Chapter 9

Climate and Climate Change

CALIFORNIA Standards Preview

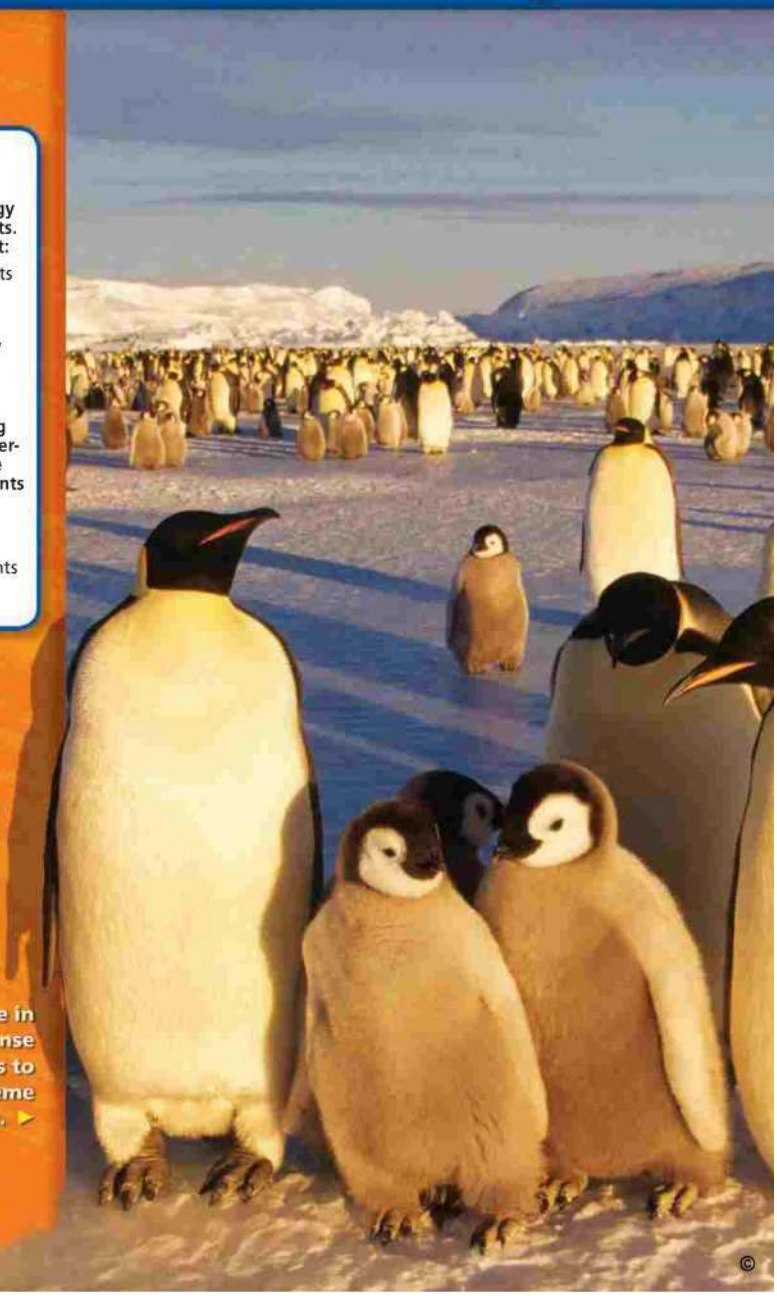
S 6.4 Many phenomena on Earth's surface are affected by the transfer of energy through radiation and convection currents. As a basis for understanding this concept:

d. Students know that convection currents distribute heat in the atmosphere and oceans.

e. Students know differences in pressure, heat, air movement, and humidity result in changes in weather.

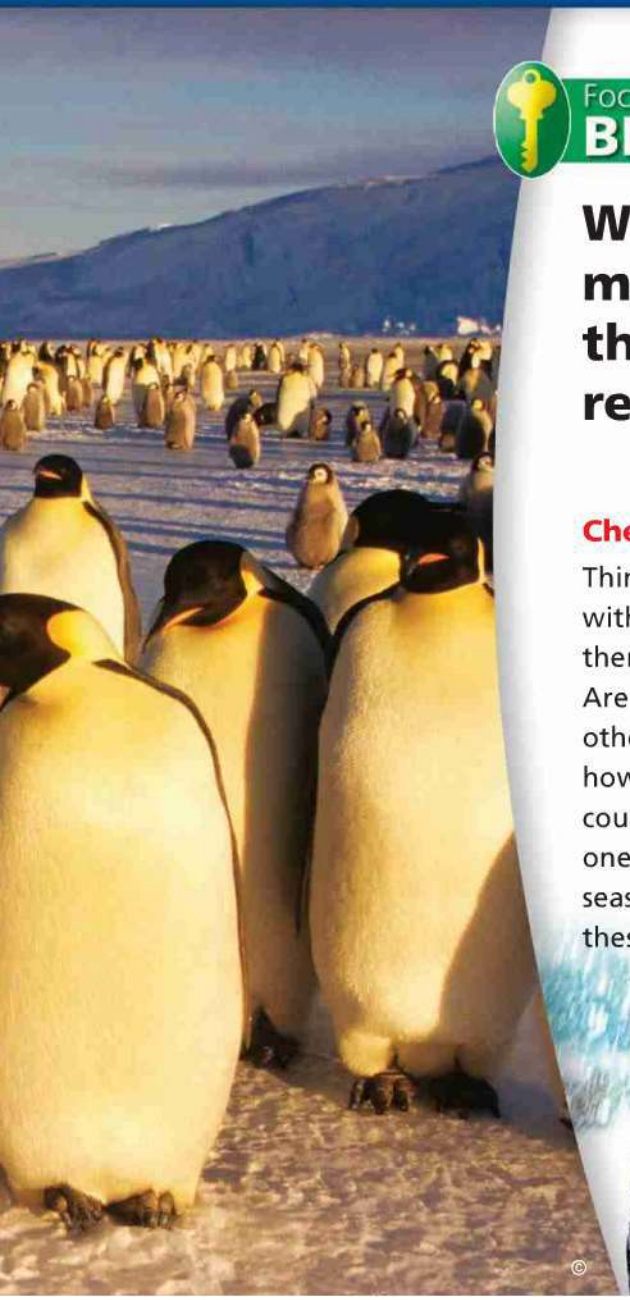
S 6.7 Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

c. Construct appropriate graphs from data and develop qualitative statements about the relationships between variables.



Emperor penguins live in Antarctica. Their dense network of feathers helps to protect them from extreme cold and strong winds. ►

Video Preview
Discovery Channel School
Climate and Climate Change



Focus on the
BIG Idea

S 6.4.e

What are the major factors that influence a region's climate?

Check What You Know

Think about how the weather changes with the seasons where you live. Is there a dry season and a rainy season? Are certain months usually hotter than others? Write a paragraph describing how the weather changes over the course of a year where you live and in one other location with very different seasonal changes. Explain why you think these seasonal changes occur.

Build Science Vocabulary

The images shown here represent some of the key terms in this chapter. You can use this vocabulary skill to help you understand the meaning of some key terms in this chapter.

Vocabulary Skill

High-Use Academic Words

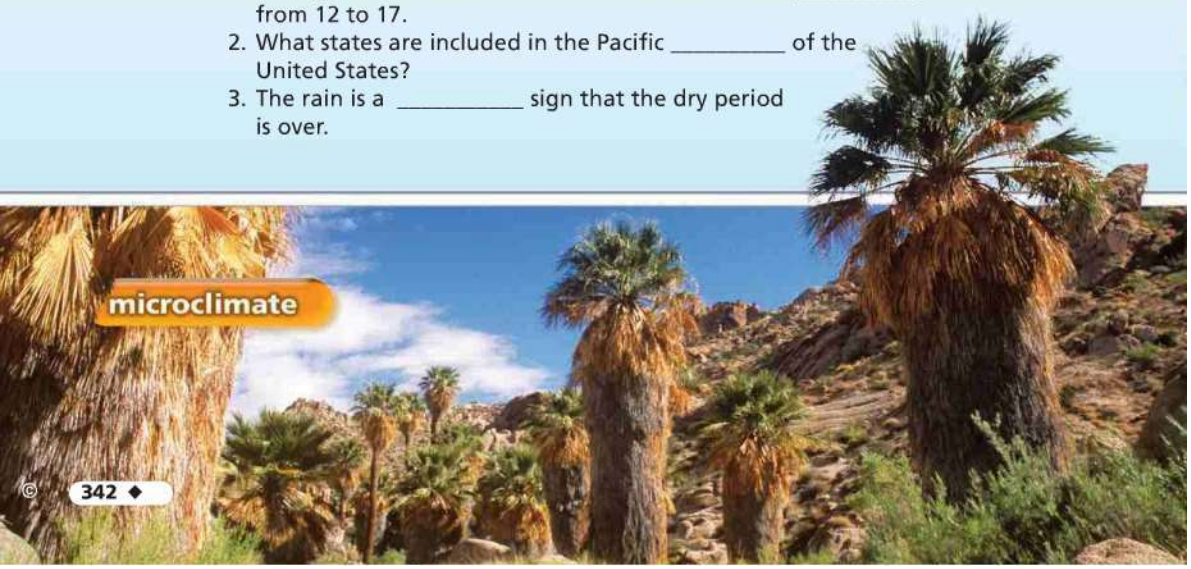
High-use academic words are words that are used frequently in academic reading, writing, and discussions.

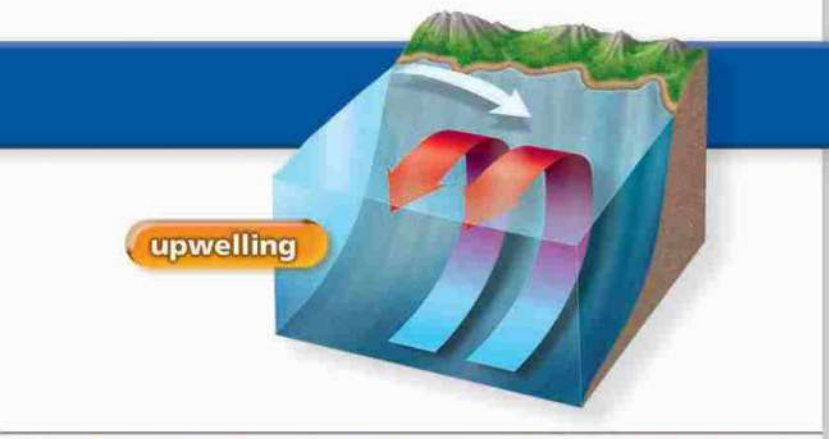
Word	Definition	Example Sentence
major (MAY jur) p. 376	*adj.* Great in size, amount, number, or importance	Hurricanes often cause major damage in Florida.
positive (PAHZ uh tiv) p. 377	*adj.* Having a good or useful effect; hopeful	She received positive comments on her science project.
range (raynj) p. 347	*v.* To extend or reach in a given direction	The temperature in our nation's capital can range from about –3°C to 32°C.
region (REE jun) p. 346	*n.* Part of the surface of Earth; an area	The southern region of the United States has the warmest weather.

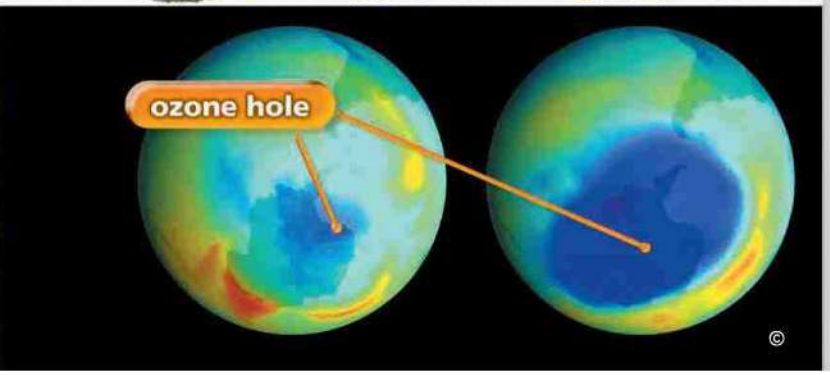
Apply It!

Choose the word from the table that best completes the sentence.

1. The age of the students at the science conference _____ from 12 to 17.
2. What states are included in the Pacific _____ of the United States?
3. The rain is a _____ sign that the dry period is over.







Chapter 9 Vocabulary

Section 1 (page 346)

climate
microclimate
tropical zone
polar zone
temperate zone
marine climate
continental climate
ocean current
windward
leeward
monsoon

Section 2 (page 356)

El Niño
La Niña
salinity
upwelling

Section 3 (page 362)

rain forest
savanna
desert
steppe
chaparral
humid subtropical
subarctic
tundra
permafrost

Section 4 (page 374)

ice age
global warming
greenhouse gas
ozone hole
chlorofluorocarbon

Interactive Textbook

Build Science Vocabulary *Online*

Use interactive flashcards

How to Read Science

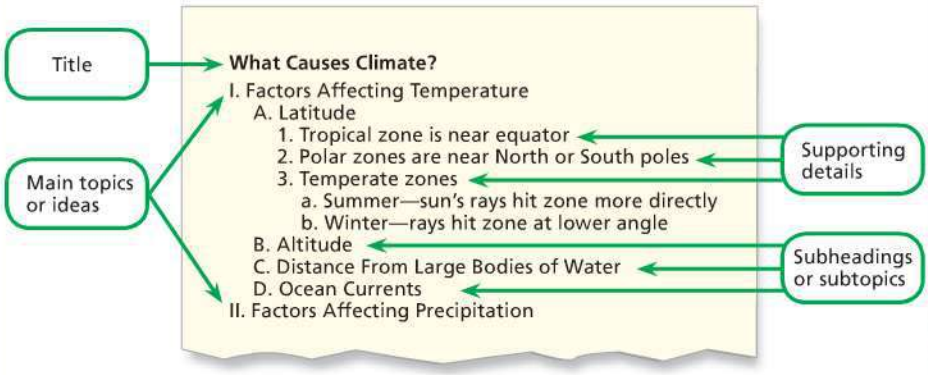
Reading Skill

Create Outlines

You have learned to use headings and to identify main ideas and details to guide you as you read. An outline uses these skills to show the relationship between main ideas and supporting details.

