Fifth Edition

Introducing Physical Geography
Introduction

Physical Geography and the Tools Geographers Use

The circular plan of this traditional village, north of Antananarivo, Madagascar, with its central walled area and radial paths leading outward, is found early in the development of many civilizations. With its aligned buildings, town square, and areas of gardens and bowers along the periphery, the village center has the basic elements of many modern towns and cities. Surrounding the village are the supporting lands—agricultural plots and pastures on which the village depends. The modern city also has its supporting areas of suburban development and agricultural hinterlands surrounding the city center. The main road at the bottom of the photo is a transportation corridor that connects the village to the outside world. Large cities have many such transportation links, including roads, rivers, and railways.

Human settlements have a physical setting that places bounds on the kinds of human and economic activities that take place in and around the settlement. In this book, we will focus on the natural processes that shape the physical landscape and provide the habitat of the human species.
Introducing Geography
HUMAN AND PHYSICAL GEOGRAPHY

Spheres, Systems, and Cycles
THE SPHERES—FOUR GREAT EARTH REALMS
SCALE, PATTERN, AND PROCESS
SYSTEMS IN PHYSICAL GEOGRAPHY
TIME CYCLES

Physical Geography, Environment, and Global Change
GLOBAL CLIMATE CHANGE
THE CARBON CYCLE
BIODIVERSITY
 POLLUTION
EXTREME EVENTS

Tools in Physical Geography
Maps and Cartography
MAP PROJECTIONS
SCALES OF GLOBES AND MAPS
SMALL-SCALE AND LARGE-SCALE MAPS
CONFORMAL AND EQUAL-AREA MAPS
INFORMATION CONTENT OF MAPS
MAP SYMBOLS
PRESENTING NUMERICAL DATA ON THEMATIC MAPS

The Global Positioning System

Geographic Information Systems
SPATIAL OBJECTS IN GEOGRAPHIC INFORMATION SYSTEMS
KEY ELEMENTS OF A GIS

Remote Sensing for Physical Geography
COLORS AND SPECTRAL SIGNATURES
THERMAL INFRARED SENSING
RADAR
DIGITAL IMAGING
ORBITING EARTH SATELLITES

Earth Visualization Tools
GOOGLE EARTH
OTHER EARTH VISUALIZATION TOOLS
Introducing Geography

What is geography? Put simply, geography is the study of the evolving character and organization of the Earth’s surface. It is about how, why, and where human and natural activities occur and how these activities are interconnected.¹

What makes geography different from other disciplines? Geography adopts a unique set of perspectives to analyze the world and its human and natural phenomena. These perspectives include the spatial viewpoint of geographers, the interest of geographers in the synthesis of ideas across the boundaries of conventional studies, and geographers’ usage of tools to represent and manipulate spatial information and spatial phenomena. Figure I.1 shows these perspectives in the form of a cube with each perspective displayed on a different face.

The first unique perspective of geography is its spatial viewpoint. Geographers are interested not only in how something happens, but also where it happens and how it is related to other happenings nearby and far away. The spatial viewpoint can focus at three levels. At the place level, geographers study how processes are integrated at a single location or within a single region. For example, an urban geographer may study the spatial structure of a particular city—how and where neighborhoods and commercial centers develop and take on their unique characteristics. Or a physical geographer may study the ecology, climate, and soils of a national park. At the space level, geographers look at how places are interdependent. An economic geographer may examine how flows of goods, information, or money connect cities and towns that are of different sizes and at different distances apart. Or a physical geographer may map the sources of sediment flowing into a river and chart their downstream effects. Geographers also look at human and natural activities at different

Physical Geography and the Tools Geographers Use

Geography as a discipline has a unique set of perspectives. Geographers look at the world from the viewpoint of geographic space, focus on synthesizing ideas from different disciplines, and develop and use special techniques to represent and manipulate spatial information.

scales, sometimes zooming in for a close look at something small or pulling back for an overview of something large. Often what looks important at one scale is less important at another.

The second perspective of geography is synthesis. Geographers are very interested in putting ideas together from different fields and assembling them in new ways—a process called synthesis. Of particular interest to geographers are studies that link conventional areas of study. In physical geography, for example, a biogeographer may investigate how streamside vegetation affects the flood flow of rivers, thus merging the physical geography subfields of ecology and hydrology. A human geographer may study how economic innovation—developing new kinds of goods and services—varies from region to region according to cultural and legal factors, thus merging the human geography subfields of economics, politics, and sociology. The many connections between environmental processes and human activities are also subjects of geographic synthesis. For example, a classic study area in geography is perception of hazards—why do people build houses next to rivers or beaches when it is only a matter of time before floods or storms will wash their homes away? Here, geographers study the interaction of hydrology with perception and cognitive learning.

The third perspective of geography is geographic representation. Here, geographers develop and perfect tools for representing and manipulating information spatially. Cartography—the art and science of making and drawing maps—is a subfield of geography that focuses on visual display of spatial relationships. Visual display also includes remote sensing—acquiring images of the Earth from aircraft or spacecraft and enhancing them to better display spatial information. Verbal descriptions use the power of words to explain or evoke geographic phenomena. Mathematical and statistical models predict how a phenomenon of interest varies over space and through time. Geographic information systems store, manipulate, and display spatial information in very flexible ways. Cognitive representation refers to spatial relationships as they are stored in the human brain—mental mapping of real space into the subjective space that people experience.

Taken together, the perspectives of viewpoint, synthesis, and representation define geography as a unique discipline that focuses on how the natural and human patterns of the Earth’s physical and cultural landscape change and interact in space and time.

Another way to illustrate geographic perspectives is by an example—Vancouver, British Columbia, illustrated in Figure I.2. The image, a visual display, shows a place, the central city of Vancouver, set in the space of the Strait of Georgia and Pacific and Vancouver Island Ranges and imaged at a local scale. In the geographer’s view, Vancouver is a unique landscape shaped by both environmental and human processes and their interactions.

HUMAN AND PHYSICAL GEOGRAPHY

Like many other areas of study, geography can be regarded as having a number of subfields, each with a different focus but often overlapping and interlocking with other subfields. We can organize these subfields into two broad realms—human geography, which deals with social, economic and behavioral processes that differentiate places, and physical geography, which examines the natural processes occurring at the Earth’s surface that provide the physical setting for human activities. Figure I.3 is a diagram showing the principal fields of physical and human geography. Reading downward from the left, we see five fields of physical geography, from climatology to biogeography, which are illustrated in Figure I.4. These topics are the main focus of this text.

Climatology is the science that describes and explains the variability in space and time of the heat and moisture states of the Earth’s surface, especially its land surfaces. Since heat and moisture states are part of what we call weather, we can think of climate as a description of average weather and its variation at places around the world. Chapters 1–7 will familiarize you with the essentials of climatology, including the processes that control the weather we experience daily. Climatology is also concerned with climate change, both past and future. One of the most rapidly expanding and challenging areas of climatology is global climate modeling, which we touch on in several chapters. This field attempts to predict how human activities, such as converting land from forest to agriculture or releasing CO₂ from fossil fuel burning, will change global climate.

Geomorphology is the science of Earth surface processes and landforms. The Earth’s surface is constantly being altered under the combined influence of human and natural factors. The work of gravity in the collapse and movement of Earth materials, as well as the work of flowing water, blowing wind, breaking waves, and moving ice, acts to remove and transport soil and rock and to sculpt a surface that is constantly being renewed through volcanic and tectonic activity. The closing chapters of our book (Chapters 12–17) describe...
1.2 Vancouver, British Columbia

This cosmopolitan city enjoys a spectacular setting on the Strait of Georgia, flanked by the Pacific and Vancouver Island Ranges.

**EYE ON THE LANDSCAPE**  What else would the geographer see? (A) For the physical geographer, Vancouver’s environment combines snow-capped peaks eroded by glaciers, conifer forests adapted to the cool, maritime climate, and an arm of the ocean that erodes the coast by wave and tidal action. (B) For the human geographer, the image shows a center of economic activity marked by Vancouver’s office and residential towers. Areas of low buildings document the differentiation of the city into districts with different characters and history. The road and freeway network demonstrates the city’s reliance on cars and trucks to move people and goods within the city. (C) The physical environment interacts with human activity through Vancouver’s role as a port city, where land- and water-borne transportation modes meet. Large commercial vessels in the bay mingle with sailboats and powerboats, showing the importance of the city’s marine setting to both shipping and recreation.

these geomorphic processes, while the basic geologic processes that provide the raw material are covered in Chapters 11–12. Modern geomorphology also focuses on modeling landform-shaping processes to predict both short-term, rapid changes, such as landslides, floods, or coastal storm erosion, and long-term, slower changes, such as soil erosion in agricultural areas or as a result of strip mining.

The field of **coastal and marine geography** combines the study of geomorphic processes that shape shores and coastlines with their application to coastal development and marine resource utilization. Chapter 16 describes these processes and provides some perspectives on problems of human occupation of the coastal zone.

