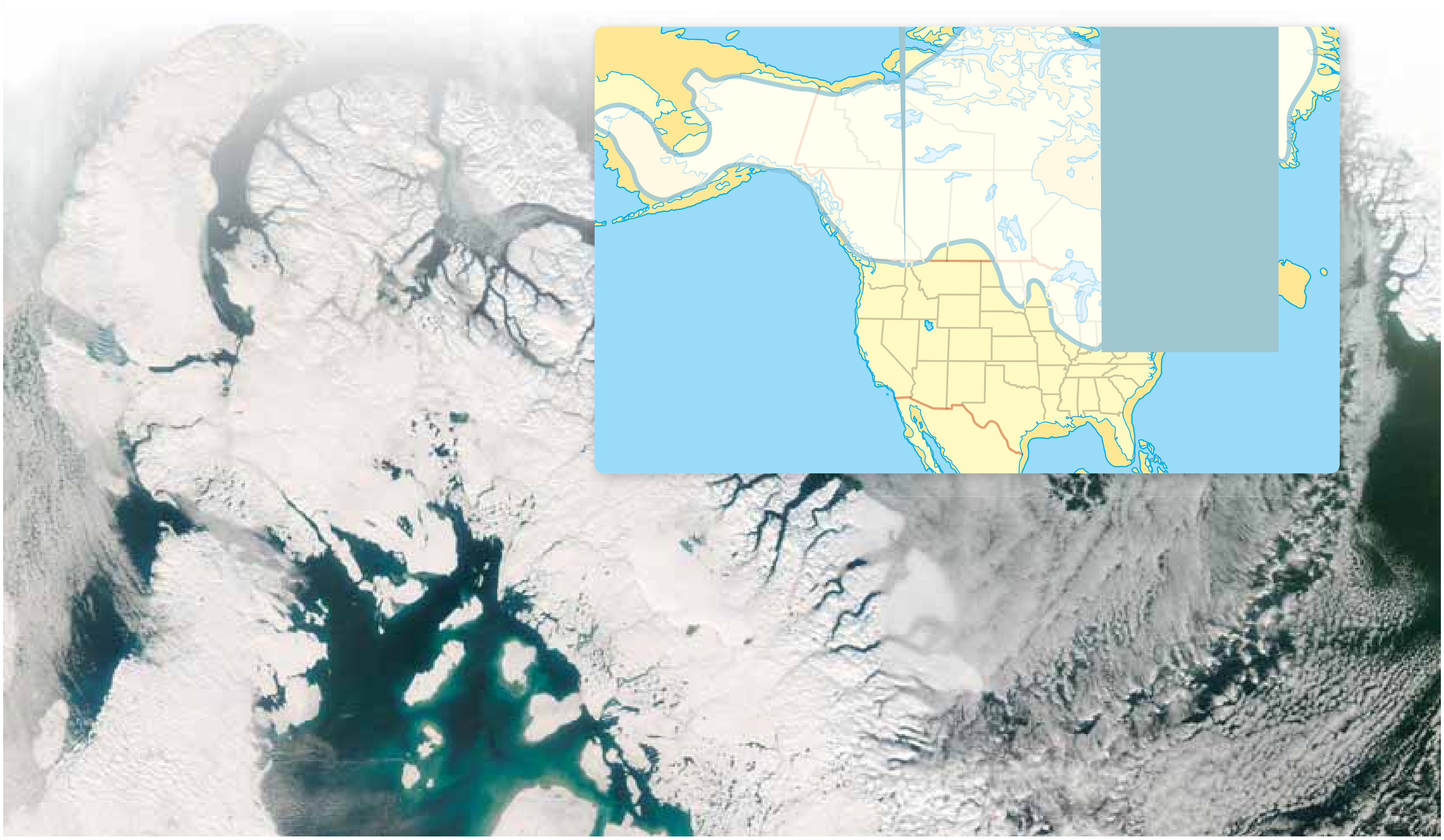

Earth and the Sun

Energy from the Sun is the single most important factor that affects climate on Earth. Solar energy travels through space as light and heat. The intensity of the energy that reaches Earth's surface affects the temperature of the air, water, and land on the planet. This heat produces the winds, rain, and other features of the climate. The amount of solar energy that reaches Earth's surface varies with changes in solar activity. The amount of solar energy also depends on the shape of the planet and on Earth's angle of tilt and orbit around the Sun.

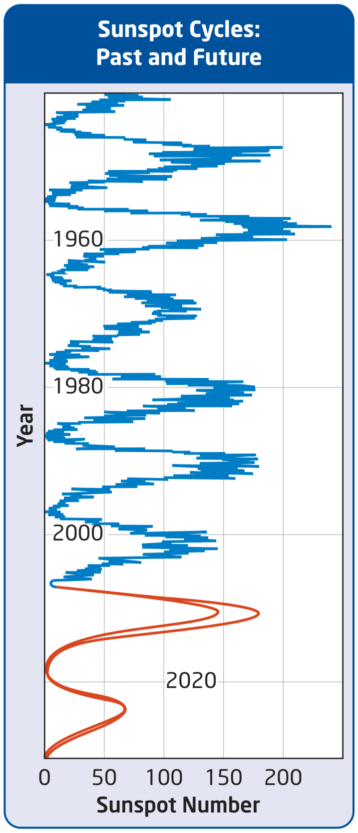

Figure 7.2 This graph shows how the number of sunspots changes over time. When the number of sunspots is high, the Sun emits higher amounts of solar radiation.

