Chapter 11

Climate change occurs through natural processes and human activities.

Polar bears have become a symbol for global climate change. Their habitat in northern Canada and the Arctic is disappearing. The ice on which they live, hunt, and feed is melting rapidly, forcing the polar bears to swim farther between rafts of floating ice in search of prey. They have been seen as far out as 60 km in the open ocean. Biologists predict that, if the current rate of global warming continues, the species will disappear by the end of the century. Are other species threatened by global warming? How should the human species respond to climate change? In this chapter, you will learn about the natural forces that have caused Earth's climate to change over billions of years. You will also examine the role of human activity in climate change in modern times.

What You Will Learn

In this chapter, you will
- **explain** how natural phenomena can affect climate
- **describe** how human activities can influence climate
- **describe** how climate change affects natural systems
- **evaluate** possible responses to climate change

Why It Is Important

As global temperatures increase, climates on Earth will change. To respond effectively to these changes, it is important that people understand the causes and effects of climate change.

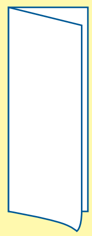
Skills You Will Use

In this chapter, you will
- **model** Earth's atmosphere and the greenhouse effect
- **graph** measurements of greenhouse gases and global temperatures
- **evaluate information** on climate change and its impact on natural systems
- **work co-operatively** to solve problems and create action plans

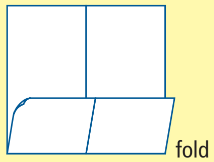
FOLDABLES™ Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 11.

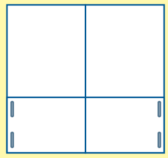
STEP 1 **Make** a hotdog fold. **Crease** and **open**.



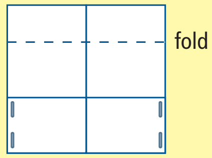
STEP 2 **Fold** the short side of the paper upwards to create a 7.5 cm tab. **Crease**.



STEP 3 **Staple** or **glue** the outer edges of the 7.5 cm tab to create a pocket.



STEP 4 **Fold** the top edge of the fold down by 5 cm, **crease**, and **unfold** to create a heading space for a two-column chart.



Summarize As you read the chapter, write headings and record the main ideas in the two-column chart. Use the pockets of the Foldable to store your work and notes.

11.1 Natural Causes of Climate Change

Climate describes a region's long-term weather patterns. Geologic evidence shows that Earth has undergone many climate changes, including ice ages and periods of warming. The processes that contribute to climate change are complex and include factors that affect Earth's radiation budget and heat transfer around the globe. Scientists have identified several factors that affect climate: greenhouse gases in the atmosphere, Earth's tilt and orbit, heat transfer by the oceans, and catastrophic events, such as volcanic eruptions and meteor impacts.

Words to Know

biogeoclimatic zone
carbon sink
carbon sources
El Niño
El Niño–Southern Oscillation (ENSO)
greenhouse gases
La Niña
natural greenhouse effect
paleoclimatologists

Connection

Section 1.1 has more information about different biomes in British Columbia.

Did You Know?

Earth has gone through several ice ages. During an ice age, large sheets of ice cover much of the planet's surface. The most recent ice age ended about 10 000 years ago. The time of warming between ice ages ranges from 12 000 to 28 000 years.

Climate change is not new to our planet. Throughout its history, Earth has undergone periods of freezing followed by periods of warming. The cycles that transfer heat throughout Earth's systems have been operating for billions of years and will continue for billions more.

Describing Climate

You may think of climate in terms of year-to-year changes. Some years are colder than others, some wetter, and some hotter and drier. In fact, **climate** describes the average conditions of the atmosphere in a large region over 30 years or more. Climate includes such characteristics as clouds and precipitation, average temperature, humidity, atmospheric pressure, solar radiation, and wind. Climate can refer to conditions in a region as small as an island or to conditions across an entire planet. Because of its varied geography, British Columbia has a range of climates (Figure 11.1).

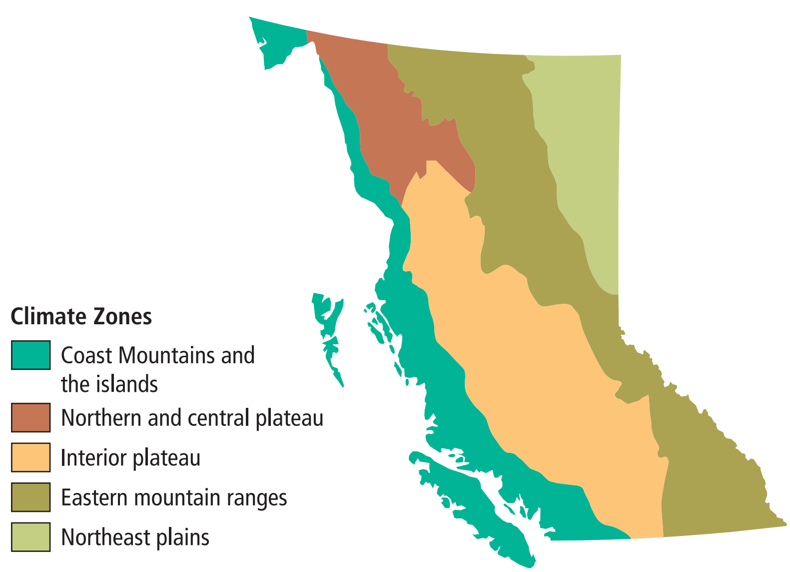
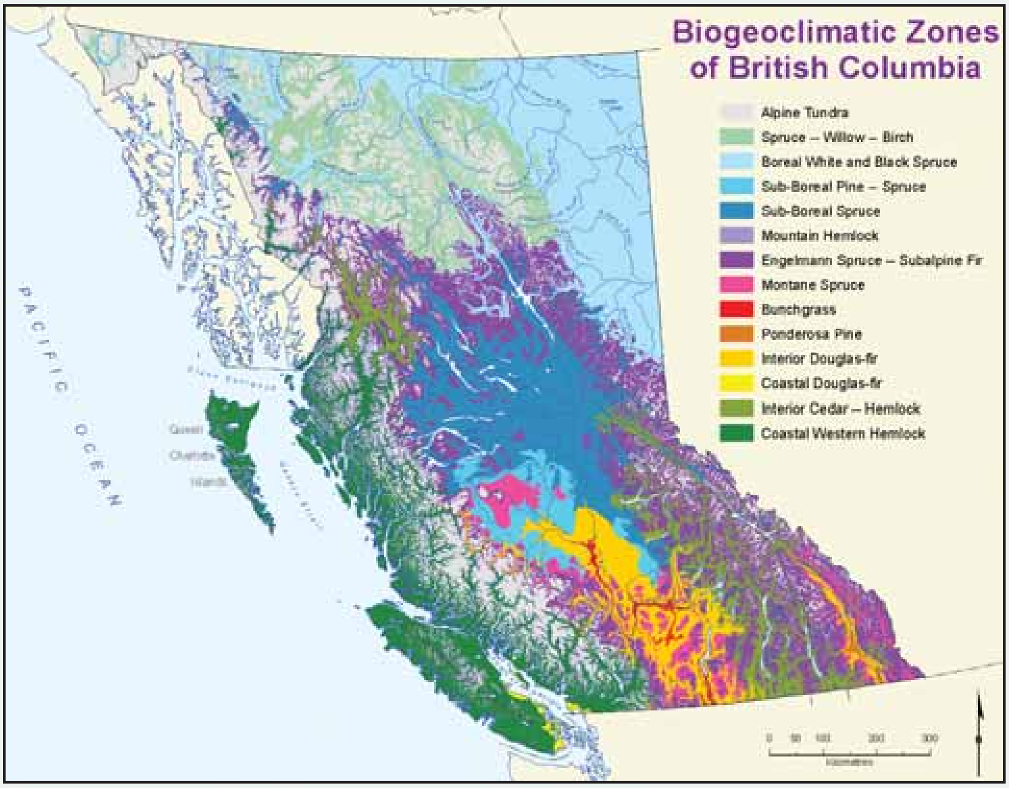


Figure 11.1 From the Cassiar Mountains in the north to the Interior Plateau, British Columbia has a range of climates. In this map, each type of climate is represented by a different colour.

