Mixed Phase Clouds in the -20 to -35 ^{o}C Range: Remote Sensing Results

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

Robert P. d'Entremont

Atmospheric and Environmental Research, Inc., Lexington, MA

Two Types of Mixed Phase Clouds:

1. LW fraction > ~50%
   a. Typical of Arctic
   b. Ice phase affects lifecycle

2. LW fraction < ~20%
   a. -35 < T < 0 °C
   b. Liquid phase strongly affects optical properties

Ice clouds sampled during ISDAC had temperatures > -40 °C. Did some contain low levels of LW? If so, what percentage?

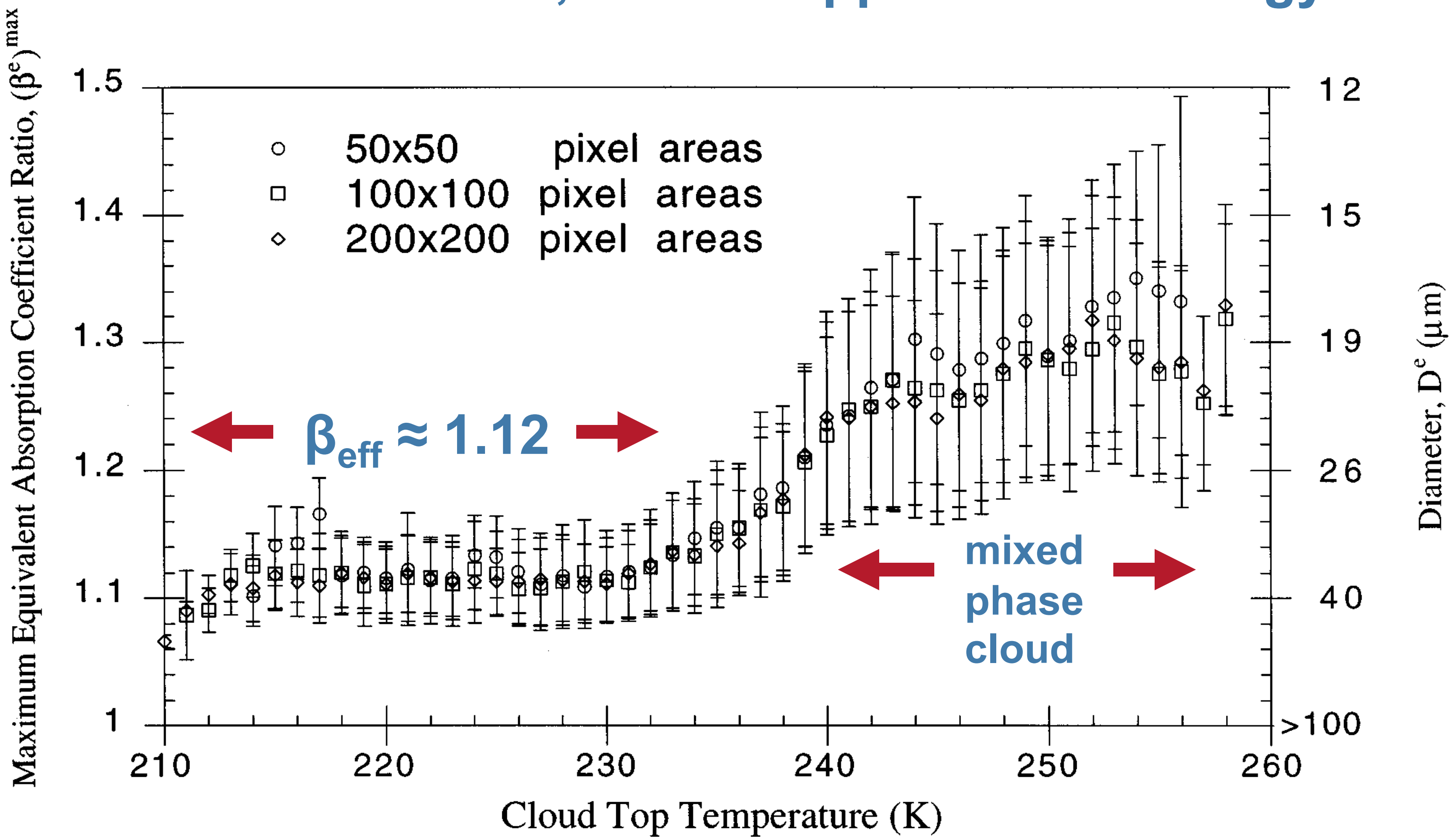
Basis for Mixed Phase Cloud Retrieval

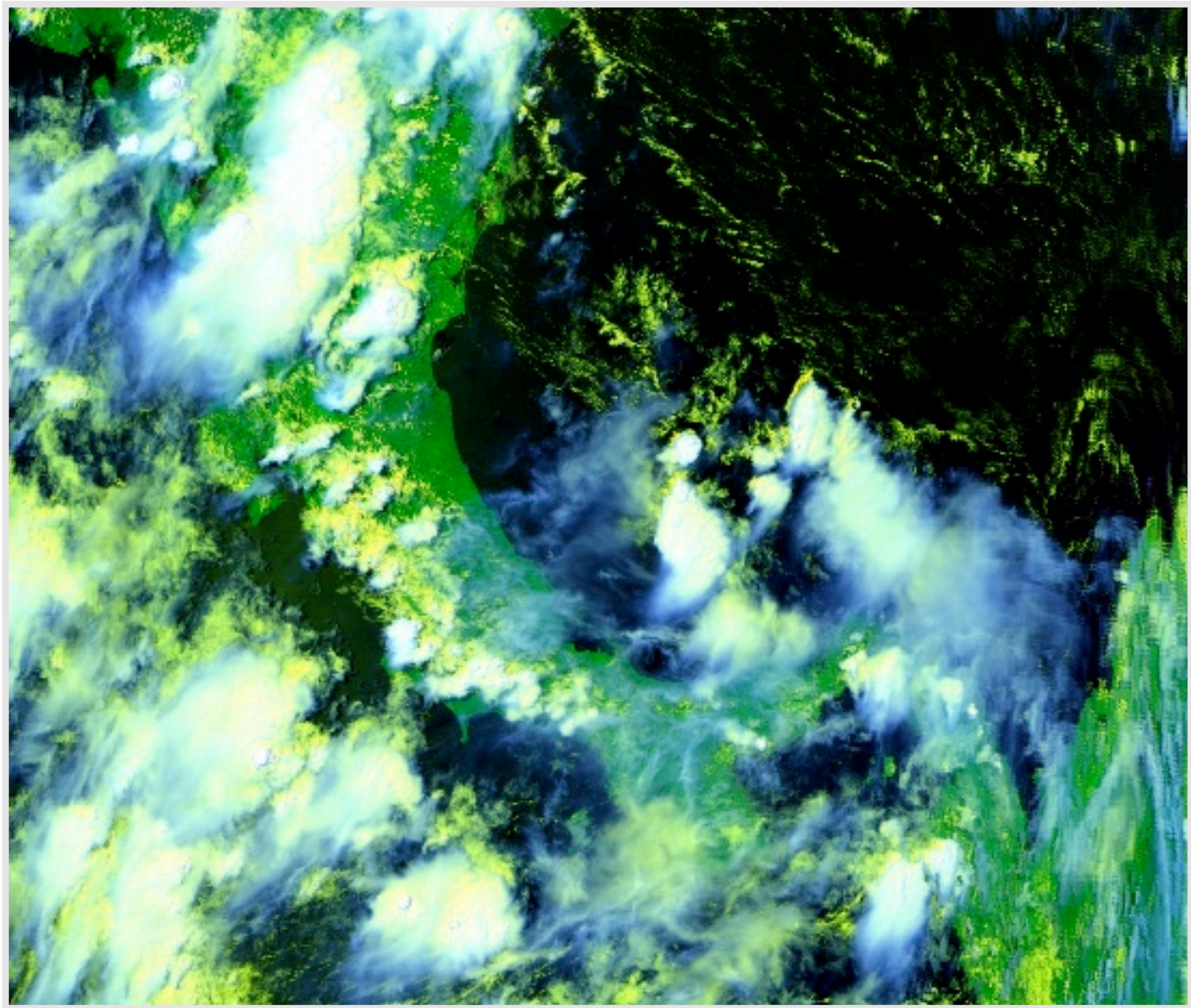
1. **Use the 12/11 μm absorption optical depth ratio, β, to estimate the %LW.**

2. **β is quasi-constant for all-ice clouds but increases with a growing presence of a liquid phase.**

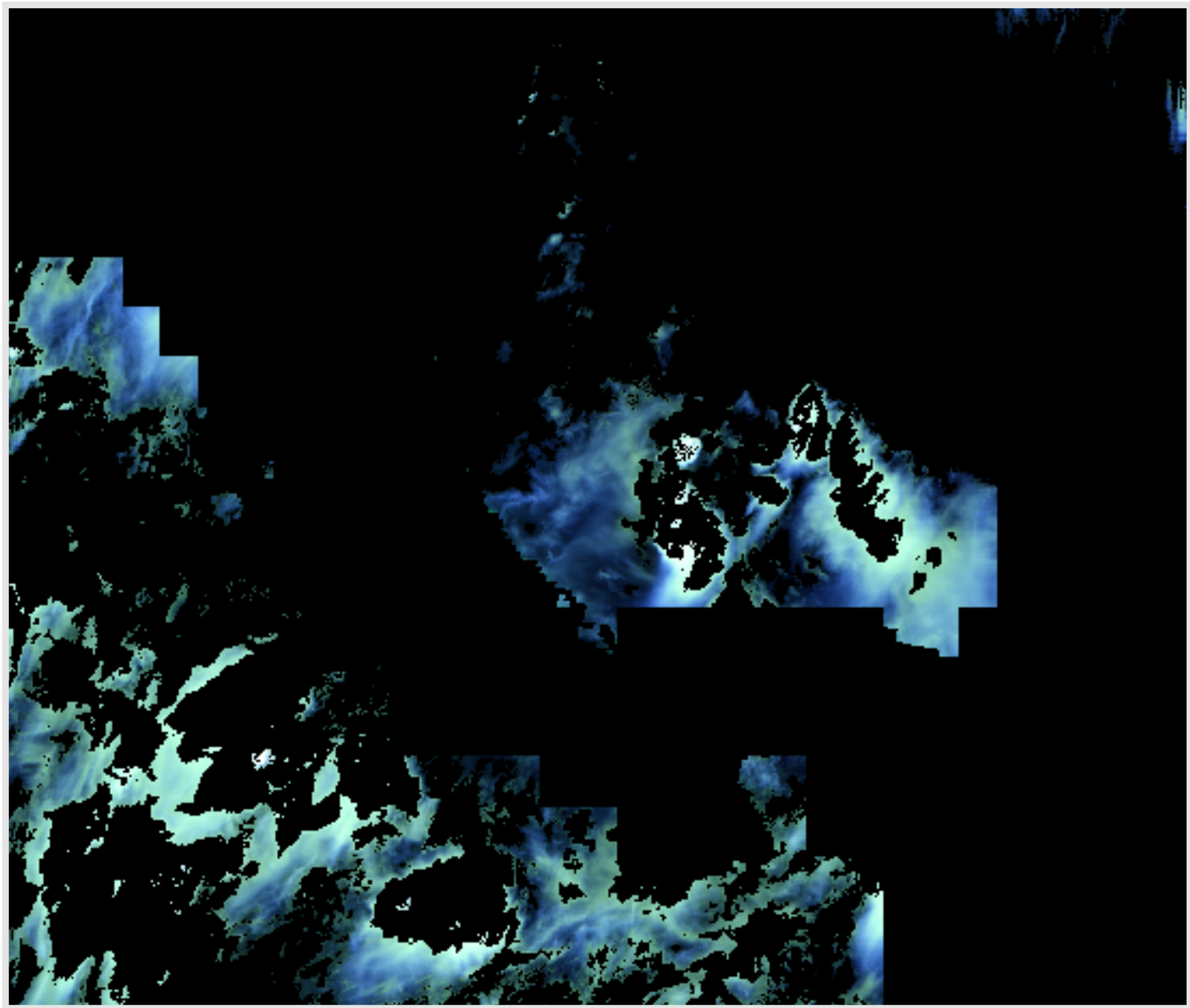
3. **The mean LW fraction can be estimated from the mean departure of β from its ice threshold value.**