An outline usually is set up like the one below. Roman numerals show the main topics or headings. Capital letters show the subheadings. Numbers show supporting details and key terms.

Look at the sample outline of the first part of Section 1.



Apply It!

Use the outline above to answer the following questions.

1. What are the main topics in this outline?
2. What details describe how latitude affects temperature?

Copy the outline above into your notebook. Use the headings, subheadings, and key terms to help you select information to complete the outline for Section 1. Then create outlines for Section 2 and Section 3.

Lab zone

Standards Investigation

S 6.4.e, 6.7.c

Investigating Microclimates

A microclimate is a small area with its own climate. As you work through this chapter, you will investigate microclimates in your community.

Your Goal

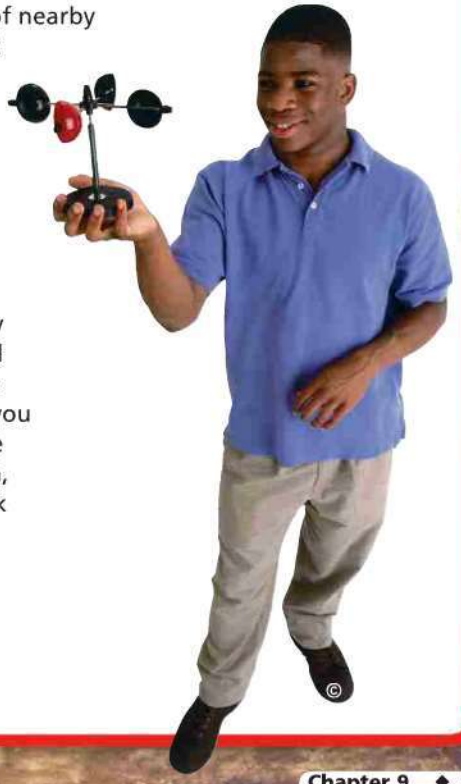
To compare weather conditions from at least three microclimates

To complete your investigation, you must

- hypothesize how the microclimates in three areas differ from each other
- collect data from your locations at the same time each day
- relate each microclimate to the plants and animals found there

Plan It!

Begin by brainstorming a list of nearby places that may have different microclimates. How are the places different? Keep in mind weather factors such as temperature, precipitation, humidity, wind direction, and wind speed. Consider areas that are grassy, sandy, sunny, or shaded.



You will need to measure daily weather conditions and record them in a logbook. Collect the instruments you need before you begin your investigation. Once you have collected all the data, construct your graphs and look for patterns. Then plan your presentation.

Section 1

What Causes Climate?

CALIFORNIA Standards Focus

S 6.4.a Students know the sun is the major source of energy for phenomena on Earth's surface; it powers winds, ocean currents, and the water cycle.

S 6.4.e Students know differences in pressure, heat, air movement, and humidity result in changes in weather.

- What factors influence temperature?
- What factors influence precipitation?
- What causes the seasons?

Key Terms

- climate
- microclimate
- tropical zone
- polar zone
- temperate zone
- marine climate
- continental climate
- ocean current
- windward
- leeward
- monsoon

Lab zone Standards Warm-Up

How Does Latitude Affect Climate?

1. On a globe, tape a strip of paper from the equator to the North Pole. Divide the tape into three equal parts. Label the top section *poles,* the bottom section *equator,* and the middle section *mid-latitudes.*
2. Tape the end of an empty toilet paper roll to the end of a flashlight. Hold the flashlight about 30 cm from the equator. Turn on the flashlight to represent the sun. On the paper strip, have a partner draw the area the light shines on.
3. Move the flashlight up slightly to aim at the "mid-latitudes." Keep the flashlight horizontal and at the same distance from the globe. Again, draw the lighted area.
4. Repeat Step 3, but this time aim the light at the "poles."

Think It Over

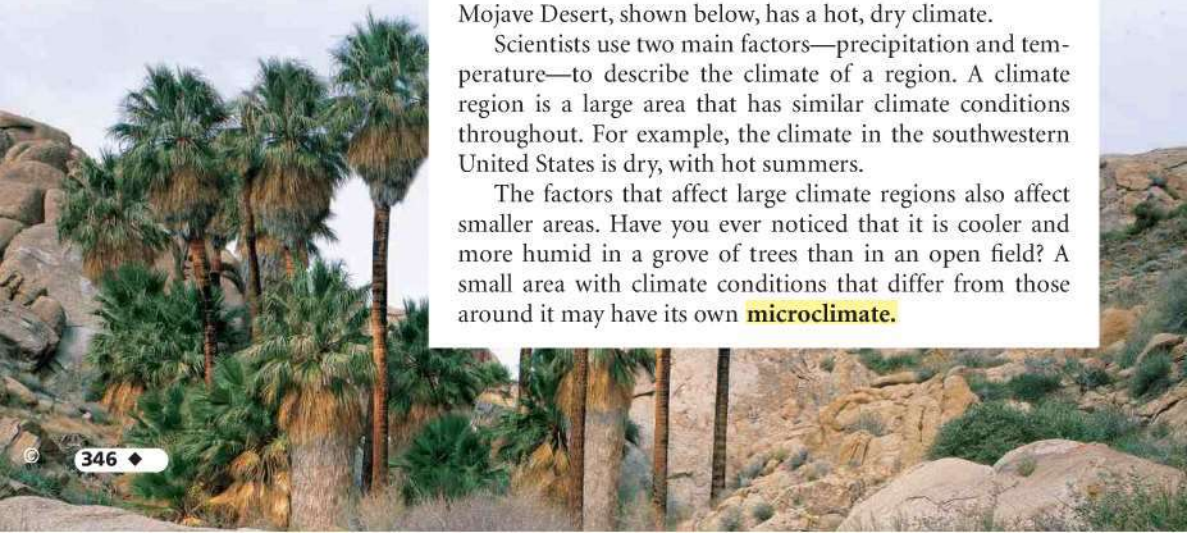
Observing How does the size of the illuminated area change? Do you think the sun's rays heat Earth's surface evenly?

The weather in an area changes every day. At a given location, the weather may be cloudy and rainy one day and clear and sunny the next. **Climate,** on the other hand, refers to the long-term, average conditions of temperature, precipitation, winds, and clouds in an area. For example, California's Mojave Desert, shown below, has a hot, dry climate.

Scientists use two main factors—precipitation and temperature—to describe the climate of a region. A climate region is a large area that has similar climate conditions throughout. For example, the climate in the southwestern United States is dry, with hot summers.

The factors that affect large climate regions also affect smaller areas. Have you ever noticed that it is cooler and more humid in a grove of trees than in an open field? A small area with climate conditions that differ from those around it may have its own **microclimate.**

An oasis in the Mojave Desert ▼



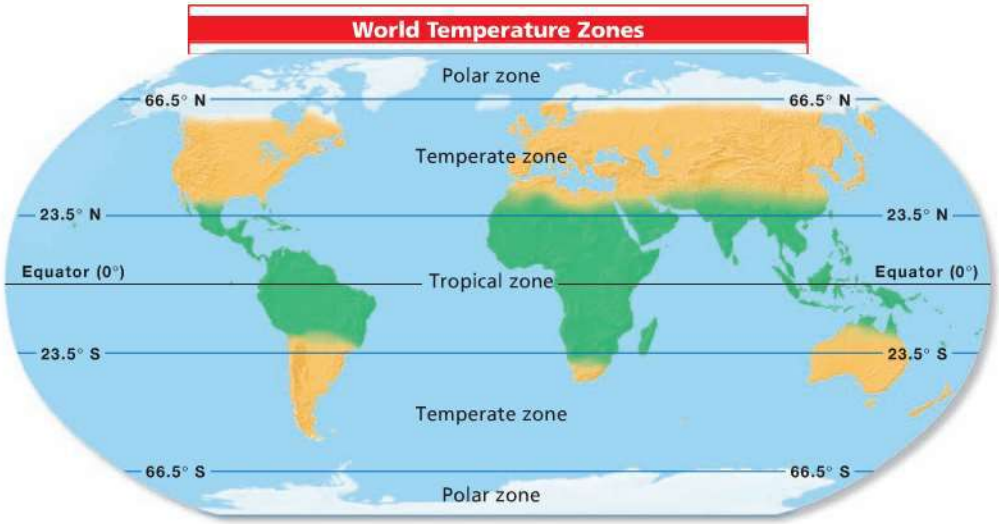


FIGURE 1
The tropical zone has the warmest climates. Cold climates occur in the polar zone. In between lies the temperate zone, where climates vary from warm to cool.
Interpreting Maps *In which temperature zone is most of the United States located?*

Factors Affecting Temperature

Why are some places warm and others cold? **The main factors that influence temperature are latitude, altitude, distance from large bodies of water, and ocean currents.**

Latitude In general, climates of locations near the equator are warmer than climates far from the equator. The main reason is that the sun's rays hit Earth's surface most directly at the equator. At the poles, the same amount of solar radiation is spread over a larger area, and therefore brings less warmth.

Recall that latitude is the distance from the equator, measured in degrees. Based on latitude, Earth's surface can be divided into the three temperature zones shown in Figure 1. The **tropical zone** is the area near the equator, between about 23.5° north latitude and 23.5° south latitude. The tropical zone receives direct or nearly direct sunlight all year round, making climates there warm.

In contrast, the sun's rays always strike at a lower angle near the North and South poles. As a result, the areas near both poles have cold climates. These **polar zones** extend from about 66.5° to 90° north and 66.5° to 90° south latitudes.

Between the tropical zones and the polar zones are the **temperate zones.** In summer, the sun's rays strike the temperate zones more directly. In winter, the sun's rays strike at a lower angle. As a result, the weather in the temperate zones ranges from warm or hot in summer to cool or cold in winter.

FIGURE 2
Effect of Altitude
Mount Kilimanjaro, in Tanzania, is near the equator.
Relating Cause and Effect
What factor is responsible for the difference between the climate at the mountaintop and the climate at the base?

Altitude The peak of Mount Kilimanjaro towers high above the plains of East Africa. Kilimanjaro is covered in snow all year round, as shown in Figure 2. Yet it is located near the equator, at 3° south latitude. Why is Mount Kilimanjaro so cold?

In the case of high mountains, altitude is a more important climate factor than latitude. In the troposphere, temperature decreases about 6.5 Celsius degrees for every 1-kilometer increase in altitude. As a result, highland areas everywhere have cool climates, no matter what their latitude. At nearly 6 kilometers, the air at the top of Kilimanjaro is about 39 Celsius degrees colder than the air at sea level at the same latitude.

Distance From Large Bodies of Water Oceans or large lakes can also affect temperatures. Oceans greatly moderate, or make less extreme, the temperatures of nearby land. Water heats up more slowly than land. It also cools down more slowly. Therefore, winds off the ocean often prevent extremes of hot and cold in coastal regions. Much of the west coasts of North America, South America, and Europe have mild **marine climates,** with relatively mild winters and cool summers. The Pacific Ocean moderates the temperatures of coastal California.

The centers of North America and Asia are too far inland to be warmed or cooled by the ocean. Most of Canada and of Russia, as well as the central United States, have continental climates. **Continental climates** have more extreme temperatures than marine climates. Winters are cold, while summers are warm or hot.

Ocean Currents Marine climates are influenced by **ocean currents,** streams of water within the oceans that move in regular patterns. As you will learn in the next section, ocean currents may flow either near the surface or deep below it.

Some warm surface currents move heat from the tropics toward the poles. This affects climate as the warm ocean water warms the air above it. The warmed air then moves over nearby land. In the same way, cold currents bring cold water from the polar zones toward the equator. A cold surface current brings cool air.

The best-known warm-water current is the Gulf Stream. As shown in Figure 3, the Gulf Stream begins in the Gulf of Mexico and then flows north along the east coast of the United States. When it crosses the North Atlantic, it becomes the North Atlantic Drift. This warm surface current brings mild, humid air to Iceland, Ireland, and southern England. As a result, these areas have a mild, wet climate despite their relatively high latitude.

The cool California Current and warm Davidson Current affect the climates of coastal California. You will learn more about these currents in the next section.

Reading Checkpoint **What effect do oceans have on the temperatures of nearby land areas?**

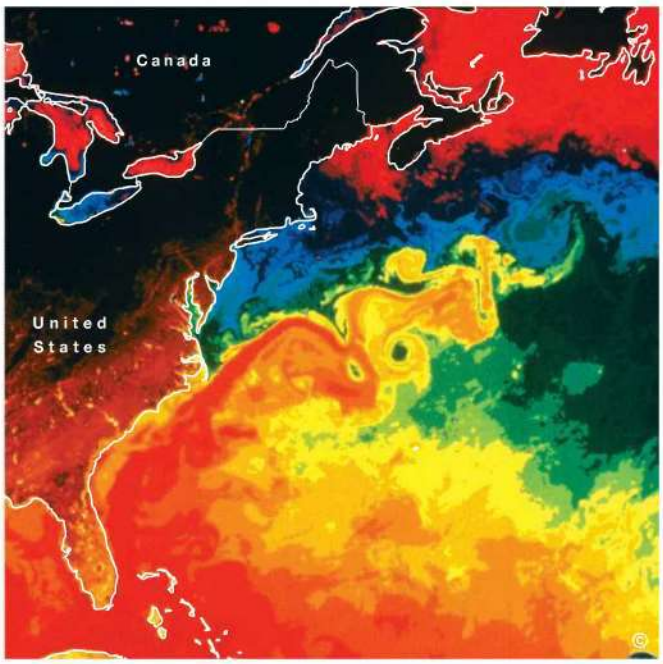


FIGURE 3
Surface Currents and Climate
This satellite image of the Atlantic Ocean has been enhanced with colors that show water temperature. Red and orange indicate warmer water, while green and blue indicate colder water.
Interpreting Maps *The Gulf Stream flows around Florida in the lower left of the map. Is the Gulf Stream a warm or a cold current?*

Factors Affecting Precipitation

The air masses that pass over an area may bring rain or snow. The amount of precipitation varies from year to year. But over time, total precipitation tends toward a yearly average. What determines the amount of precipitation an area receives?

