ALAN F. ARBOGAST

DISCOVERING
PHYSICAL GEOGRAPHY

Fourth Edition

WILEY

Discovering Physical Geography

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ALAN F. ARBOGAST
Michigan State University

WILEY

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For Jenn, Hannah, and Rosie

About the Author

William Lovis

ALAN F. ARBOGAST is Professor and Chairperson in the Department of Geography, Environment, and Spatial Sciences at Michigan State University in East Lansing, Michigan. He is an award-winning instructor at MSU where he teaches a variety of classes at the undergraduate and graduate levels. Most of these courses are related to physical geography, geomorphology, and human-environment interactions. Alan frequently teaches large lecture classes and is known as an enthusiastic instructor who uses innovative approaches. He has also taught extensively in Australia and New Zealand in association with MSU's study abroad program.

Alan's research focuses on the Holocene landscape evolution of eolian, coastal, and fluvial environments in the Great Lakes region. Most of his research focuses on the age and formation of coastal sand dunes along Michigan's Great Lakes. Alan has published over 30 scientific papers, book chapters, and monographs related to this work. His research has been funded by the National Aeronautics and Space Administration, the National Science Foundation, and the state of Michigan. He is a member of the Association of American Geographers, Geological Society of America, St. George Geographical Society, and American Quaternary Association. Alan is married to Jennifer and has two daughters, Hannah and Rosie.

Follow Alan on Twitter at: @ArbogastDPG, where he posts regularly on topics related to geography and the environment.

Preface

Introduction to Physical Geography is a high-enrollment course at most universities. The usual goal of this course is to help students understand the Earth as a natural system and how various processes on the planet operate over time and space. Given the interactions that occur among these natural processes, physical geography requires the integration of many different topics. For example, students are expected to understand how seasonal Earth–Sun relationships affect atmospheric circulation, which in turn influences the distribution of vegetation. In addition, physical geography is an applied discipline that can inform decisions about environmental issues such as global warming, earthquake hazards, coastal erosion in populated areas, soil degradation, and deforestation, to name only a few.

Discovering Physical Geography: A Visually Oriented, Interactive Approach

Everyone associated with geography is fully aware that geographical literacy in the United States is generally very poor. This poor comprehension exists not only with respect to the fundamental issue of locating places, but also in understanding the age and processes associated with physical landscapes. Because many students enroll in a physical geography course only to fulfill a general education requirement in natural science, they frequently have little enthusiasm for the subject or fail to see the relevance of the class in their lives. In addition, a high percentage of students are simply afraid of science and are thus intimidated by the course. As a result, they believe that their chances of success in the class are low.

Discovering Physical Geography confronts these barriers to learning and classroom success in a number of unique ways. Most importantly, the text is written in a conversational style that is easily understandable to the average nonmajor. This writing style was not chosen at the expense of science, as the topics covered are dealt with in the scope and breadth as they are elsewhere. In fact many topics, such as Earth/Sun geometry, reconstructing past climates, ongoing climate change, geologic time, tides, and formation of sand dunes, to name a few, are covered in a more comprehensive way in this text than in others. The discussions are just presented in a more accessible way to help the nonmajors and those intimidated by science as they grapple with the concepts. My goal was to help them connect with the content a bit more readily.

Another way that this text confronts learning barriers is by offering students rich graphics and striking photos that depict physical processes and the natural variability of the landscape in memorable ways. The quality and breadth of the illustrations are designed to spark students' interest and help them see the relevance of physical geography to their daily lives. The illustrations are accompanied by a dynamic tool, the *Geo Media Library,* which is an interactive, Web-based multimedia resource. The *Geo Media Library* consists of a variety of animations and simulations that allow students to visualize and manipulate many of the factors associated with geographical processes and see the results over time and space. The multimedia will enhance students' learning as they participate more closely in geographical processes and will reinforce the integrative nature of the discipline by showing related variables in motion. This form of active learning will, in turn, help promote long-term retention of the material. The multimedia is fully integrated within the chapter text in distinct sections that direct students to the related modules on the website and explain to students what they should expect to learn by interacting with it.

Each module in the *Geo Media Library* also includes a variety of self-assessment questions for students. Students can use these questions to test their understanding of topics, or instructors can assign them as homework. Such questions allow both students and instructors to assess learning. They also provide the foundation for exam questions that are independent of class lectures. The *Geo Media* modules should motivate more students to interact with the textbook and media because they will more readily see their connection with the course. They contain a variety of self-assessment tools that will engage the interest of *all* students enrolled in physical geography, not just those who are scientifically inclined or have a background in Earth science.

Changes for the Fourth Edition

Students and faculty often wonder why it is necessary to produce new editions of textbooks. The need for new editions in geography is particularly necessary because events frequently occur that change the nature of the cultural and physical landscape. Similarly, scientists learn more about Earth processes between editions that advance the state of knowledge. Since the third edition of this text was written, a number of important events have occurred on Earth that require coverage in a fourth edition. These updates include:

1. *El Niño*—With respect to the Earth system, the term El Niño refers to above-average warming of the eastern Pacific Ocean that occurs on average about every 7 years. This topic is discussed in Chapter 6. One of the strongest El Niño events ever recorded occurred since the third edition, specifically in the winter of 2015/2016. In addition to bringing abundant rain to the southern U.S., this El Niño helped spawn Hurricane Patricia, which struck

the western coast of Mexico as the strongest storm *ever* recorded in the Atlantic and eastern North Pacific basins. The massive storm had winds that exceeded 322 km (200 mph) per hour.

2. *Recent Droughts in the U.S.*—One of the most indirect ways that physical geography is relevant to people is when weather patterns change and drought conditions evolve. Such a drought enveloped the central United States from 2011 to 2013, which was discussed in Chapter 7 of the 3rd edition. The drought was particularly bad in the summer of 2012 when searing temperatures and low rainfall burned crops throughout the region to a crisp. Although drought conditions in this important agricultural region eased shortly thereafter, even drier conditions developed in the southwestern U.S., particularly in California where the worst drought in 1,200 years developed. The impact of this ongoing drought has been profound, with major implications for water supplies and management, food prices, and fire frequency.
3. *Greenhouse Warming and Global Climate Change*—On the climate front, concentrations of atmospheric carbon dioxide on Earth have risen still further, from about 395 ppm since the third edition to almost 407 ppm in June 2016. This continued increase, which is discussed in Chapter 9, is causing the vast majority of climate scientists to be even more concerned about the effects of climate change and the potential future warming of Earth. Signs of warming abound. For example, the average temperature on Earth in 2015 was the warmest ever recorded, with 10 of the 12 months being the warmest respective months since records began to be kept over 130 years ago. As a result, the melting of the Greenland ice cap (as well as other glaciers on Earth) apparently continues to accelerate and global weather patterns may be changing.

Aside from the new coverage of topics in this edition, another reason to create a new one was simply to improve upon the third edition and make it a better and more efficient resource for students. The first three editions were well received, and a number of reviewers and users offered excellent suggestions to strengthen the text. A key area of emphasis in the 3rd edition, for example, was to enhance the Human Interactions theme of the text by including features such as the *United States Public Land Survey* and *The Anthropocene*, to name a few. The primary goal of this edition was to streamline the text by moving all of the chapter features online so they could be viewed concurrently on separate platforms. This transfer increases the book's efficiency and saves space.

