Single-Scattering Properties of Aggregates of Bullet Rosettes in Cirrus

Contributors

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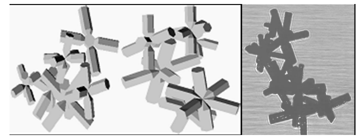
Research Highlight

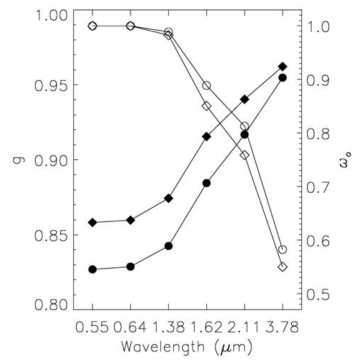
Cirrus consists almost exclusively of nonspherical ice crystals with various shapes and sizes (e.g., bullet rosettes, columns, plates, aggregates, and irregular crystals). Therefore, knowledge of the single-scattering properties (e.g., phase function, asymmetry parameter g and single-scattering albedo ω_o) of non-spherical ice crystals is required because the general circulation models (GCMs) and remote sensing studies used to determine the influence of cirrus on solar and infrared radiation make assumptions about such scattering properties. In the past, the single-scattering properties of ice crystals have been calculated assuming pristine ice crystal shapes. However, in situ observations reveal the frequent presence of aggregate ice crystals consisting of combinations of various shapes of ice crystals. The scattering properties of these aggregates are not as well known because few models exist to describe their shapes.

During the March 2000 Cloud Intensive Operational Period, the University of North Dakota Citation executed spiral descents through mid-latitude cirrus of a non-convective origin over the Atmospheric Radiation Measurement Program (ARM) Climate Research Facility (ACRF) Southern Great Plains (SGP) site. High-resolution (2.3 µm) images of aggregates of bullet rosettes observed using a laser imaging probe developed by the Stratton Park Engineering Research Company, called the Cloud Particle Imager (CPI), were used to derive a relationship between the length and width of bullets that are the fundamental components of the bullet rosettes. Six bullet rosettes, each with six bullets of the same size but with varying sized bullets in each rosette, are then combined together randomly to define a model for aggregates of bullet rosettes. Using a geometric ray tracing program, where the refraction and diffraction of several million rays through crystals with several thousand random orientations are modeled, the angular dependence of the scattered intensity (the phase function), an integrated measure used to represent the directional scattering in GCMs (the asymmetry parameter g), and a ratio of scattering to extinction also used in GCMs (single-scattering albedo ω_o) of the aggregates and their component bullets and bullet rosettes are calculated at the solar and near-infrared wavelengths (λ) of 0.55, 0.64, 1.38, 1.62, 2.11, and 3.78 µm where satellite imaging spectroradiometers operate.

The g, ω_o, and phase function depended on the number of attached bullets, their aspect ratio and on the shape of the aggregates. For example, as the aspect ratio of the component bullets increased, the forward scattering increased by up to 1.3% and the lateral and backward scattering decreased by up to 8.9% and 10.2% respectively for bullet rosettes at non-absorbing λ (0.55 µm). For longer λ, light absorption decreased the rate at which these scatterings changed with aspect ratio. In terms of shape, the model for the aggregates of bullet rosettes constructed here scattered up to 4.4 (7.0; 20.4)% with 34.2 (11.1; 32.7)% more light in the lateral and backward directions and 1.2 (1.3; 2.4)% less in the forward direction compared to



Two images of idealized geometry of the representation of aggregates of bullet rosettes (left panel) assumed in this study and real image from CPI (right panel).



Asymmetry parameter (g) of the equivalent projected area bullet rosette (1_br_1025, filled diamonds) and aggregates of bullet rosettes (filled circles) and single-scattering albedo (ω_o) of the equivalent projected area bullet rosettes (1_br_1025, open diamonds) and aggregates of bullet rosettes (open circles) at six wavelengths.

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the component bullets (component bullet rosettes; equivalent projected area bullet rosette), resulting in up to 2.5 (1.6; 3.8)% decrease in g at 0.55 µm. In addition, g at 0.55 µm increased by up to 1.8% and decreased by up to 2.0% as the aspect ratio and several attached bullets in the aggregates increased, and by 2.0% and 0.3% at 2.11 µm and 1.1% and 0.5% at 3.78 µm. Such changes in g can have an impact on estimates of radiative forcing derived from modeling studies. As an implication for remote sensing studies, the difference in the bidirectional reflectance distribution function (BRDF) calculated using the aggregate model and a bullet rosette was shown to vary by up to 107% at moderately absorbing (2.11 µm) and by up to 35% and 28% at non-absorbing (0.55 µm) and strongly absorbing (3.78 µm) wavelengths.

Because the bulk scattering properties used to represent the effect of ice crystals on radiation in both GCMs and remote sensing retrievals depend on both the shapes of aggregate ice crystals and the aspect ratios of their components, it is critical that models used to represent these crystals resemble those observed in nature as closely as possible and that distributions of ice crystals with varying shapes and sizes, and their dependence on meteorological conditions, be determined.

Reference(s)

Um, J, and G. M. McFarquhar. 2007. Single-scattering properties of aggregates of bullet rosettes in cirrus. Journal of Applied Meteorology and Climatology, 46, 757-775.

Working Group(s)

Radiative Processes