SECTION 3

Global Warming

Have you ever gotten into a car that has been sitting in the sun for a while with all its windows closed? Even if the day is cool, the air inside the car is much warmer than the air outside. On a hot summer day, opening the door to the car can seem like opening the door of an oven.

The reason heat builds up inside the car is that the sun's energy streams into the car through the clear glass windows in the form of sunlight. The carpets and upholstery in the car absorb the light and change it into heat energy. Heat energy does not pass through glass as easily as light energy does. Sunlight continues to stream into the car through the glass, but heat cannot get out. The heat continues to build up and is trapped inside the car. A greenhouse works the same way. By building a house of glass, gardeners trap the sun's energy and grow delicate plants in the warm air inside the greenhouse even when there is snow on the ground outside.

Objectives

- Explain why Earth's atmosphere is like the glass in a greenhouse.
- Explain why carbon dioxide in the atmosphere appears to be increasing.
- Explain why many scientists think that the Earth's climate may be becoming increasingly warmer.
- Describe what a warmer Earth might be like.

Key Terms

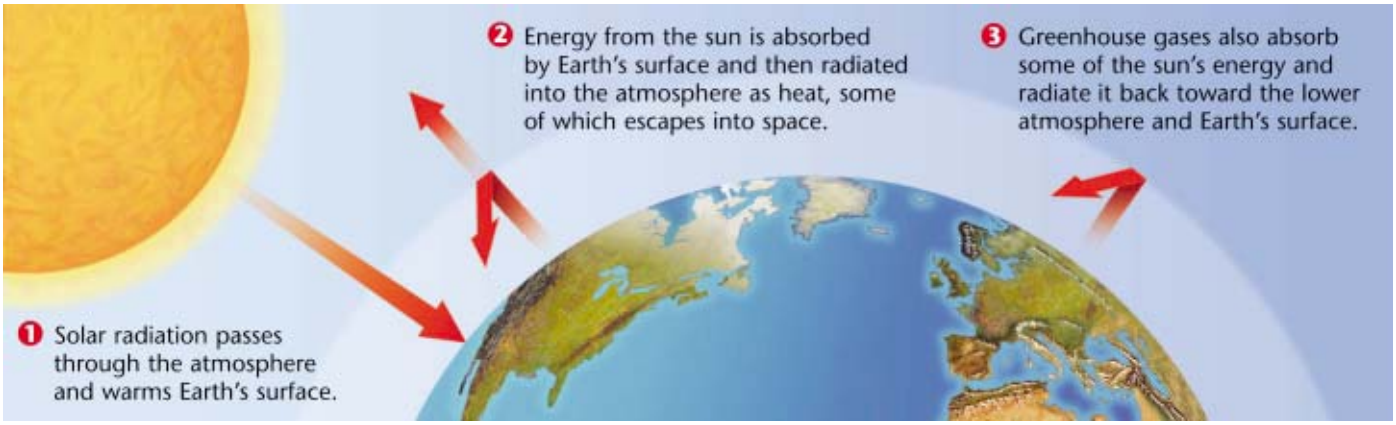
greenhouse gases
global warming
Kyoto Protocol

The Greenhouse Effect

The Earth is similar to a greenhouse. The Earth's atmosphere acts like the glass in a greenhouse. As shown in **Figure 14,** sunlight streams through the atmosphere and heats the Earth. As this heat radiates up from Earth's surface, some of it escapes into space. The rest of the heat is absorbed by gases in the troposphere and warms the air. This process of heat absorption is called the *greenhouse effect.*

Not every gas in our atmosphere absorbs heat in this way. The gases that do absorb and radiate heat are called **greenhouse gases.** The major greenhouse gases are water vapor, carbon dioxide, chlorofluorocarbons, methane, and nitrous oxide. Of these, water vapor and carbon dioxide account for most of the absorption of heat that occurs in the atmosphere.

Figure 14 ▶ How the Greenhouse Effect Works



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FIELD ACTIVITY

Carbon Dioxide Create a question dealing with carbon dioxide or carbon dioxide levels in the atmosphere. Investigate the FAQ section of the Carbon Dioxide Information Analysis Center's Web site to see if your question has already been answered. If not, click on "Ask Us a Question," and e-mail your question to the center. Report your findings to the class.

Measuring Carbon Dioxide in the Atmosphere In 1958, a geochemist named Charles David Keeling installed an instrument at the top of a tall tower on the volcano Mauna Loa in Hawaii. Keeling wanted to precisely measure the amount of carbon dioxide in the air, far away from forests and cities. In a forest, carbon dioxide levels rise and fall with the daily rhythms of photosynthesis. Near cities, carbon dioxide from traffic and industrial pollution raises the local concentration of the gas. The winds that blow steadily over Mauna Loa have come thousands of miles across the Pacific Ocean, far from most forests and human activities, swirling and mixing as they traveled. Keeling reasoned that at Mauna Loa, the average carbon dioxide levels for the entire Earth could be measured.

Keeling's first measurement, in March of 1958, was 314 parts per million of carbon dioxide in the air, or 0.0314 percent. The next month the levels rose slightly. By summer the levels were falling, but in the winter they rose again. During the summer, growing plants use more carbon dioxide for photosynthesis than they release in respiration. This causes carbon dioxide levels in the air to decrease in the summer. In the winter, dying grasses and fallen leaves decay and release the carbon that was stored in them during the summer. So, carbon dioxide levels rise.

