# 19 Air Pressure and Wind

Big idea

## Weather and Climate

**Q:** What determines local and global wind patterns?

VIRGINIA SCIENCE STANDARDS OF LEARNING

ES.1.c, ES.1.d, ES.11.c, ES.12.b, ES.12.c.
**See lessons for details.**

*Wind farms such as this one in Southern California harness energy from wind to generate electricity.*

# INQUIRY
## TRY IT!

### HOW DO GRADIENTS INFLUENCE SPEED?

#### Procedure

**1.** Build a steep ramp using textbooks, wooden blocks, or other items in your classroom. Roll a tennis ball down the ramp.

**2.** Now build another ramp. This ramp should have a slope, or gradient, that is much less steep. Keep the length of the ramp the same as in step 1.

**3.** Roll the tennis ball down the second ramp. Compare the speeds of the ball for both ramps.

#### Think About It

**1.** **Observe** Which ramp setup caused the ball to roll the fastest?

**2.** **Apply Concepts** Like the ramps you built, air pressure also forms gradients. Wind is air that flows down the "slopes" of air pressure gradients. What air pressure conditions do you think would favor faster wind speeds?

# 19.1 Understanding Air Pressure

**ES.11** The student will investigate and understand the origin and evolution of the atmosphere and the interrelationship of geologic processes, biologic processes, and human activities on its composition and dynamics. Key concepts include **c.** atmospheric regulation mechanisms including the effects of density differences and energy transfer.

## Key Questions

***Describe how air pressure is exerted on objects.***

***What happens to the mercury column of a barometer when air pressure changes?***

***What is the ultimate energy source for wind?***

***How does the Coriolis effect influence free-moving objects?***

## Vocabulary

- air pressure
- barometer
- isobars
- pressure gradient
- Coriolis effect
- jet stream

## Reading Strategy

**Identify Main Ideas** Copy the table below. As you read, write the main ideas for each topic.

| Topic | Main Ideas |
|---|---|
| Air Pressure Defined | Air pressure is the weight of air above. It is exerted in all directions. |
| Measuring Air Pressure | a. ___?___ |
| Factors Affecting Wind | b. ___?___ |

**OF THE VARIOUS** elements of weather and climate, changes in air pressure are the least noticeable. When you listen to a weather report, you probably focus on precipitation, temperature, and humidity. Most people don't wonder about air pressure. Although you might not perceive hour-to-hour and day-to-day variations in air pressure, they are very important in producing changes in our weather. For example, variations in air pressure from place to place can generate winds such as those shown in **Figure 1.** The winds, in turn, bring change in temperature and humidity. Air pressure is one of the basic weather elements and is an important factor in weather forecasting. Air pressure is closely tied to the other elements of weather in a cause-and-effect relationship.

## Air Pressure

**Air pressure** is simply the pressure exerted by the weight of air above. Average air pressure at sea level is about 1 kilogram per square centimeter. This pressure is roughly the same pressure that is produced by a column of water 10 meters in height. You can calculate that the air pressure exerted on the top of a 50-centimeter-by-100-centimeter school desk exceeds 5000 kilograms, which is about the mass of a 50-passenger school bus. Why doesn't the desk collapse under the weight of the air above it? **Air pressure is exerted in all directions—down, up, and sideways. The air pressure pushing down on an object balances the air pressure pushing up on the object.**

**Reading Checkpoint** *What is average air pressure at sea level?*

**FIGURE 1 Winds** These palm trees in Corpus Christi, Texas, are being pounded by hurricane-force winds.

Imagine a tall aquarium that has the same dimensions as the desktop in the previous example. When this aquarium is filled to a height of 10 meters, the water pressure at the bottom equals 1 atmosphere, or 1 kilogram per square centimeter. Now imagine what will happen if this aquarium is placed on top of a student desk so that all the force is directed downward. The desk collapses because the pressure downward is greater than the pressure exerted in the other directions. When the desk is placed inside the aquarium and allowed to sink to the bottom, however, the desk does not collapse in the water because the water pressure is exerted in all directions, not just downward. The desk, like your body, can withstand the pressure of 1 atmosphere.

## Measuring Air Pressure

When meteorologists measure atmospheric pressure, they use a unit called the millibar (mb). Standard sea-level pressure is 1013.2 millibars. You might have heard the phrase "inches of mercury," which is used by the media to describe atmospheric pressure. In 1643, Torricelli, a student of the famous Italian scientist Galileo, invented the mercury barometer. A **barometer** is a device used for measuring air pressure (*bar* = pressure, *metron* = measuring instrument).

Torricelli correctly described the atmosphere as a vast ocean of air that exerts pressure on us and all objects around us. To measure this force, he filled a glass tube, closed at one end, with mercury. He then put the tube upside down into a dish of mercury, as shown in **Figure 2A.** The mercury flowed out of the tube until the weight of the column was balanced by the pressure that the atmosphere exerted on the surface of the mercury in the dish. In other words, the weight of the mercury in the column (tube) equaled the weight of the same size column of air that extended from the ground to the top of the atmosphere.

**When air pressure increases, the mercury in the barometric tube rises. When air pressure decreases, so does the height of the mercury column.** With some improvements, the mercury barometer is still the standard instrument used today for measuring air pressure.

The need for a smaller and more portable instrument for measuring air pressure led to the development of the *aneroid barometer.* The aneroid barometer uses a metal chamber with some air removed. This partially emptied chamber is extremely sensitive to variations in air pressure. It changes shape and compresses as the air pressure increases, and it expands as the pressure decreases. One advantage of the aneroid barometer is that it can be easily connected to a recording device, as shown in **Figure 2B.** The device, called a barograph, provides a continuous record of pressure changes over time.

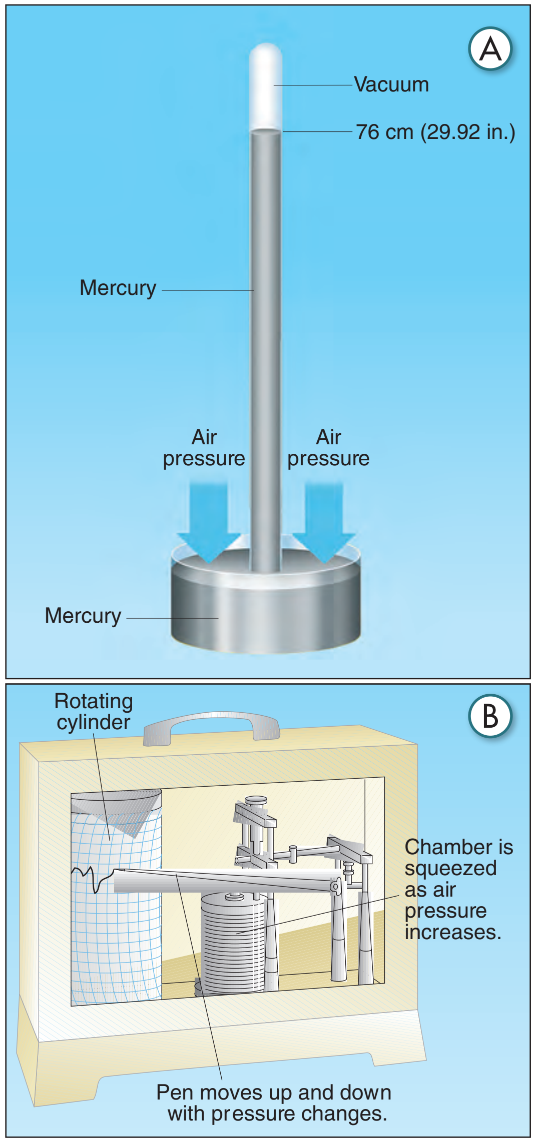



**FIGURE 2**
**Two Types of Barometers**
**A Mercury Barometer** Standard atmospheric pressure at sea level is 29.92 inches of mercury.
**B Aneroid Barometer** The recording mechanism provides a continuous record of pressure changes over time.
**Apply Concepts** ***How would a continuous record help weather forecasters?***

**ACTIVE ART**

**For:** Measuring Air Pressure Activity
**Visit:** PearsonSchool.com
**Web Code:** czp-6191

## INQUIRY APPLY IT!

**Q:** ***What is the lowest barometric pressure ever recorded at Earth's surface?***

**A:** All of the lowest recorded barometric pressures have been associated with strong hurricanes. The record for the United States is 888 millibars (26.20 inches) measured during Hurricane Gilbert in September 1988. The world's record, 870 millibars (25.70 inches), occurred during Typhoon Tip, a Pacific hurricane, in October 1979. Although tornadoes undoubtedly have produced even lower pressures, they have not been accurately measured.

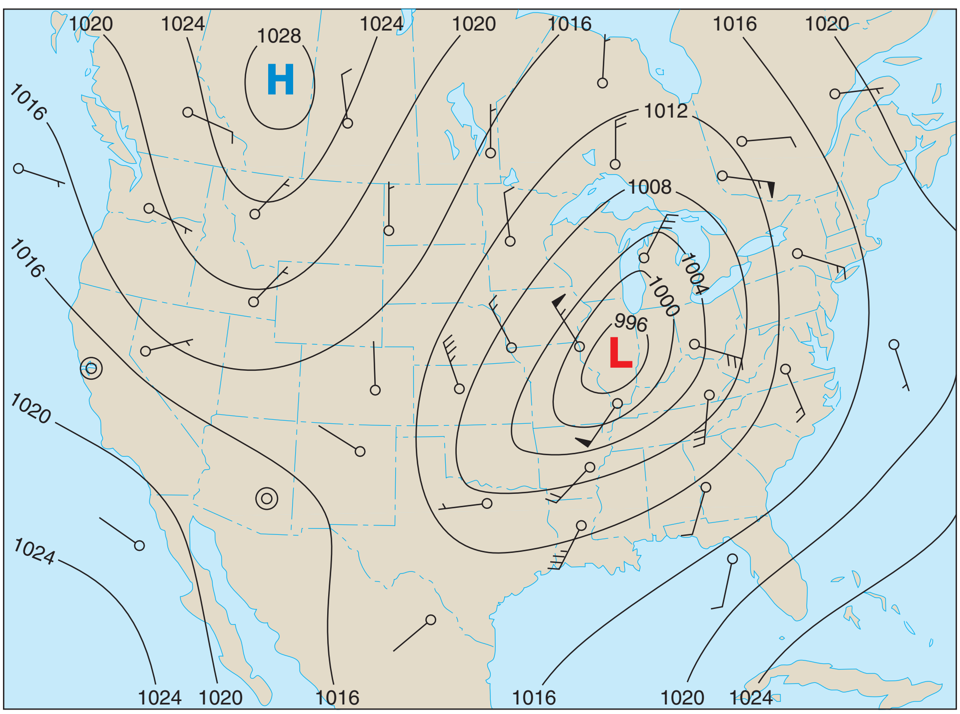
# Factors Affecting Wind

As important as vertical motion is, far more air moves horizontally, the phenomenon we call wind. What causes wind? **Wind is the result of horizontal differences in air pressure. Air flows from areas of higher pressure to areas of lower pressure.** You may have experienced this flow of air when opening a vacuum-packed can of nuts or tennis balls. The noise you hear is caused by air rushing from the higher pressure outside the can to the lower pressure inside. Wind is nature's way of balancing such inequalities in air pressure. **The unequal heating of Earth's surface generates pressure differences. Solar radiation is the ultimate energy source for most wind.**

