# Supplying Satellite Estimates of IWP and Cirrus Size Distribution Retrievals to the GCM Community

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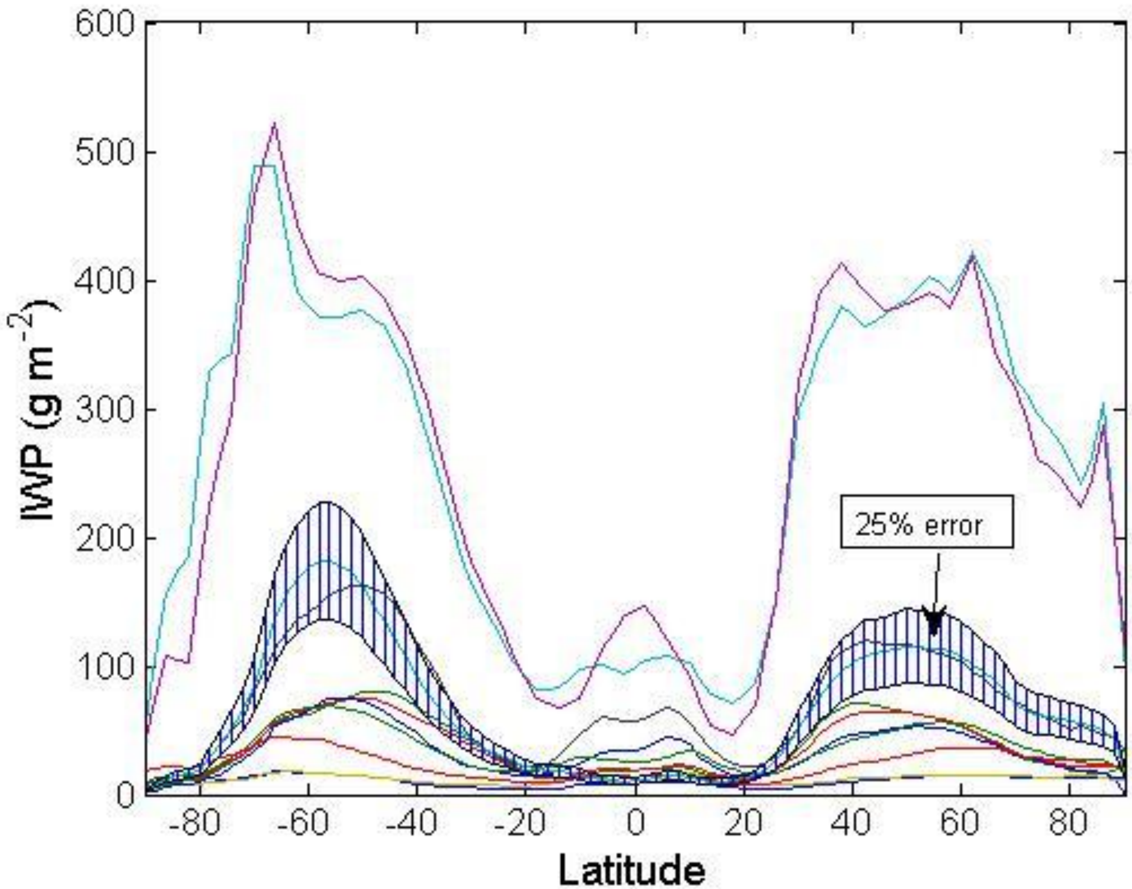
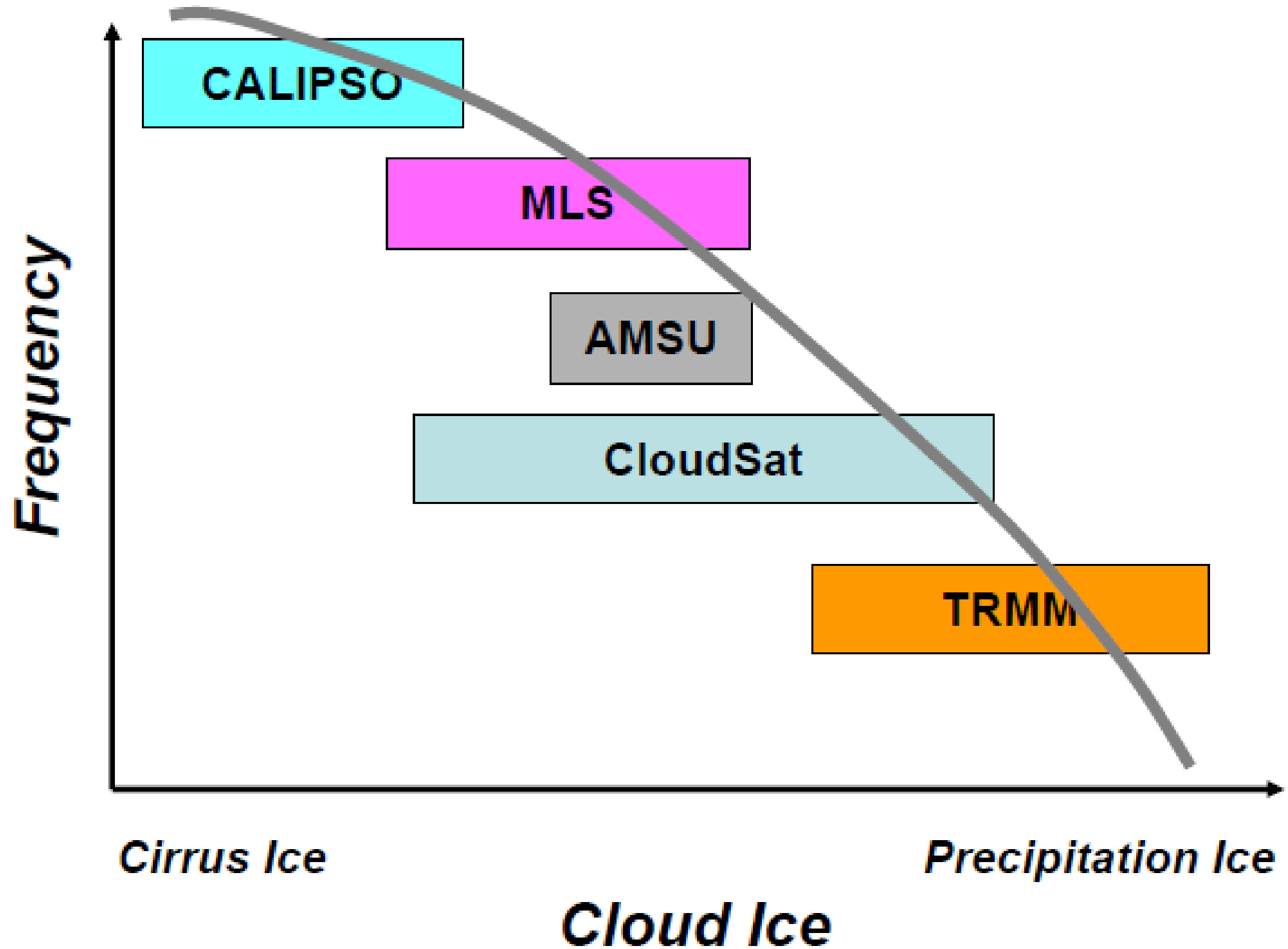
## Discrepancy in Mean IWP Between Climate Models

Courtesy of Steve Ackerman, Dave Starr, Gail Jackson and Frank Evans




**The climatology of zonal, annual mean IWP from various GCMs. Obtained from the IPCC AR4 data archive .**

# Satellite Sensor Sensitivity to Cloud Ice



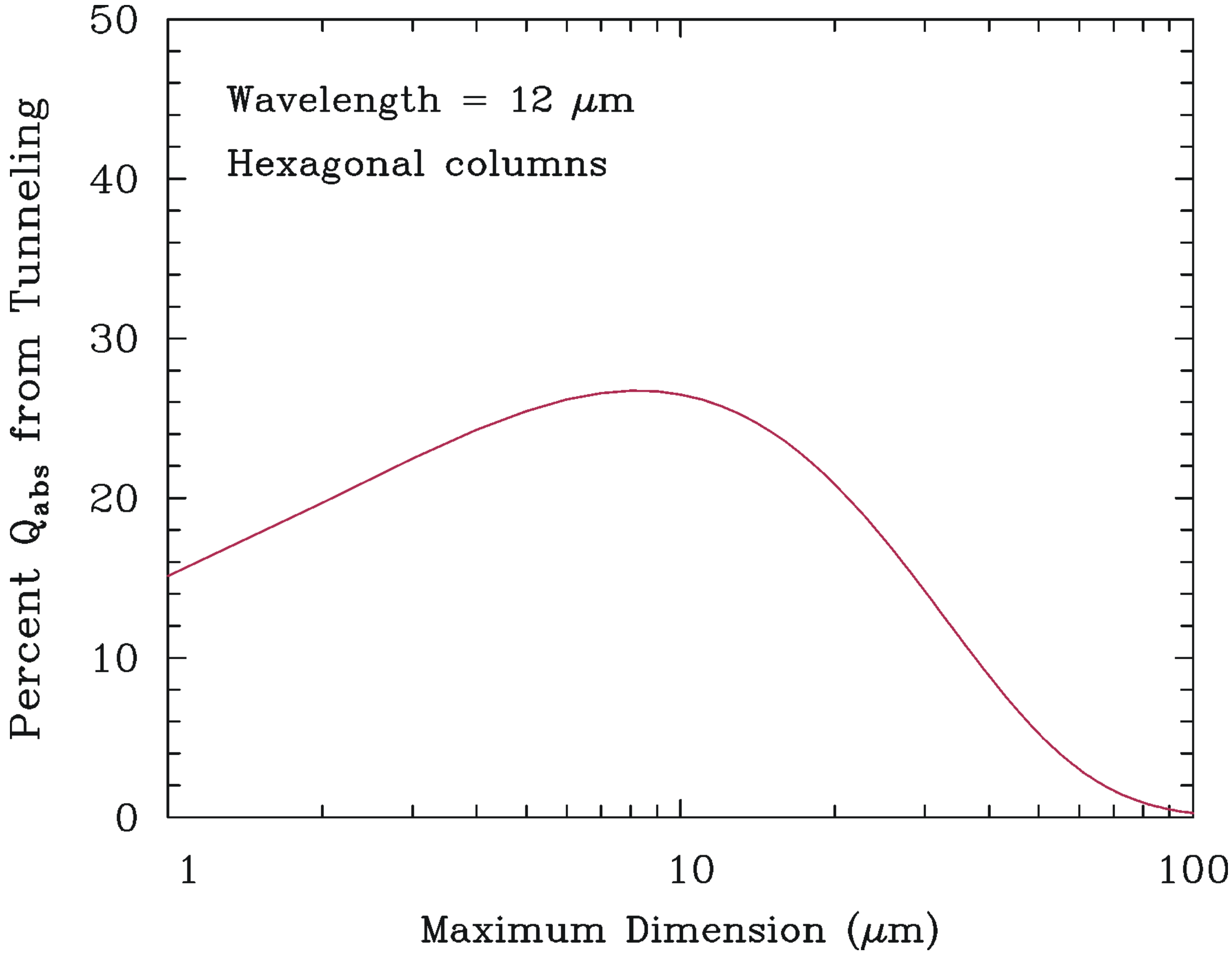
# Outline of talk

1. Monomodal or bimodal? Can satellite retrieval results provide answers?
   a. Photon tunneling signal ➡ degree of bimodality
   b. Explicit retrieval only possible for monomodal PSD

