

Geosystems

An Introduction to Physical Geography

Tenth Edition

CHRISTOPHERSON
BIRKELAND



What processes are at work in this image?



ATMOSPHERE

Winter brings freezing temperatures, low Sun angle, and short days at 52° N latitude.

Solar energy drives atmospheric heating and cooling.

Freeze-thaw action causes weathering of the rock surface.

Icicles, formed as waves wash ashore and freeze, show the change of liquid water to solid ice.

LITHOSPHERE

For 25 million years, two vast slabs of Earth's crust have slowly pulled apart along the deep rift zone occupied by the lake. Lake bottom sediments, thousands of feet thick, contain clues to past climates.

HYDROSPHERE

The lake's large size moderates local temperatures. Ice covers the lake for 4 to 5 months each year.

BIOSPHERE

Over 80% of the lake's plants and animals occur nowhere else in the world. Many are adapted to life on and under the lake ice, from microscopic phytoplankton, to fish, to the Baikal seal.

Lake ice expands and contracts with changing temperature, causing cracks and ridges.

ENVIRONMENTAL CHANGES

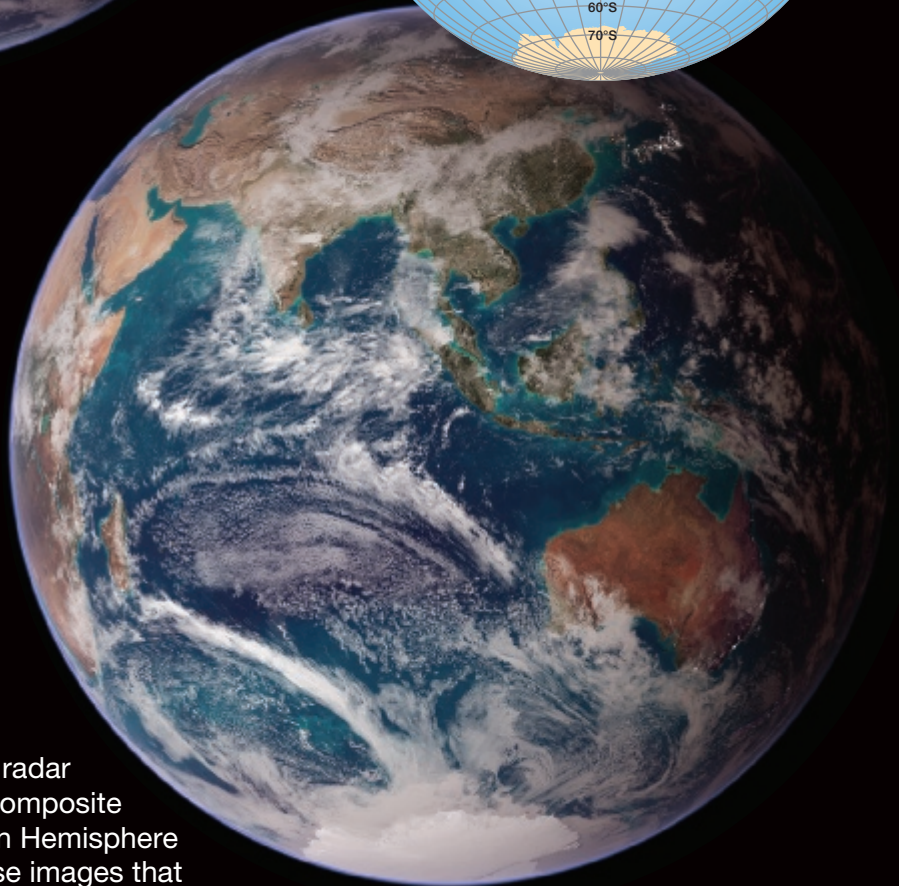
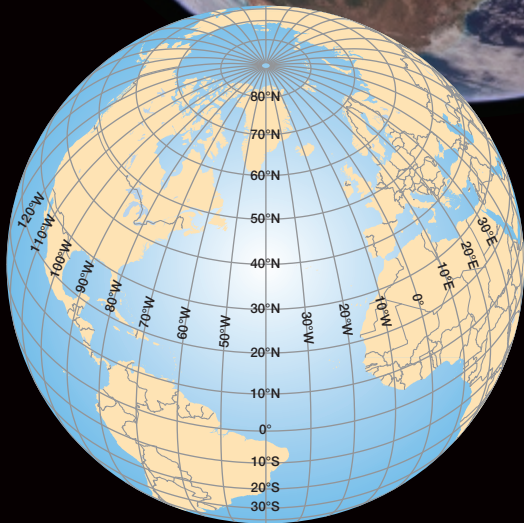
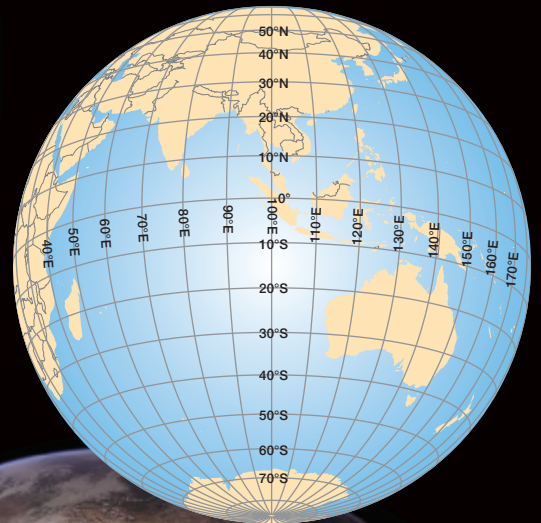
Lake Baikal's surface water temperature has increased over recent decades. Ice now forms later in the fall and breaks up earlier in the spring, and average ice thickness has decreased. These and other changes related to human activities affect living organisms and all Earth systems.

This outcrop juts from an island in Russia's Lake Baikal—the world's deepest lake and the largest by volume. In this photograph, a geographer can see evidence of the forces that shaped the landscape linked to Earth's four immense open systems: the atmosphere, hydrosphere, lithosphere, and biosphere.

Western Hemisphere

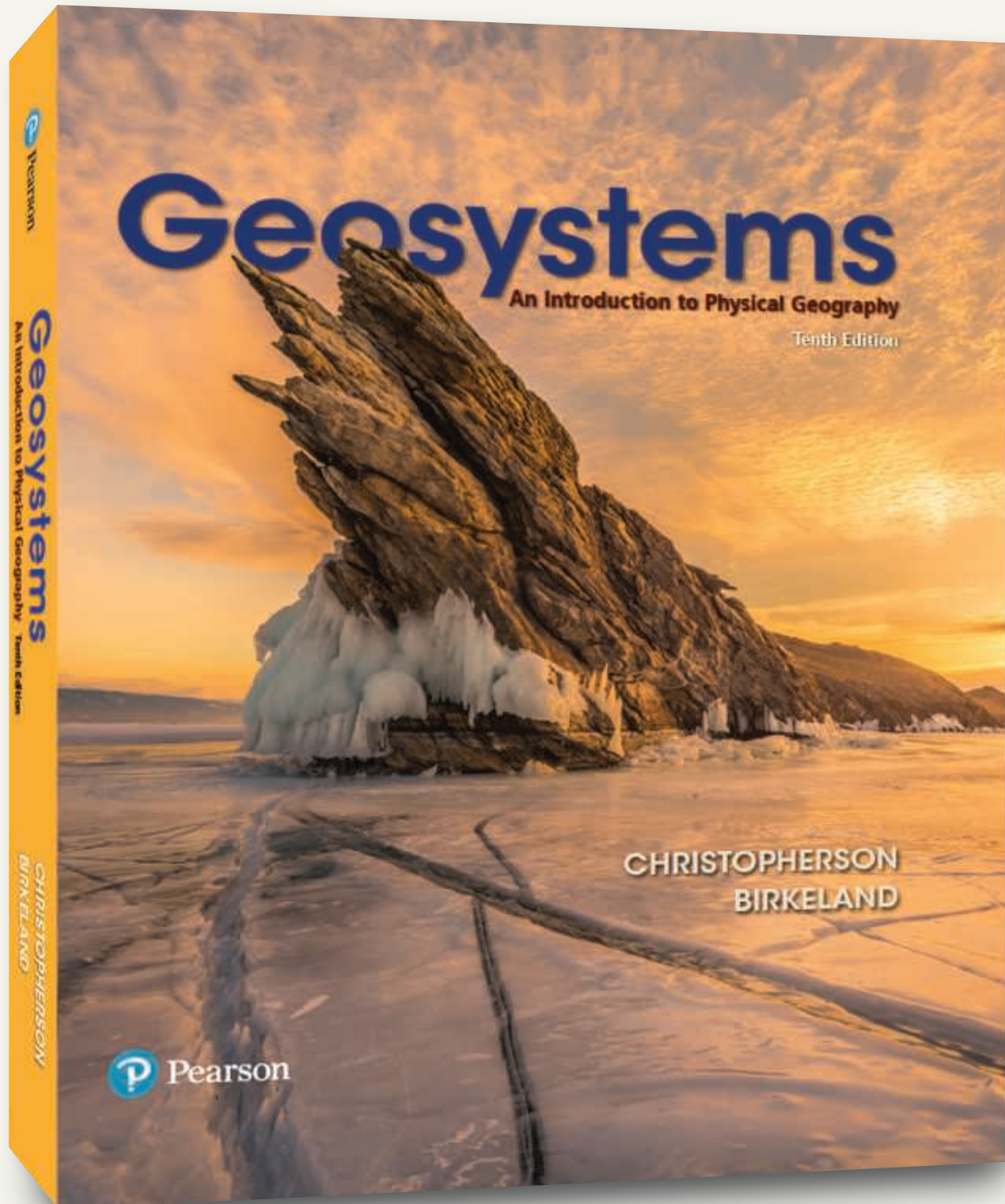


Eastern Hemisphere



Multiple images from satellites *Terra*, *Aqua*, *Radarsat*, and *Defense Meteorological Satellite*, and from Space Shuttle *Endeavor*'s radar data of topography, all merge in a dramatic composite to show the Western Hemisphere and Eastern Hemisphere of Earth. What indications do you see on these images that tell you the time of year? These are part of NASA's Blue Marble Next Generation image collection.

The Authoritative Introduction to Physical Geography with New Real-World Applications



Real-World Physical Geography

everydayGEOSYSTEMS

Carried by the *Aedes aegypti* and *Aedes albopictus* mosquitoes, viruses are spreading into new areas as climatic conditions change. Transmitted by both species, the Zika virus has spread rapidly through South America, Central America, the Caribbean, and into the United States. The estimated U.S. ranges of both mosquito species indicate the potential for Zika to spread to all but 10 states. Dengue fever is spreading through the movement of *Aedes aegypti* mosquitoes into previously unaffected parts of India and into Nepal and Bhutan. In the United States, dengue is still uncommon, but reported cases are rising.



► Figure 9.1
Estimated ranges of Zika-carrying mosquitoes in the United States, 2016. (Photo: Nigel Carlson/Kenny; Map: CDC Vital Signs, www.cdc.gov/atsis/zika.)



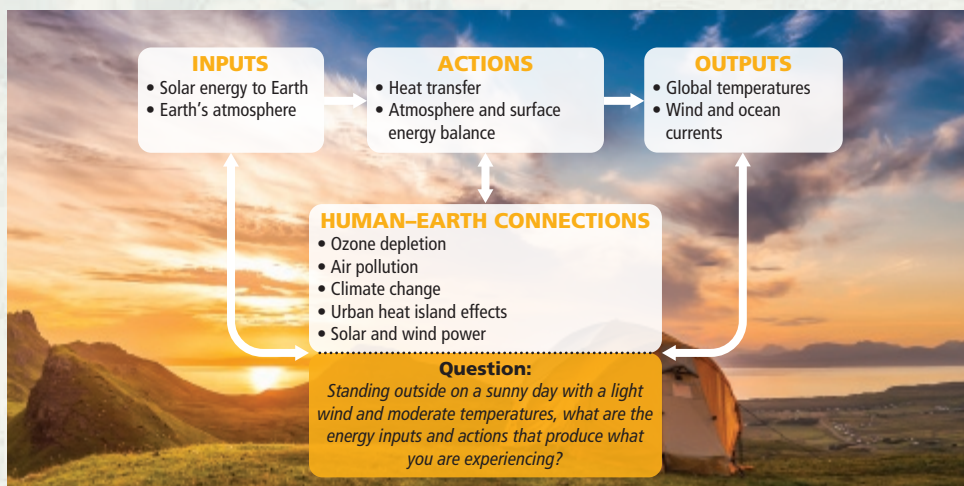
NEW! Everyday Geosystems features at the beginning of each chapter invite the reader to explore the “why” and “how” application of physical geography concepts to everyday phenomena.