The climate and geography of each region of British Columbia supports the growth of specific types of plants and other organisms. For example, rainforest ecosystems are common in moist, coastal environments. Very different ecosystems are found high in the mountains and in desert regions. A **biogeoclimatic zone** is a region with a certain type of plant life, soil, geography, and climate. British Columbia has 14 biogeoclimatic zones.

11-1A Biogeoclimatic Zones of British Columbia

Find Out ACTIVITY



In this activity, you will compare the climate zones of British Columbia with its biogeoclimatic zones.

What to Do

1. Copy a large version of the following table into your notebook. Give your table a title. Working with a partner, compare the map of biogeoclimatic zones with the map of the climate zones of British Columbia (Figure 11.1 on the previous page). In your table, list all the biogeoclimatic zones found in each climate zone.

Climate Zone	Biogeoclimatic Zones
Coast Mountains and the islands	
Northern and central plateau	
Interior plateau	
Eastern mountain ranges	
Northeast plains	

2. Locate the biogeoclimatic zone that you live in. Compare this biogeoclimatic zone with one that is 300 km away from your location and one that is 600 km away. Describe the types of plant life and other organisms, geography, and climate of the three biogeoclimatic zones.

What Did You Find Out?

1. Which climatic zone or zones include the greatest variety of biogeoclimatic zones?
2. Which biogeoclimatic zone appears to cover the largest area of British Columbia? Explain your answer.
3. How does the pattern of biogeoclimatic zones match the geographic features of British Columbia?
4. What are some factors that influence the types of plant life found in a certain biogeoclimatic zone?

Figure 11.2 This cross-section through a tree trunk reveals dozens of tree rings. The tree grew an additional ring every year. In drier years, the tree produced thin rings. In wetter years, the tree produced thick rings.

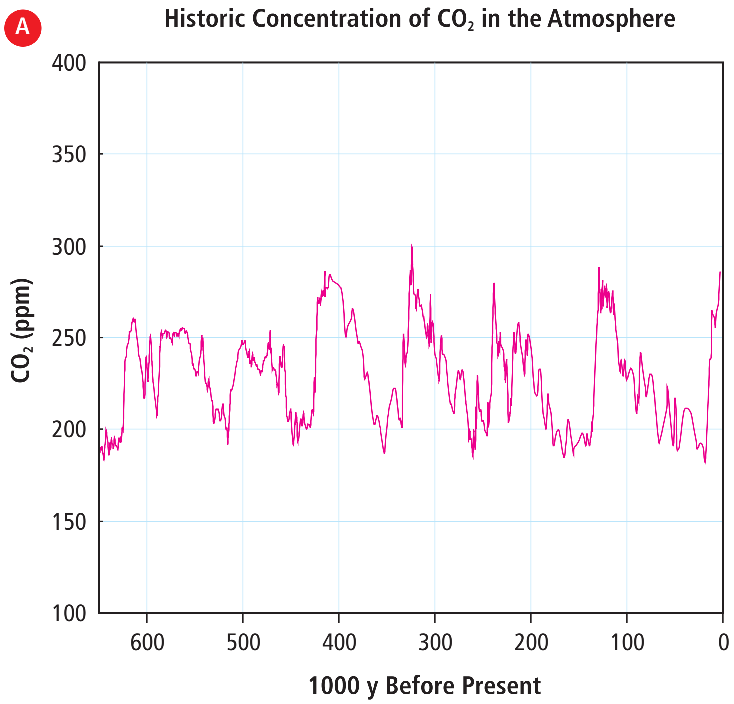
Looking Forward by Studying the Past

To understand the nature of climate change, we must learn from the past. People who study past climates are called **paleoclimatologists**. These scientists look at long-term patterns in vast regions to help them describe Earth's climate. Various types of evidence provide clues to ancient weather patterns. For example, paleoclimatologists may study fossils—the remains of past life. Plant fossils can help paleoclimatologists determine whether a region used to be cold and dry or warm and wet. These scientists may look at the rings in tree trunks, which show yearly changes in the weather (Figure 11.2). Paleoclimatologists may examine layers of sediment from the bottom of a river to find out what type of precipitation a region used to receive. In drier periods, less water is available to carry and deposit sediments.

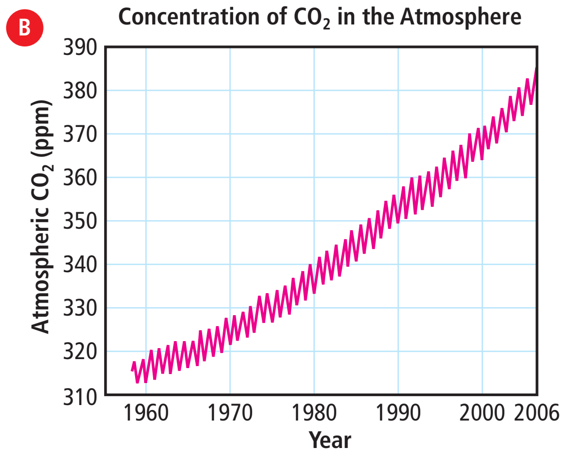
Observations of fossils and sediments from around the world indicate dramatic changes in Earth's climate have taken place over time. Ice ages and periods of warming have occurred several times. Only 21 000 years ago, most of Canada and parts of northern Europe were buried under sheets of ice called glaciers. In British Columbia, the ice reached depths of more than 2 km.

Paleoclimatologists also gather information about glaciers to help them understand climate changes. Thousands of years ago, as the glaciers formed, air bubbles were trapped in the ice. Scientists study the ice using **ice cores**, cylinders of ice drilled from thick glaciers. Scientists examine ice cores to determine what types and amounts of gases existed in the atmosphere when the ice was formed (Figure 11.3). Ice core data have been used to estimate the concentration of carbon dioxide gas (CO_2) that was in the atmosphere over the past 650 000 years (Figure 11.4 on the next page). In contrast, scientists have tested air samples for CO_2 for about 50 years.

Figure 11.3 This drilling rig is used to obtain ice cores (A). Scientists will examine the ice core shown here to find out what the atmosphere was composed of when the ice was formed (B).



Sources: Petit et al. 1999 and Siegenthaler et al. 2005



Source: Woods Hole Oceanographic Institution 2006

Figure 11.4 Gases from the atmosphere can be trapped in ice for thousands of years. The left graph of CO_2 concentrations in the atmosphere used data taken from ice cores (A). The current concentration of CO_2 in the atmosphere is also shown. The graph on the right shows CO_2 concentrations in the atmosphere based on data collected by sampling the air over the Mauna Loa Observatory in Hawaii (B). CO_2 concentrations are given in parts per million (ppm).

Scientists draw conclusions about climate change by observing current climates and by comparing these observations with evidence of past climates. Scientists believe that several factors influence climates. Some of these factors may cause dramatic climate changes:

- the composition of Earth's atmosphere
- Earth's tilt, rotation, and orbit around the Sun
- the water cycle
- ocean currents
- the carbon cycle
- catastrophic events

Each is discussed in detail on the following pages.

