Satellite Remote Sensing of Liquid Water in Cold Clouds for CAM Validation

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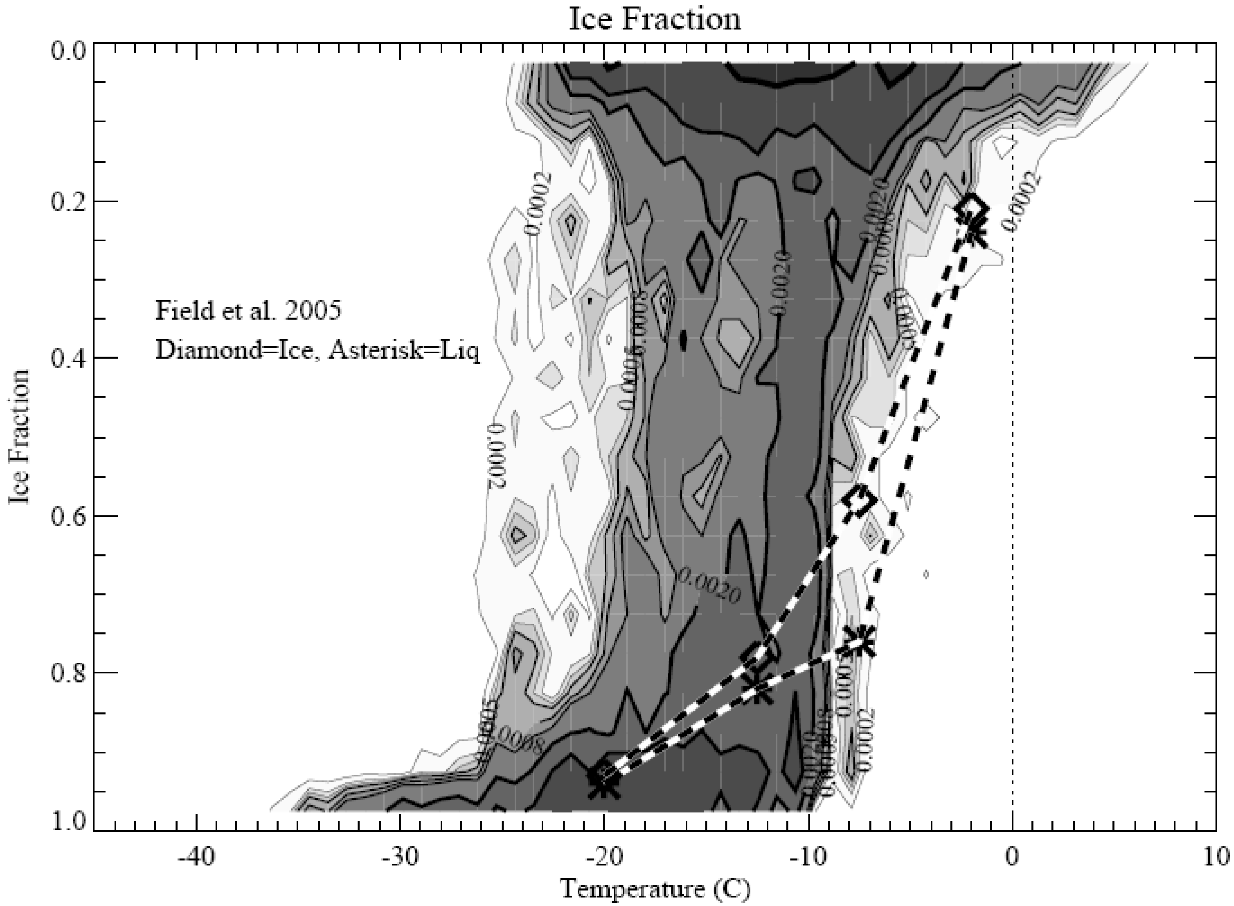


Figure 3. PDF of ice mass fraction as a function of temperature for the ICE case (black filled contours). Model output is from 1000–100hPa and 90°S–90°N. In situ observations from *Field et al.* [2005] shown for ice (diamond) and liquid (asterisk) dominated conditions. Contours are logarithmic, 3 per decade (1,2,5).

From Korolev et al. 2003, QJRMS

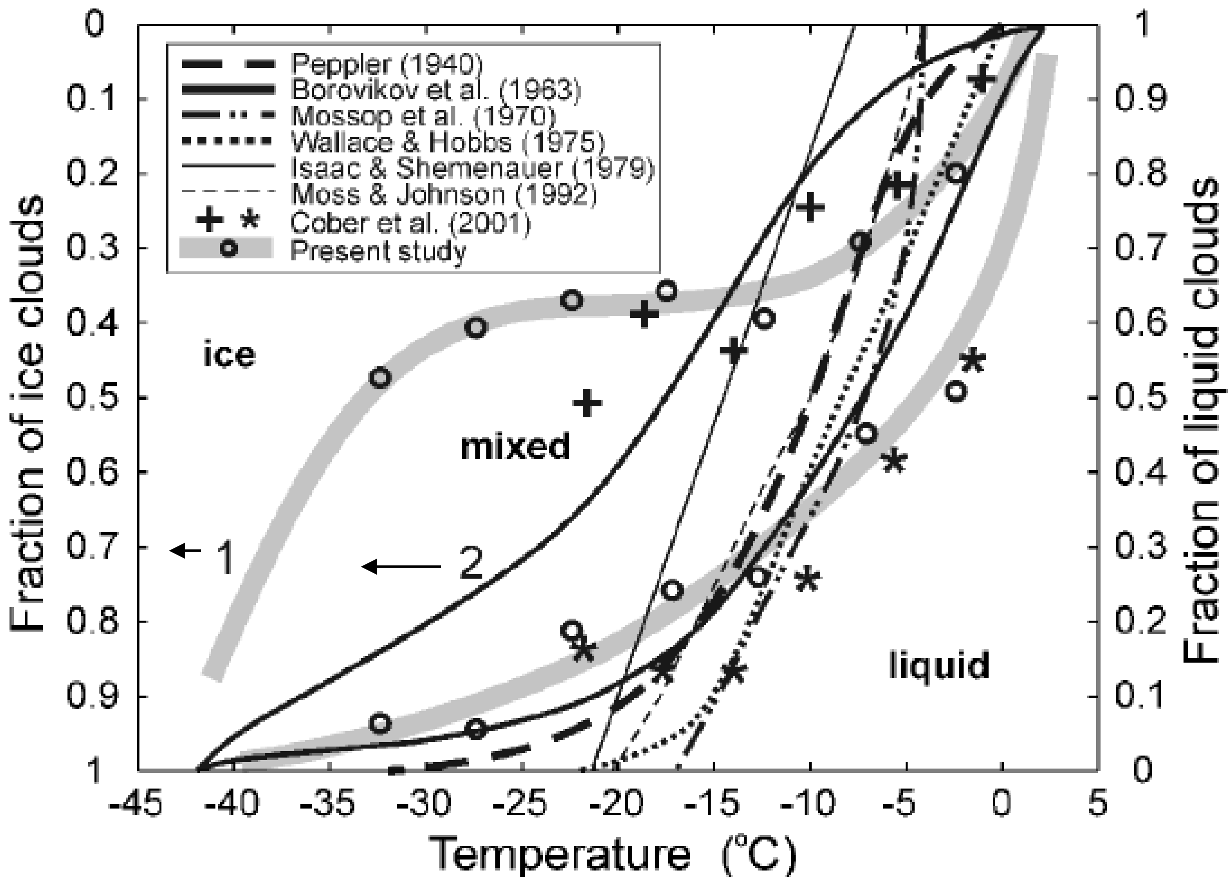


Figure 14. Comparison of fraction of ice , mixed- and liquid-clouds from the present and previous studies. Note that the left-hand and right-hand $y-$axes are in opposing senses. Lines labelled 1 and 2 should be referred to the left-hand axis and all other curves to the right-hand axis.

