Improved Representations of Ice Particle Fallspeeds For Use in Global Scale Cloud Resolving Models

Andrew Heymsfield
NCAR

Outline

I. Relevance of Problem

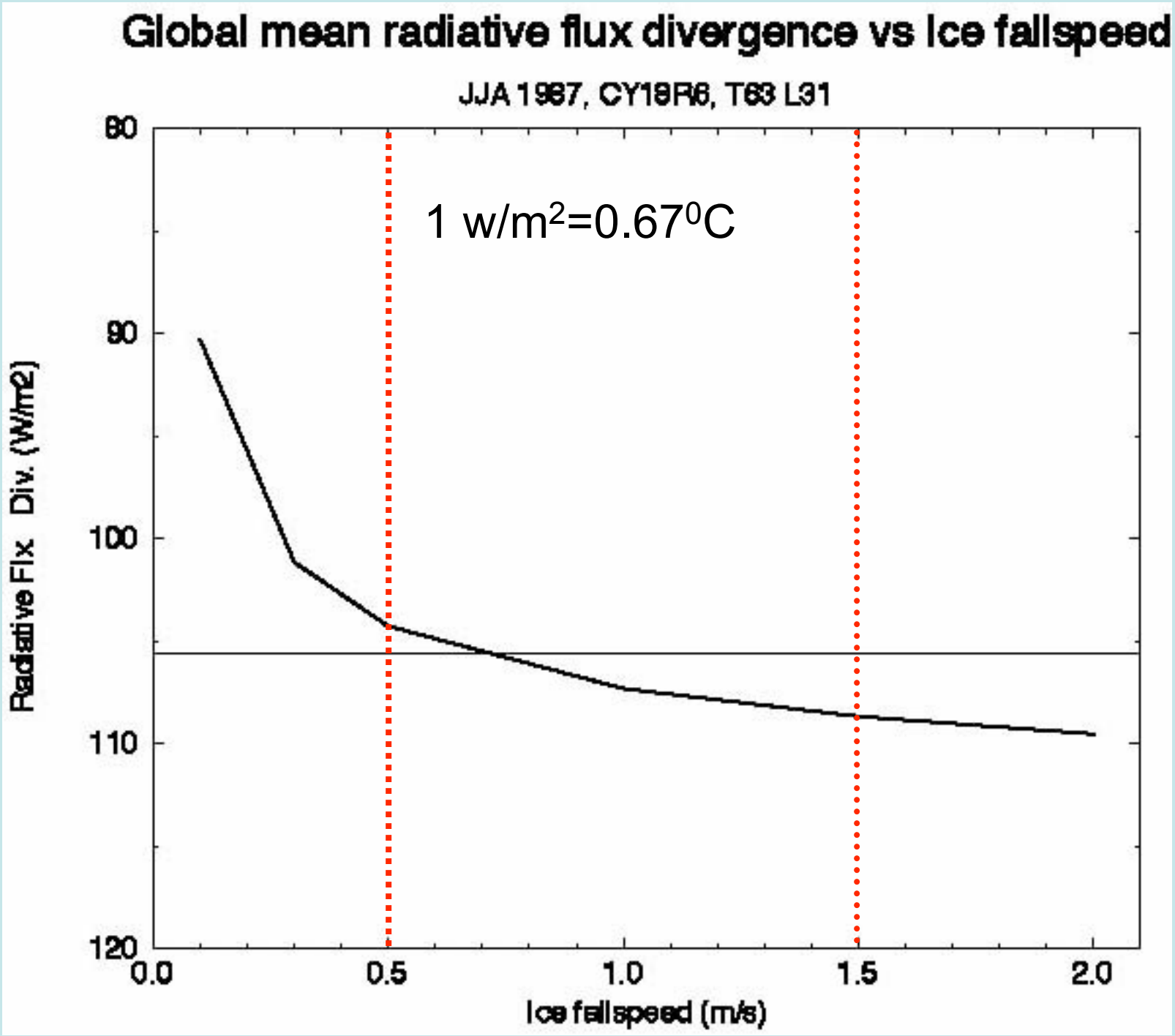
II. How Can Progress be Made?

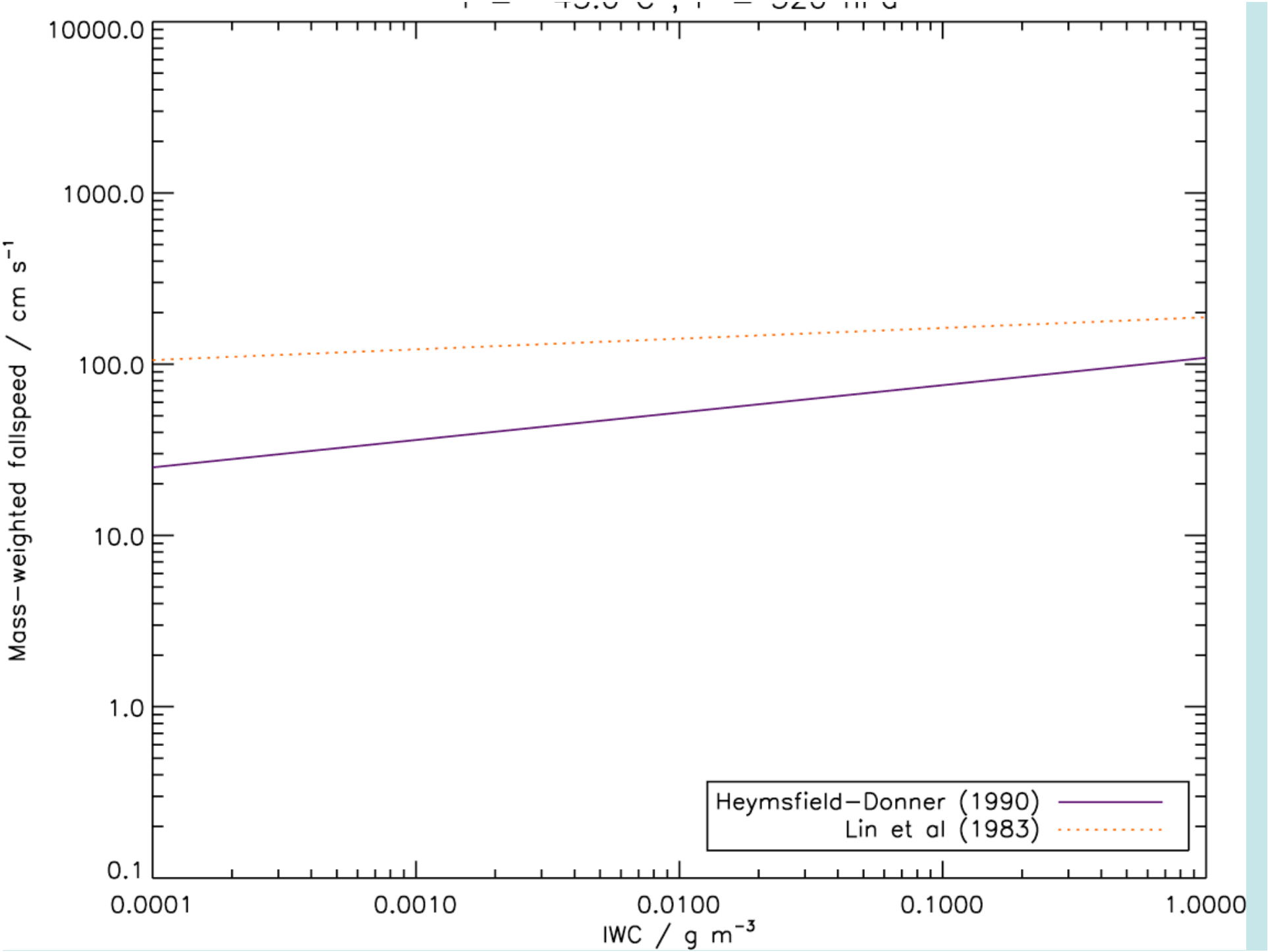
III. Cirrus Observations

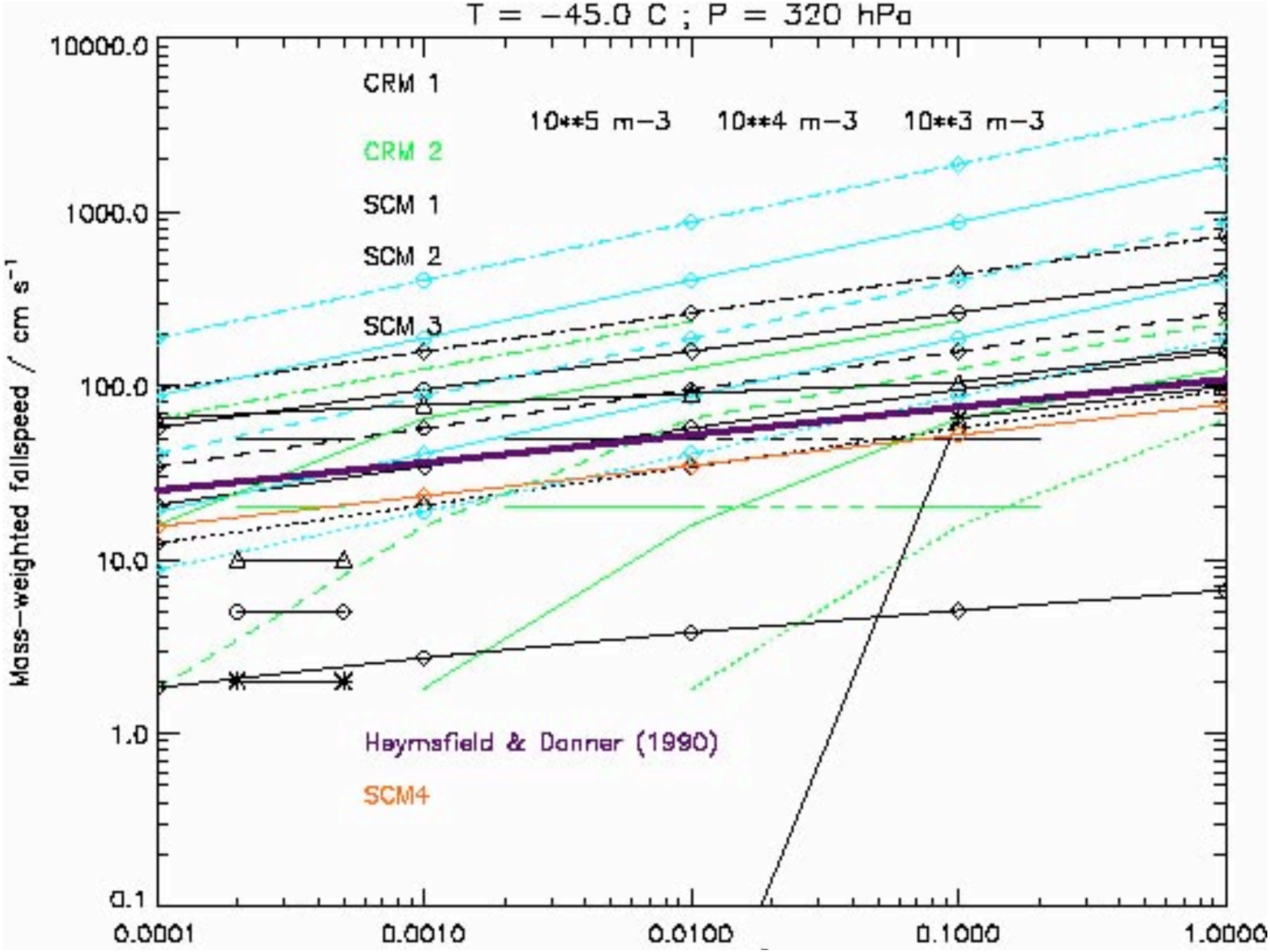
IV. Precipitating Ice Cloud Observations

V. Synthesis

VII. Summary and Conclusions


Global mean radiative flux divergence vs Ice fallspeed
JJA 1987, CY19R6, T63 L31
1 w/m2=0.670C
Radiative Flx Div. (W/m2)
80
90
100
110
120
0.0
0.5
1.0
1.5
2.0
Ice fallspeed (m/s)


10000.0
1000.0
100.0
10.0
1.0
0.1
Mass−weighted fallspeed / cm s^{-1}
0.0001
0.0010
0.0100
0.1000
1.0000
IWC / g m^{-3}
Heymsfield−Donner (1990)
Lin et al (1983)


T = −45.0 C ; P = 320 hPa
10000.0
1000.0
100.0
10.0
1.0
0.1
Mass−weighted fallspeed / cm s−1
0.0001
0.0010
0.0100
0.1000
1.0000
CRM 1
10**5 m−3
10**4 m−3
10**3 m−3
CRM 2
SCM 1
SCM 2
SCM 3
Heymsfield & Donner (1990)
SCM4

What is needed for ensemble fallspeed estimates?

