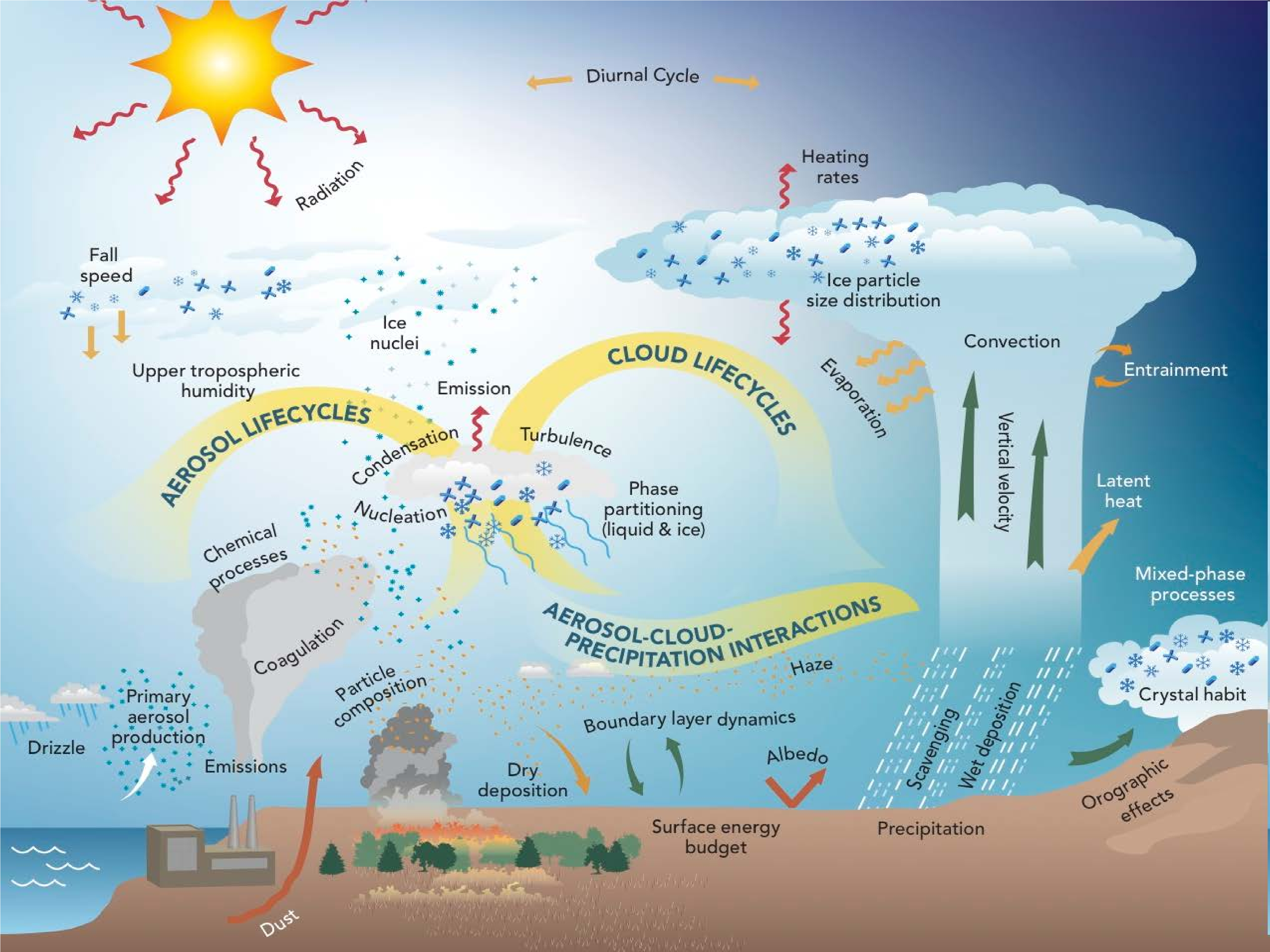
Ice Cloud Microphysics Issues

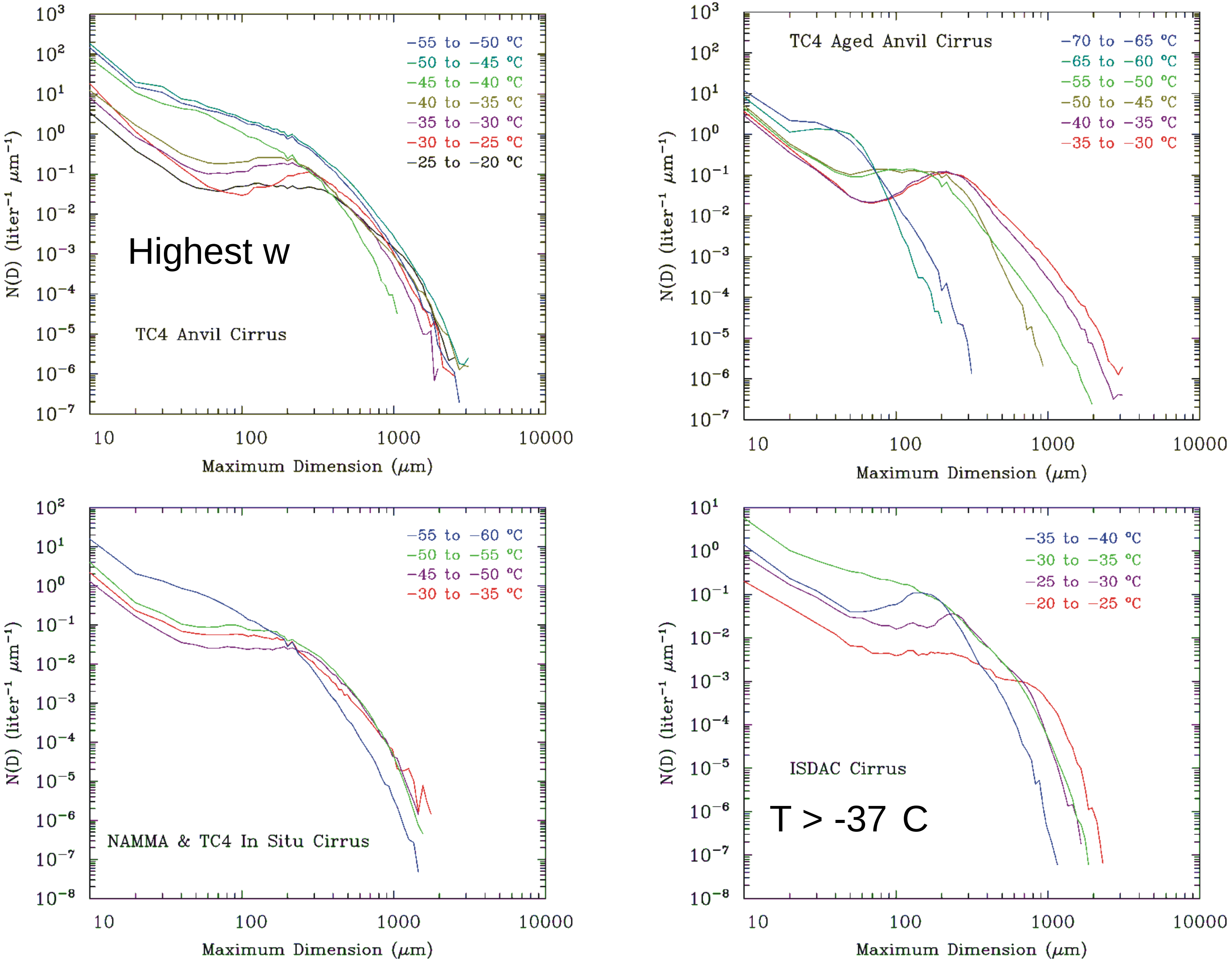
David L. Mitchell and Subhashree Mishra
Desert Research Institute, **Reno, Nevada**

