Climate

What You'll Learn

- What causes different climates.
- How climates are classified.
- How climates change as a result of natural events and human activities.

Why It's Important

This rain forest is one example of the wide variety of plants found in different climates. Climate affects where we live, what we wear, and what we eat. Changes in climate can have far-reaching effects on agriculture, industry, transportation, and recreation.

Earth Science Online

To find out more about climate, visit the Earth Science Web Site at **earthgeu.com**

Temperate rain forest, Australia

CONTENTS

Discovery Lab

Model Cloud Cover

Some areas are generally more cloudy than others. This affects both the temperature and the amount of precipitation that these areas receive. In this activity, which should be done only when the weather forecast calls for clear, calm skies overnight, you'll model the effect of cloud cover on local temperatures.

1. On a calm, clear afternoon, lay two sheets of dark construction paper on the grass in an open area. Place a rock on each sheet of paper to prevent them from blowing away.

2. Open an umbrella and prop it on the ground over one of the sheets of paper.

3. The next morning, observe what has happened to the sheets of paper.

Observe In your science journal, describe any differences in dew formation that you observed. How is the umbrella in this activity similar to clouds in the atmosphere? Based on your observations, infer how temperatures during the night might differ between climates with extensive cloud cover and climates with fewer clouds.

SECTION 14.1 *What is climate?*

OBJECTIVES

- **Describe** *different types of climate data.*
- **Recognize** *limits associated with the use of normals.*
- **Explain** *why climates vary.*

VOCABULARY

climatology   tropics
climate   temperate zone
normal   polar zone

Fifty thousand years ago, the United States had much different weather patterns than those that exist today. The average temperature was several degrees cooler, and the jet stream was probably farther south. Understanding and predicting such climatic changes are the basic goals of climatology. **Climatology** is the study of Earth's climate and the factors that affect past, present, and future climatic changes.

CLIMATE: MORE THAN JUST AVERAGE WEATHER

Climate, as you'll recall from Chapter 12, describes the long-term weather patterns of an area. These patterns include much more than average weather conditions. Climate also describes annual variations of temperature, precipitation, wind, and other weather variables. Studies of climate show extreme fluctuations of these variables over time. For example, climatic data can indicate the warmest and coldest temperatures ever recorded for a location. This type of information, combined with comparisons between recent conditions and

long-term averages, can be used by companies to decide where to locate new facilities and by people who have medical conditions that require them to live in certain climates.

NORMALS

The data used to describe an area's climate are compiled from meteorological records, which are continuously gathered at thousands of locations around the world. These data include daily high and low temperatures, amounts of rainfall, wind speed and direction, humidity, and air pressure. Once the data are gathered, they are averaged on a monthly or annual basis for a period of at least 30 years to determine the **normals,** or standard values, for a location. The *Problem-Solving Lab* below lists some normals for Jacksonville, Florida.

Problem-Solving Lab

Making and Using Tables

Infer climatic conditions from normals Normals offer a comprehensive look at local weather conditions over relatively long periods of time. Use the data provided in the table to answer the following questions about the climate of Jacksonville, Florida.

Analysis

1. According to normal daily maximum temperatures, during what months would you expect the temperature to reach at least 90°F?
2. What were the highest and lowest temperatures ever recorded in this city, and in what month and year?

Thinking Critically

3. Use graph paper to plot the monthly values for normal daily maximum temperatures which cover the 30-year time period from 1966 through 1996. Next, use the monthly values to calculate the average daily maximum temperature for the 30-year period.
4. Which months were warmer than the average daily maximum temperature of the 30-year period? Which months were colder?

Normals for Jacksonville, Florida													
Temperature F°	Time Period (Years)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Normal Daily Maximum	30	64.2	67.0	73.0	79.1	84.7	89.3	91.4	90.7	87.2	80.2	73.6	66.8
Highest Daily Maximum	55	85	88	91	95	100	103	105	102	100	96	88	84
Year of Occurrence		1947	1962	1974	1968	1967	1954	1942	1954	1944	1951	1986	1994
Normal Daily Minimum	30	40.5	43.3	49.2	54.9	62.1	69.1	71.9	71.8	69.0	59.3	50.2	43.4
Lowest Daily Minimum	55	7	19	23	34	45	47	61	63	48	36	21	11
Year of Occurrence		1985	1996	1980	1987	1992	1984	1972	1984	1981	1989	1970	1983

While normals offer valuable information, they must be used with caution. Weather conditions on any given day might differ widely from normals. For instance, the average high temperature in January for a city might be 0°C. However, it's possible that no one day in January had a high of exactly 0°C. Normals are not intended to describe usual weather conditions. They are simply the average values over a long period of time.

Another issue complicates the use of normals. While climate describes the average weather conditions for a region, normals apply only to the specific place where the meteorological data were collected. Most meteorological data are gathered at airports, which cannot operate without up-to-date, accurate weather information. Do you know anyone who lives at an airport? Probably not. In fact, many airports are located well outside city limits because of the noise and traffic that they generate. When climatic normals are based on airport data, they may differ quite a lot from actual weather conditions in nearby cities. Why? Changes in elevation and other factors such as proximity to large bodies of water can cause climates to vary, as you'll learn next.

WHAT CAUSES CLIMATES?

One glance at the map shown in *Figure 14-1* shows that climates around the country vary greatly. For example, average daily temperatures are much warmer in Dallas, Texas, than in Minneapolis,
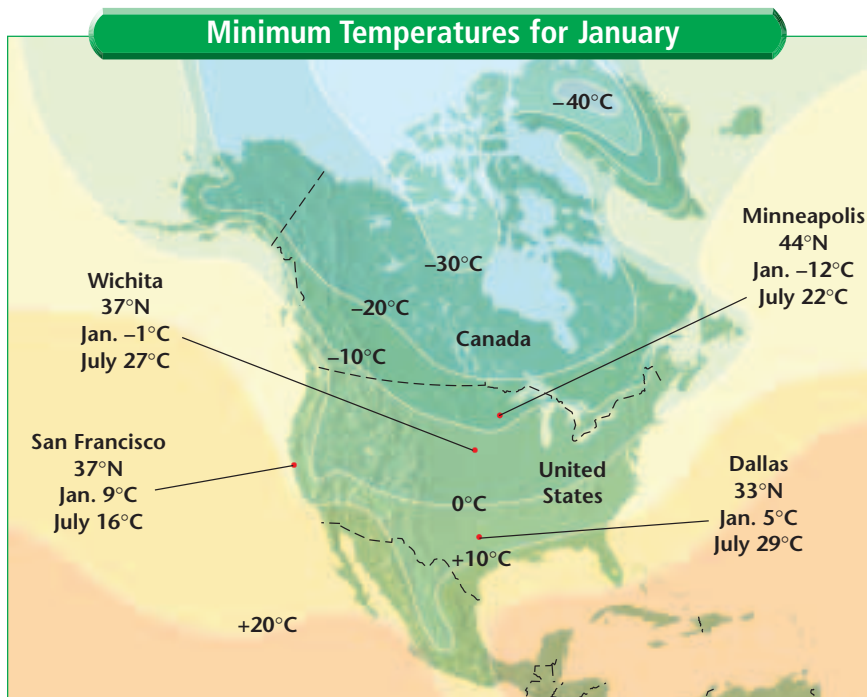

Minimum Temperatures for January

−40°C

Minneapolis
44°N
Jan. −12°C
July 22°C

−30°C

Wichita
37°N
Jan. −1°C
July 27°C

−20°C

−10°C

Canada

San Francisco
37°N
Jan. 9°C
July 16°C

0°C

United
States

Dallas
33°N
Jan. 5°C
July 29°C

+10°C

+20°C

Figure 14-1 This map shows daily minimum temperature in January across the United States. The latitudes of the cities are shown because, as you'll learn on the next page, latitude greatly affects climate.
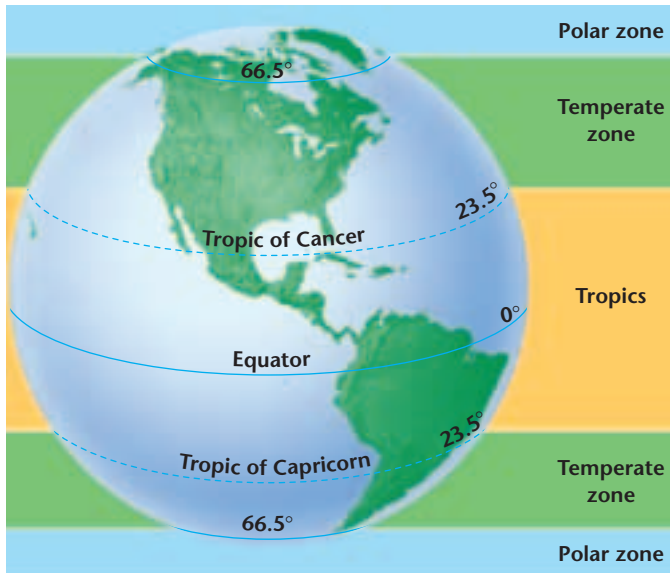
Figure 14-2 Latitude has a great effect on climate. The amount of solar radiation received on Earth decreases in intensity from the equator to the poles.

