Although some years are warmer, colder, drier, or wetter than others, Earth's climate remains fairly consistent for long periods of time. In Earth's distant past, however, the climate was sometimes much colder and sometimes much warmer than it is today. Geological and fossil records show that the climate of different areas has changed dramatically. Fossils of tropical plants and animals found in polar and temperate regions indicate warmer worldwide climates in the past (see Figure 11.32). Glacier erosion and deposition around the world show that within the past two million years, glaciers covered large parts of Earth's surface during periods that we call the ice ages. During Earth's past, ice ages lasting 60 000 and 12 000 years have alternated with warm periods called interglacial periods. Ice cores drilled in Greenland show that cold spells, lasting 1000 years or more, changed rapidly to warm spells that lasted just as long. Today, Earth is in an interglacial period that began about 11 500 years ago at the end of the last ice age.

Canada's Paleoclimate

When scientists want to make predictions about the future, they often look at the past. Paleoclimatology is the study of past climates. A change in lake levels, for example, can reveal the past balance between rainfall and evaporation. Other stories about Earth’s climate are contained in time capsules such as glacier ice — air bubbles in Antarctic and Greenland ice cores. Scientists get information from pollen preserved in amber or from lake sediments and tree rings.

The Geological Survey of Canada has recently completed a reconstruction of Canada's paleoclimate, including vegetation zones, from 6000 years ago (see Figure 11.33). Scientists used pollen, plant fossils, and lake sediments to reconstruct the lay of the land and subsequent climatic conditions in Canada. They inferred conditions from 6000 years ago. They compared those conditions to today's climates and discovered an apparent change in climate. From Alberta to the Maritimes, vegetation zones moved northward; fires happened more often; and the water table declined. In the Rocky Mountains, plant life moved further up the slopes. The average annual temperature increased from one to two degrees throughout Canada, with the exception of British Columbia, Yukon, and the islands of the high Arctic.

In the following Find Out Activity you will take on the role of climate researcher.
Analyzing Tree Rings

Climate records going as far back as 8000 years have been obtained from Earth’s oldest trees. Dendochronology is the study that measures the width of annual growth rings in trees. Wet years produce wide rings, while dry years produce narrow rings. Tree rings are also affected by cloud cover, competition for resources, soil nutrients, and pests.

**Materials**

- a cross-section of a tree grown in your biome
- ruler
- notebook to record measurements

**Procedure**

1. Examine the growth rings of the cross-section. Note that the oldest wood is in the centre.

2. Measure the thickness of several rings near the centre and near the perimeter in your sample. Record the measurements. Wash your hands when you have completed the activity.

**Find Out**

**What Did You Find Out?**

1. How did the length of the growing season change as the tree grew older? Describe what evidence you found for this.

2. If scientists examine growth rings in petrified wood samples from different geologic times, what can they learn about climates of earlier periods? What other ways can scientists learn about these paleoclimates?

**Extension**

3. Research the changes in climate that have occurred in your biome over the last 30 years. Do these changes in temperature and amount of precipitation make sense in terms of the growth rings in your piece of wood? List the other factors that must be taken into consideration when examining the width of tree rings.

**Tools of Science**

By examining air bubbles trapped in glaciers, scientists learn about climates of earlier geologic eras. Scientists use long drills to remove cores of ice-age samples from ice sheets. Then they examine the trapped air by cutting the core into small pieces and putting the pieces in a vacuum chamber. In the sealed chamber, steel needles crush the ice. The trapped air escapes and is sucked into a tube. A laser beam of infrared light shoots through the tube to measure the amount of carbon dioxide in the sample of air.

Scientists have discovered that the amount of carbon dioxide varies within ice cores. During warmer periods in the past, when ice formed slowly, concentrations of carbon dioxide ranged from 260–280 parts per million (ppm). In colder times, when ice layers formed quickly, concentrations of carbon dioxide ranged from 190–200 ppm.
Causes of Natural Climate Change

Though sometimes difficult, it is possible to collect and analyze data and determine how climates have changed throughout the world. However, it is much more difficult to explain why these changes occurred. Scientists have suggested several possibilities but cannot fully explain natural climate change. Some of the possible causes of climate change are discussed over the next few pages.

