Representing Ice Fall Speeds and Effective Diameter In Climate Models: Results from TC4 and ISDAC

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Photo courtesy of Paul Lawson/J.H. Bain
Most climate models (e.g., CAM, GFDL) have two-moment (mass and concentration) prognostic microphysics schemes, and the effective diameter ($D_e$) of ice crystals which are used in the radiation and gravitational settlement calculations are calculated from model predicted mass and number of ice crystals.

If microphysics package is not producing reliable estimates of $D_e$ values, use (1)

$$(V_m, D_e) = f(T, IWC)$$
The size resolved 2D-Stereo measurements of number, projected area and mass concentration appear reasonable.

Number concentration PSD were bimodal for $T > -40^\circ$ C and monomodal (due to higher concentrations of smaller ice crystals) for $T < -40^\circ$ C.

PSD associated with higher updrafts (fresh anvils) had relatively high concentrations of small ($D < 60 \mu$m) ice crystals for $T < -40^\circ$ C, suggesting homogeneous freezing nucleation may have been active at times.
The 2D-S estimates of ice water content (IWC), based on PSD integrations using the area-mass relationship, generally agree well (within ~20%) with Counter flow Virtual Impactor (CVI) measurements of IWC during the TC4 campaign—Provides some level of confidence that the 2D-S IWCs are realistic.

A: Time series of the 2D-S and CVI IWC for a TC4 case study. CVI response time lagged 6 seconds behind 2D-S measurements, producing a slight offset.

B: 2D-S IWCs compared with CVI IWCs for 12,000 1-Hz measurements (averaged over 10-s) in TC4 anvils cirrus.

Residual moisture in the CVI chamber

Mitchell et al. (2010)
Lawson et al. (2010)
Comparison of Fall velocity using two methods

In a measurement context,

\[ V_m = \sum V(D) m(D) N(D) \Delta D / \sum m(D) N(D) \Delta D \]

\[ D_e = \left( \frac{3}{2} \right) \sum m(D) N(D) \Delta D / \left( \rho_i \sum A(D) N(D) \Delta D \right) \]

\[ V(D) = \text{ice particle fall velocity} \]
\[ m(D) = \text{ice particle mass} \]
\[ N(D) = \text{size distribution} \]
\[ D = \text{ice particle maximum dimension at bin midpoint} \]
\[ \Delta D = \text{bin width}. \]
\[ m(D) \& A(D) \text{ are bin mass or bin area concentration/bin number conc.} \]

HW: Improved drag coefficients and terminal velocity representation - works very well for all area ratios.

HW and MH methods showed comparable fall speeds which indicates the presence of compact crystal shapes during TC4.


A regression with T (IWP) to $D_e$ accounts for 75% (53%) of the variance shared by the two variables in TC4 data. A multiple regression diagnosis of $D_e$ using both T and IWC shows improvement in statistics.
A regression with $T$ (IWP) to $V_m$ accounts for similar variance shared by the two variables as seen for $D_e$ in TC4 data. To estimate $V_m$ when only $T$ and IWC are available, a multiple regression was performed, relating $V_m$ to both $T$ and IWC.
BEST METHOD FOR DIAGNOSING $V_m$ FROM PROGNOSTIC MICROPHYSICS
- High correlation since both $D_e$ and $V_m$ are based on ice particle mass/area ratio

\[
V_m = 0.8052 \, D_e - 25.4
\]
\[
r^2 = 0.9647, \; N = 59
\]
No correlation for $D_e$-IWC or $V_m$-IWC
Crude diagnostics for $D_e$ and $V_m$

Crystal shapes (greater variety of habits) are possibly different as compared to TC4
BEST METHOD FOR DIAGNOSING $V_m$ FROM PROGNOSTIC MICROPHYSICS

- High correlation since both $D_e$ and $V_m$ are based on ice particle mass/area ratio -

ISDAC and TC4 cloud types showed almost similar linear relations for $V_m$-$D_e$

**Equation:**

$$V_m = 0.7260 \ D_e - 21.2$$

**Coefficient of determination:** $r^2 = 0.911$, $N = 162$
Arctic cirrus crystals have different area ratios than seen in TC4. Arctic cirrus crystals showed different PSD area ratios than seen in TC4. Longer/thin habits?
1. For tropical anvil and in situ cirrus, the mass-weighted ice fall speed and effective size can be diagnosed in terms of temperature and ice water content.

2. For Arctic cirrus, the ice fall speed and effective size can be roughly approximated using a temperature relationship.

3. Alternatively, for tropical anvil, in situ and Arctic cirrus, the ice fall speed can be accurately diagnosed from a prognostic effective size predicted from the model microphysics.

4. PSD associated with higher updrafts (fresh anvils) had relatively high concentrations of small (D < 60 µm) ice crystals for T < -40 °C, suggesting homogeneous freezing nucleation may have been active at times.