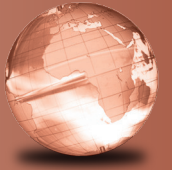


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An Introduction to Physical Geography

NINTH EDITION



Robert W. Christopherson • Ginger H. Birkeland

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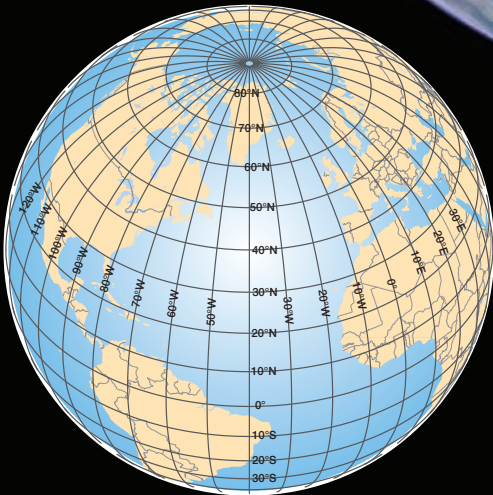
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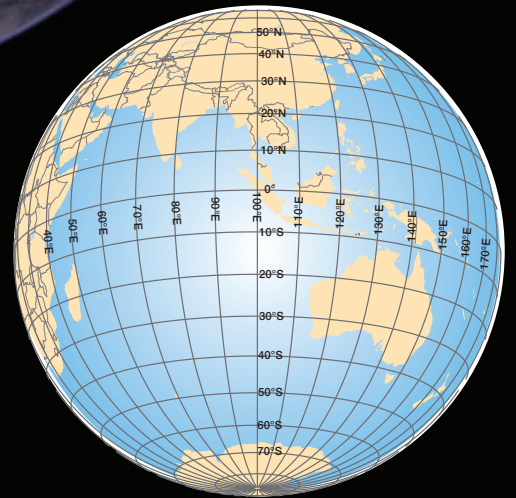
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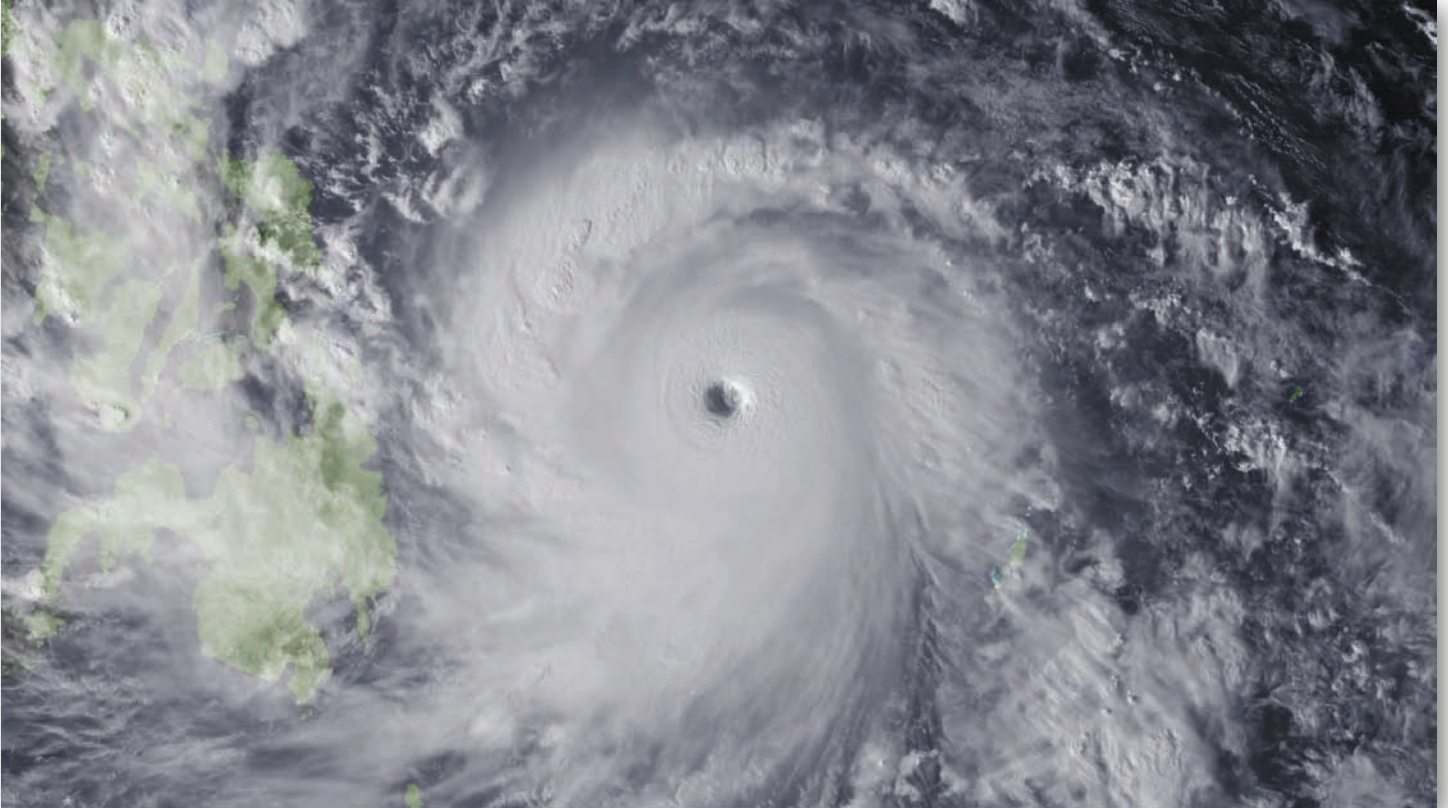
Multiple images from satellites *Terra*, *Aqua*, *Radarsat*, and *Defense Meteorological Satellite*, and from Space Shuttle *Endeavor*'s radar data of topography, all merge in a dramatic composite to show the Western Hemisphere and Eastern Hemisphere of Earth. What indications do you see on these images 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.]