NEW! Mobile Field Trips

by acclaimed geoscientist, photographer, and pilot Michael Collier transport students out into the field to explore the patterns and processes of North America’s physical geography.



NEW! Condor Quadcopter Videos capture stunning footage of the Mountain West region with a quadcopter and a GoPro camera. Annotation, sketching, and narrations help students learn about monoclines, streams, terraces, and much more.



UPDATED! Systems Diagrams on all part-opener and chapter-opener pages emphasize the interactions and flow of Earth systems’ concepts relative to each part and chapter. These pages now include questions that make readers reflect on the topics they are about to explore within their real-world context.

Applying the Tools & Practices of Science

NEW! Geospatial Analysis exercises at the end of each chapter are capstone mini-lab activities, sending students outside of the book to primary science tools and data sets from organizations such as NASA, USGS, and NOAA, to perform critical geospatial data analysis.

GEO.SPATIAL ANALYSIS

Citizen Science

Citizens collecting high quality data can make a big contribution to the science community. These data are used by scientists to fill in gaps in the data and improve forecasts.

Activities

Go to the CoCoRaHS website at <http://www.cocorahs.org/> and find a county near you with a CoCoRaHS station. Click on "View Data" and then click on "Daily Precipitation Reports." Enter the name of the state and county. Choose a start date of one week ago and an end date of today so you can examine the last 7 days of data. Click "Search" to display the stations in your county. If there are multiple stations enter the Station Number for one of the stations in the "Station Fields" box and check "Station Number." Click "Search."

1. During the last seven days, how many days had precipitation reports?

2. What is the precipitation total for the week? If applicable, how many inches of snow?

3. Do these reports reflect what you experienced during those same days? Explain and analyze.

Go back and find a county that is reporting precipitation and has multiple CoCoRaHS observation stations.

4. Notice that for a given day not all of the stations report the same amount of precipitation. What might be an explanation for this?

5. What is the precipitation total for the week? How many inches of snow?

GEO.SPATIAL ANALYSIS

Recent Volcanic Activity

The Smithsonian Institution Global Volcanism Program and the USGS report new and changing volcanic activity worldwide. NOAA issues Volcanic Ash Advisories to alert aircraft downwind from volcanic eruptions.

Activities

Go to the Weekly Volcanic Activity Report page at http://volcano.si.edu/reports_weekly.cfm.

1. Where is volcanic activity occurring according to the map?
2. Click on "Criteria and Disclaimers." Why are some volcanoes not displayed on the map?
3. Click on "Weekly Report." List the new volcanic activity locations and list at least 3 locations of ongoing activity.

Click on a volcano under "New Activity Highlights."

1. List the city, country, volcanic region, latitude and longitude, and dates of recent volcanic activity.

2. What are the key features for this type of volcano?
 3. Is this volcano located near a tectonic plate boundary or hot spot? Explain.
 4. Click on "Archive." Click on this volcano, and summarize its eruptive history.
- Go to the Volcanic Ash Advisory Center (VAAC) page at: <http://www.ssd.noaa.gov/VAAC/washington.html>.
1. List the 9 VAAC locations.
 2. Click on "Current Volcanic Ash Advisories." According to the list for the present year, what is the most active VAAC region? What is the name of the volcano with the most ash advisories?

NEW! *Work It Out* activities integrated throughout each chapter give students a chance to practice basic conceptual or quantitative reasoning as they read.



WORKITOUT 4.1

Coastal and Inland Temperatures

Using the map, graphs, and other data in Figures 4.27 and 4.28, complete the following:

1. Using the graphs in Figure 4.27, determine the lowest minimum average monthly temperatures for San Francisco and Wichita. Explain the difference between the two temperatures.
2. Why does San Francisco's average monthly temperature peak occur later in the summer than that of Wichita?
3. Determine the annual temperature ranges for Verkhoyansk and Wichita. Which location has the larger temperature range, and why?



WORKITOUT 17.1

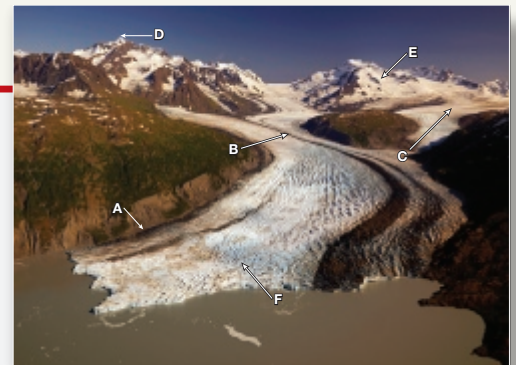
Identify Glacial Features

The Colony Glacier is located in Alaska's Chugach Mountains (Figure WIO 17.1).

1. Using the figures in this chapter as a guide, identify the features that correspond with each letter on the photo. (Hint: Choose among cirque, arête, horn, erratic, medial moraine, lateral moraine, terminal moraine, crevasses, piedmont glacier, and valley glacier.)

A. _____	C. _____	E. _____
B. _____	D. _____	F. _____

2. Does this glacier appear to have a positive or negative mass balance? Explain.



▲ **Figure WIO 17.1** Erosional features of alpine glaciation. [P.A. Lawrence, LLC/Alamy.]

NEW! *Apply Concepts* features, part of the text's hallmark *Focus Studies*, are active learning tasks and short activities that compel students to reflect on the information they have learned from these rich case studies.

APPLYconcepts Determine the suitability of wind power in your state, based on wind speed (see Figure 5.2.1) and site-specific conditions (described in "Conditions for Wind Power"). Write a sentence summarizing your state's overall wind power potential.

Suitability for wind power

Highest wind speed	_____
Lowest wind speed	_____
Site-specific conditions	a. _____ b. _____

APPLYconcepts Referring to the map in Figure 7.1.1b and the chapter's sections "Storm Development" and "Physical Structure," explain key events in the life cycle of Hurricane Patricia.

October 23, atmospheric pressure reading	a. How did Patricia's 872 mb pressure on October 23 affect the storm's intensity? Explain. _____
October 23, landfall	b. What area(s) probably experienced the strongest winds as Patricia came ashore? Explain. _____
October 24, moving inland	c. How and why did Patricia's intensity change after the storm made landfall? _____

Our Changing Earth, Changing Content

UPDATED! Unique to physical geography, Chapter 10: *Climate Change*, presents a comprehensive overview of climate change science, exploring paleoclimatology, climate feedback, evidence and causes of present climate change, climate models and projections, and steps we can take to moderate Earth's changing climate.

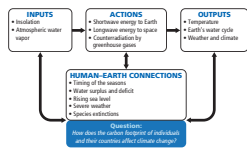
10 Climate Change



The densely populated city of Manila, capital of the Philippines, is at risk of inundation during this century as sea level rises with climate change. Over 80% of Manila is lower than 1 m (3.3 ft) above sea level, and the entire island is lower than 3 m (9.8 ft). The government is buying land in Australia to relocate its people as the seas rise. (Michael Shuff-Grey Imaging)

KEY LEARNING CONCEPTS

- After reading the chapter, you should be able to:
- Describe scientific tools used to study paleoclimatology.
 - Discuss several natural factors that influence Earth's climate and describe climate feedbacks, using examples.
 - List the key lines of evidence for present global climate change.
 - Summarize the scientific evidence for anthropogenic forcing of climate and list some climate projections for the 21st century.
 - Describe several mitigation measures to slow rates of climate change.



GEOSYSTEMS NOW

Rising Atmospheric CO₂ Affects Oceans and Marine Ecosystems

When was the last time you ate shellfish such as oysters, clams, scallops, or mussels? Depending on where you live, these may be a staple of your diet or be part of local and regional economies in your area. The U.S. shellfish industry along the Pacific, Atlantic, and Gulf Coasts is valued at over \$700 million per year. As atmospheric carbon dioxide (CO₂) levels increase, seawater is absorbing CO₂ and becoming more acidic. In addition, as air temperatures rise, oceans are taking up some of the excess atmospheric thermal energy. In the cold coastal waters of the U.S. Northeast and Northwest, shellfish face an uncertain future unless they can adapt to warmer, more acidic seawater.

Oceans Absorb Atmospheric CO₂ As part of an ongoing natural cycling of carbon through Earth systems, the oceans absorb about one-quarter of the CO₂ emitted into the atmosphere. As atmospheric CO₂ increases, the oceans naturally offset the increase by taking up more CO₂. This triggers the process of ocean acidification, in which dissolved CO₂ mixes with seawater to form carbonic acid (H₂CO₃). Ocean acidification is now occurring across the globe.

Earth System Effects The movement of CO₂ from the atmosphere to the oceans has system-wide effects. The good news is that the oceanic uptake of CO₂ slows the warming of the atmosphere. The bad news is that increasingly acidic seawater threatens organisms that are vital to the health of ocean ecosystems, including some types of plankton—tiny organisms that are the base of the marine food web. The increased acidity changes seawater chemistry and harms marine organisms, especially those that build shells and other external structures from calcium carbonate (Figure 10.1).

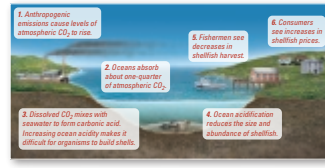


Figure 10.1 Effects of ocean acidification on the U.S. shellfish industry. Increasing acidification affects shell-building organisms, leading to decreased harvest and rising prices for consumers.

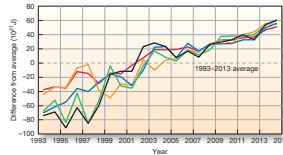


Figure 10.2 Recent increases in upper ocean heat content. Five different data sources show an upward trend in ocean heat content at depths from 0 to 700 m (2300 ft), represented on the vertical axis as the differences from the 1950-2013 average (dashed line). (NOAA Climate.gov)

The effects of ocean acidification are already in evidence, especially with regard to bivalve mollusks (oysters, mussels, clams, scallops) that have a two-part, 'inged' shell. In the U.S. Pacific Northwest, oyster larvae are dying in hatcheries exposed to corrosive seawater that prevents the young animals from developing shells. Between 2005 and 2009, oyster seed production declined up to 80%, costing the shellfish industry some \$110 million and thousands of jobs. Along the Atlantic coast in Maine, mussels face the same problems in waters where acidification is augmented by acid deposition on the landscape, discussed in Chapter 3. Large storm events rine acids from the land into rivers and eventually into coastal waters.

Oceans Also Absorb Thermal Energy As the oceans acidify, they are also absorbing excess thermal energy from the warming atmosphere. Data from buoys and satellites show significant increases in the heat content of the upper ocean (the region above 700 m, or 2300 ft) over the past 2 decades (Figure 10.2). Even deep-ocean currents that flow in cycles lasting thousands of years are showing a decisive warming trend.

Oceanic warming affects shellfish in different ways. For example, warming in the Gulf of Maine has allowed green crabs to move in, where they devour juvenile clams and mussels and destroy eelgrass that provides a protected nursery for shellfish and other species. Since 2012, squid, black sea bass, and Atlantic blue crabs have also invaded the Gulf, with unknown effects on the shellfish and the marine ecosystem. As atmospheric CO₂ continues to increase, ocean acidification and warming are changing marine ecosystems. These changes ultimately affect food resources for many of the world's people.

1. Describe the process of ocean acidification and explain how it is affecting shellfish in coastal waters of the Pacific Northwest.
2. How are increasing ocean temperatures affecting marine ecosystems?

the HUMAN denominator 17 Population, Sustainability, and Earth Systems

EARTH SYSTEMS IMPACT HUMAN POPULATION

- What are some of the critical natural resources for human societies across the globe?

HUMAN POPULATION IMPACTS EARTH SYSTEMS

- Growing population and resource use affects all Earth systems; we examine specific impacts in every chapter of Geosystems.



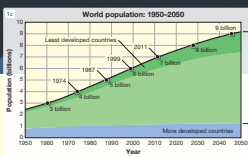
Known for parking, entertainment, and nightlife, Las Vegas is the most populous city in Nevada. The greater urban area is home to more than 2 million people, while the combined county of the Las Vegas Strip, suburban areas, and other parts of the city cover over 40 million acres every year. Water is a critical resource in this desert climate. (Shutterstock.com)



Just over 10% of the world's population lives in China. With a population over 24 million, Shanghai is the largest city by population in China and the world, and one of the world's busiest ports for container shipping. Imagine the impact on natural systems with such a high concentration of people living in one location. (Shutterstock.com)



This 2012 composite image from the WorldPop satellite shows Earth's population density and economic activity. Bright colors represent light at night from urban areas. (PLOS ONE)



Since 1950, population has increased in less-developed countries (LDCs) far more than in more-developed countries (MDCs), a trend that is expected to continue until at least 2050. (Population Reference Bureau, <http://www.prb.org/2015/05/20/2015-population-forecast.html>, fig. 10.1)

ISSUES FOR THE 21ST CENTURY

1. Many critical issues relate to the sustainability of Earth's resources: global food supply, energy supply and demand, climate change, loss of biodiversity, and air and water pollution.
2. To achieve sustainability for humans and Earth, we need to address these issues in new ways.
3. Understanding Earth's physical geography helps you make informed decisions on these issues.

