CLOUD AND PRECIPITATION MICROPHYSICS – PRINCIPLES AND PARAMETERIZATIONS

Numerous studies have demonstrated that cloud and precipitation parameterizations are essential components for accurate numerical weather prediction and research models on all scales, including the cloud scale, mesoscale, synoptic scale, and global climate scale.

This book focuses primarily on bin and bulk parameterizations for the prediction of cloud and precipitation at various scales. It provides a background to the fundamental principles of parameterization physics, including processes involved in the production of clouds, ice particles, rain, snow crystals, snow aggregates, frozen drops, graupels and hail. It presents complete derivations of the various processes, allowing readers to build parameterization packages, with varying levels of complexity based on information in this book. Architectures for a range of dynamical models are also given, in which parameterizations form a significant tool for investigating large non-linear numerical systems. Model codes are available online at www.cambridge.org/straka.

Written for researchers and advanced students of cloud and precipitation microphysics, this book is also a valuable reference for all atmospheric scientists involved in models of numerical weather prediction.

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Principles and Parameterizations

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This book is specially dedicated to Katharine, Karen, and Michael

"All men dream, but not equally. Those who dream by night in the dusty recesses of their minds wake in the day to find that it was vanity; but dreamers of the day are dangerous men, for they may act their dream with open eyes, to make it possible. This I did."

Seven Pillars of Wisdom (A Triumph) by T. E. Lawrence

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Preface

Through the experience of the author and his interaction with others that teach cloud and precipitation physics at the University of Oklahoma over the course of at least the past 17 years, it became apparent that there were no current reference books or textbooks on the specific topic of the principles of parameterization of cloud and precipitation microphysical processes. This is despite the knowledge that the research community in numerical simulation models of clouds regularly uses microphysical parameterizations. Moreover, the operational community would find that numerical weather prediction models are not possible without microphysical parameterizations. Therefore, it is hoped that this book will be one that begins to fill this niche and provides a reference for the research and operational communities, as well as a textbook for upper-level graduate students.

Researchers and students should have a prerequisite of a basic graduate-level course in cloud and precipitation physics before using this book, though every effort has been made to make the book as self-contained as possible. The book provides a single source for a combination of the principles and parameterizations, where possible, of cloud and precipitation microphysics. It is not intended to be a comprehensive text on microphysical principles in the spirit of Pruppacher and Klett's book *Microphysics of Clouds and Precipitation*. Not every existing parameterization available is included in the book, as this would be an overwhelmingly daunting task, though every effort has been made to include the more common and modern parameterizations. There are some elegant, modern parameterizations that are not covered, though the reader will find references to them. Some simpler early parameterizations such as those used in one-moment parameterizations (mixing ratio of vapor or hydrometeor) are omitted for practical reasons, and because these are quickly becoming outdated. Some operational numerical weather-prediction modelers cling to these simpler microphysics parameterizations as their mainstay owing to their low memory overhead,

and computational cost. Furthermore, an appendix of symbols was deemed to be essentially impossible to make user-friendly, as characters and symbols are recycled time and time again throughout the literature, and thus, they are recycled in this book. Admittedly, this is unfortunate for the reader. Hopefully variables are defined in enough detail where used so that what they represent can be easily understood. Enough material is presented for readers to make educated choices about the types of parameterizations they might find necessary for their work or interest. Every attempt has been made to include state-of-the-art science on the topic by drawing heavily from the peer-reviewed literature. Each chapter covers specific microphysical processes, and includes many theoretical principles on which the parameterization designs are based, where such principles exist. It should be interesting to the reader just how ad hoc some parameterizations actually are in reality and how poorly or well some of them perform.

Gratitude is extended to the publishers who have granted permission for the reproduction of figures throughout the text. Some of my own research is included in the book, and for the support of this work as well as time spent on this book, I acknowledge the National Science Foundation in the USA. First and foremost, however, this book would not have at all been possible without the contribution of various derivations and the often tedious and repeated editing provided by my wife and colleague, Dr. Katharine M. Kanak. Next I would like to thank Dr. Robert Ballentine for trusting in me as an undergraduate and graduate student and teaching me the finer points of numerical modeling. I also would like to thank my Ph.D. Advisor, Professor Pao K. Wang for stimulating my initial interest in cloud and precipitation physics, and in particular research on hail initiation and growth. In addition I extend a special thanks to Drs. Matthew Gilmore, Erik Rasmussen, Alan Shapiro, and Ted Mansell for many stimulating conversations about microphysics parameterizations, along with many others, too numerous to list, with whom I had various degrees of complex discussions on the principles and parameterizations presented in this book.

Special thanks are owed to Cambridge University Press Syndicate, and especially Dr. Susan Francis, Commissioning Editor, Earth and Planetary Science, for her guidance, assistance, and opinions in the production and the publication of this book. Diya Gupta, the assistant editor, was invaluable for guidance and help. Eleanor Collins, Production Editor, and Zoë Lewin, Copy Editor, were a pleasure to work with and helped tremendously with getting the book in its present form.

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