- Ice water content is given by the ice particle mass integrated over the size distribution. Mass (m)=aD^b, where *a* and *b* are habit-dependent. Typical values of b=2.0 (+/- 0.5)
- The mean mass weighted fallspeed is the product of the ice particle mass and fallspeed integrated over the size distribution divided by the ice water content
- Ice particle size distributions
- Size dependent particle mass
- Size dependent particle area

Terminal Velocity Calculation

$$V_t = AD^B$$

$$A = a_1 \nu^{1-2b_1} \left(\frac{2ag}{\rho_a \gamma}\right)$$

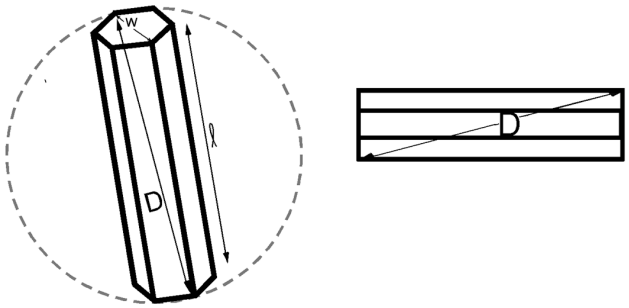
$$B = b_1(b - \sigma + 2) - 1$$

a_1, b_1 are related to the drag coefficient

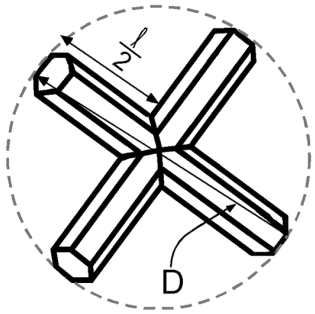
ν, ρ_a on the thermodyanmics

$m = aD^b$, $A = \gamma D^\sigma$

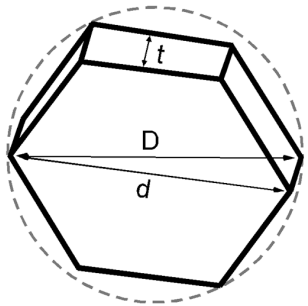
Idealized Crystal Geometries



