

1 FOCUS

Section Objectives

- 18.6** Describe what happens to air when it is compressed or allowed to expand.
- 18.7** List four mechanisms that cause air to rise.
- 18.8** Compare and contrast movements of stable and unstable air.
- 18.9** Describe the conditions in air that favor condensation of water.

Reading Focus

Build Vocabulary

L2

LINCS Have students use the LINCS strategy to learn and review the terms *adiabatic*, *orographic*, and *inversion*. In LINCS exercises, students **List** what they know about each term, **Imagine** a picture that describes the word, **Note** a “sound-alike” word, **Connect** the terms to the sound-alike word by making up a short story, and then perform a brief Self-test.

Reading Strategy

L2

- Adiabatic temperature changes are those that occur without the addition or subtraction of heat.
- Stability measurements are made using meteorological instruments that measure the temperature profile of the atmosphere.
- Degrees of stability relate to the tendency of air to resist vertical movement (stable) ranging to air that tends to rise (unstable).

Reading Focus

Key Concepts

- What happens to air when it is compressed or allowed to expand?
- List four mechanisms that can cause air to rise.
- Contrast movements of stable and unstable air.
- What conditions in air favor condensation of water?

Vocabulary

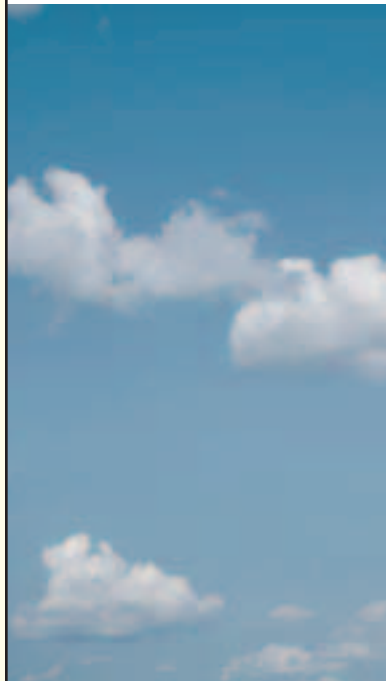
- ◆ dry adiabatic rate
- ◆ wet adiabatic rate
- ◆ orographic lifting
- ◆ front
- ◆ temperature inversion
- ◆ condensation nuclei

Reading Strategy

Identifying Main Ideas Copy the table. As you read, write the main idea for each topic.

Topic	Main Idea
Adiabatic temperature changes	a. _____ ?
Stability measurements	b. _____ ?
Degrees of stability	c. _____ ?

Figure 6 Clouds form when air is cooled to its dew point.



Recall that condensation occurs when water vapor changes to a liquid. Condensation may form dew, fog, or clouds. Although these three forms are different, all require saturated air to develop. Saturation occurs either when enough water vapor is added to air or, more commonly, when air is cooled to its dew point.

Near Earth’s surface, heat is quickly exchanged between the ground and the air above. During evening hours, the surface radiates heat away, causing the surface and adjacent air to cool rapidly. This radiational cooling causes the formation of dew and some types of fog. In contrast, clouds, like those shown in Figure 6, often form during the warmest part of the day. Clearly, some other process must cool air enough to generate clouds.

Air Compression and Expansion

If you have pumped up a bicycle tire, you might have noticed that the pump barrel became warm. The increase in temperature you felt resulted from the work you did on the air to compress it. When air is compressed, the motion of gas molecules increases and the air temperature rises. The opposite happens when air is allowed to escape from a bicycle tire. The air expands and cools. The expanding air pushes on the surrounding air and cools by an amount equal to the energy used up.

Adiabatic Temperature Changes Temperature changes that happen even though heat isn’t added or subtracted are called *adiabatic temperature changes*. They result when air is compressed or allowed to expand. ➤ **When air is allowed to expand, it cools, and when it is compressed, it warms.**

Expansion and Cooling As you travel from Earth's surface upward through the atmosphere, the atmospheric pressure decreases. This happens because there are fewer and fewer gas molecules. Any time a volume of air moves upward, it passes through regions of successively lower pressure. As a result, the ascending air expands and cools. Unsaturated air cools at the constant rate of 10°C for every 1000 meters of ascent. In contrast, descending air encounters higher pressures, compresses, and is heated 10°C for every 1000 meters it moves downward. This rate of cooling or heating applies only to unsaturated air and is called the **dry adiabatic rate**.