Eastern Hemisphere



Geosystems



Super Typhoon Haiyan made landfall in the central Philippines on the morning of November 7, 2013, with sustained winds over 306 kmph (190 mph), the strongest ever recorded for a tropical cyclone at landfall using satellite measurements. In *Geosystems*, we discuss tropical cyclones and other severe weather events on Earth, including the effects of Superstorm Sandy on the U.S. East Coast in 2012 (see Focus Study 8.1 in Chapter 8). [NOAA.]



Sandstone cliffs along the Virgin River in Zion National Park, Utah. [GeoStills/Alamy]

AN INTRODUCTION TO PHYSICAL GEOGRAPHY

global edition
ninth edition

Geosystems

Robert W. Christopherson

Ginger H. Birkeland

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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

brief contents

1 Essentials of Geography 28

PART I The Energy–Atmosphere System 62

2 Solar Energy to Earth and the Seasons 66

3 Earth’s Modern Atmosphere 86

4 Atmosphere and Surface Energy Balances 110

5 Global Temperatures 134

6 Atmospheric and Oceanic Circulations 160

PART II The Water, Weather, and Climate Systems 192

7 Water and Atmospheric Moisture 194

8 Weather 218

9 Water Resources 250

10 Global Climate Systems 284

11 Climate Change 314

PART III The Earth–Atmosphere Interface 350

12 The Dynamic Planet 352

13 Tectonics, Earthquakes, and Volcanism 384

14 Weathering, Karst Landscapes, and Mass Movement 420

15 River Systems 448

16 Oceans, Coastal Systems, and Wind Processes 482

17 Glacial and Periglacial Landscapes 522

PART IV Soils, Ecosystems, and Biomes 554

18 The Geography of Soils 556

19 Ecosystem Essentials 586

20 Terrestrial Biomes 620

Appendix A Maps in this Text and Topographic Maps **A-1**

Appendix B The Köppen Climate Classification System **A-6**

Appendix C Common Conversions **A-9**

Preface 16
 Digital and Print Resources 20
 Book Walkthrough 22



1 Essentials of Geography 28

KEY LEARNING **concepts** 28
 GEOSYSTEMS**now** Shale Gas: An Energy Resource for the Future? 29
The Science of Geography 31
 The Geographic Continuum 31
 Geographic Analysis 32
 The Scientific Process 33
 Human–Earth Interactions in the 21st Century 35
Earth Systems Concepts 36
 Systems Theory 36
 Systems Organization in *Geosystems* 39

Earth's Dimensions 42
Location and Time on Earth 44
 Latitude 45
 Longitude 47
 Great Circles and Small Circles 47
 Meridians and Global Time 48
Maps and Cartography 50
 The Scale of Maps 50
 Map Projections 52
Modern Tools and Techniques for Geoscience 54
 Global Positioning System 55
 Remote Sensing 56
 Geographic Information Systems 59
 GEOSYSTEMS**connection** 61
 KEY LEARNING **concepts review** 61
geosystems in action 1 Exploring Earth Systems 40
CRITICAL THINKING 1.1 What is Your Footprint? 36
CT 1.2 Latitudinal Geographic Zones and Temperature 47
CT 1.3 Where are You? 48
CT 1.4 Find and Calculate Map Scales 52
CT 1.5 Test Your Knowledge about Satellite Imagery 59
GEOreports: 7 REPORTS 57

PART I The Energy–Atmosphere System 64



2 Solar Energy to Earth and the Seasons 66

KEY LEARNING **concepts** 66
 GEOSYSTEMS**now** Chasing the Subsolar Point 67
The Solar System, Sun, and Earth 68
 Solar System Formation 69
 Dimensions and Distances 69
Solar Energy: From Sun to Earth 69
 Solar Activity and Solar Wind 70

Electromagnetic Spectrum of Radiant Energy 71
 Incoming Energy at the Top of the Atmosphere 73
The Seasons 75
 Seasonality 76
 Reasons for Seasons 76
 Annual March of the Seasons 79
 KEY LEARNING **concepts review** 84
geosystems in action 2 Earth–Sun Relations 80
CRITICAL THINKING 2.1 A Way to Calculate Sunrise and Sunset 76
CT 2.2 Astronomical Factors Vary over Long Time Frames 78
CT 2.3 Use the Analemma to Find the Subsolar Point 82
 THE **human** DENOMINATOR: **The Earth–Sun System and the Seasons** 83
GEOreports: 4 REPORTS 69