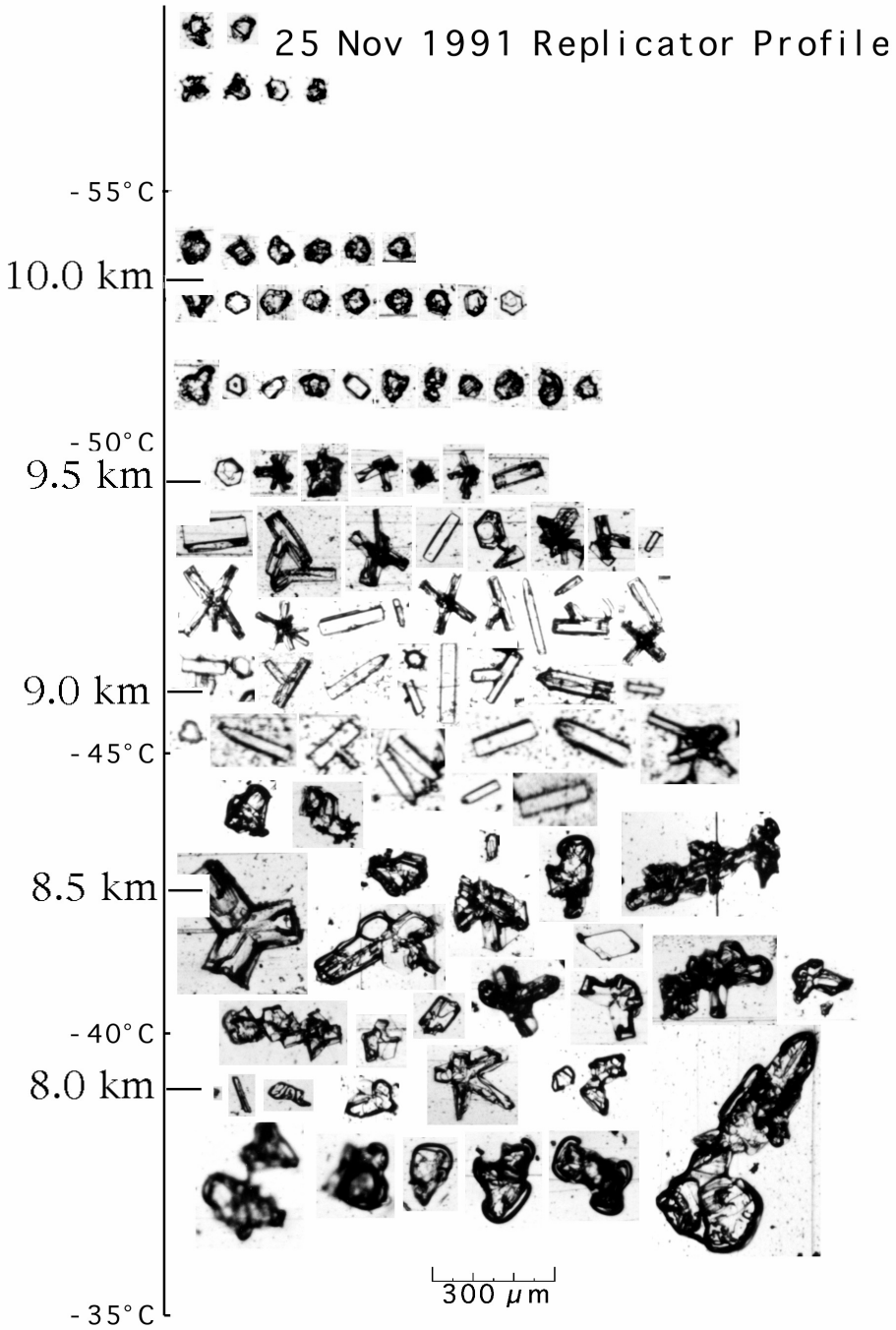
Hexagonal column



Bullet rosette



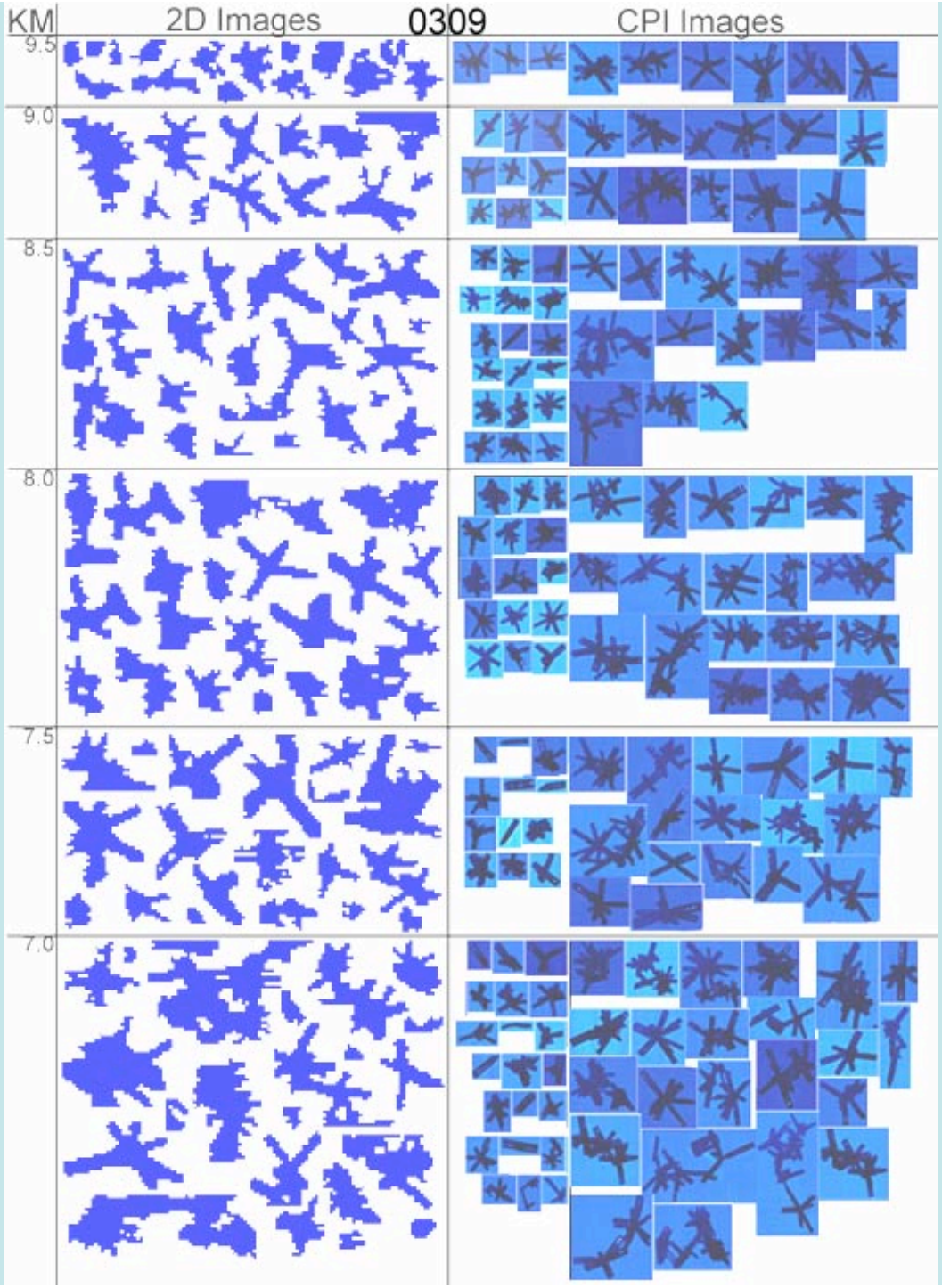
Plate


25 Nov 1991 Replicator Profile
-55°C
10.0 km
-50°C
9.5 km
9.0 km
-45°C
8.5 km
-40°C
8.0 km
-35°C
300 μm

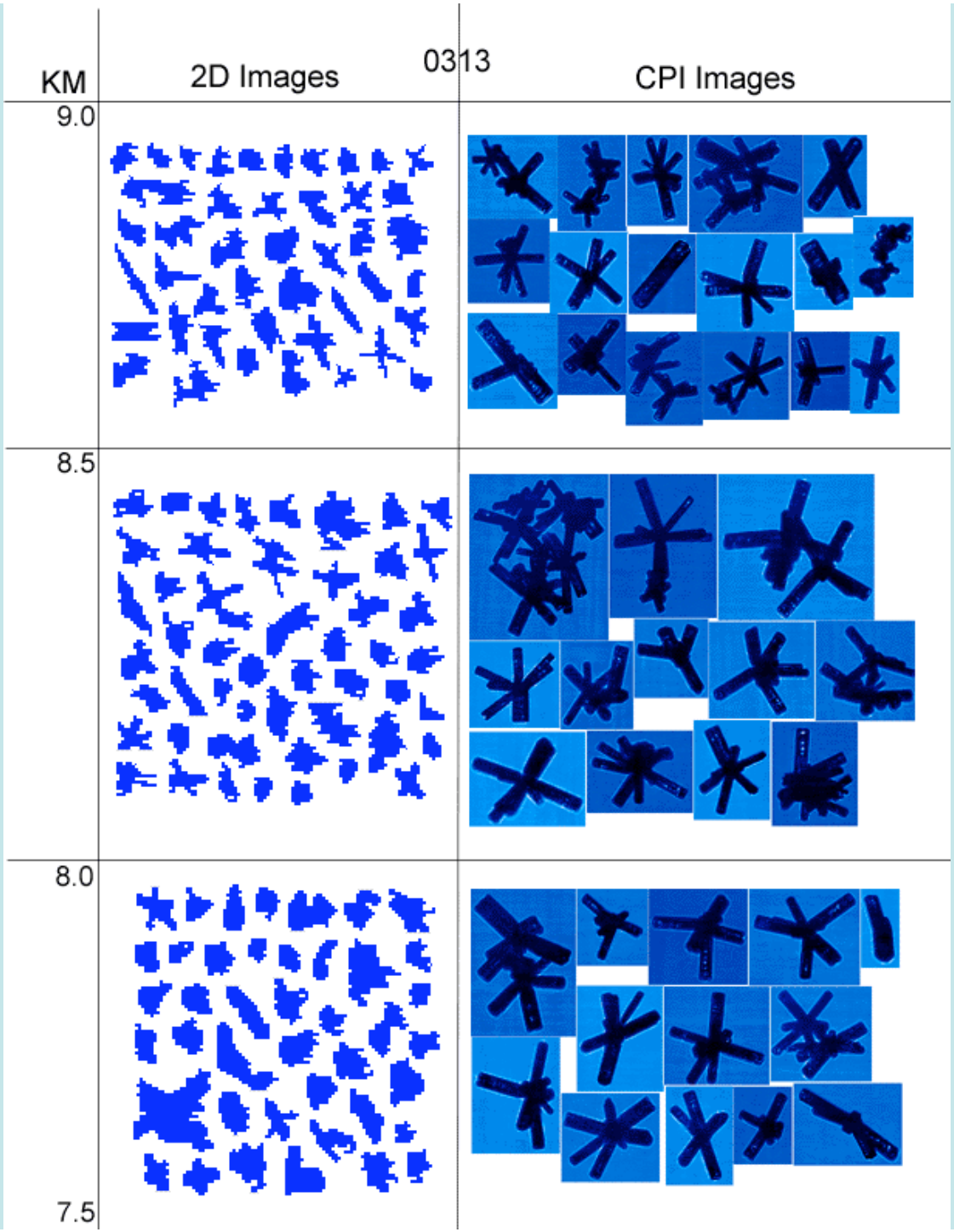
Data Sources

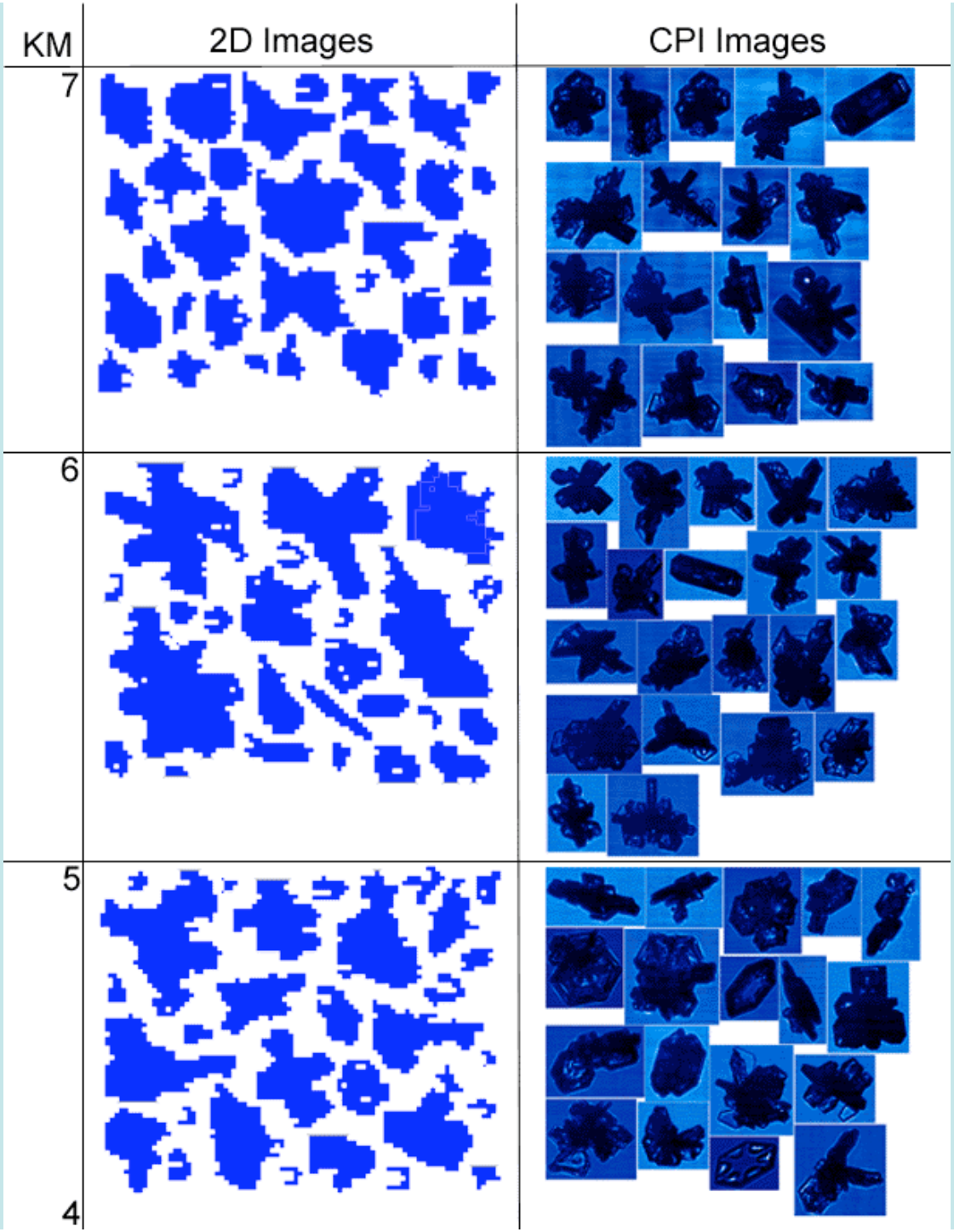
- SGP ARM IOP 2000
  - 3 cases (2 cirrus, one warm case)
    - In-situ measurements of IWC,particle imagery and size distributions, Doppler radar measurements
- Alliance Icing Research Study II

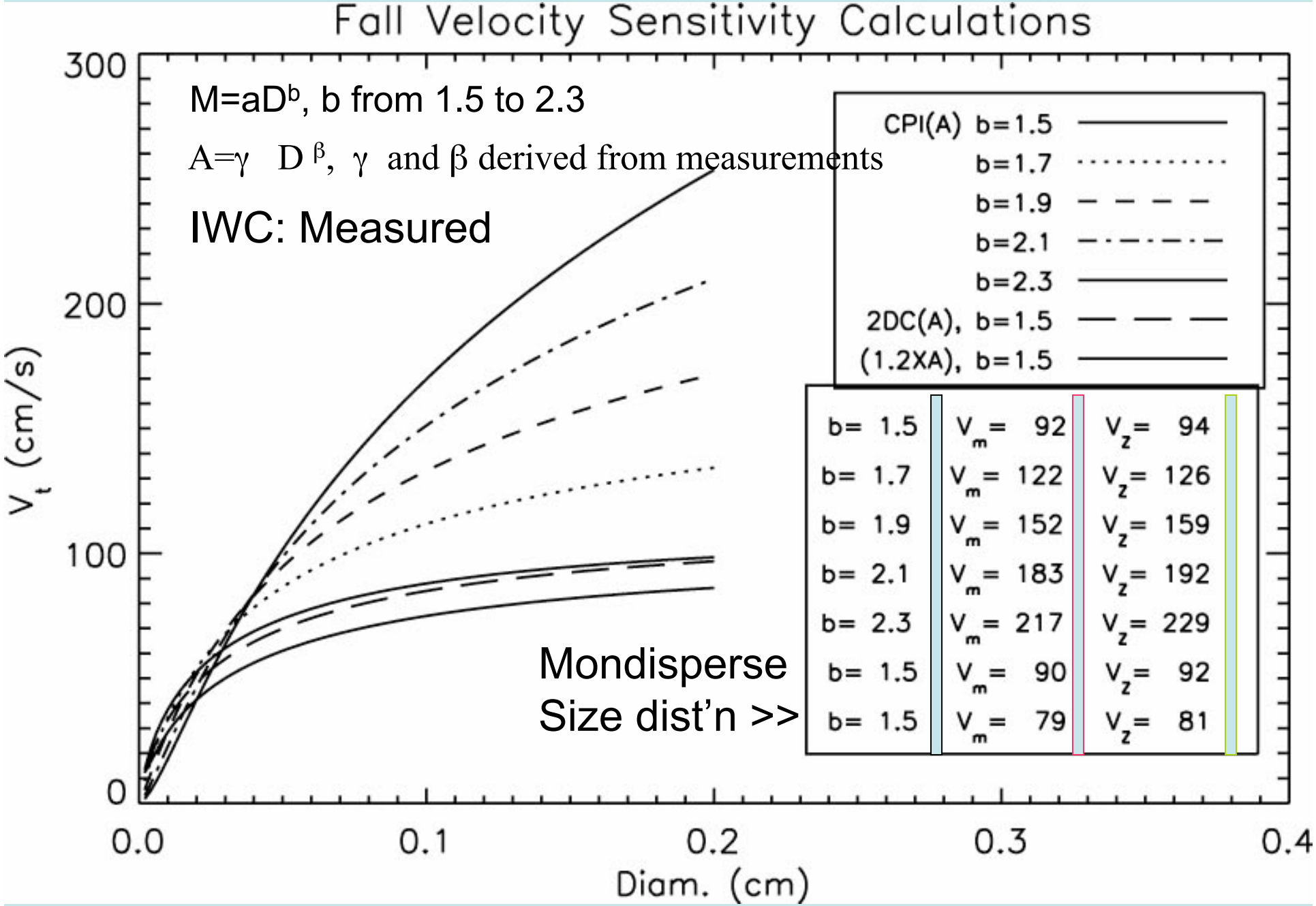
  1 case study in wintertime precipitating cloud layers, similar data sets.
- 3 years of SGP ARM Doppler radar observations

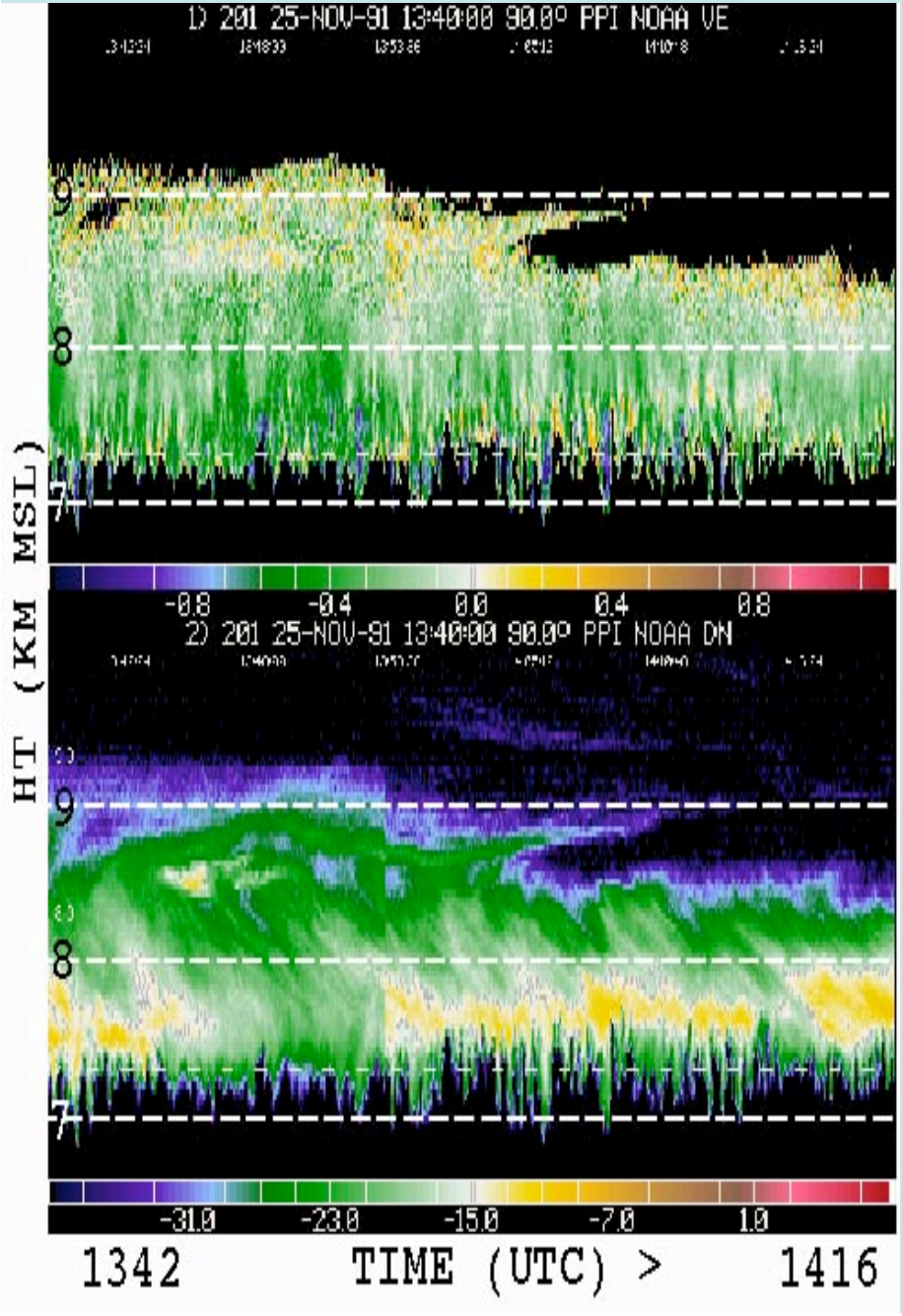


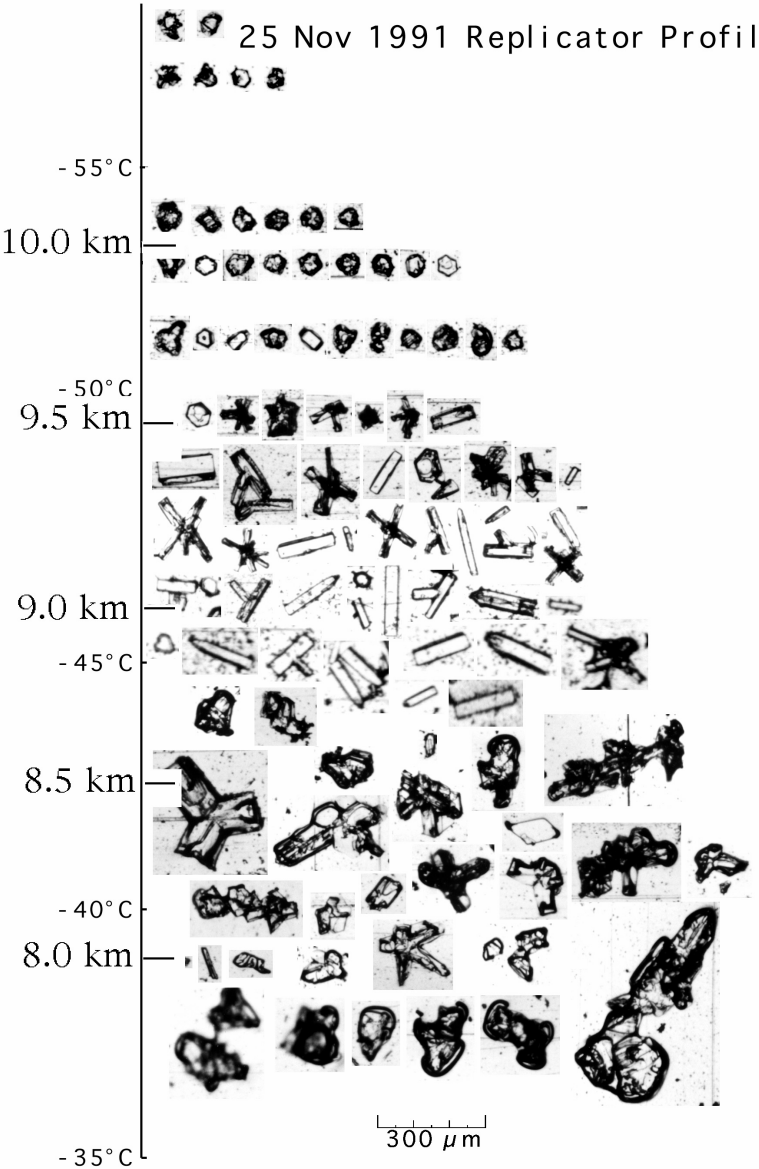
Vertical Distribution Of Ice Particles Observed on 9 March 2000, over SGP ARM Site.

