Atmosphere and Climate Change

CHAPTER 13

READING WARM-UP

Before you read this chapter, take a few minutes to answer the following questions in your ***EcoLog.***

1. What do you think are the main factors that determine the weather in the area where you live?
2. Why do you think the warming of the Earth by gases such as water vapor, carbon dioxide, methane, and nitrous oxide is called the *greenhouse effect*?

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

SECTION 1
Climate and Climate Change

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

Objectives

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

Key Terms

climate
latitude
El Niño
La Niña

What Factors Determine Climate?

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

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

Ecofact

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

Latitude

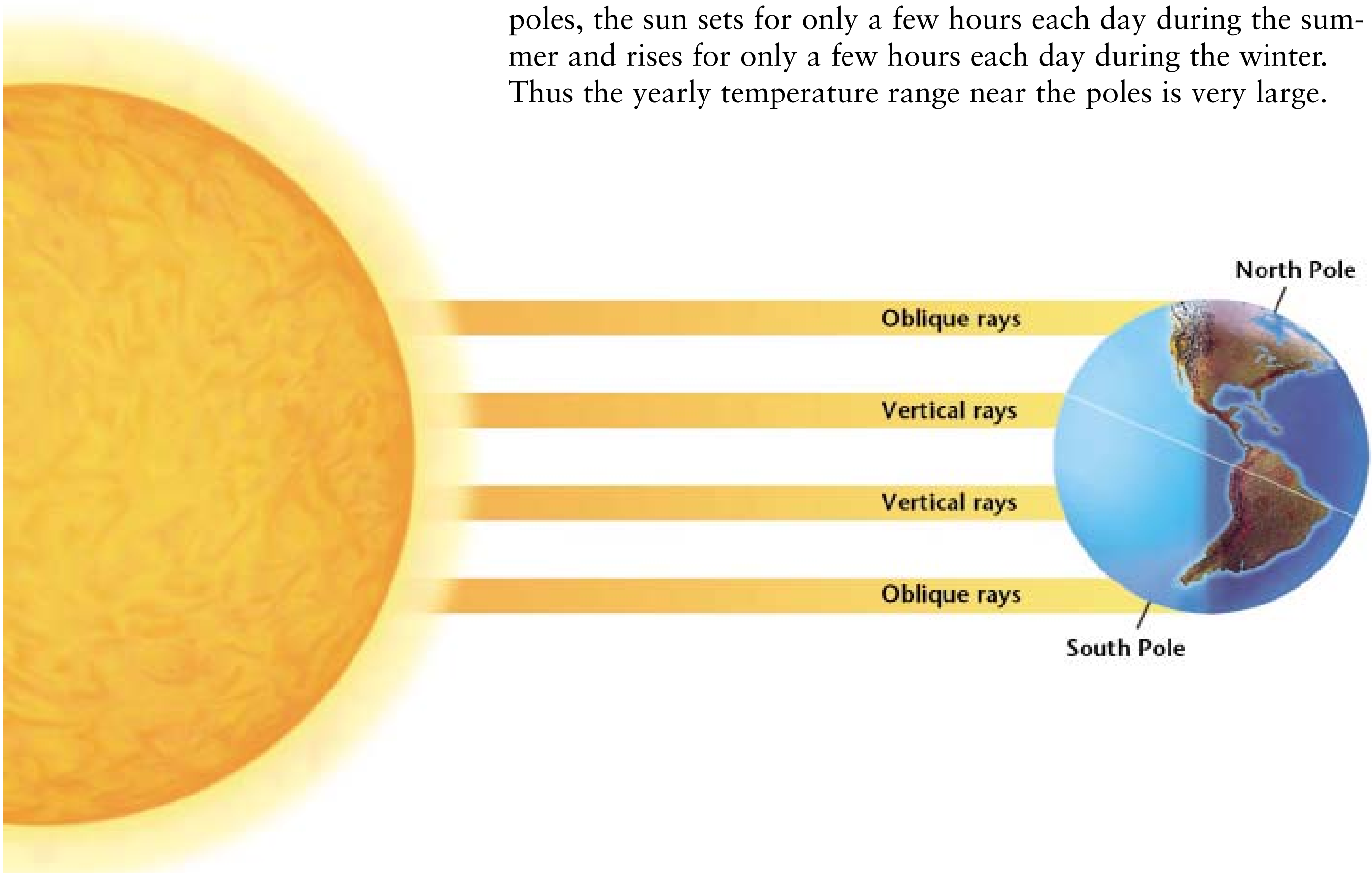
The distance from the equator measured in degrees north or south of the equator is called **latitude.** The equator is located at 0° latitude. The most northerly latitude is the North Pole, at 90° north, whereas the most southerly latitude is the South Pole, at 90° south.