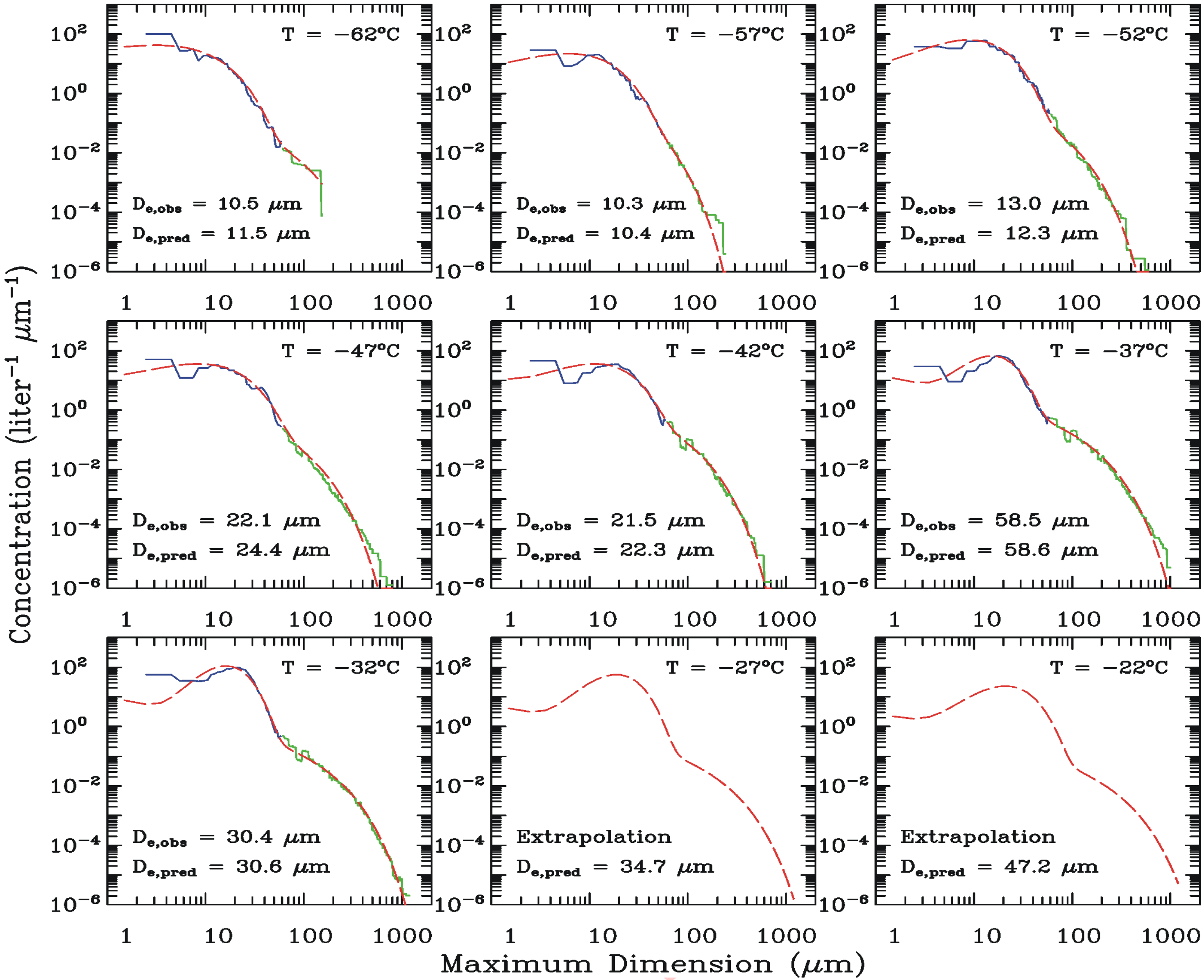
2. Testing of retrieved PSD using TWP-ICE in situ measurements

3. Sensitivity of retrieved IWP, $D_e$ & size distribution slope (for ice sedimentation rates) to ice particle mass-dimension relationship (i.e. crystal shape)

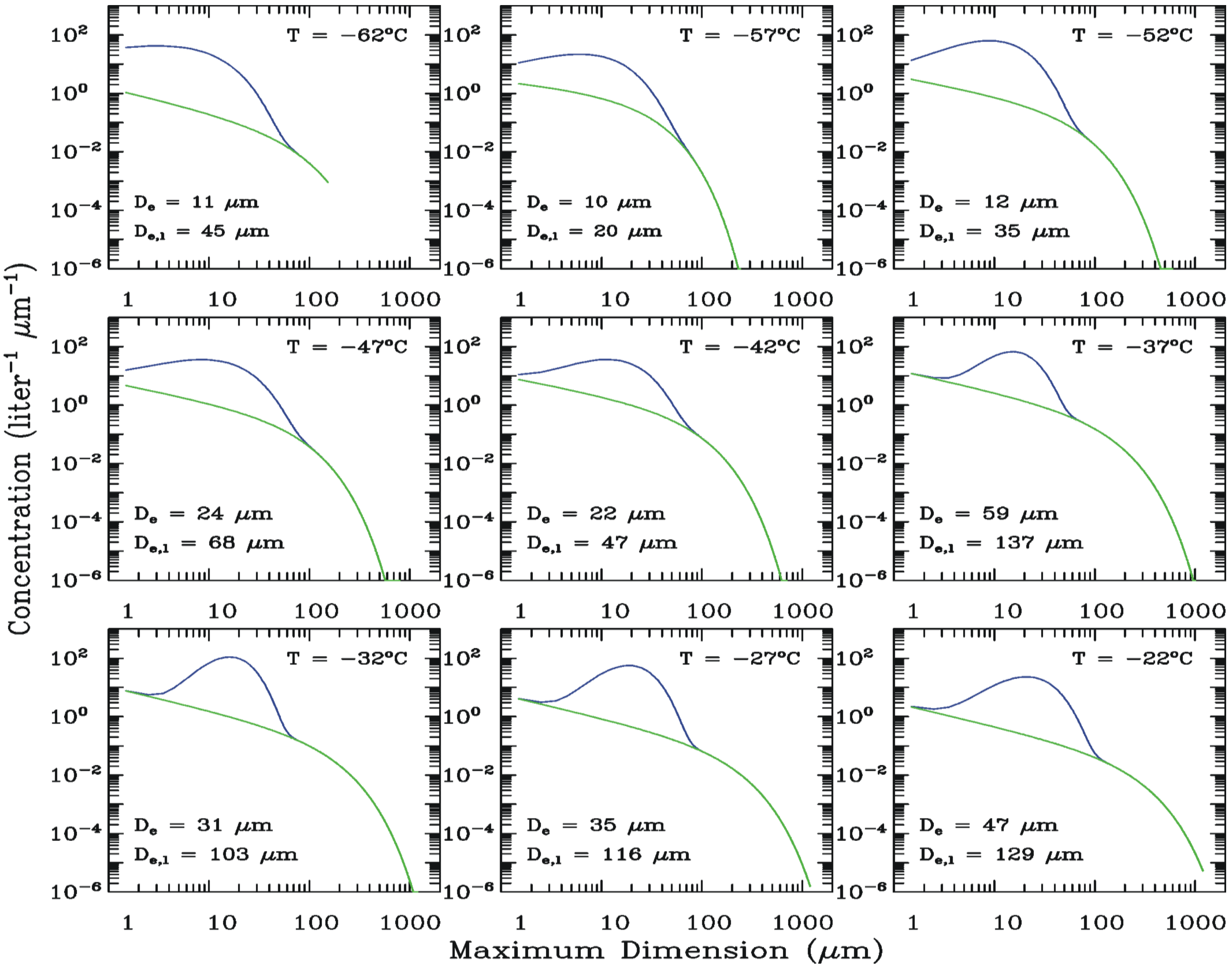
# Size dependence of tunneling for single ice crystals



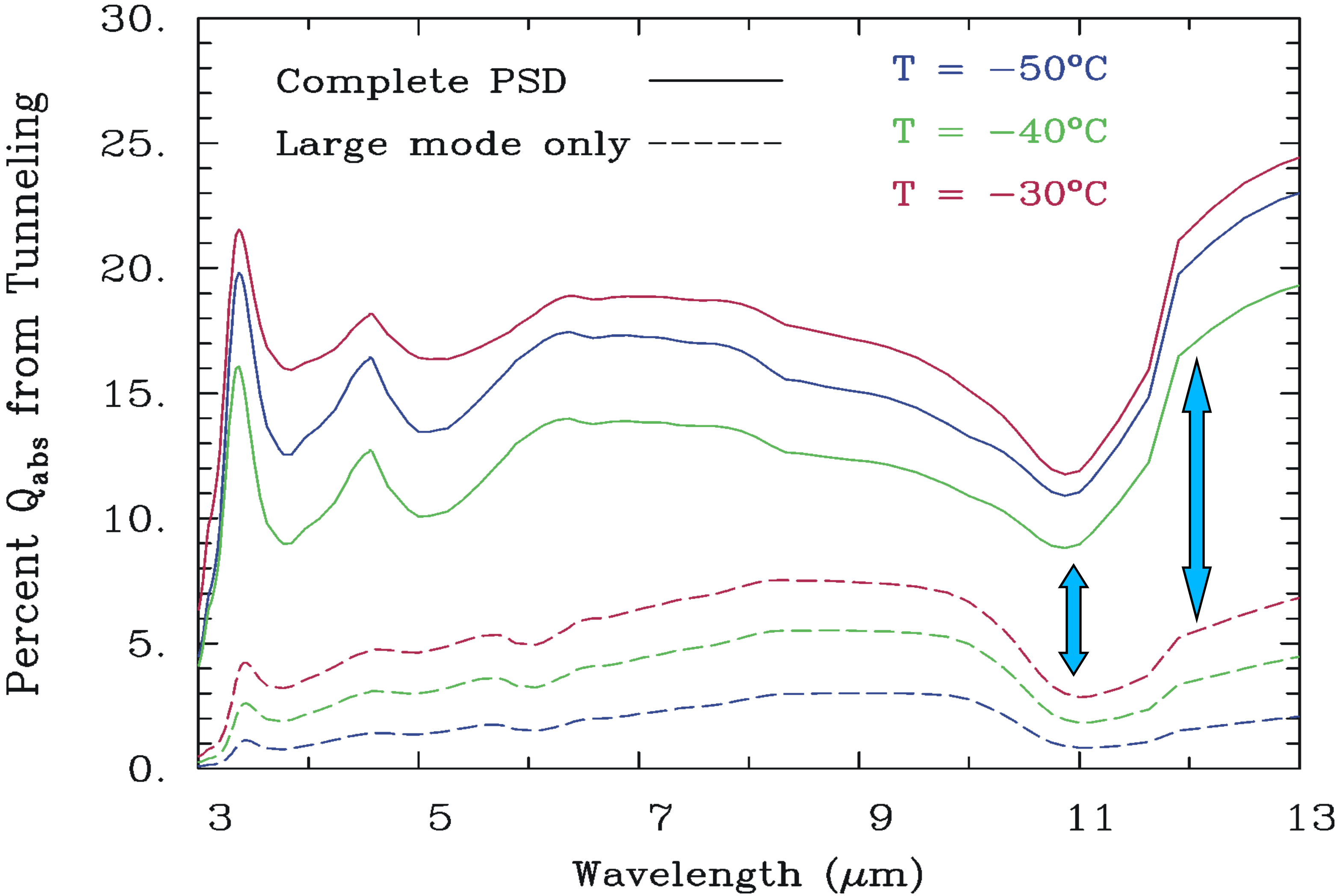
# SPEC ice particle size distribution (PSD) scheme for evaluating potential tunneling contributions



