A Comparison of Arctic Cirrus Microphysical Properties with mid-latitude and tropical cirrus features

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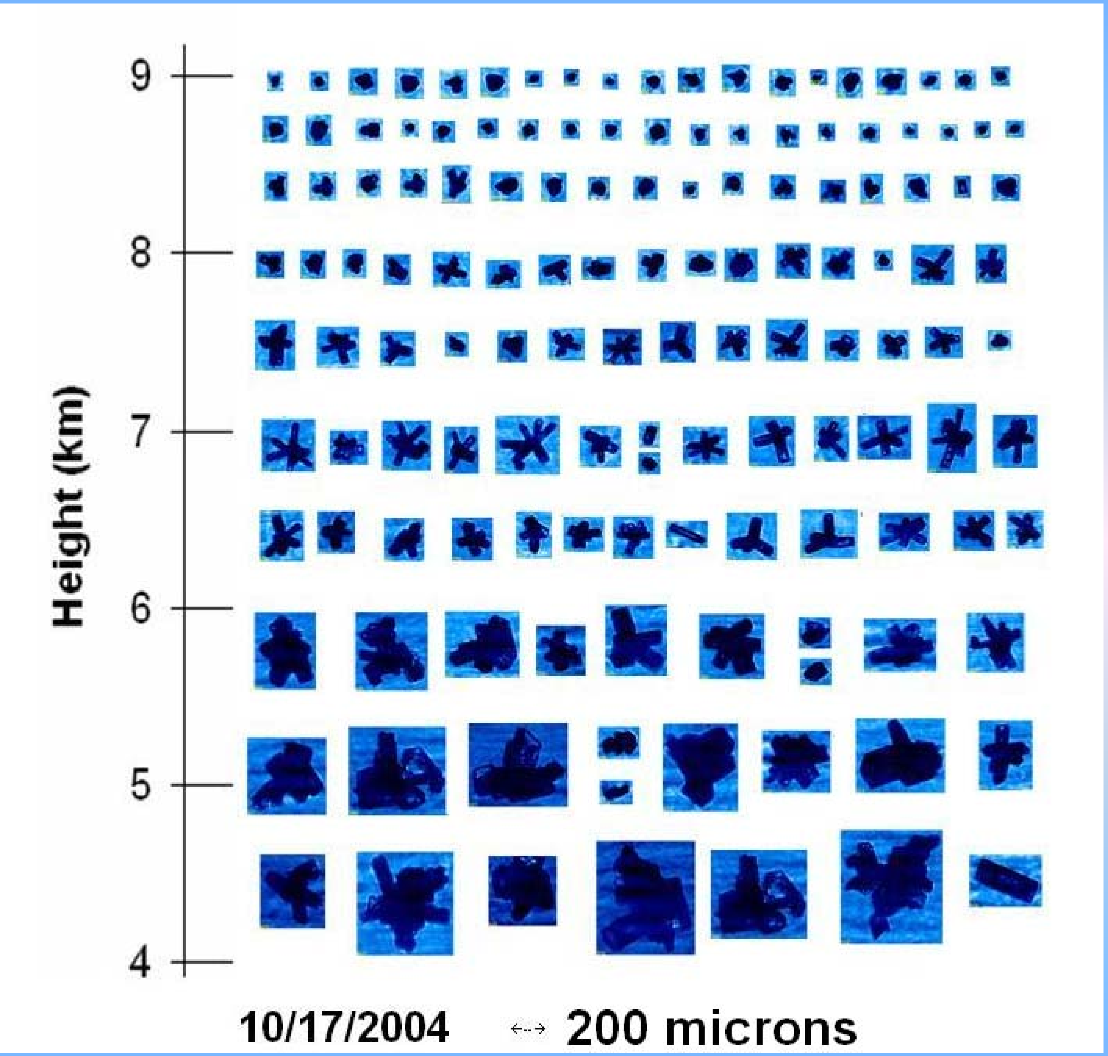
18th ARM Science Team Meeting



In-situ aircraft observations of cirrus give us pretty pictures of ice crystals!

But, how do we go from pretty pictures to something that helps tell us how cirrus affects radiation?

How do pictures help us represent processes such as fallout, radiative heating profiles & cloud feedbacks in models?

Outline

1. Introduction:
   - Why worry about arctic cirrus?
   - What do we need to know about arctic cirrus?
2. MPACE Experiment
   - Observations of cirrus on 17 and 18 October
3. Shape information on arctic cirrus
   - How they differ from mid-latitudes/Tropics
4. Bulk parameters for arctic cirrus
   - How they differ from mid-latitudes/Tropics
5. Summary

Acknowledgments

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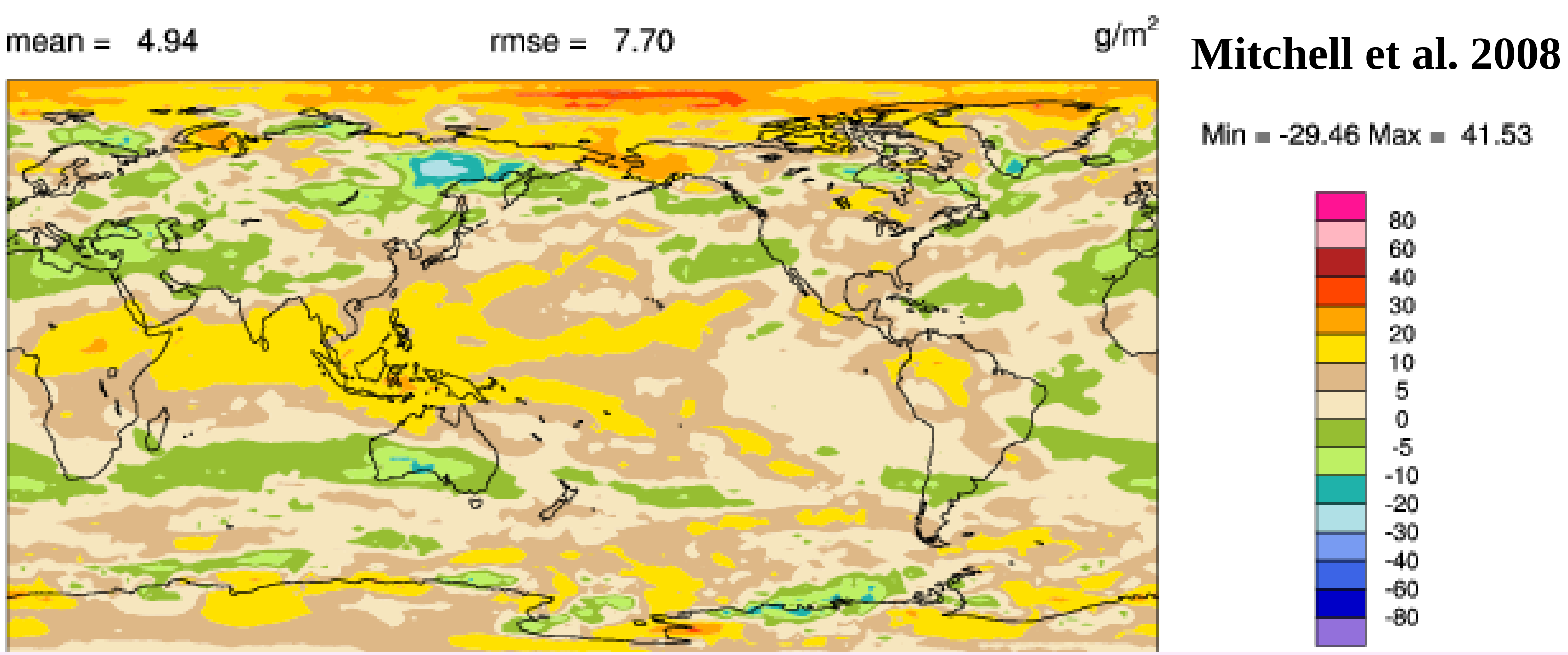
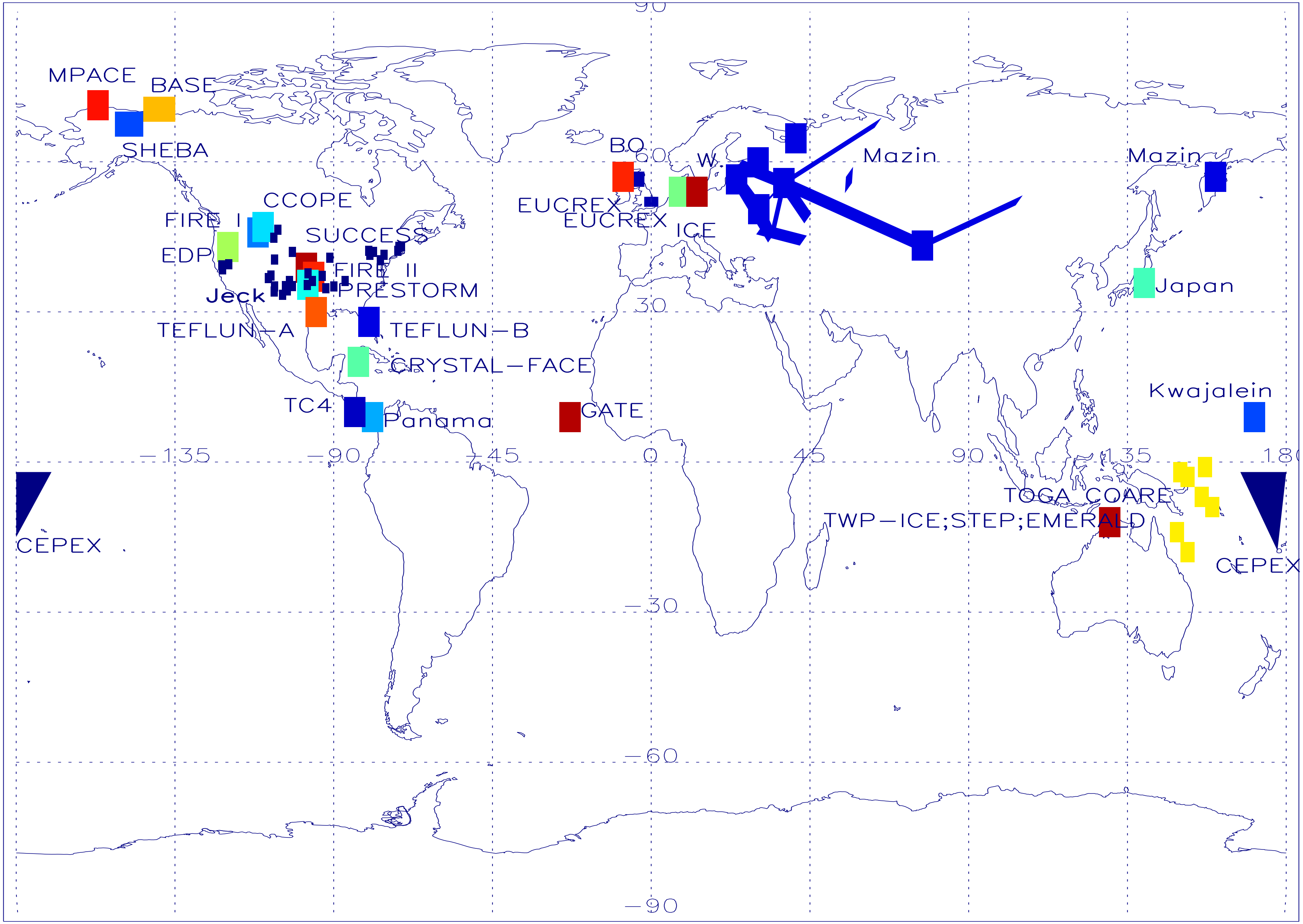
- **Robert McCoy, Sandia National Laboratories**
- **Andrew Heymsfield, NCAR**
- **Zhien Wang, University of Wyoming**
- **Matt Shupe, NOAA Boulder**
- **David Mitchell, Desert Research Institute**



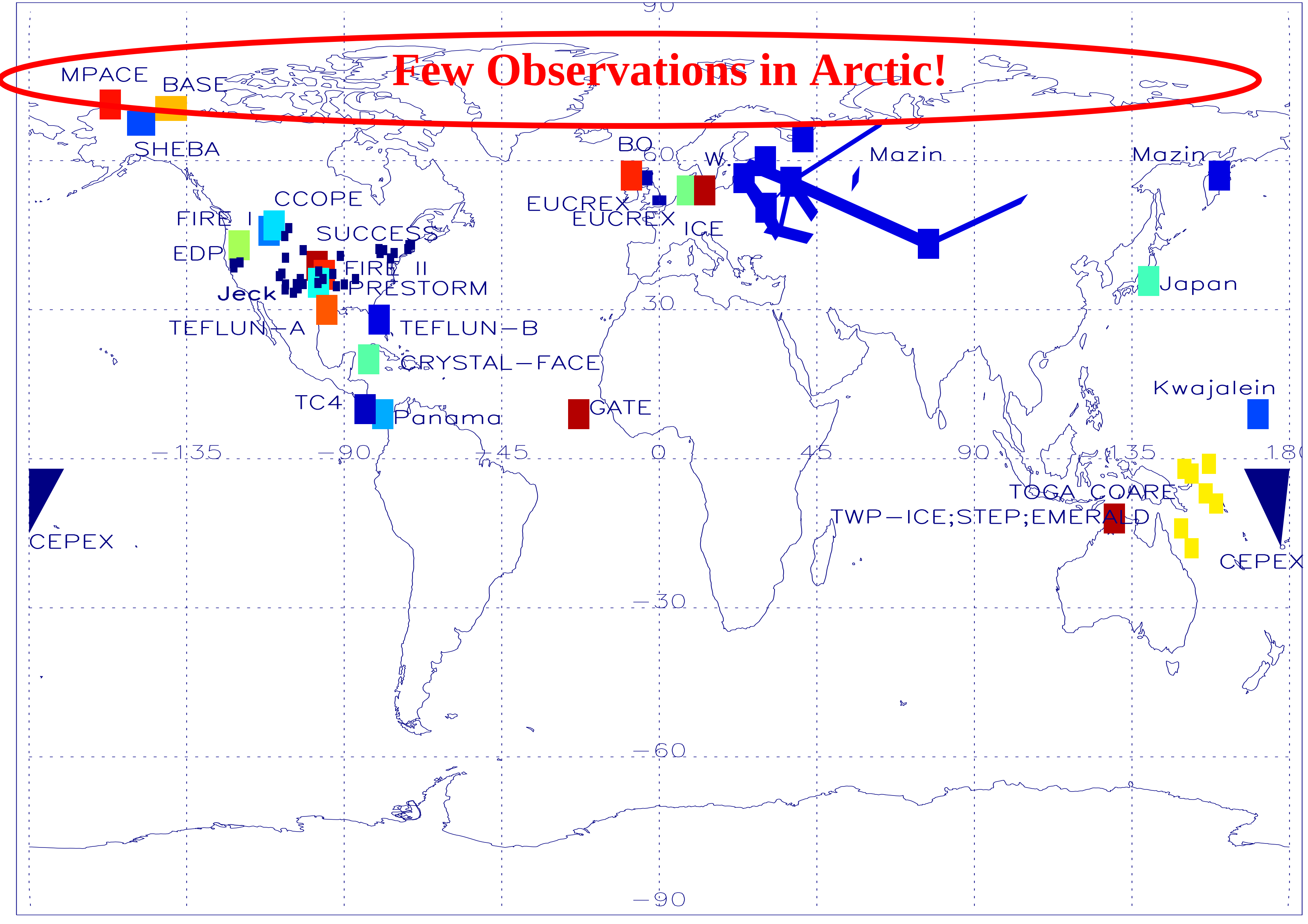
Assumptions about shapes/sizes of ice crystals in clouds has big impact on climate simulations

- **Differences in assumed cirrus size distributions have big impacts on IWP predicted by CAM3**
- **In Arctic, differences are up to 40 g m^{-2}!**
- **Shape/size of ice crystals has big impact on sedimentation**

Locations of Past Ice Cloud Measurements



Locations of Past Ice Cloud Measurements



CALIPSO and CloudSat data show cirrus occurrence from 5 to 25%, largest in winter & summer