Changes in Solar Activity

The Sun may appear unchanging, but the amount of radiation it produces varies. Measurements of solar radiation show that irregular fluctuations occur in the amount of energy produced by the Sun. In addition, a more regular solar cycle (or sunspot cycle) occurs approximately every 11 years, as shown in **Figure 7.2**. These solar variations differ by about 0.1 percent. Some scientists have proposed that variations in solar output have been the main cause of climate change in the past.

Movements of Earth in Space

Earth rotates (spins) once every 24 hours around its axis—an imaginary line running from the North Pole to the South Pole. While continuously rotating on its axis, Earth makes a year-long journey around the Sun. Throughout this path, or orbit, Earth remains in the same orbital plane, as though it were travelling on a flat surface. Earth's axis of rotation is tilted at an angle of about 23.5° from a line perpendicular to the orbital plane. The combination of Earth's annual orbit around the Sun and its tilted axis produces our seasons, as illustrated in **Figure 7.3**.

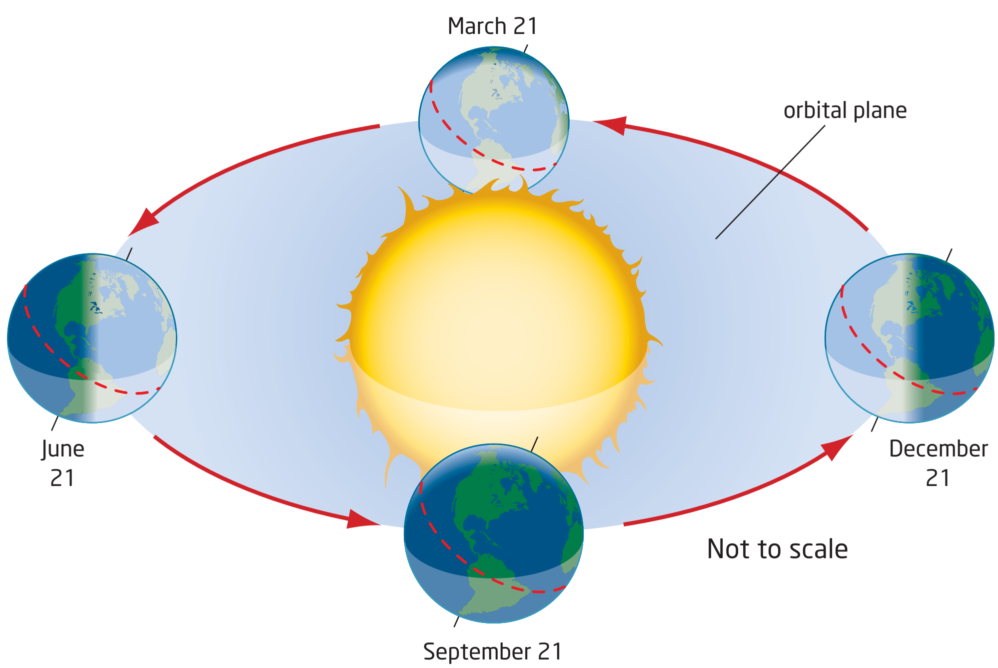

Figure 7.3 The positions of Earth in its orbit vary throughout a single year. The angle of sunlight on Earth's surface determines the seasons.

Changes in Earth's Rotation, Orbit, and Tilt

Throughout its history, Earth's orbit, tilt, and rotation have varied slightly in repeating cycles. In the early 1900s, a Serbian mathematician, Milutin Milankovic, calculated that these variations changed the amount and location of solar radiation reaching Earth. He proposed that these changes in solar intensity produced changes in the climate. This theory helps describe large patterns of climate change over a long time scale. However, it does not fully explain all of the recent changes that have been observed and measured using other evidence.

Eccentricity Due to the gravitational attraction of other planets in the solar system, Earth's orbit fluctuates slightly over a cycle of about 100 000 years. Its path around the Sun changes very slowly from being almost circular to being more elliptical, and then back again, as shown in **Figure 7.4**. When Earth's orbit is more elliptical, the planet receives much more solar radiation when it is nearest the Sun than it does when it is farthest from the Sun. When the orbit is more circular, the amount of solar radiation varies less throughout the year. These differences affect the length and intensity of the seasons.

Tilt The angle of Earth's tilt on its axis changes by approximately 2.4° over a period of about 41 000 years, as shown in **Figure 7.5**. The greater the tilt is, the greater the temperature differences are between summer and winter. Currently, Earth is tilted at about 23.44°, or roughly halfway between its extremes, and the angle is slowly decreasing.

