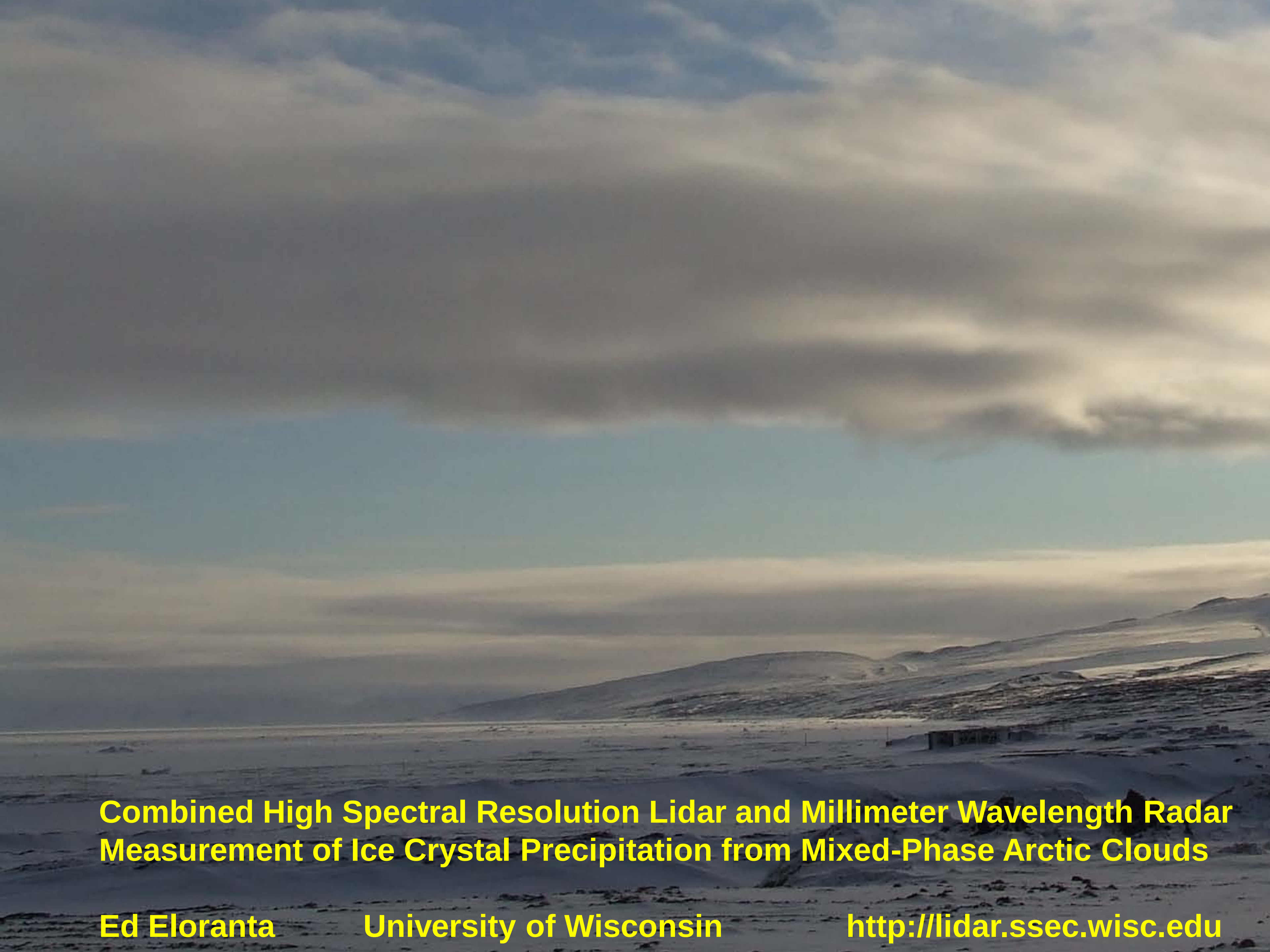
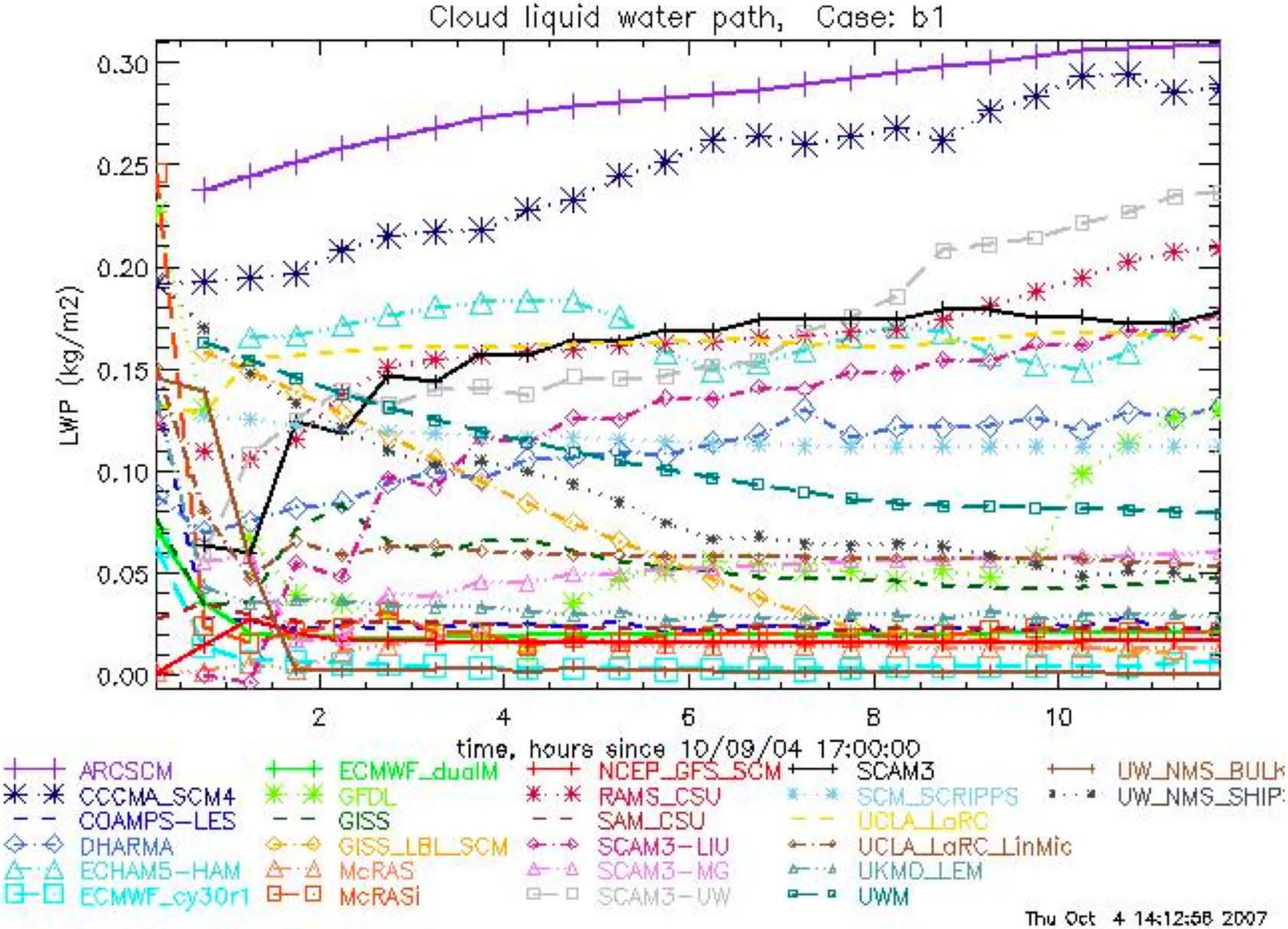


Combined High Spectral Resolution Lidar and Millimeter Wavelength Radar Measurement of Ice Crystal Precipitation from Mixed-Phase Arctic Clouds

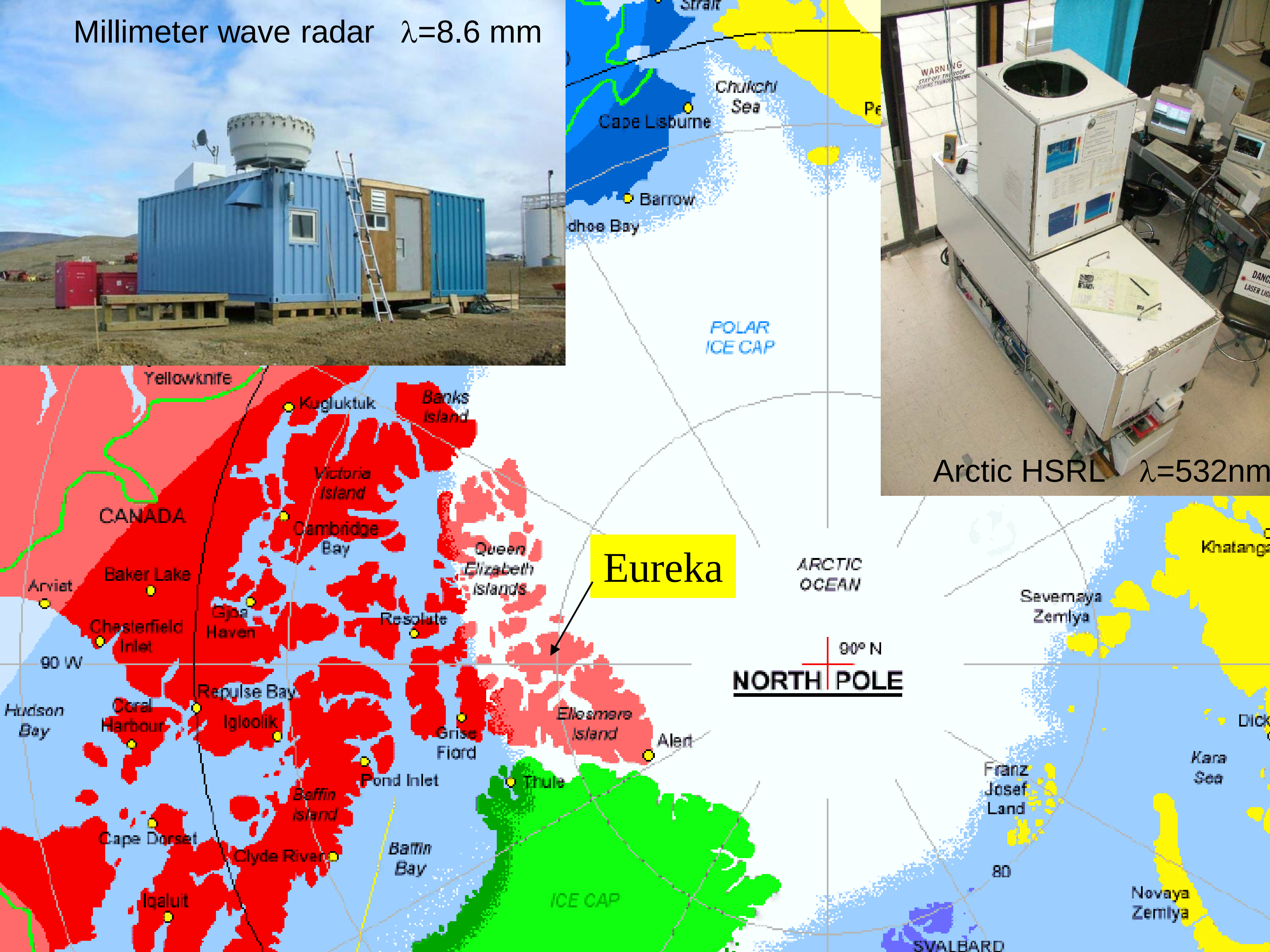
Ed Eloranta University of Wisconsin http://lidar.ssec.wisc.edu



From ARM Model intercomparison (Klein et al.)

