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Wayne K. Hocking , Jürgen Röttger , Robert D. Palmer , Toru Sato , Phillip B. Chilson
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Atmospheric Radar

Richly illustrated, and including both an extensive bibliography and index, this indispensable guide brings together the theory, design, and application of atmospheric radar. It explains the basic thermodynamics and dynamics of the troposphere, stratosphere, and mesosphere, and discusses the physical and engineering principles behind one of the key tools used to study these regions – MST radars. Key topics covered include antennas, signal propagation, and signal processing techniques. A wide range of practical applications is discussed, including the use of atmospheric radar to study wind profiles, tropospheric temperature, and gravity waves. A detailed overview of radar designs provides a wealth of knowledge and tools, providing readers with a strong basis for building their own instruments. This is an essential resource for graduate students and researchers working in the areas of radar engineering, remote sensing, meteorology, and atmospheric physics, as well as for practitioners in the radar industry.

Wayne K. Hocking is a Professor of Physics at the University of Western Ontario and a Fellow of the Royal Society of Canada and of the Australian Institute of Physics. He has built over 40 radars world-wide and edited multiple special issues of journals. He is the recipient of the Medal for Outstanding Achievement in Industrial/Applied Physics from the Canadian Association of Physicists and the Pawsey Medal from the Australian Academy of Science. He has also received a citation from NASA for his work on the Space Shuttle re-entry environment.

Jürgen Röttger is a Fellow of the Royal Astronomical Society and holds the Minerva Medal of the Max Planck Society. He has also held the position of Chair Professor at National Central University. In the 1970s he was a leading developer of the SOUSY radar. In 1985 he headed atmospheric sciences at the Arecibo Observatory, and from 1986–1997 was the Director of EISCAT, where he was awarded the EISCAT Beynon Medal for his role in the development of the EISCAT Svalbard radar. He also led the design of the Chung-Li MST radar in Taiwan.

Robert D. Palmer is the Executive Director of the Advanced Radar Research Center and the Craighead Chair in the School of Meteorology at the University of Oklahoma. He also serves as the University's Associate Vice President for Research. He has published widely in the area of radar sensing of the atmosphere, with an emphasis on imaging problems, waveform design, clutter mitigation, and the application of array/signal processing techniques to observations of both the clear-air environment and severe weather. Professor Palmer is a Fellow of the American Meteorological Society.

Toru Sato is a Professor in the Graduate School of Informatics at Kyoto University. He has been engaged in data analysis of Jicamarca and Arecibo radars, and has contributed to the design and operation of Japanese MST/IS radars, notably the MU radar, Equatorial Atmosphere radar, and PANSY radar. He has published more than 160 journal papers, and in 2015 received the Commendation for Contributors to Promotion of an Oceanic State from the Prime Minister of Japan.

Phillip B. Chilson is a Professor in the School of Meteorology at the University of Oklahoma and a member of the University's Advanced Radar Research Center. He has been involved in atmospheric radar research and development for over 25 years and has helped to develop many advanced radar signal processing tools. Professor Chilson has previously held positions at the Max Planck Institute for Astronomy, the Swedish Institute of Space Physics, and the University of Colorado in Boulder.

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Application and Science of MST Radars in the Earth's Mesosphere, Stratosphere, Troposphere, and Weakly Ionized Regions

WAYNE K. HOCKING
University of Western Ontario

JÜRGEN RÖTTGER
Max Planck Institute for Solar System Research

ROBERT D. PALMER
University of Oklahoma

TORU SATO
Kyoto University

PHILLIP B. CHILSON
University of Oklahoma

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Preface

This book is about designing, building, and using atmospheric radars. Of course the term "atmospheric radar" covers a wide and diverse set of instruments, which can be used to study a wide range of atmospheric phenomena, and we cannot cover all radar types nor all applications. However, radars used for MST (Mesosphere-Stratosphere-Troposphere) studies employ a very high percentage of the techniques used in atmospheric studies, and cover an extraordinary range of physical processes. Therefore we have chosen this field as our focus. A reader familiar with this book should not only have developed a broad comprehension of the MST region, but should be able to diversify easily to other fields of atmospheric radar work.

