Parameterizing the Ice Fall Speed in Climate Models: Results from TC4 and ISDAC

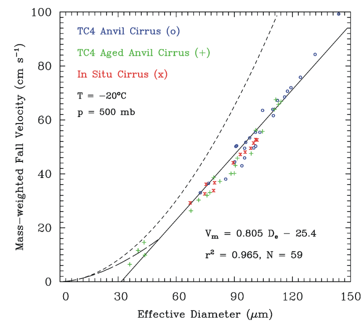
Research Highlight

The ice fall velocity in cirrus clouds has been shown to have a strong impact on global climate model (GCM) predictions of the Earth's climate response to CO2 radiative forcing. Various GCMs estimate that this response amplifies the initial CO2 forcing (4 W m-2) by a factor between 2 and 4, depending on key feedback parameters like the ice fall speed. The mass-weighted ice fall speed, or Vm, used to determine ice mass sedimentation rates in GCMs, depends on the ice particle size distribution (PSD) and ice particle mass and projected area. Limitations in our ability to accurately measure these quantities are at least partially responsible for the cloud of uncertainty surrounding Vm.

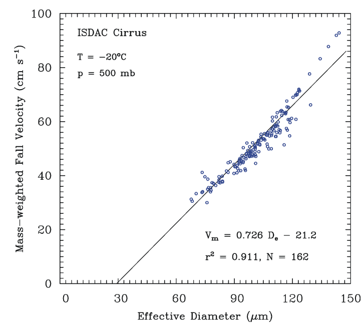
Historical PSD measurements have been compromised by ice artifacts produced by the shattering of ice particles at the inlet tube of the PSD sampling probe. New probe designs and ice artifact removal algorithms/software (based on ice particle interarrival times) have greatly reduced the level of artifact contamination and have been employed in a number of recent field campaigns. PSD data from two of these field campaigns (the Tropical Composition, Cloud and Climate Coupling (TC4) campaign in 2007 and the Indirect and Semi-Direct Aerosol Campaign (ISDAC) in 2008) are used in this study to calculate effective diameter De and Vm in relation to cloud temperature T and the ice water content (IWC), as well as producing De-Vm relationships. The 2D-Sterio (2D-S) probe was used to measure size distributions of ice particle number and projected area concentration, with 10 µm resolution for evaluating ice particle size and area (previously 25 µm resolution was the standard). Ice particle mass was estimated from ice particle area, yielding IWCs that agreed well with direct measurements of the IWC from the Counter-flow Virtual Impactor (CVI) during TC4. These PSD measurements of ice particle number, area and mass were used to directly calculate De and Vm, avoiding the use of ice particle area- and mass-dimension power laws and PSD approximations that increase uncertainty.

This analysis resulted in significant correlations that relate De and Vm to temperature T and IWC for the TC4 measurements, while the correlations were relatively poor for ISDAC measurements. Regarding TC4, the strongest correlations were multiple regressions relating De or Vm to both T and IWC, with an r2 of 0.82 and 0.78, respectively. This diagnostic expression of Vm may be well suited for climate models having single-moment microphysical schemes that only predict the ice mixing ratio. In addition, this Vm relationship and associated Vm-IWC-T measurements were found to agree well with a Vm scheme based on cloud radar retrievals of Vm and IWC and corresponding T measurements at ARM Tropical Western Pacific sites.

However, the above diagnostic Vm treatment will not be sensitive to aerosol impacts on cirrus PSDs or to microphysical processes affecting the ice particle mass/area ratio. Given the important role of Vm in climate predictions, Vm needs to be coupled with the cloud microphysics and radiation modules in climate models having two-moment microphysical schemes. This is easily accomplished by predicting Vm in terms of De, provided cloud optical properties are predicted using De. For both ISDAC and TC4 data, De and Vm were strongly correlated with an r2 of 0.911 and 0.965, respectively, owing to their mutual dependence on the ice particle mass/area ratio. Since Vm affects the IWC and coverage of cirrus clouds, predicting Vm through De enables De to influence cirrus cloud radiative forcing in two ways: (1) directly through cloud optical properties and (2) indirectly through Vm (affecting IWC and cloud coverage). This makes it critical to accurately predict De, with the climate sensitivity of a GCM becoming more dependent on De.



Relationship between De and Vm for all tropical cirrus cloud types (solid line). The dashed curve is the best fit curve obtained by Heymsfield et al. (2003) for anvil cirrus sampled during the TRMM project. The long-dashed curve estimates Vm in the viscous flow regime while fitting the observations.



Same relationship as shown in Figure 1, but for ISDAC data.

Finally, satellite retrievals of De and Vm using MODIS scenes of cloud fields observed during TC4 were found to be consistent with our temperature-dependent measurements of De and Vm during TC4. This retrieval is based on the MODIS 11 and 12 µm channels, with the temperature dependence of retrieved De and Vm having some sensitivity to the PSD shape assumed. If the retrievals are accurate, this implies that the cirrus clouds sampled during TC4 are representative of the greater cloud field sampled by satellite.

Reference(s)

Mitchell DL, S Mishra, and RP Lawson. 2011. "Representing the ice fall speed in climate models: Results from Tropical Composition, Cloud and Climate Coupling (TC4) and the Indirect and Semi-Direct Aerosol Campaign (ISDAC)." Journal of Geophysical Research – Atmospheres, 116, D00T03, doi:10.1029/2010JD015433.

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Working Group(s)

Cloud Life Cycle, Cloud-Aerosol-Precipitation Interactions