If Earth did not rotate, and if there were no friction between moving air and Earth's surface, air would flow in a straight line from areas of higher pressure to areas of lower pressure. But both factors do exist, so the flow of air is not that simple. **Th ee factors combine to control wind: pressure differences, the Coriolis effect, and friction.**

**Pressure Differences** Wind is created by differences in pressure—the greater these differences are, the greater the wind speed is. Over Earth's surface, variations in air pressure are determined from barometric readings taken at hundreds of weather stations. These pressure data are shown on a weather map, such as the one in **Figure 3,** using isobars. **Isobars** are lines on a map that connect places of equal air pressure. The spacing of isobars indicates the amount of pressure change occurring over a given distance. These pressure changes are expressed as the **pressure gradient.**

**FIGURE 3 Isobars** Isobars, with numbers indicating air pressure in millibars, connect places having equal air pressure. The lines connected to the circles indicate the speed and direction of wind. Wind blows toward the circles. **Interpret Visuals** ***Use the data on this map to explain which pressure cell, high or low, has the fastest wind speeds.***




| Symbol for Wind Speed | Miles per hour |
|---|---|
| ◎ | Calm |
| | 1–2 |
| | 3–8 |
| | 9–14 |
| | 15–20 |
| | 21–25 |
| | 26–31 |
| | 32–37 |
| | 38–43 |
| | 44–49 |
| | 50–54 |
| | 55–60 |
| | 61–66 |
| | 67–71 |
| | 72–77 |
| | 78–83 |
| | 84–89 |
| | 119–123 |

A steep pressure gradient, similar to a ball rolling down a steep hill, causes greater acceleration of a parcel of air. A less steep pressure gradient causes a slower acceleration. **Closely spaced isobars indicate a steep pressure gradient and high winds. Widely spaced isobars indicate a weak pressure gradient and light winds.** The pressure gradient is the driving force of wind. The pressure gradient has both magnitude and direction. Its magnitude is reflected in the spacing of isobars. The direction of force is always from areas of higher pressure to areas of lower pressure and at right angles to the isobars. Friction affects wind speed and direction. The Coriolis effect affects wind direction only.

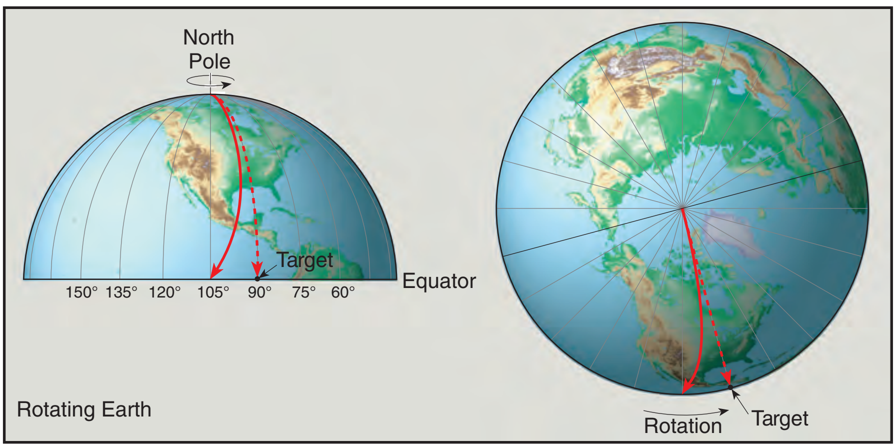
**Coriolis Effect** The weather map in **Figure 3** shows typical air movements associated with high- and low-pressure systems. Air moves out of the regions of higher pressure and into the regions of lower pressure. However, the wind does not cross the isobars at right angles as you would expect based solely on the pressure gradient. This change in movement results from Earth's rotation and has been named the **Coriolis effect**.

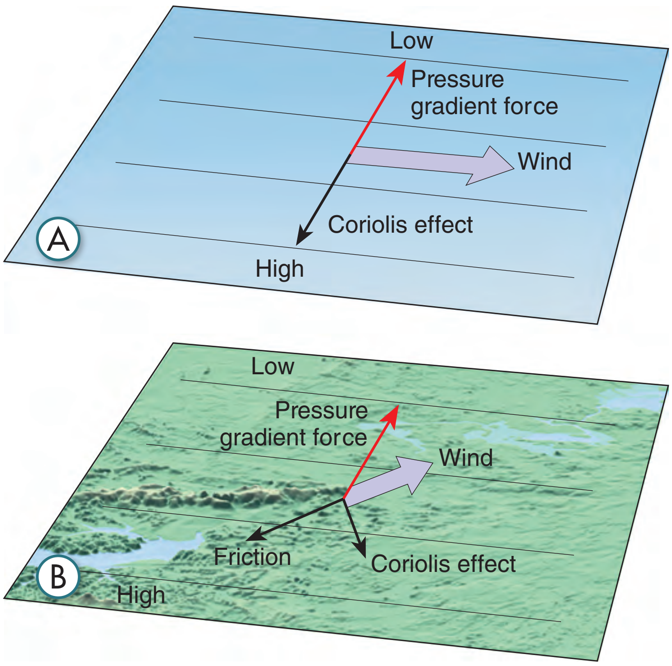
**The Coriolis effect describes how Earth's rotation affects moving objects. All free-moving objects or fluids, including the wind, are deflected to the right of their path of motion in the Northern Hemisphere. In the Southern Hemisphere, they are deflected to the left.** The reason for this deflection is illustrated in **Figure 4.** Imagine the path of a rocket launched from the North Pole toward a target located on the equator. The true path of this rocket is straight, and the path would appear to be straight to someone out in space looking down at Earth. However, to someone standing on Earth, it would look as if the rocket swerved off  ts path and landed 15 degrees to the west of its target.

This slight change in direction happens because Earth would have rotated 15 degrees to the east under the rocket during a one-hour fli  ht. The counterclockwise rotation of the Northern Hemisphere causes path deflection to the right. In the Southern Hemisphere, the clockwise rotation produces a similar deflection, but to the left   f the path of motion.

The apparent shift in    ind direction is attributed to the Coriolis effect. This deflection: 1) is always directed at right angles to the direction of airflow; 2) affects only wind direction and not wind speed; 3) is affected by wind speed—the stronger the wind, the greater the deflection; and 4) is strongest at the poles and weakens toward the equator, becoming nonexistent at the equator.

**FIGURE 4 The Coriolis Effect**
Because Earth rotates 15° each hour, the rocket's path is curved and veers to the right from the North Pole to the equator.
**Calculate** ***How many degrees does Earth rotate in one day?***






**VISUAL SUMMARY**

EFFECT OF FRICTION

**FIGURE 5** **A** Upper-level wind flow is balanced by the Coriolis effect and pressure gradient forces. **B** Friction causes surface winds to cross isobars and move toward lower-pressure areas.

**Friction** The effect of friction on wind is important only within one kilometer of Earth's surface. Friction acts to slow air movement, which changes wind direction. To illustrate friction's effect on wind direction, fi st think about a situation in which friction does not play a role in wind direction.

When air is above the friction layer, the pressure gradient causes air to move across the isobars. As soon as air starts to move, the Coriolis effect acts at right angles to this motion. The faster the wind speed is, the greater the deflection. The pressure gradient and Coriolis effect balance in high-altitude air, and wind generally flows parallel to isobars, as shown in **Figure 5A.** The most prominent features of airflow high above the friction layer are the jet streams. **Jet streams** are fast-moving rivers of air near the tropopause, which can be as high as 16 kilometers over the equator and 6 kilometers over the geographic poles. Jet streams travel between 120 and 240 kilometers per hour in a west-to-east direction. One jet stream is situated over the polar front, which is the zone separating cool polar air from warm subtropical air. Jet streams were fi st encountered by high-flying bombers during World War II.

For air close to Earth's surface, the roughness of the terrain determines the angle of airflow across the isobars. Over the smooth ocean surface, friction is low, and the angle of airflow is small. Over rugged terrain, where the friction is higher, winds move more slowly and cross the isobars at greater angles. As shown in **Figure 5B,** friction causes wind to flow across the isobars at angles as great as 45 degrees. Slower wind speeds caused by friction decrease the Coriolis effect.

# 19.1 Assessment

## Review Key Concepts

**1.** Why don't objects such as a table collapse under the weight of the air above them?

**2.** Suppose the height of a column in a mercury barometer is decreasing. What is happening?

**3.** What is the ultimate energy source for most wind?

**4.** How does the Coriolis effect influence the motion of free-moving objects?

**5.** Why do jet streams flow parallel to isobars?

## Think Critically

**6.** **Interpret Visuals** Study Figures 5A and 5B. Why are the wind arrows drawn to different lengths in these figures?

**CONNECTING CONCEPTS**

**7.** **Apply Concepts** Review Lesson 17.3 Temperature Controls. Describe examples of unequal heating of Earth's atmosphere that could lead to air pressure differences that would ultimately influence wind.

# 19.2 Pressure Centers and Winds

**ES.11** The student will investigate and understand the origin and evolution of the atmosphere and the interrelationship of geologic processes, biologic processes, and human activities on its composition and dynamics. Key concepts include **c.** atmospheric regulation mechanisms including the effects of density differences and energy transfer. **ES.12** The student will investigate and understand that energy transfer between the sun and Earth and its atmosphere drives weather and climate on Earth. Key concepts include **b.** prediction of weather patterns; and **c.** severe weather occurrences, such as tornadoes, hurricanes, and major storms.

**PRESSURE CENTERS** are among the most common features on any weather map. By knowing just a few basic facts about centers of high and low pressure, you can increase your understanding of present and forthcoming weather. You can make some weather generalizations based on pressure centers. For example, centers of low pressure are frequently associated with cloudy conditions and precipitation. By contrast, clear skies and fair weather may be expected when an area is under the influence of high pressure, as shown in **Figure 6.**

## Highs and Lows

Lows, or **cyclones** (*kyklon* = moving in a circle) are centers of low pressure. Highs, or **anticyclones,** are centers of high pressure. **In cyclones, the pressure decreases from the outer isobars toward the center. In anticyclones, just the opposite is the case—the values of the isobars increase from the outside toward the center.**

**FIGURE 6 High Pressure Weather** These people in New York's Central Park are enjoying weather associated with a high-pressure center.

