A NEW APPROACH TO MODELING ICE CRYSTAL AGGREGATES AND ITS IMPLICATIONS FOR RADAR REMOTE SENSING

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1. INTRODUCTION

The remote sensing of clouds is important for meteorological and climatological studies [1]. Millimeter wave radars are increasingly being used for this purpose [2]. Retrieval of ice water content (IWC) is important for remote sensing applications and radar reflectivity measurements are essential for this purpose [3]. Hence, evaluating the electromagnetic scattering properties of ice crystal aggregates is necessary for understanding radar observations of ice clouds. This study presents a new approach for modeling ice crystal aggregates and shows significant differences with the currently used bulk models, especially at millimeter wave frequencies.

2. SCATTERING COMPUTATIONS

The conventional approach to computing the scattering characteristics of ice crystal aggregates exploits a bulk model for the particles. An effective dielectric constant is generated for a mixture of air and ice using the Maxwell Garnet formulation [4]. The ice particles are generally assumed to have shapes that are spherical or spheroidal [5], and the T-matrix method is used for the scattering computations [6]. This study develops a new and more detailed approach for modeling ice crystal aggregates and utilizes the Generalized Multiparticle Mie (GMM) method for computing the electromagnetic scattering characteristics of the model aggregates and compares them with the T-matrix results based on the bulk model representation. The GMM method is an analytical solution of scattering by a set of non-overlapping spheres with arbitrary position and size. This method is an extension of Mie theory taking into account the interaction fields between each sphere and has been shown to compare very well with measurements [7], [8].

3. ICE CRYSTAL AGGREGATE MODEL

The aggregates are constructed from columnar crystals of random lengths, each column is composed of a string of touching ice spheres with diameter (d) equal to the column's width. The width (d) is a function of the length (L) of a column through the relation $d = 0.129\ L^{0.437}$ (with d and L in mm) [9]. Each aggregate is a cluster made of a number of columnar crystals having random lengths, orientation, and position. Each added new column is required to have an overlapping sphere with one of the columns already in the aggregate. A circumscribing oblate spheroid with a given equivalent volume diameter (D) and aspect ratio (ratio of the minor and major axes) is used to generate an aggregate. Parts of any column that protrudes from this spheroid are removed. The aggregate generating code uses an iterative technique in order to obtain the desired aggregate bulk density, which is calculated as the ratio between the mass of the ice and the volume of the circumscribing oblate spheroid. The desired density is obtained by increasing or decreasing the number of columns. The density is computed using the relationship $\rho = 0.15\ D^{-1}$ [g/cm^3] (with D in mm units) given in [10]. Fig. 1 shows an aggregate generated in this manner.

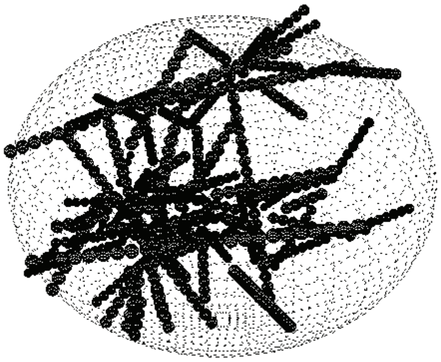

Fig. 1 Aggregate generated from columnar crystals composed of touching ice spheres. The circumscribing spheroid is also shown.

4. RESULTS AND CONCLUSIONS

Results have been generated at 35.6 GHz for aggregates with equivalent diameters ranging from 2.5 to 10 mm and aspect ratio 0.4. Fig. 2 shows the average (over 10 aggregate realizations for each size) backscattering scattering cross-sections at horizontal polarization (σ_{hh}) and the backscattering cross-section ratios at horizontal and vertical polarizations (σ_{hh}/σ_{vv}), based on the GMM method and the T-matrix method for the bulk model. Notice the large differences in both σ_{hh} and σ_{hh}/σ_{vv} between the bulk model and the GMM results; for D > 3 mm the difference in σ_{hh} exceeds 7 db. It is clear that the bulk model results do not produce accurate backscattering cross section results at this frequency (35.6 GHz) and for this size range (3 to 10 mm). These differences are not as pronounced at S-band frequencies, e.g.,3 GHz (not shown here). Hence, bulk models of ice crystal aggregates must be used with caution when evaluating radar observations based on the backscattering cross section.

5. REFERENCES

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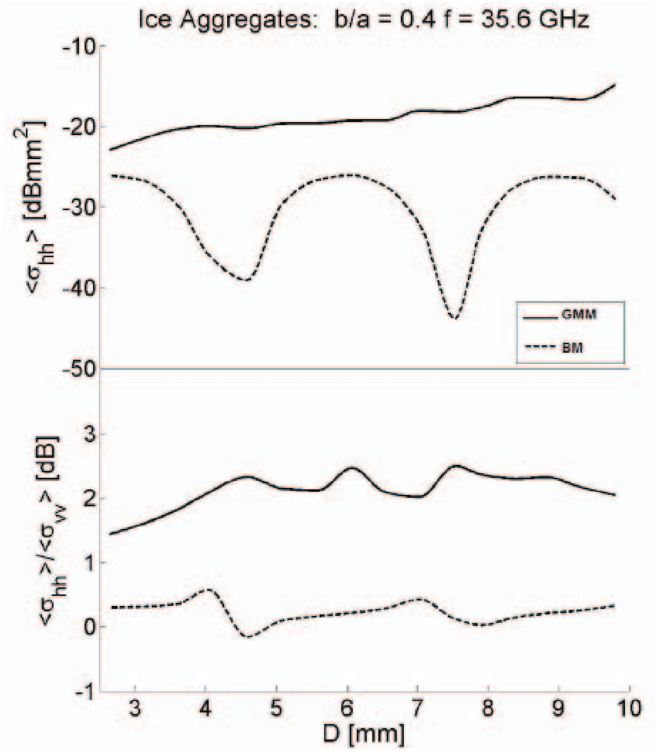

Fig.2 Backscattering cross section at horizontal polarization, and backscattering cross section ratio computed with the GMM method and with the T-matrix method for bulk models (BM) of ice crystal aggregates.