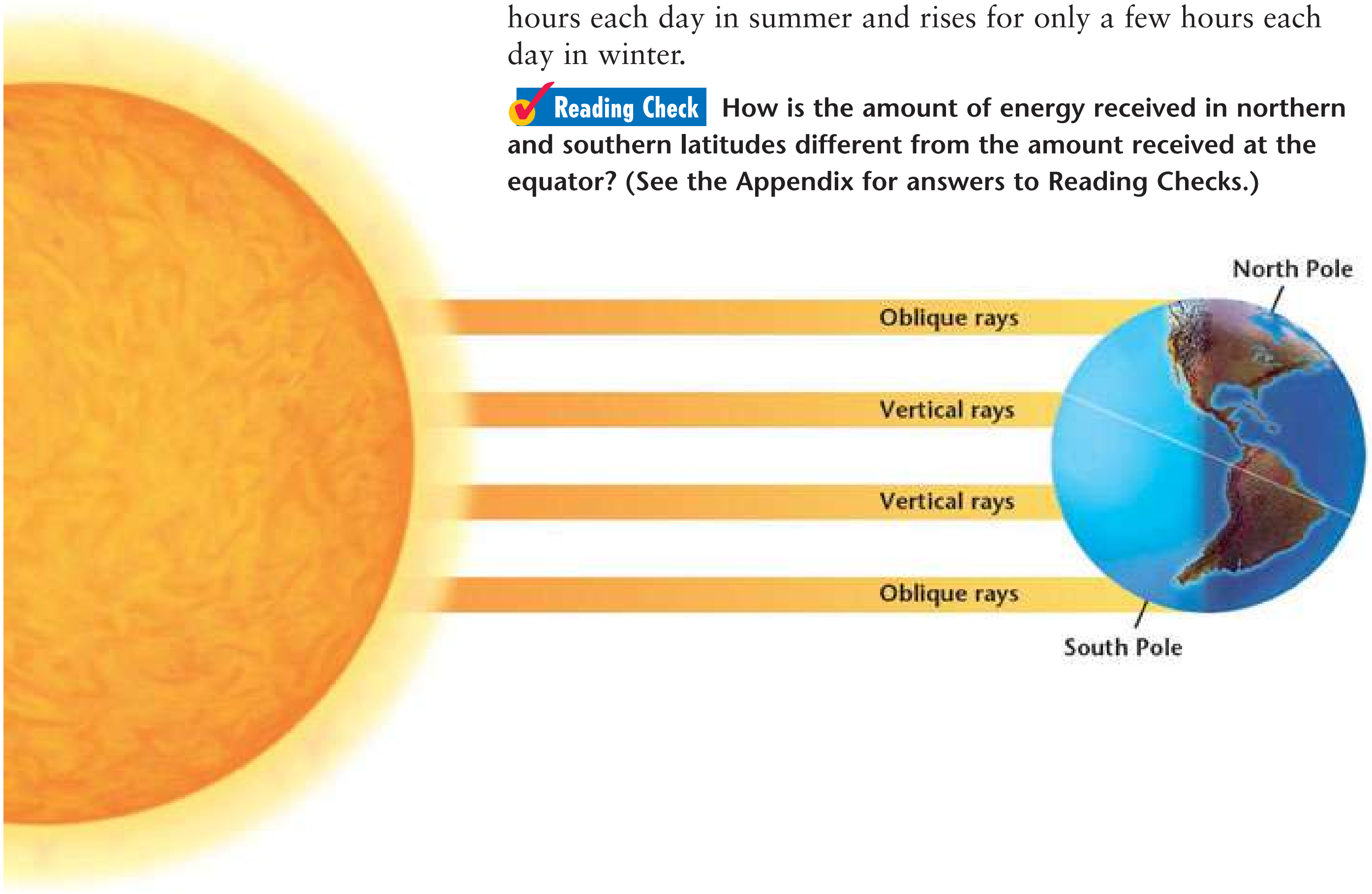
High Latitudes In regions closer to the poles, the amount of energy arriving at the surface is reduced. In the northern and southern latitudes, sunlight hits the Earth at an oblique angle and spreads over a larger surface area than it does at the equator. Yearly average temperatures near the poles are therefore lower than they are at the equator. The hours of daylight also vary. At 45° north and south latitude, there is as much as 16 hours of daylight each day in summer and as little as 8 hours of sunlight each day in winter. Near the poles, the sun sets for only a few hours each day in summer and rises for only a few hours each day in winter.

Reading Check **How is the amount of energy received in northern and southern latitudes different from the amount received at the equator? (See the Appendix for answers to Reading Checks.)**

Ecofact

Coral Reefs Corals need sunlight to grow. They require water that is clear, warm, and has a stable temperature. Because of these requirements, coral reefs occur in shallow waters of tropical oceans between the Tropic of Cancer (23.5° north latitude) and the Tropic of Capricorn (23.5° south latitude). Water between these latitudes has an annual average temperature of about 21°C, which corals need to survive.

Figure 2 ▶ At the equator, sunlight hits the Earth vertically. The sunlight is concentrated on a smaller surface area at the equator. Away from the equator, sunlight hits the Earth at an oblique angle and spreads over a larger surface area.



Atmospheric Circulation

Three important properties of air illustrate how air circulation affects climate. First, cold air sinks because it is denser than warm air. As cold air sinks, it compresses and warms. Second, warm air rises. It expands and cools at it rises. Third, warm air can hold more water vapor than cold air can. Therefore, when warm air cools, the water vapor it contains may condense into liquid water to form rain, snow, or fog.

Solar energy heats the ground, which warms the air above it. The warm air rises, and cooler air moves in to replace it. This movement of air within the atmosphere is called *wind*. Because the Earth rotates, and because different latitudes receive different amounts of solar energy, the pattern of global atmospheric circulation shown in **Figure 3** results. This circulation pattern determines Earth's precipitation pattern. For example, the intense solar energy striking the Earth's surface at the equator causes the surface as well as the air above the equator to become very warm. The warm air can hold large amounts of water that evaporate from the equatorial oceans and land. As the warm air rises, however, it cools, which reduces some of its ability to hold water. Thus, areas near the equator receive large amounts of rain.

Ecofact

Deserts Air that is warmed at the equator rises and flows northward and southward to 30° north and south latitude, where it sinks. The sinking air is compressed and its temperature increases. As the temperature of the air increases, the air is able to hold a larger quantity of water vapor. Evaporation from the land surface is so great beneath these sinking warm air masses that little water returns to Earth in the form of precipitation. Thus, most of the Earth's deserts lie at 30° north and south latitude.

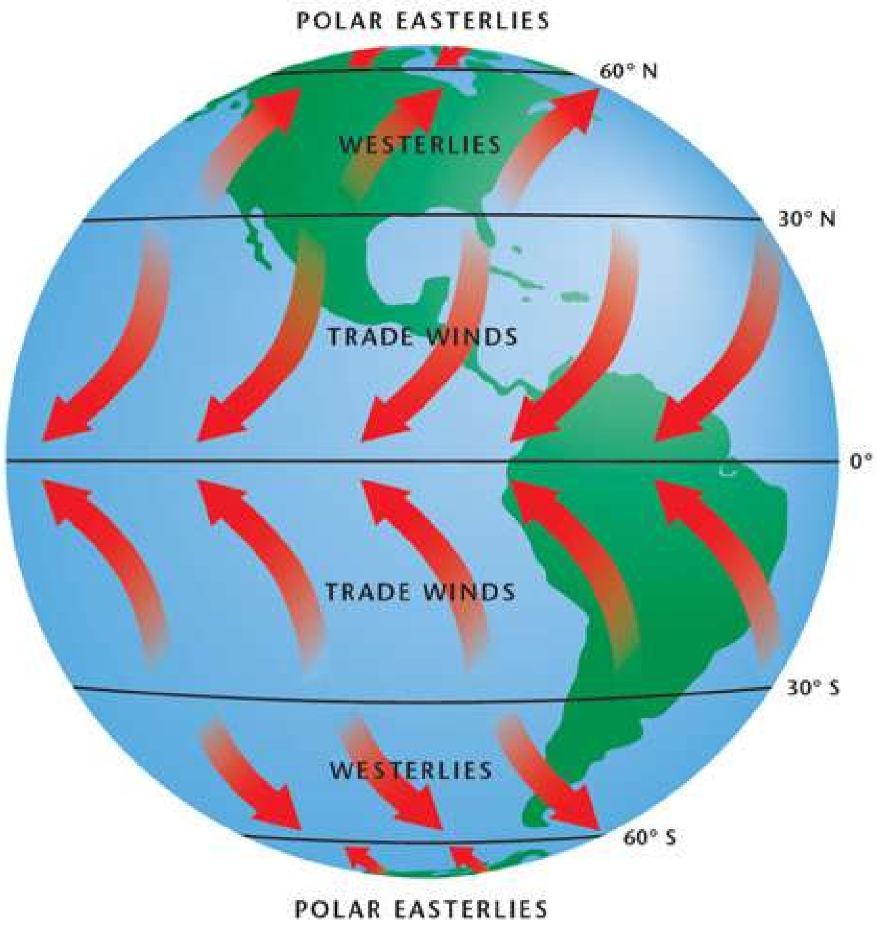


Figure 3 ▶ Three belts of prevailing winds occur in each hemisphere.

QuickLAB

Investigating Prevailing Winds

Procedure

1. Cut a 20 cm diameter disk out of **cardboard.**
2. Insert a **pencil** through the center of the disk. Place the tip of the eraser on a table so that the cardboard is tilted slightly.
3. Place a few drops of **water** near the center of the cardboard, and spin the cardboard on the pencil tip. What happens?

Analysis

1. How is the motion of the water related to the prevailing winds?

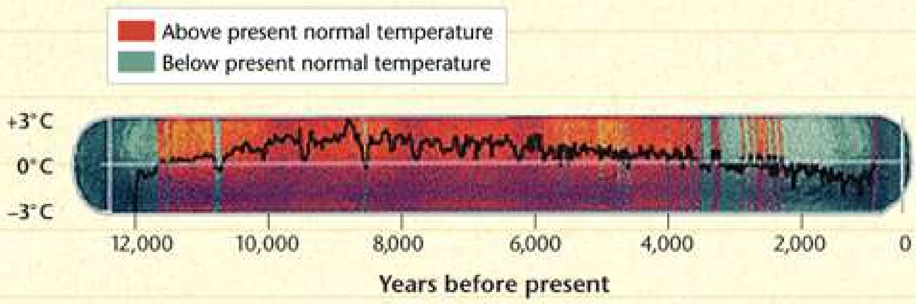
Global Circulation Patterns Cool air normally sinks, but cool air over the equator cannot sink because hot air is rising below the cool air. As a result, the cool air rises and is forced away from the equator toward the North and South Poles. At about 30° north latitude and 30° south latitude, some of this cool air sinks back down to the Earth's surface. The air becomes warmer as it descends. The warm, dry air moves across the surface of the Earth and causes water to evaporate from the land below, which creates dry conditions.

Air descending at 30° north latitude and 30° south latitude either moves toward the equator or toward the poles. Air moving toward the poles warms while it is near Earth's surface. At about 60° north latitude and 60° south latitude, this air collides with cold air traveling from the poles. The warm air rises. When this rising air reaches the top of the troposphere, a small amount of the air returns back to the circulation pattern between 60° and 30° north latitude and 60° and 30° south latitude. However, most of this uplifted air is forced toward the poles. Cold, dry air descends at the poles, which are essentially very cold deserts.

CASE STUDY

EARTH SCIENCE CONNECTION

Ice Cores: Reconstructing Past Climates



Source: National Glaciological Program.

▶ With the help of ice cores, scientists are beginning to reconstruct Earth's climate history over hundreds of thousands of years.