Maximum Estimate of β_{eff} vs. Cloud Temperature From Giraud et al., 1997 J. Applied Meteorology

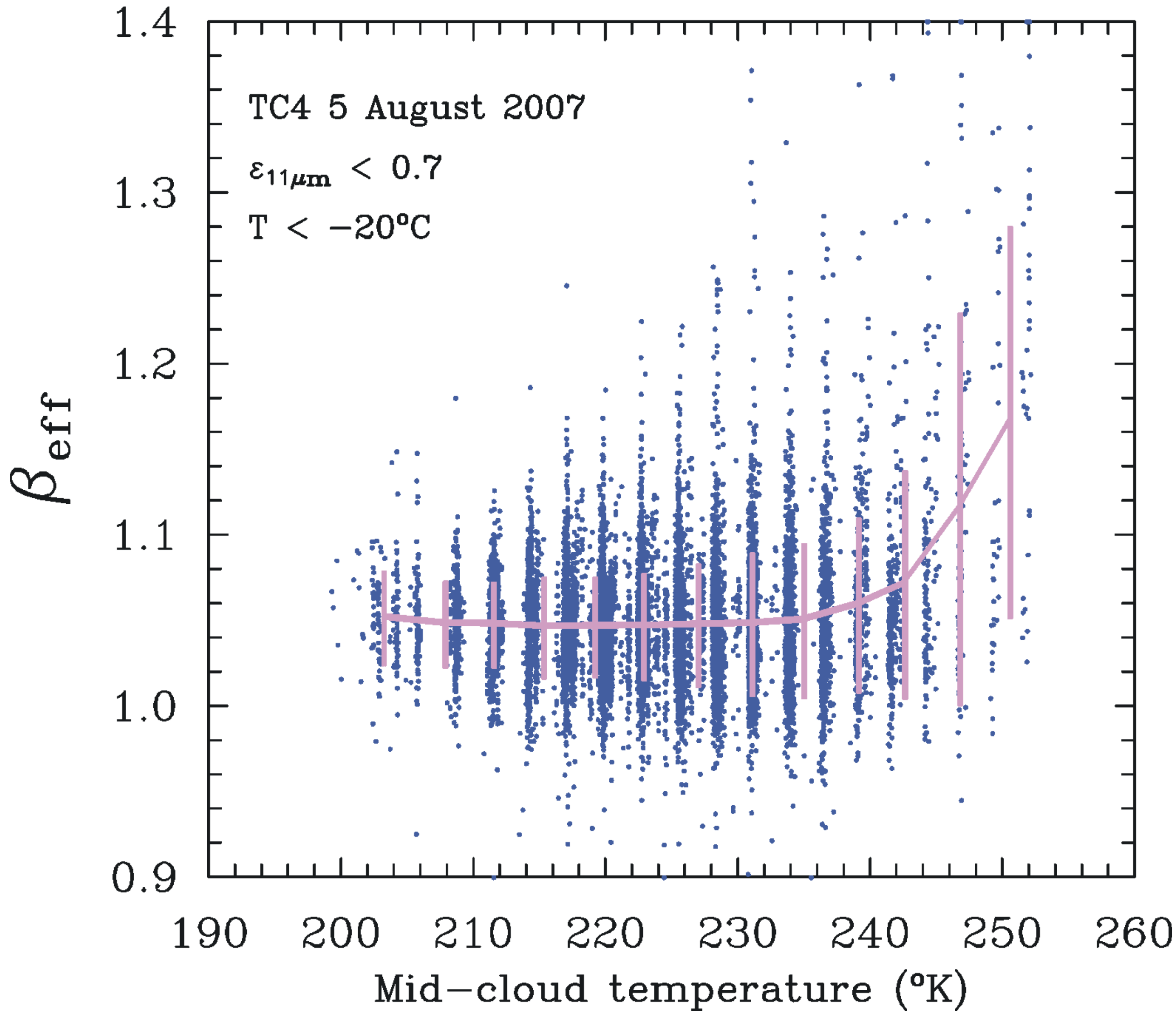




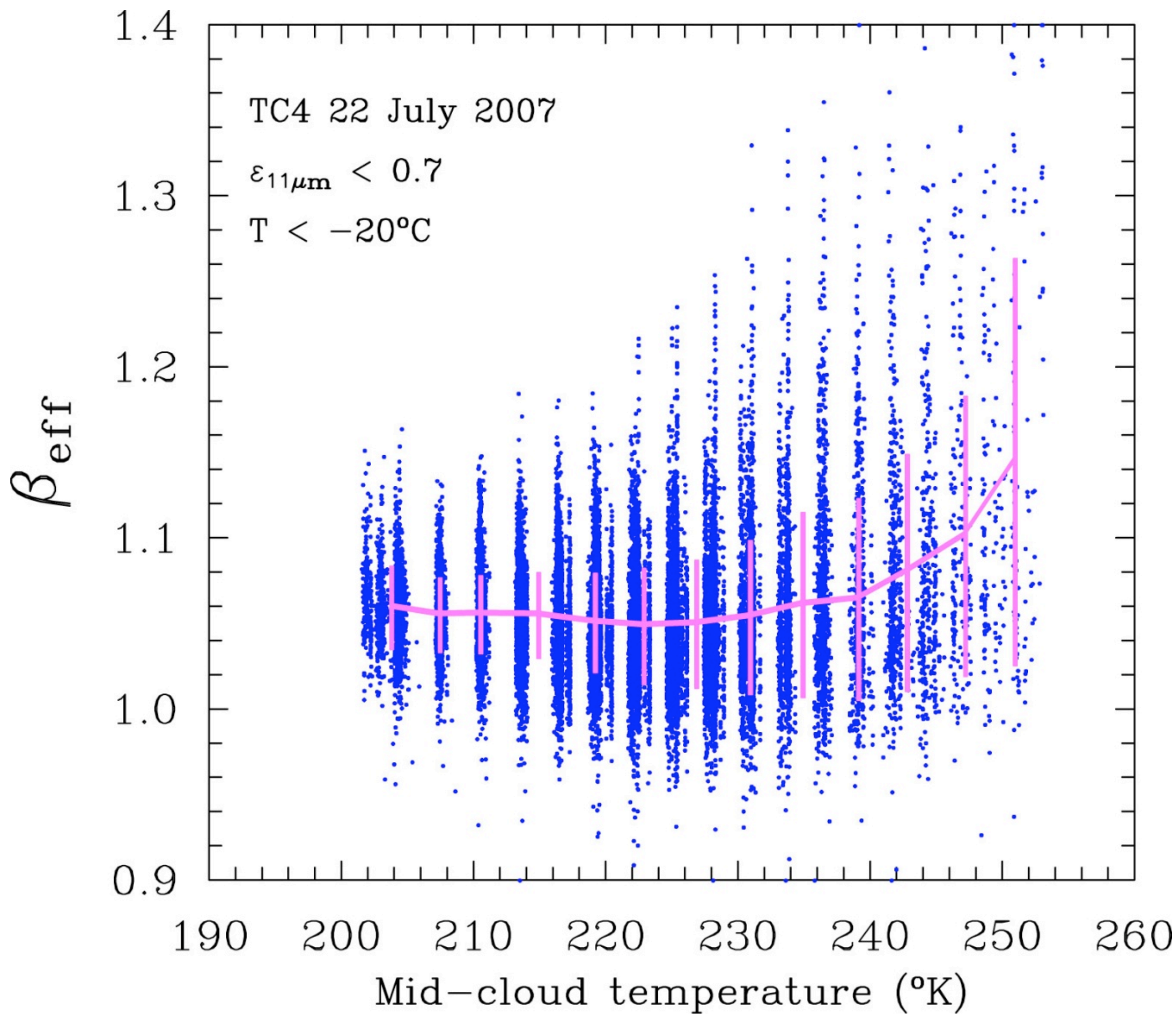
0.63 0.86 11.02 um Color composite 1900 UTC 05 Aug 07



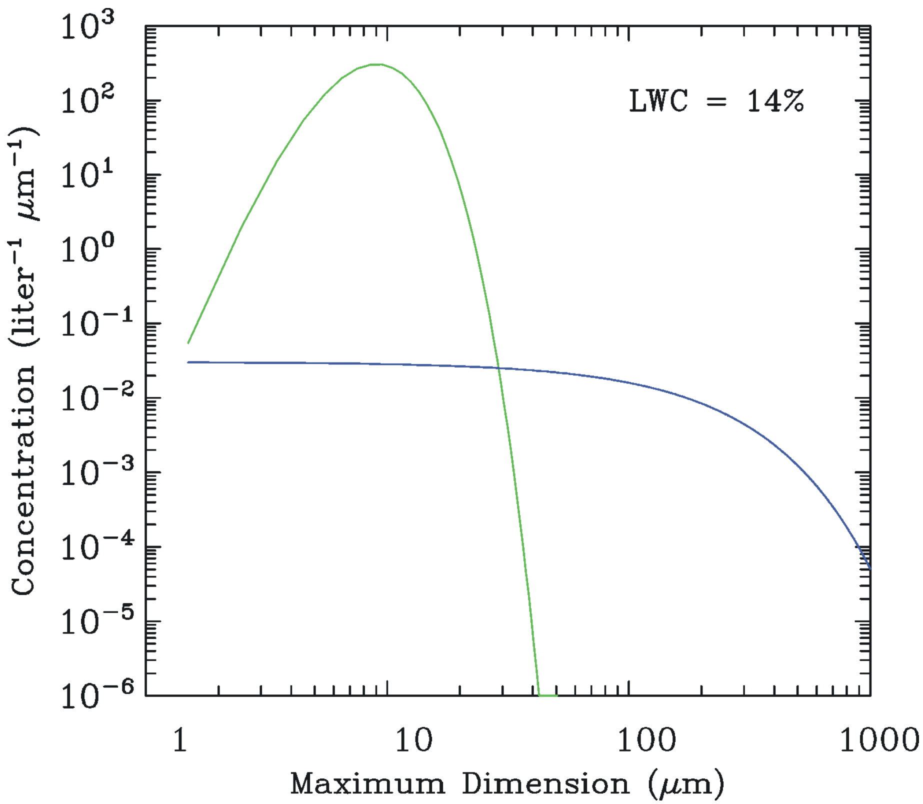
Cirrus-only over-ocean pixels



TC4 5 August 2007
$\varepsilon_{11\mu m} < 0.7$
T < −20°C
1.4
1.3
1.2
1.1
1.0
0.9
β_{eff}
190
200
210
220
230
240
250
260
Mid−cloud temperature (°K)



