HSRL-KAZR Retrievals of Liquid Water, Particle Size, and Precipitation During MAGIC

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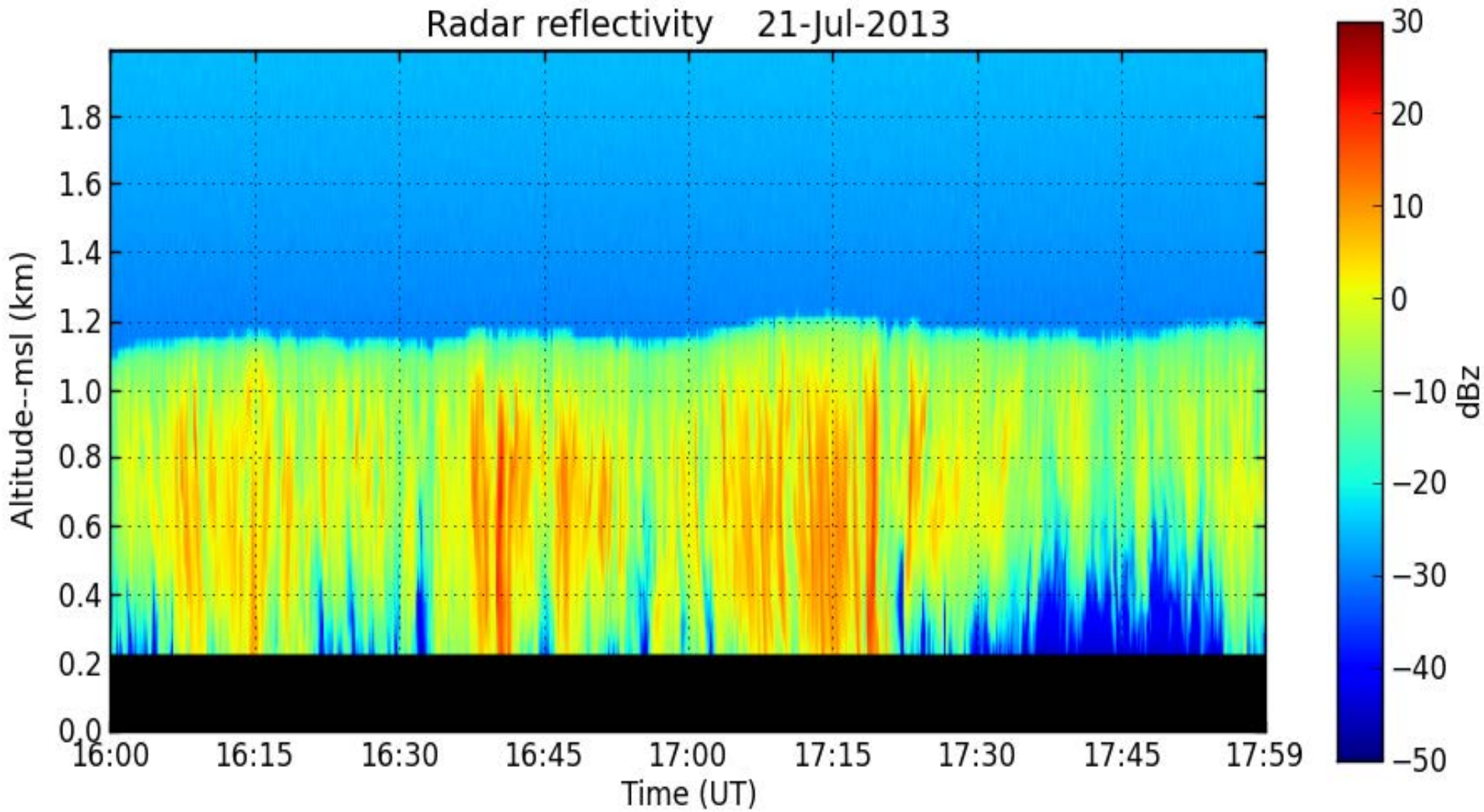