AGU San Francisco, 14 December, 2007

Models have great difficulty predicting the lifetime of Arctic clouds

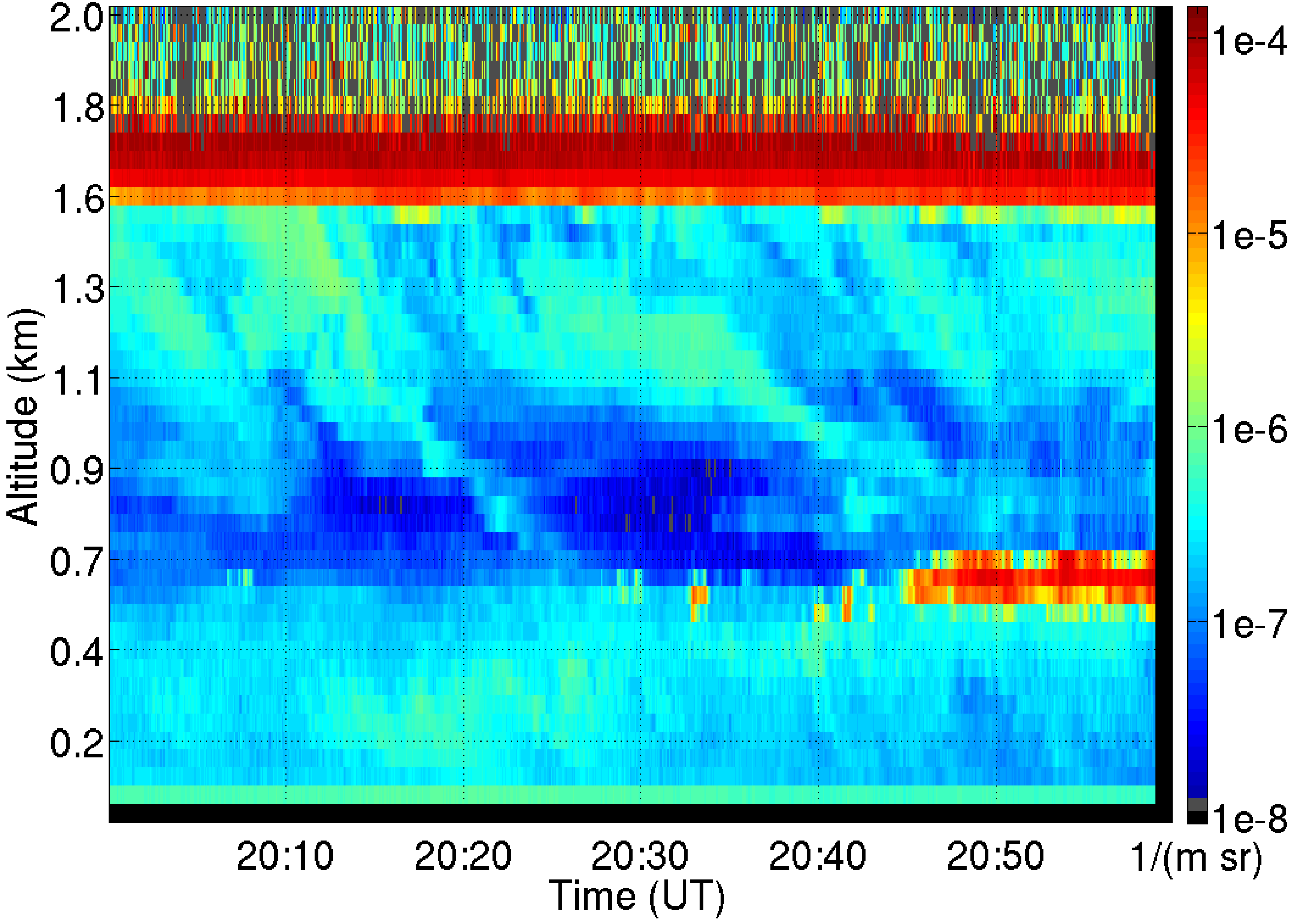


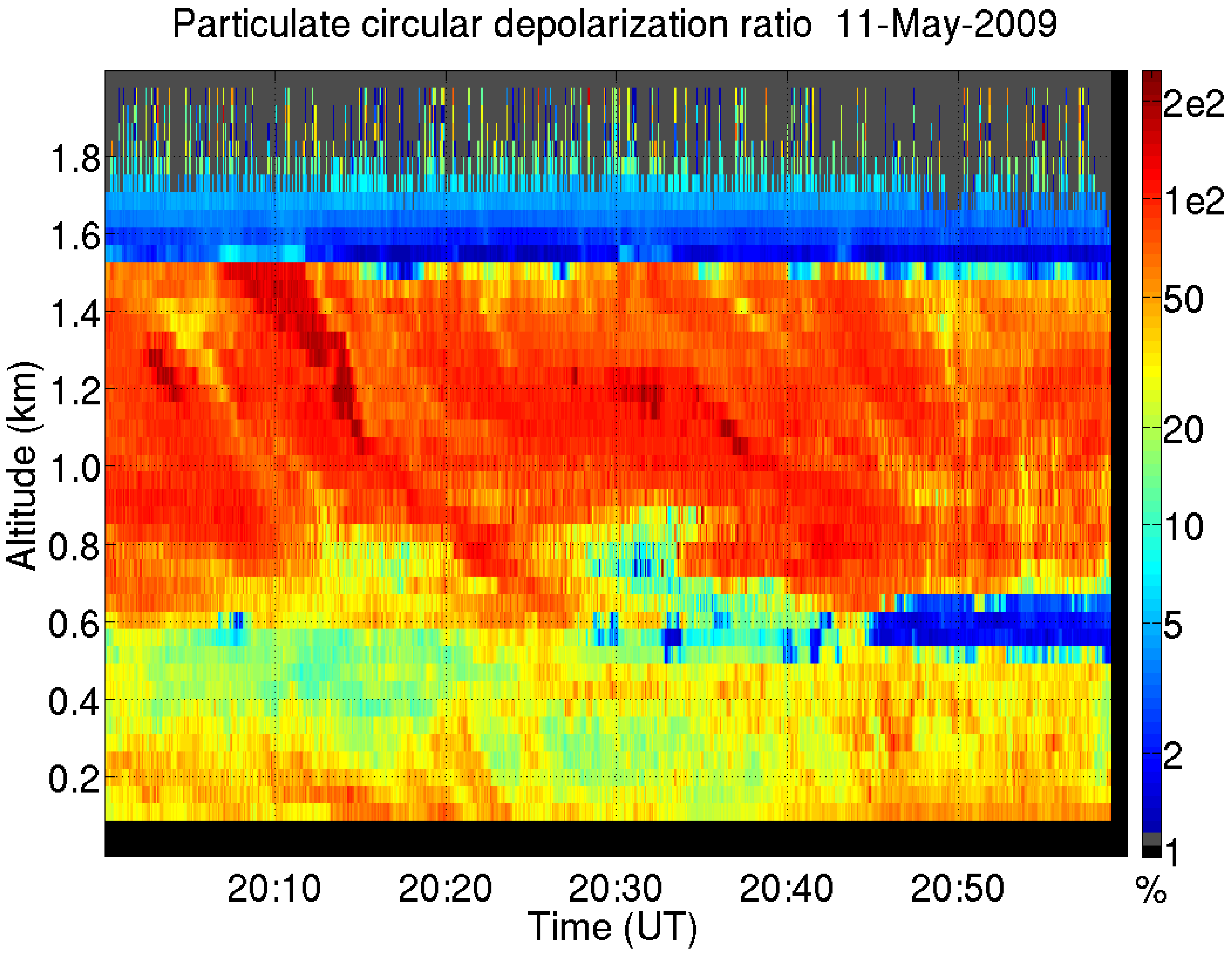
Millimeter wave radar $\lambda=8.6$ mm

Arctic HSRL $\lambda=532$nm

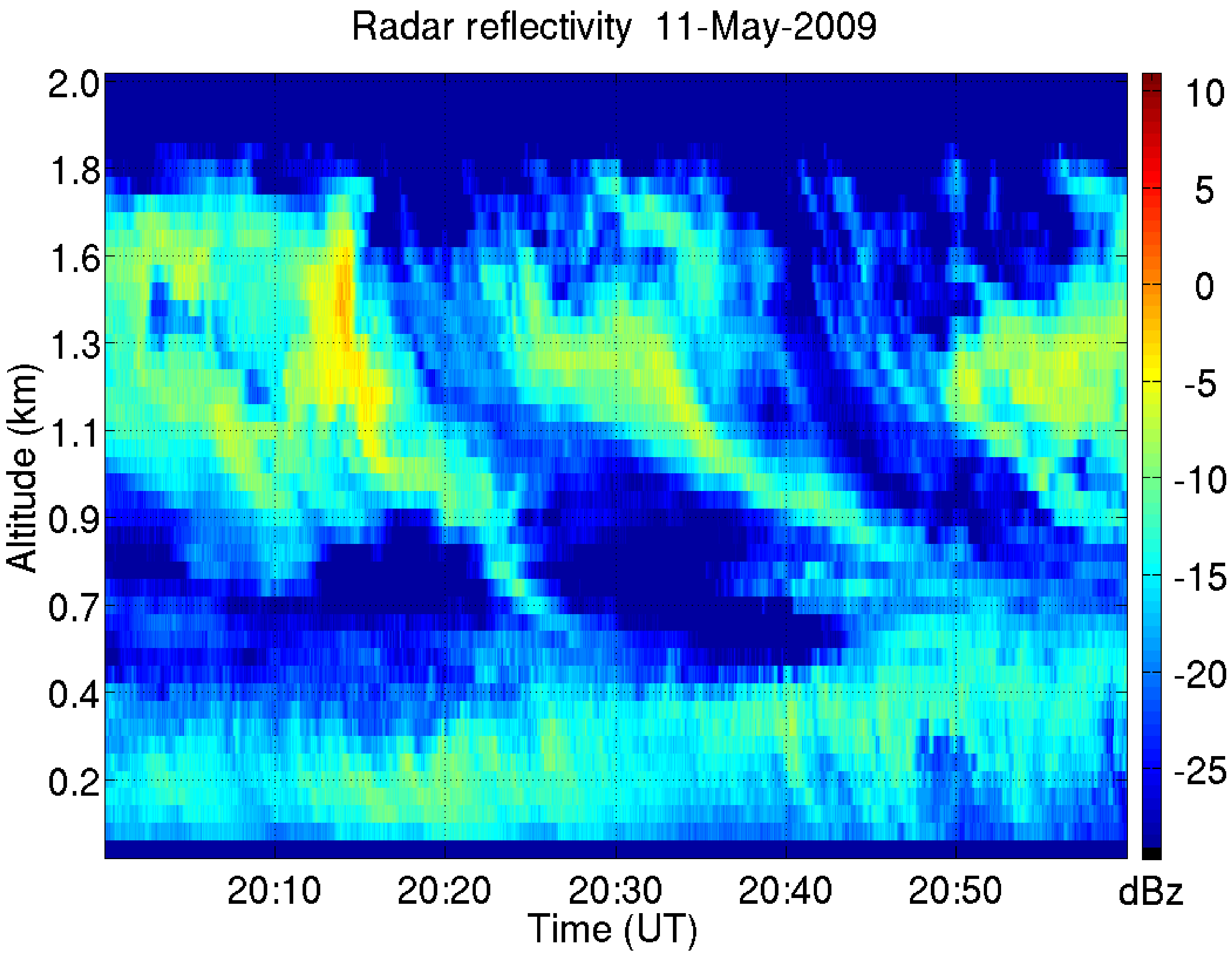
Eureka

Particulate Backscatter Cross Section, 11-May-09,





Particulate circular depolarization ratio 11-May-2009


Radar reflectivity 11-May-2009
Altitude (km)
2.0
1.8
1.6
1.3
1.1
0.9
0.7
0.4
0.2
20:10
20:20
20:30
20:40
20:50
Time (UT)
10
5
0
-5
-10
-15
-20
-25
dBz

Lidar-Radar Measurement of Effective Diame

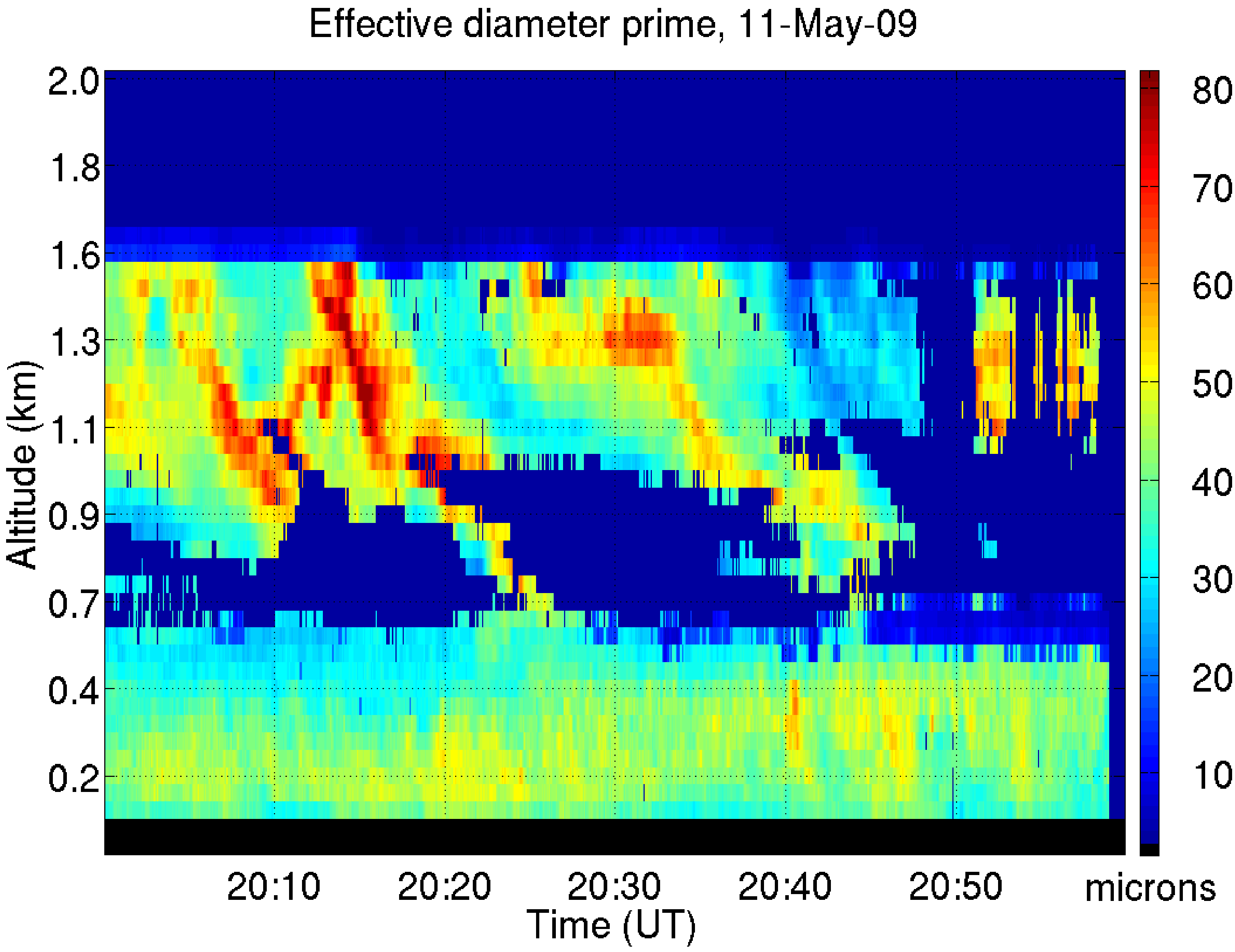
Radar scattering cross section ~ <Mass^2> ~ ρ <Volume^2> ~ D^6

Lidar scattering cross section ~ <Area> ~ D^2

$$D_{\text{eff\_prime}} \sim \sqrt[4]{\Bigg(\bigg(\frac{\langle\text{Radar scattering cross section}\rangle}{\langle\text{Lidar scattering cross section}\rangle}\Bigg)}$$

Notice that this differs for the usual definition:

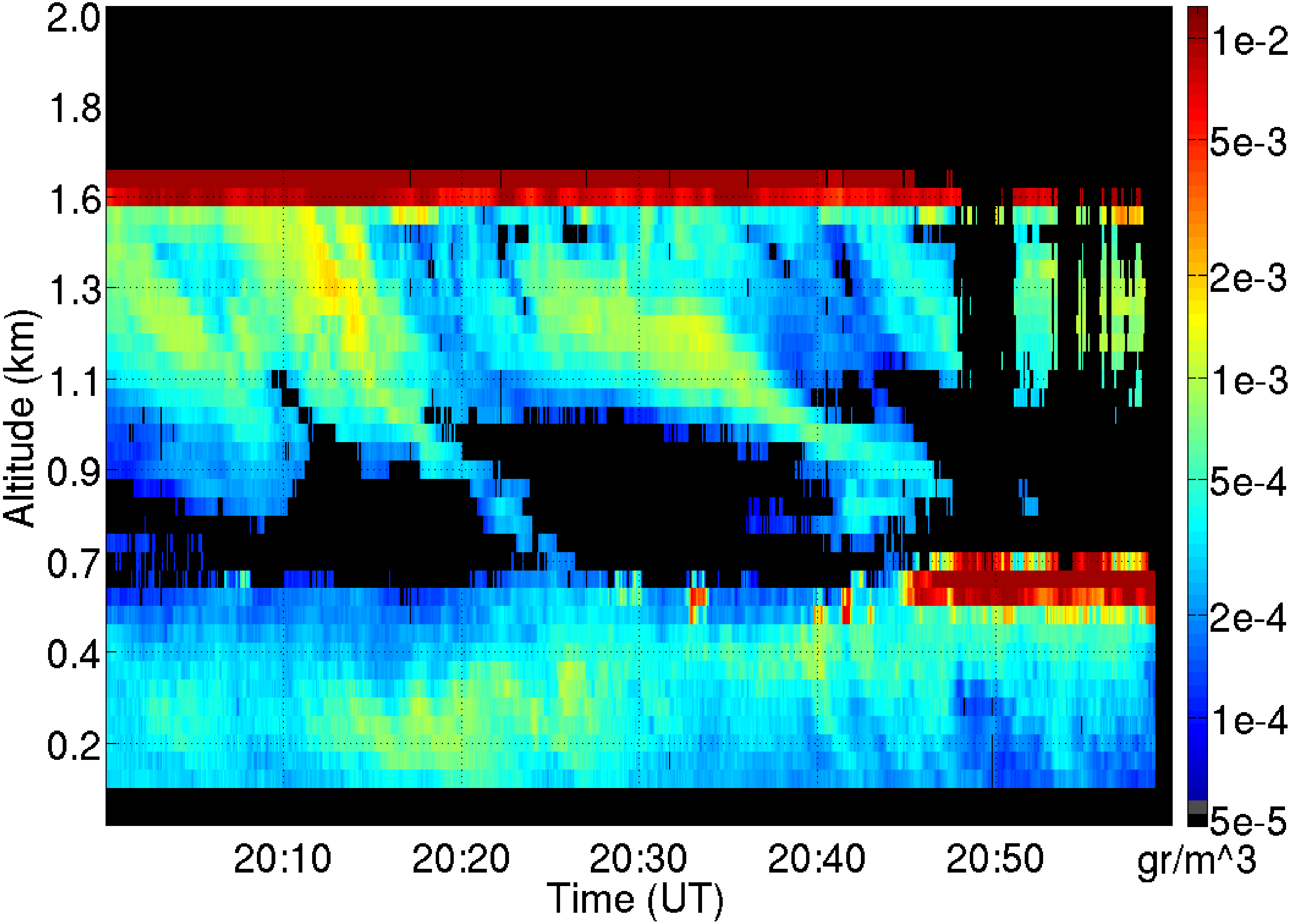
$$D_{\text{eff}} = \frac{\langle\text{Particle volume}\rangle}{\langle\text{Particle area}\rangle}$$


