Chapter 1
Introduction to the Atmosphere

Outline

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<u>Key Learning Outcomes</u>

Meteorology is the scientific study of the atmosphere and the phenomena of weather. We define weather as the state of the atmosphere at a given time and place whereas we consider climate to be the sum of all statistical weather information that helps describe a place or region. We rely upon scientific inquiry as the most accurate way to gather data and form conclusions about our natural world.

Possible challenges: The scientific method may be revered by generations of scientists, but usually not by generations of students. Most college students will have some familiarity with it, but often not real understanding. They may hear the terms "hypothesis" and "theory" thrown around in public discourse (yawn!), but what relevance do these terms really have to them?

Important first lesson for students: What science instructors teach is based on the work of many scientists over years of careful observations, rigorous testing, and pain-staking research. Isaac Newton famously stated, "If I have seen further, it is only by standing on the shoulders of giants." The information passed on in the classroom is the best of our knowledge to date. Many topics covered in *The Atmosphere* may be considered controversial in the public realm, but generally not as much in the scientific one. Most of these *hypotheses* have survived decades of skepticism and challenges, and we now use the word *theory* to describe our strong confidence in our current information.

Unfortunately, "theory," when used in the public realm, is usually considered analogous to "a guess." Many theories that are widely accepted among scientists are thought to just be educated guesses in the eyes of the general public. The normal debate that occurs in the scientific community whenever a new hypothesis is presented is often seen by the layperson as a sign that scientists really aren't sure of the answer. An old saying in science states: "Science can never really prove anything; it can only disprove." This is not what people want to hear from the "experts"—they want answers!

Bottom line: Students really need to know the difference between a hypothesis and a theory and how scientists arrive at each. The Strategies for Teaching below offer a few suggestions for approaching this topic.

The atmosphere is composed of a mixture of different gases, with roughly 99 percent of pure dry air consisting of two gases, nitrogen and oxygen. Neither gas contributes to the formation of weather. The remaining 1 percent is composed primarily of argon and carbon dioxide, but only the latter affects weather. It is carbon dioxide and the highly variable (in terms of volume) gas water vapor that have the strongest effect on weather, and both of these will be discussed in some detail in later chapters. Finally, the presence of aerosols in the atmosphere can affect cloud formation and the amount of solar radiation reaching Earth's surface.

Possible challenges: While students should be familiar with the major constituent gases that make up the atmosphere, the focus will be on carbon dioxide, water vapor, and aerosols for the remainder of the textbook. Water vapor should be familiar to students; carbon dioxide less so, but both gases are key players in the *greenhouse effect*. Aerosols, frequently released into the atmosphere as pollutants, can also have a variety of interesting and significant effects.

> **Ozone (tri-atomic oxygen) is an important gas in the part of the atmosphere known as the stratosphere, where it absorbs deadly ultraviolet radiation from the Sun. However, the release of certain human-made compounds into the atmosphere in the last century has depleted the amount of ozone in the stratosphere, resulting in an increase in ultraviolet radiation reaching Earth's surface. This has the potential to cause many undesirable effects.**

Possible challenges: This is the first of several controversial topics in meteorology, although the controversy exists mainly in the public forum and not the scientific community. The depletion of the ozone layer, particularly over the Antarctic, has been verified through satellite observations over many years, and its effects have been documented by researchers around the globe. But this is also an *economic* issue, and whenever science and economics favor different conclusions, the battle is bound to be messy. The fight against reducing/banning CFCs, the chemicals best known for depleting ozone, was waged hotly in the 1980s and into the early 1990s. Finally, the evidence became so great that most nations of the world agreed to sign on to the Montreal Protocol, an effort toward global reduction and outright banning of CFCs and other ozone-depleting compounds. (The U.S., although the world's leading producer of CFCs at that time, was not exactly a leader in this fight. At the beginning, it pushed hard to weaken some of the requirements.)

Instructors shouldn't fear to wade right into this one, particularly in light of the previous discussion of scientific inquiry. The Montreal Protocol has undergone many revisions but is widely considered to be one of the most successful international agreements of modern times.

