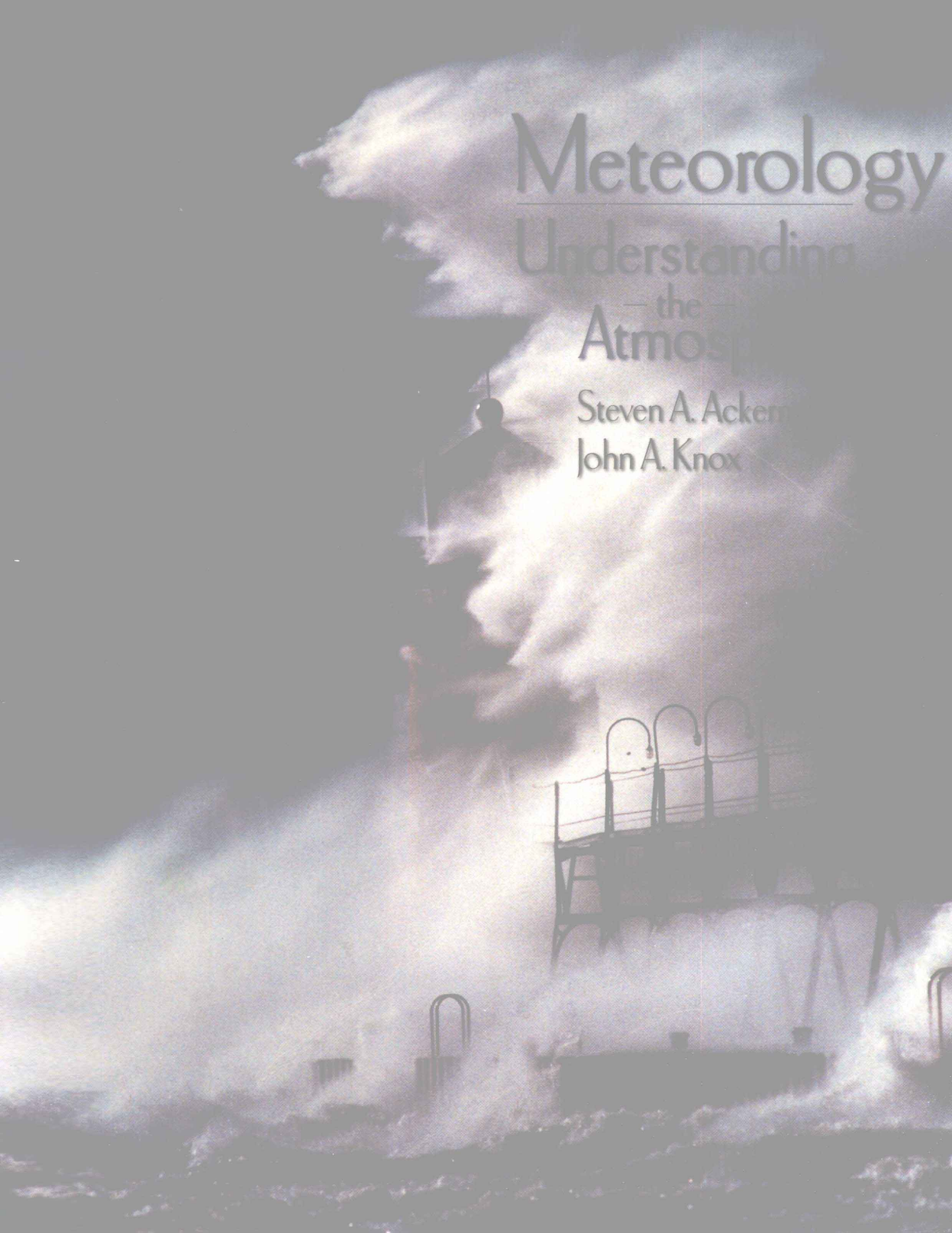
Meteorology

Understanding the Atmosphere

Steven A. Ackerman
John A. Knox



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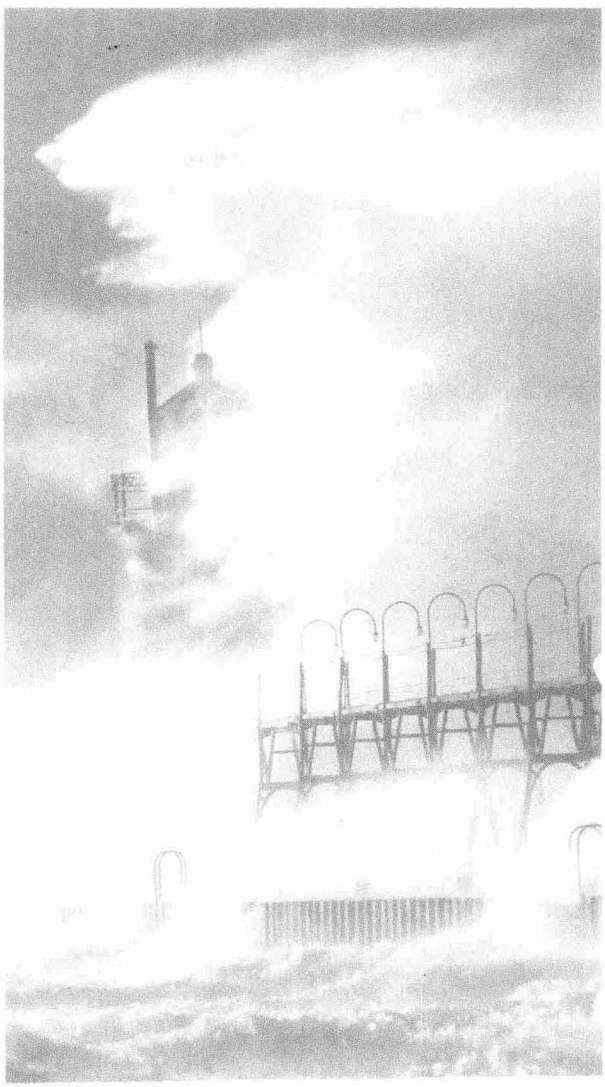

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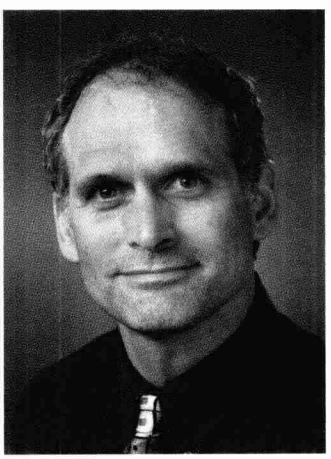
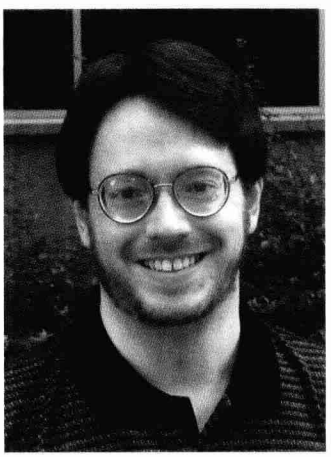


Steven Ackerman is Professor of Atmospheric and Oceanic Sciences at the University of Wisconsin, Madison and is Director of the Cooperative Institute for Meteorological Satellite Studies (CIMSS). He received his B.S. degree in physics from the State University of New York-Oneonta, and his Ph.D. in atmospheric sciences at Colorado State University. Renowned for his ability to inspire active student participation in his classes, Ackerman has won numerous teaching and academic awards, including the Chancellor's Award for Distinguished Teaching (University of Wisconsin). Ackerman is also a member of the University of Wisconsin Teaching Academy. Ackerman's research interests center on understanding how changes in the radiation balance affect and are affected by changes in other climate variables such as clouds, aerosols, water vapor, and surface properties.



John Knox is Associate Research Scientist and Lecturer in the Department of Biological and Agricultural Engineering at the University of Georgia, where he has taught introductory weather and climate, weather analysis and forecasting, and aviation meteorology. He has also taught meteorology at Valparaiso University and Barnard College of Columbia University. A National Science Foundation Graduate Research Fellow and Rhodes Scholar finalist, Knox received his B.S. in mathematics from the University of Alabama at Birmingham and his Ph.D. in atmospheric sciences from the University of Wisconsin, Madison. He was a post-doctoral fellow in climate systems at Columbia University in conjunction with the NASA/Goddard Institute for Space Studies (NASA/GISS) in New York City. At Wisconsin, Knox won the Eberhard Wahl Teaching Award and was a College of Letters and Science Teaching Fellow. He has published journal articles in geoscience education and served on the *Journal of College Science Teaching*'s Board of Advisors. His research in atmospheric dynamics focuses on Rossby waves, nonlinear balance, clear-air turbulence, and cyclone-induced windstorms, and is currently supported by NASA.

