Chapter 22

Climate

Chapter Outline

Why It Matters

By learning about climate, we can understand more about the atmospheric conditions of Earth in the past and how human activities may affect atmospheric conditions in the future.

Inquiry Lab

30 min

Calculating Average and Yearly Temperatures

Use the **Internet** or the **library** to research the average monthly temperatures for the area in which you live. Using **graph paper,** construct a graph of the average monthly temperatures, with the temperatures on the *y*-axis and the months on the *x*-axis. Next, find the average yearly temperature by calculating the average of the monthly temperatures you used to make the graph. Finally, find the yearly temperature range by determining the difference between the highest average monthly temperature and the lowest average monthly temperature.

Questions to Get You Started

1. How does the temperature change throughout the year in your area?
2. Why is it important to know the average yearly temperature and the yearly temperature range of an area?

READING TOOLBOX

These reading tools will help you learn the material in this chapter.

FoldNotes

Key-Term Fold A key-term fold can help you learn the key terms in this chapter.

Your Turn Create a key-term fold as described in **Appendix A.**

1. Write one key term from the Chapter Summary on the front of each tab.
2. As you read the chapter, write the definition of each term under its tab.
3. Use this FoldNote to study the key terms.

Describing Time

Temporal Language *Temporal language* is language that is used to describe time. Paying careful attention to temporal language can help you understand events and processes in the environment.

Your Turn Make a two-column table. As you read this chapter, write words or phrases that refer to time in the first column of your table. In the second column, write whether the word or phrase describes a specific time, duration, frequency, or sequence of events.

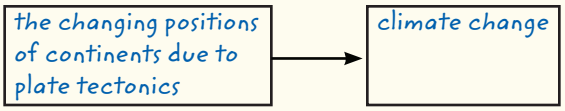
Temporal word or phrase	Describes
over millions of years	duration
today	specific time

Graphic Organizers

Cause-and-Effect Maps You can use cause-and-effect maps to show visually how physical processes depend on one another. To make a cause-and-effect map, follow these steps:

1. Draw a box, and write a cause inside the box. You can have as many cause boxes as you want.
2. Draw another box to represent an effect of the cause. You can have as many effect boxes as you want.
3. Connect each cause box to one or more effect boxes with an arrow.
4. If an effect is also the cause of another effect, you may connect the effect box to another effect box.

Your Turn On a separate sheet of paper, complete the cause-and-effect map started below about the causes of climate change. Add at least three more causes.



For more information on how to use these and other tools, see **Appendix A.**

SECTION 1

ENVIRONMENTAL CONNECTION

Factors That Affect Climate

Key Ideas	Key Terms	Why It Matters
❯ Identify two major factors used to describe climate. ❯ Explain how latitude determines the amount of solar energy received on Earth. ❯ Describe how the different rates at which land and water are heated affect climate. ❯ Explain the effects of topography on climate.	**climate** **specific heat** **El Niño** **monsoon**	Climate change is big in the news these days. Understanding the factors that affect climate can help us evaluate the news and make informed decisions about our role in climate change.

The weather conditions for an area over a long period of time are referred to as **climate.** Climate is different from weather in that weather is the condition of the atmosphere at a particular time. Weather conditions vary from day to day. Climate is a pattern that varies on a much longer basis.

climate the weather conditions in an area over a long period of time

Temperature and Precipitation

Climates are chiefly described by using average temperature and precipitation. To estimate the average daily temperature, add the high and low temperatures of the day and divide by two. The monthly average is the average of all the daily averages for a given month. The yearly average temperature can be found by averaging the 12 monthly averages. However, using only average temperatures to describe climate can be misleading. As you can see in **Figure 1,** areas that have similar average temperatures may have very different temperature ranges. Another way scientists describe climate is by using the *yearly temperature range,* or the difference between the highest and lowest monthly averages.

Precipitation is also described by using monthly and yearly averages, as well as ranges. As with temperature, average yearly precipitation alone is not enough to describe climate. The months that have the largest amount of precipitation are also important. When describing climate, extremes of temperature and precipitation, as well as averages, have to be considered. The factors that have the greatest influence on both temperature and precipitation are latitude, heat absorption and release, and topography.

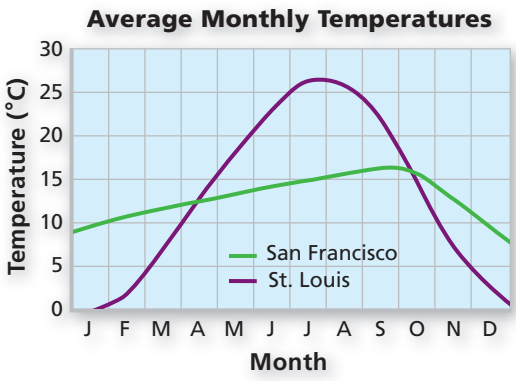


Figure 1 Both St. Louis and San Francisco have the same average yearly temperature. However, St. Louis (right) has a climate of cold winters and hot summers, while San Francisco (left) has a generally mild climate all year.

Latitude

One of the most important factors that determines a region's climate is latitude. Different latitudes on Earth's surface receive different amounts of solar energy. Solar energy determines the temperature and wind patterns of an area, which influence the average annual temperature and precipitation.

Solar Energy

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Topic: What Affects Climate?
Code: HQX1652

The higher the latitude of an area is, the smaller the angle at which the sun's rays hit Earth is and the smaller the amount of solar energy received by the area is. At the equator, or 0° latitude, the sun's rays hit Earth at a 90° angle. So, temperatures at the equator are high. Nearer the poles, the sun's rays hit Earth at a smaller angle, and solar energy is spread over a larger area. So, temperatures at the poles are low.

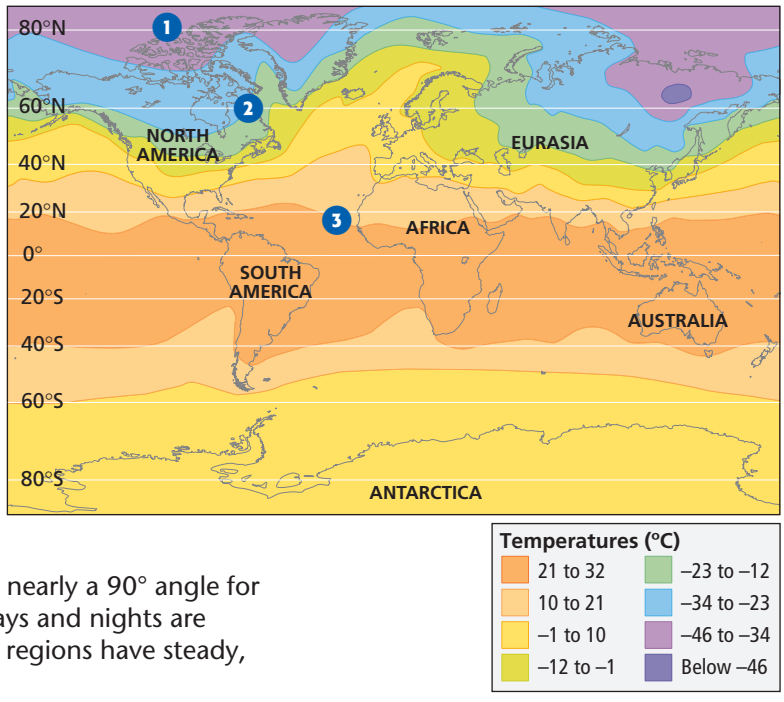
Because Earth's axis is tilted, the angle at which the sun's rays hit an area changes as Earth orbits the sun. During winter in the Northern Hemisphere, the northern half of Earth is tilted away from the sun. Thus, light that reaches the Northern Hemisphere hits Earth's surface at a smaller angle than it does in summer, when the axis is tilted toward the sun. Because of the tilt of Earth's axis during winter in the Northern Hemisphere, areas of Earth at higher northern latitudes directly face the sun for less time than during summer. As a result, the days are shorter and the temperatures are lower during the winter months than during the summer months. **Figure 2** describes these effects.

Figure 2 **Average Sea-Level Temperatures During Winter in the Northern Hemisphere**

1 In polar regions, the amount of daylight varies from 24 h of daylight in the summer to 0 h in the winter. Thus, the annual temperature range is very large, but the daily temperature ranges are very small.

2 At middle latitudes, the sun's rays strike Earth at an angle of less than 90°. The energy of the rays is spread over a large area. Thus, average yearly temperatures at middle latitudes are lower than those at the equator. The lengths of days and nights vary more than they do at the equator. Therefore, the yearly temperature range is large.

3 At the equator, the sun's rays strike Earth at nearly a 90° angle for much of the year. In equatorial regions, both days and nights are about 12 h long throughout the year. So, these regions have steady, high temperatures year-round.



