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.

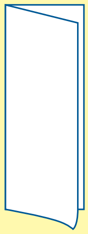
Skills You Will Use

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

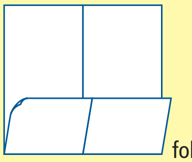
FOLDABLES™
Reading & Study Skills

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

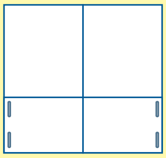
STEP 1 **Make** a hotdog fold. **Crease** and **open**.



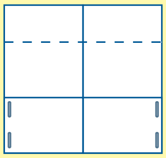
STEP 2 **Fold** the short side of the paper upwards to create a 7.5 cm tab. **Crease**.



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).

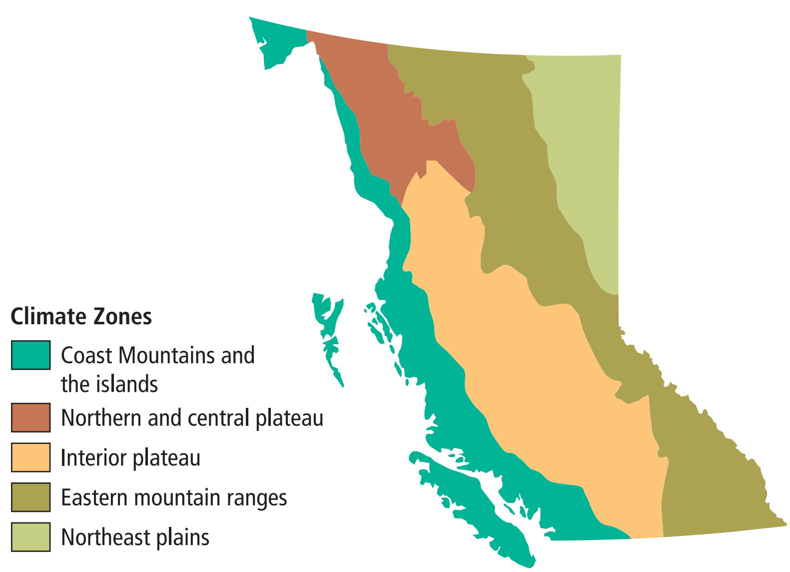


Figure 11.1 From the Cassiar Mountains in the north to the Interior Plateau, British Columbia has a range of climates. In this map, each type of climate is represented by a different colour.

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.

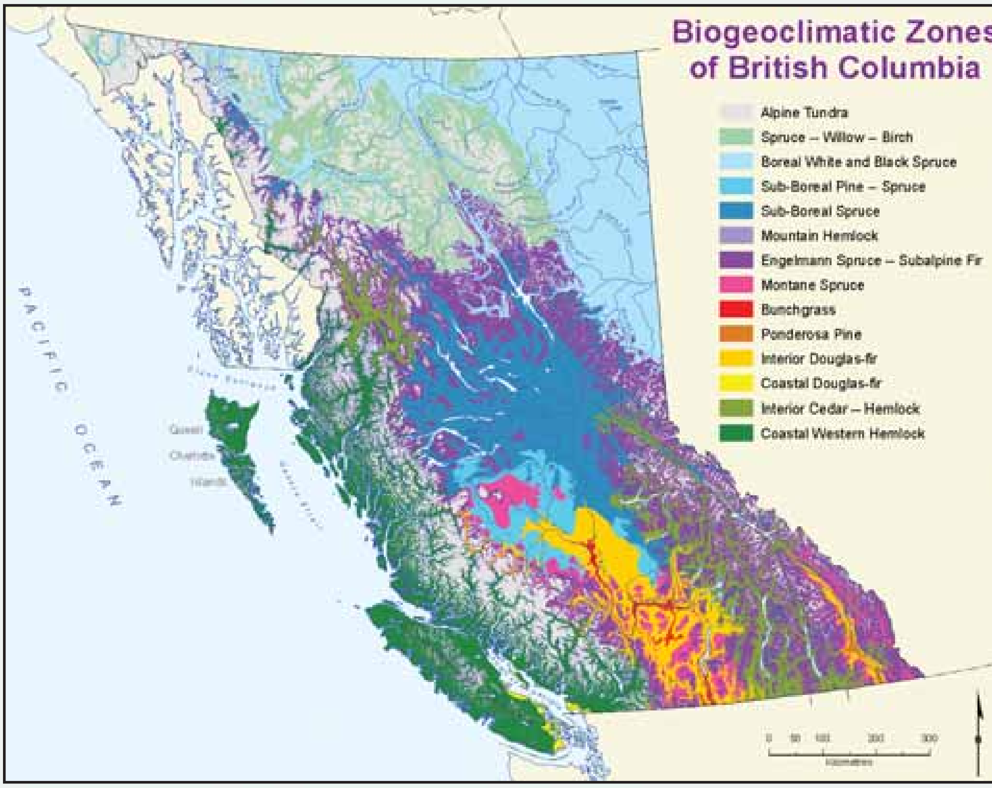
11-1A Biogeoclimatic Zones of British Columbia

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.

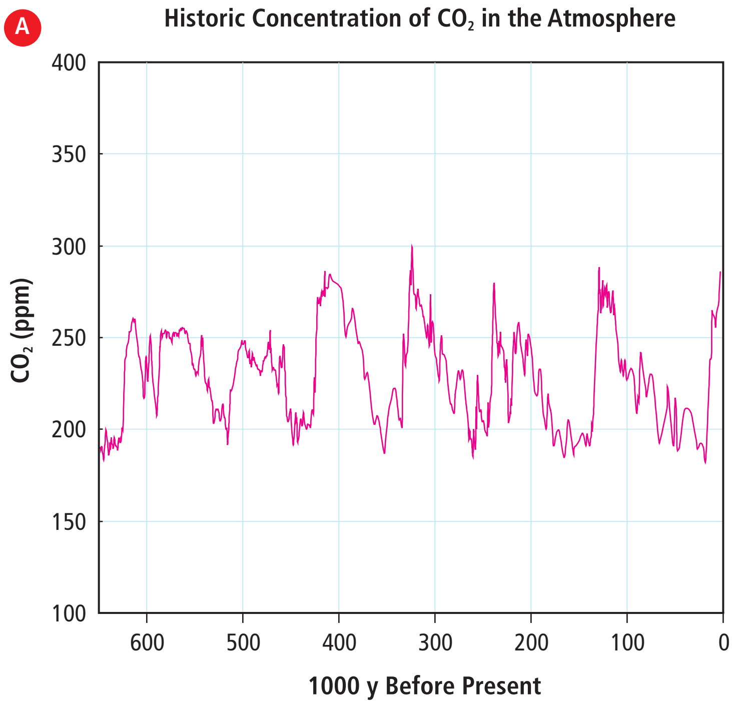
Looking Forward by Studying the Past

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.

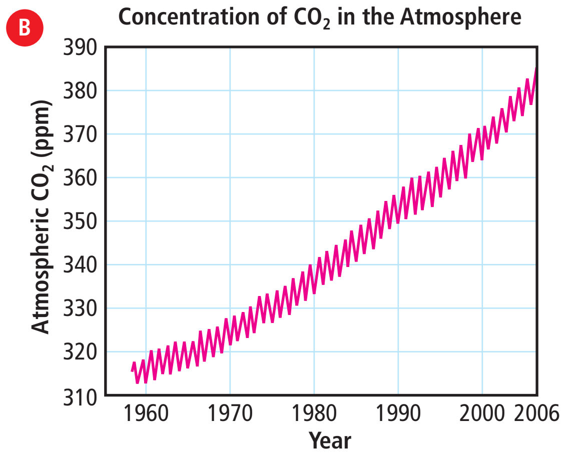
Observations of fossils and sediments from around the world indicate dramatic changes in Earth's climate have taken place over time. Ice ages and periods of warming have occurred several times. Only 21 000 years ago, most of Canada and parts of northern Europe were buried under sheets of ice called glaciers.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

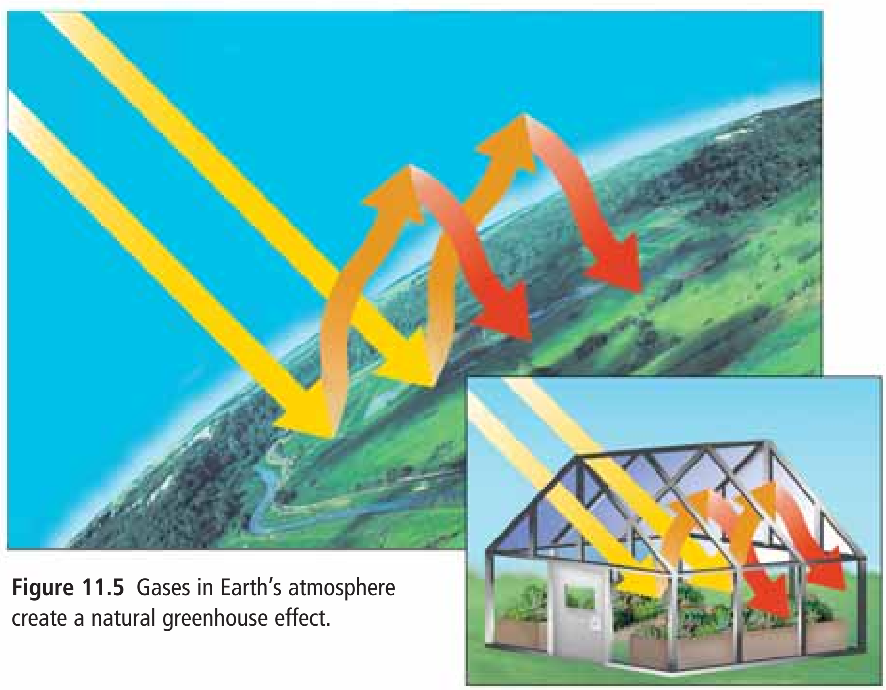


Figure 11.5 Gases in Earth's atmosphere create a natural greenhouse effect.

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.

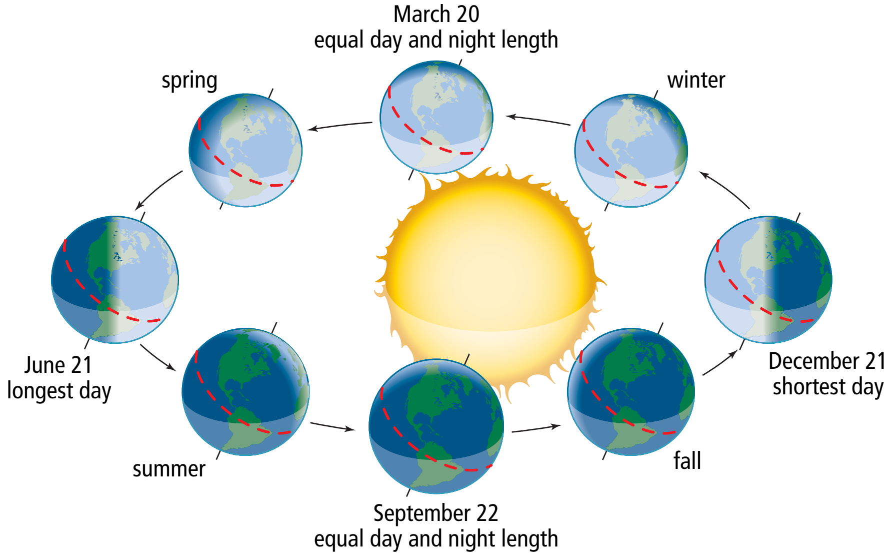


Figure 11.6 Earth takes a year to orbit the Sun. The seasons experienced in the northern hemisphere are indicated in this figure. The northern hemisphere's tilt away from the Sun is greatest at the winter solstice (December 21), and its tilt toward the Sun is greatest at the summer solstice (June 21). (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

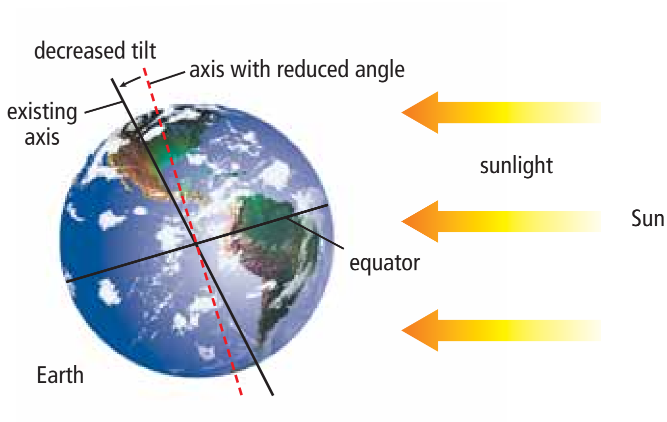


Figure 11.7 Earth rotates on an axis that is tilted 23.5° relative to Earth's orbit around the Sun. Earth's tilt affects the angle of incidence of the Sun's rays.