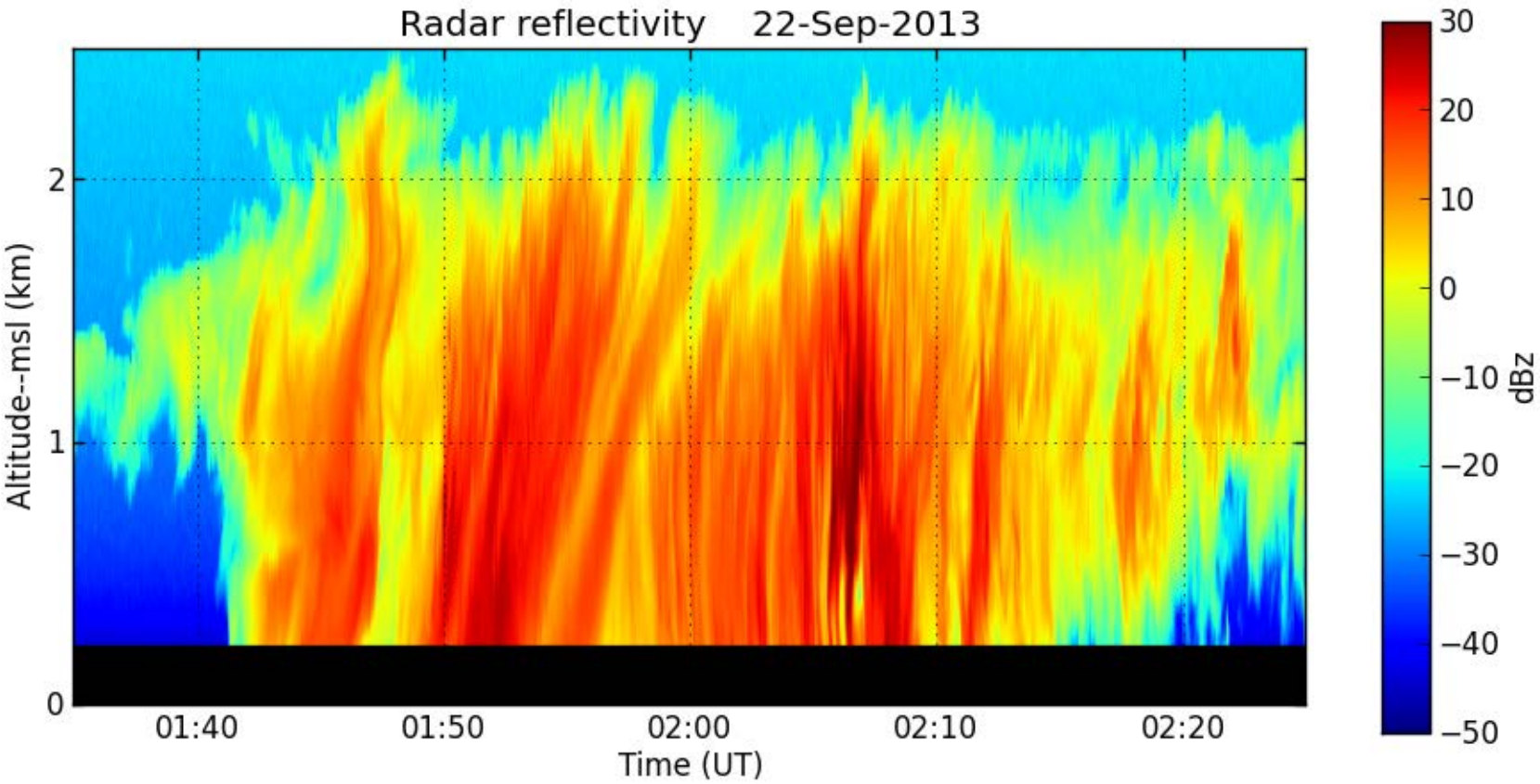
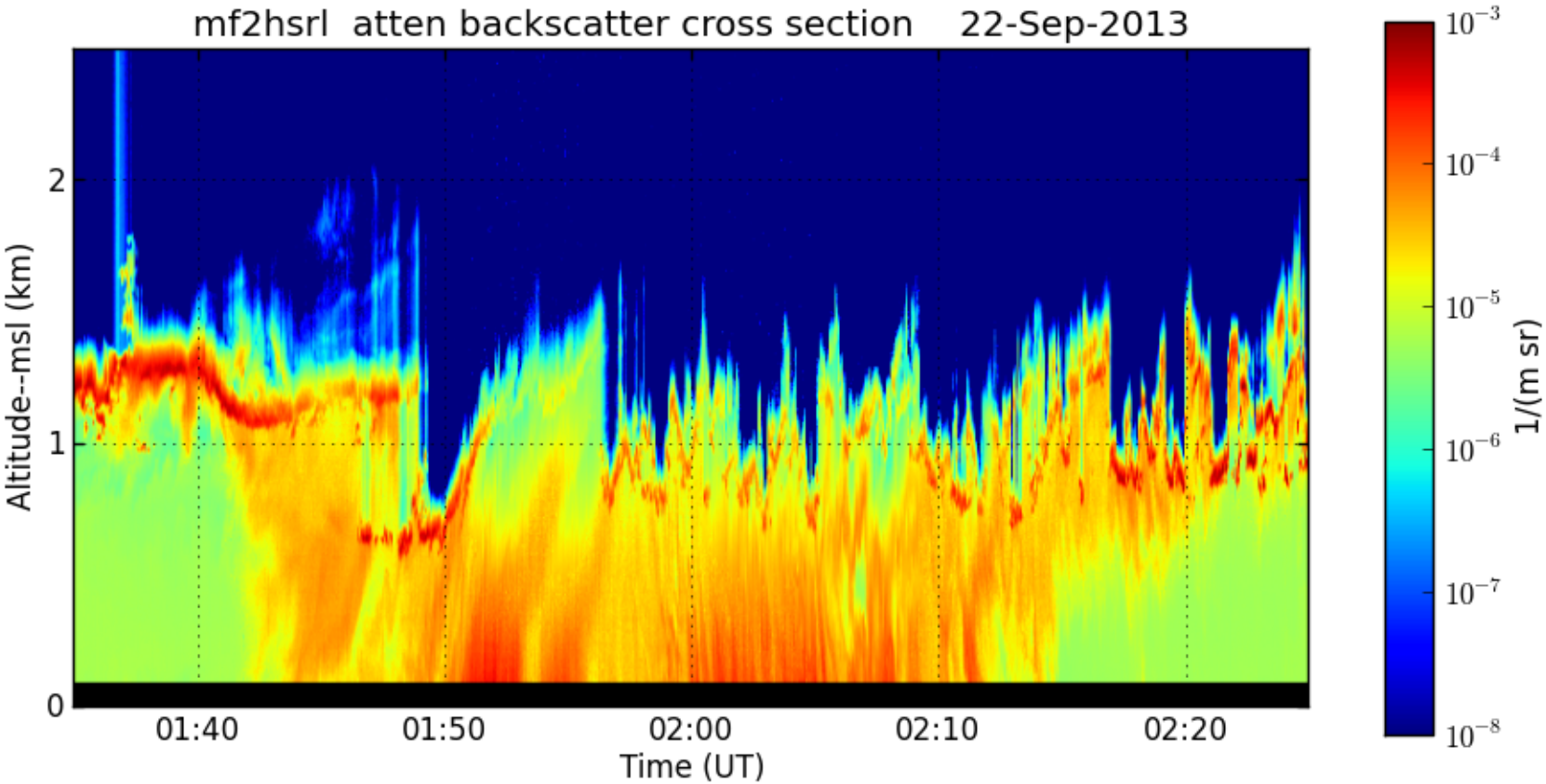
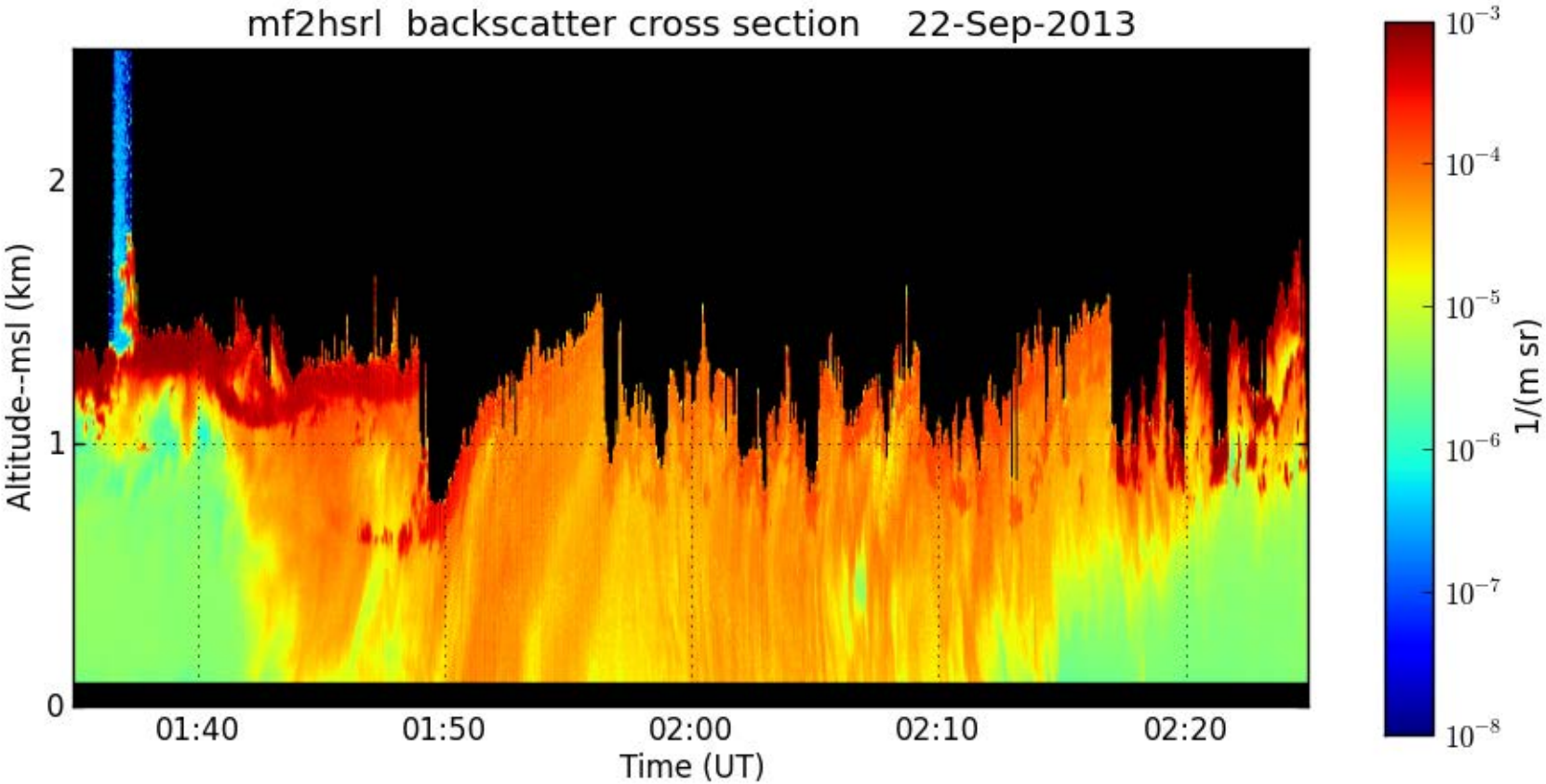
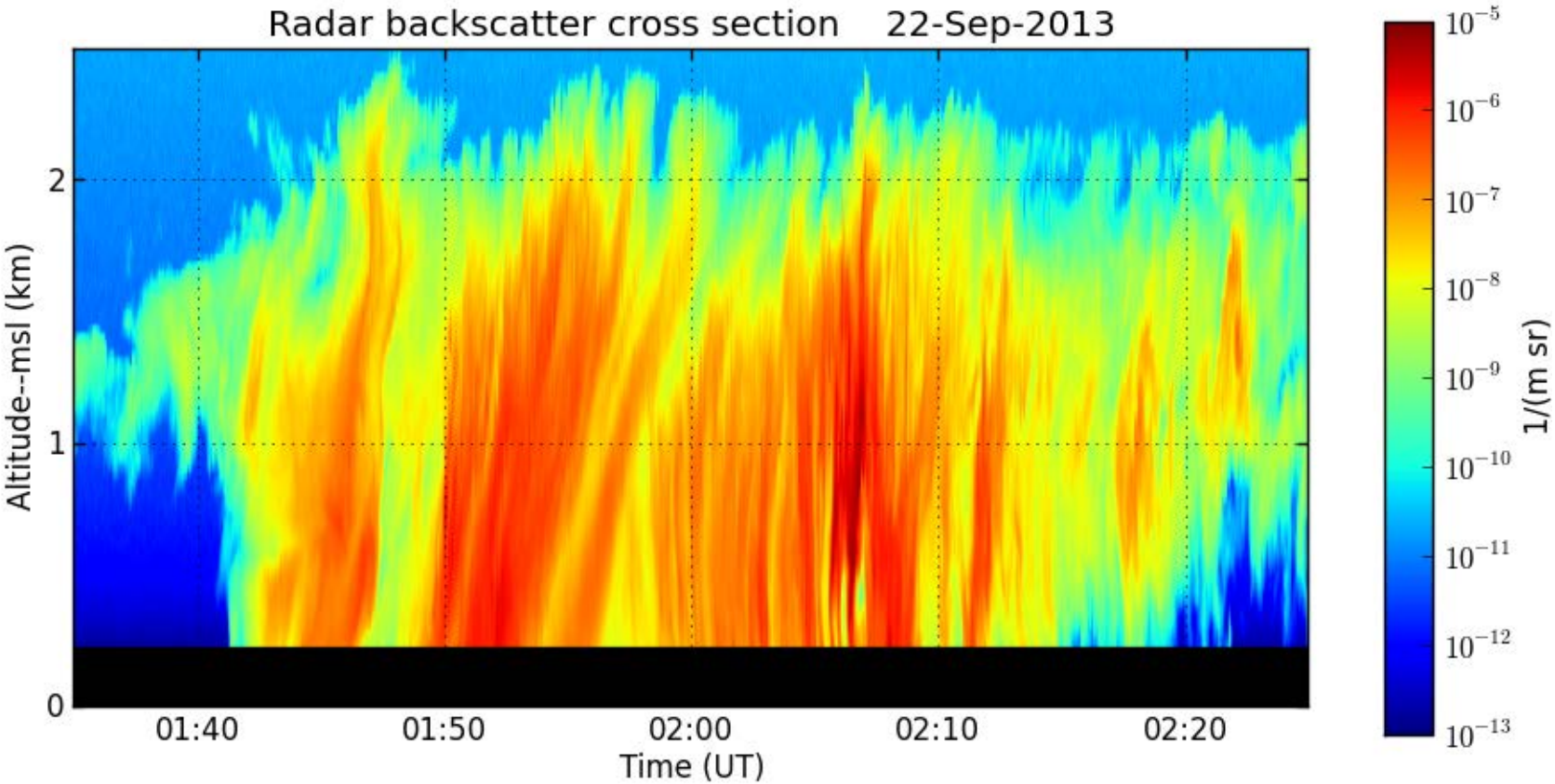



