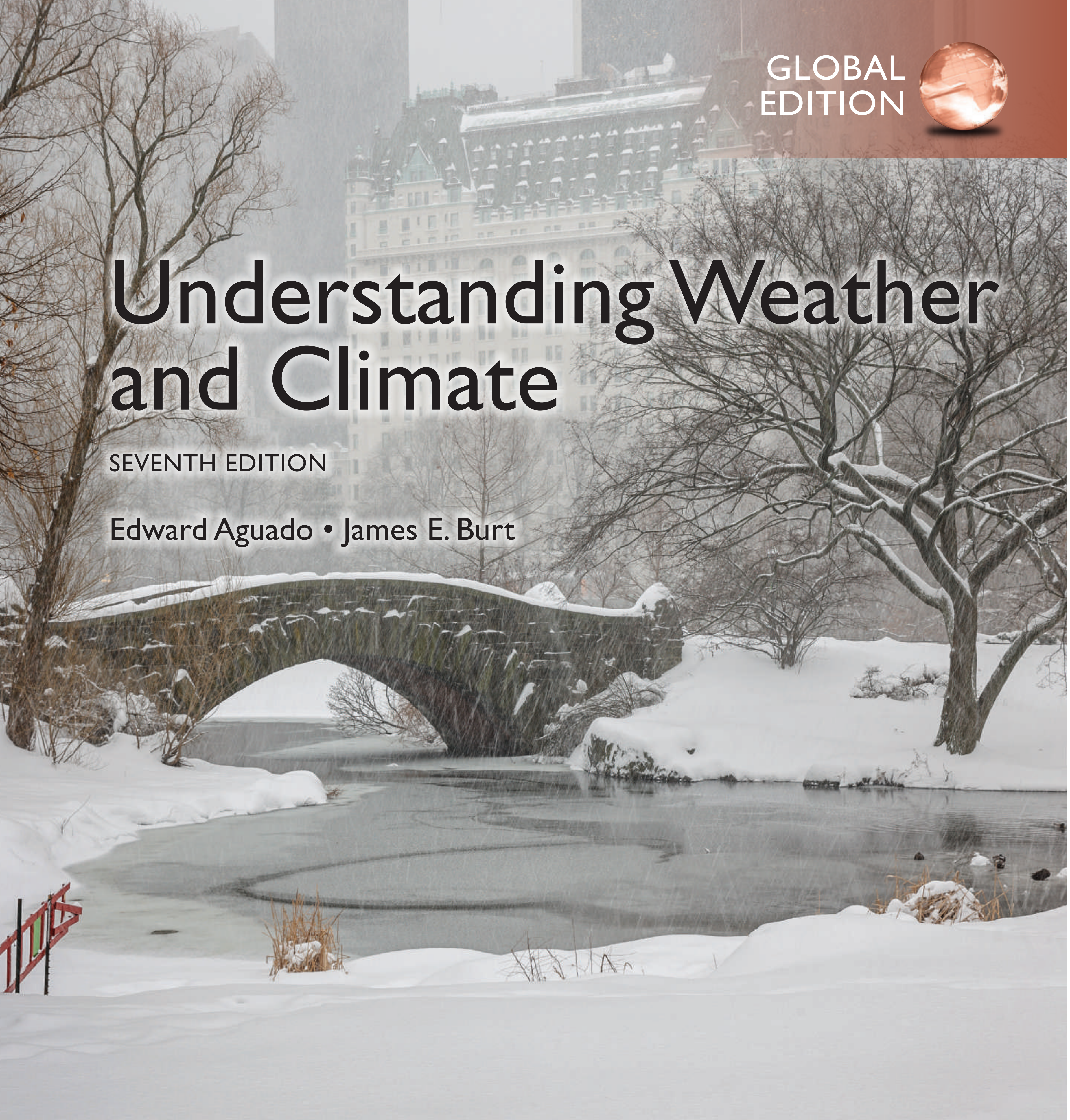

GLOBAL EDITION

Understanding Weather and Climate

SEVENTH EDITION

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ALWAYS LEARNING

PEARSON

Observations suggest a 4 percent overall increase between 1970 and the early 21st century.

Despite the increase in moisture content, the average relative humidity across the globe has not increased. This is due to the effect of temperature on the saturation point. As the amount of water vapor in the air has increased, so, too, has the amount of water vapor that *can* exist because of higher temperatures. Over most oceanic areas the relative humidities have remained fairly constant, as increasing water vapor contents have been offset by increases in the saturation specific humidity. Over certain land areas the increases in specific humidity have been more than offset by increases in the saturation levels, leading to locally unchanged or slightly reduced relative humidities.