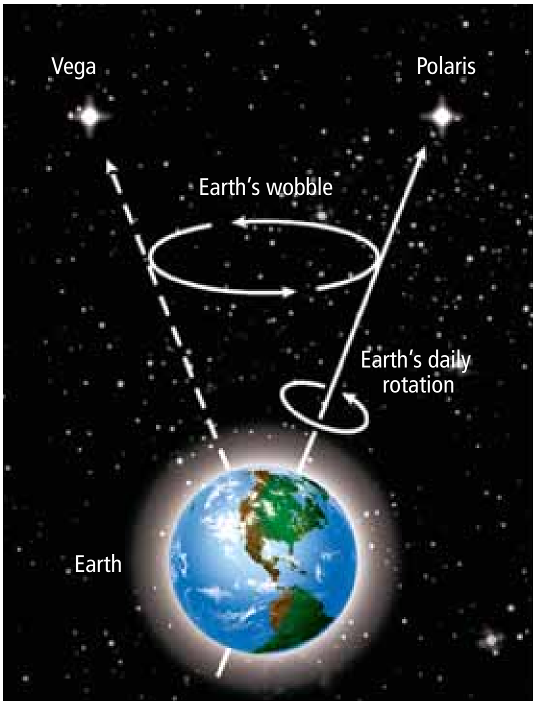


Figure 11.8 Earth wobbles as it rotates on its axis.

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.

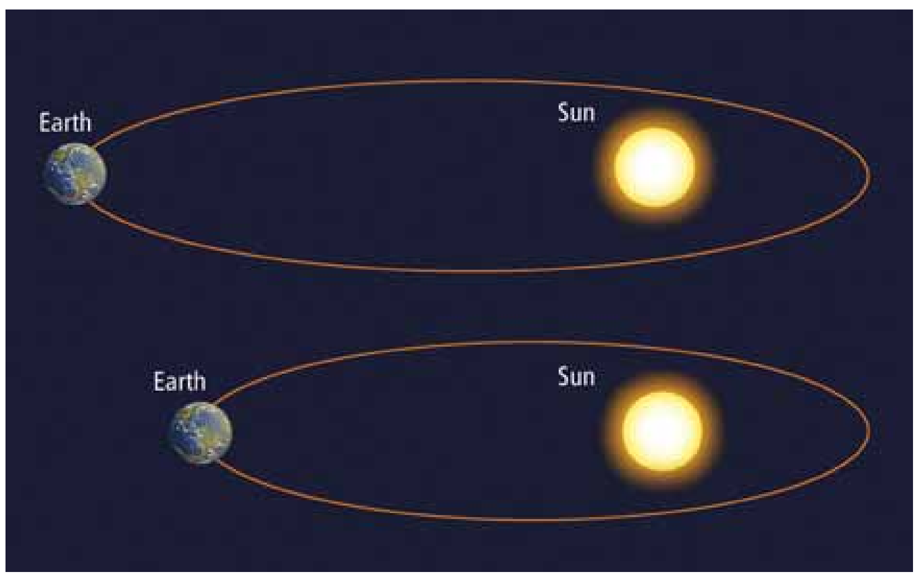


Figure 11.9 Earth's orbit changes shape over 100 000 y cycles.

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.

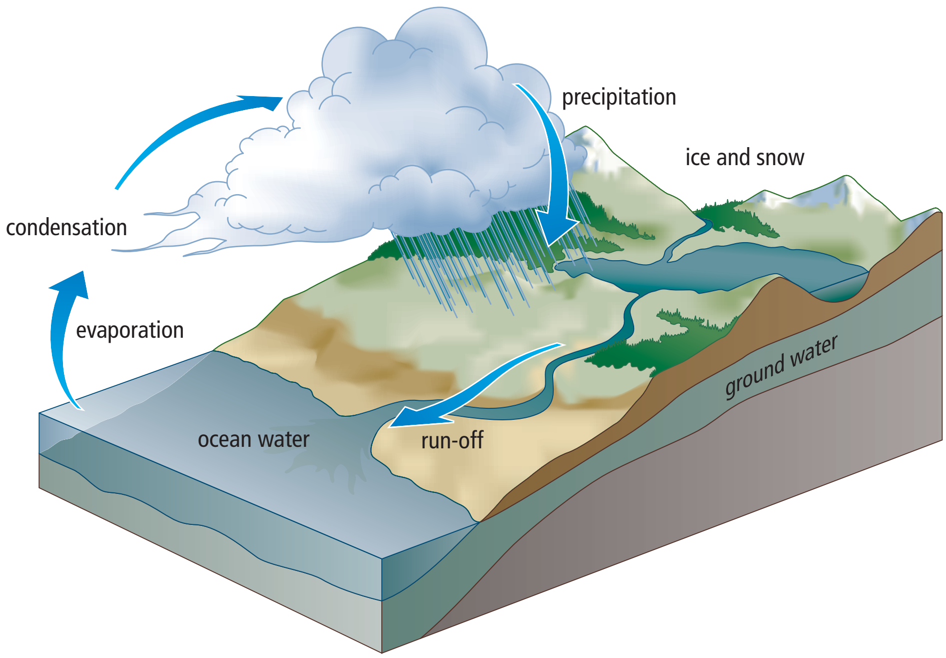


Figure 11.10 The water cycle. Precipitation brings water down to Earth's surface. Some of the water from precipitation runs off the land and into bodies of water. Evaporation from bodies of water and plant life (not shown) returns water to the atmosphere.

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.

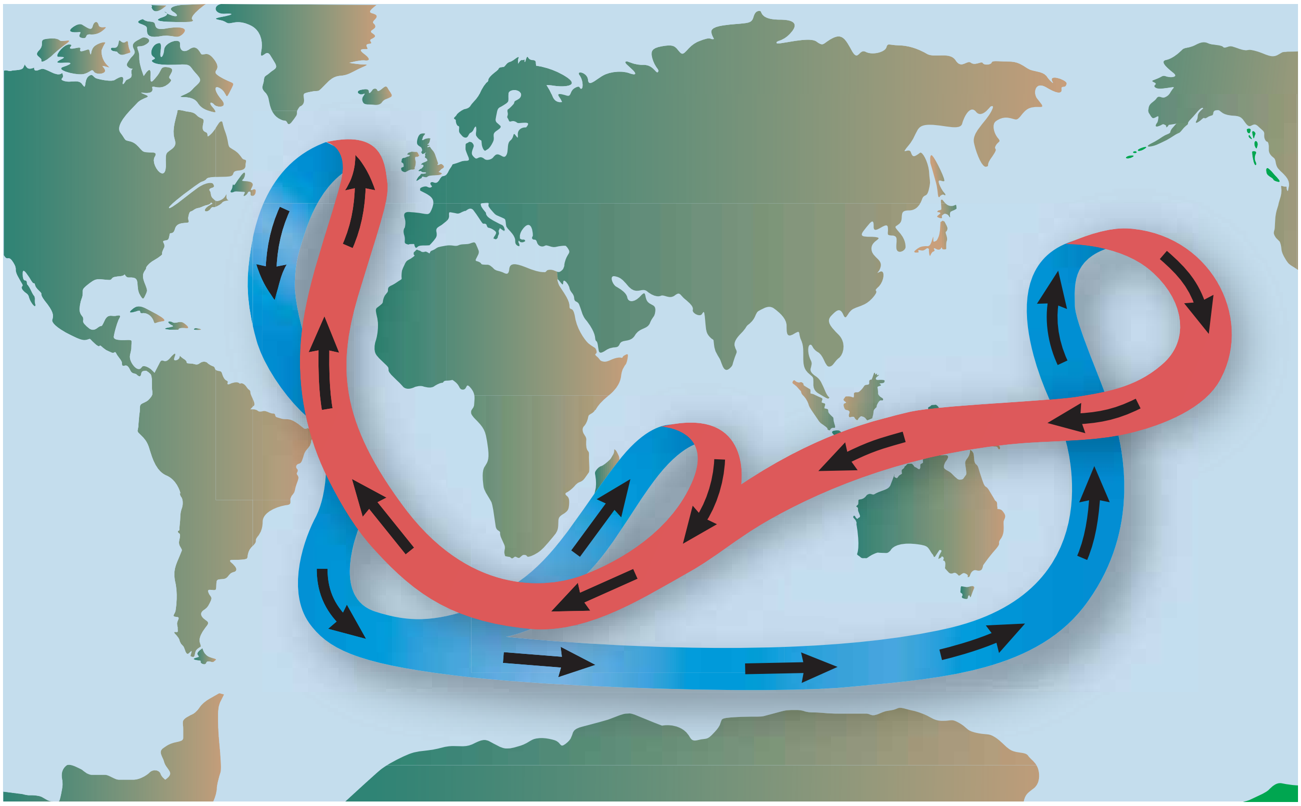


Figure 11.11 Deep-ocean currents form a global conveyer belt. Cold and salty water (blue lines) sinks below warmer, less salty water (red lines), resulting in convection currents.

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)**.

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.

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.**

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.

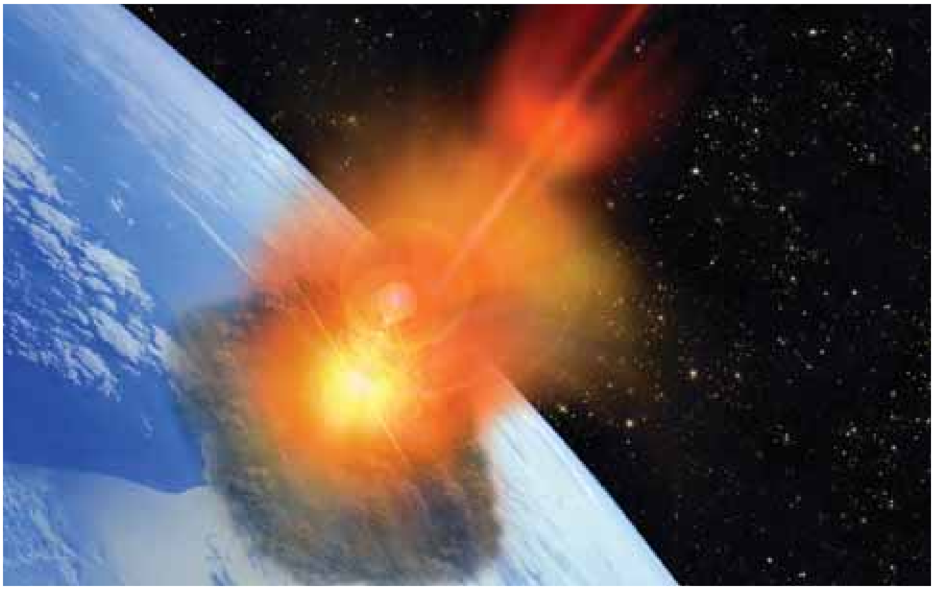


Figure 11.13 About 65 million years ago, a massive meteorite struck what is now the Chicxulub region of Mexico. The resulting debris would have blocked out sunlight and could have disrupted climates for many years.

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°				

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.
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°.

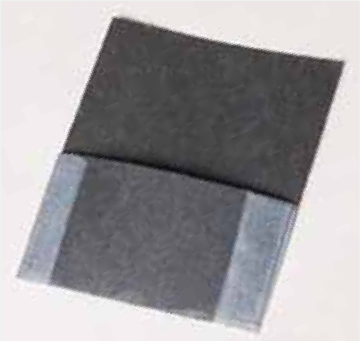


Figure A

Figure B

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

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

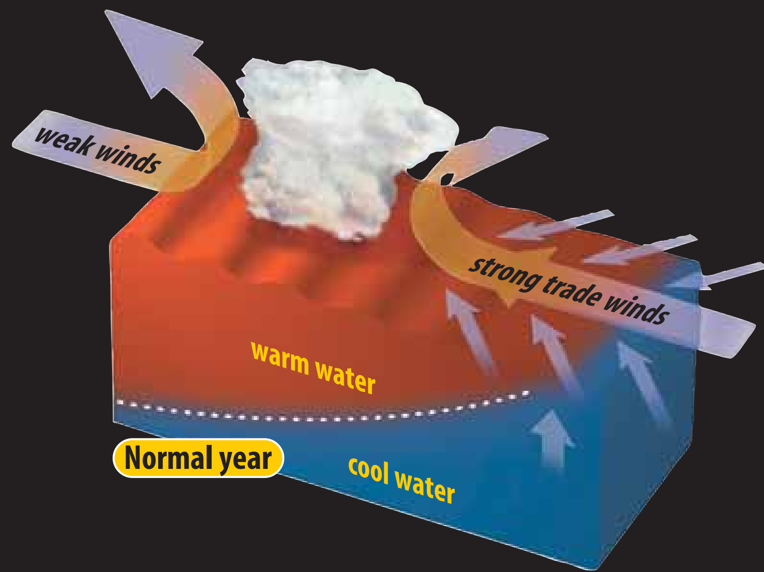
Conclude and Apply

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?