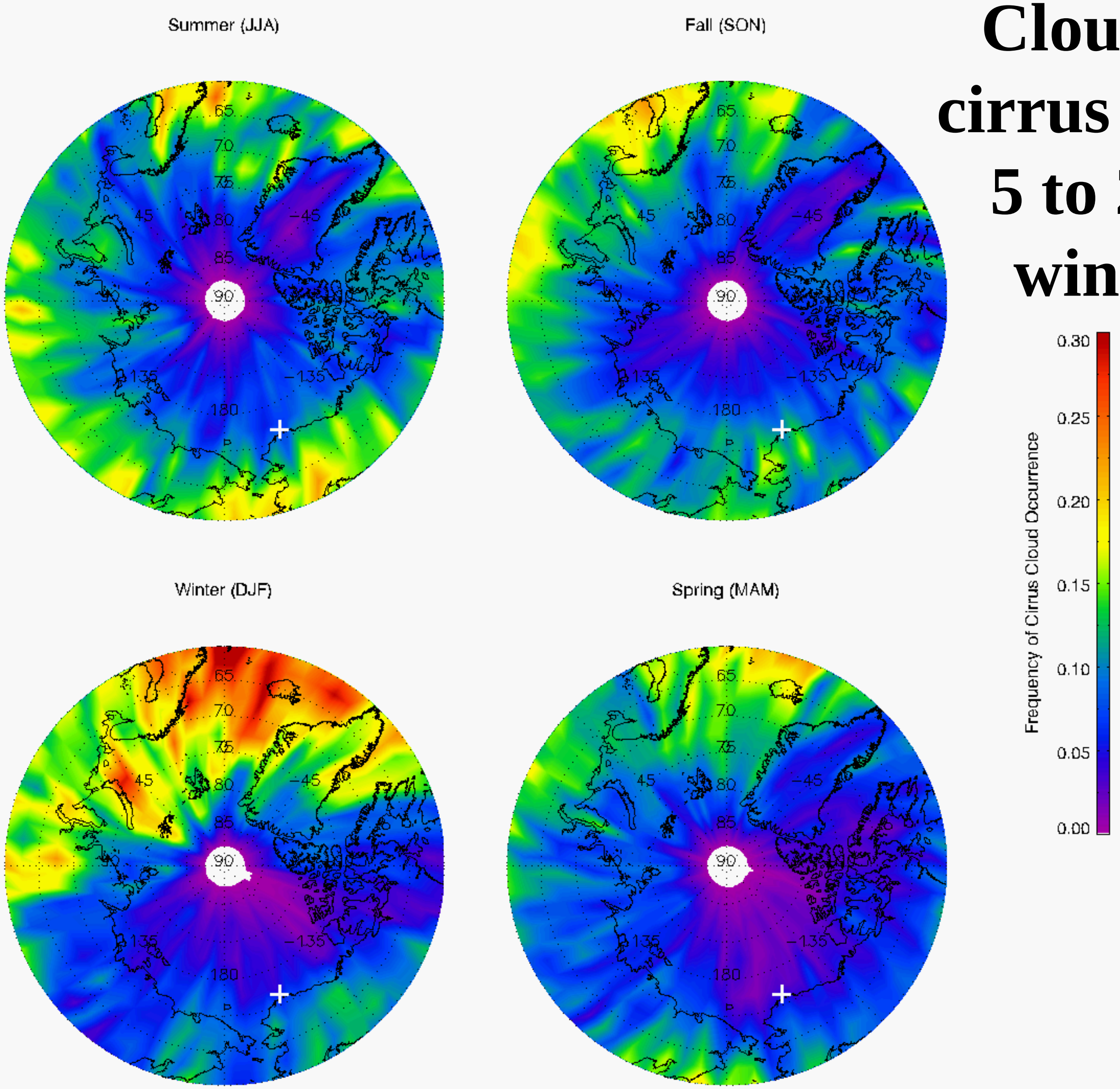
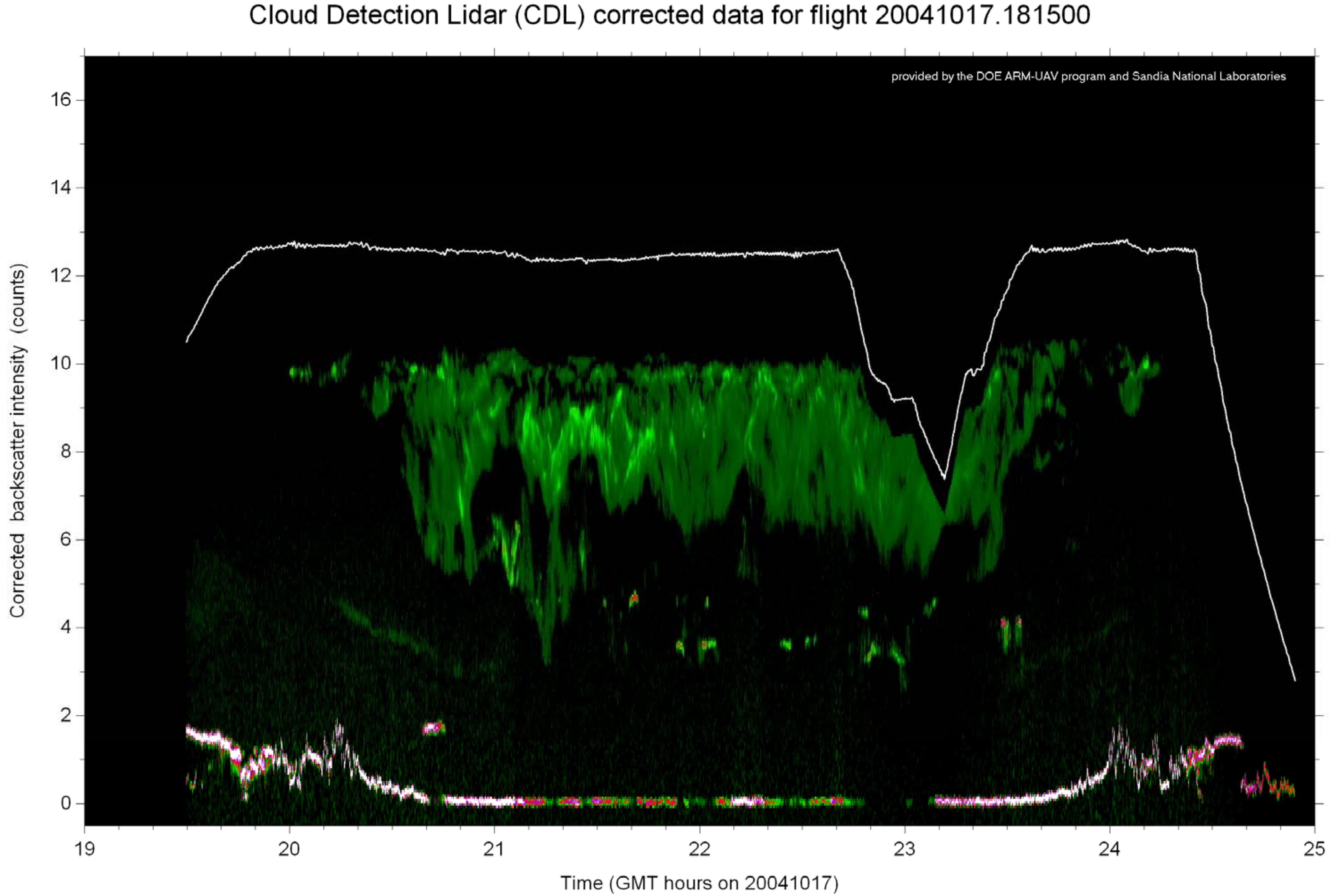
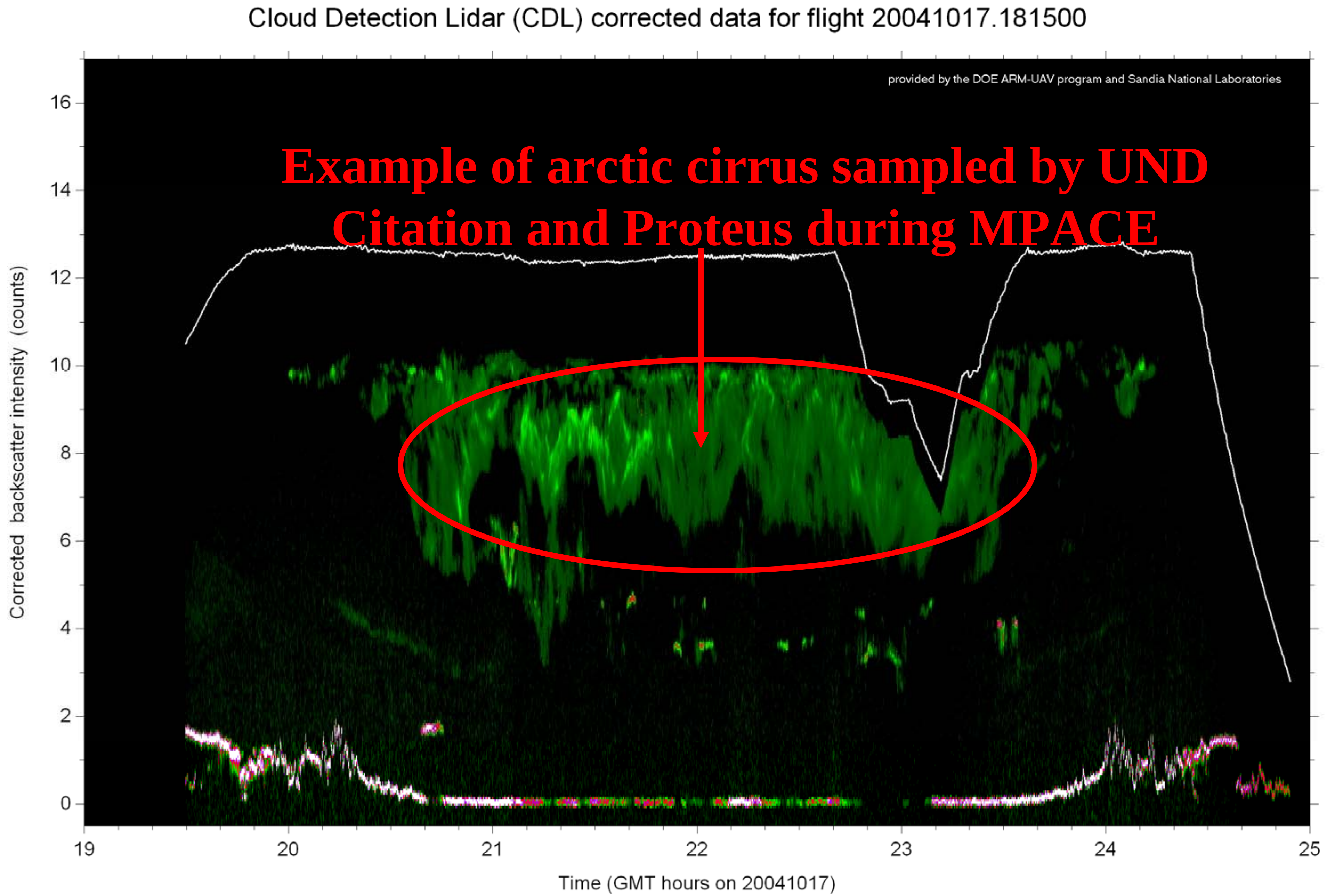
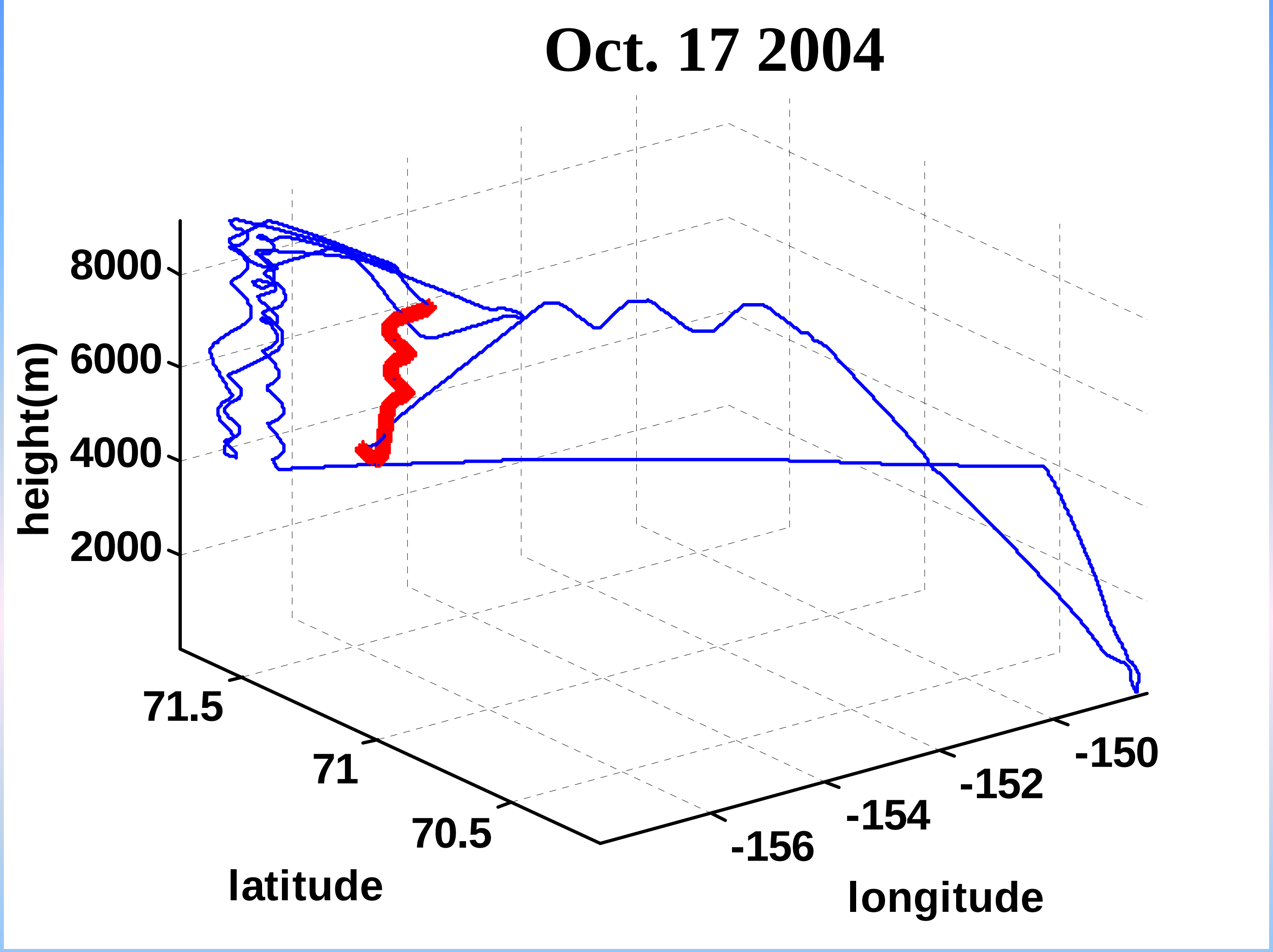


Figure: Courtesy Z. Wang

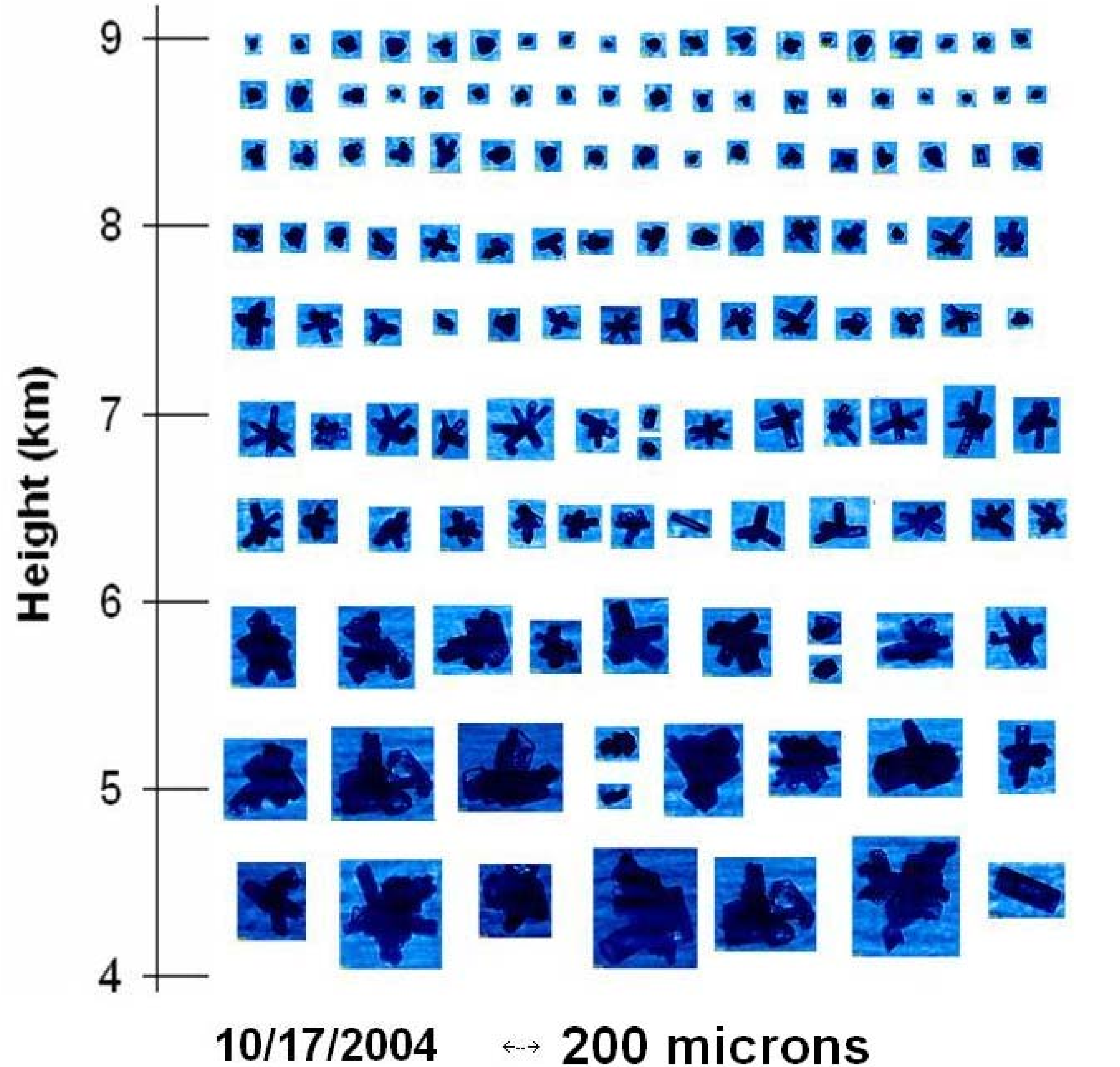

Cloud Detection Lidar (CDL) corrected data for flight 20041017.181500
provided by the DOE ARM-UAV program and Sandia National Laboratories
Corrected backscatter intensity (counts)
16
14
12
10
8
6
4
2
0
19
20
21
22
23
24
25
Time (GMT hours on 20041017)