Global Wind Patterns

Because Earth receives different amounts of solar energy at different latitudes, belts of cool, dense air form at latitudes near the poles, while belts of warm, less dense air form near the equator. Because cool air is dense, it forms regions of high pressure, while warm air forms regions of low pressure. Differences in air pressure create wind. Because air pressure is affected by latitude, the atmosphere is made up of global wind belts that run parallel to lines of latitude. Winds affect many weather conditions, such as precipitation, temperature, and cloud cover. Thus, regions that have different global wind belts often have different climates.

In the equatorial belt of low pressure, called the *doldrums,* the air rises and cools, and water vapor condenses. Thus, this region generally has large amounts of precipitation. The amount of precipitation generally decreases as latitude increases. In the regions between about 20° and 30° latitude in both hemispheres, or the *subtropical highs,* the air sinks, warms, and decreases in relative humidity. Thus, little precipitation occurs in these regions. Most of the world's deserts are located in these regions. In the middle latitudes, at about 45° to 60° latitude in both hemispheres, warm tropical air meets cold polar air, which leads to belts of greater precipitation. In the high-pressure areas, above 60° latitude, the air masses are cold and dry, and average precipitation is low.

As seasons change, global wind belts shift in a north or south direction, as shown in **Figure 3.** As the wind and pressure belts shift, the belts of precipitation associated with them also shift.

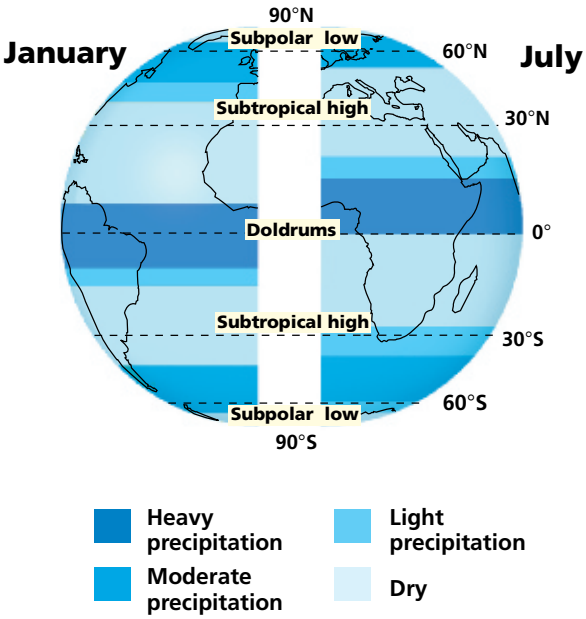


Figure 3 During winter in the Northern Hemisphere, global wind and precipitation belts shift to the south.

Academic Vocabulary

area (ER ee uh) the measure of the size of a surface or region

Heat Absorption and Balance

Latitude and cloud cover affect the amount of solar energy that an area receives. However, different areas absorb and release energy differently. Land heats faster than water and thus can reach a higher temperature in the same amount of time. One reason for this difference is that the land surface is opaque and unmoving. Surface ocean water, on the other hand, is transparent and moves continuously. Waves, currents, and other movements continuously replace warm surface water with cooler water from the ocean depths. This action prevents the surface temperature of the water from increasing rapidly. However, the surface temperature of the land can continue to increase as more solar energy is received. In turn, the temperature of the land or ocean influences the amount of heat that the air above the land or ocean absorbs or releases. The temperature of the air then affects the climate of the area.

Reading Check **How do wind and ocean currents affect the surface temperature of oceans?** (See Appendix G for answers to Reading Checks.)

READING TOOLBOX

Key-Term Fold

Make a FoldNote for terms related to how climate is affected by the temperature differences between land and water. List each term, and explain its effect on climate.

Specific Heat and Evaporation

specific heat the quantity of heat required to raise a unit mass of homogeneous material 1 K or 1 °C in a specified way, given constant pressure and volume

Even if not in motion, water warms more slowly than land does. Water also releases heat energy more slowly than land does. This is because the specific heat of water is higher than that of land. **Specific heat** is the amount of energy needed to change the temperature of 1 g of a substance by 1 °C. A given mass of water requires more energy than land of the same mass does to experience an increase in temperature of the same number of degrees.

The average temperatures of land and water at the same latitude also vary because of differences in the loss of heat through evaporation. Evaporation affects water surfaces much more than it affects land surfaces.

Math Skills

Specific Heat Use the following equation to calculate the amount of energy needed to heat 200 kg of water 6 °C, given that the specific heat of water is 4,186 J/kg•K.

energy = specific heat × mass × temperature change

Ocean Currents

The temperature of ocean currents that come in contact with the air influences the amount of heat absorbed or released by the air. If winds consistently blow toward shore, ocean currents have a strong effect on air masses over land. For example, the combination of a warm Atlantic current and steady westerly winds gives northwestern Europe a high average temperature for its latitude. In contrast, the warm Gulf Stream has little effect on the eastern coast of the United States. This is because westerly winds usually blow the Gulf Stream and its warm tropical air away from the coast.

Reading Check **Why does land heat faster than water does?**

Quick Lab Evaporation

30 min

Procedure

1. On a piece of paper, make a data table similar to the one shown here.
2. Assemble a ring stand on a table. Use a meterstick to place the support rings at heights of 20 cm and 40 cm above the base. Position a portable clamp lamp that has an incandescent bulb directly over the rings, at a height of 60 cm.
3. Place three Petri dishes or watch glasses as follows: one on the base of the stand and one on each of the two rings.
4. Take three thermometers, and lay one across each dish. Turn on the lamp. Use a stopwatch to record the temperature every 3 min for 9 min.
5. Remove the thermometers, and add 30 mL of water to each of the three dishes.
6. Keep the lamp on and over the dishes for 24 h.

Dish	Temperature	Amount of water evaporated
1		
2		
3		

DO NOT WRITE IN THIS BOOK

7. Turn off the lamp. Carefully pour the water from the first dish into a graduated cylinder, and record any change in volume. Repeat this process for the other two dishes.

Analysis

1. At what distance from the lamp did the most water evaporate? the least water evaporate?
2. Explain the relationship between temperature and the rate of evaporation.
3. Explain why puddles of water dry out much more quickly in summer than they do in fall or winter.

El Niño–Southern Oscillation

The *El Niño–Southern Oscillation,* or *ENSO,* is a cycle of changing wind and water-current patterns in the Pacific Ocean. Every 3 to 10 years, **El Niño,** which is the warm-water phase of the ENSO, causes surface-water temperatures along the west coast of South America to rise. The event changes the interaction of the ocean and the atmosphere, which can change global weather patterns. During El Niño, an increase in typhoons, cyclones, and floods may occur in the Pacific Ocean region. Droughts may strike other areas around the world, such as Indonesia and Australia. The ENSO has a cool-water phase, called *La Niña,* as well. La Niña also affects weather patterns, such as increasing the number of Atlantic hurricanes.

El Niño the warm-water phase of the El Niño–Southern Oscillation; a periodic occurrence in the eastern Pacific Ocean in which the surface-water temperature becomes unusually warm

monsoon a seasonal wind that blows toward the land in the summer, bringing heavy rains, and that blows away from the land in the winter, bringing dry weather

Seasonal Winds

Temperature differences between the land and the ocean sometimes cause winds to shift seasonally in some regions. During the summer, the land warms more quickly than the ocean. The warm air rises and is replaced by cool air from the ocean. Thus, the wind moves toward the land. During the winter, the land loses heat more quickly than the ocean does, and the cool air flows away from the land. Thus, the wind moves seaward. Such seasonal winds are called **monsoons.**

Monsoon climates, such as that in southern Asia, are caused by heating and cooling of the northern Indian peninsula. In the winter, continental winds bring dry weather and sometimes drought. In the summer, winds carry moisture to the land from the ocean and cause heavy rainfall and flooding, as shown in **Figure 4.** Monsoon conditions also occur in eastern Asia and affect the tropical regions of Australia and East Africa.

Figure 4 Effects of Monsoon Climates

Because monsoon rains cause regular flooding, such as this flood in eastern India, people who live in monsoon regions have adapted to living in flood conditions.

People who live in monsoon climates must adjust to periodic droughts, such as the drought that affected this cropland in southern India.

