Measurements for Guiding Ice Nucleation, PSD and Morphology Parameterizations in CAM5

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Atmospheric System Research

ARM

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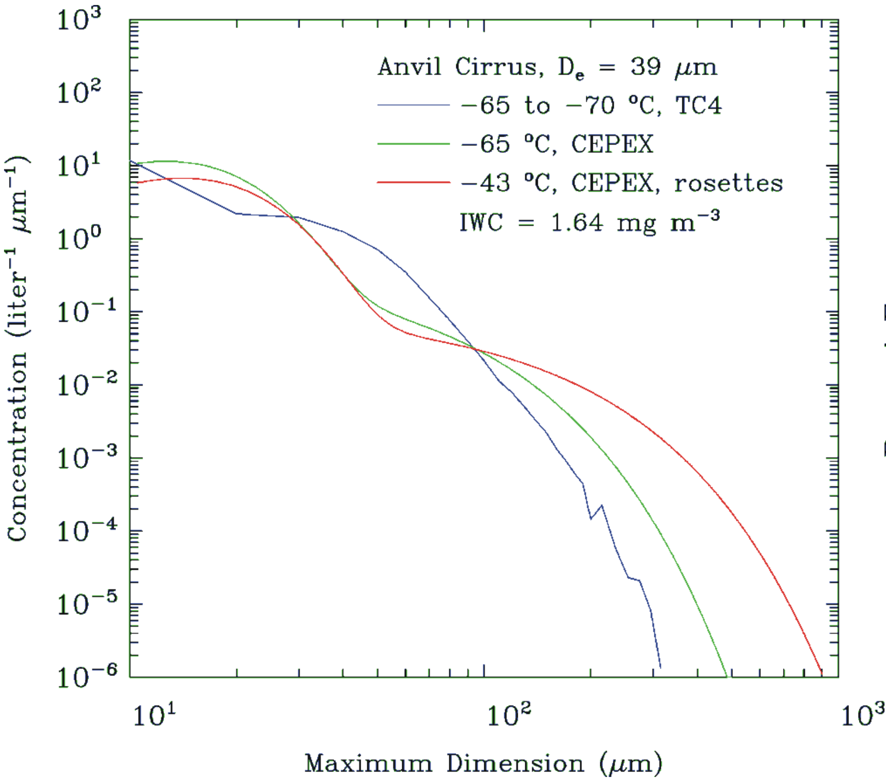
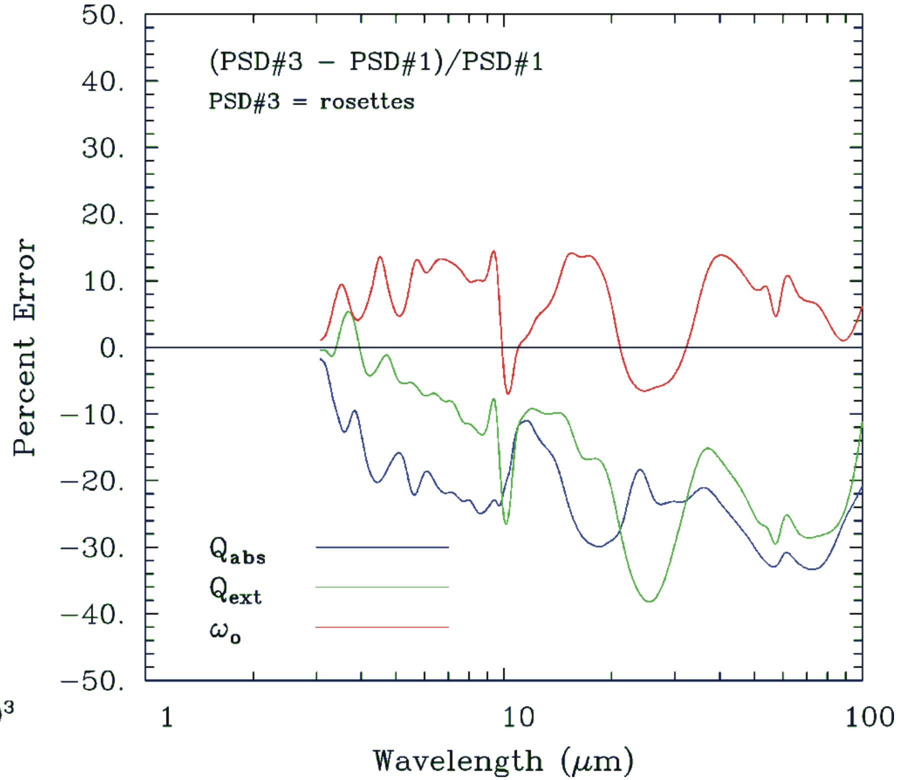
Uncertainties in CAM5 Microphysics:

1. Ice nucleation
2. Ice fall speed
3. Ice particle shape (A-D and m-D power laws)
4. PSD shape

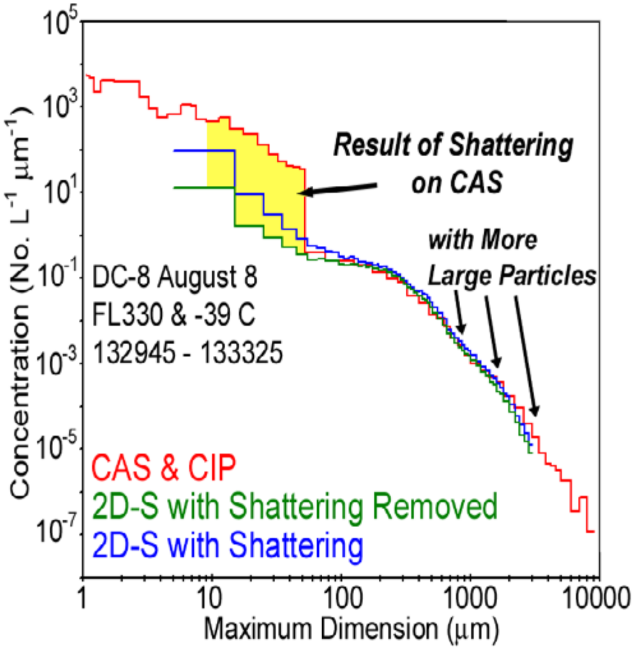




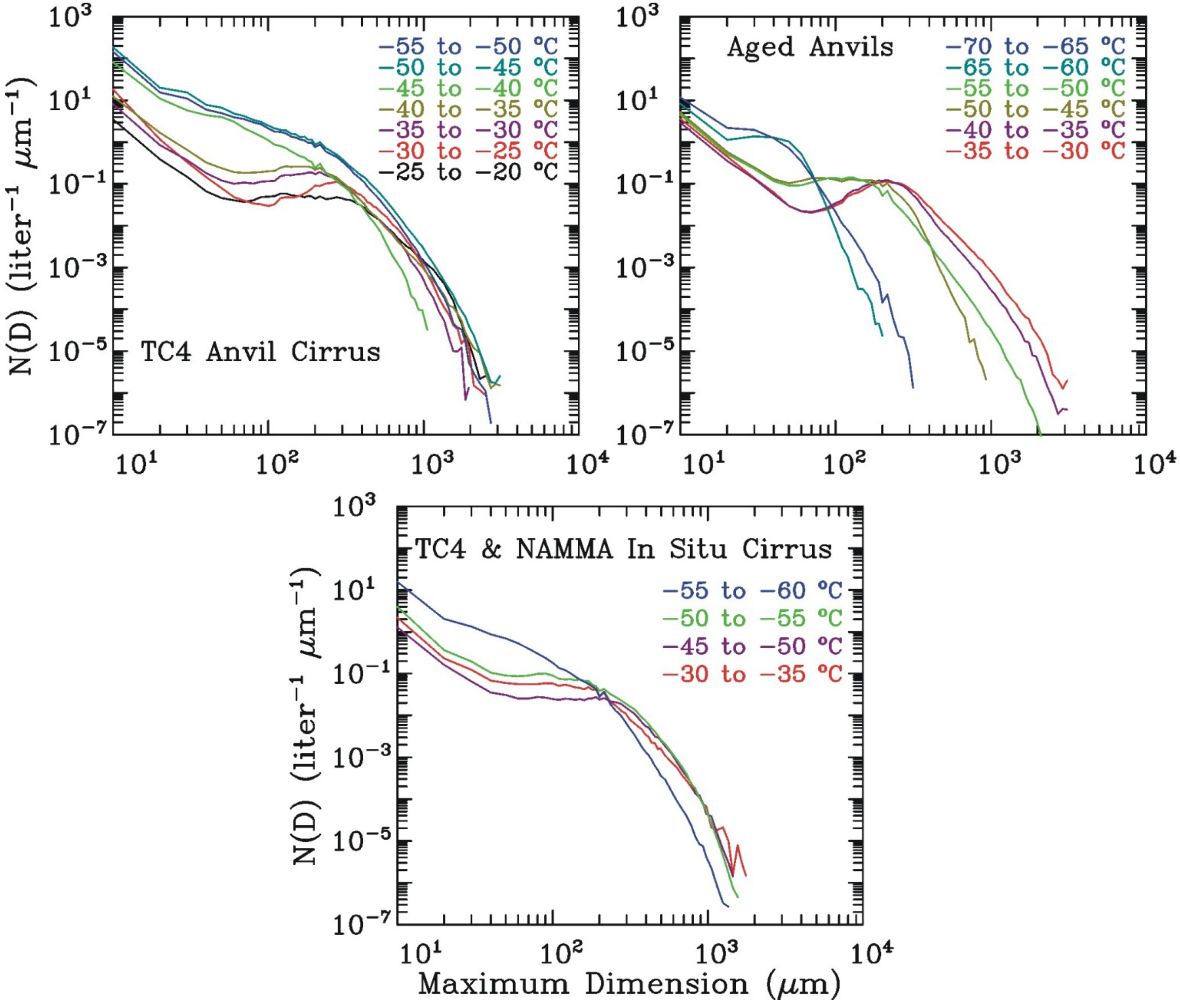
From Mitchell et al. 2011, ACP

Historical PSD measurements in cirrus clouds were subject to small ice crystal artifacts due to shattering at the probe inlet. This swarm of ice artifacts masked the dependence of small ice crystals on ice nucleation processes. The 2D-S probe was used during SPARTICUS and due to its design and data processing the concentration of ice artifacts now appear to be greatly reduced. This study shows what the 2D-S data may imply regarding ice nucleation and ice crystal morphology in cirrus clouds.