# Decomposition of the two PSD modes

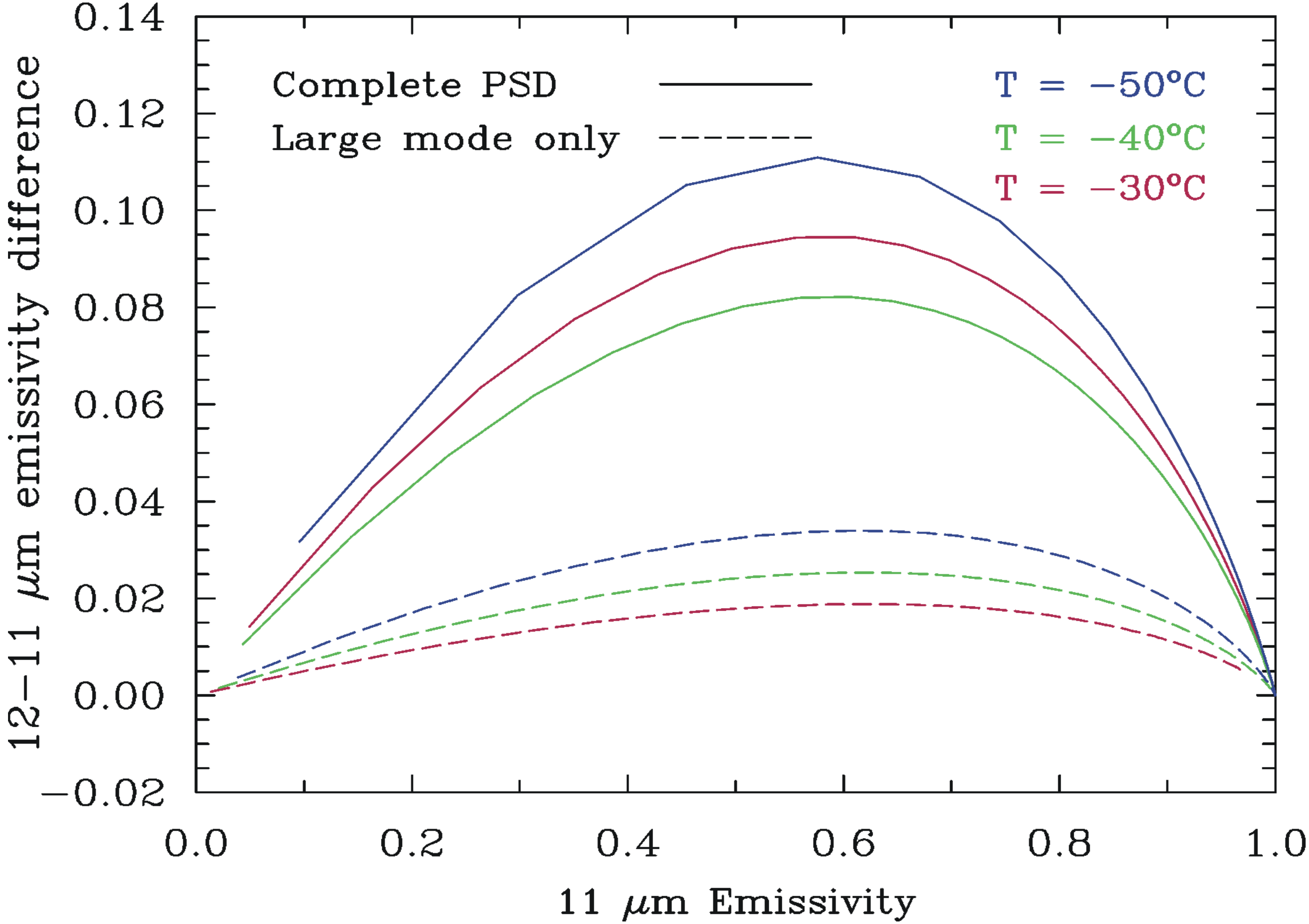


# MADA calculation using climatological ice crystal shapes



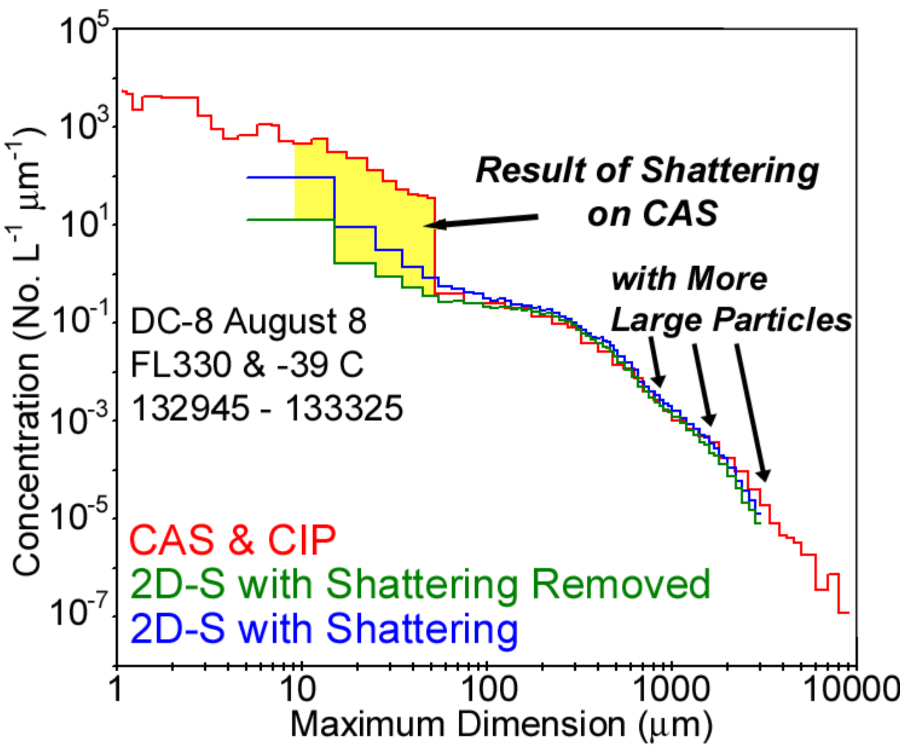
# Method for Estimating Small Crystal Concentrations

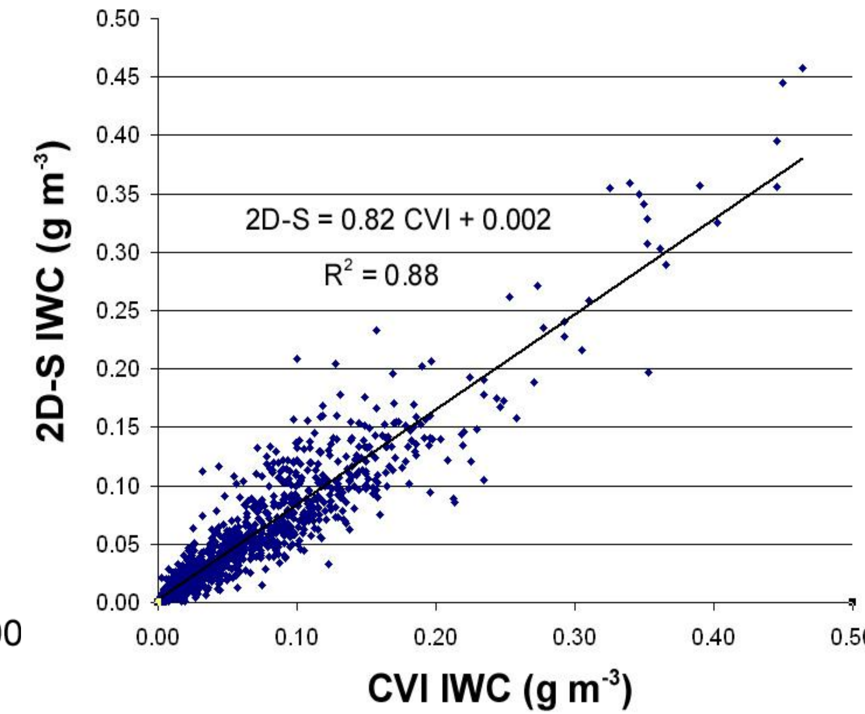
## - using effective emissivities -



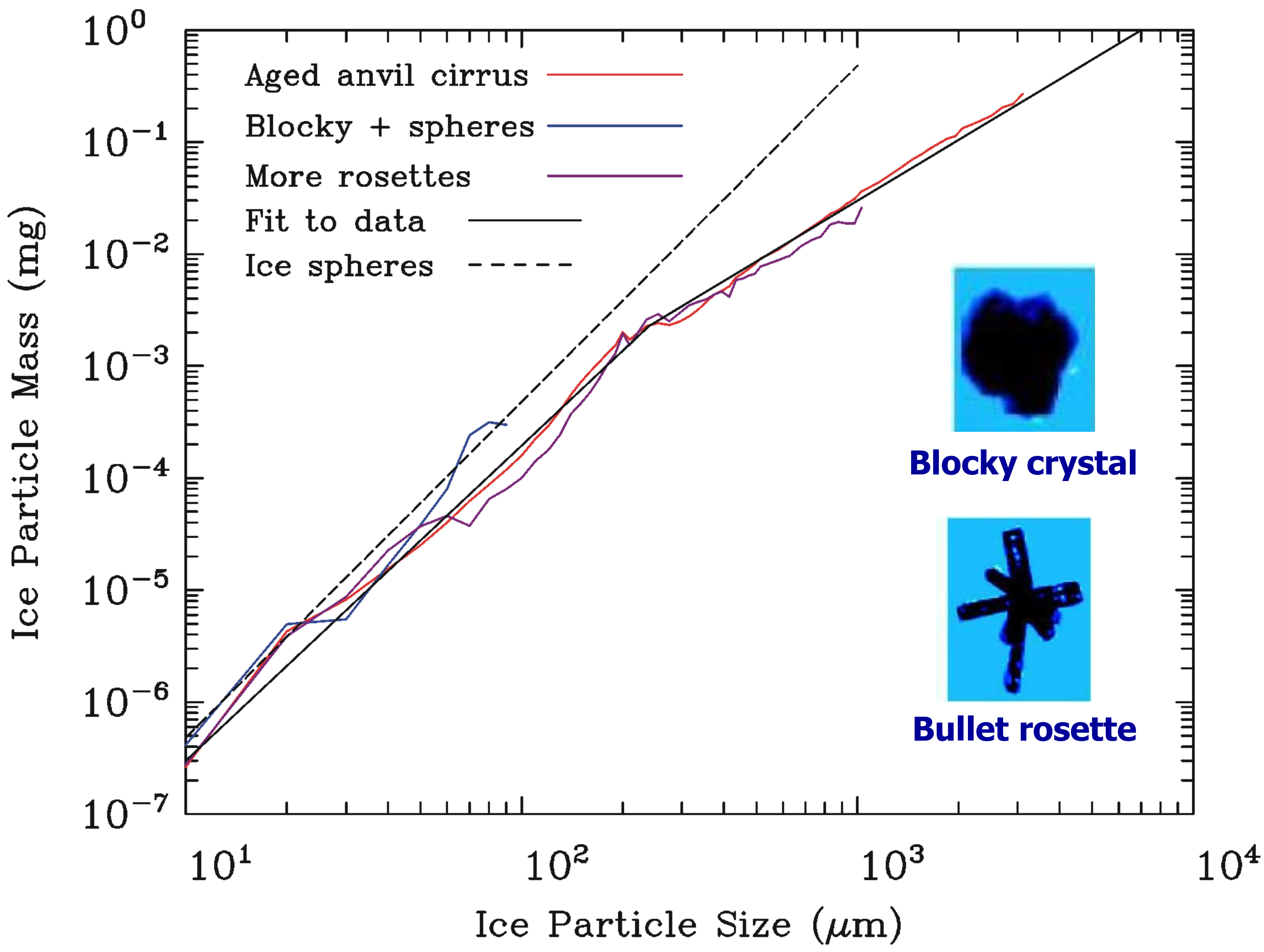
# Reducing Uncertainty from Ice Crystal Shape

IWC from 2DS probe during TC4 generally agreed well with the CVI IWC. Being relatively free from shattering artefacts, we can use the ice mass measured in 2DS bins to calculate representative ice particle m-D relationships to use in the retrieval algorithm.