To Anne, Erin, and Alana, who are always lovingly patient with my meteorological distractions. I thank my parents and siblings for their good humor.

S.A.A.

To my family, most of all Pam and Evan; to my students; and to the two people who most inspired me to study and teach meteorology: the late Dr. Lyle Horn of the University of Wisconsin and J.B. Elliott of the National Weather Service (Birmingham, retired)

J.A.K.

Preface

To The Student

Weather engulfs us. Its influence can be both dramatic and subtle. Weather tempers how we dress, how we live, the music we play, and the art we create. It can destroy our homes and threaten our lives. It affects our daily activities, leisure, holidays, transportation, commerce, agriculture, and nearly every other aspect of our lives. Our fascination with the weather has led to 24-hour weather networks, feature-length motion pictures, and an explosion of detailed weather data over the Internet.

Mark Twain said, "everyone talks about the weather, but nobody does anything about it." You may not be able to change the weather, but you can discover the processes that determine weather. We think that learning about meteorology can and should be both enjoyable and relevant to your everyday life. Knowledge gained from reading this book can help you better understand nightly television weather reports and interpret news articles on severe weather, impending climate change, greenhouse warming, the depletion of the ozone layer, and the causes and effects of El Niño. You will experience and be influenced by these events throughout your lifetime. *Meteorology: Understanding the Atmosphere* will help you to grasp the fundamentals and gain an appreciation of the complexities involved with these issues.

The World Wide Web has enhanced your opportunity to learn meteorology by applying textbook concepts to real-time weather conditions. A flood of sophisticated weather information that once was restricted to a few scientists is now just a click away on the World Wide Web. *Meteorology: Understanding the Atmosphere* will help you to make sense of the abundant weather information available to you on the Internet, serving as a reference as you investigate current conditions. In addition, dozens of Java applets on our text's Web site will help you understand the material in this book and allow you to explore topics in even greater detail.

Meteorology is a topic that easily generates interest in and an appreciation of a natural science. Our goal in writing this book was to provide you with a perspective on meteorology as a science in which observations play a key role. Thus, we provide many observations, both personal and from scientific instruments, throughout this book along with analysis of those observations. This approach of observing and then analyzing the atmosphere to gain an understanding is a scientific way of thinking, and it is how we, the authors, explore and understand the atmosphere ourselves. We hope that you find this approach exciting and that it inspires you to a lifetime of watching and understanding the weather.

To The Instructor

Meteorology: Understanding the Atmosphere is designed for use in a wide range of college and university introductory courses in meteorology and in weather and climate. This book is written in an interesting and clear manner that allows your students to immediately apply material to the world around them.

Our text emphasizes **observing the atmosphere and using those observations to explain atmospheric phenomena.** Just by paying attention to the weather outside, it is possible for a newcomer to the subject to observe key clues that explain how the atmosphere works. By learning how to interpret scientific observations of the atmosphere, students can deepen their understanding even more. The observations we examine in this text range from those made by students themselves to cutting-edge scientific measurements from radar and from space. Many of the images here have never appeared before in print. Throughout the text, weather phenomena come alive via conceptual models to explain their existence, visualization of their life cycles, and weather safety information to keep weather from becoming a killer.

This book focuses on understanding the basic concepts of meteorology. Most students have a better understanding of the world around them through observations and experiences than through mathematics. For this reason, throughout the text we begin by asking about a weather phenomenon, "what does it look like?" before delving into the theory behind it. Therefore, the book is accessible to those not majoring in geography or meteorology, while still providing detailed mathematics for more advanced students. We employ narratives and metaphors that in some chapters allow us to explore topics more deeply than is done in texts that use extensive mathematics.