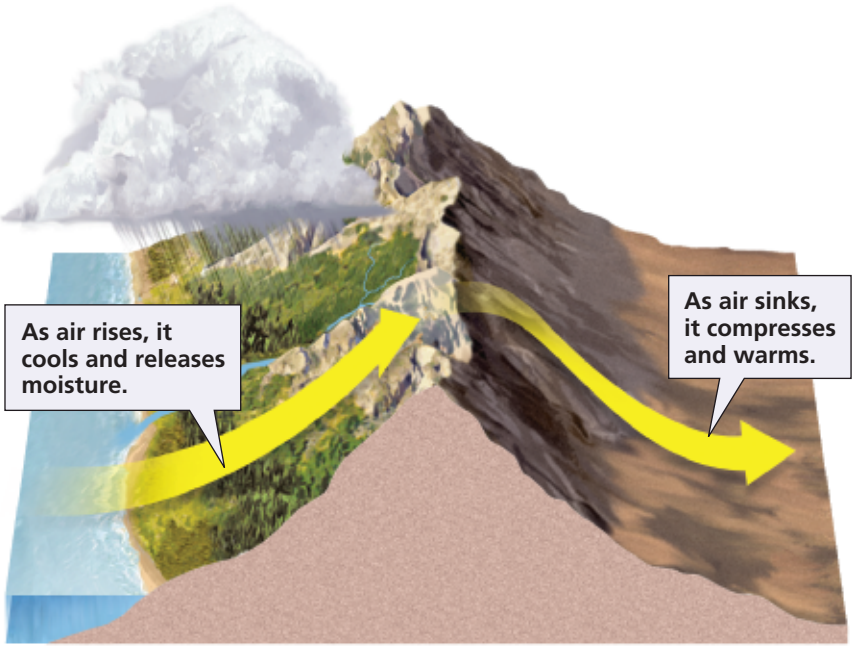


Figure 5 Mountains cause air to rise, cool, and lose moisture as the air passes over them. This process affects the climate on both sides of the mountains.

Topography

The surface features of the land, or *topography*, also influence climate. Topographical features, such as mountains, can control the flow of air through a region.

Elevation

The elevation, or height of landforms above sea level, produces distinct temperature changes. Temperature generally decreases as elevation increases. For example, for every 100 m increase in elevation, the average temperature decreases by 0.7 °C. Even along the equator, the peaks of high mountains can be cold enough to be covered with snow.

Rain Shadows

When a moving air mass encounters a mountain range, the air mass rises, cools, and loses most of its moisture through precipitation, as shown in **Figure 5.** As a result, the air that flows down the other side of the range is usually warm and dry. This effect is called a *rain shadow*. One type of warm, dry wind that forms in this way is the *foehn* (FAYN), a dry wind that flows down the slopes of the Alps. Similar dry, warm winds that flow down the eastern slopes of the Rocky Mountains are called *chinooks*.

Section 1 Review

Key Ideas

1. **Identify** two factors that are used to describe climate.
2. **Explain** how latitude determines the amount of solar energy received on Earth.
3. **Describe** how latitude determines wind patterns.
4. **Describe** how the different rates at which land and water are heated affect climate.
5. **Explain** the El Niño–Southern Oscillation cycle.
6. **Summarize** the conditions that cause monsoons.
7. **Explain** how elevation affects climate.
8. **Describe** a rain shadow and the resulting local winds.

Critical Thinking

9. **Making Inferences** If land and water had the same specific heat, how might climate be different around the world?
10. **Analyzing Processes** On a mountain, are you likely to find more vegetation on the side facing prevailing winds or on the side facing away from them?
11. **Recognizing Relationships** Why might you find snow-capped mountains in Hawaii even though Hawaii is closer to the equator than Florida is?

Concept Mapping

12. Use the following terms to create a concept map: *climate, temperature range, wind, doldrums, subtropical high, monsoon, El Niño,* and *topography.*

SECTION 2

Climate Zones

ENVIRONMENTAL CONNECTION

Key Ideas	Key Terms	Why It Matters
❯ Describe the three types of tropical climates. ❯ Describe the five types of middle-latitude climates. ❯ Describe the three types of polar climates. ❯ Explain why city climates may differ from rural climates.	**tropical climate** **middle-latitude climate** **polar climate** **microclimate**	Identifying and studying the different types of climates on Earth helps you better understand the factors that influence the climate where you live.

Earth has three major types of climate zones—tropical, middle-latitude, and polar—each with distinct temperature characteristics. Each zone also has several types of climates because the amount of precipitation within each zone varies.

Tropical Climates

Climates characterized by high temperatures and located in the equatorial region are referred to as **tropical climates.** These climates have an average monthly temperature of at least 18 °C, even during the coldest months. Within the tropical zone, there are three types of tropical climates, as shown in **Table 1.**

tropical climate a climate characterized by high temperatures and heavy precipitation during at least part of the year

Tropical rain-forest climates are humid and warm. Central Africa, the Amazon River basin of South America, Central America, and Southeast Asia have areas with tropical rain-forest climates.

Tropical desert climates receive very little precipitation. The largest belt of tropical deserts extends across north Africa and southwestern Asia.

Savanna climates are located in South America, Africa, Southeast Asia, and northern Australia. These climates are described in **Table 1.**

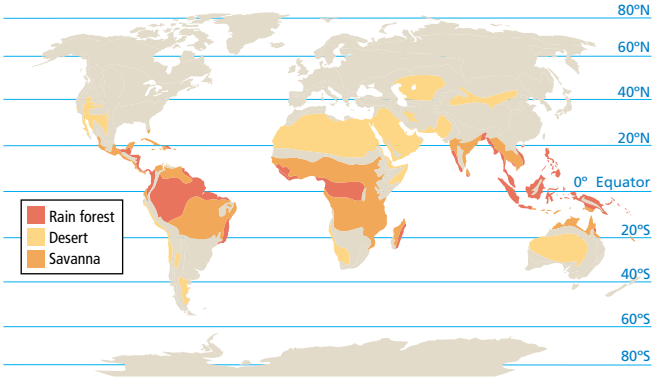
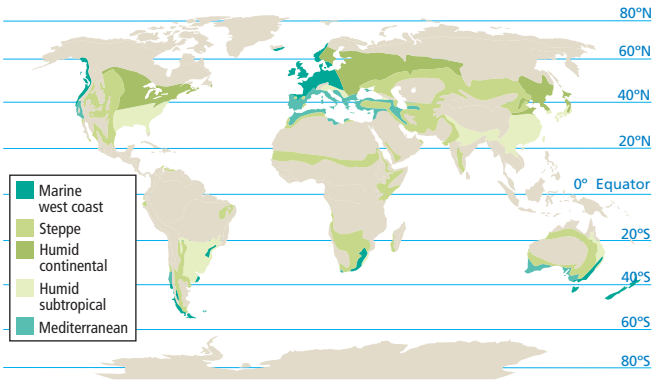


Table 1 Tropical Climates

Climate	Temperature and precipitation	Description
Rain forest	small temperature range; annual rainfall of 200 cm	characterized by dense, lush vegetation; broadleaf plants; and high biodiversity
Desert	large temperature range, with hot days and cold nights; annual rainfall of less than 25 cm	characterized by little to no vegetation and organisms adapted to dry conditions
Savanna	small temperature range; annual rainfall of 50 cm; alternating wet and dry periods	characterized by open grasslands that have clumps of drought-resistant shrubs

Table 2 Middle-Latitude Climates

Climate	Temperature and precipitation	Description
Marine west coast	small annual temperature range; frequent rainfall throughout the year	characterized by deciduous trees and dense forests; mild winters and summers
Steppe	large annual temperature range; annual precipitation of less than 40 cm	characterized by drought-resistant vegetation; cold, dry winters and warm, wet summers
Humid continental	large annual temperature range; annual precipitation of greater than 75 cm	characterized by a wide variety of vegetation and evergreen trees; variable weather
Humid subtropical	large annual temperature range; annual precipitation of 75 to 165 cm	characterized by broadleaf and evergreen trees; high humidity
Mediterranean	small annual temperature range; average annual precipitation of about 40 cm	characterized by broadleaf and evergreen trees; long, dry summers and mild, wet winters



middle-latitude climate a climate that has an average maximum temperature below 18 °C in the coldest month and an average minimum temperature above 10 °C in the warmest month

Middle-Latitude Climates

Climates that have an average maximum temperature below 18 °C in the coldest month and an average minimum temperature above 10 °C in the warmest month are referred to as **middle-latitude climates.** There are five middle-latitude climates, which are described in **Table 2.**

Marine west coast climates receive about 60 to 150 cm of precipitation annually. The average temperature is 20 °C in the summer and 7 °C in the winter. The Pacific Northwest of the United States has a marine west coast climate.

Steppe climates are dry climates that receive less than 40 cm of precipitation per year. The average summer temperature is about 23 °C. The winters are very cold and have an average temperature of −1 °C. The Great Plains of the United States has a steppe climate.

