Weather: A Concise Introduction

From a world-renowned team at the Department of Atmospheric Sciences at the University of Washington, Seattle, *Weather: A Concise Introduction* is an accessible and beautifully illustrated text covering the foundations of meteorology in a concise, clear, and engaging manner. Designed to provide students with a strong foundation in the physical, dynamical, and chemical processes taking place in the atmosphere, this introductory textbook will appeal to students with a wide range of mathematical and scientific backgrounds.

This textbook provides a practical approach to the study of meteorology. It features: a single case study of a midlatitude cyclone which is referred to throughout the whole book to illustrate the basic principles driving atmospheric dynamics and phenomena; boxes on more advanced topics; appendices for additional coverage; chapter summaries listing the "take-home" points discussed; and color figures and charts clearly illustrating the fundamental concepts. Key terms are evident throughout, and a glossary explains the terms that students will need to understand and become familiar with.

Gregory J. Hakim has undergraduate degrees in Mathematics and Atmospheric Science and a PhD in Atmospheric Science from the University at Albany, State University of New York. He joined the Department of Atmospheric Sciences at the University of Washington in 1999, where he served as Department Chair from 2012 to 2017 and is currently a Professor. He is also a leading scientist in the areas of weather analysis, predictability, and dynamics, and his research interests include weather and climate prediction, hurricanes, past climates, and polar circulation patterns.

He has served on the advisory panel for the Directorate of Geosciences at the National Science Foundation, as Chair of the advisory panel for the Mesoscale and Microscale Meteorology Laboratory at the National Center for Atmospheric Research (NCAR), as a member of the NCAR Advisory Panel, as a member of the NCAR Strategic Planning Council, and as Chair of the University Corporation for Atmospheric Research's President's Advisory Committee on University Relations.

Jérôme Patoux earned a Master in Environmental Engineering from the University of Texas at Austin and a PhD in Atmospheric Science from the University of Washington. He has been funded by the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the Office of Naval Research (ONR), and the National Oceanic and Atmospheric Administration (NOAA). He has taught undergraduate introductory meteorology for many years, and has been funded by the NSF to develop weather and climate curriculum. He is a former faculty member from the Department of Atmospheric Sciences at the University of Washington, and currently teaches meteorology at the University of Nantes in France.

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GREGORY HAKIM
University of Washington

JÉRÔME PATOUX
University of Washington

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Preface

Having taught introductory classes on weather many times, we came to see the need for a textbook on the subject that covers the foundations of meteorology in a concise, clear, and engaging manner. We set out to create an informative, cost-effective text that meets the needs of students who may not have any background in mathematics and science. The result – *Weather: A Concise Introduction* – is an introductory meteorology textbook designed from scratch to provide students with a strong foundation in the physical, dynamical, and chemical processes taking place in the atmosphere.

This textbook is unique in that it:

- provides a concise and practical approach to understanding the atmosphere;
- introduces the basic physical laws early on and then ties them together with a single case study spanning the book;
- presents weather analysis tools early in the book to allow instructors to engage in discussions of current weather in tandem with the basic concepts, thus attracting and retaining student interest; and
- facilitates students' learning and understanding of the fundamental aspects of weather analysis and forecasting, as well as practical skills, through a careful description of the forecasting process. Modern methods, such as ensemble forecasting, are central to the approach.

Features

Case Study: February 2014 Cyclone

The main concepts of the book are illustrated in Chapters 2–13 by a single case study: a midlatitude cyclone that swept through the eastern half of the USA between February 19 and 22, 2014. This rich case study serves as a common thread throughout the book, allowing students to study it from multiple perspectives. Viewing the storm in the context of different topics provides a familiar setting for mastering new subjects and for developing an holistic understanding of midlatitude cyclones.

Boxes on More Advanced Topics

Instructors have the option of including more advanced coverage through use of boxes that provide insights on various topics. For example, in Chapter 1, Weather Variables, boxes include an in-depth description of the four laws of physics that are central to the study of the atmosphere. The book contains 25 boxes, affording instructors the opportunity to tailor the level of the material that they present to students in their course.

Appendixes for Additional Coverage

Appendixes at the ends of Chapters 2, 3, 6, 7, and 10 include additional material on important cloud signatures found in satellite imagery, the concept of dynamic equilibrium, the cloud classification, some optical phenomena, southern hemisphere midlatitude cyclones, and the Bergen School of meteorology.

Summary

A summary of key points has been included at the end of each chapter so that students can, at a glance, confirm that they have understood the significant takeaway facts and ideas.

Figures, Charts, and Maps

Figures have been designed to convey the key concepts in a simple and self-explanatory way, keeping in mind that clean representations of information are more helpful to students than complex drawings. Graphs and maps have been created with real data as much as possible, obtained from NOAA, NASA, ECMWF, and similar research-quality sources referenced in the text.

Key Terms and Glossary

The main text contains terms (in bold) that students need to understand and become familiar with. Many of these terms are listed in the Glossary at the back of the book. The Glossary allows the reader to look up terms easily whenever needed and can also be used to review important topics and key facts.