Special Features of the Text

To help students navigate their way through the book and better appreciate the nature and scope of physical geography, the chapters include a number of special and innovative features:

- **Discover . . .** —This feature presents an opportunity for students to discover the patterns and causes of particularly interesting geographic phenomena, such as rainbows, wildfires, and unusual clouds (to name a few) on Earth. Each chapter has one such feature, which includes a photo and explanation of how geographers interpret this aspect of the Earth system. The goal of this feature is to make students realize that there is more to the physical landscape than meets the eye, which will hopefully spark their interest in what they see around them. A variety of new such features have been included in this edition, such as the *Mars Rover* (Chapter 2), *What Is the Land Skin Temperature?* (Chapter 5), *Fossil Fuels* (Chapter 12), *Earthquake Prediction and the Italian Legal System* (Chapter 13), *Prehistoric Cliff Dwellings in the Southwestern U.S.* (Chapter 14), and *Coastal Dunes Along the Eastern Shore of Lake Michigan* (Chapter 19).
- **Geo Media Library**—Each chapter contains several multimedia modules that explain to students what they can expect to see and learn as they interact with the simulations and animations on the text's website. The website media also include a variety of self-assessment questions for students.
- **Visual Concept Check**—To provide students with a means of self-testing within the flow of chapter content, this feature offers a scenario with an illustration and questions to test students' understanding of key chapter concepts. Answers to the visual concept checks also appear online.
- **Key Concepts to Remember**—This feature is an interim summary that appears after specific sections of the chapter to help students check their comprehension of the key concepts covered.
- **Locator Maps with Photographs**—Photographs of non-U.S. sites are accompanied by a small map indicating the location of the site shown.
- **Marginal Glossary**—Key terms are set in boldface type in the text and defined at the foot of the page for easy recognition and reference.
- **Summary of Key Concepts**—The main points of the chapter are summarized.
- **Check Your Understanding**—Self-assessment questions at the end of the chapter allow students to test their comprehension.

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A project of this scope naturally required the help and support of a number of people. I would first like to thank the friendly people at John Wiley & Sons, Inc., for their faith in my vision and for giving me the freedom and resources to see it through. I am also grateful for the great job that Karen Berry did on guiding the production process, and to Nichole Urban for overseeing the project at Wiley.

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Discovering Physical Geography Instructor's Site (www.wiley.com/college/arbogast)

This comprehensive website includes numerous resources to help you enhance your current presentations, create new presentations, and employ our premade PowerPoint presentations. These resources include:

- **Discover.** This online feature presents an opportunity for students to discover the patterns and causes of particularly interesting geographic phenomena, such as rainbows, wildfires, and unusual clouds (to name a few) on Earth. Each chapter has one such feature, which includes a photo and explanation of how geographers interpret this aspect of the Earth system. The goal of this feature is to make students realize that there is more to the physical landscape than meets the eye, which will hopefully spark their interest in what they see around them. A variety of new such features have been included in this edition, such as the Mars Rover (Chapter 2), What Is the Land Skin Temperature? (Chapter 5), Fossil Fuels (Chapter 12), Earthquake Prediction and the Italian Legal System (Chapter 13), Prehistoric Cliff Dwellings in the Southwestern U.S. (Chapter 14), and Coastal Dunes Along the Eastern Shore of Lake Michigan (Chapter 19).
- **Image Gallery.** We provide online electronic files for the line illustrations and maps in the text, which the instructor can customize for presenting in class (for example, in handouts, overhead transparencies, or PowerPoints).
- A complete collection of **PowerPoint presentations**, available in beautifully rendered, four-color format, has been resized and edited for maximum effectiveness in large lecture halls.
- A comprehensive **Test Bank** with multiple-choice, fill-in, matching, and essay questions is distributed via the secure Instructor's website as electronic files, which can be saved into all major word-processing programs.
- **Geo Media Library.** In addition to the modules from the book, this easy-to-use website offers lecture launchers that help reinforce and illustrate key concepts from the text through the use of animations, videos, and interactive exercises. Students can use the resources for tutorials as well as self-quizzing to complement the textbook and enhance understanding of geography. Easy integration of this content into course management systems and homework assignments gives instructors the opportunity to integrate multimedia with their syllabi and with more traditional reading and writing assignments. Resources include:
  - ***Animations:*** Key diagrams and drawing from our rich signature art program have been animated to provide a virtual experience of difficult concepts. These animations have proven beneficial to the understanding of this content for visual learners.
  - ***Videos:*** Brief video clips provide real-world examples of geographic features and put these examples into context with the concepts covered in the text.
  - ***Simulations:*** Computer-based models of geographic processes allow students to manipulate data and variables to explore and interact with virtual environments.
  - ***Interactive Exercises:*** Learning activities and games built off our presentation material give students an opportunity to test their understanding of key concepts and explore additional visual resources.
- **Visual Concept Check**—To provide students with a means of self-testing within the flow of chapter content, this online feature offers a scenario with an illustration and questions to test students' understanding of key chapter concepts. Answers to the visual concept checks appear at the end of the chapter.
- An online database of photographs, **www.ConceptCaching.com**, allows professors and students to explore what a physical feature looks like. Photographs and GPS coordinates are "cached" and categorized along core concepts of geography. Professors can access the images or submit their own by visiting www.ConceptCaching.com.
- **Instructor's Manual.** This manual includes chapter overviews, lecture suggestions, and classroom activities.

Wiley Faculty Network This peer-to-peer network of faculty is ready to support your use of online course management tools and discipline-specific software/learning systems in the classroom. The Wiley Faculty Network will help you apply innovative classroom techniques, implement software packages, tailor the technology experience to the needs of each individual class, and provide you with virtual training sessions led by faculty for faculty.

Student Companion Website (www.wiley.com/college/arbogast)

This easy-to-use and student-focused website helps reinforce and illustrate key concepts from the text. It also provides interactive media content that helps students prepare for tests and improve their grades. This website provides additional resources that complement the textbook and enhance your students' understanding of physical geography:

- **Flashcards** offer an excellent way to drill and practice key concepts, ideas, and terms from the text.
- **The Geo Media Library** allows students to explore key concepts in greater depth using videos, animations, and interactive exercises.
- **Chapter Review Quizzes** provide immediate feedback to true/false, multiple-choice, and short-answer questions.
- **Annotated Web Links** put useful electronic resources into context.

A Guide to the Features

DISCOVER . . .—This online feature presents a photo and demonstrates how visual clues contained within it can be used to “discover” the character of the landscape or environment. The goal of this feature is to make students realize that there is more to the physical landscape than meets the eye, which will hopefully spark their interest in what they see around them.

DISCOVER...

FASCINATING CLOUDS ASSOCIATED WITH THUNDERSTORMS

In addition to strong wind, lightning, and thunder, powerful thunderstorms sometimes produce fascinating cloud patterns diagnostic of distinct meteorological processes. One such cloud formation is a *shelf cloud* like the one pictured here. A shelf cloud develops when a cold downdraft within a storm surges outward along the ground after it reaches the surface. As it does so, it lifts the relatively warm and moist air ahead of the storm up to the level of condensation, forming this shelf-like feature. Such a cloud is often accompanied by a cold gust front.