3 Earth's Modern Atmosphere 86

KEY LEARNING **concepts** 86

GEOSYSTEMS **now** Humans Help Define the Atmosphere 87

Atmospheric Composition, Temperature, and Function 88

Atmospheric Profile 88

Atmospheric Composition Criterion 89

Atmospheric Temperature Criterion 91

Atmospheric Function Criterion 93



4 Atmosphere and Surface Energy Balances 110

KEY LEARNING **concepts** 110

GEOSYSTEMS **now** Melting Sea Ice Opens Arctic Shipping Lanes, However... 111

Energy-Balance Essentials 112

Energy and Heat 112

Energy Pathways and Principles 114



5 Global Temperatures 134

KEY LEARNING **concepts** 134

GEOSYSTEMS **now** The Mystery of St. Kilda's Shrinking Sheep 135

Temperature Concepts and Measurement 137

Temperature Scales 137

Measuring Temperature 138

Pollutants in the Atmosphere 95

Natural Sources of Air Pollution 95

Anthropogenic Pollution 98

Natural Factors That Affect Pollutants 102

Benefits of the Clean Air Act 106

GEOSYSTEMS **connection** 107

KEY LEARNING **concepts review** 108

geosystems in action 3 Air Pollution 104

Focus Study 3.1 Pollution 96

Focus Study 3.2 Pollution 100

CRITICAL THINKING 3.1 Where is Your Tropopause? 93

CT 3.2 Finding Your Local Ozone 94

CT 3.3 Evaluating Costs and Benefits 106

THE **human** DENOMINATOR: **The Shared Global Atmosphere** 107

GEOreports: 5 REPORTS 88

Energy Balance in the Troposphere 118

The Greenhouse Effect and Atmospheric Warming 118

Earth–Atmosphere Energy Balance 119

Energy Balance at Earth's Surface 123

Daily Radiation Patterns 123

A Simplified Surface Energy Budget 124

The Urban Environment 128

GEOSYSTEMS **connection** 131

KEY LEARNING **concepts review** 132

geosystems in action 4 Earth–Atmosphere Energy Balance 120

Focus Study 4.1 Sustainable Resources 126

CRITICAL THINKING 4.1 A Kelp Indicator of Surface Energy Dynamics 122

CT 4.2 Applying Energy-Balance Principles to a Solar Cooker 125

CT 4.3 Looking at Your Surface Energy Budget 130

THE **human** DENOMINATOR: **Changes in Atmosphere and Surface Energy Budgets** 131

GEOreports: 3 REPORTS 115

Principal Temperature Controls 140

Latitude 140

Altitude and Elevation 140

Cloud Cover 141

Land–Water Heating Differences 142

Earth's Temperature Patterns 148

January and July Global Temperature Maps 149

January and July Polar-Region Temperature Maps 151

Annual Temperature Range Map 152

Recent Temperature Trends and Human Response 152

Record Temperatures and Greenhouse Warming 153

Heat Stress and the Heat Index 155

GEOSYSTEMS **connection** 157

KEY LEARNING **concepts review** 158

geosystems in action 5 Earth's Highest Land Surface Temperatures 139

Focus Study 5.1 Climate Change 154**CRITICAL THINKING 5.1** Compare and Explain Coastal and Inland Temperatures 145**6 Atmospheric and Oceanic Circulations** 160KEY LEARNING **concepts** 160GEOSYSTEMS **now** Ocean Currents Bring Invasive Species 161**Wind Essentials** 163

Air Pressure 163

Wind: Description and Measurement 164

Driving Forces Within the Atmosphere 166

Pressure Gradient Force 166

Coriolis Force 166

Friction Force 168

Summary of Physical Forces on Winds 168

High- and Low-Pressure Systems 170

CT 5.2 Begin a Full Physical Geography Profile of Your Area 150THE **human** DENOMINATOR: **Global Temperatures** 157

GEOreports: 4 REPORTS 137

Atmospheric Patterns of Motion 170

Primary Pressure Areas and Associated Winds 170

Upper Atmospheric Circulation 173

Monsoonal Winds 178

Local Winds 179

Oceanic Currents 181

Surface Currents 181

Thermohaline Circulation—The Deep Currents 182

Natural Oscillations in Global Circulation 183

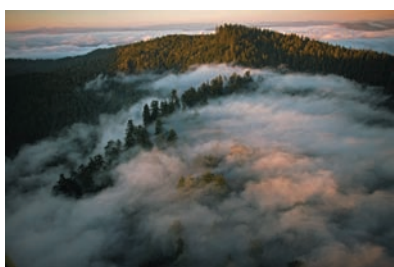
El Niño–Southern Oscillation 183

Pacific Decadal Oscillation 186

North Atlantic and Arctic Oscillations 187

GEOSYSTEMS **connection** 188KEY LEARNING **concepts review** 189**geosystems in action 6** Atmospheric Circulation 174**Focus Study 6.1 Sustainable Resources** 184**CRITICAL THINKING 6.1** Measure the Wind 166**CT 6.2** What Causes the North Australian Monsoon? 179**CT 6.3** Construct Your Own Wind-Power Assessment Report 180THE **human** DENOMINATOR: **Global Circulation** 188

GEOreports: 5 REPORTS 163

PART II The Water, Weather, and Climate Systems 192**7 Water and Atmospheric Moisture** 194KEY LEARNING **concepts** 194GEOSYSTEMS **now** Summer Fog Protects the World's Tallest Trees 195**Water's Unique Properties** 196