Imagine having at your fingertips a record of Earth's climate that extends back several thousand years. Today, ice cores are providing scientists an indirect glimpse of Earth's climate history. These ice cores have been drilled out of ice sheets thousands of meters thick in Canada, Greenland, and Antarctica.

How do scientists reconstruct the climate history of our planet from ice cores? As snow falls to Earth, the snow carries substances that are in the air at the time. If snow falls in a cold climate where it does not melt, the snow turns to ice because of the weight of the snow above it. The substances contained in snow, such as soot, dust, volcanic ash, and chemical compounds, are buried year after year, one layer on top of another. Air between snowflakes and grains becomes trapped in bubbles when the snow is compacted. These bubbles of air can provide information about the composition of the atmosphere over time.

How do scientists date ice cores? Scientists have learned that differences exist between snow layers that are deposited in the winter and in the summer. Knowing these differences allows scientists to count and place dates with the annual layers of ice.

Scientists can discover important events in Earth's climate history by studying ice cores. For example, volcanoes produce large quantities of dust, so a history of volcanic

Prevailing Winds Winds that blow predominantly in one direction throughout the year are called *prevailing winds*. Because of the rotation of the Earth, these winds do not blow directly northward or southward. Instead these winds are deflected to the right in the Northern Hemisphere. They are deflected to the left in the Southern Hemisphere.

Belts of prevailing winds blow most of the time in both hemispheres between 30° north and south latitudes and the equator. These belts of wind are called the *trade winds*. The trade winds blow from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere.

Prevailing winds known as the westerlies are produced between 30° and 60° north latitudes and 30° and 60° south latitudes. In the Northern Hemisphere, these westerlies are southwest winds. In the Southern Hemisphere, these westerlies are northwest winds, as shown in **Figure 4.** The polar easterlies blow from the poles to 60° north and south latitudes.

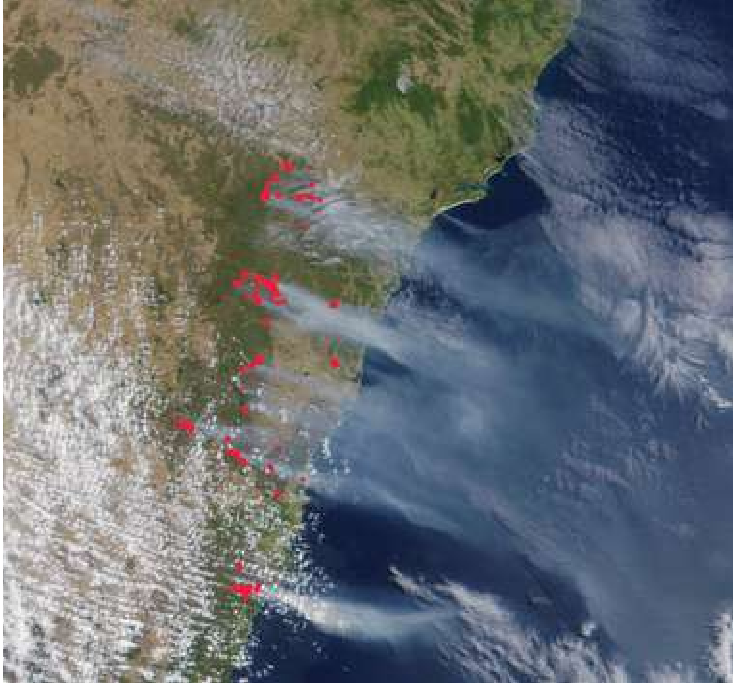


Figure 4 ▶ The red areas indicate fires around Sydney, Australia, at about 32° south. The smoke is blown by the prevailing westerly winds.

▶ Whether scientists work on ice cores in the field or in the laboratory, all ice cores must be handled in such a way that the cores do not become contaminated by atmospheric pollutants.

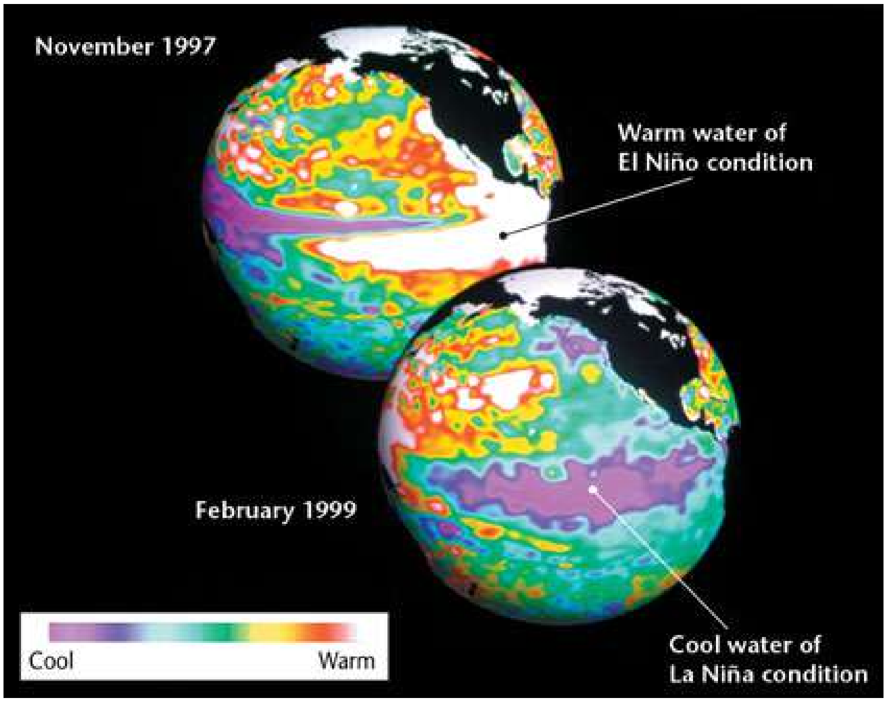
activity is preserved in ice cores. Most important, a record of concentrations of carbon dioxide, an important greenhouse gas, has been preserved in air bubbles trapped in the ice. Some scientists who study ice cores have come to believe that rapid, global climate change may be more the norm than the exception. Evidence of increases in global temperature of several Celsius degrees over several decades has been discovered in ice cores from thousands of years ago.

CRITICAL THINKING

1. Expressing Viewpoints How might information about past carbon dioxide concentrations on Earth contribute to scientists' understanding of present carbon dioxide concentrations?

2. Applying Ideas What information, besides what is mentioned in this Case Study, might scientists learn about Earth's climatic history from ice cores?

Figure 5 ▶ The El Niño-Southern Oscillation (ENSO) is a periodic change in the location of warm and cold water masses in the Pacific Ocean. The phase of ENSO in which the eastern Pacific surface water is warm is called *El Niño,* and the phase in which it is cool is called *La Niña.*



Oceanic Circulation Patterns

Ocean currents have a great effect on climate because water holds large amounts of heat. The movement of surface ocean currents is caused mostly by winds and the rotation of the Earth. These surface currents redistribute warm and cool masses of water around the planet. Some surface currents warm or cool coastal areas year-round.

Surface currents affect the climate in many parts of the world. Here, we will only discuss surface currents that change their pattern of circulation over time.

El Niño—Southern Oscillation **El Niño** (el NEEN yoh) is the name given to the short-term (generally 6- to 18-month), periodic change in the location of warm and cold water masses in the Pacific Ocean. During an El Niño, winds in the western Pacific Ocean, which are usually weak, strengthen and push warm water eastward. Rainfall follows this warm water eastward and produces increased rainfall in the southern half of the United States and in equatorial South America. El Niño causes drought in Indonesia and Australia. During **La Niña** (lah NEEN yah), on the other hand, the water in the eastern Pacific Ocean is cooler than usual. El Niño and La Niña are opposite phases of the *El Niño–Southern Oscillation* (ENSO) cycle. El Niño is the warm phase of the cycle, and La Niña is the cold phase, as illustrated in **Figure 5.**

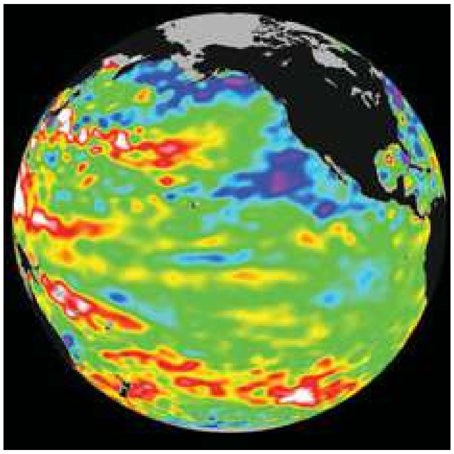


Figure 6 ▶ This satellite image shows the cool phase of the Pacific Decadal Oscillation. During the cool phase, cooler water (purple and blue) can be seen in the eastern Pacific Ocean. During the warm phase, the situation is reversed.

Pacific Decadal Oscillation The *Pacific Decadal Oscillation* (PDO), shown in **Figure 6,** is a long-term, 20- to 30-year change in the location of warm and cold water masses in the Pacific Ocean. PDO influences the climate in the northern Pacific Ocean and North America. It affects ocean surface temperatures, air temperatures, and precipitation patterns.

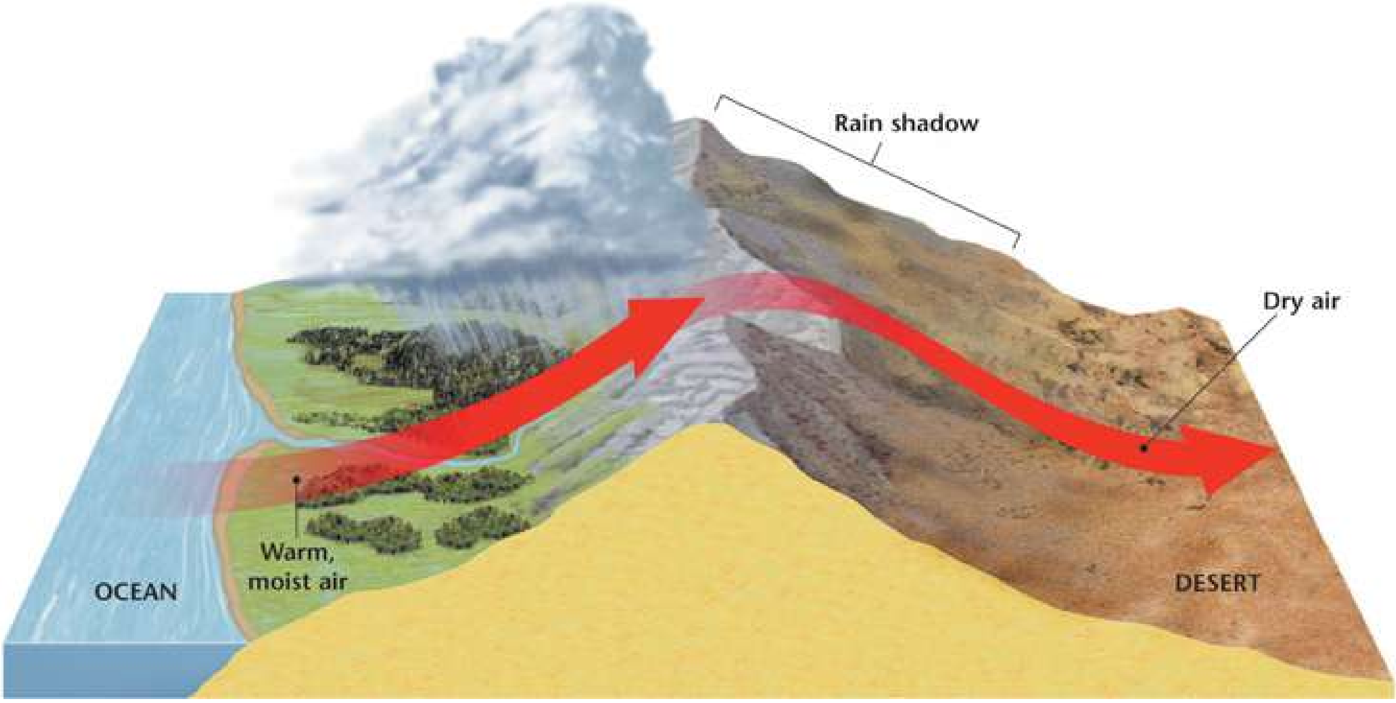


Figure 7 ▶ Moist ocean air moves up the coastal side of a mountain range. The air cools and releases its moisture as rain or snow. Air then becomes drier as it crosses the range. When the dry air descends on the inland side of the mountains, the air warms and draws up moisture from the surface.