Another interesting and diagnostic cloud formation associated with thunderstorms is *mammatus clouds*. Also known as *mammatocumulus*, which means “mammary cloud,” mammatus clouds look like pouches or lobes hanging eerily upside down in the air like those shown here. These clouds are usually found on the base of a spreading anvil downwind of a large thunderstorm. Their formation is poorly understood but may be somehow related to overturning pockets of colder air that descend into warmer air at high altitudes. Although they are usually composed of ice, they also contain liquid water and can seem translucent. Mammatus clouds are more common during warm months and are more often seen in the Midwest and the eastern parts of the country.

Mike Hollingshead / Science Source

Tom Fleming/Photo Researchers/Getty Images

GEO MEDIA LIBRARY MULTIMEDIA—Multimedia in every chapter explain to students what they can expect to see and learn as they interact with the simulations, animations, and videos in the Geo Media Library.

Geo Media

Formation of a Midlatitude Cyclone

We can now examine how the development of midlatitude cyclones occurs in an animated way by viewing the animation ***Formation of a Midlatitude Cyclone*** in the ***Geo Media Library***. This module allows you to see the process of cyclogenesis in motion. Figure 8.9 is the foundation of this animation. As you watch the animation, follow how an initial kink in the atmosphere evolves into a mature cyclone that spins counterclockwise in the Northern Hemisphere. This animation will help you better understand how these systems and associated processes cause highly variable weather when they migrate through a region. Once you have completed the animation, be sure to answer the questions at the end of the module to test your understanding of this concept.

KEY CONCEPTS TO REMEMBER—This feature is an interim summary that appears after specific sections of the chapter to help students check their comprehension of the key concepts covered.

Key Concepts to Remember

About Air Masses and Fronts

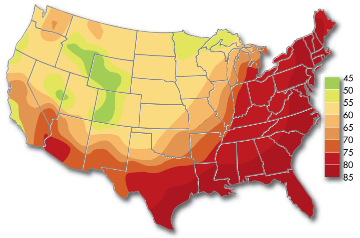
1. An air mass is a large body of air that has distinctive characteristics and forms in specific geographic regions.

VISUAL CONCEPT CHECK—To provide students with a means of self-testing within the flow of chapter content, this online feature offers a scenario with an illustration and questions to test students' understanding of key chapter concepts. Answers to the visual concept checks also appear online.

VISUAL CONCEPT CHECK 8.1

This image shows temperature in the United States. Where is the approximate location of the cold front?

a) Western Texas.
b) Florida.
c) It cuts across the states of Washington and Oregon.
d) It extends from western Michigan to central Texas.



GLOSSARY—Key terms are set in boldface type in the text and defined at the foot of the page for easy recognition and reference.

With respect to tornado monitoring, the most significant technological development in the past few decades has been Doppler radar, such as the Next Generation Weather Radar (NEXRAD) used by the National Weather Service (**Figure 8.20**). Prior to this development, tornado warnings were based largely on direct observations, which were often too late to save lives. In contrast to conventional radar, which shows the intensity of precipitation in any given storm, Doppler radar can detect *both* rainfall patterns and the actual rotation of a tornado. It does that occurs relative to each side of the twister (Figure 8.20a). This rotation is seen by the meteorologist in the weather laboratory as a distinct **hook echo** on the computer screen (Figure 8.20b, 8.20c). If such a feature is identified, a tornado

Hook echo The diagnostic feature in Doppler radar indicating that strong rotation is occurring within a thunderstorm and that tornado development is thus possible.

SUMMARY OF KEY CONCEPTS—The main points of the chapter are summarized.

Summary of Key Concepts

1. An air mass is a large body of air that forms in specific geographic regions and thus has distinctive characteristics. Five principal air masses affect North America. Continental air masses include continental Polar (cP), continental Arctic (cA), and continental Tropical (cT). The maritime air masses are maritime Tropical (mT) and maritime Polar (mP).
2. Air masses have distinct boundaries called fronts. At a stationary front, contrasting air masses are flowing parallel to one another. A warm front is a place where warm air is advancing into relatively cool air. Given that warm air slowly slides over the top of the cooler air along a warm front, rainfall is slow and steady. A cold front is a place where cold air is advancing into relatively warm air. Given the higher density of colder air, rainfall is intense and of short duration along the stream at the 500-mb pressure level. As a cyclone spins, it pulls warm (mT) air up from the south on its eastern side. This warm, moist air encounters cold air as it moves to the north. The cyclone also pulls cold air (cP) down from the north on its western side. This cold, dry air encounters warm air as it moves to the south.
4. In general, the most severe midlatitude storms form along strong cold fronts when warm, moist (mT) air ahead of the front is rapidly forced aloft. Thunderstorms evolve in predictable stages, including the cumulus stage, mature stage, and dissipating stage, that are related to the upward and downward flow of air. The strongest storms associated with midlatitude weather are tornadoes, which are localized bodies of intense low pressure that develop in association with supercell thunderstorms.

CHECK YOUR UNDERSTANDING—Self-assessment questions at the end of the chapter allow students to test their comprehension.

Check Your Understanding

1. Define an air mass.
2. What are the specific characteristics of an mT air mass, and how do they differ from the characteristics of a cP air mass?
3. Which air mass is most likely to be associated with precipitation—an mT air mass or a cP air mass? Why?
4. Discuss the evolution and migration of a midlatitude cyclone.
5. Why are midlatitude cyclones a mechanism through which contrasting air masses are mixed?
6. How does the formation of an upper air trough at the 500-mb level result in the development of a midlatitude cyclone?
7. What is the basic difference between a warm front and a cold front? Why is the term *front* used in association with these concepts?
8. Precipitation along a warm front is gradual and long-lasting, whereas it is short-lived and often violent along a cold front. Why does this difference exist?
9. Describe the evolution of a thunderstorm and the various stages it goes through during its life cycle.
10. What is a downdraft, and why is it the first step in the dissipation of a thunderstorm?
11. Discuss the evolution of a hurricane in the Northern Hemisphere, including its various stages, movement, and relationship with ocean temperature.

Brief Contents

Contents

CHAPTER 1

Kyu Oh/Getty Images

This view of Mt. Hood in Oregon reflects many geographical processes discussed in this text, including the character of the atmosphere, how water is stored and flows within the hydrosphere, the role of climate and its impact on vegetation, and the way landscapes evolve over time.

Introduction to Physical Geography

I want to welcome you to this introductory textbook about physical geography, an exciting scientific discipline that examines the Earth and how it functions. Physical geographers study a wide variety of interesting things, ranging from climate and weather to soils, glaciers, and beaches, to name just a few. Their purpose is to understand the location and character of certain features on the landscape, such as mountain ranges and river valleys, and to explain why they came to be and how they differ from a geographical perspective. This text seeks to encapsulate the essence of physical geography in a way that is appropriate for a beginning student of the discipline such as yourself. As you read through it, your first goal should be to investigate the various physical processes on Earth and how they operate and combine to form distinctive geographical features and patterns. At a secondary level, you will be asked to examine how aspects of physical geography affect human lives and, in turn, how people impact them. This opening chapter outlines the topics discussed in this book and places them in the context of the overall discipline of geography. Then we discuss the various components and features of the book and how they will assist with your learning.

CHAPTER PREVIEW

LEARNING OBJECTIVES

1. Comprehend the character and scope of geography as a scientific discipline.
2. Discuss the concept of spatial analysis and how it relates to geography.
3. Define the subdisciplines of physical geography.
4. Explain the concept of a natural system.
5. Define the four Earth spheres.
6. Describe how the scientific method is used in physical geography.
7. Discuss why physical geography is relevant to many human/environment issues.