QUESTIONS TO CONSIDER

1. HDI shows that, in 1950, people in MDCs constituted roughly one-third of the world's population. What was the fraction (roughly) of MDCs to total world population in 2017?
2. Using the graph in HDI and the chapter text, calculate the interval of years between each billion-mark milestone for human population. Begin with the 3 billion mark reached in 1960.

the HUMAN denominator 19 Ecosystems and Biodiversity

ECOSYSTEM PROCESSES IMPACT HUMANS

- All life depends on healthy, functioning ecosystems, which provide the food and all other natural resources that humans use.

HUMANS IMPACT ECOSYSTEM PROCESSES

- Human activities cause declining biodiversity. For example,
 - Habitat loss occurs as natural areas are converted for agriculture and urban development.
 - Pesticides and other pollutants poison organisms in food webs.
 - Climate change affects plant and animal distributions and overall ecosystem health.
 - Fertilizer use and industrial activities alter biogeochemical cycles, as when dead zones disrupt the nitrogen cycle.



Hunted to near-extinction by the early 1900s, the Durian (shown here) is a large, spiky, and smelly fruit native to Southeast Asia. The Durian is a keystone species in the region, and its loss would have severe impacts on the local ecosystem. (David Johnson/Getty Images)



Seawater with high temperatures and low oxygen levels can cause sea turtles to become stranded on beaches. A 2012 study showed that sea turtles are dying in large numbers, and researchers are working to identify the causes. (PLOS ONE)



The new Andean flamingo population is growing, but it is still recovering from the loss of its wetland habitat. (PLOS ONE)



Shanghai's water system across the China River in Shanghai is under stress. A 2012 study showed that the population is declining rapidly from overfishing, which has recently increased in Shanghai and in other countries. (PLOS ONE)

ISSUES FOR THE 21ST CENTURY

- Species and ecosystem conservation and restoration will be essential to save species from extinction.
- Fire ecology will become increasingly important as climate change leads to prolonged drought in some areas and as human populations spread further into wildlands.
- Addressing and mitigating climate change may become essential to preserving a future for all species, including humans.

QUESTIONS TO CONSIDER

1. How do beavers change the environment and affect biodiversity in the areas where they live?
2. What abiotic factors discussed in this chapter affect sea turtle migration?

UPDATED! The Human Denominator at the end of most chapters helps students explore the connections between humans and Earth's physical environment and the critical issues facing us in the 21st century. New Questions to Consider ask students to interpret graphs and maps in the feature and connect information to topics within the chapter.

... with the New Tenth Edition

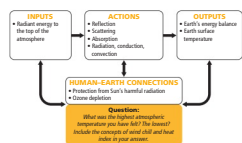
4 Atmospheric Energy and Global Temperatures



Solar photovoltaic panels convert energy from the Sun to electricity near Guadix, Andalusia, in southern Spain, one of the top ten countries in the world for installed solar power capacity. (Global Warming Images/Getty Images)

KEYLEARNINGconcepts

- After reading the chapter, you should be able to:
- Identify alternative pathways for solar energy on its way through the troposphere to Earth's surface and review the concept of albedo (reflectivity).
 - Explain four types of heat transfer: radiation, conduction, convection, and advection.
 - Explain the effect of greenhouse gases, clouds, and aerosols on atmospheric heating and cooling.
 - Review the Earth-atmosphere energy balance and the patterns of net radiation at the surface.
 - Define the concept of temperature and review the principle temperature controls that produce global temperature patterns.
 - Interpret the patterns of Earth's temperatures on January and July temperature maps and on a map of annual temperature ranges.
 - Explain heat waves and describe the human response to temperature extremes.
 - Describe urban heat island conditions and global temperature increases associated with human activities.



GEOSYSTEMSnow

Global Effects of Melting Arctic Sea Ice

In January 2015, during the 24-hour polar night, a Norwegian research ship with a host of scientists on board set anchor in the Arctic pack ice. This was its second attempt at attachment—the previous ice floe had shattered—in order to resume its drift across the frozen Arctic Ocean. The mission: Set up camp on the moving sea ice for a 5-month-long study of the causes and effects of Arctic ice melt.

The Nature of Arctic Sea Ice Unlike Antarctica, a land mass surrounded by ocean, the Arctic region is an ocean surrounded by land (Figure GN 4.1). The Arctic Ocean is covered in pack ice—masses of drifting ice, unattached to shore—consisting mainly of sea ice (frozen seawater). In the winter months, the region is nearly covered in floating ice. During the summer, pack ice thins and sometimes breaks up. Recent global temperature increases have accelerated melting, causing declines in the minimum ice extent during summer (usually occurring in September) as well as in the maximum ice extent during winter (usually occurring between February and April).

Why Is Arctic Ice Important? Arctic sea ice plays a key role in Earth's climate system by helping to keep the planet cool. This cooling

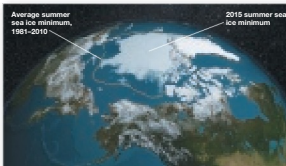


Figure GN 4.1 Arctic summer sea ice minimum extent in 2015 as compared to average. The 2015 minimum is the fourth lowest on record; the lowest occurred in 2012. (NASA/ESA)

effect results from the presence of lighter surfaces, which reflect sunlight back into space. Snow- and ice-covered surfaces reflect about 60%–95% of the solar energy received. Without an ice cover, incoming sunlight reaches the darker ocean surface, which reflects only 4%–10% of solar radiation received. This percentage is albedo, the reflective value of a surface (Figure GN 4.2). Changes in the amount of Arctic sea ice, and the resulting changes in albedo, can create a positive feedback that amplifies global cooling or warming trends. If Earth's climate cools, more ice forms, causing more reflected sunlight, causing cooler temperatures, allowing more ice to form, and so on. If Earth's climate warms, the ice-covered area decreases, reflection decreases, darker water receives direct sunlight and absorbs more heat, temperatures warm, more ice melts, and so on. This so-called ice-albedo feed-

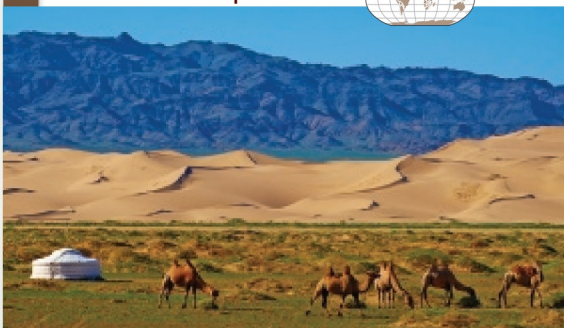
back, described in Chapter 1 (Figure 1.10), is happening today as global temperatures rise. With increasing losses of sea ice, the Arctic Ocean has opened to commercial ship traffic. Since 2009, container ships have used these northern sea routes during the summer months. Ship stack emissions include particulates and soot (black carbon) that eventually settle on snow and ice surfaces, decreasing the albedo. In addition, particulates from Northern Hemisphere wildfires travel on winds and ultimately fall on Arctic ice, darkening the color, decreasing albedo, and accelerating melting. Beneath the ice, ecosystems are adapted to seasonal changes. As light returns in the spring, huge algal blooms feed plankton that are a food source for fish, birds, whales, and other marine mammals. Thinner ice and earlier spring melt disrupt the timing of the cycle, affecting organisms that sustain the marine food chain. If winter ice declines and summer sea ice disappears, some species will be unable to adapt. Since satellite measurements began in 1979, half of the total volume of Arctic sea ice has disappeared. Some computer models show that the Arctic Ocean could be ice-free during the summer within a decade. The melting of Arctic sea ice seems remote, yet its effects link to all Earth systems. How might these changes ultimately affect the area where you live?

- How do global temperatures, the albedo of ice and water, and Arctic sea ice extent interconnect to form a positive feedback?
- What are two sources of pollutants that contribute to the melting of Arctic ice?

NEW! Chapter 4: Atmospheric Energy and Global Temperatures consolidates coverage of atmospheric and surface energy balances with global temperatures (previously chapters 4 and 5 in the 9th edition).

NEW! Chapter 15: Eolian Processes and Arid Landscapes is restored as a standalone chapter in the 10th edition, helping teachers focus coverage on wind processes, deserts, and arid landscapes.

15 Eolian Processes and Arid Landscapes



At the foot of the Gurbantautai Mountains in the Gobi Desert of southern Mongolia lie the Khongoryn Els sand dunes, known as the "sliding sands" for the sound made by moving sand grains. Bactrian camels, which inhabit the steppes of central Asia, graze nearby. (Tud and Bruno Mirand/Getty Images)

KEYLEARNINGconcepts

- After reading the chapter, you should be able to:
- Describe eolian transport of dust and sand.
 - Discuss eolian erosion and the resultant landforms.
 - Explain the formation of sand dunes and describe loess deposits and their origins.
 - Discuss the causes and human impacts of desertification.
 - List some landforms unique to arid regions and explain their formation.



GEOSYSTEMSnow

Sliding Rocks on Death Valley's Racetrack Playa

In a remote, low-elevation basin between mountain ranges in southern California and Nevada, rocks are moving with no obvious cause. From year to year, unseen by humans, the rocks shift position along a flat, hard-surfaced plain, a dry lakebed. The rocks leave trails behind them, furrows in the silty lakebed sediments as proof of their movement (Figure GN 15.1). The tracks are hundreds of meters in length, and some of the rocks weigh hundreds of kilograms. The movement is episodic and unpredictable—years, even decades, can pass between movement events.

Possible Causes for Movement The rock trails on Racetrack Playa suggest that movement happens when the playa is wet from infrequent rains and the sediments form a soft mud. If animals or humans were moving the rocks, they would leave tracks on the playa's surface. If gravity were moving the rocks, a slope would be present, but the playa surface is nearly flat. If streams were moving the rocks, a channel would be present, as well as other alluvial material. Eliminating these factors leaves two possibilities: the force of wind and ice. For years, scientists sought an explanation for the sliding rocks. The dominant hypothesis was that strong winds were the force for rock movement. The prevailing winds on Racetrack Playa blow from the southwest, parallel to most of the rock tracks. However, some of the heaviest sliding rocks were embedded several centimeters into the playa sediments. Could strong winds alone be enough to force their movement?

On Racetrack Playa, winter rains sometimes produce a shallow lake that lasts for weeks or months. Every three years, conditions are such that a shallow lake forms and then freezes so that a thin layer of ice on the surface covers the water below. During the day, the ice breaks up and melts, and then at night it refreezes. If the rocks become embedded in the ice layer, could wind work together with ice to move the rocks over the wet, slippery surface?

Solving the Mystery In 2011, researchers set up a weather station and time lapse cameras on Racetrack Playa to test this hypothesis. On the playa surface, they placed rocks with GPS trackers designed to record position and speed at the onset of movement. Then they waited, and in December 2013, rock movement occurred. Measurements and observations in 2013 and 2014 showed that the rocks slide across the wet surface of the playa on sunny days that follow nights with subfreezing temperatures. At night, the shallow water on the playa freezes to form a thin layer of ice at the surface (Figure GN 15.2). During the late morning, as the sun warms the basin, the ice breaks up into thin panes. Then wind—both light breezes and strong gusts—moves the ice panes, effectively "bulldozing" the rocks across the saturated, muddy surface of the playa.



Figure GN 15.1 A sliding rock at rest on Racetrack Playa, Death Valley National Park, California. When in motion, the rocks slide over the wet playa as slow speeds for brief periods of time, sometimes only for seconds. (David O'Rourke/Getty Images)

The conditions necessary for rock movement occur infrequently at Racetrack Playa. A shallow lake must be present at the same time that nighttime temperatures dip below freezing to initiate surface freeze. The winters of 2010–2011 and 2011–2012 included infrequent snow and rain events but not enough moisture to form a lake. Once formed, a lake that persists over weeks or months in combination with temperature conditions that promote nighttime freezing and daytime ice breakup can have numerous rock sliding events. (For more information, see <http://www.pubs.org/doi/10.1126/science.1217190>.)

- What conditions did scientists observe at the playa surface when rock movement occurred?
- Why do the rocks on Racetrack Playa move in some years and not in others?