R. Paul Lawson and Brad Baker
SPEC, Inc., Boulder, Colorado

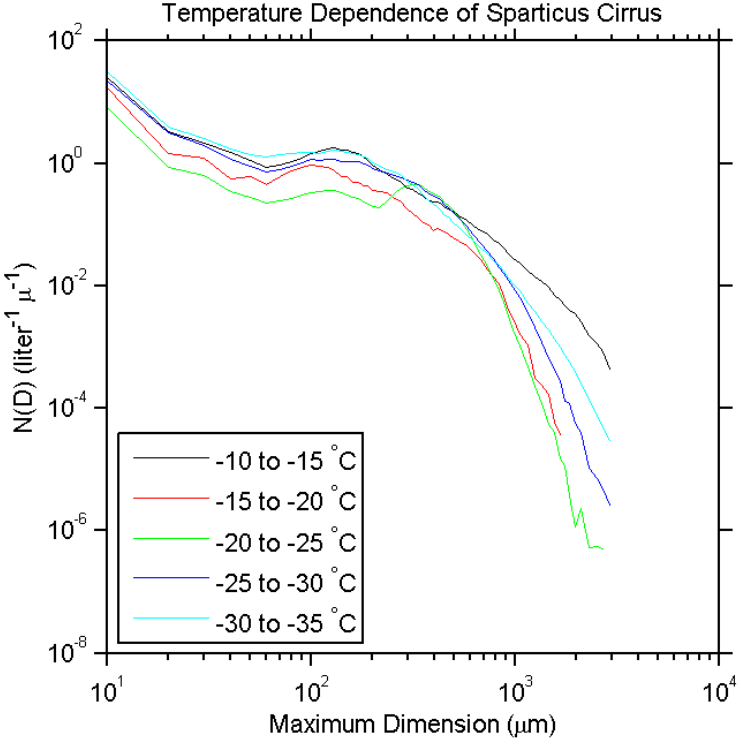


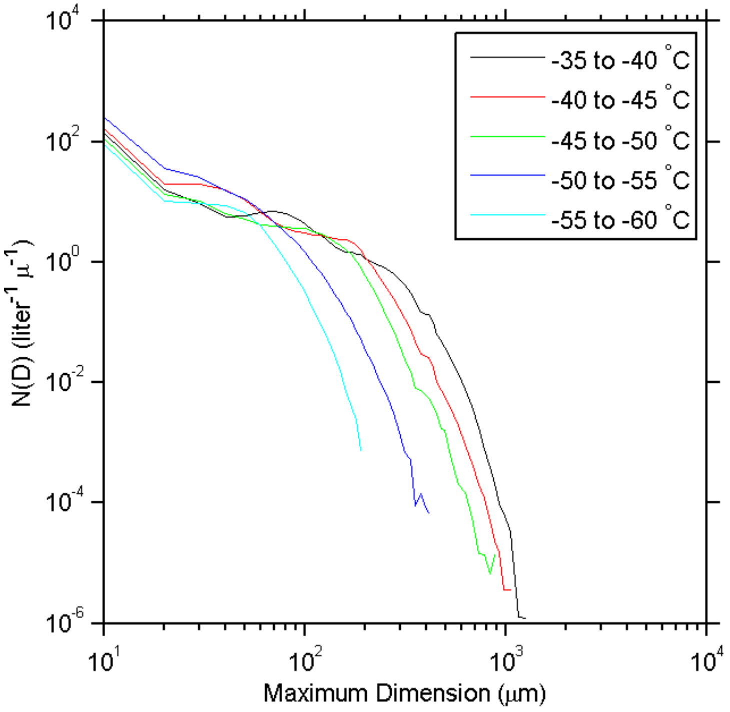
Diurnal Cycle
Radiation
Heating rates
Fall speed
Ice nuclei
Ice particle size distribution
Upper tropospheric humidity
Emission
CLOUD LIFECYCLES
Evaporation
Convection
Entrainment
AEROSOL LIFECYCLES
Condensation
Turbulence
Vertical velocity
Phase partitioning (liquid & ice)
Nucleation
Latent heat
Chemical processes
Mixed-phase processes
AEROSOL-CLOUD-PRECIPITATION INTERACTIONS
Coagulation
Haze
Crystal habit
Particle composition
Primary aerosol production
Boundary layer dynamics
Drizzle
Scavenging
Wet deposition
Emissions
Albedo
Dry deposition
Orographic effects
Surface energy budget
Precipitation
Dust

Homogeneous freezing nucleation at higher updrafts?

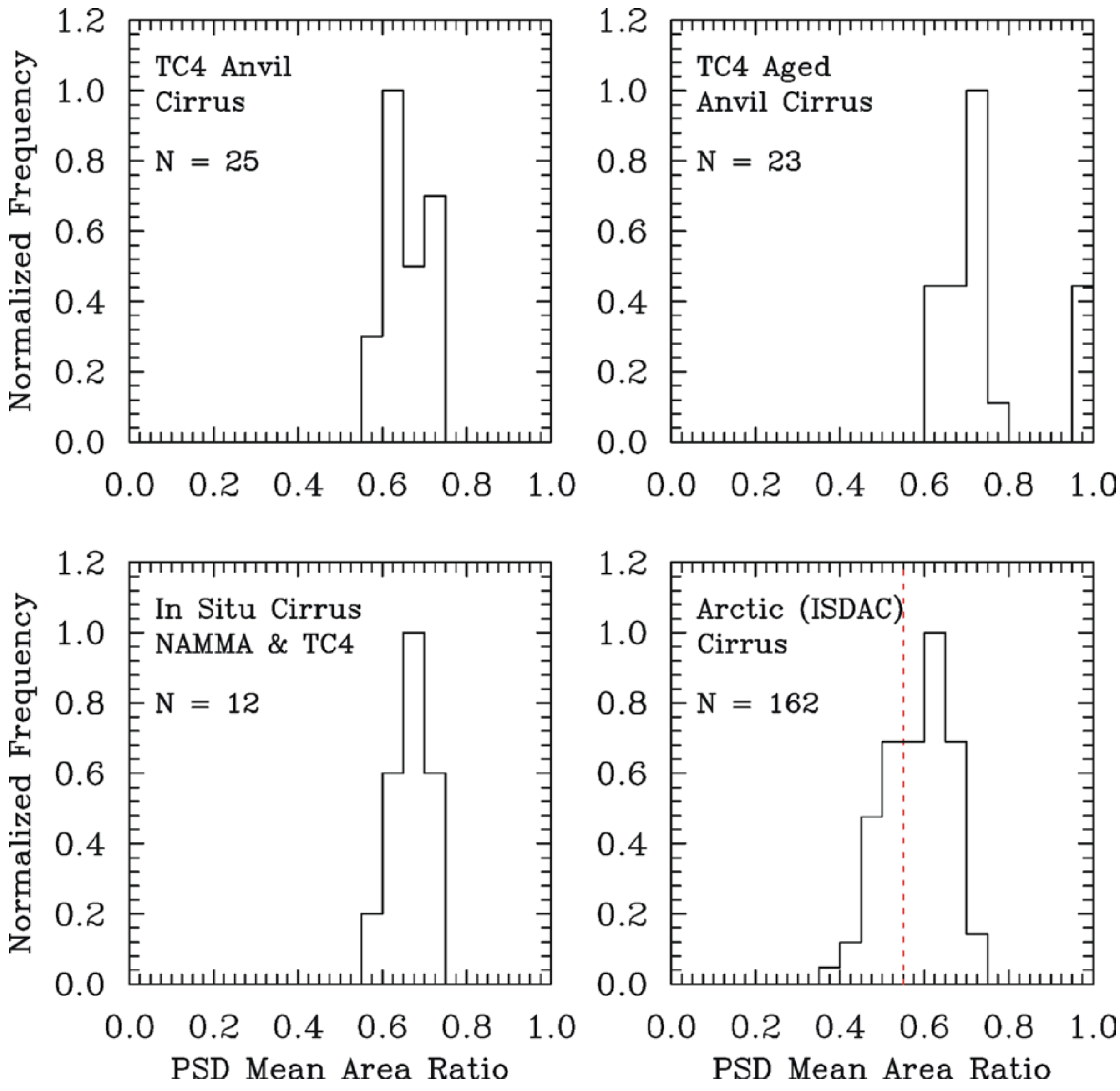


Homogeneous freezing nucleation in synoptic midlatitude cirrus?



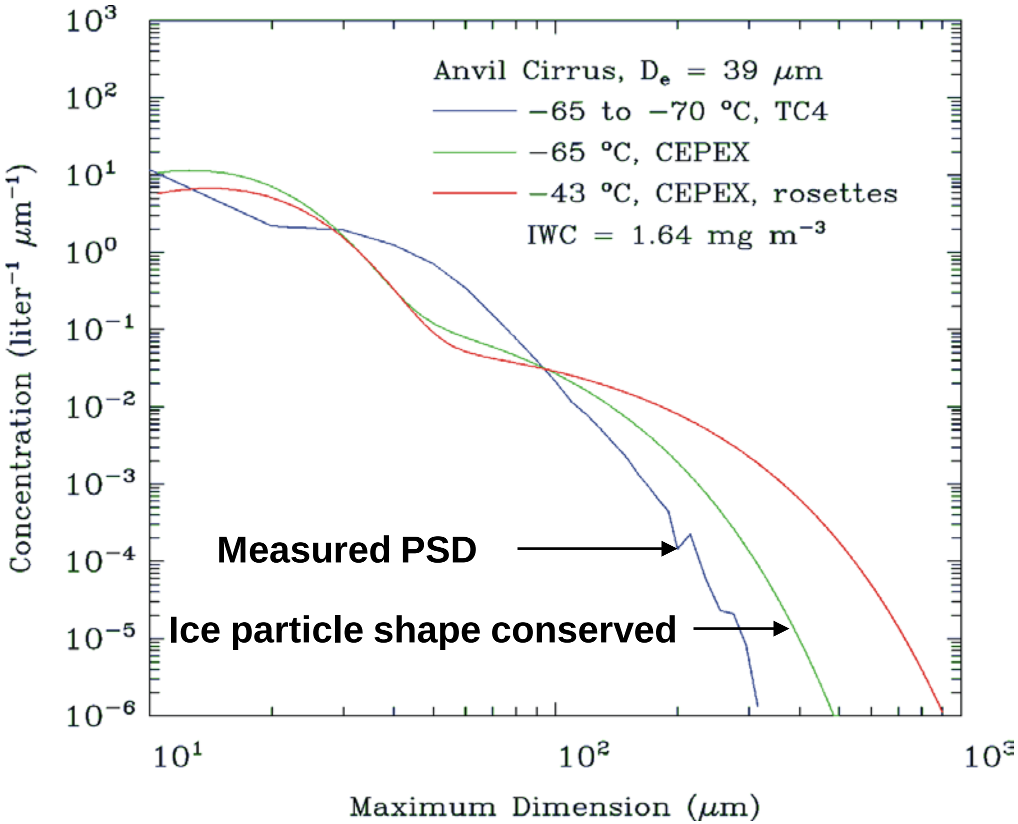


Arctic cirrus crystals have different area ratios

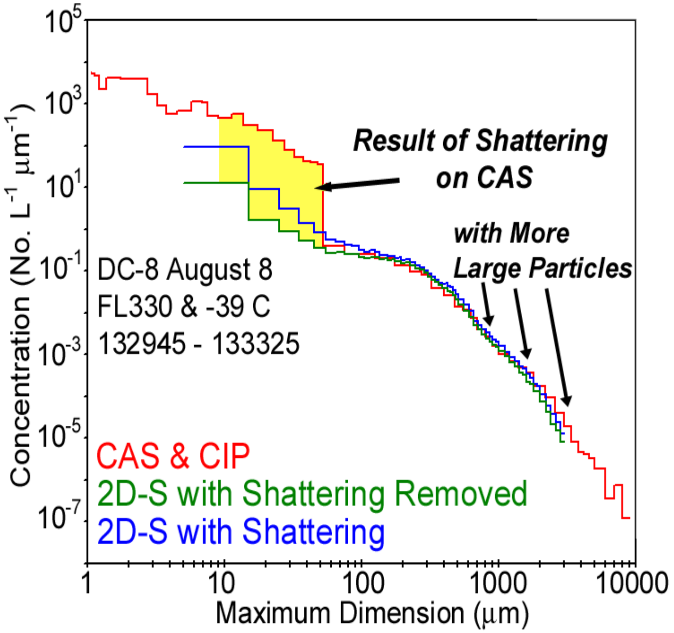


Conventional wisdom is that for a given D_e and IWC, ice cloud optical properties are not sensitive to ice crystal shape and PSD shape. Often this is not true.