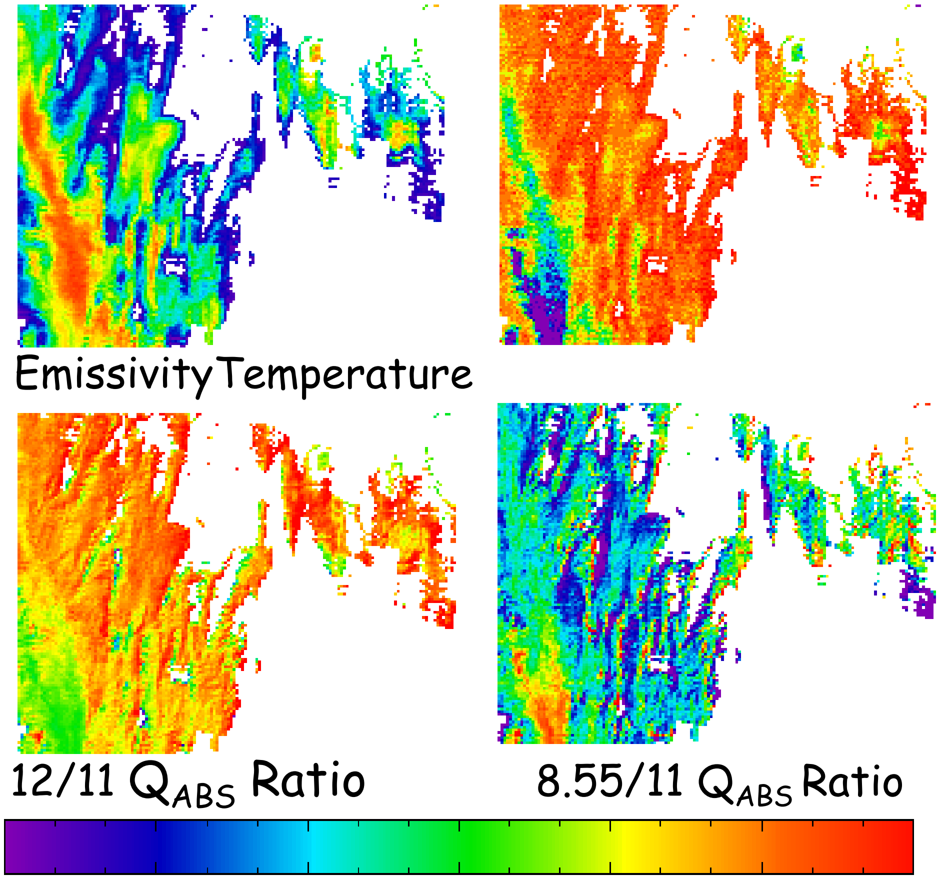


# Improved m-D relationships based on CVI and 2DS probes

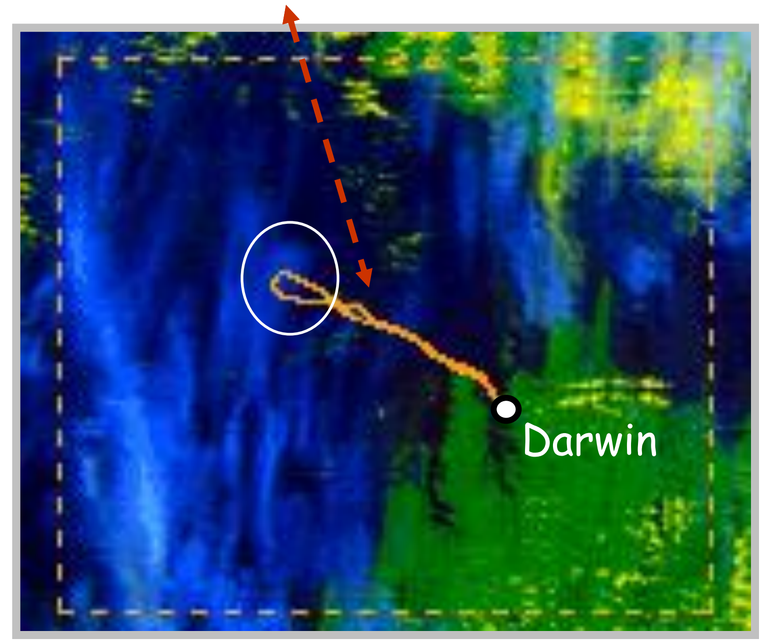


# Monomodal or bimodal? A TWP-ICE case study



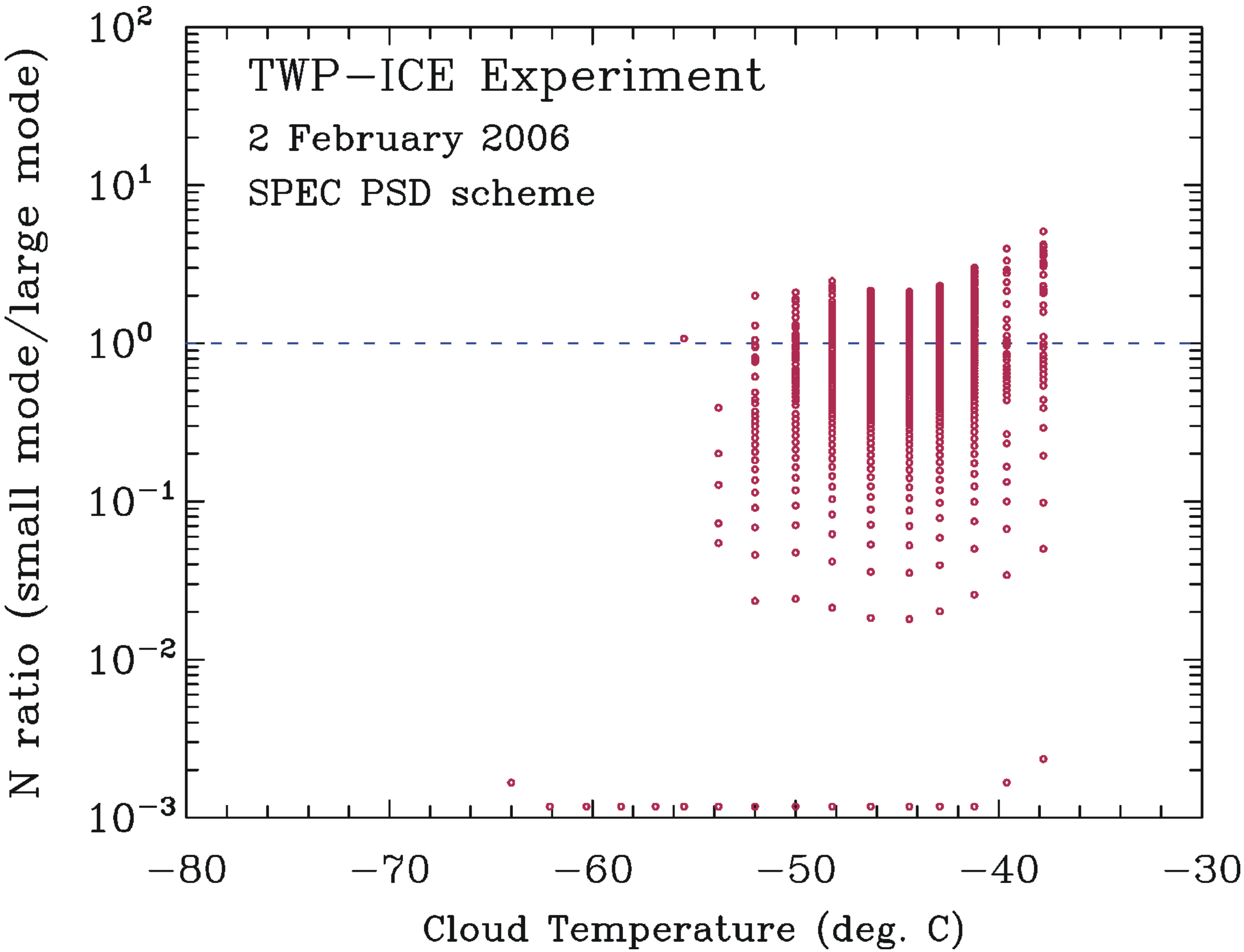

| | | | | | |
|---|---|---|---|---|---|
| 0.1 | 0.33 | 0.55 | 0.78 | 1.0 | 11-µm Emissivity |
| 200 | 209 | 218 | 227 | 235 | Cirrus Temperature (K) |
| 15 | 14 | 13 | 12 | 11 | Cirrus Height (km) - Same as $T_{CI}$ |
| 0.73 | 0.84 | 0.95 | 1.06 | 1.16 | $Q_{ABS}$ Ratios |