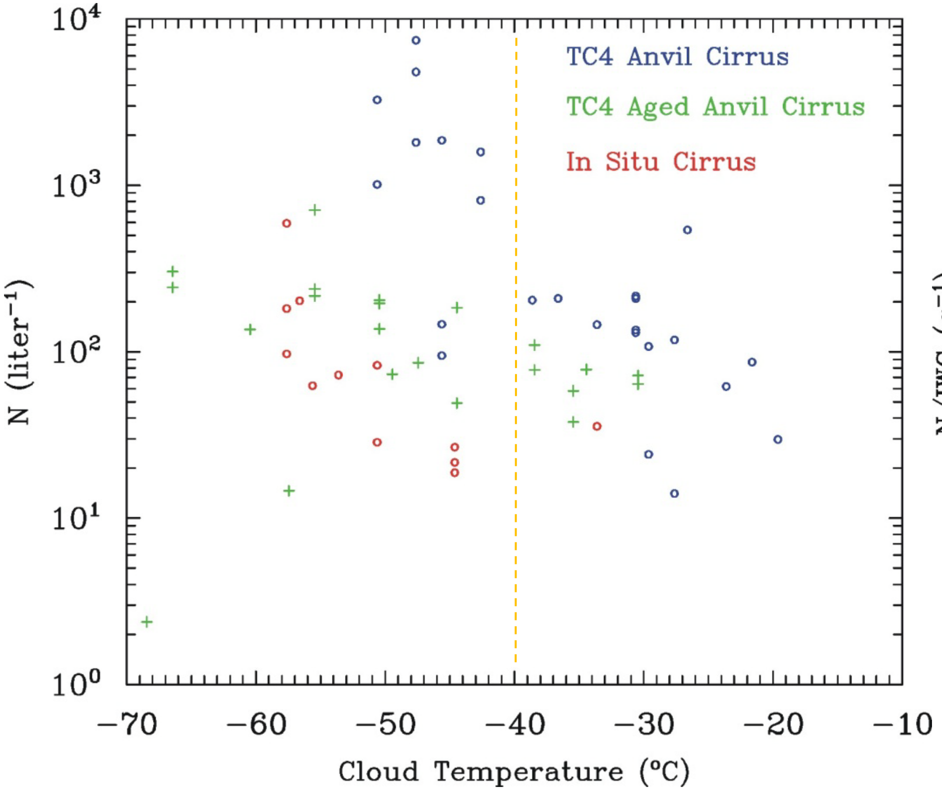
Shattering often increases small crystals by 10^2

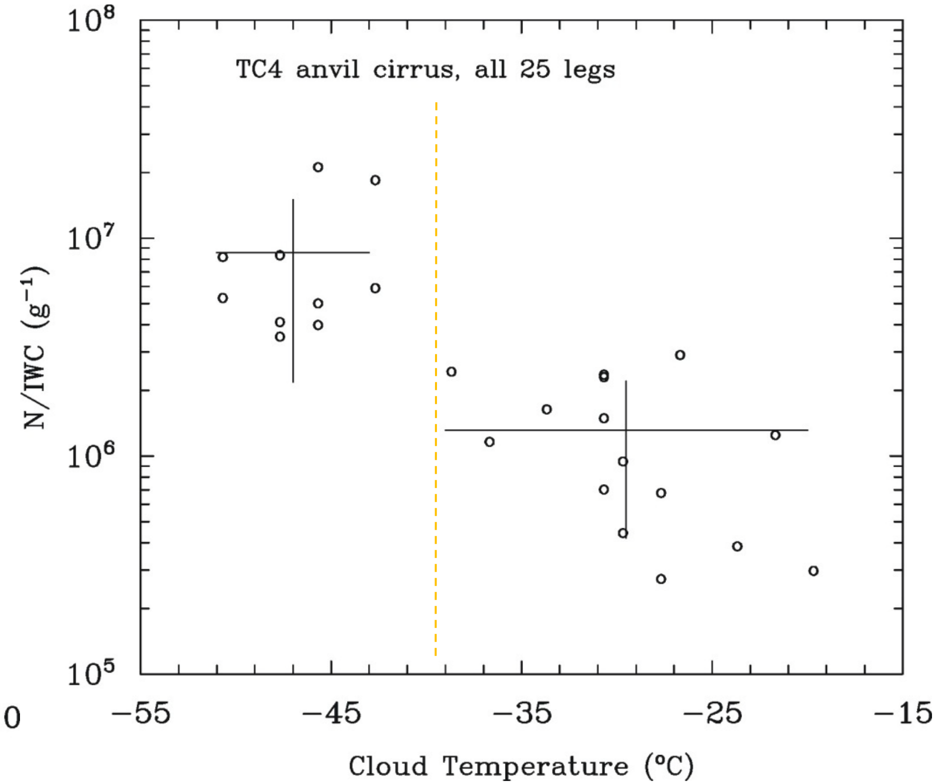


TC4 Results


TC4 Anvil Cirrus
−55 to −50 °C
−50 to −45 °C
−45 to −40 °C
−40 to −35 °C
−35 to −30 °C
−30 to −25 °C
−25 to −20 °C
Aged Anvils
−70 to −65 °C
−65 to −60 °C
−55 to −50 °C
−50 to −45 °C
−40 to −35 °C
−35 to −30 °C
TC4 & NAMMA In Situ Cirrus
−55 to −60 °C
−50 to −55 °C
−45 to −50 °C
−30 to −35 °C
N(D) (liter⁻¹ μm⁻¹)
Maximum Dimension (μm)

Evidence for homogeneous freezing nucleation in fresh anvil cirrus

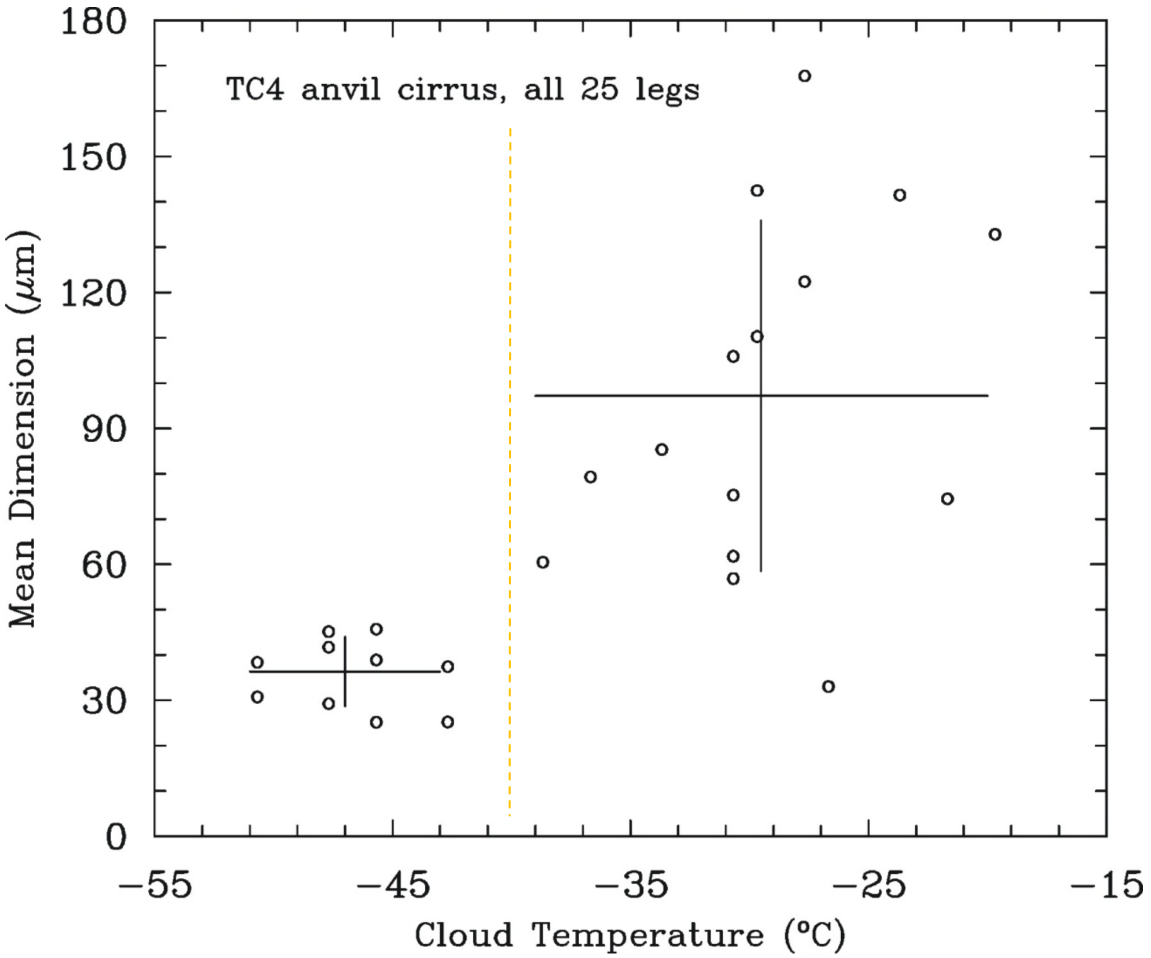




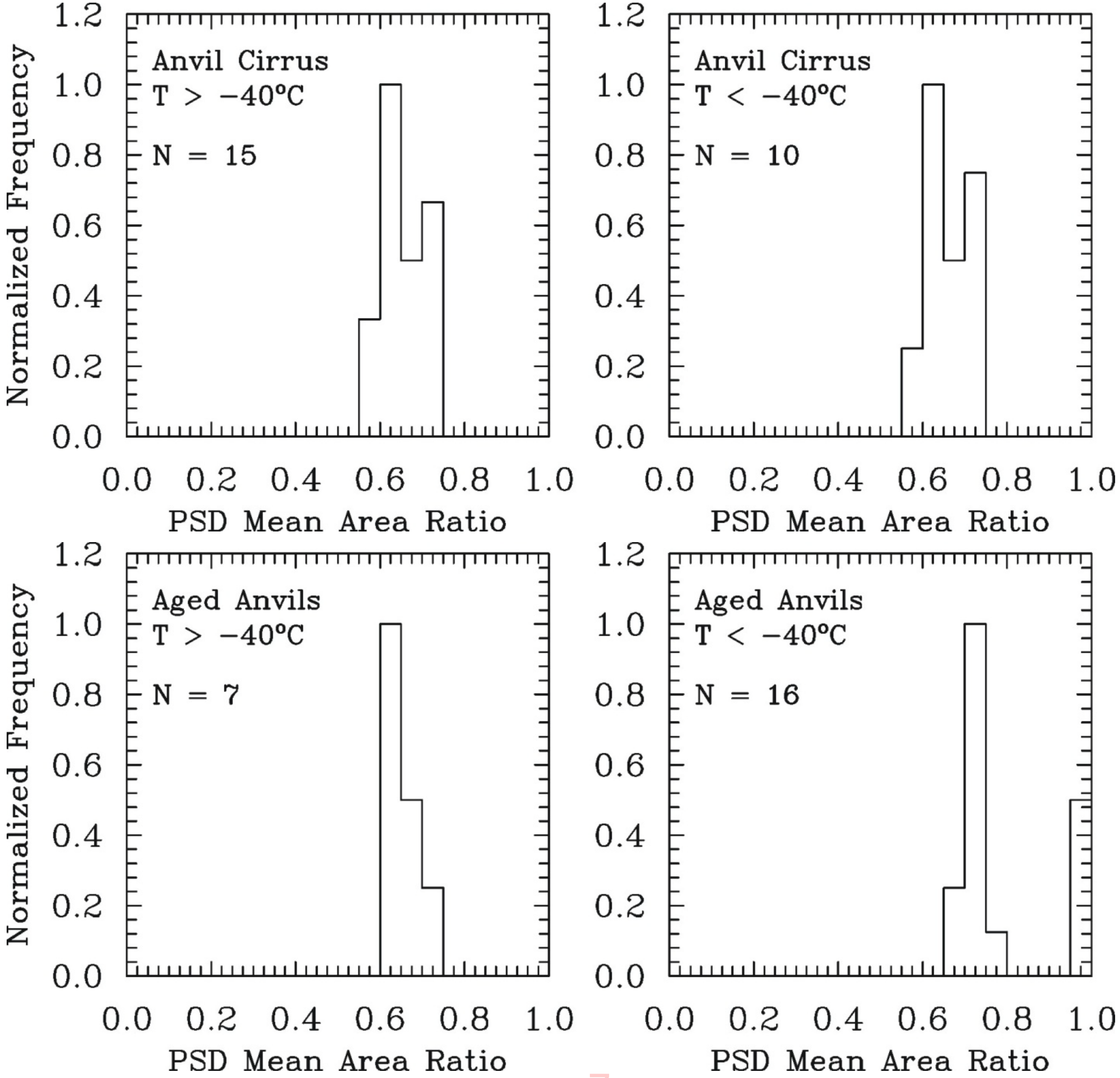
Ignoring aggregation & advection, the ratio N/IWC appears related to the nucleation rate coefficient J (# g^{-1} s^{-1}): $N/IWC \equiv \int_{t_o}^{t_f} J(t)\,dt$

where t_o = ice initiation and t_f = sampling time of ascending parcel.