Wobble The third factor in Milankovic's calculations of Earth's movements involves a change in the direction of the axis of rotation, known as *precession*, which is illustrated in **Figure 7.5**. Because Earth is not a perfect sphere, it wobbles slightly as it rotates on its axis. This wobble affects the amount and intensity of solar energy that is received by the northern and southern hemispheres at different times of the year. This variation determines whether the two hemispheres have similar contrasts between seasons, or whether one hemisphere has greater temperature differences between seasons than the other hemisphere does.

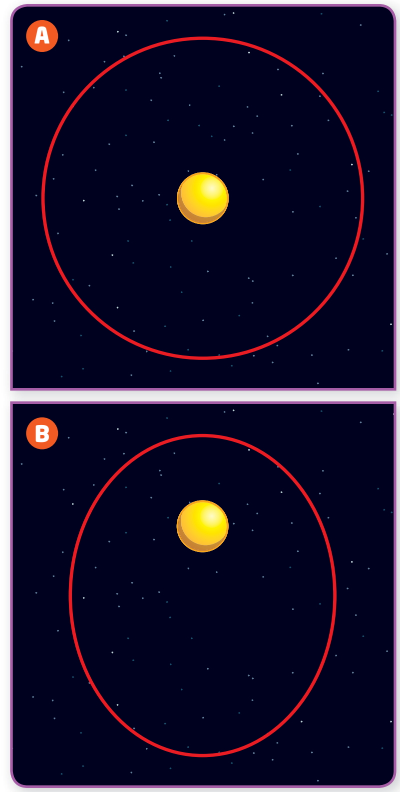

Figure 7.4 Over a period of about 100 000 years, Earth's path around the Sun changes from being **A** nearly circular, to being **B** slightly more elliptical, and back again.

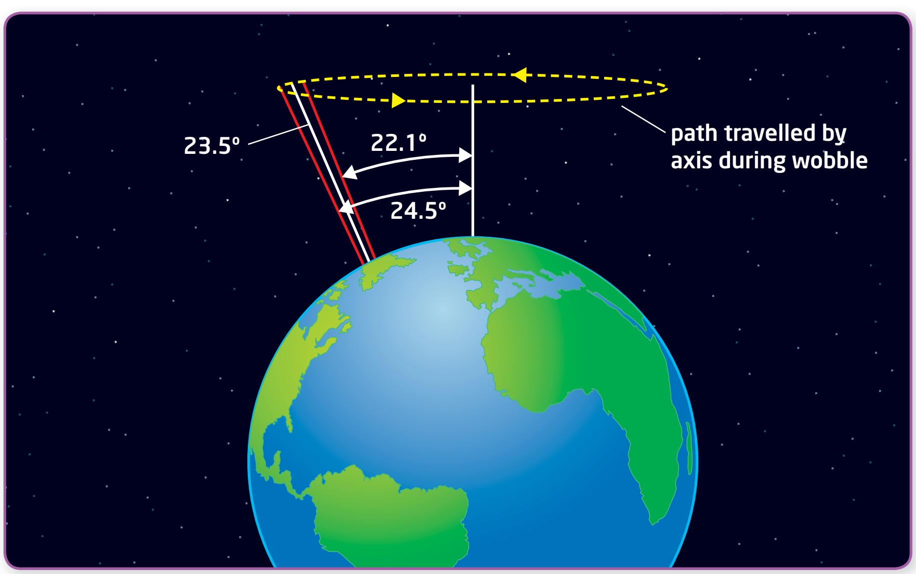

Figure 7.5 Earth's angle of tilt varies between 22.1° and 24.5° from the perpendicular over a period of about 41 000 years. Precession varies cyclically over the course of about 26 000 years.

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The Effect of Latitude on Climate and Seasons

Why is the climate in Ecuador hotter than the climate in Canada? The answer lies in the curved shape of Earth and in the different angles at which the Sun's rays strike the planet's surface. **Figure 7.6** illustrates the relationship between incoming solar rays and Earth's curvature.

Compare the amount of surface area illuminated by a ray of sunlight at the equator, by an identical ray at 45° south, and by a third ray at the North Pole. The Sun's rays striking the equator are perpendicular to Earth's surface. At latitude 45° south, the Sun's rays strike the surface at an angle. Because of this angle, the energy in the rays is spread over a larger area—nearly 1.5 times as large as the area on the equator. Therefore, each square metre of Earth's surface at latitude 45° absorbs only about two thirds as much energy as the same area absorbs at the equator. At the poles, a ray of sunlight is spread over an even larger area. Because each square metre receives less solar energy, the surface near the poles heats up much less than does the surface at the equator.

Figure 7.6 shows Earth as if it were not tilted relative to the Sun. If this were actually the case, average temperatures at different latitudes would remain the same throughout the year. Earth's tilt on its axis combined with its orbit creates the change of temperature with the seasons.

