Chapter 9

Global and Local Precipitation Measurements by Radar

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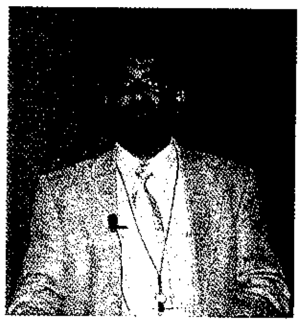

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1. Introduction

The detection and measurement of precipitation by radar has been pursued since its introduction as a meteorological tool. The main advantage of using radar for precipitation estimation is that measurements can be made over large areas, with either fairly high temporal and spatial resolution or extensive spatial coverage (about 10 000 km^2 for ground-based radars and an order of magnitude more for space-based radars). To sample the area covered by a typical ground-based radar, substituting each radar spatial sample with a rain gauge, would require about a quarter-million gauges. Using a similar analogy to space radars, nearly one-half-million gauges would be required per orbit. Since the radar transmitter and receiver normally use the same antenna (monostatic operation), the measurements are sent to a central location at the speed of light by "natural wireless networks." In addition, radars can provide fairly rapid updates of the three-dimensional structure of precipitation. Because of these advantages, radar measurements of precipitation have enjoyed widespread use for meteorological applications, independent of the accuracy or the type of algorithm used to derive precipitation estimates.

Approaches to rainfall measurement can be broadly classified into 1) physically based and 2) statistical–engineering based. Physically based rainfall algorithms, as defined here, rely on physical models of the rain medium without feedback from ground observations, whereas statistical–engineering solutions rely on modifications to the algorithm based on the volumetric structure of radar echoes or on the information from gauge observations. Physically based approaches attempt to solve the inverse electromagnetic problem of obtaining resolution-volume-averaged precipitation estimate from radar backscatter and forward scatter measurements such as reflectivity Z, differential reflectivity Z_{dr}, specific differential propagation phase K_{dp}, or specific attenuation (A). Engineering solutions, on the other hand, seek the best possible estimate of rainfall on the ground, using some feedback mechanism such as gauge data, recognizing that the radar measurements are made aloft. Though not stated in this form, this fundamental distinction was recognized by Zawadzki (1984). Both physically based techniques and engineering solutions have their role in precipitation measurements. Physically based techniques, such as the polarimetric radar measurements, can distinguish rain from frozen hydrometeors such as hail or graupel and from nonmeteorological echoes. Discrimination among hydrometeors is valuable not only for precipitation physics, but it is an important step prior to application of precipitation algorithms. Engineering techniques focus primarily on accurate estimation of rainfall or snowfall on the ground. These range from simple techniques such as tuning the algorithm coefficients with season or with radar range to more sophisticated approaches such as the derivation of nonparametric Z–R relations and the use of neural networks.

Areal rainfall estimates using propagation measurements such as K_{dp} have shown great success recently. Similarly, physically based approaches such as dual-polarization radar estimates of rainfall have been adapted to statistical/engineering techniques such as probability-matched methods. In addition, polarimetric algorithms can be used to determine the amount of rain in a rain–hail mixture. A class of hybrid procedures are evolving that combine the advantages of physically based and statistical/engineering solutions.

Ground-based weather radars have excellent temporal resolution but are usually limited to land-based deployment and do not cover all the land surface of the earth. Space-borne radar is complementary to the ground radar in that it can provide global coverage but is severely limited in its ability to monitor the temporal evolution of precipitation systems. Although most current space-based algorithms are physically based, statistical methods hold great promise, particularly in the estimation of rainfall over large space–timescales. Spaceborne methods of rain estimation differ significantly from ground-based approaches, primarily because of differences in the radar systems deployed on these platforms. The first major difference is the operating frequency. The current space radar for measuring precipitation, the Tropical Rainfall Measuring Mission Precipitation Radar (TRMM PR), operates at 13.8 GHz. This and the proposed space-borne radars at frequencies of 13.6, 35, and 95 GHz are significantly higher than S-band or C-band radars typically used on the ground. While the use of higher frequencies yields adequate resolution from space for a modest antenna size, attenuation correction must be done before parameters of the rainfall can be estimated. In addition, strong backscattering from the surface of the earth limits the lowest altitude at which rainfall estimates can be computed. Comparisons of radar reflectivity factors and rainfall rates derived from space- and ground-based radars suggest that a single-wavelength space-borne radar can yield reasonably accurate estimates of these quantities. Next-generation space-borne sensors will include a dual wavelength and a millimeter cloud radar. These instruments are expected to improve global estimates of precipitation and cloud parameters and will constitute an integral part of our rain and cloud monitoring capabilities.

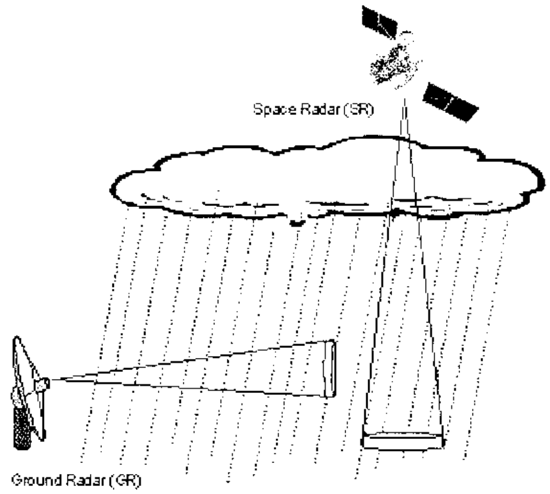

FIG. 9.1. Geometry of space- and ground-based radars. The shaded areas show the resolution volumes.

The potential applications of quantitative radar precipitation measurements are very broad: from hydrology, agriculture, and forestry through water cycle and water resources studies, to nowcasting and finally numerical modeling validation and data assimilation. The aim of radar meteorology is to establish the error structure of quantitative radar precipitation measurements and their time- and space-scale dependence.

This paper provides a summary of some ground- and space-based radar precipitation estimation techniques. In addition, the paper will emphasize the most critical practical elements of "rainfall estimation" that impact the measurement accuracy. We also attempt to provide some insight into new instruments and techniques that are expected to improve our understanding of local and global precipitation. The paper is organized as follows. Section 2 defines the radar basis for characterizing precipitation for both ground and spaceborne radars. The practical issues facing radar measurements of precipitation are discussed extensively, with section 3 focusing on reflectivity-based estimates, section 4 on dual-polarization techniques and section 5 on spaceborne measurements. The paper will conclude with some projections on the future of rainfall estimation from radars.