Reading Check

1. What does the term "climate" describe?
2. What is a biogeoclimatic zone?
3. How has the climate in Canada changed since 21 000 years ago?
4. Name one method paleoclimatologists use to determine how much carbon dioxide was in the atmosphere in the distant past.

The composition of Earth's atmosphere

Florists and farmers use greenhouses to grow plants when the plants would not grow as well outside. A greenhouse maintains the right balance of heat and light for plant growth, regardless of the weather. The **natural greenhouse effect** is the absorption of thermal energy by the atmosphere. This keeps Earth's temperature within a certain range.

Some of the solar radiation that reaches Earth's surface is absorbed and emitted into the atmosphere. **Greenhouse gases** in the atmosphere absorb and emit radiation as thermal energy (Figure 11.5). Without greenhouse gases, much of this energy would radiate back into space, and the average temperature at Earth's surface would be about 34°C lower than it is today. On the other hand, an increased amount of greenhouse gases in the atmosphere would make Earth much warmer.

Life on Earth is adapted to the conditions provided by the natural greenhouse effect. These conditions result from a balance of incoming solar radiation to outgoing heat.

Suggested Activity

Design an Investigation 11-1B on page 476

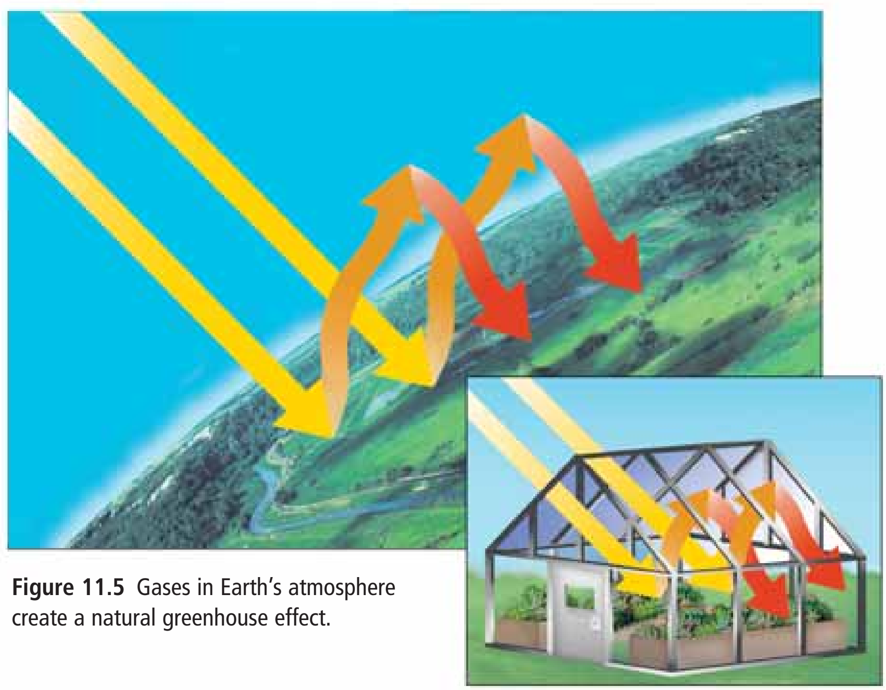


Figure 11.5 Gases in Earth's atmosphere create a natural greenhouse effect.

Earth's tilt, rotation, and orbit around the Sun

Three characteristics of Earth's movement in space affect the global climate system: Earth's tilt, rotation, and orbit around the Sun. At higher latitudes, one of the most noticeable features of the climate is the predictable change of seasons. Earth experiences seasons because of the combination of its tilt and yearly orbit around the Sun. Figure 11.6 shows the position of Earth at different points in its orbit relative to the Sun.

During winter in the northern hemisphere, the climate is cooler because the North Pole is tilted away from the Sun. The angle of incidence of the Sun's rays is large, and so the amount of solar radiation reaching the northern hemisphere is low. During summer in the northern hemisphere, the North Pole is tilted toward the Sun. At this time of year, the northern hemisphere receives more solar radiation, which warms the region.

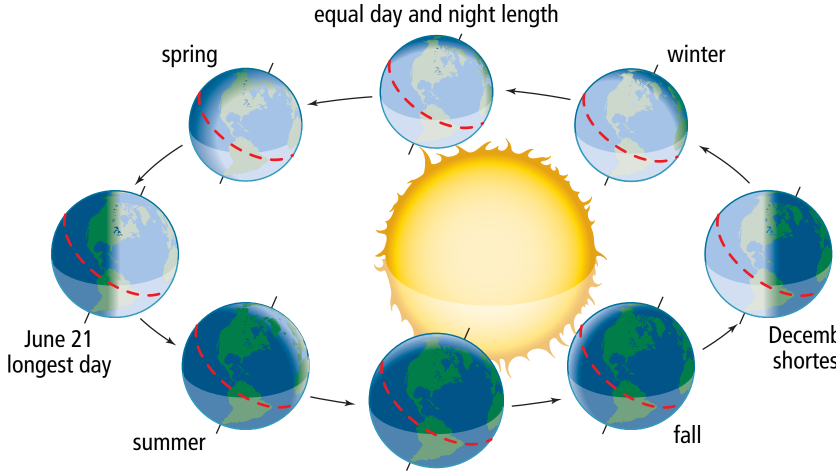


Figure 11.6 Earth takes a year to orbit the Sun. The seasons experienced in the northern hemisphere are indicated in this figure. The northern hemisphere's tilt away from the Sun is greatest at the winter solstice (December 21), and its tilt toward the Sun is greatest at the summer solstice (June 21). (Not drawn to scale.)

As Chapter 10 describes, Earth's axis of rotation is tilted 23.5° relative to its orbit around the Sun. If Earth had no tilt, the seasonal changes at higher latitudes would be less noticeable (Figure 11.7). Scientists think that the angle of Earth's tilt varies between 22.1° and 24.5° in cycles of about 41 000 years. They reason that seasonal changes would be most extreme when Earth's tilt is greatest. The northern hemisphere, for example, would receive even less solar radiation in winter than it does now and much more solar radiation in summer. Therefore winters would be colder and summers would be warmer.

Suggested Activity

Conduct an Investigation 11-1C on page 477

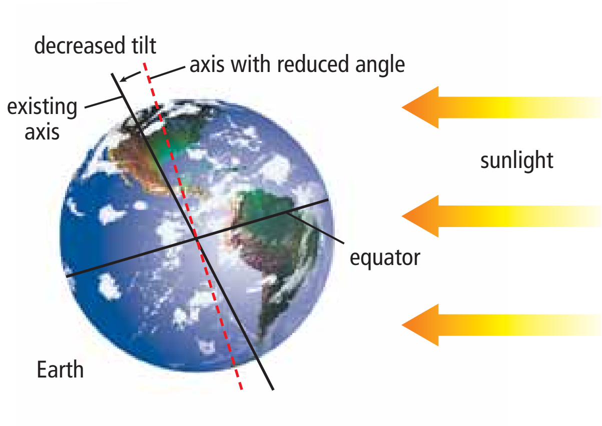


Figure 11.7 Earth rotates on an axis that is tilted 23.5° relative to Earth's orbit around the Sun. Earth's tilt affects the angle of incidence of the Sun's rays.

