Scattering Computations of Snow Aggregates from Simple Particle Models

Liang Liao
GESTAR/MSU, Greenbelt, MD

Robert Meneghini
NASA/GSFC, Greenbelt, MD

Holly Nowell
FSU, FL

Guosheng Liu
FSU, FL

Introduction

Accurately characterizing electromagnetic scattering from snow aggregates is one of the essential components in the development of algorithms for the Global Precipitation Measurement (GPM) Dual-frequency Precipitation Radar (DPR) and Microwave Imager (GMI). Recently several realistic aggregate models have been developed by using randomized procedures. For these particles, a numerical scheme is needed to compute the scattered fields. These computations, however, are usually time consuming. As an alternative to these complex models, the simple geometric models are useful for radar and radiometer applications if their scattering results can be shown to closely approximate those from complex aggregate structures.

To find simplified particle models that can be used to approximate radar and radiometer scattering parameters of the aggregates over DPR and GMI frequencies, spherical and spheroidal particles are used along with two mass density models, namely the variable and fixed snow density models. The scattering results from these models will be compared with the results from direct computations of snow aggregates composed of 6-branch bullet rosettes. The aggregates are constructed in a way that the mass density of the circumscribing sphere of an aggregate follows a specified density-size relationship. In the variable snow density model the snow density is changed as a function of the particle size while for the fixed snow density model, the density is taken to be constant with particle size. The primary purpose of this study is to evaluate the accuracy of using simple particle shapes (spherical/spheroidal), with two different mass density assumptions, to reproduce the scattering properties of snow aggregates over the range of GPM frequencies from ~10 to 183 GHz.

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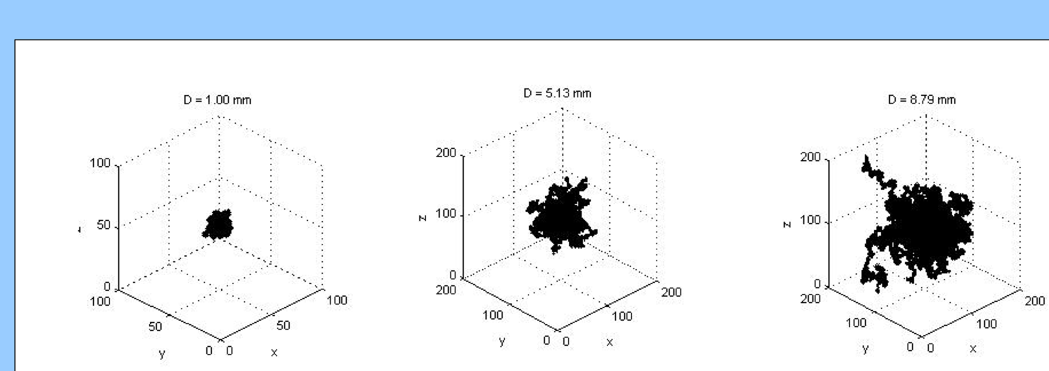
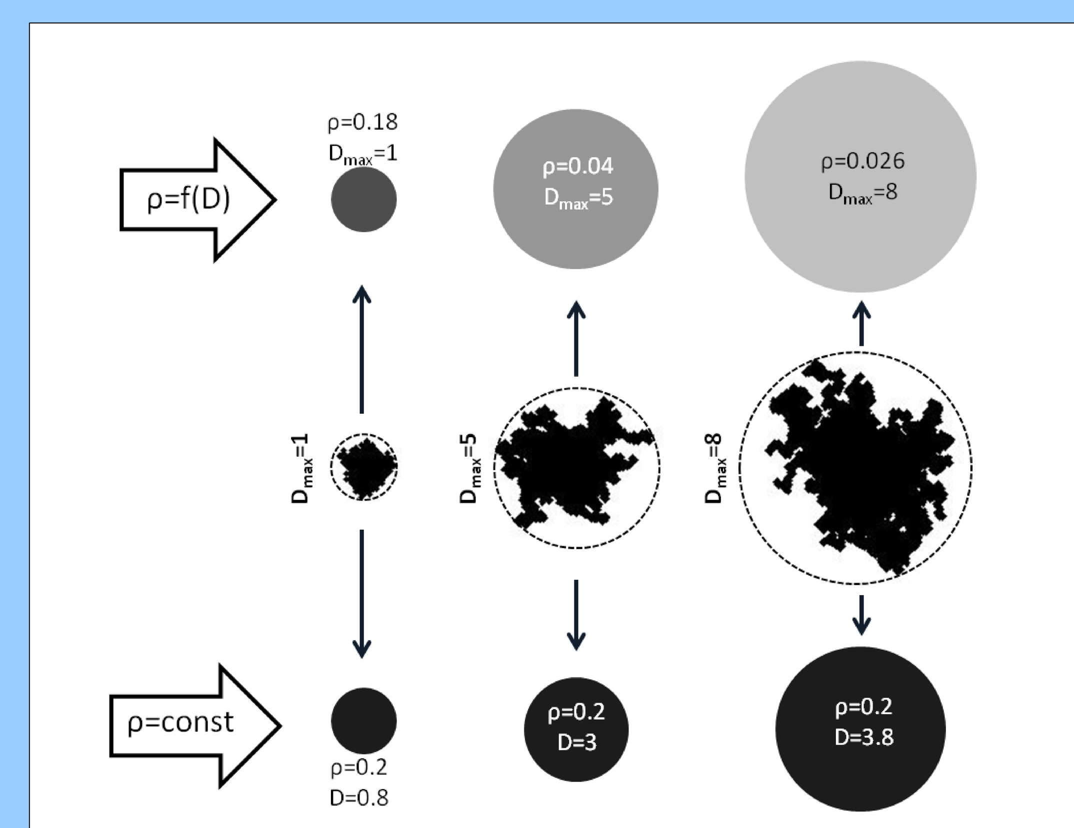
Aggregates