Topography

Mount Kilimanjaro, a 5,896 m extinct volcano in Tanzania, is about 3° south of the equator, but snow covers its peak year-round. Kilimanjaro illustrates the important effect of height above sea level (elevation) on climate. Temperatures fall by about 6°C (about 11°F) for every 1,000 m increase in elevation.

Mountains and mountain ranges also influence the distribution of precipitation. For example, consider the Sierra Nevada mountains of California. Warm air from the Pacific Ocean blows east, hits the mountains, and rises. As the air rises, it cools, which causes it to rain on the western side of the mountains. By the time the air reaches the eastern side of the mountains, it is dry. This effect is known as a rain shadow, as shown in **Figure 7.**

Other Influences on Earth's Climate

Both the sun and volcanic eruptions influence Earth's climate. At a *solar maximum*, shown in **Figure 8,** the sun emits an increased amount of ultraviolet (UV) radiation. UV radiation produces more ozone, warming the stratosphere. The increased radiation can also warm the lower atmosphere and surface of the Earth a little.

In large-scale volcanic eruptions, sulfur dioxide gas can reach the upper atmosphere. The sulfur dioxide gas reacts with smaller amounts of water vapor and dust in the stratosphere. This reaction forms a bright layer of haze that reflects enough sunlight to cause the global temperature to decrease.

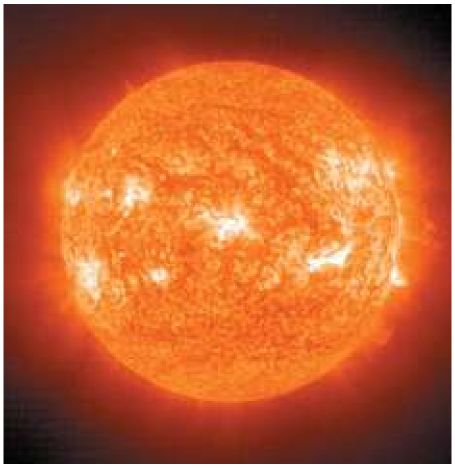


Figure 8 ▶ The sun has an 11-year cycle in which it goes from a maximum of activity to a minimum.

Reading Check **How do large-scale volcanic eruptions influence Earth's climate?**

MATHPRACTICE

Precipitation Extremes on Earth Cherrapunji, India, which is located in eastern India near the border of Bangladesh, is the wettest spot on Earth. Cherrapunji has an annual average precipitation of 1,065 cm. Arica, Chile, is located in extreme northern Chile near the Peruvian border. Arica is the driest spot on Earth and has an annual average precipitation of 0.8 mm. What is the difference in millimeters between the annual average precipitation in Cherrapunji and the annual average precipitation in Arica?

Seasonal Changes in Climate

You know that temperature and precipitation change with the seasons. But do you know what causes the seasons? As shown in **Figure 9,** the seasons result from the tilt of Earth's axis (about 23.5° relative to the plane of its orbit). Because of this tilt, the angle at which the sun's rays strike the Earth changes as the Earth moves around the sun.

During summer in the Northern Hemisphere, the Northern Hemisphere tilts toward the sun and receives direct sunlight. The number of hours of daylight is greatest in the summer. Therefore, the amount of time available for the sun to heat the Earth becomes greater. During summer in the Northern Hemisphere, the Southern Hemisphere tilts away from the sun and receives less direct sunlight. During summer in the Southern Hemisphere, the situation is reversed. The Southern Hemisphere is tilted toward the sun, whereas the Northern Hemisphere is tilted away.

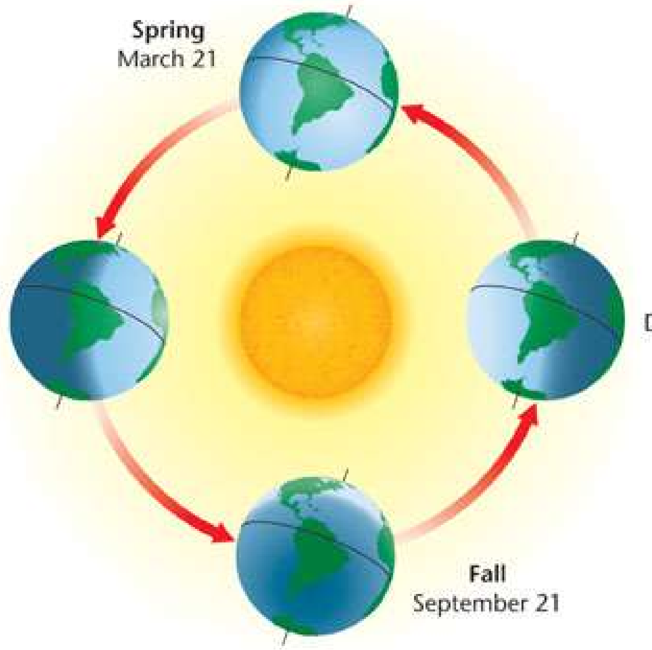


Figure 9 ▶ Because of the Earth's tilt, the angle at which the sun's rays strike the Earth changes as the Earth orbits the sun. This change in angle accounts for seasonal climate differences around the world. The seasons for the Northern Hemisphere are shown here.

SECTION 1 Review

1. **Explain** the difference between weather and climate.
2. **Name** four factors that determine climate.
3. **Explain** why different parts of the Earth have different climates.
4. **Explain** what causes the seasons.

CRITICAL THINKING

5. **Making Comparisons** At the equator, there are no summers or winters, only wet and dry seasons. Based on what you have learned about atmospheric circulation patterns, why do you think there are no seasons? Write a paragraph that explains your answer. WRITING SKILLS
6. **Analyzing Processes** If the Earth were not tilted in its orbit, how would the climates and seasons be affected at the equator and between 30° north and south latitudes?

SECTION 2

The Ozone Shield

EARTH SCIENCE CONNECTION

The **ozone layer** is an area in the stratosphere where ozone is highly concentrated. *Ozone* is a molecule made of three oxygen atoms. The ozone layer absorbs most of the ultraviolet (UV) light from the sun. Ultraviolet light is harmful to organisms because it can damage the genetic material in living cells. By shielding the Earth's surface from most of the sun's ultraviolet light, the ozone in the stratosphere acts like a sunscreen for the Earth's inhabitants.

Objectives

- Explain how the ozone layer shields the Earth from much of the sun's harmful radiation.
- Explain how chlorofluorocarbons damage the ozone layer.
- Explain the process by which the ozone hole forms.
- Describe the damaging effects of ultraviolet radiation.
- Explain why the threat to the ozone layer is still continuing today.

Key Terms

ozone layer
chlorofluorocarbons (CFCs)
ozone hole
polar stratospheric clouds

Chemicals That Cause Ozone Depletion

During the 1970s, scientists began to worry that a class of human-made chemicals called **chlorofluorocarbons (CFCs)** might be damaging the ozone layer. For many years CFCs were thought to be miracle chemicals. They are nonpoisonous and nonflammable, and they do not corrode metals. CFCs quickly became popular as coolants in refrigerators and air conditioners. They were also used as a gassy "fizz" for making plastic foams and as a propellant in spray cans of everyday products such as deodorants, insecticides, and paint.

At the Earth's surface, CFCs are chemically stable. So, they do not combine with other chemicals or break down into other substances. But CFC molecules break apart high in the stratosphere, where UV radiation, a powerful energy source, is absorbed. Once CFC molecules break apart, parts of the CFC molecules destroy protective ozone.

Over a period of 10 to 20 years, CFC molecules released at the Earth's surface make their way into the stratosphere. **Figure 10** shows how the CFCs destroy ozone in the stratosphere. Each CFC molecule contains from one to four chlorine atoms, and scientists have estimated that a single chlorine atom from CFC can destroy 100,000 ozone molecules.

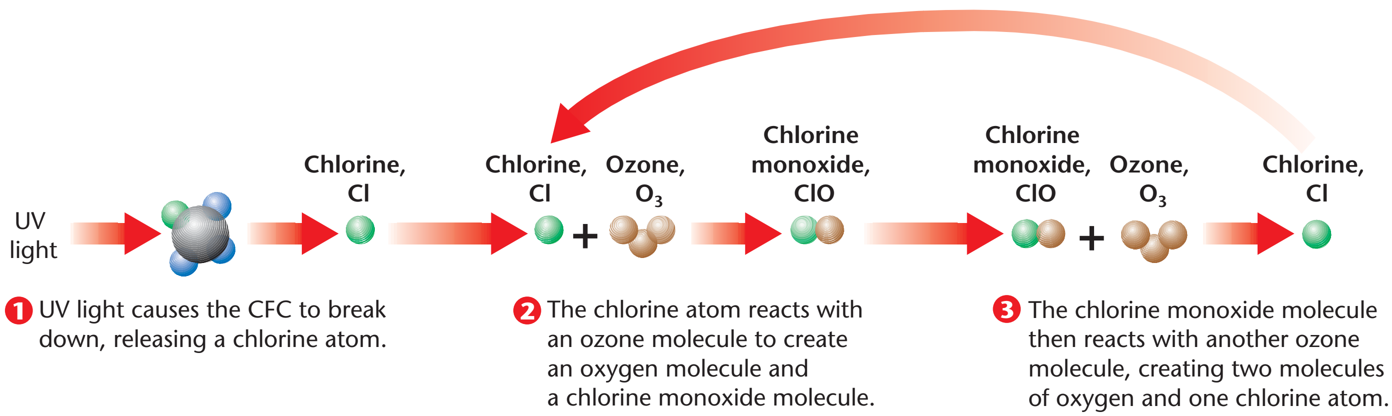
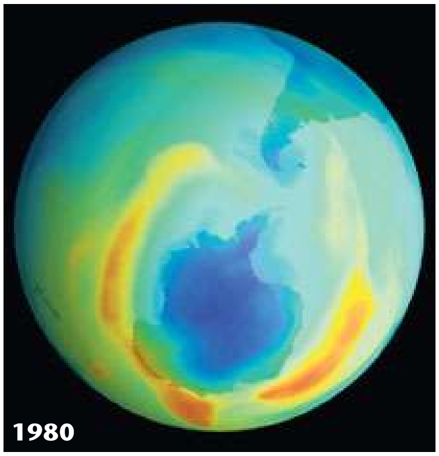
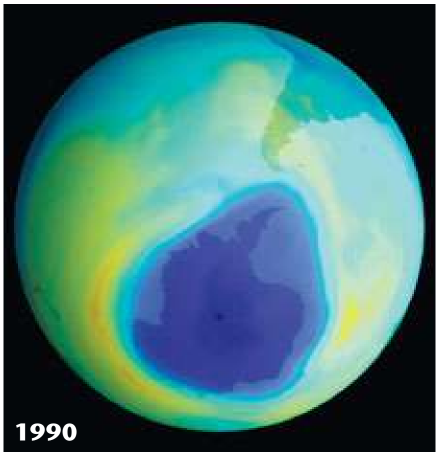


Figure 10 ▶ The CFC molecule in this illustration contains a single chlorine atom. This chlorine atom continues to enter the cycle and repeatedly destroys ozone molecules.





