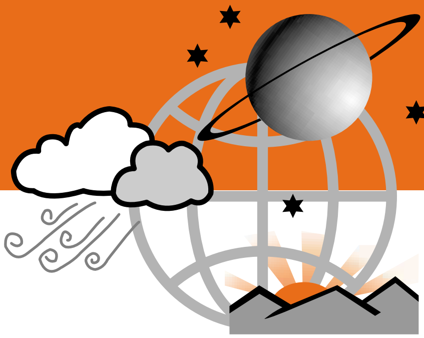


Chapter 23

Weather Hazards and the Changing Atmosphere

THE COST OF NATURAL DISASTERS

There are many ways to measure natural disasters. One measure is the cost to repair damage from the event. Hurricane Andrew crossed southern Florida in 1992, causing an estimated $25 billion in damage. The loss of human lives is an even greater tragedy. A disastrous cyclone (the name then applied to a hurricane in the Indian Ocean) struck Bangladesh in 1970. Bangladesh is a poor nation in the delta region of the Ganges River east of India. Scientists estimate that this storm took the lives of 300,000 people. It is difficult to estimate these grim statistics because such storms wipe out whole families and often destroy public records. Without such documents, the names and numbers of people living in the area at the time of the storm cannot be determined. Among all violent natural disasters, only a few of the largest earthquakes have killed more people than the 1970 Bangladesh hurricane.

In the United States, the greatest loss of life in any natural disaster occurred in 1900. At that time, Galveston, Texas, was the wealthiest city in the state and its major shipping port. A hurricane struck the city in September of that year. Galveston's geographic setting and the lack of advanced warning were the most important factors in this disaster. The city was built on a low-lying barrier island at the entrance to Galveston Bay. The highest point in the city was only 3 meters (10 feet) above sea level.

On the morning of the day the storm struck, no one could predict the events that would unfold in the next 12 hours. The storm came ashore when the storm surge had elevated the ocean nearly 4 meters (13 feet) above the normal high tide level, flooding the city. About 20 percent of the Galveston population of 38,000 people was lost in the 1900 storm. Figure 23-1 is a photograph taken in Galveston just after the 1900 hurricane.

A hurricane of similar strength struck the city 15 years later, but relatively few people were lost in that storm. To protect the city from the storm surge and pounding waves, a 5-meter-high sea wall had been built. Sand was used to raise the level of some parts of the island as high as the new sea wall.

Figure 23-1 Damage caused by the 1900 Galveston Hurricane.

Today, the residents of Galveston would know several days in advance if a major hurricane was approaching. The weather service gathers data primarily from weather radar and satellite images to provide storm warnings. A planned evacuation of the city could also save many lives.

WHAT WEATHER EVENTS POSE HAZARDS?

You have learned that the atmosphere can store great quantities of solar energy, primarily in water vapor. Some weather events concentrate that energy and release it to generate strong winds, excessive precipitation, and other hazards. Understanding storm systems and predicting their movements can save lives and property.

Thunderstorms

You have probably witnessed the build up of clouds leading to a thunderstorm. A **thunderstorm** produces rain, lightning, thunder, and sometimes strong winds and hail. Although thunderstorms can occur at any time of year, they are especially common during humid summer weather. Rapid updrafts caused by an approaching cold front may trigger the formation of massive storm clouds. Thunderstorms also are common in humid, tropical air masses. Some thunderstorm clouds extend to the top of the troposphere. Figure 23-2 on page 574 shows the vertical development and flared top characteristic of clouds that produce thunderstorms.

For reasons that scientists do not yet fully understand, positive and negative electrical charges separate in thunderstorm clouds. Sudden electrical discharges are observed as **lightning**. These electrical currents heat the air to temperatures higher than the surface of the sun. The electromagnetic energy they give off is observed as a flash of light, and the sudden expansion of air causes the sound of thunder.

Figure 23-2 Strong updrafts and flared tops are characteristics of clouds that produce thunderstorms.

Lightning can occur within clouds as well as between clouds, and between clouds and the ground. Lightning strikes cause about 100 deaths each year in the United States. Most lightning deaths are isolated events so they are seldom reported in the news media outside the local area. In many years, lightning is the leading cause of weather-related human fatalities in the United States.

ACTIVITY 23-1 LIGHTNING DISTANCE

(**NOTE:** Thunderstorms can be dangerous. Perform this activity only if you are in a well-protected location and under the supervision of a responsible adult.)

Light travels so fast that you see it essentially the moment it occurs. However, the sound of thunder travels much more slowly. Here is a way to estimate the delay in seconds between the flash of lightning and the sound of thunder arriving at our location. When you see the flash of lightning, begin counting slowly, one thousand one, one thousand two, one thousand three, etc., until you hear the clap of thunder. The distance to the lightning strike is about 1000 feet per second of separation, or about 1 mile for a 5-second delay (1 km for each 3-second delay.)

Flooding, strong winds, and damage from hail are other costly effects of violent thunderstorms. On a summer Saturday in 1976, a strong late afternoon thunderstorm hovered over the Rocky Mountains of Colorado. The storm dropped an estimated 10 to 12 inches of rain. Over a period of three hours the discharge of the Big Thompson River increased by a factor of 200. The water swept into a narrow canyon popular for recreational and camping activities. Along the river, 400 houses were destroyed and 145 lives were lost. Many of the victims had sought refuge from the rain and rising floodwaters in their cars. The flood swept the cars into the river, carrying them and their occupants away. Others, who abandoned their cars and scrambled up the rocks at the side of the canyon, survived and were rescued the next day.

Flash floods are a major hazard throughout the United States. They are a special hazard in the desert southwest where local roads often cross dry streambeds without bridges. Summer monsoon thunderstorms are common in this region. These storms may wash away small bridges, but the flood waters only block these crossings for a few hours at a time. The majority of flood deaths in this country are people who are swept away in their cars when they attempt to drive along roads that cross flooded streams.

The pellets of ice that fall during thunderstorms are called **hail**. Hail begins as small drops of frozen rain high in a thunderstorm cloud. As the ice is blown about within the cloud, it is repeatedly coated by liquid water. Each coating of water freezes and forms a new layer of ice. Eventually, the hailstones become too heavy to be held up by the strong updrafts, and they fall to the ground. Most hail pellets are less than 1 cm (0.4 inch) in diameter but hailstones the size of softballs have been recorded in the midwestern United States. Although rare, such large hailstones can break windows and dent cars. Figure 23-3 on page 576 shows the parts of the United States that have the most frequent thunderstorms.

