CHAPTER 20

PREVIEW

▶ FOCUS QUESTIONS In this chapter you will study weather and learn more about the key questions below.

Section 1 What are air masses? How and where do they originate?

Section 2 How do fronts and pressure systems affect weather patterns?

Section 3 What atmospheric conditions cause thunderstorms and tornadoes?

Section 4 How do scientists define hurricanes and winter storms? How do these phenomena start?

Section 5 By what means do meteorologists predict weather?

▶ REVIEW TOPICS As you investigate weather, you will need to use information from earlier chapters.

- Coriolis effect **(p. 75)**

▶ READING STRATEGY

PREVIEW

Before you read, look through Chapter 20, noting the key ideas, key vocabulary, images, and captions. In your science notebook, make a list of things you expect to learn about in the chapter.

INTERNET RESOURCES
CLASSZONE.COM

At our Web site, you will find the following Internet support for this chapter.

DATA CENTER

EARTH NEWS

VISUALIZATIONS

- Air Mass Movement across North America
- Warm and Cold Fronts
- Thunderstorm
- Tornado
- Hurricane

LOCAL RESOURCES

CAREERS

INVESTIGATIONS

- How Does a Mid-Latitude Low Develop into a Storm System?
- How Well Can You Predict Tomorrow's Weather?

20.1

KEY IDEAS

An air mass is a large body of air that has similar characteristics throughout.

The temperature and humidity of an air mass depend on where the air mass originates.

KEY VOCABULARY

- meteorology
- air mass

Air Masses and Weather

Weather influences our lives every day. It helps determine, for example, whether we carry an umbrella or put on sunblock, and whether our airplanes are delayed. Because of weather's influence, we depend on knowing ahead of time what weather to expect. **Meteorology,** the study of processes that govern Earth's atmosphere, helps make weather predictions possible. Meteorologists, the scientists who specialize in this study, perform tasks ranging from making weather forecasts to studying how tornadoes develop. To perform their work, they need to know how air masses form and also how the interactions of air masses generate weather.

Origin of an Air Mass

An **air mass** is a large body of air in the lower troposphere that has similar characteristics throughout. An air mass can be several thousand kilometers in diameter and several kilometers high. Two or three air masses can cover all of the continental United States. Throughout an air mass, temperature and humidity are nearly uniform.

The temperature and humidity of an air mass depend on where the air mass originates. For example, in polar regions, the lack of sunlight in winter causes the ground to be very cold. If an air mass stays in a polar region for days or weeks, it becomes cold as well. In the tropics, sunlight strikes directly and heats the ground. Thus an air mass staying in the tropics for an extended period becomes hot. The moisture content of an air mass also depends on the underlying surface. For example, an air mass that stays over land for a long time becomes dry, whereas an air mass over the ocean absorbs water vapor and becomes moist.

When an air mass travels from one area to another, it takes with it the temperature and humidity of its place of origin. For example, when the air in Chicago, Illinois, turns crisp and cool in the fall, it is because an air mass that originated in Canada has moved southward. When Chicago becomes hot and muggy in the summer, it is because an air mass from the Gulf of Mexico has moved northward.

As an air mass travels, its characteristics may change. For example, when a cold polar air mass moves south, it affects not only the weather of the area it enters but also gradually heats up as it moves over a warmer surface. Earth's topography can also contribute to changes in the temperature and humidity of an air mass as it travels.

DESERT AIR The hot, dry air over this desert used to be cool, moist air over the Pacific Ocean. The air was modified when it passed over mountains. As it rose, it lost moisture. When it sank on the other side of the mountains, it was compressed and warmed.

Types of Air Masses

Meteorologists classify air masses according to where they originate. The diagram below shows the principal North American air masses. The temperature of each type of air mass depends on whether the air mass originates in an arctic, polar, or tropical region. The humidity depends on whether the air mass comes from land (continental) or sea (maritime).

VISUALIZATIONS
CLASSZONE.COM

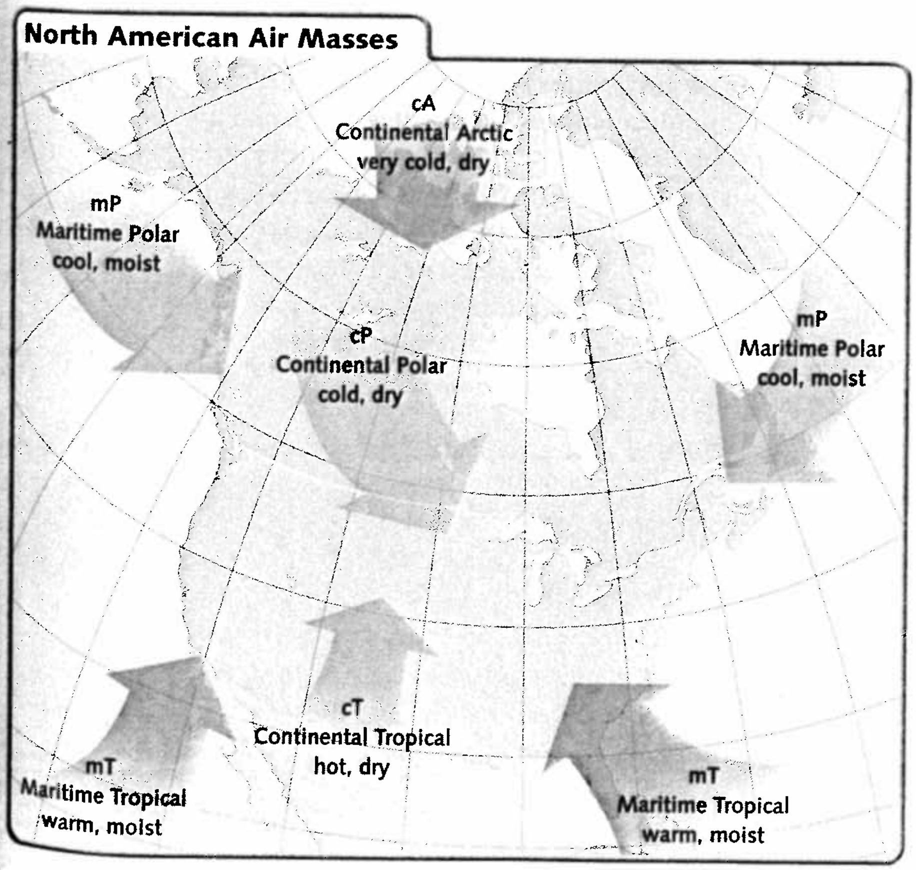
View satellite movies of air masses moving across North America.
Keycode: ES2001

Continental Arctic

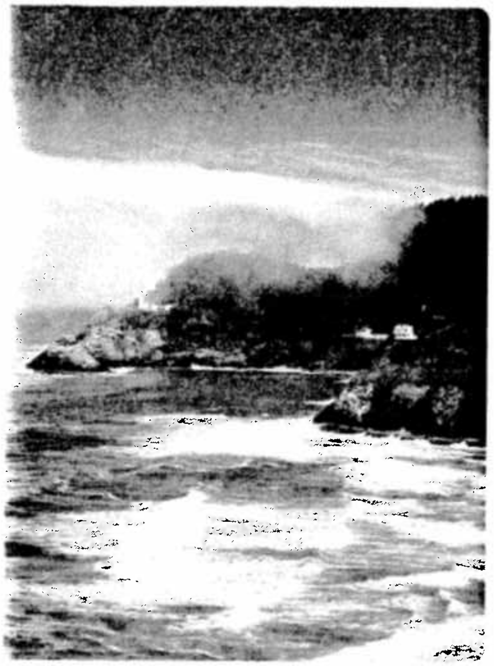
Continental arctic (cA) air masses originate in the arctic regions, where the air becomes extremely cold. Although these air masses may warm as they move southward, they are still capable of causing extreme cold waves in the regions they enter, particularly if they pass over snow-covered ground along the way. Because cold air is incapable of containing much moisture, cA air masses are also very dry.

Continental Polar

Continental polar (cP) air masses originate over the inland regions of Alaska and Canada. These air masses are somewhat warmer than cA air masses, but the difference in temperature, as well as in humidity, between cA and cP air can be slight. The brilliantly sunny, cold winter days in some regions of the United States are usually caused by cP air. Although this air is usually just cold and dry, in some regions it can create precipitation. For example, if cP air passes over the Great Lakes in the late fall when the water is still warm, the cold, dry air picks up moisture from the lakes, then deposits the moisture downwind from the lakes as heavy snow, called lake-effect snow.



AIR MASSES The characteristics of an air mass depend on where it originates.



MARITIME POLAR AIR These low clouds over the coast of Lane County, Oregon, may have been caused by continental cooling of maritime polar air.

Maritime Polar

Maritime polar (mP) air masses originate over the ocean in high latitudes. These air masses are both cold and damp. However, mP air is not usually as cold as cP air because of the contrast in temperature between the land (colder) and the oceans (warmer). If mP air cools to its dew point, fog, clouds, or precipitation results. For example, in the Pacific Northwest, ocean air masses passing inland hit the Olympic and Cascade mountain ranges and rise abruptly, expanding and cooling; this sudden cooling brings the air to its dew point, resulting in the wet winter climate of the area. Occasionally, mP air from the North Atlantic brings heavy snowstorms, called nor'easters, to the East Coast in the winter and cool, clear weather to the area in the summer.

Maritime Tropical

When an air mass originates over a warm tropical ocean, it acquires both warmth and moisture. Such air masses are known as maritime tropical (mT) air masses. In the summer, mT air from the Bahamas and the Gulf of Mexico moves clockwise around the high pressure over the Atlantic Ocean bringing heat and humidity to the Midwestern and Eastern United States. Because the air contains a large amount of moisture, thunderstorms often develop during the heat of the day. As the summer sun heats the ground, the moist mT air is heated from below and rises, forming thunderclouds. When the sun sets, the clouds and thunderstorms dissipate as the surface cools. Thunderstorms will be covered in greater detail in Section 20.3.

Continental Tropical

Air masses that originate over deserts are hot and dry and are known as continental tropical (cT) air masses. Often, a cT air mass originates as a maritime air mass but becomes dry as it passes over mountains. In the summer, cT air produces tremendous heat waves in much of the United States. Whereas mT air usually produces temperatures no higher than 100°F, cT air is much hotter, with temperatures exceeding 100°F. In addition, since cT air is dry, it doesn't bring clouds or thunderstorms to cool the air as the moist mT air does. If cT air advances into an agricultural region and stays for a long time, it can cause serious damage to crops.

20.1 *Section Review*

1. Explain how cold and hot air masses originate.
2. Explain how moist and dry air masses originate.
3. Give two examples of factors that can modify the characteristics of an air mass.
4. List the principal North American air masses, identify where each originates, and describe the temperature and humidity characteristics of each.
5. CRITICAL THINKING Explain how continental polar air can bring clear weather to one region while causing heavy snow in another.

Fronts and Lows

20.2

KEY IDEA

The movements of fronts and lows greatly influence the weather at mid-latitudes.

KEY VOCABULARY

- front
- cold front
- warm front
- occluded front
- stationary front

Weather in the mid-latitudes can be quite changeable. One day might be mild and sunny, the next cold and clear, the next snowy and windy. These changes in weather result mostly from the movement of low-pressure systems and their associated frontal systems.

