On the Equivalence of Dual-Wavelength and Dual-Polarization Equations for Estimation of the Raindrop Size Distribution

ROBERT MENEGHINI

NASA GSFC, Greenbelt, Maryland

LIANG LIAO

Goddard Earth Sciences and Technology Center/Caelum Research Corp., Rockville, Maryland

(Manuscript received 4 May 2006, in final form 21 August 2006)

ABSTRACT

For air- and spaceborne weather radars, which typically operate at frequencies of 10 GHz and above, attenuation correction is usually an essential part of any rain estimation procedure. For ground-based radars, where the maximum range within the precipitation is usually much greater than that from air- or spaceborne radars, attenuation correction becomes increasingly important at frequencies above about 5 GHz. Although dual-polarization radar algorithms rely on the correlation between raindrop shape and size, while dual-wavelength weather radar algorithms rely primarily on non-Rayleigh scattering at the shorter wavelength, the equations for estimating parameters of the drop size distribution (DSD) are nearly identical in the presence of attenuation. Many of the attenuation correction methods that have been proposed can be classified as one of two types: those that employ a kZ (specific attenuation–radar reflectivity factor) relation, and those that use an integral equation formalism where the attenuation is obtained from the DSD parameters at prior gates, either stepping outward from the radar or inward toward the radar from some final range gate. The similarity is shown between the dual-polarization and dual-wavelength equations when either the kZ or the integral equation formulation is used. Differences between the two attenuation correction procedures are illustrated for simulated measurements from an X-band dual-polarization radar.

1. Introduction

The close connection between dual-polarization and dual-wavelength radar algorithms can be understood from similarities in the two sets of measurements. Typically, two parameters of the hydrometeor size distribution are estimated from two independent radar reflectivity factor measurements. In the dual-polarization case, the independent data are the copolarized radar reflectivity factors at horizontal and vertical polarizations. The dual-wavelength radar provides radar reflectivity factors at two wavelengths at the same polarization state.

A further similarity between the two situations is that the measured or apparent reflectivity factors must be corrected for attenuation before the estimation of the size distribution parameters can be made. The attenuation correction can proceed either in the forward direction, with increasing radar range, or in the backward direction, starting from a final gate and progressing inward toward the radar. However, the forward-going solutions tend to be unstable because the attenuation out to the range of interest becomes "large" in some sense. This is analogous to the case of a single attenuating-wavelength radar where the forward solution to the Hitschfeld–Bordan (Hitschfeld and Bordan 1954) equation becomes unstable as the attenuation increases. To circumvent this problem, the equations can be expressed in a form that includes an independent estimate of path attenuation. For the dual-polarization radar, it has been shown that a measurement of the differential phase between horizontal and vertical polarizations (Testud et al. 2000; Bringi et al. 2001; Matrosov et al. 2002, 2005) provides a good estimate of path attenuation at the two polarizations. For airborne and spaceborne dual-wavelength measurements, the surface ref-

Corresponding author address: Robert Meneghini, Code 614.6, Instrumentation Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, MD 20771.
E-mail: bob@neptune.gsfc.nasa.gov

DOI: 10.1175/JTECH2005.1

erence technique can be used to estimate path attenuation at both wavelengths.

In this paper, two types of attenuation correction procedures are formulated for application to dual-wavelength and dual-polarization weather radar data. In the integral equation approach, which has been used in the analysis of dual-wavelength airborne radar data, the parameters of the drop size distribution (DSD) are used to adjust the path attenuation to the adjacent range gate, which, in turn, is used to correct the measured reflectivity factors at that gate. In this way, a recursion procedure is defined. The most notable use of the kZ (specific attenuation–radar reflectivity factor) parameterization approach was provided by Hitschfeld and Bordan (1954) who analyzed the radar equation for a single attenuating-wavelength radar. Modification of this estimate to include an independent path attenuation constraint has led to its application in the analysis of airborne and spaceborne radar data. An important recent development is the application of methods of this type to polarimetric data. The approach has not, however, been widely used for the analysis of dual-wavelength radar data.

The primary objective of the paper is to make clear the relationships between the polarimetric and dual-wavelength equations in the presence of attenuation for both the integral equation and kZ parameterization approaches. We begin by writing the integral equations for the median mass diameter D_0 and number concentration N_t that are applicable to both dual-polarization and dual-wavelength radar returns for the initial value and final value cases. This is followed by a similar development for the kZ parameterization. For this case, however, only the final value version is discussed. Simulations of the retrievals are presented for the case of an X-band polarimetric radar with an emphasis on the differences between the backward solutions using the integral equation and kZ parameterization.

5. Discussion and summary

Integral equations for the parameters of the particle size distribution have several useful features in that they explicitly include path attenuation constraints and provide attenuation correction in terms of the particle size distribution parameters determined in earlier steps (range gates) of the procedure. Because the dual-wavelength and dual-polarization radar data are governed by essentially the same equations, a common theoretical framework is provided by which errors in the retrievals can be assessed. This should be beneficial to the proposed Global Precipitation Measurement Mission (Iguchi et al. 2002) where quantities derived from a dual-wavelength spaceborne radar can be expected to be compared with similar quantities derived from ground-based dual-polarization radars. Making good use of these data will depend on an understanding of the inherent errors in both spaceborne and ground-based algorithms.

By using the kZ parameterization, similar sets of equations applicable to dual-wavelength and dual-polarization radars can be derived. For the polarization radar, these equations are similar in content to those derived by Testud et al. (2000) and Bringi et al. (2001), and recently analyzed by Gorgucci and Chandrasekar (2005). As illustrated in the examples of section 4, despite differences, the two formulations function in a somewhat similar manner. Advantages of the integral equation approach were noted in cases of errors in the shape parameter μ or in Z. On the other hand, the kZ formulation was seen to be more accurate than the integral equation solution in the presence of errors in path attenuation.

In a study comparing what is here called the kZ formulation with an attenuation correction obtained directly from the differential phase estimate (Matrosov et al. 2002), Gorgucci and Chandrasekar (2005) concluded that neither approach was best in all cases. A similar conclusion can be drawn for the kZ and integral equation approaches, implying that for polarimetric data at attenuating wavelengths, comparisons among the three approaches should be useful as a diagnostic tool. Comparisons of results from kZ and integral equation formulations should also be useful for dual-wavelength data.

It is worth noting that apart from the integral equation and kZ parameterization formulations, other dual-wavelength techniques have been proposed (e.g., Marzoug and Amayenc 1994; Adhikari and Nakamura 2003; Grecu and Anagnostou 2004; Iguchi 2005). In view of the close relationship between dual-wavelength and dual-polarization algorithms, some of these formulations may also be applicable to both types of data.