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Essentials of Geography



The Vista House observatory, built in 1918 as a rest stop for travelers and a memorial to the Oregon pioneers, sits on a dramatic promontory overlooking the Columbia River Gorge. Rivers serve as corridors of movement and transportation, physical and political boundaries, sites for recreation, and sources of hydropower. The ongoing interaction of humans with their environment is one of the essential themes in geographic science, discussed in Chapter 1. [Erik Harrison/Shutterstock.]

KEY LEARNING CONCEPTS

After reading the chapter, you should be able to:

- **Define** geography in general and physical geography in particular.
- **Discuss** human activities and human population growth as they relate to geographic science and **summarize** the scientific process.
- **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** modern geoscience techniques—the Global Positioning System (GPS), remote sensing, and geographic information systems (GIS)—and **explain** how these tools are used in geographic analysis.



Shale Gas: An Energy Resource for the Future?

In an area stretching 965 km (600 mi) from Ohio to western New York, methane lies deeply buried in a sedimentary rock deposit, the Marcellus Shale. Methane is the primary constituent of natural gas, and scientists suggest that this ancient rock layer, underlying 60% of Pennsylvania, may be one of the most significant reservoirs of natural gas in the world. Pennsylvania alone is dotted with nearly 6000 shale gas wells extracting pressurized methane (**Figure GN 1.1**).

Sources of Methane Methane is a chemical compound with the formula CH_4 and is a by-product of several natural processes: digestive activity of animals (cattle, sheep, bison) and termites; burning associated with wildfires; melting of arctic permafrost; and bacterial activity in bogs, swamps, and wetlands. Nearly 60% of the methane in our atmosphere comes from human sources, including natural gas production, beef and dairy production, rice cultivation, coal and oil extraction and burning, landfills, and wastewater treatment. In the United States, the natural gas industry makes up the largest percentage of methane emissions.

Drilling for Methane To release methane trapped within shale layers, the rock must be broken up so that gas diffuses into the cracks and flows upward. Over the past 20 years, advances in horizontal drilling techniques, combined with the process of hydraulic fracturing, or “fracking,” opened access to large amounts of natural gas previously deemed too expensive or difficult

to tap. A typical shale gas well descends vertically 2.4 km (1.5 mi), turns, and then extends horizontally into the rock strata. Horizontal drilling exposes a greater area of the rock, allowing more of it to be broken up and more gas to be released (**Figure GN 1.2**).

A pressurized fluid is pumped into the well to break up the rock. This fluid is 90% water, 9% sand or glass beads that prop open the fissures, and 1% chemical additives that act as lubricants. The specific chemicals used are as yet undisclosed by the industry. This use of an injected fluid to fracture the shale is the process of fracking. Gas then flows up the well to be collected at the surface.

Fracking uses massive quantities of water: approximately 15 million L (4 million gal) for each well system, flowing at a rate of 16,000 L (4200 gal) per minute—far more than could be provided by a public water system. In some regions, such intensive water use for energy extraction may deplete natural water sources, affecting stream or lake ecosystems, or redirect water from other uses.

The U.S. Energy Information Administration (EIA) projects a boom in shale gas extraction and production from fracking over the next 20 years, with U.S. production rising from 34% of all natural gas production in 2011 to 50% in 2040.

Environmental Effects As with other resource-extraction techniques, fracking leaves hazardous by-products. It produces large amounts of toxic wastewater, often held in wells or containment ponds. Any leak or failure of pond retaining walls spills pollutants into surface water supplies and groundwater.

Methane gas may leak around well casings, which tend to crack during the fracking process. Leaks can cause buildup of methane in groundwater, leading to contaminated drinking water wells, flammable tap water, methane

accumulation in barns and homes, and possible explosions.

Methane adds to air pollution as a constituent in smog and is a potent greenhouse gas, absorbing heat from the Sun near Earth’s surface and contributing to global climate change. In addition, scientific evidence links the injection of fluid into wastewater wells to earthquake activity and ground instability in Oklahoma, Texas, Ohio, West Virginia, and parts of the Midwest.

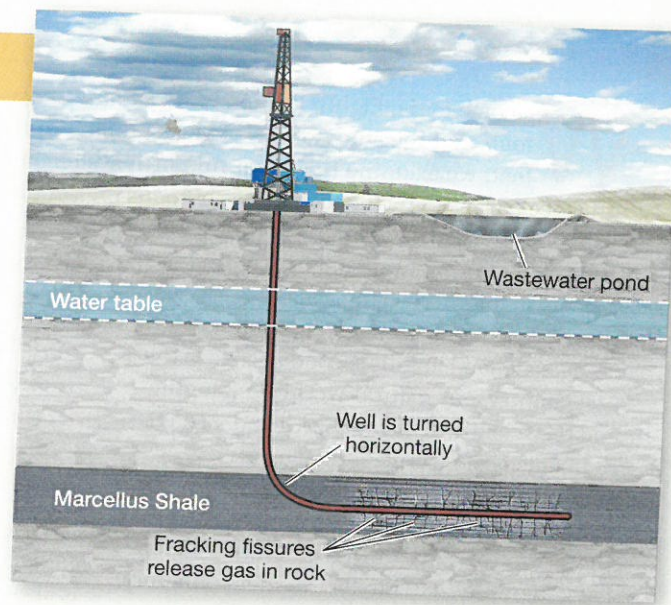
This rapidly expanding energy resource has varied impacts on air, water, land, and living Earth systems. However, many of the environmental effects of shale gas extraction remain unknown; further scientific study is critical.

Shale Gas and Elemental Geosystems

Resource location and distribution and human–environment interactions are important issues associated with shale gas extraction; these issues are also at the heart of geographic science. In this chapter, you work with several “Essentials of Geography”: spatial concepts, the scientific process, human–Earth connections, Earth systems thinking, and mapping. Throughout *Elemental Geosystems*, we expand the story of shale gas and its potential effects on global climate, surface water and groundwater resources, earthquake hazards, and ecosystem functions.

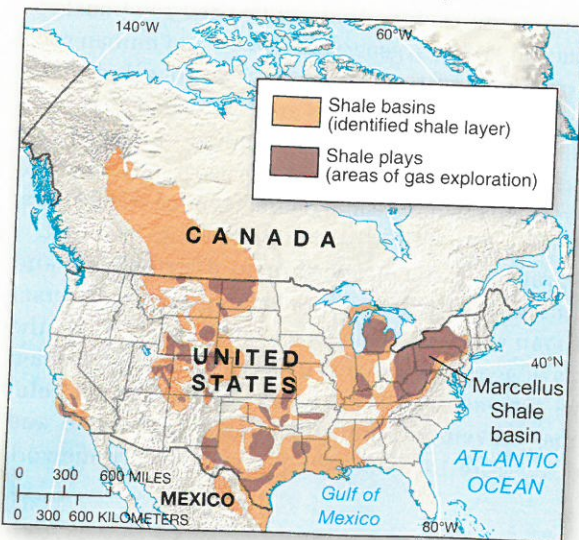
QUESTION AND EXPLORE To work with an interactive diagram called “Breaking Fuel from the Rock,” go to <http://ngm.nationalgeographic.com/2012/12/methane/lavelle-text>. For another perspective, go to <http://www.energyfromshale.org/shale-extraction-process>. Should the United States and other countries expand shale gas as an energy resource for the future?

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▲Figure GN 1.2 Horizontal drilling for hydraulic fracturing (fracking) and shale gas extraction.

▼Figure GN 1.1 Shale deposits and areas of exploration for natural gas extraction, United States and Canada. [U.S. Energy Information Administration.]



Welcome to the Eighth 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. Physical geography involves the study of Earth's environments, including the systems that form the landscapes, seascapes, atmosphere, and ecosystems on which humans depend. In this second decade of the 21st century, our natural world is changing, and the scientific study of Earth and its environments is more crucial than ever.

Consider as examples the following events and the questions they raise for the study of Earth's systems and physical geography. This text provides tools for answering these questions and addressing the underlying issues.

- In October 2012, Hurricane Sandy made landfall along the U.S. East Coast, hitting New York and New Jersey at high tide with hurricane-force winds and record storm surges. The storm cost 110 human lives and over \$42 billion in New York State alone, approaching \$100 billion in damages overall. What atmospheric processes explain the formation and movement of this storm? Why the unprecedented size and intensity? How does this storm relate to record air and ocean temperatures?
- In March 2011, a magnitude 9.0 earthquake and resultant 10- to 20-m (33- to 66-ft) tsunami devastated Honshu Island, Japan—at US\$309 billion, Earth's most expensive natural disaster so far. Why do earthquakes occur in particular locations across the globe? What produces tsunami, and how far and fast do they travel? How have prevailing winds and ocean currents dispersed tsunami debris across the Pacific?
- In 2014, the U.S. National Park Service finished the deconstruction of two dams on the Elwha River in Washington—the largest dam removals in the world to date. The project will restore a free-flowing river for fisheries and associated ecosystems. How do dams change river environments? Can rivers be restored after dam removal?
- In 2011, the world released 2.4 million pounds of carbon dioxide (CO₂) into the atmosphere every second, mainly from the burning of fossil fuels. This “greenhouse gas” contributes to climate change by trapping heat near Earth's surface. Each year atmospheric CO₂ levels rise to a new record, altering Earth's climate. What are the effects on Earth systems?

Physical geography uses a *spatial* perspective to examine processes and events happening at specific locations and follow their effects across the globe. Why does the environment vary from equator to midlatitudes and between tropical and polar regions? What produces the patterns of wind, weather, and ocean currents? How does solar energy influence the distribution of trees, soils, climates, and human populations? In this book, we explore those questions, and more, through geography's unique perspective.

Physical geography uses a spatial perspective to examine processes and events happening at specific locations and follow their effects across the globe.

Perhaps more than any other issue, climate change has become an overriding focus of the study of Earth systems. The past decade experienced the highest air temperatures over land and water in the instrumental record. In response, the extent of sea ice in the Arctic Ocean continues to decline to record lows. At the same time, melting of the Greenland and Antarctica Ice Sheets is accelerating; together, they now lose more than three times the ice they lost annually 20 years ago. As sea ice and ice sheets melt, sea level is rising. Elsewhere, intense weather events, drought, and flooding continue to increase. In presenting the state of the planet, *Elemental Geosystems* surveys climate change evidence and considers its implications. In every chapter, we present up-to-date science and information to help you understand our dynamic Earth systems. Welcome to an exploration of physical geography!

In this chapter: We begin with a look at the science of physical geography, which uses an integrative spatial approach, guided by the scientific process, to study Earth systems. The role of humans is an increasingly important focus of physical geography, as are questions of global sustainability as Earth's population grows.

Physical geographers study the environment by analyzing air, water, land, and living systems. Therefore, we discuss systems and the feedback mechanisms that influence system operations. We then consider location on Earth as determined by the coordinated grid system of latitude and longitude, and the determination of world time zones. Next, we examine maps as critical tools that geographers use to display physical and cultural information. This chapter concludes with an overview of technologies that are adding exciting new dimensions to geographic science: the Global Positioning System, remote sensing from space, and geographic information systems.

The Science of Geography

Geographic science is concerned with much more than place names. **Geography** (from *geo*, “Earth,” and *graphein*, “to write”) is the science that studies the relationships among natural systems, geographic areas, and human society and culture, and the interdependence of all of these, *over space*. These last two words are key, for geography is a science that is in part defined by its method—a special way of analyzing phenomena over space. In geography, the term **spatial** refers to the nature and character of physical space, its measurement, and the distribution of things within it.

Geographic concepts pertain to distributions and movement across Earth and how these processes interact with human actions. Given this spatial perspective, the concerns of geographic science are traditionally divided into five themes: **location, region, human–Earth relationships, movement, and place**, each illustrated and defined in **Figure 1.1**. These themes provide a framework

Location

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



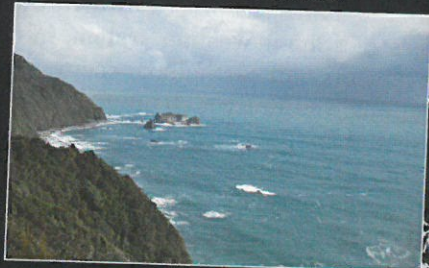
Place

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.



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

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



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 examples of each theme? This satellite image shows New Zealand's South Island. [Photos by Karl Birkeland, except Movement by Ian Dagnall/Alamy. Terra MODIS image, NASA/GSFC.]

for understanding geographic concepts and asking geographic questions. How does solar energy influence the distribution of climates, soils, and living organisms in particular places and across regions? How do natural systems affect human populations, and, in turn, what impact are humans having on natural systems?

Although geography is not limited to place names, maps and location are central to the discipline and are important tools for conveying geographic data. Evolving technologies such as geographic information systems and the Global Positioning System are widely used for scientific applications and in today's society as hundreds of millions of people access maps and locational information every day on computers and mobile devices.

In response to increasing globalization and environmental change, the geography education guidelines—updated by the National Council for Geographic Education (NCGE)—have now redefined the essential elements (or themes) of geography, expanding their number to six: *the spatial world, places and regions, physical systems, human systems, environment and society, and uses of geography in today's society*. These categories emphasize the spatial and environmental perspectives within the discipline and reflect the growing importance of human–environment interactions.

The Geographic Continuum

Because many subjects can be examined geographically, geography is an eclectic science that integrates subject matter from a wide range of disciplines. Even so, it splits broadly into two primary fields: *physical geography*, comprising specialty areas that draw largely on the physical and life sciences; and *human geography*, comprising specialty areas that draw largely on the social and cultural sciences (Figure 1.2). The growing complexity of the human–Earth relationship in the 21st century has shifted the study of geographic processes even farther toward the center of the continuum, resulting ultimately in a more balanced, more holistic perspective—such is the thrust of *Elemental Geosystems*.

Within physical geography, research now emphasizes human influences on natural systems in all specialty areas, effectively moving this end of the continuum closer to the middle. For example, physical geographers monitor air

pollution, examine the vulnerability of human populations to climate change, study impacts of human activities on forest health and the movement of invasive species, study changes in river systems caused by dams and dam removal, and examine the response of glacial ice to changing climate.

Geographic Analysis

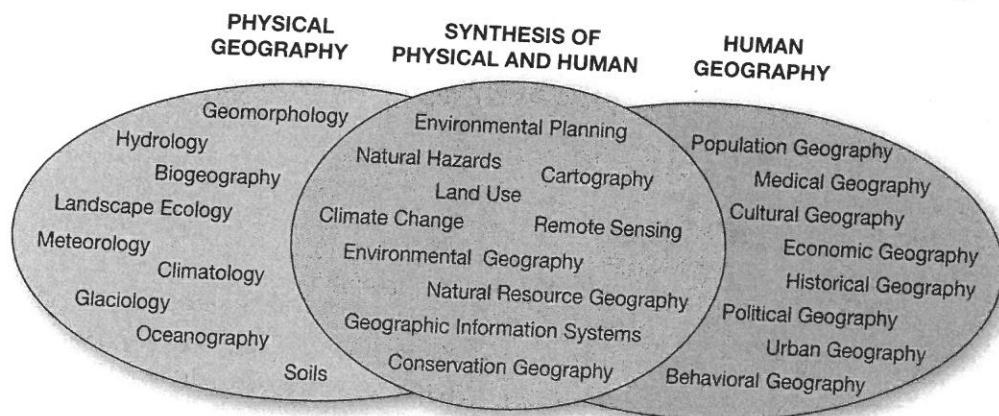
As mentioned earlier, the science of geography is unified more by its method than by a specific body of knowledge. The method is **spatial analysis**. Geographers view phenomena as occurring across spaces, areas, and locations. The language of geography—territory, zone, pattern, distribution, place, location, region, sphere, province, and distance—reflects this spatial view. Geographers analyze the differences and similarities between places.