Carbon dioxide contents will continue to increase at least for some time to come, which will likely lead to further atmospheric warming. With greater warming we can also anticipate further increases in specific humidity and more effective absorption of outgoing longwave radiation. So will this positive feedback ultimately result in cataclysmic temperature increases? Not necessarily, because strong negative feedbacks also operate (Chapter 16). The most important of these is increasing emission of longwave radiation as temperature rises. Recall from Chapter 2 that for blackbodies, emission grows with the fourth power of temperature. Although Earth does not emit to space as a perfect blackbody, increasing longwave emission acts counter to the water vapor feedback.

Another feedback is related to clouds: It might be that increasing water vapor concentrations will lead to increases in global cloud cover. The effects of cloud cover on shortwave and longwave radiation depend on the type of cloud cover, the height of the clouds, and their location. Under some conditions an increase in cloud cover can lead to a substantial reduction in absorbed solar radiation that suppresses further warming. However, clouds are strong absorbers of longwave radiation, thus they also limit radiation emitted to space. This reduction in outgoing radiation can exceed the reduction in solar radiation absorption, thereby promoting further warming. Even on a global basis, it is an open question as to whether clouds will emerge as a negative or positive feedback in the future. This issue will be discussed in Chapter 16.

Video Global Evaporation Rates

http://goo.gl/bBKAbl

CHECKPOINT

5.25 What kind of change in moisture content has occurred since the mid 1970s?

5.26 How will negative feedbacks affect further changes in moisture content in the atmosphere?

Summary

5.1 Describe the hydrologic cycle.

- Water in its three phases—solid, liquid, and gas—constantly moves across the interface between the atmosphere and Earth's surface through what is known as the *hydrologic cycle*.
- Despite the fact that water accounts for only a small proportion of the mass of the air, in its three phases it is extremely important to the atmosphere—and to all life on Earth.

5.2 Explain the concept of saturation.

- The process of saturation begins at the surface of liquid water as molecules constantly move about. Some randomly break free of the surface to become water vapor.
- As long as the rate of evaporation exceeds condensation, the amount of water vapor increases. When the condensation rate becomes equal to the evaporation rate, and saturation occurs.
- In the atmosphere, clouds and fog persist as long as there is equilibrium between evaporation and condensation rates. When evaporation and condensation are in equilibrium, the air is saturated and small droplets remain in the air without evaporating.

5.3 Identify the indices used in measuring the atmosphere's water vapor content.

- The amount of water vapor, or humidity, is affected by the pressure it exerts (vapor pressure).
- The specific humidity and mixing ratio are ratios that relate the mass of water vapor to the air in which it is contained and to the mass of the other gases, respectively.
- Relative humidity is the amount of water vapor in the air relative to the amount that can exist at the current temperature.
- The dew point is the temperature to which the air temperature must be lowered for saturation to occur.
- Condensation is controlled by two factors having opposite effects: curvature retards condensation, and the abundance of hygroscopic nuclei facilitates it.

5.4 Describe how humidity is measured.

- Humidity can be determined using paired thermometers (a psychrometer) that provide dry and wet bulb temperatures. The difference between the two temperatures is the wet bulb depression, which, when combined with the dry bulb temperature, permits the use of simple tables to determine relative humidity and dew point.

5.5 Describe how water vapor is distributed in the atmosphere.

- The water vapor content changes both seasonally and spatially. In North American summers dew points are typically greater east of the Rockies than out west, and are higher in the deep South, decreasing northward.

- Because of the lower temperatures experienced in winter, dew points are considerably lower on average in winter than in summer.

5.6 Explain the processes that lead to saturation.

- For any kind of condensation (such as dew, fog, or clouds) to form, the dew point must equal the air temperature. This can result from raising the vapor content of the air to the saturation level; mixing warm, moist air with cooler, dry air; or by lowering the air temperature to the dew point. The latter process is most important for cloud formation.

5.7 Explain the factors that affect condensation.

- Water droplets have considerable curvature, which increases the amount of moisture needed for them to be maintained relative to larger masses of water with flat surfaces.
- The curvature effect is largely offset by the fact that droplets do not occur as pure water but instead exist as solutions.

5.8 Describe how diabatic and adiabatic processes produce cooling and condensation.

- Lowering the air temperature does not require that heat be removed from the air. In fact, most clouds form by adiabatic cooling—the lowering of the air temperature without the removal of heat. Adiabatic cooling results from the expansion of air that occurs when it is lifted and is a direct application of the first law of thermodynamics. The most important diabatic process is the cooling that takes place when the surface loses longwave radiation, cools, and chills the air in contact with it.

