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

Ramesh Vellore and David L. Mitchell
Desert Research Institute, Reno, Nevada

Paul Lawson, Brad Baker and Qixu Mo
SPEC, Inc., Boulder, Colorado

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.

Improvement of ice fall speed representation in climate models

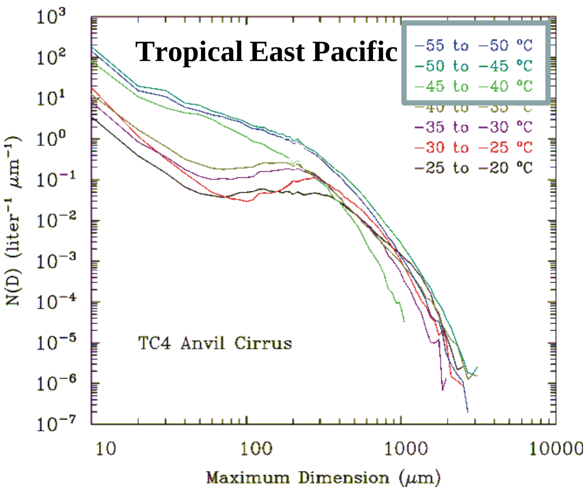
(1) Relate ice fall speed (V_m) and D_e to T and IWC

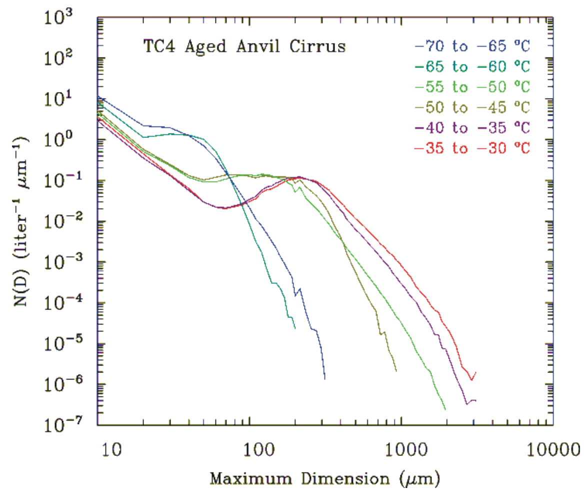
$$(V_m, D_e) = f(T, IWC)$$

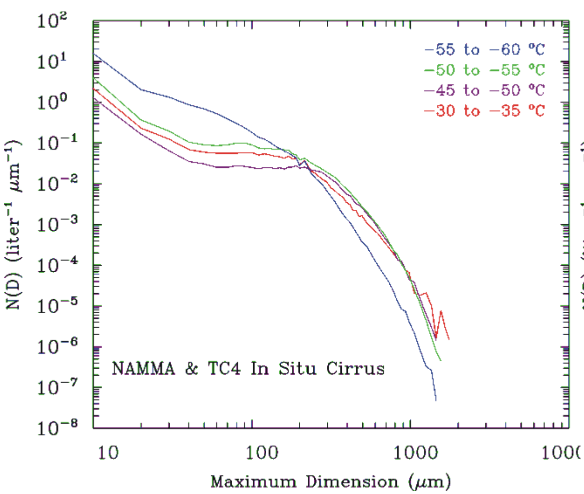
Relate V_m directly to effective diameter (D_e)

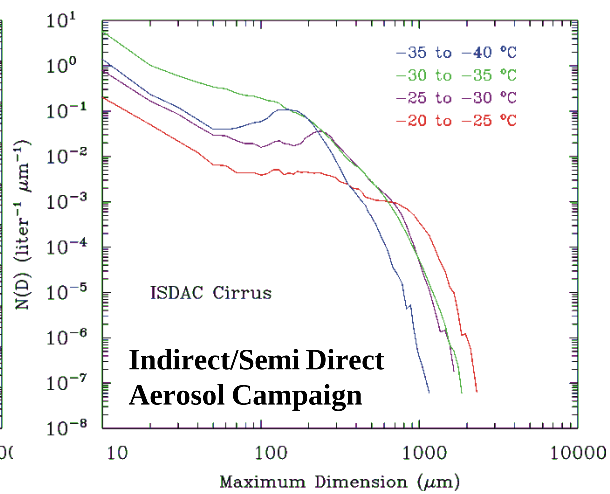
If microphysics package is not producing reliable estimates of D_e values, use (1)