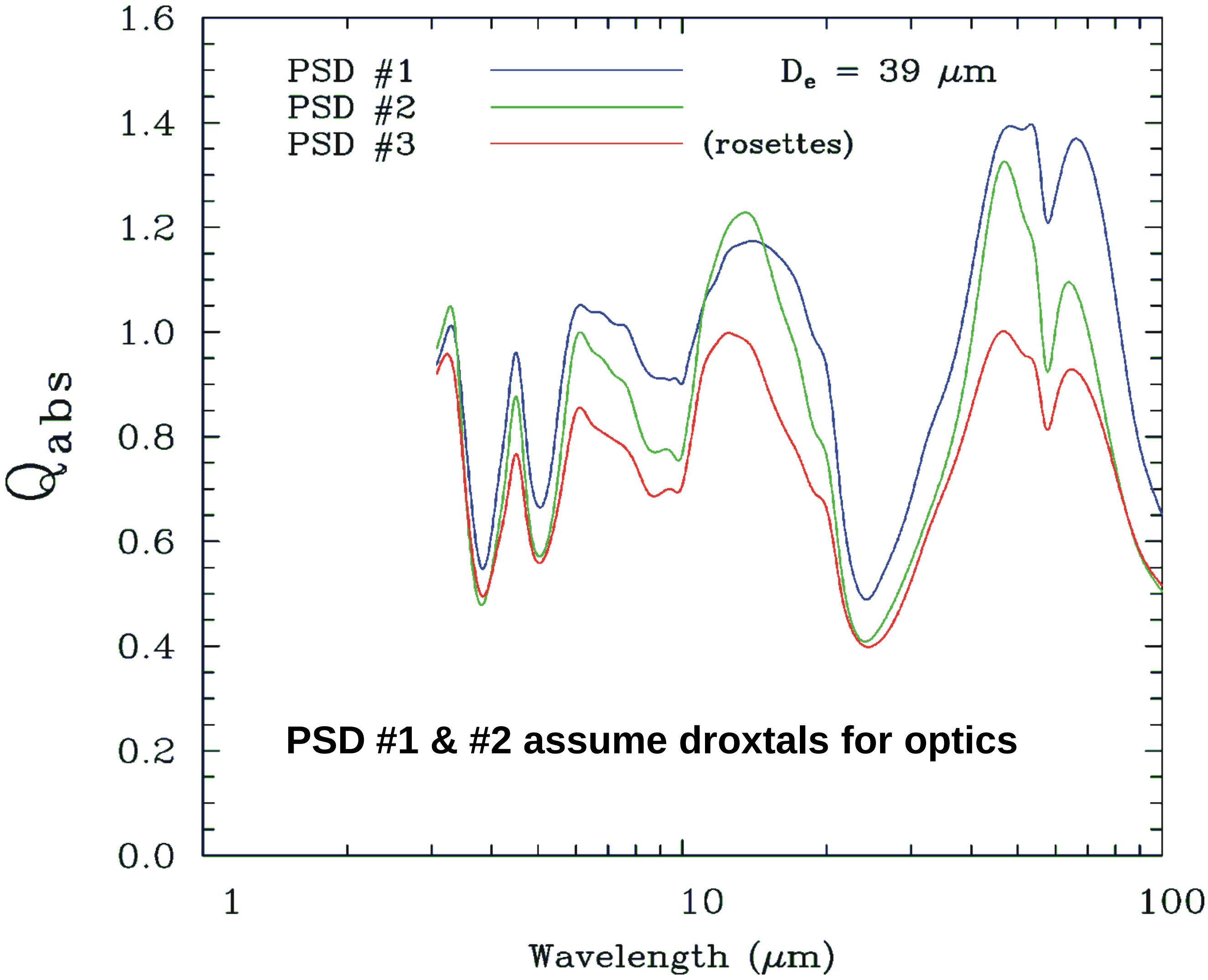
Changing the ice crystal shape changes the PSD for constant D_e & IWC (red curve).



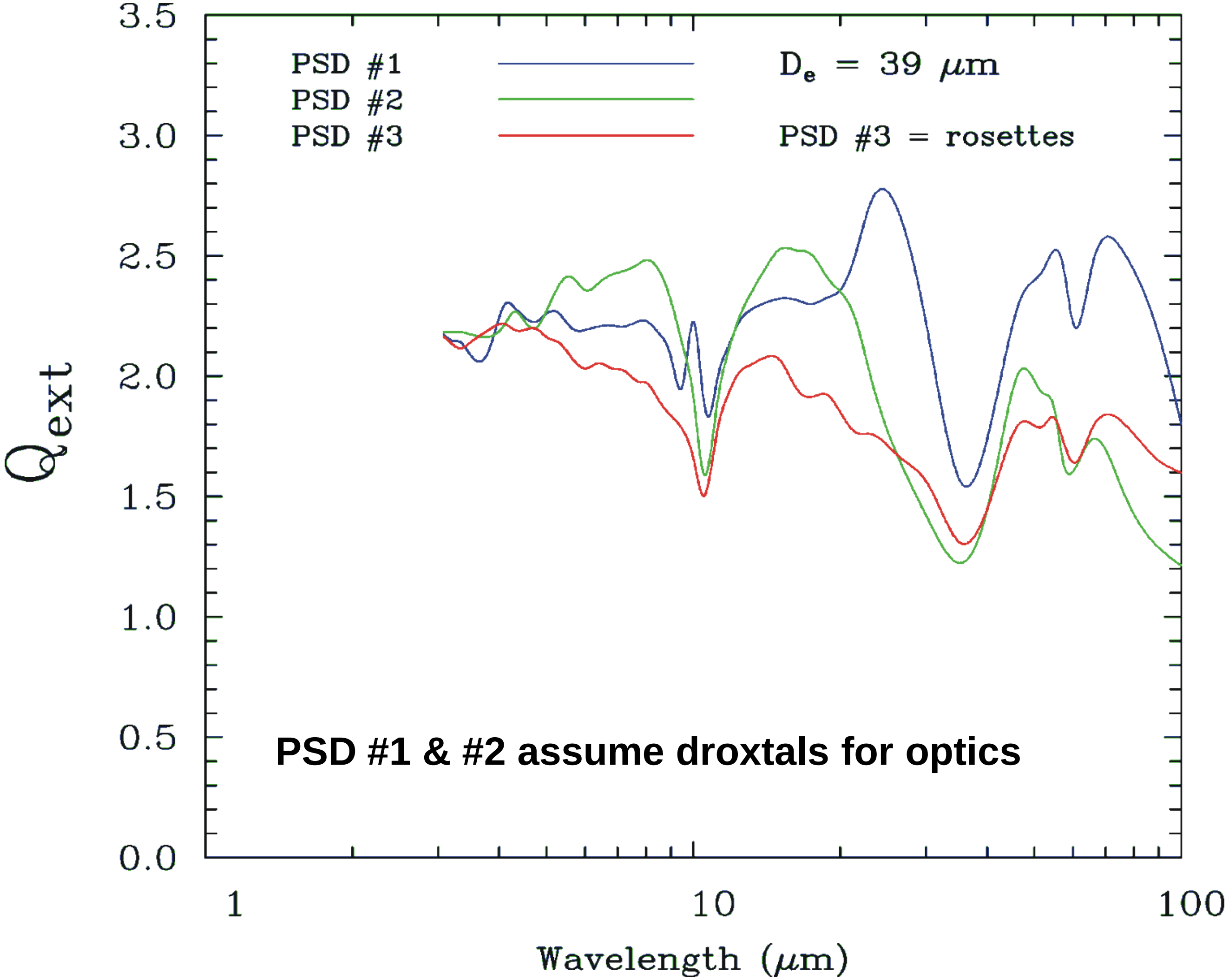
Shattering often increases small crystals by 10^2