What Is a Front?

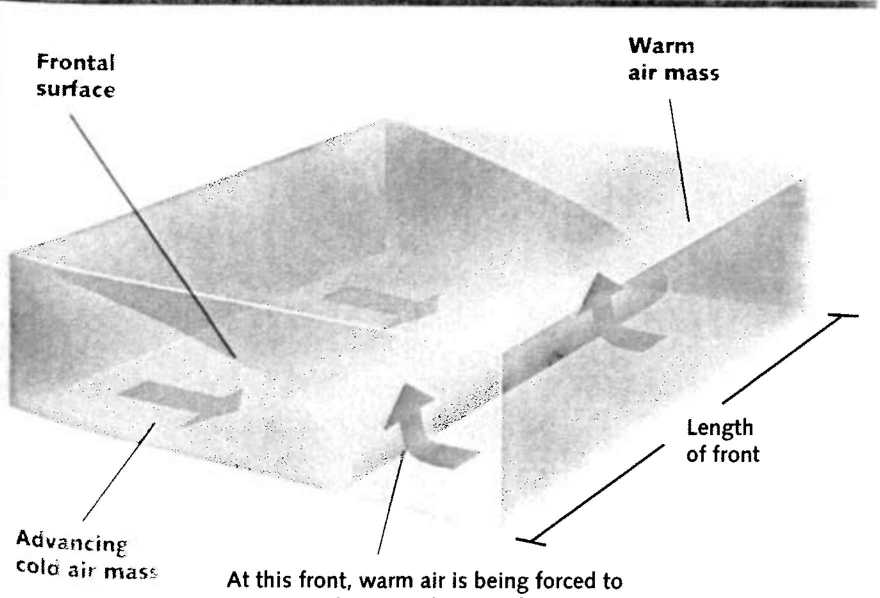
Air masses of different types don't easily mix. The boundary that separates opposing air masses is known as a **front.** The width of a front can range from 200 meters to 200 kilometers. It can be as high as 5 kilometers and as long as 2000 kilometers and can affect weather patterns in areas hundreds of kilometers wide. Fronts are most common at mid-latitudes, where southward-moving polar air masses and northward-moving tropical air masses often meet.

The air masses on either side of a front may differ in temperature, in humidity, or in both. At the front, the less-dense air mass is forced to rise over the denser air mass. As a result, the front is roughly wedge shaped, as shown in the illustration below, which depicts warm air being forced to rise over advancing denser and colder air. You will learn about the characteristics of different kinds of fronts later in this section.

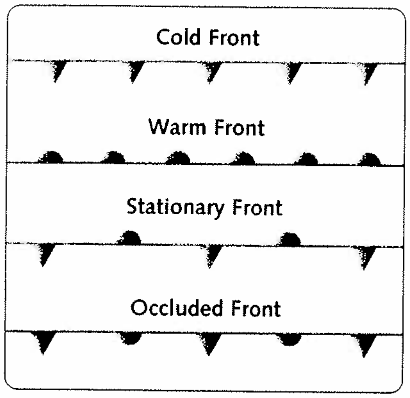
Fronts can have steep slopes. The slope may range from about 1 over 50 to 1 over 300. A slope of 1 over 50 means that the frontal surface rises 1 kilometer for every 50 kilometers of horizontal distance. Such a slope is much steeper than one that rises 1 kilometer for every 300 horizontal kilometers.

Fronts usually bring precipitation. At the frontal surface, the less-dense air rises high into the troposphere. The air cools as it rises, and if the air is humid enough, clouds and precipitation form.

Front



At this front, warm air is being forced to rise over advancing denser cold air.



INTERNATIONAL WEATHER SYMBOLS

VISUALIZATIONS
CLASSZONE.COM

Compare and contrast warm and cold fronts.
Keycode: ES2002

Kinds of Fronts

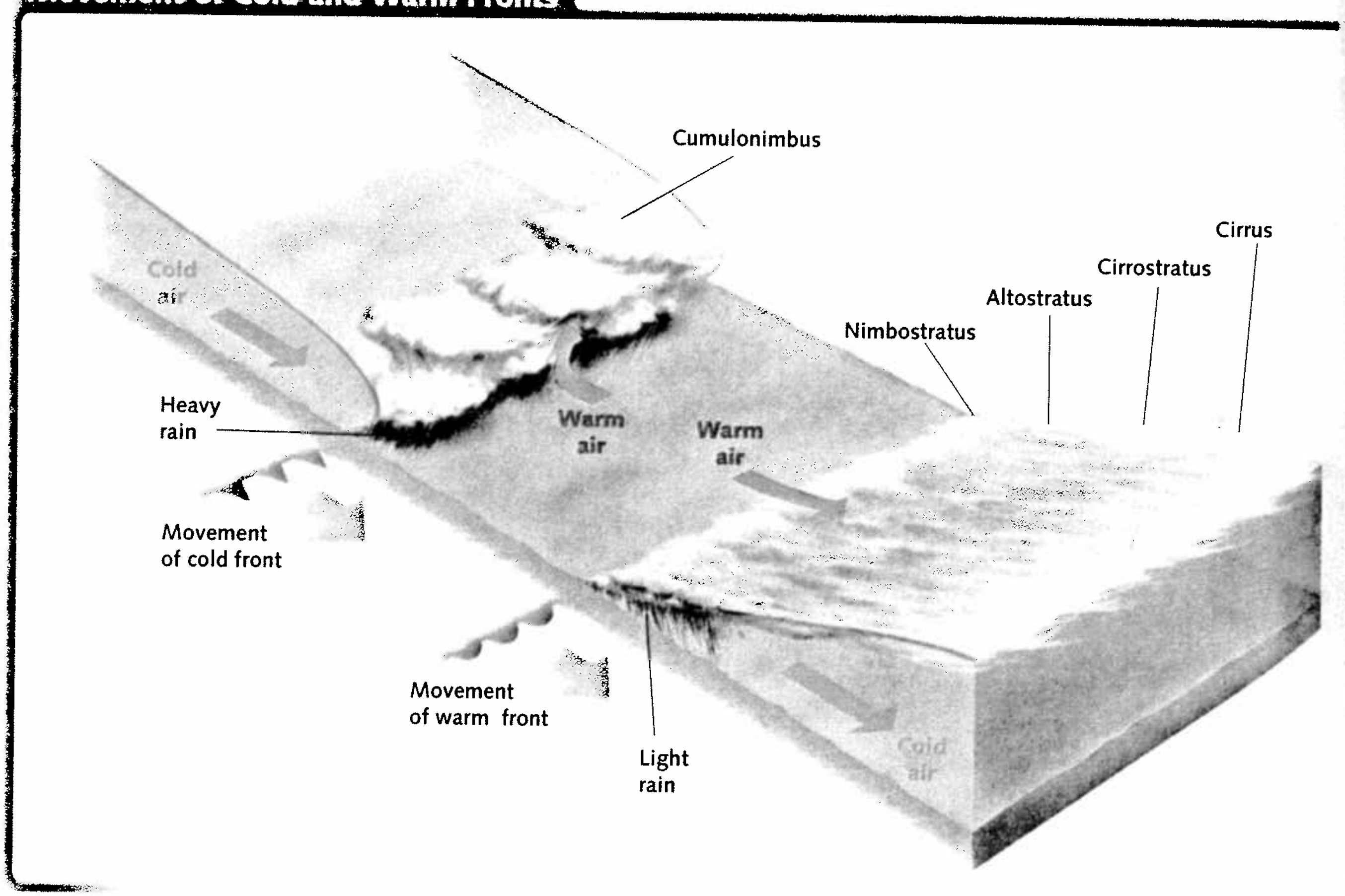
The weather associated with a particular front depends on the types of air masses involved and the speed at which the front is moving. Although fronts occasionally occur between air masses that have the same temperature (but different humidity), scientists usually define fronts according to the temperature of the advancing air mass. There are four basic kinds of fronts: cold, warm, occluded, and stationary.

Cold Fronts

A **cold front** is the boundary between an advancing cold air mass and the warmer air mass it is displacing. Since cold air is denser than warm air, the cold air slides underneath the warm air and forces it upward. Friction from moving along the ground causes the lower part of the cold air mass to lag behind the upper part, as shown in the illustration below. Cold fronts have steep slopes, often as steep as 1 in 50.

The type of weather a cold front brings depends to a large degree on the type of air mass it is displacing. For example, when cold cP air displaces warm, humid mT air in the summer, thunderstorms often form along the front as the moist mT air is forced upward. On the other hand, if the cold air displaces hot, dry cT air, the rising air contains little moisture so there may be no precipitation. The passing front may cause no greater change than a shift in wind direction. In the summer, some cold fronts cause a

Movement of Cold and Warm Fronts



decrease in humidity but little change in temperature. In the winter, a cold front may be marked by rain or snow showers.

Because a cold front has a steep slope, the precipitation associated with the front covers only a narrow band of ground. A cold front moves relatively quickly, and precipitation usually ends shortly after the front passes.

Warm Fronts

If warm air displaces cold air, the boundary between the air masses is known as a **warm front.** The advancing warm air rises above the denser cold air mass, which retreats slowly. The slope of a warm front—usually only about 1 in 150—is more gradual than that of a cold front, and the weather changes associated with the warm front are less dramatic.

The first signs of the approach of a warm front are high cirrus clouds, which are followed by cirrostratus and lower and thicker stratiform clouds. Such clouds form in the warm, stable air sliding up the frontal surface. The clouds may stretch 1500 kilometers ahead of the place where the warm front touches the ground; thus cirrus clouds may warn of approaching precipitation more than a day before it arrives.

Following the cirrus and cirrostratus are altostratus clouds, which almost screen out the sun and the moon. Finally, the heavy nimbostratus clouds arrive, and steady rain or snow begins. This area of rain and snow can stretch hundreds of kilometers ahead of where the front touches the ground, and the precipitation may last for a day or more. Although thunderstorms occasionally form, they are not typical of a warm front. After the front passes, the weather warms.

Occluded and Stationary Fronts

Cold fronts typically move about twice as fast as warm fronts. If a cold front "catches up" to a warm front, the result is an **occluded front.** The warm air that is caught between the two colder air masses is forced to rise. As this warm air rises, it cools, often causing cloudiness and precipitation.

If a front is not moving forward, it is called a **stationary front.** As with other fronts, the warmer air rises over the denser, colder air, and clouds and precipitation may result. If the front remains stationary for too long, flooding can occur.

Life Cycle of a Mid-Latitude Low

Fronts are usually connected to mid-latitude low-pressure systems. In fact, a low-pressure system often starts out as a small ripple on a stationary polar front where cold polar air meets warm tropical air. Under certain conditions, this small ripple can grow into an intense storm system.

Shortly after the end of World War I, Norwegian meteorologists developed a theory explaining the life cycle of mid-latitude low-pressure systems. This theory has been modified over time as scientists have gathered new information, but the basic aspects of the theory remain a cornerstone of modern meteorology.

