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Modeling radar backscattering from melting snowflakes using spheroids with nonuniform distribution of water

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ABSTRACT

In a number of studies it is reported that at the early stages, melting of aggregate snowflakes is enhanced at lower parts. In this paper, the manifestation of the resulting nonuniform distribution of water is studied for radar backscattering cross sections at C, Ku, Ka and W bands. The melting particles are described as spheroids with a mixture of water and air at the bottom part of the particle and a mixture of ice and air at the upper part. The radar backscattering is modeled using the discrete-dipole approximation in a horizontally pointing geometry. The results are compared to the T-matrix method, Mie theory, and the Rayleigh approximation using the Maxwell Garnett mixing formula. We find that the differential reflectivity and the linear depolarization ratio show systematic differences between the discrete-dipole approximation and the T-matrix method, but that the differences are relatively small. The horizontal cross sections show only small differences between the methods with the aspect ratio and the presence of resonance peaks having a larger effect on it than the nonuniform distribution of water. Overall, the effect of anisotropic distribution of water, reported for early stages of melting, is not significant for radar observations at the studied frequencies.

1. Introduction

Recently, importance of snowflake shapes in electromagnetic scattering has received a lot of attention. It was shown that in many cases the application of a spheroid shape model could result in an underestimation of backscattering cross [1–3] relative to more realistic models using the discrete-dipole approximation (DDA). It is also important to understand whether a nonuniform distribution of water in the melting process produces detectable radar signatures and needs to be taken into account. Although the melting behavior is guided by the snow crystal habit [4–6], for snowflakes, both Fujiyoshi [7] and Mitra et al. [8] described the early stages of melting to be more intense on the lower side of the flake. The combined effect of snowflake shape and melting on radar observations was studied in [1]. However, this approach does not allow for separating the effects. In this paper we have selected a simpler, spheroidal shape model of a snowflake, and focused our study on the impact of anisotropy of the early melting stage.

In the present paper, radar backscattering from fluffy and wet, inhomogeneous spheroidal/spherical ice particles is studied using DDA, and the results are compared to T-matrix

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(TMM)/Mie computations using the Maxwell Garnett (MG) effective medium approximation (EMA). We use a nonuniform melting model in DDA by melting only the dipoles at the bottom part of the generated particles. EMA is also used for the DDA shape model, where the upper part is a mixture of ice and air, and the bottom part is a mixture of water and air representing the fluffy structure of snowflakes. The computations are performed at C (5.6 GHz), Ku (13.6 GHz), Ka (35.6 GHz) and W (94.0 GHz) bands, which are common frequencies in ground-based weather and cloud radars.

There are three main reasons why we have chosen the spheroidal model for melting snowflakes. Firstly, the accuracy of DDA for partially melted snowflakes at microwave frequencies has been poorly studied. It was shown by Tyynelä et al. [9] that adding a thin layer of dipoles consisting of liquid water, and modeling backscattering at the C band (5.6 GHz) produces relative errors in the backscattering cross section in the order of 25% due to the large refractive index of liquid water at microwave frequencies (see Section 3). They attributed the error to inadequate electromagnetic modeling of the skin layer of an absorbing particle. Zubko et al. [10] showed that the dipole spacing needs to be a few times smaller than the skin layer, which is determined by the imaginary part of the refractive index. In our study, this means that the grid sizes would need to be about three times larger at the W band. Due to the fluffiness of snowflakes, we use EMA, which circumvents the problem with large refractive indices. This is not possible with complex, more realistic models, which need to take into account the skin layer, and can result in too large grid sizes to be feasible at the moment. Some studies, such as [1], have used the superposition method for multiple spheres, which is more accurate at large refractive indices. Yurkin et al. [11] provide an alternate form to the polarizability of dipoles to improve the accuracy of DDA. We have adopted this form in our study.

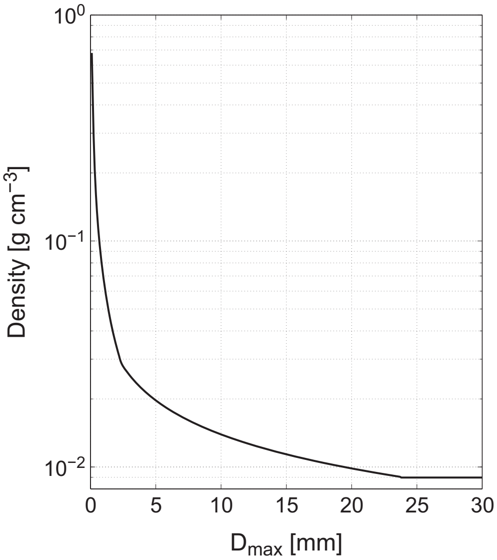

Fig. 2. The density of snowflakes as a function of particle diameter. The mass of snowflakes is taken from [17].

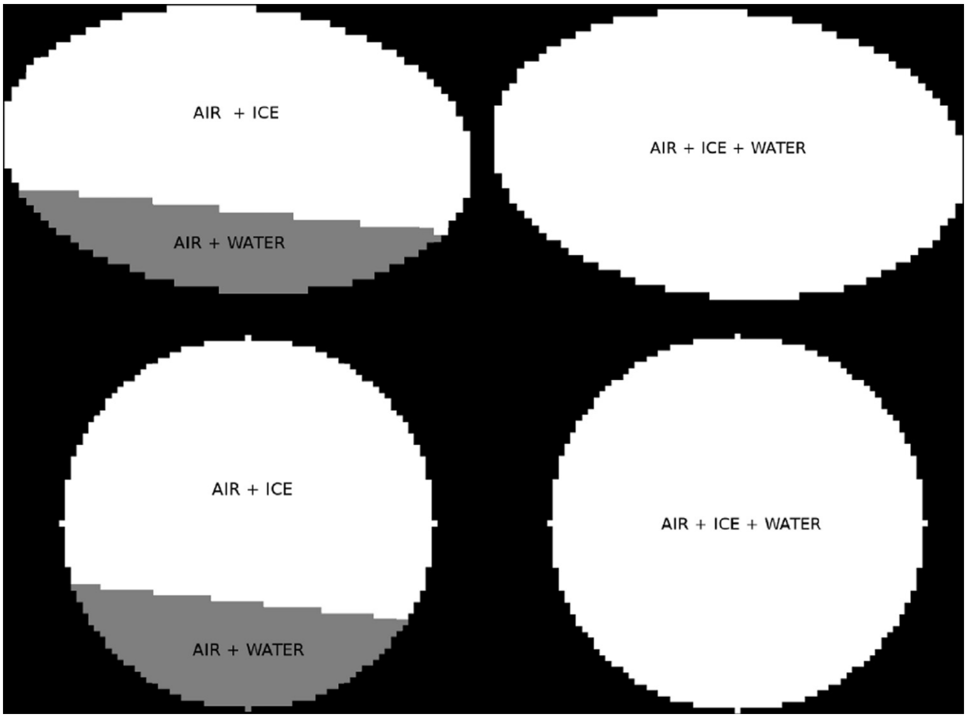

Fig. 1. Example shapes of fluffy snowflakes used in the computations with 20% water content and 6° canting angle. Two different shape models are used, namely spheres (bottom panels) and spheroids (top panels), which can be either homogeneous (right panels) or inhomogeneous (left panels). The presence of liquid water in the inhomogeneous particles is indicated with grey shading.