Particle size distribution from TC4 and ISDAC









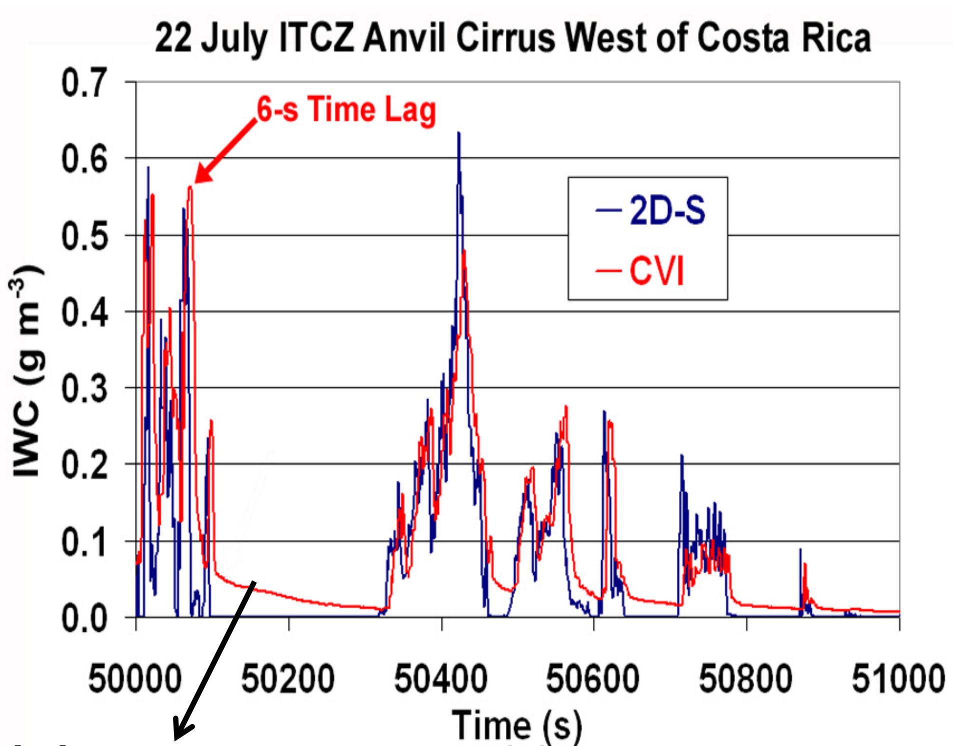
NASA African Monsoon Multi-disciplinary Analysis

The size resolved 2D-Stereo measurements of number, projected area and mass concentration appear reasonable.

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

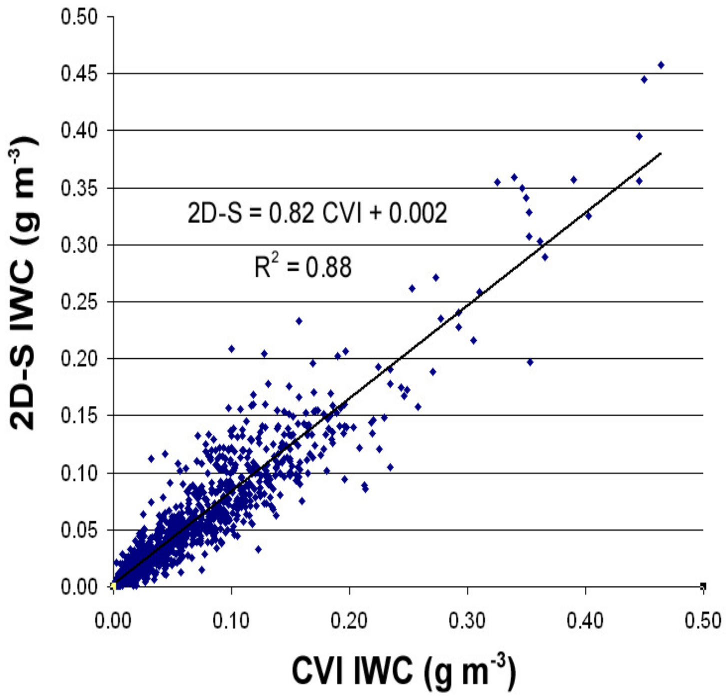
PSD associated with higher updrafts (fresh anvils) had relatively high concentrations of small (D < 60 µm) ice crystals for T < -40 ºC, suggesting homogeneous freezing nucleation may have been active at times.

COMPARISON OF IWCs from 2D-S AND CVI DURING TC4



Residual moisture in the CVI chamber

(A)



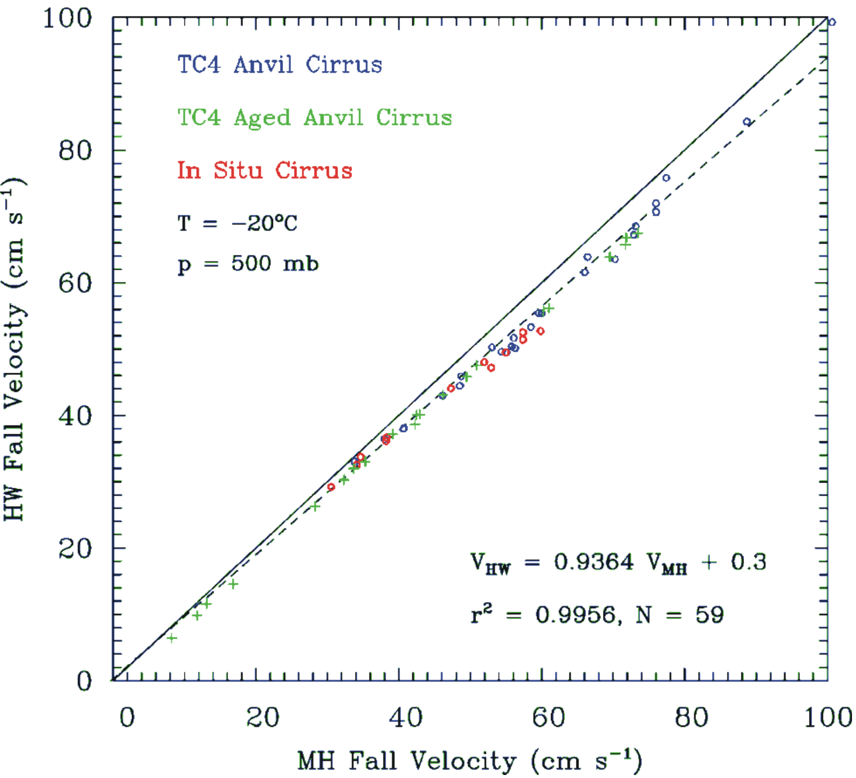
(B)

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.