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

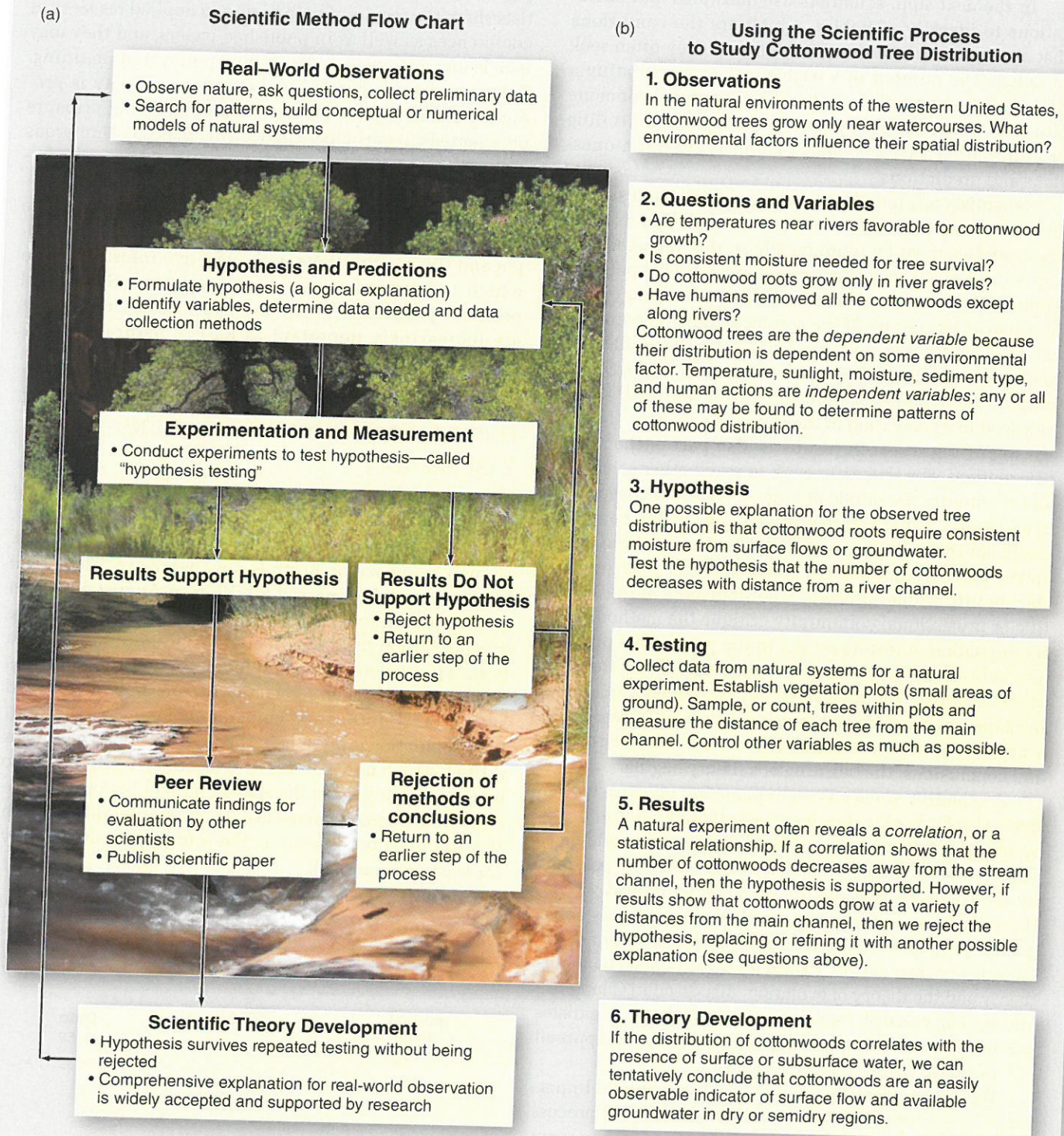
Therefore, **physical geography** is the spatial analysis of all the physical elements, processes, and systems that make up the environment: energy, air, water, weather, climate, landforms, soils, animals, plants, microorganisms, and Earth itself. Today, in addition to its place in the geographic continuum, physical geography encompasses the field of **Earth systems science**, the area of study that seeks to understand Earth as a complete entity, an interacting set of physical, chemical, and biological systems. With these definitions in mind, we now discuss the general process and methods used by scientists, including geographers.

The Scientific Process

The process of science consists of observing, questioning, testing, and understanding elements of the natural world. The **scientific method** is the traditional recipe of a scientific investigation; it can be thought of as simple, organized steps leading toward concrete, objective conclusions (Figure 1.3). There is no single, definitive method for scientific



◀Figure 1.2 The geographic continuum. Geography combines Earth topics and human topics, blending ideas from many different sciences. This book focuses on physical geography, but integrates pertinent human and cultural content for a whole-Earth perspective.



▲Figure 1.3 Scientific method flow chart and example application. [Ginger Birkeland.]

inquiry; scientists in different fields and even in different subfields of physical geography may approach their scientific testing in different ways. However, the end result must be a conclusion that is reproducible by other scientists, and that can be tested repeatedly and possibly shown as true or as false. Without this characteristic, it is not science.

Using the Scientific Method Scientists who study the physical environment begin with the clues they see in nature, followed by an exploration of the relevant published scientific literature on their topic. Brainstorming with others, continued observation, and preliminary data collection may occur at this stage.

In the next step, scientists use questions and observations to identify variables, which are the conditions that change in an experiment or model. They often seek to reduce the number of variables when formulating a *hypothesis*—a tentative explanation for the phenomena observed. Since natural systems are complex, controlling or eliminating variables helps simplify research questions and predictions.

Scientists test hypotheses using experimental studies in laboratories or natural settings. The methods used for these studies must be reproducible so that repeat testing can occur. Results may support or disprove the hypothesis, or predictions made according to the hypothesis may prove accurate or inaccurate. If the results disprove the hypothesis, the researcher will need to adjust data-collection methods or refine the hypothesis statement. If the results support the hypothesis, repeated testing and verification may lead to its elevation to the status of a *theory*.

Reporting research results is also part of the scientific method. For scientific work to reach other scientists and eventually the public at large, it should be described in a scientific paper and published in one of the many scientific journals. When a scientist submits a paper to a scientific journal, that journal sends it out for *peer review*. During this critical process, other members of the scientific or professional community critique the methods and interpretation of results set out in the paper. This process also helps detect any personal or political bias on the part of the scientist. The reviewers may recommend rejecting the paper or accepting and revising it for publication. Once a number of papers are published with similar results and conclusions, the building of a theory begins.

A scientific *theory* is an explanation constructed on the basis of several extensively tested hypotheses and can be reevaluated or expanded according to new evidence. Thus, a scientific theory is not absolute truth; the possibility always exists that the theory could be proved wrong. However, theories can be expanded to represent truly broad general principles—unifying concepts that tie together the laws that govern nature. Examples include plate tectonics theory and the theory of evolution, discussed in Chapters 9 and 16. The value of a scientific theory is that it stimulates continued observation, testing, understanding, and pursuit of knowledge within scientific fields.

While the scientific method is of fundamental importance in guiding scientific investigation, the real process of science is more dynamic and less linear, leaving room for questioning and thinking “out of the box.” Flexibility and creativity are essential to the scientific process, which may not always follow the same sequence of steps or use the same methods for each experiment or research project.

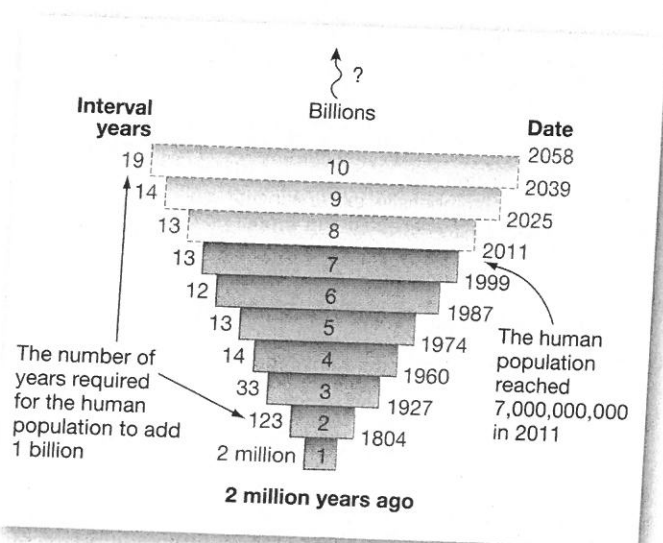
Applying Scientific Results Scientific studies described as “basic” are designed largely to help advance knowledge and build scientific theories. Other research is designed to produce “applied” results tied directly to real-world problem solving. Applied scientific research may advance new technologies, affect natural resource

policy, or directly impact management strategies. Scientists share the results of both basic and applied research at conferences as well as in published papers, and they may take leadership roles in developing policy and planning. For example, the 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 practical scientific involvement.

Science is objective by nature and 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 important as Earth's natural systems respond to the impacts of modern civilization.

Human–Earth Interactions in the 21st Century

Issues surrounding the growing influence of humans on Earth systems are central concerns of physical geography; we discuss them in every chapter of *Elemental Geosystems*. Human influence on Earth is now pervasive. The global human population passed 6 billion in August 1999 and continued to grow at the rate of 82 million per year, adding another billion by 2011, when the 7 billionth human was born. More people are alive today than at any previous moment in the planet's long history, unevenly distributed among 193 countries and numerous colonies. Virtually all new population growth is in the less-developed countries (LDCs), which now possess 81% (about 5.75 billion) of the total population. Over the span of human history, billion-mark milestones occurred at ever closer intervals through the sixth-billion milestone; the interval is now slightly increasing (**Figure 1.4**).



▲Figure 1.4 Human population growth. Note the population forecasts through 2058.

The Human Denominator We consider the totality of human impact on Earth to be the *human denominator*. Just as the denominator in a fraction tells how many parts a whole is divided into, so the growing human population and its increasing demand for resources and rising planetary impact suggest the stresses on the whole Earth system that must support us. Yet Earth's resource base—the numerator in this fraction—remains relatively fixed.

The population in just two countries makes up 37% of Earth's human count: 19.1% live in China and 17.9% in India—2.63 billion people combined. Considered overall, the planetary population is young, with some 26% still under the age of 15 years.*

Population in most of the more-developed countries (MDCs) is no longer increasing. In fact, some European countries are actually declining in growth or are near replacement levels. However, people in these developed countries have a greater impact on the planet per person and therefore constitute a population impact crisis. The United States and Canada, with about 5% of the world's population, produce about 25% (\$16.2 trillion and \$1.8 trillion in 2012, respectively) of the world's gross domestic product (GDP). These two countries use more than 2 times the energy per capita of Europeans, more than 7 times that of Latin Americans, 10 times that of Asians, and 20 times that of Africans. Therefore, the impact of this 5% on the state of Earth systems, natural resources, and sustainability of current practices in the MDCs is critical.

Global Sustainability Recently, **sustainability science** emerged as a new, integrative discipline, broadly based on concepts of sustainable development related to functioning Earth systems. Geographic concepts are fundamental to this new science, with its emphasis on human well-being, Earth systems, and human–environment interactions.

Dr. Carol Harden, past president of the Association of American Geographers, pointed out the important role of geographical concepts in sustainability science in 2009. She wrote that the idea of a human “footprint,” representing the human impact on Earth systems, relates to sustainability and geography. When the human population of over 7 billion is taken into account, the human footprint on Earth is enormous in terms of both its spatial extent and the strength of its influence. Shrinking this footprint ties to sustainability science in all of its forms—for

example, sustainable development, sustainable resources, sustainable energy, and sustainable agriculture. Geographers are now part of the effort to articulate this emerging field, which seeks to directly link science and technology with sustainability.

If we consider some of the key issues for this century, many of them fall beneath the umbrella of sustainability science, such as global food supply, energy supplies and demands, climate change, loss of biodiversity, and air and water pollution. These are issues that should be addressed in new ways if we are to achieve sustainability for both human and Earth systems. Understanding Earth's physical geography and geographic science informs your thinking on these issues.

Earth Systems Concepts

The word *system* is in our lives daily: “Check the car's cooling system”; “A weather system is approaching.” *Systems analysis* techniques in science began with studies of energy and temperature (thermodynamics) in the 19th century. Today, systems methodology is an important analytical tool. In this book's 4 parts and 17 chapters, the content is organized along logical flow paths consistent with systems thinking.

Systems Theory

Simply stated, a **system** is any set of ordered, interrelated components and their attributes, linked by flows of energy and matter, as distinct from the surrounding environment outside the system. The elements within a system

CRITICAL thinking 1.1

What Is Your Footprint?

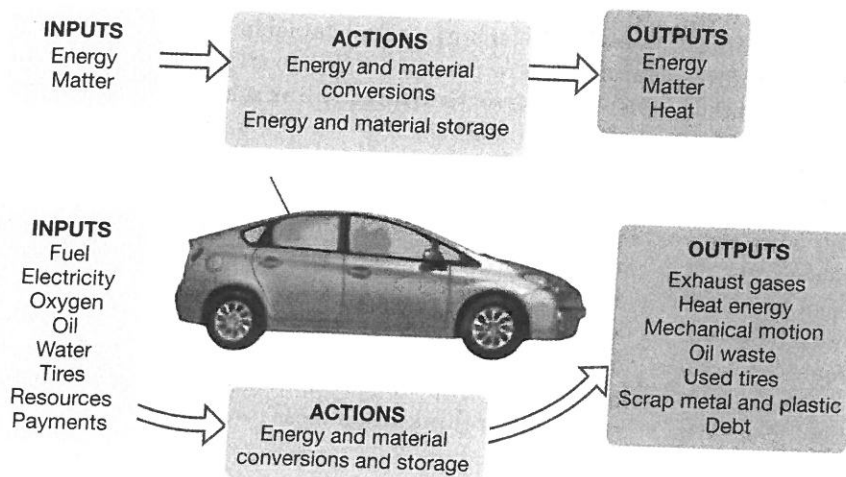
The concept of an individual's “footprint” has become popular—ecological footprint, carbon footprint, lifestyle footprint. The term has come to represent the costs of affluence and modern technology to our planetary systems. Footprint assessments are gross simplifications, but they can give you an idea of your impact and even an estimate of how many planets it would take to sustain that lifestyle and economy if everyone lived like you. Calculate your carbon footprint online at <http://www.epa.gov/climatechange/ghgemissions/ind-calculator.html>, one of many such websites, for housing, transportation, or food consumption. How can you reduce your footprint at home, at school, at work, or on the road? How does your footprint compare to the U.S. and worldwide average footprints?

*Data for 2013 from the Population Reference Bureau (<http://www.prb.org>) and the U.S. Census Bureau's *POPClock Projection* (<http://www.census.gov/popclock>).



GEoreport 1.1 Welcome to the Anthropocene

The human population on Earth reached 7 billion in 2011. Many scientists now agree that the *Anthropocene*, a term coined by Nobel Prize-winning scientist Paul Crutzen, is an appropriate name for the most recent years of geologic history, when humans have influenced Earth's climate and ecosystems. Some scientists mark the beginning of agriculture, about 5000 years ago, as the start of the Anthropocene; others place the start at the dawn of the Industrial Revolution, in the 18th century. To see a video charting the growth of humans as a planetary force, go to <http://www.anthropocene.info>.



