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978-0-521-80875-0 - Mesoscale Dynamics
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MESOSCALE DYNAMICS

Mesoscale weather systems are responsible for numerous natural disasters, such as damaging winds, blizzards, and flash flooding. A fundamental understanding of the underlying dynamics involved in these weather systems is essential in forecasting their occurrence. This book provides a systematic approach to this subject, and covers a more complete spectrum of mesoscale dynamics than other texts.

The opening chapters introduce the basic equations governing mesoscale weather systems and their approximations. The subsequent chapters cover four major areas of mesoscale dynamics: wave dynamics, moist convection, front dynamics, and mesoscale modeling. Wave dynamics covers wave generation and maintenance, orographically forced flow, and thermally forced flow. The moist convection part covers mesoscale instabilities, isolated storms, mesoscale convective systems, orographic precipitation, and introduces tropical cyclone dynamics. The dynamics of synoptic-scale fronts, mesoscale fronts, and jet streaks are discussed in the front dynamics part. The last part of the book introduces basic numerical modeling techniques, parameterizations of major physical processes, and the foundation for mesoscale numerical weather prediction.

Mesoscale Dynamics is an ideal reference on this topic for researchers in meteorology and atmospheric science. This book could also serve as a textbook for graduate students, and it contains over 100 problems, with password-protected solutions available to instructors at www.cambridge.org/9780521808750. Modeling projects, providing hands-on practice for building simple models of stratified fluid flow from a one-dimensional advection equation, are also described.

YUH-LANG LIN's research in mesoscale dynamics and modeling includes moist convection, orographic effects on airflow and weather systems, gravity waves, tropical, lee and coastal cyclogeneses, storm dynamics, wake vortex, aviation turbulence, forest fire, and modeling of the Martian atmosphere.

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Preface

Mesoscale weather systems, such as thunderstorms, mesoscale convective systems, supercells, fronts, jet streaks, gravity waves, severe downslope winds, low-level jets, sea breezes, heat island circulations, and clear air turbulence, are responsible for numerous natural disasters, such as blizzards, torrential rain, flash flooding, damaging winds, and aviation accidents. Thus, a fundamental understanding of their underlying dynamics, the mesoscale dynamics, is essential to help forecast their occurrence. Although textbooks are available in individual subdisciplines such as cloud dynamics, storm dynamics, convection, and synoptic-dynamic meteorology, there are no textbooks which take a systematic approach and cover a more complete spectrum of the mesoscale dynamics. In particular, due to the rapid advancements in research in the past three decades or so, there is a need for a mesoscale dynamics textbook.

The text is presented in four parts: wave dynamics, moist convection, front dynamics, and mesoscale modeling. There are no clear boundaries among these parts. In the opening chapters, the basic equations governing mesoscale weather systems and their approximations are introduced. The wave dynamics include wave generation and maintenance, orographically forced flow, and thermally forced flow. The moist convection part includes mesoscale instabilities, isolated storms, mesoscale convective systems, and orographic precipitation. Traditionally, tropical cyclones are not viewed as a mesoscale phenomenon due to the wide range of scales involved in their genesis, movement, circulations, and convective systems. However, we may also view a hurricane or typhoon as an intense, rotating convective system once it has formed. Thus, for completeness, tropical cyclone dynamics are briefly introduced in the moist convection part of the text. The front dynamics covers dynamics of large scale fronts, mesoscale fronts, and jet streaks.

The last part of the text is devoted to the introduction of mesoscale modeling and the foundation for mesoscale numerical weather prediction. Since the 1970s, numerical models have become an important tool for studying mesoscale weather systems, thus making it essential to understand the fundamental properties of numerical models. In this part of the text, we briefly introduce the basic knowledge on numerical

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modeling techniques and parameterizations of major physical processes such as planetary boundary layer, cumulus convection, microphysical processes, and radiative transfer. This part of the text is not intended to replace advanced textbooks in mesoscale meteorological modeling or numerical weather prediction, but will instead provide the basic knowledge and background so that the readers have a better understanding of numerical schemes when they choose to use models to investigate mesoscale weather phenomena, rather than using a numerical model as a black box. The modeling exercise provides a hands-on practice for building a simple model of stratified fluid flow from a one-dimensional advection equation, two-dimensional shallow-water model, and three-dimensional shallow-water model.