**Geography of soils** includes the study of the distribution of soil types and properties and the processes of soil formation. It is related to both geomorphic processes of rock breakup and weathering, and to biological processes of growth, activity, and decay of organisms living in the soil (Chapter 10). Since both geomorphic and biologic processes are influenced by the surface temperature and availability of moisture, broad-scale soil patterns are often related to climate.
Biogeography, covered in Chapters 8 and 9, is the study of the distributions of organisms at varying spatial and temporal scales, as well as the processes that produce these distribution patterns. Local distributions of plants and animals typically depend on the suitability of the habitat that supports them. In this application, biogeography is closely aligned with ecology, which is the study of the relationship between organisms and environment. Over broader scales and time periods, the migration, evolution, and extinction of plants and animals are key processes that determine their spatial distribution patterns. Thus, biogeographers often seek to reconstruct past patterns of plant and animal communities from fossil evidence of various kinds. Biodiversity—the assessment of biological diversity from the perspective of maintaining the diversity of life and life-forms on Earth—is a biogeographic topic of increasing importance as human impact on the environment continues. The present global-scale distribution of life-forms as the great biomes of the Earth provides a basic context for biodiversity.

In addition to these five main fields of physical geography, two others are strongly involved with applications of physical geography—water resources and hazards assessment. Water resources is a broad field that couples basic study of the location, distribution, and movement of water, for example, in river systems or as ground water, with the utilization and quality of water for human use. This field involves many aspects of human geography, including regional development and planning, political geography, and agriculture and land use. We touch on water resources briefly in this book by discussing water wells, dams, and water quality in Chapters 14 and 15.

Hazard assessment is another field that blends physical and human geography. What are the risks of living next to a river, and how do inhabitants perceive those risks? What is the role of government in protecting citizens from floods or assisting them in recovery from flood damages? Answering questions such as these requires not only knowledge of how physical systems work, but also how humans perceive and interact with their physical environment as both individuals and as societies. In this text, we develop an understanding of the physical processes of floods, earthquakes, landslides, and other disaster-causing natural events as a background for appreciating hazards to humans and their activities.

Many of the remaining fields of human geography have linkages with physical geography. For example, climatic and biogeographic factors may determine the spread of disease-carrying mosquitoes (medical geography). Mountain barriers may isolate populations and increase the cost of transporting goods from one place to another (cultural geography, transportation geography). Unique landforms and landscapes may be destinations for tourism (geography of recreation, tourism, and sport). Nearly all human activities take place in a physical environment that varies in space and time, so the physical processes that we examine in this text provide a background useful for further learning in any of geography’s fields.
1.4 Fields of physical geography

▲ Climatology  Climatology studies the transfers of energy and matter between the surface and atmosphere that control weather and climate.

▲ Geomorphology  Geomorphology is the study of landform-making processes.

▼ Coastal and marine geography  Coastal and marine geography examines coastal processes, marine resources, and their human interface.
Biogeography

Biogeography examines the distribution patterns of plants and animals and relates them to environment, migration, evolution, and extinction.

Geography of soils
Soils are influenced by their parent material, climate, biota, and time.
Spheres, Systems, and Cycles

As a part of your introduction to physical geography, it will be useful to take a look at the big picture and examine some ideas that arch over all of physical geography—that is, spheres, systems, and cycles. The first of these ideas is that of the four great physical realms, or spheres of Earth—atmosphere, lithosphere, hydrosphere, and biosphere. These realms are distinctive parts of our planet with unique components and properties. Another big idea is that of systems—viewing the processes that shape our landscape as a set of interrelated components that comprise a system. The systems viewpoint stresses linkages and interactions and helps us to understand complex problems, such as global climate change or loss of biodiversity. The last big idea is that of cycles—regular changes in systems that reoccur through time.

THE SPHERES—FOUR GREAT EARTH REALMS

The natural systems that we will encounter in the study of physical geography operate within the four great realms, or spheres, of the Earth. These are the atmosphere, the lithosphere, the hydrosphere, and the biosphere (Figure I.5).

The atmosphere is a gaseous layer that surrounds the Earth. It receives heat and moisture from the surface and redistributes them, returning some heat and all the moisture to the surface. The atmosphere also supplies vital elements—carbon, hydrogen, oxygen, and nitrogen—that are needed to sustain life.

The outermost solid layer of the Earth, or lithosphere, provides the platform for most Earthly life-forms. The solid rock of the lithosphere bears a shallow layer of soil in which nutrient elements become available to organisms. The surface of the lithosphere is sculpted into landforms. These features—such as mountains, hills, and plains—provide varied habitats for plants, animals, and humans.

The liquid realm of the Earth is the hydrosphere, which is principally the mass of water in the world’s oceans. It also includes solid ice in mountain and continental glaciers, which, like liquid ocean and fresh water, is subject to flow under the influence of gravity. Within the atmosphere, water occurs as gaseous vapor, liquid droplets, and solid ice crystals. In the lithosphere, water is found in the uppermost layers in soils and in ground water reservoirs.
The biosphere encompasses all living organisms of the Earth. Life-forms on Earth utilize the gases of the atmosphere, the water of the hydrosphere, and the nutrients of the lithosphere, and so the biosphere is dependent on all three of the other great realms. Figure I.6 diagrams this relationship.

Most of the biosphere is contained in the shallow surface zone called the life layer. It includes the surface of the lands and the upper 100 m or so (about 300 ft) of the ocean (Figure I.6). On land, the life layer is the zone of interactions among the biosphere, lithosphere, and atmosphere, with the hydrosphere represented by rain, snow, still water in ponds and lakes, and running water in rivers. In the ocean, the life layer is the zone of interactions among the hydrosphere, biosphere, and atmosphere, with the lithosphere represented by nutrients dissolved in the upper layer of sea water. Throughout our exploration of physical geography, we will often refer to the life layer and the four realms that interact within it.

**SCALE, PATTERN, AND PROCESS**

As we saw earlier, geographers have unique perspectives that characterize a geographic approach to understanding the physical and human organization of the Earth’s surface. Three interrelated themes that often arise in geographic study are scale, pattern, and process. Scale refers to the level of structure or organization at which a phenomenon is studied. Pattern refers to the variation in a phenomenon that is seen at a particular scale. Process describes how the factors that affect a phenomenon act to produce a pattern at a particular scale.

To make these ideas more real, imagine yourself as an astronaut, returning to Earth from a voyage to the Moon. As you approach the Earth and finally touch down on land, your view of our planet takes in scales ranging from global to local. As the scale changes, so do the patterns and processes that you observe (Figure I.7).

At the global scale, you see the Earth’s major physical features—oceans of blue water, continents of brown Earth, green vegetation, and white snow and ice, and an atmosphere of white clouds and clear air. The pattern of land and ocean is created by the processes of plate tectonics, which shape land masses and ocean basins across the eons of geologic time. The pattern of white clouds, which includes a band of persistent clouds near the Earth’s equator and spirals of clouds moving across the globe, is created by atmospheric circulation processes that depend on solar heating coupled with the Earth’s slow rotation on its axis. These processes act much more quickly and on a finer spatial scale than those of plate tectonics.

At the continental scale, we see the broad differentiation of land masses into regions of dry desert and moister vegetated regions, a pattern caused by atmospheric processes that provide some areas with more precipitation than others. In some regions, air temperatures keep liquid water frozen, producing sea ice and glaciers. Air temperature and precipitation are the basic elements of climate, and so we may regard climate as a major factor affecting the landscape on a continental level.

At the regional scale, mountain ranges, deserts, lakes, and rivers create a varied pattern caused by interaction between geologic processes that raise mountains and lower valleys with atmospheric processes that provide water to run off the continents while supporting the growth of vegetation. Also evident at the regional scale are broad patterns of human activity, such as the deforestation of the Amazon (Figure 1.7C). Agricultural regions are clearly visible, distinguished by repeating geometric patterns of fields.

At the local scale, we zoom in on a landscape showing a distinctive pattern in fine detail. For example, our image of the San Francisco Bay region (Figure I.7D) reveals both the natural processes that carve hillslopes and canyons from mountain masses and the human processes that superimpose city and suburb on the natural landscape. At the finest scale, we see individual-scale landscape features, such as sand dunes, bogs, or freeways, each of which is the result of a different process.

These examples illustrate the themes of scale, pattern, and process as they apply to the landscapes of our planet. Keep in mind, however, that these themes are quite general ones. Throughout this book, we will see many examples of scale, pattern, and process applied to such diverse phenomena as climate, vegetation, soils, and landforms. We will zoom in and out, examining processes at local scales and applying them to regions to create and explain broad patterns observed at continental and global scales.
I.7 Scale, pattern, and process

As the Earth is viewed at increasingly finer scales, different patterns, created by different processes, emerge.

- **Global scale** At the global scale, the major surface features of the Earth and atmospheric circulation are readily visible.

- **Continental scale** At the continental scale, climate determines the pattern of vegetation. Here, green colors indicate healthy vegetation, with reds and browns showing sparse vegetation cover and desert.

In this way, you will gain a better understanding of how the Earth’s surface changes and evolves in response to natural and human activities.