Radar reflectivity 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
30
20
10
0
−10
−20
−30
−40
−50
dBz


mf2hsrl atten backscatter cross section 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1/(m sr)


mf2hsrl backscatter cross section 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1/(m sr)


Radar backscatter cross section 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
1/(m sr)

HSRL-Radar particle size measurement

For droplets which are small compared to the radar wavelength
but large compared to the lidar wavelength:

Radar scattering cross section = $\beta_{radar} \sim \langle V^2 \rangle \sim \langle D^6 \rangle$ ------- Rayleigh scattering
Lidar extinction cross section = $\beta_{lidar} \sim \langle A \rangle \sim \langle D^2 \rangle$ ------- Geometric optics

Where:

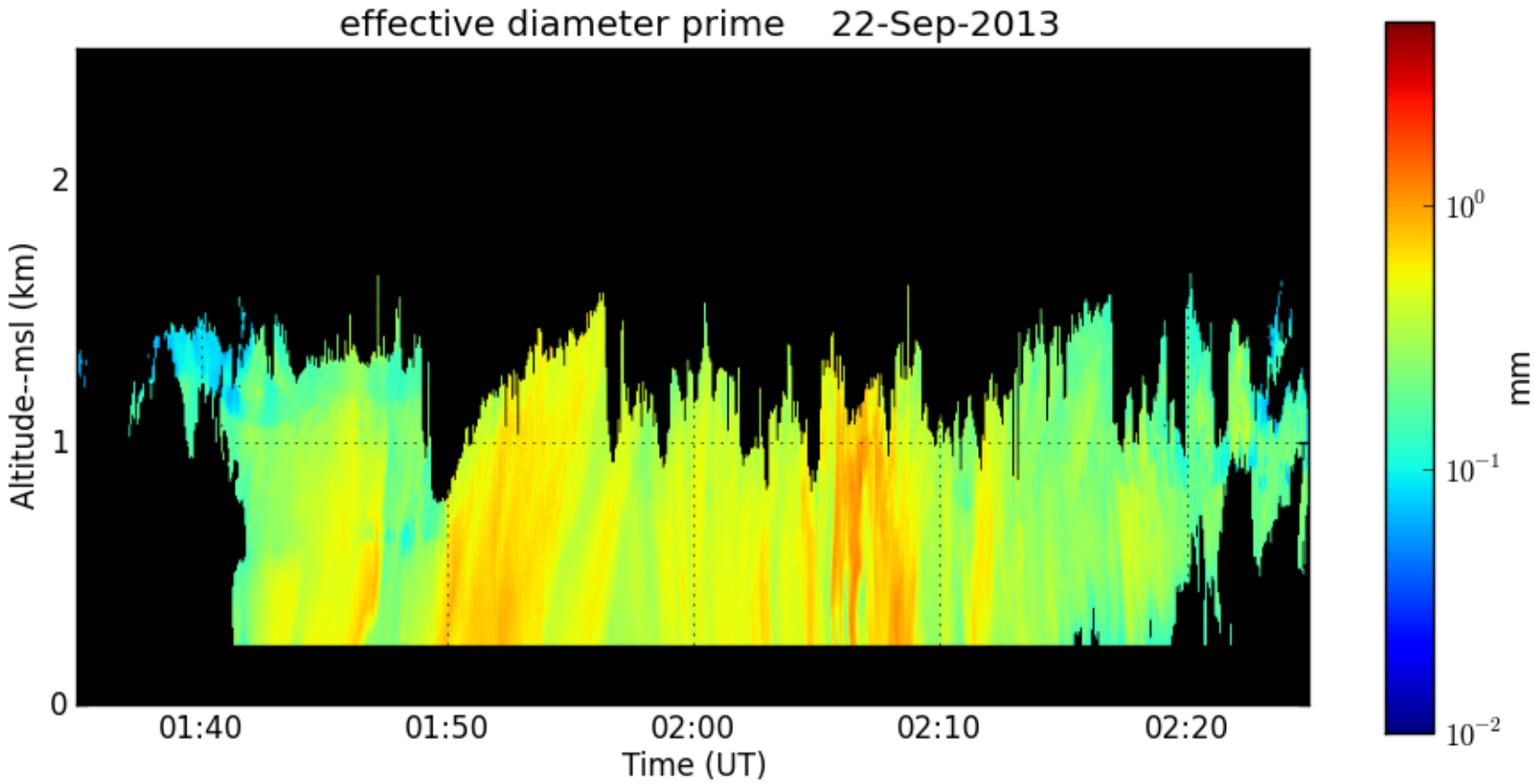
$\langle V^2 \rangle$ = average volume squared of the particles
$\langle A \rangle$ = average projected area of the particles

We can define:

$$D'_{eff} = \left(\frac{\lambda_{radar}}{\pi}\right) \cdot \left(\frac{3 \cdot \beta_{radar}}{4 \cdot k_w^2 \cdot \beta_{lidar}}\right)^{\frac{1}{4}}$$

Where:

λ_{radar} = radar wavelength
k_w = dielectric constant of water


effective diameter prime 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
10^0
10^{-1}
10^{-2}
mm

Assuming a gamma distribution of particle diameters:

$$N = a \int_0^\infty D^\alpha \cdot exp(-\frac{\alpha}{\gamma} \cdot (\frac{D}{D_m})^\gamma) \cdot dD$$

Where:

N = number of particles

D = particlle Diameter

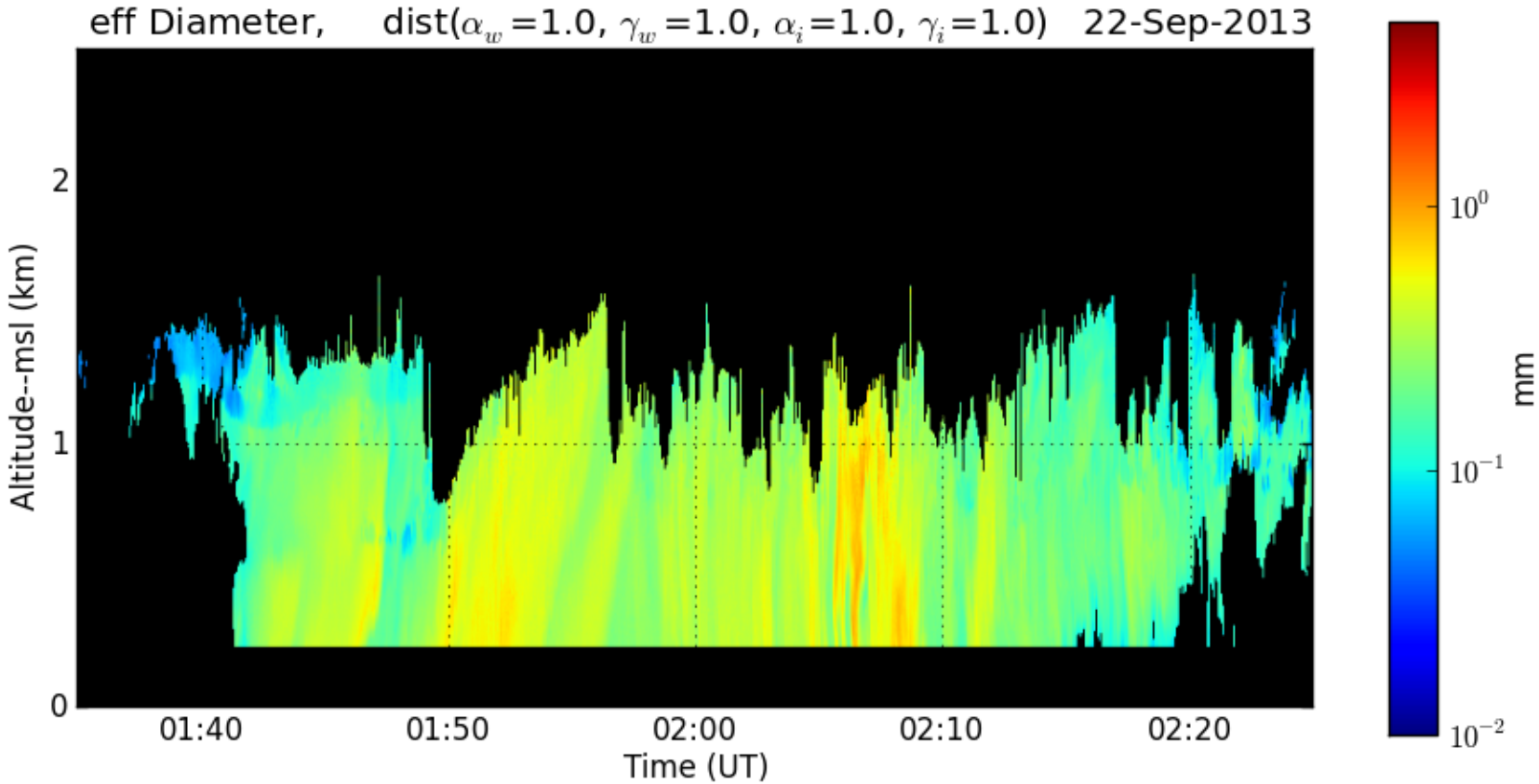
D_m= mode diameter

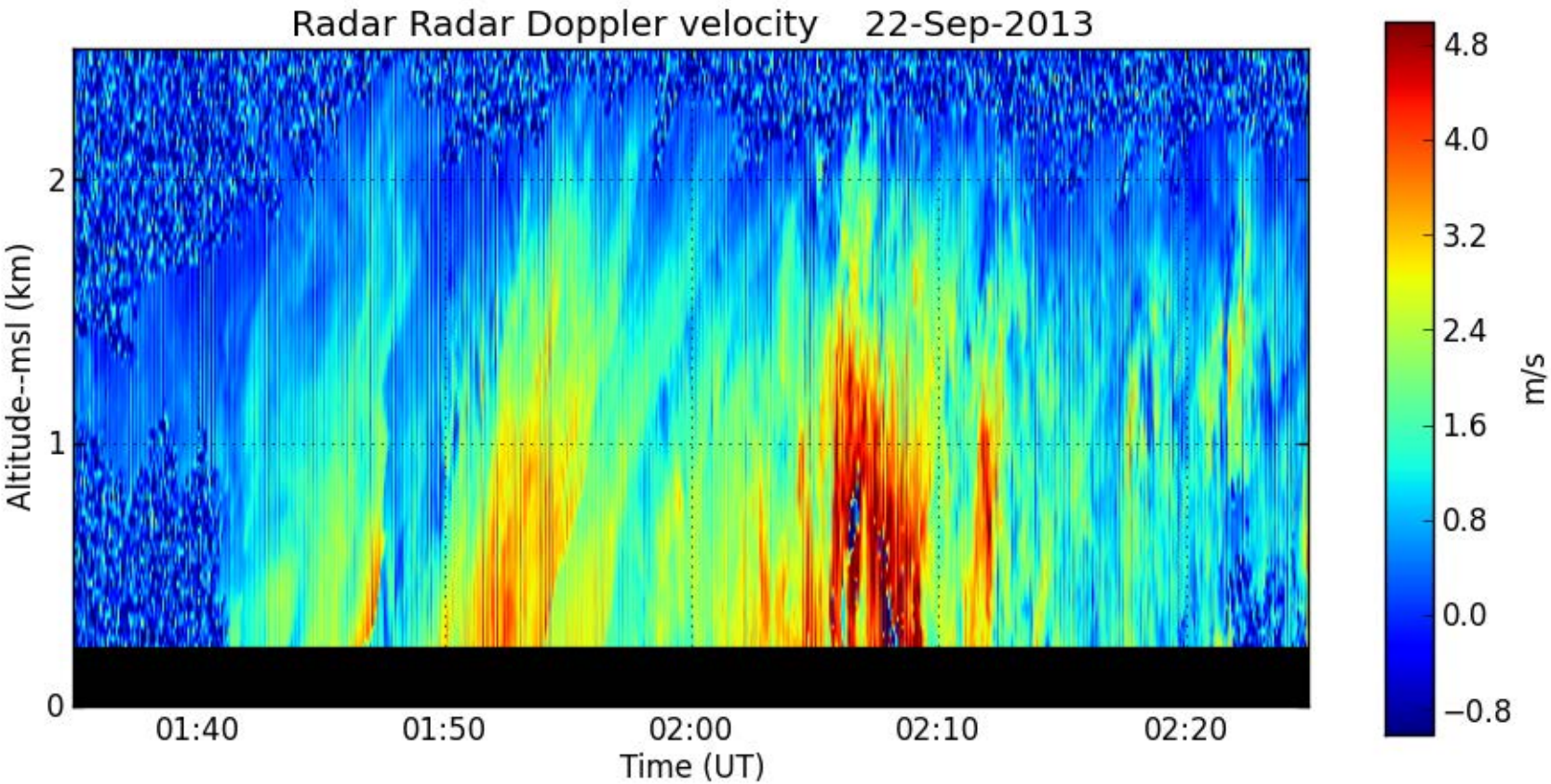
The effective diameter prime can be written as:

$$D'_{eff} = \frac{\int D^{\alpha+6} \cdot exp(-\frac{\alpha}{\gamma} \cdot \frac{D}{D_m}^\gamma) \cdot dD}{\int D^{\alpha+2} \cdot exp(-\frac{\alpha}{\gamma} \cdot \frac{D}{D_m}^\gamma) \cdot dD} = \frac{\frac{\alpha}{\gamma}^{\frac{1}{\gamma}} \cdot D_m \cdot \Gamma(\frac{\alpha+7}{\gamma})}{\Gamma(\frac{\alpha+3}{\gamma})}$$

Solving for the mode diameter, D_m:

$$D_m = D'_{eff} \cdot (\frac{\alpha}{\gamma})^{\frac{1}{\gamma}} \cdot (\frac{\Gamma(\frac{\alpha+3}{\gamma})}{\Gamma(\frac{\alpha+7}{\gamma})})^{\frac{1}{4}}$$


eff Diameter, dist(α_w=1.0, γ_w=1.0, α_i=1.0, γ_i=1.0) 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
10^0
10^{-1}
10^{-2}
mm


Radar Radar Doppler velocity 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
4.8
4.0
3.2
2.4
1.6
0.8
0.0
−0.8
m/s

The radar weighted fall velocity, $<V_{rf}>$:

$$< V_{rf} >= \frac{\int V_f \cdot D^{\alpha+6} \cdot exp(-\frac{\alpha}{\gamma} \cdot \frac{D}{D_m}^{\gamma}) \cdot dD}{\int D^{\alpha+6} \cdot exp(-\frac{\alpha}{\gamma} \cdot \frac{D}{D_m}^{\gamma}) \cdot dD}$$

And the mass weighted fall velocity, $<V_{mf}>$:

$$< V_{mf} >= \frac{\int V_f \cdot D^{\alpha+3} \cdot exp(-\frac{\alpha}{\gamma} \cdot \frac{D}{D_m}^{\gamma}) \cdot dD}{\int D^{\alpha+3} \cdot exp(-\frac{\alpha}{\gamma} \cdot \frac{D}{D_m}^{\gamma}) \cdot dD}$$

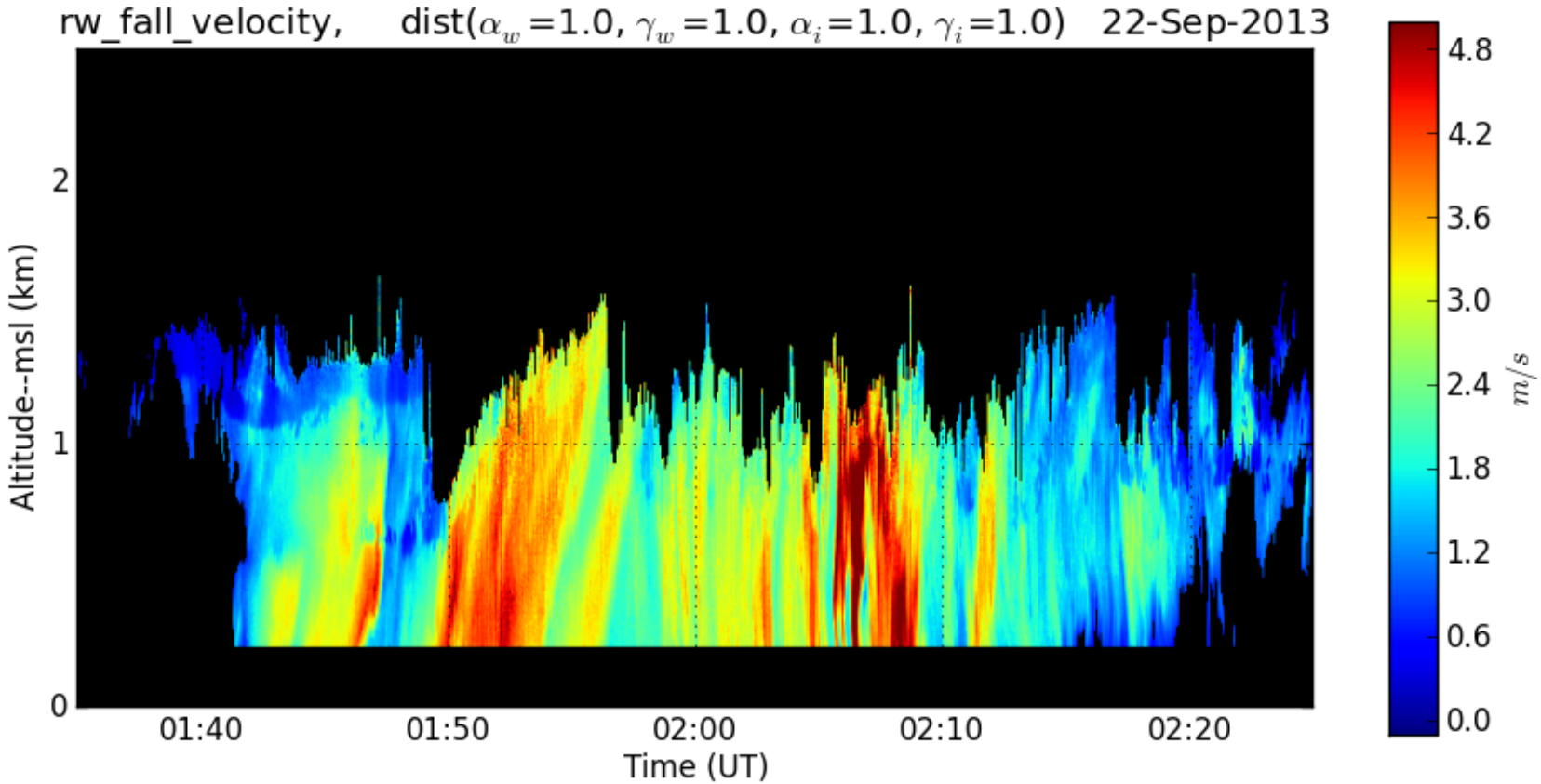
Where the fall velocity, V_f , is computed from:

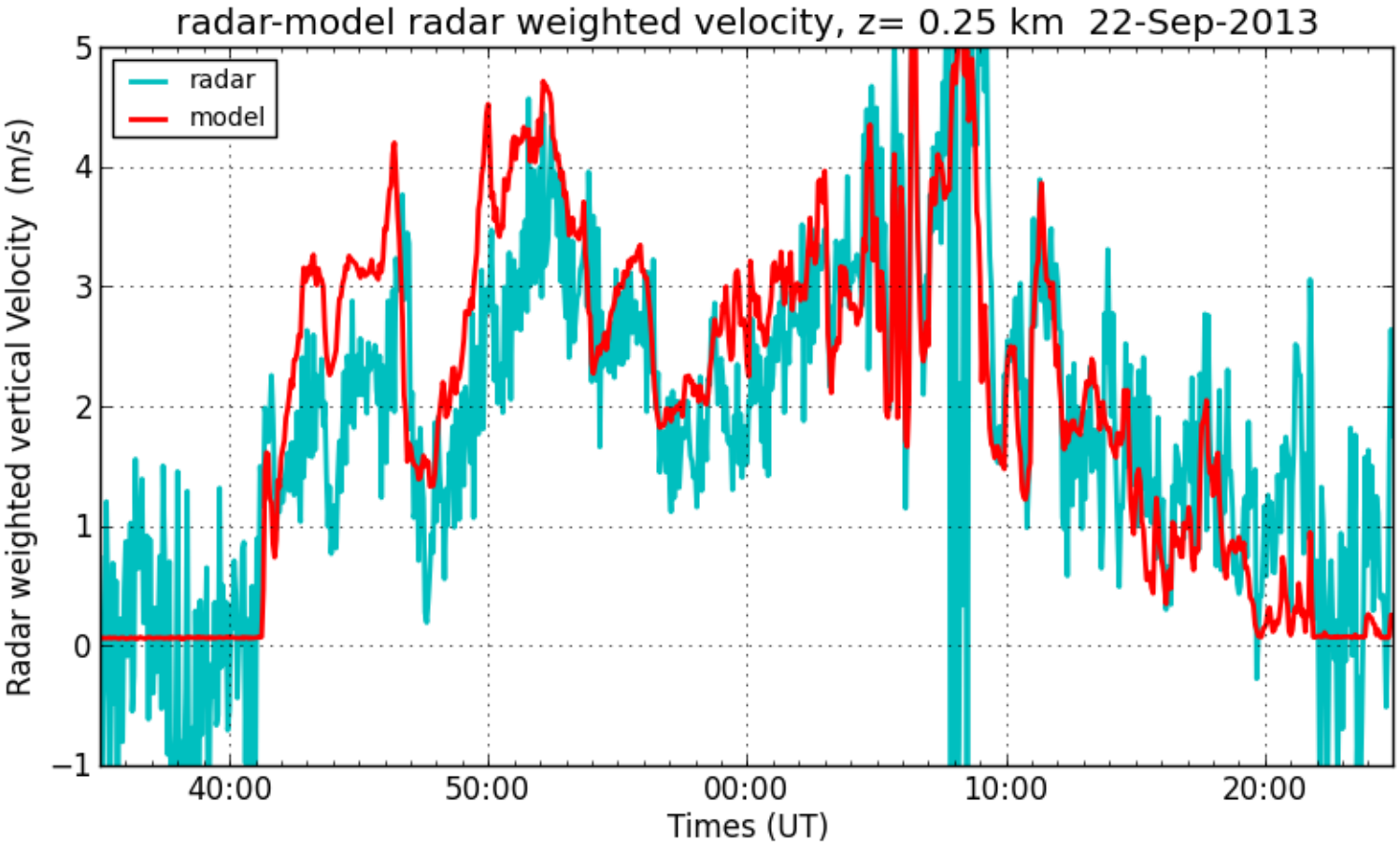
$$V_f = \frac{\eta}{\rho_{air} D} \left(\frac{\delta_0^2}{4} \left[\left(1 + C_1 X^{\frac{1}{2}}\right)^{\frac{1}{2}} - 1 \right]^2 - a_0 X^{b_0} \right)$$

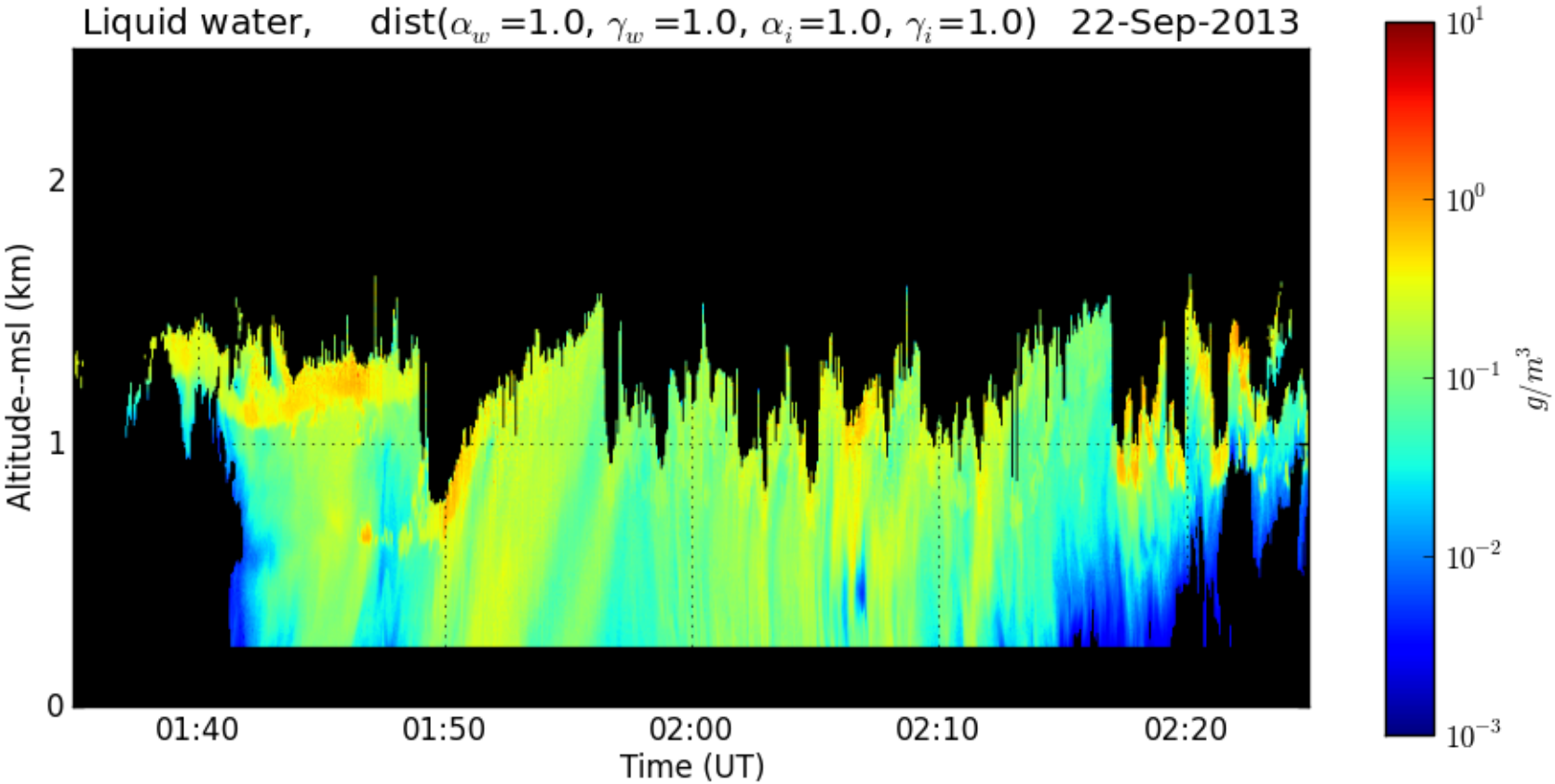
Khovostyanov and Curry, JAS May 2005, Vol 62

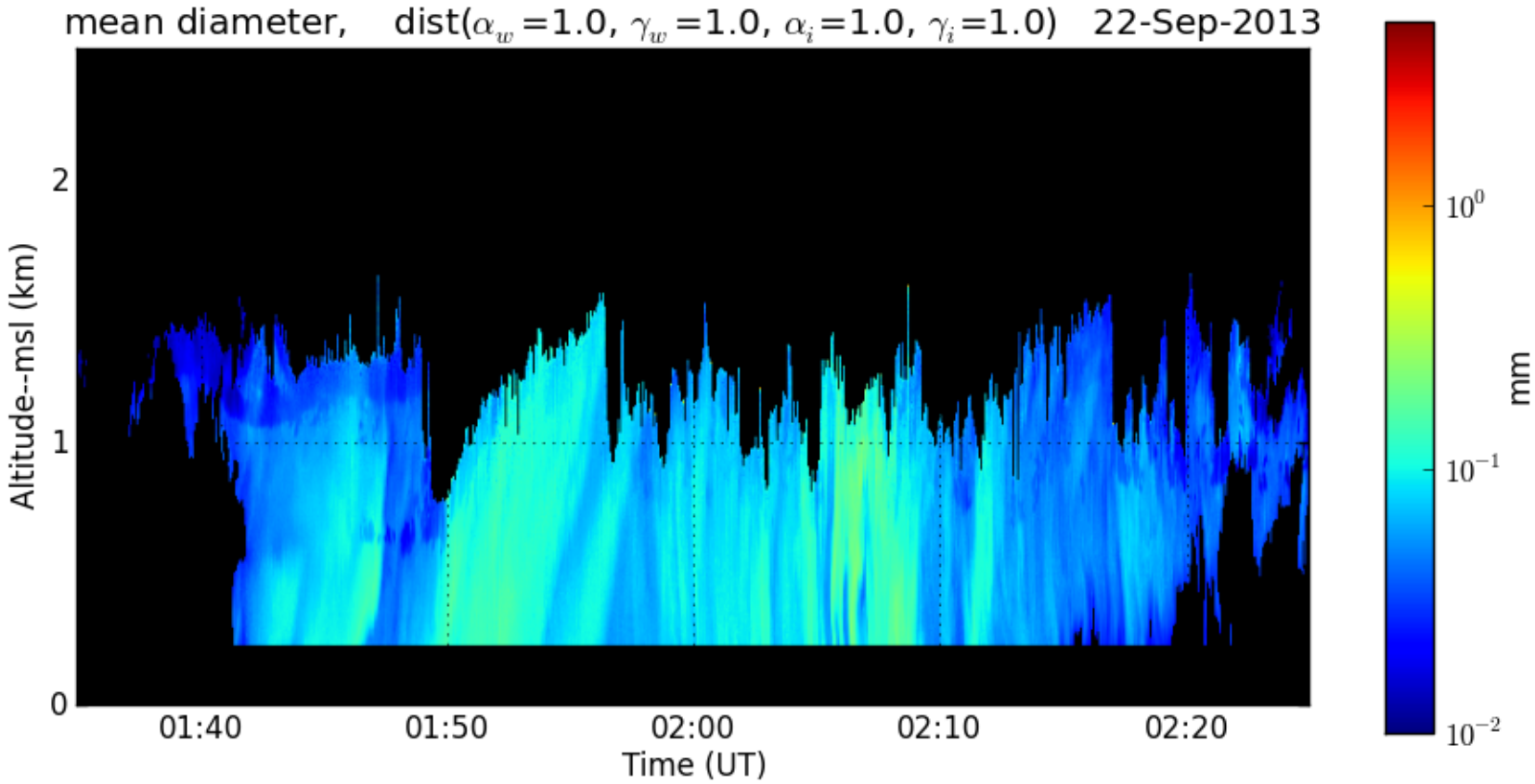
And the Beard Number, X expressed in terms of particle area, volume and density along with the acceleration of gravity, air density, particle diameter and the dynamic viscosity:

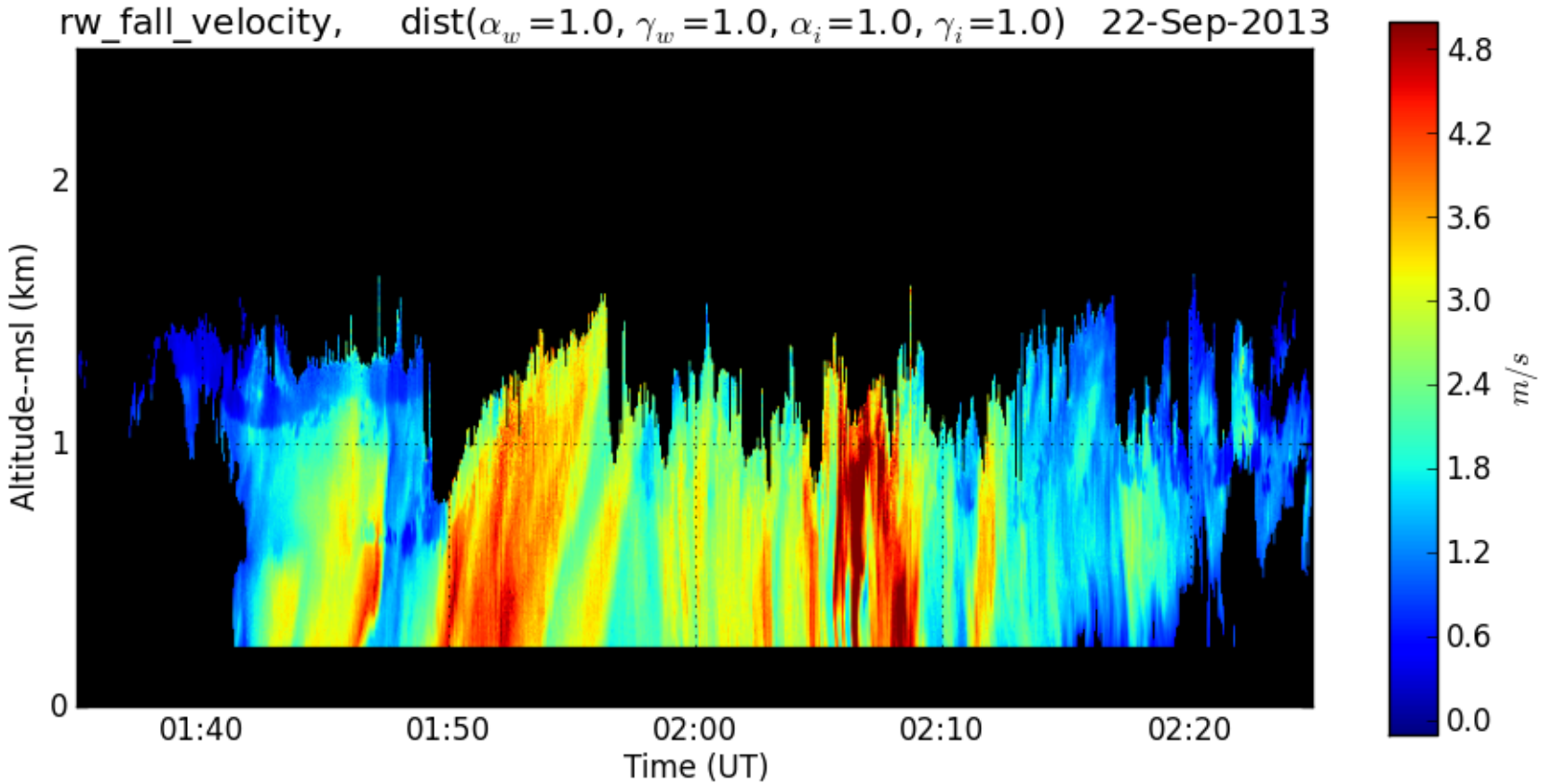
$$X = \frac{2 \cdot volume \cdot \rho_{particle} \cdot \rho_{air} \cdot g \cdot D^2}{area \cdot \eta^2}$$

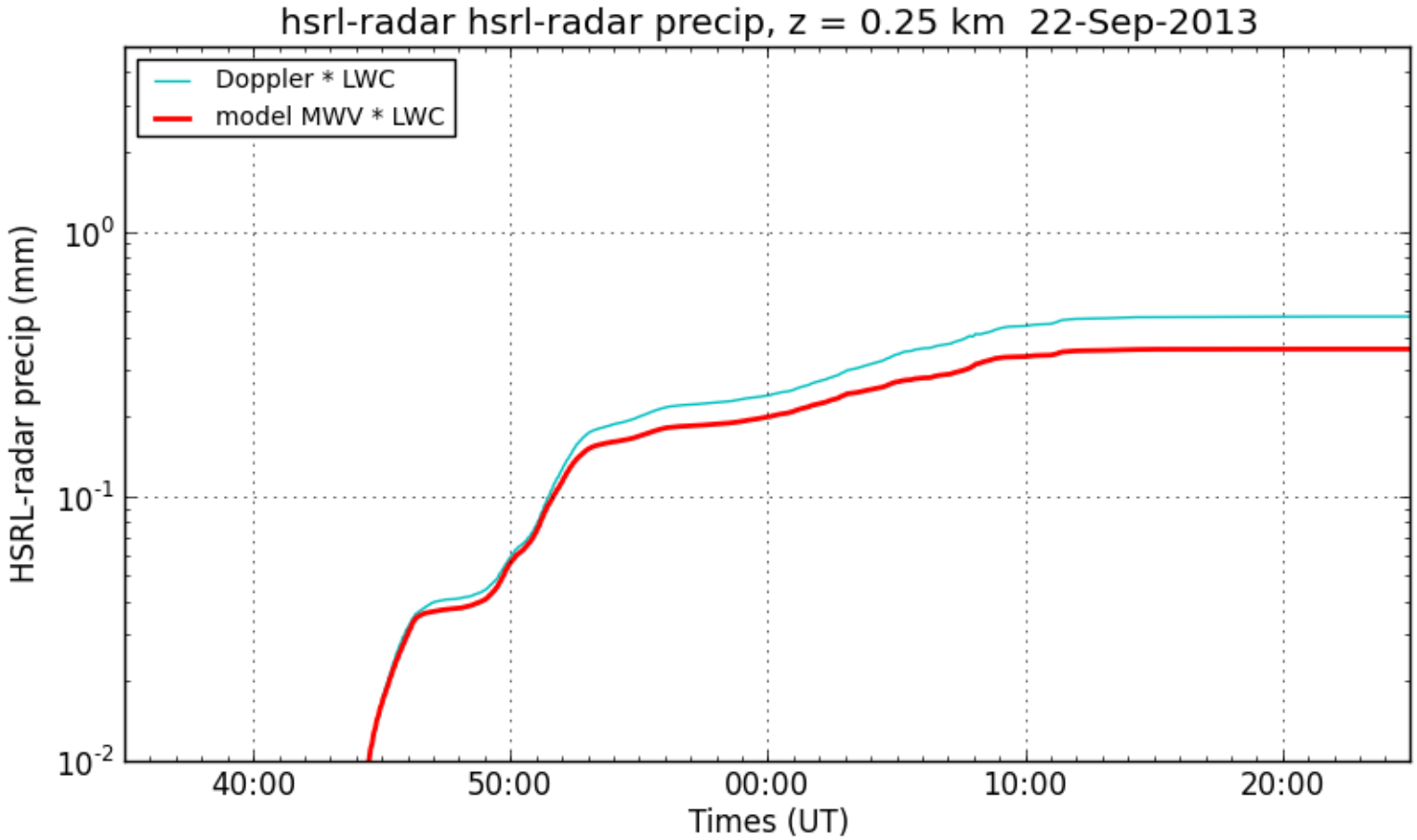

rw_fall_velocity, dist(α_w=1.0, γ_w=1.0, α_i=1.0, γ_i=1.0) 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0.0
m/s