Minnesota. There are several reasons for such climatic variations, including latitude, topography, closeness of lakes and oceans, availability of moisture, global wind patterns, ocean currents, and air masses.

Latitude Recall that different parts of Earth receive different amounts of solar radiation. The amount of solar radiation received by any one place varies because Earth is tilted on its axis, and this affects how the Sun's rays strike Earth's surface. As *Figure 14-2* shows, the area between 23.5° south of the equator and 23.5° north of the equator, known as the **tropics,** receives the most solar radiation because the Sun's rays strike that area from almost directly overhead. As you might expect, temperatures in the tropics are generally warm year-round. The **temperate zones** lie between 23.5° and 66.5° north and south of the equator. As their name implies, temperatures in these regions are moderate. The **polar zones** are located from 66.5° north and south of the equator to the poles. Solar radiation strikes the polar zones at a low angle. Thus, polar temperatures are nearly always cold.

Topographic Effects Water heats up and cools down more slowly than land. Thus, large bodies of water affect the climates of coastal areas. Many coastal regions are warmer in the winter and cooler in the summer than inland areas of similar latitude.

Also, temperatures in the lower atmosphere generally decrease with altitude. Thus, mountain climates are usually cooler than those at sea level. In addition, climates often differ on either side of a mountain. Air rises up one side of a mountain as a result of orographic lifting. The rising air cools, condenses, and drops its moisture. The climate on this side of the mountain—the windward side—is usually wet and cool. On the opposite side of the mountain—the leeward side—the air is dry, and it warms as it descends. For this reason, deserts are common on the leeward sides of mountains, as shown in *Figure 14-3.*

CONTENTS

A

B

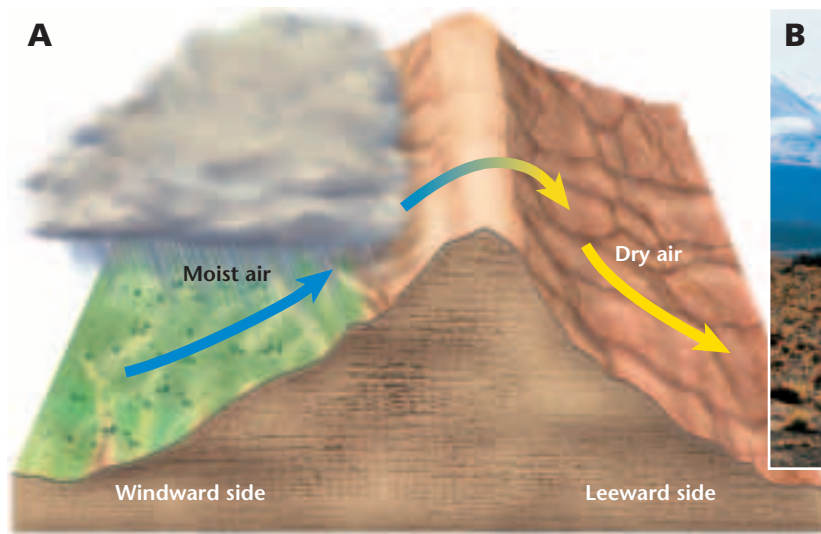Moist air

Dry air

Windward side

Leeward side

Figure 14-3 On the windward side of a mountain, moist air is forced upward, cools, condenses, and drops its moisture **(A).** The air and the climate on the leeward side of the mountain are dry. Deserts such as the Atacama in Chile are common on leeward sides of mountains **(B).**

Air Masses Two of the main causes of weather are the movement and interaction of air masses. Air masses affect climate, too. They have distinct regions of origin, caused primarily by differences in the amount of solar radiation. The properties of air masses are also dependent on whether they formed over land or water.

Average weather conditions in and near regions of air-mass formation are fairly similar to those exhibited by the air masses themselves. For example, consider an island in the tropical Atlantic Ocean. Because this island is located in an area where maritime tropical (mT) air masses dominate the weather, the island's average weather conditions, or climate, have maritime tropical characteristics.

SECTION ASSESSMENT

1. Compare and contrast temperatures in the tropics, temperate zones, and polar zones.

2. Infer how climate data can be used by farmers.

3. What are some limits associated with the use of normals?

4. Describe two topographic features that cause variations in climate.

5. **Thinking Critically** Average daily temperatures for one city, located at 15° south latitude, are 5°C cooler than average daily temperatures for a second city, located at 30° south latitude. What might account for the cooler temperatures in the first city, which lies so near the equator?

SKILL REVIEW

6. **Forming a Hypothesis** Suppose that meteorological data for an area are normally gathered at an airport located 10 km from a large lake. Hypothesize how normals for the area might change if the data were gathered from the edge of the lake. For more help, refer to the *Skill Handbook.*
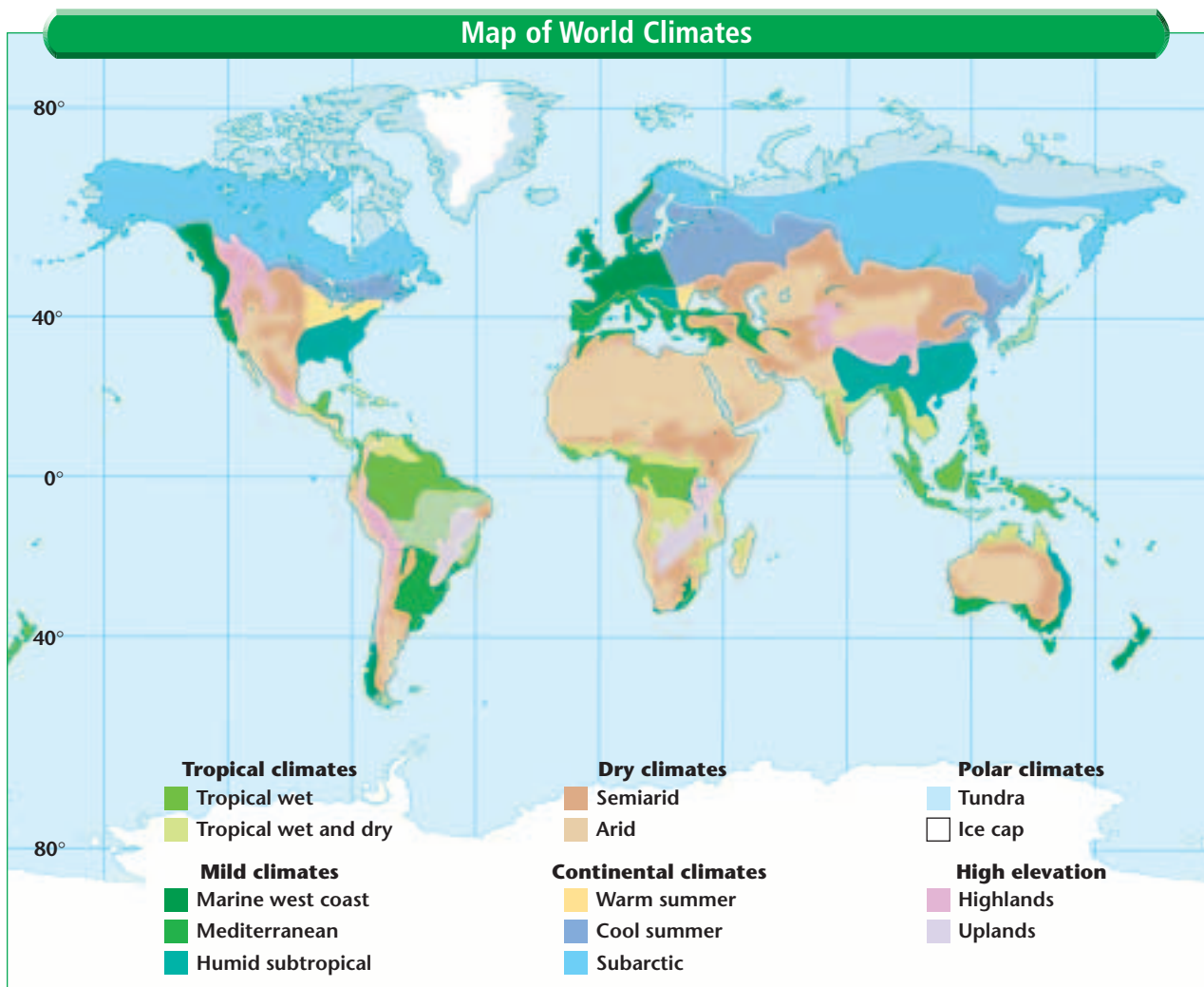
Climate Classification

