Pearson New International Edition

McKnight's Physical Geography
A Landscape Appreciation

Darrel Hess Dennis Tasa

Eleventh Edition

ALWAYS LEARNING

PEARSON

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INTRODUCTION TO EARTH

From Chapter 1 of *Physical Geography: A Landscape Appreciation*, Eleventh Edition. Darrel Hess.

INTRODUCTION TO EARTH

IF YOU OPENED THIS BOOK EXPECTING THAT THE STUDY OF geography was going to be memorizing names and places on maps, you'll be surprised to find that geography is much more than that. Geographers study the location and distribution of things—tangible things such as rainfall, mountains, and trees, as well as less tangible things such as language, migration, and voting patterns. In short, geographers look for and explain patterns in the physical and human landscape.

In this text you'll learn about fundamental processes and patterns in the natural world—the kinds of things you can see whenever you walk outside: clouds in the sky, mountains, streams and valleys, and the plants and animals that inhabit the landscape. You'll also learn about human interactions with the natural environment—how events such as hurricanes, earthquakes, and floods affect our lives and the world around us, as well as how human activities are increasingly altering our environment. You'll understand—in other words you'll appreciate—the landscape in new ways.

This chapter sets the stage for your study of physical geography. Here we introduce concepts and terms.

As you study this chapter, think about these key questions:

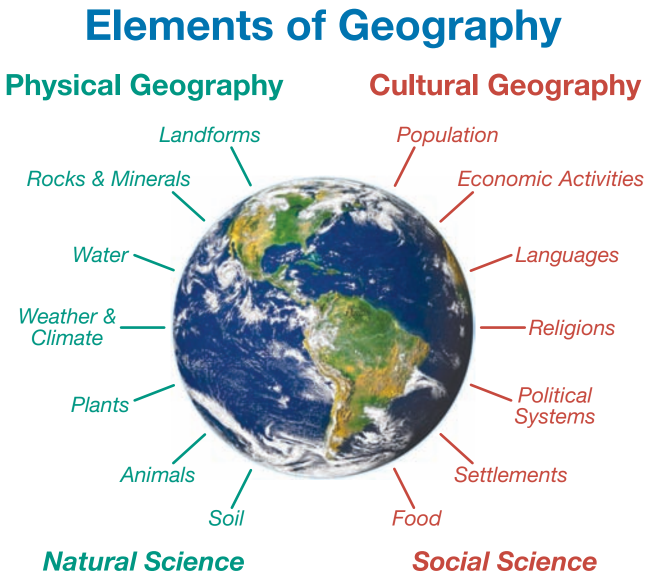
- **How do geographers study the world and use science to explain and understand the natural environment?**
- **What are the overlapping environmental "spheres" of Earth, and how does the concept of Earth systems help us understand the interrelationships of these spheres?**
- **How does Earth fit in with the solar system, and how does the size of Earth compare with the size of its surface features?**
- **How does the system of latitude and longitude describe location on Earth?**
- **What causes the annual change of seasons, and how do patterns of sunlight around Earth change during the year?**
- **How is the system of time zones used to establish times and dates around the world?**

GEOGRAPHY AND SCIENCE

The word *geography* comes from the Greek words meaning "Earth description." Several thousand years ago many scholars were indeed "Earth describers," and therefore geographers, more than anything else. Nonetheless, over the centuries there was a trend away from generalized Earth description toward more specialized disciplines—such as geology, meteorology, economics, and biology—and so geography as a field of study was somewhat overshadowed. Over the last few hundred years, however, geography reaffirmed its place in the academic world, and today geography is an expanding and flourishing field of study.

Seeing Geographically

This is a natural color, composite satellite image of Earth created by NASA. In the image can you see any indications of human presence? What might explain the differences in the color of land areas? What might explain the differences in the color of ocean areas?



▲ **Figure 1** The elements of geography can be grouped into two broad categories. Physical geography primarily involves the study of natural science, whereas cultural geography primarily entails the study of social science.

Studying the World Geographically

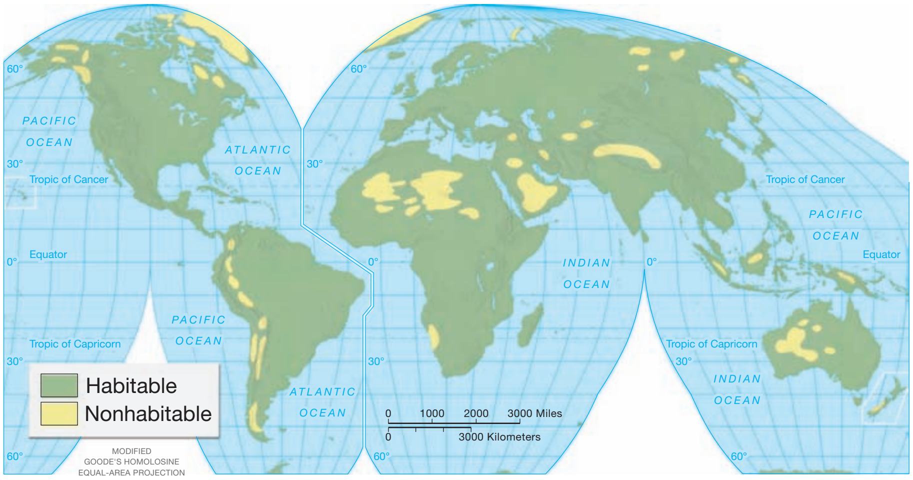
Geographers study how things differ from place to place—the distributional and locational relationships of things around the world (what is sometimes called the "spatial" aspect of things). Figure 1 shows the kinds of "things" geographers study, divided into two groups representing the two principal branches of geography. The elements of **physical geography** are natural in origin, and for this reason physical geography is sometimes called *environmental geography*. The elements of **cultural geography** are those of human endeavor, so this branch is sometimes referred to as *human geography*. The almost unlimited possible combinations of these various elements create the physical and cultural landscapes of the world that geographers study.

All of the items shown in Figure 1 are familiar to us, and this familiarity highlights a basic characteristic of geography as a field of learning: Geography doesn't have its own body of facts or objects that only geographers study. The focus of geology is rocks, the attention of economics is economic systems, demography examines human population, and so on. Geography, on the other hand, is much broader in scope than most other disciplines, "borrowing" its objects of study from related fields. Geographers, too, are interested in rocks and economic systems and population—especially in describing and understanding their location and distribution. We sometimes say that geography asks the fundamental question, "Why what is where and so what?"

Learning Check 1 **What are the differences between physical geography and cultural geography?**

Another basic characteristic of geography is its interest in interrelationships. One cannot understand the distribution of soils, for example, without knowing something about the rocks from which the soils were derived, the slopes on which the soils developed, and the climate and vegetation under which they developed. Similarly, it is impossible to comprehend the distribution of agriculture without an understanding of climate, topography, soil, drainage, population, economic conditions, technology, historical development, and many other factors, both physical and cultural. Because of its wide scope, geography bridges the academic gap between natural science and social science, studying all of the elements in Figure 1 in an intricate web of geographic interrelationships.

In our study of physical geography, our emphasis is on understanding the surface environment of Earth and the ways in which humans utilize and alter this environmental home. The habitable environment for humans exists over almost the entire land surface of Earth (Figure 2). It is only in the most extremely dry, cold, and rugged places that humans rarely venture, and even in such locations,



◀ **Figure 2** Most of Earth's land surface is habitable. The uninhabitable areas are too hot, too cold, too wet, too dry, or too rugged to support much human life—such as parts of the Arctic, most of Greenland, Antarctica, various mountainous regions, and several deserts.

other forms of life may be found. Earth's "life zone," encompassing oceanic, terrestrial, and atmospheric life, extends from the bottom of the deepest oceanic trench to the atmosphere above the highest mountain peaks—a zone perhaps 30 kilometers (20 miles) deep. It is primarily within this shallow life zone that geographers focus their interests and do their work.

In this text we concentrate on the physical elements of the landscape, the processes involved in their development, their distribution, and their basic interrelationships. As we proceed, this notion of landscape development by natural processes and landscape modification by humans serves as a central focus. We will pay attention to elements of cultural geography only when they help to explain the development or patterns of the physical elements—especially the ways in which humans influence or alter the physical environment.

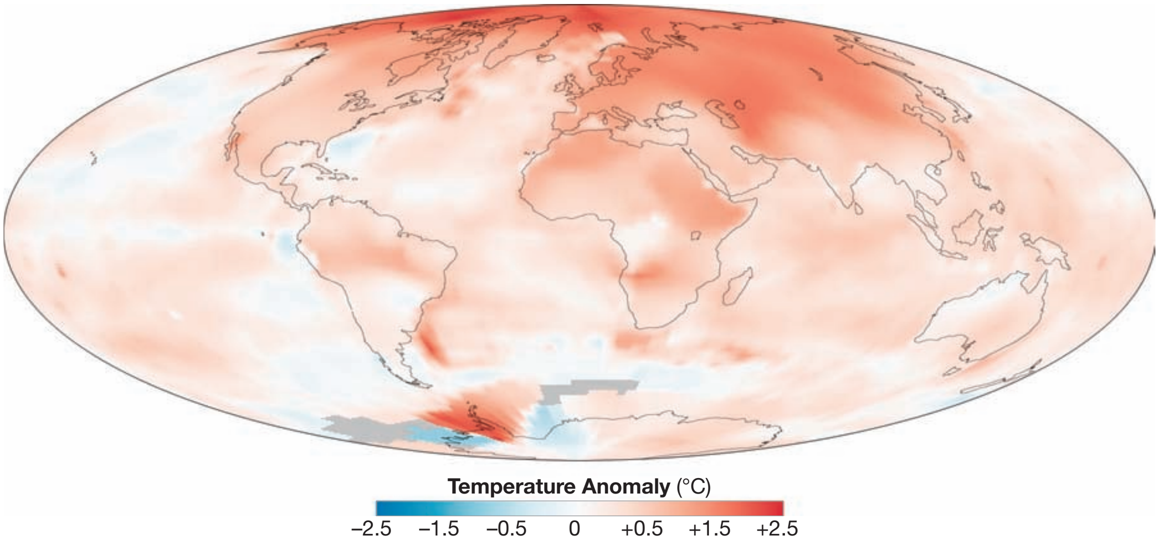
Global Environmental Change: Several broad geographic themes run through this book. One of these themes is *global environmental change*—both the human-caused and natural processes that are currently altering the landscapes of the world. Some of these changes can take place over a period of just a few years, whereas others require many decades or even thousands of years (Figure 3). We pay special attention to the accelerating impact of human activities on the global environment.

Rather than treat global environmental change as a separate topic, we integrate this theme throughout the text. To help with this integration, we supplement the main text with short boxed essays, such as those entitled "People and the Environment" that focus on specific cases of human interaction with the natural environment, as well as boxes entitled "Energy for the 21st Century" that focus on the challenge of supplementing—and perhaps eventually replacing—fossil fuels with renewable sources of energy. These essays serve to illustrate the connections between many aspects of the environment, such as the relationships between changing global temperatures, changing sea level, changing quantities of polar ice, and the changing distribution of plant and animal species, and the global economy and human society.

Globalization: A related but less obvious theme running through this text is *globalization*. In the broadest terms, globalization refers to the processes and consequences of an increasingly interconnected world—connections between the economies, cultures, and political systems of the world. Although globalization is most commonly associated with the cultural and economic realms of world, it is important to recognize the environmental components of globalization as well. For example, the loss of tropical rainforest for timber or commercial agriculture in some regions of the world is driven in part by growing demand for commodities in countries far away from the tropics (Figure 4). Similarly, rapid economic growth in newly industrialized countries is contributing to the already high atmospheric greenhouse gas emissions of industrialized countries—the interconnected economies of the world are thus interconnected in their influence on the natural environment.

Because of geography's global perspective and its interest in both the natural and human landscape, geographers are able to offer insights into many of the world's most pressing problems—problems too complex to address from a narrower perspective. For example, the detrimental consequences of climate change cannot be addressed if we ignore the economic, social, historical, and political aspects of the issue. Similarly, global inequities of wealth and political power cannot be addressed if we ignore environmental and resource issues.

Just about everything in the world is in one way or another connected with everything else! Geography helps us understand these connections.



◀ **Figure 3** Earth's climate is changing. This image shows the difference in temperature (the *temperature anomaly* in °C) during the period 2000 to 2009 compared with the average temperatures for the baseline period 1951 to 1980. *(NASA)*

▲ **Figure 4** Deforestation in some parts of the tropics is influenced by consumer demand in other parts of the world. This logging operation is in Perak, Malaysia.

Learning Check 2 **Why are physical geographers interested in globalization?**

The Process of Science

Because physical geography is concerned with processes and patterns in the natural world, knowledge in physical geography is advanced primarily through the study of science, and so it is useful for us to say a few words about science in general.

Science is often described—although somewhat simplistically—as a process that follows the *scientific method*:

1. Observe phenomena that stimulate a question or problem.
2. Offer an educated guess—a *hypothesis*—about the answer.
3. Design an experiment to test the hypothesis.
4. Predict the outcome of the experiment if the hypothesis is supported, and if the hypothesis is not supported.
5. Conduct the experiment and observe what actually happens.
6. Draw a conclusion or formulate a simple generalized "rule" based on the results of the experiment.

In practice, however, science doesn't always work through experimentation; in many fields of science, data collection through observation of a phenomenon is the basis of knowledge. In some regards science is best thought of as a process—or perhaps even as an attitude—for gaining knowledge. The scientific approach is based on observation, experimentation, logical reasoning, skepticism of unsupported conclusions, and the willingness to modify or even reject long-held ideas when new evidence contradicts them. For example, up until the 1950s most Earth scientists thought it impossible that the positions of continents could change over time; however, by the late 1960s enough new evidence had been gathered to convince them that their earlier ideas were wrong—the configuration of continents has changed, and continues to change!

Although the term "scientific proof" is sometimes used by the general public, strictly speaking, science does not "prove" ideas. Instead, science works by eliminating alternative explanations—eliminating explanations that aren't supported by evidence. In fact, in order for a hypothesis to be "scientific," there must be some test or possible observation that could *disprove* it—if there is no way to disprove an idea, then that idea simply cannot be supported by science.

The word "theory" is often used in everyday conversation to mean a "hunch" or conjecture. However, in science a *theory* represents the highest order of understanding for a body of information—a logical, well-tested explanation that encompasses a wide variety of facts and observations. Thus, the "theory of plate tectonics" represents an empirically supported, broadly accepted, overarching framework for understanding processes operating within Earth.

The acceptance of scientific ideas and theories is based on a preponderance of evidence, not on “belief” and not on the pronouncements of “authorities.” New observations and new evidence often cause scientists to revise their conclusions and theories or those of others. Much of this self-correcting process for refining scientific knowledge takes place through peer-reviewed journal articles. Peers—that is, fellow scientists—scrutinize a scientific report for sound reasoning, appropriate data collection, and solid evidence before it is published; reviewers need not agree with the author’s conclusions, but they strive to ensure that the research meets rigorous standards of scholarship before publication.

Because new evidence may prompt scientists to change their ideas, good science tends to be somewhat cautious in the conclusions that are drawn. For this reason, the findings of many scientific studies are prefaced by phrases such as “the evidence suggests,” or “the results most likely show.” In some cases, different scientists interpret the same data quite differently and so disagree in their conclusions. Frequently, studies find that “more research is needed.” The kind of uncertainty sometimes inherent in science may lead the general public to question the conclusions of scientific studies—especially when presented with a simple, and perhaps comforting nonscientific alternative. It is, however, this very uncertainty that often compels scientists to push forward in the quest for knowledge and understanding!

In this text we present the fundamentals of physical geography as it is supported by scientific research and evidence. In some cases, we will describe how our current understanding of a phenomenon developed over time; in other cases we will point out where uncertainty remains, where scientists still disagree, or where intriguing questions still remain.

Learning Check 3 **Why is the phrase “scientific proof” somewhat misleading?**

Numbers and Measurement Systems

Because so much of science is based on observation and measurable data, any thorough study of physical geography entails the use of mathematics. Although this text introduces physical geography primarily in a conceptual way without the extensive use of mathematical formulas, numbers and measurement systems are nonetheless important for us. Throughout the text, we use numbers and simple formulas to help illustrate concepts—the most obvious of which are numbers used to describe distance, size, weight, and temperature.

Two quite different systems of measurement are used around the world today. In the United States much of the general public is most familiar with the so-called *English System* of measurement—using measurements such as miles, pounds, and degrees Fahrenheit. However, most of the rest of the world—and the entire scientific community—uses the **International System** of measurement (abbreviated S.I. from the French *Système International*; also sometimes called the “metric system”)—using measurements such as kilometers, kilograms, and degrees Celsius.

TABLE 1 **Unit Conversions—Quick Approximations**

	S.I. to English Units	English to S.I. Units
Distance:	1 centimeter = a little less than ½ inch	1 inch = about 2½ centimeters
	1 meter = a little more than 3 feet	1 foot = about ⅓ meters
	1 kilometer = about ⅔ mile	1 yard = about 1 meter
		1 mile = about 1½ kilometers
Volume:	1 liter = about 1 quart	1 quart = about 1 liter
		1 gallon = about 4 liters
Mass:	1 gram = about 1⁄30 ounce	1 ounce = about 30 grams
	1 kilogram = about 2 pounds	1 pound = about ½ kilogram
Temperature:	1°C change = 1.8°F change	1°F change = about 0.6°C change

You will notice that this text gives measurements In both S.I. and English units. If you are not familiar with both systems, Table 1 provides some quick approximations to help you learn the basic equivalents in each.

ENVIRONMENTAL SPHERES AND EARTH SYSTEMS

From the standpoint of physical geography, the surface of Earth is a complex interface where four principal components of the environment meet and to some degree overlap and interact (Figure 5). These four components are often referred to as Earth’s *environmental spheres*.

Earth’s Environmental Spheres

The solid, inorganic portion of Earth is sometimes called the **lithosphere**[1] (*litho* is Greek for “stone”), comprising the rocks of Earth’s crust as well as the unconsolidated particles of mineral matter that overlie the solid bedrock. The lithosphere’s surface is shaped into an almost infinite variety of landforms, both on the seafloors and on the surfaces of the continents and islands.

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[1] In the context of *plate tectonics* and our study of landforms, the term “lithosphere” is used specifically to refer to large “plates” consisting of Earth’s crustal and upper mantle rock.

▲ **Figure 5** The physical landscape of Earth is composed of four overlapping and interacting systems called "spheres." The atmosphere is the air we breathe. The hydrosphere is the water of rivers, lakes, and oceans, the moisture in soil and air, as well as the snow and ice of the cryosphere. The biosphere is the habitat of all earthly life, as well as the life forms themselves. The lithosphere is the soil and bedrock that cover Earth's surface. This scene shows Wonder Lake and Mt. McKinley (Denali) in Denali National Park, Alaska.

The gaseous envelope of air that surrounds Earth is the **atmosphere** (*atmo* is Greek for "air"). It contains the complex mixture of gases needed to sustain life. Most of the atmosphere is close to Earth's surface, being densest at sea level and rapidly thinning with increased altitude. It is a very dynamic sphere, kept in almost constant motion by solar energy and Earth's rotation.

The **hydrosphere** (*hydro* is Greek for "water") comprises water in all its forms. The oceans contain the vast majority of the water found on Earth and are the moisture source for most precipitation. A subcomponent of the hydrosphere is known as the **cryosphere** (*cry* comes from the Greek word for "cold")—water frozen as snow and ice.

The **biosphere** (*bio* is Greek for "life") encompasses all the parts of Earth where living organisms can exist; in its broadest and loosest sense, the term also includes the vast variety of earthly life forms (properly referred to as *biota*).

These "spheres" are not discrete and separated entities but rather are considerably interconnected. This intermingling is readily apparent when considering an ocean—a body that is clearly a major component of the hydrosphere and yet may contain a vast quantity of fish and other organic life that are part of the biosphere. An even better example is soil, which is composed largely of bits of mineral matter (lithosphere) but also contains life forms (biosphere), along with air (atmosphere), soil moisture (hydrosphere), and perhaps frozen water (cryosphere) in its pore spaces.

The environmental spheres can serve to broadly organize concepts for the systematic study of Earth's physical geography and are used that way in this text.

Learning Check 4 **Briefly define the lithosphere, atmosphere, hydrosphere, cryosphere, and biosphere.**

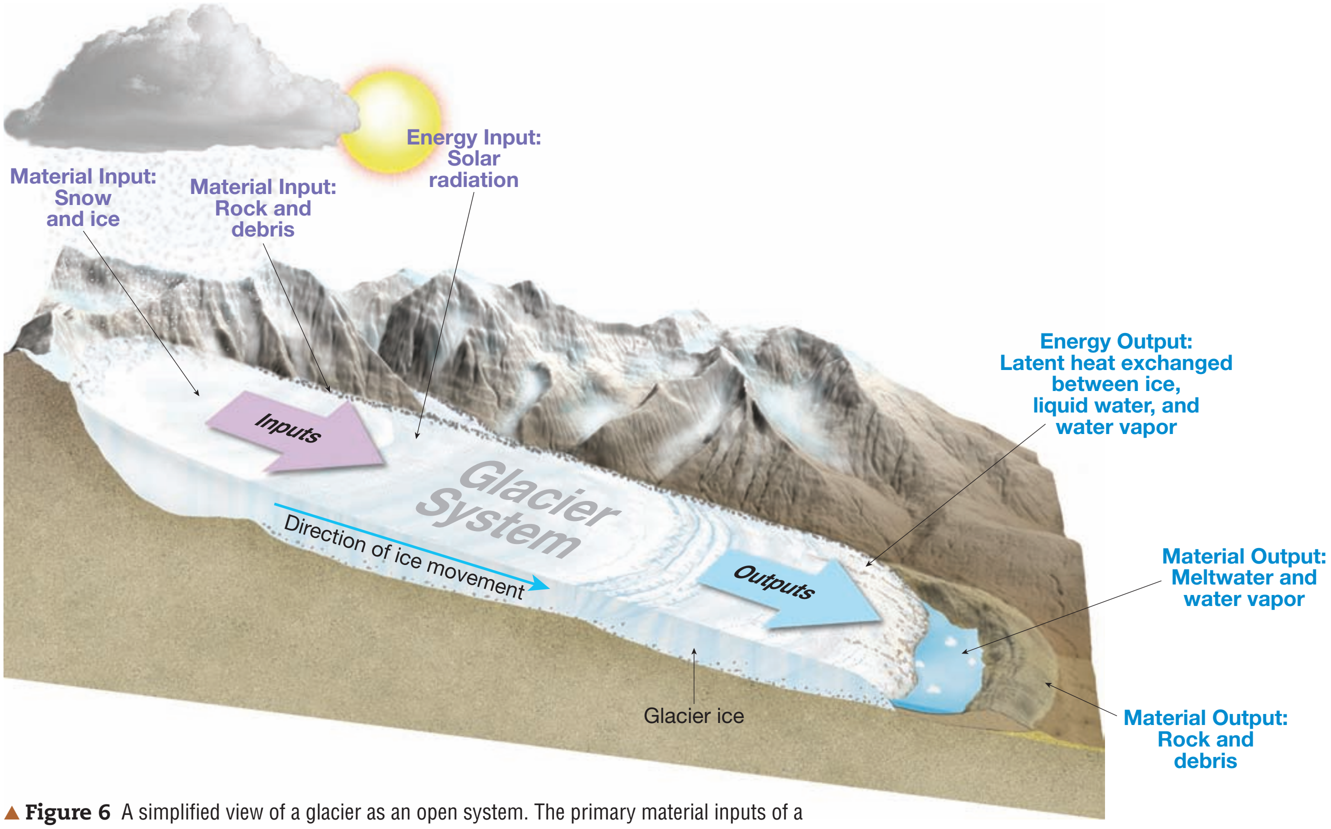
Earth Systems

Earth's environmental spheres operate and interact through a complex of *Earth systems*. By "system" we mean a collection of things and processes connected together and operating as a whole. In the human realm, for example, we talk of a global "financial system" that encompasses the exchange of money between institutions and individuals, or of a "transportation system" that involves the movement of people and commodities. In the natural world, systems entail the interconnected flows and storage of energy and matter.

Closed Systems: Some systems are effectively self-contained and therefore isolated from influences outside that system—and so are called *closed systems*. It is rare to find closed systems in nature. Earth as a whole is essentially a closed system with regard to matter—currently there is no significant increase or decrease in the amount of matter (the "stuff") of Earth, although relatively small but measurable amounts of meteoric debris arrives from space, and tiny amounts of gas are lost to space from the atmosphere. Energy, on the other hand, does enter and exit the Earth system constantly.

Open Systems: Most Earth systems are *open systems*—both energy and matter are exchanged across the system boundary. Matter and energy that enter the system are called *inputs*, and losses from the system to its surroundings are called *outputs*. For example, a glacier behaves as an open system (Figure 6). The material inputs to a glacier include water in the form of snow and ice, along with rocks and other materials picked up by the moving ice; the material outputs of a glacier include the meltwater and water vapor lost to the atmosphere, as well as the rock transported and eventually deposited by the ice. The most obvious energy input into a glacial system is solar radiation that melts the ice by warming the surrounding air and by direct absorption into the ice itself. But also at work are less obvious exchanges of energy that involve *latent heat*—energy stored by water during melting and evaporation, and released during freezing and condensation.

Equilibrium: When inputs and outputs are in balance over time, the conditions within a system remain the same; such a system can be described as being in *equilibrium*. For



▲ **Figure 6** A simplified view of a glacier as an open system. The primary material inputs of a glacier include snow, ice, and rock, whereas its outputs include meltwater, water vapor, and rock transported by the flowing ice. The energy interchange includes incoming solar radiation and the exchange of latent heat between ice, liquid water, and water vapor.

instance, a glacier will remain the same size over many years if its inputs of snow and ice are balanced by the loss of an equivalent amount of ice through melting. If, however, the balance between inputs and outputs changes, equilibrium will be disrupted—increasing snowfall for several years, for example, can cause a glacier to grow until a new equilibrium size is reached.

Interconnected Systems: In physical geography we study the myriad of interconnections between Earth's systems and subsystems. Continuing with our example of a glacier: The system of an individual glacier is interconnected with many other Earth systems, including Earth's solar radiation budget, wind and pressure patterns, and the hydrologic cycle—if inputs or outputs in those systems change, a glacier may also change. For instance, if air temperature increases through a change in Earth's solar radiation budget, both the amount of water vapor available to precipitate as snow and the rate of melting of that snow, may change, causing an adjustment in the size of the glacier.

Learning Check 5 **What does it mean when we say a system is in equilibrium?**

Feedback Loops: Some systems produce outputs that "feedback" into that system, reinforcing change. Over the last few decades increasing temperatures in the Arctic have reduced the amount of highly reflective, summer sea ice. As the area of sea ice has diminished, the darker, less reflective ocean has absorbed more solar radiation, contributing to the temperature increase—which in turn has reduced the amount of sea ice even more, further reducing reflectance and increasing absorption. Were Arctic temperatures to decrease, an expanding cover of reflective sea ice would reduce absorption of solar radiation and so reinforce a cooling trend. These are examples of *positive feedback loops*—change within a system continuing in one direction.

Conversely, *negative feedback loops* tend to inhibit a system from changing—in this case increasing a system input tends to *decrease* further change, keeping the system in equilibrium. For example, an increase in air temperature may increase the amount of water vapor in the air; this greater amount of water vapor may in turn condense and increase the cloud cover—which can reflect incoming solar radiation and so prevent a further temperature increase.

Although systems may resist change through negative feedback loops, at some point a system may reach a *tipping point* or *threshold* beyond which the system becomes unstable and changes abruptly until it reaches a new equilibrium. For instance, it is possible that the increasing freshwater runoff from melting glaciers in the Arctic could disrupt the energy transfer of the slow, deep ocean *thermohaline circulation* in the Atlantic Ocean, triggering a sudden change in climate.

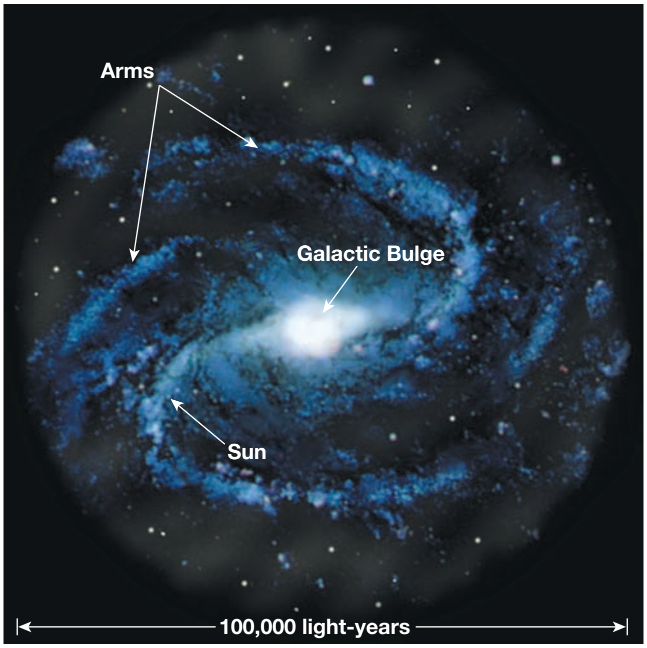
The preceding examples are not intended to confuse you, but rather to illustrate the great complexity of Earth's interconnected systems! Because of this complexity, in this text we often first describe one process or Earth system in isolation before presenting its interconnections with other systems.

Learning Check 6 What is the difference between a positive feedback loop and a negative feedback loop?

EARTH AND THE SOLAR SYSTEM

Animation
Solar System Formation

Earth is part of a larger *solar system*—an open system with which Earth interacts. Earth is an extensive rotating mass of mostly solid material that orbits the enormous ball of superheated gases we call the Sun. The geographer's concern with spatial relationships properly begins with the relative location of this "spaceship Earth" in the universe.



▲ **Figure 7** The structure of the Milky Way Galaxy showing the approximate location of our Sun on one of the spiral arms.

The Solar System

Earth is one of eight planets of our solar system, which also contains more than 160 natural satellites or "moons" revolving around the planets, an uncertain number of smaller *dwarf planets* such as Pluto, scores of comets (bodies composed of frozen liquid and gases together with small pieces of rock and metallic minerals), more than 500,000 asteroids (small, rocky, and sometimes icy objects, mostly less than a few kilometers in diameter), and millions of meteoroids (most of them the size of sand grains).

The medium-massed star we call the Sun is the central body of the solar system and makes up more than 99.8 percent of its total mass. The solar system is part of the Milky Way Galaxy, which consists of at least 200,000,000,000 stars arranged in a disk-shaped bared-spiral that is about 100,000 light-years in diameter (1 light-year equals about 9.5 trillion kilometers—the distance a beam of light travels over a period of one year) and 10,000 light-years thick at the center (Figure 7). The Milky Way Galaxy is only one of hundreds of billions of galaxies in the universe.

