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Examination of Effective Dielectric Constants Derived from Non-Spherical Melting Hydrometeor

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The bright band, a layer of enhanced radar echo associated with melting hydrometeors, is often observed in stratiform rain. Understanding the microphysical properties of melting hydrometeors and their scattering and propagation effects is of great importance in accurately estimating parameters of the precipitation from spaceborne radar and radiometers. However, one of the impediments in the study of the radar signature of the melting layer is the determination of effective dielectric constants of melting hydrometeors. Although a number of mixing formulas are available to compute the effective dielectric constants, their results vary to a great extent when water is a component of the mixture, such as in the case of melting snow. It is also physically unclear as to how to select among these various formulas. Furthermore, the question remains as to whether these mixing formulas can be applied to computations of radar polarimetric parameters from non-spherical melting particles.

Recently, several approaches using numerical methods have been developed to derive the effective dielectric constants of melting hydrometeors, i.e., mixtures consisting of air, ice and water, based on more realistic melting models of particles, in which the composition of the melting hydrometeor is divided into a number of identical cells. Each of these cells is then assigned in a probabilistic way to be water, ice or air according to the distribution of fractional water contents for a particular particle. While the derived effective dielectric constants have been extensively tested at various wavelengths over a range of particle sizes, these numerical experiments have been restricted to the co-polarized scattering parameters from spherical particles. As polarimetric radar has been increasingly used in the study of microphysical properties of hydrometeors, an extension of the theory to polarimetric variables should provide additional information on melting processes. To account for polarimetric radar measurements from melting hydrometeors, it is necessary to move away from the restriction that the melting particles are spherical.

In this study, our primary focus is on the derivation of the effective dielectric constants of non-spherical particles that are mixtures of ice and water. The computational model for the ice-water particle is described by a collection of 128x128x128 cubic cells of identical size. Because of the use of such a high-resolution model, the particles can be described accurately not only with regard to shape but with respect to structure as well. The Cartesian components of the mean internal electric field of particles, which are used to infer the effective dielectric constants, are calculated at each cell by the use of the Conjugate Gradient-Fast Fourier Transform (CG-FFT) numerical method. In this work we first check the validity of derived effective dielectric constant from a non-spherical mixed phase particle by comparing the polarimetric scattering parameters of an ice-water spheroid obtained from the CGFFT to those computed from the T-matrix for a homogeneous particle with the same geometry as that of the mixed phase particle (such as size, shape and orientation) and with an effective dielectric constant derived from the internal field of the mixed-phase particle. The accuracy of the effective dielectric constant can be judged by whether the scattering parameters of interest can accurately reproduce those of the exact solution, i.e., the T-matrix results.

The purpose of defining an effective dielectric constant is to reduce the complexity of the scattering calculations in the sense that the effective dielectric constant, once obtained, may be applicable to a range of particle sizes, shapes and orientations. Conversely, if a different effective dielectric constant is needed for each particle size or shape, then its utility would be marginal. Having verified that the effective dielectric constant defined

for a particular particle with a fixed shape, size, and orientation is valid, a check is performed to see if this effective dielectric constant can be used to characterize a class of particle types (with arbitrary sizes, shapes and orientations) if the fractional ice-water contents of melting particles remain the same. Among the scattering and polarimatric parameters used for examination of effective dielectric constant in this study, are the radar backscattering, extinction and scattering coefficients, asymmetry factor, differential reflectivity factor (ZDR), phase shift and linear polarization ratio (LDR). The goal is to determine whether the effective dielectric constant approach provides a means to compute accurately the radar polarimetric scattering parameters and radiometer brightness temperature quantities from the melting layer in a relatively simple and efficient way.