Rising Carbon Dioxide Levels After only a few years of measuring carbon dioxide, it became obvious that the levels were changing in ways other than just the seasonal fluctuations. Each year, the high carbon dioxide levels of winter were higher, and each year, the summer levels did not fall as low. **Figure 15** shows the carbon dioxide measured from 1958 to 2000. By 2000, the average level of carbon dioxide was about 368 parts per million. Thus, in 42 years, carbon dioxide has gone from 314 to 368 parts per million, an increase of 54 parts per million or 17 percent. This increase may be due to the burning of fossil fuels.

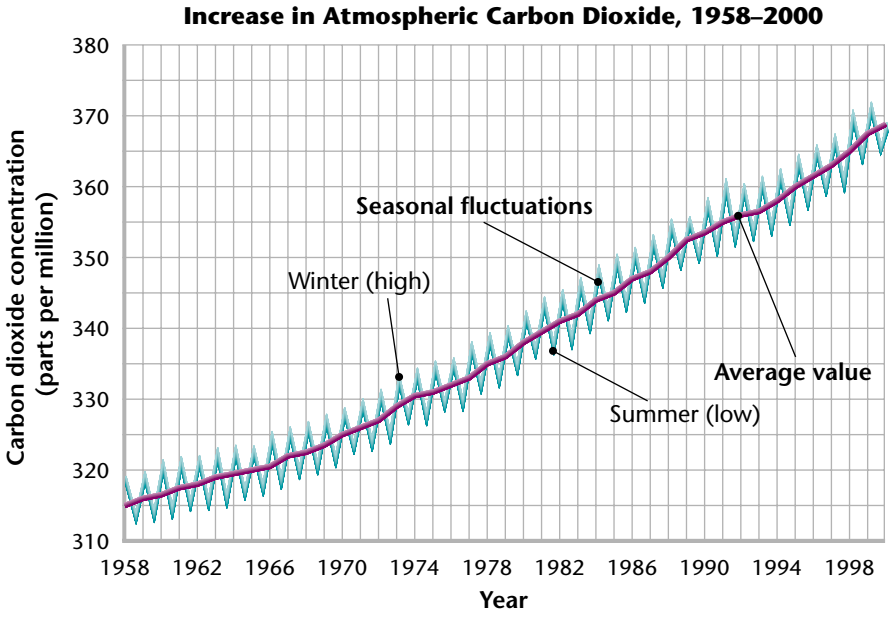

Figure 15 ▶ The graph shows that the average yearly concentration of carbon dioxide in the atmosphere has increased since 1958.

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Greenhouse Gases and the Earth's Temperature Many scientists think that because greenhouse gases trap heat near the Earth's surface, more greenhouse gases in the atmosphere will result in an increase in global temperature. A comparison of carbon dioxide in the atmosphere and average global temperatures for the past 400,000 years supports that view.

Today, we are releasing more carbon dioxide than any other greenhouse gas into the atmosphere. Millions of tons of carbon dioxide are released into the atmosphere each year from power plants that burn coal or oil and from cars that burn gasoline. Millions of trees are burned in tropical rain forests to clear the land for farming. Thus, the amount of carbon dioxide in the atmosphere increases. We are also releasing other greenhouse gases, such as CFCs, methane, and nitrous oxide, in significant amounts. **Table 2** shows the sources of some major greenhouse gases.

Table 2 ▼

Major Greenhouse Gases and Their Sources

Carbon dioxide, CO_2: burning fossil fuels and deforestation

Chlorofluorocarbons (CFCs): refrigerants, aerosols, foams, propellants, and solvents

Methane, CH_4: animal waste, biomass burning, fossil fuels, landfills, livestock, rice paddies, sewage, and wetlands

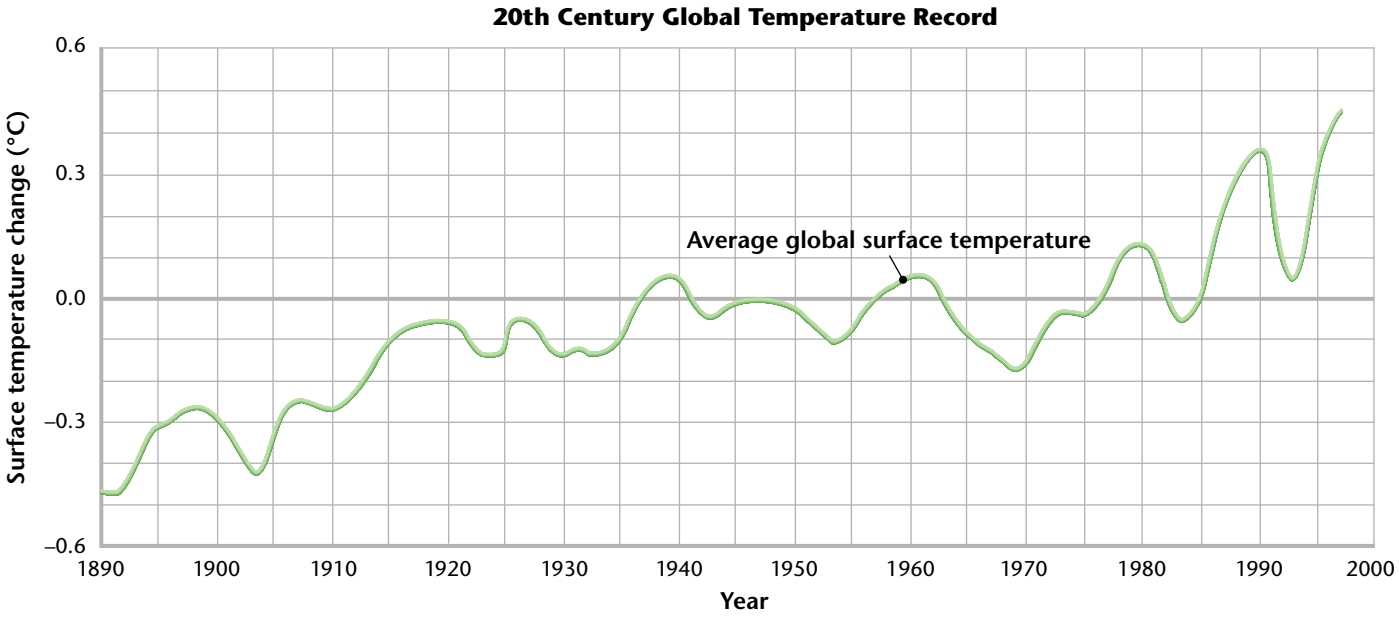
Nitrous Oxide, N_2O: biomass burning, deforestation, burning of fossil fuels, and microbial activity on fertilizers in the soil