Phase Changes and Heat Exchange 197

Latent Heat Transfer Under Natural Conditions 199

Humidity 200

Relative Humidity 200

Specialized Expressions of Humidity 202

Instruments for Measuring Humidity 203

Atmospheric Stability 204

Adiabatic Processes 204

Stable and Unstable Atmospheric Conditions 205

Clouds and Fog 208

Cloud Formation Processes 208

Cloud Types and Identification 208

Processes That Form Fog 211

GEOSYSTEMS **connection** 214KEY LEARNING **concepts review** 215**geosystems in action 7** Adiabatic Heating and Cooling 206**CRITICAL THINKING 7.1** Iceberg Analysis 198**CT 7.2** Using Relative Humidity and Dew-Point Maps 203**CT 7.3** Identify Two Kinds of Fog 212THE **human** DENOMINATOR: **Atmospheric Moisture** 214

GEOreports: 3 REPORTS 198



8 Weather 218

KEY LEARNING **concepts** 218

GEOSYSTEMS **now** On the Front Lines of Intense Weather 219

Air Masses 220

Air Masses Affecting North America 220

Air Mass Modification 221

Atmospheric Lifting Mechanisms 221

Convergent Lifting 222

Convictional Lifting 222

Orographic Lifting 223

Frontal Lifting (Cold and Warm Fronts) 225

Midlatitude Cyclonic Systems 228

Life Cycle of a Midlatitude Cyclone 228

Weather Maps and Forecasting 229

Violent Weather 232

Ice Storms and Blizzards 232

Thunderstorms 232

Derechos 236

Tornadoes 237

Tropical Cyclones 239

GEOSYSTEMS **connection** 247

KEY LEARNING **concepts review** 248

geosystems in action 8 Midlatitude Cyclones 230

Focus Study 8.1 Natural Hazards 244

CRITICAL THINKING 8.1 Analyzing a Weather Map 233

CT 8.2 Hazard Perception and Planning: What Seems to be Missing? 246

THE **human** DENOMINATOR: **Weather** 247

GEOREPORTS: 5 REPORTS 223



9 Water Resources 250

KEY LEARNING **concepts** 250

GEOSYSTEMS **now** Earth's Largest Lake

Warms with Changing Climate 251

Water on Earth 252

Worldwide Equilibrium 253

Distribution of Earth's Water Today 253

The Hydrologic Cycle 254

Water in the Atmosphere 254

Water at the Surface 255

Water in the Subsurface 256

Water Budgets and Resource Analysis 256

Components of the Water Budget 256

The Water-Budget Equation 260

Sample Water Budgets 260

Water-Budget Application: Hurricane Camille 261

Drought: The Water Deficit 262

Surface Water Resources 263

Snow and Ice 263

Rivers and Lakes 263

Wetlands 269

Groundwater Resources 269

The Groundwater Environment 270

Overuse of Groundwater 271

Pollution of Groundwater 276

Our Water Supply 276

Water Supply in the United States 278

Water Withdrawal and Consumption 279

Future Considerations 279

GEOSYSTEMS **connection** 280

KEY LEARNING **concepts review** 281

geosystems in action 9 Groundwater 272

Focus Study 9.1 Climate Change 266

Focus Study 9.2 Sustainable Resources 274

CRITICAL THINKING 9.1 Your Local Water Budget 260

CT 9.2 Calculate Your Water Footprint 277

CT 9.3 That Next Glass of Water 279

THE **human** DENOMINATOR: **Water Use** 280

GEOREPORTS: 4 REPORTS 252



10 Global Climate Systems 284

KEY LEARNING **concepts** 284

GEOSYSTEMS **now** A Large-Scale Look at Puerto Rico's Climate 285

Review of Earth's Climate System 286

Classifying Earth's Climates	287
Tropical Rain Forest Climates	292
Tropical Monsoon Climates	293
Tropical Savanna Climates	294
Humid Subtropical Hot-Summer Climates	295
Humid Subtropical Winter-Dry Climates	295
Marine West Coast Climates	295
Mediterranean Dry-Summer Climates	297
Humid Continental Hot-Summer Climates	300
Humid Continental Mild-Summer Climates	300
Subarctic Climates	301
Tundra Climates	304
Ice-Cap and Ice-Sheet Climates	305
Polar Marine Climates	305



11 Climate Change 314

KEY LEARNING **concepts** 314

GEOSYSTEMS**now** Greenhouse Gases Awaken in the Arctic 315

Population Growth and Fossil Fuels—The Setting for Climate Change 316

Deciphering Past Climates 318

Methods for Long-Term Climate Reconstruction	319
Earth's Long-Term Climate History	321
Methods for Short-Term Climate Reconstruction	323
Earth's Short-Term Climate History	325

Mechanisms of Natural Climate Fluctuation 327

Solar Variability	327
Earth's Orbital Cycles	327
Continental Position and Topography	328
Atmospheric Gases and Aerosols	328

Climate Feedbacks and the Carbon Budget 328

Earth's Carbon Budget	328
Water-Vapor Feedback	329
Carbon–Climate Feedbacks	329
CO ₂ –Weathering Feedback	329

Characteristics of Dry Climates	306
Tropical, Subtropical Hot Desert Climates	307
Midlatitude Cold Desert Climates	308
Tropical, Subtropical Hot Steppe Climates	308
Midlatitude Cold Steppe Climates	308

Climate Regions and Climate Change 316

GEOSYSTEMS**connection** 311

KEY LEARNING **concepts review** 312

geosystems in action 10 Earth's Climate System 288

CRITICAL THINKING 10.1 Finding Your Climate 287

THE **human**DENOMINATOR: **Climate Regions** 311

GEOreports: 3 REPORTS 294

Evidence for Present Climate Change 332

Temperature	333
Ice Melt	333
Sea-Level Rise	335
Extreme Events	336

Causes of Present Climate Change 336

Contributions of Greenhouse Gases	337
Sources of Radiative Forcing	339
Scientific Consensus	341