25-Minute **Mini LAB**

Graphing a Front

Materials

- 5 sheets of graph paper
- tape
- straightedge
- pencil

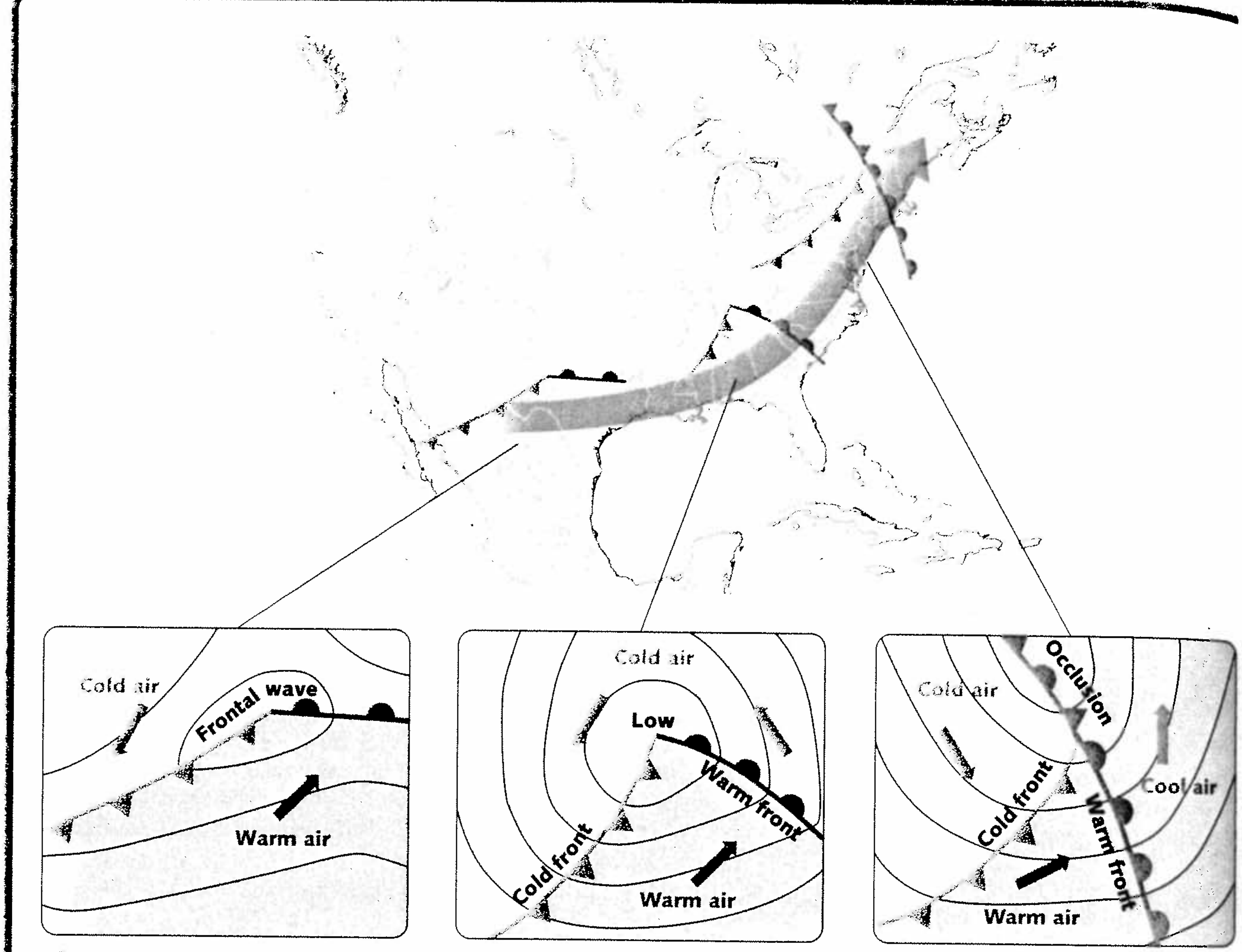
Procedure

1. Cut the sheets of paper in half lengthwise.
2. Tape the sheets of paper side by side to form one piece that is more than 500 grid squares long.
3. Draw a front that is 5 kilometers high and has a slope of $\frac{1}{100}$. Use the scale 1 square grid length = 1 kilometer. Label the warm and cold fronts.

Analysis

Describe the slope of the front drawn on the graph. Using the straightedge, estimate the slope between the warm and cold fronts.

Norwegian Model of Low-Pressure System



1 When conditions are favorable, surface air pressure at the polar front drops and a wave forms on the front. The pressure is lowest at the peak of the wave.

2 In the Northern Hemisphere, winds blow counterclockwise around the low. As the central pressure continues to drop, warm tropical air on the east side moves northward, and cold polar air on the west side moves southward.

3 The quicker-moving cold front eventually catches up to the warm front, resulting in an occluded front. The storm is most intense at this stage. Eventually, the system loses energy and begins to weaken.

It generally takes 12 to 24 hours for a low-pressure system to pass through the first two stages shown above. After reaching the occluded stage, the low can last for three days or more. Although the original low usually weakens during the occluded stage, meteorologists must continue to monitor the system, since the low can still be strong, with high winds and rains. Sometimes a new low will develop where the cold, warm, and occluded fronts meet.

Not all lows are like the simple one shown in the diagram. Some are associated with more than two fronts, while others are associated with only one front. Yet if you read weather maps over a period of time, you will notice that many low-pressure systems follow a life cycle similar to the one described by the Norwegian model.

Upper-Air Flow

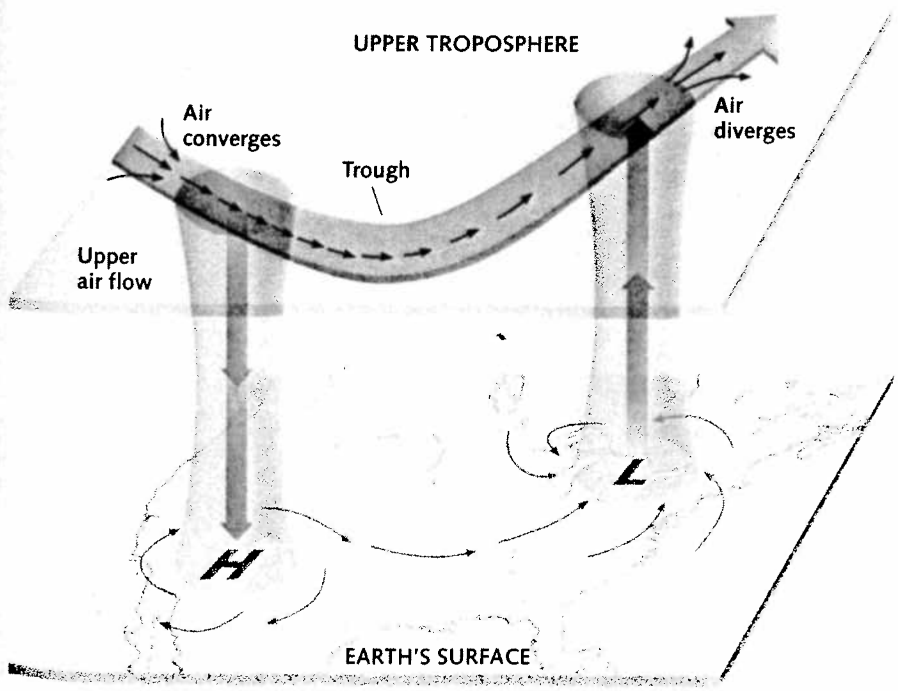
Throughout the life of a low-pressure system, upper-air flow is what controls the surface low's path and intensity. At Earth's surface, air is constantly spiraling into the low-pressure system. You might expect that this addition of air would increase the pressure in the center of the low-pressure system, making it weaker. Instead, though, lows often strengthen over time. The behavior of upper-air flow can help explain this unexpected fact.

If you look at a weather map, you will see that the upper-air flow is seldom straight, but curves back and forth like a winding road. Meteorologists call some bends ridges and others troughs, depending on the air pressure.

Troughs are like traffic jams in the upper-air flow. As upper-level winds approach a trough, the air crowds together like cars slowing down before a traffic jam. Some of the air sinks to Earth's surface, like cars taking a detour around the traffic jam. This sinking air increases the air pressure at the surface. If more air enters the high from above than spirals out of it at the ground, the high strengthens.

Eventually, the air spreading out from the high at the surface will spiral into a surface low. Here, the air rises and rejoins the upper-air flow beyond the trough. If more air rises out of a surface low than spirals into it at the ground, the low will strengthen.

The amount of air that sinks into surface highs and rises out of surface lows depends both on how sharp a bend the upper-air flow makes and on how fast the upper-air flow is moving. Meteorologists must monitor the upper-air flow to predict whether a surface high or low is likely to strengthen or weaken.



TROUGHS The upper-level flow is similar to cars slowing down and getting closer together (converging) as they approach a traffic jam (the trough), then speeding up and getting farther apart (diverging) after the traffic jam breaks up.

INVESTIGATIONS CLASSZONE.COM

How Does a Mid-Latitude Low Develop into a Storm System?
Analyze the development of a storm as it moves across North America.
Keycode: ES2003

Weather Associated With Pressure Systems

When a low-pressure system passes, the weather you will experience depends on where the center of the low passes in relation to you. For example, in the Northern Hemisphere, if a low passes north of you, a warm front may move over you, followed by a cold front. If the low passes to the south, no fronts will move over you, but you may experience steady snow or rain.

The text below describes the weather that you would experience if a low heading east passes to the north of you.

- As the warm front approaches from the west, cirrus clouds lead to cirrostratus, altostratus, nimbostratus, and stratus clouds. Steady snow or rain, followed by drizzle, marks the front's approach.
- When the warm front passes, the temperature warms, winds shift, and the skies may slowly clear. If the air is humid, showery precipitation may occur, particularly nearer the center of the low.
- As the cold front approaches, it is preceded by scattered showers and possibly thunderstorms.
- As the cold front passes, the temperature drops, winds shift again, and the sky clears.

RADAR IMAGE This color radar image of the eastern United States shows the weather associated with a low-pressure system.

High-pressure areas are associated with fair weather. Because the air in a high is sinking, the skies are clear. Days may be hot, depending on the ground cover, and nights may be cold as heat radiates out to space. Inversions can form in the mornings, trapping pollution until the sun warms the ground.

Winds blow outward from a high. In the Northern Hemisphere, the winds spiral outward in a clockwise direction. There is little or no wind in the center of the high. The still air there takes on the characteristic temperature and humidity of the area, so highs are where air masses generally form. Whereas a low is surrounded by two or more air masses, a high represents a single air mass.

20.2 Section Review

1. What is a front?
2. Describe the weather conditions associated with warm and cold fronts. Why do these conditions differ?
3. Describe the life cycle of a mid-latitude low-pressure system.
4. Explain how upper-air flow can cause a high to strengthen.
5. CRITICAL THINKING If an observer in the Northern Hemisphere sees snow falling heavily with winds from the northeast, where is the low-pressure system relative to the observer? Explain your reasoning.
6. APPLICATION A low is predicted to pass through Florida in the winter. Do you forecast warm or cold temperatures for Georgia? Why?