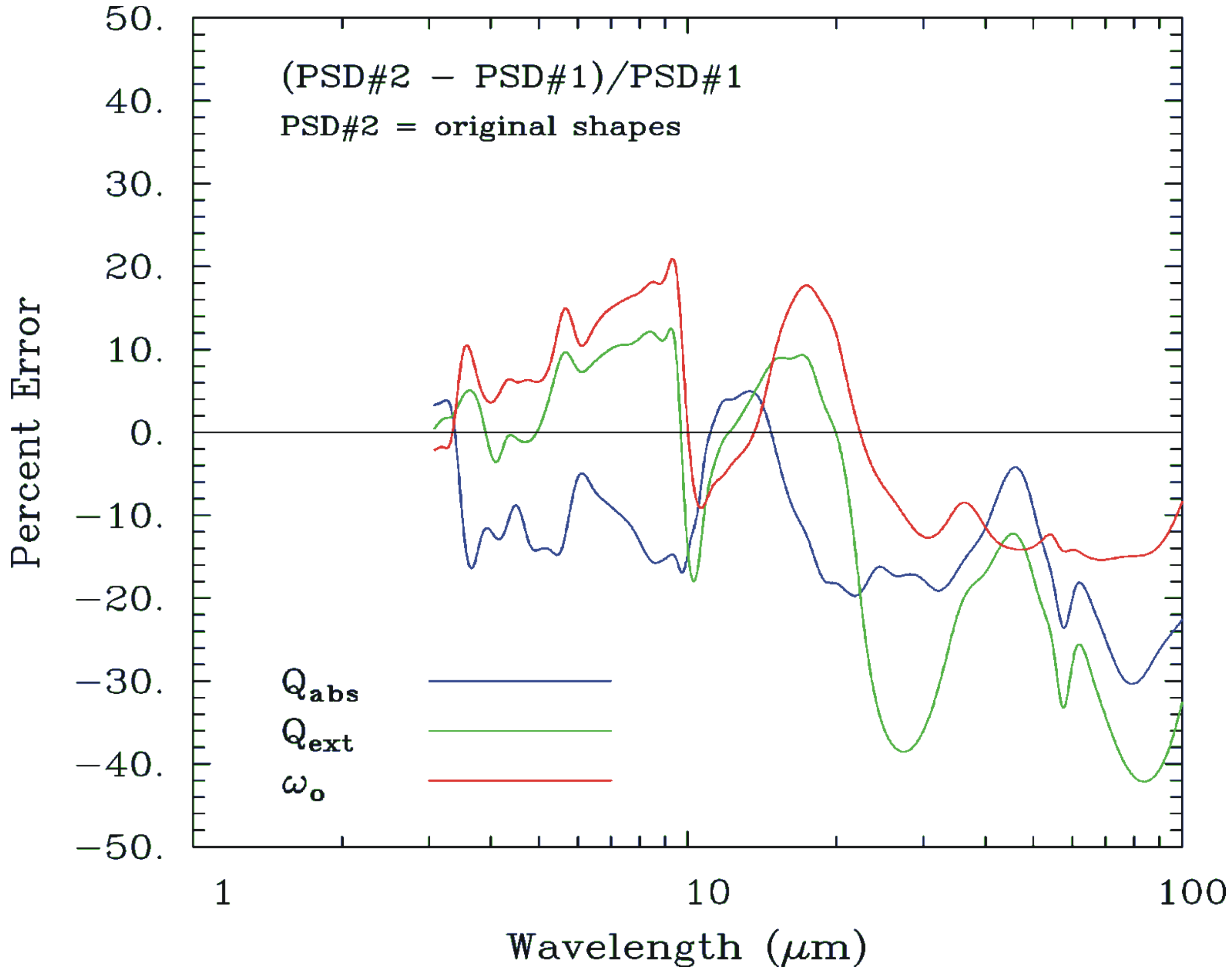
Calculate optical properties for (1) measured PSD; (2) altered PSD with same particle shapes; (3) altered PSD with bullet Rosettes. All use ice optics database of Yang et al. (2005).



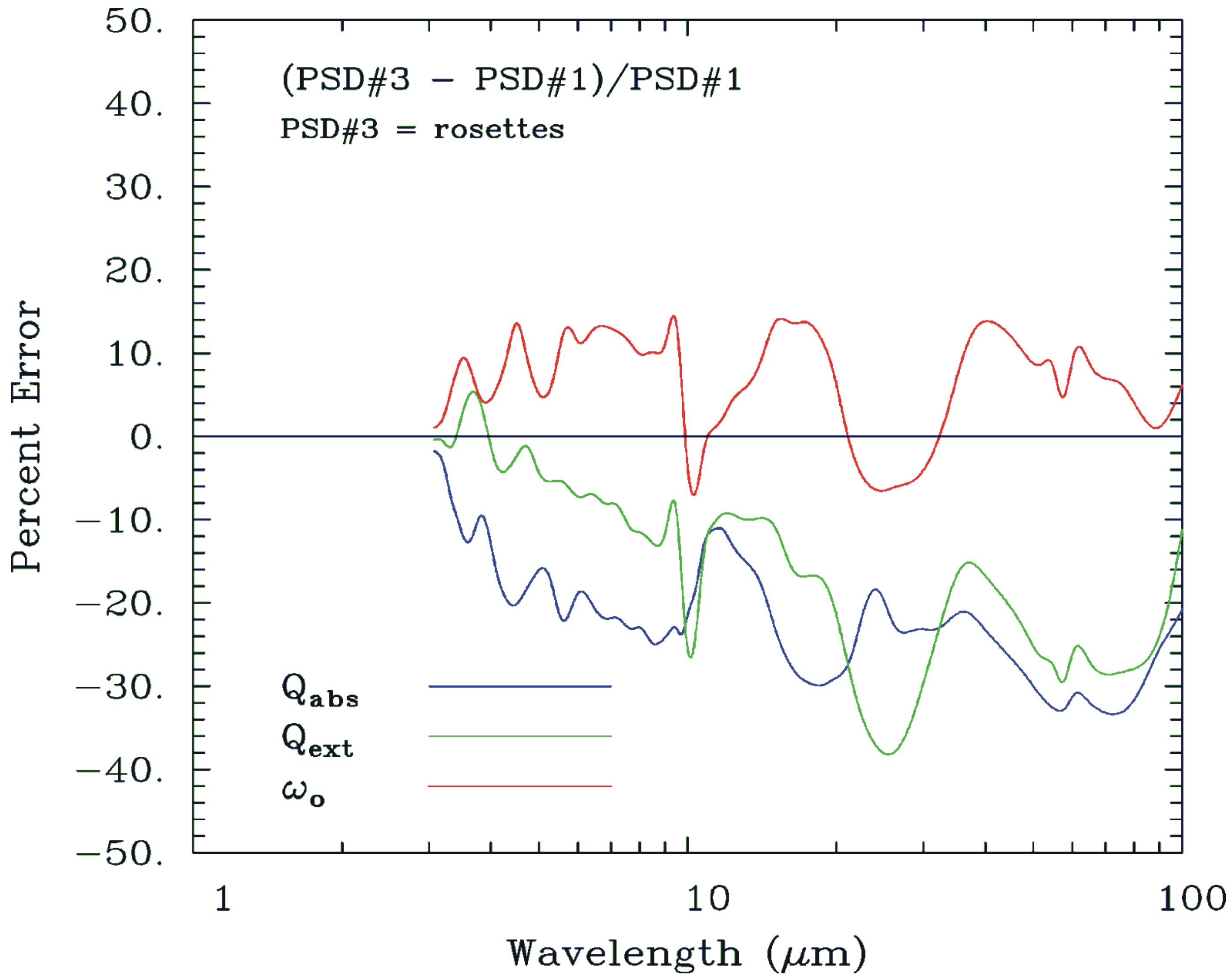
Extinction efficiencies for (1) measured PSD; (2) altered PSD with same particle shapes; (3) altered PSD with bullet rosettes.



Errors when only PSD shape changes and ice particle shapes remain constant. Implications for cloud radar.



Errors when both PSD shape and ice particle shape change



ICE OPTICS CONCLUSIONS

1. Changes in PSD shape alone (while holding D_e and particle shape constant) substantially affects IR ice optical properties.

2. For constant D_e, changing the ice particle shape assumption further changes the PSD shape, which further changes optical properties relative to the reference (i.e. measured) PSD.

3. Climate modeling challenge can be met by using the Modified Anomalous Diffraction Approximation (MADA) that is formulated in terms of PSD parameters and ice particle shape attributes.