Water vapor, H_2O: evaporation, plant respiration

How Certain Is Global Warming?

Many scientists think that the increasing greenhouse gases in our atmosphere result in increasing the average temperature on Earth. The result, they believe, will be a warmer Earth. This predicted increase in global temperature is known as **global warming.** As is shown by the graph in **Figure 16**, Earth's average global temperature increased during the 20th century. Many scientists project that the warming trend that began in the 20th century will continue throughout the 21st century. However, not all scientists agree that the observed global warming is due to greenhouse gases. Some scientists believe that the warming is part of natural climatic variability. They point out that widespread fluctuations in temperature have occurred throughout geologic time.

Figure 16 ▶ As shown by the graph, the surface of the Earth warmed during the 20th century.



Source: National Center for Atmospheric Research.

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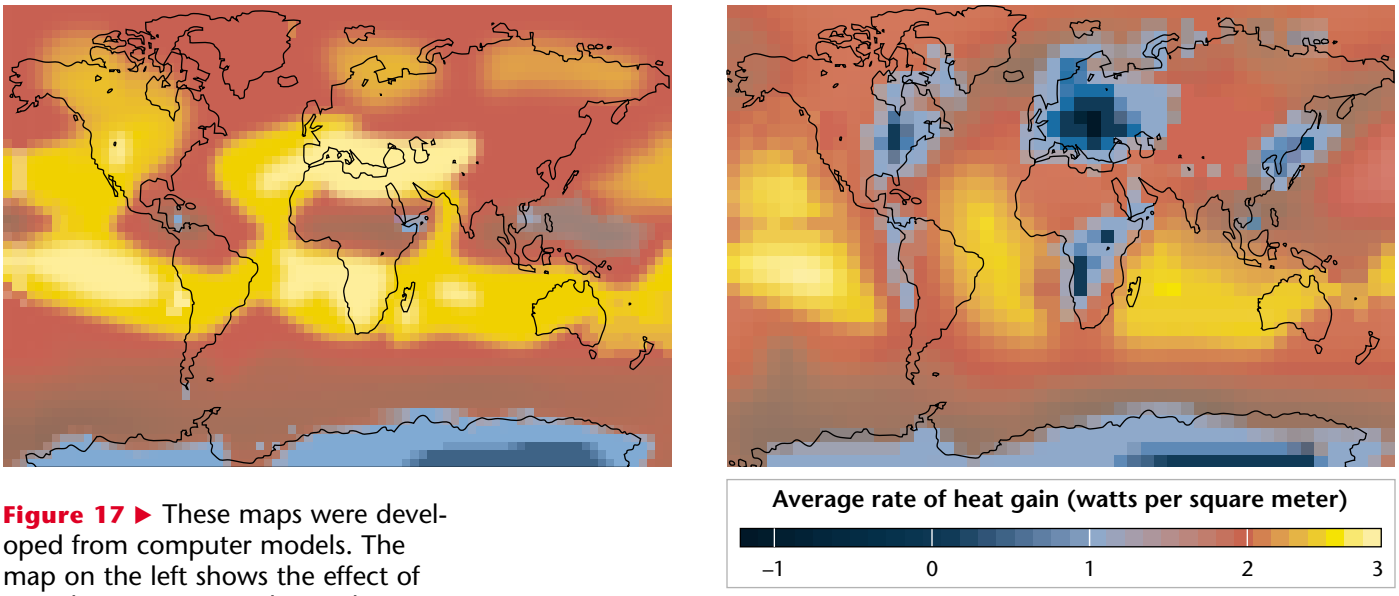

Figure 17 ▶ These maps were developed from computer models. The map on the left shows the effect of greenhouse gases on the Earth before sulfur pollution was added. The map on the right shows how the addition of the sulfur pollution variable shows a cooling effect.

Modeling Global Warming Scientists are currently unable to make accurate predictions about the rate of global warming because climatic patterns are complex and too many variables must be taken into account to be solved even using today's fastest computers. Predictions about climate change are based on computer models, such as the models shown in **Figure 17.** Scientists write equations representing the atmosphere and oceans. Scientists also enter data about carbon dioxide levels, prevailing winds, and many other variables. The computer models predict how phenomena such as temperature, rainfall patterns, and sea level will be affected. Computer modeling is complicated by the Earth's feedback processes that sometimes make it necessary to use different equations under changing simulated environments. These feedback processes are related to clouds, water vapor, ice, circulation changes within the oceans, changes in ocean chemistry, and changes in vegetation. Computer models of Earth's climate are becoming more reliable as more data are available, as additional factors are taken into consideration, and as faster computers are built.