### Key Questions

- ***Describe how winds blow around pressure centers in the Northern and Southern Hemispheres.***
- ***What are the air pressure patterns within cyclones and anticyclones?***
- ***How does friction control net flow of air around a cyclone and an anticylone?***
- ***How does the atmosphere attempt to balance the unequal heating of Earth's surface?***

### Vocabulary

- cyclone
- anticyclone
- trade winds
- westerlies
- polar easterlies
- polar front
- monsoon

### Reading Strategy

**Compare and Contrast** Copy the table below. As you read about pressure centers and winds, fill in the table indicating to which hemisphere the concept applies. Use N for Northern Hemisphere, S for Southern Hemisphere, and B for both.

| | |
|---|---|
| Cyclones rotate counterclockwise. | a. ? |
| Net flow of air is inward around a cyclone. | b. ? |
| Anticyclones rotate counterclockwise. | c. ? |

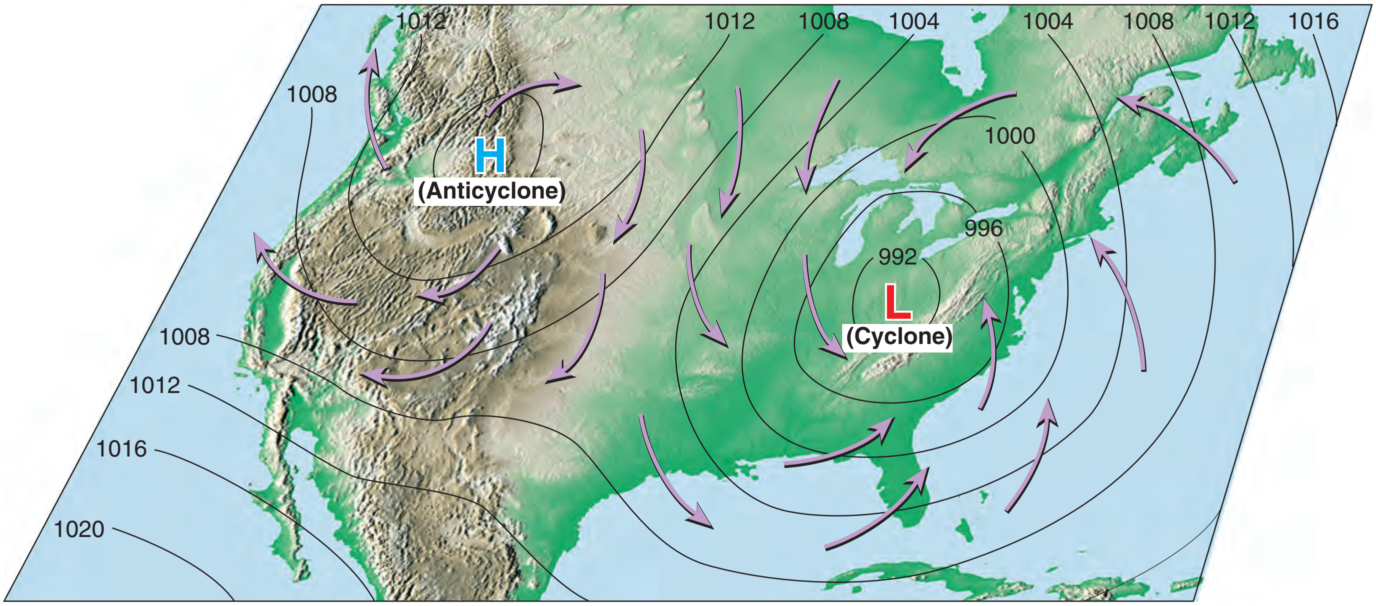



**FIGURE 7 Cyclonic and Anticyclonic Winds** This map shows cyclonic and anticyclonic winds in the Northern Hemisphere. The purple arrows show that winds blow into and counterclockwise around a low. Around a high, winds blow outward and clockwise. Pressure is measured in millibars.

**Cyclonic and Anticyclonic Winds** You learned that the two most significant factors that affect wind are the pressure gradient and the Coriolis effect. Winds move from higher pressure to lower pressure and are deflected to the right or left y Earth's rotation. **When the pressure gradient and the Coriolis effect are applied to pressure centers in the Northern Hemisphere, winds blow counterclockwise around a low. Around a high, winds blow clockwise.** Notice the wind directions in **Figure 7.**

In the Southern Hemisphere, the Coriolis effect deflects the winds to the left. Therefore, winds around a low move clockwise. Winds around a high move counterclockwise. **In both hemispheres, differences in air pressure cause a net flow of air inward around a cyclone and a net flow of air outward around an anticyclone.**

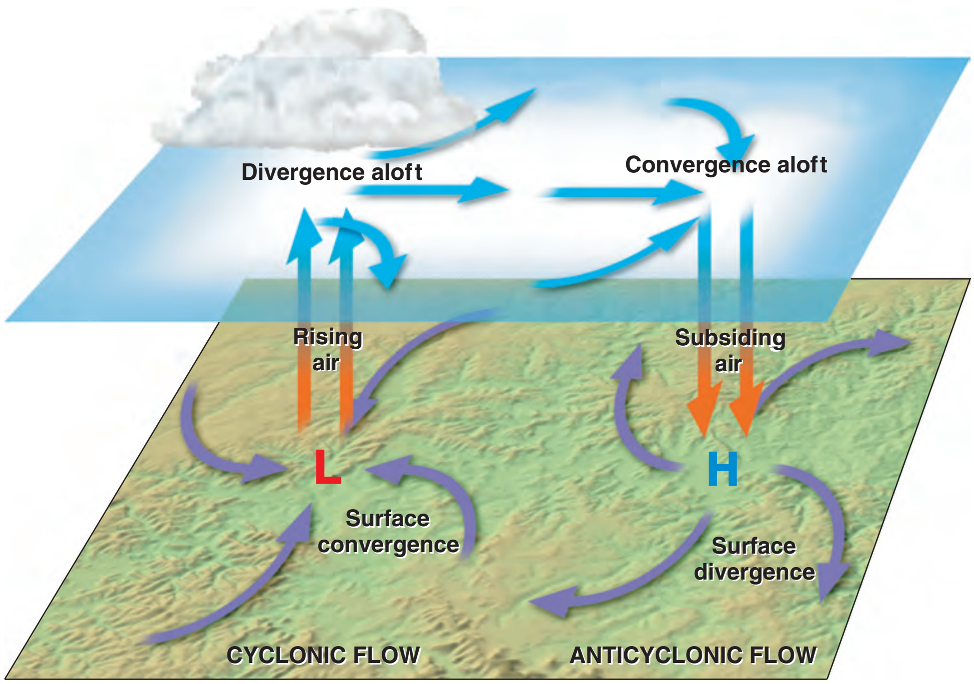
**Weather and Air Pressure** Rising air is associated with cloud formation and precipitation, whereas sinking air produces clear skies. Imagine a surface low-pressure system where the air is spiraling inward. Here the net inward movement of air causes the area occupied by the air mass to shrink—a process called *horizontal convergence.* Whenever air converges (or comes together) horizontally, it must increase in height to allow for the decreased area it now occupies. This increase in height produces a taller and heavier air column. A surface low can exist only as long as the column of air above it exerts less pressure than does the air in surrounding regions. This seems to be a paradox—a low-pressure center causes a net accumulation of air, which increases its pressure.

**Reading Checkpoint** *What type of weather is associated with rising air?*

VISUAL SUMMARY

## AIRFLOW PATTERNS, SURFACE AND ALOFT

**FIGURE 8** Air spreads out, or diverges, above surface cyclones, and comes together, or converges, above surface anticyclones. The red arrows represent warmer air, and the blue arrows represent cooler air.
**Apply Concepts** *Why is fair weather associated with a high?*




In order for a surface low to exist for very long, converging air at the surface must be balanced by outflows aloft. For example, surface convergence could be maintained if divergence, or the spreading out of air, occurred above the low at a rate equal to the inflow below. **Figure 8** shows the relationship between surface convergence (inflow) and divergence (outflow) needed to maintain a low-pressure center. Surface convergence around a cyclone causes a net upward movement. Because rising air often results in cloud formation and precipitation, a low-pressure center is generally related to unstable conditions and stormy weather.

Like cyclones, anticyclones also must be maintained from above. Outflow near the surface is accompanied by convergence in the air above and a general sinking of the air column, as shown in Figure 8.

**Weather Forecasting** Now you can see why weather reports emphasize the locations and possible paths of cyclones and anticyclones. The villain in these reports is always the low-pressure center, which can produce bad weather in any season. Lows move in roughly a west-to-east direction across the contiguous United States, and they require a few days, and sometimes more than a week, for the journey. Their paths can be somewhat unpredictable, making accurate estimation of their movement difficult. Because surface conditions are linked to the conditions of the air above, it is important to understand total atmospheric circulation.

PLANET DIARY

For an activity on **Weather Forecasting**, visit PlanetDiary.com/HSES.

## Global Winds

The underlying cause of wind is the unequal heating of Earth's surface. In tropical regions, more solar radiation is received than is radiated back to space. In regions near the poles the opposite is true—less solar energy is received than is lost. **The atmosphere balances these differences by acting as a giant heat-transfer system. Th s system moves warm air toward high latitudes and cool air toward the equator.** On a smaller scale, but for the same reason, ocean currents also contribute to this global heat transfer. Global circulation is very complex, but you can begin to understand it by fi st thinking about circulation that would occur on a non-rotating Earth.

**Reading Checkpoint** *How does the atmosphere balance the unequal heating of Earth's surface?*

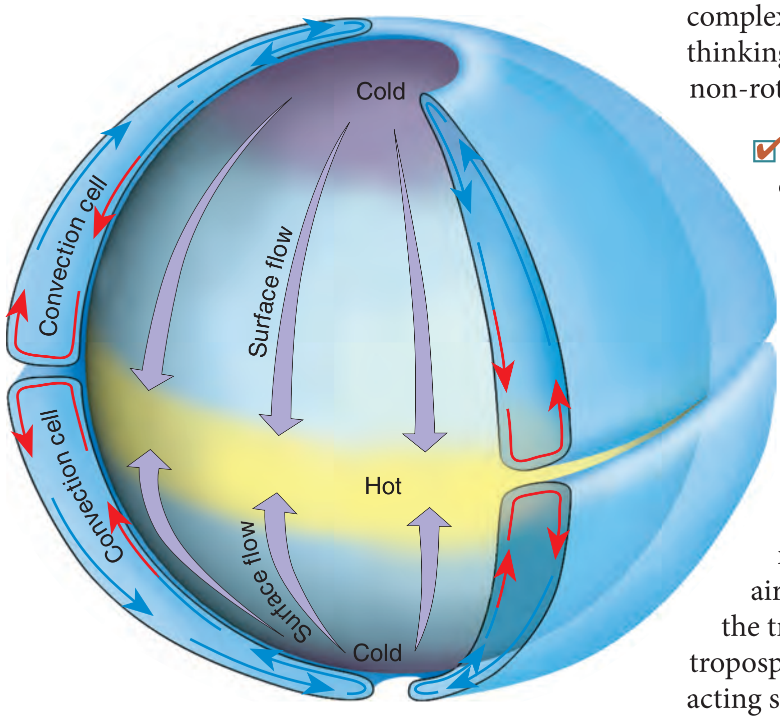



**FIGURE 9 Circulation on a Nonrotating Earth**
A simple convection system is produced by unequal heating of the atmosphere. Here, and in other illustrations, the red arrows represent warmer air and the blue arrows represent cooler air.
**Relate Cause and Effect** ***Why would air sink after reaching the poles?***

**Nonrotating Earth Model** On a hypothetical nonrotating planet with a smooth surface of either all land or all water, two large, thermally produced, convection cells would form, as shown in **Figure 9.** In a *convection cell,* air circulates because warmer, less dense air rises above cooler, denser air. The heated air at the equator would rise until it reached the tropopause—the boundary between the troposphere and the stratosphere. The tropopause, acting similar to a lid, would deflect this air toward the poles. Eventually, the upper-level airflow would reach the poles, sink, spread out in all directions at the surface, and move back toward the equator. Once at the equator, it would be reheated and begin its journey over again. This hypothetical circulation system has upper-level air flowing toward the pole and surface air flowing toward the equator.