The main factors that affect precipitation are prevailing winds, the presence of mountains, and seasonal winds.

Prevailing Winds As you know, weather patterns depend on the movement of huge air masses. Air masses are moved from place to place by prevailing winds, the directional winds that usually blow in a region. Air masses can be warm or cool, dry or humid. The amount of water vapor in the air mass influences how much rain or snow will fall. The amount of water vapor in prevailing winds also depends on where the winds come from. Winds that blow inland from oceans or large lakes carry more water vapor than winds that blow from over land.

Mountain Ranges A mountain range in the path of prevailing winds can also influence where precipitation falls. When humid winds blow from the ocean toward coastal mountains, they are forced to rise, as shown in Figure 4. The rising air cools and its water vapor condenses, forming clouds. Rain or snow falls on the **windward** side of the mountains, the side the wind hits first.

By the time the air has moved over the mountains, it has lost much of its water vapor, so it is cool and dry. The land on the **leeward** side of the mountains—downwind—is in a rain shadow. Little precipitation falls there.

The Sierra Nevada mountains have a major effect on California's climate. As shown in Figure 4, a great deal of precipitation falls on the western, windward side of the mountain range. Extremely dry areas such as the Mojave Desert are located on the leeward side of the mountains.

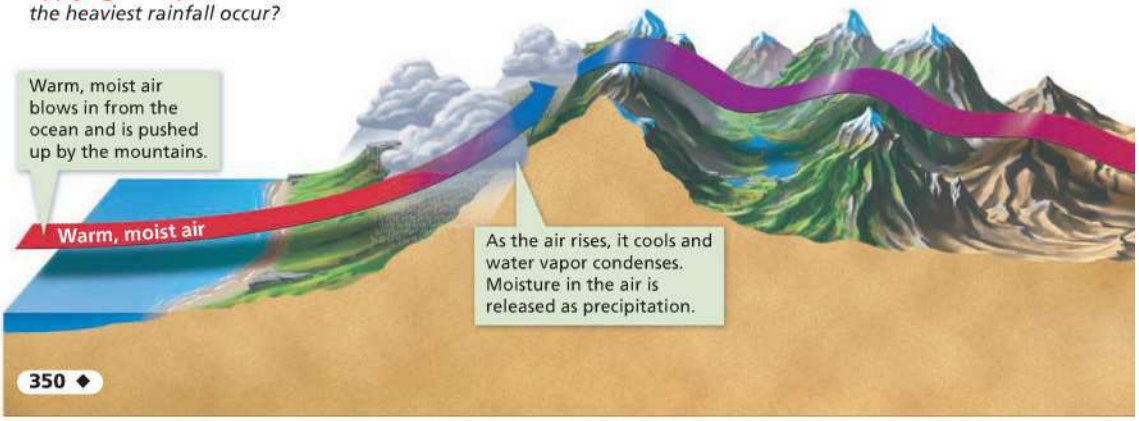
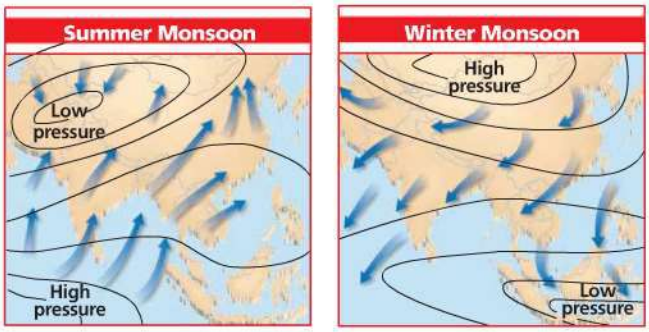


FIGURE 4
Rain Shadow
A mountain range can form a barrier to the movement of humid air. Humid air cools as it is blown up the side of a mountain range.
Applying Concepts *Where does the heaviest rainfall occur?*



Seasonal Winds A seasonal change in wind patterns can affect precipitation. These seasonal winds are similar to land and sea breezes, but occur over a wider area. Sea and land breezes over a large region that change direction with the seasons are called **monsoons.** What produces a monsoon? In the summer in South and Southeast Asia, the land gradually gets warmer than the ocean. A "sea breeze" blows steadily inland from the ocean all summer, even at night. The air blowing from the ocean during this season is very warm and humid. As the humid air rises over the land, the air cools. This causes water vapor to condense into clouds, producing heavy rains.

Thailand and parts of India receive much of their rain from the summer monsoons. Monsoon winds also bring rain to coastal areas in West Africa and northeastern South America.

Regions affected by monsoon winds receive very little rain in winter. In the winter, the land cools and becomes colder than the ocean. A "land breeze" blows steadily from the land to the ocean. These winds carry little moisture.

The Santa Ana winds are hot, dry winds that often blow in Southern California during fall and early winter. Cool air from the desert blows toward the coast. As air flows down the mountains, it is compressed and warms up. The humidity of the air drops and vegetation dries out, creating a potential fire hazard.

Reading Checkpoint **Why does precipitation fall mainly on the windward sides of mountains?**

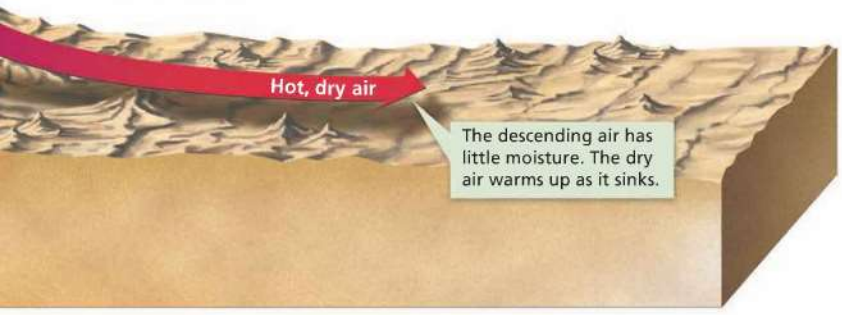


FIGURE 5
Monsoons
In a summer monsoon, wind blows from the ocean to the land. In the winter, the monsoon reverses and blows from the land to the ocean. Summer monsoons in Nepal cause heavy rain (above).

Math Skills

Percentage Light from the sun strikes Earth's surface at different angles. An angle is made up of two lines that meet at a point. Angles are measured in degrees. A full circle has 360 degrees.

When the sun is directly overhead near the equator, it is at an angle of 90° to Earth's surface. A 90° angle is called a right angle. What percentage of a circle is it?

$$\frac{90 \text{ degrees}}{360 \text{ degrees}} = \frac{d\%}{100\%}$$

$$90 \times 100 = 360 \times d$$

$$\frac{90 \times 100}{360} = d = 25$$

A 90° angle is 25 percent of a full circle.

Practice Problem Earth's axis is tilted at an angle of 23.5°. About what percentage of a right angle is this?

The Seasons

Although you can describe the average weather conditions of a climate region, these conditions are not constant all year long. Instead, most places outside the tropics have four seasons: winter, spring, summer, and fall. When it is summer in the Northern Hemisphere it is winter in the Southern Hemisphere. So the seasons are not a result of changes in the distance between Earth and the sun. In fact, Earth is farthest from the sun during the summer in the Northern Hemisphere. The sun itself transfers a nearly constant amount of energy to Earth throughout the year.

Tilted Axis **The seasons are caused by the tilt of Earth's axis as Earth travels around the sun.** The axis is an imaginary line through Earth's center that passes through both poles. Earth rotates, or turns, around this axis once each day. Earth's axis is not straight up and down, but is tilted at an angle of 23.5°. As Earth travels around the sun, its axis always points in the same direction. So the north end of the axis is pointed away from the sun for one part of the year and toward the sun for another part of the year.

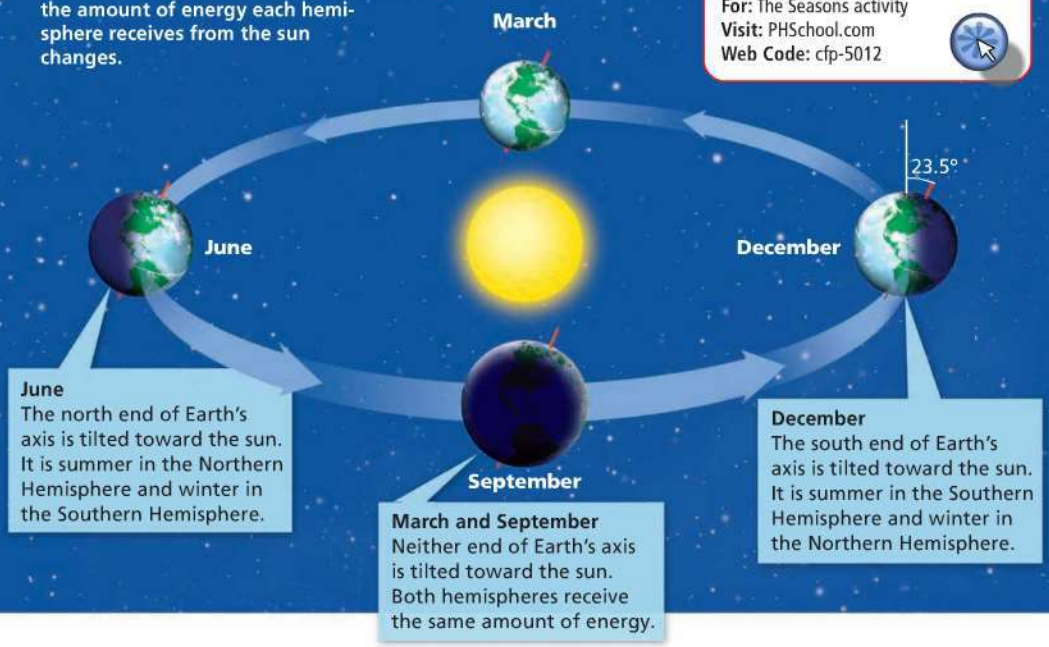
Effect of the Tilted Axis Look at Figure 7. Which way is the north end of Earth's axis tilted in June? Notice that the Northern Hemisphere receives radiation from the sun at a more direct angle. Also, in June the days in the Northern Hemisphere are longer than the nights. The combination of more direct solar radiation and longer days makes Earth's surface warmer in the Northern Hemisphere than at any other time of the year. It is summer in the Northern Hemisphere. At the same time, the Southern Hemisphere is experiencing winter.

In December, on the other hand, the north end of Earth's axis is tilted away from the sun. It is winter in the Northern Hemisphere and summer in the Southern Hemisphere.

Reading Checkpoint **In June, what season is it in the Southern Hemisphere?**

FIGURE 6
Summer and Winter
There can be a striking difference between summer and winter in the same location. **Inferring** *During which season does the area shown receive more solar energy?*

FIGURE 7
The Seasons
The seasons are a result of Earth's tilted axis. The seasons change as the amount of energy each hemisphere receives from the sun changes.



June
The north end of Earth's axis is tilted toward the sun. It is summer in the Northern Hemisphere and winter in the Southern Hemisphere.

March and September
Neither end of Earth's axis is tilted toward the sun. Both hemispheres receive the same amount of energy.

December
The south end of Earth's axis is tilted toward the sun. It is summer in the Southern Hemisphere and winter in the Northern Hemisphere.

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Section 1 Assessment

S 6.4.a, 6.4.e,
E-LA: Reading 6.1.0

Vocabulary Skill High-Use Academic Words
Complete the sentence to show you understand the meaning of the word *range*. The weather in the temperate zones can range _____.

Reviewing Key Concepts

HINT
1. a. **Identifying** Name four factors that affect temperature.

HINT
b. **Describing** How does temperature vary in Earth's temperature zones?

HINT
c. **Comparing and Contrasting** Two locations are at the same latitude in the temperate zone. One is in the middle of a continent. The other is on a coast affected by a warm ocean current. How will their climates differ?

HINT
2. a. **Listing** List three factors that affect precipitation.

HINT
b. **Summarizing** How do prevailing winds affect the amount of precipitation an area receives?

HINT
c. **Relating Cause and Effect** How does a mountain range in the path of prevailing winds affect precipitation on either side of the mountains?

HINT
3. a. **Reviewing** What causes the seasons?

HINT
b. **Describing** Describe how the seasons are related to Earth's orbit around the sun.

HINT
c. **Developing Hypotheses** How might Earth's climates be different if Earth were not tilted on its axis?

Math Practice

4. **Percentage** At noon at a particular location, the sun makes an angle of 66.5° with Earth's surface. What percentage of a full circle is this?

Lab zone **Skills Lab**
Guided Inquiry

S 6.3.d, 6.7.c

Sunny Rays and Angles

Materials


black construction paper


pencil and ruler


clear tape and scissors


3 thermometers or temperature probes


books and protractor


100-W incandescent lamp

graph paper


clock or watch

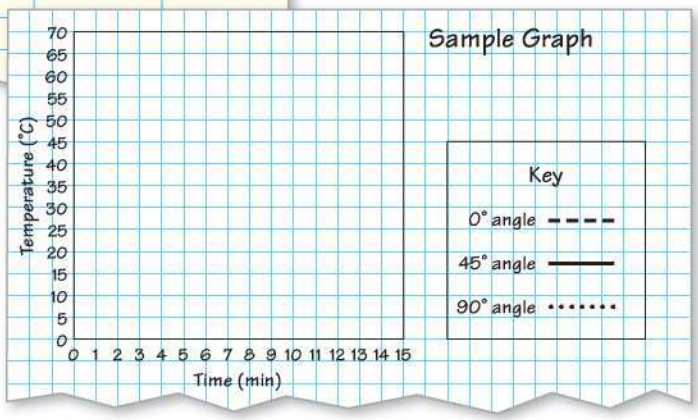
Problem How does the angle of a light source affect the rate at which the temperature of a surface changes?

