

# Chapter 13

# The Nature of Storms

## What You'll Learn

- How thunderstorms, tornadoes, and hurricanes form.
- What the effects of severe weather are.
- How repetitive weather patterns can cause droughts, floods, and other hazards.

## Why It's Important

Severe weather can result in extensive property damage and loss of life. To implement safety measures and make other preparations for severe weather, it's necessary to understand when and where severe weather is likely to occur.



To find out more about severe weather, visit the Earth Science Web site at [earthgeu.com](http://earthgeu.com)



## Discovery Lab

Did you know that lightning causes thunder? During a thunderstorm, lightning can reach temperatures of 30 000°C. This extreme heat causes the air around the lightning to expand rapidly, then quickly cool and contract. The rapid expansion of air generates sound waves heard as thunder. You can model thunder using a paper bag.

1. Blow into a brown paper lunch bag until it is full of air.
2. Hold the top of the bag firmly in one hand and twist it so that the air inside is trapped. Take care not to tear the bag.

## Model Thunder

3. Strike the bag sharply with your other hand so that the bag breaks.

  **CAUTION:** Always wear safety goggles in the lab.

**Observe** What did you hear when the bag broke? How is this similar to the thunder produced by a lightning bolt? Light moves much faster than sound. Knowing this, what can you infer about the movement of a thunderstorm if the amount of time between when you see the lightning and hear the thunder increases between each lightning flash?



### SECTION

## 13.1

## Thunderstorms

### OBJECTIVES

- **Identify** the processes that form thunderstorms.
- **Compare and contrast** different types of thunderstorms.
- **Describe** the life cycle of a thunderstorm.

### VOCABULARY

air-mass thunderstorm  
sea-breeze thunderstorm  
frontal thunderstorm

At any given moment, nearly 2000 thunderstorms are occurring around the world. Most do little more than provide welcome relief on a muggy summer afternoon. Some, however, grow into atmospheric monsters capable of producing hail the size of baseballs, swirling tornadoes, and surface winds of more than 160 km/h. These severe thunderstorms can also provide the energy for nature's most destructive storms: hurricanes. All thunderstorms, regardless of intensity, have certain characteristics in common.

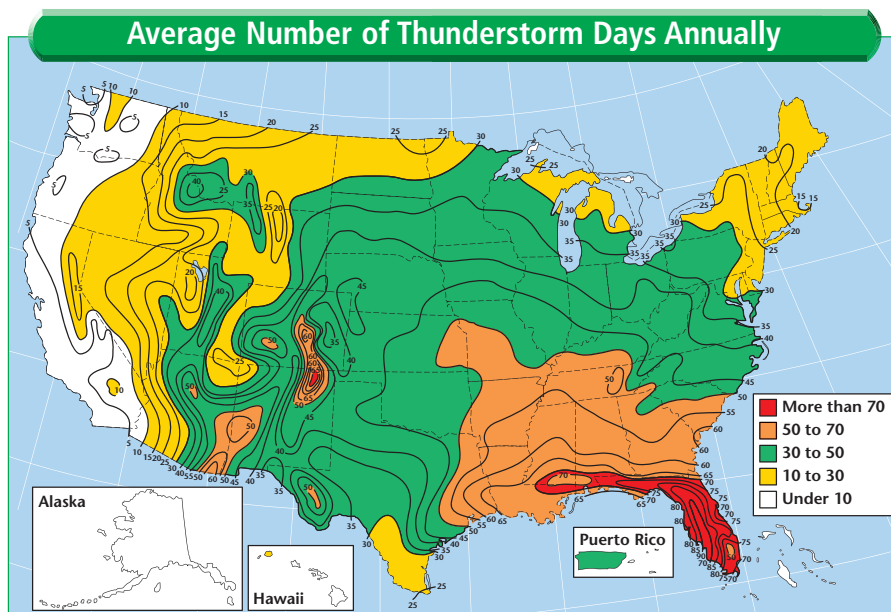
### HOW THUNDERSTORMS FORM

In Chapter 11, you learned that under the right conditions, convection can cause a cumulus cloud to grow into a cumulonimbus cloud. You also learned that cumulonimbus clouds produce thunderstorms. What conditions are necessary for this to happen? For a thunderstorm to form, three conditions must exist. First, there must be an abundant source of moisture in the lower levels of the atmosphere.

As this moisture condenses, it releases latent heat. The release of latent heat keeps the cloud warmer than the air around it, which is crucial in maintaining the upward motion of the cloud. Second, some mechanism must lift the air so that the moisture can condense and release latent heat. You'll read about these mechanisms on the next page. Last, the portion of the atmosphere through which the cloud grows must be unstable. In other words, the air must continue to cool with increasing altitude for the growing cloud to stay warmer than the surrounding air. Recall that air can rise only if it's warmer than the air around it. If an air mass is stable, even the release of latent heat will not keep that air warmer than the air around it. The upward motion and growth of the cloud will stop.

**Limits to Growth** If the three conditions just described are met, the air will keep rising, causing more moisture to condense and creating more latent heat. This process will continue until the rising air meets a layer of stable air that it cannot overcome, or until the rate of condensation, which diminishes with height, is insufficient to generate enough latent heat to keep the cloud warmer than the surrounding air. This second factor limits most cumulonimbus clouds to a height of around 18 000 m. Because of factors which you'll learn about later in this section, typical thunderstorms last only about 30 minutes, and individual storms are only about 24 km in diameter. *Figure 13-1* shows which areas of the United States experience the most thunderstorms annually.

**Figure 13-1** Geography and the movement of air masses both play roles in making thunderstorms most common in the south-eastern United States.



Source: National Climatic Data Center, NOAA

## AIR-MASS THUNDERSTORMS

Earlier you learned that some mechanism must lift air through a growing cloud so that its moisture can condense and release latent heat. Thunderstorms are often classified according to the mechanism that caused the air to rise. If the air rose because of unequal heating of Earth's surface within one air mass, the thunderstorm is called an **air-mass thunderstorm**. The unequal heating of Earth's surface reaches its maximum during mid-afternoon. Thus, air-mass thunderstorms are most common then.

There are two common types of air-mass thunderstorms. Mountain thunderstorms occur when an air mass rises as a result of orographic lifting, which, as you learned in Chapter 11, involves air moving up the side of a mountain. Sea-breeze thunderstorms are common along coastal areas during the summer, especially in the tropics and subtropics. **Sea-breeze thunderstorms** are local air-mass thunderstorms caused in part by extreme temperature differences between the air over land and the air over water, as shown in *Figure 13-2*.

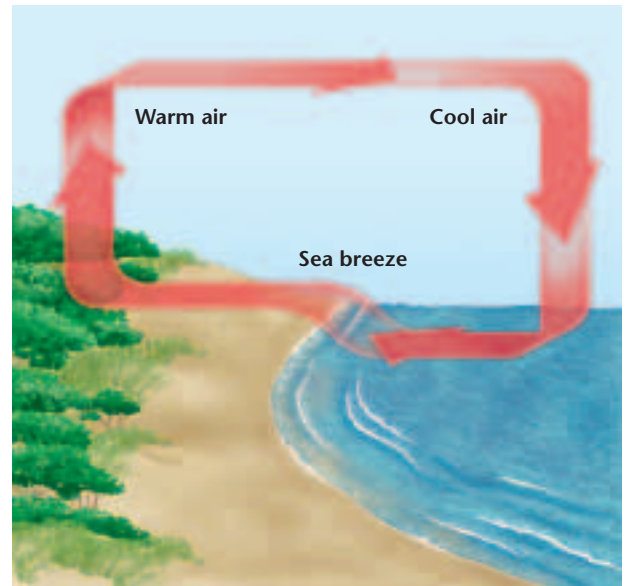
## FRONTAL THUNDERSTORMS

The second main classification of thunderstorms is **frontal thunderstorms**, which are produced by advancing cold fronts and, more rarely, warm fronts. In a cold front, cold air pushes warm air rapidly up the steep cold-front boundary. This rapid upward motion can produce a line of thunderstorms, sometimes hundreds of kilometers long, along the leading edge of the cold front. Cold-front thunderstorms get their initial lift from the push of the cold air. Because they are not dependent on daytime heating for their initial lift, cold-front thunderstorms can persist long into the night.

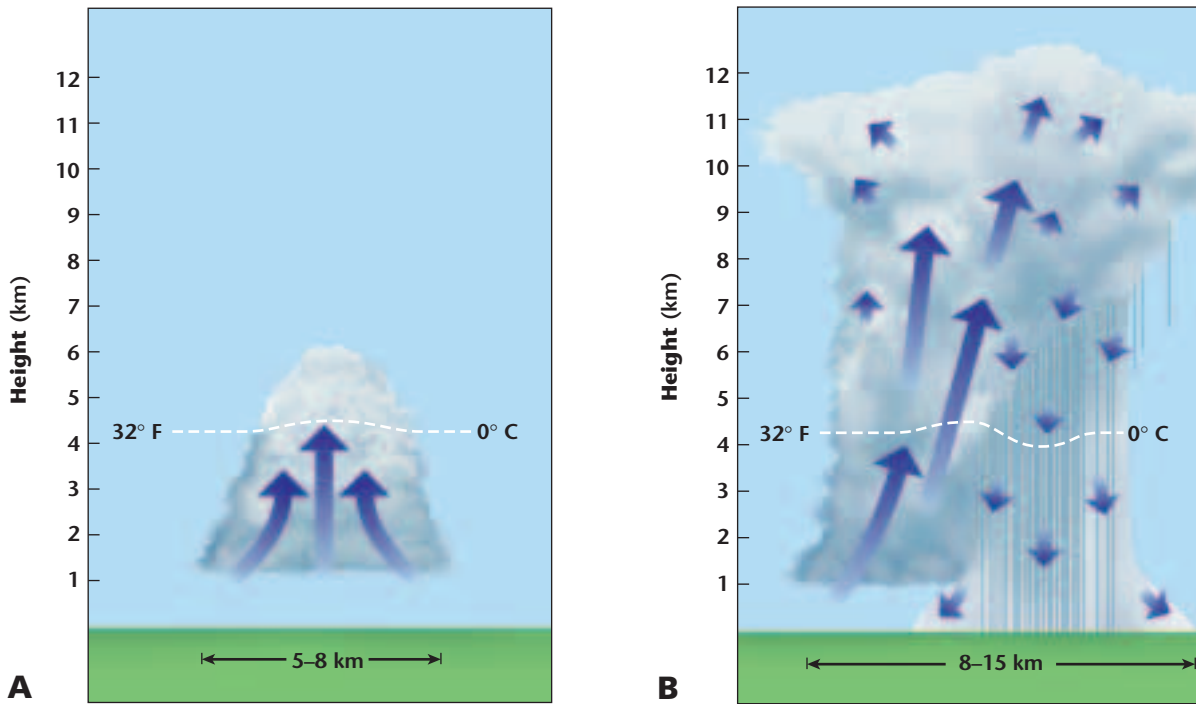
Less frequently, thunderstorms can develop along the advancing edge of a warm front. In a warm front, a warm air mass slides up and over a cold air mass. The boundary between the two air masses is not steep; thus, the air rises gradually. However, if the warm air behind the warm front is unstable and moisture levels are sufficiently high, a relatively mild thunderstorm can develop.

