Geosystems

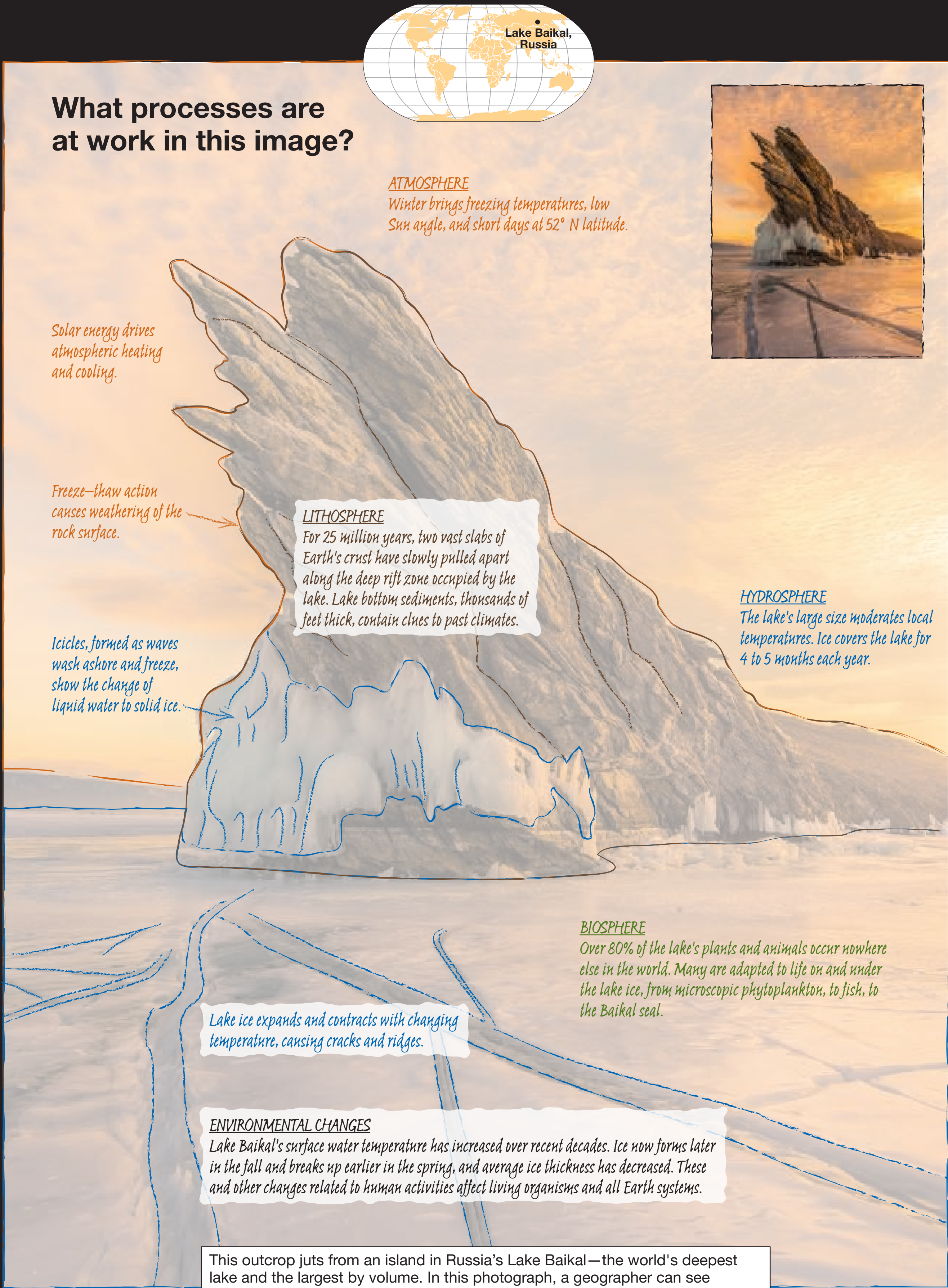
An Introduction to Physical Geography

Tenth Edition

CHRISTOPHERSON
BIRKELAND

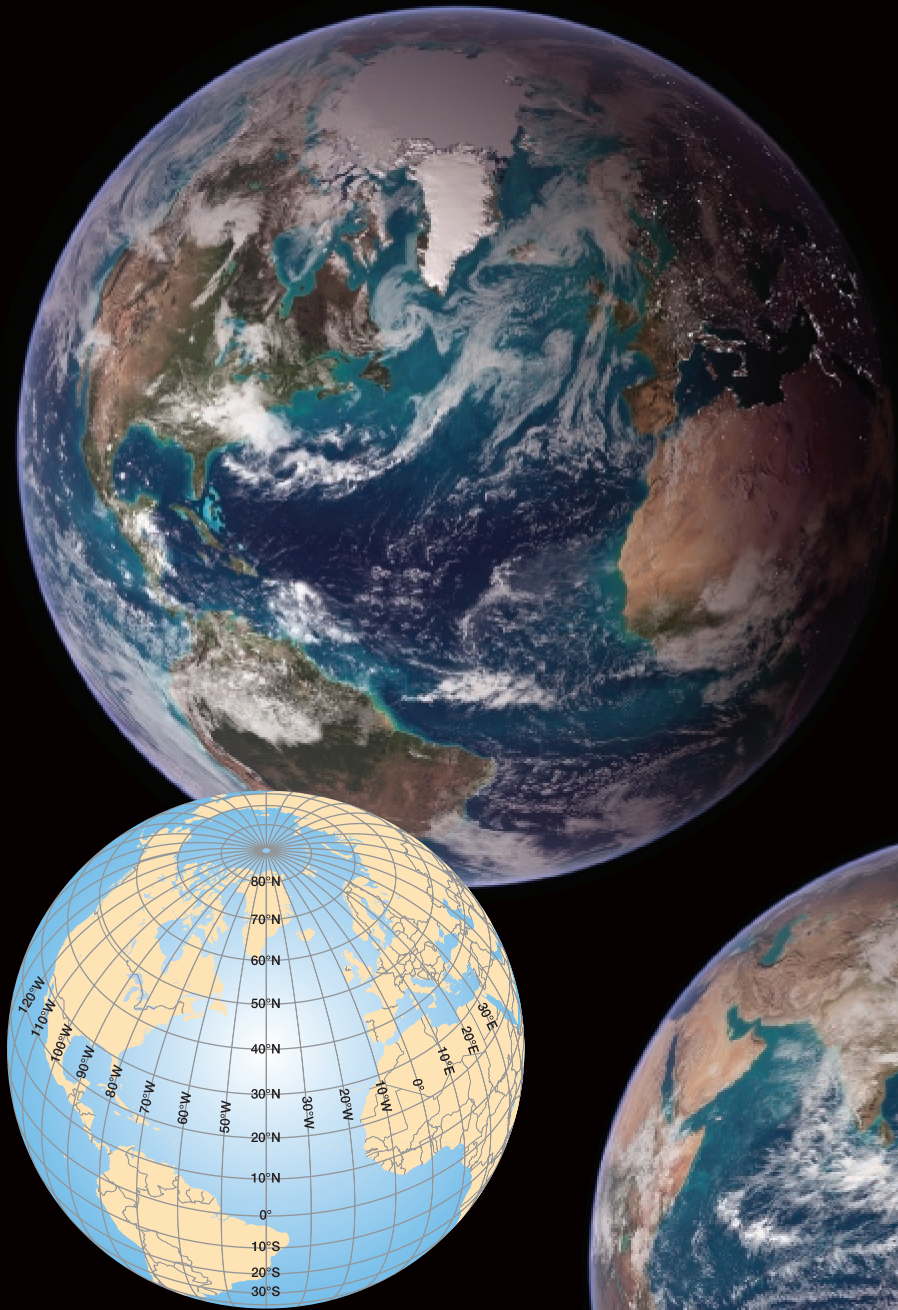
Pearson

What processes are at work in this image?

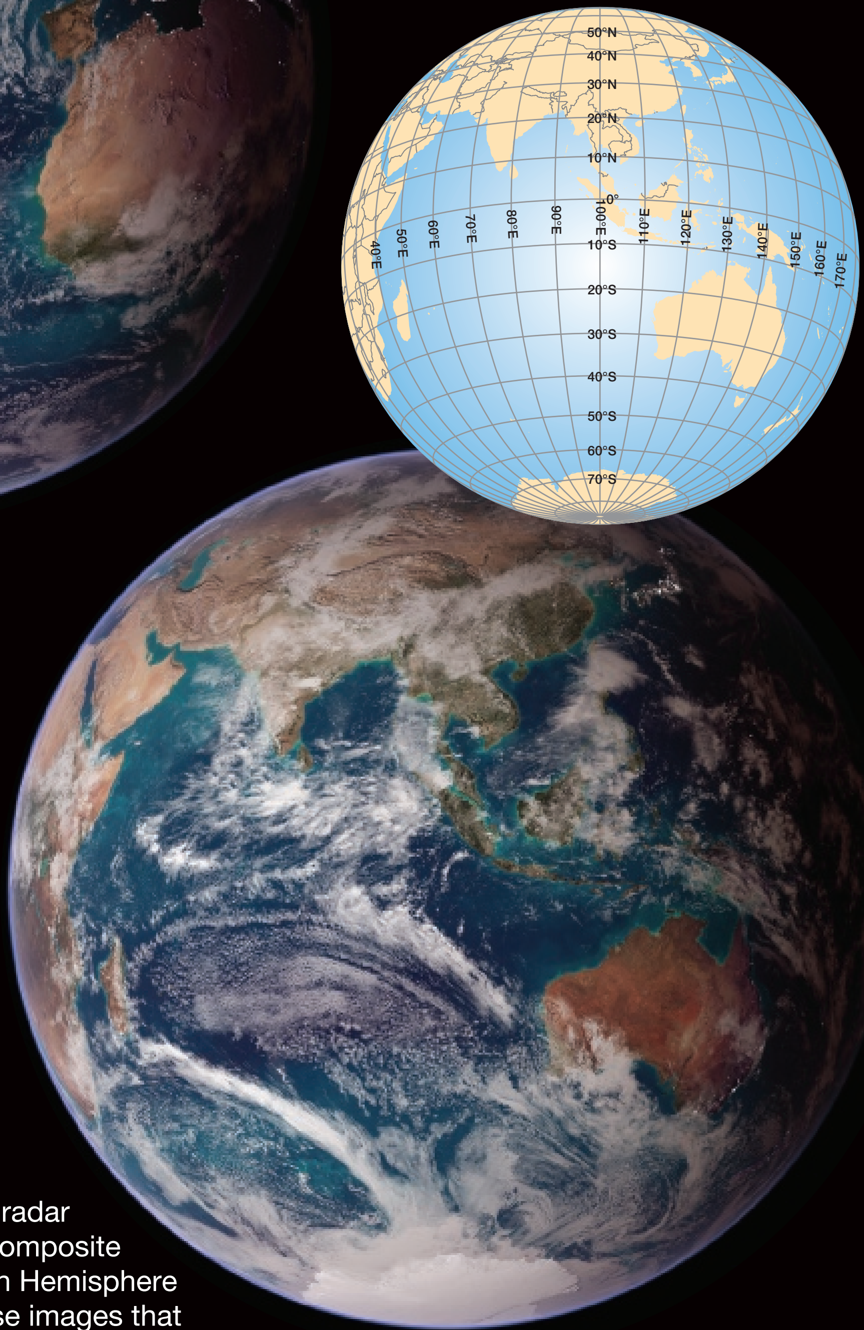


This outcrop juts from an island in Russia's Lake Baikal—the world's deepest lake and the largest by volume. In this photograph, a geographer can see evidence of the forces that shaped the landscape linked to Earth's four immense open systems: the atmosphere, hydrosphere, lithosphere, and biosphere.

