MODELING ATTENUATION OF MELTING HYDROMETEORS WITH A METHOD BASED ON VOLUME INTEGRAL EQUATIONS

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1. INTRODUCTION

Precipitation plays a significant role in Earth's hydrological cycle, and both measuring and modeling its intensity, distribution, and form reveals essential information for climate change and meteorological research. NASA's Global Precipitation Measurement (GPM) mission will cover the Earth with a dual-frequency precipitation radar (DPR) operating in Ka-and Ku-bands and high resolution multi-channel passive microwave (GMI) radiometers, offering important data on precipitation, concentrating on its solid and mixed-phase forms such as snow, mixed rain and snow, and hail [1]. On a regional scale, the Finnish ground-based weather radar network will be renewed in coming years with dual-polarimetric systems improving the identification of different atmospheric hydrometeors. Both of these projects, with similar others, arouse interest on algorithms for the classification of solid and mixed-phase hydrometeors and improved accuracy of remotely sensed quantitative precipitation estimation (QPE).

2. METHOD

In this study, melting hydrometeors are modeled and their scattering and attenuation properties are calculated in C-band using a volume integral method, which is similar to the discrete-dipole approximation (DDA), and the zeroth-order radiative transfer theory (RT) [2]. DDA is utilized widely in various scattering problems, including microwaves and hydrometeors. In [3] different shapes of snow particles such as hexagonal columns, four-arm rosettes, and six-arm rosettes are modeled with DDA at frequencies between 95 GHz and 340 GHz; based on these modeling results an algorithm for snow crystal brightness temperatures is developed [4]. A similar study, also for ice crystals and aggregates, has been performed at lower frequencies (from C- to Ku-Band) by [5]. In [6] spheres, spheroids and clusters are modeled in C-band with DDA and compared to the T-matrix method. The particles are assumed to be either purely ice or water, or ice particles coated with water. According to [6] the performance of DDA is sufficient for homogeneous particles, but for inhomogeneous particles with conductive coating a very high-resolution grid is needed to model them realistically. We have applied volume integral method and RT also for melting particles in Ku- and Ka-band. The idea is, based on these studies, to develop an algorithm for detecting melting precipitation particles for the GPM mission. At the moment the validation of the method is performed in C-band and the results are encouraging. They show that in the two polarization components the fine structure of the solid precipitation can be seen, i.e. the differential accumulation of the water inside a particle creates a notable attenuation effect. Thus the improved polarimetric algorithm in C-band provides a deeper insight into the problem, which will no doubt result in more accurate validation of the algorithms at higher frequencies in the GPM mission. In the coming winter, we will also conduct simulations with a surface-integral equation method and effective medium approximation (EMA) for homogeneous particles in Ku- and Ka-bands and these results are presented in the conference as a comparison.

For simplicity, the modeled particles are described as spheroids with four specific melting stages and with an orientation angle defined with respect to the axis of rotational symmetry. The actual individual snowflakes are far from spheroidal in shape, but, statistically, when ensemble-averaged, they can be described as spheroidal [7] and in this study the emphasis is on modeling the effect of increasing liquid water inside the particle for attenuation considerations. In the four stages the particle is described as

1. Dry snow sphere with the permittivity calculated according to generalized mixing formula [8] with a specific ice/air volume ratio.
2. Snow sphere with random water inclusions at the outer edge of the particle, when the inner part is still assumed to be snow.
3. Snow sphere with most of the water gathered at the bottom of the particle. In the electromagnetic point of view the shape of the particle becomes oblate, since the permittivity of water is much larger than that of snow (Fig.1.).
4. Oblate water spheroid (axial ratio of 0.9) with a permittivity calculated from the Debye equation [8].

The scattering properties of the particles at different stages are calculated with the volume integral method. As with DDA, it is a flexible and a generic technique for calculating the electrical properties of particles with arbitrary shapes and compositions. To solve both the scattering and attenuation properties of a layer consisting of hydrometeors with a specific numerical density, an assumption of independent scattering is made, and the zeroth-order of the RT is used.