Cloud Detection Lidar (CDL) corrected data for flight 20041017.181500
provided by the DOE ARM-UAV program and Sandia National Laboratories
Example of arctic cirrus sampled by UND Citation and Proteus during MPACE
Corrected backscatter intensity (counts)
Time (GMT hours on 20041017)
0
2
4
6
8
10
12
14
16
19
20
21
22
23
24
25

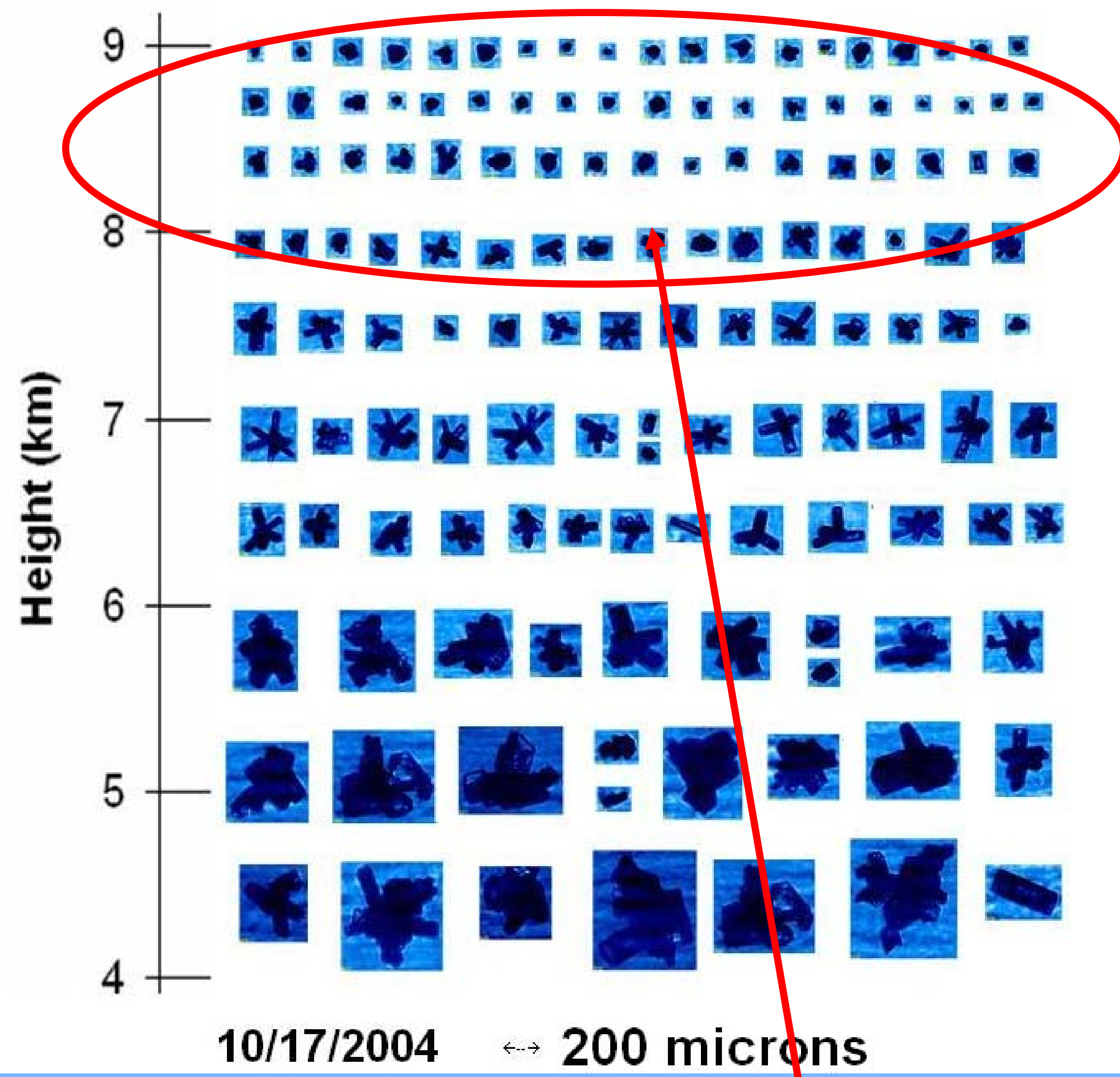


• **Examples of flight sampling strategy used to measure during M-PACE**

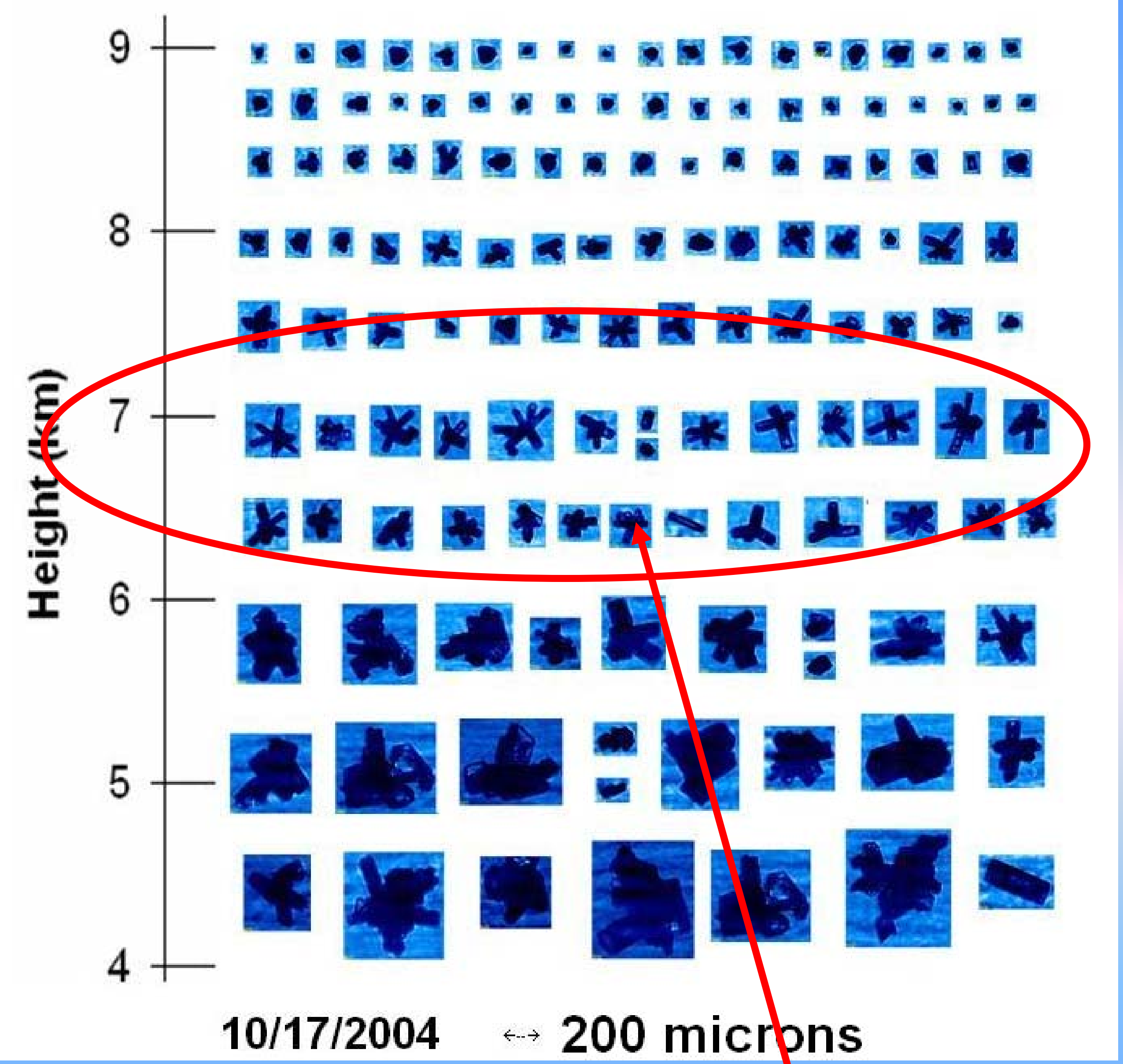
•**Spirals above ground sites**



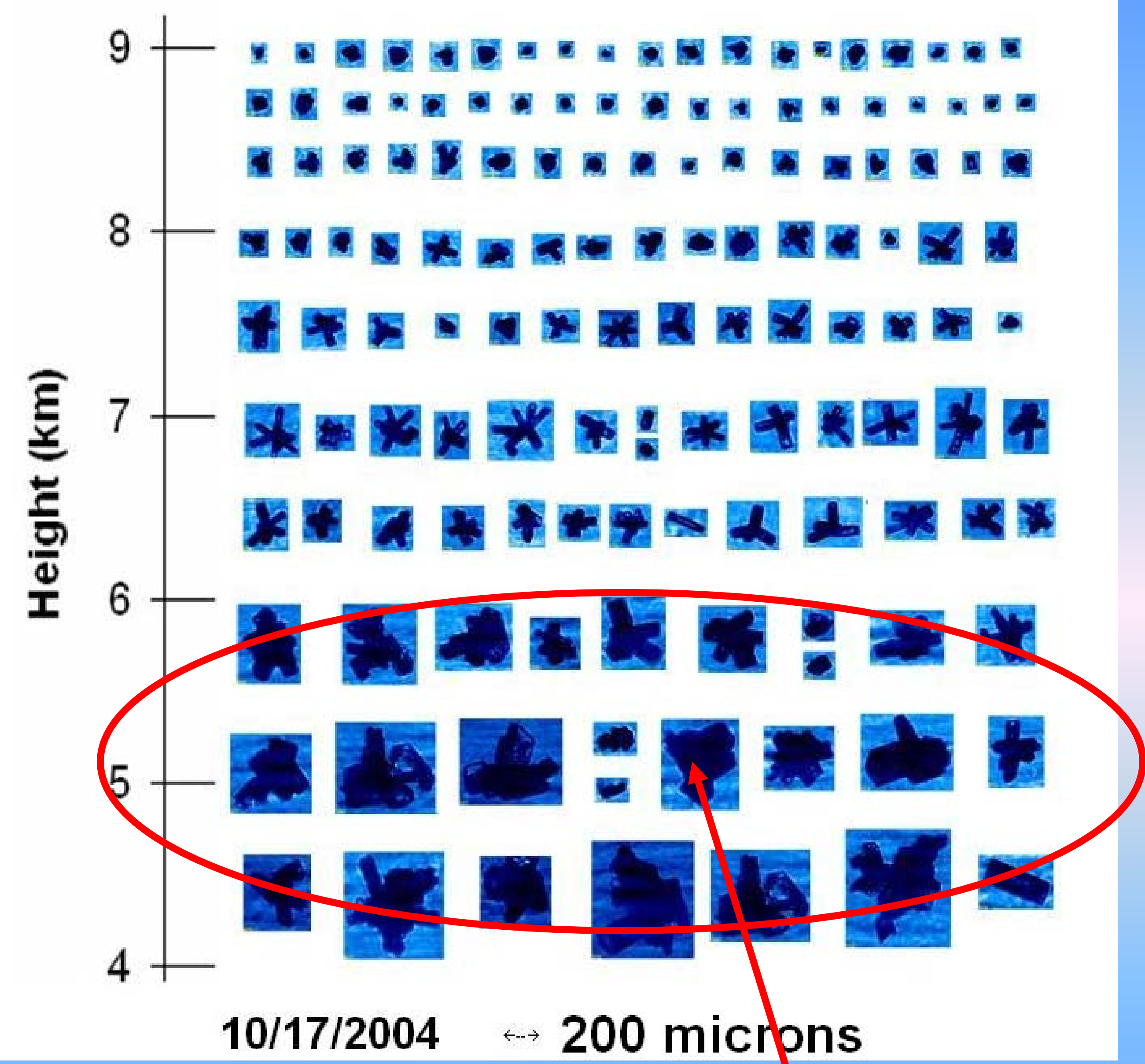
Height (km)
9
8
7
6
5
4
10/17/2004
200 microns



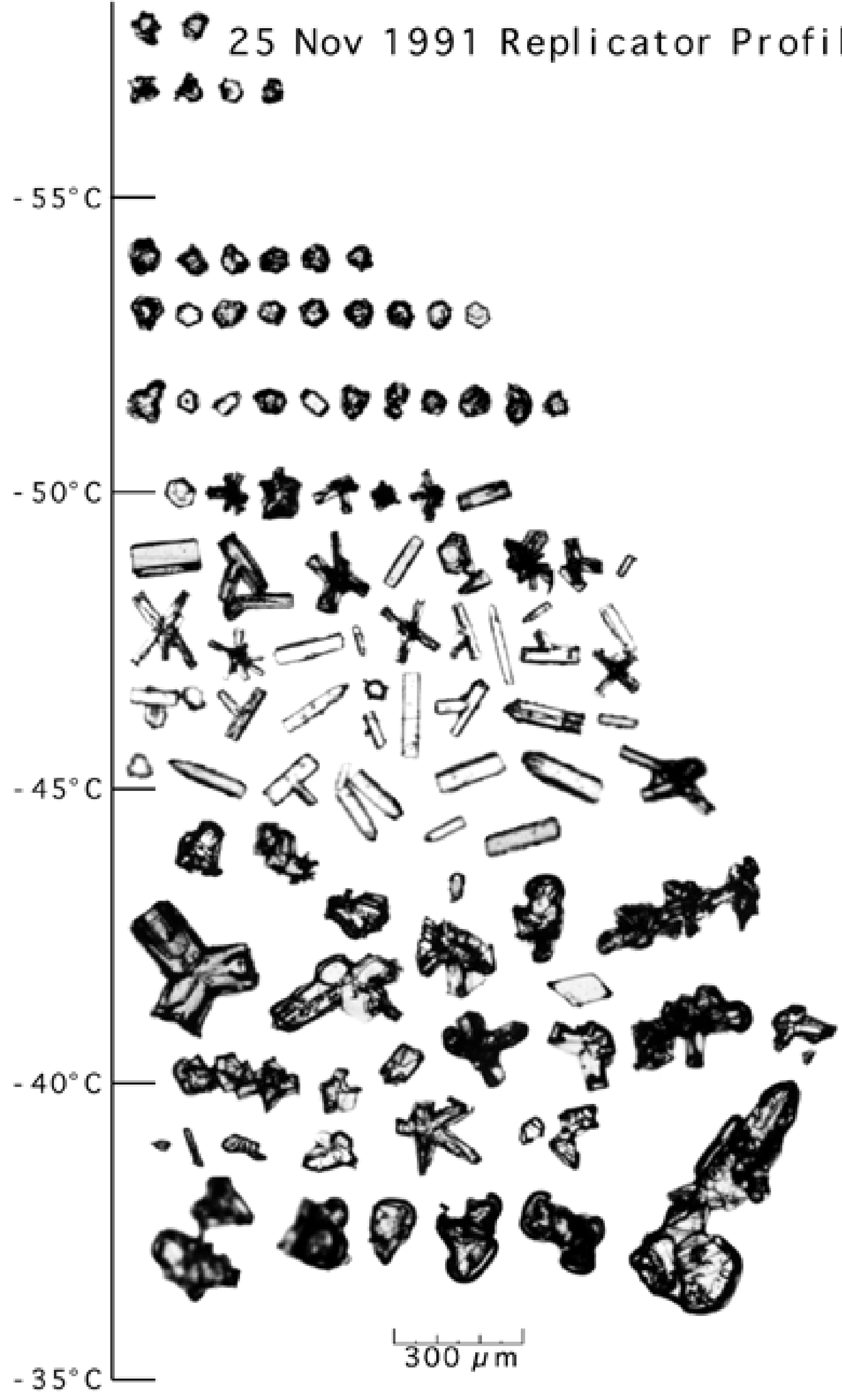
Small particles predominantly near cloud top