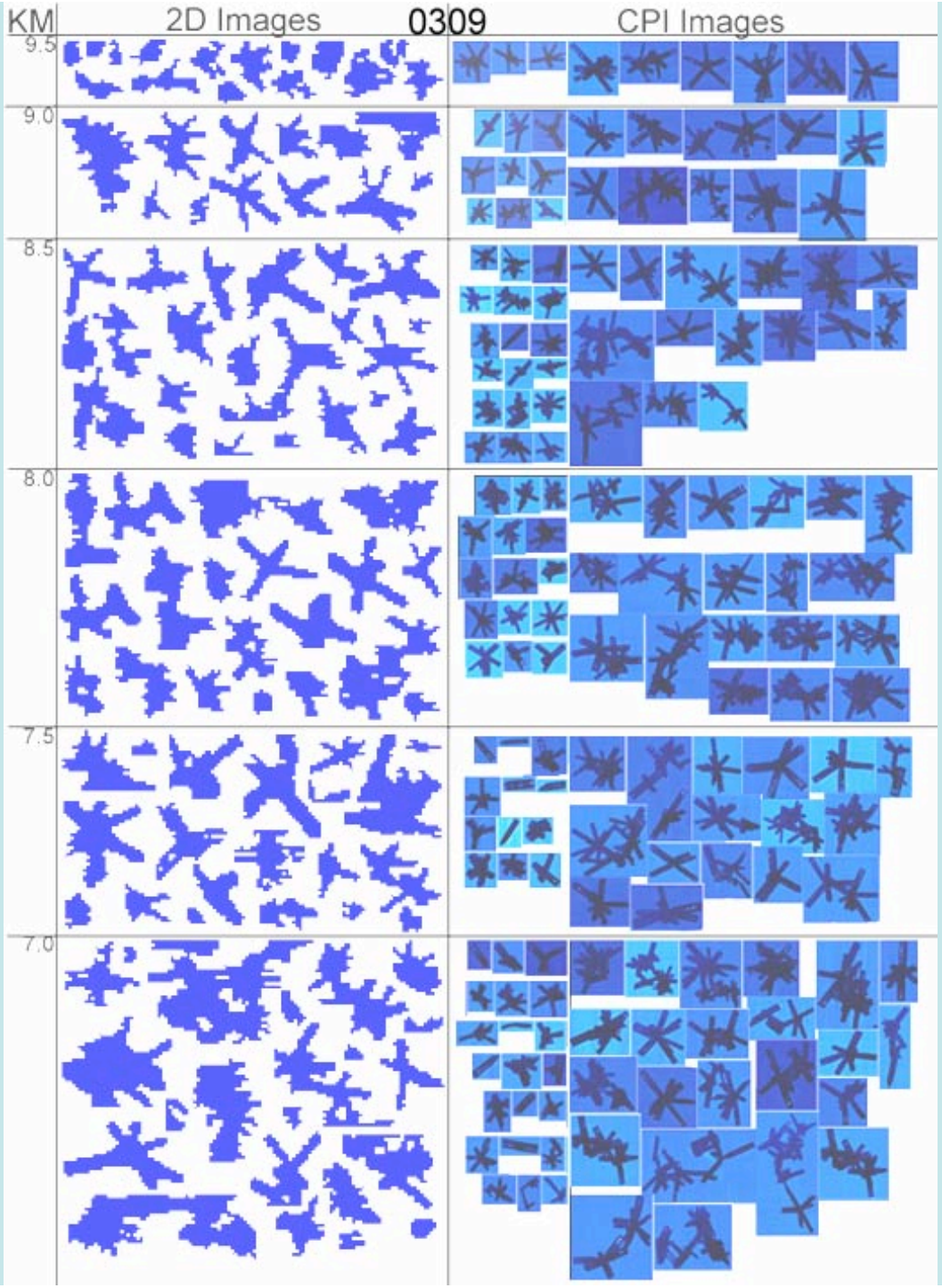

KM
2D Images
0313
CPI Images
9.0
8.5
8.0
7.5


KM
2D Images
CPI Images
7
6
5
4


Fall Velocity Sensitivity Calculations
M=aD^b, b from 1.5 to 2.3
A=γ D^β, γ and β derived from measurements
IWC: Measured
CPI(A) b=1.5
b=1.7
b=1.9
b=2.1
b=2.3
2DC(A), b=1.5
(1.2XA), b=1.5
b= 1.5 V_m= 92 V_z= 94
b= 1.7 V_m= 122 V_z= 126
b= 1.9 V_m= 152 V_z= 159
b= 2.1 V_m= 183 V_z= 192
b= 2.3 V_m= 217 V_z= 229
b= 1.5 V_m= 90 V_z= 92
b= 1.5 V_m= 79 V_z= 81
Mondisperse
Size dist'n >>
V_t (cm/s)
300
200
100
0
0.0
0.1
0.2
0.3
0.4
Diam. (cm)


1) 201 25-NOV-91 13:40:00 90.0° PPI NOAA VE
-0.8 -0.4 0.0 0.4 0.8
2) 201 25-NOV-91 13:40:00 90.0° PPI NOAA DN
-31.0 -23.0 -15.0 -7.0 1.0
HT (KM MSL)
1342 TIME (UTC) > 1416


25 Nov 1991 Replicator Profile
-55°C
10.0 km
-50°C
9.5 km
9.0 km
-45°C
8.5 km
-40°C
8.0 km
-35°C
300 μm



Use each 5 sec PSD, IWC msts to find ***a*** coefficient for ***b*** of from 1.5 to 2.3

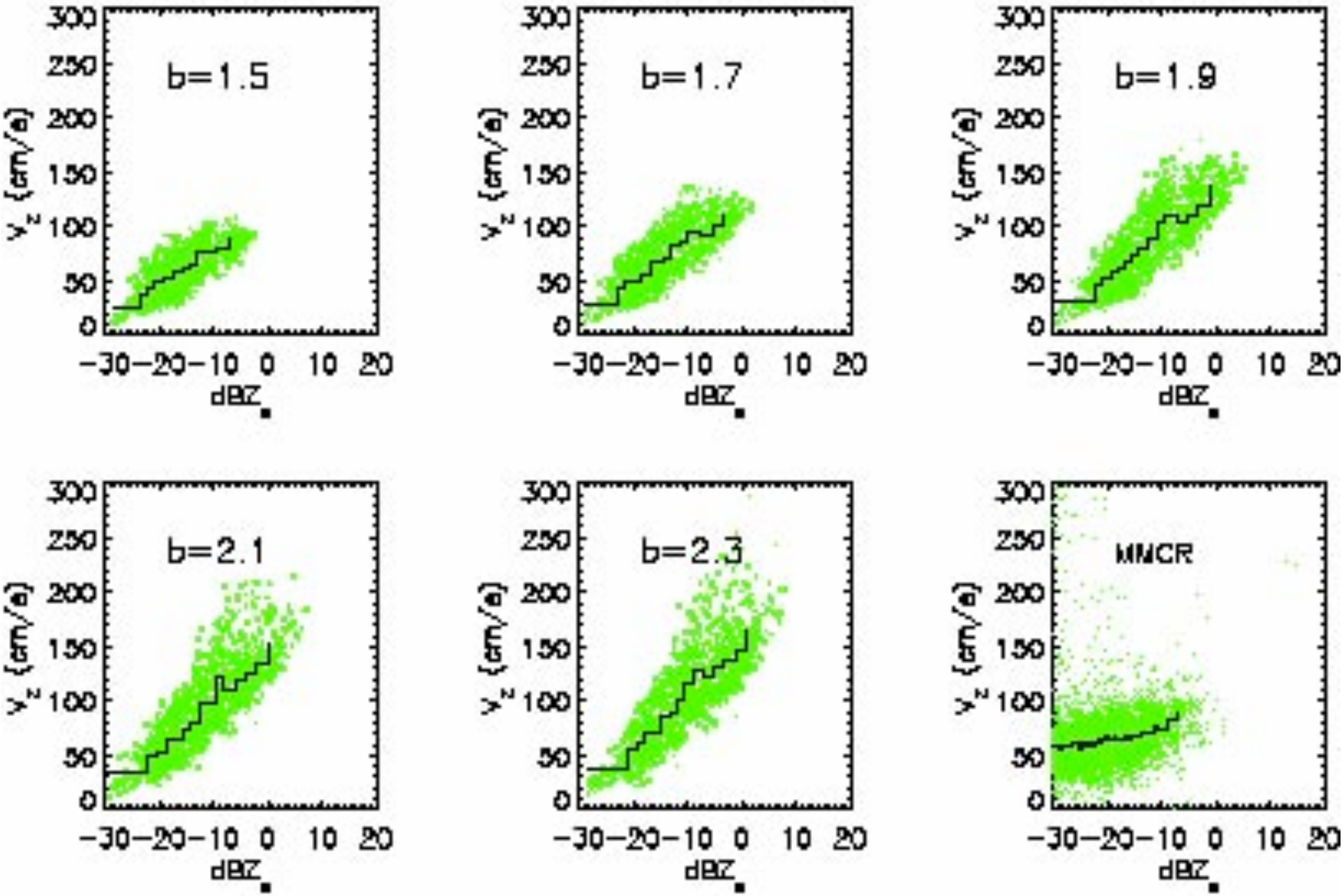
Use area's from imaging probe data

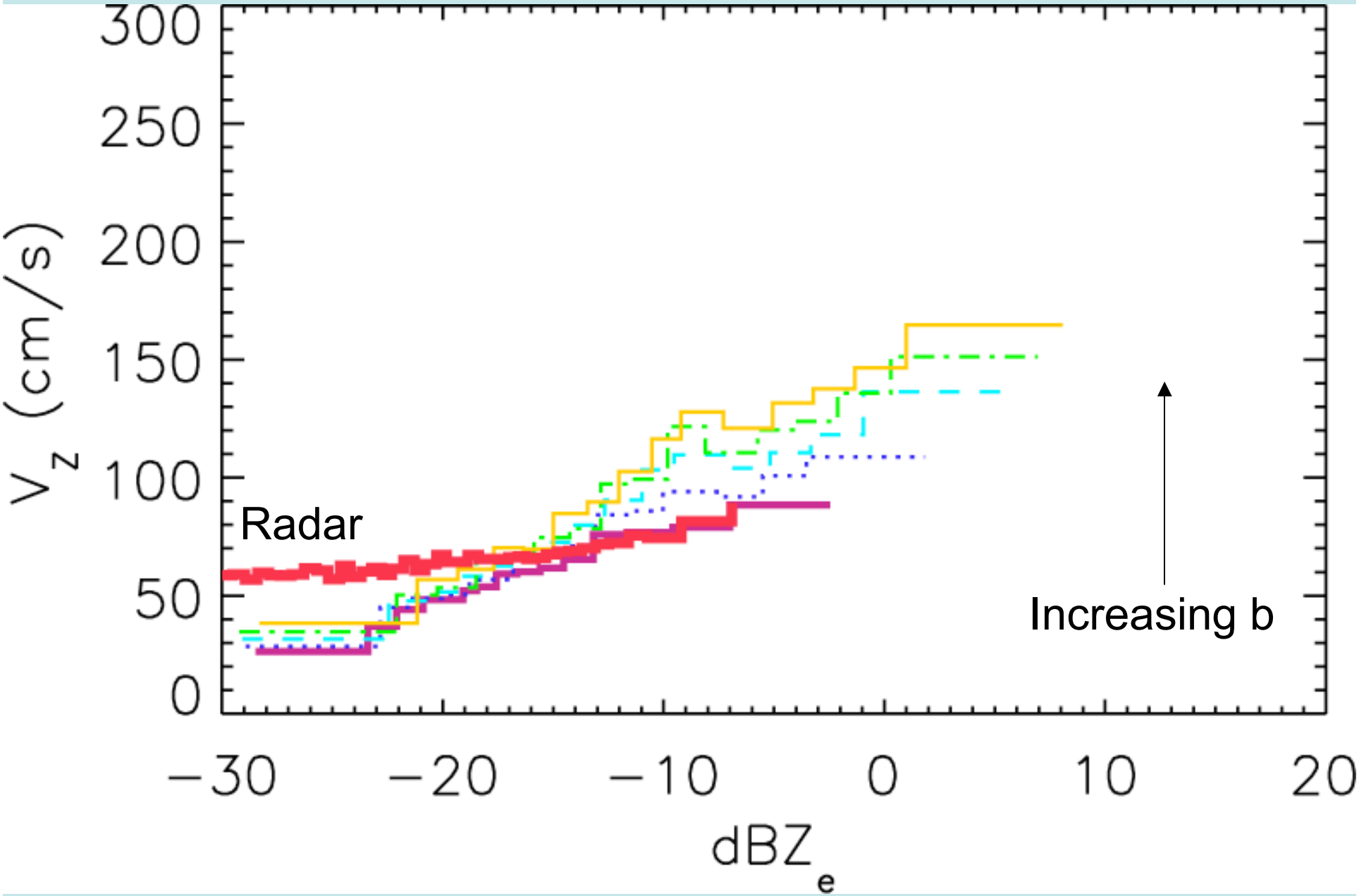
Calculate Doppler Radar parameters V_Z, Z_e

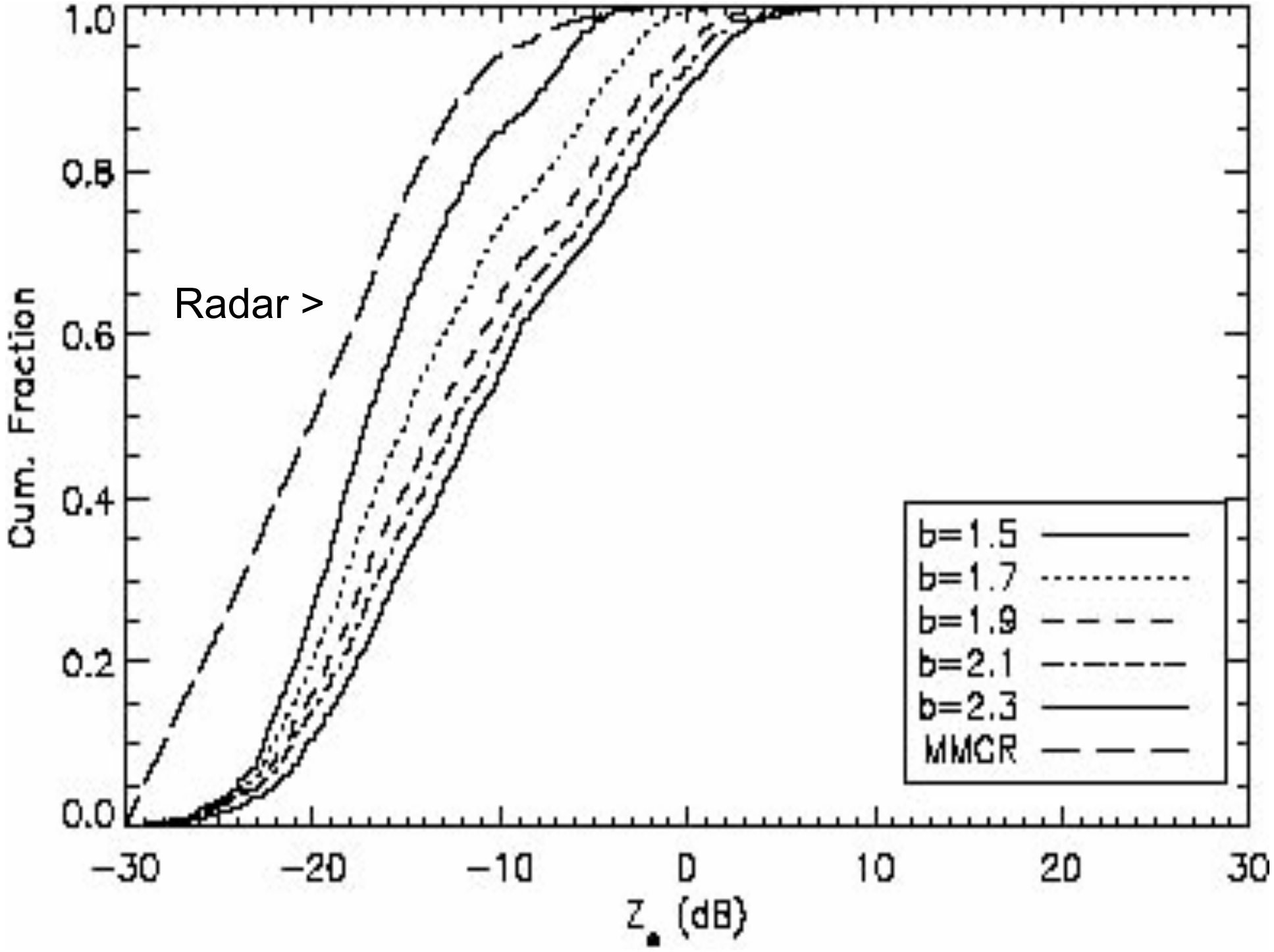
Compare trends to radar msts, rather than compare directly calcs.with msmts. for few colocations

