Chapter 12

Meteorology

What You'll Learn

- What determines global weather patterns.
- How air masses move and change.
- How the strengths and weaknesses of weather forecasts differ.
- How to create a weather chart.

Why It's Important

Few aspects of the environment have as much impact on our everyday decisions as weather does. A basic knowledge of weather processes can make those decisions easier and sometimes far safer.

Earth Science Online

To find out more about meteorology, visit the Earth Science Web Site at earthgeu.com

Discovery Lab

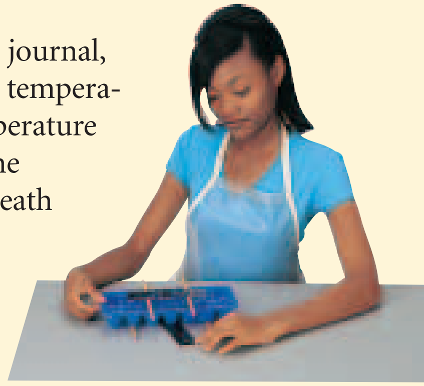
Model a Cold Air Mass

An air mass is a large body of air that takes on the characteristics of the area over which it forms. You can demonstrate the formation of a cold air mass using simple materials.

1. Place a tray full of ice cubes on a table with a pencil underneath each end of the tray so that the tray is slightly elevated.
2. Slide a liquid-crystal temperature strip underneath the ice-cube tray.
3. Rest another temperature strip on two pencils on top of the tray.
4. Record the temperature of each strip at one-minute intervals for about five minutes.

CAUTION: Always wear protective clothing in the lab.

Observe In your science journal, make a graph showing the temperature changes for each temperature strip. What happened to the temperature of the air beneath the tray and the air above the tray? Explain how this model represents a cold air mass.



SECTION 12.1 The Causes of Weather

OBJECTIVES

- **Compare** *and* **contrast** *weather and climate.*
- **Analyze** *how imbalances in the heating of Earth's surface create weather.*
- **Describe** *how and where air masses form.*

VOCABULARY

meteorology
weather
climate
air mass
air mass modification

Have you ever sat back and watched the sky on a lazy summer afternoon? You might have noticed clouds of different shapes, or felt the warmth of the sun against your face or an occasional puff of wind as it cooled your skin. All of these phenomena are part of a highly organized sequence of events with specific causes. Those events and the factors that cause them are all part of meteorology. **Meteorology** is the study of atmospheric phenomena. The root of the word *meteorology*—*meteor*—is the name given in modern times to a flaming rock falling through space. But the ancient Greek meaning of *meteor* was "high in the air," and it is this meaning that pertains to meteorology.

Clouds, raindrops, snowflakes, fog, dust, and rainbows are all types of atmospheric "meteors." The primary types are cloud droplets and forms of precipitation that contain water in any phase; they are known as hydrometeors. Smoke, haze, dust, and other condensation nuclei are called lithometeors. Thunder and lightning are examples of electrometeors, which are visible or audible manifestations of atmospheric electricity. These various phenomena are the objects and events that meteorologists study.

Weather and Climate

Atmospheric phenomena, shown in ***Figure 12-1,*** interact to affect the environment and life on Earth. This is basically what we call weather. **Weather** is the current state of the atmosphere. When we speak of weather, we are referring mainly to short-term variations in the atmosphere. These variations can take place over minutes, hours, days, weeks, or months. Long-term variations in weather for a particular area make up the **climate** of that area. Climate is usually averaged over the course of 30 years or more. You'll learn more about climate in Chapter 14. For now, simply recognize that meteorology, weather, and climate are related. Meteorology is the study of the atmosphere; weather is the current state of the atmosphere, including short-term variations that affect our lives; and climate describes the average weather over a long period of time.

A Question of Balance

As you've learned, the Sun heats the surface of Earth, and Earth radiates back to space about as much energy as it receives over the course of a year. In meteorology, a crucial question is how that radiation is distributed around the planet. You know that the Sun feels hotter during the afternoon, when its rays strike Earth more directly, than it does in the early morning or evening, when its rays strike Earth at a low angle. The Sun's rays are more spread out when they strike Earth at a low angle, as you'll see in the *MiniLab* later in this chapter. The same amount of energy is spread over a larger area. As shown in ***Figure 12-2,*** the solar radiation reaching Earth's surface at the poles is therefore less intense. This explains, in part, why the tropics are warmer than the poles. But why don't the tropics become steadily warmer if the Sun is always directly overhead? How do regions manage to maintain fairly constant average temperatures?

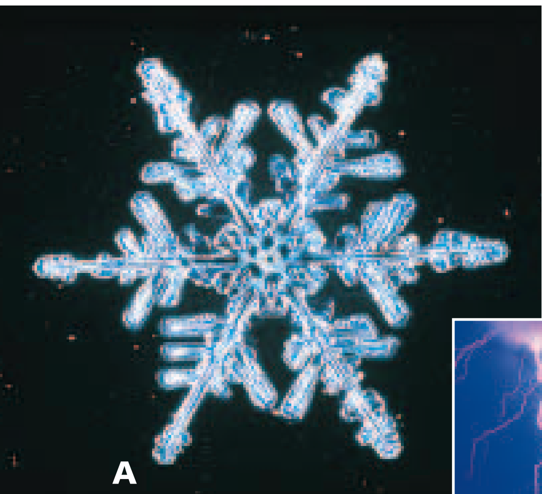


Figure 12-1 Snowflakes **(A),** lightning **(B),** and fog **(C)** are types of atmospheric phenomena.

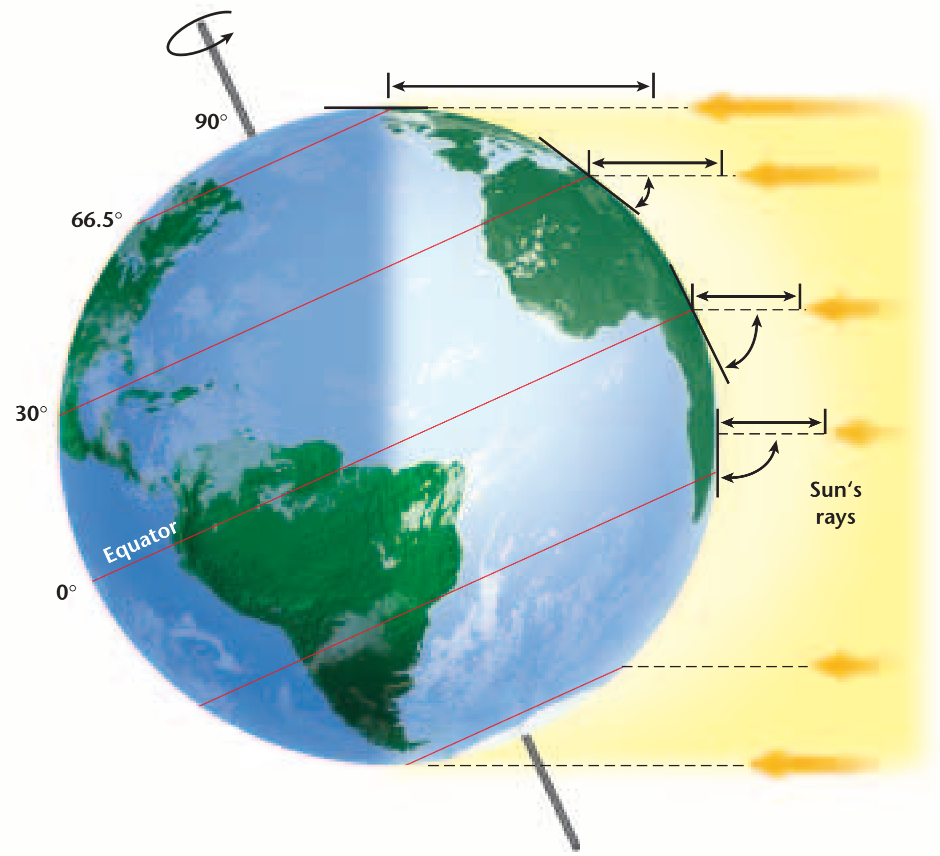


Figure 12-2 The Sun's rays strike Earth more directly at the tropics than they do at the poles. At the poles, the same amount of solar radiation is spread over a larger area than at the equator. Therefore, polar regions are never very warm.

Balancing the Budget The tropics and other places maintain fairly constant average temperatures because heat energy is redistributed around the world. The continual motion of air and water reallocates heat energy among Earth's surface, oceans, and atmosphere and brings it into balance. Virtually everything that we consider to be weather—every atmospheric motion from the tiniest convection current to thunderstorms to large-scale weather systems—is part of this constant redistribution of Earth's heat energy.

Air Masses

In Chapter 11, you learned that when air over a warm surface, such as a parking lot, becomes warmer than the surrounding air because of conduction, the warm air rises. Now, imagine this same process taking place over thousands of square kilometers. Imagine that the warm air remains over this same area for days or weeks. The result is the formation of an air mass. An **air mass** is a large body of air that takes on the characteristics of the area over which it forms. Meteorologists call the region over which an air mass forms the source region. Air masses form over land or water. Those that form

MiniLab

How does the angle of the Sun's rays differ?

Model the angle at which sunlight reaches Earth's surface. This angle greatly affects the intensity of solar energy received in any one place.

Procedure

1. Hold a flashlight several centimeters above a piece of paper and point the flashlight straight down.
2. Use a pencil to trace the outline of the light on the paper. The outline models how the Sun's rays strike the equator.
3. Keeping the flashlight at the same distance above the paper, tilt the top of the flashlight to roughly a 30° angle.
4. Trace the new outline of the light. This is similar to how the Sun's rays are received at the poles.

Analyze and Conclude

1. Describe how the outline of the light differed between step 1 and step 3. Explain why it differed.
2. How do you think the change in area covered by the light affects the intensity of light received at any one place?
3. The flashlight models solar radiation striking the surface of Earth. Knowing this, compare how much heat energy is absorbed near the equator and near the poles.

over land have less exposure to large amounts of moisture, so they are drier than those that form over water. Air masses take on the temperature of the source region, too.