Pristine ice crystals seen: growth in mid-cloud regions

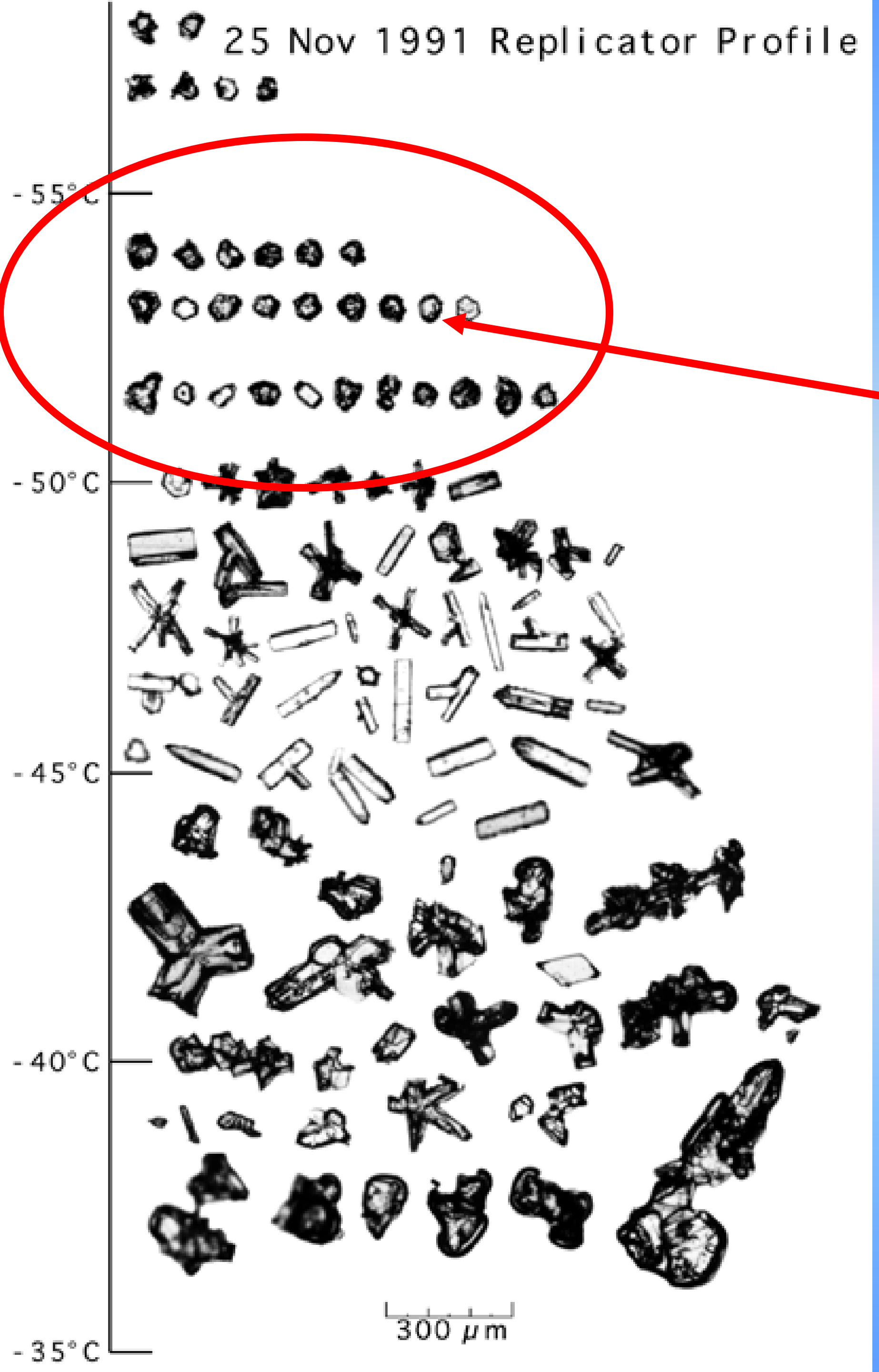


Larger particles, rounded edges (aggregation/sublimation)



Mid-latitude clouds have similar structure:

Heymsfield et al. 1996



Mid-latitude clouds have similar structure:

Zone 1: Ice Crystal Initiation Zone

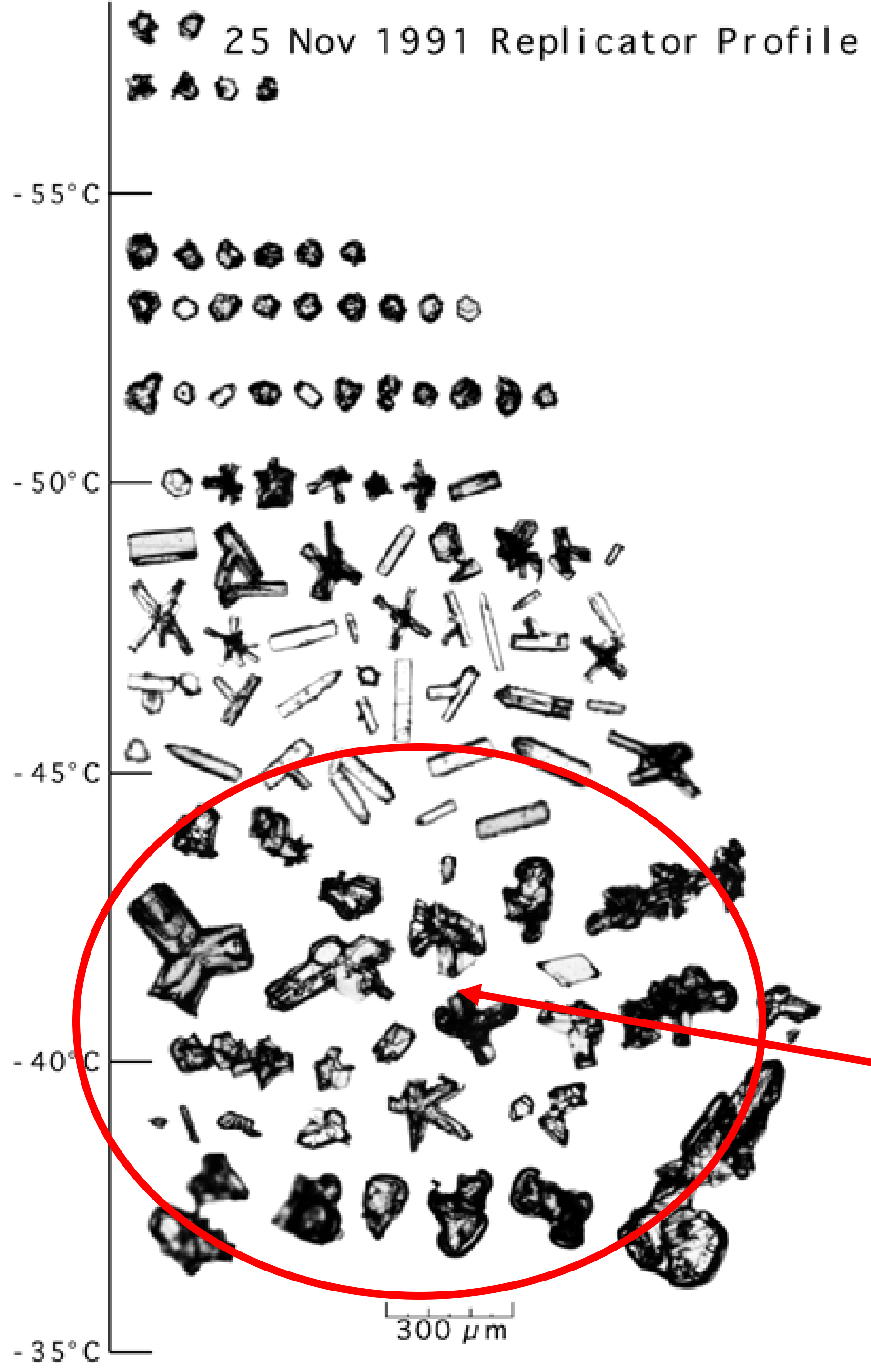
Heymsfield et al. 1996

Mid-latitude clouds have similar structure:

Zone 1: Ice Crystal Initiation Zone

Zone 2: Growth Zone

Heymsfield et al. 1996



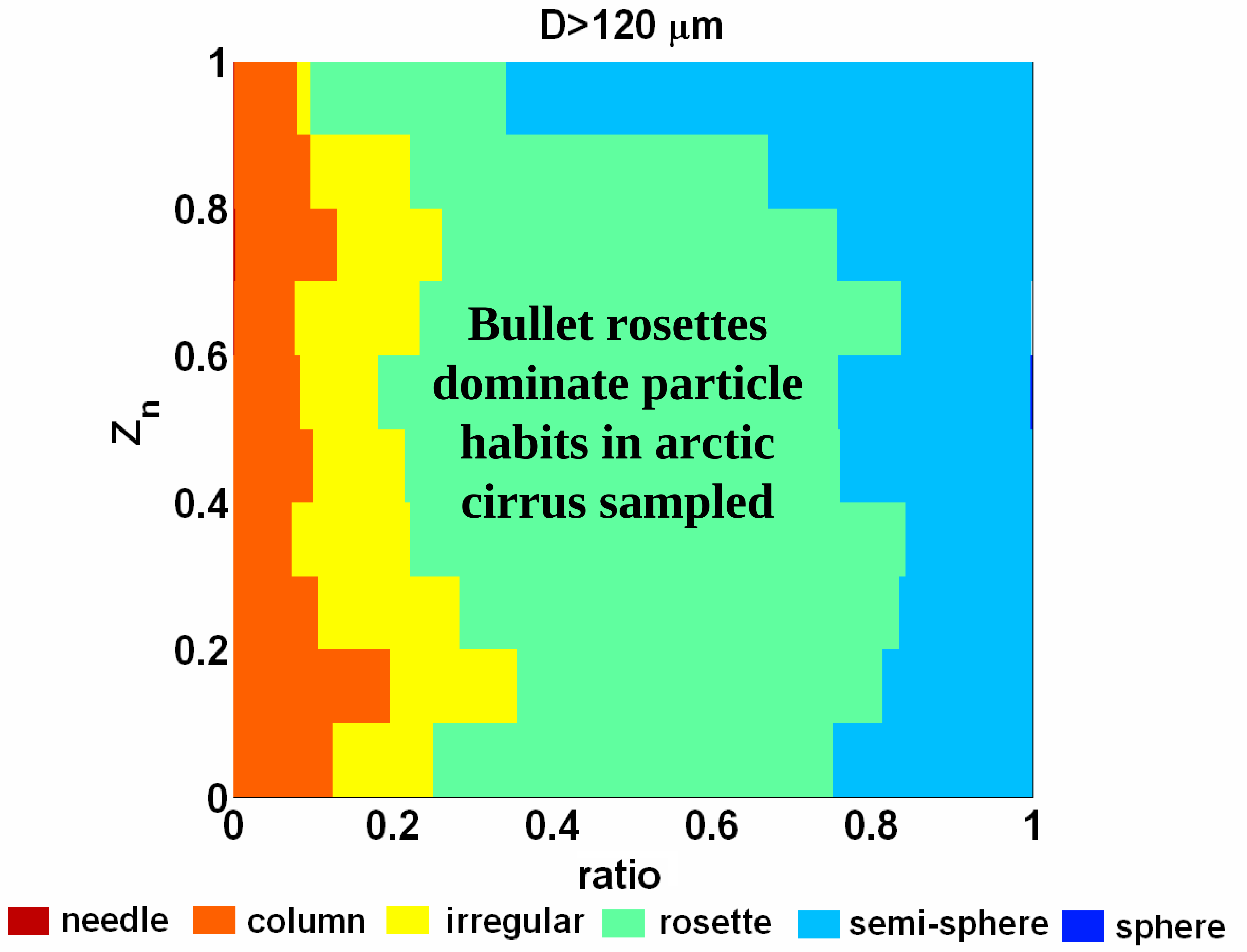
Mid-latitude clouds have similar structure:

Zone 1: Ice Crystal Initiation Zone

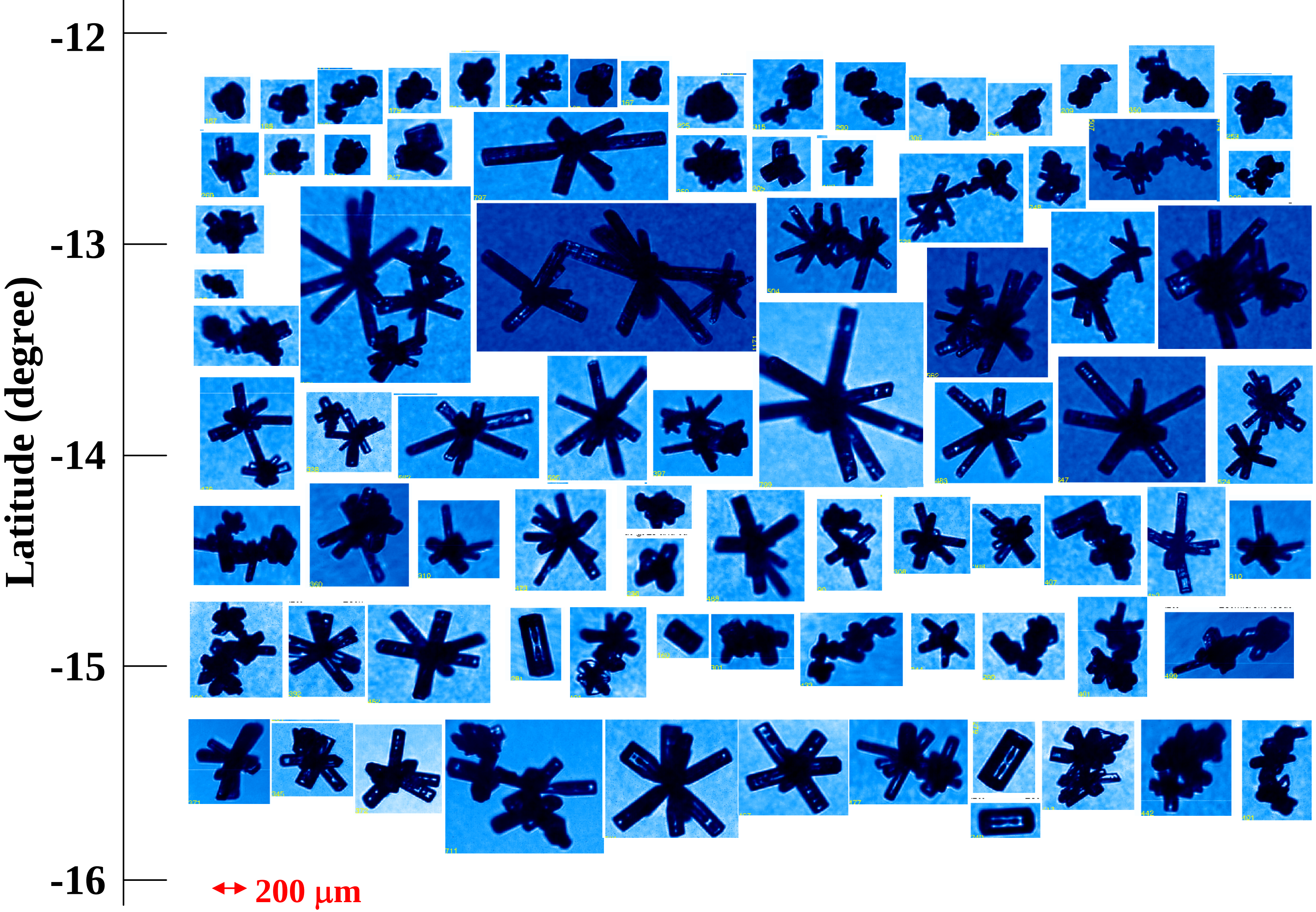
Zone 2: Growth Zone

Zone 3: Sublimation Zone

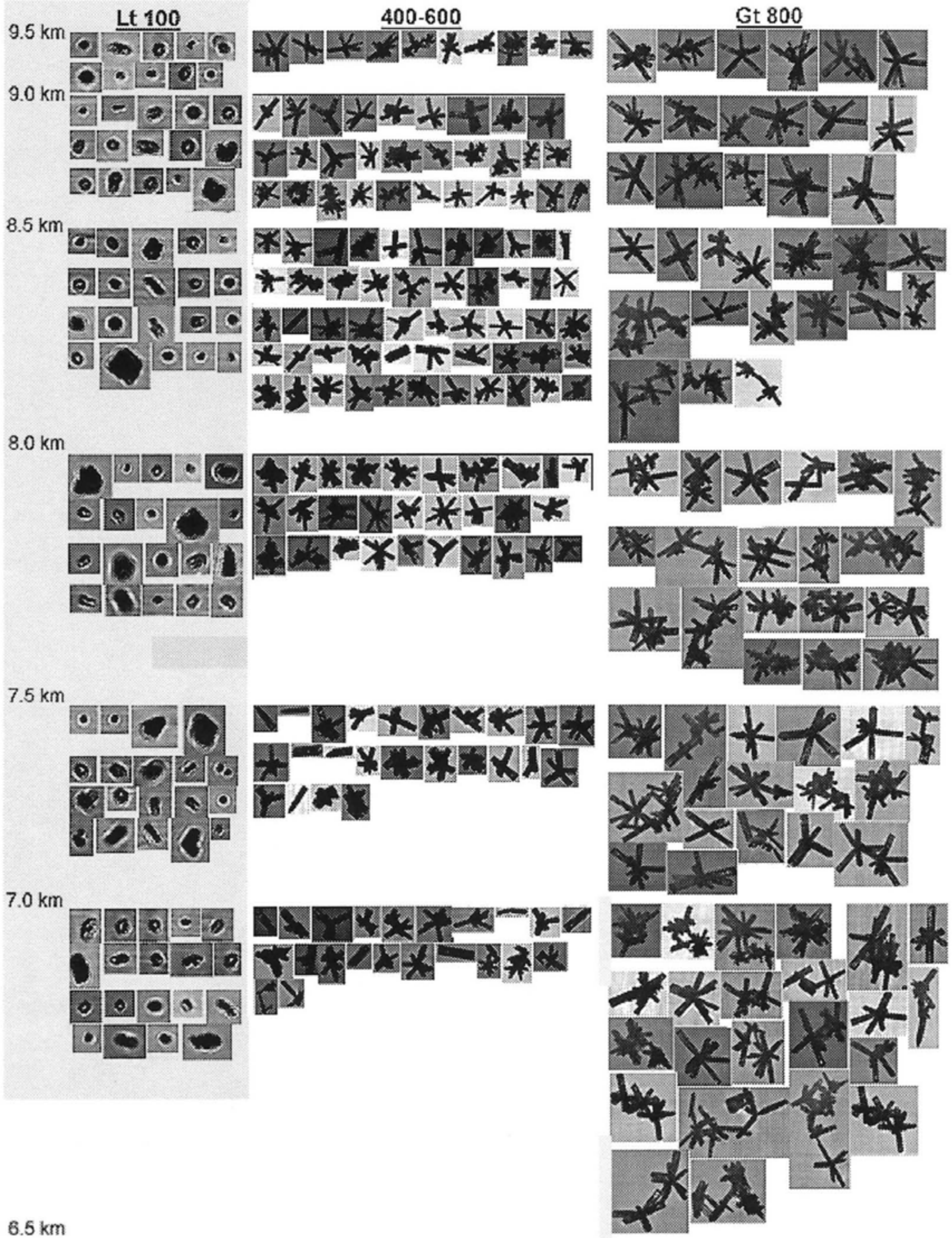
Heymsfield et al. 1996



D>120 μm
Bullet rosettes dominate particle habits in arctic cirrus sampled
Z_n
ratio
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
needle
column
irregular
rosette
semi-sphere
sphere