Effective diameter prime, 11-May-09
2.0
1.8
1.6
1.3
1.1
0.9
0.7
0.4
0.2
Altitude (km)
20:10
20:20
20:30
20:40
20:50
Time (UT)
800
700
600
500
400
300
200
100
microns

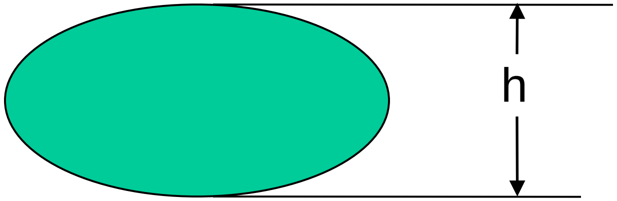
Problem:
Ice crystals are not spherical

Photos by Kenneth Libbrecht

Water content assuming bullet rosettes, 11-May-09



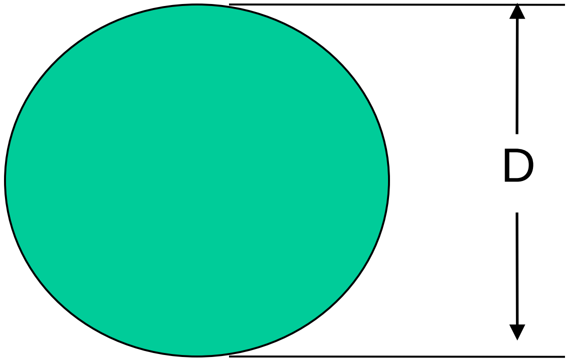
Spheroid model to represent measureable properties of a snowflake



Side view

$h = a\,D^{\zeta}$ (Auer and Veal)

$\text{mass} = \pi/6\;D^2h$



Top view

projected area $= \pi/4\;D^2$

We assume a modified Gamma distribution

$N(D) \sim D^{\alpha}\exp(-bD^{\gamma})$

Radar backscatter ~ particle concentration <mass^2>

Lidar extinction ~ particle concentration <projected area>

Fall Velocity ~ F(mass, projected area)

The size distribution and the spheroid model are used to compute the observable quanities:

Integrating over the size distribution N(D) to derive D'_{eff}

$$D'_{eff} = \sqrt[4]{\frac{9\langle V^2\rangle}{\pi\langle A\rangle}} = \sqrt[4]{\frac{\int a^2 D^4 D^{2\zeta} N(D)dD}{\int D^2 N(D)dD}} = \sqrt[4]{\frac{2\lambda^4\beta_{radar}}{\pi^3 k^2_{ice}\beta_s}}$$

Radar reflectivity weighted fall velocity:

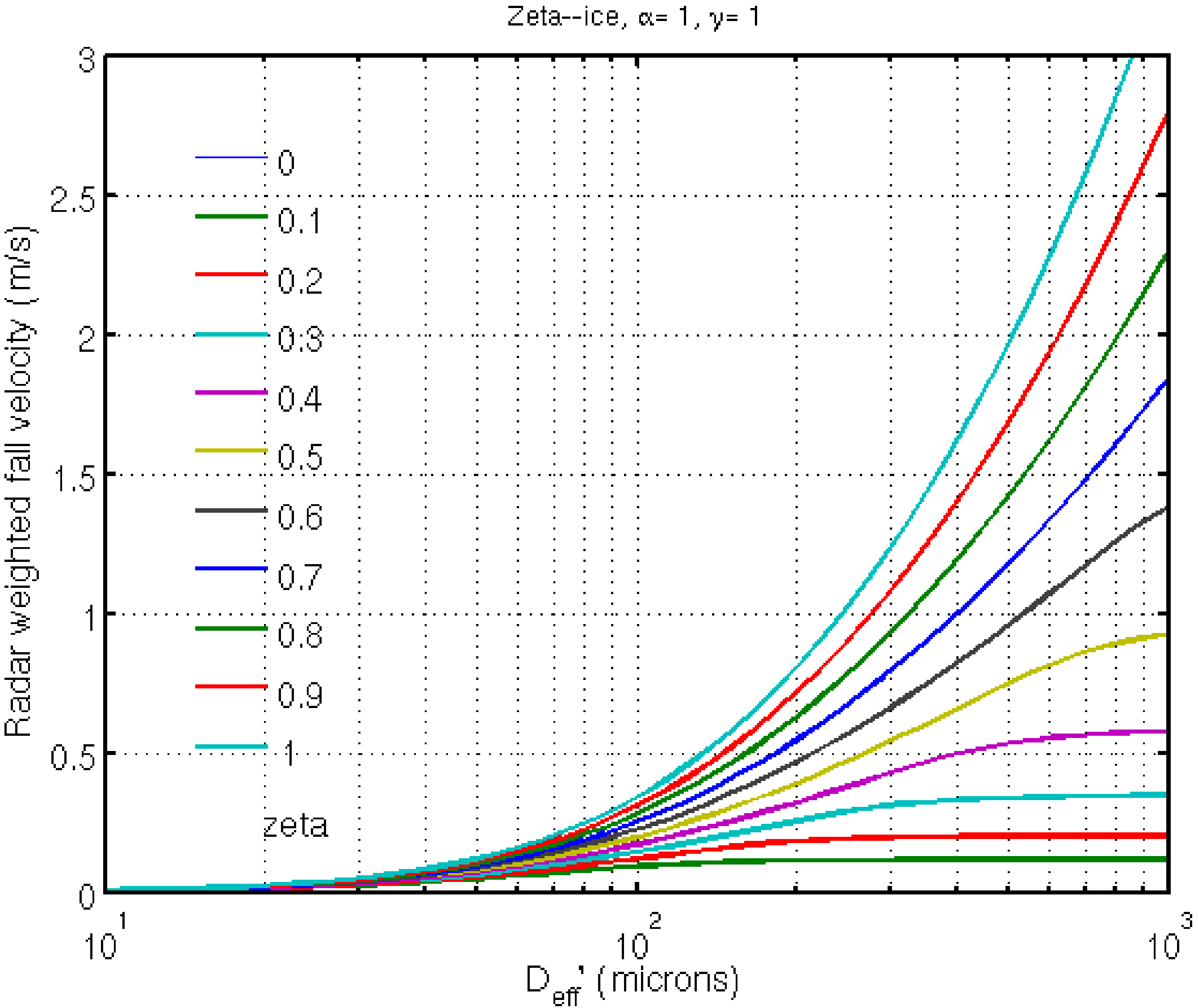
$$\langle V_f\rangle = \frac{\int V_f \; D^4 D^{2\zeta} N(D)dD}{\int D^4 D^{2\zeta} N(D)dD}$$

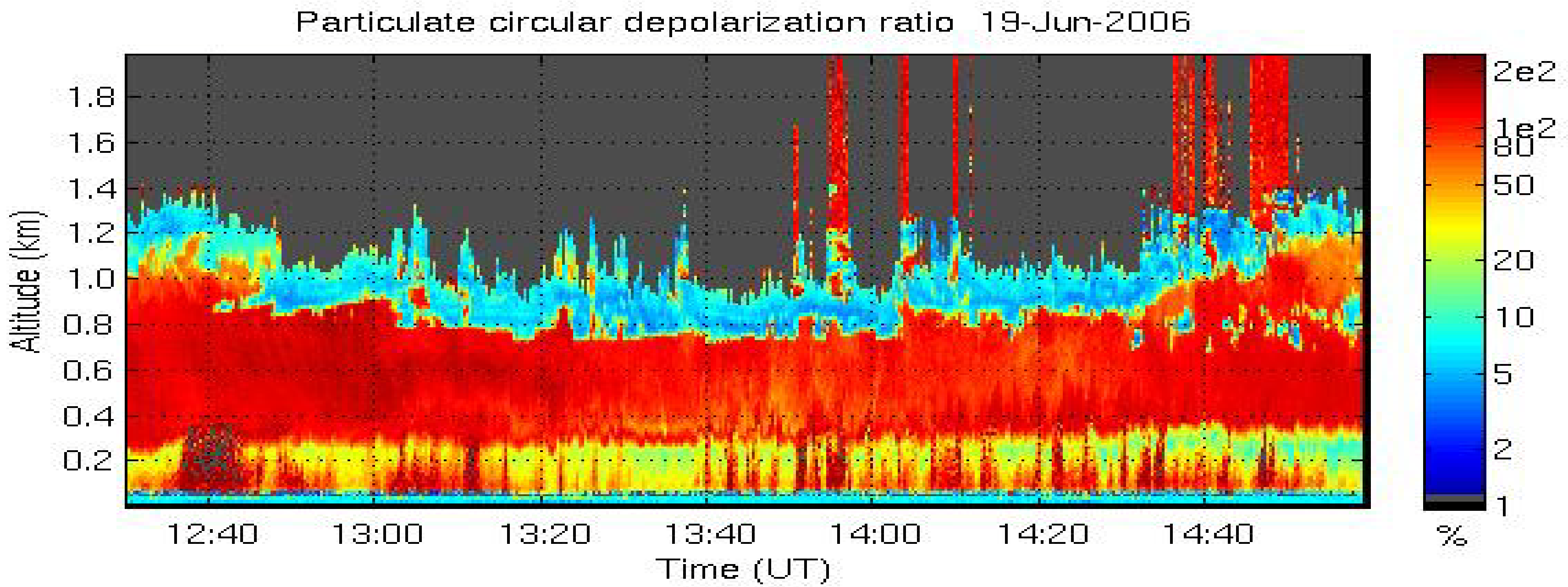
Fall velocity is parameterized in terms of X, the Best # :

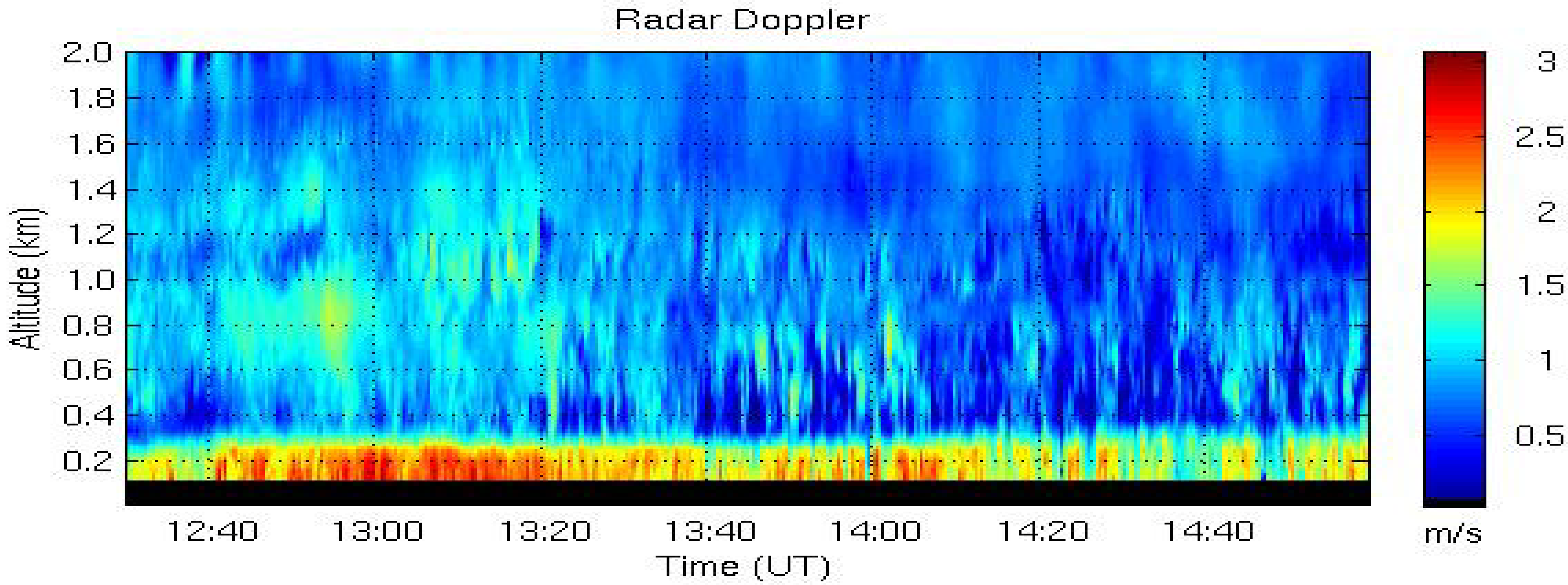
$$V_f = (\eta/(\rho_{air} D))\{(d^2_o/4)[(1+C_1 X^{1/2})^{1/2} - a_o X^{bo}\}$$

$$X = (2 \text{ mass } \rho_{air} \text{ g } D^2)/(\text{area } \eta^2)$$

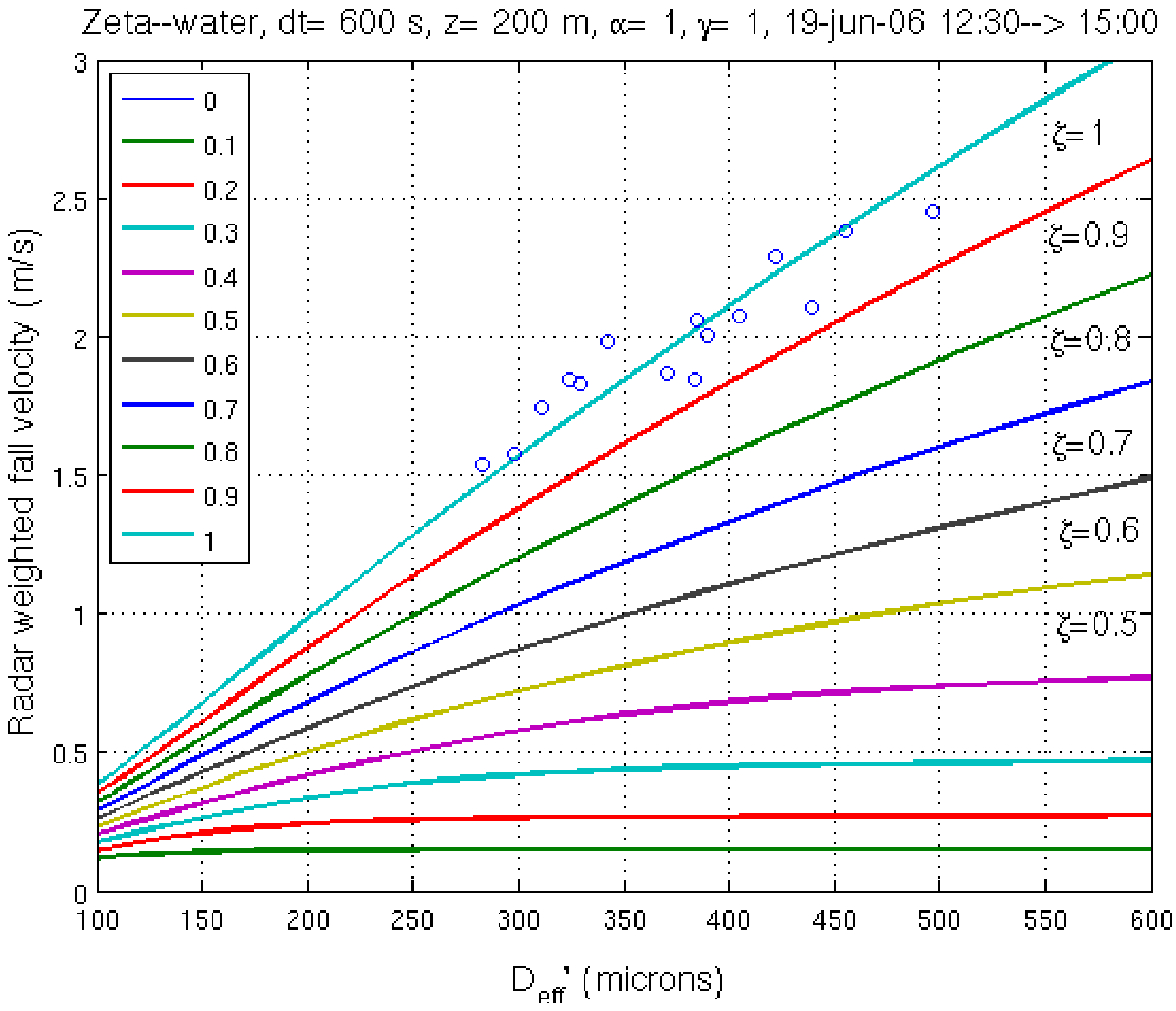
Using the gamma size distribution model, the Best # based fall velocity model, and spheroid representation of particles we can generate the following plot.