Classifying Air Masses Air masses are classified exactly as we have already described them: according to their source regions. The main types of air masses, shown in ***Figure 12-3,*** are warm and dry continental tropical (cT), warm and humid maritime tropical (mT), cold and dry continental polar (cP), cold and humid maritime polar (mP), and arctic (A). An arctic air mass is basically the same as a continental polar air mass, but much colder. It's the type you may have heard most about because it brings the most frigid outbreaks of winter. Extremely cold arctic air masses are usually associated with very high pressure as a result of the massive sinking of cold air over a large area.

Source Regions All five main types of air masses can be found in North America because of the continent's proximity to the source regions associated with each air mass. Maritime polar air forms over the cold waters of the North Atlantic and North Pacific. It primarily affects the West Coast, bringing occasionally heavy rains in winter. Continental polar air forms over the interior of Canada and Alaska and can be quite frigid in the winter, when nights are long. In the summer, however, cP air can bring pleasant relief from heat and humidity because of its cool and relatively dry composition.

The origins of maritime tropical air are tropical and subtropical oceans, such as the Caribbean Sea and the Gulf of Mexico. In the summer, mT air brings hot, oppressively humid weather to the eastern two-thirds of the United States and Canada. The desert Southwest and Mexico are the source regions

Figure 12-3 Each of the major air masses that affects weather in the United States has a similar temperature and moisture content as the area over which it formed.

of continental tropical air, which is hot and dry, especially in summer. Arctic air develops over latitudes above 60°N in the ice- and snow-covered regions of Siberia and the Arctic Basin. During the winter, this area receives almost no solar radiation but continues to radiate heat out to space, so it can get very cold indeed. In addition to temperature and humidity, another important characteristic of an air mass is its stability. The stability of air is an important factor in its ability to produce clouds and precipitation.

Air Mass Modification Like the warm air over a large city during a summer afternoon, air masses do not stay in one place indefinitely. Eventually, they move, transferring heat from one area to another and thus establishing the heat balance discussed earlier. As an air mass moves, it may travel over land or water that has different

Table 12-1 Air Mass Characteristics				
	Source Region Stability		Characteristics	
Air Mass Type	Winter	Summer	Winter	Summer
A	Stable		Bitter cold, dry	
cP	Stable	Stable	Very cold, dry	Cool, dry
cT	Unstable	Unstable	Warm, dry	Hot, dry
mP (Pacific)	Unstable	Unstable	Mild, humid	Mild, humid
mP (Atlantic)	Unstable	Stable	Cold, humid	Cool, humid
mT (Pacific)	Stable	Stable	Warm, humid	Warm, humid
mT (Atlantic)	Unstable	Unstable	Warm, humid	Warm, humid

characteristics from those of its source region. The air mass then starts to acquire some of the characteristics of the new surface beneath it. When this happens, it is said to undergo **air mass modification,** which is the exchange of heat or moisture with the surface over which an air mass travels. ***Table 12-1*** summarizes the characteristics of the main types of air masses before modification.

All air masses become modified to some extent as they move away from their source regions. Eventually, an air mass becomes modified to such a degree that its characteristics are almost the same as the new surface over which it is traveling. At this point, the air mass has lost its original identity and is now simply part of the air over the new source region it has encountered.

SECTION ASSESSMENT

1. What is the difference between weather and climate? How do both relate to the science of meteorology?
2. What must happen to keep the poles from steadily cooling off and the tropics from heating up over time?
3. What method of heat transfer plays the primary role in the formation of an air mass?
4. Describe how the moisture in a maritime polar (mP) air mass that formed over the North Pacific Ocean would modify as it moved inland over the western coast of North America.
5. **Thinking Critically** Explain why an arctic air mass is usually more stable than a maritime tropical air mass. In other words, why does the arctic air resist rising more than the tropical air does?

SKILL REVIEW

6. **Predicting** Which type of air mass would you expect to become modified more quickly: an arctic air mass moving over the Gulf of Mexico in winter or a maritime tropical air mass moving into the southeastern United States in summer? For more help, refer to the *Skill Handbook.*

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SECTION 12.2 *Weather Systems*

If Earth were either all land or all water and did not rotate on its axis, a large convection cell would form in each hemisphere with the colder and denser air at the poles sinking to the surface and flowing toward the tropics. There, it would force the warm air already at the equator to rise, and then it would cool and flow back toward the poles. The problem with this proposal is that Earth does rotate from west to east. This rotation causes the **Coriolis effect,** wherein moving particles such as air are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. The Coriolis effect, illustrated in ***Figure 12-4A,*** combines with the heat imbalance found on Earth to create distinct global wind systems that transport colder air to warmer areas and warmer air to colder areas. The end result is the balancing of heat energy on Earth.

OBJECTIVES

- **Describe** *how the rotation of Earth affects the movement of air.*
- **Compare** *and* **contrast** *wind systems.*
- **Identify** *the various types of fronts.*

VOCABULARY

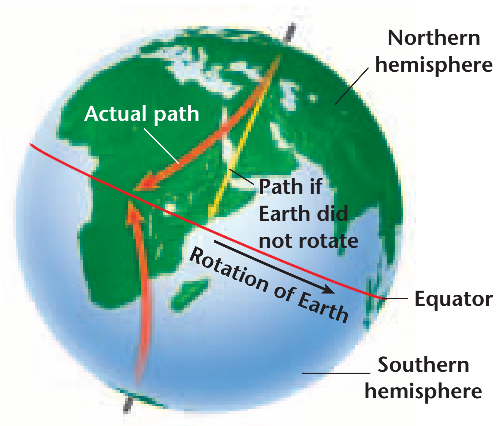
Coriolis effect
trade winds
prevailing westerlies
polar easterlies
jet stream
front

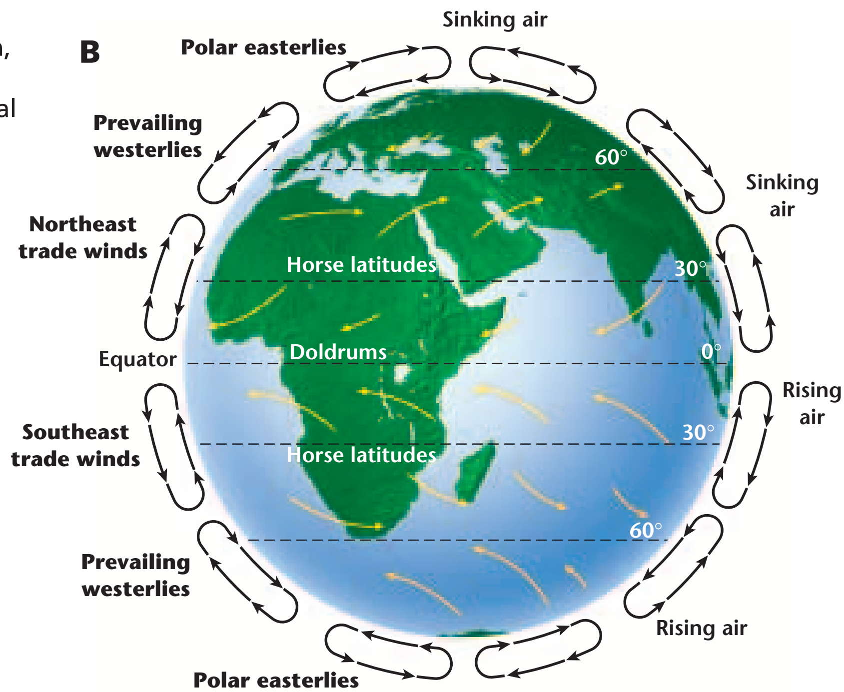
GLOBAL WIND SYSTEMS

There are three basic zones, or wind systems, in each hemisphere, as shown in ***Figure 12-4B.*** The first, known as the **trade winds,** occurs at 30° north and south latitude. There, air sinks, warms, and moves toward the equator in a westerly direction. When the air reaches the equator, it rises again and moves back toward latitude 30°, where it sinks and the process starts anew. The circulation pattern for the trade

Figure 12-4 The rotation of Earth causes the Coriolis effect **(A),** which, along with the heat imbalance on Earth, creates the three major global wind systems **(B).** The convection cells show the movement of air in each zone.

A





winds closely fits a model proposed by English scientist George Hadley in 1735; thus, this zone is sometimes known as the Hadley cell.

Around 30° latitude, the sinking air associated with the trade winds creates a belt of high pressure that in turn causes generally weak surface winds. Spanish sailors called this belt the horse latitudes because their ships became stranded in these waters as a result of the near-calm winds. According to legend, they could no longer feed or water their horses and were forced to throw them overboard.

Near the equator, the trade winds from both hemispheres move together from two different directions, as shown in ***Figure 12-4.*** The air converges, is forced upward, and creates an area of low pressure. This process, called convergence, can occur on a small or large scale. Near the equator, it occurs over a large area called the intertropical convergence zone (ITCZ). As ***Figure 12-5*** shows, the ITCZ migrates south and north of the equator as the seasons change. In essence, it follows the path of the Sun's rays, which are directly over the equator in September and March. Because the ITCZ is a region of rising air, it is characterized by a band of cloudiness and occasional showers that help provide the moisture for many of the world's tropical rain forests. Note that the ITCZ is also called the doldrums. As in the horse latitudes, sailing ships were often stranded in this belt of light winds.

Other Wind Zones The second wind system, the **prevailing westerlies,** flows between 30° and 60° north and south latitude in a circulation pattern opposite that of the trade winds. In this zone, surface winds move toward the poles in a generally easterly direction, as shown in ***Figure 12-4.*** Note that wind is named for the direction

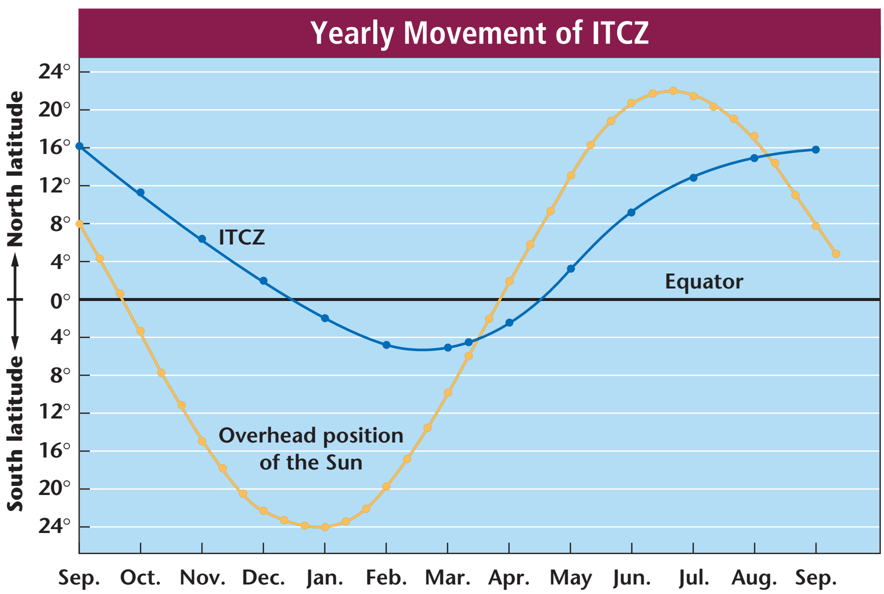


Figure 12-5 The mean position of the ITCZ basically follows the path of the Sun's rays throughout the year. The two paths don't match exactly because the ITCZ responds gradually to changes in the Sun's position, and thus lags behind the Sun.

