Single-scattering Properties of Aggregates of Plates

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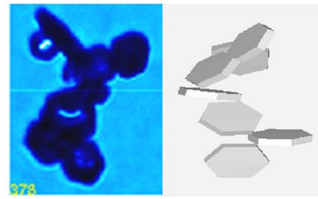
Research Highlight

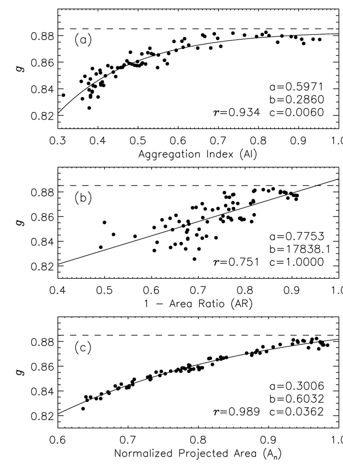
Cirrus differs from liquid clouds in that it consists of non-spherical ice crystals which have a wide variety of shapes and sizes. To determine cirrus radiative properties, their representation in general circulation models (GCMs), and hence the influence of cirrus on the climate system, the fundamental single-scattering properties (e.g., scattering phase function P11, asymmetry parameter **g**, and single-scattering albedo ω) of distributions of ice crystals are required. To determine these properties, observations of ice crystal size and shape distributions and the single-scattering properties of individual ice crystals are needed. The single-scattering properties of idealized models of pristine ice crystals (e.g., columns, plates, and bullet rosettes) have been calculated by theoretical methods for solar and infrared wavelengths. However, in situ observations reveal the frequent presence of aggregate ice crystals consisting of combinations of various shapes of ice crystals that do not match these idealized models. The scattering properties of these aggregates are not as well known as few models exist to describe their shapes. In this study, single-scattering properties of aggregates of plates observed from 2006 Tropical Warm Pool International Cloud Experiment (TWP-ICE) are calculated.

During the 2006 TWP-ICE sponsored by the Atmospheric Radiation Measurement program, the Scaled Composites Proteus aircraft flew spiral profiles and horizontal legs through aging anvils, fresh anvils, and cirrus of unknown origin in the vicinity of Darwin, Australia. Pristine ice crystals including both plates and bullet rosettes, their aggregates, and unclassifiable ice crystals were observed by a Cloud Particle Imager that provides 2.3 μm resolution images. The widths of observed plates ranged between 80 μm and 200 μm. When a fresh dissipating anvil was observed on 2 February, aggregates of plates contributed 46.2% of the total area of measured ice crystals with maximum dimensions greater than 200 μm.

The dependence of the scattering phase function P11, asymmetry parameter **g**, and single-scattering albedo ω on 3 parameters (the area ratio AR, normalized projected area An, aggregation index AI which varies between 0 and 1 with ice crystals with more compact shape having lower AI values) that define the three-dimensional shapes of aggregates of plates were calculated using a geometric ray-tracing method at three wavelengths ω of 0.55, 1.38, and 2.13 μm. Variations in P11 cause the **g** of an aggregate of a plate with a high AI of 0.818 to differ by +6.89% (+6.44%; +4.55%) from that with a lower AI of 0.378 at ω of 0.55 μm (1.38 μm; 2.13μm), but only by +0.29% (+0.25%; -0.03%) from those of their component plates. The ω at absorbing μ increases with AI, 1-AR, and An. Adding ray distortion to the aggregates causes a decrease in the forward scattering and an increase in the lateral and backward scattering, resulting in a decrease of **g**, an effect that weakens with μ due to absorption. The effect of ray distortion depends heavily on the AI and aggregates of plates with low AI are more influenced by ray distortion



Aggregates of plates imaged by Cloud Particle Imager (left panel) and idealized geometry of aggregates of plates with AI=0.61 (right panel).



Asymmetry parameter (**g**) at λ=0.55 μm of 80 different aggregates of seven 100 μm plates attached together, as functions of (a) AI, (b) 1-AR, and (c) An. The correlation coefficient and constants for a fitting equation, y=a+b(1-c^x), are embedded.

compared to those with high AI. The dependence of scattering properties on crystal morphology noted here should be considered in future remote sensing studies and large-scale model parameterization development.

Ice crystals with maximum dimensions larger than 200 μm are frequently aggregates of plates in anvils generated by convective systems, and such crystals scatter less light in the forward direction and more light in the lateral and backward direction compared with their component plates. The scattering angular distributions depend highly on the three-dimensional shapes and small-scale structure of the aggregates of plates, with the differences in scattering due to the varying AI large enough to influence satellite retrievals of cirrus properties and the corresponding **g**, used in climate studies. Although this study has examined the single-scattering properties of only one habit, the frequent occurrence of the aggregates of plates and the large difference in scattering properties between the aggregates and their components means that there will also be climatic and remote sensing impacts when examining bulk scattering properties of cirrus where averages are computed over habits and size distributions. Therefore, careful consideration must be taken to construct aggregate ice crystals with proper AI as functions of the geographic location and meteorological conditions.

Reference(s)

Um J and GM McFarquhar. 2009. "Single-scattering properties of aggregates of plates." Quarterly Journal Royal Meteorological Society, 135, 291-304.

Working Group(s)

Radiative Processes