Hail should not be confused with sleet. **Sleet** forms when drops of rain falling through a layer of cold air near Earth's surface freeze completely. Unlike hail, the ice particles in sleet are always the size of a raindrop or smaller (less than 5 mm), and sleet pellets are transparent. Sleet shows no evidence of

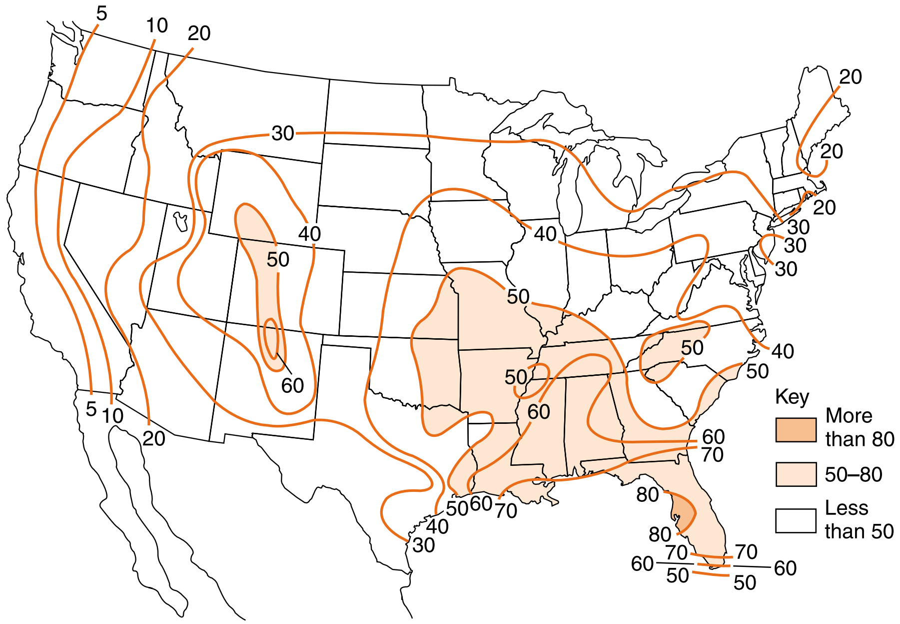


Figure 23-3
Thunderstorms are most common in the southeastern states where warm, humid conditions occur and cool continental air masses clash with tropical air masses.

multiple cycles of coating by water followed by uplift into cold air aloft where each coating freezes. Therefore, the formation of sleet does not require the violent updrafts that produce hail.

Blizzards

A **blizzard** is a winter snowstorm that produces heavy snow and winds of 35 mph (56 km/h) or greater. Blowing snow, limited visibility, and cold temperatures are typical of these storms. People can be stranded by blizzard conditions. Deep snow on county roads or city streets can shut down commerce and services. The wind and snow can break electric and telephone lines. Fire trucks and ambulances may not be able to reach places where they are needed. Some residents, especially the elderly, may be in danger because they run out of food or fuel. People caught outdoors in the storm or those who perform vital emergency services may suffer from frostbite and loss of body heat (hypothermia).

Major lake-effect winter storms were discussed in Chapter 20. Most of them are associated with outbreaks of arctic air masses. These storms usually involve fierce winds and blowing snow that can pile into deep drifts. Away from major lakes, cold continental air masses usually produce limited snowfall amounts. Greater snowfall is often associated with blizzards that draw moist air off the ocean as they move north through the Atlantic coastal states.

The legendary Blizzard of 1888 dumped nearly 2 feet (60 cm) of snow on New York City. The storm brought down recently installed electrical, telephone, and telegraph wires. Public transportation was crippled for several days. Even more snow fell in inland areas, but the "modern technologies" that made the city a marvel of its age also left it more vulnerable to the storm. Figure 23-4 is a weather map of a late winter blizzard that occurred in 1993. This unusual blizzard included snowfalls as deep as 4 feet (125 cm) in some inland areas. Notice the extreme pressure gradient shown by the closely spaced isobars. This pressure gradient caused winds of hurricane force in the 1993 storm.

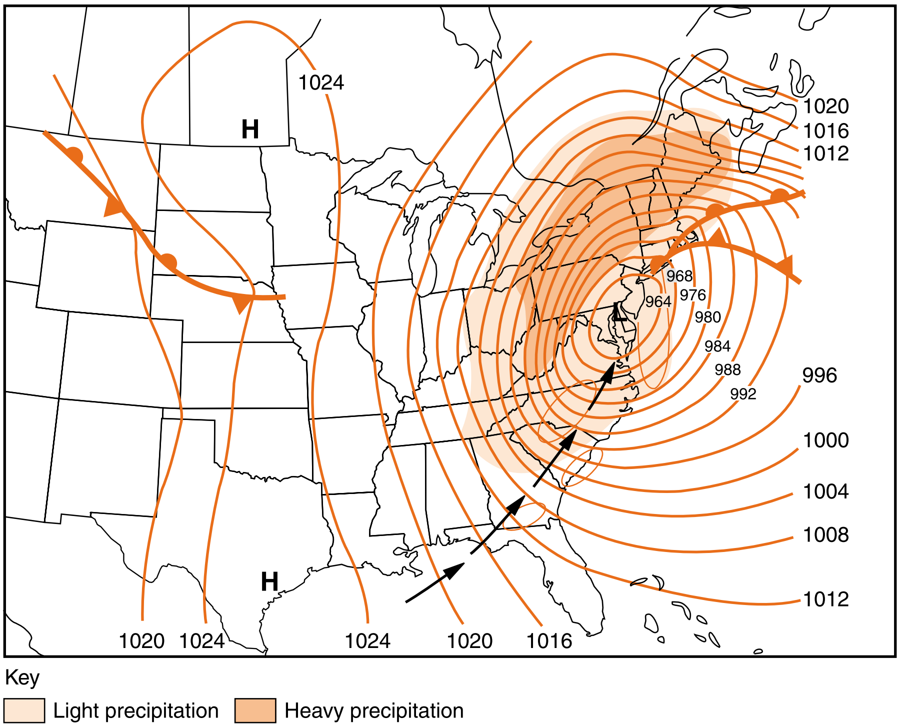


Figure 23-4 A late winter storm moved up the East Coast dumping as much as 4 feet of snow in some areas. The shading shows the most intense areas of snowfall on the morning of March 13, 1993. Notice the tightly spaced isobars, indicating an intense pressure gradient and unusually strong winds.