**SYSTEMS IN PHYSICAL GEOGRAPHY**

The processes that interact within the four realms to shape the life layer and differentiate global environments are varied and complex. A helpful way to understand the relationships among these processes is to study them as systems. “System” is a common English word that we use in everyday speech. It typically means a set or collection of things that are somehow related or organized. An example is the solar system—a collection of planets that revolve around the Sun. In the text, we will use the word “system” in this way quite often. Sometimes it refers to a scheme for naming things. For example, we will introduce a climate system in Chapter 7 and a soil classification system in Chapter 10. However, we will also use system to mean a group of interrelated processes that operate simultaneously in the physical landscape.

When we study physical geography using a systems approach, we look for linkages and interactions among processes. For example, global warming should enhance the process of evaporation of water from oceans and moist land surfaces, generating more clouds. But an increase in clouds also affects the process of solar reflection, in which white, fleecy clouds reflect solar radiation back out to space. This leaves less radiation to be absorbed by the atmosphere and surface and so should tend to cool our planet, reducing global warming. This is actually an example of negative feedback, in which one process counteracts another process to reduce its impact. (We’ll present more information about this topic in Chapter 6.) Throughout the text there will be more examples of this systems viewpoint in physical geography.²

**TIME CYCLES**

Many natural systems show time cycles—rhythms in which processes change in a regular and repeatable fashion. For example, the annual revolution of the Earth around the Sun generates a time cycle of incoming solar energy flow. We speak of this cycle as the rhythm of the

Regional scale
At the regional scale, broad patterns of human activity are visible, such as this example of deforestation in Rondonia, in the Brazilian Amazon.

Local scale
At the local scale, the details of development emerge, as well as the shapes of individual landforms.

seasons. The rotation of the Earth on its axis sets up the night-and-day cycle of darkness and light. The Moon, in its monthly orbit around the Earth, sets up its own time cycle, which we see in ocean tides.

The astronomical time cycles of Earth rotation and solar revolution appear at several places in our early chapters. Other time cycles with durations of tens to hundreds of thousands of years describe the alternate growth and shrinkage of the great continental ice sheets. Still others, with durations of millions of years, describe cycles of the solid Earth in which supercontinents form, break apart, and re-form anew.

Physical Geography, Environment, and Global Change
Physical geography is concerned with the natural world around us—in short, with the human environment. Because natural processes are constantly active, the Earth’s environments are constantly changing (Figure I.8). Sometimes the changes are slow and subtle, as when crustal plates move over geologic time to create continents and ocean basins. At other times, the changes are rapid, as when hurricane winds flatten vast areas of forests or even tracts of houses and homes.

Environmental change is now produced not only by the natural processes that have acted on our planet for millions of years but also by human activity. The human race has populated our planet so thoroughly that few places remain free of some form of human impact. Global change, then, involves not only natural processes, but also human processes that interact with them. Physical geography is the key to understanding this interaction.

Environment and global change are sufficiently important that we have set off these topics by placing them in special sections identified with Eye on Global Change that open each chapter. What are some of the important topics in global change that lie within physical geography? Let’s examine a few.

GLOBAL CLIMATE CHANGE
Are human activities changing global climate? It seems that almost every year we hear that it has been the hottest year, or one of the hottest years, on record. But climate is notoriously variable. Could such a string of hot years be part of the normal variation? This is the key question facing scientists studying global climate...
I.8 Dimensions of global change

The dimensions of global change touch on many human activities.

- **Global climate change** Is the Earth’s climate changing? Nearly all global change scientists have concluded that human activities have resulted in climate warming and that weather patterns, shown here in this satellite image of clouds and weather systems over the Pacific Ocean, are changing.

- **Carbon cycle** Clearcutting of timber, shown here on the Olympic Peninsula, Washington, removes carbon from the landscape, while regrowth returns carbon through photosynthesis.

- **Biodiversity** Reduction in the area and degradation of the quality of natural habitats is reducing biodiversity. The banks of this stream in the rainforest of Costa Rica are lined with several species of palms.

- **Pollution** Human activity can create pollution of air and water, causing change in natural habitats as well as impacts on human health. The discharge from this pulp mill near Port Alice, British Columbia, is largely water vapor, but pulp mill pollutants often include harmful sulfur oxides.

- **Extreme events** Hurricanes, severe storms, droughts, and floods may be becoming more frequent as global climate warms. A tornado flattened this neighborhood in Kansas City, Kansas, May 2003.
change. Over the past decade, nearly all scientists have come to the opinion that human activity has, indeed, begun to change our climate. How has this happened?

The answer lies in the greenhouse effect. As human activities continue to release gases that block heat radiation from leaving the Earth, the greenhouse effect intensifies. The most prominent of these gases is CO$_2$, which is released by fossil fuel burning. Others include methane (CH$_4$), nitrous oxide (NO), and the chlorofluorocarbons that until recently served as coolants in refrigeration and air conditioning systems and as aerosol spray propellants. Taken with other gases, they act to raise the Earth’s surface temperature, with consequences including dislocation of agricultural areas, rise in sea level, and increased frequency of extreme weather events, such as severe storms or record droughts.

Climate change is a recurring theme throughout this book, ranging from the urban heat island effect that tends to raise city temperatures (Chapter 3) to the El Niño phenomenon that alters global atmospheric and ocean circulation (Chapter 5), to the effect of clouds on global warming (Chapter 6), and to rising sea level due to the expansion of sea water with increasing temperature (Chapter 16).

THE CARBON CYCLE

One way to reduce human impact on the greenhouse effect is to slow the release of CO$_2$ from fossil fuel burning. But since modern civilization depends on the energy of fossil fuels to carry out almost every task, reducing fossil fuel consumption to stabilize the increasing concentration of CO$_2$ in the atmosphere is not easy. However, some natural processes reduce atmospheric CO$_2$. Plants withdraw CO$_2$ from the atmosphere by taking it up in photosynthesis to construct plant tissues, such as cell walls and wood. In addition, CO$_2$ is soluble in sea water. These two important pathways, by which carbon flows from the atmosphere to lands and oceans, are part of the carbon cycle. Biogeographers and ecologists are now focusing in detail on the global carbon cycle in order to better understand the pathways and magnitudes of carbon flow. They hope that this understanding will suggest alternative actions that can reduce the rate of CO$_2$ buildup without penalizing economic growth. The processes of the carbon cycle are described in Chapter 8.

BIODIVERSITY

Among scientists, environmentalists, and the public, there is a growing awareness that the diversity in the plant and animal forms harbored by our planet—the Earth’s biodiversity—is an immensely valuable resource that will be cherished by future generations. One important reason for preserving as many natural species as possible is that, over time, species have evolved natural biochemical defense mechanisms against diseases and predators. These defense mechanisms involve bioactive compounds that can sometimes be very useful, ranging from natural pesticides that increase crop yields to medicines that fight human cancer.

Another important reason for maintaining biodiversity is that complex ecosystems with many species tend to be more stable and to respond better to environmental change. If human activities inadvertently reduce biodiversity significantly, there is a greater risk of unexpected and unintended human effects on natural environments. Biogeographers focus on both the existing biodiversity of the Earth’s many natural habitats and the processes that create and maintain biodiversity. These topics are treated in Chapters 8 and 9.

Human activity is reducing the biodiversity of many of the Earth’s natural habitats. Environmental pollution degrades habitat quality for humans as well as other species. Extreme weather events, which will become more frequent with human-induced climate change, as well as other rare natural events, are increasingly destructive to our expanding human population.

POLLUTION

As we all know, unchecked human activity can degrade environmental quality. In addition to releasing CO$_2$, fuel burning can yield gases that are hazardous to health, especially when they react to form such toxic compounds as ozone and nitric acid in photochemical smog. Water pollution from fertilizer runoff, toxic wastes of industrial production, and acid mine drainage can severely degrade water quality. Such degradation impacts not only the ecosystems of streams and rivers, but also the human populations that depend on rivers and streams as sources of water supply. Ground water reservoirs can also be polluted or turn salty in coastal zones when drawn down excessively.

Environmental pollution, its causes, its effects, and the technologies used to reduce pollution, form a subject that is broad in its own right. As a text in physical geography that emphasizes the natural processes of the Earth’s land surface, we touch on air and water pollution in several chapters—Chapter 4 for air pollution and Chapter 14 for surface water pollution, irrigation effects, and ground water contamination.
EXTREME EVENTS

Catastrophic events—floods, fires, hurricanes, earthquakes, and the like—can have great and long-lasting impacts on both human and natural systems. Are human activities increasing the frequency of these extreme events? As our planet warms in response to changes in the greenhouse effect, global climate modelers predict that weather extremes will become more severe and more frequent. Droughts and consequent wildfires and crop failures will happen more often, as will spells of rain and flood runoff. In the last decade, we have seen numerous examples of extreme weather events, from Hurricane Katrina in 2005—the most costly storm in U.S. history—to the Southeast drought of 2007, which devastated crops in large parts of the southeastern United States. Is human activity responsible for the increased occurrence of these extreme events? Significant evidence now points in that direction.