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

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

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

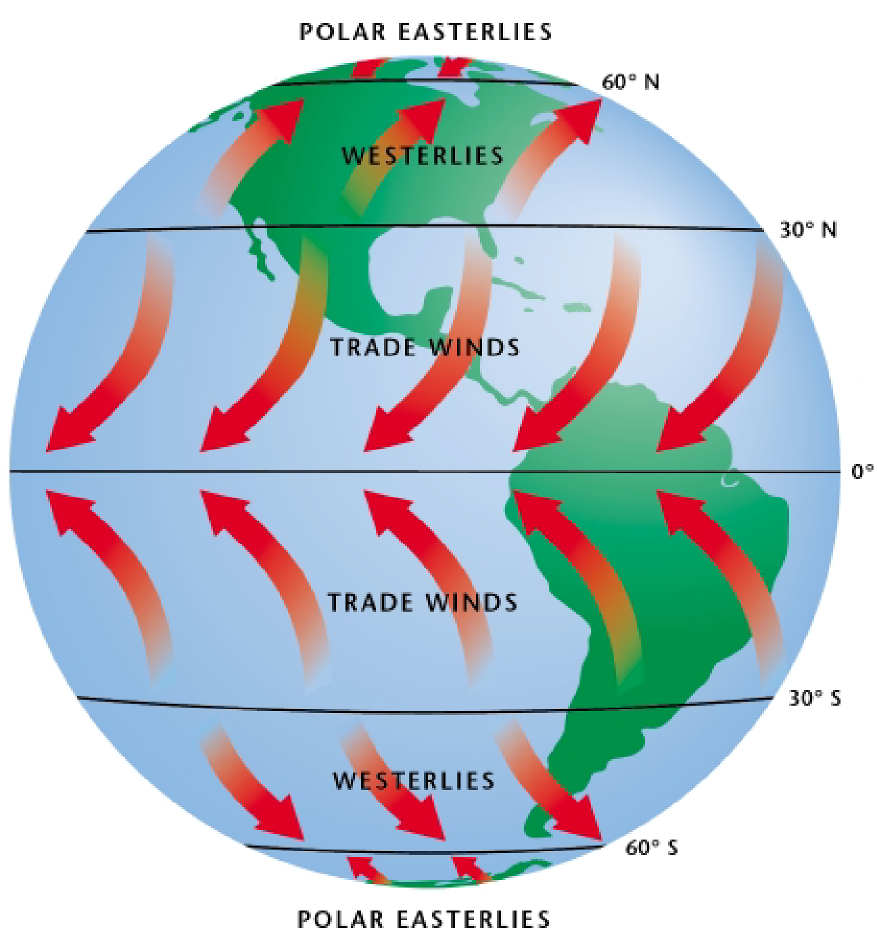
Figure 2 ▶ At the equator, sunlight hits the Earth vertically. The sunlight is concentrated on a smaller surface area at the equator. Away from the equator, sunlight hits the Earth at an oblique angle and spreads over a larger surface area.