Skills Focus controlling variables, graphing, interpreting data, making models

Procedure

1. Cut a strip of black construction paper 5 cm by 10 cm. Fold the paper in half and tape two sides to form a pocket.
2. Repeat Step 1 to make two more pockets.
3. Place the bulb of a thermometer inside each pocket. If youre usin g a temperature probe, see your teacher for instructions.
4. Place the pockets with thermometers close together, as shown in the photo. Place one thermometer in a vertical position (90° angle), one at a 45° angle, and the third one in a horizontal position (0° angle). Use a protractor to measure the angles. Support the thermometers with books.
5. Position the lamp so that it is 30 cm from each of the thermometer bulbs. Make sure the lamp will not move during the activity.

Data Table			
Time (min.)	Temperature (°C)		
	0° Angle	45° Angle	90° Angle
Start			
1			
2			
3			
4			
5			



6. Copy a data table like the one above into your notebook.
7. In your data table, record the temperature on all three thermometers. (All three temperatures should be the same.)
8. Switch on the lamp. In your data table, record the temperature on each thermometer every minute for 15 minutes. **CAUTION:** *Be careful not to touch the hot lampshade.*
9. After 15 minutes, switch off the lamp.

Analyze and Conclude

1. **Controlling Variables** In this experiment, what was the manipulated variable? What was the responding variable?
2. **Graphing** Graph your data. Label the horizontal axis and vertical axis of your graph as shown on the sample graph. Use solid, dashed, and dotted lines to show the results from each thermometer, as shown in the key.
3. **Interpreting Data** Based on your data, at which angle did the temperature increase the most?
4. **Interpreting Data** At which angle did the temperature increase the least?
5. **Making Models** What part of Earth's surface does each thermometer represent?
6. **Drawing Conclusions** Why is air at the North Pole still very cold in the summer even though the Northern Hemisphere is tilted toward the sun?
7. **Communicating** Write a paragraph explaining what variables were held constant in this experiment.

Design an Experiment

Design an experiment to find out how the results of the investigation would change if the lamp were placed farther from the thermometers. Then, design another experiment to find out what would happen if the lamp were placed closer to the thermometers.

Section 2

Currents and Climate

CALIFORNIA Standards Focus

S 6.4.d Students know that convection currents distribute heat in the atmosphere and oceans.

S 6.4.e Students know differences in pressure, heat, air movement, and humidity result in changes in weather.

- What causes surface currents and deep currents, and what effects do they have?
- What are El Niño and La Niña?
- How does upwelling affect the distribution of nutrients in the ocean?

Key Terms

- El Niño
- La Niña
- salinity
- upwelling

Lab zone Standards Warm-Up

Which Is More Dense?

1. Fill a plastic container three-quarters full with warm water. Wait for the water to stop moving.
2. Add several drops of food coloring to a cup of ice water and stir.
3. Gently dribble colored water down the inside of the container. Observe.

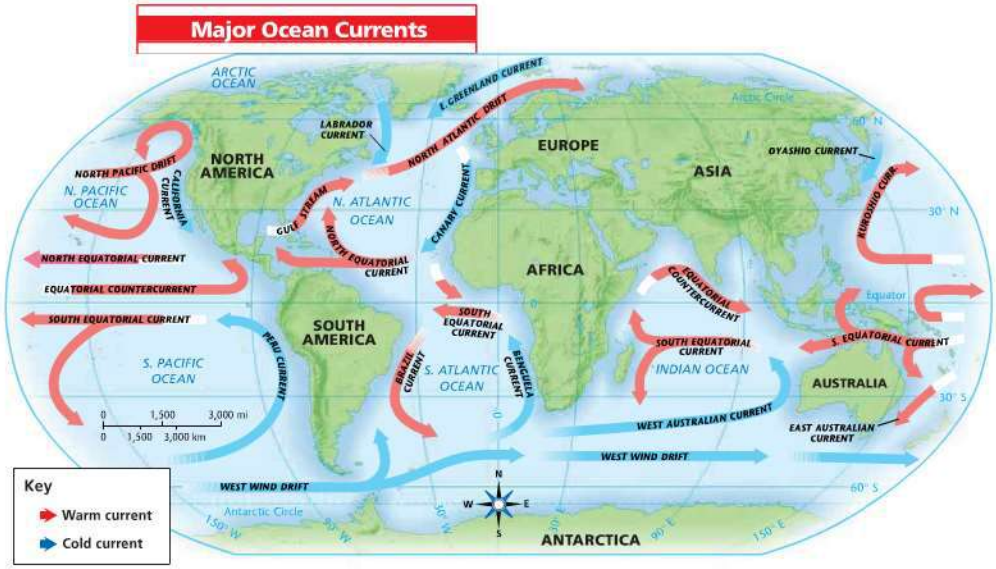
Think It Over

Inferring Describe what happened to the cold water. Which is more dense, warm water or cold water? Explain.

One spring day, people strolling along a beach in Washington State saw an amazing sight. Hundreds of sneakers of all colors and sizes were washing ashore from the Pacific Ocean! This "sneaker spill" was eventually traced to a cargo ship accident. Containers of sneakers had fallen overboard and now the sneakers were washing ashore.

But the most amazing part of the story is this—scientists could predict where the sneakers would wash up next. And just as the scientists had predicted, sneakers washed up in Oregon, and then thousands of kilometers away in Hawaii!

How did the scientists know that the sneakers would float all the way to Hawaii? The answer is that the sneakers were transported by a well-known ocean current. Recall from Section 1 that a current is a large stream of moving water that flows through the oceans. Unlike waves, currents carry water from one place to another. Some currents move water at the surface of the ocean, while other currents move water deep in the ocean.



Surface Currents

Figure 8 shows the major surface currents in Earth's oceans. Notice that surface currents move in circular patterns in the major oceans. Most of the currents flow east or west, and then double back to complete the circle.

Surface currents, which affect water to a depth of several hundred meters, are driven mainly by winds. For example, in the mid-latitudes of the Northern Hemisphere, the prevailing westerlies blow from the southwest and push water at the ocean's surface eastward.

Recall from Chapter 7 that winds are caused by differences in air pressure, which are in turn the result of the unequal heating of the atmosphere by the sun. Thus, the sun's radiation is the ultimate source of energy that powers global winds and surface currents in the ocean.

Coriolis Effect Global winds are not the only factors that influence surface currents. Continents block and redirect the flow of currents. In addition, the Coriolis effect, which you learned about in Chapter 7, also influences surface currents. Recall that the Coriolis effect causes global winds to curve as a result of Earth's rotation. In the same way as the Coriolis effect changes global winds, it causes surface currents to curve to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. For example, the Gulf Stream curves eastward across the Atlantic as a result of the Coriolis effect.

FIGURE 8
Large surface currents generally move in circular patterns in Earth's oceans. **Interpreting Maps** *Name four currents that flow along the coasts of North America. State whether each current is warm or cold.*

Lab zone Skills Activity

Inferring

Look at the currents in Figure 8 in the South Pacific, South Atlantic, and Indian oceans. What pattern can you observe? Now compare currents in the South Atlantic to those in the North Atlantic. What might be responsible for differences in the current patterns?

FIGURE 9
California Surfer
Mild temperatures due to the surface currents off the coast of California allow surfers to surf year round.

Effects on Climate Currents affect climate by moving cold and warm water around the globe. In general, surface currents carry warm water from the tropics toward the poles and bring cold water back toward the equator. **A surface current warms or cools the air above it, influencing the climate of the land near the coast.**

Winds pick up moisture as they blow across warm-water currents. In contrast, cold-water currents cool the air above them. Since cold air holds less moisture than warm air, these currents tend to bring cool, dry weather to the land areas in their path.

The California Current and, in winter, the Davidson Current are very important to people who live near coastal California. These currents help to moderate the temperatures of coastal California throughout the year.

The cool California Current flows southward approximately 3,000 kilometers from southern Canada to near Baja California. The California Current carries cool water toward the equator, making summer climates along the West Coast cooler than you would expect at those latitudes.

Although the California Current flows all year long, the direction of the prevailing winds changes in winter. The weak Davidson Current carries warmer water northward during the winter months, closer to the coast than the California Current. This helps to keep coastal climates in California mild in winter.

Lab zone Skills Activity

Drawing Conclusions

Locate the Benguela Current in Figure 8 on the previous page. Near the southern tip of Africa, the winds blow from west to east. Using what you have learned about surface currents and climate, what can you conclude about the impact of this current on the climate of the southwestern coast of Africa?

FIGURE 10
Viewing El Niño and La Niña From Space
In these false-color satellite images, warmer water is red and white. Cooler water is blue and purple.

El Niño and La Niña

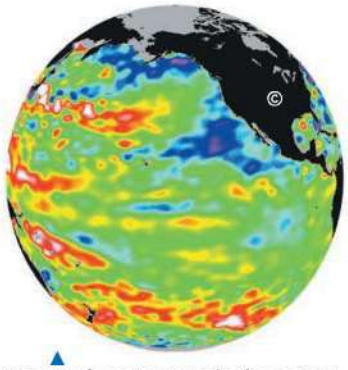
Changes in ocean currents and winds can greatly affect climate. **El Niño and La Niña are short-term changes in the tropical Pacific Ocean caused by changes in ocean surface currents and prevailing winds.** El Niño and La Niña both influence weather patterns all over the world.

El Niño The warm-water event known as **El Niño** begins when an unusual pattern of winds forms over the western Pacific. This causes a vast sheet of warm water to move eastward toward the South American coast, as shown in Figure 10. El Niño causes the surface of the ocean in the eastern Pacific to be unusually warm. El Niño typically occurs every two to seven years.

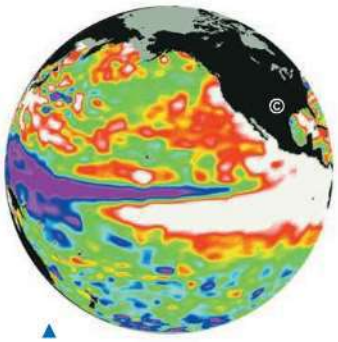
The arrival of El Niño's warm surface water disrupts the cold ocean currents along the western coast of South America and changes weather patterns there. El Niño also affects weather patterns around the world, often bringing severe conditions such as heavy rains or droughts. For example, in 1997–1998, a major El Niño caused an especially warm winter in the northeastern United States. However, it was also responsible for heavy rains, flooding, and mudslides in California. El Niño conditions can last for one to two years before normal winds and currents return.

La Niña When surface waters in the eastern Pacific are colder than normal, a climate event known as **La Niña** occurs. A La Niña event is the opposite of an El Niño event. La Niña typically brings colder than normal winters and greater precipitation to the Pacific Northwest and the north central states. La Niña also causes greater hurricane activity in the western Atlantic.

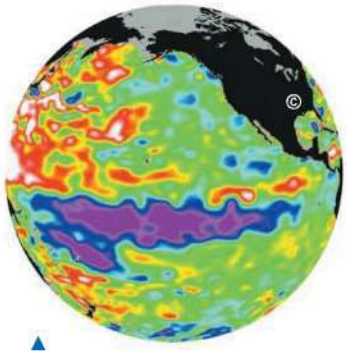
Reading Checkpoint **How often does El Niño typically occur?**



In **normal years**, water in the eastern Pacific is kept relatively cool by currents along the coast of North and South America.



When **El Niño** occurs, warm surface water from the western Pacific moves east toward the coast of South America.



La Niña occurs when surface waters in the eastern Pacific Ocean are colder than normal.

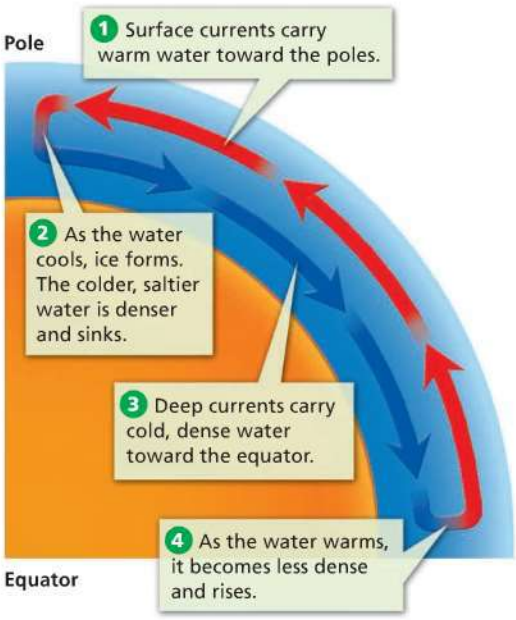


FIGURE 11
Deep Currents
Deep currents are caused by differences in the density of ocean water.
Relating Cause and Effect *Why does ocean water sink near the poles and rise near the equator?*

Deep Currents

Deep below the ocean's surface, another type of current causes chilly waters to creep slowly across the ocean floor. **Deep currents are caused by differences in the density of ocean water.**

Ocean Water Density

The density of ocean water depends on its temperature and its salinity. **Salinity** is the total amount of dissolved salts in a water sample.

When a warm surface current moves from the equator toward one of the poles, it gradually cools. As ice forms near the poles, the salinity of the water increases from the salt left behind during freezing. As its temperature decreases and its salinity increases, the water becomes denser and sinks. Then, the cold water flows back along the ocean floor toward the equator as a deep current. Like surface currents, deep currents are affected by the Coriolis effect, which causes them to curve.

A Global Conveyer Belt

Deep currents move and mix water around the world. They carry cold water from the poles toward the equator. Deep currents flow slowly. They may take as long as 1,000 years to flow from the pole to the equator and back again!

The conveyer belt at a supermarket checkout counter moves objects from one place to another as it turns in a continuous path. Similarly, surface currents and deep currents together form a global "conveyer belt" in which water circulates through the oceans.

As Figure 11 shows, this "conveyer belt" is actually a series of convection currents that move warm water from the tropics toward the poles and cold water toward the equator. As these currents flow, heat is transferred through the ocean. This process influences global climates by altering ocean water temperatures and by releasing heat into the atmosphere.

As dense water sinks near the poles, it slowly spreads out and mixes with surrounding waters in the deep ocean. This process brings dissolved oxygen down into the ocean depths, where it helps to sustain life.

