SIMULATION OF THE EXTINCTION PROPERTIES OF REALISTICALLY SHAPED PRECIPITATION PARTICLES

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1. ABSTRACT INTRODUCTION

Passive and active microwave remote sensing of cold-cloud precipitation requires accurate knowledge of not only the physical state of the scene being observed, but also the relationship between that physical state and the radiation being observed. However, for ice-phase precipitation and cloud particles, this relationship remains poorly understood due primarily to a lack of direct and in-situ measurements of these relationships. A major complicating factor in remote sensing of these clouds is that it is generally impossible to know the true particle shapes, sizes, and their distributions within the scene being observed. This raises two questions: (1) Is it necessary, from a remote sensing perspective, to know the exact shapes and sizes of every particle in a precipitating ice-phase cloud? (2) If not, what parameterizations or assumptions will provide the desired relationships while providing retrievals with the desired accuracy?

Assuming that the answer to (1) is "no", then answer(s) to (2) depend largely on the capabilities of the remote sensing instrument and the algorithm used to infer information from the observations obtained by that instrument. A sensor, whether active or passive, having wavelengths significantly longer than the size of the particles of interest is unlikely to be strongly sensitive to those particles. Conversely if the wavelength is too short relative to the particle size, then the observation is likely to be too sensitive to other physical properties, reducing the signal from the ice-particles themselves. Therefore, appropriate wavelength/channel selection is critical for having a strong sensitivity to particles of a certain size. However, size is not the only factor of importance – particle shape has been shown to be a significant source of uncertainty with respect to simulated radiative properties. It is not difficult to imagine that a hexagonal plate will have different scattering and extinction properties compared to a more spherically shaped particle of the same mass.

The present research examines the relationships between the shape of ice-phase particles common in precipitating clouds and their associated radiative properties as are employed in remote sensing applications. We use two common methods to compute the scattering and absorption properties of these particles: (1) the discrete dipole approximation (DDSCAT), and (2) Mie theory for reduced density spheres (aka "fluffy" spheres). We also identify issues with various applications of Mie theory and DDSCAT, which have potentially important implications for other researchers doing similar computations.

2. PHYSICAL PROPERTIES OF ICE-PHASE PRECIPITATION

Ice-phase precipitation comes in a wide variety of shapes and sizes. The primary growth mechanism of ice-phase particles is that of vapor deposition, which has been shown to produce a large variety of particle shapes depending on the physical characteristics of the environment in which it has formed. Collision and collection processes, such as riming and aggregation, create conglomerate particles out of smaller ice-crystals, resulting in distinct connected particles which are much larger than their individual constituents.

The shape characteristics of these "aggregates" generally do not resemble the shapes of their constituent particles. Casual inspection of commonly occurring aggregates of snow crystals reveals a plethora of possible configurations of shape. In the consideration of how to simulate such shapes, we believe that it would be cumbersome to try and simulate all realizable combinations of aggregate shapes. Instead, we postulate that a small set of "characteristic" shapes are sufficient to span the range of variations in scattering and absorption properties of these particles. However, it is, at present, difficult to validate such a postulation – our only refuge being that we can show that our simulated observations have the same statistics as actual observations of precipitating clouds (specifically with respect to the TB "scattering" signal by ice particles aloft and radar reflectivity profile statistics). If our characteristic shapes, when employed in a forward model, cannot reproduce the observed ranges and spectral correlations of observed brightness temperatures, then we should re-examine our assumptions.

3. COMPUTATION OF THE SCATTERING AND ABSORPTION PROPERTIES

The simplest approximation of an ice-phase particle's shape is that of a sphere. Mie Theory can be employed to accurately compute the extinction properties of homogeneous spheres, subject to the accuracy of the numerical methods by which Mie Theory is computed. By adjusting the density of the sphere, which reduces the average dielectric constant by introducing "air" into the particle, one can roughly approximate the bulk scattering properties expected from actual particle and aggregate shapes. Figure 1, below illustrates three of the characteristic particle shapes used in this research, a 5 flake aggregate, a single snowflake, and a reduced density ice-air sphere.

However, because Mie Theory requires that the sphere be comprised of a homogeneous dielectric material, one has to choose among a number of methods to compute the "average" dielectric constant for various combinations of ice and air. Two commonly employed methods are those of the Effective Medium Theory (EMT/Bruggeman) and the Matrix Inclusion Method (Maxwell Garnett). For the current study we use only the Bruggeman method [1]. For the characteristic non-spherical hydrometeor shapes, we use the DDA formulation of Draine and Flatau [2] to compute their respective scattering and absorption properties.