The Scope of Geography

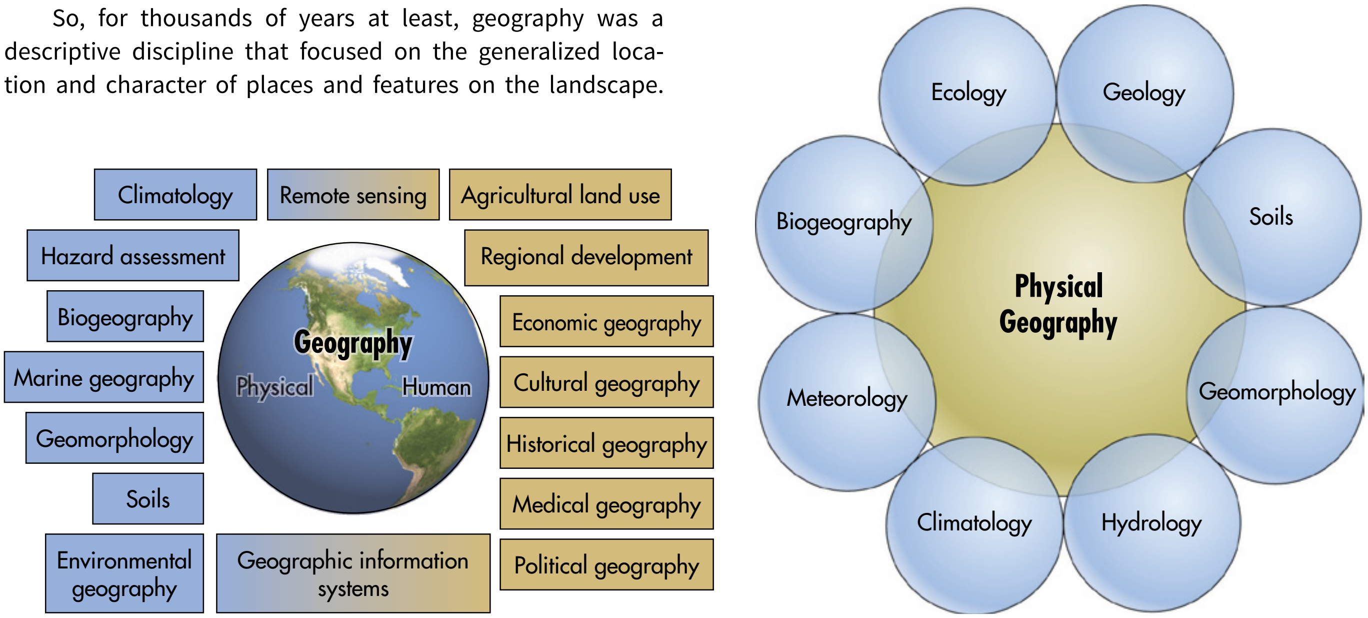
When most people are asked to describe the nature of geography, a common response is that the discipline focuses primarily on the locations of countries, capital cities, rivers, and oceans. They also assume that most of the work geographers do involves maps in some way. Although such an understanding of the discipline is accurate to some degree, the field actually encompasses *far* more than the average person realizes. In fact, geography is a discipline that is highly relevant to everyday life in myriad ways, ranging from analysis of traffic patterns to importation of economic goods, migration of ethnic groups, cost of gasoline, and earthquake hazards, to name a very few. In addition to maps, geographers use a fascinating array of techniques and technologies to conduct their work, such as computer models, field reconnaissance, personal interviews, satellite imagery, global positioning systems, and even shovels.

Geography, a word derived from the Greek words for “Earth description,” is an ancient discipline that examines the spatial attributes of the Earth’s surface and how they differ from one place to another. The concept of geography has likely been important to the human experience for tens of thousands of years. It is easy to imagine, for example, that prehistoric hunters and gatherers were intimately aware of their surroundings, including the location and character of forests, streams, lakes, berry patches, migrating animal herds, and competing groups of people. In short, this *geographical awareness* would have been absolutely essential for people to sustain themselves and their communities. It would also have been critically important to pass this awareness on to future generations so that they, in turn, could successfully compete for resources.

So, for thousands of years at least, geography was a descriptive discipline that focused on the generalized location and character of places and features on the landscape. As civilization evolved, however, geography slowly became an academic discipline with numerous specialized subfields. Scientists became experts in areas such as geology, meteorology, ecology, and human cultural differences. Interest in geography grew especially between the 15th and 19th centuries when explorers such as Christopher Columbus, Ferdinand Magellan, James Cook, Charles Darwin, and Lewis and Clark began to investigate parts of the world that were previously unknown to people of European descent (including Americans). These explorers, as well as many others, brought detailed descriptions of exotic places and animals to a keenly interested public. The new knowledge and perspectives gained from this time provided a major driving force for the development of the modern world.

The trend toward increased specialization in geography has continued to the present time. Most geographers generally consider themselves primarily either physical or human specialists. Within these two broad fields are a range of geographical subdisciplines, as shown in **Figure 1.1a**. Although each of these subfields has a unique focus, such as soils or agricultural land use, geographers draw from many of these subfields when they analyze any particular spatial pattern. For example, to fully understand human settlement patterns in Africa, it is important to consider the interaction of subfields such as climatology, soils, and vegetation. In turn, to understand the nature of soils in any given place, you must consider the effects of climatology, vegetation, geomorphology (**Figure 1.1b**), and perhaps even regional cultural practices.

Although this book focuses on physical geography, it is useful to know that all subfields of geography are based on the same five themes of location, movement, place, human/



(a) (b)

FIGURE 1.1 Subdisciplines of geography. (a) The field of geography can be broadly subdivided into physical and human geography. Many subfields occur within these two broad categories, with many that overlap. (b) Physical geography itself overlaps with several other areas of science. Many of these areas require a good understanding of chemistry and physics as well.

environment interactions, and region. Location refers to the exact position where something is found on Earth. As the name implies, movement is related to the way that geographical variables flow from one locality to another. The concept of place is an important theme in geography because it reflects the characteristics that make a certain location distinct. Human/environment interactions acknowledge the complex bond between people and nature. Finally, a region is a large area that shares one or more common characteristics.

In the context of these five themes, all geographers share a common methodology that makes them part of the overall discipline. Geographers use a method known as **spatial analysis**, which attempts to explain patterns or distributions of specific variables across physical space. At a fundamental level, most geographers want to know the answer to a pair of important questions about any geographical variable: *where* and *why*. In other words, geographers want to know where a specific environmental or cultural variable is located and why it happens to be there.

To see how these questions are important and work in tandem, let's briefly consider an example involving cultural diversity in the Middle East. As you may know, this region has many different religious sects, dialects, and tribal identities. Although this diversity has produced a rich heritage, it has also resulted in a great deal of conflict between and among various cultural groups. A cultural geographer can examine the spatial distribution of the many groups in the area (in other words, *where are they?*), as well as study why people in one place differ in, say, their political or religious views, from people someplace else. The geographer might look for similarities (such as language or religion) among groups across physical space, which might explain why certain people align themselves politically with others. In the course of this study, the geographer would have integrated several variables into one picture, including language, religion, history, and climate. Such a study might contribute to an understanding of why people differ across this region and why sources of conflict remain.

