CHAPTER FIVE

The Bigger Picture: Global Climate

After completing the investigations in Chapter 4, you should realize that your sense of what is "normal" weather at any particular time of the year may actually be very different from someone living elsewhere. Whether the days are cold or warm, rainy or dry, sunny or partly cloudy, you become used to the conditions you expect in your home place. But what if they started to change?

If you pay attention to the news, you've heard much talk about climate. Measurements show that climate change is happening, but there are different projections about what this means. As citizens, it's hard to know how to react to all these warnings. You may be asking questions such as: Are these warnings valid? Is climate change really going to affect me? Or simply, why should I care?

The story in this chapter is somewhat different from the ones you've encountered earlier in the course, because it poses questions not fully addressed in this chapter or even in this course: What is causing the climate to change, and what impact will this have on local communities during your lifetime? You will continue to follow the story of humanity's quest to understand climate change and its implications as you watch and read news accounts over the coming years. Instead of trying to provide answers, this course will help you develop the basic understandings necessary so that you can assess what you hear about climate change and understand what this might mean to you.

This chapter covers the fundamental factors that cause energy to be absorbed and held in Earth's atmosphere, and can cause the atmosphere near Earth's surface to become warmer or cooler over time. In Chapter 6, you'll look back millions of years into Earth's history and investigate how these factors, coupled with long-term changes in Earth's surface features and its orbit, have caused the planet's climate to be very different in the past from the way it is today.

So now you know that the temperature near Earth's surface is related to whether energy is reflected into space or trapped by greenhouse gases such as CO_2. The more CO_2 in the atmosphere, the more heat will be trapped, and the more Earth's temperature will rise. So where does this CO_2 come from? Explore this in the next two activities.

ACTIVITY 3

Moving Carbon Around

Setting the Stage: Carbon in Earth's Systems

The element carbon is one of the essential components of every cell. Did you know that the carbon in your body has been around since before Earth formed 4.6 billion years ago? In fact, it formed in the center of a star that lived and died before Earth's Sun was formed.

Since the carbon in your body first formed, it has combined with other atoms and changed form many times. It has resided in various parts of Earth—the soil, the rocks, the oceans, living things, and the atmosphere. These parts of Earth's systems that contain carbon are also known as carbon reservoirs. Table 5.1 shows the approximate amount of carbon that resides in each of Earth's major carbon reservoirs.

Table 5.1: The Approximate Amount of Carbon in Earth's Major Carbon Reservoirs in Gigatons (1 gigaton = 1 billion tons)[2]

MAJOR CARBON RESERVOIR	APPROXIMATE AMOUNT OF CARBON (gigatons)
Vegetation	610
Soils	1,560
Atmosphere (preindustrial)	600
Ocean mixed layer*	1,000
Deep ocean	38,000
Sediments and rocks	66,000,000

*Ocean mixed layer: the shallower parts of the oceans where more mixing with air occurs.

The carbon moves in and out of some of these reservoirs (such as vegetation) relatively quickly. On the other hand, carbon typically is stored in other reservoirs—particularly rocks—for very long periods of time. The term *carbon flux* refers to the amount of carbon that is transferred from one reservoir to another during a given time period.

How does a carbon atom get from rocks to the atmosphere? From water to rocks? In this next activity, you'll investigate the processes that move carbon atoms around.

Materials

PARTS A AND C
FOR EACH TEAM OF STUDENTS:

- 1 calcium atom (green)
- 3 carbon atoms (black)
- 8 hydrogen atoms (white)
- 10 oxygen atoms (red)
- 20 covalent bonds (white tubes)

PART B
FOR EACH GROUP OF STUDENTS:

- 1 bottle of limewater, ($Ca(OH)_2$)
- 1 wide mouth bottle with plug-style cap
- 1 small candle
- 1 foil square
- access to matches or lighter

Procedure

Record all observations and answers in your notebook as you work.

Part A: Modeling Combustion

1. Use the structural diagrams in Figure 5.8 and the molecular modeling pieces to create one molecule of propane (C_3H_8), a common fuel, and one molecule of oxygen gas (O_2).

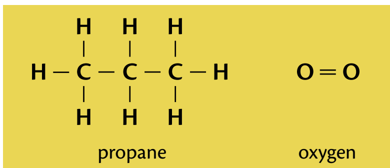

FIGURE 5.8
The molecular structure of propane and oxygen.

2. Model the combustion of propane by:
   a. Making 4 more O_2 models then putting any unused modeling pieces away.
   b. Modeling the breaking of the reactant bonds by removing all the white bonds from the atoms of all six reactant molecules (one C_3H_8 and five O_2).
   c. Modeling the formation of the products by reassembling all the bonds and atoms from the "broken" reactant molecules to make as many water (H_2O) and carbon dioxide (CO_2) molecules as you can.
3. Count up the number of H_2O and CO_2 molecules you made in Step 2 then complete the chemical equation below that shows the combustion of propane. Write the completed equation in your notebook.