Proteus flight track




0.47 0.86 11.03-µm Composite

# Bimodal PSD retrievals indicate monomodal spectra



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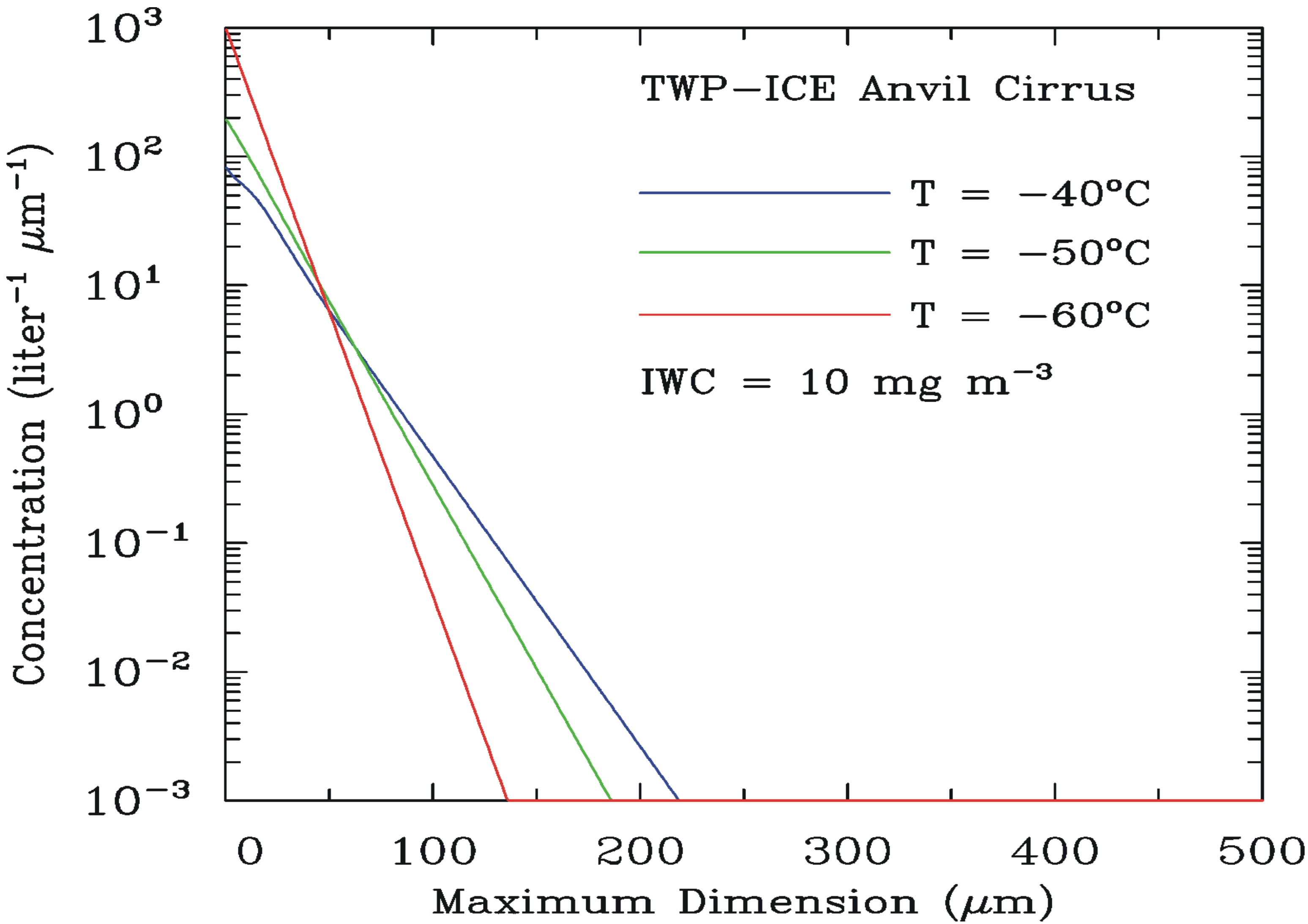
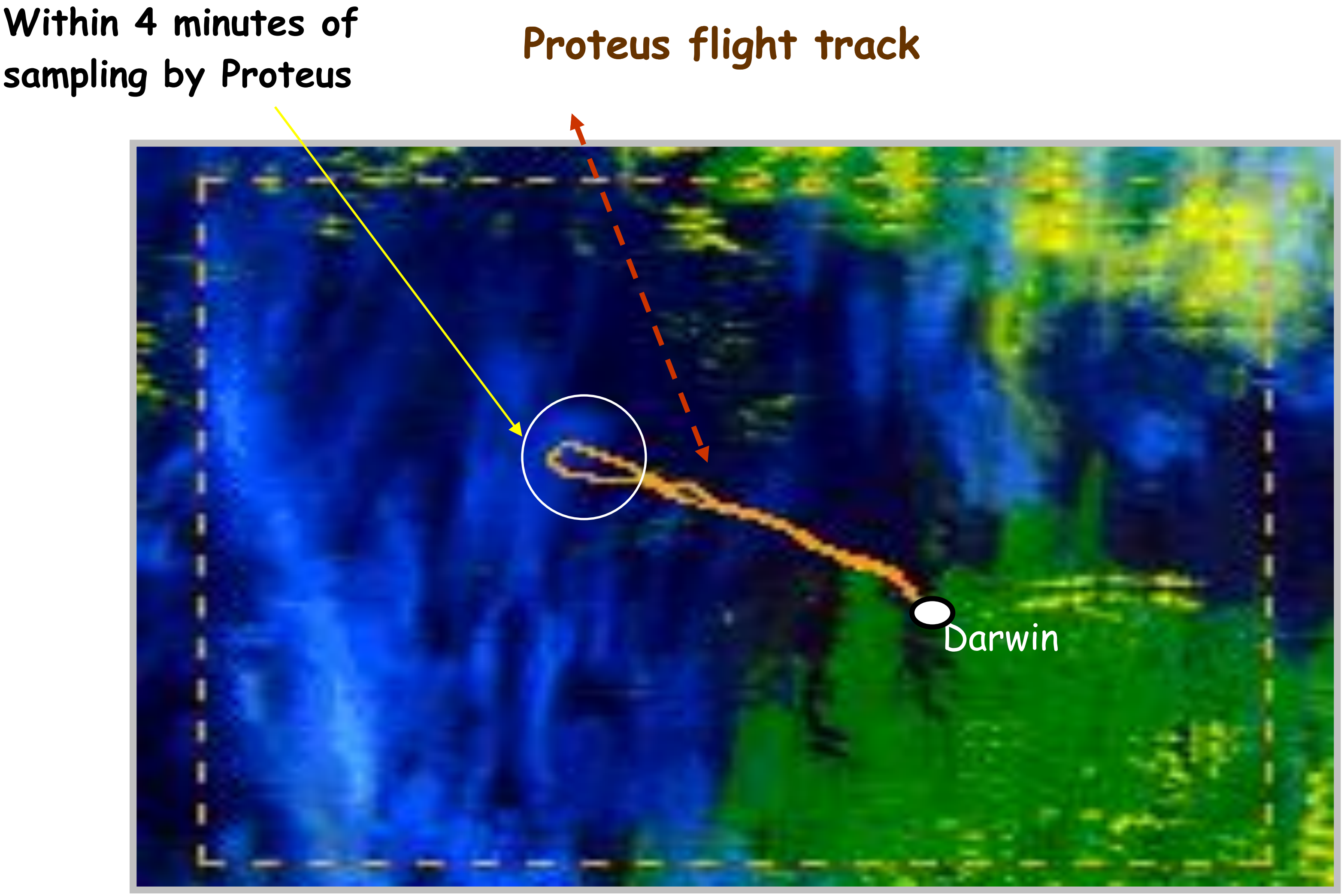


# Testing the monomodal retrieval scheme with in situ measurements

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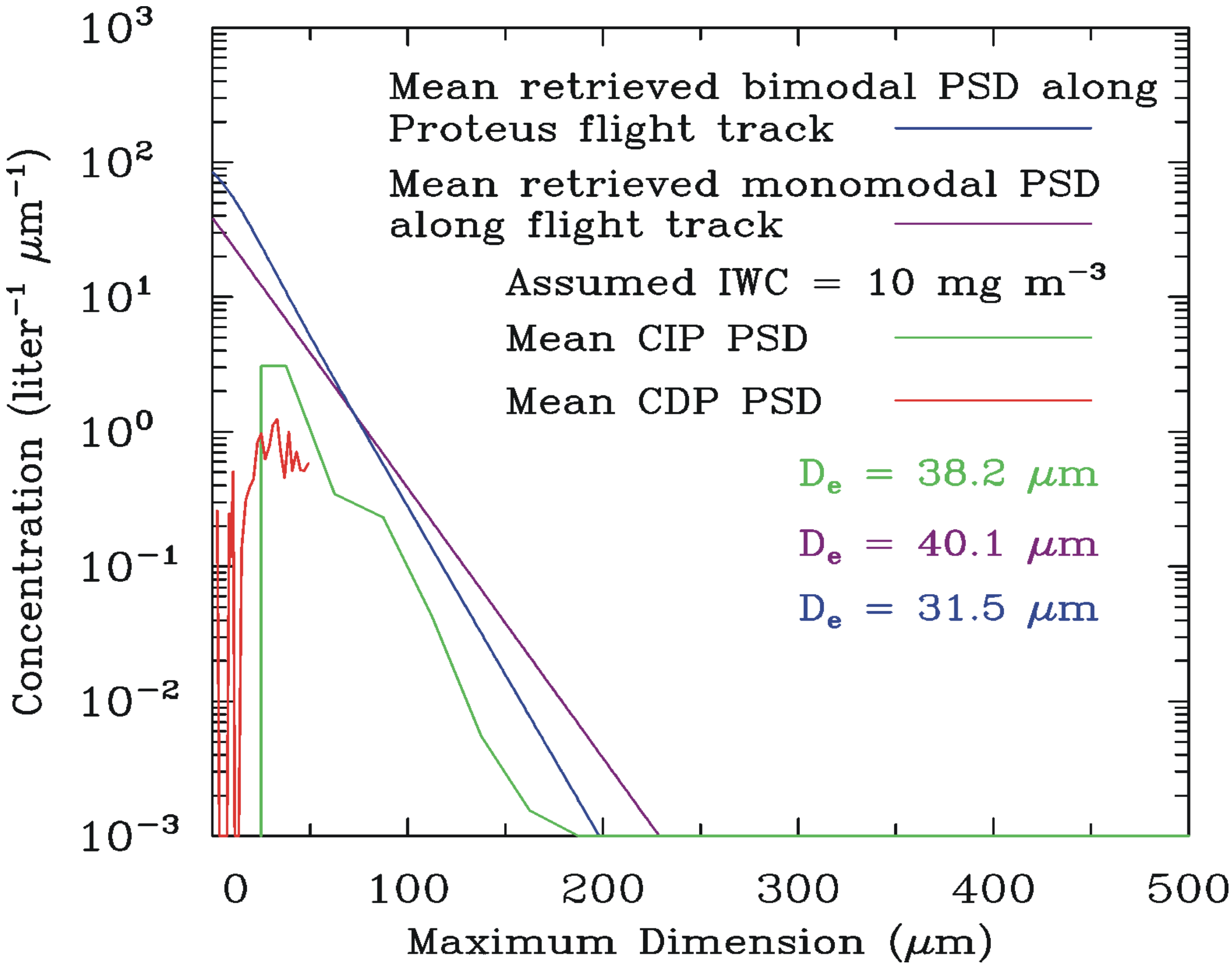
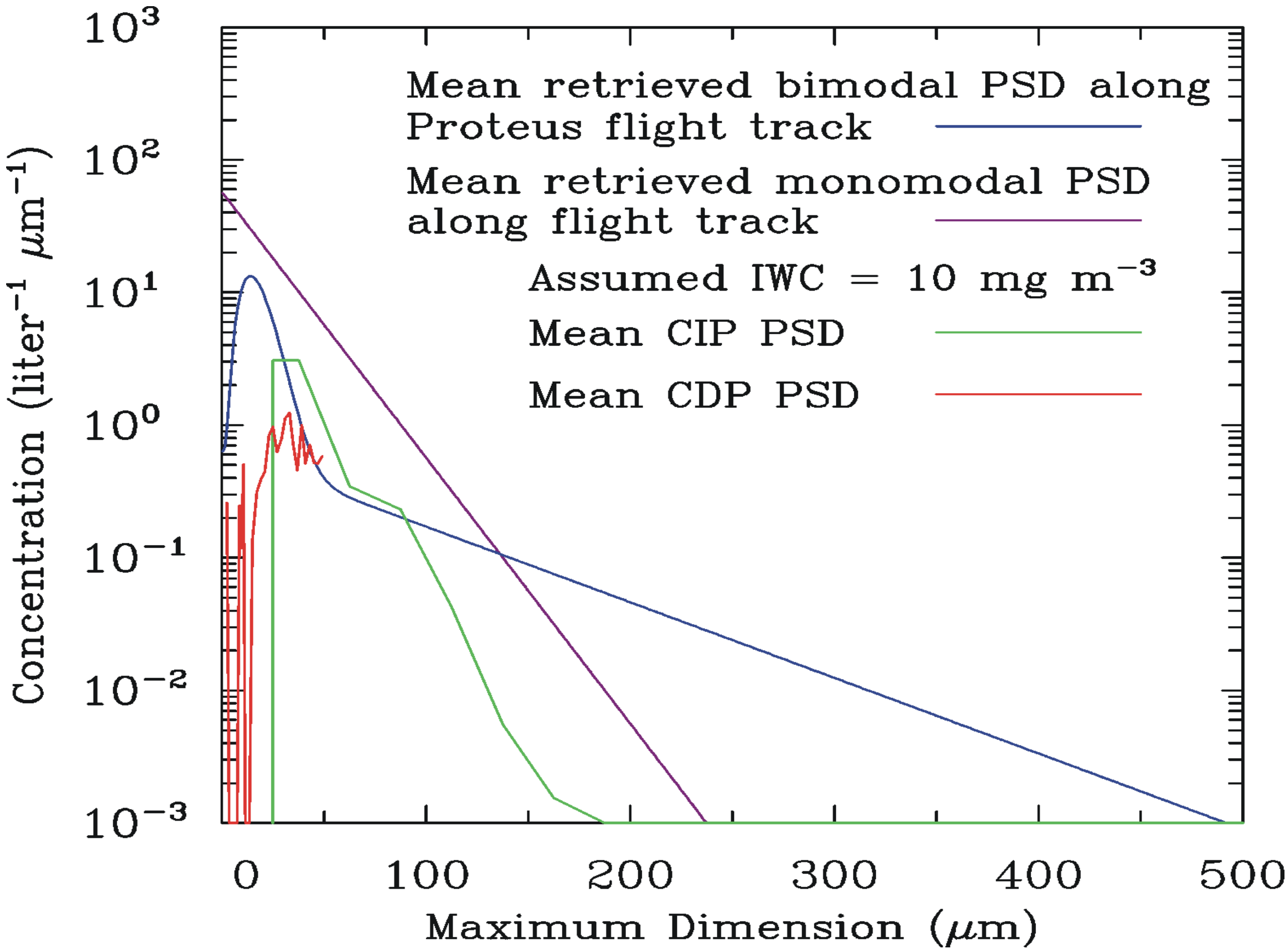