Other extreme events, such as earthquakes, volcanic eruptions, and seismic sea waves (wrongly called tidal waves), are produced by forces deep within the Earth that are not affected by human activity. But as the human population continues to expand and comes to rely increasingly on a technological infrastructure ranging from skyscrapers to the Internet, we are becoming more sensitive to damage and disruption of these systems by extreme events.

This text describes many types of extreme events and their causes. In Chapters 4 and 6, we discuss thunderstorms, tornadoes, cyclonic storms, and hurricanes. Droughts in the African Sahel are presented in Chapter 7. Earthquakes, volcanic eruptions, and seismic sea waves are covered in Chapter 12. Floods are described in Chapter 14.

Tools in Physical Geography

Geographers use a number of specialized tools to examine, explore, and interact with spatial data (Figure I.9). One of the oldest tools is the map—a paper representation of space showing where things are. While maps will never go out of style, computers have enhanced our ability to store, retrieve, and analyze spatial data through the development of geographic information systems (GIS). Acquiring geographic information for input to GIS has recently been made much easier through use of the global positioning system (GPS), which allows hand-held electronic equipment, linked to signals from orbiting spacecraft, to easily determine the exact latitude, longitude, and elevation of any point on the Earth’s surface to within a few meters.

Satellites bearing imaging instruments have provided a wealth of information about the Earth’s surface layers, including land, oceans, and atmosphere, that is vital to geographic study. The field of processing, enhancing, and analyzing images and measurements made from aircraft and spacecraft is known as remote sensing. Recent developments linking remote sensing, GIS, and GPS with the Internet have produced new Earth visualization tools, such as Google Earth, that are also of great interest to geographers.

Tools in geography also include mathematical modeling and statistics. Using math and computers to model geographic processes is a powerful approach to understanding both natural and human phenomena. Statistics provides methods that can be used to manipulate geographic data so that we can ask and answer questions about differences, trends, and patterns. Because these tools rely heavily on specialized knowledge, they are not included here. Our text does, however, present many examples of geographic information obtained using modeling and statistics.

Maps and Cartography

Cartography is the field of geography concerned with making maps. A map is a paper representation of space showing point, line, or area data—that is, locations, connections, and regions. It typically displays a set of characteristics or features of the Earth’s surface that are positioned on the map in much the same way that they occur on the surface. The map’s scale links the true distance between places with the distance on the map.

Maps play an essential role in the study of physical geography because much of the information content of geography is stored and displayed on maps. Map literacy—the ability to read and understand what a map shows—is a basic requirement for day-to-day functioning in our society. Maps appear in almost every issue of a newspaper and in nearly every TV newscast. Most people routinely use highway maps and street maps. Maps also pop up on web sites. The purpose of this part of our chapter is to provide additional information on the art and science of maps.

MAP PROJECTIONS

Cartographers record position on the Earth’s surface using latitude and longitude. You’ll read more about latitude and longitude in Chapter 1, but for now, you probably know that latitude measures position in a north-south direction and that longitude measures position in an east-west direction. Lines of equal latitude are parallels, and lines of equal longitude are meridians.
1.9 Tools of Physical Geography

Geographers rely on specialized tools to analyze spatial data.

▲ Cartography A portion of the U.S. Geological Survey 1:24,000 topographic map of Green Bay, Wisconsin. Using symbols, the map shows creeks and rivers, a bay, swampy regions, urban developed land, streets, roads, and highways.

▲ Geographic information systems (GIS) Computer programs that store and manipulate geographic data are essential to modern applications of geography. This screen from the ARCInfo GIS program package shows earthquake centers in eastern Asia superimposed on a political map underlain by a shaded relief map of undersea topography.

▼ Remote sensing Remote sensing includes observing the Earth from the perspective of an aircraft or spacecraft. Wildfires on the Greek island of Peloponnesos, seen in a Landsat image from July 2000, are an example.

▲ Mathematical modeling By describing a phenomenon using a mathematical model, a geographer can predict outcomes and examine “what-if” scenarios. These equations demonstrate the calculation of an exponential growth factor.

▲ Statistics Statistical tools, such as this graph, allow the exploration of geographic data to determine trends and develop mathematical models. The plot shows the value of the Southern Oscillation Index, an indicator of El Niño conditions.

\[
M = e^{RT} = e^{0.04 \times 20} = 2.718^{0.80} = 2.26
\]
A map projection is an orderly system of lines of latitude and longitude used as a base to draw a map on a flat surface. A projection is needed because the Earth’s surface is not flat but, rather, curved in a shape that is very close to the surface of a sphere. All map projections misstate the shape of the Earth in some way. It’s simply impossible to transform a spherical surface to a flat (planar) surface without violating the true surface as a result of cutting, stretching, or otherwise distorting the information that lies on the sphere.

Perhaps the simplest of all map projections is a grid of perfect squares. In this simple map, horizontal lines are parallels and vertical lines are meridians. They are equally spaced in degrees, so this projection is sometimes called an equal-angle grid. A grid of this kind can show the true spacing (approximately) of the parallels, but it fails to show how the meridians converge toward the two poles. This convergence causes the grid to fail dismally in high latitudes, and the map usually has to be terminated at about 70° to 80° north and south.

Early attempts to find satisfactory map projections made use of a simple concept. Imagine the spherical Earth grid as a cage of wires located on meridians and parallels. A tiny light source is placed at the center of the cage, and the image of the wire grid is cast upon a surface outside the sphere. This situation is like a reading lamp with a lampshade. Basically, three kinds of “lampshades” can be used, as shown in Figure I.10.

First is a flat paper disk perched on the north pole. The shadow of the wire grid on this plane surface will appear as a combination of concentric circles (parallels) and radial straight lines (meridians). Here we have a polar-centered, or polar projection. Second is a cone of paper resting point-up on the wire grid. The cone can be slit down the side, unrolled, and laid flat to produce a map that is some part of a full circle. This is called a conic projection. Parallels are arcs of circles, and meridians are radiating straight lines. Third, a cylinder of paper can be wrapped around the wire sphere so as to be touching all around the equator. When slit down the side along a meridian, the cylinder can be unrolled to produce a cylindrical projection, which is a true rectangular grid.

None of these three projection methods can show the entire Earth grid, no matter how large a sheet of paper is used to receive the image. Obviously, if the entire Earth grid, or large parts of it, are to be shown, some quite different system must be devised. In Chapter 1, we describe three types of projections used throughout the
book—the polar projection; the Mercator projection, which is a cylindrical projection; and the Winkel Tripel projection, which uses special mathematics that provide minimum distortion in a global map.

**SCALES OF GLOBES AND MAPS**

All globes and maps depict the Earth’s features in much smaller size than the true features they represent. Globes are intended in principle to be perfect scale models of the Earth itself, differing from the Earth only in size. The scale of a globe is the ratio between the size of the globe and the size of the Earth, where “size” is some measure of length or distance (but not of area or volume).

Take, for example, a globe 20 cm (about 8 in.) in diameter, representing the Earth, which has a diameter of about 13,000 km. The scale of the globe is the ratio between 20 cm and 13,000 km. Dividing 13,000 by 20, we see that one centimeter on the globe represents 650 kilometers on the Earth. This relationship holds true for distances between any two points on the globe.

Scale is often stated as a simple fraction, termed the scale fraction. It can be obtained by reducing both Earth and globe distances to the same unit of measure, which in this case is centimeters. (There are 100,000 centimeters in one kilometer.) The advantage of the scale fraction is that it is entirely free of any specified units of measure, such as the foot, mile, meter, or kilometer. It is usually written as a fraction with a numerator of one using either a colon or with the numerator above the denominator. For the example shown above, the scale fraction is obtained by reducing \( \frac{20}{1300000000} \) to \( \frac{1}{65000000} \) or 1:65,000,000.

In contrast to a globe, a flat map cannot have a constant scale. In flattening the curved surface of the sphere to conform to a plane surface, all map projections stretch the Earth’s surface in a nonuniform manner, so that the map scale changes from place to place. However, it is usually possible to select a meridian or parallel—the equator, for example—for which a scale fraction can be given, relating the map to the globe it represents.

**SMALL-SCALE AND LARGE-SCALE MAPS**

When geographers refer to small-scale and large-scale maps, they mean the value of the scale fraction. For example, a global map at a scale of 1:65,000,000 has a scale fraction value of 0.00000001534, which is obtained by dividing 1 by 65,000,000. A hiker’s topographic map might have a scale of 1:25,000, for a scale value of 0.000040. Since the global-scale value is smaller, it is a small-scale map, while the hiker’s map is a large-scale map.

Note that this contrasts with common use of the terms large-scale and small-scale. When we refer in conversation to a large-scale phenomenon or effect, we typically refer to something that takes place over a large area and that is usually best presented on a small-scale map.

Maps of large scale show only small sections of the Earth’s surface. Because they “zoom in,” they are capable of carrying an enormous amount of geographic information in a convenient and an effective manner. Most large-scale maps carry a graphic scale, which is a line marked off into units representing kilometers or miles. Figure I.11 shows a portion of a large-scale map on which sample graphic scales in miles, feet, and kilometers are superimposed. Graphic scales make it easy to measure ground distances.