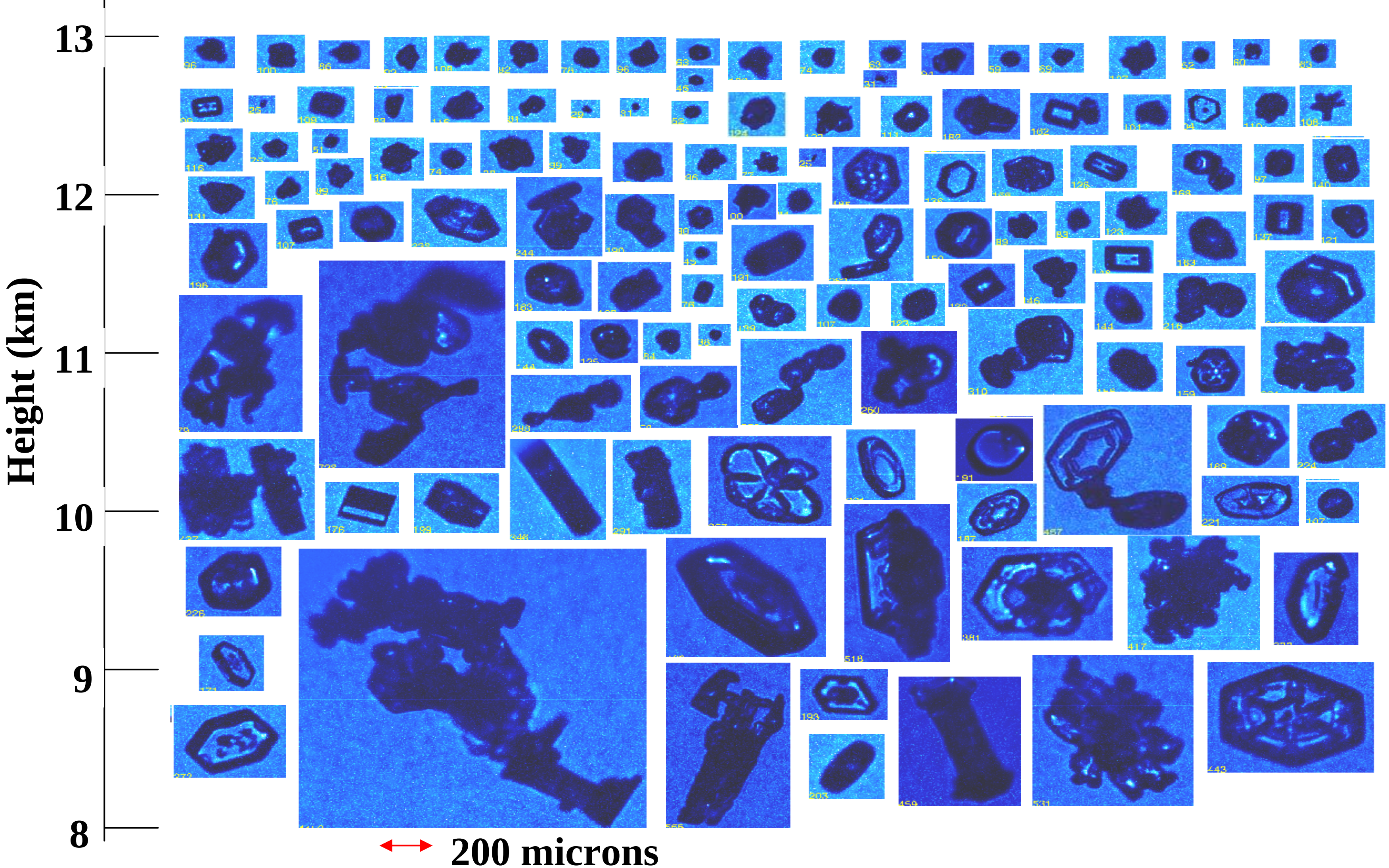


Bullet rosettes also seen in regenerating cells in tropical cirrus (TWP-ICE)



Bullet rosettes also observed in synoptically generated cirrus at SGP

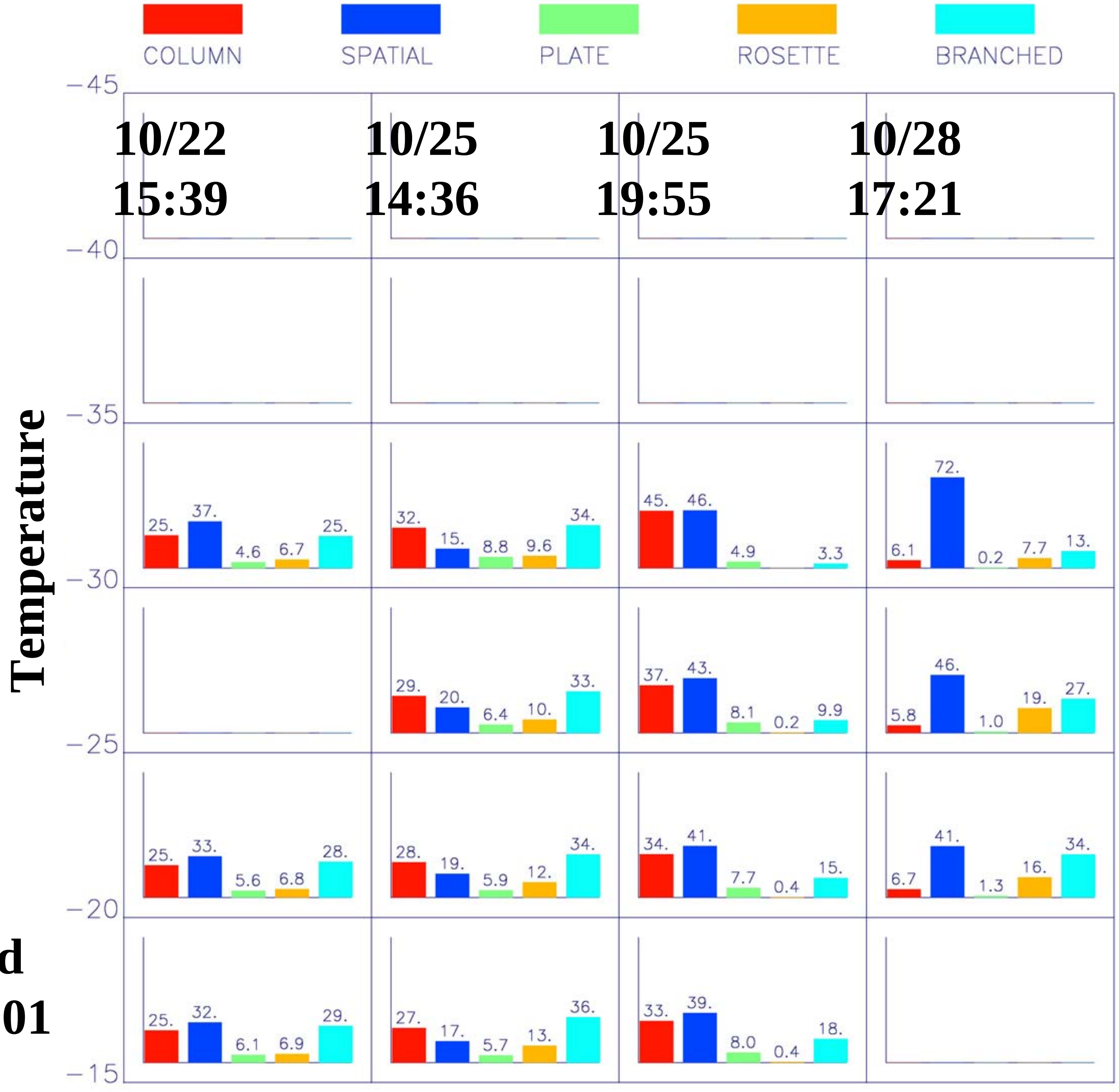
Heymsfield et al. 2002



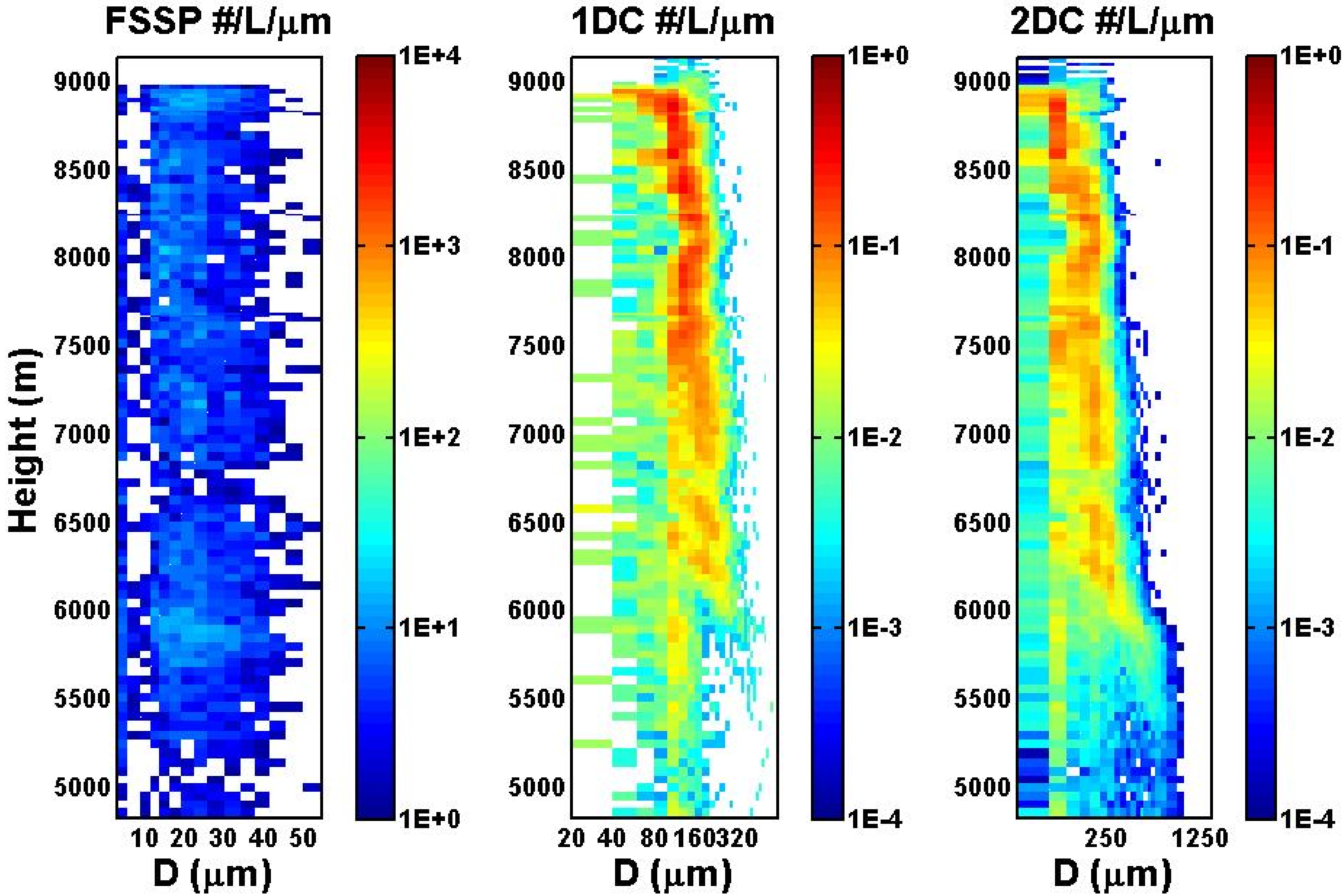
Bullet rosettes are not always dominant:

Fresh anvil during TWP-ICE

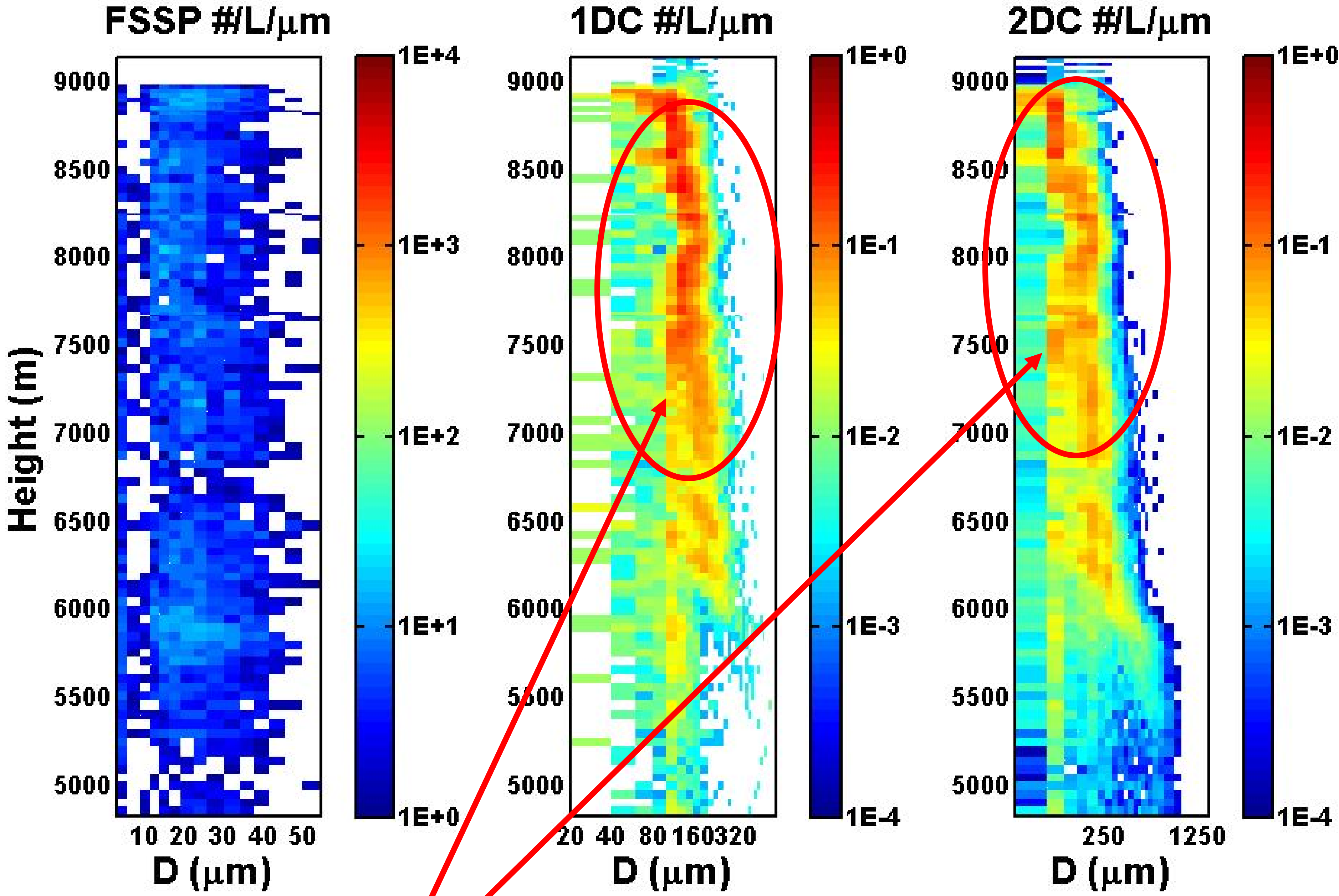
Rosettes during some FIRE flights were small fraction of crystals



