

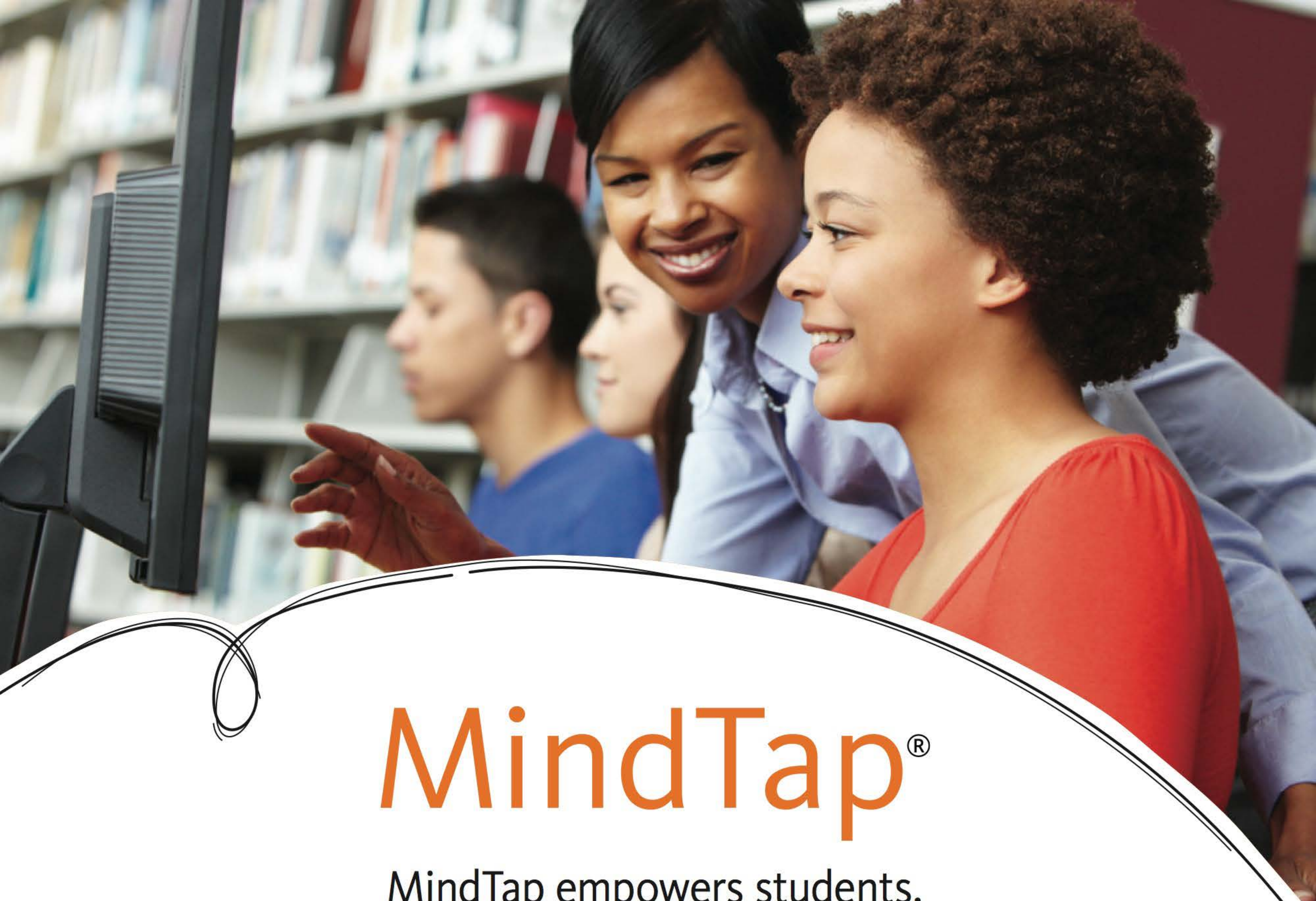
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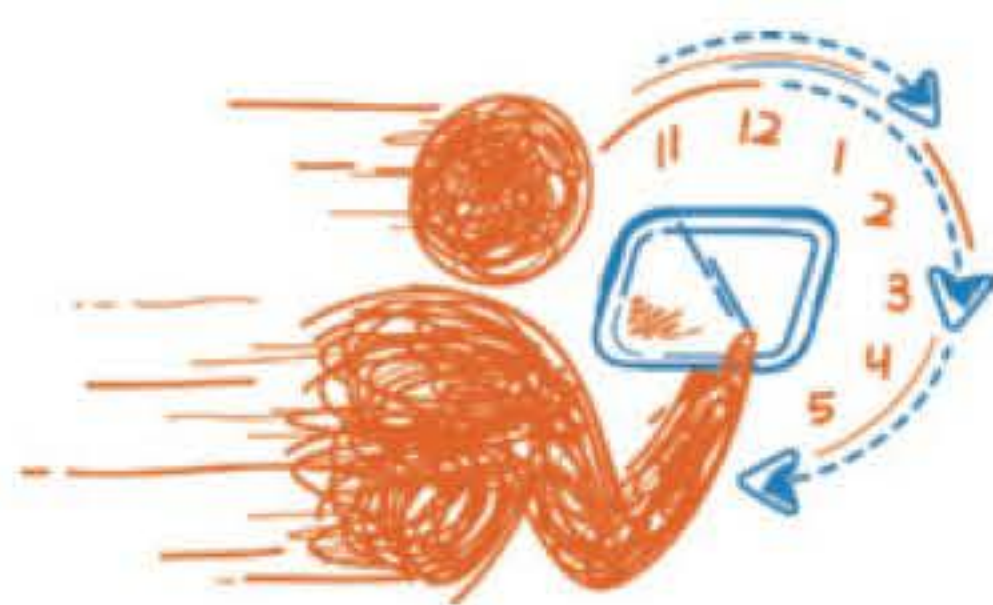
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# **METEOROLOGY TODAY**

AN INTRODUCTION TO WEATHER, CLIMATE, AND THE ENVIRONMENT



SECOND CANADIAN EDITION

# METEOROLOGY TODAY

AN INTRODUCTION TO WEATHER, CLIMATE, AND THE ENVIRONMENT

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**Meteorology Today, Second Canadian Edition**

by C. Donald Ahrens, Peter L. Jackson,  
and Christine E.J. Jackson

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Higher Education:**  
Anne Williams

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Content:**  
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**Marketing Manager:**  
Terry Fedorkiw

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MPS Limited

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**Cover Design:**  
Jennifer Stimson

**Cover Image:**  
Dave Reede/First Light/  
Getty Images

**Art Coordinator:**  
Sue Peden

**Illustrators:**  
Michael Borop, Dave McKay,  
MPS Limited

**Compositor:**  
MPS Limited

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Education Ltd.