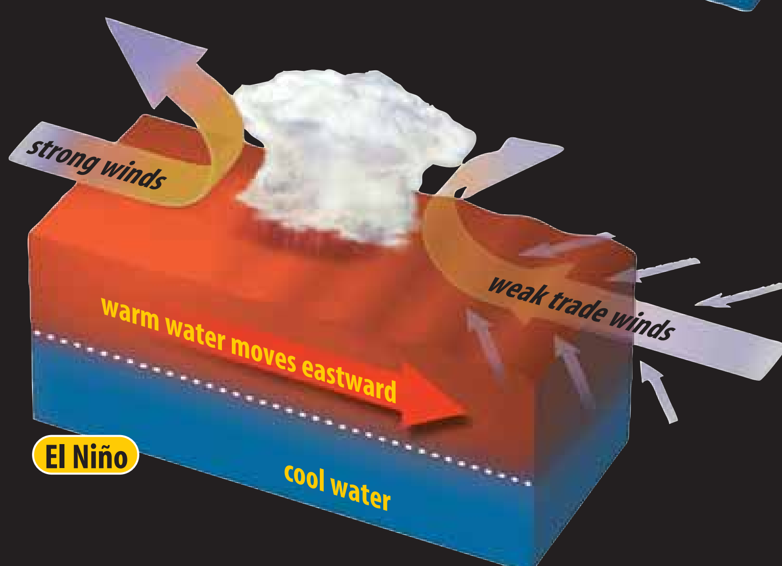
Visualizing El Niño and La Niña

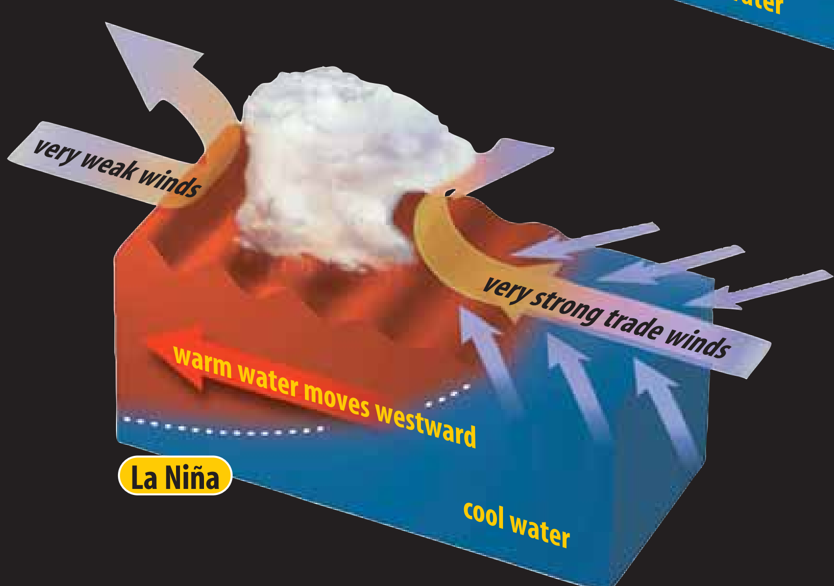
NATIONAL GEOGRAPHIC

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.

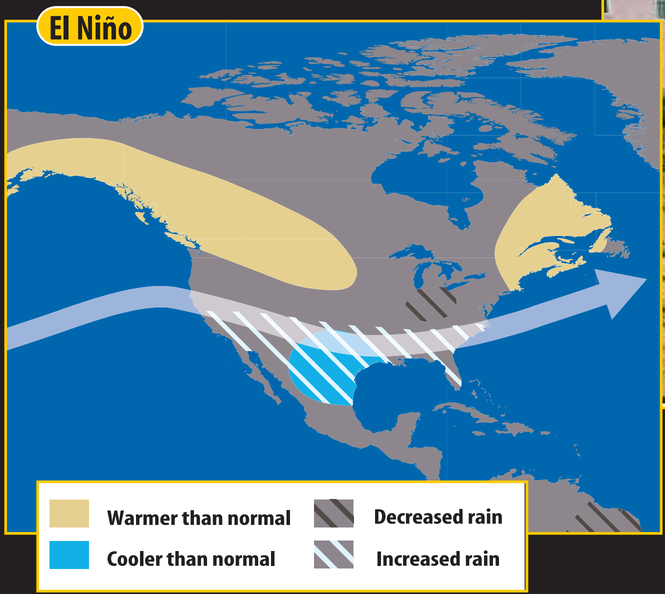


EL NIÑO During El Niño years, winds blowing west weaken and may even reverse. When this happens, warm waters in the western Pacific move eastward, preventing cold water from upwelling. This can alter global weather patterns and trigger changes in precipitation and temperature across much of North America.



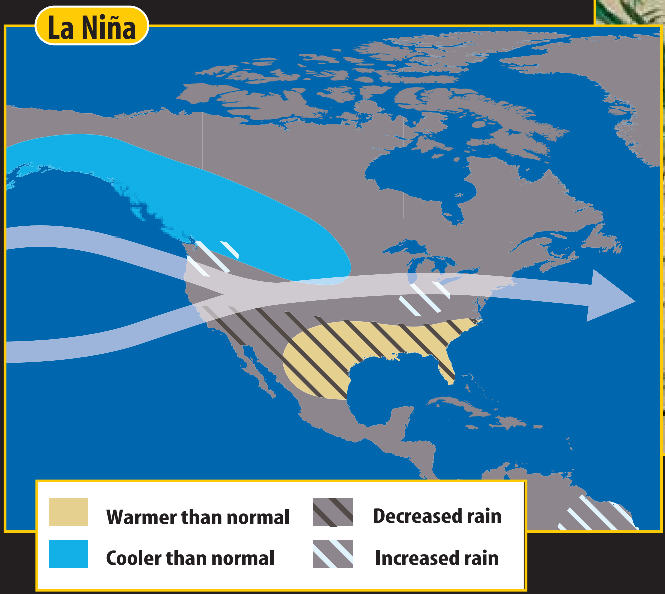


LA NIÑA During La Niña years, stronger-than-normal winds push warm Pacific waters farther west, toward Asia. Cold, deep-sea waters then well up strongly in the eastern Pacific, bringing cooler temperatures to northwestern North America.



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.



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.

Crater Lake

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.

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.

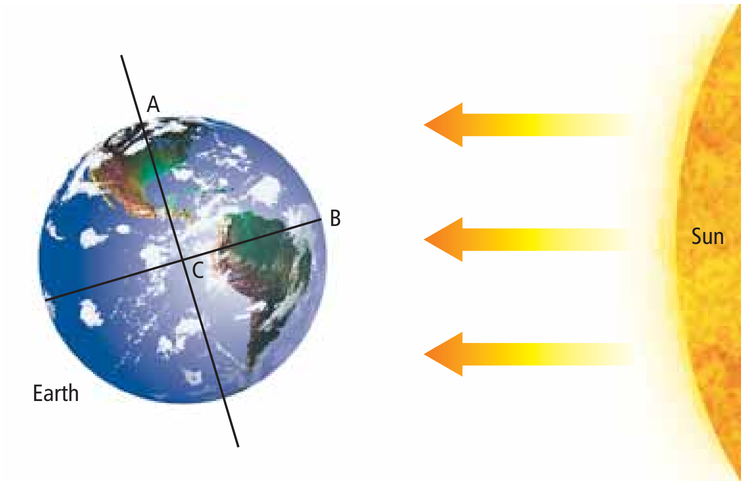
Catastrophic events such as volcanic eruptions do not occur on a human schedule and, very often, not even on a human timescale. There may be hundreds, or thousands of years between such events. As philosopher and writer William Durant once stated, "civilization exists by geological consent—subject to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

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?

11.2 Human Activity and Climate Change

Climate change refers to changes in long-term weather patterns in certain regions. Global warming, an increase in Earth's average global temperature, is one aspect of climate change. The current increase in global temperature is caused by an increase in greenhouse gas emissions, especially carbon dioxide, from the burning of fossil fuels and other human activities. Various regions of Earth are expected to undergo changes in temperature, precipitation patterns, and the amount of ice. Climate change is expected to affect society, economies, and the environment.

Words to Know

climate change
enhanced greenhouse effect
general circulation models (GCMs)
global warming
global warming potential (GWP)
permafrost
precautionary principle

The amount of Arctic sea ice is shrinking by 2 percent to 3 percent every decade. The average sea level is rising at about 3 mm per year. Since the 1970s, the average global temperature has risen by about 0.55°C. Few people doubt that Earth is undergoing a change in climate. But are these climate observations related? And if so, how? What are the natural processes that influence climate and what role do humans play? In this section, you will investigate possible answers to these questions.

Global Warming

The term "climate change" can be misleading because it suggests that the entire climate of the planet changes all at once. Instead, **climate change** refers to changes in long-term weather patterns in certain regions, such as regions of the northern hemisphere. These changes affect the redistribution of thermal energy around Earth.

One aspect of climate is temperature. Paleoclimatologists have evidence that Earth has undergone many cycles of cooling and warming (Figure 11.14). Several ice ages have occurred in the past 1 million years alone. Over the past century, in particular, scientists have noted a definite warming trend (Figure 11.15 on the next page).

The increase in global average temperature is known as **global warming**. Average global temperature can be measured in different ways, but it often refers to the combined average temperatures of ocean surface waters and air over land and oceans.

Did You Know?

Global warming is causing sea level to rise—but not only because of melting ice in Greenland, the Arctic, and Antarctica, as scientists once believed. The major reason for the increasing sea levels is the thermal expansion of seawater as temperatures increase.

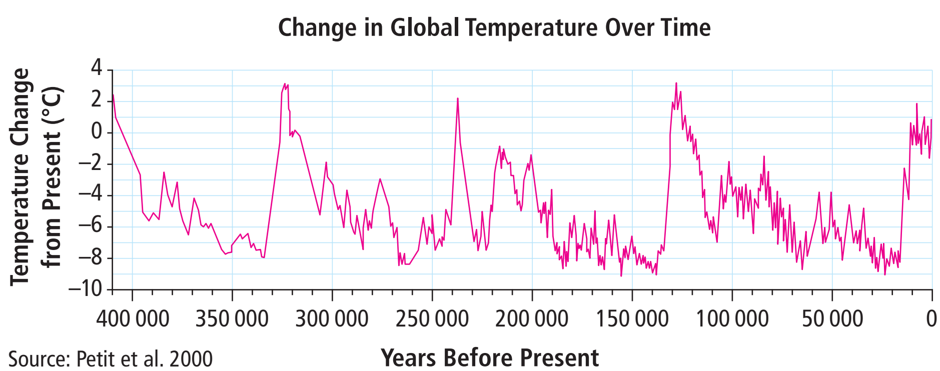


Figure 11.14 Estimated change in average global temperature at Earth's surface over the past 400 000 years

The average global temperature increased by about 0.74°C from 1906 to 2005. Predictions based on computer models suggest that the average global temperature could increase by 1°C to 2.5°C in the next 50 years and by as much as 6°C in the next 100 years. A few degrees may seem insignificant when viewed on a local scale. However, when Canada was covered with ice 21 000 years ago, the average global temperature was only 3-5°C cooler than today.

It is difficult to anticipate the effects of global warming on a system as large as Earth and its atmosphere. Most scientists agree that global warming will affect climates around the world. To what extent natural processes and human activities influence global warming has been the subject of much debate.

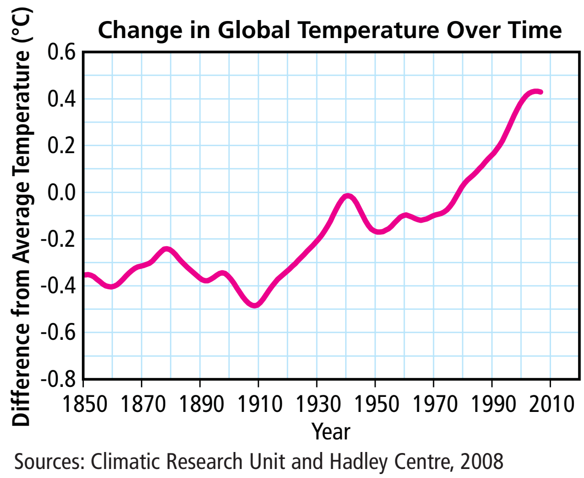


Figure 11.15 Change in global average temperature since 1850. Data from other research teams also show a trend of increasing temperatures.