> **As one ascends through the atmosphere, dramatic changes in both pressure and temperature rapidly become apparent. Pressure decreases with height, but temperature varies due to several factors. We divide our atmosphere into layers based on temperature changes: the troposphere, in which temperature decreases with altitude; the stratosphere, which experiences an increase in temperature due to the presence of ozone; the mesosphere, where temperature again falls; and finally the thermosphere, the thin tenuous outer layer in which temperature again rises. In addition, the lower part of the thermosphere also houses the ionosphere, an electrically charged layer responsible for the magnificent auroras.**

Possible challenges: The changes in the vertical structure of the atmosphere, particularly through the troposphere, are responsible for much of our weather phenomena. Students should have a good understanding of what happens, in terms of both temperature and pressure, as one rises through the troposphere. Our concentration for the remainder of the textbook will be on the troposphere, because this is where all weather occurs, but an introduction to the other layers is valuable in order to understand all the factors involved. The *why* of temperature changes in each layer reinforces the importance of these factors.

There are lots of interesting stories involving humankind's attempts to soar into the upper atmosphere, and interesting stories are a very effective technique to help students remember key concepts! Strategies for Teaching will give some examples, and you might have a few of your own. Personalize the material as much as you can.

Strategies for Teaching *Introduction to the Atmosphere*

A. Focus on the Atmosphere

Show the weather: Meteorology (indeed, any science course) can be intimidating for non-science majors. An effective way to begin could be to access one of the many online weather sites and take the students through the daily weather. One of the appeals of taking a meteorology class is learning how to first understand, and then forecast, the daily weather. Starting every class with an online look at that day's weather will introduce students to important concepts early in the course.

B. The Nature of Scientific Inquiry

Tell a story: Stories can be one of the most effective ways to help students remember crucial information. Science is full of stories that describe great advancements made through use of the scientific method. Whether it be Copernicus or Darwin or Einstein, pick your favorite and explain how a very controversial hypothesis was proposed, a storm of criticism followed, and then eventual acceptance (at least by the scientific community) was achieved as more and more researchers were able to replicate the results. A real-life story can better demonstrate that, no matter how outrageous the hypothesis may seem at the beginning, the scientific method *does* work to uncover basic truths about the natural world.

A good article that cautions all who teach science to be careful of *how* we present our material can be found here: http://coehp.uark.edu/pase/TheMythsOfScience.pdf

C. Composition of the Atmosphere

1. Figure 1.17 shows the composition of pure, dry air within the first 50 miles of Earth's surface. Box 1.2 describes how each gas built up in the atmosphere, and these explanations may help students remember the presence of each gas.

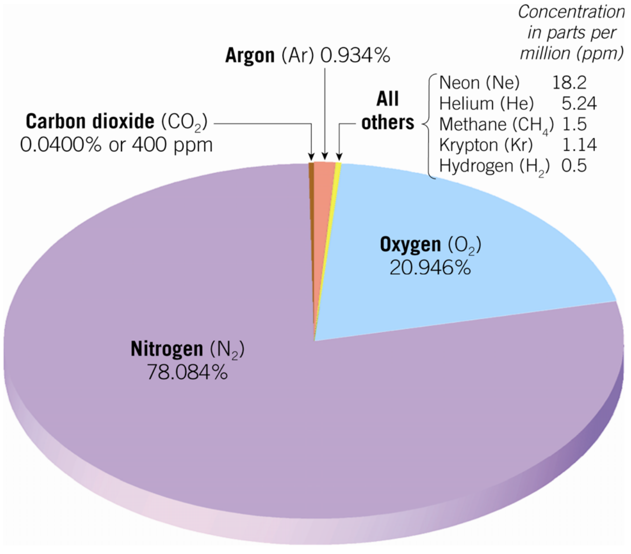


Figure 1.17 Composition of the atmosphere Proportional volume of gases composing dry air. Nitrogen and oxygen obviously dominate.

Actually, though, only carbon dioxide will be significant in weather. Water vapor, which varies greatly across Earth's surface depending upon geographical location (almost 0 percent over the Atacama Desert of Chile and more than 4 percent over the Amazon River basin), will be the other significant gas. Water vapor will be covered extensively in later chapters. Carbon dioxide can be examined in more detail here.