Adapted from *Meteorology Today*,  
Tenth Edition, by C. Donald Ahrens,  
published by Brooks/Cole, Cengage  
Learning. Copyright © 2013 by  
Brooks/Cole, Cengage Learning.

Printed and bound in the United  
States of America  
1 2 3 4 18 17 16 15

For more information contact Nelson  
Education Ltd.,  
1120 Birchmount Road, Toronto,  
Ontario, M1K 5G4. Or you can visit  
our Internet site at  
<http://www.nelson.com>

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**Library and Archives Canada  
Cataloguing in Publication**

Ahrens, C. Donald, author

*Meteorology today: an  
introduction to weather, climate,  
and the environment* / C. Donald  
Ahrens (Emeritus, Modesto Junior  
College), Peter L. Jackson (University  
of Northern British Columbia),  
Christine E.J. Jackson (University of  
Northern British Columbia).  
— Second Canadian edition.

Includes index.  
ISBN 978-0-17-653079-2 (bound)

1. Meteorology—Textbooks.
2. Meteorology—Canada—Textbooks.  
I. Jackson, Peter L. (Peter Lawrence),  
1960–, author II. Jackson, Christine E.  
J., 1961–, author III. Title.

QC861.3.A47 2015 551.5  
C2015-903622-4

ISBN-13: 978-0-17-653079-2  
ISBN-10: 0-17-653079-7

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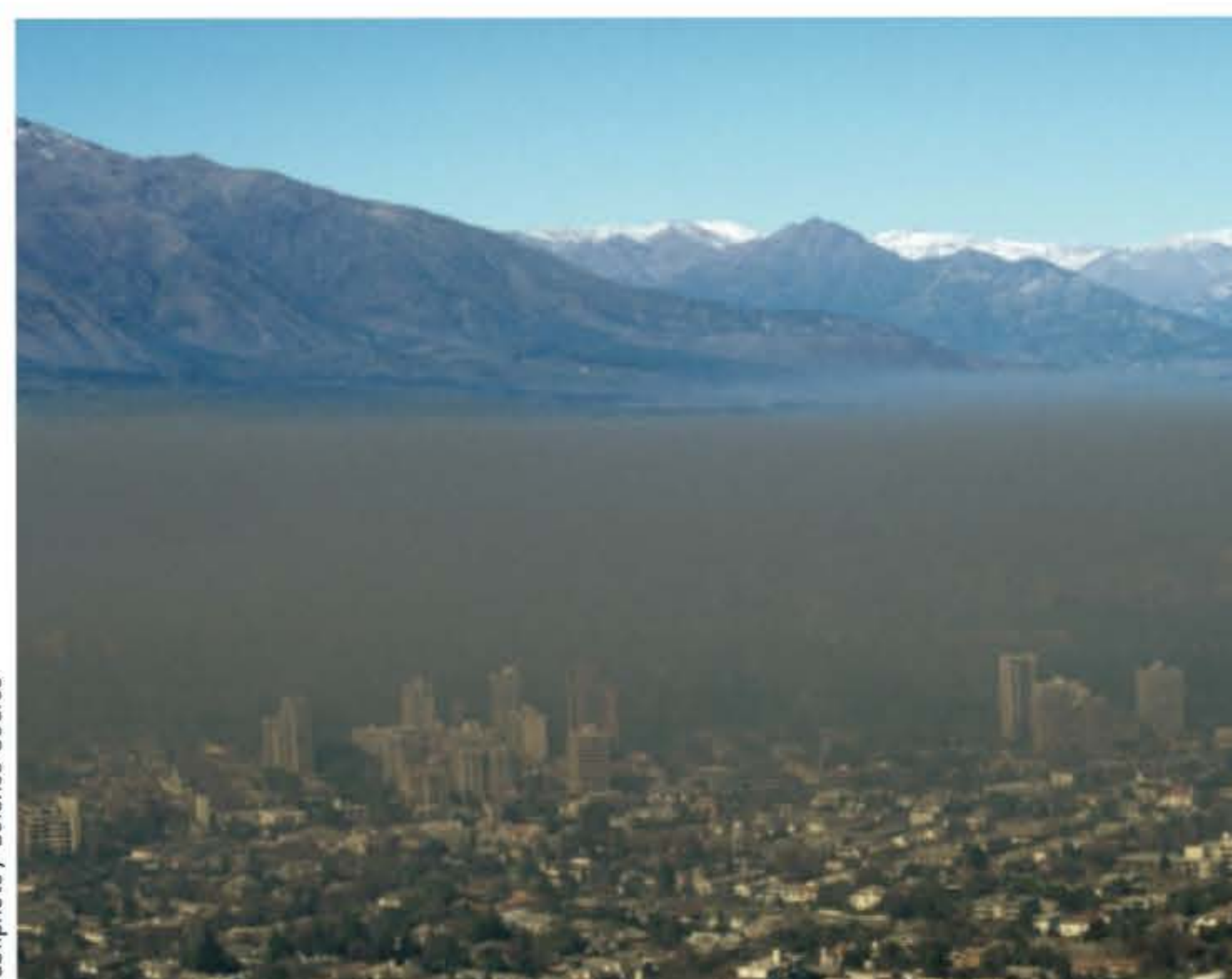


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## About This Book

*Meteorology Today: An Introduction to Weather, Climate, and the Environment*, Second Canadian Edition, customizes C. Donald Ahrens' classic U.S. textbook *Meteorology Today* for Canadians. *Meteorology Today* is well known for making the key concepts in meteorology accessible, and the Canadian edition benefits from the solid foundation that Professor Ahrens refined over nearly three decades. It uses clear writing, tables, graphics, and illustrations combined with nontechnical explanations, and adds content, practices, and examples useful for Canadian university and college students. This book is a comprehensive survey of the atmosphere that emphasizes understanding processes and the application of meteorological principles. Full-colour photographs and figures are used throughout the book to clearly show concepts and engage the reader.

This book is organized into 19 core chapters plus a short introductory chapter intended to enhance reader awareness of strategies for learning from the text. The core chapters are largely self-contained and organized so that instructors can select whole or partial chapters to tailor their use of the text to their course needs. The coverage is broad but comprehensive, with enough material for more than a single semester course. Additionally, each chapter has features that engage students and enhance their comprehension of the content. Readers are also encouraged to extend their knowledge and are supported in doing so through exposure to higher-level topics and practical techniques for understanding weather.

## New in the Second Canadian Edition

Our goals in producing this book were to ensure the information is current, streamline the text without losing its comprehensiveness, make it more readable, and increase its learning value for Canadian readers. In the first Canadian edition, we adapted the 9th U.S. edition of *Meteorology Today*, creating a comprehensive text with information, examples, and conventions that reflect how meteorology is practised in Canada. More than 300 new or revised figures or photos were incorporated. Canadian contributors wrote 16 Canadian content *Focus On* sections, and an *Earth Systems Guide* was developed. This guide contextualizes atmospheric processes and phenomena within Earth's systems through the use of graphical images and text.