Connection to Biology

Ocean Warming Commercial fishing in the northern Atlantic Ocean depends heavily on a fish called a *cod*. In recent years, the numbers of cod in the North Atlantic have greatly decreased. In 2001, English scientists embarked on a research project to find out if the decline in the numbers of cod was linked to the changing global climate. They sailed the ocean waters between Greenland and Iceland collecting samples of zooplankton. The scientists found that zooplankton levels have drastically decreased since 1963, the date of the last survey. The scientists believe that slowly warming ocean-water temperatures have in some way affected zooplankton in the North Atlantic Ocean and have in turn impacted the animals such as the cod that rely on the zooplankton as food.

The Consequences of a Warmer Earth

The Earth's climate has changed dramatically in the past. Many of those changes, however, occurred over thousands or millions of years. Scientists are not sure how quickly the Earth will warm or how severe the effects of global warming might be. Different computer models give different answers to these questions.

The impacts of global warming could include a number of potentially serious environmental problems. These problems range from the disruption of global weather patterns and global rise in sea level to adverse impacts on human health, agriculture, and animal and plant populations. Other impacts on the environment that could not be predicted by computer models might also arise.

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Figure 18 ▶ This is a satellite map of a 11,000 km² iceberg—the size of Connecticut!—that split off from the Ross Ice Shelf in Antarctica in March of 2000. Many scientists believe that scenarios like this would become more common if the poles grow warmer.

Melting Ice and Rising Sea Levels If the global temperature increased, the amount of ice and snow at the poles would decrease. The melting of ice and snow at the poles would cause sea levels around the world to rise. The rise in sea level might affect coastal areas in a number of ways. Coastal wetlands and other low-lying areas might be flooded. Enormous numbers of people who live near coastlines could lose their homes and sources of income. Beaches could be extensively eroded. The salinity of bays and estuaries might increase, which could adversely affect marine fisheries. Also, coastal freshwater aquifers could become too salty to be used as sources of fresh water.

Global Weather Patterns If the Earth warms up significantly, the surface of the oceans will absorb more heat, which may make hurricanes and typhoons more common. Some scientists are concerned that global warming will also cause a change in ocean current patterns, such as shutting off the Gulf Stream. Such a change could significantly affect the world's weather. For instance, some regions might have more rainfall than normal, whereas other regions might have less. Severe flooding could occur in some regions at the same time that droughts devastate other regions.

Human Health Problems Warmer average global temperatures could pose threats to human health. Greater numbers of heat-related deaths could occur as a result of global warming. Both very young people and very old people would have the greatest risk of heat exhaustion during periods of high temperatures. Concentrations of ground-level ozone could increase as air temperatures rise. Consequently, respiratory illnesses could increase, especially in urban areas. Furthermore, global warming could cause insectborne diseases to spread. Warmer temperatures might enable mosquitoes, which carry diseases such as malaria and encephalitis, to greatly increase in number.

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Figure 19 ▶ If climate change caused extreme weather to become more frequent, global agriculture would become severely impacted.

Agriculture Agriculture would be most severely impacted by global warming if extreme weather events, such as droughts, became more frequent. The effects of drought are shown in **Figure 19.** Higher temperatures could result in decreased crop yields. The demand for irrigation could increase, which would further deplete aquifers that have already been overused.

Effects on Plants and Animals Climate change could alter the range of plant species and could change the composition of plant communities. A warmer climate could cause trees to colonize northward into cooler areas. Forests could shrink in area in the southern part of their range and lose diversity.

Global warming may cause a shift in the geographical range of some animals. For example, birds that live in the Northern Hemisphere may not have to migrate as far south during the winter. Warming in the surface waters of the ocean might cause a reduction of zooplankton, tiny, shrimplike animals, that many marine animals depend on for food. The crabeater seal, shown in **Figure 20,** would be just one of the animals affected by a reduction in zooplankton. Warming in tropical waters may kill the microscopic algae that nourish corals, thus destroying coral reefs.

Figure 20 ▶ In spite of its name, the crabeater seal actually feeds on zooplankton. This seal is a resident of Antarctica.

Recent Findings

The Intergovernmental Panel on Climate Change (IPCC) is a network of approximately 2,500 of the world's leading climatologists from 70 countries. In 2001, the IPCC issued its Third Assessment Report (TAR). TAR describes what is currently known about the global climate system and provides future estimates about the state of the global climate system. Some of the findings of the IPCC included that the average global surface temperature increased by 0.6°C during the 20th century, that snow cover and ice extent have decreased, and that the average global sea level has risen. The IPCC has also reported that concentrations of atmospheric greenhouse gases have continued to increase as a result of human activities. It has also predicted that human influences will continue to change the composition of the Earth's atmosphere and continue to warm the Earth throughout the 21st century.

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Reducing the Risk

In 1997, representatives from 160 countries met and set timetables for reducing emissions of greenhouse gases. These timetables will go into effect when a treaty called the *Kyoto Protocol* is ratified by 55 percent of the attending nations. The **Kyoto Protocol** requires developed countries to decrease emissions of carbon dioxide and other greenhouse gases by an average of 5 percent below their 1990 levels by 2012. In March of 2001, the United States decided not to ratify the Kyoto Protocol. Most developed nations are going ahead with the treaty.

