Modeling of microwave extinction and scattering by complex snow aggregates for GPM

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1. Introduction

a) Background

Historically, physical models for the microwave properties of snowflakes, as required for both radar applications and passive microwave radiometry, have typically been based the "fluffy sphere" approximation -- that is, the assumption that they are mass-equivalent homogeneous spheres whose effective dielectric properties correspond to a suitable blend of ice and air, and possibly liquid water, using the Bruggeman or Maxwell Garnett formulations.

Actual snowflake structures are of course quite complex and far from either spherical or homogeneous. A long-standing question, therefore, has been whether the "fluffy sphere" approximation is really "good enough" for the physically based remote sensing of precipitation.

b) Relevance to the Precipitation Measuring Mission (PMM)

Especially with the advent of dual-frequency radars and combined radar-radiometer methods based on physical models, it is no longer just the ballpark backscatter and extinction properties that are important but also their (a) precise spectral dependence and (b) the precise relationship between radar backscatter and bulk attenuation and scattering at selected radiometer frequencies.

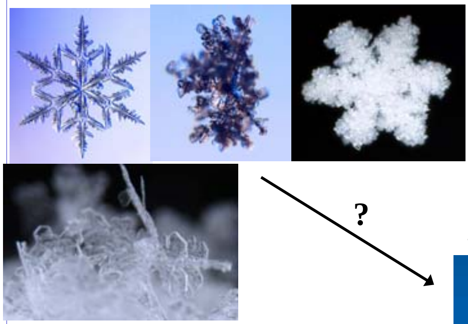
While direct field measurements of microwave attenuation and scattering by snowfall would be extremely valuable for validating or refuting the fluffy sphere assumption, such measurements are expensive and, to date, have not been undertaken under a sufficiently wide range of conditions or for a complete set of relevant frequences. For the time being, we therefore must continue to rely on physical models.

c) Problem definition

There are two distinct and essential parts to the modeling of the microwave properties of snow particles:

- create a reasonably representative model of the geometric structure of a snow crystal aggregate or aggregate, and
- solve the electromagnetic wave equation for the chosen structure.

This poster describes our recent progress with both problems.



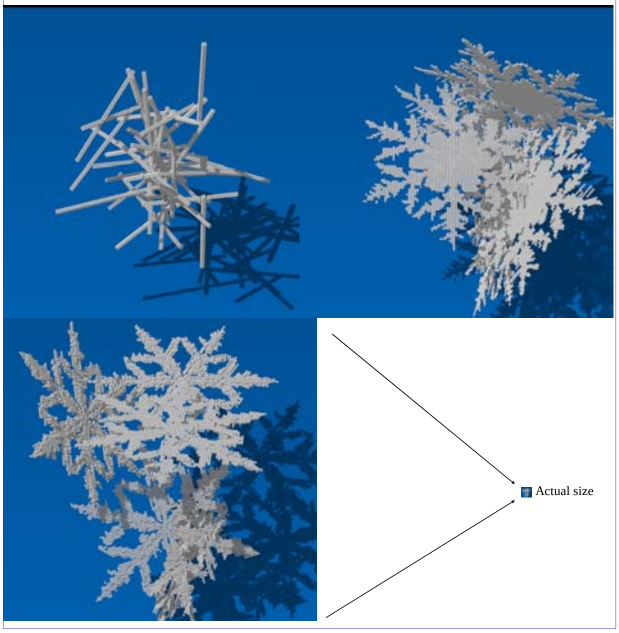
"Fluffy sphere" model

2. Geometric Model

To construct a quasi-realistic snowflake, we first define the shapes of elemental structures, such as ice needles or dendrites. The shapes are expressed as collections of regularly-spaced nodes, each one of which will subsequently be treated as an elementary electrically polarizable particle.

Needles are approximated as rectangular prism of large aspect ratio. Dendrites are most easily constructed by digitizing at fairly course resolution actual photographs of snowflakes, such as those collected by Libbrecht (above, far left).

We then use a stochastic algorithm to assemble these elemental structures into aggregates. The figures below show examples of aggregates assembled from three different types of elemental crystals.