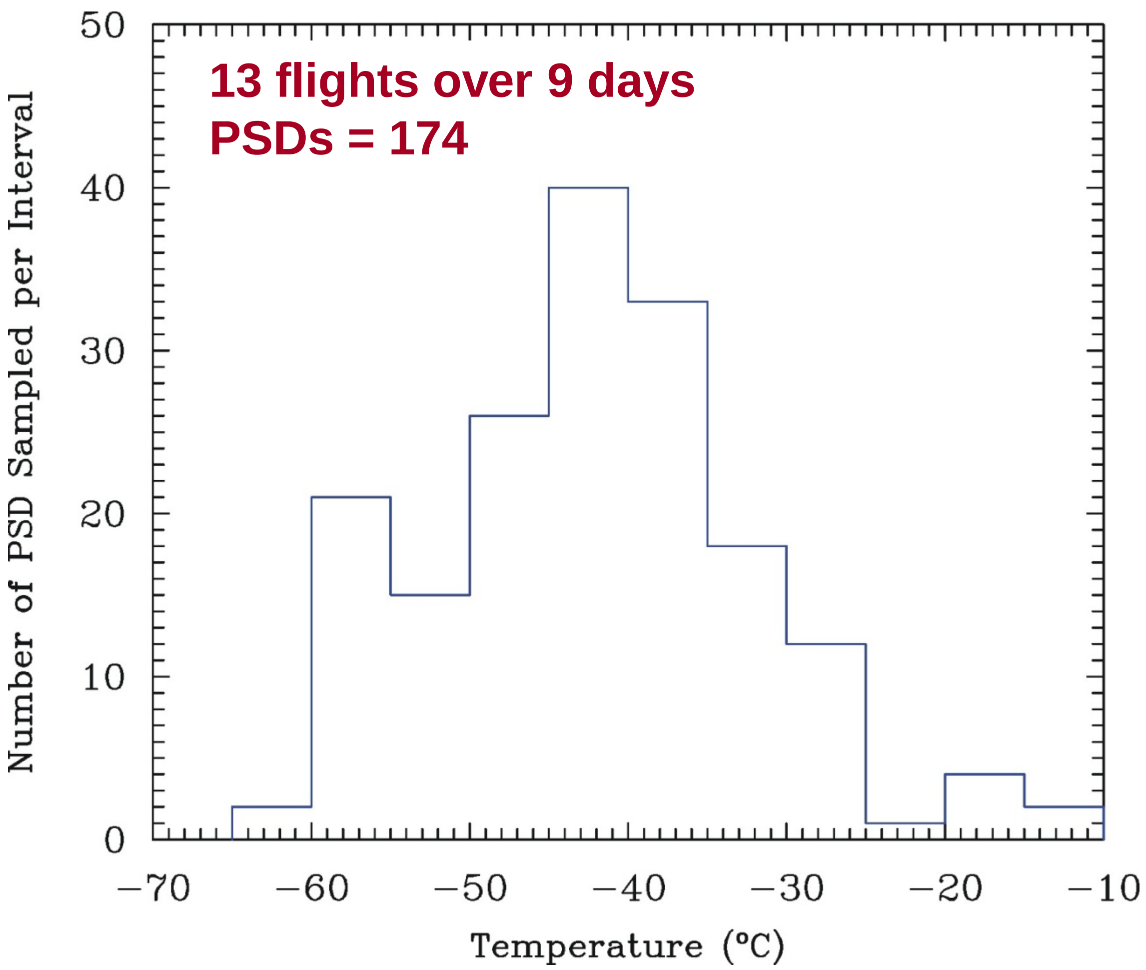
Evidence for homogeneous freezing nucleation in fresh anvil cirrus (continued)



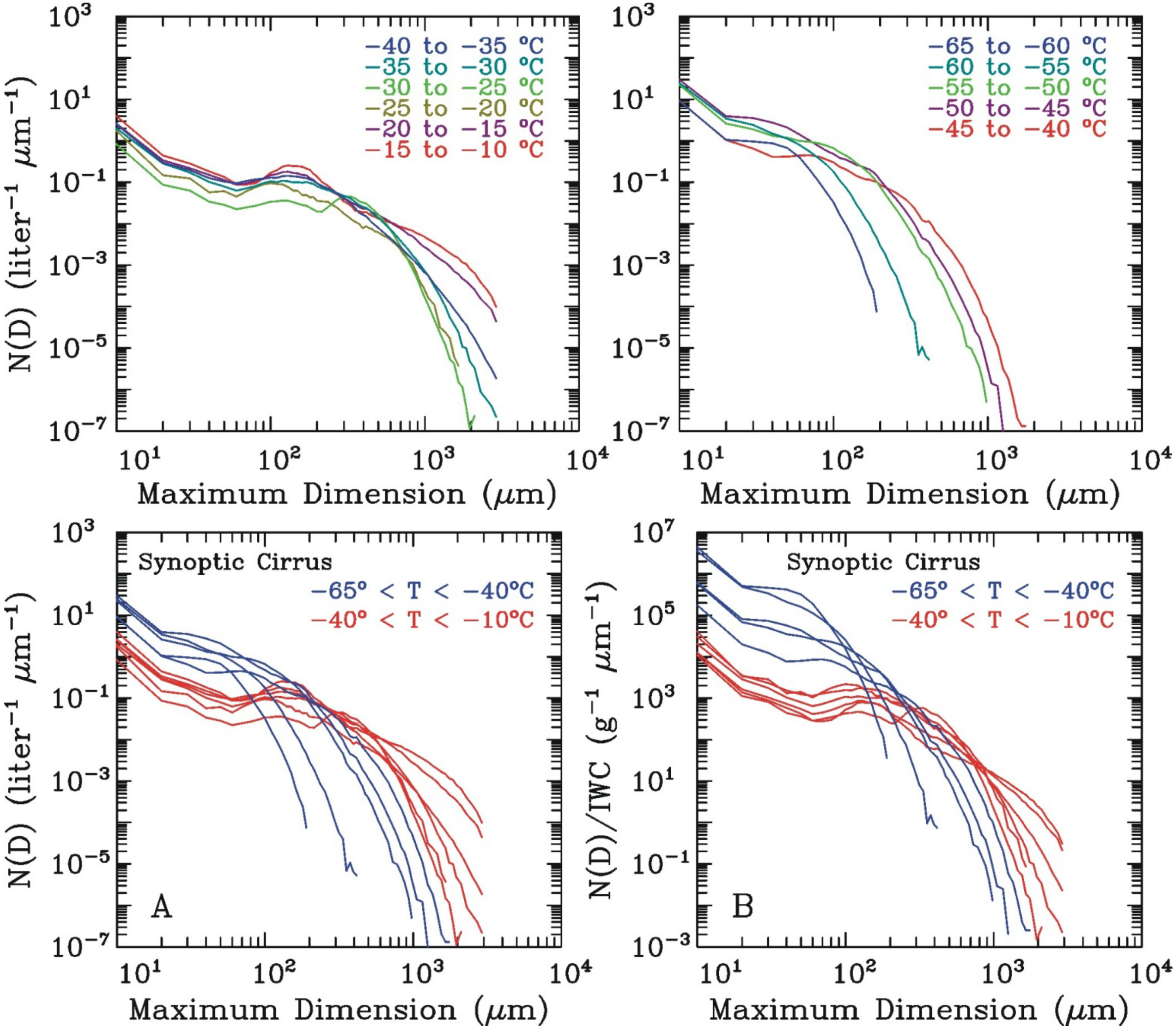
Temperature dependence of ice particle shape



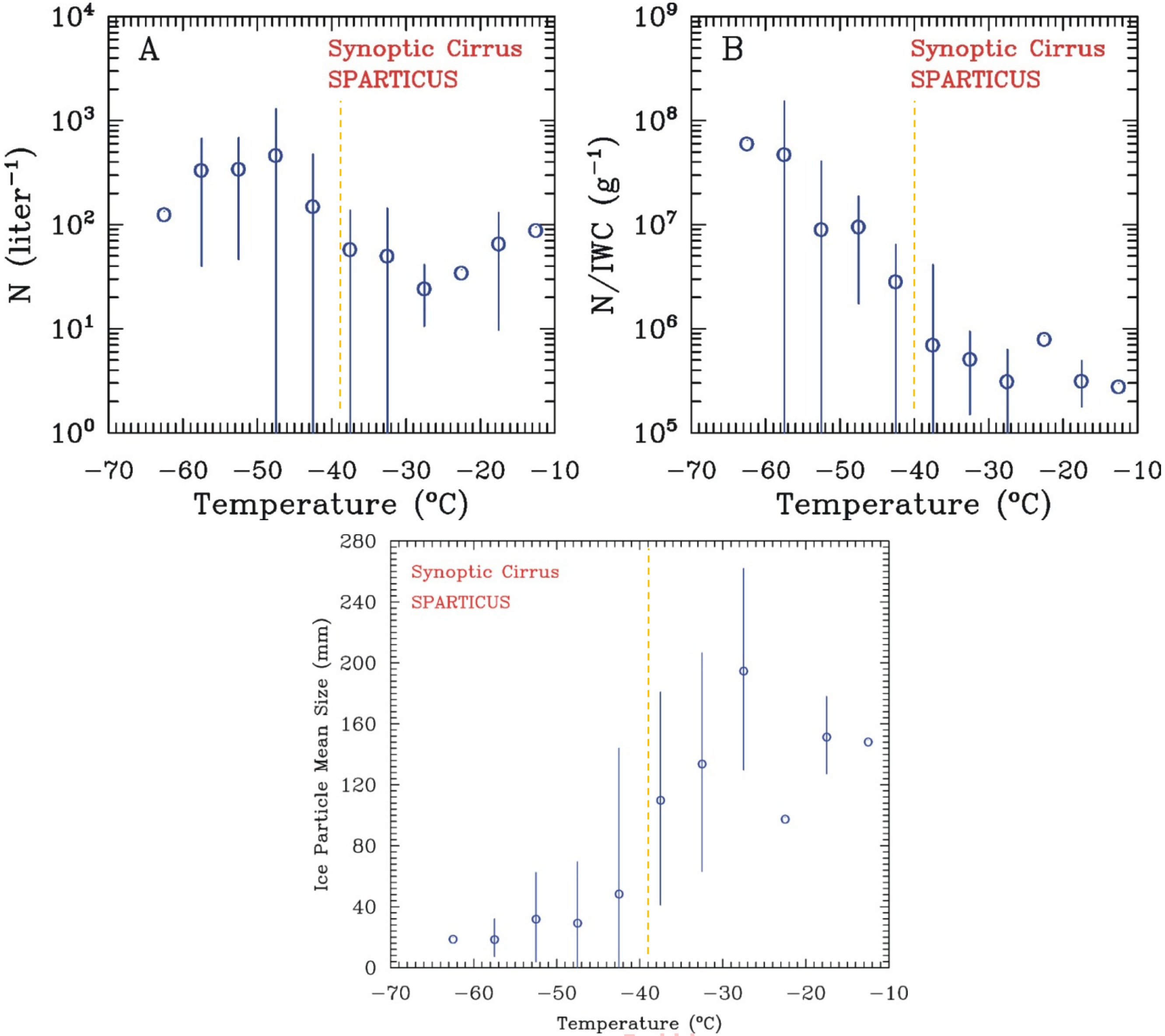
SPARTICUS RESULTS FOR SYNOPTIC CIRRUS CLOUDS