The *humid continental climate* and *humid subtropical climate* both have high annual precipitation. However, the humid continental climate has a much greater temperature range between the summers and winters than the humid subtropical climate. In the United States, the humid subtropical climate is in the southeast and the humid continental climate is in the northeast.

The *mediterranean climate* is a mild climate that has a small temperature range between summer and winter. This climate is named after the sea between Africa and Europe, where this climate is located. However, this climate is also found along the coast of central and southern California.

Reading Check **Which subclimates have high annual precipitation?**

READING TOOLBOX

Cause-and-Effect Map

Draw a cause-and-effect map that shows how different climate conditions affect vegetation.

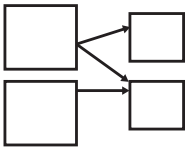


Figure 1 Subarctic climates, as shown here at Tombstone Valley in Yukon, Canada, support sparse tree growth.

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Topic: Polar Climates
Code: HQX1175

Polar Climates

polar climate a climate that is characterized by average temperatures that are near or below freezing

The climates of the polar regions are referred to as the **polar climates.** There are three types of polar climates: the subarctic climate, shown in **Figure 1,** the tundra climate, and the polar icecap climate. The *subarctic climate* has the largest annual temperature range of all climates. The difference between summer and winter temperatures in the subarctic climate has been as much as 63 °C. The *tundra climate* has a smaller annual temperature range than the subarctic climate does. However, the average temperature of the tundra climate is colder than that of the subarctic climate. In the *polar icecap climate,* most of the land surface and much of the ocean are covered in thick sheets of ice year-round. The average temperature never rises above freezing. The polar climates are described in **Table 3.**

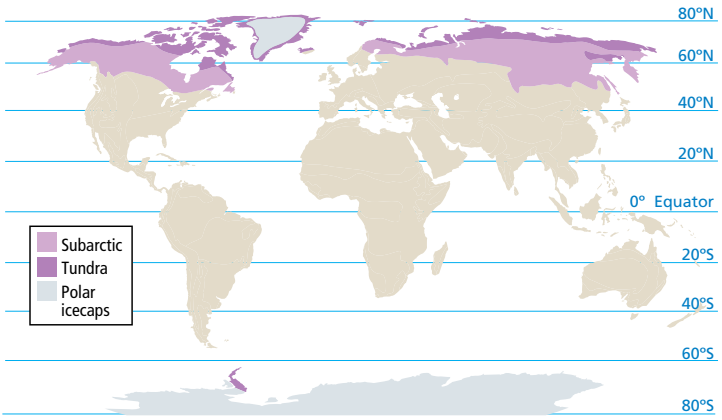


Table 3 Polar Climates

Climate	Temperature and precipitation	Description
Subarctic	largest annual temperature range (63 °C); annual precipitation of 25 to 50 cm	characterized by evergreen trees; brief, cool summers and long, cold winters
Tundra	average temperature below 4 °C; annual precipitation of 25 cm	characterized by treeless plains; nine months of temperatures below freezing
Polar icecap	average temperature below 0 °C; low annual precipitation	characterized by little or no life; temperatures below freezing year-round and high winds

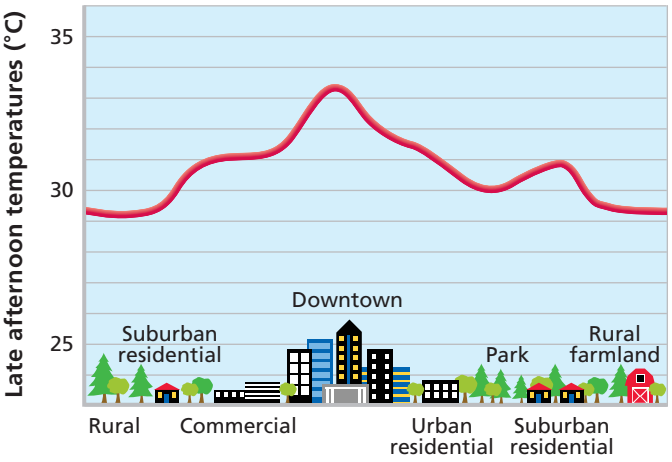


Figure 2 The less vegetation and more pavement and buildings an area has, the higher the temperatures in the area tend to be.

Local Climates

The climate of a small area is called a **microclimate.** Microclimates are influenced by density of vegetation, by elevation, and by proximity to large bodies of water and structures built by humans. For example, in a city, pavement and buildings absorb solar energy and then reradiate that energy as heat, which raises the temperature of the air above and creates a "heat island," as shown in **Figure 2.** As a result, the average temperature may be a few degrees higher in the city than it is in surrounding rural areas. In contrast, vegetation in rural areas does not reradiate as much energy, so temperatures in those areas are lower.

microclimate the climate of a small area

Effects of Elevation

Elevation also may affect local climates. As elevation increases, temperature decreases and the climate changes. For example, the *highland climate* is characterized by large variations in temperature and precipitation over short distances because of changes in elevation. Highland climates are commonly located in mountainous regions—even in tropical areas.

Academic Vocabulary

variation (VER ee AY shuhn) a difference in the usual form or function

Effects of Large Bodies of Water

Large bodies of water, such as lakes, influence local climates. The water absorbs and releases heat slower than the land does. Thus, the water moderates the temperature of the nearby land. Large bodies of water can also increase precipitation. Therefore, microclimates near large bodies of water have a smaller range of temperatures and higher annual precipitation than other locations at the same latitude do.

Section 2 Review

Key Ideas

1. **Identify** the three types of climate zones.
2. **Describe** the three types of tropical climates.
3. **Describe** the five types of middle-latitude climates.
4. **Describe** the three types of polar climates.
5. **Identify** three factors that influence microclimates.
6. **Explain** why city climates may differ from rural climates.

Critical Thinking

7. **Making Inferences** What would happen to the temperature of a rural location if the vegetation were replaced with a parking lot?
8. **Compare and Contrast** Compare latitude lines with the boundaries of major climate zones. Why do they align in some regions but not in others?

Concept Mapping

9. Use the following terms to create a concept map: *tropical climate, subarctic, tundra, steppe, polar icecap, mediterranean, middle-latitude climate, rain forest, savanna, desert,* and *polar climate.*

SECTION 3

Climate Change

ENVIRONMENTAL CONNECTION

Key Ideas	Key Terms	Why It Matters
❯ Compare four methods used to study climate change. ❯ Describe four factors that may cause climate change. ❯ Identify potential impacts of climate change. ❯ Identify ways that humans can minimize their effect on climate change.	**climatologist** **global warming**	There's no doubt that climate changes. Understanding how and why it changes will help guide your response to issues like global warming.

Scientists who study and compare past and present climates are called **climatologists.** Climatologists look at past climates to find patterns in the changes that occur. Identifying those patterns allows the scientists to make predictions about future climates.

Studying Climate Change

When trying to learn about factors that influence climate change, scientists study the evidence left by past climates. This evidence can be left in the remains of plants and animals from earlier time periods. For example, *fossils* of a plant or animal may show adaptations to a particular environment that can reveal clues about the environment's climate. Even polar icecaps contain evidence of past climates. By studying the concentration of gases trapped within *ice cores,* scientists can learn about the gas composition of the atmosphere thousands of years ago. **Table 1** describes some of the methods used to study past climates.

climatologist a scientist who gathers data to study and compare past and present climates and to predict future climate change

Table 1 Methods of Studying Past Climates

Method	What is measured	What is indicated	Length of time measured
Ice cores	concentrations of gases in ice and meltwater	High levels of CO_2 indicate warmer climate; ice ages accompany decreases in CO_2.	hundreds of thousands of years
Sea-floor sediment	concentration of ^{18}O in shells of microorganisms	High ^{18}O levels indicate cool water; lower ^{18}O levels indicate warm water.	hundreds of thousands of years
Fossils	pollen types, leaf shapes, and animal body adaptations	Flower pollens and broad leaves indicate warm climates; evergreen pollens and small, waxy leaves indicate cool climates. Animal fossils show adaptations to climate changes.	millions of years
Tree rings	ring width	Thin rings indicate cool weather and/or less precipitation.	hundreds to thousands of years
Speleothems	concentrations of ^{13}C and ^{18}O in stalagmites	High levels of ^{13}C indicate El Niño events. Low levels of ^{18}O record individual hurricanes.	weeks to hundreds of years

Figure 1 Scientists need to use powerful computers to process the amount of data required to study climates.

Modeling Climates

Because so many factors influence climate, studying climate change is a complicated process. Currently, scientists use computers to create models to study climate, as shown in **Figure 1.** These models incorporate millions of pieces of data and help sort the complex sets of variables that influence climate. They are called *general circulation models,* or *GCMs*. GCMs simulate changes in one variable when other variables are unchanged. For example, if the sulfur dioxide level is raised in a particular model, the model indicates a decrease in incoming solar radiation because sulfur dioxide reflects sunlight.