Thunderstorms and Tornadoes

Storms come in various sizes. Mid-latitude storms, such as the low-pressure systems you studied in Section 20.2, can be 2000 kilometers across, and hurricanes, hundreds of kilometers across. In contrast, **thunderstorms**—storms with lightning, thunder, rain, and sometimes hail—may be only a few kilometers across. A storm's size is not a good indicator of the damage it can cause. For example, a thunderstorm can produce a deadly tornado along a narrow path, whereas a typical mid-latitude low may produce only rain or snow over a large area. In this section, you will learn about some of the more violent types of storms.

20.3

KEY IDEA

Thunderstorms, which form in warm, moist, unstable air, can result in destructive weather, including tornadoes.

KEY VOCABULARY

- thunderstorm
- squall line
- supercell
- lightning
- tornado

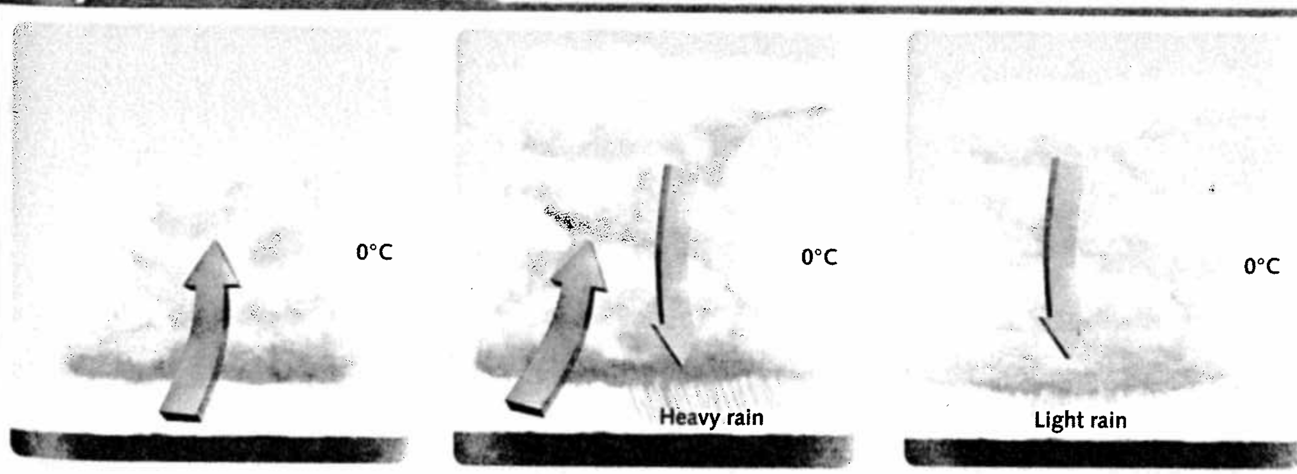
Thunderstorms

Thunderstorms, and their cumulonimbus clouds, form in warm, moist, unstable air. The storm clouds may attain heights of up to 20 kilometers in the atmosphere, and the weather they bring may include torrential rain, damaging winds, lightning, thunder, hail, and tornadoes.

Although thunderstorms can occur at any hour, they often occur during the afternoon because surface warming throughout the day causes the air to become unstable. Within this unstable atmosphere, a thunderstorm develops like this: some "trigger" forces part of the air to begin rising. The trigger can be a mountainside or a front standing in the way of the unstable air, or the air can collide with an opposing wind. As the rising air reaches the condensation level, the heat released during condensation makes this air warmer and less dense than the surrounding air. A cumulonimbus cloud quickly grows (as described in Chapter 18), and a thunderstorm begins.

VISUALIZATIONS
CLASSZONE.COM
Observe an animation of a thunderstorm.
Keycode: ES2004

Life Cycle of a Thunderstorm Cell



1 CUMULUS STAGE Air rises and a cumulus cloud forms. The rising air is called an updraft. The updraft prevents precipitation from reaching the ground.

2 MATURE STAGE The precipitation becomes heavy enough to fall through the updraft and reach the ground. The falling precipitation creates a downdraft.

3 DISSIPATING STAGE The downdraft weakens the updraft, eventually cutting off the supply of moist air rising to the cloud. The cloud begins to evaporate.

Safety Tips

Lightning

Stay or go indoors, and stay away from ungrounded appliances, electrical cords, metal pipes, and running water. Do not use the phone.

If caught outside, get into a hardtop car, not a convertible. Do not touch the metal frame.

Avoid tall objects like lone trees, flagpoles, and telephone poles. Avoid metal objects like umbrellas, bicycles, and wire fences. If caught in the open, squat low to the ground. Do not lie down.

Keep away from bodies of water, and do not stand in water. Watch out for flooding in low-lying areas.

NEVER stay under a lone tree.

DATA CENTER
CLASSZONE.COM
Learn more about lightning safety.
Keycode: ES2005

Thunderstorms consist of one or more convection cells, each of which usually has a lifetime of an hour or less. The life cycle of a single thunderstorm cell is shown in the illustration on page 445. The formation of new cells may extend the lifetime of a thunderstorm. Some multicell thunderstorms may cover a whole state and last as long as a day.

Thunderstorms often form along fronts because the frontal boundary forces air to rise. Frontal thunderstorms are associated with large-scale low pressure systems and may start and stop for days.

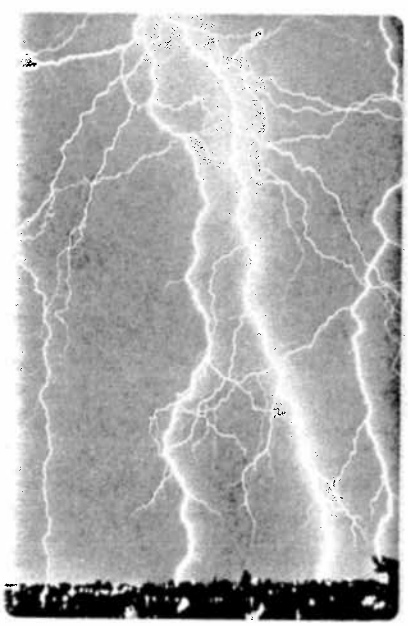
Frontal thunderstorms often occur in lines hundreds of kilometers long along the frontal surface. They also occur in lines ahead of the front, called **squall lines.** Strong winds often precede squall lines. This happens because the falling rain within a thunderstorm causes the air to cool. Since cold air is denser than warm air, the cold air sinks and spreads out ahead of the squall line. The sinking air within a thunderstorm is known as a downdraft. The downdraft of the thunderstorm's mature stage can transport upper-level winds to Earth's surface. Because frontal systems are often associated with strong winds aloft, frontal thunderstorms can cause severe wind damage. If a front or squall line moves slowly, its heavy rains can cause flooding.

Supercells are very large single-cell thunderstorms with particularly strong updrafts. The updraft of a supercell rotates, which can cause a tornado to develop. It is the supercell thunderstorm that produces the highest wind, the most damaging hail, and the most destructive tornadoes.

Lightning

All thunderstorms produce lightning. **Lightning** is a discharge of electricity from a thundercloud to the ground, to another cloud, or to another spot within the cloud itself. Lightning can also occur in the clouds of snowstorms, dust storms, or volcanic eruptions. No one is completely sure how clouds become electrically charged. Most scientists believe that when larger and smaller cloud particles collide within a cloud, the larger ones become negatively charged and the smaller ones positively charged. Most larger, heavier particles fall to the cloud's bottom, while most smaller ones rise to the top. When separate positive and negative charges flow toward one another, they produce a spark, which travels along the narrow path of charged ions and becomes a lightning bolt. The lightning heats the air, which expands explosively, causing the sound of thunder. Because sound takes about three seconds to travel a kilometer, and light travels at 300,000 kilometers per second, you see the lightning before you hear the thunder. Lightning can heat the air to more than 25,000°C. It can severely burn any living thing or damage nearby electrical equipment.

Lightning moving from a cloud to the ground often strikes the highest point available, and is more likely to strike protruding objects than flat ones. Once lightning strikes the ground, it may flow along the surface for a distance. Because lightning is an electrical charge, it flows best through materials that conduct electricity. These include metal, water, and wet ground.



LIGHTNING bolts, such as the ones seen over Tucson, Arizona, in this time-lapse photograph, are formed when separate positive and negative charges in a thundercloud flow toward one another and create a spark.

Tornadoes

A thunderstorm's most destructive possible byproduct is a tornado. A **tornado** is a violently rotating column of air that usually touches the ground. Because tornadoes can cause severe property damage, personal injury, and loss of life, scientists are trying to determine how they form so that they will be easier to predict.

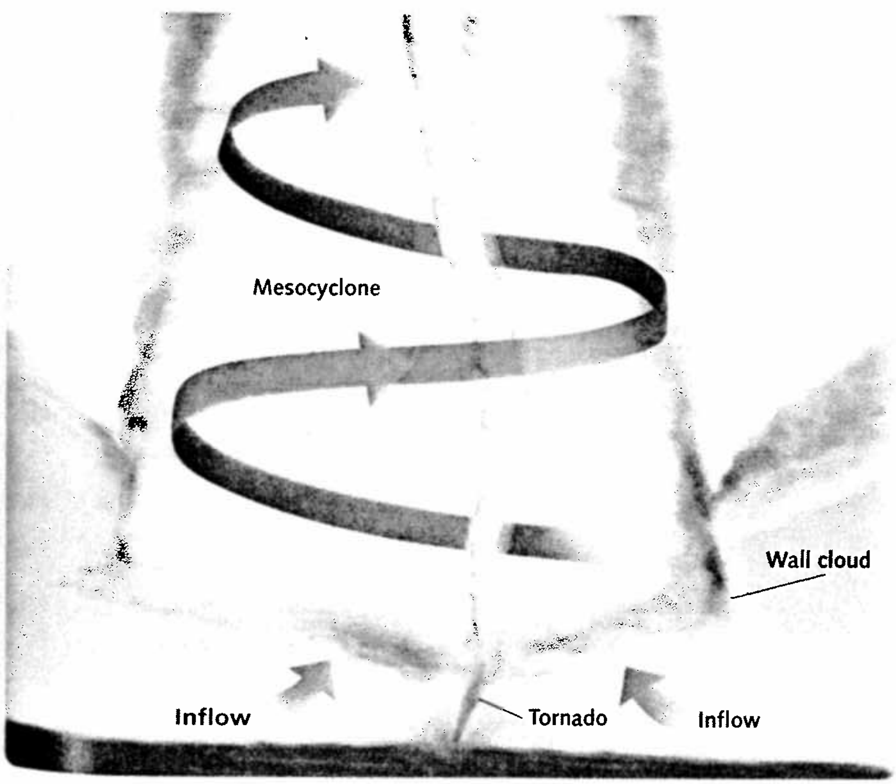
Tornado Formation

Because tornadoes are destructive and often unpredictable, they are difficult to study directly. Scientists have tried to place instruments in the paths of tornadoes, but it is difficult to do so without damaging the instruments and without putting people in danger. Predicting the path of a tornado also is difficult.

By observing from a distance, scientists have discovered that for a severe thunderstorm to produce a tornado, it must contain a rotating updraft called a mesocyclone. Such an updraft occurs when low-altitude winds are blowing at a different speed and in a different direction than winds higher up.

Before a tornado develops, the rotating clouds of the mesocyclone may become visible at the base of the storm and may lower to form a wall cloud. About 10 to 20 minutes later, a tornado may descend from the wall cloud. However, only a third of all mesocylones produce tornadoes, and a tornado may form without a visible mesocyclone or wall cloud.

