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THE SENSITIVITY OF COMPUTED MICROWAVE BRIGHTNESS TEMPERATURES FROM PRECIPITATING CLOUDS TO MODELS OF SPHERICAL MIXED-PHASE HYDROMETEORS

BENJAMIN JOHNSON★, GRANT PETTY
[1]*Department of Atmospheric and Oceanic Sciences, University of Wisconsin-Madison, Madison, Wisconsin*

1. INTRODUCTION

Passive microwave remote sensing from satellites has become the primary basis for global monitoring of precipitation. Cold-cloud precipitation processes, dominant in midlatitude systems, are often composed of a variety of ice-phase and mixed-phase hydrometeors. Accurate models of the microwave optical properties of mixed- and ice-phase hydrometeors are critical to the success of physically based precipitation retrieval algorithms. To date, however, microwave radiative transfer calculations have generally relied on ad hoc assumptions about hydrometeor properties.

The research presented here consists of two primary components. A hydrometeor model, in which an effective medium approximation (Bruggeman 1935) is used for the computation of the average dielectric properties of an exponential size distribution of spherical mixed- and ice-phase hydrometeors; Mie theory is used for computation of the optical properties for the modeled hydrometeor ensemble. For the second component of the research a plane-parallel, polarized radiative transfer model (RT4) by Evans and Stephens (1995) is used to compute brightness temperatures of a semi-infinite layer of hydrometeors.

The ultimate objective of this work is to establish empirical constraints on hydrometeor properties assumed in radiative transfer models, based in part on comparisons between observed and simulated multichannel microwave radiances from current sensors, such as the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI), the Advanced Microwave Scanning Radiometer (AMSR), and the Advanced Microwave Sounding Unit (AMSU).

★ *Corresponding author address*: Benjamin Johnson, AOS Dept., UW-Madison, 1225 W. Dayton Street, Madison, WI 53706; e-mail: jbenjam@aos.wisc.edu

2. MODEL DESCRIPTION

2.1 *Hydrometeor Model*

Because we are interested in simulating the effects of the physical composition of mixed- and ice-phase hydrometeors on observed microwave brightness temperatures, it is necessary to incorporate some approximation of physical reality into the model. As a basic approximation, any hydrometeor can be represented by three volume fractions: liquid water f_{liq}, ice phase f_{ice}, and air f_{air}. Air volume fraction is represented by

$$f_{air} = (1 - f_{liq} - f_{ice})\,. \tag{2.1}$$

Water, ice, and air have significantly different dielectric functions. The dielectric function of a material determines how it interacts with a particular frequency of radiation. To simulate the dielectric function of a mixed-phase hydrometeor, the effective medium approximation of Bruggeman (1935) for two-components is used,

$$f_1 \frac{\varepsilon_1 - \varepsilon_{av}}{\varepsilon_1 + 2\varepsilon_{av}} + (1 - f_1)\frac{\varepsilon_2 - \varepsilon_{av}}{\varepsilon_2 + 2\varepsilon_{av}} = 0\,, \tag{2.2}$$

where f_1 is the ratio of the volume fraction of material 1 to material 2, and ε_1, ε_2 are the dielectric functions of materials 1 and 2 respectively. This is generalized to include three components by applying the two-component method (Eqn. 2.2) twice; first, to two of the components, and then to the average and the third component.

In this way, a single homogeneous spherical hydrometeor with an average dielectric function and expanded physical radius — an effect of the air component — can be used as a model of an actual hydrometeor having similar physical characteristics.

To model the properties of a ensemble of hydrometeor sizes, a simple two-parameter exponential size distribution is used,

$$N(D) = N_0 \exp(-\Lambda D), \tag{2.3}$$

where D is the liquid (or mass) equivalent particle diameter, Λ controls the size dependence of $N(D)$, and thus the mass-weighted optical properties of the hydrometeors. N_0 can be computed by quantities such as rain-rate (in the case of rain) etc. In this case, we consider a reasonable fixed value of N_0 for simplicity, as is described later.

Using the Mie code based on Bohren and Huffman (1983), the optical properties of a single particle are determined. In particular, we are interested in the single scatter albedo (ϖ_0), asymmetry parameter (g), and mass extinction coefficient (κ). Averaging over the size distribution, "bulk" optical properties are obtained for the ensemble of hydrometeors.

2.2 *Radiative Transfer Model*

For microwave brightness temperature calculations, the one dimensional, polarized, plane-parallel model (RT4) described briefly in Evans and Stephens (1995) was used. Plane-parallel refers to the method in which the model layers are treated as being horizontally homogeneous and for our purposes infinite in extent. Polarized 4×4 phase matrices are calculated for each hydrometeor from Mie theory. It should be noted that while polarization is considered to be an important topic, the focus here is on the variation in the magnitudes of the brightness temperatures.

2.3 *Model Setup*

For the cases presented here, we assumed a semi-infinite layer of hydrometeors. The purpose of a semi-infinite layer is to obscure emission from the surface, and to provide brightness temperatures due to thermal emission from the layer of hydrometeors. By changing the model parameters, it is straightforward to observe the changes in the resultant brightness temperatures. It is possible to determine the relative sensitivity of the computed microwave brightness temperatures to those changes in the model parameters.