$$C_3H_8 + 5O_2 \longrightarrow \_\_\_\_ CO_2 + \_\_\_\_ H_2O$$

Part B: Producing and Sequestering CO_2

4. Work in groups of 4. Obtain the Part B materials from your teacher.
5. Place the bottle cap upside down on the table and fill it almost completely up with limewater. Holding the bottle upside down, push it down firmly onto the cap. Then flip the capped bottle right side up. Observe and describe the limewater.
6. Gently shake the bottle 10 times then place it upright on the table. Observe the limewater and record changes, if any, to its appearance.
7. Uncap the bottle. Place the cap on the table and then carefully pour the limewater back into the cap. Place the cap with limewater somewhere safe because you will use it again in Step 10.
8. Place the candle in the center of the foil square as shown in Figure 5.9.
9. Carefully light the candle then hold the bottle upside-down so that the bottle-mouth is 2–5 cm (1–2 inches) over the candle flame. Hold it there for about 20–30 seconds to catch the combustion gases.

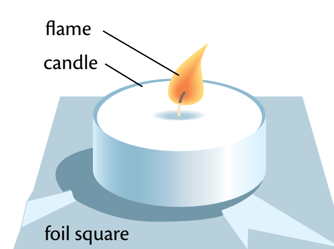

FIGURE 5.9
Setup for producing and sequestering CO_2 in Activity 3.

10. Keeping the bottle upside down, quickly, but carefully, move it over the cap filled with limewater and push the bottle down firmly onto the cap.
11. Gently blow the candle out then flip the capped bottle right side up, gently shake it 10 times, and place it upright on the table. Observe the contents and record your observations.
12. Put the bottle someplace safe so it can sit undisturbed while you complete Part C.

Part C: Forming Limestone (working in pairs)

13. Use the structural diagrams in Figure 5.10 and the molecular modeling pieces to create one molecule of carbon dioxide (CO_2) and one molecule of calcium hydroxide ($Ca(OH)_2$). Put any unused modeling pieces away.

O = C = O	H – O – Ca – O – H
carbon dioxide	calcium hydroxide

FIGURE 5.10
The molecular structure of carbon dioxide and calcium hydroxide.

14. Limestone rock is made of calcite molecules ($CaCO_3$). To model limestone formation, remove all the white bonds from between all the atoms of the CO_2 and $Ca(OH)_2$ molecules.

    Reassemble all the bonds and atoms from the "broken" reactant molecules into a calcite molecule ($CaCO_3$) and a water molecule (H_2O).
15. Write down the chemical equation for the formation of limestone.
16. Observe the bottle of limewater again and record your observations.

Analysis

With your group, complete the following questions and record your answers in your notebook. Be prepared to share your answers with the rest of the class

1. The combustion of any hydrocarbon results in the production of the same two substances. Name these two substances.
2. What happens when CO_2 is mixed with limewater? Explain why you think this happens.
3. CO_2 dissolves readily in seawater, which contains abundant Ca^{2+} ions. What do you think would happen to Earth's climate if a lot of CO_2 were to dissolve from the atmosphere into seawater? Explain why you think this would happen.

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Carbon dioxide is an important greenhouse gas, and its concentration in the atmosphere is an important driver of climate change. What are the factors that can cause CO_2 levels in the atmosphere to rise? What processes in Earth's systems subtract CO_2 from the atmosphere? What types of human activities affect CO_2 levels in the atmosphere? In Activity 4, explore these questions.

