

Essentials of Geography



KEY LEARNING CONCEPTS

After reading the chapter, you should be able to:

- **Define** geography and physical geography in particular.
- **Describe** systems analysis, open and closed systems, and feedback information, and **relate** these concepts to Earth systems.
- **Explain** Earth's reference grid: latitude and longitude and latitudinal geographic zones and time.
- **Define** cartography and mapping basics: map scale and map projections.
- **Describe** remote sensing and the geographic information system (GIS), and **explain** how both tools are used in geographic analysis.

Gough Island (40.2° S 9.5° W) is in the south Atlantic Ocean, about 425 km (264 mi) from the nearest settlement. This volcanic island of just 65 km² area (25 mi²) is a wildlife reserve and has been a UNESCO World Heritage Site since 1994. Boat landings are not permitted and only a six-person remote weather station is occupied. Despite its remote location, this unique place is not immune to human impacts. In 2004, discovery of bird nest predation, by accidentally introduced house mice, launched scientific studies to control and eradicate the mice to protect endangered wildlife. To understand such a place, we see the value of the integrative science of physical geography. [Bobbé Christopherson.]

Where Is Four Corners, Exactly?

➤ Amidst the high desert landscape of the American Southwest is the unique Four Corners landmark, where a monument marks the intersection of Colorado, New Mexico, Arizona, and Utah. This location is the only point in the United States where four states touch. It is a must-see destination for many visitors, a place where feet and hands can each be in a different state and families and friends can straddle the disk marking the precise location where state boundaries meet. The original surveyor, Chandler Robbins, marked the spot with a 2.1-m (7-ft) sandstone monument in 1875. The present monument and visitor plaza date to 1992 and are owned and operated by the Navajo Nation Parks and Recreation Department (Figure GN 1.1).

In the spring of 2009, news reports claimed that the location of Four Corners was in error, that in fact the monument was located 4 km (2.5 mi) west of the precise location. The reports claimed that new surveys by the National Geodetic Survey (NGS) using Global Positioning System (GPS) satellites and state-of-the-art mapping technology refuted the original 1875 surveys. For such an important landmark, this was shocking news. Did the monument now need to be moved, or was the news in error?

For the average visitor, such precise measurement details are unimportant. For the scientist, engineer, or natural resource professional, such an error has wide-ranging implications. Four Corners is an established benchmark in the western United States upon which other surveys and locations are based.

The question of accuracy relates to which meridian was used for the original survey. Congress ordered Chandler Robbins in 1875 to use the Greenwich meridian, London, which later became the official 0° prime meridian, from which we measure longitude west or east on



(a)



(b)

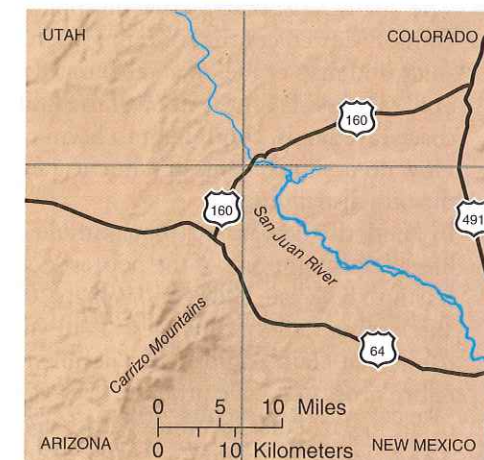


FIGURE GN 1.1 Four Corners landmark and benchmark.

(a) The Four Corners tourist plaza just off US Highway 160. (b) Survey benchmark 1992 replacement. (c) Map of the Four Corners region. [USGS.]

Earth. However, in the late 1800s many western states were set with surveys using the Washington meridian, which is about 77° 3' west longitude from Greenwich. If Robbins' survey had used the Washington meridian, the marker would be off as described by the media reports.

A few weeks later the news stories were corrected as the details of the original survey came to light. While the monument does appear to be offset from its intended location, the actual offset is only 548 m (1800 ft) to the east rather than the west. However, according to NGS, the monument is in the right spot. It turns out that the location of a physical monument is usually the ultimate authority in delineating a boundary.

Thus, once the Four Corners monument was established and accepted by all parties involved—in this case, the four territories and the U.S. Congress—it became the exact spot where the four states meet. The location, set for more than 125 years, is used in the modern National Spatial Reference System and is in the right place—36° 59' 56.3150" north latitude by 109° 02' 42.6210" west longitude (<http://www.glorerecords.blm.gov/>).

At the heart of geographic science are such topics as place, location, latitude and longitude, the Greenwich prime meridian, and mapping. In this chapter, you work with these concepts, the "Essentials of Geography." ■

Welcome to the Seventh Edition of *Elemental Geosystems* and the study of physical geography! In this text, we examine the powerful Earth systems that influence our lives and the many ways humans impact those systems. In this second decade of the 21st century, a century that will see many changes to the natural environment, we find ourselves in an exciting time to study physical geography, learning about the building blocks that form the landscapes, seascapes, atmosphere, and ecosystems upon which we depend.

Much has happened since *Elemental Geosystems'* last edition. Consider the following events, among many—and the questions they raise for the study of Earth's systems:

- The 2010 eruption of the Eyjafjallajökull volcano in Iceland disrupted airline schedules and global travel as prevailing winds spread ash over Europe and Asia. What atmospheric forces affected the ash movement from such a volcanic event?
- The 2010 *Deepwater Horizon* oil spill disaster in the Gulf of Mexico continues to unfold as scientists study and map crude oil and chemical dispersants. Spill oil persists on the floor of the Gulf and along coastal wetlands, continuing to harm marine life. How do ocean currents and hurricanes play a part in the oil's distribution?
- In Haiti, the January 2010 magnitude 7.0 earthquake literally brought one of the poorest countries on Earth to collapse, killing more than 200,000 people and leaving millions homeless. Estimates set the damage in Haiti at more than double the country's entire gross domestic product. Why do earthquakes occur in particular locations across the globe?
- The March 2011 magnitude 9.0 earthquake and 10-m to 20-m (33 to 66 ft) tsunami devastated Honshu Island, Japan—at \$309 billion (USD), Earth's most expensive natural disaster. This caused the worst multiple nuclear power plant catastrophe in history, with 3 core meltdowns, releasing huge quantities of radioactivity onto the land, into the food web, and into the ocean and atmosphere. What causes a tsunami, and how far does it travel? How will prevailing winds and currents disperse the radiation across the globe?
- This past decade experienced the highest temperatures over land and water in the instrumental record. The year 2010 tied 2005 as the warmest year on record for global temperatures. In response, the extent of sea ice in the Arctic Ocean continues to decline to record lows. Intense weather events and flooding continue to increase. And, 2011 set tornado records, causing such devastation in Tuscaloosa, Alabama, Joplin, Missouri, and elsewhere.

Climate change science will be an overriding topic for the global society this century. The Intergovernmental Panel on Climate Change (IPCC; <http://www.ipcc.ch/>) completed its *Fourth Assessment Report* in 2007. The Climate Congress held an International Climate Change Conference in Copenhagen, Denmark, in March 2009, as

an update to the IPCC with more than 80 countries and 2500 scientists (<http://climatecongress.ku.dk/>). The Climate Congress concluded:

The *worst-case* IPCC (2007) projections, or even worse, are being realized. . . . Emissions are soaring, projections of sea-level rise are higher than expected, and climate impacts around the world are appearing with increasing frequency.

Financial data from 15 of the world's largest financial institutions estimated that annual weather-related damage losses (from drought, floods, hail, tornadoes, derechos, tropical systems, monsoon intensity, storm surges, blizzards and ice storms, and wildfires) could exceed \$1 trillion by 2040 (adjusted to current dollars)—up from \$210 billion in 2005 (Hurricane Katrina alone produced \$125 billion in losses). Global climate change is driving this increasing total, at a pace that is accelerating. A new study published in 2011 found that flooding frequencies and extreme weather events more than doubled since 1970.

Imagine the challenge society as a whole and we in physical geography face to understand how Earth's systems operate and then to forecast changes. Physical geography uses a *spatial* perspective and gives you the tools to understand what is happening in specific locations and across the globe. In every chapter, *Elemental Geosystems* continues to present updated science and information to help you understand our dynamic Earth systems.

Why does the environment vary from equator to mid-latitudes, between deserts and polar regions? How does solar energy influence the distribution of trees, soils, climates, and lifestyles? Why are we experiencing record levels of wildfires? Why are earthquakes and volcanoes active in certain regions and what is the risk? What produces the patterns of wind, weather, and ocean currents? Why are global sea levels on the rise? How do natural systems affect human populations, and, in turn, what impact are humans having on natural systems? Why are record levels of plants and animals facing extinction? In this book, we explore those questions, and more, through geography's unique perspective. Welcome to an exploration of physical geography!

In this chapter: Our study of *Elemental Geosystems*—Earth systems—begins with a look at the science of physical geography and the geographic tools we use. Physical geography is key to studying entire Earth systems because of its integrative spatial approach.

Physical geographers analyze systems to study the environment. Therefore, we discuss systems and the feedback mechanisms that influence system operations. We then consider location, a key theme of geographic inquiry—the latitude, longitude, and time coordinates that inscribe Earth's surface and the new technologies in use to measure them. Next, we examine maps as critical tools that geographers use to portray physical and cultural information. This chapter concludes with an overview of the technology that is adding exciting new dimensions to geography: remote sensing from space and computer-based geographic information systems.

The Science of Geography

Now is the era of **Earth systems science**. This science contributes to our emerging view of Earth as a complete entity—an interacting set of physical, chemical, and biological systems that produce a whole Earth. Physical geography is at the heart of Earth systems science as we answer the *spatial* questions concerning Earth's physical systems and their interaction with living things.

Geography (from *geo*, “Earth,” and *graphein*, “to write”) is the science that studies the relationships among natural systems, geographic areas, society, cultural activities, and the interdependence of all of these *over space*. The term **spatial** refers to the nature and character of physical space, its measurement, and the distribution of things within it.

For example, think of your own route to the classroom or library today or the way you get to work and how you used your knowledge of street patterns, traffic trouble spots, one-way streets, parking spaces, or bike rack locations to minimize walking distance. All these are spatial considerations that influence human actions.

To help in this definition, we separate geographic science into five spatial themes: **location, region, human–Earth relationships, movement, and place**, each illustrated and defined in Figure 1.1. *Elemental Geosystems* draws on each theme.

Geographic Analysis

Within these five geographic themes, a method rather than a specific body of knowledge governs geography. The method is **spatial analysis**. Using this method, geography synthesizes (brings together) topics from many fields, integrating information to form a whole-Earth concept. Geographers view phenomena as occurring in spaces, areas, and locations. The language of geography reflects this spatial view: space, territory, zone, pattern, distribution, place, location, region, sphere, province, and distance. Geographers analyze the differences and similarities among places.

Process, a set of actions or mechanisms that operate in some special order, is central to geographic analysis. As examples in *Geosystems*, numerous processes are involved in Earth's vast water–atmosphere–weather system, or in continental crust movements and earthquake occurrences, or in ecosystem functions, or in a river's drainage basin dynamics. Geographers use spatial analysis to examine how Earth's processes interact over space or area.

Therefore, **physical geography** is the spatial analysis of all the physical elements and process systems that make up the environment: energy, air, water, weather, climate, landforms, soils, animals, plants, microorganisms, and Earth itself. As with any science, physical geographers employ the **scientific method**. Focus Study 1.1 on page 6 explains this essential process of science.

The Geographic Continuum

Geography is eclectic, integrating a wide range of subject matter from diverse fields; virtually any subject can be examined geographically. Figure 1.2 shows a continuous distribution—a continuum—along which the content of geography is arranged. Physical and life sciences are at one end, and human and cultural sciences are at the other. As the figure shows, various specialties within geography draw from these subject areas.

The continuum in Figure 1.2 reflects a basic duality, or split, within geography—*physical geography* versus *human/cultural geography*. Some societies parallel this duality. Humans at times think of themselves as exempt from physical Earth processes—like actors not paying attention to their stage, props, and lighting. We all depend on Earth's systems to provide oxygen, water, nutrients, energy, and materials to support life. The growing complexity of the human–Earth relationship requires that we shift our study of geographic processes toward the center of the continuum in Figure 1.2 to attain a more balanced perspective—such is the thrust of *Elemental Geosystems*. Such a synthesis is key to environmental planning and resource sustainability strategies.

Earth Systems Concepts

The word *system* is in our lives daily: “Check the car's cooling system”; “Is a broadband system available for my Internet browser?”; “How does the grading system work?”; “A weather system is approaching.” *Systems analysis* techniques began with studies of energy and temperature (thermodynamics) in the 19th century and were further developed in engineering during World War II. Systems methodology is an important analytical tool. In this book's 4 parts and 17 chapters, content is organized along logical flow paths consistent with systems thinking.

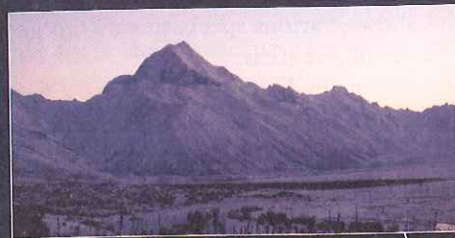
Systems Theory

Simply stated, a **system** is any ordered, interrelated set of things and their attributes, linked by flows of energy and matter, as distinct from the surrounding environment outside the system. The elements within a system may be arranged in a series or interwoven with one another. A system comprises any number of subsystems. Within Earth's systems, both matter and energy are stored and retrieved, and energy is transformed from one type to another. (Remember: *Matter* is mass that assumes a physical shape and occupies space; *energy* is a capacity to change the motion of, or to do work on, matter.)

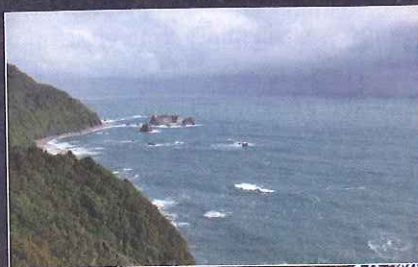
Open Systems Systems in nature are generally not self-contained: Inputs of energy and matter flow into the system, and outputs of energy and matter flow from the system. Such a system is an **open system**. Within a system, the parts function in an interrelated manner, acting together in a way that gives each system its operational

Location

Location identifies a specific address or absolute and relative position on Earth. Mount Cook is the highest point in New Zealand, located at 43°35' S latitude and 170°8' E longitude.

**Region**

A region is an area defined by uniform physical or human characteristics. The West Coast region, between the Southern Alps and the Tasman Sea, is dominated by a marine west coast climate, cool and moist.

**Movement**

New Zealand receives 2.5 million international visitors each year; Milford Sound is a major attraction, Mitre Peak in background. Communication, migration, and diffusion across Earth's surface represent movement in our interdependent world.

Place

No two places on Earth are exactly alike. Place describes the characteristics – both human and physical – of a location. Untracked powder attracts skiers in the backcountry near Mount Hutt.

**Human–Earth Relationships**

Natural hazards are one type of human–environment connection. An equipment shed stands in ruins after being hit by an avalanche at Ohau Ski Field in 2009.

FIGURE 1.1 Five themes of geographic science.

Drawing from your own experience, can you think of several examples of each theme? [Photos by Karl Birkeland, except Movement by Ian Dagnall/Alamy; image NASA/GSFC.]

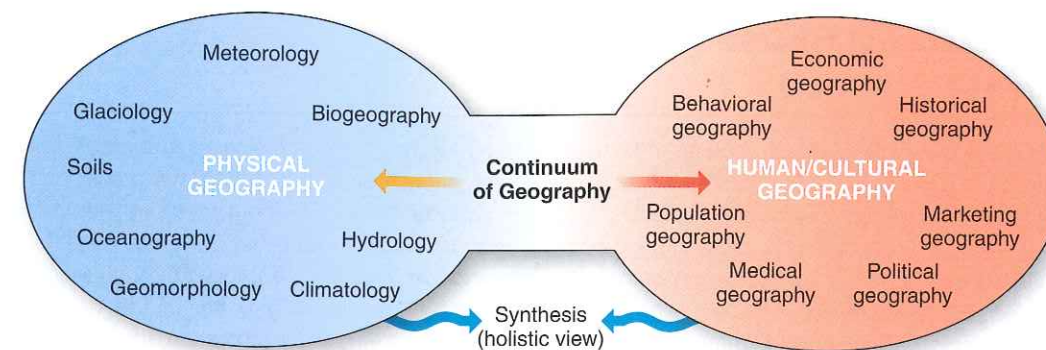


FIGURE 1.2 The content of geography.

Geography derives subject matter from many different sciences. The focus of this book is physical geography, but we also integrate some human and cultural components. Movement toward the middle of the continuum suggests a synthesis of Earth topics and human topics.

character (Figure 1.3). Earth is an open system in terms of energy because solar energy enters freely and heat energy leaves, going back into space. Most natural systems are open in terms of energy.

Earth systems are dynamic (energetic, in motion) because of the tremendous infusion of radiant energy from the Sun. This energy comes through the outermost edge of Earth's atmosphere to power terrestrial systems, being transformed along the way into various forms of energy, such as kinetic energy (of motion), potential energy (of position), or chemical or mechanical energy—setting the fluid atmosphere and ocean in motion. Eventually, Earth radiates this energy back to the cold vacuum of space as heat energy.

Closed Systems A system that is shut off from the surrounding environment so that it is self-contained is a **closed system**. Although such closed systems are rarely found in nature, Earth is essentially a closed system in terms of physical matter and resources—air, water, and material resources. The only exceptions are the slow escape of lightweight gases (such as hydrogen) from the atmosphere into space and the input of frequent, but tiny meteors and cosmic dust. The fact that Earth is a closed material system makes recycling efforts inevitable if we want a sustainable global economy.

System Example Figure 1.4 on page 8 illustrates a simple open-flow system, using plant photosynthesis as an example. In photosynthesis, plants use sunlight as an

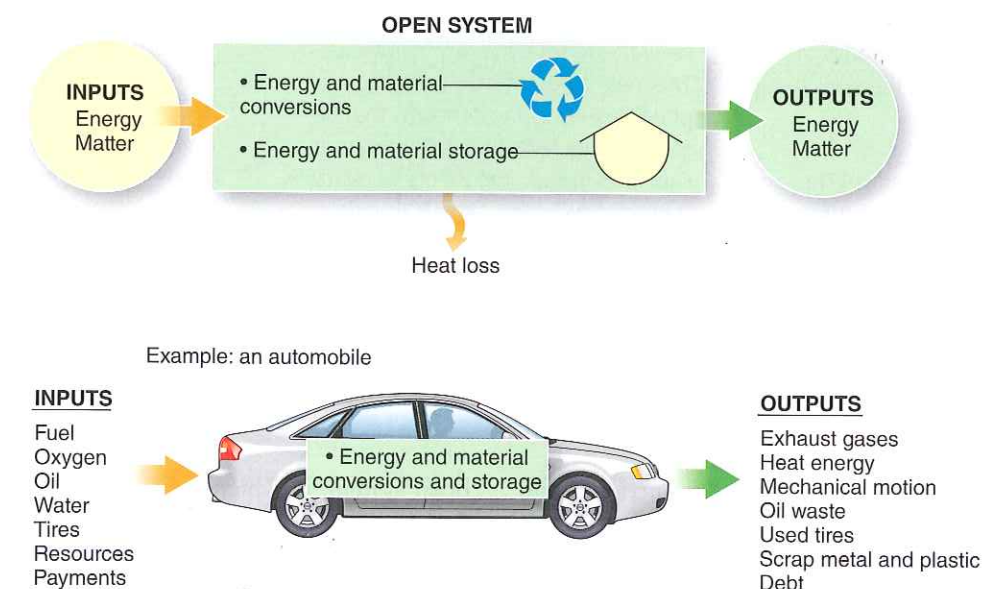


FIGURE 1.3 An open system.

In an open system, inputs of energy and matter undergo conversions and are stored as the system operates. Outputs include energy and matter and heat energy (waste) that flow from the system. See how the various inputs and outputs are related to the operation of a car—an open system. Expand your viewpoint to the entire system of auto production, from raw materials, to assembly, to sales, to car accidents, to junkyards. Can you identify other open systems that you encounter in your daily life?

FOCUS STUDY 1.1

The Scientific Method

The term *scientific method* may have an aura of complexity, but it shouldn't. The scientific method is simply the application of common sense in an organized and objective manner. A scientist observes, makes a general statement to summarize the observations, formulates a hypothesis, conducts experiments to test the hypothesis, and develops a theory and governing scientific laws. Sir Isaac Newton (1642–1727) developed this method of discovering the patterns of nature, although the term *scientific method* was applied later.

Complexity dominates nature, making several outcomes possible as a system operates. Science serves an important function in understanding such uncertainty. Yet the more knowledge we have, the more our awareness of and uncertainty about other possible outcomes and events increase. This, in turn, demands more precise and aggressive science.

Follow the scientific method illustration in Figure 1.1.1. The scientific method begins with our perception of the real world and a determination of what we know, what we want to know, and the many unanswered questions that exist.

Scientists who study the physical environment begin with the clues they see in nature.