To generate more realistic aggregate models, 6-branch bullet rosettes are used as the basic elements of snowflake aggregates, and two sizes of single bullet rosettes with maximum dimensions of 200 and 400 μm are employed to form snow aggregates. Shown in Figure are examples of simulated snow aggregates with maximum dimensions of 1, 5.13 and 8.79 mm. Each aggregate is constructed in a way such that the bulk density of a circumscribing spherical particle satisfies the Brandes et al. density-size relationship (2007).



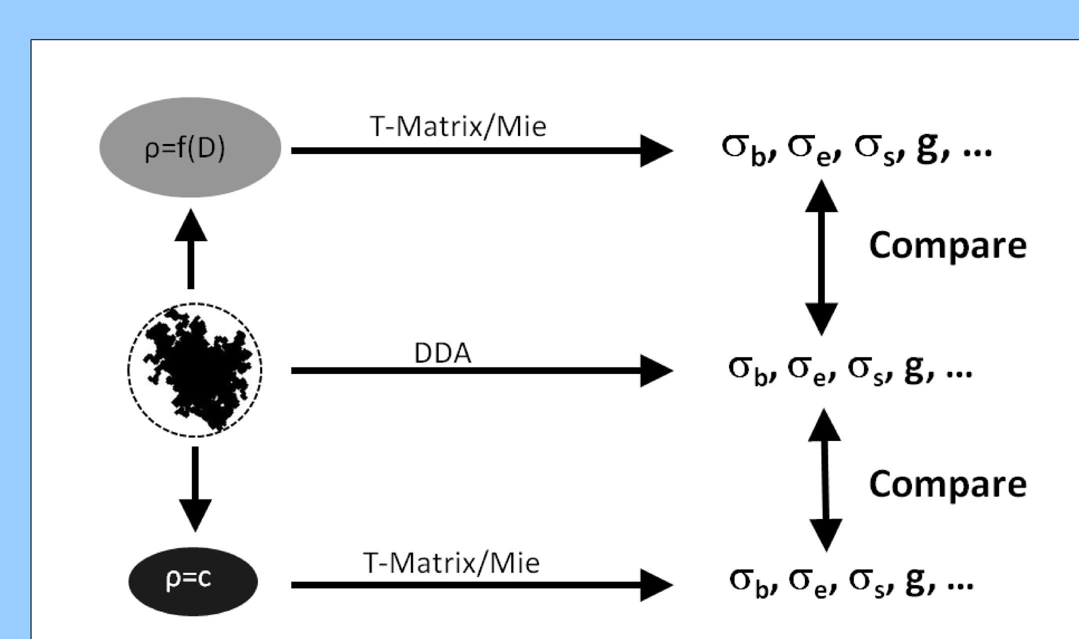
Simple Models

To improve the computational efficiency of aggregate scattering, the sphere or spheroid and an effective dielectric constant for the ice-air mixture are used to represent the aggregates so that the aggregate is replaced by a homogeneous spherical/spheroidal particle. Shown below is an illustration of modeling a snow aggregate (middle row) as a sphere with a mass equal to the mass of the aggregate. The spherical model for which the mass density (ρ) is defined by the ratio of the aggregate mass to the volume of circumscribing sphere with a diameter equal to the maximum dimension (D_{max}) of the aggregate (top row), is referred to as the variable snow density model, $\rho=f(D_{max})$. The spherical model with a constant density, e.g., $\rho=0.2$ g/cm^3 and its diameter (D) determined by the mass of the aggregate (bottom row) is referred to as the fixed snow density model, i.e., ρ=const.