Western Hemisphere



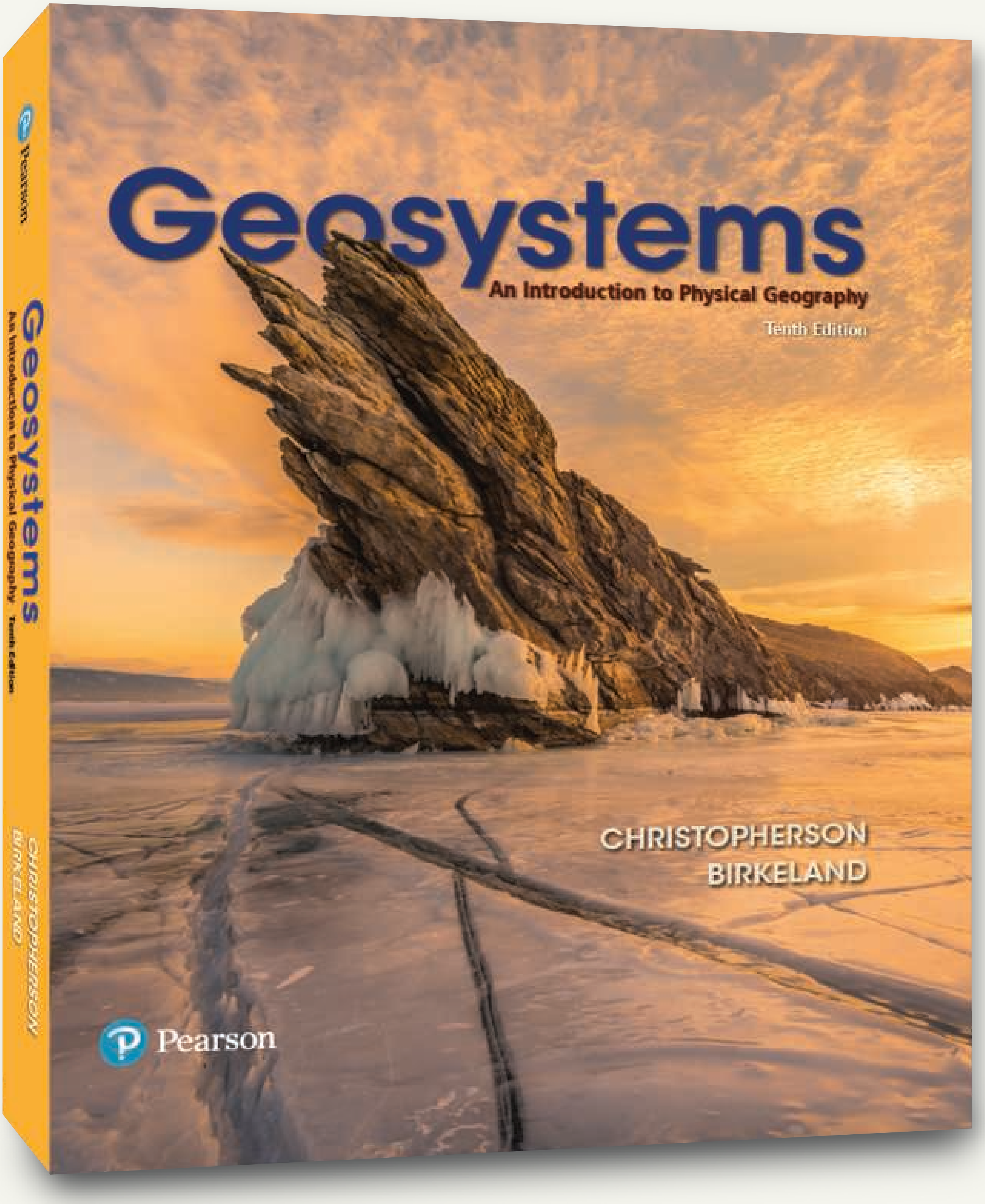
Eastern Hemisphere



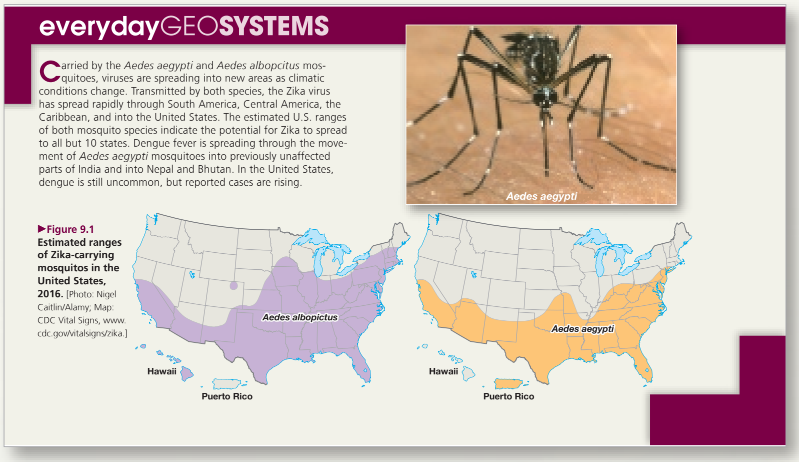
Multiple images from satellites *Terra*, *Aqua*, *Radarsat*, and *Defense Meteorological Satellite*, and from Space Shuttle *Endeavor's* radar data of topography, all merge in a dramatic composite to show the Western Hemisphere and Eastern Hemisphere of Earth. What indications do you see on these images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

[NASA images by Reto Stöckli, based on data from NASA and NOAA.]

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



Real-World Physical Geography



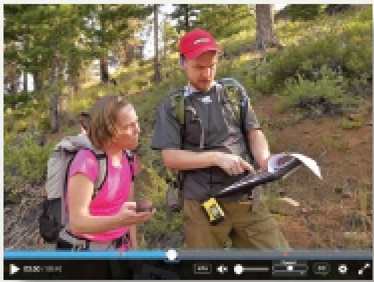
everydayGEOSYSTEMS

Carried by the *Aedes aegypti* and *Aedes albopcitus* 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.

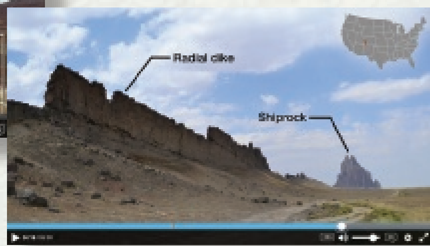
▶**Figure 9.1 Estimated ranges of Zika-carrying mosquitos in the United States, 2016.** [Photo: Nigel Caitlin/Alamy; Map: CDC Vital Signs, www.cdc.gov/vitalsigns/zika.]

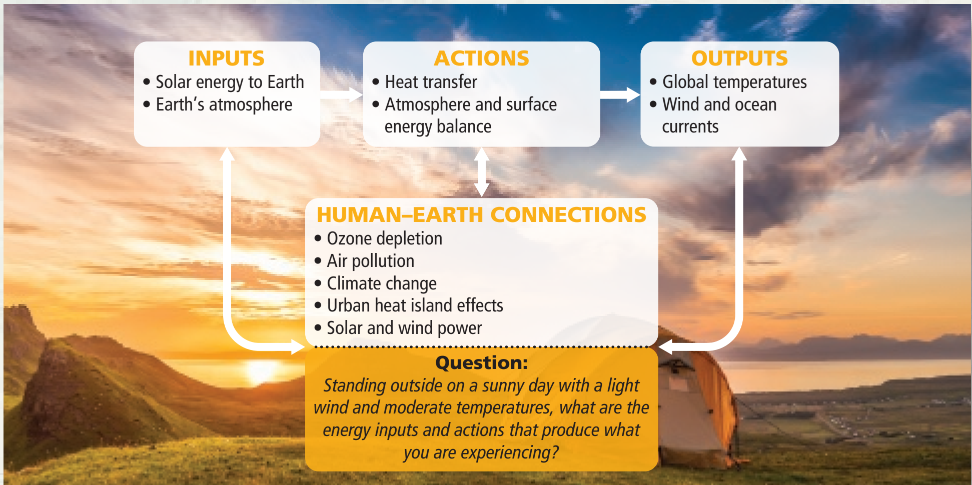
NEW! Everyday Geosystems features at the beginning of each chapter invite the reader to explore the "why" and "how" application of physical geography concepts to everyday phenomena.

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?

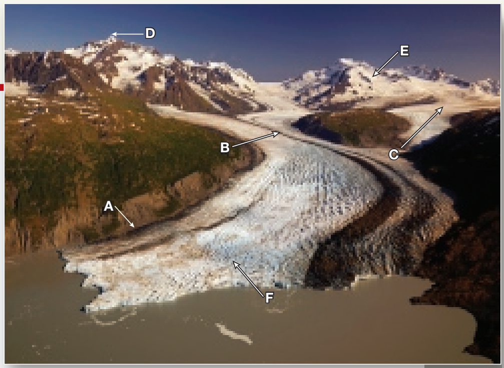
WORKITOUT 17.1
Identify Glacial Features

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.