If a parcel of air rises high enough, it will eventually cool to its dew point. Here the process of condensation begins. From this point on as the air rises, latent heat of condensation stored in the water vapor will be released. Although the air will continue to cool after condensation begins, the released latent heat works against the adiabatic cooling process. This slower rate of cooling caused by the addition of latent heat is called the **wet adiabatic rate**. Because the amount of latent heat released depends on the quantity of moisture present in the air, the wet adiabatic rate varies from $5\text{--}9^{\circ}\text{C}$ per 1000 meters.

Figure 7 shows the role of adiabatic cooling in the formation of clouds. Note that from the surface up to the condensation level the air cools at the dry adiabatic rate. The wet adiabatic rate begins at the condensation level.



What happens to heat stored in water vapor when it is cooled to its dew point?

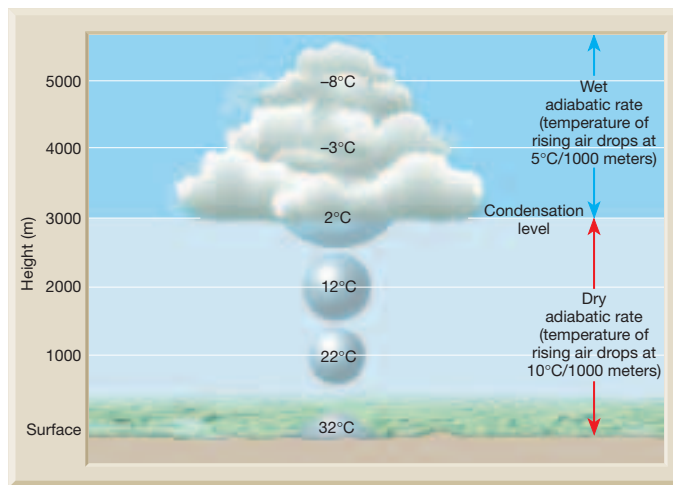


Figure 7 Cloud Formation by Adiabatic Cooling Rising air cools at the dry adiabatic rate of 10°C per 1000 meters, until the air reaches the dew point and condensation (cloud formation) begins. As air continues to rise, the latent heat released by condensation reduces the rate of cooling.

Interpreting Diagrams Use this diagram to determine the approximate air temperature at 3500 m.

2 INSTRUCT



Air Compression and Expansion

Compression and Expansion L2

Purpose Students observe how compression and expansion of air cause temperature changes.

Materials bicycle tire, bicycle pump, can of compressed air duster

Procedure Ask students what they think will happen to the bicycle pump when you use it to add air to the tire. Pump up the tire a bit, then let the student feel the barrel of the pump. Ask them why the pump got warm. (*Energy was used to compress the air.*) Now ask students what they think will happen to the can of compressed air duster when you release some air from it. Release some air, then let students feel the can. Ask them why the can became cold. (*Energy was absorbed by the expanding air.*)

Expected Outcomes The bicycle pump will get warm, and the can will get cold.

Kinesthetic, Logical

Build Science Skills

Relating Cause and Effect Go through each step in what happens as a parcel of air rises through the atmosphere. Ask: **Why does air cool as it rises?** (*It expands, a process that absorbs heat.*) **Why does air cool more slowly after it reaches its dew point?** (*Above the dew point, condensation begins. Condensation releases heat, which somewhat counteracts the cooling effect of expansion.*) **Why does the wet adiabatic rate vary?** (*The amount of heat released varies with the amount of moisture. The more moisture, the more heat is released and the slower the cooling is.*)

Logical

Customize for English Language Learners

Students who are learning English can benefit from real-life examples that relate to science content. Encourage students to think of observations they have made about rising objects or processes that cause objects to rise.

For example, they likely have seen a helium balloon rising. They may also have seen wedges such as those used as doorstops. Encourage students to share their observations with the class.

Answer to . . .

Figure 7 The temperature is -0.5°C .



Latent heat is released.

Processes That Lift Air

Use Visuals

L1

Figure 8: A and B Use this diagram to explain how air can be lifted by mountains or cooler air masses. Ask: **What happens as air rises up the side of a mountain?** (It cools, often creating clouds and precipitation.) **What happens when warm and cold air masses collide?** (The colder, denser air forces the warmer air up.) **How are the processes in A and B similar?** (In both cases, air is forced to rise by a barrier, often resulting in clouds and precipitation.)