**Rotating Earth Model** If the effect of rotation were added to the global circulation model, the two-cell convection system would break down into smaller cells. **Figure 10** illustrates the three pairs of cells that carry on the task of redistributing heat on Earth—Hadley cells, Ferrel cells, and polar cells. The polar cells and tropical Hadley cells retain the characteristics of the thermally generated convection described earlier. The nature of circulation at the middle latitudes, however, is more complex.

Near the equator, rising air produces a pressure zone known as the equatorial low—a region characterized by abundant precipitation. As shown in Figure 10, the upper-level flow from the equatorial low reaches 20 to 30 degrees, north or south latitude, and then sinks back toward the surface. This sinking of air and its associated heating due to compression produce hot, arid conditions. The center of this zone of sinking dry air is the subtropical high, which encircles the globe near 30 degrees north and south latitude. The great deserts of Australia, Arabia, and the Sahara in North Africa exist because of the stable dry conditions associated with the subtropical highs.

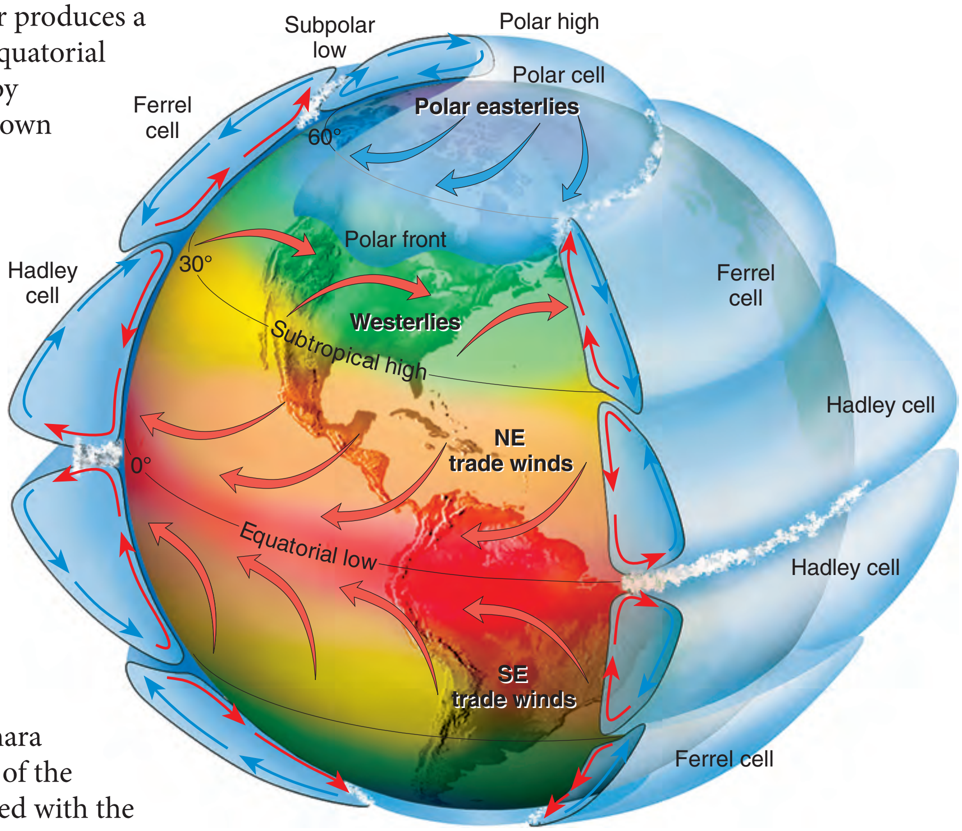



**FIGURE 10 Circulation on a Rotating Earth** This model of global air circulation proposes three pairs of cells.
**Interpret Visuals** *Describe the patterns of air circulation at the equatorial and subpolar lows.*

At the surface, airflow moves outward from the center of the subtropical high. Some of the air travels toward the equator and is deflected by the Coriolis effect, producing the trade winds. **Trade winds** are two belts of winds that blow almost constantly from easterly directions. The trade winds are located between the subtropical highs and the equator. The remainder of the air travels toward the poles and is deflected, generating the prevailing **westerlies** of the middle latitudes. The westerlies make up the dominant west-to-east motion of the atmosphere that characterizes the regions on the poleward side of the subtropical highs. As the westerlies move toward the poles, they encounter the cool polar easterlies in the region of the subpolar low. The **polar easterlies** are winds that blow from the polar high toward the subpolar low. These winds are not constant winds like the trade winds. In the polar region, cold polar air sinks and spreads toward the equator. The interaction of these warm and cool air masses produces the stormy belt in the middle latitudes known as the **polar front.**

This simplified global circulation is dominated by four pressure zones. The subtropical and polar highs are areas of dry subsiding (sinking) air that flows outward at the surface, producing the prevailing winds. The low-pressure zones of the equatorial and subpolar regions are associated with inward and upward airflow accompanied by clouds and precipitation.

**Reading Checkpoint** *What is the polar front?*

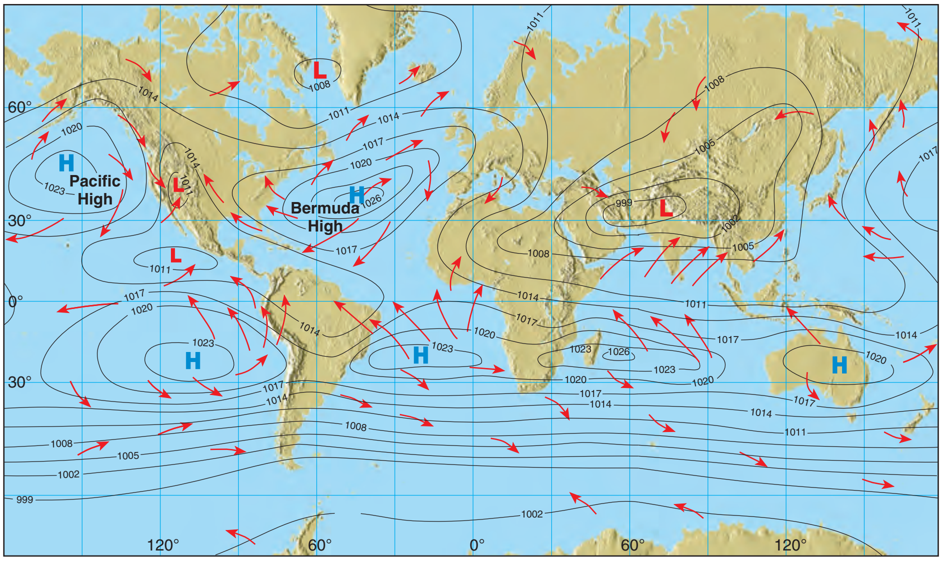



**FIGURE 11 Average Surface Pressure and Global Circulation, July** In July, low-pressure cells develop over the continents in the Northern Hemisphere.

## Influence of Continents

Where landmasses break up the ocean surface, large seasonal temperature differences disrupt the global pattern of pressure zones in the atmosphere. Large landmasses, particularly in the Northern Hemisphere, become cold in the winter when a seasonal high-pressure system develops. From this high-pressure system, surface airfl w is directed off he land. In the summer, landmasses are heated and develop low-pressure cells, which permit air to fl w onto the land as shown in **Figure 11.** These seasonal changes in wind direction are known as the **monsoons.** During warm months, areas such as India experience a fl w of warm, water-laden air from the Indian Ocean, which produces the rainy summer monsoon. The winter monsoon is dominated by dry continental air. A similar situation exists to a lesser extent during summer over North America. Rising, unstable air along the western side of the Bermuda High brings rain to the East Coast. At the same time, thunderstorms occur in the Southwest as moist air streams into the region from the Gulf of Mexico and the Gulf of California.

# 19.2 Assessment

## Review Key Concepts

1. Describe how winds blow around pressure centers in the Northern Hemisphere.
2. Compare the air pressure for a cyclone with that for an anticyclone.
3. How do differences in air pressure control the net flow of air around a cyclone and an anticyclone?
4. Describe how the atmosphere balances the unequal heating of Earth's surface.
5. What is the only truly continuous pressure belt? Why is it continuous?
6. In general, what type of weather can you expect if a low-pressure system is moving into your area?

## Think Critically

7. **Identify Cause and Effect** What must happen in the air above for divergence at the surface to be maintained? What type of pressure center accompanies surface divergence?

**MATH PRACTICE**

8. **Interpret Maps** Examine Figure 7. What is the approximate range of barometric pressure indicated by the isobars on the map? What is the pressure interval between adjacent isobars?

# 19.3 Regional Wind Systems

**ES.11** The student will investigate and understand the origin and evolution of the atmosphere and the interrelationship of geologic processes, biologic processes, and human activities on its composition and dynamics. Key concepts include **c.** atmospheric regulation mechanisms including the effects of density differences and energy transfer. **ES.12** The student will investigate and understand that energy transfer between the sun and Earth and its atmosphere drives weather and climate on Earth. Key concepts include **b.** prediction of weather patterns.

**CIRCULATION IN THE** middle latitudes is complex and does not fit the convection system described for the tropics. Between about 30 and 60 degrees latitude, the general west-to-east flow, known as the *westerlies,* is interrupted by migrating cyclones and anticyclones. In the Northern Hemisphere, these pressure cells move from west to east around the globe.