ACTIVITY 4

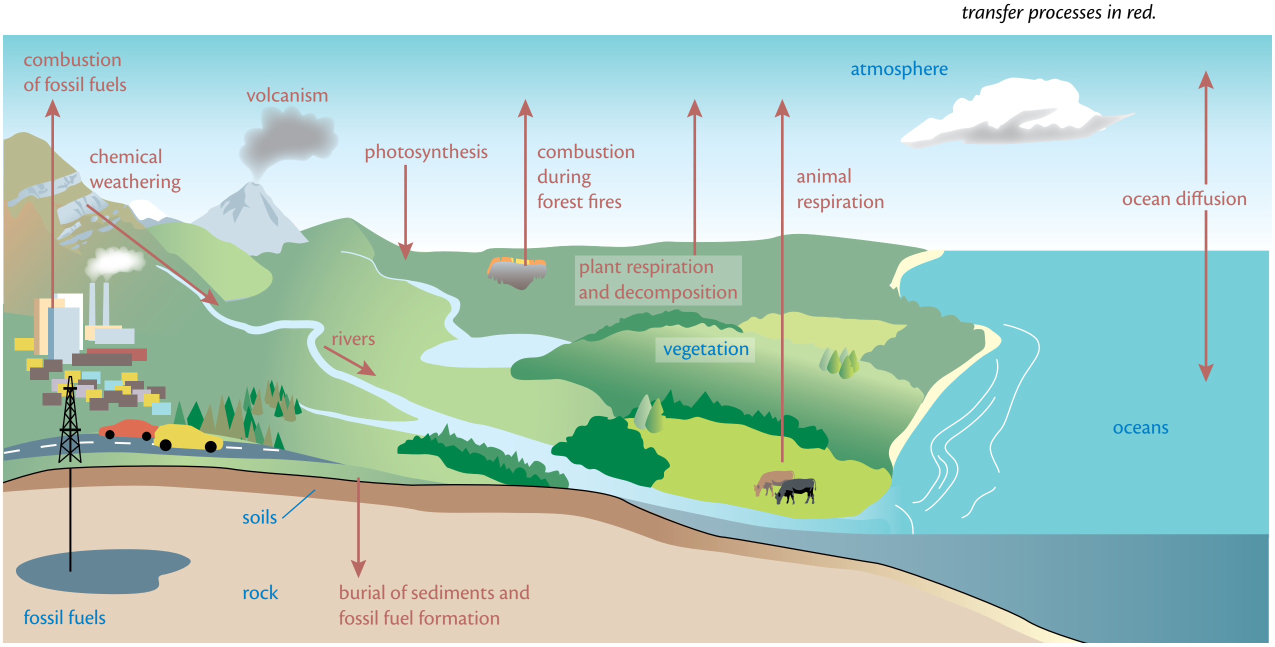
Calling All Carbons

Setting the Stage: The Carbon Cycle

The element carbon is critical to life on Earth. All living organisms contain many different and essential carbon-based molecules. Food is made from carbon-based molecules. Carbon dioxide (CO_2) is needed for plants to survive and if the atmosphere did not have any, the Earth would be much colder, perhaps too cold for living things to survive. However, too much CO_2 in the atmosphere could make the planet too hot for living things. Several Earth processes work together to cycle carbon from one carbon reservoir to another and to keep the amount in each reservoir stable. There are several major transfer processes that occur constantly that help carbon—most often in the form of CO_2—move from reservoir to reservoir. These carbon reservoirs and transfer processes work together to create Earth's carbon cycle. Because the actual carbon cycle is so vast and complex (it includes every plant, animal, microbe, ocean lake, river, puddle, soil, sediment, volcanic eruption, etc.), it is often simplified to show only the most important reservoirs and processes, as shown in Figure 5.11.

Because the amount of CO_2 in the atmosphere is so critical to Earth's climate, you will focus on how CO_2 is added to and subtracted from the atmosphere in this activity. Some processes add CO_2 to the atmosphere and are called CO_2 sources; other processes remove CO_2 from the atmosphere and store it in various places called carbon sinks. This movement of carbon from one reservoir to another is called the **carbon flux** and when properly balanced, it keeps the amount of carbon in each place relatively constant. This helps maintain stable conditions in Earth's biosphere, hydrosphere, atmosphere, and geosphere.

FIGURE 5.11
Simplified diagram of the carbon cycle, showing reservoirs in blue and carbon transfer processes in red.



Procedure

Record all observations and answers in your notebook as you work.

1. With your group, study the information on all 8 Carbon Cards and make sure everyone in your group knows the name of each process and understands how the process works. You might do this by splitting up the cards and explaining the processes to each other.
2. Sort the 7 Carbon Transfer Process Cards into groups, based on whether each process is a CO_2 source or contributes to a carbon sink. Record your results.
3. Sort the cards within each group (sources and sinks), in order from highest annual carbon flux to lowest carbon flux. Record your results.
4. Summarize your findings by drawing a table in your notebook with seven rows beneath the headings shown in Table 5.2 below. Then fill in the information.

Table 5.2

NAME OF PROCESS	HOW PROCESS WORKS	SOURCE OR SINK	ANNUAL CARBON FLUX

5. Write answers to the Analysis questions in your notebook. Be prepared to discuss them with the class.

Materials

FOR EACH GROUP OF STUDENTS

- 1 set of 8 Carbon Cards

Carbon Transfer Process: Chemical Weathering of Rocks

NET EFFECT: *removes CO_2 from atmosphere and stores it in the ocean*

CARBON FLUX: *0.1 billion metric tons/year*

Rainwater (H_2) and carbon dioxide (CO_2) from the atmosphere combine in soil and rock crevices on the land to form a weak acid called carbonic acid (H_2CO_3). This carbonic acid weathers and chemically breaks down the rocks, as shown in Figure 5.12, and rainwater washes away dissolved ions. These ions are carried by rivers to the sea where some of them (Si^{+4}, Ca^{+2}, and $C0_3^{-2}$) are taken up in the growing shells of microorganisms ($CaCO_3$ and SiO_2). These shells settle to the bottom of the ocean when they die. The net effect of this entire multistep process is that CO_2 is removed from the atmosphere and stored in the shells of organisms. A generalized chemical equation for this process is

$$CaSiO_3 + CO_2 \longrightarrow CaCO_6 + SiO_2$$

rocks — *from the atmosphere* — *calcite in shells* — *quartz dissolved in seawater or incorporated into shells*

FIGURE 5.12
Weathered rocks.

Carbon Transfer Process: Volcanism Associated with Tectonic Plate Processes

NET EFFECT: *adds CO_2 to the atmosphere that was previously stored in rocks*

CARBON FLUX: *0.2 billion metric tons/year*

Rocks of Earth's crust containing carbon are recycled by tectonic plate processes. This carbon is released in the form of CO_2 when the rocks are melted, and the gas separates out and is erupted from volcanoes, such as the one shown in Figure 5.13. These volcanoes most commonly occur near plate boundaries, along subduction zones and seafloor spreading ridges. The net effect of this process is that carbon stored in rocks is released in the form of CO_2 to the atmosphere.