The need to slow global warming has been recognized by the global community. Some nations and organizations have engaged in reforestation projects to reduce carbon dioxide, such as the project shown in **Figure 21.** However, the attempt to slow global warming is made difficult by the economic, political, and social factors faced by different countries. Conflict has already arisen between developed and developing countries over future CO_2 emissions, the projections of which are shown in **Figure 22.**

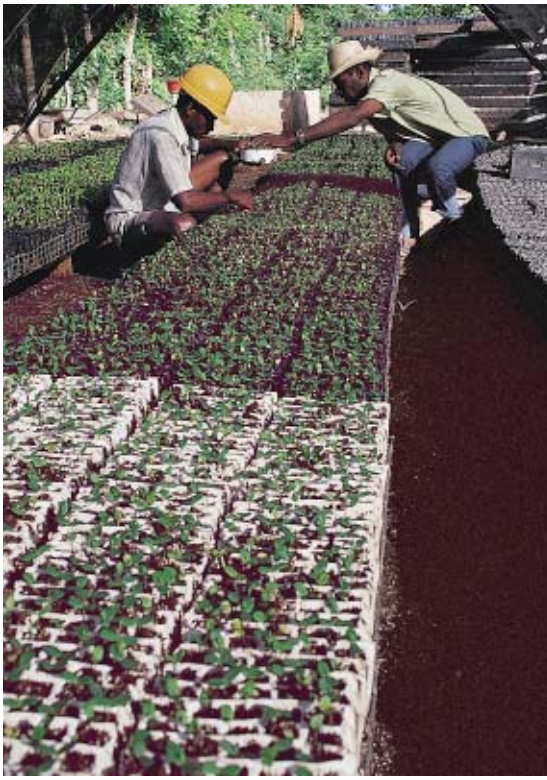
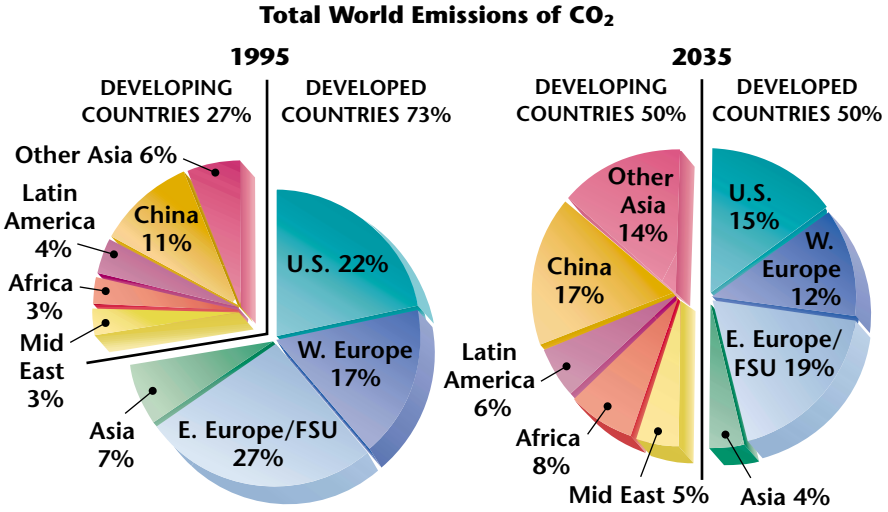


Figure 21 ▶ Because plants take in carbon dioxide during photosynthesis, reforestation projects such as this project in Haiti may help to offset a portion of global carbon dioxide emissions.



Source: U.S. Environmental Protection Agency.

Figure 22 ▶ Developing countries are projected to make up half of all CO_2 emissions by 2035. In 1995, total carbon released as CO_2 was 6.46 billion tons (5.86 billion metric tons). In 2035, total carbon emissions are projected to be 11.71 billion tons (10.62 billion metric tons).

SECTION 3 Review

1. **Explain** why Earth's atmosphere is like the glass in a greenhouse.
2. **Explain** why carbon dioxide in the atmosphere appears to be increasing.
3. **Explain** why many scientists believe Earth's climate may be getting increasingly warmer.
4. **Name** some of the possible consequences of a warmer Earth.

CRITICAL THINKING

5. **Making Predictions** Read the text under the heading "Modeling Global Warming." What difficulties do scientists face when they attempt to construct models that accurately predict the rate of global warming? READING SKILLS
6. **Analyzing Relationships** How could environmental problems in developing countries that result from global climate change affect the economies of developed countries, such as the United States?

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CHAPTER 13

Highlights

1 Climate and Climate Change

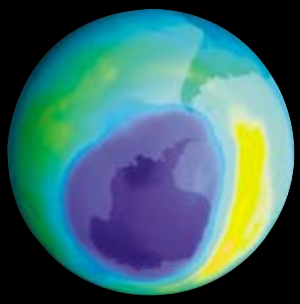
Key Terms

climate, 327
latitude, 328
El Niño, 332
La Niña, 332

Main Ideas

- Climate represents the long-term prevailing weather conditions at a particular place based on records taken.
- Factors that determine climate include latitude, atmospheric and oceanic circulation patterns, local geography, and solar and volcanic activity. Latitude is the most important determining factor of climate.
- The angle at which the sun's rays strike the Earth changes as the Earth moves around the sun. This change in angle is what causes the seasons to change.

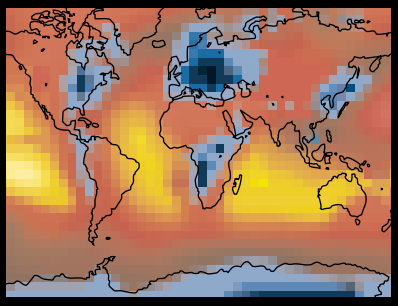
2 The Ozone Shield



ozone layer, 335
chlorofluorocarbons (CFCs), 335
ozone hole, 336
polar stratospheric clouds, 336

- The ozone layer in Earth's stratosphere absorbs most of the ultraviolet (UV) light from the sun.
- Chlorofluorocarbons are human-made chemicals that destroy ozone molecules and damage the ozone layer.
- Ozone levels measured over the polar regions have been decreasing over the past several decades.
- The thinning of the ozone layer may increase the harmful effects of ultraviolet light that reaches Earth's surface.
- In 1997, representatives from 160 countries ratified the Kyoto Protocol, which set timetables for reducing emissions of greenhouse gases.