## Local Winds

Small-scale winds produced by a locally generated pressure gradient are known as *local winds.* **The local winds are caused either by topographic effects or by variations in surface composition—land and water—in the immediate area.**

**Land and Sea Breezes** In coastal areas during the warm summer months, the land surface is heated more intensely during the daylight hours than an adjacent body of water is heated. As a result, the air above the land surface heats, expands, and rises, creating an area of lower pressure. As shown in **Figure 12,** a *sea breeze* then develops because cooler air over the water at higher pressure moves toward the warmer land and low pressure air. The breeze starts developing shortly before noon and generally reaches its greatest intensity during the mid- to late afternoon. These relatively cool winds can be a moderating influence on afternoon temperatures in coastal areas.

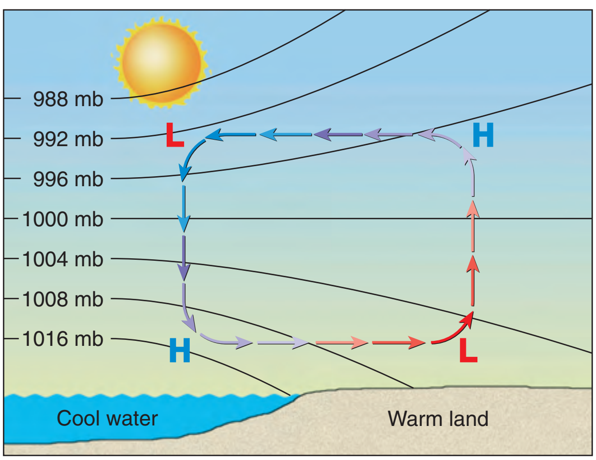



**FIGURE 12 Sea Breeze** During daylight hours, the air above land heats and rises, creating a local zone of lower air pressure. Cooler, denser air over the water moves onto the land, generating a sea breeze. Pressure is measured in millibars (mb).

### Key Questions

***What causes local winds?***

***Describe the general movement of weather in the United States.***

***What happens when unusually strong, warm ocean currents flow along the coasts of Ecuador and Peru?***

***How is a La Niña event triggered?***

### Vocabulary

- prevailing wind
- anemometer
- El Niño
- La Niña

### Reading Strategy

**Preview** Copy the table below. Before you read, use Figure 18 to locate examples of the driest and wettest regions on Earth. After you read, identify the dominant wind system for each location.

| Precipitation | Location | Dominant Wind System |
|---|---|---|
| Extremely low | a. ? | b. ? |
| Extremely high | c. ? | d. ? |

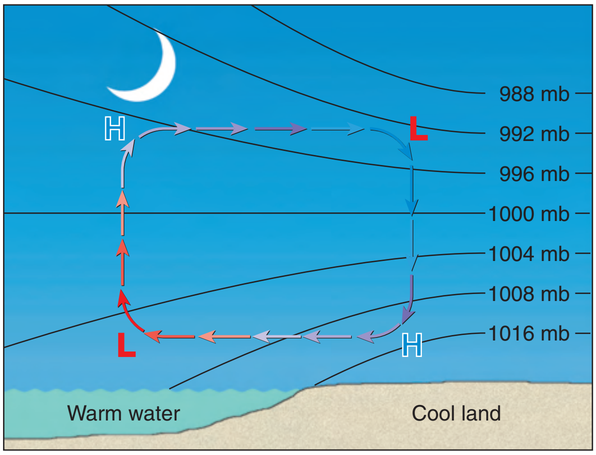



**FIGURE 13 Land Breeze** At night, the land cools more rapidly than the sea, generating an offshore flow called a land breeze.

**Infer** ***How would the isobar lines be oriented if there were no air pressure change across the land–water boundary?***

At night, the reverse may take place. The land cools more rapidly than the sea, and a *land breeze* develops, as shown in **Figure 13.** The cooler air at higher pressures over the land moves to the sea, where the air is warmer and at lower pressures.

Small-scale sea breezes also can develop along the shores of large lakes. People who live in a city near the Great Lakes, such as Chicago, recognize this lake effect, especially in the summer. They are reminded daily by weather reports of the cooler temperatures near the lake as compared to warmer outlying areas.

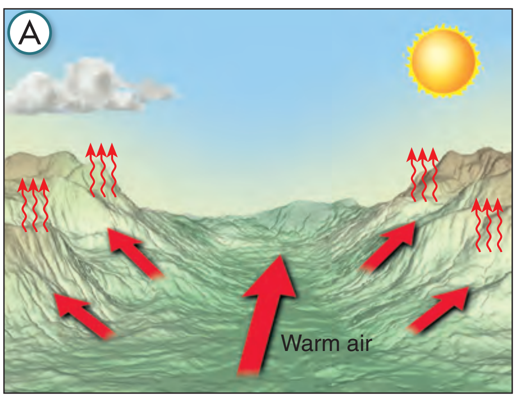
**Valley and Mountain Breezes** A daily wind similar to land and sea breezes occurs in many mountainous regions. During daylight hours, the air along the slopes of the mountains is heated more intensely than the air at the same elevation over the valley floor. Because this warmer air on the mountain slopes is less dense, it glides up along the slope and generates a *valley breeze,* as shown in **Figure 14A.** The occurrence of these daytime upslope breezes can often be identified by the cumulus clouds that develop on adjacent mountain peaks.

After sunset, the pattern may reverse. The rapid cooling of the air along the mountain slopes produces a layer of cooler air next to the ground. Because cool air is denser than warm air, it moves downslope into the valley. Such a movement of air, illustrated in **Figure 14B,** is called a *mountain breeze.* In the Grand Canyon at night, the sound of cold air rushing down the sides of the canyon can be louder than the sound of the Colorado River below.

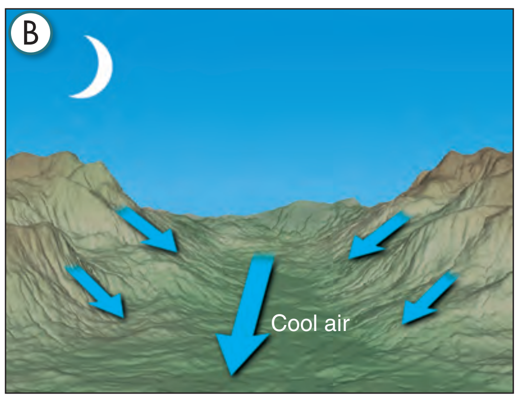
The same type of cool air drainage can occur in places that have very modest slopes. The result is that the coldest pockets of air are usually found in the lowest spots. Like many other winds, mountain and valley breezes have seasonal preferences. Although valley breezes are most common during the warm season when solar heating is most intense, mountain breezes tend to be more dominant in the cold season.

☑ **Reading Checkpoint** *What type of local wind can form in the Grand Canyon at night?*

**FIGURE 14 Mountain and Valley Breezes**




**A Valley Breeze** Heating during the day generates warm air that rises from the valley floor.




**B Mountain Breeze** After sunset, cooling of the air near mountain slopes can result in cool air moving into the valley.

## How Wind Is Measured

Two basic wind measurements—direction and speed—are particularly important to the weather observer. Winds are always labeled by the direction from which they blow. A north wind blows from the north toward the south. An east wind blows from the east toward the west. The instrument most commonly used to determine wind direction is the wind vane, shown in **Figure 15.** Wind vanes are commonly located on buildings, and they always point into the wind. The wind direction is often shown on a dial connected to the wind vane. The dial indicates wind direction, either by points of the compass—N, NE, E, SE, etc.—or by a scale of 0° to 360°. On the degree scale, 0° or 360° is north, 90° is east, 180° is south, and 270° is west.

**Reading Checkpoint** *Toward which direction does a SE wind blow?*

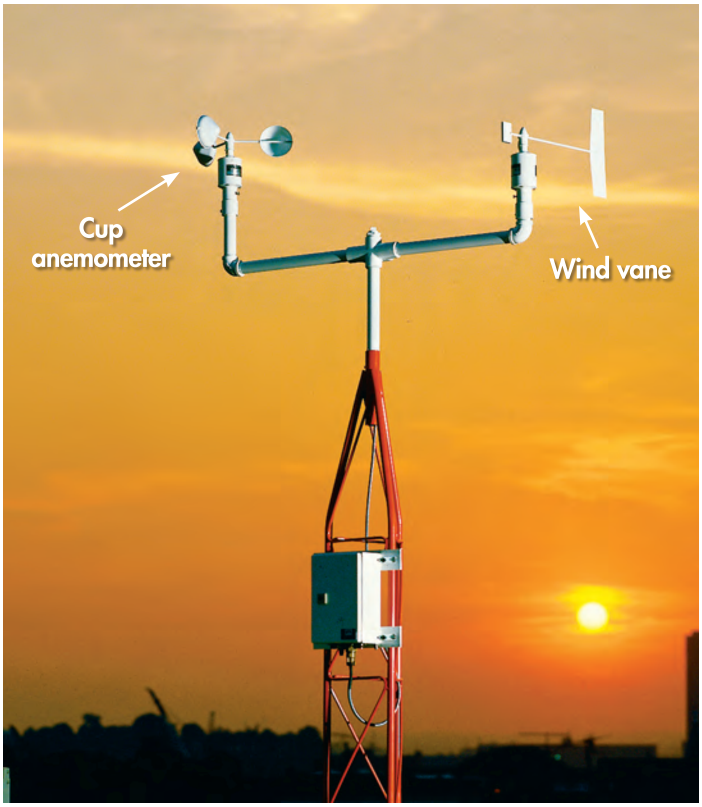



**FIGURE 15 Wind Vane and Cup Anemometer**
**Interpret Visuals** *How does the position of a wind vane tell you which direction the wind is blowing?*

### Wind Direction

When the wind consistently blows more often from one direction than from any other, it is called a **prevailing wind.** Recall the prevailing westerlies that dominate circulation in the middle latitudes. **In the United States, the westerlies consistently move weather from west to east across the continent.** Within this general eastward flow are cells of high and low pressure with the characteristic clockwise and counterclockwise flows. As a result, the winds associated with the westerlies, as measured at the surface, often vary considerably from day to day and from place to place. In contrast, the direction of airflow associated with the trade winds is much more consistent.

### Wind Speed

The instrument commonly used to measure wind speed is an **anemometer** (*anemo* = wind, *metron* = measuring instrument). One type of anemometer, a cup anemometer, is shown in Figure 15. The wind speed is read from a dial much like the speedometer of an automobile. Places where winds are steady and speeds are relatively high are potential sites for tapping wind energy.

A *wind sock* is a simple device that can be used to determine both wind direction and wind speed. A wind sock is a cone-shaped bag that is open at both ends and is free to change position with shifts in ind direction. The degree to which the sock is inflated is an indication of wind speed. Wind socks are commonly used at small airports and landing strips.