11-2A What's All the Hot Air About CO_2? Find Out ACTIVITY

With the Industrial Revolution of the late 19th century came large factories and the first automobiles. The new technologies ran on fossil fuels, which release carbon dioxide when they burn. In this activity, you will track the carbon dioxide emissions from human activities since the Industrial Revolution. You will also track the amount of carbon dioxide in the atmosphere and the global temperature increase over time.

Carbon Dioxide and Average Global Temperature

Year	Industrial CO_2 Emissions (Gigatonnes)*	CO_2 Concentration in the Atmosphere (parts per million per volume)	Temperature Increase Since 1861 (°C)
1861	0.67	285	0.00
1880	1.15	292	0.00
1900	2.63	298	0.05
1920	3.42	303	0.29
1940	4.95	307	0.46
1960	9.98	318	0.35
1980	20.72	340	0.41
2000	23.42	365	0.63

Source: Carbon Dioxide Information Analysis Center (CDIAC)
* 1 gigatonne = 1 billion tonnes

Materials

- graph paper
- coloured pencils or pens

What to Do

1. Use the data from the table to make the following three line graphs. Draw a best-fit line for each graph.
   (a) Year versus Industrial CO_2 Emissions
   (b) Year versus CO_2 Concentration in the Atmosphere
   (c) Year versus Temperature Increase Since 1861
2. Using a different colour, extend each of the line graphs to 2020. This technique is known as extrapolating the data.

What Did You Find Out?

1. Describe the shape of each of graph.
2. Describe the trends since 1861 for each of the following:
   (a) industrial CO_2 emissions
   (b) CO_2 concentration in the atmosphere
   (c) average global temperature increase
3. What connections can you make among the graphs?
4. What might affect the accuracy of the extrapolated data?

The Enhanced Greenhouse Effect

Did You Know?

In 2003, people in Europe endured what was very likely the hottest summer in the region since 1500.

The **enhanced greenhouse effect** is the increased capacity of the atmosphere to absorb and emit thermal energy because of an increase in greenhouse gases. The scientific community is concerned about the role of human activities in the enhanced greenhouse effect. Other than water vapour, the principal gases in the atmosphere are nitrogen (78 percent) and oxygen (21 percent). The remaining percentage is made up of trace gases, which occur in very small concentrations, including certain greenhouse gases.

Scientists have identified several important greenhouse gases produced by human activities and the gases' global warming potentials (Table 11.1). **Global warming potential (GWP)** describes the ability of a substance to warm the atmosphere by absorbing and emitting thermal energy. CO_2 is assigned a GWP of 1. The GWP of every other greenhouse gas expresses the warming ability of that gas compared to the warming ability of CO_2 over the same timeframe. Nitrous oxide, for example, has about 298 times the warming ability of CO_2 over 100 years.

Although Figure 11.16 shows water vapour is an important greenhouse gas, it is not included in the table because human activities have very little direct effect on the amount of water vapour in the atmosphere. Ozone is not included in the table because it is continually broken down and reformed in the atmosphere, and so it is very difficult to determine its GWP.

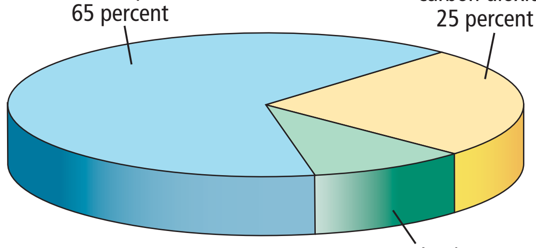


Figure 11.16 The approximate contribution of greenhouse gases to the greenhouse effect

Table 11.1 Greenhouse Gases and Global Warming Potential

Greenhouse Gas	Chemical Formula	Atmospheric Lifetime (years)	Source from Human Activity	Global Warming Potential (GWP)
carbon dioxide	CO_2	variable	• combustion of fossil fuels • deforestation	1
methane	CH_4	about 12	• processing of fossil fuels • livestock agriculture • waste dumps • rice paddies	25
nitrous oxide	N_2O	114	• production of chemical fertilizers • burning waste • industrial processes	298
chlorofluorocarbons (CFCs)	various	45	• liquid coolants • refrigeration • air conditioning	4750–5310

Source: Intergovernmental Panel on Climate Change 2007

Carbon dioxide

Before the 19th century, levels of CO_2 in the atmosphere remained in balance because of the carbon cycle. The start of the increase in CO_2 levels has been linked to the Industrial Revolution. The Industrial Revolution was so named because it marked explosive growth of industry, manufacturing, and transportation. With this expansion came an increase in the use of fossil fuels. Fossil fuels, such as coal, oil, and gas, form when the remains of ancient organisms are compressed. Fossil fuels contain large amounts of carbon, which is released when the fuels are burned (Figure 11.17). Fossil fuel combustion is the greatest carbon source resulting from human activity.

Deforestation also converts major carbon sinks—forests—into carbon sources. This adds to the amount of CO_2 going into the atmosphere.

Many people are making an effort to reduce CO_2 emissions by reducing their energy use and purchasing electric energy from wind farms and other alternative energy sources. Another possible strategy is to plant more trees in order to remove CO_2 from the atmosphere. A number of countries have tree planting projects to expand forested areas.

Figure 11.17 Idling automobiles produce greenhouse gases and air pollution that directly affects human health.

internet connect

A carbon offset is an emission reduction credit that people buy to help make up for their greenhouse gas emissions. Organizations that work to reduce CO_2 emissions sell carbon offsets. A wind farm, for example, might sell carbon offsets to a touring musical group to help make up for the greenhouse gas emissions produced by air travel. Find out more about carbon offsets. Begin your search at **www.bcscience10.ca.**

Methane

Methane (CH_4) is a gas that is very efficient at absorbing and emitting thermal energy. Although it is less abundant than CO_2 and water vapour, CH_4 is 25 times more powerful than CO_2 at absorbing and emitting the heat radiating from Earth's surface. In oxygen-free environments, bacteria break down waste materials, releasing CH_4. A major source of CH_4 is decomposing garbage in landfills. One solution is to collect and burn the CH_4 for fuel, although this process releases CO_2.

Other sources of CH_4 are also important. CH_4 is released during the process of animal digestion (Figure 11.18). Like natural wetlands, rice paddies are a source of CH_4. In northern regions, when frozen swampland (muskeg) thaws, it releases CH_4. In addition, extracting, producing, and burning fossil fuels can release CH_4. Since 1750, the amount of CH_4 in the atmosphere has increased more than 150 percent. The increase is thought to be related to rapid growth in the human population since that time.

Figure 11.18 Livestock produce 18 percent of the total amount of the methane in the atmosphere.

Nitrous oxide

Although present in small amounts, nitrous oxide (N_2O or dinitrogen oxide) is the third-largest contributor to the enhanced greenhouse effect. N_2O is formed from biological processes of bacteria in ocean water, soil, and manure. Humans produce large amounts of N_2O from the use of nitrogen-rich chemical fertilizers in farming and the improper disposal of human and animal waste. Automobile exhausts also release N_2O.

Ozone

Ozone (O_3) is a molecule that occurs naturally in the stratosphere at altitudes between 10 km and 50 km. At this level, it forms the ozone layer, which filters out harmful ultraviolet radiation from the Sun. However, close to Earth's surface, O_3 occurs naturally in only trace amounts. And yet, over the last few decades, scientists have recorded a steady climb in the amount of surface O_3. In the upper Fraser Valley of British Columbia, for example, high surface levels of O_3 have been affecting the quality and quantity of some crops grown.

O_3 results from chemical reactions between sunlight and air pollution from the burning of fossil fuels, mainly in cars and trucks. Much of the ozone-producing pollution in the Fraser Valley comes from traffic in the Greater Vancouver Regional District. The pollution includes hydrocarbons and nitrogen oxides. As the global use of fossil fuels increases, so does the quantity of surface ozone.

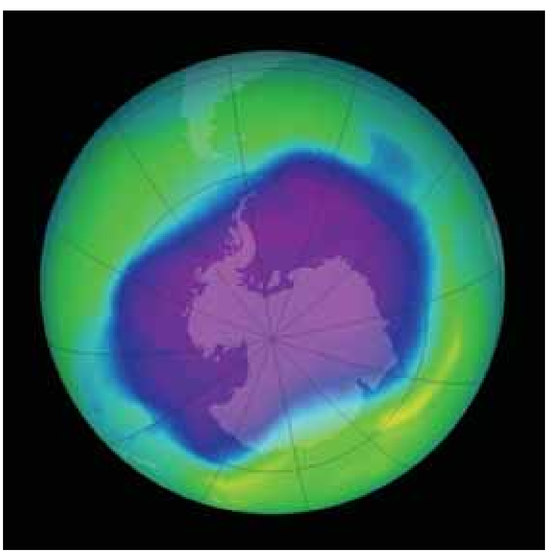


Figure 11.19 A satellite image of the ozone hole over the Antarctic observed September 21–30, 2006. Although ozone-depleting CFCs have been banned in most developed nations, these chemicals last a long time in the atmosphere. It may take decades before the full effect of reducing CFCs is seen.

Chlorofluorocarbons

Chlorofluorocarbons (CFCs) are a group of human-made greenhouse gases with powerful global warming potential. CFCs are made up of chlorine, fluorine, and carbon. The main use of CFCs is as coolants for refrigerators and air conditioners.

Many nations have signed an agreement called the Montreal Protocol to ban the use of CFCs. In addition to being greenhouse gases, CFCs are thought to be the main cause of the depletion of Earth's protective ozone layer (Figure 11.19). In the 1970s, scientists discovered that the CFCs commonly used in aerosol spray cans (such as hair spray and spray paint cans), air conditioners, refrigerators, and even fire extinguishers were getting into the atmosphere in large quantities. When CFCs reach the atmosphere, the chlorine atoms are released and break apart O_3 molecules. Not only has stratospheric ozone been thinning in many places, but scientists also think that CFCs are the main reason for the massive hole in the ozone layer over Antarctica. The ozone hole could potentially increase global warming by allowing more solar radiation to reach Earth's surface.

Albedo and Climate

The albedo at Earth's surface affects the amount of solar radiation that a region receives. As Figure 11.20 shows, different materials have very different albedos. Changes in albedo at Earth's surface could affect the climate in various ways. Figure 11.21 shows the variation in albedo around Earth. If large stretches of Arctic sea ice were to melt, for example, the albedo in the Arctic would drop. This region would then absorb more solar radiation. Would this cause more sea ice to melt? Or would some other consequence result? It is difficult to predict what might happen.

Evidence does suggest that the low albedo of some types of forests plays an important role in regulating climates. Boreal forests have low albedo and so they absorb solar radiation. Deforestation increases albedo, causing more solar radiation to be reflected back into space. Forests are an important carbon sink, but do they affect the average global temperature in other ways? Scientists try to answer questions like this using a variety of methods.

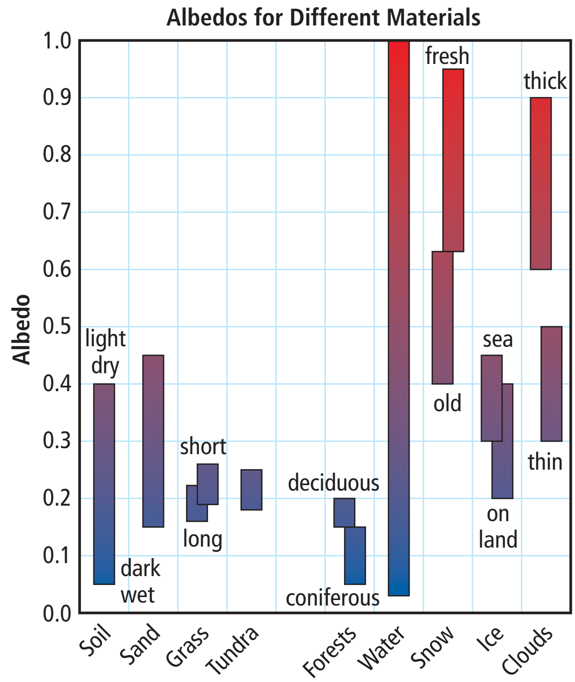


Figure 11.20 Albedos for different surfaces vary widely

Reading Check

1. What is the difference between the natural greenhouse effect and the enhanced greenhouse effect?
2. What does GWP describe?
3. List three greenhouse gases that are released when fossil fuels are burned.
4. Name a greenhouse gas that does not occur naturally.
5. Which has a higher albedo: sea ice or soil?