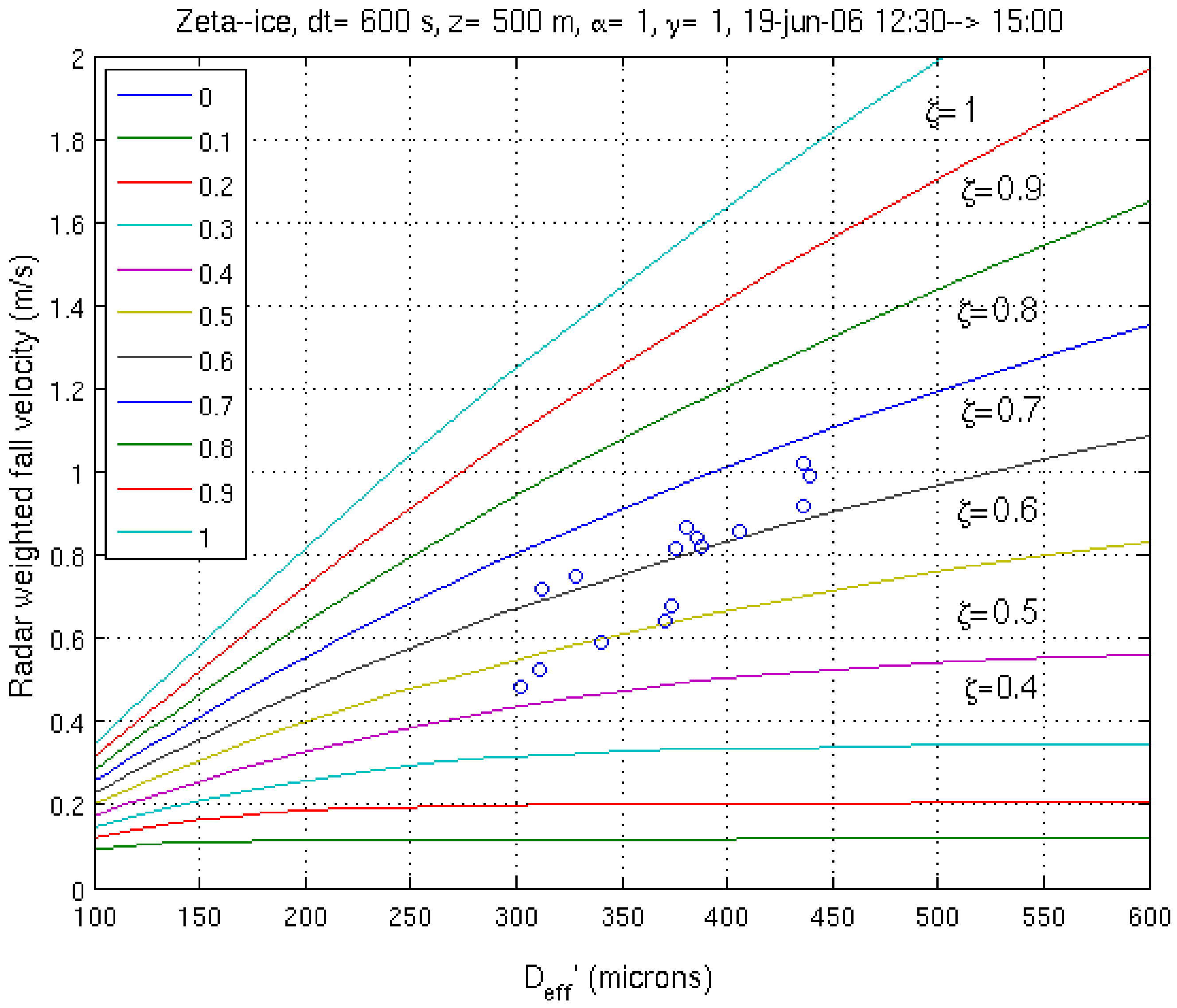

Particulate circular depolarization ratio 19-Jun-2006

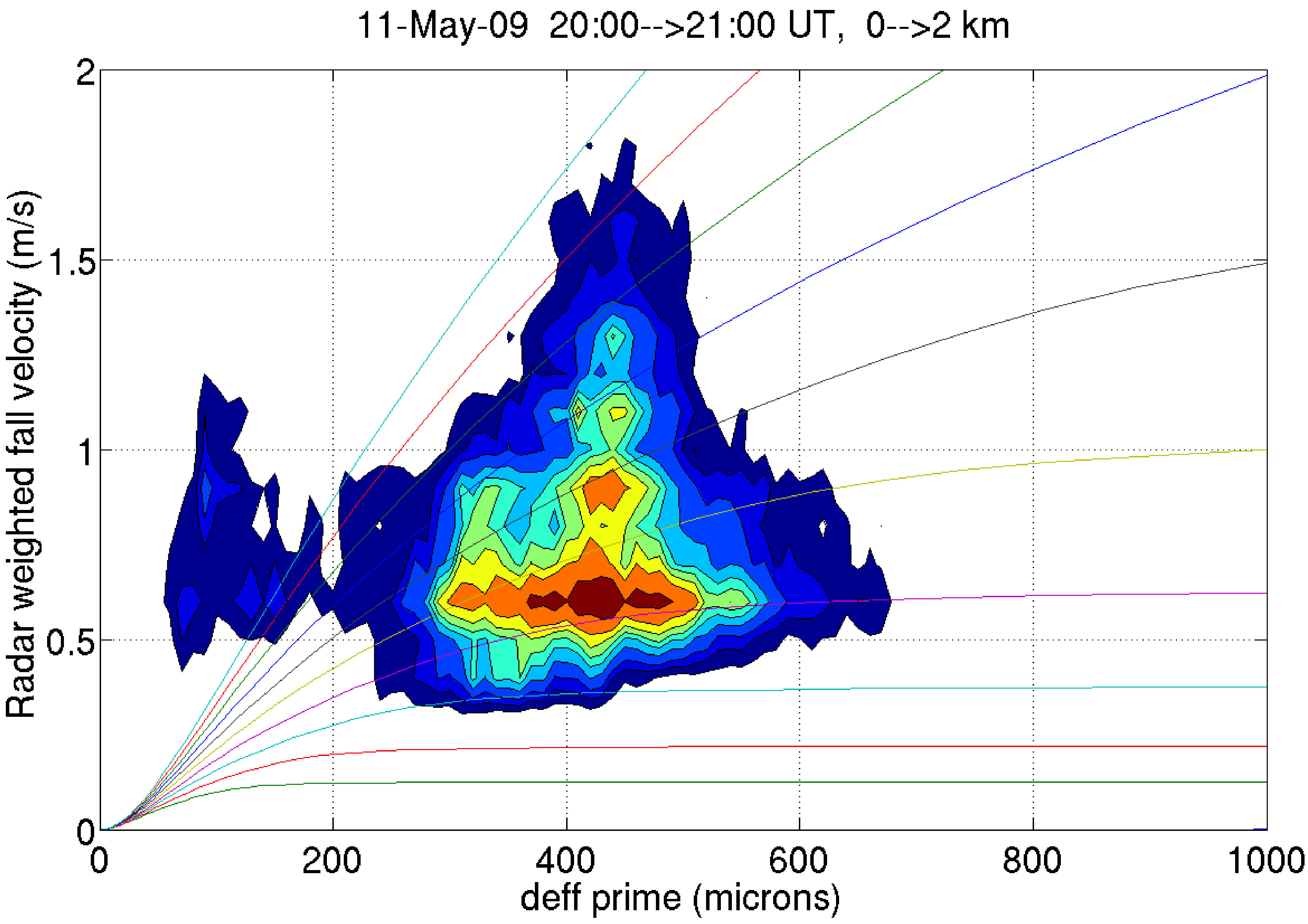

Radar Doppler

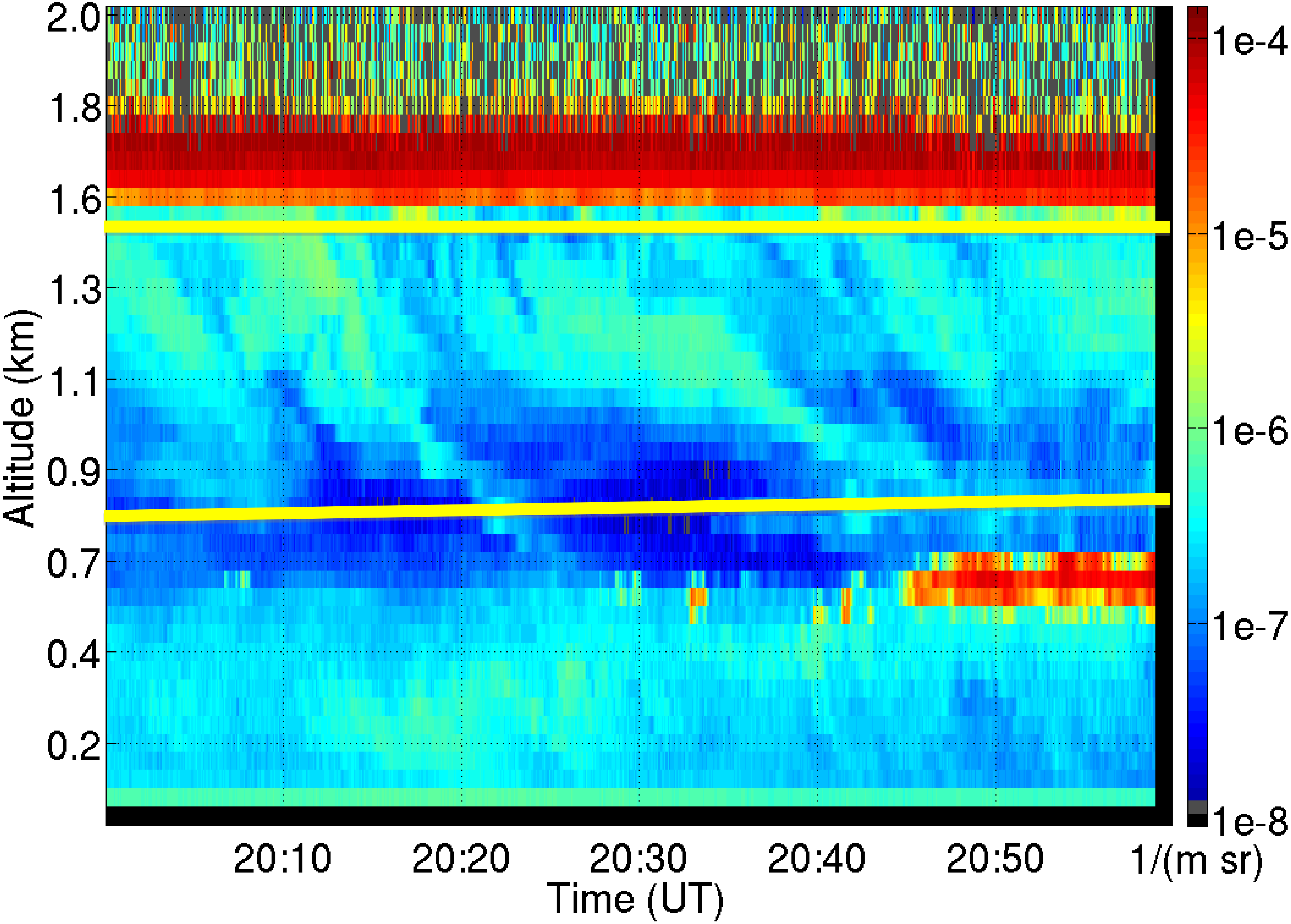
Doppler velocity vs. $D_{\text{eff prime}}$ below melting layer



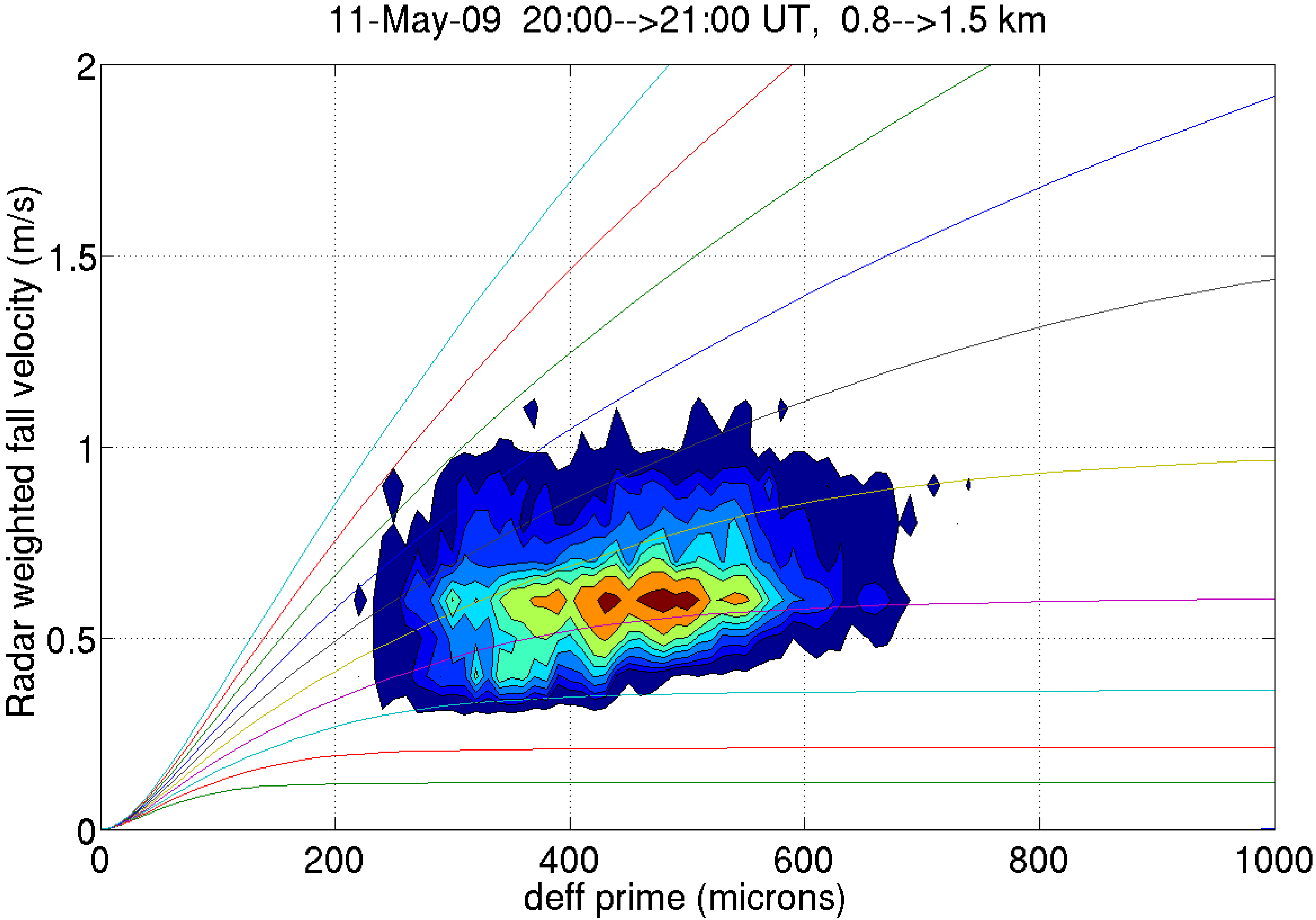
Doppler velocity vs. $D_{eff\ prime}$ in snow layer