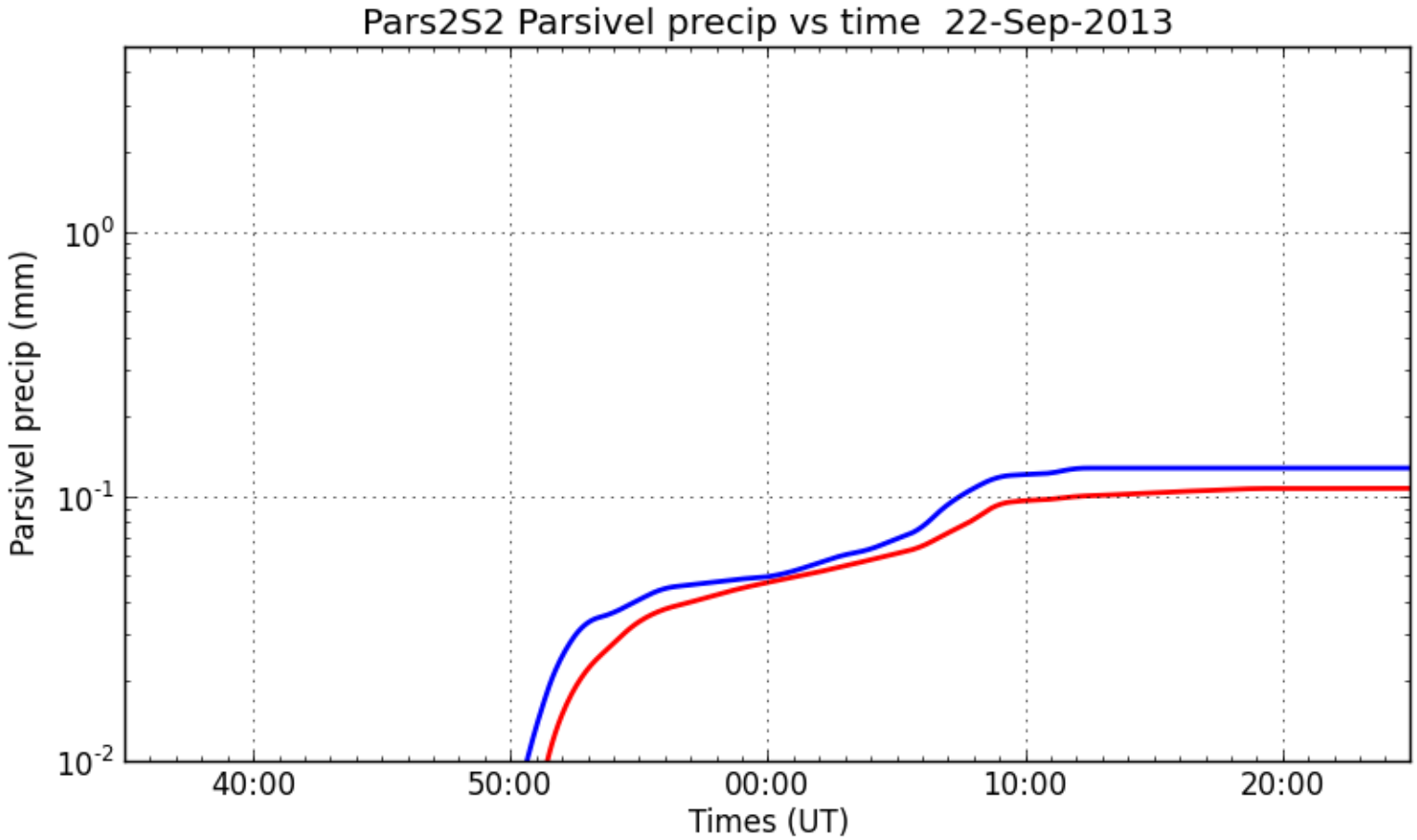

radar-model radar weighted velocity, z= 0.25 km 22-Sep-2013
radar
model
Radar weighted vertical Velocity (m/s)
5
4
3
2
1
0
−1
40:00
50:00
00:00
10:00
20:00
Times (UT)

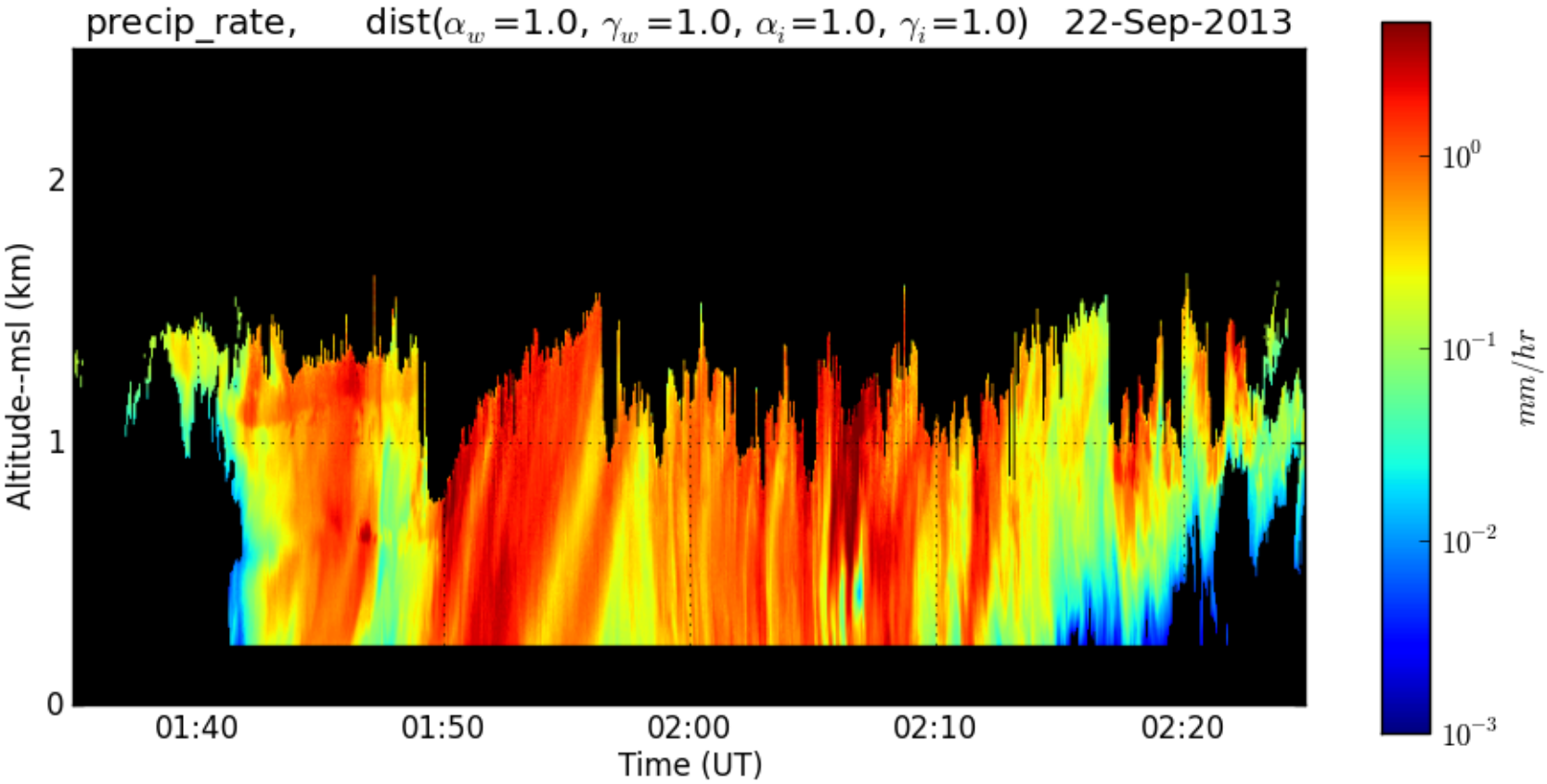

Liquid water, dist(α_w =1.0, γ_w =1.0, α_i =1.0, γ_i =1.0) 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
g/m^3

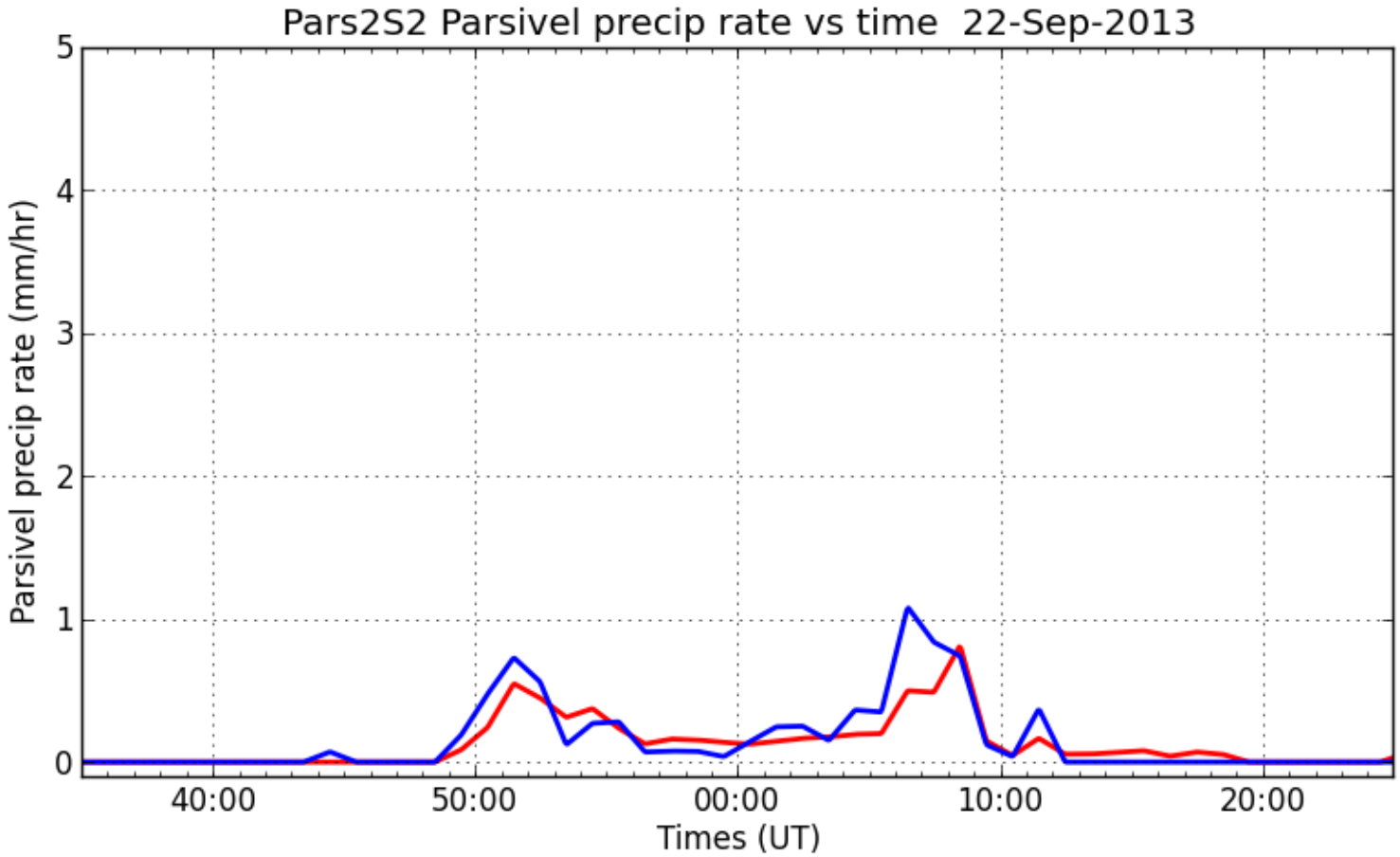

mean diameter, dist(α_w=1.0, γ_w=1.0, α_i=1.0, γ_i=1.0) 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
10^0
10^{-1}
10^{-2}
mm