3 Global Warming



greenhouse gases, 339
global warming, 341
Kyoto Protocol, 345

- Gases that absorb and radiate heat in the atmosphere are called *greenhouse gases*. The important greenhouse gases are water vapor, carbon dioxide, CFCs, methane, and nitrous oxide.
- The predicted increase in global temperature that occurs as a result of increasing greenhouse gases in the atmosphere is called *global warming*.
- Because climate patterns are complex, scientists use computer models to attempt to predict the rate of global warming.
- Global warming could produce a number of potentially serious environmental problems.

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CHAPTER 13 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *latitude*
2. *El Niño*
3. *chlorofluorocarbons*
4. *polar stratospheric clouds*
5. *Kyoto Protocol*

For each pair of terms, explain how the meanings of the terms differ.

6. *weather* and *climate*
7. *El Niño* and *La Niña*
8. *ozone layer* and *ozone hole*
9. *greenhouse gases* and *global warming*

STUDY TIP

Qualifiers When taking a test that contains multiple-choice, true/false, fill-in-the-blank, or matching questions, locate qualifiers in the sentences. Qualifiers are words, such as adjectives or adverbs, or groups of words that modify or limit the meaning of another word or group of words. *Never, always, all, some, none, greatest,* and *least* are examples of qualifiers. These words are the keys to the meaning of sentences.

Understanding Key Ideas

10. The belt of prevailing winds that is produced between 30° and 60° north latitude 30° and 60° and south latitude is called the
    a. doldrums.
    b. westerlies.
    c. polar easterlies.
    d. trade winds.
11. Which of the following statements about El Niño is true?
    a. El Niño is the cold phase of the El Niño–Southern Oscillation cycle.
    b. El Niño is a long-term change in the location of warm and cold water masses in the Pacific Ocean.
    c. El Niño produces storms in the northern Pacific Ocean.
    d. El Niño produces winds in the western Pacific Ocean that push warm water eastward.
12. Polar stratospheric clouds convert the products of CFCs into
    a. carbon dioxide.
    b. hydrochloric acid.
    c. nitric acid.
    d. molecular chlorine.
13. Which of the following is *not* an adverse effect of high levels of ultraviolet light?
    a. disruption of photosynthesis
    b. disruption of ocean food chains
    c. premature aging of the skin
    d. increased amount of carbon dioxide in the atmosphere
14. In which season (in the Northern Hemisphere) does carbon dioxide in the atmosphere decrease as a result of natural processes?
    a. fall
    b. winter
    c. summer
    d. spring
15. Which of the following gases is a greenhouse gas?
    a. carbon dioxide
    b. water vapor
    c. methane
    d. all of the above
16. Which of the following substances is *not* a source of methane?
    a. fossil fuels
    b. sewage
    c. fertilizer
    d. rice
17. The average global temperature increased by how many Celsius degrees during the 20th century?
    a. 0.4°C
    b. 0.6°C
    c. 0.8°C
    d. 1.0°C
18. Which of the following countries decided not to ratify the Kyoto Protocol?
    a. Russia
    b. United States
    c. Canada
    d. Australia

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CHAPTER 13 Review

Short Answer

19. Name three properties of air that are important for understanding how air circulation affects global climate.

20. Explain how local geography can influence the local pattern of precipitation.

21. Describe the properties chlorofluorocarbons possess that made them seem like miracle chemicals when they were discovered.

22. Explain why stratospheric ozone protection has been considered an environmental success story.

23. Explain the general process scientists use to make computer models of global warming.

24. Describe some of the environmental problems that rising sea level might cause.

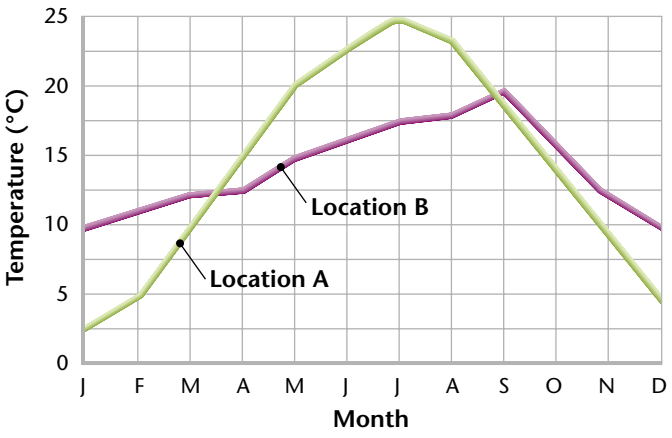
25. Describe what is currently known about the state of the climate system as reported in the 3rd Assessment Report of the Intergovernmental Panel on Climate Change.

Interpreting Graphics

The graph below shows the average monthly temperature of two locations that are at the same latitude but are in different parts of the United States. Use the graph to answer questions 26–27.

26. Which location has the smallest temperature range between summer and winter?

27. What factors could cause the difference in climate between the two locations?



Concept Mapping

28. Use the following terms to create a concept map: *ozone layer, ultraviolet (UV) light, chlorofluorocarbons, polar vortex, polar stratospheric clouds,* and *ozone hole*.

Critical Thinking

29. Making Predictions Over a long period of time, how might living things adapt to increased carbon dioxide levels and global warming? Do you think most species will adapt, or are many species likely to go extinct? Write a short essay that explains your answers. WRITING SKILLS

30. Analyzing Relationships Read about the harmful effects that ultraviolet light can have on humans as a result of ozone thinning under the head "Effects of Ozone Thinning on Humans." However, ultraviolet light serves an extremely important function that benefits life on Earth. Can you recall what that function is and how it helps make life on Earth possible? READING SKILLS

Cross-Disciplinary Connection

31. Economics Insurance companies set some of their rates by estimating the number of destructive natural events, such as hurricanes and floods, that will occur in the next 20 years. Explain why insurance companies would be interested in knowing scientists' predictions about global warming for the next two decades.