Step 1 Observe and measure. The process begins as scientists figure out what data are needed and begin to collect those data. These observations are analyzed to identify coherent patterns that may exist. This search for patterns

requires inductive reasoning, or the process of drawing generalizations from specific facts. This step is important in modern geographic science, in which the goal is to understand a whole functioning Earth, rather than isolated, small compartments of information. Such understanding allows the scientist to construct models of general operations of Earth systems.

Step 2 Form and test a hypothesis. If patterns are discovered, the researcher may formulate a *hypothesis*—a tentative explanation for the phenomena observed. Further observations are related to the general principles established by the hypothesis. More data gathering may support or disprove the hypothesis, or predictions made according to it may prove accurate or inaccurate. These findings provide negative feedback, requiring the researcher to adjust data collection and model building and to refine the hypothesis statement. Verification of the hypothesis after exhaustive testing may lead to its elevation to the status of a *theory*.

Step 3 Formulate a theory. The word *theory* can be confusing as used by the media and general public. A theory is constructed on the basis of several extensively tested hypotheses. Theories represent truly broad general principles—unifying concepts that tie together the laws that govern nature. Examples include the theory of relativity, theory of evolution, atomic theory, Big Bang theory, stratospheric ozone depletion theory, and plate tectonics theory. A theory is a powerful device with which to understand both the order and

the chaos (disorder) in nature. Using a theory allows predictions to be made about things not yet known, the effects of which can be tested and verified or disproved through tangible evidence. The value of a theory is the continued observation, testing, understanding, and pursuit of knowledge that the theory stimulates. A general theory reinforces our perception of the real world, acting as positive feedback.

Pure science does not make value judgments. Instead, pure science provides people and their institutions with objective information on which to base their own value judgments. Social and political judgments about the applications of science are increasingly critical as Earth's natural systems respond to the impact of modern civilization. Scientist Jane Lubchenco, the first female administrator of the National Oceanic and Atmospheric Administration (NOAA), in her 1997 American Association for the Advancement of Science Presidential Address stated:

Science alone does not hold the power to achieve the goal of greater sustainability, but scientific knowledge and wisdom are needed to help inform decisions that will enable society to move toward that end.

The growing awareness that human activity is producing global climate change places increasing pressure on scientists to participate in decision making. Numerous editorials in scientific journals have called for such applied science involvement.

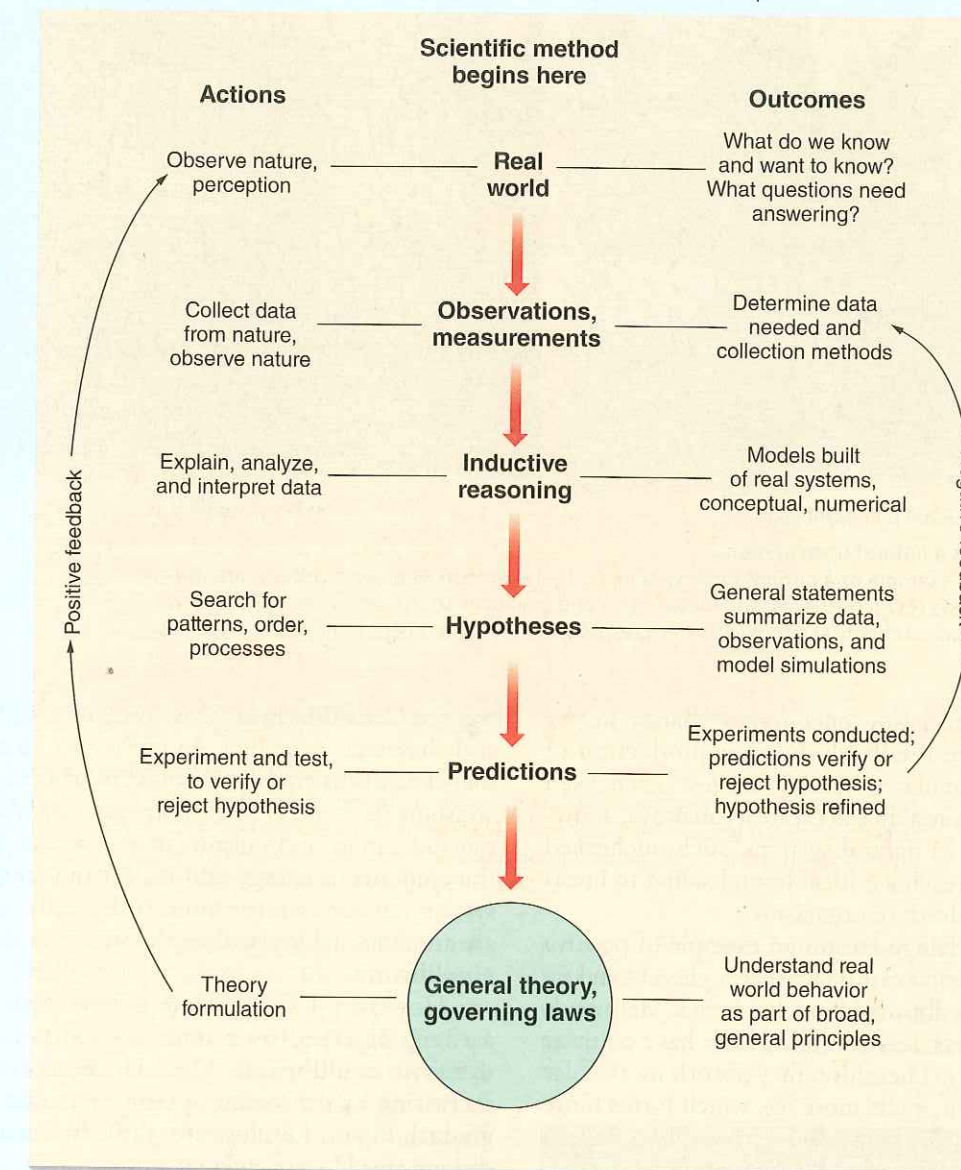


FIGURE 1.1.1 Scientific method flow chart.

The scientific method process: from perceptions, to observations, reasoning, hypothesis, and predictions, and possibly to general theory and natural laws.

energy input and material inputs of water, nutrients, and carbon dioxide. The photosynthetic process converts these inputs to stored chemical energy in the form of plant sugars (carbohydrates). The process also releases an output from the plant system: the oxygen we breathe.

Reversing the process, plants derive energy for their operations from respiration. In respiration, the plant consumes inputs of chemical energy (carbohydrates) and oxygen and releases outputs of carbon dioxide, water, and heat energy into the environment. Thus, a plant acts as an

open system, in which both energy and materials freely flow into and out of the plant. (Chapter 15 discusses photosynthesis and respiration processes.)

System Feedback As a system operates, it generates outputs that influence its own operations. These outputs function as "information" that returns to various points in the system via pathways, or **feedback loops**. Feedback information can guide, and sometimes control, further system operations. In the plant's photosynthetic system

(see Figure 1.4), any increase or decrease in daylength (sunlight availability), carbon dioxide, or water produces feedback that causes specific responses in the plant. For example, decreasing the water input slows the growth process; increasing daylength increases the growth process, within limits.

If the feedback information discourages change in the system, it is **negative feedback**. Further production of such feedback opposes system changes. Such negative feedback informs and causes self-regulation in a natural

system, stabilizing the system. Negative feedback loops are common in nature, since they lead to stability. For example, the growth of riparian, or streamside, vegetation in a river system stabilizes the banks and inhibits erosion, providing a negative feedback. In many ecosystems, predator populations provide negative feedback for other animals; the size of the prey population tends to achieve a balance with the number of predators. If a predator population drops abruptly, prey populations increase and cause ecosystem instability.

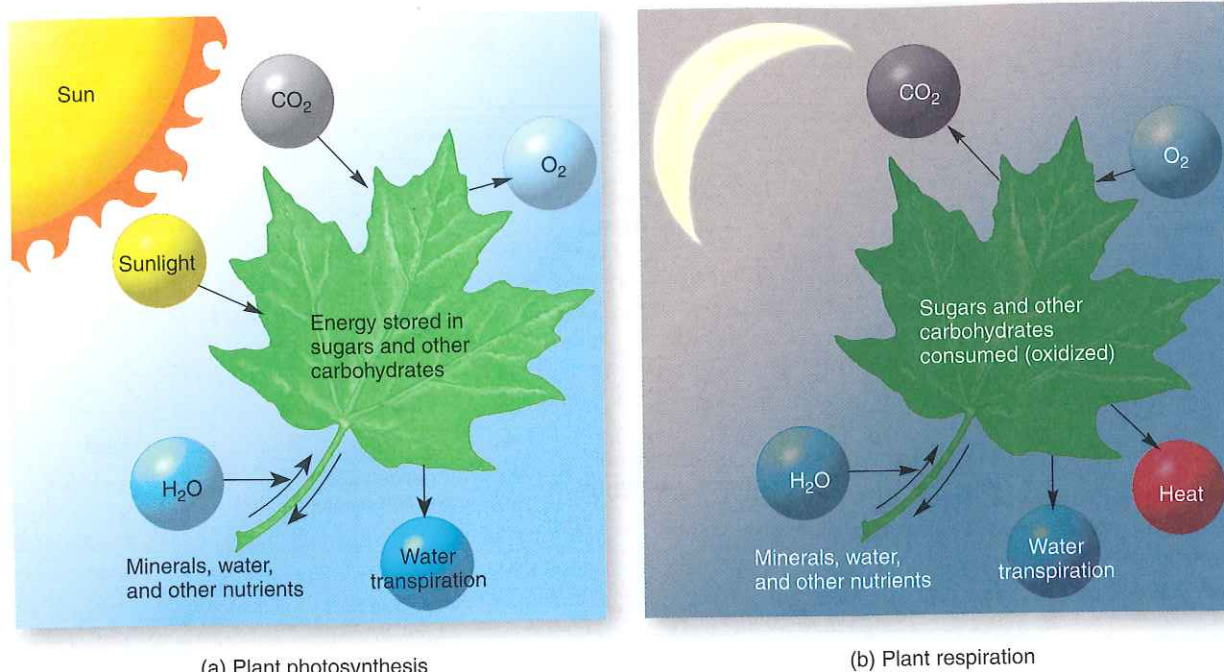


FIGURE 1.4 A leaf is a natural open system. A plant leaf provides an example of a natural open system. (a) In the process of photosynthesis, plants consume light, carbon dioxide (CO_2), nutrients, and water (H_2O) and produce outputs of oxygen (O_2) and carbohydrates (sugars) as stored chemical energy. (b) Plant respiration, illustrated here at night, approximately reverses this process.

If feedback information encourages change in the system, it is **positive feedback**. Further production of positive feedback stimulates system changes. Unchecked positive feedback in a system can create a runaway (“snowballing”) condition. In natural systems, such unchecked system changes can reach a critical limit, leading to instability, disruption, or death of organisms.

Global climate change creates an example of positive feedback as meltponds increase on ice sheets, glaciers, and ice shelves worldwide, as illustrated in Chapter 13. Meltponds are darker and reflect less sunlight; they have a lower albedo, or reflectivity. Therefore, they absorb more solar energy, which, in turn, melts more ice, which forms more meltponds, and so forth. Thus, a positive feedback loop is in operation, further enhancing the effects of higher temperatures and warming trends.

Based on satellite images and aerial surveys, scientists determined a spatial increase in meltpond distribution of 400% across the Arctic since 2000. Overall ice-mass losses from Greenland more than doubled between 1996 and 2010. The meltponds are symptomatic of climatic warming. Likewise, as sea ice melts, the darker open water absorbs more sunlight, which produces increased air and water temperatures.

Think of the numerous devastating wildfires that occurred globally in the last decade, including record wildfires in terms of area burned in the western United States, Australia, and elsewhere, as examples of positive feedback. As the fires burned, they dried wet shrubs and green wood around the fire, thus providing more fuel for combustion. The greater the fire is, the greater the availability of fuel becomes, and thus more fire is possible—a positive feedback for the fire.

System Equilibrium Most systems maintain structure and character over time. An energy and material system that remains balanced over time, in which conditions are constant or recur, is in a *steady-state condition*. When the rates of inputs and outputs in the system are equal and the amounts of energy and matter in storage within the system are constant (or more realistically, as they fluctuate around a stable average), the system is in **steady-state equilibrium**.

However, a steady-state system may demonstrate a changing trend over time, a condition described as **dynamic equilibrium**. These changing trends of either increasing or decreasing system operations may appear gradual. Figure 1.5 illustrates these two equilibrium conditions, steady-state and dynamic.

Note that systems try to maintain their functional operations; they tend to resist abrupt change. However, a system may reach a **threshold**, or *tipping point*, where it can no longer maintain its character, so it lurches to a new operational level. This abrupt change places the system in a *metastable equilibrium*. An example of such a condition is a hillside or coastal bluff that adjusts after a sudden landslide. A new equilibrium is eventually achieved among slope, materials, and energy over time.

This threshold concept raises concern in the scientific community, especially if some natural systems reach their tipping-point limits. The relatively sudden collapse of ice shelves surrounding a portion of Antarctica, the sudden crack-up of ice shelves on the north coast of Ellesmere Island, Canada, and the recent extinctions of animal species serve as examples of systems at a threshold that are changing to a new status.

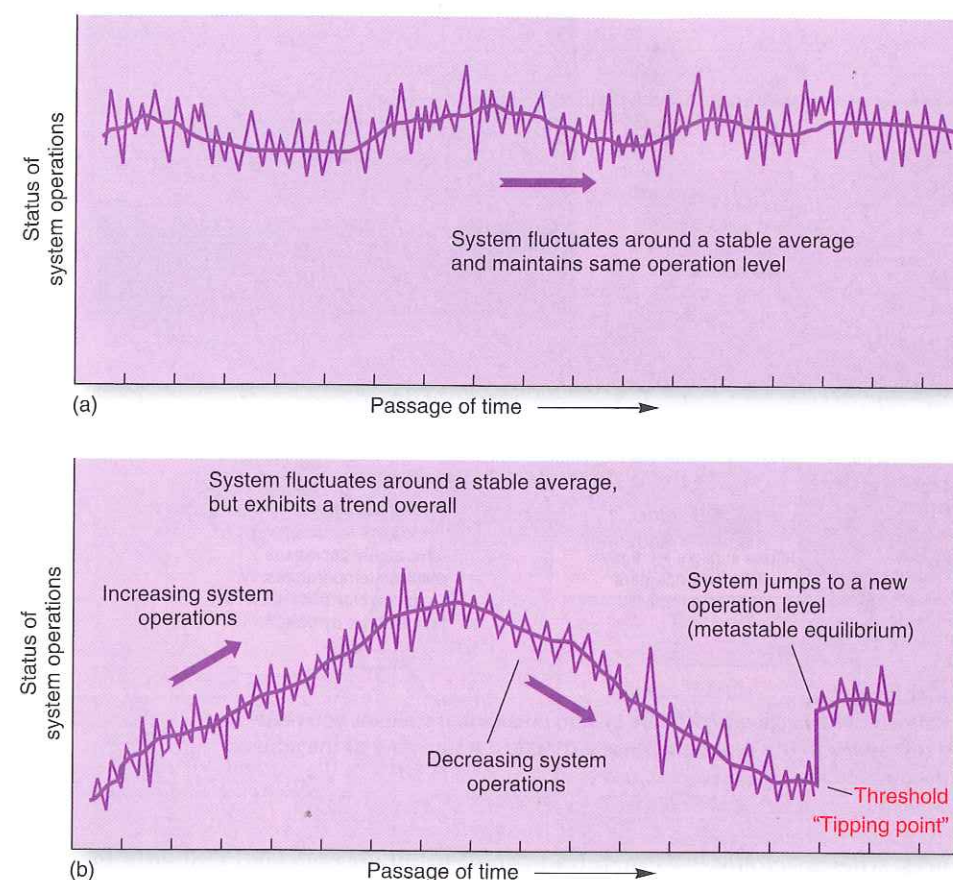


FIGURE 1.5 System equilibria: Steady-state and dynamic. (a) A steady-state equilibrium over time; system operations fluctuate around a stable average. (b) A dynamic equilibrium condition, where system fluctuations show a trend over time. Landslides along the Pacific Coast south of San Francisco moved the cliff face some 30.5 m (100 ft) inland during January 2010. A threshold was reached and the bluffs collapsed. [Inset photo by Bobbé Christopherson.]

Thresholds can also be reached in plant and animal communities. The bleaching (death) of living coral reefs worldwide accelerated dramatically after 1997, when warming conditions in oceans combined with pollution to lead coral systems to a threshold. Today, about 50% of the corals on Earth are ailing or nearing collapse (more on this in Chapter 12). Harlequin frogs of tropical Central and South America are another example of species reaching a tipping point, with increased extinctions since 1986 (Figure 1.6).

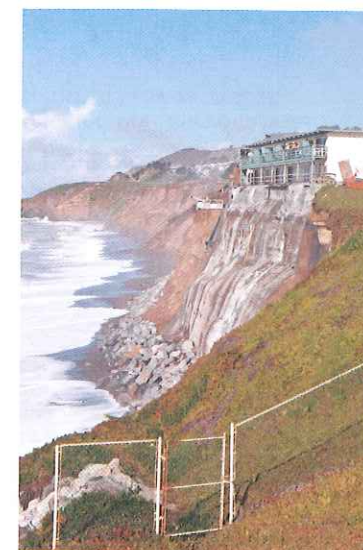
Systems Analysis and Species Extinction Scientists found that the key to understanding extinctions of harlequin frog (*Atelopus varius*) and golden toad (*Bufo periglenes*) species in the Monteverde Cloud Forest Reserve, Costa Rica, and elsewhere in Central and South America was a consideration of climate change and how this alters transmission of diseases and pathogens. One infectious agent, the *chytrid fungus* (*Batrachochytrium dendrobatidis*), has spread as thermal-optimum conditions were reached in its mid-elevation range (1000 m to 2400 m; 3280 ft to 7874 ft) in the mountain-cloud forest.

Human-forced climate change is increasing the temperature of the ocean and atmosphere. Higher temperatures cause higher evaporation rates, which affect the condensation level (see Chapter 5). As the warm, moist

air moves onshore and reaches the mountains, the air lifts and cools, and condensation occurs at higher elevations than before. Increased clouds affect the daily temperature range: Clouds at night, acting like insulation,



FIGURE 1.6 Harlequin frog extinction alarm. About two-thirds of harlequin frog species went extinct over the last two decades as a result of climate change. This “rana dorado,” or golden frog, survives only in captivity. [Dante Fenolio/Photo Researchers.]



Coastal systems pass a threshold.

GLOBAL IMPACTS OF MOUNT PINATUBO ERUPTION—JUNE 15, 1991

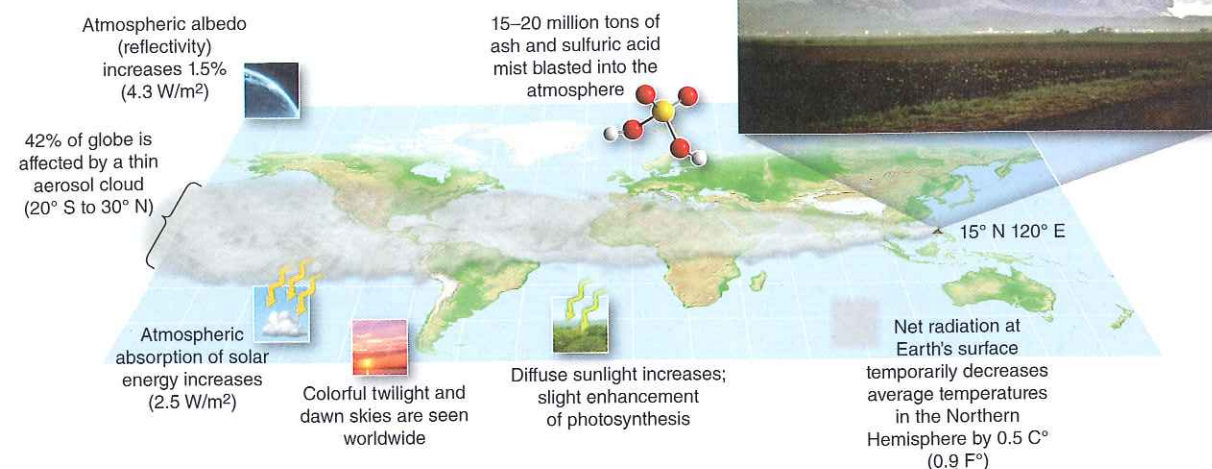


FIGURE 1.7 The eruption of Mount Pinatubo.

The 1991 Mount Pinatubo eruption affected the Earth–atmosphere system on a global scale. As you read *Elemental Geosystems*, you will find references to this eruption in many chapters. A summary of the impacts is in Chapter 9. [Inset photo by Dave Harlow, USGS.]

raise nighttime minimum temperatures, whereas clouds during the day act as reflectors, lowering daytime maximum temperatures (see Chapter 3).

The chytrid fungus does best when temperatures are between 17°C and 25°C (63°F and 77°F). The new cloud cover keeps the daytime maximum below 25°C (77°F) at the forest floor. In these more favorable conditions, the disease pathogen flourishes. Harlequin frogs have moist, porous skin that the fungus penetrates, killing the frog. Between 1986 and 2006, approximately 67% of the 110 known species of harlequin frogs went extinct—extinction is forever.