▲ **Figure 1.5 An open system.** In an open system, inputs of energy and matter undergo conversions and are stored or released as the system operates. Outputs include energy, matter, and heat energy (waste). After considering how the various inputs and outputs listed here are related to the operation of the car, expand your thinking 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?

may be arranged in a series or intermingled. A system may comprise 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. (*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** (Figure 1.5). Within a system, the parts function in an interrelated manner, acting together in a way that gives each system its operational character. Earth is an open system in terms of energy because solar energy enters freely and heat energy leaves, going back into space.

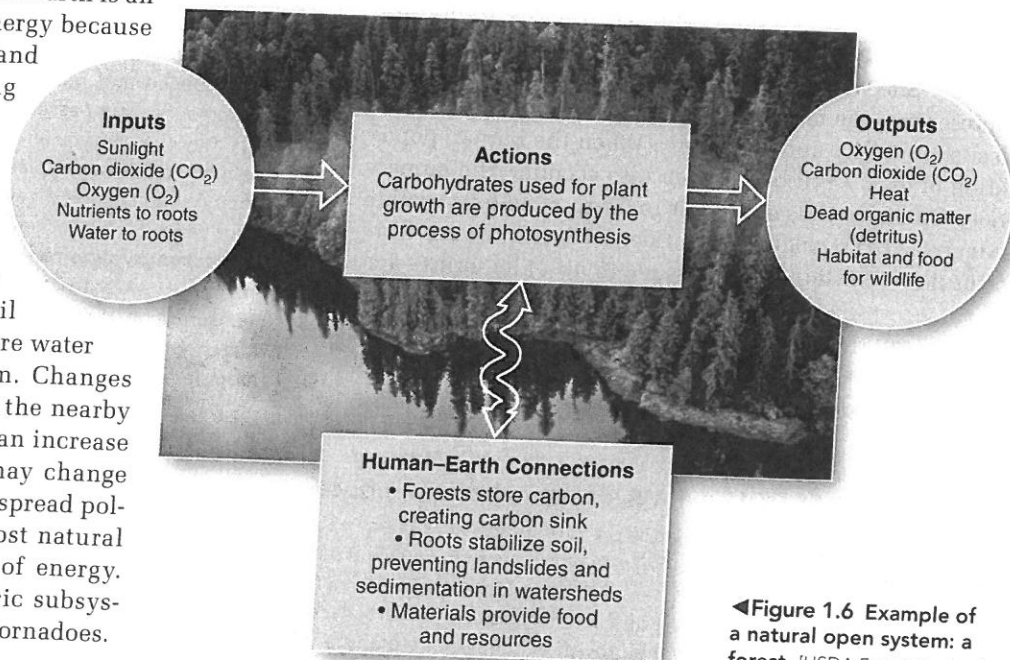
Within the Earth system, many subsystems are interconnected. Free-flowing rivers are open systems: Inputs consist of solar energy, precipitation, and soil and rock particles; outputs are water and sediments to the ocean. Changes to a river system may affect the nearby coastal system; for example, an increase in a river's sediment load may change the shape of a river mouth or spread pollutants along a coastline. Most natural systems are open in terms of energy. Examples of open atmospheric subsystems include hurricanes and tornadoes.

Earth systems are dynamic—active and energetic—because of the tremendous infusion of radiant energy from the Sun. As this energy passes through the outermost edge of Earth's atmosphere, it is transformed into various kinds of energy that power terrestrial systems, such as kinetic energy (of motion), potential energy (of position), and chemical or mechanical energy—setting the fluid atmosphere and ocean in motion. Eventually, Earth radiates this energy back to 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.

Natural System Example A forest is an example of an open system (Figure 1.6). Through the process of photosynthesis, trees and other plants use sunlight as an energy input and water, nutrients, and carbon dioxide as material inputs. The photosynthetic process converts these inputs to stored chemical energy in the form of plant



◀ **Figure 1.6 Example of a natural open system: a forest.** [USDA Forest Service.]

sugars (carbohydrates). The process also releases an output from the forest system: the oxygen that we breathe.

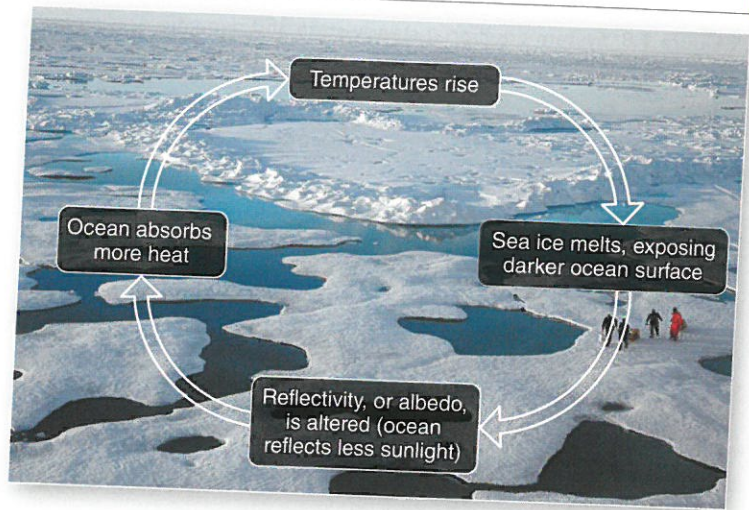
Forest outputs also include products and activities that link to other broad-scale Earth systems. For example, forests store carbon and are thus referred to as “carbon sinks.” A 2011 study found that forests absorb about one-third of the carbon dioxide released through the burning of fossil fuels, making them a critical part of the climate system as global carbon dioxide levels rise. Forest roots stabilize soil on hillslopes and stream banks, connecting them to land and water systems. Finally, the food and habitat resources provided by forests link them closely to other living systems, including humans. (Chapters 11, 16, and 17 discuss these processes and interactions.)

The connection of human activities to inputs, actions, and outputs of forest systems is indicated by the double-headed arrow in Figure 1.6. This interaction has two causal directions, since forest processes affect humans and humans influence forests. Forests affect humans through the outputs of carbon storage (which mitigates climate change), soil stabilization (which prevents erosion and sedimentation into source areas for drinking water), and food and resources. Human influences on forests include direct impacts such as logging for wood resources, burning to make way for agriculture, and clearing for development as well as indirect impacts from human-caused climate change, which may enhance the spread of disease and insects, and pollution, which affects tree health.

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 called **feedback loops**. Feedback information can guide, and sometimes control, further system operations.

If the feedback information discourages change in the system, it is **negative feedback**. Further production of such feedback opposes system changes and leads to stability. Such negative feedback causes self-regulation in a natural system. Negative feedback loops are common in nature. In a forest, for example, healthy trees produce roots that stabilize hillslopes and inhibit erosion, providing a negative feedback. If the forest is damaged or removed, perhaps by fire or logging practices, the hillslope may become unstable and subject to landslides or mudslides. This instability affects nearby systems as sediment is deposited into streams, along coastlines, or into developed areas.

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.



▲**Figure 1.7** The Arctic sea ice–albedo positive feedback loop. Average ice thickness in the Arctic summer has dropped dramatically, leaving thinner ice that melts more easily. Since 2000, 70% of the September ice volume has disappeared. If this rate of loss continues, the first ice-free Arctic September might happen before 2017. [NOAA.]

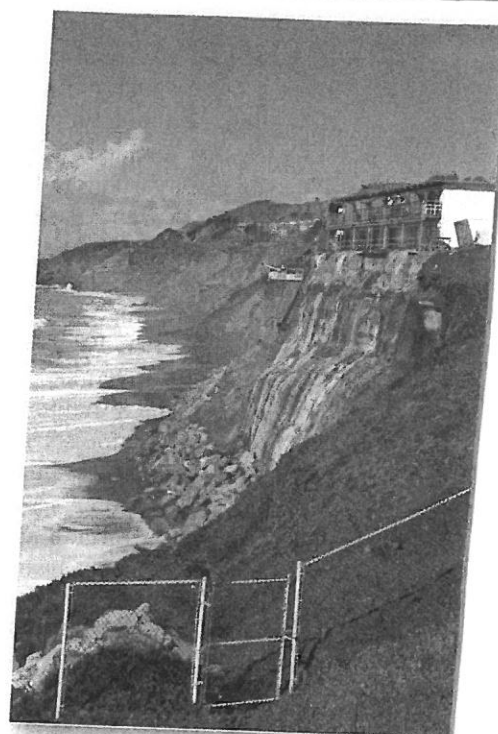
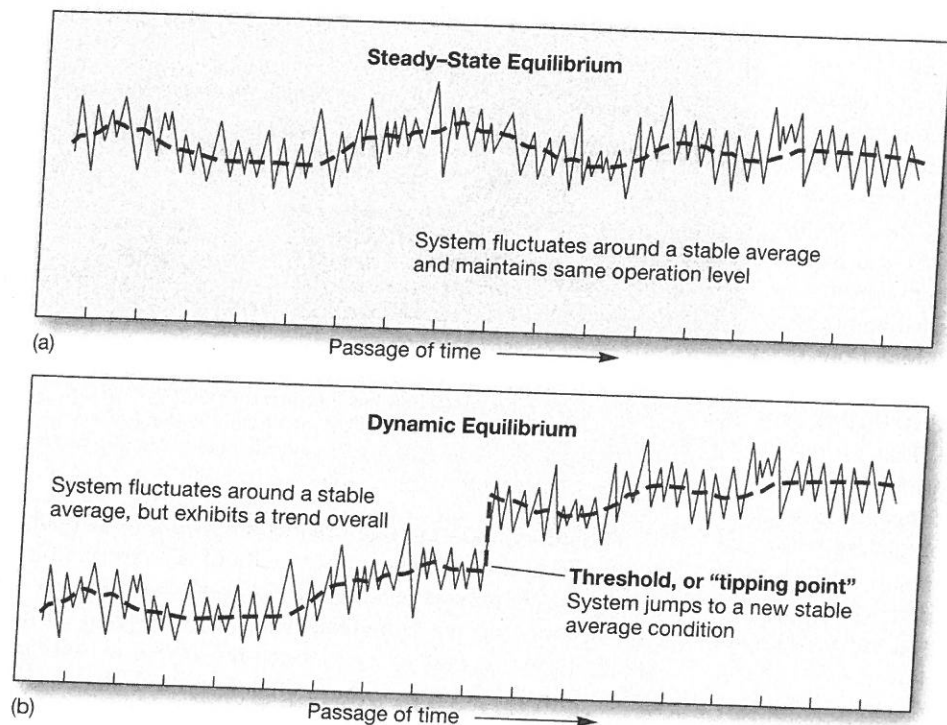
Global climate change creates an example of positive feedback as summer sea ice melts in the Arctic (discussed in Chapters 3, 8, and 14). As arctic temperatures rise, summer sea ice and glacial melting accelerate. This causes light-colored snow and sea-ice surfaces, which reflect sunlight and so remain cooler, to be replaced by darker-colored open ocean surfaces, which absorb sunlight and become warmer. As a result, the ocean absorbs more solar energy, which raises the temperature, which, in turn, melts more ice, and so forth (Figure 1.7). This is a positive feedback loop, further enhancing the effects of higher temperatures and warming trends.

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, fluctuate around a stable average), the system is in **steady-state equilibrium**. For example, river channels commonly adjust their form in response to inputs of water and sediment; these inputs may change in amount from year to year, but the channel form represents a stable average—a steady-state condition.

However, a steady-state system may demonstrate a changing trend over time, a condition described as **dynamic equilibrium**. These changing trends may appear gradually and are compensated for by the system. A river may tend toward channel widening as it adjusts to greater inputs of sediment over some time scale, but the overall system will adjust to this new condition and thus maintain a dynamic equilibrium. Figure 1.8 illustrates the steady-state and dynamic equilibrium conditions.

Note that systems in equilibrium tend to maintain their functional operations and resist abrupt change.

▼ **Figure 1.8 System equilibria: steady-state and dynamic.** The vertical axis represents the value of a typical systems variable, such as stream channel width or hillslope angle. [(c) Bobbé Christopherson.]



(c) Wave action and heavy rainfall caused slope instability along the Pacific Coast south of San Francisco in January 2010. When a threshold was reached, the bluffs collapsed, and the cliff face retreated inland some 30.5 m (100 ft).

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. A large flood in a river system may push the river channel to a threshold where it abruptly shifts, carving a new channel. Another 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. Plant and animal communities can reach thresholds. For example, harlequin frogs in tropical Central and South America are reaching a tipping point, with the extinctions of over 100 known species occurring between 1986 and 2006.

Models of Systems A **model** is a simplified, idealized representation of part of the real world. Scientists design models with varying degrees of specificity. A conceptual model is usually the most generalized and focuses on how processes interact within a system. A numerical model is more specific and is usually based on data collected from field or laboratory work. The simplicity of a model makes a system easier to understand and to simulate in experiments. A good example is a model of the *hydrologic system*, which represents Earth's entire water system; its related energy flows; and the atmosphere, surface, and subsurface environments through which water moves (see Figure 6.4 in Chapter 6). Predictions associated with climate change are often based on computer

models of atmospheric processes, discussed in Chapter 8. We discuss many system models in this text.

Adjusting the variables in a model simulates 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.

Systems Organization in Elemental Geosystems

From general layout to presentation of specific topics, *Elemental Geosystems* follows a systems flow. The part structure is designed around Earth systems pertaining to air, water, land, and living organisms. These are Earth's four "spheres" and represent the broadest level of organization within the book. Within each part, chapters and topics are arranged according to systems thinking, focusing on inputs, actions, and outputs, with an emphasis on human–Earth interactions and on interrelations among the parts and chapters. Specific subjects, such as the eruption of Mount Pinatubo in the Philippines discussed just ahead, recur in many chapters, illustrating systems connections. The illustration in Geosystems in Action 1, on the following pages, outlines the part structure and chapter content corresponding to Earth's four spheres.

Earth's Four "Spheres" Earth's surface is a vast area of 500 million km² (193 million mi²) where four immense open systems interact. The three **abiotic**, or nonliving, systems overlap as the framework for the realm of the **biotic**, or living, system. The abiotic spheres are the *atmosphere*, *hydrosphere*, and *lithosphere*. The biotic sphere is the *biosphere*. Together, these spheres form a simplified model of Earth 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 5–8)** 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 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 9–14)** 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 15–17)** 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 of the three 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, undergoes extinctions, and manages to flourish.

Within each part, the sequence of chapters generally follows a systems flow of energy and materials.

Each of the four part-opening page spreads summarizes the main system linkages; these diagrams are presented together in Geosystems in Action 1. As an example of our systems organization, Part I, "The Energy–Atmosphere System," begins with the Sun (Chapter 2). The Sun's energy flows across space to the top of the atmosphere and through the atmosphere to Earth's surface, where it is balanced by outgoing energy from Earth (Chapters 2 and 3). Then we look at system 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.

Mount Pinatubo—Global System Impact A dramatic example of interactions between Earth systems in response to a volcanic eruption illustrates the strength of the systems approach used throughout 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 (see photos in GIA 1). This was the second greatest eruption during the 20th century; Mount Katmai in Alaska in 1912 was the only one greater. The eruption materials from Mount Pinatubo affected Earth systems in several ways, as 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 six chapters: Chapter 1 (discussion of systems theory), Chapter 3 (effects on energy budgets in the atmosphere), Chapter 4 (satellite images of the spread of debris by atmospheric winds), Chapter 8 (temporary effect on global atmospheric temperatures), Chapter 10 (volcanic processes), and Chapter 16 (effects on net photosynthesis). These discussions help us see the linkages and global impacts of such a volcanic explosion.