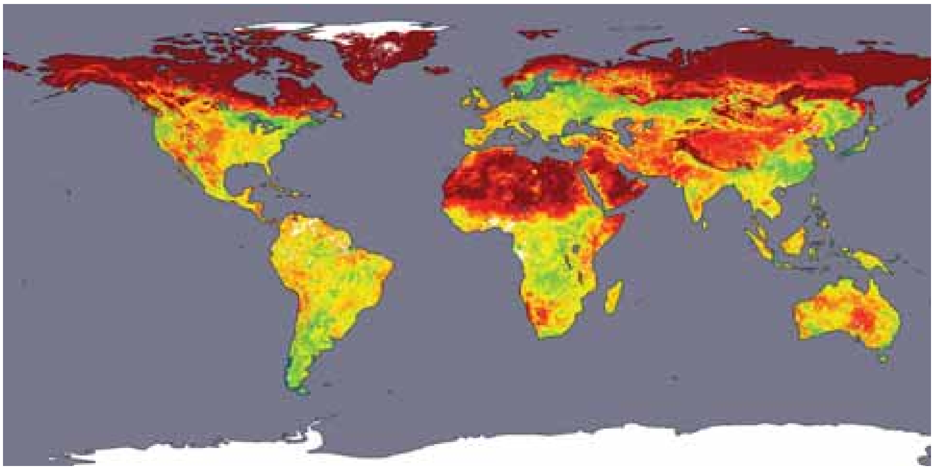


Figure 11.21 A satellite image of global albedo. Red areas have the highest albedos, yellow and green areas have intermediate albedos, and blue and purple areas have the lowest albedos. No data are shown for the white areas and oceans.

The Role of Science in Understanding Climate Change

Suggested Activity

Find Out Activity 11-2B on page 497

Research and analysis of climate data require cooperation and commitment from people around the world. It would be extremely difficult and inaccurate to base conclusions about global climate change on single observations made at specific locations. To increase reliability, many measurements must be taken. By compiling multiple measurements from around the world and over time, researchers have noticed trends. These trends can be analyzed by using computer models.

General circulation models (GCMs) are computer models designed to study climate. GCMs take into account multiple factors, such as changes in greenhouse gas concentrations, albedo, ocean currents, winds, and surface temperatures. GCMs are used for weather forecasting, climate analysis, and climate change predictions. The models are very sophisticated and factor in the properties of fluids, chemical reactions, and how organisms affect their environment. The goal of scientists who use GCMs is to better understand the complex nature of climate and the effects of human activities on it (Figure 11.22).

As technology and scientific understanding improve through better satellite analysis, more observation tools in the ocean, and increased knowledge among researchers, the accuracy of the computer models increases. Computer models have successfully reproduced the climate of the past 100 years, and simulations have also matched temperature changes over the past 1000 years. Currently, GCMs provide the best predictions of future conditions of our atmosphere and global climate.

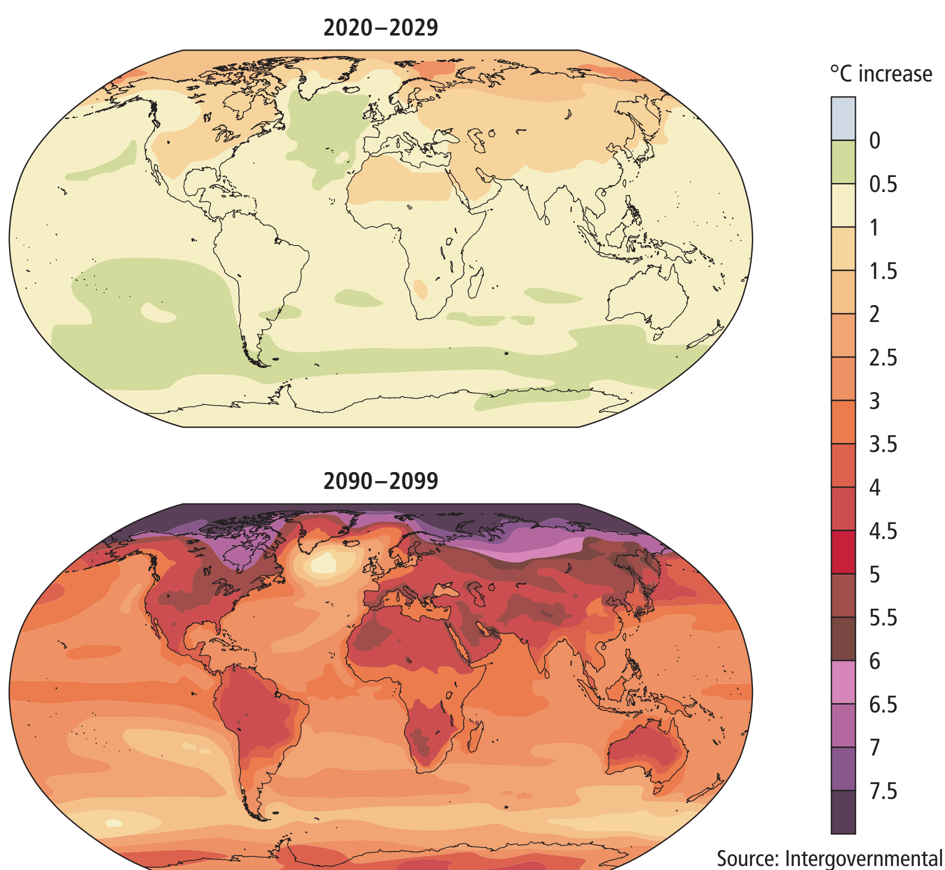


Figure 11.22 These maps of projected global temperatures were based on predictions from GCMs. The maps represent a worst-case scenario of increasing greenhouse gas emissions.

Source: Intergovernmental Panel on Climate Change

The Role of International Cooperation in Dealing with Climate Change

Paleoclimatologists think that Earth's climate has been relatively stable for thousands of years. Only in your parents' generation and in your own have major climate changes thought to be caused by human activities been observed. To address the global concern about climate change and global warming, the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) formed the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established in 1988 and includes experts from about 130 countries around the world. The goal of the IPCC is to assess evidence of the human influence on climate change and possible ways to respond. The IPCC looks at the social and economic issues related to climate change as well as the environmental issues.

In addition, the United Nations has set up an international environmental treaty called the United Nations Framework Convention on Climate Change (UNFCCC). The treaty is designed to encourage countries around the word to reduce greenhouse gas emissions in order to reduce the rate of global warming (Figure 11.23). The treaty does not set binding rules. Instead, countries meet to determine what the greenhouse gas emission limits should be.

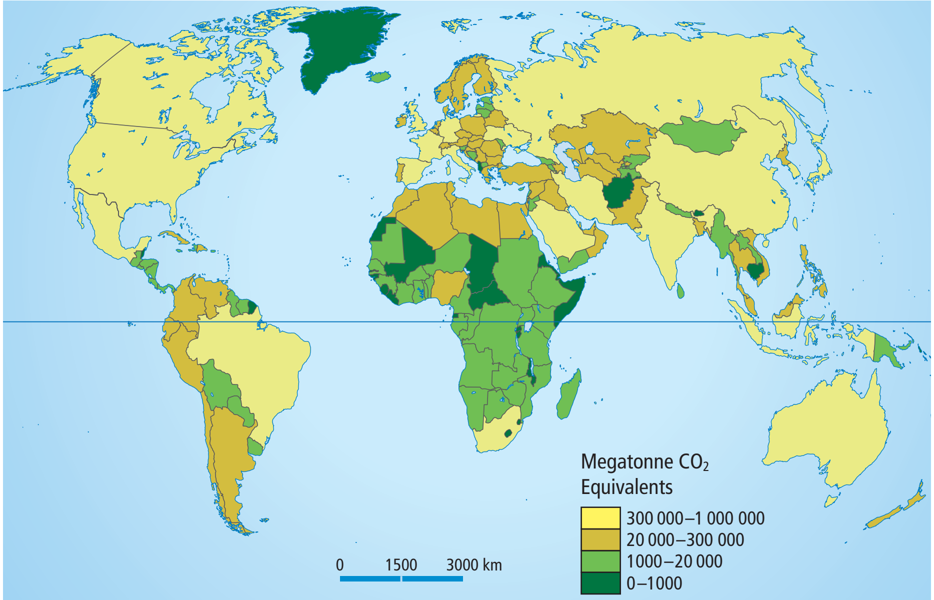


Figure 11.23 The total emissions of greenhouse gases for various countries. The developed nations of the world contribute the most greenhouse gas emissions.

Source: Adapted from Globalis 2003

Global Impacts of Climate Change

Current climate change models predict that temperatures will increase more in arctic regions than in equatorial regions and more on land than in the oceans. Some models predict a temperature rise of 6°C in northern regions and a sea level rise of almost 88 cm within the next 100 years. Predicting the exact effects of these changes on particular locations is very difficult. Figure 11.24 on the next page lists some potential global effects of climate change, assuming that greenhouse gas emissions continue to rise.

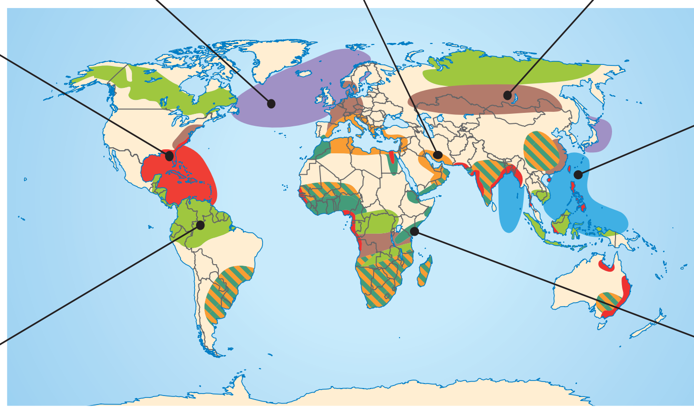


Figure 11.24 This map shows how climate change could potentially affect all nations of the world.

Impacts of Climate Change on Canada

As a country located in the northern hemisphere, where the effects of global warming could be most severe, Canada may be one of the most affected nations. Statistics Canada reports that, in some areas of the country, 22 out of 23 recent winters have had temperatures above normal. Surface temperatures have increased between 0.5°C and 1.5°C in parts of southern Canada, with the greatest warming occurring in the west. Temperatures have been rising in northern Canada as well, especially in the arctic regions. Areas of permafrost are melting. **Permafrost** is ground that usually remains frozen year-round. The ice cover in the Arctic Ocean is rapidly shrinking.

Climate change will affect weather patterns, such as winter and summer temperatures and the amount and location of rainfall. Satellite data have shown that the growing seasons are already becoming longer each year. Aspen trees in Alberta bloom a full 28 days sooner than they did a century ago. In the past decade, total precipitation over Canada has increased by 12 percent, with the greatest increase over Nunavut (25 percent to 45 percent).

Scientists suggest that, in future, we can expect heavier spring rains and longer heat waves in some parts of the country (Figure 11.25). These changes will affect biomes across Canada (Figure 11.26). Continuing changes in the patterns of precipitation will also affect the quantity and the quality of water available for people's homes, agriculture, and industrial uses, such as obtaining oil. One of the most important industries in Canada is the fisheries. Changes to the temperature, water quality, and currents in oceans, lakes, and streams could have devastating effects on fish populations.

Forestry is another important industry across Canada. An increase of CO_2 in the atmosphere might help the forests to grow. However, warmer temperatures will create better conditions for forest fires, for the insects that harm trees, and for a variety of different plants.

The general health of Canadians could also be affected by climate change. High summer temperatures would worsen the health effects of air pollution. Warm winters would allow disease-carrying insects to survive farther north than in the past. More violent storms that could interrupt power supplies and damage roads are also possible, making it difficult for hospitals and other essential services to function.