Our second Canadian edition includes many updates unique to the Canadian edition and also

incorporates several updates made in the recent U.S. 10th and 11th editions. Content throughout the book was streamlined and new scientific findings and data were incorporated. For example, Chapter 17 was updated to include the latest climate change information from the Intergovernmental Panel on Climate Change. New sections were added to several chapters, such as sections on forecasting severe thunderstorms and hurricanes in Chapters 13 and 14. Twelve new *Weather Watch* boxes were added on topics such as the polar vortex, the use of smartphones to collect weather data, and air quality in Beijing.

Some chapter content was reorganized. A new brief introductory chapter was written to help readers use the textbook most effectively. It provides a concise rationale for studying the atmosphere and a history of meteorology. It also explains how to use Earth Systems Guides and the various textbook features that aid learning. The chapters were streamlined to clarify writing and to synthesize repeated information. For example, some information from Chapter 1 was relocated to later chapters; Chapters 2 and 3 were synthesized to reduce redundancy; and detailed cloud classification material from Chapter 5 was moved to Appendix B to improve readability.

More than half the chapter opening stories were rewritten—several were given a Canadian twist. This improves their linkage with chapter content and provides a broader understanding of the topics. The chapter-opening format was changed to accommodate the expanded opening vignettes and provide a more complete roadmap of chapter content. The Earth Systems Guide was moved to a regular spot on the first main page of each chapter, following the opening spread.

The order of some chapters was changed to follow a more logical sequence: the *Weather Forecasting* chapter (15) was moved so it now appears after the chapters on *Thunderstorms and Tornadoes* (13) and *Hurricanes* (14); the chapter on *Earth's Changing Climate* (17) was moved after the chapter on *Global Climate* (16).

Each figure and photo was reviewed; more than 170 were revised or replaced, and 10 new figures were added. The format of many tables was revised to improve readability. The *Glossary* and inside back cover reference map were extensively revised, as were all Appendices. New *Focus On* sections were added: two new sections from the U.S. edition were adapted for this edition (on the forecast funnel in Chapter 15, and on the combined effects of heat and poor air quality on health in Chapter 18), one new *Focus On* section was written on water budgets in Chapter 4, and four new *Focus On* sections by renowned

Canadian experts were added to complement the 16 of these from the first edition. John Clague (Simon Fraser University) contributed a new *Focus On* section in Chapter 16 on how climate change impacts natural disasters; in Chapter 7, John Pomeroy (University of Saskatchewan) with Paul Whitfield and Ronald Stewart wrote a *Focus On* section on the 2013 floods that affected southern Alberta; Edward Wiebe and Andrew Weaver (University of Victoria) added a *Focus On* section in Chapter 3 on a citizen-science network of personal weather stations at schools on Vancouver Island; and Jon Warland (University of Guelph) provided a new *Focus On* section, also in Chapter 3, on human thermal comfort.

## About the Authors

C. DONALD AHRENS is emeritus professor at Modesto Junior College and the award-winning author of several best-selling meteorology textbooks. The Textbook and Academic Authors Association awarded him its 2009 McGuffey Longevity Award, and in 2007 the National Weather Association awarded him its Lifetime Achievement Award. Dr. Ahrens's books have influenced both meteorology professionals and hundreds of thousands of students who used his books to expand their knowledge of weather and climate.

PETER L. JACKSON is a professor at the University of Northern British Columbia. Before becoming an academic, he was a meteorologist/weather forecaster with Environment Canada. He teaches undergraduate and graduate courses on weather and climate, storms, biometeorology, and air pollution, as well as research methods. His research focuses on the interaction between the atmosphere and Earth's surface in mountains, as well as air quality.

CHRISTINE E. J. JACKSON is a senior laboratory instructor in the University of Northern British Columbia's Geography Program where she develops, coordinates, and teaches experiential labs for introductory weather, geomorphology, and soil science courses. She has worked in a wide variety of educational settings—colleges, schools, museums, and community science and environmental literacy programs—and is interested in improving understanding of the natural environment through applied learning.

## Acknowledgments

Creating a textbook is a team effort. C. Donald Ahrens provided the excellent student-centred material upon which the Canadian edition is based. His original work, *Meteorology Today*, continues in its 11th U.S. edition, now with co-author Robert Henson. We have appreciated their perspective as we revised the second Canadian edition.

We have also been privileged to work with Nelson's excellent team of professionals. Jackie Wood supervised the process. Our development editor, Suzanne Simpson Millar, guided, encouraged, and accommodated us through a longer-than-expected writing process; for her infinite patience we are forever grateful. Melody Tolson ably researched many of the new pictures and sorted out copyright permissions. Dawn Hunter's sharp copy editing makes us look more literate than we actually are. The design team created a modern look and managed production. Naman Mahisauria of MPS Limited supervised the team that masterfully produced the book.

Additionally, the input of multiple disciplinary specialists has been invaluable. Thanks to each of them: Brad Snyder for providing advice on current practices and taking pictures of contemporary Meteorological Service of Canada weather forecasting technology. Gerard Szejwach for suggestions on improving confusing wording and correcting an error concerning superior mirages. The 22 renowned experts listed alphabetically below, who contributed *Focus On* sections for topics of particular relevance to Canadians:

Dr. Yongsheng Chen	Dr. John Pomeroy
Dr. John Clague	Clifford Raphael
Dr. Stephen Déry	Dr. Gerhard Reuter
Dr. Chris Fogarty	Dr. Ronald Stewart
Dr. William Gough	Dr. Douw Steyn
Dr. Ismail Gultepe	Dr. Ian Strachan
Patrick King	Dr. James Voogt
Dr. René Laprise	Dr. Jon Warland
Claire Martin	Dr. Andrew Weaver
Dr. Ian McKendry	Dr. Paul Whitfield
Dr. Ruping Mo	Edward Wiebe

We also appreciated the invaluable advice, suggestions, and feedback from the reviewers of our first edition of this book. As colleagues who teach introductory meteorology courses at other Canadian universities, their comments have guided our modifications. Thank you,

Phil Graniero, University of Windsor  
 John Maclachlan, McMaster University  
 Mark Moscicki, University of Windsor  
 Gerhard Reuter, University of Alberta  
 Ian B. Strachan, McGill University  
 Jon Warland, University of Guelph  
 John Yackel, University of Calgary

Finally, on a personal note, we thank our family and friends for their patience and support as we were preoccupied with this project.