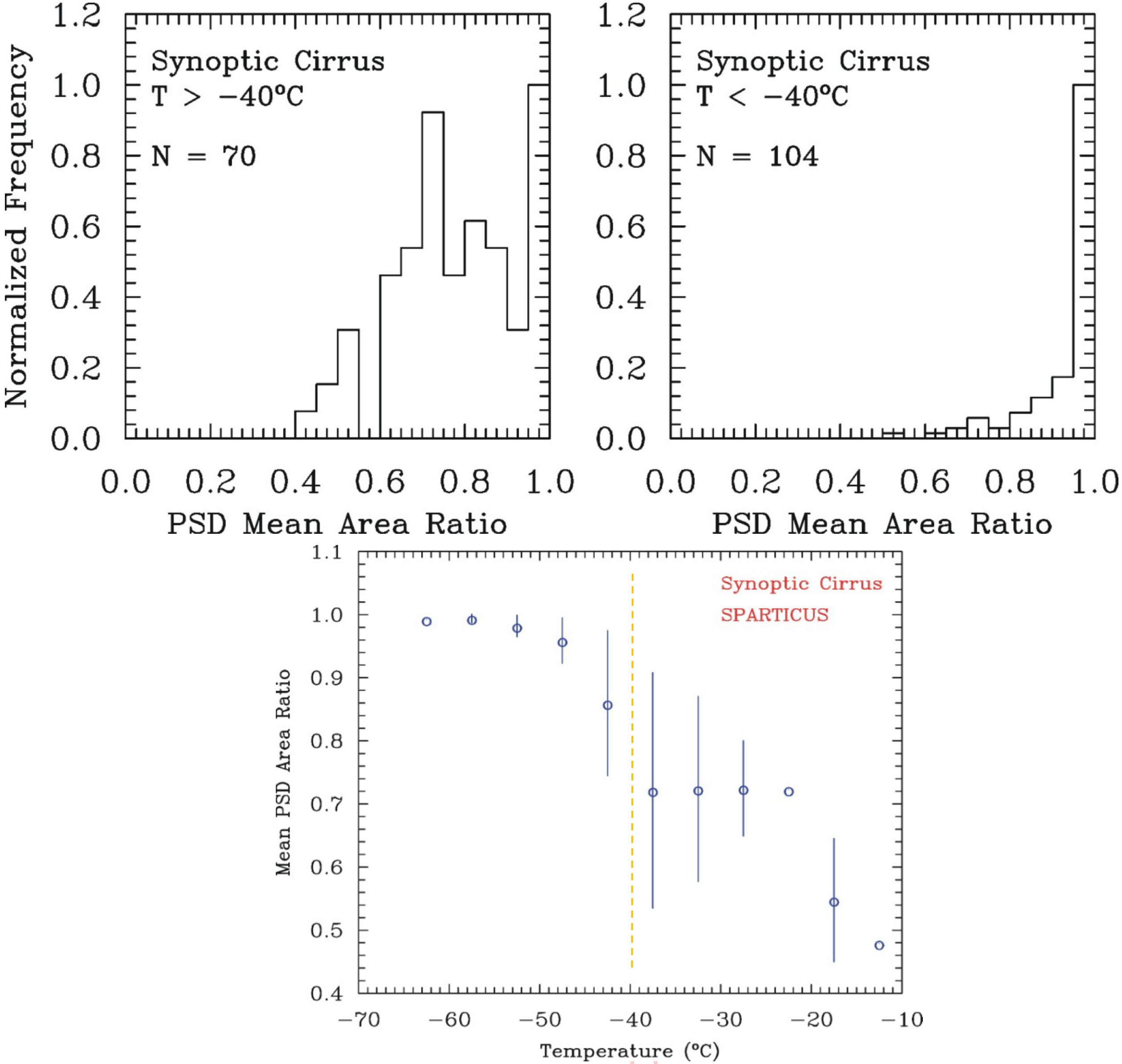
Temperature dependence of SPARTICUS PSD

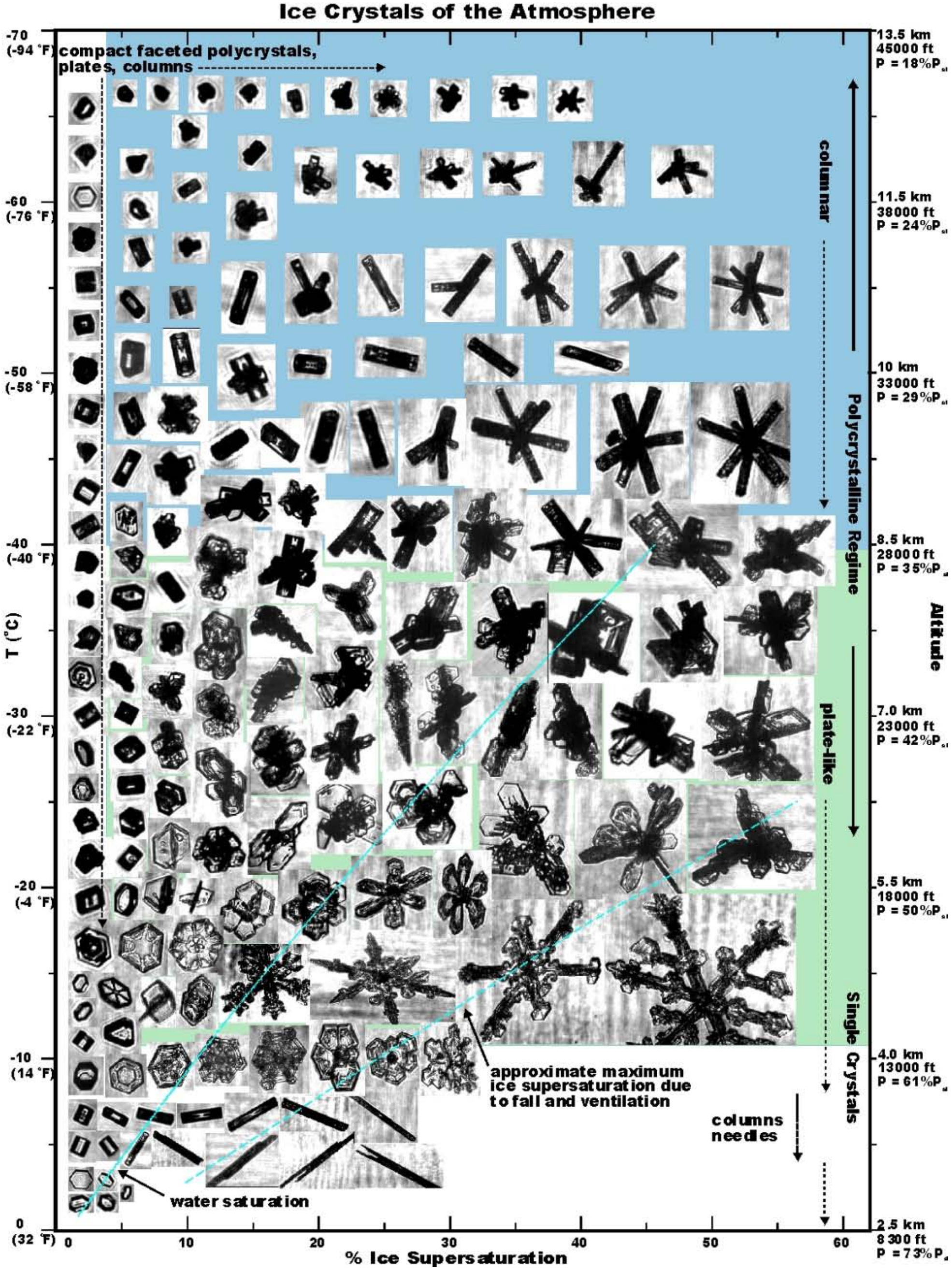


Evidence of homogeneous freezing nucleation?



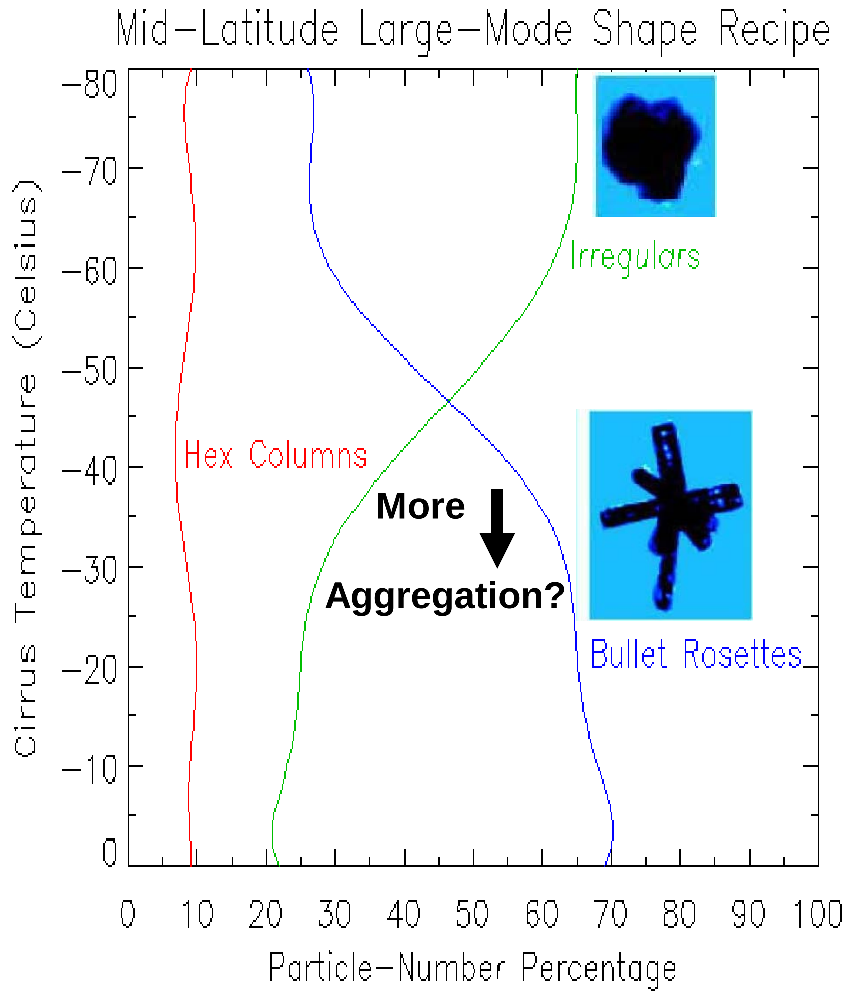
Temperature dependence of ice particle shape



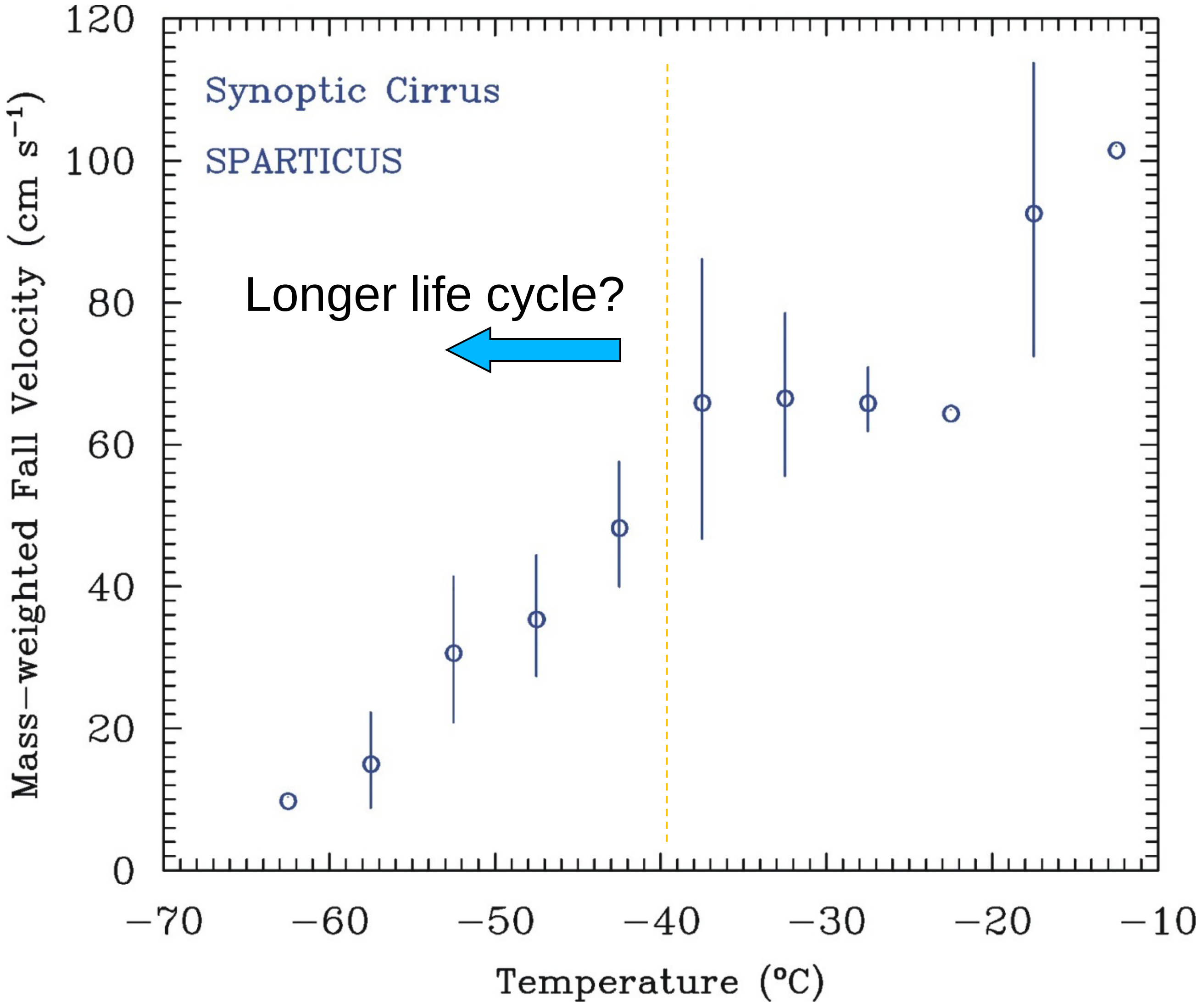


From Bailey & Hallett (2009)