FIGURE 5.13
Mount St. Helens.

Carbon Transfer Process: Formation of Fossil Fuels

NET EFFECT: *CO_2 is removed from the atmosphere and incorporated into rocks*

CARBON FLUX: *$<$ 1 billion metric tons/year*

Usually, when living things die, they decompose, releasing the carbon from which they are built to the atmosphere. In some (rare) cases, these organic remains are instead preserved in an oxygen-poor environment such as the bottom of certain ocean basins or in stagnant swamps such as the coal swamp in Figure 5.14. These remains accumulate and, over millions of years, are buried and incorporated into rock. Heat and pressure transform the preserved organic material into oil, natural gas, and coal. Oil and natural gas form primarily from the remains of microscopic marine organisms. Coal forms from land plants. It is estimated that approximately 100 tons of ancient life is converted to 1 gallon of gasoline. The net effect is to store carbon in the rocks of Earth.

FIGURE 5.14
Picture of a coal swamp.

Carbon Transfer Process: Combustion of Fossil Fuels and Other Organic Matter (such as wood)

NET EFFECT: *CO_2 that was stored in rocks is added to the atmosphere*

CARBON FLUX: *5 billion metric tons/year*

When fossil fuels such as oil, natural gas, and coal are extracted from Earth and burned (combusted), carbon and hydrogen in the fuel reacts with oxygen from the air to form CO_2, water, and heat. The CO_2, water vapor, and other by-products are released to the air through smokestacks such as the ones at the coal-burning power plant in Figure 5.15. The heat may be transformed into electricity and transported to people's homes and businesses for power, or may be transformed into mechanical energy in cars, trucks, or other vehicles. When wood or other organic material is burned, it also releases CO_2. The net effect of the combustion of fossil fuels and other organic materials is to release CO_2 into the atmosphere.

FIGURE 5.15
Coal-burning power plant.

Carbon Transfer Process: Photosynthesis

NET EFFECT: *removes CO_2 from the atmosphere and stores it in plants*

CARBON FLUX: *102 billion metric tons/year*

Plants such as the one in Figure 5.16 remove CO_2 from the atmosphere and store it. Photosynthesis uses CO_2 from the atmosphere, energy from the Sun, and water to produce carbohydrates (sugar) and oxygen. Light energy from the Sun is stored in the chemical bonds of the sugar molecule. Some of these carbohydrates are incorporated into plant tissue, where they are stored. The net effect of this process is that CO_2 is removed from the atmosphere and stored in the tissue of plants. A generalized chemical equation for the process of photosynthesis is

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 \text{ (sugar)} + 6O_2$$

FIGURE 5.16:
Plants use CO_2, water, and energy from the Sun during photosynthesis.

Carbon Transfer Process: Respiration and Decomposition

NET EFFECT: *removes carbon from plants and adds CO_2 to the atmosphere*

CARBON FLUX: *100 billion metric tons/year*

Respiration (the reverse of photosynthesis) involves the breakdown of sugar using oxygen to obtain energy and building blocks to form new biomolecules. These reactions release CO_2, water, and energy as products and by-products. Respiration occurs in both plants and animals, such as the dog in Figure 5.17. Another important way that CO_2 is added to the atmosphere is decomposition. When organisms decompose, they are consumed mostly by bacteria and fungi, and CO_2 is released. The net effect of respiration and decomposition is carbon stored in carbohydrates within plants and animals is released into the atmosphere in the form of CO_2. A generalized chemical equation for the process of respiration is

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6H_2O + 6CO_2$$

FIGURE 5.17
This dog is breathing in oxygen and breathing out CO_2.

Carbon Transfer Process: Diffusion of Carbon Dioxide Into and Out of the Ocean

NET EFFECT: *variable; depends on temperature of ocean*

CARBON FLUX: ~ *92 billion metric tons/year from atmosphere into ocean; 90 billion metric tons/year from ocean into atmosphere*

There is a certain amount of CO_2 that can be dissolved in seawater. That amount depends on the temperature of the water. Cold water can hold more CO_2 than warm water, so cold seawater tends to absorb CO_2 from the atmosphere. Warmer water has higher kinetic energy. This higher kinetic energy increases molecular motion, which breaks intermolecular bonds and causes gases to escape from the solution. Therefore, warm seawater tends to release CO_2 to the atmosphere. So the net effect of the oceans on atmospheric CO_2 varies with the ocean temperature, as shown in Figure 5.18. Higher latitude oceans tend to remove more CO_2 from the atmosphere than they release (although as the water warms, this balance can change), and tropical oceans tend to release more CO_2 to the atmosphere than they take up.