Mitchell et al. (2010)
Lawson et al. (2010)

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.

Comparison of Fall velocity using two methods



In a measurement context,

$$V_m = \Sigma\, V(D)\, m(D)\, N(D)\, \Delta D \,/\, \Sigma\, m(D)\, N(D)\, \Delta D$$

$$D_e = (3/2)\, \Sigma\, m(D)\, N(D)\, \Delta D \,/\, (\rho_i\, \Sigma\, A(D)\, N(D)\, \Delta D)$$

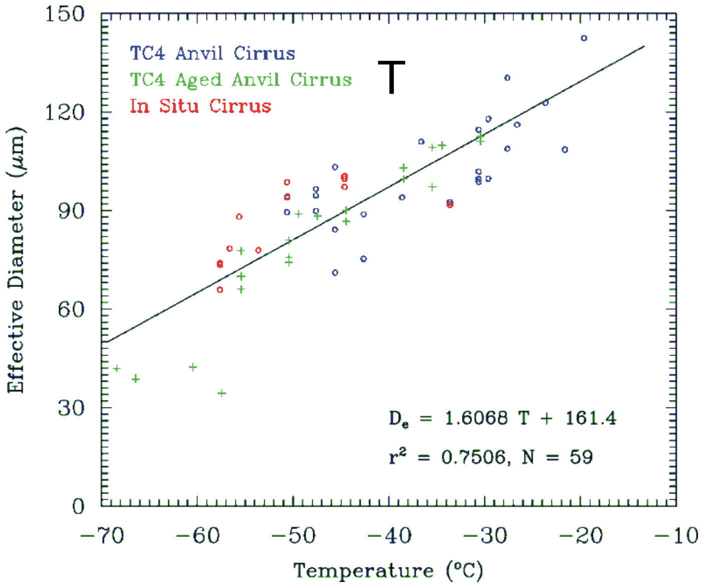
V(D) = ice particle fall velocity
m(D) = ice particle mass
N(D) = size distribution
D = ice particle maximum dimension at bin midpoint
ΔD = bin width.
m(D) & A(D) are bin mass or bin area concentration/ bin number conc.

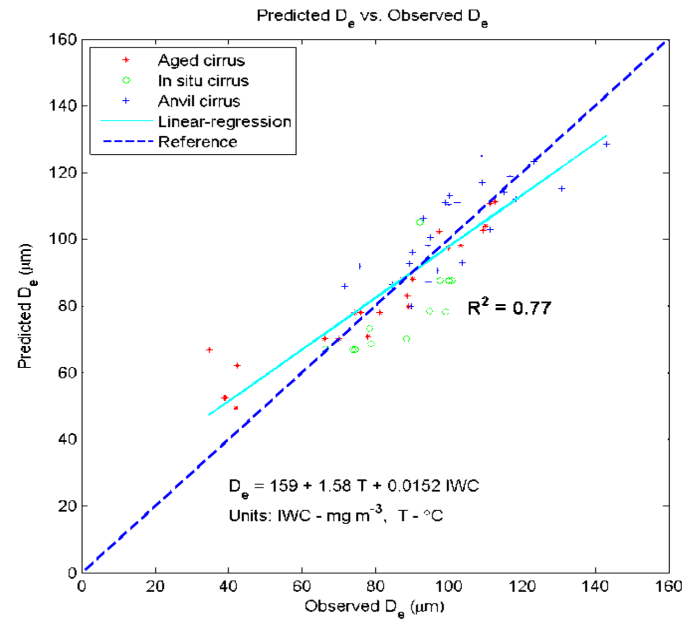
HW: Improved drag coefficients and terminal velocity representation - works very well for all area ratios

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

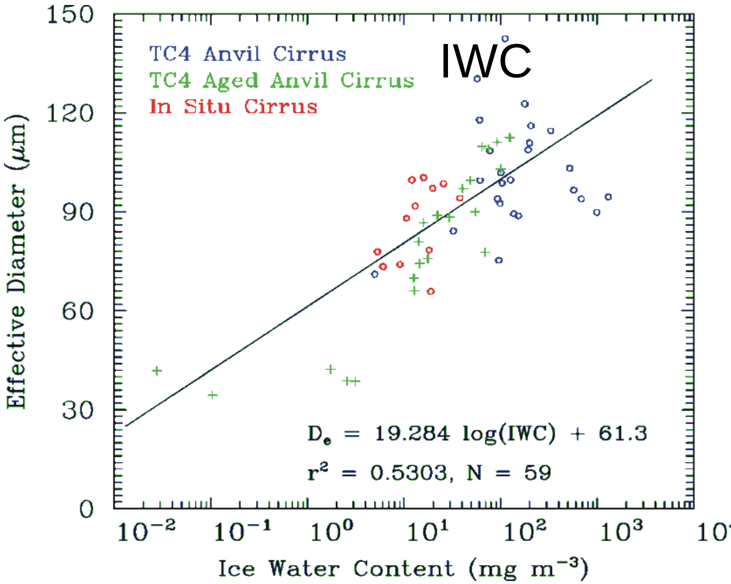
HM: Heymsfield and Westbrook (2010): Advances in the estimation of the ice particle speeds using Laboratory field measurements. J. Atmos. Sci., (2010).
MH: Mitchell and Heymsfield (2005): Refinements in the treatment of ice particle terminal velocities, highlighting aggregates, J. Atmos. Sci., (2005).