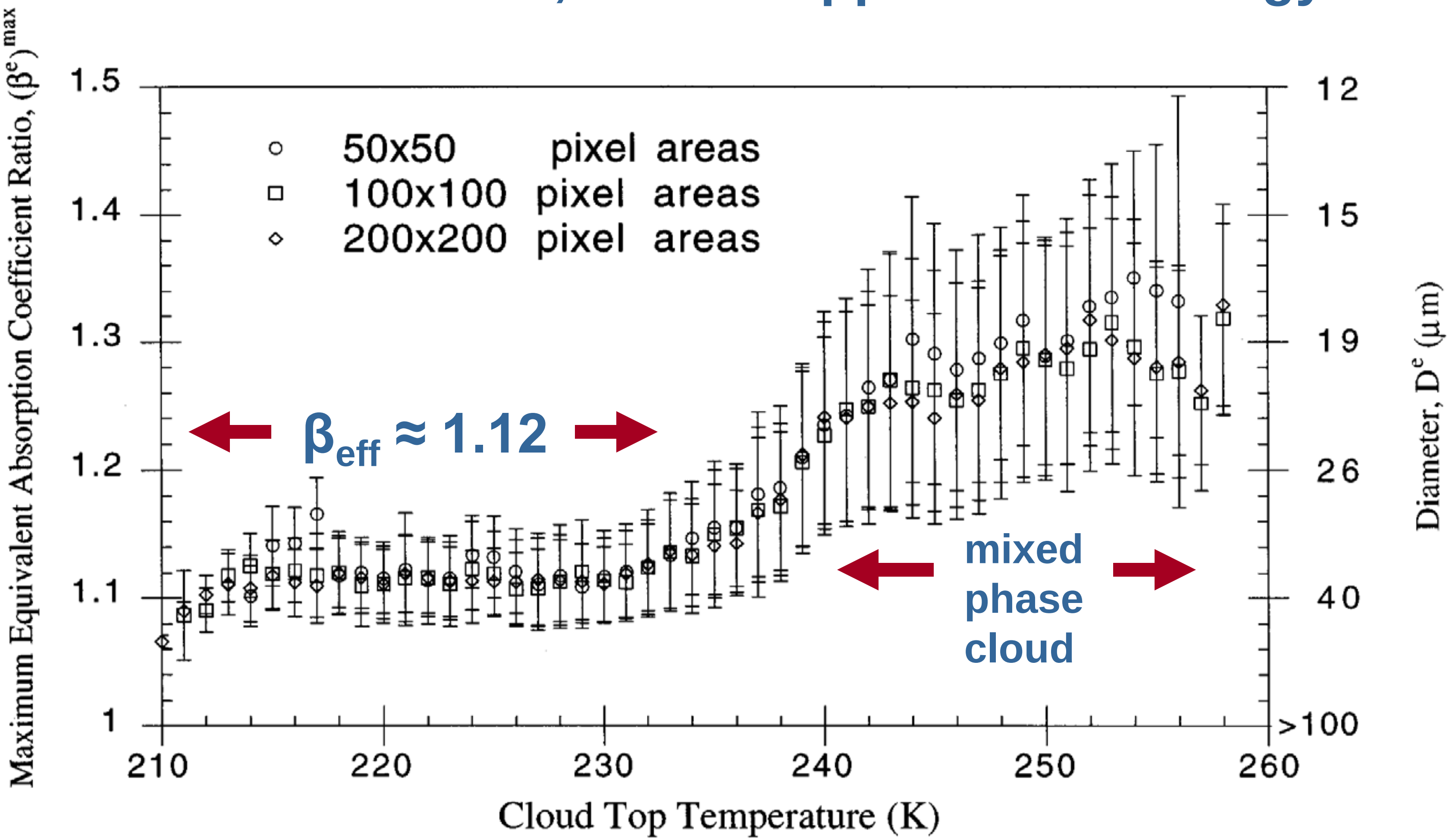
Basis for Mixed Phase Cloud Retrieval

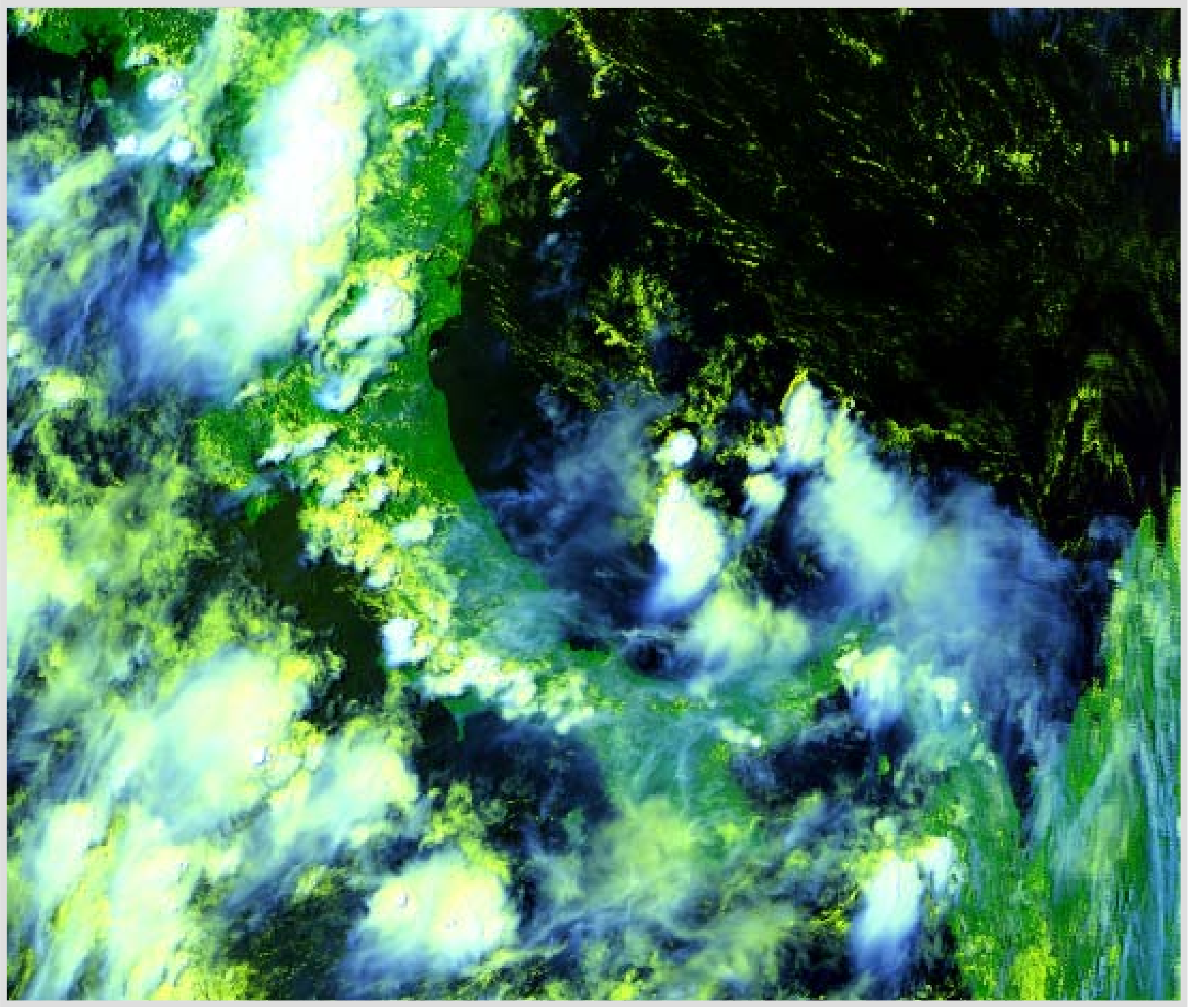
1. Use the 12/11 μm absorption optical depth ratio, β, to estimate the %LW.

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

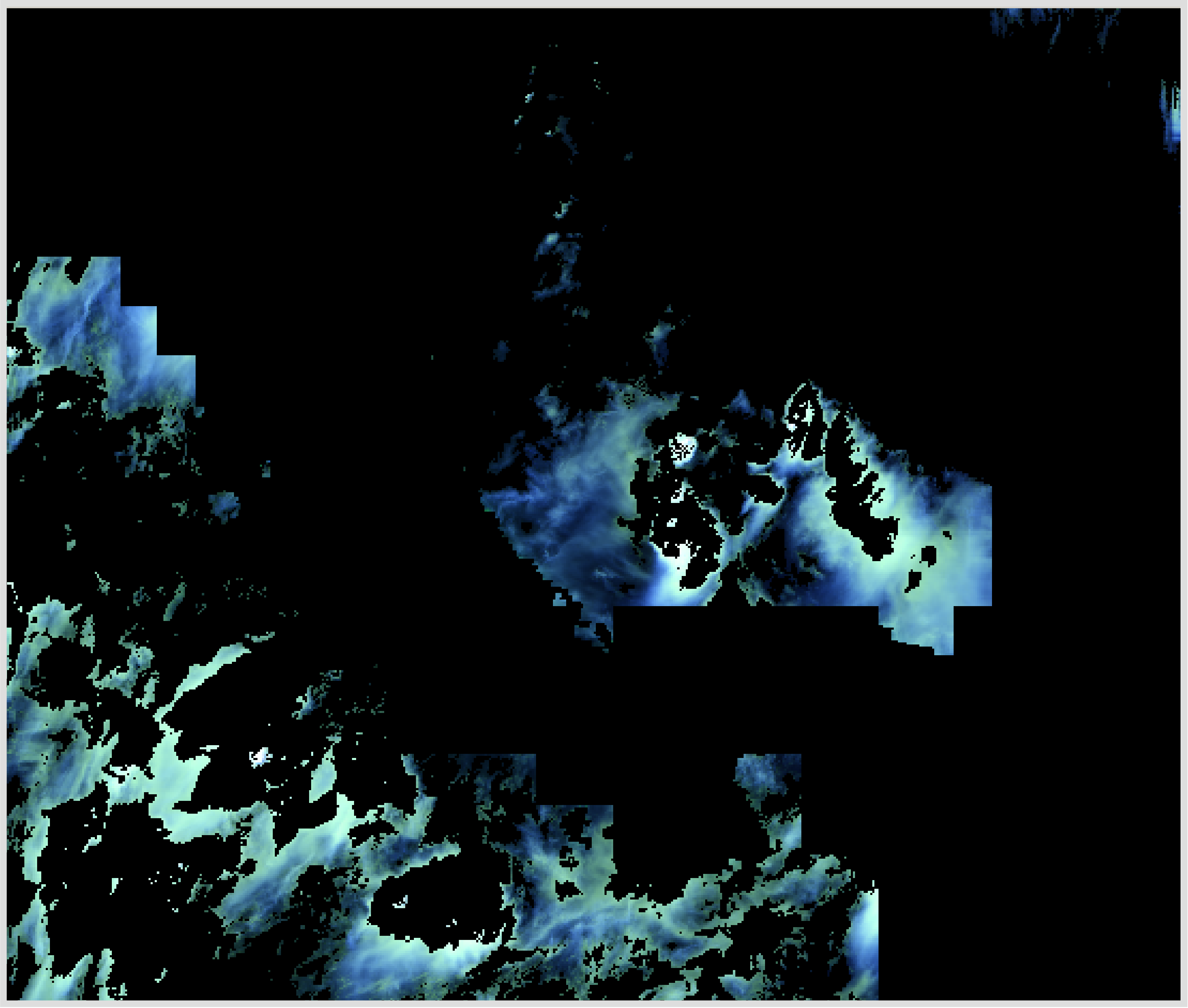
3. The mean LW fraction can be estimated from the mean departure of β from its ice threshold value.

