On Characterizing the Conditions Where Columnar and Needle-Like Crystals are Found in Tropical Maritime Convection during ICE-T

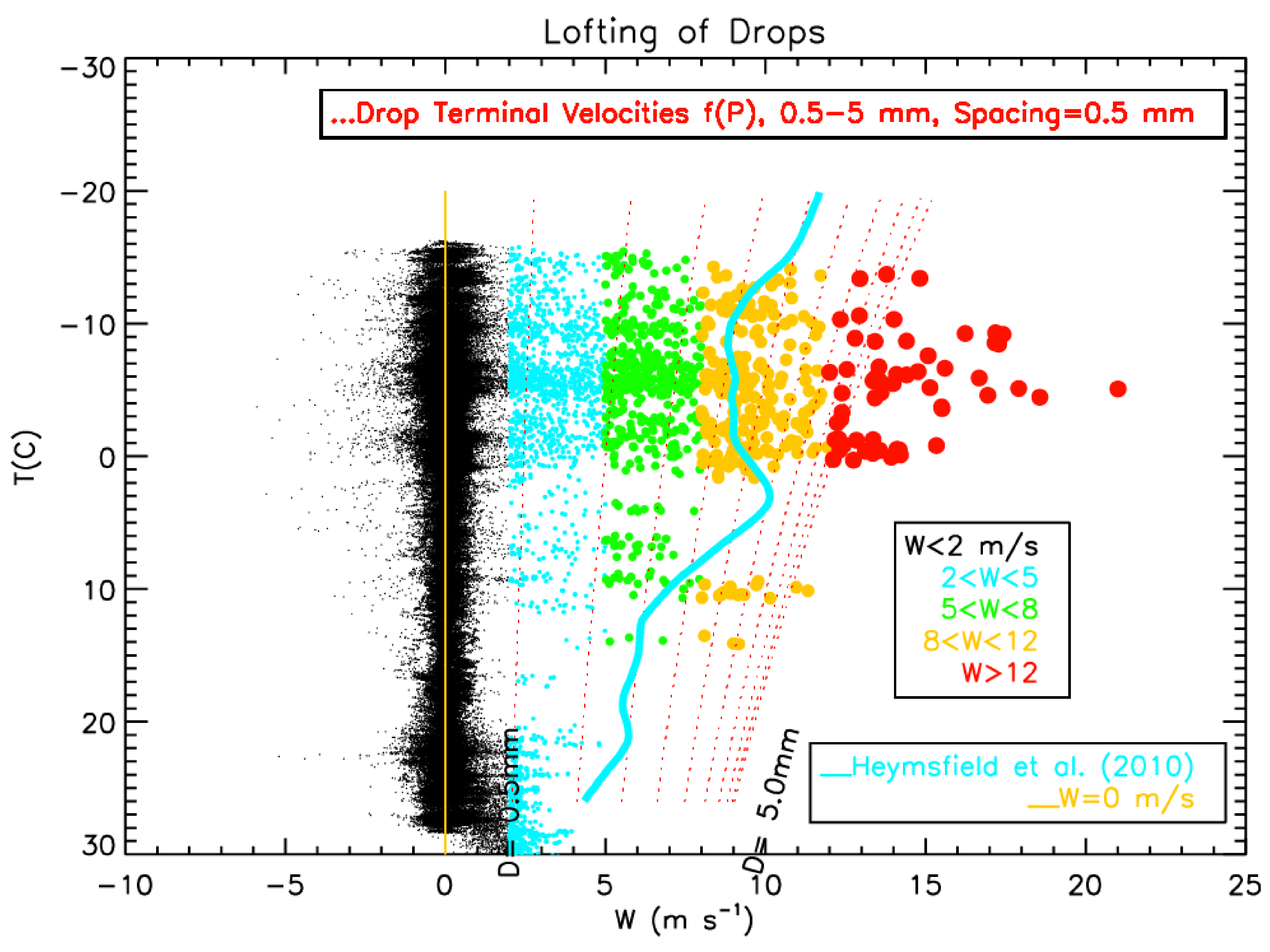
by

Andrew Heymsfield

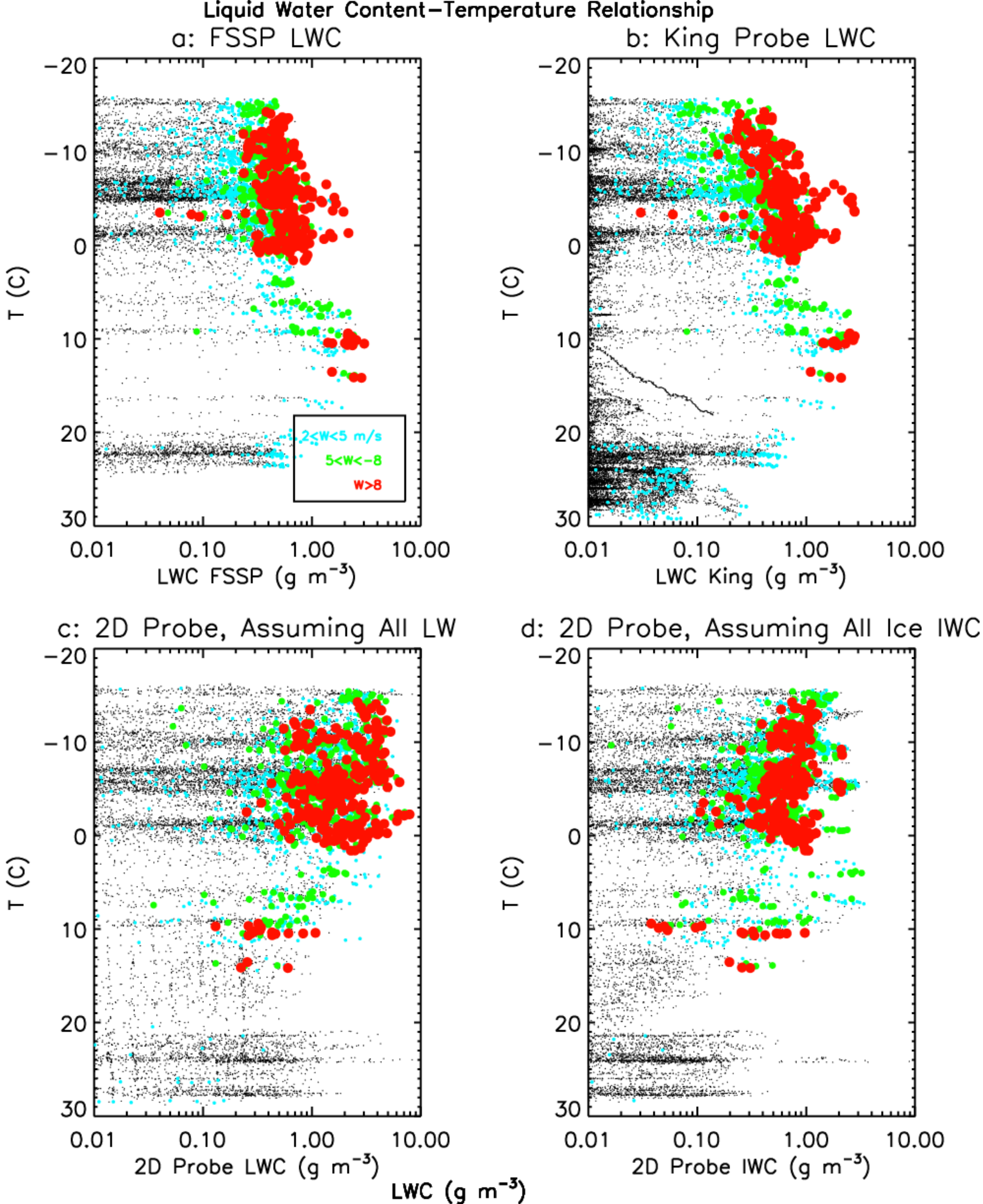
NCAR, Boulder CO

Secondary Ice Production

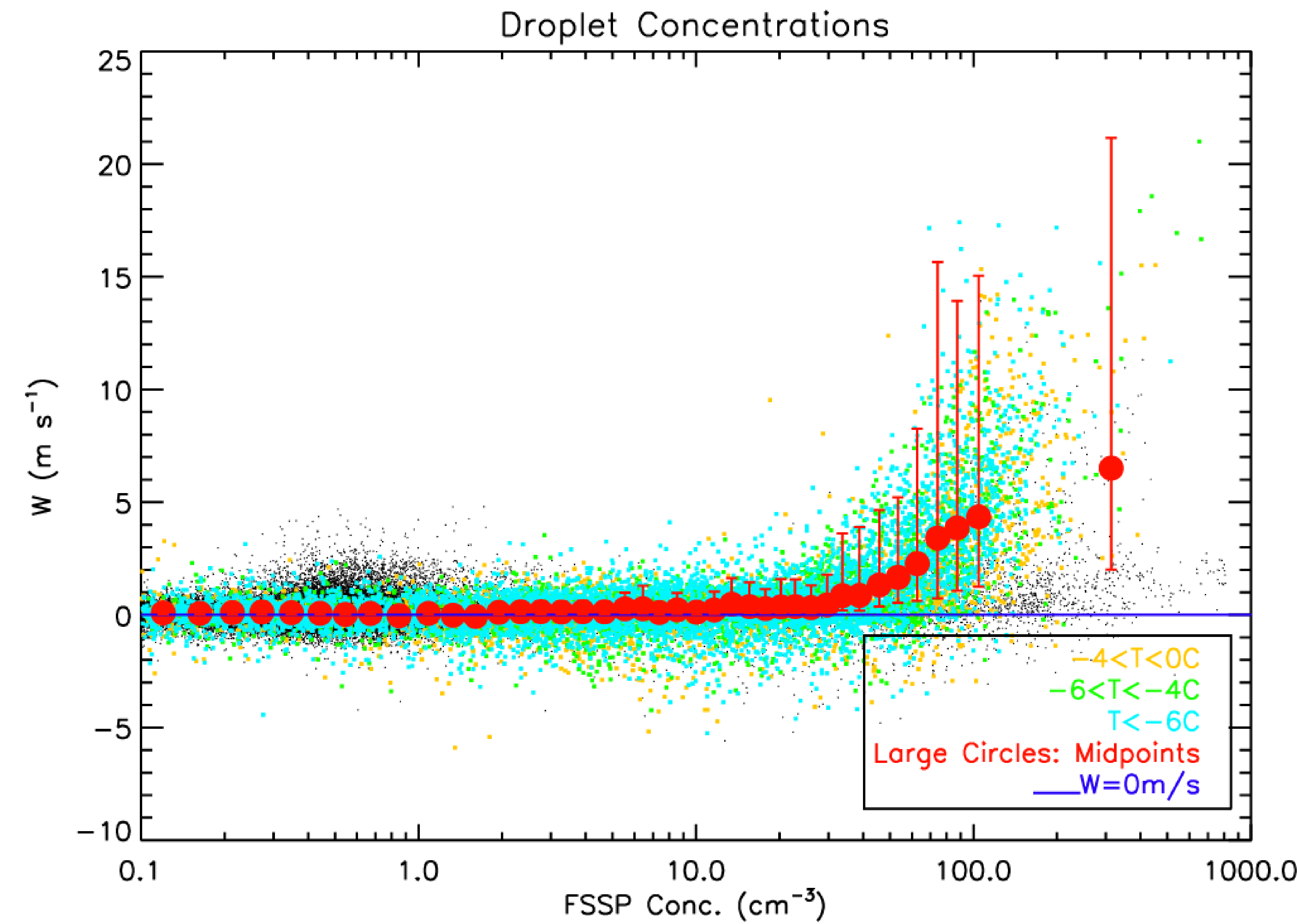
- The conditions for the production of secondary ice particles in clouds in the critical temperature range -3 to -8C where primary ice nuclei are relatively scarce has been studied in natural and laboratory clouds and is thought to involve riming of ice particles by supercooled drops.
- Using a ice-covered rod circularly rotating through a supercooled laboratory cloud that simulated the riming of a graupel particle in a natural cloud, Hallett and Mossop (1974) indeed documented the production of secondary ice particles at temperatures from -4 to -6C.
- Heymsfield and Mossop (1984) demonstrated that what matters for the splinter formation mechanism is the surface temperature of the riming ice particle rather than the air temperature. For a maximum ice production rate, the surface temperature of the riming ice particle needs to be near -5C.
- The process of ice splinter production by a riming ice particle was photographically recorded by Choularton et al. (1980) and Griggs and Choularton (1983, 1986).
- Secondary ice production occurs in 1/250 collisions of drops w/riming particle but needs >25 micron and <13 micron drops to operate.
- Ice multiplication occurs when large drops collect secondary ice and a chain reaction multiplying the initial secondary ice is thought to occur.