Relationship of D_e with temperature and Ice water content during TC4



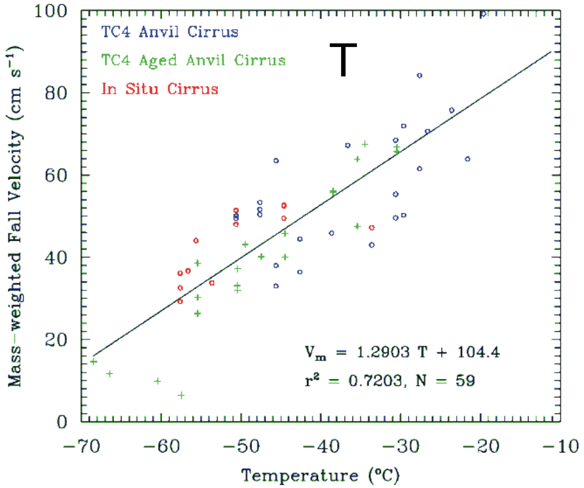


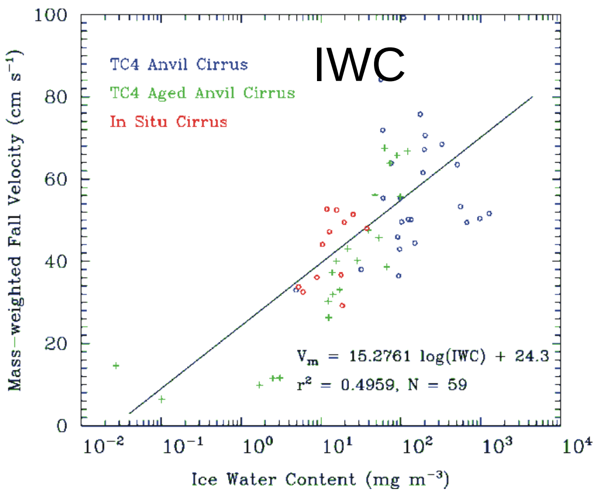
D_e = f(T, IWC): Observed vs. Predicted

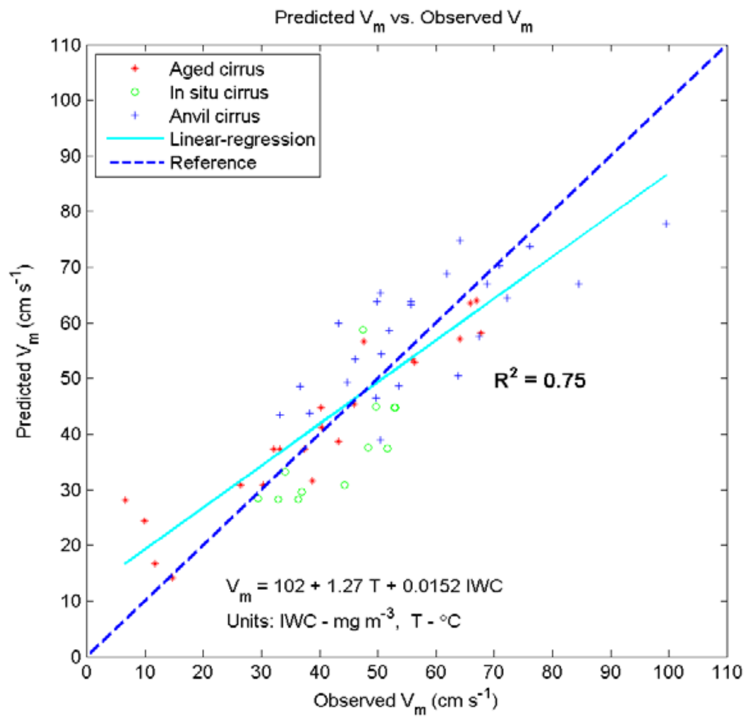


A regression with T (IWP) to D_e accounts for 75% (53%) of the variance shared by the two variables in TC4 data. A multiple regression diagnosis of D_e using both T and IWC shows improvement in statistics.