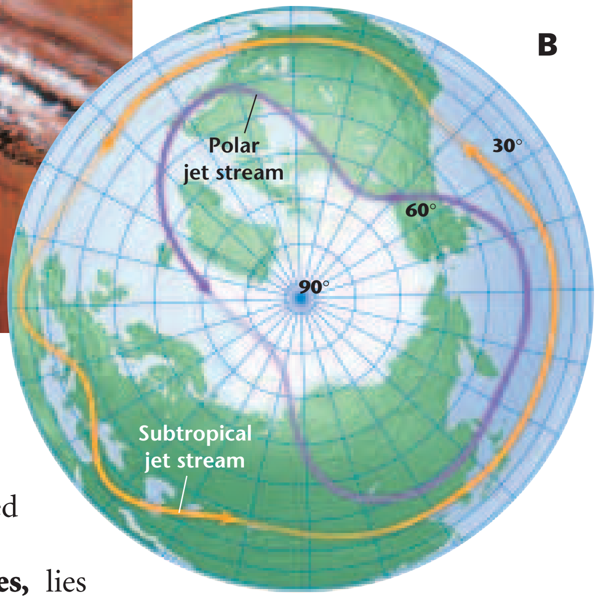


Figure 12-6 This satellite image shows the jet stream over the Middle East **(A).** The polar jet stream ranges from roughly 40° to 60° north latitude, and the subtropical jet stream ranges from roughly 20° to 30° north latitude **(B).**

from which it blows, so that a wind blowing from the west toward the east is considered a westerly wind. The prevailing westerlies are responsible for much of the movement of weather across the United States and Canada.

The last major wind zone, the **polar easterlies,** lies between 60° latitude and the poles. Similar to the trade winds, the polar easterlies flow from the northeast to the southwest in the northern hemisphere. Note that global wind direction reverses in the southern hemisphere. South of the equator, for instance, the polar easterlies flow from the southeast to the northwest. In both hemispheres, the polar easterlies are characterized by cold air.

Jet Streams

Earth's weather is strongly influenced by atmospheric conditions and events that occur at the boundaries between wind zones. On either side of these imaginary boundaries, both surface and upper-level air differs greatly in temperature and pressure. Remember that wind, temperature, and pressure are related. Differences in temperature and pressure cause wind. Therefore, a large temperature gradient in upper-level air should result in strong westerly winds, and indeed, this is what happens. Narrow bands of fast, high-altitude, westerly winds called **jet streams** flow at speeds up to 185 km/h at elevations of 10.7 km to 12.2 km. Jet streams, shown in ***Figure 12-6,*** are so named because they resemble jets of water. The most significant one, the polar jet stream, separates the polar easterlies from the prevailing westerlies. A second version, the subtropical jet stream, is located where the trade winds meet the prevailing westerlies.

Large-Scale Weather Systems Disturbances form along jet streams and give rise to large-scale weather systems that transport surface cold air toward the tropics and surface warm air toward the poles. Keep in mind that the position of the jet stream varies. It can dive almost directly south or north, instead of following its normal westerly direction. It can also split into different branches and later reform into a single stream. Whatever form or position it takes, the jet stream represents the strongest core of westerly winds. Together, these winds form a sort of atmospheric railroad track, with large-scale weather systems serving as the atmospheric trains. Weather systems generally follow the path of these winds. The jet stream also affects the intensity of weather systems by moving air of different temperatures from one region to another. Thus, despite its altitude, it has a significant impact on weather.

FRONTS

The different temperatures and pressures of air masses have other consequences apart from the jet stream. In the middle latitudes, air masses with different characteristics sometimes collide, forming a front. A **front** is the narrow region separating two air masses of different densities. The density differences are caused by differences in temperature, pressure, and humidity. Fronts can stretch over thousands of kilometers across Earth's surface. The interaction between the colliding air masses can bring dramatic changes in weather. As shown in ***Figure 12-7,*** there are four main types of fronts: cold fronts, warm fronts, stationary fronts, and occluded fronts.

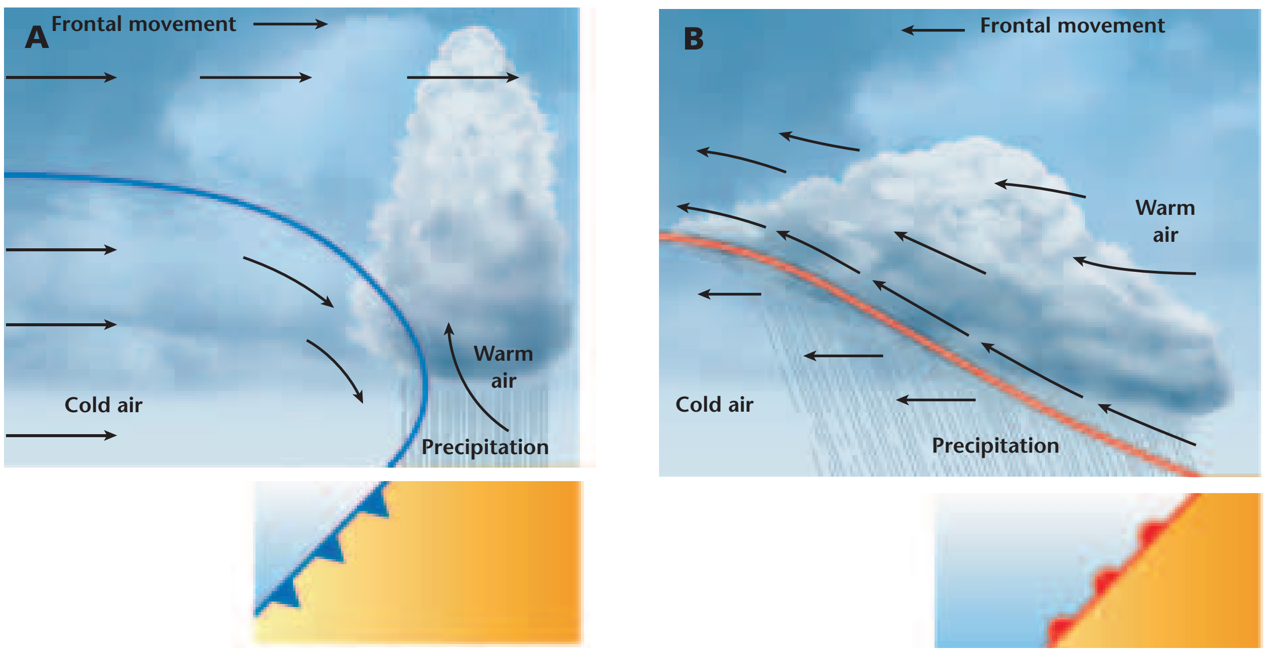


Figure 12-7 These diagrams show the structures of the four main types of fronts. Symbols below each diagram indicate how the fronts are represented on a weather map. A cold front often moves quickly. Thunderstorms may form along the front **(A).** In a warm front, precipitation often occurs over a wide band. High-altitude cirrus clouds may form as water vapor condenses **(B).** Light wind and precipitation are sometimes associated with a stationary front **(C).** Strong winds and heavy precipitation may occur along an occluded front **(D).**

CONTENTS

Cold Fronts In a cold front, shown in ***Figure 12-7A,*** cold, dense air displaces warm air and forces the warm air up along a steep front. As the warm air rises, it cools and condenses. Clouds, showers, and sometimes thunderstorms are associated with cold fronts. A cold front is represented on a weather map as a solid blue line with blue triangles that point in the direction of the front's motion.

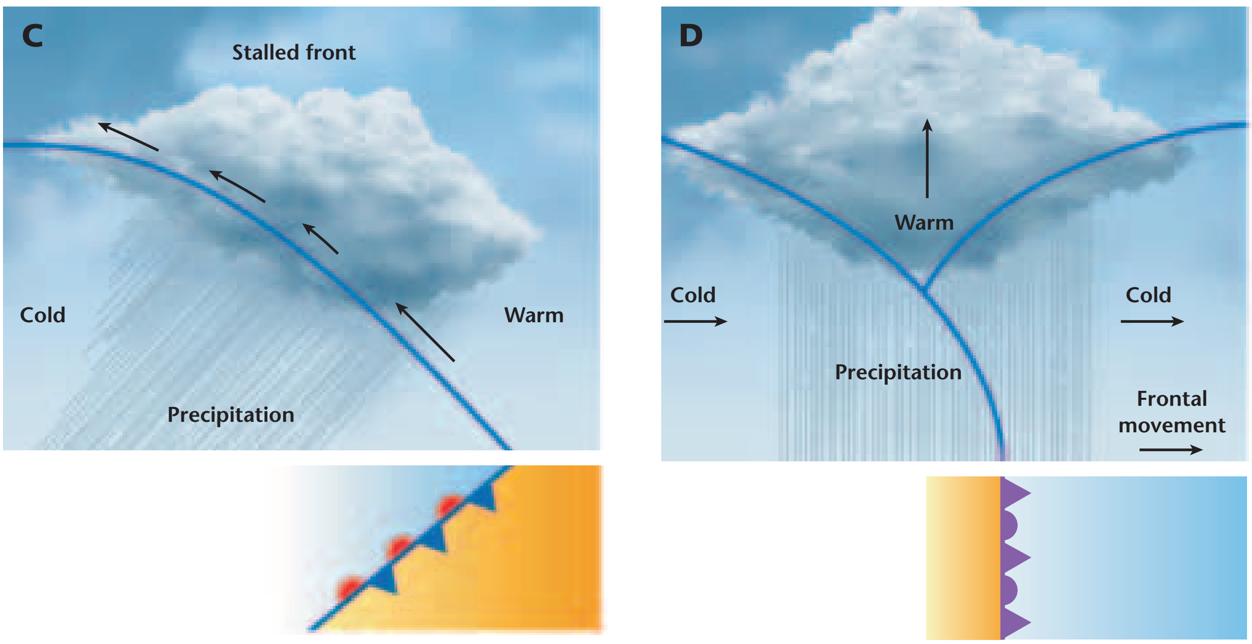
Warm Fronts In a warm front, advancing warm air displaces cold air, as shown in ***Figure 12-7B.*** Because the air ahead of a warm front moves more slowly than does an advancing cold air mass, the warm air encounters less friction with the ground and thus develops a gradual frontal slope rather than a steep boundary. A warm front is characterized by extensive cloudiness and precipitation. On a weather chart, a warm front appears as a solid red line with regularly spaced, solid red semicircles pointing in the direction of the front's motion.