5.9 List different forms of condensation.

- Noncloud forms of condensation—dew, frost, frozen dew, and fog—are distinguished from clouds by their proximity to or direct contact with Earth's surface.
- Though one type of fog (upslope fog) results from adiabatic processes, the others result from diabatic cooling of the air, involving the loss of energy.

5.10 Describe the distribution of fog.

- Fog in the United States is most prevalent along the Pacific Northwest, New England, and the southern and middle Appalachians.

5.11 Describe the formation and dissipation of cloud droplets.

- Unsaturated air that is lifted cools at 1 °C per every 100 meters of ascent until the air temperature is lowered to the dew point. At that level, the air begins to cool at the saturated adiabatic lapse rate (approximately 0.5 °C/100 m).
- New cloud droplets initially form after saturation occurs, but after a certain amount of lifting, condensation then occurs onto existing droplets. If the air is then lowered, the air and dew point are the same at each height as they were during the ascent of the air parcel.

5.12 Explain how the effects of humidity on human discomfort are rated.

- Humidity affects a human's susceptibility to heat-related dangers. This susceptibility is reflected in the heat index, a combination of the temperature and humidity.
- The apparent temperature reflects the combination of high temperature and high humidity.
- When the air is warm, high amounts of humidity increase the rate of discomfort and susceptibility to heat exhaustion and heat stroke.

5.13 Describe possible effects of global warming, including its effects on evaporation rates and atmospheric water vapor content.

- Because temperatures have risen over much of the globe, the specific humidity has increased near the surface over most regions, although not all regions have experienced a concomitant increase in relative humidity. This is important not just for its immediate effect, but also because it amplifies greenhouse gas warming and because of its potential to impact cloud formation and patterns.

Key Terms

absolute humidity *p. 153*
adiabatic process *p. 169*
advection fogs *p. 175*
apparent temperature *p. 178*
aspirated psychrometer *p. 161*
condensation *p. 152*
condensation nuclei *p. 166*
deposition *p. 152*
dew *p. 172*
dew point (temperature) *p. 156*
dew point lapse rate *p. 178*
diabatic process *p. 169*
dry adiabatic lapse rate (DALR) *p. 169*
dry bulb thermometer *p. 157*
environmental (ambient) lapse rate (ELR) *p. 171*
evaporation *p. 152*
evapotranspiration *p. 150*
first law of thermodynamics *p. 170*
frost *p. 173*
frost point *p. 157*
frozen dew *p. 173*
hair hygrometer *p. 161*
haze *p. 167*
heat index *p. 178*
heterogeneous nucleation *p. 166*
homogeneous nucleation *p. 166*
humidity *p. 152*
hydrologic cycle *p. 150*
hygroscopic *p. 166*
hygrothermograph *p. 161*
ice nuclei *p. 167*
lifting condensation level (LCL) *p. 171*
mixing ratio *p. 154*
precipitation fog *p. 164*
radiation fogs *p. 174*
relative humidity (RH) *p. 154*
saturated (wet or moist) adiabatic lapse rate (SALR) *p. 171*
saturation *p. 152*

Review Questions

1. What is the hydrologic cycle?
2. Why is it incorrect to refer to the air as "holding" water vapor?
3. Explain the concepts of equilibrium and saturation.
4. What is vapor pressure? In what units of measure is it expressed?
5. What are deposition and sublimation?
6. What units of measurement are used to describe mixing ratio and specific humidity? Why are the two values nearly equal?
7. Why is absolute humidity seldom used?
8. Define *relative humidity*.
9. Why is relative humidity a poor indicator of the amount of water vapor in the air?
10. Define *dew point*. What characteristics make this measure superior to relative humidity?
11. Why can't the dew point temperature exceed the air temperature? What happens if the air temperature is lowered to a value below the initial dew point?
12. Describe the distribution of average dew point across the United States in summer and winter.
13. What are the three general methods by which the air can become saturated?
14. Why doesn't homogeneous nucleation form water droplets in the atmosphere?
15. What are the effects of droplet curvature and solution on the amount of water vapor needed for saturation?
16. What are condensation nuclei and ice nuclei? Are they typically made of the same materials? Which is more abundant in the atmosphere?
17. What is supercooled water?
18. What are psychrometers? How do they work?
19. What is the heat index?
20. What is the first law of thermodynamics and how does it apply to cloud development?
21. Define *dry bulb temperature, wet bulb temperature,* and *wet bulb depression*.
22. Explain the difference between diabatic and adiabatic processes.
23. What are the numerical values of the dry and saturated adiabatic lapse rates? Under what circumstances are they applicable?
24. What does the environmental lapse rate refer to?
25. Describe the various processes that can lead to the formation of fog.
26. Describe the various processes that can lead to the formation of dew.
27. What is the difference between frozen dew and frost?