Visual, Logical

Build Reading Literacy

L1

Refer to p. 306D in Chapter 11, which provides the guidelines for KWL (Know/Want to Know/Learned).

KWL Teach this independent study skill as a whole-class exercise. 1. Draw a three-column KWL chart on the board for students to copy. 2. Have students complete the Know column with facts, examples, and other information that they already know about processes that lift air. Have students use one row for each of the four processes. 3. Tell students to complete the Want to Know column with questions about these processes. 4. Have students read pp. 512–513 to learn more about these processes. As they read, have them note answers in the Learned column, along with other facts, examples, and details they learned. 5. Have students draw an Information I Expect to Use box below their KWL chart. Have them review the information in the Learned column and categorize the useful information in the box.

Verbal

Go Online

PLANETDIARY

Find links to additional activities and have students monitor phenomena that affects Earth and its residents.

Processes that Lift Air

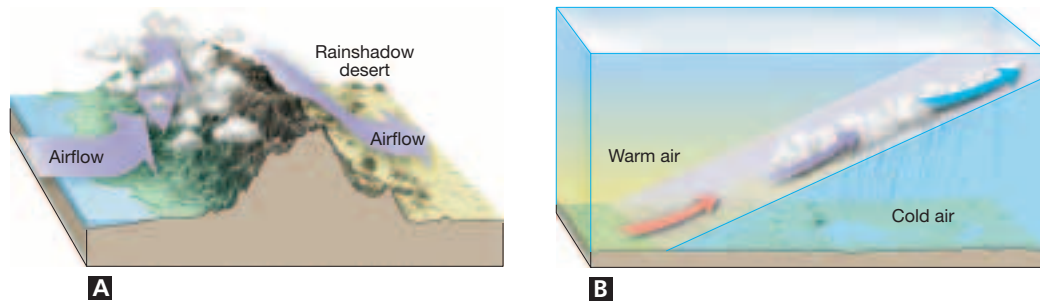


Figure 8 A Orographic Lifting
B Frontal Wedging

Relating Cause and Effect Why does the warm air mass move upward over the cold air mass?

Go Online

PLANETDIARY

For: Links on orographic lifting and rainfall

Visit: PHSchool.com

Web Code: czd-6182

Processes That Lift Air

In general, air resists vertical movement. Air located near the surface tends to stay near the surface. Air far above the surface tends to remain far above the surface. Some exceptions to this happen when conditions in the atmosphere make air buoyant enough to rise without the aid of outside forces. In other situations, clouds form because there is some mechanical process that forces air to rise. 🌩️ **Four mechanisms that can cause air to rise are orographic lifting, frontal wedging, convergence, and localized convective lifting.**

Orographic Lifting When elevated terrains, such as mountains, act as barriers to air flow, **orographic lifting** of air occurs. Look at Figure 8A. As air goes up a mountain slope, adiabatic cooling often generates clouds and precipitation. Many of the rainiest places on Earth are located on these windward mountain slopes.

By the time air reaches the leeward side of a mountain, much of its moisture has been lost. If the air descends, it warms adiabatically. This makes condensation and precipitation even less likely. A rain shadow desert can occur on the leeward side of the mountain. For example, the Great Basin Desert of the western United States lies only a few hundred kilometers from the Pacific Ocean, cut off from the ocean's moisture by the Sierra Nevada Mountains.

Frontal Wedging If orographic lifting was the only mechanism that lifted air, the relatively flat central portion of North America would be an expansive desert instead of the nation's breadbasket. Fortunately, this is not the case.

In central North America, masses of warm air and cold air collide, producing a **front**. Here the cooler, denser air acts as a barrier over which the warmer, less dense air rises. This process, called frontal wedging, is shown in Figure 8B. Weather-producing fronts are associated with specific storm systems called middle-latitude cyclones. You will study these in Chapter 20.

Facts and Figures

The phrase *parcel of air* is often used in meteorology to help understand and simplify discussion of principles. It refers to an imaginary volume of air isolated from other air by, for example, a thin elastic cover. (Picture a hot-air balloon.) A parcel is typically considered to be a few hundred cubic meters in volume. It is

assumed to act independently of the surrounding air. It is also assumed that no heat is transferred into or out of the parcel. Although parcels are imaginary, over short time periods, a parcel is a good model for the actual behavior of a volume of air moving vertically through the atmosphere.