Parameterizing the Ice Fall-speed from In Situ Measurements: General Approach

1. The size resolved 2D-S measurements of number, projected area and mass concentration appear reasonable.
   - Ice artifacts from shattering greatly reduced
   - Good agreement between 2D-S and CVI IWC during TC4

2. Therefore calculate V_m and D_e **directly** from these measurements:

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

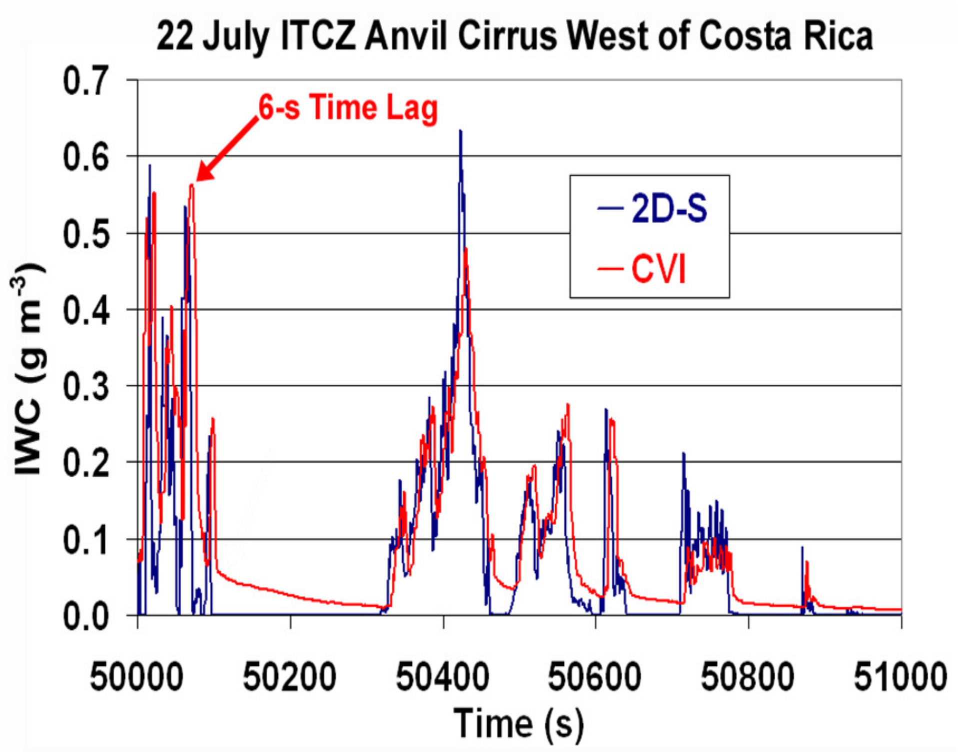
   $$D_e = (3/2)\, \Sigma\, m(D)\, N(D)\, \Delta D \,/\, (\rho_i\, \Sigma\, A(D)\, N(D)\, \Delta D)$$

   - m(D) & A(D) are bin mass or bin area concentration / bin number conc.

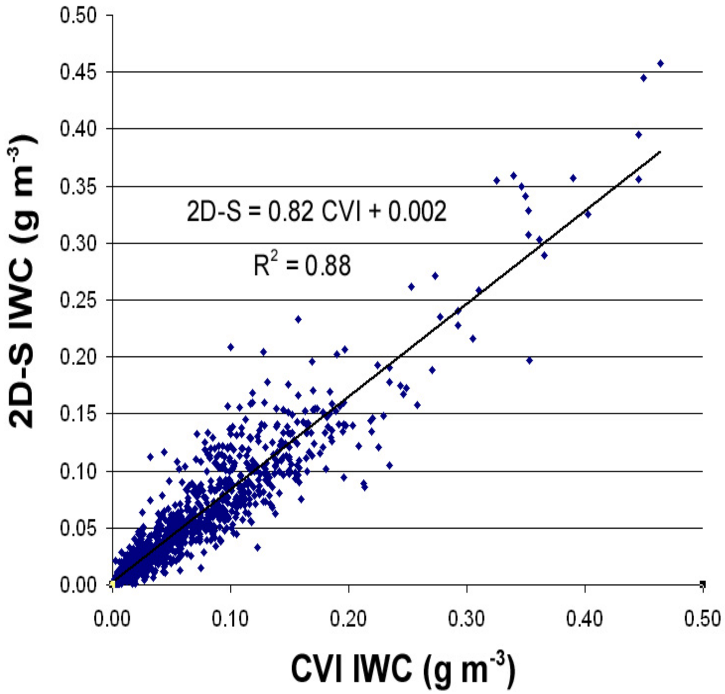
3. Relate V_m and D_e to T and IWC for model validation purposes

4. Relate V_m to D_e to predict V_m from the model microphysics scheme

COMPARISON OF 2D-S AND CVI IWCs DURING TC4



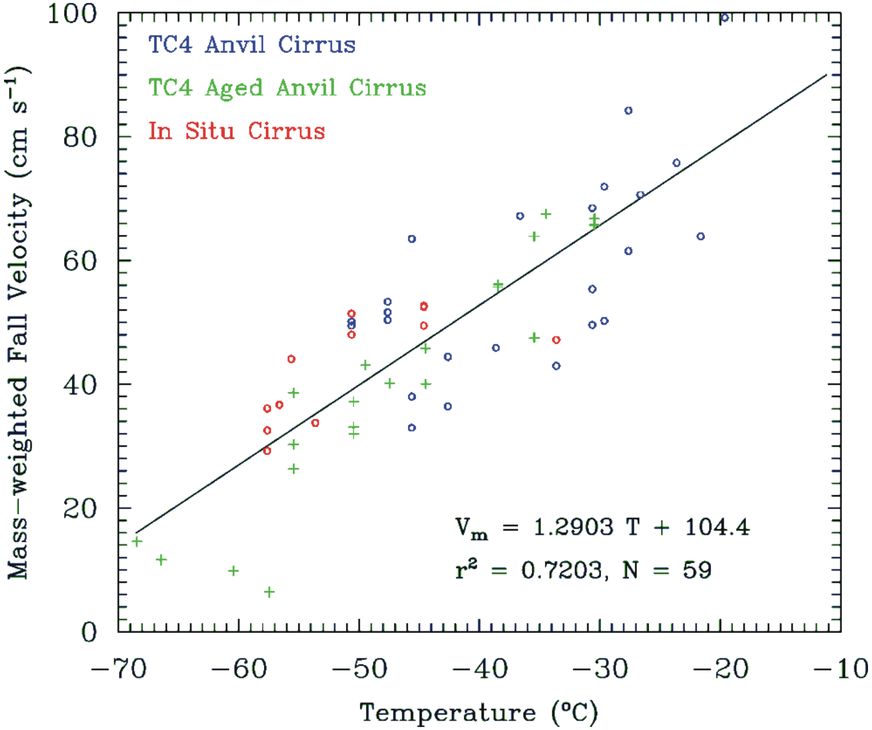
(A)

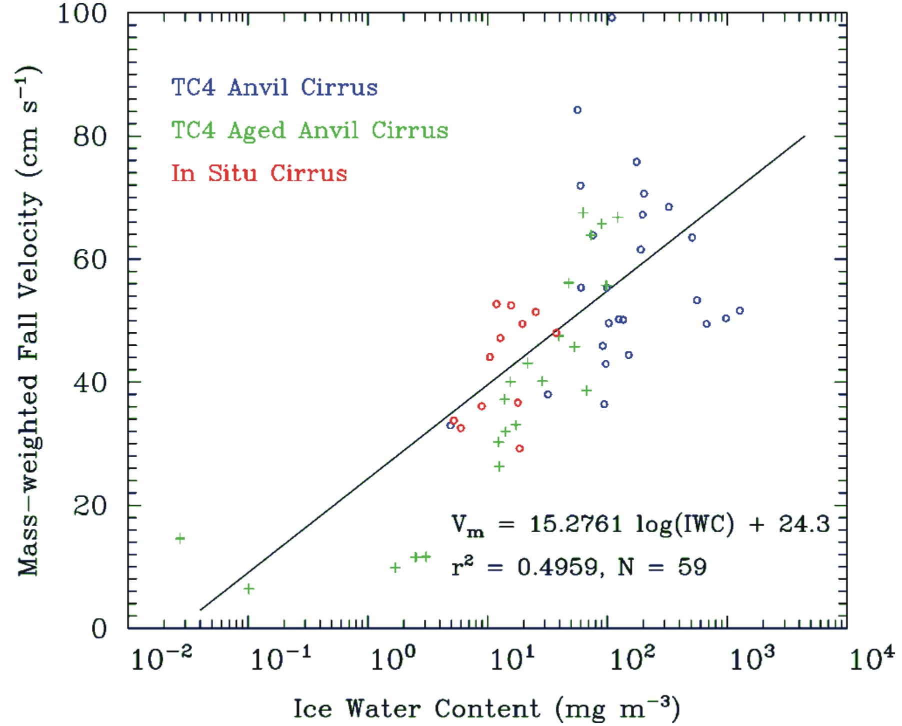


(B)

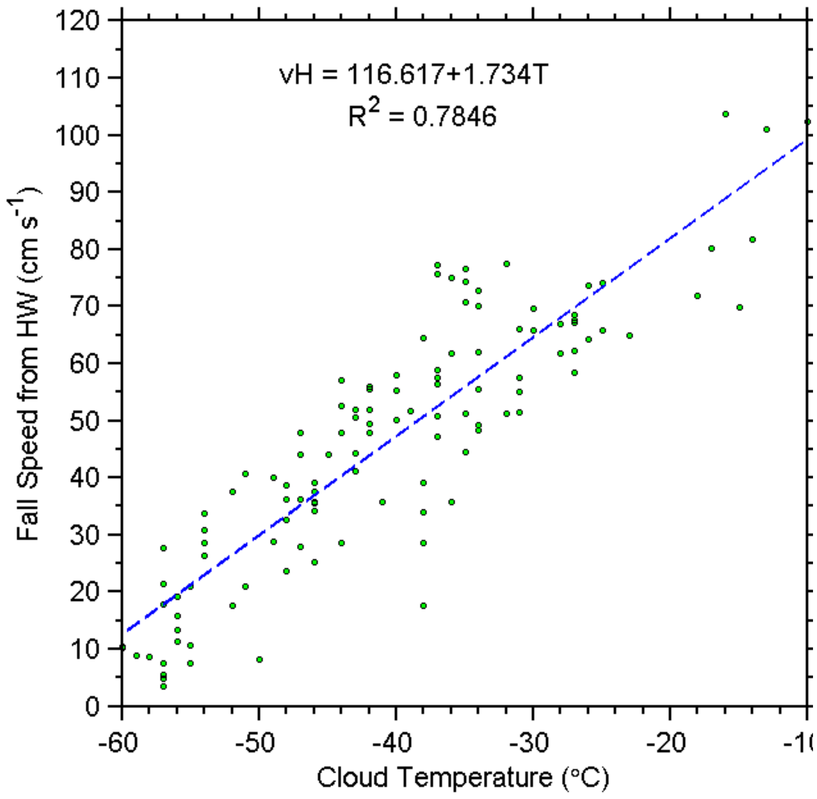
A: Time series of the 2D-S and CVI IWC for a TC4 case study. CVI response time lagged 6 seconds behind 2D-S measurements, producing a slight offset. B: 2D-S IWCs compared with CVI IWCs for 12,000 1-Hz measurements (averaged over 10-s) in TC4 anvils cirrus.