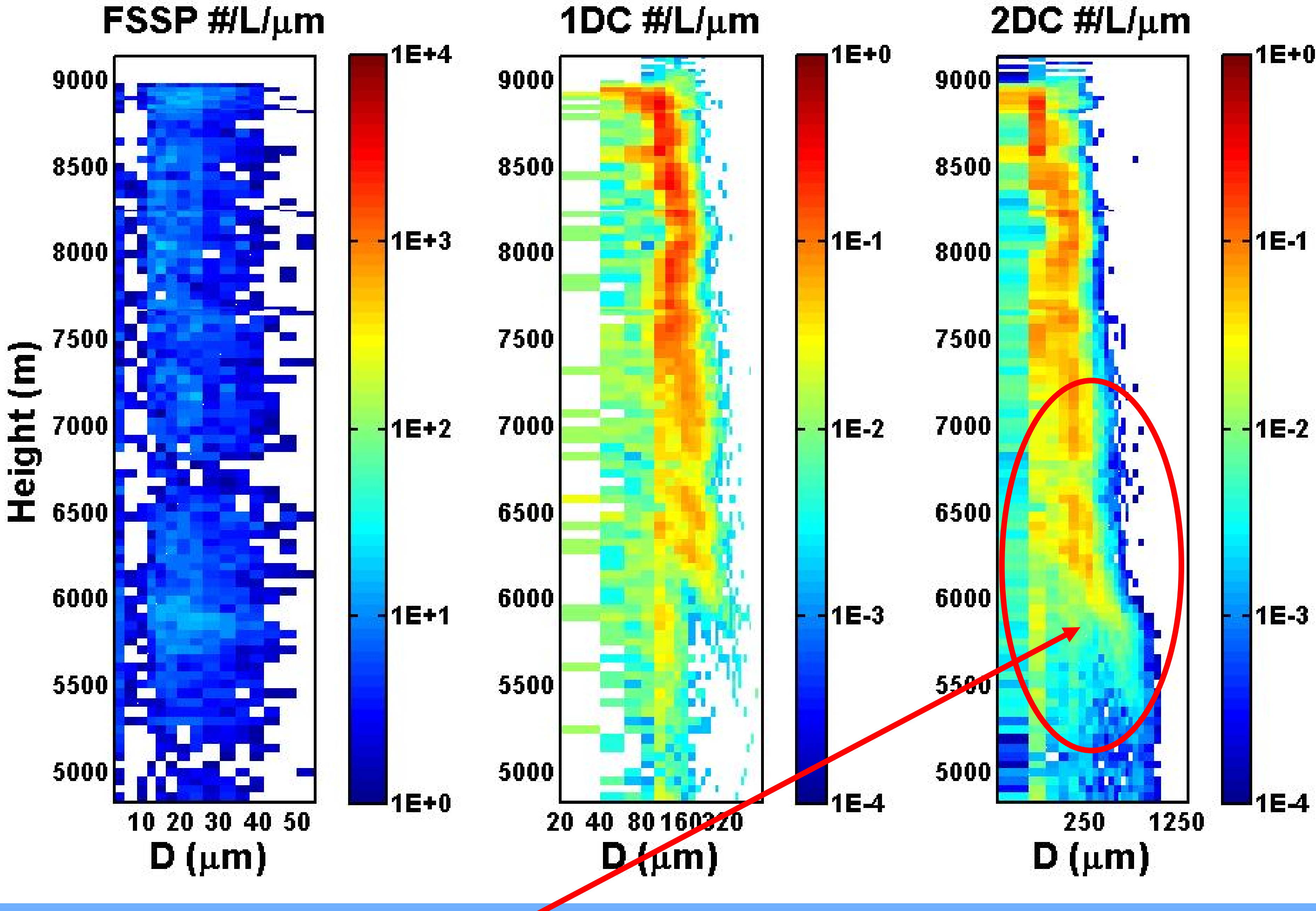
Heymsfield and McFarquhar 2001



FSSP #/L/μm
1DC #/L/μm
2DC #/L/μm
Height (m)
9000
8500
8000
7500
7000
6500
6000
5500
5000
10 20 30 40 50
20 40 80 160320
250 1250
D (μm)
1E+4
1E+3
1E+2
1E+1
1E+0
1E+0
1E-1
1E-2
1E-3
1E-4



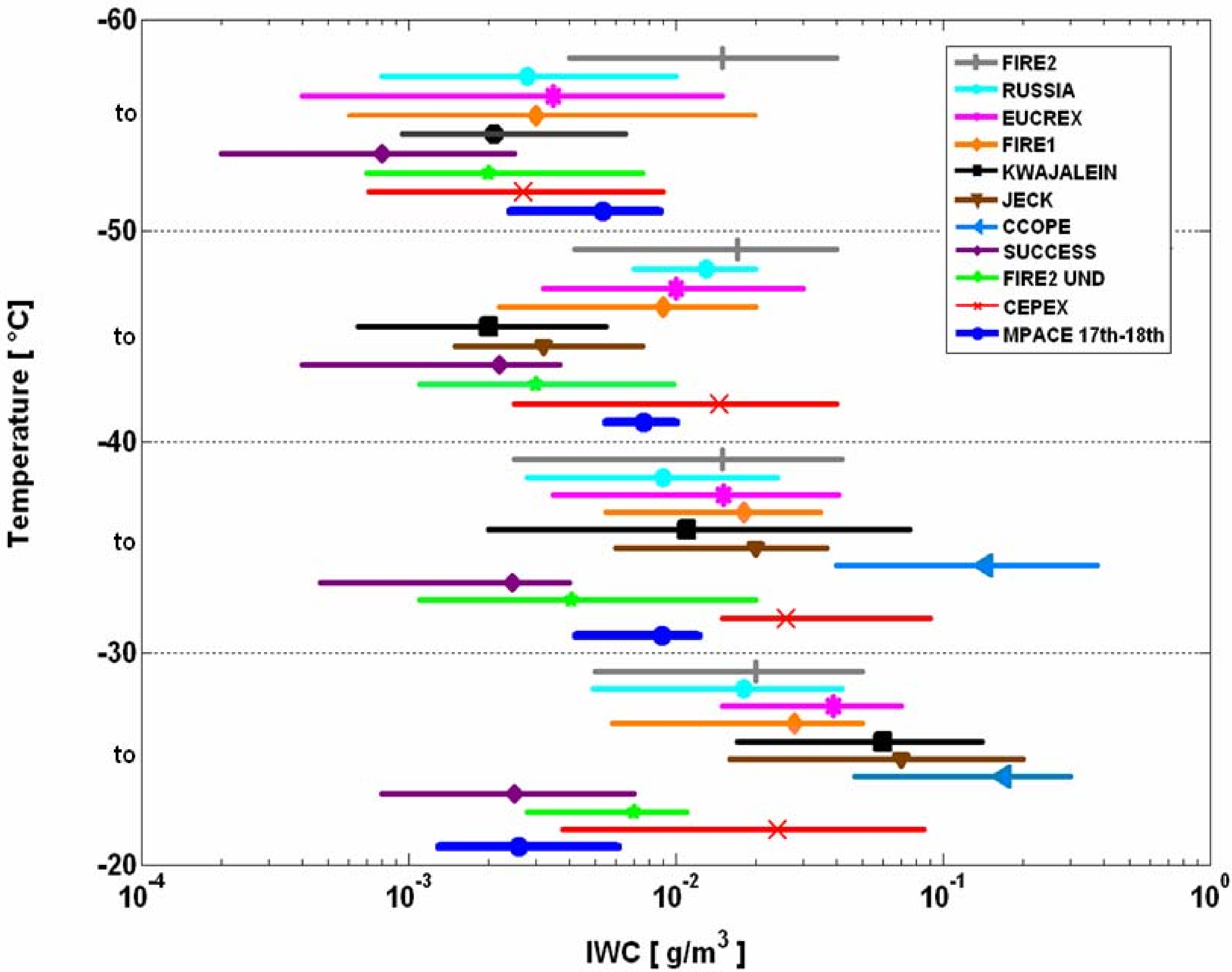
More small particles near cloud top



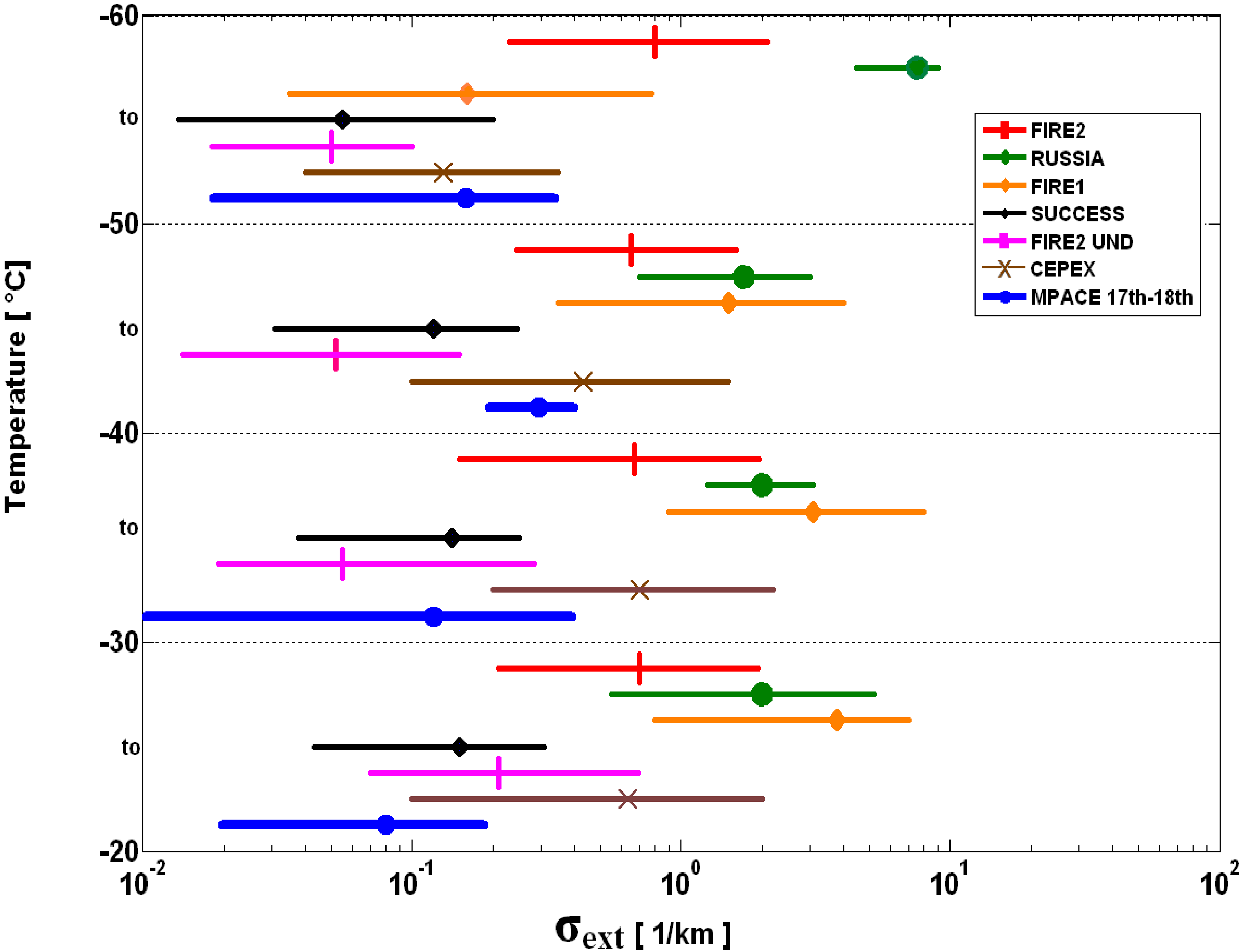
More precipitating ice near cloud base

Analysis Strategy

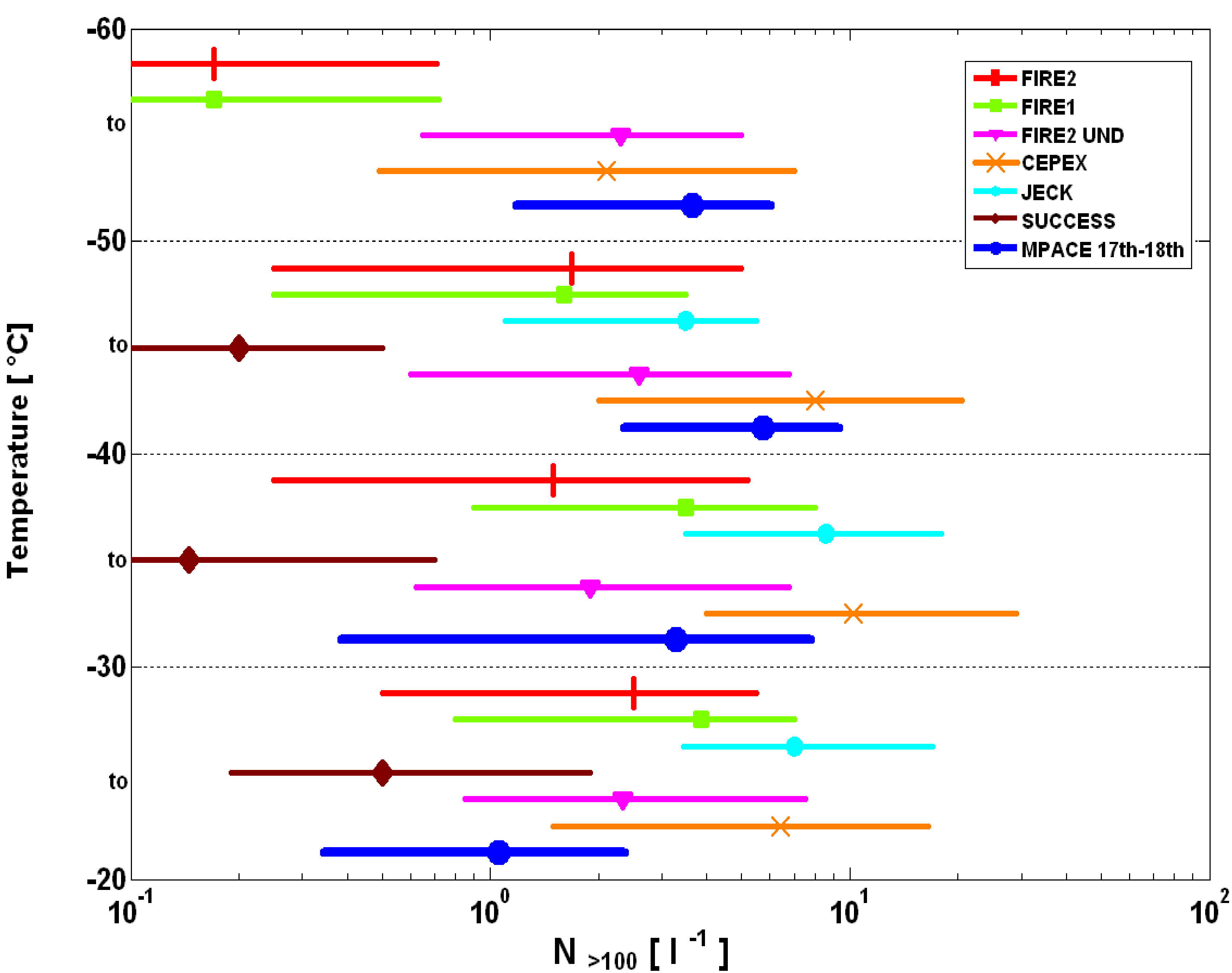
- **Can use size distributions and particle shapes to calculate bulk properties of arctic cirrus**
- **Compare them as function of temperature against observations in other locations**



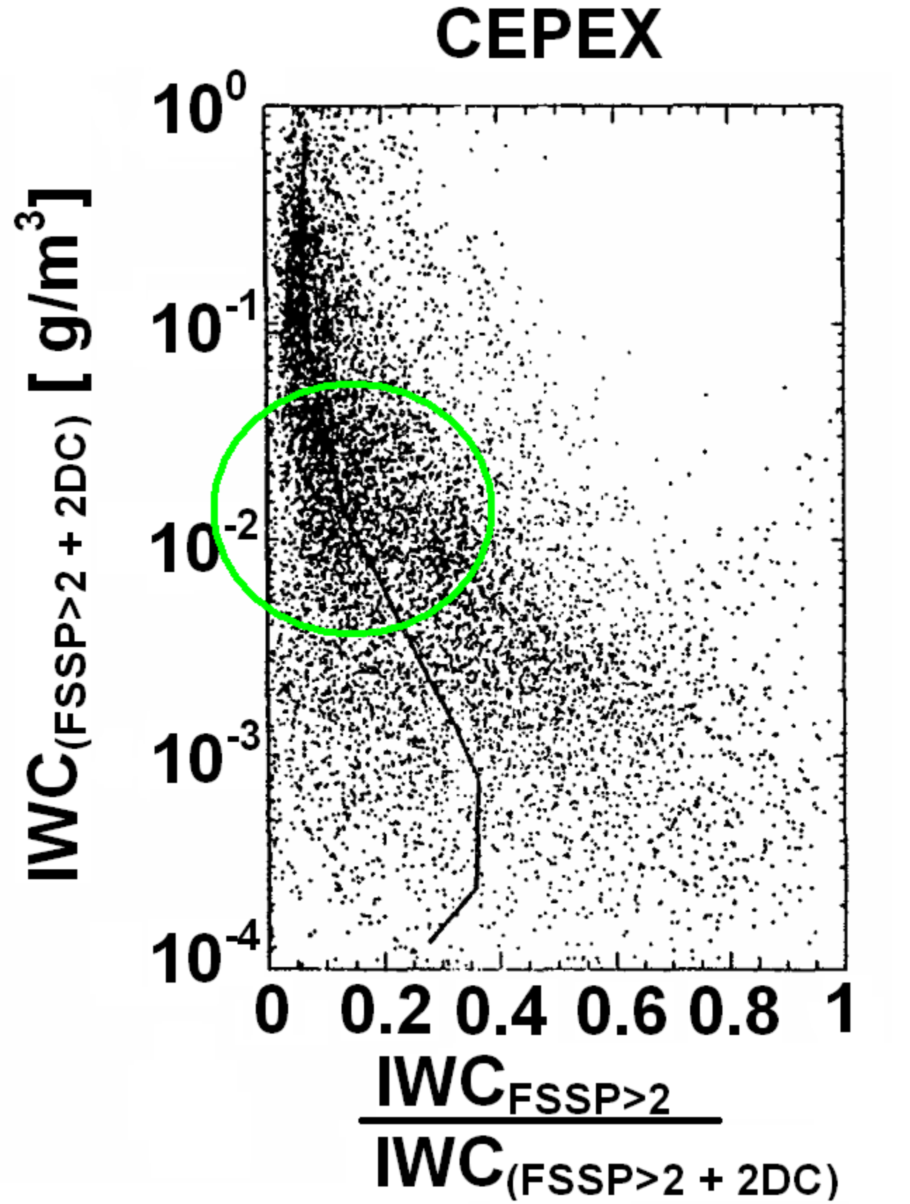
-60
-50
-40
-30
-20
to
to
to
to
Temperature [°C]
10^-4
10^-3
10^-2
10^-1
10^0
IWC [g/m^3]
FIRE2
RUSSIA
EUCREX
FIRE1
KWAJALEIN
JECK
CCOPE
SUCCESS
FIRE2 UND
CEPEX
MPACE 17th-18th