2. As one of the major gases involved in the *greenhouse effect*, carbon dioxide serves a vital role in keeping Earth at a livable temperature. The greenhouse effect will be covered in more detail in Chapter 2 and *global warming*, an acceleration of the greenhouse effect, will be addressed in Chapter 14, but this is a good place to introduce this important gas. Students should understand the role that carbon plays not only in the atmosphere but in all life processes. This role of carbon in life processes will help explain *part* of SmartFigure 1.18, but the key point is the steady rise in carbon dioxide concentrations since the beginning of the Industrial Revolution. Be sure to access the icon and QR code associated with this figure.

3. Aerosols can have numerous effects. The presence of aerosols is responsible for the colors of the sunset (Figure 1.19b) and the famous, elusive "green flash" (many pictures can be found online; http://mintaka.sdsu.edu/GF/index.html is a good place to start). After the explosion of Krakatoa in Indonesia in 1883, artists all over the world recorded brilliant sunrises and sunsets in their paintings. Aerosols are also important in helping to form clouds and in scattering sunlight, both of which will be addressed in later chapters.

D. Ozone Depletion

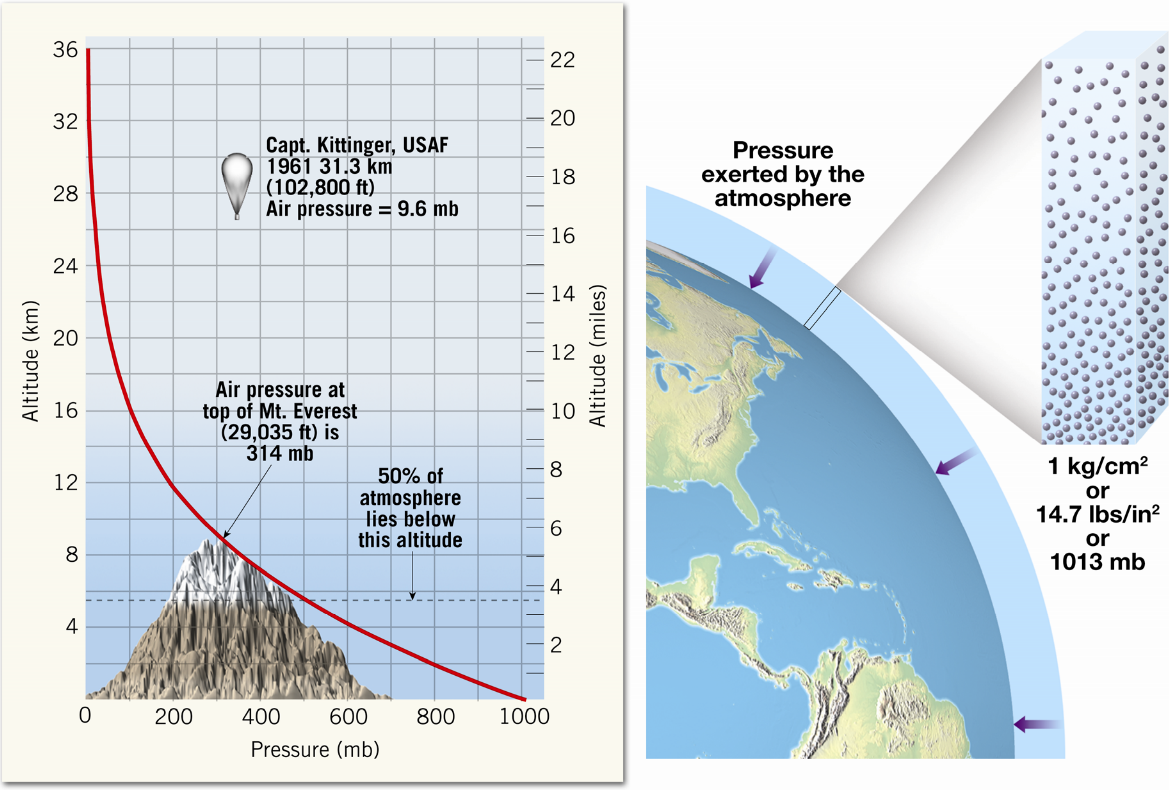
1. The scientific method works! The depletion of the vital ozone layer illustrates how the international community can come together to avert a global crisis when facts, not politics, are allowed to take center stage. This is a good time to reinforce the methods of scientific inquiry studied in an earlier section. The Instructor's Resources has an animation and a PowerPoint presentation that will help to explain some of the more complex parts of this problem. Be sure to access SmartFigure 1.20.