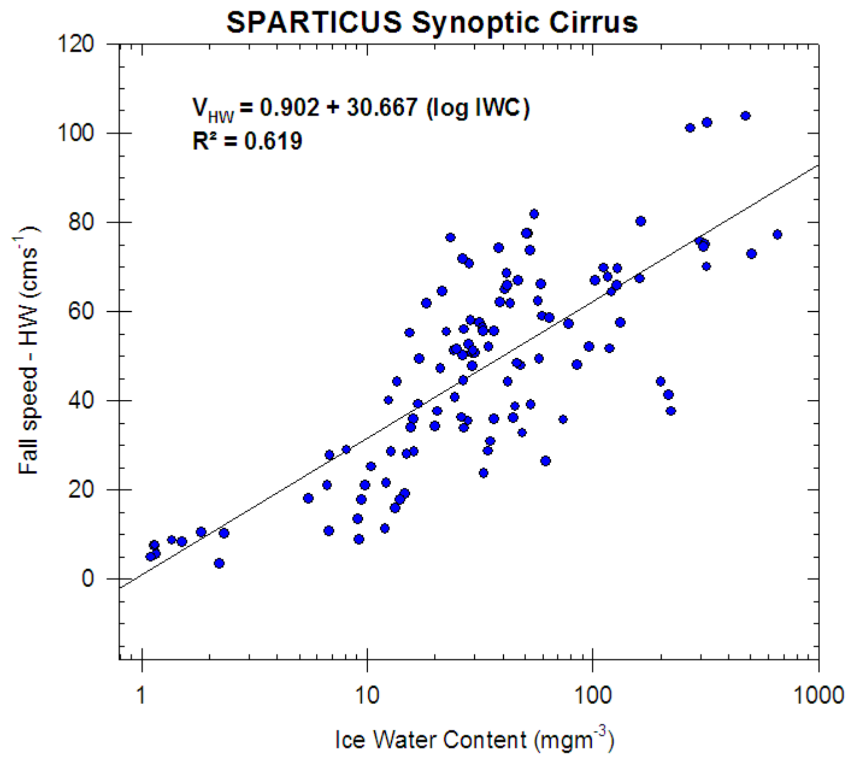
Mass-weighted fall velocity was related to both temperature and IWC during TC4 and SPARTICUS but not during ISDAC. Why?



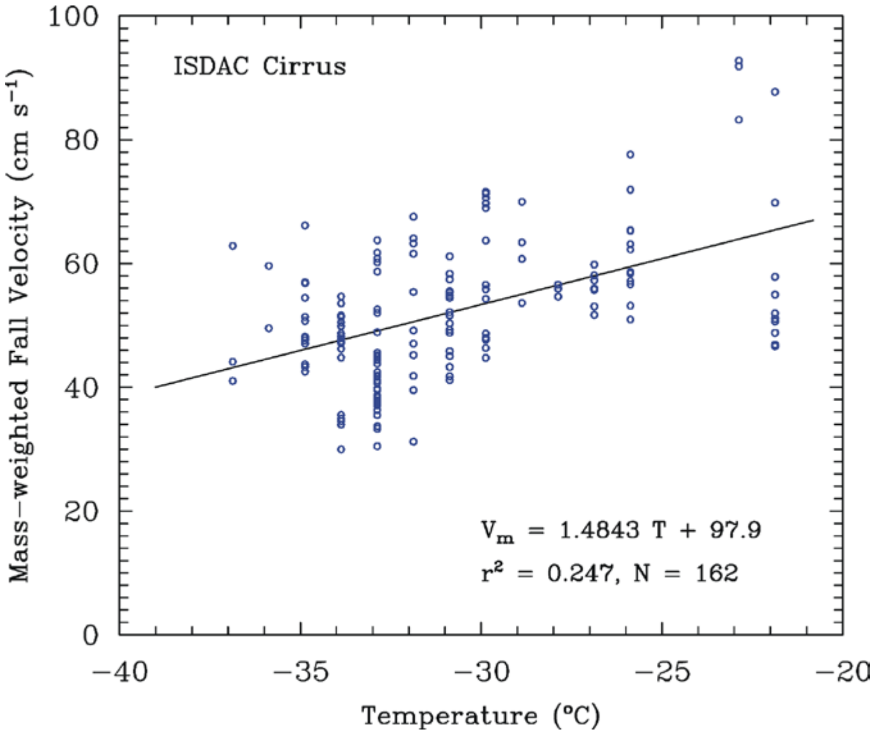


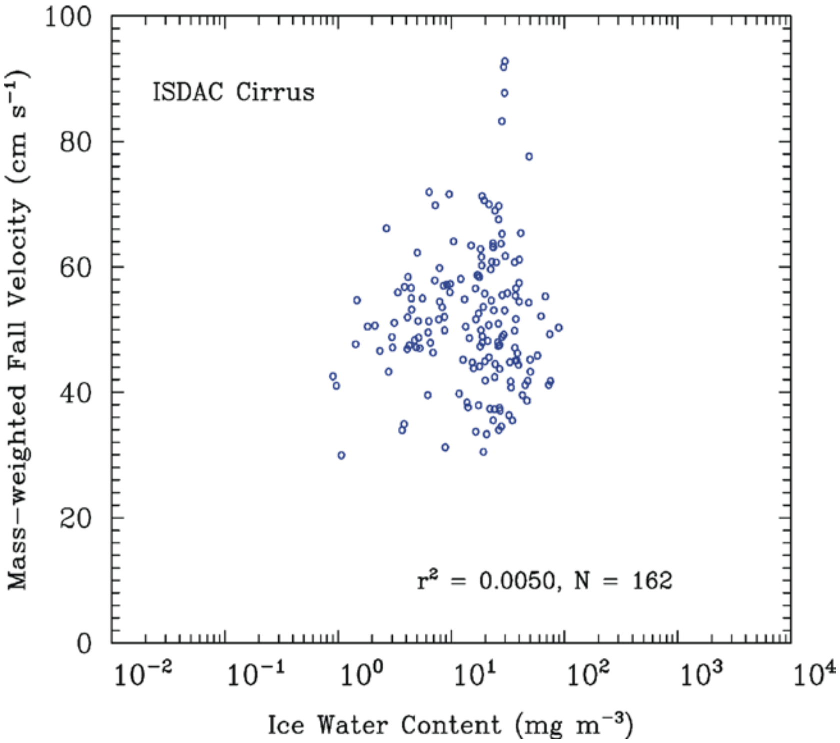
SPARTICUS SYNOPTIC CIRRUS: V_m vs. T and V_m vs. IWC