## STAGES OF DEVELOPMENT

A thunderstorm usually has three stages: the cumulus stage, the mature stage, and the dissipation stage. The stages are classified according to the direction in which the air is moving.



**Figure 13-2** During the day, cool air over the ocean moves inland and creates a sea breeze. The cool air forces warm air over the land to rise. The rising air cools and sinks, creating a convection cell. These conditions can produce strong updrafts that result in thunderstorms.

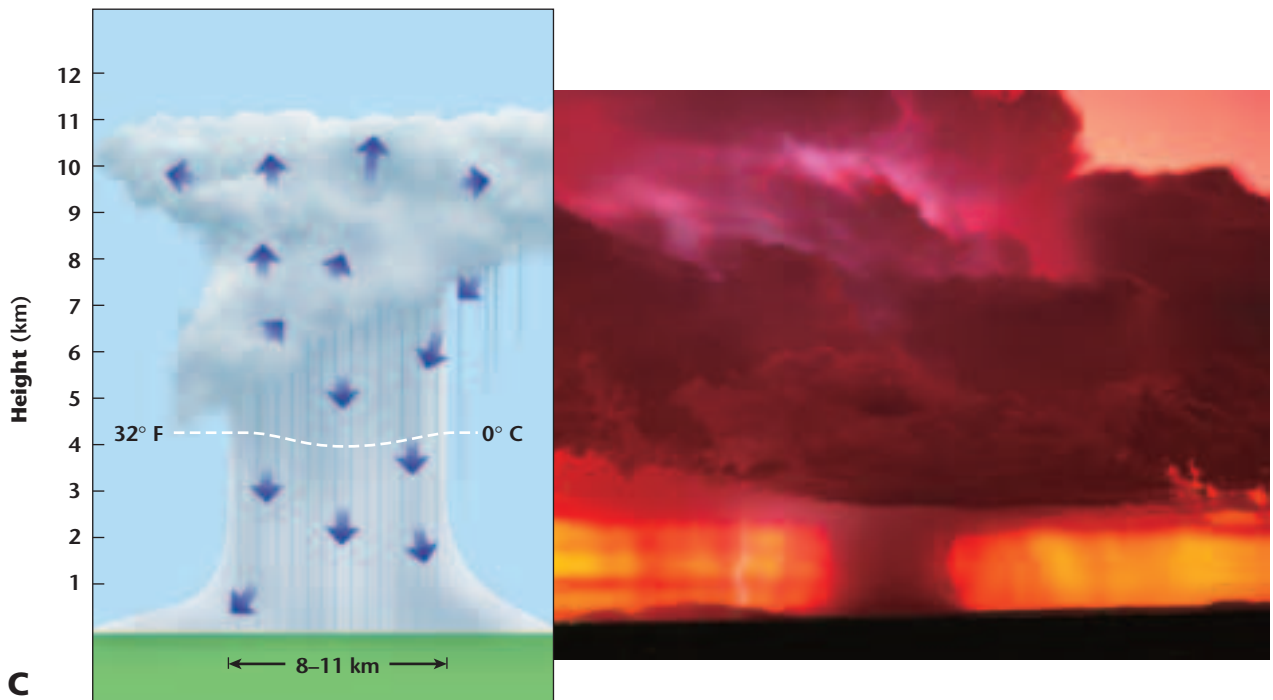


**Figure 13-3** The cumulus stage of a thunderstorm is characterized mainly by updrafts **(A)**. The mature stage is characterized by strong updrafts and downdrafts **(B)**. The storm loses energy in the dissipation stage **(C)**.

**Cumulus Stage** In the cumulus stage, air starts to rise nearly vertically upward, as shown in *Figure 13-3A*. This creates updrafts, which transport moisture to the upper reaches of the cloud. The moisture condenses into visible cloud droplets and releases latent heat. As the cloud droplets coalesce, they form larger and larger droplets, which eventually fall to Earth as precipitation. This begins the mature stage of a thunderstorm.

**Mature Stage** Precipitation in a thunderstorm is composed of water droplets that formed at high, cool levels of the atmosphere. As the precipitation falls, it cools the air around it. The newly cooled air is more dense than the surrounding air, so it sinks rapidly to the ground along with the precipitation. This creates downdrafts. As *Figure 13-3B* shows, the updrafts and downdrafts form a convection cell that produces the gusty surface winds associated with thunderstorms. In the mature stage, nearly equal amounts of updrafts and downdrafts exist side by side in the cumulonimbus cloud.

**Dissipation Stage** The production of downdrafts is ultimately the thunderstorm's undoing. The convection cell can exist only if there is a steady supply of warm, moist air at Earth's surface. Once that supply runs out, the updrafts slow and eventually stop. In a thunderstorm, shown in the photo on the next page, the supply of warm, moist air runs out because the cool downdrafts spread in all directions when they reach Earth's surface. This cools the areas from which the storm



draws its energy. Without the warm air, the updrafts cease and precipitation can no longer form. The storm is then in the dissipation stage, as shown in **Figure 13-3C**. This stage, which is characterized primarily by lingering downdrafts, will last until the cloud runs out of previously formed raindrops. Next, you'll explore the destructive forces that can be unleashed when a severe thunderstorm strikes.

## SECTION ASSESSMENT

1. It's 2:00 A.M. in the northeastern United States. A thunderstorm rumbles on the horizon. What type is it most likely to be? Why?
2. What conditions must be present for a thunderstorm to form?
3. Explain why a cold-front thunderstorm is usually more severe than a warm-front thunderstorm.
4. **Thinking Critically** In the tropics, where the tropopause is higher than in other areas, cumulonimbus clouds commonly reach towering heights of 15 000 m. Why is the height of the tropopause a factor in how tall a cumulonimbus cloud can grow?

### SKILL REVIEW

5. **Concept Mapping** Use the following phrases to complete an events-chain concept map about the life cycle of a thunderstorm. For more help, refer to the *Skill Handbook*.

1. water droplets coalesce

2. updrafts stop

3. surface air is warmed by conduction

4. precipitation ends

5. water vapor condenses

6. warm air rises, creating updrafts

7. surface air is cooled by downdrafts

8. latent heat is released

9. precipitation and downdrafts begin



**OBJECTIVES**

- **Explain** why some thunderstorms are more severe than others.
- **Recognize** the dangers of severe thunderstorms, including lightning, hail, high winds, and floods.
- **Describe** how tornadoes form.

**VOCABULARY**

supercell

downburst

tornado

Fujita tornado intensity scale

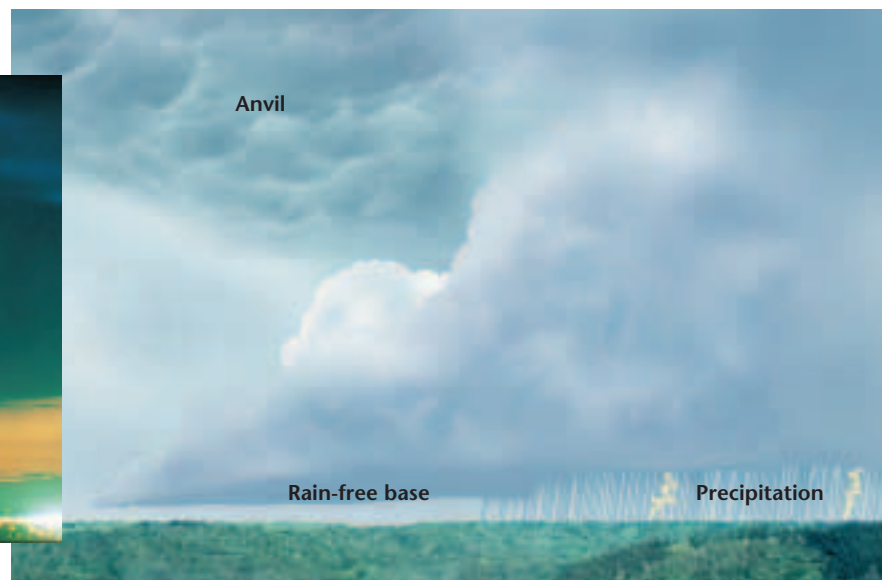
**Figure 13-4** An anvil-shaped cumulonimbus cloud is characteristic of many severe thunderstorms **(A)**. The most severe thunderstorms are supercells **(B)**.

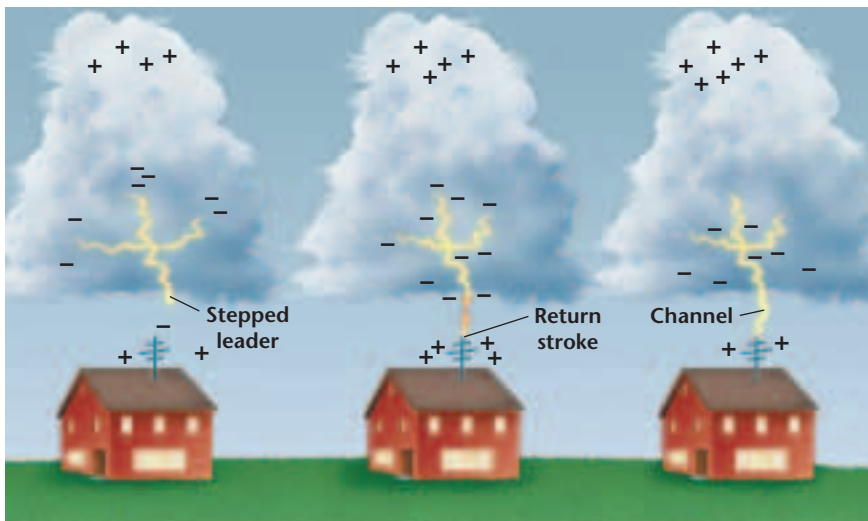
**A**

All thunderstorms are not created equal. Some die out within minutes, while others flash and thunder throughout the night. What makes one thunderstorm more severe than another? Occasionally, weather events come together in such a way that there is a continuous supply of surface moisture. This happens along a cold front that moves into warmer territory and can lift and condense a continuous supply of warm air. In this case, a line of thunderstorms can last for hours or even days as they continually regenerate themselves with the new, warm air that is introduced into the updrafts.