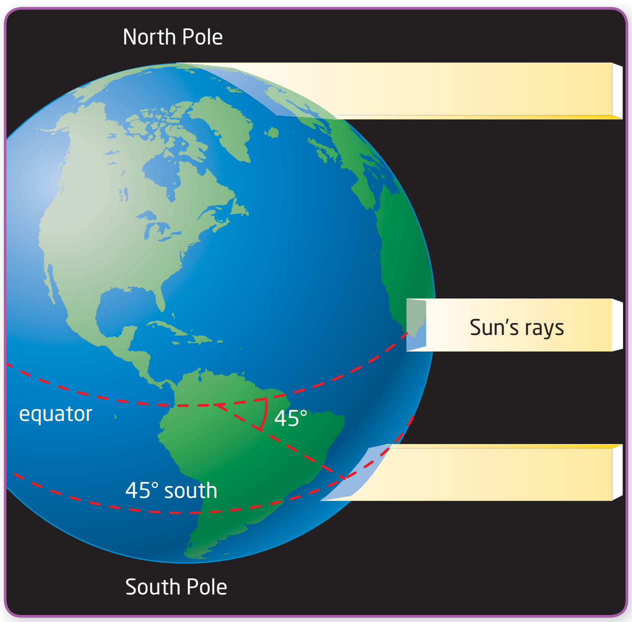

Figure 7.6 Because Earth's surface is curved, a beam of sunlight illuminates different-sized areas at different latitudes.

Learning Check

1. What is climate?
2. How do changes in solar activity affect climate?
3. Using **Figure 7.6** as a source, draw and label a diagram that illustrates how latitude affects climate.
4. In the summer, Canada experiences more hours of daylight and warmer temperatures than in the winter. Explain this difference.

How the Atmosphere Affects Climate

The atmosphere extends from Earth's surface up to about 560 km into space. It is composed mainly of the gases nitrogen (N_2) and oxygen (O_2), as well as water vapour (H_2O), very small concentrations of other gases, and particles of solids.

Earth's atmosphere absorbs thermal energy from the Sun and thermal energy that is emitted by Earth's surface. This process, called the **greenhouse effect**, is outlined in **Figure 7.7**. The greenhouse effect is a natural part of Earth's climate system. This process helps to keep Earth's temperature fluctuations within a certain range. Without this process, most of the solar energy reaching Earth would radiate back into space, and the average temperature at the planet's surface would be about 34°C lower than it is today.

greenhouse effect the natural warming caused when gases in Earth's atmosphere absorb thermal energy that is radiated by the Sun and Earth

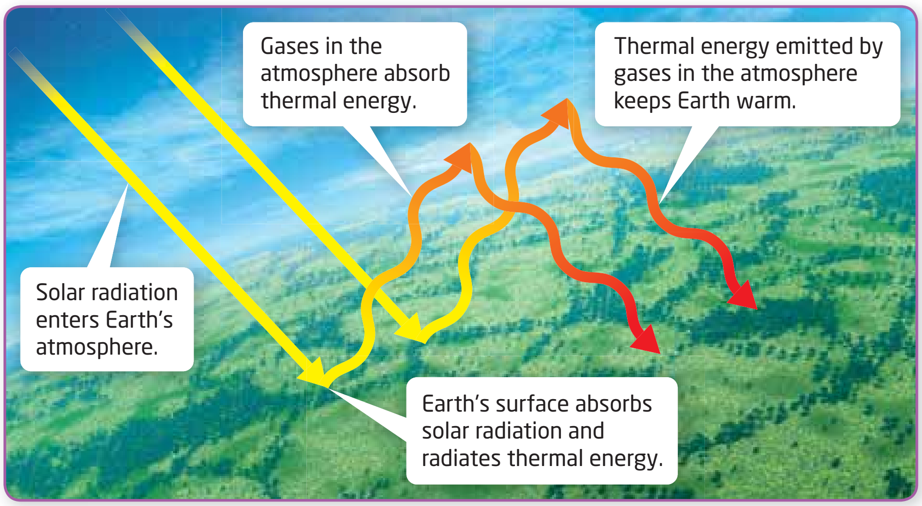

Figure 7.7 Earth's atmosphere retains energy from the Sun through a process known as the greenhouse effect.

Winds Disperse Energy through the Atmosphere

Wind is the movement of air from an area of high pressure to an area of lower pressure. All winds begin as a result of uneven heating of Earth's surface, as shown in **Figure 7.8**. This movement of air as wind transfers thermal energy around the world from warm areas to cooler areas. In addition, the movement of air affects ocean currents and precipitation patterns.