ACTIVITY 23-2 STORM SURVIVAL

List supplies that can be stored at home to help your family get through a major storm event. When your list is finished, number the items from most important to least important to keep in stock. Compare your list with classmates' lists.

ACTIVITY 23-3 A LOCAL WEATHER EVENT

Use local records such as newspaper articles to investigate and prepare a report on a historical weather event in your community.

Hurricanes

Hurricanes are the most destructive storms on Earth. Most hurricanes occur in the late summer and early autumn when the tropical ocean's surface water is warmest. Solar energy and the warmth of the ocean support evaporation, which carries water vapor and energy into the atmosphere. Hurricanes begin as tropical depressions (mild low-pressure regions) that become tropical storms when their winds exceed 39 mph (63 km/h). Vertical air currents and energy released by cloud formation (condensation) strengthen the storm. When sustained winds in a tropical storm exceed 74 mph (120 km/h), the storm is classified as a **hurricane**. In the eastern Pacific, these storms are known as typhoons, and in the Indian Ocean they are called cyclones.

Atlantic hurricanes commonly begin as small disturbances off the western coast of Africa. They gather strength as they drift to the west with the northeast trade winds. Some of them turn north before they reach North America and lose strength over the cooler water of the North Atlantic Ocean. Other hurricanes come ashore along the East Coast or move parallel to the coast, causing destruction for hundreds of miles.

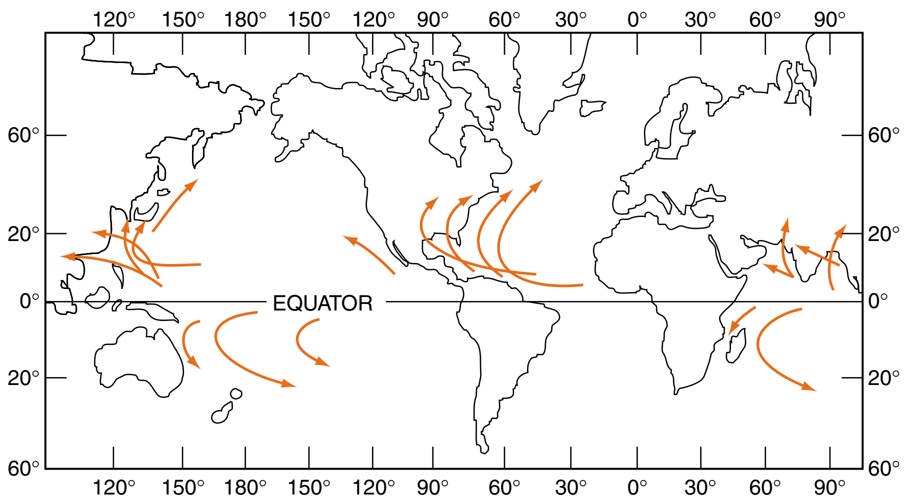


Figure 23-5 Hurricanes in the Atlantic Ocean usually drift westward toward North America. Most turn north until they enter the zone of prevailing west winds and finally drift to the east as they die out over land or cooler ocean water.

Hurricanes also originate over the Caribbean Sea or the Gulf of Mexico. They gather strength over these tropical seas before they hit land. When they move over North America they weaken because they are deprived of their fuel: water vapor from the warm ocean surface. Friction with land features is also an important reason that hurricanes usually weaken after they come ashore. Wind speed quickly decreases as the weakened hurricanes break up into a disorganized group of rainstorms that may cause flooding in inland areas. After turning northward, the remains of the storm are picked up by the eastward flowing jet stream or the zone of prevailing southwest winds. Figure 23-5 shows the most common paths taken by these tropical storms.

Hurricanes are very large. Some are more than 400 miles (600 km) in diameter. As in other Northern Hemisphere cyclones, winds circulate counterclockwise as they converge toward the center. From the outer bands of clouds to the center of the storm, wind speed generally increases, as does the intensity of precipitation. At the center of the strongest hurricanes, there is a small round area of relative calm known as the eye of the storm. In this region, the winds are light and the skies may be mostly clear. However, the calm of the eye is surrounded by the most violent part of the hurricane called the "eye wall" where the fastest winds and most intense rainfall occur. Some people think the storm is suddenly over when

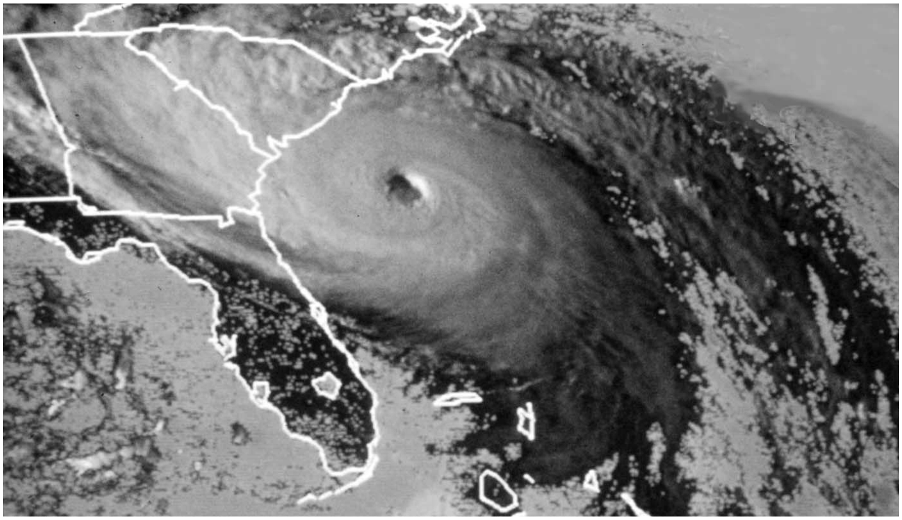


Figure 23-6 This is a satellite image of Hurricane Hugo. The cloud pattern of this major hurricane shows winds circulating counterclockwise as they converge toward the eye of the storm.

the eye of the storm passes over them. The approaching eye wall quickly brings them back to the reality of the second half of the storm. Figure 23-6 is a satellite image of Hurricane Hugo as it approached the coast of South Carolina in 1989.

The strength of hurricanes is measured on the Saffir-Simpson scale of hurricane intensity as shown in Table 23-1. Category 1 hurricanes are likely to do little damage to homes and other well-constructed buildings as long as they are not built directly along the coast. However, a category 5 hurricane will cause widespread damage and pose danger to nearly anyone caught in the strongest part of the storm.