OBJECTIVES

• **Describe** *the criteria used to classify climates.*

• **Compare** *and* **contrast** *different climates.*

VOCABULARY

Koeppen classification system
microclimate
heat island

Picture a parched desert with wind-blown dunes stretching toward the horizon. Now, imagine a glistening iceberg floating amid a polar sea. These images represent vastly different climates. What criteria would you use to classify them? Temperature is an obvious choice, as is amount of precipitation. The **Koeppen classification system,** a widely used classification system for climates, uses both of these criteria. Developed by Russian-born German climatologist Wladimir Koeppen (1846–1940), the system is based on the average monthly values of temperature and precipitation. It also takes into account the distinct vegetation found in different climates.

Figure 14-4 Koeppen's classification system, shown here in a modified version, is made up of six main divisions.

Map of World Climates

Tropical climates
- Tropical wet
- Tropical wet and dry

Mild climates
- Marine west coast
- Mediterranean
- Humid subtropical

Dry climates
- Semiarid
- Arid

Continental climates
- Warm summer
- Cool summer
- Subarctic

Polar climates
- Tundra
- Ice cap

High elevation
- Highlands
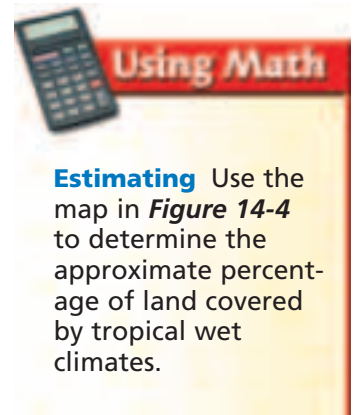- Uplands

CONTENTS

KOEPPEN CLASSIFICATION SYSTEM

Koeppen decided that a good way to distinguish among different climatic zones was by natural vegetation. Palm trees, for instance, are not located in polar regions; they are largely limited to tropical and subtropical regions. Koeppen later realized that quantitative values would make his system more objective and therefore more scientific. Thus, he revised his system to include the numerical values of temperature and precipitation. A map of global climates according to a modified version of Koeppen's classification system is shown in *Figure 14-4.*

Tropical Climates Constant high temperatures characterize tropical climates. In some tropical areas, the heat is accompanied by up to 600 cm of rain each year. The combination of heat and rain produces tropical rain forests, which contain some of the most dramatic vegetation on Earth. You saw an example of a tropical rain forest in the photograph at the beginning of this chapter. Tropical regions are almost constantly under the influence of maritime tropical air. The transition zones that border the rainy tropics north and south of the equator, known as tropical wet and dry zones, have distinct dry winter seasons as a result of the occasional influx of dry continental air masses. Tropical wet and dry zones include savannas, as shown in *Figure 14-5.* These tropical grasslands are found in Africa, among other places.

Dry Climates Dry climates, which cover about 30 percent of Earth's land area, make up the largest climatic zone. Most of the world's deserts, such as the Sahara, the Gobi, and the Australian, are classified as dry climates. In these climates, continental tropical (cT) air dominates, precipitation is low, and vegetation is scarce. Many of these areas are located near the tropics. Thus, intense amounts of solar radiation result in high rates of evaporation and few clouds. Overall, evaporation rates exceed precipitation rates. The resulting moisture deficit gives this zone its name. Within this classification, there are two subtypes: arid regions or deserts, and semi-arid regions or steppes. Steppes are more humid than deserts; they generally separate arid regions from bordering wet climates.

Using Math

Estimating Use the map in *Figure 14-4* to determine the approximate percentage of land covered by tropical wet climates.

Figure 14-5 This watering hole in Botswana is found in a savanna.

Figure 14-6 The Golden Gate Bridge in San Francisco, California, is nearly hidden beneath a dense layer of fog. Fog is characteristic of marine west coast climates.

Mild Climates Mild climates can be classified into three subtypes: humid subtropical climates, marine west coast climates, and mediterranean climates. Humid subtropical climates are influenced by the subtropical high-pressure systems that are normally found over oceans in the summer. The southeastern United States has this type of climate. There, warm, muggy weather prevails during the warmer months and dry, cool conditions predominate during the winter. The marine west coast climates are dominated by the constant inland flow of air off the ocean, which creates mild winters and cool summers, with abundant precipitation throughout the year. An example of this type of climate is shown in *Figure 14-6.* Mediterranean climates, found in Italy and parts of Spain, among other places, are influenced by the Mediterranean Sea. Summers in these climates are generally warm because the lack of cool ocean currents in the Mediterranean Sea results in relatively warm water temperatures.

Continental Climates Continental climates are also classified into three subtypes: warm summer climates, cool summer climates, and subarctic climates. Located in the zone dominated by the polar front, continental climates are battlegrounds for clashing tropical and polar air masses. Thus, these zones experience rapid and sometimes violent changes in weather. Both summer and winter temperatures can be extreme because the influence of polar air masses is strong in winter, while warm tropical air dominates in summer. The presence of warm, moist air causes summers to be generally wetter than winters, especially in latitudes that are relatively close to the tropics.

Polar Climates To the north of continental climates lie the polar climates, the coldest regions on Earth. Just as the tropics are known for their year-round warmth, polar climates are known for their constant cold—the mean temperature of the warmest month is less than 10°C. Precipitation is generally low because cold air holds less moisture than warm air. Also, the amount of heat radiated by Earth's surface is too low to produce the strong convection currents needed to release heavy precipitation. *Figure 14-7A* shows an ice-cap polar climate.

A variation of the polar climate is found at high elevations. This type of climate includes parts of the Andes Mountains of South America, shown in *Figure 14-7B,* which lie near the equator. The intense solar radiation found near such equatorial regions is offset by the decrease in temperature that occurs with altitude.

Figure 14-7 Penguins are one of the few species that can survive in Antarctica's ice-cap polar climate **(A).** Llamas are common in the high-elevation climates of the Andes Mountains **(B).**

MICROCLIMATES

Sometimes, the climate of a small area can be much different from that of the larger area surrounding it. A localized climate that differs from the main regional climate is called a **microclimate.** If you climb to the top of a mountain, you can experience a type of microclimate; the climate becomes cooler with increasing elevation. You'll learn more about microclimates in the *Design Your Own GeoLab* at the end of this chapter. *Figure 14-8* shows a microclimate in a city.
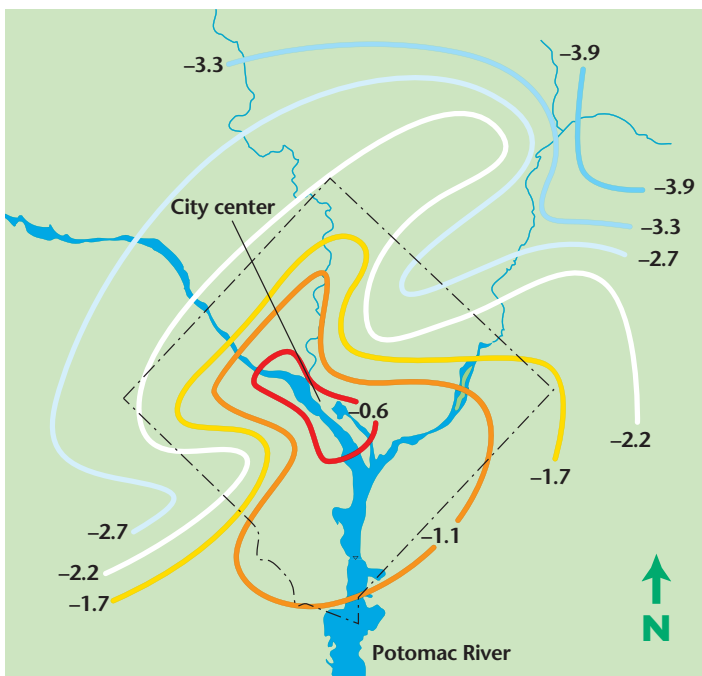