Portfolio Project

32. Designing a Pamphlet Design a pamphlet that documents the harmful effects of ultraviolet light on living things. Table 1 can be used as a source of information. You might also collect information by checking out the Web sites of the American Cancer Society and the Environmental Protection Agency. Distribute the pamphlet to your classmates, and include it in your portfolio.

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MATH SKILLS

33. **Making Calculations** In 1958, the carbon dioxide level measured in Earth's atmosphere was approximately 315 parts per million. In 2000, the carbon dioxide level in the atmosphere had increased to approximately 368 ppm. What was the average annual increase in carbon dioxide in the atmosphere between 1958 and 2000 measured in parts per million?

WRITING SKILLS

34. **Communicating Main Ideas** Imagine that you are a scientist who is studying the effects of chlorofluorocarbons on stratospheric ozone. Follow the path of a chlorine atom from the time it is released into the atmosphere from a CFC source through the time it has destroyed ozone molecules. Summarize your findings in a brief essay.

35. **Writing Persuasively** Imagine you are a scientist who has been studying the subject of global warming. You have been asked by the President of the United States to write a recommendation for his environmental policy on the subject. The President has asked you to provide important facts that can be used to promote the proposed policies. Summarize your recommendations in a brief letter.

36. **Writing Persuasively** You are the mayor of a low-lying coastal town. Write a plan of expansion for your town. The plan should takes global warming into account. Report your plan of expansion in front of the class.

READING FOLLOW-UP

Now that you have read the chapter, take a moment to review your answers to the **Reading Warm-Up** questions in your ***EcoLog.*** If necessary, revise your answers.

STANDARDIZED TEST PREP

Read the passage below, and then answer the questions that follow.

During photosynthesis, a plant takes in carbon dioxide from the air. Some of the carbon in the carbon dioxide becomes part of the plant's body. That carbon is not returned to the air until the leaves fall or the plant dies and decays.

Some plants, however, never completely decay. Instead, they are covered by sediments. After millions of years of being buried, the plants become coal, oil, or natural gas, which are fossil fuels. When fossil fuels are burned, they release the stored carbon as carbon dioxide. Millions of tons of carbon dioxide are released into the atmosphere each year from power plants that burn coal or oil and from cars that burn gasoline.

The burning of living plants also releases carbon dioxide. This process increases the carbon dioxide in the air in two ways. First, a burning plant gives off carbon dioxide. Second, when a living plant is burned, there is one less plant to remove carbon dioxide from the air by photosynthesis. As millions of trees are burned in tropical rain forests to clear the land for farming, the amount of carbon dioxide in the atmosphere increases.

1. According to the above paragraph, plants give off carbon dioxide
   a. when they are buried under sediments.
   b. when they die and decay.
   c. when they are burned.
   d. Both (b) and (c)

2. According to the paragraph above, which of the following is a process that does *not* add carbon dioxide to the atmosphere?
   a. burning gasoline in cars
   b. photosynthesis
   c. burning trees in tropical rain forests
   d. burning coal in power plants

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CHAPTER 13

Inquiry Lab: MODELING

Objectives

- **Examine** a model that shows how the movement of air creates a system of wind currents on Earth.
- USING SCIENTIFIC METHODS **Hypothesize** why the closed system of an aquarium is like the Earth and its atmosphere.

Materials

aquarium, 15 gal, glass, with cover
goose-neck lamp, adjustable, with a 100 W incandescent bulb
ice cubes, large (24)
incense stick
masking tape
matches
thermometers, outdoor (2)

Build a Model of Global Air Movement

Warm air rises and cools, and cold air sinks and warms. This is true whether we are observing the temperature and air circulation in a room or around the globe. On Earth, this movement of air creates a system of wind currents that you will demonstrate by building a model. You will build a closed system in which ice represents the polar regions and a lamp represents the equator. You will follow the movement of the air over these regions by watching a trail of smoke as it traces the path of air. (Remember that in the global circulation pattern, warm air moving toward the poles collides with cold air that is traveling from the poles. This collision, which takes place at about 60° north latitude and 60° south latitude, causes the warm air to rise.)

Procedure

1. Stack the ice cubes on the bottom of the aquarium against one end of it. Place the lamp outside the other end of the aquarium, and direct the bulb at the bottom half of that end. Use masking tape to attach one thermometer to each end inside of the aquarium. Make sure the thermometers can be read from the outside of the aquarium. Place the cover on the aquarium.
2. Wait 5 minutes. Then read and record the temperature at each end of the aquarium.
3. Light the end of the incense stick so that it produces a steady plume of smoke.

▶ **Step 1** Attach a thermometer to each end of the aquarium, making certain that the thermometers can be read from the outside of the aquarium.

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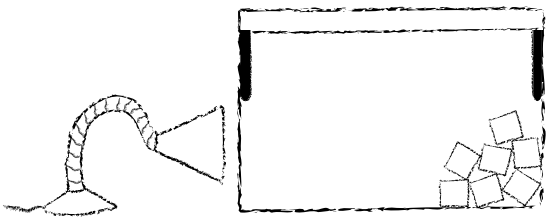
4. Lift the aquarium cover very slightly so that you can insert the incense stick. Hold it steadily in place over the ice about 5 cm from the cover, and observe the smoke.
5. Observe the movement of the smoke. How does the smoke behave? Draw a diagram of the aquarium. Use arrows to indicate the movement of the smoke in the aquarium.
6. Remove several ice cubes and record your observations.
7. Remove all of the ice cubes and record your observations.