From this example, can you see the power of systems analysis? Global warming intensifies the hydrologic cycle, raises air and water temperatures, and increases evaporation, all of which change the nature of cloud formations and alter daily temperature patterns.

Mount Pinatubo—Global System Impact A dramatic example of interactions between volcanic eruptions and Earth systems illustrates the strength of spatial analysis in the organization of this textbook. Mount

Pinatubo in the Philippines erupted violently in 1991, injecting 15–20 million tons of ash and sulfuric acid mist into the upper atmosphere (Figure 1.7). This was the second greatest eruption during the 20th century; Mount Katmai in Alaska (1912) was the only one greater. The eruption materials from Mount Pinatubo affected Earth systems in several ways, which are noted on the map. For comparison, the 2010 eruption of Eyjafjallajökull in Iceland was about 100 times smaller in terms of the volume of material ejected, with debris reaching only the lower atmosphere.

As you progress through this book, you see the story of Mount Pinatubo and its implications woven through eight chapters: Chapter 1 (systems theory), Chapter 3 (effects on energy budgets in the atmosphere), Chapter 4 (satellite images of the spread of debris by atmospheric winds), Chapter 7 (temporary effect on global atmospheric temperatures), Chapters 8 and 9 (volcanic processes), Chapter 13 (past climatic effects of volcanoes), and Chapter 15 (effects on net photosynthesis). Instead of simply describing the eruption, we see the linkages and global impacts of such a volcanic explosion.

GEO REPORT 1.1 Amphibians at thresholds

Amphibian species are a threatened group of animals, with approximately one-third of recognized species now at risk of extinction. According to the International Union for Conservation of Nature (IUCN) Amphibian Specialist Group, two new initiatives are aimed at stopping the amphibian decline: increased habitat protection for species that are found in only a single location and stepped-up efforts at testing antifungal drugs to halt the killer frog disease and ease the current amphibian extinction crisis (more at <http://www.amphibians.org/>).

Systems in Elemental Geosystems

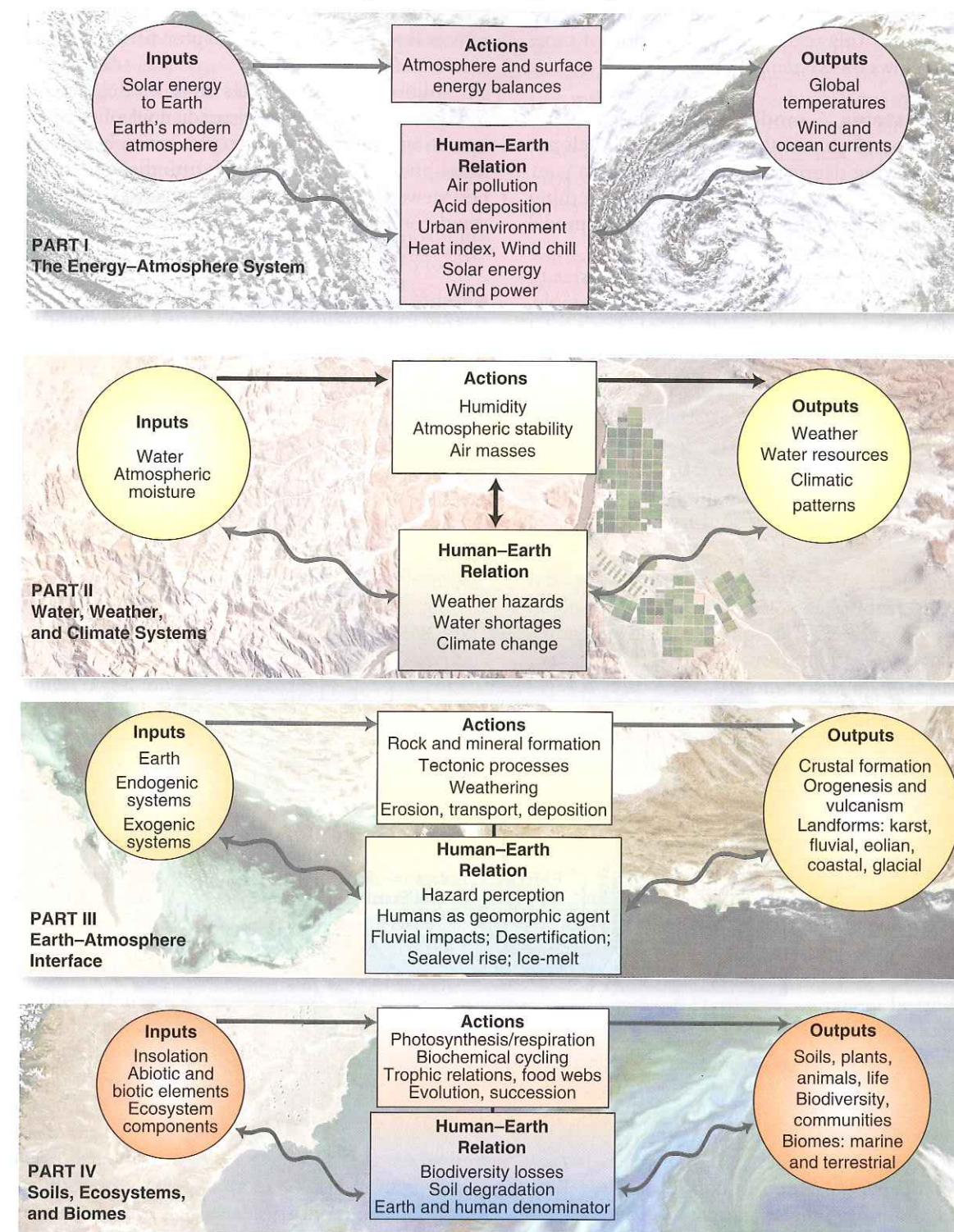


FIGURE 1.8 The systems in *Elemental Geosystems*.

The sequence of systems flow in the organization of PARTS I, II, III, and IV.

Systems in Elemental Geosystems

To further illustrate the systems organization in this textbook, notice the flow of energy, materials, and information throughout the 4 parts and 17 chapters (Figure 1.8). This book presents subjects in the same sequence in which they occur in nature. In this way, topics follow a logical progres-

sion that unfolds according to the energy and material flows within individual systems or with time and the flow of events.

In Figure 1.8, you see the Sun begins PART I. The energy flows across space to the top of the atmosphere and through the atmosphere to the surface and surface energy budgets (Chapters 2 and 3). Then we look at the outputs

of temperature (Chapter 3) and winds and ocean currents (Chapter 4). Note the same logical systems flow in the other three parts of this text. The organization of most chapters also follows this systems flow.

Models of Systems A **model** is a simplified, idealized representation of part of the real world. Models are designed with varying degrees of generalization. In your life, you may have built or drawn a model of something that was a simplification of the real thing—such as a model airplane or model house.

The simplicity of a model makes a system easier to understand and to simulate in experiments (for example, the leaf model in Figure 1.4). A good example is a model of the *hydrologic system*, which models Earth's entire water

system, its related energy flows, and the atmosphere, surface, and subsurface environments through which water moves (see Figure 6.1 in Chapter 6). We discuss many *system models* in this text.

Adjusting the variables in a model produces differing conditions and allows predictions of possible system operations. However, predictions are only as good as the assumptions and accuracy built into the model. A model is best viewed for what it is—a simplification to help us understand complex processes. Each of Earth's four "spheres" represents such a model of Earth's systems.

Earth's Four "Spheres" Earth's surface is a vast area of 500 million km² (193 million mi²) where four immense open systems interact. Figure 1.9 shows a simple model

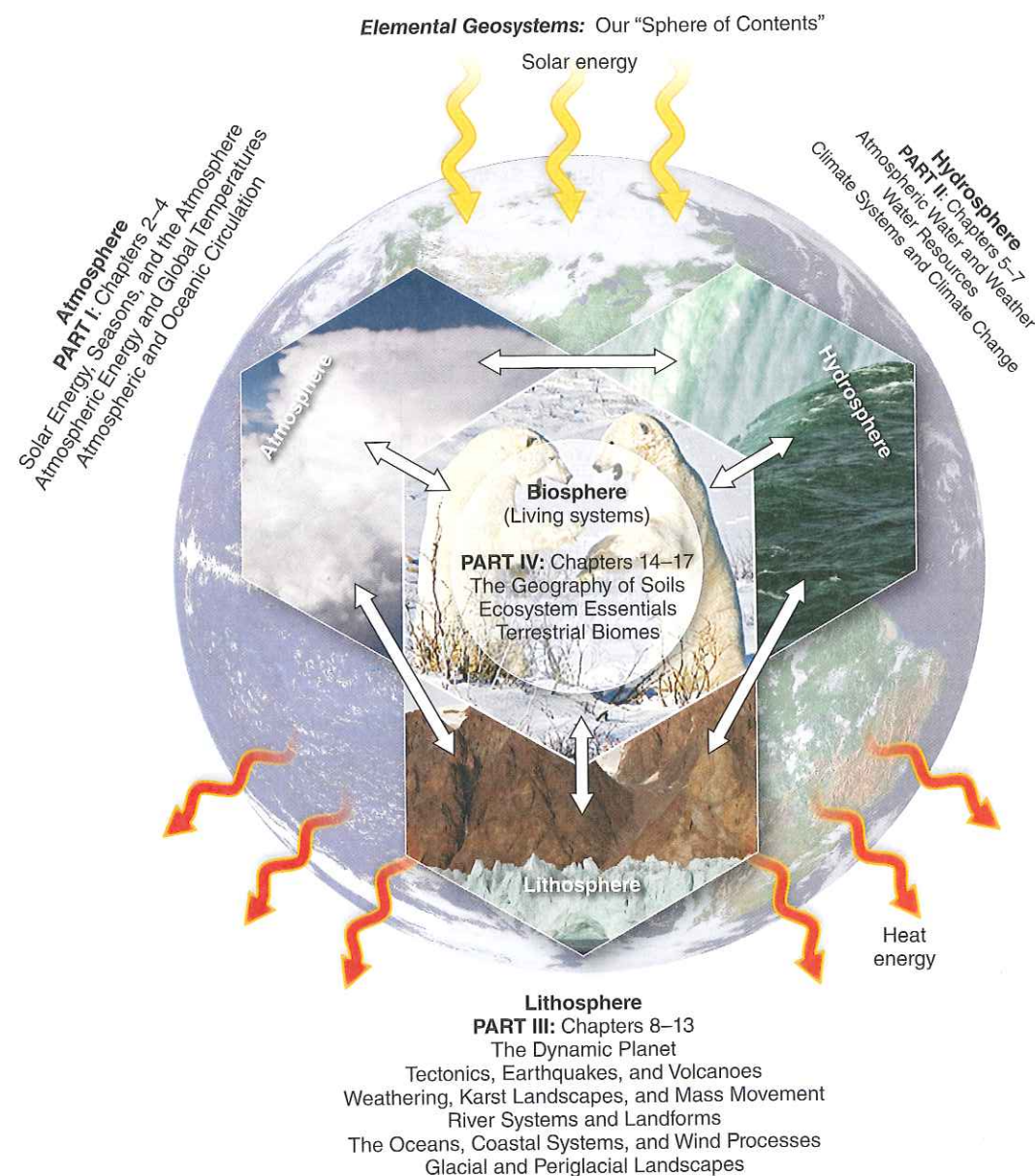


FIGURE 1.9 Earth's four spheres form the "Sphere of Contents" for *Elemental Geosystems*. Each sphere is a model of vast Earth systems. This four-part structure is the organizational framework for *Elemental Geosystems*. [Inset photos by Bobbé Christopherson; whole Earth image NASA.]

of three **abiotic**, or nonliving, systems overlapping to form the realm of the **biotic**, or living system. The abiotic spheres are the *atmosphere*, *hydrosphere*, and *lithosphere*. The biotic sphere is the *biosphere*.

As noted in the figure, these four spheres form the part structure in which chapters are grouped in this book. The various arrows in the figure show that content in each part and among chapters interrelates as we build our discussion of Earth's abiotic and biotic systems.

- **Atmosphere (Part I, Chapters 2–4)** The **atmosphere** is a thin, gaseous veil surrounding Earth, held to the planet by the force of gravity. Formed by gases arising from within Earth's crust and interior and the exhalations of all life over time, the lower atmosphere is unique in the Solar System. It is a combination of nitrogen, oxygen, argon, carbon dioxide, water vapor, and trace gases.
- **Hydrosphere (Part II, Chapters 5–7)** Earth's waters exist in the atmosphere, on the surface, and in the crust near the surface. Collectively, these waters form the **hydrosphere**. That portion of the hydrosphere that is frozen is the **cryosphere**—ice sheets, ice caps and fields, glaciers, ice shelves, sea ice, and subsurface ground ice. Water of the hydrosphere exists in all three states: liquid, solid (the frozen cryosphere), and gaseous (water vapor). Water occurs in two general chemical conditions, fresh and saline (salty).
- **Lithosphere (Part III, Chapters 8–13)** Earth's crust and a portion of the upper mantle directly below the crust form the **lithosphere**. The crust is quite brittle compared with the layers deep beneath the surface, which move slowly in response to an uneven distribution of heat energy and pressure. In a broad sense, the term *lithosphere* sometimes refers to the entire solid planet. The soil layer is the *edaphosphere* and generally covers Earth's land surfaces. In this text, soils represent the bridge between the lithosphere (Part III) and biosphere (Part IV).
- **Biosphere (Part IV, Chapters 14–17)** The intricate, interconnected web that links all organisms with their physical environment is the **biosphere**, or **ecosphere**. The biosphere is the area in which physical and chemical factors form the context of life. The biosphere exists in the overlap among the abiotic, or nonliving, spheres, extending from the seafloor, the upper layers of the crustal rock, to about 8 km (5 mi) into the atmosphere. Life is sustainable within these natural limits. The biosphere evolves, reorganizes itself at times, faces extinctions, and manages to flourish.

A Spherical Planet

We all have heard that some people in the past believed Earth was flat. Yet Earth's *sphericity*, or roundness, is not as modern an idea as many think. For instance, more than two millennia ago, the Greek mathematician and philosopher Pythagoras (ca. 580–500 B.C.) determined through observation that Earth is spherical. We do not know what observations led Pythagoras to this conclusion. Can you guess at what he saw to deduce Earth's roundness?

He might have noticed ships sailing beyond the horizon and apparently sinking below the water's surface, only to arrive back at port with dry decks. Perhaps he noticed Earth's curved shadow cast on the lunar surface during an eclipse of the Moon. He might have deduced that the Sun and Moon are not just the flat disks they appear to be in the sky, but are spherical, and that Earth must be a sphere as well.

Earth's sphericity was generally accepted by the educated populace as early as the first century A.D. Christopher Columbus, for example, knew he was sailing around a sphere in 1492; this is one reason why he thought he had arrived in the East Indies.

Earth as a Geoid Until 1687, the spherical-perfection model was a basic assumption of **geodesy**, the science that determines Earth's shape and size by surveys and mathematical calculations. But in that year, Sir Isaac Newton postulated that Earth, along with the other planets, could not be perfectly spherical. Newton reasoned that the more rapid rotational speed at the equator—the equator being farthest from the central axis of the planet and therefore moving faster—produces an equatorial bulge as centrifugal force pulls Earth's surface outward. He was convinced that Earth is slightly misshapen into an *oblate spheroid*, or, more correctly, an *oblate ellipsoid* (*oblate* means "flattened"), with the oblateness occurring at the poles.

Earth's equatorial bulge and its polar oblateness are universally accepted and confirmed with tremendous precision by satellite observations. The "geoidal epoch" is our modern era of Earth measurement because Earth is a **geoid**, meaning literally that "the shape of Earth is Earth-shaped." Imagine Earth's geoid as a sea-level surface that extends uniformly worldwide, beneath the continents. Both heights on land and depths in the oceans measure from this hypothetical surface. Think of the geoid surface as a balance among the gravitational attraction of Earth's mass, the distribution of water and ice along its surface, and the outward centrifugal pull caused by Earth's rotation. Figure 1.10 gives Earth's average polar and equatorial circumferences and diameters.

GEO REPORT 1.2 Water in the Solar System

Among the planets in the Solar System, only Earth possesses surface water in such quantity, some 1.36 billion km³ (0.33 billion mi³), although subsurface water was discovered on the Moon in its polar areas, Mars, Jupiter's moon Europa, and Saturn's moons Enceladus and Titan. In the Martian polar region, remote spacecraft are studying ground ice and patterned ground phenomena caused by freezing and thawing water, as discussed for Earth in Chapter 13. In the Universe, deep-space telescopes reveal traces of water in nebula and distant planetary objects.

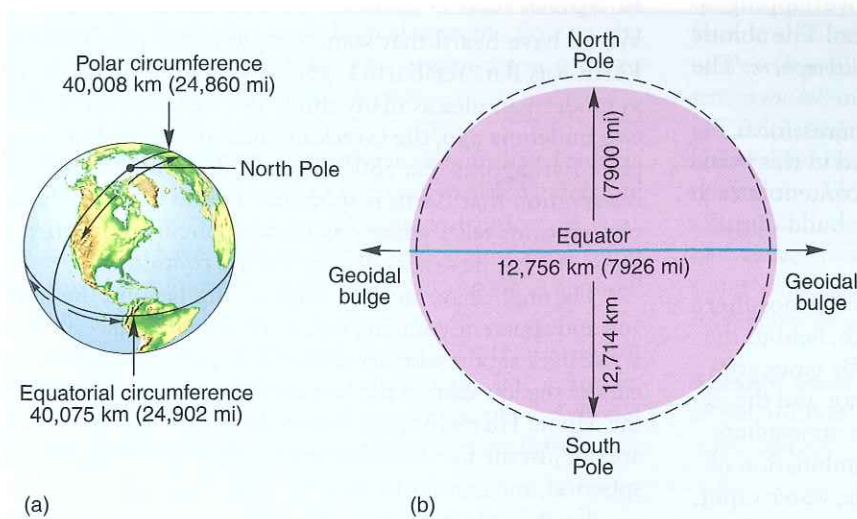


FIGURE 1.10 Earth's dimensions. Earth's (a) equatorial and polar circumference and (b) diameter. The dashed line is a perfect circle for reference to Earth's geoid.

Measuring Earth in 247 B.C.

Eratosthenes (ca. 276–195 B.C.) served as the librarian of Alexandria in Egypt during the third century B.C. He was a Greek geographer and astronomer in a position of scientific leadership. Alexandria's library was the finest in the ancient world. Among his achievements was calculating Earth's polar circumference to a high level of accuracy. Here's how he did it. As you read, follow along on Figure 1.11.

Travelers told Eratosthenes that on June 21 they saw the Sun's rays shine directly to the bottom of a well at Syene, the location of present-day Aswan, Egypt. This meant that the Sun was directly overhead on that day.

North of Syene in Alexandria, Eratosthenes knew from his own observations that the Sun's rays never were directly overhead, even at noon on June 21. This day is when the noon Sun is at its northernmost position in the sky. He knew objects in Alexandria, unlike objects in Syene, always cast a noontime shadow on June 21. Using his knowledge of geometry, Eratosthenes conducted an experiment to explain the different observations.

In Alexandria at noon on June 21, he measured the angle of a shadow cast by an obelisk (a perpendicular column). Knowing the height of the obelisk and measuring the length of the Sun's shadow from its base, he solved the triangle for the angle of the Sun's noon rays, which he

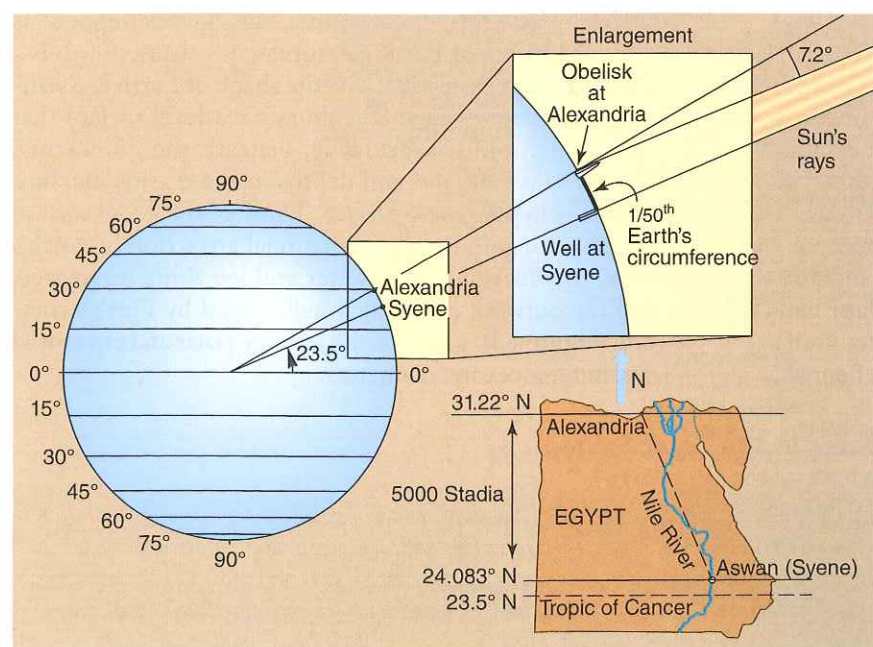


FIGURE 1.11 Eratosthenes' calculation. Eratosthenes' work teaches the value of observing carefully and integrating all observations. Calculating Earth's circumference required application of his knowledge of Earth–Sun relationships, geometry, and geography.

determined to be 7.2° off from directly overhead. However, at Syene on the same day, the angle of the Sun's rays was 0° from a perpendicular, arriving from directly overhead.