**SEVERE THUNDERSTORMS**

Other factors also play a role in causing some storms to be more severe than others. Cold fronts are usually accompanied by upper-level, low-pressure systems that are marked by pools of cold air. This cold, high air increases the temperature difference between the upper and lower parts of the storm, which causes the air to become more unstable. As the instability of the air increases, the strength of the storm's updrafts and downdrafts intensifies. The storm is then considered to be severe. Severe thunderstorms can produce some of the most violent weather conditions on Earth. They may develop into self-sustaining, extremely powerful storms called **supercells**, which are characterized by intense, rotating updrafts. **Figure 13-4B** shows an illustration of a supercell. These furious storms can last for several hours and can have updrafts as strong as 240 km/h.

**B**



Source: NOAA

**Figure 13-5** When a stepped leader nears an object on the ground, a powerful surge of electricity from the ground moves upward to the cloud, and lightning is produced.

Of the estimated 100 000 thunderstorms that occur each year in the United States, only about ten percent are considered to be severe, and fewer still reach classic supercell proportions. But when certain atmospheric conditions come together in the right way, the results can be spectacular and sometimes deadly, as you'll learn next.

## LIGHTNING

Have you ever touched a metal object on a dry winter day and been zapped by a spark of electricity? If so, you were, in a sense, playing with lightning. Lightning is electricity caused by the rapid rush of air in a cumulonimbus cloud. A lightning bolt forms when friction between the updrafts and downdrafts within a cumulonimbus cloud separates electrons from some of their atoms either in the cloud or near the ground. The atoms that lose electrons become positively charged ions. Other atoms receive the extra electrons and become negatively charged ions. As **Figure 13-5** shows, this creates regions of air with opposite charges. To relieve the electrical imbalance, an invisible channel of negatively charged air, called a stepped leader, moves from the cloud toward the ground. When the stepped leader nears the ground, a channel of positively charged ions, called the return stroke, rushes upward to meet it. The return stroke surges from the ground to the cloud, illuminating the channel with about 100 million V of electricity. That illumination is lightning. You'll learn more about lightning in the *Science & Technology* feature at the end of this chapter.

**The Power of Lightning** A lightning bolt heats the surrounding air to about 30 000°C. That's about five times hotter than the surface of the Sun! The thunder you hear is the sound produced as this superheated air rapidly expands and contracts. Because sound waves travel



## Table 13-1 Thunderstorm and Lightning Safety

### When Thunderstorms Approach . . .

- Remember: If you can hear thunder, you are close enough to the storm to be struck by lightning. Go to a safe shelter immediately.
- Move to a sturdy building or car. Do not take shelter in small sheds, under isolated trees, or in convertible automobiles.
- If lightning is occurring and a sturdy shelter is not available, get inside a hard-topped automobile and keep the windows up.
- Get out of boats and away from water.
- Telephone lines and metal pipes can conduct electricity. Unplug appliances not necessary for obtaining weather information. Avoid using any electrical appliances. Use phones ONLY in an emergency.

### If You Are Caught Outdoors and No Shelter Is Nearby . . .

- Find a low spot away from trees, fences, and poles. Make sure the place you choose is not subject to flooding.
- If you are in the woods, take shelter under the shorter trees.
- If you feel your skin tingle or your hair stand on end, squat low to the ground on the balls of your feet. Place your hands on your knees with your head between them. Make yourself the smallest target possible, and minimize your contact with the ground.

Source: NOAA



#### Topic: Thunderstorms

To find out more about thunderstorms, visit the Earth Science Web site at [earthgeu.com](http://earthgeu.com)

**Activity:** Design a bookmark with 10 facts on thunderstorms. Include safety tips.

more slowly than light waves, you may see lightning well before you hear thunder, even though they are generated at the same time.

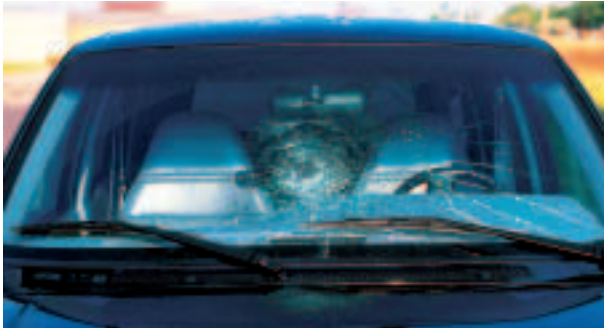
Each year in the United States, lightning accounts for about 7500 forest fires, which result in the loss of millions of acres of forest. In addition, lightning strikes in the United States cause a yearly average of 300 injuries and 93 deaths to humans. **Table 13-1** lists safety tips to follow to avoid property damage and loss of life from lightning strikes.

## THE FURY OF THE WIND

Recall that rain-cooled downdrafts descend to Earth's surface during a thunderstorm and spread out as they reach the ground. Sometimes, however, instead of dispersing that downward energy over a large area underneath the storm, the energy becomes concentrated in a local area. The resulting winds are exceptionally strong, with speeds of more than 160 km/h. Violent downdrafts that are concentrated in a local area are called **downbursts**.

Based on the size of the area they affect, downbursts are further classified as either macrobursts or microbursts. Macrobursts can cause a path of destruction up to 5 km wide. They have wind speeds of more than 200 km/h and can last up to 30 minutes. Smaller in size, though





**Figure 13-6** This car was damaged by large hailstones similar to the one shown here.

deadlier in force, microbursts affect areas of less than 3 km but can have winds exceeding 250 km/h. Despite lasting less than 10 minutes on average, a microburst is especially deadly because its smaller size makes it extremely difficult to detect and thus prepare for.

### HAIL

Each year in the United States, almost \$1 billion in damage is caused by another danger associated with thunderstorms: hail. Hail is precipitation in the form of balls or lumps of ice. It can do tremendous damage to crops, particularly in the Central United States, where hail occurs most frequently. Hail is most common during the spring growing season. *Figure 13-6* shows the damage that hail can cause.

Hail forms because of two characteristics common to thunderstorms. First, water droplets exist in the liquid state in the parts of a cumulonimbus cloud where the temperature is actually below freezing. When these supercooled water droplets encounter ice pellets, the water droplets freeze on contact and cause the ice pellets to grow larger. The second characteristic that allows hail to form is an abundance of strong updrafts and downdrafts existing side by side within a cloud. The growing ice pellets are caught alternately in the updrafts and downdrafts, so that they are constantly encountering more supercooled water droplets. The ice pellets keep growing until they are too heavy for even the strongest updrafts to keep aloft, and they finally fall to Earth as hail.

### FLOODS

Sometimes, the wind currents in the upper atmosphere that cause weather systems to move are weak, and the weather systems and resulting storms move slowly. When this happens, a storm may dump its rain over a limited location, rather than spreading it over a large area. Floods such as the one in *Figure 13-7* can occur. The situation can worsen if there is abundant moisture available not just at Earth's surface, but also throughout the atmosphere. This makes the whole process of condensation, coalescence, and precipitation much more

**Figure 13-7** This rural community was devastated by a flood in Arizona.



efficient and thus produces more rainfall. If the rain falls faster than the ground can absorb it, or faster than streams and rivers can transport it out of the area, flooding can occur. Floods are the main cause of thunderstorm-related deaths in the United States each year.

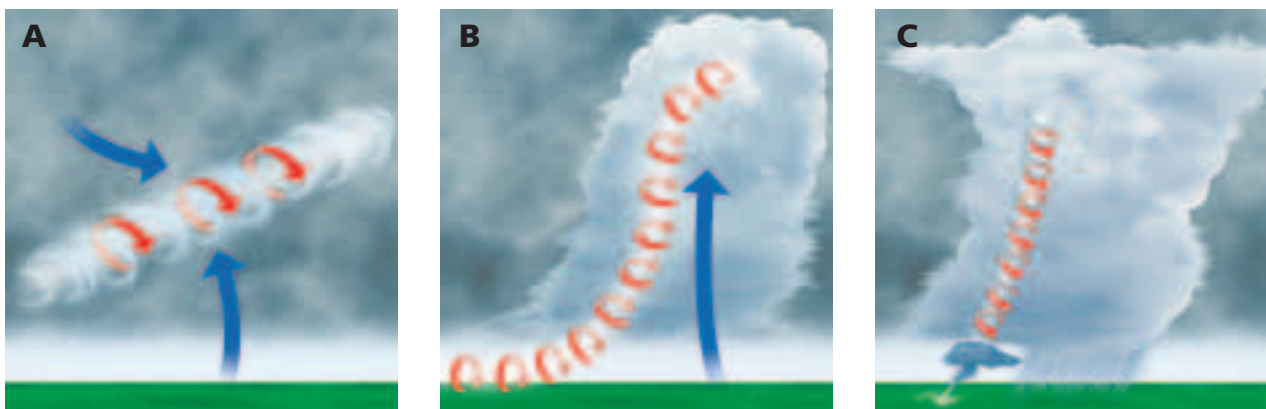
## TORNADOES

Of all the dangers associated with thunderstorms, the most impressive by far is a tornado. A **tornado** is a violent, whirling column of air in contact with the ground. Before a tornado reaches the ground, it is called a funnel cloud. Tornadoes are often associated with supercells, the most severe thunderstorms. The air in a tornado is made visible by dust and debris drawn into the swirling column, or by the condensation of water vapor into a visible cloud. Over the area it covers, few storms on Earth can match a tornado's violence.

A tornado forms when wind speed and direction change suddenly with height, a phenomenon known as wind shear. Under the right conditions, this can produce a horizontal rotation near Earth's surface, as shown in *Figure 13-8*. If this rotation takes place close enough to the thunderstorm's updrafts, the twisting column of wind can be tilted from a horizontal to a vertical position. As updrafts accelerate the rotation, air is removed from the center of the column, which in turn lowers air pressure in the center. The extreme pressure gradient between the center and the outer portion of the tornado produces the violent winds associated with tornadoes. Although tornadoes rarely exceed 200 m in diameter and usually last only a few minutes, they can be extremely destructive. In fact, they are classified according to their destructive force.

