Levent Gürel

Weather Radar Polarimetry

by Guifu Zhang

Reviewed by Ugur Oguz

This is a valuable reference book on weather radars and their associated algorithms, and it is written by a vital member of the University of Oklahoma Advanced Radar Research Center. As someone who originally studied physics for his B.S. degree and then, apparently, became an enthusiast of the physical interactions occurring around hydrometeorological targets, Prof. Zhang has poured all of the necessary physical explanations, relevant equations, and measurement techniques involving modern polarimetric weather radar into this book.

The work is impressively organized in the ascending complexity of the topics it covers. An engineer or scientist who is new to the subject will find it very easy to read, since it covers almost all of the necessary preliminary information in a highly descriptive manner—amazingly, without forcing the reader to check many of the previous references.

Another thing that struck me as I looked deeper into the book was its treatment of some quantitative comparisons and its evaluations of complicated or even controversial topics in polarimetric weather radar and their associated measurements. Since the weather radar's received signals' statistical diversity is not comparable to that of any other radar system, this uncertainty is an issue that the weather radar engineer or scientist has to live with every day. Probably owing to the collective experience of the members of the University of Oklahoma Advanced Radar Research Center and his personal experience in the field, Prof. Zhang provides some invaluable data that would save a vast amount of time for a regular weather radar scientist or algorithm designer.

One thing I, as a radar engineer, was not accustomed to was the book's minimal emphasis on the radar hardware itself. But I think that is my problem, not Prof. Zhang's. The author has actually compiled and provided a most thorough array of information for meteorologists, weather radar users, radar system engineers, and especially for algorithm and signal/data processing designers. We can find the hardware design methodologies in other weather radar textbooks. Indeed, this volume is a unique source for engineers and scientists who would like to explore polarimetry in weather radars. In that context, I believe the book earns its name *Weather Radar Polarimetry* by keeping a steady focus on its main topic of polarimetry.

In the first chapter, the author briefly summarizes the historical development of and background information about

EDITOR'S NOTE

In this issue of *IEEE Antennas and Propagation Magazine*, the "Book Review" column spotlights *Weather Radar Polarimetry*, by Prof. Guifu Zhang, who received his B.S. degree in physics, his M.S. degree in radio physics, and his Ph.D. degree in electrical engineering. Currently, he is with the School of Meteorology at the University of Oklahoma.

I would like to thank Ugur Oguz for helping out with the review of this book. Ugur is an electrical engineer by education (B.Sc. and M.S. degrees) and a radar engineer by profession. Throughout his career, Ugur undertook both engineering and managerial duties. He worked on various radar development projects in both the military and civilian spheres, including phased-array and airborne radars. Since 2012, he has been serving as the chief technology officer of RST (Remote Sensing Technologies), a high-technology company in Ankara, Turkey. The reason I asked Ugur for his assistance in reviewing this book (and I really appreciate his graciousness in immediately accepting my request) is his hands-on experience in leading the RST team in the development of a new X-band polarimetric weather radar system, which is the first of its kind in Turkey. I feel very fortunate, both personally and on behalf of our readers, that we have landed the right person for the task. Thank you, Ugur!

—Levent Gürel

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weather radars and the employment of various major instruments in weather radars, and introduces the main theme of the book: polarimetry. In addition to this historical information, the chapter covers the organization of the book itself.

In Chapter 2, the reader can find critical background information on the physical and statistical properties of hydrometeors and cloud particles as well as the instruments used to measure their properties. The pictures acquired by cloud particle imagers provide an excellent feeling for the hydrometeor shapes that weather radar engineers work on.

By using effective diagrams to visualize the transitions between the microphysical states of the clouds and precipitation, the second chapter concisely explains all of the hydrometeor types in relevant subsections. This includes perhaps one of the most important weather radar topics, the drop size distribution (DSD) phenomenon. The comparisons of actual data to commonly used models are very helpful, not only for weather radar engineers but also for radar meteorologists, who are much more curious about the statistics underlying the measured data. This chapter is a perfect reference for scientists and engineers looking for a thorough description of the problems that weather radar engineers have to tackle.

Prof. Zhang examines hydrometeor drop shapes, fall velocities, and particle/DSD models explicitly. In addition, he elaborates the hydrometeors' dielectric structures in detail, thereby subtly introducing the bright band phenomenon. The book's thorough narrative approach emphasizes the importance the author gives to the physical interactions that occur.

The third chapter introduces mathematical representations of the wave-scattering mechanisms of a single droplet. This is an essential chapter for new weather radar engineers, since it makes it easier to understand how polarimetry works in the first place. The author covers the central theories, such as Rayleigh scattering, Mie theory, and the T-matrix method. He also adequately provides all of the radar fundamentals, eliminating the need for beginner radar engineers and scientists to go back and forth to basic electromagnetics textbooks.