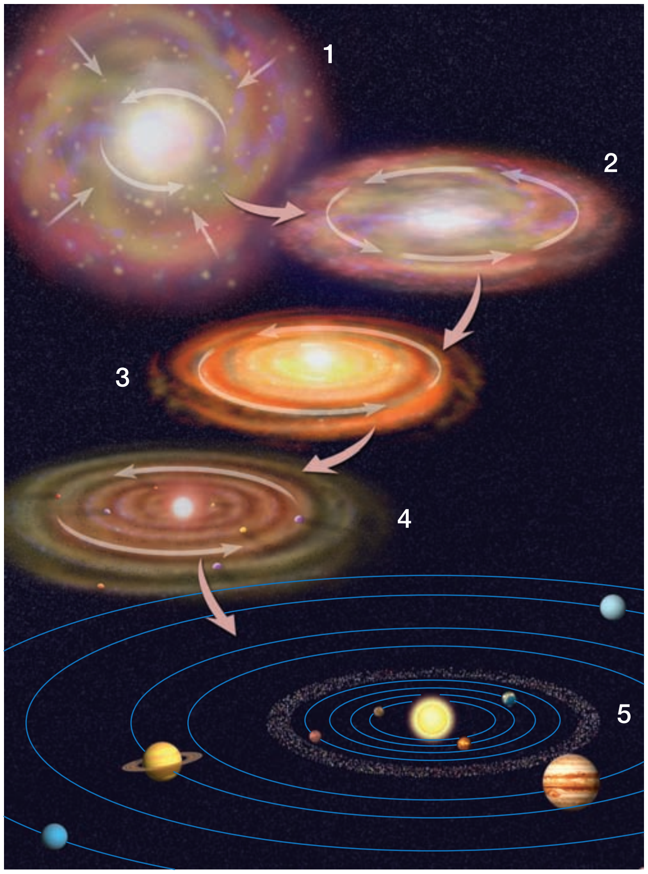
To begin to develop an understanding for astronomical distances, we might consider a reduced-scale model of the universe: if the distance between Earth and the Sun, which is about 150,000,000 kilometers (93,000,000 miles), is taken to be 2.5 centimeters (1 inch), then the distance from Earth to the nearest star would be 7.2 kilometers (4.5 miles), and the distance from Earth to the next similar-sized galaxy beyond the Milky Way would be about 240,000 kilometers (150,000 miles)!

Origins: The origin of Earth, and indeed of the universe, is incompletely understood. It is generally accepted that the universe began with a cosmic event called the *big bang*. The most widely held view is that the big bang took place some 13.7 billion years ago—similar to the age of the oldest known stars. The big bang began in a fraction of a second as an infinitely dense and infinitesimally small bundle of energy containing all of space and time started to expand away in all directions at extraordinary speeds, pushing out the fabric of space and filling the universe with the energy and matter we see today.

Our solar system originated between 4.5 and 5 billion years ago when a *nebula*—a huge, cold, diffuse cloud of gas and dust—began to contract inward, owing to its own gravitational collapse, forming a hot, dense *protostar* (Figure 8). This hot center—our Sun—was surrounded by a cold, revolving disk of gas and dust that eventually condensed and coalesced to form the planets.

All of the planets revolve around the Sun in elliptical orbits, with the Sun located at one focus (looking "down" on the solar system from a vantage point high above the North Pole of Earth, the planets appear to orbit in a counterclockwise direction around the Sun). All the planetary orbits are in nearly the same plane (Figure 9), perhaps revealing their relationship to the original spinning direction of the nebular disk. The Sun rotates on its axis from west to east. Moreover, most of the planets rotate from west to east on their own axes (Uranus rotates "sideways" with its rotational axis almost parallel to its orbital plane; Venus rotates from east to west). The planets revolve more slowly and generally have a lower temperature as their distance from the Sun increases.

The Planets: The four inner *terrestrial planets*—Mercury, Venus, Earth, and Mars—are generally smaller, denser, and less oblate (more nearly spherical), and they rotate more slowly on their axes than the four outer



▲ **Figure 8** The birth of the solar system. (1) Diffuse gas cloud, or nebula, begins to contract inward. (2) Cloud flattens into nebular disk as it spins faster around a central axis. (3) Particles in the outer parts of the disk collide with each other to form protoplanets. (4) Protoplanets coalesce into planets and settle into orbits around the hot center. (5) The final product: a central Sun surrounded by eight orbiting planets (solar system not shown in correct scale). The original nebular disk was much larger than our final solar system.

Jovian planets—Jupiter, Saturn, Uranus, and Neptune. Also, the inner planets are composed principally of mineral matter and, except for airless Mercury, have diverse but relatively shallow atmospheres.

By contrast, the four Jovian planets tend to be much larger, more massive (although they are less dense), and much more oblate (less perfectly spherical) because they rotate more rapidly. The Jovian planets are mostly composed of elements such as hydrogen and helium—liquid near the surface, but frozen toward the interior—as well as ices of compounds such as methane and ammonia. The Jovian planets generally have atmospheres that are dense, turbulent, and relatively deep.

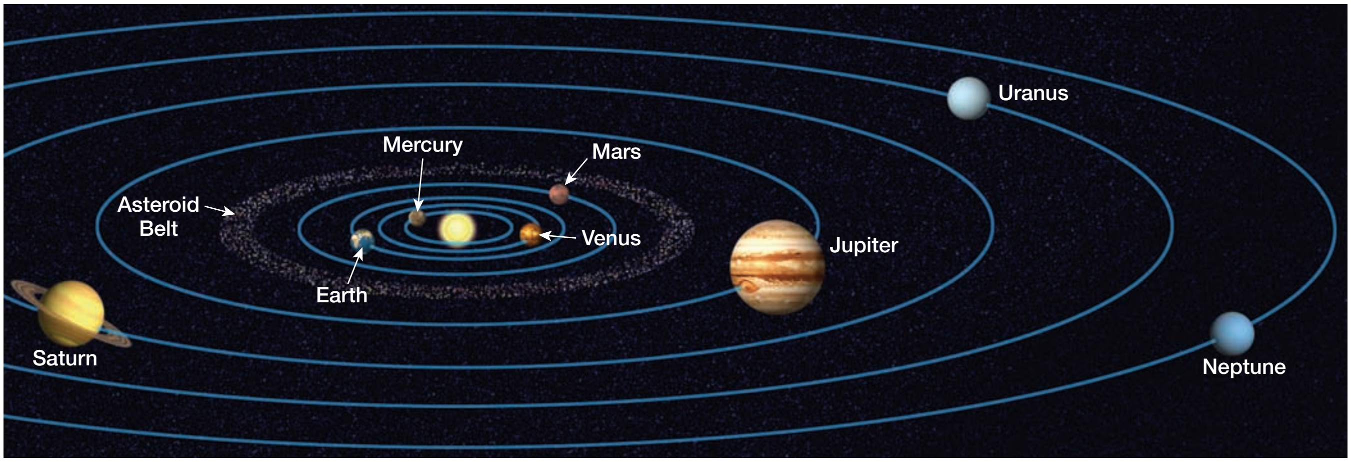
It was long thought that tiny Pluto was the ninth and outermost planet in the solar system. In recent years, however, astronomers have discovered other icy bodies, such as distant Eris, Makemake, and Haumea that are similar to Pluto and orbiting the Sun beyond Neptune in what is referred to as the *Kuiper Belt* or *trans-Neptunian region*. In June 2008 the International Astronomical Union reclassified Pluto as a special type of dwarf planet known as a *plutoid*. Some astronomers speculate that there may be several dozen yet-to-be-discovered plutoids and other dwarf planets in the outer reaches of the solar system.

Learning Check 7 **Contrast the characteristics of the terrestrial and Jovian planets in our solar system.**

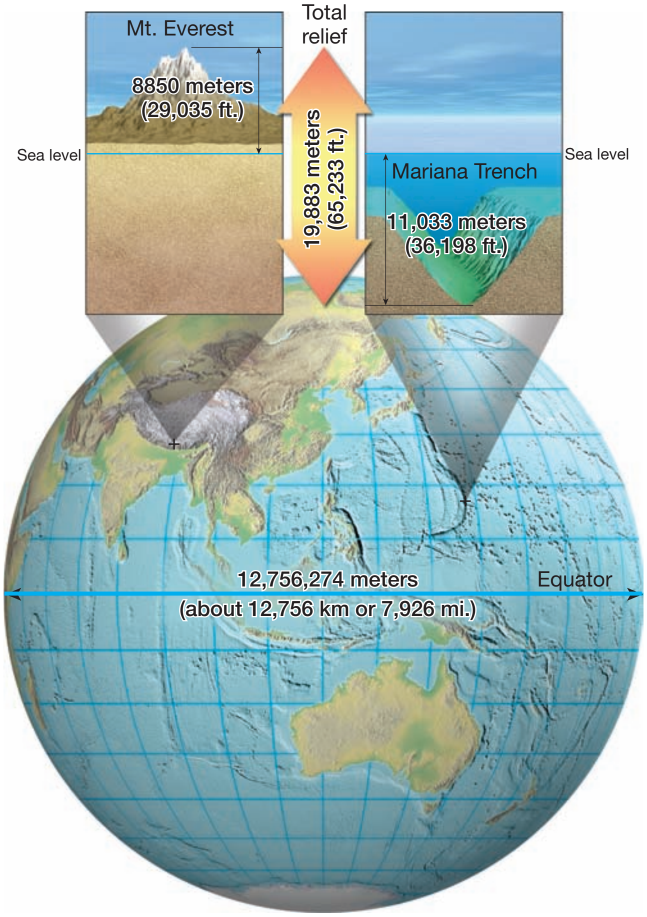
The Size and Shape of Earth

Is Earth large or small? The answer to this question depends on one's frame of reference. If the frame of reference is the universe, Earth is almost infinitely small. The diameter of our planet is only about 13,000 kilometers (7900 miles), a tiny distance at the scale of the universe—for instance, the Moon is 385,000 kilometers (239,000 miles) from Earth, the Sun is 150,000,000 kilometers (93,000,000 miles) away, and the nearest star is 40,000,000,000,000 kilometers (25,000,000,000,000 miles) distant.

The Size of Earth: In a human frame of reference, however, Earth is impressive in size. Its surface varies in elevation from the highest mountain peak, Mount Everest, at 8850 meters (29,035 feet) above sea level, to the deepest oceanic trench, the Mariana Trench of the Pacific Ocean, at



▲ **Figure 9** The solar system (not drawn to correct scale). The Sun is not exactly at the center of the solar system—the planets revolve around the Sun in elliptical orbits. The Kuiper Belt, which includes dwarf planets such as Pluto, begins beyond Neptune.



▲ **Figure 10** Earth is large relative to the size of its surface features. Earth's maximum relief (the difference in elevation between the highest and lowest points) is 19,883 meters (65,233 feet) or about 20 kilometers (12 miles) from the top of Mount Everest to the bottom of the Mariana Trench in the Pacific Ocean.

11,033 meters (36,198 feet) below sea level, a total difference in elevation of 19,883 meters (65,233 feet).

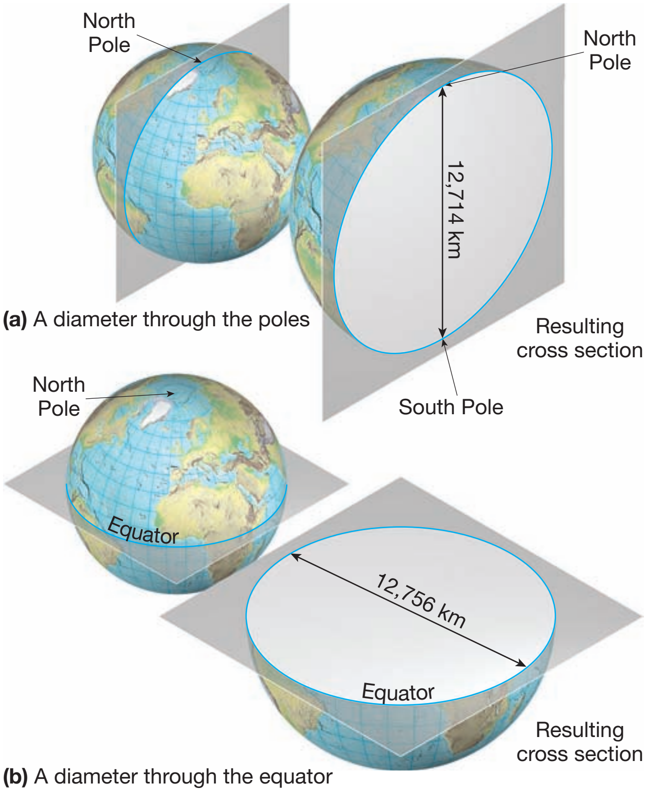
Although prominent on a human scale of perception, this difference is minor on a planetary scale, as Figure 10 illustrates. If Earth were the size of a basketball, Mount Everest would be an imperceptible pimple no greater than 0.17 millimeter (about 7 thousandths of an inch) high. Similarly, the Mariana Trench would be a tiny crease only 0.21 millimeter (about 8 thousandths of an inch) deep—this represents a depression smaller than the thickness of a sheet of paper.

Our perception of the relative size of topographic irregularities on Earth is often distorted by three-dimensional wall maps and globes that emphasize such landforms. To portray any noticeable appearance of topographic variation, the vertical distances on such maps are usually exaggerated 8 to 20 times their actual proportional dimensions—as are many diagrams used in this text. Further, many diagrams illustrating features of the atmosphere also exaggerate relative sizes to convey important concepts.

More than 2600 years ago Greek scholars correctly reasoned Earth to have a spherical shape. About 2200 years ago, Eratosthenes, the director of the Greek library at Alexandria, calculated the circumference of Earth trigonometrically. He determined the angle of the noon Sun rays at Alexandria and at the city of Syene, 960 kilometers (600 miles) away. From these angular and linear distances he was able to estimate an Earth circumference of almost 43,000 kilometers (26,700 miles) which is reasonably close to the actual figure of 40,000 kilometers (24,900 miles).

The Shape of Earth: Earth is almost, but not quite, spherical. The cross section revealed by a cut through the equator would be circular, but a similar cut from pole to pole would be an ellipse rather than a circle (Figure 11). Any rotating body has a tendency to bulge around its equator and flatten at the polar ends of its rotational axis. Although the rocks of Earth may seem quite rigid and immovable to us, they are sufficiently pliable to allow Earth to develop a bulge around its middle. The slightly flattened polar diameter of Earth is 12,714 kilometers (7900 miles), whereas the slightly bulging equatorial diameter is 12,756 kilometers (7926 miles), a difference of only about 0.3 percent. Thus, our planet is properly described as an *oblate spheroid* rather than a true sphere. However, because this variation from true sphericity is exceedingly small, in most cases in this text we will treat Earth as if it were a perfect sphere.

Learning Check 8 **What are Earth's highest and lowest points, and what is the approximate elevation difference between them?**



(a) A diameter through the poles

(b) A diameter through the equator

▲ **Figure 11** Earth is not quite a perfect sphere. Its surface flattens slightly at the North Pole and the South Pole and bulges out slightly around the equator. Thus, a cross section through the poles, shown in (a), has a diameter slightly less than the diameter of a cross section through the equator, shown in (b).

THE GEOGRAPHIC GRID—LATITUDE AND LONGITUDE

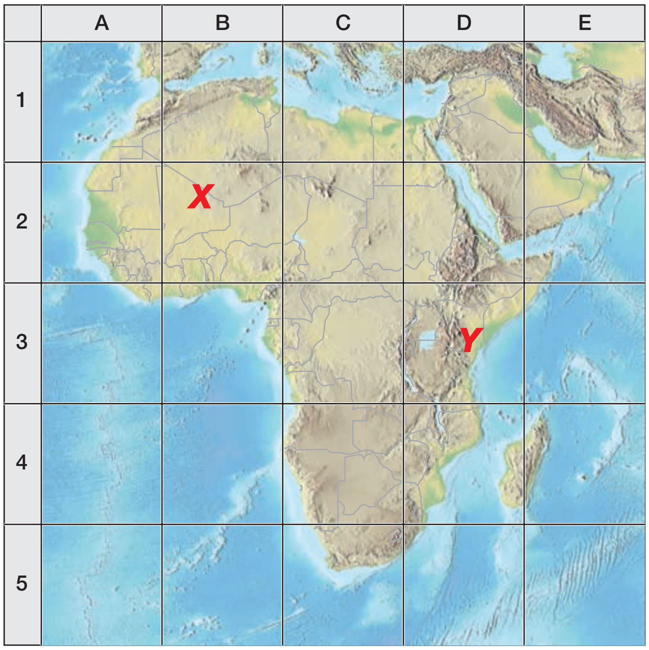
Any understanding of the distribution of geographic features over Earth's surface requires some system of accurate location. The simplest technique for achieving this is a grid system consisting of two sets of lines that intersect at right angles, allowing the location of any point on the surface to be described by the appropriate intersection, as shown in Figure 12. Such a rectangular grid system has been reconfigured for Earth's spherical surface.

If our planet were a nonrotating body, the problem of describing surface locations would be more difficult than it is: imagine trying to describe the location of a particular point on a perfectly round, perfectly clean Ping-Pong ball. Because Earth does rotate, we can use its rotation axis as a starting point to describe locations.

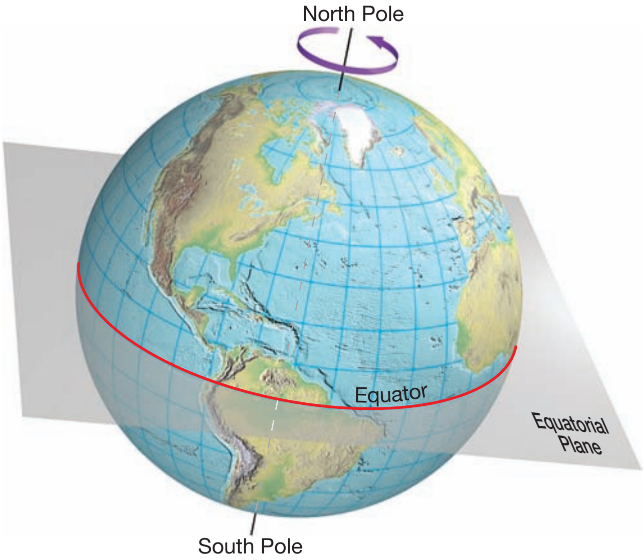
Earth's rotation axis is an imaginary line passing through Earth that connects the points on the surface called the **North Pole** and the **South Pole** (Figure 13). Further, if we visualize an imaginary plane passing through Earth halfway between the poles and perpendicular to the axis of rotation, we have another valuable reference feature: the *plane of the equator*. Where this plane intersects Earth's surface is the imaginary midline of Earth, called simply the **equator**. We use the North Pole, South Pole, rotational axis, and equatorial plane as natural reference features for measuring and describing locations on Earth's surface.

Great Circles: Any plane that is passed through the center of a sphere bisects that sphere (divides it into two equal halves) and creates what is called a **great circle** where it intersects the surface of the sphere (Figure 14a). The equator is such a great circle. Planes passing through any other part of the sphere produce what are called *small circles* where they intersect the surface (Figure 14b). Great circles have two properties of special interest for us:

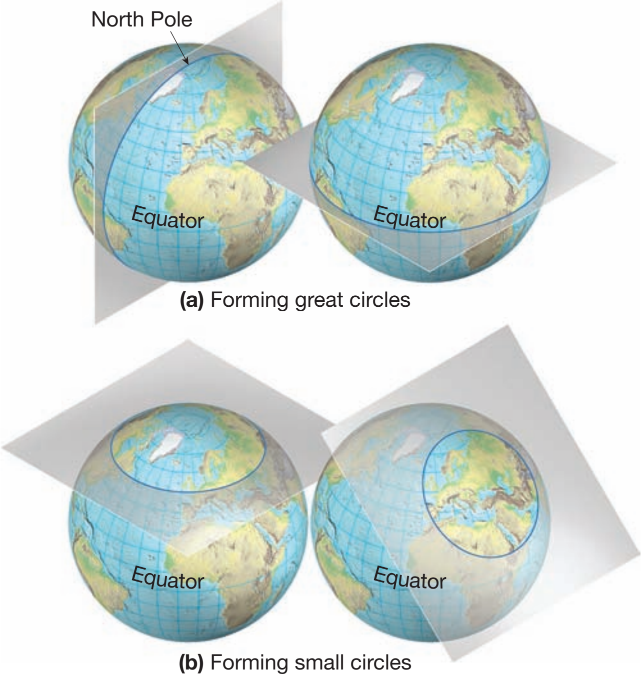
1. A great circle is the largest circle that can be drawn on a sphere; it represents the circumference of that sphere and divides its surface into two equal halves or *hemispheres*. As we'll see later in this chapter, the



▲ **Figure 12** An example of a grid system. The location of point X can be described as 2B or as B2; the location of Y is 3D or D3.



▲ **Figure 13** Earth spins around its rotation axis, an imaginary line that passes through the North Pole and the South Pole. An imaginary plane bisecting Earth midway between the two poles defines the equator.



(a) Forming great circles

(b) Forming small circles

▲ **Figure 14** Comparison of great and small circles. (a) A great circle results from the intersection of Earth's surface with any plane that passes through Earth's center. (b) A small circle results from the intersection of Earth's surface with any plane that does not pass through Earth's center.

dividing line between the daytime and nighttime halves of Earth is a great circle.

2. A path between two points along the arc of a great circle is always the shortest route between those points. Such routes on Earth are known as *great circle routes*.

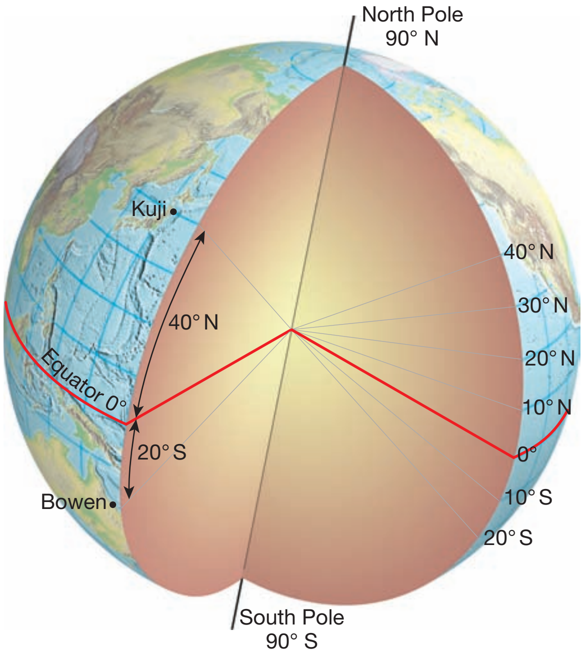
The geographic grid used as the locational system for Earth is based on the principles just discussed. Furthermore, the system is closely linked with the various positions assumed by Earth in its orbit around the Sun. The grid system of Earth is referred to as a *graticule* and consists of lines of latitude and longitude.

Learning Check 9 **What is a great circle? Provide one example of a great circle.**

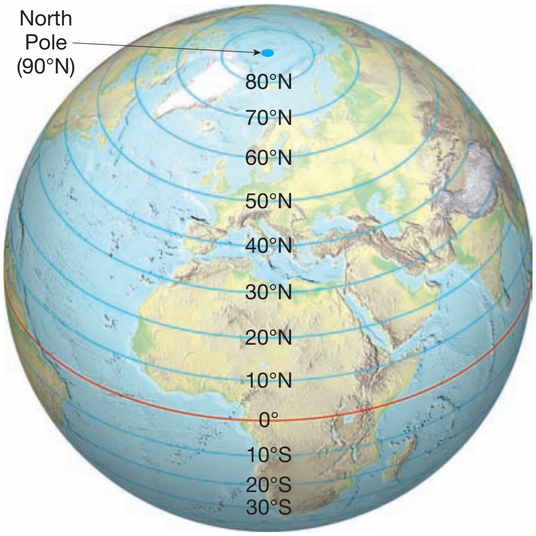
Latitude

Latitude is a description of location expressed as an angle north or south of the equator. As shown in Figure 15, we can project a line from any location on Earth's surface to the center of Earth. The angle between this line and the equatorial plane is the latitude of that location.

Latitude is expressed in degrees, minutes, and seconds. There are 360 degrees (°) in a circle, 60 minutes (') in one degree, and 60 seconds (″) in one minute. With the advent of GPS navigation, it is increasingly common to see latitude and longitude designated using decimal notation, for example, 38°22´47″ N can be written 38°22.78´ N or even 38.3797° N.



▲ **Figure 15** Measuring latitude. An imaginary line from Kuji, Japan, to Earth's center makes an angle of 40° with the equator. Therefore, Kuji's latitude is 40° N. An imaginary line from Bowen, Australia, to Earth's center makes an angle of 20°, giving this city a latitude of 20° S.



▲ **Figure 16** Lines of latitude indicate north-south location. They are called *parallels* because they are always parallel to each other.

Latitude varies from 0° at the equator to 90° north at the North Pole and 90° south at the South Pole. Any position north of the equator is north latitude, and any position south of the equator is south latitude (the equator itself is simply referred to as having a latitude of 0°).

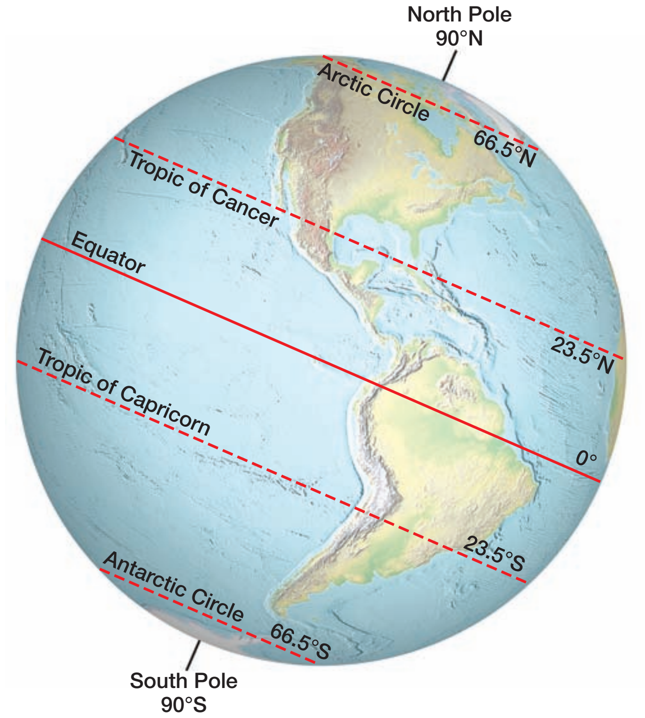
A line connecting all points of the same latitude is called a **parallel**—because it is parallel to all other lines of latitude (Figure 16). The equator is the parallel of 0° latitude, and it, alone of all parallels, constitutes a great circle. All other parallels are small circles—all aligned in true east–west directions on Earth's surface. Because latitude is expressed as an angle, it can be infinitely subdivided—parallels can be constructed for every degree of latitude, or even for fractions of a degree of latitude.

Although it is possible to either construct or visualize an unlimited number of parallels, seven latitudes are of particular significance in a general study of Earth (Figure 17):

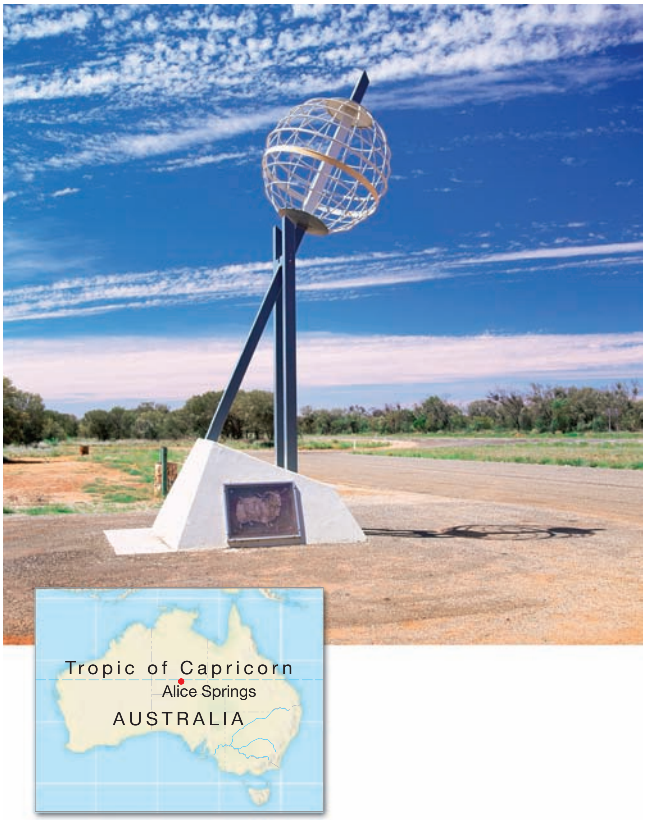
1. Equator, 0°
2. Tropic of Cancer, 23.5° N
3. Tropic of Capricorn, 23.5° S (Figure 18)
4. Arctic Circle, 66.5° N
5. Antarctic Circle, 66.5° S
6. North Pole, 90° N
7. South Pole, 90° S

The North Pole and South Pole are of course points rather than lines, but can be thought of as infinitely small parallels. The significance of these seven parallels will be explained later in this chapter when we discuss the seasons.

Learning Check 10 **Why are lines of latitude called parallels?**



▲ **Figure 17** Seven important parallels. As we will see when we discuss the seasons, these latitudes represent special locations where rays from the Sun strike Earth's surface on certain days of the year.



▲ **Figure 18** The Tropic of Capricorn; like all other parallels of latitude, is an imaginary line. As a significant parallel, however, its location is often commemorated by a sign. This scene is near Alice Springs in the center of Australia.