TC4 22 July 2007
$\varepsilon_{11\mu m} < 0.7$
T < −20°C
β_{eff}
1.4
1.3
1.2
1.1
1.0
0.9
190
200
210
220
230
240
250
260
Mid−cloud temperature (°K)



Procedure:

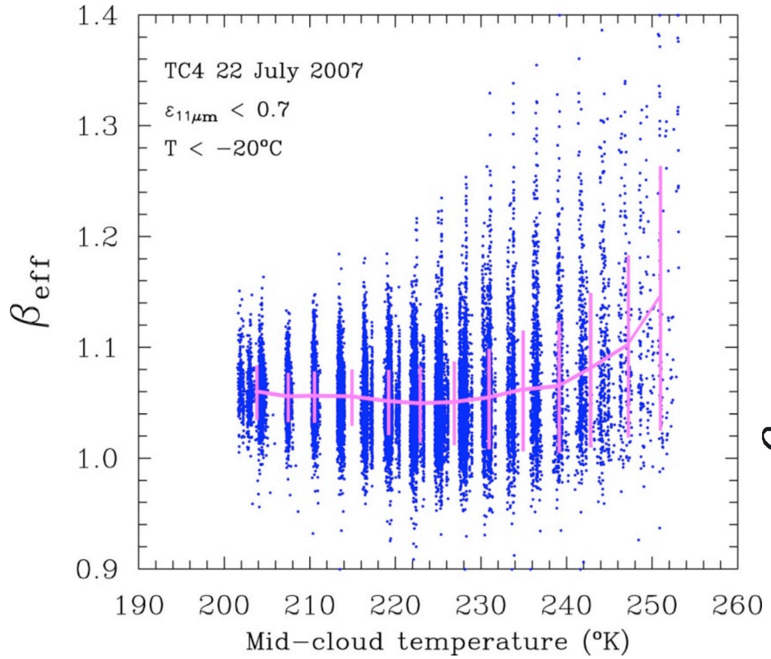
1. Use tropical anvil PSD scheme for ice portion & a representative mean diameter & dispersion param. for liquid portion of PSD.

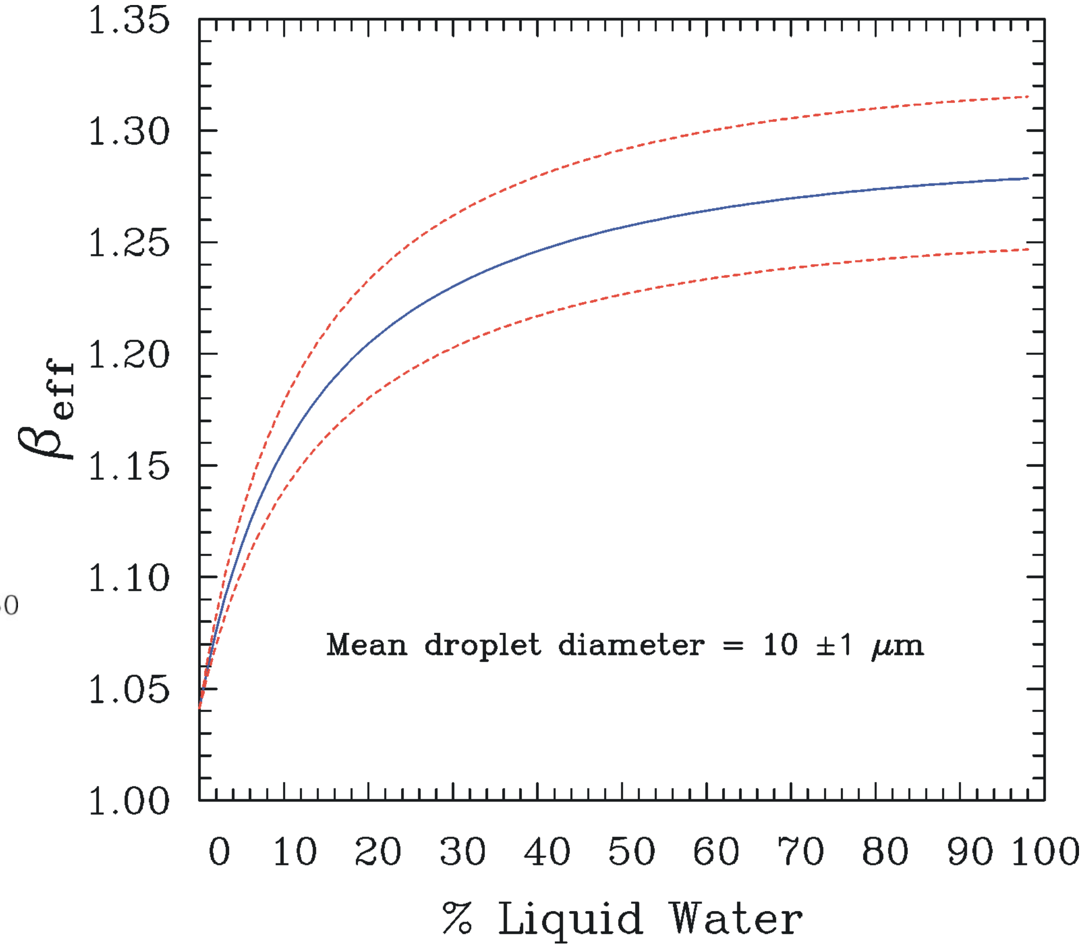
2. Increase LW in droplet PSD until observed and predicted β_{eff} match.
- Account for changes in n_r/n_i

Evaluate Uncertainties:

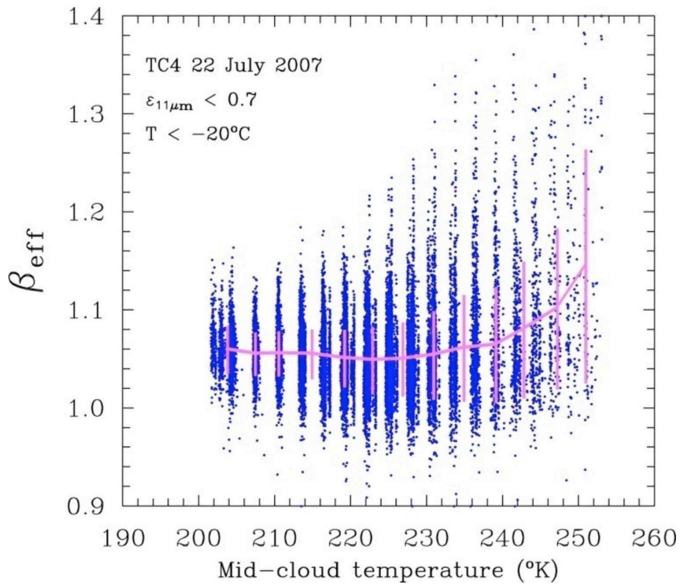
1. **Mean droplet size**
2. **Mean ice particle size**
3. **m-D power laws for ice**
4. **Dispersion param. for ice PSD**

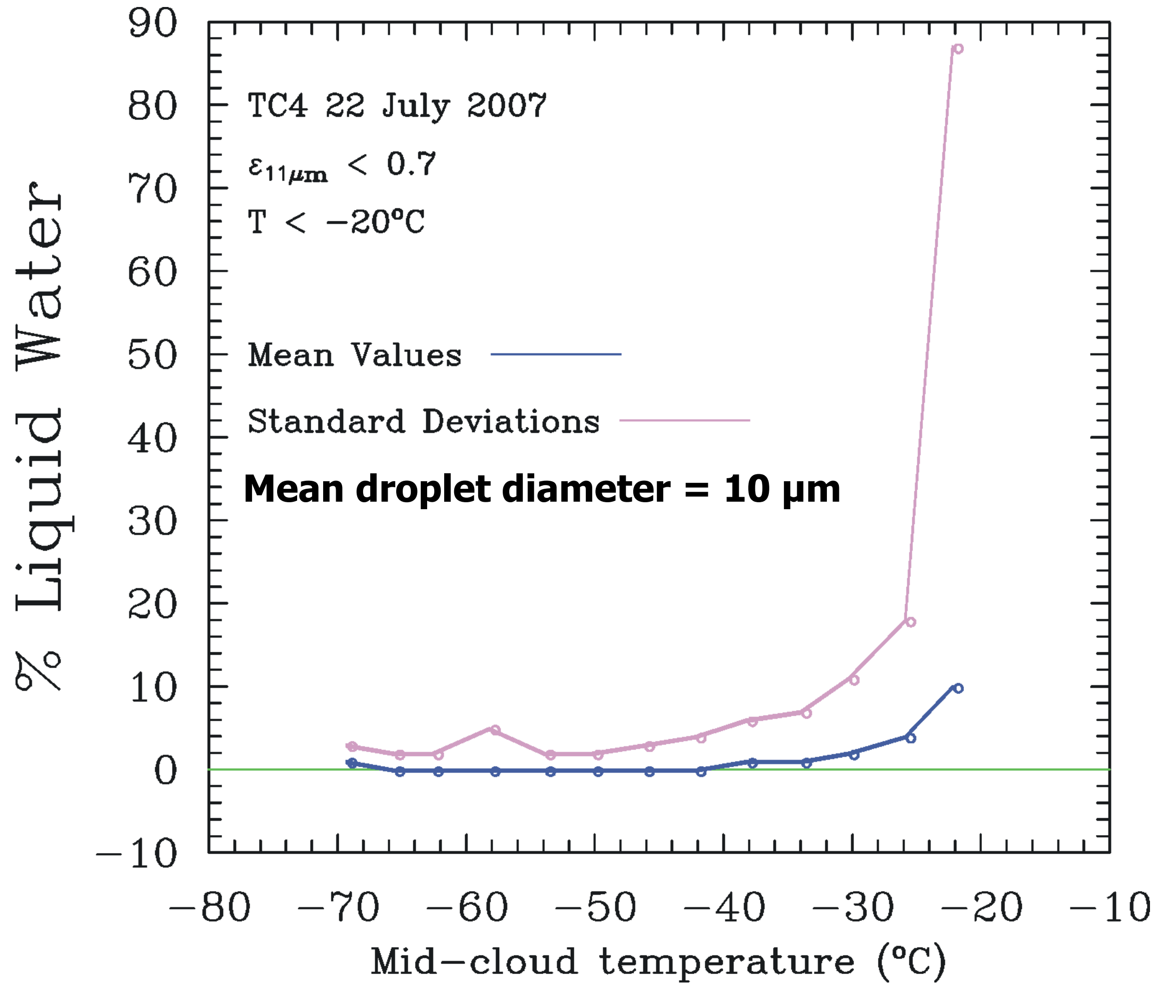
%LW is sensitive to mean droplet size, but range of β restricts the possibilities.