## Comparing bimodal retrieval using the CEPEX PSD scheme

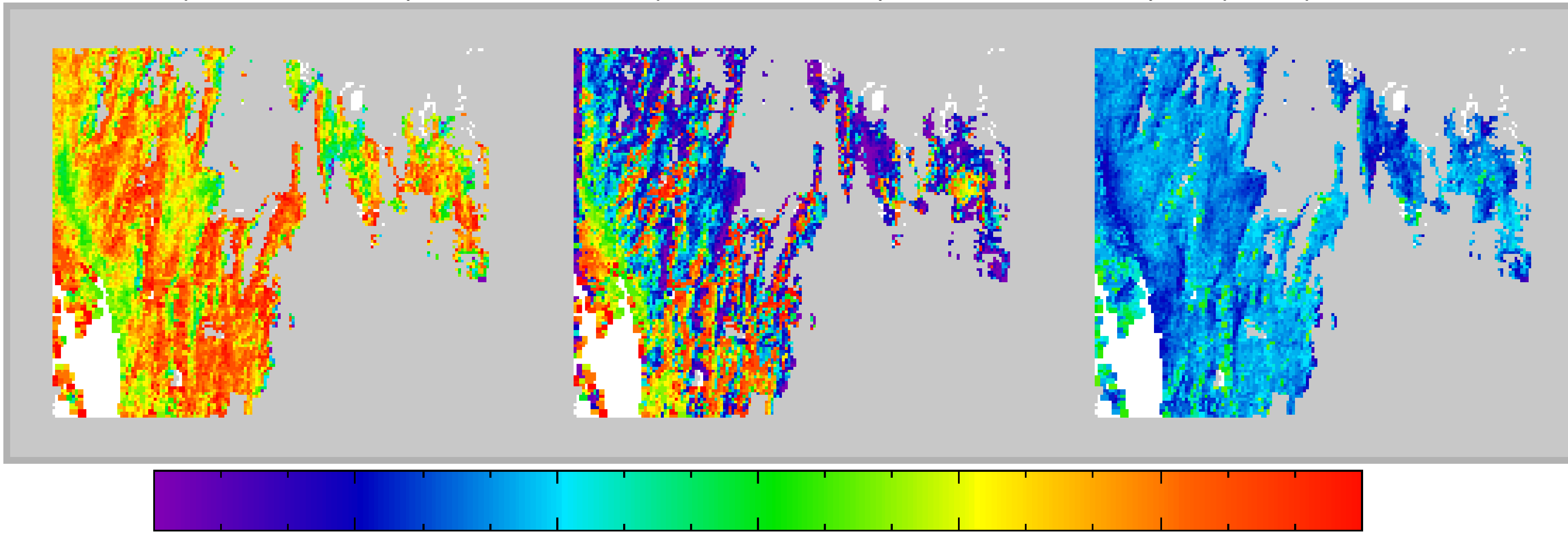


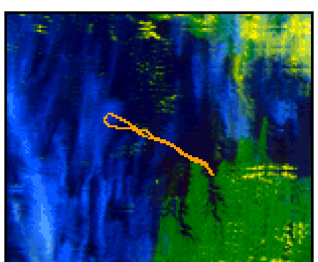
# Sensitivity to different microphysical assumptions

Bimodal w CEPEX PSD - std crystal shapes

Monomodal - std crystal shapes

Bimodal – Planar polycrystals



0.47 0.86 11.03-μm Composite

# Sensitivity to different microphysical assumptions

Bimodal w CEPEX PSD - std. crystal shapes

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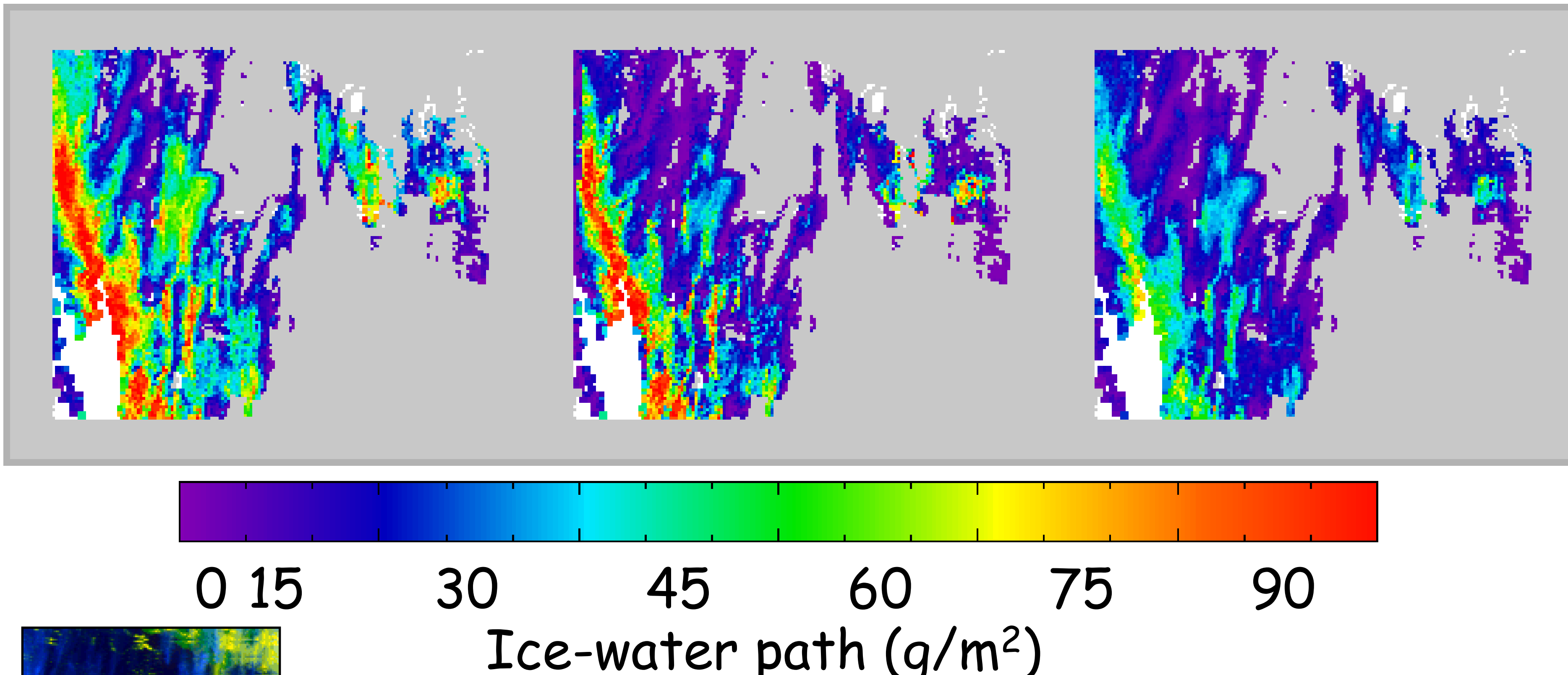
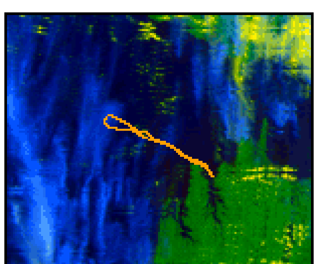


0.47 0.86 11.03-μm Composite

# Summary

1. Retrieval results thus far indicate that the cirrus PSD is generally monomodal and that the measured bimodality was due to shattering.

2. For monomodal PSD, the retrieved cloud properties depend much less on *a priori* information. Retrievals include the small-to-large mode ice crystal concentration ratio, IWP, $D_e$ and the PSD slope (for calculating ice sedimentation rates).

3. The retrieval was tested using a MODIS image coinciding with aircraft measurements during TWP-ICE. The measured and retrieved PSD slope and $D_e$ were very similar.

4. Observed changes in the ice particle m-D relationship can easily change the retrieved IWP and $D_e$ by a factor of 2. Advances in estimating this m-D relationship are incorporated into this retrieval.

5. IWP retrievals available for CAM4 validation consist of 3 MODIS scenes from the TWP-ICE and TC4 field campaigns (~ 12,000 sq. mi.).