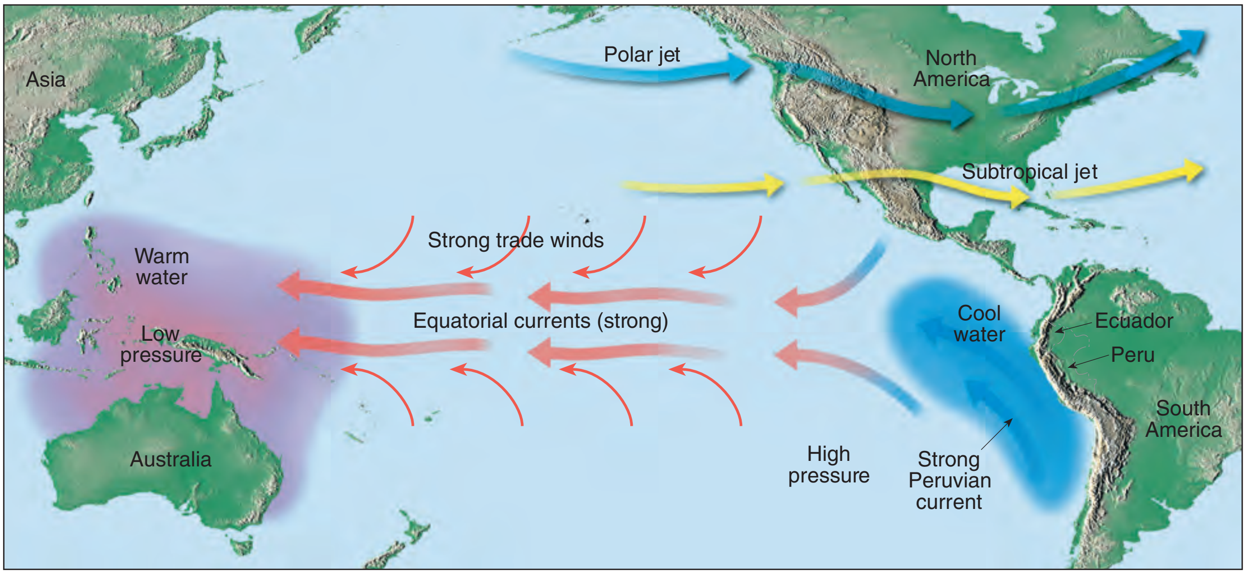



**FIGURE 16 Normal Conditions** Trade winds and strong equatorial ocean currents flow toward the west.

# El Niño and La Niña

Look at **Figure 16.** The cold ocean Peruvian current flows toward the equator along the coasts of Ecuador and Peru. This flow encourages upwelling of cold nutrient-filled waters that support the growth of plankton—a food source for millions of fish, particularly anchovies. Near the end of the year, however, a warm ocean current that flows southward along the coasts of Ecuador and Peru replaces the cold Peruvian current. During the nineteenth century, the local residents named this warm current El Niño ("the child"). Normally, these warm countercurrents last for a few weeks and then give way to the cold Peruvian flow again.

## El Niño

**At irregular intervals of three to seven years, these warm countercurrents become unusually strong and replace normally cold offshore waters with warm equatorial waters.** Scientists use the term **El Niño** for these episodes of ocean warming that affect the eastern tropical Pacific.

The onset of El Niño is marked by abnormal weather patterns that drastically affect the economies of Ecuador and Peru. As shown in **Figure 17,** these unusually strong countercurrents accumulate large quantities of warm water that block the upwelling of colder, nutrient-filled water. As a result, the anchovies starve, devastating the local fishing industry. At the same time, some inland areas that are normally arid receive an abnormal amount of rain. Here, pastures and cotton fields have yields far above the average. These climatic fluctuations have been known for years, but they were originally considered local phenomena. It now is understood that El Niño is part of the global circulation and that it affects the weather at great distances from Peru and Ecuador.

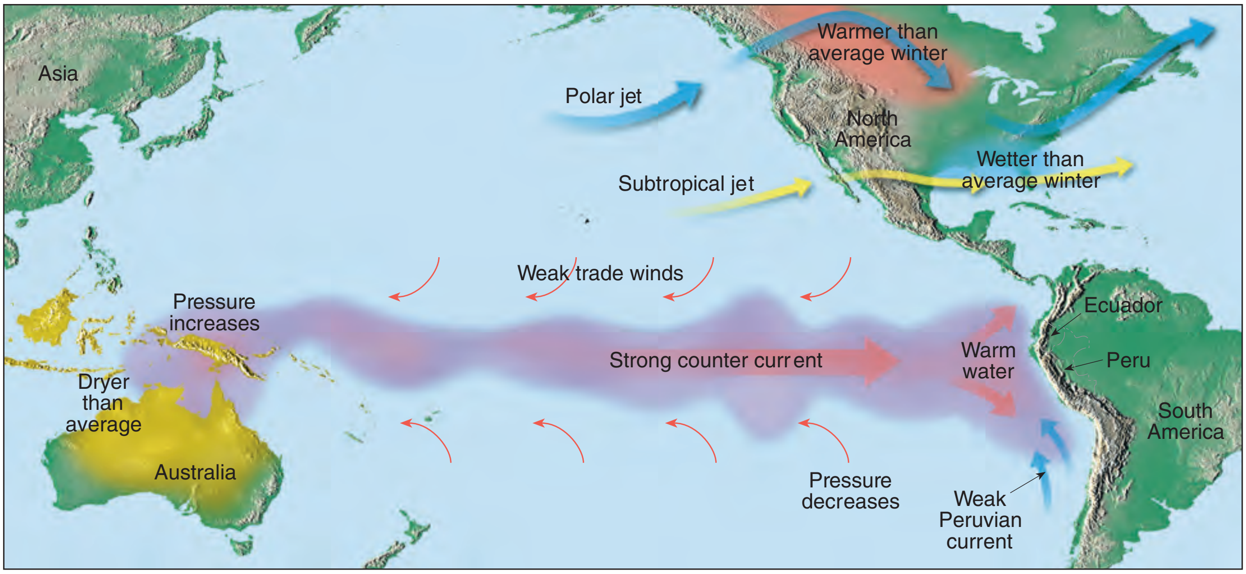



**FIGURE 17 El Niño**
Warm countercurrents cause the reversal of pressure patterns in the western and eastern Pacific.

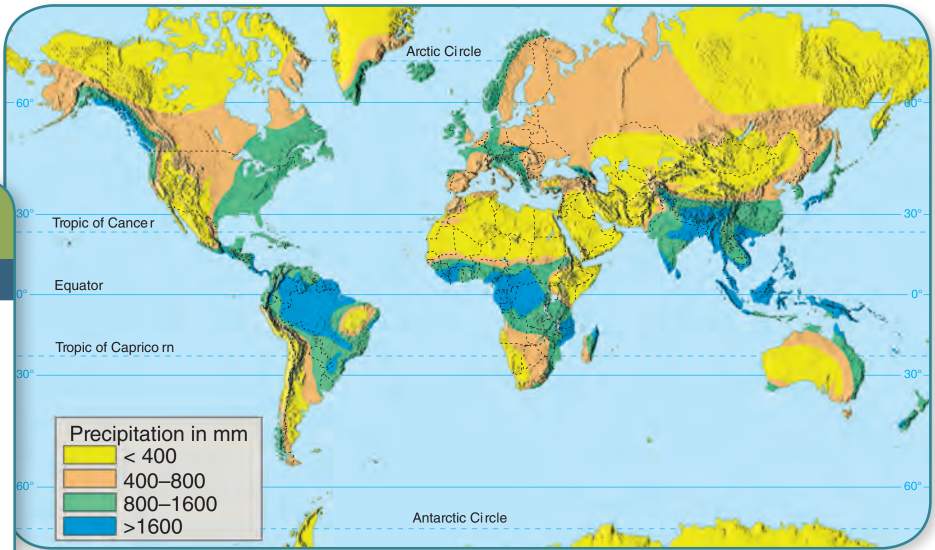
When an El Niño began in the summer of 1997, forecasters predicted that the pool of warm water over the Pacific would displace the paths of both the subtropical and midlatitude jet streams, as shown in Figure 17. The jet streams steer weather systems across North America. As predicted, the subtropical jet stream brought rain to the Gulf Coast. Tampa, Florida, received more than three times its normal winter precipitation. The midlatitude jet stream pumped warm air far north into the continent. As a result, winter temperatures west of the Rocky Mountains were significantly above normal.

**Reading Checkpoint** *What is an El Niño, and what effect does it have on weather?*

**La Niña** The opposite of El Niño is an atmospheric phenomenon known as **La Niña.** Once thought to be the normal conditions that occur between two El Niño events, meteorologists now consider La Niña an important atmospheric phenomenon in its own right. **Researchers have come to recognize that when surface temperatures in the eastern Pacific are colder than average, a La Niña event is triggered that has a distinctive set of weather patterns.** A typical La Niña winter blows colder than normal air over the Pacific Northwest and the northern Great Plains. At the same time, it warms much of the rest of the United States. The Northwest also experiences greater precipitation during this time. During the La Niña winter of 1998–99, a world-record snowfall for one season occurred in Washington State. La Niña can also increase hurricane activity. A recent study concluded that the cost of hurricane damage in the United States is 20 times greater in La Niña years as compared to El Niño years.

The effects of both El Niño and La Niña on world climate are widespread and vary greatly. These phenomena remind us that the air and ocean conditions of the tropical Pacific influence weather almost everywhere.

**FIGURE 18** **Global Precipitation**




**MAP IT! ACTIVITY**

The map in Figure 18 shows average annual precipitation in millimeters. **Interpret Maps** Determine the range of precipitation that dominates Northern Africa.

**Relate Cause and Effect** Which weather pattern influences precipitation in this area?

## Global Distribution of Precipitation

**Figure 18** shows that the tropical region dominated by the equatorial low is the rainiest region on Earth. It includes the rain forests of the Amazon basin in South America and the Congo basin in Africa. In these areas, the warm, humid trade winds converge to yield abundant rainfall throughout the year. In contrast, areas dominated by the subtropical high-pressure cells are regions of extensive deserts. Variables other than pressure and wind complicate the pattern. For example, the interiors of large land masses commonly experience decreased precipitation. However, you can explain a lot about global precipitation if you apply your knowledge of global winds and pressure systems.

## 19.3 Assessment

### Review Key Concepts

**1.** What are local winds, and how are they caused?

**2.** Describe the general movement of weather in the United States.

**3.** What happens when strong, warm countercurrents flow along the coasts of Ecuador and Peru?

**4.** How is a La Niña event recognized?

**5.** What two factors mainly influence global precipitation?

### Think Critically

**6.** **Interpret Visuals** Study Figure 17. How could air pressure changes resulting from El Niño influence weather patterns in this region?

**BIGIDEA** WEATHER AND CLIMATE

**7.** **Compare and Contrast** Write a paragraph comparing the features and effects of El Niño and La Niña. Include specific weather patterns associated with each phenomenon.