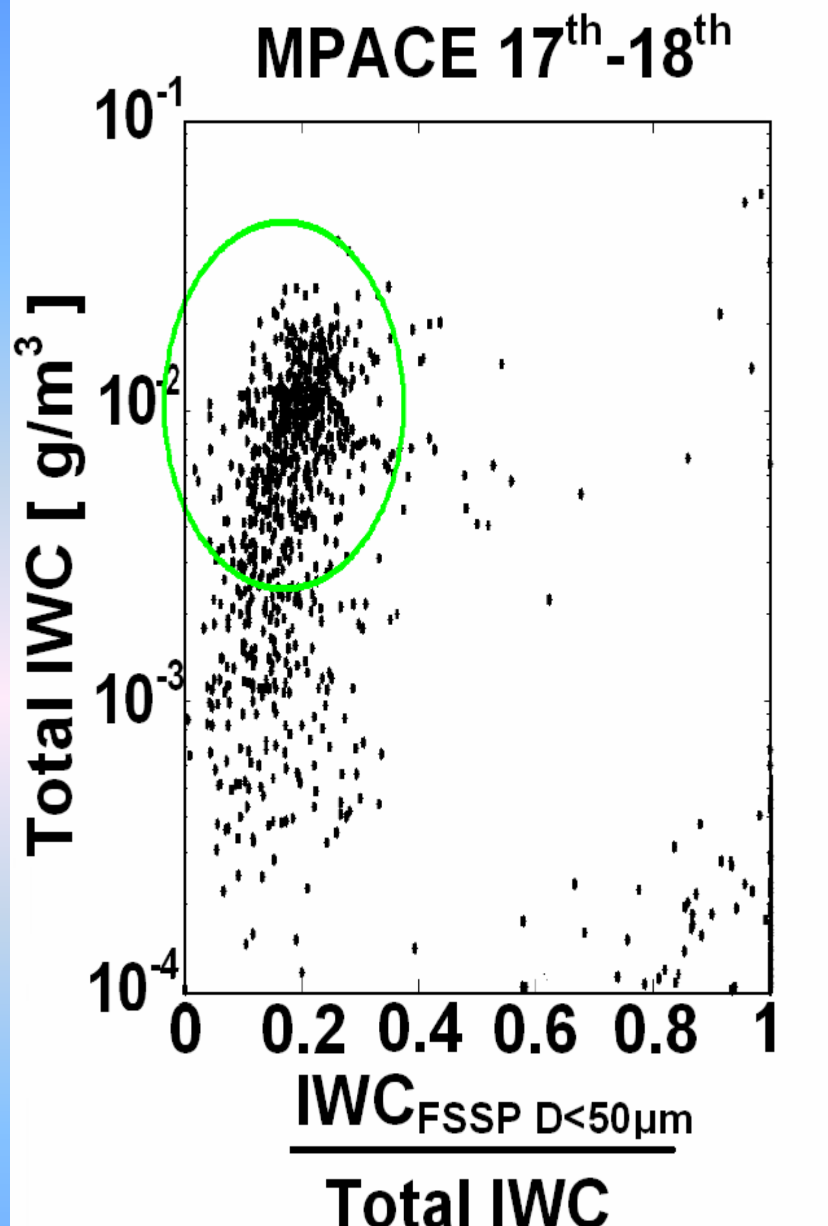


-60
to
-50
to
-40
to
-30
to
-20
Temperature [°C]
FIRE2
RUSSIA
FIRE1
SUCCESS
FIRE2 UND
CEPEX
MPACE 17th-18th
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
σ_{ext} [1/km]



-60
-50
-40
-30
-20
to
to
to
to
Temperature [°C]
10^{-1}
10^{0}
10^{1}
10^{2}
$N_{>100}$ [l^{-1}]
FIRE2
FIRE1
FIRE2 UND
CEPEX
JECK
SUCCESS
MPACE 17th-18th





Contributions of small crystals from FSSP are similar for M-PACE and tropical CEPEX data sets: real result or instrument artifact?

Summary

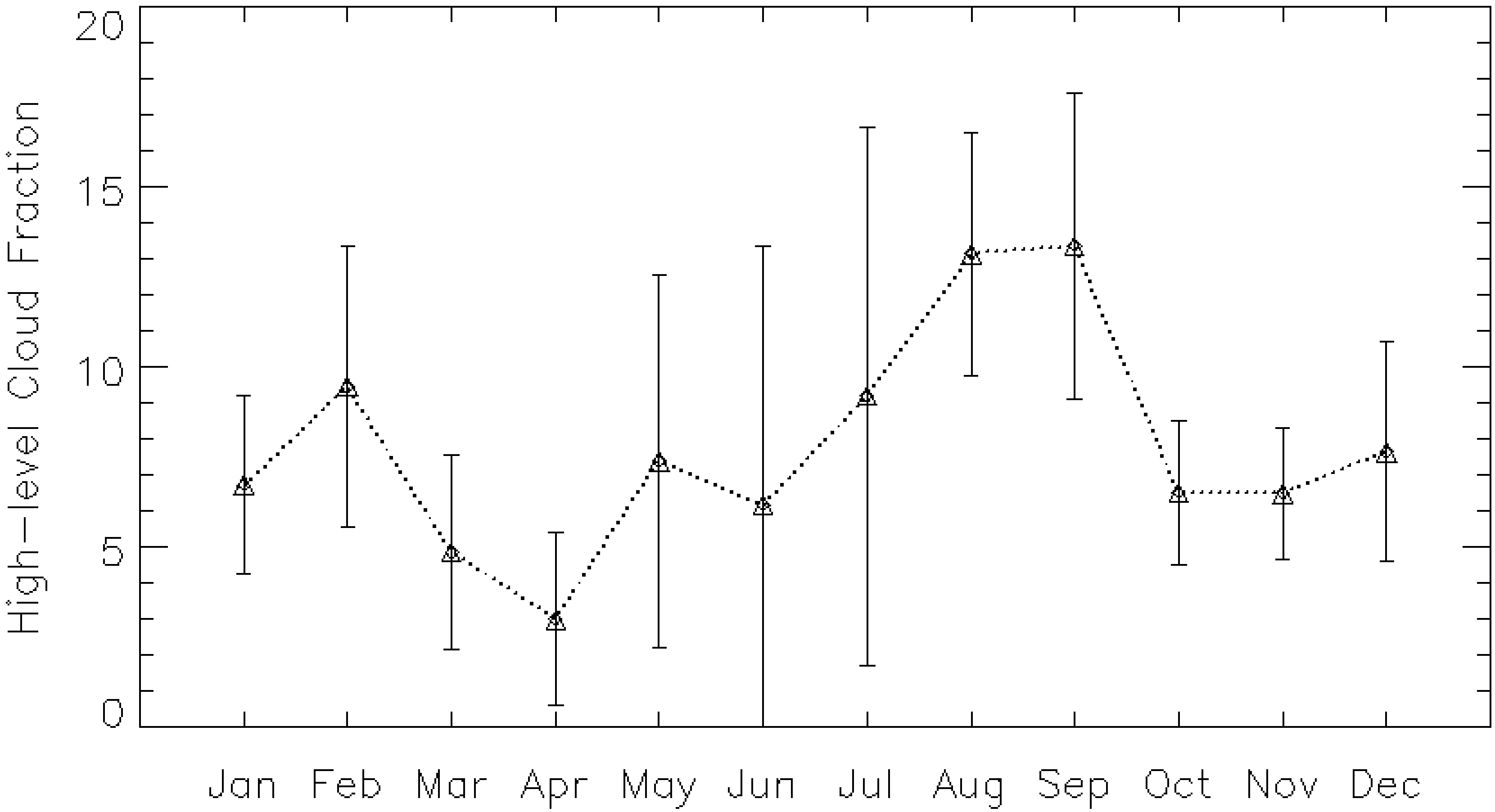
1. Bullet rosettes dominate habits as in some synoptically generated mid-latitude cirrus & tropical regenerating cells.
2. Nucleation zone, growth zone and sublimation zone seen in arctic cirrus cases analyzed.
3. IWC, σ and $N_{>100}$ within range of other cirrus observations even though lower than other locations for $T > -40^{o}C$
4. Do not see drastically different small crystal contributions from M-PACE & other data sets
5. More observations in arctic cirrus needed to determine what controls shapes and size distributions


QUESTIONS?

What do we need to know about cirrus?

- Sub-grid variability of cloud components
  - 100 km grid boxes; probability distributions
- Cloud macrophysical quantities
  - Thickness, heights, coverage, overlap schemes
- Cloud microphysical quantities
  - Distributions of particle size, phase and shape
  - IWP, τ_e, g, P(Θ), ω_0 & vertical profiles

Figure Courtesy Z. Wang



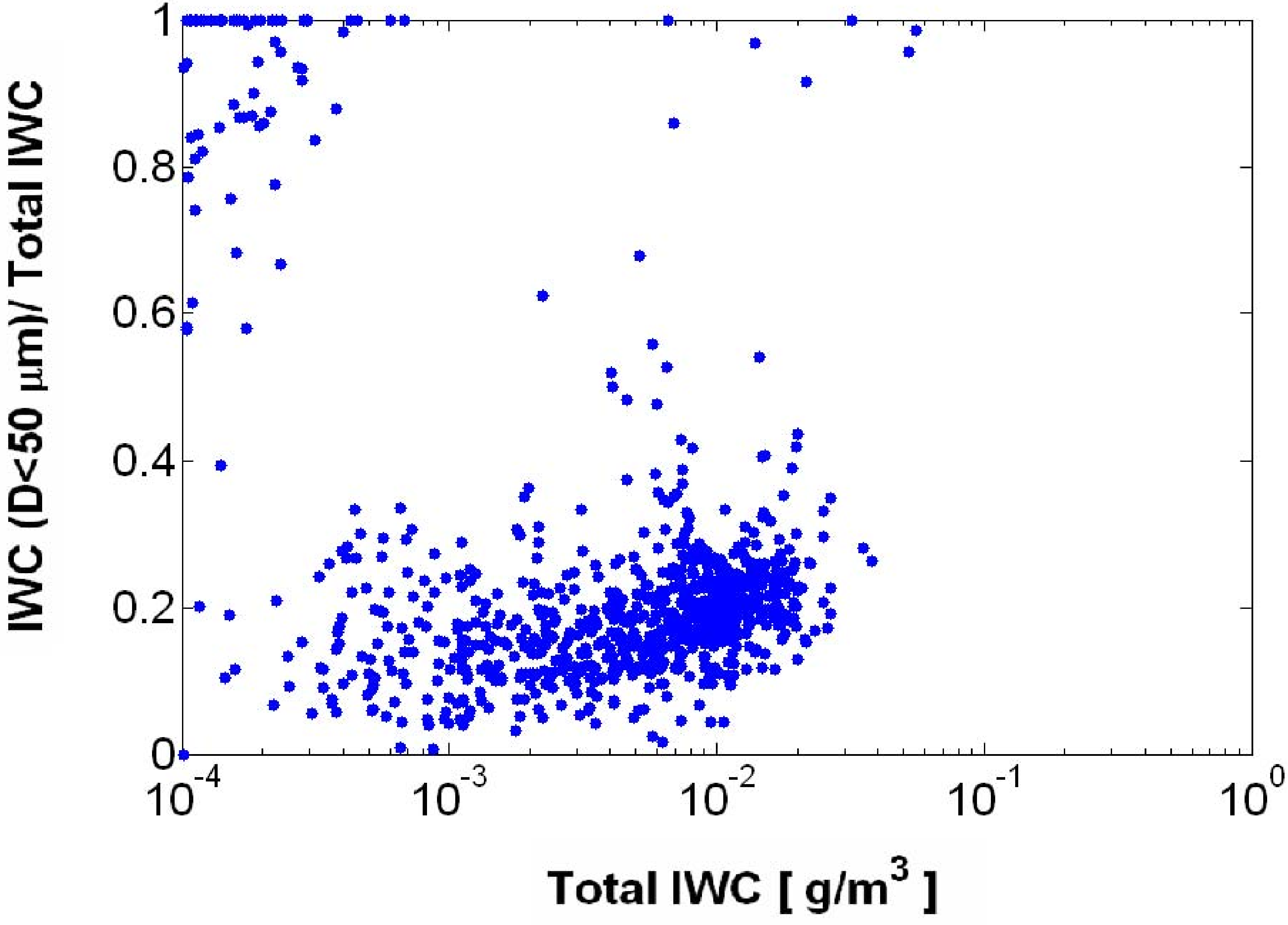
Ground-based observations also show cirrus frequencies of between 5 and 15%

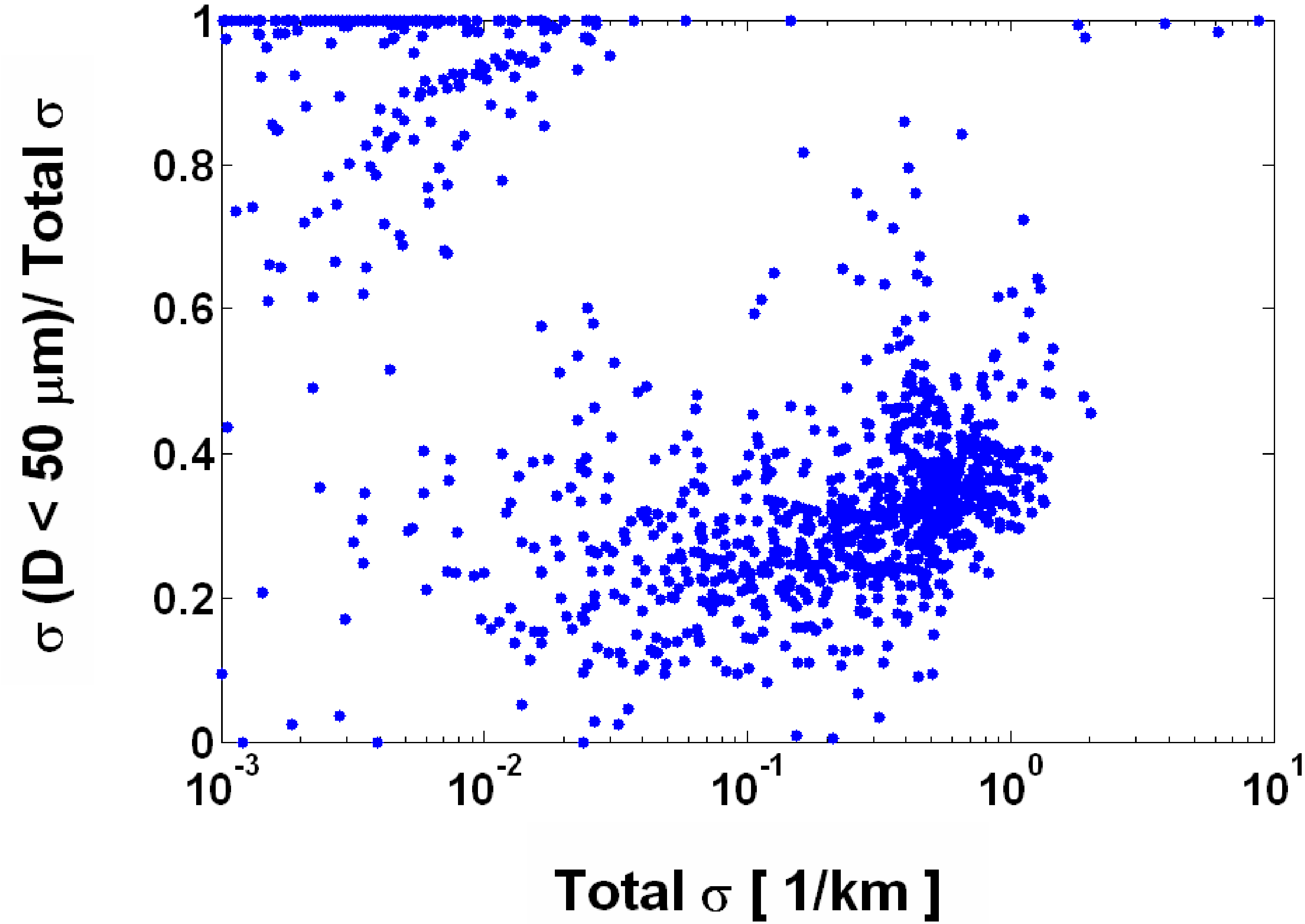
Proteus Instrumentation

- **Active Remote Sensing**
  - **1.053 μm 5kHz lidar (48 μJ/pulse)**
- **Passive Remote Sensing**
  - **Broadband Radiometers (.3-4 and 4-40 μm)**
  - **Spectral Radiance Package (VIS, NIR, A-band)**
  - **Solar Spectral Flux Radiometer (300-1700 nm)**
  - **Diffuse Field Cameras (VIS & NIR)**
  - **Infrared Thermometers (8-10 μm; 9.6 to 11.5 μm)**
  - **Scanning High-Resolution Interferometer Sounder (3.3-18 μm)**
- **In-situ Microphysics & State Parameters**
  - **CAPS (CAS: .35-50 μm; CIP: 25-1550 μm; LWCD .1-3 g m^{-3})**
  - **Cloud Integrating Nephelometer (g, β_{ext})**
  - **Nevzorov Probe (LWC, TWC: .003 to 3 g m^{-3})**
  - **Video Ice Particle Sampler (10-200 μm)**
  - **MET package (laser & cryogenic hygrometers, state parameter**