TABLE 23-1 Saffir-Simpson Scale of Hurricane Intensity Categories

	Sustained Winds		Storm Surge		
Category	km/hr	mi/hr	m	ft	Potential Damage
1	119–154	74–95	1–2	4–5	Scattered
2	155–178	96–110	2–3	6–8	Moderate
3	179–210	111–130	3–4	9–12	Extensive
4	211–250	131–155	4–6	13–18	Extreme
5	>250	>155	>6	>18	Catastrophic

Hurricanes present the greatest danger to people in low-lying coastal cities, such as New Orleans, Louisiana, and Charleston, South Carolina, and even parts of New York City. Deadly hurricanes have come ashore along the coastline from Texas to New England. While hurricanes bring strong winds and heavy rainfall, the greatest cause of damage and fatalities is the storm surge. A storm surge forms as the result of the combination of very low atmospheric pressure and strong on-shore winds. These conditions can elevate the ocean's level to the point that the beach no longer protects buildings and other structures from the storm waves. The water rises so high that the waves hammer directly on homes and other structures along the oceanfront. People who have not evacuated the area may find themselves with no escape route, stranded for hours by violent seawater in a collapsing building. If the storm comes ashore at high tide, the height of the storm surge presents an even greater danger.

Over the past century, the cost of hurricane damage in the United States has increased, but the death toll has dropped as shown in Figure 23-7. People can move to higher ground, especially when evacuation routes have been established and updated warnings are given on radio and television. The principal cause of the increasing cost of hurricane damage is the development of shoreline areas. Although people can leave the shore for higher ground, the homes and resorts along the ocean remain vulnerable.

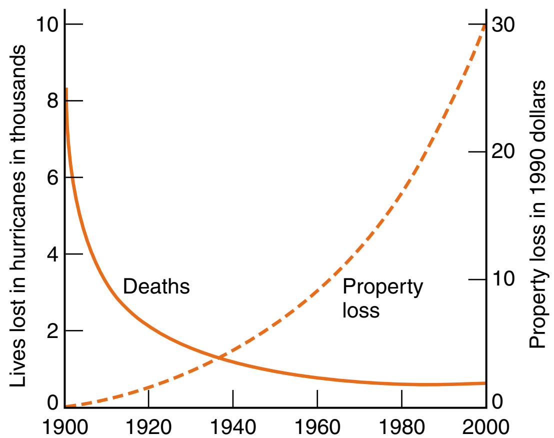


Figure 23-7 Over the past century, the number of deaths and injuries from hurricanes has decreased due to advanced storm warnings and emergency planning. However, property losses have increased due to the development of beachfront areas.

ACTIVITY 23-4 HURRICANE TRACKING

For this activity you will need an outline map that includes the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. The map must be clearly marked with terrestrial coordinates. Use the Internet or printed references to obtain tracking coordinates of a major Atlantic or Gulf of Mexico hurricane. Plot its daily path over the period of time that it was a strong storm system. Explain why the storm formed where it did and how it died out.

Tornadoes

In terms of area, tornadoes are very small storms, usually less than a third of a mile (0.5 km) in diameter. Most touch down for fewer than 10 minutes although some last for hours and skip from place to place over Earth's surface. Tornadoes are known to have the fastest winds on Earth: sometimes in excess of 300 mph (500 km/h). This is twice as fast as winds in the most violent hurricanes.

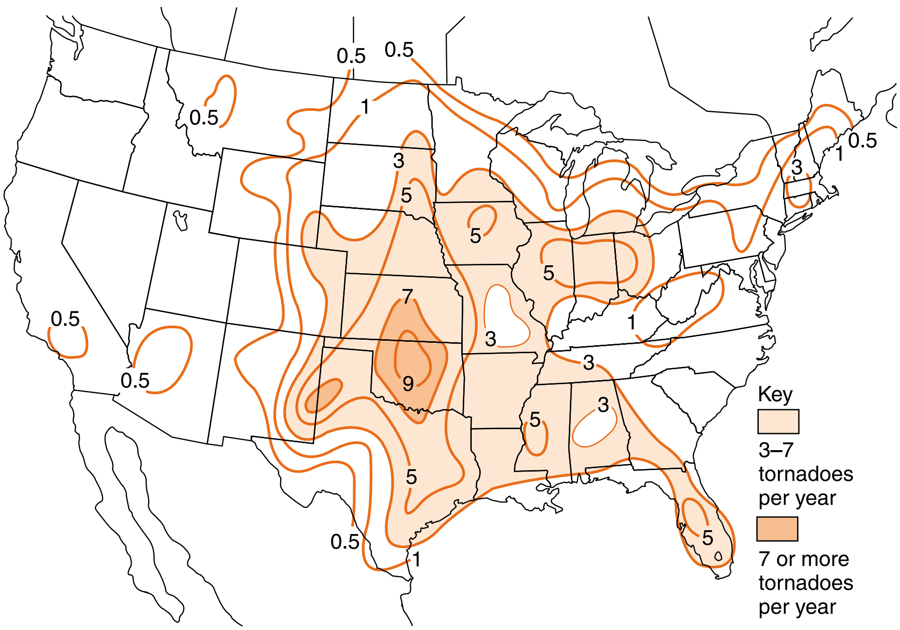


Figure 23-8 This map shows the annual number of tornadoes per 10,000 square miles. Note the similarity to the thunderstorm frequency map in Figure 23-3.

Tornadoes can occur throughout the United States and at any time of year. Nevertheless, they are most common in the Midwest and southern states from March through May as shown in Figure 23-8. At this time, strong cold fronts form in this region at the interface between polar and tropical air masses. Most tornadoes are born as swirling winds within a thunderstorm that intensify and extend upward into the cloud as well as down to the ground. The Fujita scale (F-scale) classifies tornadoes by their wind speed and damage from an F0 which causes light damage to F5 which causes total destruction along its path. Table 23-2 is the Fujita scale of tornado intensity.

Tornadoes can occur in swarms such as the outbreak of April 3–4, 1974. A total of 127 tornadoes, some of them F5, killed 315 people and injured more than 6000 along a path that ranged from Mississippi to western New York State. New York usually gets one or two confirmed tornadoes each year.

TABLE 23-2 Fujita Scale of Tornado Intensity

	Wind Speed		
Scale	**km/hr**	**mi/hr**	**Damage Potential**
F0	68–118	40–73	Light
F1	119–181	74–112	Moderate
F2	182–253	113–157	Considerable
F3	254–332	158–206	Severe
F4	333–419	207–260	Devastating
F5	420–513	261–318	Incredible

Recent research indicates that some of the greatest damage done in strong hurricanes is actually caused by tornadoes that form within the hurricane. Tornadoes are difficult to notice in the fury of the hurricane, but evidence of tightly swirling winds has been found in the debris left by some major hurricanes such as Hurricane Andrew that devastated a region south of Miami in 1992.