Citation Vertical Profiles

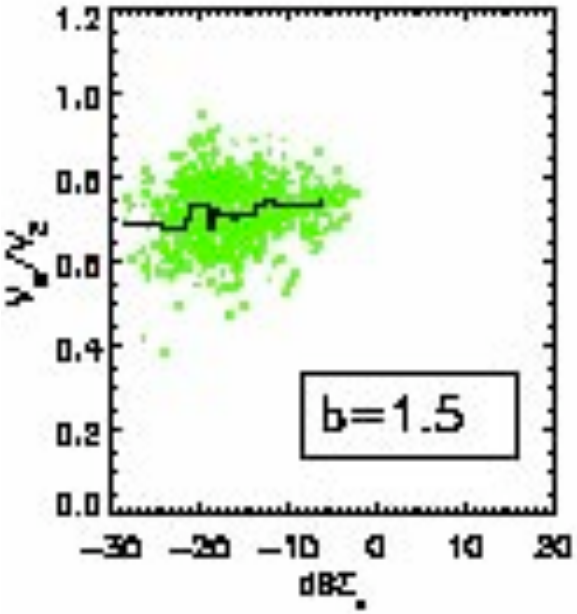
9 March 2000

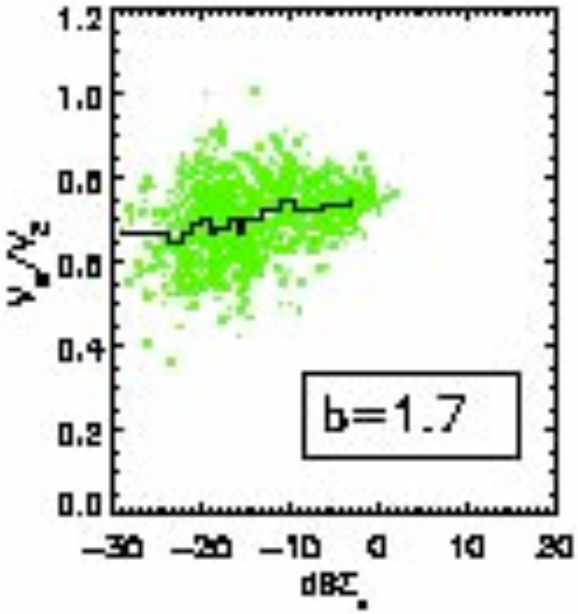


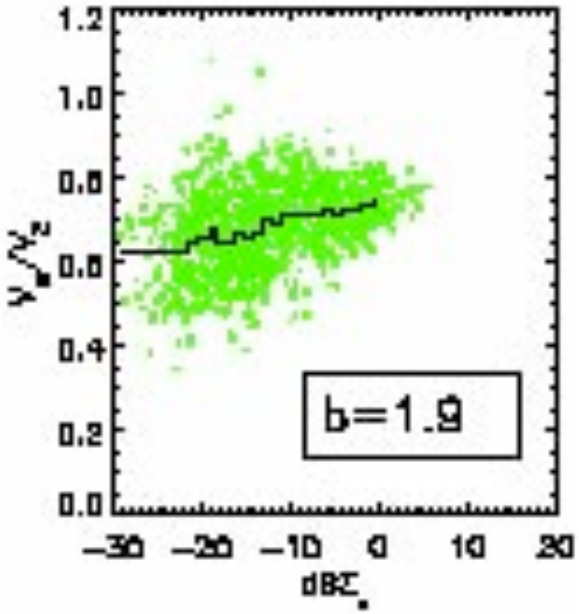

300
250
200
150
100
50
0
V_z (cm/s)
Radar
Increasing b
−30
−20
−10
0
10
20
dBZ_e

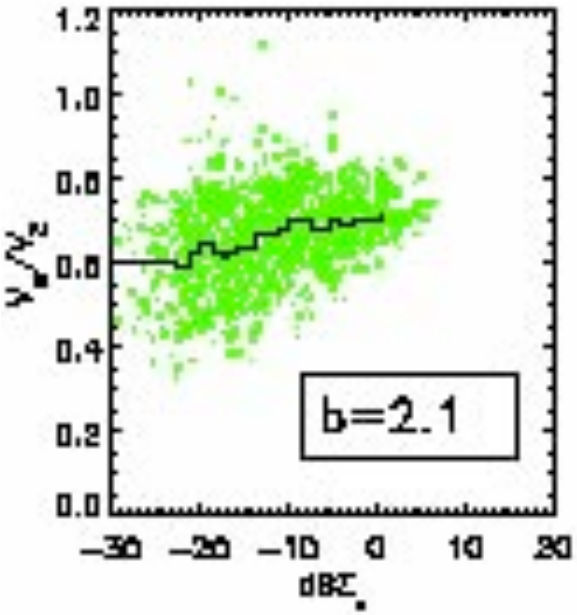

1.0
0.8
0.6
0.4
0.2
0.0
Cum. Fraction
Radar >
b=1.5
b=1.7
b=1.9
b=2.1
b=2.3
MMCR
−30
−20
−10
0
10
20
30
Z_e (dB)