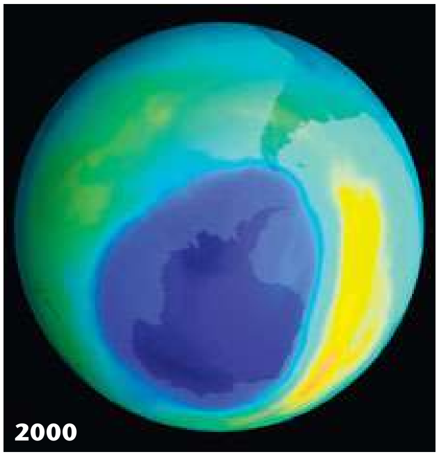


Figure 11 ▶ These satellite images show the growth of the ozone hole, which appears purple, over the past two decades.

The Ozone Hole

In 1985, an article in the scientific journal *Nature* reported the results of studies by scientists working in Antarctica. The studies revealed that the ozone layer above the South Pole had thinned by 50 to 98 percent. This was the first news of the **ozone hole,** a thinning of stratospheric ozone that occurs over the poles during the spring.

After the results were published, NASA scientists reviewed data that had been sent to Earth by the *Nimbus 7* weather satellite since the satellite's launch in 1978. They were able to see the first signs of ozone thinning in the data from 1979. Although the concentration of ozone fluctuates during the year, the data showed a growing ozone hole, as shown in **Figure 11.** Ozone levels over the Arctic have decreased as well.

How Does the Ozone Hole Form? During the dark polar winter, strong circulating winds over Antarctica, called the *polar vortex*, isolate cold air from surrounding warmer air. The air within the vortex grows extremely cold. When temperatures fall below about –80°C, high-altitude clouds made of water and nitric acid, called **polar stratospheric clouds,** begin to form.

On the surfaces of polar stratospheric clouds, the products of CFCs are converted to molecular chlorine. When sunlight returns to the South Pole in spring, molecular chlorine is split into two chlorine atoms by ultraviolet radiation. The chlorine atoms rapidly destroy ozone. This causes a thin spot, or ozone hole, which lasts for several months. Some scientists estimate that as much as 70 percent of the ozone layer can be destroyed during the spring.

Because ozone is also being produced as air pollution, you may wonder why this ozone does not repair the ozone hole in the stratosphere. The answer is that ozone is very chemically reactive. Ozone produced by pollution breaks down or combines with other substances in the troposphere long before it can reach the stratosphere to replace the ozone that is being destroyed.

Reading Check **What evidence showed that a hole had formed in the ozone layer?**

Connection to Meteorology

Polar Stratospheric Clouds
Because the stratosphere is extremely dry, clouds normally do not form in this layer of the atmosphere. However, during polar winters, temperatures become low enough to cause condensation and cloud formation. These clouds, which occur at altitudes of about 21,000 m, are known as polar stratospheric clouds, or PSCs. Because of their iridescence, PSCs are called mother-of-pearl or nacreous clouds. Outside of the poles, the stratosphere is too warm for these clouds to form. Because these clouds are required for the breakdown of CFCs, ozone holes are confined to the Antarctic and Arctic regions.

Effects of Ozone Thinning on Humans As the amount of ozone in the stratosphere decreases, more ultraviolet light is able to pass through the atmosphere and reach Earth's surface, as shown in **Figure 12.** UV light is dangerous to living things because it damages DNA. DNA is the genetic material that contains the information that determines inherited characteristics. Exposure to UV light makes the body more susceptible to skin cancer, and may cause certain other damaging effects to the human body.

Effects of Ozone Thinning on Animals and Plants High levels of UV light can kill single-celled organisms called *phytoplankton* that live near the surface of the ocean. The loss of phytoplankton could disrupt ocean food chains and reduce fish harvests. In addition, a reduction in the number of phytoplankton would cause an increase in the amount of carbon dioxide (CO_2) in the atmosphere.

Some scientists believe that increased UV light could be especially damaging for amphibians, such as toads and salamanders. Amphibians lay eggs that lack shells in the shallow water of ponds and streams. UV light at natural levels kills many eggs of some species by damaging unprotected DNA. Higher UV levels might kill more eggs and put amphibian populations at risk. Ecologists often use the health of amphibian populations as an indicator of environmental change due to the environmental sensitivity of these creatures.

UV light can damage plants by interfering with photosynthesis. This damage can result in lower crop yields. The damaging effects of UV light are summarized in **Table 1**.

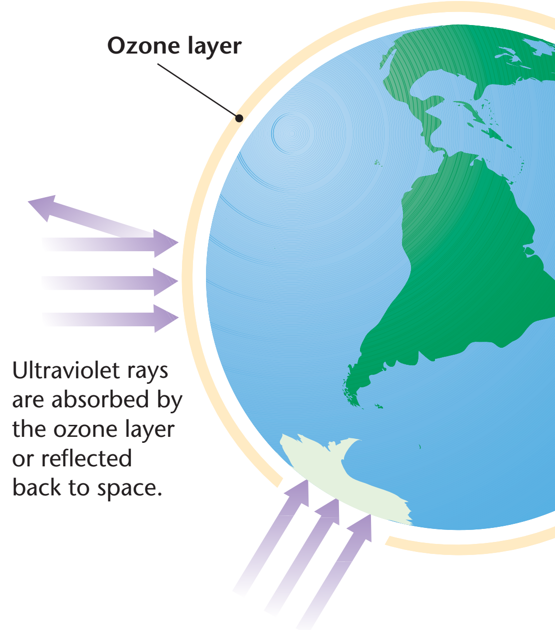


Figure 12 ▶ Depletion of the ozone layer allows more ultraviolet (UV) radiation to reach the surface of the Earth.

Table 1 ▼

Damaging Effects of UV Light	
Humans	• increased incidence of skin cancer • premature aging of the skin • increased incidence of cataracts • weakened immune response
Amphibians	• death of eggs • genetic mutations among survivors • reduction of populations
Marine Life	• death of phytoplankton in surface water • disruption of food chain • reduction in the number of photosynthesizers
Land Plants	• interference with photosynthesis • reduced crop yields

Protecting the Ozone Layer

In 1987, a group of nations met in Canada and agreed to take action against ozone depletion. Under an agreement called the Montreal Protocol, these nations agreed to sharply limit their production of CFCs. A second conference on the problem was held in Copenhagen, Denmark, in 1992. Developed countries agreed to eliminate most CFCs by 1995. The United States pledged to ban all substances that pose a significant danger to the ozone layer by 2000.

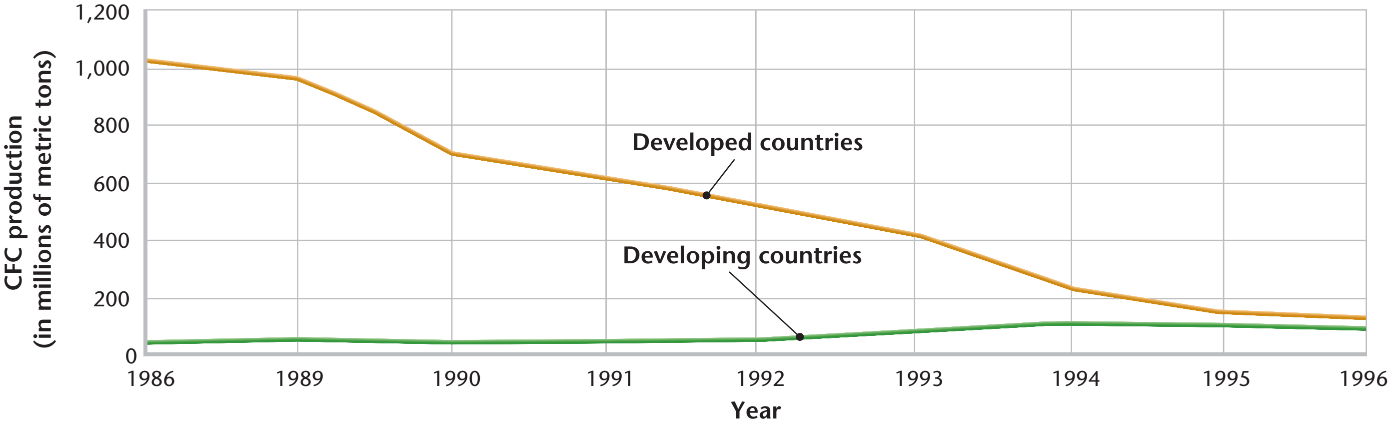
After developed countries banned most uses of CFCs, chemical companies developed CFC replacements. Aerosol cans no longer use CFCs as propellants, and air conditioners are becoming CFC-free. Because many countries were involved and decided to control CFCs, many people consider ozone protection an international environmental success story. **Figure 13** illustrates the decline in world CFC production since the 1987 Montreal Protocol.

The battle to protect the ozone layer is not over. CFC molecules remain active in the stratosphere for 60 to 120 years.

SCILINKS.
www.scilinks.org
Topic: Ozone Shield
Code: HE81100

Reading Check **How did the Montreal Protocol help to protect the ozone layer?**

World CFC Production



Source: UN Environment Programme.

Figure 13 ▶ Chlorofluorocarbon production has declined greatly since developed countries agreed to ban CFCs in 1987.

SECTION 2 Review

1. **Describe** the process by which chlorofluorocarbons destroy ozone molecules in the stratosphere.
2. **Describe** the process by which the ozone hole forms over Antarctica in spring.
3. **List** five harmful effects that UV radiation could have on plants or animals as a result of ozone thinning.
4. **Explain** why it will take years for the ozone layer to recover, even though the use of CFCs has declined significantly. Write a paragraph that explains your answer. WRITING SKILLS

CRITICAL THINKING

5. **Making Decisions** If the ozone layer gets significantly thinner during your lifetime, what changes might you need to make in your lifestyle?
6. **Analyzing Relationships** CFCs were thought to be miracle chemicals when they were first introduced. What kinds of tests could be performed on any future miracle chemical to make sure serious environmental problems do not result from its use?

SECTION 3
Global Warming

EARTH SCIENCE CONNECTION

Objectives

- Explain why Earth's atmosphere is like the glass in a greenhouse.
- Explain why the carbon dioxide content of the atmosphere is increasing.
- Identify one possible explanation for the increase in average global temperature.
- Describe what a warmer Earth might be like.

Key Terms

greenhouse gases
global warming
Kyoto Protocol

Have you ever gotten into a car that has been sitting in the sun for a while with all its windows closed? Even if the day is cool, the air inside the car is much warmer than the air outside. On a hot summer day, opening the door of a car can seem like opening the door of an oven.

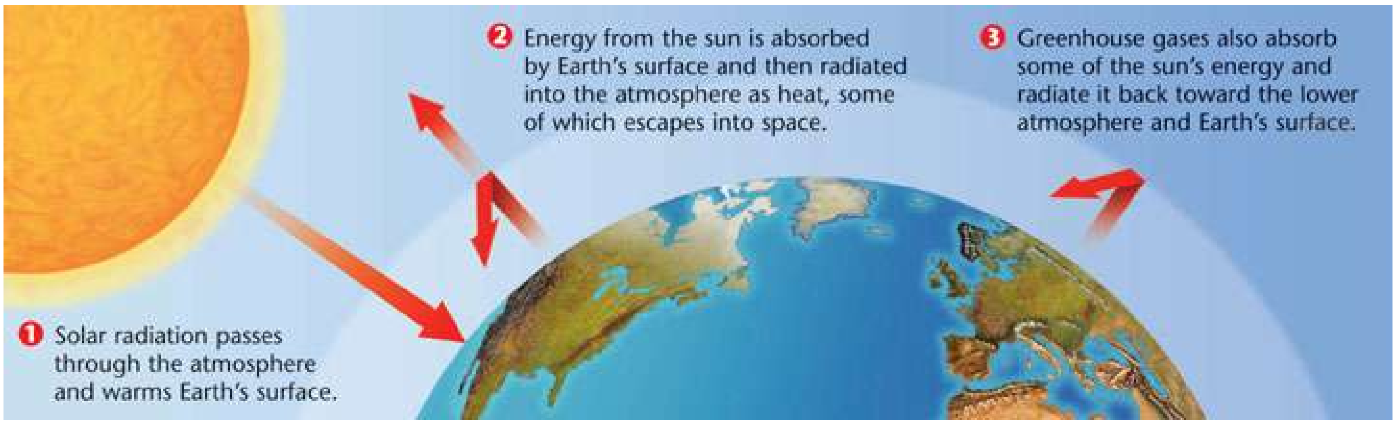
The reason heat builds up inside a car is that the sun's energy streams into the car through the clear glass windows in the form of sunlight. The carpets and upholstery in the car absorb the light and change it into heat energy. Heat energy does not pass through glass as easily as light energy does. Sunlight continues to stream into the car through the glass, but heat cannot get out. The heat continues to build up and is trapped inside the car. A greenhouse works the same way. By building a house of glass, gardeners trap the sun's energy and grow delicate plants in the warm air inside the greenhouse even when there is snow on the ground outside.