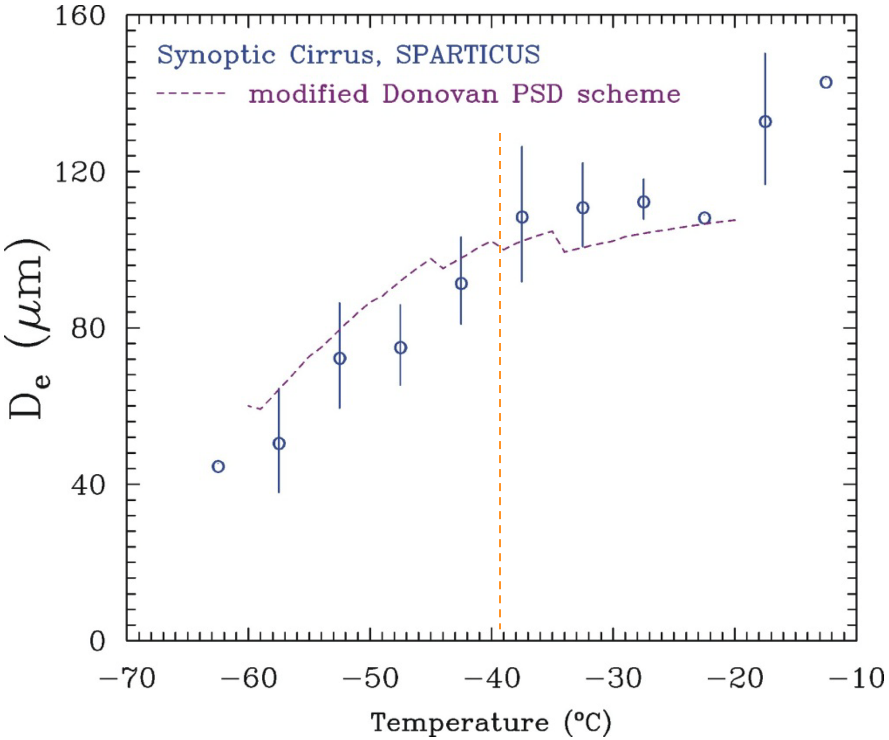
Extrapolated observations from Lawson et al. (2006)

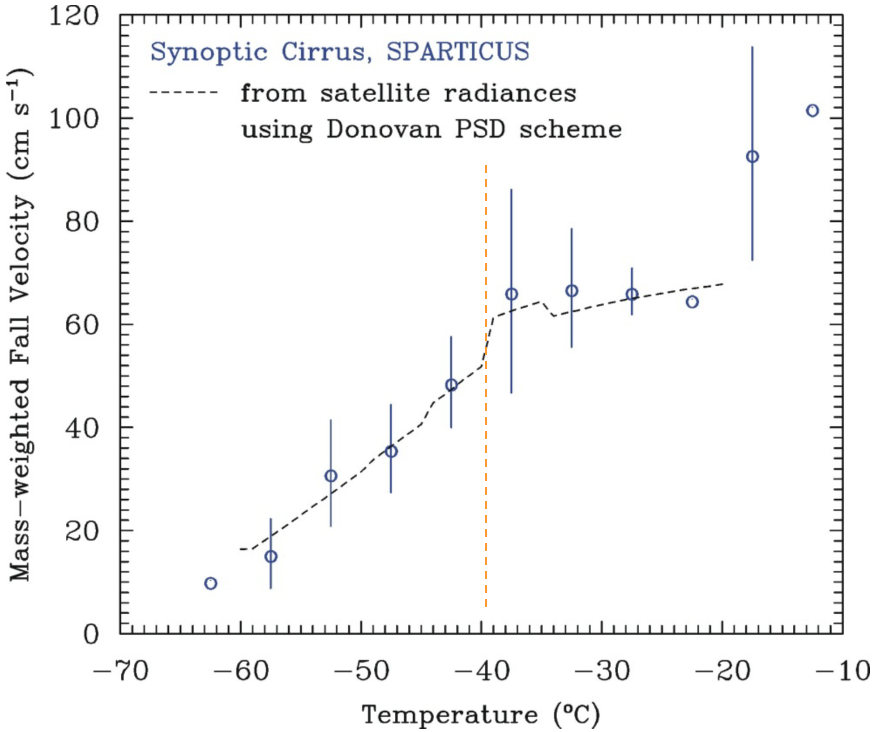


Temperature dependence of the mass-weighted ice fall-speed



Comparison of measurement-derived D_e and V_m with values derived from Donovan PSD scheme modified using satellite radiances





Satellite PSD retrievals described in Mitchell et al. 2010: Inferring cirrus size distributions through satellite remote sensing and microphysical databases, J. Atmos. Sci., 67, 1106-1125.

Tentative Suggestions for Improving CAM5

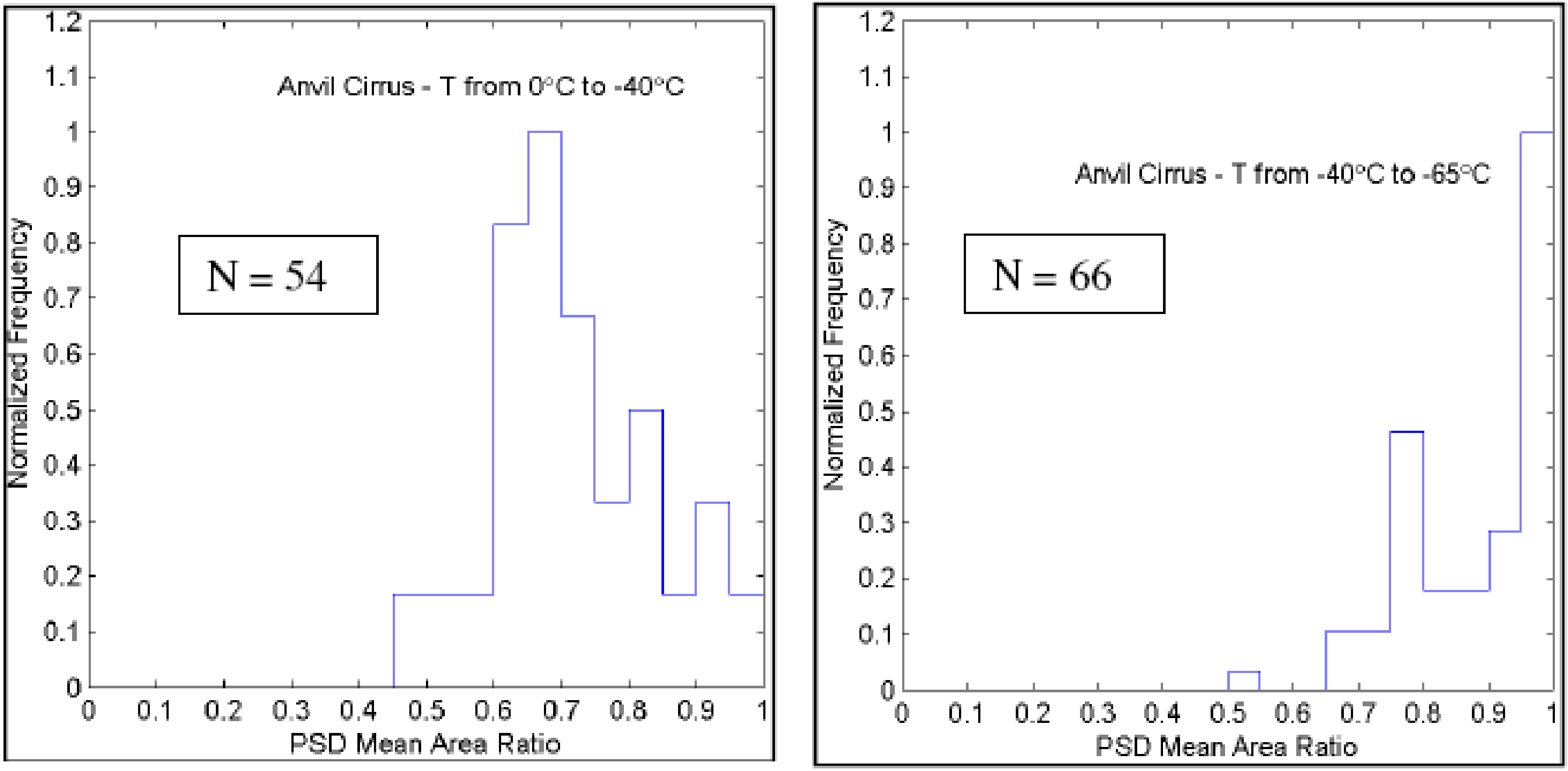
1. Achieve consistency between measured and predicted N / IWC, and predict V_m from D_e. This will link microphysics/radiation/dynamics.

2. For T < -20°C, two ice particle shape regimes appear to exist for ML synoptic and anvil (not shown) cirrus. Characterize A-D and m-D power laws for ice particles in each regime and update the ice optics.
   - Only one regime for tropics based on TC4

3. For T < -20°C, two PSD regimes appear to exist, separated near -40°C. Enable CAM5 PSD to conform to these regimes and update the ice optics to conform with these regimes.

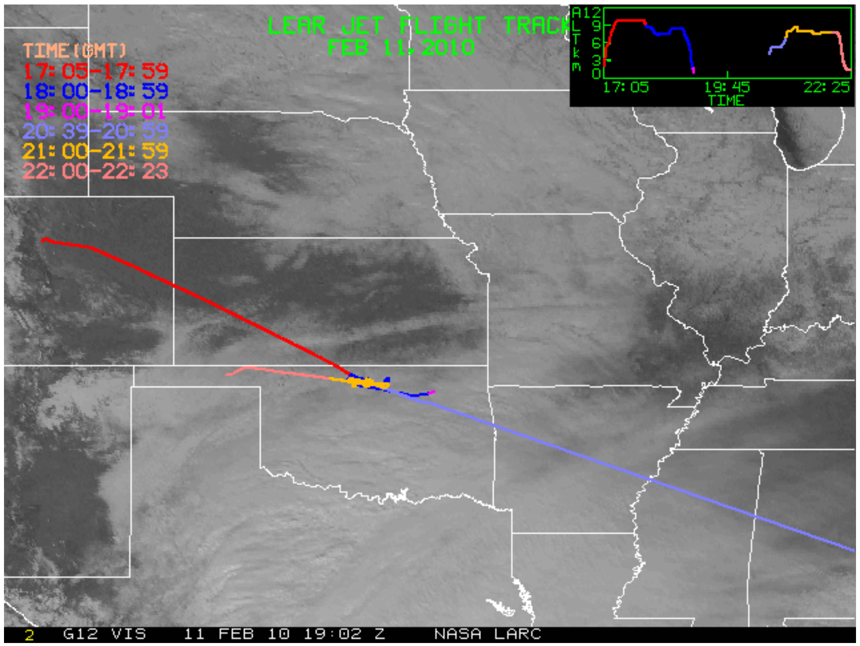
4. Bimodality for T > -40°C may be due to lower nucleation rates and higher aggregation rates from more complex crystal shapes. Might consider aggregation rates in each regime to improve N / IWC ratios, D_e and V_m.