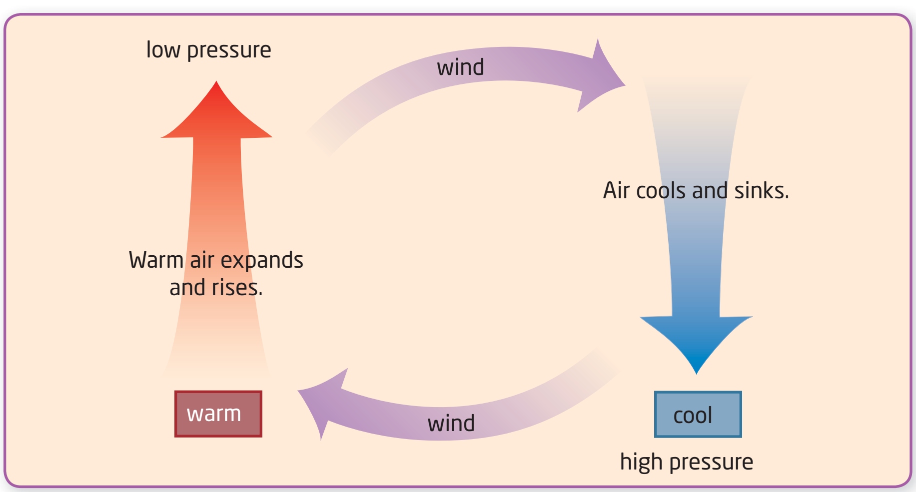

Figure 7.8 Air above warm areas expands and rises, while air above cooler areas sinks. These pressure differences create winds as air moves.

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Winds Move Ocean Currents

The movement of currents at the surface of the oceans is driven by winds blowing over the water. You can see this effect if you blow gently across the surface of warm soup in a wide bowl. Energy from the moving air is transferred to the surface of the water, which causes the water to move. Because the oceans absorb energy from the Sun, the movement of the water results in the transfer of heat around Earth's surface. Winds blow in fairly constant directions around the world. These air currents are known as *prevailing winds*. A map of prevailing global wind patterns and ocean currents is shown in **Figure 7.9**.

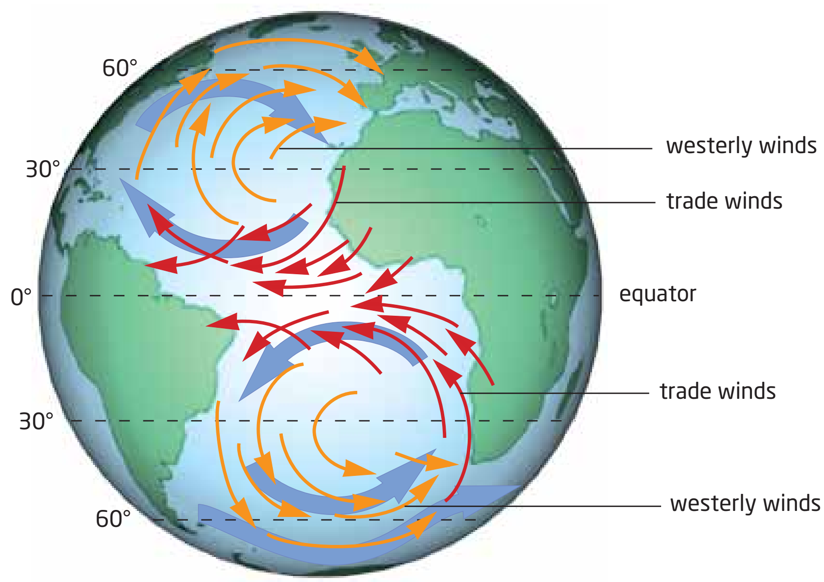


Figure 7.9 Winds (red and orange arrows) travel clockwise north of the equator and counterclockwise south of the equator. Ocean currents (blue arrows) move around the world in the same direction as the winds.

Winds Affect Precipitation

As air masses of different densities move across Earth's surface, they interact. When air masses meet, one air mass usually rises over the other. The rising air cools, and any water vapour in the air condenses to form precipitation.

Winds also affect precipitation through *jet streams*. Jet streams are high-altitude winds that travel long distances at very high speeds. These winds may carry warm, moist air, which can produce precipitation in areas far from the origin of the jet stream. They may also carry dry, cool air, which causes dry weather in areas affected by the jet stream. Canada's weather is particularly influenced by the polar jet stream.

hydrosphere the collective mass of water found on, under, and over the surface of Earth in the form of liquid water, ice, and water vapour

How the Hydrosphere Affects Climate

Seen from space, Earth is a blue planet, as shown in **Figure 7.10**. Oceans cover about two thirds of Earth's surface. Invisible water vapour and clouds of water droplets drift through the atmosphere, and ice and snow cap the mountaintops and poles. All of the water in its different forms on Earth composes the **hydrosphere**. Together with the atmosphere, water transfers heat from one part of the planet to another.

Figure 7.10 Earth's blue oceans absorb energy and transfer that energy around the planet's surface.

Oceans and Lakes Act as Heat Reservoirs

The oceans can hold much more heat than the atmosphere can. In fact, the top 2.3 metres of the world's oceans holds as much heat as all of the planet's air does. As a result, the oceans act as a "heat reservoir" that buffers temperature changes in the atmosphere.