Descriptive Zones of Latitude: Regions on Earth are sometimes described as falling within general bands or zones of latitude. The following common terms associated with latitude are used throughout this text (note that there is some overlap between several of these terms):

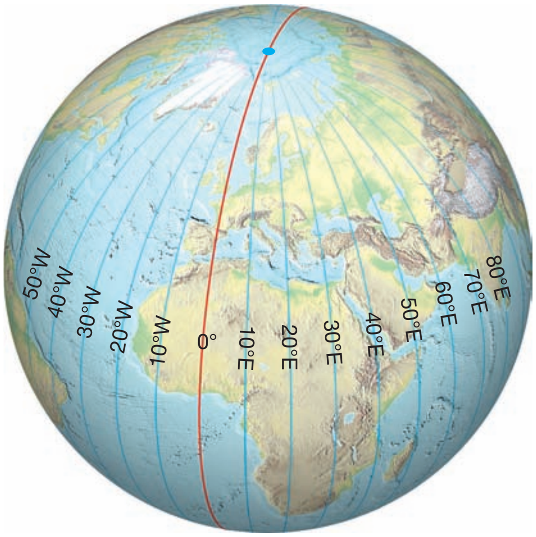
- *Low latitude*—generally between the equator and 30° N and S
- *Midlatitude*—between about 30° and 60° N and S
- *High latitude*—latitudes greater than about 60° N and S
- *Equatorial*—within a few degrees of the equator
- *Tropical*—within the tropics (between 23.5° N and 23.5° S)
- *Subtropical*—slightly poleward of the tropics, generally around 25–30° N and S
- *Polar*—within a few degrees of the North or South Pole

Nautical Miles: Each degree of latitude on the surface of Earth covers a north–south distance of about 111 kilometers (69 miles). The distance varies slightly with latitude because of the flattening of Earth at the poles. The distance measurement of a *nautical mile*—and the description of speed known as a *knot* (one nautical mile per hour)—is defined by the distance covered by one minute of latitude (1´), the equivalent of about 1.15 statute ("ordinary") miles or about 1.85 kilometers.

Longitude

Latitude comprises the north–south component of Earth's grid system. The other half is **longitude**—an angular description of east–west location, also measured in degrees, minutes, and seconds.

Longitude is represented by imaginary lines extending from pole to pole and crossing all parallels at right angles. These lines, called **meridians**, are not parallel to one another except where they cross the equator. Any pair of meridians is farthest apart at the equator, becoming increasingly close together northward and southward and finally converging at the poles (Figure 19).



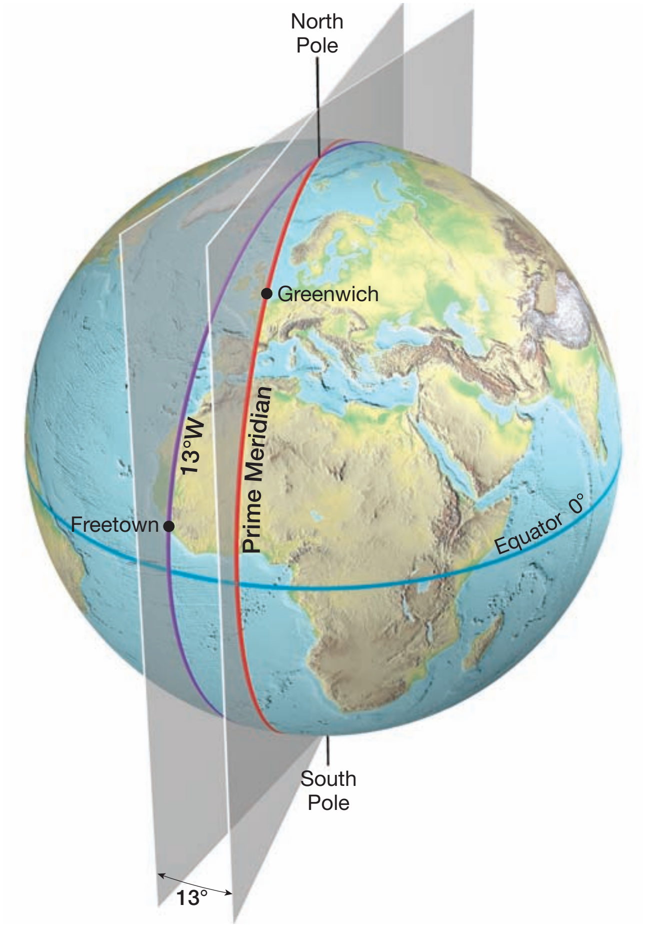
▲ **Figure 19** Lines of longitude, or *meridians*, indicate east–west location and all converge at the poles.

Establishing the Prime Meridian: The equator is a natural baseline from which to measure latitude, but no such natural reference line exists for longitude. Consequently, for most of recorded history, there was no accepted longitudinal baseline; each country would select its own "prime meridian" as the reference line for east–west measurement. Thus, the French measured from the meridian of Paris, the Italians from the meridian of Rome, and so forth. At least 13 prime meridians were in use in the 1880s. Not until the late 1800s was standardization finally achieved.

United States and Canadian railway executives adopted a standard time system for all North American railroads in 1883, and the following year an international conference was convened in Washington, D.C., to achieve the same goal on a global scale and to agree upon a single prime meridian. After weeks of debate, the delegates chose the meridian passing through the Royal Observatory at Greenwich, England, just east of London, as the **prime meridian** for all longitudinal measurement (Figure 20). The principal argument for adopting the Greenwich meridian as the prime meridian was a practical one: more than two-thirds of the world's shipping lines already used the Greenwich meridian as a navigational base.

▲ **Figure 20** The prime meridian of the world, longitude 0°0′0″ at Greenwich, England, which is about 8 km (5 miles) from the heart of London.

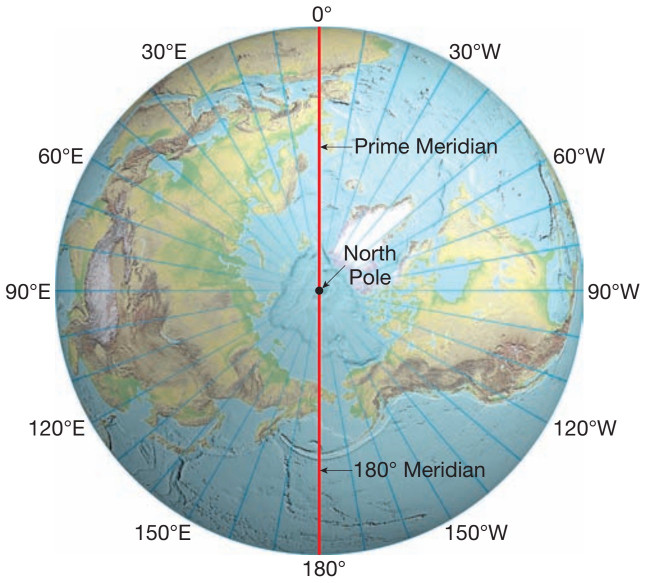
Thus, an imaginary north–south plane passing through Greenwich and through Earth's axis of rotation represents the plane of the prime meridian. The angle between this plane and a plane passed through any other point and the axis of Earth is a measure of longitude. For example, the angle between the Greenwich plane and a plane passing through the center of the city of Freetown (in the western African country of Sierra Leone) is 13 degrees, 15 minutes, and 12 seconds. Because the angle is formed west of the prime meridian, the longitude of Freetown is written 13°15′12″ W (Figure 21).



▲ **Figure 21** The meridians that mark longitude are defined by intersecting imaginary planes passing through the poles. Shown here are the planes for the prime meridian through Greenwich, England, and the meridian through Freetown, Sierra Leone, at 13° west longitude.

Measuring Longitude: Longitude is measured both east and west of the prime meridian to a maximum of 180° in each direction. Exactly halfway around the globe from the prime meridian, in the middle of the Pacific Ocean, is the 180° meridian (Figure 22). All places on Earth, then, have a location that is either east longitude or west longitude, except for points exactly on the prime meridian (described simply as 0° longitude) or exactly on the 180th meridian (described as 180° longitude).

The distance between any two meridians varies predictably. At the equator, the surface length of one degree of longitude is about the same as that of one degree of latitude. However, because meridians converge at the poles, the distance covered by one degree of longitude decreases poleward (Figure 23), diminishing to zero at the poles where all meridians meet at a point.



▲ **Figure 22** A polar view of meridians radiating from the North Pole. Think of each line as the top edge of an imaginary plane passing through both poles. All the planes are perpendicular to the plane of the page.

Locating Points on the Geographic Grid

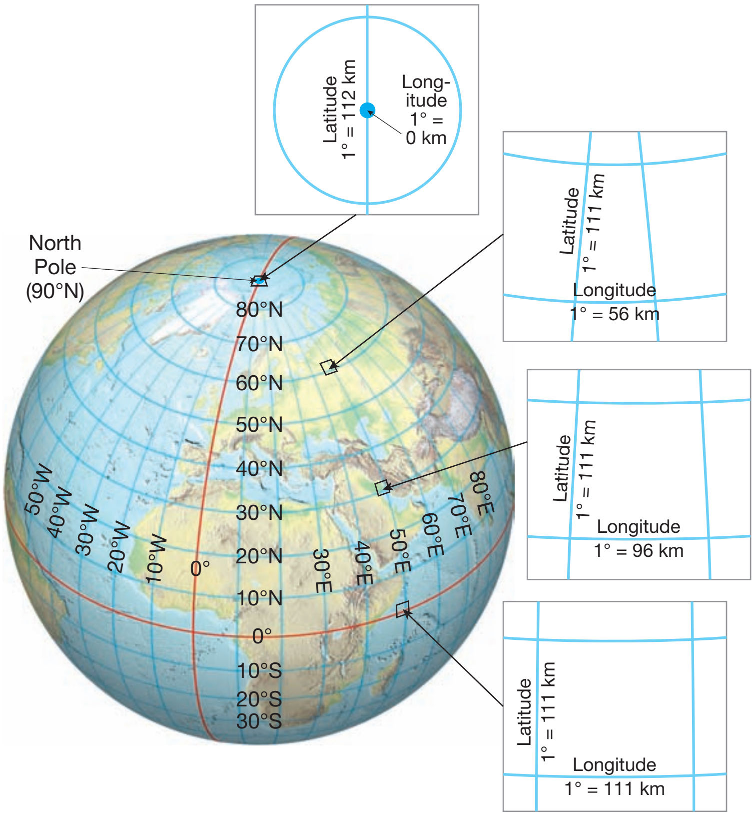
The network of intersecting parallels and meridians creates a geographic grid over the entire surface of Earth (see Figure 23). The location of any place on Earth's surface can be described with great precision by reference to detailed latitude and longitude data. For example, at the 1964 World's Fair in New York City, a time capsule (a container filled with records and memorabilia of contemporary life) was buried. For reference purposes, the U.S. Coast and Geodetic Survey determined that the capsule was located at 40°28´34.089″ north latitude and 73°43´16.412″ west longitude. At some time in the future, if a hole were to be dug at the spot indicated by those coordinates, it would be within 15 centimeters (6 inches) of the capsule.

Learning Check 11 **Are locations in North America described by east longitude or west longitude?**

EARTH–SUN RELATIONS AND THE SEASONS

Nearly all life on Earth depends on solar energy; therefore, the relationship between Earth and the Sun is of vital importance. Because of the perpetual motions of Earth, this relationship does not remain the same throughout the year. We begin with a description of Earth movements and the relationship of Earth's axis to the Sun, and then we offer an explanation of the change of seasons.

Animation
Earth–Sun Relations



◀ **Figure 23** The complete grid system of latitude and longitude—the *graticule.* Because the meridians converge at the poles, the distance of 1° of longitude is greatest at the equator and diminishes to zero at the poles, whereas the distance of 1° of latitude varies only slightly (due to the slight flattening of Earth at the poles).

Earth Movements

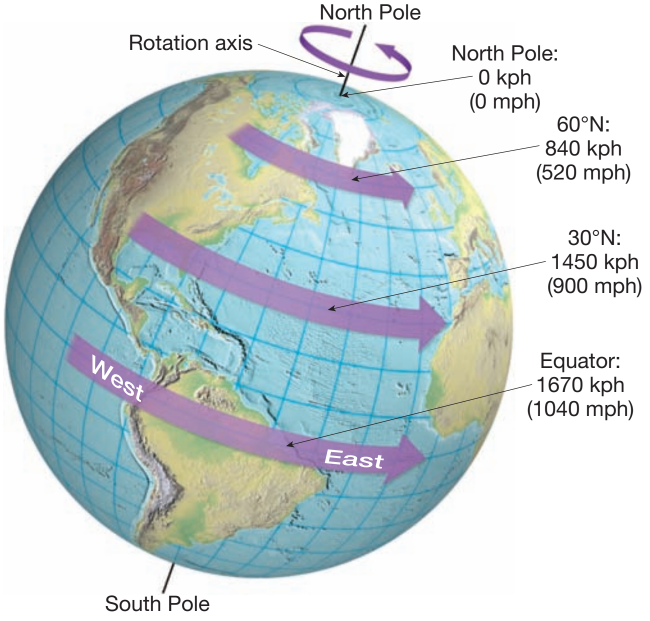
Two basic Earth movements—its daily rotation on its axis and its annual revolution around the Sun—along with the inclination and "polarity" of Earth's rotation axis, combine to change Earth's orientation to the Sun—and therefore produce the change of seasons.

Earth's Rotation on Its Axis: Earth rotates from west to east on its axis (Figure 24), a complete **rotation** requiring 24 hours (from the vantage point of looking down at the North Pole from space, Earth is rotating in a counterclockwise direction). The Sun, the Moon, and the stars appear to rise in the east and set in the west—this is, of course, an illusion created by the steady eastward spin of Earth.

Rotation causes all parts of Earth's surface except the poles to move in a circle around Earth's axis. Although the speed of rotation varies by latitude (see Figure 24), it is constant at any given place on Earth and so we experience no sense of motion. This is the same reason that we have little sense of motion on a smooth jet airplane flight at cruising speed—only when speed changes, such as during takeoff and landing, does motion become apparent.

Rotation has several important effects on the physical characteristics of Earth's surface:

1. Earth's constant rotation causes an apparent deflection in the paths of both wind and ocean currents—to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This phenomenon is called the *Coriolis effect*.
2. The rotation of Earth brings any point on the surface through the increasing and then decreasing gravitational pull of the Moon and the Sun. Although the land areas of Earth are too rigid to be significantly moved by these oscillating gravitational attractions, oceanic waters move onshore and then recede in a rhythmic pattern of *tides*.
3. Undoubtedly the most important effect of earthly rotation is the *diurnal* (daily) alternation of daylight and darkness, as portions of Earth's surface are turned first toward and then away from the Sun. This variation in exposure to sunlight greatly influences local temperature, humidity, and wind movements. Except for the organisms that live either in caves or in the ocean deeps, all forms of life have adapted to this sequential pattern of daylight and darkness. We human beings fare poorly when our *circadian* (24-hour cycle) rhythms are misaligned as the result of high-speed air travel that significantly interrupts the normal sequence of daylight and darkness. We are left with a sense of fatigue known as "jet lag," which can include unpleasant changes in our usual patterns of appetite and sleep.



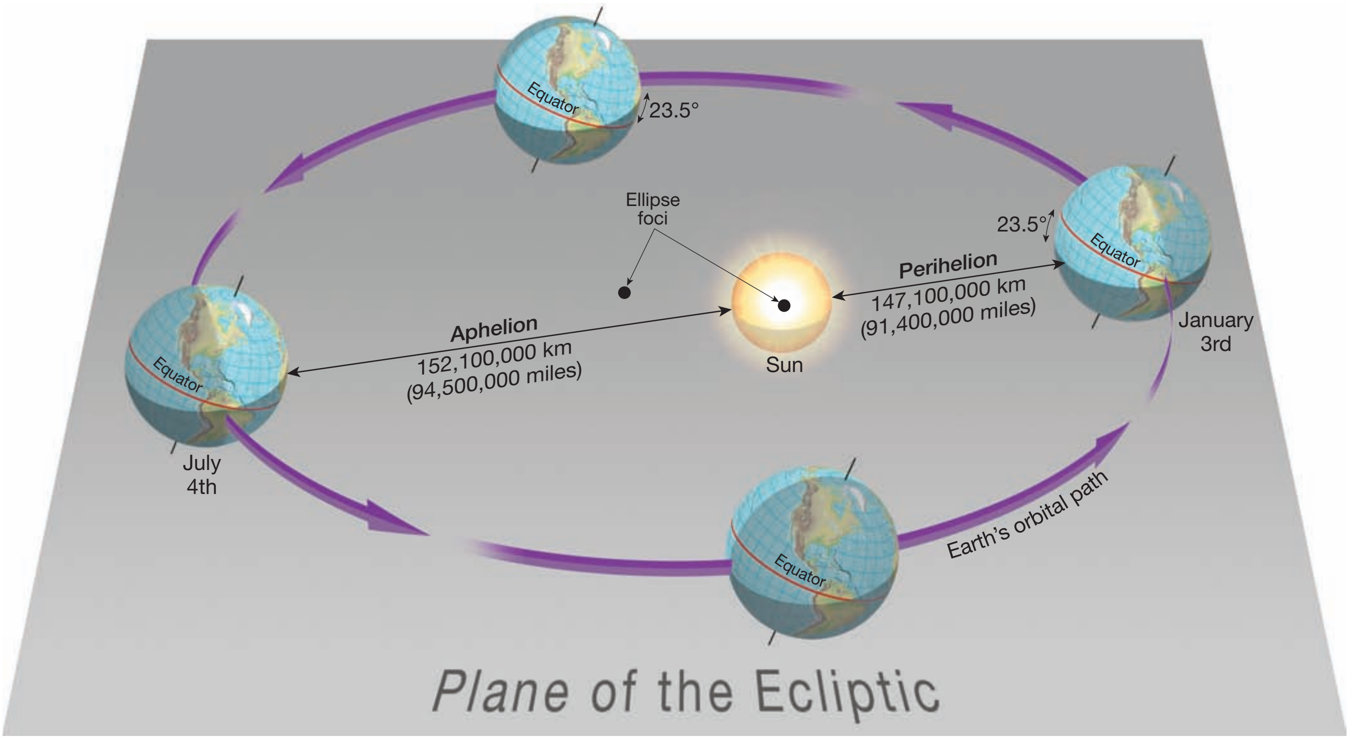
▲ **Figure 24** Earth rotates from west to east. Looking down at the North Pole from above, Earth appears to rotate in a counterclockwise direction. The speed of Earth's rotation is constant but it varies by latitude, being greatest at the equator, and effectively diminishing to zero at the poles. The speed of rotation at different latitudes is shown in kilometers per hour (kph) and miles per hour (mph).

Earth's Revolution around the Sun: Another significant Earth motion is its **revolution** or orbit around the Sun. Each revolution takes 365 days, 5 hours, 48 minutes, and 46 seconds, or 365.242199 days. This is known officially as the *tropical year* and for practical purposes is usually simplified to 365.25 days. (Astronomers define the year in other ways as well, but the duration is very close to that of the tropical year and need not concern us here.)

The path followed by Earth in its journey around the Sun is not a true circle but an ellipse (Figure 25). Because of this elliptical orbit, the Earth–Sun distance is not constant; rather, it varies from approximately 147,100,000 kilometers (91,400,000 miles) at the closest or **perihelion** position (*peri* is from the Greek and means "around" and *helios* means "Sun") on about January 3, to approximately 152,100,000 kilometers (94,500,000 miles) at the farthest or **aphelion** position (*ap* is from the Greek and means "away from") on about July 4. The average Earth–Sun distance is defined as one *astronomical unit* (1 AU) and is about 149,597,871 kilometers (92,960,117 miles). Earth is 3.3 percent closer to the Sun during the Northern Hemisphere winter than during the Northern Hemisphere summer, an indication that variations in the distance between Earth and the Sun do not cause the change of seasons; instead, two additional factors in the relationship of Earth to the Sun—inclination and polarity—work together with rotation and revolution to produce the change of seasons.

Learning Check 12 **Distinguish between Earth's rotation and its revolution.**

Inclination of Earth's Axis: The imaginary plane defined by the orbital path of Earth around the Sun is called the **plane of the ecliptic** (see Figure 25). However,



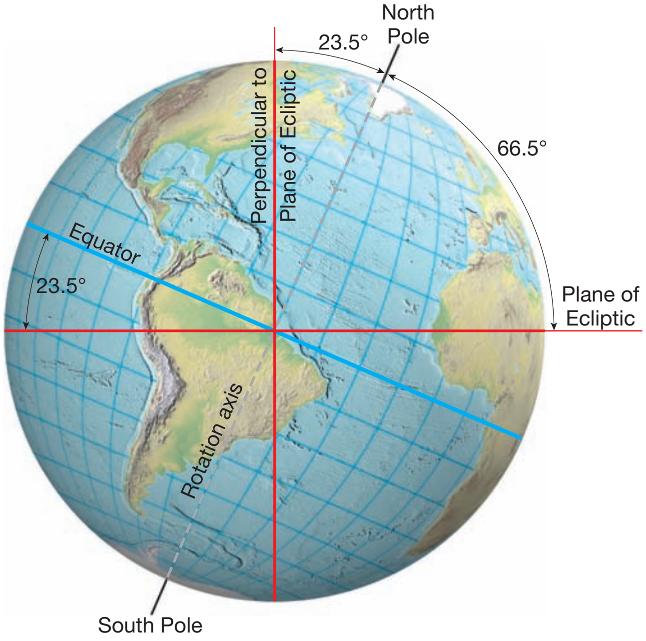
▲ **Figure 25** The plane of the ecliptic is the orbital plane of Earth. Because Earth's rotation axis is tilted, the plane of the ecliptic and the equatorial plane do not coincide. The path Earth follows in its revolution around the Sun is an ellipse with the Sun at one focus. Earth reaches perihelion (its closest point to the Sun) on about January 3rd and aphelion (its farthest point from the Sun) on about July 4th. (In this diagram the elliptical shape of Earth's orbit is greatly exaggerated.)

Earth's rotation axis is not perpendicular to the plane of the ecliptic. Rather, the axis is tilted about 23.5° from the perpendicular (Figure 26) and maintains this tilt throughout the year. This tilt is referred to as the **inclination of Earth's axis**.

Polarity of Earth's Axis: Not only is Earth's rotation axis inclined relative to its orbital path, no matter where Earth is in its orbit around the Sun the axis always points in the same direction relative to the stars—toward the North Star, Polaris (Figure 27). In other words, at any time during the year, Earth's rotation axis is parallel to its orientation at all other times. This characteristic is called the **polarity of Earth's axis** (or **parallelism**).

The combined effects of rotation, revolution, inclination, and polarity result in the seasonal patterns experienced on Earth. Notice in Figure 27 that at one point in Earth's orbit, around June 21, the North Pole is oriented most directly toward the Sun, whereas six months later, around December 21, the North Pole is oriented most directly away from the Sun—this is the most fundamental feature of the annual march of the seasons.

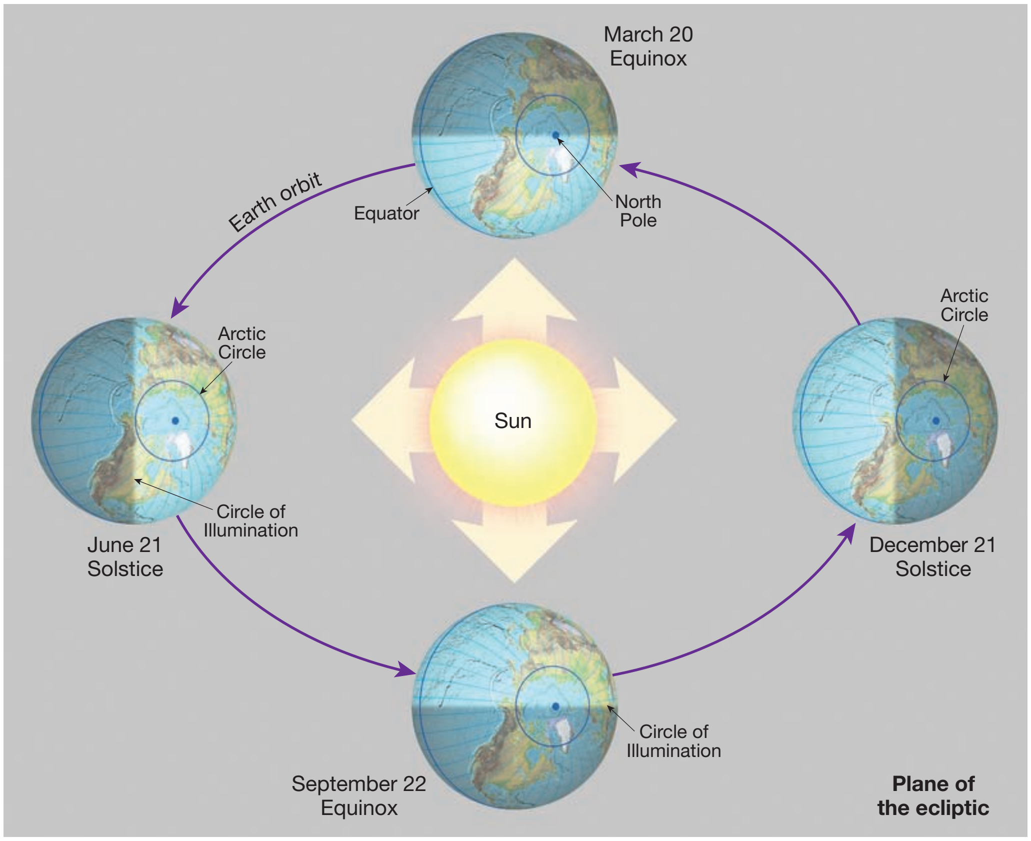
Learning Check 13 **Does the North Pole lean toward the Sun throughout the year? If not, how does the North Pole's orientation change during the year?**



▲ **Figure 26** Earth's rotation axis is inclined 23.5° from a line perpendicular to the plane of the ecliptic.

The Annual March of the Seasons

During a year, the changing relationship of Earth to the Sun results in variations in day length and in the angle at which the Sun's rays strike the surface of Earth. These changes are



▲ **Figure 27** A "top view" of the march of the seasons. Earth's rotational axis maintains polarity (points in the same direction) throughout the year, so on the June solstice the North Pole leans most directly toward the Sun, whereas on the December solstice the North Pole leans most directly away from the Sun (the dates shown are approximate). One-half of Earth is illuminated at all times during the year. The line between the two halves is called the *circle of illumination*.

most obvious in the mid- and high latitudes, but important variations take place within the tropics as well.

As we discuss the annual march of the seasons, we will pay special attention to three conditions:

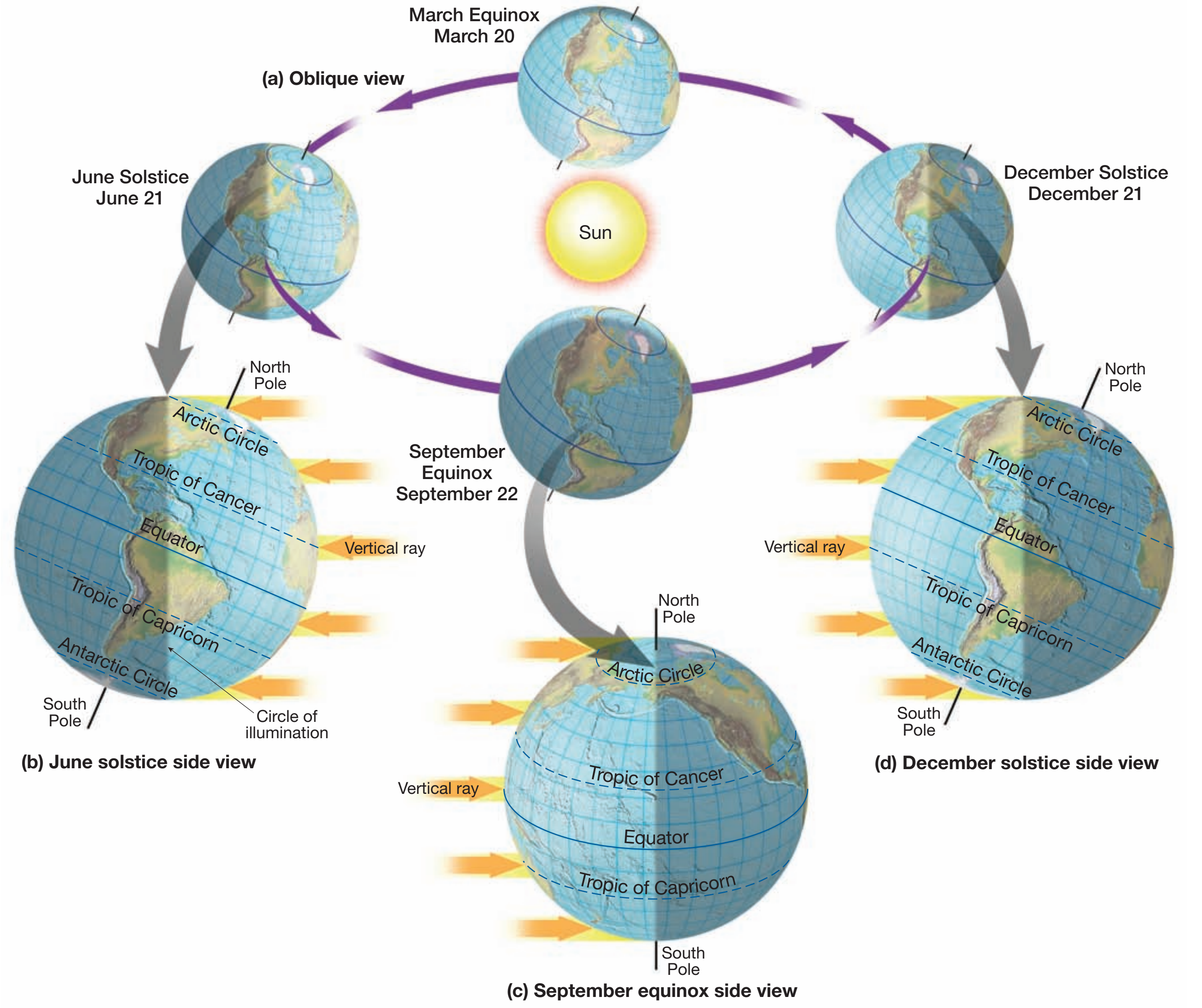
1. The latitude receiving the vertical rays of the Sun (rays striking the surface at a right angle), also referred to as the *subsolar point* or the *declination of the Sun*.
2. The **solar altitude** (the height of the Sun above the horizon) at different latitudes.
3. The length of day (number of daylight hours) at different latitudes.

Initially, we emphasize the conditions on four special days of the year: The March equinox, the June solstice, the September equinox, and the December solstice (Figure 28). As we describe the change of seasons, the significance of the "seven important parallels" discussed earlier in this chapter will become clear. We begin with the June solstice.

June Solstice: On the **June solstice**, which occurs on or about June 21 (the exact date varies slightly from year to year), the Earth reaches the position in its orbit where the North Pole is oriented most directly toward the Sun. On this day, the vertical rays of the Sun at noon are striking the **Tropic of Cancer**, 23.5° north of the equator (Figure 28b). Were you at the Tropic of Cancer on this day, the Sun would be directly overhead in the sky at noon (in other words, the solar altitude would be 90°). The Tropic of Cancer marks the northernmost location reached by the vertical rays of the Sun during the year.