Anvil cirrus: Temperature dependence of ice crystal shape

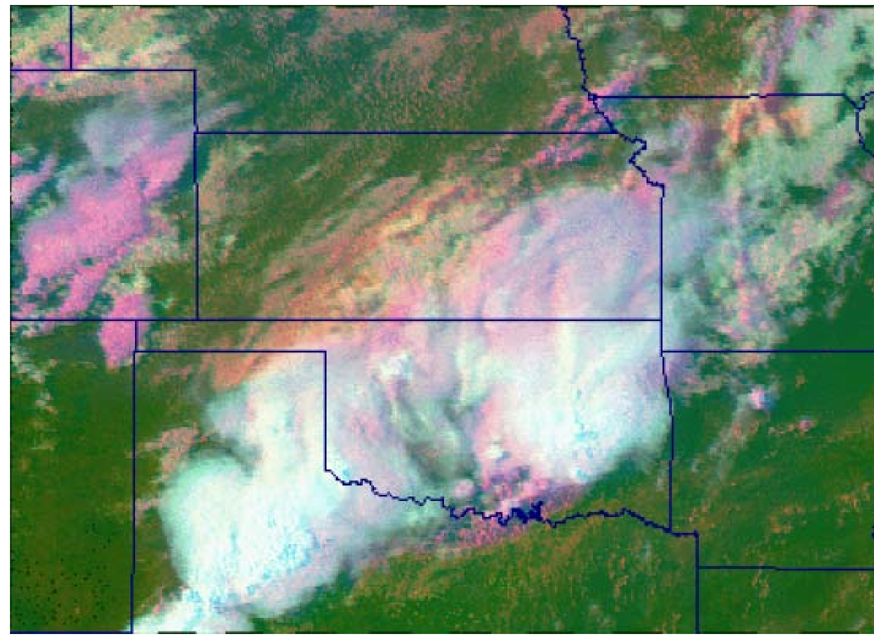


SPartICus cirrus were identified as synoptic or anvil using satellite imagery and flight notes.

Contains synoptic cirrus



Contains anvil cirrus



Source: P. Minnis (NASA Langley)

http://www-angler.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=ARM-SPARTICUS

Selected Case Studies

Synoptic Cirrus (174 segments)

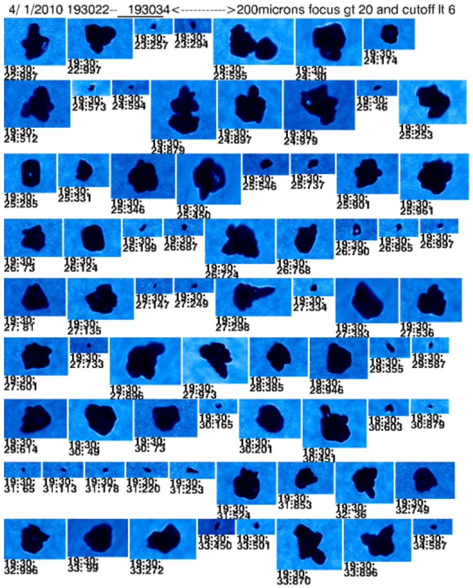
- Jan 19th
- Jan 20th
- Jan. 27th
- Feb. 11th
- March 23rd
- March 26th
- April 1st

Anvil Cirrus (122 segments)

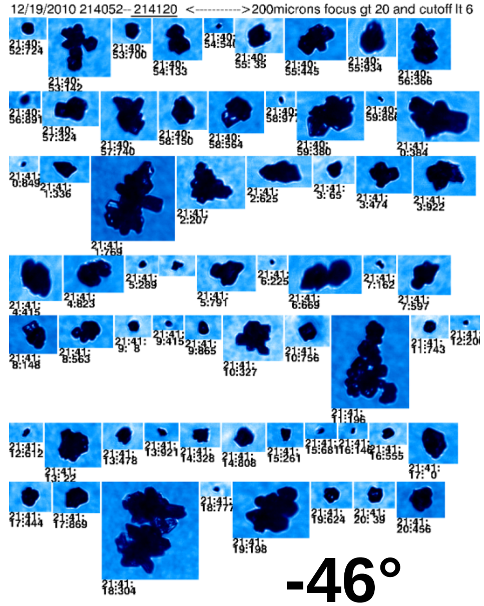
- April 22nd
- April 28th
- June 12th
- June 14th
- June 15th
- June 24th

Cloud segments are identified for each case by making sure that

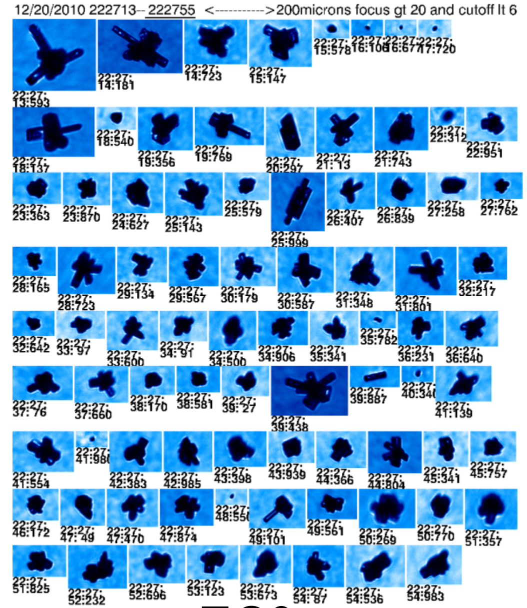
- they contain no liquid water,
- they have good sampling statistics and utilize a good fraction of the data
- they are sampled under relatively steady microphysical conditions



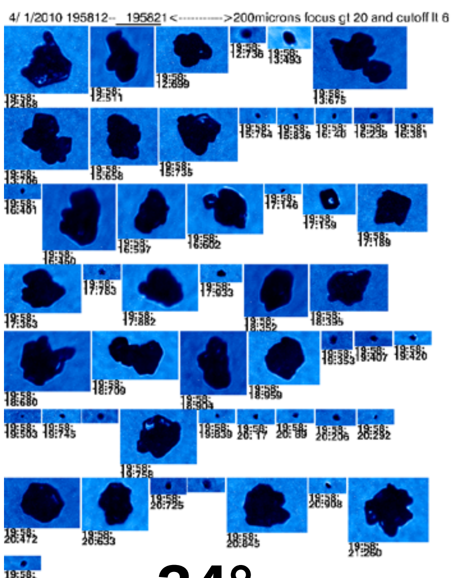
-46°



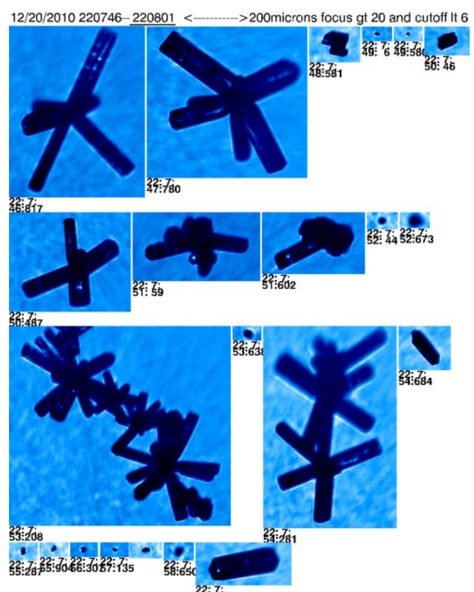
-46°



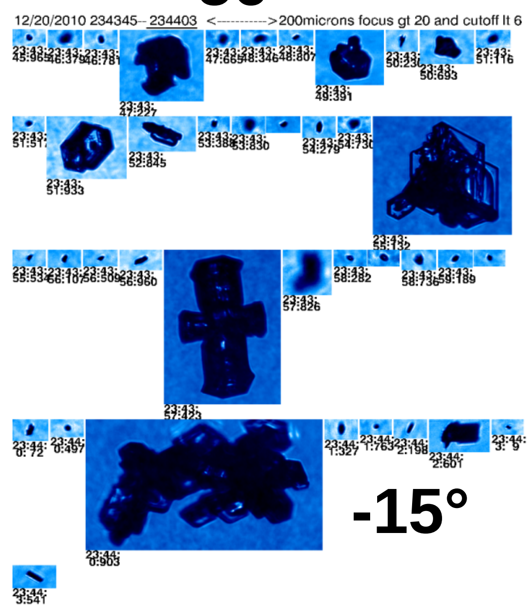
-56°



-34°

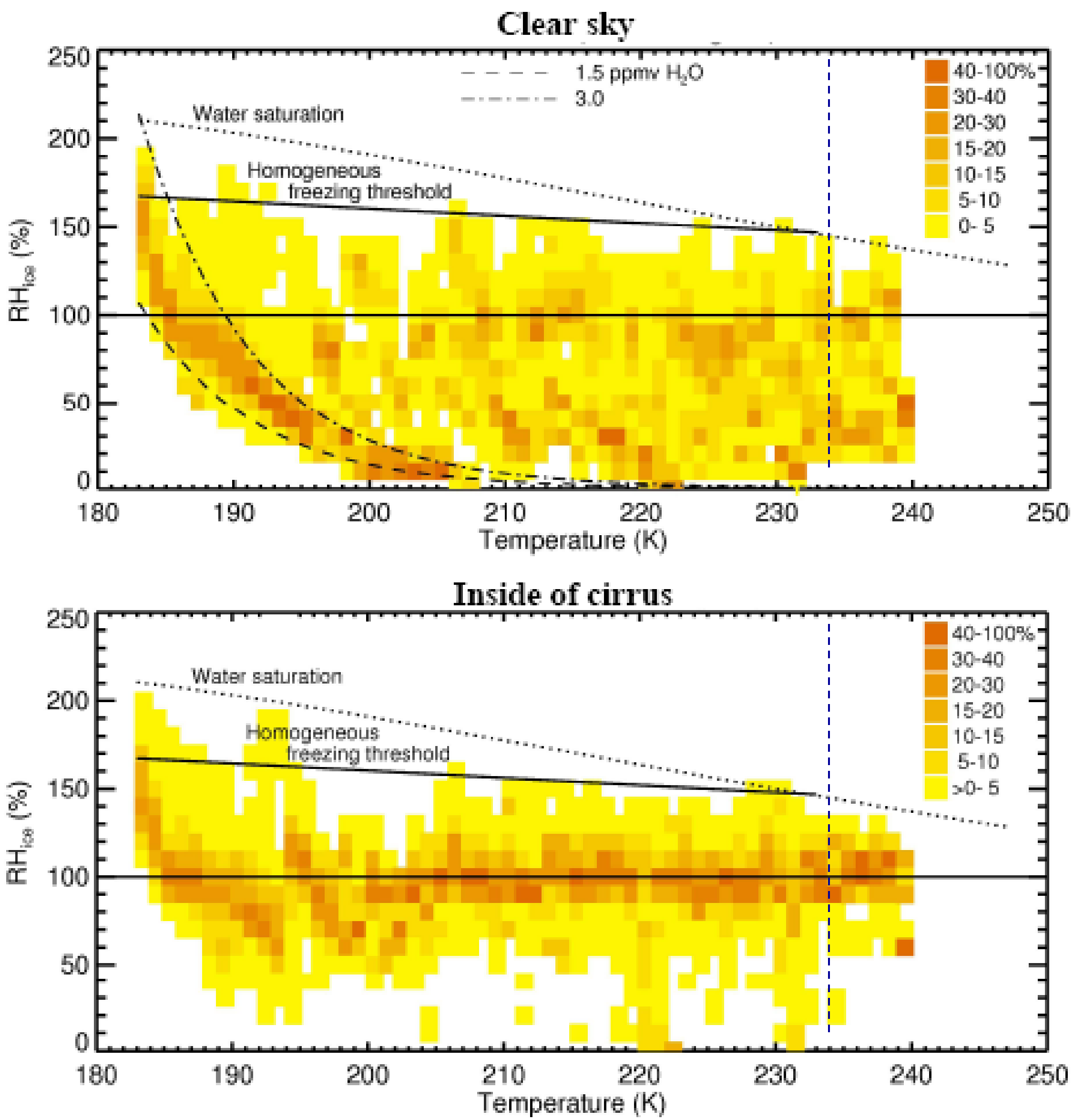


-35°



-15°

CPI imagery for synoptic cirrus clouds sampled during SPARTICUS; random sampling.