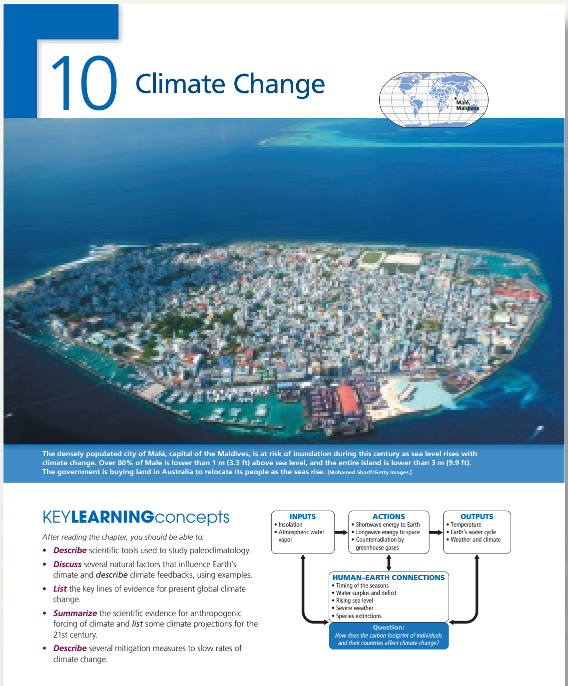
Suitability for wind power	
Highest wind speed	________
Lowest wind speed	________
Site-specific conditions	a. ________ b. ________

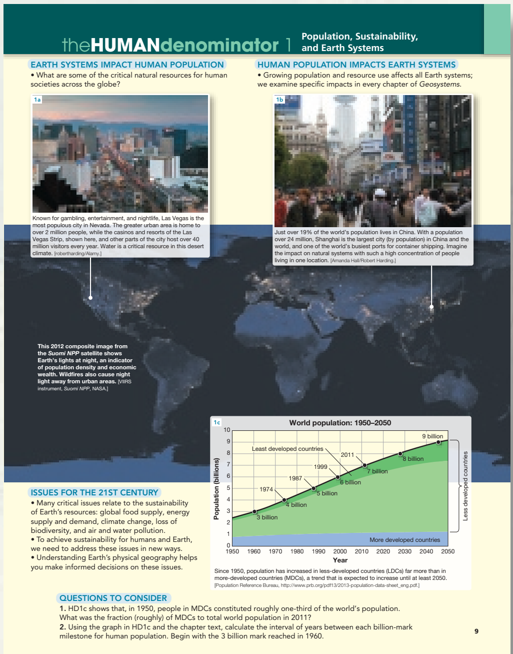
APPLYconcepts Referring to the map in Figure 7.1.1b and the chapter's sections "Storm Development" and "Physical Structure," explain key events in the life cycle of Hurricane Patricia.

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

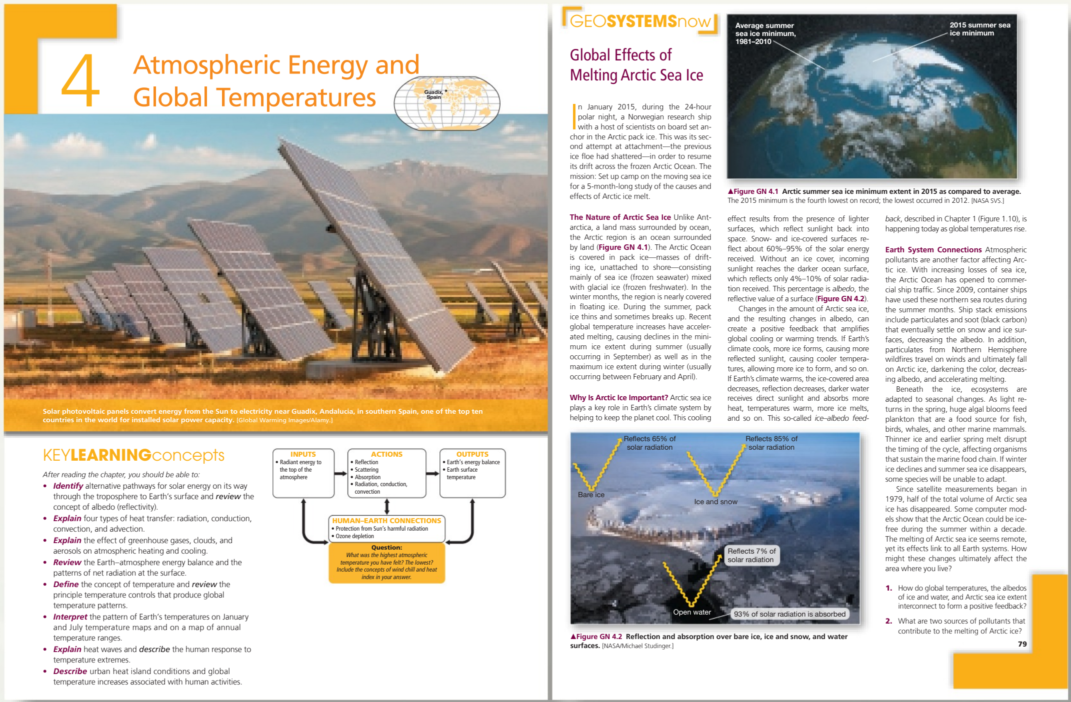
UPDATED! Unique to physical geography, Chapter 10: *Climate Change*, presents a comprehensive overview of climate change science, exploring paleoclimatology, climate feedback, evidence and causes of present climate change, climate models and projections, and steps we can take to moderate Earth's changing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





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

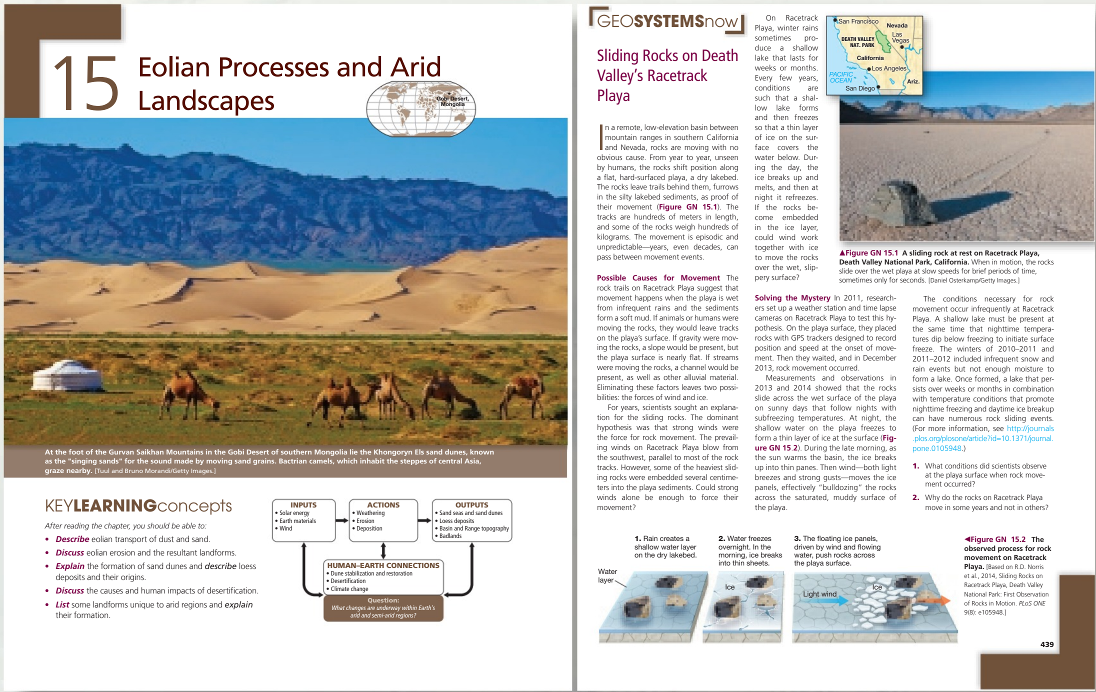


4 Atmospheric Energy and Global Temperatures

GEOSYSTEMSnow — Global Effects of Melting Arctic Sea 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.



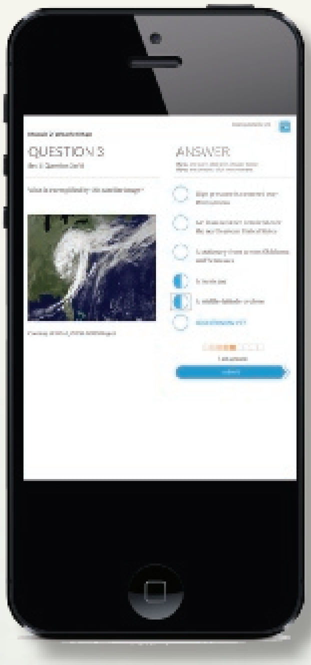
15 Eolian Processes and Arid Landscapes

GEOSYSTEMSnow — Sliding Rocks on Death Valley's Racetrack Playa

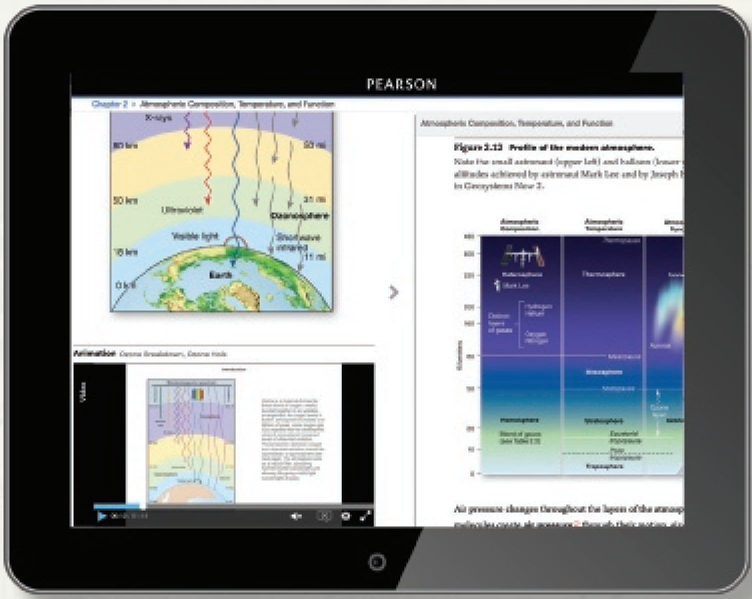
Continuous Learning Before, During, and After Class