Peter and Chris Jackson

# VISUAL WALKTHROUGH

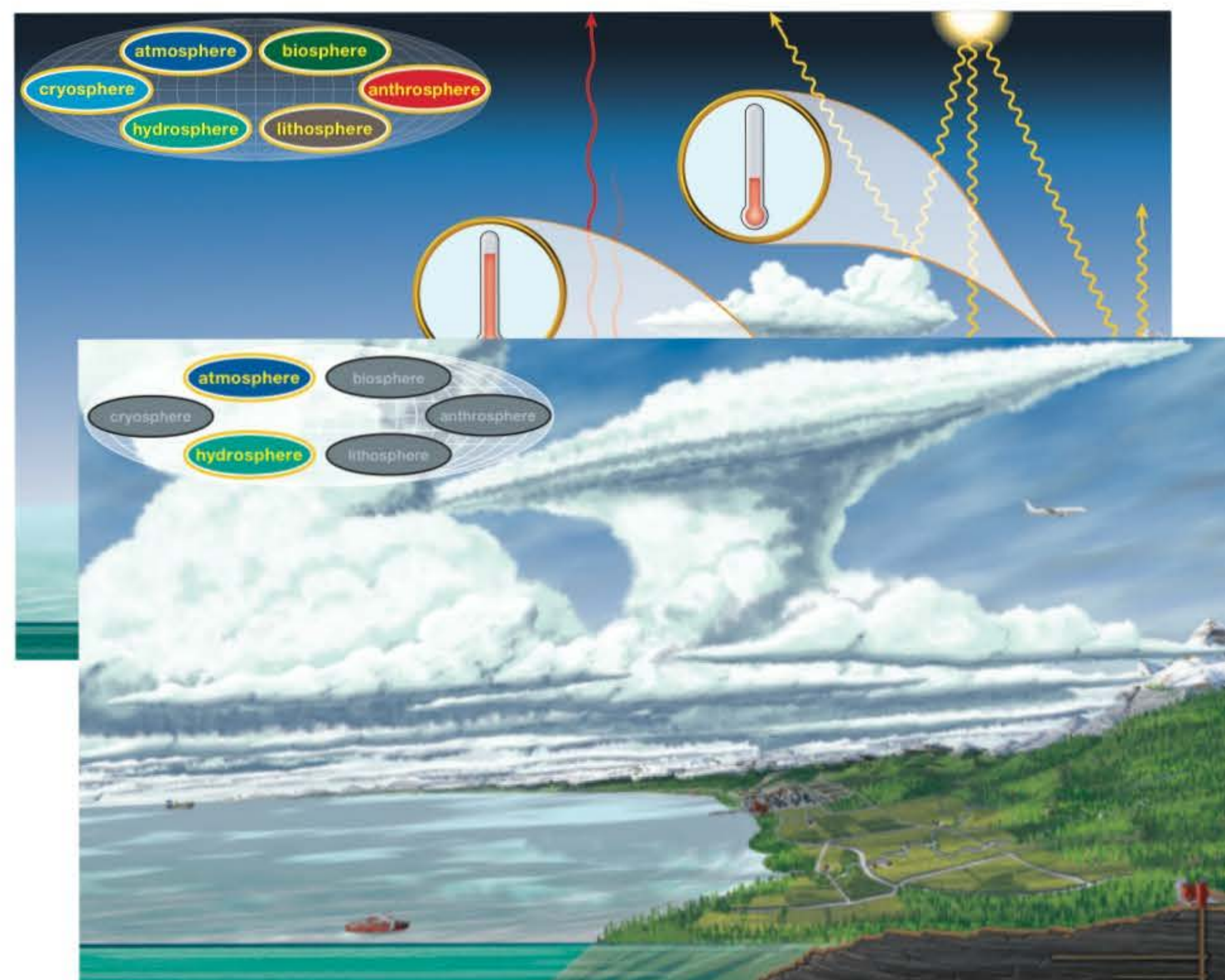
**EARTH SYSTEMS GUIDE** The Canadian edition contains a feature that situates atmospheric phenomena and process in the context of Earth's systems. Chapter phenomena are represented in the image and Earth systems are represented as buttons: the atmosphere, hydrosphere (including the cryosphere), lithosphere, and biosphere (including the anthrosphere). For each chapter, relevant buttons are highlighted and image features are altered to indicate the linkages between the chapter content and Earth systems. The relationships between the chapter content and Earth systems are expanded on in the introductory text. The purpose of this feature is to help readers understand the big picture and how each chapter's content is related to Earth as a whole.

**FOCUS ON** Each chapter contains *Focus On* sections that either extend specific chapter content, or provide more in-depth coverage. More than 80 *Focus On* boxes are spread throughout the book. These are categorized into five different types:

- *Focus on a Special Topic*
- *Focus on an Environmental Issue*
- *Focus on an Observation*
- *Focus on an Advanced Topic*
- *Focus on Social and Economic Impacts*

Twenty-two renowned Canadian scientists were invited to contribute *Focus On* sections on topics of particular relevance to Canadians, such as drought on the Canadian Prairies, East Coast storms, the pineapple express, Southern Alberta's 2013 floods, and changing sea ice in the Arctic and its impacts. Additionally, *Focus on an Advanced Topic* sections provide quantitative discussions of important equations, such as the geostrophic wind equation and the hydrostatic equation, and concepts, such as the tephigram (the thermodynamic chart used in Canada). Other *Focus On* sections explain observation techniques, such as radiosonde measurements, sky colours and what they mean, and how to measure cloud ceilings. Look for these interesting sections that both break up and augment each chapter's content.

**WEATHER WATCH** These mini-boxes appear throughout the book. They provide anecdotes, examples, or unexpected weather facts related to the chapter topic and are included to stimulate reader interest in the content.



## FOCUS ON A SPECIAL TOPIC 3.6 Human Thermal Comfort

Jon Warland  
School of Environmental Sciences,  
University of Guelph

People's sensation of being hot, cold, or comfortable is called their *thermal comfort*. Though this feeling has subjective psychological aspects, discussed more below, it is general closely related to the energy budget of a person. Just as a stone floor may feel colder on