2. Updates on the status of the Antarctic hole (and the ozone layer in general) can be found at: http://ozonewatch.gsfc.nasa.gov/index.html. An interesting site for students to try is: http://ozoneaq.gsfc.nasa.gov/tools/ozonemap/.

3. However, under the heading of "a problem's not solved until it's solved," in August of 2014 a NASA study found that unexpectedly large amounts of the ozone-depleting compound carbon tetrachloride (CCl_4), banned in 1987, were being emitted into the atmosphere from an unknown source.

E. Vertical Structure of the Atmosphere

1. Pressure changes: The key point is shown in Figure 1.21—pressure *falls* as one ascends through the atmosphere.

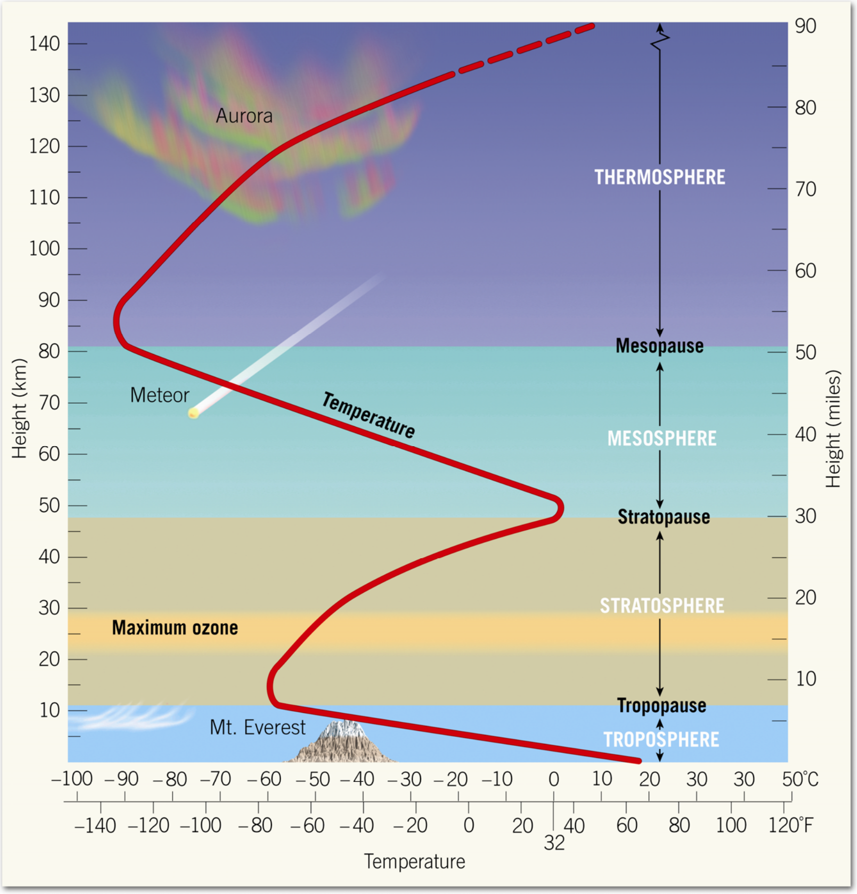


▲ **Figure 1.21 Air pressure changes with altitude** The rate of pressure decrease with an increase in altitude is not constant. Pressure decreases rapidly near Earth's surface and more gradually at greater heights. Put another way, the figure shows that the vast bulk of the gases making up the atmosphere is very near Earth's surface and that the gases gradually merge with the emptiness of space.

There are many interesting examples to bring this point home, and one briefly mentioned in Figure 1.21 is the 1961 free-fall adventure of U.S. Air Force Captain Joseph Kittinger. Look online for videos of his actual high-altitude dive. However, two of his records (for the longest free-fall and the greatest speed) were broken by Felix Baumgartner in 2012: http://www.redbull.com/us/en/stories/1331615537327/the-space-jump-that-shook-the-world, followed by Google's Alan Eustace breaking Baumgartner's free-fall record in October 2014 by falling 135,890 feet: http://www.nytimes.com/2014/10/25/science/alan-eustace-jumps-from-stratosphere-breaking-felix-baumgartners-world-record.html?_r=0.