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

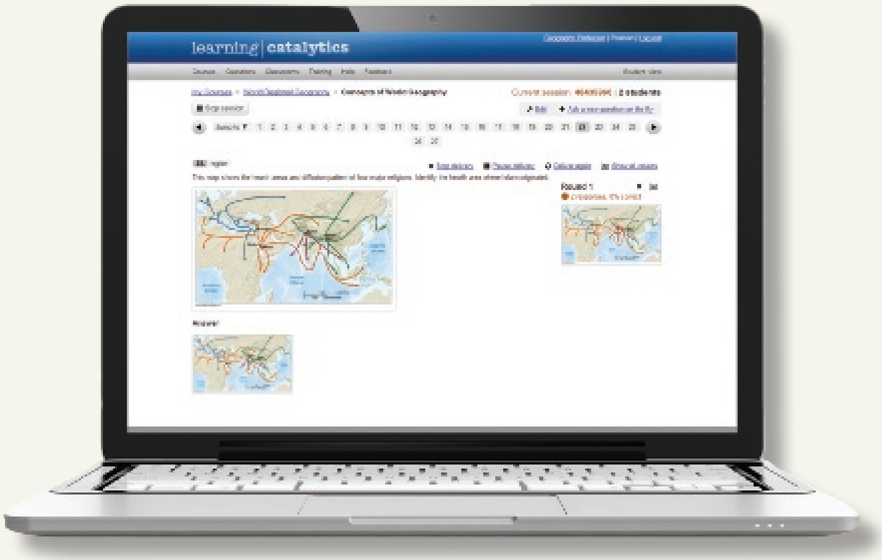
. . . with MasteringGeography™

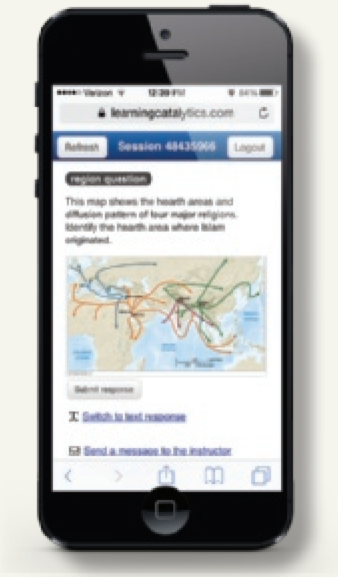
DURING CLASS

Engage Students with Learning Catalytics

What has teachers and students excited? Learning Cataltyics, 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

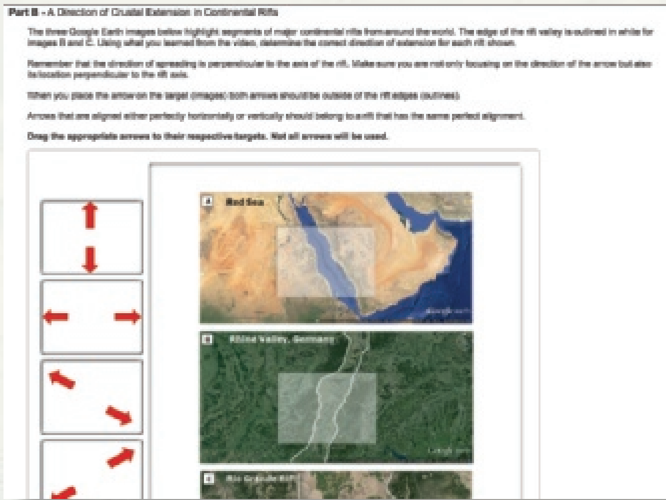
Continuous Learning Before, During, and After Class

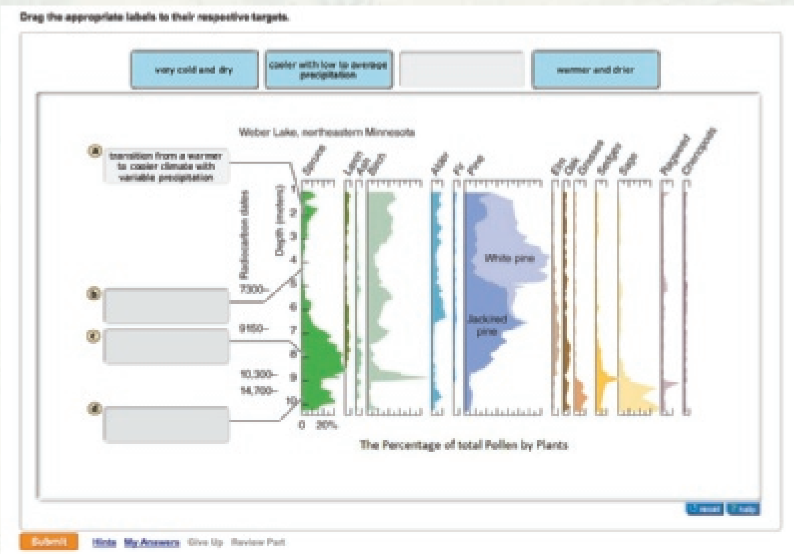
AFTER CLASS

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

NEW! 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.

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.



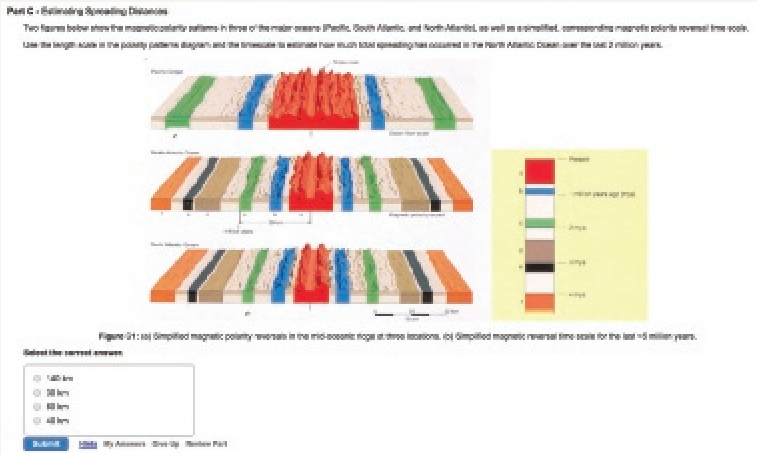


HALLMARK! GeoTutor Activities help students master the most challenging physical geoscience concepts with highly visual, kinesthetic, and data-rich activities focused on critical thinking and the application of core geoscience concepts.

www.masteringgeography.com

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.

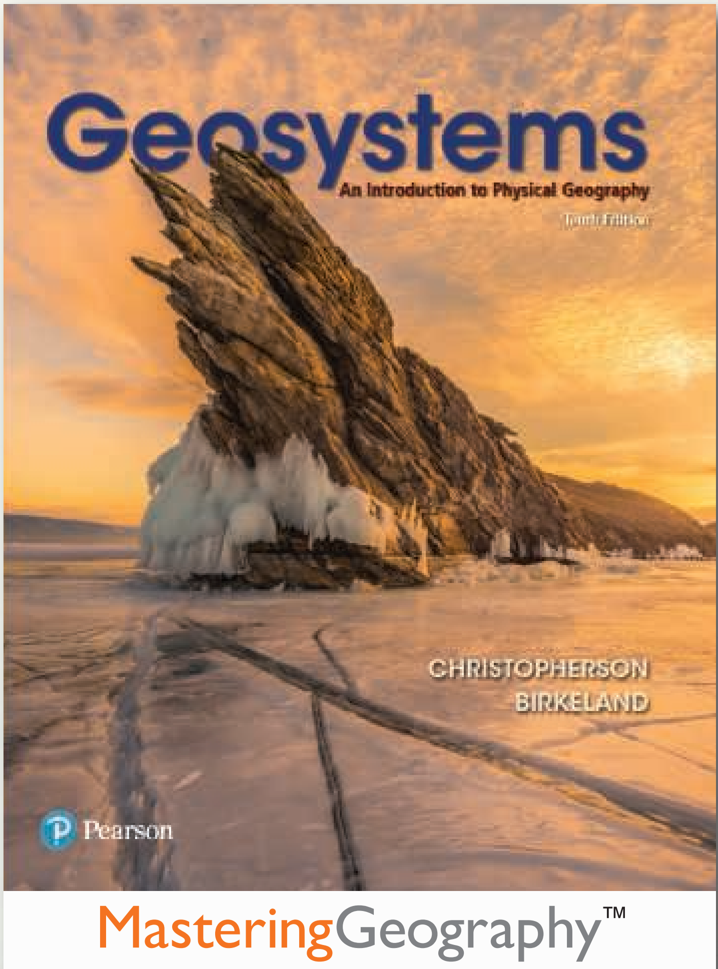
NEW! GeoLab Activities augment the chapters with online, automatically graded, and data-rich applied lab activities.