Climate Models and Forecasts 342

Radiative Forcing Scenarios	342
Future Temperature Scenarios	343
Sea-Level Projections	343

The Path Ahead 344

Taking a Position on Climate Change	344
Action Now Means “No Regrets”	345
Mitigating Climate Change: What Can You Do?	345
GEOSYSTEMS connection	347

KEY LEARNING **concepts review** 348

geosystems in action 11 The Global Carbon Budget 330

Focus Study 11.1 Climate Change 340

CRITICAL THINKING 11.1 Crossing The 450-ppm Threshold for Carbon Dioxide 318

CT 11.2 Thinking Through an Action Plan to Reduce Human Climate Forcing 340

THE **human**DENOMINATOR: **Taking Action on Climate Change** 347

GEOreports: 3 REPORTS 335

PART III The Earth–Atmosphere Interface 350



12 The Dynamic Planet 352

KEY LEARNING **concepts** 352

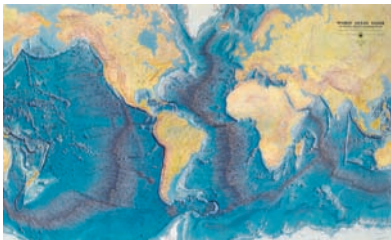
GEOSYSTEMS**now** Earth's Migrating Magnetic Poles 353

The Pace of Change 354

Earth's Structure and Internal Energy 356

Earth's Core and Mantle	357
-------------------------	-----

- Earth's Crust 357
- The Asthenosphere and Lithosphere 358
- Adjustments in the Crust 358
- Earth's Magnetism 359
- Earth Materials and the Rock Cycle 360**
 - Igneous Processes 361
 - Sedimentary Processes 362
 - Metamorphic Processes 366
 - The Rock Cycle 366
- Plate Tectonics 368**
 - Continental Drift 368
 - Seafloor Spreading 368
 - Subduction 372
 - Plate Boundaries 372
 - Earthquake and Volcanic Activity 373



13 Tectonics, Earthquakes, and Volcanism 384

- KEY LEARNING **concepts** 384
- GEOSYSTEMS **now** The San Jacinto Fault Connection 385
- Earth's Surface Relief 386**
 - Studying Earth's Topography 386
 - Orders of Relief 387
 - Earth's Hypsometry 387
 - Earth's Topographic Regions 388
- Crustal Formation 389**
 - Continental Shields 389
 - Building Continental Crust and Accretion of Terranes 390
- Crustal Deformation 391**
 - Folding and Broad Warping 392
 - Faulting 394
- Orogenesis (Mountain Building) 397**
 - Types of Orogenesis 399



14 Weathering, Karst Landscapes, and Mass Movement 420

- KEY LEARNING **concepts** 420

- Hot Spots 374
- The Geologic Cycle 378**
 - GEOSYSTEMS **connection** 379
- KEY LEARNING **concepts review** 382
 - geosystems in action 12** The Geologic Cycle 380
 - Focus Study 12.1 Sustainable Resources 376**
 - CRITICAL THINKING 12.1** Thoughts about an "Anthropocene Epoch" 356
 - CT 12.2** Tracking Your Location Since Pangaea 372
 - CT 12.3** How Fast is the Pacific Plate Moving? 378
- THE **human** DENOMINATOR: **Earth Material and Plate Tectonics 379**
- GEOREPORTS: 4 REPORTS 357

- The Tetons and the Sierra Nevada 399
- The Appalachian Mountains 402
- Earthquakes 402**
 - Earthquake Anatomy 403
 - Earthquake Intensity and Magnitude 404
 - Fault Mechanics 405
 - Earthquake Forecasting 408
 - Earthquake Planning 409
- Volcanism 410**
 - Settings for Volcanic Activity 411
 - Volcanic Materials 411
 - Volcanic Landforms 411
 - Effusive Eruptions 412
 - Explosive Eruptions 414
 - Volcano Forecasting and Planning 415
- GEOSYSTEMS **connection** 417
- KEY LEARNING **concepts review** 418
 - geosystems in action 13** Mountain Building 400
 - Focus Study 13.1 Natural Hazards 406**
 - CRITICAL THINKING 13.1** Comparing Topographic Regions at Different Scales 388
 - CT 13.2** Ocean-Floor Tectonics Tour 415
- THE **human** DENOMINATOR: **Tectonics 417**
- GEOREPORTS: 4 REPORTS 388

- GEOSYSTEMS **now** Human-Caused Mass Movement at the Kingston Steam Plant, Tennessee 421

- Landmass Denudation 422**
 - Dynamic Equilibrium Approach to Understanding Landforms 423
 - Slopes 423
- Weathering Processes 426**
 - Factors Influencing Weathering Processes 427
 - Physical Weathering Processes 428
 - Chemical Weathering Processes 429
- Karst Topography 433**
 - Formation of Karst 434

Features of Karst Landscapes	434
Caves and Caverns	436
Mass-Movement Processes	438
Mass-Movement Mechanics	438
Classes of Mass Movements	439
Humans as a Geomorphic Agent	443
GEOSYSTEMS connection	445
KEY LEARNING concepts review	446