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

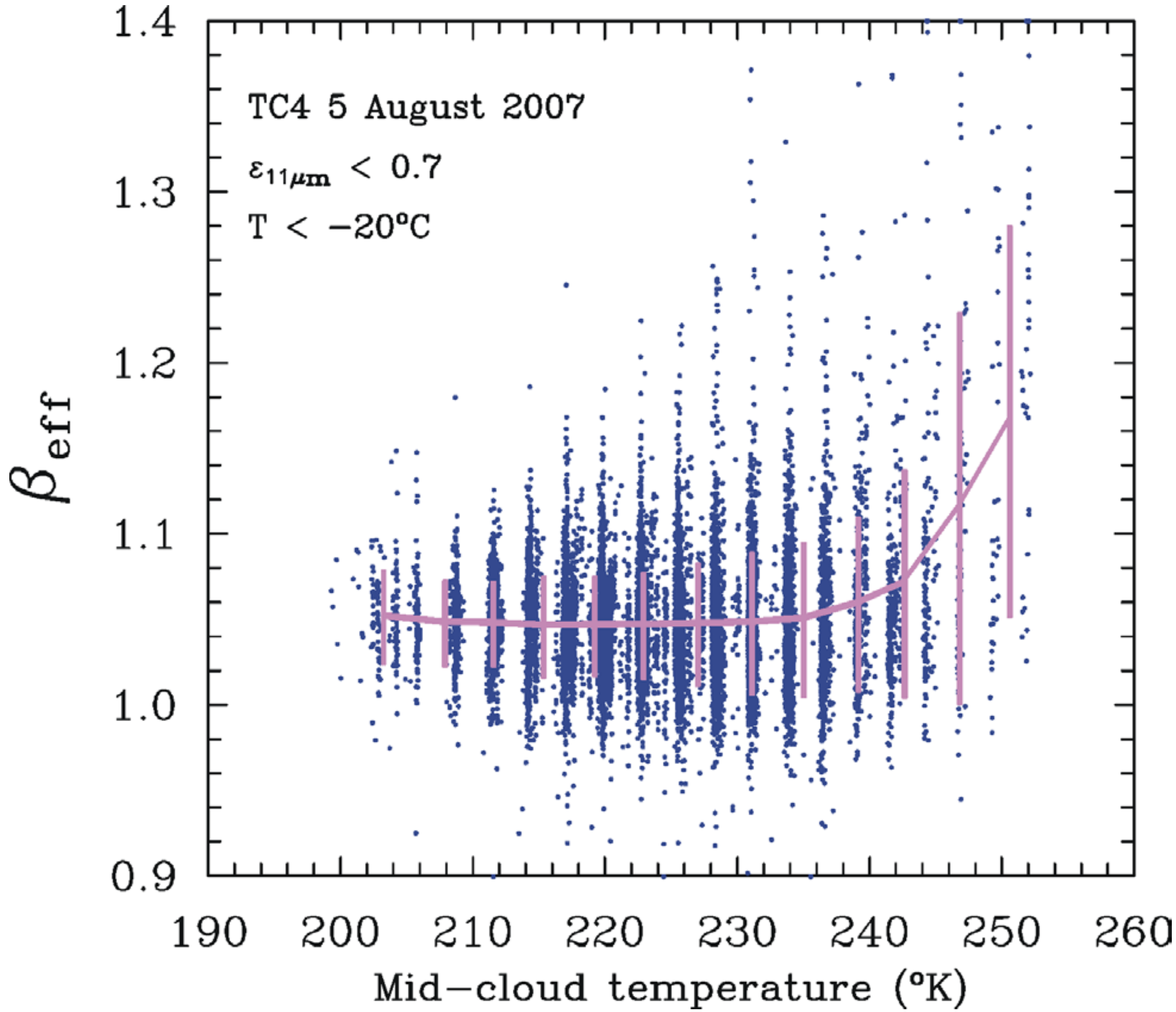




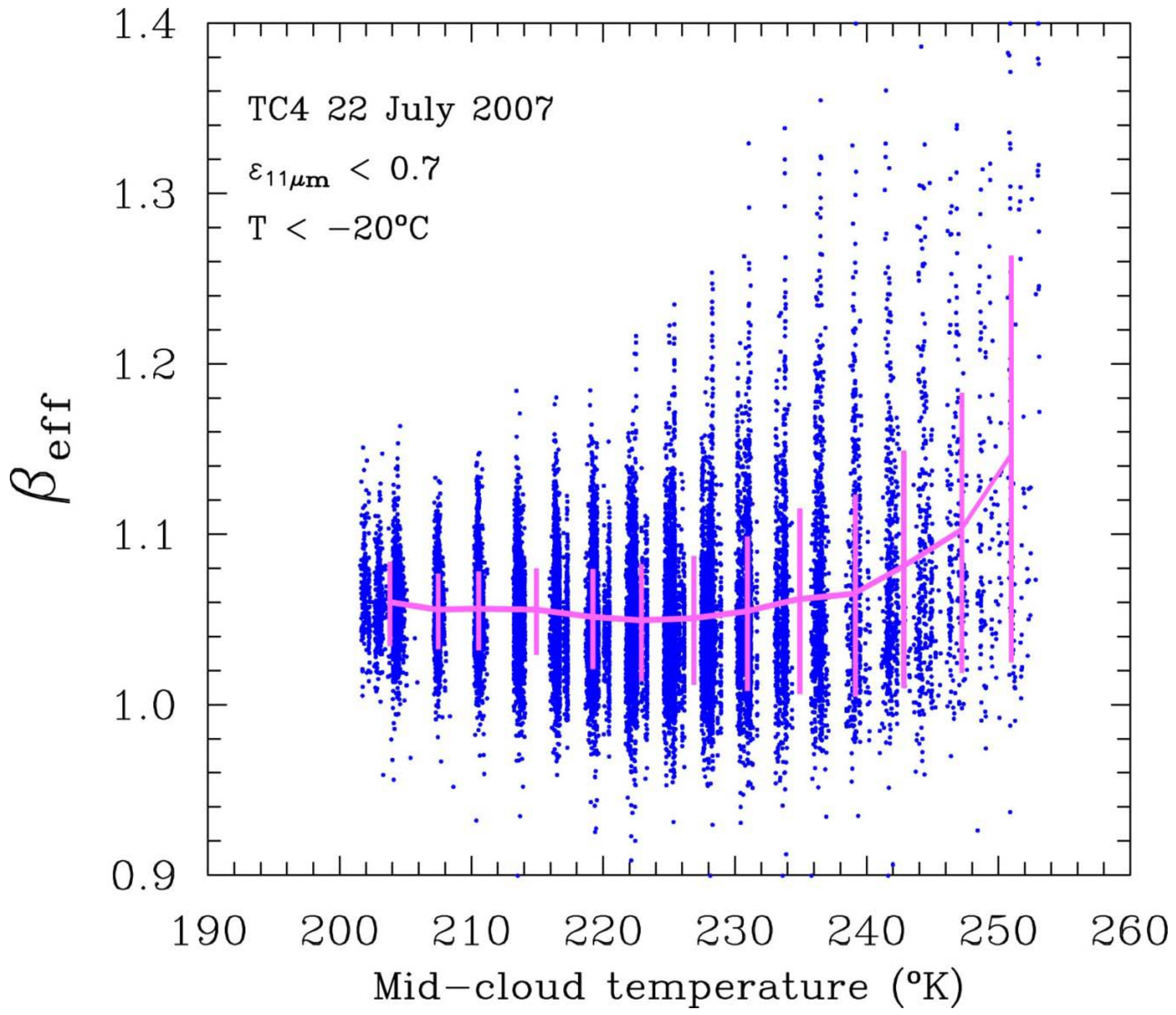
0.63 0.86 11.02 um Color composite 1900 UTC 05 Aug 07

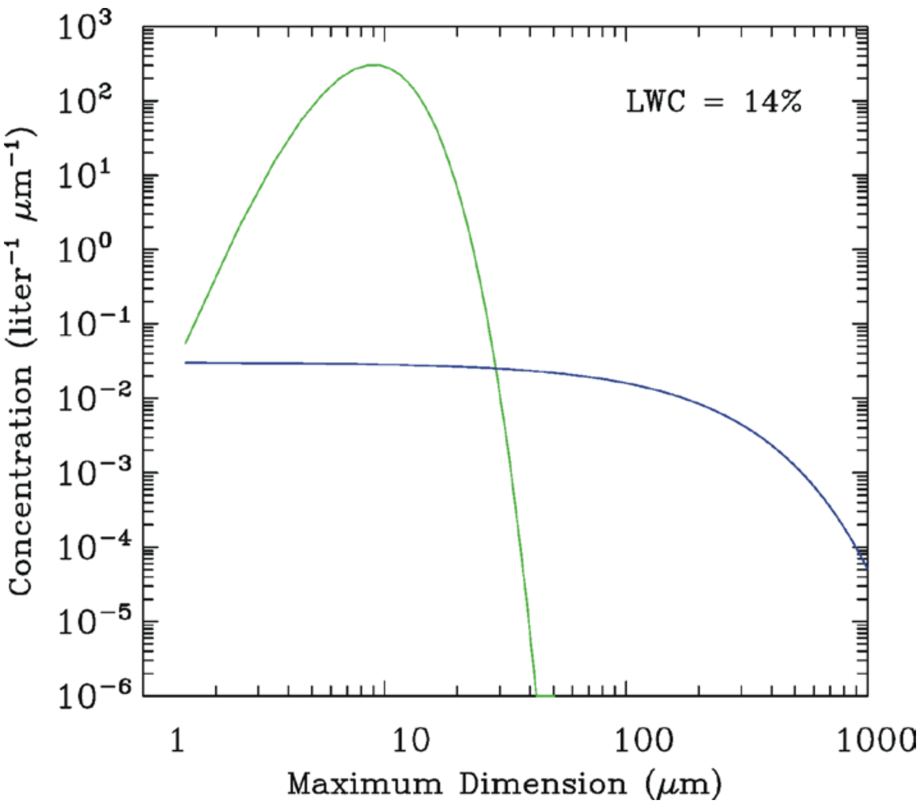


Cirrus-only over-ocean pixels



TC4 5 August 2007
$\varepsilon_{11\mu m}$ < 0.7
T < −20°C
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)