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

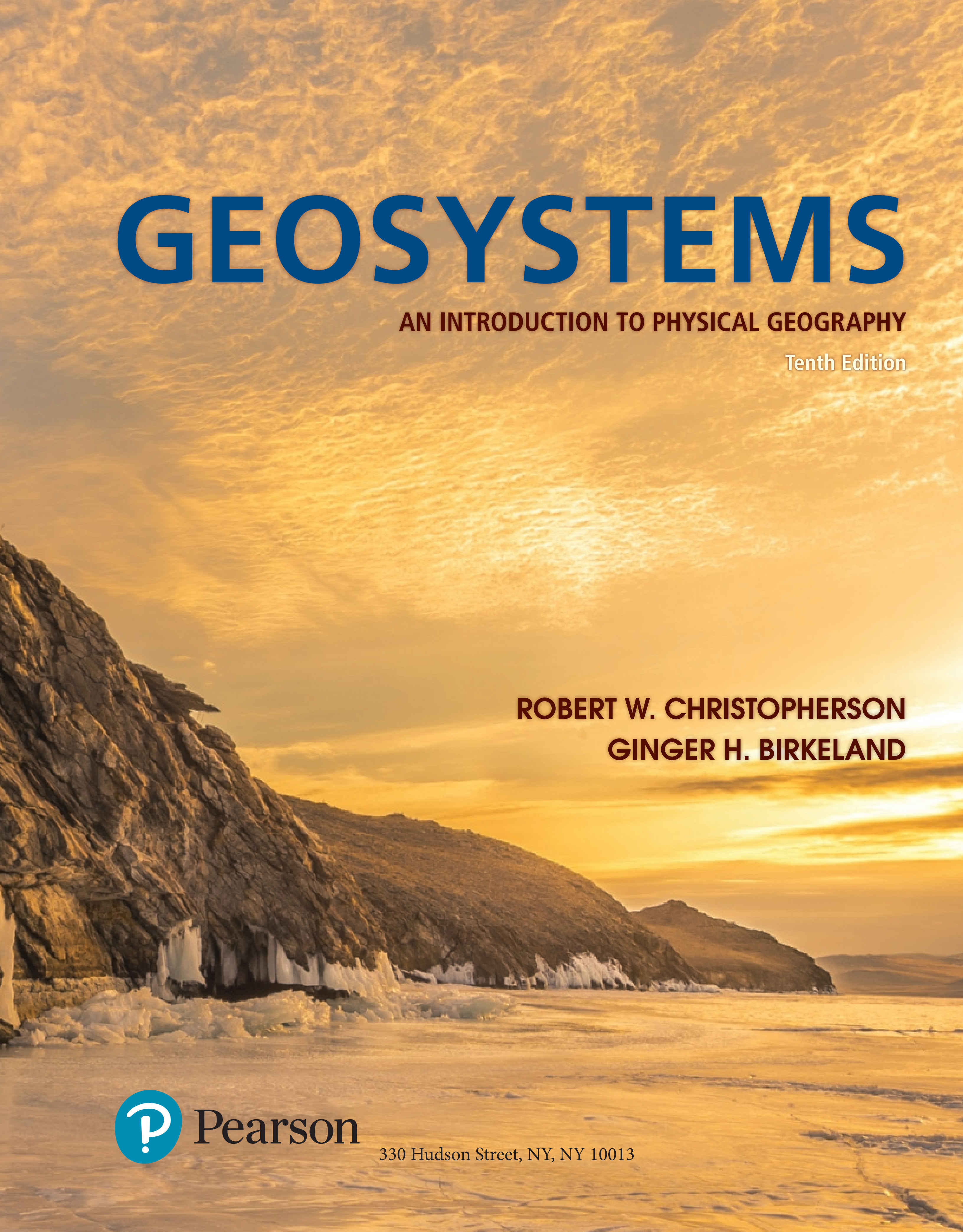
Measuring Student Learning Outcomes

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

Pearson
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
Compositor: Cenveo® Publisher Services
Design Manager: Mark Ong
Interior/Cover Designer: Preston Thomas
Illustrators: Lachina and International Mapping Associates
Rights & Permissions Manager: Ben Ferrini
Photo Researchers: Kristin Piljay, Danny Meldung
Manufacturing Buyer: Maura Zaldivar-Garcia
Executive Product Marketing Manager: Neena Bali
Senior Field Marketing Manager: Mary Salzman
Associate Media Content Producer: Mia Sullivan
Cover Photo: *Island in Lake Baikal*, by Chalermkiat Seedokmai/Getty Images.

Dedication Page Quote: Barbara Kingsolver, Small Wonder (New York: Harper Collins Publications, 2002), p. 39.

Acknowledgements of third party content appear on page C-1, which constitutes an extension of this copyright page.

Library of Congress Cataloging-in-Publication Data

Names: Christopherson, Robert W., author. | Birkeland, Ginger H., author.
Title: An introduction to physical geography : geosystems / Robert W. Christopherson, Ginger H. Birkeland.
Description: Tenth edition. | Hoboken, NJ : Pearson, 2017. | Includes index.
Identifiers: LCCN 2016051486| ISBN 9780134597119 (alk. paper) | ISBN 0134597117 (alk. paper)
Subjects: LCSH: Physical geography.
Classification: LCC GB54.5 .C48 2017 | DDC 910/.02--dc23
LC record available at https://lccn.loc.gov/2016051486

1 16

Pearson

ISBN-10: 0-134-59711-7; ISBN-13: 978-0-134-59711-9

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.

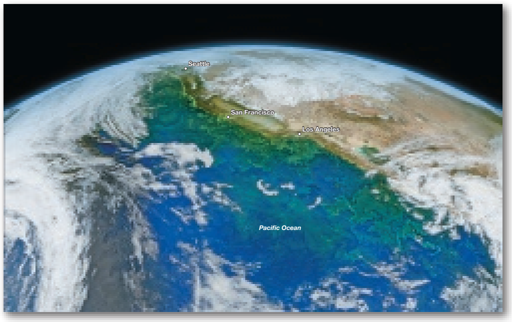
—Barbara Kingsolver

BRIEF CONTENTS

CONTENTS

3 Earth's Atmosphere 56

4 Atmospheric Energy and Global Temperatures 78



5 Atmospheric and Oceanic Circulations 118

10 Climate Change 278

III The Earth–Atmosphere Interface 314

11 The Dynamic Planet 316

12 Tectonics, Earthquakes, and Volcanism 348

13 Weathering, Karst Landscapes, and Mass Movement 380

MasteringGeography Mobile-Ready Animations & Videos

Seismographs
Volcano Types
The Eruption of Mount Saint Helens

Condor Quadcopter Videos
Anticlines and Synclines
Monoclines of the Colorado Plateau
Faults versus Joints
Continental Rifting
Cinder Cones and Basaltic Lava Flows

Mobile Field Trips
San Andreas Fault
Kilauea Volcano

13 Weathering, Karst Landscapes, and Mass Movement

Animations
Mass Movements
Physical Weathering

Mobile Field Trips
The Critical Zone at Boulder Creek
Mammoth Cave
Landslides
Yosemite
Tar Sands

14 River Systems

Mobile Field Trips
Mississippi River Delta
Streams of the Great Smoky Mountains

Condor Quadcopter Videos
Meandering Rivers
River Terraces and Base Level

Animations
Stream Processes, Floodplains
Oxbow Lake Formation
Meandering Streams
Stream Terrace Formation

15 Eolian Processes and Arid Landscapes

Animations
How Wind Moves Sand
Dune Formation and Cross-Bedding

Mobile Field Trip
Desert Geomorphology

Condor Quadcopter Video
Characteristics of Alluvial Fans

16 Oceans and Coastal Systems

Animations
Midlatitude Productivity
Tidal Forces
Monthly Tidal Cycles
Wave Motion, Wave Refraction
Beach Drift, Coastal Erosion
Coastal Stabilization Structures
Movement of a Barrier Island in Response to Rising Sea Level
Seamounts & Coral Reefs

Video
Making of a Superstorm

Mobile Field Trip
Gulf Coast Processes

Mobile Field Trip
Introduction to Physical Geography
https://goo.gl/pRdrGU

17 Glacial Landscapes and the Cryosphere

Animations
Glacial Processes
Flow of Ice within a Glacier
End of the Last Ice Age

Videos
A Tour of the Cryosphere
Operation Ice Bridge

Mobile Field Trips
The Glaciers of Alaska
Yosemite
Cape Cod: Land Sculpted by Ice & Storm

18 The Geography of Soils

Animation
The Soil Moisture (SMAP) Mission

Website
Soil Science of America

19 Ecosystem Essentials

Animations
Net Primary Productivity
Biological Productivity in Midlatitude Oceans

Video
The Ocean's Green Machines

Mobile Field Trip
Forest Fires in the West

20 Terrestrial Biomes

Animations
Plant Productivity in a Warming World
Amazon Deforestation

Mobile Field Trip
The Cloud Forest of Monteverde

everydayGEOSYSTEMS & GEOreports

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*.

Author Acknowledgments

After all these years, the strength of a publishing team remains ever essential. Continuing thanks to President Paul Corey for his leadership since 1990 and to Beth Wilbur, Senior Vice-President and Editorial Director for Geosciences, for her vision. Thanks to Executive Geosciences Editor Christian Botting for his guidance and for the attention devoted to the *Geosystems* texts and to his newest edition, a son, Lucas Lockwood Botting. Thanks to Content Producer Anton Yakovlev and Editorial Assistant Emily Bornhop for their careful attention. We offer special thanks to development editors Jonathan Cheney and Jay McElroy for advice and suggestions that improved many aspects of this edition.

Our appreciation to designers Preston Thomas and Mark Ong for such skill in a complex book design. Thanks to Marketing Managers Neena Bali and Mary Salzman, and the many publisher representatives who spend months in the field communicating the *Geosystems* approach. Our gratitude is extended to the entire "*Geosystems* Team" for allowing us to participate in the publishing process.

Our sincere appreciation for production coordination goes to Editorial Director for Higher Education Cindy Miller of Cenveo LLC for the sustaining care through nine books and to Jeanine Furino, our Cenveo production manager, for her ability to oversee manuscript, copy editing, complex compositing, and page proofs. With so many changes in this edition, her skills make it work. To photo researchers Kristin Piljay and Danny Meldung, copy editor Jane Loftus, proofreader Denne Wesolowski, and indexer Pam Reigeluth we give thanks for quality work. Our appreciation also goes to Redina Herman, who contributed the *Geospatial Analysis* activities for this edition as well as the second Chapter 1 Focus Study. Thanks to all the colleagues who served as reviewers on one or more editions of each book or who offered helpful suggestions in conversations at our national and regional geography meetings. Thanks to the accuracy reviewers of all tenth edition chapters: Todd Fagin, *Oklahoma University*, and Ricardo Nogueira, *Georgia State University*. Thanks also to Todd Fagin for authoring the Test Bank for this edition and to Charlie Thomsen, *American River College*, for authoring the *Instructor Resource Manual*, the Lecture PowerPoints, and the Clicker questions.