Climate models simulate many factors of climate, including temperature, precipitation, wind patterns, and sea-level changes. These computer models are complex because they model interactions between oceans, wind, land, clouds, and vegetation. As computers become more powerful, computer-generated climate models will provide greater detail about the global climate system and will help scientists better understand climate change.

Reading Check **Why do scientists use computers to model climate?**

Why It Matters

Ice Tells a Story

Have you ever had a frozen treat with several layers that were different colors or textures? You probably inferred that each layer would have a different flavor. Similarly, each layer of ice in the Arctic and Antarctica was formed under different conditions, such as temperature, wind patterns, and amount of precipitation. Scientists study layers of ice in ice cores and make inferences about the conditions under which each layer formed. Ice cores are obtained by drilling thousands of meters down into polar ice. Ice cores can help scientists understand past climate change and develop models to predict future climate change.

EYE ON THE ENVIRONMENT

Each annual snowfall creates a distinct layer of polar ice, which can provide scientists with annual climate data.

YOUR TURN

ONLINE RESEARCH

Research how scientists use ice cores to study past volcanic events.

Potential Causes of Climate Change

By studying computer-generated climate models, scientists have determined several potential causes of climate change. Factors that might cause climate change include the movement of tectonic plates, changes in Earth's orbit, human activity, and atmospheric changes.

READING TOOLBOX

Temporal Language
As you read about climate change, make a table that describes the temporal language that is used.

Plate Tectonics

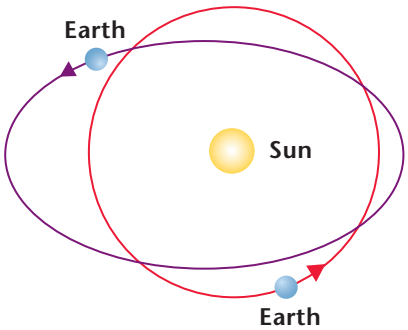
The movement of continents over millions of years caused by tectonic plate motion may affect climate change. The changing position of the continents changes wind flow and ocean currents around the globe. These changes affect the temperature and precipitation patterns of the continents and oceans. Thus, the climate of any particular continent is not the same as it was millions of years ago.

Orbital Changes

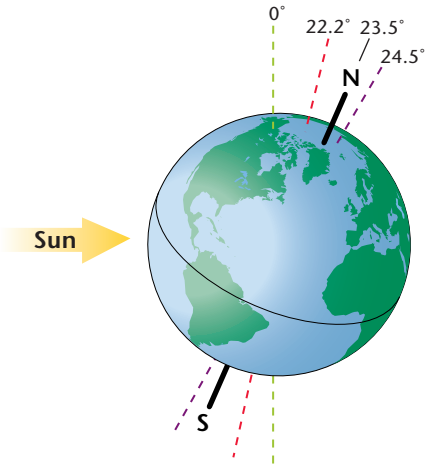
Periodic changes in the shape of Earth's orbit, changes in Earth's tilt, and the wobble of Earth on its axis can lead to climate change, as shown in **Figure 2.** The combination of these factors is described by the *Milankovitch theory*. Each change of motion has a different effect on climate. Variation in the shape of Earth's orbit, from elliptical to more circular, affects Earth's distance from the sun. Earth's distance from the sun affects the temperature of Earth and therefore affects the climate. Decreasing tilt decreases temperature differences between seasons. The wobble of Earth on its axis changes the direction of Earth's tilt and can reverse the seasons. These changes occur in cycles of 100,000, 41,000, and 26,000 years respectively.

THINK central
INTERACT ONLINE
Keyword: HQXCLIF2

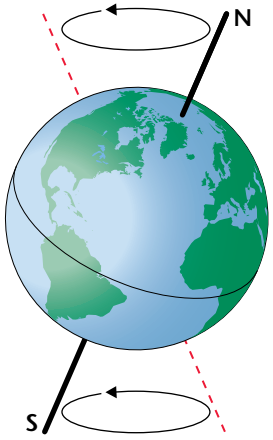
Figure 2 Earth's Orbital Changes



Eccentricity Earth encounters more variation in the energy that it receives from the sun when Earth's orbit is elongated than it does when Earth's orbit is more circular.



Tilt The tilt of Earth's axis varies between 22.2° and 24.5°. The greater the tilt angle is, the more solar energy the poles receive.



Precession A gradual change, or "wobble," in the orientation of Earth's axis affects the relationship between Earth's tilt and eccentricity.

Figure 3 Most deforestation in Brazil is caused by farmers who clear the land for planting crops.

Quick Lab

15 min

Hot Stuff

Procedure

1. In mid-afternoon, use a **thermometer** to measure the air temperature over a grassy field or other vegetated area. Make sure to shield the thermometer from direct sunlight.
2. Measure the air temperature over a parking lot. Take the measurement at the same height above the surface as the height of the measurement over the vegetated area. Again, make sure that the thermometer is not directly in the sunlight.

Analysis

1. How did the results differ for each location?
2. How would you explain the difference in the results?
3. What suggestion for how to keep cooling costs low would you give to someone who is building a new store?

Academic Vocabulary

impact (IM PAKT) the effect of one thing on another

Human Activity

Human activity affects climate through emissions and land use. Pollution from transportation and industry releases carbon dioxide, CO_2, into the atmosphere. Increases in CO_2 concentrations may lead to global warming, an increase in temperatures around Earth. CO_2 is also released into the atmosphere when trees are burned to provide land for agriculture and urban development. Because vegetation uses CO_2 to make food, deforestation, as shown in **Figure 3,** also affects one of the natural ways of removing CO_2 from the atmosphere. As scientists continue to study climate, they will learn more about how human activity affects climate and about how changes in climate may affect us.

Volcanic Activity

Large volcanic eruptions can influence climates around the world. Sulfur and ash from eruptions can decrease temperatures by reflecting sunlight back into space. These changes last from a few weeks to several years and depend on the strength and duration of the eruption.

Potential Impacts of Climate Change

Scientists are concerned about climate changes because of the potential impacts of these changes. Earth's atmosphere, oceans, and land are all connected, and each influences both local and global climates. Changes in the climate of one area can affect climates around the world. Climate change affects not only humans but also plants and animals. Even short-term changes in the climate may lead to long-lasting effects that may make the survival of life on Earth more difficult for both humans and other species. Some of these potential climate changes include global warming, sea-level changes, and changes in precipitation.

Reading Check **What things are influenced by climate change?**

Global Warming

Global temperatures have increased approximately 1 °C over the last 100 years. Researchers are trying to determine if this increase is a natural variation or the result of human activities, such as deforestation and pollution. A gradual increase in average global temperatures is called **global warming.** This process may result from an increase in the concentration of greenhouse gases, such as CO_2, in the atmosphere.

global warming a gradual increase in the average global temperature

An increase in global temperature can lead to an increase in evaporation. Increased evaporation could cause some areas to become drier than they are now. Some plants and animals would not be able to live in these drier conditions. An increase in evaporation in other areas could cause crops to suffer damage. However, an increase in temperatures due to global warming might improve conditions for crops in colder, northern regions.

An increase in global temperatures could also cause ice at the poles to melt. If a significant amount of ice melts, sea levels around the world could rise. This rise in sea levels would cause flooding around coastlines, where many cities are located.

SCILINKS
www.scilinks.org
Topic: Global Warming
Code: HQX0681

Sea-Level Changes

Using computer models, some scientists have predicted an increase in global temperature of 2 to 4 °C during this century. An increase of only a few degrees worldwide could melt the polar ice-caps and raise sea level by the addition of water to the oceans and by thermal expansion of the ocean water itself. On a shoreline that has a gentle slope, the shoreline could shift inland many miles, as shown in **Figure 4.** Many coastal inhabitants would be displaced, and freshwater and agricultural land resources would be diminished. Because approximately 50% of the world's population lives near coastlines, this sea-level rise would have devastating effects.

Figure 4 As sea level rises, shorelines could shift inland many miles. ***Which two states would lose the most area if sea level were to rise by 3 m?***

Figure 5 People from the Wangari Maathai Green Belt Movement in Kenya, Africa, prepare seedlings for planting.

What Humans Can Do

Many countries are working together to reduce the potential effects of global warming. Treaties and laws have been passed to reduce pollution. Industrial practices are being monitored and changed. Even community projects to reforest areas, such as the one shown in **Figure 5,** have been developed on a local level.