Earth’s Tilt

You discovered in Chapter 10 that the amount of solar radiation reaching any specific location on Earth depends on the tilt of Earth (and the time of the year). As shown in Figure 11.34, Earth today is tilted on its axis at 23.5° to the plane of its orbit around the Sun. In the past, this tilt has fluctuated between 22.3° and 24.5°. When Earth’s tilt is at its maximum, the poles receive more solar radiation. As a result, the regions farther from the equator are, on the average, warmer than at other times. When the tilt is at its minimum, the poles receive less solar radiation, which results in a colder climate for the regions farther from the equator.

![Image of Earth's Tilt](image)

Scientific evidence shows that Earth “wobbles” very gradually on its axis.

Earth’s Orbit

The shape of Earth’s orbit fluctuates over periods of about 100,000 years. Sometimes the orbit is almost a perfect circle. About 50,000 years later, the orbit has an oval shape. These changes in the shape of its orbit change the amount of solar energy reaching Earth during different seasons. Some scientists think that these changes distances from the Sun are partially responsible for the periods of glaciation.

Continental Drift

You might have studied continental drift in previous science courses. According to this theory, all land-forms sit on tectonic plates that float on the hot, liquid core of Earth. The theory further proposes that about 225 million years ago, the tectonic plates all formed a single supercontinent (see Figure 11.35). Scientists call this continent Pangaea, which comes from the Greek word meaning “all lands.”

About 200 million years ago, as the tectonic plates moved, the continents began to split apart. By 65 million years ago, most of the continents were in a form that you could recognize (see Figure 11.35). The best examples of continents fitting together are the east coast of Brazil and the southwest coast of Africa. Strong evidence that these continents were once attached is revealed in the similar fossils of plants and animals found in the east coast of Brazil and the west coast of Africa.
The slow movement of the continents and the opening and closing of ocean basins affect the transfer of thermal energy on Earth’s surface. In turn, this transfer affects wind and precipitation patterns. Through time, these altered patterns can change climates. As well, if the continents moved from one latitude to another, the climate would certainly change. The movement of tectonic plates could explain some of the evidence for climate change over the last several million years.

![Continental Drift Images](image)

**Figure 11.35** Strong evidence, found by scientists, indicates that over millions of years, the continents “drifted” until they reached their current locations. What evidence suggests that the plates are still moving?

**Weathering**

One role that the lithosphere plays in removing excess carbon dioxide from the atmosphere is not easily recognized. **Weathering** is the process that breaks down rocks into smaller pieces. Weathering involves both physical and chemical processes. Chemical weathering usually involves carbonic acid. This acid can be formed when carbon dioxide gas reacts with water vapour in the atmosphere. Chemical weathering uses up atmospheric carbon dioxide by a chemical reaction in which calcium carbonate is the product. Erosion transports the material to oceans and lakes. Some of the calcium carbonate is used to build the skeletons of phytoplankton. Much of the calcium carbonate that enters oceans eventually forms sedimentary rocks.

**Catastrophic Events**

Catastrophic events, such as a large meteor or asteroid colliding with Earth, or a major volcanic eruption, would put enormous volumes of dust, ash, and smoke particles into the atmosphere (see Figure 11.36 on the next page). Many scientists suggest that such events in the past, could have caused a dark thick cloud of soot, dust or smog to form. The cloud would reflect or absorb sunlight, preventing it from reaching Earth’s surface. Photosynthesis in plants and algae would slow down considerably and temperatures would drop. The sudden reduction of plant material might have caused starvation for many animal species. Such an event might have led to the mass extinction of animals including the dinosaurs. In addition, some scientists suggest that the climate would have warmed up due to the increase in carbon dioxide and other greenhouse gases.
Evidence in the rock record indicates that a large meteorite might have struck Earth in the Yucatan peninsula (shown on the map) about 65 million years ago. The crater in the photograph was taken in New Zealand. It shows the force with which meteors can strike Earth.