We are grateful for the generosity of ideas and sacrifice of time. Thanks to all reviewers who have provided valuable feedback on *Geosystems* over the years:

Jason Allard, *Valdosta State University*
Michael Allen, *Kent State University*
Philip P. Allen, *Frostburg State University*
Ted J. Alsop, *Utah State University*
Nathaniel Amador, *Ohio Wesleyan University*
Ward Barrett, *University of Minnesota*
Steve Bass, *Mesa Community College*
Stefan Becker, *University of Wisconsin–Oshkosh*
Daniel Bedford, *Weber State University*
Bradley Bereitschaft, *University of Nebraska—Omaha*
David Berner, *Normandale Community College*
Trent Biggs, *San Diego State University*
Franco Biondi, *University of Nevada, Reno*
Peter D. Blanken, *University of Colorado, Boulder*
Patricia Boudinot, *George Mason University*
Anthony Brazel, *Arizona State University*
David R. Butler, *Southwest Texas State University*
Mary-Louise Byrne, *Wilfred Laurier University*
Janet Cakir, *Rappahannock Community College*
Ian A. Campbell, *University of Alberta–Edmonton*
Randall S. Cerveny, *Arizona State University*
Fred Chambers, *University of Colorado, Boulder*
Philip Chaney, *Auburn University*
Muncel Chang, *Butte College* Emeritus
Jordan Clayton, *Georgia State University*
Andrew Comrie, *University of Arizona*
C. Mark Cowell, *Indiana State University*
Richard A. Crooker, *Kutztown University*
Stephen Cunha, *Humboldt State University*
Armando M. da Silva, *Towson State University*
Dennis Dahms, *University of Northern Iowa*
J. Michael Daniels, *University of Denver*
Shawna Dark, *California State University, Northridge*
Stephanie Day, *University of Kansas*
Dirk H. de Boer, *University of Saskatchewan*
Lisa DeChano-Cook, *Western Michigan University*
Mario P. Delisio, *Boise State University*
Joseph R. Desloges, *University of Toronto*
Lee R. Dexter, *Northern Arizona University*
Vicki Drake, *Santa Monica College*
Don W. Duckson, Jr., *Frostburg State University*
Daniel Dugas, *New Mexico State University*
Anthony Dzik, *Shawnee State University*
Kathryn Early, *Metropolitan State College*
Christopher H. Exline, *University of Nevada–Reno*
Todd Fagin, *Oklahoma University*
Michael M. Folsom, *Eastern Washington University*
Mark Francek, *Central Michigan University*
Glen Fredlund, *University of Wisconsin–Milwaukee*
Dorothy Friedel, *Sonoma State University*
William Garcia, *University of N. Carolina–Charlotte*
Doug Goodin, *Kansas State University*
Mark Goodman, *Grossmont College*
David E. Greenland, *University of N. Carolina–Chapel Hill*
Duane Griffin, *Bucknell University*
Barry N. Haack, *George Mason University*
Roy Haggerty, *Oregon State University*
John W. Hall, *Louisiana State University–Shreveport*
Vern Harnapp, *University of Akron*
John Harrington, *Kansas State University*
Blake Harrison, *Southern Connecticut University*
Jason "Jake" Haugland, *University of Colorado, Boulder*
James Hayes, University of Nebraska—Omaha
Gail Hobbs, *Pierce College*
Thomas W. Holder, *University of Georgia*
David H. Holt, *University of Southern Mississippi*
Robert Hordon, *Rutgers University*
David A. Howarth, *University of Louisville*
Patricia G. Humbertson, *Youngstown State University*
David W. Icenogle, *Auburn University*
Philip L. Jackson, *Oregon State University*
J. Peter Johnson, Jr., *Carleton University*
Gabrielle Katz, *Appalachian State University*
Guy King, *California State University–Chico*
David Kitchen, *University of Richmond*
Ronald G. Knapp, *SUNY–The College at New Paltz*
Peter W. Knightes, *Central Texas College*
Jean Kowal, *University of Wisconsin – Whitewater*
Thomas Krabacher, *California State University–Sacramento*
Hsiang-te Kung, *University of Memphis*
Richard Kurzhals, *Grand Rapids Junior College*
Kara Kuvakas, *Hartnell College*
Steve Ladochy, *California State University, Los Angeles*
Charles W. Lafon, *Texas A & M University*
Paul R. Larson, *Southern Utah University*
Robert D. Larson, *Southwest Texas State University*
Derek Law, *University of Kentucky*
Elena Lioubimtseva, *Grand Valley State University*
Joyce Lundberg, *Carleton University*
Scott Mandia, *Suffolk County Community College, Long Island*
W. Andrew Marcus, *Montana State University*
Giraldo Mario, *California State University, Northridge*
Brian Mark, *Ohio State University*

Nadine Martin, *University of Arizona*
Elliot G. McIntire, *California State University, Northridge*
Norman Meek, *California State University, San Bernardino*
Leigh W. Mintz, *California State University–Hayward*, Emeritus
Sherry Morea-Oaks, Boulder, CO
Debra Morimoto, *Merced College*
Patrick Moss, *University of Wisconsin – Madison*
Steven Namikas, *Louisiana State University*
Lawrence C. Nkemdirim, *University of Calgary*
Ricardo Nogueira, *Georgia State University*
Sherry Oaks, Front Range Community College—Westminster
Andrew Oliphant, *San Francisco State University*
John E. Oliver, *Indiana State University*
Bradley M. Opdyke, *Michigan State University*
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*
Leslie Rigg, *Northern Illinois University*
Dar Roberts, *University of California–Santa Barbara*
Wolf Roder, *University of Cincinnati*
Robert Rohli, *Louisiana State University*
Bill Russell, *L.A. Pierce College*
Dorothy Sack, *Ohio University*
Erinanne Saffell, *Arizona State University*
Randall Schaetzl, *Michigan State University*
Glenn R. Sebastian, *University of South Alabama*
Daniel A. Selwa, *U.S.C. Coastal Carolina College*
Debra Sharkey, *Cosumnes River College*
Marshall Shepherd, *University of Georgia*
Peter Siska, *Austin Peay State University*
Lee Slater, *Rutgers University*
Thomas W. Small, *Frostburg State University*
Daniel J. Smith, *University of Victoria*
Richard W. Smith, *Hartford Community College*
Stephen J. Stadler, *Oklahoma State University*
Michael Talbot, *Pima Community College*
Paul E. Todhunter, *University of North Dakota*
Susanna T.Y. Tong, *University of Cincinnati*
Liem Tran, *Florida Atlantic University*
Suzanne Traub-Metlay, *Front Range Community College*
Jill Trepanier, *Louisiana State University*
Alice V. Turkington, *The University of Kentucky*
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*
Brenton M. Yarnal, *Pennsylvania State University*
Catherine H. Yansa, *Michigan State University*
Keith Yearwood, *Georgia State University*
Stephen R. Yool, *University of Arizona*
Kenneth Young, *University of Texas—Austin*
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, Téyenna, 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, Bobbé Christopherson. Bobbé 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**

Pearson recognizes the environmental challenges facing this planet, as well as acknowledges our responsibility in making a difference. This book is carefully crafted to minimize environmental impact. The binding, cover, and paper come from facilities that minimize waste, energy consumption, and the use of harmful chemicals. Pearson closes the loop by recycling every out-of-date text returned to our warehouse. Along with developing and exploring digital solutions to our market's needs, Pearson has a strong commitment to achieving carbon-neutrality. As of 2009, Pearson became the first carbon- and climate-neutral publishing company, having reduced our absolute carbon footprint by 22% since then. Pearson has protected over 1,000 hectares of land in Columbia, Costa Rica, the United States, the UK and Canada. In 2015, Pearson formally adopted The Global Goals for Sustainable Development, sponsoring an event at the United Nations General Assembly and other ongoing initiatives. Pearson sources 100% of the electricity we use from green power and invests in renewable energy resources in multiple cities where we have operations, helping make them more sustainable and limiting our environmental impact for local communities. The future holds great promise for reducing our impact on Earth's environment, and Pearson is proud to be leading the way. We strive to publish the best books with the most up-to-date and accurate content, and to do so in ways that minimize our impact on Earth. To learn more about our initiatives, please visit **https://www.pearson.com/sustainability.html**.

DIGITAL & PRINT RESOURCES

For Students & Teachers

MasteringGeography™ with Pearson eText. The *Mastering* platform is the most widely used and effective online homework, tutorial, and assessment system with resources for before, during, and after class. It delivers self-paced tutorials that provide individualized coaching, focus on course objectives, and are responsive to each student's progress. The *Mastering* system helps teachers maximize class time with customizable, easy-to-assign, and automatically graded assessments that motivate students to learn outside of class and arrive prepared for lecture. MasteringGeography™ offers:

- **Assignable activities** that include GIS-inspired MapMaster™ interactive map activities, *Encounter* Google Earth™ Explorations, video activities, *Mobile Field Trips, Project Condor* Quadcopter videos, Geoscience Animation activities, map projections activities, Hazard City context-rich problems, GeoTutor coaching activities on the toughest topics in geography, Dynamic Study Modules that provide each student with a customized learning experience, end-of-chapter questions and exercises, reading quizzes, *Test Bank* questions, and more.
- **A student Study Area** with MapMaster™ interactive maps, videos, *Mobile Field Trips, Project Condor* Quadcopter videos, Geoscience Animations, web links, glossary flashcards, "In the News" articles, chapter quizzes, PDF downloads of regional outline maps, an optional Pearson eText and more.

Pearson eText gives students access to the text whenever and wherever they can access the Internet. Features of Pearson eText include:

- Now available on smartphones and tablets.
- Seamlessly integrated videos and other rich media.
- Fully accessible (screen-reader ready).
- Configurable reading settings, including resizable type and night reading mode.
- Instructor and student note-taking, highlighting, bookmarking, and search. **www.masteringgeography.com**

Television for the Environment Earth Report Geography Videos, DVD (0321662989). This three-DVD set helps students visualize how human decisions and behavior have affected the environment and how individuals are taking steps toward recovery. With topics ranging from the poor land management promoting the devastation of river systems in Central America to the struggles for electricity in China and Africa, these 13 videos from Television for the Environment's global *Earth Report* series recognize the efforts of individuals around the world to unite and protect the planet.

Geoscience Animation Library, 5th edition, DVD (0321716841). Created through a unique collaboration among Pearson's leading geoscience authors, this resource offers over 100 animations covering the most difficult-to-visualize topics in physical geography, meteorology, earth science, physical geology, and oceanography.

Practicing Geography: Careers for Enhancing Society and the Environment by Association of American Geographers (0321811151). This book examines career opportunities for geographers and geospatial professionals in the business, government, nonprofit, and education sectors. A diverse group of academic and industry professionals shares insights on career planning, networking, transitioning between employment sectors, and balancing work and home life.

Teaching College Geography: A Practical Guide for Graduate Students and Early Career Faculty by Association of American Geographers (0136054471). This two-part resource provides a starting point for becoming an effective geography teacher from the very first day of class. Part One addresses "nuts-and-bolts" teaching issues. Part Two explores being an effective teacher in the field, supporting critical thinking with GIS and mapping technologies, engaging learners in large geography classes, and promoting awareness of international perspectives and geographic issues.

Aspiring Academics: A Resource Book for Graduate Students and Early Career Faculty by Association of American Geographers (0136048919). Drawing on several years of research, this set of essays is designed to help graduate students and early career faculty start their careers in geography and related social and environmental sciences.