3. Computational Method

a) The Discrete Dipole Method

With the advent of inexpensive CPU power and memory, the so-called Discrete Dipole Approximation (DDA; also known as the Coupled Dipole Approximation; originally proposed by Purcell and Pennypacker, 1973) has gained popularity as the method of choice for computing the scattering and absorption properties of non-spherical ice crystals (e.g., bullets, rosettes, plates, etc.) in the microwave band (Kim 2005, Liu 2004).

b) DDSCAT

The most commonly used DDA software package is for the above simulations DDSCAT (Draine and Flatau, 1994). DDSCAT becomes impractical, however, for modeling the highly complex and sparse structures characteristic of snow aggregates and rimed dendrites. This is because the particle shape must be defined on a regular three-dimensional rectangular grid, and large amounts of memory must be allocated both to space that is empty as well as space that is occupied by a dielectric medium such as ice. For example, some of the structures depicted here would require over 4 GB of physical memory to simulate using DDSCAT. Even moderately more complex particles would swamp the memory resources of all but the largest computers.

c) SDDA

We have developed an alternative DDA code, called the Sparse Discrete Dipole Approximation, or SDDA, that relaxes the above restriction, allocating memory only to occupied portions of the domain, thereby greatly reducing the the memory and making calculations more tractable for large but sparse particles. Furthermore, constituent dipoles need not lie on Cartesian grid points. It is therefore possible to construct aggregates of randomly oriented complex crystals with greater realism and with the need for fewer dipoles than would be possible with DDSCAT.

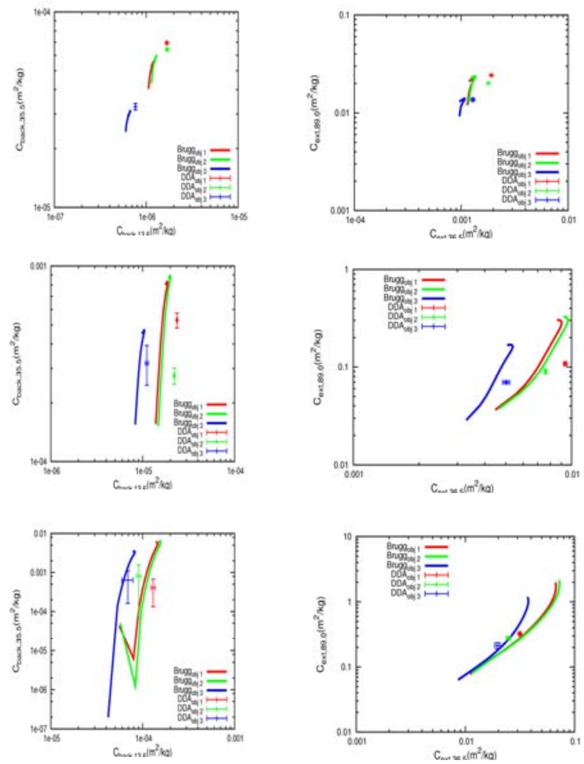
For particles occupying a low volume fraction, the memory requirements of SDDA are approximately 1000 times smaller than those of DDSCAT.

d) Validation

We validate the performance of SDDA by computing the electrodynamic properties of spheres having a known fraction of the space inside in the sphere occupied by randomly distributed dipoles. The results from SDDA in this case can be directly compared with the "fluffy sphere" results based on Mie theory combined with suitable dielectric mixing formulas. We find that the agreement between the two methods is excellent over a wide range of sizes and particle densities, lending credence to both SDDA and the validity of the mixing formulas.

Radar backscatter cross-section is the variable that suffers most when the dipole representation of the particle becomes too coarse. We therefore require the dipole spacing to be no more than about 2% of the shortest wavelength of interest.

4. Results



5. Conclusions

These simulations suggest that the common "fluffy sphere" approximation fails to produce accurate ratios of radar backscatter cross-sections at the two GPM frequencies or between backscatter cross-sections and microwave attenuation at radar and radiometer frequencies.

Further calculations will be needed in order to determine whether the "fluffy sphere" approximation can be salvaged via empirical corrections or whether an entirely new parameterization of these properties is required.

Furthermore, considerable work is still required on the problem of melting snowflakes. The definition of suitable geometric models may be the most difficult part of that problem; hence, field measurements remain extremely desirable.

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