Chapter 6 goes into much more detail regarding air pressure, but introducing standard atmospheric pressure measurements now—and a barometer, if you have one—will help reinforce these concepts. And constant reinforcement is critical in aiding students' learning.

2. Temperature changes: Temperature changes throughout the atmosphere are trickier because they vary with height. Students need to understand the *causes* behind these temperature changes in order to keep them straight in their minds. Temperature *falls* in the troposphere, due to the fact that Earth is heated from the ground *up*. This temperature distribution is responsible for the large amount of convection—and weather—that occurs here. Temperature *rises* in the stratosphere due to the presence of ozone (just covered in the last section). It *falls* again in the mesosphere as ozone becomes too thin and the distance from Earth increases. Finally, at the edge of the atmosphere, exposure to ultraviolet radiation causes the temperature to *rise* again.



▲ **Figure 1.23 Thermal structure of the atmosphere** Earth's atmosphere is traditionally divided into four layers, based on temperature.

Another intriguing story to introduce here involves a different “flying” adventurer, Californian Larry Walters, who, back in 1982, decided to take flight in a lawn chair tied to weather balloons (http://www.check-six.com/Crash_Sites/Walters-BalloonRide.htm). His adventure into the colder, thinner air at higher altitudes should help reinforce what happens as one ascends through the troposphere.

Also, if it’s possible to get an old radiosonde (Fig. 1.24) from the local weather service, this could give students their first look at actual weather instruments. The importance of gathering accurate data was stressed in the earlier section on scientific inquiry, so demonstrating some of the instruments used in meteorology helps to emphasize this point.

F. Vertical Variations in Composition

This final unit allows you, the instructor, to engage in more interesting examples and pull up some beautiful pictures! The ionosphere can influence radio transmission to distant places on Earth. Many examples can be found online. Auroras are produced in the ionosphere (Fig. 1.26), and a wealth of beautiful pictures and videos are available online, such as here: http://www.geo.mtu.edu/weather/aurora/.

Answers to Chapter Questions

Answers to Concept Check 1.1

1. Meteorology is the scientific study of the atmosphere and the phenomena of weather. Weather refers to the state of the atmosphere at a given time and place. Weather is constantly changing, sometimes from hour to hour and at other times from day to day. Climate is a description of aggregate weather conditions based on observations that have been accumulated over many decades (usually at least 30 years). Climate is often summarized by average or mean values of the weather elements, but it also includes the extremes and variations.

2. The basic elements of weather and climate are those quantities or properties that are measured regularly and include (a) air temperature, (b) humidity, (c) type and amount of clouds, (d) type and amount of precipitation, (e) air pressure, and (f) wind speed and direction.

3. Examples of storm-related atmospheric hazards would be lightning, hurricane (winds and water), tornadoes, blizzards, hail and even freezing rain. Atmospheric hazards not necessarily storm related would include heat and cold waves, fog, wildfires, and drought.

Answers to Box 1.1

1. The highest rainfall total is approximately 14–15 inches (350–380 mm).

2. In addition to providing us with a unique perspective, satellites can also accurately gather data in remote areas (such as over oceans, as shown in Figure 1.A) where data can be scarce.

Answers to Concept Check 1.2

1. A scientific hypothesis is a tentative untested explanation regarding a natural event or process. A scientific theory is an explanation that has been tested many times by comparisons to measured data. Among the most important tests that a theory must pass is that of prediction. A successful theory must be able to correctly predict the nature of data or observations that are not otherwise known.
2. The basic steps would be: (1) A question is raised about the natural world; (2) scientific data are collected that relate to the question (Fig. 1.8); (3) questions are posed that relate to the data, and one or more working hypotheses are developed that may answer these questions; (4) observations and experiments are developed to test the hypotheses; (5) the hypotheses are accepted, modified, or rejected, based on extensive testing; (6) data and results are shared with the scientific community for critical and further testing.