Defining Physical Geography

Now that the general character of geography has been defined, let's focus on a more detailed definition of physical geography. You probably already have an interest in this part of the discipline, whether you know it or not. For example, do you like big storms and wonder why they happen? You may know that tornadoes frequently occur in the central United States, especially in the springtime (**Figure 1.2a**). Do you know why? Maybe you wonder why large mountains are found in Washington but not in Texas (**Figure 1.2b**). Perhaps you have heard about the Sahara Desert and wonder why it is so dry there and why much of it is covered with sand dunes (**Figure 1.2c**). Like many people, you might enjoy the seashore and wonder why nice beaches form in some places (**Figure 1.2d**) but not in others. If you have asked

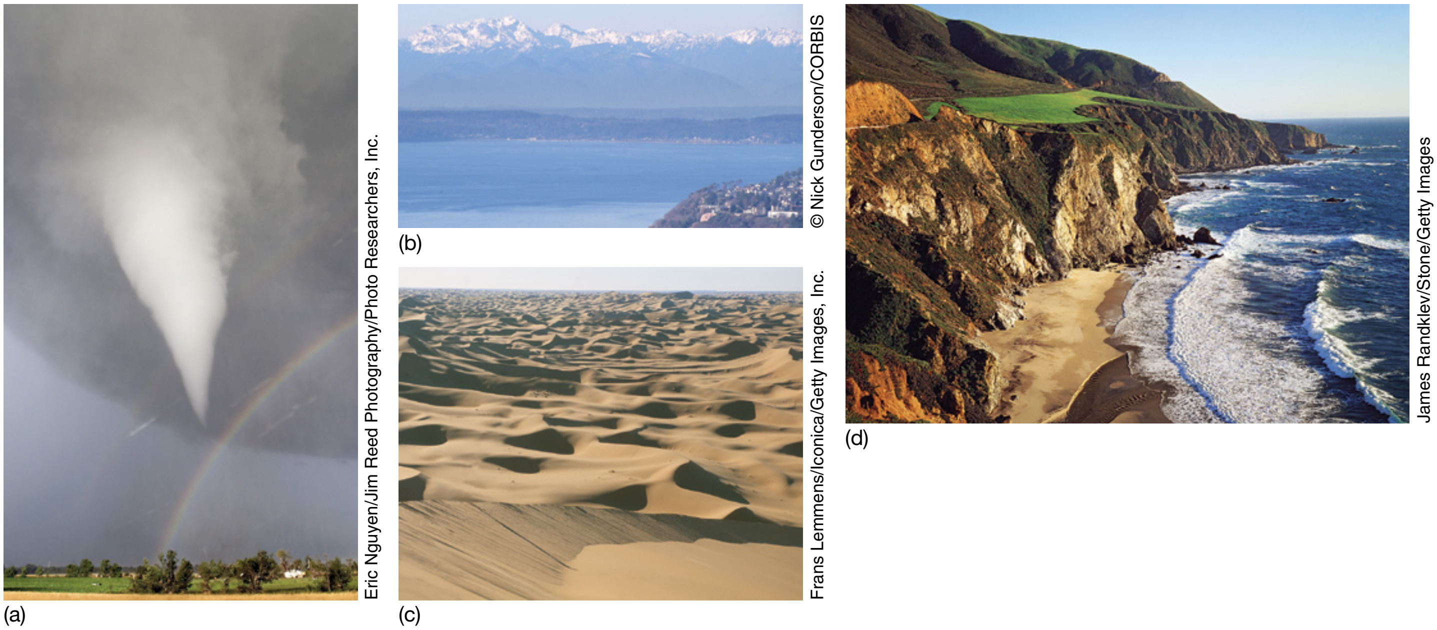
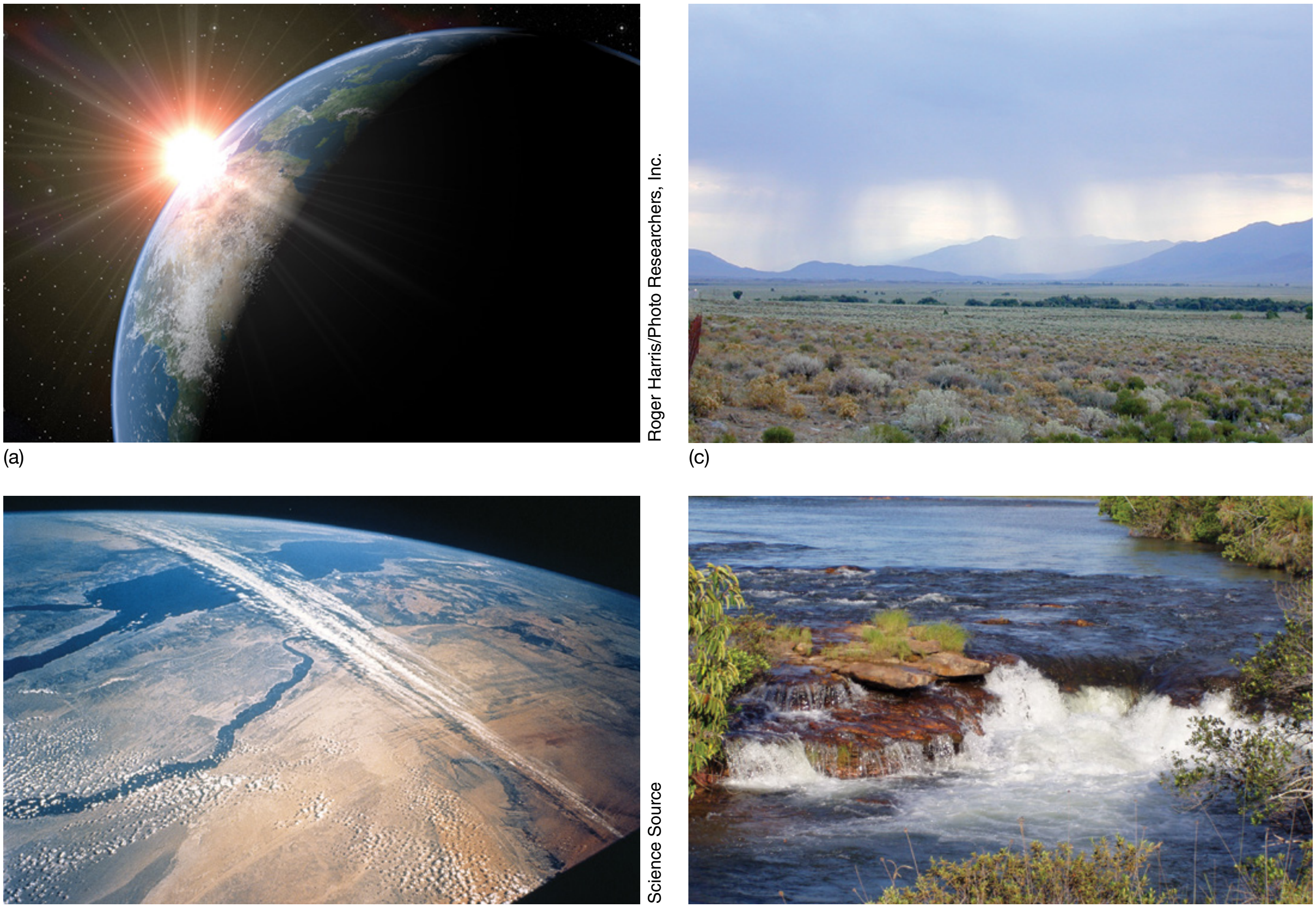


FIGURE 1.2 **Some elements of physical geography.** (a) A tornado in the central United States (see Chapter 8). (b) The Olympic Mountains overlooking Puget Sound in Washington (see Chapter 13). (c) Sand dunes in the Sahara Desert (see Chapters 9 and 18). (d) Coastline at Big Sur in northern California (see Chapter 19).