Location and Time on Earth

Earth's *sphericity*, or roundness, was first determined more than two millennia ago by the Greek mathematician and philosopher Pythagoras (ca. 580–500 B.C.). The idea of a spherical rather than a flat Earth 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.

Until 1687, the spherical-perfection model was a basic assumption of **geodesy**, the science that determines

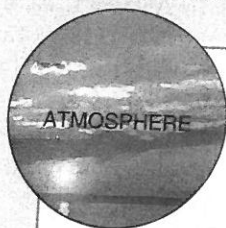
(text continues on page 14)



GEOREPORT 1.2 Earth's unique hydrosphere

The hydrosphere on Earth is unique among the planets in the Solar System: Only Earth possesses surface water in such quantity, some 1.36 billion km³ (0.33 billion mi³). Subsurface water exists on other planets and their satellites—on the Moon and on the planets Mercury and Mars, on Jupiter's moon Europa, and on Saturn's moons Enceladus and Titan. The Curiosity rover in 2012 landed in an area of Mars that billions of years ago was flooded with waist-deep water.

Earth's four "spheres"—the atmosphere, hydrosphere, lithosphere, and biosphere—are the open systems that form the part structure for *Elemental Geosystems*: The Energy–Atmosphere System; Water, Weather, and Climate Systems; The Earth–Atmosphere Interface; and Soils, Ecosystems, and Biomes. In each part, the chapter sequence generally follows the system inputs, actions, and outputs. Human–Earth connections are an integral part of all Earth systems and their interactions.

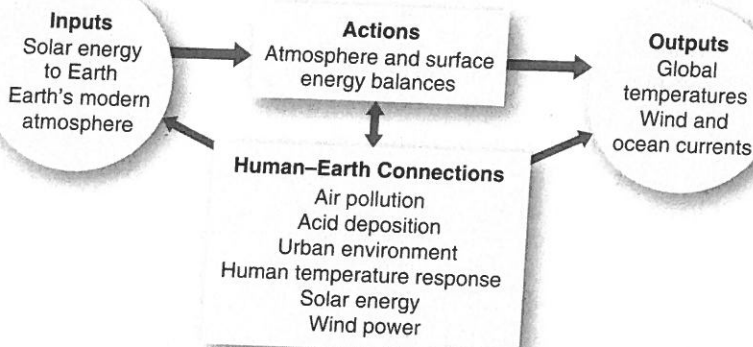


Part I The Energy-Atmosphere System

Incoming solar radiation provides the energy input that drives Earth's physical systems, determining weather and climate patterns and influencing living organisms.

Chapters 2–4

- 2 Solar Energy, Seasons, and the Atmosphere
- 3 Atmospheric Energy and Global Temperatures
- 4 Atmospheric and Oceanic Circulations

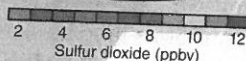


Throughout *Elemental Geosystems*, we discuss the linkages and global impacts of the Mount Pinatubo volcanic explosion. Begin in southeast Asia, and follow the effects counterclockwise around the map.

Aerosol cloud causes colorful twilight and dawn skies worldwide, and increases atmospheric reflectivity (albedo) by 1.5%.



A thin aerosol cloud affects 42% of globe (20° S to 30° N)



Effects on Earth systems:

Reduced sunlight at Earth's surface decreases average temperatures in the Northern Hemisphere by 0.5 C° (0.9 F°)

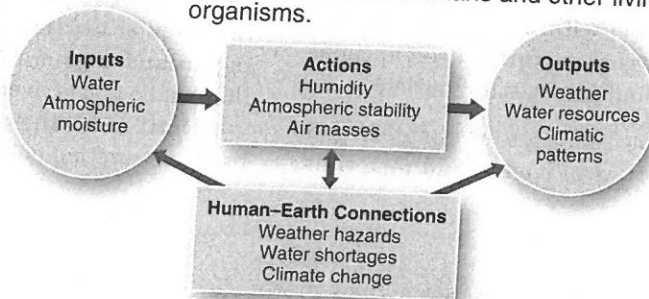


Part II Water, Weather, and Climate Systems

The distribution and circulation of water in Earth's atmosphere and hydrosphere are key influences on weather and determine the water available for humans and other living organisms.

Chapters 5–8

- 5 Atmospheric Water and Weather
- 6 Water Resources
- 7 Earth's Climatic Regions
- 8 Climate Change



Video
The Changing Face of Earth



<http://goo.gl/yevjleg>

MasteringGeography™

Visit the Study Area in MasteringGeography™ to explore Earth systems.

Visualize: Study geosciences animations of Earth's radiation balance, the hydrologic cycle, and the rock cycle.

Assess: Demonstrate understanding of Earth-system interactions (if assigned by instructor).



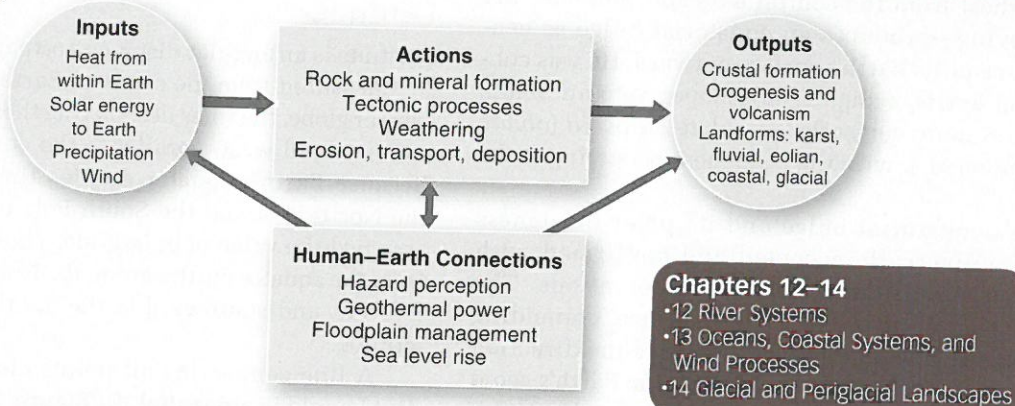
Part III The Earth-Atmosphere Interface

Mount Pinatubo before the eruption

Earth's surface is shaped by internal processes that build, warp, and break Earth's crust and by external processes that carve, shape, and wear down the landscape.

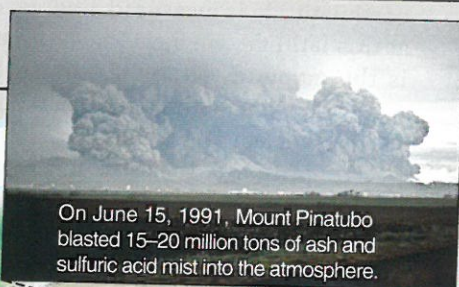
Chapters 9–11

- 9 The Dynamic Planet
- 10 Tectonics, Earthquakes, and Volcanism
- 11 Weathering, Karst Landscapes, and Mass Movement



Chapters 12–14

- 12 River Systems
- 13 Oceans, Coastal Systems, and Wind Processes
- 14 Glacial and Periglacial Landscapes



On June 15, 1991, Mount Pinatubo blasted 15–20 million tons of ash and sulfuric acid mist into the atmosphere.



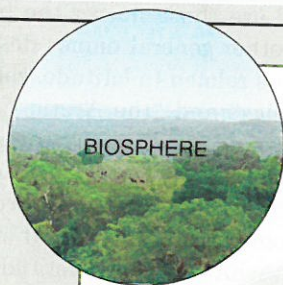
Mount Pinatubo, a year after the eruption with new lake in the caldera.

Winds spread the ash cloud westward

15° N 120° E

Effects on Earth systems:

Diffuse sunlight increases, causing a slight enhancement of photosynthesis and plant growth

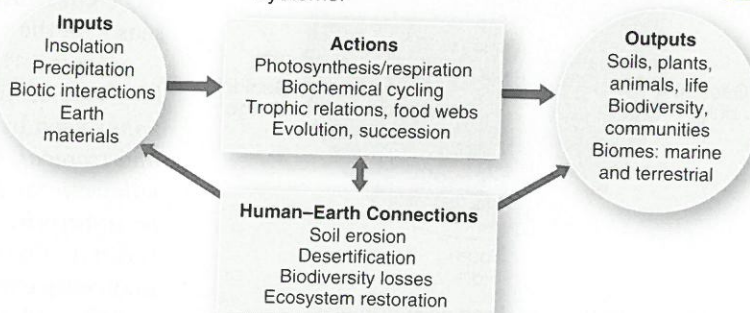


Part IV Soils, Ecosystems, and Biomes

Solar energy powers the biosphere through photosynthesis, in which plants and algae convert sunlight into food. Soil is the essential link between plants, the lithosphere, and the rest of Earth's physical systems.

Chapters 15–17

- 15 The Geography of Soils
 - 16 Ecosystem Essentials
 - 17 Terrestrial Biomes
- Human–Earth Interactions: All chapters



GEOquiz

1. Explain: Which spheres represent Earth's abiotic environment? How are these spheres distinct from one another?

2. Summarize: What were the overall effects of the Mount Pinatubo eruption on Earth's systems?

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 part of the planet farthest from the central axis and therefore the fastest moving—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 today universally accepted and confirmed with tremendous precision by satellite observations. The unique, irregular shape of Earth's surface, coinciding with mean sea level and perpendicular to the direction of gravity, is described as a **geoid**. Imagine Earth's geoid as a constant sea-level surface that extends 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 upon its surface, and the outward centrifugal pull caused by Earth's rotation. **Figure 1.9** gives Earth's polar and equatorial circumferences and diameters.

To determine location on our not-quite-spherical planet, we use a coordinated grid system that is internationally accepted. The terms *latitude* and *longitude* for the lines of this grid were in use on maps as early as the first century A.D., with the concepts themselves dating to earlier times.

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

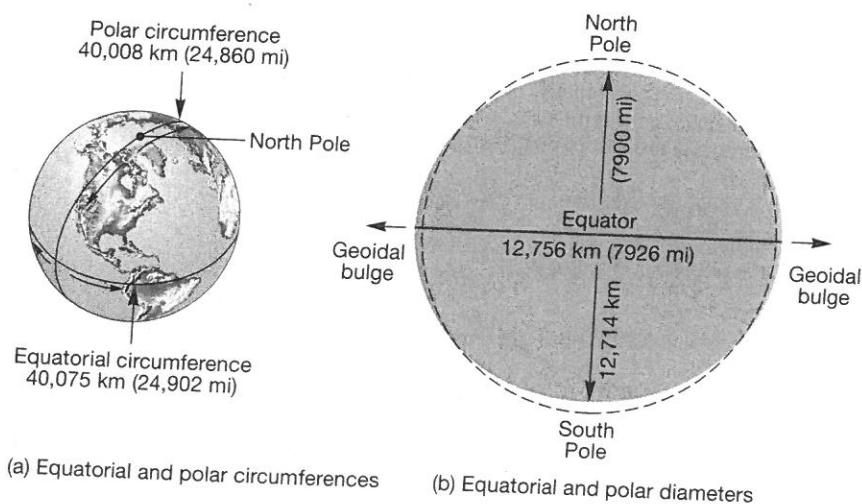
Latitude is an angular distance north or south of the equator, measured from the center of Earth (**Figure 1.10a**). On a map or globe, the lines designating these angles of latitude run east and west, parallel to the equator (**Figure 1.10b**). Because Earth's equator divides the distance between the 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, 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 **Figure 1.10**, 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.

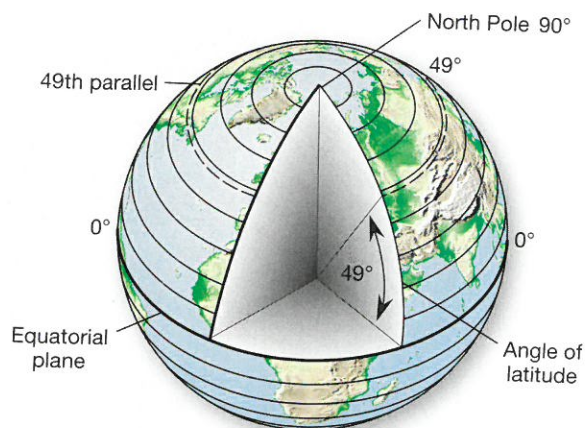
To pinpoint location more precisely, we divide degrees into 60 minutes and minutes into 60 seconds. For example, Mount Cook, South Island, New Zealand, in **Figure 1.1** sits at 43 degrees, 35 minutes, 42 seconds (43° 35' 42") south latitude. Alternatively, many geographic information systems and Earth visualization programs such as Google Earth™ use decimal notation for latitude and longitude degrees (an online conversion is at <http://www.csgnetwork.com/gpscoordconv.html>). In decimal units, Mount Cook is at -43.5950° latitude—the negative sign is for south latitude; a positive sign indicates north latitude.

“Lower latitudes” are those nearer the equator, whereas “higher latitudes” are those nearer the poles. You may be familiar with other general names describing regions related to latitude, such as “the tropics” and “the Arctic.” Such terms refer to natural environments that 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.

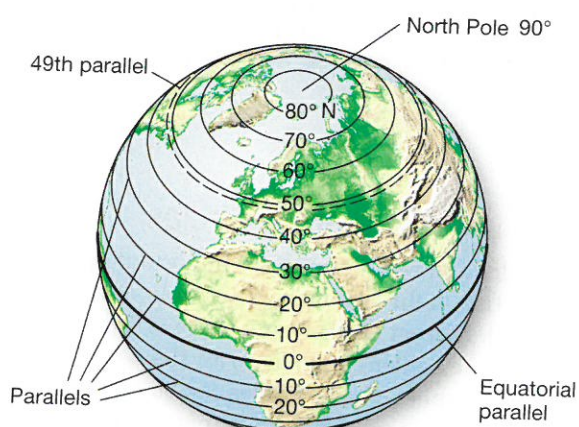
Figure 1.11 displays the names and locations of the *latitudinal geographic zones* used by geographers: *equatorial* and *tropical*, *subtropical*, *midlatitude*, *subarctic* or *subantarctic*, and *arctic* or *antarctic*. These generalized latitudinal zones are useful for reference and comparison, but they do not have rigid boundaries; rather, think of them as transitioning one to another. We discuss specific lines of latitude, such as



▲**Figure 1.9** Earth's dimensions. The dashed line is a perfect circle for comparison to Earth's geoid.



(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.

▲ **Figure 1.10** Parallels of latitude. Do you know your present latitude?

the Tropic of Cancer and the Arctic Circle, in Chapter 2 as we learn about the seasons.