Figure 14-8 This diagram shows winter temperatures in Washington, D.C. The buildings and paved surfaces of the city create a microclimate. The temperature in the center of the city is –0.6°C, nearly 3°C warmer than temperatures in some parts of the surrounding area.
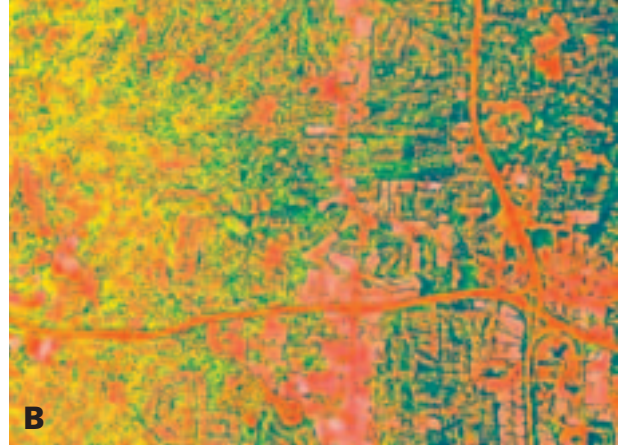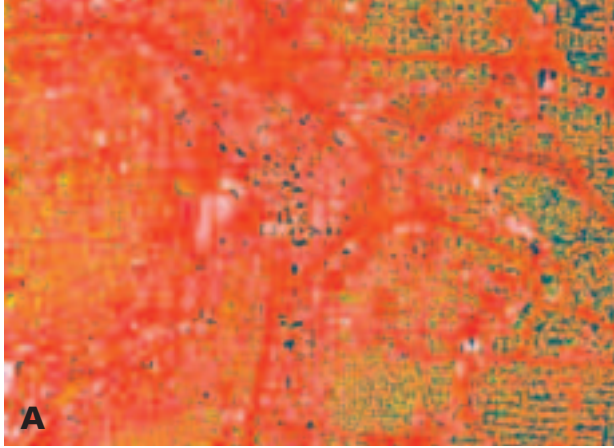
A

B

Figure 14-9 These images show differences in daytime temperatures between an urban area **(A)** and a suburban area **(B).** The coolest temperatures are represented by blue; the warmest temperatures are represented by red.

Heat Islands The mere presence of a building can create microclimates in the area immediately surrounding it. How? The building casts shadows that lower air temperature. The presence of many concrete buildings and large expanses of asphalt can create **heat islands,** wherein the climate is warmer than in surrounding rural areas. This effect was recognized as long ago as the early nineteenth century, when Londoners noticed that the temperature in their city was noticeably warmer than in the surrounding countryside.

The heat-island effect occurs because large areas of asphalt and concrete radiate far more heat into the air than do grasslands, wooded areas, and bodies of water. This causes mean temperatures in large cities to be significantly warmer than in surrounding areas, as shown in *Figure 14-9.* The heat-island effect also causes greater changes in temperature with altitude, which sparks strong convection currents. This in turn produces increased cloudiness and up to 15 percent more total precipitation in cities.

Heat islands are examples of climatic change on a small scale. In the next sections, we'll examine large-scale climatic changes caused by both natural events and human activities.

SECTION ASSESSMENT

1. Compare and contrast the five main climate types.
2. What criteria is the Koeppen climate classification system based on?
3. What are microclimates? What climatic effects do heat islands have on large cities?
4. Describe the climate of your area. Which zone do you live in? What type of air masses generally affect your climate?

5. **Thinking Critically** Of the different types of climates, which do you think would be most strongly influenced by the polar jet stream? Why?

SKILL REVIEW

6. **Making and Using Tables** Make a table of the Koeppen climate classification system. Include major zones, subzones, and characteristics of each. For more help, refer to the *Skill Handbook.*

SECTION 14.3 *Climatic Changes*

Some years may be warmer, cooler, wetter, or drier than others, but during the average human lifetime, climates do not appear to change significantly. However, a study of Earth's history over hundreds of thousands of years shows that climates always have been, and currently are, in a constant state of change. These changes usually take place over extremely long time periods. Geologic records show that in the past, Earth was sometimes much colder or warmer than it is today.

ICE AGES

A good example of climatic change involves glaciers, which have alternatively advanced and retreated over the past 2 million years. At times, much of Earth's surface was covered by vast sheets of ice. During these periods of extensive glacial coverage, called **ice ages,** average global temperatures decreased by an estimated 5°C. Although this may not seem like a large decrease, global climates became generally colder and snowfall increased, which sparked the advance of existing ice sheets. Ice ages alternate with warm periods called interglacial intervals—we are currently experiencing such an interval. The most recent ice age ended only about 10 000 years ago. In North America, glaciers spread from the east coast to the west coast and as far south as Indiana, as shown in *Figure 14-10.* The results of this glacial period are apparent in the Great Lakes and the Finger Lakes of central New York, which were scoured out as the glaciers retreated.

OBJECTIVES

• **Distinguish** *among different types of climatic changes.*

• **Recognize** *why climatic changes occur.*

VOCABULARY

ice age
season
El Niño
Maunder minimum

Figure 14-10 The last ice age covered large portions of North America, Europe, and Asia. Average global temperatures were roughly 5°C lower than normal.

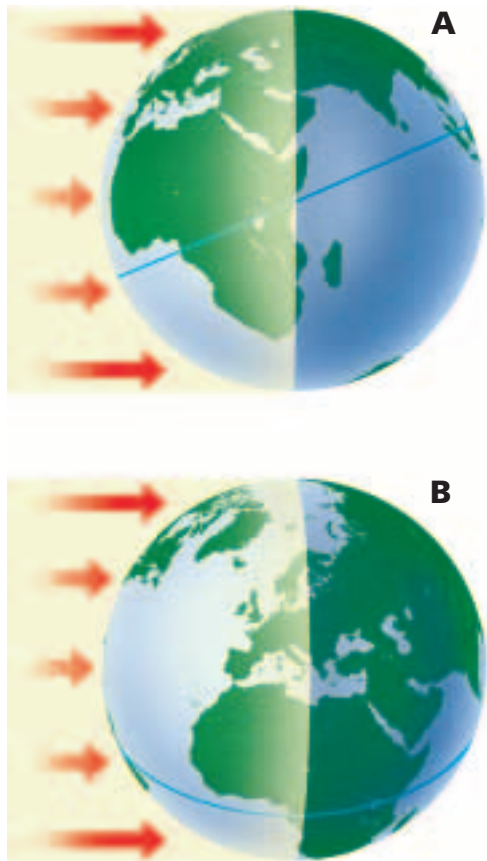14.3 *Climatic Changes* **369**

◄ CONTENTS ►

A

B

Figure 14-11 When the north pole is pointed toward the Sun, the northern hemisphere experiences summer and the southern hemisphere experiences winter **(A).** During spring and fall, neither pole points toward the Sun **(B).**

SHORT-TERM CLIMATIC CHANGES

While ice ages take place over many thousands of years, other climatic changes take place in much shorter time periods. The most obvious of these are **seasons,** which are short-term periods of climatic change caused by regular variations in daylight, temperature, and weather patterns. These variations are the result of changes in the amount of solar radiation an area receives. As *Figure 14-11* shows, the tilt of Earth on its axis as it revolves around the Sun causes different areas of Earth to receive different amounts of solar radiation. During summer in the northern hemisphere, the north pole is tilted toward the Sun, and this hemisphere experiences long hours of daylight and warm temperatures. At the same time, it is winter in the southern hemisphere. The south pole is tilted away from the Sun, and the southern hemisphere experiences long hours of darkness and cold temperatures. Throughout the year, the seasons are reversed in the north and south hemispheres.