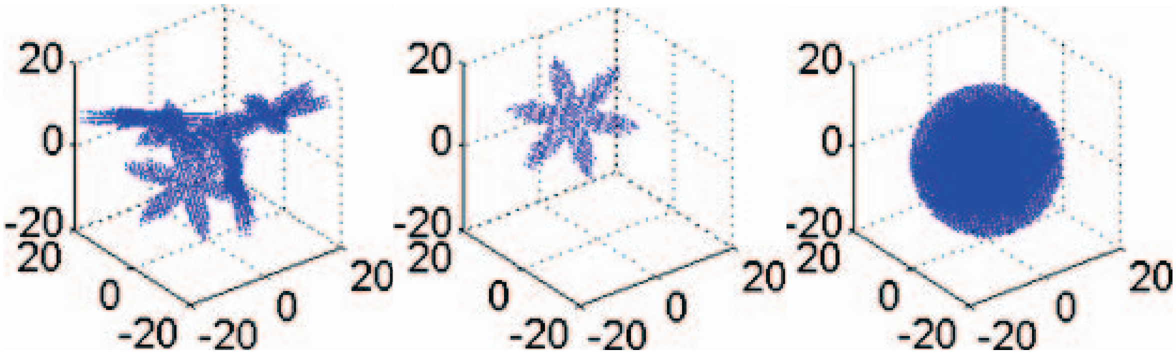
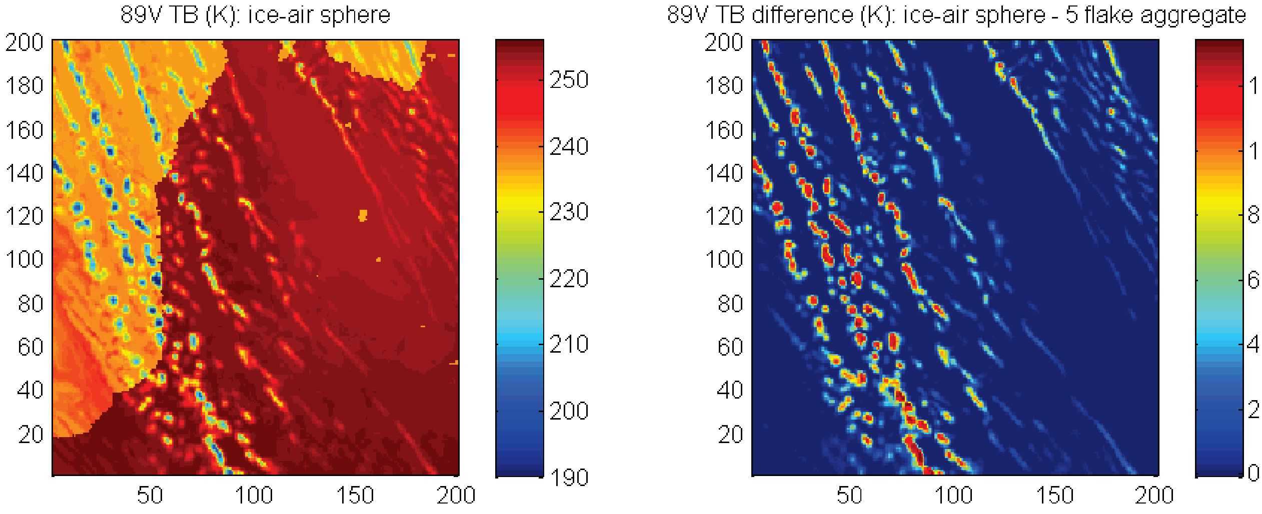


Figure 1: Example of a 5-snowflake aggregate, a single snowflake, and an ice-air sphere for use in DDA type applications.

4. EXAMPLE RESULTS

Using the forward model described by [Johnson, 2009] on a semi-infinite layer of hydrometeors, we can compute the "worst case" passive microwave TBs for each of the characteristic shapes (including mass-equivalent fluffy spheres). Preliminary results from an earlier study are shown in figure 2, which compares forward modeled 89 GHz TBs using WRF data simulating a lake-effect snowfall event. The second panel shows the difference in TBs if spherical particles are replaced by 5 flake aggregates (without changing the mass/IWP). Figure 3, below, shows an example retrieval using a Bayesian algorithm on passive microwave data simulated from WRF data.