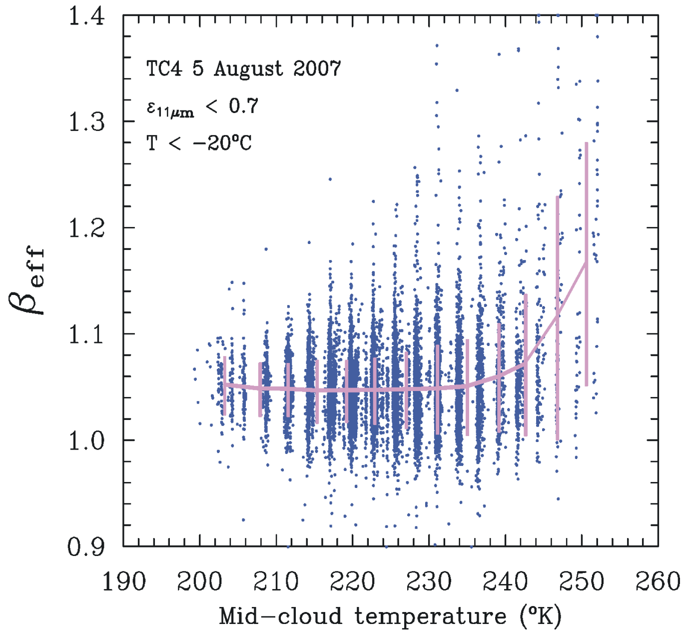


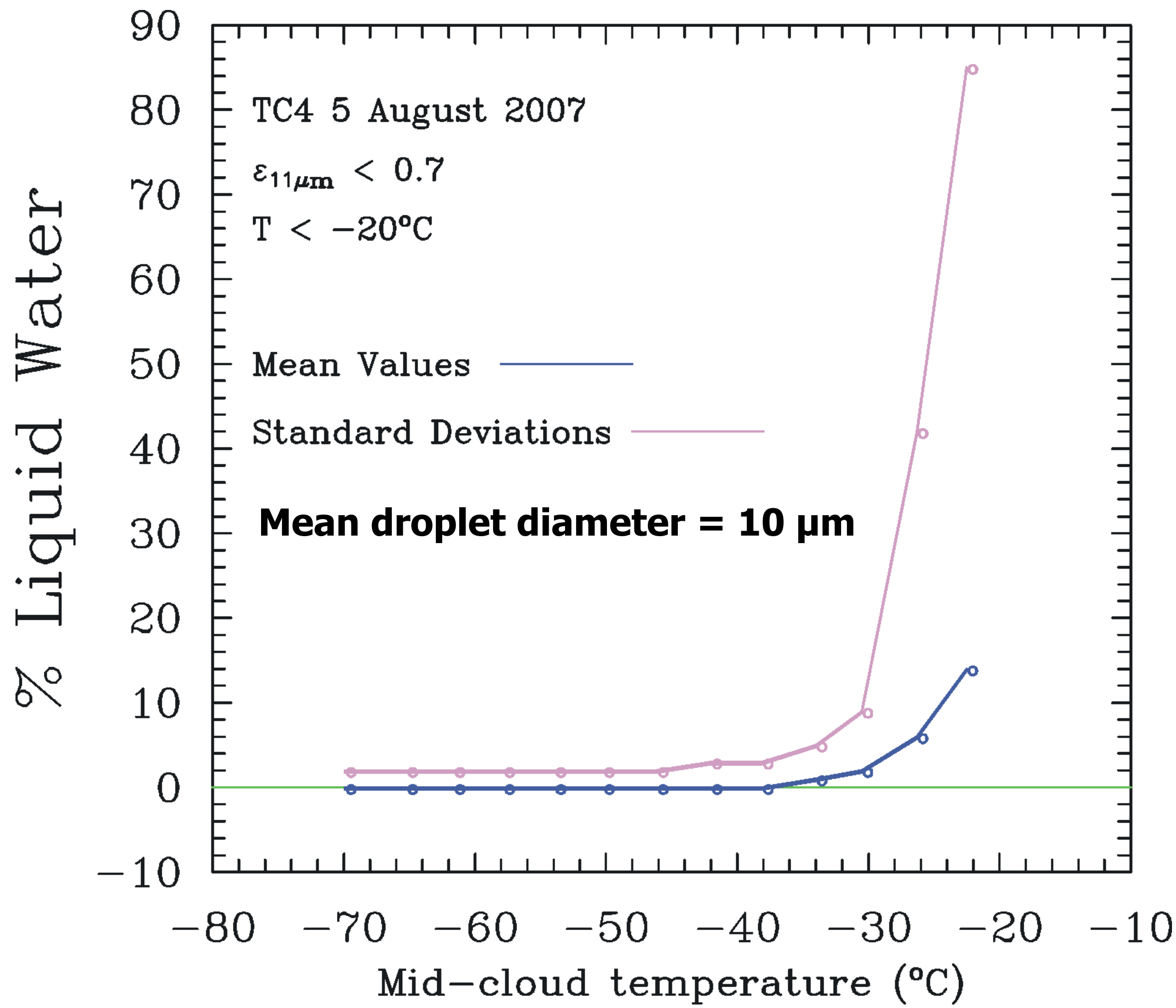
22 July Case Study Results



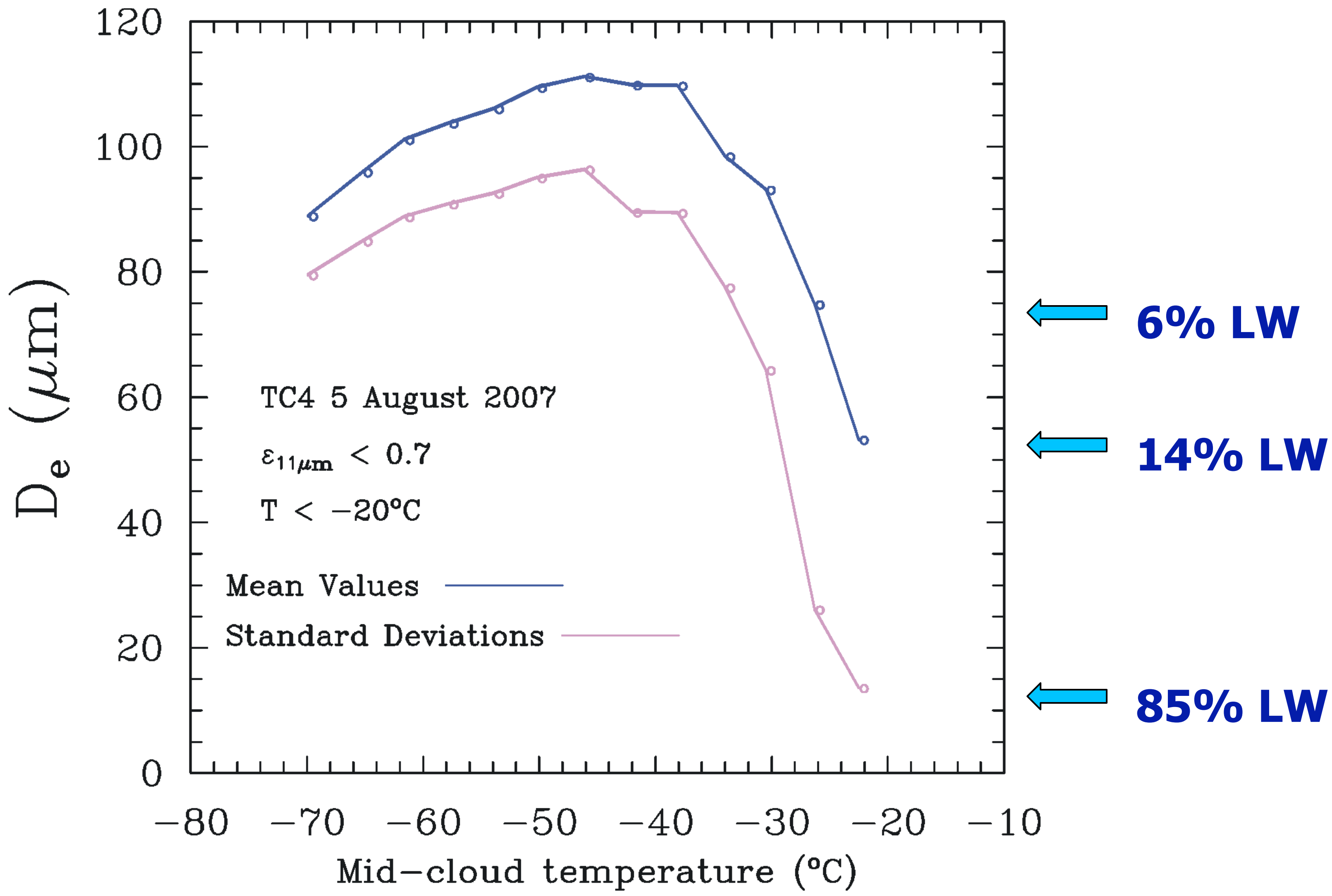


5 August Case Study Results

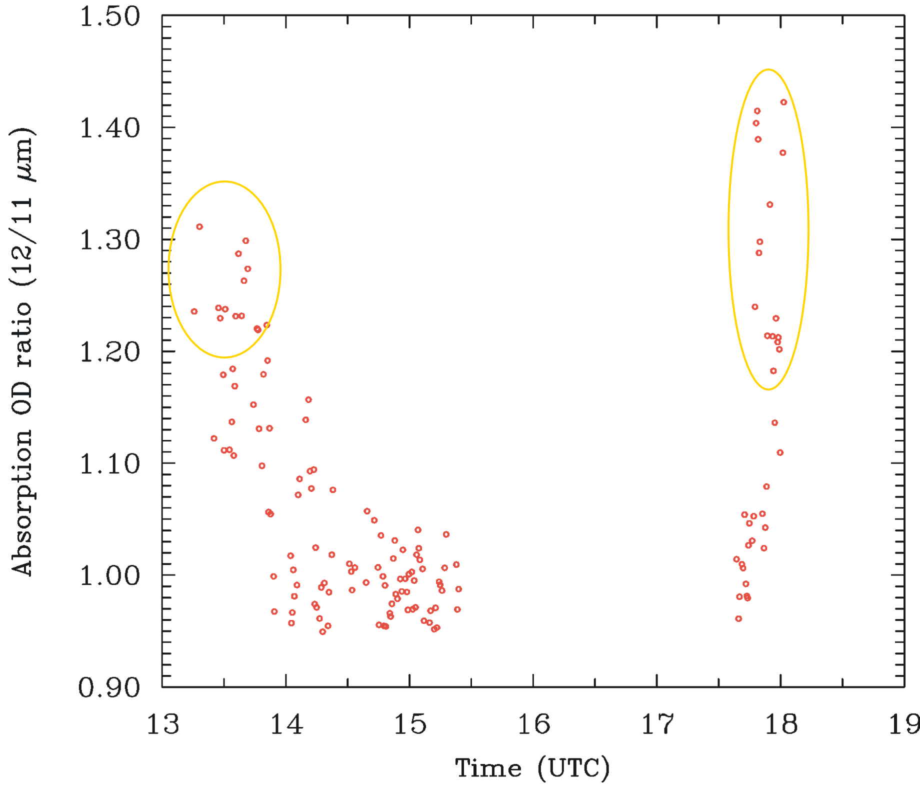




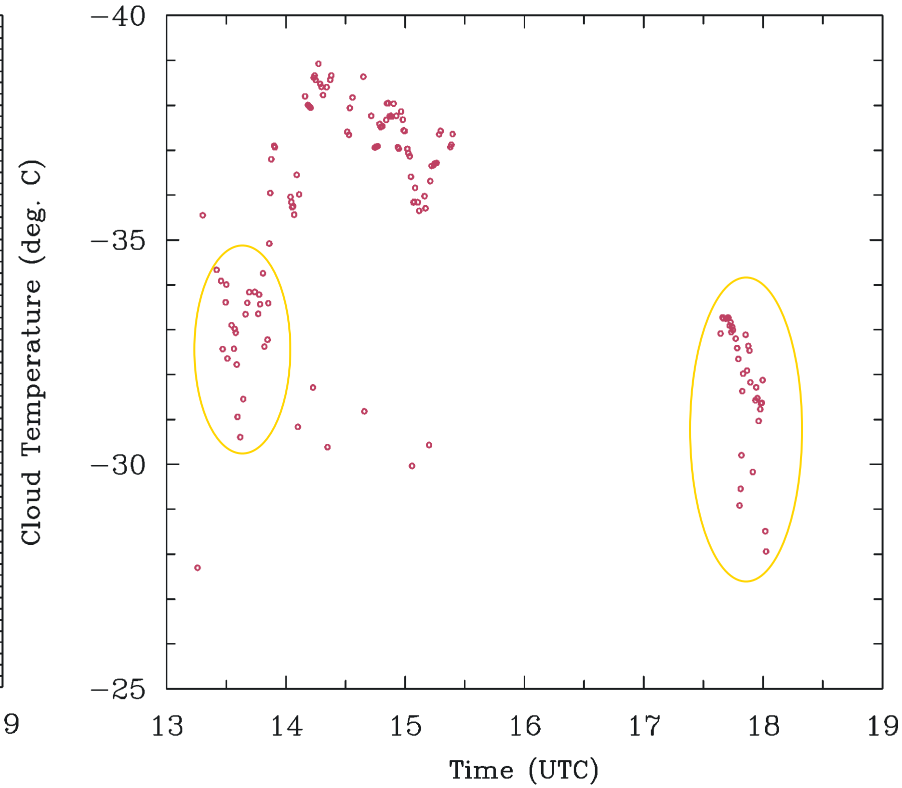
Sensitivity of D_e to % Liquid Water



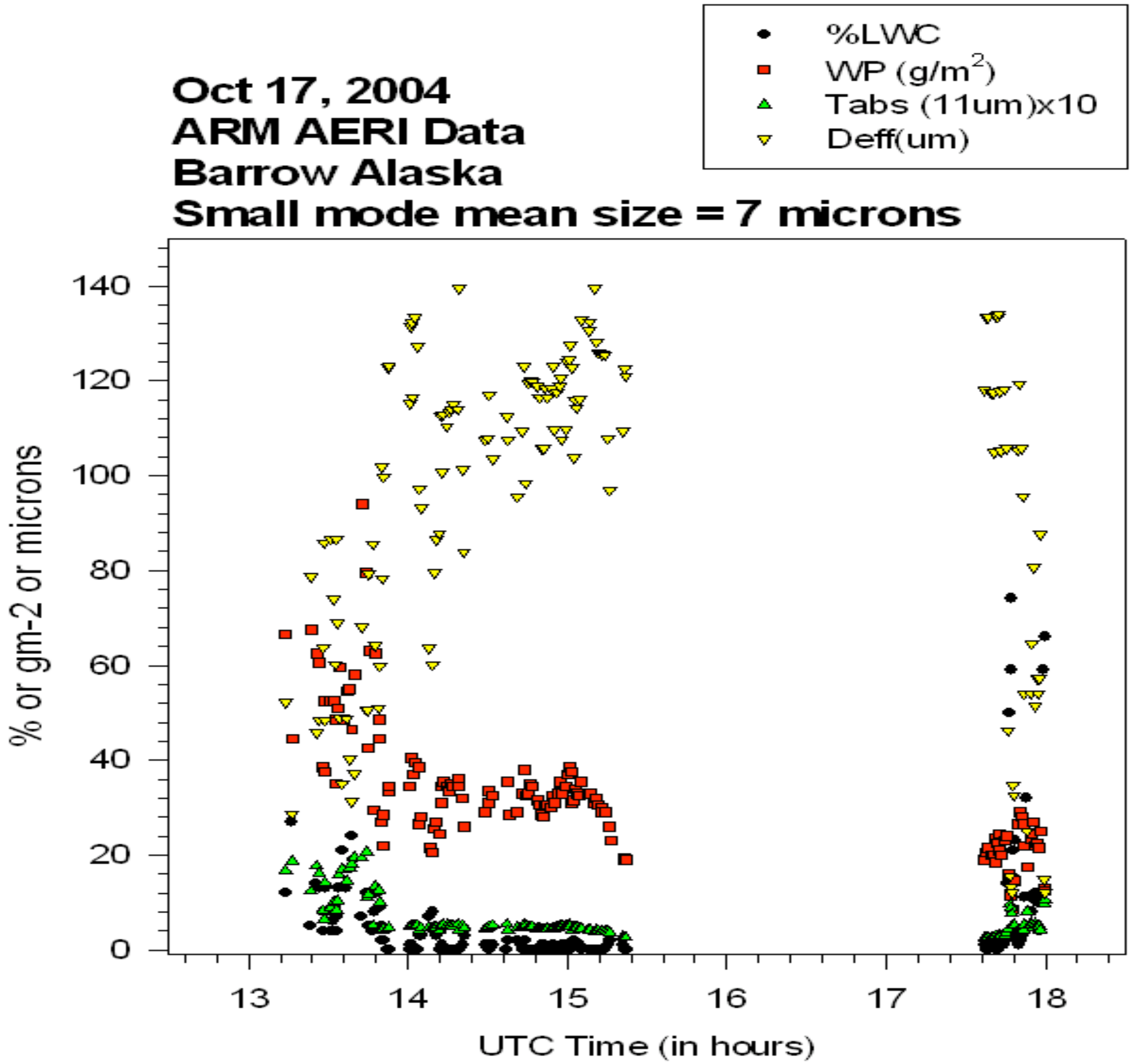
M-PACE Cirrus: Evidence of liquid water?