Atmospheric Circulation

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

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



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

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

QuickLAB

Investigating Prevailing Winds

Procedure

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

Analysis

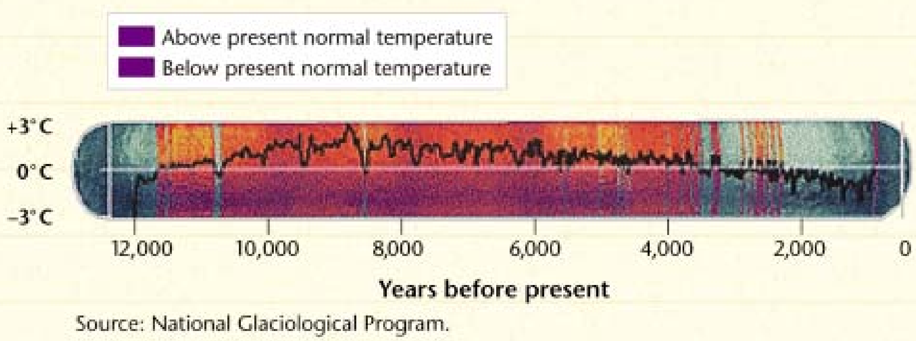
1. How is the motion of the water related to the prevailing winds?

Global Circulation Patterns Cool air normally sinks, but cool air over the equator cannot descend because hot air is rising below the cool air. This cool air rises and is forced away from the equator toward the North and South Poles. At about 30° north latitude and 30° south latitude, air begins to accumulate in the upper atmosphere. Some of this air sinks back to the Earth's surface and becomes warmer as it descends. The warm, dry air moves across the surface and causes water to evaporate from the land below, creating dry conditions.

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

CASE STUDY

Ice Cores: Reconstructing Past Climates



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

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

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

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

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

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

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

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

Figure 4 ▶ The red areas indicate fires around Sydney, Australia, the smoke from which shows the direction the wind is blowing.

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

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

CRITICAL THINKING

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

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

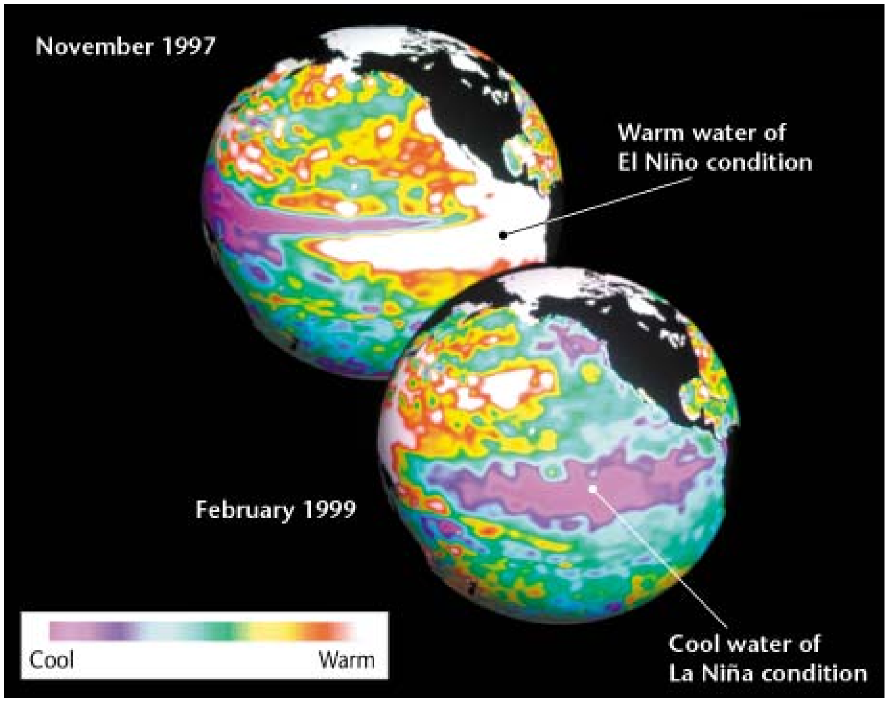


Figure 5 ▶ The El Niño-Southern Oscillation (ENSO) is a periodic change in the location of warm and cold water masses in the Pacific Ocean. The phase of ENSO in which the eastern Pacific surface water is warm is called *El Niño,* and the phase where it is cool is called *La Niña.*