Individual Efforts

Each individual person can also help to reduce pollution that is caused by the burning of fossil fuels, such as running automobiles and using electricity. These activities increase CO_2 concentrations in the atmosphere. Therefore, humans can have a significant effect on pollution rates by turning lights off when they are not in use, by turning down the heat in the winter, and by reducing air conditioner use in the summer. Recycling is also helpful because less energy is needed to recycle some products than to create them.

Transportation Solutions

Using public transportation and driving fuel-efficient vehicles can also help to release less CO_2 into the atmosphere. All vehicles burn fuel more efficiently when they are properly tuned and the tires are properly inflated. Driving at a consistent speed also allows a vehicle to burn fuel efficiently. Car manufacturers have been developing cars that are more fuel efficient. For example, *hybrid cars* use both gasoline and electricity. These cars release less CO_2 into the atmosphere from burning fuel than other cars do.

Section 3 Review

Key Ideas

1. **Compare** four methods that climatologists use to study climate.
2. **Identify** four factors that may cause climate change.
3. **Describe** how orbital changes may affect climate.
4. **Explain** how changes in CO_2 concentrations affect global temperatures.
5. **Explain** one potential negative impact of global warming.
6. **Identify** two ways that countries can work together to reduce their impact on, and the potential effects of, global warming.
7. **Identify** four ways that an individual can reduce their own impact on global warming.

Critical Thinking

8. **Making Predictions** How would the melting of small icebergs affect sea level? Explain your answer.
9. **Evaluating Models** Can short-term climate changes be explained using the cycles described by the Milankovitch theory? Explain your answer.

Concept Mapping

10. Use the following terms to create a concept map: *climatologist, general circulation models, global warming, ice cores, tree rings, fossils,* and *isotopes.*

Why It Matters

Polar Bears on Thin Ice

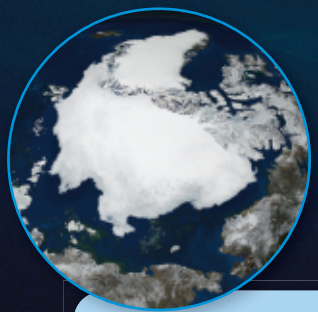
SCIENCE & SOCIETY

What would you do if a corner store, where you bought milk, juice, and snacks, became farther away each day? What would you do if a trip to this store involved not only a longer distance but also more difficult conditions, which you were not adapted to?

As the ice cover in the Arctic decreases, polar bears are facing these kinds of challenges in their search for food. Many researchers predict that, if climate models are correct, at least two-thirds of the polar bear population will be gone by 2050 and the species will not survive the century.

Some polar bears have drowned trying to travel longer and longer distances between ice floes.

Polar bears depend on ice as a platform from which to hunt seals. With less ice, some bears are starving to death.



2005 **2007**

Sea ice in the Arctic has been decreasing dramatically as temperatures rise.

YOUR TURN

CRITICAL THINKING

Why do you think polar bears are often used to symbolize climate change?

UNDERSTANDING CONCEPTS

Seals give birth and nurse their young on ice. How might this further affect polar bears as the ice cover in the Arctic decreases?

Inquiry **Lab**

45 min

Factors That Affect Climate

Many factors affect climate. One of the most significant factors that influence climate is the distribution of land and water. Because land and water absorb and release thermal energy (or energy as heat) differently, they affect the atmosphere differently. In turn, the differences between land and water affect climate. In this lab, you will explore how the properties of land and water affect climate.

What You'll Do

- **Determine** whether land or water absorbs heat faster.
- **Explain** how the properties of land and water affect climate.

What You'll Need

container (2)
heat lamp
meterstick
soil
thermometer, Celsius (2)
water

Safety

Ask a Question

1. How do the properties of land and water affect climate?

Form a Hypothesis

2. On a separate piece of paper, write a hypothesis that is a possible answer to the question above.

Test the Hypothesis

3. Fill one container with soil and the other container with water. Place both containers on a flat surface next to each other.

Step 5

4. Place the thermometer in the soil, as shown below. The bulb of the thermometer should be covered by no more than 0.5 cm of soil. Record the temperature.
5. Place the second thermometer in the container of water, as shown in the photo on the previous page. Make sure that the bulb of the thermometer is covered by no more than 0.5 cm of water.
6. Place the heat lamp 25 cm above both containers. Turn on the heat lamp.
7. Create a data table like the one at the right. In your table, record the temperature of each sample at 1, 3, 5, and 10 min intervals.
8. Disconnect the lamp, and move it aside. Record the temperature of the soil and water after 5 min. **CAUTION** Be sure to let the heat lamp cool before storing it.

Data Table

Time (min)	Temperature of soil (°C)	Temperature of water (°C)
1		
3		
5		
10		
5 (after light off)		

Analyze the Results

1. **Analyzing Data** Which substance absorbed more thermal energy: water or soil?
2. **Analyzing Results** Which substance lost thermal energy faster when the heat source was turned off: water or soil?

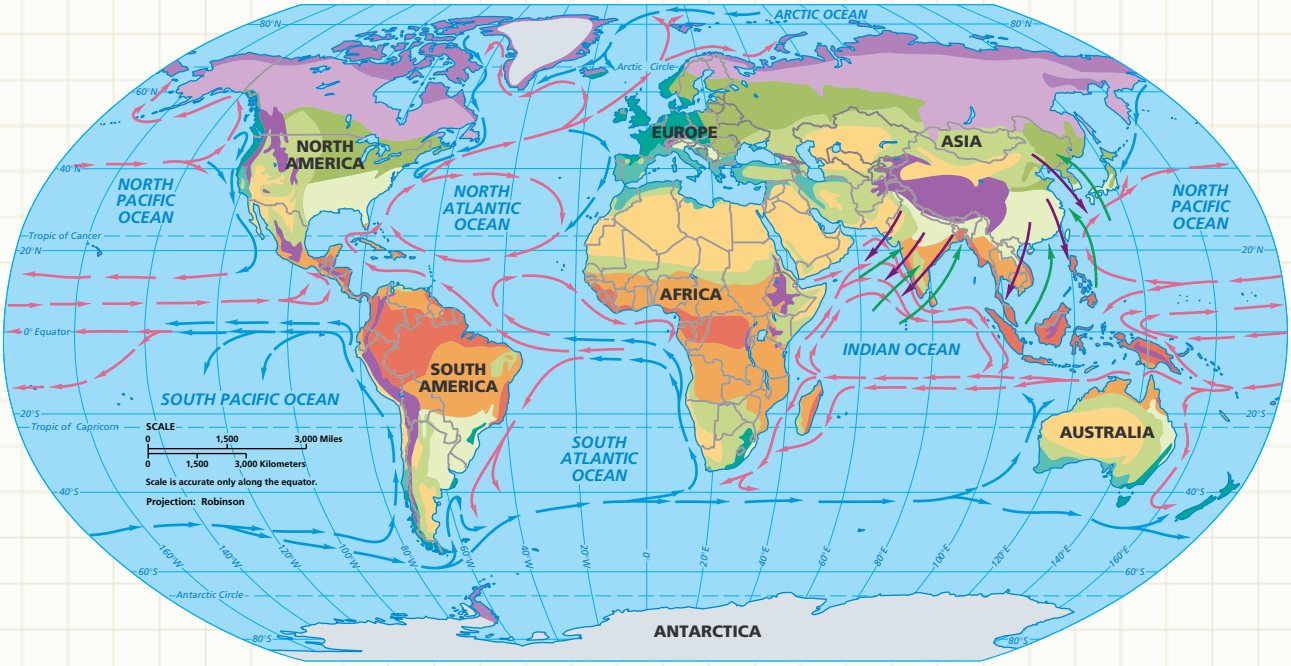
Draw Conclusions

3. **Evaluating Conclusions** What conclusion can you draw about how land and water on Earth are heated by the sun?
4. **Analyzing Methods** Does this experiment describe how proximity to a body of water affects the temperature of a region? If so, explain your answer. If not, how could you test that variable?

Extension

Applying Ideas Repeat this experiment, but modify the angle at which the light strikes the surface of the soil and the water. How do your results differ from the results of the original experiment? How does the angle of the light affect temperature change in water and soil?

Climates of the World



Tropical Climates
- Rain forest
- Desert
- Savanna

Mid Latitude Climates
- Marine west coast
- Steppe
- Humid continental
- Humid subtropical
- Mediterranean

Polar Climates
- Subarctic
- Tundra
- Polar icecaps
- Highland

Monsoon Air Flow
- Wet monsoon
- Dry monsoon

Major World Ocean Currents
- Cool currents
- Warm currents

Map Skills Activity

This map shows the climate regions of Earth and the locations of warm and cold ocean currents. Use the map to answer the questions below.