Answers to Concept Check 1.3

1. The four spheres that constitute the Earth system are: the geosphere, or solid portion of Earth; the hydrosphere, or water portion of Earth; the atmosphere, Earth's gaseous envelope of air; and the biosphere, the totality of life on Earth.
2. The geosphere extends from the surface of Earth to the center of the planet, a depth of about 6400 kilometers (nearly 4000 miles). Although Earth's atmosphere extends from the surface thousands of miles outward into space, more than 99 percent of the atmosphere is within 30 kilometers (20 miles) of Earth's surface.
3. The oceans cover nearly 71 percent of Earth's surface and represent about 97 percent of the Earth's water supply.
4. A system is a group of interacting, or interdependent, parts that form a complex whole. Examples might be a car's cooling system, a city's transportation system, a country's political system, an approaching weather system, and Earth's solar system.
5. The Earth system receives its energy from the Sun and from internal heat left over from its formation and radioactivity.

Answers to Box 1.2

1. *Outgassing,* through which gases trapped in the planet's interior are released, formed Earth's first enduring atmosphere.
2. Earth's oxygen was released through the process of photosynthesis by early bacteria.

Answers to Concept Check 1.4

1. No. Air is a mixture of many discrete gases.
2. The two major components of clean, dry air are nitrogen (78 percent) and oxygen (20.9 percent).
3. Carbon dioxide is an efficient absorber of energy emitted by Earth and thus influences the heating of the atmosphere. Water vapor is the source of all clouds and precipitation, also

exerts a strong influence upon energy transfer through the atmosphere, and finally plays an important role in transferring heat from one place to another because of the heat absorbed and released during changes of state (termed *latent heat*). Latent heat also provides some of the energy to drive storms. Aerosols can act as surfaces upon which water vapor condenses, influence the amount of sunlight reaching the lower atmosphere by intercepting and reflecting some incoming solar energy, and contribute to optical phenomena such as an orange or red sunset.

4. Ozone is a form of oxygen that combines three oxygen atoms into each molecule (O_3). Ozone is very important to life on Earth because it absorbs damaging ultraviolet radiation from the Sun. If ozone were not present, our planet would be uninhabitable for most life as we know it. The term CFCs is an abbreviation for chlorofluorocarbons, a group of chemicals commonly used in refrigeration and air-conditioning systems and the production of certain plastics. When CFCs reach the stratosphere, chlorine atoms are released, which react with the ozone and convert some of it into ordinary oxygen. The net effect is depletion of the ozone layer.

Answers to Eye on the Atmosphere 1.1

1. Atmospheric pressure at 10 kilometers (6.2 miles) is approximately 250–270 millibars.
2. Approximately 75 percent of the atmosphere is below the jet.

Answers to Eye on the Atmosphere 1.2

1. The instrument package is called a radiosonde.
2. At 1 kilometer () (0.62 mile), the balloon is in the troposphere.
3. The atmosphere cools at an average of 6.5°C per kilometer (3.5°F per 1000 feet), so at 1 kilometer, the radiosonde would record a temperature of (17°C–6.5°C) or 10.5°C (51°F).
4. The balloon should expand due to falling atmospheric pressure.

Answers to Concept Check 1.5

1. Decrease, but the rate of pressure decrease is not constant. Air is highly compressible and pressure decreases at a decreasing rate with an increase in altitude until, beyond an altitude of about 3 kilometers (22 miles), the decrease is negligible.
2. No, the atmosphere rapidly thins as you travel away from Earth, until there are too few gas molecules to detect.
3. The lowermost layer of the atmosphere is the *troposphere*. It is in the troposphere that practically all of our weather occurs. The next layer is the *stratosphere*, followed by the *mesosphere*, and finally the *thermosphere*.
4. The presence of ozone in the stratosphere is responsible for the heating within this layer as the ozone molecules absorb ultraviolet radiation from the Sun.
5. Although the temperature of the gases in the thermosphere is high, the quantity of gas present is very small. Thus, little heat would be transferred to an object such as a satellite because only very few of the fast-moving molecules would collide with any foreign object.

6. The ionosphere is an electrically charged layer located in the altitude range between 80 and 400 kilometers (50 to 250 miles), where molecules of nitrogen and atoms of oxygen are readily ionized as they absorb high-energy shortwave solar energy. As clouds of charged particles emitted during magnetic storms on the Sun approach Earth, they are captured by Earth's magnetic field, which guides them toward the magnetic poles. As the ions enter Earth's upper atmosphere near the poles, they energize atoms of oxygen and molecules of nitrogen, causing them to emit light.