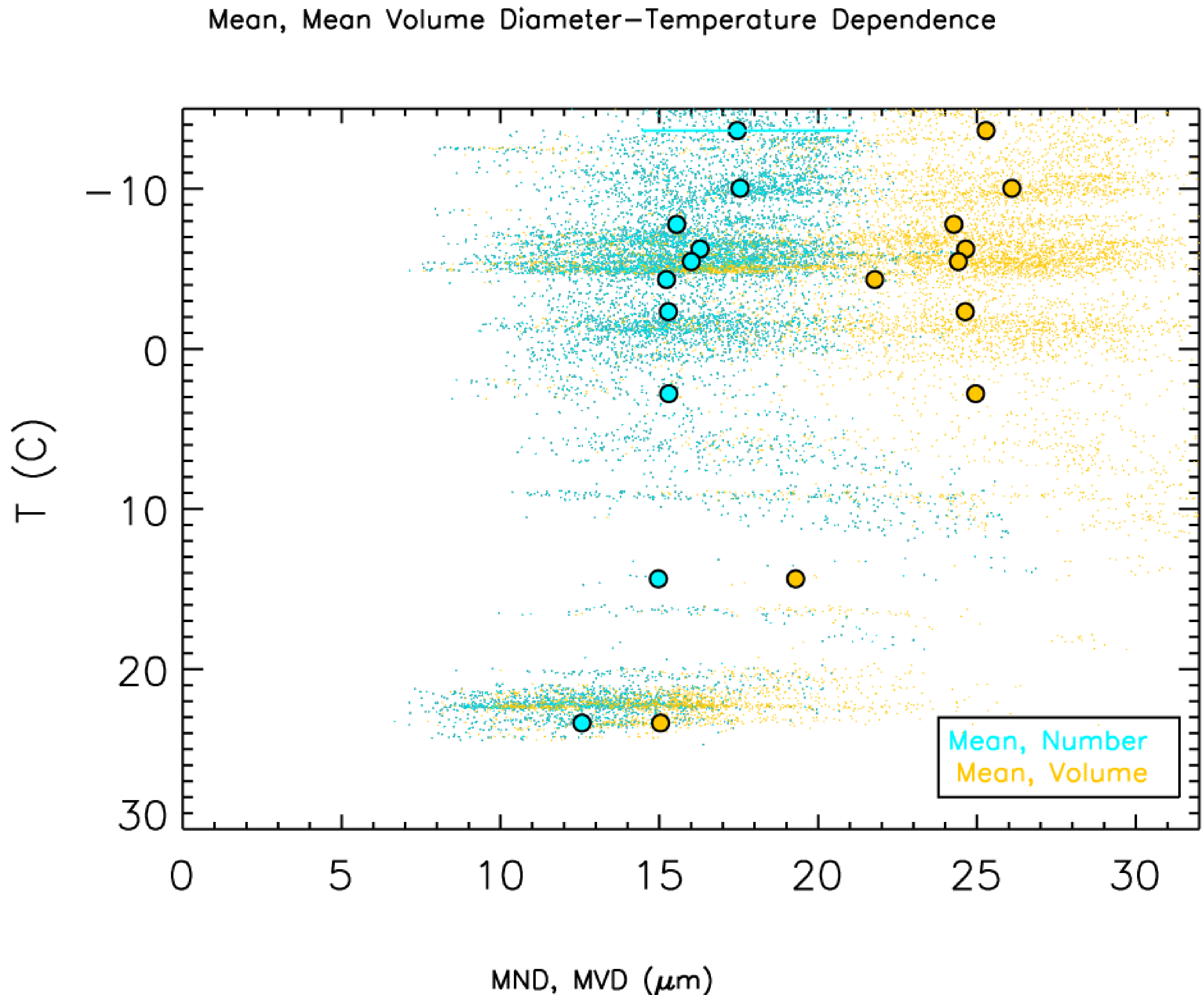


Lofting of Drops
...Drop Terminal Velocities f(P), 0.5–5 mm, Spacing=0.5 mm
W<2 m/s
2<W<5
5<W<8
8<W<12
W>12
__Heymsfield et al. (2010)
__W=0 m/s
D= 0.5mm
D= 5.0mm
T(C)
W (m s⁻¹)
-30
-20
-10
0
10
20
30
-10
-5
0
5
10
15
20
25

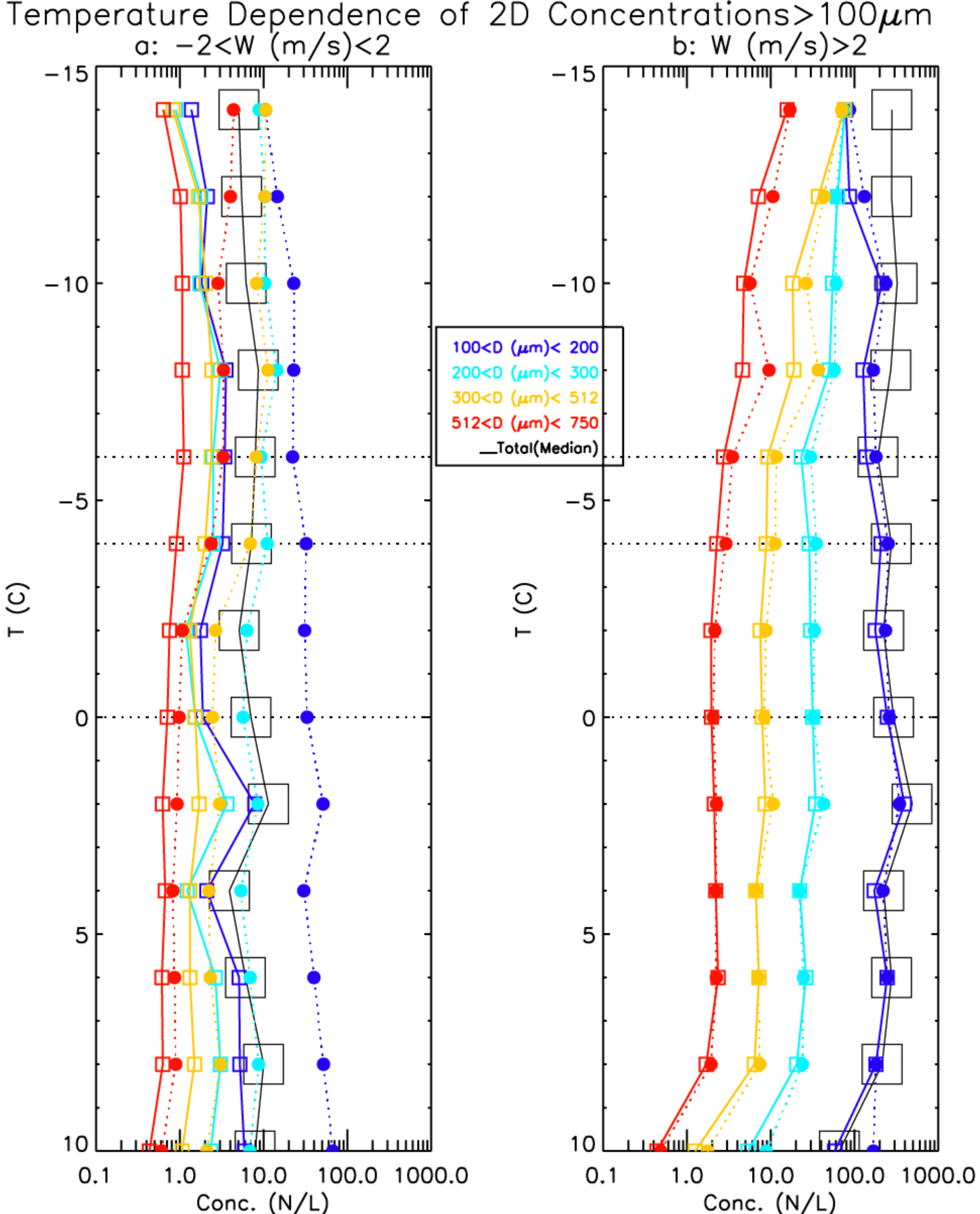


Liquid Water Content–Temperature Relationship
a: FSSP LWC
b: King Probe LWC
c: 2D Probe, Assuming All LW
d: 2D Probe, Assuming All Ice IWC
T (C)
LWC FSSP (g m⁻³)
LWC King (g m⁻³)
2D Probe LWC (g m⁻³)
2D Probe IWC (g m⁻³)
LWC (g m⁻³)
2<W<5 m/s
5<W<-8
W>8