In particular, we focus here on how changing the volume fraction of ice, water, and air can affect the brightness temperature results. The purpose for doing this is to determine to what extent more simplistic treatment of hydrometeors are valid, or alternatively when a realistic treatment of hydrometeor composition becomes important.

3. EXAMPLE APPLICATIONS

3.1 *Hydrometeors*

A snowflake is an individual ice crystal grown by vapor deposition. As it falls in the atmosphere, it can collect other snowflakes and ice crystals forming a larger "clump" of crystals called an aggregate. Aggregates are thought to be important for the initiation of precipitation-sized-particle growth (Pruppacher and Klett 1997).

To model a snowflake aggregate and graupel using the hydrometeor model, somewhat subjective choices are made regarding the composition of the particle. Indeed, the individual aggregate is a loose collection of ice crystals; therefore, the volume fraction of ice compared to air will be low. For graupel, we expect a higher volume fraction of ice. Melting graupel would contain a small volume fraction of melted ice. Table 1 lists the choices for the model parameters for the three example cases.

	Water (f_{liq})	Ice (f_{ice})	Λ (cm^{-1})
Aggregate	0.0	0.2	25
Graupel 1	0.0	0.5	25
Graupel 2	0.1	0.4	25

Table 1: Volume fractions for selected hydrometeor simulations as examples. $1/\Lambda$ gives the mode diameter of the exponential size distribution.

In figure 1, the brightness temperature is plotted versus frequency for the three examples in table 1. Comparisons between the three curves show differences in the brightness temperature signatures, indicating that choices regarding the physical characteristics of hydrometeors, even in an ensemble, can potentially be important in algorithm applications.

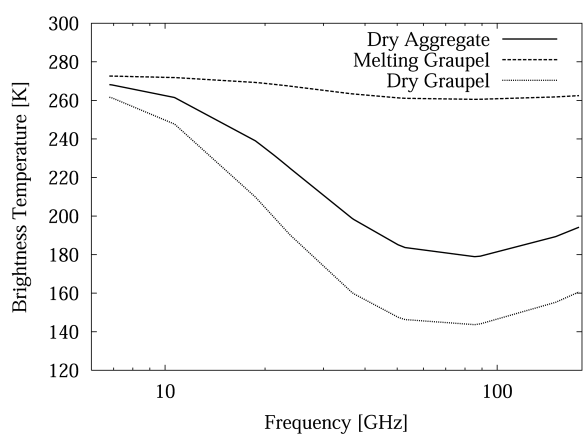

Figure 1: Simulated brightness temperature versus frequency for three example hydrometeors.

Of particular note is the effect of water. In figure 1, we find that the addition of 0.1 volume fraction water as compared to the dry graupel leads to a brightness temperature change as great as 100 K for the semi-infinite layer of hydrometeors. This is a potentially important source for error, and indicates that the knowledge or assumptions regarding hydrometeor composition should be taken seriously.

Figure 2 explores the effects of water on the brightness temperature as a contour plot. The left axis shows the water volume fraction, and the right axis shows the corresponding ice volume fraction. In this case, there is no air present. The presence of even a small amount of liquid water significantly impacts the radiances from the layer of hydrometeors.

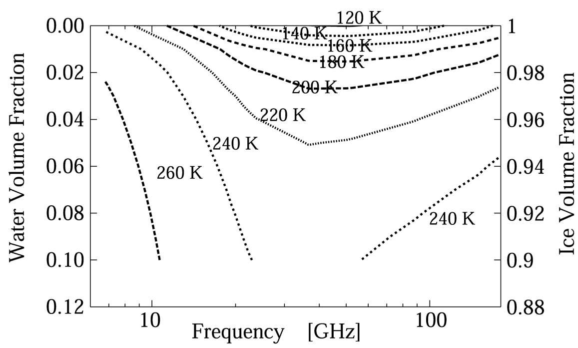

Figure 2: Contours of brightness temperature (K) for changing volume fraction of ice and water.

4. CONCLUSION

The model generated brightness temperatures for an semi-infinite layer of thermally emitting hydrometeors indicates that there is a strong sensitivity to the choices and assumptions of the physical properties of modeled hydrometeors. It was shown that small amounts of liquid water present can significantly impact the observed brightness temperature. Additionally, it can be seen that the effect of air component can have a lesser impact on the model brightness temperatures. These results illustrate the consequences of overly simplistic and/or ad hoc treatments of ice particles in algorithms or models.

Furthermore, the research presented here, a small sample of a more thorough sensitivity study in progress, will be used to improve current and future algorithms by providing empirical constraints through comparisons with observations and model simulations.

Future work will involve comparisons with actual data and empirical measurements of hydrometeors to more realistically constrain the range of model parameters. Additionally, shape considerations will be taken into account, along with polarization (vertical and horizontal). Actual measurements of the dielectric properties of hydrometeors would be greatly useful as a guide for decisions regarding model choices, especially with respect to the method of averaging dielectric constants.

5. REFERENCES

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