$V_m = f(T, IWC)$: Observed vs. Predicted



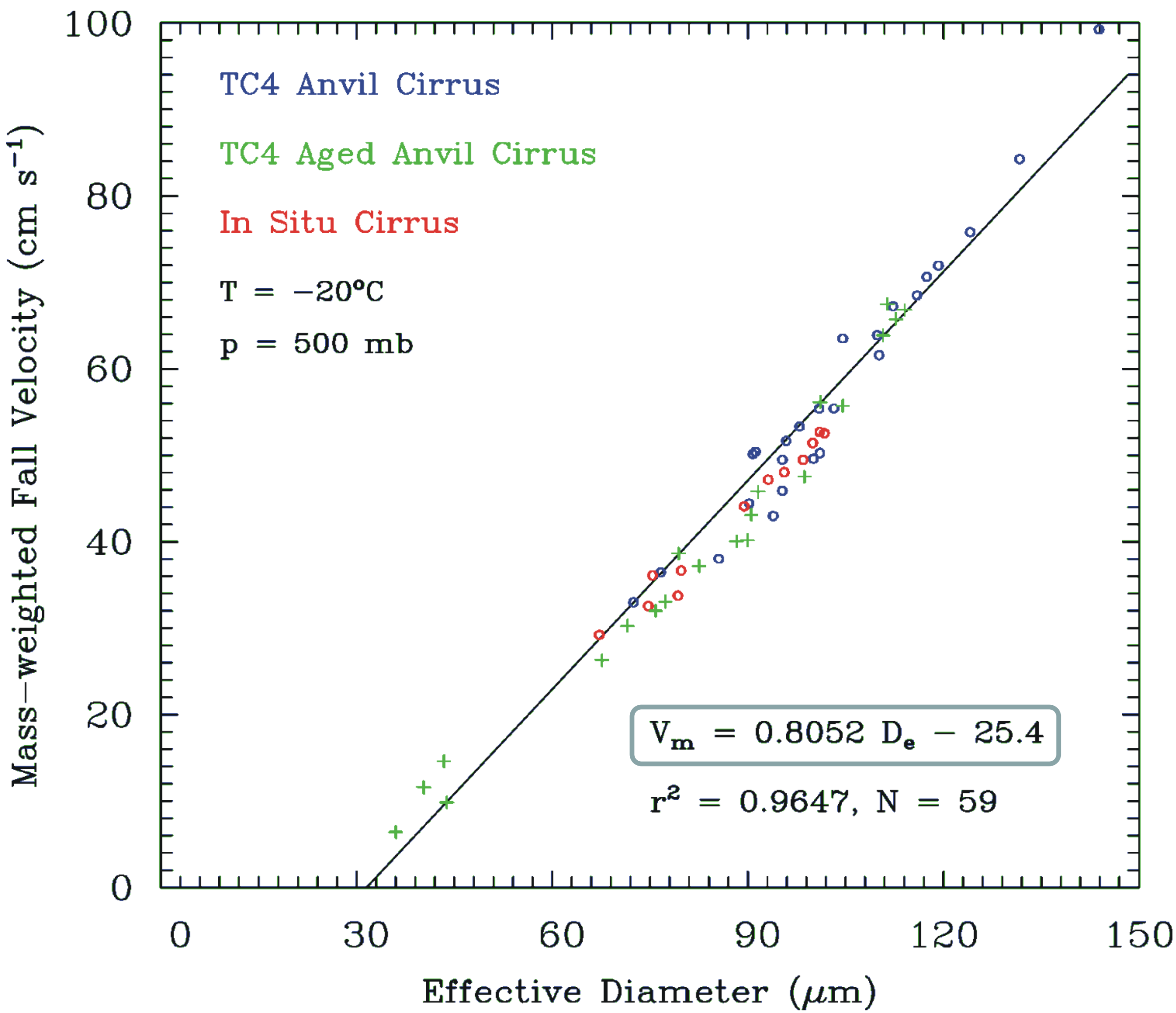




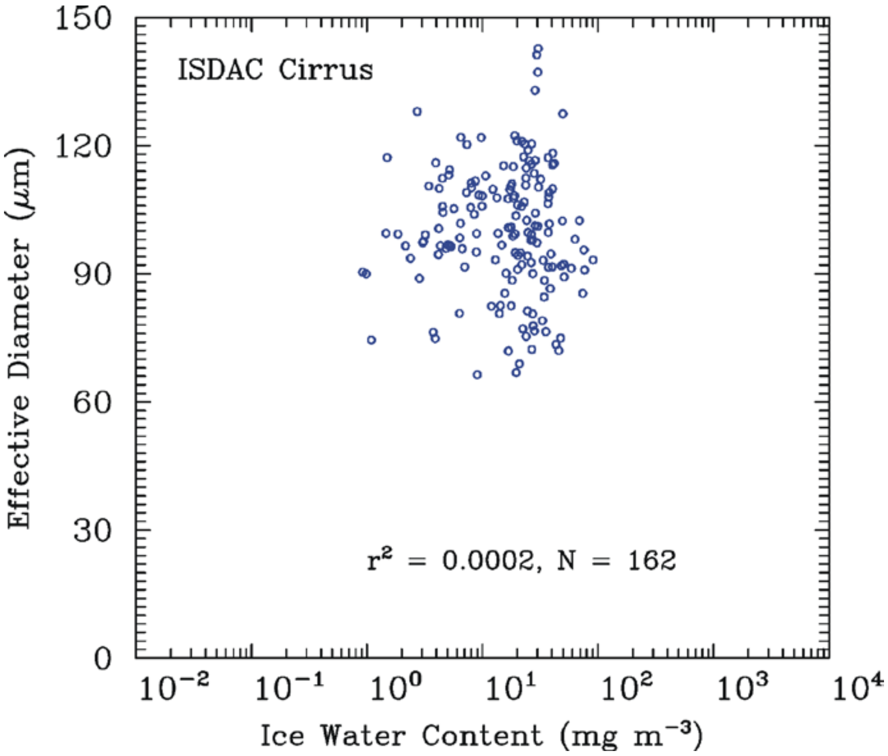
A regression with T (IWP) to V_m accounts for similar variance shared by the two variables as seen for D_e in TC4 data. To estimate V_m when only T and IWC are available, a multiple regression was performed, relating V_m to both T and IWC.