SI Units

We have consistently used SI units throughout the book, while providing alternative units whenever possible or relevant.

Organization

The first two chapters provide a general overview of key variables and weather maps used by meteorologists, which facilitates daily weather map discussions early in the course. We have found that motivating lecture topics with real-time examples using weather map discussions is a very effective way to engage students in the lecture material, and it allows instructors to introduce aspects of weather forecasting at their discretion well in advance of discussing the material more completely in Chapter 13. As a result, students are more invested in adding to their knowledge, which builds systematically toward understanding and predicting weather systems.

Chapters 3–8 provide foundational material on the composition and structure of the atmosphere, along with the application of the laws of classical physics to emphasize and explain the role of energy, water, and wind in weather systems.

Chapters 9–12 apply the foundational material to understanding the general circulation of the atmosphere (Chapter 9), midlatitude cyclones and fronts (Chapter 10), thunderstorms (Chapter 11), and tropical cyclones (Chapter 12).

Chapters 13–15 build further on the first twelve chapters by applying the concepts developed to explain processes that affect how weather forecasts are made (Chapter 13), air pollution (Chapter 14), and climate change (Chapter 15).

Instructor Resources

A companion website at www.cambridge.org/weather contains PowerPoint slides of the figures in the text as well as a testbank of questions.

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This project would not have come to life without the support, help, influence, and constructive criticism from many fellow professors, teaching assistants, and students. We cannot acknowledge them all here by name, but we thank them nevertheless for the important role they have played in shaping the development of this book.

Introduction

Why should we study our atmosphere? Why should we learn about the causes and mechanisms of our weather? Weather affects our daily life: the clothes we wear (rain coat, shorts, hat, should we take an umbrella or sunglasses...?), the means of transportation we choose (walk, take a bus, ride our bike...?), our activities (ski, sail, water our plants, read a book in a coffee shop...?), and probably more. But beyond our daily concerns, weather affects society at large. Schools close when snow impedes traffic. Visitors to ski resorts might be more impatient for snow, while the ski instructors will be keeping an eye on the possibility of avalanches. Rangers are concerned with fog, thunderstorms, and flash floods. Fire patrols look for weather patterns that are conducive to forest fires (dryness, wind). Electricity providers are concerned by wind storms that can damage the infrastructure of the electrical grid and, on larger timescales, also need to plan how weather will affect upcoming energy needs (minimum temperatures impact heating, while maximum temperatures impact air-conditioning). Weather averages, such as prevailing winds, the typical temperature range, and mean precipitation determine how we build our homes and what locations are sensitive to extreme events, such as droughts, floods, hurricanes, tornadoes, etc. On longer timescales, we can ask how humans are changing the atmosphere, and what those changes imply for the weather and climate of the future.

To start answering those questions, we need to understand how the atmosphere works. We need to identify the basic processes that drive the atmosphere, and the laws that govern atmospheric processes. By doing so, we will be able to explain the weather phenomena we experience around the year and throughout the world. Furthermore, we will also be able to apply these laws to the current state of the atmosphere, and *predict* how it will evolve in the future.

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There is a lot of value in becoming a knowledgeable observer of the atmosphere. After reading this book, you will look at the sky differently, you will gain an understanding of weather and climate that will make you more attentive to the world around you. You will have a basic understanding of weather phenomena, of cyclones, thunderstorms, and hurricanes, and you will understand the basic aspects of weather forecasting. You will see beyond the weather forecast you get on your phone, radio, TV, or the internet, and you will be able to make your own forecast in many situations.

Weather and Climate

Before we continue, let us clarify an important distinction between weather and climate. **Weather** is the *condition of the atmosphere at a particular time and location*. Weather varies on timescales of minutes to days. **Climate**, by contrast, is an *average of the weather*. It varies on timescales of decades to centuries and beyond. In this textbook, we will be mostly concerned with weather – even though many of the concepts have direct application to climate.

Getting Started

Our exploration of weather will start with a quick overview of important weather elements that we can observe or measure, and analyze. The choice of variables to observe is influenced by the laws of physics that govern the atmosphere. As we will see shortly, the atmosphere is made of *matter* (air and water etc.), it contains *energy* (heat), and it is in *motion* (wind, convection). Our understanding of weather is based on the fundamental notion that matter, energy, and motion obey *conservation laws*. To apply these conservation laws to the atmosphere requires observations of temperature (conservation of energy), pressure (conservation of mass), wind (conservation of momentum), along with humidity, precipitation, and clouds. One step at a time, and one building block over another, we will then investigate the physical processes that underlie the atmosphere at work. Finally, we will articulate these processes together to build a picture of weather systems such as midlatitude cyclones, thunderstorms, and hurricanes. In doing so, we will follow the precepts of René Descartes, who advocated, as early as 1637, that every difficult problem should be divided into small parts, and that one should always proceed from the more simple to the more complex. This cornerstone of the scientific method, still in favor today, will be an important aspect of our exploration as we elaborate a thorough understanding of the atmosphere from its most fundamental constituents at the molecular scale to its most complex inner workings as a system for moving heat at the global scale.