Meteorology: Understanding the Atmosphere has several unique features. Weather maps and weather watches and warnings are introduced immediately in Chapter 1 to allow instructors the option of using current weather to explore topics discussed in each chapter. The physics of energy transfer in the atmosphere is presented in an accessible manner to students without a physics background in Chapter 2. These concepts are applied in Chapter 3 to describe observed temperature variations. Chapter 4 on the atmospheric water cycle combines clouds with other water phases. It is a concise and unified treatment of how water circulates through the atmosphere. Chapter 5 is an integrated approach that combines visual observations of the state of the atmosphere, including optics, with explanations of scientific measurements such as satellite imagery. Chapter 6 approaches the usually difficult discussion of forces via the simplifying idea of "balance," which is also how today's researchers make sense of this subject. These ideas are applied worldwide in Chapter 7 in the form of conceptual models of global winds.

The second half of our text examines topics in weather and climate in a variety of innovative ways. Tropical cyclones and El Niño are appropriately covered together in Chapter 8, a unified chapter on atmosphere–ocean interactions that reflects our growing appreciation of how the atmosphere and ocean interact to affect weather and climate. Chapter 9 enlivens the standard discussion of fronts and air masses with apt analogies to regional accents. Chapter 10 is a state-of-the art chapter on extratropical cyclones and anticyclones, presented in the compelling contexts of the stories of the *Edmund Fitzgerald* shipwreck and the John F. Kennedy, Jr., plane crash. Chapter 11 views the life cycles of severe weather from a variety of angles: the ground, the air, Doppler radar, and satellite. Chapter 12 is a comprehensive look at small-scale winds across the United States and the globe. Chapter 13 is the most complete weather forecasting chapter ever written for this level and is made accessible with three narratives illustrating the advances in forecasting during the past century. Chapters 14 and 15 address past climates and climate change as mysteries to be solved, rather than as cataclysmic scenarios. Finally, complex topics,

such as global warming and adiabatic and diabatic temperature changes, are visited throughout the entire textbook.

The instructor-friendly structure of this book is based on our combined teaching experiences at five different universities. For example, Chapter 5 discusses how we observe the atmosphere using both our senses and scientific instruments. The modular structure of this chapter allows this material to be covered all at once or as a function of weather parameter. The tropical cyclone section in Chapter 8 comes early enough in the text that fall-semester instructors may easily cover it during hurricane season. Chapter 10 synthesizes and reinforces the material on forces, air masses and fronts from Chapters 6 and 9. Finally, Chapter 12's modular design allows instructors to cover as much, or as little, of small-scale winds as desired and to focus on a particular geographic region. Throughout the text, intertextual icons indicate related Java applets and Blue Skies exercises that expand your students' abilities to explore these topics beyond the confines of the lecture hall.

Our Web site—http://info.brookscole.com/ackerman—includes over three dozen unique Java applets that have been already acclaimed by the meteorology education community. These learning tools extend the textbook treatment of key topics such as weather map analysis, atmospheric circulation patterns, and numerical models.

Chapter Features

- Outlines and chapter goal lists at the beginning of each chapter
- Introductions focusing on observations of the atmosphere
- Intertextual icons that identify Java applets and Blue Skies exercises relating to material
- Extended boxes delving into advanced and unusual topics in each chapter
- End-of-chapter summaries to review the main ideas presented in the chapter
- A list of key terms at the end of each chapter
- Chapter-ending review questions that integrate chapter materials with the *Blue Skies* CD-ROM and the text's World Wide Web site

Web Features

The accompanying Web site includes over three dozen interactive Java applets that extend the textbook treatment of key topics such as weather map analysis, satellite interpretation, and numerical weather models. These applets are well tested and have received acclaim by the meteorology education community. The Web site also includes animations of weather phenomena and tools for assessing student learning.

Acknowledgments

This book could not have been possible without the efforts of many. Teri Hyde, Keith Dodson, and Nina Horne at Wadsworth and Brooks/Cole deserve special mention for their advice and captaining of the editorial process, which has resulted in a final product we are very proud of. Kim Leistner energized this project during its formative stages. Sam Subity has ably assisted in the development of this text's Web site, a key component of any 21st-century text. Tom Whittaker has created some of the world's best meteorological Java applets—try a few at info.brookscole.com/ackerman. Dick Morel became a special member of this project as a developmental editor and key advisor. Mike Ederer and John Denk at Graphic World Publishing Services shouldered much of the burden of editing and artwork. Terry Powell and her associates at The Photographer's Window dealt with myriad photo searches, and Stephanie Keough-Hedges handled a blizzard of

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CHAPTER

1

Introduction to the Atmosphere

Brief Contents

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