1. Rain creates a shallow water layer on the dry lakebed.

2. Water freezes overnight. In the morning, ice breaks into thin sheets.

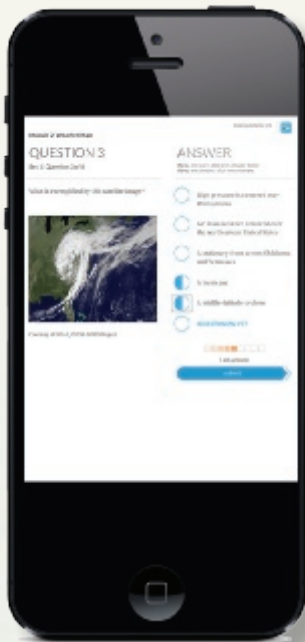
3. The floating ice panes, driven by wind and flowing water, push rocks across the playa surface.

Figure GN 15.2 The observed process for rock movement on Racetrack Playa. (Based on K. O. Harris et al., 2014, "Sliding Rocks on Racetrack Playa, Death Valley National Park: First Observations of Rocks in Motion." *PNAS* 111(10): 3688–3693.)

Continuous Learning Before, During, and After Class

BEFORE CLASS

Mobile Media and Reading Assignments Ensure Students Come to Class Prepared

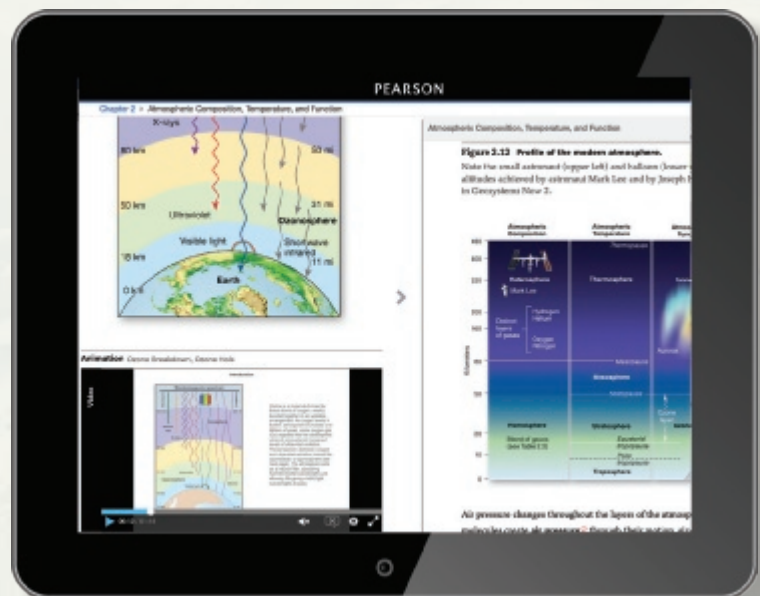


UPDATED! **Dynamic Study Modules** help students study more effectively by continuously assessing student performance and providing practice in areas where students struggle the most. Each Dynamic Study Module, accessed by computer, smartphone, or tablet, promotes fast learning and long-term retention.

NEW! Interactive eText 2.0

gives students access to the text whenever they can access the Internet. eText features include:

- Available on smartphones and tablets.
- Seamlessly integrated videos and animations.
- Accessible (screen-reader ready).
- Configurable reading settings, including resizable type and night reading mode.
- Instructor and student note taking, highlighting, bookmarking, and searching.



Pre-Lecture Reading Quizzes are easy to customize and assign

UPDATED! Reading Quiz Questions ensure that students complete the assigned reading before class and stay on track with reading assignments. Reading Questions are 100% mobile ready and can be completed by students on mobile devices.

Optional eText upgrades for accompanying books

- *Dire Predictions: Understanding Climate Change*, 2nd Edition, by Michael Mann and Lee Kump
- *Goode's World Atlas*, 23rd Edition by Rand McNally

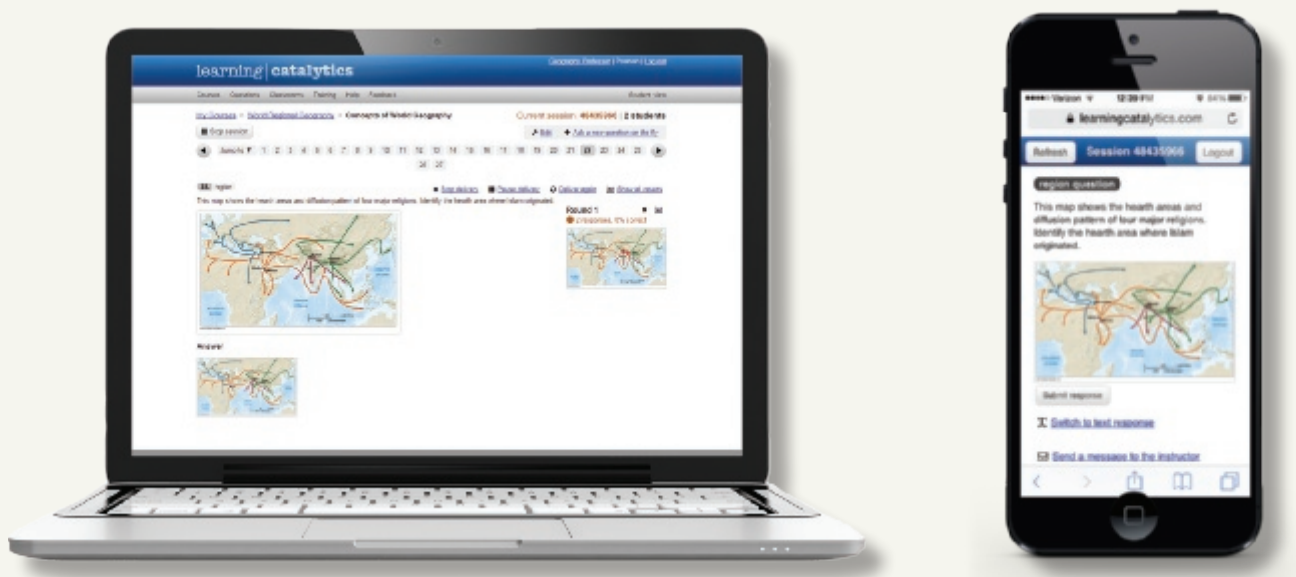
... with MasteringGeography™

DURING CLASS

Engage Students with Learning Catalytics

What has teachers and students excited? Learning Catalytics, a “bring your own device” student engagement, assessment, and classroom intelligence system, allows students to use their smartphone, tablet, or laptop to respond to questions in class. With Learning Catalytics, you can:

- Assess students in real time using open-ended question formats, such as word clouds, sketching, and image upload, to uncover student misconceptions and adjust lectures accordingly.
- Automatically create groups for peer instruction based on student response patterns to optimize discussion.



“My students are so busy and engaged answering Learning Catalytics questions during the lecture that they don’t have time for Facebook.”

Declan De Paor, Old Dominion University

Continuous Learning Before, During, and After Class

AFTER CLASS

Easy to Assign, Customizable, Media-Rich, and Automatically Graded Assignments



NEW! Condor Quadcopter Videos capture stunning footage of the Mountain West region with a quadcopter and a GoPro camera. Annotation, sketching, and narrations help students learn about monoclines, streams, terraces, and so much more. Teachers can assign the videos with quizzes in MasteringGeography to assess student understanding.

NEW! Mobile Field Trips by acclaimed geoscientist, photographer, and pilot Michael Collier transport students out into the field to explore the patterns and processes of North America's physical geography. Teachers can assign the videos with quizzes in MasteringGeography to assess student understanding.

Part B - A Direction of Crustal Extension in Continental Rifts

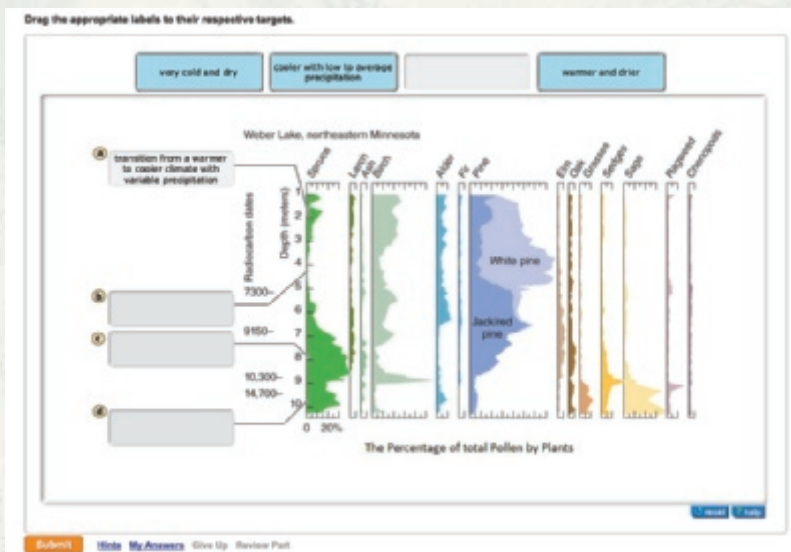
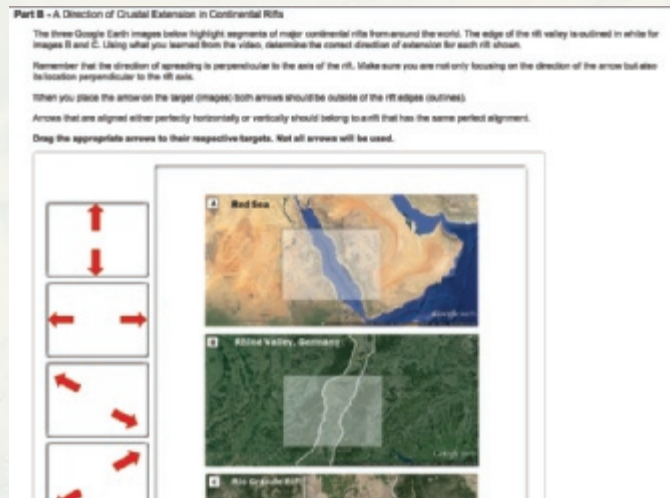
The three Google Earth images below highlight segments of major continental rifts from around the world. The edge of the rift valley is outlined in white for Images B and C. Using what you learned from the video, determine the correct direction of extension for each rift shown.

Remember that the direction of spreading is perpendicular to the axis of the rift. Make sure you are not only focusing on the direction of the arrow but also its location perpendicular to the rift axis.

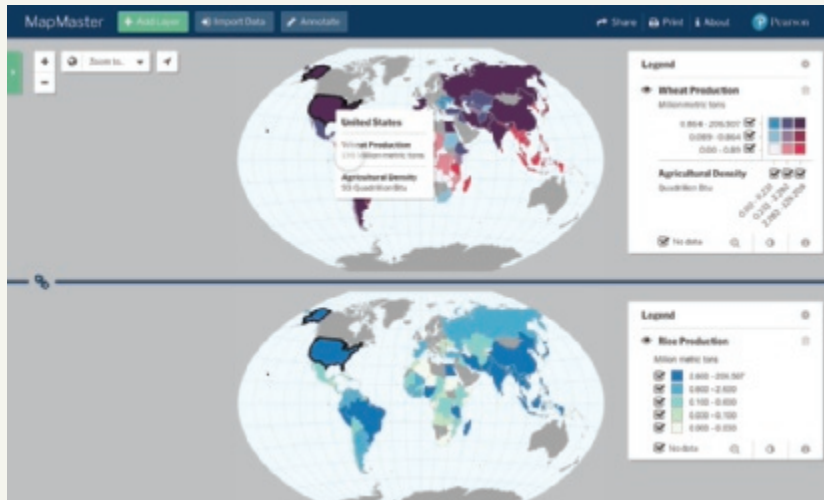
When you place the arrow on the target (images), both arrows should be outside of the rift edges (outlines).

Arrows that are aligned either perfectly horizontally or vertically should belong to a rift that has the same perfect alignment.

Drag the appropriate arrows to their respective targets. Not all arrows will be used.



HALLMARK! GeoTutor Activities help students master the most challenging physical geoscience concepts with highly visual, kinesthetic, and data-rich activities focused on critical thinking and the application of core geoscience concepts.



New! MapMaster 2.0 Interactive Map Activities are inspired by GIS, allowing students to layer various thematic maps to analyze spatial patterns and data at regional and global scales. The maps are now fully mobile, with enhanced analysis tools, such as split screen, allowing students to geolocate themselves in the data and upload their own data for advanced mapmaking. This tool includes zoom and annotation functionality, with hundreds of map layers leveraging recent data from sources such as the PRB, the World Bank, NOAA, NASA, USGS, United Nations, the CIA, and more.

NEW! GeoLab Activities augment the chapters with online, automatically graded, and data-rich applied lab activities.

Part C - Estimating Spreading Distances

Two figures below show the magnetic polarity patterns in three of the major oceans (Pacific, South Atlantic, and North-Atlantic), as well as a simplified, corresponding magnetic polarity reversal time scale. Use the length scale in the polarity patterns diagram and the timescale to estimate how much total spreading has occurred in the North Atlantic Ocean over the last 2 million years.