ACTIVITY 23-5 A MODEL OF A TORNADO

You will need two 1-liter soda bottles for this activity. Place waterproof, high-tack tape across the top of one bottle and put a small hole in the tape. Fill the second 1-liter soda bottle with water. With the full bottle at the bottom, tape the bottles one on top of the other at their necks. (Some science stores and suppliers sell special caps that connect these bottles, allowing water to flow between them.) When the connected bottles are turned upside down and gently rotated, the water falling into the empty bottle will form a tornado-like vortex.

How is this similar to a real tornado and how is it different?

Floods

In recent years, floods have taken the greatest toll of lives and property in the United States. Some are sudden events such as the flash flood that swept through Big Thompson Canyon in Colorado in 1976. Others are long-term events associated with unusual periods of above average precipitation or spring snowmelt.

The deadliest flood in American history occurred in Johnstown, a small industrial city in western Pennsylvania, in 1889. An earthen dam holding back a private recreational reservoir had been elevated above its original height, and then poorly maintained. The dam failed during an unusually heavy rainstorm. Water surged 24 miles (39 km) along the valley and down 400 feet (120 m) in elevation to the city of Johnstown. Built in a narrow valley, the city was destroyed in minutes and the lives of more than 2000 people were lost.

The Mississippi River and its tributaries have been subject to flooding throughout recorded history. Heavy regional rains and rapid snowmelt have led to spring floods, especially when the ground in the watershed is saturated. In 1993, floodwater covered an area the size of the state of Indiana and set new high-water marks at St. Louis. **Levees** are a high bank along a river of natural or human origin. Artificial levees have been constructed along most of the lower parts of the river to confine the river and prevent flooding of valuable farmland when the river runs high.

However, these structures have prevented floodwater from spreading over the floodplain. Levees also make the river run higher when it floods, thus increasing the danger if the levees break or overflow at flood stage. The levees have also allowed people to live in low areas near the river where breaks in the levees have caused extensive property losses.

Droughts

Many of the same areas subject to sudden flooding also suffer from drought. Rainfall is especially unpredictable in the Great Plains region of the United States. The climate has cycles of wet and dry years. Encouraged by several years of good precipitation, farmers rely on these conditions. However, the droughts return, and without irrigation, farming becomes impossible. Droughts do not lead to sudden loss of life as do storm events, but their long-term economic impact is probably greater.

HOW CAN WE PROTECT OURSELVES FROM WEATHER HAZARDS?

Although major storms cannot be predicted more than a few days in advance, people can make long-range plans to deal with them when they do occur. Advanced planning can prevent property losses. Educational programs about weather hazards help people learn what to do before the storm and how to survive if they are caught in potentially hazardous situations.

Historical Information

It is valuable to know what kinds of destructive weather events have occurred in your area in the past. These are the most likely weather hazards that will occur in the future. For example, hurricanes occasionally pass over New York State, causing damage related to storm surges, wave action, and winds in coastal areas such as Long Island. The greater threat from hurricanes in upstate New York has been flooding of low-lying areas along streams and rivers. Blizzards and thunderstorms are known to cause power and telephone outages and make travel difficult. Damage and danger from these storms can be avoided by careful planning.

Location

People who live in rural regions of New York State know that they can be isolated for days by blizzards and other storms. They need to keep emergency supplies of food and fuel for these events. Floods primarily affect homes and businesses in low-lying areas along streams and rivers. Coastal areas such as Long Island are subject to damage from hurricane storm surges and wave action.

Local Building Codes and Zoning

Perhaps the most important function of government is to protect people from harm. For example, construction codes are designed to require that buildings are made strong enough to withstand most local weather hazards and protect the people inside. Most communities have zoning laws that do not allow the construction of homes in areas at risk from weather hazards such as floods. Steep and unstable land may require special permits and inspections to ensure that the property is not prone to landslides and other forms of mass wasting. Many shoreline communities restrict construction close to the ocean to protect fragile beach environments and prevent storm damage to property.

Emergency Planning

Citizens can learn the best ways to protect themselves in case of weather-related emergencies. When a thunderstorm occurs, people should avoid exposed areas such as hilltops and open fields. It is also important to stay away from tall trees that may be hit or toppled by a lightning strike. Inside buildings, avoid anything that could provide a path for electricity such as electrical wires and water pipes. Automobiles, as long as they are not located in a flood zone, are usually safe locations in a thunderstorm because the metal shell of the vehicle conducts electrical energy around the occupants and into the ground.

Special plans can be made to notify and evacuate people from hazardous areas in case of severe weather. Residents can be informed of impending danger through the news media and loud sirens. Advanced planning helps to coordinate police and emergency services to evacuate people from locations prone to flooding. Roads and bridges in shore areas can be changed to one-way routes leading people to safety and preventing others from entering a danger zone.

ACTIVITY 23-6 COMPREHENSIVE EMERGENCY PLANNING

With the class divided into five groups, each group will select a different weather hazard: thunderstorm, blizzard, flood, tornado, or hurricane. The group will prepare a plan to deal with its weather hazard. The reports should include a section on the greatest dangers, how to prepare for the event, and what people should do (and not do) if caught in a severe weather event.

Early Warning Systems

Hurricanes, blizzards, and floods can usually be predicted several days in advance. The weather service broadcasts its forecast of approaching hazards on special radio frequencies and communicates these reports to the news media. Three levels of alert are used. An advisory indicates conditions that could produce a storm are expected in the near future. The second level is a storm watch, which means that conditions already exist for storm development. A storm warning indicates that a storm has actually been observed in the area, or that a storm is likely to appear at any moment.

Thunderstorms and tornadoes are especially difficult to predict because they are more localized than other weather hazards and they can appear with little or no warning. Doppler radar has become an important tool in identifying these hazards. It enables the weather service to identify swirling winds in storm systems many miles away. In November of 2002, many lives were saved by an early tornado warning in Van Wert, Ohio. In a movie theater, 50 patrons, including a large school group, were moved from the auditorium into bathrooms and interior hallways that were more structurally sound. When a tornado passed through 28 minutes after the warning, these were the only parts of the building left standing. Miraculously, no one in the theater was injured.