15 River Systems 448

KEY LEARNING concepts	448
GEOSYSTEMS now Environmental Effects of Dams on the Nu River in China	449
Drainage Basins and Drainage Patterns	450
Drainage Divides	451
Drainage Basins as Open Systems	453
International Drainage Basins	453
Internal Drainage	453
Drainage Patterns	454
Basic Fluvial Concepts	455
Gradient	455



16 Oceans, Coastal Systems, and Wind Processes 482

KEY LEARNING concepts	482
GEOSYSTEMS now Sand Dunes Prevent Coastline Erosion during Hurricane Sandy	483
Global Oceans and Seas	484
Properties of Seawater	485
Physical Structure and Human Impacts	486
Coastal System Components	487
The Coastal Environment	489
Sea Level	490
Coastal System Actions	491
Tides	491
Waves	493
Coastal System Outputs	498

geosystems in action 14 Hillslopes As Open Systems	424
Focus Study 14.1 Natural Hazards	441
CRITICAL THINKING 14.1 Find a Slope; Apply the Concepts	426
THE human DENOMINATOR: Weathering, Karst, and Hillslopes	445
GEOreports: 5 REPORTS	428

Base Level	455
Stream Discharge	456
Fluvial Processes and Landforms	458
Stream Channel Processes	459
Channel Patterns	461
Graded Streams	465
Depositional Landforms	469
Floods and River Management	474
Humans and Floodplains	474
Flood Protection	475
Flood Probability	476
Floodplain Management	476
GEOSYSTEMS connection	478
KEY LEARNING concepts review	479
geosystems in action 15 Meandering: Streams	466
Focus Study 15.1 Environmental Restoration	462
CRITICAL THINKING 15.1 Locate Your Drainage Basin	453
CT 15.2 Identifying Drainage Patterns	455
THE human DENOMINATOR: Rivers, Floodplains, and Deltas	478
GEOreports: 3 REPORTS	473

Coastal Erosion	498
Coastal Deposition	500
Barrier Beaches and Islands	503
Coral Formations	505
Coastal Wetlands	507
Wind Processes	509
Eolian Transport of Dust and Sand	509
Eolian Erosion	510
Desert Pavement	512
Eolian Deposition	512
GEOSYSTEMS connection	518
KEY LEARNING concepts review	519
geosystems in action 16 Wind-Blown Dune Forms	514
Focus Study 16.1 Pollution	488
Focus Study 16.2 Natural Hazards	498
CRITICAL THINKING 16.1 Thinking Through a Rising Sea Level	491
CT 16.2 Allocating Responsibility and Cost for Coastal Hazards	505
CT 16.3 The Nearest Eolian Features	517
THE human DENOMINATOR: Oceans, Coasts, and Dunes	518
GEOreports: 5 REPORTS	486



17 Glacial and Periglacial Landscapes 522

KEY LEARNING **concepts** 522

GEOSYSTEMS **now** Tidewater Glaciers and Ice Shelves Give Way to Warming 523

Snow into Ice—The Basis of Glaciers 524

- Properties of Snow 524
- Formation of Glacial Ice 525

Types of Glaciers 525

- Alpine Glaciers 526
- Continental Ice Sheets 527

Glacial Processes 528

- Glacial Mass Balance 528
- Glacial Movement 529

Glacial Landforms 533

- Erosional Landforms 533
- Depositional Landforms 536

Periglacial Landscapes 539

- Permafrost and Its Distribution 539
- Periglacial Processes 541
- Humans and Periglacial Landscapes 543

The Pleistocene Epoch 543

- Ice-Age Landscapes 543
- Paleolakes 545

Arctic and Antarctic Regions 546

- Recent Polar Region Changes 547
- GEOSYSTEMS **connection** 550

KEY LEARNING **concepts review** 551

geosystems in action 17 Glaciers As Dynamic Systems 530

Focus Study 17.1 Natural Hazards 526

CRITICAL THINKING 17.1 Looking for Glacial Features 535

CT 17.2 A Sample of Life at the Polar Station 547

CT 17.3 The IPY Accomplishment Continues 549

THE **HUMAN DENOMINATOR: Glaciers and Permafrost** 550

GEOreports: 4 REPORTS 527

PART IV SOILS, ECOSYSTEMS, AND BIOMES 554



18 The Geography of Soils 556

KEY LEARNING **concepts** 556

GEOSYSTEMS **now** Desertification: Declining Soils and Agriculture in Earth's Drylands 557

Soil-Formation Factors and Soil Profiles 558

- Natural Factors in Soil Development 558
- Soil Horizons 559

Soil Characteristics 560

- Physical Properties 560
- Chemical Properties 564

Human Impacts on Soils 565

- Soil Erosion 565
- Desertification 567

Soil Classification 568

- Soil Taxonomy 568
- The 12 Soil Orders of the Soil Taxonomy 569
- GEOSYSTEMS **connection** 583