Stationary Fronts Sometimes, two air masses meet and neither advances into the other's territory. In this case, the boundary between the air masses stalls. This type of front, called a stationary front, frequently occurs when two air masses have become so modified in their travels that the temperature and pressure gradients between them are small. Stationary fronts seldom have extensive cloud and heavy precipitation patterns; any patterns that do occur are somewhat similar to those of a warm front. A stationary front is represented on a weather map by a combination of short segments of cold- and warm-front symbols as shown in ***Figure 12-7C.***

Earth Science Online

Topic: Weather
To find out more about weather fronts, visit the Earth Science Web Site at earthgeu.com

Activity: Obtain a weather map showing today's weather. Label the weather fronts.



Using Math

Using Numbers Most weather occurs in the troposphere between the surface of Earth and an altitude of 11 km. Suppose the temperature in an area drops about 7°C for each kilometer of increase in altitude. If the surface temperature is 15°C, what is the temperature at an altitude of 3 km?

Occluded Fronts Sometimes, a cold air mass moves so rapidly that it overtakes a warm front. The advancing cold air wedges the warm air upward, as shown in ***Figure 12-7D*** on page 309. Recall that a warm front involves warm air gliding over a cold air mass. When the warm air is lifted, this cold air mass collides with the advancing cold front. The warm air is thus squeezed upward between the two cold air masses. This is called an occluded front and is represented on a weather map by a line with alternating purple triangles and semicircles that point toward the direction of motion. Precipitation is common on both sides of an occluded front.

PRESSURE SYSTEMS

You have learned that at Earth's surface, rising air is associated with low pressure and sinking air is associated with high pressure. Rising or sinking air, combined with the Coriolis effect, results in the formation of rotating low- and high-pressure systems in the atmosphere. Air in these systems moves in a general circular motion around either a high- or low-pressure center.

High-Pressure Systems In a surface high-pressure system, air sinks, so that when it reaches Earth's surface, it spreads away from the center. The deflection of air to the right caused by the Coriolis effect makes the overall circulation around a high-pressure center move in a clockwise direction in the northern hemisphere, as shown in ***Figure 12-8A.*** Keep in mind that the Coriolis effect is reversed in the southern hemisphere; there, high-pressure systems rotate in a counterclockwise direction. Some high-pressure systems are associated with cold air masses that move and modify; others, such as subtropical high-pressure systems, are more stationary.

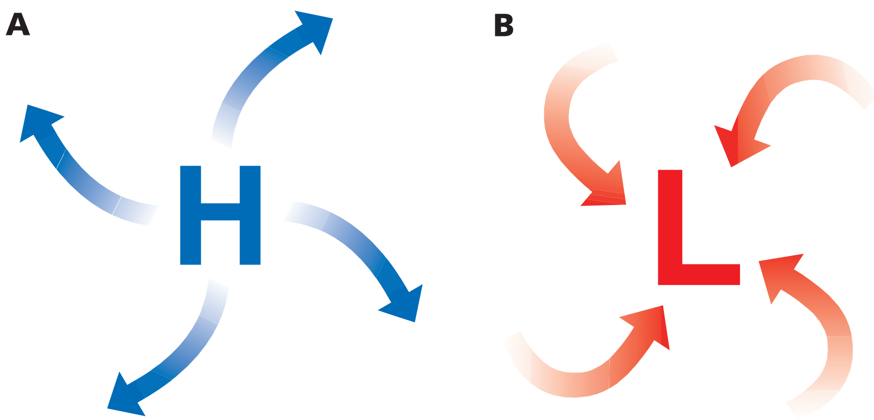


Figure 12-8 In the northern hemisphere, winds in a high-pressure system rotate in a clockwise direction **(A),** and winds in a low-pressure system rotate in a counterclockwise direction **(B).**

Low-Pressure Systems In surface low-pressure systems, air rises. The rising air must be replaced by air from outside the system, so the net flow is inward toward the center and then upward. In contrast to air in a high-pressure system, air in a low-pressure system in the northern hemisphere moves in a counterclockwise direction, as shown in ***Figure 12-8B.*** This movement is reversed in the southern hemisphere.

Recall from Chapter 11 that it's difficult for clouds to form when air is sinking, as it does in high-pressure systems. Thus, high-pressure systems are usually associated with fair weather, while low-pressure systems are associated with clouds and precipitation. In fact, most of Earth's subtropical oceans are dominated by large high-pressure systems with generally pleasant conditions. One of the main producers of inclement weather in the middle latitudes, meanwhile, is a specific type of low-pressure system called a wave cyclone. A wave cyclone usually begins along a stationary front. Some imbalance in temperature, pressure, or density causes part of the front to move south as a cold front and another part of the front to move north as a warm front. This sets up a counterclockwise or cyclonic circulation, as shown in ***Figure 12-9.*** Eventually, if upper-level conditions are favorable, a fully developed low-pressure system forms. Pushed by the prevailing westerlies, this system may travel thousands of kilometers affecting large areas in the middle latitudes.

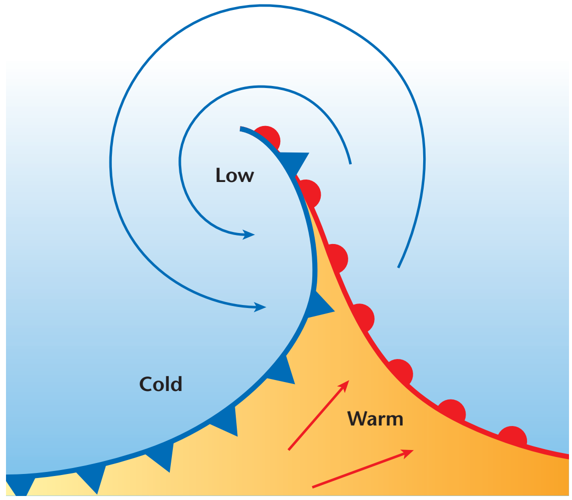


Figure 12-9 The counterclockwise circulation is characteristic of a wave cyclone.

Section Assessment

1. Describe the main global wind systems. Give characteristics of each.
2. Explain why most tropical rain forests are located near the equator.
3. How does the jet stream affect the movement of air masses?
4. What is the Coriolis effect? How does it affect air in the northern and southern hemispheres?
5. Compare and contrast a low-pressure system and a high-pressure system.
6. **Thinking Critically** Based on what you know about the three major zones of global air circulation, form a hypothesis about why most of the world's deserts are located between 10° and 30° north and south latitudes.

Skill Review

7. **Interpreting Scientific Illustrations** Refer to the illustrations of the four types of fronts shown in ***Figure 12-7.*** Sketch the fronts in your science journal or use a computer graphics program to make a model of them. Label the warm and cold air masses. Indicate the direction of their movement and describe the type of weather associated with each front. For more help, refer to the *Skill Handbook.*

earthgeu.com/self_check_quiz

SECTION 12.3 *Gathering Weather Data*

OBJECTIVES

- **Recognize** *the importance of accurate weather data.*
- **Describe** *the technology used to collect weather data.*
- **Analyze** *the strengths and weaknesses of weather observation systems.*

VOCABULARY

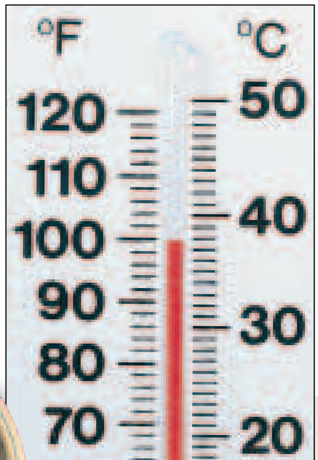
thermometer
barometer
anemometer
hygrometer
ceilometer
radiosonde
Doppler effect

When you visit a doctor, she or he first measures your temperature and blood pressure to make an accurate diagnosis and prescribe treatment. If the doctor's data are incomplete or inaccurate, the diagnosis is likely to be inaccurate as well. The same principle applies to meteorology. Meteorologists measure the atmospheric variables of temperature, air pressure, wind, and relative humidity to make accurate weather forecasts. The quality of the data is critical. In fact, two of the most important factors in weather forecasting are the accuracy and the density of the data—density in this case refers to the amount of data available. Just as a doctor uses several different instruments to assess your health, meteorologists use several types of technology to gather information about the atmosphere.