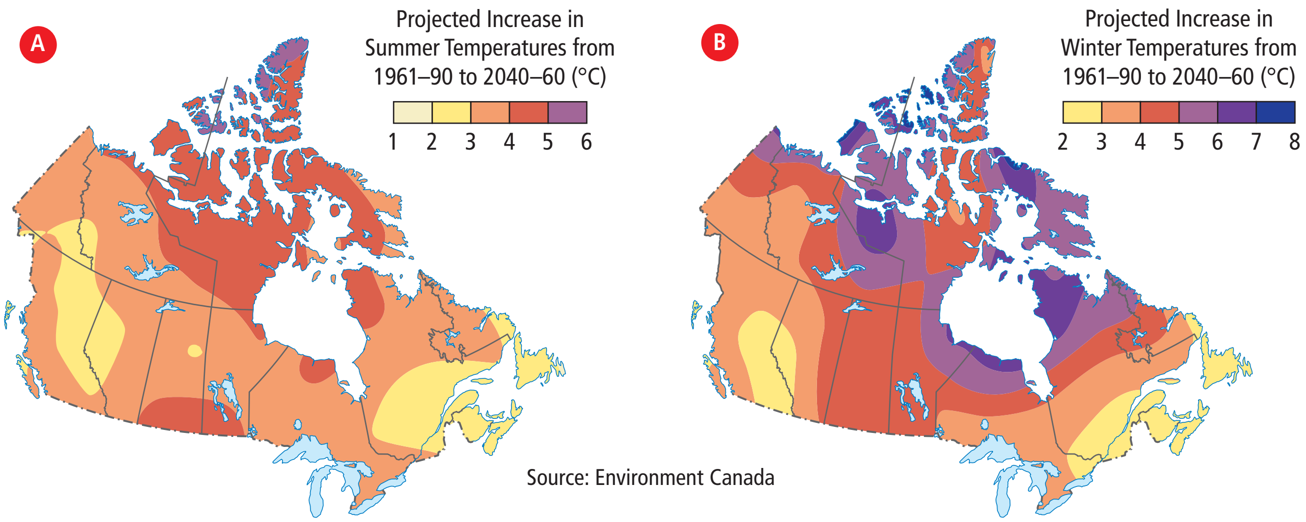


Figure 11.25 Projected temperature change for Canada in 2050, summer (A). Projected temperature change for Canada in 2050, winter (B). The maps are based on the Coupled Global Climate Model developed by Environment Canada.

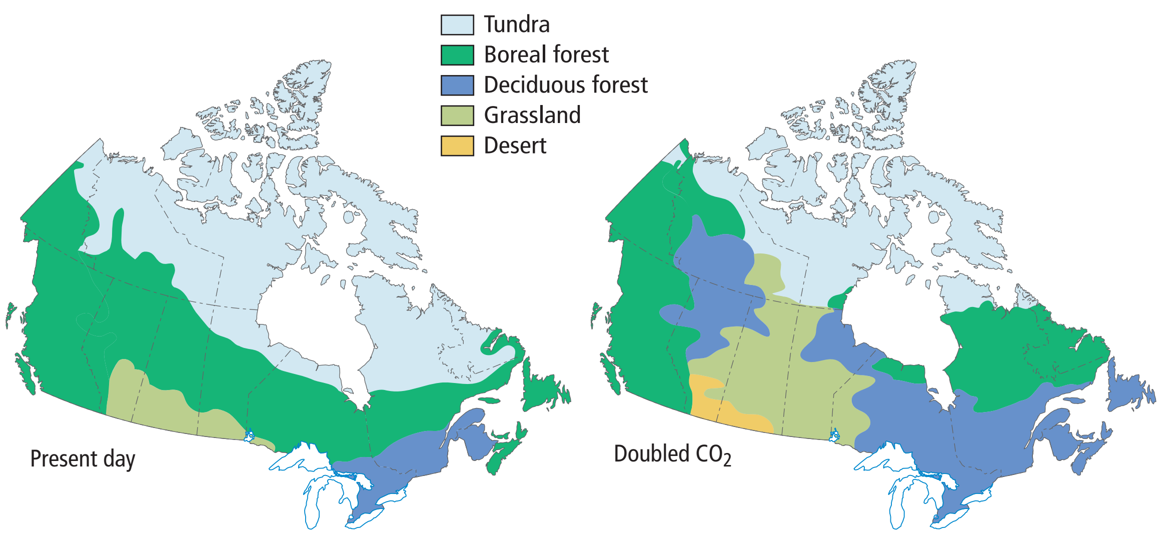


Figure 11.26 Changes projected for Canada's biomes if the concentration of CO_2 doubles from what it was before the Industrial Revolution.

Impacts of Climate Change on British Columbia

In future, most regions of British Columbia will be warmer. The amounts and effects of greenhouse gases on the global climate system will influence how great the temperature change will be. Figure 11.27 shows projections for increases in temperature.

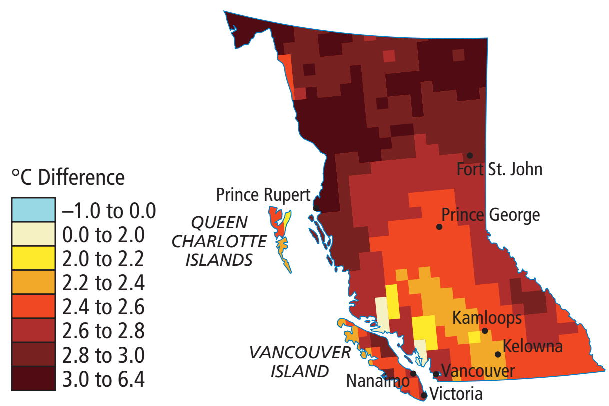
The effects of climate change and global warming on British Columbia may be significant. Some computer models suggest an almost 30 cm rise in the sea level along the northern coast of British Columbia over the next century. A rise in sea level would pose a serious flood threat to some coastal communities and low-lying areas as well as to port facilities and docks. In addition, a change in weather patterns could bring more rain to some areas and drought to others (Figure 11.28).

Freshwater glaciers are an important source of drinking water in British Columbia. These glaciers have been shrinking since the 1980s and will continue to shrink because of global warming (Figure 11.29 on the next page).

Table 11.2 on the next page summarizes some of the possible effects of climate change on the province.

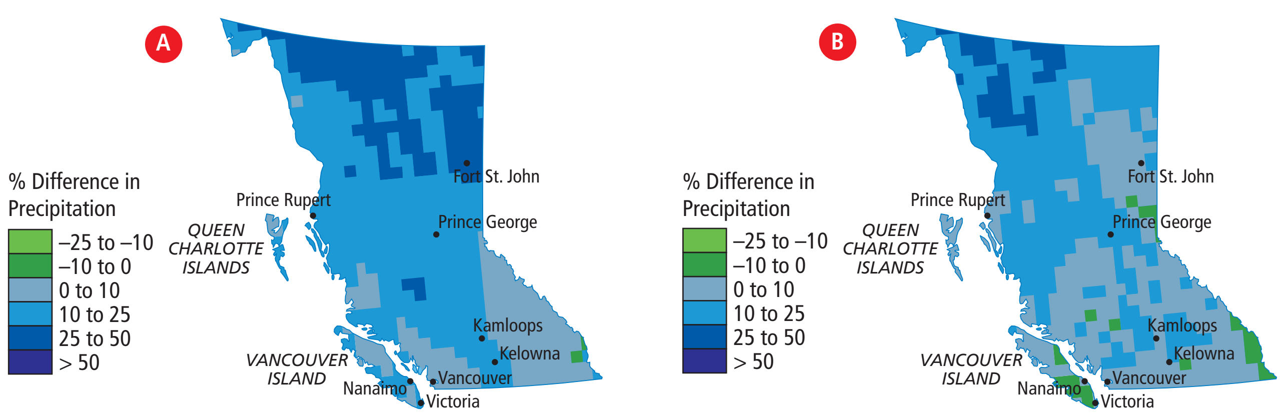
internet connect

What will the climate be like where you live in 20 years? In 100 years? Go to **www.bcscience10.ca** to link to online climate modelling programs.



Source: Adapted from Rodenhuis et al. 2007

Figure 11.27 The projected change in average annual temperatures in British Columbia for 2041–2070 from historical temperatures.



Source: Adapted from Rodenhuis et al. 2007

Figure 11.28 The projected change in precipitation in British Columbia for 2041–2070 from historical amounts. The projected changes for winter (A) and summer (B) precipitation are shown in separate maps.

Table 11.2 Predicted Effects of Climate Change on British Columbia

Segment Affected	Effects of Climate Change
Fisheries	• Changes in ocean life could occur; for example, warm water species, such as tuna and mackerel, may replace cold water species, such as salmon. • Salmon may migrate northwards to find colder water.
Forestry	• Northern regions will become warmer, extending the range of some tree species. • Droughts will affect many species of trees and favour the spread of grasslands. • Drought will increase the risk of fire in the forests. • Incidence of disease and insect infestations will increase.
Wetlands	• Current flood-prevention measures may not be able to contain floods along the coast and in interior British Columbia. • Ecosystems in wetlands, estuaries, and deltas will be affected by a rise in water levels.
Water	• A change in weather patterns will affect the supply and, therefore, the demand for water. • Spring thaws will arrive earlier, and droughts will happen more often and last longer. • Rising sea levels could mean saltwater flooding of low-lying farming areas.
Wildlife	• Changing temperatures will alter habitats, food supplies, and shelter for many species of wildlife. • An increase in the amount of CO_2 dissolved in the ocean will make ocean water more acidic, which could harm ocean life and even result in the loss of some species.

Figure 11.29A Helm Glacier in British Columbia (A)

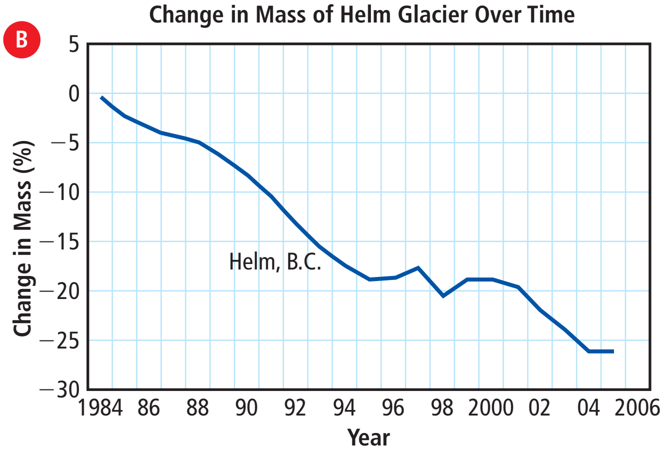


Figure 11.29B The mass of Helm Glacier has changed from year to year, and has decreased overall. The glacier loses more ice in summer than it gains in winter.

Reading Check

1. What is a general circulation model?
2. Why was the IPCC formed?
3. List a possible social impact of global climate change.
4. Describe one possible effect of global warming on Canadian biomes.
5. List three possible environmental effects of climate change on British Columbia.

Table 11.3 Likelihood Terminology used by the IPCC

Term	Probability of Event Occurring
Virtually certain	> 99 percent
Extremely likely	> 95 percent
Very likely	> 90 percent
Likely	> 66 percent
About as likely as not	33–66 percent
Unlikely	< 33 percent
Very unlikely	< 10 percent
Extremely unlikely	< 5 percent

Uncertainty and Decision

Predictions about climate change cannot be certain. For this reason, scientists use specific terms when discussing the likelihood of their predictions coming true. As shown in Table 11.3, the term "virtually certain" means that a prediction will probably be correct. The term "extremely unlikely" means that a prediction probably will not come true. Considering the likelihood of specific predictions about climate change can help people decide how to respond.

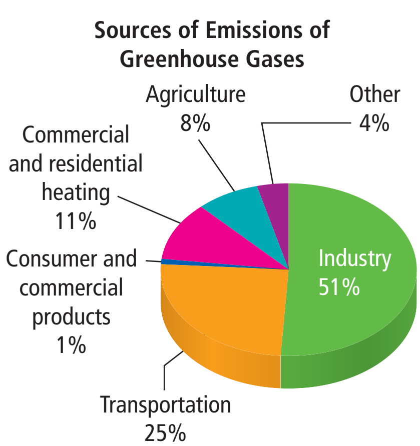
The response to climate change will affect society, the economy, and the environment. One of the greatest barriers to limiting greenhouse gas emissions is the cost. People in developed countries are concerned that the cost of implementing changes will be overwhelming. People in developing countries are reluctant to slow their economic growth. Figure 11.30 shows the amount of greenhouse gas emissions from a variety of sources in Canada. To reduce greenhouse gases from any one source, we would have to change the way we live. What changes could we make? Would these changes be worth it? For example, the manufacturing industry produces large amounts of greenhouse gases but we rely on manufactured goods such as clothing, electronics, and cars. Some people argue that it makes sense to buy manufactured goods that will last as long as possible, even if they cost more, and to charge a fee to companies for products that do not last very long.