**Feedback**

Responses, or feedbacks, to climate change can result in additional changes to the climate. These responses can include changes in cloud cover, the extent of glaciers, and concentration of carbon dioxide in the atmosphere. An example of a negative feedback loop is related to the concentration of carbon dioxide and water vapour (see Figure 11.37A). These natural greenhouse gases trap long-wave infrared radiation, keeping Earth warm. An increase in Earth’s temperature can lead to an increase in the evaporation of water. More water in the atmosphere will result in the formation of more clouds. Clouds reflect incoming solar radiation back into space before it can reach Earth’s surface. The result is global cooling. Thus, increased cloud cover that is a result of global warming can eventually lead to global cooling.

Another example of feedback is related to the amount of ice and snow on Earth’s surface. Earth’s temperature and the subsequent formation of sea ice are controlled by a positive feedback loop (see Figure 11.37B). A drop in Earth’s temperature results in the formation of sea ice. An increase in sea ice would result in more solar radiation being reflected back into space. This would result in further cooling of Earth’s atmosphere and the formation of more sea ice.

Any or all events described above might be responsible for natural climate change. See what you can learn about a change that occurred in northern Africa about 10,000 years ago by completing the following activity.

(A) Negative feedback describes a situation in which a change in one direction (warming) triggers another condition that reverses the direction of the change (cooling).

(B) Positive feedback describes a situation that perpetuates itself. In this example, cooling causes a new condition (more ice), which causes more cooling.
From a Savanna to the Sahara

The tropical savanna is a biome characterized by tall grasses and occasional trees. Savannas are always found in tropical climates where the annual rainfall ranges from 50 to 130 cm per year. Rainfall occurs in six to eight months of the year. The rainy season is followed by a long period of drought when fires can occur. If rains were distributed throughout the year, many savannas could become tropical forests.

A desert biome is characterized by daily temperature extremes and rainfall that is usually very low and/or concentrated in short bursts between long rainless periods. Evaporation rates usually exceed rainfall rates. Desert surfaces receive more solar radiation than humid regions and they re-emit almost twice as much heat at night. Deserts are characterized by sparse vegetation. The organisms that live in deserts are specially adapted to withstand or avoid water stress.

The Sahara, the world’s largest desert, stretches across most of North Africa. However, ancient cave paintings in the mountains of southern Algeria show that the Sahara desert was a lush and hospitable place 5000 to 10 000 years ago. Over a very short time, in terms of geologic history, this region changed from a savanna to a desert. Summer temperatures increased rapidly, the rate of evaporation increased, and rainfall decreased dramatically to about 1.5 cm per year.

Why did these changes occur? It was once thought that the Sahara desert changed from a savanna to a desert due to the way that people farmed and used the land in that region. Now evidence suggests that North Africa dried out as a result of natural climate change after the last ice age. Could it have been a combination of natural climate change and human activity that led to the desertification — the formation of a desert — of this region?

Find Out

Procedure
1. Use a variety of print and electronic resources, including the Internet, to research the desertification of the savanna that lead to the formation of the Sahara Desert.
2. Prepare a short position paper that answers this question: Was the formation of the Sahara Desert the result of natural climate change or human activity?
3. Your position paper should include the following:
   (a) an introduction to the issue
   (b) a description of the climate of this region before and after desertification
   (c) the possible causes of desertification of this area due to natural climate changes
   (d) the possible connection of human activities in this region to the formation of the Sahara desert
   (e) a final section summarizing your position on this issue

What Did You Find Out?

1. What evidence supports the view that human activity changed the savanna biome into what is now the Sahara desert?
2. What evidence supports the view that natural climate change caused the savanna biome to become the Sahara desert?
Mass Extinction Events

As you now know, living organisms respond to seasonal climatic change. How might they respond to a greater, sudden change?

Earth’s biological history includes many examples of “mass extinctions,” during which many of the world’s species were wiped out. Perhaps the largest mass extinction occurred 245 million years ago. About 80 percent of all species died. Another mass extinction followed 37 million years later or about 208 million years ago. This event marked the beginning of the age of dinosaurs. This event might have removed the competition and thus ensured the success of early reptiles, which were then no larger than small dogs.

The most famous mass extinction is that of the dinosaurs about 65 million years ago. Most of these events coincide with relatively dramatic changes in climate. Scientists hypothesize that asteroid collisions with Earth at those times filled Earth’s atmosphere with dust particles.