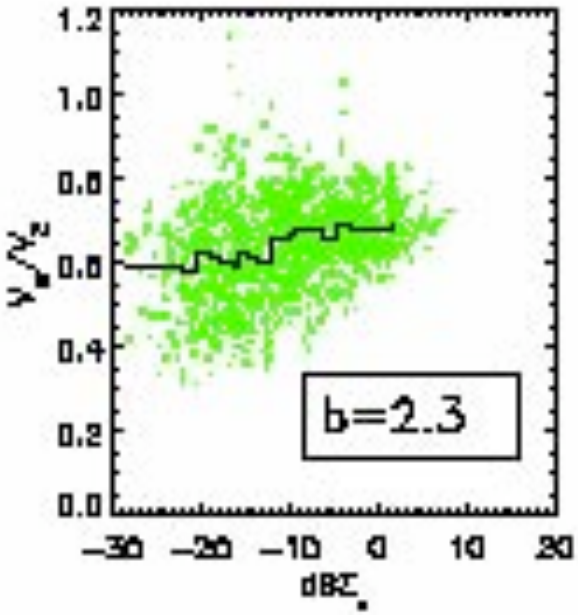
Mass Weighted Fall Velocities

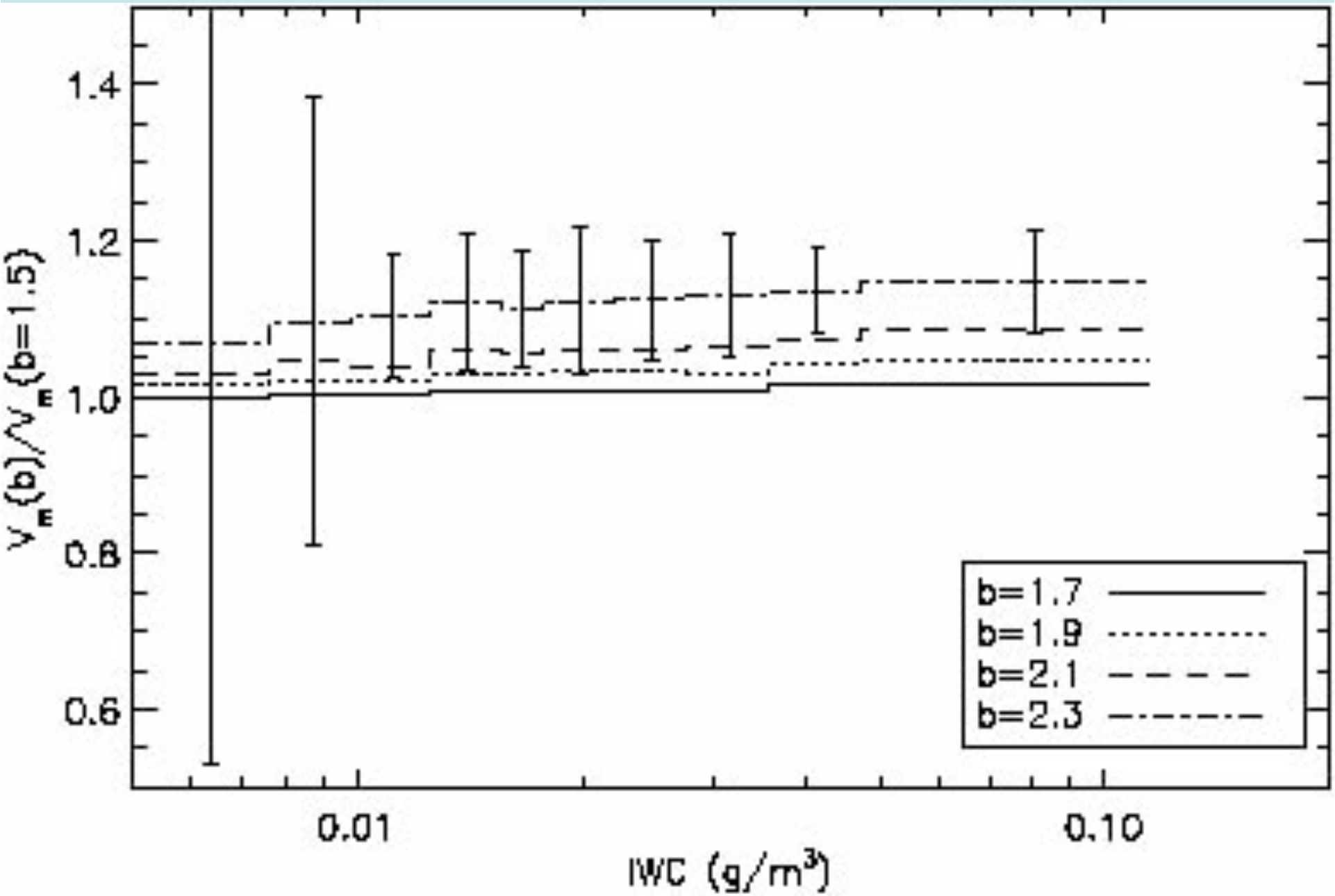


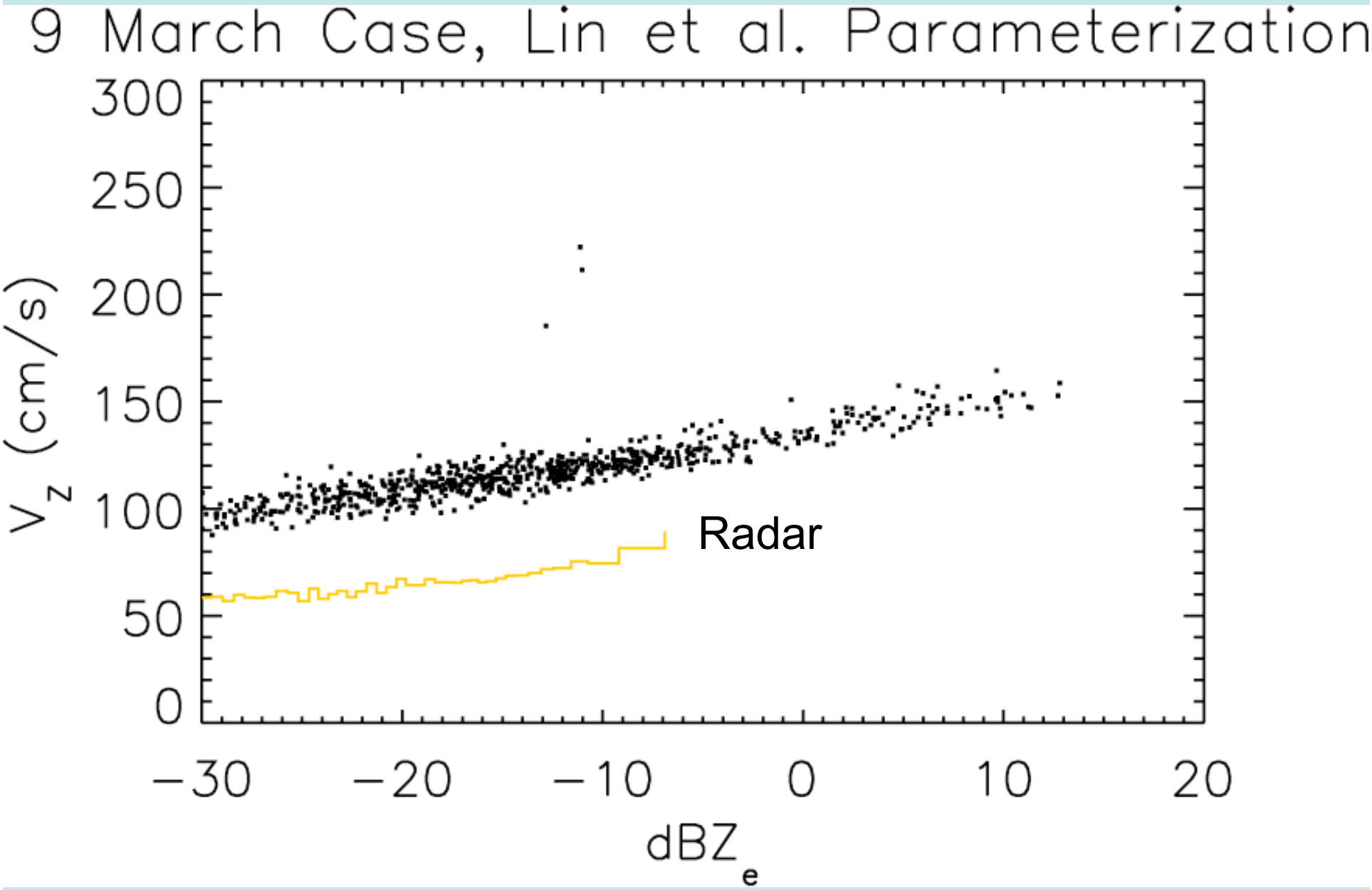


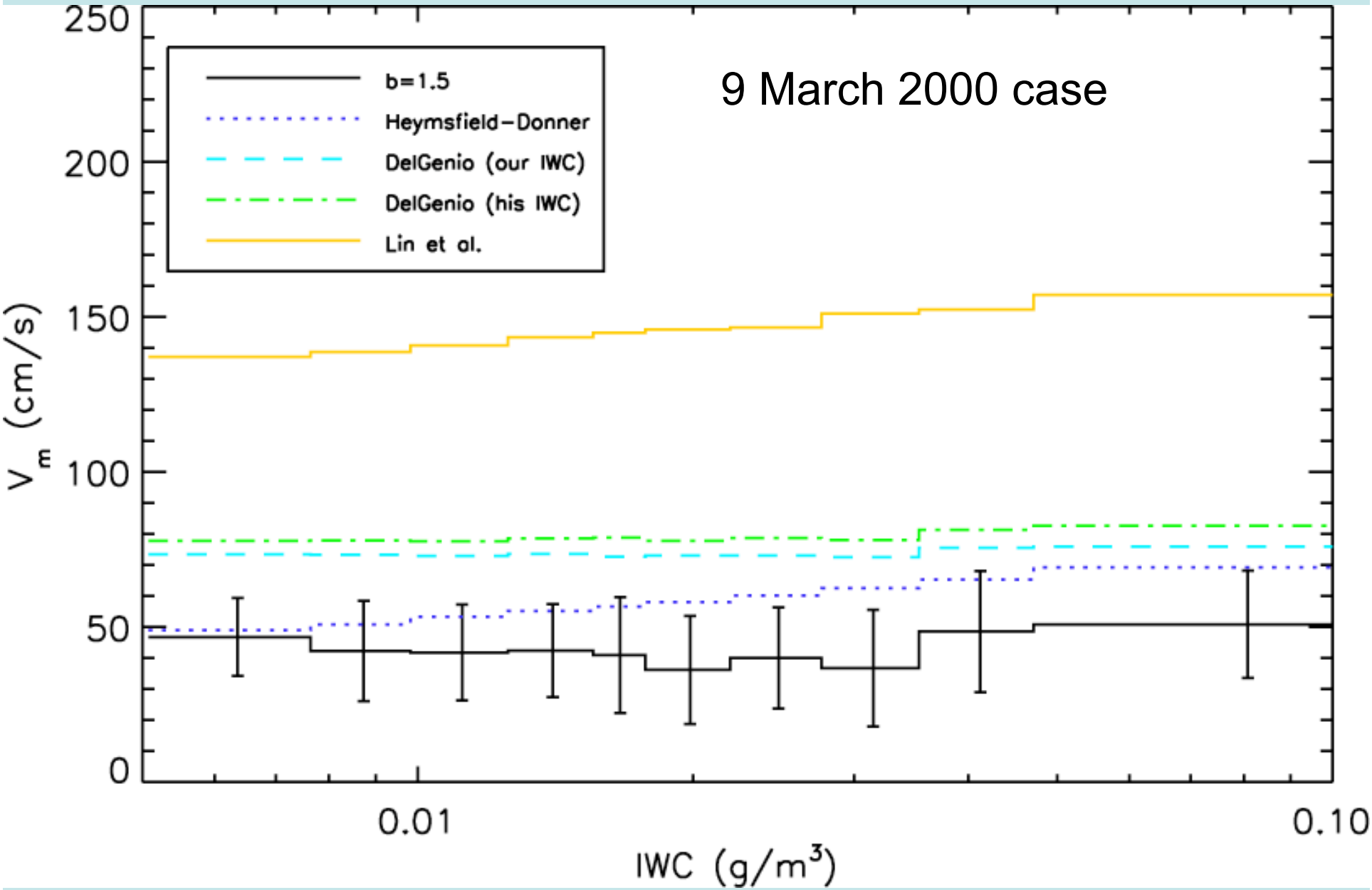


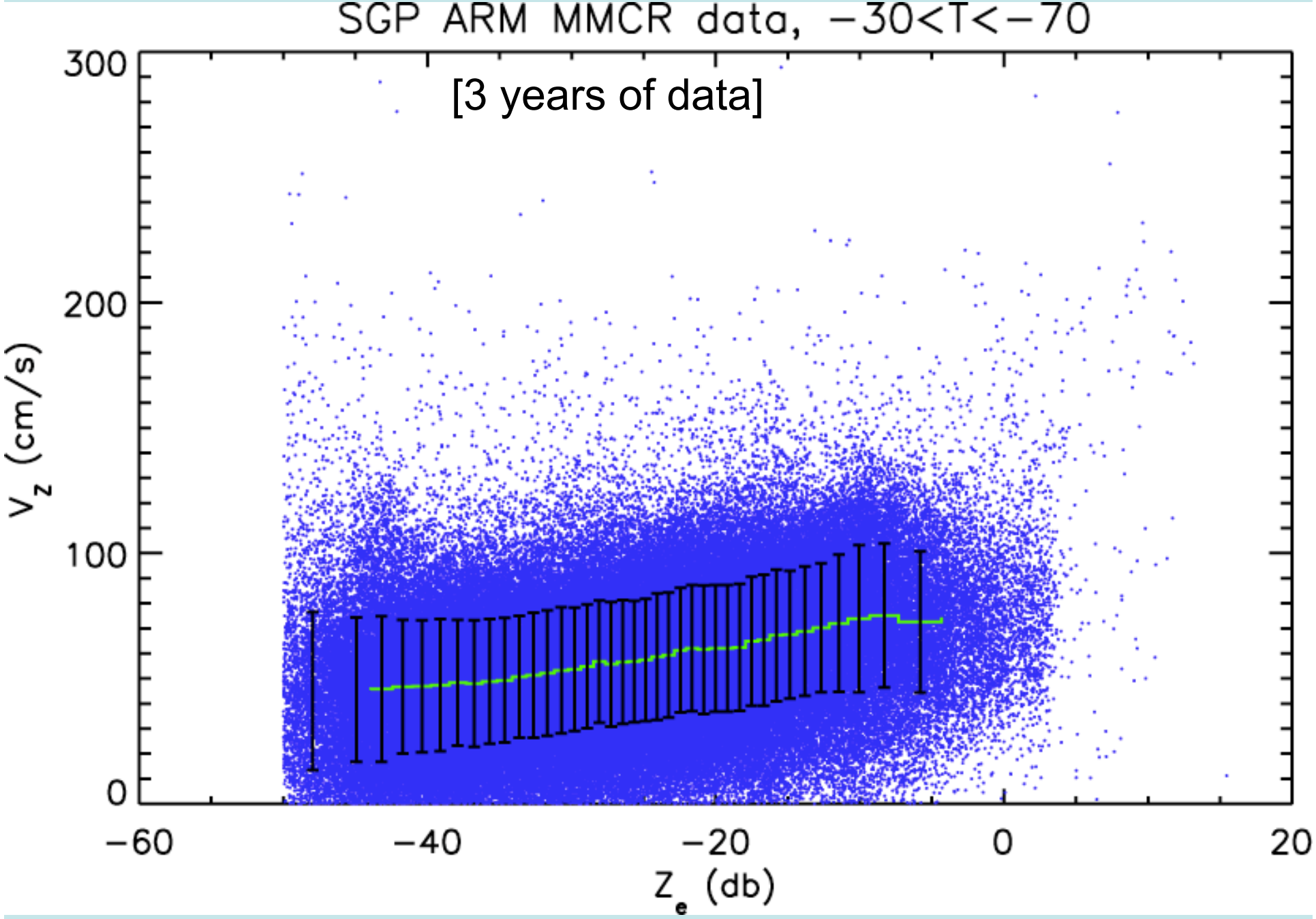


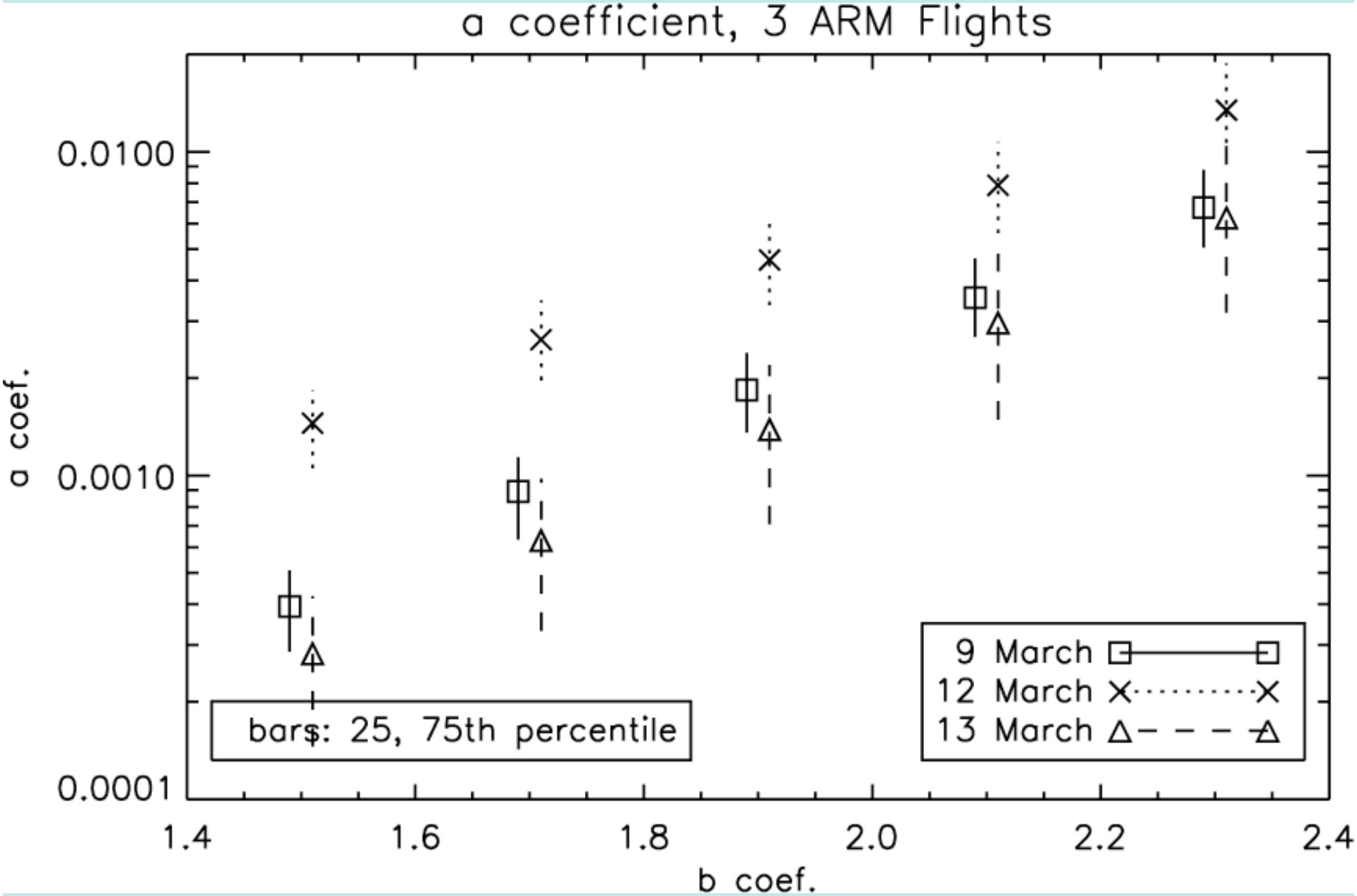


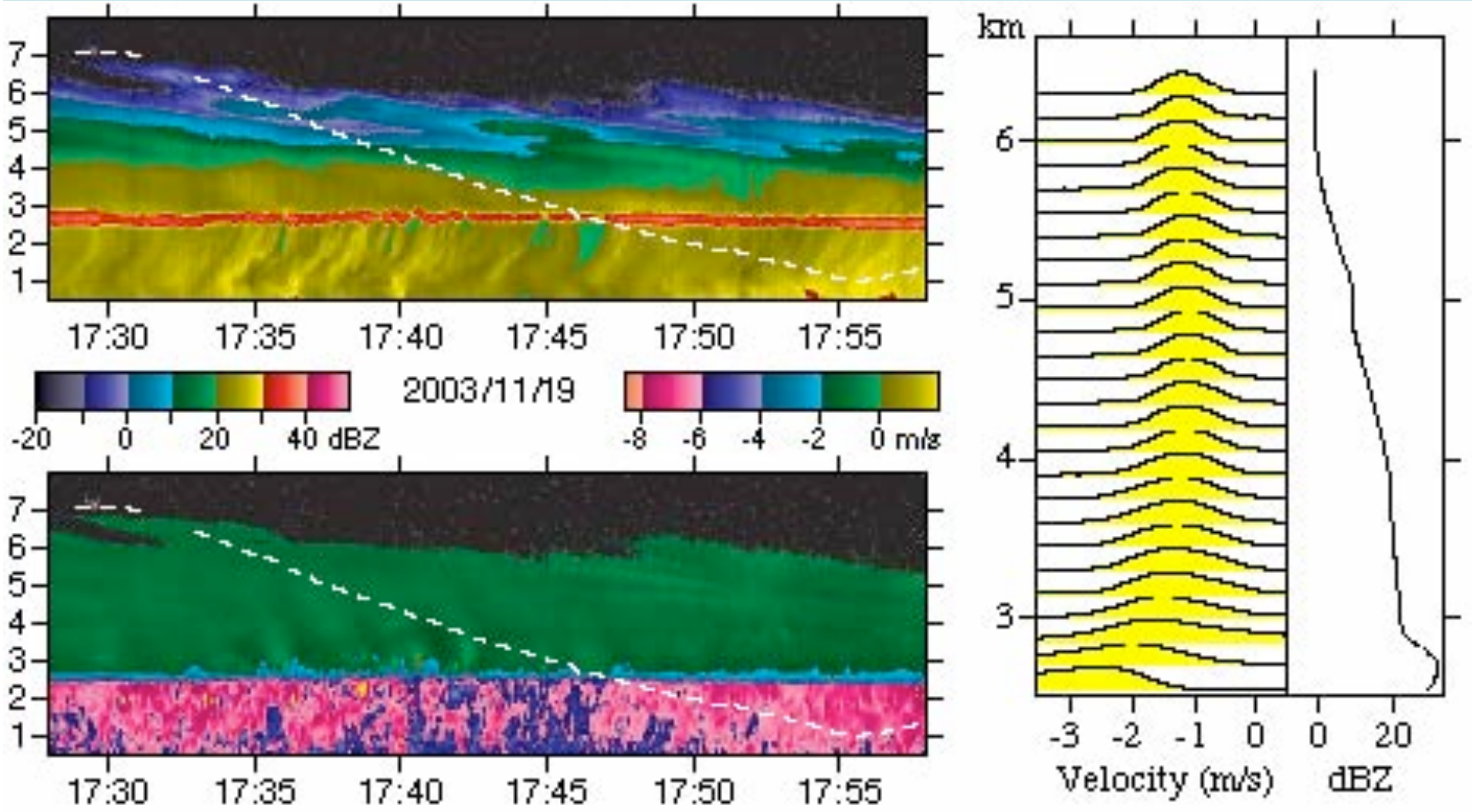

1.4
1.2
1.0
0.8
0.6
$v_e(b)/v_e(b=1.5)$
0.01
0.10
IWC (g/m^3)
b=1.7
b=1.9
b=2.1
b=2.3


9 March Case, Lin et al. Parameterization
300
250
200
150
100
50
0
V_z (cm/s)
Radar