Spatial analysis A method of analyzing data that specifically includes information about the location of places and their defining characteristics.



(a) Roger Harris/Photo Researchers, Inc.
(c) Alan Arbogast
(b) Science Source
(d) Alan Arbogast

FIGURE 1.3 Examples of energy flows on Earth. (a) Earth receives its energy from the Sun in the form of solar radiation (see Chapters 3 and 4). (b) The atmosphere circulates energy around Earth, as can be seen in this stream of clouds (see Chapter 7). (c) Some energy is transferred when water flows from the atmosphere to Earth as rain (see Chapter 5). (d) Some of the energy on the surface of Earth is transferred by flowing water (see Chapter 16).

yourself questions like these, then you are probably interested in physical geography at some level. The fact is that most people have such interests; they just do not realize it.

Simply stated, **physical geography** involves the spatial analysis of the various physical components and natural processes of the Earth. Some examples of Earth's physical components are air, water, rocks, vegetation, and soil. The term **process** broadly refers to a series of actions that can be measured and that produce a predictable end result. In physical geography, these processes are often products of the energy that flows from the Sun to Earth in the form of solar radiation. Once this energy reaches Earth, it then flows from one place to another on the planet in various forms. Some examples of natural processes directly related to the flow of solar radiation (**Figure 1.3**) are the circulation of the atmosphere (Chapter 7), the distribution of vegetation (Chapter 10), the formation of soils (Chapter 11), and the movement of water in the air and streams, and collection in lakes (Chapters 5 and 16).

As you will see throughout this book, many processes behave in an interconnected way within *natural systems* where one environmental variable has a direct impact on another. Given these relationships, physical geographers often invoke **systems theory** in their studies because it is a holistic framework through which they can analyze and/or describe a group of variables that work together to produce some definable result. Another way to look at natural systems is to recognize that they

Physical geography Spatial analysis of the physical components and natural processes that combine to form the environment.

Process A naturally occurring series of events or reactions that can be measured and that result in predictable outcomes.

Systems theory The examination of interactions involving energy inputs and outputs that result in predictable outcomes.

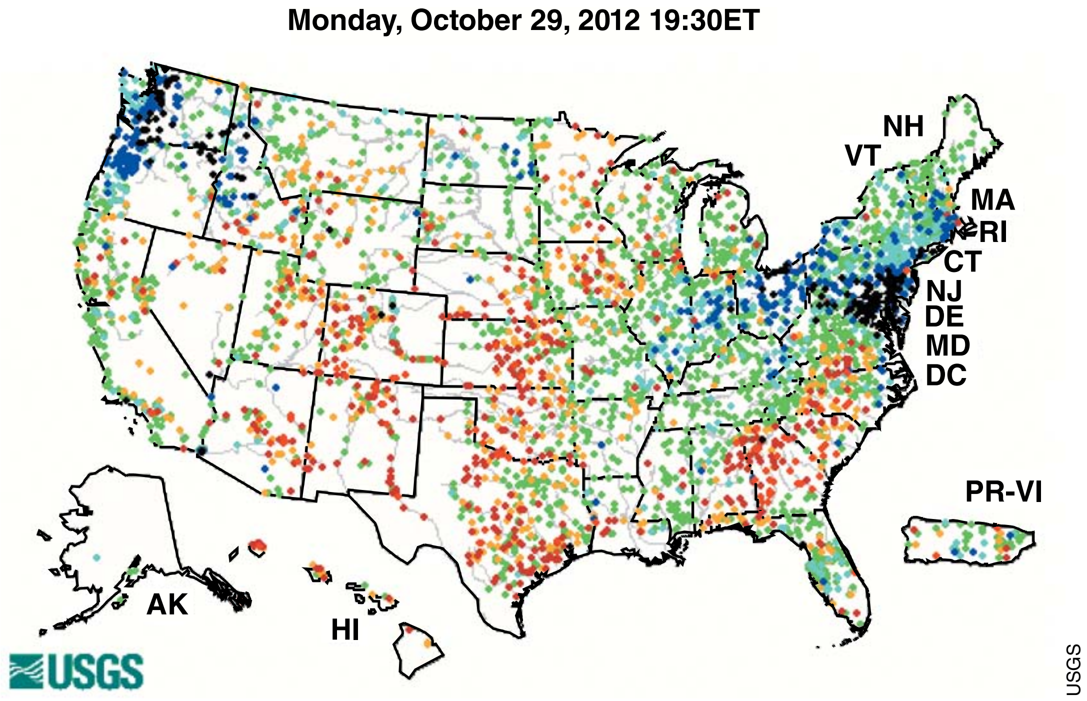
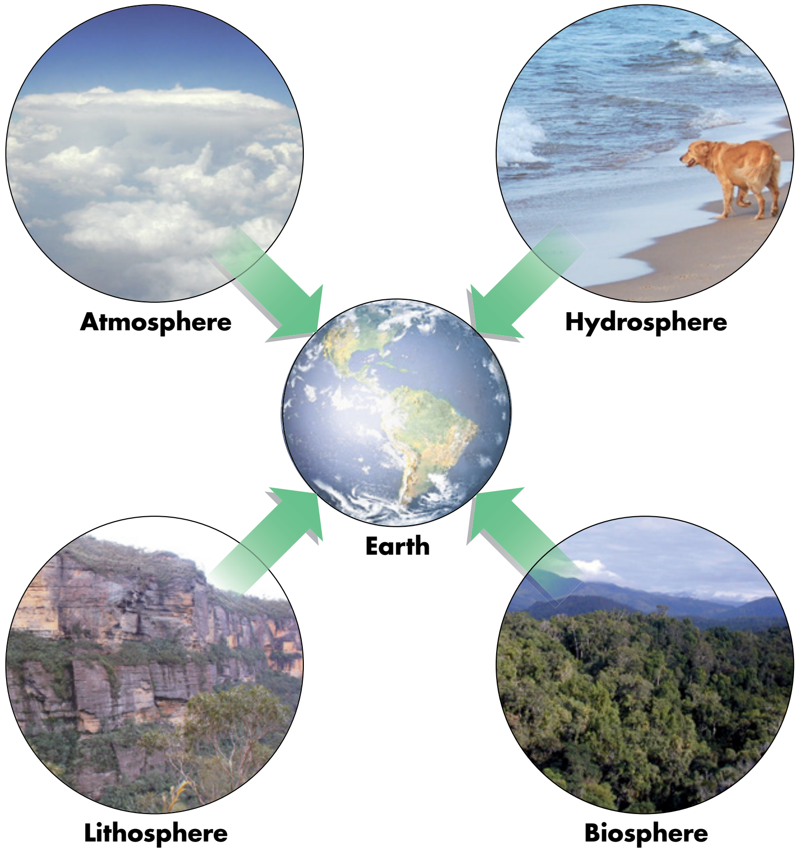


FIGURE 1.4 **Location of stream-gaging stations in the United States.** The dense concentration of stations in the eastern half of the country reflects the fact that many more streams occur in the eastern United States than in the interior western states. The map is color-coded to illustrate the amount of water in any given stream on October 29, 2012, relative to its average flow on that day calculated over time. For example, red dots reflect very low water levels, whereas dark blue/purple dots mean that stream flow was relatively high on that day. Black dots represent localities on streams that have very high flow and may be close to flooding. The concentration of black dots along the central Atlantic coast reflects prodigious rains dropped by Hurricane Sandy on this day.

are greater than the sum of their parts. Such systems depend on a set of energy inputs that flow in some way to various kinds of predictable outputs. Physical geographers understand that natural systems are complex and that processes within them do not occur in isolation from one another. Instead, they are interconnected in often complicated ways that may at first appear chaotic. Despite this apparent complexity, natural systems are, in fact, self-organizing entities that internally adjust toward an equilibrium condition. These adjustments can be readily explained by understanding how dynamic feedbacks, oscillations, and delays in reaction time influence outcomes.