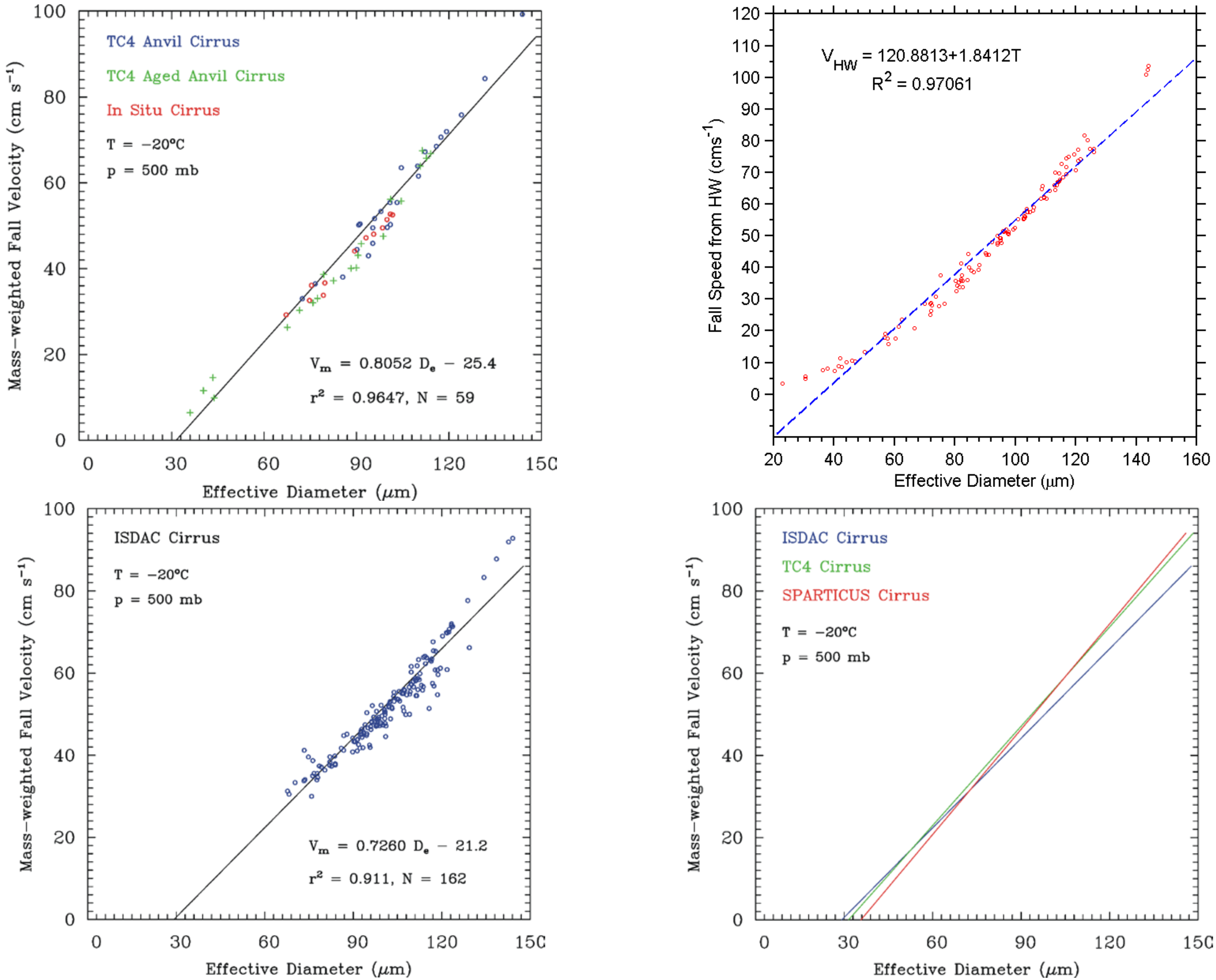




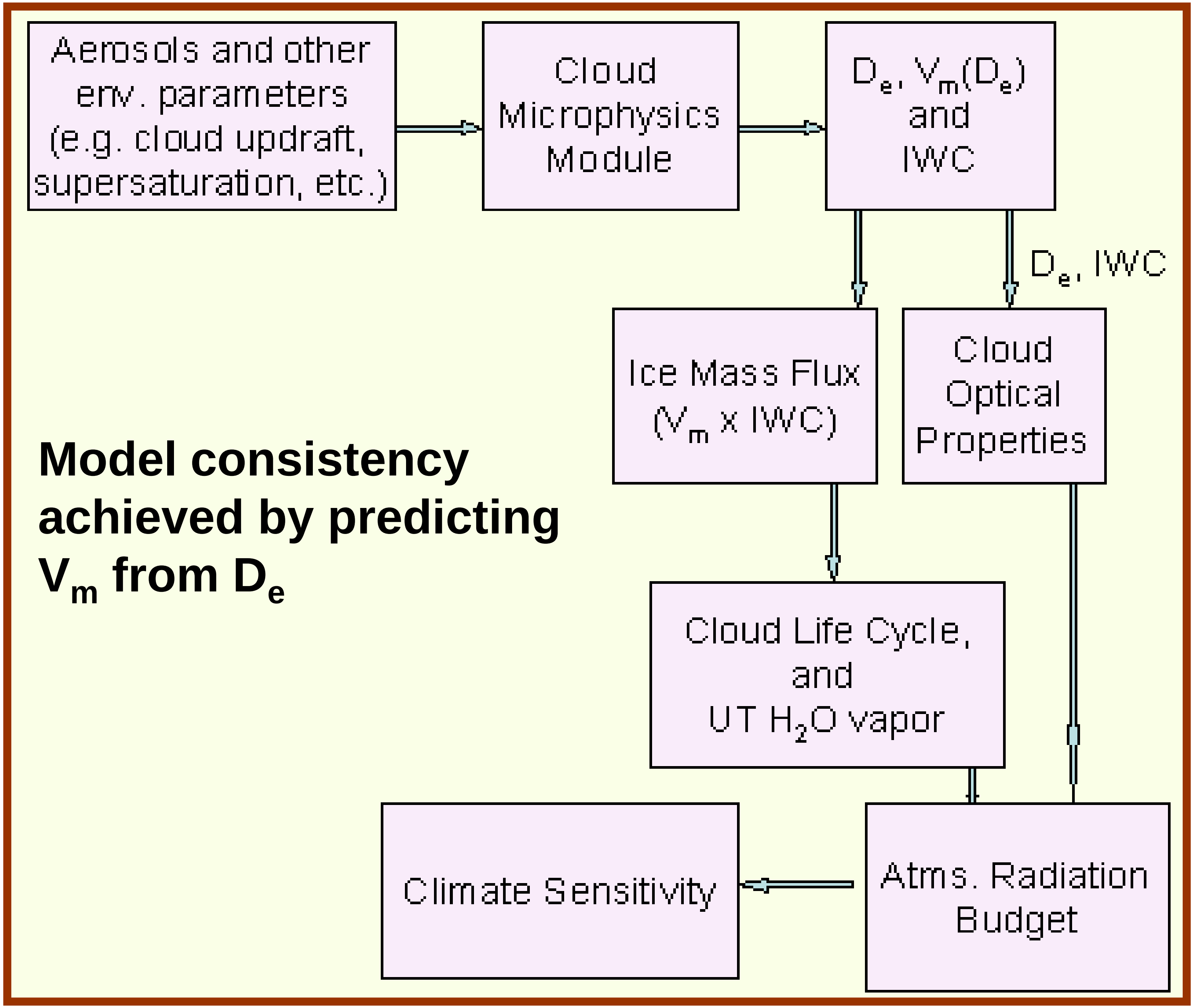
ISDAC FIELD CAMPAIGN





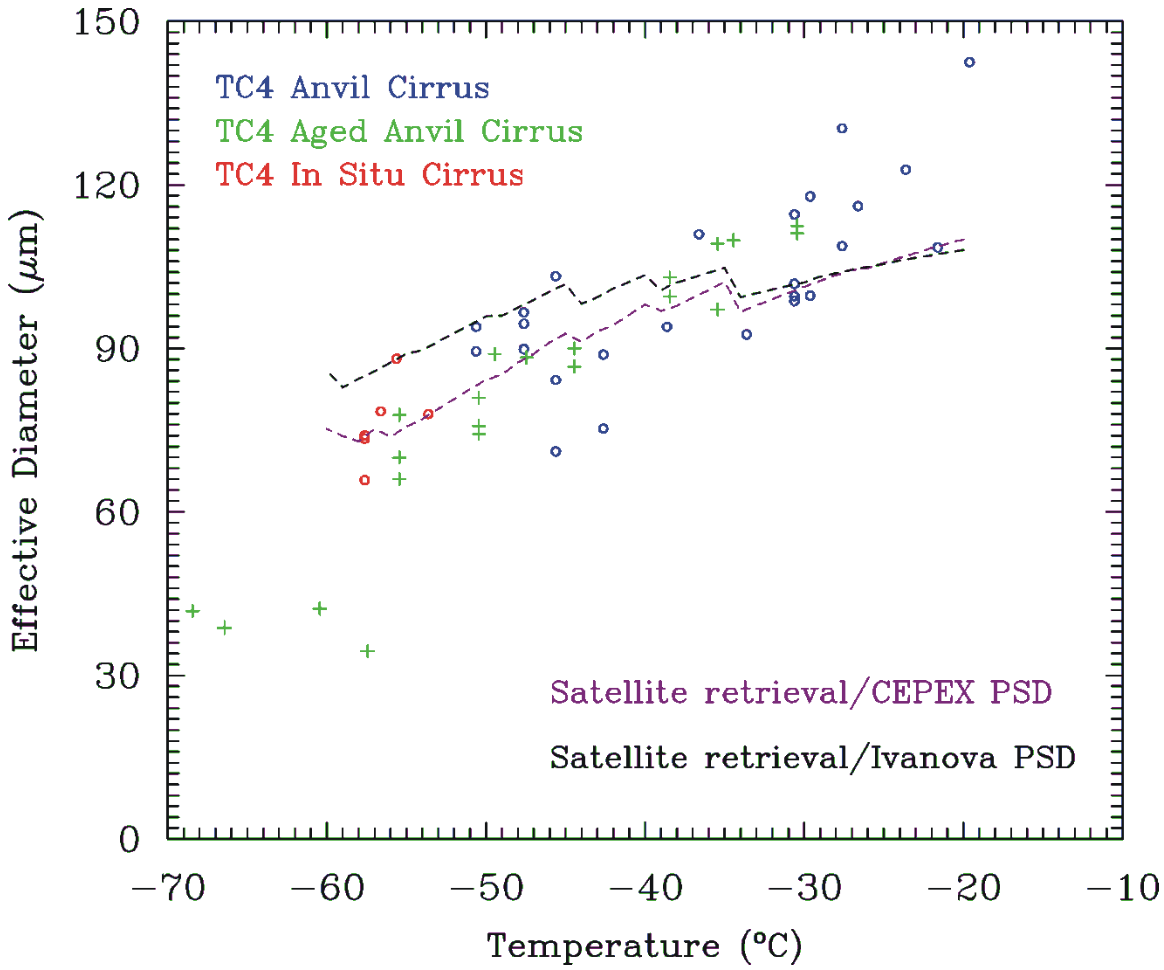


TC4 Anvil Cirrus
TC4 Aged Anvil Cirrus
In Situ Cirrus
T = −20°C
p = 500 mb
$V_m = 0.8052\ D_e - 25.4$
$r^2 = 0.9647$, N = 59
Mass−weighted Fall Velocity (cm s^{-1})
Effective Diameter (μm)
$V_{HW} = 120.8813+1.8412T$
$R^2 = 0.97061$
Fall Speed from HW (cms^{-1})
Effective Diameter (μm)
ISDAC Cirrus
T = −20°C
p = 500 mb
$V_m = 0.7260\ D_e - 21.2$
$r^2 = 0.911$, N = 162
Mass−weighted Fall Velocity (cm s^{-1})
Effective Diameter (μm)
ISDAC Cirrus
TC4 Cirrus
SPARTICUS Cirrus
T = −20°C
p = 500 mb
Mass−weighted Fall Velocity (cm s^{-1})
Effective Diameter (μm)