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



Procedure:

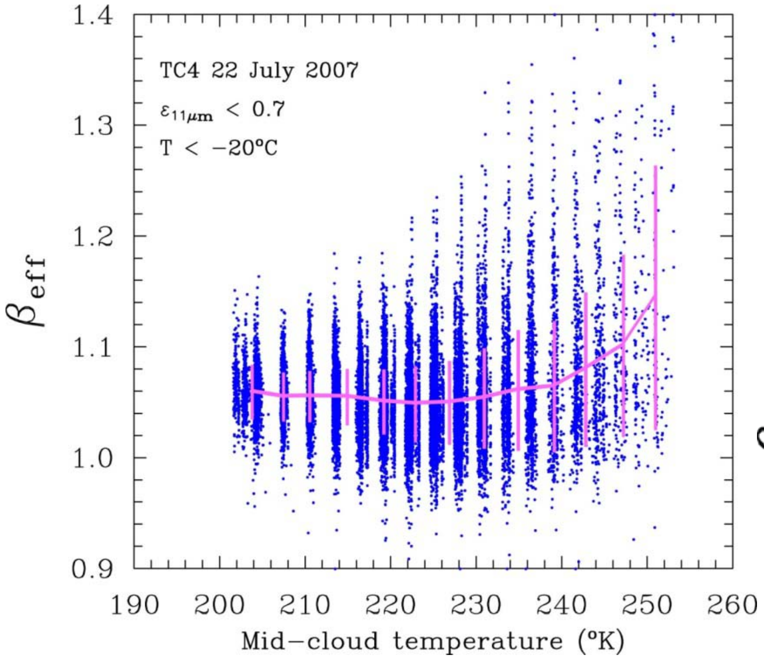
1. Use tropical anvil PSD scheme for ice portion & a representative mean diameter & dispersion param. for liquid portion of PSD.

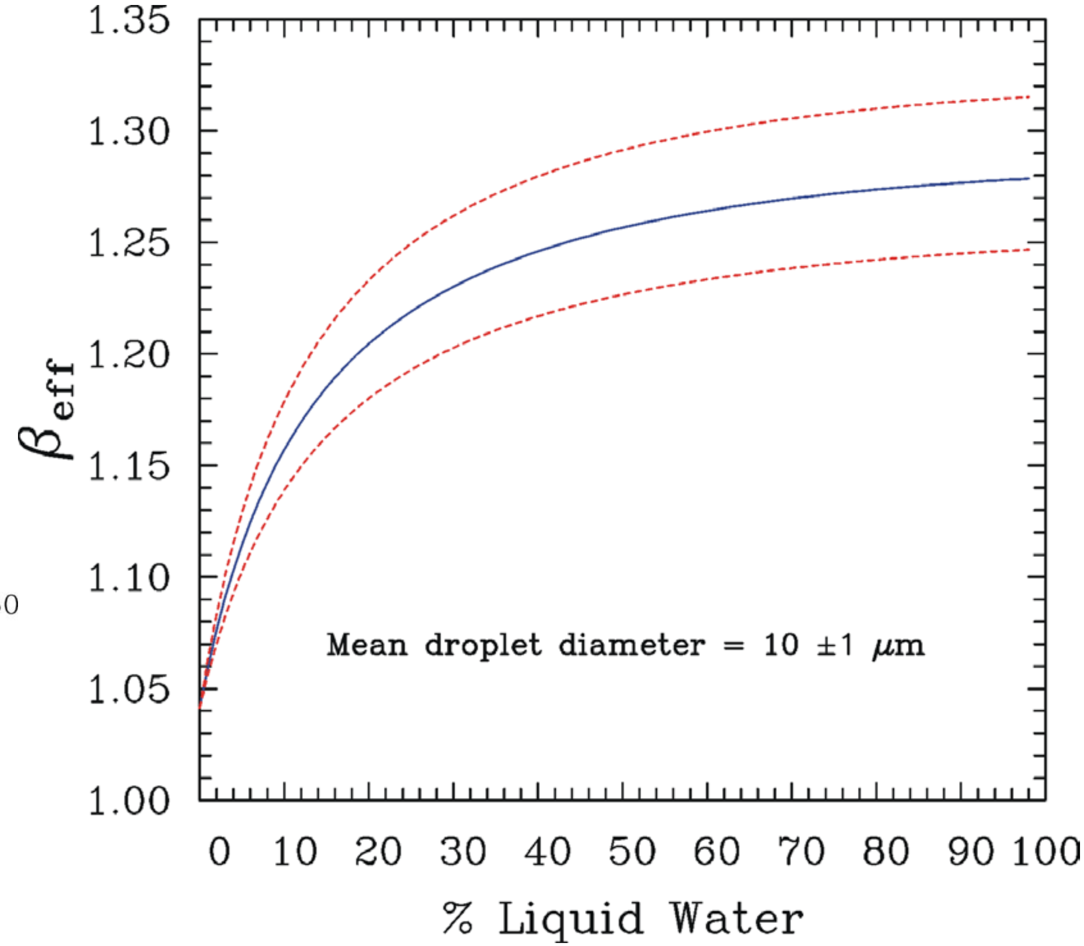
2. Increase LW in droplet PSD until observed and predicted β_{eff} match.
- Account for changes in n_r / n_i

Evaluate Uncertainties:

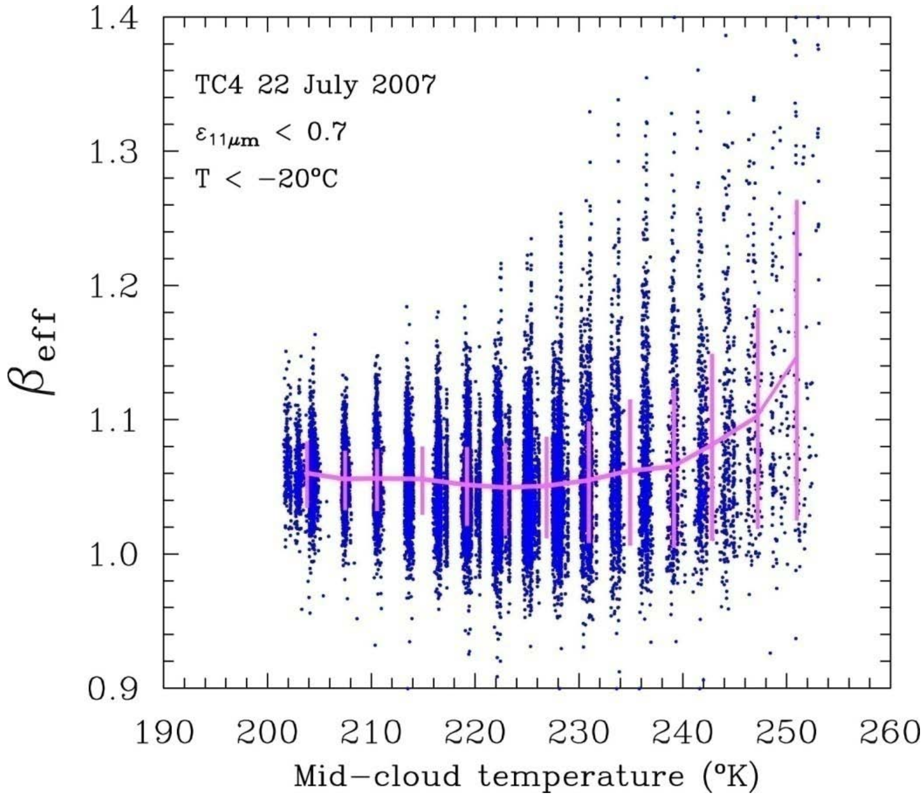
1. **Mean droplet size**
2. **Mean ice particle size**
3. **m-D power laws for ice**
4. **Dispersion param. for ice PSD**

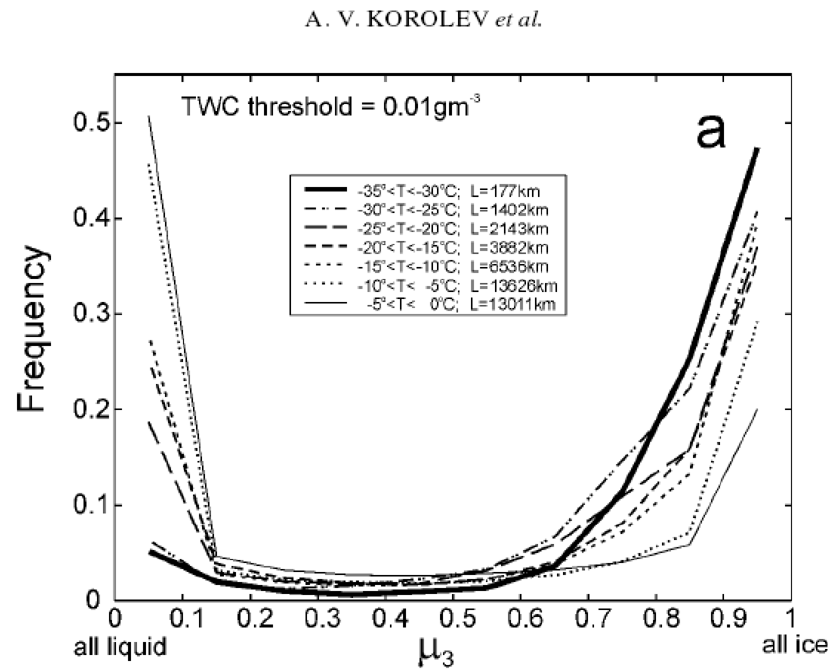
%LW is sensitive to mean droplet size, but range of β restricts the possibilities.





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.

