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Empirical Z-Visibility Relation

Found by Fog Measurements at an Airport

by Cloud Radar and Optical Fog Sensors

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Can a cloud radar measure fog?

Though operating cloud radars for many years we did not know because these radars where operated vertically and therefore the interesting part of the fog is below the lowest range gate.

To investigate this we set up a scanning cloud radar at the airport in Munich during the fog season 2011/2012.

MIRA-36 cloud radar

35 GHz

30 kW
1:1000

Magnetron/Dopplerized

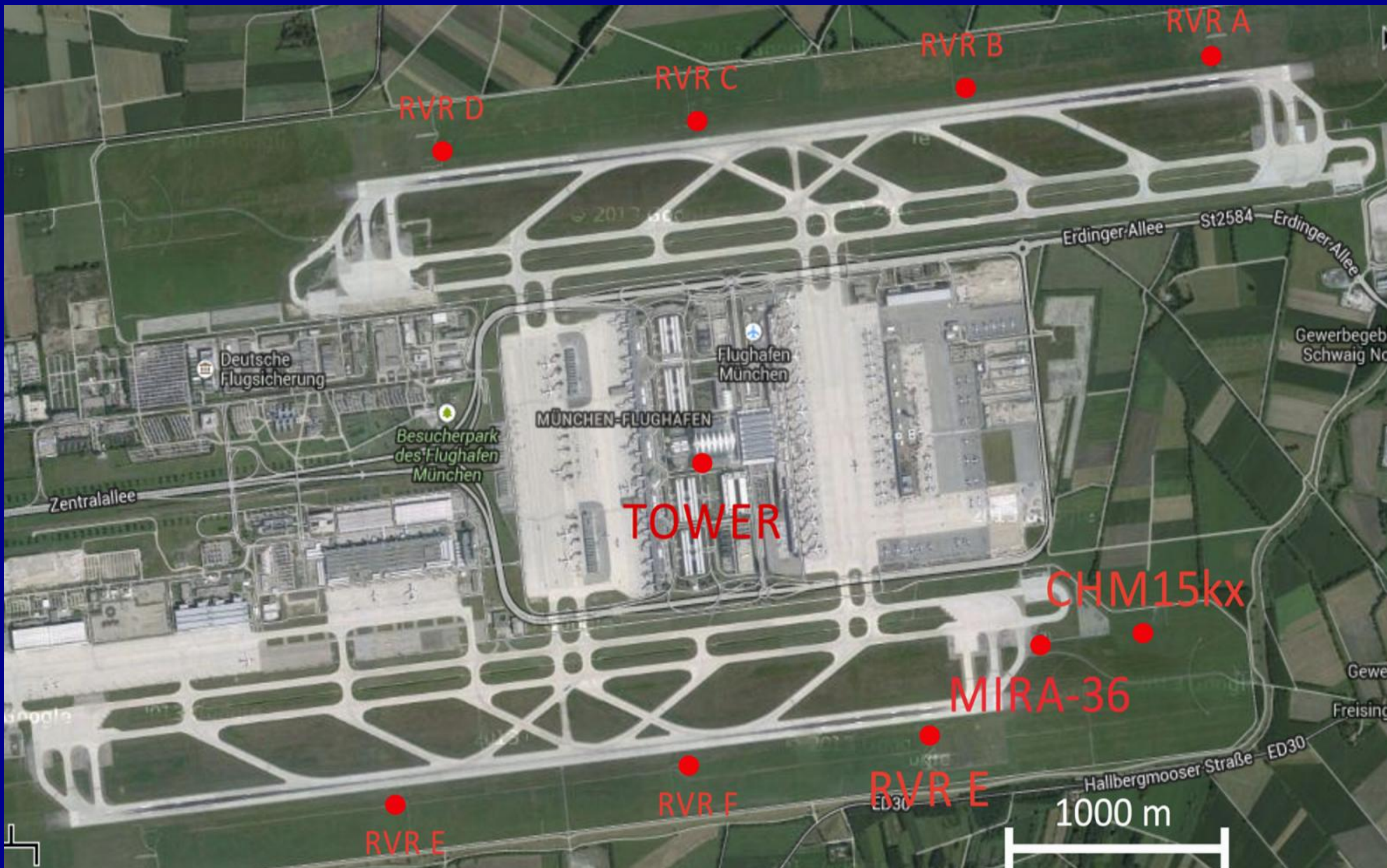
Linear polarization on tx

Receiving Co + Cross simultaneously

Sensitivity:
-65 dBZ at 1 km,
5 s averaging, NFFT=256,
Vel. Range +/- 10.5 m/s

Field Campaign Nov 2011 – Feb 2012

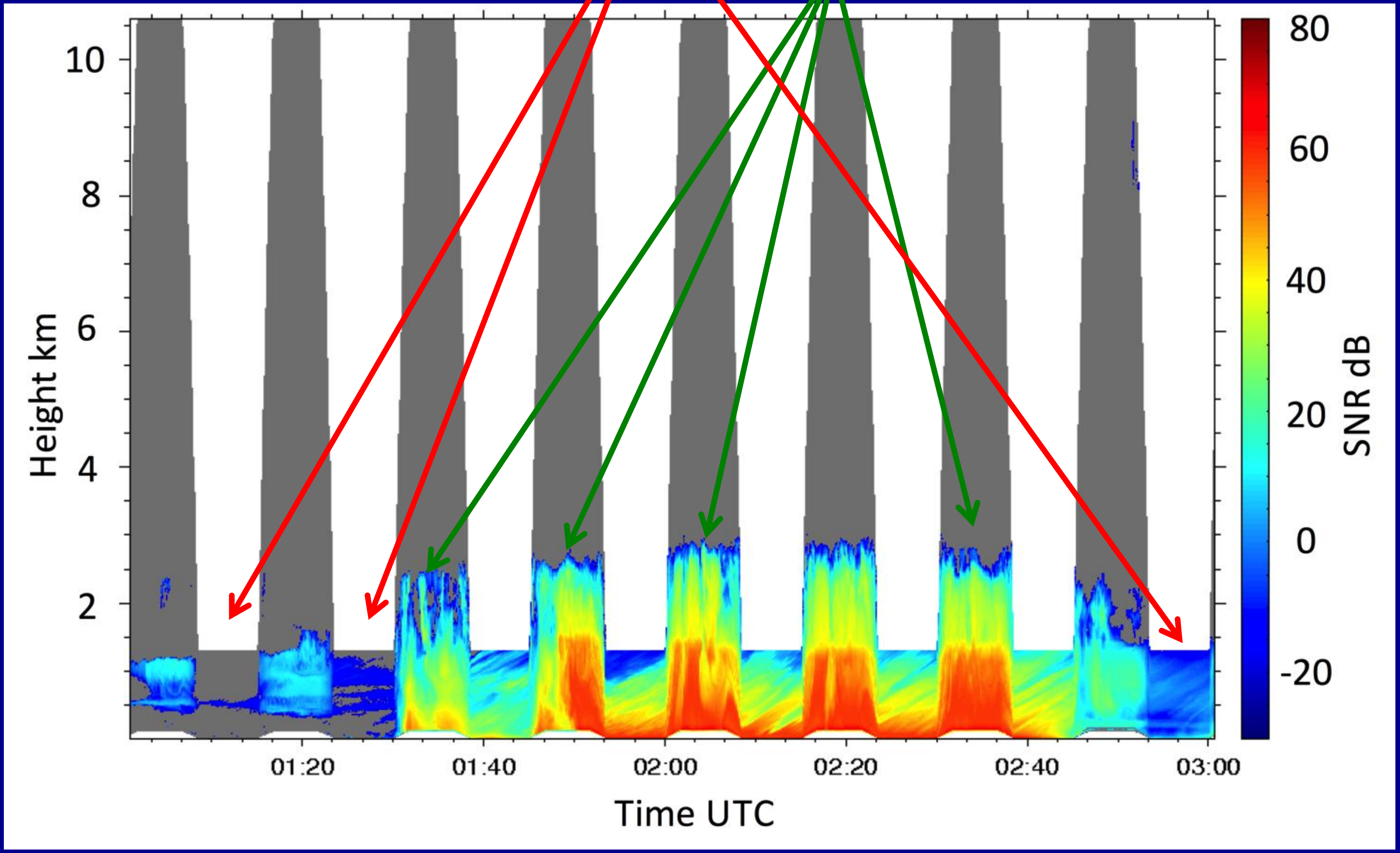
Cloud Radar + RVR + METAR Visibility + Jenoptic CHM15kx