TORNADO Sometimes referred to as a "twister," the rotating column of air at the base of a tornado is visible because it contains either moisture or dust and debris.



TORNADO FORMATION A rotating updraft of air may form a spinning column called a mesocyclone, which can eventually touch down on the ground as a tornado.

VISUALIZATIONS
CLASSZONE.COM

Examine an animation of a tornado.
Keycode: ES2006

TORNADO DAMAGE Because a tornado can be only meters across, it can destroy some buildings completely while leaving structures next door virtually untouched.

A tornado often appears as a vortex or a funnel-shaped cloud of flying debris. Some tornadoes are rope shaped, and others wedge shaped with more than one vortex. A tornado's funnel cloud results when the air pressure at its center is very low and air sucked into the funnel expands and cools; water vapor in the air condenses, forming a funnel-shaped cloud. If the air is drier, or the pressure inside the tornado is higher, the tornado may consist of a cloud of dust and debris, creating a loud roaring sound. Tornadoes can be just a few meters or more than a kilometer wide.

A tornado usually appears at the back edge of its parent thunderstorm and travels with the thunderstorm. Because upper-level winds often guide thunderstorms to the northeast, tornadoes often appear at the southwest edges of storms. However, tornadoes can travel in any direction and often move erratically. If a tornado is approaching, it may be hidden behind rain falling from the main body of the thunderstorm.

Tornadoes can occur anywhere throughout the United States and at any time of year. However, they occur most often in an area called Tornado Alley in the spring and early summer. Tornado Alley extends from Texas northward to South Dakota. The increased sunlight of spring and early summer warms the air near the ground while the air higher up stays quite cold. The temperature difference makes the air unstable, resulting in severe thunderstorms. Wind conditions in Tornado Alley can be ideal for the formation of mesocyclones within the storms because wind direction often changes with elevation. Warm, moist air may blow from the south near the ground, while cool, dry air may blow from the southwest or west higher up.

Effects of Tornadoes

The weakest tornadoes can damage chimneys, break tree branches, and blow over signs, while the most violent ones can rip sturdy houses from their foundations. Meteorologists classify tornadoes as weak, strong, or violent according to the Fujita scale, which is named for the tornado researcher Tetsuya "Ted" Fujita. Weak tornadoes, which are most common, are strong enough to down trees or shift mobile homes off their foundations. A violent tornado, which is rare, can destroy everything in its path, causing fatalities and doing millions of dollars' worth of damage.

Fujita Tornado Intensity Scale

Category	F-Scale	Estimated Wind Speed	Effects
Weak	F0	65–118 km/h	Minor damage, snaps small branches, breaks some windows
	F1	119–181 km/h	Downs trees, shifts mobile homes off foundations
Strong	F2	182–253 km/h	Rips roofs off houses, destroys mobile homes, uproots large trees
	F3	254–332 km/h	Partially destroys buildings, lifts cars
Violent	F4	333–419 km/h	Levels sturdy buildings, tosses cars
	F5	420–513 km/h	Lifts and transports sturdy buildings

Predicting Tornadoes

Improvements in radar have helped meteorologists to spot and even predict tornadoes more reliably. They use conventional radar to create a map of precipitation in the surrounding area, and newer, Doppler radar can identify which way winds are moving within a storm.

Conventional radar works by emitting pulses of microwaves, some of which bounce back to the radar receiver when they hit drops of precipitation. The time it takes the microwaves to return indicates how far away the precipitation is.

A tornado often appears on conventional radar as a hook-shaped area of precipitation. However, sometimes the hook does not form until after the tornado touches ground; sometimes it does not form at all. Thus conventional radar is not always reliable for predicting tornadoes.

Doppler radar uses a principle called the Doppler effect to identify mesocyclones that may produce tornadoes. The Doppler effect is what causes the sound of a car to drop in pitch when the car drives by you quickly. When the car is approaching, its sound seems higher pitched than when it is going away from you. Meteorologists can use Doppler radar to tell whether a part of a storm cloud is moving toward or away from the radar receiver. By analyzing how the air in the cloud is moving, meteorologists can identify a rotating mesocyclone and give people in the area about 20 minutes advance warning of tornado formation.

Storm or Tornado Watches and Warnings

The National Weather Service issues watches and warnings to give people time to find shelter before a severe thunderstorm or tornado arrives. A severe thunderstorm is one that has wind gusts of at least 80 kilometers per hour, hail that is at least two centimeters in diameter, or a funnel cloud or tornado. If there is a chance that a severe thunderstorm will form, meteorologists issue a thunderstorm watch. If a severe thunderstorm approaches, they issue a thunderstorm warning for the areas in its path. If conditions are such that a tornado may form, they issue a tornado watch, and volunteer tornado watchers in the area begin looking for tornadoes. If they spot one, or if meteorologists detect one using radar, radio and television stations broadcast a tornado warning. In some communities, a siren sounds. Although the tornado warning system is not completely effective, deaths from tornadoes have decreased over the past 30 years despite a significant increase in population.

20.3 Section Review

1. What conditions are necessary for the formation of a thunderstorm?
2. What is a mesocyclone?
3. What should you do if a tornado is approaching?
4. CRITICAL THINKING Can thunder occur without lightning? Explain.

SAFETY TIPS

TORNADOES

Stay or go indoors.

If possible, go quickly to a basement or storm cellar. Otherwise, go to a small inner hallway or room without windows, such as a bathroom or closet, on the ground floor of a strong building. Avoid large spaces like auditoriums and malls. Stay away from windows and outside walls. Get under a mattress or sturdy piece of furniture and hold onto it. Protect your head and neck.

Avoid mobile homes and cars.

Do not try to outdrive a tornado.

If you are caught outside, lie in a ditch or low-lying area. Protect your head and neck. Watch for flooding.

DATA CENTER
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Learn more about tornado safety.
Keycode: ES2007

20.4

KEY IDEAS

Hurricanes develop over warm water, fueled by the heat water releases during condensation.

Snow, wind, and freezing-cold temperatures can occur with mid-latitude lows in winter.

KEY VOCABULARY

- hurricane
- storm surge
- Saffir-Simpson scale
- blizzard

Hurricanes and Winter Storms

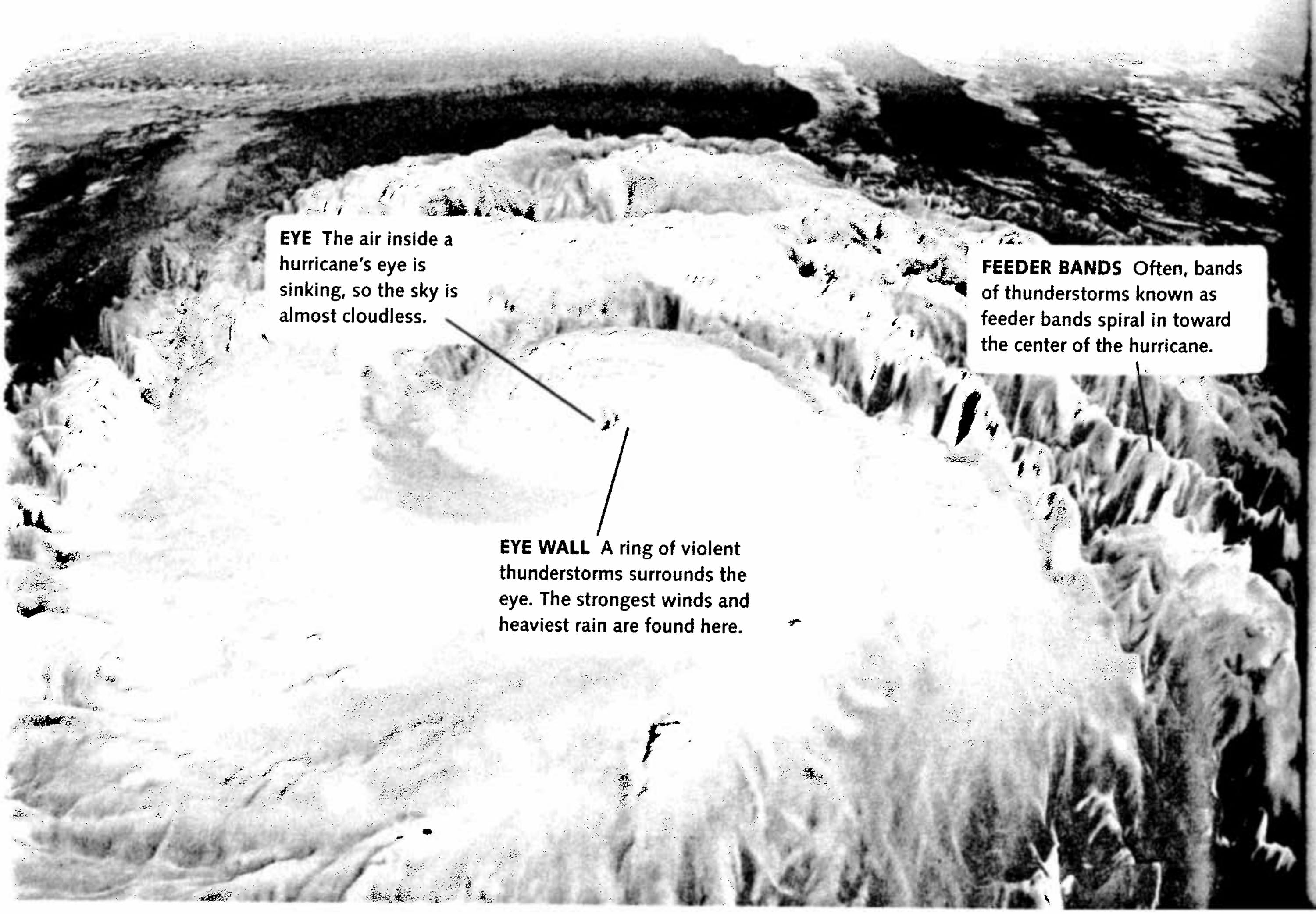
While thunderstorms and tornadoes are short-lived and cover a relatively small area, a hurricane or winter storm can last for a day or more and affect an area several hundred kilometers wide.

Hurricanes

A **hurricane** is a large rotating storm of tropical origin that has sustained winds of at least 119 kilometers per hour. The air pressure at the center of a hurricane is very low. Unlike a mid-latitude low, which gets its energy from the temperature contrast between air masses, a hurricane gets its energy from the heat of surface ocean water. Hurricanes have different names, depending on where they occur. For example, when they occur in the Pacific Ocean, they are called typhoons.

Hurricanes have a spiral structure, as seen in the satellite image below. At a hurricane's outer edge, rain and wind are comparatively mild. They increase as the winds spiral in toward the low-pressure area, or eye, at the hurricane's center. Winds and rain are strongest at the eye wall surrounding the eye, where the air rises to form giant thunderstorms. When the eye wall passes over an area, great damage can result. Inside the eye, winds are mild and there is no rain.

HURRICANE LINDA This computer-enhanced satellite image shows the structure of the hurricane as it approaches Baja, California, in 1997.