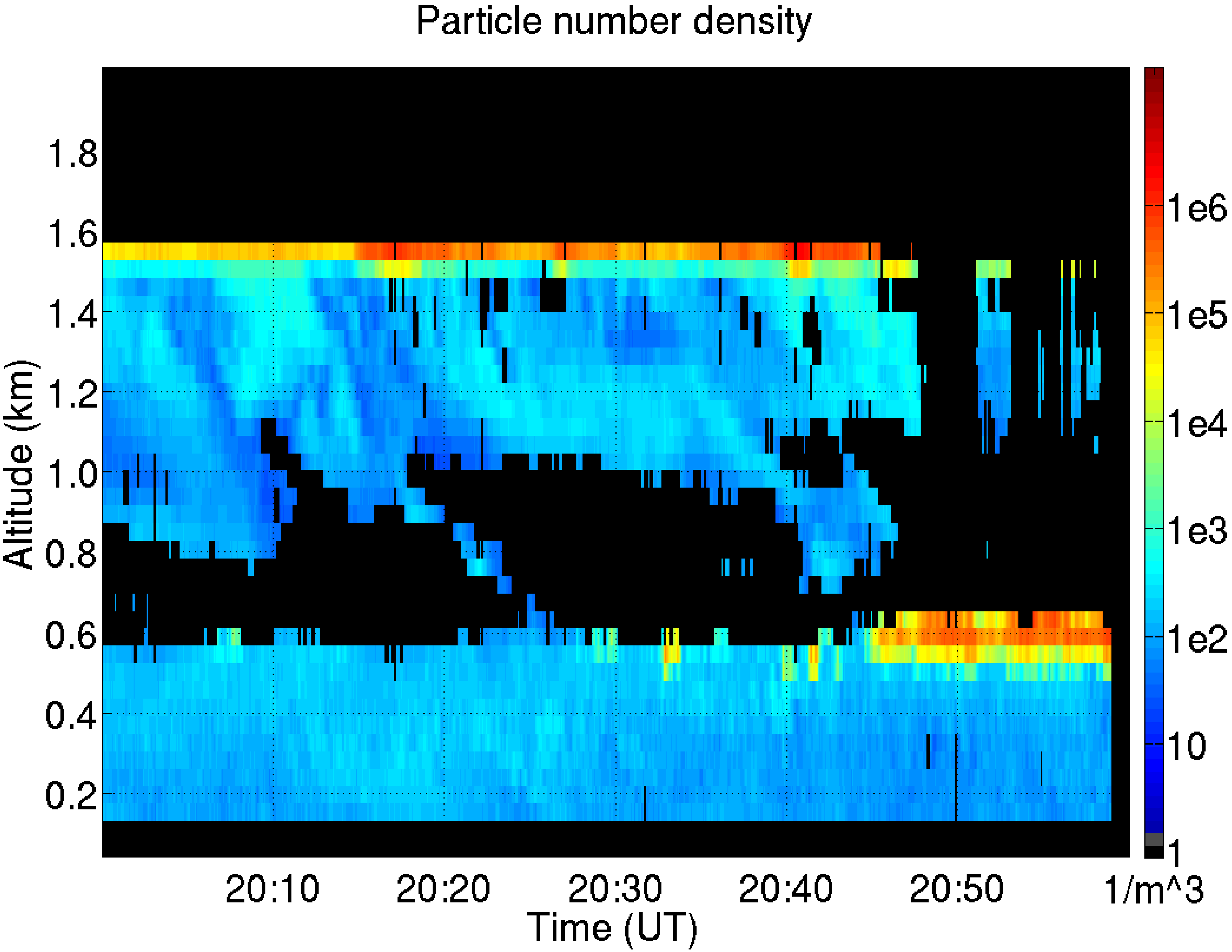


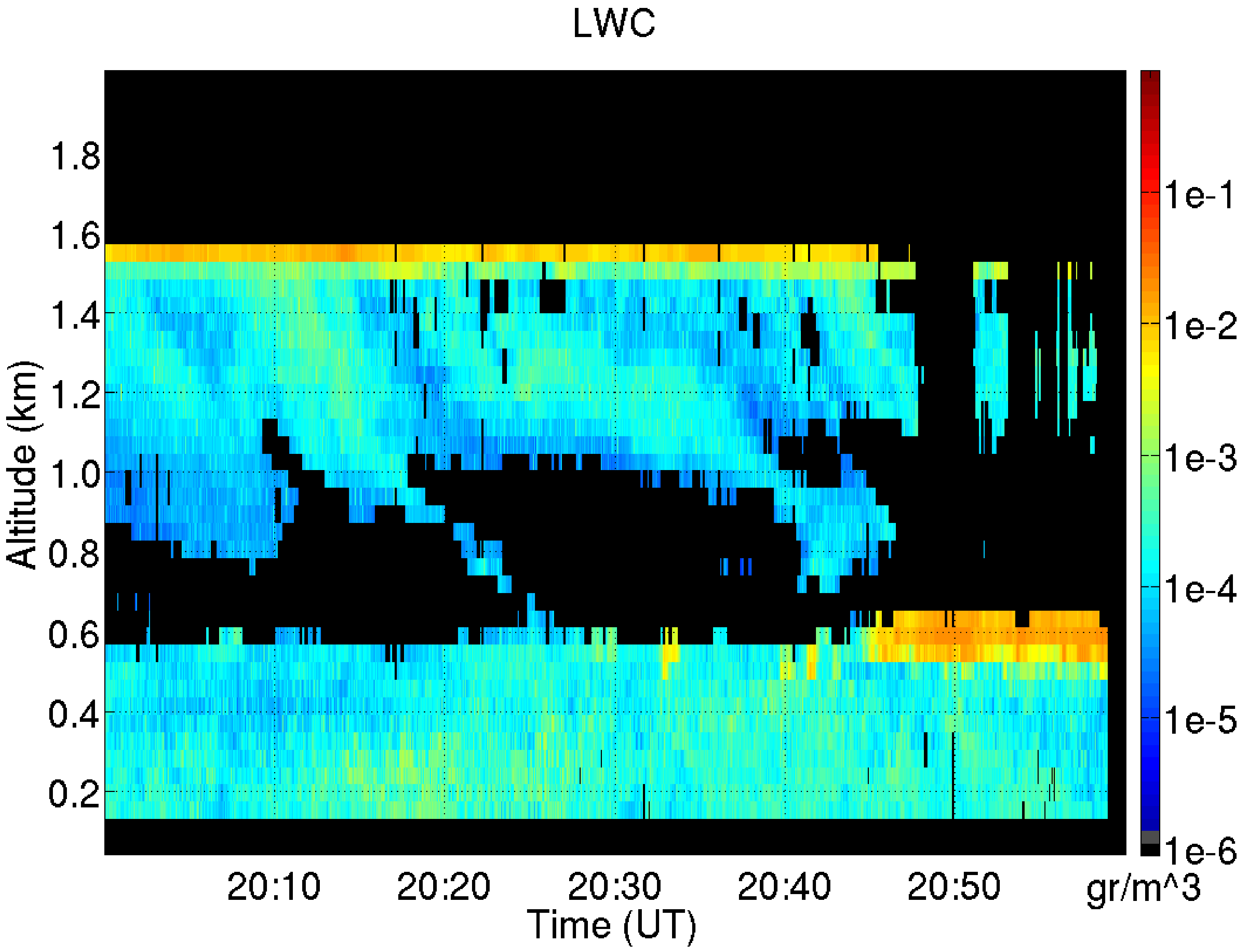

11-May-09 20:00-->21:00 UT, 0-->2 km
Radar weighted fall velocity (m/s)
deff prime (microns)
0
0.5
1
1.5
2
0
200
400
600
800
1000

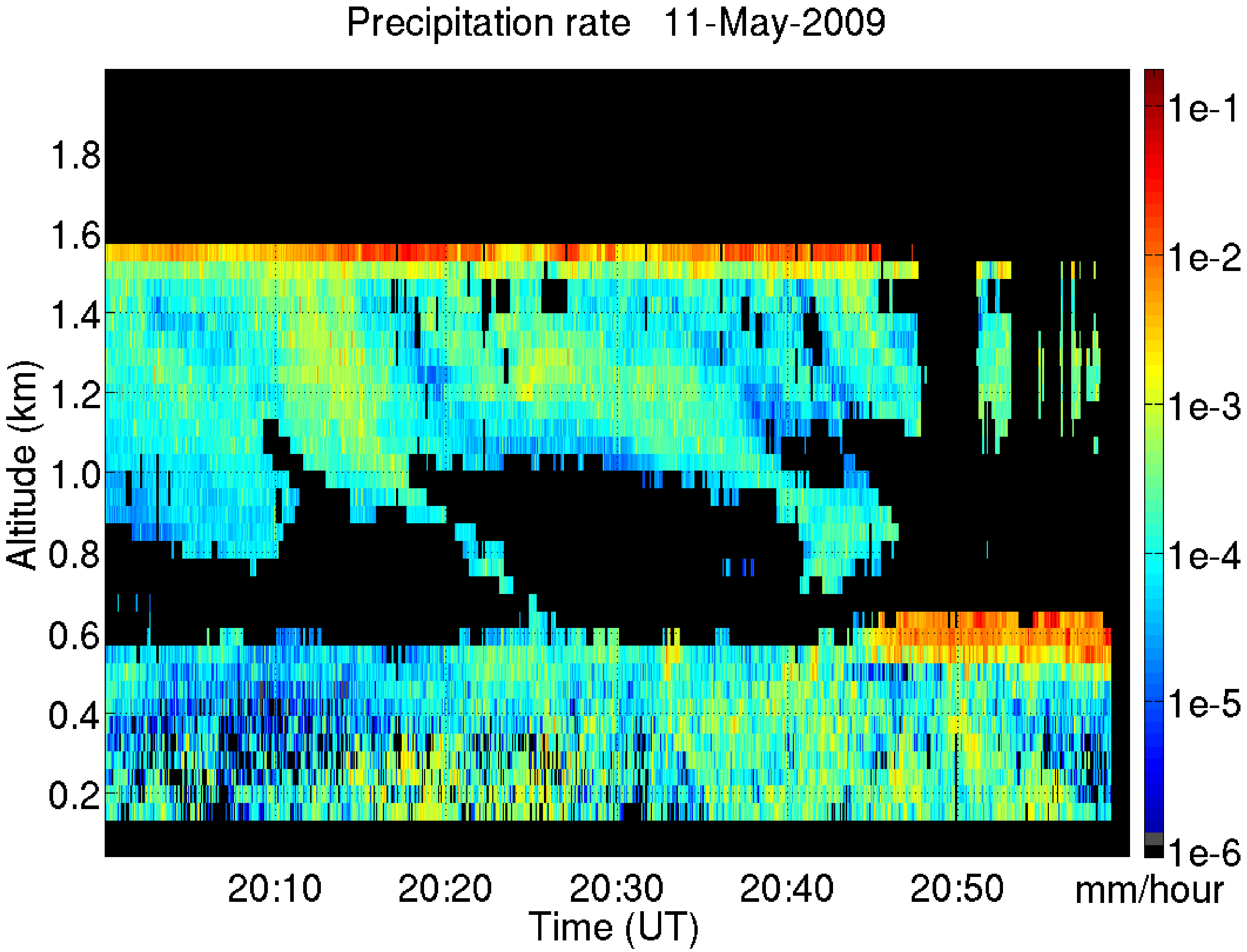


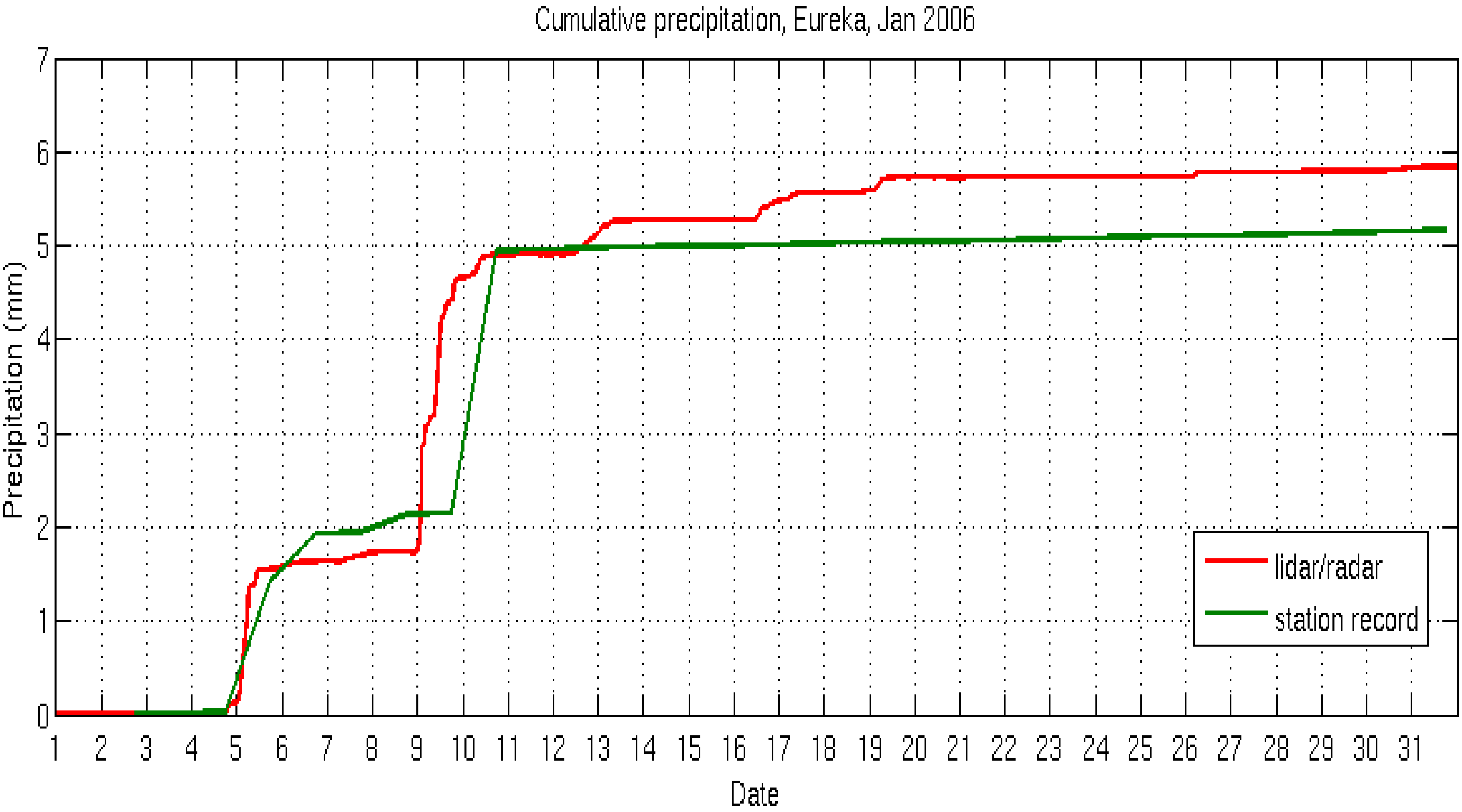
Particulate Backscatter Cross Section, 11-May-09,