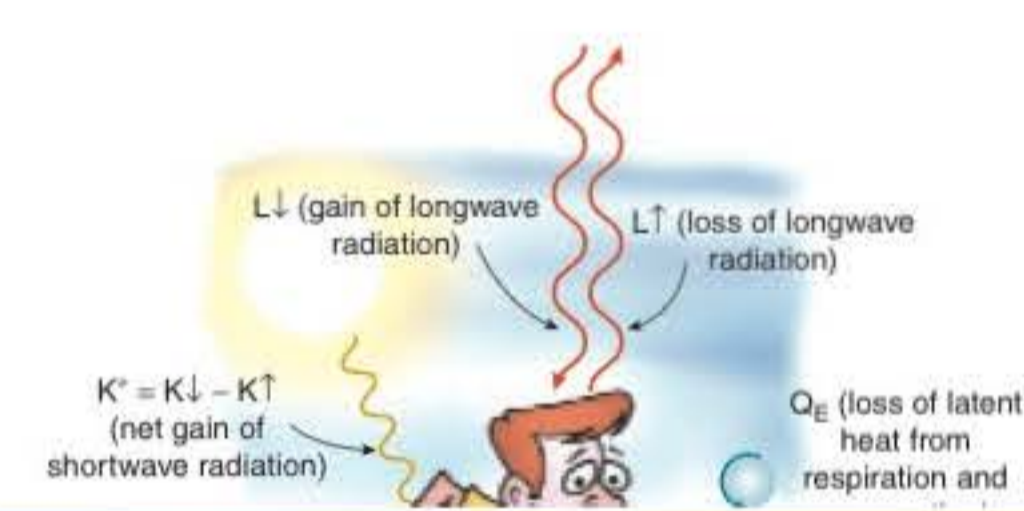


FIGURE 4 The inputs and outputs of energy to a human body.

## FOCUS ON AN OBSERVATION 3.7 The Vancouver Island School-Based Weather Station Network

Edward Wiebe and Andrew Weaver  
School of Earth and Ocean Sciences,  
University of Victoria

Measuring the weather has never been easier. Anyone interested in what the atmosphere is doing outside his or her front door can now easily set up an inexpensive automatic weather station. The simplest of these display observations on a screen indoors. More advanced versions can be connected to a computer so that data can be logged, analyzed, and uploaded to the Internet. Keen amateur weather observers everywhere, as

This idea was the origin of the Vancouver Island School-Based Weather Station Network.

Since 2001 we have installed about 150 weather stations on schools in communities around Vancouver Island, one of which is shown in Figure 5. Most of these are located on the eastern side of the island, but some are located in the west adjacent to the Pacific Ocean. Schools are a good location to install weather stations because they have Internet access and are generally somewhat evenly dispersed throughout neighbourhoods of towns and cities. At some schools, the students really take owner-



## WEATHER WATCH

Talk about an enhanced greenhouse effect! The atmosphere of Venus, which is mostly carbon dioxide, is considerably denser than that of Earth. Consequently, the greenhouse effect on Venus is exceptionally strong, producing a surface air temperature of about 462°C.

## ADDITIONAL LEARNING AIDS

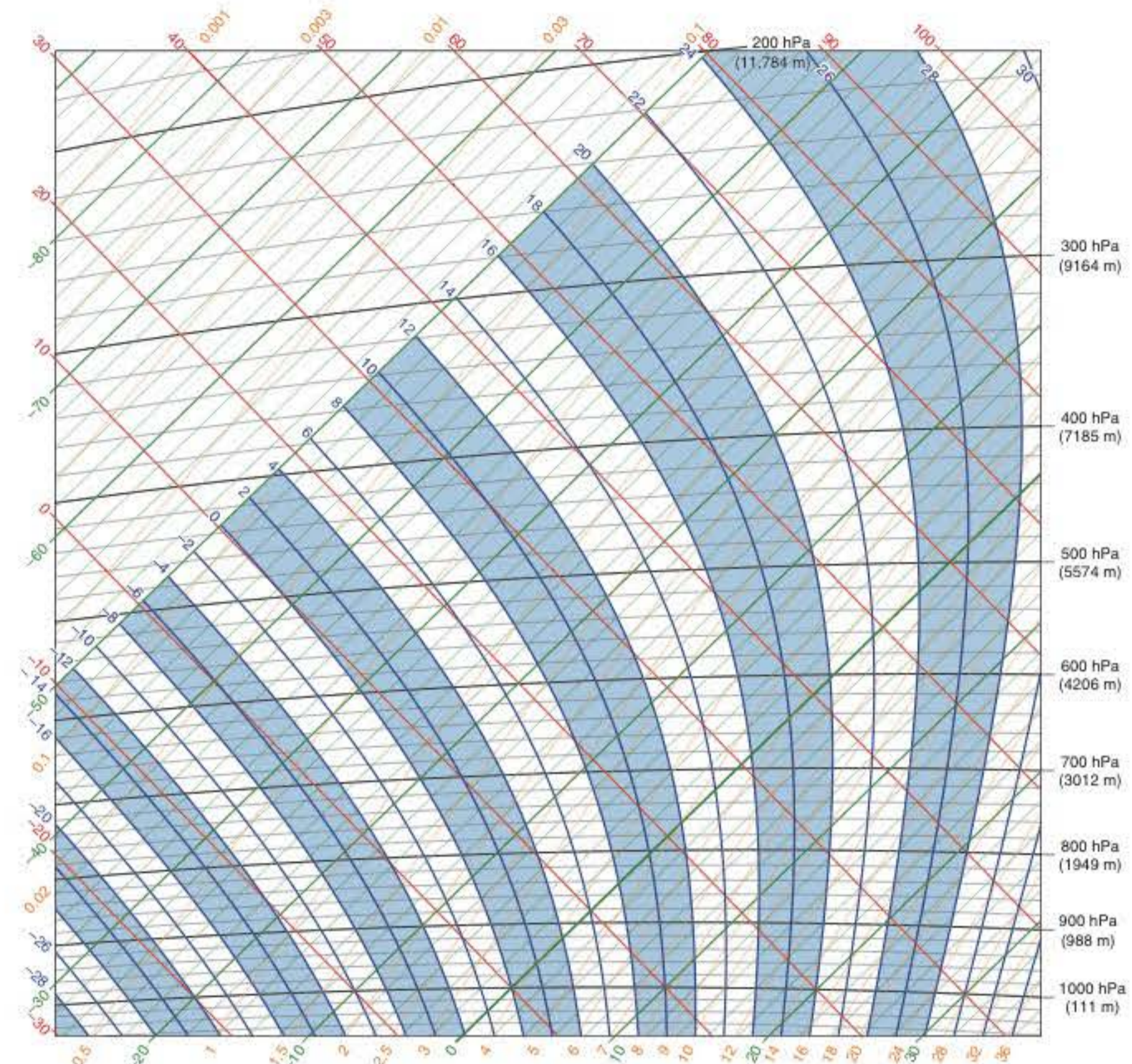
- A short introductory chapter orients readers to the discipline and book features that aid readers in their learning.
- Content-related vignettes at the start of each chapter are designed to pique reader interest and show how chapter contents relate to other aspects of life.
- Key terms are in **bold**. These are repeated in a *Key Terms* list at the end of the chapter and are defined in the *Glossary* at the end of the book.
- Important words and phrases are *italicized*.
- *Brief Reviews* summarize main points and are provided once or twice in each chapter.
- *Summaries* at the end of each chapter review the main ideas.
- End-of-chapter supplemental materials aid students in assimilating content.
- Table and figure references are identified with a specific symbol when first given in the text so that students can easily find their way back to where they were reading after viewing one of these items. Active Figures have accompanying online support material that aid in understanding more complex topics.
- *Appendixes* provide meteorological charts, maps, computational resources, and symbol legends that support text activities and provide useful reference material.