SURFACE DATA

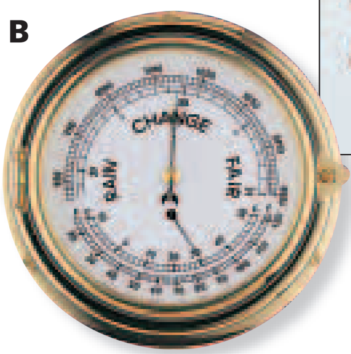
One of the most common weather instruments is a **thermometer,** a device used to measure temperature. Usually, thermometers contain liquids such as mercury or alcohol, which expand when heated. The height of the liquid column indicates temperature. Another common weather instrument, the barometer, also uses mercury to obtain weather data. **Barometers** measure air pressure. In a mercury barometer, changes in air pressure are indicated by changes in the height of a column of mercury. An aneroid barometer contains a vacuum

A



C

B



D

Figure 12-10 A thermometer **(A),** barometer **(B),** anemometer **(C),** and hygrometer **(D)** are commonly used weather instruments.

inside a metal chamber. The chamber contracts or expands with changes in air pressure. A thermometer and a mercury barometer are shown in ***Figures 12-10A*** and ***12-10B.***

Other Surface Instruments An **anemometer,** shown in ***Figure 12-10C,*** is used to measure wind speed. The simplest type of anemometer has cupped arms that rotate as the wind blows. A **hygrometer** measures relative humidity. One type of hygrometer, shown in ***Figure 12-10D,*** uses wet- and dry-bulb thermometers. As water evaporates from the wet bulb, the bulb cools, creating a temperature difference between the wet bulb and the dry bulb. This temperature difference is used in conjunction with a relative humidity chart to determine relative humidity. See *Appendix F* for an example of a relative humidity chart.

Automated Surface Observing System To make weather forecasts, meteorologists analyze and interpret data gathered from weather instruments. In this regard, timing is crucial. Data must be gathered at the same time at many different locations. Why? It would do no good to analyze how temperature and air pressure are interacting in the atmosphere if the two variables were measured at different times. Meteorologists need an accurate "snapshot" of the atmosphere at a particular moment in time to develop a reliable forecast. Thus, the National Weather Service in the United States has established a surface observation network across the country. Made up of some 1700 official sites, the network gathers data in a consistent manner at regular intervals—usually a minimum of once an hour. Most of these data are collected by the Automated Surface Observing System (ASOS), shown in ***Figure 12-11.*** In addition to the weather instruments already discussed, the ASOS uses a rain gauge for measuring rainfall, as well as a **ceilometer,** which measures the height of cloud layers and estimates the amount of sky covered by clouds. You'll learn more about the ASOS in this chapter's *Science & Technology* feature.

Figure 12-11 This automated weather system measures surface data.

Upper-Level Data

While surface weather data are important, the weather that we experience is largely the result of changes that take place high in the troposphere. To make accurate forecasts, meteorologists must gather atmospheric data at heights of up to 30 000 m. This is a more formidable task than gathering surface data, and therefore it requires more sophisticated technology.

Figure 12-12 Radiosondes are used to gather upper-level weather data.

At present, the instrument of choice for gathering upper-level data is a balloon-borne package of sensors called a **radiosonde,** shown in ***Figure 12-12.*** The sensors on a radiosonde measure temperature, air pressure, and humidity. These readings are constantly sent back by radio signal to a ground station that tracks the movements of the radiosonde. Tracking is a crucial component of upper-level observations—meteorologists can determine wind speed and direction by tracking how fast and in what direction the radiosonde is moving. The various data are plotted on a chart, giving meteorologists a profile of the temperature, pressure, humidity, wind speed, and wind direction of a particular part of the troposphere. Such charts are used to forecast atmospheric changes that affect surface weather. While radiosondes provide accurate snapshots of atmospheric conditions, they are quite expensive. It is hoped that in the future, data from satellites will replace or greatly supplement radiosonde observations.

Weather Radar

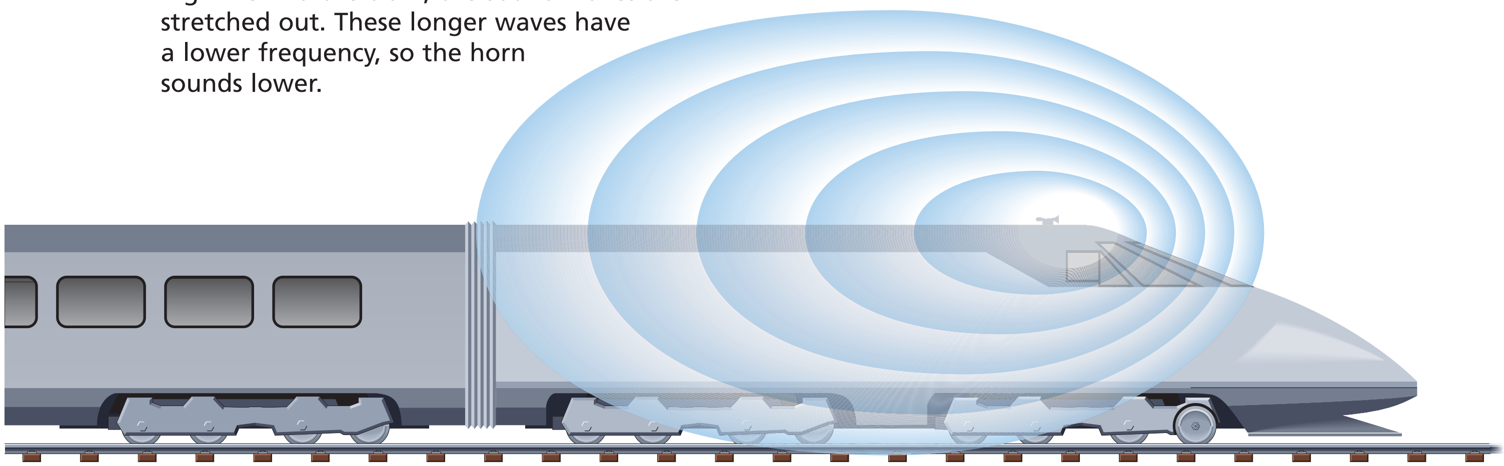
There are thousands of surface observation sites and 100 upper-level observation sites across the United States. Yet the data from these sites cannot pinpoint where rain is falling at any given moment. For that purpose, a weather radar system is needed. The term *radar* stands for "radio detecting and ranging." A radar system is made of several parts. A transmitter generates electromagnetic waves, which leave the transmitter through antennae. In weather radar systems, the waves are programmed to ignore small cloud droplets and to bounce off large raindrops. The large raindrops scatter some of the radio waves. These scattered waves, or echoes as they are often called, are received by other antennae. An amplifier increases the wave signals of the scattered waves. A computer then processes the signals and displays them on a screen. From this, meteorologists can compute the distance to the raindrops and the location of the rain relative to the receiving antennae. The radar system rotates in a circle, allowing meteorologists to gauge where rain is falling within the radar's range—usually an area with a diameter of about 400 km.

Doppler Radar Many advanced weather radar systems take advantage of a phenomenon called the Doppler effect. The **Doppler effect** is the change in wave frequency that occurs in energy, such as sound or light, as that energy moves toward or away from an observer. You've probably noticed that sounds produced by a horn from an approaching train change once the train has passed. Look at ***Figure 12-13.*** As the train approaches, the frequency and pitch of the sound coming from the horn are high. As the train passes, the frequency and pitch lower. This is the Doppler effect in action. Meteorologists use Doppler radar, which is based on the Doppler effect, to plot the speed at which raindrops move toward or away from a radar station. Because the motion of the moving raindrops is caused by wind, Doppler radar provides a good estimation of the wind speeds associated with precipitation areas, including those that are experiencing severe weather such as thunderstorms and tornados. The ability to measure wind speeds gives Doppler radar a distinct advantage over conventional weather radar systems.

Weather Satellites

In addition to communications, one of the main uses of satellites in orbit around Earth is to observe weather. Cameras mounted aboard a weather satellite take photos of Earth at regular intervals. These photos are beamed back to ground stations and their data are plotted on maps. Unlike weather radar, which tracks precipitation but not clouds, satellites track clouds but not necessarily precipitation. By combining data from the two types of technology, meteorologists can determine where both clouds and precipitation are occurring.

Figure 12-13 As the train approaches, the sound waves ahead of it are compressed. These short waves have a high frequency, so the horn sounds high. Behind the train, the sound waves are stretched out. These longer waves have a lower frequency, so the horn sounds lower.



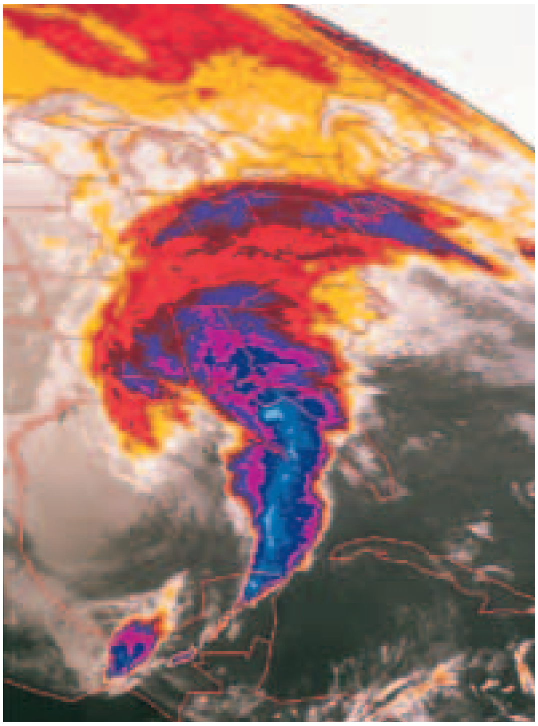


Figure 12-14 This infrared image shows a huge storm system over the eastern United States.

Infrared Imagery Weather satellites use both visible light and invisible radiation to observe the atmosphere. The satellites discussed thus far use cameras that need visible light to take photos. When such a satellite is observing a portion of Earth that is in darkness, however, its cameras are useless. Thus, some satellites are designed to use infrared imagery. Infrared imagery detects differences in thermal energy, which are used to map either cloud cover or surface temperatures. In an infrared image, such as the one shown in ***Figure 12-14,*** objects that radiate warmth at slightly different frequencies show up as different colors. As you learned in Chapter 11, different types of clouds form at different levels of the atmosphere, which are characterized by different temperatures. Infrared images allow meteorologists to determine the temperature of a cloud. From this, they can infer what type it is and estimate its height. Infrared imagery is especially useful in detecting strong thunderstorms that extend to great heights in the atmosphere and consequently show up as very cold areas on an infrared image. Because the strength of a thunderstorm is related to its height, infrared imagery can be used to establish a storm's potential to produce severe weather.