For practical reasons, maps are printed on sheets of paper usually less than a meter (3 ft) wide, as in the case of the ordinary highway map or navigation chart. Bound books of maps—atlases, that is—usually have pages no larger than 30 by 40 cm (about 12 by 16 in.), whereas maps found in textbooks and scientific journals are even smaller.

**CONFORMAL AND EQUAL-AREA MAPS**

With regard to the map projections shown in Figure I.10, it seems obvious that the shape and area of a small feature, like an island or peninsula, will change as the feature is projected from the surface of the globe to a map. With some projections, the area will change, but the shape will be preserved. Such a projection is referred to as conformal. The Mercator projection (Figure 1.11) is an example. Here, every small twist and turn of the shoreline of each continent is shown in its proper shape. However, the growth of the continents with increasing latitude shows that the Mercator projection does not depict land areas uniformly. A projection that does show area uniformly is referred to as equal-area. Here continents show their relative areas correctly, but their shapes are distorted. No projection can be both conformal and equal-area—only a globe has that property.

**INFORMATION CONTENT OF MAPS**

The information conveyed by a map projection grid system is limited to one category only: absolute location of points on the Earth’s surface. To be more useful, maps also carry other types of information. Figure I.11 is a portion of a large-scale multipurpose map. Map sheets published by national governments, such as this one, are usually multipurpose maps. Using a great variety of symbols, patterns, and colors, these maps carry a high information content. Appendix 3 shows a larger...
show objects in their true outline form. As map scale is decreased, representation becomes more and more generalized. In physical geography, an excellent example is the depiction of a river, such as the lower Mississippi, shown in Figure I.13. The level of depiction of fine detail in a map is described by the term resolution. Maps
Maps of the Mississippi River on three scales. (Maps slightly enlarged for reproduction.)

![1:20,000 scale](image1) This map shows a detailed plan of the river and even includes contours on the river bed.

![1:250,000 scale](image2) At this scale, the river is depicted by two lines showing its banks and color showing the area of the river.

![1:3,000,000 scale](image3) At a very small scale, the river is shown as a solid line.

PRESENTING NUMERICAL DATA ON THEMATIC MAPS

In physical geography, we often need to display numerical information on maps. Weather data provides an example—here we might wish to display air temperature, air pressure, wind speed, or amount of rainfall. Another category of information consists simply of the presence or absence of something. In this case, we can simply place a dot to mean “present,” so that when entries are completed, the map shows a field of scattered dots (Figure I.14).

In some scientific programs, measurements are taken uniformly, for example, at the centers of grid squares laid over a map. For many classes of data, however, the locations of the observation points are predetermined by a fixed and nonuniform set of observing stations. For example, weather and climate data are often collected at stations typically located at airports. Whatever the
Table I.1 Examples of Isopleths

<table>
<thead>
<tr>
<th>Name of Isopleth</th>
<th>Greek Root</th>
<th>Property Described</th>
<th>Examples in Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isobar</td>
<td>barros, weight</td>
<td>Barometric pressure</td>
<td>5.17</td>
</tr>
<tr>
<td>Isotherm</td>
<td>therme, heat</td>
<td>Temperature of air, water, or soil</td>
<td>3.20</td>
</tr>
<tr>
<td>Isotach</td>
<td>tachos, swift</td>
<td>Fluid velocity</td>
<td>5.26</td>
</tr>
<tr>
<td>Isohyet</td>
<td>hyetos, rain</td>
<td>Precipitation</td>
<td>4.17</td>
</tr>
<tr>
<td>Isohypse</td>
<td>hypso, height</td>
<td>Elevation</td>
<td>19.9</td>
</tr>
<tr>
<td>(topographic contour)</td>
<td></td>
<td></td>
<td>19.10</td>
</tr>
</tbody>
</table>

Isopleth maps show lines of equal value. Choropleth maps show categorical information associated with particular areas.

Isopleth maps are important in various branches of physical geography. Table I.1 gives a partial list of isopleths of various kinds used in the Earth sciences, together with their names and the kinds of information they display. A special kind of isopleth, the topographic contour (or isohypse), is shown on the maps in Figures I.11, I.13A, and in the portion of the San Rafael topographic map in Appendix 3. Topographic contours show the configuration of land surface features, such as hills, valleys, and basins.

In contrast to the isopleth map is the choropleth map, which identifies information in categories. Our global maps of vegetation (Figure 9.6) and soils (Figure 10.16) are examples of thematic choropleth maps.

Cartography is a rich and varied field of geography with a long history of conveying geographic information accurately and efficiently. If you are interested in maps and mapmaking, you might want to investigate cartography further.

**The Global Positioning System**

The latitude and longitude coordinates of a point on the Earth’s surface describe its position exactly. But how are those coordinates determined? For the last few hundred years, we have known how to use the position of the stars in the sky coupled with an accurate clock to determine the latitude and longitude of any point. Linked with advances in mapping and surveying, these techniques became highly accurate, but they were impractical for precisely determining locations in a short period of time.

Thanks to new technology originally developed by the U.S. Naval Observatory for military applications, there is now in place a global positioning system (GPS) that can provide location information to an accuracy of about 20 meters within a minute or two. The system uses 24 satellites that orbit the Earth every 12 hours, continuously broadcasting their position and a highly accurate time signal (Fig. I.15).

To determine location, a receiver listens simultaneously to signals from four or more satellites. The receiver compares the time readings transmitted by each satellite with the receiver’s own clock to determine how long it took for each signal to reach the receiver. Since the radio signal travels at a known rate of speed, the receiver can convert the travel time into the distance between the receiver and the satellite. Coupling the distance to
each satellite with the position of the satellite in its orbit at the time of the transmission, the receiver calculates its position on the ground to within about 20 m (66 ft) horizontally and 30 m (98 ft) vertically.

The accuracy of the location is affected by several types of errors. One of the larger sources is the effect of the atmosphere on the radio waves of the satellite signal as they pass from the satellite to the receiver. Charged particles at the outer edge of the atmosphere (ionosphere) and water vapor in the lowest atmospheric layer (troposphere) act to slow the radio waves. Since the conditions in these layers can change within a matter of minutes, the speed of the radio waves varies in an unpredictable way. Another transmission problem is that the radio waves may bounce off local obstructions and then reach the receiver, causing two slightly different signals to arrive at the receiver at the same time. This “multipath error” creates noise that confuses the receiver.

There is a way, however, to determine location within about 1 m (3.3 ft) horizontally and 2 m (6.6 ft) vertically. The method uses two GPS units, one at a base station and one that is mobile and used to determine the desired locations. The base station unit is placed at a position that is known with very high accuracy. By comparing its exact position with that calculated from each satellite signal, it determines the small deviations from orbit of each satellite, any small variations in each satellite’s clock, and the exact speed of that satellite’s radio signal through the atmosphere at that moment. It then broadcasts that information to the GPS field unit, where it is used to calculate the position more accurately. Because this method compares two sets of signals, it is known as **differential GPS**.

In North America, differential GPS information is now available everywhere using the **Wide Area Augmentation System** (WAAS), which is provided by the U.S. Federal Aviation Administration and the Department of Transportation. The system includes about 25 ground receiving stations that monitor the signals of GPS satellites and provide a stream of differential correction information. This information is uploaded to a geostationary satellite, where it is rebroadcast to receivers on the ground. A GPS unit with a built-in WAAS receiver can determine position to within a few meters.

The enhanced accuracy of differential GPS is required for coastal navigation, where a few meters in position can make the difference between a shipping channel and a shoal. It is also required for the new generation of aircraft landing systems that will allow much safer instrument landings with equipment that is much lower in cost than existing systems.

As GPS technology has developed, costs have fallen exponentially. It is now possible to buy a small, hand-held GPS receiver for less than $100. Besides plotting your progress on a computer-generated map as you drive your car or sail your boat, GPS technology can even help parents keep track of children at a theme park. And with the coupling of wireless telephones and GPS, you can even get driving directions over your phone.

**GEODESICYSOS** Global Positioning Systems
Watch an animation on the Navistar Global Positioning System to learn more about how the system works.

**Geographic Information Systems**

Maps, like books, are very useful devices for storing information, but they have limitations. Recent advances in computing capability have enabled geographers to develop a powerful new tool to work with spatial data—the **geographic information system** (GIS). A GIS is a computer-based system for acquiring, processing, storing, querying, creating, analyzing, and displaying spatial data. Geographic information systems have allowed geographers, geologists, geophysicists, ecologists, planners, landscape architects, and others to develop applications of spatial data processing ranging from planning land subdivisions on the fringes of suburbia to monitoring the deforestation of the Amazon Basin.

**SPATIAL OBJECTS IN GEOGRAPHIC INFORMATION SYSTEMS**

Geographic information systems are designed to manipulate spatial objects. A **spatial object** is a geographic point, line, or area to which some information is attached. This information may be as simple as a place name or as complicated as a large data table with many types of information. Some spatial objects are illustrated in Figure I.16.