The Greenhouse Effect

The Earth is similar to a greenhouse. The Earth's atmosphere acts like the glass in a greenhouse. As shown in **Figure 14,** sunlight streams through the atmosphere and heats the Earth. As this heat radiates up from Earth's surface, some of it escapes into space. The rest of the heat is absorbed by gases in the troposphere and warms the air. This process of heat absorption is called the *greenhouse effect.*

Not every gas in our atmosphere absorbs heat in this way. The gases that do absorb and radiate heat are called **greenhouse gases.** The major greenhouse gases are water vapor, carbon dioxide, chlorofluorocarbons, methane, and nitrous oxide. Of these, water vapor and carbon dioxide account for most of the absorption of heat that occurs in the atmosphere.

Figure 14 ▶ How the Greenhouse Effect Works



FIELD ACTIVITY

Carbon Dioxide Create a question dealing with carbon dioxide or carbon dioxide levels in the atmosphere. Investigate the FAQ section of the Carbon Dioxide Information Analysis Center's Web site to see if your question has already been answered. If not, click on "Ask Us a Question," and e-mail your question to the center. Report your findings to the class.

Measuring Carbon Dioxide in the Atmosphere In 1958, a geochemist named Charles Keeling installed an instrument at the top of a tall tower on the volcano Mauna Loa in Hawaii. Keeling wanted to measure the amount of CO_2 in the air, far from forests and cities where CO_2 levels vary every day. The winds that blow steadily over Mauna Loa have come thousands of miles across the Pacific Ocean, mixing as they traveled. Keeling reasoned that at Mauna Loa, the average CO_2 levels in the air could be measured for the entire Earth.

Most of the CO_2 that is released into the air dissolves in the ocean or is used by plants for photosynthesis. As a result, the levels of CO_2 in the air vary with the seasons. During the summer, growing plants use more CO_2 for photosynthesis than they release in respiration. This causes CO_2 levels in the air to decrease in the summer. In the winter, dying grasses and fallen leaves decay and release the carbon that was stored in them during the summer. As a result, CO_2 levels naturally rise.

Rising Carbon Dioxide Levels After only a few years of measuring CO_2 levels, it became obvious that they were changing in ways other than just the seasonal fluctuations. **Figure 15** shows that CO_2 levels in the atmosphere have increased by over 20 percent in less than 50 years. This increase is due largely to the CO_2 released into the air when fossil fuels are burned.

The data in Figure 15 provide a record of changes in CO_2 levels since 1958. Levels of CO_2 in the atmosphere thousands of years ago can be determined by analyzing ice cores drilled from ice sheets. These measurements show that CO_2 levels in the atmosphere today are higher than they have been for the last 420,000 years, and probably for the last 20 million years.

Reading Check **What are two advantages of setting up instruments for measuring carbon dioxide on top of Mauna Loa?**

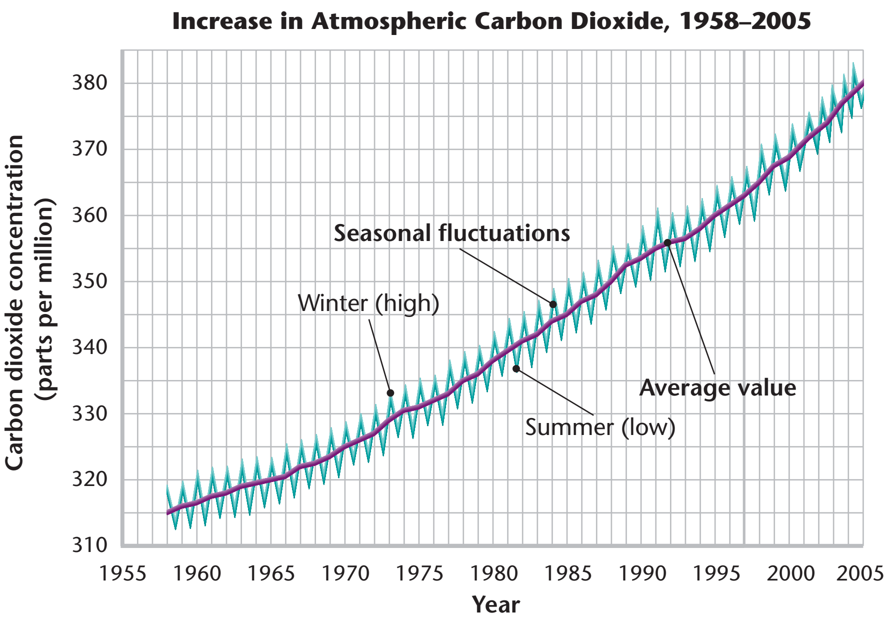


Figure 15 ▶ The graph shows that the average yearly concentration of carbon dioxide in the atmosphere has increased since 1958.

Greenhouse Gases and the Earth's Temperature Many scientists think that because greenhouse gases trap heat near the Earth's surface, more greenhouse gases in the atmosphere will result in an increase in global temperature. A comparison of carbon dioxide in the atmosphere and average global temperatures for the past 400,000 years supports this view.

Today, we are releasing more carbon dioxide than any other greenhouse gas into the atmosphere. Millions of tons of carbon dioxide are released into the atmosphere each year from power plants that burn coal or oil and from cars that burn gasoline. Millions of trees are burned in tropical rain forests to clear the land for farming. Thus, the amount of carbon dioxide in the atmosphere is increasing. We are also releasing other greenhouse gases, such as CFCs, methane, and nitrous oxide, in significant amounts. **Table 2** shows the sources of some major greenhouse gases.

Table 2 ▼

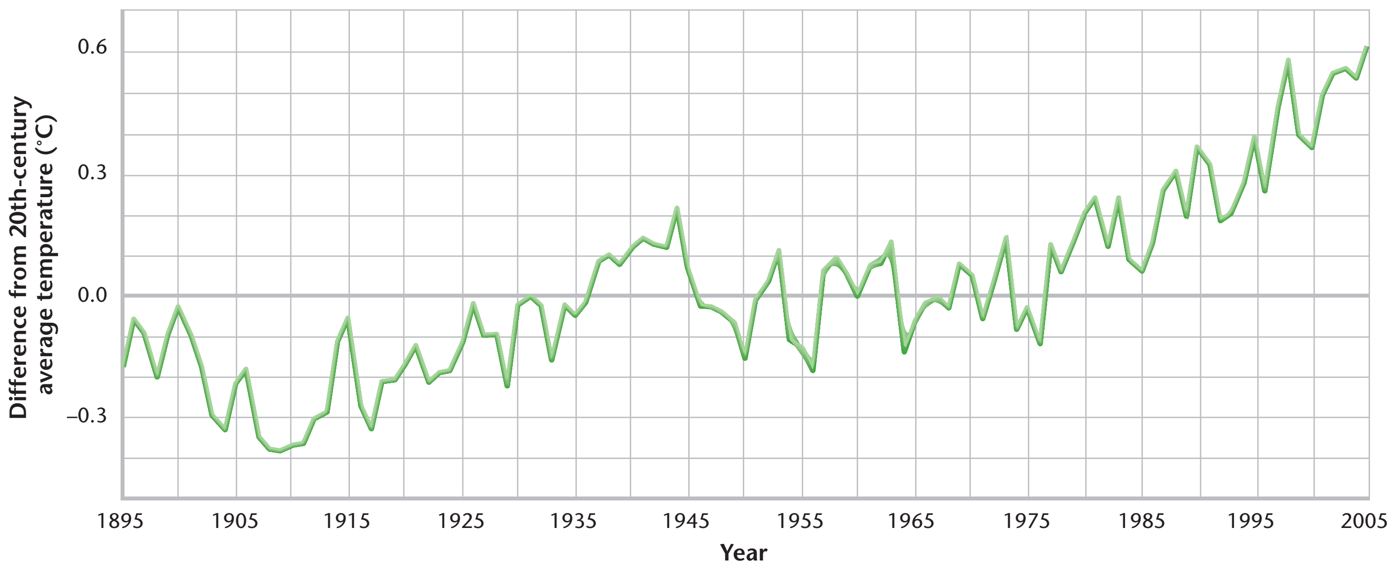
Major Greenhouse Gases and Their Sources
Carbon dioxide, CO_2: burning fossil fuels and deforestation
Chlorofluorocarbons (CFCs): refrigerants, aerosols, foams, propellants, and solvents
Methane, CH_4: animal waste, biomass burning, fossil fuels, landfills, livestock, rice paddies, sewage, and wetlands
Nitrous oxide, N_2O: biomass burning, deforestation, burning of fossil fuels, and microbial activity on fertilizers in the soil
Water vapor, H_2O: evaporation, plant respiration

Global Warming

Figure 16 shows that the average temperature at Earth's surface increased during the twentieth century. This increase is known as **global warming.** Because the temperature is rising at a similar rate to the increase in greenhouse gases in the atmosphere, many scientists have hypothesized that the increase in greenhouse gases has caused the increase in temperature. Thousands of experiments and computer models support this hypothesis. The increase in temperature is predicted to continue throughout the 21st century. This does not mean that temperatures are rising at a constant rate, or that they are rising in all parts of the world. It is not possible to rule out natural climatic variability. For example, we know that fluctuations in temperatures on Earth occur naturally over the centuries.

Figure 16 ▶ This graph shows that the average surface temperature of Earth warmed during the 20th century. For example, the average global surface temperature in the year 2005 was 0.61°C above the 20th-century average temperature.

Variation from 20th-Century Average Global Surface Temperature



Source: National Climatic Data Center.