# How Photon Tunneling Can be Used to Remotely Detect Small Ice Crystals in Cirrus

**Photon Tunneling is the process by which radiation beyond the physical cross-section of a particle is either absorbed or scattered outside the forward diffraction peak. Tunneling is strongest when:**

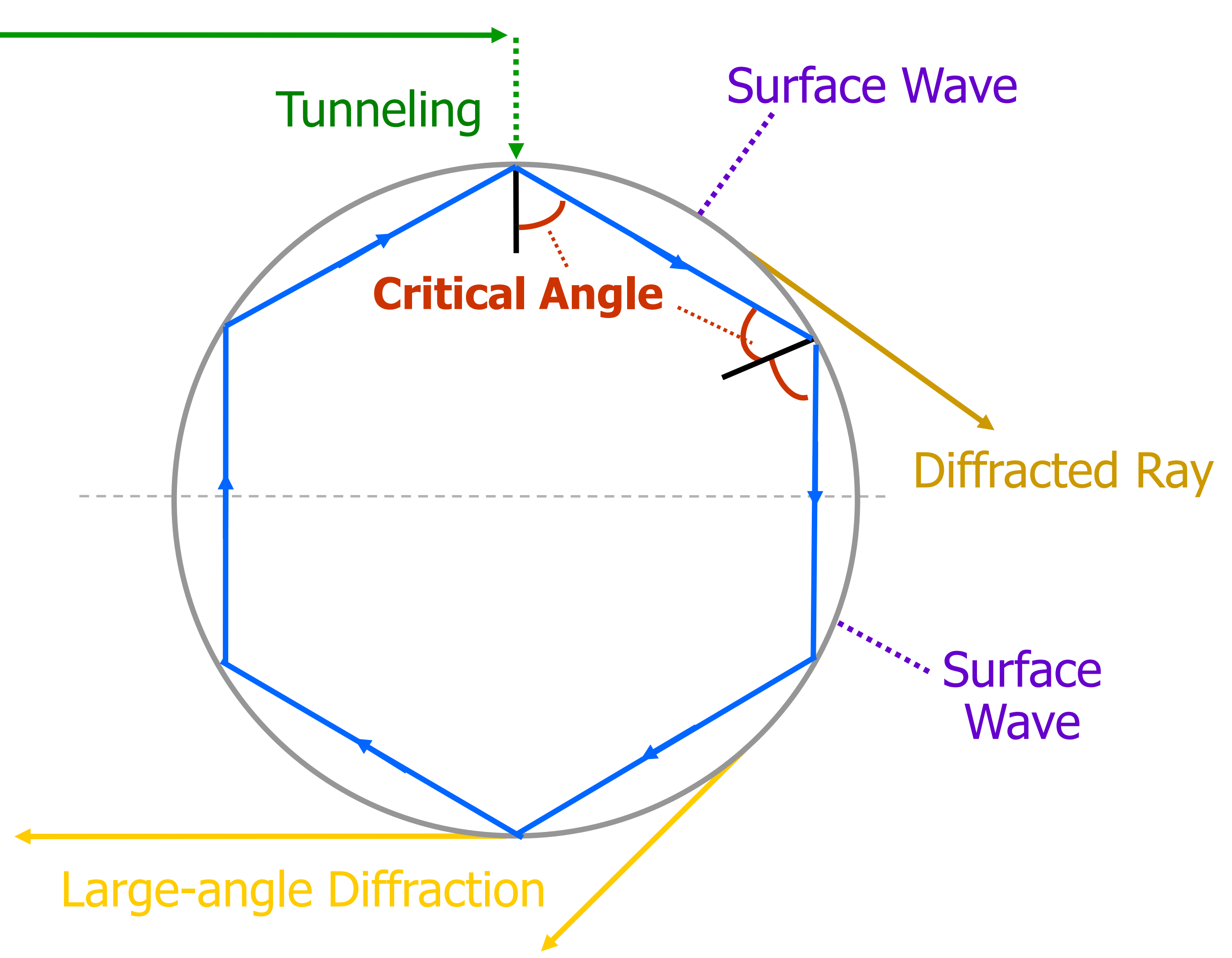
**1) Effective size and wavelength are comparable**

**1) Particle shape is spherical or quasi-spherical**

**1) The real refractive index is relatively large**

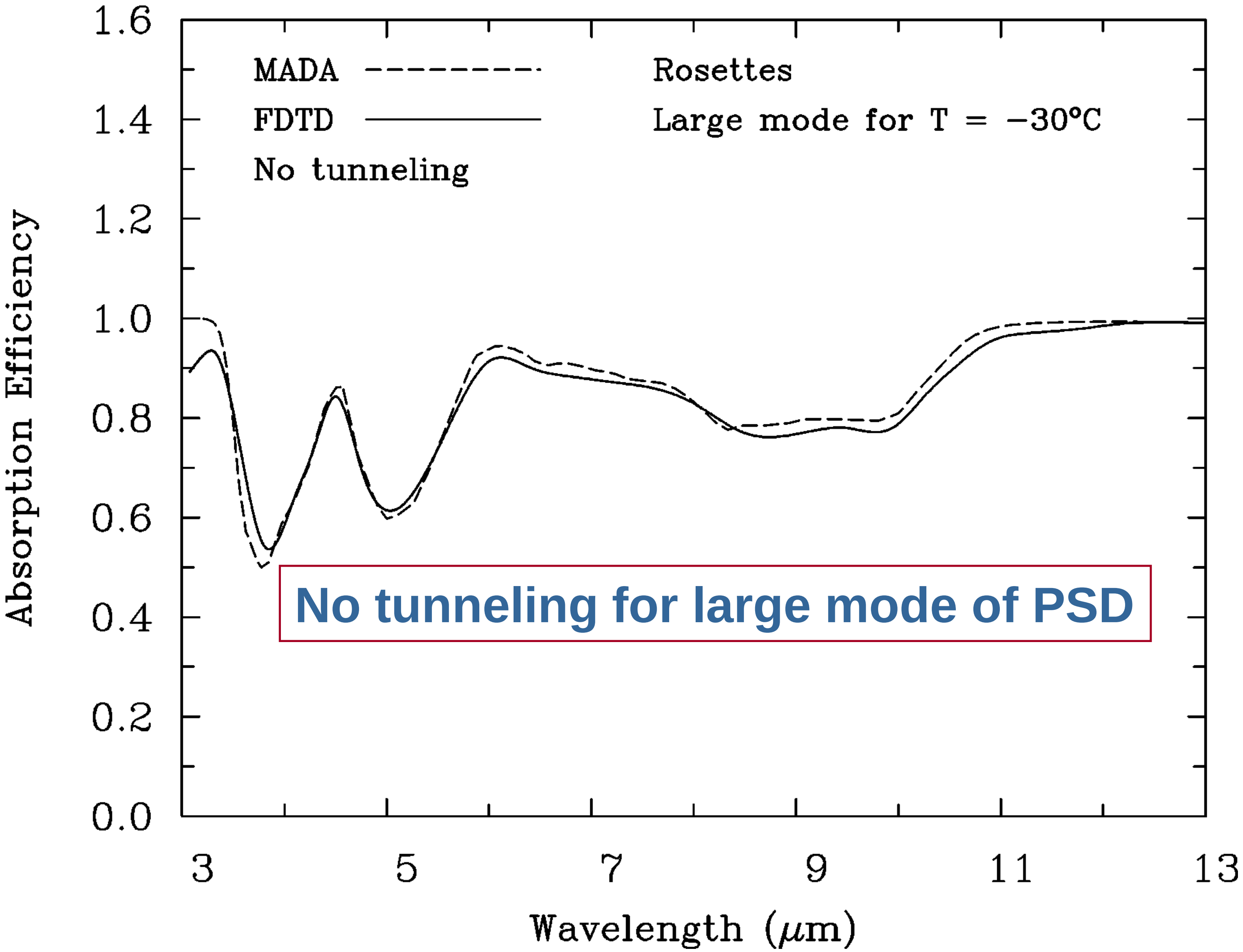
**Therefore tunneling contributions at terrestrial wavelengths are greatest for smallest ($D < 60$ μm) ice crystals. To detect the tunneling signal is to detect small ice crystals.**

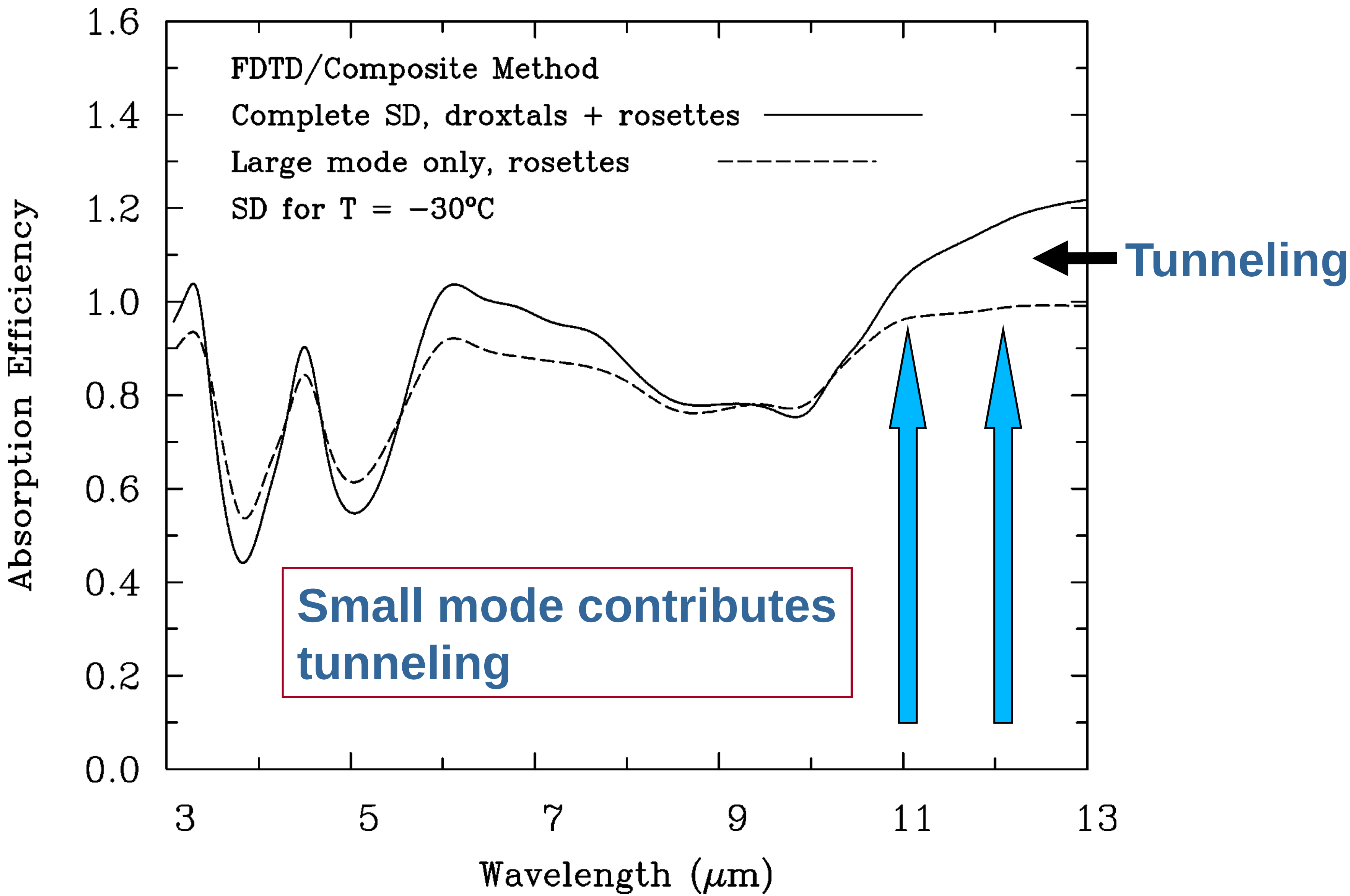
# Remote Sensing of Small Ice Crystals (D < 60 μm) and the Process of Photon Tunneling




Tunneling depends on real refractive index, which changes abruptly between 11 and 12 μm wavelength.

Tunneling can account for up to 45% of absorption in ice clouds for terrestrial radiation.


MADA
FDTD
No tunneling
Rosettes
Large mode for T = −30°C
No tunneling for large mode of PSD
Absorption Efficiency
Wavelength (μm)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
3
5
7
9
11
13



FDTD/Composite Method
Complete SD, droxtals + rosettes
Large mode only, rosettes
SD for T = −30°C
Tunneling
Small mode contributes tunneling
Absorption Efficiency
Wavelength (μm)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
3
5
7
9
11
13

# Retrieval of Cirrus Temperature and Emissivity

- For two $CO_2$ channels A and B, cirrus emissivity $\varepsilon$ will be the same due to similar refractive indices. Solving for $\varepsilon$ using the simple non-scattering formulation, and equating $\varepsilon_A = \varepsilon_B$,

$$I_{OBS} = (1 - \varepsilon)\, I_{CLR} + \varepsilon\, B(T_{CLD})$$

and

$$\frac{I_{A,OBS} - I_{A,CLR}}{B_A(T_{CLD}) - I_{A,CLR}} = \frac{I_{B,OBS} - I_{B,CLR}}{B_B(T_{CLD}) - I_{B,CLR}} \, .$$

We then solve for the one unknown, cirrus temperature $T_{CLD}$.