The next chapter builds upon the description of volumetric scattering and propagation mechanisms of the basic single-drop phenomenon just elaborated.

Prof. Zhang has poured all of the necessary physical explanations, relevant equations, and measurement techniques involving modern polarimetric weather radar into his recent book.

But here, Prof. Zhang introduces the reader to dealing with the random particle distribution that creates the variation and statistical distribution in radar echoes. He explains, step by step, the subjects of coherent addition approximation, mean wave field, wave intensity and independent scattering, and time-correlated scattering. And he derives the mean Doppler velocity and spectral-width calculations with the autocorrelation functions. Beneficial for algorithm designers are the representation of the weather radar signals from hydrometeors, the Gaussian distributions, and the pulse integration methodologies for reducing error. In addition, the treatment of the fluctuation of differential propagation phases between polarizations due to the random positions of scatterers is worth closely reading. The text introduces and details wave statistics based on mean, covariance, and probabilistic density functions in the way that they are actually used in polarimetric weather radar calculations.

Chapter 5 starts with a brief weather radar description, which provides a quick introduction for most radar engineers. Following that brief touch on the hardware, the author elaborates on methods for deriving the polarimetric radar equations and weather radar parameters. This chapter presents methods to improve the quality of the parameters for the raw data extracted by the radar. This is essential information, since a polarimetric radar suffers from various sources of error and other mechanisms that limit the accuracy of the outputs. Frankly, this chapter is one of the most interesting to me, as a systems engineer, who has to deal with all kinds of such error sources. Here, the author impressively provides a detailed description of the performance of the two- to four-lag autocorrelation function estimators for the spectral-width parameter, which we rarely find in the open literature on weather radar products. He presents the issue of ground clutter and the state-of-the-art methods to mitigate such signals. To solve the clutter mitigation problem efficiently, he offers a fascinating algorithm called *spectrum-time estimation processing*.

After presenting the methods to attain highly accurate results with a weather radar signal processor, the author switches, in Chapter 6, to what radar users will find highly attractive: weather radar products. The text generously provides some basic descriptions and examples of weather radar images to explain weather phenomena such as precipitation, convection, and various storm levels. Prof. Zhang offers a thorough review of hydrometeor classification methods, followed by a similar elaboration of rain fall-rate estimation, DSD retrieval, and attenuation correction methods. These state-of-the-art methodologies are essential for producing accurate data with high-frequency polarimetric weather radars.

The author presents the topics in Chapters 1–6 in great simplicity, eliminating the need for checking references in previous chapters. But in the seventh chapter, he properly addresses topics for experienced scientists and engineers. It starts with brief descriptions of dual-frequency radar systems and their potential advantages, moving on to some advanced DSD retrieval methods, without neglecting to explain the necessity of simultaneous DSD retrieval and attenuation correction processes. Then he provides some quantitative comparisons, which are, again, rare in the open literature, offering a critical benchmark for engineers and algorithm designers. Toward the end of Chapter 7, the author mentions how experienced engineers and scientists are essential in the fields of both numerical weather prediction and radar polarimetry for advancing weather nowcasting and forecasting. These comments emphasize that there is still much work to be done here, a motivation for readers who may consider pursuing a career in this area.

In the eighth and final chapter, the writer opens up a recently explored field in weather radar: phased arrays. A phased-array approach, although inevitably costing more than traditional rotating radars, will have two main advantages: a reduced weather information update time and multifunctionality. Another plus might be phased arrays' maintainability and their well-known graceful degradation feature.

Prof. Zhang introduces the reader to dealing with the random particle distribution that creates the variation and statistical distribution in radar echoes.

Prof. Zhang details and compares the temporal requirements of a standard volumetric coverage in various scenarios. This is, again, one of the welcome inputs the author provides for readers who cannot find similar quantitative information in the literature. The main drawback of phased arrays in weather radar applications is their limitation in polarimetric measurements, an area that Prof. Zhang explores, along with methods to make corrections in these measurements. Another topic that he delves into for experienced radar engineers is the cylindrical phased-array radar system, which has been built by the University of Oklahoma Advanced Radar Research Center and the National Severe Storms Laboratory, Norman, Oklahoma. It is interesting to learn some details about this system, since it is quite popular even on social media today for its employment in SpaceX's vertical landing studies.

ABOUT THE REVIEWER

Ugur Oguz (uoguz@rstteknoloji.com.tr) is the chief technology officer of RST (Remote Sensing Technologies) in Ankara, Turkey. After he received his M.S. degree in 1997 under the supervision of Prof. Levent Gürel, he went on to become an expert in radar systems.

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