β as measured by the AERI instrument vs. time for 17 Oct. 2004 case study.



Mean cloud temperature (°C) vs. time for the same case study.



AERI retrieval for M-PACE cirrus case study

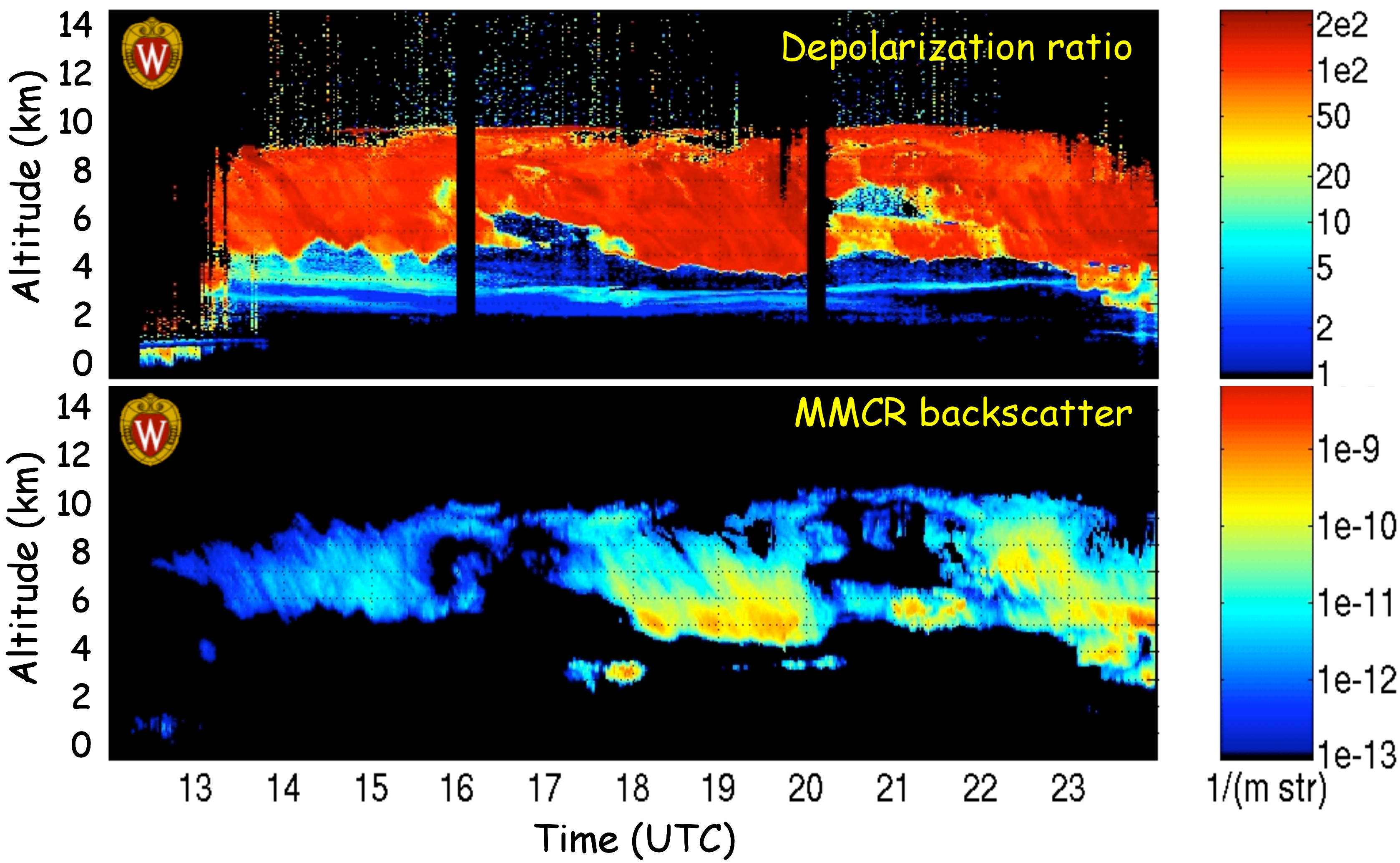


Figure 9. Lidar depolarization ratios and MMCR backscatter for the M-PACE 17 October case study at Barrow, Alaska, courtesy of Ed Eloranta (Univ. of Madison, WI).