Answers to Concepts in Review

1.1 Hebes Mountain was experiencing a localized thunderstorm. Sinbad Country overall appears to have a very dry (desert) climate.

1.3 Glacial ice—frozen water—is part of the hydrosphere. If melted, it will rejoin the hydrologic cycle.

1.4 The graph shows changes in carbon dioxide levels. Levels have been gradually rising and just famously reached 400 ppm. The line is wavy due to the fluctuating levels of CO_2 in the atmosphere between seasons; levels fall in spring and summer when plants absorb more CO_2 and rise in the fall and winter when plants die and decompose.

Answers to Give It Some Thought

1. a) weather; b) climate; c) climate; d) weather; e) weather; f) climate; g) weather and climate; h) weather
2. a) climate; b) sunny; c) yes, based on long-term weather averages, you *should* experience a sunny day. However, on any particular day, the weather could differ according to the prevailing weather systems.
3. a) The light bulb has burned out; b) The power has been shut off; c) The light switch is defective.
4. A few examples: Figure 1.A provides information via satellite (Tropical Rainfall Measuring Mission) on global rainfall for a 7-day period in February 2014. Satellite images give us perspectives that are difficult to gain from more traditional sources. Moreover, the high-tech instruments aboard many satellites enable scientists to gather information from remote regions where data are otherwise scarce. Figure 1.8 shows an Automated Surface Observing System (ASOS) installation, one of nearly 900 in use for data gathering as part of the U.S. primary surface observing network. Data can be gathered across a broad area with relatively little effort and a composite picture of the atmosphere can then be created. SmartFigure 1.20 shows satellite images that can measure the level of depletion in the Antarctic ozone hole, allowing us to monitor vital ozone levels from a great distance. Figure 1.24 shows scientists releasing a weather balloon with a radiosonde, which can gather important data on upper-level atmospheric conditions.
5. a) about three (at 314 mb, need about three breaths to equal 1000 mb)

   b) At 12 kilometers (7.5 miles) air pressure is approximately 200 millibars, which means about 80 percent of the atmosphere is beneath the jet.

6. Answer: *c.* Thermometer. As one ascends, the different layers of the atmosphere are distinguished by the changes in temperature as one moves from one layer to the next.

7. Over Hawaii. Due to greater surface heating accompanied by well-developed thermal mixing at this latitude, the air expands and the troposphere is thicker over Hawaii than Alaska. The troposphere over Alaska may also be thicker in July than January due to greater atmospheric heating as well.

8. In a way, all four spheres may be thought to be involved. First, the geosphere is involved because it was the steep slopes and soil of the geosphere that provided the material for the mudslide. Because the biosphere also contributes material to the soil, the biosphere may be said to be involved as well. The hydrosphere was involved because it provided the rain that contributed to the mudslide, and finally the atmosphere provided the weather system that generated the rain.

Answers to end of the chapter Problems

1. a) Central New York State: 50s; northwest corner of Arizona: 20s

b) Coldest: Wyoming and south central Montana; Warmest: southern Florida

c) Fair weather

d) Central Maine. This is opposite to what one would normally expect (central Texas is generally warmer than central Maine).

2. a) January: 4°C (42°F); July: 29°C (85°F) (Answers may vary 1–2 degrees.)

b) Highest: 42°C (108°F); Lowest: –19°C (–2°F) (Answers may vary 1–2 degrees.)

3. Year 2011; 14 events; year 2005

4. a) 400 mb

b) 250 mb

c) Decreasing rate

5. 10°C (6.5°C/km × 2 km =13°C)

6. a) Height is 47 kilometers (30 miles); temperature is 0°C (32°F) (Answers may vary slightly.)

b) Altitude of 83 to 93 kilometers (50 to 55 miles); temperatures is –90°C (–130°F) (Answers may vary slightly.)

7. a) the poles

b) Lowest: poles; altitude of 9 kilometers (5.6 miles); temperature of –55°C (–67°F).

Highest: tropics; altitude of 17 kilometers (X10.5 miles); temperature of –75°C (–103°F).

8. a) temperature falls 65°C; at 6.5°C/km, tropopause would be 10 kilometers high

b) temperature would fall 104°C (6.5°C/km × 16 km = 104°C) to reach –79°C