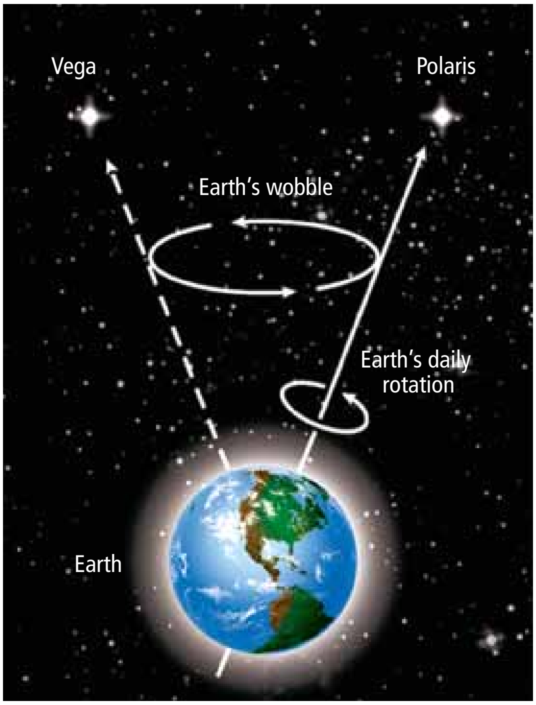


Figure 11.8 Earth wobbles as it rotates on its axis.

In addition to its tilt, Earth's rotation also has a wobble—much like a top wobbles as it spins on a flat surface. As the top spins, its axis of rotation traces out a circle (Figure 11.8). Currently, Earth's North Pole points to the North Star, also known as Polaris. Because of Earth's wobble, in about 12 000 years, the North Pole will point to a star called Vega. This change in Earth's axis of rotation will affect the angle of incidence of the Sun's rays.

Earth's path around the Sun is elliptical, or oval. Over a cycle of about 100 000 years, however, the shape of this path changes (Figure 11.9). Sometimes the orbit becomes more circular, and at other times, less so. When the orbit is more elliptical, Earth's orbit takes it farther from the Sun, and less solar radiation reaches Earth's surface.

The combined effects of tilt, wobble, and the shape of Earth's orbit can greatly influence climate. Scientists believe that these factors have caused the global climate to cool in the past, resulting in the ice ages.

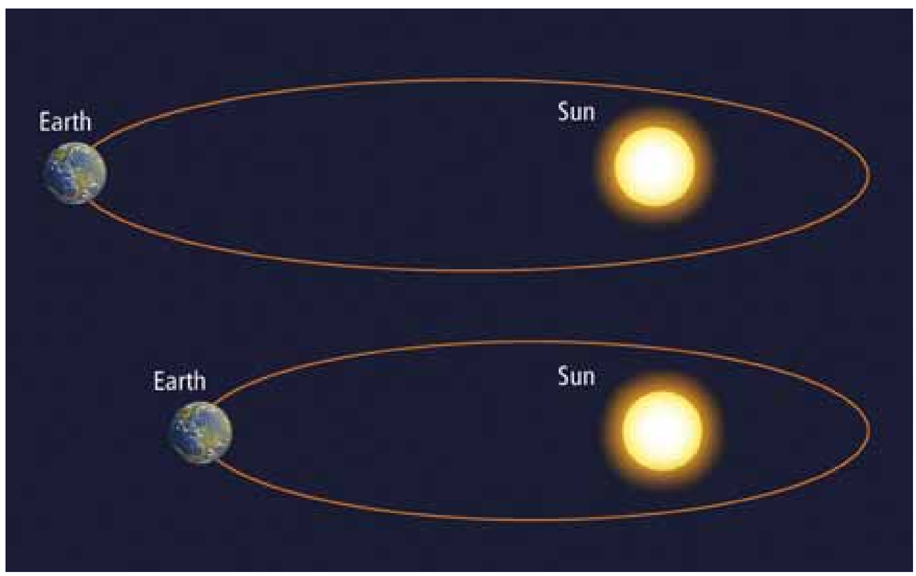


Figure 11.9 Earth's orbit changes shape over 100 000 y cycles.

Connection

Section 7.3 has more information on the Sun's energy.

Reading Check

1. What is the natural greenhouse effect?
2. How does Earth's tilt affect the amount of solar radiation that reaches Earth's surface?
3. What is the shape of Earth's orbit around the Sun?
4. List three ways in which Earth moves in space.

The water cycle

The **water cycle** describes the circulation of water on, above, and below Earth's surface. At different stages in the cycle, water's state changes (Figure 11.10). Water vapour (H_2O) is the most abundant greenhouse gas in the atmosphere. High temperatures increase the evaporation of water and the capacity of air to hold water vapour. Therefore, as surface temperatures rise, so does the amount of water vapour in the atmosphere.

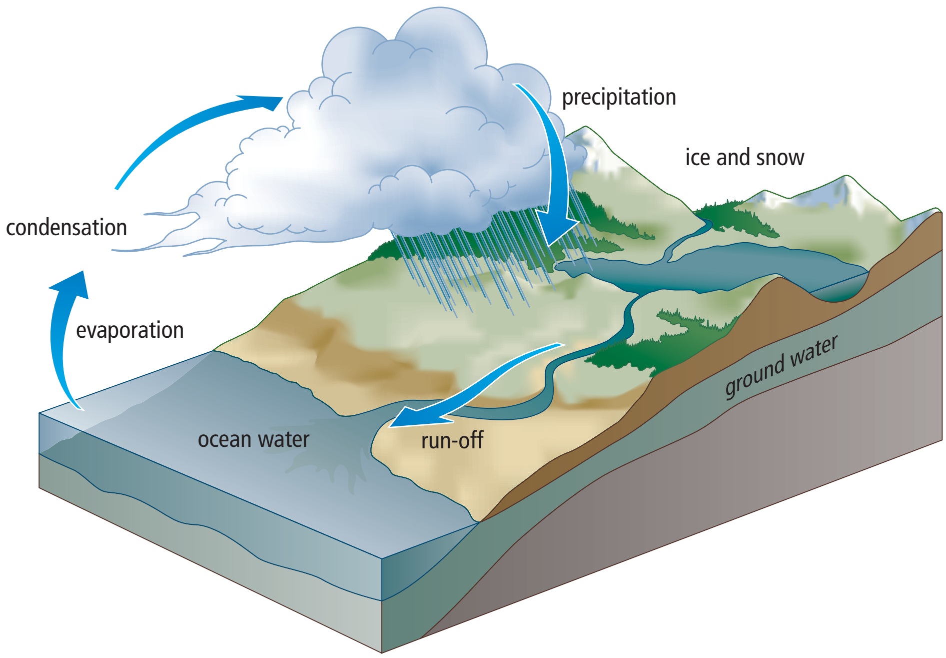


Figure 11.10 The water cycle. Precipitation brings water down to Earth's surface. Some of the water from precipitation runs off the land and into bodies of water. Evaporation from bodies of water and plant life (not shown) returns water to the atmosphere.

As average yearly temperatures increase, the atmosphere holds more water vapour and traps more thermal energy. The resulting increase in temperature at Earth's surface causes even more water to evaporate.

Ocean currents

Convection currents in the oceans transport large amounts of heat around the globe. Deep-ocean currents occur below 500 m. Surface currents extend to an average depth of 500 m. Both types are connected to climate.

The sinking and rising of deep ocean waters produces giant convection currents. These deep ocean currents act as a global conveyer belt that transports water—and thermal energy—around Earth (Figure 11.11 on the next page). Deep-ocean currents are driven by differences in the density of water, which is affected by temperature and salinity (salt content). Cold water is denser than warm water, and salty water is denser than fresh water. As a result, cold, salty water will sink below warmer, less salty water.