Figure 21.12 Simplified magnetic polarity reversals in the mid-oceanic ridges at three locations. (a) Simplified magnetic reversal time scale for the last 10 million years.

Select the correct answer.

- 140 km
- 30 km
- 80 km
- 40 km

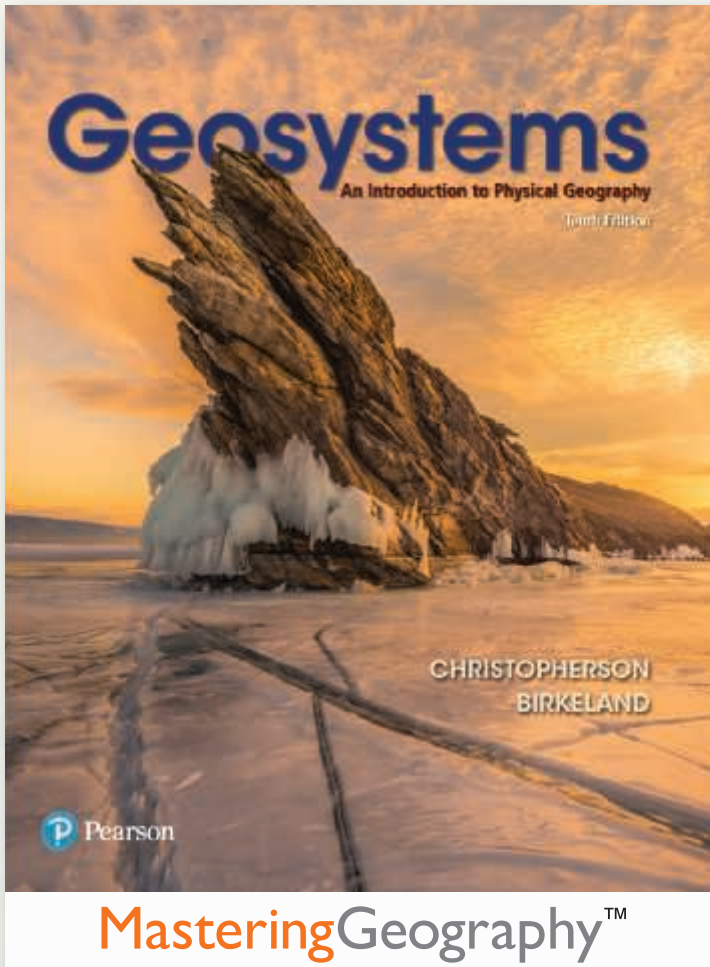
SUBMIT **My Answers** **Show Up** **Review Part**



NEW! Video Activities from sources such as the BBC, Financial Times, and Television for the Environment's *Life* and *Earth Report* series provide students with applied real-world examples of physical geography in action, giving a sense of place, and allowing students to explore a range of locations and topics.

Resources for YOU, the Instructor

MasteringGeography provides you with everything you need to prep for your course and deliver a dynamic lecture, in one convenient place. Resources include:



LECTURE PRESENTATION ASSETS FOR EACH CHAPTER

- PowerPoint Lecture Outlines
- PowerPoint Clicker Questions
- Files for all illustrations, tables, and photos from the text

TEST BANK

- The *Test Bank* in Microsoft Word formats
- TestGen Computerized Test Bank, which includes all the questions from the printed test bank in a format that allows you to easily and intuitively build exams and quizzes

TEACHING RESOURCES

- *Instructor Resource Manual* in Microsoft Word and PDF formats
- Pearson Community Website (<https://communities.pearson.com/northamerica/s/>)
- Goode's *World Atlas*, 23rd Edition
- Mann/Kump, *Dire Predictions: Understanding Climate Change*, 2nd Edition
- *Applied Physical Geography: Geosystems in the Lab*, 10th Edition

Measuring Student Learning Outcomes

All of the MasteringGeography assignable content is tagged to key learning concepts from the book, the National Geography Standards, and Bloom's Taxonomy. You also have the ability to add your own learning outcomes, helping you track student performance against your course goals. You can view class performance against the specified learning outcomes and share those results quickly and easily by exporting to a spreadsheet.

GEOSYSTEMS

AN INTRODUCTION TO PHYSICAL GEOGRAPHY

Tenth Edition



GEOSYSTEMS

AN INTRODUCTION TO PHYSICAL GEOGRAPHY

Tenth Edition

**ROBERT W. CHRISTOPHERSON
GINGER H. BIRKELAND**



330 Hudson Street, NY, NY 10013

Executive Editor, Geosciences Courseware: Christian Botting
Content Producer: Anton Yakovlev
Courseware Specialist: Jonathan Cheney
Courseware Analyst: Jay McElroy
Editorial Assistant: Emily Bornhop
Courseware Director, Portfolio Management: Beth Wilbur
Courseware Director, Content Development: Ginnie Simione Jutson
Managing Producer, Science: Mike Early
Production Management: Jeanine Furino, Cenveo® Publisher Services
Copyeditor: Kathy Pruno

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Design Manager: Mark Ong
Interior/Cover Designer: Preston Thomas
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Photo Researchers: Kristin Piljay, Danny Meldung
Manufacturing Buyer: Maura Zaldivar-Garcia
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Dedication Page Quote: Barbara Kingsolver, *Small Wonder* (New York: Harper Collins Publications, 2002), p. 39.

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DEDICATION

To the students and teachers of Earth, and
to all the children and grandchildren, for it
is their future and home planet.

*The land still provides our genesis, however
we might like to forget that our food comes
from dank, muddy Earth, that the oxygen
in our lungs was recently inside a leaf, and
that every newspaper or book we may pick
up is made from the hearts of trees that
died for the sake of our imagined lives.
What you hold in your hands right now,
beneath these words, is consecrated air and
time and sunlight.*

—Barbara Kingsolver

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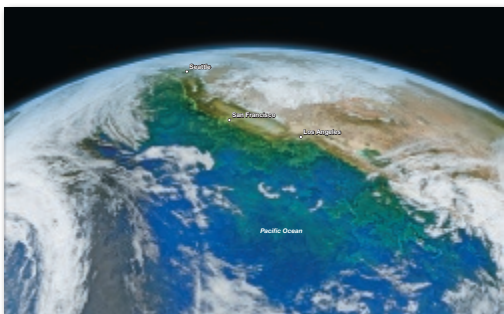
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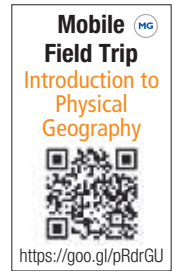
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PREFACE

Welcome to the tenth edition of *Geosystems*! This edition features updated content, new active learning activities to engage students, and many new photos and illustrations. We continue to build on the success of the first nine editions, as well as the companion texts, *Elemental Geosystems*, now in its eighth edition; *Geosystems, Canadian Edition*, fourth edition; and the newest *Geosystems Core*, first edition. Students and teachers appreciate the systems organization, integration of figures and text, and overall relevance to what is happening to Earth systems in real time. *Geosystems* continues to tell Earth's story in student-friendly language.

New to the Tenth Edition

Nearly every page of *Geosystems*, tenth edition, presents new content in text and figures, and new features. Significant content changes include:

- **Chapter 4, Atmospheric Energy and Global Temperatures:** We consolidated content from Chapters 4 and 5 in previous editions into a new chapter. The discussion of atmospheric and surface energy balances now leads into the material on global temperatures, with improved connections between the two topics.
- **Chapter 6, Water and Atmospheric Moisture:** We updated, reorganized, and clarified content and added a new section on precipitation processes.
- **Chapter 15, Eolian Processes and Arid Landscapes:** We restored our coverage of wind processes and desert landscapes as a stand-alone chapter, with updated and expanded coverage from previous editions.
- **Chapter 10, Climate Change:** This edition features extensive updates to our stand-alone chapter on climate change, offering an overview of climate change science. The chapter explores paleoclimatology, climate feedbacks, evidence and causes of present climate change, climate models and projections, and steps we can take to moderate Earth's changing climate.
- **Mobile Field Trip Videos** have students accompany acclaimed photographer and pilot Michael Collier in the air and on the ground to explore iconic landscapes of North America and beyond. Readers scan Quick Response (QR) links in the book to access the 20 videos as they read. Also available within MasteringGeography.
- **Project Condor Quadcopter Videos**, linked via QR codes, take students out into the field through narrated quadcopter footage, exploring the physical processes that have helped shape North American landscapes. Readers scan Quick Response (QR) links in the book to access the 10 videos as they read. Also available within MasteringGeography.
- **New systems diagrams** on all chapter-opener pages emphasize the inputs, actions, outputs, and human–Earth connections relevant to each chapter. These chapter-specific diagrams expand on the systems diagrams on part-opener pages that remain a hallmark of this text.
- **New and revised illustrations and maps** improve student learning in every chapter. More than 250 new photos and images bring real-world scenes into the classroom.

Also new to the tenth edition are features that help students relate physical geography topics to the real world and apply concepts as they learn.

- A new **Everyday Geosystems** feature at the beginning of each chapter invites students to explore the “why” and “how” application of physical geography concepts to everyday phenomena. Example topics are:
 - *How much water is needed to produce the food I eat?* (Chapter 8)
 - *What kind of damage occurs when a river floods?* (Chapter 14)
 - *Have you noticed fewer bees in your neighborhood?* (Chapter 19)
- New **Work It Out** activities in each chapter give students a chance to practice basic conceptual or quantitative reasoning. Integrated into appropriate sections of each chapter, these activities give students the opportunity to demonstrate understanding of learned concepts and practice critical thinking as they read.
- New **Geospatial Analysis** exercises at the end of each chapter are summative mini-lab activities, sending students outside of the book to access and explore online science tools and data sets from sources such as NASA, USGS, and NOAA, to perform critical geospatial data analysis.
- New **Apply Concepts** features, part of the text's hallmark Focus Studies, are active learning tasks that compel students to reflect on the information they have learned and perform short activities.
- New **Questions to Consider** within the *Human Denominator* feature in each chapter ask students to interpret graphs and maps in the feature and connect information to topics within the chapter.

Hallmark Features and Content Updates

- Twenty **Focus Studies**, with either updated or new content, explore relevant applied topics in greater depth and are a popular feature of the *Geosystems* texts. These features are grouped by topic into categories: Pollution, Sustainable Resources, Environmental Extremes,

Climate Change, Natural Hazards, and Environmental Restoration. Eleven new Focus Study topics include:

- Forms of Energy (Chapter 1)
 - Geographic Information Systems (Chapter 1)
 - Summer Fog Protects the World's Tallest Trees (Chapter 6)
 - The 2015 Northern Hemisphere Tropical Cyclone Season (Chapter 7)
 - Melting Permafrost Releases Greenhouse Gases in the Arctic (Chapter 10)
 - Human-caused Earthquakes on the Increase (Chapter 12)
 - Is Summer Heat a Trigger for Yosemite Rockfalls? (Chapter 13)
 - Petra, Jordan—Human Impacts on an Ancient City in an Arid Land (Chapter 15)
 - Sand Dunes Protect Coastlines during Superstorm Sandy (Chapter 16)
 - Greenland and Antarctica: Melting at the Edges of the Continental Ice (Chapter 17)
 - The 1930s Dust Bowl: Regional-Scale Soil Erosion (Chapter 18)
- The chapter-opening **Geosystems Now** features present brief original case studies and current issues in geography and Earth systems science. The 20 new *Geosystems Now* topics in the tenth edition include citizen science in the 21st century (Chapter 1), storm chasing (Chapter 7), the U.S. Pacific Northwest earthquake hazard (Chapter 12), and coral reefs in decline (Chapter 16). Many of these features emphasize linkages across Earth systems, exemplifying the Geosystems approach.
 - **Geosystems In Action** features focus on key topics, processes, systems, or human–Earth connections. In every chapter, these features offer a one- to two-page highly visual presentation of a topic central to the chapter, with active learning questions and links to media in *MasteringGeography*, as well as a GeoQuiz to aid student learning. The feature is updated and streamlined from the past edition and includes two new topics: atmospheric temperature (Chapter 3) and precipitation processes (Chapter 6).
 - **The Human Denominator** feature at the end of every chapter links chapter topics to human examples and applications. The feature includes updated maps, photos, graphs, and other diagrams to provide visual examples of many human–Earth interactions. In this edition, all Human Denominators end with two new *Questions to Consider*.
 - **GeoReports** continue to describe timely and relevant events related to the discussion in the chapter, and offer new sources of information and citizen science opportunities. Example topics from the more than 40 *GeoReports* in this edition include:
 - Crowdsourcing precipitation with the free MPING app (Chapter 6)
 - Citizen science using satellite imagery to assess tropical cyclones (Chapter 7)

- A luxury cruise ship crosses the Northern Passage (Chapter 17)
- Rising sea level causes the first mammal extinction (Chapter 19)

- **Key Learning Concepts** appear at the outset of each chapter, helping students prioritize chapter learning objectives. Each chapter concludes with the *Key Learning Concepts Review*, which summarizes the chapter using the opening objectives.
- *Geosystems* continues to embed URLs within the text, linking to original science sources. More than 60 appear in this edition. These allow students to pursue topics of interest to greater depth, or to obtain the latest information about weather and climate, tectonic events, or floods
- The book is supported by MasteringGeography™, the most widely used and effective online homework, tutorial, and assessment system with resources for before, during, and after class. Assignable media and activities include Geoscience Animations, videos, *Mobile Field Trip* videos, *Project Condor* Quadcopter videos, *Encounter Physical Geography* Google Earth™ explorations, GIS-inspired MapMaster™ interactive maps, Hazard City context-rich problems, GeoTutor coaching activities on the toughest topics in geography, end-of-chapter questions and exercises, reading quizzes, and Test Bank questions. Students have access to *Dynamic Study Modules* that provide each student with a customized learning experience. Students also have access to a text-specific Study Area with study resources, including a Pearson eText version of *Geosystems*—all at www.masteringgeography.com.
- *Learning Catalytics*, a “bring your own device” student engagement, assessment, and classroom intelligence system, is integrated with *MasteringGeography*.