**Figure 13-8** A change in wind direction and speed creates a horizontal rotation in the lower atmosphere (A). Strong updrafts tilt the rotating air from a horizontal to a vertical position (B). A tornado forms within the rotating winds (C).

**Tornado Classification** Tornadoes can vary greatly in size and intensity. They are classified according to the **Fujita tornado intensity scale**, which ranks tornadoes according to their path of destruction, wind speed, and duration. The Fujita scale was named



for Japanese tornado researcher Dr. Theodore Fujita. The scale ranges from F0, which is characterized by winds of up to 118 km/h, to the incredibly violent F5, which can pack winds of more than 500 km/h. Most tornadoes do not exceed the F1 category. In fact, only about one percent ever reach the violent categories of F4 and F5. Those that do, however, can lift entire buildings from their foundations and toss automobiles and trucks around like toys. The Fujita scale is shown in *Table 13-2*.

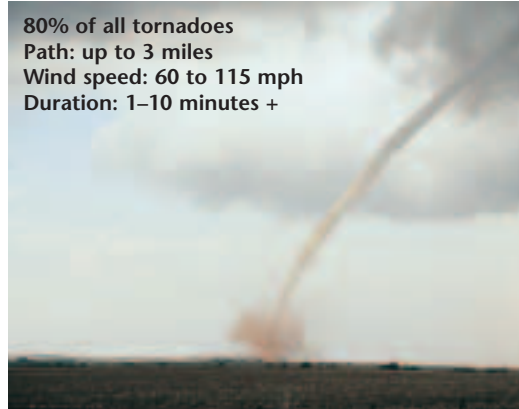
**Tornado Distribution** While tornadoes can occur at any time and at any place, there are some times and locations that are more conducive to their formation. Most tornadoes—especially the violent ones—form in the spring during the late afternoon and evening, when the temperature contrasts between polar air, which still has winter characteristics, and tropical air, which is steadily becoming warmer, are the greatest. These large temperature contrasts often spark the development of supercells, which are each capable of producing several strong tornadoes. Large temperature contrasts occur most frequently in the Central United States, where cold continental polar air collides with maritime tropical air moving northward from the Gulf of Mexico. More than 700 tornadoes touch down each year in the United States. Many of these occur in a region called “Tornado Alley,” which extends from northern Texas through Oklahoma, Kansas, and Missouri.

**Tornado Safety** In the United States, an average of 80 deaths and 1500 injuries result from tornadoes each year. In an ongoing effort to reduce tornado-related fatalities, the National Weather Service issues tornado watches and warnings before a tornado actually strikes. These advisories are broadcast on local radio stations when tornadoes are

**Table 13-2 Fujita Scale**

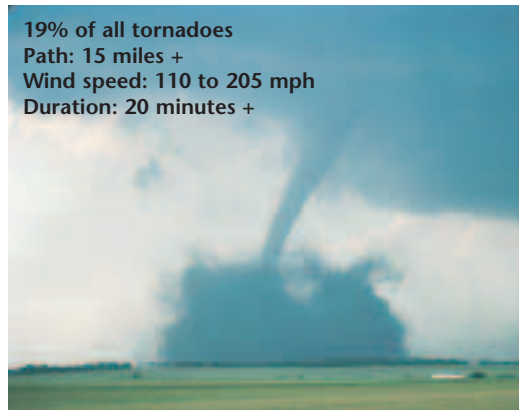
**Weak Tornadoes (F0 and F1)**

80% of all tornadoes  
Path: up to 3 miles  
Wind speed: 60 to 115 mph  
Duration: 1–10 minutes +



**Strong Tornadoes (F2 and F3)**

19% of all tornadoes  
Path: 15 miles +  
Wind speed: 110 to 205 mph  
Duration: 20 minutes +



**Violent Tornadoes (F4 and F5)**

1% of all tornadoes  
Path: 50 miles +  
Wind speed: 200 mph +  
Duration: 1 hour +



**Table 13-3 Tornado Safety**

**If a Warning Is Issued or If Threatening Weather Approaches . . .**

- If you are in a home or building, move to a predesignated shelter, such as a basement.
- If an underground shelter is not available, move to an interior room or hallway on the lowest floor and get under a sturdy piece of furniture.
- Stay away from windows.
- Get out of automobiles.
- Do not try to outdistance a tornado in a car; instead, leave the car immediately.
- If you are caught outside or in a vehicle, lie flat in a nearby ditch or depression.
- Mobile homes, even when tied down, offer little protection from tornadoes and should be abandoned.

Source: NOAA

indicated on weather radar or spotted in the region. During a severe thunderstorm, the presence of dark, greenish skies, a towering wall of clouds, large hailstones, and a loud, roaring noise similar to that of a freight train are signs of an approaching or developing tornado. **Table 13-3** lists safety measures recommended by the National Weather Service in the event of a tornado. The agency stresses that despite advanced tracking systems, some tornadoes develop exceedingly quickly. In these cases, advance warnings may not be possible. However, the threat of tornado-related injury can be substantially decreased when people seek shelter at the first sign of threatening skies. In the next section, you'll learn about another type of severe weather: tropical storms.

**SECTION ASSESSMENT**

1. Describe two characteristics of thunderstorms that lead to hail formation.
2. Compare and contrast a macroburst and a microburst.
3. What type of front would you expect to be associated with flooding? Why?
4. Why are some thunderstorms more severe than others?
5. If the time between when you see lightning and hear thunder is increasing, a storm is moving away from you. Why is this true?

6. **Thinking Critically** Based on what you know about stepped leaders and return strokes, why are tall objects more likely to be struck by lightning than shorter ones?

**SKILL REVIEW**

7. **Recognizing Cause and Effect** In the United States, most thunderstorms occur in Florida, yet the central states experience the strongest tornadoes. Why doesn't Florida have more violent tornadoes? For more help, refer to the *Skill Handbook*.



If you wanted to search for the origin of the most violent type of storm on Earth, the last place you'd probably look would be the calm, sunny tropics. However, during summer and fall, the sunny tropics are the birthing grounds of large, rotating, low-pressure storms called **tropical cyclones**. The strongest of these cyclonic storms are known in the United States and other parts of the Atlantic Ocean as hurricanes. *Figure 13-9* illustrates the rotating nature of a typical hurricane.

### TROPICAL CYCLONES

Unlike midlatitude storms that derive their energy from the contrast between warm and cold air masses, tropical cyclones thrive on the tremendous amount of energy in warm, tropical oceans. As water evaporates from the ocean surface, latent heat is stored. This latent heat is later released when the air begins to rise and water vapor condenses into clouds and rain. The air usually rises because of some sort of existing weather disturbance moving across the tropics. Many such disturbances originate along the Intertropical Convergence Zone (ITCZ), which you learned about in Chapter 12. As these disturbances produce more precipitation, more energy is released. In addition, the rising air creates an area of low pressure at the ocean surface. As more warm air moves toward the low-pressure center to replace the air that has risen, the Coriolis effect causes the moving air to turn counterclockwise in the northern hemisphere. This produces the cyclonic rotation of a tropical cyclone.

As the moving air approaches the center of the growing storm, it rises, rotates faster and faster, and increases in speed as more energy is released through condensation. In the process, air pressure in the center of the system continues to decrease, while surface wind speeds

### OBJECTIVES

- **Identify** where tropical cyclones originate.
- **Describe** the life cycle of a tropical cyclone.
- **Recognize** the dangers of hurricanes.

### VOCABULARY

tropical cyclone

eye

eyewall

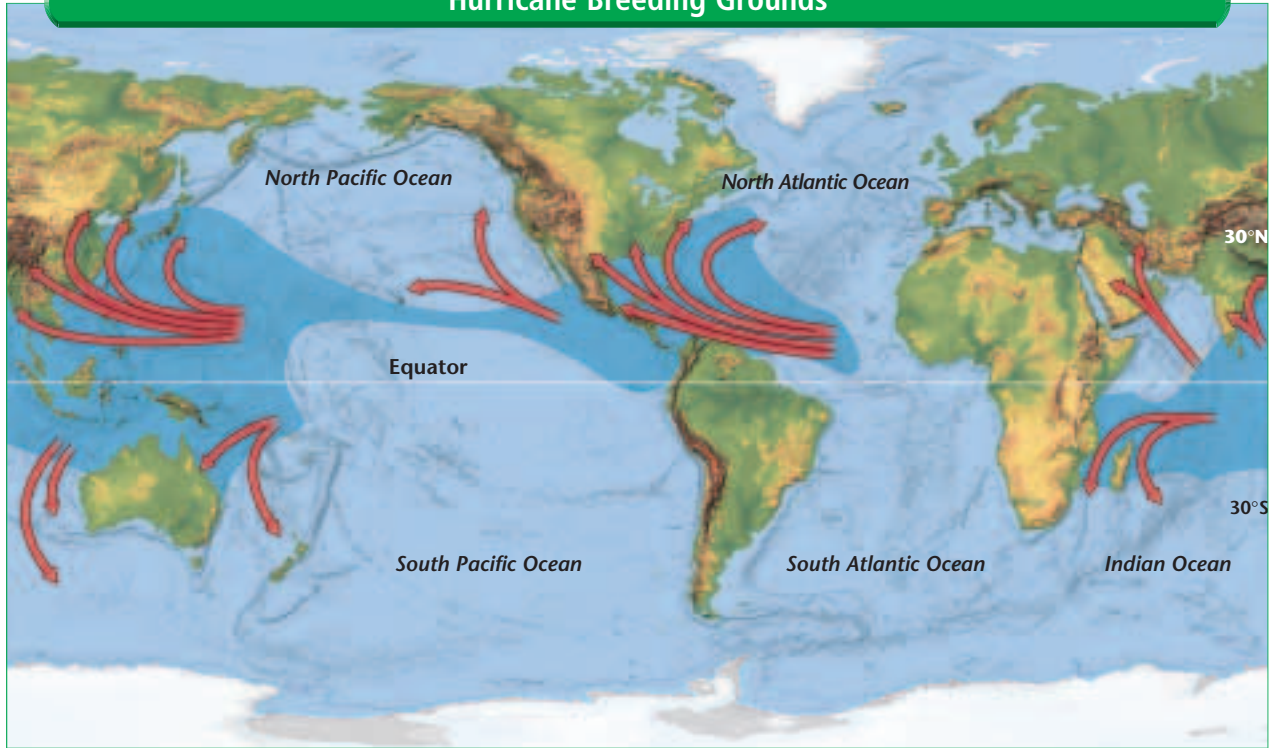
Saffir-Simpson hurricane scale

storm surge



**Figure 13-9** The characteristic rotating nature of cyclonic storms is evident in this hurricane that formed over the Atlantic Ocean.