The dividing line between the daylight half of Earth and nighttime half of Earth is a great circle called the **circle of illumination.** On the June solstice, the circle of illumination bisects ("cuts in half") the equator (Figure 28b), so on this day the equator receives equal day and night—12 hours of daylight and 12 hours of darkness. However, as we move north of the equator, the portion of each parallel in daylight increases—in other words, as we move north of the equator, day length increases. Conversely, day length decreases as we move south of the equator.

Notice in Figure 28b that on the June solstice, the circle of illumination reaches 23.5° *beyond* the North Pole to a latitude of 66.5° N. As Earth rotates, all locations north of 66.5° remain continuously in daylight and so on this day experience 24 hours of daylight. By contrast, all points south of 66.5° S are always outside the circle of illumination and so have 24 continuous hours of darkness. These special parallels defining the equatorward limit of 24 hours of light



▲ **Figure 28** (a) The annual march of the seasons showing Earth–Sun relations on the June solstice, September equinox, December solstice, and March equinox (the dates shown are approximate). The circle of illumination is the dividing line between the daylight and nighttime halves of Earth. (b) On the June solstice the vertical rays of the noon Sun strike 23.5° N latitude. (c) On the March equinox and September equinox, the vertical rays of the noon Sun strike the equator. (d) On the December solstice, the vertical rays of the noon Sun strike 23.5° S latitude.

and dark on the solstice dates are called the *polar circles*. The northern polar circle, at 66.5° N, is the **Arctic Circle**; the southern polar circle, at 66.5° S, is the **Antarctic Circle.**

The June solstice is called the *summer solstice* in the Northern Hemisphere and the *winter solstice* in the Southern Hemisphere (what are commonly called the "first day of summer" and the "first day of winter" in their respective hemispheres).

Learning Check 14 **What is the latitude of the vertical rays of the Sun on the June solstice?**

September Equinox: Three months after the June solstice, on approximately September 22 (as with solstice dates, this date also varies slightly from year to year), Earth experiences the **September equinox.** Notice in Figure 28c that the vertical rays of the Sun are striking the equator. Notice also that the circle of illumination just touches both poles, bisecting all other parallels—on this day all locations on Earth experience 12 hours of daylight and 12 hours of darkness (the word "equinox" comes from the Latin, meaning "the time of equal days and equal nights"). At the equator—and only at the equator—every day of the year has virtually 12 hours of daylight and 12 hours of darkness; all other locations have equal day and night only on an equinox.

The September equinox is called the *autumnal equinox* in the Northern Hemisphere and the *vernal equinox* in the Southern Hemisphere (and what are commonly called the "first day of fall" and the "first day of spring" in their respective hemispheres).

December Solstice: On the **December solstice**, which occurs on or about December 21, the Earth reaches the position in its orbit where the North Pole is oriented most directly away from the Sun; the vertical rays of the Sun now strike 23.5° S, the **Tropic of Capricorn** (Figure 28d). Once again, the circle of illumination reaches to the far side of one pole and falls short on the near side of the other pole—areas north of the Arctic Circle are in continuous darkness, whereas areas south of the Antarctic Circle are in daylight for 24 hours.

Although the latitude receiving the vertical rays of the Sun has shifted 47° from June 21 to December 21, the relationships between Earth and the Sun on the June solstice and the December solstice are very similar—the conditions in each hemisphere are simply reversed. The December solstice is called the *winter solstice* in the Northern Hemisphere and the *summer solstice* in the Southern Hemisphere (what are commonly called the "first day of winter" and the "first day of summer," respectively).

March Equinox: Three months after the December solstice, on approximately March 20, Earth experiences the **March equinox.** The relationships of Earth and the Sun are virtually identical on the March equinox and the September equinox (Figure 28c). The March equinox is called the *vernal equinox* in the Northern Hemisphere and the *autumnal equinox* in the Southern Hemisphere (what are commonly called the "first day of spring" and the "first day of fall," respectively). Table 2 summarizes the conditions present during the solstices and equinoxes.

Learning Check 15 **How much does day length at the equator change during the year?**

Seasonal Transitions

In the preceding discussion of the solstices and equinoxes, we mainly emphasized the conditions on just four special days of the year. It is important to understand the transitions in day length and Sun angle that take place between those days as well.

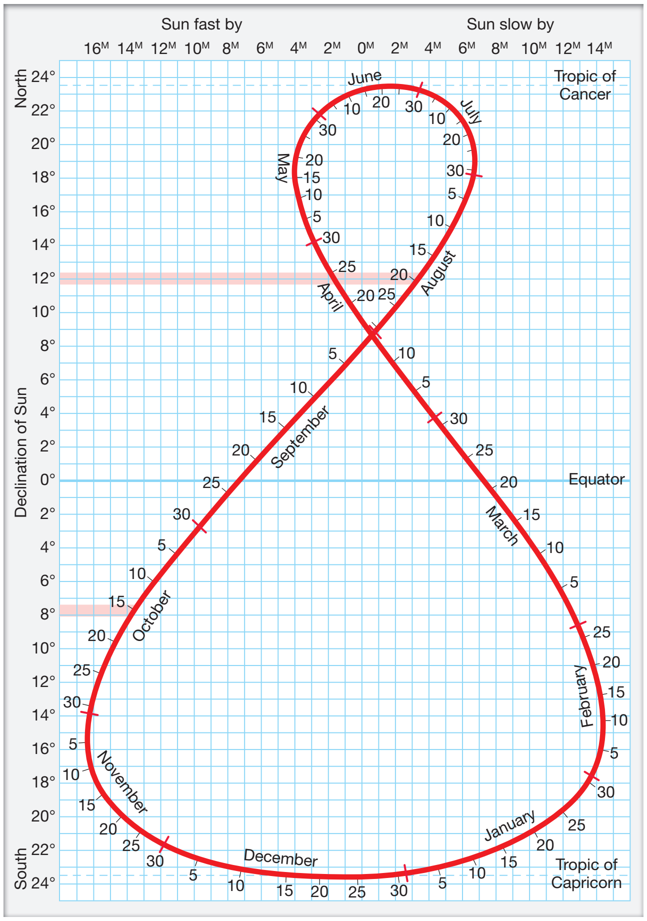
Latitude Receiving the Vertical Rays of the Sun: The vertical rays of the Sun only strike Earth between the Tropic of Cancer and the Tropic of Capricorn. After the March equinox, the vertical rays of the Sun migrate north from the equator, striking the Tropic of Cancer on the June solstice (although latitudes north of the Tropic of Cancer never experience the vertical rays of the Sun, the June solstice marks the day of the year when the Sun is highest in the sky in those latitudes). After the June solstice, the vertical rays migrate south, striking the equator again on the September equinox and finally to their southernmost latitude on the December solstice (the December solstice marks the day of the year when the Sun is lowest in the sky in the Northern Hemisphere). Following the December solstice, the vertical rays migrate northward, reaching the equator once again on the March equinox. The changing latitude of the vertical rays of the Sun during the year is shown graphically on a chart known as the *analemma* (Figure 29).

Day Length: Only at the equator is day length constant throughout the year—virtually 12 hours of daylight every day of the year.

For all regions in the Northern Hemisphere up to the latitude of the Arctic Circle, after the shortest day of the year on the December solstice, the number of hours

TABLE 2 **Conditions on Equinoxes and Solstices**

	March Equinox	June Solstice	September Equinox	December Solstice
Latitude of Vertical Rays of Sun	0°	23.5° N	0°	23.5° S
Day length at Equator	12 hours	12 hours	12 hours	12 hours
Day length in midlatitudes of Northern Hemisphere	12 hours	Day length becomes longer with increasing latitude north of equator	12 hours	Day length becomes shorter with increasing latitude north of equator
Day length in midlatitudes of Southern Hemisphere	12 hours	Day length becomes shorter with increasing latitude south of equator	12 hours	Day length becomes longer with increasing latitude south of equator
24 hours of daylight	Nowhere	From Arctic Circle to North Pole	Nowhere	From Antarctic Circle to South Pole
24 hours of darkness	Nowhere	From Antarctic Circle to South Pole	Nowhere	From Arctic Circle to North Pole
Season in Northern Hemisphere	Spring	Summer	Autumn	Winter
Season in Southern Hemisphere	Autumn	Winter	Spring	Summer



▲ **Figure 29** The analemma shows the latitude of the vertical rays of the noon Sun (the *declination of the Sun*) throughout the year. For example, on August 20 the vertical rays of the Sun are striking 12° N, whereas on October 15 they are striking 8° S. The values across the top of the analemma show the *equation of time*—the number of minutes that solar noon is fast or slow compared with mean (average) time.

TABLE 3 Day Length at Time of June Solstice

Latitude	Day Length	Noon Sun Angle (degrees above horizon)
90° N	24 h	23.5
60° N	18 h 53 min	53.5
30° N	14 h 05 min	83.5
0°	12 h 07 min	66.5
30° S	10 h 12 min	36.5
60° S	05 h 52 min	6.5
90° S	0	0

Source: After Robert J. List, *Smithsonian Meteorological Tables*, 6th rev. ed. Washington, D.C.: Smithsonian Institution, 1963, Table 171.

of daylight gradually increases, reaching 12 hours of daylight on the March equinox. After the equinox, day length continues to increase until the longest day of the year on the June solstice. (During this period, day length is diminishing in the Southern Hemisphere.)

Following the longest day of the year in the Northern Hemisphere on the June solstice, the pattern is reversed, with the days getting shorter in the Northern Hemisphere—reaching 12 hours on the September equinox, and then diminishing until the shortest day of the year on the December solstice. (During this period, day length is increasing in the Southern Hemisphere.)

Overall, the annual variation in day length is the least in the tropics and greatest in the high latitudes (Table 3).

Learning Check 16 **On which days of the year do the vertical rays of the Sun strike the equator?**

Day Length in the Arctic and Antarctic: The patterns of day and night in the Arctic and Antarctic deserve special mention. For an observer exactly at the North Pole, the Sun rises on the March equinox and is above the horizon continuously for the next six months—circling the horizon higher and higher each day until the June solstice, after which it circles lower and lower until setting on the September equinox.

Week by week after the March equinox, the region experiencing 24 hours of daylight grows, extending from the North Pole until the June solstice—when the entire region from the Arctic Circle to the North Pole experiences 24 hours of daylight. Following the June solstice, the region in the Arctic experiencing 24 hours of daylight diminishes week by week until the September equinox—when the Sun sets at the North Pole and remains below the horizon continuously for the next six months.

Week by week following the September equinox, the region experiencing 24 hours of darkness extends from the North Pole until the December solstice—when the entire region from the Arctic Circle to the North Pole experiences 24 hours of darkness. Following the December solstice, the region experiencing 24 hours of darkness diminishes week by week until the March equinox—when the Sun again rises at the North Pole.

In the Antarctic region of the Southern Hemisphere, these seasonal patterns are simply reversed.

Significance of Seasonal Patterns

Both day length and the angle at which the Sun's rays strike Earth determine the amount of solar energy received at any particular latitude. As a generalization, the higher the Sun is in the sky, the more effective is the warming. Day length influences patterns of solar energy receipt on Earth as well. For example, short periods of daylight in winter and long periods of daylight in summer contribute to seasonal differences in temperature in the mid- and high latitude regions of Earth.

Thus, the tropical latitudes are generally always warm because they always have high Sun angles and consistent day lengths that are close to 12 hours long. Conversely, the polar regions are consistently cold because they always have low Sun angles—even the 24-hour days in summer do not compensate for the low angle of incidence of sunlight. Seasonal temperature differences are large in the midlatitudes because of sizable seasonal variations in Sun angles and length of day.

Learning Check 17 **For how many months of the year does the North Pole go without sunlight?**

TELLING TIME

Comprehending time around the world depends on an understanding of both the geographic grid of latitude and longitude, and of Earth–Sun relations. As Malcolm Thomson, a Canadian authority on the physics of time has noted, there are really only three natural units of time: the *tropical year*, marked by the return of the seasons; the *lunar month*, marked by the return of the new moon; and the *day*, marked by passage of the Sun. All other units of time measurement—such as a second, an hour, or a century—are human-made to meet the needs of society.

In prehistoric times, the rising and setting of the Sun were probably the principal means of telling time. As civilizations developed, however, more precise timekeeping was required. Early agricultural civilizations in Egypt, Mesopotamia, India, China, and England, as well as the Aztec and Mayan civilizations in the Western Hemisphere, observed the Sun and the stars to tell time and keep accurate calendars.

Local *solar noon* can be determined by watching for the moment when objects cast their shortest shadows. The Romans used sundials to tell time (Figure 30) and gave great importance to the noon position, which they called the *meridian*—the Sun's highest (*meri*) point of the day (*diem*). Our use of A.M. (*ante meridian*: "before noon") and P.M. (*post meridian*: "after noon") was derived from the Roman world.

When nearly all transportation was by foot, horse, or sailing vessel, it was difficult to compare time at different localities. In those days, each community set its own time by correcting its clocks to high noon at the moment of the shortest shadow. A central public building, such as a temple in India or a county courthouse in Kansas, usually had a large clock or loud bells to toll the hour. Periodically, this time was checked against the shortest shadow.

Standard Time

As the telegraph and railroad began to speed words and passengers between cities, the use of local solar time created increasing problems. A cross-country rail traveler in the United States in the 1870s might have experienced as many as 24 different local time standards between the Atlantic and Pacific coasts. Eventually, the railroads stimulated the development of a standardized time system.

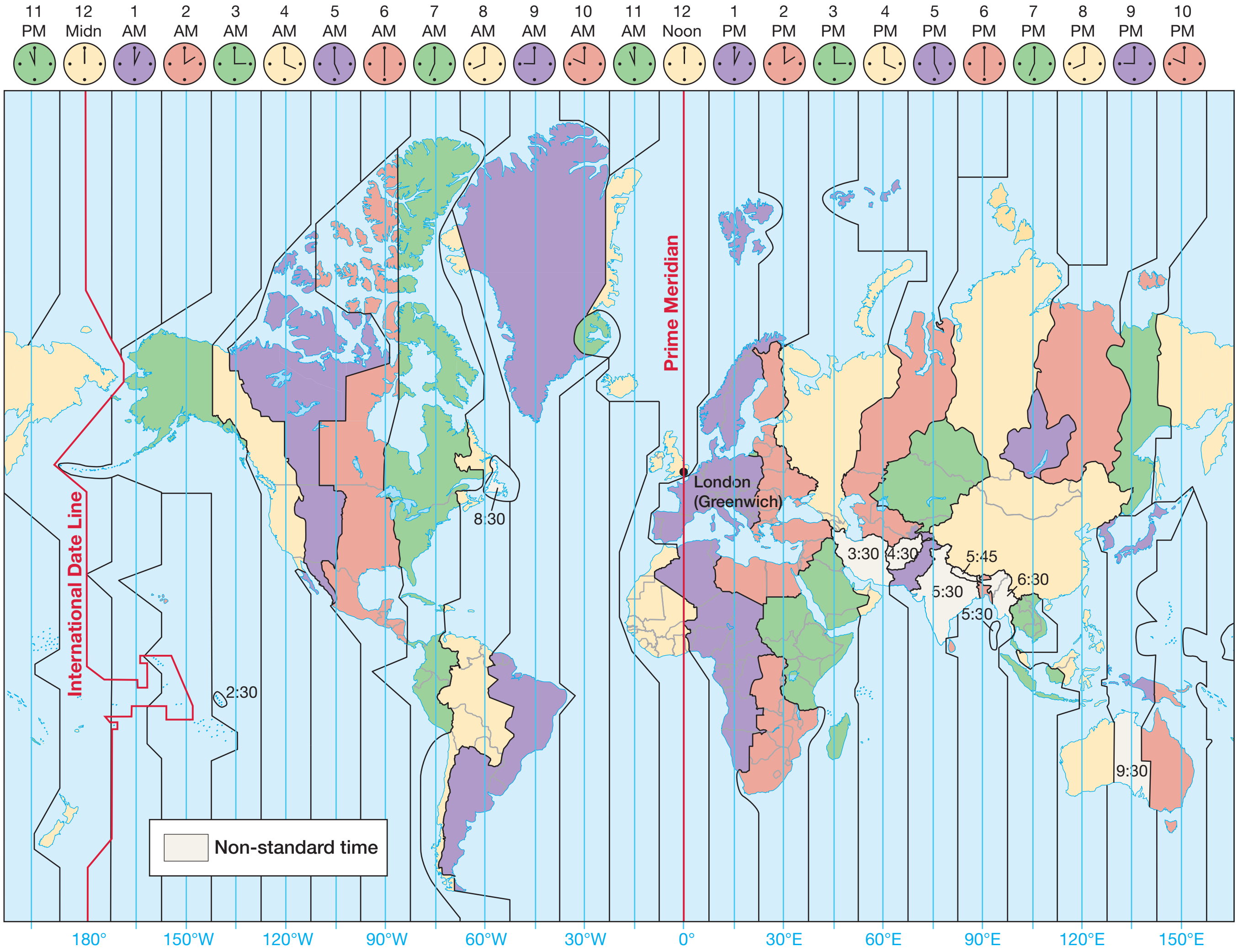
At the 1884 International Prime Meridian Conference in Washington, D.C., countries agreed to divide the world into 24 standard **time zones**, each extending over 15° of longitude. The mean local solar time of the Greenwich (prime) meridian was chosen as the standard for the entire system. The prime meridian became the center of a time zone that extends 7.5° of longitude to the west and 7.5° to the east of the prime meridian. Similarly, the meridians that are multiples of 15° both east and west of the prime meridian, were set as the *central meridians* for the 23 other time zones (Figure 31).

Although **Greenwich Mean Time (GMT)** is now referred to as **Universal Time Coordinated (UTC)**, the prime meridian is still the reference for standard time. Because it is always the same number of minutes after the hour in all standard time zones (keeping in mind that a few countries, such as India, do not adhere to standard one-hour-interval time zones), to know the exact local time, we usually need to know only how many hours later or earlier our local time zone is compared to the time in Greenwich. Figure 31 shows the number of hours later or earlier than UTC it is in each time zone of the world.

Most of the countries of the world are sufficiently small in their east–west direction so as to lie totally within a single time zone. However, large countries may encompass several zones: Russia occupies nine time zones; including Alaska and Hawai'i, the United States spreads over six (Figure 32); Canada, six; and Australia, three. In international waters, time zones are defined to be exactly 7°30´ to the east and 7°30´ to the west of the central meridians. Over land areas, however, zone boundaries vary to coincide with appropriate political and economic boundaries. For example, continental Europe from Portugal to Poland shares one time zone, although longitudinally covering about 30°. At the extreme, China extends across four 15° zones, but the entire nation, at least officially, observes the time of the 120° east meridian, which is the one closest to Beijing.

In each time zone, the central meridian marks the location where clock time is the same as mean Sun time

◀ **Figure 30** A typical sundial. The edge of the vertical *gnomon* slants upward from the dial face at an angle equal to the latitude of the sundial, pointing toward the North Pole in the Northern Hemisphere and the South Pole in the Southern Hemisphere. As the Sun appears to move across the sky during the course of a day, the position of the shadow cast by the gnomon changes. The time shown in this photograph of a sundial in Cornwall, United Kingdom, is about 11:00 A.M.



▲ **Figure 31** The 24 time zones of the world, each based on central meridians spaced 15° apart. Especially over land areas, these boundaries have been significantly adjusted.

(i.e., the Sun reaches its highest point in the sky at 12:00 noon). On either side of that meridian, of course, clock time does not coincide with Sun time. The deviation between the two is shown for one U.S. zone in Figure 33.

From the map of time zones of the United States (Figure 32), we can recognize a great deal of manipulation of the time zone boundaries for economic and political convenience. For example, the Central Standard Time Zone, centered on 90° W extends all the way to 105° W (which is the central meridian of the Mountain Standard Time Zone) in Texas to keep most of that state within the same zone. By contrast, El Paso, Texas, is officially within the Mountain Standard Time Zone in accord with its role as a major market center for southern New Mexico, which observes Mountain Standard Time. In the same vein, northwestern Indiana is in the Central Standard Time Zone with Chicago.

Learning Check 18 **What happens to the hour when crossing from one time zone to the next going from west to east?**

International Date Line

In 1519, Ferdinand Magellan set out westward from Spain, sailing for East Asia with 241 men in five ships. Three years later, the remnants of his crew (18 men in one ship) successfully completed the first circumnavigation of the globe. Although a careful log had been kept, the crew found that their calendar was one day short of the correct date. This was the first human experience with time change on a global scale, the realization of which eventually led to the establishment of the **International Date Line.**

One advantage of establishing the Greenwich meridian as the prime meridian is that its opposite arc is in the Pacific Ocean. The 180th meridian, transiting the sparsely populated mid-Pacific, was chosen as the meridian at which new days begin and old days exit from the surface of Earth. The International Date Line deviates from the 180th meridian in the Bering Sea to include all of the Aleutian Islands of Alaska within the same day and again in the South Pacific to keep islands of the same group (Fiji, Tonga) within the same

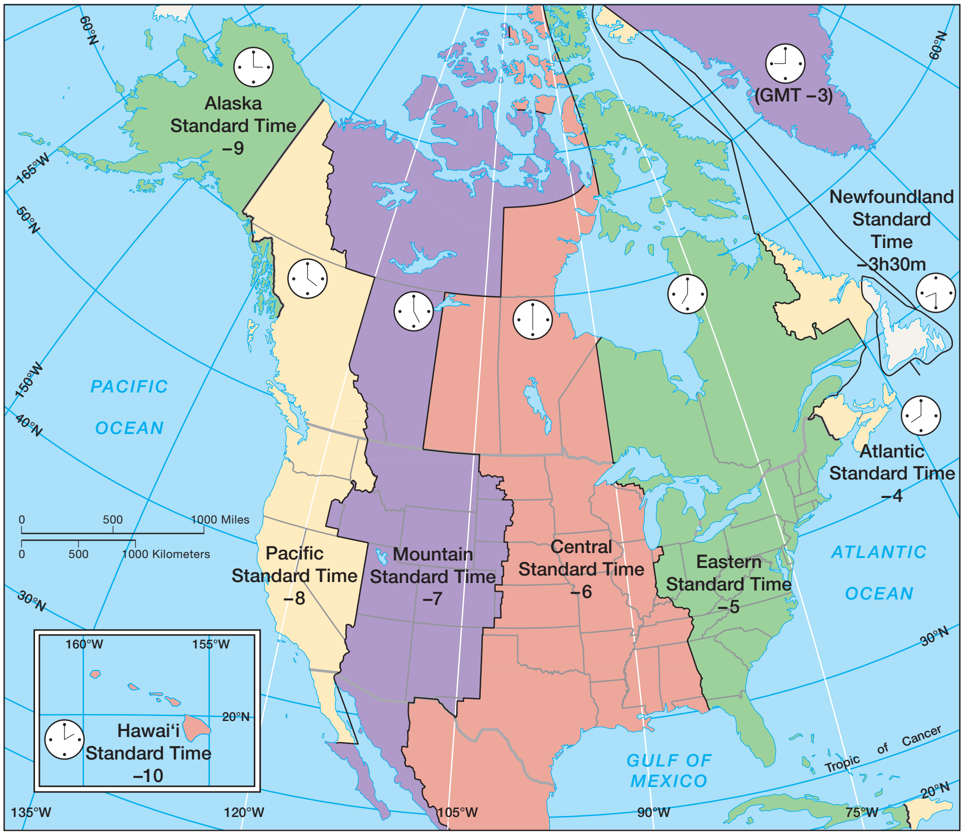


Figure 32 Times zones for Canada, the United States, and northern Mexico. The number in each time zone refers to the number of hours earlier than UTC (GMT).

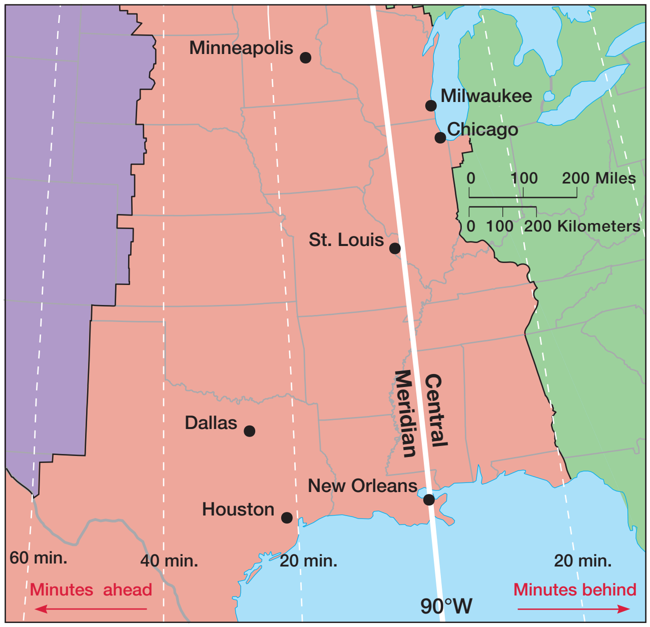


Figure 33 Standard clock time versus Sun time. The Sun reaches its highest point in the sky at 12:00 noon in St. Louis and New Orleans because these two cities lie on the central meridian. For places east of the central meridian, the Sun is highest in the sky a few minutes before standard time noon; for locations west, local solar noon is a few minutes after. In Chicago, for instance, the Sun is highest in the sky at 11:50 A.M. and in Dallas it is highest in the sky at 12:28 P.M.

day (Figure 34). The extensive eastern displacement of the date line in the central Pacific is due to the widely scattered locations of the many islands of the country of Kiribati.

The International Date Line is in the middle of the time zone defined by the 180° meridian. Consequently, there is no time (i.e., hourly) change when crossing the International Date Line—only the calendar changes, not the clock. When you cross the International Date Line going from west to east, it becomes one day earlier (e.g., from January 2 to January 1); when you move across the line from east to west, it becomes one day later (e.g., from January 1 to January 2).

Learning Check 19 **What happens to the day when crossing the International Date Line going from west to east?**

Daylight-Saving Time

To conserve energy during World War I, Germany ordered all clocks set forward by an hour. This practice allowed the citizenry to "save" an hour of daylight by shifting the daylight period into the usual evening hours, thus reducing the consumption of electricity for lighting. The United States began a similar policy in 1918, but

▲ **Figure 34** The International Date Line generally follows the 180th meridian, but it deviates around various island groups, most notably Kiribati.

many localities declined to observe "summer time" until the Uniform Time Act made the practice mandatory in all states that had not deliberately exempted themselves. Hawai'i, and parts of Indiana and Arizona, have exempted themselves from observance of **daylight-saving time** under this act.

Russia has adopted permanent daylight-saving time (and double daylight-saving time—two hours ahead of Sun time—in the summer). In recent years, Canada, Australia, New Zealand, and most of the nations of western Europe have also adopted daylight-saving time. In the Northern Hemisphere, many nations, like the United States, begin daylight-saving time on the second Sunday in March (in the spring we "spring forward" one hour) and resume standard time on the first Sunday in November (in the fall we "fall back" one hour). In the tropics, the lengths of day and night change little seasonally, and there is not much twilight. Consequently, daylight-saving time would offer little or no savings for tropical areas.

LEARNING REVIEW

After studying this chapter, you should be able to answer the following questions. Key terms from each text section are shown in **bold type**. Definitions for key terms are also found in the glossary at the end of this chapter.

KEY TERMS AND CONCEPTS

Geography and Science

1. Contrast **physical geography** and **cultural geography**.
2. If an idea cannot be disproven by some possible observation or test, can such an idea be supported by science? Explain.
3. What is the approximate *English System* of measurement equivalent of one kilometer in the **International System (S.I.)**?

Environmental Spheres and Earth Systems

4. Briefly describe the environmental "spheres": **atmosphere**, **hydrosphere**, **cryosphere**, **biosphere**, and **lithosphere**.
5. Contrast *closed systems* and *open systems*.
6. What does it mean when a system is in *equilibrium*?
7. How does a *positive feedback loop* differ from a *negative feedback loop*?

Earth and the Solar System

8. In what ways do the inner and outer planets (the terrestrial and Jovian planets) of our solar system differ from each other?
9. Compare the size of Earth to that of its surface features and atmosphere.
10. Is Earth perfectly spherical? Explain.

The Geographic Grid—Latitude and Longitude

11. Define the following terms: **latitude**, **longitude**, **parallel**, **meridian**, and **prime meridian**.
12. Latitude ranges from _____° to _____° north and south, whereas longitude ranges from _____° to _____° east and west.
13. State the latitude (in degrees) for the following "special" parallels: **equator**, **North Pole**, **South Pole**, **Tropic of Cancer**, **Tropic of Capricorn**, **Arctic Circle**, and **Antarctic Circle**.

14. What is a **great circle**? A small circle? Provide examples of both.

Earth–Sun Relations and the Seasons

15. Describe and explain the four factors in Earth–Sun relations associated with the change of seasons: **rotation**, **revolution** around the Sun, **inclination of Earth's axis**, and **polarity (parallelism) of Earth's axis**.
16. Does the **plane of the ecliptic** coincide with the plane of the equator? Explain.
17. On which day of the year is Earth closest to the Sun **(perihelion)**? Farthest from the Sun **(aphelion)**?
18. Provide the approximate date for the following special days of the year: **March equinox**, **June solstice**, **September equinox**, and **December solstice**.
19. What is the **circle of illumination**?
20. What is meant by the **solar altitude**?
21. Briefly describe Earth's orientation to the Sun during the Northern Hemisphere summer and the Northern Hemisphere winter.
22. Beginning with the March equinox, describe the changing latitude of the vertical rays of the noon Sun during the year.
23. In the midlatitudes of the Northern Hemisphere, on which day of the year is the Sun highest in the sky? Lowest in the sky?
24. For the equator, describe the approximate number of daylight hours on the following days of the year: *March equinox*, *June solstice*, *September equinox*, and *December solstice*.
25. What is the longest day of the year (the day with the greatest number of daylight hours) in the midlatitudes of the Northern Hemisphere? What is the longest day in the Southern Hemisphere?
26. For the North Pole, describe the approximate number of daylight hours on the following days of the year: March equinox, June solstice, September equinox, and December solstice.
27. For how many months of the year does the North Pole have no sunlight at all?

Telling Time

28. What happens to the hour when crossing a **time zone** boundary moving from west to east?
29. What is meant by **UTC (Universal Time Coordinated)** and **Greenwich Mean Time (GMT)**?
30. What happens to the day when crossing the **International Date Line** moving from east to west?
31. When **daylight-saving time** begins in the spring, you would adjust your clock from 2:00 A.M. to _____.