A **point** is a spatial object without an area, only a location. A **line** is also a spatial object with no area, but it has two points associated with it, one for each end of the line. These special points are often referred to as **nodes**. Normally a line is straight, but it can also be defined as a smooth curve having a certain shape. If the two nodes marking the ends of the line are
24 Introduction  Physical Geography and the Tools Geographers Use

Conservation areas
Well locations
Road network
Vegetation types

I.17 Data layers in a GIS
A GIS allows easy overlay of spatial data layers for such queries as “Identify all wells on conservation land.”

I.16 Spatial objects
Spatial objects in a GIS can include points, lines of various types, intersecting lines, and polygons.

Differentiated as starting and ending, then the line has a direction. If the line has a direction, then its two sides can be distinguished. This allows information to be attached to each side—for example, labels for land on one side and water on the other. Lines connect to other lines when they share a common node. A series of connected lines that form a closed chain is a polygon. A polygon identifies an area, the last type of spatial object.

By defining spatial objects in this way, computer-based geographic information systems allow easy manipulation of the objects and permit many different types of operations to compare objects and generate new objects. As an example, suppose we have a GIS data layer composed of conservation land in a region represented as polygons and another layer containing the location of preexisting water wells as points within the region (Figure I.17). It is very simple to use the GIS to identify the wells that are on conservation land. Or the conservation polygons containing wells may also be identified and even output as a new data layer. By comparing the conservation layer with a road network layer portrayed as a series of lines, we could identify the conservation polygons containing roads.

We could also compare the conservation layer to a layer of polygons showing vegetation type, and tabulate the amount of conservation land in forest, grassland, brush, and so forth. We could even calculate distance zones around a spatial object, for example, to create a map of buffer zones that are located within, say, 100 meters of conservation land. Many other possible manipulations exist.

KEY ELEMENTS OF A GIS
A geographic information system consists of five elements: data acquisition, preprocessing, data management, data manipulation and analysis, and product generation. Each is a component or process needed to ensure the functioning of the system as a whole.

In the data acquisition process, data are gathered together for the particular application. These may include maps, air photos, tabular data, and other forms as well. In preprocessing, the assembled spatial data are converted to forms that can be ingested by the GIS to produce data layers of spatial objects and their associated information.

The data management component creates, stores, retrieves, and modifies data layers and spatial objects. It is essential to proper functioning of all parts of the GIS. The manipulation and analysis component is the real workhorse of the GIS. Utilizing this component, the user asks and answers questions about spatial data and creates new data layers of derived information.

The last component of the GIS, product generation, produces output products in the form of maps, graphics, tabulations, or statistical reports that are the end products desired by the users. Taken together, these components provide a system that can serve many geographic applications at many scales.
Many new and exciting areas of geographic research are associated with geographic information systems, ranging from development of new ways to manipulate spatial data to the modeling of spatial processes using a GIS. An especially interesting area is understanding how outputs are affected by errors and uncertainty in spatial data inputs, and how to communicate this information effectively to users.

Geographic information systems is a rapidly growing field of geographic research and application. Given the rate at which computers become ever more powerful as technology improves, we can expect great strides in this field in future years.

Remote Sensing for Physical Geography

Another important geographic technique for acquiring spatial information is remote sensing. This term refers to gathering information from great distances and over broad areas, usually through instruments mounted on aircraft or orbiting spacecraft. These instruments, or remote sensors, measure electromagnetic radiation coming from the Earth’s surface and atmosphere as received at the aircraft or spacecraft platform. The data acquired by remote sensors are typically displayed as images—photographs or similar depictions on a computer screen or color printer—but are often processed further to provide other types of outputs, such as maps of vegetation condition or extent, or of land-cover class. Information obtained can range from fine local detail—such as the arrangement of cars in a parking lot—to a global-scale picture—for example, the “greenness” of vegetation for an entire continent. As you read this textbook, you will see many examples of remote sensing, especially images from orbiting satellites.

All substances, whether naturally occurring or synthetic, are capable of reflecting, transmitting, absorbing, and emitting electromagnetic radiation. For remote sensing, however, we are only concerned with energy that is reflected or emitted by an object and that reaches the remote sensor. For remote sensing of reflected energy, the Sun is the source of radiation in many applications. As we will see in Chapter 2, solar radiation reaching the Earth’s surface is largely in the form of light energy that includes visible, near-infrared, and shortwave infrared light. Remote sensors are commonly constructed to measure radiation reflected from the Earth in all or part of this range of light energy. For remote sensing of emitted energy, the object or substance itself is the source of the radiation, which is related largely to its temperature.

COLORS AND SPECTRAL SIGNATURES

Most objects or substances at the Earth’s surface possess color to the human eye. This means that they reflect radiation differently in different parts of the visible spectrum. Figure I.18 shows how the reflectance of water,

![Reflectance spectra of vegetation, soil, and water](image)

The amount of energy reflected by surfaces of vegetation, soil, and water depends on the wavelength of the light. Note that water vapor in the atmosphere absorbs radiation strongly at wavelengths from about 1.2 to 1.4 µm and 1.75 to 1.9 µm, so it is not possible for a space-borne remote sensor to “see” the surface at those wavelengths.
vegetation, and soil varies with light ranging in wavelength from visible to shortwave infrared. Water surfaces are always dark but are slightly more reflective in the blue and green regions of the visible spectrum. Thus, clear water appears blue or blue-green to our eyes. Beyond the visible region, water absorbs nearly all radiation it receives and so looks black in images acquired in the near-infrared and shortwave infrared regions.

Vegetation appears dark green to the human eye, which means that it reflects more energy in the green portion of the visible spectrum while reflecting somewhat less in the blue and red portions. But vegetation also reflects very strongly in near-infrared wavelengths, which the human eye cannot see. Because of this property, vegetation is very bright in near-infrared images. This distinctive behavior of vegetation—appearing dark in visible bands and bright in the near-infrared—is the basis for much of vegetation remote sensing, as we will see in many examples of remotely sensed images throughout this book.

The soil spectrum shows a slow increase of reflectance across the visible and near-infrared spectral regions and a slow decrease through the shortwave infrared. Looking at the visible part of the spectrum, we see that soil is brighter overall than vegetation and is somewhat more reflective in the orange and red portions. Thus, it appears brown. (Note that this is just a “typical” spectrum—soil color can actually range from black to bright yellow or red.)

We refer to the pattern of relative brightness within the spectrum as the spectral signature of an object or type of surface. Spectral signatures can be used to recognize objects or surfaces in remotely sensed images in much the same way that we recognize objects by their colors. In computer processing of remotely sensed images, spectral signatures can be used to make classification maps, showing, for example, water, vegetation, and soil.

### THERMAL INFRARED SENSING

While objects reflect some of the solar energy they receive, they also emit internal energy as heat that can be remotely sensed. Warm objects emit more thermal radiation than cold ones, so warmer objects appear brighter in thermal infrared images. Besides temperature, the intensity of infrared emission depends on the emissivity of an object or a substance. Objects with higher emissivity appear brighter at a given temperature than objects with lower emissivities. Differences in emissivity affect thermal images. For example, two different surfaces might be at the same temperature, but the one with the higher emissivity will look brighter because it emits more energy.

Some substances, such as crystalline minerals, show different emissivities at different locations in the thermal infrared spectrum. In a way, this is like having a particular color, or spectral signature, in the thermal infrared spectral region. In Chapter 11 we will see examples of how some rock types can be distinguished and mapped using thermal infrared images.

### RADAR

There are two classes of remote sensor systems: passive and active. Passive systems acquire images without providing a source of wave energy. The most familiar passive system is the camera, which uses electronic detectors or photographic film to sense solar energy reflected from the scene. Active systems use a beam of wave energy as a source, sending the beam toward an object or surface. Part of the energy is reflected back to the source, where it is recorded by a detector.

**Radar** is an example of an active sensing system that is often deployed on aircraft or spacecraft. Radar systems in remote sensing use the microwave portion of the electromagnetic spectrum, so named because the waves have a short wavelength compared to other types of radio waves. Radar systems emit short pulses of microwave radiation and then “listen” for a returning microwave echo. By analyzing the strength of each return pulse and the exact time it is received, an image is created showing the surface as it is illuminated by the radar beam.

Radar systems used for land imaging emit microwave energy that is not significantly absorbed by water. This means that radar systems can penetrate clouds to provide images of the Earth’s surface in any weather. In contrast, ground-based weather radars use microwaves that are scattered by water droplets or ice crystals and produce an image of precipitation over a region. They detect rain, snow, and hail and are used in local weather forecasting.

Figure I.19 shows a radar image of the folded Appalachian Mountains in south-central Pennsylvania. It is produced by an airborne radar instrument that sends pulses of radio waves downward and sideward as the airplane flies forward. Surfaces oriented most nearly at right angles to the slanting radar beam will return the strongest echo and therefore appear lightest in tone. In contrast, those surfaces facing away from the beam...
will appear darkest. The effect is to produce an image resembling a three-dimensional model of the landscape illuminated at a strong angle. The image shows long mountain ridges running from upper right to lower left and casting strong radar shadows to emphasize their three-dimensional form. The ridges curve and turn sharply, revealing the geologic structure of the region. Between the ridges are valleys of agricultural land, which are distinguished by their rougher texture in the image. In the upper left is a forested plateau that has a smoother appearance.