***Hazard City* for MasteringGeography** (0321970349) is a collection of eleven online problem-solving assignments that demonstrate the work of practicing geoscientists and environmental professionals. The activities allow the student to step into the role of a practicing geoscientist to analyze potential disasters in the fictional town of *Hazard City*. Students learn to research and explore on their own in areas such as Map Reading, Ground Water Contamination, Volcanic Hazard Assessment, Earthquake Damage Assessment, Shoreline Property Assessment, and much more. **www.masteringgeography.com**

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.

Goode's World Atlas, 23rd Edition (0133864642). First published by Rand McNally in 1923, *Goode's World Atlas* is the gold standard for college reference atlases. It features hundreds of physical, political, and thematic maps, graphs, and tables, as well as a comprehensive pronouncing index. The 23rd Edition introduces dozens of new maps, incorporating the latest geographic scholarship and technologies, with expanded coverage of the Canadian Arctic, Europe's microstates, Africa's island states, and U.S. cities. It introduces several new thematic maps on critical topics such as: oceanic environments, earthquakes and tsunamis, desertification vulnerability, maritime political claims, megacities, human trafficking, labor migration . . . and many other topics important to contemporary geography. Available in eText formats from Pearson.

Pearson's Encounter Series provides rich, interactive explorations of geoscience concepts through Google Earth™ activities. For those who do not use *MasteringGeography*™, all chapter explorations are available in print workbooks, as well as in online quizzes at www.mygeoscienceplace.com. Each exploration consists of a worksheet, online quizzes whose results can be emailed to teachers, and a corresponding Google Earth™ KMZ file.

- *Encounter Physical Geography* by Jess C. Porter and Stephen O'Connell (0321672526)
- *Encounter World Regional Geography* by Jess C. Porter (0321681754)
- *Encounter Human Geography* by Jess C. Porter (0321682203)

Dire Predictions: Understanding Global Climate Change 2nd Edition by Michael Mann, Lee R. Kump (0133909778). Periodic reports from the Intergovernmental Panel on Climate Change (IPCC) evaluate the risk of climate change brought on by humans. In just over 200 pages, this practical text presents and expands upon the essential findings of the IPCC in a visually stunning and undeniably powerful way to the lay reader. Scientific findings that provide validity to the implications of climate change are presented in clear-cut graphic elements, striking images, and understandable analogies. The Second Edition covers the latest climate change data and scientific consensus from the IPCC *Fifth Assessment Report* and integrates mobile media links to online media. The text is also available in various eText formats, including an eText upgrade option from Mastering-Geography courses.

For Teachers

Learning Catalytics is a "bring your own device" student engagement, assessment, and classroom intelligence system. With Learning Catalytics, you can:

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students' critical-thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics fit your course exactly.
- Manage student interactions with intelligent grouping and timing.

Learning Catalytics is a technology that has grown out of twenty years of cutting-edge research, innovation, and implementation of interactive teaching and peer instruction. Available integrated with *MasteringGeography*™.

Instructor Resource Manual (Download) by Charlie Thomsen (0134700244). The manual includes lecture outlines and key terms, additional source materials, teaching tips, and a complete annotation of chapter review questions. Available from www.pearsonhighered.com/irc and in the Instructor Resources area of *MasteringGeography*™.

TestGen® Test Bank (Download) by Todd Fagin (013470021X). TestGen® is a computerized test generator that lets you view and edit *Test Bank* questions, transfer questions to tests, and print tests in a variety of customized formats. This *Test Bank* includes around 3,000 multiple-choice and short answer/essay questions. All questions are correlated against the National Geography Standards, textbook key learning concepts, and Bloom's Taxonomy. The *Test Bank* is also available in Microsoft Word® and importable into Blackboard. Available from www.pearsonhighered.com/irc and in the Instructor Resources area of *MasteringGeography*™.

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

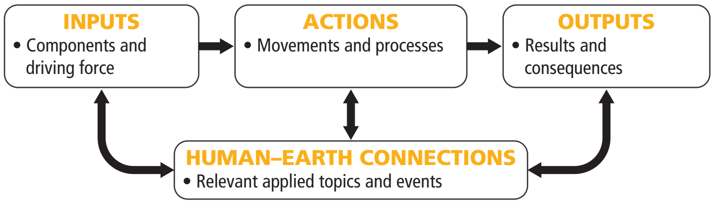
Queenstown, New Zealand, is known for snowsports, rafting, fishing, mountain biking, and boating on Lake Wakatipu, the country's longest lake. The city is also the tourist gateway to the glacial landscapes of the Southern Lakes region of the South Island. [Beerpixs/Getty Images.]

KEY**LEARNING**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.

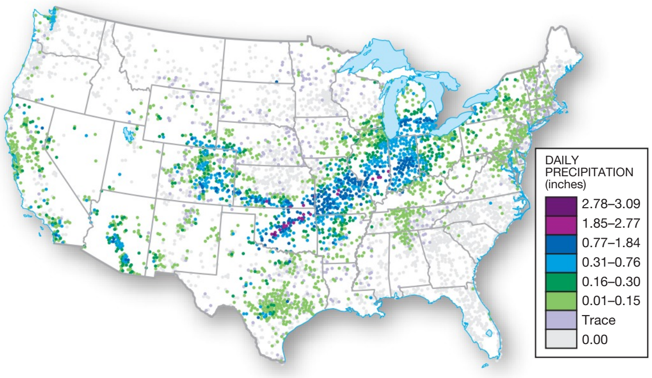
A Geosystems schematic diagram appears in this space in all subsequent chapters. The content of each chapter is laid out as a system to demonstrate chapter organization. The Geosystems approach studies content in this sequence:



GEOSYSTEMSnow

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**).

◀**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.]

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.

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.

Mobile Field Trip
Introduction to Physical Geography
https://goo.gl/pRdrGU

◀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?

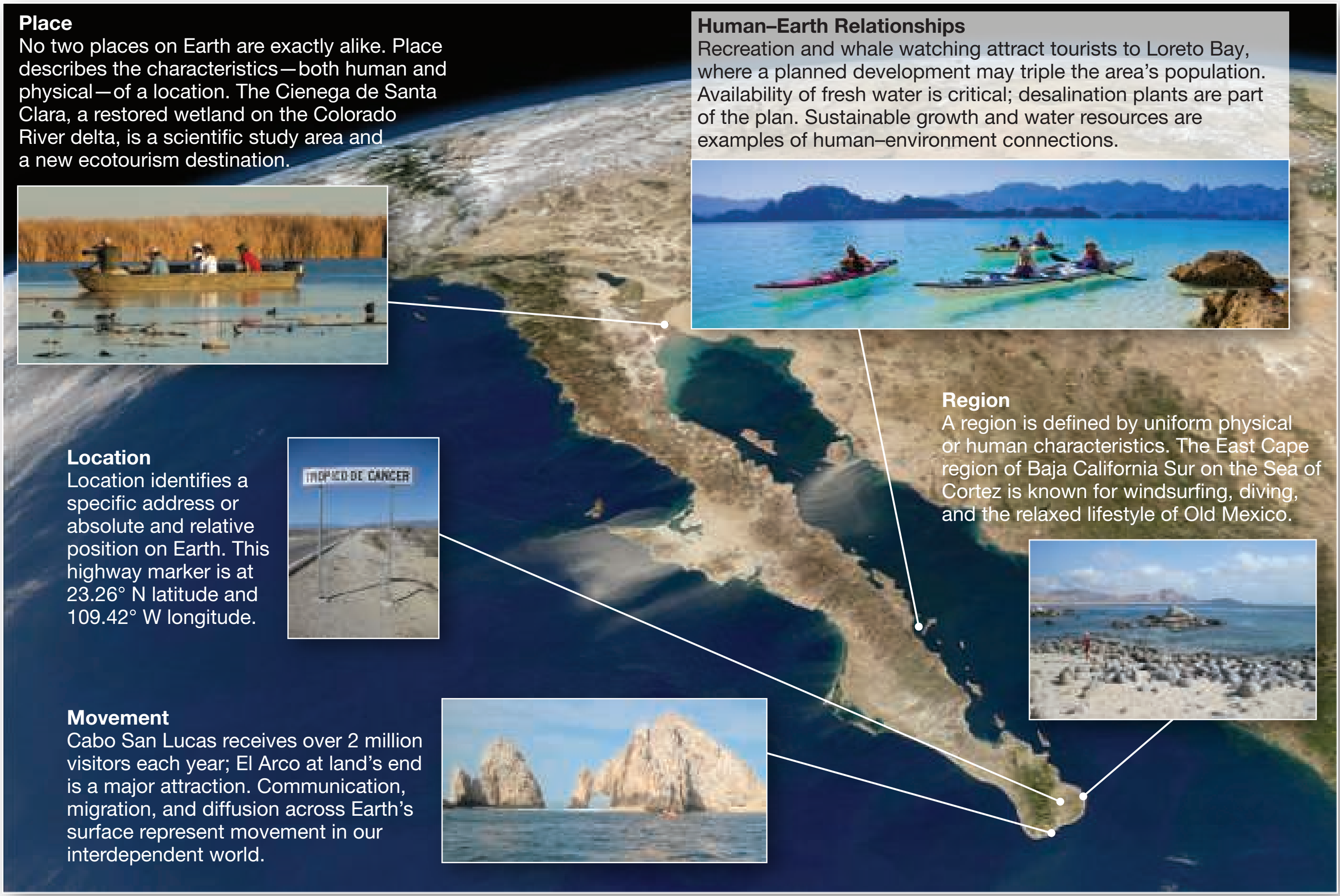
Perhaps more than any other issue, climate change has become an overriding focus of the study of Earth systems. Rising atmospheric concentrations of carbon dioxide and other greenhouse gases are changing Earth's energy balance and are linked to increasing global temperatures. Rising air and ocean temperatures 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.