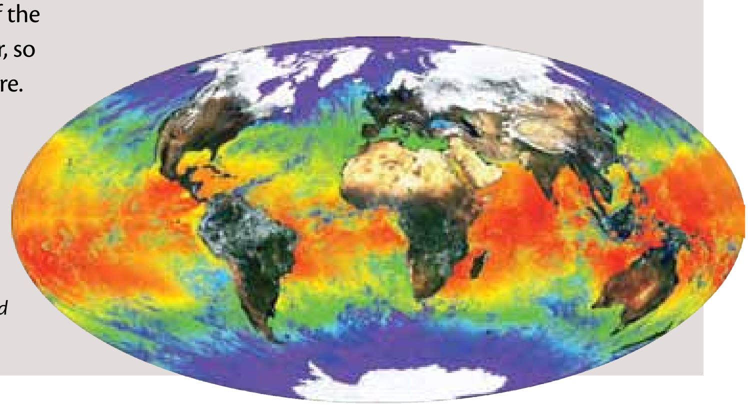


FIGURE 5.18
Sea surface temperature: The orange areas are the highest temperatures and the dark blue areas are the lowest.

Analysis

Complete the following questions and record your answers in your notebook. Be prepared to share your answers with the rest of the class.

1. List Earth's major carbon reservoirs.
2. Describe a process that has the net effect of removing carbon from the atmosphere.
3. Describe a process that has the net effect of adding carbon to the atmosphere.
4. Describe a process that both adds carbon to and subtracts carbon from the atmosphere.
5. During the 19th century, much of the forested land area in the eastern United States was cleared for agriculture. What effect would you expect this to have on CO_2 levels in the atmosphere? Explain your thinking.
6. If a large volcanic eruption were to occur somewhere on Earth, how would you expect this to affect CO_2 levels in the atmosphere?
7. Compare the carbon flux rates of the various carbon transfer processes. Which processes absorb or release CO_2 at a lower rate, and which processes have a higher yearly flux rate?
8. Scientists have related the increased use of fossil fuels by humans to the warming of Earth's atmosphere that is occurring. Using data from the Carbon Cards and what you've learned about the greenhouse effect, explain how increases in fossil-fuel use could cause the climate to warm.
9. Energy can also be produced from biomass, such as corn and sugar cane, and proponents of biofuels say this is a better alternative than fossil fuels. Based on what you know about the carbon cycle, what do you think of this idea?
10. Describe and explain other natural events and processes or human activities that could affect CO_2 levels in the atmosphere.

By now you should understand that, although there's a clear link between CO_2 levels and Earth's temperature, there are many other factors that need to be considered. This next reading discusses how Earth's systems can interact to either stabilize the climate or accelerate climate change.

READING

The Greenhouse Effect, the Albedo Effect, the Carbon Cycle, and Feedback Loops

Since the mid-1800s, when fossil-fuel burning began in earnest, CO_2 emissions have significantly increased (Figure 5.19). When CO_2 levels rise in the atmosphere, Earth's surface warms, and this warming has a variety of effects within Earth's systems. Some effects can actually accelerate the warming, making the climate change even faster. Other effects can reduce or reverse the warming trend and stabilize the climate.

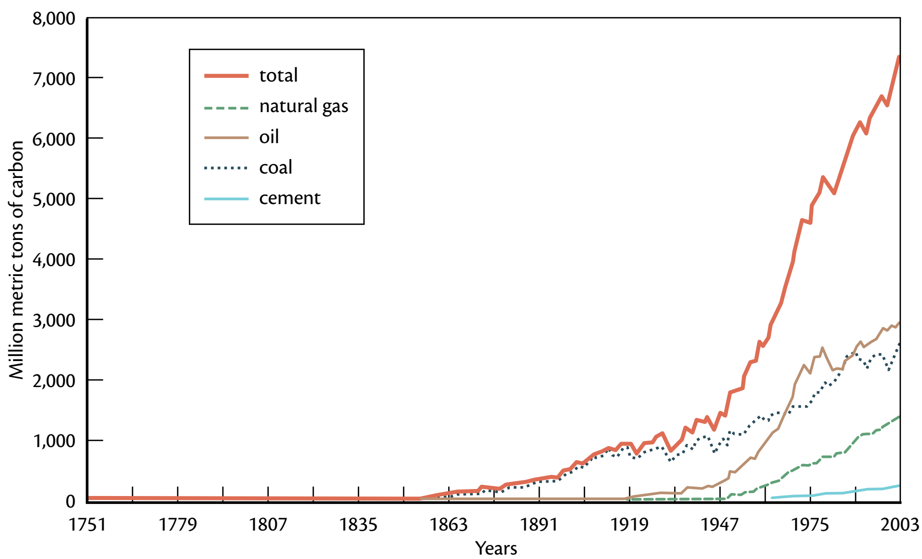


FIGURE 5.19
Global CO_2 emissions from fossil fuel use and cement production between 1751 and 2003.

When the concentration of greenhouse gases in the atmosphere causes more heat to be retained, the warmer temperatures decrease the amount of snow and ice cover in arctic regions, and this can initiate a **positive feedback loop** (a feedback that tends to accelerate change), as shown in Figure 5.20. From your work in Activity 2, you know that decreases in snow and ice cover lower Earth's albedo. When more heat is absorbed rather than reflected by the surface of Earth, this tends to increase the temperature of the atmosphere even more. The warmer temperatures mean that more snow and ice melts, lowering the albedo and raising the temperature even more, and so on. These types of positive feedback loops accelerate the warming trend—particularly as the amount of snow and ice decreases and forests expand northward over significant portions of the globe.