Large bodies of water influence climate because water has a large specific heat capacity compared with other substances. *Specific heat capacity* is the amount of heat required to raise the temperature of one gram of a substance by one degree Celsius. Because water has a large specific heat capacity, a large quantity of energy is required to raise its temperature compared with the energy needed to change the temperature of land. As a result, the temperature of large bodies of water tends to change slowly and by small amounts. The temperature of land masses changes more quickly and by larger amounts.

Ice and Snow Reflect Heat

Because of their light colour, snow and ice reflect solar radiation. The fraction of energy that is reflected by a surface is known as **albedo**. The amount of energy reflected or absorbed depends largely on the colour of the surface. In general, light-coloured surfaces reflect energy, and dark surfaces absorb energy. The ocean surface reflects about 7 percent of solar energy. By contrast, a field covered by fresh snow, such as the one shown in **Figure 7.11**, can reflect as much as 80 to 90 percent of the solar energy that strikes it. Because of their large differences in albedo, the distribution of water, ice, and land on Earth's surface greatly affects the average global temperature.

albedo the fraction of incident light or electromagnetic radiation that is reflected by the surface of an object, such as from Earth back into space; an object's ability to reflect sunlight

tectonic plate a piece of Earth's outer shell (the lithosphere) that moves around on the slowly flowing, underlying rock layer (the asthenosphere)

How Moving Continents Affect Climate

Earth's outer layer is composed of massive pieces of solid rock known as **tectonic plates**. Earth has about 12 major plates that move at a rate of a few centimetres each year, carrying the continents with them. As a result, the shapes of the oceans and continents are always changing. The changing distribution of land and water affects patterns of air and water circulation and the transfer of thermal energy around the world. The formation of mountain chains also affects the pattern of wind and precipitation around the globe.

Suggested Investigation

Inquiry Investigation 7-A, Specific Heat Capacity of Earth Materials, on page 300

Figure 7.11 These corn fields in Canada reflect a great deal of solar energy during the winter. The white snow has a high albedo and reflects most of the sunlight that reaches the snow-covered ground.

Volcanic Eruptions

Figure 7.12 Mount St. Helens, in Washington State, erupted in 1980 and sent 1 km^3 of rock and dust into the air.

Another way in which plate movement affects climate is by producing volcanic activity. Most volcanoes are located at the boundaries of tectonic plates. In these areas, molten rock and gases from below Earth's crust rise up through cracks in the rock and spew into the air as volcanic eruptions. Scientists think that volcanic activity helped form the atmosphere at an early stage in Earth's history.

Volcanic eruptions, such as the one shown in **Figure 7.12**, spew ash and other particles into the atmosphere. These particles, called *aerosols*, reflect solar radiation and have a cooling effect on the global climate. They also scatter light and cause brilliantly red sunsets. This effect may last from a few years to several decades, until the particles are removed from the atmosphere by precipitation and settling. For example, the 1815 eruption of Tambora, in the Philippines, was followed by the "Year Without a Summer." On the other hand, some types of volcanic eruptions may raise global temperatures by releasing greenhouse gases.

Activity 7-2

Modelling the Effects of Volcanoes on Climate

How does ash from a single volcanic eruption affect global climate? In this activity, you will model the process by which volcanic eruptions affect Earth's atmosphere.

Safety Precautions

- Exercise caution when using electrical devices and water in close proximity, to avoid electric shock.
- Clean up any spills or splashes immediately.

Materials

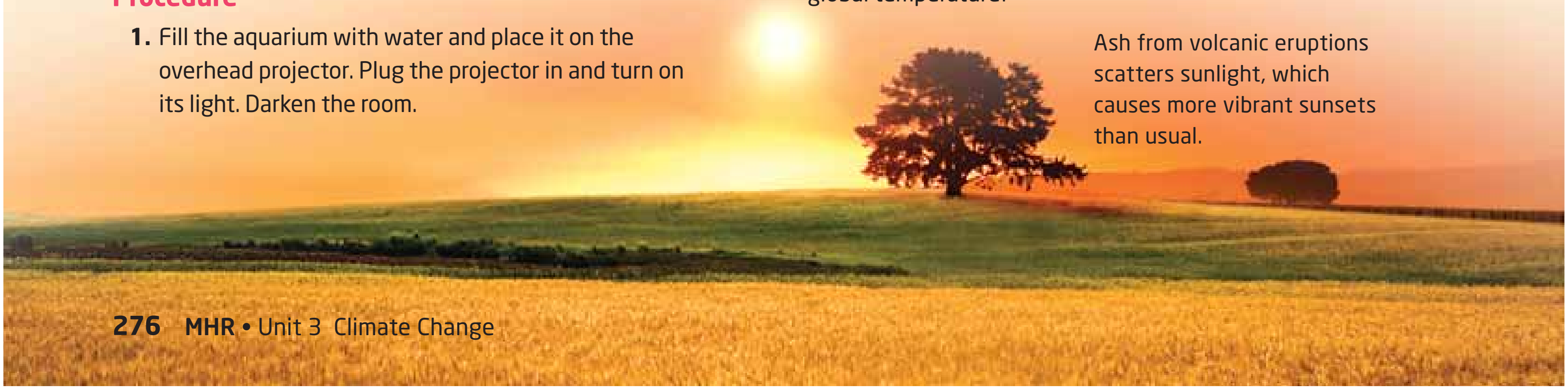
- overhead projector (or another light source)
- water
- small aquarium (5 L to 10 L)
- coffee creamer
- 5 mL measuring spoon