Procedures

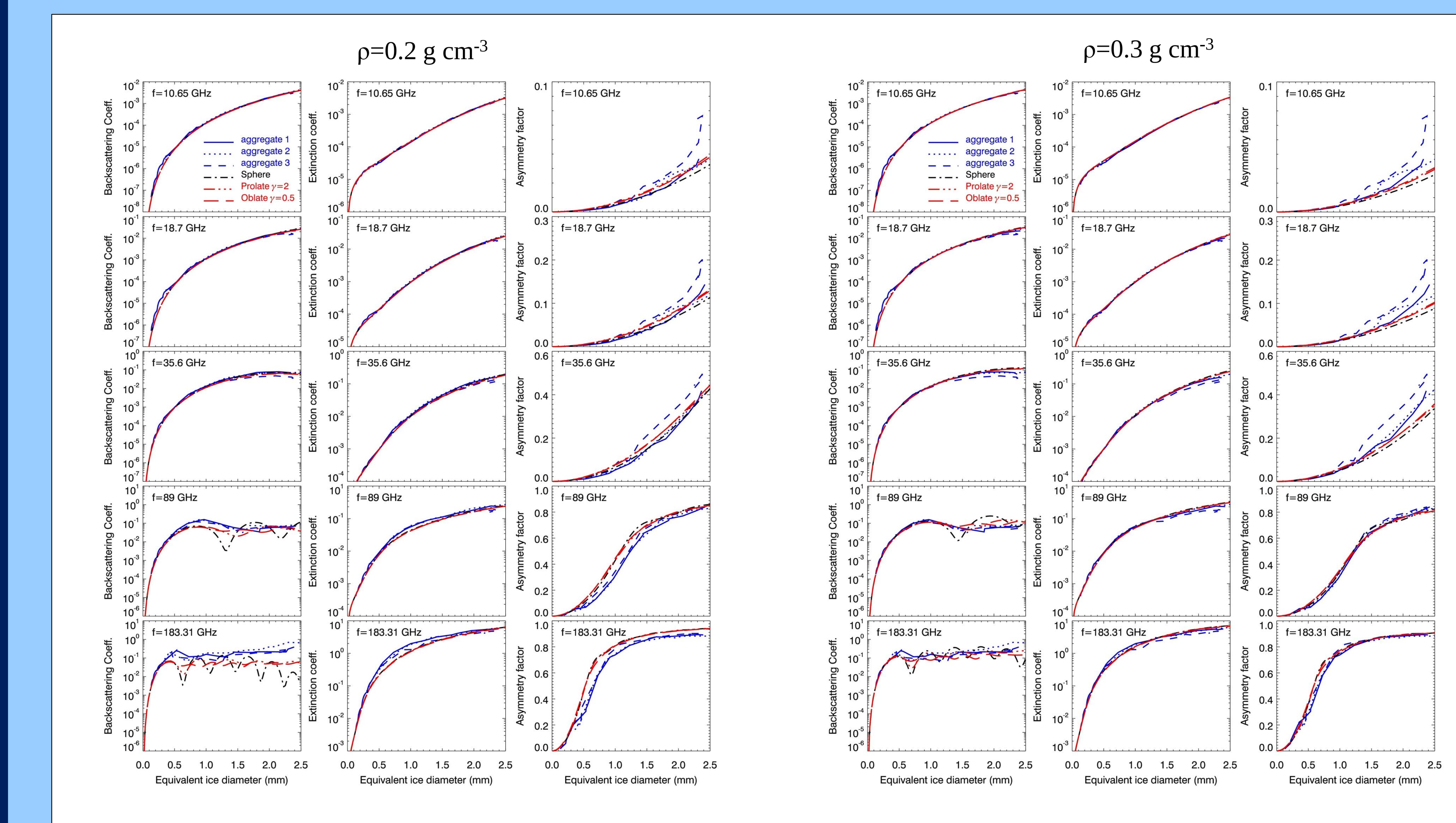
Figure depicts schematic diagram showing the procedures used to test the validity of the spherical and spheroidal models with variable snow density ($\rho=f(D)$) and fixed snow density ($\rho=c$) by comparing scattering results of the models with direct numerical (DDA) computations from the aggregates. The scattering parameters used in the comparisons include backscattering (σ_b), scattering (σ_s) and extinction (σ_e) coefficients as well as asymmetry factor.