Section Assessment

1. If your goal was to vastly improve the density of weather data in the United States, would you focus on gathering more surface data or more upper-level data? Explain.
2. What is the main advantage of Doppler radar over conventional weather radar?
3. Compare and contrast infrared imagery and visible-light imagery.
4. What is the main disadvantage of radiosondes?
5. **Thinking Critically** All else being equal, would you expect weather forecasts to be more accurate for the state of Kansas or a Caribbean island? Why?

Skill Review

6. **Concept Mapping** Use the following terms to construct a concept map about instruments that gather surface weather data. For more help, refer to the *Skill Handbook*.

1. anemometer	2. hygrometer	3. humidity
4. barometer	5. thermometer	6. temperature
7. weather instruments	8. air pressure	9. wind speed

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CONTENTS

SECTION 12.4 Weather Analysis

OBJECTIVES

- **Analyze** *a basic surface weather chart.*
- **Distinguish** *between analog and digital forecasting.*
- **Describe** *problems with long-term forecasts.*

VOCABULARY

station model
isopleth
digital forecast
analog forecast

After weather observations are gathered, meteorologists plot the data on a map, using station models for individual cities or towns. A **station model** is a record of weather data for a particular site at a particular time. Meteorological symbols, such as the ones shown in ***Figure 12-15,*** are used to represent weather data in a station model. (For a more complete list of the symbols that meteorologists use to represent weather data, see *Appendix E.*) A station model allows meteorologists to fit a large amount of data into a small space. It also gives meteorologists a uniform way of communicating weather data. You'll use station models and weather maps to forecast the weather in the *Mapping GeoLab* at the end of this chapter.

SURFACE ANALYSIS

Station models provide information for individual sites. To plot data nationwide or globally, meteorologists use **isopleths,** which are lines that connect points of equal or constant values. The values represent different weather variables, such as pressure or temperature. Lines of equal pressure, for example, are called isobars; lines of equal temperature are called isotherms. The lines themselves are similar to the contour lines—lines of equal elevation—that you studied in Chapter 2. Just as you can make inferences about elevation by studying contour intervals on a map, you can also make inferences about weather by studying isobars or isotherms on a map. For instance, you can tell how fast wind is blowing in an area by noting how closely isobars are spaced. Isobars that are close together indicate a large

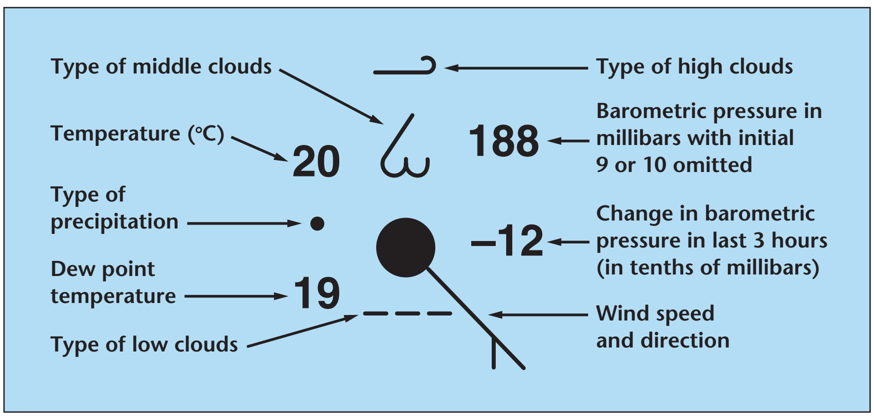


Figure 12-15 A station model shows weather data for a particular area at a particular time.

pressure difference over a small area. A large pressure difference causes strong winds. Conversely, isobars that are spread far apart indicate a small difference in pressure. Winds in these areas would be light. As shown in ***Figure 12-16,*** isobars also indicate the locations of high- and low-pressure systems. This information is especially useful when combined with isotherms, which identify temperature gradients and, consequently, frontal systems. Using isobars, isotherms, and station-model data, meteorologists can analyze current weather conditions for a particular time and place. This is crucial information—meteorologists must understand current weather conditions before they can move on to forecasting the weather. You'll learn more about isobars in the *Problem-Solving Lab* on this page.

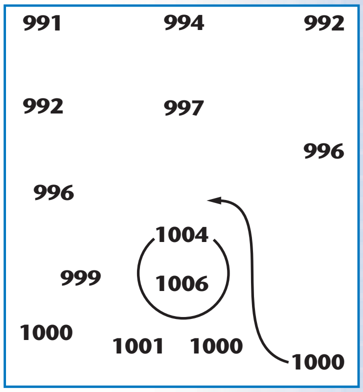
SHORT-TERM FORECASTS

In the early days of weather forecasting, meteorologists simply observed current weather conditions, compared these conditions to those that had occurred a day or two before, and then extrapolated the changes a day or two into the future. The resulting positions of

Problem-Solving Lab

Interpreting Scientific Illustrations

Create and analyze isobars on a weather map Areas of high and low pressure can be indicated on a weather map by lines of approximately equal pressure called isobars.



Analysis

1. On a blank piece of paper, trace the diagram shown here, along with the pressure values at various locations, which are given in millibars (mb).
2. A 1004-mb isobar that encircles one location on this map has been drawn and labeled. Complete and label the 1000-mb isobar that has been started. Finally, draw a 996-mb isobar and a 992-mb isobar. The isobars may not completely encircle a location in a map of this scale.

Thinking Critically

3. What is the contour interval of the isobars on this map?
4. A blue letter *H* and a red letter *L* in the centers of closed isobars mark the areas of highest and lowest pressure, respectively. On your map, place a blue *H* or a red *L*—whichever is appropriate—inside the closed 1004-mb isobar.
5. What type of weather is commonly associated with this pressure system?

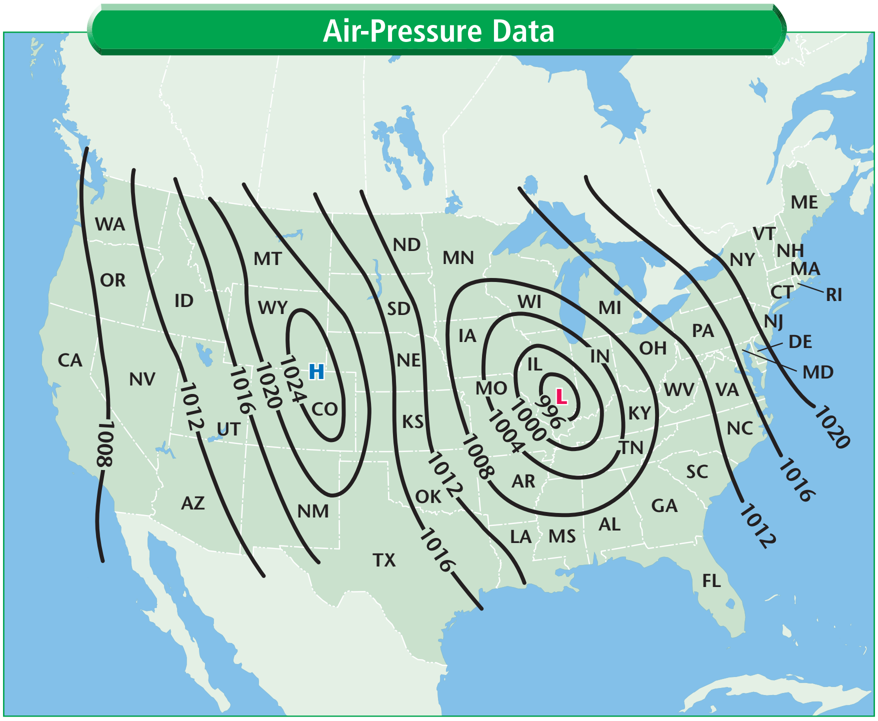


Figure 12-16 This map shows air-pressure data for the United States. ***Where would you expect light winds?***

the weather systems served as the basis for their forecasts. Weather forecasting, however, is too complicated to rely on extrapolating the past movements of weather systems. Weather systems change directions, speed, and intensity with time. These changes take place in response to changes in the upper atmosphere, so a reliable forecast must analyze data from different levels in the atmosphere.

Digital Forecasts The key to unlocking the forecast puzzle lies in the fact that the atmosphere behaves much like a fluid. Thus, we can apply many of the same principles to the atmosphere and its variables, such as temperature, pressure, density, and so on, that we can apply to a fluid. Furthermore, these principles can be expressed in mathematical equations to determine how atmospheric variables change with time. For meteorologists to solve these equations on a global or national level would take an impossibly large amount of time. Fortunately, high-speed computers can do the job. A forecast such as this that relies on numerical data is known as a **digital forecast.** Digital forecasting is the main method used by modern meteorologists, such as the one shown in ***Figure 12-17.*** It is highly dependent on the density of the data available—basically, the more data, the more accurate the forecast.

Figure 12-17 This meteorologist is preparing a weather forecast.

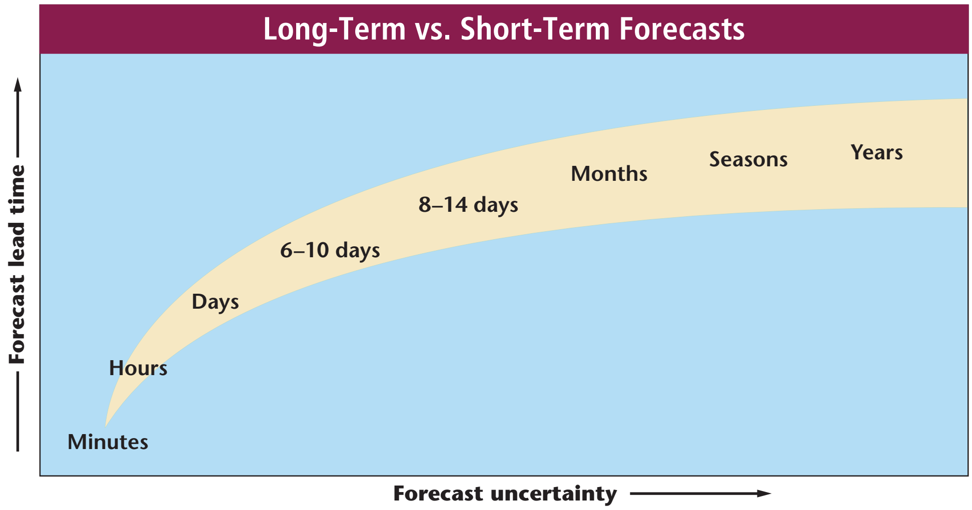


Figure 12-18 This graph shows that forecast uncertainty increases with time.