Summary

1. The 12/11 μm absorption optical depth ratio (β) exhibits quasi-constant behavior for ice clouds but is sensitive to the presence of a liquid phase, making it a possible metric for estimating the liquid water fraction for LW < 50%.

2. The increase in β can be interpreted using a microphysics/optical property algorithm that attributes liquid water to the small mode of a bimodal PSD.

3. The retrieval of %LW is sensitive to the mean droplet diameter, but the dispersion of β might define this value.

4. Evidence of low levels of liquid water were found in single-layer tropical ice clouds where $-35\ ^{o}C < T < -20\ ^{o}C$, as well as for an M-PACE cirrus case study. Low LW levels greatly affect the overall D_e and optical properties.

5. It is suggested that ice clouds warmer than $-36\ ^{o}C$ be better characterized regarding a possible liquid fraction.

From Korolev et al. 2003, QJRMS

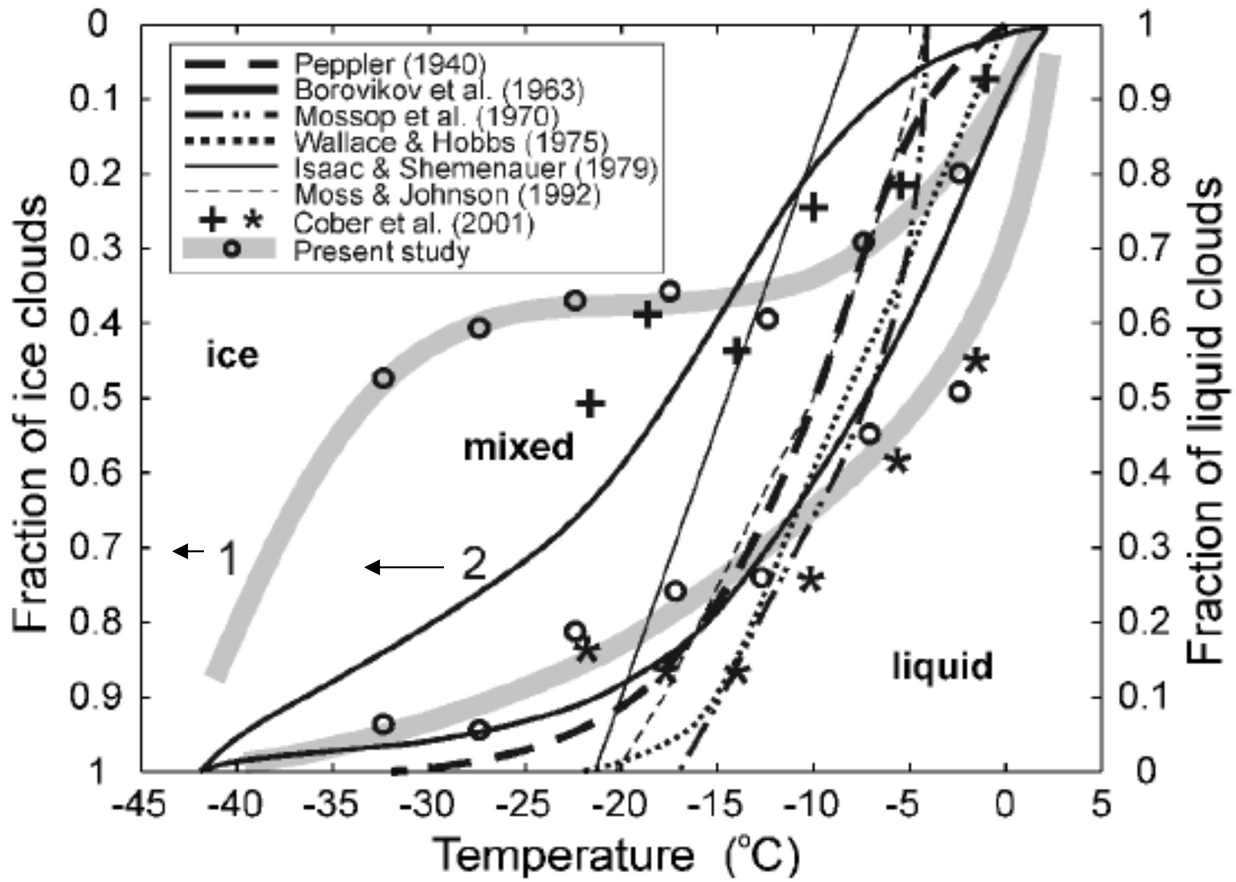
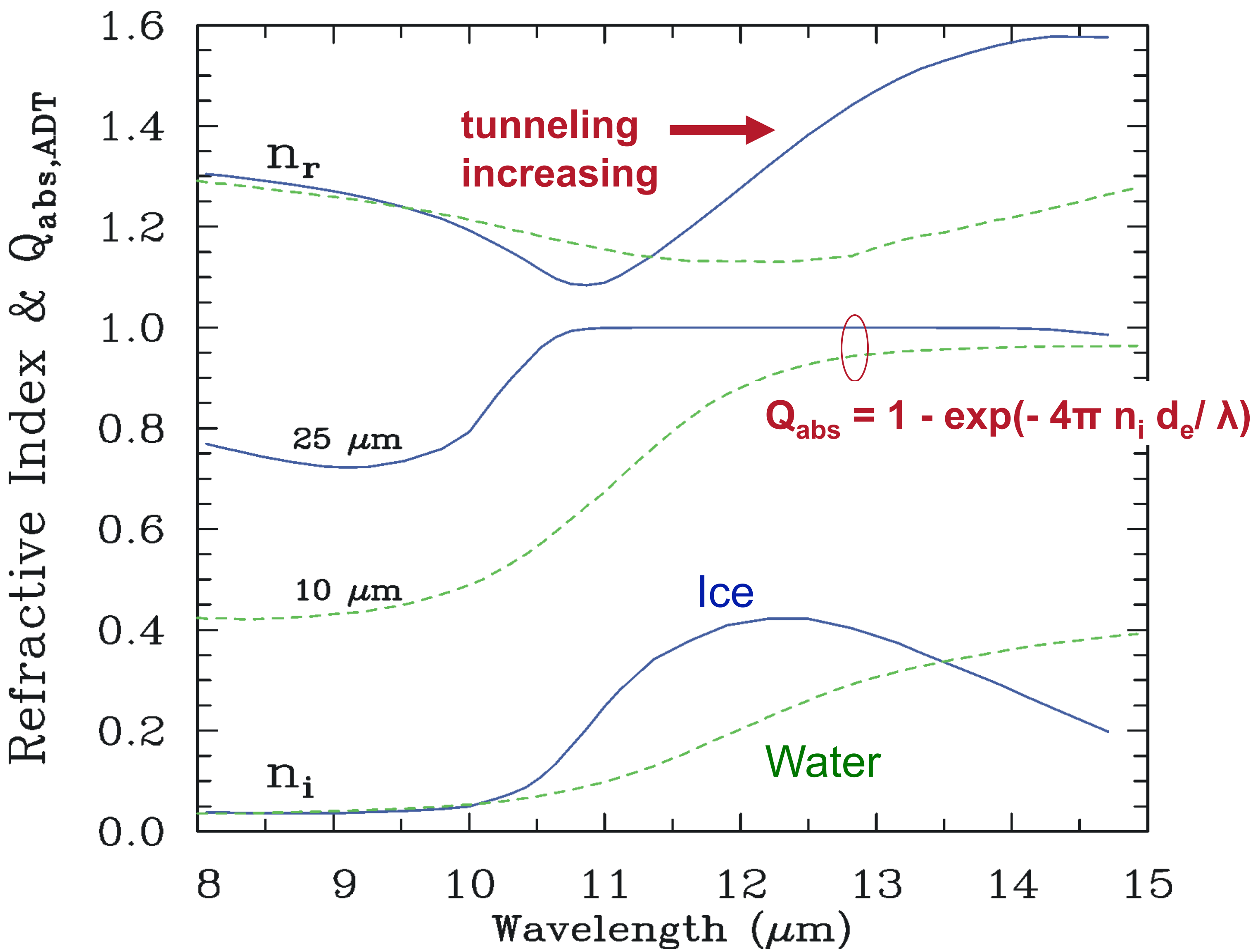
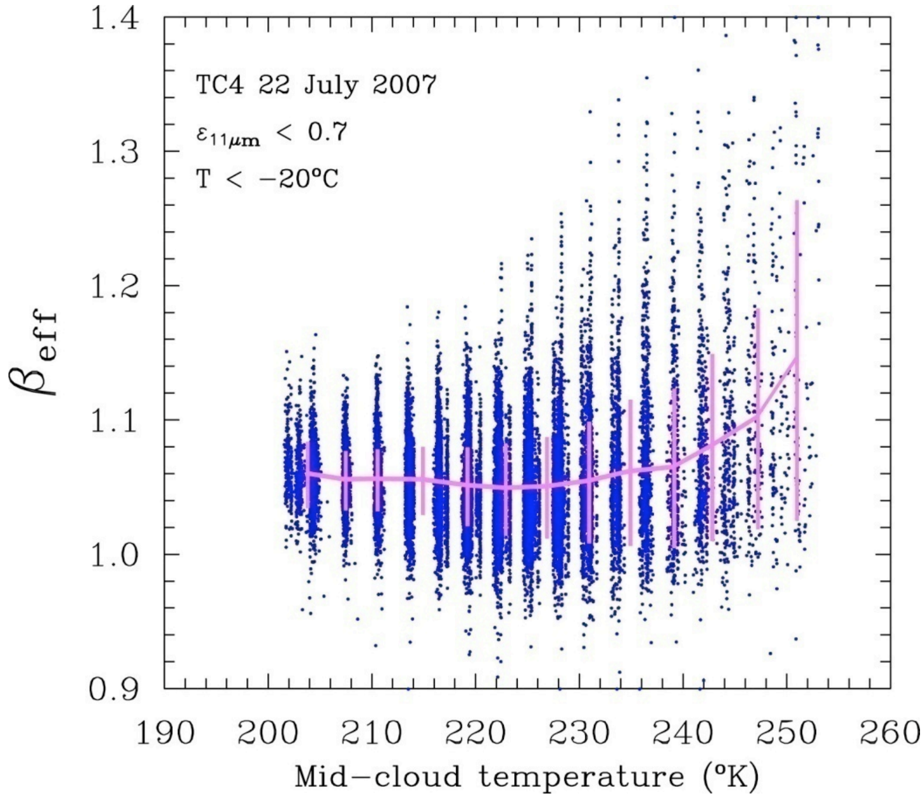