Eratosthenes knew from geometry that the distance on the ground between Alexandria and Syene formed an arc of Earth's circumference equal to the angle of the Sun's rays at Alexandria. Since 7.2° is roughly 1/50 of the 360° ($360^\circ \div 7.2^\circ = 50$) in Earth's total circumference, he knew the distance between Alexandria and Syene must represent approximately 1/50 of Earth's total polar circumference.

Next, Eratosthenes measured the surface distance between the two cities as 5000 stadia. A *stadium*, a Greek unit of measure, equals approximately 185 m (607 ft). He then multiplied 5000 stadia by 50 to determine that Earth's polar circumference is about 250,000 stadia. Eratosthenes' calculations convert to roughly 46,250 km (28,738 mi), which is remarkably close to the correct value of 40,008 km (24,860 mi) for Earth's polar circumference. Not bad for 247 B.C.!

Location and Time on Earth

Geographic science requires an internationally accepted, coordinated grid system to determine location on Earth. You can see the importance from the chapter-opening photo of Gough Island; or, in the photo at the end of this chapter and the *Geosystems Now* in Chapter 2, tracking the location of the subsolar point. The terms *latitude* and *longitude* were in use on maps as early as the first century A.D., with the concepts themselves dating back to Eratosthenes and others.

The geographer, astronomer, and mathematician Ptolemy (ca. A.D. 90–168) contributed greatly to the development of modern maps, and many of his terms are still used today. Ptolemy divided the circle into 360 degrees (360°), with each degree having 60 minutes (60') and each minute having 60 seconds (60'') in a manner adapted from the ancient Babylonians. He located places using these degrees, minutes, and seconds. However, the precise length of a degree of latitude and a degree of longitude remained unresolved for the next 17 centuries.

Latitude

Latitude is an angular distance north or south of the equator, measured from the center of Earth (Figure 1.12a). On a map or globe, the lines designating these angles of latitude run east and west, parallel to the equator (Figure 1.12b). Because Earth's equator divides the distance between the North Pole and the South Pole exactly in half, it is assigned the value of 0° latitude. Thus, latitude increases from the equator northward to the North Pole,

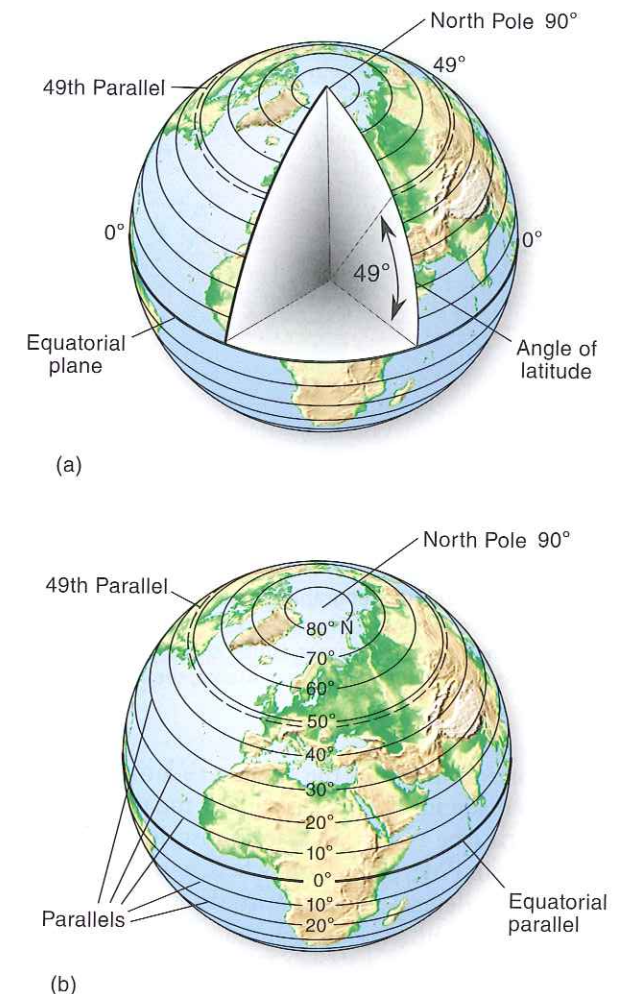


FIGURE 1.12 Parallels of latitude. (a) Latitude is measured in degrees north or south of the equator (0°). Earth's poles are at 90°. Note the measurement of 49° latitude. (b) These angles of latitude determine parallels along Earth's surface. Do you know your present latitude?

at 90° north latitude, and southward to the South Pole, at 90° south latitude.

A line connecting all points along the same latitudinal angle is a **parallel**. In the figure, an angle of 49° north latitude is measured, and, by connecting all points at this latitude, we have the 49th parallel. Thus, *latitude* is the name of the angle (49° north latitude), *parallel* names the line (49th parallel), and both indicate distance north of the equator.

Latitude is readily determined by observing *fixed celestial objects* such as the Sun or the stars, a method dating to ancient times. During daylight hours, the angle of the Sun

GEO REPORT 1.3 The value of a stadium

From the Greek *stade*, the value of a Greek stadium varied in time and place. For this calculation related to Eratosthenes' measurement, we used 185 m (607 ft) as a stadium length. This represents an average value in the Greek era. The word for the stadium measure was expanded to be the word to describe the arena in which foot races took place—thus our modern stadiums. Think of Eratosthenes' work when you see a stadium on campus.

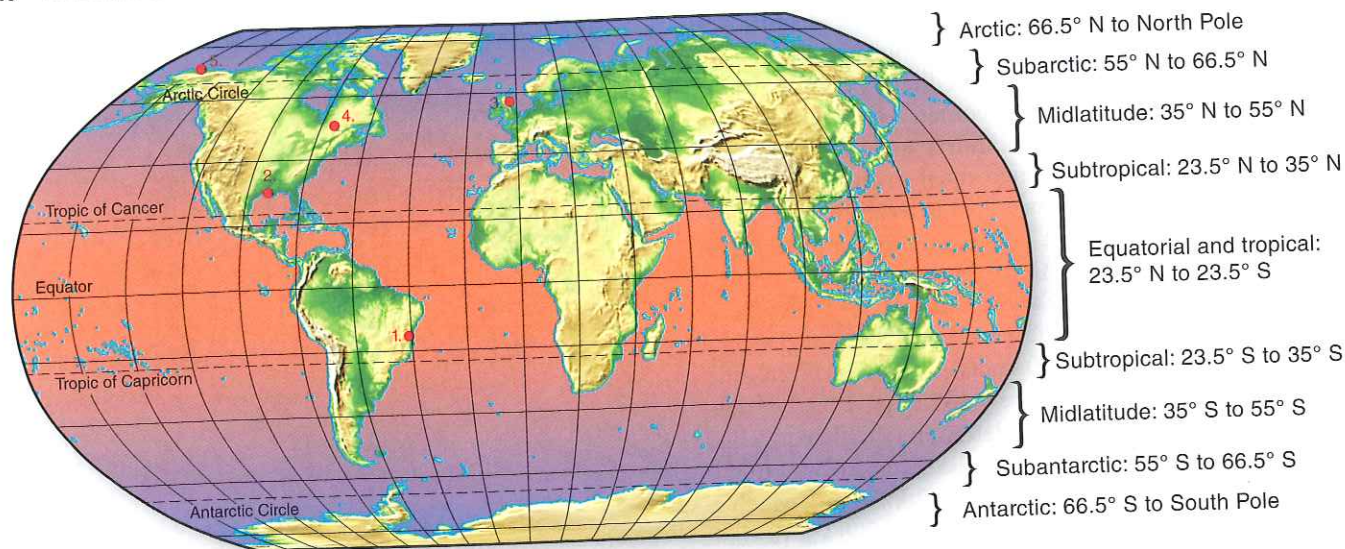


FIGURE 1.13 Latitudinal geographic zones. Geographic zones are generalizations that characterize various regions by latitude. Think of these as transitioning into one another over broad areas. Noted cities: 1. Salvador, Brazil; 2. New Orleans, Louisiana; 3. Edinburgh, Scotland; 4. Montreal, Quebec; 5. Barrow, Alaska, see Critical Thinking 1.1 below.

above the horizon indicates the observer's latitude, after adjustment is made for the season and for the time of day. Because Polaris (the North Star) is almost directly overhead at the North Pole, persons anywhere in the Northern Hemisphere can determine their latitude at night simply by sighting Polaris and measuring its angle above the local horizon. The angle of elevation of Polaris above the horizon indicates the latitude of the observation point. Go to this chapter on our *MasteringGeography* web site to see an illustration of sighting on Polaris to determine latitude.

In the Southern Hemisphere, Polaris cannot be seen because it is below the horizon. Instead, latitude south of the equator is measured by sighting on a constellation that points to a celestial location above the South Pole. This indicator constellation is the Southern Cross (*Crux Australis*).

Latitudinal Geographic Zones Natural environments differ dramatically from the equator to the poles. These differences result from the amount of solar energy received, which varies by latitude and season of the year. As a convenience, geographers identify *latitudinal geographic zones* as regions. "Lower latitudes" are those nearer the equator, whereas "higher latitudes" are those nearer the poles.

Figure 1.13 portrays these zones, their locations, and their names: *equatorial* and *tropical*, *subtropical*, *midlatitude*, *subarctic* or *subantarctic*, and *arctic* or *antarctic*. These generalized latitudinal zones are useful for reference and comparison, but they do not have rigid boundaries; rather, think of them as transitioning one to another.

The *Tropic of Cancer* (about 23.5° north parallel) and the *Tropic of Capricorn* (about 23.5° south parallel) are the most extreme northern and southern parallels that experience perpendicular (directly overhead) rays of the Sun at local noon. When the Sun arrives overhead at these tropics, it marks the first day of summer in each hemi-

sphere. (Further discussion of the tropics is in Chapter 2.) The *Arctic Circle* (about 66.5° north parallel) and the *Antarctic Circle* (about 66.5° south parallel) are the parallels farthest from the poles that still experience 24 uninterrupted hours of night (including dawn and twilight) during local winter and continuous day during local summer.

CRITICAL THINKING 1.1

Latitudinal zones and temperature

Refer to the graph in Figure 3.16 that plots annual temperature data for five cities from near the equator to beyond the Arctic Circle. Note the geographic location for each of the five cities on the latitudinal geographic zone map in Figure 1.13. In which zone is each city located? To approximate locations use an atlas, web site, or encyclopedia. Roughly characterize changing temperature patterns through the seasons as you move away from the equator. Describe what you discover.

Longitude

Longitude is an angular distance east or west of a point on Earth's surface, measured from the center of Earth (Figure 1.14a). On a map or globe, the lines designating these angles of longitude run north and south (Figure 1.14b). A line connecting all points along the same longitude is a **meridian**. In the figure, a longitudinal angle of 60° E is measured. These meridians run at right angles (90°) to all parallels, including the equator.

Thus, *longitude* is the name of the angle, *meridian* names the line, and both indicate distance east or west of an arbitrary **prime meridian**—a meridian designated as 0° (Figure 1.14b). Earth's prime meridian passes through the old Royal Observatory at Greenwich, England, as set by an 1884 treaty—the *Greenwich prime meridian*.

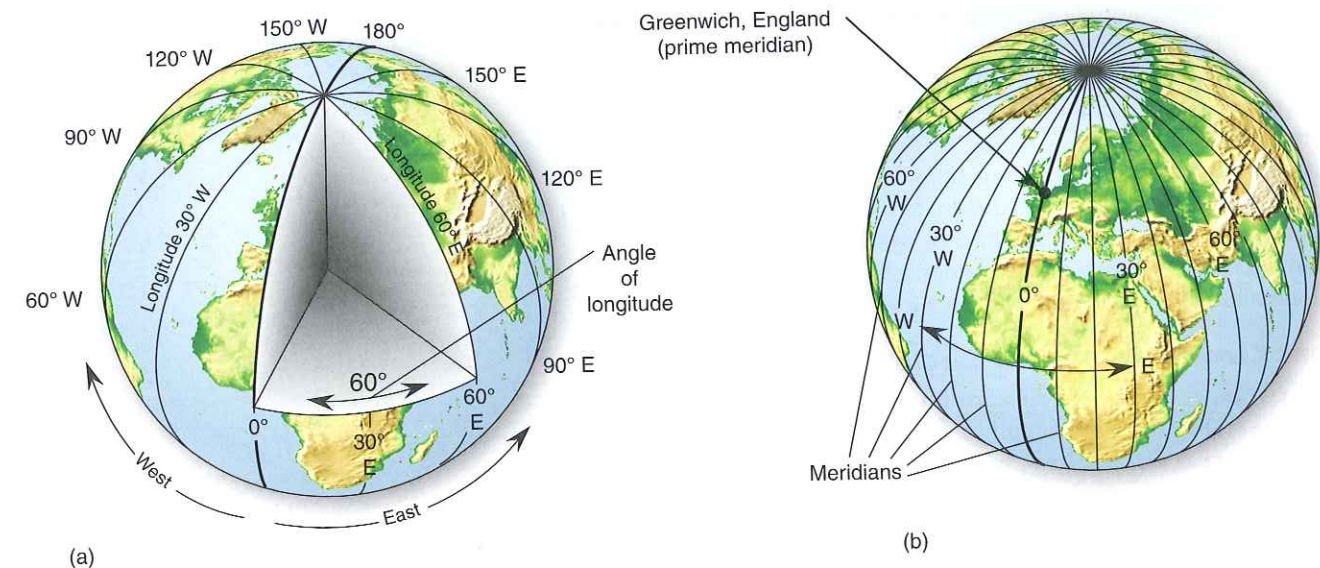


FIGURE 1.14 Meridians of longitude.

(a) Longitude is measured in degrees east or west of a 0° starting line, the prime meridian. Note the measurement of 60° E longitude. (b) Angles of longitude measured from the prime meridian determine other meridians. North America is west of Greenwich; therefore, it is in the Western Hemisphere. Do you know your present longitude?

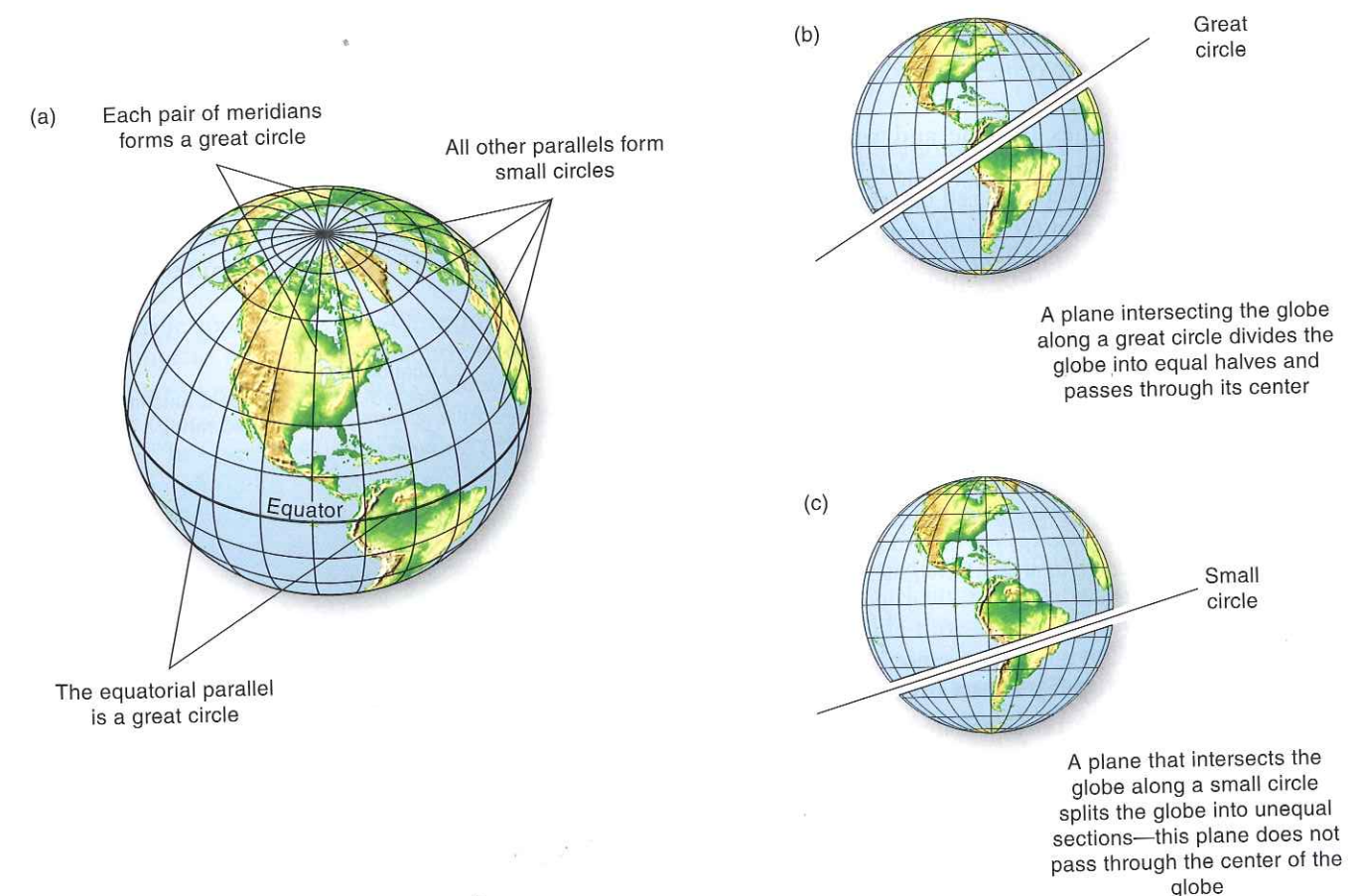


FIGURE 1.15 Great circles and small circles.

(a) Examples of great circles and small circles on Earth. (b) Any plane that divides Earth into equal halves intersects the globe along a great circle; this great circle is a full circumference of the globe and is the shortest distance between any two surface points. (c) Any plane surface that splits the globe into unequal portions intersects the globe along a small circle.

We noted that latitude is determined easily by sighting the Sun or the North Star or by using the Southern Cross as a pointer. In contrast, a method of accurately determining longitude, especially at sea, remained a major difficulty in navigation until after 1760. The key to measuring the longitude of a place lies in accurately knowing time and required the invention of a clock without a pendulum. In Chapter 1 on the *MasteringGeography* web site, you find an exciting chapter in human discovery focusing on the relationship between time and longitude called “The Timely Search for Longitude.”

Great Circles and Small Circles

Great circles and small circles are important concepts that help summarize latitude and longitude (Figure 1.15, page 17). A **great circle** is any circle of Earth’s circumference whose center coincides with the center of Earth. An infinite number of great circles can be drawn on Earth. Every meridian is one-half of a great circle that passes through the poles. On flat maps, airline and shipping routes appear to arch their way across oceans and landmasses. These are *great circle routes*, the shortest distance between two points on Earth (discussed on the *MasteringGeography* web site).

In contrast to meridians, only one parallel is a great circle—the *equatorial parallel*. All other parallels diminish in length toward the poles and, along with any other non-great circles that one might draw, constitute **small circles**. These circles have centers that do not coincide with Earth’s center.

Figure 1.16 combines latitude and parallels with longitude and meridians to illustrate Earth’s complete coordinate grid system. Note the red dot that marks our measurement of 49° N and 60° E, a location in western Kazakhstan. Next time you look at a world globe, follow the parallel and meridian that converge on your location.

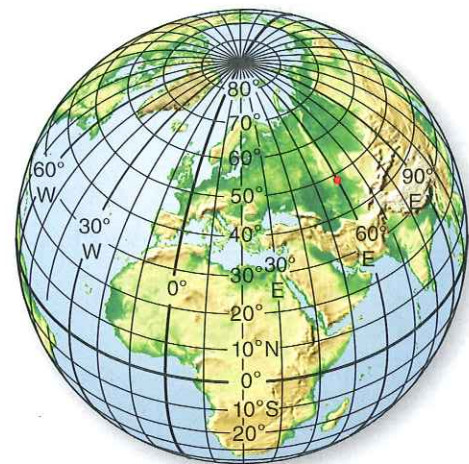


FIGURE 1.16 Earth’s coordinate grid system.

Latitude and parallels and longitude and meridians allow us to locate all places on Earth precisely. The red dot is at 49° N latitude and 60° E longitude.

Every possible square meter of Earth’s surface has its own address relative to the latitude–longitude grid.

A GPS receiver, now built into cell phones, digital cameras, and camcorders, senses signals from a minimum of three satellites for location and four satellites to measure the receiver’s altitude. This is accomplished by calculating the distance between each satellite and receiver using clocks built into each instrument that time radio signals traveling at the speed of light between them (Figure 1.17). The receiver reports latitude, longitude, and elevation (Figure 1.18). Within *Differential GPS (DGPS)*, accuracy increases to 1 m to 3 m by comparing readings with another base station (reference receiver) for a differential correction.