## Hurricane Breeding Grounds



**Figure 13-10** Hurricanes form in all of Earth's tropical oceans except in the relatively cool waters of the South Pacific and South Atlantic Oceans.

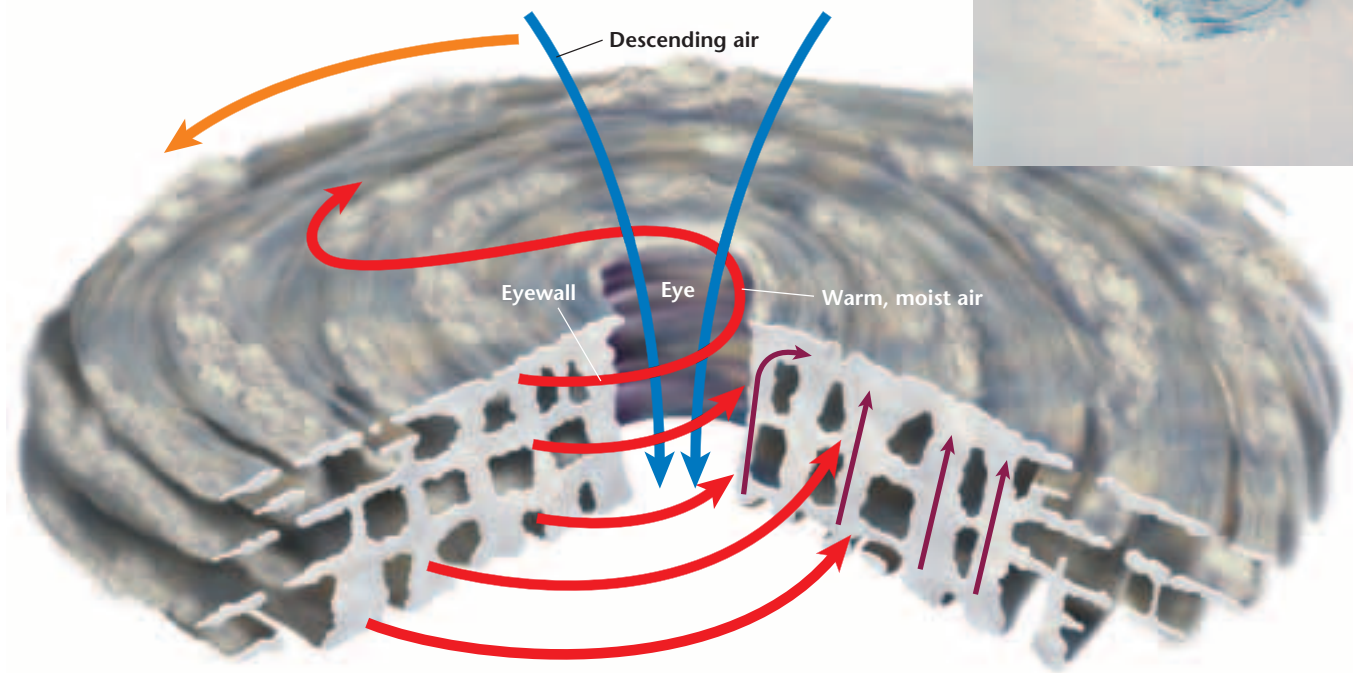
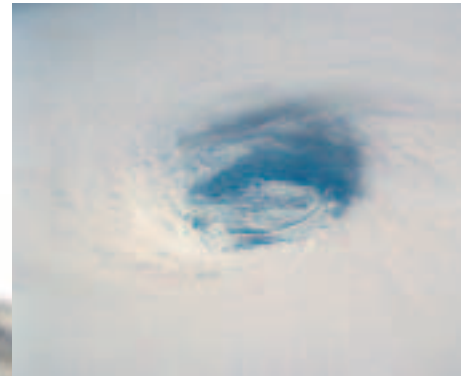
increase—sometimes in excess of 240 km/h. This process will continue as long as atmospheric conditions allow warm air to be fed into the system at the surface and to be removed from the system in the upper atmosphere.

**Formation of Tropical Cyclones** Tropical cyclones require two basic conditions to form: an abundant supply of very warm ocean water and some sort of disturbance to lift warm air and keep it rising. These conditions exist in all tropical oceans except the South Atlantic Ocean and the Pacific Ocean west of the South American Coast. Ocean waters in these areas are somewhat cooler. In addition, the ITCZ is positioned farther north. As a consequence, tropical cyclones do not occur in these areas. They do occur in the large expanse of warm waters in the western Pacific Ocean, where they are known as typhoons. To people living near the Indian Ocean, they are known as cyclones. Near the Atlantic Ocean, the Caribbean Sea, the Gulf of Mexico, and along the western coast of Mexico, they are called hurricanes. The map in *Figure 13-10* shows where hurricanes generally form. They occur most frequently in the late summer and early fall, when Earth's oceans contain their greatest amount of stored heat energy.

**Movement of Tropical Cyclones** Like all large-scale storms, tropical cyclones move according to the wind currents that steer them. Recall that many of the world's oceans are home to subtropical high-pressure systems that are present to some extent throughout the year. In the deep tropics, tropical cyclones are often caught up in the circulation of these high-pressure systems. They move steadily toward the west, then eventually turn poleward when they reach the far edges of the high-pressure systems. There, they are guided by prevailing westerlies and begin to interact with midlatitude systems. At this point, the interaction of the various wind and weather systems makes the movement of the storms unpredictable.

**Stages of Tropical Cyclones** A traveling tropical disturbance, which can cause air in a developing tropical cyclone to rise, is the first stage of a tropical cyclone. Disturbances can originate either from the ITCZ or as weak, low-pressure systems called tropical waves. These disturbances are common during the summer and early fall. Sometimes, midlatitude weather disturbances can move into the tropics, become stranded there, and gradually acquire tropical characteristics. Whatever their origin, only a small percentage of tropical disturbances ever develop into full-fledged hurricanes. This is because conditions throughout the atmosphere must be such that rising air can be dispersed into the upper atmosphere. *Figure 13-11* shows a cross section of a hurricane.

**Figure 13-11** In this hurricane cross section, the rising, moist air—indicated by small red arrows—forms clouds in bands around the eye. The photo shows the eye of a hurricane that formed over the Pacific Ocean in 1991.





**Table 13-4 Saffir-Simpson Hurricane Scale**

Scale Number (Category)	Sustained Winds (mph)	Damage	Examples of Hurricanes and the States Affected
1	74–95	Minimal	Florence, 1988 (LA) Charley, 1988 (NC)
2	96–110	Moderate	Kate, 1985 (FL Panhandle) Bob, 1991 (RI)
3	111–130	Extensive	Alicia, 1983 (N. TX) Emily, 1993 (NC Outer Banks)
4	131–155	Extreme	Andrew, 1992 (S. FL) Hugo, 1989 (SC)
5	> 155	Catastrophic	Camille, 1969 (LA/MS) Labor Day Hurricane, 1935 (FL Keys)

Source: National Weather Service



### Using Math

#### Using Numbers

Suppose that a hurricane has been spotted at 25°N, 50°W, which is roughly 2900 km from Miami, Florida. The hurricane is moving west at 25 km/h. How long will it take the hurricane to reach Miami?

When a disturbance over a tropical ocean acquires a cyclonic circulation around a center of low pressure, it has reached the next developmental stage, which is known as a tropical depression. When wind speeds around the low-pressure center of a tropical depression exceed 65 km/h, the system is called a tropical storm. If air pressure continues to fall and winds around the center reach at least 120 km/h, the storm is officially classified as a hurricane. Once winds reach these speeds, another phenomenon takes place—the development of a calm center of the storm called an **eye**. The strongest winds in a hurricane are usually concentrated in a band immediately surrounding the eye called the **eyewall**.

### CLASSIFYING HURRICANES

The **Saffir-Simpson hurricane scale** classifies hurricanes according to wind speed, air pressure in the center, and potential for property damage. As shown in *Table 13-4*, the Saffir-Simpson hurricane scale ranges from Category 1 hurricanes, which have minimum wind speeds of 74 mph (120 km/h), to the monstrous Category 5 storms, which can have winds in excess of 155 mph (250 km/h). Once a hurricane reaches Category 3 status, it is considered to be a major hurricane, with good reason. Most of the deadliest hurricanes that strike the United States were classified as major hurricanes.

**Running Out of Energy** A hurricane will last until it can no longer produce enough energy to sustain itself. This usually happens when the storm moves over land and no longer has access to the warm ocean surface from which it draws its energy, or when the



storm moves over colder water. During its life cycle, a hurricane can undergo several fluctuations in intensity as it interacts with other atmospheric systems.