EARTH & ITS SYSTEMS

# Tracking El Niño from Space

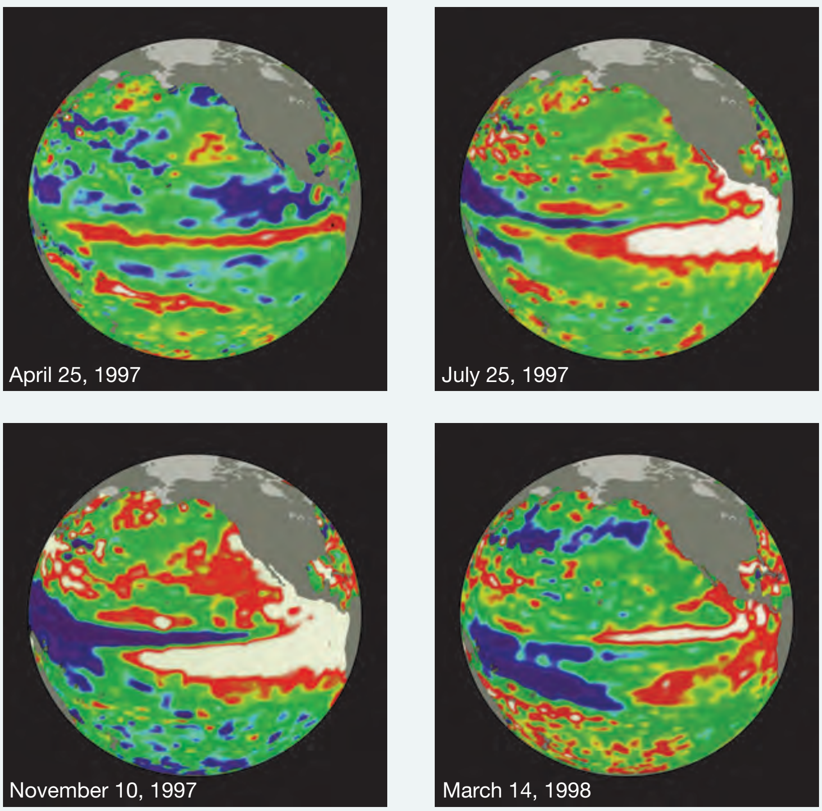
The images in **Figure 19** show the progression of the 1997–98 El Niño. Th s El Niño episode was particularly strong. Th  images were derived from data collected by the satellite TOPEX/Poseidon.* This satellite bounces radar signals off the ocean surface to precisely measure the distance between the satellite and the sea surface. When combined with high-precision data from the Global Positioning System (GPS) of satellites, maps of sea-surface topography such as these can be produced. These maps show the relative positions and elevations of the sea surface. The presence of hills indicates warmer-than-average water, and the areas of low topography, or valleys, indicate cooler-than-normal water, because liquid water expands as it warms and contracts as it cools. Using water topography, scientists can determine the speed and direction of surface ocean currents.

The colors in these images show sea-level height relative to the average. When you focus on the images, remember that hills are warm colors and valleys are cool colors. The white and red areas indicate places of higher-than-normal sea-surface heights. In the white areas, the sea surface is between 14 and 32 centimeters above normal. In the red areas, sea level is elevated by about 10 centimeters. Green areas indicate average conditions, whereas blue shows zones that are at least 18 centimeters below average sea level.

The images show the progression of the large warm-water mass from west to east across the equatorial Pacific Ocean. At its peak in November 1997, the surface area covered by the warm water mass was about one and one half times the size of the 48 contiguous United States. The amount of warm water added to the eastern Pacific with a temperature between 21°C and 30°C was about 30 times the combined volume of the water in all of the United States Great Lakes.

**Source: NASA's Goddard Space Flight Center*

**FIGURE 19**
**Progression of the 1997–98 El Niño**



# INQUIRY
## EXPLORATION LAB

# Observing Wind Patterns

**Problem** How can surface barometric pressure maps be interpreted?

**Materials** 1 copy each of **Figure 1** and **Figure 2,** paper, pencil

**Skills** Observe, Analyze Data, Calculate

**Connect to the Big idea** Atmospheric pressure and wind are two elements of weather that are closely related. Most people don't usually pay attention closely to the pressure given in a weather report. However, pressure differences in the atmosphere drive the winds that often bring changes in temperature and moisture.

## Procedure

1. Look at Figure 1. This map shows surface global wind patterns and average global barometric pressure in millibars for January.
2. Examine the individual pressure cells in Figure 1. Then complete the diagrams in your copy of Figure 2. Label the isobars with appropriate pressures, and use arrows to indicate the surface air movement in each pressure cell.
3. Copy the data table on the next page. Indicate the movements of air in high- and low-pressure cells by completing the table.

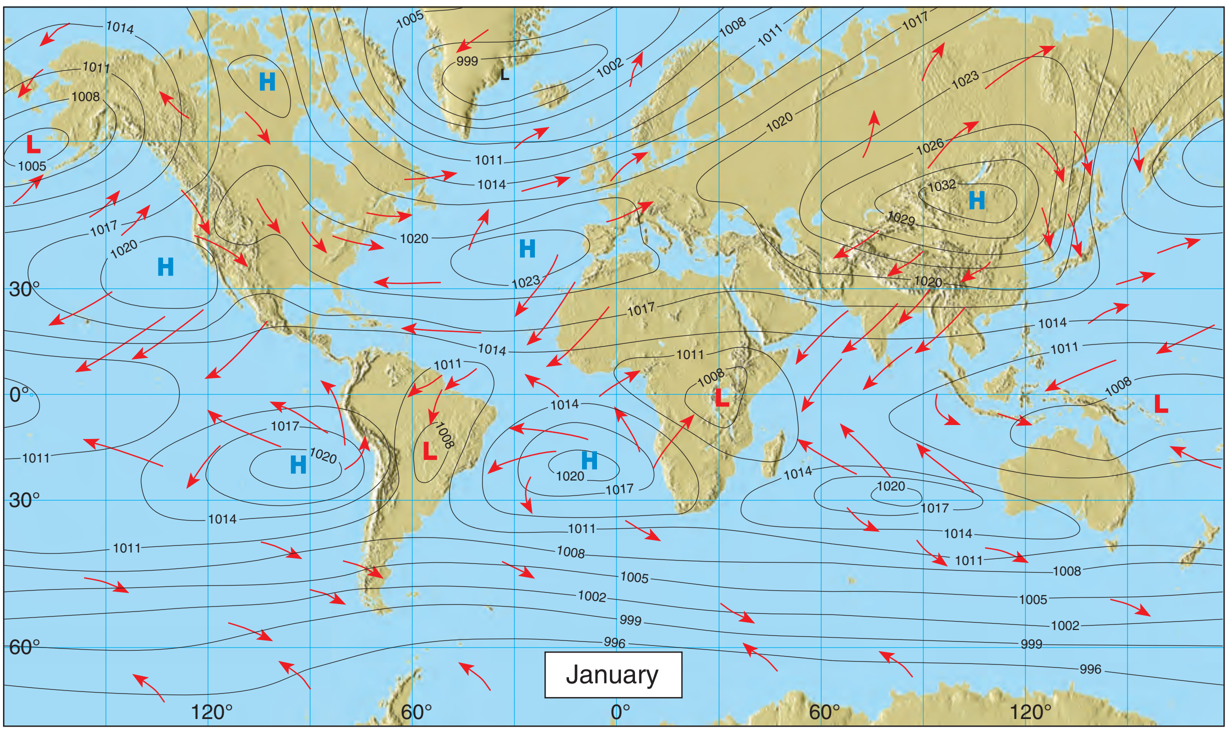
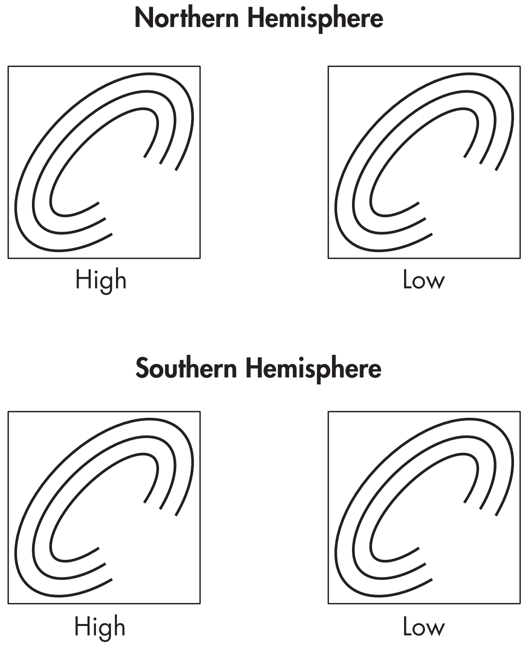



**FIGURE 1 Surface Global Wind Patterns and Average Global Barometric Pressure**

## Analyze and Conclude

1. **Compare and Contrast** Summarize the differences and similarities in surface air movement between a Northern Hemisphere cyclone and a Southern Hemisphere cyclone.
2. **Interpret Visuals** Use your textbook as a reference to locate and write the name of each global wind belt at the appropriate location on your copy of the map in Figure 1. Also indicate the region of the polar front.
3. **Apply Concepts** Label areas on your copy of Figure 1 where you would expect high wind speeds to occur.
4. **Apply Concpets** Label an area on your copy of Figure 1 where circulation is most like the idealized global wind model for a rotating Earth. Explain why this region on Earth is so much like the model.

**FIGURE 2** Isobars




| Air Movement in Pressure Cells Data Table | | | | |
|---|---|---|---|---|
| Air Movement | Northern Hemisphere High | Northern Hemisphere Low | Southern Hemisphere High | Southern Hemisphere Low |
| into/out of | | | | |
| rises/sinks | | | | |
| rotates CW/CCW* | | | | |
| | | | | |

* CW = clockwise; CCW = counterclockwise

**ES.1** The student will plan and conduct investigations in which **c.** scales, diagrams, charts, graphs, tables, imagery, models, and profiles are constructed and interpreted; and **d.** maps and globes are read and interpreted, including location by latitude and longitude.

# 19 Study Guide

**Big idea** Weather and Climate

## 19.1 Understanding Air Pressure

Air pressure is exerted in all directions—down, up, and sideways. The air pressure pushing down on an object balances the air pressure pushing up on the object.

When air pressure increases, the mercury in a barometric tube rises. When air pressure decreases, so does the height of the mercury column.

Wind is the result of horizontal differences in air pressure. Air flows from areas of higher pressure to areas of lower pressure.

The unequal heating of Earth's surface generates pressure differences. Solar radiation is the ultimate energy source for most wind.

Three factors control wind: pressure differences, the Coriolis effect, and friction.

Closely spaced isobars indicate a steep pressure gradient and high winds. Widely spaced isobars indicate a weak pressure gradient and light winds.

The Coriolis effect describes how Earth's rotation affects moving objects. All free-moving objects or fluids, including the wind, are deflected to the right of their path of motion in the Northern Hemisphere. In the Southern Hemisphere, they are deflected to the left.