While the primary targets of this book are new and advanced graduate science and engineering students working with radar to study the atmosphere, we have also aimed to make it accessible and useful to a wider audience. The extensive references and diagrams should make it valuable as a general reference resource even for more experienced workers in the field. The level of difficulty in each chapter has been adapted to suit the standards of a student with a modest background in mathematics and signal-processing. Some level of understanding of Fourier methods, including Fourier integrals, is desirable, although not mandatory. Nevertheless, some of the chapters are pitched at a level which could be followed even by an interested amateur. Chapter 2, for example, gives a moderately detailed history of the development of atmospheric radar, examining the development of experimental radio applications for both meteorology and world-wide communication following World War II, and would be of interest to, and easily comprehenced by, an enthusiastic radar hobbyist or history buff. Yet the detail on scatter processes in Chapter 3 in regard to the refractive index of the atmosphere and ionosphere should be enough to satisfy more discerning tastes in mathematical complexity.

The layout of the chapters has been carefully developed, mixing the areas of technical detail and practical application in a way that we hope will keep the reader stimulated as we develop parallel themes of radar engineering, experimental design, application and understanding of meteorological/atmospheric physics and chemistry.

We begin with an overview of the atmosphere which can easily be comprehended by a reader with no knowledge at all of radar. We place the region of interest in context by considering it as part of the larger atmospheric picture, even spending a little time discussing the magnetosphere and outer ionosphere, the chemical and ion composition of the ionosphere and upper atmosphere, and the processes of atmospheric heating.

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We then focus in on the middle atmosphere, giving a moderately detailed discussion of the large-scale dynamical circulation of that region which could be of value even to a student of meteorology and atmospheric physics with little interest in radar. Chapter 2 then changes to the quite separate topic of the history of atmospheric radar, which has a fascinating chronology all of its own. Chapter 3 pertains to the refractive index of the atmosphere, and therefore to the fundamental mechanism that causes the radar backscattered signal. The chapter is mathematically complex but of use to a general student of optics and electromagnetic theory, and could be used as the basis of a small independent course on essential radio-optics and plasma processes.

At this point, we had two choices. One option was to further develop Chapter 1, and discuss the basic physics and fluid dynamics of the atmosphere, so that the reader could have a good background of the topics that can be studied with an atmospheric radar. With this strategy, discussions about radar techniques would be left till later. The alternative was to now launch into discussions of radar techniques, even though the applicable atmospheric physics was a little under-developed. Since the book is directed at radar users, we adopted the latter approach, leaving further details about atmospheric processes to Chapters 11 and 12. So the decision to split the discussions of basic fluid dynamics to the start and end of the book was a deliberate one. Sufficient detail is given in Chapter 1 to permit the reader to usefully apply the more engineering-based aspects of Chapters 4 to 6, but the focus of these three chapters is definitely on radar engineering and design.

Following detailed discussions of radar design and principles in Chapters 4 and 5, Chapter 6 gives several examples of design details of early and more recent radars. We present a mixture of large, powerful and expensive systems and low-cost units that can be built even by a modestly-funded research group. In Chapter 7, we start to unify the areas of atmospheric physics and radar engineering, discussing the important atmospheric parameters that can be measured using a radar. Signal processing is an important aspect of radar studies, not only at the native level of data acquisition, but also in the post-acquisition phase, so Chapter 8 focuses on this area.

One of the areas of greatest recent application has been that of spaced antenna and interferometric studies. This goes considerably beyond the simpler concepts of fixed-beam-pointing and Doppler studies, and allows studies at a more detailed level, including sub-pulse resolution and resolutions smaller than the radar beamwidth (subject to certain assumptions), so Chapter 9 is dedicated to this topic.

Of course the desire of any serious researcher is to produce publications and advance the state of human knowledge. This can be done with standard applications of the techniques developed in the foregoing chapters, but one common agenda of many researcher in the field, and the basis of many of the more significant papers, is the desire to "push the limits" of the radar studies into uncharted territory. Chapter 10 is all about such adventures into such extraneous activities, many of which in time have become mainstream areas of study.

Finally Chapters 11 and 12 bring us back to more complex extensions of Chapter 1, allowing us to delve more thoroughly into the atmospheric processes from waves and turbulence to general atmospheric flows, storms, and even severe weather. It is in these

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areas that the potential for research into the physical sciences is greatest, and these topics can form the basis of many theses and projects.

We hope there is something in this book for everyone, but at the same time that it can be a valuable learning tool for those new to the field and an important resource to the more experienced members of the research community.

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