STUDY QUESTIONS

1. Why are physical geographers interested in globalization of the economy?
2. Why is a distance covered by 1° of longitude at the equator different from the distance covered by 1° of longitude at a latitude of 45° N?
3. What is the significance of *aphelion* and *perihelion* in Earth's seasons?
4. In terms of the change of seasons, explain the significance of the Tropic of Cancer, the Tropic of Capricorn, the Arctic Circle, and the Antarctic Circle.
5. Is the noon Sun ever directly overhead in Madison, Wisconsin (43° N)? If not, on which day of the year is the noon Sun *highest* in the sky there, and on which day is it lowest?
6. What would be the effect on the annual march of the seasons if Earth's axis was *not* inclined relative to the plane of the ecliptic?
7. What would be the effect on the annual march of the seasons if the North Pole was always leaning toward the Sun?
8. If Earth's axis was tilted only 20° from perpendicular, what would the latitudes of the Tropic of Cancer and Arctic Circle become?
9. Why are standard time zones 15° of longitude wide?
10. Most weather satellite images are "time-stamped" using UTC or "Zulu" time (UTC expressed using 24-hour or military time) instead of the local time of the region below. Why?

EXERCISES

1. Using formulas found in Table 1, make the following conversions between the International System (S.I.) and English systems of measurements:
   a. 12 centimeters = _____ inches
   b. 140 kilometers = _____ miles
   c. 12,000 feet = _____ meters
   d. 3 quarts = _____ liters
   e. 5 kilograms = _____ pounds
   f. 10°C = _____ °F
2. Using a world map or globe, estimate the latitude and longitude of both New York City and Sydney, Australia. Be sure to specify if these locations are north or south latitude, and east or west longitude.
3. The solar altitude (the angle of the noon Sun above the horizon) can be calculated for any latitude on Earth for any day of the year, by using the formula: SA = 90° – AD, where SA is the "solar altitude" and AD is the "arc distance" (the difference in latitude between the declination of the Sun and the latitude in question). Use the analemma (Figure 29) to determine the declination of the Sun, and then calculate the solar altitude at the following locations on the day given:
   a. Beijing, China (40° N) on November 25th
   b. Nairobi, Kenya (1° S) on September 25th
   c. Fairbanks, Alaska (65° N) on July 10th
4. Using the map of North American time zones (Figure 32) for reference, if it is 5:00 P.M. standard time on Thursday in New York City (41° N, 74° W), what is the day and time in Los Angeles (34° N, 118° W)?
5. Using the map of world time zones (Figure 31) for reference, if it is 11:00 A.M. UTC (Universal Time Coordinated or Greenwich Mean Time), what is the standard time in Seattle (48° N, 122° W)?

Seeing Geographically

Look again at the image of Earth at the beginning of the chapter. What evidence can you see of each of Earth's "spheres" in this image? What is the approximate latitude and longitude of the center of the image? Based on the position of the circle of illumination, is it early morning or late afternoon in Beijing, China? Generally, how do the clouds look different in the tropics compared with the clouds in higher latitudes?

MasteringGeography™

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LEARNING CHECK ANSWERS

1: *Physical geography* primarily focuses on patterns in the natural environment and on human interaction with the environment; *cultural geography* primarily focuses on patterns of human activity and culture. **2:** Many patterns and processes in the natural environment can be influenced by economic activity—such as the consequences of the extraction of resources or the burning of fossil fuels; economic activity in one part of the world can influence the environment in another part of the world. **3:** Strictly speaking, science uses evidence to eliminate unsupported ideas or hypotheses; science must always leave open the possibility that new evidence will cause us to come to new conclusions. **4:** The *lithosphere* is the solid part of Earth, the *atmosphere* the gases surrounding Earth, the *hydrosphere* the waters of Earth, the *cryosphere* the frozen water of Earth, and the *biosphere* the living organisms on Earth. **5:** When the inputs to a system are balanced by the outputs, the conditions within a system remain the same over time. **6:** With a *positive feedback loop*, change in one direction tends to reinforce change in that direction; with a *negative feedback loop*, change tends to bring the system back toward equilibrium. **7:** Terrestrial planets are relatively small and are composed primarily of mineral material; Jovian planets are larger, less dense, and composed primarily of gases, liquids, and ices. **8:** Earth's highest point is Mount Everest (8850 m; 29,035 ft.) and its lowest point is the bottom of the Mariana Trench (–11,033 m; –36,198 ft.)—a difference of about 19,883 m (65, 233 ft.). **9:** A *great circle* is the largest circle that can be drawn on a sphere, dividing it into two hemispheres; the equator is a great circle. **10:** Because all parallels are parallel to each other—they never cross or touch. **11:** North America is west of the prime meridian, so it is described by west longitude. **12:** Earth rotates, or "spins," on its axis; Earth revolves, or "orbits," around the Sun. **13:** No; the North Pole leans most directly toward the Sun on the June solstice and leans most directly away from the Sun on the December solstice. **14:** 23.5° N. **15:** Not at all—the equator has virtually 12 hours of daylight every day of the year. **16:** On the March equinox and September equinox. **17:** 6 months. **18:** Crossing from west to east into a new time zone it becomes one hour later. **19:** Crossing the IDL going from west to east it becomes the previous day.

GLOSSARY

Antarctic Circle The parallel of 66.5° south latitude.

aphelion The point in Earth's elliptical orbit at which Earth is farthest from the Sun (about 152,100,000 kilometers or 94,500,000 miles).

Arctic Circle The parallel of 66.5° north latitude.

atmosphere The gaseous envelope surrounding Earth.

biosphere The living organisms of Earth.

circle of illumination The edge of the sunlit hemisphere that is a great circle separating Earth into a light half and a dark half.

cryosphere Subsphere of the hydrosphere that encompasses water frozen as snow or ice.

cultural geography The study of the human and/or cultural elements of geography.

daylight-saving time Shifting of clocks forward one hour.

December solstice Day of the year when the vertical rays of the Sun strike the Tropic of Capricorn; on or about December 21; winter solstice in the Northern Hemisphere.

equator The parallel of 0° latitude.

great circle Circle on a globe formed by the intersection of Earth's surface with any plane that passes through Earth's center.

Greenwich Mean Time (GMT) Time in the Greenwich time zone. Today more commonly called *UTC* or *Universal Time Coordinated*.

hydrosphere Total water realm of Earth, including the oceans, surface waters of the lands, groundwater, and water held in the atmosphere.

inclination [of Earth's axis] The tilt of Earth's rotational axis relative to its orbital plane (the *plane of the ecliptic*).

International Date Line The line marking a time difference of an entire day from one side of the line to the other. Generally, this line falls on the 180th meridian except where it deviates to avoid separating an island group.

International System of measurement (SI) Popularly known as the "metric system" of measurement.

June solstice Day of the year when the vertical rays of the Sun strike the Tropic of Cancer; on or about June 21; summer solstice in the Northern Hemisphere.

lithosphere Tectonic plates consisting of the crust and upper rigid mantle. Also used as a general term for the entire solid Earth (one of the Earth "spheres").

longitude Location described as an angle measured (in degrees, minutes, and seconds) east and west from the prime meridian on Earth's surface.

March equinox One of two days of the year when the vertical rays of the Sun strike the equator; every location on Earth has equal day and night; occurs on or about March 20 each year.

meridian An imaginary line of longitude extending from pole to pole, crossing all parallels at right angles, and being aligned in true north–south directions.

North Pole Latitude of 90° north.**parallel** A line connecting all points of equal latitude; such a line is parallel to all other parallels.

parallelism See *polarity*.

perihelion The point in its orbit where Earth is nearest to the Sun (about 147,100,000 kilometers or 91,400,000 miles).

physical geography Study of the physical elements of geography.

plane of the ecliptic The imaginary plane that passes through the Sun and through Earth at every position in its orbit around the Sun; the orbital plane of Earth.

polarity [of Earth's rotation axis] A characteristic of Earth's axis wherein it always points toward Polaris (the North Star) at every position in Earth's orbit around the Sun. Also called *parallelism*.

prime meridian The meridian passing through the Royal Observatory at Greenwich (England), just east of central London, and from which longitude is measured.

revolution [around the Sun] The orbital movement of Earth around the Sun over the year.

rotation [of Earth] The spinning of Earth around its imaginary north–south axis.

September equinox One of two days of the year when the vertical rays of the Sun strike the equator; every location on Earth has equal day and night; occurs on or about September 22 each year.

solar altitude Angle of the Sun above the horizon.

South Pole Latitude of 90° south.

time zone Region on Earth (generally a north–south band defined by longitude) within which the agreed-upon local time is the same.

Tropic of Cancer The parallel of 23.5° N latitude, which marks the northernmost location reached by the vertical rays of the Sun in the annual cycle of Earth's revolution.

Tropic of Capricorn The parallel of 23.5° S latitude, which marks the southernmost location reached by the vertical rays of the Sun in the annual cycle of Earth's revolution.

Universal Time Coordinated (UTC) or Coordinated Universal Time The world time standard reference; previously known as *Greenwich mean time (GMT)*.

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Figure 3: From the NASA Earth Observatory website; Table 3: Source: Smithsonian Meteorological Tables.

PORTRAYING EARTH

From Chapter 2 of *Physical Geography: A Landscape Appreciation*, Eleventh Edition. Darrel Hess.

THE SURFACE OF EARTH IS THE FOCUS OF THE GEOGRAPHER'S interest. The enormity and complexity of this surface would be difficult to comprehend and analyze without tools to systematically organize the varied data.

Although many kinds of tools are used in geographic studies, the most important are maps. The mapping of a geographic feature is often an essential first step toward understanding the spatial distributions and relationships of that feature. This text is a case in point—it contains numerous maps of various kinds, each included to further your understanding of some concept, fact, or relationship.

The purpose of this chapter is twofold: (1) To describe the basic characteristics of maps, including their capabilities and limitations; and (2) to describe the various ways a landscape can be portrayed—through maps, globes, photographs, and remotely sensed imagery (Figure 1).

As you study this chapter, think about these key questions:

- **Why can no map of the world be as accurate as a globe?**
- **What is meant by the *scale* of a map, and what are the different ways that map scale is described?**
- **What are the differences between *equivalent* ("equal area") maps and *conformal* maps, and when are these properties most important in geographic studies?**
- **How do the four major families of map projections differ from each other, and what are some of the best uses for maps in each of these families of projections?**
- **How are *isolines* used to convey information on a map?**
- **How does a GPS unit know where we are, and what are some common uses of GPS?**
- **What is *remote sensing*, and what kinds of information can be gathered in this way?**
- **How does GIS help in the analysis of geographic data?**

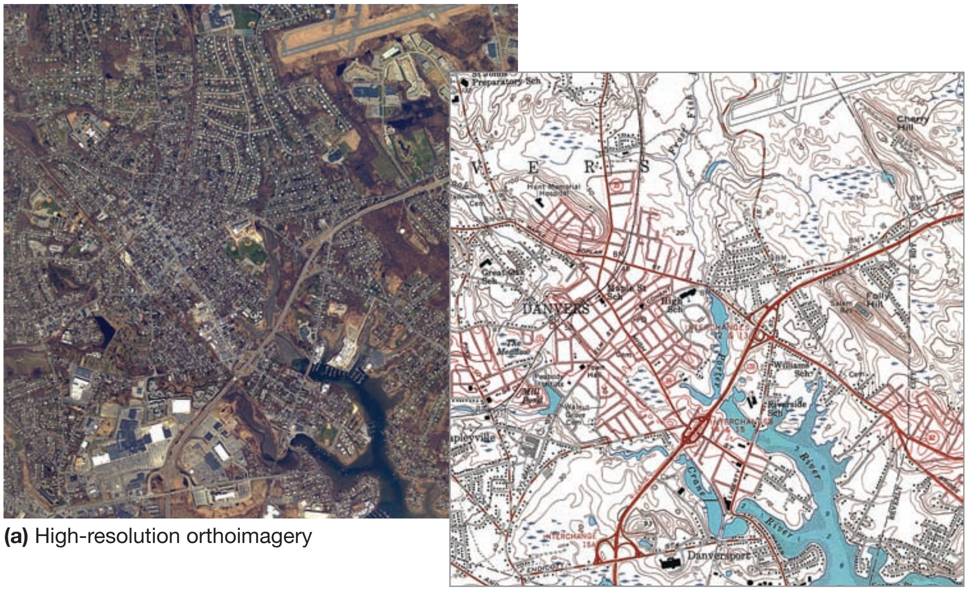
MAPS AND GLOBES

For portraying the geographic features of Earth as a whole, there is no substitute for a globe (Figure 2). Not only does a well-made globe accurately convey the spherical shape of Earth, it can show, essentially without distortion, the spatial relationships of Earth's surface, maintaining correct size, shape, distance, and direction relationships of features around the planet.

A globe, of course, has limitations. Most importantly, almost all globes are constructed at a very small scale, which means that they cannot show much detail. In order for a globe to show as much detail as the maps in Figure 1, it would need to be about 500 meters (1600 feet) in diameter! Because maps are much more portable and versatile than globes, there are literally billions of maps in use over the world, whereas globes are extremely limited both in number and variety.

Seeing Geographically

This natural color satellite image of Baja, Mexico, was taken on November 27, 2011, with the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument aboard NASA's Aqua satellite. Strong winds have caused dust to blow off of mainland Mexico and the Baja peninsula. From which direction were the winds blowing on this day? How do the mountaintops and sky conditions change as you look north of Mexico into the United States?



(a) High-resolution orthoimagery

(b) Topographic map

(c) Geologic map

(d) Google map

▲ **Figure 1** Different types of maps convey different kinds of information about the landscape, as shown in these four maps of a region near Salem, Massachusetts. (a) High-resolution orthophoto imagery (original scale 1:24,000). (b) Topographic map with elevation contour lines (original scale 1:24,000). (c) Geologic map showing rock types: orange = coarse glacial deposits; blue = glaciomarine deposits; green = glacial till; lavender = swamp deposits (original scale 1:50,000). (d) Google™ Map showing streets and highways.

Maps

In the simplest terms, a **map** is a flat representation of Earth, shown reduced in size with only selected features or data showing. A map serves as a surrogate (a substitute) for any surface we wish to portray or study. Although any kind of surface can be mapped—the lunar surface, for instance, or that of Mars—all the maps in this text portray portions of Earth's surface.

The basic attribute of maps is their ability to show distance, direction, size, and shape in their horizontal (that is to say, two-dimensional) spatial relationships. In addition to these fundamental graphic data, most maps show other kinds of information as well. Most maps have a special purpose, and that purpose is usually to show the distribution of one or more phenomena (see Figure 1). Such *thematic maps* may be designed to show street patterns, the distribution of Tasmanians, the ratio of sunshine to cloud, the number of earthworms per cubic meter of soil, or any of an infinite number of other facts or combinations of facts. Because they depict graphically "what is where" and because they are often helpful in providing clues as to "why" such a distribution occurs, maps are indispensable tools for geographers. Even so, it is important to realize that maps have limitations.

▲ **Figure 2** A model globe provides a splendid broad representation of Earth at a very small scale, but few details can be portrayed.

Map Distortions: Although most people understand that not everything we may read in a book, in a newspaper, or on the Internet is necessarily correct (thus the somewhat cynical adage, "Don't believe everything you read"), these same people may uncritically accept all information portrayed on a map as being correct. However, no map can be perfectly accurate because it is impossible to portray the curved surface of Earth on a flat map without distortion. Imagine trying to flatten an orange peel—in order to do this, you must either stretch or tear the peel; effectively, the same thing must happen to Earth when we flatten its surface onto a map.

The extent to which the geometric impossibility of flattening a sphere without distortion becomes a problem on a map depends on two related variables. First: how much of Earth is being shown on the map—for example, these distortions are always significant on a world map, but less so on a map showing a very limited region of Earth. Second: the *scale* of the map—the topic to which we turn next.

Learning Check 1 **Why can't a map represent Earth's surface as perfectly as a globe?**

MAP SCALE

Because a map is smaller than the portion of Earth's surface it represents, in order to understand the geographic relationships (distances or relative sizes, for example) depicted on that map, we must know how to use a **map scale**. The scale of a map describes the relationship between distance measured on the map and the actual distance that represents on Earth's surface. Knowing the scale of a map makes it possible to measure distance, determine area, and compare sizes.

Because Earth's surface is curved and a map's surface is flat, scale can never be perfectly correct over an entire map. In practice, if the map is of a small area a single scale can be used across the entire map. However, if the map is showing a large portion of Earth's surface (such as a world map), there may be significant scale differences from one part of the map to the next—such a map, for example, might need to list different scales for different latitudes.

Scale Types

Three ways of portraying map scale are widely used: the graphic scale, the fractional scale, and the verbal scale (Figure 3).

Graphic Map Scales: A **graphic map scale** uses a line marked off in distances to represent actual distance on Earth's surface. To use a graphic map scale, we measure off the distance between two points on the map (such as by making two pencil marks along the edge of a piece of paper), and then compare that measured distance to the graphic map scale—the graphic scale gives you a direct reading of the actual distance. The advantage of a graphic scale is its simplicity: you determine approximate distances on the surface of Earth by measuring them directly on the map (such as a motorist can do to estimate travel distances on a road map). Moreover, a graphic scale remains correct when a map is enlarged or reduced in size because the length of the graphic scale line is also changed as the map size is changed.

Fractional Map Scales: A **fractional map scale** conveys the relationship between distance measured on a map and the actual distance that represents on Earth with a fraction or ratio called a *representative fraction*. For example,

▲ **Figure 3** All three types of scale are shown on this map. Included are a fractional scale, a verbal scale, and a graphic (shown in both miles and kilometers).

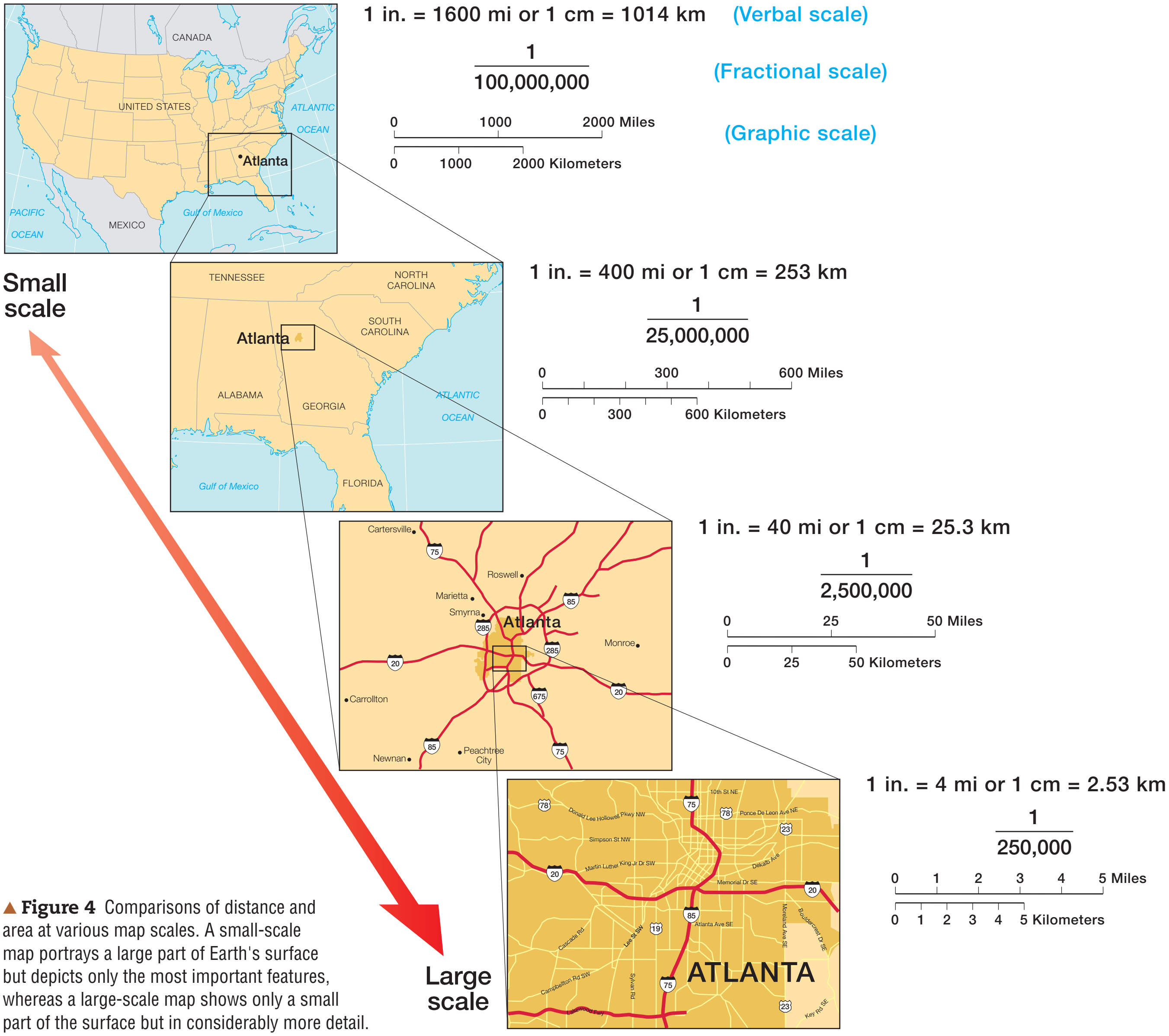
a common fractional scale uses the representative fraction 1/63,360 (often expressed as the ratio 1:63,360): this notation means that 1 unit of measure on the map represents an actual distance of 63,360 units of measure on Earth. The "units of measure" are the same on both sides of the fraction, so 1 millimeter measured on the map represents an actual distance of 63,360 millimeters on Earth's surface, whereas 1 inch measured on the map represents an actual distance of 63,360 inches on Earth's surface, and so forth.

Verbal Map Scales: A **verbal map scale** (or *word scale*) states in words the relationship between the distance on the map and the actual distance on Earth's surface, such as "one centimeter to ten kilometers" or "one inch equals five miles." A verbal scale is simply a mathematical manipulation of the fractional scale. For instance, there are 63,360 inches in 1 mile, so on a map with a fractional scale of 1:63,360 we can say that "1 inch represents 1 mile."

Learning Check 2 **On a map with a fractional scale of 1:10,000, one centimeter measured on the map represents what actual distance on Earth's surface?**

Large and Small Scale Maps

The adjectives large and small are comparative rather than absolute. In other words, scales are "large" or "small" only in comparison with other scales (Figure 4). A **large-scale map** is one that has a relatively large representative fraction, which means that the denominator is small. Thus, 1/10,000 is a larger value than, say, 1/1,000,000, and so a scale of 1:10,000 is large in comparison with one of 1:1,000,000; consequently, a map at a scale of 1:10,000 is called a large-scale map—such a map portrays only a small portion of Earth's surface but portrays it in considerable detail. For example, if



▲ **Figure 4** Comparisons of distance and area at various map scales. A small-scale map portrays a large part of Earth's surface but depicts only the most important features, whereas a large-scale map shows only a small part of the surface but in considerably more detail.

this page were covered with a map having a scale of 1:10,000, the map would be able to show just a small part of a single city, but that area would be rendered in great detail.

A **small-scale map** has a small representative fraction—in other words, one having a large denominator. A map having a scale of 1:10,000,000 is classified as a small-scale map. If it were covered with a map of that scale, this page would be able to portray about one-third of the United States, but only in limited detail.

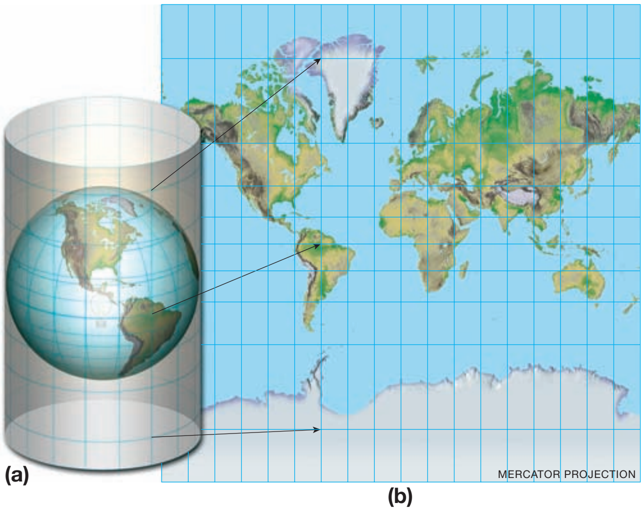
MAP PROJECTIONS AND PROPERTIES

Animation
Map Projections

The challenge to the cartographer (mapmaker) is to try to combine the geometric exactness of a globe with the convenience of a flat map. This melding has been attempted for many centuries, and further refinements continue to be made. The fundamental problem is always the same: to transfer data from a spherical surface to a flat map with a minimum of distortion. This transfer is accomplished with a *map projection*.

Map Projections

A **map projection** is a system in which the spherical surface of Earth is transformed for display on a flat surface. The basic principle of a map projection is simple. Imagine a transparent globe on which are drawn meridians, parallels, and continental boundaries; also imagine a lightbulb in the center of this globe. A piece of paper, either held flat or rolled into some shape such as a cylinder or cone, is placed over the globe as in Figure 5. When the bulb is lighted, all the lines on the globe are projected outward onto the paper. These lines are then sketched on the paper. When the paper is laid out flat, a map projection has been produced. Few map projections have been made by actual "optical" projection from a globe onto a piece of paper; instead, map projections are derived by mathematically transferring the features of a sphere onto a flat surface.



▲ **Figure 5** The concept of map projection. A cylinder is wrapped around a globe with a light in its center (a), and the features of the globe are projected onto the adjacent cylinder. (b) The resulting map is called a cylindrical projection.

Because a flat surface cannot be closely fitted to a sphere without wrinkling or tearing, no matter how a map projection is made, data from a globe (parallels, meridians, continental boundaries, and so forth) cannot be transferred to a map without distortion of shape, relative area, distance, and/or direction. However, the cartographer can choose to control or reduce one or more of these distortions—although all distortions cannot be eliminated on a single map.

Learning Check 3 **What is a map projection?**

Map Properties

Cartographers often strive to maintain accuracy either of size or of shape—map properties known as *equivalence* and *conformality*, respectively (Figure 6).

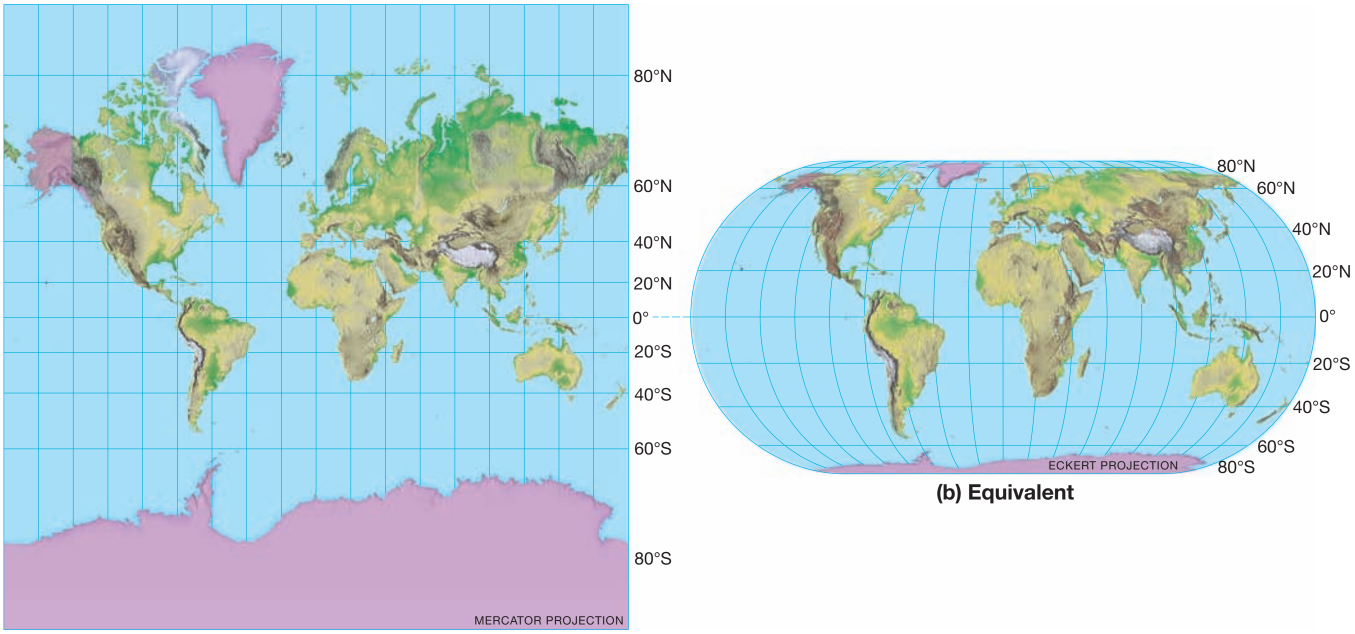
Equivalence: In an **equivalent map projection** (also called an **equal area map projection**) the correct size ratio of area on the map to the corresponding actual area on Earth's surface is maintained over the entire map. For example, on an equivalent world map, if you were to place four dimes at different places (perhaps one on Brazil, one on Australia, one on Siberia, and one on South Africa), the area on Earth covered by each coin would be the same.

Equivalent projections are very desirable because, with them, misleading impressions of size are avoided. The world maps in this text are mostly equivalent projections because they are so useful in portraying distributions of the various geographic features we will be studying.

There are trade-offs, of course, with equivalent maps. Equivalence is difficult to achieve on small-scale maps because correct shapes must be sacrificed in order to maintain proper area relationships. Most equivalent world maps (which are necessarily small-scale maps) show distorted shapes of landmasses—especially in the high latitudes. For example, as Figure 6b shows, on equivalent maps the shapes of Greenland and Alaska are usually shown as more "squatty" than they actually are.

Conformality: A **conformal map projection** is one in which proper angular relationships are maintained across the entire map so that the shapes of features such as coastlines are the same as on Earth. It is impossible to depict true shapes for large areas such as a continent, but they can be approximated, and in practice for small areas we can say that conformal maps show correct shapes. All conformal projections have meridians and parallels crossing each other at right angles, just as they do on a globe.

The main problem with conformal projections is that the size of an area must often be considerably distorted to depict the proper shape. Thus, the scale necessarily changes from one region to another. For example, a



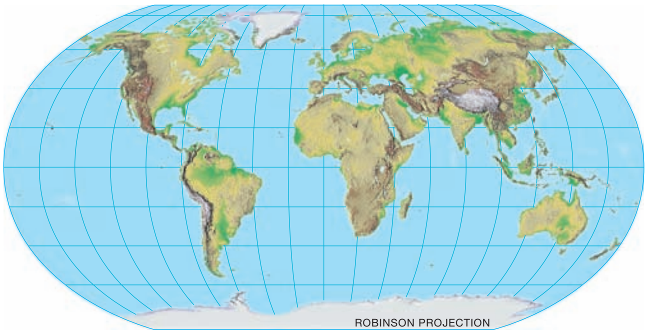
(b) Equivalent

(a) Conformal

▲ **Figure 6** Conformal and equivalent maps. (a) A conformal projection (the Mercator) depicts accurate shapes, but the sizes are severely exaggerated in high latitudes. (b) An equivalent (equal area) projection (the Eckert) is accurate with regard to size, but shapes are badly distorted in high latitudes. It is impossible to portray both correct size and correct shape on a world map. Compare the sizes and shapes of Antarctica, Alaska, and Greenland in these examples.

conformal map of the world normally greatly enlarges sizes in the high latitudes. Figure 6a shows the conformal projection known as a Mercator projection (discussed in greater detail later in this chapter)—notice the exaggerated apparent sizes of landmasses toward the poles.