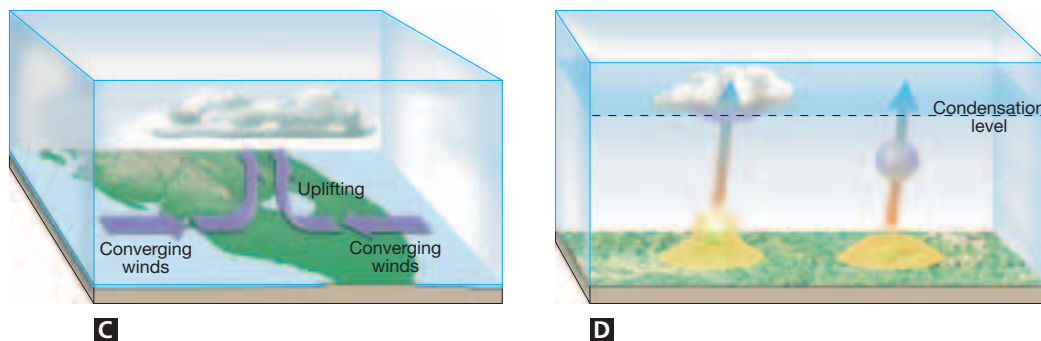


Figure 8 C Convergence
D Localized Convective Lifting

Convergence Recall that the collision of contrasting air masses forces air to rise. In a more general sense, whenever air in the lower atmosphere flows together, lifting results. This is called convergence. When air flows in from more than one direction, it must go somewhere. Because it cannot go down, it goes up, as shown in Figure 8C. This leads to adiabatic cooling and possibly cloud formation.

The Florida peninsula provides an example of how convergence can cause cloud development and precipitation. On warm days, the airflow is from the ocean to the land along both coasts of Florida. This leads to a pileup of air along the coasts and general convergence over the peninsula. This pattern of air movement and the uplift that results is helped along by intense solar heating of the land. The result is that the peninsula of Florida experiences the greatest number of mid-afternoon thunderstorms in the United States.

Localized Convective Lifting On warm summer days, unequal heating of Earth's surface may cause pockets of air to be warmed more than the surrounding air. For example, air above a paved parking lot will be warmed more than the air above an adjacent wooded park. Consequently, the parcel of air above the parking lot, which is warmer and less dense than the surrounding air, will move upward, as shown in Figure 8D. These rising parcels of warmer air are called thermals. The process that produces rising thermals is localized convective lifting. Birds such as hawks and eagles use these thermals to carry them to great heights where they can gaze down on unsuspecting prey. People have learned to use these warm parcels effectively for hang gliding. When warm parcels of air rise above the condensation level, clouds form. These clouds may produce mid-afternoon rain showers.



What are thermals?

Use Visuals

L1

Figure 8: C and D Use this diagram to explain convergence and convective lifting. Ask: **What happens when two similar air masses converge and collide?** (Air is forced up at the center, possibly causing cloud formation.) **How does local convective lifting occur?** (A pocket of air may be warmed more than surrounding air, causing it to rise.) **What happens when such a parcel rises above the condensation level?** (Water vapor condenses, forming clouds.) **Visual, Logical**

Integrate Biology

L2

Birds and Thermals Tell students that using thermals is important to many birds of prey, such as hawks and vultures. Ask: **How do birds of prey use thermals?** (Birds use thermals to be carried up to great heights, where they can look for prey.) **What would happen if the birds could not use thermals?** **What problem would this cause?** (Birds would have to flap their wings to gain altitude. Doing so would waste a lot of energy.) **Logical**

Answer to . . .

Figure 8 Warm air is less dense, and therefore more buoyant, than the cold air mass is.



Thermals are rising parcels of air that are warmer than surrounding air.