Critical Thinking

1. When rubbing alcohol is applied to a person's skin, it feels colder than the application of water would. Why?
2. A person parks her car in the driveway on a warm afternoon and notices a small puddle of water beneath the car a few minutes later. Explain how using the car's air conditioning can account for the puddle.
3. A crowded classroom is filled with students. In what way might the presence of the students affect the dew point and relative humidity in the room?
4. A person sleeps through the night without waking up, but awakes in the morning weighing slightly less than the night before. What happened?
5. The temperature within a forest is −2 °C (28 °F) and there is frost on the trees but no fog. Outside the woods there is a fog. Why wasn't this fog in the woods?
6. A map of North America shows the average distribution of vapor pressure across the continent. Will the distribution on the map be *only* a function of the amount of water vapor in the air, or will the distribution be affected by another factor as well? Explain.
7. At Wheeling, West Virginia, the evening temperature is 13 °C (55 °F) and the dew point is 9 °C (48 °F). How would you assess the likelihood of fog forming overnight?

8. Is fog more likely to occur downwind or upwind of an oil refinery? Why?

9. All fogs are made of water droplets or ice crystals. Despite the fact that they have the same composition, how would you know if a particular fog is a radiation, advection, or upslope fog?

10. Diesel engines, like four-stroke engines, work because of burning fuel, but they do not require a spark plug or similar device for initiating the burning. Apply your knowledge of the first law of thermodynamics to explain how the fuel can be forced to burn.

Problems & Exercises

1. Assume that a kilogram of air consists of 995 g of dry air and 5 g of water vapor. Show that the specific humidity and mixing ratio are very nearly equal.

2. Assume that a kitchen measures 4 meters by 5 meters by 3 meters. If the air density is 1 kg/m^3 and the specific humidity is 10 g water vapor per kilogram of air, how much water vapor is in the room? If the doors and windows were sealed shut, would boiling 1 kg of water into the air make a substantial change in the humidity of the room?

3. The dry and wet bulb readings in Honolulu are 27 °C and 21 °C (80 °F and 69 °F), respectively. At Charlottesville, Virginia, the readings are 10 °C and 7 °C (50 °F and 45 °F).

a. Use Tables 5–2 and 5–3 to determine the relative humidity and the dew point for both locations.

b. Which of the two locations is more humid?

4. Assume a parcel of air starts out at the surface with a temperature of 12 °C (54 °F) and a dew point of 9.6 °C (49 °F). Then it is lifted.

a. What will the air temperature be at the 100 m level?

b. What will the dew point be at the 100 m level? (*Hint:* Don't forget the dew point lapse rate.)

c. At what height will condensation occur?

d. What will the temperature be when condensation occurs?

e. What will the dew point be when condensation occurs?

f. What will the temperature be 500 m above the surface?

g. If the parcel of air is lowered back to the surface (assuming none of the condensed moisture was removed as rain), what will the temperature and dew point be?

6. The dry and wet bulb temperatures are 21 °C and 12 °C (70 °F and 54 °F). Use Tables 5–2 and 5–3 to answer the following questions:

a. What are the dew point and the relative humidity?

b. What will the dew point and relative humidity be if the air temperature increases to 27 °C (80 °F)? (*Hint:* Do not assume the same wet bulb depression.)

c. What will the dew point and relative humidity be if the air temperature drops to 4 °C (39 °F)? (*Hint:* You don't need the tables for this one.)

d. What will the dew point and relative humidity be if the air temperature drops further, to 2 °C (35 °F)?

5. The numerical value of the specific heat for air in the first law of thermodynamics, c_v, is strictly valid only for air with no water vapor. Water vapor has a specific heat approximately twice as great as that of c_v. Therefore, will a humid mass of air undergoing expansion undergo more or less cooling than would a dry mass of air?