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 Richard L. Orndorff, *University of Nevada, Las Vegas*
 FeiFei Pan, *University of North Texas*
 Patrick Pease, *East Carolina University*
 James Penn, *Southeastern Louisiana University*
 Rachel Pinker, *University of Maryland, College Park*
 Greg Pope, *Montclair State University*
 Robin J. Rapai, *University of North Dakota*
 Philip Reeder, *University of South Florida*
 Philip D. Renner, *American River College*
 William C. Rense, *Shippensburg University*
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 Dar Roberts, *University of California—Santa Barbara*
 Wolf Roder, *University of Cincinnati*
 Robert Rohli, *Louisiana State University*
 Bill Russell, *L.A. Pierce College*
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 Erinanne Saffell, *Arizona State University*
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 Daniel A. Selwa, *U.S.C. Coastal Carolina College*
 Debra Sharkey, *Cosumnes River College*
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 Jon Van de Grift, *Metropolitan State College*
 David Weide, *University of Nevada—Las Vegas*
 Forrest Wilkerson, *Minnesota State University, Mankato*
 Thomas B. Williams, *Western Illinois University*
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Stephen R. Yool, *University of Arizona*
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 Don Yow, *Eastern Kentucky University*
 Susy Svatek Ziegler, *University of Minnesota*

From Robert: The tenth edition marks the 25th anniversary since the first edition in 1992. I thank my family for believing in this work, and especially the next generation: Chavon, Bryce, Payton, Brock, Trevor, Blake, Chase, T yenna, and Cade. When I look into our grandchildren’s faces, I see the reason we work toward a sustainable future.

I give special gratitude to all the students during my 30 years teaching at American River College, for it is in the classroom crucible that the *Geosystems* books were forged. Special continued thanks to Charlie Thomsen for his creative work and collaboration on *Encounter Geosystems*, the *Applied Physical Geography* lab manual, work on *MasteringGeography* media and assessments, and ancillaries, and the new *Geosystems Core* text, with Stephen Cunha. I offer a special thanks to Ginger Birkeland, Ph.D., my continuing coauthor on the *Geosystems* texts, for her essential work, attention to detail, and original thinking. Ginger understands the *Geosystems* approach as a different way to teach physical geography and influenced the power of this tenth edition from our first preplanning meetings. She has worked as a river guide operating boats on the Colorado River, and I feel her at the helm of *Geosystems*! I believe the future of the *Geosystems* franchise looks bright.

As you read this book, you will learn from many content-specific photographs made by my wife, photographer, and expedition partner, Bobb  Christopherson. Bobb  is my colleague, wife, and best friend.

From Ginger: Many thanks to my husband, Karl Birkeland, and my daughters, Erika and Kelsey, for their ongoing patience, support, and inspiration. Special thanks to Robert Christopherson for inviting and supporting me on this *Geosystems* journey. I hope our raft runs smoothly and stays upright on the voyage ahead!

From us both: We thank the many authors and scientists who published research that enriches this work. Thanks for all the dialogue received from students and teachers shared through e-mails from across the globe.

Physical geography teaches us a holistic view of the intricate supporting web that is Earth’s environment and our place in it. Dramatic global change is underway in human–Earth relations as we alter physical, chemical, and biological systems. Our attention to climate change science and applied topics is in response to the impacts we are experiencing and the future we are shaping. All things considered, this is a critical time for you to be enrolled in a physical geography course! The best to you in your studies—and *carpe diem!*

Robert W. Christopherson
 Roseville, CA
 E-mail: bobobbe@aol.com

Ginger H. Birkeland
 Bozeman, Montana

About Our **Sustainability Initiatives**

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For Students

Applied Physical Geography—Geosystems in the Laboratory, Tenth Edition by Charlie Thomsen and Robert Christopherson (0134686365). A variety of exercises provides flexibility in lab assignments. Each exercise includes key terms and learning concepts linked to *Geosystems*. The Tenth Edition includes exercises on climate change, soils, and rock identification, a fully updated exercise on basic GIS using ArcGIS online, and more integrated media, including Google Earth™ and Quick Response (QR) codes linking to Pre-Lab videos. Supported with online worksheets as well as KMZ files for all of the Google Earth™ exercises found in the lab manual.

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- *Encounter Physical Geography* by Jess C. Porter and Stephen O'Connell (0321672526)
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Instructor Resource Materials (Download) (0134700252). The *Instructor Resource Materials* provide a collection of resources to help teachers make efficient and effective use of their time. All digital resources can be found in one well-organized, easy-to-access place. The IRM includes:

- All textbook images as JPEGs, and PowerPoint™ Presentations
- Pre-authored Lecture Outline PowerPoint® Presentations which outline the concepts of each chapter with embedded art and can be customized to fit teachers' lecture requirements
- CRS “Clicker” Questions in PowerPoint™
- The TestGen software, *Test Bank* questions, and electronic files of the *Instructor Resource Manual* and *Test Bank*

This *Instructor Resource* content is also available online via the Instructor Resources section of *MasteringGeography™* and www.pearsonhighered.com/irc.

1

Essentials of Geography



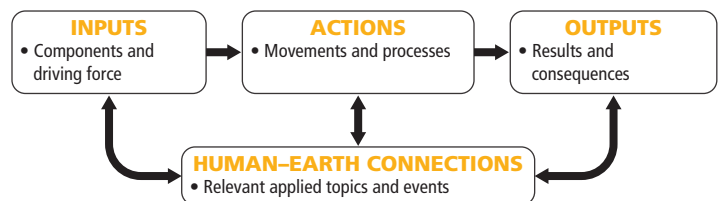
Queenstown, New Zealand, is known for snowsports, rafting, fishing, mountain biking, and boating on Lake Wakatipu, the country's longest lake. The city is also the tourist gateway to the glacial landscapes of the Southern Lakes region of the South Island. [Beerpix/Getty Images.]

KEYLEARNING concepts

After reading the chapter, you should be able to:

- **Define** geography and physical geography, and **describe** spatial analysis.
- **Summarize** the scientific process and **discuss** human population growth as it relates to geographic science.
- **Describe** open and closed systems, feedback, and equilibrium concepts as they relate to Earth systems.
- **Explain** Earth's shape and reference grid: latitude, longitude, latitudinal geographic zones, and time zones.
- **Define** cartography and mapping basics: map scale and map projections.
- **Describe** three geoscience tools—the Global Positioning System (GPS), remote sensing, and geographic information systems (GIS)—and **explain** how these tools are used in geographic analysis.

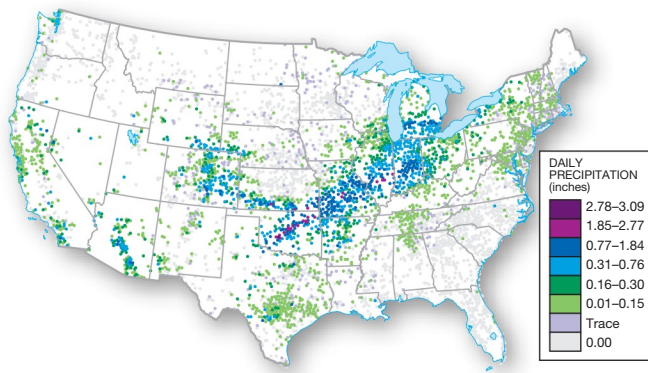
A Geosystems schematic diagram appears in this space in all subsequent chapters. The content of each chapter is laid out as a system to demonstrate chapter organization. The Geosystems approach studies content in this sequence:



Citizen Science in the 21st Century

Is weather your go-to conversation starter when an awkward silence sets in? Would you be interested in expanding your inventory of weather small talk by observing

and reporting weather in your own backyard? If the answer is yes, then you won't be alone. In one national effort, the *Community Collaborative Rain, Hail, and Snow Network* (CoCoRaHS), about 20,000 volunteers post daily rain and snow amounts, measured in their own yard, to <http://www.cocorahs.org> (Figure GN 1.1). Volunteers are everyday citizens with a range of age and experience, from elementary students to retirees. The result of this grassroots effort, part of a growing movement called citizen science, is a vast precipitation database used for education, research, and natural resource management.



▲Figure GN 1.1 Map of precipitation reported to CoCoRaHS on April 11, 2016. [www.cocorahs.org]

What Is Citizen Science? *Citizen science* is the practice of using public participation for scientific data collection and monitoring. It is a form of *crowdsourcing* because it uses small contributions from a large

number of people. CoCoRaHS, like many other organized efforts, offers training through its interactive website. The necessary equipment—for example, precipitation gauges and hail pads—is simple and inexpensive. Volunteers record their measurements on data sheets and submit them online, then turn in equipment such as used hail pads at the nearest CoCoRaHS office.

Citizen science occurs over a wide-ranging spatial scale. CoCoRaHS, for example, is a national network of precipitation data. The effort began in 1998 in Fort Collins, Colorado, a year after a flood killed five people and caused \$200 million in damage—the city's worst natural disaster. *BioBlitz*, an international effort focusing on biodiversity, is an example of a community project. The goal of *BioBlitz* is for volunteers to find and identify as many species as possible in a specific area over a short time period (Figures GN 1.2 and 1.3).

Public participation in scientific research is not new. For example, community wildlife surveys began well over 100 years ago. However, in the last decade or so, citizen science has greatly expanded with advances in technology, in particular the prevalence of smartphones that allow easy and convenient online information sharing. Smartphones have built-in GPS receivers that enable real-time location, essential for reporting species sightings and weather observations. (We discuss the Global Positioning System in this chapter.) Evolving technology may soon add air quality and temperature sensors to mobile devices, expanding citizen science possibilities.

Citizen Science and Geosystems One of the strengths of citizen science is the production of a large dataset that allows for spatial analysis, the study of phenomena across spaces, areas, and locations—issues at the heart of geographic science. In Chapter 1 we present the framework for our study of Earth systems and physical geography: spatial concepts, the scientific process, human–Earth connections, Earth systems thinking, and geographic tools. Throughout *Geosystems*, we look at citizen science news and opportunities (check the GeoReports in each chapter).

1. What types of Earth systems science interest you?
2. As you read the chapter, make a list of physical geography topics you might like to investigate as a citizen scientist volunteer.



◀Figure GN 1.2 **Inventory of insects.** Volunteers inventory insects at Lily Lake in Rocky Mountain National Park, Colorado, as part of a national Park Service *BioBlitz* in 2012. [Karine Aigner/NPS]



◀Figure GN 1.3 **Citizen scientist looks for mountain goats, Glacier National Park, Montana, gathering data for a species count.** [Melissa Sladek/NPS.]

Welcome to *Geosystems* and the study of physical geography! In this text, we examine Earth's natural environments, including their living and nonliving elements, the processes that shape them, and their connections to human societies. Physical geography studies environments across and within landscapes, including processes in the atmosphere, at Earth's surface, and within living ecosystems. Throughout *Geosystems*, we emphasize the study of Earth *systems*, the interconnected parts that make up the whole. In the 21st century, as our natural world changes with the growing influence of humans, the scientific study of physical geography and Earth systems is more exciting and relevant than ever.