KEY LEARNING **concepts review** 584

geosystems in action 18 Biological Activity in Soils 563

Focus Study 18.1 Pollution 574

CRITICAL THINKING 18.1 Soil Losses—What to Do? 568

CT 18.2 Soil Observations 569

THE **HUMAN DENOMINATOR: Soils and Land Use** 583

GEOreports: 4 REPORTS 562



19 Ecosystem Essentials 586

KEY LEARNING **concepts** 586

GEOSYSTEMS**now** Species' Distributions Shift with Climate Change 587

Energy Flows and Nutrient Cycles 588

Converting Energy to Biomass 589

Elemental Cycles 592

Energy Pathways 595

Communities and Species Distributions 601

The Niche Concept 601

Species Interactions 602

Abiotic Influences 603

Limiting Factors 604

Disturbance and Succession 607

Biodiversity, Evolution, and Ecosystem Stability 609

Biological Evolution Delivers Biodiversity 610

Biodiversity Fosters Ecosystem Stability 611

Biodiversity on the Decline 612

GEOSYSTEMS**connection** 616

KEY LEARNING **concepts review** 617

geosystems in action 19 Coastal Dead Zones 596

Focus Study 19.1 Natural Hazards 606

Focus Study 19.2 Environmental Restoration 614

CRITICAL THINKING 19.1 Mutualism? Parasitism? Where Do We Fit in? 603

CT 19.2 Observe Ecosystem Disturbances 605

THE **human** DENOMINATOR: **Ecosystems and Biodiversity** 616

GEOreports: 4 REPORTS 595



20 Terrestrial Biomes 620

KEY LEARNING **concepts** 620

GEOSYSTEMS**now** Invasive Species Arrive at Tristan da Cunha 621

Biogeographic Divisions 622

Biogeographic Realms 622

Biomes 623

Invasive Species 624

Earth's Terrestrial Biomes 627

Tropical Rain Forest 627

Tropical Seasonal Forest and Scrub 631

Tropical Savanna 631

Midlatitude Broadleaf and Mixed Forest 634

Boreal and Montane Forest 635

Temperate Rain Forest 636

Mediterranean Shrubland 637

Midlatitude Grassland 638

Deserts 639

Arctic and Alpine Tundra 640

Conservation, Management, and Human Biomes 642

Island Biogeography for Species Preservation 642

Focus Study 20.1 Environmental Restoration 643

Aquatic Ecosystem Management 644

Anthropogenic Biomes 644

GEOSYSTEMS**connection** 645

KEY LEARNING **concepts review** 646

geosystems in action 20: Tropical Rain Forests and Amazon Deforestation 632

CRITICAL THINKING 20.1 Reality Check 627

CT 20.2 Tropical Forests: A Global or Local Resource? 631

CT 20.3 A Shifting-Climate Hypothetical 641

THE **human** DENOMINATOR: **Anthropogenic Environments** 645

GEOreports: 5 REPORTS 623

Appendix A Maps in this Text and Topographic Maps **A-1**

Appendix B The Köppen Climate Classification System **A-6**

Appendix C Common Conversions **A-9**

Glossary G-1

Index I-1

preface

Welcome to the Ninth Edition of *Geosystems*. This edition marks the addition of Dr. Ginger Birkeland as a coauthor to Robert Christopherson. This Ninth Edition features significant revision, with a new chapter on climate change, new features, updated content, and many new photos and illustrations. We continue to build on the success of the first eight editions, as well as the companion texts, *Elemental Geosystems*, now in its Seventh Edition, and *Geosystems, Canadian Edition*, Third Edition. Students and teachers appreciate the systems organization, scientific accuracy, integration of figures and text, clarity of the summary and review sections, and overall relevancy to what is happening to Earth systems in real time. *Geosystems* continues to tell Earth's story in student-friendly language.

The goal of physical geography is to explain the spatial dimension of Earth's dynamic systems—its energy, air, water, weather, climate, tectonics, landforms, rocks, soils, plants, ecosystems, and biomes. Understanding human–Earth relations is part of physical geography as it seeks to understand and link the planet and its inhabitants. Welcome to physical geography!

New to the Ninth Edition

Nearly every page of *Geosystems*, Ninth Edition, presents updated material, new content in text and figures, and new features. A sampling of new features includes:

- A **new chapter on climate change**. Although climate change science affects all systems and is discussed to some extent in every chapter of *Geosystems*, we now present a stand-alone chapter covering this topic—Chapter 11, Climate Change. This chapter covers paleoclimatology and mechanisms for past climatic change (expanding on topics covered in Chapter 17 in previous editions), climate feedbacks and the global carbon budget, the evidence and causes of present climate change, climate models and projections, and actions that we can take to moderate Earth's changing climate. This new Chapter 11 expands on the climate change discussion that was formerly part of Chapter 10, Climate Systems and Climate Change, in previous editions.
- A new ***Geosystems in Action*** feature focusing on key topics, processes, systems, or human–Earth connections. In every chapter, *Geosystems in Action* is a one- to two-page highly visual presentation of a topic central to the chapter, with active learning questions as well as a GeoQuiz to aid student learning. Throughout each part of the *Geosystems in Action* figure, students are asked to analyze, explain, infer, or predict based on the information

presented. Topics include Earth–Sun Relations (Chapter 2), Air Pollution (Chapter 3), Earth–Atmosphere Energy Balance (Chapter 4), The Global Carbon Budget (Chapter 11), Glaciers as Dynamic Systems (Chapter 17), and Biological Activity in Soils (Chapter 18).

- A new feature, ***The Human Denominator***, that links chapter topics to human examples and applications. At the end of Chapters 2 through 20, this new feature includes maps, photos, graphs, and other diagrams to provide visual examples of many human–Earth interactions. This feature replaces and expands on the former Chapter 21 in previous *Geosystems* editions, called *Earth and the Human Denominator*.
- New and revised illustrations and maps to improve student learning. More than 250 new photos and images bring real-world scenes into the classroom. Our photo and remote sensing program, updated for this edition, exceeds 500 items, integrated throughout the text.
- New images and photos for the 20 chapter openers, and redesigned schematics and photos for the 4 part openers.