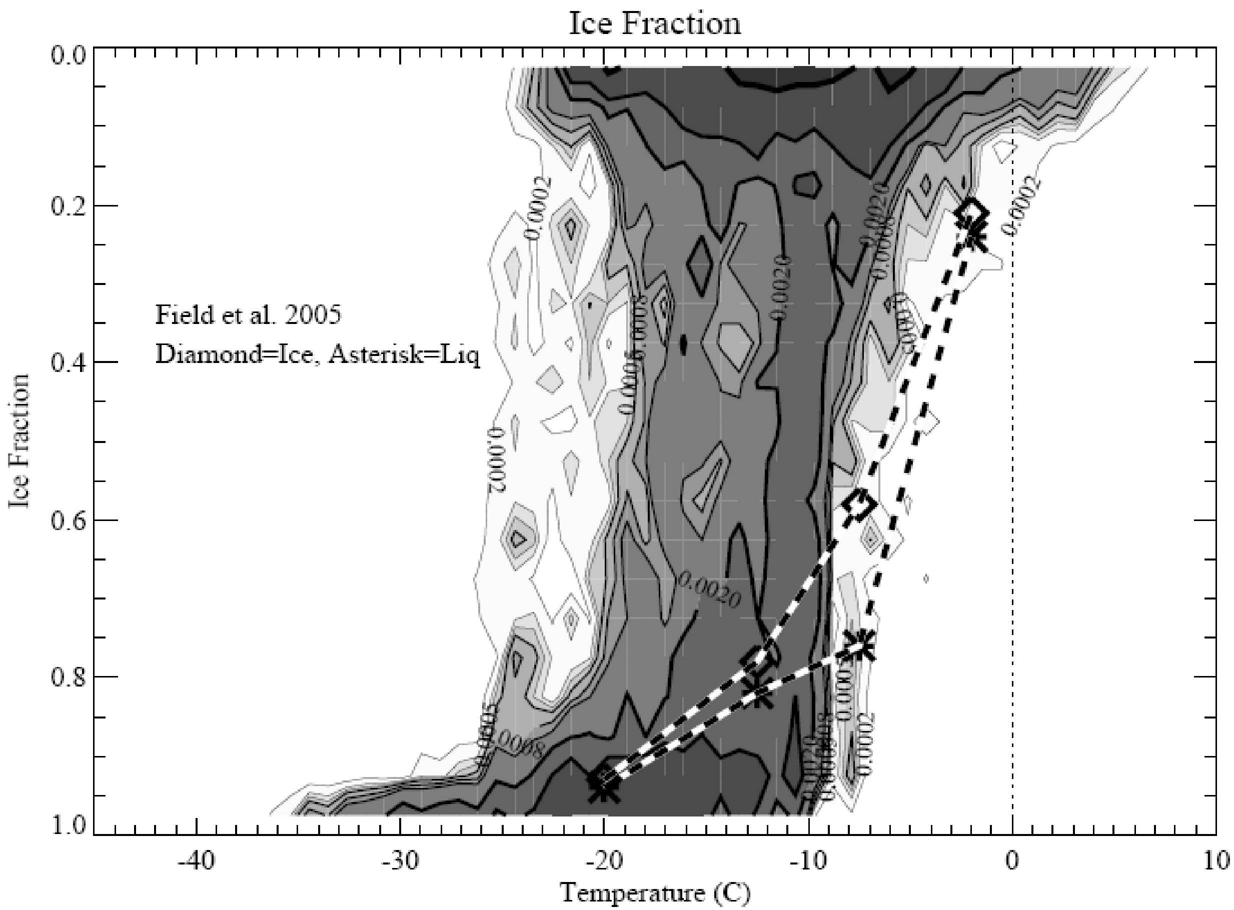
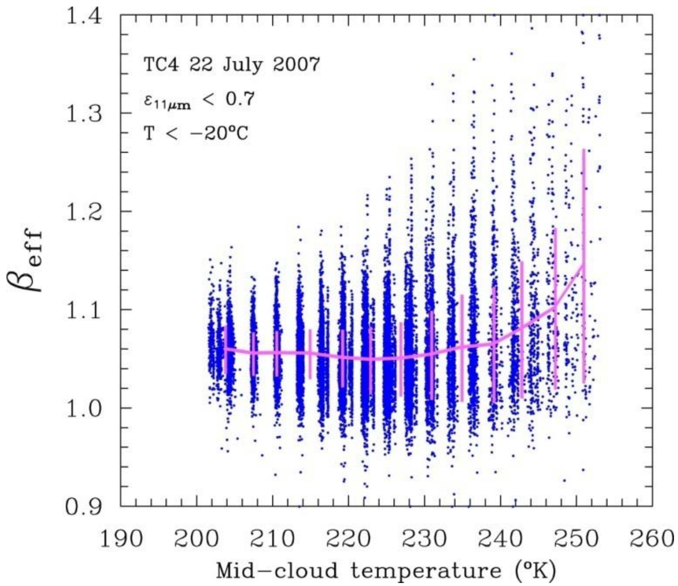
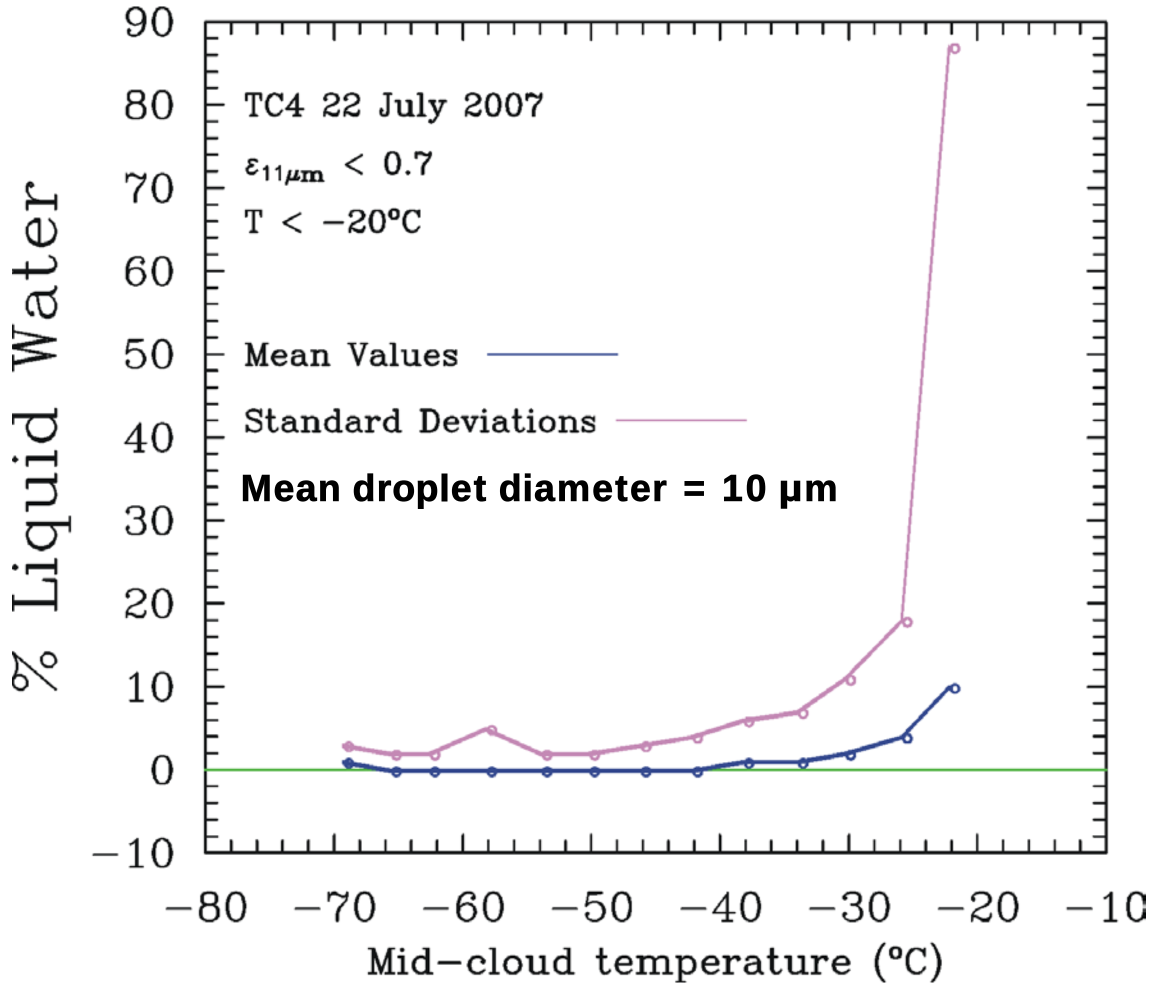


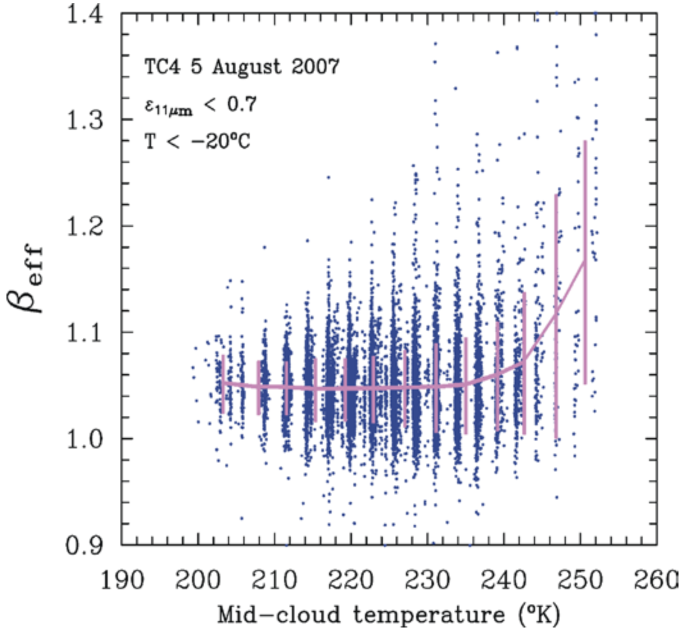
Figure 3. PDF of ice mass fraction as a function of temperature for the ICE case (black filled contours). Model output is from 1000–100hPa and 90°S–90°N. In situ observations from *Field et al.* [2005] shown for ice (diamond) and liquid (asterisk) dominated conditions. Contours are logarithmic, 3 per decade (1,2,5).