Longitude

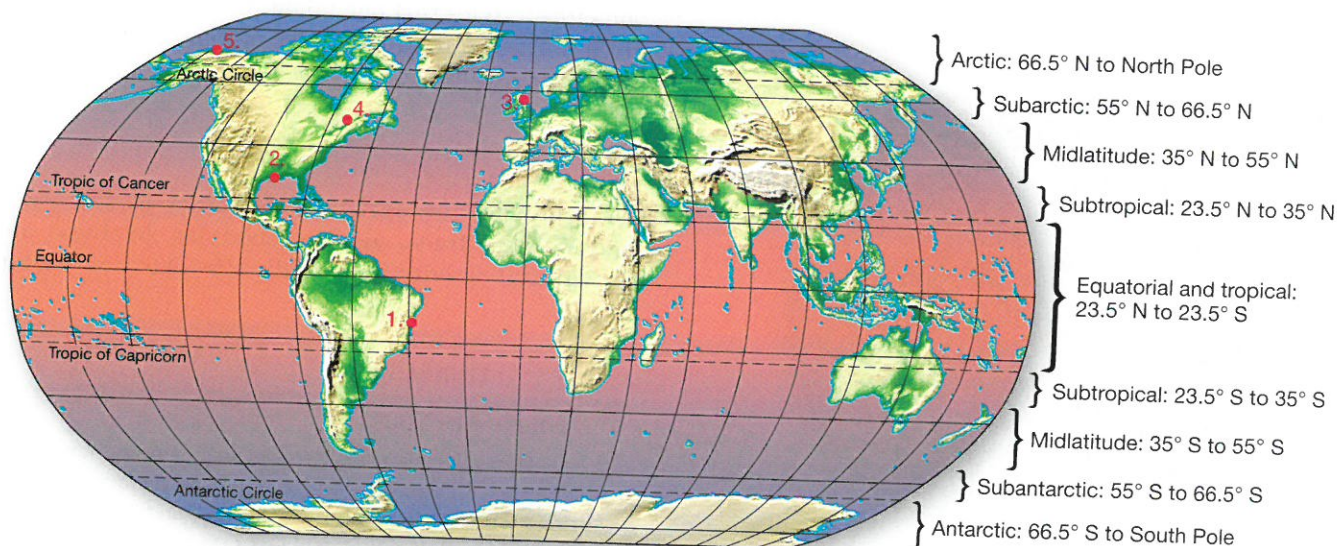
Longitude is an angular distance east or west of a point on Earth's surface, measured from the center of Earth (**Figure 1.12a**). On a map or globe, the lines designating these angles of longitude run north and south (**Figure 1.12b**). A line connecting all points along the same longitude is a **meridian**. 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 1.12b**). Earth's prime meridian passes through the old Royal Observatory at Greenwich, England, as set by an 1884 treaty; this is the *Greenwich prime meridian*. Because meridians of longitude converge toward the poles, the actual distance on the ground spanned by

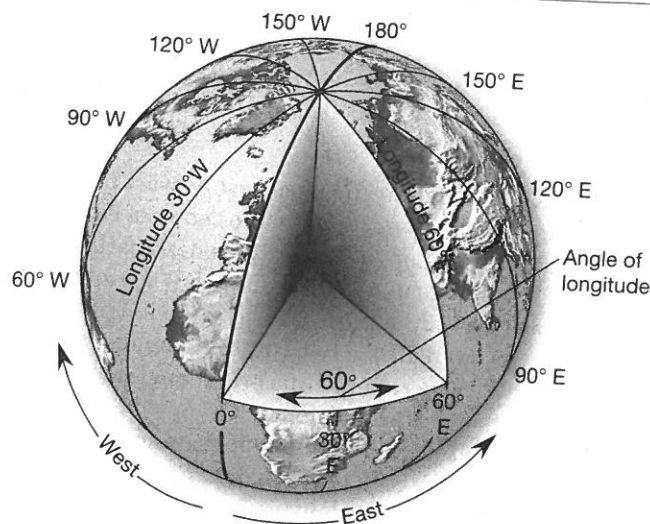
CRITICAL thinking 1.2

Latitudinal Geographic Zones and Temperature

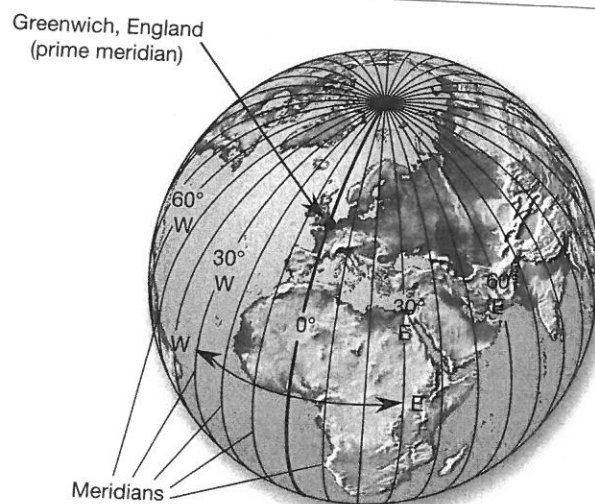
Refer to the graph in Figure 3.14, which plots annual temperature data for five cities from near the equator to beyond the Arctic Circle. Note the geographic location for each of the five cities on the latitudinal geographic zone map in Figure 1.11. In which zone is each city located? Roughly characterize changing temperature patterns through the seasons as you move away from the equator. Describe what you discover.



▲ **Figure 1.11** Latitudinal geographic zones. Geographic zones are generalizations that characterize various regions by latitude. Numbered cities (see Critical Thinking 1.2): 1. Salvador, Brazil; 2. New Orleans, Louisiana; 3. Edinburgh, Scotland; 4. Montreal, Quebec; 5. Barrow, Alaska.



(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.

▲ **Figure 1.12 Meridians of longitude.** Do you know your present longitude?

a degree of longitude is greatest at the equator (where meridians separate to their widest distance apart) and diminishes to zero at the poles (where meridians converge). As with latitude, longitude is expressed in degrees, minutes, and seconds or in decimal degrees. Mount Cook in Figure 1.1 is located at $170^{\circ} 8' 32''$ east longitude, or $+170.1421^{\circ}$; east longitude has a positive decimal value, while west longitude is negative.

Figure 1.13 combines latitude and parallels with longitude and meridians to illustrate Earth's complete coordinate grid system. Note the red dot that marks 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 1.13 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.

Great Circles and Small Circles

Great circles and small circles are important navigational concepts that help summarize latitude and longitude (**Figure 1.14**). 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*, tracing the shortest distances between two points on Earth (see Figure 1.20).

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.

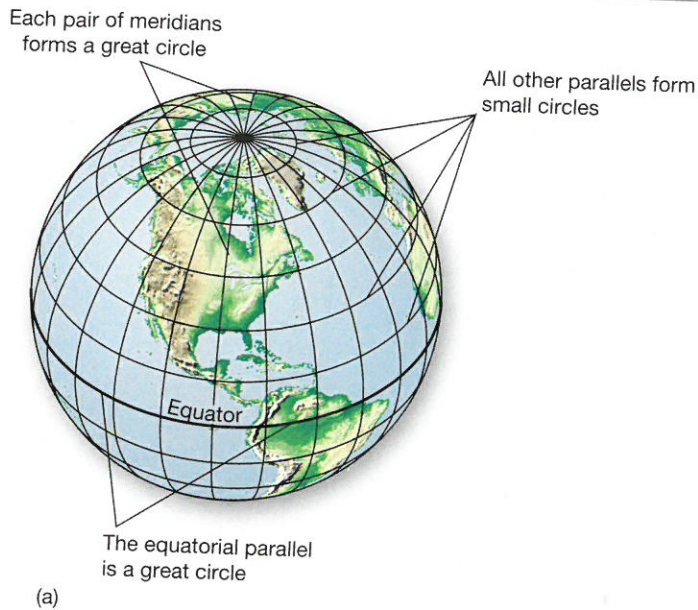
Meridians and Global Time

A worldwide time system is necessary to coordinate international trade, airline schedules, business and agricultural activities, and daily life. Our time system

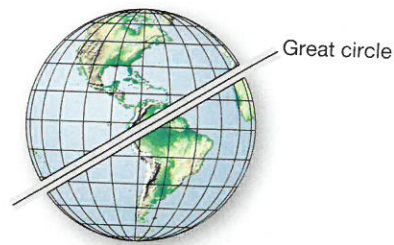
CRITICAL thinking 1.3

Where Are You?

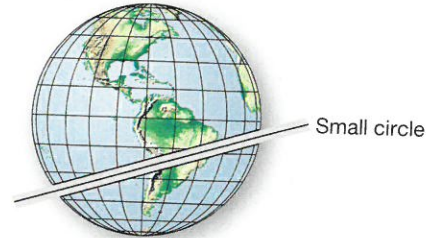
Select a location (for example, your campus, home, or workplace or a city) and determine its latitude and longitude—both in degrees, minutes, and seconds and as decimal degrees. Describe the resources you used to gather this geographic information, such as an atlas, website, Google Earth™, or GPS measurement.



▲Figure 1.14 Great circles and small circles.



(b) A plane intersecting the globe along a great circle divides the globe into equal halves and passes through its center.



(c) A plane that intersects the globe along a small circle splits the globe into unequal sections—this plane does not pass through the center of the globe.

is based on longitude, the prime meridian, and the fact that Earth rotates on its own axis, revolving 360° every 24 hours, or 15° per hour ($360^\circ \div 24 = 15^\circ$).

In 1884 at the International Meridian Conference in Washington, DC, a prime meridian was set as the official standard for the world time zone system—**Greenwich Mean Time (GMT)** (see <http://www.greenwichmeantime.com/>). This standard time system established 24 standard meridians around the globe at equal intervals from the prime meridian, with a time zone of 1 hour spanning 7.5° on either side of each of these *central meridians*. Before this universal system, time zones were problematic, especially in large countries. In 1870, railroad travelers going from Maine to San Francisco made 22 adjustments to their watches to stay consistent with local time! 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 (Figure 1.15).

Using the international time zones in Figure 1.15, you can determine that when it is 9:00 P.M. in Greenwich, then it is 4:00 P.M. in New York (–5 hr), 3:00 P.M. in Chicago (–6 hr), 2:00 P.M. in Denver (–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 Riyadh, 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 A.M. is 3:00 hours; 3 P.M. is 15:00 hours.

Figure 1.15 also shows that national or state boundaries and political considerations distort time boundaries. For example, China spans four time zones, but its

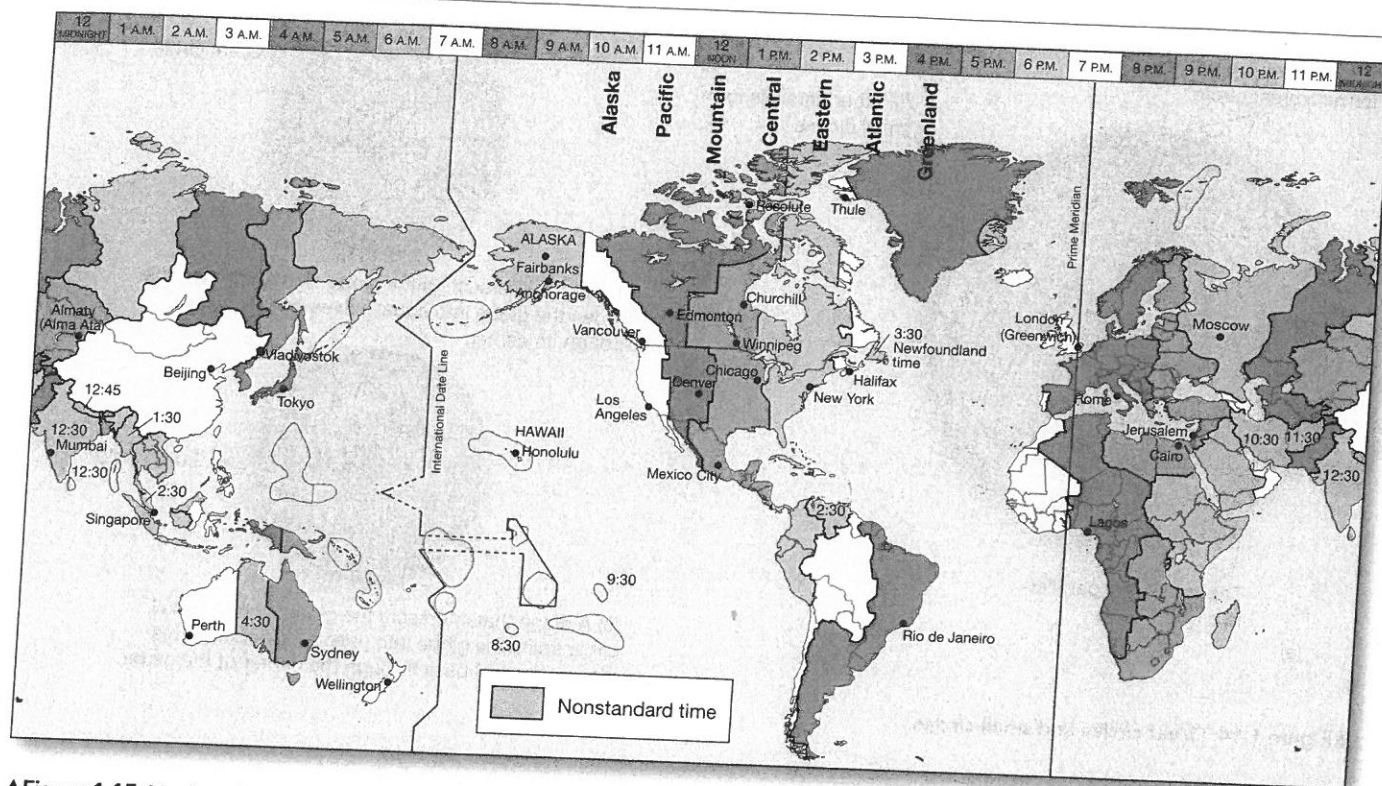
government decided to keep the entire country operating at the same time. Thus, in some parts of China clocks are several hours off from what the Sun is doing. In the United States, parts of Florida and west Texas are in the same time zone.

Coordinated Universal Time For decades, GMT was determined using the Royal Observatory’s astronomical clocks and was the world’s standard for accuracy. However, Earth rotation, on which those clocks were based, varies slightly over time, making it unreliable as a basis for timekeeping. For example, 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 invention of a quartz clock in 1939 and atomic clocks in the early 1950s improved the accuracy of measuring time. In 1972, the **Coordinated Universal Time (UTC)*** time-signal system replaced GMT and became the legal reference for official time in all countries. 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.

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

*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 timekeeping applications; use of the term GMT is discouraged.



▲Figure 1.15 Modern international standard time zones. 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.]

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 (Figure 1.16).

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. Note in the illustration the departures from the IDL and the 180° meridian; this deviation is due to local administrative and political preferences.

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 extended the number of weeks of daylight saving time. Currently, 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 (Hawai’i, Arizona, and Saskatchewan). In Europe, the last Sundays in March and October mark the beginning and ending of the “summer-time period.”*

Maps and Cartography

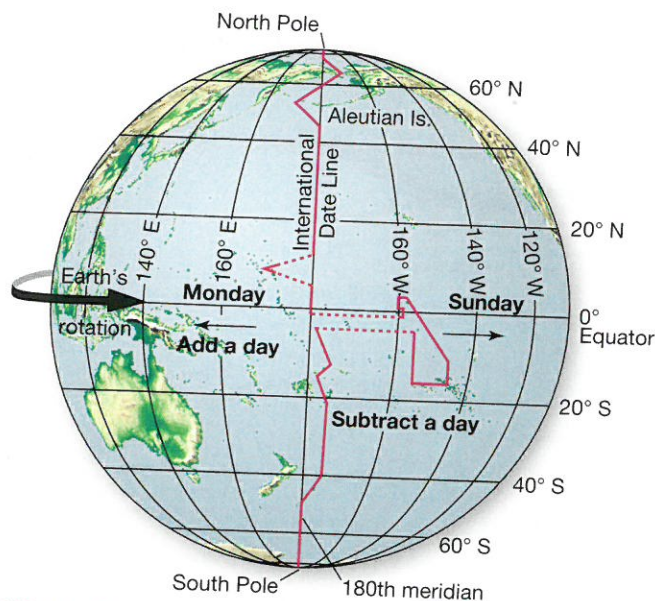
For centuries, geographers have used maps as tools to display spatial information and analyze spatial relationships. A **map** is a generalized view of an area, usually some portion of Earth’s surface, as seen from above and greatly reduced in size. A map usually represents a specific

*see <http://webexhibits.org/daylightsaving>.