El Niño Other short-term climatic changes are caused by **El Niño,** a warm ocean current that occasionally develops off the western coast of South America. In the Southeast Pacific Ocean, atmospheric and ocean currents along the coast of South America normally move north, transporting cold water from the Antarctic region. Meanwhile, the trade winds and ocean currents move westward across the tropics, keeping warm water in the western Pacific. This circulation, driven by a semipermanent high-pressure system, creates a cool, dry climate along much of the northwestern coast of South America.

Occasionally, however, for reasons that are not fully understood, this high-pressure system and its attendant trade winds weaken drastically, which allows the warm water from the western Pacific to surge eastward toward the South American coast. The sudden presence of this warm water heats the air near the surface of the water. Convection currents strengthen, and the normally cool and dry northwestern coast of South America becomes much warmer and wetter. The increased precipitation pumps large amounts of heat and moisture into the upper atmosphere, where upper-level winds transport the hot, moist air eastward across the tropics. This hot, moist air in the upper atmosphere is responsible for dramatic climatic changes. Sharp temperature differences in the upper air allow the jet stream to shift farther south. This causes weather systems to take a more southerly track, bringing violent storms to California and the Gulf Coast, which are usually south of the storm tracks.

Figure 14-12 During El Niño, some areas of the world experience extreme droughts while other areas are ravaged by heavy floods.

The effects of hot, moist upper air spread farther east, bringing stormy weather to areas that are normally dry and drought conditions to areas that are normally wet. The end result is extensive property damage and untold human suffering. This is especially true in tropical regions, where the effects of El Niño are most pronounced. El Niño does have one positive effect—the strong upper winds it produces keep tropical disturbances from increasing to hurricane-strength storms in the Atlantic Ocean. This results in fewer hurricanes in that region for the duration of El Niño. Eventually, the South Pacific high-pressure system becomes reestablished and El Niño weakens, but not before it causes the climatic effects shown in *Figure 14-12.* The warm water moves back across the Pacific Ocean, and conditions along the South American coast cool off.

CHANGE CAN BE NATURAL

Much discussion has taken place in recent years about whether Earth's climate is changing as a result of human activities. We'll discuss this in the next section. For now, it's important to note that climatic changes occurred long before humans came on the scene. Studies of tree rings, ice-core samples, fossils, and radiocarbon samples provide evidence of past climatic changes. These changes in Earth's climate were caused by natural events such as variations in solar activity, changes in Earth's tilt and orbit, and volcanic eruptions.

Figure 14-13 Very few sunspots occurred during the Maunder minimum, and temperatures were lower than normal. Thus, scientists theorize solar activity may be linked to climatic changes.

Climate and Sunspots
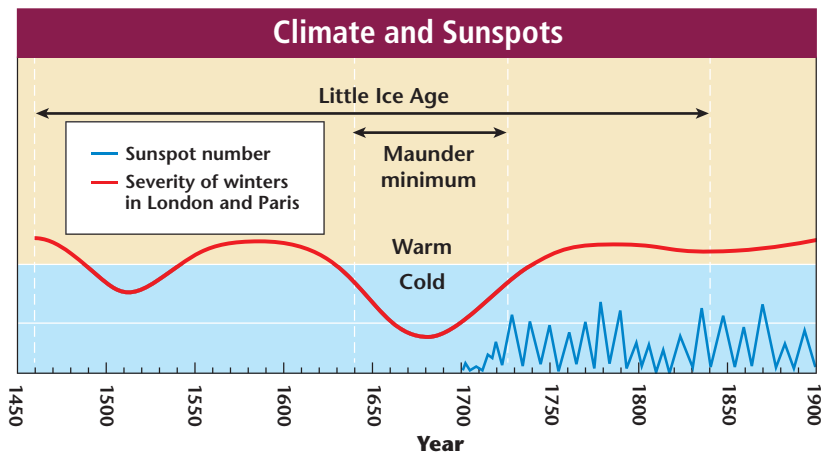
Solar Activity Evidence of a possible link between solar activity and Earth's climate was provided by English astronomer E. W. Maunder in 1893. The existence of sunspot cycles lasting approximately 11 years had been recognized since the days of Galileo. However, Maunder found that from 1645 to 1716, sunspot activity was scarce to nonexistent. This period of very low sunspot activity, called the **Maunder minimum,** closely corresponds to an unusually cold climatic episode called the "Little Ice Age." During this time, much of Europe experienced bitterly cold winters and below-normal temperatures year-round. Residents of London are said to have ice-skated on the Thames River in June. The relationship between climate and periods of low sunspot activity is illustrated in *Figure 14-13.* Studies indicate that increased solar activity coincides with warmer-than-normal climates, while periods of low solar activity, such as the Maunder minimum, coincide with cold climatic conditions.

Figure 14-14 Scientists theorize that a more elliptical orbit around the Sun could produce significant changes in Earth's climate.
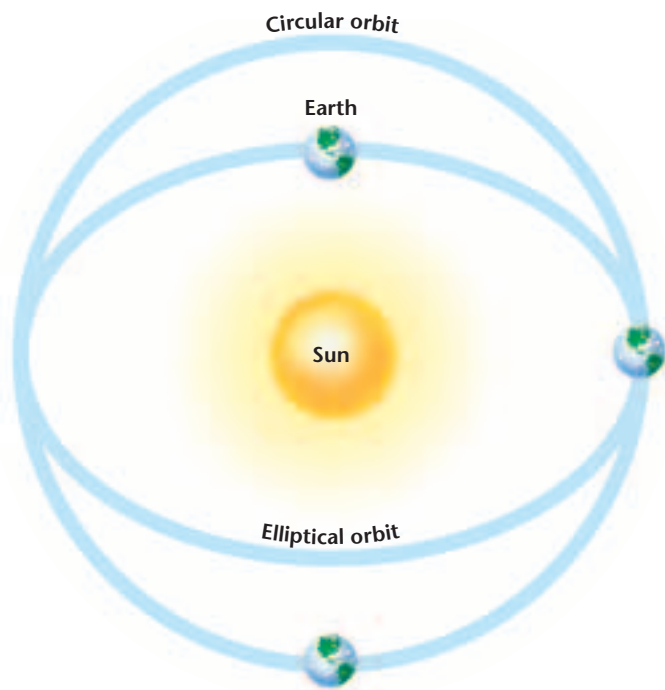
Earth's Orbit Climatic changes may also be triggered by changes in Earth's axis and orbit. The shape of Earth's elliptical orbit appears to change, becoming more elliptical, then more circular, over the course of a 100 000-year cycle. As *Figure 14-14* shows, when the orbit elongates, Earth passes closer to the Sun, and temperatures become warmer than normal. When the orbit is more circular, Earth is farther from the Sun and temperatures dip below average. The amount of radiation
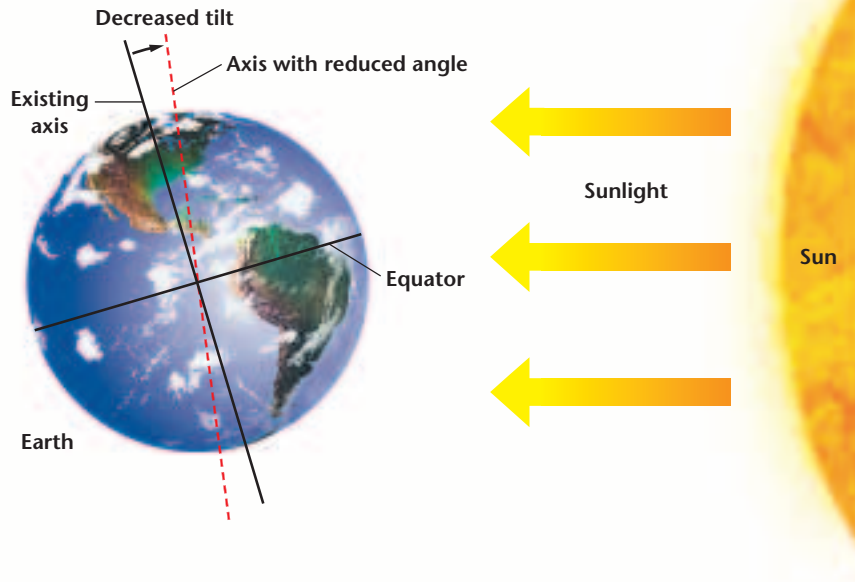
Figure 14-15 If the angle of tilt of Earth's axis decreased, there would be less temperature contrast between summer and winter.

Earth receives when its orbit elongates is much higher than when its orbit is more circular.