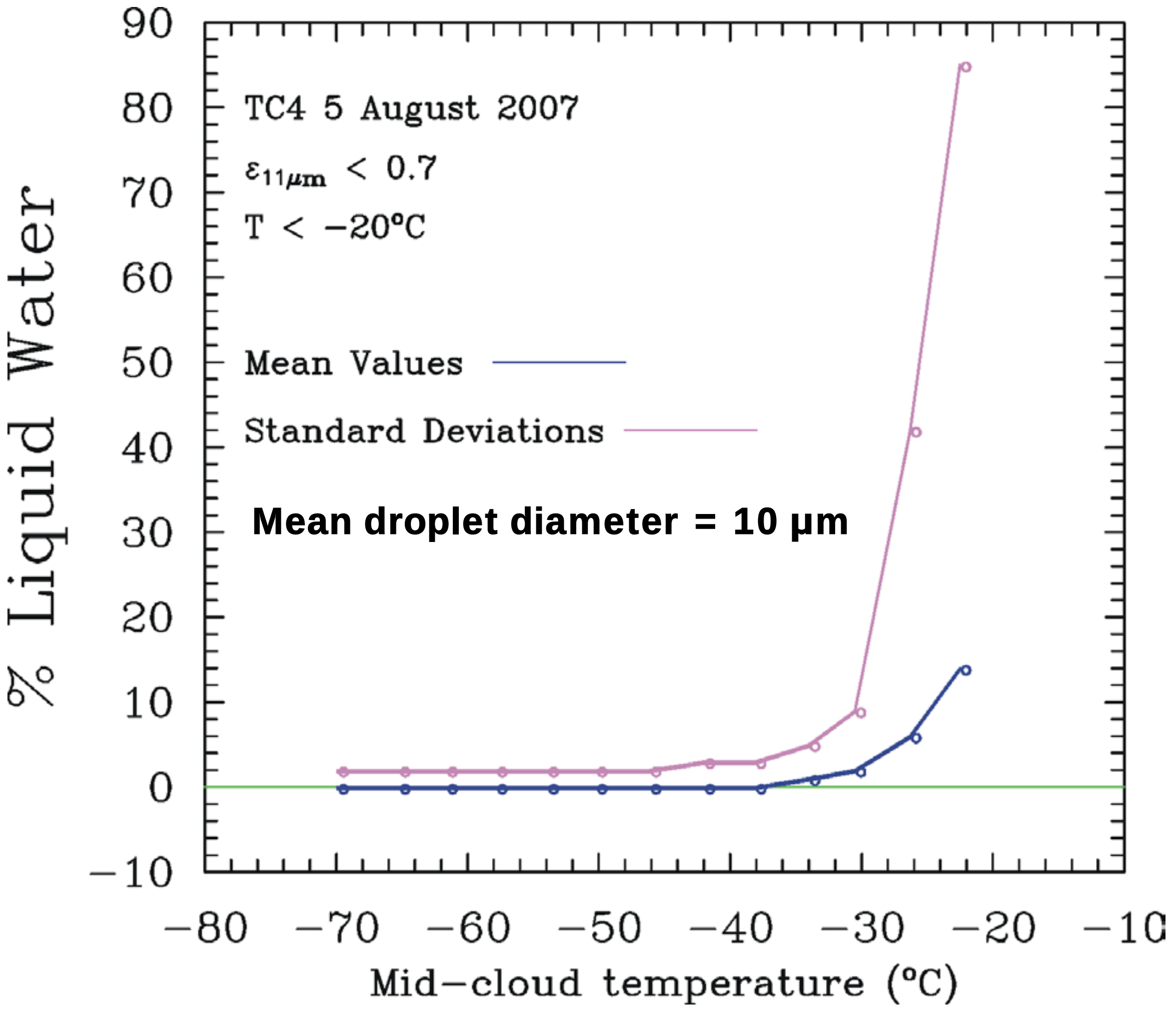
22 July Case Study Results



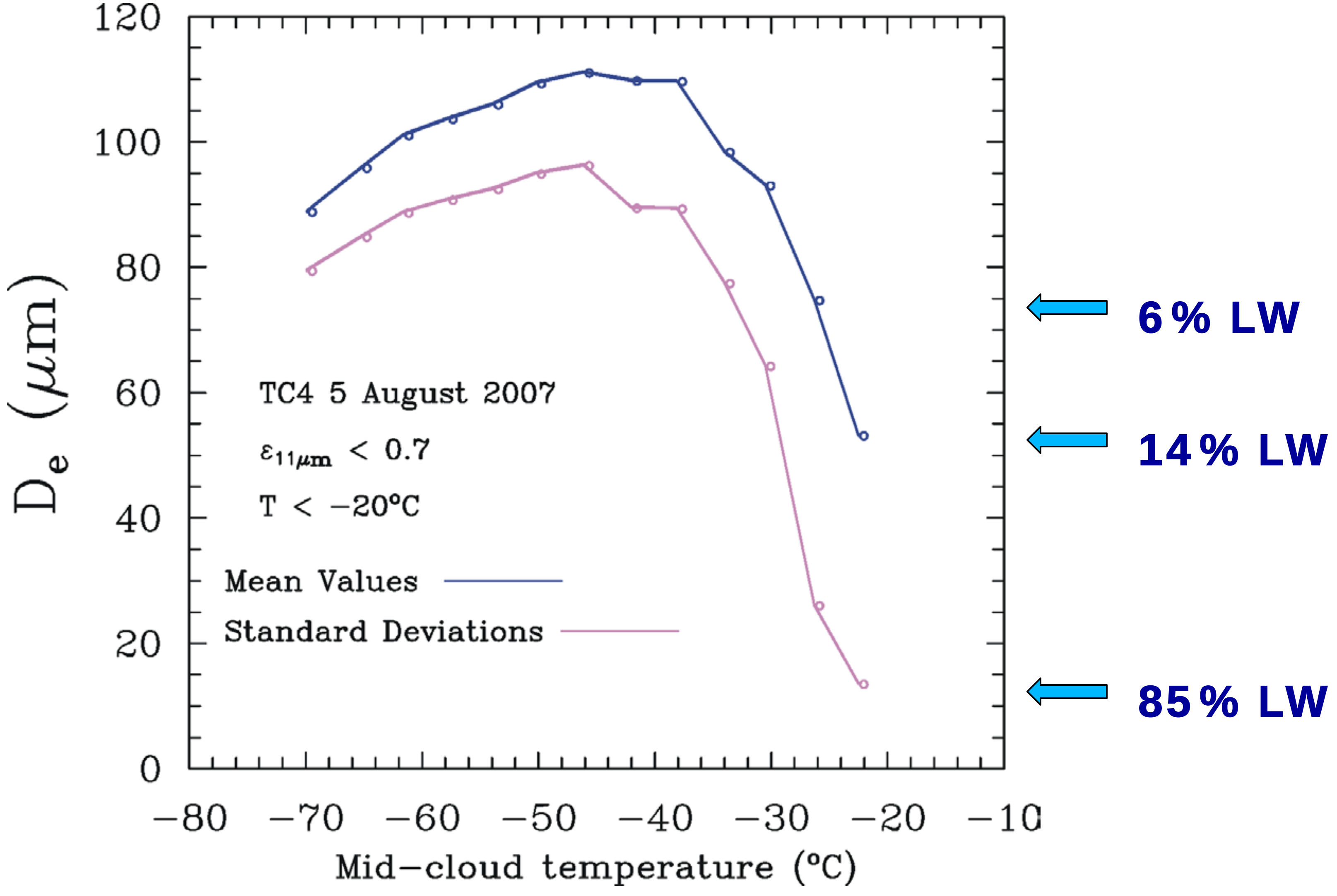


5 August Case Study Results





Sensitivity of D_e to % Liquid Water



Summary

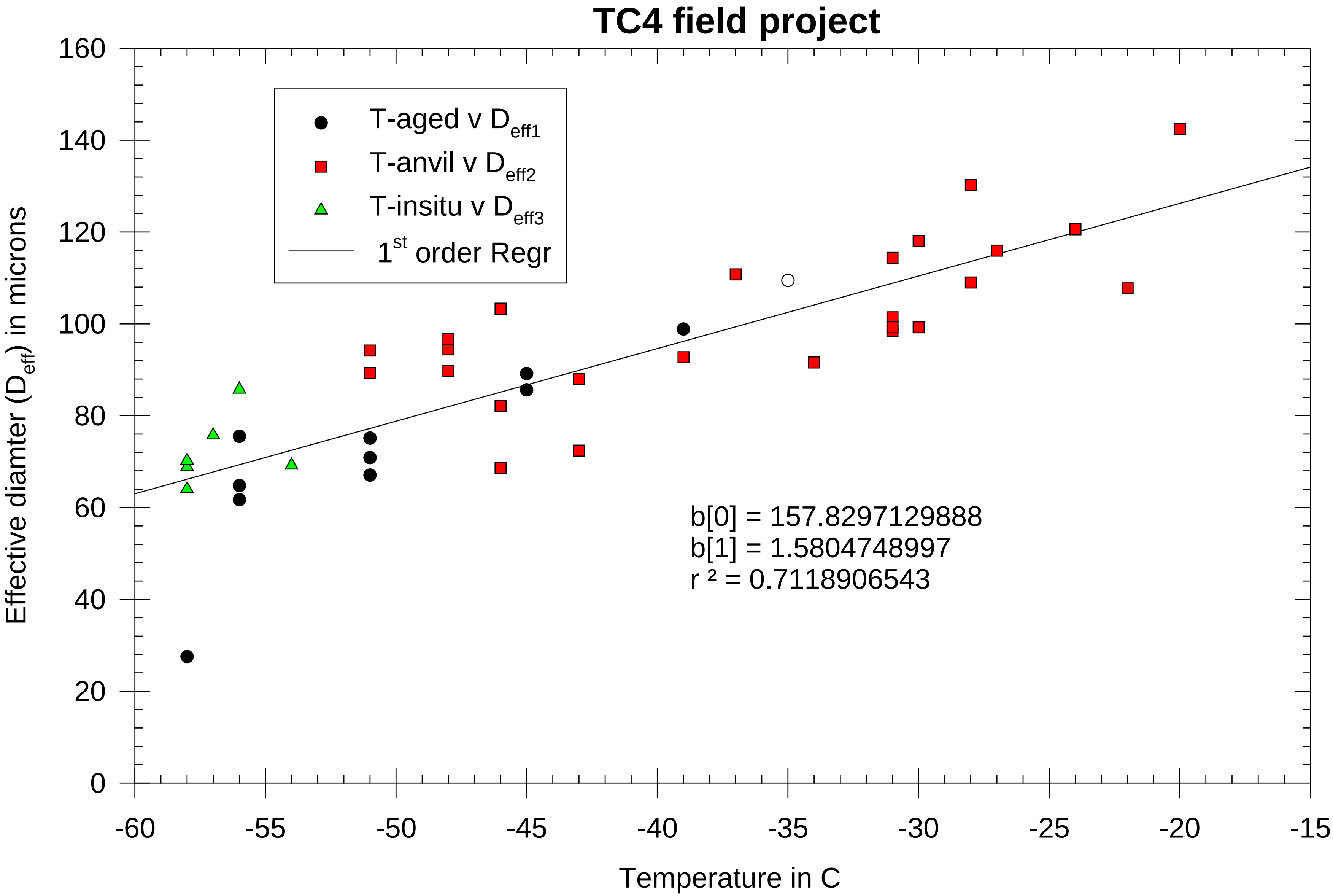
1. **The 12/11 μm absorption optical depth ratio (β) exhibits quasi-constant behavior for ice clouds but is sensitive to the presence of a liquid phase, making it a possible metric for estimating the liquid water fraction for LW < 50%.**