ACTIVITY 23-7 COMMUNITY PLANNING MAP

Use a map of your community to identify places where natural hazards are most likely to cause loss of lives and property. Make recommendations about building codes and how residents in those areas should prepare for natural hazards.

HOW IS EARTH'S ATMOSPHERE CHANGING?

Earth's atmosphere is nearly as old at the planet itself. When magma comes to the surface, pressure is reduced and bubbles of hot gas escape into the atmosphere. This process is known as **outgassing**. Gases collected from erupting volcanoes are about 80 percent water vapor, 10 percent carbon dioxide, and 10 percent other gases including nitrogen.

The world's oceans originated from water vapor vented during volcanic eruptions. The water vapor condensed and fell as precipitation. Carbon dioxide and other gases remained as Earth's atmosphere. Objects in space that are much smaller than Earth, such as our moon, do not have enough gravity to prevent gases from escaping into space. However, Earth has been able to hold onto its atmosphere and oceans.

Atmosphere and Life

If carbon dioxide is the most plentiful gaseous component of magma after water vapor, why is the atmosphere composed primarily of nitrogen and oxygen? Only a very small fraction of 1 percent of the present atmosphere is carbon dioxide. Both Mars and Venus have atmospheres that are mostly carbon dioxide.

Unlike our neighboring planets, conditions on Earth are favorable for the development of abundant life on the surface. The history of life and the evolution of the atmosphere are tightly coupled. Earth's earliest life-forms were primitive bacteria that thrived in an atmosphere that had no oxygen. Chemical evidence of these earliest life-forms has been found in rocks 3.5 billion years old. That is only 1 billion years after Earth formed.

The distance between Earth and the sun has played an important part in Earth's development. Consequently, Earth has moderate temperatures. Ocean water protected early life-forms from destructive solar radiation. Early plantlike life-forms in the oceans began to use the energy of sunlight to make food through *photosynthesis*. During photosynthesis, oxygen is produced as a waste product.

In fact, as oxygen built up in the atmosphere, the original life-forms could no longer live at the surface. Their descendants now occupy the deep oceans and subsurface environments where there is little free oxygen. As the atmosphere changed, other organisms, such as animals including humans, evolved that thrived in an environment of abundant

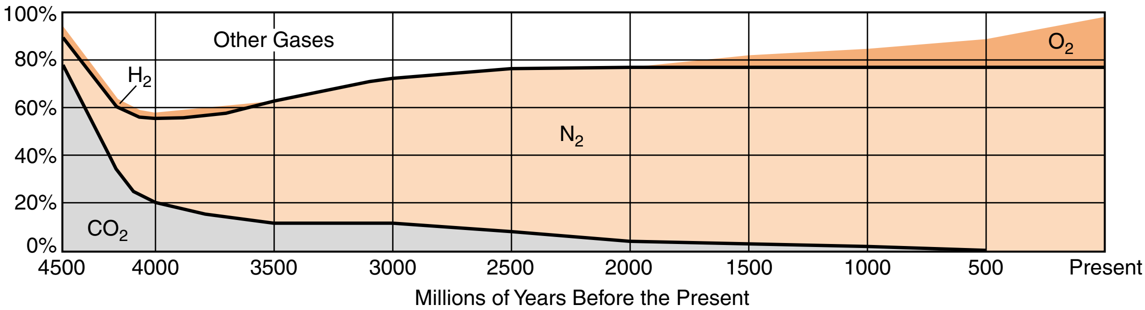


Figure 23-9 Earth's changing atmosphere.

oxygen. Oxygen also supports the ozone layer in the upper atmosphere that protects land dwellers from short-wave ultraviolet radiation. Today's atmosphere is in a dynamic balance sustained by plants that produce oxygen and animals that consume it. Figure 23-9 represents the changing composition of Earth's atmosphere throughout geologic history. The composition of Earth's atmosphere is still changing.

People Affect the Atmosphere

One major factor changing the atmosphere is the production of carbon dioxide through the burning of fossil fuels. As noted earlier, the concern is not simply the increasing carbon dioxide content of the atmosphere. Scientists are more concerned about global warming that could cause the melting of Earth's polar ice caps and other climatic changes.

The fuels that add carbon dioxide to the atmosphere also add oxides of nitrogen and sulfur. These compounds can act as condensation nuclei to form clouds. They also make the cloud droplets acidic. Nitric acid and sulfuric acid are strong acids. Although some of the acidity in the atmosphere comes from volcanoes venting the same substances, the human-generated part of the problem is much more troubling. Figure 23-10 shows smog caused by air pollution over the city of Los Angeles, California. **Smog** is a mixture of fog and smoke.

Acid clouds yield **acid precipitation** when the moisture falls as rain or snow. Some kinds of bedrock, such as lime-

Figure 23-10 The clouds obscuring downtown Los Angeles and the San Gabriel Mountains are smog caused mainly by emissions from burning fossil fuels.

stone and marble that contain calcite, can react chemically with these acids to neutralize them. However, most rocks do not.

The Adirondack Mountains are hit with a three-part problem of acid damage. Air pollution from the industrial sections of the Midwest drifts eastward into the Adirondacks on the prevailing southwesterly winds. Damage to trees from acid clouds is evident in the higher parts of the mountains and other places where trees cling to life in severe environmental conditions. Furthermore, there is little calcite in most of the rocks of the Adirondacks so the acid runs into streams and lakes. Some of the lakes in the Adirondacks are remarkably clear because normal plants and fish cannot live in the acid water. Acid damage is most severe when spring snowmelt brings a sudden rush of acidic water just when fish and plants are most vulnerable.

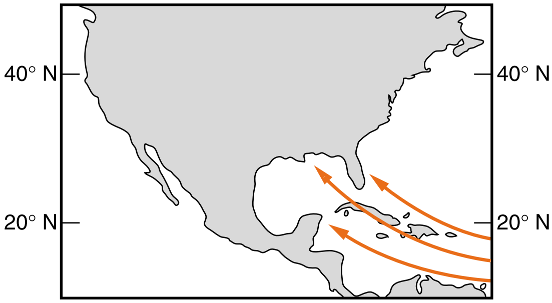
A historical look at Earth's atmosphere reveals three important facts. First, the composition of Earth's atmosphere has changed through geologic history, primarily in response to living organisms. Second, in the past century, human activities have become the most important cause of change in Earth's atmosphere. Those changes may have even more dramatic results in the next few centuries. Third, people need to understand the changes in the atmosphere and how they are likely to affect them. People may be facing a choice between reducing their effect on the atmosphere and adapting their lives to the changes that occur as a result of human technologies.