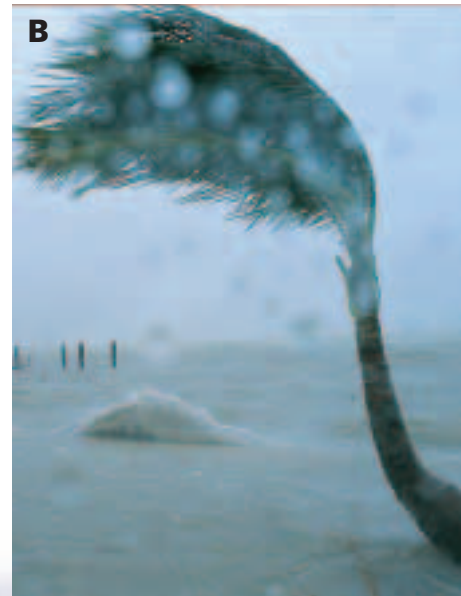
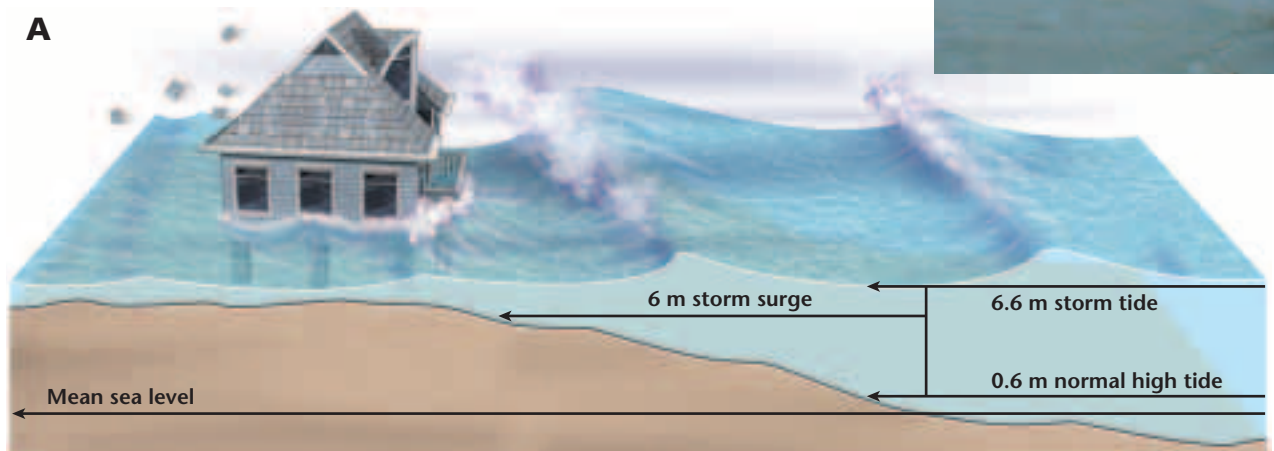
## HURRICANE HAZARDS

Hurricanes can cause a lot of damage, particularly along coastal areas where human populations have increased. Much of this damage is associated with violent winds. The strongest winds in a hurricane are usually confined to the eyewall, the band about 40 to 80 km wide that surrounds the calm eye. Outside of the eyewall, winds taper off with distance from the center, although winds of more than 60 km/h can extend as far as 400 km from the center of a hurricane.

**Storm Surges** Strong winds moving onshore in coastal areas are partly responsible for another major hurricane threat: storm surges. A **storm surge** occurs when hurricane-force winds drive a mound of ocean water toward coastal areas, where it washes over the land. Storm surges can sometimes reach 6 m above normal sea level, as shown in *Figure 13-12*. When this occurs during high tide, the surge can cause enormous damage. In the northern hemisphere, a storm surge occurs primarily on the right side of a storm relative to its eye, where the strongest onshore winds occur.

The heat released through the condensation of vast amounts of water vapor fuels hurricanes. This condensation also produces great amounts of rain. Thus, floods are an additional hurricane hazard, particularly if the storm moves over mountainous areas, where orographic lifting enhances the upward motion of air.

**Figure 13-12** Storm surges can sometimes reach 6 m above normal sea level and cause enormous damage (A). This storm surge in the Florida Keys was caused by Hurricane Irene (B).



**Table 13-5 Hurricane Safety**

- Turn the refrigerator to the maximum cold setting and open it only when necessary.
- Turn off utilities if told to do so by authorities.
- Unplug small appliances.
- Turn off propane tanks.
- Fill bathtubs and large containers with water for sanitary purposes.

**If Winds Become Strong . . .**

- Stay away from windows and doors even if they are covered. Take refuge in a small interior room, closet, or hallway.
- Close all interior doors. Secure and brace external doors.
- If you are in a two-story house, go to an interior first-floor room, such as a bathroom or closet.
- If you are in a multiple-story building and away from water, go to the first or second floor and take refuge in a hall or other interior room away from windows.
- Lie on the floor under a table or other sturdy object.

Source: NOAA

**Hurricane Advisories** The National Hurricane Center, which is responsible for tracking and forecasting the intensity and motion of tropical cyclones in the western hemisphere, issues a hurricane warning at least 24 hours before a hurricane strikes. The center also issues regular advisories that indicate a storm's position, strength, and movement. Using this information, people can then track a storm on a hurricane-tracking chart, such as the one you'll use in the *Internet GeoLab* at the end of this chapter. This type of awareness, combined with proper safety precautions such as those listed in **Table 13-5**, has greatly reduced death tolls associated with hurricanes in recent years.

**SECTION ASSESSMENT**

1. Identify the four main stages of a tropical cyclone.
2. Describe the changing wind systems that guide a tropical cyclone as it moves from the tropics to the midlatitudes.
3. Why don't tropical cyclones form in the South Atlantic Ocean or off the western coast of South America?
4. What two conditions must exist for a tropical cyclone to form?
5. **Thinking Critically** Suppose that you live on the eastern coast of the United States and are advised that the center

of a hurricane is moving inland 70 km north of your location. Would you predict that a storm surge will be a major problem in your area? Why or why not?

**SKILL REVIEW**

6. **Making and Using Tables** Research at least ten hurricanes that have occurred throughout the world since 1980. Based on the Saffir-Simpson scale, make a data table showing wind speed, air pressure in the center, and property damage associated with each hurricane. For more help, refer to the *Skill Handbook*.






## SECTION

## 13.4

*Recurring Weather*

 On a hot, summer day, a sudden thunderstorm is a welcome event. Such rains are not so welcome, however, when they continue for hours or even days. Persistent or repetitive weather can negatively affect agriculture, transportation, and recreation.

**FLOODS AND DROUGHTS**

An individual thunderstorm can unleash enough rain to produce floods, and hurricanes are notorious for their torrential downpours. Floods can also occur, however, when weather patterns cause even mild storms to persist over the same area. For example, a storm with a rainfall rate of 1.5 cm/h is not much of a problem—providing that it lasts only an hour or two. If this same storm were to remain over one spot for 18 hours, however, total rainfall would be 27 cm, which is more than enough to create flooding in most areas. You will learn more about floods in the *MiniLab* on the following page.

On the other hand, too much dry weather can create nearly as much havoc as too much rainfall. **Droughts** are extended periods of well-below-normal rainfall. One of the most extreme droughts occurred during the 1930s in the Central United States. **Figure 13-13** shows a dust storm that occurred in the Dust Bowl, which was the name given to the affected states. This extended drought put countless farmers out of business, as rainfall for several seasons was inadequate to grow crops.

**OBJECTIVES**

- **Describe** recurring weather patterns and the problems they create.
- **Identify** atmospheric events that cause recurring weather patterns.

**VOCABULARY**

*drought*  
*heat wave*  
*cold wave*  
*wind-chill factor*



**Figure 13-13** The dust blowing over this highway was caused by a severe drought in the Central United States during the 1930s.

## MiniLab

### How can mild rains cause floods?

**Model** the effects of repeated, slow-moving storms that drop rain over the same area for a long period of time.

#### Procedure

1. Place an ice-cube tray on the bottom of a large sink or tub.
2. Pour water into a clean, plastic dishwashing-detergent bottle until it is two-thirds full. Replace the cap on the bottle.
3. Hold the bottle upside down with the cap open about 8 cm above one end of the ice-cube tray. Gently squeeze the bottle to maintain a constant flow of water into the tray. Slowly move the bottle from one end of the tray to the other over the course of 30 seconds. Try to put approximately equal amounts of water in each ice-cube compartment.
4. Measure the depth of water in each compartment. Calculate the average depth.
5. Repeat steps 1–4, but move the bottle across the ice-cube tray in 15 seconds.

#### Analyze and Conclude

1. How did the average depth of the water differ in steps 4 and 5? How might you account for the difference?
2. Based on these results, infer how the speed of a moving storm affects the amount of rain received in any one area.
3. How could you alter the experiment to simulate different rates of rainfall?

Droughts are usually the result of shifts in global wind patterns that allow large high-pressure systems to persist for weeks or months over continental areas. Under a dome of high pressure, air sinks on a large scale. Because the sinking air will resist any attempt to lift moisture through it, condensation cannot occur, and drought will set in until global patterns shift enough to move the high-pressure system out of the way.

**Heat Waves** An unpleasant side effect of droughts often comes in the form of **heat waves**, which are extended periods of above-normal temperatures. Heat waves can be formed by the same high-pressure systems that cause droughts. As the air under a large high-pressure system sinks, it warms by compression and causes above-normal temperatures. The high-pressure system also blocks cooler air masses from moving into the area, so there is little relief from the heat. Because it is difficult for condensation to occur under the sinking air of the high-pressure system, there are few, if any, clouds to block the blazing sunshine. To make matters worse, the jet stream, or “atmospheric railway,” that weather systems follow is farther north and weaker during the summer. Thus, the upper-air currents that might guide the high-pressure system are so weak that the system scarcely moves.

Even increasing humidity does not ease the discomfort of a heat wave. Human bodies cool by evaporating moisture from the surface of the skin. In the process, heat is removed from the body. If air is humid, the rate of evaporation is reduced, which diminishes the body’s ability to regulate internal temperature. In heat waves, this can lead to serious health problems such as heatstroke, sunstroke, and even death.

**Table 13-6 The Heat Index**

Relative Humidity (%)	Air Temperature (°F)										
	70	75	80	85	90	95	100	105	110	115	120
	Apparent Temperature (°F)										
0	64	69	73	78	83	87	91	95	99	103	107
10	65	70	75	80	85	90	95	100	105	111	116
20	66	72	77	82	87	93	99	105	112	120	130
30	67	73	78	84	90	96	104	113	123	135	148
40	68	74	79	86	93	101	110	123	137	151	
50	69	75	81	88	96	107	120	135	150		
60	70	76	82	90	100	114	132	149			
70	70	77	85	93	106	124	144				
80	71	78	86	97	113	136					
90	71	79	88	102	122						
100	72	80	91	108							

Source: National Weather Service, NOAA

Because of the extreme dangers posed by the lethal combination of heat and humidity, the National Weather Service routinely reports the heat index, shown in **Table 13-6**. Note that the National Weather Service uses the Fahrenheit scale in the heat index because most U.S. citizens are most familiar with this scale. The heat index assesses the effect of the body's increasing difficulty in regulating its internal temperature as relative humidity rises. For example, an air temperature of 85°F (29°C) combined with relative humidity of 80 percent would require the body to cool itself at the same rate as if the air temperature were 97°F (36°C). Do the *Problem-Solving Lab* on the following page to learn more about heat waves.

## COLD WAVES

The flip side of a heat wave is a **cold wave**, which is an extended period of below-normal temperatures. Interestingly, cold waves are also brought on by large, high-pressure systems. However, cold waves are caused by systems of continental polar or arctic origin. During the arctic winter, little sunlight is available to provide warmth. At the same time, the snow-covered surface is constantly radiating its limited heat back to space. The combined effect of these two factors is the development of large pools of extremely cold air over polar continental areas. Because cold air sinks, the pressure near the surface increases, creating a strong high-pressure system.