Reading Checkpoint **What is salinity?**

Upwelling

In most parts of the ocean, surface waters do not usually mix with deep ocean waters. However, mixing sometimes occurs when winds cause upwelling. **Upwelling** is the movement of cold water upward from the deep ocean. As winds blow away the warm surface water, cold water rises to replace it.

Upwelling brings up tiny ocean organisms, minerals, and other nutrients from the deeper layers of the water. Without this motion, the surface waters of the open ocean would be very scarce in nutrients. Because nutrients are plentiful, zones of upwelling are usually home to huge schools of fish.

Upwelling occurs in the Pacific Ocean off the west coasts of North America and South America. Many people depend on this rich fishing area for food and jobs. Along the California coast, upwelling generally takes place from March through September as prevailing winds push surface waters offshore. The arrival of El Niño prevents upwelling from occurring. Without the nutrients brought by upwelling, fish die or go elsewhere to find food, reducing the fishing catch that season and hurting people's livelihoods.

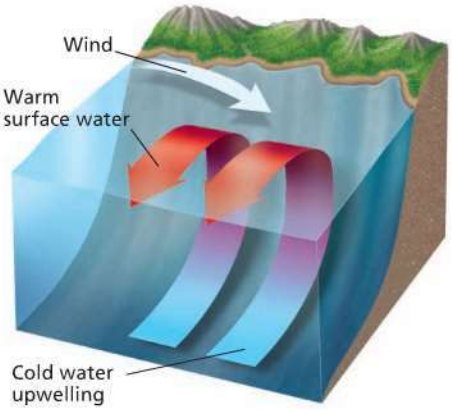


FIGURE 12
Upwelling
As cold water rises from the deep ocean, it brings a new supply of nutrients to the surface.

Section 2 Assessment

S 6.4.d, 6.4.e,
E-LA: Reading 6.2.4

Target Reading Skill Create Outlines
Complete your outline for this section. What details did you include about El Niño and La Niña?

Reviewing Key Concepts

HINT
1. a. Describing How do surface currents affect the climate of coastal areas?

HINT
b. Predicting What type of climate might a coastal area have if nearby currents are cold?

HINT
c. Explaining Explain how deep currents form and move in the ocean.

HINT
d. Comparing and Contrasting Compare the causes and effects of deep currents and surface currents.

HINT
2. a. Describing Describe the changes that occur in the Pacific Ocean and the atmosphere above it during El Niño.

HINT
b. Relating Cause and Effect What effects does El Niño have on weather and climate?

HINT
3. a. Reviewing What causes upwelling?

HINT
b. Explaining Why are huge schools of fish usually found in zones of upwelling?

HINT
c. Applying Concepts Why would the ability to predict the occurrence of El Niño be important for the fishing industry on the western coast of South America?

Lab zone At-Home Activity

Modeling the Coriolis Effect With the help of a family member, use chalk and a globe to model the Coriolis effect. Have your family member slowly rotate the globe in an easterly direction. As the globe rotates, draw a line from the North Pole to the equator. Use your knowledge of the Coriolis effect to explain why the line is curved.

Section 3

Climate Regions

CALIFORNIA Standards Focus

S 6.4.e Students know differences in pressure, heat, air movement, and humidity result in changes in weather.

- What factors are used to classify climates?
- What are the six main climate regions?

Key Terms

- rain forest
- savanna
- desert
- steppe
- chaparral
- humid subtropical
- subarctic
- tundra
- permafrost

Lab zone Standards Warm-Up

How Do Climates Differ?

1. Collect pictures from magazines and newspapers of a variety of land areas around the world.
2. Sort the pictures into categories according to common weather characteristics.

Think It Over

Forming Operational Definitions Choose several words that describe the typical weather for each category. What words would you use to describe the typical weather where you live?

Suppose you lived for an entire year near the equator. It would be very different from where you live now. The daily weather, the amount of sunlight, and the pattern of seasons would all be new to you. You would be in another climate region.

Scientists classify climates according to two major factors: temperature and precipitation. They also consider the distinct vegetation in different areas. This system, developed around 1900 by Wladimir Köppen, identifies broad climate regions, each of which has smaller subdivisions.

There are six main climate regions: tropical rainy, dry, temperate marine, temperate continental, polar, and highlands. California has a wide variety of climate regions, including dry, temperate marine, and highlands.

Maps show boundaries between the climate regions. In the real world, of course, no clear boundaries mark where one climate region ends and another begins. Each region blends gradually into the next.

Tropical Rainy Climates

The tropics have two types of rainy climates: tropical wet and tropical wet-and-dry. Tropical wet climates are found in low-lying lands near the equator.

Tropical Wet In areas that have a tropical wet climate, many days are rainy, often with afternoon thunderstorms. These thunderstorms are triggered by midday heating. Another source of precipitation is prevailing winds. In many areas with a tropical wet climate, the trade winds bring moisture from the oceans. With year-round heat and heavy rainfall, vegetation grows lush and green. Dense rain forests grow in these rainy tropical climates. **Rain forests** are forests in which large amounts of rain fall year-round. Tropical rain forests are important because it is thought that at least half of the world's species of land plants and animals are found there.

In the United States, only the windward sides of the Hawaiian islands have a tropical wet climate. Rainfall is very heavy—over 10 meters per year on the windward side of the Hawaiian island of Kauai. The rain forests of Hawaii have a large variety of plants, including ferns, orchids, and many types of vines and trees.

FIGURE 13
Tropical Rain Forests
Lush tropical rain forests grow in the tropical wet climate.

Tropical Wet-and-Dry Areas that have tropical wet-and-dry climates receive slightly less rain than tropical climates and have distinct dry and rainy seasons. Instead of rain forests, there are tropical grasslands called **savannas.** Scattered clumps of trees that can survive the dry season dot the coarse grasses. Only a small part of the United States—the southern tip of Florida—has a tropical wet-and-dry climate. The graphs in Figure 14 show how temperature and precipitation vary in Makindu, Kenya, in East Africa.

Reading Checkpoint **What parts of the United States have tropical rainy climates?**

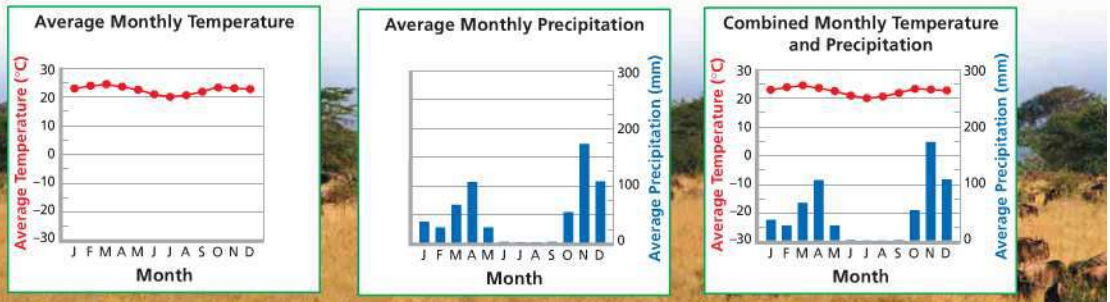


FIGURE 14
Climate Graphs
A graph of average temperature (left) can be combined with a graph of average precipitation (middle) to form a climate graph. These graphs show data for a tropical wet-and-dry region.

FIGURE 15

Climate Regions

Climate regions are classified according to a combination of temperature and precipitation. Climates in highland regions change rapidly as altitude changes.

Tropical Rainy
Temperature always 18°C or above

Tropical wet Always hot and humid, with heavy rainfall (at least 6 centimeters per month) all year round

Tropical wet-and-dry Always hot; alternating wet and dry seasons; heavy rainfall in the wet season

Dry
Occurs wherever potential evaporation is greater than precipitation; may be hot or cold

Semiarid Dry but receives about 25 to 50 centimeters of precipitation per year

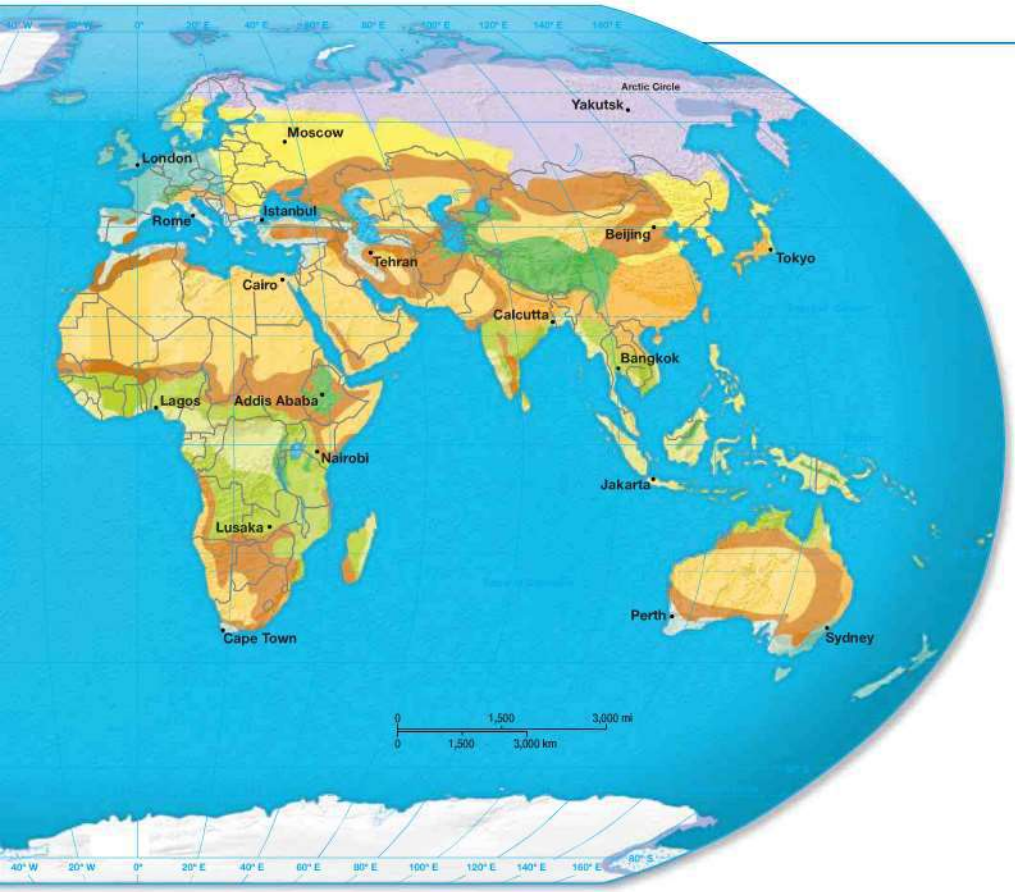
Arid Desert, with little precipitation, usually less than 25 centimeters per year

Temperate Marine
Averages 10°C or above in warmest month, between –3°C and 18°C in the coldest month

Mediterranean Warm, dry summers and rainy winters

Humid subtropical Hot summers and cool winters

Marine west coast Mild winters and cool summers, with moderate precipitation all year



Temperate Continental
Average temperature 10°C or above in the warmest month, –3°C or below in the coldest month

Humid continental Hot, humid summers and cold winters, with moderate precipitation year round

Subarctic Short, cool summers and long, cold winters; light precipitation, mainly in summer

Polar
Average temperature below 10°C in the warmest month

Tundra Always cold with a short, cool summer—warmest temperature about 10°C

Ice cap Always cold, average temperature at or below 0°C

Highlands

Generally cooler and wetter than nearby lowlands; temperature decreasing with altitude

FIGURE 16
Arid Climate
California's deserts are home to a variety of animals, including the kit fox.
Interpreting Graphs *Which month has the highest average temperature?*

Dry Climates

A climate is "dry" if the amount of precipitation that falls is less than the amount of water that could potentially evaporate. Because water evaporates more slowly in cool weather, a cool place with low rainfall may not be as dry as a warmer place that receives the same amount of rain. **Dry climates include arid and semiarid climates.**

Look at the map of world climate regions in Figure 15. What part of the United States is dry? Why is precipitation in this region so low? As you can see, dry regions often lie inland, far from oceans that are the source of humid air masses. In addition, much of the region lies in the rain shadow east of the Sierra Nevada and Rocky Mountains. Humid air masses from the Pacific Ocean lose much of their water as they cross the mountains. Little rain or snow is carried to dry regions.

Arid When you think about **deserts,** or arid regions, you may picture blazing heat and drifting sand dunes. Some deserts are hot and sandy, but others are cold or rocky. On average, arid regions, or deserts, get less than 25 centimeters of rain a year. Some years may bring no rain at all. Only specialized plants such as cactus and yucca can survive the desert's dryness and extremes of hot and cold. Much of California's southeast, including Death Valley and the rest of the Mojave Desert, has an arid climate.

Semiarid Locate the semiarid regions in Figure 15. As you can see, large semiarid areas are usually located on the edges of deserts. These semiarid areas are called steppes. A **steppe** is dry but gets enough rainfall for short grasses and low bushes to grow. For this reason, a steppe may also be called a prairie or grassland. The Great Plains are the major steppe region of the United States. Portions of southeastern California are considered semiarid.

Reading Checkpoint **What is a desert?**

Temperate Marine Climates

Look once again at Figure 15. Along the coasts of continents in the temperate zones, you will find the third main climate region, temperate marine. **There are three kinds of temperate marine climates: marine west coast, Mediterranean, and humid subtropical.** Because of the moderating influence of oceans, all three are humid and have mild winters.

Marine West Coast The coolest temperate marine climates are found on the west coasts of continents north of 40° north latitude and south of 40° south latitude. Humid ocean air brings mild, rainy winters. Summer precipitation can vary considerably.

In North America, the marine west coast climate extends from northern California to southern Alaska. In the northwestern United States, humid air from the Pacific Ocean hits the western slopes of the Coastal Ranges. The air rises up the slopes of the mountains, and it cools. As the air cools, large amounts of rain or snow fall on the western slopes. The eastern slopes lie in the rain shadow of the mountains and receive little precipitation.