Oceanic Circulation Patterns

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

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

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

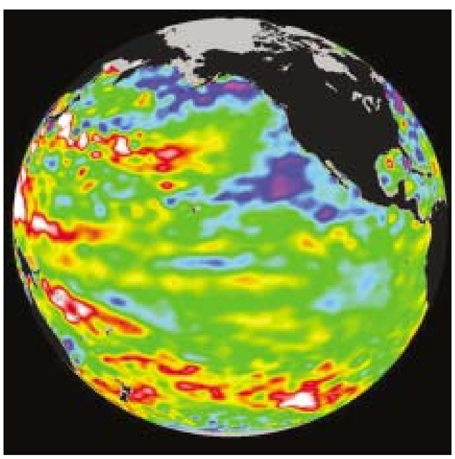


Figure 6 ▶ This satellite image shows the cool phase of the Pacific Decadal Oscillation. During this phase, cooler water (purple and blue) can be seen in the eastern Pacific Ocean. During the warm phase, the situation is reversed.

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

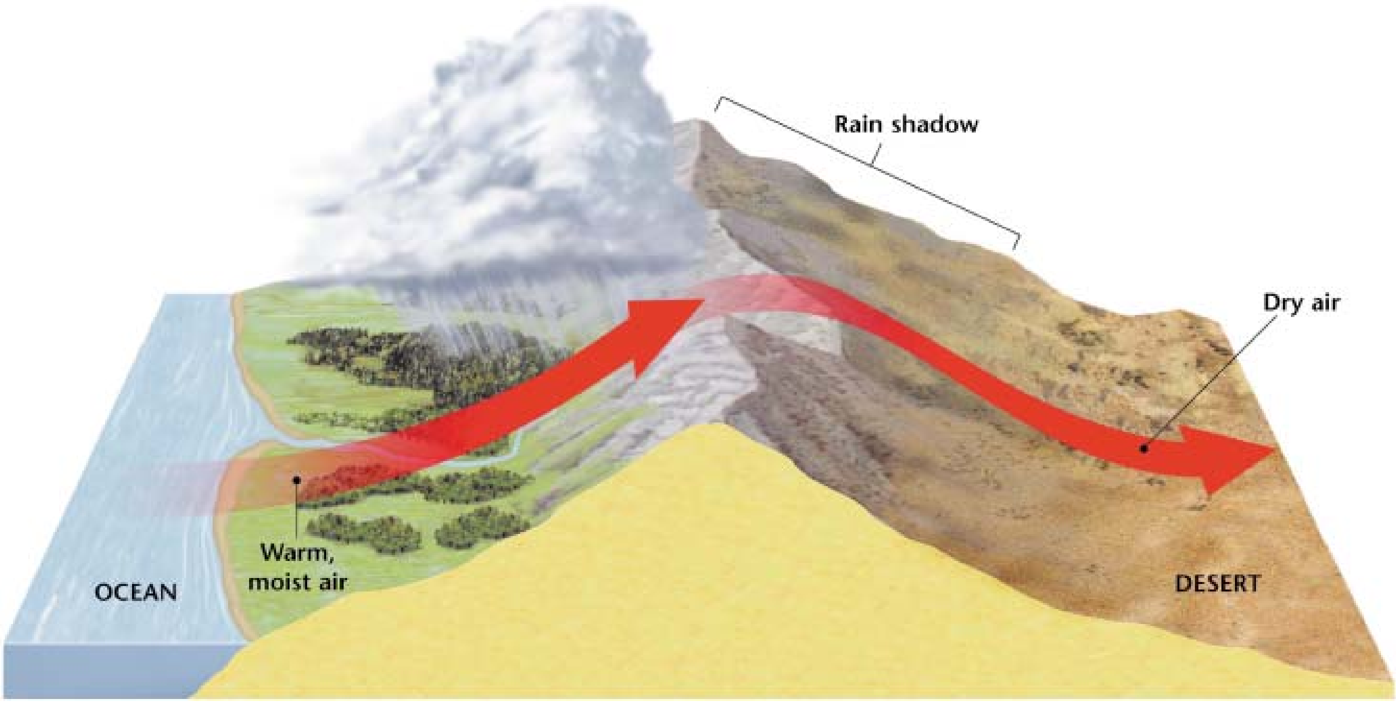


Figure 7 ▶ Moist ocean air moves up the coastal side of a mountain range. The air cools and releases its moisture as rain or snow. Air then becomes drier as it crosses the range. When the dry air descends on the inland side of the mountains, the air warms and draws up moisture from the surface.

Topography

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