Stability

Build Science Skills

L2

Designing

Experiments Ask students to design experiments to

determine the effects of temperature on the buoyancy of a helium balloon. They should compare buoyancy for at least two different temperatures. Students may use materials of their choosing, with the exception of open flames. They should write a hypothesis, develop an experimental plan, submit the plan to you for approval, do the experiment, draw conclusions, and report their results. *(One approach is to heat the balloon, using hot water, and/or cool it, using cold water or ice. Buoyancy can be tested by releasing the balloon at a fixed distance above the floor and using a meter stick and stopwatch to measure how fast the balloon rises or falls.)*

Logical, Visual



Figure 9 Hot-air balloons will rise as long as the air inside them is warmer than the air in the atmosphere surrounding them.



514 Chapter 18

Stability

If a volume of air was forced to rise, its temperature would drop because of expansion. If this volume of air was cooler than the surrounding environment, it would be denser, and if allowed to do so, it would sink to its original position. Air of this type, called stable air, resists vertical movement.

Density Differences If this imaginary volume of rising air was warmer and therefore less dense than the surrounding air, it would continue to rise until it reached an altitude where its temperature equaled that of its surroundings. This is exactly how a hot-air balloon works. The balloon rises as long as it is warmer and less dense than the surrounding air, as shown in Figure 9. This type of air is classified as unstable air. 🌱 **Stable air tends to remain in its original position, while unstable air tends to rise.**

Stability Measurements Air stability is determined by measuring the temperature of the atmosphere at various heights. The rate of change of air temperature with height is called the environmental lapse rate. This rate is determined from observations made by aircraft and by radiosondes. A radiosonde is an instrument designed to collect weather data high in the atmosphere. Radiosondes are often carried into the air by balloons.

Degrees of Stability Air is stable when the temperature decreases gradually with increasing altitude. The most stable conditions happen when air temperature actually increases with height, called a **temperature inversion**. Temperature inversions frequently happen on clear nights as a result of radiation cooling off Earth's surface. The inversion is created because the ground and the air immediately above the ground will cool more rapidly than air higher above the ground. Under these conditions, there is very little vertical air movement. In contrast, air is considered unstable when the air close to the surface of Earth is significantly warmer than the air higher above the surface, indicating a large environmental lapse rate. Under these conditions, the air actually turns over, as the warm air below rises and is displaced by the colder air higher above the ground.

Facts and Figures

A hot-air balloon has three main parts: the basket, the envelope, and the burner. The basket holds the balloonist, passengers, propane tanks, navigation equipment, and other needed supplies. The basket is often made out of wicker because it is fairly lightweight but also strong and flexible enough to absorb some of the energy of landings. The envelope, which is essentially

a large nylon bag, holds the hot air. The burner is somewhat like a giant Bunsen burner. It burns propane that is stored as a liquid in large tanks. When the balloonist fires the burner, it heats the air inside the balloon and increases its buoyancy, lifting the balloon. To lower the balloon, the balloonist pulls a cord that opens a parachute valve at the top of the balloon and lets some of the hot air out.



Stability and Daily Weather Recall that stable air resists vertical movement and that unstable air rises freely. But how do these facts apply to the daily weather?

Because stable air resists upward movement, you might conclude that clouds won't form when stable conditions are present in the atmosphere. Although this seems reasonable, remember that there are processes that force air above Earth's surface. These include orographic lifting, frontal wedging, and convergence. When stable air is forced above Earth's surface, the clouds that form are widespread and have little vertical thickness when compared to their horizontal dimension. Precipitation, if any, is light to moderate.

In contrast, clouds associated with the lifting of unstable air are towering and often generate thunderstorms and occasionally even a tornado. For this reason, on a dreary, overcast day with light drizzle, stable air has been forced above Earth's surface. During a day when cauliflower-shaped clouds appear to be growing as if bubbles of hot air are surging upward, the air moving up is unstable. Figure 10 shows cauliflower-shaped clouds caused by the rising of unstable air.



What types of weather can result when stable air rises?

Figure 10 These clouds provide evidence of unstable conditions in the atmosphere.

Build Science Skills L2

Comparing and Contrasting

Compare the behavior of stable and unstable air parcels. Ask: **What factors cause stable air to rise?** (*orographic lifting, frontal wedging, and convergence*)

Why are clouds formed from stable air widespread and thin? (*Because the air is stable, it all stays at roughly the same altitude.*)

What factors cause unstable air to rise? (*localized convective lifting*)

Why are clouds formed from unstable air often towering? (*Strong convection lifts and spreads out the clouds.*)

Logical

Condensation



Making a Cloud L2

Purpose Students observe how a cloud forms.