1. **Analyzing Data** Estimate the latitude range for the desert climate of northern Africa.
2. **Making Comparisons** Why does the eastern coast of the United States have a different climate than the western coast does, even though the coasts are at similar latitudes?
3. **Analyzing Ideas** If the ocean current that flows off the western coast of Australia were a warm current, how would it affect the climate of western Australia?
4. **Using a Key** Identify the latitudes where monsoons are located.
5. **Evaluating Data** Explain why the western coast of South America is desert while the inland part of the continent at the same latitude is humid.

Chapter 22

Summary

THINK central
SUPER SUMMARY
Keyword: HQXCLIS

Key Ideas	Key Terms

Section 1

Factors That Affect Climate

- The climate of a region is described by the region's temperature and precipitation.
- Latitude determines the angle at which the sun's rays hit Earth. At higher latitudes, the angle is smaller so areas receive less solar energy. At lower latitudes, the angle is larger so areas receive more solar energy.
- The temperature of land or water influences the amount of heat that the air above the land or water can absorb or release. The temperature of the air then affects the climate of the area.
- Topography affects climate by causing temperature variations due to elevation and by creating rain shadows.

climate, p. 605
specific heat, p. 608
El Niño, p. 609
monsoon, p. 609

Section 2

Climate Zones

- The three tropical climates, which are located near the equator, are tropical rain forest, tropical desert, and savanna climates.
- The five middle-latitude climates are marine west coast, steppe, humid continental, humid subtropical, and mediterranean climates.
- The three polar climates are subarctic, tundra, and polar icecap climates.
- Due to the heat island effect, the average temperature in a city is a few degrees higher than it is in surrounding rural areas.

tropical climate, p. 611
middle-latitude climate, p. 612
polar climate, p. 613
microclimate, p. 614

Section 3

Climate Change

- By using ice cores, sea-floor sediment, fossils, tree rings, and speleothems, scientists have been able to study past climates.
- Natural processes and human activity may be causing changes in Earth's climate, including global warming.
- One potential effect of climate change is a rise in sea levels, which could lead to flooding around coastlines.
- Humans can minimize their contribution to climate change by reducing pollution from burning fossil fuels, recycling, and using public transportation.

climatologist, p. 615
global warming, p. 619

Chapter 22 Review

1. Cause-and-Effect Map Draw a cause-and-effect map that shows how elevation affects climate.

READING TOOLBOX

USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *specific heat*

3. *microclimate*

4. *climatologist*

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

5. *climate* and *microclimate*

6. *El Niño* and *monsoon*

7. *tropical climate* and *polar climate*

UNDERSTANDING KEY IDEAS

8. At the equator, the sun's rays always strike Earth
a. at a low angle.
b. at nearly a 90° angle.
c. 18 h each day.
d. no more than 8 h each day.

9. Which of the following is *not* used as evidence of past climates?
a. ice cores
b. general circulation models
c. tree rings
d. fossils

10. Water cools
a. more slowly than land does.
b. more quickly than land does.
c. only during evaporation.
d. during global warming.

11. Ocean currents influence temperature by
a. eroding shorelines.
b. heating or cooling the air.
c. washing warm, dry sediments out to sea.
d. dispersing the rays of the sun.

12. Winds that blow in opposite directions in different seasons because of the differential heating of the land and the oceans are called
a. chinooks.
b. foehn.
c. monsoons.
d. El Niño.

13. When a moving air mass encounters a mountain range, the air mass
a. stops moving.
b. slows and sinks.
c. rises and cools.
d. reverses its direction.

14. In regions that have a mediterranean climate, almost all of the yearly precipitation falls
a. during monsoons.
b. in the summer.
c. in the winter.
d. during hurricanes.

15. The climate that has the largest annual temperature range is the
a. subarctic climate.
b. middle-latitude desert climate.
c. mediterranean climate.
d. humid continental climate.

16. The pavement and buildings in cities affect the local climate by
a. decreasing the temperature.
b. increasing the temperature.
c. increasing the relative humidity.
d. decreasing the precipitation.

SHORT ANSWER

17. Describe the Milankovitch theory, including how it may explain some climate changes.

18. What are the possible effects of global warming?

19. Compare marine west coast and humid continental climates.

CRITICAL THINKING

20. Making Predictions Describe how the climate in California might be affected if all of the trees in California were cut down.

21. Making Inferences Explain why the vegetation in areas that have a tundra climate is sparse even though these areas receive enough precipitation to support plant life.

22. Analyzing Ideas Explain why climates cannot be classified only by latitude.

23. Predicting Consequences How would global climate be affected if Earth were not tilted on its axis? Explain your reasoning.

CONCEPT MAPPING

24. Use the following terms to create a concept map: *fossil, ice cores, climate, polar climate, climatologist, steppe, temperature range, tropical climate, middle-latitude climate,* and *savanna*.

MATH SKILLS

Math Skills

25. Using Equations Temperature generally decreases about 6.5 °C for every kilometer above sea level. If T_N = temperature at a new altitude, a = altitude in kilometers, and T_I = initial temperature at sea level, what equation can be used to find the temperature at a given altitude?

26. Making Calculations From 1970 to 2005, nitrogen-oxide, NO_X, emissions in the United States decreased from about 26.9 million to about 19.0 million tons per year. By what percentage did NO_X emissions decrease over these years?

WRITING SKILLS

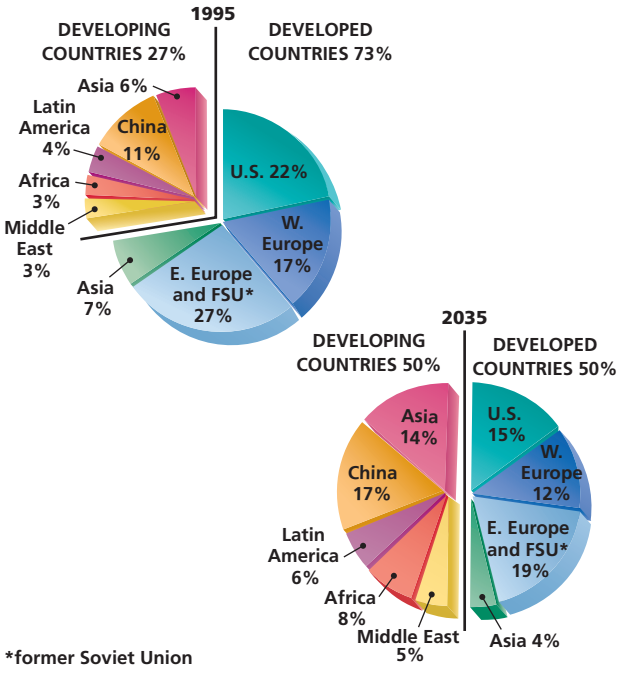
27. Researching Topics Research greenhouse gases to determine how they are produced. Then, write a brief essay that outlines how they can be reduced.

28. Communicating Main Ideas Imagine that you are going to build a vacation house. Research three locations where you would like to build your vacation house, and outline the climate features that would make each location ideal.

INTERPRETING GRAPHICS

The pie graphs below show world emissions of carbon dioxide, CO_2, in 1995 and predict emissions in 2035. Use these graphs to answer the questions that follow.

Total World Emissions of Carbon Dioxide



*former Soviet Union

29. In 1995, which country or region emitted the most CO_2? Which emitted the least CO_2?

30. What percentage of the total CO_2 was emitted by developing countries in 1995?

31. Why do you think researchers predict that CO_2 emissions of developing countries will equal those of developed countries by 2035?

Chapter 22 Standardized Test Prep

Understanding Concepts

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

1. Which statement best compares how land and water are heated by solar energy?
   - **A.** Water heats up faster and to a higher temperature than land does.
   - **B.** Land heats up faster and to a higher temperature than water does.
   - **C.** Water heats up more slowly but reaches a higher temperature than land does.
   - **D.** Land heats up more slowly and reaches a lower temperature than water does.
2. Which of the following statements best describes the El Niño–Southern Oscillation?
   - **F.** a change in global wind patterns that occurs in the Southern Hemisphere
   - **G.** a warming of surface waters in the eastern Pacific due to the effects of changing wind patterns on ocean currents near the equator
   - **H.** a cooling of surface waters in the eastern Pacific due to the effects of changing wind patterns on ocean currents near the equator
   - **I.** a global wind and precipitation belt between 20°N and 30°N latitude
3. A seasonal wind that blows toward the land in the summer and brings heavy rains is called a
   - **A.** trade wind.
   - **B.** jet stream.
   - **C.** doldrum.
   - **D.** monsoon.
4. In samples of atmospheric gases taken from an ice core, high levels of carbon dioxide indicate that the sample is from a time period that had
   - **F.** a warm climate.
   - **G.** a cool climate.
   - **H.** high amounts of precipitation.
   - **I.** low amounts of precipitation.