Hurricane Formation

For a hurricane to form, there must be a supply of warm, moist air for a long period of time. Water that evaporates from the ocean later condenses within storm clouds, releasing large amounts of heat. This heat fuels the gradual development of a full-blown hurricane.

Hurricane formation begins in the tropics with a mild atmospheric disturbance that causes humid air to rise. As the air rises, it cools, and water condenses, releasing heat. Humid air flows in at the surface to replace the rising air, and as this humid air rises, more water condenses and releases heat. This process continues for as long as humid air is available at the surface and air is leaving the disturbance at higher levels.

For a mild atmospheric disturbance to develop into a hurricane, it must begin to rotate. The Coriolis effect causes air flowing into the disturbance at the surface to flow counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Near the equator, the Coriolis effect is so weak that hurricanes do not form. Consequently, hurricanes are born over warm water, generally between 5° and 20° latitude.

Scientists classify a tropical disturbance according to the speed of its strongest winds. A tropical depression has wind speeds of up to 61 kilometers per hour, a tropical storm's strongest winds are between 61 and 119 kilometers per hour, and a hurricane has wind speeds of 119 kilometers per hour or greater. Each year, only a few tropical depressions develop into hurricanes.

Because hurricanes rely on the transfer of heat from the ocean, they form only when surface ocean waters are sufficiently warm, and they weaken as soon as they make landfall or move over cold ocean water. Surface ocean water is warmest in summer and early fall, so the hurricane season in the United States is usually June through November.

Throughout their development, hurricanes are steered by the global wind patterns that you read about in Sections 19.3 and 19.4. Hurricanes that form in the Atlantic Ocean north of the equator initially move west or northwest, but then often curve toward the north and may eventually head east. However, the actual paths of hurricanes can vary considerably, and erratic changes in a path can take forecasters by surprise.

Effects of Hurricanes

Although a hurricane weakens rapidly once it makes landfall, it can still cause a tremendous amount of damage along the coast and inland. The damage can include winds, inland flooding, and a large wave of water called a storm surge.

A **storm surge** results, in part, from the strong winds of the eye wall, which blow water into a broad dome. When the hurricane makes landfall, this dome of water can raise the sea level several meters higher than it would be otherwise. When the storm surge coincides with high tide, the sea level can be dangerously high, swamping low-lying coastal areas. Hurricane winds also create huge waves, which batter the shore. One of the greatest hurricane disasters in United States history was the

VISUALIZATIONS CLASSZONE.COM

Observe an animation of a hurricane.
Keycode: ES2008

SAFETY TIPS

HURRICANES

Listen to weather updates. Gather a portable radio, fresh batteries, flashlights, drinking water, food, and medicines. Set refrigerator to high and open only if necessary.

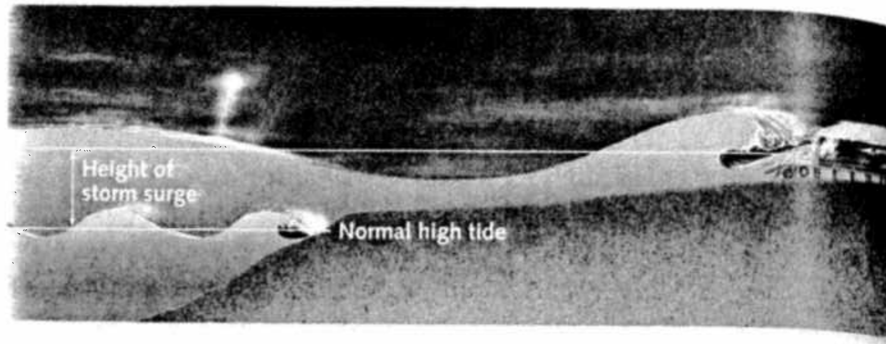
Outdoors, secure loose objects and moor boats. Shutter or board up windows. Secure doors. If in a mobile home, check tie-downs and go to a shelter.

Have a flood-free evacuation route planned. If ordered to evacuate, do so immediately. Shut off water and electricity.

During the hurricane, stay indoors, away from windows. After, beware of downed wires, unsafe roads, flooded areas, animals sheltering indoors, and broken gas lines.

DATA CENTER CLASSZONE.COM

Learn more about hurricane safety.
Keycode: ES2009



STORM SURGE When a storm surge coincides with high tide, it can raise the sea surface to dangerous levels.

great Galveston, Texas, hurricane of 1900, which produced a storm surge that killed 6000 people.

Hurricane Watches and Warnings

Meteorologists can track a hurricane throughout its life by satellite. When they expect a hurricane to arrive in a community within 24 to 36 hours, they issue a hurricane watch. When they expect the hurricane within 24 hours or less, they issue a hurricane warning. Because a hurricane's path is often erratic, meteorologists must issue the warning for a stretch of coastline that is much wider than the size of the hurricane path. Along the East Coast, meteorologists also announce the percent chance that the eye of the hurricane will pass within 105 kilometers of a particular community.

Because such a large area of the coast must receive each hurricane warning, people often feel they have unnecessarily spent time and money on preparation if the hurricane does not hit their community. However, loss of life due to hurricanes has decreased significantly over the last century. Property loss, on the other hand, has increased significantly, probably because of the population increase in coastal areas.

Saffir-Simpson Hurricane Scale

Category	Wind Speed (km/h)	Storm Surge (m)	Damage
1	119–153	1.0–1.7	Minimal. Trees and unanchored mobile homes damaged. Some coastal flooding.
2	154–177	1.8–2.6	Moderate. Minor damage to buildings. Some trees blown down.
3	178–209	2.7–3.8	Extensive. Some structural damage to small buildings. Mobile homes destroyed.
4	210–250	3.9–5.6	Extreme. Some roofs destroyed. Evacuations as far as 10 kilometers inland.
5	>250	>5.7	Catastrophic. Buildings destroyed. Evacuations as far as 16 kilometers inland.

Meteorologists rate a hurricane's strength using the **Saffir-Simpson scale,** shown on page 452. This scale can help predict the damage that will occur when the hurricane makes landfall.

Winter Storms

A mid-latitude-low pressure system occurring in winter, known as a winter storm, can bring several types of weather. It can produce heavy snow, ice, or rain depending on the storm track, its intensity, and the temperature of the atmosphere. Often, a single region will have several zones containing different types of precipitation. The northern zone may produce only snow. Slightly to the south might be a zone of freezing rain and sleet. Farthest south and closest to the warm front, only rain may occur.

One special breed of winter storm is a blizzard. Although people often use the term to refer to heavy snowstorms, a true blizzard involves more than heavy snow. A **blizzard** is a winter storm characterized by high winds, low temperatures, and falling or blowing snow. To be classified as a blizzard, a storm must meet three criteria:

- The winds must exceed 56 kilometers per hour.
- The temperature must be −7°C or lower.
- The falling and/or blowing snow must reduce visibility.

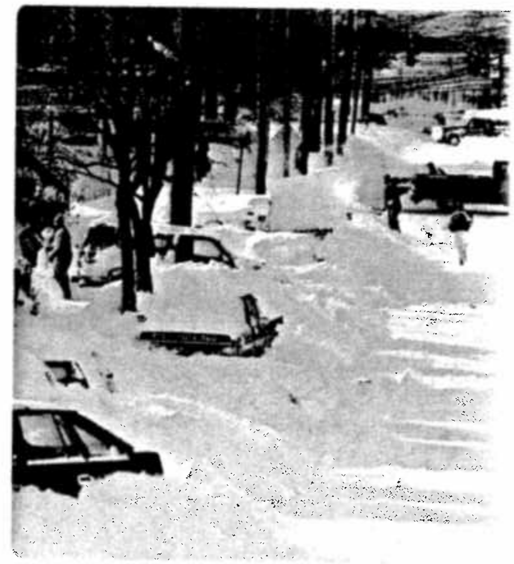
A severe blizzard is one with winds greater than 72 kilometers per hour and temperatures of −12°C or lower.

In the United States, blizzards occur most often in the northern Great Plains states. However, they have also occurred, though rarely, as far south as Texas.

On the East Coast, storms known as nor'easters produce extremely heavy snow when a low-pressure system over the North Atlantic Ocean causes maritime polar air to blow over the land from the northeast. However, the temperatures are usually not cold enough for the storm to qualify as a blizzard. A major exception was the blizzard of 1888. Snowfall amounts from this nor'easter ranged from 50 to 100 centimeters, with drifts much higher. The blizzard brought life to a standstill from Philadelphia, Pennsylvania, to Albany, New York. Although reports vary, as many as 400 people were killed, half of the deaths occurring in New York City alone. The blizzard of 1888 has not been equaled since.

20.4 Section Review

1. Describe how a hurricane forms.
2. What is the difference between a snowstorm and a blizzard?
3. CRITICAL THINKING Explain why heavy rain accompanies a hurricane.
4. BIOLOGY Describe some positive and negative ways in which hurricanes may affect plants.



BLIZZARD When a blizzard strikes, it may last for days and dump several feet of snow, the removal of which takes several more days.

Safety Tips

WINTER STORMS

Be sure you have food that doesn't need cooking, flashlights, batteries, medicines, fire extinguishers, and a way to safely make heat if electricity or gas is cut off. Check smoke detectors.

Stay indoors and dress warmly. Turn faucets on to drip. Conserve fuel.

If you are caught outside, find shelter from the wind and stay dry. Exercise to stay warm but avoid sweating. Avoid walking on ice. Cover your mouth. Watch for signs of frostbite and hypothermia.

If you are in a car, leave it running only if the exhaust pipe is clear of snow. Do not drive in icy conditions.

DATA CENTER CLASSZONE.COM

Learn more about winter storm safety.
Keycode: ES2010

SCIENCE & Technology

Extreme Science: Flying into the Storm

Unlike a tornado, a hurricane can span hundreds of kilometers, and can damage thousands of square kilometers of land. Because of this potential for destruction and loss of life, meteorologists need every type of technology available to predict a hurricane's severity before it reaches the shoreline.

Since weather-model predictions can vary, how can a forecaster know for certain whether an approaching hurricane is extremely dangerous? Is there a way meteorologists can obtain absolutely accurate measurements?

CAREFUL NAVIGATION is required to fly safely through a hurricane and to make the desired scientific observations.

Satellite photography can give a meteorologist some idea of a hurricane's strength as it approaches land. However, the only foolproof way to determine the severity of a hurricane is to fly into it. Pilots known as hurricane hunters fly directly into the storms, in specially designed aircraft. Instruments on the planes gather and feed out information on the wind strength in the eye wall of the hurricane and on the sea-level pressure in the eye.

The eye wall is the most intense part of the hurricane, consisting of violent winds and torrential rains. It surrounds the storm's eye, the central region where the storm is relatively mild, and has lower wind speed and less precipitation.

For a hurricane hunter to take measurements in the eye, the plane must "punch through" the eye wall. Once in the eye, the plane drops an instrument known as a dropsonde. A dropsonde measures the barometric pressure, which indicates the hurricane's strength. After obtaining this measurement, the pilot relays it to the National Hurricane Center, which then issues statements based on the measurement. ■

A HURRICANE HUNTER uses radar (bottom center) and other instrumentation to navigate near the eye of a hurricane (left).