Because of the location and the time of year in which they occur, winter high-pressure systems are much more influenced by the jet stream than are summer high-pressure systems. Moved along by the jet stream, these high-pressure systems rarely linger in any area. However, the winter location of the jet stream may remain essentially unchanged for days or even weeks. This means that several polar high-pressure systems can follow the same path and subject the same areas to bout after bout of numbing cold. *Figure 13-14* shows some effects of prolonged periods of cold weather.

Because wind transports heat away from the body, the effects of cold air are worsened by wind. This phenomenon is known as the **wind-chill factor**. The wind-chill factor is measured by the wind-chill index, which estimates the heat loss from human skin caused by the combination of cold air and wind. This index estimates how cold the air actually feels to the human body. As with the heat index, the National Weather Service records the wind-chill index in U.S. units

## Problem-Solving Lab

### Making and Using Graphs

**Charting a heat wave** The following data represent the daily maximum and minimum temperatures for ten consecutive summer days in a major city.

Daily Temperatures			
Day	Maximum	Minimum	Average
1	92	76	84
2	91	75	83
3	94	78	86
4	95	75	85
5	93	77	85
6	96	76	86
7	94	80	87
8	96	72	84
9	92	74	83
10	94	68	81

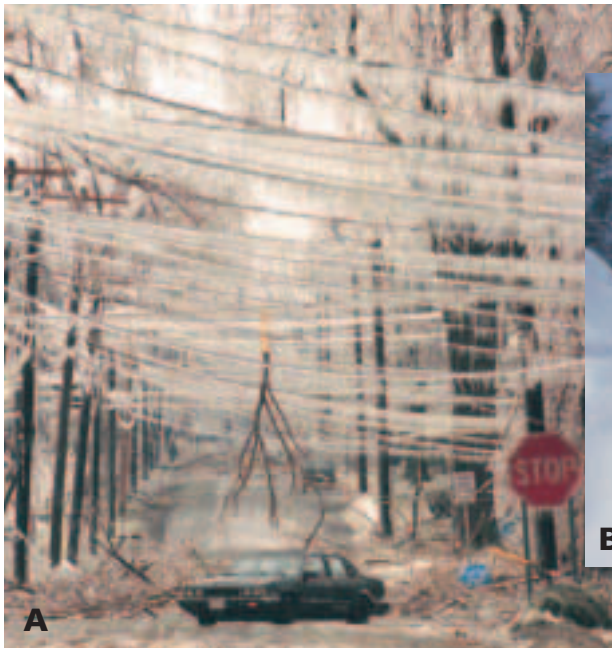
#### Analysis

1. Copy the data table in your science journal. Calculate the average temperature for each day, then include those temperatures in your data table.

- Plot the daily maximum temperatures on a graph with the days on the x-axis and the maximum temperatures on the y-axis. Connect the data points to show how the maximum temperature changed over the ten-day period.
- Repeat step 2 for the minimum and average temperatures.

#### Thinking Critically

- A heat wave is defined as two or more consecutive days with an average temperature of 85°F or higher. On what day did the city begin its heat wave? How long did the heat wave last?
- Calculate the average temperature for the days of the heat wave only. Compare this to the average temperature of the remaining days.
- What safety measures could residents of the city take to minimize the effects of a heat wave?



**Figure 13-14** An ice storm in 1990 damaged utility lines in Watertown, New York **(A)**. Nearly 2.3 m of snow fell near Lake Ontario in 1996 **(B)**.

for the sake of convenience. While the wind-chill index is helpful, it does not account for individual variations in sensitivity to cold, the effects of physical activity, or humidity. Some scientists, noting that this system has been in place since the 1940s, are calling for the development of new methods that more accurately estimate the effects of cold weather on the human body. 🌿

## SECTION ASSESSMENT

1. Why are droughts usually associated with high-pressure systems?
2. Describe a situation wherein a relatively light rain could cause flooding.
3. Compare and contrast a cold wave and a heat wave.
4. What is the wind-chill factor? What does the wind-chill index measure?
5. Using **Table 13-6**, estimate the heat index for air with a temperature of 80°F and relative humidity of 90 percent.
6. Extreme floods occur more often in summer than any other time of the year. Use your knowledge of the jet stream to explain why this is true.
7. **Thinking Critically** Air in a summer high-pressure system warms by compression. Based on what you know about molecular motion, explain why air in a winter high-pressure system doesn't warm by compression, too.

### SKILL REVIEW

8. **Forming a Hypothesis** A key requirement for the formation of snow is cold air. Yet some parts of the United States have more annual snowfall than Canada, which is farther north and should therefore be colder. Form a hypothesis to explain the apparent discrepancy. For more help, refer to the *Skill Handbook*.



## Tracking a Hurricane

**H**urricanes are violent storms. That's why it's important to have plenty of advance warning before they hit land. By tracking the changing position of a storm on a chart and connecting these positions with a line, you can determine a hurricane's path.

### Preparation

#### Problem

What information can you obtain by studying the path of a hurricane?

#### Hypothesis

Gather information about the path of a hurricane. **Form a hypothesis** about how the hurricane's path can be used to predict the strength of the storm and where most damage might be inflicted.

#### Objectives

- **Gather** and **communicate** data about hurricanes.

- **Plot** data on a hurricane-tracking chart.
- **Predict** where storm-inflicted damage might occur.

#### Data Sources

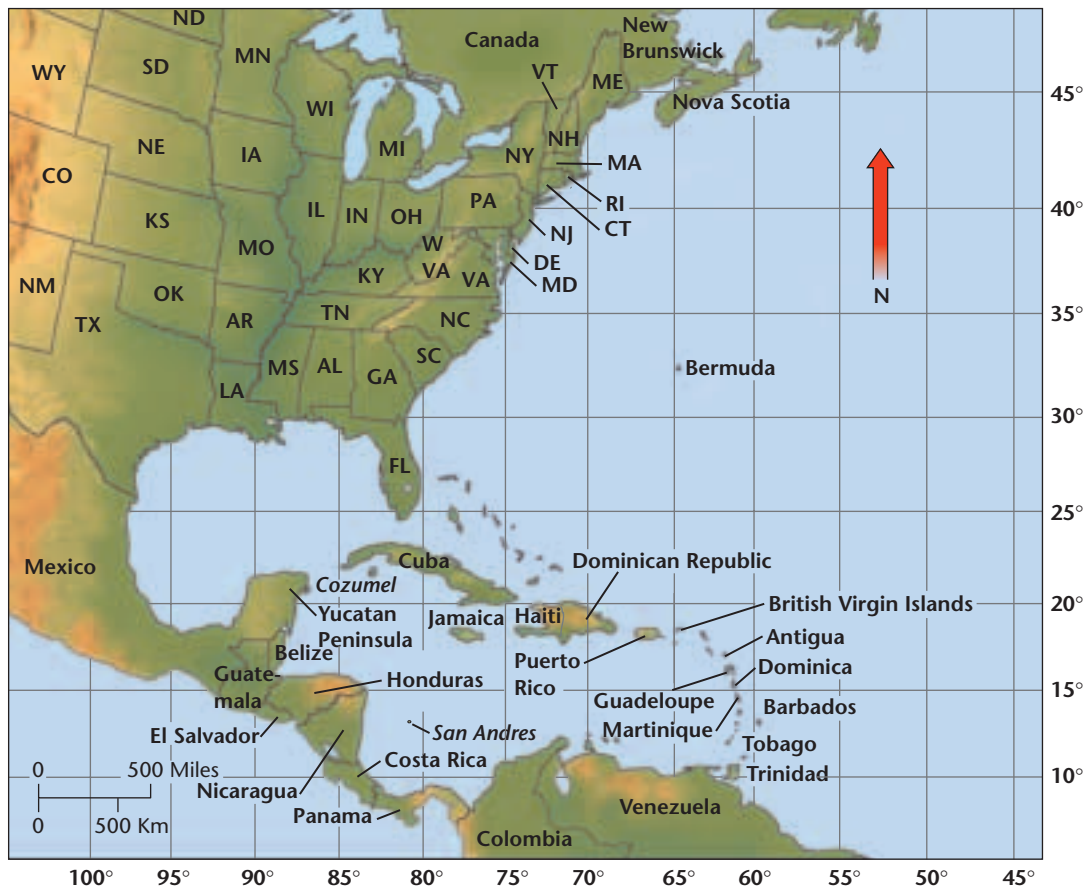
Go to the Earth Science Web site at [earthgeu.com](http://earthgeu.com) to find links to hurricane data, or use information provided by your teacher. Make copies of the hurricane-tracking chart in this lab or download a chart from the Web site.

### Plan the Experiment

1. Find a resource that lists major hurricanes that have occurred within the past five years. The Earth Science Web site provides a list of sites that have information about hurricanes.
2. Choose a hurricane to research. Some recent major hurricanes include Hurricane Claudette, Hurricane Isabel, and Hurricane Floyd.
3. Gather data about the hurricane from the links on the Earth Science Web site or the library.

### Procedure

1. Incorporate your research into a data table. Add any additional information that you think is important.
2. Go to the Earth Science Web site at [earthgeu.com](http://earthgeu.com) to post your data.
3. Visit sites listed on the Earth Science Web site for information on other major hurricanes.

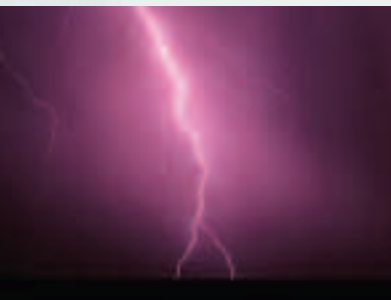


## Conclude & Apply

**Sharing Your Data** Find this *Internet GeoLab* on the Earth Science Web site at [earthgeu.com](http://earthgeu.com). Post your data in the table provided for this activity. Use the additional data from other students to complete your chart and answer the Conclude & Apply questions.

1. Plot the position, air pressure, wind speed, and stage of the hurricane at six-hour intervals throughout its existence.
2. Plot the changing position of the hurricane on your hurricane-tracking chart.
3. What was the maximum wind speed in knots that the hurricane reached?
4. Multiply the value from question 3 by 1.15 to find the wind speed in miles per hour. Based on this value, how would the hurricane be classified on the Saffir-Simpson scale?
5. Using your completed hurricane-tracking chart, list the landmasses over which the hurricane passed.
6. Where would you expect the storm surge to have been greatest? Explain. Compare your answer to the information you gathered on the damage inflicted by the storm. Was your answer correct?
7. How was the hurricane's strength affected when its center passed over land?