Droplet Concentrations
W (m s^{-1})
FSSP Conc. (cm^{-3})
25
20
15
10
5
0
−5
−10
0.1
1.0
10.0
100.0
1000.0
−4<T<0C
−6<T<−4C
T<−6C
Large Circles: Midpoints
W=0m/s



Mean, Mean Volume Diameter–Temperature Dependence
–10
0
10
20
30
T (C)
0
5
10
15
20
25
30
MND, MVD (μm)
Mean, Number
Mean, Volume



Temperature Dependence of 2D Concentrations>100μm
a: −2<W (m/s)<2
b: W (m/s)>2
T (C)
Conc. (N/L)
100<D (μm)< 200
200<D (μm)< 300
300<D (μm)< 512
512<D (μm)< 750
Total(Median)

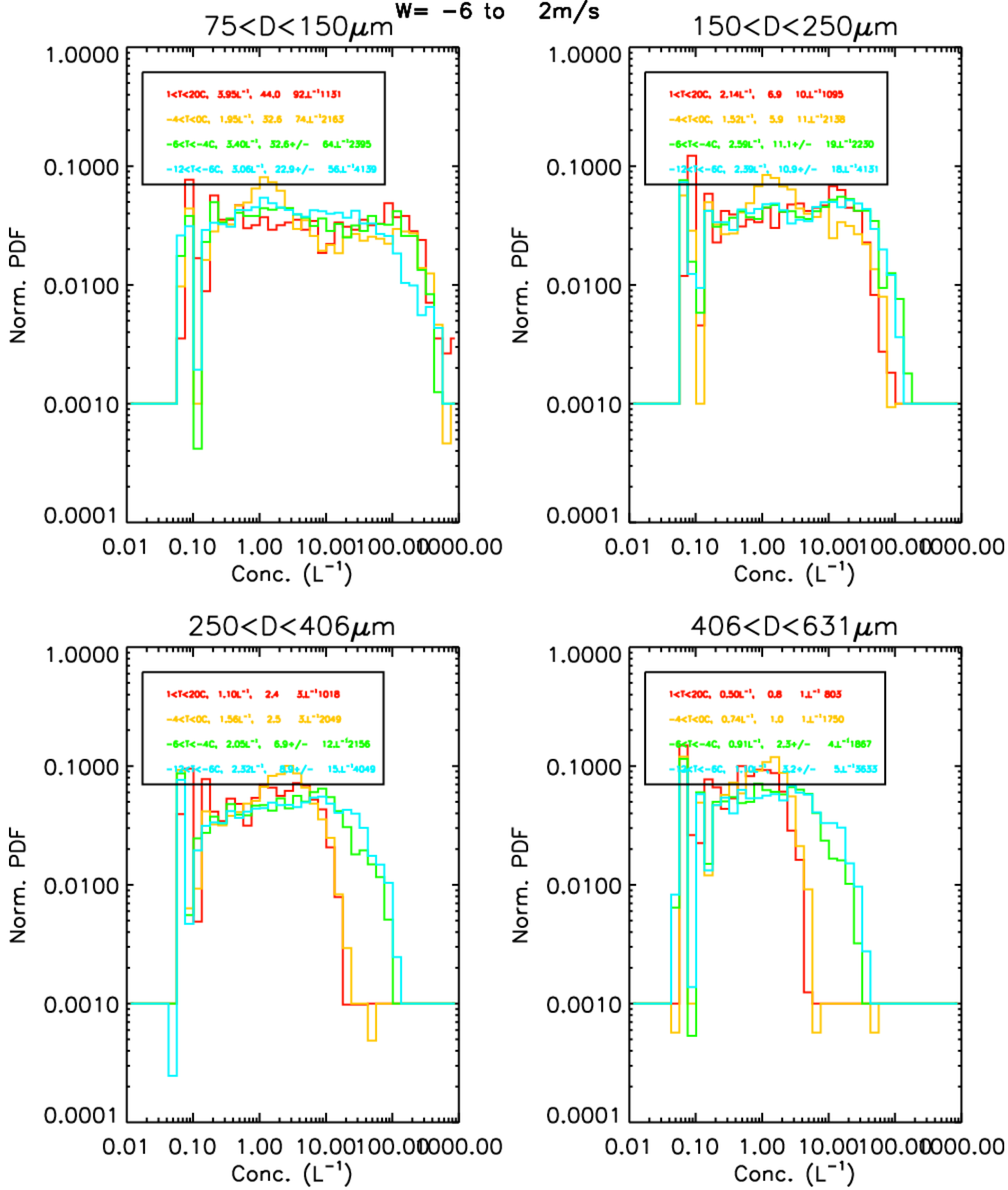
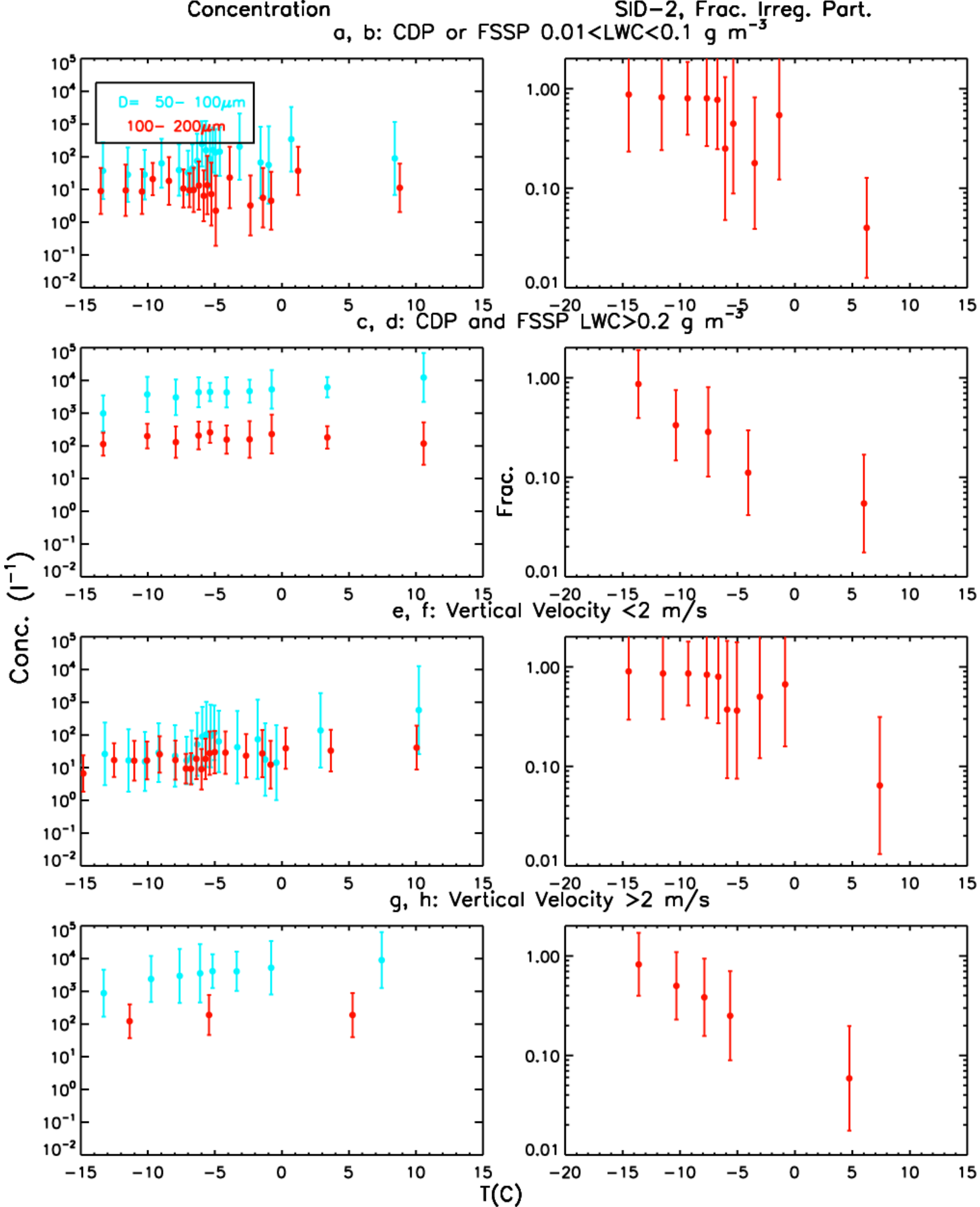
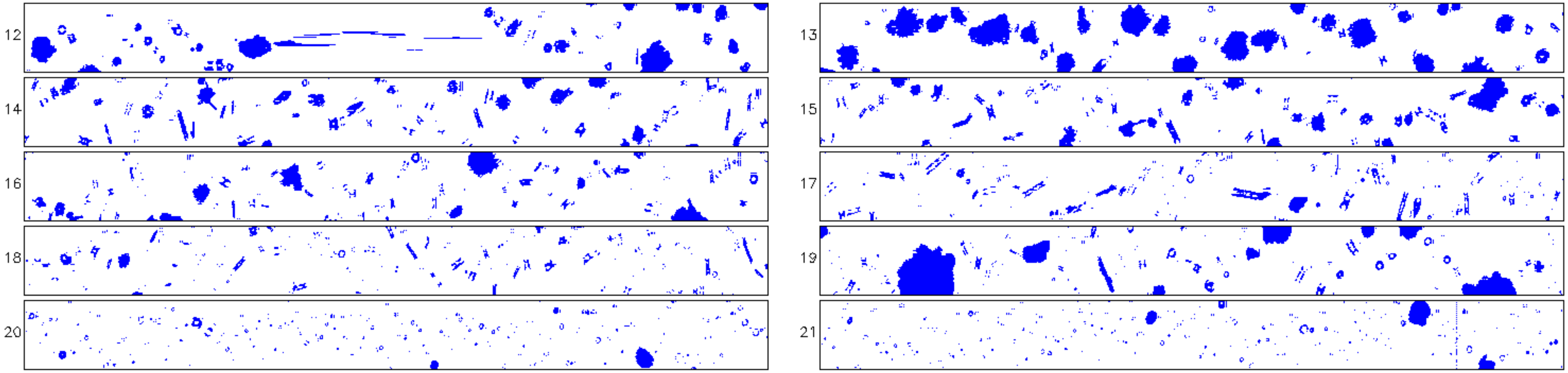
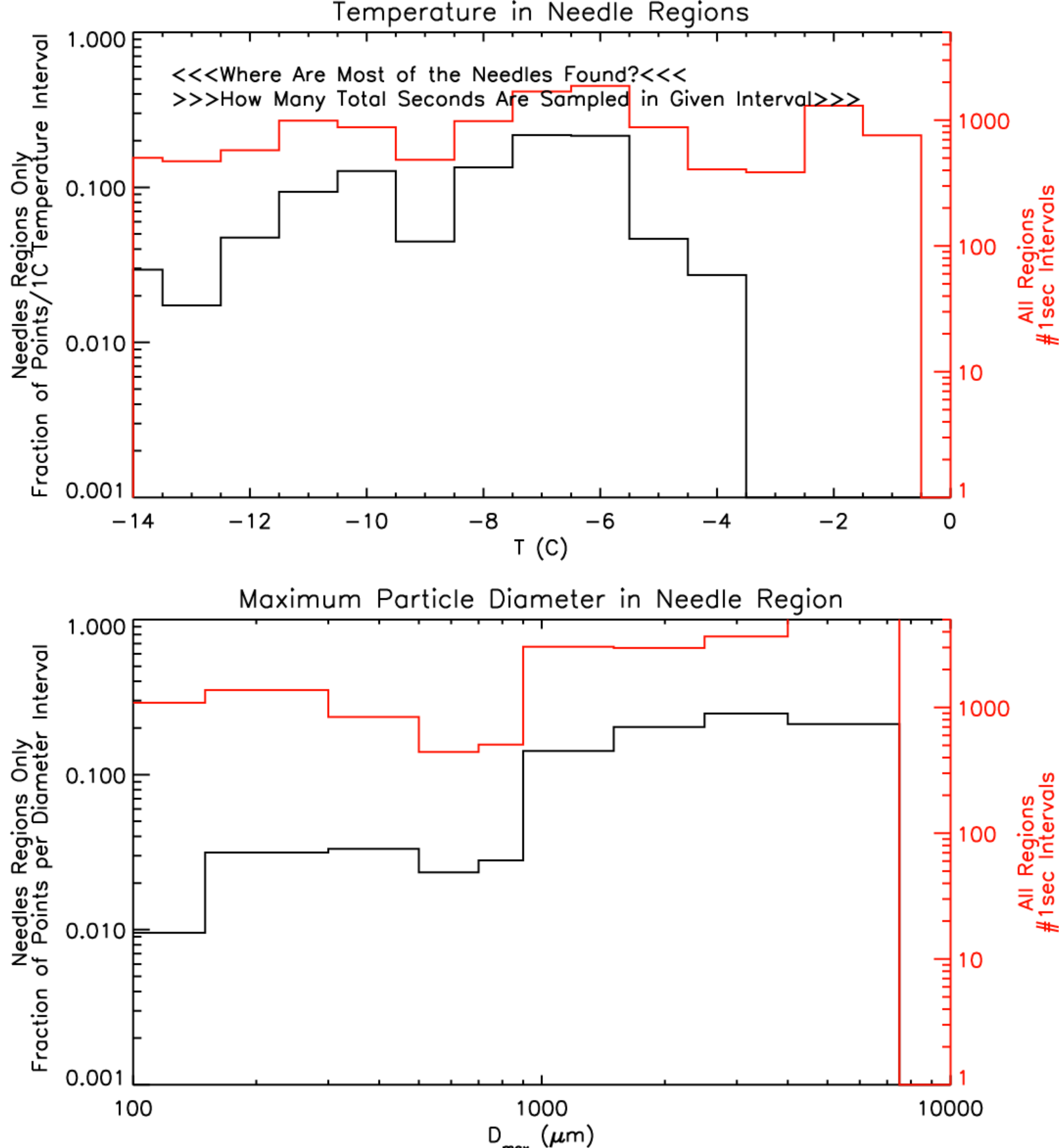