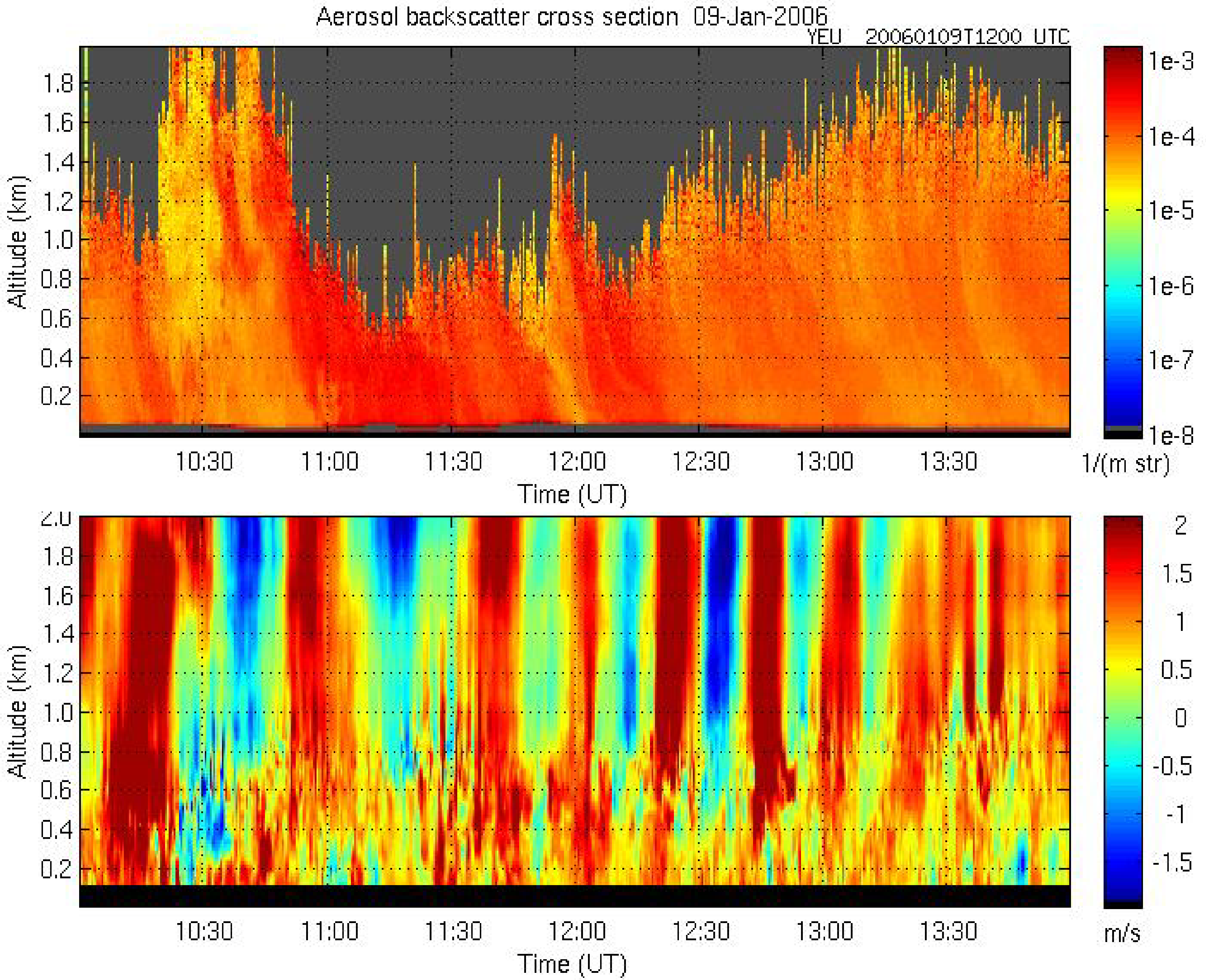

11-May-09 20:00-->21:00 UT, 0.8-->1.5 km
Radar weighted fall velocity (m/s)
2
1.5
1
0.5
0
0
200
400
600
800
1000
deff prime (microns)

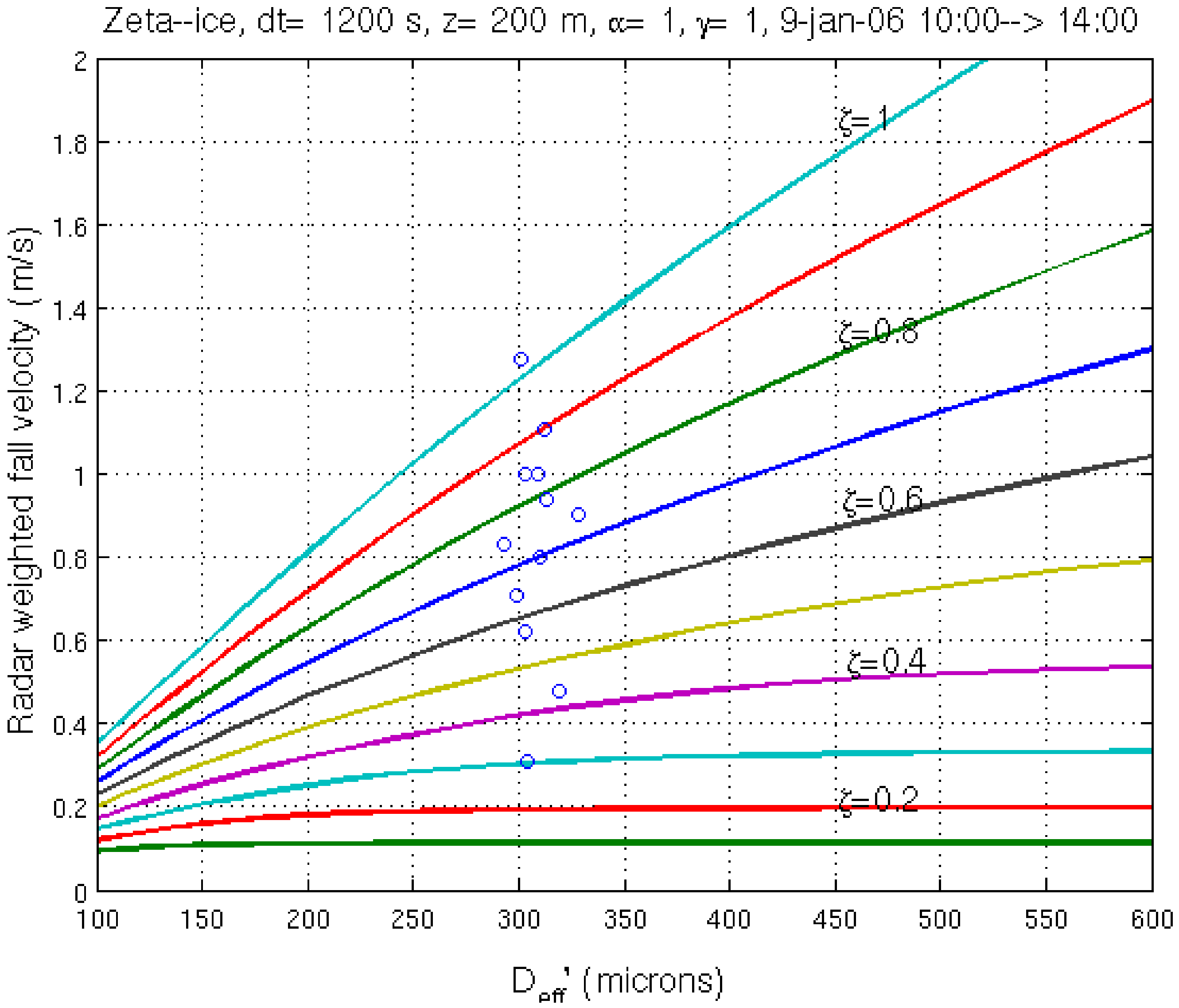

Particle number density
Altitude (km)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
20:10
20:20
20:30
20:40
20:50
Time (UT)
1e6
1e5
1e4
1e3
1e2
10
1
1/m^3

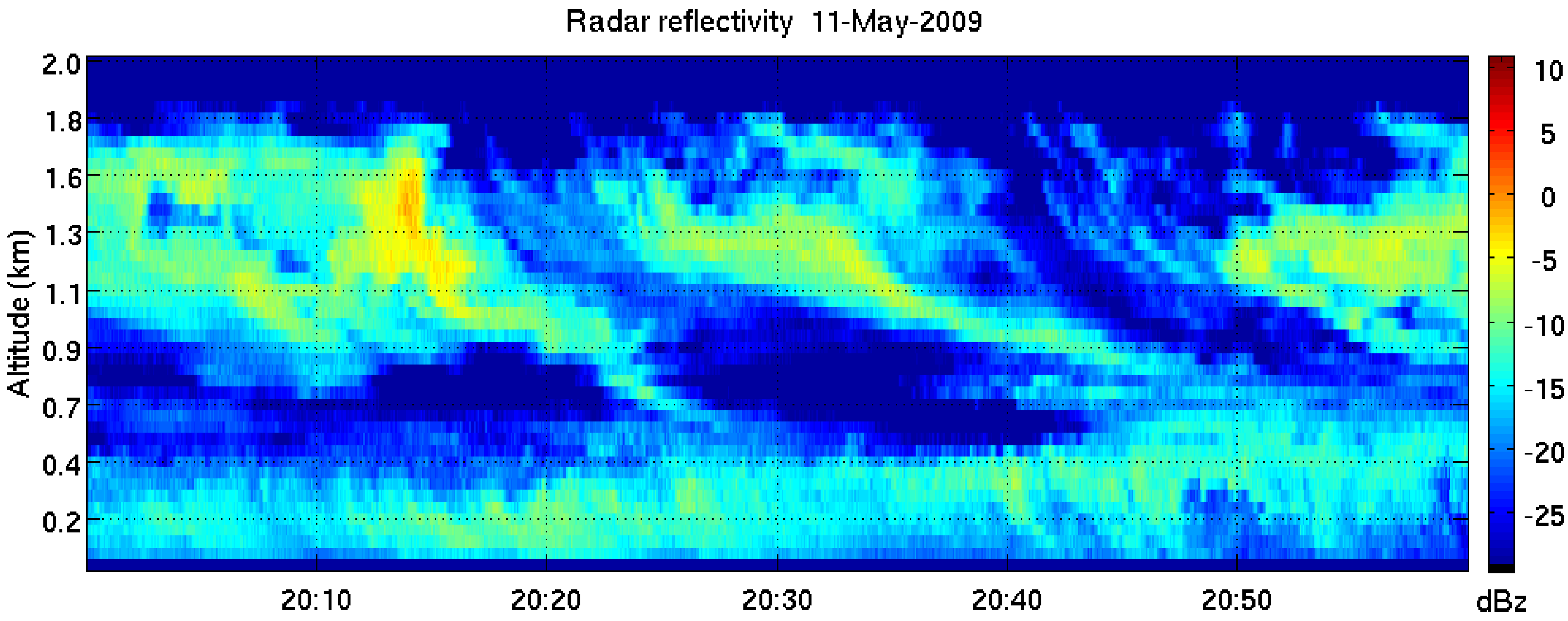

LWC
Altitude (km)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
20:10
20:20
20:30
20:40
20:50
Time (UT)
1e-1
1e-2
1e-3
1e-4
1e-5
1e-6
gr/m^3


Precipitation rate 11-May-2009
Altitude (km)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
20:10
20:20
20:30
20:40
20:50
Time (UT)
1e-1
1e-2
1e-3
1e-4
1e-5
1e-6
mm/hour

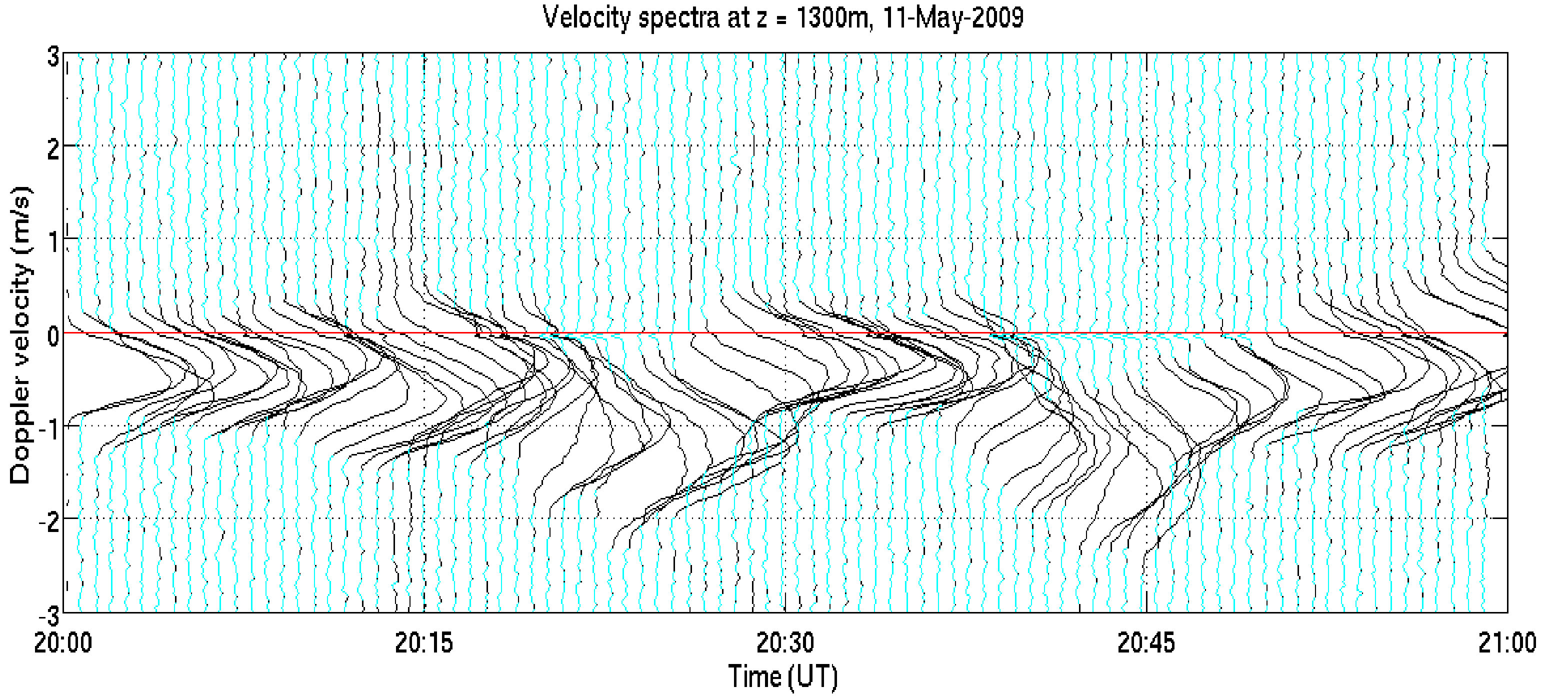

Cumulative precipitation, Eureka, Jan 2006
Precipitation (mm)
0
1
2
3
4
5
6
7
Date
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
lidar/radar
station record