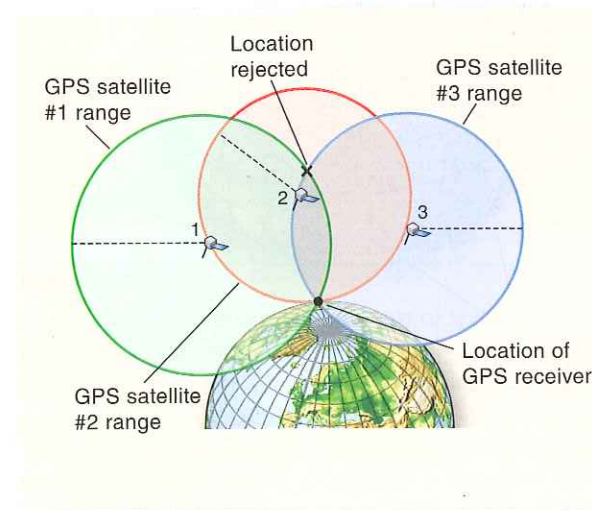


FIGURE 1.17 Using satellites to triangulate location through GPS.

Imagine a ranging sphere around each of three GPS satellites. These spheres intersect at two points, one easily rejected because it is some distance above Earth and the other at the true location of the GPS receiver. In this way, three satellites can determine location; adding a fourth satellite measures elevation.



FIGURE 1.18 GPS in action.

Location coordinates on a GPS unit in operation on a research ship as it crosses Earth’s equator at 0° latitude. Locate these latitude and longitude coordinates on a globe or map. How far from the nearest land is the ship? What is the name of this ocean? [Bobbé Christopherson.]

The GPS satellite measurements help refine our knowledge of Earth’s exact shape and how this shape is changing. The GPS is useful for diverse applications, such as navigating on the ocean, surveying land, tracking small changes in Earth’s crust, managing the movement of fleets of trucks, mining and mapping resources, tracking wildlife migration and behavior, carrying out police and security work, and conducting environmental planning. Outdoor recreationists and sportspersons commonly carry handheld GPS devices that allow them to track their own location. Commercial airlines use the GPS to improve accuracy of routes flown and thus increase fuel efficiency. Through GPS technology, modern cell phones know where they are on Earth.

Scientific applications of GPS technology are extensive. Relative to earthquakes in southern California, the GPS Observation Office monitors a network of 250 continuously operating GPS seismic stations—the Southern California Integrated GPS Network (SCIGN; <http://www.scign.org/>). This system can record fault movement as small as 1 mm (0.04 in.). In 1998, scientists used GPS technology to accurately determine the height of Mount Everest in the Himalayan Mountains (Figure 1.19), raising its elevation by 2 m (6 ft). GPS measurements of Mount Kilimanjaro in Africa lowered its summit from 5895 m to 5892 m (19,340 ft to 19,330 ft).

In *precision agriculture*, farmers use GPS devices to determine crop yields on specific parts of their farms. A detailed plot map is made to guide the farmer in the addition of more fertilizer, proper seed distribution, precise



FIGURE 1.19 GPS used to measure Everest’s summit height.

Installation of a Trimble 4800 GPS unit at Earth’s highest benchmark, only 18 m (60 ft) below the 8850-m (29,035-ft) summit. Previously, the height was set at 8848 m. Scientists using GPS data accurately analyzed the rate the mountain range is moving due to tectonic forces. [Photo and GPS installation by adventurer/climber Wally Berg, May 20, 1998.]

irrigation applications, or other work needed. A computer and GPS unit on board the farm equipment guide the work. This is the science of *variable-rate technology*, made possible by GPS technology.

The GPS is important to a locational, spatial geographic science because this precise technology reduces the need to maintain ground control points for location, mapping, and spatial analysis. Instead, geographers working in the field can easily determine their position, as well as boundaries and other data points, accurately as they work, reducing the need for traditional surveys.

Prime Meridian and Standard Time

Coordination of international trade, airline schedules, business and agricultural activities, and daily living depends on a worldwide time system. Today, we take for granted standard time zones and an agreed-upon prime meridian, but such a standard is a relatively recent development.

Setting time was not a great problem in small European countries, most of which are less than 15° wide. But in North America, which spans more than 90° of longitude

CRITICAL THINKING 1.2

Where are you?

Select a location (for example, your campus, home, or workplace or a city) and determine the following: elevation, latitude, and longitude—including the coordinates in degrees, minutes, and seconds. Describe the resources you used to gather this geographic information, such as an atlas, web site, Google Earth™, or GPS measurement.

Global Positioning System

Today, using a handheld instrument that receives radio signals from satellites, you can accurately calibrate latitude, longitude, and elevation—and even know where your car is as you drive along, often with an electronic voice telling you where to turn.

The **Global Positioning System (GPS)** comprises 24 orbiting satellites, in six orbital planes, that transmit navigational signals for Earth bound use (backup GPS satellites are in orbital storage as replacements). Think of the satellites as a constellation of navigational beacons with which you interact to determine your unique location.

GEO REPORT 1.4 GPS origins

Originally devised in the 1970s by the Department of Defense for military purposes, GPS is now commercially available worldwide. In 2000, the Pentagon shut down its Pentagon Selective Availability security control, making commercial resolution the same as military applications. Additional frequencies were added in 2003 and 2006, which increased accuracy significantly to less than 10 m (33 ft). For a GPS overview, see http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html.

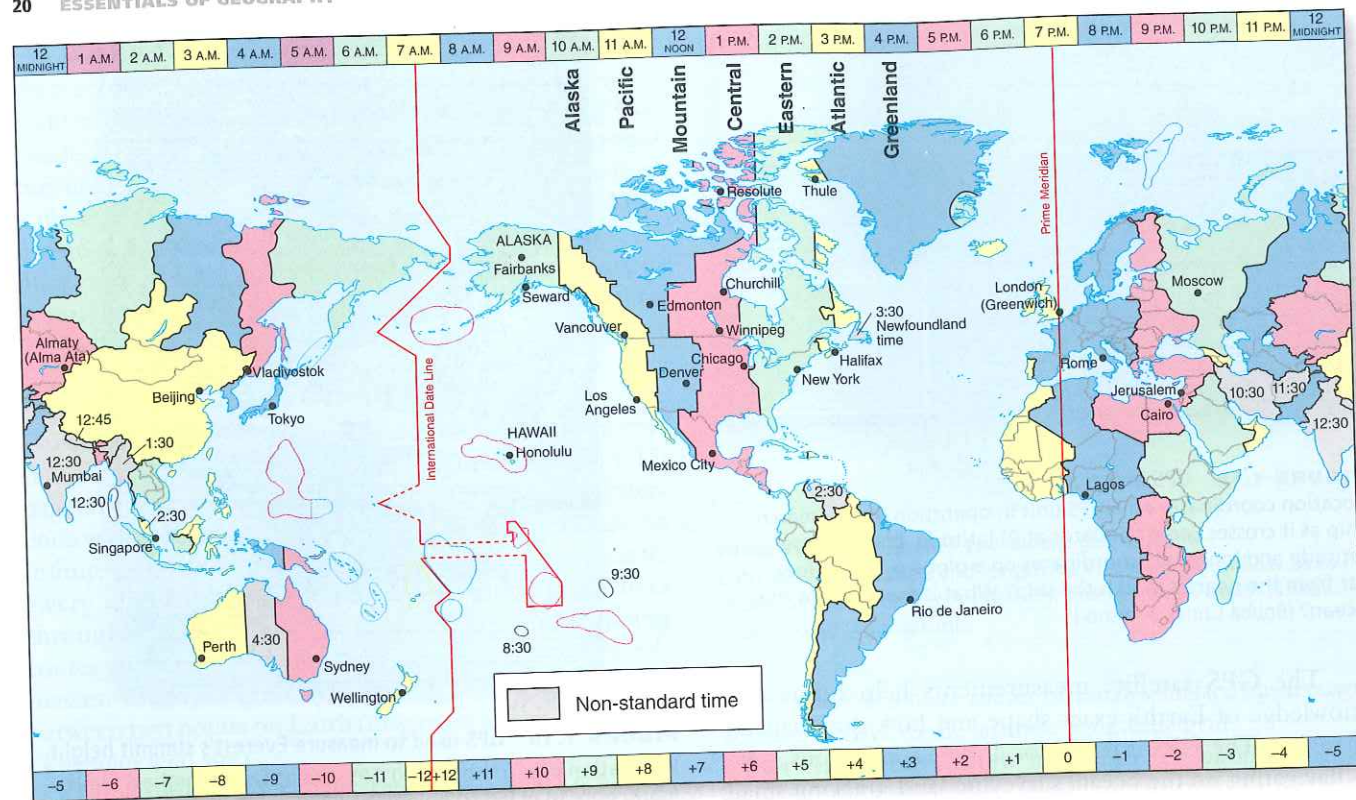


FIGURE 1.20 Modern international standard time zones. Numbers along the bottom of the map indicate how many hours each zone is earlier (plus sign) or later (minus sign) than Coordinated Universal Time (UTC) at the prime meridian. If it is 7 P.M. in Greenwich, determine the present time in Moscow, London, Halifax, Chicago, Winnipeg, Denver, Los Angeles, Fairbanks, Honolulu, Tokyo, and Singapore. [Adapted from Defense Mapping Agency. See http://aa.usno.navy.mil/faq/docs/world_tzones.html.]

(the equivalent of six 15° time zones), the problem was serious. In 1870, railroad travelers going from Maine to San Francisco made 22 adjustments to their watches to stay consistent with local time.

In Canada, Sir Sanford Fleming directed the fight for standard time and for an international agreement on a prime meridian. His struggle led the United States and Canada to adopt a standard time in 1883. Twenty-seven countries attended the 1884 International Meridian Conference in Washington, DC, to set a global standard. Most participating nations chose the highly respected Royal Observatory at Greenwich, London, England, as the place for the prime meridian of 0° longitude for maps. Thus, a world standard was set—**Greenwich Mean Time (GMT)**—and a consistent Universal Time was established (see <http://wwp.greenwichmeantime.com/>).

The basis of time is that Earth revolves 360° every 24 hours, or 15° per hour ($360^\circ \div 24 = 15^\circ$). Thus, a time zone of 1 hour is established, spanning 7.5° on either side

of a *central meridian*. Today, only three adjustments are needed in the continental United States—from Eastern Standard Time to Central, Mountain, and Pacific—and four changes across Canada.

Assuming it is 9:00 P.M. in Greenwich, then it is 4:00 P.M. in Baltimore (+5 hr), 3:00 P.M. in Oklahoma City (+6 hr), 2:00 P.M. in Salt Lake City (+7 hr), 1:00 P.M. in Seattle and Los Angeles (+8 hr), noon in Anchorage (+9 hr), and 11:00 A.M. in Honolulu (+10 hr). To the east, it is midnight in Ar Riyāḍ, Saudi Arabia (−3 hr). The designation A.M. is for *ante meridiem*, “before noon,” whereas P.M. is for *post meridiem*, “after noon.” A 24-hour clock avoids the use of these designations: 3 P.M. is stated as 15:00 hours; 3 A.M. is 3:00 hours.

As you can see from the modern international time zones in Figure 1.20, national boundaries and political considerations distort time boundaries. For example, China spans four time zones, but its government decided to keep the entire country operating at the same time. Thus, in some parts of China clocks are several hours off

from what the Sun is doing. In the United States, parts of Florida and west Texas are in the same time zone.

International Date Line An important corollary of the prime meridian is the 180° meridian on the opposite side of the planet. This meridian is the **International Date Line (IDL)**, which marks the place where each day officially begins (at 12:01 A.M.). From this “line,” the new day sweeps westward. This *westward* movement of time is created by Earth’s turning *eastward* on its axis. Locating the date line in the sparsely populated Pacific Ocean minimizes most local confusion.

At the IDL, the west side of the line is always one day ahead of the east side. No matter what time of day it is when the line is crossed, the calendar changes a day (Figure 1.21). Note in the illustration the departures from the IDL and the 180° meridian; this deviation is due to local administrative and political preferences.

Coordinated Universal Time For decades, Greenwich Mean Time (GMT) from the Royal Observatory’s astronomical clocks was the world’s Universal Time (UT) standard for accuracy. GMT was broadcast using radio time signals as early as 1910. Taking the initiative in 1912, the French government called a gathering of countries to better coordinate radio time signals. At this conference, GMT was made standard, and a new organization was set up to be the custodian of “exact” time—the International Bureau of Weights and Measures (BIPM; see <http://www.bipm.org>). Progress was made in accurately measuring time with the invention of a quartz clock in 1939 and atomic clocks in the early 1950s.

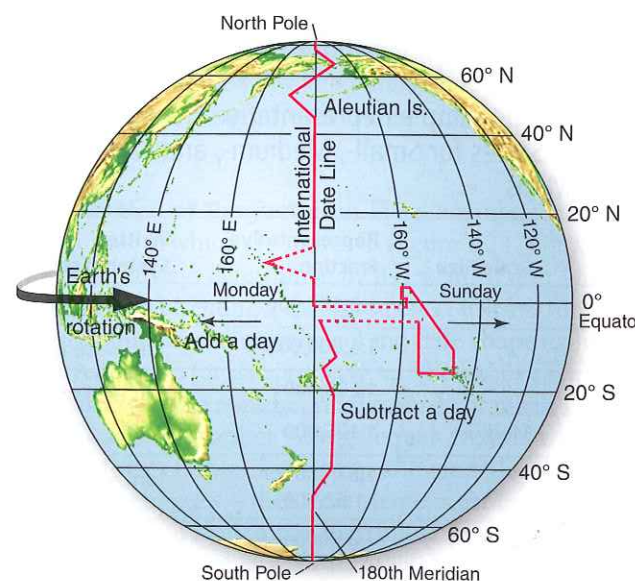


FIGURE 1.21 International Date Line. International Date Line location is approximately along the 180th meridian (see the IDL location on Figure 1.20). Note the dotted lines on the map— island countries set their own time zones, but their political control extends only 3.5 nautical miles (4 mi) off-shore. Officially, you gain 1 day crossing the IDL from east to west.

Accurate time is not a matter of simply keeping track of Earth’s rotation, since it is slowing down from the tug of tidal forces and rearrangement of water. Note that 150 million years ago a “day” was 22 hours long, and 150 million years in the future a “day” will be approaching 27 hours in length.

The **Coordinated Universal Time (UTC*)** time-signal system replaced GMT universal time in 1972 and became the legal reference for official time in all countries. Although the prime meridian still runs through Greenwich, UTC is based on average time calculations from atomic clocks collected worldwide. You might still see official UTC referred to as GMT or Zulu time.

Time and Frequency Services of the National Institute for Standards and Technology (NIST), U.S. Department of Commerce, operates several of the most advanced clocks. For the time, call 303-499-7111 or 808-335-4363, or see <http://nist.time.gov/> for UTC. In Canada, the Institute for Measurement Standards, National Research Council Canada, participates in determining UTC, English, 613-745-1578; French, 613-745-9426; for more see <http://time5.nrc.ca/JavaClock/timeDisplayWE.shtml>.

Daylight Saving Time In 70 countries, mainly in the temperate latitudes, time is set ahead 1 hour in the spring and set back 1 hour in the fall—a practice known as **daylight saving time**. The idea to extend daylight for early evening activities (at the expense of daylight in the morning), first proposed by Benjamin Franklin, was not adopted until World War I and again in World War II, when Great Britain, Australia, Germany, Canada, and the United States used the practice to save energy (1 less hour of artificial lighting needed).

In 1986 and again in 2007, the United States and Canada increased daylight saving time. Time “springs forward” 1 hour on the second Sunday in March and “falls back” 1 hour on the first Sunday in November, except in a few places that do not use daylight saving time (Hawaii, Arizona, and Saskatchewan). In Europe, the last Sundays in March and October are used to begin and end the “summer-time period.” (See <http://webexhibits.org/daylightsaving/>.)

Maps, Scales, and Projections

The earliest known graphic maps date to 2300 B.C., when the Babylonians used clay tablets to record information about the region of the Tigris and Euphrates Rivers (the area of modern-day Iraq). Today, the making of maps and charts is a specialized science as well as an art, blending aspects of geography, engineering, mathematics, graphics, computer science, and artistic specialties. It is similar in ways to architecture, in which aesthetics and utility combine to produce a useful product.

A **map** is a generalized view of an area, usually some portion of Earth’s surface, as seen from above and greatly

*UTC is in use because agreement was not reached on whether to use the English word order, CUT, or the French order, TUC. UTC was the compromise and is recommended for all time-keeping applications; use of the term *GMT* is discouraged.

GEO REPORT 1.5 Magellan’s crew loses a day

Early explorers had a problem before the date-line concept. For example, Magellan’s crew returned from the first circumnavigation of Earth in 1522, confident from their ship’s log that it was Wednesday, September 7. They were shocked when informed by local residents that it was actually Thursday, September 8. Without an International Date Line, they had no idea that they must advance a day somewhere when sailing around the world in a westward direction. Imagine the confusion of the arriving crew.

reduced in size. **Cartography** is that part of geography that involves mapmaking. Maps are critical tools with which geographers depict spatial information and analyze spatial relationships.

We all use maps at some time to visualize our location in relation to other places, or maybe to plan a trip, or to coordinate commercial and economic activities. Have you found yourself looking at a map, planning real and imagined adventures to far-distant places? Maps are wonderful tools! Understanding a few basics about maps is essential to our study of physical geography.

The Scale of Maps

Architects, toy designers, and mapmakers have something in common: They all create scale models. They reduce real things and places to the more convenient scale of a drawing; a model car, train, or plane; a diagram; or a map. An architect renders a blueprint of a structure to guide the building contractors, selecting a scale so that a centimeter (or inch) on the drawing represents so many meters (or feet) on the proposed building. Often, the drawing is 1/50 or 1/100 real size.

The cartographer does the same thing in preparing a map. The ratio of the image on a map to the real world is **scale**; it relates a unit on the map to a similar unit on the ground. A 1:1 scale means that a centimeter on the map represents a centimeter on the ground, although this is an impractical map scale, since the map is as large as the area mapped! A more appropriate scale for a local map is 1:24,000, in which 1 unit on the map represents 24,000 identical units on the ground.

Cartographers express map scale as a representative fraction, a graphic scale, or a written scale (Figure 1.22). A *representative fraction* (RF, or *fractional scale*) is expressed with either a colon or a slash, as in 1:125,000 or 1/125,000. No actual units of measurement are mentioned because any unit is applicable as long as both parts of the fraction are in the same unit: 1 cm to 125,000 cm, 1 in. to 125,000 in., or even 1 arm length to 125,000 arm lengths.

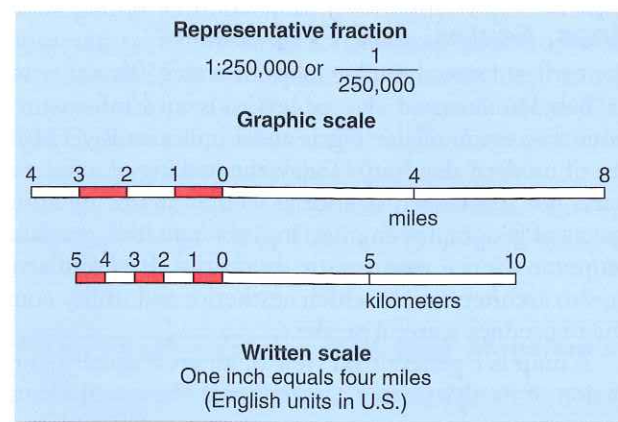


FIGURE 1.22 Map scale.

Three common expressions of map scale—representative fraction, graphic scale, and written scale.

A *graphic scale*, or *bar scale*, is a bar graph with units to allow measurement of distances on the map. An important advantage of a graphic scale is that, if the map is enlarged or reduced, the graphic scale enlarges or reduces along with the map. In contrast, written and fractional scales become incorrect with enlargement or reduction. As an example, if you shrink a map from 1:24,000 to 1:63,360, the written scale “1 in. to 2000 ft” will no longer be the correct. The new correct written scale is 1 in. to 5280 ft (1 mi).

Scales are *small*, *medium*, and *large*, depending on the ratio described. In relative terms, a scale of 1:24,000 is a large scale, whereas a scale of 1:50,000,000 is a small scale. The greater the denominator in a fractional scale (or the number on the right in a ratio expression), the smaller the scale and the more abstract the map in relation to what is being mapped. Examples of selected representative fractions and written scales are listed in Table 1.1 for small-, medium-, and large-scale maps.

CRITICAL THINKING 1.3

Find and calculate map scales

Find a globe or map in the library or geography department and check the scale at which it was drawn. See if you can find examples of fractional, graphic, and written scales on wall maps, on highway maps, and in atlases. Find some examples of small- and large-scale maps, and note the different subject matter they portray.

Look at a world globe that is 61 cm (24 in.) in diameter. (Use different values depending on the globe you are using.) We know that Earth has an equatorial diameter of 12,756 km (7926 mi), so the scale of such a globe is the ratio of 61 cm to 12,756 km. To calculate the representative fraction for the globe in centimeters, divide Earth's actual diameter by the globe's diameter (12,756 km ÷ 61 cm). (Hint: 1 km = 1000 m, 1 m = 100 cm; therefore, Earth's diameter of 12,756 km represents 1,275,600,000 cm; and the globe's diameter is 61 cm.) In general, do you think a world globe is a small- or a large-scale map of Earth's surface?