−30
−20
−10
0
10
20
dBZ_e


9 March 2000 case
b=1.5
Heymsfield–Donner
DelGenio (our IWC)
DelGenio (his IWC)
Lin et al.
250
200
150
100
50
0
V_m (cm/s)
0.01
0.10
IWC (g/m^3)

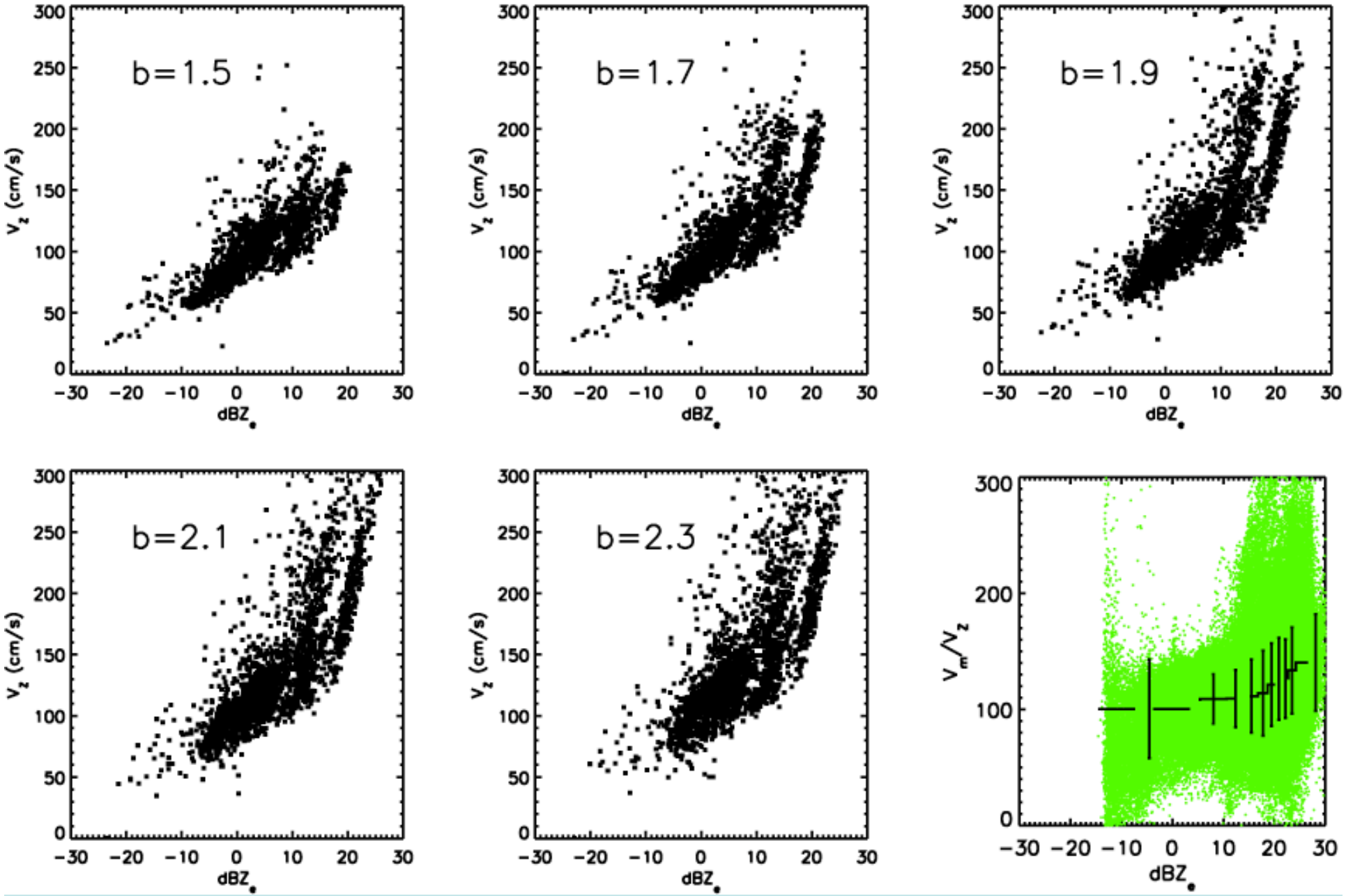

SGP ARM MMCR data, −30<T<−70
[3 years of data]
300
200
100
0
V_z (cm/s)
−60
−40
−20
0
20
Z_e (db)

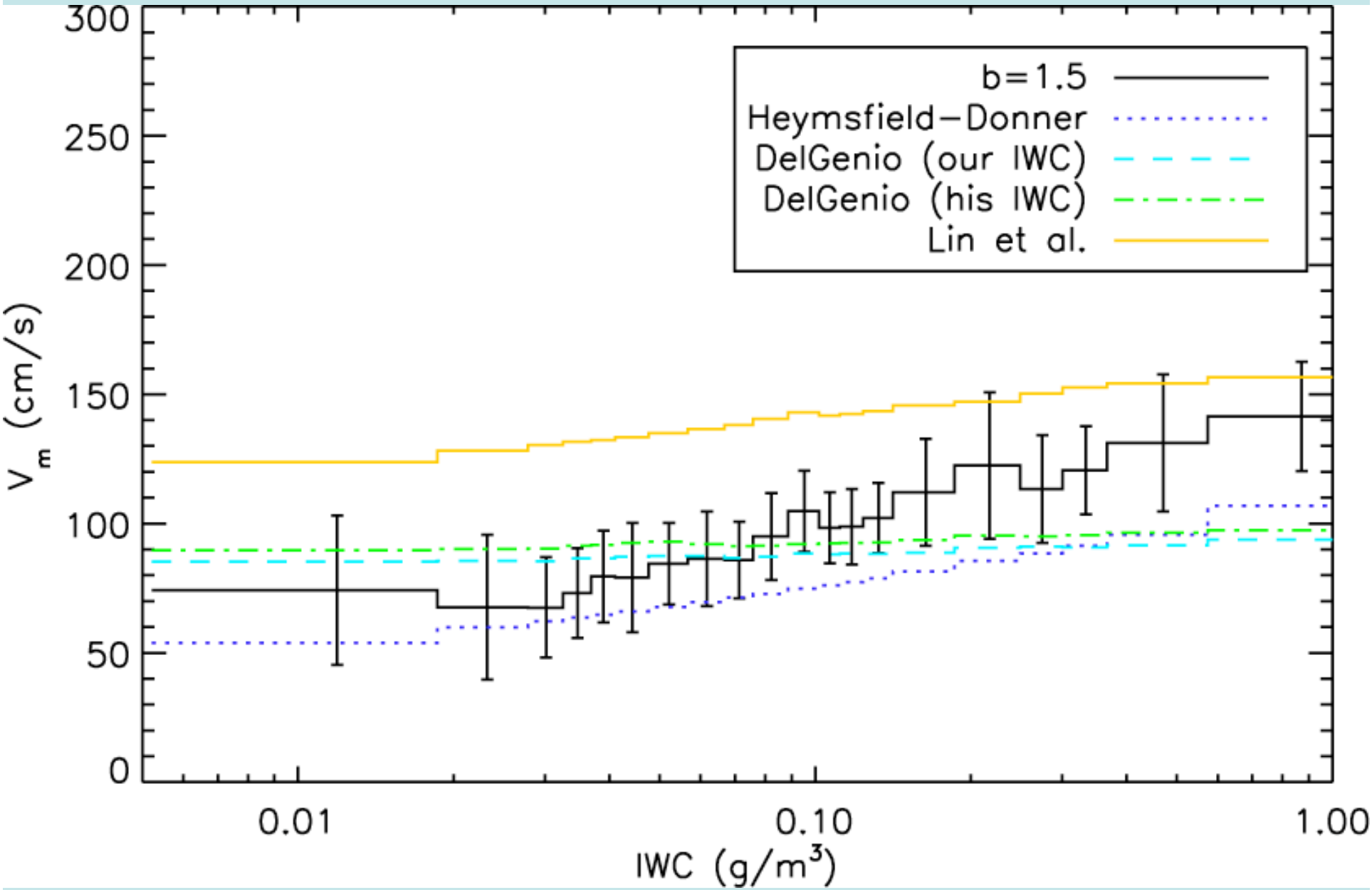

a coefficient, 3 ARM Flights
a coef.
0.0100
0.0010
0.0001
1.4
1.6
1.8
2.0
2.2
2.4
b coef.
bars: 25, 75th percentile
9 March
12 March
13 March