GEOREPORT 1.3 The world’s most accurate clock

The National Institute of Standards and Technology (NIST), U.S. Department of Commerce, operates the world’s most accurate clock. The NIST-F1 cesium atomic clock, housed in Boulder, Colorado, will not gain or lose a second in nearly 20 million years. For accurate time in the United States, see <http://www.time.gov>, operated by NIST and the U.S. Naval Observatory. In Canada, the Institute for Measurement Standards, National Research Council Canada, participates in determining UTC; see http://time5.nrc.ca/webclock_e.shtml.



▲ **Figure 1.16 International Date Line.** The IDL location is approximately along the 180th meridian (see the IDL location on Figure 1.15). The dotted lines on the map show where island countries have set their own time zones, but their political control extends only 3.5 nautical miles (4 mi) offshore. Officially, you gain one day crossing the IDL from east to west.

characteristic of a place or area, such as rainfall, airline routes, or political features such as state boundaries and place names. **Cartography** is the science and art of map-making, often blending aspects of geography, engineering, mathematics, computer science, and art. It is similar in ways to architecture, in which aesthetics and utility combine to produce a useful product.

We all use maps to visualize our location in relation to other places, or maybe to plan a trip, or to understand a news story or current event. 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 represent real things and places with the convenience of a model; examples are a drawing; a pretend car, train, or plane; a diagram; and a map. In most cases, the model is smaller than the reality. For example, an architect renders a blueprint of a structure to guide the building contractors, preparing the drawing so that a centimeter (or inch) on the blueprint 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 the map's **scale**; it relates the size of a unit on the map to the size of a similar unit on the ground. A 1:1 scale means that any unit (for example, a centimeter) on the map represents that same unit (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 1.17**). 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.

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" is no longer correct. The new correct written scale is "1 in. to 5280 ft (1 mi)."

Scales are *small* or *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 of the map. Small-scale maps show a greater area in less detail; a small-scale map of the world is little help in finding an exact location, but works well for illustrating global wind patterns or ocean currents. Large-scale maps show a smaller area in more detail and are useful for applications needing precise location or navigation over short distances.

Map Projections

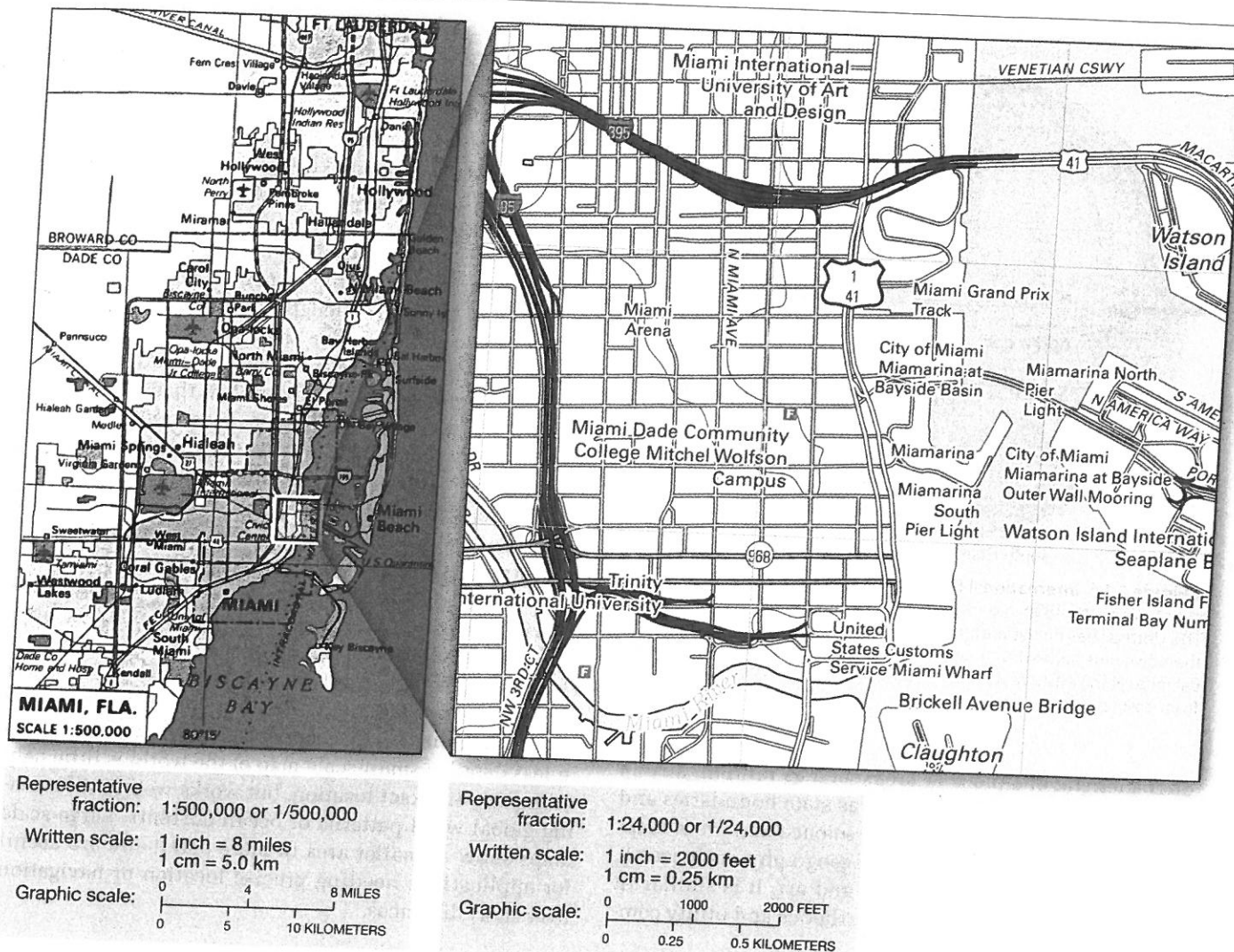
A globe is not always a helpful map representation of Earth. When you go on a trip, you need more-detailed information than a globe can provide. To provide local

CRITICAL thinking 1.4

Find and Calculate Map Scales

Find globes or maps in the library or geography department, and check the scales at which they were 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 (or adapt the following values to whatever 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, and 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?



(a) Relatively small scale map of Miami area shows less detail.

(b) Relatively large scale map of the same area shows a higher level of detail.

▲**Figure 1.17 Map scale.** Examples of maps at different scales, with three common expressions of map scale—representative fraction, written scale, and graphic scale. Both maps are enlarged, so only the graphic scale is accurate. [USGS. Courtesy of University of Texas Libraries, University of Texas at Austin.]

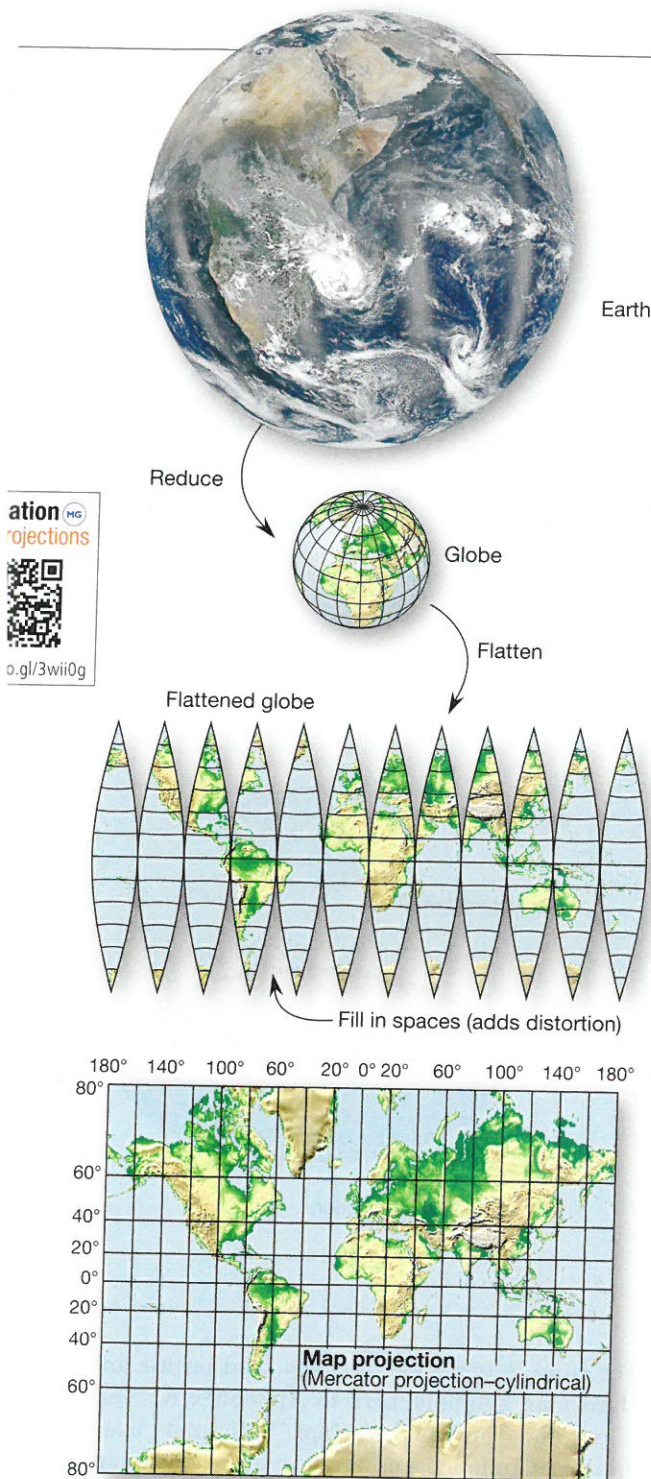
detail, cartographers prepare large-scale *flat maps*, which are two-dimensional representations (scale models) of our three-dimensional Earth. Unfortunately, such conversion from three dimensions to two causes distortion.

A globe can provide a fairly good representation of *distance, direction, area, shape, and proximity* on Earth. A flat map distorts these properties. Therefore, in preparing a flat map, the cartographer must decide which characteristics 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 the 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 simultaneously on a flat surface. Simply taking a globe apart and laying it flat on a table illustrates the challenge faced by cartographers (**Figure 1.18**). 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**, and 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.



▲Figure 1.18 From globe to flat map. Conversion of the globe to a flat map projection requires a decision about which properties to preserve and the amount of distortion that is acceptable. [NASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring.]

Equal Area or True Shape? The best map projection is always determined by the intended use of the map. The major decisions in selecting a map projection involve the properties of **equal area** (equivalence) and **true shape** (conformality). A decision favoring 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.

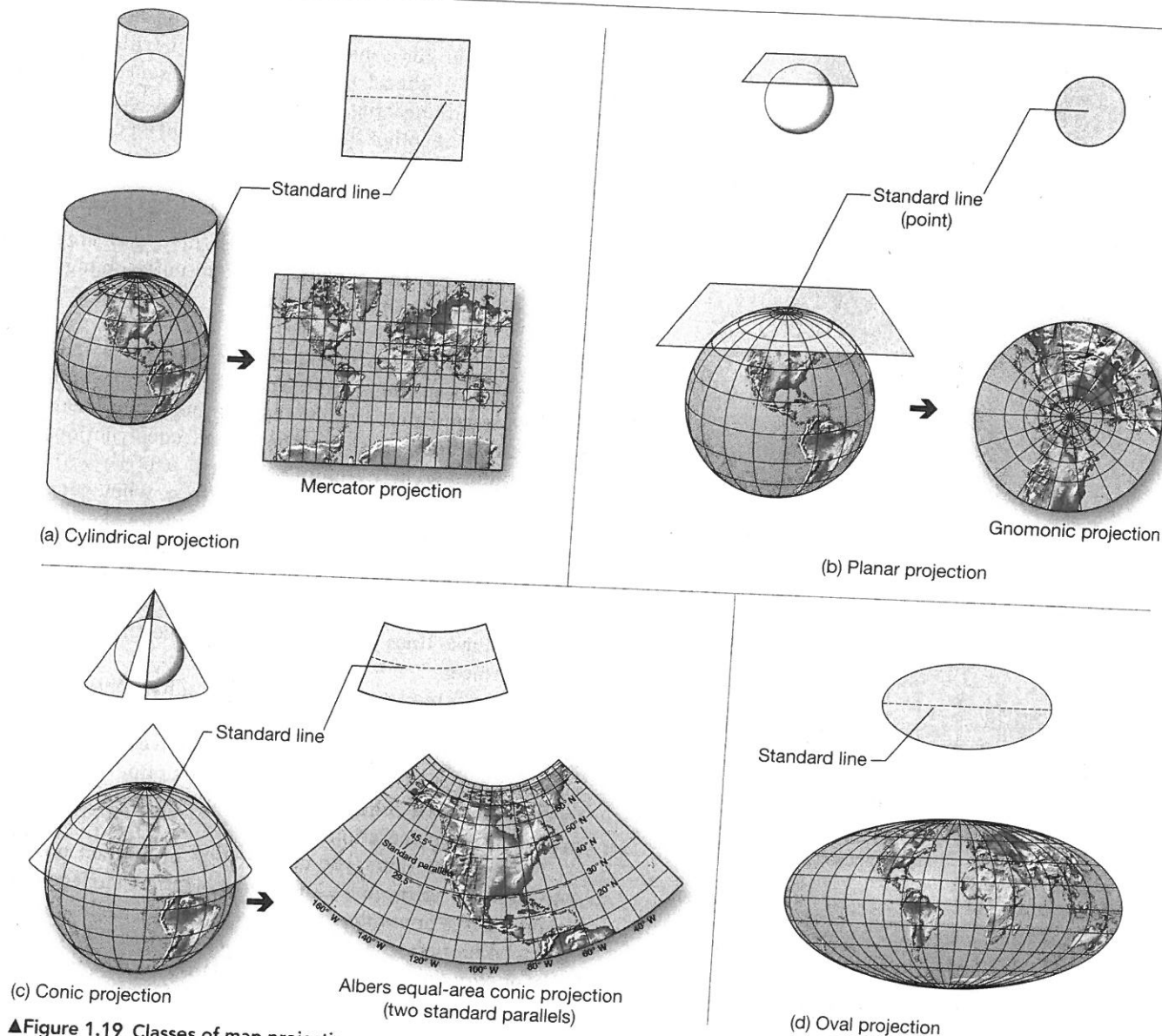
Classes of Projections Figure 1.19 illustrates four classes of map projections and the perspective from which each class is generated. Despite the fact that modern cartographic technology uses mathematical constructions and computer-assisted graphics, we still use the word *projection*. The term comes from times past, when geographers actually projected the shadow of a wire-skeleton globe onto a geometric surface, such as a *cylinder*, *plane*, or *cone*. The wires represented parallels, meridians, and outlines of the continents. A light source casts a shadow pattern of these lines from the globe onto the chosen geometric surface.