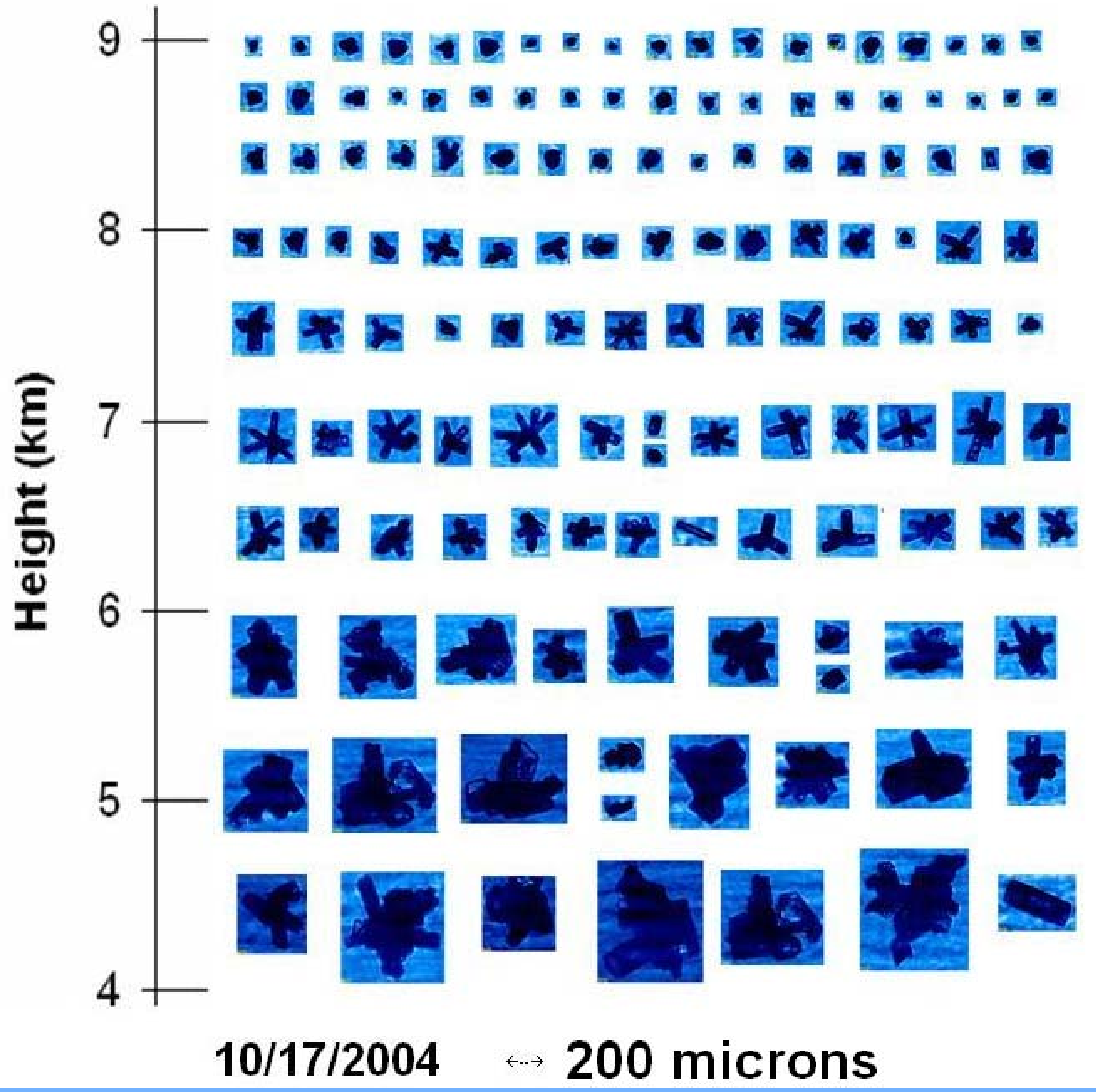
Citation Instrumentation

Instrument	Derived Parameters	Nominal Range	Comments
FSSP	PSDs, N_t, LWC	1 – 55 μm	Uncertain in mixed-phase
1DC	PSDs, N_t, LWC	20 –620 μm	Use between 50-120 μm
CPI	Images (2.3 μm resolution); habits	15-2000 μm	Small sample volume
2DC	PSDs, N_t, LWC/ IWC, images	32-960 μm	125 < D < 960 μm
HVPS	PSDs, N_t, LWC/ IWC, images	400 – 40000 μm	D > 960 μm
DMT CSI	TWC	Bulk measure	
King	LWC	Bulk measure	
RICE	Supercooled H_2O	Presence	

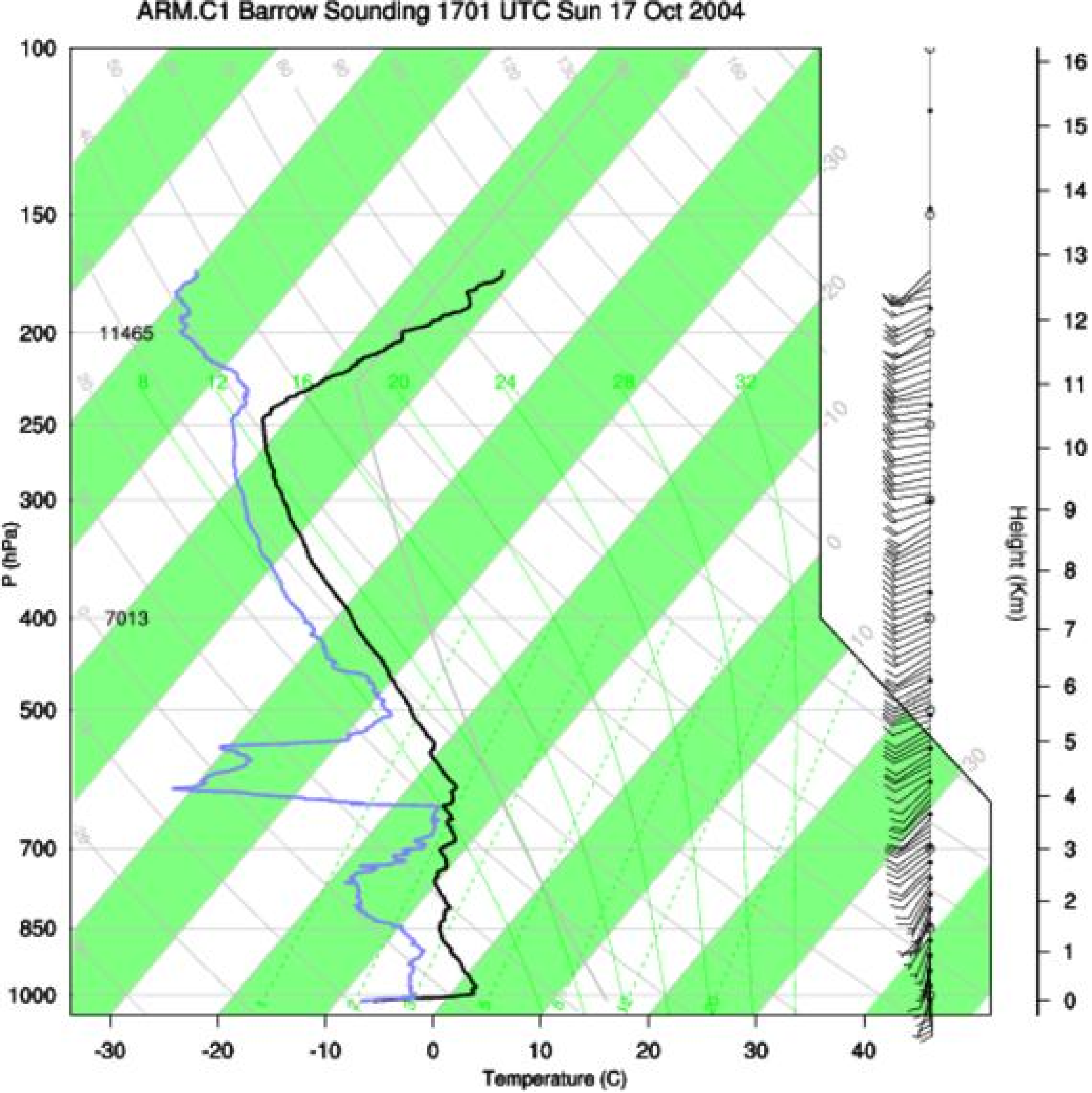

IWC (D<50 μm)/ Total IWC
0
0.2
0.4
0.6
0.8
1
10^-4
10^-3
10^-2
10^-1
10^0
Total IWC [g/m^3]



σ (D < 50 μm)/ Total σ
1
0.8
0.6
0.4
0.2
0
10-3
10-2
10-1
100
101
Total σ [1/km]

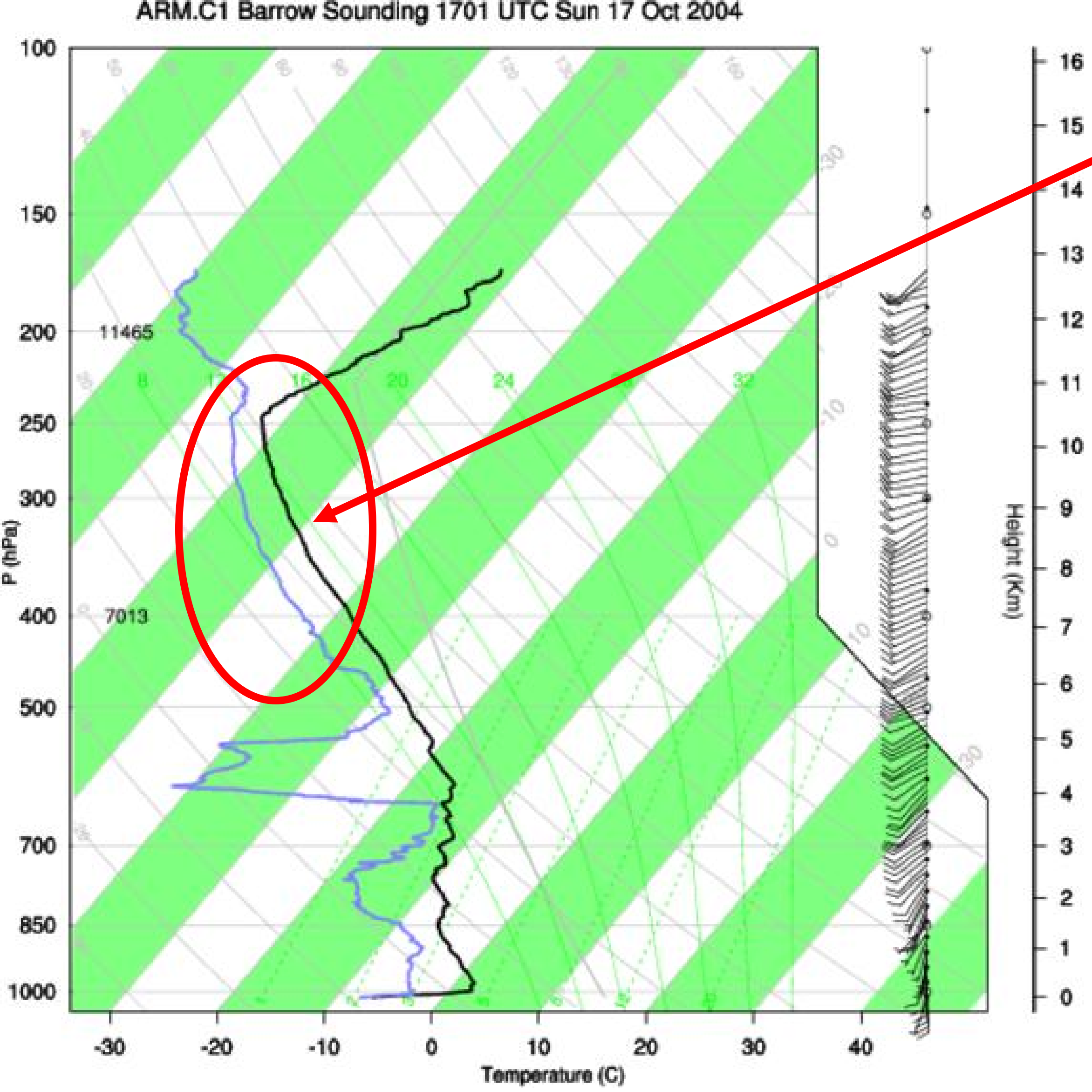


Bullet rosettes seem to dominate crystal shapes



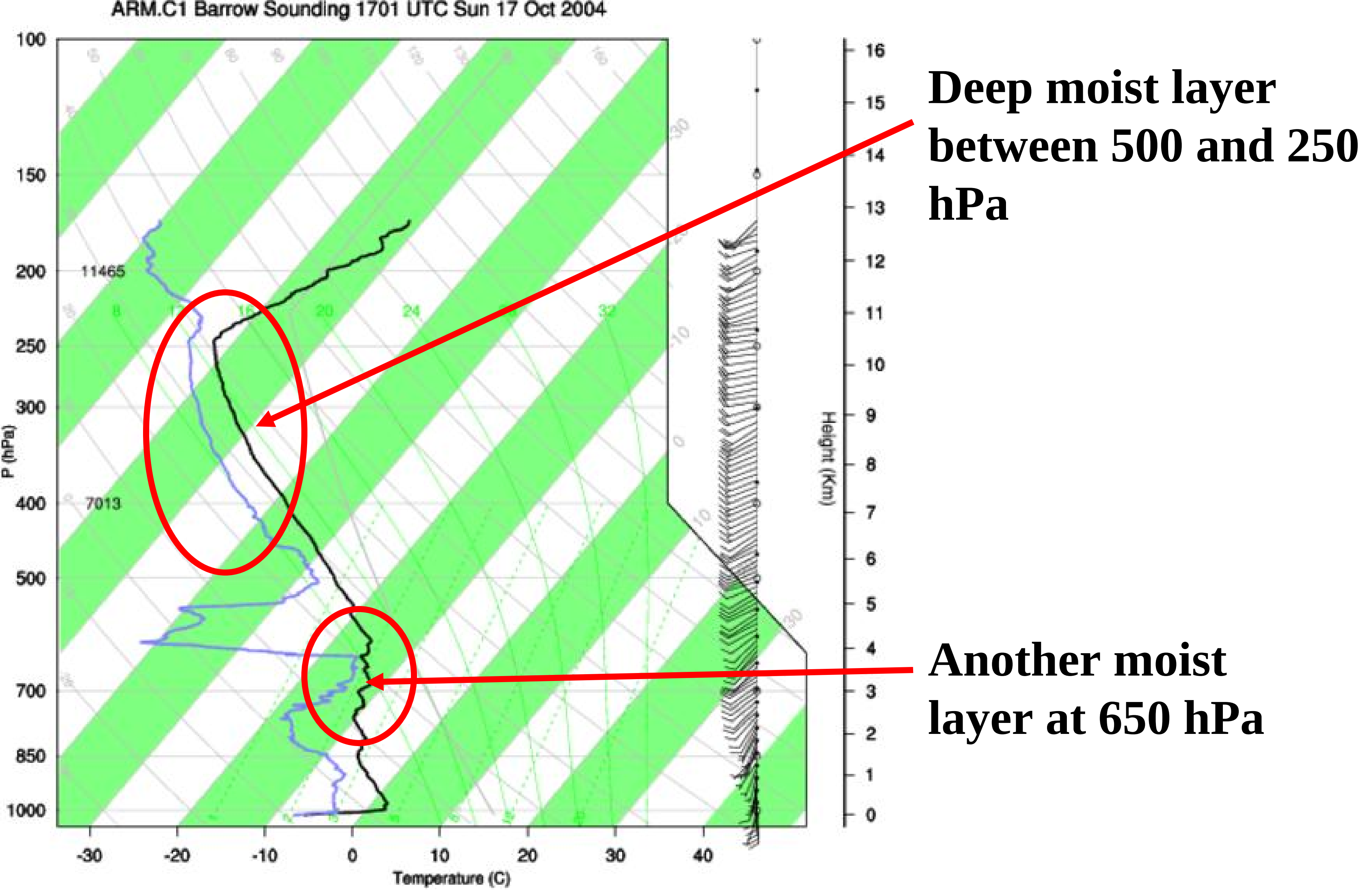
Verlinde et al. 2007

Oct. 17 & 18: Mid- and upper- level clouds in advance of strong front approaching Barrow



Deep moist layer between 500 and 250 hPa

Oct. 17 & 18: Mid- and upper- level clouds in advance of strong front approaching Barrow



Oct. 17 & 18: Mid- and upper- level clouds in advance of strong front approaching Barrow