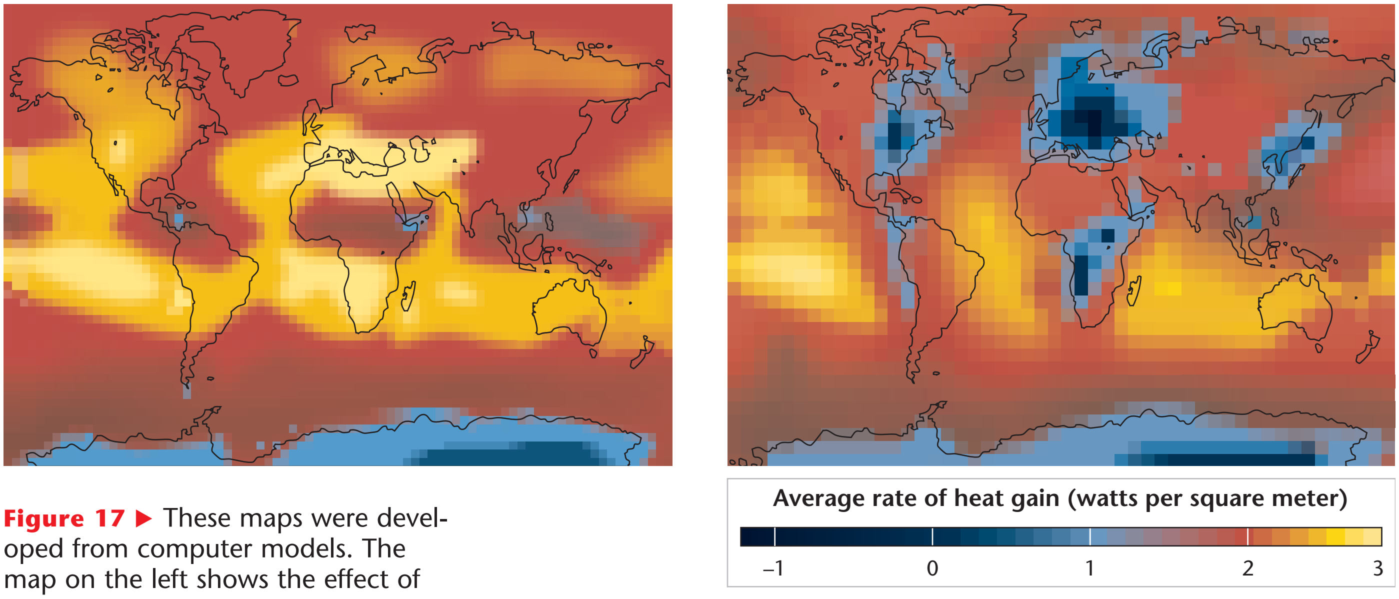


Figure 17 ▶ These maps were developed from computer models. The map on the left shows the effect of greenhouse gases on the Earth before sulfur pollution was added. The map on the right shows how the addition of the sulfur pollution variable causes a cooling effect.

Connection to Biology

Ocean Warming Commercial fishing in the northern Atlantic Ocean depends heavily on a fish called a *cod*. In recent years, the numbers of cod in the North Atlantic have greatly decreased. In 2001, English scientists embarked on a research project to find out if the decline in the numbers of cod was linked to the changing global climate. They sailed the ocean waters between Greenland and Iceland collecting samples of zooplankton. The scientists found that zooplankton levels have drastically decreased since 1963, the date of the last survey. The scientists believe that slowly warming ocean-water temperatures have in some way affected zooplankton in the North Atlantic Ocean, which has in turn impacted animals such as cod that rely on the zooplankton for food.

Modeling Global Warming Predictions about future changes in climate are based on computer models. Scientists write equations that represent the atmosphere and oceans. Then they enter data about CO_2 levels, prevailing winds, and many other variables. The resulting models can be used to predict how factors such as temperature and sea level will be affected, as shown in **Figure 17.**

Weather forecasters use programs similar to those used by climate scientists. You have probably been rained on when a forecaster predicted dry weather, so you know that the programs and the models they produce are not always accurate. Computer models are becoming more reliable, however, as more data are available and additional variables are included.

The Consequences of a Warmer Earth

In North America, tree swallows, Baltimore orioles, and robins are nesting about 11 days earlier than they did 50 years ago. These are birds that winter in the south and return north to breed in the spring. In Britain, at least 200 species of plants are flowering up to 55 days earlier in the year than they did 40 years ago. There is no evidence that these changes are caused by global warming. Scientists know, however, that the time at which birds nest and the time at which plants flower are both strongly influenced by temperature.

Scientists are not sure how quickly the Earth will warm or how severe the effects will be. Different computer models give different predictions. The possible effects of global warming include a number of potentially serious environmental problems. These problems include changes in weather patterns and rising sea levels. The possible effects of a warmer Earth will not be the same everywhere. For instance, some ecosystems are less sensitive to changes in climate than others are. Countries, too, will vary in their ability to respond to problems caused by changes in climate.

Figure 18 ▶ This is a satellite map of an 11,000 km^2 iceberg—the size of Connecticut!—that split off from the Ross Ice Shelf in Antarctica in March of 2000.

Melting Ice and Rising Sea Levels Ice melts as global temperatures increase, causing the amount of ice near the poles to decrease, as shown in **Figure 18.** The melting of ice and snow from polar landmasses, such as Greenland and Antarctica, causes sea levels around the world to rise. The rise in sea levels could affect coastal areas in several ways. Coastal wetlands and other low-lying areas could be flooded. Enormous numbers of people who live near coastlines could lose their homes and sources of income. Beaches could be extensively eroded. The salinity of bays and estuaries might increase, which could adversely affect marine fisheries. Also, coastal freshwater aquifers could become too salty to be used as sources of fresh water.

Global Weather Patterns If the Earth warms up significantly, the surface of the oceans will absorb more heat, which may make hurricanes and typhoons more common. Some scientists are concerned that global warming will also cause a change in ocean current patterns, such as shutting off the Gulf Stream. Such a change could significantly affect the world's weather. For instance, some regions might have more rainfall than normal, whereas other regions might have less. Severe flooding could occur in some regions at the same time that droughts devastate other regions.

Human Health Problems Warmer average global temperatures pose potential threats to human health. Greater numbers of heat-related deaths could occur. Very young and very old city dwellers are at greatest risk during heat waves. Since trees and flowering plants, such as grasses, would flower earlier and for longer than they do now, people who are allergic to pollen would suffer from allergies for more of the year. As well, warmer temperatures could enable mosquitoes—vectors of diseases such as malaria, dengue fever, and encephalitis—to establish themselves in areas that are too cold for them at the moment.

Graphic Organizer **Spider Map**
Create the **Graphic Organizer** entitled "Spider Map" described in the Appendix. Label the circle "Consequences of Global Warming." Create a leg for each consequence of global warming. Then, fill in the map with details about each consequence of global warming.

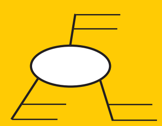


Figure 19 ▶ These corn plants died from a lack of water.

Agriculture Agriculture would be most severely impacted by global warming if extreme weather events, such as droughts, became more frequent. The effects of drought are shown in **Figure 19.** Higher temperatures could result in decreased crop yields. The demand for irrigation could increase, which would further deplete aquifers that have already been overused.

SCILINKS. www.scilinks.org
Topic: Global Warming
Code: HE80681

Effects on Plants and Animals Climate change could alter both the range of plant species and the composition of plant communities. Trees could colonize cooler areas. Forests could shrink in the warmer part of their range and lose diversity.

Global warming may cause a shift in the geographical range of some animals. For example, birds in the Northern Hemisphere may not have to migrate as far south for winter. Warming in the surface waters of the ocean might cause a reduction of zooplankton, which many marine animals depend on for food. The crabeater seal, shown in **Figure 20,** would be just one of the animals affected by fewer zooplankton. Warming in tropical waters may kill the algae that nourish corals, thus destroying coral reefs.

Figure 20 ▶ In spite of its name, the crabeater seal actually feeds on zooplankton. This seal is a resident of Antarctica.

Recent Findings

The Intergovernmental Panel on Climate Change (IPCC) is a network of approximately 2,500 of the world's leading climatologists from 70 countries. In 2001, the IPCC issued its Third Assessment Report (TAR). TAR describes what is currently known about the global climate system and provides future estimates about the state of the global climate system. Some of the findings of the IPCC included that the average global surface temperature increased by 0.6°C during the 20th century, that snow cover and ice extent have decreased, and that the average global sea level has risen. The IPCC has also reported that concentrations of atmospheric greenhouse gases have continued to increase as a result of human activities. It has also predicted that human influences will continue to change the composition of the Earth's atmosphere throughout the 21st century.

Reading Check **What are two ways that drought could affect agriculture on a warmer Earth?**

Reducing the Risk

In 1997, representatives from 160 countries met and set timetables for reducing emissions of greenhouse gases. These timetables will go into effect when a treaty called the *Kyoto Protocol* is ratified by 55 percent of the attending nations. The **Kyoto Protocol** requires developed countries to decrease emissions of carbon dioxide and other greenhouse gases by an average of 5 percent below their 1990 levels by 2012. In March of 2001, the United States decided not to ratify the Kyoto Protocol. Most developed nations are going ahead with the treaty.

The need to slow global warming has been recognized by the global community. Some nations and organizations have engaged in reforestation projects to reduce CO_2, such as the project shown in **Figure 21.** However, the attempt to slow global warming is made difficult by the economic, political, and social factors faced by different countries. Conflict has already arisen between developed and developing countries over future CO_2 emissions, the projections of which are shown in **Figure 22.**

Figure 21 ▶ Because plants take in carbon dioxide during photosynthesis, reforestation projects such as this project in Haiti help to offset a portion of global carbon dioxide emissions.

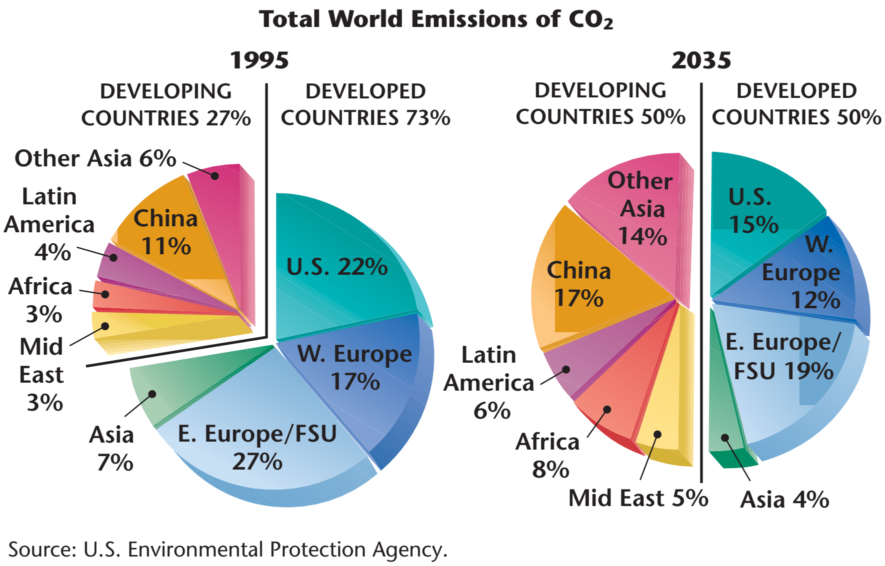


Figure 22 ▶ Developing countries are projected to make up half of all CO_2 emissions by 2035. In 1995, total carbon released as CO_2 was 6.46 billion tons (5.86 billion metric tons). In 2035, total carbon emissions are projected to be 11.71 billion tons (10.62 billion metric tons).

SECTION 3 Review

1. **Explain** why Earth's atmosphere is like the glass in a greenhouse.
2. **Explain** why carbon dioxide in the atmosphere is increasing.
3. **Explain** one theory for why Earth's climate is becoming warmer.
4. **Name** some of the possible consequences of a warmer Earth.

CRITICAL THINKING

5. **Making Predictions** Read the text under the heading "Modeling Global Warming." What difficulties do scientists face when they attempt to construct models that accurately predict the rate of global warming? READING SKILLS
6. **Analyzing Relationships** How could environmental problems in developing countries that result from global climate change affect the economies of developed countries, such as the United States?

CHAPTER 13 Highlights

1 Climate and Climate Change

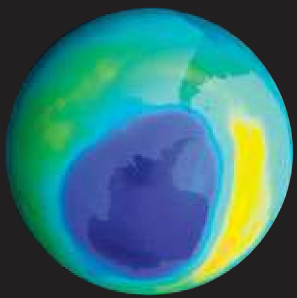
Key Terms

climate, 351
latitude, 352
El Niño, 356
La Niña, 356

Main Ideas

- Climate is the long-term prevailing weather conditions at a particular place.
- Factors that determine climate include latitude, atmospheric and oceanic circulation patterns, local geography, and solar and volcanic activity. Latitude is the most important determining factor of climate.
- The angle at which the sun's rays strike the Earth changes as the Earth moves around the sun. This change in angle is what causes the seasons to change.