Because of the heavy precipitation, thick forests of tall trees grow in this region, including coniferous, or cone-bearing, trees such as Sitka spruce, Douglas fir, redwoods, and Western red cedar, as shown in Figure 17. One of the main industries of this region is harvesting and processing wood for lumber, paper, and furniture.

Lab zone **Try This Activity**

Modeling a Climate

Here's how you can create humidity.

1. Put the same amount of water in each of two small plastic bowls.
2. Place a sheet of transparent plastic wrap over each bowl. Secure each sheet with a rubber band.
3. Place one bowl on a warm, sunny windowsill or near a radiator. Put the other bowl in a cool location.
4. Wait a day and then look at the two bowls. What do you see on the plastic wrap over each bowl?

Inferring Would you expect to find more water vapor in the air in a warm climate or in a cool one? Why? Explain your results in terms of solar energy.

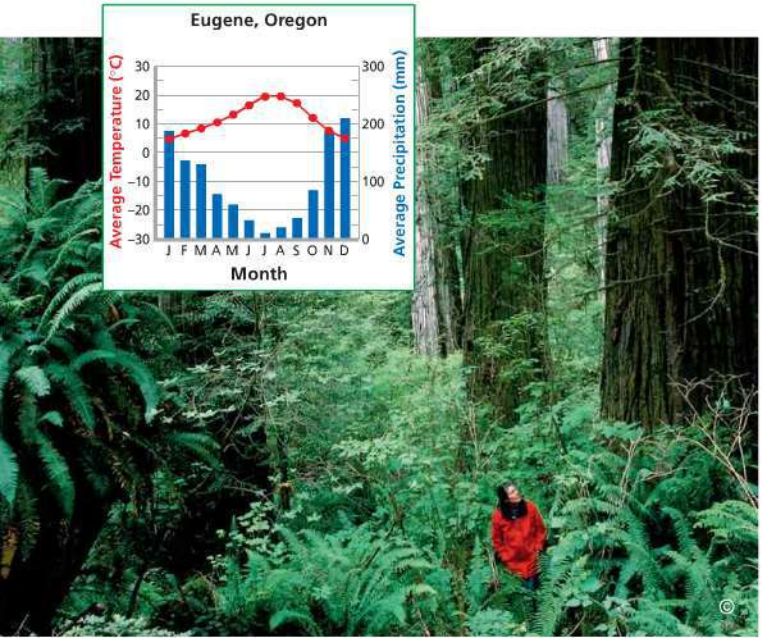


FIGURE 17
Marine West Coast Climate
Redwoods, Douglas firs, and Sitka spruce dominate the lush forests found in marine west coast climates.

FIGURE 18
Mediterranean Climate
Santa Barbara, on the coast of southern California, has a Mediterranean climate. Mild temperatures throughout the year make the area ideal for growing olives and citrus fruits.
Interpreting Graphs *How much precipitation does Santa Barbara receive in July? In January?*

Mediterranean A coastal climate that is drier and warmer than west coast marine is known as Mediterranean. Most areas with this climate are found around the Mediterranean Sea. In the United States, much of coastal California has a Mediterranean climate. This climate is mild, with two seasons. In winter, marine air masses bring cool, rainy weather. Summers are somewhat warmer, with little rain.

Mediterranean climates have two main vegetation types. One is made up of dense shrubs and small trees, called **chaparral** (shap uh RAL). The other vegetation type includes grasses with a few large trees.

Agriculture is important to the economy of California's Mediterranean climate region. Using irrigation, farmers grow many different crops, including rice, many vegetables, fruits, and nuts.

Humid Subtropical The warmest temperate marine climates are along the edges of the tropics. **Humid subtropical** climates are wet and warm, but not as constantly hot as the tropics. Locate the humid subtropical climates in Figure 15.

The southeastern United States has a humid subtropical climate. Summers are hot, with much more rainfall than in winter. Maritime tropical air masses move inland, bringing tropical weather conditions, including thunderstorms and occasional hurricanes, to southern cities such as Houston, New Orleans, and Atlanta. Winters are cool to mild, with more rain than snow. However, polar air masses moving in from the north can bring freezing temperatures and frosts.

Mixed forests of oak, ash, hickory, and pines grow in the humid subtropical region of the United States. Important crops in this region include oranges, peaches, peanuts, sugar cane, and rice.

Reading Checkpoint **What region of the United States has a humid subtropical climate?**

Lab zone Skills Activity

Classifying

The table shows some climate data for three cities.

	City A	City B	City C
Average Jan. Temp. (°C)	12.8	18.9	−5.6
Average July Temp. (°C)	21.1	27.2	20
Annual Precipitation (cm)	33	152	109

Describe the climate you would expect each city to have. Identify the cities of Miami, Florida; Los Angeles, California; and Portland, Maine. Use Figure 15 to help identify each city's climate.

FIGURE 19
Subarctic Climate
Subarctic climates have cool summers and cold winters. The world's largest subarctic regions are in Russia, Canada, and Alaska. This emperor goose is breeding in the subarctic climate region in Alaska.

Temperate Continental Climates

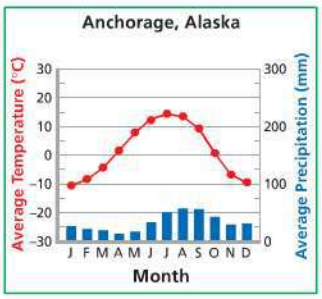
Temperate continental climates are not influenced very much by oceans, so they commonly have extremes of temperature. **Temperate continental climates are only found on continents in the Northern Hemisphere, and include humid continental and subarctic.** The parts of continents in the Southern Hemisphere south of 40° south latitude are not far enough from oceans for dry continental air masses to form.

Humid Continental Shifting tropical and polar air masses bring constantly changing weather to humid continental climates. In winter, continental polar air masses move south, bringing bitterly cold weather. In summer, tropical air masses move north, bringing heat and high humidity. Humid continental climates receive moderate amounts of rain in the summer. Smaller amounts of rain or snow fall in winter.

What parts of the United States have a humid continental climate? The eastern part of the region—the Northeast—has a range of forest types, from mixed forests in the south to coniferous forests in the north. Much of the western part of this region—the Midwest—was once tall grasslands, but is now farmland.

Subarctic The **subarctic** climates lie north of the humid continental climates. Summers in the subarctic are short and cool. Winters are long and bitterly cold.

In North America, coniferous trees such as spruce and fir make up a huge northern forest that stretches from Alaska to eastern Canada. Wood products from this forest are an important part of the economy. Many large mammals, including bears and moose, live in the forest. Birds of many species breed in the subarctic.



Reading Checkpoint **Which area of the United States has a subarctic climate?**

Go Online
SCILINKS NSTA
For: Links on climates of the world
Visit: www.SciLinks.org
Web Code: scn-0942

Polar Climates

The polar climate is the coldest climate region, and includes the ice cap and tundra climates. Ice cap and tundra climates are found only in the far north and south, near the North and South poles. Most polar climates are relatively dry, because the cold air holds little moisture.

Ice Cap As Figure 15 shows, ice cap climates are found mainly on Greenland and in Antarctica. With average temperatures always at or below freezing, the land in ice cap climate regions is covered with ice and snow. Intense cold makes the air dry. Lichens and a few low plants may grow on the rocks.

Tundra The **tundra** climate region stretches across northern Alaska, Canada, and Russia. Short, cool summers follow bitterly cold winters. Because of the cold, some layers of the tundra soil are always frozen. This permanently frozen tundra soil is called **permafrost.** Because of the permafrost, water cannot drain away, so the soil is wet and boggy in summer.

It is too cold on the tundra for trees to grow. Despite the harsh climate, during the short summers the tundra is filled with life. Mosquitoes and other insects hatch in the ponds and marshes above the frozen permafrost. Mosses, grasses, lichens, wildflowers, and shrubs grow quickly during the short summers. In North America, herds of caribou eat the vegetation and are in turn preyed upon by wolves. Some birds, such as the white-tailed ptarmigan, live on the tundra year-round. Others, such as the arctic tern and many waterfowl, spend only their summer breeding seasons there.

Reading Checkpoint **What type of vegetation is found on the tundra?**

FIGURE 20
Tundra Climate
The Nenet people are reindeer herders on the tundra of northern Russia. These reindeer are grazing on some short shrubs typical of tundra plants.

Highlands

Why are highlands a distinct climate region? **Temperature falls as altitude increases, so highland regions are colder than the regions that surround them.** Increasing altitude produces climate changes similar to the climate changes you would expect with increasing latitude. Precipitation also increases as air masses carrying moisture pass over highland areas.

The climate on the lower slopes of a mountain range is like that of the surrounding countryside. The Rocky Mountain foothills, for instance, share the semiarid climate of the Great Plains. But as you go higher up into the mountains, temperatures become lower and precipitation increases. Climbing 1,000 meters up in elevation is like traveling 1,200 kilometers toward the poles. The climate higher in the mountains is like that of the subarctic: cool with coniferous trees. The high mountains of California, including the Sierra Nevada, have a highland climate.

Above a certain elevation—the tree line—temperatures are too low for trees to grow. The climate above the tree line is like that of the tundra. Only low plants, mosses, and lichens can grow there.

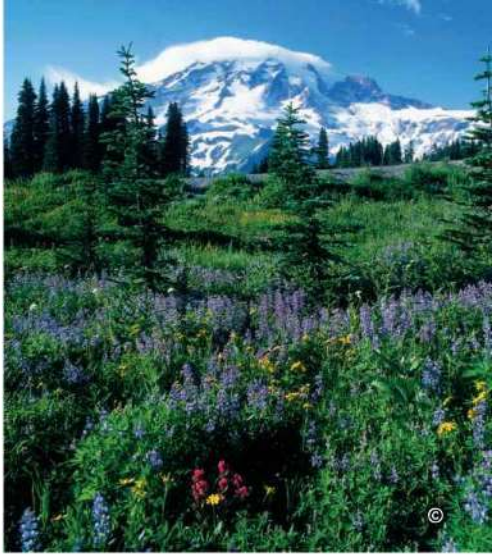


FIGURE 21
Highland Climate
Highland climates are generally cooler than surrounding regions. The Mount Ranier area in Washington State has short summers and long, severe winters.
Classifying *What climate zone does the mountaintop resemble?*

Section 3 Assessment

S 6.4.e, E-LA: Reading 6.2.4

Target Reading Skill **Create Outlines** Complete your outline for this section. What important ideas did you include about temperate marine climates?

Reviewing Key Concepts

HINT
1. a. **Listing** What two major factors are used to classify climates?

HINT
b. **Reviewing** What other factor did Köppen use in classifying climates?

HINT
2. a. **Identifying** What are the six main climate regions?

HINT
b. **Comparing and Contrasting** How is a tropical wet climate similar to a tropical wet-and-dry climate? How are they different?

HINT
c. **Inferring** In what climate region would you find plains covered with short grasses and small bushes? Explain.

HINT
d. **Relating Cause and Effect** Why do marine west coast climates have much precipitation?

HINT
e. **Predicting** Which place would have more severe winters—central Russia or the west coast of France? Why?

HINT
f. **Sequencing** Place the following climates in order from coldest to warmest: tundra, subarctic, humid continental, ice cap.

HINT
g. **Relating Cause and Effect** How could a forest grow on a mountain that is surrounded by a desert?

Lab zone At-Home Activity

What's Your Climate? Describe to your family the characteristics of the climate region in which you live. What plants and animals live in your climate region? What characteristics do these plants and animals have that make them well adapted to the region?

Lab zone **Consumer Lab**
Guided Inquiry

S 6.4.e, 6.7.c

Cool Climate Graphs

Materials

3 pieces of graph paper

black, blue, red, and green pencils

ruler

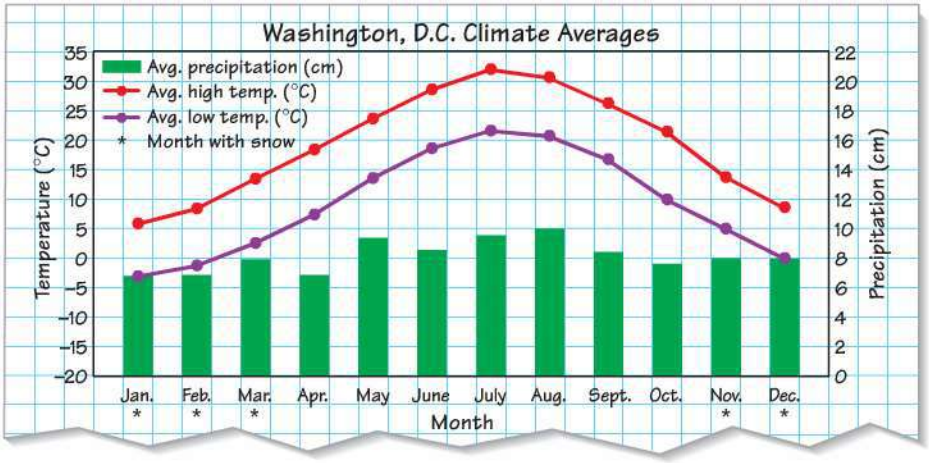
calculator

Problem **Based on climate data, what is the best time of year to visit various cities to enjoy particular recreational activities?**

Skills Focus **graphing, interpreting data**

Procedure

1. Work in groups of three. Each person should graph the data for a different city, A, B, or C.
2. On graph paper, use a black pencil to label the axes as on the climate graph below. Title your climate graph City A, City B, or City C.
3. Use your green pencil to make a bar graph of the monthly average amount of precipitation. Place a star below the name of each month that has more than a trace of snow.
4. Use a red pencil to plot the average monthly maximum temperature. Make a dot for the temperature in the middle of each space for the month. When you have plotted data for all 12 months, connect the points into a smooth curved line.
5. Use a blue pencil to plot the average monthly minimum temperature for your city. Use the same procedure as in Step 4.
6. Calculate the total average annual precipitation for this city and include it in your observations. Do this by adding the average precipitation for each month.