Analog Forecasts Another type of forecast, an **analog forecast,** involves comparing current weather patterns to patterns that took place in the past. The assumption is that weather systems behave in a similar fashion. Analog forecasting is so called because meteorologists look for a pattern from the past that is analogous, or similar to, a current pattern. To ensure an accurate analog forecast, meteorologists must find a past event that is similar to a current event through all levels of the atmosphere, and also over a large area. This is the main drawback of analog forecasting. Still, analog forecasting is useful for conducting monthly or seasonal forecasts, which are based mainly on the past behavior of cyclic weather patterns. Let's explore the strengths and weaknesses of long-term forecasts.

Long-Term Forecasts

Regardless of the forecasting method used, all forecasts become less reliable when they attempt to predict long-term changes in the weather. Why? Even high-tech computers cannot model every factor that affects the weather. Recall that mountains, valleys, rivers, lakes, cities, and countless other features on Earth's surface affect the amount of heat absorbed in a particular location. This, in turn, affects the pressure and therefore the wind of that area, which in turn affects cloud formation and virtually all other aspects of the weather. Over time, all these factors interact to create progressively more complicated scenarios.

The most accurate and detailed forecasts are short-term in nature, as shown in ***Figure 12-18.*** For hourly forecasts, extrapolation is a reliable forecasting method because the current weather is dominated by small-scale weather features that are readily observable by radar and satellite. Forecasts in the one- to three-day range, however, are no longer based on the movement of observed clouds and precipitation, which change by the hour. These forecasts are dependent on the behavior of larger surface and upper-level features, such as low-pressure systems. A one- to three-day forecast can somewhat accurately predict whether the day will be rainy or dry, and, if rainy, when the precipitation will occur. At this range, however, the forecast will not be able to pinpoint an exact temperature or sky condition at a specific time.

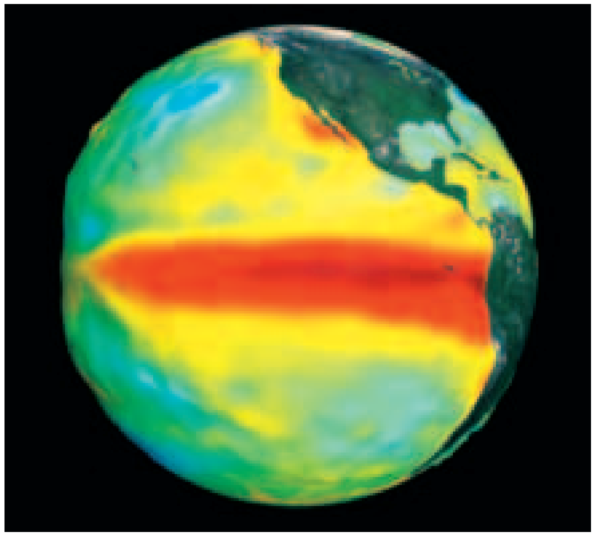


Figure 12-19 Changes in ocean-surface temperatures can trigger changes in weather patterns. This satellite image shows a cyclic event known as El Niño wherein the Pacific Ocean warms along the equator and triggers short-term climatic changes.

Accuracy Declines with Time At the four- to seven-day range, forecasts must attempt to predict changes in surface weather systems based on circulation patterns throughout the troposphere and lower stratosphere. Meteorologists can estimate each day's weather but can offer little detail as to when or what exact weather conditions will occur. At the one- to two-week range, forecasts are based on changes in large-scale circulation patterns. Thus, these forecasts are vague and based mainly on analogous conditions.

Long-term forecasts involving months and seasons are based largely on patterns or cycles. Several of these cycles, such as the one shown in ***Figure 12-19,*** involve changes in the atmosphere, ocean currents, and solar activity, all of which might be occurring at the same time. The key to future improvement in weather forecasts lies in identifying the many influences involved, understanding these influences and how they interact, and finally, determining their ultimate effect on weather over progressively longer periods of time.

SECTION ASSESSMENT

1. Find an example of a station model in your local newspaper and describe the symbols on the model.
2. Compare and contrast analog and digital forecasting.
3. Explain why long-term forecasts aren't always accurate.
4. **Thinking Critically** Based on what you have learned about digital forecasting, what single improvement do you think would be necessary to increase the reliability of this type of forecasting?

SKILL REVIEW

5. **Forming a Hypothesis** For a time period of three days or less, hypothesize which would be more accurate: digital forecasting or analog forecasting. Explain your hypothesis. For more help, refer to the *Skill Handbook.*

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Mapping GeoLab

Interpreting a Weather Map

It's time to put your knowledge of meteorology into action. The surface weather map on the following page shows actual weather data for the United States. In this activity, you will use the station models, isobars, and pressure systems on the map to forecast the weather.

Preparation

Problem

How can you use a surface weather map to interpret information about current weather and to forecast future weather?

Materials

pencil
ruler

Procedure

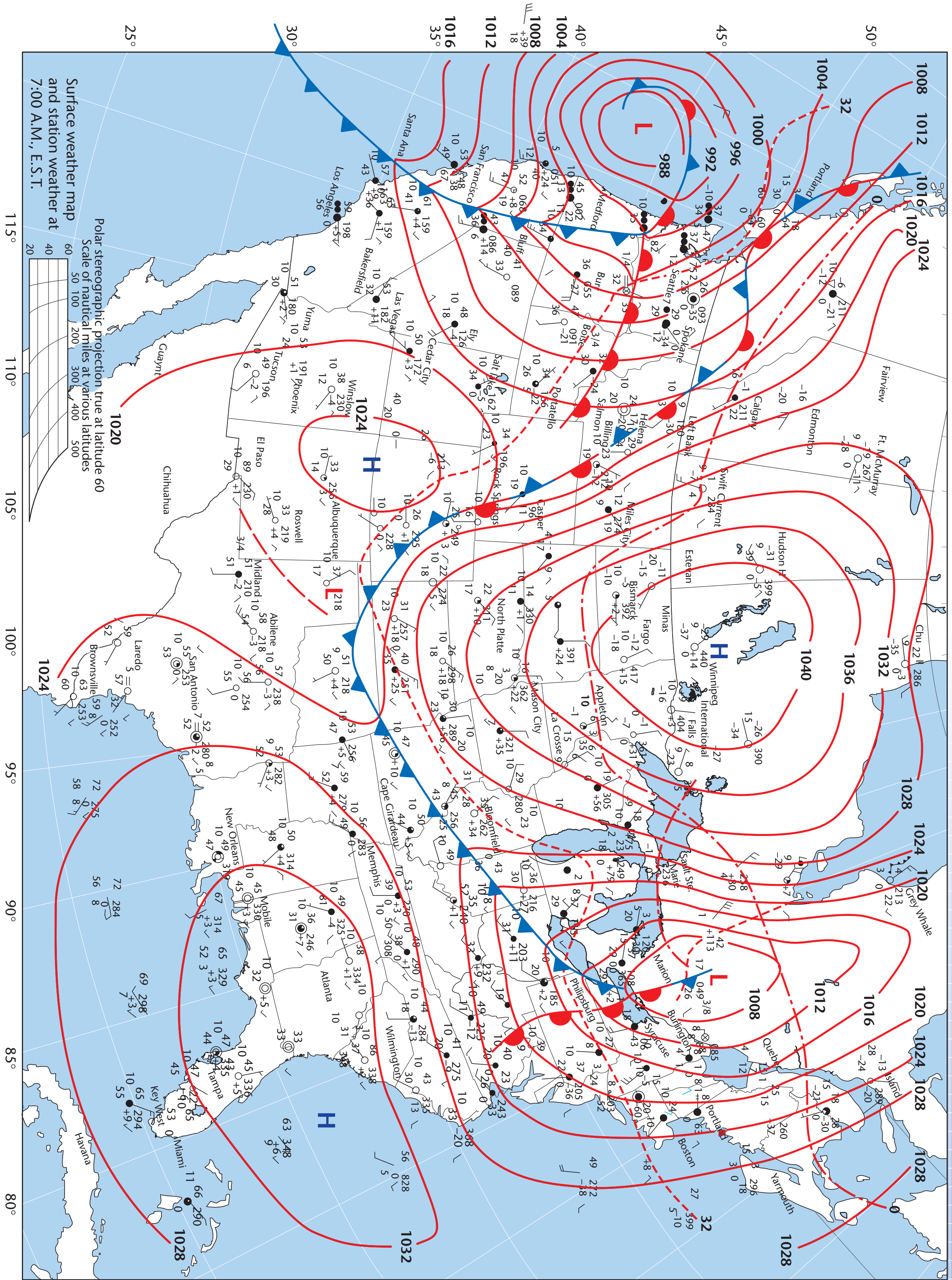
1. The map scale is given in nautical miles. Refer to the scale when calculating distances.
2. The unit for isobars is millibars (mb). In station models, pressure readings are abbreviated. For example, 1021.9 mb is plotted on a station model as 219 but read as 1021.9.
3. Wind shafts point in the direction from which the wind is blowing.

Analyze

1. What is the contour interval of the isobars?
2. What are the highest and lowest isobars? Where are they located?
3. In which direction are the winds blowing across Texas and Louisiana?
4. What and where are the coldest and warmest temperatures that you can find in the continental United States?

Conclude & Apply

1. Would you expect the weather in Georgia and Florida to be clear or rainy? Why?
2. Both of the low-pressure systems in eastern Canada and off the Oregon coast are moving toward the east at about 15 mph. What kind of weather would you predict for Oregon and for northern New York for the next few hours? Explain.