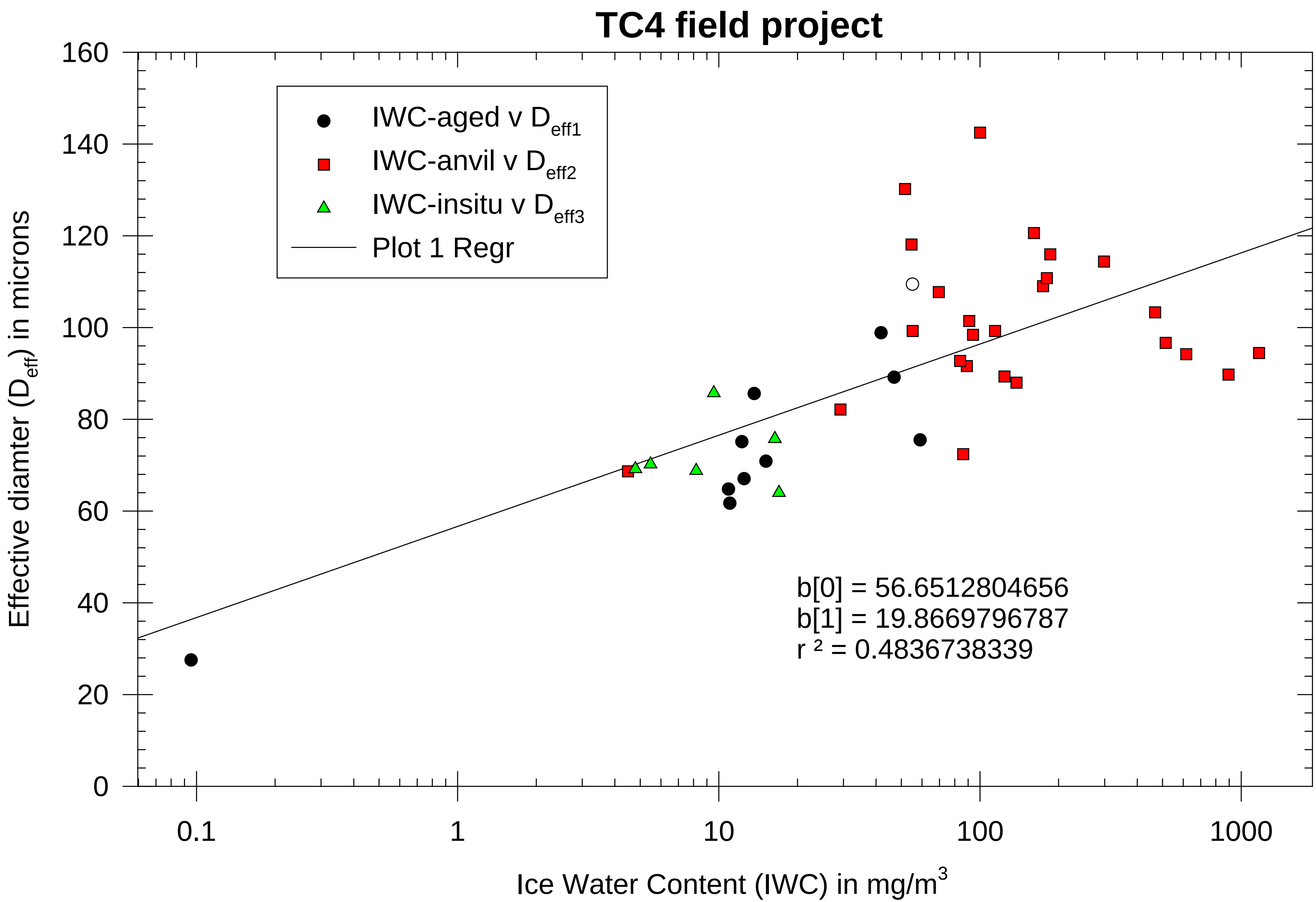
2. **The increase in β can be interpreted using a microphysics/optical property algorithm that attributes liquid water to the small mode of a bimodal PSD.**

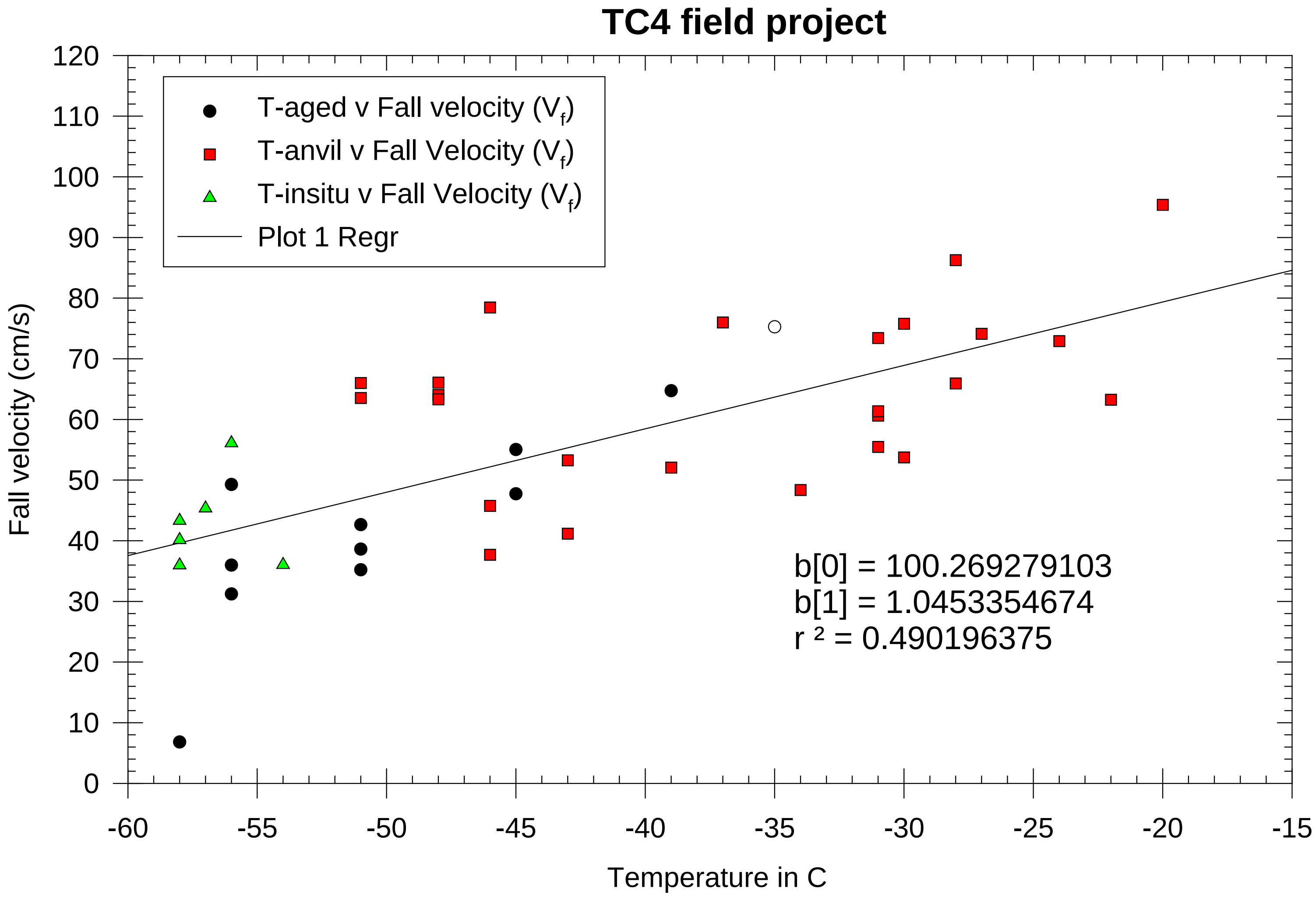
3. **The retrieval of %LW is sensitive to the mean droplet diameter, but the dispersion of β might help define this value.**