Climate Data												
Washington, D.C.	**Jan.**	**Feb.**	**Mar.**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Average High Temp. (°C)	6	8	14	19	24	29	32	31	27	21	14	8
Average Low Temp. (°C)	−3	−2	3	8	14	19	22	21	17	10	5	0
Average Precipitation (cm)	6.9	6.9	8.1	6.9	9.4	8.6	9.7	9.9	8.4	7.6	7.9	7.9
Months With Snow	*	*	*	trace	—	—	—	—	—	trace	*	*
City A	**Jan.**	**Feb.**	**Mar.**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Average High Temp. (°C)	13	16	16	17	17	18	18	19	21	21	17	13
Average Low Temp. (°C)	8	9	9	10	11	12	12	13	13	13	11	8
Average Precipitation (cm)	10.4	7.6	7.9	3.3	0.8	0.5	0.3	0.3	0.8	3.3	8.1	7.9
Months With Snow	trace	trace	trace	—	—	—	—	—	—	—	—	trace
City B	**Jan.**	**Feb.**	**Mar.**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Average High Temp. (°C)	5	7	10	16	21	26	29	27	23	18	11	6
Average Low Temp. (°C)	−9	−7	−4	1	6	11	14	13	8	2	−4	−8
Average Precipitation (cm)	0.8	1.0	2.3	3.0	5.6	5.8	7.4	7.6	3.3	2.0	1.3	1.3
Months With Snow	*	*	*	*	*	—	—	—	trace	*	*	*
City C	**Jan.**	**Feb.**	**Mar.**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Average High Temp. (°C)	7	11	13	18	23	28	33	32	27	21	12	8
Average Low Temp. (°C)	−6	−4	−2	1	4	8	11	10	5	1	−3	−7
Average Precipitation (cm)	2.5	2.3	1.8	1.3	1.8	1	0.8	0.5	0.8	1	2	2.5
Months With Snow	*	*	*	*	*	trace	—	—	trace	trace	*	*

Analyze and Conclude

Use all three climate graphs, plus the graph for Washington, D.C., to answer these questions.

1. **Interpreting Data** Which of the four cities has the least change in average temperatures during the year?
2. **Interpreting Maps** Use the climate map on pages 364–365 to help find the climate region in which each city is located.
3. **Applying Concepts** Which of the cities below matches each climate graph?
   Colorado Springs, Colorado; latitude 39° N
   San Francisco, California; latitude 38° N
   Reno, Nevada; latitude 40° N
4. **Inferring** The four cities are at approximately the same latitude. Why are their climate graphs so different?
5. **Graphing** What factors do you need to consider when setting up and numbering the left and right *y*-axes of a climate graph so that your data will fit on the graph?
6. **Communicating** Imagine that you are writing a travel brochure for one of the four cities. Write a description of the climate of the city and discuss the best time to visit to do a selected outdoor activity.

More to Explore

What type of climate does the area where you live have? Find out what outdoor recreational opportunities your community has. How is each activity particularly suited to the climate of your area?

Section 4

Climate Change

CALIFORNIA Standards Focus

S 6.4.e Students know differences in pressure, heat, air movement, and humidity result in changes in weather.

- How might human activities be affecting the temperature of Earth's atmosphere?
- How have human activities affected the ozone layer?

Key Terms

- ice age
- global warming
- greenhouse gas
- ozone hole
- chlorofluorocarbon

Lab zone Standards Warm-Up

What Is the Greenhouse Effect?

1. Cut two pieces of black construction paper to fit the bottoms of two shoe boxes.
2. Place a thermometer in each box. Record the temperatures on the thermometers. Cover one box with plastic wrap.
3. Place the boxes together where sunlight or a light bulb can shine on them equally. Make sure the thermometers are shaded by the sides of the boxes.
4. Wait 15 minutes and read the thermometers again. Record the temperatures.

Think It Over

Inferring How can you explain any temperature difference between the two boxes?

The amount of energy transferred from the sun to Earth remains nearly constant over time. As a result, Earth's climates tend to be fairly stable for thousands of years. However, climates have gradually changed throughout Earth's history. Over millions of years, warm periods have alternated with cold periods known as **ice ages**. During an ice age, huge sheets of ice called glaciers cover large parts of Earth's surface.

In the past two million years there have been many major ice ages. Each one lasted 100,000 years or longer. Long, warmer periods occurred between the ice ages. Some scientists think that we are now in a warm period between ice ages.

The last ice age ended only about 10,500 years ago. Ice sheets covered much of northern Europe and North America, reaching as far south as present-day Iowa and Nebraska. In some places, the ice was more than 3 kilometers thick. So much water was frozen in the ice sheets that the average sea level was much lower than it is today. When the ice sheets melted, the rising oceans flooded coastal areas. Inland, the Great Lakes and many smaller bodies of water formed.

Video Field Trip
Discovery Channel School
Climate and Climate Change

Global Warming

Most past changes in world climates were caused by natural factors, such as volcanic activity and the motion of the continents. But recently scientists have observed climate changes that may be the result of human activities. For example, over the last 120 years, the average temperature of the troposphere has risen by about 0.7 Celsius degree. This gradual increase in the temperature of Earth's atmosphere is called **global warming.**

The Greenhouse Hypothesis Recall that gases in Earth's atmosphere hold in heat from the sun, keeping the atmosphere at a comfortable temperature for living things. Recall that the process by which gases in Earth's atmosphere trap this energy is called the greenhouse effect. Look at the greenhouse in Figure 22. Notice that sunlight does not heat the air in the greenhouse directly. Instead, sunlight first heats the soil, benches, and pots. Then infrared radiation from these surfaces heats the air in the greenhouse. The greenhouse effect in Earth's atmosphere is similar in some ways.

Gases in the atmosphere that trap energy are called **greenhouse gases.** Carbon dioxide, water vapor, and methane are some of the greenhouse gases. **Many scientists have hypothesized that human activities that add greenhouse gases to the atmosphere are warming Earth's atmosphere.**

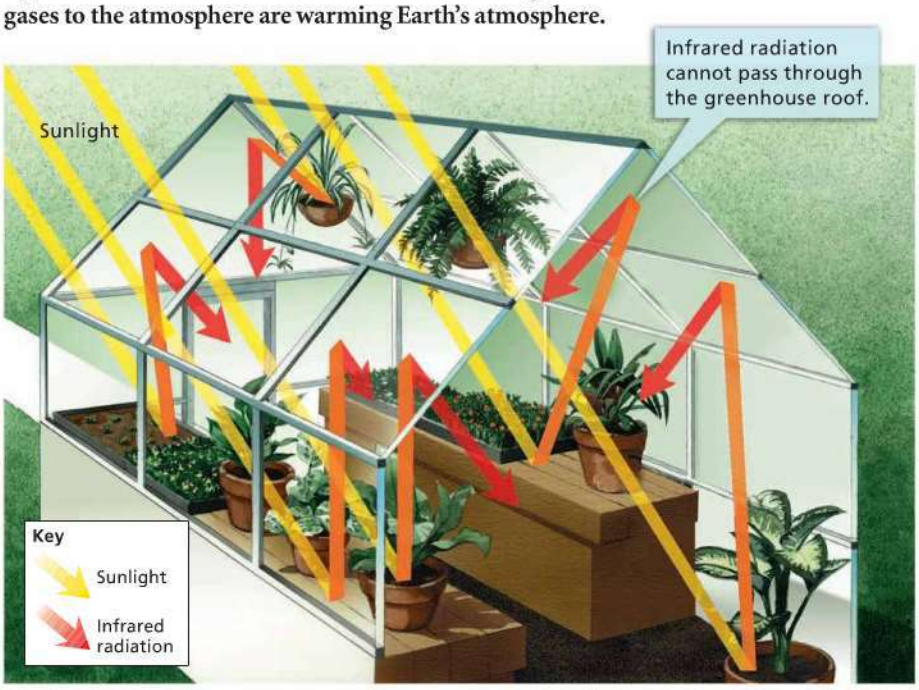


FIGURE 22
Greenhouse Effect
Sunlight enters a greenhouse and is absorbed. The interior of the greenhouse radiates back energy in the form of infrared radiation, or heat. Much of the heat is trapped and held inside the greenhouse, warming it.
Applying Concepts *What gases in Earth's atmosphere can trap heat like a greenhouse?*

FIGURE 23
Ice Core Samples
These scientists are taking an ice core from the glacier that covers Antarctica. Data from ice cores enable scientists to measure changing levels of carbon dioxide in the atmosphere.

Changing Levels of Carbon Dioxide Scientists think that an increase in carbon dioxide is a major factor in global warming. Until the late 1800s, the level of carbon dioxide in the atmosphere remained about the same. How did scientists determine this? They measured the amount of carbon dioxide in air bubbles trapped in Antarctic ice. They obtained these samples of ancient air from ice cores, as shown in Figure 23. The glacier that covers Antarctica formed over millions of years. Gas bubbles in the ice cores provide samples of air from the time the ice formed.

Is global warming caused by human activities, or does it have a natural cause? Scientists have done a great deal of research to try to answer this question.

Since the late 1800s, the level of carbon dioxide in the atmosphere has increased steadily. Most scientists think that this change is a result of increased human activities. For example, the burning of wood, coal, oil, and natural gas adds carbon dioxide to the air. During the last 100 years, these activities have increased greatly in many different countries. Some scientists predict that the level of carbon dioxide could double by the year 2100. If that happens, then global temperature could rise by 1.5 to 4.5 Celsius degrees.

Math: Algebra and Functions 6.2.0

Math Analyzing Data

Carbon Dioxide Levels

The graph shows estimated carbon dioxide levels in the atmosphere over the last 1,000 years.

1. **Reading Graphs** What variable is shown on the *x*-axis of the graph? On the *y*-axis?
2. **Interpreting Data** What pattern do you see in these data? How would you explain this pattern?
3. **Interpreting Data** How much did carbon dioxide levels increase between 1800 and 1900? Between 1900 and 2000?
4. **Predicting** Given the trend in carbon dioxide levels between 1900 and 2000, predict the level of carbon dioxide in the atmosphere in 2100. If your prediction is correct, what might be the result?

Atmospheric Carbon Dioxide, 1000–2000

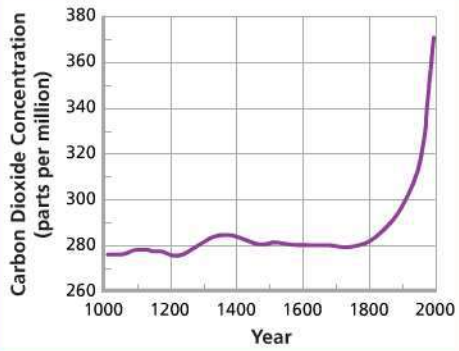


FIGURE 24
Melting Glaciers
The photos show the Burroughs glacier in Alaska. The photo on the left was taken in 1960. The photo on the right, taken in1990, shows the large amount of melting that has taken place. **Developing Hypotheses** *What do you think was responsible for the melting shown in the photos?*

Climate Variation Hypothesis Not all scientists agree about the causes of global warming. Some scientists think that the 0.7 Celsius degree rise in global temperatures over the past 120 years may be due in part to natural variations in climate.

Satellite measurements have shown that the amount of energy the sun produces increases and decreases slightly from year to year. Even such minor changes in solar energy could be causing periods of warmer and cooler climates. Climate change could be a result of changes in both carbon dioxide levels and the amount of solar energy.

Possible Effects Global warming could have some positive effects. Farmers in some areas that are now cool could plant two crops a year instead of one. Places that are too cold for farming today could become farmland. However, many effects of global warming are likely to be less positive. Higher temperatures would cause water to evaporate from exposed soil, such as plowed farmland. Dry soil blows away easily. Thus, some fertile fields might become "dust bowls."

A rise in temperatures of even a few degrees will warm up water in the oceans. Some scientists think warmer ocean water would increase the strength of hurricanes.

As the water warms, it would expand, raising sea level around the world. The melting of glaciers and polar ice caps could also increase sea level. Sea level has already risen by 10 to 20 centimeters over the last 100 years, and could rise another 25 to 80 centimeters by the year 2100. Even such a small rise in sea level would flood low-lying coastal areas.

Reading Checkpoint **What are three possible effects of global warming?**

Go Online
PLANET DIARY
For: More on the greenhouse effect
Visit: PHSchool.com
Web Code: cfd-4044

Lab zone Try This Activity

It's Your Skin!

Compare how well sunscreens block out ultraviolet rays.

1. Close the blinds or curtains in the room. Place one square of sun-sensitive paper inside each of three plastic sandwich bags.
2. Place three drops of one sunscreen on the outside of one bag. Spread the sunscreen as evenly as possible. Label this bag with the SPF number of the sunscreen.
3. On another bag, repeat Step 2 using a sunscreen with a different SPF. Wash your hands after spreading the sunscreen. Leave the third bag untreated as a control.
4. Place the bags outside in direct sunlight. Bring them back inside after 3 minutes or after one of the squares turns completely white.

Drawing Conclusions Did both of the sunscreens block ultraviolet radiation? Was one better than the other? Explain.

Ozone Depletion

Another global change in the atmosphere involves the ozone layer. Ozone in the stratosphere filters out much of the harmful ultraviolet radiation from the sun, as shown in Figure 25.

In the 1970s, scientists noticed that the ozone layer over Antarctica was growing thinner each spring. A large area of reduced ozone, or **ozone hole,** was being created. In 2000, the ozone hole reached a record size of more than 28.5 million km^2—almost the size of Africa. By 2004, the maximum size of the ozone hole decreased to about 20 million km^2. What created the ozone hole? **Chemicals produced by humans have been damaging the ozone layer.**

Chlorofluorocarbons A major cause of ozone depletion is a group of compounds called **chlorofluorocarbons,** or CFCs. CFCs were used in air conditioners and refrigerators, as cleaners for electronic parts, and in aerosol sprays, such as deodorants.

Most chemical compounds released into the air eventually break down. CFCs, however, can last for decades and rise all the way to the stratosphere. In the stratosphere, ultraviolet radiation breaks down the CFC molecules into atoms, including chlorine. The chlorine atoms then break ozone down into oxygen atoms.