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

Other Influences on Earth's Climate

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

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

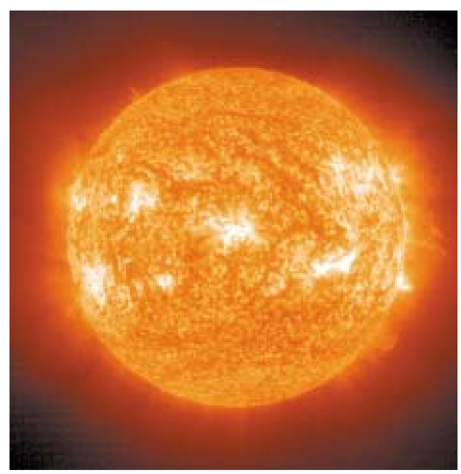


Figure 8 ▶ The sun has an 11-year cycle in which it goes from a maximum of activity to a minimum.

MATHPRACTICE

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

Seasonal Changes in Climate

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

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

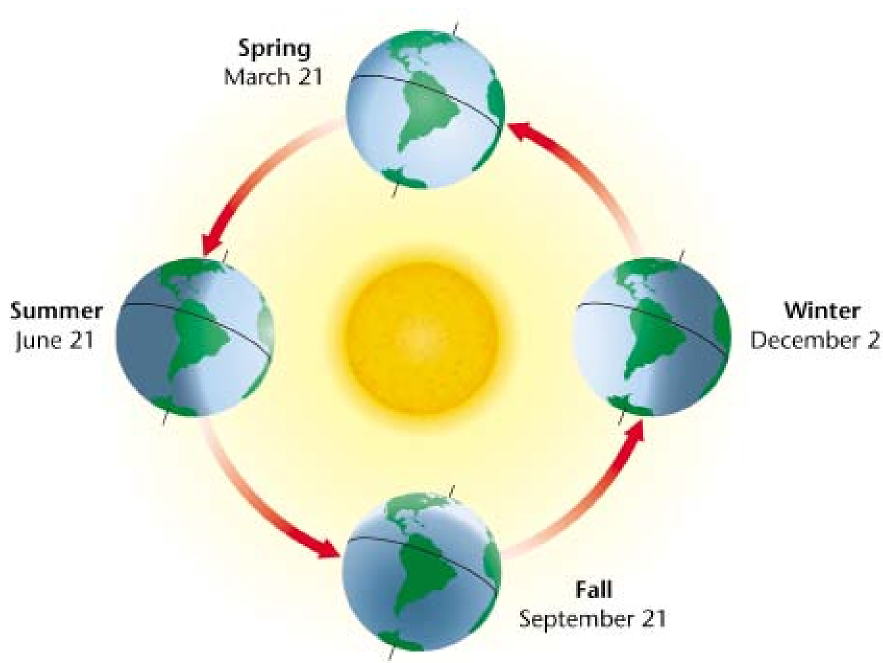


Figure 9 ▶ Because of the Earth's tilt, the angle at which the sun's rays strike the Earth changes as the Earth orbits the sun. This change in angle accounts for seasonal climate differences around the world.

SECTION 1 Review

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

CRITICAL THINKING

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