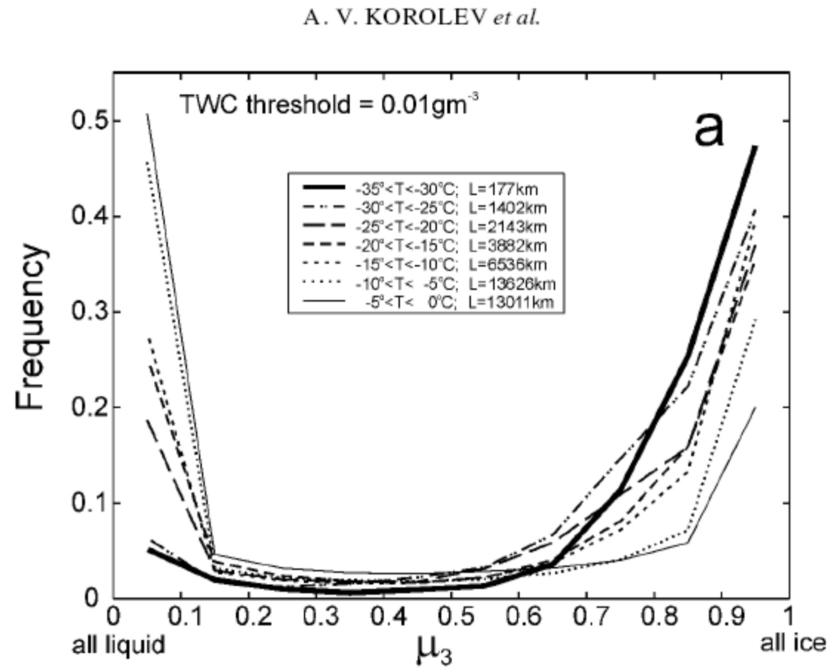
Figure 14. Comparison of fraction of ice , mixed- and liquid-clouds from the present and previous studies. Note that the left-hand and right-hand y−axes are in opposing senses. Lines labelled 1 and 2 should be referred to the left-hand axis and all other curves to the right-hand axis.

Wavelength dependence of tunneling

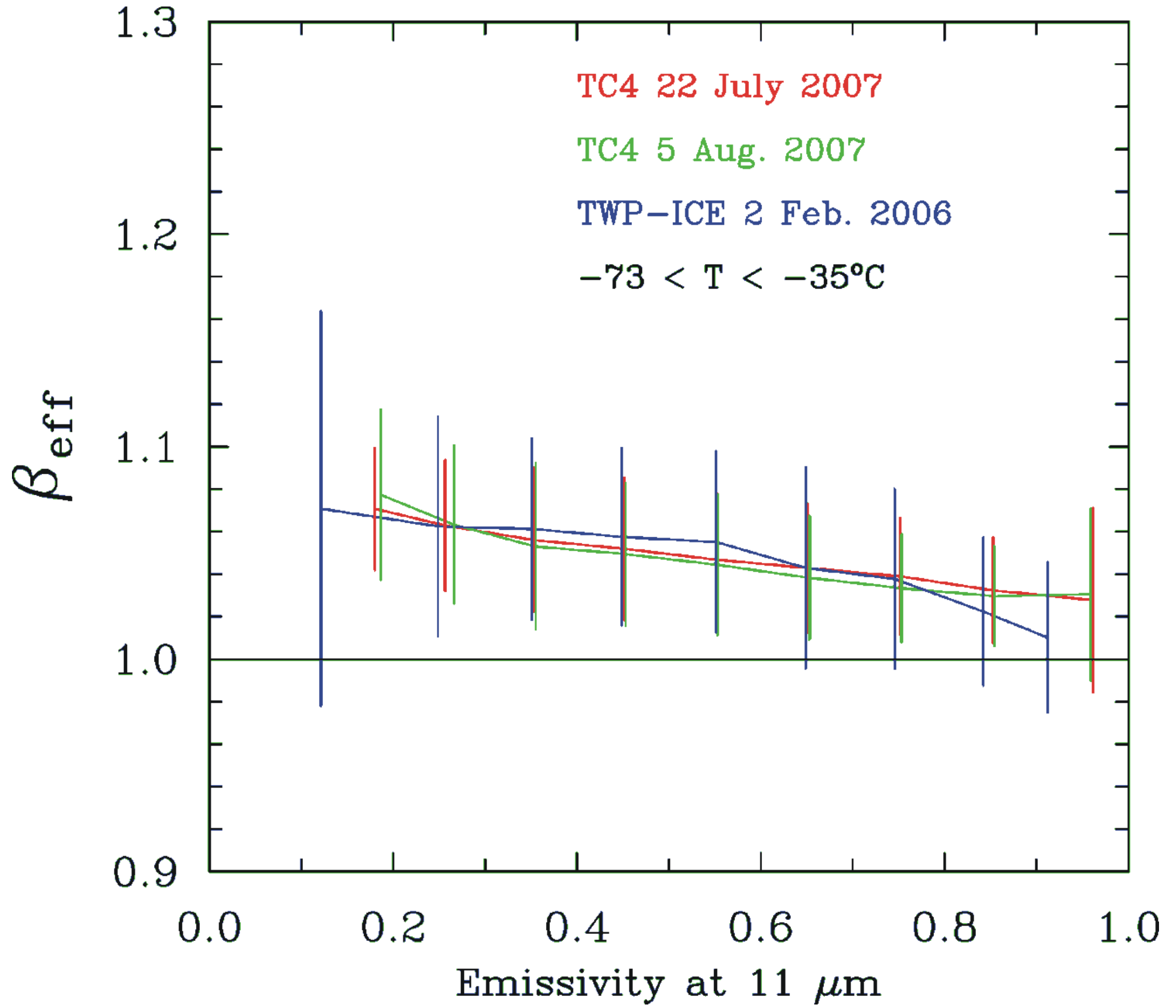


Dispersion of β at warmer temperatures appears similar to frequency distribution of cloud ice fraction from Korolev et al. (2003, QJRMS)





Frequency vs.ice fraction of cloud for different temperature intervals; From Korolev et al. 2003, QJRMS.



TC4 22 July 2007
TC4 5 Aug. 2007
TWP–ICE 2 Feb. 2006
−73 < T < −35°C
β_{eff}
1.3
1.2
1.1
1.0
0.9
0.0
0.2
0.4
0.6
0.8
1.0
Emissivity at 11 μm

Calculation of ε_{eff} in Retrieval Algorithm

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

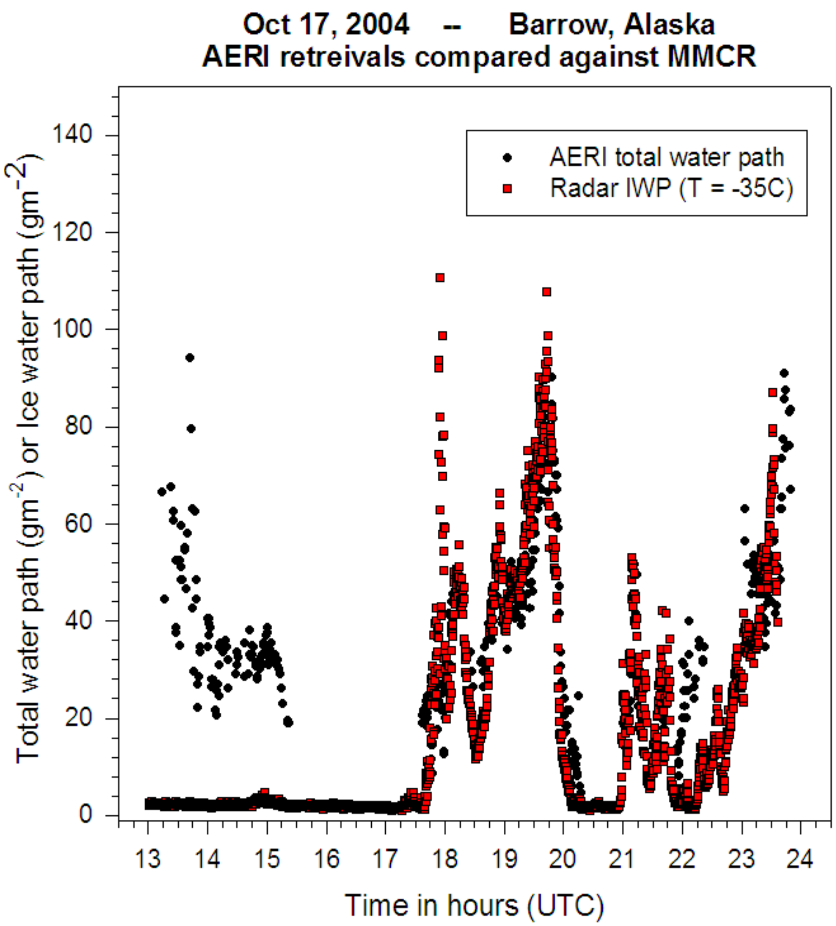
Since some scattering may occur, ε retrieved in this way is an effective emissivity, ε_{eff}, which implicitly includes the effects of scattering through its dependence on asymmetry parameter g:

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

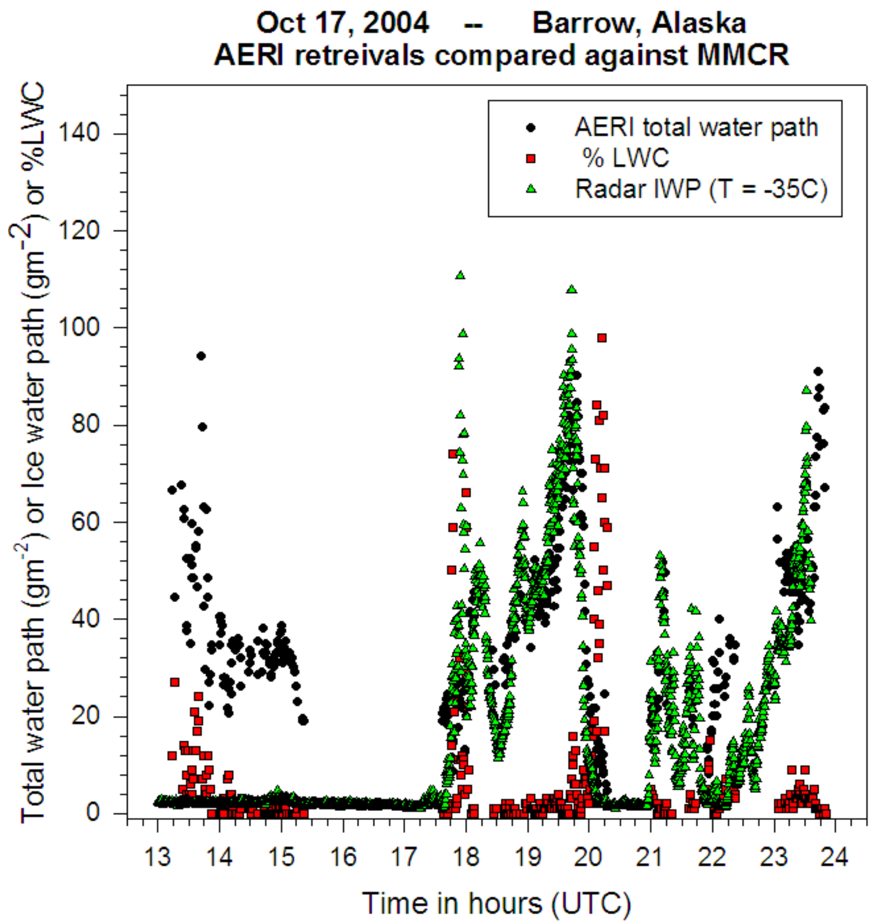
$$\beta_{eff} = Q_{abs,eff(12\ \mu m)}/Q_{abs,eff(11\ \mu m)}$$

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

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



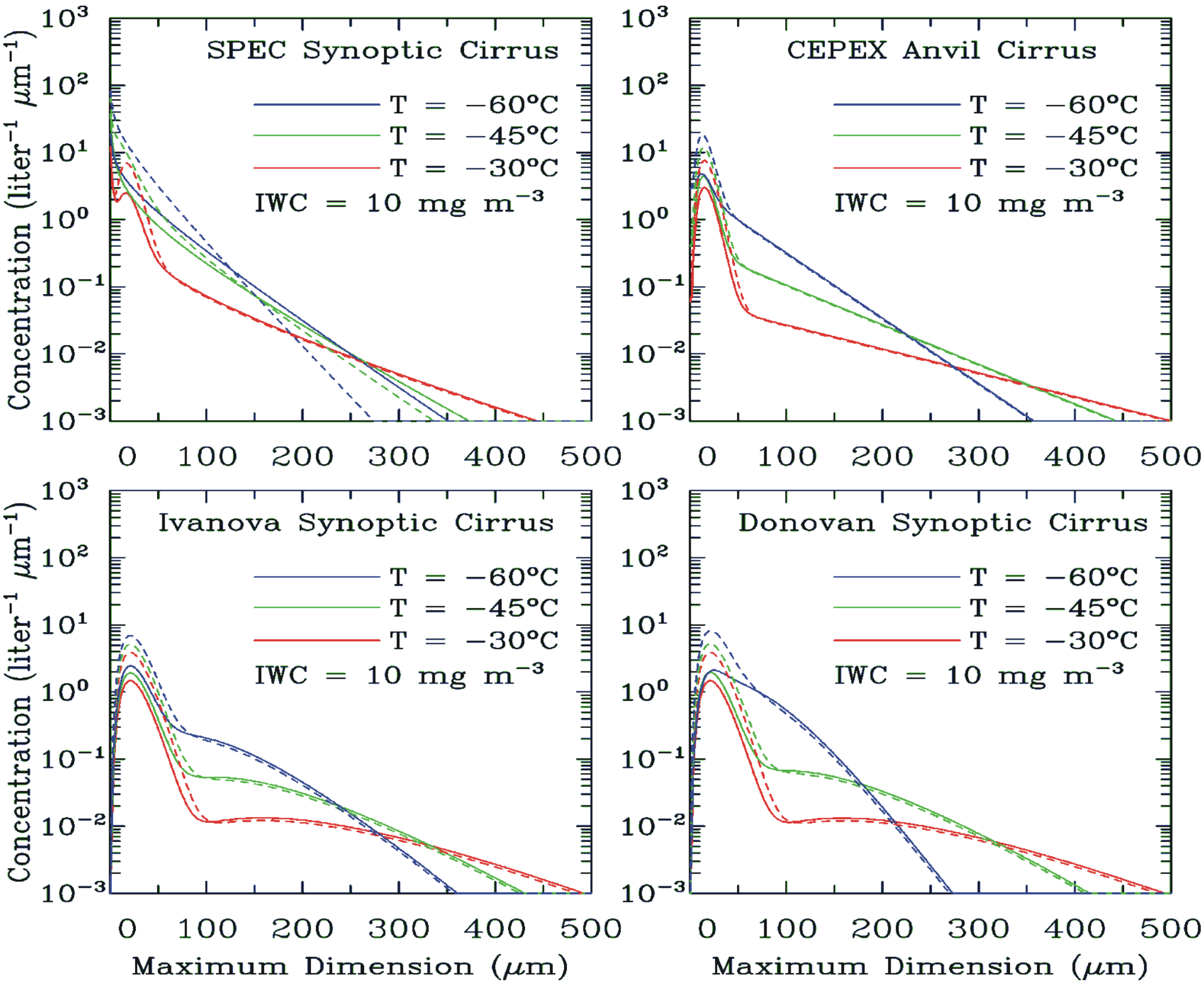
Oct 17, 2004 -- Barrow, Alaska
AERI retreivals compared against MMCR
AERI total water path
Radar IWP (T = -35C)
Total water path (gm^-2) or Ice water path (gm^-2)
Time in hours (UTC)
0
20
40
60
80
100
120
140
13
14
15
16
17
18
19
20
21
22
23
24



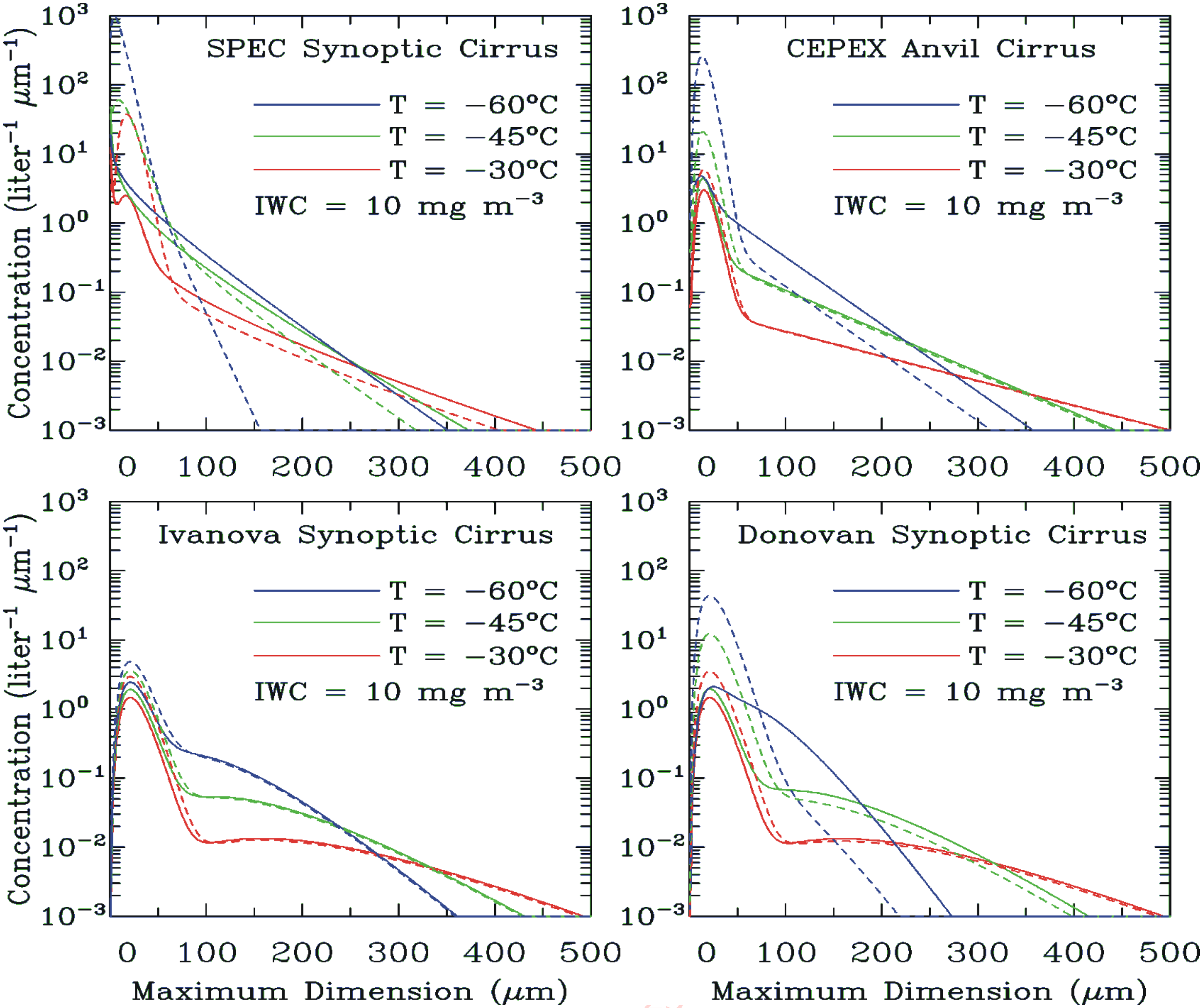
Oct 17, 2004 -- Barrow, Alaska
AERI retreivals compared against MMCR
AERI total water path
% LWC
Radar IWP (T = -35C)
Total water path (gm^-2) or Ice water path (gm^-2) or %LWC
Time in hours (UTC)
0
20
40
60
80
100
120
140
13
14
15
16
17
18
19
20
21
22
23
24

AERI

Retrieved PSD having mean and maximum small crystal concentrations



Comparison of original PSD scheme (dashed) with retrieved PSD (solid)



Cloud Optical Properties Depend on the Ice Crystal Mass- and Projected Area-Dimension Relationships That Characterize the PSD

1. Mass = m = αD^{β}
2. Projected area = P = γD^{σ}

Constants giving P & m = function of temperature for mid-latitude cirrus. Based on 22 cirrus flight missions, 104 horizontal legs and 15,000 km of in-cloud sampling, and Heymsfield et al. (2007).