## END-OF-CHAPTER MATERIAL

- *Summaries* at the end of each chapter review the main ideas.
- Three kinds of questions are provided to review and test students' knowledge and as supplements for lab activities:
  - *Questions for Review* act to check how well students have assimilated chapter content.
  - *Questions for Thought* require students to synthesize concepts for deeper understanding.
  - *Problems and Exercises* provide a technical challenge for students through activities or calculations based on chapter content.

## TEXT ENDMATTER

- Seven appendixes contain meteorological tables, charts, maps, definitions, symbols, equations, and constants. Included is a tephigram, the chart used in Canada to assess the vertical structure of the atmosphere.



- A tear-out, laminated, colour *Cloud Chart* is intended for readers to use outside to learn cloud identification.
- A *Glossary* defines key terms used throughout the book.
- A quick-reference map shows North American physiographic features (water bodies, mountain ranges, land surface cover), political boundaries, and place names referred to in the text.



## Instructor Resources



The **Nelson Education Teaching Advantage (NETA)** program delivers research-based instructor resources that promote student engagement and higher-order thinking to enable the success of Canadian students and educators. Visit Nelson Education's **Inspired Instruction** website at <http://www.nelson.com/inspired> to find out more about NETA.

The following instructor resources have been created for *Meteorology Today*, Second Canadian Edition. Access these ultimate tools for customizing lectures and presentations at [www.nelson.com/instructor](http://www.nelson.com/instructor).

**NETA TEST BANK** This resource was written by Mark Mosciki, University of Western Ontario. It includes over 1400 multiple-choice questions written according to NETA guidelines for effective construction and development of higher-order questions. Also included are more than 250 essay questions.



The NETA Test Bank is available in a new, cloud-based platform. **Nelson Testing Powered by Cognero**® is a secure online testing system that allows instructors to author, edit, and manage test bank content from anywhere Internet access is available. No special installations or downloads are needed, and the desktop-inspired interface, with its drop-down menus and familiar, intuitive tools, allows instructors to create and manage tests with ease. Multiple test versions can be created in an instant, and content can be imported or exported into other systems. Tests can be delivered from a learning management system, the classroom, or wherever an instructor chooses. Testing Powered by Cognero for *Meteorology Today* can also be accessed through [www.nelson.com/instructor](http://www.nelson.com/instructor).

**NETA POWERPOINT** Microsoft® PowerPoint® lecture slides for every chapter have been created by Tim Phaneuf, University of Northern British Columbia. There are an average of 43 slides per chapter, many featuring key figures, tables, and photographs from *Meteorology Today*,

Second Canadian Edition. NETA principles of clear design and engaging content have been incorporated throughout, making it simple for instructors to customize the deck for their courses.

**IMAGE LIBRARY** This resource consists of digital copies of figures, short tables, and photographs used in the book. Instructors may use these jpegs to customize the NETA PowerPoint or create their own PowerPoint presentations.

**NETA INSTRUCTOR'S MANUAL** This resource was written by Mark Mosciki, University of Western Ontario. It is organized according to the textbook chapters and addresses key educational concerns, such as typical stumbling blocks student face and how to address them. Other features include a discussion of Earth systems and how the chapter connects to the world of practice, study projects, and multimedia content.

**DAY ONE SLIDES** Day One—Prof InClass is a PowerPoint presentation that instructors can customize to orient students to the class and their text at the beginning of the course.



**MINDTAP** Offering personalized paths of dynamic assignments and applications, **MindTap** is a digital learning solution that turns cookie-cutter into cutting-edge, apathy into engagement, and memorizers into higher-level thinkers. MindTap enables students to analyze and apply chapter concepts within relevant assignments, and allows instructors to measure skills and promote better outcomes with ease. A fully online learning solution, MindTap combines all student learning tools—readings, multimedia, activities, and assessments—into a single Learning Path that guides the student through the curriculum. Instructors personalize the experience by customizing the presentation of these learning tools to their students, even seamlessly introducing their own content into the Learning Path.

Items accompanying this text's MindTap include the following:

- **Videos.** Various videos illustrating weather and climate concepts are provided to engage students in seeing the text concepts come alive.
- **Active Figures.** Scattered throughout the text, select figures are labelled as *Active Figures*. *Active Figures*

are computer animations or visualizations of the figures in this text. By expanding and further illustrating important but difficult concepts presented in the text, these *Active Figures* aid student comprehension. Examples of *Active Figures* include such topics as the Coriolis force, Bergeron process, hail formation, the life cycle of a thunderstorm, and development of a cumulus cloud.

- **Pre- and post-tests** to help students test their mastery of concepts.
- **Test** for assessment, online videos, ebook, and more!

## Student Ancillaries

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- Videos provide additional visual support to concepts in the text.

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Earth's atmosphere: the view from *Apollo 17* as it travels toward the moon on December 7, 1972.  
Image courtesy NASA Johnson Space Center

# INTRODUCTION

*“Climate is what we expect, weather is what we get.”*

—Anonymous

Meteorology is the study of the atmosphere and its phenomena. *Weather* is the condition of the atmosphere at any particular time and place. Weather is always changing. It is composed of *weather elements*, especially *temperature, humidity, pressure, clouds, precipitation, wind, and visibility*. If we measure and observe weather elements over many years, we would obtain the typical weather in an area. In addition, if we track the variability in each weather element, we can define the *climate* of that area.

Weather and climate play major roles in our lives. Weather dictates our choice of clothes for the day, our preparations for outdoor activities, and the success of our crops. Climate, on the other hand, influences the clothing we buy, the activities we enjoy, and the type of crops we plant. Even when we are properly dressed for the weather, wind, humidity, and precipitation change our perception of how warm or cold it feels. On a humid summer day, we feel uncomfortably warm and blame it on the humidity. On a cold, windy day, the effects of wind chill make it feel much colder than it really is. In Canada, talking about the weather is a favourite pastime. You might recognize these regional expressions: *“Snow’s comin’ down like dinner plates,”* or *“How’d you recognize someone from Saskatchewan? They fall over when the wind stops blowing.”* In fact, some scholars consider the weather a part of our national identity and describe us as a nation huddled against the cold.

When the weather turns colder or warmer than normal, it directly affects our lives. Many natural disasters are weather related. Major cold spells accompanied by heavy snow and ice can snarl traffic, curtail airport services, close schools, and down power lines. For example, a huge ice storm in 1998 left millions of people without power for as long as a month. It caused over \$3 billion in damage in Eastern Canada, making it one of Canada’s costliest natural disasters.