**DIGITAL IMAGING**

Modern remote sensing relies heavily on computer processing to extract and enhance information from remotely sensed data. This requires that the data be in the form of a **digital image**. In a digital image, large numbers of individual observations, termed *pixels*, are arranged in a systematic way related to the Earth position from which the observations were acquired.

The great advantage of digital images over photographic images is that they can be processed by computer, for example, to increase contrast or sharpen edges (Figure I.20). **Image processing** refers to the manipulation of digital images to extract, enhance, and display the information that they contain. In remote sensing, image processing is a very broad field that includes many methods and techniques for processing remotely sensed data.

Many remotely sensed digital images are acquired by scanning systems, which may be mounted in aircraft or on orbiting space vehicles. Scanning is the process of receiving information instantaneously from only a very small portion of the area being imaged (Figure I.21). The scanning instrument senses a very small field of view that runs rapidly across the ground scene. Light from the field of view is focused on a detector that responds very quickly to small changes in light intensity. Electronic circuits read out the detector at very short time intervals and record the intensities. Later, the computer reconstructs a digital image of the ground scene from the measurements acquired by the scanning system.

Most scanning systems in common use are **multispectral scanners**. These devices have multiple detectors and measure brightness in several wavelength regions simultaneously. An example is the Thematic Mapper instrument used aboard the Landsat series of Earth-observing satellites. This instrument simultaneously collects reflectance data in seven spectral bands. Six wavebands sample the visible, near-infrared and short-wave infrared regions, while a seventh records thermal infrared emissions. Figure I.22 shows a color composite of the Boston region acquired by the Landsat Thematic Mapper. The image uses red, near-infrared, and short-wave infrared wavebands to show vegetation in green, beaches and bare soils in pink, and urban surfaces in shades of blue.

An alternative to scanning is **direct digital imaging** using large numbers of detectors arranged in a two-dimensional array (Figure I.23). This technology is in common use in digital cameras and is also used in some imagers on spacecraft. The array has millions of tiny detectors arranged in rows and columns that individually measure the amount of light they receive during an exposure. Electronic circuitry reads out the measurement made by each detector, composing the entire image rapidly. Advanced digital cameras now record detail as finely as film cameras.

**ORBITING EARTH SATELLITES**

With the development of orbiting Earth satellites carrying remote sensing systems, remote sensing has expanded into a major branch of geographic research. Because orbiting satellites can image and monitor large geographic areas or even the entire Earth, we can now
I.20 Image processing

These four panels show an image of the island of Martha’s Vineyard, Massachusetts, acquired by the Landsat Enhanced Thematic Mapper instrument on August 26, 2000.

▲ As originally acquired, the image lacks contrast.

▲ The color scales are adjusted to show a wider range of colors.

▲ An edge enhancement computation shows edges within the image as bright pixels.

▲ When the edge image is added to contrast-enhanced image, the result is an image that appears clearer and sharper than the original.

I.21 Multispectral scanning from aircraft

As the aircraft flies forward, the scanner sweeps from side to side. The result is a digital image covering the overflight area.

carry out global and regional studies that cannot be done in any other way.

Most satellites designed for remote sensing use a Sun-synchronous orbit (Figure I.24a). As the satellite circles the Earth, passing near each pole, the Earth rotates underneath it, allowing all of the Earth to be imaged after repeated passes. The orbit is designed so that the images of a location acquired on different days are taken at the same hour of the day. In this way, the solar lighting conditions remain about

A Sun-synchronous orbit allows a remote imager to cover nearly all the Earth’s surface with only slowly varying illumination conditions. A geostationary orbit places the imager above a single point on the equator, watching an area of about half the Earth.
I.24 Satellite orbits

Earth track of a Sun-synchronous orbit: With the Earth track inclined at 80° to the Equator, the orbit slowly swings eastward at about 30° longitude per month, maintaining its relative position with respect to the Sun. This keeps the solar lighting conditions similar from one image of a location to the next. Between March 1 and May 1 (shown) the orbit moves about 60°.

Motion of a geostationary satellite: Because the satellite revolves around the Earth above the Equator at the same rate as the Earth’s rotation, it appears fixed in the sky above a single point on the Equator.

The center part of this computer chip is covered by an array of tiny light detectors arranged in rows and columns.

above the poles, a satellite in geostationary orbit constantly revolves above the equator. The orbit height, about 35,800 km (22,200 mi), is set so that the satellite makes one revolution in exactly 24 hours in the same direction that the Earth turns. Thus, the satellite always remains above the same point on the Equator. From its high vantage point, the geostationary orbiter provides a view of nearly half of the Earth at any moment.

Geostationary orbits are ideal for observing weather, and the weather satellite images readily available on
television and the Internet are obtained from geostationary remote sensors. Geostationary orbits are used by communications satellites. Since a geostationary orbiter remains at a fixed position in the sky for an Earthbound observer, a high-gain antenna can be pointed at the satellite and fixed in place permanently, providing high-quality, continuous communications. Satellite television systems also use geostationary orbits.

Remote sensing is an exciting, expanding field within physical geography and the geosciences in general. As you read the rest of this text, you will see many examples of remotely sensed images.

### Earth Visualization Tools

Within the last few years, remote sensing, geographic information systems, and GPS technology have been integrated into new and exciting Internet tools for visualizing the Earth. Google Earth and World Wind are outstanding examples of these Earth visualization tools.

#### I.25 Google Earth images

These four images show screens for Google Earth.

- The opening screen shows a view of the globe centered on the United States. At the left are saved locations, called placemarks, and a list of GIS features that can be enabled.

- Zooming in to the San Francisco Bay region, we can see many physical and cultural features identified by name.
GOOGLE EARTH

Google Earth is a program for personal computers that allows users to roam the Earth’s surface at will and zoom in on images showing the surface in detail. The program uses the Internet to access a large database of images maintained by Google (Figure I.25). The spatial resolution of the images varies from location to location, depending on the Earth imagery available. Basic coverage is provided largely by Landsat satellite data, with pixels 15 or 30 m (50 or 100 ft) on a side. But many areas of much higher spatial detail are present, using other satellite sources as well as air photos. Some states and a number of European countries are covered by images at 1-m spatial resolution. A few locations are covered at resolutions as fine as 15 cm (6 in.). Most of the images are less than three years old.

The images in Google Earth are linked to an elevation database that was also provided by an application of remote sensing using radar mapping technology. As a result, the elevation of each pixel is known to an accuracy...
of 5–10 m, depending on the location. This allows computation of synthetic three-dimensional views of the landscape, including simulated fly-overs. By placing the viewer in motion over the landscape, the fly-over gives a strong visual impression of three-dimensional terrain, even though it is viewed on a flat computer screen.

Also linked to the image database are layers of GIS information. These include natural features, such as rivers and peaks, as well as political land boundaries and place names. A road network can also be superimposed. A search capability allows the user to type in a location (for example, the name of a city or town) and have the program zoom in to a close view. You can even ask to see restaurants, lodgings, parks, and recreation areas through the GIS linkages.

Because Google Earth provides a view of nearly every point on land, it is a very useful tool for studying physical geography. Our web site provides fly-over tours for each chapter. These are files of placemarks locating views of interest that can be downloaded and opened with the Google Earth application.

OTHER EARTH VISUALIZATION TOOLS

Although Google Earth is at present the most technologically advanced web-based Earth visualization tools, several other tools are readily available. NASA’s World Wind is a similar window on the Earth that starts with a global view and allows zooming in for fine detail. It also uses an elevation database, so it can provide three-dimensional renderings of the surface as well as realistic fly-overs.

TerraServer.com provides overhead high-resolution photos, with spatial resolutions as fine as 30 cm (11.8 in.) per pixel over many urbanized areas of the United States. Outside of the United States, most of the coverage is at 15 m (50 ft) per pixel with some inset areas in higher resolution. The service requires a subscription and payment for downloading images.

TerraServer-USA, a service of the U.S. Geological Survey, provides on-line topographic maps for the United States. Many of these are orthophoto maps that use high-resolution air photos as a base. The Geological Survey also hosts the National Map on the web, an extensive database with a large number of map layers, including administrative boundaries, geographic names, geology, land use and cover, natural hazards, topography, and transportation.

A Look Ahead

Our chapter has presented an introduction to geography, to physical geography, and to some of the big ideas that arch over physical geography. We have introduced some of the key environmental and global change topics that will appear in our text. We have also described some of the special tools that geographers use, including maps, Geographic Information Systems, and remote sensing. Armed with these tools and ideas, we are ready to proceed to the subject itself. We will start with weather and climate, where we will see how solar energy drives a vast circulation of atmosphere and oceans that changes our physical environment from day to day, week to week, and year to year.

Humans are now the dominant species on the planet. Nearly every part of the Earth has felt human impact in some way. As the human population continues to grow and rely more heavily on natural resources, our impact on natural systems will continue to increase. Each of us is charged with the responsibility to treat the Earth well and respect its finite nature. Understanding the processes that shape our habitat as they are described by physical geography helps us all to become better citizens of our home planet.