The main map projection classes include the cylindrical, planar (also called 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** (invented by Gerardus Mercator in 1569) is a cylindrical projection (Figure 1.19a). The Mercator is a conformal 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 Figures 1.18 and 1.19a that the Mercator projection is cut off near 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.



▲Figure 1.19 Classes of map projections.

The advantage of the Mercator projection is that a line of constant direction, known as a **rhumb line**, is straight and therefore facilitates plotting directions between two points (Figure 1.20). Thus, the Mercator projection is useful in navigation and is standard for nautical charts prepared by the National Ocean Service.

The *gnomonic projection* in Figure 1.19b is a type of planar (azimuthal) projection 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 1.20a). 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 1.20b).

For more information on maps used in this text and standard map symbols, turn to Appendix A, "Maps in This Text and Topographic Maps." Scientists use topographic maps for landscape analysis, since such maps add a vertical component to the landscape. Travelers and others using the outdoors use these maps for navigation. The U.S. Geological Survey (USGS) *National Map* (available at <http://nationalmap.gov/>) provides downloadable digital topographic data for the entire United States.

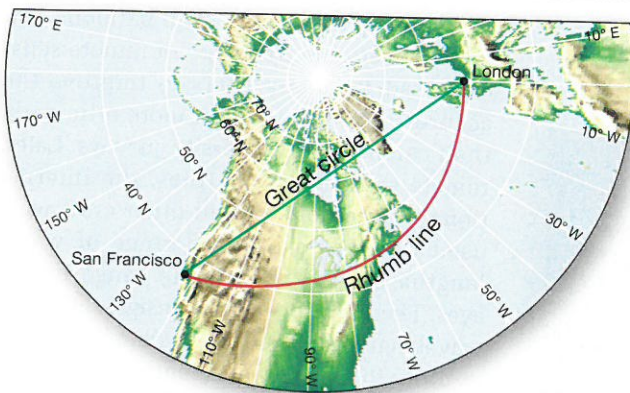
Modern Tools and Techniques for Geoscience

Geographers and Earth scientists analyze and map Earth using a number of relatively recent and evolving technologies—the Global Positioning System (GPS), remote

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Map Proje

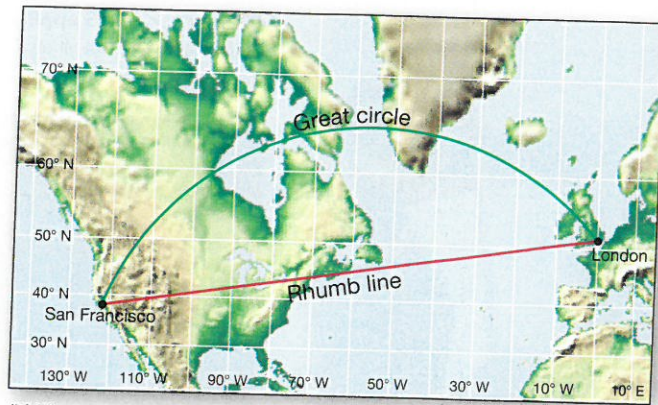


<http://goo.g>



(a) The gnomonic projection 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.

▲Figure 1.20 Determining great circle routes.



(b) The great circle route is then plotted on a Mercator projection, which has true compass direction. Note that straight lines or bearings on a Mercator projection (rhumb lines) are not the shortest route.

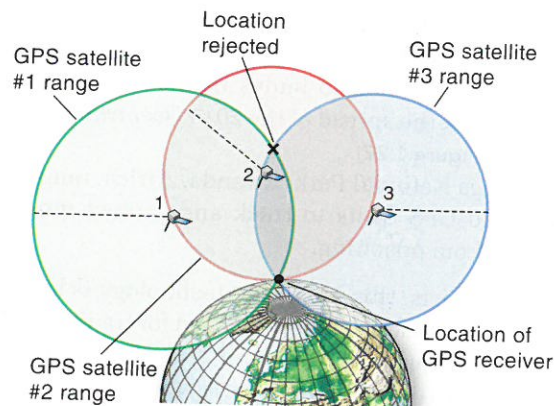
sensing, and geographic information systems (GIS). GPS relies on satellites in orbit to provide precise location and elevation. Remote sensing utilizes spacecraft, aircraft, and ground-based sensors to provide visual data that enhance our understanding of Earth. GIS is a means for storing and processing large amounts of spatial data as separate layers of geographic information; geographic information science is the geographic subfield that uses this technique.

Global Positioning System

The **Global Positioning System (GPS)** uses radio signals from satellites to accurately determine latitude, longitude, and elevation anywhere on or near the surface of Earth. The system comprises at least 27 orbiting satellites, in six orbital planes, that transmit navigational signals to Earth-bound receivers (backup GPS satellites are in orbital storage as replacements). Think of the satellites as a constellation of navigational beacons with which you can interact to determine your unique location. As we know, every possible square meter of Earth's surface has its own address relative to the latitude–longitude grid.

A GPS receiver senses signals from at least four satellites—a minimum of three satellites for location and a fourth to determine accurate elevation. The distance between each satellite and the GPS receiver is calculated using clocks built into each instrument that time radio signals traveling at the speed of light between them (Figure 1.21). The receiver calculates its true position—latitude, longitude, and elevation—using trilateration (determining a position using the distance from three known points). GPS units also report accurate time to within 100 billionths of a second. This allows GPS base stations to have perfectly synchronized timing, essential to worldwide communication, finance, and many industries.

GPS receivers are built into many smartphones, wristwatches, and motor vehicles and can be bought as



▲Figure 1.21 Using satellites to determine 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, signals from three satellites can reveal the receiver's location; adding a fourth satellite determines elevation.

handheld units. Standard cell phones not equipped with a GPS receiver determine location based on the position of cell phone towers—a process not as accurate as GPS measurement.

The GPS is useful for diverse applications. For example, commercial airlines use the GPS to improve accuracy of routes flown and thus increase fuel efficiency. Scientific applications of GPS technology are extensive. Consider these examples:

- In geodesy, GPS helps refine knowledge of Earth's exact shape and how this shape is changing.
- Scientists used GPS technology in 1998 to accurately determine the height of Mount Everest in the Himalayan Mountains, raising its elevation by 2 m (6 ft).
- On Mount St. Helens in Washington, a network of GPS stations measure ground deformation associated with earthquake activity. In southern California, a similar



(a) Students deploy a "drifter" (with GPS unit attached to the top of the mast) in the Gulf of Mexico in 2010.

▼Figure 1.22 GPS application in the Gulf of Mexico. [(a) Monty Graham, Dauphin Island Sea Lab. (b) NOAA.]



(b) Movement of the drifters with surface currents helped scientists track and predict the movement of oil.

GPS system can record fault movement as small as 1 mm (0.04 in.).

- GPS units attached to buoys in the Gulf of Mexico helped track the spread of the 2010 *Deepwater Horizon* oil spill (Figure 1.22).
- In Virunga National Park, Rwanda, Africa, rangers use handheld GPS units to track and protect mountain gorillas from poaching.

For scientists, this important technology is both convenient and precise, reducing the need for traditional land surveys that require point-to-point line-of-sight measurements on the ground. In your daily life and travels, have you ever used a GPS unit? How did GPS assist you?

Remote Sensing

The acquisition of information about distant objects without having physical contact is **remote sensing**. In this era of observations from satellites outside the atmosphere, from aircraft within it, and from remote submersibles in the oceans, scientists obtain a wide array of remotely sensed data (Figure 1.23). 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 by registering energy from the visible-wavelength portion of the electromagnetic spectrum (discussed in Chapter 2). Similarly, when a camera intercepts the wavelengths for which its film or sensor is designed, it remotely senses energy that is reflected or emitted from a scene.

Aerial photographs from balloons and aircraft were the first type of remote sensing, used for many years to improve the accuracy of surface maps more efficiently than can be done by on-site surveys. Later, remote sensors on satellites, the International Space Station, and other craft were used to sense a broader range of wavelengths beyond the visible range of our eyes. These sensors can be designed to "see" wavelengths shorter than visible light (such as ultraviolet) and wavelengths longer than visible light (such as infrared and microwave radar). As examples, infrared sensing produces images based on the temperature of objects on the ground, microwave sensing reveals features below Earth's surface, and radar sensing shows land-surface elevations, even in areas that are obscured by clouds.

Satellite Imaging During the last 50 years, satellite remote sensing has transformed Earth observation. Physical elements of Earth's surface emit radiant energy in wavelengths that are sensed by satellites and other craft and sent to receiving stations on the ground. The receiving stations sort these wavelengths into specific bands, or ranges. 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 a detailed image when the pixels are matched to the wavelengths they emit.

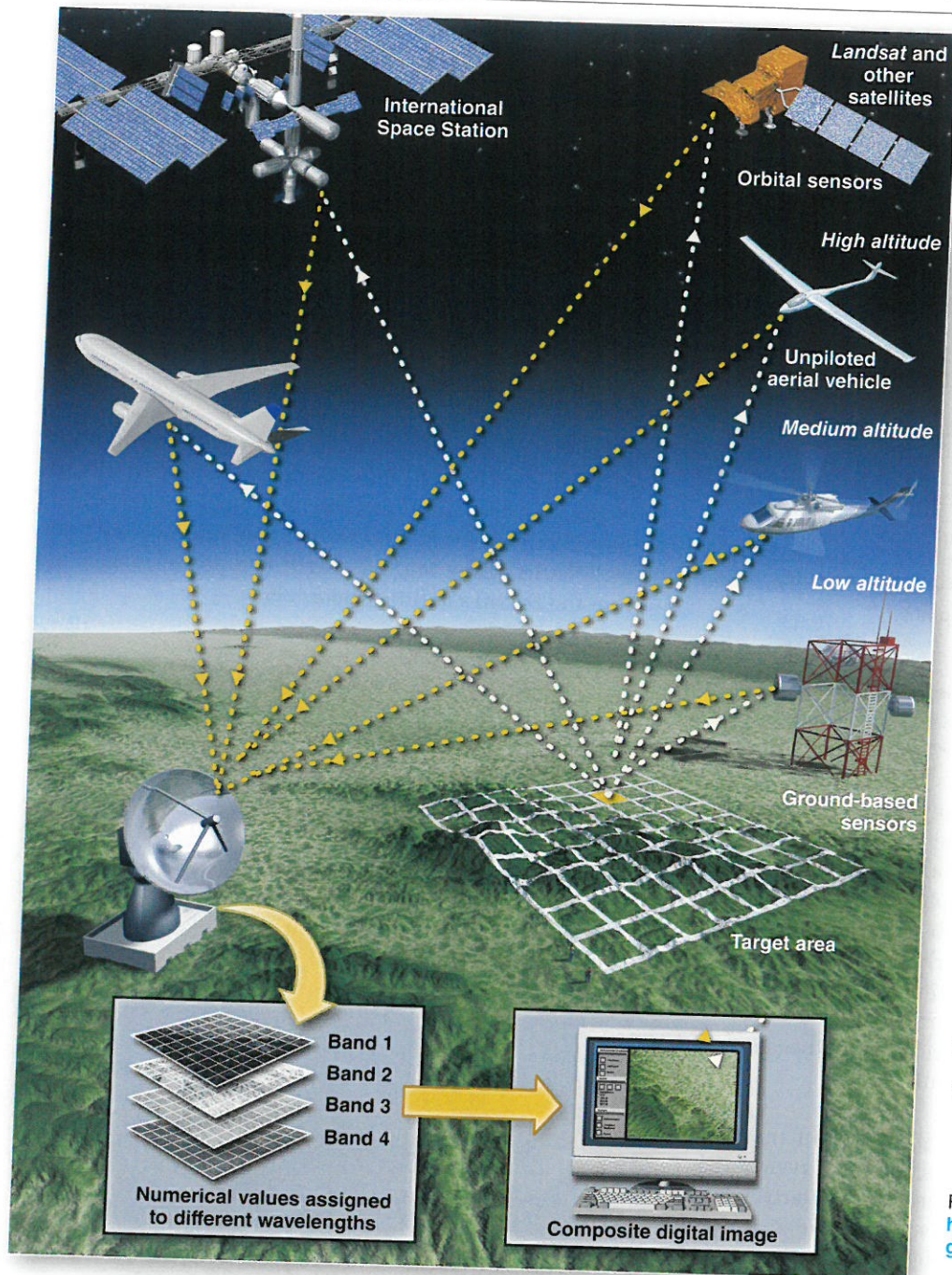
A single remotely sensed image requires a large amount of data, which are recorded in digital form for later processing, enhancement, and image generation. Digital data are processed in many ways to enhance their utility: with simulated natural color, "false" color to highlight a particular feature, enhanced contrast, signal filtering, and different levels of sampling and resolution.

Satellites can be set in specific orbital paths (Figure 1.24) that affect the type of data and imagery produced. Geostationary (or geosynchronous) orbits, typically at an altitude of 35,790 km (22,239 mi), are *high Earth orbits* that effectively match Earth's rotation speed so that one orbit is completed in about 24 hours. Satellites can therefore remain "parked" above a specific location, usually the equator (Figure 1.24a). This "fixed" position means that satellite antennas on Earth can be pointed permanently at one position in the sky where the satellite is located;



GEOREPORT 1.4 GPS origins

The GPS devices commercially available worldwide were originally devised in the 1970s by the U.S. Department of Defense for military purposes. 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). *Differential GPS (DGPS)* achieves accuracy of 1 to 3 m by comparing readings with another base station (reference receiver) for a differential correction. For a GPS overview, see <http://www.gps.gov/>.



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-12, -13, -14, and -15.

GRACE: Accurately maps Earth's gravitational field.

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

Landsat: *Landsat-1* in 1972 to *Landsat-7* in 1999 and *Landsat-8* in 2013; have provided millions of images for Earth systems science and study of 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 Sensor) 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 information, see:
<http://www.nasa.gov/centers/goddard/missions/index.html>

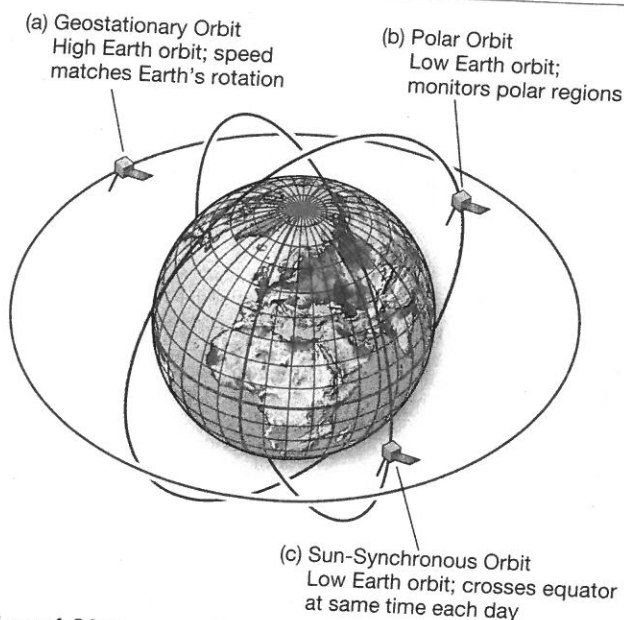
▲ **Figure 1.23 Remote-sensing technology.** Remote-sensing technology measures and monitors Earth's systems from orbiting spacecraft, aircraft, and ground-based sensors. Various wavelengths (bands) are detected by sensors; computers process these data and produce digital images for analysis. A sampling of remote-sensing platforms is listed along the side of the illustration. Also, see the "Remote-Sensing Status Report" on the *MasteringGeography* website.

many communications and weather satellites use these high Earth orbits.