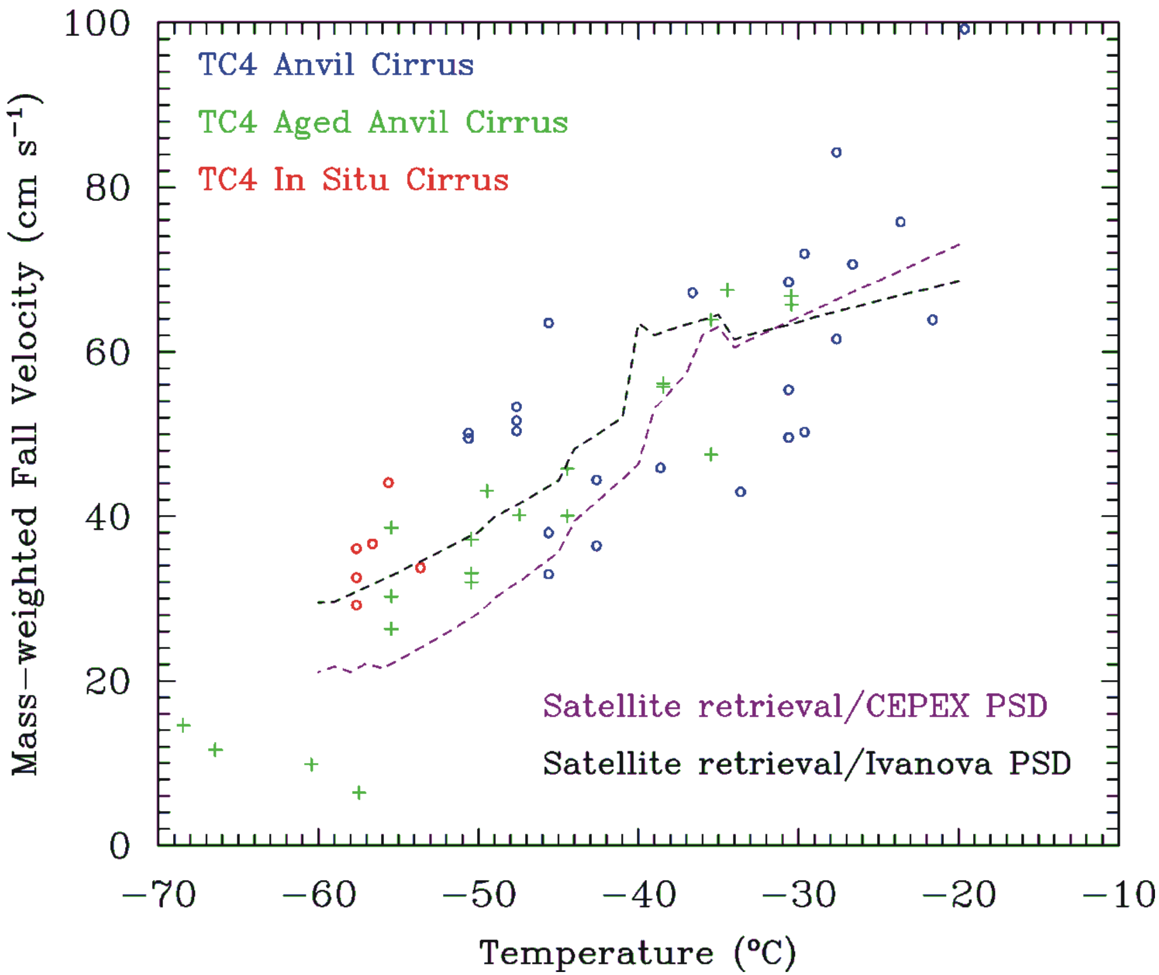


Model consistency achieved by predicting V_m from D_e

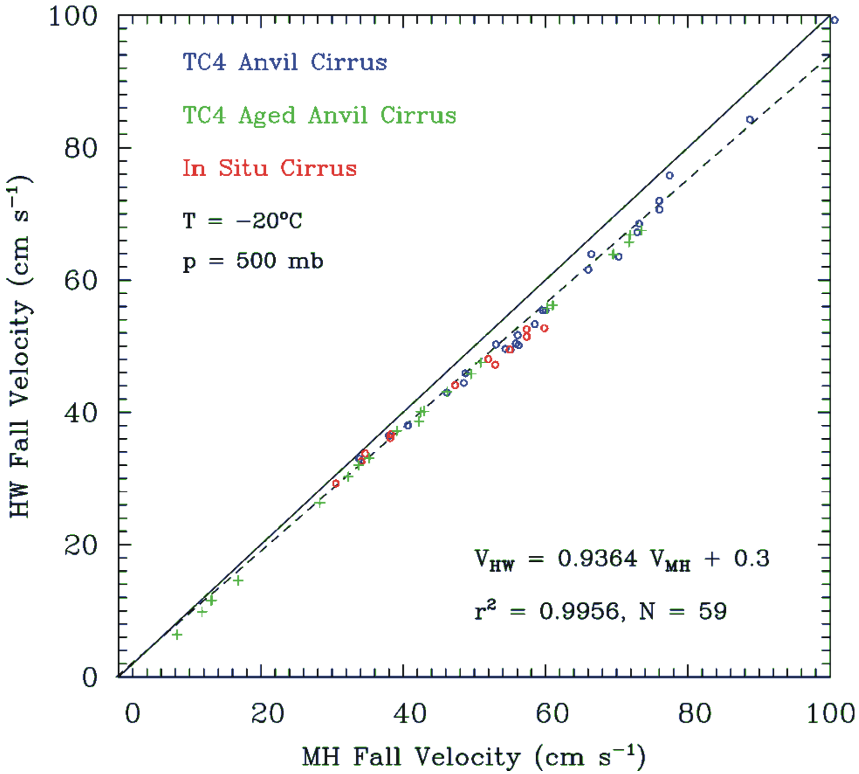
EXTRA SLIDES



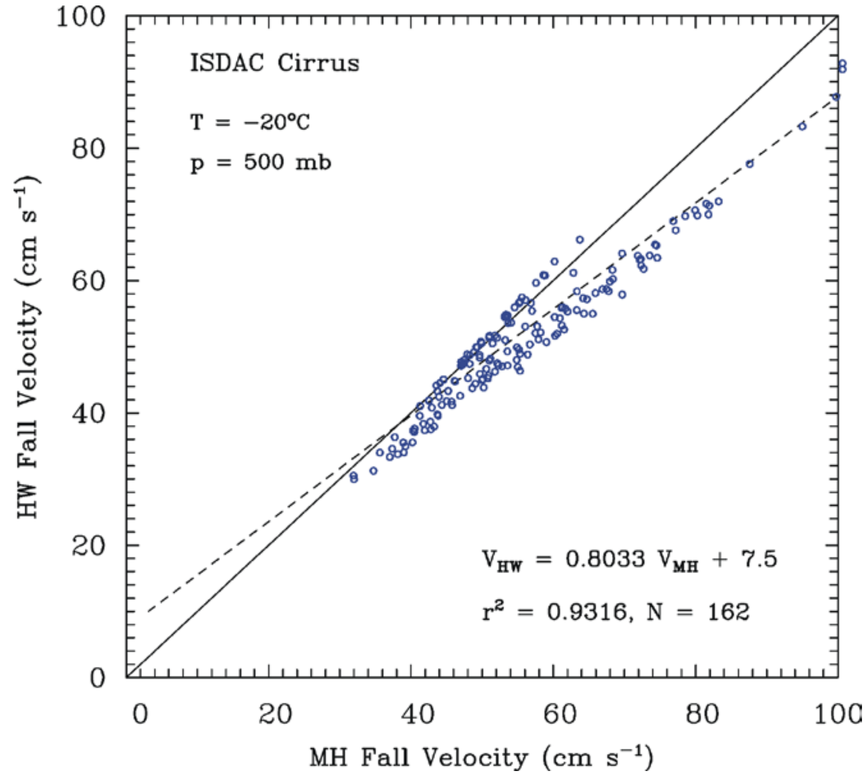
150
120
90
60
30
0
−70
−60
−50
−40
−30
−20
−10
Effective Diameter (μm)
Temperature (°C)
TC4 Anvil Cirrus
TC4 Aged Anvil Cirrus
TC4 In Situ Cirrus
Satellite retrieval/CEPEX PSD
Satellite retrieval/Ivanova PSD



TC4 Anvil Cirrus
TC4 Aged Anvil Cirrus
TC4 In Situ Cirrus
Satellite retrieval/CEPEX PSD
Satellite retrieval/Ivanova PSD
Mass−weighted Fall Velocity (cm s−1)
Temperature (°C)
100
80
60
40
20
0
−70
−60
−50
−40
−30
−20
−10



TC4 Anvil Cirrus
TC4 Aged Anvil Cirrus
In Situ Cirrus
T = −20°C
p = 500 mb
$V_{HW} = 0.9364\ V_{MH} + 0.3$
$r^2 = 0.9956$, N = 59
HW Fall Velocity (cm s^{-1})
MH Fall Velocity (cm s^{-1})
0
20
40
60
80
100



ISDAC Cirrus
T = −20°C
p = 500 mb
$V_{HW} = 0.8033\ V_{MH} + 7.5$
$r^2 = 0.9316$, N = 162
HW Fall Velocity (cm s^{-1})
MH Fall Velocity (cm s^{-1})
0
20
40
60
80
100