From Krämer et al. 2009, ACP

Peak RH_i is similar for both clear sky and inside cirrus conditions. Relatively high RH_i can exist < ~150% under clear conditions, suggesting heterogeneous nucleation processes often do not produce cirrus for such conditions.

Most in-cloud conditions have 85% < RH_i < 115% → isometric or compact ice crystals.

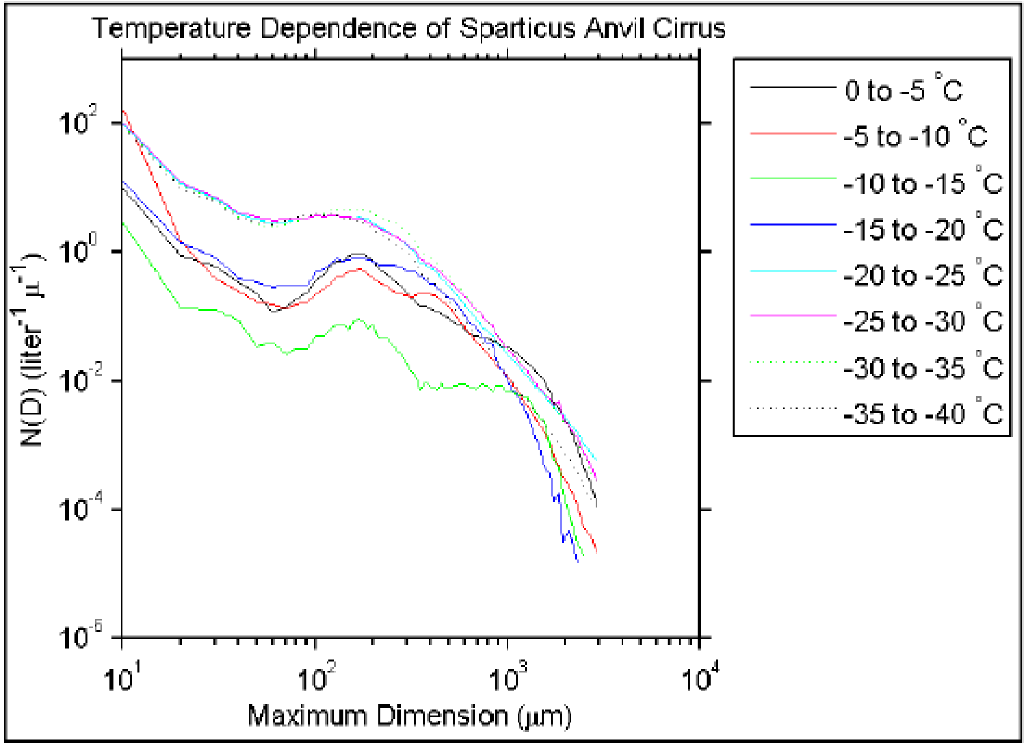
Paradox: Homogeneous freezing nucleation appears to contribute most of the ice crystals in mid-latitude synoptic cirrus. However, this requires $RH_i > \sim 140\%$, and in-cloud cirrus measurements show that typically $85\% < RH_i < 115\%$.

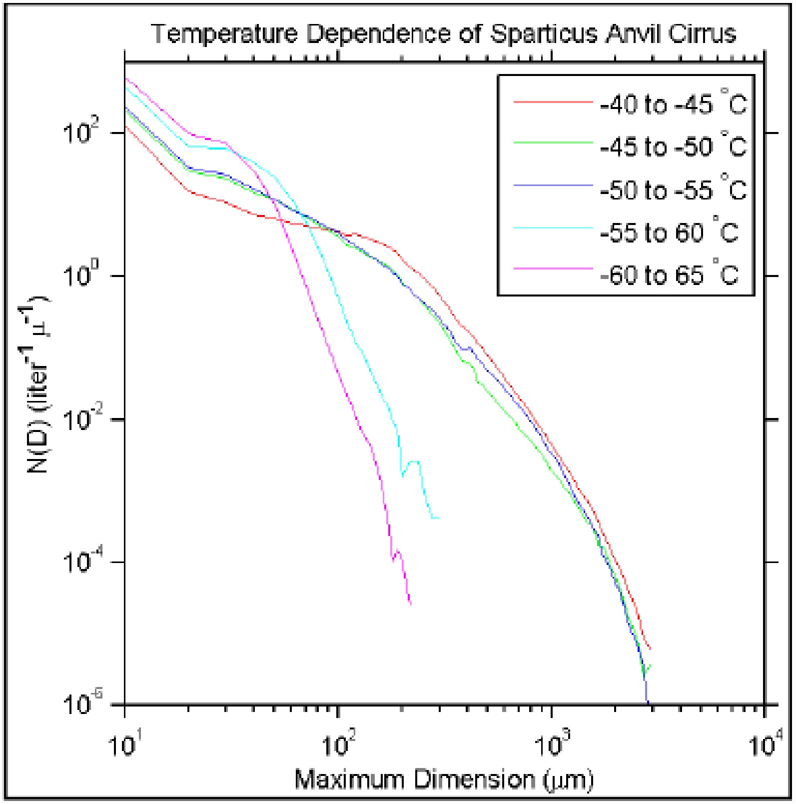
Possible explanation: A moist layer in the upper troposphere undergoes gradual ascent until RH_i reaches homo. nucl. threshold, resulting in a sudden production of ice crystals with relatively high N. RH_i then rapidly approaches ice saturation (within ~ 5-10 min.). Thereafter ice crystals grow as compact or isometric. This may explain SPARTICUS observations. This may also explain the Krämer et al. observations, since high RH_i would be short-lived.

Another aspect is whether ice crystal shape depends on the nucleation process. Are dense, compact crystals associated with frozen haze or cloud droplets? Are more branched crystals associated with deposition or condensation freezing nucleation?