Compromise Projections: Except for maps of very small areas (in other words, large-scale maps), where both properties can be closely approximated, conformality and equivalence cannot be maintained on the same projection, and thus the art of mapmaking, like politics, is often an art of compromise. For example, Figure 7 shows a Robinson projection—a **compromise map projection;** it is neither equivalent nor conformal, but instead balances reasonably accurate shapes with reasonably accurate areas. The Robinson projection is a popular choice as a general-purpose classroom map.



▲ **Figure 7** Many world maps are neither purely conformal nor purely equivalent, but a compromise between the two. One of the most popular compromises is the Robinson projection shown here.

As a rule of thumb, it can be stated that some map projections are purely conformal, some are purely equivalent, none are both conformal and equivalent, and many are neither, but are instead a compromise between the two.

Learning Check 4 **What is the difference between an equivalent map and a conformal map?**

FAMILIES OF MAP PROJECTIONS

Because there is no way to avoid distortion completely, no map projection is ideal for all uses. So, hundreds of different map projections have been devised for one purpose or another. Most of them can be grouped into just a few families. Projections in the same family generally have similar properties and related distortion characteristics.

Cylindrical Projections

As Figure 5 shows, a **cylindrical projection** is obtained by mathematically "wrapping" the globe with a cylinder of paper in such a way that the paper touches the globe only at the globe's equator. We say that paper positioned this way is tangent to the globe at the equator, and the equator is called the *circle of tangency* (some cylindrical projections choose a circle of tangency other than the equator). The curved parallels and meridians of the globe then form a perfectly rectangular grid on the map. Having the equator as the tangency line produces a right-angled grid (meridians and parallels meet at right angles) on a rectangular map. There is no size distortion at the circle of tangency, but size distortion increases progressively with increasing distance from this circle, a characteristic clearly exemplified by the *Mercator projection*.

Mercator: The Most Famous Projection: Although some map projections were devised centuries ago, projection techniques have improved right up to the present day. Thus, it is remarkable that the most famous of all map projections, the **Mercator projection,** originated in 1569 by a Flemish geographer and cartographer, is still in common usage today without significant modification (see Figure 6a).

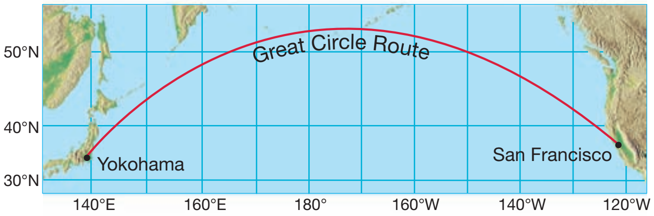
Gerhardus Mercator produced some of the best maps and globes of his time. His place in history, however, is based largely on the fact that he developed a special-purpose projection that became inordinately popular for general-purpose use.

The Mercator projection is a conformal map projection designed to facilitate oceanic navigation. The prime advantage of a Mercator map is that it shows *loxodromes* as straight lines. A **loxodrome**, also called a *rhumb line*, is a curve on the surface of a sphere that crosses all meridians at the same angle and represents a line of constant compass direction. A navigator first plots the shortest distance between origin and destination on a map projection in which great circles are shown as straight lines, such as the gnomonic projection shown in Figure 8a, and then transfers that route to a Mercator projection with straight-line loxodromes. This procedure allows the navigator to generally take the shorter path of a great circle route by simply making periodic changes in the compass course of the airplane or ship. Today, of course, these calculations are all done by computer.

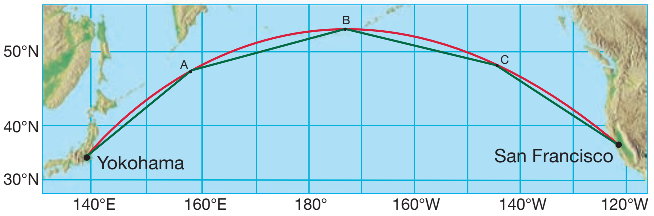
A Mercator map is relatively undistorted in the low latitudes. However, because the meridians do not converge at the poles but instead remain parallel to each other, size distortion increases rapidly in the mid- and high latitudes. Further, to maintain conformality and the map's navigational virtues, Mercator compensated for the east–west stretching by spacing the parallels of latitude increasingly farther apart so that north–south stretching occurs at the same rate. This procedure allowed shapes to be approximated with reasonable accuracy, but at great expense to proper size relationships. Area is distorted by 4 times at the 60th parallel of latitude and by 36 times at the 80th parallel. If the North Pole could be shown on a Mercator projection, it would be a line as long as the equator rather than a single point!

The Mercator projection was a major leap forward in cartography when it was devised, and it remains an excellent choice for large-scale navigation maps and other uses where conformality is important. Unfortunately, by the early twentieth century, Mercator projections were widely used in American classrooms and atlases. Indeed, several generations of American students have passed through school with their principal view of the world provided by a Mercator map. This has created many misconceptions, not the least of which is confusion about the relative sizes of high-latitude landmasses: on a Mercator projection, the island of Greenland appears to be as large as or larger than Africa, Australia, and South America. Actually, however, Africa is actually 14 times larger than Greenland, South America is 9 times larger, and Australia is 3.5 times larger.

(a) Gnomonic Projection



(b) Mercator Projection



(c) Mercator Projection

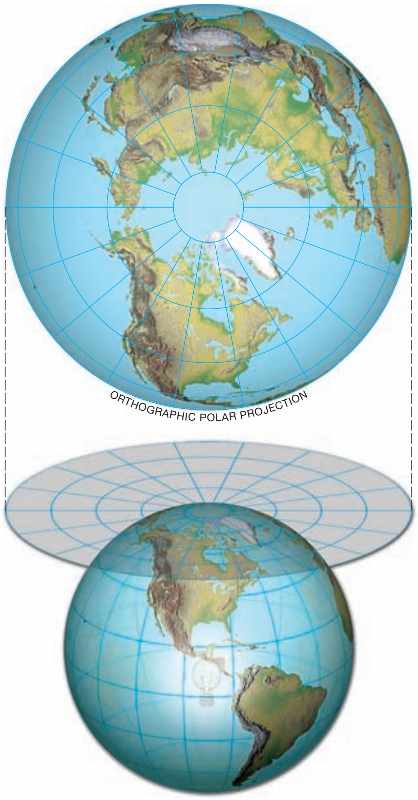
▲ **Figure 8** The prime virtue of the Mercator projection is its usefulness for straight-line navigation. (a) The shortest distance between two locations—here San Francisco and Yokohama—can be plotted on a *gnomonic* projection (on which great circles are shown as straight lines). (b) The great circle route can be transferred to a Mercator projection. (c) On the Mercator projection, straight-line loxodromes can then be substituted for the curved great circle. The loxodromes allow the navigator to maintain constant compass headings over small distances while still approximating the curve of the great circle.

The Mercator projection was devised several centuries ago for a specific purpose, and it still serves that purpose well. Its fame, however, is significantly due to its misuse.

Learning Check 5 **Would a Mercator projection be a good choice for a map used to study the loss of forest cover around the world? Why or why not?**

Planar Projections

A **planar projection** (also called a *plane*, *azimuthal*, or *zenithal projection*) is obtained by projecting the markings of a center-lit globe onto a flat piece of paper that is tangent to the globe at one point (Figure 9)—usually the North or South Pole, or some point on the equator. There

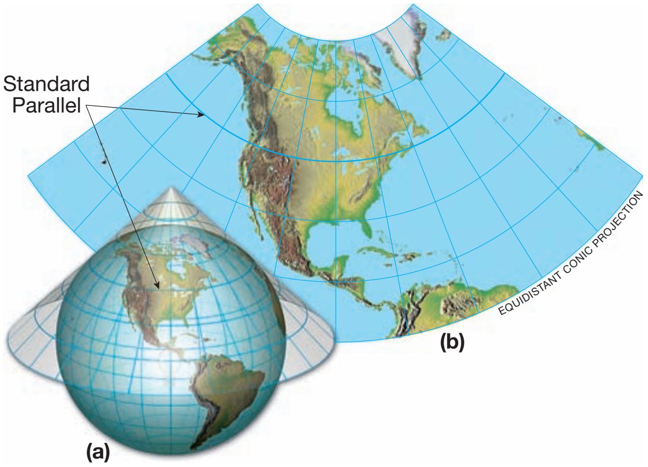


▲ **Figure 9** The origin of a planar projection, as illustrated by a globe with a light in its center, projecting images onto an adjacent plane. The resulting map goes by various names: azimuthal projection, plane projection, or zenithal projection.

is no distortion immediately around the point of tangency, but distortion increases progressively away from this point.

Typically, planar projections show only one hemisphere, and some types can provide a perspective of Earth similar to the view one gets when looking at a globe or that of an astronaut looking at Earth from space (Figure 10). This half-view-only characteristic can be a drawback, of course, just as it is with a globe, although planar projections can be useful for focusing attention on a specific region, and they are common projections when mapping the Arctic and Antarctic regions.

▲ **Figure 10** An orthographic planar projection showing Earth as it would appear from space.



▲ **Figure 11** The origin of a conic projection, as illustrated by a globe with a light in its center (a), projecting images onto a cone. (b) The resulting map is called a conic projection.

Conic Projections

A **conic projection** is obtained by projecting the markings of a center-lit globe onto a cone wrapped tangent to, or intersecting, a portion of the globe (Figure 11). Normally the apex of the cone is positioned above a pole, which means that the circle of tangency coincides with a parallel. This parallel then becomes the *standard parallel* of the projection; distortion is least in its vicinity and increases progressively as one moves away from it. Consequently, conic projections are best suited for regions of east–west orientation in the midlatitudes, being particularly useful for maps of the United States, Europe, or China.

It is impractical to use conic projections for more than one-fourth of Earth's surface (a semihemisphere), but they are particularly well adapted for mapping relatively small areas, such as a state or county.

Pseudocylindrical Projections

A **pseudocylindrical projection** (also called an *elliptical* or *oval projection*) is a roughly football-shaped map, usually of the entire world (see the Eckert in Figure 6b and the Robinson in Figure 7), although sometimes only the central section of a pseudocylindrical projection is used for maps of lesser areas. Mathematically, a pseudocylindrical projection wraps around the equator like an ordinary cylindrical projection, but then further "curves in" toward the poles, effectively conveying some of the curvature of Earth.

In most pseudocylindrical projections, a central parallel (usually the equator) and a central meridian (often the prime meridian) cross at right angles in the middle of the map, which is a point of no distortion; distortion in size and/or shape normally increases progressively as one moves

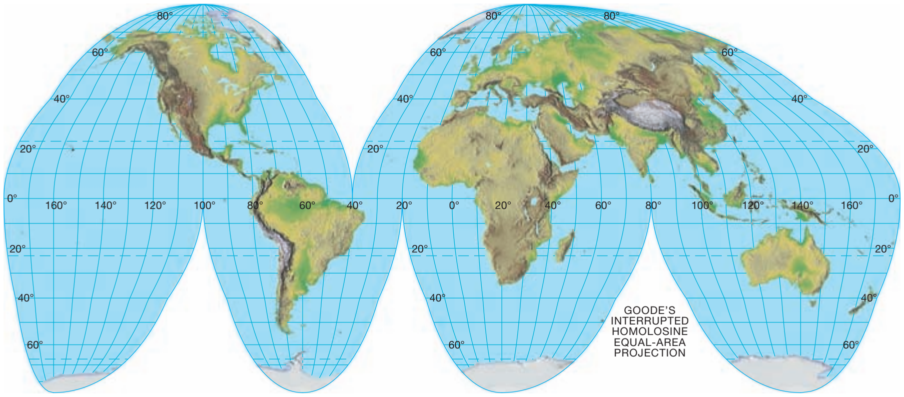


Figure 12 An interrupted projection of the world. The purpose of the interruptions is to portray certain areas (usually continents) more accurately, at the expense of portions of the map (usually oceans) that are not important to the map's theme. The map shown here is a *Goode's interrupted homolosine equal-area projection*. A variation of this projection is used for many maps in this text.

away from this point in any direction. All of the parallels are drawn parallel to each other, whereas all meridians, except the central meridian, are shown as curved lines.

Interrupted Projections: One technique used with pseudocylindrical projections to minimize distortion of the continents is to "interrupt" oceanic regions—*Goode's interrupted homolosine equal-area projection* (Figure 12) is a popular example of this. Goode's projection is equivalent, and, although it is impossible for this map to be conformal, the shapes of continental coastlines are very well maintained even in high latitudes.

When global distributions are mapped, the continents are often more important than the oceans, and yet the oceans occupy most of the map space in a typical projection. A projection can be interrupted ("torn apart") in the Pacific, Atlantic, and Indian Oceans and then based on central meridians that pass through each major landmass—with no land area far from a central meridian, shape and size distortion is greatly decreased. For world maps that emphasize ocean areas, continents can be interrupted instead of ocean basins. You'll see that many of the maps used in this text employ variations of Goode's interrupted projection.

Learning Check 6 **What are the advantages of an "interrupted" projection, such as the Goode's projection?**

CONVEYING INFORMATION ON MAPS

Now that we have described the fundamentals of map scale, properties and projections, let's think about some of the ways that information is presented on maps. We begin with basic features of all maps.

Map Essentials

Maps come in an infinite variety of sizes and styles and serve a limitless diversity of purposes. Regardless of type, however, every map should contain a few basic components to facilitate its use (Figure 13). Omission of any of these essential components decreases the clarity of the map and may make it more difficult to interpret.

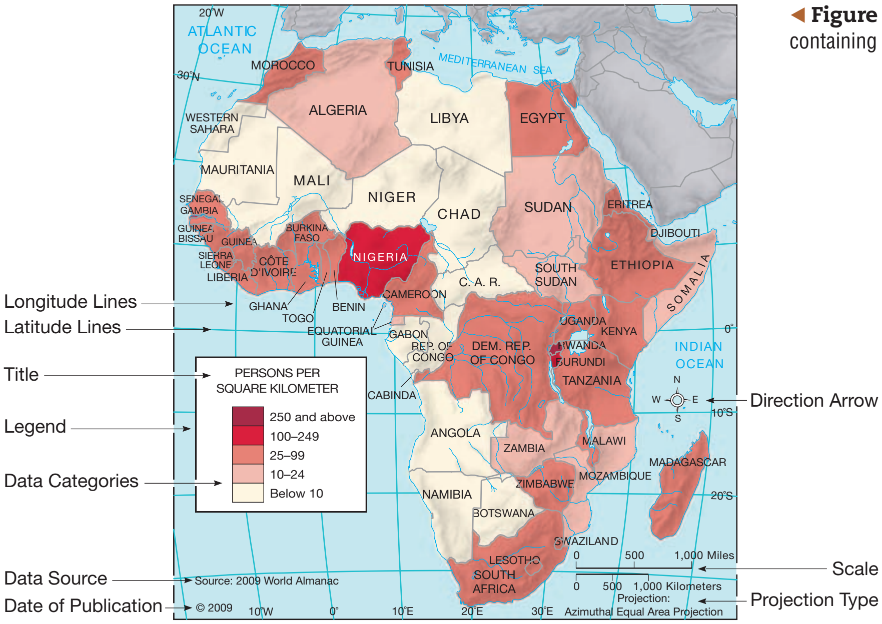


Figure 13 A typical thematic map containing all of the essentials.

Title: This should be a brief summary of the map's content or purpose. It should identify the area covered and provide some indication of content, such as "Road Map of Kenya," or "River Discharge in Northern Europe."

Date: This should indicate the time span over which the information was collected. In addition, some maps also give the date of publication of the map. Most maps depict conditions or patterns that are temporary or even momentary. For a map to be meaningful, therefore, the reader must be informed when the data were gathered, as this information indicates how timely or out of date the map is.

Legend: Most maps use symbols, colors, shadings, or other devices to represent features or the amount, degree, or proportion of some quantity. Some symbols are self-explanatory, but it is usually necessary to include a legend box in a corner of the map to explain the symbolization.

Scale: Any map that serves as more than a pictogram must be drawn to scale, at least approximately. A graphic, verbal, or fractional scale is, therefore, necessary.

Direction: Direction is normally shown on a map by means of the geographic grid of parallels and meridians. If no grid is shown, direction may be indicated by a straight arrow pointing northward, which is called a *north arrow*. A north arrow is aligned with the meridians and thus points toward the north geographic pole.

Location: Although the grid system of latitude and longitude is the most common system of location seen on maps, other types of reference grids may also be used on maps. For example, some large-scale maps (such as road maps) use a simple x- and y-coordinate grid to locating features, and some maps display more than one coordinate system.

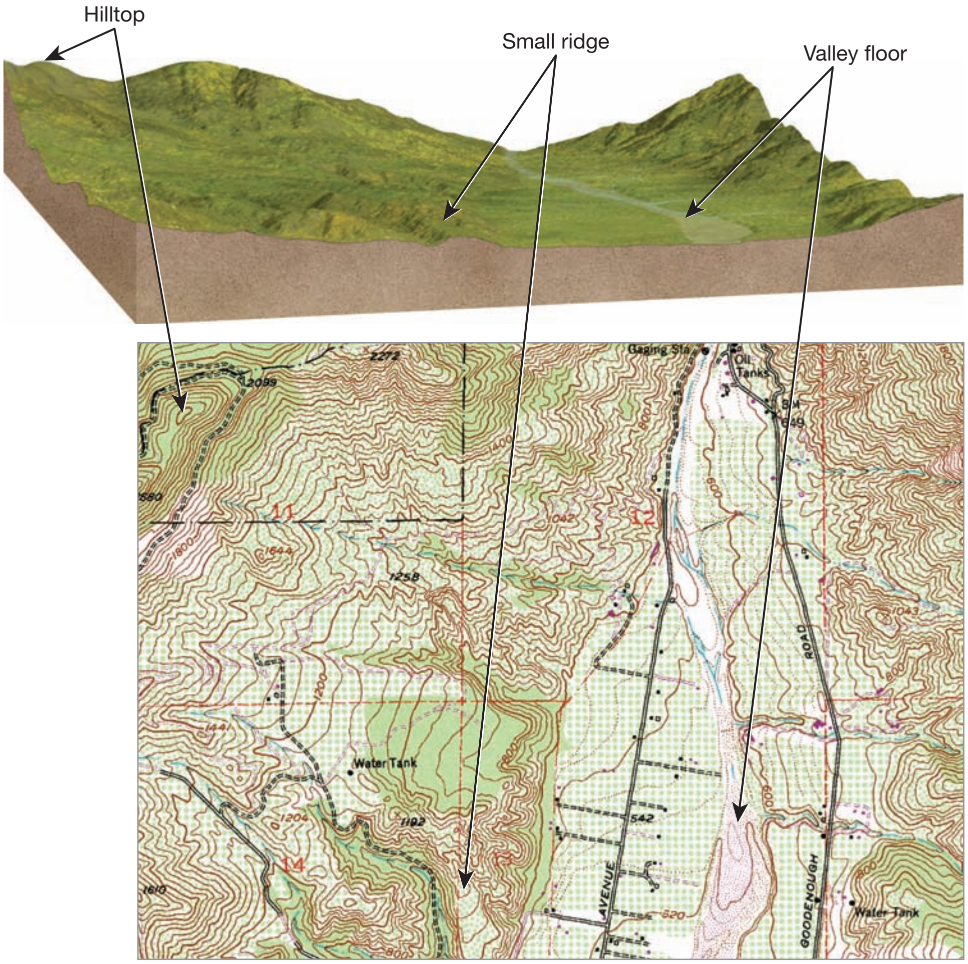
Data Source: For most thematic maps, it is useful to indicate the source of the data.

Projection Type: On many maps, particularly small-scale ones, the type of map projection is indicated to help the user assess the kinds of distortions on the map.

Isolines

Maps can display data in a number of different ways. One of the most widespread techniques for portraying the geographic distribution of some phenomenon is the *isoline* (from the Greek *isos*, meaning "equal"). **Isoline** is a generic term that refers to any line that joins points of equal value of something.

Some isolines represent tangible surfaces, such as the **elevation contour lines** on a topographic map (Figure 14). Most, however, signify such intangible features as temperature and precipitation, and some express relative



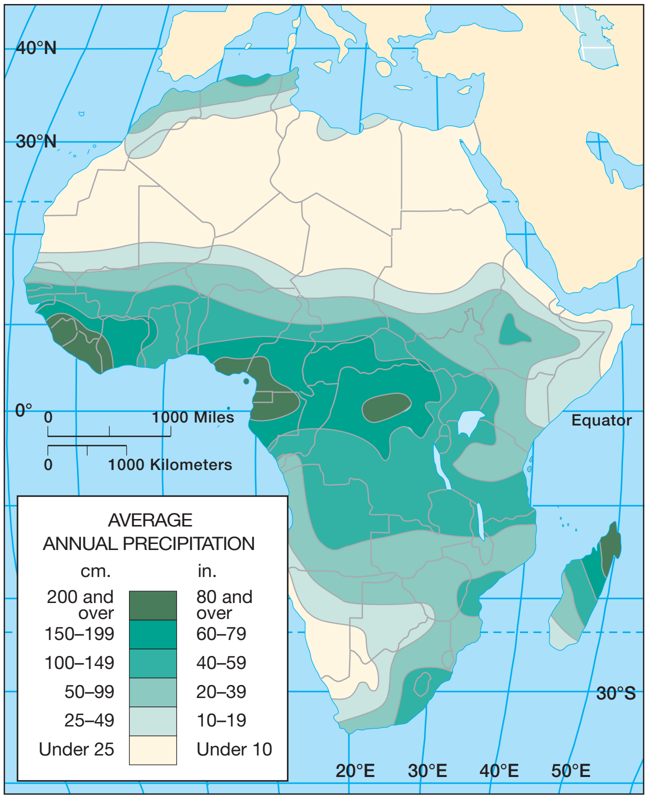
▶ **Figure 14** This portion of a typical United States Geological Survey topographic map quadrangle illustrates the use of contour lines, shown here with a matching landscape diagram and labeled features. This is a section of the Fillmore, California, quadrangle. The original map scale was 1:24,000; the contour interval is 40 feet (12 meters).

values such as ratios or proportions (Figure 15). More than 100 kinds of isolines have been identified by name, ranging from *isoamplitude* (used to describe radio waves) to *isovapor* (water vapor content of the air), but only a few types are important in an introductory physical geography course:

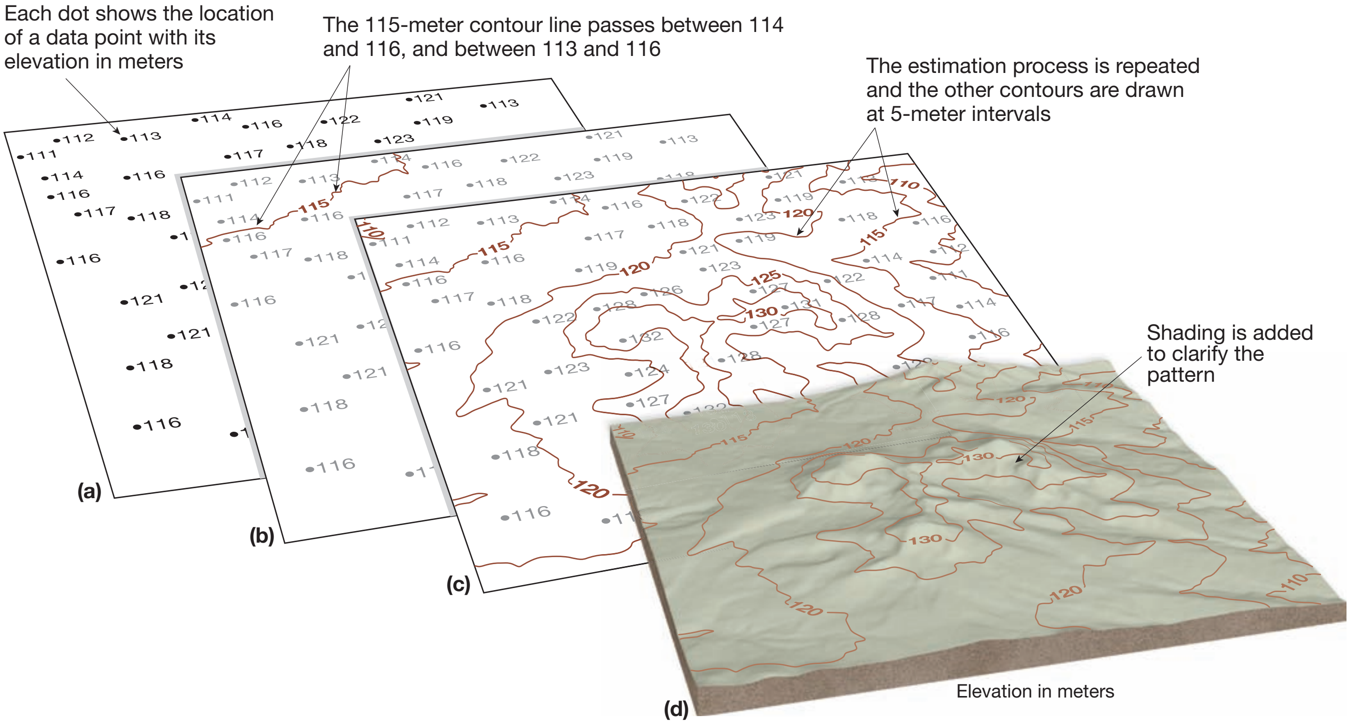
- *Elevation contour line*—a line joining points of equal elevation
- *Isotherm*—a line joining points of equal temperature
- *Isobar*—a line joining points of equal atmospheric pressure
- *Isohyet*—a line joining points of equal quantities of precipitation (*hyeto* is from the Greek, meaning "rain")
- *Isogonic line*—a line joining points of equal magnetic declination

Drawing Isolines: To draw an isoline on a map, it is often necessary to estimate values that are not available. As a simple example, Figure 16 illustrates the basic steps in constructing an isoline map—in this case, an **elevation contour line** map. Each dot in Figure 16a represents a data collection location, and the number next to each dot is the elevation above sea level in meters.

We begin by drawing the 115-meter elevation contour: the 115-meter contour line passes between 114 and 116, and between 113 and 116 (Figure 16b). In Figure 16c this estimation process is repeated for other elevation contours, and in Figure 16d shading is added to clarify the pattern.



▲ **Figure 15** Isolines can be used to show the spatial variation of even intangible features, such as in this map that shows average annual precipitation for the continent of Africa (on this map the areas between isolines have been shaded to clarify the pattern).


Each dot shows the location of a data point with its elevation in meters

The 115-meter contour line passes between 114 and 116, and between 113 and 116

The estimation process is repeated and the other contours are drawn at 5-meter intervals

Shading is added to clarify the pattern

▲ **Figure 16** Drawing isolines. (a) Each dot represents an elevation above sea level in meters. (b) The 115-meter elevation contour is drawn. (c) The other contour lines at 5-meter intervals are drawn. (d) Shading is added for clarity.

Characteristics of Isolines: The basic characteristics of isolines include:

- Conceptually, isolines are always closed lines; that is, they have no ends. In practice, however, an isoline often extends beyond the edge of a map, such as in Figure 16.
- Because they represent gradations in quantity, isolines can never touch or cross one another, except under special circumstances.
- The numerical difference between one isoline and the next is called the *interval*. Although intervals can be varied according to the wishes of the mapmaker, it is normally more useful to maintain a constant interval all over a given map.
- Isolines close together indicate a steep gradient (in other words, a rapid change); isolines far apart indicate a gentle gradient.

Edmund Halley (1656–1742), an English astronomer and cartographer (for whom Halley's Comet is named), was not the first person to use isolines, but in 1700 he produced a map that was apparently the first published map to have isolines. This map showed isogonic lines in the Atlantic Ocean. Isoline maps are now commonplace and are very useful to geographers even though an isoline is an artificial construct—that is, it does not occur in nature. For instance, an isoline map can reveal spatial relationships that might otherwise go undetected. Patterns that are too large, too abstract, or too detailed for ordinary comprehension are often significantly clarified by the use of isolines.

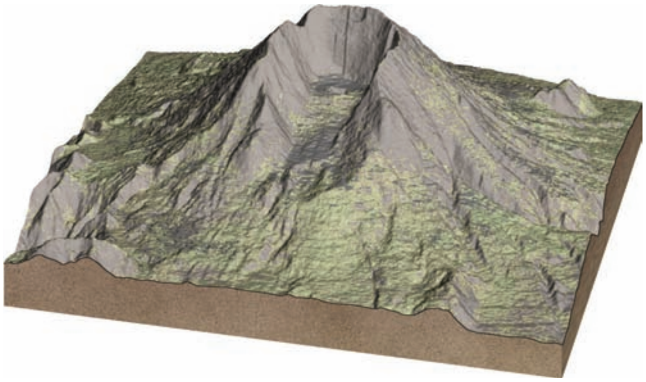
Learning Check 7 **Define "isoline" and give one example of a kind of distribution pattern that can be mapped with isolines.**

Portraying the Three-Dimensional Landscape

Although many maps are simply flat representations of Earth, in physical geography the vertical aspect of the landscape is often an important component of study. In addition to actual raised-relief models of landforms, many other methods can be used to convey the three-dimensional aspect of the landscape on a two-dimensional map.

Elevation Contours: For many decades, topographic maps using elevation contour lines were a workhorse of landform study (see Figure 14)—and remain so today even as we transition from traditional paper maps to electronic maps such as those available from the U.S. Geological Survey (USGS) on its online *National Map* site (http://nationalmap.gov/).

Digital Elevation Models: A remarkable recent advance in cartography has been the use of **digital elevation models (DEM)** to convey topography. The starting point for creating a DEM image is a detailed database of precise elevations. For example, the USGS maintains such a database for the United States at several different spatial resolutions—a 30-meter grid being one of the most commonly used (meaning that elevation data are available at distance intervals of 30 meters, both north–south and east–west, across the entire country). Similar digital elevation data are increasingly available for the entire world.



▲ **Figure 17** An oblique shaded-relief digital elevation model of post-1980 eruption Mount St. Helens.