Aerosol backscatter cross section 09-Jan-2006
YEU 20060109T1200 UTC
Altitude (km)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
10:30
11:00
11:30
12:00
12:30
13:00
13:30
Time (UT)
1e-3
1e-4
1e-5
1e-6
1e-7
1e-8
1/(m str)
2.0
Altitude (km)
Time (UT)
2
1.5
1
0.5
0
-0.5
-1
-1.5
m/s


Zeta--ice, dt= 1200 s, z= 200 m, α= 1, γ= 1, 9-jan-06 10:00--> 14:00
Radar weighted fall velocity (m/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
100
150
200
250
300
350
400
450
500
550
600
D_eff' (microns)
ζ=1
ζ=0.8
ζ=0.6
ζ=0.4
ζ=0.2

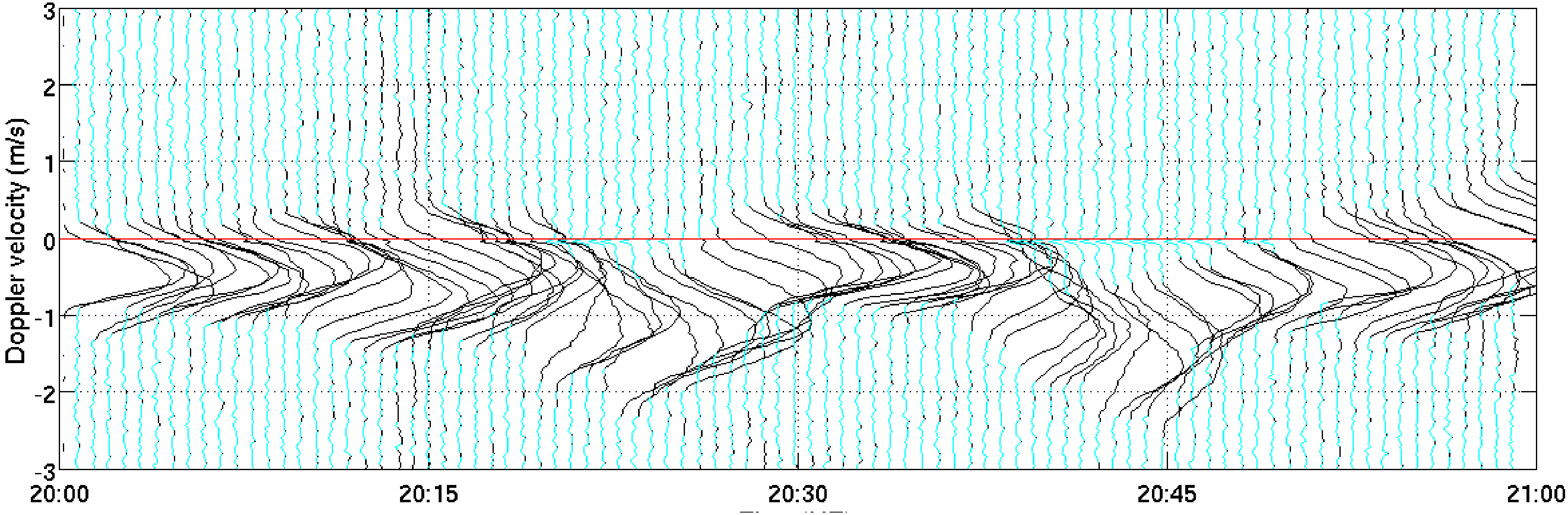


Radar reflectivity 11-May-2009

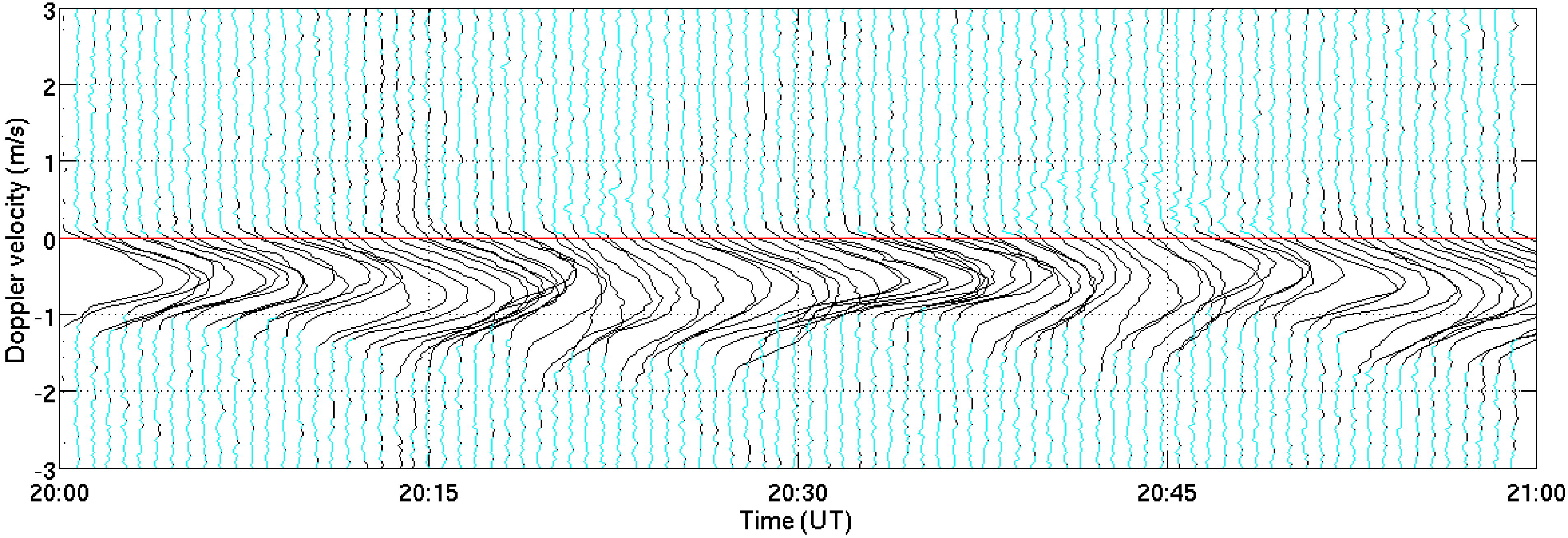


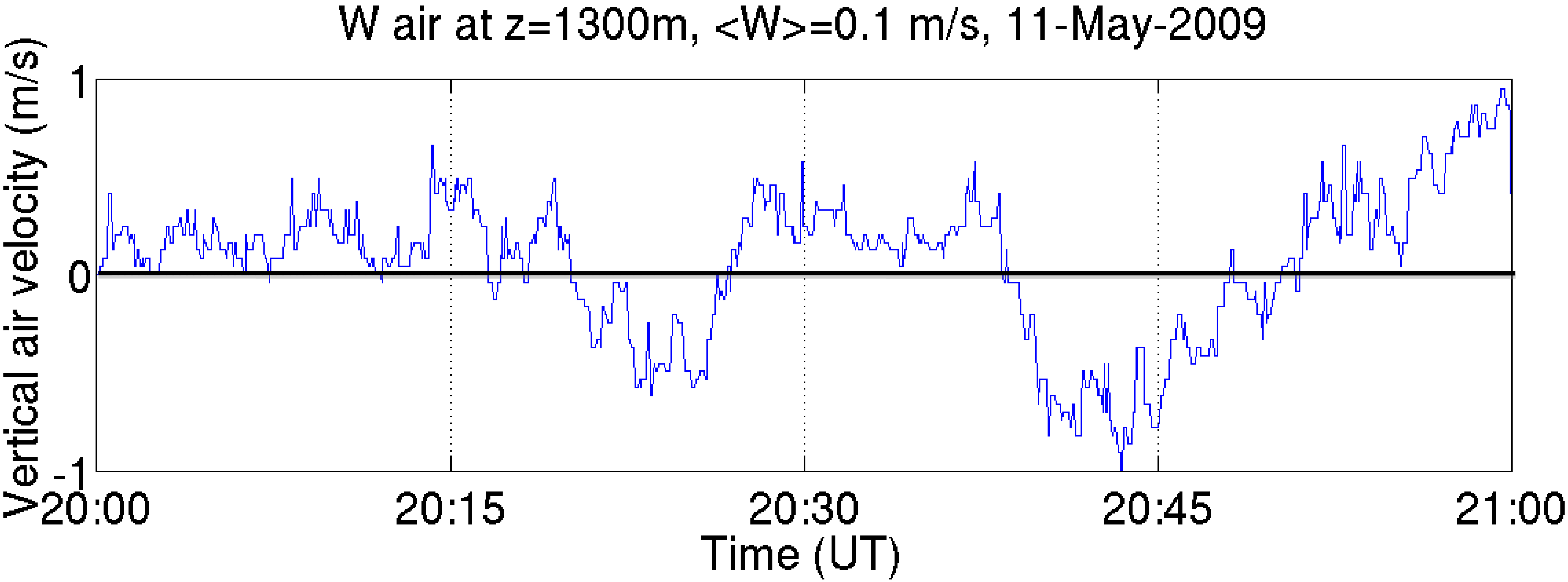
Velocity spectra at z = 1300m, 11-May-2009

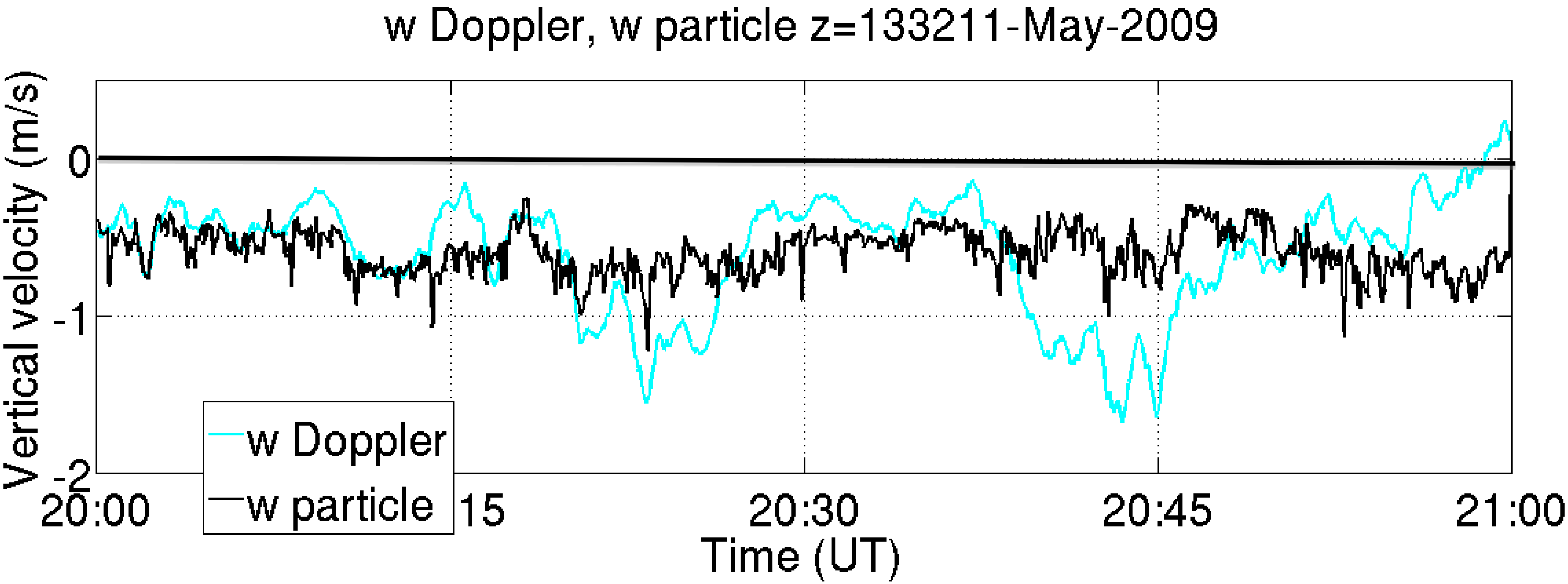
Velocity spectra at z = 1300m, 11-May-2009

