Ice Particle Projected Area- and Mass-Dimension Expressions for Cirrus Clouds

Research Highlight

The microphysical and optical properties of ice clouds can be described as functions of ice particle mass- and projected area-dimension (i.e., m-D and A-D, respectively) expressions. This approach provides a common basis for these properties, making them self-consistent. Ground- and satellite-based remote sensing of cirrus cloud properties often depends strongly on the m-D expression assumed. Because the cirrus m-D relationship is poorly constrained, considerable uncertainty is produced in predicted and retrieved cloud properties. This study uses ARM in situ data from the Small Particles In Cirrus (SPARTICUS) field campaign and other field measurements to develop both A-D and m-D expressions over a broad range of ice particle size (20 µm to 4 mm length) for the temperature (T) range -65°C < T < -20°C for synoptic and anvil ice clouds.

Although there has long been evidence that a single m-D or A-D power law often is not valid over all ice particle sizes, few studies have offered a solution to this conundrum. This study develops self-consistent m-D and A-D expressions that are not power laws, but can easily be reduced to power laws for the ice particle size (maximum dimension or D) range of interest. A non-standard approach was taken that combines aircraft measurements and estimates of ice particle projected area and mass, respectively, with single ice particle field measurements of m and D from a winter cloud seeding program called the Sierra Cooperative Pilot Project (SCPP). The SCPP m-D measurements used here, described in Mitchell et al. (1990), were for unrimed ice particle shapes corresponding to T < -20°C; these measurements are averaged over size-bin intervals shown by the purple dots in Figure 1, yielding reliable m-D measurements for D > 20 µm. For D # 100 µm, the Cloud Particle Imager (CPI) flown during SPARTICUS was used since at these sizes ice crystals have compact shapes that can be approximated as short hexagonal columns. The CPI measures the ice particle area (A) and the length-to-width ratio, which can be deconvolved to determine an estimate of the true aspect ratio (AR). From A and AR, m can be estimated for D # 100 µm. For D # 200 µm, m can be estimated from A as measured by the SPARTICUS 2D-Stereo (2D-S) probe using the m-D power law developed by Baker and Lawson (2006 a,b). Figure 1 shows the curve fit based on the CPI and SCPP data (black) and the curve fit based on the CPI and 2D-S data (blue) obtained from the same sampling times and locations between -40°C and -20°C. The close agreement between the two curve fits validates the use of 2D-S data for estimating m over this T range for this cloud type. Moreover, this enables us to estimate m from 2D-S area measurements at colder temperatures and in anvil cirrus clouds provided the ice particle shape mixture does not change significantly (relative to this T-interval). The shape mixture was characterized by the ice particle area ratio ("A" divided by the area of a circle having same D) of each size bin. We found that the area ratio distributions did not significantly change for -55°C < T < -20°C, but did change significantly at colder temperatures, making the m-D expressions at these colder temperatures more uncertain.

This analysis yielded second-order polynomial fits for the A-D and m-D expressions, using CPI and 2D-S measurements for anvil cirrus clouds and for synoptic cirrus clouds outside the temperature range -20°C to -40°C. By accounting for the nonlinear dependence of log m (or log A) on log D, the uncertainty associated with these expressions was greatly reduced. The m-D curve fits shown in Figure 1 exhibit close agreement with the m-D expressions from two relatively recent studies. For a given moment of the ice particle size distribution, these m-D and A-D expressions reduce to simple power laws that can be used in the existing model architecture of most bulk microphysics schemes (BMPs). A methodology for applying these m-D and A-D expressions in BMPs is described in this paper.

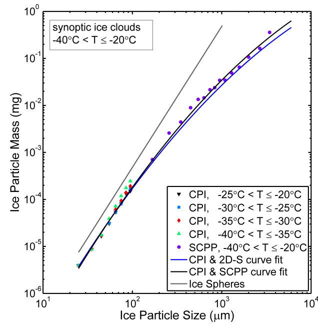

Figure 1. The m-D expression (black curve) for synoptic ice clouds between -20°C and -40°C based on SCPP m-D measurements (purple dots) and CPI estimates of ice particle mass for D#100 µm. The blue curve also is based on these CPI mass estimates, but at larger sizes it is based on mass estimates from the 2D-S probe for this temperature interval and cloud type. The line for ice spheres shows the maximum value for ice particle mass at any given size.

Finally, the calculation in BMPs of the ice particle number concentration N, the effective diameter D_e and the mass-weighted ice fall speed V_m were examined using 1) this new m-D/A-D approach, 2) a closest-match fixed power law approach, and 3) a power law approach using the prefactors and exponents used in the Community Atmosphere Model version 5 (CAM5) where ice spheres are assumed. While significant differences are found between 1) and 2), the differences between 1) and 3) were much larger, underscoring the potential hazards of assuming spherical geometry for ice particles in climate models.

Additional References:

Lawson RP and BA Baker. 2006a. "Improvement in Determination of Ice Water Content from Two-Dimensional Particle Imagery. Part I: Image-to-Mass Relationships." **Journal of Applied Meteorology and Climatology** 45:1282–1290. doi:http://dx.doi.org/10.1175/JAM2399.1

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Reference(s)

Erfani E and DL Mitchell. 2015. "Developing and bounding ice particle mass- and area-dimension expressions for use in atmospheric models and remote sensing." Atmospheric Chemistry and Physics, 15(20), 10.5194/acpd-15-28517-2015.

Contributors

David L. Mitchell, *Desert Research Institute*

Working Group(s)

Cloud Life Cycle