As you know, seasons are caused by the tilt of Earth's axis. At present, the angle of the tilt is 23.5°. However, the angle of tilt varies from a minimum of 22.1° to a maximum of 24.5° every 41 000 years. Scientists theorize that these changes in angle cause seasons to become more severe. For example, a decrease in the angle of the tilted axis, as shown in *Figure 14-15,* might cause a decrease in the temperature difference between winter and summer. Winters would be warmer and wetter, and summers would be cooler. The additional snow in latitudes near the poles would not melt in summer because temperatures would be cooler than average. This could result in expanded glacial coverage. In fact, some scientists hypothesize that changes in the angle of Earth's tilted axis cause ice ages.

Earth's Wobble Another movement of Earth may be responsible for climatic changes. Over a period of about 26 000 years, Earth wobbles as it spins on its axis. Currently, the axis points toward the North Star, Polaris, as shown in *Figure 14-16.* Because of Earth's wobbling, however, the axis will tilt toward another star, Vega, by about the year 14 000. Currently, winter occurs in the northern hemisphere when Earth is closest to the Sun, and summer occurs when Earth is farthest from the Sun. When the axis tilts toward Vega, however, winter will occur in the northern hemisphere when Earth is farthest from the Sun, and summer will occur when Earth is closest to the Sun. This will cause warmer summers and colder winters than those that we now experience.

Figure 14-16 By about the year 14 000, Earth's axis will point toward the star, Vega. Winter will then occur in the northern hemisphere when Earth is farthest from the Sun, causing winters to be colder.
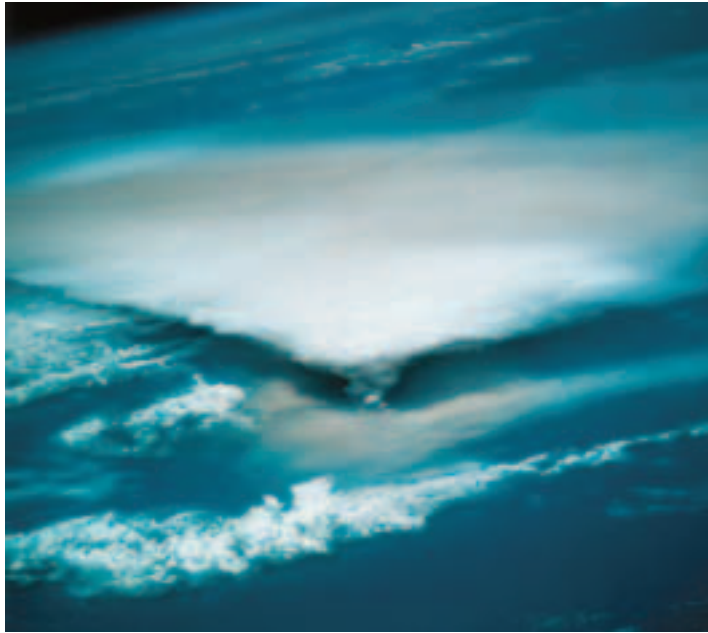

14.3 *Climatic Changes* **373**
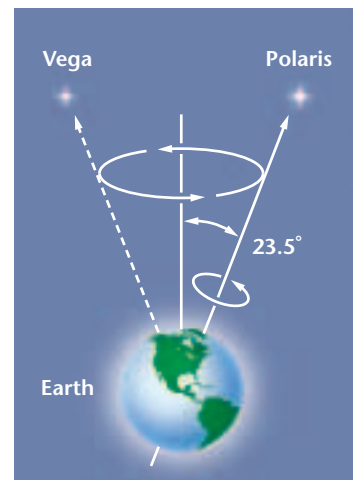
Figure 14-17 The dust and gases released by this volcanic eruption in New Guinea blocked incoming solar radiation and affected global climates.

Volcanic Activity Climatic changes can also be triggered by the immense quantities of dust released into the atmosphere during major volcanic eruptions, shown in *Figure 14-17.* Volcanic dust can remain suspended in the atmosphere for several years, blocking incoming solar radiation and thus lowering global temperatures. Some scientists theorize that periods of high volcanic activity cause cool climatic periods. This theory is supported by records over the past century because several large eruptions have been followed by below-normal global temperatures. For instance, the ash released during the 1991 eruption of Mt. Pinatubo in the Philippines resulted in slightly cooler temperatures around the world the following year. Generally, volcanic eruptions appear to have only short-term effects on climate. These effects, as well as the others you've read about thus far, are a result of natural causes. In the next section, you'll learn about climatic changes caused by human activities.

SECTION ASSESSMENT

1. What three changes in Earth's movement in space might result in long-term climatic changes?

2. What are seasons? What causes them?

3. Explain how El Niño might affect weather in California and along the Gulf Coast.

4. Why are the greatest effects of El Niño experienced mainly in the tropics?

5. How does volcanic activity affect climate? Are these effects examples of short-term or long-term climatic change?

6. **Thinking Critically** What might be the effect on seasons if Earth's orbit became more elliptical and, at the same time, the angle of the tilt of Earth's axis increased?

SKILL REVIEW

7. **Concept Mapping** Use the following phrases to complete a concept map of the effects of El Niño. For more help, refer to the *Skill Handbook.*

1. upper-level winds transport heated air across the tropics

2. precipitation increases

3. jet stream shifts south

4. convection currents strengthen

5. trade winds weaken

6. warm water surges eastward, heating surface air

7. high-pressure system becomes reestablished

SECTION 14.4 *The Human Factor*

One of the most significant influences on Earth's climate is the atmosphere. As you learned in Chapter 11, solar radiation that is not reflected by clouds passes freely through the atmosphere. It's then absorbed by Earth's surface and released as long-wavelength radiation. This radiation is absorbed by atmospheric gases such as water vapor, methane, and carbon dioxide. The atmospheric gases then reradiate the stored energy, so that Earth receives energy from two sources: the Sun and the atmosphere.

THE GREENHOUSE EFFECT

The retention of heat by the atmosphere results in the **greenhouse effect,** which is the natural heating of Earth's surface caused by certain atmospheric gases called greenhouse gases. Without the greenhouse effect, which is illustrated in *Figure 14-18,* life as we know it could not exist on Earth. Our planet would be cold, like Mars, which has an extremely thin atmosphere and surface temperatures that dip to –90°C. On the other hand, a marked increase in the greenhouse effect might cause our planet to be hot, like Venus, which, because of

OBJECTIVES

- **Compare** *and* **contrast** *the greenhouse effect and global warming.*
- **Identify** *how humans impact climate.*
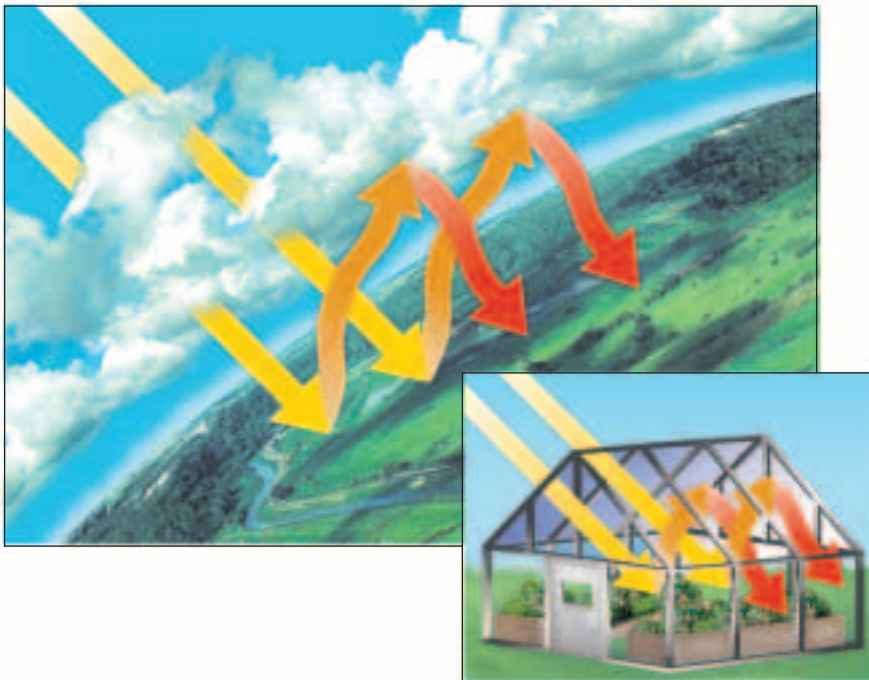
VOCABULARY

greenhouse effect
global warming

Figure 14-18 Solar radiation reaches Earth's surface and is reradiated as long-wavelength radiation. This radiation cannot escape through the atmosphere, and is absorbed and re-released by atmospheric gases. This process is called the greenhouse effect because it is similar to the way that heat is trapped and released in a greenhouse.