One way to think about the response to climate change is to consider two extreme scenarios:

(1) Climate change will not greatly affect our lives or the environment.

(2) Climate change will cause drastic changes in weather patterns that will greatly affect our lives and the environment.

We cannot be sure which scenario will occur. One response would be not to act. Another response would be to make changes that might influence the course of climate change or help people to adapt to changing climates. What would be the consequences of not taking action if the first scenario is correct and climate change does not greatly affect people or the environment?



Source: Adapted from Environment Canada

Figure 11.30 Sources of emissions of greenhouse gases in Canada

The United Nations suggests that governments should use the precautionary principle to guide their responses to climate change. The **precautionary principle** is the principle that a lack of complete scientific certainty should not be used as a reason to postpone cost-effective measures to prevent serious environmental damage.

An Action Plan for the Global Community

Our ability to deal with climate change will not come from the actions of one individual, one corporation, or even one country. Decreasing overall greenhouse gas emissions will require global cooperation.

In a recent report on climate change, the IPCC suggests that major polluters should be taxed based on the type, impact, or amount of greenhouse gas emissions. The report adds that employing different, healthier strategies could eventually enhance economic growth.

Table 11.4 on the next page shows the key components of the IPCC action plan for addressing global warming and climate change.

Suggested Activity

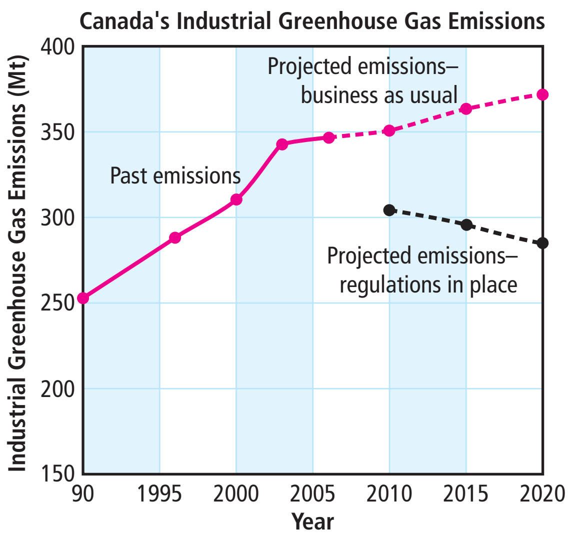
Think About It 11-2C on pages 498–499

Canada's Response to Climate Change

Industry and transportation account for about 75 percent of the total greenhouse gases produced by Canada (Figure 11.31). These sectors are the focus of plans that the Canadian government has implemented to reduce our greenhouse gases:

- reducing greenhouse gas emissions from cars and trucks
- introducing policies requiring major greenhouse gas-producing industries to reduce emissions
- increasing the types of energy-efficient products available
- setting guidelines for improving indoor air quality

The use of consumer goods accounts for about 12 percent of all greenhouse gas emissions in Canada. Switching to energy-efficient lights, dishwashers, refrigerators, and air conditioners would lower the per person emissions of greenhouse gases. In addition, green building codes outline how to construct new energy-efficient buildings and update existing buildings to improve their energy efficiency.



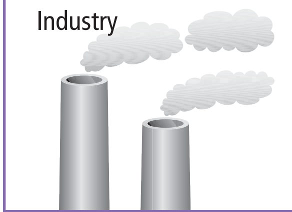
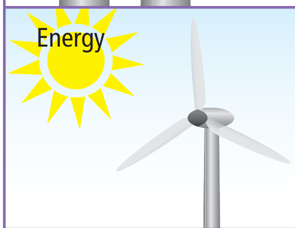
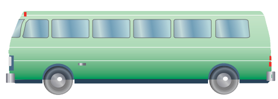
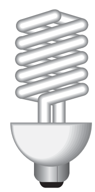
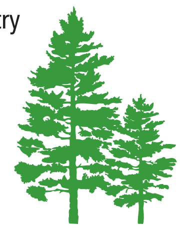
Sources: The Pembina Institute and Environment Canada

Figure 11.31 Two scenarios for Canada's projected greenhouse gas emissions: if business continues as usual, or if emissions are reduced to meet specific targets

Explore More

Imagine spraying perfume into the air and then trying to put the perfume back in the bottle. This is what it would be like trying to capture CO_2 from the atmosphere once it has been released during industrial processes. However, new techniques are being used to capture CO_2 at the source and store the gas underground. Known as carbon capture and storage, the technologies prevent large amounts of CO_2 from entering the atmosphere. Find out more about carbon capture and storage and Canada's leading role in developing these technologies. Begin your search at **www.bcscience10.ca.**

Table 11.4 Strategies for Addressing Climate Change

Sector	Strategy for Reduction of Greenhouse Gas Emission
Industry 	• Switch to more energy-efficient electric equipment, heat, and power sources. • Increase the amount of recycling. • Monitor and control non-CO_2 greenhouse gas emissions.
Energy 	• Develop more efficient ways of producing energy. • Research renewable energy sources (hydroelectric, wind, solar, biofuels, and geothermal power). • Store CO_2 underground after it is removed from natural gas.
Transportation 	• Improve fuel efficiency for vehicles. • Introduce hybrid vehicles, which do not rely on fossil fuels alone. • Introduce alternative fuels, such as hydrogen or biofuels. • Shift from road transport to rail. • Improve and promote the use of public transportation.
Construction 	• Switch to high-efficiency lighting. • Use energy-efficient appliances, heating systems, and air conditioning systems. • Improve insulation of buildings. • Use solar and geothermal heating and cooling.
Agriculture 	• Improve fertilizer (nitrogen) use. • Specify crops used for energy purposes (i.e., corn, soybeans). • Increase use of soil carbon storage. • Improve management of livestock waste. • Improve techniques for cultivating rice crops. • Reclaim and reuse lands damaged by agriculture.
Forestry 	• Promote worldwide planting of trees and reforestation. • Encourage efficient use of forest products for energy. • Encourage better forest-management strategies.
Waste management 	• Promote recycling, composting, and minimizing waste. • Encourage the burning of waste for energy recovery. • Recover methane gas from decomposition in garbage dumps and landfills.

11-2B Calculating Carbon Emissions

Find Out ACTIVITY

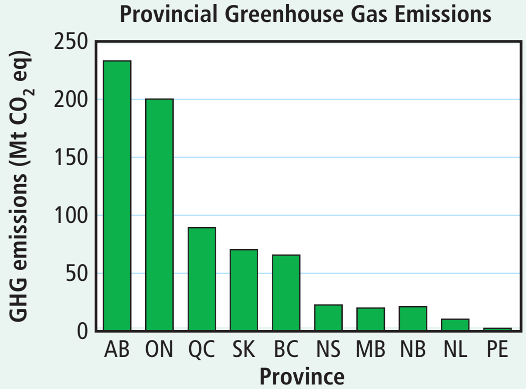
Everyone adds some CO_2 to the atmosphere, but the more fossil fuels we use, the more CO_2 we produce. What is British Columbia's contribution? In this activity, you will calculate, compare, and contrast the per capita (per person) carbon dioxide emissions for each province in Canada.

Materials

- calculator

What to Do

1. Examine the bar graph and table shown below. The graph shows the total amount of greenhouse gas emissions for each province of Canada. The table gives the population of each province.



Source: Environment Canada 2005

2. Copy the table into your notebook. Read the graph and fill in the CO_2 emission values in the third column of the table in your notebook. Amounts are given in megatonnes of equivalent CO_2.
(**HInt:** 1 Mt = 1 000 000 tonnes)
3. Before making any calculations, predict which provinces you think will have the greatest per capita CO_2 emissions.
4. Divide the total CO_2 emission values by the population numbers to calculate the per capita CO_2 emissions.

What Did you Find Out?

1. Did your calculated results match your prediction? Explain.
2. (a) Which three provinces have the highest CO_2 emission values?
   (b) Why do you think these three might have the highest values?
3. Some regions of Canada are especially rich in fossil fuels. Obtaining and processing fossil fuels produces greenhouse gases. How might the distribution of fossil fuel sources in Canada relate to the per capita CO_2 emission values that you calculated?

Canadian Population

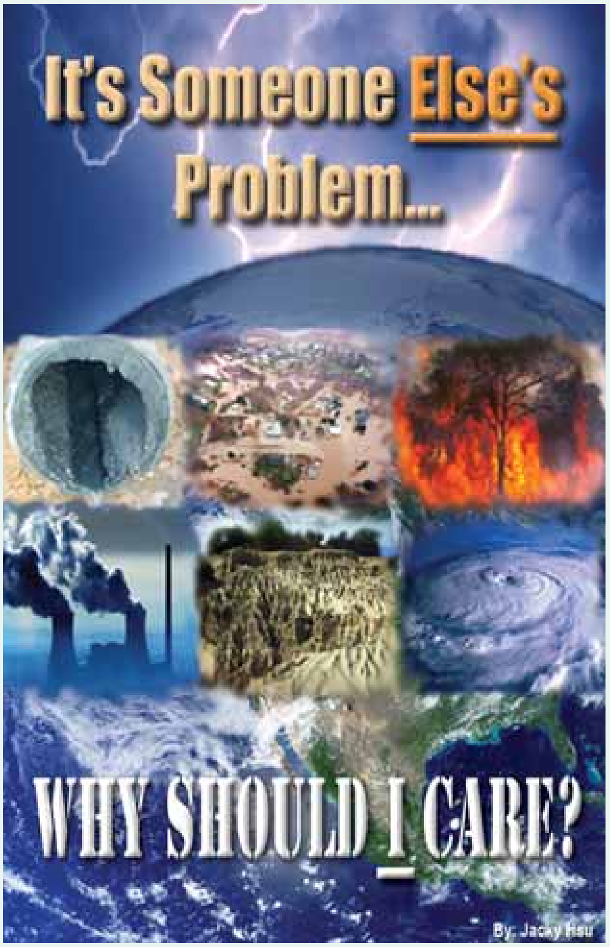
Region	Population, 2006	CO_2 Emissions (millions of tonnes)	CO_2 Emissions Per Capita (tonnes)
Canada	31 612 897	739	
Ontario	12 160 282		
Quebec	7 546 131		
British Columbia	4 113 487		
Alberta	3 290 350		
Manitoba	1 148 401		
Saskatchewan	968 157		
Nova Scotia	913 462		
New Brunswick	729 997		
Newfoundland and Labrador	505 469		
Prince Edward Island	135 851		

11-2C Pondering Posters

The terms "climate change" and "global warming" can evoke emotional debate about the nature and extent of a looming international crisis. Each poster shown here was created by one or more high school students as a project on climate change and global warming. In this activity, you will analyze the students' responses to each term.

What to Do

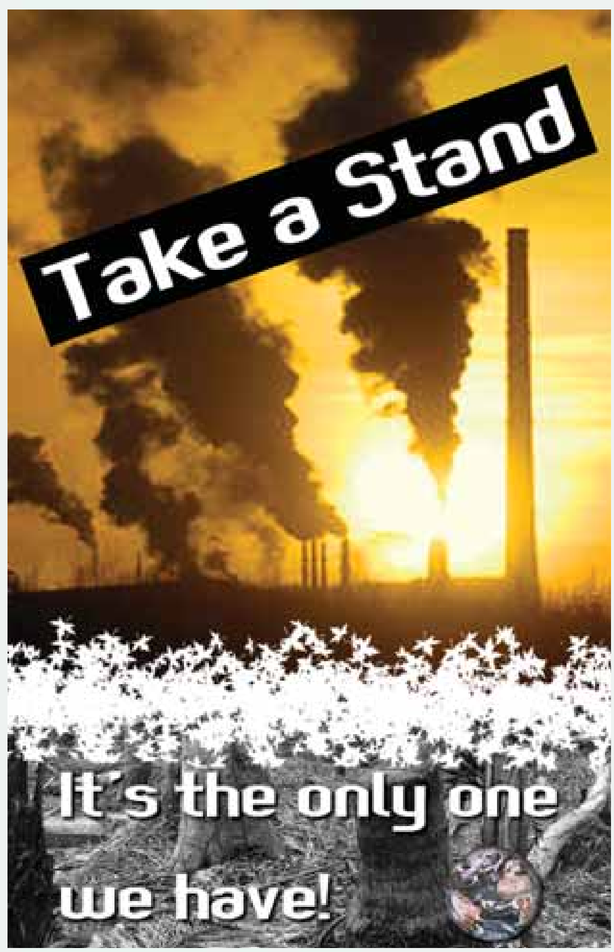
1. Look at the students' posters. For each one, write down the title and write a brief paragraph explaining your interpretation of the poster. Address the following in your interpretation:
    - the artists' personal responses to the issue
    - an explanation of any symbolism used
    - the scientific basis for the information presented
    - the clarity and impact of the statement being made
2. After you have finished, share your interpretations of the posters with your classmates. Explain whether you feel that each poster conveyed the students' message well or whether the message was vague.