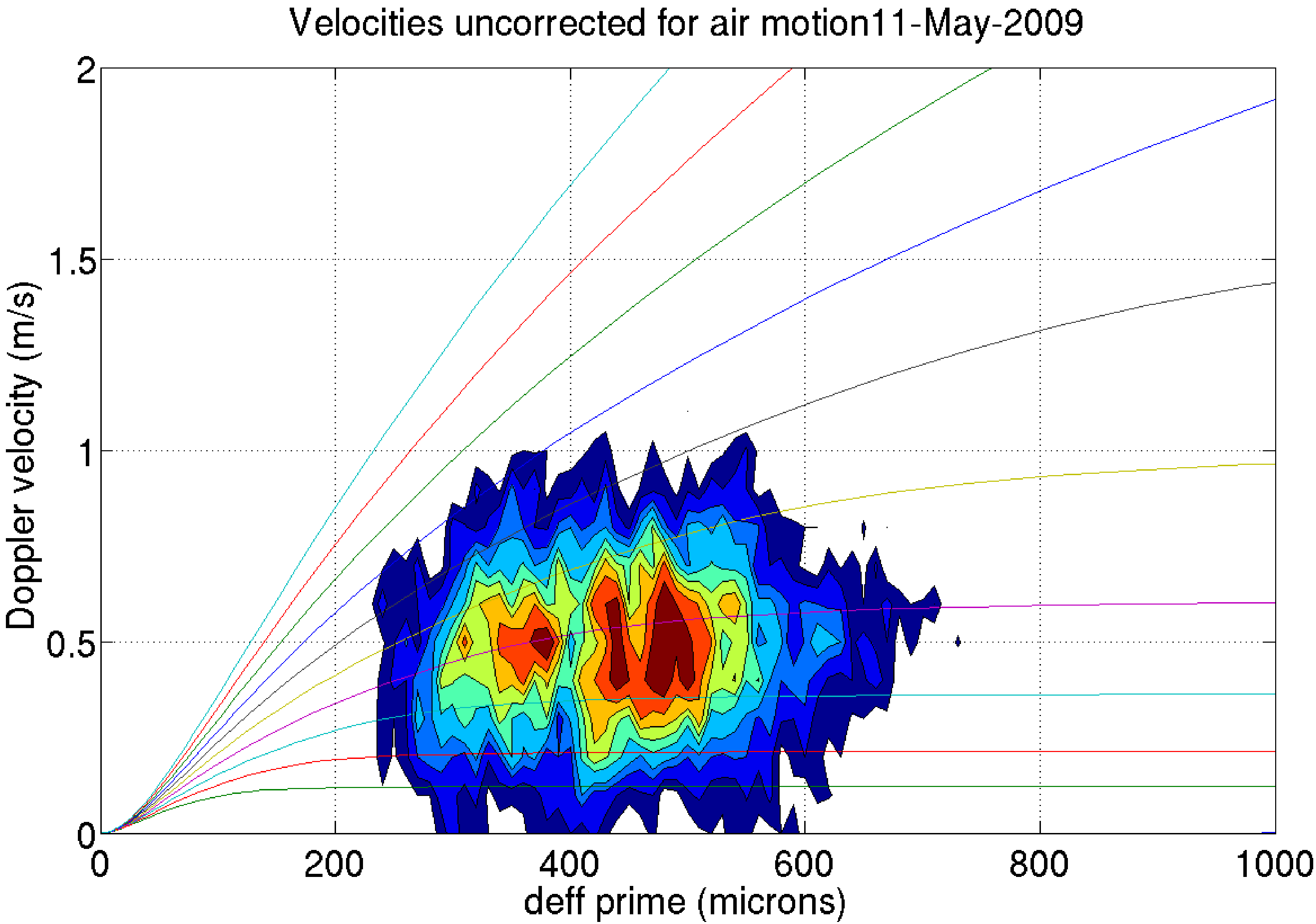


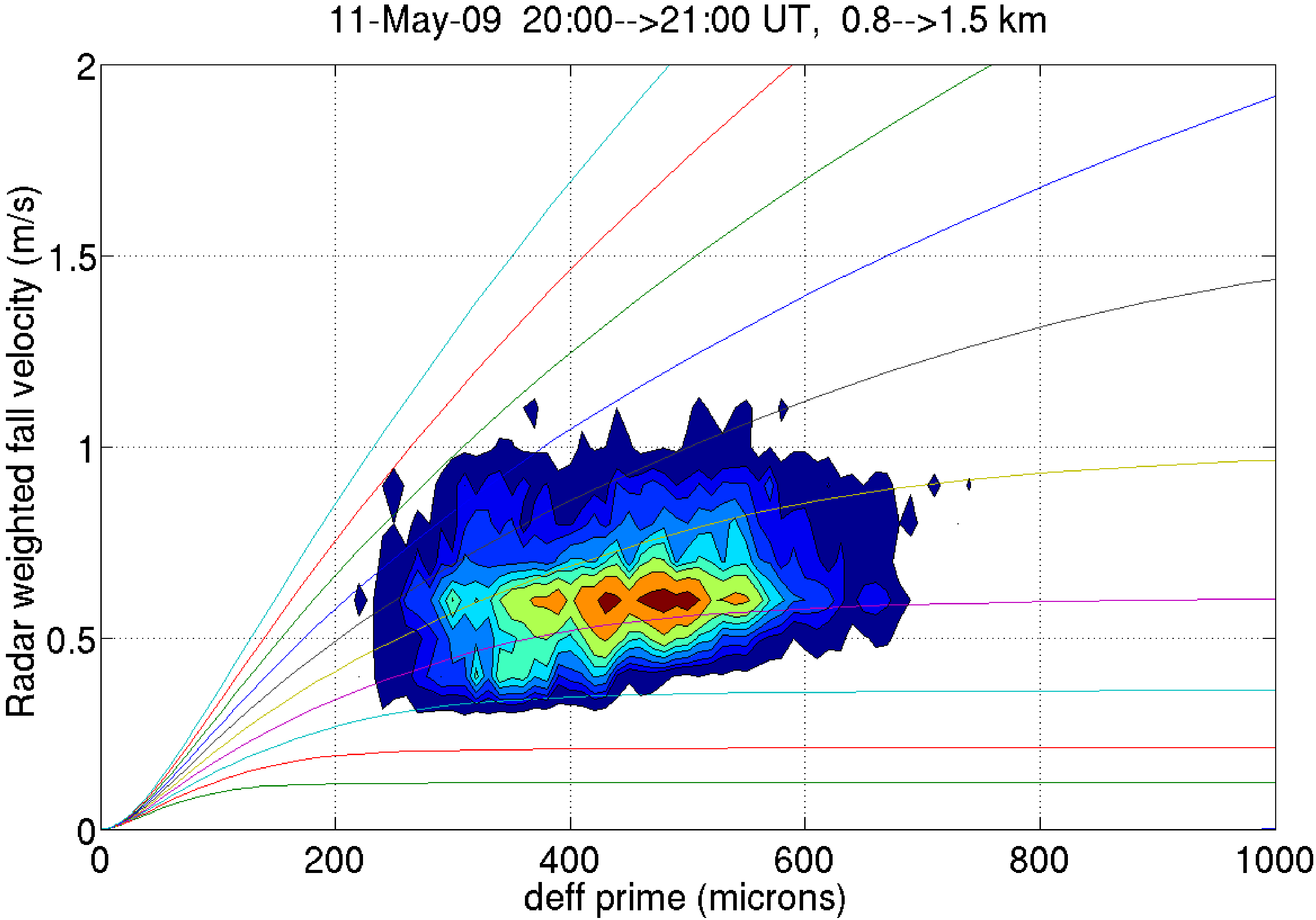
Corrected velocity spectra at z=1332m, 11-May-2009



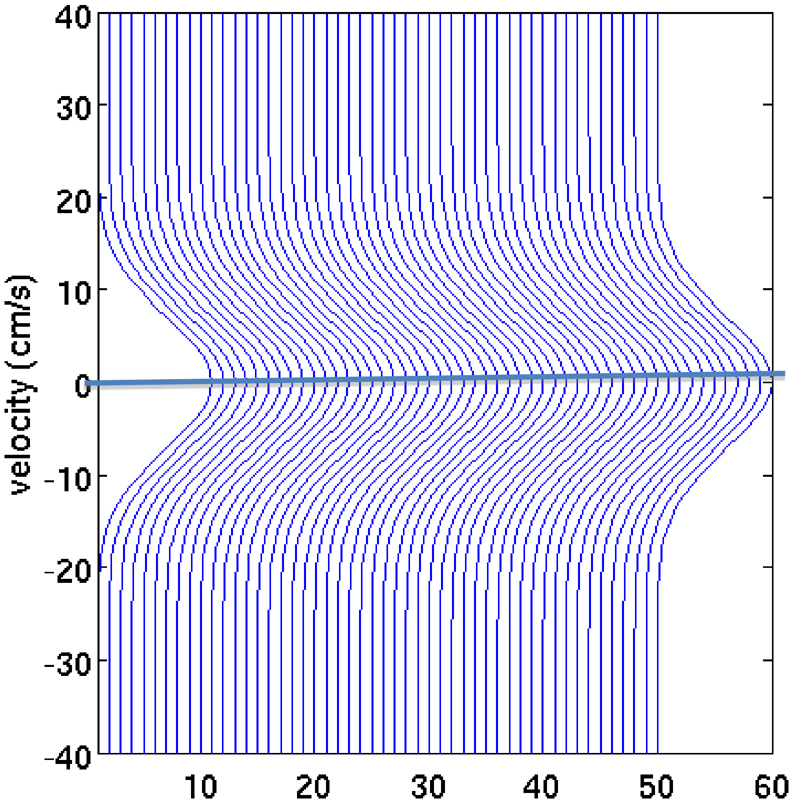

W air at z=1300m, <W>=0.1 m/s, 11-May-2009
Vertical air velocity (m/s)
1
0
-1
20:00
20:15
20:30
20:45
21:00
Time (UT)


w Doppler, w particle z=133211-May-2009
Vertical velocity (m/s)
0
-1
-2
w Doppler
w particle
20:00
15
20:30
20:45
21:00
Time (UT)


Velocities uncorrected for air motion11-May-2009
Doppler velocity (m/s)
deff prime (microns)
0
0.5
1
1.5
2
0
200
400
600
800
1000

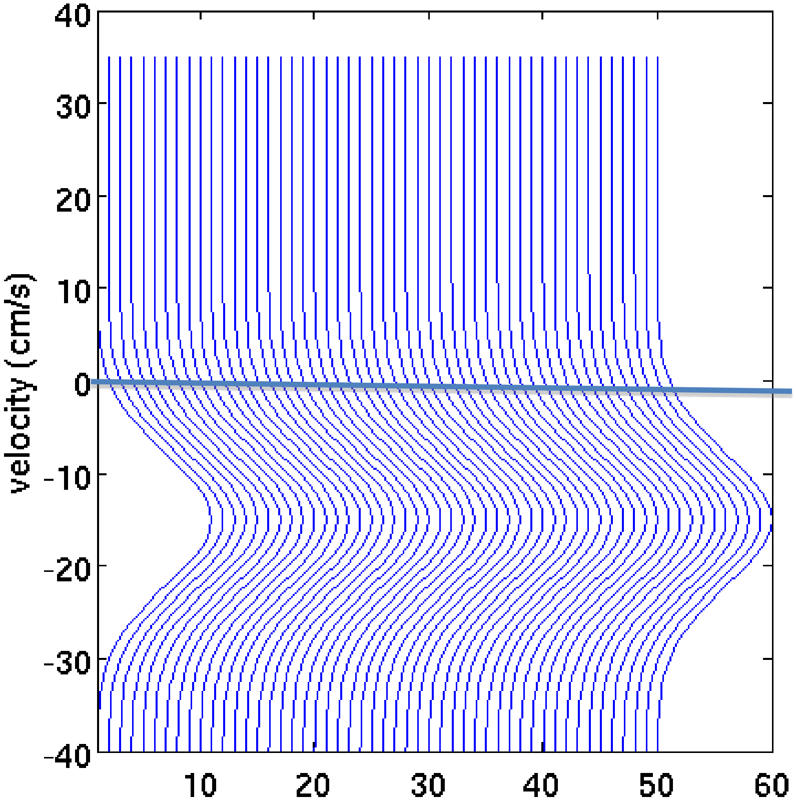

11-May-09 20:00-->21:00 UT, 0.8-->1.5 km

Error due to turbulence broadening of velocity spectra

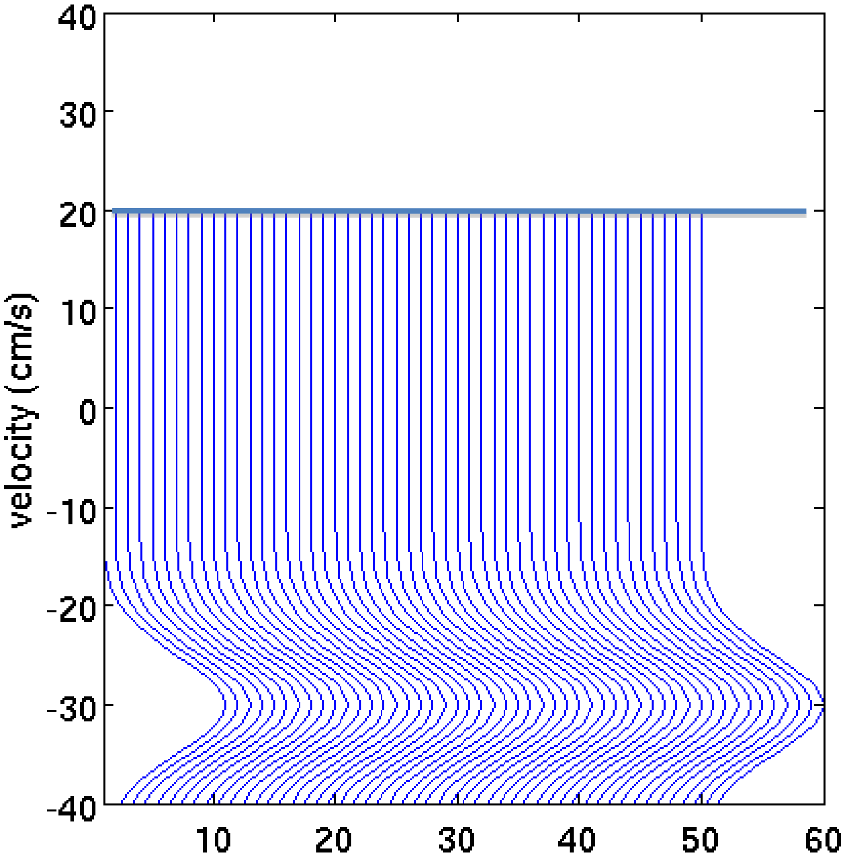


The fall velocity spectrum may be broadened by turbulence within the radar averaging volume—here we show spectra for very slowly falling particles broadened by turbulence

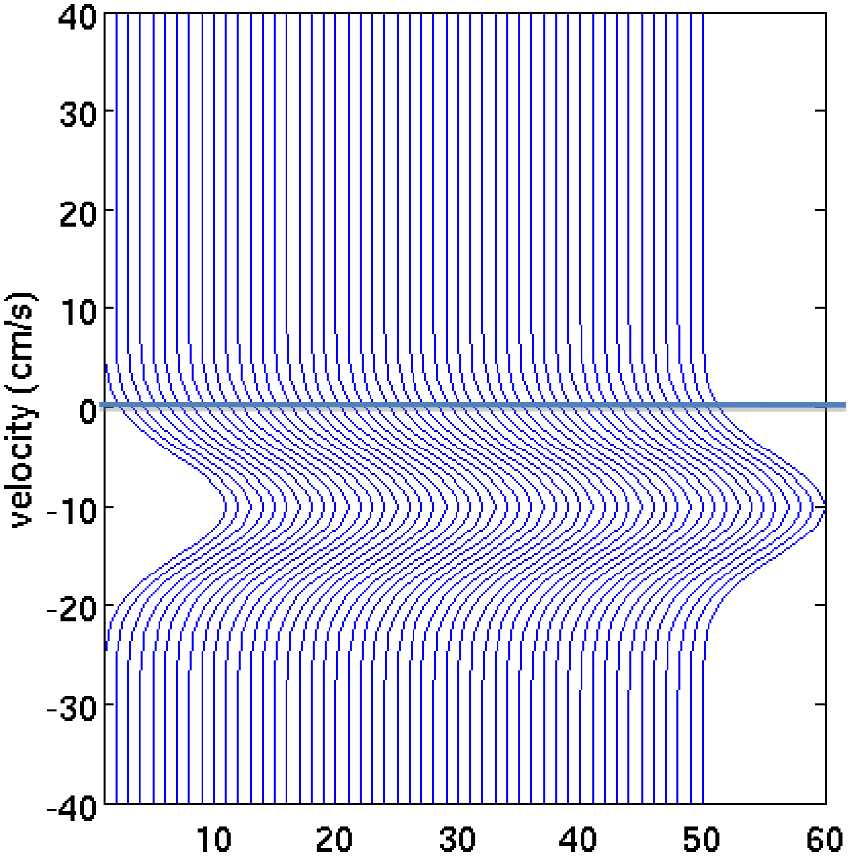
When the low velocity edge is assumed to be generated by particles with negligible fall velocity, the particles appear to be falling much faster in a rising air mass.



Error due to the absence of small particles detected by radar



When the low velocity edge of the spectra is assumed to be generated By particles with negligible fall velocity, the particles appear to fall too slowly In a downward moving air mass.



Small particles may not be present or their returns may be below the noise floor of the radar. Larger, faster falling particles may be detected generating spectra displayed from zero without any vertical motion of the air.

Looking for more information
and better algorithms