Results & Remarks

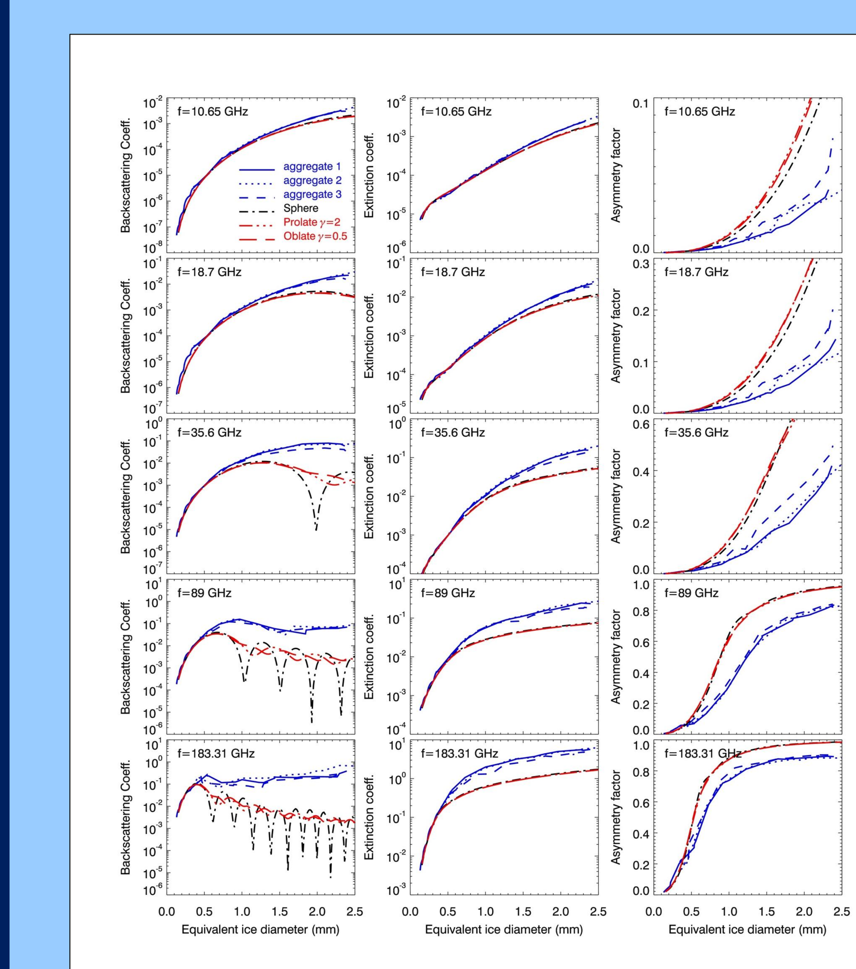
1. Fixed Snow Density Model

Displayed are comparisons of scattering results of 3 snow aggregates with the results from the sphere, oblate and prolate spheroids at several frequencies in terms of equivalent ice diameter. Constant snow density of 0.2 g/cm^3 (left) and 0.3 g/cm^3 (right) are assumed for all spherical and spheroidal particle models. The oblate and prolate spheroids are randomly oriented with aspect ratios (γ) of 0.5 and 2, respectively.



2. Variable Snow Density Model

For the spheres and spheroids, the variable snow density model is used. For all particle models, aggregate as well as sphere/spheroid, the snow density defined by the circumscribing sphere follows the Brandes et al. density-size relationship.



3. Remarks

Comparisons of scattering results between the complex aggregate and simple models indicate that the scattering parameters of large complex aggregates differ significantly from those obtained from the equivalent-mass spherical- and spheroidal-shaped particles when the variable snow density is assumed. In contrast to the variable snow density model, the scattering properties of the aggregates are fairly well reproduced by the fixed snow density model. Although the results from a fixed snow densities between 0.2 and 0.3 g/cm^3 reveal good overall agreement with those from the aggregates, the value of 0.2 g/cm^3 yields the best agreement for the frequencies less than or equal to 35.6 GHz while the model results with a density set to 0.3 g/cm^3 show the best match with the aggregates at frequencies higher than 35.6 GHz. Moreover, scattering parameters of the randomly-oriented spheroidal ice-air mixtures tend to agree better with those from the aggregates than do spherical snow particles.