Surface weather map and station weather at 7:00 A.M., E.S.T.
Polar stereographic projection true at latitude 60
Scale of nautical miles at various latitudes
Seattle
Spokane
Portland
Medford
San Francisco
Santa Ana
Los Angeles
Bakersfield
Las Vegas
Yuma
Tucson
Phoenix
Winslow
Albuquerque
El Paso
Roswell
Midland
Abilene
San Antonio
Laredo
Brownsville
Salt Lake City
Pocatello
Boise
Helena
Billings
Calgary
Edmonton
Fairview
Swift Current
Casper
Rock Springs
Cedar City
Ely
Estevan
Bismarck
Fargo
Winnipeg
International Falls
North Platte
Mason City
La Crosse
Appleton
Sault Ste. Marie
Bloomfield
Cape Girardeau
Memphis
New Orleans
Mobile
Atlanta
Wilmington
Tampa
Key West
Miami
Havana
Syracuse
Philipsburg
Burlington
Marion
Boston
Yarmouth
Quebec
Grey Whale
Chihuahua
Guaymas
Ft. McMurray
Hudson H
Minas
Left Bank
Miles City

CONTENTS

Science & Technology

Tracking Atmospheric Change

On July 16, 1999, John F. Kennedy Jr. piloted a small private plane bound for Martha's Vineyard. The plane never reached its destination. Searchers determined that the plane crashed into the Atlantic Ocean, killing all three people on board. While no one will know exactly what happened, the dense fog may have been a factor in the crash.

Safety is a priority in the aviation industry. Pilots must be aware of weather conditions to avoid crashing when landing or taking off. Prior to 1990, National Weather Service personnel were responsible for gathering and communicating weather data to pilots. These professionals collected data on air pressure, wind speed, temperature, cloud cover, and precipitation.

ASOS

Concern about possible human errors prompted scientists to develop a more efficient system for transmitting weather data to pilots. The resulting computerized system, called the Automated Surface Observing System (ASOS), is now the cornerstone of weather forecasting and communication in this country.

The Pros and Cons

Today, more than 1000 ASOS units are in operation at major airports, continuously recording air pressure, temperature, wind speed and direction, runway visibility, cloud ceiling, and precipitation intensity. Data are automatically updated every minute. While human observations are based on what can be seen from a given vantage point, computerized observations are not affected by varying light and terrain conditions. For this reason, many aviation professionals believe that ASOS data are more consistent than manually collected data.

Some aviation professionals, however, disagree. The National Air Traffic Controllers Association believes that human observers were replaced by machines primarily to save money, and that the loss of trained weather observers is detrimental to aviation safety. On the evening that Kennedy's plane went down, the ASOS indicated that visibility was 13 to 16 km. In actuality, visibility was reported to be so poor by other pilots that the lights of Martha's Vineyard could not be seen from the air. The National Weather Service admits that the ASOS needs to be refined and continues to implement upgrades. Still, this group insists that widespread use of the ASOS will reduce weather-related aviation accidents.

Activity

Does your local airport use the ASOS? Go to the Earth Science Web Site at earthgeu.com to research which airports use the ASOS, or contact your local airport. Write to airport officials for statistics on aviation accidents both prior to and after the installation of the ASOS. Has there been a change in the number of aviation accidents since the airport implemented the ASOS? Use this information to write a short opinion piece on the continued use of the ASOS.

Study Guide

Summary

SECTION 12.1

The Causes of Weather

Main Ideas

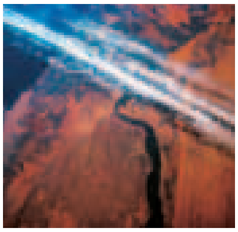
- Meteorology is the study of the atmosphere. Weather is the current state of the atmosphere, and climate is the average weather over a long period of time.
- An air mass is a large body of air that takes on the characteristics of the area over which it forms.

Vocabulary

air mass (p. 301)
air mass modification (p. 304)
climate (p. 300)
meteorology (p. 299)
weather (p. 300)

SECTION 12.2

Weather Systems



Main Ideas

- The Coriolis effect deflects air to the right in the northern hemisphere and to the left in the southern hemisphere. The Coriolis effect combines with the heat imbalance found on Earth to form the trade winds, prevailing westerlies, and polar easterlies.
- Weather in the middle latitudes is strongly influenced by fast-moving, high-altitude jet streams.
- A front is the boundary between two air masses of different densities. The four types of fronts are cold fronts, warm fronts, occluded fronts, and stationary fronts.

Vocabulary

Coriolis effect (p. 305)
front (p. 308)
jet stream (p. 307)
polar easterlies (p. 307)
prevailing westerlies (p. 306)
trade winds (p. 305)

SECTION 12.3

Gathering Weather Data

Main Ideas

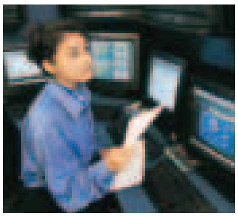
- Two of the most important factors in weather forecasting are the accuracy and the density of the data. Surface data are easier to gather than upper-level data.
- The most common instrument for collecting upper-level data is a balloon-borne radiosonde. Radiosondes measure temperature, pressure, humidity, wind speed, and wind direction.
- Weather radar pinpoints exactly where precipitation occurs. Weather satellites use both visible-light imagery and infrared imagery to observe weather conditions on Earth.

Vocabulary

anemometer (p. 313)
barometer (p. 312)
ceilometer (p. 313)
Doppler effect (p. 315)
hygrometer (p. 313)
radiosonde (p. 314)
thermometer (p. 312)

SECTION 12.4

Weather Analysis



Main Ideas

- A station model is a record of weather data for a particular site at a particular time. On a weather map, lines of equal pressure are called isobars and lines of equal temperature are called isotherms.
- Digital forecasting uses numerical data. Analog forecasting compares current weather patterns to patterns that took place in the past. All forecasts become less reliable when they attempt to predict long-term changes in the weather.

Vocabulary

analog forecast (p. 320)
digital forecast (p. 319)
isopleth (p. 317)
station model (p. 317)

earthgeu.com/vocabulary_puzzlemaker

CHAPTER 12

Assessment

Understanding Main Ideas

1. Which term best describes a snowflake?
   a. hydrosphere **c.** lithometeor
   b. hydrometeor **d.** electrometeor

2. What winds blow between 30° and 60° north and south latitude?
   a. trade winds **c.** polar easterlies
   b. prevailing westerlies **d.** jet streams

3. What would be the most likely classification for an air mass originating over Alaska and Canada?
   a. mT **c.** cT
   b. cP **d.** mP

4. What would be the most likely dominant air mass over the eastern United States in summer?
   a. cT **c.** mT
   b. cP **d.** mP

5. What instrument is used to measure the heights of the bases of clouds?
   a. radiosonde **c.** hygrometer
   b. ceilometer **d.** barometer

6. Which term describes changes in air motion resulting from Earth's rotation?
   a. jet stream **c.** Coriolis effect
   b. convergence **d.** Hadley cell

7. What forecast method is best for researching past weather events?
   a. digital **c.** extrapolation
   b. analog **d.** numerical

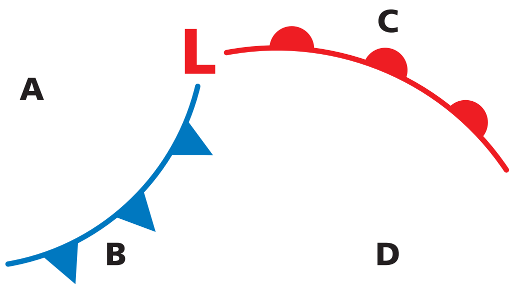
8. Which of the following is NOT characteristic of a high-pressure system?
   a. sinking air **c.** fair weather
   b. dense air **d.** thunderstorms

9. Which of the following would NOT be included in a station model?
   a. humidity **c.** pressure
   b. wind **d.** temperature

10. What does an anemometer measure?
    a. humidity **c.** wind speed
    b. air pressure **d.** wind direction

11. Describe the relationship among meteorology, weather, and climate.

Use the surface weather chart below to answer questions 12 and 13.



12. What location will soon experience a warm front?

13. At what location would you forecast the greatest probability of thunderstorms? At what location would you forecast the weather to turn colder over the next day?

Test-Taking Tip

FOCUS While you take a test, pay absolutely no attention to anyone other than the teacher or proctor. If someone tries to talk with you during a test, don't answer. You'll become distracted. Also, the proctor may think that you were cheating. Don't take the chance. Focus on the test, and nothing else.

CHAPTER 12

Assessment

Applying Main Ideas

14. Is meteorological data easier to gather on land or on water? Explain your answer.
15. What is Doppler radar?
16. What happens to an air mass as it moves away from its source region?
17. Why are rain showers common near the ITCZ?
18. In your own words, describe the global wind systems.
19. Construct a station model using the following data: temperature: –5°F; dew point: –12°F; wind: north, 20 knots; barometric pressure: 1038.5 mb; sky: clear.

Thinking Critically

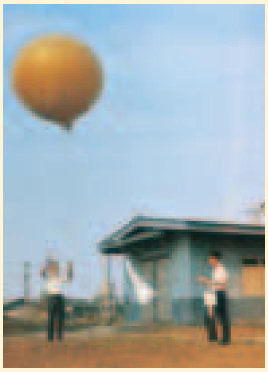
20. Forecast the weather for the next 24 hours for an area experiencing the same conditions as those included in the station model you constructed in question 19.
21. Like the north pole, the south pole receives little solar radiation during the winter. Unlike the north pole, however, the south pole does not send outbreaks of extremely frigid air as far as the subtropics. Why? (Hint: You may want to study a world map to answer this question.)
22. You hear on a news report that an area has received nearly twice its normal snowfall during the winter. What can you infer about the position of the jet stream from this report?
23. Review ***Figure 12-4*** on page 305, which shows global wind systems, then note the relative positions of North America and Europe on a world map. Hypothesize why the winds that blow between 30° north and south latitude and the equator are called the trade winds.

Standardized Test Practice

1. Which of the following types of air masses are most likely to form over land near the equator?
   a. mP **c.** cP
   b. mT **d.** cT

2. Which wind system flows between 30° and 60° latitude north and south of the equator in an easterly direction toward the poles?
   a. trade winds **c.** prevailing westerlies
   b. Coriolis effect **d.** polar easterlies

INTERPRETING DATA Use the photo to answer question 3.



3. Meteorologists use many different instruments to gather atmospheric information. What is the instrument shown here called?
   a. a hygrometer **c.** a radiosonde
   b. a ceilometer **d.** radar

4. What does Doppler radar monitor?
   a. the motion of moving raindrops
   b. atmospheric pressure
   c. temperature, air pressure, and humidity
   d. the height of cloud layers

5. The data gathered by Doppler radar can be used to make a type of forecast that relies on numerical data. What is this type of forecast called?
   a. an analog forecast **c.** an isopleth
   b. a digital forecast **d.** ASOS

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