Results of Ozone Depletion Because ozone blocks ultraviolet radiation, a decrease in ozone means an increase in the amount of ultraviolet radiation that reaches Earth's surface. Ultraviolet radiation can cause eye damage and several kinds of skin cancer.

In the late 1970s, the United States and many other countries banned most uses of CFCs in aerosol sprays. In 1990, many nations agreed to phase out the production and use of CFCs. Because ozone depletion affects the whole world, such agreements must be international to be effective. Worldwide production of the chemicals has greatly decreased. In the United States, at the current rate it will take until 2010 to completely eliminate the use of CFCs. The size of the ozone hole is expected to gradually shrink over time as these agreements take effect.

Reading Checkpoint **What are CFCs?**

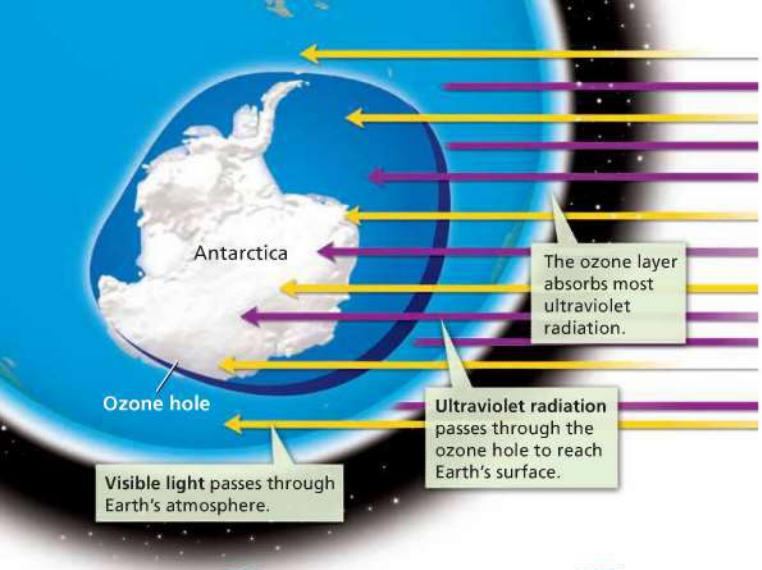
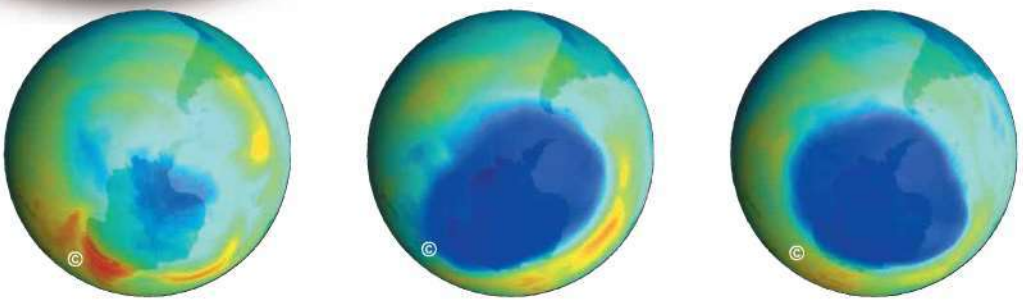


FIGURE 25

The Ozone Hole

The ozone layer blocks much of the ultraviolet radiation (purple) coming from the sun. Visible light (yellow) can pass through the ozone layer. The satellite images below show the concentration of ozone over the South Pole for three years. The dark area shows where the ozone layer is thinnest. **Observing** *How has the size of the ozone hole changed over time?*



1979 2000 2003

Section 4 Assessment

S 6.4.e, E-LA: Reading 6.1.0

Vocabulary Skill High-Use Academic Words

Complete the following sentence to show you understand the word *major*. Some major factors that scientists believe are affecting global warming are _____.

Reviewing Key Concepts

1. a. **Defining** What is global warming?
   b. **Identifying** What human actions increase the amount of carbon dioxide in the atmosphere?
   c. **Relating Cause and Effect** How do scientists think that increased carbon dioxide levels are contributing to global warming?
   d. **Inferring** Much of the atmosphere of the planet Venus is made up of carbon dioxide. How do you think this influences the surface temperatures on Venus?

2. a. **Reviewing** What effect have human activities had on the ozone layer?
   b. **Summarizing** Summarize the cause of ozone depletion and the steps taken to reverse it.
   c. **Relating Cause and Effect** Explain the effect of ozone depletion on human health.

HINT HINT HINT HINT HINT HINT

Lab zone At-Home Activity

Sun Protection Visit a drugstore with your family. Compare the SPF (sun protection factor) of the various sunscreens for sale. Explain why it is important to protect your skin from ultraviolet radiation. Determine the best value for the money in terms of SPF rating and price.

Chapter 9 Study Guide

The BIG Idea The main factors that influence a region's climate include latitude, altitude, distance from large bodies of water, ocean currents, prevailing winds, the presence of mountains, and seasonal winds.

1 What Causes Climate?

Key Concepts S 6.4.a, 6.4.e

- The main factors that influence temperature are latitude, altitude, distance from large bodies of water, and ocean currents.
- The main factors that influence precipitation are prevailing winds, the presence of mountains, and seasonal winds.
- The seasons are caused by the tilt of Earth's axis as Earth travels around the sun.

Key Terms

climate
microclimate
tropical zone
polar zone
temperate zone
marine climate
continental climate
ocean current
windward
leeward
monsoon

2 Currents and Climate

Key Concepts S 6.4.a, 6.4.d

- Surface currents are driven mainly by winds. A surface current warms or cools the air above it, influencing the climate of the land near the coast.
- El Niño and La Niña are short-term changes in the tropical Pacific Ocean caused by changes in ocean surface currents and prevailing winds.
- Deep currents are caused by differences in the density of ocean water. Deep currents move and mix water around the world. They carry cold water from the poles toward the equator.
- Upwelling brings up tiny ocean organisms, minerals, and other nutrients from the deeper layers of the water.

Key Terms

El Niño
La Niña
salinity
upwelling

3 Climate Regions

Key Concepts S 6.4.e

- Scientists classify climates according to two major factors: temperature and precipitation.
- There are six main climate regions: tropical rainy, dry, temperate marine, temperate continental, polar, and highlands.
- The tropics have two types of rainy climates: tropical wet and tropical wet-and-dry.
- Dry climates can be arid and semiarid climates.
- There are three kinds of temperate marine climates: marine west coast, Mediterranean, and humid subtropical.
- Temperate continental climates are only found on continents in the Northern Hemisphere, and include humid continental and subarctic.
- The polar climate is the coldest climate region, and includes the ice cap and tundra climates.
- Temperature falls as altitude increases, so highland regions are colder than regions that surround them.

Key Terms

rain forest
savanna
desert
steppe
chaparral
humid subtropical
subarctic
tundra
permafrost

4 Climate Change

Key Concepts S 6.4.e

- Many scientists have hypothesized that human activities that add greenhouse gases to the atmosphere are warming Earth's atmosphere.
- Chemicals produced by humans have been damaging the ozone layer.

Key Terms

ice age
global warming
greenhouse gas
ozone hole
chlorofluorocarbon

Review and Assessment

Go Online
PHSchool.com
For: Self-Assessment
Visit: PHSchool.com
Web Code: cwa-3090

Target Reading Skill

Create Outlines Complete your outline for Section 1.

What Causes Climate?

I. Factors Affecting Temperature
  A. Latitude
  B. Altitude
  C. Distance From Large Bodies of Water
  D. Ocean Currents
II. Factors Affecting Precipitation
  A.
  B.

Reviewing Key Terms

Choose the letter of the best answer.

HINT **1.** The average conditions of temperature, precipitation, wind, and clouds in an area over a period of years make up its
  a. weather.
  b. latitude.
  c. climate.
  d. season.

HINT **2.** Winds and currents move in curved paths because of
  a. the Coriolis effect.
  b. El Niño.
  c. upwelling.
  d. tides.

HINT **3.** A wet, warm climate zone on the edge of the tropics is
  a. humid subtropical.
  b. tundra.
  c. subarctic.
  d. continental climate.

HINT **4.** A tropical grassland with scattered clumps of trees is a
  a. steppe.
  b. desert.
  c. savanna.
  d. rain forest.

HINT **5.** The main cause of ozone depletion is
  a. global warming.
  b. chlorofluorocarbons.
  c. greenhouse gases.
  d. sunspots.

Complete the following sentences so that your answers clearly explain the key terms.

HINT **6.** **Climate** is different than weather because _____.

HINT **7.** **El Niño,** which is _____, can disrupt weather patterns around the world.

HINT **8.** **Upwelling,** which is _____, provides nutrients that attract huge schools of fish.

HINT **9.** Rain or snow often falls on the **windward** side of a mountain range, meaning _____.

HINT **10.** Higher levels of carbon dioxide in the atmosphere may produce **global warming,** which is _____.

Writing in Science

Expedition Plan Suppose that you are preparing to take a trip back in time to the last ice age. Write a list of the equipment you will need to bring with you and describe what the climate will be like.

Video Assessment
Discovery Channel School
Climate and Climate Change

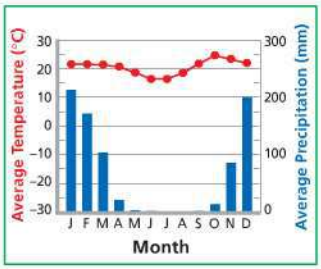
Review and Assessment

Checking Concepts

11. Explain how distance from large bodies of water can affect the temperature of nearby land areas.
12. What are monsoons, and how do they affect climate in the regions where they occur?
13. What causes Earth's seasons?
14. What is the Coriolis effect? How does it influence ocean currents?
15. How do warm-water currents influence climate?
16. How are "dry" climates defined? How do the two types of dry climate differ?
17. To be effective, why must agreements aimed at preventing or reducing ozone depletion be international?

Thinking Critically

18. **Relating Cause and Effect** Describe three ways in which water influences climate.
19. **Comparing and Contrasting** How are El Niño and La Niña similar? How are they different?
20. **Relating Cause and Effect** Why do parts of the United States have a semiarid climate while neighboring areas have a humid continental climate?
21. **Reading Graphs** Which month shown on the graph has the warmest average temperature? Which month is the wettest? What type of climate is indicated by the graph?

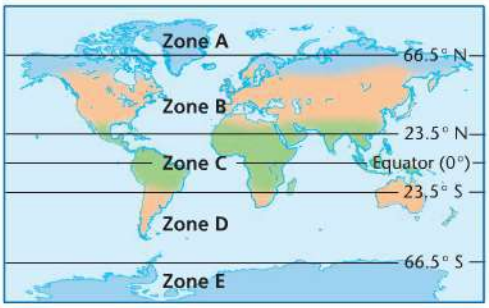


Math Practice

22. **Percentage** Suppose a city receives an average of 35 cm of precipitation each November. If an average of 140 cm of precipitation falls there in a year, what percentage falls in November?

Applying Skills

Use the map of world temperature zones to answer Questions 23–26.



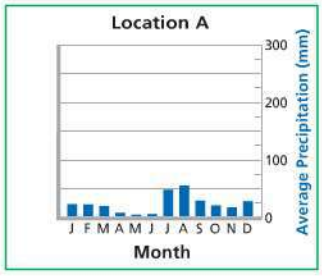
23. **Interpreting Maps** Name each of the five zones shown on the map.
24. **Measuring** What is the name of the temperature zone that includes the equator? How many degrees of latitude does this zone cover?
25. **Interpreting Data** Which of the five zones shown on the map has the greatest amount of land area suitable for people to live?
26. **Drawing Conclusions** Which zone has the highest average temperatures all year round? Explain why.

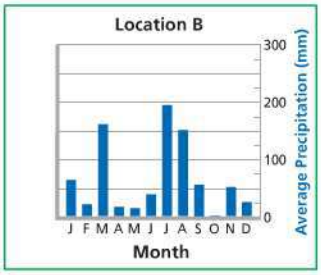
Lab zone Standards Investigation

Performance Assessment Now share your investigation with your class. In your presentation, describe the patterns you found in your graphs. Then explain what you think causes different microclimates. After your presentation, think about how you could have improved your investigation.

Choose the letter of the best answer.

The graphs below show average monthly precipitation for two locations in Arizona. Use the information and your knowledge of science to answer Questions 1–2.





1. During which months do these locations receive the most precipitation?
   - **A** January through March
   - **B** April through June
   - **C** July through September
   - **D** October through December

   S 6.4.e

2. Although they are only a few kilometers apart, Location B receives nearly three times as much precipitation as Location A. What is the best explanation for this fact?
   - **A** Location B is in a rain shadow.
   - **B** Location B is near a mountain top.
   - **C** Location A is dried by prevailing winds.
   - **D** Location A is much colder than Location B.

   S 6.4.e

3. Predict what type of climate would be the most likely in an area located in the interior of a large continent, on the east side of a major mountain range. Winds in the area commonly blow from west to east.
   - **A** dry
   - **B** polar
   - **C** temperate marine
   - **D** tropical rainy

   S 6.4.e

4. What two major factors are usually used to classify climates?
   - **A** precipitation and altitude
   - **B** temperature and air pressure
   - **C** temperature and precipitation
   - **D** air pressure and humidity

   S 6.4.e

5. The major method by which heat flows between the ocean's surface and the deep ocean is
   - **A** conduction.
   - **B** convection.
   - **C** radiation.
   - **D** global warming.

   S 6.3.c, 6.4.d

6. Heat is carried through the ocean from the tropics to the polar regions mainly by
   - **A** waves.
   - **B** upwelling.
   - **C** surface currents.
   - **D** deep currents.

   S 6.3.a, 6.4.d

7. What is the major result at Earth's surface of ozone depletion in the stratosphere?
   - **A** an increase in the amount of ultraviolet radiation reaching the surface
   - **B** a decrease in the amount of ultraviolet radiation reaching the surface
   - **C** an increase in global temperatures
   - **D** a decrease in global temperatures

   S 6.4.e

Apply the BIG Idea

8. Identify three factors that can have a significant effect on a region's climate. Explain how each of these factors can influence climate.

   S 6.4.d, 6.4.e