To see an example of how environmental variables relate to one another and can be viewed holistically within a natural system, imagine you want to explain the spatial distribution of rivers in the United States. One way to see the geographical concentration of rivers in the country is with a map showing the location of gaging stations, which are places where the U.S. Geological Survey continuously monitors the flow of water in the streams (**Figure 1.4**). Observe that the eastern part of the country contains many more gaging stations than the interior west in places such as Nevada and Utah. This pattern reflects the fact that far more streams are found in the eastern part of the United States than in the interior west.

The question a geographer would ask about this pattern is: *Why* do more rivers occur in the eastern United States than in the western part of the country? This question would naturally lead you to holistically examine streams as natural systems that reflect the input of water from some kind of source to the output of water actually flowing in rivers and creeks. Understanding these relationships, in turn, helps explain the geographical patterns observed in Figure 1.4. The simple reason for the geographical distribution of streams in the United States is that far more precipitation falls in the eastern part of the United States than in the western states. You will later study why this geographical variability occurs, but for now it is sufficient to say it exists because the atmosphere over the eastern United States typically contains more water than in the interior parts of the western states. Thus, more water flows from the atmosphere to the ground as precipitation in the eastern United States than in the western states. Some of this water flows directly across the Earth's surface as input into streams. A great deal of it slowly absorbs into the ground, where it is steadily released into streams. As a result of these interconnected processes, the eastern United States contains more streams than the western part of the country.



Center photo: Hal Pierce, Laboratory for Atmospheres, NASA Goddard Space Flight Center.
Surrounding photos: Alan Arbogast

FIGURE 1.5 **The four Earth spheres.** Each sphere encompasses a major component of the Earth's natural environment.

The Earth's Four Spheres

As you can imagine, a huge number of component/process combinations exist for geographical study in a holistic way. In physical geography, these various combinations can be grouped into the four "spheres" on Earth (**Figure 1.5**):

1. **Atmosphere**—The atmosphere is the gaseous shell that surrounds Earth. This sphere is composed of many critical components essential to life, such as oxygen, carbon, water, and nitrogen, that flow around Earth.
2. **Lithosphere**—The lithosphere is the solid part of Earth, including soil and minerals. A good example of a natural system in this sphere is the way in which water, minerals, and organic matter flow in the outermost layer of the Earth to form soil. This sphere provides the habitat and nutrients for many life-forms.
3. **Hydrosphere**—The hydrosphere is the part of Earth where water, in all its forms (solid ice, liquid water, and gaseous water vapor), flows and is stored. This sphere is absolutely critical to life and is one with which humans regularly interact—for example, through irrigation and navigation.
4. **Biosphere**—The biosphere is the living portion of Earth and includes all the plants and animals (including humans) on the planet. Various components of this sphere regularly flow from one place to another, both on a seasonal basis and through human intervention. Humans interact with this sphere in a wide variety of ways, with agriculture being an obvious example.

These four spheres overlap to form the natural environment that makes Earth a unique place within our solar system. Physical geography examines the spatial variation within these spheres, how natural systems work within them, the observable outcomes in each, and the manner in which components flow from one sphere to another.

Physical geography can be a descriptive discipline that simply characterizes the nature of the Earth's spheres in specific regions. A simple example of such a descriptive focus would be to acknowledge that the western part of the United States is mountainous, whereas the central part of the country consists mostly of relatively level plains. Physical geography is also a science because research is conducted within the framework of the scientific method, which is the systematic pursuit of knowledge through the recognition of a problem,

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Atmosphere The gaseous shell that surrounds Earth.

Lithosphere A layer of solid, brittle rock that comprises the outer 70 km (44 mi) of Earth.

Hydrosphere The part of Earth where water, in all its forms, flows and is stored.

Biosphere The portion of Earth and its atmosphere that supports life.

FIGURE 1.6 Examples of collecting scientific data about Earth. (a) Certain satellites are designed to obtain measurements about the atmosphere, oceans, and the distribution and character of plants, among many other things. (b) To learn about the behavior of streams in the past, scientists study the type of sediment deposited by the stream through time. This picture is from one of my class field trips in the Great Plains. (c) One way to learn about past climate changes on Earth is to obtain samples of ancient ice on the Greenland and Antarctic ice caps. (d) Digital technology enables spatial scientists to easily obtain accurate measurements about elevation and location.

the formulation of hypotheses, and the testing of hypotheses through the collection of data by measurement, observation, and experiment. The conclusions derived from the systematic application of the scientific method contribute to the formulation of scientific theories and laws that explain how Earth functions.

A simple example of using the scientific method in physical geography would be to test the hypothesis that water in streams within a certain region is acidic. This hypothesis would best be tested by collecting water samples from a number of streams and conducting chemical analyses on them to determine their acid levels. If high acid levels were indeed obtained, then an effort would be made to explain why that pattern occurred. In addition to the understanding produced in these kinds of analyses, physical geographers also test hypotheses about all sorts of natural phenomena by collecting information from the atmosphere, rocks, soils, ice cores, satellite images, the Earth's magnetic field, and even other planets (**Figure 1.6**). For these investigations to occur, it is essential that scientists understand physical laws and have the ability to mathematically analyze and compare them.

Organization of This Book

The chapters in this book are organized to provide you with a good understanding of the fundamental concepts associated with physical geography. They contain information that ranges in scale from global to local, which will allow you to better grasp your place both in the world and even in your neighborhood. Chapter 2 focuses on the various kinds of tools that geographers use in their work, such as maps, remote sensing, and geographical information systems. Chapters 3 through 5 examine our relationship with the Sun (Chapter 3), the way we receive solar radiation (Chapter 4), and how those interactions relate to temperature (Chapter 5). The processes discussed in these chapters will prepare you for the topics that will be covered in the rest of the book. Chapters 6 through 9 revolve around the atmosphere, including the way that air circulates within it (Chapter 6), precipitation processes (Chapter 7), weather systems (Chapter 8), and global climate patterns (Chapter 9). The text then examines the influence of the atmosphere and how it interacts with Earth's other spheres by focusing on plant geography in Chapter 10 and soils in Chapter 11.

Chapters 12 through 19 deal mainly with the lithosphere and hydrosphere. Chapter 12 describes the Earth's internal structure, rock cycle, and geologic time. This discussion leads directly into Chapter 13, which focuses on the lithosphere and tectonic landforms. From there, we turn your attention in Chapter 14 to the way that rocks weather and how sediment moves through mass wasting processes. Chapters 15 and 16 discuss the way that water moves on Earth and how it is stored within it. Chapter 15 focuses specifically on groundwater processes and the formation of landforms such as caves. In Chapter 16 we look at how water flows across the surface in stream systems and the landforms that result. Chapters 17 through 19 are devoted to specific geomorphic processes and the resulting landforms, including glaciers (Chapter 17), eolian (wind) processes and arid landscapes (Chapter 18), and coastal regions (Chapter 19).