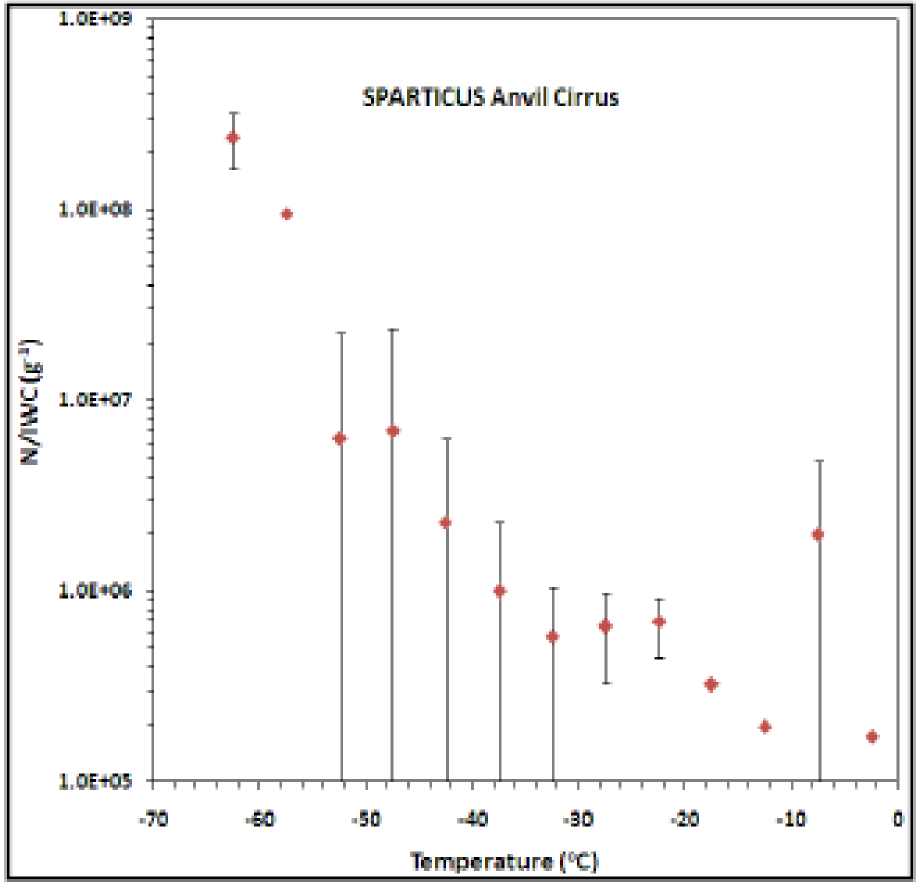
Some Anvil-Synoptic Cirrus Comparisons

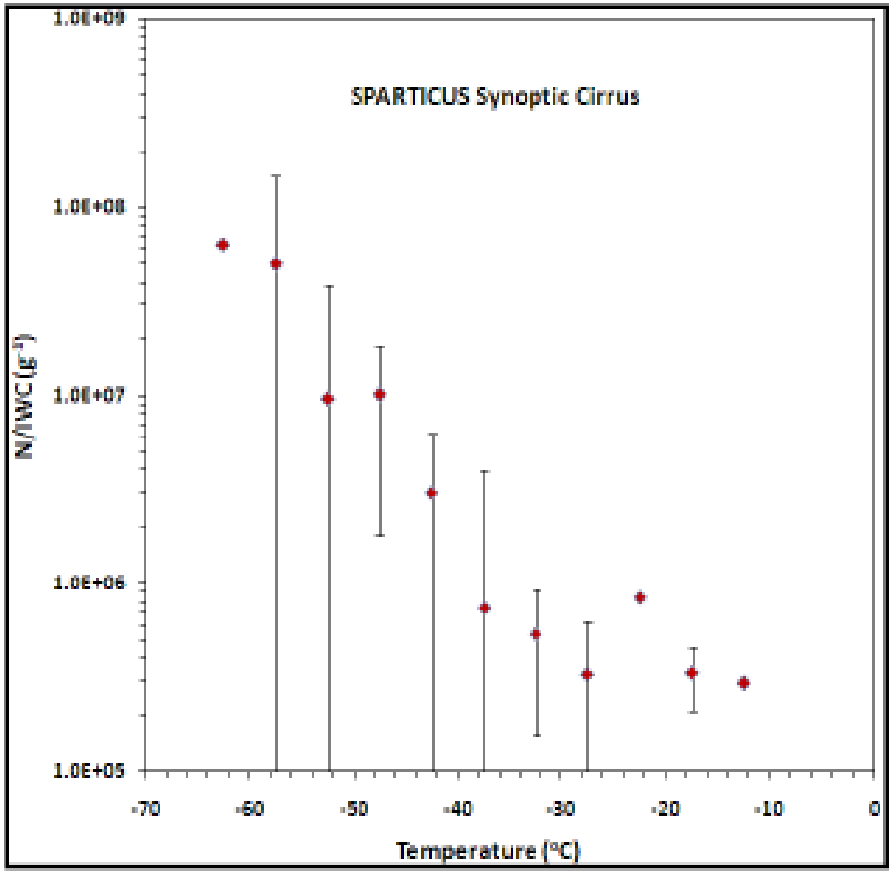
Anvil cirrus PSD temperature dependence



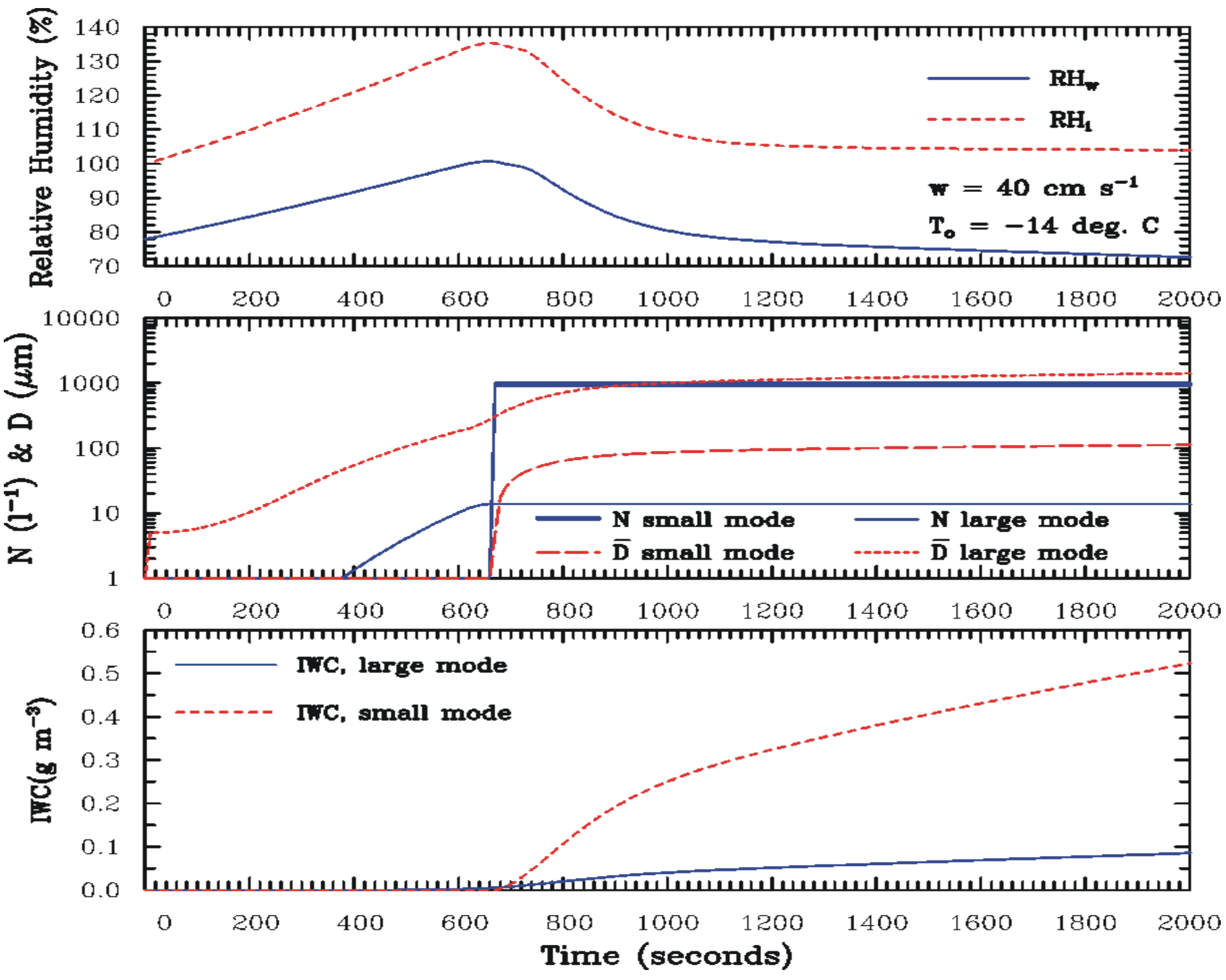


Mass-normalized number concentration

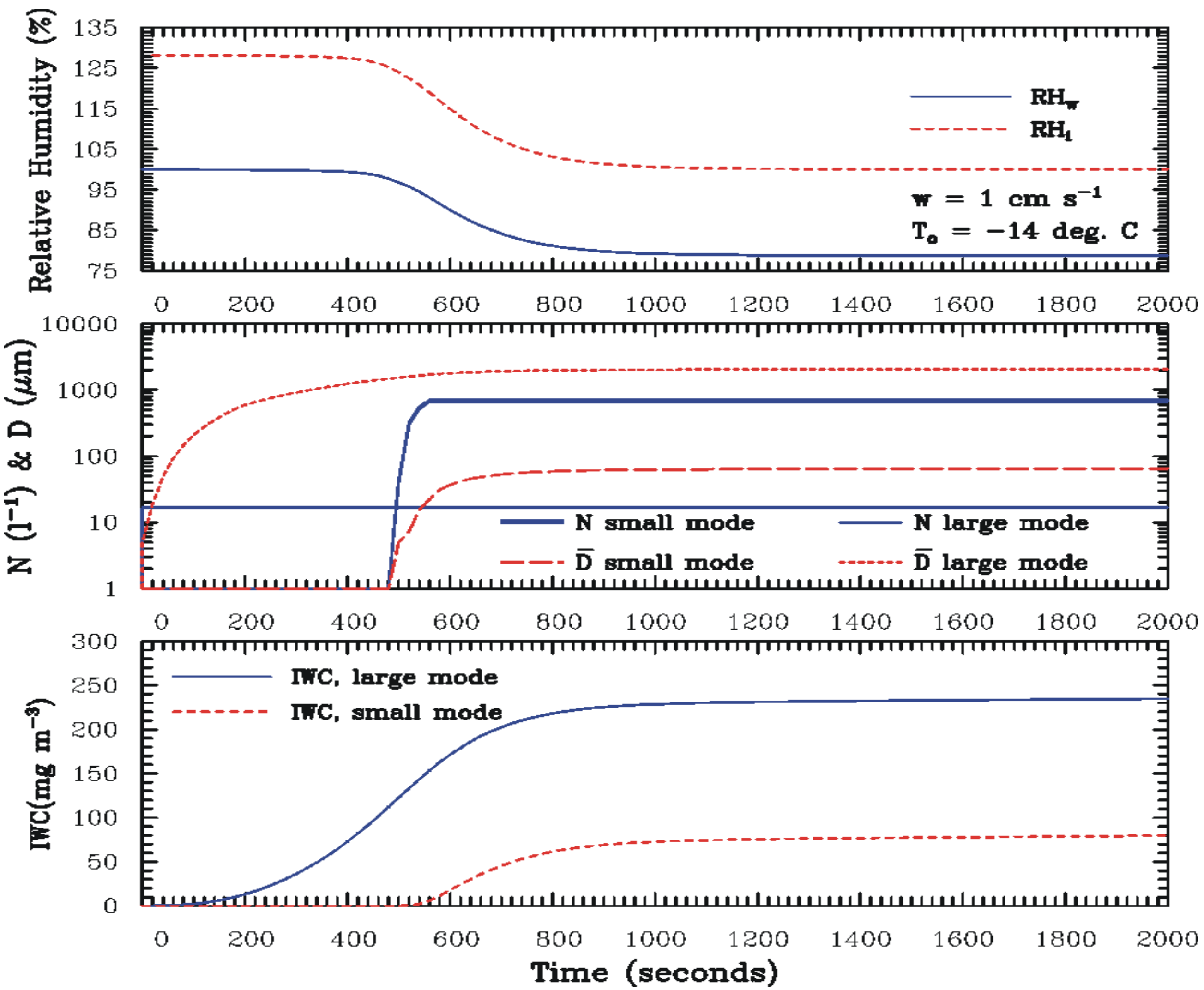


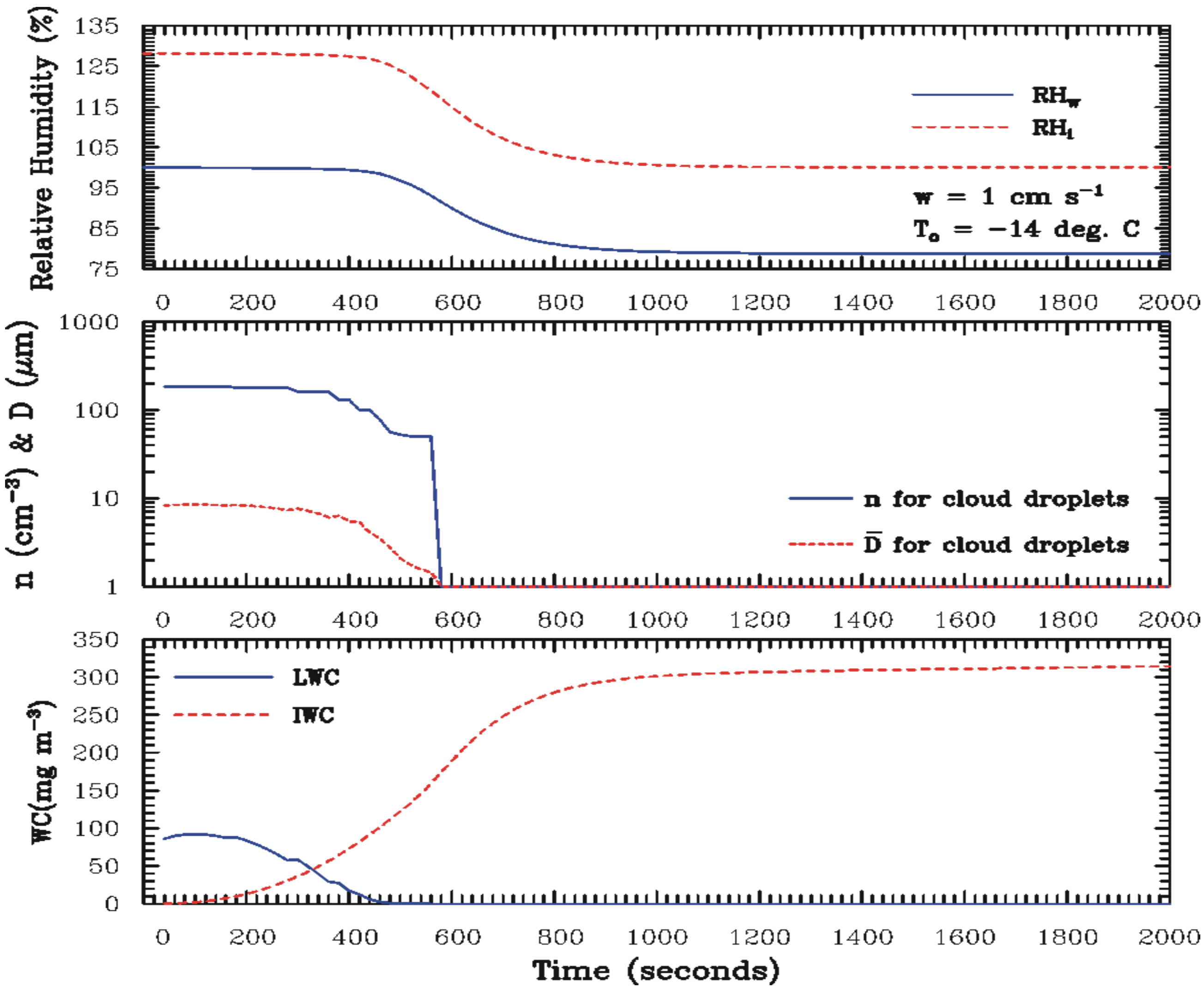


2-stage nucleation process in an updraft



2-stage nucleation process with negligible vertical motion. Initial droplet diameter = 10 µm, LWC = 0.10 g m^{-3}.





Relative Humidity (%)
RHw
RHi
w = 1 cm s−1
To = −14 deg. C
n (cm−3) & D (μm)
n for cloud droplets
D for cloud droplets
WC(mg m−3)
LWC
IWC
Time (seconds)