When a climate changes, species that are best adapted to the new conditions are most likely to survive. Climate change that happens quickly, such as the one that wiped out the dinosaurs, usually kills organisms before species have a chance to adapt. Climate change that occurs over a longer period can cause different scenarios. These scenarios include animal migrations, evolution of physical characteristics, changes in diet, a decrease in the population, and forests moving farther north or south (see Figure 11.38).

![Figure 11.38](image-url) The boreal forest today is shown in green. The red outline shows the boreal forest 6000 years ago. A long-term increase in temperature stimulated northward movement of the boreal forest and an increase in forest fires. The amounts of charcoal in samples of pollen and plant fossils helped scientists determine forest fire frequencies.
Dr. Robert (Bob) Schemenauer has done a fair bit of travelling since his early days in Prince Albert, Saskatchewan. His office is now at Environment Canada in Toronto, but you might find him in a developing country helping to provide a simple and inexpensive solution to water supply problems. What does he do? He collects fog.

When clouds interact with Earth's surface, they become fog. Fog droplets are much smaller than rain droplets. Because they are so light, they can travel horizontally in a light breeze. A vertical surface, such as a tree, can make a good fog collector as fog droplets drift onto the surface, then run down to the base. However, in an arid climate there might not be any trees or other vertical structures. For example, the coastal area of Chile is extremely dry, even though it is often foggy. In 1987, Dr. Schemenauer worked with other scientists to design fog collectors using simple local materials to make screens with gutters along the bottom to collect and channel the water. The results were very impressive — each square metre of collecting surface gathered an average of 3 L a day of water. That project has since been expanded and now supplies about 15 000 L of water each day.

Does it upset the balance in the ecosystem to collect fog? "We take such a tiny amount of fog water out that it has no effect," says Dr. Schemenauer. "The fog is maybe 200 m thick going over the ridgeline, and we work in the bottom 4 or 5 m, so 196 m goes by above our collectors." Because the fog water is used close to where it is collected, it does not leave the ecosystem.

Other fog collecting projects are now underway in South Africa, the Dominican Republic, Israel, and Nepal. Plastic mesh (shown behind Dr. Schemenauer in the photo) is usually used as the screening material because it is efficient and inexpensive. Dr. Schemenauer points out that fog collecting is not just a technology for arid coastal regions. It is also useful in foggy areas where the ground water is contaminated with bacteria. "Only wind and gravity are required to collect and deliver fog water," says Dr. Schemenauer. "It is an environmentally friendly, sustainable water resource."

The study of past climates requires the analysis and interpretation of data gathered by researchers in many fields. For example, a cave scientist might examine layered mineral cave formations, an oceanographer might collect deep sea cores, and an anthropologist might research oral records of past harvests. Work with a partner to make a list of different careers that might contribute to paleoclimatology. Then choose the career you think is most interesting. Research to discover the training and skills required, and the contributions the position could make to paleoclimatology. Summarize your research on an index card and add it to a class bulletin board.
Section 11.3 Summary

Earth’s biomes experience natural climate change. At different times in its geologic history, Earth was warmer and colder than it is today. Paleoclimatology is the study of ancient climates. Paleoclimatologists have found evidence for a climate change in Canada by studying pollen and plant fossils and lake sediments. Some possible causes of natural climate change are listed here.

- Earth’s tilt: The angle of inclination of Earth’s axis varies between 22.3° and 24.5°. At Earth’s minimum tilt, the areas near the poles become colder. At its maximum tilt, the poles become warmer.
- Earth’s orbit: The shape of Earth’s orbit fluctuates. This fluctuation changes the distance from Earth to the Sun.
- Continental drift: The movement of continents on tectonic plates has changed the distribution of land and water on Earth’s surface, thus changing the wind and ocean currents. Continents have moved from one major climate zone to another.
- Weathering: As rocks break down the new surfaces can react with carbonic acid and remove carbon dioxide from the air.
- Catastrophic Events: The impact of meteorites from space or the eruption of volcanoes can fill the air with tonnes of dust and soot. This dust in the air can reflect sunlight and cause the temperature to decrease.
- Feedback: A change in the climate due to any cause can trigger another change.