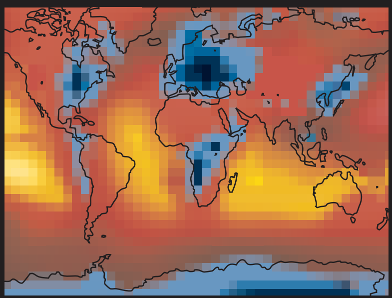
2 The Ozone Shield



ozone layer, 359
chlorofluorocarbons (CFCs), 359
ozone hole, 360
polar stratospheric clouds, 360

- The ozone layer in Earth's stratosphere absorbs most of the ultraviolet (UV) light from the sun.
- Chlorofluorocarbons are human-made chemicals that destroy ozone molecules and damage the ozone layer.
- Ozone levels measured over the polar regions have been decreasing over the past several decades.
- Thinning of the ozone layer increases the amount of ultraviolet light that reaches Earth's surface.

3 Global Warming



greenhouse gases, 363
global warming, 365
Kyoto Protocol, 369

- Gases that absorb and radiate heat in the atmosphere are called *greenhouse gases*. The important greenhouse gases are water vapor, carbon dioxide, CFCs, methane, and nitrous oxide.
- The predicted increase in global temperature that occurs as a result of increasing greenhouse gases in the atmosphere is called *global warming*.
- Because climate patterns are complex, scientists use computer models to attempt to predict the rate of global warming.
- Global warming could produce a number of potentially serious environmental problems.
- In 1997, representatives from 160 countries ratified the Kyoto Protocol, which set timetables for reducing emissions of greenhouse gases.

CHAPTER 13 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *latitude*
2. *El Niño*
3. *chlorofluorocarbons*
4. *polar stratospheric clouds*
5. *Kyoto Protocol*

For each pair of terms, explain how the meanings of the terms differ.

6. *weather* and *climate*
7. *El Niño* and *La Niña*
8. *ozone layer* and *ozone hole*
9. *greenhouse gases* and *global warming*

STUDY TIP

Qualifiers When taking a test, locate qualifiers in the sentences. Qualifiers are words that modify or limit the meaning of another word or group of words. *Never, always, all, some, none, greatest,* and *least* are examples of qualifiers.

Understanding Key Ideas

10. The belt of prevailing winds that is produced between 30° and 60° north latitudes and 30° and 60° south latitudes is called the
    a. doldrums.
    b. westerlies.
    c. polar easterlies.
    d. trade winds.
11. Which of the following statements about El Niño is true?
    a. El Niño is the cold phase of the El Niño–Southern Oscillation cycle.
    b. El Niño is a long-term change in the location of warm and cold water masses in the Pacific Ocean.
    c. El Niño produces storms in the northern Pacific Ocean.
    d. El Niño produces winds in the western Pacific Ocean that push warm water eastward.
12. Polar stratospheric clouds convert the products of CFCs into
    a. carbon dioxide.
    b. hydrochloric acid.
    c. nitric acid.
    d. molecular chlorine.
13. Which of the following is *not* an adverse effect of high levels of ultraviolet light?
    a. disruption of photosynthesis
    b. disruption of ocean food chains
    c. premature aging of the skin
    d. increased amount of carbon dioxide in the atmosphere
14. In which season (in the Northern Hemisphere) does carbon dioxide in the atmosphere decrease as a result of natural processes?
    a. fall
    b. winter
    c. summer
    d. spring
15. Which of the following gases is a greenhouse gas?
    a. carbon dioxide
    b. water vapor
    c. methane
    d. all of the above
16. Which of the following substances is *not* a source of methane?
    a. fossil fuels
    b. sewage
    c. fertilizer
    d. rice
17. The average global temperature increased by how many Celsius degrees during the 20th century?
    a. 0.4°C
    b. 0.6°C
    c. 0.8°C
    d. 1.0°C
18. Which of the following countries decided not to ratify the Kyoto Protocol?
    a. Russia
    b. United States
    c. Canada
    d. Finland

CHAPTER 13 Review

Short Answer

19. Name three properties of air that are important for understanding how air circulation affects global climate.

20. Explain how local geography can influence the local pattern of precipitation.

21. Describe the properties chlorofluorocarbons possess that made them seem like miracle chemicals when they were discovered.

22. Explain why stratospheric ozone protection has been considered an environmental success story.

23. Explain the general process scientists use to make computer models of global warming.

24. Describe some of the environmental problems that rising sea level might cause.

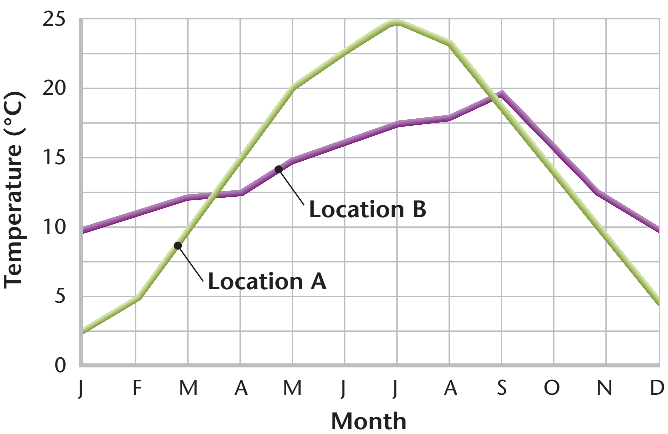
25. Describe what is currently known about the state of the climate system as reported in the Third Assessment Report of the Intergovernmental Panel on Climate Change.

Interpreting Graphics

The graph below shows the average monthly temperature of two locations that are at the same latitude but are in different parts of the United States. Use the graph to answer questions 26–27.

26. Which location has the smallest temperature range between summer and winter?

27. What factors could cause the difference in climate between the two locations?



Concept Mapping

28. Use the following terms to create a concept map: *ozone layer, ultraviolet (UV) light, chlorofluorocarbons, polar vortex, polar stratospheric clouds,* and *ozone hole.*

Critical Thinking

29. Making Predictions Over a long period of time, how might living things adapt to increased carbon dioxide levels and global warming? Do you think most species will adapt, or are many species likely to go extinct? Write a short essay that explains your answers. **WRITING SKILLS**

30. Analyzing Relationships Read about the harmful effects that ultraviolet light can have on humans as a result of ozone thinning under the heading "Effects of Ozone Thinning on Humans." However, ultraviolet light serves an extremely important function that benefits life on Earth. What is this function and how does it help make life on Earth possible? **READING SKILLS**

Cross-Disciplinary Connection

31. Economics Insurance companies set some of their rates by estimating the number of destructive natural events, such as hurricanes and floods, that will occur in the next 20 years. Explain why insurance companies would be interested in knowing scientists' predictions about global warming for the next two decades.

Portfolio Project

32. Designing a Pamphlet Design a pamphlet that documents the harmful effects of ultraviolet light on living things. Table 1 can be used as a source of information. You might also collect information by checking out the Web sites of the American Cancer Society and the Environmental Protection Agency. Distribute the pamphlet to your classmates, and include it in your portfolio.

MATH SKILLS

33. **Making Calculations** In 1958, the carbon dioxide level measured in Earth's atmosphere was approximately 315 parts per million. In 2000, the carbon dioxide level in the atmosphere had increased to approximately 368 ppm. What was the average annual increase in carbon dioxide in the atmosphere between 1958 and 2000 measured in parts per million?

WRITING SKILLS

34. **Communicating Main Ideas** Imagine that you are a scientist who is studying the effects of chlorofluorocarbons on stratospheric ozone. Follow the path of a chlorine atom from the time it is released into the atmosphere from a CFC source through the time it has destroyed ozone molecules. Summarize your findings in a brief essay.
35. **Writing Persuasively** Imagine you are a scientist who has been studying the subject of global warming. You have been asked by the President of the United States to write a recommendation for his environmental policy on the subject. The President has asked you to provide important facts that can be used to promote the proposed policies. Summarize your recommendations in a brief letter.
36. **Writing Persuasively** You are the mayor of a low-lying coastal town. Write a plan of expansion for your town. The plan should take global warming into account. Report your plan of expansion in front of the class.

READING SKILLS

Read the passage below, and then answer the questions that follow.

During photosynthesis, a plant takes in carbon dioxide from the air. Some of the carbon in the carbon dioxide becomes part of the plant's body. That carbon is not returned to the air until the leaves fall or the plant dies and decays.

Some plants, however, never completely decay. Instead, they are covered by sediments. After millions of years of being buried, the plants become coal, oil, and natural gas, which are fossil fuels. When fossil fuels are burned, they release the stored carbon as carbon dioxide. Millions of tons of carbon dioxide are released into the atmosphere each year from power plants that burn coal or oil and from cars that burn gasoline.

The burning of living plants also releases carbon dioxide. This process increases the carbon dioxide in the air in two ways. First, a burning plant gives off carbon dioxide. Second, when a living plant is burned, there is one less plant to remove carbon dioxide from the air by photosynthesis. As millions of trees are burned in tropical rain forests to clear the land for farming, the amount of carbon dioxide in the atmosphere increases.

1. According to the above passage, plants give off carbon dioxide
   a. when they are buried under sediments.
   b. when they die and decay.
   c. when they are burned.
   d. Both (b) and (c)

2. According to the passage above, which of the following is a process that does *not* add carbon dioxide to the atmosphere?
   a. the decay of plants
   b. photosynthesis
   c. burning trees in tropical rain forests
   d. burning coal in power plants

Standardized Test Prep

Understanding Concepts

Directions (1–4): **For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 Which of the following is the most important factor in determining climate?
- **A.** volcanic activity
- **B.** nearness to an ocean
- **C.** distance from the equator
- **D.** atmospheric circulation patterns

2 What causes the changes of seasons on Earth?
- **F.** the relatively constant flow of oceanic currents
- **G.** the tilt of Earth's axis as Earth moves around the sun
- **H.** the distribution of precipitation influenced by topography
- **I.** the changes in prevailing wind patterns at different latitudes

3 The development and widespread use of CFCs led to what scientific discovery?
- **A.** CFC molecules are chemically stable.
- **B.** CFC molecules contain chlorine atoms.
- **C.** CFC molecules are destroying the ozone layer.
- **D.** CFC molecules are protecting the ozone layer.

4 Why would global warming have an effect on sea levels?
- **F.** The warmth would cause polar icecaps to melt.
- **G.** There would be widespread beach erosion.
- **H.** Rainfall would increase all around the globe.
- **I.** There would be increased cloud cover blocking the sunlight.

Directions (5): **Write a short response for the queston below.**

5 The Earth's atmosphere acts like the glass in a greenhouse. Predict what would happen to life on Earth if Earth did not have a greenhouse effect.

Reading Skills

Directions (6–7): **Read the passage below. Then answer the questions.**

Many scientists hypothesize that the increasing greenhouse gases in our atmosphere will result in increasing average temperatures on Earth. Scientists are currently unable to make accurate predictions about the rate of global warming because climatic patterns are complex and too many variables must be taken into account to be solved even using today's fastest computers. The computer models predict how phenomena such as temperature, rainfall patterns, and sea level, will be affected by carbon dioxide levels, prevailing winds, and other variables.

Computer modeling is complicated by Earth's feedback systems which sometimes make it necessary to use different equations under changing simulated environments.

6 How could faster computers influence the predictions of climate change?
- **A.** Faster computers could produce more data.
- **B.** Faster computers could solve more complex equations.
- **C.** Faster computers could reduce the number of variables needed.
- **D.** Faster computers could increase the degree of certainty over a prediction.

7 Assess the information needed by scientists to build computer models that can predict climate change.

Directions (8): **Read the passage below. Then answer the question.**

El Niño is the name given to the periodic change in the location of warm and cold water masses in the Pacific Ocean. During an El Niño, winds in the western Pacific Ocean, which are usually weak, strengthen and push warm water eastward.

