IRS2012-215
International Radiation Symposium 2012
Dahlem Cube, Berlin, Germany, 06 – 10 August 2012

Optimal numerical methods for determining the orientation average of single-scattering properties of atmospheric ice crystals

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Lidar and radar observations show that ice clouds cover 17% of the Earth and up to 60% of the Tropics. The wide variety of shapes and sizes of non-spherical ice crystals makes it more difficult to represent cirrus in numerical models compared to water clouds. Current methods of representing the bulk scattering properties of cirrus for numerical models and satellite retrieval algorithms require weighting the single-scattering properties of certain shapes and sizes of ice crystals by their observed concentrations. Thus, to determine the influence of cirrus on solar and infrared radiation, as required for climate studies, knowledge of the single-scattering properties of ice crystals is required.

Except for a few large ice crystals, most ice crystals in clouds do not have preferred orientations. Thus, the corresponding single-scattering properties of ice crystals used for numerical models and remote sensing retrievals are typically calculated assuming random orientations. The Euler's angle, selected using a random number generator, has been exclusively used to determine the crystals' orientation for such calculations. When more orientations are used in the calculations, the scattering properties are determined with higher accuracy. However, computational resources limit the number of orientations that can be used in these calculations.

Past studies used several efficient orientation-averaging schemes (e.g., quasi-Monte-Carlo and optimal cubature on the sphere) for calculating light scattering properties. These studies mainly focused on small sizes and considered relatively simple shapes, such as spheres and sphere aggregates. Atmospheric ice crystals are non-spherical and their sizes are much larger than those studied previously.

In this study, the minimum numbers of orientations needed to determine the single-scattering properties of four different realistically shaped atmospheric ice crystals (i.e. column, droxtal, Gaussian random sphere, and budding Bucky ball) with predefined accuracy levels are determined using the Amsterdam discrete dipole approximation (ADDA) version 1.0. The results of the calculations are also used to quantify how the scattering and absorption efficiency, the single-scattering albedo, asymmetry parameter, and scattering phase function depend on sphericity, a parameter that is defined as the ratio of the surface area of a sphere with the same volume of given particle to the surface area of the particle. To generate the random orientations of ice crystals, the Euler's angles are selected using a quasi-Monte-Carlo method that uses a number sequence instead of a random number generator; its efficiency is compared with that of the internal orientation average method of ADDA. Further, simulations with varying sizes of ice crystals determine the influences of ice crystal size on the minimum number of orientations required to achieve the desired accuracy of the single-scattering properties. The results are reported for three different wavelengths of incident light, non-absorbing (0.55 μm), moderate absorbing (2.13 μm), and strongly absorbing (11 μm).