▶ **Diagramming Smoke Flow** Make a simple diagram of the aquarium showing the position of the light source and the ice cubes. Draw arrows to indicate the movement of the smoke in the aquarium.

Analysis

1. **Explaining Events** Did the air movement pattern change after some ice was removed? Explain your answer.
2. **Explaining Events** Did the air movement pattern change after all of the ice was removed? Explain your answer.

Conclusions

3. **Drawing Conclusions** Why is the difference between temperatures at the two ends of the aquarium an important factor in the flow of heat through the aquarium?
4. **Making Predictions** Predict how air movement patterns will change if polar ice begins to thaw because of global warming.

Extension

1. **Analyzing Models** A closed system is a collection of elements that nothing can escape from or enter. Your aquarium is an example of a closed system. Convection is the movement of warm air relative to cooler air. Discuss your observations of convection in the closed system of the aquarium. How can you apply this information to the movement of air over the Earth?
2. **Analyzing Models** How is the Earth and its atmosphere like the closed system of your aquarium? What factors that affect air movement, climate, and weather exist on Earth but not in your model?

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Making a difference

OZONE SCIENTIST

Susan Solomon will not soon forget crawling across the roof of an Antarctic field station in windchill temperatures of –62°C (–80°F), moving heavy equipment, and adjusting mirrors while the winds howled and whipped about her. Sounds like an adventure, right? It sure was! But it is just part of what Solomon has done to establish herself as one of the world's leading authorities on ozone destruction.

Q: Is it true that you have traveled to the ends of the Earth to get information about the ozone layer?
A: Yes, I guess it is. My colleagues and I have studied the ozone hole in Antarctica, and we've measured and documented ozone chemistry above Greenland. But it's not all adventure. When I'm not visiting one of the poles, I run computer simulations of the atmosphere and study data at the National Oceanic and Atmospheric Administration (NOAA) in Boulder, Colorado.

Q: What is the significance of discoveries regarding the ozone hole?
A: Before British scientists discovered the ozone hole in Antarctica, no one was sure about ozone changes in the atmosphere. The popular belief was that in 100 years there might be 5 percent less ozone. So there were questions about whether it was a serious environmental problem. But when the British researchers released data that showed 50 percent less ozone over Antarctica in 1985 than was present 20 years earlier, the research raised our awareness that the problem was far more serious than previously thought.

▶ The ozone hole can be seen in this satellite image. The hole is the pale blue and black region immediately above Solomon's shoulder.

Q: How have you contributed to the study of ozone?
A: Well, when the British data was first released, no one had much of an explanation about what was causing the destruction of the ozone layer. I thought about the problem a lot. Later that year, I sat in on a lecture about types of clouds called *polar stratospheric clouds*. These are beautifully colored clouds that are known for their iridescence. While I was looking at these clouds, which are common in the Antarctic but rare elsewhere, it occurred to me that they may have something to do with ozone depletion. Perhaps they provide a surface for chemical reactions that activate reactive chlorine from CFCs (human-made chlorofluorocarbons). If so, once activated, the chlorine could contribute to reactions that destroy ozone.

Q: Did you get the chance to test your hypothesis?
A: Yes, the next year the National Science Foundation chose me to lead a group of 16 scientists for a nine-week expedition in Antarctica. We were the first team of scientists from the United States sent to the Antarctic to study the ozone hole. Within one month we could see that unnaturally high levels of chlorine dioxide did occur in the stratosphere during ozone depletion. This discovery was very exciting because it seemed that we were on the right track. We kept collecting data that year and collected more data during a second trip the next year. Pretty soon, the evidence seemed to support my hypothesis that CFCs and ozone depletion are linked.

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▶ Polar stratospheric clouds like these led Susan Solomon to make important discoveries about the cause of ozone depletion.

▶ Solomon has braved freezing polar temperatures to gather data about the ozone hole.

Q: How did this discovery make you feel?
A: On the one hand, it's very exciting scientifically to be involved in something like this. On the other hand, sometimes I think it's a little depressing. It would be nice to be involved in something more positive, to bring people good news. So far, we've brought nothing but bad news. We were hoping that we wouldn't find the same ozone chemistry in the Arctic that we found in the Antarctic. Unfortunately, we did. We hope for a positive result for the planet, but we don't always get it.

Q: How has your research helped to make a difference in our world?
A: Since our findings and others were announced, many of the world's countries have agreed to restrict or ban the use of CFCs. As a result, the ozone hole will eventually go away, but it will take a very long time. So although most countries have slowed their use of CFCs, CFCs from years past will still be hanging around in our atmosphere for the next 50 to 100 years. But I think our work has led in a small way to the realization that our actions do have consequences, and this realization should bring positive change.

Dr. Solomon has received international recognition for her work on the ozone hole over the Antarctic. She is a member of the U.S. Academy of Sciences, the European Academy of Sciences, and the Académie des Sciences de France. In 2000, Dr. Solomon was awarded the National Medal of Science and the American Meteorological Society's Carl-Gustav Rossby Medal. In April 2002, she was nominated co-chair of the United Nations Climate Change Working Panel.

For More Information

If you would like free information about the ozone layer and what you can do to protect it, contact the Environmental Protection Agency, Public Outreach, 401 M St. SW, Washington, DC 20460.

What Do You Think?

If Susan Solomon had not sat in on the lecture about polar stratospheric clouds and did not realize the role that these clouds play in ozone destruction, where do you think our current understanding of the ozone hole would be? How does this reinforce the idea that a single person can make a tremendous contribution to humankind?

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