TERMS TO KNOW

acid precipitation
blizzard
freezing rain
hazard
hurricane
levee
lightning
outgassing
rain
rain showers
sleet
smog
snow showers
thunder
thunderstorm
tornado
velocity

CHAPTER REVIEW QUESTIONS

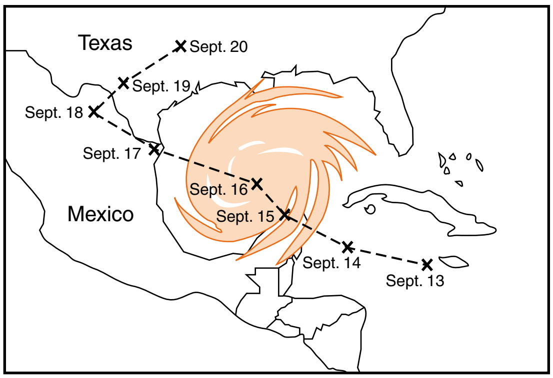
1. The map below shows part of North America.



The arrows on this map most likely represent the direction of movement of

(1) Earth's rotation.
(2) prevailing northeast winds.
(3) ocean conduction currents.
(4) Atlantic Ocean hurricanes.

Use the map below to answer questions 2 and 3. The map represents a satellite image of Hurricane Gilbert in the Gulf of Mexico. Each X represents the position of the center of the storm on the date indicated.



2. Which hazard caused by Hurricane Gilbert was probably the greatest threat to life and property along the coastline at the Texas-Mexico border?

(1) high air temperatures
(2) high barometric pressure
(3) sinking air currents from the upper atmosphere
(4) wave action at a time of high water levels

3. Why did Hurricane Gilbert weaken between September 16 and September 18?

(1) The hurricane changed into an anticyclone.
(2) The hurricane season ended in mid-September.
(3) The hurricane lost its source of warm ocean water.
(4) The pressure gradient within the hurricane increased.

4. Why do hurricane winds usually decrease when a hurricane from the Gulf of Mexico moves over North America?

(1) Land surfaces are always cooler than the ocean surface.
(2) Hurricanes usually turn to the west over North America.
(3) The air pressure gradient is greater over land.
(4) Vegetation and other features on the land surface slow the winds.

5. On a certain day, the isobars on a weather map are very close together over eastern New York State. To make the people of this area aware of possible risk to life and property in this situation, the National Weather Service should issue

(1) a dense-fog warning.
(2) a high-wind advisory.
(3) a heat-index warning.
(4) an air pollution advisory.

6. Venus has a greater concentration of carbon dioxide (CO_2) in its atmosphere than does Earth. As a result, surface temperatures on Venus are

(1) warmer due to absorption of long-wave (infrared) radiation.
(2) warmer due to absorption of short-wave (ultraviolet) radiation.
(3) cooler due to absorption of long-wave (infrared) radiation.
(4) cooler due to absorption of short-wave (ultraviolet) radiation.

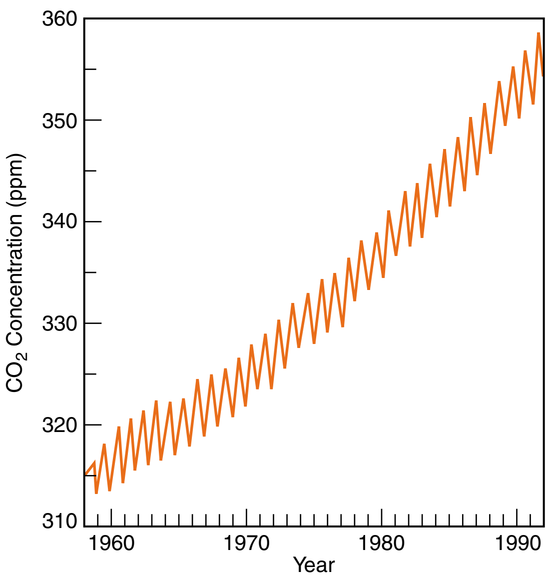
7. Scientists believe that Earth's early atmosphere changed in composition as a result of

(1) the appearance of oxygen-producing organisms.
(2) drifting of the continents.
(3) changes in Earth's magnetic field.
(4) transfer of gases from the sun.

8. An increase in which gas would cause the most greenhouse warming of Earth's atmosphere?

(1) nitrogen
(2) oxygen
(3) carbon dioxide
(4) hydrogen

9. The graph below shows the change in carbon dioxide concentration in parts per million (ppm) in Earth's atmosphere from 1960 to 1990.



The most likely cause of this overall change in the level of carbon dioxide is an increase in the

(1) number of violent storms.
(2) number of volcanic eruptions.

(3) use of nuclear power.
(4) use of fossil fuels.

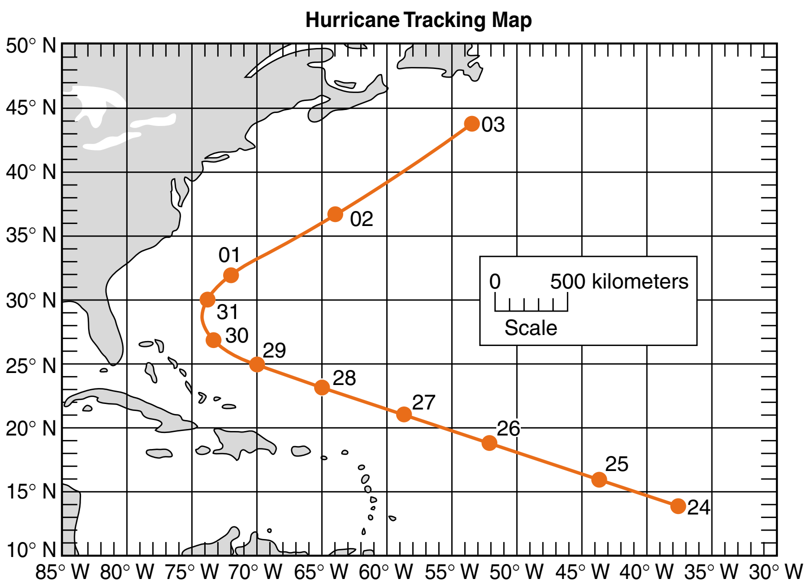
10. Which area is most likely to have the *least* ecological damage due to acid precipitation?