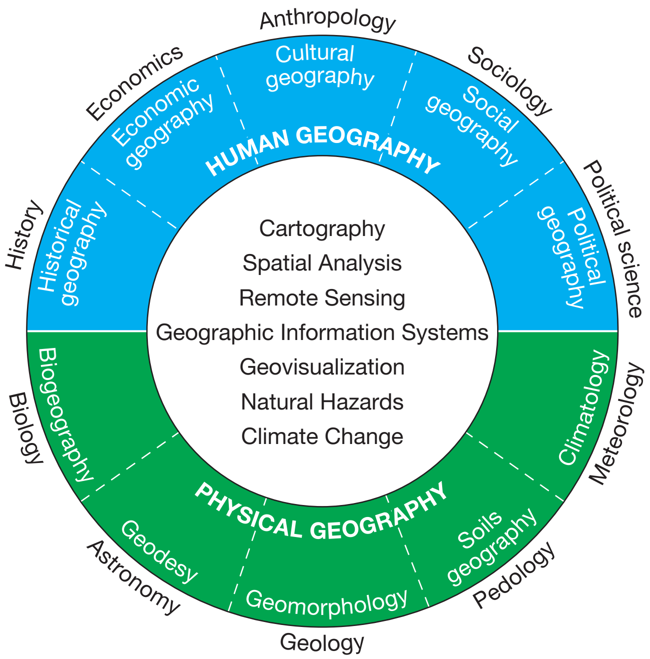
▲**Figure 1.2 Five themes of geographic science.** This 2011 satellite image shows the entire length of Mexico's Baja peninsula, including Earth's curvature. [Photos by Karl Birkeland, except Place by Cheryl Zook/National Geographic and Human–Earth by Gary Luhm/garyluhm.net. Image from *Aqua* satellite/Norman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



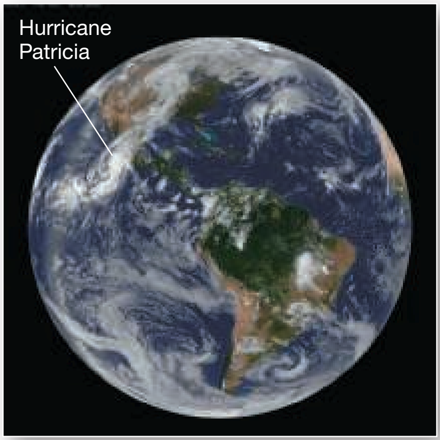
▲**Figure 1.3 The scope of geography.** Geography combines Earth topics and human topics, blending ideas from many different sciences. Numerous subfields, especially those focused on geographic techniques, fall into the overlap between physical and human geography.

Geographic Investigation

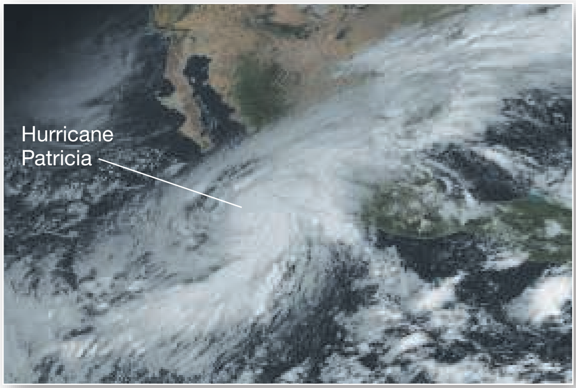
In addition to spatial analysis, the concepts of process, scale, and systems are central to physical geography investigations. **Process** refers to a set of actions or mechanisms that operate in some special order. In *Geosystems*, we examine processes in every chapter: for example, those involved in 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.

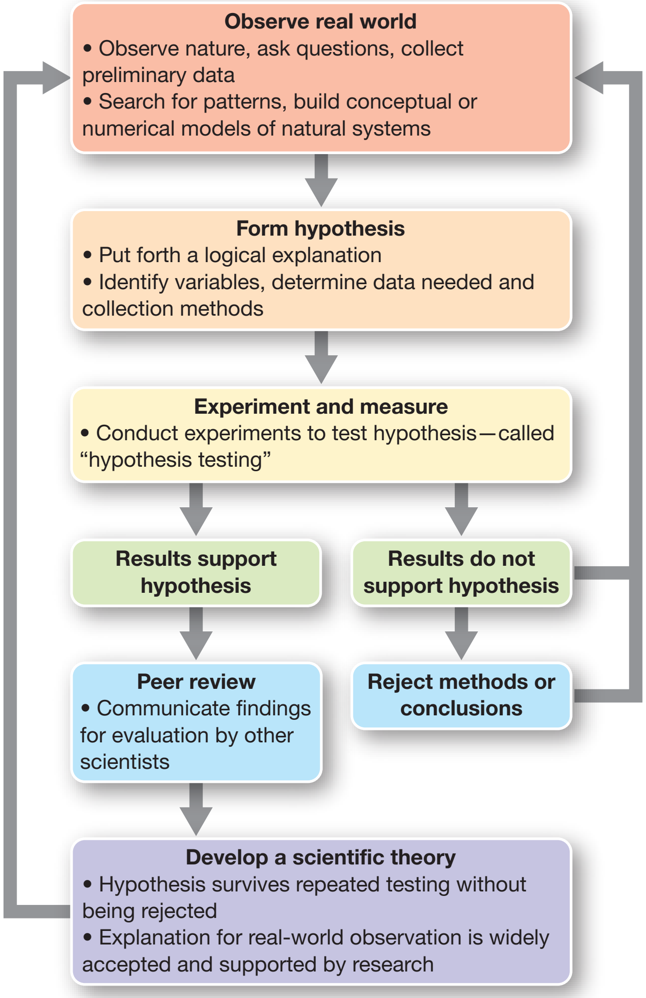
Systems analysis is fundamental to physical geography, and we discuss systems at length later in this chapter. Physical geography encompasses the field of **Earth systems science**, the area of study that seeks to understand Earth as an interacting set of physical, chemical, and biological systems. We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



▲Figure 1.5 **Scientific method flow chart.**

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).

theHUMANdenominator 1 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

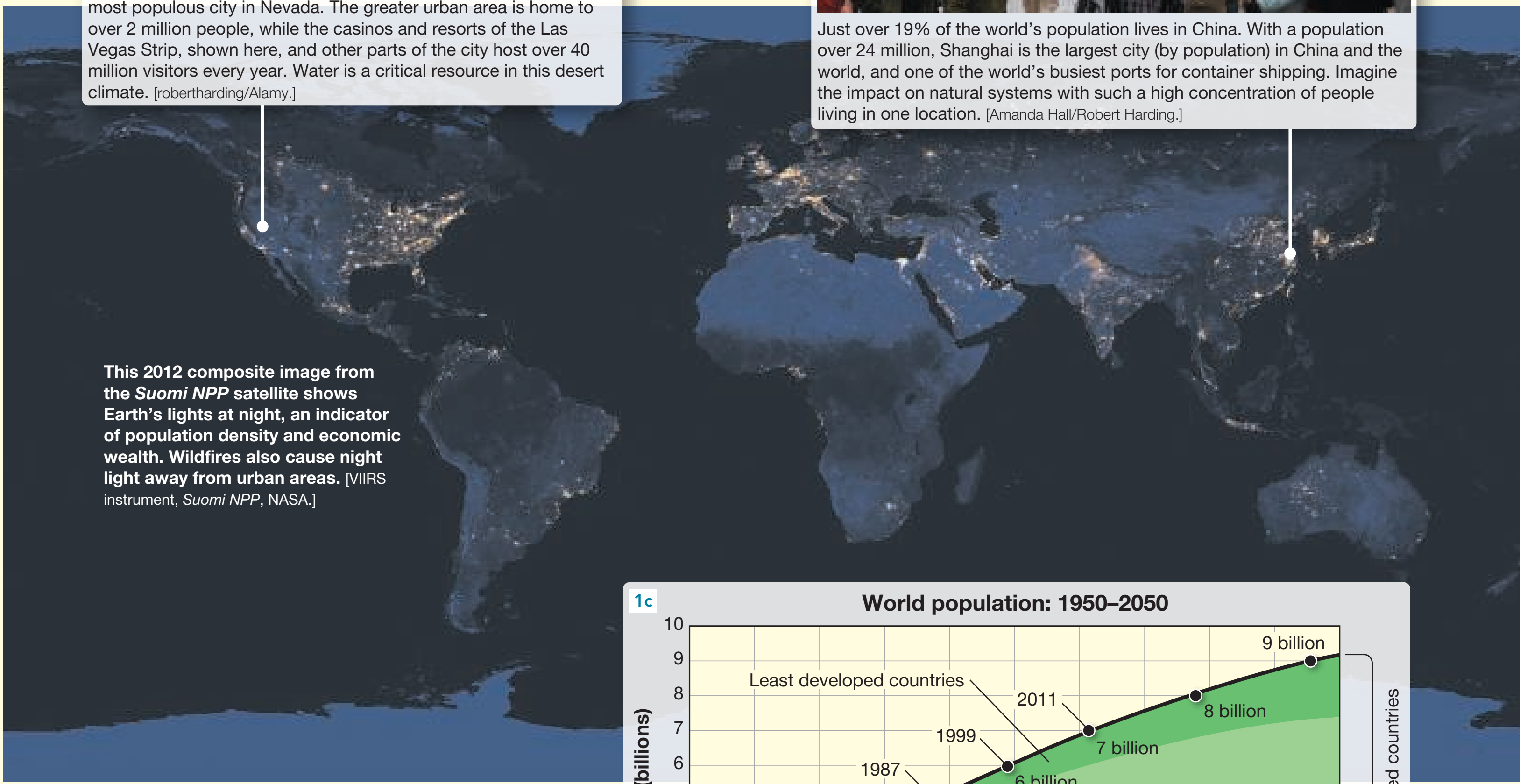
• Growing population and resource use affects all Earth systems; we examine specific impacts in every chapter of *Geosystems*.

1a

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.]

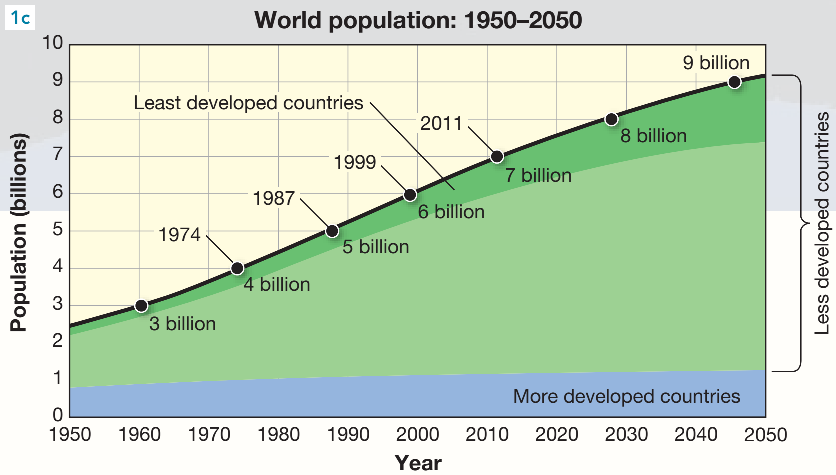
1b

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.]

1c



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.]

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.

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.