Think back to some recent events in the news, for example, a flood in the U.S. Midwest, a tropical storm in the Pacific or hitting the U.S. Southeast coast, or dangerous air pollution in China. What processes caused these events and how did they impact human lives? Why do these processes occur in some places and not others? These questions, typical for physical geographers, are *spatial* in nature, meaning that they seek to understand physical processes across spaces, locations, and regions (Figure 1.1). Such questions encompass the connections between humans and their environment, from the air we breathe to the water we drink to the soils we plant with crops to the natural disasters that take human lives.

Consider these specific examples and the question they raise for the study of physical geography and Earth systems. This text provides tools for answering these questions and understanding the underlying issues.

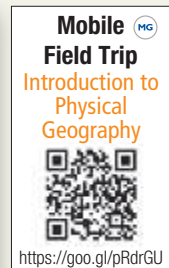
- In April 2015, a magnitude 7.8 earthquake devastated the small Himalayan nation of Nepal, causing more than 8800 deaths and 18,000 injuries. Why do earthquakes occur in particular locations across the globe?
- In 2014, the U.S. National Park Service finished the deconstruction of two dams on the Elwha River in Washington—the largest dam removals in the world to date. The project has restored a free-flowing river for fisheries and associated ecosystems. How do dams change river environments? Can other rivers be restored with dam removal?
- In 2016, carbon dioxide—the primary greenhouse gas emitted by human activities such as the burning of fossil fuels—reached its highest concentrations in Earth's atmosphere in over 800,000 years, and continues to rise. What is the role of this gas in our atmosphere, and how will rising concentrations affect life on Earth?
- During the winter of 2014–2015, the city of Boston, Massachusetts, received over 110 inches of snow—their highest yearly snowfall since record-keeping began in the 1800s. This snow accumulation occurred

everydayGEOSYSTEMS

Where and how far do pollutants move in the atmosphere?

Pollutants are carried by winds, affecting human health and living ecosystems over a wide region. Smoke and particulates, emerging from the smokestack at right, are by-products of burning coal to produce power. Water vapor, emerging from the towers at left, is another by-product that combines with pollutants to form

acid precipitation. Carbon dioxide gas from fossil fuel burning traps heat in the atmosphere near Earth's surface, contributing to climate change. Physical geographers analyze air pollution and other environmental issues with a spatial focus on movement, distribution, and pattern, emphasizing human–Earth relationships.



◀ **Figure 1.1**
Geography's
spatial view.

Smoke and water vapor enter the air at the Bruce Mansfield Power Station near Shippingport, Pennsylvania. [Clarence Holmes Photography/Alamy.]

during the two warmest years on record for global temperature. What atmospheric processes explain the formation of winter storms? Why did heavy snow occur in the U.S. Northeast during a year when record high air temperatures occurred across the globe?

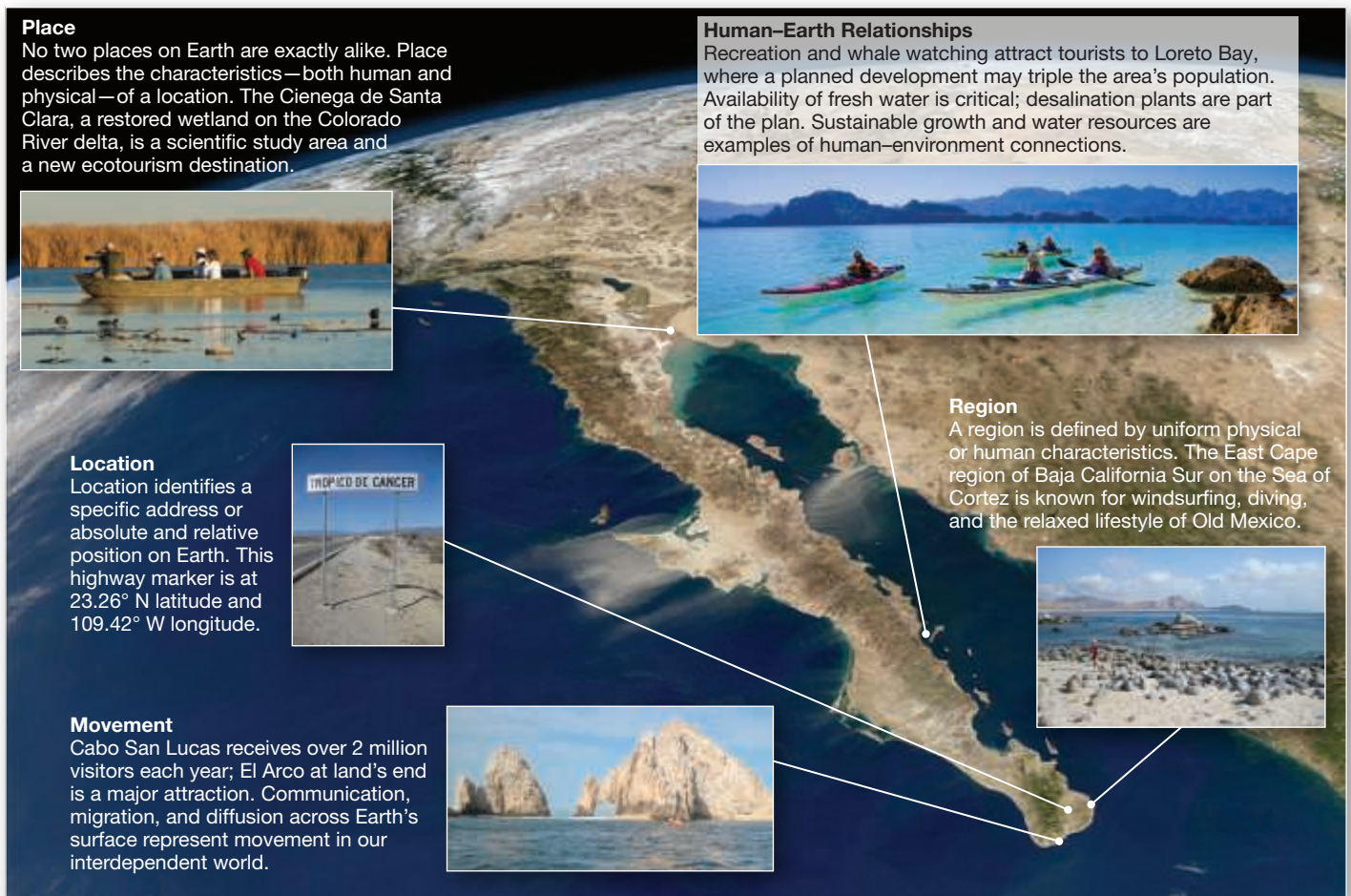
Perhaps more than any other issue, climate change has become an overriding focus of the study of Earth systems. Rising atmospheric concentrations of carbon dioxide and other greenhouse gases are changing Earth's energy balance and are linked to increasing global temperatures. Rising air and ocean temperatures affect the entire planet, from the poles to the equator. As a result, Arctic sea ice is declining and the Greenland and Antarctic Ice Sheets are melting at accelerating rates. Sea level is rising, affecting human populations living in coastal regions. Globally, intense weather events, droughts, and flooding continue to increase. In presenting the state of the planet, *Geosystems* surveys climate change evidence and considers its implications. How can your actions make a difference? In every chapter, we present up-to-date science and information to help you understand our dynamic Earth systems. Welcome to an exploration of physical geography!

The Science of Geography

Geographic science is concerned with much more than place names. **Geography** (from *geo*, “Earth,” and *graphein*, “to write”) is the science that studies the relationships among natural systems, geographic areas, human culture, and the interdependence of all of these, *over space*. These last two words are important, for geography is a science that is in part defined by its method—analyzing phenomena in relation to space.

In geography, the term *spatial* refers to the nature and character of physical space and the distribution of things within it. The unifying method of geography is **spatial analysis**, the view of phenomena as occurring across space. The language of geography—territory, zone, pattern, distribution, place, location, region, sphere, province, and distance—reflects this spatial view.

Given this spatial perspective, geographic teaching and research has traditionally been divided into five themes: **Location, place, movement, region, and human–Earth relationships**, with examples illustrated and defined in **Figure 1.2**. These themes provide a framework for understanding geographic concepts and asking geographic questions.



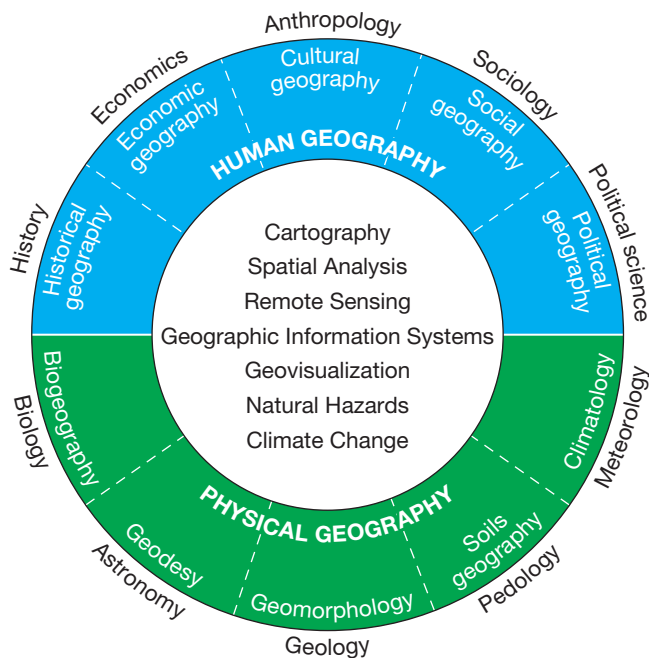
▲ **Figure 1.2 Five themes of geographic science.** This 2011 satellite image shows the entire length of Mexico's Baja peninsula, including Earth's curvature. [Photos by Karl Birkeland, except Place by Cheryl Zook/National Geographic and Human–Earth by Gary Luhm/garylulm.net. Image from *Aqua* satellite/Norman Kuring, Ocean Color Team, NASA/GSFC.]

Although geography is not limited to place names, maps and location are central to the discipline and are important tools for conveying geographic data. Evolving technologies such as the Global Positioning System (GPS) and geographic information systems (GIS) are widely used for scientific and everyday applications as hundreds of millions of people access maps and locations on smartphones, tablets, and computers. We discuss these geospatial tools, including remote sensing and geovisualization, later in this chapter.

Geographic Subfields

Because many subjects can be examined geographically, geography is a diverse science that integrates subject matter from a wide range of disciplines. Even so, it splits broadly into two primary subfields: *physical geography*, comprising specialty areas that draw largely on the physical and life sciences, and *human geography*, comprising specialty areas that draw largely on the social and cultural sciences (Figure 1.3). With the increasing complexity of human–Earth connections, the focus of most geographic research has moved toward the overlapping areas of these two broad fields.

Physical geography is the spatial study of all the elements, processes, and systems that make up the natural environment: energy, air, water, weather, climate, landforms, soils, animals, plants, microorganisms, and Earth itself. Within physical geography, research in all specialty areas now emphasizes human influences on natural systems. For example, physical geographers examine the vulnerability of human populations to landslides, participate in ecosystems restoration projects, and examine the effects of drought and changing climate on regional water supplies.



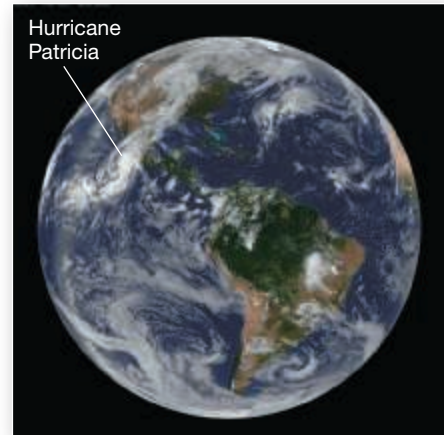
▲Figure 1.3 The scope of geography. Geography combines Earth topics and human topics, blending ideas from many different sciences. Numerous subfields, especially those focused on geographic techniques, fall into the overlap between physical and human geography.

Geographic Investigation

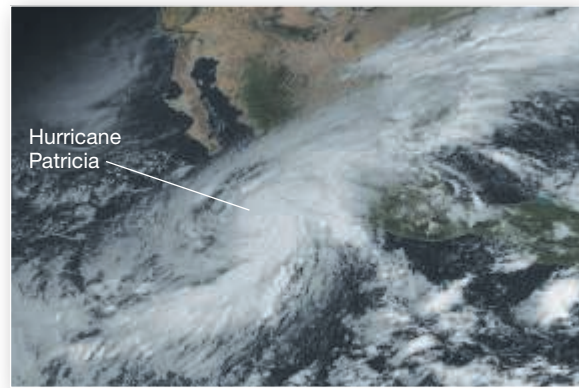
In addition to spatial analysis, the concepts of process, scale, and systems are central to physical geography investigations. **Process** refers to a set of actions or mechanisms that operate in some special order. In *Geosystems*, we examine processes in every chapter: for example, those involved in Earth’s weather patterns, in continental crust movements and earthquake occurrences, and in the spread of invasive plants and animals.