Extension

SCIENCE NOTEBOOK

Since all hurricanes are dangerous,why is it important to know the exact severity of one that is approaching? Consider how you might respond differently to different hurricane forecasts.

DATA CENTER
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Explore more about hurricanes.
Keycode: ES2011

Forecasting Weather

Weather forecasting is a complex process that requires the cooperation of countries around the world. First, meteorologists worldwide gather weather information for their regions. Then they send this information to computer centers, where other meteorologists compile it and then use it to create weather maps and forecasts. Finally, the weather maps and computer-generated forecasts go out to local forecasters, who modify the forecasts to reflect local conditions.

20.5

KEY IDEA

To prepare accurate weather forecasts, meteorologists must gather, distribute, and analyze huge amounts of atmospheric data.

KEY VOCABULARY

- station model

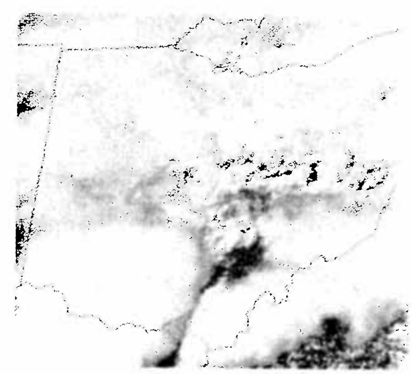
Gathering Data

Huge amounts of data are necessary for weather forecasting. The sources of these data include satellites, instruments attached to balloons, weather stations, weather radar, airplanes, and ships.

Satellites

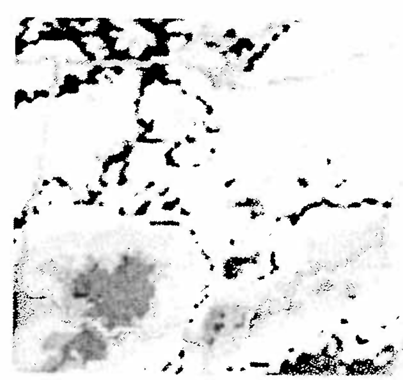
Satellite images provide weather information about every spot on Earth, even oceans and sparsely populated areas. Meteorologists use two basic types of satellite images: visible images and infrared images.

A visible satellite image is basically a black-and-white picture of Earth. The white color shows sunlight reflected off clouds or snow cover. The brighter the white, the thicker the clouds. Gray often represents land, and black often represents water. By tracking the movement of clouds in visible satellite images, meteorologists can estimate wind speed and direction or can track storms. They can also use visible satellite images to estimate the stage and severity of hurricanes. A disadvantage of visible satellite images, however, is that they aren't available at night.



VISIBLE SATELLITE IMAGE This visible image shows thunderclouds over Ohio.

In contrast infrared (IHN-fruh-REHD) satellite imagery uses temperature, rather than light, to create pictures. Therefore, infrared images can be taken day or night. On an infrared satellite image, bright areas represent cold temperatures and usually indicate the cold, high tops of clouds. Darker areas are warmer and represent lower clouds or a lack of clouds. Because temperature decreases with height, meteorologists can use the temperatures of cloud tops to determine how tall the clouds are. The taller the cumulus clouds, the more severe the thunderstorms they produce. By tracking clouds on infrared images, meteorologists can estimate wind speed and direction occurring at different altitudes. Infrared satellites can also provide images of water vapor in the air, which help to determine temperature and humidity at different altitudes.



INFRARED SATELLITE IMAGE The various colors in this image indicate regions of differing temperatures.

Radiosondes

Meteorologists use devices called radiosondes to measure the temperature, pressure, and humidity of air at different altitudes. A radiosonde is an instrument package attached to a balloon, which carries it up into the atmosphere. The radiosonde transmits weather information to the ground, where computers track the instrument's position. Temperature and humidity data from radiosondes can help meteorologists estimate air stability and the likelihood that cumulus clouds and thunderstorms will develop. Wind speed and direction at different altitudes can help predict how air masses might move and how severe the weather might become. For example, if the wind speed and direction change rapidly with height, then the potential for tornadoes may exist. By piecing together the wind data from a network of weather stations, scientists can create weather maps for different vertical levels of air. These maps show the shape and intensity of the jet stream, which is important in determining the movement of air masses and storms.

Surface Observations

Even with the data made available by satellites and radiosondes, meteorologists still require more information in order to predict weather. Only by analyzing data from weather stations can meteorologists diagnose where in a storm it is raining and where it is snowing, or where fronts and lows are located.

On land, most weather stations are at airports, where they can easily retrieve data from commercial jets equipped with automatic weather recorders. Information on conditions over the oceans comes from ships and from automated stations on moored buoys. Weather stations typically report conditions every hour, though they may report more often if they detect significant weather. The information they provide includes temperature, dew point, barometric pressure, wind speed and

CAREER

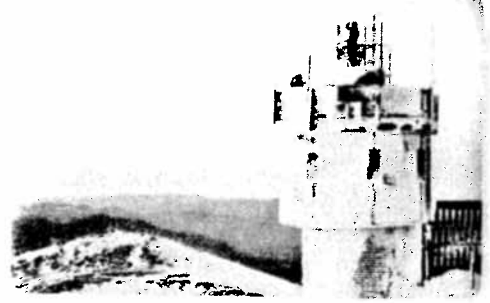
Weather Observer

Serving as a weather observer on the top of Mount Washington is an interesting and challenging career. Mount Washington is a perfect location for observing all kinds of weather. It is the highest point in New England and receives adverse weather from three different storm tracks. The orientation of the mountain range also accelerates the wind; the strongest wind recorded there was measured at 371 kilometers per hour.

Duties of the Mount Washington staff include measuring the wind, temperature, precipitation, and humidity and analyzing cloud types. Data for various research projects must also be monitored. Other duties include disseminating weather information on the radio and making sure the equipment works properly. An important part of an observer's job is to educate the public on topics such as mountain weather and the fragile nature of the mountain environment.

Being an observer on Mount Washington isn't for everyone. However, seeing the beauty of a sunrise or a sunset from the top of the mountain is an unforgettable experience.

People interested in this career need a bachelor's degree in meteorology, as well as good communication skills. For people who have those interests, Mount Washington Observatory offers an internship program. ■



MOUNT WASHINGTON OBSERVATORY WEATHER OBSERVERS are cleaning ice off instruments during a winter sunset in New Hampshire.

CAREERS CLASSZONE.COM

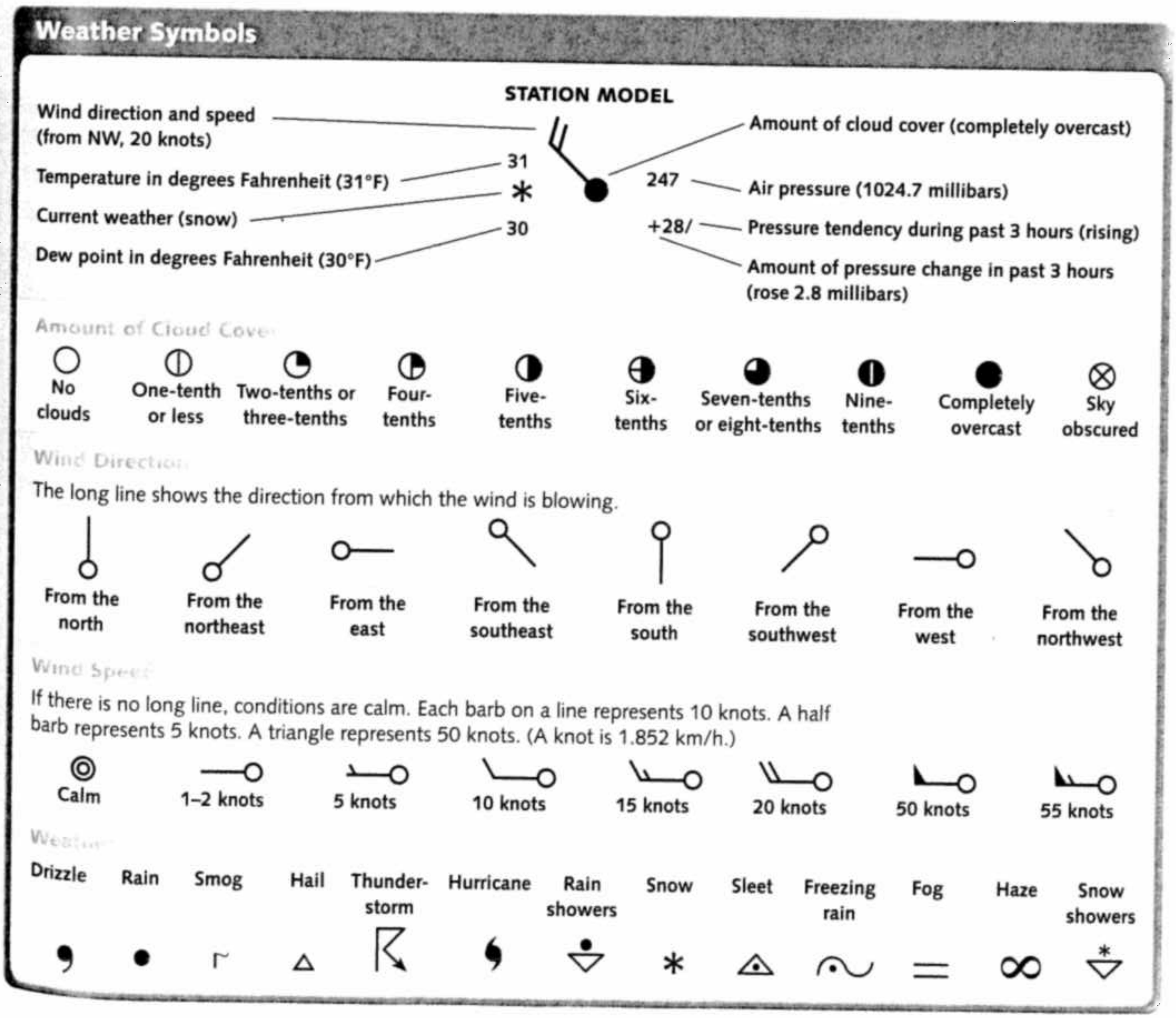
Learn more about becoming a weather observer.
Keycode: ES2012

direction, visibility, precipitation, the height of clouds, and the amount of cloud cover. As you read in Section 20.3, information on areas of precipitation comes from radar. Doppler radar can be used to predict tornadoes.

Station Model

Using the data they receive from weather stations, meteorologists create weather maps. To help fit the huge amounts of data onto a compact map, scientists developed the **station model,** which includes information on temperature, dew point, weather conditions, wind speed and direction, barometric pressure, and cloud cover. Station models can be read by the meteorologists of any country.

The station model shown below indicates that when the station took its measurements, the wind was coming from the northwest at a speed of about 20 knots, the temperature was 31°F, the dew point was 30°F, the sky was completely covered with clouds, and it was snowing. The pressure, adjusted to sea level, was 1024.7 millibars, and it had risen 2.8 millibars in the past three hours.