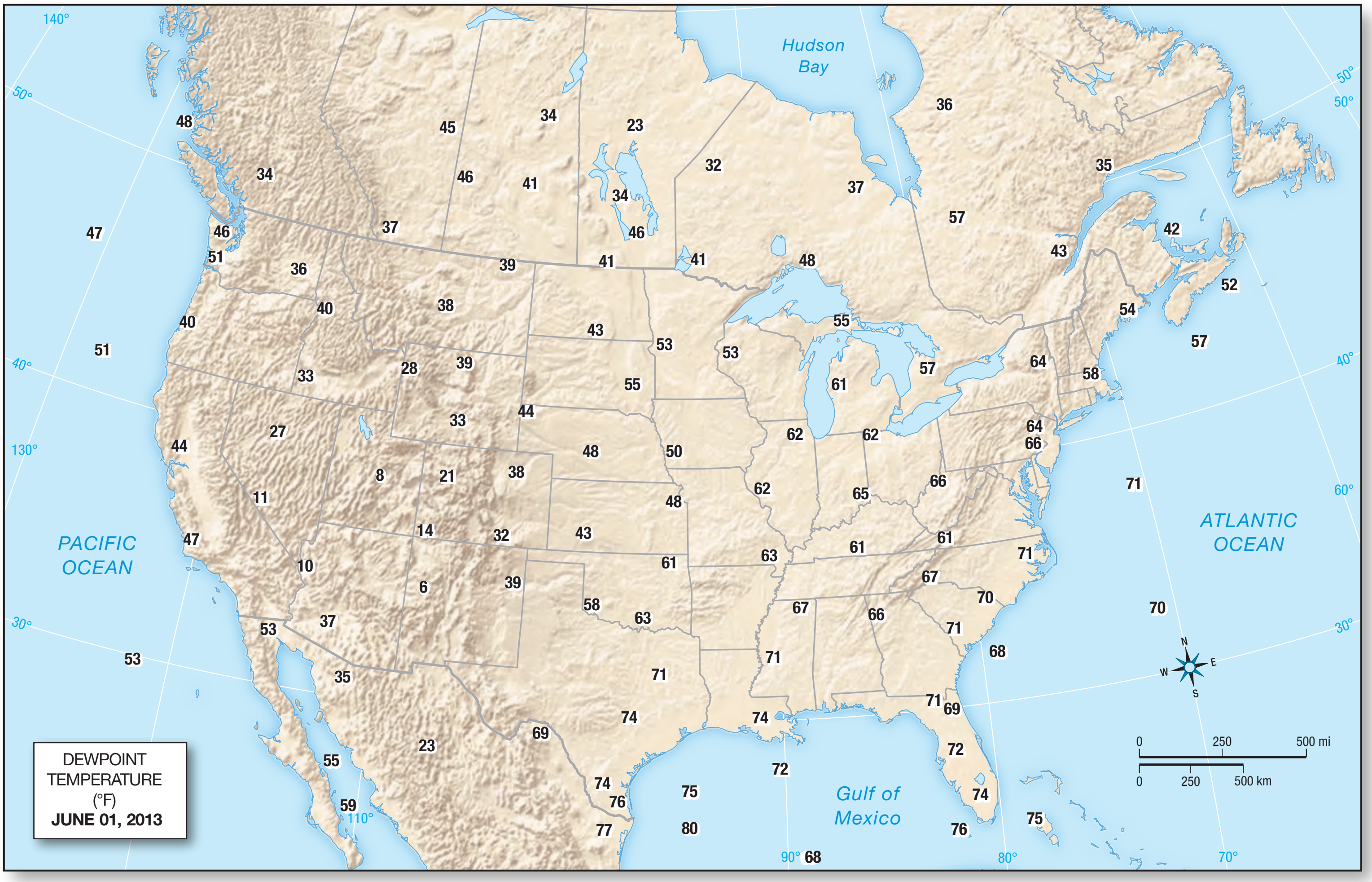
Visual Analysis

Observe the map plotting dew point temperatures across the United States on June 15, 2014, and answer the following questions:

5.1. Define the region in which the dew points indicate uncomfortably muggy conditions?

5.2. Which areas indicate dry conditions?

5.3. Why might the western United States have substantially different dew point readings from those east of the Rocky Mountains?



CHAPTER

6 Cloud Development and Forms

It's not too surprising to walk outside and catch sight of some clouds above the ground. They are so commonplace that we often forget to look for them, which is unfortunate because they can present some very beautiful skyscapes. We know that lifted air cools adiabatically and that if lifted sufficiently it can cool to the dew point and become saturated. In this chapter we will review some of the common mechanisms that allow such lifting to occur. But, as this photo shows, such lifting might occur in some unexpected locations. On this particular day in February 2012, nearly saturated air containing a lot of hygroscopic (see Chapter 5) salt particles from the adjacent beach at Panama City, Florida, drifted in over the seaside buildings. Being nearly saturated to begin with, the air required minimal uplift before producing these unusual and striking clouds. Unusual cloud formations are among the many fascinating features the atmosphere can present to us on a nearly daily basis. This chapter discusses the processes and conditions associated with the formation of clouds due to upward motions. It also describes the cloud types that form as a result of those processes.