Some satellites orbit at lower altitudes. The pull of Earth's gravity means that the closer to Earth they are, the faster their orbiting speed is. For example, GPS satellites, at altitudes of about 20,200 km (12,552 mi), have *medium Earth orbits* that move more quickly than high Earth orbits. *Low Earth orbits*, at altitudes less than 1000 km (621 mi), are the most useful for scientific monitoring. Several of the National Aeronautics and Space

Administration (NASA) environmental satellites in low Earth orbit are at altitudes of about 700 km (435 mi), completing one orbit every 99 minutes.

The angle of a satellite's orbit in relation to Earth's equator is its *inclination*, another factor affecting remotely sensed data. Some satellites orbit near the equator to monitor Earth's tropical regions; this low-inclination orbit acquires data only from low latitudes. An example is the *Tropical Rainfall Measuring Mission (TRMM)* satellite, which provides data for mapping rainfall patterns in the



▲Figure 1.24 Three satellite orbital paths.

tropics (see example images in Geosystems in Action 4 on page 121). Monitoring the polar regions requires a satellite in polar orbit, with a higher inclination of about 90° (Figure 1.24b).

One type of polar orbit important for scientific observation is a Sun-synchronous orbit (Figure 1.24c). This low Earth orbit is synchronous with the Sun, so that the satellite crosses the equator at the same local solar time each day. Ground observation is maximized in Sun-synchronous orbit because Earth surfaces viewed from the satellite are illuminated by the Sun at a consistent angle. This enables better comparison of images from year to year because lighting and shadows do not change.

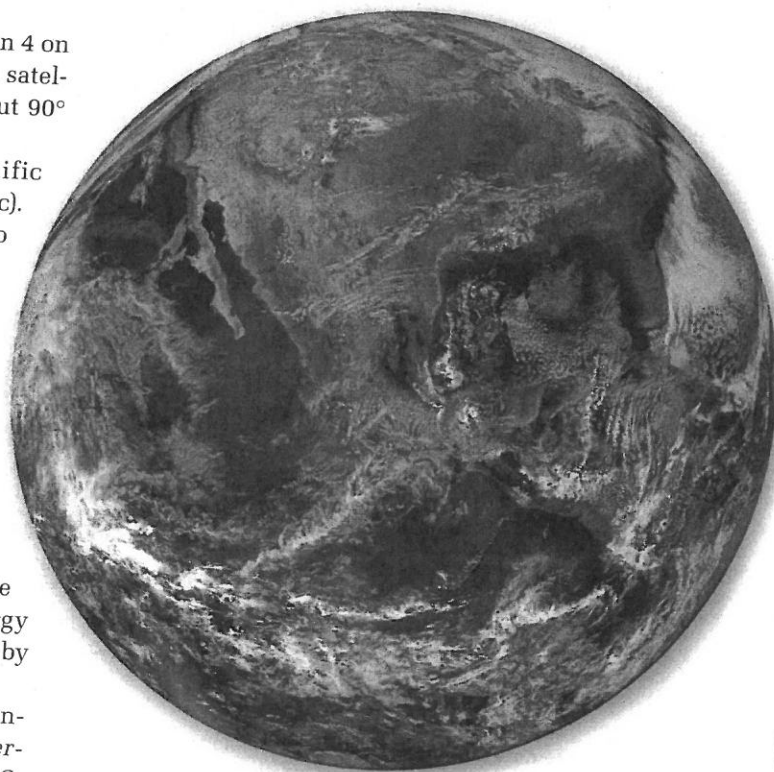
Passive Remote Sensing Like the human eye, passive remote-sensing systems record wavelengths of energy radiated from a surface, particularly visible light and infrared. Thus, passive sensors detect energy that is naturally emitted by the object or that is reflected by sunlight.

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. *GOES-12*, -13, -14, and -15 are operational; *GOES-12* sits at 60° W longitude to monitor the Caribbean and South America.

Think of these satellites as hovering over these meridians for continuous coverage, using visual wavelengths for daylight hours and infrared for nighttime views.

Scientists use data from *Landsat* satellites, which began imaging Earth in the 1970s, for comparison of changing Earth landscapes over time, among other applications (see examples in Chapter 13, Visual Analysis 13, on page 437; view more images at <http://earthobservatory.nasa.gov>). *Landsat-5* retired in 2012 after 29 years, the longest-running Earth-observing mission in history; *Landsat-8* launched in 2013, beginning the new *Landsat* program managed by the USGS.

Although the *Landsat* satellites far surpassed their predicted lifespans, most satellites are removed from orbit after 3 to 5 years. Launched in 2011, *Suomi NPP* is part of the National Polar-orbiting Partnership (NPP), the next generation of satellites that will replace NASA's aging Earth Observation Satellite fleet. Many of the beautiful NASA "Blue Marble" Earth composite images are from the *Suomi* satellite (Figure 1.25).



▲Figure 1.25 *Suomi NPP* Blue Marble image. This composite view of Earth was imaged January 2, 2012. NASA scientist Norman Kuring combined VIIRS instrument data from six orbits of the *Suomi NPP* satellite. VIIRS acquires data in 22 bands covering visible, near-infrared, and thermal infrared wavelengths. [NASA/NOAA.]

GEOREPORT 1.5 Polar-orbiting satellites predict Hurricane Sandy's path

Scientists at the European Centre for Medium-Range Weather Forecasts report that polar-orbiting satellites, such as the National Oceanic and Atmospheric Administration (NOAA) *Suomi NPP* satellite, were critical for predicting Hurricane Sandy's track. Without data from these satellites, predictions for Hurricane Sandy would have been off by hundreds of miles, showing the storm heading out to sea rather than turning toward the New Jersey coast. *Suomi* orbits Earth about 14 times each day, collecting data from nearly the entire planet (find out more at <http://npp.gsfc.nasa.gov/>).

Active Remote Sensing Instruments that direct a beam of energy at a surface and analyze the energy reflected back are active remote sensors. An example is *radar* (radio detection and ranging). A radar transmitter emits short bursts of energy that have relatively long wavelengths (0.3 to 10 cm) toward the subject terrain, penetrating clouds and darkness. Energy reflected back to a radar receiver for analysis is known as *backscatter*. Radar images collected in a time series allow scientists to make pixel-by-pixel comparisons to detect Earth movement, such as elevation changes along earthquake faults (see Chapter 10, Figure 10.1.2, on page 333).

Another active remote-sensing technology is airborne LiDAR, or *light detection and ranging*. LiDAR systems collect highly detailed and accurate data for surface terrain using a laser scanner, with up to 150,000 pulses per second, 8 pulses or more per square meter, providing 15-m (49.2-ft) resolution. GPS and navigation systems onboard the aircraft determine the location of each pulse. LiDAR data sets are often shared among private, public, and scientific users for multiple applications. Scientists are presently studying the effects of Hurricane Sandy along the U.S. East Coast using LiDAR (see Chapter 13, Figure 13.17, on page 424).

Geospatial Data Analysis

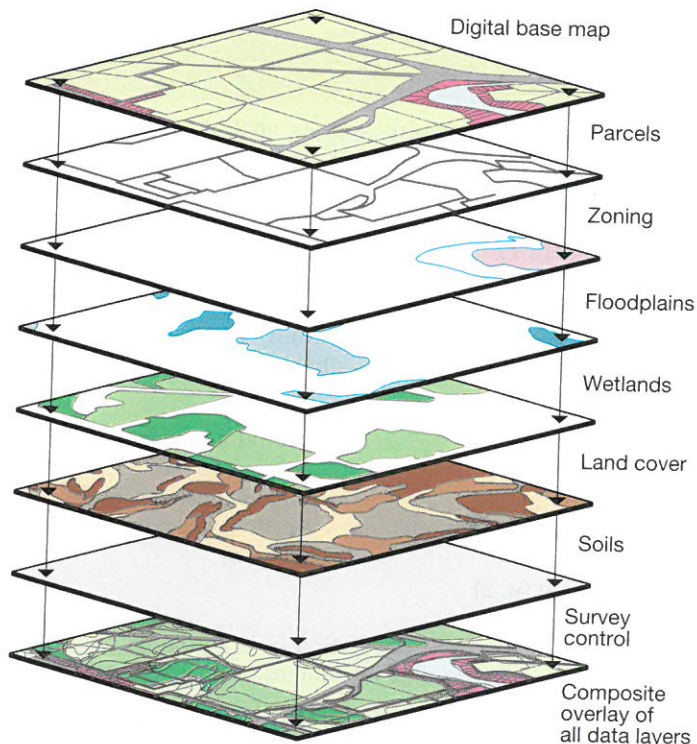
Techniques such as remote sensing acquire large volumes of spatial data that must be retrieved and processed for scientific applications. Scientists use a number of rapidly

developing technologies for analysis and visualization of large data sets.

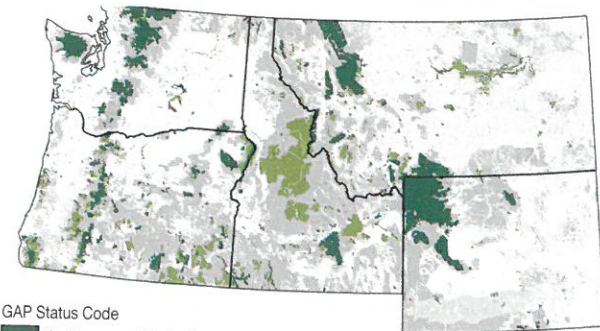
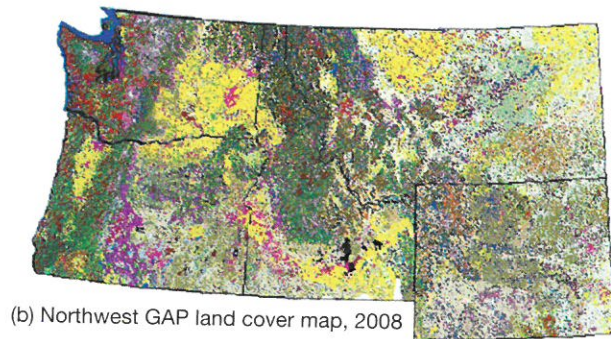
Geographic Information Systems The integration of geographic information from direct surveys (on-the-ground mapping) and remote sensing can be accomplished using a **geographic information system (GIS)**, a computer-based data-processing tool for gathering, manipulating, and analyzing geographic data. In a GIS, spatial data can be organized in layers, or planes, containing different kinds of information (Figure 1.26). The beginning component for any GIS is a map, with its associated coordinate system, such as latitude–longitude provided by GPS or digital surveys (the top layer in Figure 1.26a). This map establishes reference points against which to accurately position other data, such as remotely sensed imagery. Whereas printed maps are fixed at the time of publication, GIS maps can be easily modified and evolve instantly.

A GIS is capable of analyzing patterns and relationships within a single data plane, such as the floodplains or soils layer in Figure 1.26a. 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 is its ability to manipulate data and bring together several variables for analysis.

Figures 1.26b and c show two GIS map layers from the Northwest Gap Analysis Program (GAP), a five-state



(a) Layered spatial data in a GIS format



(c) Northwest GAP protected areas map, 2008

Figure 1.26 Geographic information system (GIS) examples. [(a) After USGS. (b) and (c) University of Idaho, Northwest Gap Analysis Project.]

assessment of terrestrial species and habitat, land stewardship, and management status that began in 2004. The Northwest GAP is part of a nationwide GAP environmental quality assessment by the USGS for species conservation; critical data layers are vegetation type, species range, and land ownership, among other environmental variables. (See <http://gapanalysis.usgs.gov/> or <http://gap.uidaho.edu> to read a project overview and to access interactive maps.)

Geographic information science (GISci) is the field that develops the capabilities of GIS technology for use within geography and other disciplines. GISci analyzes Earth and human phenomena over time. This can include the study and forecasting of diseases, the population displacement caused by Hurricane Sandy, the destruction from the Japan earthquake and tsunami in 2011, and the status of endangered species and ecosystems, to name a few examples.

GIS technology is widely used in the creation of maps with a three-dimensional perspective. These maps are produced by combining *digital elevation models* (DEMs), which provide the base elevation data, with satellite-image overlays (see examples in Chapter 10). Through GIS technology, these data are available for multiple displays, animations, and other scientific analyses.

Visualization Technologies Google Earth™ and similar programs that can be downloaded from the Internet provide three-dimensional viewing of the globe and

related geographic information. Google Earth™ allows the user to zoom in on landscapes and features of interest, using satellite imagery and aerial photography at varying resolutions. Users can select layers, as in a GIS model, depending on the task at hand and the composite overlay displayed. NASA's World Wind software is another open-source browser with access to high-resolution satellite images and multiple data layers suitable for scientific applications.

Geovisualization is a set of technologies for adjusting geospatial data sets in real time, so that users can instantly make changes to maps and other visual models. Geovisual tools are important for translating scientific knowledge into resources that nonscientists can use for decision making and planning. For example, scientists at East Carolina University, in partnership with state, local, and nonprofit organizations, are developing geovisual tools to assess the effects of sea-level rise along the North Carolina coast (see <http://www.ecu.edu/renci/Technology/GIS.html>).

Access to GIS technology, geovisualization tools, and large scientific data sets is expanding and becoming more user-friendly. Numerous open-source GIS software packages are now available. These are usually free, have online support systems, and are updated frequently (see <http://opensourcegis.org/>). In addition, public access to large remote-sensing data sets for analysis and display is now available, without the need to download large amounts of data (see examples of research applications at <http://disc.sci.gsfc.nasa.gov/>).

KEY LEARNING CONCEPTS REVIEW

Here is a handy summary designed to help you review the Key Learning Concepts listed on this chapter's title page. The recap of each concept concludes with a list of the key terms from that portion of the chapter, their page numbers, and review questions pertaining to the concept. Similar summary and review sections follow each chapter in the book.

Define geography in general and physical geography in particular.

Geography combines disciplines from the physical and life sciences with disciplines from the human and cultural sciences to attain a holistic view of Earth. Geography's **spatial** viewpoint examines the nature and character of physical space and the distribution of phenomena within it. Geographic science integrates a wide range of subject matter traditionally categorized into five major themes: **location**, **region**, **human–Earth relationships**, **movement**, and **place**. Methods of **spatial analysis** unify this diverse field, focusing on the interdependence among geographic areas, natural systems, society, and cultural activities over space. The analysis of **process**—a set of actions or mechanisms that operate in some special order—is also central to geographic understanding.

Physical geography applies spatial analysis to all the physical components and process systems that make up the environment: energy, air, water, weather, climate, landforms, soils, animals, plants, microorganisms, and Earth itself. Physical geography is an essential aspect of **Earth systems science**. The science of physical geography is uniquely qualified to synthesize the spatial, environmental, and human aspects of our increasingly complex relationship with our home planet—Earth.

geography (p. 2)	place (p. 2)
spatial (p. 2)	spatial analysis (p. 4)
location (p. 2)	process (p. 4)
region (p. 2)	physical geography (p. 4)
human–Earth relationships (p. 2)	Earth systems science (p. 4)
movement (p. 2)	

1. On the basis of information in this chapter, define physical geography and review the approach that characterizes the geographic sciences.
2. Suggest a representative example for each of the five geographic themes; for instance, an example of the movement theme might be oceanic circulation spreading debris from the Japan tsunami.