89V TB (K): ice-air sphere

89V TB difference (K): ice-air sphere - 5 flake aggregate

Figure 2: 89 GHz forward modeled brightness temperatures (nadir) assuming ice-air spheres (left panel), and the difference between the sphere results and the TB results assuming a 5 flake aggregate as shown in figure 1.

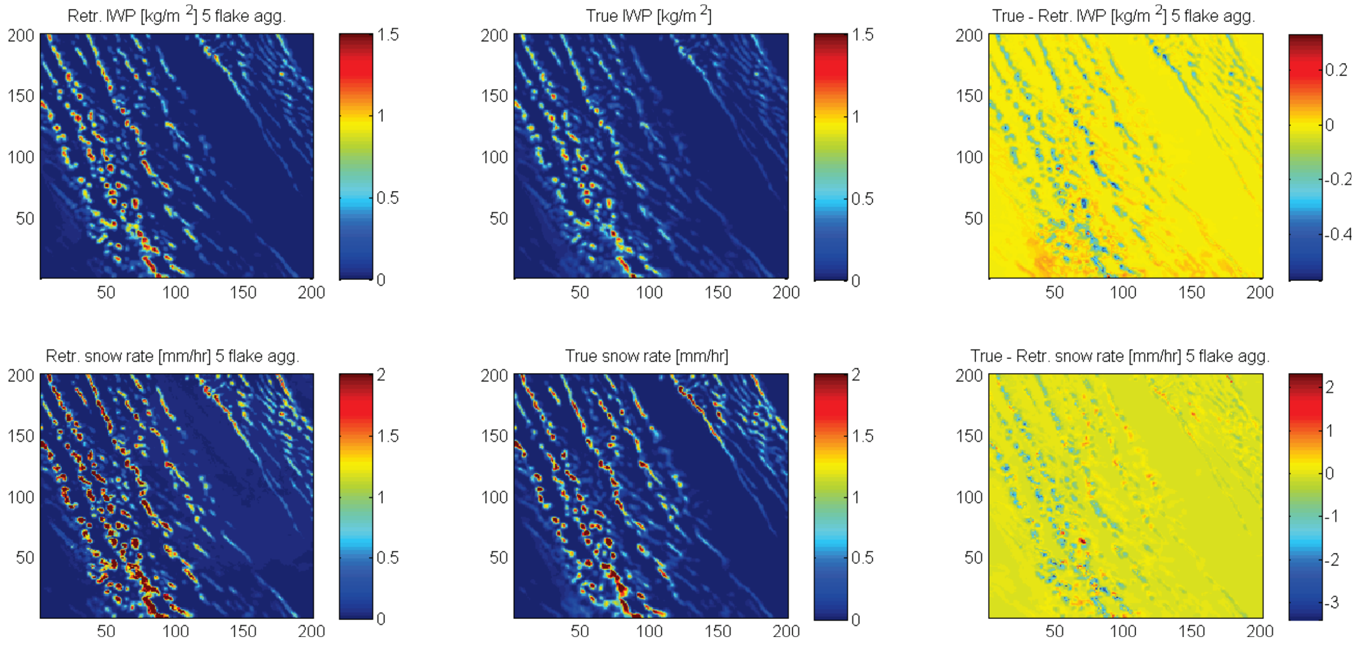


Figure 3: Comparison of retrieval assuming only the 5 flake aggregate snowflake shape and compared to the "true" IWP (based on WRF simulation) using a Bayesian retrieval method.

5. COMMENTS

The above work is ongoing and is expected to shed some new insight into how sensitive forward models and retrieval algorithms are to assumptions regarding particle shape. We can see from figure 3 that an arbitrary change in particle shape can have dramatic results in standard retrievals. This research will also help identify existing issues with (a) the computation of the scattering properties of non-spherical particles and (b) help guide the selection of which particle shapes to employ when faced with uncertainty regarding the true particle shapes, rather than simply selecting an arbitrary shape and assuming that it is correct.

6. SELECTED BIBLIOGRAPHY

[1] B. T. Johnson, "Combined Radar Radiometer Retrievals of Snowfall over Ocean," University of Wisconsin -- Madison, 2007.
[2] B.T. Draine and P.J. Flatau, "Discrete dipole approximation for scattering calculations," *J. Opt. Soc. Am. A*, Vol. 11., 1994.