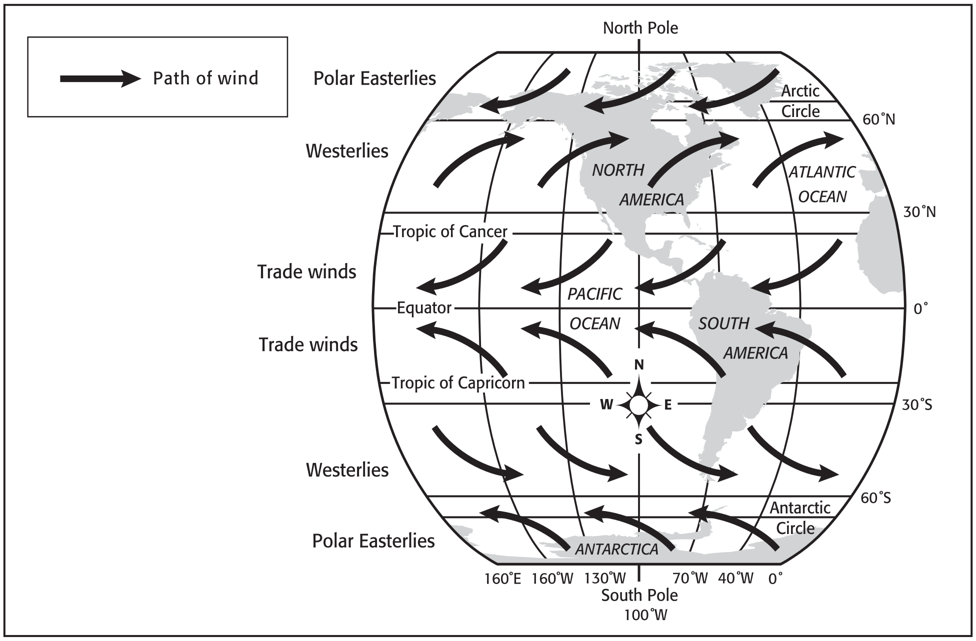
8 How would you expect El Niño to affect climate in the United States?

Interpreting Graphics

Directions (9–11): **For *each* question below, record the correct answer on a separate sheet of paper.**

The map below shows wind patterns across the Earth. Use this map to answer questions 9 through 11.

Global Wind Patterns



9 Which of the following characteristics has the **largest** effect on wind movement?

F. cardinal direction
G. latitude
H. longitude
I. seasonal change

10 Central America is located in the western hemisphere, linking North and South America. Which way does the wind blow in Central America?

A. northeast to southwest
B. southeast to northwest
C. northwest to southeast
D. southwest to northeast

11 If you were sailing from North America to Europe, in which range of latitudes would you sail?

F. 0° to 30°N
G. 30°N to 60°N
H. 0° to 30°S
I. 30°S to 60°S

Test TIP

Before looking at the answer choices for a question, try to answer the question yourself.

CHAPTER 13

Inquiry Lab: MODELING

Objectives

- **Examine** a model that shows how the movement of air creates a system of wind currents on Earth.
- USING SCIENTIFIC METHODS **Hypothesize** why the closed system of an aquarium is like the Earth and its atmosphere.

Materials

aquarium, 15 gal, glass, with cover
goose-neck lamp, adjustable, with a 100 W incandescent bulb
ice cubes, large (24)
incense stick
masking tape
matches
thermometers, outdoor (2)

Build a Model of Global Air Movement

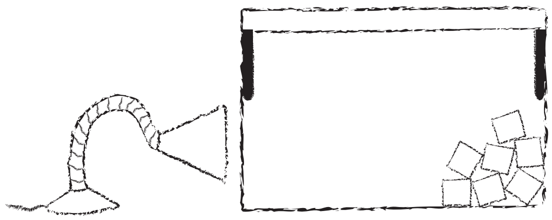
Warm air rises and cools, and cold air sinks and warms. This is true whether we are observing the temperature and air circulation in a room or around the globe. On Earth, this movement of air creates a system of wind currents that you will demonstrate by building a model. You will build a closed system in which ice represents the polar regions and a lamp represents the equator. You will follow the movement of the air over these regions by watching a trail of smoke as it traces the path of air. (Remember that in the global circulation pattern, warm air moving toward the poles collides with cold air that is traveling from the poles. This collision, which takes place at about 60° north latitude and 60° south latitude, causes the warm air to rise.)

Procedure

1. Stack the ice cubes on the bottom of the aquarium against one end of it. Place the lamp outside the other end of the aquarium, and direct the bulb at the bottom half of that end. Use masking tape to attach one thermometer to each end inside of the aquarium. Make sure the thermometers can be read from the outside of the aquarium. Place the cover on the aquarium.
2. Wait 5 minutes. Then read and record the temperature at each end of the aquarium.
3. Light the end of the incense stick so that it produces a steady plume of smoke.

Step 1 Attach a thermometer to each end of the aquarium, making certain that the thermometers can be read from the outside of the aquarium.

4. Lift the aquarium cover very slightly so that you can insert the incense stick. Hold it steadily in place over the ice about 5 cm from the cover, and observe the smoke.
5. Observe the movement of the smoke. How does the smoke behave? Draw a diagram of the aquarium. Use arrows to indicate the movement of the smoke in the aquarium.
6. Remove several ice cubes and record your observations.
7. Remove all of the ice cubes and record your observations.



▶ **Diagramming Smoke Flow** Make a simple diagram of the aquarium showing the position of the light source and the ice cubes. Draw arrows to indicate the movement of the smoke in the aquarium.

Analysis

1. **Explaining Events** Did the air movement pattern change after some ice was removed? Explain your answer.
2. **Explaining Events** Did the air movement pattern change after all of the ice was removed? Explain your answer.

Conclusions

3. **Drawing Conclusions** Why is the difference between temperatures at the two ends of the aquarium an important factor in the flow of heat through the aquarium?
4. **Making Predictions** Predict how air movement patterns will change if polar ice begins to thaw because of global warming.

Extension

1. **Analyzing Models** A closed system is a collection of elements that nothing can escape from or enter. Your aquarium is an example of a closed system. Convection is the movement of warm air relative to cooler air. Discuss your observations of convection in the closed system of the aquarium. How can you apply this information to the movement of air over the Earth?
2. **Analyzing Models** How is the Earth and its atmosphere like the closed system of your aquarium? What factors that affect air movement, climate, and weather exist on Earth but not in your model?

Making a difference

EARTH SCIENCE CONNECTION

OZONE SCIENTIST

Susan Solomon will not soon forget crawling across the roof of an Antarctic field station in windchill temperatures of –62°C (–80°F), moving heavy equipment, and adjusting mirrors while the winds howled and whipped about her. Sounds like an adventure, right? It sure was! But it is just part of what Solomon has done to establish herself as one of the world's leading authorities on ozone destruction.

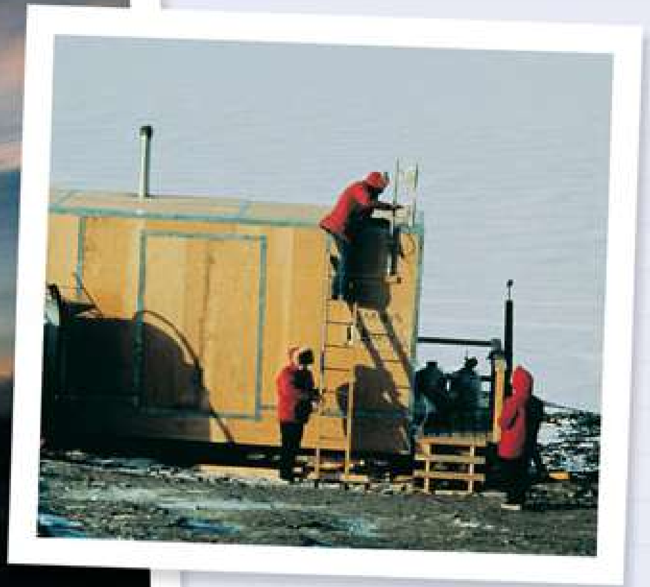
Q: Is it true that you have traveled to the ends of the Earth to get information about the ozone layer?
A: Yes, I guess it is. My colleagues and I have studied the ozone hole in Antarctica, and we've measured and documented ozone chemistry above Greenland. But it's not all adventure. When I'm not visiting one of the poles, I run computer simulations of the atmosphere and study data at the National Oceanic and Atmospheric Administration (NOAA) in Boulder, Colorado.

Q: What is the significance of discoveries regarding the ozone hole?
A: Before British scientists discovered the ozone hole in Antarctica, no one was sure about ozone changes in the atmosphere. The popular belief was that in 100 years there might be 5 percent less ozone. So there were questions about whether it was a serious environmental problem. But when the British researchers released data that showed 50 percent less ozone over Antarctica in 1985 than was present 20 years earlier, the research raised our awareness that the problem was far more serious than previously thought.

▶ The ozone hole can be seen in this satellite image. The hole is the pale blue and black region immediately above Solomon's shoulder.

Q: How have you contributed to the study of ozone?
A: Well, when the British data was first released, no one had much of an explanation about what was causing the destruction of the ozone layer. I thought about the problem a lot. Later that year, I sat in on a lecture about types of clouds called *polar stratospheric clouds*. These are beautifully colored clouds that are known for their iridescence. While I was looking at these clouds, which are common in the Antarctic but rare elsewhere, it occurred to me that they may have something to do with ozone depletion. Perhaps they provide a surface for chemical reactions that activate reactive chlorine from CFCs (human-made chlorofluorocarbons). If so, once activated, the chlorine could contribute to reactions that destroy ozone.

Q: Did you get the chance to test your hypothesis?
A: Yes, the next year the National Science Foundation chose me to lead a group of 16 scientists for a nine-week expedition in Antarctica. We were the first team of scientists from the United States sent to the Antarctic to study the ozone hole. Within one month we could see that unnaturally high levels of chlorine dioxide did occur in the stratosphere during ozone depletion. This discovery was very exciting because it seemed that we were on the right track. We kept collecting data that year and collected more data during a second trip the next year. Pretty soon, the evidence seemed to support my hypothesis that CFCs and ozone depletion are linked.



▶ Solomon has braved freezing polar temperatures to gather data about the ozone hole.

▶ Polar stratospheric clouds like these led Susan Solomon to make important discoveries about the cause of ozone depletion.

Q: How did this discovery make you feel?
A: On the one hand, it's very exciting scientifically to be involved in something like this. On the other hand, sometimes I think it's a little depressing. It would be nice to be involved in something more positive, to bring people good news. So far, we've brought nothing but bad news. We were hoping that we wouldn't find the same ozone chemistry in the Arctic that we found in the Antarctic. Unfortunately, we did. We hope for a positive result for the planet, but we don't always get it.

Q: How has your research helped to make a difference in our world?
A: Since our findings and others were announced, many of the world's countries have agreed to restrict or ban the use of CFCs. As a result, the ozone hole will eventually go away, but it will take a very long time. So although most countries have slowed their use of CFCs, CFCs from years past will still be hanging around in our atmosphere for the next 50 to 100 years. But I think our work has led in a small way to the realization that our actions do have consequences, and this realization should bring positive change.

Dr. Solomon has received international recognition for her work on the ozone hole over the Antarctic. She is a member of the U.S. National Academy of Sciences, the European Academy of Sciences, and the Académie des Sciences de France. In 2000, Dr. Solomon was awarded the National Medal of Science and the American Meteorological Society's Carl-Gustav Rossby Medal. In April 2002, she was nominated co-chair of the United Nations Climate Change Working Panel.

For More Information

If you would like free information about the ozone layer and what you can do to protect it, contact the Environmental Protection Agency, Public Outreach, 401 M St. SW, Washington, DC 20460.

What Do You Think?

If Susan Solomon had not sat in on the lecture about polar stratospheric clouds and had not realized the role that these clouds play in ozone destruction, where do you think our current understanding of the ozone hole would be? How does this reinforce the idea that a single person can make a tremendous contribution to humankind?