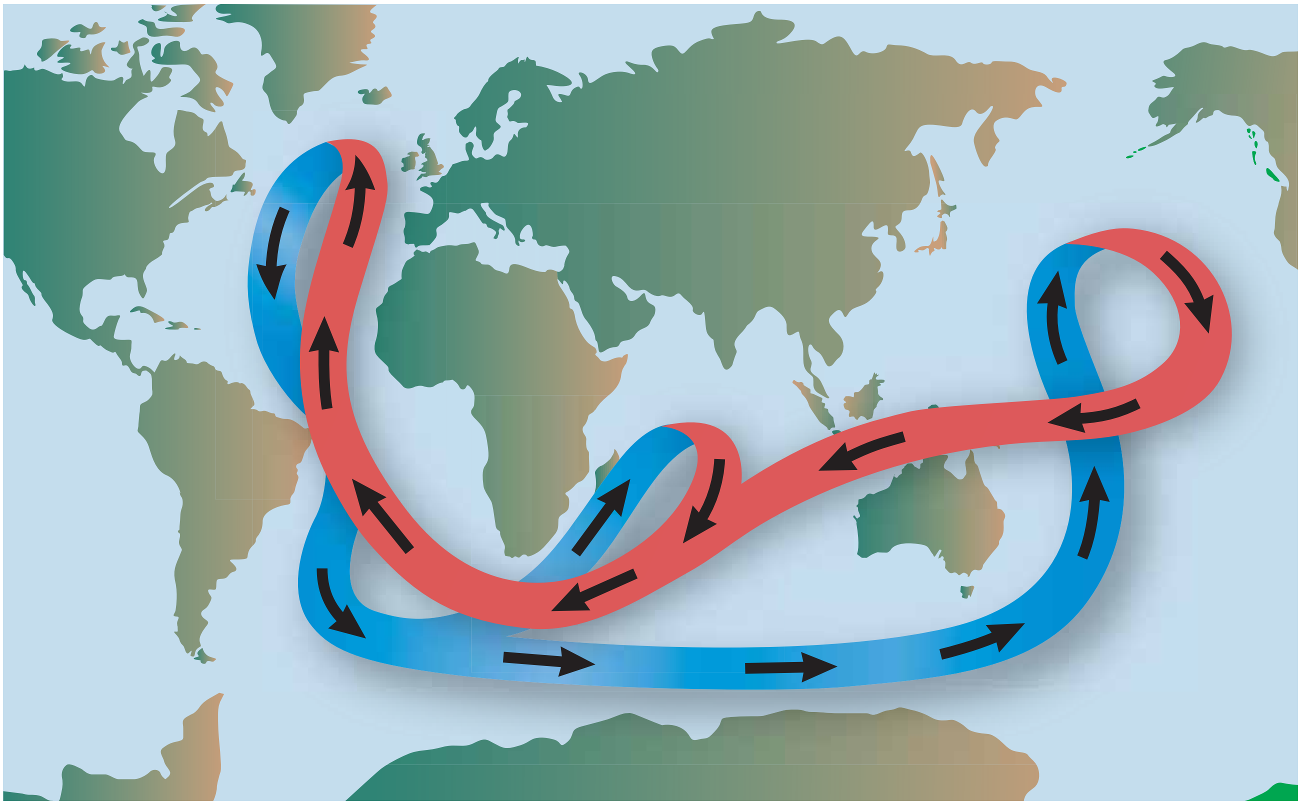


Figure 11.11 Deep-ocean currents form a global conveyer belt. Cold and salty water (blue lines) sinks below warmer, less salty water (red lines), resulting in convection currents.

Deep-ocean currents and climate have a two-way relationship. This is partly because of the effects of evaporation and precipitation and the effects of freezing and melting. Evaporation of warm surface waters leaves behind salt in the water, so the water becomes saltier. Conversely, precipitation adds water and so dilutes salty water. When ice forms, salt is left behind in the liquid water. However, when ice melts, the salty ocean water is diluted. Glaciers melting because of a warming climate could add large amounts of salt-free water to the oceans.

Surface currents exchange heat with the atmosphere, so these currents influence both weather and climate. Wind, Earth's rotation, and the shape of the continents are the main factors that influence the path of surface currents. Winds drag surface waters in the same way that winds push the sail of a sailboat. At the same time, Earth's rotation produces the Coriolis effect, which deflects the path of moving air, water, and objects. Currents of air or water are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. The shapes of the continents' coastlines also affect the direction of surface currents.

A transition zone called the **thermocline** separates the cold, deep ocean waters from the Sun-warmed surface waters. In this zone, water temperatures drop rapidly. At the thermocline is an area of mixing, where surface currents mix the Sun-warmed water with deeper water. Sometimes, deep water rises above the thermocline to the surface in a process known as upwelling.

El Niño and La Niña

Periodically, surface waters off the coast of Ecuador and Peru get unusually warm, a phenomenon known as an **El Niño** event. The warm water can result in unusually mild weather along the coast of British Columbia and in eastern Canada. In contrast, in a **La Niña** event, upwelling brings cooler-than-normal waters to the surface in the eastern Pacific Ocean. The cool surface waters also reach farther west than normal. During a La Niña event, winter temperatures are unusually warm in the southeast region of North America, and unusually cold in the northwest. The variation in the winds, including El Niño and La Niña events, are described as **El Niño–Southern Oscillation (ENSO)**.

Word Connect

The term "El Niño" is Spanish for boy child. "La Niña" is Spanish for little girl, suggesting the opposite of El Niño.

internet connect

El Niño and La Niña events have been connected with the fall of the great Inca civilizations in Central and South America. For more information about the effects of El Niño and La Niña, go to **www.bcscience10.ca.**

Reading Check

1. What is the most abundant greenhouse gas in the atmosphere?
2. List three factors that affect the path of surface currents in the ocean.
3. What property of water is affected by temperature and salinity?
4. What is the term used to describe the periodic warming of surface waters in the Pacific Ocean?

The carbon cycle

Carbon dioxide is an important greenhouse gas. Without CO_2 and other greenhouse gases in the atmosphere to absorb and emit infrared radiation from Earth's surface, the planet's temperature would plummet below freezing. However, too much CO_2 in the atmosphere would cause a large increase in temperature. But what maintains this balance?

The **carbon cycle** maintains the balance of CO_2 in the atmosphere. Biological and geological processes are both involved in maintaining the balance. The deep ocean, for example, is considered a **carbon sink**, because it removes CO_2 from the atmosphere. Some of the CO_2 that is dissolved in the ocean is converted to bicarbonate ions (HCO_3^-), which are used by marine animals to build their shells. Near the ocean's surface, micro-organisms called phytoplankton use CO_2 in photosynthesis. When they die, the carbon that they contain sinks with them to the ocean floor.

Connection

Section 2.2 has more information on the carbon cycle.

Figure 11.12 The White Cliffs of Dover in the United Kingdom are formed from the remains of ancient marine organisms. The build-up of the calcium carbonate remains resulted in these and other chalk sediments.

Over time, carbon-containing sediments build up (Figure 11.12). Weathering releases carbon from long-term storage. **Weathering** is a gradual physical or chemical process that breaks rock into smaller pieces. It is a link between carbon sinks and **carbon sources**, which release CO_2. Physical processes, such as the action of waves pounding on rock, can result in weathering. A common type of chemical weathering occurs when CO_2 reacts with water in the atmosphere to form carbonic acid (H_2CO_3). This chemical reaction removes CO_2 from the atmosphere, and H_2CO_3 falls to Earth's surface in precipitation. The weak acid dissolves some types of rocks, releasing HCO_3^- back to the oceans.

On land, forests are important carbon sinks. Trees and other types of plants remove CO_2 from the atmosphere and release oxygen gas through photosynthesis. Mature forests do not take up as much CO_2 as rapidly growing forests, but the trees and the forest floor remain carbon sinks unless the forest is cleared or burned. The burning of trees, or dead vegetation at the forest floor, creates a carbon source. Decaying vegetation is also a carbon source.

Reading Check

1. What gas do phytoplankton use in photosynthesis?
2. What is weathering?
3. Give an example of (a) a carbon sink and (b) a carbon source.