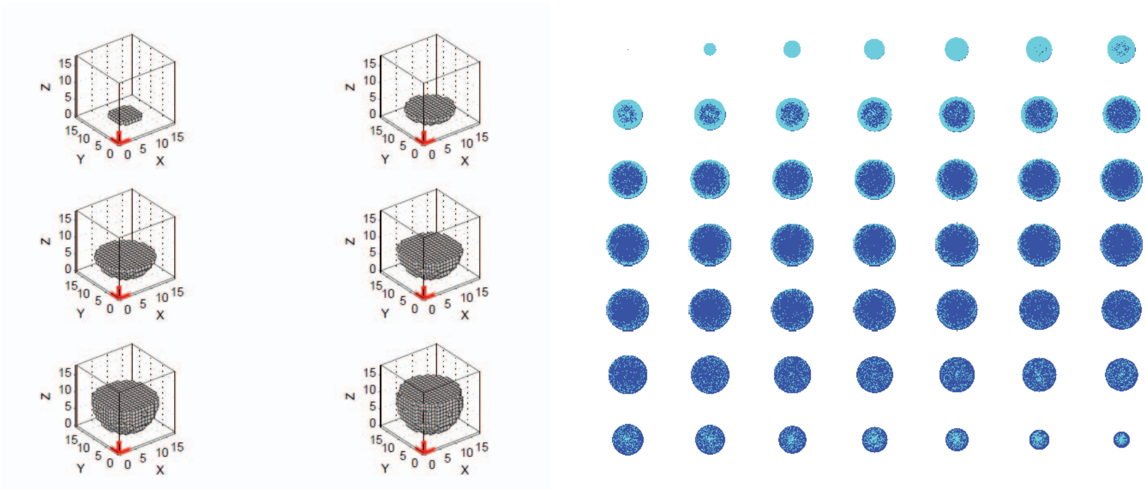

Figure 1. At left is an illustration of the particle formation with small dielectric subunits from base upwards along the z – axis; on the right side the stratification structure of a particle at stage three is demonstrated (turquoise presents water and blue snow) [9].

3. RESULTS

Preliminary results from attenuation modeling in C-band suggest that the difference between like-polarizations (HH and VV) increases strongly when more water accumulates in the bottom of the particle and when the particle changes to a flatter shape (Fig. 2). The attenuation is higher for HH- than for VV-polarization. The difference is greatest for the particles at the third stage with a mid-amount water volume fraction, even compared to the water spheroid of the fourth stage. This is attributed to the fact that the high permittivity of water causes the spherical partly melted particle, electromagnetically speaking, to resemble more an oblate shape than the water spheroid.

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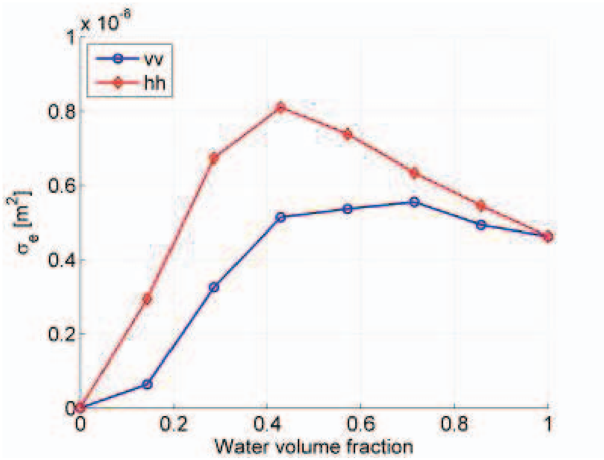

Figure 2. Extinction cross section of the third melting stage as a function of water volume fraction [9].

4. REFERENCES

[1] http://gpm.gsfc.nasa.gov/

[2] F.M. Kahnert, "Numerical methods in electromagnetic scattering theory," *Journal of Quantitative Spectroscopy and Radiative Transfer*, vol. 79-80, pp. 775-824, Jun-Sep 2003.

[3] M-J. Kim,"Single scattering parameters of randomly oriented snow particles at microwave frequencies", *Journal of Geophysical Research*, vol. 111, D14201, 2006.

[4] M-J. Kim, M.S. Kulie, C. O'Dell, R. Bennartz, "Scattering of ice particles at microwave frequencies: A physically based parameterization", *Journal of Applied Meteorology and Climatology*, vol. 46, pp. 615-632, 2007.

[5] G. Botta, D. Scaranari, M. Montopoli and F.S. Marzano, "Backscattering modeling for polarimetric radar observation of ice crystals and aggregates from C to Ka band", *ERAD 2008 the Fifth European Conference on Radar in Meteorology and Hydrology*, Helsinki, Finland 30 June - 4 July 2008.

[6] J. Tyynelä, T. Nousiainen, S. Göke, K. Muinonen, "Modeling C-band single scattering properties of hydrometeors using discrete-dipole approximation and T-matrix method, *Journal of Quantative Spectroscopy & Radiative Transfer*, vol. 110, pp.1654-1664, 2009.

[7] H.W.J. Russchenberg and L.P. Ligthart, "Backscattering by and propagation through the melting layer of precipitation: A new polarimetric model", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 34, no.1, pp. 3-14, Jan 1996.

[8] A. Sihvola, *Electromagnetic Mixing Formulas and Applications,* The Institution of Electrical Engineers, London, United Kingdom, 1999, 284 pp.

[9] T. Piepponen," Numerical modeling of the backscattering of dual-polarization weather radar", Masters thesis in Finnish, Helsinki University of Technology, 2009.