Every summer, scorching *heat waves* escalate cooling costs, increase emergency hospital visits, and even cause deaths from heat exhaustion. As in 2015, successive heat waves combined with a lack of precipitation can lead to drought, causing food shortages and global impacts. Between 1999 and 2004, the Canadian Prairies experienced the worst drought in over 100 years, devastating agriculture. In 2002 alone, this drought cost the Canadian economy \$3.6 billion and 41,000 jobs.

The atmosphere is the most dynamic Earth system; a cumulus cloud can develop into a towering thunderstorm and spawn a tornado in just an hour or two. Summertime thunderstorms and tornadoes can have severe impacts. Though not as frequent as in the United States, tornadoes in Canada are dangerous; between 1985 and 1987, they caused 39 deaths. Additionally, cloudbursts from thunderstorms can create flash floods, as well as strong downdrafts that cause damage and down airplanes. Annually, hail destroys crops worth millions of dollars, and lightning kills about seven people in Canada. Canada’s 8000 annual wildfires cause about \$14 billion in losses; lightning starts nearly half of these fires.

Anticipating these many weather-related impacts drives much of the research in meteorology. The atmosphere also has a role in most global environmental issues, such as air pollution, acid rain, ozone depletion, and climate change—defining issues for this century. For these reasons, interest in meteorology continues to grow. So, how did this science begin?

## CONTENTS

A Brief History of Meteorology 4

Earth’s Systems 4

Using This Book to Learn Effectively 5

## A Brief History of Meteorology

The term *meteorology* comes from the Greek word *meteoros*, meaning “high in the air.” It goes back to the Greek philosopher Aristotle, who wrote a book of speculations on nature entitled *Meteorologica* in about 340 BC. Although his ideas were mostly wrong, they persisted for almost 2000 years. Meteorology did not become a true science until the invention of these key weather instruments: the thermometer at the end of the 16th century, the barometer for measuring air pressure in 1643, and the hygrometer for measuring humidity in the late 18th century.

The invention of the telegraph in 1843 made the transmission of weather observations possible. Real-time communication enabled the analysis of the weather that occurred at different places at the same time, providing a regional or *synoptic* view of the current weather. By 1869, improved telegraph communication allowed crude weather maps with lines of equal air pressure to be drawn. Interest in flight, first with balloons and then aircraft, required a better understanding of the weather. Later, two world wars intensified the development of weather technology and knowledge. Around 1920, the concepts of air masses and weather fronts were formulated in Norway. By the 1940s, daily upper-air balloon observations provided a three-dimensional view of the atmosphere, and high-flying

military aircraft discovered the existence of jet streams. After World War II, surplus military radar systems were repurposed to measure precipitation.

Meteorology took another step forward in the 1950s, as rudimentary computers evolved and could solve mathematical equations—including some developed in the 1920s that quantify the behaviour of the atmosphere. Thus, numerical weather prediction was born. In 1960, the first weather satellite was launched, revolutionizing meteorology. For the first time, images of clouds and storms across broad areas could be seen and tracked over time. Both weather satellites and radar allow measurement and understanding of the otherwise inaccessible atmosphere. Continuing developments in remote sensing, computers, and numerical models have made these the fundamental tools for understanding, forecasting, tracking, and communicating weather and climate information.

The field of meteorology has progressed hand in hand with these technological and communication developments. Together, these facilitate the central goal of meteorology: to serve society and enable improved policy, planning, and safety through understanding and predicting the atmosphere. While many advances in meteorology have occurred, many mysteries and interesting problems remain for the next generation of meteorologists.

## Earth’s Systems

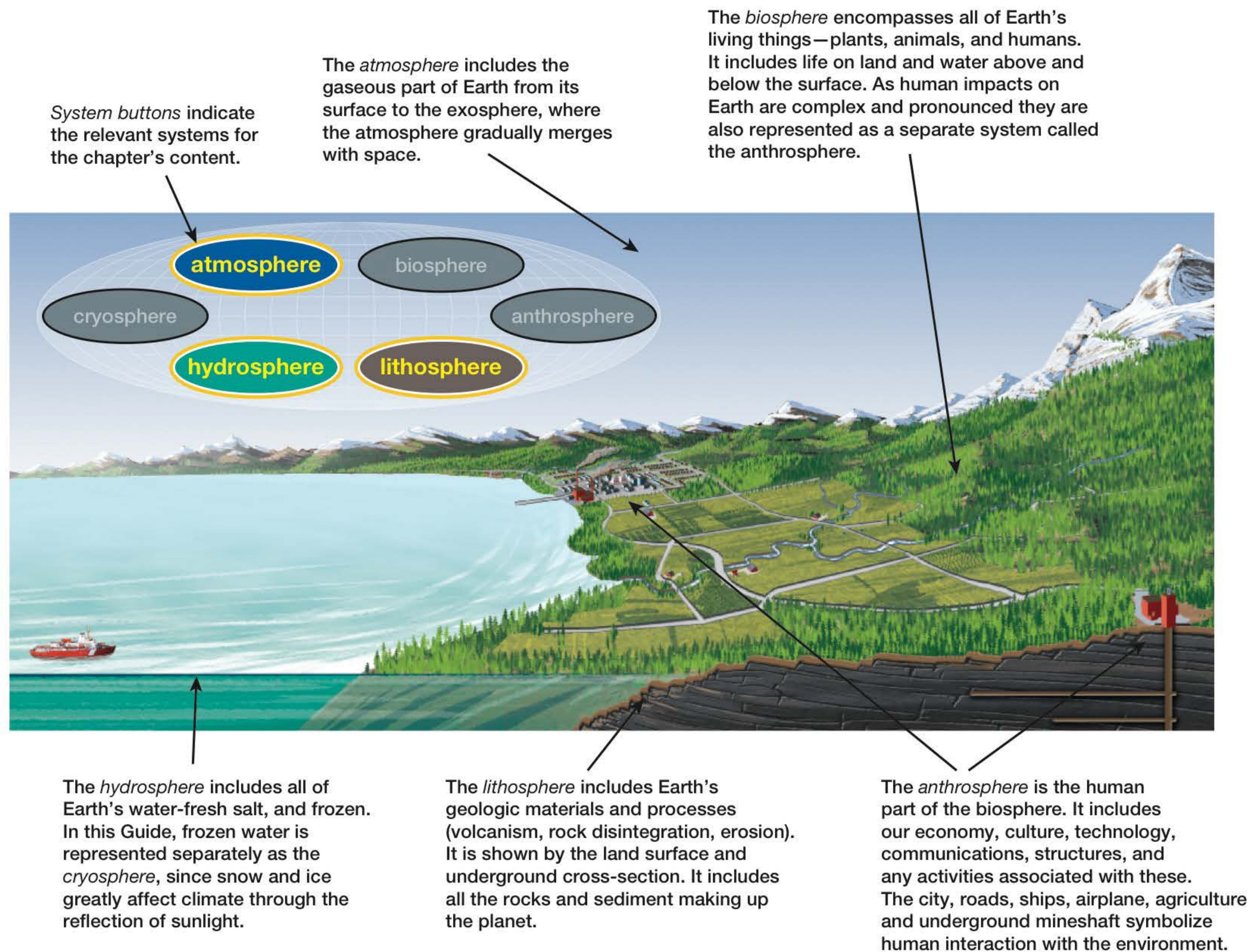
The atmosphere is one of Earth’s interlinked *systems*. Understanding the atmosphere in this context helps us to see the flows of energy and materials that govern how Earth works. First, let’s clarify that a *system* is a set of interacting, interrelated elements that form a complex whole. Systems interact with each other, and system components interact within a system. By explicitly considering the atmospheric system and how it interacts with other Earth systems, we gain a broader understanding of how the atmosphere functions. Consequently, we have created an *Earth Systems Guide* at the beginning of each chapter to graphically show how the chapter contents fit into this framework. Let’s dissect this graphic so that as you read these chapters, you can better use this information.