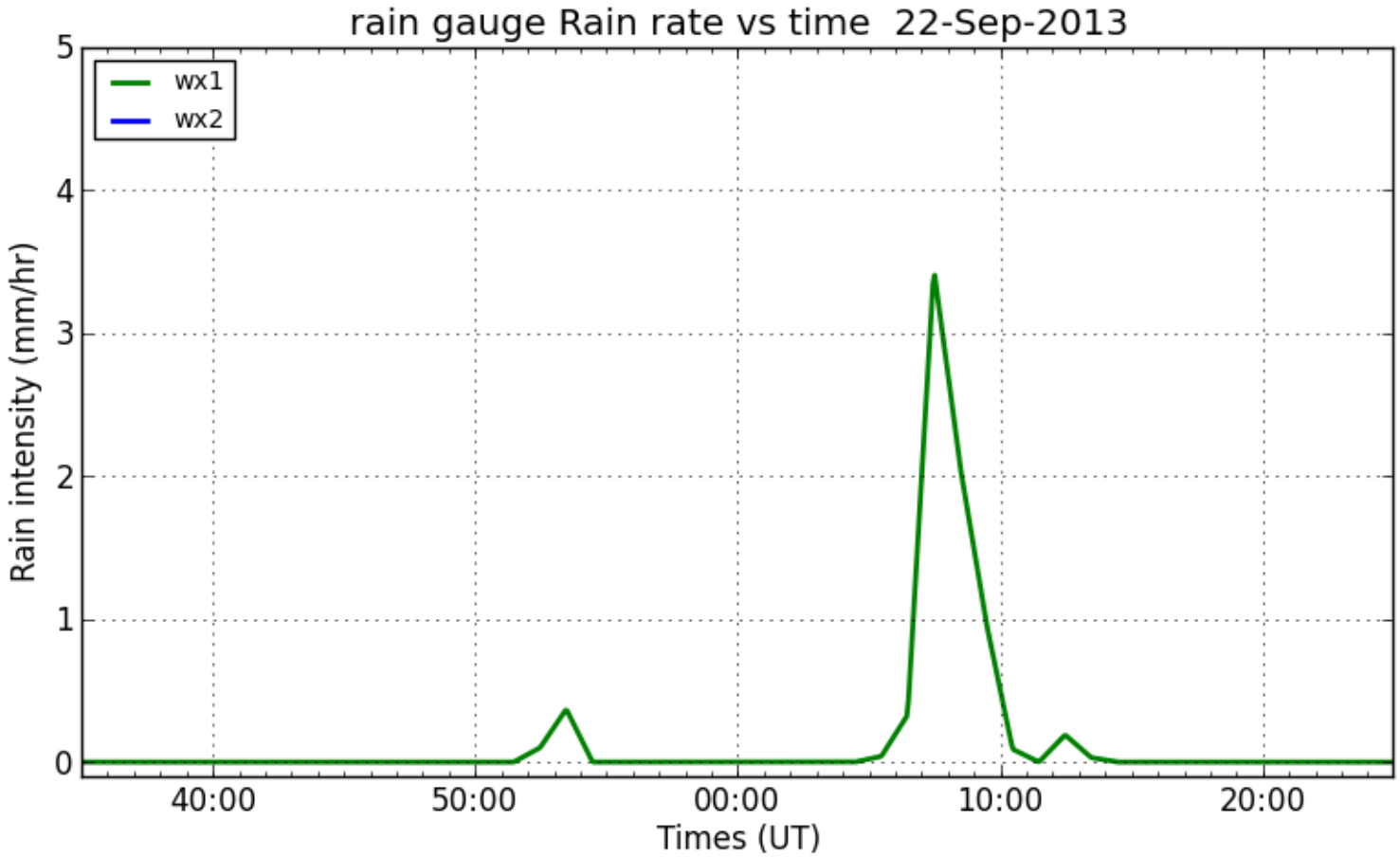

rw_fall_velocity, dist(α_w=1.0, γ_w=1.0, α_i=1.0, γ_i=1.0) 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0.0
m/s

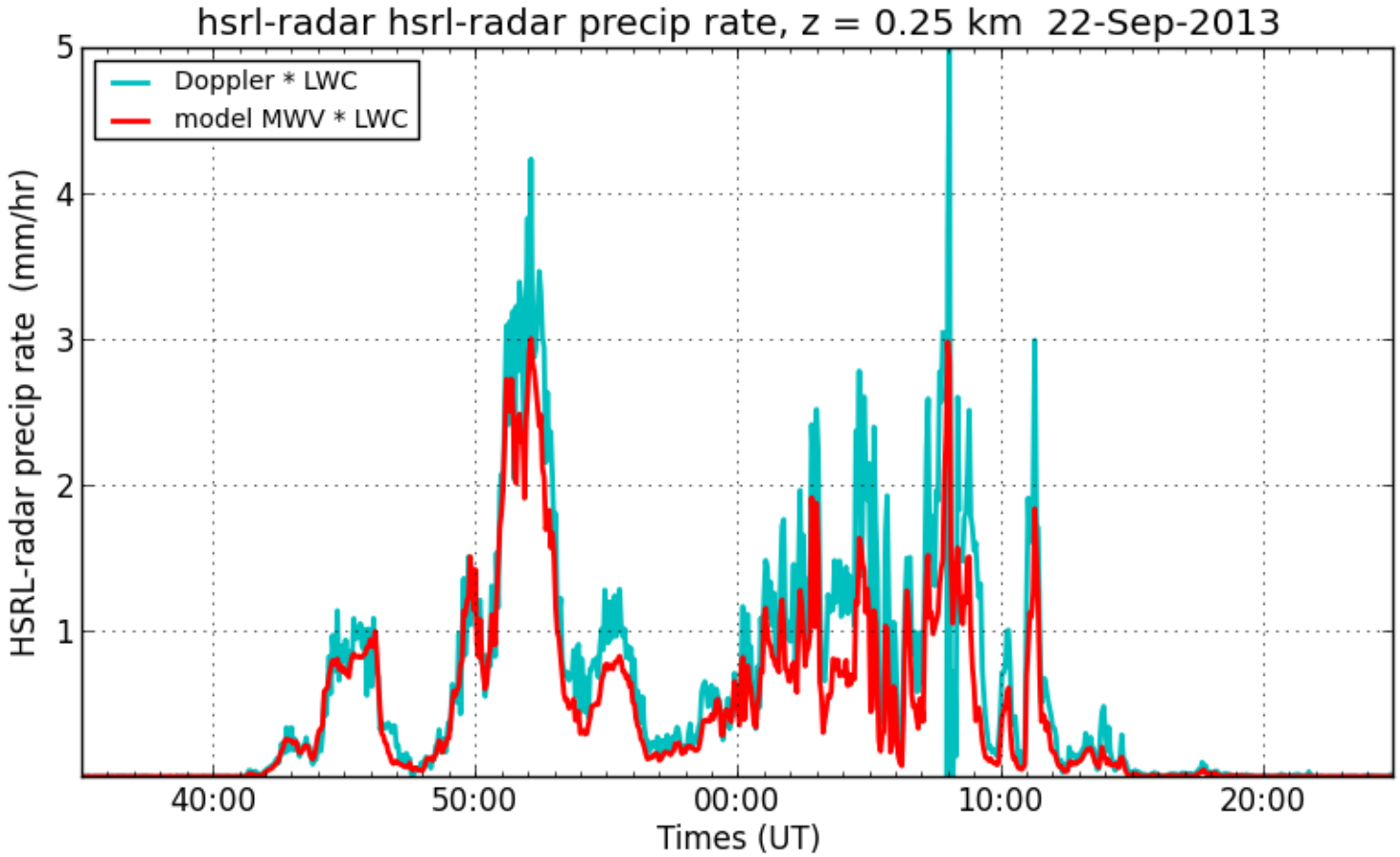

hsrl-radar hsrl-radar precip, z = 0.25 km 22-Sep-2013
Doppler * LWC
model MWV * LWC
HSRL-radar precip (mm)
10^0
10^{-1}
10^{-2}
40:00
50:00
00:00
10:00
20:00
Times (UT)


Pars2S2 Parsivel precip vs time 22-Sep-2013
Parsivel precip (mm)
10^0
10^{-1}
10^{-2}
40:00
50:00
00:00
10:00
20:00
Times (UT)


precip_rate, dist(α_w=1.0, γ_w=1.0, α_i=1.0, γ_i=1.0) 22-Sep-2013
Altitude--msl (km)
0
1
2
01:40
01:50
02:00
02:10
02:20
Time (UT)
10^0
10^{-1}
10^{-2}
10^{-3}
mm/hr


Pars2S2 Parsivel precip rate vs time 22-Sep-2013
Parsivel precip rate (mm/hr)
0
1
2
3
4
5
40:00
50:00
00:00
10:00
20:00
Times (UT)


rain gauge Rain rate vs time 22-Sep-2013
wx1
wx2
Rain intensity (mm/hr)
0
1
2
3
4
5
40:00
50:00
00:00
10:00
20:00
Times (UT)


hsrl-radar hsrl-radar precip rate, z = 0.25 km 22-Sep-2013
Doppler * LWC
model MWV * LWC
HSRL-radar precip rate (mm/hr)
5
4
3
2
1
40:00
50:00
00:00
10:00
20:00
Times (UT)