Procedure

1. Fill the aquarium with water and place it on the overhead projector. Plug the projector in and turn on its light. Darken the room.
2. Observe the colour of the water from the side of the aquarium, and the colour of the light that passes through the aquarium and hits the wall or screen.
3. Add 5 mL of coffee creamer to the water, stir, and observe again. Repeat until the liquid is translucent and more light is transmitted through the side of the aquarium than through the upper surface of the water.
4. Turn the room lights back on, unplug the overhead projector (or other light source), and empty the aquarium in the sink. Rinse it well and dry it before you put it away.

Questions

1. Describe how the colour of the transmitted light changed as the water was contaminated.
2. How does this activity model the effects of volcanic eruptions or meteorite impacts on the atmosphere?
3. What effect might this type of phenomenon have on global temperature?



Ash from volcanic eruptions scatters sunlight, which causes more vibrant sunsets than usual.

How Human Activity Affects Climate

Although solar variations, volcanic activity, moving continents, meteorites, and a wobbling planet have produced climate changes in the past, none of these causes can explain the warming trend that has occurred on Earth since the 1970s. There is growing evidence that the present change in climate is at least partly **anthropogenic** (caused by humans).

How can humans affect the climate? The main link is the effect human technology has on the atmosphere. For many centuries, a major source of energy used by people has been the burning of fossil fuels, such as coal, oil, and natural gas. In the late 1700s, a rapid increase occurred in the rate at which new machines were invented and new methods of transportation and manufacturing were adopted. All of these new inventions and processes demanded fossil fuels to power them. This period was called the *Industrial Revolution*.

From the 1700s to the present, technologies that burn fossil fuels grew and spread around the world. Trains, automobiles, ships, factories, aircraft, farming and mining equipment, home furnaces, and electricity generating stations are just some examples of technologies that use fossil fuels. When these fuels are burned to release energy, they release gases and other pollutants into the atmosphere as waste products, as shown in **Figure 7.13**. As the human use of fossil fuels has expanded, the concentration of these gases in the atmosphere has increased. Many of these gases affect the natural processes that produce the greenhouse effect. In Chapter 8, you will learn more about these processes and about the evidence for anthropogenic climate change.

anthropogenic relating to or resulting from the influence of humans

Study Toolkit

Word Origins The term *anthropogenic* is rooted in the Greek terms *anthropos* (human, man) and *genes* (that which produces). How can this information help you remember the meaning of the term?