As shown in the following figure, each Earth Systems Guide is based on the same image, which represents the interacting Earth systems, the *biosphere*, *anthrosphere*, *lithosphere*, *hydrosphere*, *cryosphere*, and *atmosphere*. In each diagram, a set of buttons in the upper-left corner also represents these systems. The buttons are “on”—coloured—when the chapter content is relevant to that system, or “off”—greyed out—when that system isn’t as relevant to the chapter. Additionally, the introductory text in each chapter further explains how the chapter’s topics fit into the Earth Systems framework. Examine ● Figure 0.1 and



©Lindsey Martin

Aurora borealis or northern lights.



● **FIGURE 0.1** Interpreting Earth Systems Guides.

notice how the image represents various components of each system.

As you read each chapter, notice how the Guide is altered to show the connections between the Earth systems and chapter concepts. For instance, ● Figure 0.2 the Chapter 19 Earth Systems Guide, superimposes an example of an atmospheric optical phenomenon—a double rainbow—and has only the atmosphere button coloured. This shows that the chapter's content doesn't relate to interacting Earth systems but is focused on atmospheric phenomena. In other chapters, the content connections to Earth systems are represented by using different graphical techniques and text explanations. Some images change their perspective, so the scene appears closer to the surface or farther in space; others have magnified sections to elaborate on unseen details. Look

for changes to both the *buttons* and the *Earth Systems Guide* image as you read.

## Using This Book to Learn Effectively

A number of features in this book will help you learn more efficiently and effectively. The Student Ancillaries section in the Preface describes how to access digital resources available with this textbook. Visit [www.nelson.com/student](http://www.nelson.com/student) to view these resources, such as quizzes, flashcards, additional video exercises, and more. Especially useful are *Active Figures*, which are linked to animated online resources that are intended to increase your understanding of the concept shown in the image. Active Figures are identified throughout the book.



● **FIGURE 0.2** The Chapter 19 Earth Systems Guide.

Additionally, within the book the following learning features may seem obvious, but they are highlighted so that every reader can benefit from their instructional value. This list follows the order that these features appear in the book.

- **TABLE OF CONTENTS**—lists how information is organized within each chapter and between the chapters of this book. Review this information before reading each chapter. Notice how chapters, headings, and subheadings show the book's framework. Experienced learners use this information to construct their own framework so that content can be related to key concepts in a meaningful way. Main headings are also listed on the opening pages of each chapter.
- **CHAPTER-OPENING VIGNETTE**—links the chapter content to a real-world application or related topical story.
- **EARTH SYSTEMS GUIDE**—visually contextualizes each chapter's content; see the previous section for details.
- **BOLD TEXT**—indicates key words that are explained in the Glossary and listed as Key Terms.
- **ITALICIZED TEXT**—indicates important words or phrases that are not Key Terms.
- **WEATHER WATCH BOXES**—short, interesting facts related to the section's content.
- **FOCUS ON BOXES**—over 80 boxes, of different types, are interspersed throughout the text: Focus on a Special Topic, Focus on an Advanced Topic, Focus on an Observation, Focus on Environmental Issue, and Focus on Social and Economic Impacts. These boxes demonstrate or expand specific chapter content. Twenty were written by renowned Canadian experts who are identified under the title.
- **ACTIVE FIGURES**—animated or interactive online resources; use these to increase your conceptual understanding.
- **BRIEF REVIEWS**—lists that occur once or twice in a chapter and summarize content mid-chapter to keep readers on track. Make Brief Reviews a learning tool by incorporating your own more detailed notes.
- **SUMMARY**—at the end of each chapter, a brief summary recounts the key points. Expand the summaries to create your own detailed study guide for each chapter.
- **KEY TERMS**—are listed at the end of each chapter and track the words indicated in bold text. Include Key Terms as another study tool when reviewing chapter concepts.
- **END-OF-CHAPTER LEARNING MATERIALS**—three types of questions are provided at the end of each chapter to increase your engagement with the chapter content:
  - **QUESTIONS FOR REVIEW** check how well you have assimilated the content.
  - **QUESTIONS FOR THOUGHT** require you to synthesize content for deeper understanding.
  - **PROBLEMS AND EXERCISES** provide more technical challenges through activities or calculations related to the content.
- **APPENDIXES**—contain useful tables, conversions, formulas, charts, symbols and definitions. Appendix titles indicate the content.
- **GLOSSARY**—provides definitions for words in bold font (Key Terms)
- **INDEX**—an alphabetical listing of main concepts or words and their page numbers. Use this tool to find information by topic.
- **PHYSIOGRAPHIC MAP OF NORTH AMERICA**—inside the back cover is a reference map showing topography, land cover, and place names used in the text.
- **CLOUD CHART**—removable and laminated; take this cloud identification tool outside and learn by doing! Start by reviewing the classification diagram. It depicts types of clouds as four major groupings (low, middle, high, and clouds with vertical development). Match the cloud photos to their image in the diagram; then regularly try to recognize the clouds you see. Compare



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Lenticular clouds.

your observations with others? Chapters 5 (clouds), 12 (mid-latitude cyclones), 13 (thunderstorms), and Appendix B (cloud classification) provide even more understanding of how sky conditions relate to weather. Meteorology is a field science based on practised observation. Tracking your observations will give further insights into weather processes and local weather patterns.

This book and its features are designed to guide your personal understanding and appreciation of Earth's dynamic atmosphere. Read the book. Go outside, look at the sky, and question what you see there!