Making a Surface Weather Map

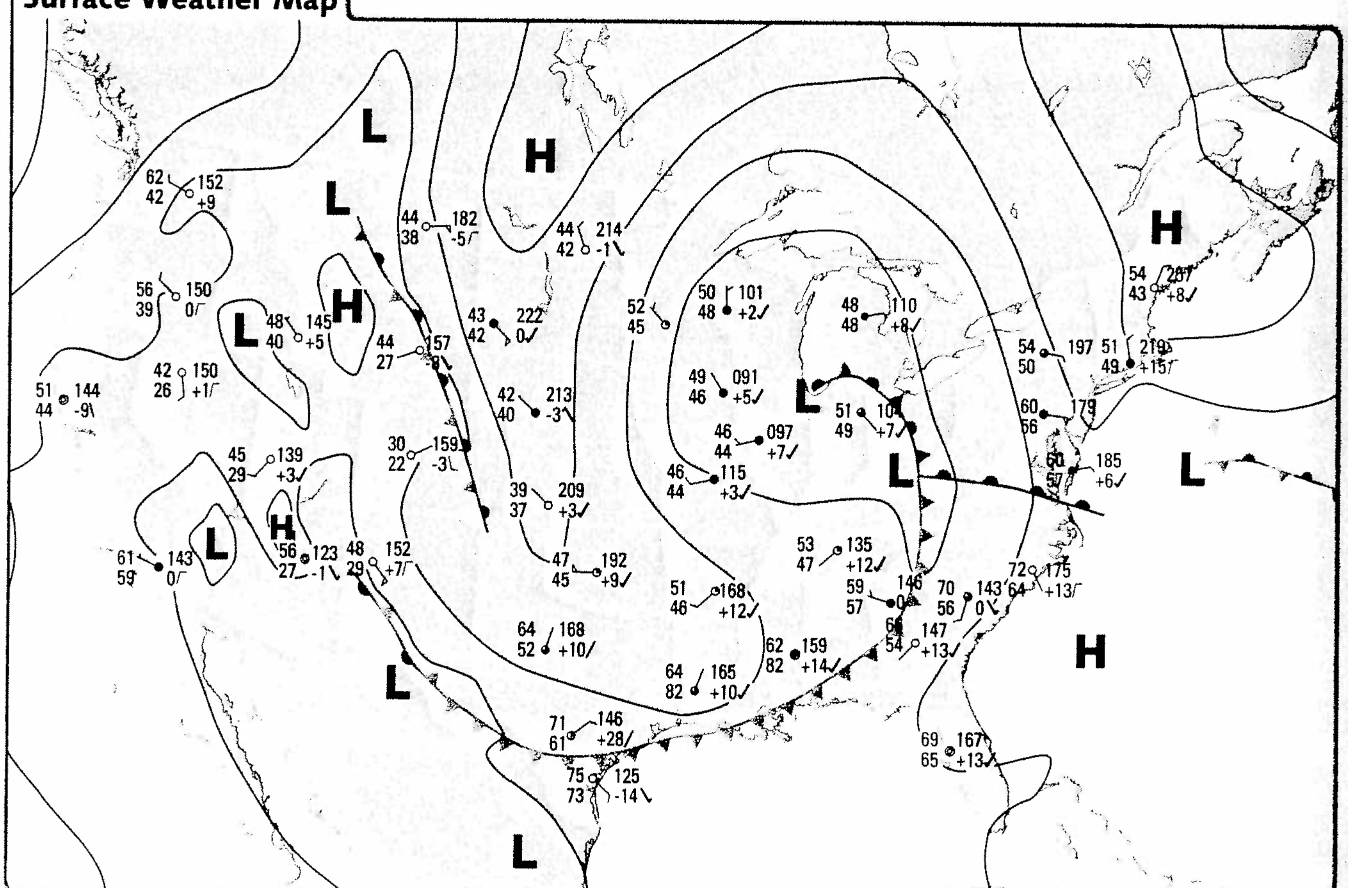
Surface weather maps are essential tools that give weather forecasters the "big picture" of current weather conditions. Official U.S. weather maps are produced every three hours by the National Center for Environmental Prediction (NCEP), located in Silver Spring, Maryland.

It takes several steps to make a surface weather map. First, a computer draws a map showing station models. Using the sea-level air pressures reported by the stations, it then draws isobars every four millibars and identifies highs and lows. After the computer draws the map showing station models, isobars, highs, and lows, forecasters draw in the fronts. Forecasters use three types of data from the station model to find fronts: temperature, wind direction, and dew point. In locating fronts, they apply the following rules:

- Wind direction changes behind fronts.
- Temperature changes sharply across fronts.
- Dew point changes sharply across fronts.

For example, if a station reports light southwest winds and high temperature and humidity, and a second station, 100 miles to the west, has strong, northwest winds, a temperature 10 degrees cooler, and a dew point 20 degrees cooler, then a forecaster can assume that a cold front lies between the two stations.

Surface Weather Map



Forecasting

Modern-day weather forecasts are based on computer weather models. Weather models are large computer programs containing mathematical equations designed to simulate atmospheric processes. Many different models are used to make forecasts. Some models are used to predict the weather up to two days in advance, while others provide information up to ten days in advance. The models used for two-day forecasts run four times per day.

Models begin with observed current weather data, such as temperature, humidity, and wind at various levels of the atmosphere. The models transfer these data into their mathematical equations and predict the future state of the atmosphere. The predictions include possible temperatures, winds, sea-level pressure, precipitation, and configurations of the jet stream.

Since the models cannot predict the weather perfectly, different models may produce different predictions. A meteorologist must understand the advantages and disadvantages of each model in order to decide which model to use as a basis for a forecast.

Although models are useful tools in the forecasting process, subtle factors not included in the models can have a large impact on the weather. One of these factors is urbanization. In large cities, concrete covers most of the ground. Since concrete is more likely than vegetation to absorb and retain heat from the sun, cities are often warmer than the surrounding countryside. Urbanization plays a large role in the intensity of heat waves. Whereas the suburbs may get nightly relief from hot summer days, the cities can remain hot through the night. This continual heat not only affects air-conditioning costs but also can be dangerous to the elderly and the very young.

Urbanization can also play a subtle, yet important, role in winter storms when the temperature is at the critical point between rain and snow. For example, a storm that produces cold rain in New York City might cover the surrounding suburbs in several inches of snow. Such local effects are too subtle for models to predict, so forecasters must use their knowledge of local weather patterns to modify the predictions they receive from models.

Scientific Thinking

APPLY

Cities tend to generate and trap heat. These urban "heat islands" can result in unique weather patterns; for example, thunderstorms can pop up around cities when cool air replaces warm air rising above a city. Using what you know about how heat is absorbed and radiated, list several characteristics of cities that help generate or trap heat. Brainstorm ways this heat might be decreased. Include both individual and community actions.

20.5 *Section Review*

1. **Describe several ways of gathering weather data for forecasts.**
2. **Interpret the station model over Florida in the map on page 458.**
3. **Describe how station-model data are used to make a weather map.**
4. **What are some advantages and disadvantages of computer models?**
5. **CRITICAL THINKING If a city is growing, what will happen to its nighttime temperatures? Explain.**
6. **APPLICATION Predict the weather for the next few hours for the station whose model is shown on page 457. Explain your reasoning.**

CHAPTER 20 REVIEW

Summary of Key Ideas

20.1 Scientists classify an air mass based on whether it originates in an arctic, in a polar, or in a tropical region and whether it forms over land (continental) or sea (maritime).

20.2 A front is the band of air between opposing air masses. Scientists classify a front based on the temperature of the advancing air mass. Fronts are usually connected to mid-latitude low-pressure systems. Upper-level air flow influences the convergence or divergence of air into and out of pressure systems.

20.3 Thunderstorms form in warm, moist, unstable air. They produce lightning, a discharge of electricity. Tornadoes can develop in thunderstorms containing rotating updrafts.

20.4 Hurricanes are large, rotating storms originating over tropical oceans. They are classified based on wind speed. Winter storms are mid-latitude low-pressure systems that occur over land in the winter.

20.5 Weather forecasters must gather huge amounts of data in order to make their predictions. They rely on sensing instruments and on computer models to provide the information they need.

KEY VOCABULARY

- **air mass** (p. 436)
- **blizzard** (p. 453)
- **cold front** (p. 440)
- **front** (p. 439)
- **hurricane** (p. 450)
- **lightning** (p. 446)
- **meteorology** (p. 436)
- **occluded front** (p. 441)
- **Saffir-Simpson scale** (p. 453)
- **squall line** (p. 446)
- **station model** (p. 457)
- **stationary front** (p. 441)
- **storm surge** (p. 451)
- **supercell** (p. 446)
- **thunderstorm** (p. 445)
- **tornado** (p. 447)
- **warm front** (p. 441)

Vocabulary Review

Write the term from the key vocabulary list that best completes the sentence.

1. When a cold front "catches up" to a warm front, the result is a(n) __?__ .
2. The type of thunderstorm that has the most damaging winds and precipitation is a(n) __?__ .
3. A rotating storm from a warm ocean area, the __?__ has sustained winds of at least 119 kilometers per hour.
4. To be classified as a(n) __?__ , a winter storm must reduce visibility and fall into specific temperature and wind-speed ranges.
5. To fit huge amounts of information onto a compact map, forecasters use a(n) __?__ .

Concept Review

6. In what directions would polar and tropical air masses move in the Southern Hemisphere?
7. What kind of air-mass weather is likely to follow the passing of a warm front? Of a cold front?
8. A wintertime continental Arctic air mass starts out very stable. Explain.
9. Explain how an occluded front forms.
10. How are hurricanes and mid-latitude lows alike? How are they different?
11. List some of the shortcomings of computer weather models.
12. **Graphic Organizer** Copy and complete the flow chart below.

? + "trigger" ?

release of heat ? thunderstorm

Critical Thinking

13. **Hypothesize** Write a hypothesis suggesting why warm and cold fronts are usually weakest in the summer months in the continental United States.
14. **Predict** You are a forecaster in Oklahoma. How will you use each of the following to foresee and then to track the occurrence of a tornado: computer-model maps, radiosonde maps, the surface-weather map, hourly weather observations, satellite data, and radar?
15. **Infer** If you hear thunder 15 seconds after seeing lightning, how far away is the storm?
16. **Infer** How can you use air masses to explain the fact that hurricanes have no fronts?

Internet Extension

INVESTIGATIONS CLASSZONE.COM

How Well Can You Predict Tomorrow's Weather?
Use current weather data to make a forecast for your local area.

Keycode: ES2013

Writing About the Earth System

SCIENCE NOTEBOOK The deadliest hurricane in United States history occurred in Galveston, Texas, in September 1900. The coastal town had no seawall for protection from flooding, and scientists did not yet have the technology to foresee a hurricane far in advance. Six thousand people died in the hurricane, including 100 residents of an orphanage. Research the Galveston hurricane. Using the information you find, compare the weather information Galveston meteorologists had on that day with what would be available now. How might specific aspects of today's forecasting methods change the human outcome of such a hurricane if it were to happen today?

Interpreting Maps

The weather map at right shows two lows and two highs. The arrows indicate wind directions.

17. How many kinds of fronts appear on the map?
18. Which color represents areas of low pressure? Which color represents areas of high pressure? What evidence do you have to support your answers?
19. Is this most likely a winter map or a summer map? How can you tell?
20. What were the probable weather conditions along the northwestern coast at the time of this weather map?

Weather Map