Exploring Cause-and-Effect Relationships Holistically

As you work through these chapters, you will constantly see how the four Earth spheres interact with each other to produce definable geographical patterns. To understand how such interactions work, let's briefly examine the searing drought in the central United States in the summer of 2012. With this issue in mind, consider the following question, one that encompasses elements of the atmosphere and the hydrosphere: How was the quantity of water in rivers in this part of the country affected by the drought? A testable hypothesis would be that the quantity of water in rivers decreased. You could test this hypothesis by collecting data from gaging stations about the amount of water in the streams during the drought and comparing those values to normal water levels. In all probability, the amount of water dropped significantly during the drought, which, in fact, is reflected in Figure 1.4. The reason for this decreased water level is that a significant drought would result in less water flowing from the atmosphere (as precipitation) to Earth. As a result, less water would then be available as an input to streams across the Earth's surface. In addition, the quantity of water stored in the ground likely decreased, which would also have reduced river levels because a great deal of water in streams is derived from the ground. Potential further impacts of this drought could have been that some forms of vegetation became less common or that the likelihood of fire increased.

This book systematically explores these kinds of cause-and-effect relationships in a variety of ways. One way is through the traditional use of text accompanied by photographs, diagrams, and tables. Each chapter contains detailed discussions that connect important concepts to events that you may have experienced.

Emphasis on Human Interactions with the Environment

Many of the scientific analyses associated with physical geography are driven by the growing impact that human activities have within and among the Earth spheres. Given the nature of human impact on the natural environment, physical geography is at the forefront of research on many environmental issues that face the world today. Among just a very few of these issues are the following.

- **Global climate change—**Human industrial activities are increasing the levels of carbon dioxide in the atmosphere. Abundant scientific evidence suggests that this relationship is contributing significantly to global climate change.
- **Deforestation—**The clearing of the tropical rainforests is occurring at a very rapid rate, leading to soil erosion, loss of wildlife habitat, and species extinctions.
- **Farmland loss—**Due to increasing global population, farmland is being converted to zones of economic development and residential housing. This loss of farmland is resulting in more intensive farming of agricultural soils still in use, which increases the risk of soil erosion and pollution due to the extensive application of fertilizers and pesticides.
- **Natural hazards—**Hazards occur when extreme events result in danger to humans. Examples of natural hazards include hurricanes, tornadoes, flooding, earthquakes, and volcanoes. Natural hazards are a particularly important area of geographical study because as the global population grows, increasing numbers of people are moving into areas that are susceptible to extreme natural events.

A recent natural disaster in the United States vividly illustrates the integrated nature of physical geography and the critical role that geographers play with respect to solving real-world problems. As you probably know, Hurricane Sandy devastated the East Coast in the fall of 2012, causing many deaths and billions of dollars of damage, much of it occurring when the New Jersey shore was extensively flooded. Before the storm reached land, geographers were at the forefront of the effort to monitor the storm's path and predict where the most significant damage would occur. Once the storm passed, geographers began conducting research on the impact that the hurricane had on a variety of issues, including the shape of the coastline, the distribution of wetlands, and the regional economy. These studies have profound implications for future environmental decisions, politics, and economic development in the region. Most chapters of this book contain sections specifically devoted to such human–environment interactions, including a discussion of solar energy production in Chapter 4, wind energy in Chapter 5, and petroleum in Chapter 12. The final chapter (Chapter 20) is devoted entirely to these kinds of issues and demonstrates how physical geography is highly relevant to human–environmental interactions.

Geo Media Library: An Interactive Tool

These holistic discussions in the text are accompanied by graphics and photographs, as well as a more dynamic tool—the Geo Media Library. This online resource contains a variety of animations and simulations that allow you to visualize and manipulate many of the factors associated with geographical processes and to see the results over time and space. The animations and simulations will enhance your learning as you participate more closely with geographical processes and will reinforce the interactive nature of the discipline by showing related variables in motion. The presentation of the media is integrated within the chapter text as distinct sections that explain what you should expect to learn when you access them in the online resource.

Here is a good example of how the Geo Media Library will enhance your learning. Let's again use flowing water in rivers as an example because it is easy to visualize. This concept is described in great detail in Chapter 16, where it is accompanied by a variety of diagrams that illustrate how water flows, using flow lines and arrows embedded within them. It is also supplemented by several animations that are accessed through the Geo Media Library or on the text's accompanying website. One of the animations in that chapter shows how streams snake across the river valley in a process called *meandering*. Through this process, the geographical position of streams actually moves through time. The Geo Media Library shows this process in animated form, which will enable you to comprehend it better. Have a look now to see what these animations are like.

Focus on Geographical Literacy

In addition to improving your overall understanding of physical geography and how it relates to human/environmental issues, another goal of this book is to enhance your geographical literacy. It is common knowledge that the overall geographical literacy of most Americans is very poor. How many Americans can identify, for example, the countries of the Middle East, where so much of our national focus is presently centered? Do they know the location and character of Afghanistan, which is where we continue to engage in the longest war in our history? In a similar vein, how many people understand the science associated with the issue of ongoing climate change, or why hurricanes may raise the cost of gasoline at the pump?

Geographical literacy also involves knowing the location of distinct physical regions on Earth, such as the Sahara Desert or the Himalaya Mountains, and why they exist. In this context, you will see that discussions include maps of the places described. I also hope that your *visual* geographical literacy will improve by using this text. In other words, this book is designed to sharpen *your eye* so that when *you* see things in the landscape, which you may have previously ignored, you might better appreciate them and why they occur. Two features that are found on the book companion site—*Discover* and *Visual Concept Check*—are specifically designed to help you improve this aspect of your geographical literacy. The *Discover* feature allows you to see certain parts of the physical landscape and what they mean about environmental conditions at the time or place they formed. The *Visual Concept Check* features are placed after key topic discussions in the text so that you can test your understanding of those topics immediately after encountering them.

Physical Geography Is Interesting, Exciting, and Very Relevant to Your Life

As with any new endeavor, you can expect that improving your understanding of physical geography may be difficult at times. Many students initially avoid this subject because they feel that geography is boring, or they are intimidated by science, or they see no relevance of geography to their lives. If you genuinely give this subject a chance, however, you will see that physical geography is indeed relevant to *your* everyday life and, most of all, is interesting and even exciting. How else can you explain the popularity of weather and nature programs, national and state parks, the travel industry, mountains, or beautiful coastlines? Why do people go on exotic vacations if not, in part, to enjoy the uniqueness of the physical landscape in new places? With a greater understanding of physical geography, you will appreciate those trips more. You may even appreciate the immediate world around you more.

In addition, an understanding of physical geography will help you make *informed* decisions when you are confronted with important environmental issues in your lifetime. Thus, you will become a better citizen, one who is capable of better protecting the best interests of your family and community. For instance, at some point in the future you may be confronted with a choice of where to place a landfill in your city or town. In order to make the most informed decision, one that perhaps ensures the safety of your drinking water, it will be important to understand the geology of the site, the character of soils, and the way water moves through the ground and is stored within it.