Continuing in the Ninth Edition

- 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. In the Ninth Edition, these features are grouped by topic into five categories: Pollution, Climate Change, Natural Hazards, Sustainable Resources, and Environmental Restoration.

Nine new Focus Study topics include:

Heat Waves (Chapter 5)
Hurricanes Katrina and Sandy: Storm Development and Links to Climate Change (Chapter 8)
Thawing Methane Hydrates—Another Arctic Methane Concern (Chapter 11)
Earthquakes in Haiti, Chile, and Japan: A Comparative Analysis (Chapter 13)
Stream Restoration: Merging Science and Practice (Chapter 15)
The 2011 Japan Tsunami (Chapter 16)
Snow Avalanches (Chapter 17)
Wildfire and Fire Ecology (Chapter 19)
Global Conservation Strategies (Chapter 20)

- The chapter-opening *Geosystems Now* case study feature presents current issues in geography and Earth systems science. These original, unique essays, updated for the Ninth Edition, immediately engage readers into the chapter with relevant, real-world examples

of physical geography. New *Geosystems Now* topics in the Ninth Edition include shale gas as an energy resource in the United States (Chapter 1), coastal redwood trees and declining summer moisture in California (Chapter 7), the effects of proposed dams on rivers in China (Chapter 15), and coastal erosion caused by Hurricane Sandy (Chapter 16). Many of these features emphasize linkages across chapters and Earth systems, exemplifying the Geosystems approach.

- *Geo Reports* continue to describe timely and relevant events or facts related to the discussion in the chapter, provide student action items, and offer new sources of information. The 75 *Geo Reports* in the Ninth Edition, placed along the bottom of pages, are updated, with many new to this edition. Example topics include:

Did light refraction sink the *Titanic*? (Chapter 4)
 The hottest temperature on Earth (Chapter 5)
 Storm causes Hawai'i hailstorm and tornado (Chapter 8)
 Satellite GRACE enables groundwater measurements (Chapter 9)
 Tropical climate zones advance to higher latitudes (Chapter 10)
 Surprise waves flood a cruise ship (Chapter 16)
 Greenland ice sheet melting (Chapter 17)
 Overgrazing effects on Argentina's grasslands (Chapter 18)

- *Critical Thinking* exercises are integrated throughout the chapters. These carefully crafted action items bridge students to the next level of learning, placing students in charge of further inquiry. Example topics include:

Applying Energy-Balance Principles to a Solar Cooker
 What Causes the North Australian Monsoon?
 Identify Two Kinds of Fog
 Analyzing a Weather Map
 Allocating Responsibility and Cost for Coastal Hazards
 Tropical Forests: A Global or Local Resource?

- The *Geosystems Connection* feature at the end of each chapter provides a preview “bridge” between chapters, reinforcing connections between chapter topics.
- *Key Learning Concepts* appear at the outset of each chapter, many rewritten for clarity. Each chapter concludes with *Key Learning Concepts Review*, which summarizes the chapter using the opening objectives.
- *Geosystems* continues to embed Internet URLs within the text. More than 200 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, floods, and the myriad other subjects covered in the book.

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For Students and Teachers

Television for the Environment Earth Report Geography Videos on 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-ROM (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 geology, physical geography, oceanography, meteorology, and earth science. The animations are provided as Flash files and preloaded into PowerPoint(R) slides for both Windows and Mac.

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. The book illustrates the value of geographic expertise and technologies through engaging profiles and case studies of geographers at work.

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. *Aspiring Academics* stresses the interdependence of teaching, research, and service—and the importance of achieving a healthy balance of professional and personal life—while doing faculty work. Each chapter provides accessible, forward-looking advice on topics that often cause the most stress in the first years of a college or university appointment.

For Students

Applied Physical Geography—Geosystems in the Laboratory, Ninth Edition (0321987284) by Charlie Thomson and Robert Christopherson. A variety of exercises provides flexibility in lab assignments. Each exercise includes key terms and learning concepts linked to *Geosystems*. The ninth edition includes new exercises on climate change, a fully updated exercise on basic GIS using ArcGIS online, and more integrated media, including Google Earth and Quick Response (QR) codes. Supported by a website with media resources needed for exercises, as well as a downloadable Solutions Manual for teachers.

Companion website for Applied Physical Geography: Geosystems in the Laboratory. The website for lab manual provides online worksheets as well as KMZ files for all of the Google Earth" exercises found in the lab manual. www.mygeoscienceplace.com

Goode's World Atlas, 22nd Edition (0321652002). *Goode's World Atlas* has been the world's premiere educational atlas since 1923—and for good reason. It features over 250 pages of maps, from definitive physical and political maps to important thematic maps that illustrate the spatial aspects of many important topics. The 22nd Edition includes 160 pages of digitally produced reference maps, as well as thematic maps on global climate change, sea-level rise, CO₂ emissions, polar ice fluctuations, deforestation, extreme weather events, infectious diseases, water resources, and energy production.

Pearson's Encounter Series provides rich, interactive explorations of geoscience concepts through Google Earth" activities, covering a range of topics in regional, human, and physical geography. All chapter explorations are available in print workbooks, as well as in online quizzes at www.mygeoscienceplace.com, accommodating different classroom needs. Each exploration consists of a worksheet, online quizzes whose results can be emailed to teachers, and a corresponding Google Earth" KMZ file.