How does the atmosphere affect the transfer of energy?

Model the greenhouse effect.

Procedure

1. On a clear day, place a cardboard box outside in a shaded area. Prop two thermometers against the box. Make sure the thermometers are not in direct sun.
2. Cover one thermometer with a clean glass jar.
3. Observe and record the temperature changes of each thermometer every two minutes over a 30-minute period.

Analyze and Conclude

1. Make a graph showing how the temperatures of the two thermometers changed over time.
2. Based on your graph, which thermometer experienced the greatest increase in temperature? Why?
3. Relate your observations to the greenhouse effect in the atmosphere.

its thick atmosphere, has surface temperatures of 470°C. You'll model the greenhouse effect in the *MiniLab* on this page.

Scientists theorize that it is possible to increase or decrease the greenhouse effect by changing the amount of atmospheric greenhouse gases, particularly carbon dioxide (CO_2). Any increase in the amount of these gases would theoretically result in the increased absorption of radiation. Levels of atmospheric carbon dioxide are increasing. This in turn can lead to a rise in global temperatures, known as **global warming.**

GLOBAL WARMING

Temperatures worldwide have indeed shown an upward trend over the past 200 years, with several of the warmest years on record having occurred within the last two decades. If the trend continues, polar ice caps might melt, sea level might rise and flood coastal cities, deserts could spread into fertile regions, and the frequency and severity of storms could increase.

Based on available evidence, many scientists agree that global warming is occurring. They disagree, however, about what is causing this warming. As you've learned, natural cycles of Earth and the Sun can affect climate. Some scientists hypothesize that these natural changes adequately explain the increased temperatures. Mounting evidence indicates, however, that the warming trend is a result of increases in atmospheric carbon dioxide. Global warming remains a controversial issue. Neither viewpoint can be proven or disproven conclusively; it might very well be that there are several factors involved. However, if increased carbon dioxide is responsible, two logical questions follow: What is causing the increase? Can anything be done to stop it?

IMPACT OF HUMAN ACTIVITIES

To find a possible cause for rising levels of atmospheric carbon dioxide, we need look no further than our driveways. Automobile exhaust is a prime source of atmospheric CO_2, as are industrial emissions. In fact, almost any process that involves the burning of fossil fuels results in the release of carbon dioxide and other gases into the atmosphere. In addition, deforestation, the mass removal of trees, plays a role in increasing levels of atmospheric CO_2. During photosynthesis, vegetation removes carbon dioxide from the atmosphere. When trees such as the ones shown in *Figure 14-19A* are cut down, rates of photosynthesis are reduced and more carbon dioxide remains in the atmosphere. Many scientists hypothesize that deforestation intensifies global warming trends.

ENVIRONMENTAL EFFORTS

Because global warming appears to be linked to human activities that cause pollution or widespread deforestation, we must closely examine those activities and work to reduce their environmental impact. Individuals can combat global warming by conserving energy, which in turn reduces the consumption of fossil fuels. Some easy ways to conserve energy include turning off appliances and lights when a room is not in use, turning down thermostats in the winter, and recycling. An additional option is shown in *Figure 14-19B.* You'll learn more about global warming in the *Science & Math* feature at the end of this chapter.

Figure 14-19 Deforestation in places such as Guatemala may increase global warming **(A).** Automobile exhaust may also increase global warming; thus, riding bikes is one way to help the environment **(B).**

SECTION ASSESSMENT

1. Why do some scientists theorize that global warming might not be the result of increases in atmospheric carbon dioxide?

2. What are some possible consequences of global warming?

3. Describe some human activities that may have an impact on Earth's climate. List several actions you can take to reduce this impact.

4. Compare and contrast global warming and the greenhouse effect.

5. **Thinking Critically** Based on what you have learned in this section, explain why tropical rain forests are often called the "lungs" of our planet.

SKILL REVIEW

6. **Designing an Experiment** When green plants photosynthesize, they take carbon dioxide out of the atmosphere. Design an experiment in which you could use green plants and glass jars to study the effects of carbon dioxide on global warming. For more help, refer to the *Skill Handbook.*

Microclimates

Microclimates can be caused by tall buildings, large bodies of water, and mountains, among other things. In this activity, you'll observe different microclimates and then attempt to determine which factors strengthen microclimates and how these factors change with distance from Earth's surface.

Preparation

Problem
Which type of surface creates the most pronounced microclimate?

Possible Materials
thermometer
psychrometer
paper strip or wind sock
meterstick
relative humidity chart *(Appendix F)*

Hypothesis
Hypothesize how different areas of Earth's surface, such as grassy lawns, asphalt parking lots, and bodies of water, affect local climates. Consider also whether distance from the ground might affect temperature, relative humidity, and wind speed.

Objectives
In this GeoLab, you will:
- **Design** and **carry out** an experiment to study microclimates both at Earth's surface and above its surface.
- **Observe** and **record** temperature, relative humidity, and wind speed.
- **Infer** how different surfaces and changes in height above these surfaces affect microclimates.

Safety Precautions
Be careful when you handle glass thermometers, especially those that contain mercury. If the thermometer breaks, do not touch it. Have your teacher properly dispose of the glass and the mercury.

Plan the Experiment

1. As a group, agree upon and write out your hypothesis. List the steps needed to test your hypothesis. Include in your plan how you will use your equipment to measure temperature, relative humidity, and wind speed at different surfaces and at various heights above these surfaces.
2. Select your sites. Possible sites include a grassy playground area, a paved parking lot, and a swimming pool.
3. Be sure to control variables. For instance, different members of your group should make observations at each site at the same time each day. You'll also need to record weather variables at several different distances above each surface. Possible distances include 5 cm, 1 m, and 2 m.
4. Make a map of your test sites. Design and construct data tables for recording your observations. You'll need separate data tables for each site.
5. Read over your entire plan to make certain all steps are in logical order. Identify constants and variables in your plan.
6. Make sure your teacher approves your plan before you proceed with your experiment.
7. Carry out your plan.

Analyze

1. **Comparing and Contrasting** Map your data. Color code the areas on your map to show which surfaces had the highest and lowest temperatures, the highest and lowest relative humidity, and the greatest and least wind speed. On your map, include data for surface areas only.
2. **Making and Using Graphs** Graph your data for each site, showing differences in temperature with height. Plot temperature on the x-axis and height on the y-axis. Repeat this step for relative humidity and wind speed.
3. **Interpreting Scientific Illustrations** Analyze your maps, graphs, and data to find patterns. Which surfaces had the most pronounced microclimates? Did height above the surface affect your data? Infer why or why not.
4. **Thinking Critically** Analyze your hypothesis and the results of your experiment. Was your hypothesis supported? Explain.

Conclude & Apply

1. Why did some areas have more pronounced microclimates than others? Which factors seemed to contribute most to the development of microclimates?
2. Which variable changed most with height: temperature, relative humidity, or wind speed? Which variable changed least? Infer why some variables changed more than others with height.

Science & Math

Global Warming

According to the National Academy of Scientists, Earth's surface temperature has risen about one degree Fahrenheit in the past 100 years. This increase in temperature can be correlated to an increase in the concentration of carbon dioxide and other greenhouse gases in the atmosphere. How might this increase in temperature affect Earth's climate?

Carbon dioxide is one of the greenhouse gases that helps keep temperatures on Earth warm enough to support life. However, a build-up of carbon dioxide and other greenhouse gases such as methane and nitrous oxide can lead to global warming, an increase in Earth's average surface temperature. Since the industrial revolution in the 1800s, atmospheric concentrations of carbon dioxide have increased by almost 30 percent, methane concentrations have more than doubled, and nitrous oxide concentrations have increased approximately 15 percent. Scientists attribute these increases to the burning of fossil fuels for automobiles, industry, and electricity, as well as deforestation, increased agriculture, land-fills, and mining.