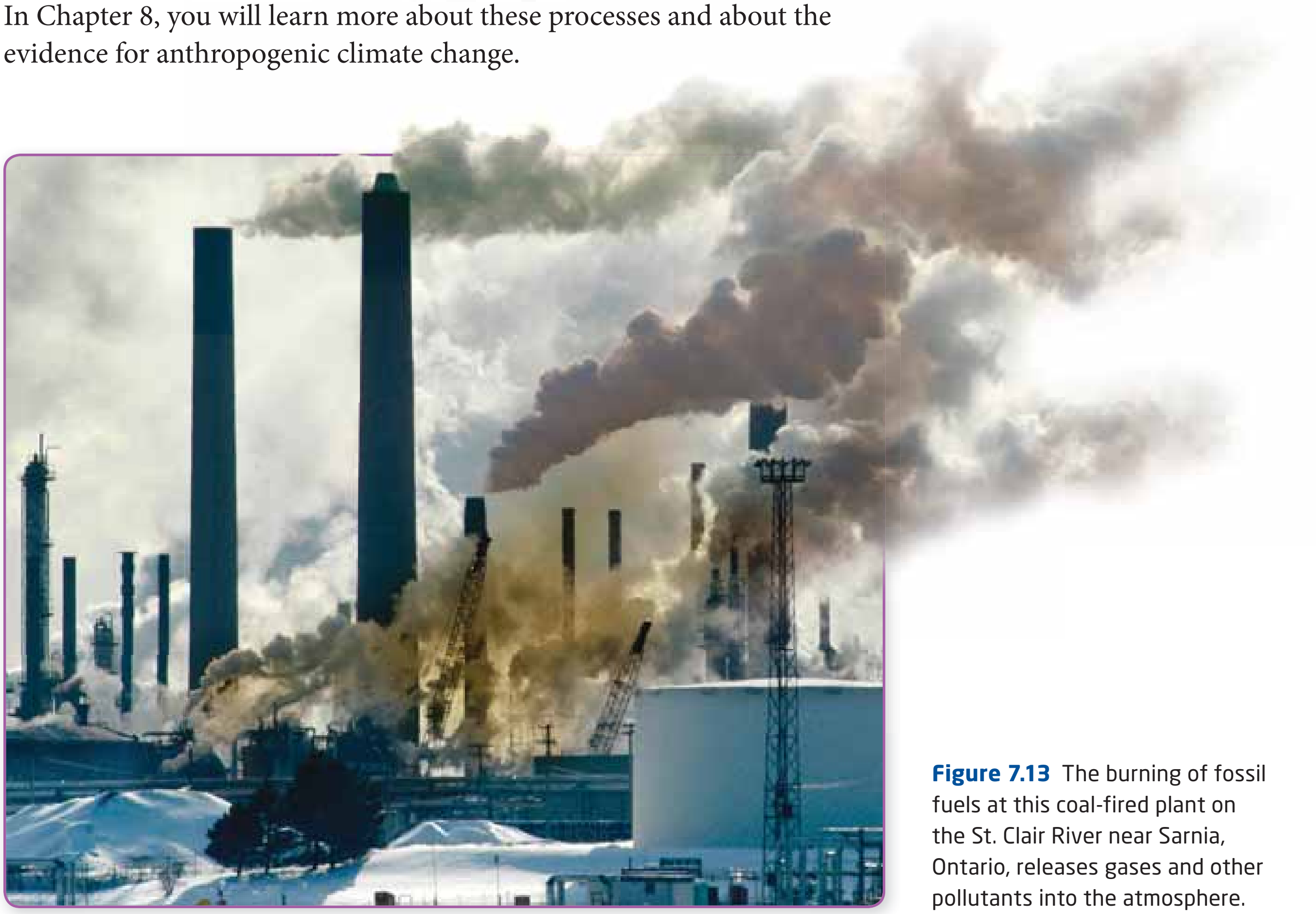


Figure 7.13 The burning of fossil fuels at this coal-fired plant on the St. Clair River near Sarnia, Ontario, releases gases and other pollutants into the atmosphere.

Section 7.1 Review

Section Summary

- Climate describes the standard weather conditions for a region at a given time of year, including expected temperatures, winds, precipitation, probability of storms, and hours of direct sunshine.
- The amount of energy that a location on the surface of Earth receives at any given time is determined by the angle of the Sun, which in turn depends on the latitude, time of year, and time of day.
- Winds, ocean currents, and the shape and size of continents affect climate.
- Earth reflects some of the solar energy that hits it back into space. The fraction of energy that is reflected by a surface is called albedo.
- Volcanic eruptions introduce gases and particles into the air that affect the reflection and absorption of energy from the Sun.
- Human activity affects climate by introducing particles and gases into the atmosphere that affect the absorption and transfer of energy from the Sun.

Review Questions

K/U **1.** How is climate different from weather?

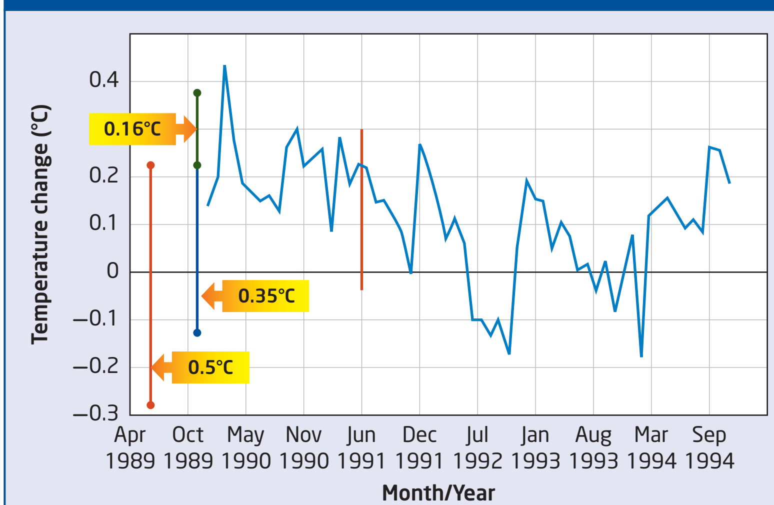
K/U **2.** Use **Figures 7.3** and **7.6** to explain how energy from the Sun affects Earth's climate.

A **3.** How do the specific heat capacities of water and rock explain why the climate in Toronto, Ontario, is more mild than the climate in Pierre, South Dakota?

T/I **4.** How might the formation of mountain chains affect climate?

A **5.** The graph on the right shows how temperature deviated from the global average temperature during the early 1990s. In June 1991, Mount Pinatubo erupted in the Philippines. How did this eruption affect global average temperature in the years following the eruption?

Global Temperature Anomaly (January 1990 to September 1994)



C **6.** Create a diagram that illustrates the major factors that affect Earth's climate. Be sure to label each factor.

T/I **7.** Which factor do you think has a stronger effect on climate, the atmosphere or the ocean? Explain your answer.

K/U **8.** What human activity may be the cause of recent rises in global temperatures?