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COMPARISON OF MEASURED ICE PARTICLE SIZE DISTRIBUTIONS WITH PARAMETERIZATIONS AND EFFECTS OF DIFFERENCES ON MICROWAVE BRIGHTNESS TEMPERATURE CALCULATIONS

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1. Introduction

Global monitoring of precipitation is largely accomplished through the use of satellite-borne passive microwave sensors. Various retrieval algorithms are used, relying on combinations of emission and scattering signatures of precipitation-sized particles. The former method depends on the presence of ice precipitation and characteristics of the ice particles. It has been shown, however, that the relationship between scattering and surface rain rate is weak, owing to the fact that a variety of cloud microphysical mechanisms are instrumental in precipitation formation.

Radiative transfer models employed in the development of precipitation retrieval methods commonly specify microphysical properties with one of several parameterizations. No single parameterization universally describes size distributions for varying cloud types, temperatures, and locations. In order to facilitate continued improvement of precipitation retrieval methods, it is important to understand the impact of the commonly used hydrometeor parameterizations on upwelling microwave brightness temperature, and to assess whether the approximations are representative of reality for particular situations.

In this work, we consider case studies derived from field programs sponsored by the Tropical Rainfall Measuring Mission (TRMM) ground validation effort. Specifically, we investigate ice particle size distributions observed in deep cirrus and precipitating stratus clouds and associated parameterizations developed by Heymsfield et al. (2002). These parameterizations are used to model the upwelling microwave brightness temperature at frequencies measured by the TRMM microwave imager, and are compared to a calculated brightness temperature from a baseline case using well-known particle size distribution parameterizations.

2. Microwave Radiative Transfer Model

To investigate the effect of ice particle size distributions on brightness temperature, a plane-parallel microwave radiative transfer model (Liu, 1998) is utilized. The model calculates dielectric constants of water and ice particles with size distributions specified by a set of parameterizations. Default size distributions include a 2-parameter gamma distribution for cloud ice particles (Matrosov et al., 1994), a Marshall-Palmer distribution which relates rain rate to rain drop size distribution, and the Sekhon and Srivastava (1970) distribution for describing snow size distributions. Baseline model runs are performed with these default distributions for comparison to runs with measured size distributions.

3. Field Experiments and Data Set

During 1998 and 1999, a series of field experiments was sponsored by the TRMM program to collect data for validation of radar and radiometer precipitation retrieval algorithms. Data used in this study were collected at Kwajalein, Marshall Islands during the Kwajalein Experiment (KWAJEX). Specifically, in situ measurements of cloud microphysical properties from the University of North Dakota Citation aircraft provide particle size distributions (PSDs) in convective and stratiform precipitation (Stith et al, 2002). PSDs were measured by the Particle

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Measuring Systems 2D-C probe in the size range from 30 microns to 1 mm and by the Stratton Park Engineering Company high volume particle spectrometer (HVPS) from 0.2 mm to about 5 cm.

Particle size distribution measurements have been analyzed during spiral descents through deep tropical cirrus and precipitating stratiform clouds by Heymsfield et al. (2002). Their results demonstrate that the observed PSDs were generally well-represented by gamma distributions of the form $N(D) = N_0D^ue^{-LD}$, where N_0, u, and L specify the intercept, slope, and dispersion of the distribution, respectively. Parameter values were derived for each case. Exponential distributions (u = 0) were also fit to each case, and the temperature dependence of each parameter was investigated.

4. Results

The effect of ice particle size distribution on upwelling brightness temperature is examined here by comparing three microphysical parameterizations for PSDs observed on August 22, 1999. Based on in situ aircraft and radar observations, the cloud layer is idealized as containing ice phase cloud- and precipitation-sized particle from 7-11 km, mixed phase particles from 4-7 km and liquid precipitation below 4 km. Liquid PSDs are assumed constant among the three assumed distributions considered here, but ice phase PSD parameterizations are varied. For case (1) we use a composite of two PSD parameterizations. Smaller ice particles (diameters up to 5 mm) are distributed according to the 2-parameter gamma distribution used as a default in the Liu (1998) model:

$$N(D) = N_0\, D^u\, e^{-(3.67+u\,)D/Dm}$$

where D_m is the median size that splits the distribution into two equal-volume parts and μ=1. Precipitation sized ice particles (0.2 – 40 mm) are given in the model by the Sekhon and Srivastava parameterization:

$$N(D) = N_0\, e^{-LD}$$

where N_0 and L are related to precipitation rate. Case (2) uses a traditional gamma distribution with parameter values specified in Heymsfield et al. (2002):

$$N(D) = N_0D^ue^{-LD}$$

where N_0, u, and L are derived from measurements. Case (3) is a simplification of case (2) with u = 0, i.e., an exponential distribution:

$$N(D) = N_0e^{-LD}$$

where N_0 and L are also derived from measurements.

Although the parameters in the gamma and exponential distribution have been shown to vary with temperature, in this simplified example the temperature dependence is not considered and the parameters are assigned constant values throughout the ice cloud layer. Parameter values are taken from fits to the August 22 aircraft measurements (Heymsfield et al., 2002). For case (2) values are N_0 = 0.001 cm^{-4-u}, L = 8 cm^{-1}, and u = -1.822. In case (3), N_0 =0.1 cm^{-4}, L = 10 cm^{-1}. Precipitation rate, ice water content, and median diameter are derived following Heymsfield et al. (2002). Figure 1 shows the particle size distributions used in the model runs.

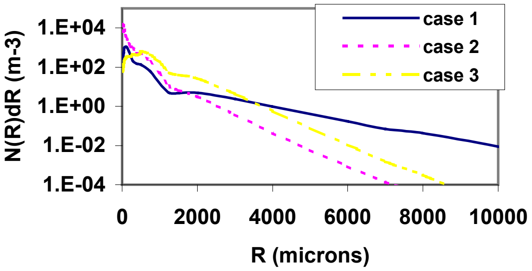

Figure 1: Particle size distributions used as model input in the three case studies.

Model runs are performed for each case at a range of microwave frequencies representing the channels of the TRMM Microwave Imager (Kummerow, 1998), and certain higher frequencies available on airborne sensors such as the Millimeter-Wave Imaging Radiometer (Racette et al., 1996). The resulting brightness temperatures at 19, 22, 37, 89, 150, 183, and 220 GHz are shown in Figure 2.

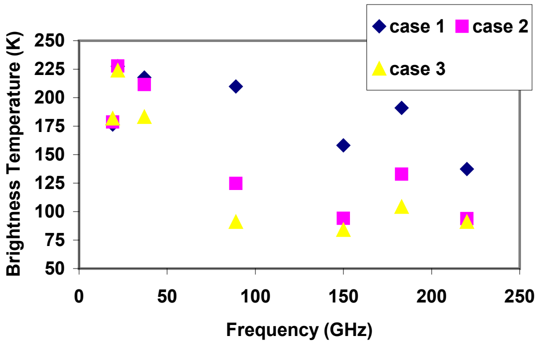

Figure 2: Upwelling brightness temperature for the three cases shown in Figure 1.

Significant differences in upwelling brightness temperature for each case are apparent at frequencies of 89 GHz and higher. At these frequencies, scattering by ice particles of sizes similar to the wavelength reduces the upwelling radiance dramatically. The August 22nd case was extreme in terms of large ice particle concentration, so we would expect scattering effects to be significant. Figure 1 shows that the smallest concentration of particles with radius less than 2000 microns occurs in case 1, and brightness temperatures in that case are therefore higher than in the other two cases. Similarly, the highest particle concentrations at those sizes occur in case 3, resulting in enhanced scattering and substantially lower brightness temperatures. This example demonstrates the significant effect of the assumed PSD on upwelling brightness temperature, and the importance of properly specifying hydrometeor properties in retrieval methods.

5. Future work

In future studies of this type, the temperature dependence of the gamma distribution parameters will be included to determine the effect of vertical variation in PSDs on upwelling brightness temperature. Modeled relationships between particle size and mass will also be modified to better represent the TRMM measurements. Additional cases will be analyzed, and model calculations of brightness temperature will be compared with coincident airborne radiometer measurements.

6. Acknowledgements

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