Geographers often use the concept of scale, both over space and time, to examine patterns and processes. We define scale for this purpose as the relative size or extent of some attribute; for example, a *spatial scale* of analysis may range from global to regional to local (Figure 1.4). A

►Figure 1.4 Viewing Hurricane Patricia, 2015, at global, regional, and local scales. [(a) GOES-13 satellite, NOAA. (b) NASA/NOAA via NOAA Environmental Visualization Laboratory. (c) Omar Torres/AFP/Getty Images.]



(a) Global scale: Western Hemisphere



(b) Regional scale: Mexico’s Pacific Coast



(c) Local scale: Damaged restaurant in Las Manzanillas, Jalisco state, Mexico

process operating at a global scale, such as the jet stream winds in the upper atmosphere, can affect those occurring at regional and local scales, bringing storms to a particular region and causing heavy precipitation or flooding in a particular community.

Many processes have different effects according to the *temporal scale* at which they are studied. For example, a landslide into a river channel has dramatic effects over a short time scale (days, months, years) by creating a temporary dam that alters habitat and channel processes. But over a long time scale (decades, centuries, millennia), a landslide is a temporary disturbance as the river eventually loosens the material and carries it away. Note that later in this chapter, we discuss *map scale*, which is a slightly different concept that relates the size of a unit of distance on a map to the size of the same unit of distance on the ground.

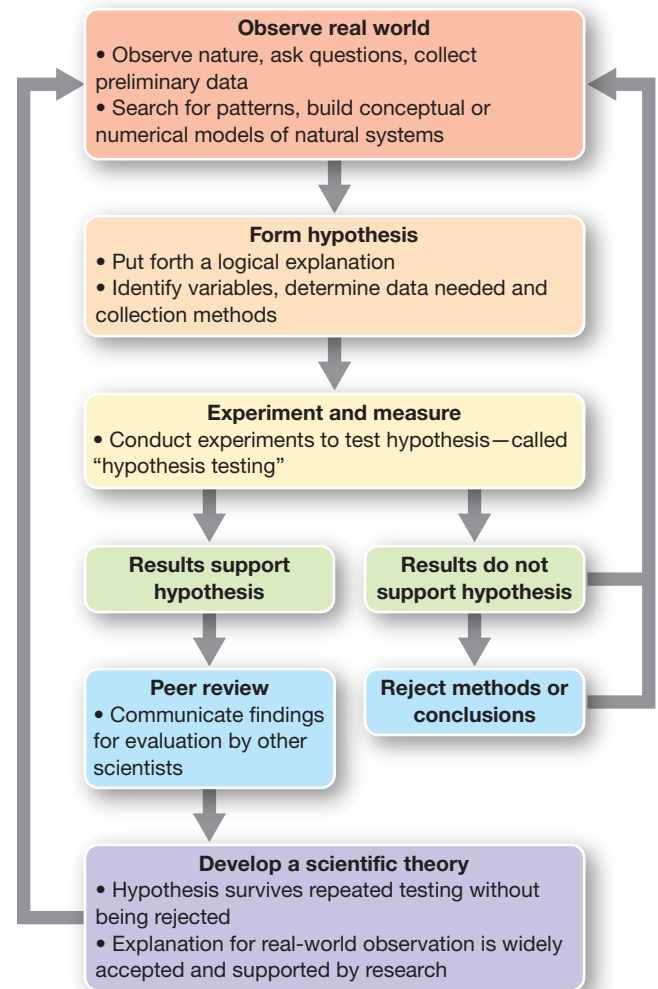
Systems analysis is fundamental to physical geography, and we discuss systems at length later in this chapter. Physical geography encompasses the field of **Earth systems science**, the area of study that seeks to understand Earth as an interacting set of physical, chemical, and biological systems. We now discuss the general process and methods used by scientists, including geographers.

The Scientific Process

In *Geosystems Now*, we introduced “citizen science” in which volunteers participate in data collection. These efforts assist scientists, but data collection alone does not define scientific research. The process of science consists of observing, questioning, testing, and understanding elements of the natural world. The **scientific method** is the traditional recipe of a scientific investigation; it can be thought of as simple, organized steps leading toward concrete, objective conclusions (Figure 1.5). There is no single, definitive method for scientific inquiry; scientists in different fields and even in different subfields of physical geography may approach their scientific testing in different ways. However, the end result must be a conclusion that is reproducible by other scientists, that can be tested repeatedly, and that possibly can be shown to be true or false. Without these characteristics, the result of an inquiry is not science.

Forming and Testing the Hypothesis After making observations and exploring relevant scientific literature, scientists formulate a *hypothesis*—a tentative explanation for the phenomena observed. In forming the hypothesis, they ask questions and identify *variables*, the conditions that change in an experiment or model. Because natural systems are complex, reducing the number of variables helps simplify research questions.

Scientists then test the hypothesis using an experimental study in a laboratory or natural settings. Data collected by citizen scientists can strengthen a study by expanding the database from which to draw results. The methods used for these studies must be reproducible so



▲Figure 1.5 Scientific method flow chart.

that repeat testing can occur. Results may support the hypothesis or not, or predictions made according to the hypothesis may prove accurate or inaccurate. If the results do not support the hypothesis, the researcher will need to adjust data-collection methods or refine the hypothesis statement. If the results support the hypothesis, repeated testing and verification may lead to its elevation to the status of a *theory*.

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

A scientific *theory* is an explanation constructed on the basis of several extensively tested hypotheses and can be reevaluated or expanded according to new evidence. Thus, a scientific theory is not absolute truth—the possibility always exists that the theory could be proved wrong. However, theories explain and tie together broad areas of knowledge about the natural world. Examples include plate tectonics theory and the theory of evolution, discussed in Chapters 11 and 19. The value of a scientific theory is that it stimulates continued observation, testing, understanding, and pursuit of knowledge within scientific fields.

While the scientific method guides investigation, the real process of science leaves room for questioning and thinking “out of the box.” Flexibility and creativity are essential to the scientific process, which may not always follow the same sequence of steps or use the same methods for each experiment or research project.

Applying Scientific Results Scientific studies described as “basic” are designed largely to help advance knowledge and build scientific theories. Other research is designed to produce “applied” results tied directly to real-world problem solving. Applied scientific research may advance new technologies, affect natural resource policy, or directly impact management strategies. Scientists share the results of both basic and applied research at conferences as well as in published papers, and they may take leadership roles in developing policy and planning.

Human–Earth Interactions in the 21st Century

Issues surrounding the growing influence of humans on Earth systems are central concerns of physical geography that we discuss in every chapter of *Geosystems*. More people are alive today than at any previous moment in the planet’s long history. The human influence on Earth is now pervasive.

The Human Denominator One way to consider the sum of the human impact on Earth is to think in terms of fractions. The denominator in a fraction tells how many parts a whole is divided into, for example $4/8$ means that the whole is divided into 8 parts. In *Geosystems*, we refer to the *human denominator* as the growing human population and its demand for Earth’s resources. The numerator in the fraction is Earth’s resource base, which remains relatively fixed. As the human denominator grows, the stresses on Earth systems increase.

We emphasize the connections between humans and Earth systems in the Human Denominator feature in each chapter (see Figure HD 1). This illustration shows important examples of human–Earth interactions using a base map, photos, and graphs with explanatory text, all organized to show that Earth systems impact humans, for example through weather or natural hazards, at the same time that humans impact Earth systems, such as by harvesting forests or polluting water sources.

Human Population Trends The global human population reached 1 billion people in 1804, and doubled to 2 billion in 1927. The time interval to add 1 billion people steadily decreased, as population passed 6 billion in August 1999 and 7 billion in 2011. At present, population growth rates are declining, a trend expected to continue. Yet despite this decline, projections show world population reaching 9 billion in the 2040s. Virtually all new population growth is in the less-developed countries (LDCs), which now possess 81% of the total population.

The population in just two countries (both categorized as LDCs with rapidly developing economies) makes up 37% of Earth’s human count: 19.2% live in China and 17.5% in India—2.7 billion people combined. Considered overall, the planetary population is young, with some 26% still under the age of 15 years (for more information, see <http://www.census.gov/popclock>).

Although population in most of the more-developed countries (MDCs) is no longer increasing, people in the MDCs have a greater impact on the planet per person than those in the LDCs. The United States and Canada, with about 5% of the world’s population, produce about 25% of the world’s gross domestic product. These two countries use more energy per person than Europeans, Latin Americans, and Asians, and up to 20 times more than Africans. Therefore, the impact of this 5% on natural resources and Earth systems is critical.

Global Sustainability Recently, **sustainability science** has emerged as a new, integrative discipline. The concept of sustainability refers to the ability of something to be sustained—to keep going, continue, or endure. The basic question underlying sustainability science is: How can we live well over the long term using the resources of one planet Earth? Sustainable development seeks to advance the condition of human society while maintaining functioning Earth systems. Geographic concepts are fundamental to this new science, with its emphasis on human well-being, Earth systems, and human–environment interactions.



GEOreport 1.1 Welcome to the Anthropocene

The human population on Earth reached 7 billion in 2011 and may reach 8 billion in 2024. Many scientists now agree that the *Anthropocene* is an appropriate name for the most recent years of geologic history, when humans have influenced Earth’s climate and ecosystems. Most scientists mark the start of the Anthropocene as either the beginning of agriculture, more than 5000 years ago, or the dawn of the Industrial Revolution, in the 18th century (see <http://www.anthropocene.info>).

EARTH SYSTEMS IMPACT HUMAN POPULATION

- What are some of the critical natural resources for human societies across the globe?



Known for gambling, entertainment, and nightlife, Las Vegas is the most populous city in Nevada. The greater urban area is home to over 2 million people, while the casinos and resorts of the Las Vegas Strip, shown here, and other parts of the city host over 40 million visitors every year. Water is a critical resource in this desert climate. [robertharding/Alamy.]

HUMAN POPULATION IMPACTS EARTH SYSTEMS

- Growing population and resource use affects all Earth systems; we examine specific impacts in every chapter of Geosystems.

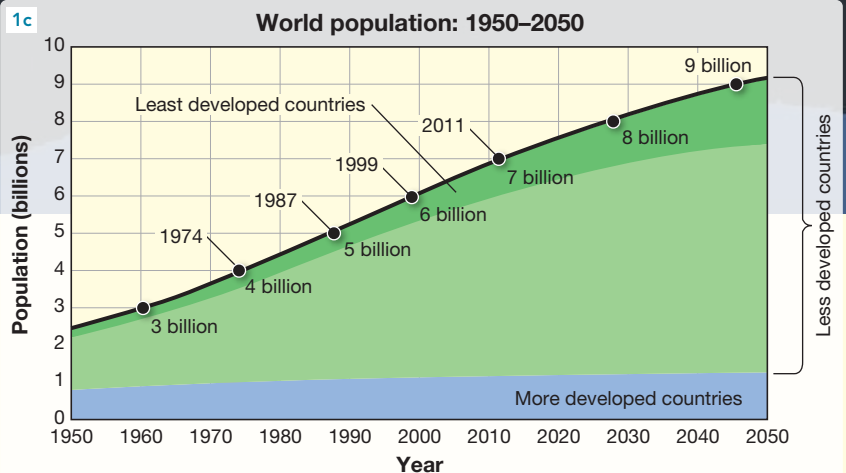


Just over 19% of the world's population lives in China. With a population over 24 million, Shanghai is the largest city (by population) in China and the world, and one of the world's busiest ports for container shipping. Imagine the impact on natural systems with such a high concentration of people living in one location. [Amanda Hall/Robert Harding.]

This 2012 composite image from the *Suomi NPP* satellite shows Earth's lights at night, an indicator of population density and economic wealth. Wildfires also cause night light away from urban areas. [VIIRS instrument, *Suomi NPP*, NASA.]

ISSUES FOR THE 21ST CENTURY

- Many critical issues relate to the sustainability of Earth's resources: global food supply, energy supply and demand, climate change, loss of biodiversity, and air and water pollution.
- To achieve sustainability for humans and Earth, we need to address these issues in new ways.
- Understanding Earth's physical geography helps you make informed decisions on these issues.



Since 1950, population has increased in less-developed countries (LDCs) far more than in more-developed countries (MDCs), a trend that is expected to increase until at least 2050. [Population Reference Bureau, http://www.prb.org/pdf13/2013-population-data-sheet_eng.pdf.]

QUESTIONS TO CONSIDER

1. HD1c shows that, in 1950, people in MDCs constituted roughly one-third of the world's population. What was the fraction (roughly) of MDCs to total world population in 2011?
2. Using the graph in HD1c and the chapter text, calculate the interval of years between each billion-mark milestone for human population. Begin with the 3 billion mark reached in 1960.