Effective Diameter in Ice Clouds and Its Application to Terrestrial Radiation

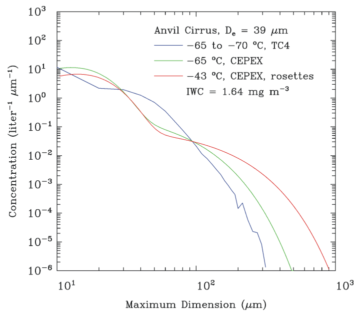
Research Highlight

While a great deal of progress has been made in quantifying the optical properties of ice crystals, their representation in climate models is still relatively crude due to the parameterized link between the optical properties of single ice crystals and their collective radiative effect in a size distribution. This weak link in the parameterization process results in potential errors that overshadow differences between methods for calculating ice crystal optical properties. The weak link here is the assumption that the optical properties of an ice particle size distribution (PSD) are uniquely defined in terms of its ice water content (IWC) and effective diameter, De.

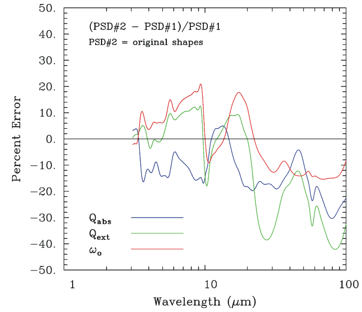
With the recent finding that historical measurements of small ice particle concentrations are often contaminated with ice artifacts from shattering at the probe inlet tube, and with improved instrument design often revealing a different PSD shape relative to these historical measurements, the question is posed whether PSD shape affects the PSD optical properties. By comparing PSD having the same IWC and De but different shapes, it was shown that treating optical properties solely in terms of De and IWC may lead to errors up to 24%, 26%, and 20% for terrestrial radiation in the window region regarding the absorption and extinction coefficients and the single-scattering albedo, respectively. Outside the window region, errors may reach 33% and 42% regarding absorption and extinction. The magnitude and sign of these errors can change rapidly with wavelength, which may produce significant errors in climate modeling, remote sensing, and other applications concerned with the wavelength dependence of radiation.

Related research has shown that such PSD shape effects on extinction are much more severe at size parameters characterizing cloud radar-ice particle interactions, where extinction backscatter may vary by a factor of two or more due to PSD shape effects alone. Thus, even more sophisticated cloud property retrievals using both lidar and radar (i.e., retrieving both De and IWC) may suffer from substantial uncertainties due to PSD shape uncertainties.

Both concerns regarding ice PSD optical properties and radar-lidar remote sensing can be addressed by developing methods for realistically describing the ice PSD in terms of temperature and IWC, based on more recent PSD measurements less vulnerable to the problem of ice particle shattering. For example, the radar reflectivity has been formulated in terms of PSD parameters, ice particle shape, and IWC, in principle reducing uncertainties in retrieved IWC provided the ice particle and PSD shape information is reliable.



Three PSD having the same De and IWC. Blue curve = measured PSD during the TC4 campaign; green curve = PSD from a tropical anvil PSD scheme based on historical PSD measurements and having the same ice particle shape attributes (particle mass and projected area) as the measured PSD; and red curve = same as green PSD except ice particle shape = bullet rosettes.



Wavelength dependence of optical property errors for PSD #2 in above figure (green curve), relative to the measured PSD (PSD #1; blue curve). Ice particle shape attributes are roughly the same in these two PSD. Efficiencies for absorption and extinction are their corresponding coefficients divided by the PSD projected area. The PSD single-scattering albedo is also shown.

Reference(s)

Mitchell DL, RP Lawson, and B Baker. 2011. "Understanding effective diameter and its application to terrestrial radiation in ice clouds." Atmospheric Chemistry and Physics, 11, doi:10.5194/acp-11-3417-2011.

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Cloud Life Cycle