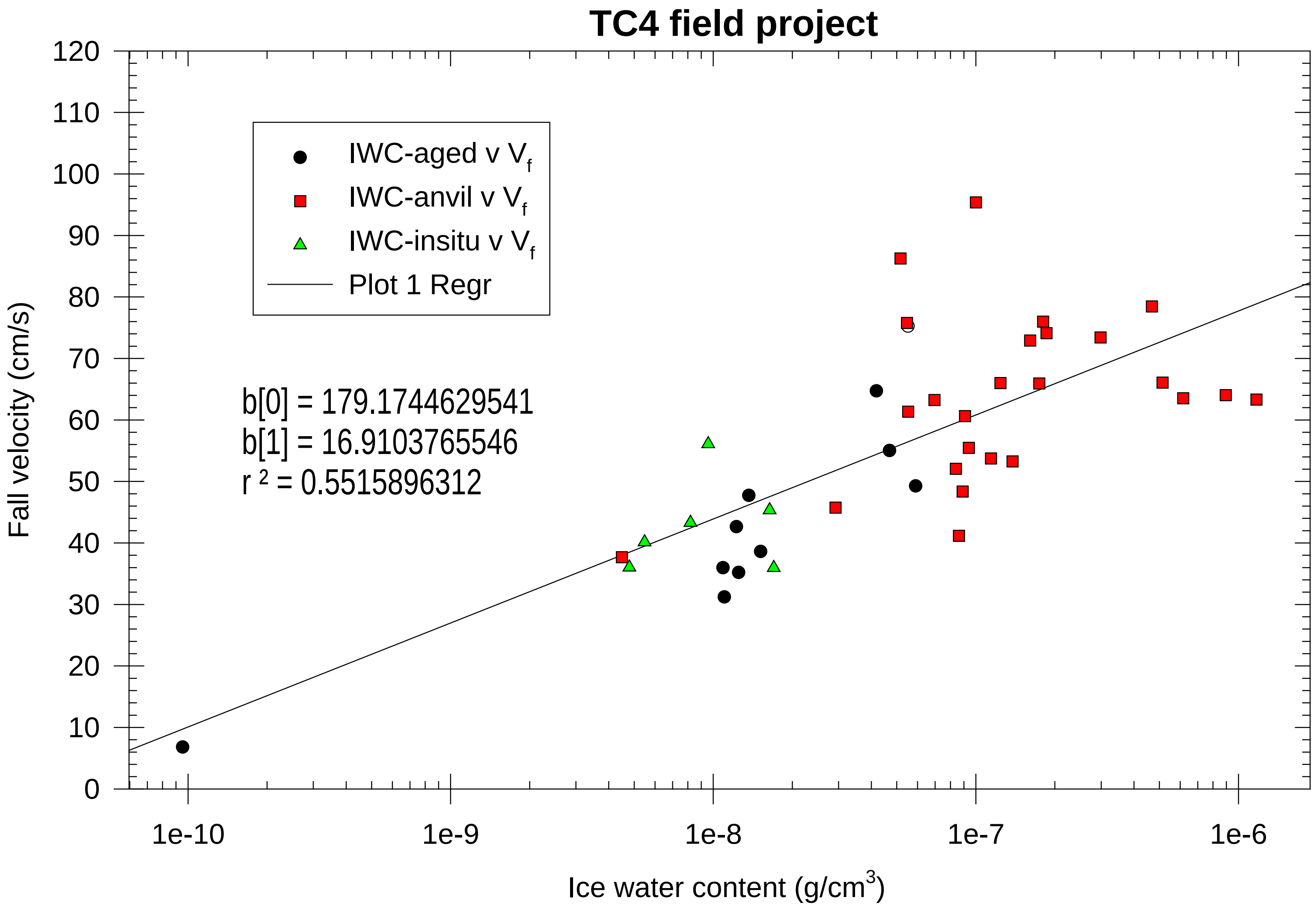
4. **Retrieval algorithm was tested on 2 case studies filtered to select single-layer cirrus clouds. For -35 ^{o}C < T < 20 ^{o}C, LW levels up to 14% were detected which greatly affect the overall D_e and optical properties.**

5. **Variability of LW fraction appears consistent with aircraft measurements and CAM4 predictions.**

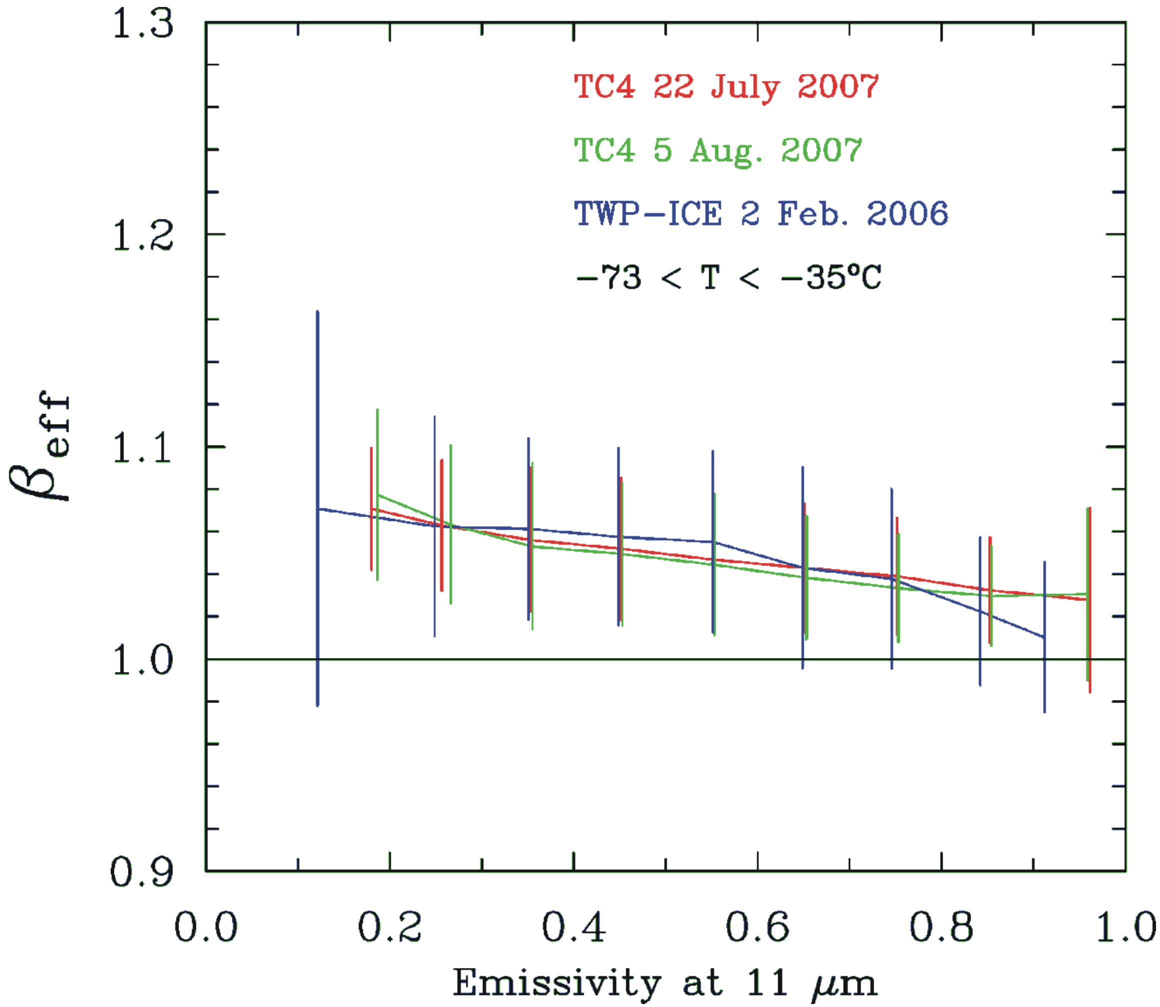

TC4 field project
T-aged v D_{eff1}
T-anvil v D_{eff2}
T-insitu v D_{eff3}
1^{st} order Regr
b[0] = 157.8297129888
b[1] = 1.5804748997
r ² = 0.7118906543
Effective diamter (D_{eff}) in microns
Temperature in C
0
20
40
60
80
100
120
140
160
-60
-55
-50
-45
-40
-35
-30
-25
-20
-15


TC4 field project
IWC-aged v D_{eff1}
IWC-anvil v D_{eff2}
IWC-insitu v D_{eff3}
Plot 1 Regr
b[0] = 56.6512804656
b[1] = 19.8669796787
r ² = 0.4836738339
Effective diamter (D_{eff}) in microns
Ice Water Content (IWC) in mg/m³
0
20
40
60
80
100
120
140
160
0.1
1
10
100
1000


TC4 field project
T-aged v Fall velocity (Vf)
T-anvil v Fall Velocity (Vf)
T-insitu v Fall Velocity (Vf)
Plot 1 Regr
b[0] = 100.269279103
b[1] = 1.0453354674
r ² = 0.490196375
Fall velocity (cm/s)
Temperature in C
0
10
20
30
40
50
60
70
80
90
100
110
120
-60
-55
-50
-45
-40
-35
-30
-25
-20
-15



TC4 field project
Fall velocity (cm/s)
Ice water content (g/cm3)
0
10
20
30
40
50
60
70
80
90
100
110
120
1e-10
1e-9
1e-8
1e-7
1e-6
IWC-aged v Vf
IWC-anvil v Vf
IWC-insitu v Vf
Plot 1 Regr
b[0] = 179.1744629541
b[1] = 16.9103765546
r 2 = 0.5515896312



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

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.

Wavelength dependence of tunneling