Figure 8 shows the distribution of concentrations of particles in (a-d) different size ranges for temperatures of 0 to -4C, -4 to -6C, and -6 to -12C. In each panel, normalized PDFô s are shown in 40 logarithmically spaced concentration bins, so that the total of all bins=1. Median concentrations and mean and standard deviations are shown. This is for Vertical Velocities below 2 m/s

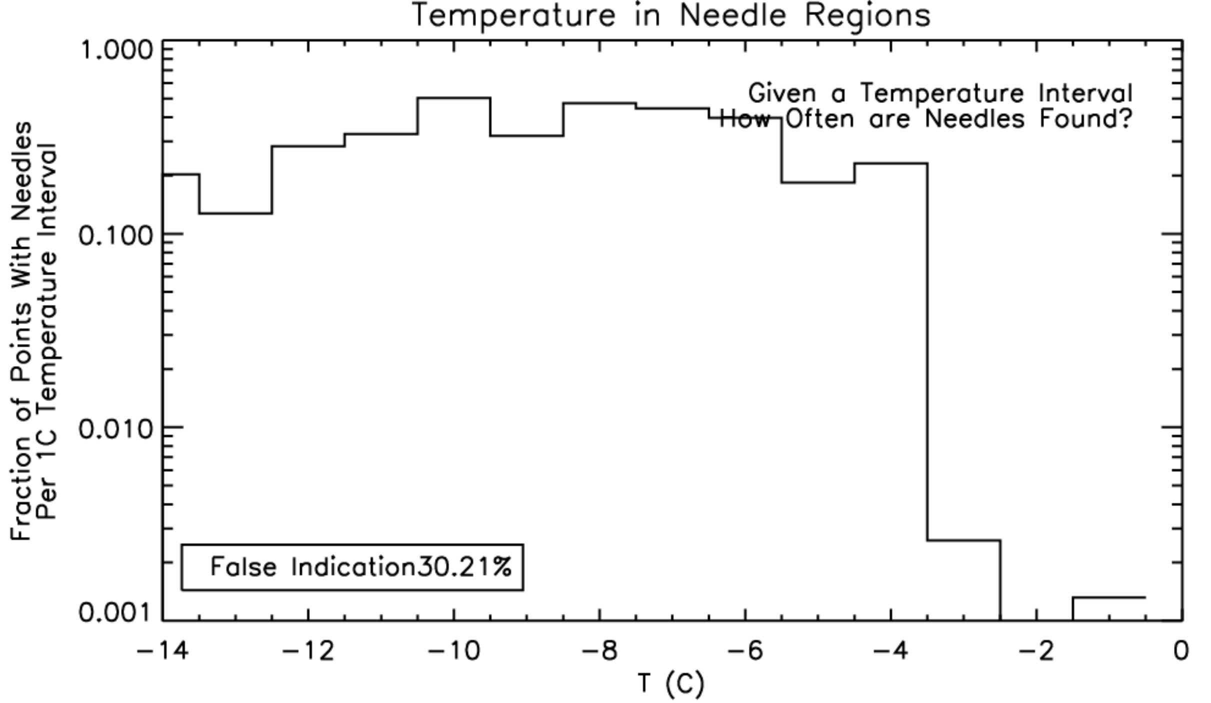
Figure 9 is for Vertical Velocitiess >2 m/s


Concentration
SID−2, Frac. Irreg. Part.
a, b: CDP or FSSP 0.01<LWC<0.1 g m−3
D= 50− 100μm
100− 200μm
c, d: CDP and FSSP LWC>0.2 g m−3
e, f: Vertical Velocity <2 m/s
g, h: Vertical Velocity >2 m/s
Conc. (l−1)
Frac.
T(C)