This textbook is based on two graduate courses, mesoscale dynamics and mesoscale modeling, taught by the author at the Department of Marine, Earth, and Atmospheric Sciences of the North Carolina State University since 1987. It is designed for a two-semester course in mesoscale dynamics at graduate level. It may also be used for a one-semester graduate course focused on mesoscale wave dynamics by using material from Chapters 1 through 7, on moist convection and front dynamics by using material from Chapters 1 through 3 and Chapters 8 through 11, or on mesoscale modeling by using material from Chapters 1 through 3 and Chapters 12 through 14. I have assumed that students should have a fundamental understanding of basic dynamic meteorology or geophysical fluid dynamics. Although I have attempted to provide as many references as possible, there are still many papers that have been left out of the text. The webpage at: http://www.cambridge.org/9780521808750 will be used by the author to communicate with the readers.

I would like to acknowledge Professor Ron Smith for introducing mountain meteorology and relevant mesoscale dynamics to me when I was a Ph.D. student at Yale University. Also, I would like to acknowledge Professor Harry Orville at the South Dakota School of Mines and Technology for teaching me cloud modeling and dynamics and getting me involved in the development of a microphysical parameterization scheme (LFO scheme) which was later adopted as a major scheme in cloud, mesoscale, and numerical weather prediction models. I also benefited from attending the 1982 summer school on mesoscale meteorology in France (sponsored by NATO), where I learned a wide range of mesoscale meteorology from lecturers and fellow attendees. I would also like to extend thanks to the students in my mesoscale dynamics and mesoscale modeling/numerical weather prediction classes in North Carolina State University, especially Hye-Yeong Chun, Ron Weglarz, Mike Kiefer, Heather Reeves, Paul Suffern, Chad Ringley, Chenjie Huang, Dave Vollmer, Kelly Mahoney, Karl Pfeiffer, and Sen Chiao, who have contributed useful suggestions in the text and exercises that have improved the quality of the book. I am indebted to all of my colleagues who have made thorough reviews and comments on the manuscript of the book, which has greatly improved the quality of the text and are highly appreciated. These include Shu-Hua Chen, Min-Dah Chou, Jay Charney, Hye-Yeong Chun, Ching-Yuang Huang, Jerry Janowitz, Mike Kaplan, Steve Koch, Gary Lackmann,

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Hsin-Mu Lin, Matt Parker, Rich Rotunno, Dave Schultz, Roger Smith, Wen-Yih Sun, Miguel Teixeira, Si-Chee Tsay, Ken Waight, Ron Weglarz, Chun-Chieh Wu, Qin Xu, Ming Xue, Ming-Jen Yang, Sandra Yuter and Fuqing Zhang. I would also like to thank Robert Mera, Michelle Lin, and Ron Weglarz for their technical editing of the manuscript and Ya-Hui Lin for her skillful drafting of the figures and patience in doing so. Jessica Lin has also assisted the drafting of the figures. The detailed copy-editing by Jon Billam is appreciated. Parts of the book reflect my own research on mesoscale dynamics and modeling, which has been sponsored by the National Science Foundation, National Aeronautics and Space Administration, Office of Naval Research, Air Force Research Laboratory, Forest Service Office of Air Force Scientific Research, and National Oceanic and Atmospheric Administration.

Finally, the encouragement, support, and love from my wife, Emily, and my daughters, Michelle and Jessica, have made it easier to go through the long writing process. I would like to dedicate this book to them.

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