IN REVIEW  INTRODUCING PHYSICAL GEOGRAPHY

- Geography is the study of the evolving character and organization of the Earth’s surface. Geography has a unique set of perspectives. Geographers look at the world from the viewpoint of geographic space, focus on the synthesis of ideas from different disciplines, and develop and use special techniques for the representation and manipulation of spatial information.

- Human geography deals with social, economic, and behavioral processes that differentiate places, and physical geography examines the natural processes occurring at the Earth’s surface that provide the physical setting for human activities.

- Climatology is the science that describes and explains the variability in space and time of the heat and moisture states of the Earth’s surface, especially its land surfaces. Geomorphology is the science of Earth surface processes and landforms. Coastal and marine geography is a field that combines the study of geomorphic processes that shape shores and coastlines with their application to coastal development and marine resource utilization. Geography of soils
includes the study of the distribution of soil types and properties and the processes of soil formation. Biogeography is the study of the distributions of organisms at varying spatial and temporal scales, as well as the processes that produce these distribution patterns. Water resources and hazards assessment are applied fields that blend both physical and human geography.

- Scale, pattern, and process are three interrelated geographic themes. Scale refers to the level of structure or organization at which a phenomenon is studied, pattern refers to the variation in a phenomenon seen at a particular scale, and process describes how the factors that affect a phenomenon act to produce a pattern at a particular scale. The processes of physical geography operate at multiple scales, including global, continental, regional, and local.
- Spheres, systems, and cycles are three overarching themes that appear in physical geography. The four great Earth realms are atmosphere, hydrosphere, lithosphere, and biosphere. The life layer is the shallow surface layer where lands and oceans meet the atmosphere and where most forms of life are found.
- Physical processes often act together in an organized way that we can view as a system. A systems approach to physical geography looks for linkages and interactions between processes.
- Natural systems may undergo periodic, repeating changes that constitute time cycles. Important time cycles in physical geography range in length from hours to millions of years.
- Physical geography is concerned with the natural world around us—the human environment. Natural and human processes are constantly changing that environment.
- Global climate is changing in response to human impacts on the greenhouse effect. Global pathways of carbon flow can influence the greenhouse effect and are the subject of intense research interest.
- Maintaining global biodiversity is important both for maintaining the stability of ecosystems and guarding a potential resource of bioactive compounds for human benefit. Unchecked human activity can degrade environmental quality and create pollution.
- Extreme events take ever-higher tolls on life and property as populations expand. Extreme weather—storms and droughts, for example—will be more frequent with global warming caused by human activity.
- Important tools for studying the fields of physical geography include maps, geographic information systems, remote sensing, mathematical modeling, and statistics.
- Cartography is the art and science of making maps, which depict objects, properties, or activities as they are located on the Earth’s surface.
- A map projection is an orderly system for displaying the curved surface of the Earth on a flat map. Common map projections include polar, conic, and cylindrical.
- The scale of a map relates distance on the Earth to distance on a globe or flat map. It is expressed by the scale fraction. Large-scale maps show small areas, while small-scale maps show large areas.
- Conformal maps preserve the shapes of geographic features, but not their areas. Equal-area maps show the areas of geographic features correctly, but distort their shape. Only a globe is both conformal and equal-area.
- Multipurpose maps use symbols, patterns, and colors to convey different types of information on the same map. Thematic maps display a single class of information, or theme.
- Map symbols include dots, lines, and patches. Resolution describes the level of detail shown on a map.
- Isopleth maps show lines of equal value for a continuously varying property. They are constructed from individual observations at points. A temperature map of isotherms is an example. A choropleth map shows categories of information, such as soil type or rock type, as areas on a map.
- The global positioning system (GPS) locates the position of an observer on the Earth using signals from Earth satellites. The fine accuracy of location is affected by the atmosphere, which is constantly changing.
- Differential GPS significantly improves location accuracy. It uses two GPS receivers, one at a base station and one at nearby locations to be plotted. In North America, the Wide Area Augmentation System provides differential GPS information by geostationary satellite broadcast.
- A geographic information system (GIS) is a computer-based tool for working with spatial data. It works with spatial objects, which include points, lines, and polygons, and manipulates information associated with spatial objects.
- A geographic information system has five elements: data acquisition, preprocessing, data management, data manipulation and analysis, and product generation.
- Remote sensing refers to acquiring information from a distance, usually of large areas, by instruments called remote sensors flown on aircraft or spacecraft. The information is obtained by measuring electromagnetic radiation reflected or emitted by an object or type of Earth surface.
- Most objects or surfaces reflect the colors of the spectrum differently, creating distinctive spectral signatures. Vegetation is dark green in the visible spectrum, but bright in the near-infrared.
- Objects or surfaces emit thermal radiation in proportion to their temperature. Emissivity, which affects the amount of radiation emitted at a given temperature, varies with the object or surface type.
Introduction  Physical Geography and the Tools Geographers Use

- Passive sensing systems rely on environmental illumination or internal emission, while active systems provide their own source of energy. Radar is an active sensing system that uses microwave radiation.
- Remote sensing uses digital images that are processed by computer. Image processing is used to extract and enhance the information content of digital images. Digital images are typically acquired by a multispectral scanner or by a direct digital imager that uses an array of detectors.
- Satellite orbits used for remote sensing include Sun-synchronous and geostationary. The Sun-synchronous orbit covers most of the Earth while maintaining similar illumination conditions for repeat images. The geostationary orbit keeps the imager always above the same point on the Equator.
- Earth visualization tools integrate remote sensing, GIS, and GPS technology to create a visual simulation of the Earth’s surface viewable on a networked computer. Google Earth is a prominent example.

### KEY TERMS

- geography, p. 4
- viewpoint, p. 4
- synthesis, p. 5
- representation, p. 5
- human geography, p. 5
- physical geography, p. 5
- climatology, p. 5
- geomorphology, p. 5
- coastal and marine geography, p. 6
- geography of soils, p. 6
- biogeography, p. 7
- water resources, p. 7
- hazards assessment, p. 7
- spheres, p. 10
- atmosphere, p. 10
- lithosphere, p. 10
- hydrosphere, p. 10
- biosphere, p. 11
- life layer, p. 11
- scale, p. 11
- pattern, p. 11
- process, p. 11
- systems, p. 12
- time cycles, p. 12
- cartography, p. 16
- map, p. 16
- map projection, p. 18
- scale fraction, p. 19
- isopleth, p. 22
- global positioning system (GPS), p. 22
- geographic information system (GIS), p. 23
- spatial object, p. 23
- remote sensing, p. 25
- spectral signature, p. 26
- radar, p. 26
- digital image, p. 27
- multispectral scanner, p. 27
- Sun-synchronous orbit, p. 28
- geostationary orbit, p. 29
- Earth visualization tool, p. 30

### REVIEW QUESTIONS

1. What is geography? Identify three perspectives used by geographers in studying the physical and human characteristics of the Earth’s surface.
2. How does human geography differ from physical geography?
3. Identify and define five important subfields of science within physical geography.
4. Identify and define three interrelated themes that often arise in geographic study.
5. Name and describe each of the four great physical realms of Earth. What is the life layer?
6. Provide two examples of processes or systems that operate at each of the following scales: global, continental, regional, and local.
7. How is the word “system” used in physical geography? What is a systems approach?
8. What is a time cycle as applied to a system? Give an example of a time cycle evident in natural systems.
9. Identify and describe two interacting components of global change.
10. How is global climate change influenced by human activity?
11. Why are current research efforts focused on the carbon cycle?
12. Why is loss of biodiversity a concern of biogeographers and ecologists?
14. How do extreme events affect human activity? Is human activity influencing the size or reoccurrence rate of extreme events?
15. Describe three types of map projections as they might occur by projecting a wire globe onto a flat sheet of paper.
16. What is the scale fraction of a map or globe? Can the scale of a flat map be uniform everywhere on the map? Do large-scale maps show large areas or small areas?
17. How do conformal and equal-area maps differ?
18. What types of symbols are found on maps, and what types of information do they carry?
19. How are numerical data represented on maps, and what types of information do they carry?
20. What is the global positioning system? How does it work? What factors cause errors in determining ground locations?
21. What is differential GPS, and why is it important?
22. What is a geographic information system?
23. Identify and describe three types of spatial objects.
24. What are the key elements of a GIS?
25. What is remote sensing? What is a remote sensor?
26. Compare the reflectance spectra of water, vegetation, and a typical soil. How do they differ in the visible spectrum? in near-infrared and shortwave infrared wavelengths?
27. What is emissivity, and how does it affect the amount of energy emitted by an object?
28. Is radar an example of an active or a passive remote sensing system? Why?
29. What is a digital image? What advantage does a digital image have over a photographic image?
30. Describe two ways of acquiring a digital image.
31. How does a Sun-synchronous orbit differ from a geostationary orbit? What are the advantages of each type?
32. What technologies are involved in earth visualization tools? How do these tools make use of the Internet?