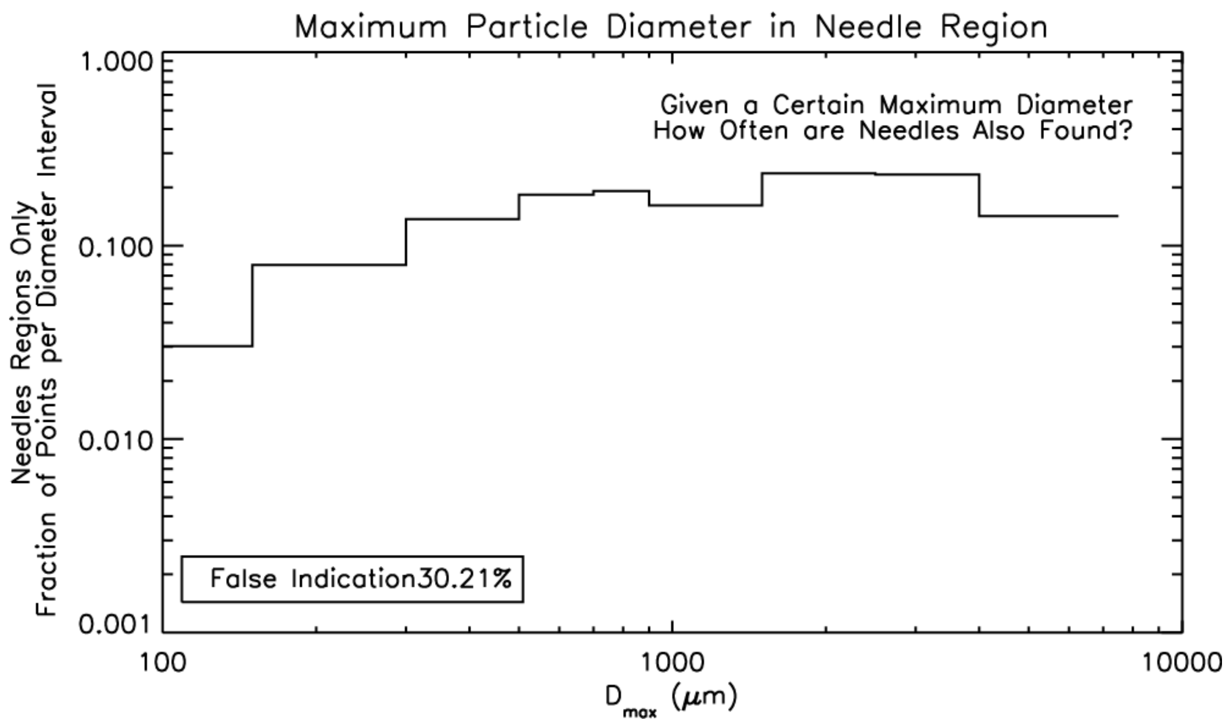




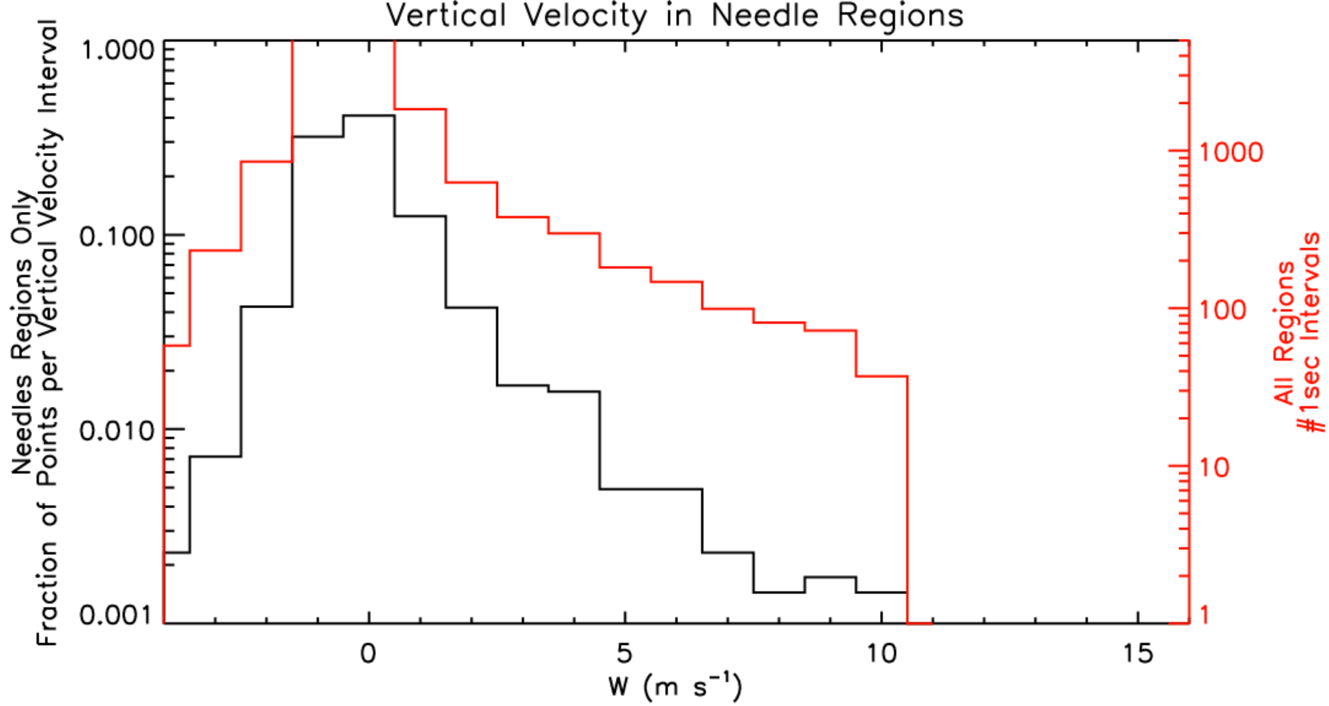
Temperature in Needle Regions
<<<Where Are Most of the Needles Found?<<<
>>>How Many Total Seconds Are Sampled in Given Interval>>>
Needles Regions Only
Fraction of Points/1C Temperature Interval
All Regions
#1sec Intervals
T (C)
1.000
0.100
0.010
0.001
1000
100
10
1
−14
−12
−10
−8
−6
−4
−2
0
Maximum Particle Diameter in Needle Region
Needles Regions Only
Fraction of Points per Diameter Interval
All Regions
#1sec Intervals
D max (μm)
100
1000
10000