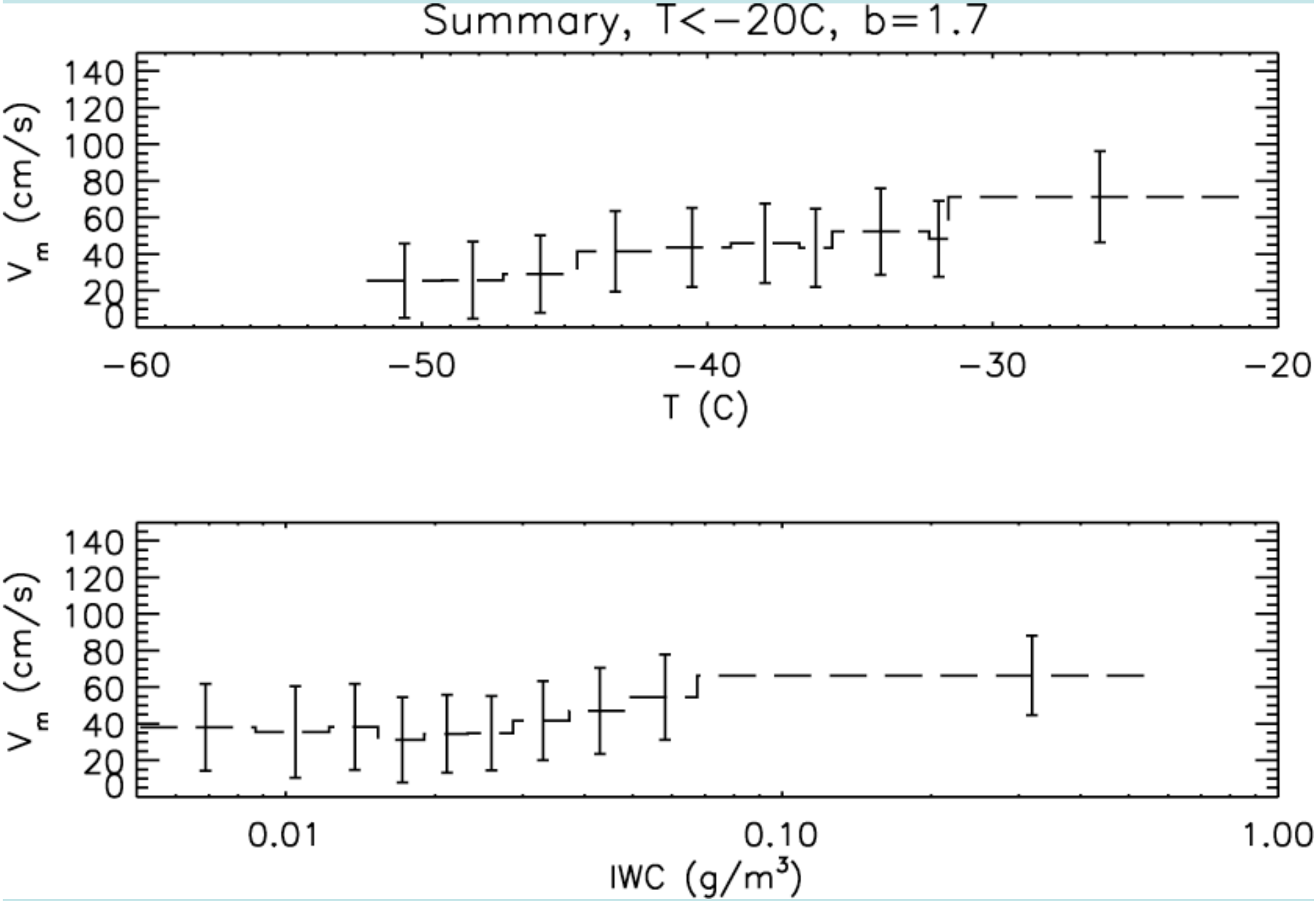


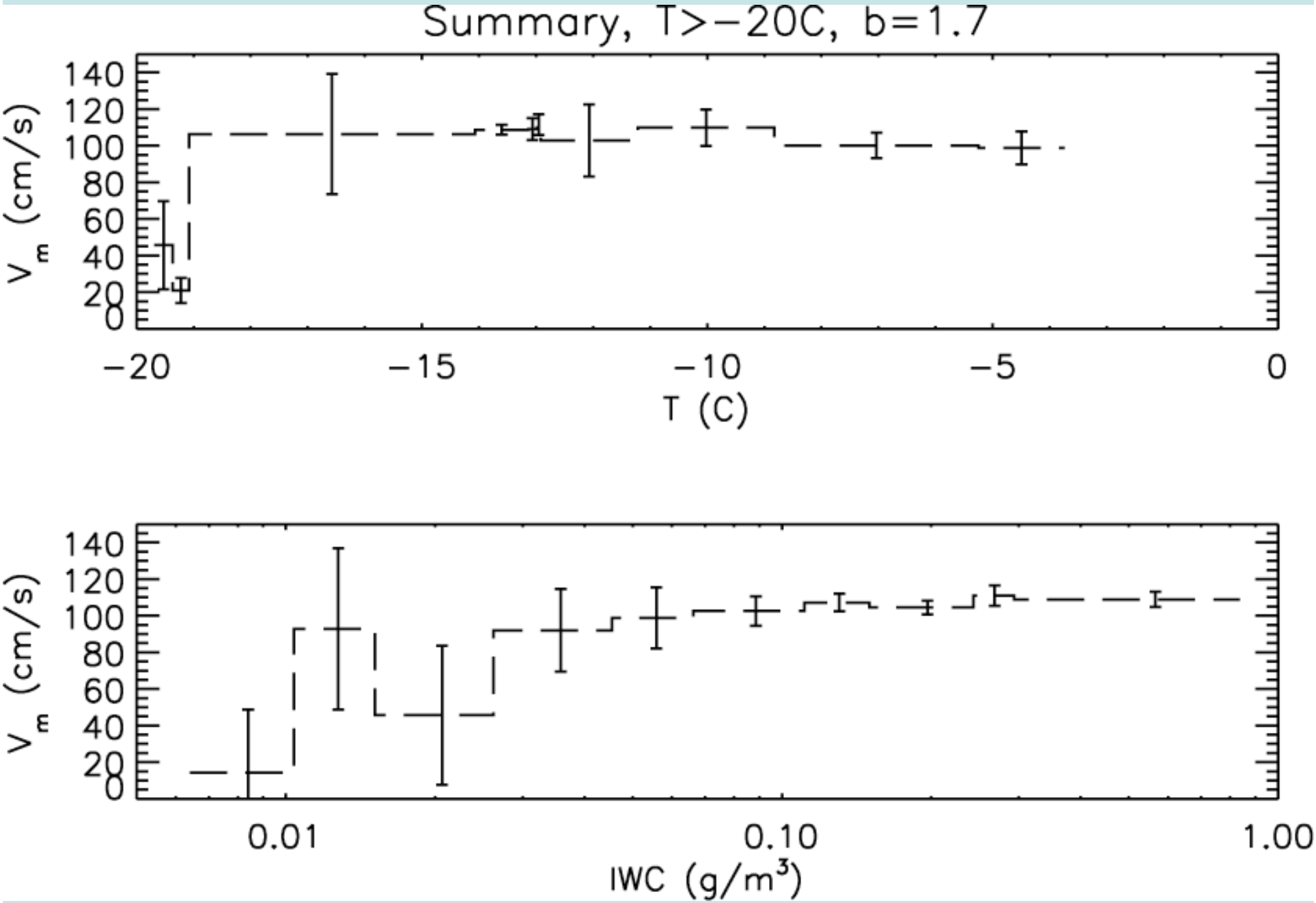
Top: Reflectivity from vertically pointing radar. Bottom: Mean Doppler velocity. C-130 airplane altitude is plotted as a dashed line when it is within 10 km of the radar. Right: Distribution of fall velocities (Doppler spectra) over the radar at ±10 minutes around the C-130 track.

AIRS, 19 November 2004



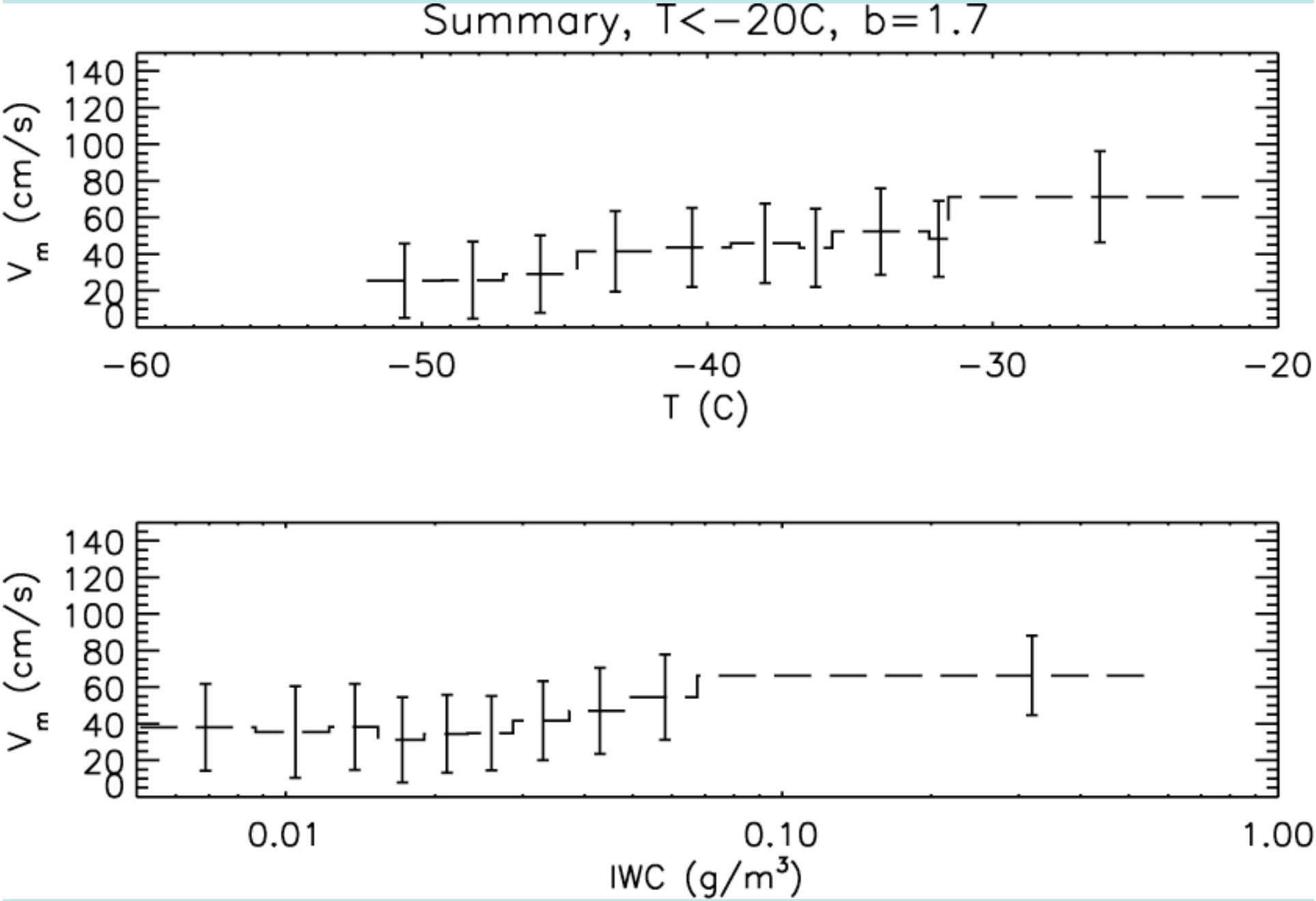

b=1.5
Heymsfield–Donner
DelGenio (our IWC)
DelGenio (his IWC)
Lin et al.
300
250
200
150
100
50
0
V_m (cm/s)
0.01
0.10
1.00
IWC (g/m^3)

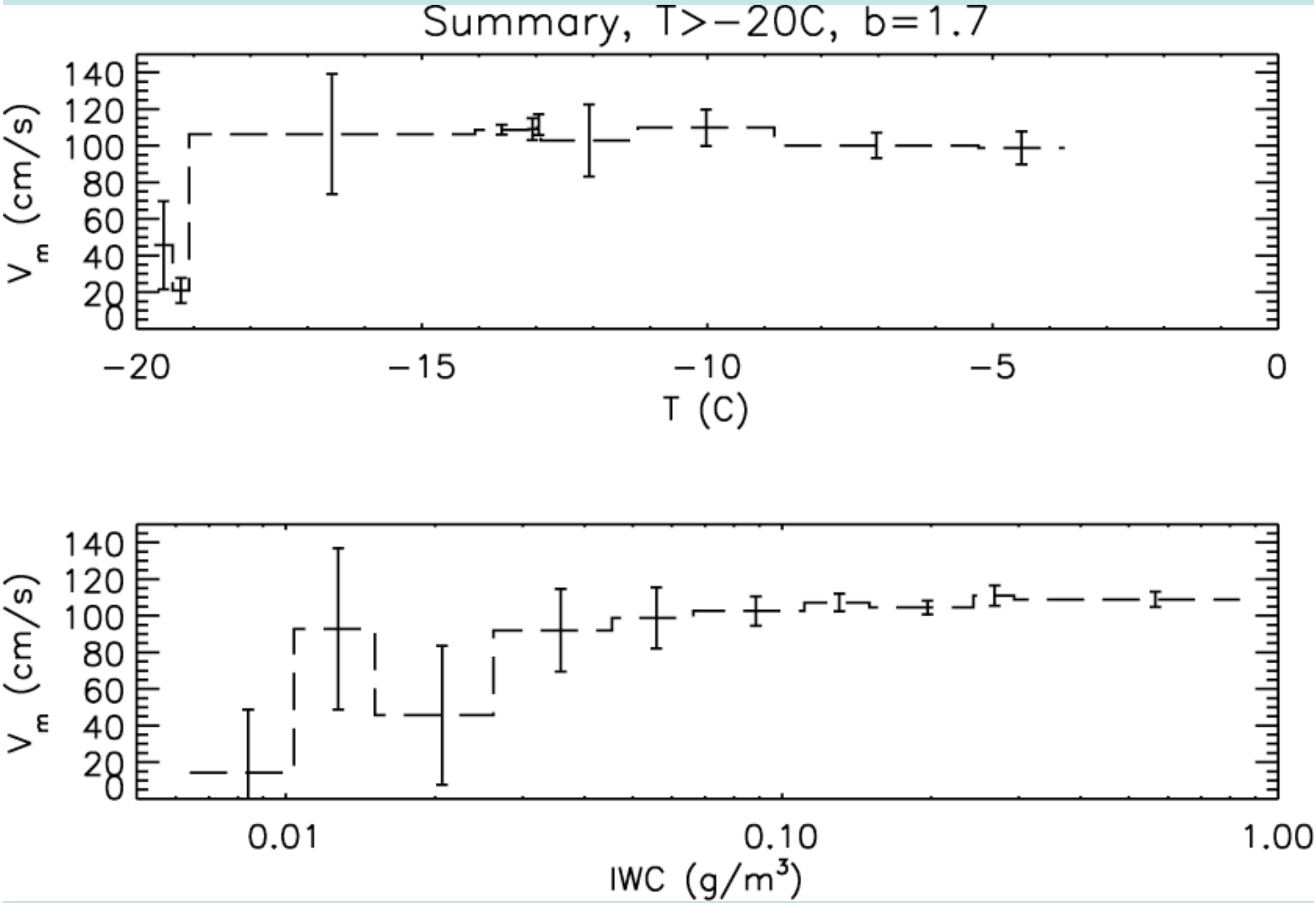

Summary, T<−20C, b=1.7
V_m (cm/s)
140
120
100
80
60
40
20
0
−60
−50
−40
−30
−20
T (C)
V_m (cm/s)
140
120
100
80
60
40
20
0
0.01
0.10
1.00
IWC (g/m³)


Summary, T>−20C, b=1.7
140
120
100
80
60
40
20
0
V_m (cm/s)
−20
−15
−10
−5
0
T (C)
140
120
100
80
60
40
20
0
V_m (cm/s)
0.01
0.10
1.00
IWC (g/m^3)

Summary and Conclusions

- A new analysis/validation/evaluation approach has been developed to derive ensemble mean particle fallspeeds for use in climate and cloud resolving models.
- This approach could be developed to either parameterize V_m in terms of the IWC and temperature for cirrus or to derive a consistent set of V_t versus D and mass versus D relationships for warmer ice cloud--currently, these are inconsistent
- In the context of MMAP, this approach could be developed for a variety of geographic locations and cloud properties


Summary, T<−20C, b=1.7
V_m (cm/s)
140
120
100
80
60
40
20
0
−60
−50
−40
−30
−20
T (C)
V_m (cm/s)
140
120
100
80
60
40
20
0
0.01
0.10
1.00
IWC (g/m³)


Summary, T>−20C, b=1.7
140
120
100
80
60
40
20
0
V_m (cm/s)
−20
−15
−10
−5
0
T (C)
140
120
100
80
60
40
20
0
V_m (cm/s)
0.01
0.10
1.00
IWC (g/m^3)