---

air pressure (532)
barometer (533)
isobars (534)
pressure gradient (534)
Coriolis effect (535)
jet stream (536)

## 19.2 Pressure Centers and Winds

In cyclones, the pressure decreases from the outer isobars toward the center. In anticyclones, just the opposite is the case—the values of the isobars increase from the outside toward the center.

When the pressure gradient and the Coriolis effect are applied to pressure centers in the Northern Hemisphere, winds blow counterclockwise around a low. Around a high, they blow outward and clockwise.

In both hemispheres, differences in air pressure cause a net flow of air inward around a cyclone and a net flow of air outward around an anticyclone.

The atmosphere balances differences in solar radiation in the tropics and the poles by acting as a giant heat-transfer system. This system moves warm air toward high latitudes and cool air toward the equator.

---

cyclone (537)
anticyclone (537)
trade winds (541)
westerlies (541)
polar easterlies (541)
polar front (541)
monsoon (542)

## 19.3 Regional Wind Systems

The local winds are caused either by topographic effects or by variations in surface composition—land and water—in the immediate area.

In the contiguous United States, the westerlies consistently move weather from west to east across the continent.

At irregular intervals of three to seven years, warm equatorial currents along the coasts of Ecuador and Peru become unusually strong and replace normally cold offshore waters with warm waters. This occurrence is referred to as an El Niño event.

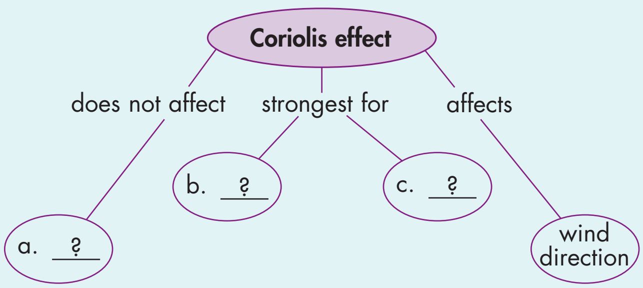
When surface temperatures in the eastern Pacific are colder than average, a La Niña event is triggered that has a distinctive set of weather patterns.

---

prevailing wind (545)
anemometer (545)
El Niño (546)
La Niña (547)

## Think Visually

Copy the concept map below onto a sheet of paper. Use information from the chapter to complete the concept map.



# 19 Assessment

## Review Content

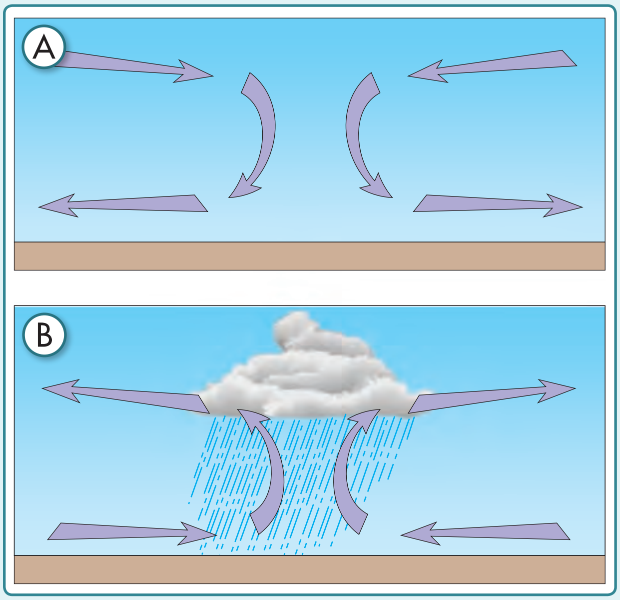
*Choose the letter that best answers the question or completes the statement.*

1. The mercurial barometer was invented by
   **a.** Galileo. **c.** Torricelli.
   **b.** Newton. **d.** Watt.
2. The force exerted by the air above is called
   **a.** air pressure. **c.** divergence.
   **b.** convergence. **d.** the Coriolis effect.
3. What are centers of low pressure called?
   **a.** air masses **c.** cyclones
   **b.** anticyclones **d.** jet streams
4. Variations in air pressure from place to place are the principal cause of
   **a.** clouds. **c.** hail.
   **b.** lows. **d.** wind.
5. In the winter, large landmasses often develop a seasonal
   **a.** high-pressure system.
   **b.** low-pressure system.
   **c.** typhoon.
   **d.** trade wind.
6. A sea breeze is most intense
   **a.** during mid- to late afternoon.
   **b.** in the late morning.
   **c.** late in the evening.
   **d.** at sunrise.
7. What is the pressure zone that is associated with rising air near the equator?
   **a.** equatorial low **c.** subtropical low
   **b.** equatorial high **d.** subtropical high
8. What are high-altitude, high-velocity winds?
   **a.** cyclonic currents **c.** jet streams
   **b.** isobars **d.** pressure gradients
9. Where is deflection of wind due to the Coriolis effect the strongest?
   **a.** near the equator **c.** near the poles
   **b.** in the midlatitudes **d.** near the westerlies
10. In what stormy region do the westerlies and polar easterlies converge?
    **a.** equatorial low **c.** polar front
    **b.** subpolar high **d.** subtropical front

## Understand Concepts

11. Describe how an aneroid barometer works.
12. Write a general statement relating the spacing of isobars to wind speed.
13. Describe the weather that usually accompanies a
    **a.** drop in barometric pressure.
    **b.** rise in barometric pressure.
14. How does the Coriolis effect modify air movement in the Southern Hemisphere?
15. The trade winds originate from which pressure zone?
16. List and briefly describe three examples of local winds.
17. On a wind vane with a degree scale, which type of wind is indicated by 90 degrees?

*Use the figure below to answer Questions 18–20.*




18. In diagram A, what type of surface air flow is shown?
19. What type of surface pressure system is illustrated in diagram B?
20. Select the diagram in which air at the surface fi st begins to pile up.

## Think Critically

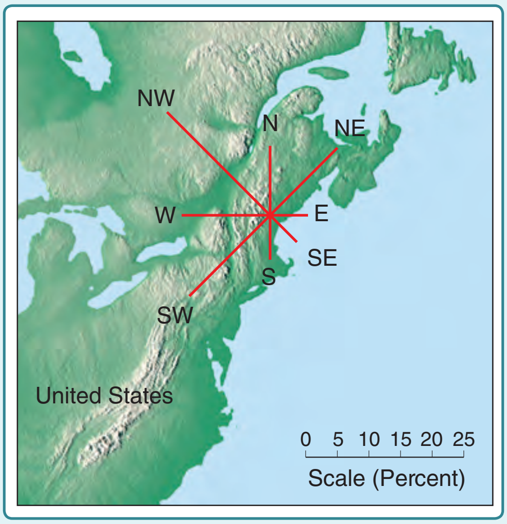
**21. Predict** If you are in the Northern Hemisphere and are directly west of the center of a cyclone, what most likely will be the wind direction? What will the wind direction be if you are west of an anticyclone in the Northern Hemisphere?

**22. Apply Concepts** If you were looking for a location to place a wind turbine to generate electricity, how would you use the spacing of isobars in making your decision?

**23. Hypothesize** What differences in the biosphere would you predict for areas dominated by low-pressure systems compared to those dominated by high-pressure systems?

## Math Skills

*The red lines on the map below indicate wind direction. The length of each line indicates the percent of the total winds that come from this direction. Use the illustration to answer Questions 24–26.*




**24. Analyze Data** According to the map, which winds dominate this region?

**25. Measure** About what percent of the time do winds blow from the east?

**26. Calculate** Determine the approximate percent of time that winds blow from either the west or the northwest in this area.

## Concepts in Action

**27. Predict** How might a La Niña event impact the weather in your area?

**28. Apply Concepts** Mercury is 13 times heavier than water. If you built a barometer using water rather than mercury, how tall would it have to be to record standard sea-level pressure? Express your answer in centimeters. (*Hint:* How many centimeters of mercury represent standard sea-level pressure?)

**29. Interpret Visuals** After studying Figure 16, explain the relationship between water temperature and the type of air pressure system that develops.

## Performance-Based Assessment

**Observe** For two weeks, keep a daily air pressure, wind, and precipitation log in your science notebook. Be sure to note any changes, and note if any of the changes occur over the course of a single day. At the end of two weeks, organize your information into a data table. Prepare a short summary that includes any patterns you determine among these variables. Report the results orally to your class.

# Virginia SOL Test Prep

**Tips for** Success

**Anticipate the Answer** When answering multiple choice questions, a useful strategy is to cover up the given answers and supply your own answer. Then compare your answer with those listed and select the one that most closely matches.

**Practice anticipating the answer in Questions 1–6.**

**Choose the letter that best answers the question.**

**1 The Sahara desert in North Africa and the Australian desert, as well as others, are associated with which pressure zone?**
**A** equatorial low
**B** polar high
**C** subpolar low
**D** subtropical high ES.12.b

**2 What does a steep air pressure gradient cause?**
**F** high winds
**H** variable winds
**G** light winds
**J** north winds ES.12.b

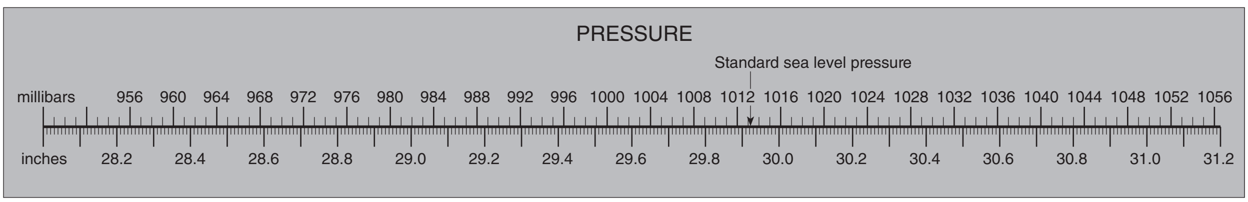
**3 Low-pressure systems are usually associated with—**
**A** descending air
**B** diverging surface winds
**C** clear weather
**D** precipitation ES.12.b

**4 A sea breeze usually originates during the—**
**F** evening and flows toward the land
**G** day and flows toward the land
**H** evening and flows toward the water
**J** day and flows toward the water ES.12.b

**Use the illustration below to answer Questions 5 and 6.**

**5 Using this scale, determine the standard sea level pressure in millibars and inches of mercury. Express your answers to the nearest millibar and to the nearest hundredth of an inch.**
**A** 1013 mb; 29.92 inches
**B** 29.92 mb; 1013 inches
**C** 1016 mb; 30.01 inches
**D** 30.01 mb; 1016 inches ES.12.a

**6 What is the corresponding pressure, in millibars, for a pressure measurement of 30.30 inches of mercury?**
**F** 1016 mb
**G** 1017 mb
**H** 1024 mb
**J** 1026 mb ES.12.a




## If You Have Trouble With . . .

| Question | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| See Lesson | 19.2 | 19.1 | 19.2 | 19.3 | 19.1 | 19.1 |