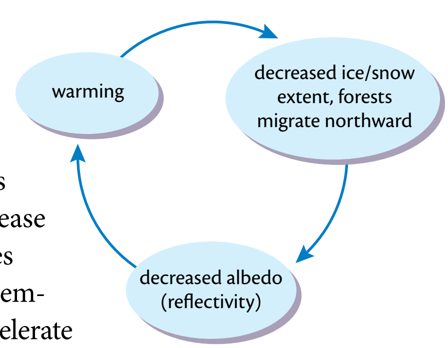


FIGURE 5.20
As warming temperatures decrease snow and ice cover in northern latitudes, this initiates a positive feedback loop and accelerates the warming trend.

Another type of feedback loop also occurs in Earth's system: a **negative feedback loop,** which tends to stabilize systems, keeping them from changing. An example of a negative feedback in Earth's climate system would be when warming temperatures lead to increased evaporation of water. If this evaporation leads to the formation of certain types of clouds—generally low clouds—

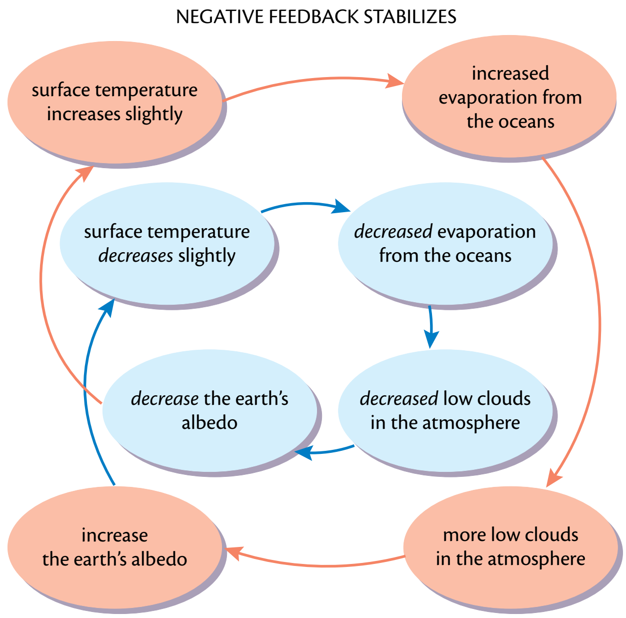


FIGURE 5.21
The warming of Earth's surface can increase evaporation rates, initiating a negative feedback loop and stabilizing Earth's climate.

the clouds tend to reflect more of the light energy from the Sun, cooling Earth's surface and stabilizing the climate, as shown above in Figure 5.21.

However, the behavior of Earth's climate system is not simple and easy to predict. Remember, that water vapor is a potent greenhouse gas and tends to trap heat energy radiating from Earth's surface. Therefore, increased rates of evaporation can also initiate a positive feedback loop, accelerating the rate of global warming. Scientists have found evidence that this type of positive feedback loop was responsible for the extremely hot conditions that exist today on Venus (although they don't expect anything so extreme to happen on Earth). Venus may have been partially covered with water (like Earth) early in the history of the solar system. Because it was a bit closer to the Sun, more of this water evaporated into the atmosphere. The water vapor in the atmosphere acted as a greenhouse gas, warming the planet even more, which evaporated more water into the atmosphere. This positive feedback loop eventually warmed the surface so much that all of the surface water boiled away. The water vapor in the atmosphere was broken apart by sunlight and the hydrogen escaped into space, so water can't form again. As you know from your work with the Carbon Cards in Activity 2, water plays a critical role in storing CO_2 in carbon sinks (in the ocean and in rocks). Without water to serve this role, CO_2 built up to extremely high levels in Venus's atmosphere.

Many other factors make it difficult to understand exactly what is happening and what is in store for Earth's climate. For example, fossil-fuel burning is also a major source of tiny airborne particles called aerosols. These aerosols have greatly increased in the lower part of Earth's atmosphere since the Industrial Revolution began in the mid-1800s. The aerosols increase the albedo of the atmosphere and tend to have a cooling effect on Earth's surface. Just how much of an effect these aerosols have is complicated to figure out, because the aerosols are difficult to measure. They vary in size and composition, are distributed unevenly in the atmosphere, and are added to and washed out of the atmosphere in a matter of days.

About the Reading

Write your responses to the following questions in your notebook. Be prepared to discuss your answers with the rest of the class.

1. Give an example of a positive feedback loop and a negative feedback loop from everyday life. Explain how these feedback loops tend to stabilize or change the conditions.
2. Scientists have determined that large amounts of carbon dioxide, and other greenhouse gases, such as methane, are locked in frozen ground (permafrost) in arctic regions. As the climate warms, these greenhouse gases are released to the atmosphere. What type of feedback loop (positive or negative) would you expect from release of these gases? Explain your thinking.
3. Describe some factors that make it difficult to predict the future of Earth's climate.

At this point, you've gathered a great deal of information about Earth's climate and the factors that can cause climate to change. Now, pull together what you have learned and prepare to play the role of a resident of Kivalina, participating in a public meeting in your community.