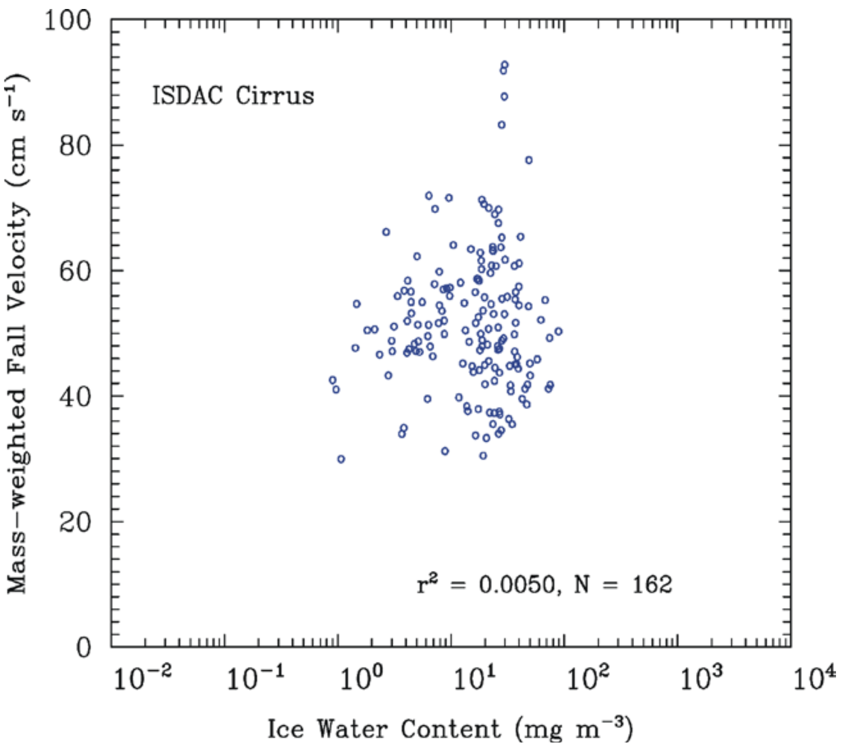
BEST METHOD FOR DIAGNOSING V_m FROM PROGNOSTIC MICROPHYSICS

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

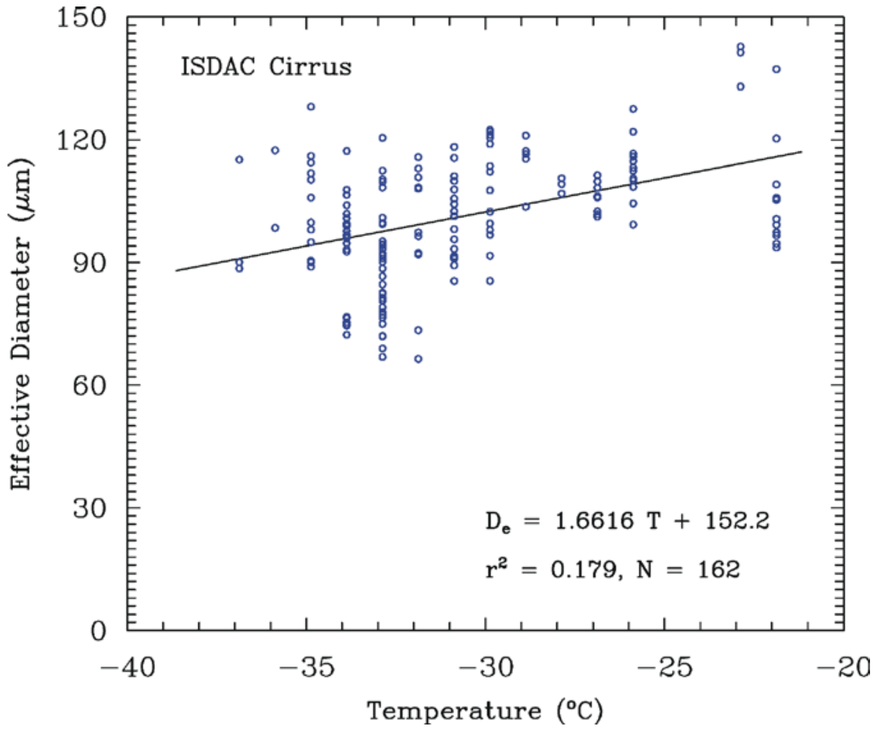


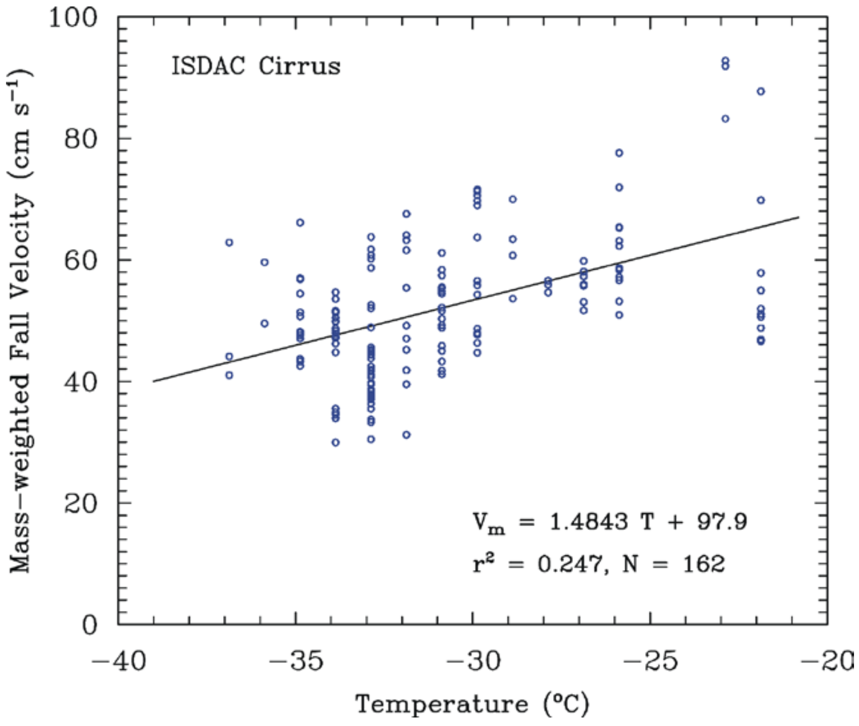
ISDAC FIELD CAMPAIGN





No correlation for D_e-IWC or V_m-IWC