TABLE 1.1 Sample Representative Fractions and Written Scales for Small-, Medium-, and Large-Scale Maps

System	Scale Size	Representative Fraction	Written System Scale
English	Small	1:3,168,000	1 in. = 50 mi
		1:1,000,000	1 in. = 16 mi
		1:250,000	1 in. = 4 mi
	Medium	1:125,000	1 in. = 2 mi
		1:63,360 (or 1:62,500)	1 in. = 1 mi
		1:24,000	1 in. = 2000 ft
System		Representative Fraction	Written System Scale
Metric		1:1,000,000	1 cm = 10.0 km
		1:25,000	1 cm = 0.25 km
		1:10,000	1 cm = 0.10 km

Map Projections

A globe is not always a helpful map representation of Earth. When you go on a trip, you need more-detailed information than a globe can provide. Consequently, to provide local detail, cartographers prepare large-scale *flat maps*, which are two-dimensional representations (scale models) of our three-dimensional Earth. Unfortunately, such conversion from three dimensions to two causes distortion.

A globe is the only true representation of *distance*, *direction*, *area*, *shape*, and *proximity*. A flat map distorts these properties. Therefore, in preparing a flat map, the cartographer must decide which characteristic to preserve, which to distort, and how much distortion is acceptable. To understand this problem, consider these important properties of a globe:

- Parallels always are parallel to each other, always are evenly spaced along meridians, and always decrease in length toward the poles.
- Meridians always converge at both poles and always are evenly spaced along any individual parallel.
- The distance between meridians decreases toward poles, with the spacing between meridians at the 60th parallel equal to one-half the equatorial spacing.
- Parallels and meridians always cross each other at right angles.

The problem is that all these qualities cannot be reproduced on a flat surface. Simply taking a globe apart and laying it flat on a table illustrates the challenge faced by cartographers (Figure 1.23). You can see the empty spaces that open up between the sections, or *gores*, of the globe. This reduction of the spherical Earth to a flat surface is a **map projection**. Thus, no flat map projection of Earth can ever have all the features of a globe. Flat maps always possess some degree of distortion—much less for large-scale maps representing a few kilometers; much more for small-scale maps covering individual countries, continents, or the entire world.

Properties of Projections There are many map projections, four of which are shown in Figure 1.24. The best projection is always determined by its intended use. The major decisions in selecting a map projection involve the properties of **equal area** (equivalence) and **true shape** (conformality). A decision for one property sacrifices the other, for they cannot be shown together on the same flat map.

If a cartographer selects equal area as the desired trait—for example, for a map showing the distribution of world climates—then true shape must be sacrificed by stretching and shearing, which allow parallels and meridians to cross at other than right angles. On an equal-area map, a coin covers the same amount of surface area no matter where you place it on the map. In contrast, if a cartographer selects the property of true shape, such as for a map used for navigational purposes, then equal area must be sacrificed, and the scale will actually change from one region of the map to another.

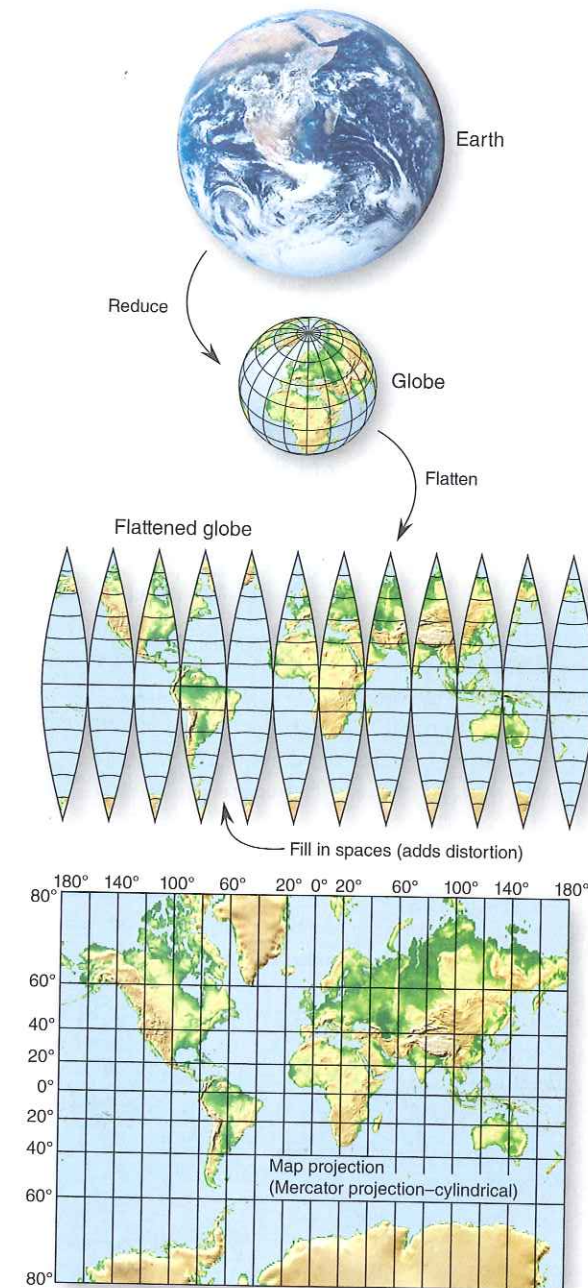


FIGURE 1.23 From globe to flat map.

Conversion of the globe to a flat map projection requires decisions about which properties to preserve and the amount of distortion that is acceptable. [NASA astronaut photo from Apollo 17, 1972.]

The Nature and Classes of Projections Despite the fact that modern cartographic technology uses mathematical constructions and computer-assisted graphics, the word *projection* is still used. The term comes from times past, when geographers actually projected the shadow of a wire-skeleton globe onto a geometric surface. The wires represented parallels, meridians, and outlines of the continents. A light source then cast a shadow pattern of latitude and longitude lines from the globe onto various geometric surfaces, such as a *cylinder*, *plane*, or *cone*.

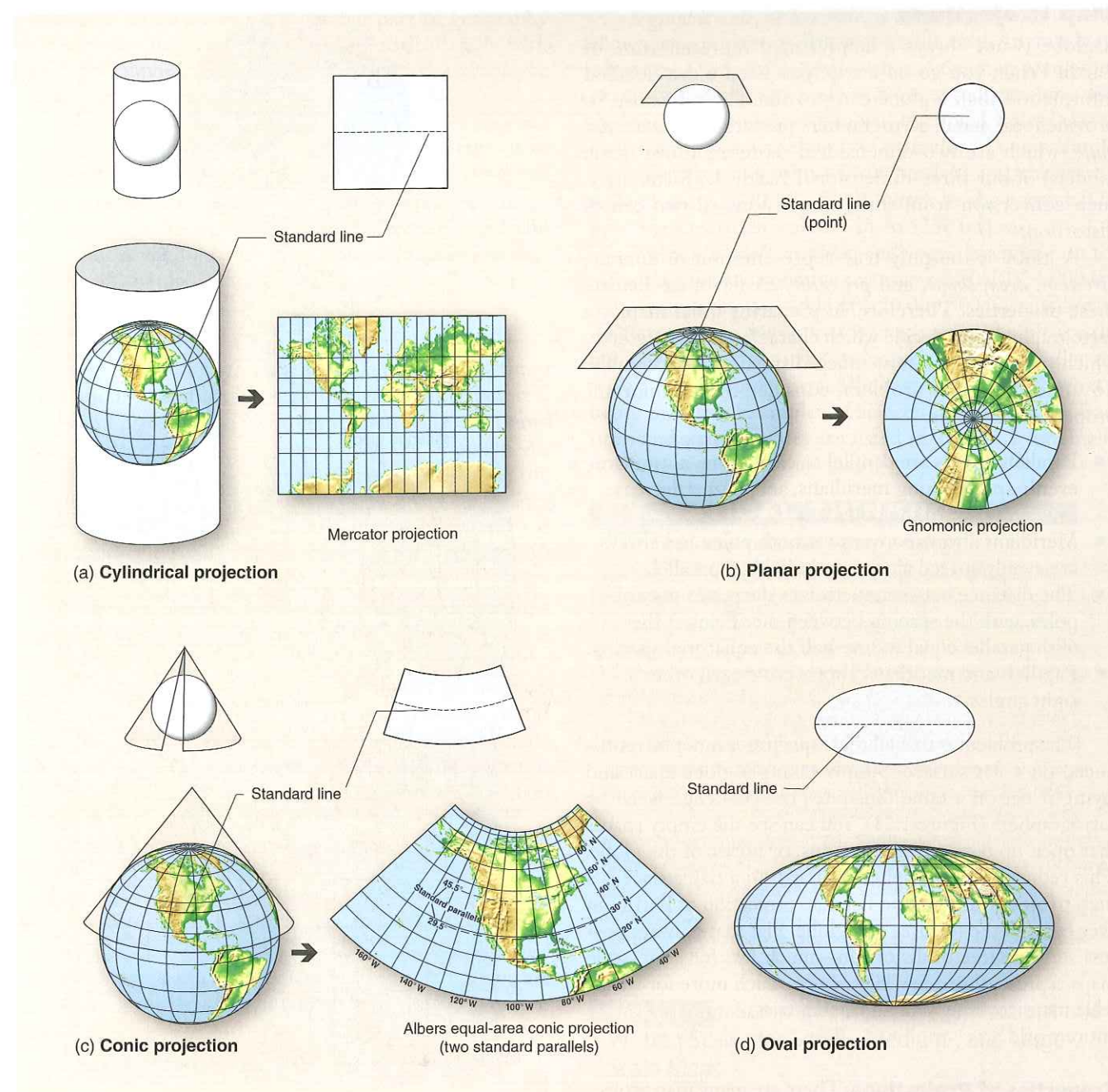


FIGURE 1.24 Classes of map projections.

Four general classes and perspectives of map projections—(a) cylindrical, (b) planar, (c) conic, and (d) oval projections.

Figure 1.24 illustrates the general classes of map projections and the perspectives from which they are generated. The classes shown include the cylindrical, planar (or azimuthal), and conic. Another class of projections, which cannot be derived from this physical-perspective approach, is the nonperspective oval shape. Still other projections derive from purely mathematical calculations.

With projections, the contact line or contact point between the wire globe and the projection surface—a *standard line* or *standard point*—is the only place where all globe properties are preserved. Thus, a *standard parallel* or *standard meridian* is a standard line true to scale along its entire length

without any distortion. Areas away from this critical tangent line or point become increasingly distorted. Consequently, this line or point of accurate spatial properties should be centered by the cartographer on the area of interest.

The commonly used **Mercator projection** (from Gerardus Mercator, A.D. 1569) is a cylindrical projection (Figure 1.24a). The Mercator is a true-shape projection, with meridians appearing as equally spaced straight lines and parallels appearing as straight lines that are spaced closer together near the equator. The poles are infinitely stretched, with the 84th N parallel and 84th S parallel fixed at the same length as that of the equator. Note in

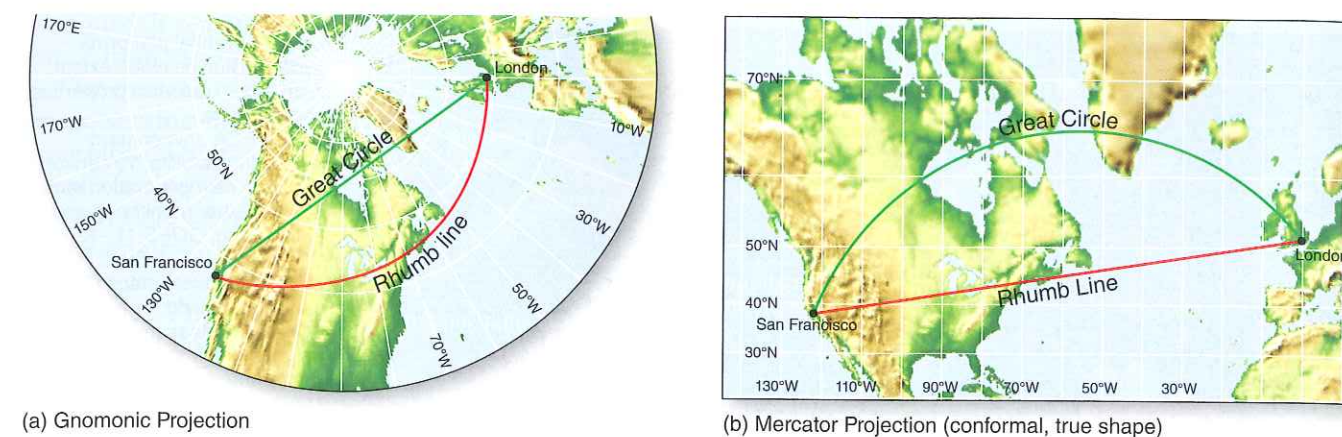


FIGURE 1.25 Determining great circle routes.

A gnomonic projection (a) is used to determine the shortest distance—great circle route—between San Francisco and London because on this projection the arc of a great circle is a straight line. This great circle route is then plotted on a Mercator projection (b), which has true compass direction. Note that straight lines or bearings on a Mercator projection—rhumb lines—are not the shortest route.

Figures 1.23 and 1.24a that the Mercator projection is cut around the 80th parallel in each hemisphere because of the severe distortion at higher latitudes.

Unfortunately, Mercator classroom maps present false notions of the size (area) of midlatitude and poleward landmasses. A dramatic example on the Mercator projection is Greenland, which looks bigger than all of South America. In reality, Greenland is an island only one-eighth the size of South America and is actually 20% smaller than Argentina alone.

The advantage of the Mercator projection is that a line of constant direction, known as a **rhumb line**, or *loxodrome*, is straight and therefore facilitates plotting directions between two points (Figure 1.25b). Thus, the Mercator projection is useful in navigation and is standard for nautical charts prepared by the National Ocean Service.

The *gnomonic*, or *planar*, projection in Figure 1.24b is generated by projecting a light source at the center of a globe onto a plane that is tangent to (touching) the globe's surface. The resulting severe distortion prevents showing a full hemisphere on one projection. However, a valuable feature is derived: All great circle routes, which are the shortest distance between two points on Earth's surface, are projected as straight lines (Figure 1.25a). The great circle routes plotted on a gnomonic projection then can be transferred to a true-direction projection, such as the Mercator, for determination of precise compass headings (Figure 1.25b).

For more information on maps used in this text and standard map symbols, turn to Appendix A, "Maps in

This Text and Topographic Maps." Topographic maps are essential tools of landscape analysis. Geographers, other scientists, travelers, and anyone visiting the outdoors may use topographic maps. Perhaps you have used a "topo" map in planning a hike. U.S. Geological Survey (USGS) topographic maps appear in several chapters of this text.

Remote Sensing and GIS

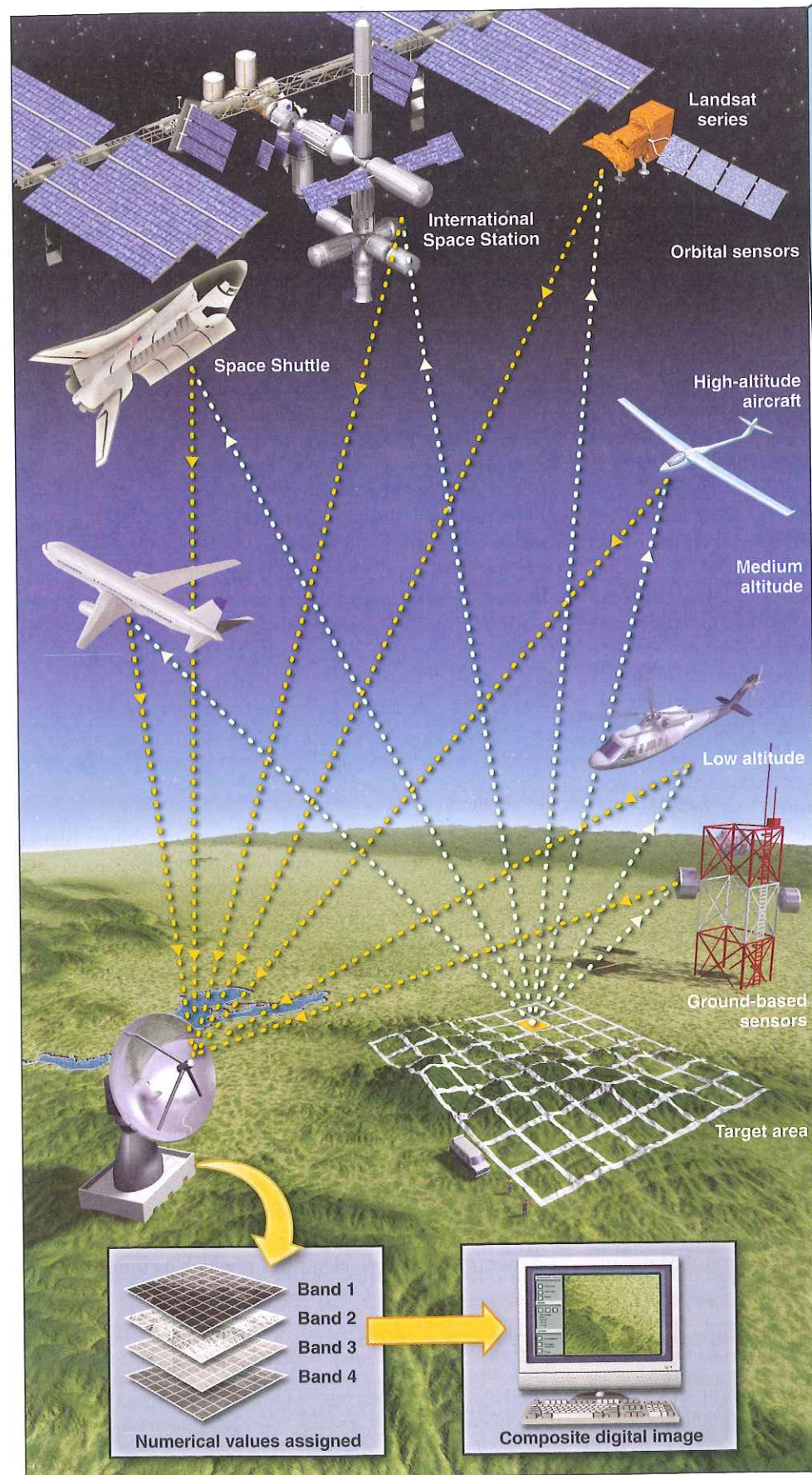
Geographers probe, analyze, and map our home planet through remote sensing and geographic information systems (GIS). These technologies enhance our understanding of Earth. Geographers use remote-sensing data to study all the subjects in this text and the human activities that produce global change and impact Earth systems.

Remote Sensing

In this era of observations from orbit outside the atmosphere, from aircraft within it, and from remote submersibles in the oceans, scientists obtain a wide array of remotely sensed data (Figure 1.26). Remote sensing is nothing new to humans; we do it with our eyes as we scan the environment, sensing the shape, size, and color of objects from a distance, registering energy from the visible-wavelength portion of the electromagnetic spectrum. Similarly, when a camera views the wavelengths for which its film or sensor

GEO REPORT 1.6 Mapping anniversary for the USGS

December 2009 marked the 125th anniversary since Congress authorized the USGS to systematically map the country. The USGS National Mapping Program is complete for the lower 48 states, numbering 53,838 separate 7.5-minute quadrangles. *The National Map* (available at <http://nationalmap.gov/>), a collaborative effort by USGS and federal, state, and local agencies, provides downloadable digital topographic data for the entire United States. These data include aerial photographs, elevation, roads, geographic names, and land cover. The National Map is an important tool for scientists, teachers, students, and the public to access geographic information.



A sample of orbital platforms:

CloudSat: Studies cloud extent, distribution, radiative properties, and structure.

ENVISAT: ESA environment-monitoring satellite; 10 sensors, including next generation radar.

GOES: Weather monitoring and forecasting; GOES-11, -12, -13, and -14.

GRACE: Accurately maps Earth's gravitational field.

JASON-1, -2: Measures sea-level heights.

Landsat: Landsat-1 in 1972 to Landsat-7 in 1999, provides millions of images for Earth systems science and global change.

NOAA: First in 1978 through NOAA-15, -16, -17, -18, and -19 now in operation, global data gathering, short- and long-term weather forecasts.

RADARSAT-1, -2: Synthetic Aperture Radar in near-polar orbit, operated by Canadian Space Agency.

SciSat-1: Analyzes trace gases, thin clouds, atmospheric aerosols with Arctic focus.

SeaStar: Carries the SeaWiFS (Sea-viewing Wide Field-of-View instrument) to observe Earth's oceans and microscopic marine plants.

Terra and Aqua: Environmental change, error-free surface images, cloud properties, through five instrument packages.

TOMS-EP: Total Ozone Mapping Spectrometer, monitoring stratospheric ozone, similar instruments on NIMBUS-7 and Meteor-3.

TOPEX-POSEIDON: Measures sea-level heights.

TRMM: Tropical Rainfall Measuring Mission, includes lightning detection and global energy budget measurements.