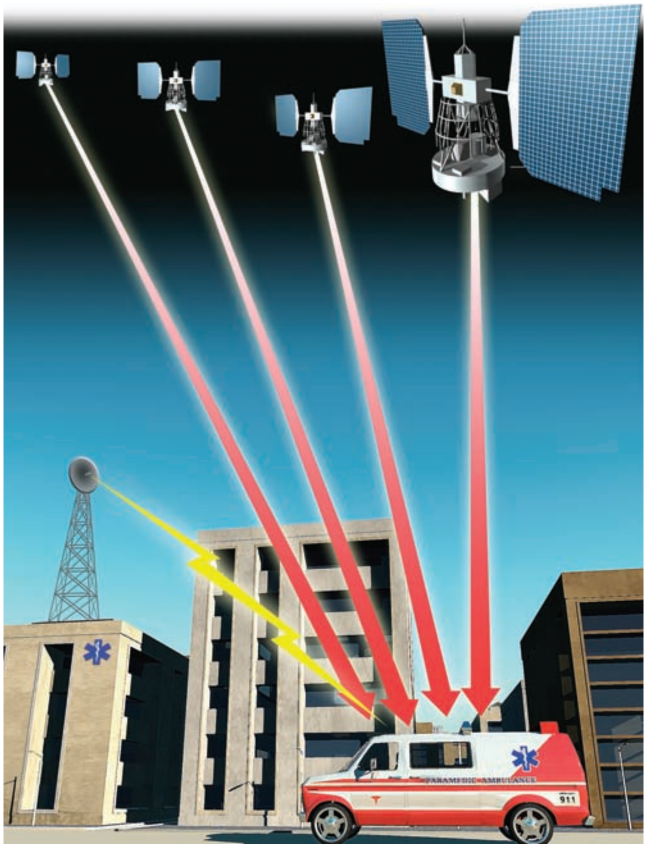
From digital elevation data, a computer can generate a shaded-relief image of the landscape by portraying the landscape as if it were illuminated from the northwest by the Sun (Figure 17). Although shaded relief maps have been drafted by hand in the past, one of the great virtues of a DEM is that the parameters of the image—such as its orientation, scale, and vertical exaggeration of the topography—can be readily manipulated. Further, various kinds of information or images can be overlain on the topography to create maps that were once impossible to conceive (for example, see Figure 29).

Learning Check 8 **How does a digital elevation model convey the topography of Earth's surface?**

GPS—THE GLOBAL POSITIONING SYSTEM

In recent decades, new electronic technologies have transformed map making. One such technology provides precise locational data for points on Earth's surface. The **Global Positioning System,** or simply **GPS,** is a global navigation satellite system for determining accurate positions on or near Earth's surface. It was developed in the 1970s and 1980s by the U.S. Department of Defense to aid in navigating aircraft, guiding missiles, and controlling ground troops. The first receivers were the size of a file cabinet, but continued technological improvement has reduced them to the size of a cell phone (Figure 18). In fact, increasingly devices such as portable computers, digital cameras, and cell phones contain built-in GPS receivers—revolutionizing both the way that data from field observations are gathered for use on maps and the way that data from maps can be retrieved in the field.

▲ **Figure 18** A handheld GPS receiver. It receives signals sent by the network of Global Positioning System satellites, calculating its position anywhere in the world to within 10 meters (33 feet).



▲ **Figure 19** Global Positioning System (GPS) satellites circling 17,700 kilometers (11,000 miles) above Earth broadcast signals that are picked up by the receiver in an ambulance and used to pinpoint the location of the ambulance at any moment. A transmitter in the ambulance then sends this location information to a dispatch center. Knowing the location of all ambulances at any given moment, the dispatcher is able to route the closest available vehicle to each emergency and then direct that vehicle to the nearest appropriate health facility.

The GPS system (formally called NAVSTAR GPS [Navigation Signal Timing and Ranging Global Positioning System]) is based on a constellation of at least 24 high-altitude satellites configured so that a minimum of four—and preferably six—are in view of any position on Earth (currently there are 31 active satellites, with several older satellites still in orbit as backups). Each satellite continuously transmits both identification and positioning information that can be picked up by receivers on Earth (Figure 19). The distance between a given receiver and each member in a group of four or more satellites is calculated by comparing clocks stored in both units, and then the three-dimensional coordinates of the receiver's position are calculated through triangulation. The greater the number of channels in a GPS unit (even inexpensive units now have 12), the greater the number of satellites that can be tracked, and so the better the accuracy. The system already has accuracy greater than that of the best base maps. Even the simplest GPS units determine position to within 15 meters (49 feet).

Wide Area Augmentation System (WAAS): Increased GPS accuracy is gained when the *Wide Area Augmentation System* (*WAAS*) is employed. Originally developed in cooperation with the Federal Aviation Administration (FAA) and the U.S. Department of Transportation, WAAS was implemented to increase the accuracy of instrument-based flight approaches for airplanes. Several dozen ground-based stations across North America monitor GPS signals from the satellites and then generate a correction message that is transmitted to GPS units. With WAAS, GPS units achieve a position accuracy of 3 meters (about 10 feet) about 95 percent of the time. WAAS capability is built into virtually all new GPS receivers today. WAAS service is not yet available around the world, although similar systems are being implemented in Asia (Japan's Multi-Functional Satellite Augmentation System) and Europe (the Euro Geostationary Navigation Overlay Service).

Continuously Operating GPS Reference Stations (CORS): The National Oceanic and Atmospheric Administration (NOAA) manages a system of permanently installed GPS receiving stations known as *Continuously Operating GPS Reference Stations* (*CORS*). These highly accurate units are capable of detecting location differences of less than 1 centimeter of latitude, longitude, and elevation. They are used, for example, for the long-term monitoring of slight changes in the ground surface caused by lithospheric plate movement or the bulging of magma below a volcano.

GPS Modernization Program: The United States has an ongoing modernization program for its GPS system. The upgrades already underway include replacing older satellites with newer ones that broadcast a *second civilian GPS signal* (known as "L2C") that allows ionospheric correction to provide greater accuracy. Further improvements for civilian, aviation, and military use are also being implemented.

GPS Applications: Since 1983, when access to GPS was made free to the public, astounding commercial growth has resulted. It is anticipated that eventually practically everything that moves in our society—airplane, truck, train, car, bus, ship, cell phone—will be equipped with a GPS receiver. Meanwhile, GPS has been employed in earthquake forecasting, ocean floor mapping, volcano monitoring, and a variety of mapping projects. For example, recognizing that GPS is a relatively inexpensive way of collecting data, the Federal Emergency Management Agency (FEMA) has used the system for damage assessment following such natural disasters as floods and hurricanes. GPS was used by workers to catalog items found in the enormous heaps of rubble at Ground Zero following the World Trade Center disaster of September 11, 2001.

Commercial applications now far outnumber military uses of the system. The sale of GPS services is now a multibillion dollar a year industry in the United States. What was born as a military system has become a national economic resource.

Because of the growing importance of GPS applications, other global navigation satellite systems are being implemented around the world. Russia's GLONASS system is operational as of this writing, and Europe's *Galileo* and China's *BeiDou* ("Compass") systems are under development.

Decimal Form of Latitude & Longitude: In part because of the great accuracy of even inexpensive GPS units, latitude and longitude are increasingly being reported in decimal form, such as 94°45.5′ W or even 94.7583° W rather than in its traditional form of 94°45′30″ W. Even the simplest handheld GPS units can provide location coordinates with a resolution of 0.01′ (1/100th minute) or even 0.001′ (1/1000th minute) of latitude and longitude (for reference, a difference in latitude of 0.001′ represents a distance of less than 2 meters [about 6 feet]).

Learning Check 9 **How does GPS determine locations on Earth?**

REMOTE SENSING

Throughout most of history, maps were the only tools available to depict anything more than a tiny portion of Earth's surface with any degree of accuracy. However, sophisticated technology developed in recent years permits precision recording instruments to operate from high-altitude vantage points, providing a remarkable new set of tools for the study of Earth. **Remote sensing** refers to any measurement or acquisition of information by a recording device that is not in physical contact with the object under study—in this case, Earth's surface.

Originally utilizing only airplanes, the use of satellites revolutionized remote sensing. We now have hundreds of satellites from dozens of countries perched high in the atmosphere where they either are circling Earth in a "low" orbit (an altitude of 20,000 kilometers [12,400 miles] or less) or in a lofty *geosynchronous orbit* (usually about 36,000 kilometers [22,400 miles] high) that allows a satellite to remain over the same spot on Earth at all times. These satellites gather data and produce images that provide communications, global positioning, weather data, and a variety of other information for a wide range of commercial and scientific applications—for example, see the box, "Focus: Using Remote Sensing Images to Study a Landscape."

Aerial Photographs

Aerial photography was almost the only form of remote sensing used for geographic purposes until the 1960s. The earliest *aerial photographs* were taken from balloons in France in 1858 and in the United States in 1860. During World War I (1914–1918), systematic aerial photographic coverage from airplanes was possible. In World War II (1939–1945) color aerial photographs became important, and by this time *photogrammetry*—the science of obtaining reliable measurements and mapping from aerial photographs—had developed.

Video
Studying Fires Using Multiple Satellite Sensors

Although satellite imagery has taken over the role of aerial photography for some applications, aerial photographs—now available in digital form from agencies such as the USGS—remain an important source of large-scale geographic imagery.

Orthophoto Maps: *Orthophoto maps* are multicolored, distortion-free photographic maps prepared from aerial photographs or digital images. Displacements caused by camera tilt or differences in terrain elevations have been removed, which gives the orthophoto the geometric characteristics of a map (Figure 20). Thus, an orthophoto can show the landscape in much greater detail than a conventional map, but retains the map characteristic of a common scale that allows precise measurement of distances. Orthophoto maps are particularly useful in flat-lying coastal areas because they can show subtle topographic detail in areas of very low relief, such as marshlands.

Visible Light and Infrared Sensing

One of the most important advancements in remote sensing came when wavelengths of radiation other than visible light were first utilized. *Electromagnetic radiation* includes a wide range of wavelengths of energy emitted by the Sun and other objects (Figure 21). The human eye (and conventional photographic film) is only sensitive to the narrow portion of the electromagnetic spectrum known as *visible light*—the colors seen in a rainbow. However, a wide range of other wavelengths of energy—such as *X-rays*, *ultraviolet radiation*, *infrared radiation*, and *radio waves*—are

FOCUS

Using Remote Sensing Images to Study a Landscape

▶ Ryan Jensen, Brigham Young University

Remote sensing provides geographers and other researchers with a great amount of spatial information that can be analyzed to improve our understanding of landscapes. Geographers can study spatial features using data collected from both aerial platforms (airplanes or helicopters) and orbital platforms (satellites). Popular websites and programs provide much remote sensing data for anyone to examine at no cost. These programs, such as Google Earth™, MapQuest™, and the U.S. Geological Survey National Map, are valuable tools that display data at a variety of scales, depending on the "Zoom" level you select. Spatial resolution (the amount of detail you can see) becomes finer the further you zoom into a landscape. The usefulness of remote sensing will only increase as human activities and natural processes change Earth's surface.

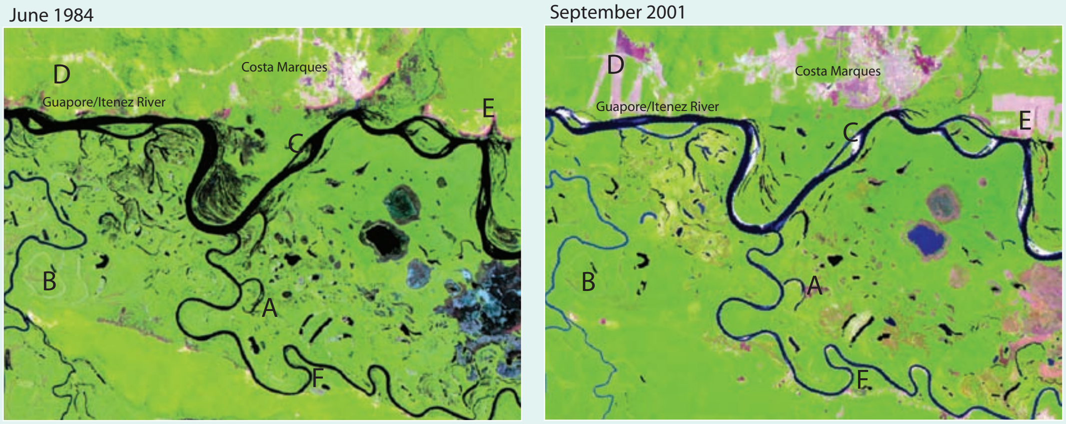
A Fluvial Landscape: To see how remote sensing data can capture characteristics of Earth's surface, look at the images of fluvial features (features formed by flowing water) in Figure A. Landsat 5 acquired the data for the Costa Marques, Brazil, area in June 1984 and again in September 2001. Costa Marques is located along the Guapore/Itenez River that forms the border between Brazil and Bolivia. Landsat data are typically acquired in 30 × 30 meter pixels. That is, each image pixel covers an area of 30 meters by 30 meters (98 feet by 98 feet), or 900 square meters (9687 square feet) over a surface area of 180 kilometers by 180 kilometers (111 miles by 111 miles). In each of the images, you can see fluvial features such as meanders, meander scars, oxbow lakes, and floodplain lakes.

The images can also be compared to study changes in the landscape. Notice that the rivers are much wider and there is more water on the floodplains in the 1984 scene than in the 2001 scene. Further, many of the oxbow lakes (Point A) had much more water in 1984 than in 2001. Meander scars that were very obvious in 1984 (Point B) are not as obvious in 2001. Sand that was not visible in 1984 (Point C) is visible in 2001. The 2001 image also shows evidence of human expansion in Costa Marques and along parts of the Guapore/Itenez River (Points D and E).

A More Detailed Look: When more detail is needed, finer spatial resolution data may be used to study an area. Such data are available from commercial websites and programs such as Google Earth, MapQuest, and many others. For example, look at Point F in Figure A. It is reasonable to assume that the river at that point will eventually create a new channel across the neck of the meander. This process cannot be clearly examined using the 30 × 30 meter Landsat data, but it can be examined using finer-resolution data. Figure B shows a more-detailed image of the same meander neck at Point F. As you can see, there might be evidence of a new channel forming at Point F. In fact, in wet years, river water may flow through the meander neck.

Consider another example: Point B in Figure B shows the same meander scars as the Landsat images in Figure A (Point B). These features can be more fully examined using the detailed image in Google Earth, which can also be used to make measurements such as length and area. Knowing the area of the lake within the scar might be useful in determining how the lake changes from season to season or year to year.

▲ **Figure B** Fine-spatial resolution data showing a meander neck and meander scars in the Costa Marques area.


June 1984

September 2001

◀ **Figure A** Two Landsat images acquired over the Costa Marques, Brazil, area in 1984 and 2001.

▲ **Figure 20** Orthophoto map of Wilmington, North Carolina; original scale: 1:24,000.

emitted, reflected, or absorbed by surfaces and can be detected by special films or instruments, yielding a wealth of information about the environment.

Color infrared (color IR) imagery uses electronic sensors or photographic film sensitive to radiation in the *near infrared* portion of the electromagnetic spectrum—wavelengths of radiation just longer than the human eye can see. With color IR imagery, sensitivity to visible blue light is replaced by sensitivity to near infrared wavelengths. The images produced in this way, even though they are "false-color" images (e.g., living vegetation appears red instead of green), are still extremely valuable. Color IR film was first widely used in World War II when it was often called "camouflage-detection" film because of its ability to discriminate living vegetation from the withering vegetation used to hide objects during the war. Today, one of the major uses of color IR imagery remains the identification and evaluation of vegetation (Figure 22).

Thermal Infrared Sensing

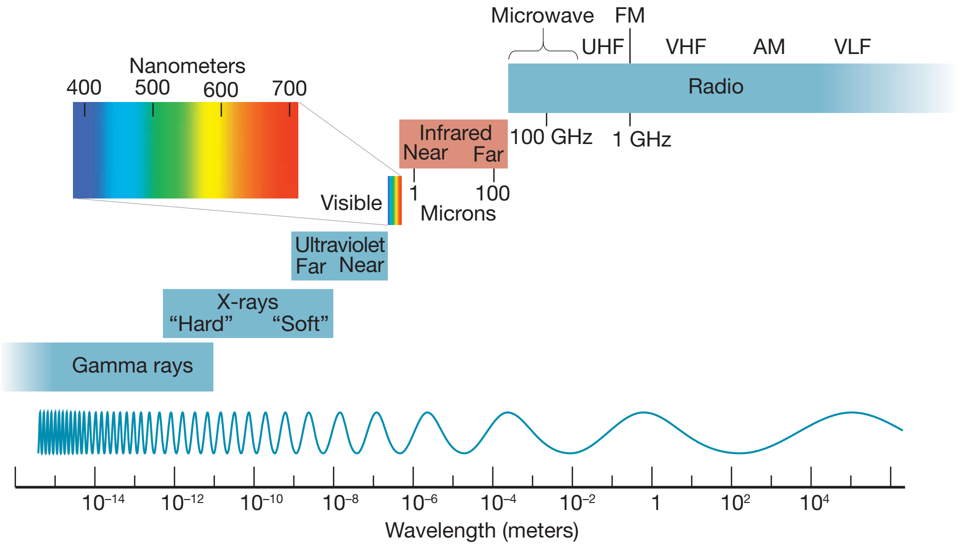
None of the middle or far infrared part of the electromagnetic spectrum, called *thermal infrared* (thermal IR), can be sensed with conventional digital cameras or traditional photographic film; as a result, special supercooled scanners are needed. Thermal scanning measures the radiant temperature of objects and may be carried out either day or night. The photograph-like images produced in this process are particularly useful for showing diurnal temperature differences between land and water, and between bedrock and alluvium, for studying thermal water pollution, and for detecting forest fires.

By far the greatest use of thermal IR scanning systems has been on meteorological satellites. Although the spatial resolution (the size of the smallest feature that can be identified) is not as high as some other kinds of sensing systems, it is more than sufficient to provide details that allow weather forecasting that is far more accurate and complete than ever before.

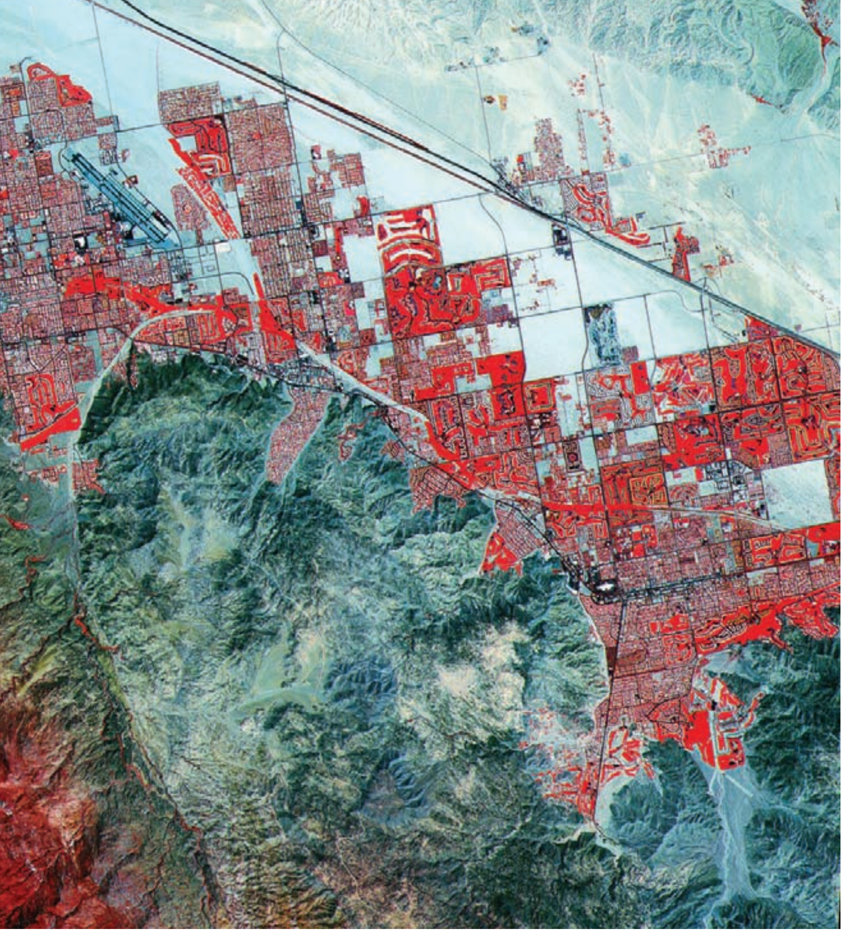
Learning Check 10 **What are the differences between "near infrared" and "thermal infrared" images, and what kinds of features might be studied with each?**

Multispectral Remote Sensing

Today, most sophisticated remote sensing satellites are **multispectral** or *multiband* (the various regions of the electromagnetic spectrum are sometimes called *bands*). These instruments detect and record many bands of the electromagnetic spectrum simultaneously. Thus, although traditional photographic film was sensitive to only a narrow band of visible radiation, a satellite equipped with a multiband instrument images the surface of Earth in several spectrum



◀ **Figure 21** The electromagnetic spectrum. The human eye can only sense radiation from the visible-light region. Conventional photography also can use only a small portion of the total spectrum. Various specialized remote-sensing scanners are capable of "seeing" radiation from other parts of the spectrum.



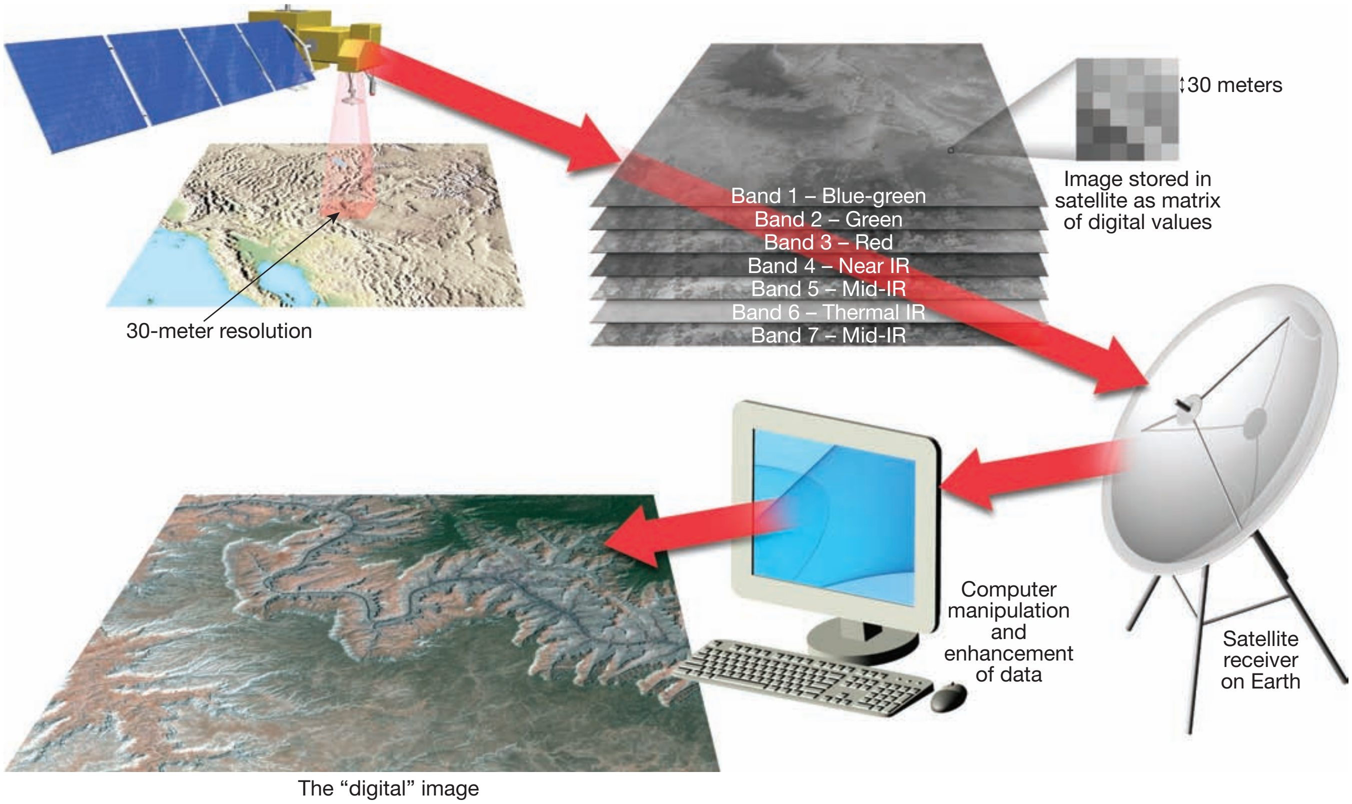
▲ **Figure 22** Color infrared image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) of the cities of Palm Springs, Cathedral City, and Palm Desert, California. In this false-color infrared image, healthy vegetation is shown in red; bare ground is shown in gray-blue.

regions at once—visible light, near infrared, middle infrared and thermal infrared—each useful for different applications.

A multispectral satellite image is digital, conveyed through a matrix of numbers, with each number representing a single value for a specific *pixel* (picture element) and band. These data are stored in the satellite, eventually transmitted to an Earth receiving station, numerically processed by a computer, and produced as a set of gray values and/or colors on a screen or hard-copy printout (Figure 23).

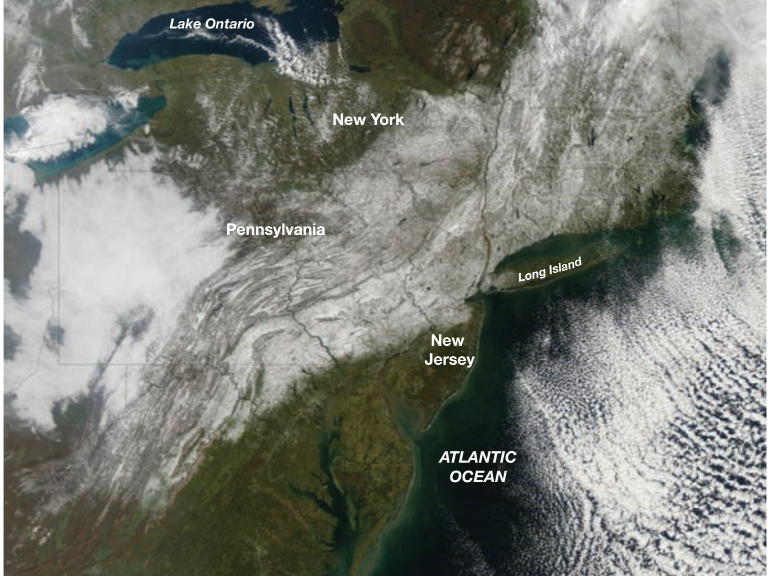
Landsat: The early NASA space missions (Mercury, Gemini, and Apollo) used multiband photography obtained through multicamera arrays. These imaging experiments were so successful that NASA then developed what was initially called the *Earth Resources Technology Satellite series* (*ERTS*) and later renamed *Landsat*. The 1970s and 1980s saw the launch of five Landsat satellites carrying a variety of sensor systems.

Landsat 7, which was launched in 1999, carries an instrument array called the Enhanced Thematic Mapper Plus that provides images in eight spectral bands with a resolution of 15 meters (49 feet) in the panchromatic band (sensitive to visible and near infrared wavelengths), 30 meters (98 feet) in the six narrow bands of visible and short infrared wavelengths, and 60 meters (197 feet) in thermal infrared (Figure 24). A description of the primary applications for the various bands is provided in Table 1. Although the satellite was originally designed for a life of less than 10 years, as of this writing Landsat 7 remains in active operation. The



▲ **Figure 23** The sequence of events that takes place as a multispectral satellite scan is converted to a digital image.

▲ **Figure 24** Landsat 7 satellite image of the island of Jeju-do, South Korea, taken with the Enhanced Thematic Mapper Plus in April 2000. The central shield volcano of Mount Halla rises to an elevation of 1950 meters (6398 ft). The provincial capital city of Jeju City is the gray patch along the northern shore. Note the subtle differences in the color of the water around the island.



▲ **Figure 25** Natural color satellite image showing the northeastern United States after an early season heavy snowstorm. This image was taken on October 30, 2011, with the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument aboard NASA's Terra satellite.

next-generation Landsat satellite, known as the *Landsat Data Continuity Mission*, is scheduled for launch in 2013.

Earth Observing System Satellites: In 1999 NASA launched the first of its *Earth Observing System* (*EOS*) satellites known as *Terra*. The key instrument of these satellites is the Moderate Resolution Imaging Spectroradiometer (MODIS), which gathers data in 36 spectral bands (Figure 25) and provides images covering the entire planet every one to two days. Other devices onboard Terra include the Clouds and the Earth's Radiant Energy System (CERES) instruments for monitoring the energy balance of Earth, and the Multiangle Image Spectroradiometer (MISR) capable of distinguishing various types of atmospheric particulates, land surfaces, and cloud forms—with special processing, three-dimensional models of image data are possible.

The more recently launched EOS satellite, *Aqua*, is designed to enhance our understanding of Earth's water cycle by monitoring water vapor, clouds, precipitation, glaciers, and soil wetness. In addition to instruments such as MODIS, Aqua includes the Atmospheric Infrared Sounder (AIRS), designed to permit very accurate temperature measurements throughout the atmosphere.

In June 2011, NASA launched an Argentine-built satellite that included an instrument called *Aquarius* that enables scientists to monitor concentrations of dissolved salts near the surface of the ocean—improving our understanding of the effects of long-term climate change and short-term phenomena such as *El Niño*.

Many satellite images are now easily available for viewing and downloading via the Internet from NASA and NOAA. For example, you can visit http://earthobservatory.nasa.gov/ and http://www.goes.noaa.gov/.

Commercial High-Resolution Satellites: In addition to imagery from government-operated satellites that is often available either free of charge or for a nominal fee (such as the GOES satellites, Landsat, and the EOS satellites), a number of satellites now offer very high-resolution imagery (up to 50- to 60-centimeter [20 to 24 in.]

TABLE 1 **Bands of the Landsat 7 Enhanced Thematic Mapper Plus**

Band Number	Bandwidth (micrometers)	Spectral Region	Resolution (meters)	Applications
1	0.45–0.52	Blue	30	Water penetration and vegetation analysis
2	0.52–0.60	Green	30	Vegetation analysis
3	0.63–0.69	Red	30	Vegetation analysis
4	0.77–0.90	Near IR	30	Biomass and soil analysis
5	1.55–1.75	Middle IR	30	Soil moisture and hydrologic analysis
6	10.4–12.5	Thermal	60	Geothermal resources and vegetation stress
7	2.08–2.35	Middle IR	30	Geologic features
8	0.52–0.90	Panchromatic	15	High-resolution images

resolution) for commercial applications, including SPOT (*Satellite Pour l'Observation de la Terre*), *GeoEye-1*, *QuickBird*, and *WorldView*. The market for these images seems to be growing remarkably.