Catastrophic events

Earth has experienced many **catastrophic events**, or large-scale disasters. Some of these events were large volcanic eruptions. In addition to molten rock and ash, which block out sunlight, volcanoes release water vapour and sulfur dioxide (SO_2). The SO_2 reacts with water vapour in the atmosphere to form sulfuric acid (H_2SO_4). Winds in the stratosphere can carry droplets of H_2SO_4 for thousands of kilometres around the globe. These droplets also reflect solar radiation back into space. As a result, the lower layer of the atmosphere, the troposphere, cools.

Several historic volcanic eruptions have affected world temperatures, including Tambora (1815), Krakatau (1883), Agung (1963), and Mount Pinatubo (1991). The Tambora eruption in Indonesia sent so many particles into the atmosphere that the climate was affected thousands of kilometres away. In Europe, 1816 was known as the year without summer. Even though volcanic eruptions are often over in days, their effects on climates can last many years.

Even larger catastrophic events have occurred when meteorites and other large pieces of rock from space have struck Earth. Some of these rocks hit Earth's surface at 10 000 m/s. The impacts vaporized rock and hurled dust, debris, and superheated gases high into the atmosphere. The resulting dusty clouds reflected and absorbed solar radiation, causing the atmosphere below to cool. With considerable sunlight blocked from reaching Earth, it is likely that many photosynthetic organisms and the animals that fed on them were affected. Scientists hypothesize that impacts of this kind were related to a number of mass extinctions. The most recent large-scale impact occurred about 65 million years ago, in the Chicxulub region of Mexico (Figure 11.13). This catastrophic event may have contributed to the extinction of many types of dinosaurs.

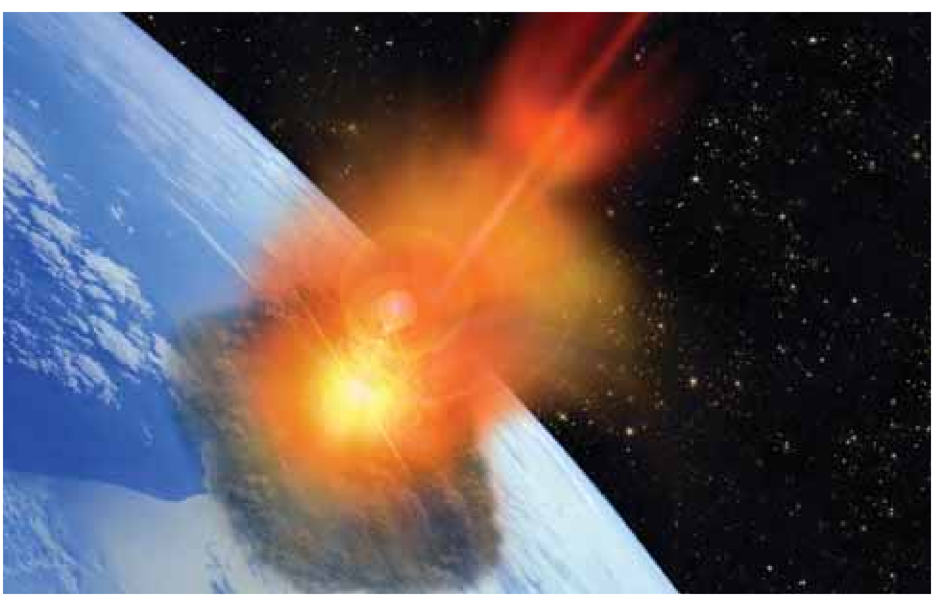


Figure 11.13 About 65 million years ago, a massive meteorite struck what is now the Chicxulub region of Mexico. The resulting debris would have blocked out sunlight and could have disrupted climates for many years.

Did You Know?

About 40 000 tonnes of microscopic dust and other particles enter Earth's atmosphere every year from space. Most of the debris never reaches Earth's surface but burns up as it falls through the atmosphere.

Explore More

Researchers at the University of Victoria have developed a computer model to help them understand how ice, the oceans, and the atmosphere have interacted to influence climate over the last 400 000 years. To learn more about the UVic Earth System Climate Model and other climate models, go to **www.bcscience10.ca**.

11-1B Generating the Greenhouse Effect

Design an INVESTIGATION

Problem-Solving Focus

SkillCheck
- Measuring
- Controlling variables
- Modelling
- Working co-operatively

Safety

- Use caution when handling the lamp as the light bulb will become very hot.

Materials

- 2 glass jars or transparent pop bottles of the same size and shape
- light bulb socket with clamp
- 100 W light bulb
- ring stand with clamp
- 2 thermometers or temperature probes
- watch, stopwatch, or clock
- clear plastic wrap
- elastic band
- graph paper
- 2 small pieces of cardboard
- masking tape

Science Skills

Go to Science Skill 2 for information about using a control.

Earth would be uninhabitable to life as we know it if it were not for the natural greenhouse effect. In this investigation, you will design two models to compare the temperatures in an environment with the greenhouse effect and an environment without the greenhouse effect.

Problem

How can you design and build a model to simulate the natural greenhouse effect?

Criteria

- You must use one container for a control and the other for the model simulating the greenhouse effect.
- You need to use all of the materials listed to construct your model.
- You must show a temperature difference between the control and the model after a 15 min trial.

Design and Construct

1. Sketch what happens to light rays after they enter a greenhouse. Share your sketch with your group members.
2. In your group, review the problem and materials. Together, decide how you will use the materials to model the greenhouse effect.
3. Prepare a sketch to show how you will model the greenhouse effect and what you will use as a control. Have your teacher approve your plan.
4. Build your model and your control.
5. Conduct a 15 min trial with your set-up, and observe and record the data.

Evaluate

1. How did your group show the difference between a greenhouse environment and a non-greenhouse environment?
2. Compare and contrast the temperature data from the model and the control.
3. (a) In what ways was your model an accurate representation of the greenhouse effect?
   (b) In what ways was your model an inaccurate representation of the greenhouse effect?
4. Share your design and results with another group. How could you refine your group's design to more accurately model the greenhouse effect?

Anchor Activity

11-1C Temperature and Angle of Incidence

Conduct an INVESTIGATION

SkillCheck

- Measuring
- Graphing
- Modelling
- Explaining systems

Inquiry Focus

In this investigation, you will vary the angle of incidence of light rays on a surface. You will measure the resulting temperatures at this surface.

Question

How does the angle at which radiant energy reaches Earth affect the temperature at Earth's surface?

	Time (min)			
Angle of Incidence	0	1	2	15
0°				
45°				
90°				

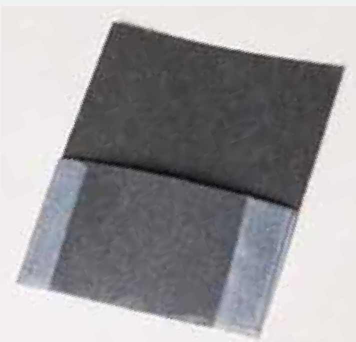


Figure A

Safety

- Use caution when handling the lamp as the bulb can become very hot.
- Do not look directly at the light.

Materials

- dark construction paper (approximately 5 cm × 10 cm)
- clear adhesive tape
- small box or stack of textbooks
- reflecting lamp with clamps
- 60 W to 100 W light bulb
- 2 ring stands with clamp
- thermometer clamp
- thermometer or temperature probe
- protractor
- clock, watch, or stopwatch
- graph paper
- coloured pens or pencil crayons

Procedure

1. Copy the table on the right into your notebook. Give your table a title.
2. Fold over the bottom third of the construction paper. Tape the sides to form a pouch, as shown in Figure A.
3. Make a platform for the pouch by using an overturned box or stack of textbooks, as shown in Figure B. Set up a ring stand and lamp so that the lamp is level with the top of the platform. The light bulb should be about 35 cm away from the pouch.
4. Place the thermometer, or temperature probe, into the pouch. Use the second ring stand and clamp to support the thermometer so that the pouch is perpendicular to the platform; measure the angle with the protractor.