- With $T_{CLD}$ retrieved and $I_{CLR}$ and $I_{OBS}$ directly measured, we can solve for $\varepsilon$ at 11 & 12 µm, where $\varepsilon_{11}$ and $\varepsilon_{12}$ are solved independently:

$$\varepsilon_{11} = \frac{I_{11,OBS} - I_{11,CLR}}{B_{11}(T_{CLD}) - I_{11,CLR}} \qquad \varepsilon_{12} = \frac{I_{12,OBS} - I_{12,CLR}}{B_{12}(T_{CLD}) - I_{12,CLR}}$$

## Calculation of $\varepsilon_{eff}$ in Retrieval Algorithm

**- Based on Parol et al. (1991, JAM) -**

Since some scattering may occur, $\varepsilon$ retrieved in this way is an effective emissivity, $\varepsilon_{eff}$, which implicitly includes the effects of scattering through its dependence on asymmetry parameter g:

$$\varepsilon_{eff}(12\ \mu m) = 1 - [1 - \varepsilon_{eff}(11\ \mu m)]^{\beta_{eff}}$$

$$\beta_{eff} = Q_{abs,eff(12\ \mu m)}/Q_{abs,eff(11\ \mu m)}$$

$$Q_{abs,eff} = Q_{abs}\,(1 - \omega_o\, g)/(1 - \omega_o)$$

When g => 1, all scattering is completely forward scattering and radiation is not redistributed.

# Method for Estimating Small Crystal Amounts

- Begin with satellite retrievals of cloud temperature and emissivity (ε) at 11 and 12 μm wavelength channels.

- Use the retrieved cloud temperature to estimate the PSD mean size $\bar{D}$ and dispersion ($\nu$) for large and small mode. Difference between the solid and dashed curves results primarily from differences in the contribution of the PSD small mode to the IWC. This also determines effective diameter, $D_e$. Note that the large mode $\bar{D}$ and $\nu$ have little effect on above curves.

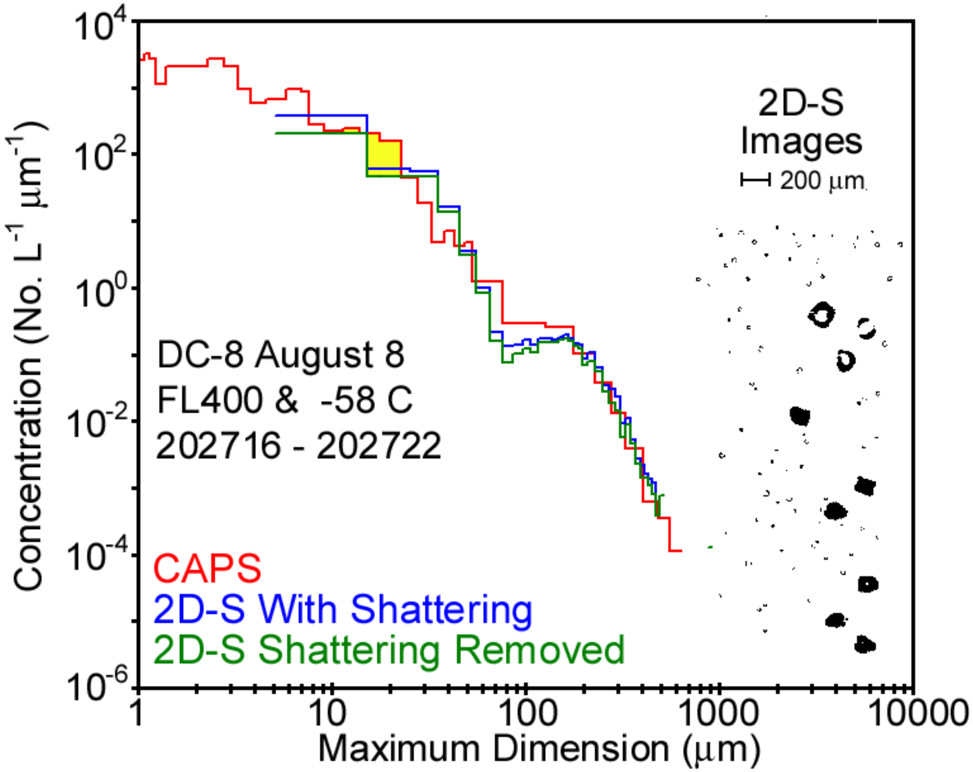
- Locate the retreived Δε and the ε(11 μm) by (1) incrementing the modeled IWP to increase ε(11 μm) and (2) incrementing the small mode IWC, which elevates the curve.

4. If all IWC is in the small mode and retrieved Δε and ε(11 μm) is still not located, then decrease small mode $\bar{D}$ to locate them.

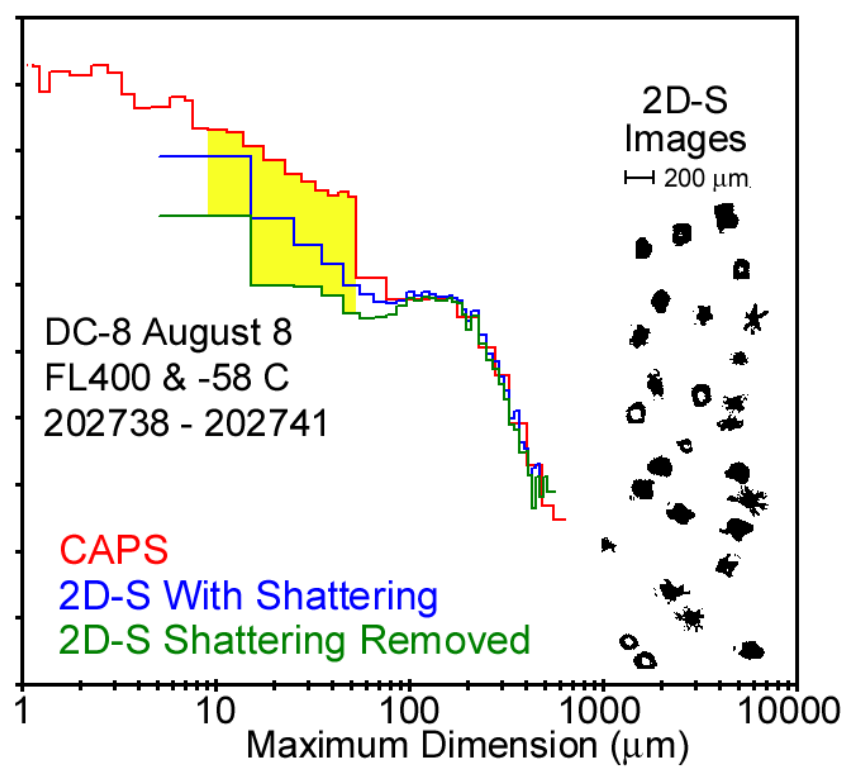
# Method for Estimating Small Crystal Amounts - continued -

1. If the retrieved point lies below the “large mode only” curve (e.g. a dashed curve), then systematically decrease $\overline{D}$ for large mode until a match is obtained. Negative $\Delta\varepsilon$ values correspond to maximum allowed large mode $\overline{D}$ values.

- This methodology retrieves IWP, $D_e$, the small-to-large mode ice crystal concentration ratio, and the ice particle concentration for a given IWC. It also estimates the complete PSD (even when it is bimodal).



Concentration (No. L$^{-1}$ µm$^{-1}$)
Maximum Dimension (µm)
2D-S Images
200 µm
DC-8 August 8
FL400 & -58 C
202716 - 202722
CAPS
2D-S With Shattering
2D-S Shattering Removed

Maximum Dimension (µm)
2D-S Images
200 µm
DC-8 August 8
FL400 & -58 C
202738 - 202741
CAPS
2D-S With Shattering
2D-S Shattering Removed

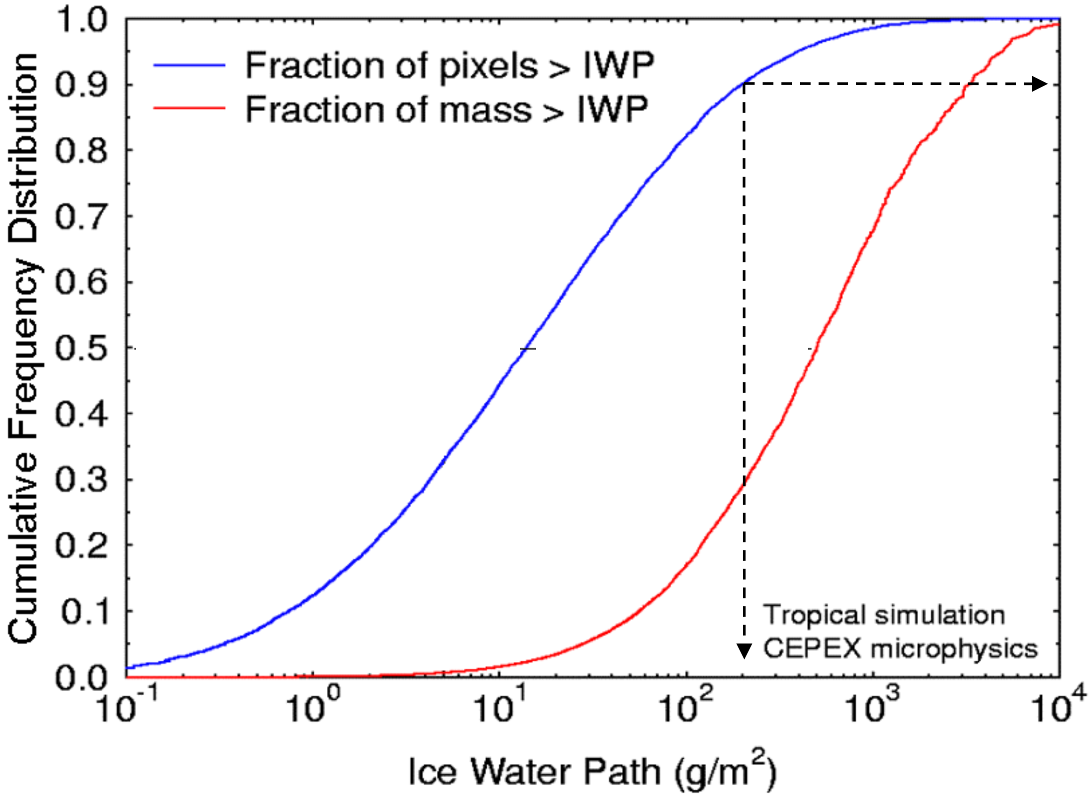
# Natural Variability in IWP

Courtesy of Steve Ackerman, Dave Starr, Gail Jackson and Frank Evans

Approximately 90% of ice clouds have IWP less than 200 g $m^{-2}$; these clouds contain less than 30% of the ice mass contained in the atmosphere.

The frequency of occurance (i.e. the areal coverage of ice clouds) dominates the Earth's radiation budget.

The large IWP end of the cumulative distribution (in blue) is important for the hydrologic cycle (related to the red curve).




**The fraction of pixels with IWP less than a given value (blue) and the fraction of the total mass in pixels with IWP less than a given value (red)**