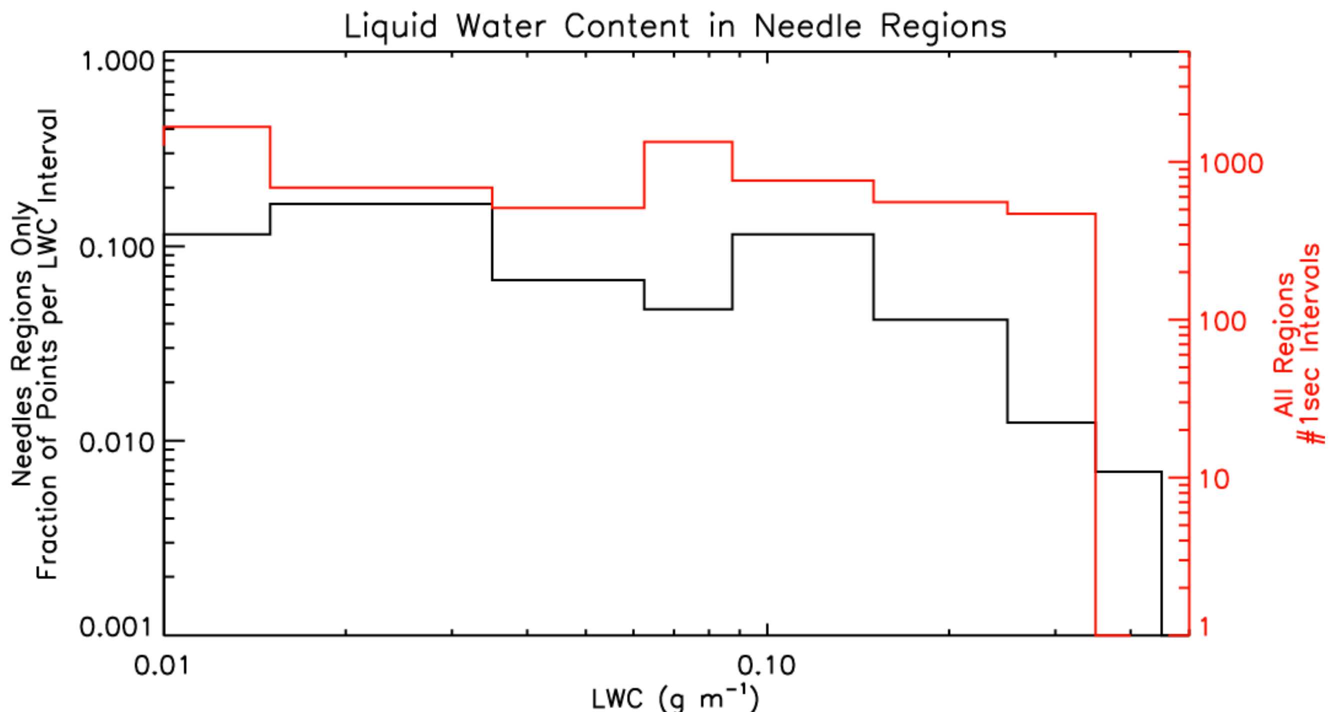


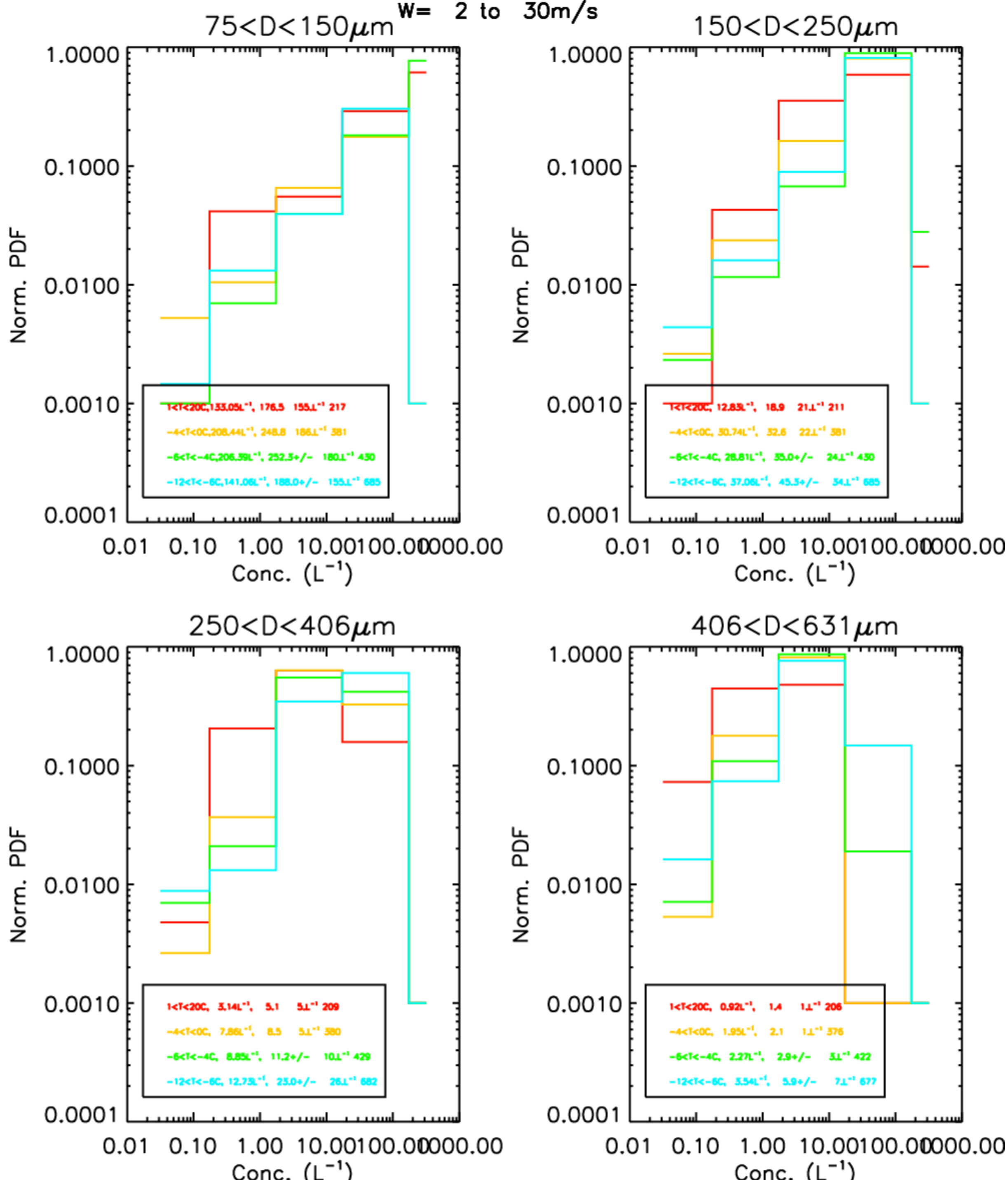
Temperature in Needle Regions
Given a Temperature Interval
How Often are Needles Found?
Fraction of Points With Needles
Per 1C Temperature Interval
False Indication30.21%
1.000
0.100
0.010
0.001
−14
−12
−10
−8
−6
−4
−2
0
T (C)



Maximum Particle Diameter in Needle Region
Given a Certain Maximum Diameter
How Often are Needles Also Found?
Needles Regions Only
Fraction of Points per Diameter Interval
False Indication30.21%
1.000
0.100
0.010
0.001
100
1000
10000
D max (μm)


Vertical Velocity in Needle Regions
1.000
0.100
0.010
0.001
Needles Regions Only
Fraction of Points per Vertical Velocity Interval
1000
100
10
1
All Regions
#1sec Intervals
0
5
10
15
W (m s⁻¹)


Liquid Water Content in Needle Regions
1.000
0.100
0.010
0.001
Needles Regions Only
Fraction of Points per LWC Interval
1000
100
10
1
All Regions
#1sec Intervals
0.01
0.10
LWC (g m⁻¹)



W= 2 to 30m/s
75<D<150μm
150<D<250μm
250<D<406μm
406<D<631μm
Norm. PDF
Conc. (L^{-1})
1.0000
0.1000
0.0100
0.0010
0.0001
0.01
0.10
1.00
10.00
100.00
1000.00
1<T<20C,133.05L^{-1}, 176.5 155.L^{-1} 217
-4<T<0C,208.44L^{-1}, 248.8 186.L^{-1} 381
-6<T<-4C,206.39L^{-1}, 252.3+/- 180.L^{-1} 430
-12<T<-6C,141.06L^{-1}, 188.0+/- 155.L^{-1} 685
1<T<20C, 12.83L^{-1}, 18.9 21.L^{-1} 211
-4<T<0C, 30.74L^{-1}, 32.6 22.L^{-1} 381
-6<T<-4C, 28.81L^{-1}, 35.0+/- 24.L^{-1} 430
-12<T<-6C, 37.06L^{-1}, 45.3+/- 34.L^{-1} 685
1<T<20C, 3.14L^{-1}, 5.1 5.L^{-1} 209
-4<T<0C, 7.86L^{-1}, 8.5 5.L^{-1} 380
-6<T<-4C, 8.85L^{-1}, 11.2+/- 10.L^{-1} 429
-12<T<-6C, 12.73L^{-1}, 23.0+/- 26.L^{-1} 682
1<T<20C, 0.92L^{-1}, 1.4 1.L^{-1} 206
-4<T<0C, 1.95L^{-1}, 2.1 1.L^{-1} 376
-6<T<-4C, 2.27L^{-1}, 2.9+/- 3.L^{-1} 422
-12<T<-6C, 3.54L^{-1}, 5.9+/- 7.L^{-1} 677

Conclusions

- The focus of this study has been to characterize the conditions in which secondary ice particles—specifically identified as needle or thin columnar types that dominate the temperatures where growth is rapid, where heterogeneously produced ice crystals through (primary nucleation) are present in low concentrations, and where the Hallett-Mossop effect is demonstrated to occur in the laboratory. Better identification of the naturally-occuring conditions may lead to better laboratory experiments that can resolve the process(es) at work. I'm not at all convinced that the current explanations can satifactorily explain the observations. For example, take RF04, where mid-level cloud produced copious columns/needles