Check Your Understanding

1. (a) What is paleoclimatology?
   (b) List four sources of data that paleoclimatologists use to find information about past climates of a region.

2. Describe the climate of Canada 6000 years ago.

3. Describe how the theory of Continental Drift could be used to explain why Canada’s climate changed from tropical to temperate over the past 225 million years.

4. How might an asteroid striking Earth cause a dramatic climate change?

5. How could a sudden change in global temperatures trigger a mass extinction of plants and animals?

6. Apply Predict what might happen to the climate of Alberta if Earth’s tilt decreased from 23.5° to 22.3°.

7. Apply Draw a positive feedback loop summarizing the impact that increasing global temperature might have on sea ice and subsequent global temperatures.

8. Thinking Critically What would be some of the problems of using ancient climate data to predict future climate change?
Now that you have completed this chapter, try to do the following. If you cannot, go back to the sections indicated in parentheses after each part.

(a) Describe a climatograph. (11.1)
(b) Define humidity and dew point temperature. (11.1)
(c) How is the biosphere organized? (11.1)
(d) Explain why it is that the higher the altitude, the colder the climate. (11.1)
(e) Name and describe the six major biomes. (11.1 and 11.2)
(f) Define physiological adaptation, structural adaptation, and behavioural adaptation. Give an example of each type of adaptation. (11.2)
(g) What are the differences between an open and closed system? Explain whether biomes are closed or open systems. (11.2)
(h) Why are biomes of the same category found in many different parts of the world? (11.2)
(i) Why are humans found in all types of biomes while many species are found in only one or two different biomes? (11.2)
(j) Define paleoclimate. (11.3)
(k) Explain two methods used by scientists to measure past climate change. (11.3)
(l) How can Earth's tilt bring about climate change? (11.3)
(m) How does weathering affect climate? (11.3)
(n) Describe how cloud cover can act as a feedback to climate change. (11.3)
(o) Explain how catastrophic events can cause climate change. Provide two examples. (11.3)
(p) What is a mass extinction event? (11.3)
15. Explain how a volcano could affect the climate of a region.

16. What is meant by natural climate change?

17. What is the meaning of the term mass extinction?

Developing Skills

18. Use the following data to construct a climatograph then answer the questions that follow.

<table>
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<th>Month</th>
<th>Precipitation (mm)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
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<td>115</td>
<td>21</td>
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<tr>
<td>F</td>
<td>110</td>
<td>22</td>
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<tr>
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<td>20</td>
</tr>
<tr>
<td>D</td>
<td>123</td>
<td>20</td>
</tr>
</tbody>
</table>

(a) In what type of biome might this city be located?
(b) In what hemisphere might this city be located?
(c) Explain the reasons for your answers to (a) and (b).

19. List three adaptations grass has to survive in the dry conditions of the grassland biome.
20. Kangaroo rats are small rodents that live in desert biomes. Predict one behavioural adaptation and one physiological adaptation that kangaroo rats might have. Do research to check your predictions.

21. Make a chain-of-events chart to explain the effect of a major volcanic eruption on climate.

Problem Solving/Applying

22. Why has the incidence of forest fires in western Canada been increasing in recent years?

23. Choose two biomes that you have studied. How have the plants, animals, and people adapted to that region?

24. What can you infer if you are digging in a desert and find fossils of tropical plants?

25. Why would you expect it to be cooler if you climb to a higher elevation in a desert?

26. How does looking at a climatograph for a location provide you with clues as to what biome you might find there?

27. Use the climatograph that follows to answer these questions:
   a) Which biome is represented by the climatograph?
   b) In your own words, summarize the climate of this region.

Critical Thinking

28. List four ways people have adapted to living in particular biomes. Choose one of these ways and explain how it applies to each biome.

29. How do you think different climates have affected the development of different civilizations around the world?

30. Why are deserts generally found between 15° and 35° North and South latitude?

31. Why was the taiga biome important to the early exploration and development of Canada?

32. Different species of rabbits and hares live in the desert and the tundra. Compare the adaptations of a desert rabbit or hare to those of a rabbit or hare living in the tundra.