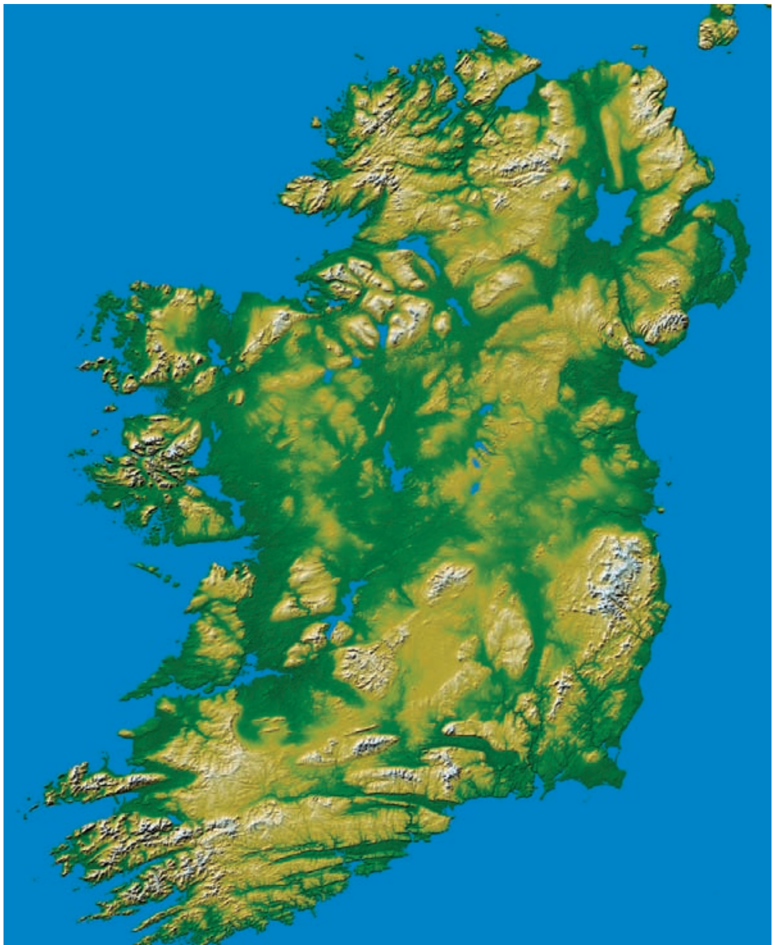
Learning Check 11 **What is "multispectral" remote sensing?**

Radar and Sonar Sensing: All the systems mentioned so far work by sensing the natural radiation emitted by or reflected from an object and are therefore characterized as *passive systems*. Another type of system, called an *active system*, has its own source of electromagnetic radiation. The most important active sensing system used in the Earth sciences is **radar**, the acronym for *radio detection and ranging*. Radar senses wavelengths longer than 1 millimeter, using the principle that the time it takes for an emitted signal to reach a target and then return to the sender can be converted to distance information.

Initially, radar images were viewed only on a screen, but they are now available in photograph-like form (Figure 26). In common with some other sensors, radar is capable of operating by day or night, but it is unique in its ability to penetrate atmospheric moisture. Thus, some wet tropical areas that could never be sensed by other systems have now been imaged by radar. Radar imagery is particularly useful for terrain analysis in places of frequent cloud cover or thick vegetation, and for meteorology—especially in the real-time study and mapping of rainfall and severe weather.

Another active remote sensing system, **sonar** (*sound navigation and ranging*), permits underwater imaging so that scientists can determine the form of that part of Earth's crust hidden by the world ocean.

▼ **Figure 26** Radar image showing the topography of the island of Ireland. The data were gathered from the Shuttle Radar Topography Mission using synthetic aperture radar aboard Space Shuttle Endeavour in 2000. The data were processed with elevations represented by different colors, ranging from green for lowlands to white for high mountaintops. Shaded relief was added to highlight the topography.



GEOGRAPHIC INFORMATION SYSTEMS (GIS)

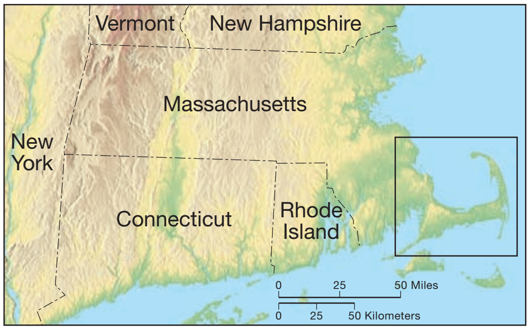
Cartographers have been at work since the days of the early Egyptians, but it was only with the introduction of computers in the 1950s that their technology has advanced beyond manual drawing on a piece of paper. Computers have provided incredible improvements in speed and image handling ability—as one example, all of the maps in this text were made with desktop computers. Of all the technological advances in cartography over the last few decades, however, one of the most revolutionary has been *geographic information systems*.

Geographic Information Systems (GIS): Geographic information systems—commonly called simply **GIS**—are computer systems designed to analyze and display spatial data. GIS involves specialized hardware and software that allow users to collect, store, retrieve, reorganize, analyze, and map geographic data from the real world (Figure 27).

Geographic information systems originally developed out of computer science, geography, and cartography, and they found their greatest early uses in surveying, photogrammetry, spatial statistics, and remote sensing. So commonly are they now used in geographical analysis that GIS has become a science of spatial analysis by itself, known as *geographic information science*, and the software has spun off a multibillion-dollar industry in spatial data and spatial information.

Geographic information systems are libraries of information that use maps to organize, store, view, and analyze information in an intuitive, visual manner. Just as an ordinary computer database management system can manipulate rows and columns of data in tabular form, a GIS allows data management using the link between data and a map. This means that the map and data are encoded, usually as numbers representing coordinates of locations at points on a grid covering the mapped area. Once the data and the map are inside the GIS, the user can organize or search the data using the map, or the map using the data. An important attribute is the capability of GIS data from different maps and sources, such as field data, map data, and remotely sensed images, to be registered together at the correct geographic location within a common database, with a common map scale and map projection.

▲ **Figure 27** Land use changes on Cape Cod from 1951 to 2005, showing the expansion of residential housing and the accompanying loss of forest. Dark green shows areas of forest, yellow shows areas of residential housing, and red shows areas of commercial and industrial development.

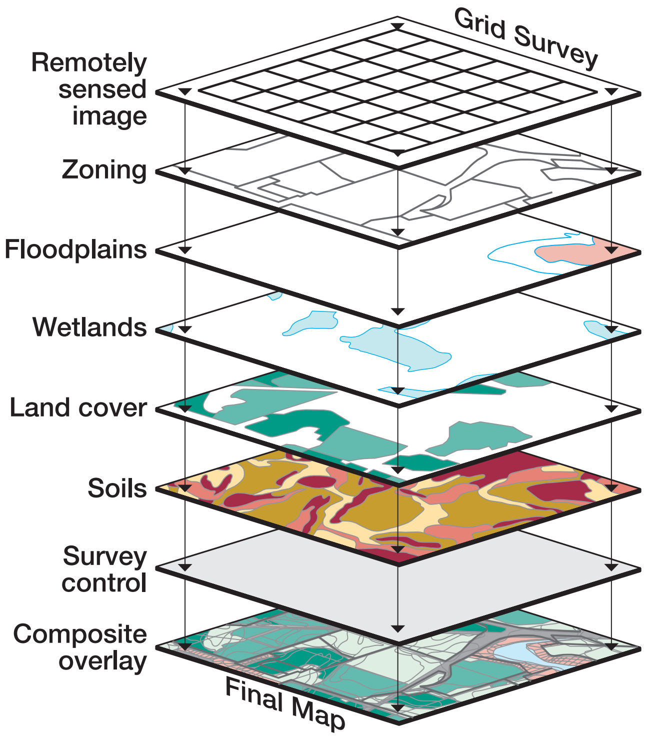


In this way, one map layer, such as the locations of rivers, can then be cross-referenced to another, such as geology, soils, or slope.

Overlay Analysis: GIS is frequently used in overlay analysis, where two or more layers of data are superimposed or integrated. GIS treats each spatially distributed variable as a particular layer in a sequence of overlays. As shown in Figure 28, input layers bring together such diverse elements as topography, vegetation, land use, land ownership, and land survey. Details of these various components are converted to digital data and are synthesized onto a reference map or data set. Particularly useful images for the study of physical geography can be developed with GIS when data or satellite images are overlain on topography generated with a digital elevation model, offering oblique views of the landscape previously impossible to obtain (Figure 29).

Geographic information systems are used today in a diverse array of applications concerned with geographic location. Because they provide impressive output maps and a powerful methodology for analytical studies, GIS can bring a new and more complete perspective to resource management, environmental monitoring, natural hazards assessment—and a host of other fields. The growth of GIS is so rapid today that there are few fields of academic study, sectors of the economy, and divisions of government not using these powerful tools.

Learning Check 12 **How is GIS different from GPS?**



▲ **Figure 28** Much GIS work involves layers of spatial data superimposed upon one another.

Tools of the Geographer

As we have just seen, a vast array of maps, remotely sensed imagery, satellite data, and GIS applications are now available, making the tools of the geographer more widely used than ever before. The effective use of these tools, however,

▲ **Figure 29** This oblique view of Bangladesh and the Himalayas was created by configuring MODIS images from the Terra satellite over a 50-times vertically exaggerated digital elevation model of the topography.

still entails thoughtful consideration. Although it is easy to download a satellite image or quickly print a handsome-looking map from the Internet, those images and maps may or may not be useful for analysis—and might actually be deceptive—unless care is taken to choose an appropriate map projection, an appropriate scale, and an appropriate selection of data to depict.

Choosing Effective Maps and Imagery: Certain types of imagery are useful for particular purposes. For example, when studying major features of the lithosphere, high-altitude space imagery is especially valuable (Figure 30), although this type of imagery might have limited use in detailed local terrain studies where large-scale oblique aerial photographs or topographic maps might be more appropriate. For studying the hydrosphere, multiband satellite images of an entire hemisphere can tell us much about the water content in clouds, air masses, glaciers, and snowfields at a given time, although detailed conventional color images might be better for discriminating complicated shoreline features.

Vegetation patterns in the biosphere are often best appreciated with color infrared imagery—overall vegetation patterns on small-scale satellite images and detailed aerial photographs for crop and forest inventory studies. Features of human creation are generally not evident on very high-altitude imagery, but they become increasingly clear as one approaches Earth, and so survey patterns, transportation lines, rural settlements, and cities are best interpreted on imagery of intermediate or large scale. And in all cases, GIS may be used to uncover or highlight geographic relationships that may not be obvious when employing any single source of data or kind of imagery.

In using these tools, the geographer should never lose sight of our major objective: to better understand Earth. Such understanding does not come simply through the application of technology, however. Understanding comes from a carefully designed investigation, often using technology, but frequently supported by such traditional sources of information as field study and observation.

◀ **Figure 30** Natural color satellite image of the Yukon River Delta, Alaska, taken with the Enhanced Thematic Mapper Plus on Landsat 7.

LEARNING REVIEW

After studying this chapter, you should be able to answer the following questions. Key terms from each text section are shown in **bold type**. Definitions for key terms are also found in the glossary at the end of this chapter.

KEY TERMS AND CONCEPTS

Maps and Globes

1. How is a **map** different from a globe?
2. Why is it impossible for a map of the world to portray Earth as accurately as can be done with a globe?

Map Scale

3. Describe and explain the concept of **map scale**.
4. Contrast **graphic map scales**, **fractional map scales**, and **verbal map scales**.
5. What is meant by a map scale with a representative fraction of 1/100,000 (also written 1:100,000)?
6. Explain the difference between **large-scale maps** and **small-scale maps**.

Map Projections and Map Properties

7. What is meant by a **map projection**?
8. Explain the differences between an **equivalent** (**equal area**) **map projection** and a **conformal map projection**.
9. Is it possible for a map to be both conformal and equivalent?
10. What is a **compromise map projection**?

Families of Map Projections

11. Briefly describe the four major families of map projections: **cylindrical projections**, **planar projections**, **conic projections**, and **pseudocylindrical projections**.
12. Why is a **Mercator projection** useful as a navigation map? Why is it not ideal for use as a general purpose map?
13. What is a **loxodrome** (rhumb line)?

Conveying Information on Maps

14. Explain the concept of **isolines**.
15. What characteristics on maps are shown by *isotherms*, *isobars*, and **elevation contour lines**?
16. How does a **digital elevation model** (DEM) depict the landscape?

GPS—The Global Positioning System

17. Briefly explain how the **Global Positioning System** (**GPS**) works.

Remote Sensing

18. What is **remote sensing**?
19. Briefly define the following terms: *aerial photograph*, *photogrammetry*, *orthophoto map*.
20. What are some of the applications of color infrared imagery?
21. What are some of the applications of thermal infrared imagery?
22. Describe **multispectral** remote sensing.
23. Compare and contrast **radar** and **sonar**?

Geographic Information Systems (GIS)

24. Distinguish between GPS and GIS (geographic information systems).

STUDY QUESTIONS

1. Why are there so many types of map projections?
2. What kind of map projection would be best for studying changes in the amount of permafrost in the Arctic? Why? Consider both the general family of projection, and its properties such as equivalence and conformality.
3. This question has been intentionally omitted from this text.
4. Isolines never just start or stop on a map—every isoline must close on itself, either on or off the map. Why?
5. A GPS receiver in your car simply calculates your current latitude and longitude. How can it use this basic locational data to determine your *speed* and *direction* of travel?
6. Describe one kind of application where radar imagery may be useful for geographical analysis. Explain the advantages of radar over other kinds of remote sensing in your example.

EXERCISES

1. On a map with a fractional scale of 1:24,000
   a. One inch represents how many feet? _________
   b. One centimeter represents how many meters? _________
   c. If the map is 18 inches wide and 22 inches tall, how many square miles are shown on the map? _________
2. If we construct a globe at a scale of 1:1,000,000, what will be its diameter? (You may give your answer in either feet or meters.)
3. Convert the following latitude and longitude coordinates presented in decimal form (as might be shown on a GPS unit) into their conventional form of degrees/minutes/seconds:
   42.6700° N = _________° _________′ _________″ N
   105.2250° W = _________° _________′ _________″ W
4. Convert the following latitude and longitude coordinates from their conventional form of degrees/minutes/seconds into decimal form:
   22°20′15″ N = _________° N
   137°30′45″ E = _________° E

Seeing Geographically

Look again at the image of Baja at the beginning of the chapter. The Baja peninsula is about 160 kilometers (100 miles) wide in the north and about 80 kilometers (50 miles) wide at its southern tip. About how far has the dust blown to the west off of Baja? In what part of the image is the shape of the land least distorted? Most distorted? Could a single graphic map scale be used to accurately measure distances everywhere on this image? Why or why not?

MasteringGeography™

Looking for additional review and test prep materials? Visit the Study Area in MasteringGeography™ to enhance your geographic literacy, spatial reasoning skills, and understanding of this chapter's content by accessing a variety of resources, including geoscience animations, MapMaster interactive maps, videos, RSS feeds, flashcards, web links, self-study quizzes, and an eText version of *McKnight's Physical Geography: A Landscape Appreciation.*

LEARNING CHECK ANSWERS

1: Because it is impossible to flatten a sphere without distortion. **2:** 10,000 centimeters. **3:** A system that mathematically transfers the graticule and features of Earth onto the flat surface of a map. **4:** An *equivalent (equal area) map* shows correct area (size) relationships over the entire map; a *conformal map* maintains correct angular (shape) relationships over the entire map. **5:** No; a *Mercator projection* shows correct shapes, but severely distorts apparent area in the high latitudes, making it unsuitable for studying area distribution patterns. **6:** *Goode's interrupted projection* is equivalent, making it suitable for studying area distribution patterns; in addition, Goode's maintains reasonable shape relationships for the continents (although it isn't conformal). **7:** A line of equal value on a map; for example, temperature patterns can be mapped with *isotherms* and topography mapped with *elevation contour* lines. **8:** An oblique view of the landscape is mathematically constructed from elevation data, using shaded relief, as if the Sun were illuminating the topography from the northwest. **9:** Timing signals from at least three satellites are received by the GPS unit; by determining the slight difference in arrival time of the signals, the GPS unit calculates the distance to each satellite, and from that information, triangulates a location. **10:** Near infrared images measure short infrared radiation, typically resulting in a "false-color" image that can, for example, be used to detect differences in living vegetation; thermal infrared imagery detects differences in emitted longwave radiation, and so, in effect, measures differences in temperature. **11:** Multispectral remote sensing detects radiation in several different bands of radiation simultaneously, such as visible light, near infrared, middle infrared, and thermal infrared. **12:** Geographic information systems (GIS) integrate data bases and maps, allowing sophisticated overlay spatial analysis; the Global Positioning System (GPS) determines location precisely.

GLOSSARY

compromise map projection A map projection that is neither conformal or equivalent, but a balance of those, or other, map properties.

conformal map projection A projection that maintains proper angular relationships over the entire map; over limited areas shows the correct shapes of features shown on a map.

conic projection A family of maps in which one or more cones is set tangent to, or intersecting, a portion of the globe and the geographic grid is projected onto the cone(s).

cylindrical projection A family of maps derived from the concept of projection onto a paper cylinder that is tangential to, or intersecting with, a globe.

digital elevation model (DEM) Computer-generated shaded-relief image of a landscape derived from a database of precise elevation measurements.

elevation contour line (contour line) A line on a map joining points of equal elevation.

equal area projection See *equivalent map projection*.

equivalent map projection A projection that maintains constant area (size) relationships over the entire map; also called an *equal area projection*.

fractional scale (fractional map scale) Ratio of distance measured on a map and the actual distance that represents on Earth's surface, expressed as a ratio or fraction; assumes that the same units of measure are used on the map and on Earth's surface.

geographic information systems (GIS) Computerized systems for the capture, storage, retrieval, analysis, and display of spatial (geographic) data.

Global Positioning System (GPS) A satellite-based system for determining accurate positions on or near Earth's surface.

graphic scale (graphic map scale) The use of a line marked off in graduated distances as a map scale.

large-scale map A map with a scale that is a relatively large representative fraction and therefore portrays only a small portion of Earth's surface, but in considerable detail.

loxodrome (rhumb line) A true compass heading; a line of constant compass direction.map A flat representation of Earth at a reduced scale, showing only selected detail.

map projection A systematic representation of all or part of the three-dimensional Earth surface on a two-dimensional flat surface.

map scale Relationship between distance measured on a map and the actual distance on Earth's surface.

Mercator projection A cylindrical projection mathematically adjusted to attain complete conformality which has a rapidly increasing scale with increasing latitude; straight lines on a Mercator projection are lines of constant compass heading (loxodromes).

multispectral [remote sensing] A remote sensing instrument that collects multiple digital images simultaneously in different electromagnetic wavelength bands.

planar projection (plane projection) A family of maps derived by the perspective extension of the geographic grid from a globe to a plane that is tangent to the globe at some point.

pseudocylindrical projection (elliptical projection) A family of map projections in which the entire world is displayed in an oval shape.

radar Radio detection and ranging.

remote sensing Measurement or acquisition of information by a recording device that is not in physical contact with the object under study; instruments used commonly include cameras and satellites.

small-scale map A map whose scale is a relatively small representative fraction and therefore shows a large portion of Earth's surface in limited detail.

sonar Sound navigation and ranging.

verbal map scale Scale of a map stated in words; also called a *word scale*.

PHOTO CREDITS

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INTRODUCTION TO THE ATMOSPHERE

From Chapter 3 of *Physical Geography: A Landscape Appreciation*, Eleventh Edition. Darrel Hess.

INTRODUCTION TO THE ATMOSPHERE

EARTH IS DIFFERENT FROM ALL OTHER KNOWN PLANETS IN A variety of ways. One of the most notable differences is the presence around our planet of an atmosphere distinctive from other planetary atmospheres. It is our atmosphere that makes life possible on Earth. The atmosphere supplies most of the oxygen that animals must have to survive, as well as the carbon dioxide needed by plants. It helps maintain a water supply, which is essential to all living things. It insulates Earth's surface against temperature extremes and thus provides a livable environment over most of the planet. It also shields Earth from much of the Sun's ultraviolet radiation, which otherwise would be damaging to most life forms.

The atmosphere is a complex and dynamic system. This chapter provides a foundation for understanding the atmosphere and the patterns and processes of weather and climate. Here we describe the composition and structure of the atmosphere, the basic elements or "ingredients" of weather and climate, and the most important "controls" or influences of weather and climate.

As you study this chapter, think about these key questions:

- **What major gases are found in the atmosphere, and what roles do small concentrations of variable gases and impurities play in weather and climate?**
- **What are the characteristics and significance of the various layers of the atmosphere, especially the troposphere?**
- **In what ways have humans altered the composition of the atmosphere, such as by releasing chemicals that deplete the ozone layer or by releasing other types of air pollution?**
- **What is the difference between "weather" and "climate," and what are the four elements of weather and climate and the seven most important controls of weather and climate?**

SIZE AND COMPOSITION OF THE ATMOSPHERE

Air—generally used as a synonym for atmosphere—is not a specific gas, but rather a mixture of gases, mainly nitrogen and oxygen. It often contains small quantities of tiny solid and liquid particles held in suspension in the air, as well as varying amounts of gaseous impurities.

Pure air is odorless, tasteless, and invisible. Gaseous impurities, on the other hand, can often be smelled, and the air may even become visible if enough microscopic solid and liquid impurities coalesce (stick together) to form particles large enough to either reflect or scatter sunlight. Clouds, by far the most conspicuous visible features of the atmosphere, represent the coalescing of water droplets or ice crystals around microscopic particles that act as condensation nuclei.

Seeing Geographically

This view looking west over the Gulf of St. Lawrence toward the Gaspé Peninsula in Canada was taken from the International Space Station. How thick does the visible part of the atmosphere appear in relation to the size of Earth itself? Where does the layer of clouds appear to be in relation to the overall thickness of the atmosphere?

Size of Earth's Atmosphere

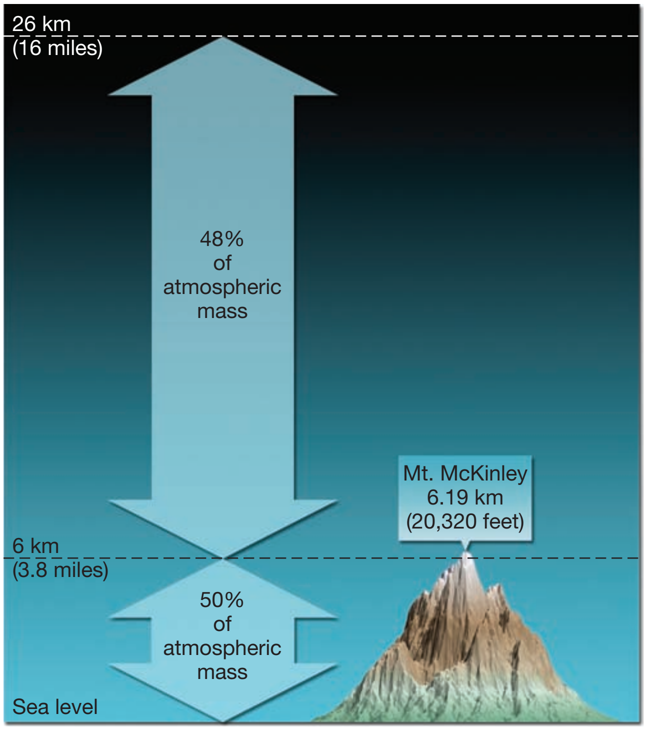
The atmosphere completely surrounds Earth and can be thought of as a vast ocean of air, with Earth at its bottom (Figure 1). It is held to Earth by gravitational attraction and therefore accompanies our planet in all its celestial motions. The attachment of Earth and atmosphere is a loose one, however, and the atmosphere can therefore move on its own, doing things that the solid Earth cannot do.

Density Decrease with Altitude: Although the atmosphere extends outward at least 10,000 kilometers (6000 miles), most of its mass is concentrated at very low altitudes. More than half of the mass of the atmosphere lies below the summit of North America's highest peak, Mount McKinley (Denali) in Alaska, which reaches an elevation of 6.2 kilometers (3.8 miles), and more than 98 percent of it lies within 26 kilometers (16 miles) of sea level (Figure 2). Therefore, relative to Earth's diameter of about 13,000 kilometers (8000 miles), the "ocean of air" we live in is a very shallow one.

In addition to reaching upward above Earth's surface, the atmosphere also extends slightly downward. Because air expands to fill empty spaces, it penetrates into caves and crevices in rocks and soil. Moreover, it is dissolved in the waters of Earth and in the bloodstreams of organisms.

The atmosphere interacts with other components of Earth's environment, and it is instrumental in providing a hospitable setting for life. Whereas we often speak of human beings as creatures of Earth, it is perhaps more accurate to consider ourselves creatures of the atmosphere. As surely as a crab crawling on the sea bottom is a resident of the ocean, a person living at the bottom of the ocean of air is a resident of the atmosphere.

▼ **Figure 1** The atmosphere completely surrounds Earth in this composite satellite image; beyond the narrow blue band of the atmosphere is the blackness of outer space.



▲ **Figure 2** Most of the atmospheric mass is close to Earth's surface. More than half of the mass is below the highest point of Mount McKinley (Denali), North America's highest peak.

Learning Check 1 **What generally happens to the density of the atmosphere with increasing altitude?**

Development of Earth's Modern Atmosphere

The atmosphere today is very different from what it was during the early history of Earth. Shortly after Earth formed about 4.6 billion years ago, the atmosphere probably consisted mostly of light elements such as hydrogen and helium. By perhaps 4 billion years ago, this ancient atmosphere was changing as those light gases were being lost and as outgassing from volcanic eruptions added large amounts of carbon dioxide and water vapor, along with small amounts of other gases such as nitrogen. It is likely that arriving comets also contributed water to Earth's atmosphere. As ancient Earth cooled, most of the water vapor condensed out of the atmosphere, forming the world ocean.

By about 3.5 billion years ago, early forms of life—such as bacteria that could survive without oxygen—were beginning to remove carbon dioxide and release oxygen into the atmosphere. Over time, oceanic and terrestrial plants continued the transformation from a carbon dioxide-rich to an oxygen-rich atmosphere through the process of *photosynthesis*. Our modern atmosphere, therefore, was significantly influenced by life on Earth.

Composition of the Modern Atmosphere

The chemical composition of pure, dry air at lower altitudes (altitudes lower than about 80 kilometers or 50 miles) is simple and uniform, and the concentrations of the major components—the *permanent gases*—are essentially unvarying over time. However, certain minor gases and nongaseous particles—the *variable gases* and *particulates*—vary markedly from place to place or from time to time, as does the amount of moisture in the air.

Permanent Gases

Nitrogen and Oxygen: The two most abundant gases in the atmosphere are nitrogen and oxygen (Figure 3). Nitrogen makes up more than 78 percent of the total, and oxygen makes up nearly 21 percent. Nitrogen is added to the air by the decay and burning of organic matter, volcanic eruptions, and the chemical breakdown of certain rocks, and it is removed by certain biological processes and by being washed out of the atmosphere in rain or snow. Overall, the addition and removal of nitrogen gas are balanced, and consequently the quantity present in the air remains constant over time. Oxygen is produced by vegetation and is removed by a variety of organic and inorganic processes; its total quantity also apparently remains stable.

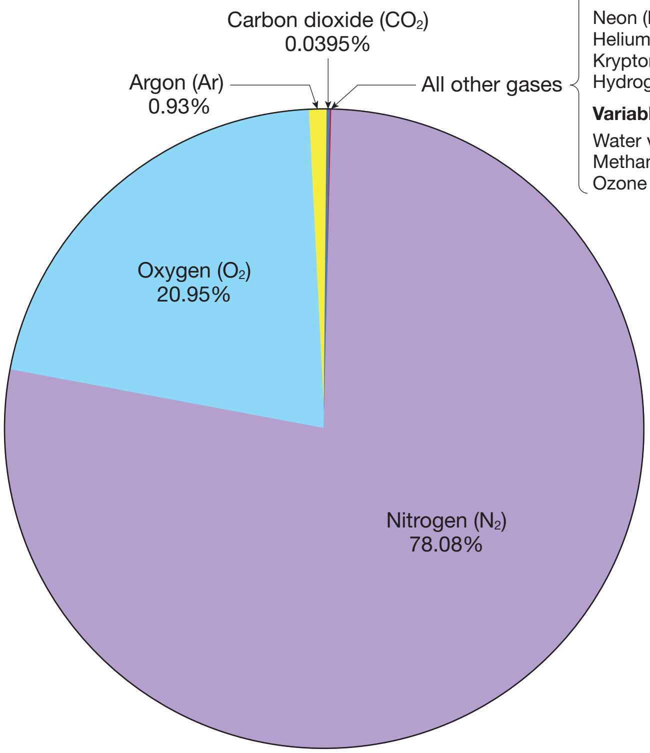
The remaining 1 percent of the atmosphere's volume consists mostly of the inert gas argon. These three principal atmospheric gases—nitrogen, oxygen, argon—have a minimal effect on weather and climate and therefore need no further consideration here. The trace gases—neon, helium, krypton, and hydrogen—also have little effect on weather and climate.

Variable Gases

Several other gases occur in sparse but highly variable quantities in the atmosphere, but their influence on weather and climate is significant.

Water Vapor: Water in the form of a gas is known as **water vapor.** Water vapor is invisible—the visible forms of water in the atmosphere, such as clouds and precipitation, consist of water in its liquid or solid form (ice). Water vapor is most abundant in air overlying warm, moist surface areas such as tropical oceans, where water vapor may amount to as much as 4 percent of total volume. Over deserts and in polar regions, the amount of water vapor is but a tiny fraction of 1 percent.

In the atmosphere as a whole, the total amount of water vapor remains nearly constant. Thus, its listing as a "variable gas" in Figure 3 means variable in location. Water vapor has a significant effect on weather and climate: it is



	Percent by volume	*Concentration in parts per million*
Permanent		
Neon (Ne)	0.00182	18.2
Helium (He)	0.00052	5.2
Krypton (Kr)	0.00011	1.1
Hydrogen (H_2)	0.00005	0.5
Variable		
Water vapor (H_2O)	0 to about 4	—
Methane (CH_4)	0.00018	1.8
Ozone (O_3)		<2

▲ **Figure 3** Proportional volume of the gases in the atmosphere. Nitrogen and oxygen are the dominant components. Although found in tiny amounts, some variable gases play important roles in atmospheric processes.