ADDRESS THE CHALLENGE

The citizens of Kivalina have called a public meeting to discuss what is happening to their community. They are trying to understand why the climate is changing and make some decisions about what they will do about it.

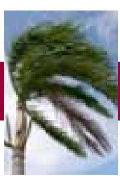
Members of the community are coming to the meeting with some opinions already formed. Generally, their thinking falls into three categories:

1. "We need to move! Our climate is changing because humans are burning more fossil fuels, and with less ice on the ocean, more heat will be absorbed and it will get even worse. We need to start looking for another home, off the island."
2. "Don't worry, we can stay—all will be fine. Our climate has been changing lately, but this is just temporary. The Earth will take care of us—whenever one thing changes, something else happens to bring it back into balance. I think we should just try to hold the sea back by building walls until the situation returns to normal."
3. "Let's wait a little longer to make a decision. The climate is complicated, and even if the global temperature is warming, we can't know what will actually happen in our community in the future. We should wait awhile longer and see what actually happens before we make a decision."

Now, prepare to attend the public meeting, representing one of the three viewpoints above. Join with others representing the same viewpoint, and get ready to convince your neighbors that your opinion is well founded. To make sure your group is ready, pull together your arguments and evidence, and prepare a written summary. Regardless of what you recommend, your written summary must include scientific information relating to all of the following concepts you studied in this chapter:

- The greenhouse effect and how CO_2 concentrations in the atmosphere can cause the climate to warm
- Other factors, such as the albedo effect, that affect how much heat is retained near Earth's surface
- Processes that contribute to or remove CO_2 from the atmosphere
- How human activities add to or subtract CO_2 from the atmosphere
- How positive and negative feedback loops can stabilize climate or accelerate change

Before the public meeting, share your written summary with your classmates, and read the summaries written by the groups with the other two viewpoints. Remember that your recommendations are being presented to your neighbors, who are not scientists. Convince them that you have a sophisticated understanding of this topic, but be sure to explain your information clearly. Think about what helps you understand a topic—use explanations that are precise and easy to understand, and use pictures and diagrams that will make the information clearer and emphasize your key points.



Consider Investigate **Process**

SHARE

You and your classmates will hold a public meeting, playing the role of members of the Kivalina community. Share your thinking about what the change in climate means for your community and what you should do. It's important for you to listen carefully to the groups that have a different viewpoint, so that you can come to a consensus about actions your community should take.

DISCUSS

Draw on the knowledge you've acquired in this chapter as you discuss these questions with your classmates. Your teacher may also ask you to record the answers in your notebook.

1. Think about how your personal ideas about the Kivalina situation were affected by the other ideas expressed at the public meeting. Describe something someone in another group said that you thought was convincing.
    a. Did your personal position initially differ from that assigned to your team? If so, how?
    b. Did you find that your position changed as you prepared your presentation?
    c. Did your position change after you listened to the arguments of the other groups?

2. Do you still have questions that need to be answered before you can decide what a community like Kivalina should do?
3. You probably found that you tried to persuade others by emphasizing information that helped your position, and deemphasizing other types of information. Give examples of how this might affect public discussion of scientific topics. How might you detect this type of bias?
4. Scientists can say with a high degree of confidence that Earth's average temperature is rising, but it is very difficult to predict the effect that will have on individual communities. Thinking back to what you learned about regional climates in Chapter 4, why are local predictions so difficult?
5. Earth's climate has changed significantly in the past, well before humans started burning fossil fuels. There have been ice ages and periods of time much warmer than today. If you wanted to figure out if the current warming trend is actually due to natural causes, how would you investigate this? Write a few questions you would have and explain how you would find the answers.
6. This chapter and the previous one provided an overview of many factors that influence regional and global climate. To understand the complex science involved in predicting climate change, you need to understand how all these factors relate to each other and how changes in one might affect the others. Create a concept map that relates the following list of terms to the concept of climate.

input of solar radiation
greenhouse effect
albedo effect
ocean currents
atmospheric circulation
water vapor
positive feedback
negative feedback
convection
continents
oceans
Hadley cell
polar cell
Ferrel cell
light energy (shortwave radiation)
snow and ice
clouds
prevailing winds
weather
precipitation
mountains
temperature
vegetation
desert
climate zones
latitude
elevation
heat capacity
carbon dioxide
heat energy (longwave, or infrared radiation)

Digging Deeper

The concepts you have been studying in this chapter play out in many different ways in the world. If you're interested in exploring more about these concepts, below are some interesting topics to investigate or research.

- Research other greenhouse gases, such as water vapor, methane, nitrous oxide, nitrogen trifluoride, and ozone. How are they added to and subtracted from the atmosphere? How significant are their effects compared to CO_2? Why?

- Research the concept of an urban heat island. How is this related to albedo? How does this affect climate?
- Look in newspapers and magazines for articles about climate change. Find one article that particularly interests you and research it further. Which scientists are referenced in the article? What is their scientific background, and what institution(s) do they work for? See if you can find links to other articles about the same topic and try to learn more. What did you learn that particularly interests you? What questions do you have after researching this article?