Materials valve stem from a car or bicycle, 2-hole rubber stopper, glass tubing, rubber tubing, hose clamp, warm water, Erlenmeyer flask, match, bicycle pump, sheet of black paper, flashlight

Procedure In advance, insert a valve stem from a car or bicycle into one hole of a 2-hole rubber stopper. Insert a piece of glass tubing into the other hole and attach a piece of rubber tubing to the glass tubing. Clamp off the rubber tubing. Pour a small amount of warm water into an Erlenmeyer flask. In front of students, light a match and hold it inside the flask for a few seconds. Insert the stopper into the flask and use a bicycle pump to increase the pressure of the flask. Stand up a sheet of black paper behind the flask and shine a flashlight through it. Now open the clamp. Ask students what they observed. (*A cloud forms.*) Ask why it formed. (*The sudden drop in pressure cooled the air, causing water vapor to condense and form a cloud of droplets.*) Ask what the role of the smoke was. (*It provided condensation nuclei on which the droplets could form.*)

Expected Outcome A small cloud will form inside the flask.

Visual, Logical

Answer to . . .



Clear weather may occur or light-to-moderate precipitation.

Section 18.2 (continued)

3 ASSESS

Evaluate Understanding

L2

Ask students in turn to explain one process that lifts air. Encourage them to draw diagrams on the board to help explain the process.

Reteach

L1

Use Figure 7 to review adiabatic cooling and its role in cloud formation. Explain why the moist adiabatic rate is slower than the dry adiabatic rate.

Connecting Concepts

The general cooling trend with height in the troposphere is called the environmental lapse rate. This is different from parcels of air that rise, expand, and cool adiabatically.

Condensation

Recall that condensation happens when water vapor in the air changes to a liquid. This may be in the form of dew, fog, or clouds. 🌧️ **For any of these forms of condensation to occur, the air must be saturated.** Saturation occurs most commonly when air is cooled to its dew point, or less often when water vapor is added to the air.

Types of Surfaces Generally, there must be a surface for water vapor to condense on. When dew forms, objects at or near the ground, such as grass and car windows, serve this purpose. But when condensation occurs in the air above the ground, tiny bits of particulate matter, called **condensation nuclei**, serve as surfaces for water-vapor condensation. These nuclei are important because if they are absent, a relative humidity much above 100 percent is needed to produce clouds.

Condensation nuclei such as microscopic dust, smoke, and salt particles from the ocean are abundant in the lower atmosphere. Because of these plentiful particles, relative humidity rarely exceeds 100 percent. Some particles, such as ocean salt, are especially good nuclei because they absorb water. When condensation takes place, the initial growth rate of cloud droplets is rapid. It diminishes quickly because the excess water vapor is quickly absorbed by the numerous competing particles. This results in the formation of a cloud consisting of millions upon millions of tiny water droplets. These droplets are all so fine that they remain suspended in air. In the next section, you will examine types of clouds and the precipitation that forms from them.

Section 18.2 Assessment

Reviewing Concepts

1. 🌧️ Describe what happens to air temperature when work is done on the air to compress it.
2. 🌧️ What does stability mean in terms of air movement?
3. 🌧️ List four mechanisms that cause air to rise.
4. 🌧️ Describe conditions that cause condensation of liquid water in air.
5. What is a temperature inversion?
6. Which types of condensation nuclei are especially good for condensation to form?

Critical Thinking

7. **Hypothesizing** Study a world map. Hypothesize about other regions on Earth, other than the Florida peninsula, where convergence might cause cloud development and precipitation.

Connecting Concepts

Air Temperature Review the description of atmospheric temperature changes in Section 17.1. Then write a paragraph explaining how these differ from adiabatic temperature changes in parcels of air.

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Section 18.2 Assessment

1. Air temperature rises when work is done on the air to compress it.
2. Stable air tends to remain in its original position, while unstable air tends to rise.
3. The mechanisms are frontal wedging, orographic lifting, convergence, and localized convective lifting.
4. Condensation of liquid water in air occurs when the air is saturated.

5. A temperature inversion is a stable-air situation in which air temperature increases with height.
6. Good condensation nuclei are those that absorb water, such as ocean salt.
7. Sample answer: Yucatan Peninsula; peninsulas in Northern Australia; New Zealand; Indonesia; tropical islands in general