(1) a region of extrusive volcanic rocks including basalt and rhyolite
(2) a region sedimentary and metamorphic rocks including limestone and marble
(3) a high mountain area where trees begin to give way to other forms of vegetation
(4) a location downwind from a major population and industrial center

Open-Ended Questions

11. Most violent weather gets its energy from water vapor in the atmosphere. What must happen to the water vapor to make this energy available?

Base your answers to questions 12–14 on the two data tables and the hurricane-tracking map below. Location, wind velocity, air pressure, and storm strength are shown for the storm's center at 3 P.M. Greenwich time each day.



Data Table I

Latitude (°N)	Longitude (°W)	Date	Wind Velocity (knots)	Air Pressure (millibars)	Storm Strength
14	37	Aug. 24	30	1006	Tropical depression
16	44	Aug. 25	70	987	Category 1 hurricane
19	52	Aug. 26	90	970	Category 2 hurricane
21	59	Aug. 27	80	997	Category 1 hurricane
23	65	Aug. 28	80	988	Category 1 hurricane
25	70	Aug. 29	80	988	Category 1 hurricane
27	73	Aug. 30	65	988	Category 1 hurricane
30	74	Aug. 31	85	976	Category 2 hurricane
32	72	Sept. 01	85	968	Category 2 hurricane
37	64	Sept. 02	70	975	Category 1 hurricane
44	53	Sept. 03	65	955	Category 1 hurricane

Data Table II

Storm Strength Scale	Relative Strength
Tropical depression	Weakest
Tropical storm	↓
Category 1	
Category 2	
Category 3	
Category 4	
Category 5	Strongest

12. Describe two characteristics of the circulation pattern of the surface winds around the center (eye) of a Northern Hemisphere low-pressure hurricane.

13. The hurricane did not continue moving in the same compass direction during the entire period shown. Explain why the hurricane changed direction.

14. Calculate the average daily rate of movement of the hurricane from 3 P.M. August 24 to 3 P.M. on August 28. The hurricane traveled 2600 miles during this four-day period.

a. Write the equation to determine the rate of change.
b. Substitute data into the equation.
c. Calculate the rate and label it with the proper units.

15. *a*. State two dangerous conditions, other than hurricane winds, that could cause human fatalities as a strong hurricane strikes the coast in North America.

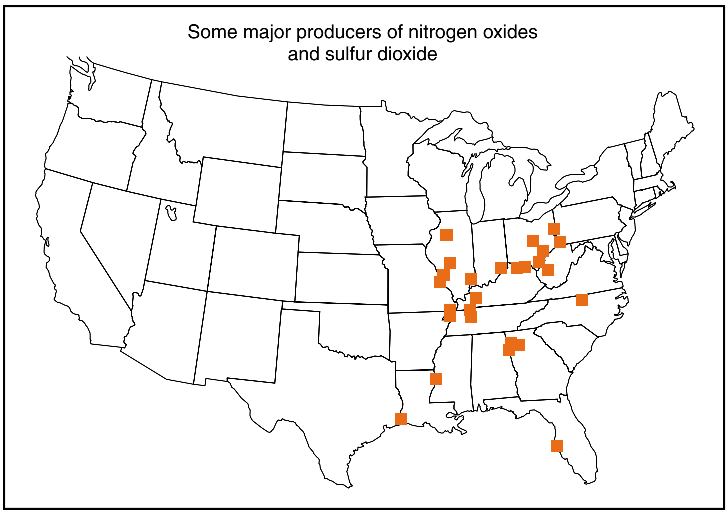
b. Describe one emergency preparation people could take to avoid a problem caused by either of the two dangerous conditions you stated in response to part *a* of this question.

16. An Earth science class is preparing a booklet on emergency preparedness. State one safety precaution that should be taken to minimize danger from each of the following hazards. You may not use the same answer twice.

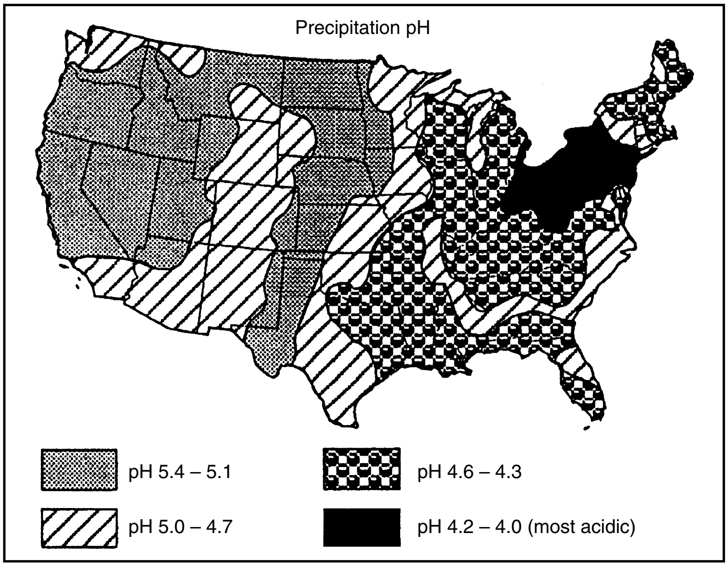
a. thunderstorm
b. tornado

Base your answers to questions 17–20 on the two maps below and the reading passage about acid rain.

Map I



Map II



Acid Rain

Acid deposition consists of acidic substances that fall to Earth. The most common type of acid deposition is rain containing nitric acid and sulfuric acid. Acid rain forms when nitrogen oxides and sulfur dioxide gases combine with water and oxygen in the atmosphere.

Human-generated sulfur dioxide results primarily from coal-burning electric utility plants and industrial plants. Human-generated nitrogen oxides result primarily from burning fossil fuels in motor vehicles and electric utility plants.

Natural events, such as volcanic eruptions, forest fires, hot springs, and geysers, also produce nitrogen oxides and sulfur dioxide.

Acid rain affects trees, human-made structures, and surface water. Acid damages tree leaves and decreases the tree's ability to carry on photosynthesis. Acid also damages tree bark and exposes trees to insects and disease. Many statues and buildings are composed of rocks containing the mineral calcite, which reacts with acid and chemically weathers more rapidly than other common minerals. Acid deposition lowers the pH of surface water. Much of the surface water in the Adirondack region has pH values too acidic for plants and animals to survive.

17. State one reason that the northeastern part of the United States has more acid deposition than other regions of the country.

18. Name one sedimentary or one metamorphic rock that is most chemically weathered by acid rain.

19. Describe one law that could be passed by the government to reduce problems caused by acid deposition.

20. Explain why completely eliminating human-generated nitrogen oxides and sulfur dioxide will not completely eliminate acid deposition.