# Science & Technology



## Taming Lightning

*In a high-voltage laboratory in Canada, scientists experiment with lightning on a regular basis. Their goal is to one day work outside, triggering lightning bolts and directing them safely away from people and property. They are among a group of scientists worldwide who are developing new and better ways to tame lightning before it strikes.*

Each year in the United States, lightning accounts for 7500 forest fires, roughly 93 deaths, several hundred injuries, and millions of dollars in damage to communications equipment, buildings, electrical systems, and power lines. To guard against loss of life and property, most homes and commercial structures are equipped with lightning-protection systems. These systems use lightning rods—slender metal rods placed upon rooftops—to gather positive charges from the ground. The positive charges attract the negative charges in the base of a thundercloud and neutralize them split seconds before they coalesce into a lightning strike. Aluminum or copper cables act as conductors, connecting the lightning rods to ground terminators, which are metal rods buried beneath the soil. The function of these rods is to guide the electrical current harmlessly into the ground.

Lightning-protection systems such as these have been around since Benjamin Franklin flew his kite in a storm some 200 years ago, demonstrating conclusively that lightning is indeed electricity. Today, one of the most promising areas of lightning-protection research involves something that Benjamin Franklin never had at his disposal—laser beams.

### Home-Grown Lightning

Let's return to the high-voltage lab in Canada. There, scientists use two huge, circular elec-

trodes to re-create the natural conditions that result in a shocking bolt of lightning. One electrode is suspended about 6 m above the other. The top electrode represents the base of a thundercloud. The bottom electrode represents the ground. Just as in nature, negative charges flow down from the “thundercloud” and positive charges flow up from the “ground.” The wave of current that surges upward to meet the downward discharge results in the bright, jagged flash known as lightning.

The goal of these scientists, however, is not simply to model lightning. They want to learn how to harness lightning—to trigger controlled strikes and guide them to safe locations. To do this, the scientists aim a laser beam through a hole in the center of the bottom electrode. The beam displaces electrons from charged particles in the air, simultaneously provoking a lightning strike and providing a guided path for the discharge to follow. Instead of a jagged bolt of lightning, the controlled strike is as straight as a laser beam.

### Activity

Where's the safest place to be during a thunderstorm? If you're caught outside in the open, what should you do? Research lightning safety tips, then develop a safety brochure for distribution at your school.

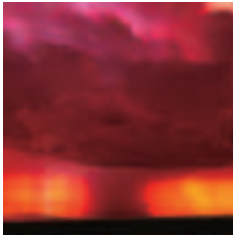
# CHAPTER 13

## Study Guide

### Summary

#### SECTION 13.1

##### Thunderstorms



##### Main Ideas

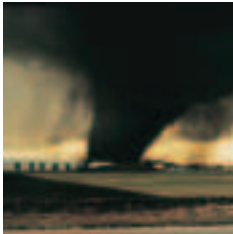
- For a thunderstorm to occur, there must be abundant moisture in the lower levels of the atmosphere and a mechanism to lift the moisture so it can condense. In addition, the air must be unstable so that the growing cloud will continue to rise.
- Thunderstorms are classified according to the mechanism that caused the air to rise. In an air-mass thunderstorm, the cloud rises because of unequal heating of Earth's surface within one air mass. In a frontal thunderstorm, the air rises because it is pushed up by an advancing air mass.

##### Vocabulary

air-mass thunderstorm (p. 331)  
frontal thunderstorm (p. 331)  
sea-breeze thunderstorm (p. 331)

#### SECTION 13.2

##### Severe Weather



##### Main Ideas

- Lightning is produced when an advancing stepped leader unites with an upward-moving return stroke. Thunder is the sound made by the rapid expansion of air around the lightning bolt as a result of extreme heating of the lightning channel.
- Thunderstorms can damage property and cause loss of life. The hazards of thunderstorms include lightning, violent winds, hail, floods, and tornadoes.
- The Fujita tornado intensity scale classifies tornadoes according to wind speed, path of destruction, and duration.

##### Vocabulary

downburst (p. 336)  
Fujita tornado intensity scale (p. 338)  
supercell (p. 334)  
tornado (p. 338)

#### SECTION 13.3

##### Tropical Storms



##### Main Ideas

- Tropical cyclones derive their energy from the evaporation of warm ocean water and the release of heat.
- The Saffir-Simpson hurricane scale classifies hurricanes according to intensity.
- Hurricane hazards include violent winds, floods, and storm surges. The National Hurricane Center tracks hurricanes and issues advance warnings to help reduce loss of life.

##### Vocabulary

eye (p. 344)  
eyewall (p. 344)  
Saffir-Simpson hurricane scale (p. 344)  
storm surge (p. 345)  
tropical cyclone (p. 341)

#### SECTION 13.4

##### Recurring Weather



##### Main Ideas

- Examples of persistent weather events include floods, droughts, cold waves, and heat waves.
- The heat index assesses the impact of humidity combined with excessive heat on the human body. The wind-chill index estimates the heat loss from human skin caused by a combination of cold air and wind.

##### Vocabulary

cold wave (p. 349)  
drought (p. 347)  
heat wave (p. 348)  
wind-chill factor (p. 350)

## CHAPTER 13

# Assessment

### Understanding Main Ideas

- Which of the following would work against the development of a thunderstorm?
  - rising air
  - stable air
  - moisture
  - unstable air
- Which of the following does NOT describe a type of damaging thunderstorm wind?
  - downburst
  - microburst
  - land breeze
  - macroburst
- Flooding is most likely to take place because of rains associated with what type of front?
  - stationary front
  - occluded front
  - cold front
  - warm front
- During what stage of a tropical cyclone does an eyewall develop?
  - tropical depression
  - tropical storm
  - hurricane
  - tropical wave
- What is the first stage of a lightning bolt?
  - return stroke
  - stepped leader
  - positive charge
  - downdraft
- Which of the following does NOT play a key role in the development of hail?
  - supercooled water
  - strong downdrafts
  - warm ocean water
  - strong updrafts
- Heat waves involve high-pressure systems that cause air to sink and warm by which of the following processes?
  - compression
  - conduction
  - evaporation
  - condensation
- Which of the following weather hazards involves lack of moisture?
  - hail
  - drought
  - storm surge
  - flood
- What percentage of tornadoes are classified as F4 or F5 on the Fujita tornado intensity scale?
  - one percent
  - ten percent
  - 50 percent
  - 75 percent
- Which of the following factors, if increased, would make a thunderstorm severe?
  - temperature
  - surface moisture
  - duration
  - conduction
- Which way do hurricanes rotate in the southern hemisphere?
  - south
  - clockwise
  - counterclockwise
  - north
- In which ocean would you NOT expect to experience a tropical cyclone?
  - West Pacific
  - Indian
  - North Atlantic
  - South Atlantic
- What weather events are cold waves most often associated with?
  - floods
  - polar high-pressure systems
  - tropical high-pressure systems
  - droughts
- Compare and contrast tornadoes and hurricanes.
- Why are cold fronts more likely to produce severe thunderstorms than warm fronts?

### Test-Taking Tip

#### CAREFULLY OBSERVE SCIENTIFIC ILLUSTRATIONS

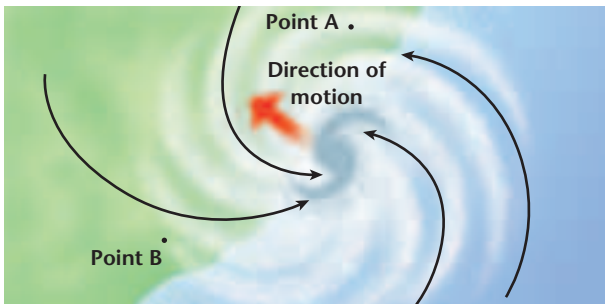
If a test question requires you to interpret a scientific illustration, look very closely at the details of the illustration. Your answer may depend on a small detail.

# CHAPTER 13 Assessment

## Applying Main Ideas

- Using *Table 13-6*, determine the heat index if the temperature is 90°F and relative humidity is 60 percent.
- Using *Table 13-4*, classify a hurricane with a maximum wind speed of 120 mph.

Use the illustration of a hurricane in the northern hemisphere to answer question 18.



- Would a storm surge be more likely to occur at point A or point B? Why?
- How might you prepare for a tornado? What safety measures would you recommend?
- In which oceans would you NOT expect to experience a tropical cyclone? Why?

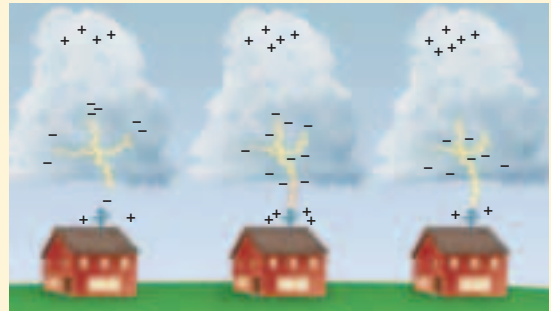
## Thinking Critically

- Extreme cold waves are more common in the northern hemisphere than in the southern hemisphere. Why?
- Tropical cyclones are never observed within about 5° north and south latitudes. What do you think might account for this?
- Supercells that produce tornadoes often produce large hailstones as well. Explain.
- Why are boats on lakes or on the ocean especially vulnerable to lightning strikes?

## Standardized Test Practice

### INTERPRETING SCIENTIFIC ILLUSTRATIONS

Use the illustration below to answer questions 1 and 2.



- Which type of cloud is lightning associated with?  
a. altocumulus      c. cirrus  
b. stratocumulus    d. cumulonimbus
- Lightning is the illumination that occurs when an invisible channel of negatively charged air descends to the ground and a channel of positively charged ions rushes upward to meet it. What is the channel of positively charged ions called?  
a. return stroke      c. ground stroke  
b. stepped leader     d. electronic leader
- What occurs when winds of at least 120 km/h drive a mound of ocean water toward coastal areas?  
a. downburst          c. storm surge  
b. cold wave          d. tornado
- Which factor is NOT associated with a heat wave?  
a. a high-pressure system  
b. a weakened jet stream  
c. above-normal temperatures  
d. increased cloud cover