Posters courtesy of Mr. Pahal's Fraser Heights Secondary Information Technology class


This is a Global Warning
We Are Being Cooked
Our Power?
2007

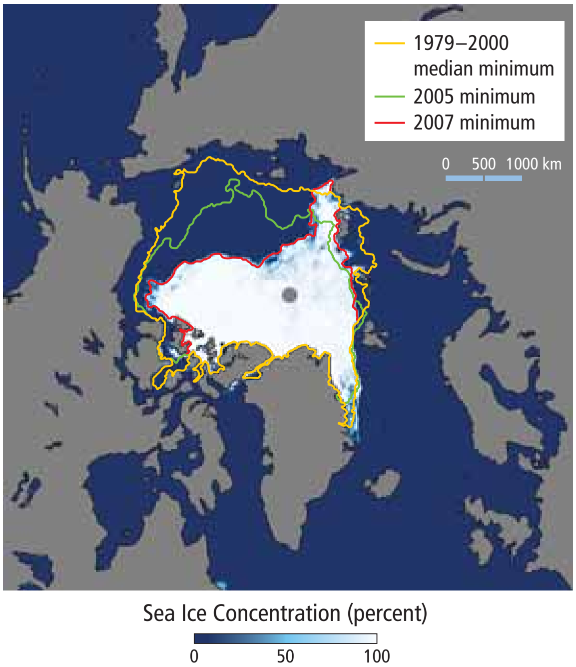

We could all go up
in smoke.


Take a Stand
It's the only one
we have!

Science Watch

Sea Ice Melt in the Arctic

The Arctic is warming about twice as fast as most of the world. One of the most visible effects of Arctic warming is melting sea ice, which brings both problems and opportunities. On September 15, 2007 the amount of Arctic sea ice reached a record low. The satellite image below shows the extent of Arctic sea ice on that day compared to the maximum amount of sea ice and minimum amount of sea ice recorded in 2005. The average amount of sea ice from 1979 to 2000 is also shown. White areas of the image show high concentrations of ice, turquoise areas are broken sea ice, and dark blue areas are open water.



Sea ice has a regulating effect on ocean water temperatures. Sea ice also keeps temperatures cool at Earth's surface by reflecting much of the solar radiation that reaches it. Without large sheets of ice, this cooling effect would be lost. Rapidly melting ice could also affect the balance of salt water to fresh water and alter ocean currents and weather patterns.

Arctic sea ice provides habitat for a rich ecosystem. Animals that rely on the sea ice include Arctic foxes, polar bears, seals, and walruses. Algae attached to the bottom of sea ice is food for marine animals such as beluga, narwhal, char, and cod. Biologists estimate that, by 2050, the polar bear population could drop by $\frac{2}{3}$ due to the shrinking amount of sea ice. In contrast, there has been an influx of animals to the Arctic that are uncommonly seen in the far north, such as robins, finches, and dolphins.

For the people who live in the Arctic, the loss of the sea ice could mean the loss of a traditional way of life. For thousands of years, the Inuit have travelled across the Arctic sea ice to hunt and fish. The sea ice is becoming increasingly unstable, however, and too dangerous to travel across.

The rapid loss of the Arctic sea ice has also marked a turning point in the history of ocean travel in the North. For as long as people have explored global trade routes, they have sought a waterway across "the top of the world." Known as the Northwest Passage, this route directly connects the Atlantic Ocean and Pacific Ocean, although, historically, ships have not been able to push through the barrier of Arctic sea ice. In 2007, the sea ice shrank enough that a ship could travel through. The direct route from ocean to ocean cuts travel by thousands of kilometres, saving time and reducing production of greenhouse gases.

Questions

1. Describe two ways in which the loss of Arctic sea ice could affect climate.
2. Identify the importance of sea ice in:
   (a) Arctic ecosystems
   (b) the traditional Inuit lifestyle
3. What are some possible results of increasing travel through the Arctic?

Check Your Understanding

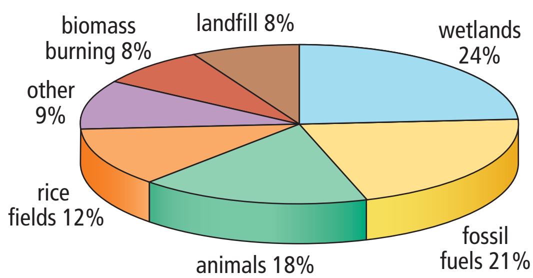
Checking Concepts

1. What does the term "climate change" mean?
2. List three observations that indicate that climate change is occurring.
3. What is the effect of greenhouse gases on heat radiated from Earth's surface?
4. Define "enhanced greenhouse effect."
5. What is global warming?
6. What is the most abundant greenhouse gas?
7. (a) What does GCM refer to?
   (b) How are GCMs used to study climate change?
   (c) List three factors that GCMs take into account.
8. (a) What does the term "carbon source" mean?
   (b) What is the largest carbon source resulting from human activity?
9. Name a source of the greenhouse gas nitrous oxide (N_2O).

Understanding Key Ideas

10. A change in room temperature of only 1°C to 2.5°C would be barely noticeable. Explain why scientists are alarmed at the potential for the same increase in the average global temperature of Earth in the next 50 years.
11. The global warming potential (GWP) of sulfur hexafluoride (SF_6) is 23 900. Compare the ability of SF_6 to absorb and emit thermal energy with that of CO_2.
12. Ozone in the stratosphere protects life on Earth from the Sun's harmful ultraviolet radiation. Why is ozone in the troposphere considered harmful?
13. Describe at least one way that global warming could affect each of the following in British Columbia.
    (a) water supplies
    (b) fisheries
    (c) wildlife
    (d) forestry
    (e) coastal ecosystems
14. Study the graph below of methane sources.
    (a) If you were going to start a program to reduce methane emissions, which source would you target and why?
    (b) Briefly explain how your program would help to reduce methane emissions.

Methane Sources



Source: Environment Canada, 2000

15. Some people have calculated that everyone could produce about 2 tonnes of CO_2 per year without disrupting the natural greenhouse effect. The average car produces about 4.3 tonnes of CO_2 each per year.
    (a) As more people in developing countries start using cars, what might happen to global CO_2 emissions?
    (b) What other factors could change your answer to (a) above?

Pause and Reflect

The table below shows examples of industries in British Columbia, the problems related to climate change for one industry, and some strategies for solving the problems. Copy the table into your notebook, and complete the other rows in your table.

Industry	Problem	Strategy for Solution
Manufacturing	• High energy use • Air pollution • Waste material	• Use energy-efficient equipment. • Monitor air quality and emissions. • Recycle material.
Construction		
Forestry		

Prepare Your Own Summary

In this chapter, you investigated how climate change is caused by natural processes and human activities. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with using graphic organizers.) Use the following headings to organize your notes:

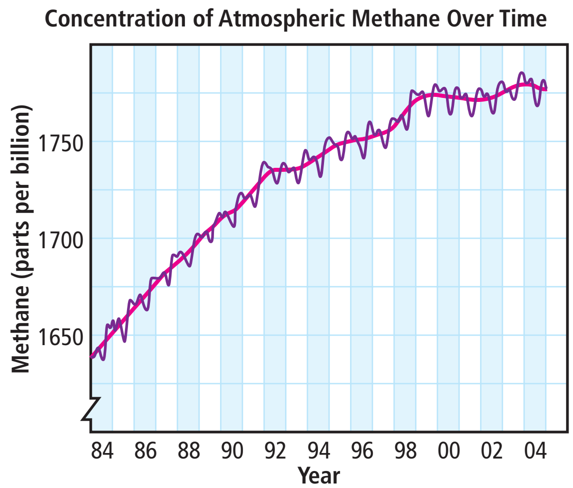
1. Studying Past Climates
2. Natural Processes that Affect Climate
3. Signs of Climate Change
4. The Enhanced Greenhouse Effect
5. Effects of Climate Change
6. Responding to Climate Change

Checking Concepts

1. Is "weather" the best term to describe the conditions of the atmosphere over a large region for many years? Explain your answer.
2. What do paleoclimatologists study?
3. Describe how the angle of incidence of the Sun's rays affects climates on Earth.
4. List two biogeoclimatic zones in British Columbia.
5. Briefly describe the role of oceans in the global climate system.
6. What is the importance of the natural greenhouse effect to living organisms?
7. What is meant by the term "climate change"?
8. What are two signs, other than increasing temperatures, that indicate that climates on Earth are changing?
9. Has Earth ever gone through global cooling? Explain.
10. Draw a Venn diagram comparing the natural greenhouse effect with the enhanced greenhouse effect. Note where human activities are involved.
11. What is the effect of carbon sources on Earth's atmosphere?
12. List three gases that are important in the enhanced greenhouse effect.

Understanding Key Ideas

13. What would happen to the seasons in British Columbia if the North Pole tilted away from the Sun in June and toward the Sun in December?
14. Describe how each of the following natural events could affect global climate.
    (a) a major volcanic eruption
    (b) a large meteor impact
    (b) a warming of ocean water
15. How does an El Niño event at the equator affect weather in northwest Canada?
16. (a) Briefly describe two effects of massive forest fires on the atmosphere.
    (b) Explain how massive forest fires could affect climates.
17. Study the graph shown below of methane in the atmosphere over time. The red line shows the average. The blue line shows seasonal variations.



Source: National Oceanic and Atmospheric Administration, Earth System Research Laboratory

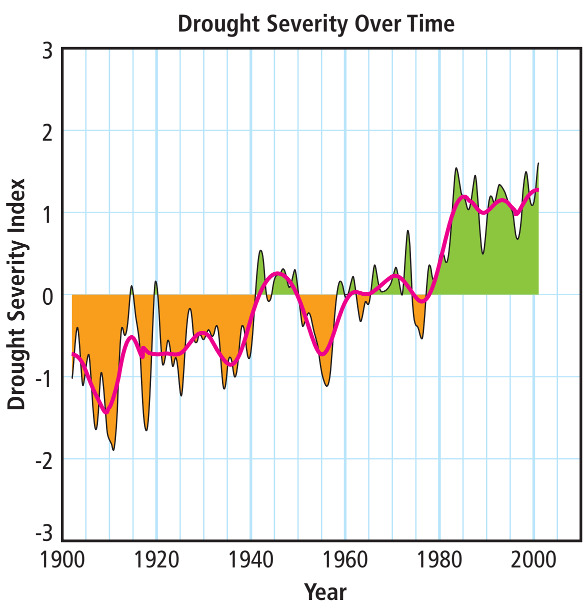
    (a) Describe the trend shown in the graph.
    (b) Is there a link between the levels of atmospheric methane and human activities? Explain.
    (c) Explain the connection between buying a hamburger at a fast-food restaurant and levels of methane in the atmosphere.

18. Without the natural greenhouse effect, Earth would be too cold for much of life as we know it to survive. Why, then, are scientists around the world so concerned about the enhanced greenhouse effect?

19. For each activity listed below, describe one strategy that could be used to reduce greenhouse gas emissions:
   (a) generating electric energy
   (b) transporting consumer goods
   (c) deforestation

Applying Your Understanding

20. Scientists with the United States' National Center for Atmospheric Research have calculated the extent of droughts over the last century. They determined the amount of surface land moisture for large regions and how surface land moisture has changed over time. Overall, they found that droughts became more severe from about 1970 to 2000. The graph below can be used to track drought severity (or wetness) in different regions. For most of Africa, southwestern Australia, and the prairies of North America, positive values on the graph indicate when these regions were drier than average. Negative values on the graph indicate when these same regions were wetter than average. The pink line shows how the amount of moisture has varied from decade to decade.



—Adapted from figures created by Dr. A. Dai of the National Center for Atmospheric Research, Boulder, Colorado, U.S.A.

   (a) When did the most severe droughts occur in Africa?
   (b) What can you conclude about changes in drought severity in most of Africa, southwestern Australia, and the prairies of North America?
   (c) Can you conclude that more droughts occur every year? Explain your answer.

Pause and Reflect

Consider the following quotation: "You should never talk about a problem without talking about a solution." This statement was often made by Dr. Dixon Thompson, a founder of the environmental movement in western Canada and a professor of environmental science. How do you interpret his statement? Review the chapter, listing five or more possible problems. For each problem, suggest a solution.