Optimal Method to Determine Orientation Average of Scattering Properties of Ice Crystals

Research Highlight

Current methods of representing the bulk scattering properties of cirrus for numerical models and satellite retrieval algorithms require weighting the single-scattering properties of specific 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 different shapes of ice crystals is required.

Except for a few large ice crystals, most ice crystals do not have preferred orientations. Thus, the corresponding single-scattering properties of ice crystals used for numerical models and remote sensing retrievals are calculated assuming random orientations. When more orientations are used to determine the mean scattering properties, the scattering properties are determined with higher accuracy. However, computational resources limit the number of orientations that can be used. Past studies used several efficient orientation-averaging schemes for calculating the light scattering properties of small crystal sizes and 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 optimal orientation averaging scheme (regular lattice grid scheme or quasi Monte Carlo (QMC) method), the minimum number of orientations, and the corresponding computing time required to calculate the average single-scattering properties (i.e., asymmetry parameter (g), single-scattering albedo (#o), extinction efficiency (Qext), scattering efficiency (Qsca), absorption efficiency (Qabs), and scattering phase function at scattering angles of 90° (P11 (90°)), and 180° (P11 (180°))) within a predefined accuracy level (i.e., 1.0 %) were determined for four different nonspherical atmospheric ice crystal models shown in Fig. 1 with maximum dimension D=10 µm using the Amsterdam discrete-dipole approximation (ADDA) version 1.0 at #=0.55, 3.78, and 11.0 µm.

The QMC required fewer orientations than the lattice grid and the use of QMC saved 55.4 (60.1, 46.3), 3065 (117, 110), 3933 (65.8, 104), and 381 (22.8, 16.0) hours of time using 300 2.6 GHz CPUs for computing all single-scattering properties within 1.0 % accuracy for the 3B, droxtal, Gaussian random sphere, and column at #=0.55 (3.78, 11.0) µm, respectively (Fig. 2). The calculations of P11 (90°), and P11 (180°) required more orientations than the calculations of integrated scattering properties (i.e., g, #o, Qext, Qsca, and Qabs) regardless of the orientation averaging scheme. The fewest orientations were required for calculating g and #o. The minimum number of orientations and the corresponding computing time required to achieve 1.0% accuracy in the single-scattering calculations decreased with an increase of wavelength. The minimum number of orientations increased with the surface-area ratio, a new parameter defined to characterize the shape of nonspherical particles as the surface area of a sphere with the same D of a given particle divided by the surface area of the particle -1.

The advanced orientation average scheme (i.e., QMC) requires fewer orientations than equal spaced orientation average schemes (i.e., lattice grid division) for calculating the single-scattering properties of nonspherical atmospheric ice crystals. Thus, its use can save a large amount of computing time, especially at nonabsorbing wavelengths and for particles with positive surface-area ratio. For large DDA simulations when a particle is much larger than the wavelength of incident light, the choice of orientation average scheme becomes more important. A subsequent study will extend this study to examine how the particles with larger sizes and more shapes with varying surface-area ratio affect the average single-scattering properties of nonspherical particles.

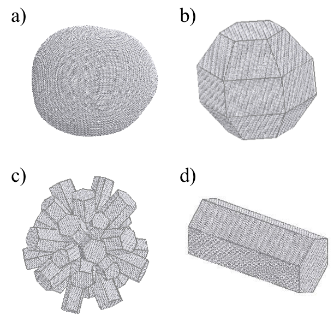

Fig.1. Idealized shapes of ice crystals used in this study: (a) Gaussian random sphere (GS), (b) droxtal (DX), (c) budding Bucky ball (3B), and (d) column (COL). All models are visualized with dipoles. For (b), (c), and (d) additional lines representing edges are embedded for clarity.

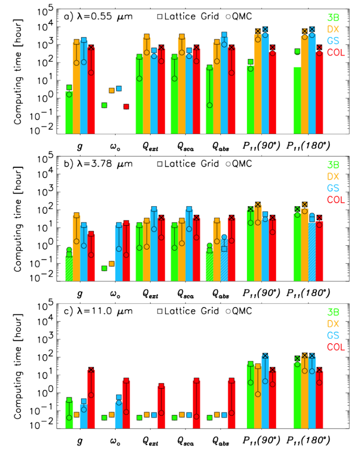

Fig.2. Computing time required to achieve 1.0% accuracy in single-scattering properties using lattice grid and QMC at (a) 0.55 µm, (b) 3.78 µm, and (c) 11.0 µm using 300 2.6 GHz CPUs. Differences in computing time are shown with bar plots. Solid filled color bars indicate positive differences, whereas negative differences are shown as striped pattern color bars. Computing time of nonconverging single-scattering properties using the lattice grid are indicated with X inside the square.

Reference(s)

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Um J and GM McFarquhar. 2013. "Optimal numerical methods for determining the orientation averages of single-scattering properties of atmospheric ice crystals." Journal of Quantitative Spectroscopy & Radiative Transfer, 127, doi:10.1016/j.jqsrt.2013.05.020.

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Cloud Life Cycle