Figure B

5. Turn on the light, and record the temperature in your data table. This first measurement is the temperature at time "0 min" (room temperature) and an angle of incidence of 0°.
6. Keep the pouch upright and record the temperature every min for 15 min.
7. Turn off the lamp and wait for the thermometer reading to drop to room temperature.
8. Repeat steps 4 to 7 with an angle of incidence of 45° and then 90°.

Analyze

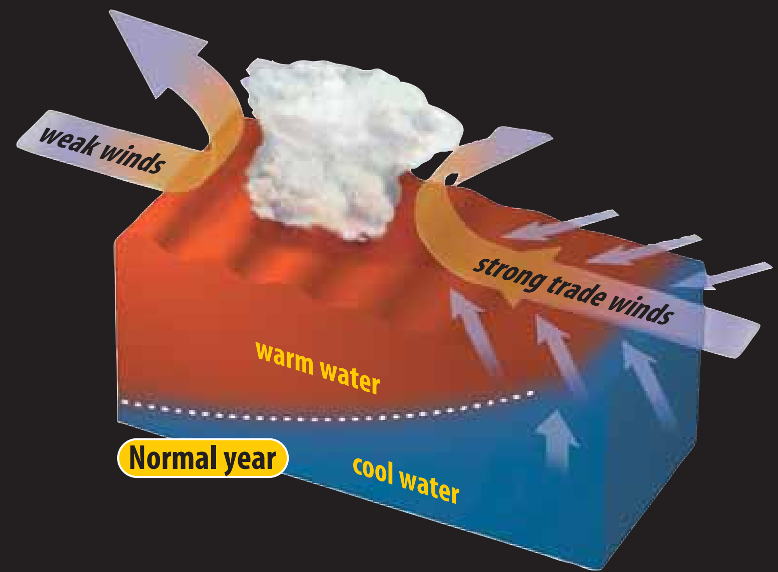
1. Create a line graph of your temperature versus time data. Use a different colour or style of line for each angle of incidence.
2. Compare the lines of best fit for each angle of incidence. State in which case the temperature rose (a) the fastest (b) the slowest

Conclude and Apply

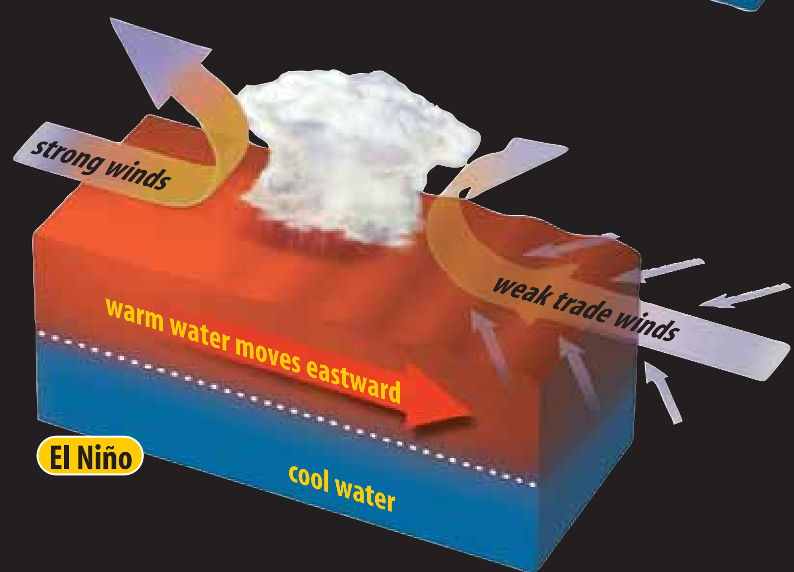
1. Explain why the temperature increased at different rates when the paper pouch was placed at different angles to the light.
2. (a) Why do locations at higher latitudes receive less solar radiation in winter than do locations at lower latitudes?
   (b) How does the angle of incidence of solar radiation affect the temperature at Earth's surface?

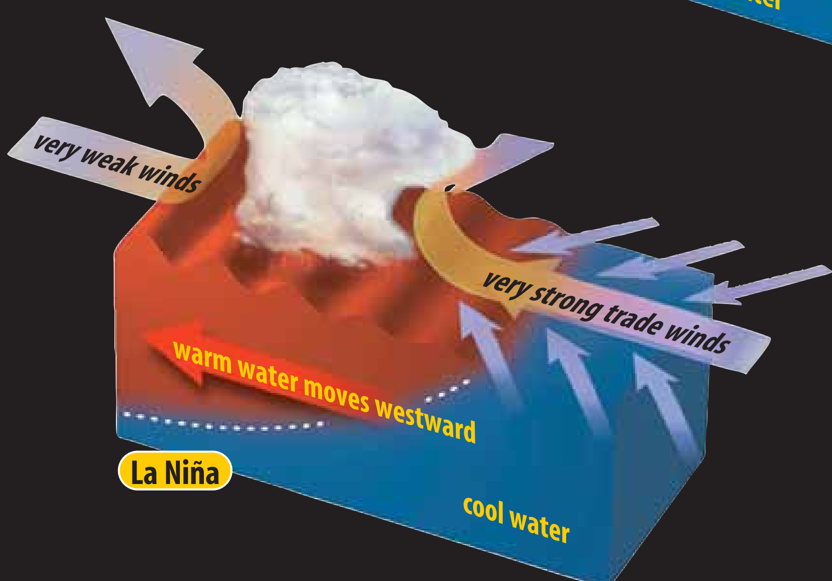
Visualizing El Niño and La Niña

Weather in Canada can be affected by changes that occur thousands of kilometres away. Out in the middle of the Pacific Ocean, periodic warming and cooling of a huge mass of seawater—phenomena known as El Niño and La Niña, respectively—can impact weather across North America. During normal years (right), when neither El Niño nor La Niña is in effect, strong winds usually keep warm surface waters contained in the western Pacific while cooler water wells up to the surface in the eastern Pacific.



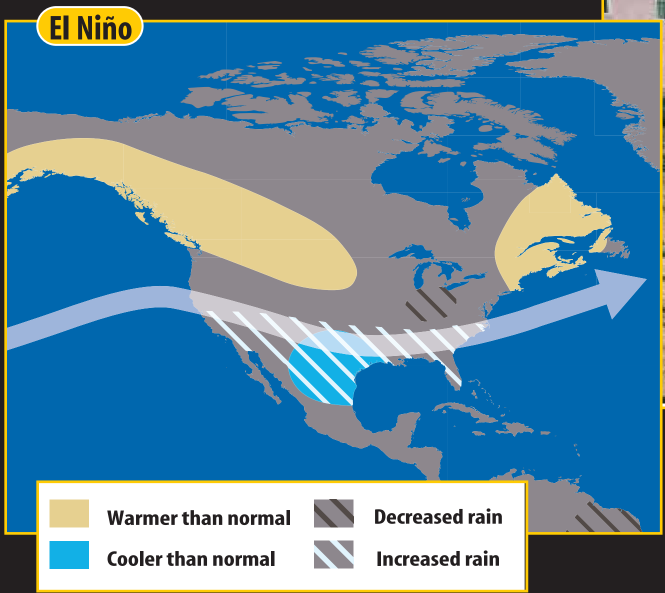
EL NIÑO During El Niño years, winds blowing west weaken and may even reverse. When this happens, warm waters in the western Pacific move eastward, preventing cold water from upwelling. This can alter global weather patterns and trigger changes in precipitation and temperature across much of North America.