Impact on Climate

Based on current data, scientists estimate that Earth's average surface temperature could rise between 1 and 4.5 degrees Fahrenheit in the next 50 years. As the temperature increases, evaporation rates increase, which can lead to increased precipitation. With increased evaporation rates, soil may become drier and intense rainstorms more frequent. Some scientists esti-mate that sea levels may rise as much as two feet along most of the U.S. coast.

Procedure

1. Create a line graph which displays the information shown in the data table below.

Challenge

1. During which time period did Earth's atmosphere experience a slow, steady increase in carbon dioxide? Describe the carbon dioxide increase in the last 50 years.

2. Assuming that carbon dioxide levels continue to increase at the current rate, predict the global atmospheric CO_2 concentration in parts per million in the year 2015.

Global Levels of Atmospheric CO_2			
Year	Global Atmospheric CO_2 Concentration (parts per million)	Year	Global Atmospheric CO_2 Concentration (parts per million)
1745	279	1949	311
1791	279.7	1958	312
1816	283.8	1965	318
1843	287.4	1974	330.1
1854	288.2	1984	344.3
1874	289.5	1994	358.8
1894	297	1995	361
1909	299.2	1996	363
1921	301.6	1997	364
1935	306.6	1998	367

Summary

SECTION 14.1
What is climate?
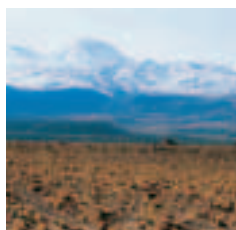
Main Ideas
- Climate describes the long-term weather patterns of a region. Climatological data include annual variations of temperature, precipitation, wind, and other weather variables, as well as extreme fluctuations in these variables.
- The factors that influence climate include latitude, topography, closeness of lakes and oceans, availability of moisture, global wind patterns, ocean currents, and air masses.

Vocabulary
climate (p. 359)
climatology (p. 359)
normal (p. 360)
polar zone (p. 362)
temperate zone (p. 362)
tropics (p. 362)

SECTION 14.2
Climate Classification

Main Ideas
- The Koeppen classification system divides climates into five basic types according to temperature, rainfall, and vegetation.
- A microclimate is a localized climate that differs from the surrounding regional climate. In cities, the numerous concrete buildings and large expanses of asphalt can create heat islands, wherein the climate is warmer than in surrounding rural areas.

Vocabulary
heat island (p. 368)
Koeppen classification system (p. 364)
microclimate (p. 367)

SECTION 14.3
Climatic Changes

Main Ideas
- Earth's climate is in a constant state of change. These changes usually take place over extremely long time periods. Fossils, ice cores, and other geologic records show that Earth was sometimes much colder or warmer than it is today.
- Periods of extensive glacial coverage, called ice ages, are examples of long-term climatic changes. Examples of short-term climatic changes include the seasons and the effects of El Niño.
- Some changes in Earth's climate may be caused by a combination of numerous natural cycles involving solar activity, changes in the tilt of Earth's axis and its orbit, and volcanic eruptions.

Vocabulary
El Niño (p. 370)
ice age (p. 369)
Maunder minimum (p. 372)
season (p. 370)

SECTION 14.4
The Human Factor

Main Ideas
- The greenhouse effect is the retention of heat by atmospheric gases that helps to keep Earth warm enough to sustain life. An increase in greenhouse gases may lead to global warming.
- Some scientists theorize that human activities such as the burning of fossil fuels and deforestation cause global warming.

Vocabulary
global warming (p. 376)
greenhouse effect (p. 375)

CONTENTS

Understanding Main Ideas

1. Which of the following does NOT influence climate?
   a. latitude   **c.** mountains
   b. satellites   **d.** large bodies of water

2. A heat island is an example of what type of climate?
   a. tropical climate   **c.** dry climate
   b. microclimate   **d.** polar climate

3. Which of the following is NOT a factor used to classify climates in the Koeppen classification system?
   a. temperature   **c.** wind
   b. moisture   **d.** vegetation

4. Which of the following is an example of a long-term climatic change?
   a. fall   **c.** summer
   b. ice ages   **d.** El Niño

5. What is El Niño?
   a. a warm wind   **c.** a cool wind
   b. a cool ocean current **d.** a warm ocean current

6. Which of the following would normals best describe?
   a. a specific location   **c.** an ocean
   b. a land mass   **d.** a mountain

7. What is the Maunder minimum?
   a. a period of low sunspot activity
   b. an ice age
   c. a volcanic eruption
   d. a cycle of Earth's orbit

8. Which of the following would NOT be likely to produce a microclimate?
   a. an ocean shoreline   **c.** a flat prairie
   b. a valley   **d.** a large city

9. Which greenhouse gas is most associated with global warming?
   a. methane   **c.** carbon dioxide
   b. ozone   **d.** carbon monoxide

10. If it's winter in the northern hemisphere, what season is it in the southern hemisphere?
   a. summer   **c.** winter
   b. fall   **d.** spring

11. El Niño develops because of a weakening of what?
   a. the polar front
   b. the trade winds
   c. the prevailing westerlies
   d. the jet stream

12. Which of the following is not a natural cause of long-term climatic change?
   a. solar activity
   b. industrialization
   c. changes in the tilt of Earth's axis
   d. changes in Earth's rotation

13. What is an ice age? When did the last ice age end?

14. What is deforestation? How is it linked to global warming?

15. On which side of a mountain would a desert most likely form? Why?

16. Compare and contrast a steppe and a savanna.

17. When Earth's orbit elongates, are temperatures warmer or cooler than normal? Explain.
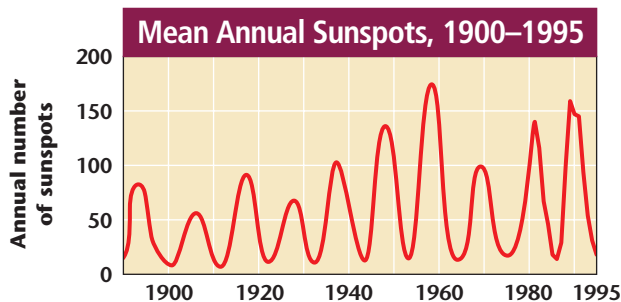
Test-Taking Tip

PLAN AHEAD Find out where and when your test will take place. If the location is unfamiliar, go there ahead of time to be sure you can find your way. Find out if you will need identification or other items on the day of the test.

Applying Main Ideas

18. The graph on this page shows sunspot activity from 1860 to 1995. Predict when the next maximum will occur.

Use this graph to answer question 18.

Mean Annual Sunspots, 1900–1995

(Graph: Annual number of sunspots vs. years 1900–1995, y-axis 0 to 200)

19. Based on the data shown in the *Problem-Solving Lab* on page 360, what months are good for planting crops that cannot survive frosts?

20. Use a world map and *Figure 14-4* to determine the climate classifications of the following cities: Paris, France; Athens, Greece; London, England; and Sydney, Australia.

Thinking Critically

21. Which would El Niño affect more: Anchorage, Alaska, or Los Angeles, California? Why?

22. How might a mountain valley produce a microclimate?

23. Based on the results of the *Discovery Lab* that you performed at the beginning of this chapter, would you expect temperatures during the night to drop more sharply in marine climates or continental climates? Why?

24. A large, three-story shopping mall is built near a town. Would you expect temperatures in the immediate region to increase, decrease, or remain the same? Explain.

Standardized Test Practice

INTERPRETING DATA Use the table below to answer questions 1 and 2.

Location	Climate Description
New Caledonia, South Pacific	Constant high temperatures, plenty of rain
Southern Israel	Humid in summer, dry in winter
Gobi Desert, Mongolia	Continental tropical air, low precipitation, scarce vegetation
Bogotá, Colombia	Mild winters, cool summers, abundant precipitation
Yukon, Canada	Year-round cold, low precipitation

1. According to the modified Koeppen classification system, Southern Israel has what kind of climate?
  a. tropical **c.** humid subtropical
  b. dry **d.** continental

2. Where is a steppe most likely to be found?
  a. New Caledonia **c.** Bogotá
  b. Gobi Desert **d.** Yukon

3. Where is a heat island most likely to be found?
  a. a farm **c.** a mountaintop
  b. a beach **d.** an inner city

4. Why is deforestation often linked to global warming?
  a. It increases the amount of dry land on Earth's surface.
  b. It releases toxic gases and pollutants into the atmosphere.
  c. It increases the amount of CO_2 released into the atmosphere.
  d. It decreases the amount of CO_2 released into the atmosphere.