For more info see:
<http://www.nasa.gov/centers/goddard/missions/index.html>

FIGURE 1.26 Remote-sensing technology. Remote-sensing technology measures and monitors Earth's systems from orbiting spacecraft, aircraft in the atmosphere, and ground-based sensors. Various wavelengths (bands) are collected from sensors. Computers process the data to produce digital images for analysis. A sample of remote-sensing platforms is listed along the side of the illustration. The Space Shuttle is shown in its inverted orbital flight mode. (Illustration is not to scale.)

is designed, it remotely senses energy that is reflected or emitted from a scene.

Our eyes and cameras are familiar means of obtaining remote-sensing information about a distant subject without having physical contact. Cartographers have used aerial photographs for years to improve the accuracy of surface maps faster and more cheaply than can be done by on-site surveys. Remote sensors on satellites, the International Space Station, and other craft sense a broader range of wavelengths than can our eyes. They can be designed to "see" wavelengths shorter than visible light (ultraviolet) and wavelengths longer than visible light (infrared and microwave radar).

Following launch, satellites can be set in several types of orbits: geostationary, polar, and Sun-synchronous, illustrated in Figure 1.27. In a geostationary (geosynchronous) orbit, typically at an altitude of 35,790 km (22,239 mi), satellites pace Earth's rotation speed and therefore remain "parked" above a specific location, usually the equator (Figure 1.27a). This "fixed" position means that satellite antennas on Earth can be pointed permanently at one position in the sky where the satellite is located; the GOES weather satellite is an example.

Figure 1.27b shows a polar-orbiting satellite typically residing at an altitude between 200 km and 1000 km (124 mi and 621 mi) and passing over every portion of the globe as Earth rotates beneath it, completing each orbit in 90 minutes. Such satellites are good for difficult regions such as the poles, for environmental studies, and for spy surveillance; examples include *Terra* and *Aqua*.

Figure 1.27c demonstrates a Sun-synchronous orbit, shifting its 600 km to 800 km (373 mi to 497 mi) altitude, near-polar track, about 1° per day (365 days in a year, 360° in a circle), providing a surface below in constant sunlight for visible-wavelength images or in constant darkness for longwave radiation images.

Satellites do not take conventional-film photographs. Rather, they record images that are transmitted to Earth-based receivers in a way similar to television satellite trans-

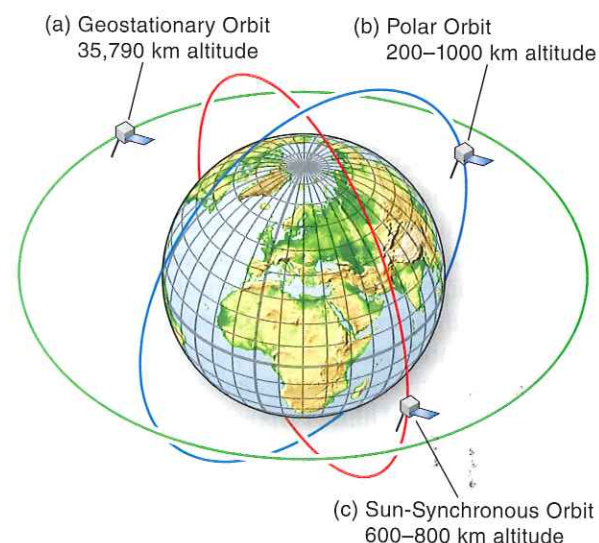


FIGURE 1.27 Three satellite orbital paths.

missions or a digital camera. A scene is scanned and broken down into pixels (*picture elements*), each identified by coordinates named *lines* (horizontal rows) and *samples* (vertical columns). For example, a grid of 6000 lines and 7000 samples forms 42,000,000 pixels, providing great detail. The large amount of data needed to produce a single image requires computer processing and data storage at ground stations.

Digital data are processed in many ways to enhance their utility: simulated natural color, "false" color to highlight a particular feature, enhanced contrast, signal filtering, and different levels of sampling and resolution. Active and passive are two types of remote-sensing systems.

Active Remote Sensing Active systems direct a beam of energy at a surface and analyze the energy reflected back. An example is *radar* (*radio detection and ranging*). A radar transmitter emits short bursts of energy that have relatively long wavelengths (0.3 cm to 10 cm) toward the subject terrain, penetrating clouds and darkness. Energy reflected back to a radar receiver for analysis is known as *backscatter*. Several important radar satellites are in orbit at this time, such as *QuikSAT*, *RADARSAT-1* and -2, and *SCISAT-1*.

A synthetic aperture radar system aboard an aircraft imaged the San Andreas fault near San Mateo, California (Figure 1.28). The Jet Propulsion Laboratory (JPL), part of the National Aeronautics and Space Administration (NASA), developed systems to repeatedly capture detailed, three-dimensional images along this fault system to track

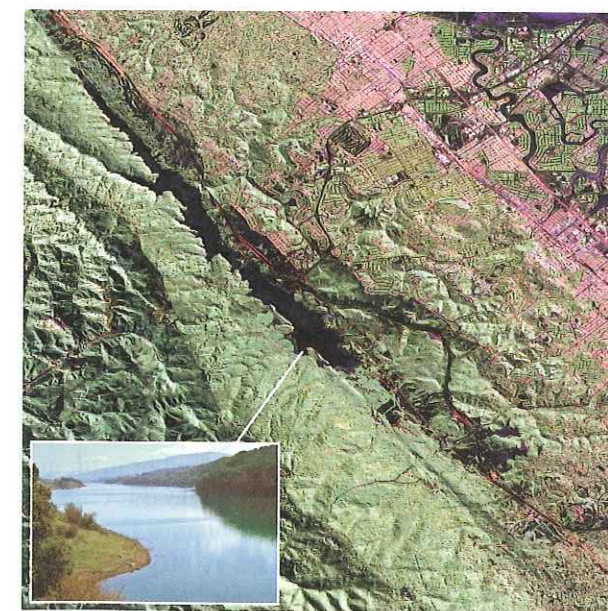


FIGURE 1.28 Radar image of active earthquake fault. Synthetic aperture radar image made from an aircraft repeatedly over time allows study of stress-accumulating portions of the fault. Discussion of this fault is in Chapter 9. Can you see the fault rift area running from southeast to northwest in this 2009 false-color image, in the area filled with a reservoir? [UACSAR image by JPL/NASA; photo by Author.]

movement and areas that are building up energy for future earthquakes. Images collected in a time series allow scientists to make pixel by pixel comparisons in computers to detect even the slightest horizontal or vertical movement between images. This type of information identifies accumulating strain along the faults.

Passive Remote Sensing Passive remote-sensing systems record energy radiated from a surface, particularly visible light and infrared. Our own eyes are passive remote sensors, as was the *Apollo 17* astronaut camera that made the photograph (film) of Earth on the back cover of this book.

Passive remote sensors on *Landsat* satellites provide a variety of data, as shown in images of New Orleans before and after Katrina in Chapter 11, and the Mississippi River in Chapter 11. Two *Landsats* remain operational, *Landsat-5* and -7. See <http://landsat.gsfc.nasa.gov/> for more information and additional links.

A number of satellites carry passive remote sensors for weather forecasting. The *Geostationary Operational Environmental Satellites*, known as *GOES*, became operational in 1994 and provide the images you see on television weather reports. The *NOAA-15* through *NOAA-19* satellites complete nearly polar orbits 14 times a day and provide data for long-term weather prediction. These are in Sun-synchronous orbits and carry the *advanced very high resolution radiometer (AVHRR)*, which uses six sensors to detect different bands of radiation wavelengths. AVHRR images showing the effects of the Mount Pinatubo eruption on the global atmosphere are in Figure 4.1.

Key to NASA's Earth Observing System (EOS) is satellite *Terra*, which began beaming back data and images in 2000 (see <http://terra.nasa.gov/>), followed by another satellite in the series, *Aqua*. Five instrument packages observe Earth systems in detail. The image of Earth on the half-title page of this book includes a cloud snapshot from *GOES* added to *Terra* MODIS images.

GOES-11 is now above 135° W for western North America and eastern Pacific Ocean weather. *GOES-12* sits above 75° W longitude to monitor central and eastern North America and the western Atlantic. Think of these satellites as hovering over these meridians for continuous coverage, using visual wavelengths for daylight hours and infrared for nighttime views. For the future, *GOES-13* and *GOES-14* are parked in orbit and are ready when needed (Figure 1.29). See the Geostationary Satellite Server at <http://www.goes.noaa.gov/>. The *GOES* Project Science appears at <http://rsd.gsfc.nasa.gov/goes/>.

For a sampling of global remote-sensing coverage from a variety of satellite platforms, go to the USGS Global Visualization Viewer, select the satellite and click on the map for a location, and then watch (<http://glovis.usgs.gov/>). For more on active and passive remote-sensing platforms, see the section "Remote sensing status report" in this chapter on the *Mastering-Geography* web site.

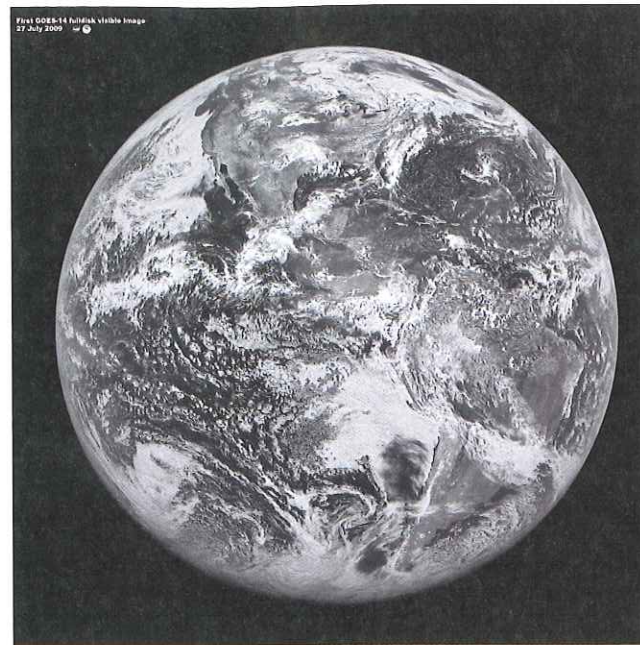


FIGURE 1.29 *GOES-14* first image. *GOES-14* made its first image July 27, 2009; the improved technology in this satellite produces 1-km (0.62-mi) resolution. Can you find the cloud-free southwestern United States? Thunderstorms along the Texas–Oklahoma border? Two tropical waves are visible in the eastern Pacific Ocean. [NASA.]

Geographic Information Systems

Techniques such as remote sensing acquire large volumes of spatial data that must be stored, processed, and retrieved in useful ways. A **geographic information system (GIS)** is a computer-based, data-processing tool for gathering, manipulating, and analyzing geographic information. Today's sophisticated computer systems allow the integration of geographic information from direct surveys (on-the-ground mapping) and remote sensing in complex ways never before possible.

Through a GIS, Earth and human phenomena are analyzed over time. This can include the study and forecasting of diseases such as H1N1 flu and West Nile virus, or the population displacement caused by Hurricane Katrina, or the destruction from the Haitian and Chilean earthquakes in 2010 and Japan in 2011, or interactive land-cover maps, to name a few examples (Figure 1.30b and c). Whereas printed maps are fixed at time of publication, GIS maps can be modified and evolve instantly.

The beginning component for any GIS is a map, with its associated coordinate system such as latitude–longitude. This establishes reference points against which to position data. The coordinate system is digitized, along with all areas, points, and lines. Increasingly, GPS units are now used to provide the basic mapping data needed for a GIS. Remotely sensed imagery and data are then added on the coordinate system. The resulting *digital elevation models (DEMs)* aid scientific analysis of topography, area–altitude distributions, slopes, and local stream-drainage characteristics, among many applications. The data then

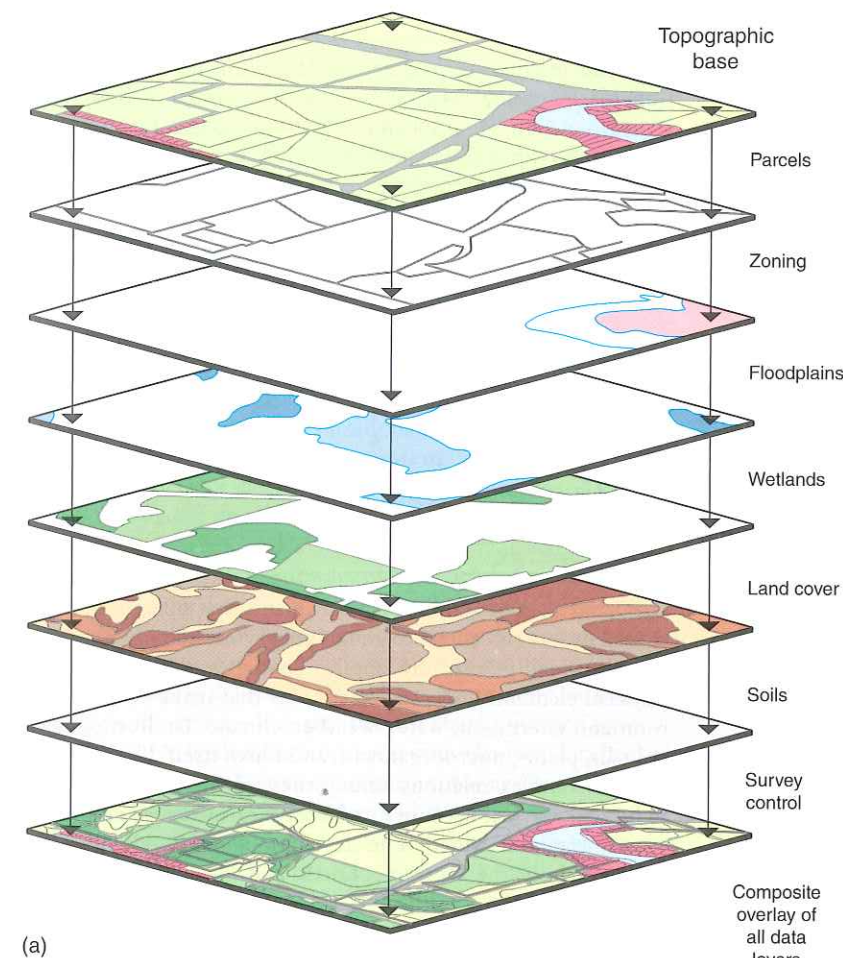


FIGURE 1.30 A geographic information system (GIS) model.

(a) Layered spatial data in a GIS format. (b) This comprehensive land-cover map is an important component of a statewide GIS analysis for Washington. The goal is to evaluate the protection of species and biodiversity. (c) A NASA GIS study uses satellite-derived temperature, humidity, and vegetation variables in a GIS overlay of environmental conditions for a probability map of the spread of West Nile virus. [(a) After USGS. (b) GIS map courtesy of Dr. Kelly M. Cassidy, *Gap Analysis of Washington State*, v. 5, Map 3, University of Washington. (c) NASA/GSFC.]

are available for computer manipulation, display, and GIS operations.

A GIS is capable of analyzing patterns and relationships within a single data plane, such as the floodplain or soil layer in Figure 1.30a. A GIS also can generate an overlay analysis where two or more data planes interact. When the layers are combined, the resulting synthesis—a *composite overlay*—is ready for use in analyzing complex problems. The utility of a GIS compared with that of a fixed map is the ability to manipulate the variables for analysis and to constantly change the map.

The applications of GIS are wide-ranging and cross many disciplines. Geographic Information Science (GISci) embodies the development, use, and application of GIS. An international conference series on GISci began in 2000 and continues biannually (see <http://gis-science.org/>). These conferences bring together leading scientists from academia, industry, and government to explore emerging research across the disciplines and to seek applications in

many fields. An important direction is toward more user-friendly GIS systems in the future.

Access to GIS is expanding with increased availability of numerous open-source GIS software packages. These are usually free, have on-line support systems, and are updated frequently (see <http://opensourcegis.org/>).

Programs for visualizing Earth, such as Google Earth™, provide three-dimensional viewing of the globe, as well as geographic information, in a program that can be downloaded from the Internet (<http://earth.google.com/>). Google Earth™ allows the user to "fly" anywhere on Earth and zoom in on landscapes and features of interest, using satellite imagery and aerial photography at varying resolutions. You can find where you live and your campus. Users can select layers, as in a GIS model, depending on the task at hand and the composite overlay displayed.

Career opportunities in GIS continue to increase. Regardless of your academic major, the ability to analyze data spatially is important. The annual ESRI (Environmental

Systems Research Institute) International Users Conference, whose attendance is approaching 15,000 people, continues to be the largest gathering of GIS professionals to share state-of-the-art applications of GIS technology (<http://www.esri.com/>).

GIS degree programs are available at many colleges and universities. GIS curriculum and certificate programs are now available at many community colleges. A consortium of three universities forms the National Center for Geographic Information and Analysis (NCGIA) for GIS education. These GIS centers are Department of Geography, University of California Santa Barbara, Santa Barbara; Department of Surveying and Engineering, University of Maine, Orono; and State University of New York–Buffalo, Buffalo. (See <http://www.ncgia.ucsb.edu/>.)

KEY LEARNING CONCEPTS REVIEW

To assist you, here is a review in handy summary form of the Key Learning Concepts listed on this chapter's title page. Each concept review concludes with a list of the key terms from the chapter, their page numbers, and review questions. Such summary and review sections follow each chapter in the book.

- **Define** geography and physical geography in particular.



Human–Earth Relationships

Human–environment connections include resource exploitation, hazard perception, and environmental pollution and modification. A *Terra* satellite image of the *Deepwater Horizon* oil spill in the Gulf of Mexico, highlighted by a sun glint on the gulf's surface. This human-caused spill is the largest offshore drilling disaster in history.

Geography brings together disciplines from the physical and life sciences with the cultural and human sciences to attain a holistic view of Earth—physical geography is an essential aspect of the emerging **Earth systems sciences**. **Geography** is a science of method, a special way of analyzing phenomena over space; **spatial** refers to the nature and character of physical space. Geography integrates a wide range of subject matter, and geographic education recognizes five major themes: **location**, **region**, **human–Earth relationships**, **movement**, and **place**. Geography's method is **spatial analysis**, used to study the interdependence among geographic areas, natural systems, society, and cultural activities over space or area. **Process**—that is,

GEOSYSTEMS CONNECTION

With the essentials of geography and the *Elemental Geosystems* approach, we now leave on a journey through the chapters in each of Earth's four spheres—Part I Atmosphere; Part II Hydrosphere; Part III Lithosphere; and Part IV Biosphere. Chapter 2 begins at the Sun, including its place in the Universe, and energy flow to Earth. We follow solar energy through the atmosphere to the surface and examine global temperature patterns and the circulation of air and water in Earth's vast wind and ocean currents.

At the end of each chapter, you find a *Geosystems Connection* to act as a bridge from one chapter to the next, helping you to cross to the next topic.

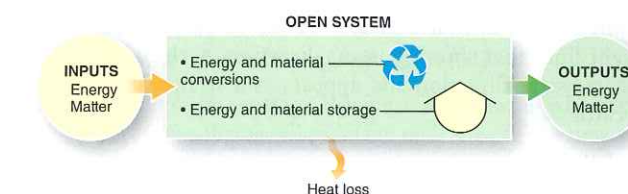
analyzing a set of actions or mechanisms that operate in some special order—is central to geographic synthesis.

Physical geography applies spatial analysis to all the physical elements and process systems that make up the environment: energy, air, water, weather, climate, landforms, soils, animals, plants, microorganisms, and Earth itself. Understanding the complex relations among these elements is important to human survival because Earth's physical systems and human society are intertwined. The development of hypotheses and theories about the Universe, Earth, and life involves the **scientific method**.

Earth systems science (p. 3)
geography (p. 3)
spatial (p. 3)
location (p. 3)
region (p. 3)
human–Earth relationships (p. 3)
movement (p. 3)
place (p. 3)
spatial analysis (p. 3)
process (p. 3)
physical geography (p. 3)
scientific method (p. 3)

1. What is unique about the science of geography? On the basis of information in this chapter, define physical geography and review the geographic approach.
2. In general terms, how might a physical geographer analyze water pollution in the Great Lakes?
3. Assess your geographic literacy by examining atlases and maps. What types of maps have you used: Political? Physical? Topographic? Do you know what map projections they employed? Do you know the names and locations of the four oceans, seven continents, and most individual countries? Can you identify the new countries that have emerged since 1990?
4. Suggest a representative example for each of the five geographic themes and use that theme in a sentence, such as, atmospheric and oceanic circulation spreading radioactive contamination is an example of the movement theme.
5. Have you made decisions today that involve geographic concepts discussed within the five themes presented? Explain briefly.

- **Describe** systems analysis, open and closed systems, and feedback information, and **relate** these concepts to Earth systems.



A **system** is any ordered, related set of things and their attributes, as distinct from their surrounding environment. Systems analysis is an important organizational and analytical tool used by geographers. Earth is an **open system** in terms of energy, receiving energy from the Sun, but it is essentially a **closed system** in terms of matter and physical resources.