LA NIÑA During La Niña years, stronger-than-normal winds push warm Pacific waters farther west, toward Asia. Cold, deep-sea waters then well up strongly in the eastern Pacific, bringing cooler temperatures to northwestern North America.

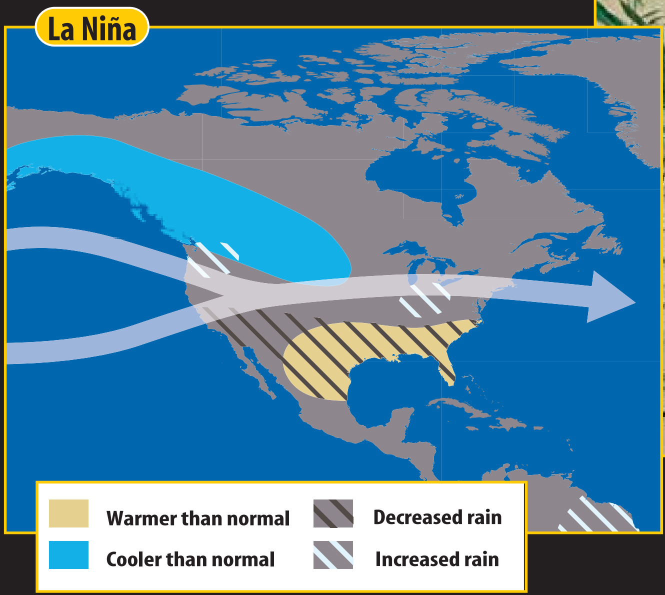
El Niño



Sun-warmed surface water spans the Pacific Ocean during El Niño years. Clouds form above the warm ocean, carrying moisture aloft. The jet stream, shown by the white arrow above, helps bring some of this warm, moist air to the United States.

LANDSLIDE Heavy rains in California resulting from El Niño can lead to landslides. This upended house in Laguna Niguel, California, took a ride downhill during the El Niño storms of 1998.

La Niña



During a typical La Niña year, warm ocean waters, clouds, and moisture are pushed away from North America. A weaker jet stream often brings cooler weather to the northern parts of the continent and hot, dry weather to southern areas.

PARCHED LAND Some areas may experience drought conditions, like those that struck these cornfields during a La Niña summer.

Wild, Weird, Wonderful

www Science

In the Shade of the Volcano

You don't have to leave British Columbia to witness the far-reaching effects of a volcanic eruption. About 7700 years ago, in an area of what is now southwestern Oregon, Mount Mazama erupted. The size of a volcanic eruption can be measured by the amount of ash produced. The eruption of Mount Mazama released a massive amount of ash and left behind a crater, known today as Crater Lake. Winds carried the ash for hundreds of kilometres before it fell to the ground. The ancient ash layer shown in the photograph below is located just a few kilometres from Kamloops, British Columbia.

Even larger than Mount Mazama, some volcanoes are known as super volcanoes. Super volcanoes cause massive eruptions that can greatly affect climates and ecosystems. There have been many super volcano eruptions throughout Earth's history. The last such eruption was that of the super volcano, Toba, in Sumatra, Indonesia. After Toba had stopped erupting, about 74 000 years ago, it had released 800 km^3 of ash. This ash would have entered the atmosphere and travelled long distances around the globe. In comparison, the 1980 eruption of Mount St. Helens produced about 1 km^3 of ash.

Crater Lake

Ash from Mount Mazama (Crater Lake) reached far into the northeast (top). Cutting away rock for a road near Kamloops revealed a prominent layer of ash from Mount Mazama's eruption (bottom).

Ice cores taken from Greenland provide a record of the composition of the atmosphere and changes in temperature over time. The data indicate that the Toba eruption sent so much ash and vapour into the atmosphere that it produced a volcanic winter. Temperatures around the world dropped, resulting in a mini-ice age. The growth of plant life, the migration of animals, and precipitation patterns would have been affected by the altered climate.

Although not a super volcano, another Indonesian volcano produced the largest volcanic eruption on Earth in the past 1800 years. Tambora erupted in 1815, releasing so much ash that in the months following the eruption, temperatures dropped throughout much of the northern hemisphere. In the North American midwest, there was frost in July. In some places, the unusually cold temperatures killed off crops and livestock.

Catastrophic events such as volcanic eruptions do not occur on a human schedule and, very often, not even on a human timescale. There may be hundreds, or thousands of years between such events. As philosopher and writer William Durant once stated, "civilization exists by geological consent—subject to change without warning."

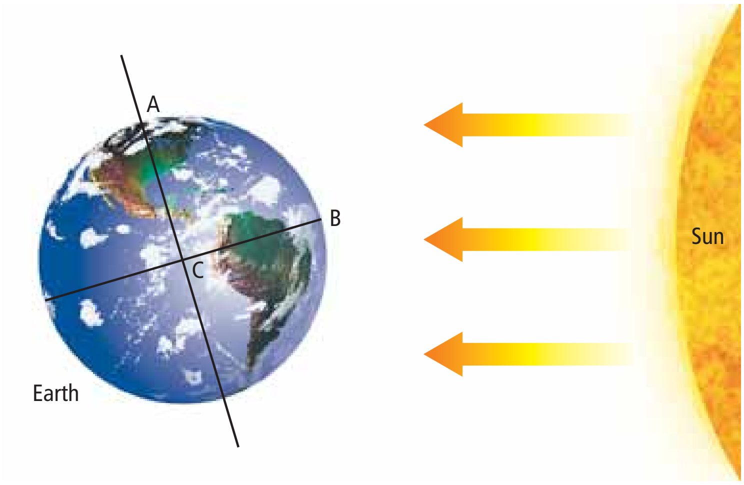
Check Your Understanding

Checking Concepts

1. Define the term "climate."
2. What is the term for scientists who study past climates?
3. List three reasons for natural climate changes on Earth.
4. Name two factors that affect the amount of solar radiation reaching Earth's surface.
5. Name a gas that is important in the natural greenhouse effect.

Understanding Key Ideas

6. What types of evidence do paleoclimatologists use to study ancient weather patterns?
7. What features are used to describe a biogeoclimatic zone?
8. What is the main difference between an El Niño event and a La Niña event?
9. Uranus is a planet that is tilted on its side at about 90°. Explain how the climate would change in your region of British Columbia if Earth were tilted:
   (a) 90° toward the Sun
   (b) 90° away from the Sun
10. Earth wobbles as it spins on its axis. How might wobble affect climate?
11. Suppose all the continents were grouped together in one giant landmass. How would this grouping affect heat transfer by the oceans?
12. How could the impact of a large meteorite influence global climate?
13. How does the shape of Earth's orbit around the Sun affect Earth's climate? Draw diagrams to help explain your answer.
14. Suppose you are analyzing an ice core. You find that the amount of CO_2 trapped in the ice core decreases with increasing depth. What would this observation suggest about changes in Earth's atmosphere over time?
15. Use the diagram of Earth shown below to answer these questions.
    (a) What season is it in the region indicated at A?
    (b) Where do the Sun's rays reach Earth at an angle of incidence of 0°: A or B? Explain your answer.
    (c) Which region receives the most direct solar radiation?
    (d) Which regions have the most similar climates: A and B, B and C, or A and C? Explain your answer.



Pause and Reflect

Paleoclimatologists have found that Earth's climate has gone through several periods of warming between ice ages. Based on studies of ice cores, scientists think that levels of CO_2 in the atmosphere were higher during periods of warming and lower during ice ages. What factors could have caused Earth's climate to warm and then cool?