Directions (5–6): For each question, write a short response.

5. What is the term for the area around a mountain that receives warm, dry winds?
6. What is the term for the weather conditions in an area over a long period of time?

Reading Skills

Directions (7–9): Read the passage below. Then, answer the questions.

The Greenhouse Effect

The greenhouse effect is Earth's natural heating process, in which gases in the atmosphere trap thermal energy. Earth's atmosphere acts like the glass windows of a car. Imagine that it is a hot day and that you are about to get inside a car. You immediately notice that it feels hotter inside the car than it does outside the car.

Many scientists hypothesize that the rise in global temperatures is due to an increase in carbon dioxide that is produced as a result of human activity. Most evidence indicates that the increase in carbon dioxide is caused by the burning of fossil fuels that release carbon dioxide into the atmosphere. Fossil fuels are organic compounds that are formed from the buried remains of ancient plants and animals. These fuels are used by humans for many things, such as heating homes and providing fuel for automobiles.

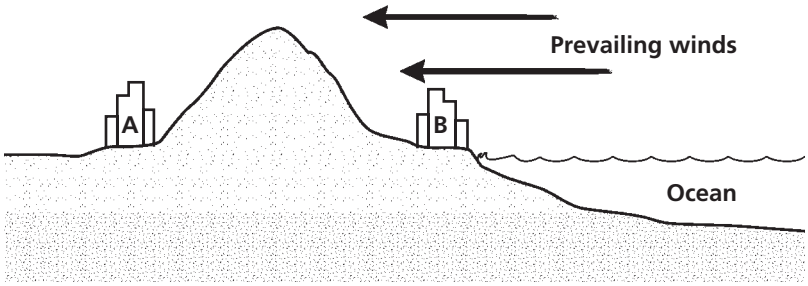
7. Based on the passage, which of the following statements is not true?
   - **A.** The way that the atmosphere of Earth traps thermal energy is similar to the way that car windows keep the interior of a car warm.
   - **B.** The greenhouse effect is a natural heating process for Earth.
   - **C.** Earth absorbs sunlight and reradiates it as carbon dioxide.
   - **D.** Human activity is one producer of the greenhouse gas carbon dioxide.
8. Which of the following statements can be inferred from the information in the passage?
   - **F.** The greenhouse effect is responsible for an increase in the use of fossil fuels by humans.
   - **G.** Humans created the greenhouse effect by burning coal for industrial uses.
   - **H.** Human activity is the only producer of gases that create the greenhouse effect.
   - **I.** Human activity may play a role in amplifying the natural process of the greenhouse effect.
9. Name some fossil fuels that are contributors to the production of carbon dioxide.

Interpreting Graphics

Directions (10–13): For each question below, record the correct answer on a separate sheet of paper.

The diagram below shows the locations of two cities at the same latitude. Use this diagram to answer questions 10 and 11.

Two Cities Separated by Coastal Mountains



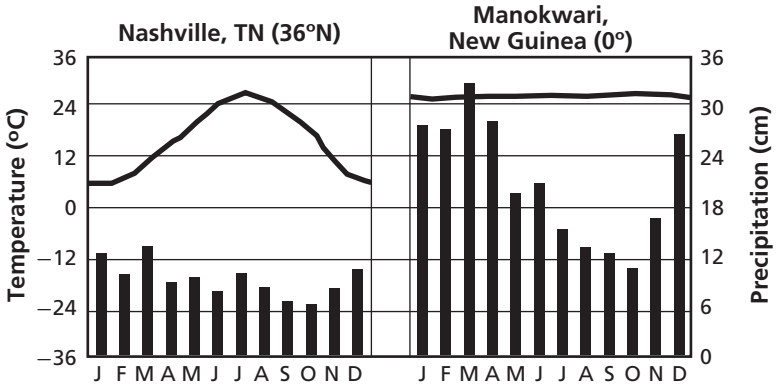
10. Which city is most likely to have the largest yearly temperature range?

A. City A would likely have the largest yearly temperature range.
B. City B would likely have the largest yearly temperature range.
C. Both cities would likely have the same temperature range.
D. There is not enough information to answer the question.

11. Which city is most likely to have a dry climate? Explain what would cause this city's climate to be drier than the other city's climate.

The climatograms below summarize average monthly precipitation and temperature data measured in two locations over a period of one year. Use these climatograms to answer questions 12 and 13.

Climatograms for Two Cities



12. Which month shows the most rainfall for both climates in the climatograms?

F. March
G. June
H. September
I. December

13. Based on the data in the climatograms, write a description of the climate in each location and the type of vegetation that is likely to occur as a result of the climate.

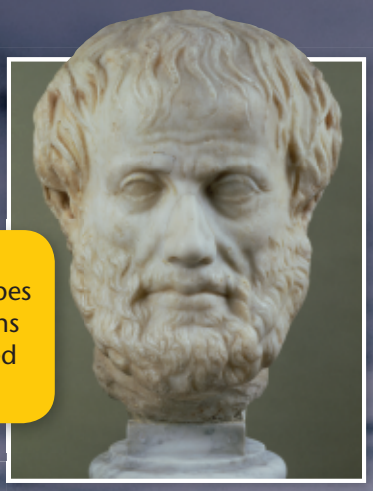
Test Tip

Read all the information, including the heads, in a table or chart before answering the questions that refer to it.

Why It Matters

Meteorology Connections

Science, technology, and society are closely linked. This flowchart shows just a few of the connections in the history of meteorology.



340 B.C.E. Aristotle describes weather patterns in his book titled *Meteorologica*.

1654 Ferdinando II de Medici invents the first sealed, modern-style thermometer.

1782 The first hot-air balloon is invented by brothers Joseph-Michel and Jacques-Etienne Montgolfier.

1887 Heinrich Hertz experiments with creating radio waves in his laboratory.

1930 The first radiosonde is launched, attached to a weather balloon.

1935 Radar is designed for use in air defense in Britain.

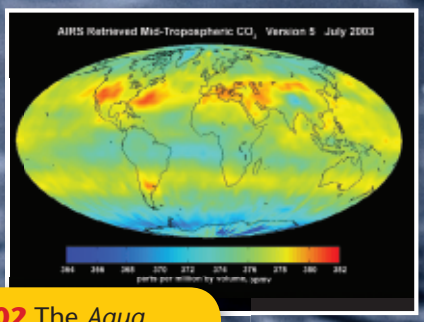
1943 Radar is first used for storm tracking.

1946 A radar air-traffic control system is used experimentally.

2007 The Hartsfield-Jackson International Airport in Atlanta, Georgia, manages 994,346 flights.

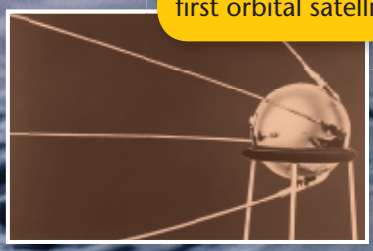
1926 Robert Goddard invents the first practical liquid-fueled rocket.

1960 The first successful weather satellite, *TIROS*, is launched from Cape Canaveral.



2002 The *Aqua* satellite gathers data about Earth's surface and atmosphere.

1957 The Soviet Union launches *Sputnik I*, the first orbital satellite.



1969 The first "Internet," ARPANET, becomes functional.

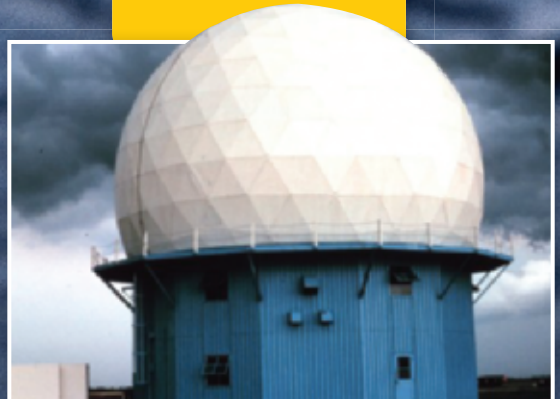
2007 Local weather information is available for almost any place on Earth.

1939 World War II breaks out in Europe.

1946 Scientists develop the first computer, ENIAC.

2005 Accurate prediction of the path of Hurricane Rita allows for evacuations.

1988 The National Weather Service initiates a nationwide Doppler radar system.



HISTORY IN SCIENCE

YOUR TURN

UNDERSTANDING CONCEPTS

How did Robert Goddard contribute to the study of meteorology?

CRITICAL THINKING

How has the study of weather benefited from the work of scientists outside the field of meteorology?