REVIEW

- Earth's climate system is driven primarily by energy received from the Sun in the form of light energy, or electromagnetic radiation. Some of this energy is absorbed by the clouds and Earth's surface, and some is reflected back into space.
- Most of the light energy that is absorbed by Earth's surface is reradiated as longer-wavelength heat energy. The greenhouse gases in Earth's atmosphere trap the longer-wavelength heat energy, which warms the Earth. Without this greenhouse effect, Earth would not be habitable.
- Earth's temperature is affected by the level of greenhouse gases in the atmosphere. As the concentrations of these gases increase, Earth's average temperature increases.
- Another factor that influences Earth's temperature is the albedo effect. Albedo is a measure of the percentage of incoming light energy that is reflected. Surfaces with an albedo of 1 reflect 100% of the light energy and will appear white. Surfaces with an albedo of 0 absorb all the light energy that strikes them and will appear black.
- Most of the surfaces struck by sunlight in Earth's atmosphere, land, and oceans have albedos between these two extremes. As Earth's albedo changes—the amount of heat energy absorbed versus reflected—the temperature at Earth's surface rises and falls. This causes regional, seasonal, and long-term global changes in Earth's temperature.
- Scientists relate the current global warming trend to increased levels of CO_2, a greenhouse gas, in the atmosphere. CO_2 is added to and subtracted from the atmosphere by way of a variety of human-induced and natural processes. Carbon continually cycles among vegetation, soils, the atmosphere, the ocean, sediment, and rocks via processes that occur over long and short time periods.
- CO_2 is transferred into and out of the atmosphere over the short term via photosynthesis, respiration, the diffusion of CO_2 into (and out of) the ocean, and the combustion of fossil fuels and organic material. Other processes also add CO_2 to the atmosphere over the short term, such as the burning or logging of forests and the melting of permafrost.

- CO_2 is transferred into the atmosphere over the long term by the volcanic activity associated with tectonic plate processes. CO_2 is removed from the atmosphere over the long term by the chemical weathering of rocks and the formation of rocks containing fossil fuels, such as coal, oil, and natural gas. These fossil fuels form over millions of years from the remains of plants and animals.
- Large amounts of carbon are stored as fossil fuels in rocks within Earth's crust. Scientists believe CO_2 levels are currently rising in the atmosphere because of the increased use of fossil fuels since the Industrial Revolution. These fossil fuels took millions of years to form, but the CO_2 is released in a very short time period via combustion.
- Earth's climate system is affected by negative and positive feedback loops. Negative feedbacks have a stabilizing effect and tend to keep conditions the same. Positive feedbacks are destabilizing and tend to cause a change in conditions.
- Earth's climate is not determined by one factor but by multiple interacting factors that vary through time. To predict how changes in any one variable, such as albedo or the level of greenhouse gases, will affect climate in the long run requires an understanding of the complex interactions of many aspects of Earth's climate system.

ASSESSMENT

1. Which of the following best describes how greenhouse gases raise the average temperature of Earth?
   a. They allow more light to penetrate the atmosphere.
   b. They are naturally hotter than other, nongreenhouse gases.
   c. They allow in short-wavelength light energy but prevent some of the long-wavelength heat energy from leaving the atmosphere.
   d. They have a very high albedo, which traps heat energy.
2. The walls of a building are to be painted to reflect as much light as possible. What color should they be painted?
   a. white
   b. red
   c. black
   d. pink
3. On a warm sunny day, you will feel cooler wearing light-colored clothes because they
   a. reflect more light energy.
   b. prevent sweating.
   c. are not as heavy as dark clothes.
   d. let more air in.

4. Rank the following surfaces from lowest to highest albedo:
   a. temperate forest
   b. desert
   c. ocean
   d. polar ice
5. Carbon can be stored in:
   a. vegetation
   b. rocks
   c. the atmosphere
   d. all of the above
6. The following is an example of a process that subtracts CO_2 from Earth's atmosphere:
   a. photosynthesis
   b. volcanism
   c. combustion
   d. respiration and decomposition
7. The following is an example of a process that adds CO_2 to Earth's atmosphere:
   a. volcanism
   b. respiration and decomposition
   c. both a and b
   d. neither a nor b
8. Scientists have proposed that the burning of fossil fuels increases the concentration of CO_2 in the atmosphere. This is because
   a. the burning of fossil fuels is creating a hole in the ozone layer.
   b. humans are burning fossil fuels at a much higher rate than fossil fuels are formed.
   c. fossil-fuel combustion creates particulate air pollution, which reflects more sunlight.
   d. chemical weathering processes are releasing CO_2 into the atmosphere.
9. Draw a diagram of the incoming light energy from the Sun that shows its absorption and reflection by Earth's atmosphere and by Earth's surface. Use arrows to indicate direction and relative amounts.
10. What is the albedo effect and why is it important?
11. Scientists have documented that global warming is causing the melting of ice at high latitudes. Describe how this could initiate a positive feedback loop.
12. As the temperatures near Earth's surface warm, this can lead to increased evaporation rates and cloud formation. Describe how the increased formation of clouds could initiate a negative feedback loop.
13. Is it possible that the increased formation of clouds could also lead to a positive feedback loop? Explain your answer.