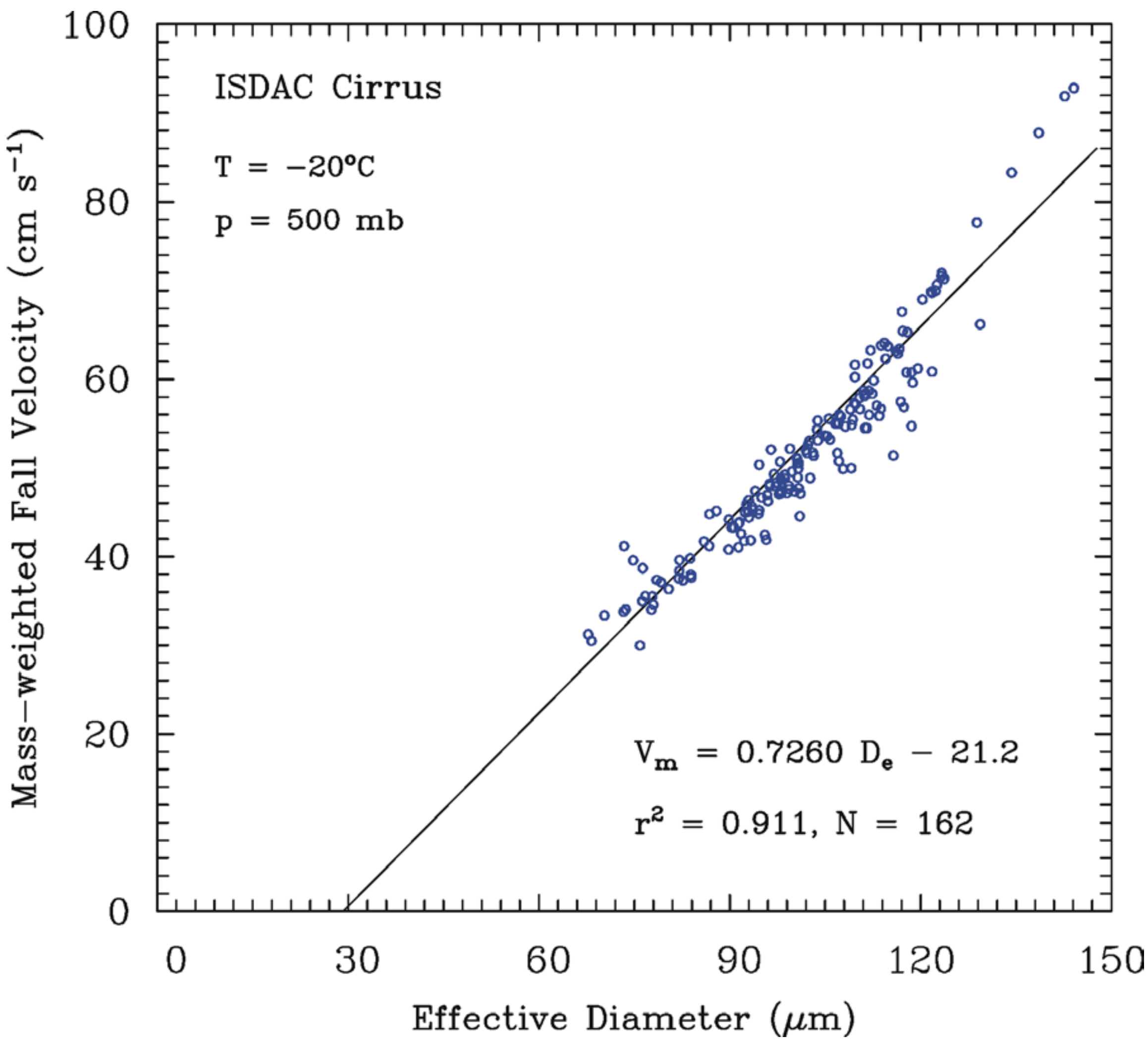


Crude diagnostics for D_e and V_m

Crystal shapes (greater variety of habits) are possibly different as compared to TC4

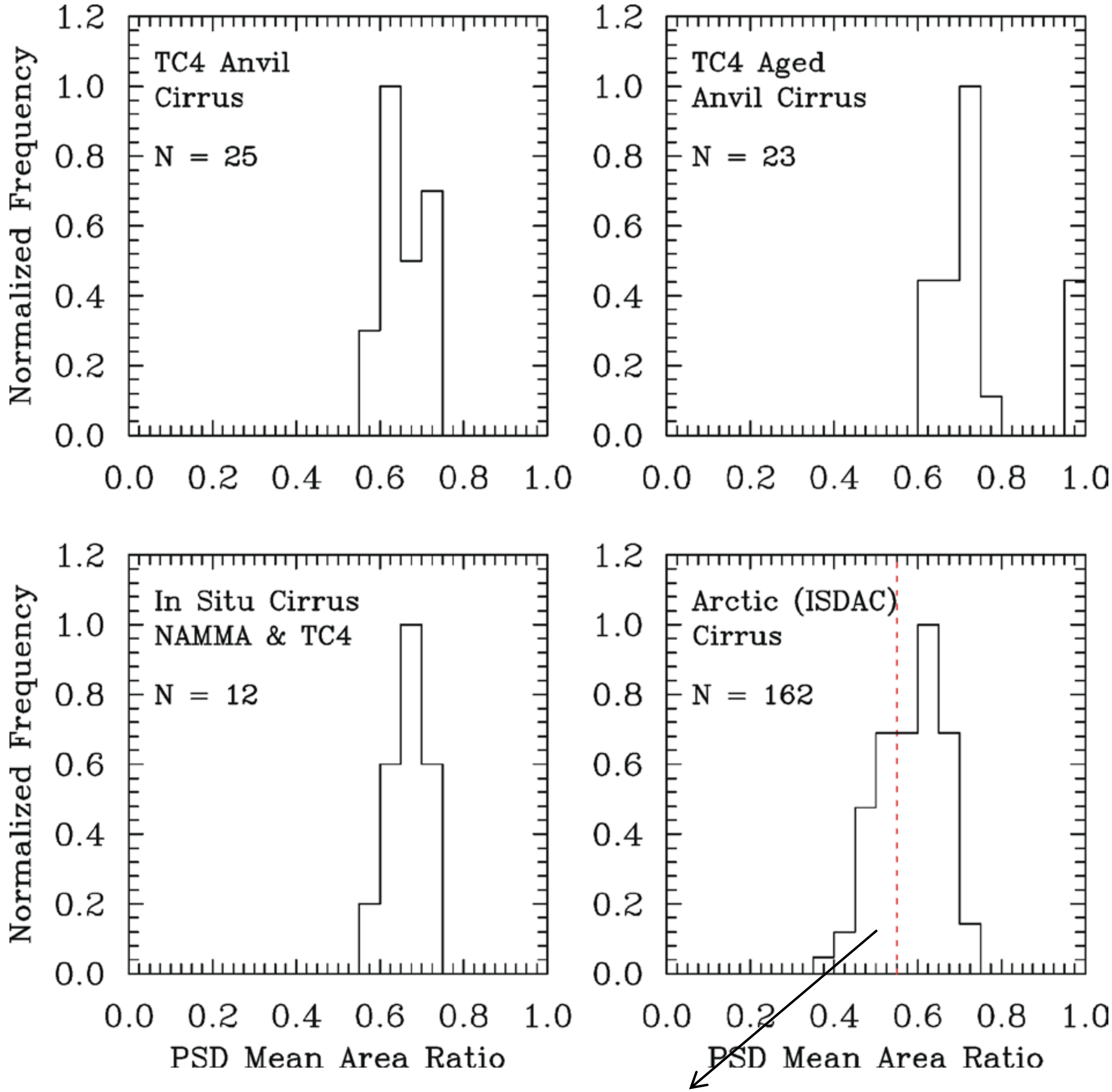
BEST METHOD FOR DIAGNOSING V_m FROM PROGNOSTIC MICROPHYSICS

- 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

Arctic cirrus crystals have different area ratios



Arctic cirrus crystals showed different PSD area ratios than seen in TC4

Longer/thin habits?

Summary

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 ^{o}C, suggesting homogeneous freezing nucleation may have been active at times.