As a system operates, “information” is returned to various points in the system via pathways of **feedback loops**. If the feedback information discourages change in the system, it is **negative feedback**. Further production of such feedback opposes system changes. Such negative feedback causes self-regulation in a natural system, stabilizing the system. If feedback information encourages change in the system, it is **positive feedback**. Further production of positive feedback stimulates system changes. Unchecked positive feedback in a system can create a runaway (“snowballing”) condition. When the rates of inputs and outputs in the system are equal and the amounts of energy and matter in storage within the system are constant (or when they fluctuate around a stable average), the system is in **steady-state equilibrium**. A system that demonstrates a steady increase or decrease in system operations—a trend over time—is in **dynamic equilibrium**. A **threshold**, or tipping point, is the moment at which a system can no longer maintain its character, so it lurches to a new operational level, one that may not be compatible with previous conditions. Geographers often construct a simplified **model** of natural systems to better understand them.

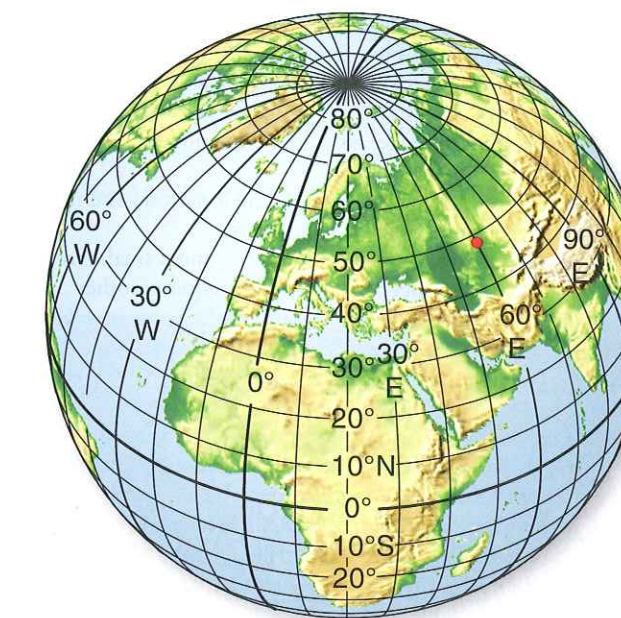
Four immense open systems powerfully interact at Earth's surface: three **abiotic**, or nonliving, systems—the **atmosphere**, **hydrosphere** (including the **cryosphere**), and **lithosphere**—and a **biotic**, or living, system—the **biosphere**, or **ecosphere**.

system (p. 3)
open system (p. 3)
closed system (p. 5)
feedback loop (p. 6)
negative feedback (p. 7)
positive feedback (p. 8)
steady-state equilibrium (p. 8)
dynamic equilibrium (p. 8)
threshold (p. 8)
model (p. 12)
abiotic (p. 12)
biotic (p. 12)
atmosphere (p. 13)
hydrosphere (p. 13)
cryosphere (p. 13)
lithosphere (p. 13)
biosphere (p. 13)
ecosphere (p. 13)

6. Define systems theory as an organizational strategy. What are open systems, closed systems, and negative feedback?

- When is a system in a steady-state equilibrium condition? What type of system (open or closed) is the human body? A lake? A wheat plant?
7. Describe Earth as a system in terms of both energy and matter; use simple diagrams to illustrate your description.
 8. What are the three abiotic spheres that make up Earth's environment? Relate these to the biotic sphere: the biosphere.

- **Explain** Earth's reference grid: latitude and longitude and latitudinal geographic zones and time.



The science that studies Earth's shape and size is **geodesy**. Earth bulges slightly through the equator and is oblate (flattened) at the poles, producing a misshapen spheroid, a **geoid**. Absolute location on Earth is described with a specific reference grid of **parallels of latitude** (measuring distances north and south of the equator) and **meridians of longitude** (measuring distances east and west of a prime meridian). A historic breakthrough in navigation and timekeeping occurred with the establishment of an international **prime meridian** (0° through Greenwich, England) and the invention of precise chronometers that enabled accurate measurement of longitude. A **great circle** is any circle of Earth's circumference whose center coincides with the center of Earth. Great circle routes are the shortest distance between two points on Earth. **Small circles** are those whose centers do not coincide with Earth's center. Latitude, longitude, and elevation are accurately calibrated using a handheld **Global Positioning System (GPS)** instrument that reads radio signals from satellites.

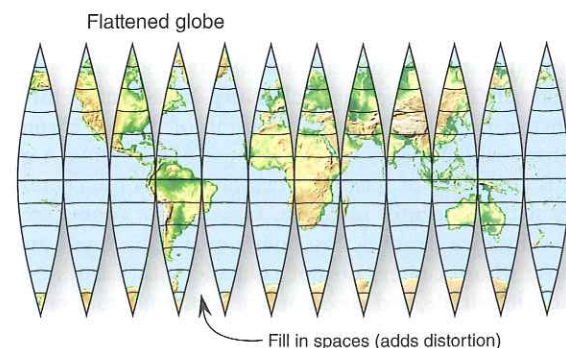
The prime meridian provided the basis for **Greenwich Mean Time (GMT)**, the world's first universal time system. A corollary of the prime meridian is the 180° meridian, the **International Date Line**, which marks the place where each day officially begins. Today, **Coordinated Universal Time (UTC)** is the worldwide standard and the basis for international time zones. **Daylight saving time** is a seasonal change of clocks by 1 hour in summer months.

geodesy (p. 13)
geoid (p. 13)

latitude (p. 15)
parallel (p. 15)
longitude (p. 16)
meridian (p. 16)
prime meridian (p. 16)
great circle (p. 18)
small circle (p. 18)
Global Positioning System (GPS) (p. 18)
Greenwich Mean Time (GMT) (p. 20)
International Date Line (p. 21)
Coordinated Universal Time (UTC) (p. 21)
daylight saving time (p. 21)

9. Draw a simple sketch describing Earth's shape and size.
10. How did Eratosthenes use Sun angles to figure out that the 5000-stadia distance between Alexandria and Syene was 1/50 of Earth's circumference? Once he knew this fraction of Earth's circumference, how did he calculate the entirety of Earth's circumference?
11. Define latitude and parallel and define longitude and meridian using a simple sketch with labels.
12. Define a great circle, great circle routes, and a small circle. In terms of these concepts, describe the equator, other parallels, and meridians.
13. Identify the various latitudinal geographic zones that roughly subdivide Earth's surface. In which zone do you live?
14. What does timekeeping have to do with longitude? Explain this relationship. How is Coordinated Universal Time (UTC) determined on Earth?
15. What and where is the prime meridian? How was the location originally selected? Describe the meridian that is opposite the prime meridian on Earth's surface.
16. What is GPS and how does it assist you in finding location and elevation on Earth? Give a couple of examples where GPS technology was utilized to correct heights for some famous mountains.

■ **Define** cartography and mapping basics: map scale and map projections.



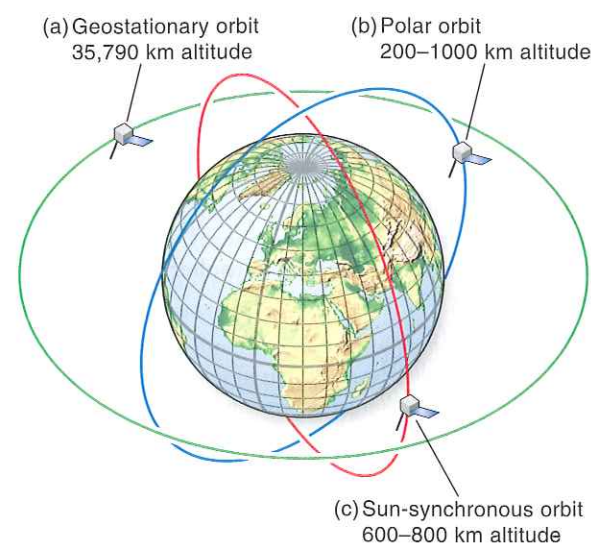
A **map** is a generalized view of an area, usually some portion of Earth's surface, as seen from above and greatly reduced in size. **Cartography** is the science and art of mapmaking. For the spatial portrayal of Earth's physical systems, geographers use maps. **Scale** is the ratio of the image on a map to the real world; it relates a unit on the map to an identical unit on the ground. Cartographers create a **map projection** for specific purposes, selecting the best compromise of projection for each

application. Compromise is always necessary because Earth's round, three-dimensional surface cannot be exactly duplicated on a flat, two-dimensional map. **Equal area** (equivalence), **true shape** (conformality), true direction, and true distance are all considerations in selecting a projection. The **Mercator projection** is in the cylindrical class; it has true-shape qualities and straight lines that show constant direction. A **rhumb line** denotes constant direction and appears as a straight line on the Mercator.

map (p. 21)
cartography (p. 22)
scale (p. 22)
map projection (p. 23)
equal area (p. 23)
true shape (p. 23)
Mercator projection (p. 24)
rhumb line (p. 25)

17. Define cartography. Explain why it is an integrative discipline.
18. What is map scale? In what three ways may it be expressed on a map?
19. State whether the following ratios are large scale, medium scale, or small scale: 1:3,168,000; 1:24,000; 1:250,000.
20. Describe the differences between the characteristics of a globe and those that result when a flat map is prepared.
21. What type of map projection is used in Figure 1.13? In Figure 1.20? (See Appendix A.)

■ **Describe** remote sensing and the geographic information system (GIS), and **explain** how both tools are used in geographic analysis.



Orbital and aerial **remote sensing** analyzes the operation of Earth's systems. Satellites do not take photographs, but record images that are transmitted to Earth-based receivers. Satellite images are recorded in digital form for later processing, enhancement, and generation.

The mountain of data collected is put to work using **geographic information system (GIS)** technology. Computers process geographic information from direct surveys and remote sensing in complex ways never before possible. GIS methodol-

ogy is an important step in better understanding Earth's systems and is a vital career opportunity for geographers.

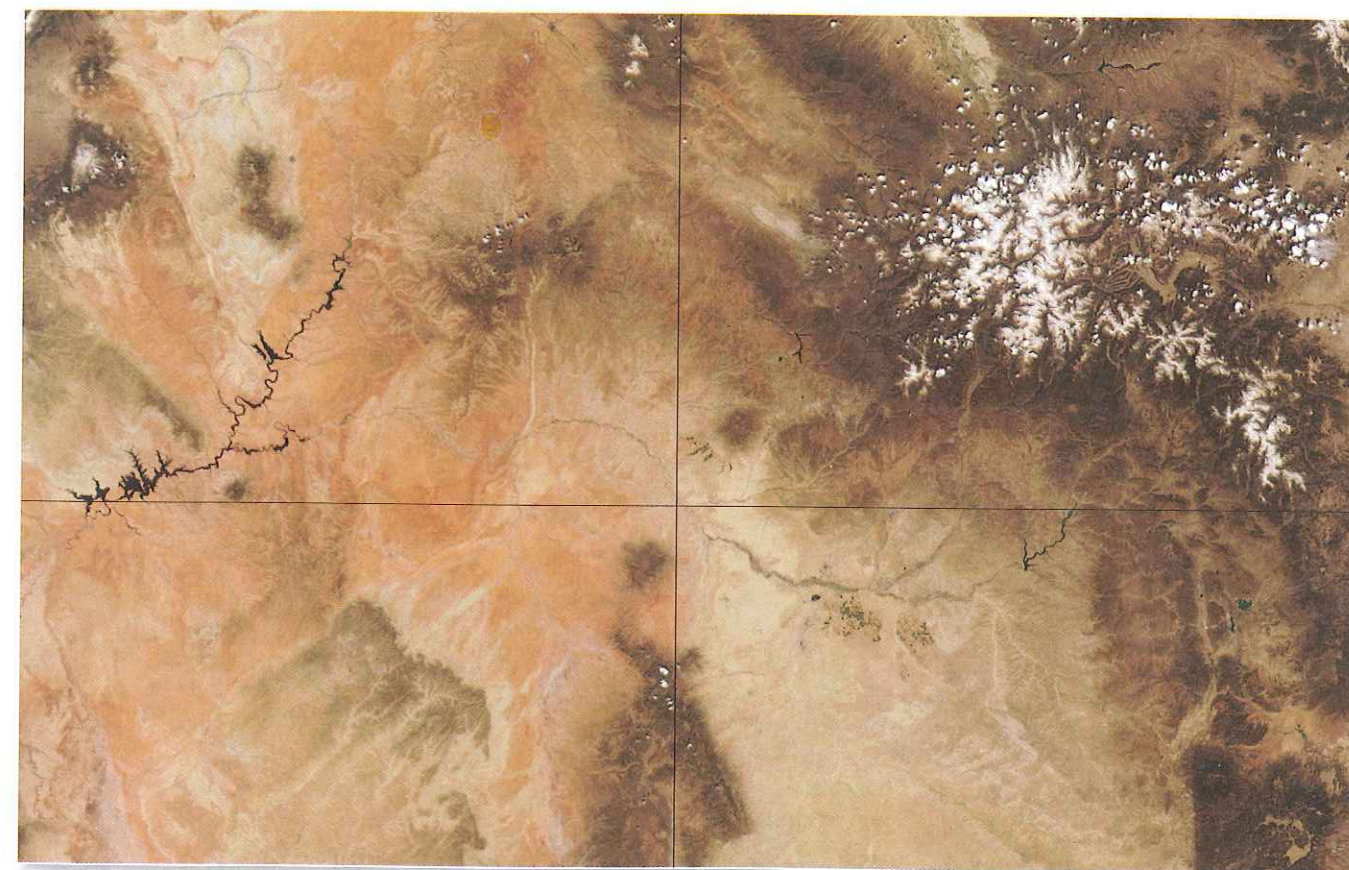
The science of physical geography is in a unique position to synthesize the spatial, environmental, and human aspects of our increasingly complex relationship with our home planet—Earth.

remote sensing (p. 27)
geographic information system (GIS) (p. 28)

22. What is remote sensing? What are you viewing when you observe a weather satellite image on TV or in the newspaper? Explain.

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Visit <http://www.masteringgeography.com/> for several figure animations, satellite loops, self-study quizzes, flashcards, visual glossary, case studies, career links, textbook reference maps, RSS Feeds, and an ebook version of *Elemental Geosystems*. Included are many geography web links to interesting Internet sources that support this chapter.

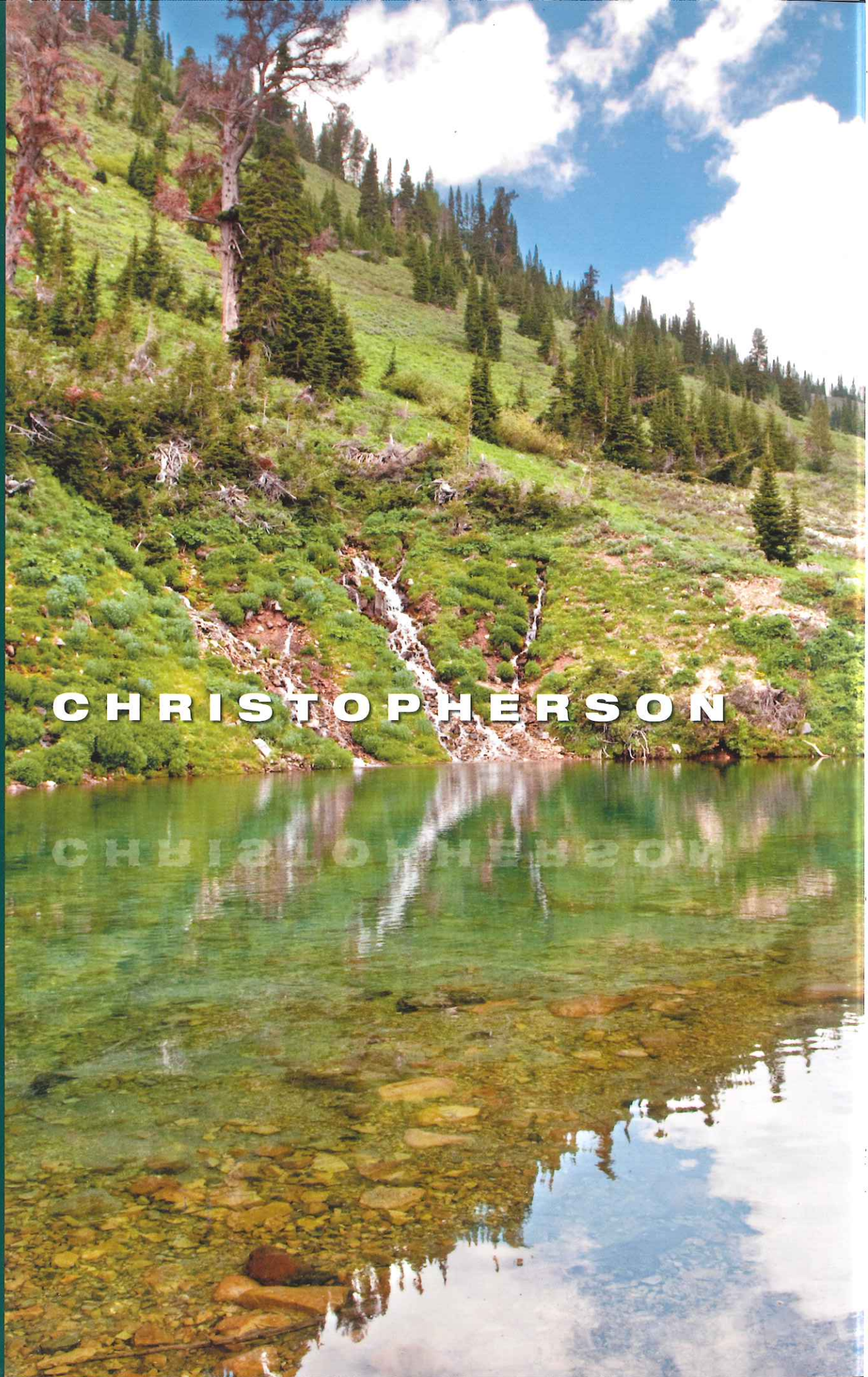


The Four Corners region featured in the *Geosystems Now* case study for this chapter, imaged by NASA's *Terra* Satellite. *Terra* is a polar-orbiting satellite that began service in 2000 and is managed by NASA at its Goddard Space Flight Center in partnership with the Jet Propulsion Laboratory. *Terra*'s MODIS sensor captures true-color images and is an important tool in monitoring and analyzing Earth's systems. The more than 5-ton craft orbits at an average altitude of 670 km (416 mi). Clockwise from the upper-left in the scene is Utah, then Colorado, New Mexico, and Arizona. Checking a map of the region can you identify some of the features? [NASA/GSFC.]

ELEMENTAL GEOSYSTEMS

SEVENTH
EDITION

CHRISTOPHERSON



ELEMENTAL GEOSYSTEMS

SEVENTH EDITION

ROBERT W. CHRISTOPHERSON

The diversity of organisms in the biosphere is a response to interactions of the atmosphere, hydrosphere, and lithosphere, all powered by solar energy. The scope of physical geography is reflected in the four-part structure of *Elemental Geosystems*.



PART I THE ENERGY-ATMOSPHERE SYSTEMS

Radiant energy from the Sun powers our lives. Earth's atmosphere acts as an efficient filter. Unevenness of daily energy receipt empowers atmospheric and surface energy budgets, giving rise to global patterns of temperature and circulation of wind and ocean currents.

◀ *Extratropical cyclones southeast of Iceland.*



PART II WATER, WEATHER, AND CLIMATE SYSTEMS

Earth is the water planet. We see the daily dynamics of the atmosphere—interaction of moisture and energy, of stability and instability, and cloud forms—as daily weather patterns, the hydrologic cycle, water resources, and climate. Scenes of an ice-free Arctic Ocean remind us of the importance of climate change science in physical geography.

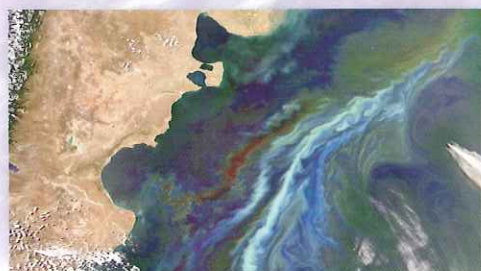
◀ *Irrigated lands along the Orange River, Namibia–South Africa border.*



PART III EARTH'S CHANGING LANDSCAPE SYSTEMS

Earth is a dynamic planet whose surface is shaped by two broad systems. The endogenic system of internal processes produces flows of heat and material to Earth's crust, which responds by moving, warping, and breaking. At the same time, the exogenic system of external processes (of air, water, and ice) carves, shapes, and reduces the landscape.

◀ *The Gulf of Oman at the Straits of Hormuz and the Persian Gulf.*



PART IV SOILS, ECOSYSTEMS, AND BIOMES

Earth is the home of the only known biosphere, a unique, complex, and interactive system of abiotic (nonliving) and biotic (living) components working to sustain a tremendous diversity of life. Today we face crucial issues, principally the preservation of the diversity of life. The resilience of the biosphere, as we know it, is being tested in a real-time, one-time experiment, as global climate systems shift.

◀ *Phytoplankton bloom in the Atlantic Ocean near Argentina.*



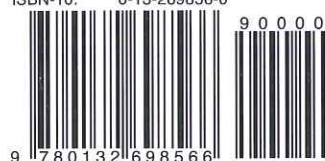
Planet Earth photographed from approximately 37,000 km (23,000 mi), December 1972.



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