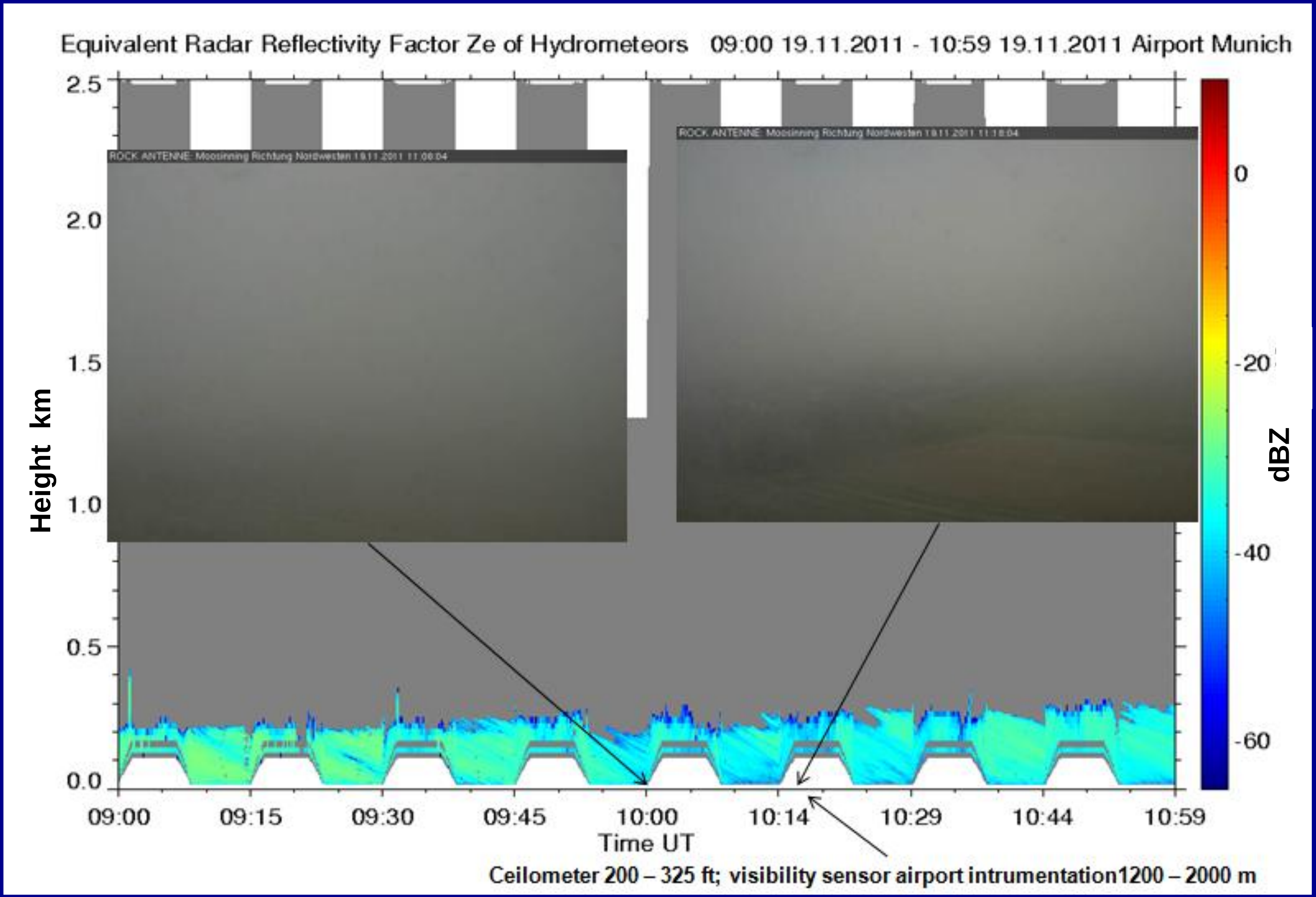
Quarter hourly scanning procedure:

Elevation 5° Azimuth 82° gliding path dwell

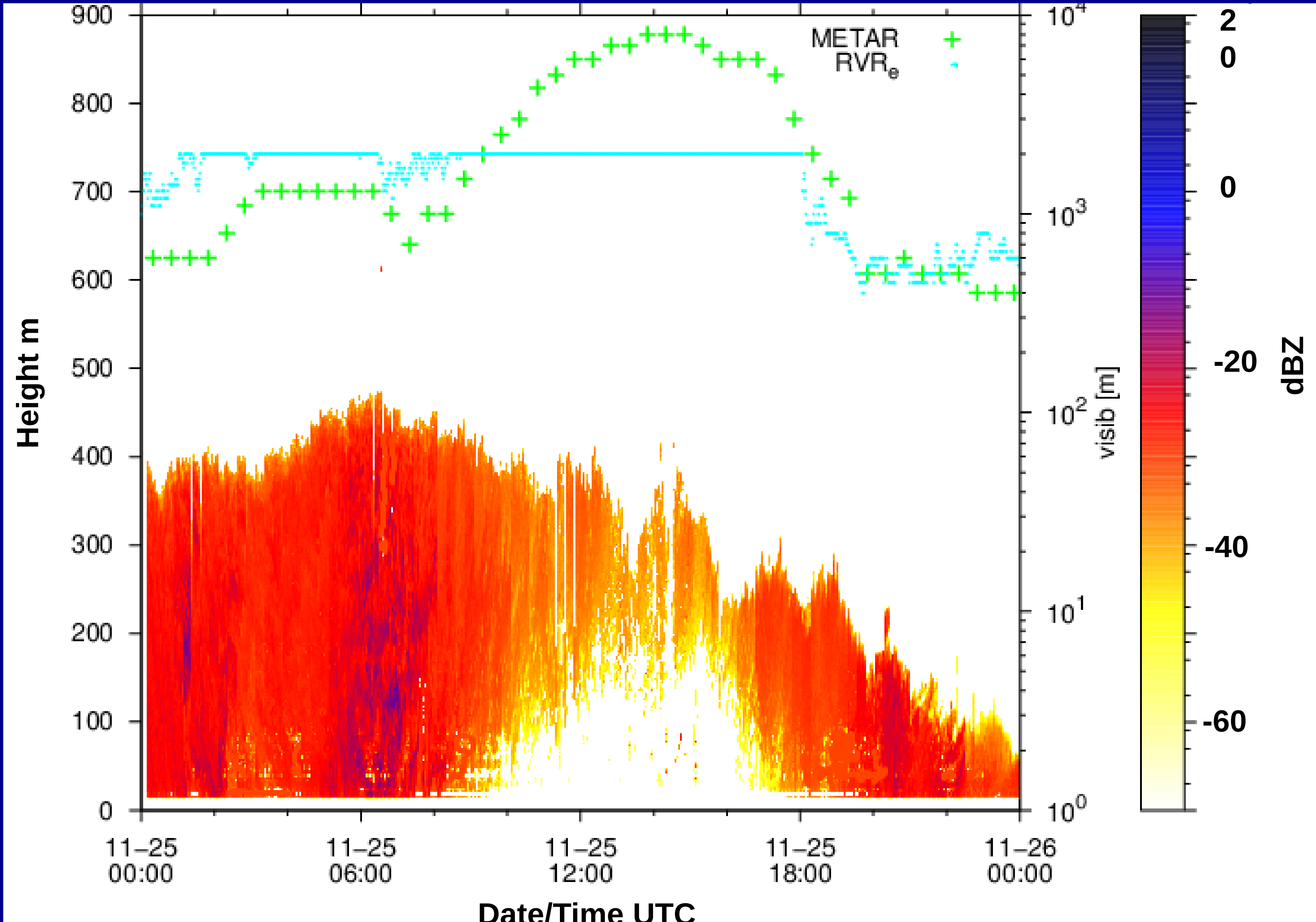
PPI scan 360° Elevation 45°



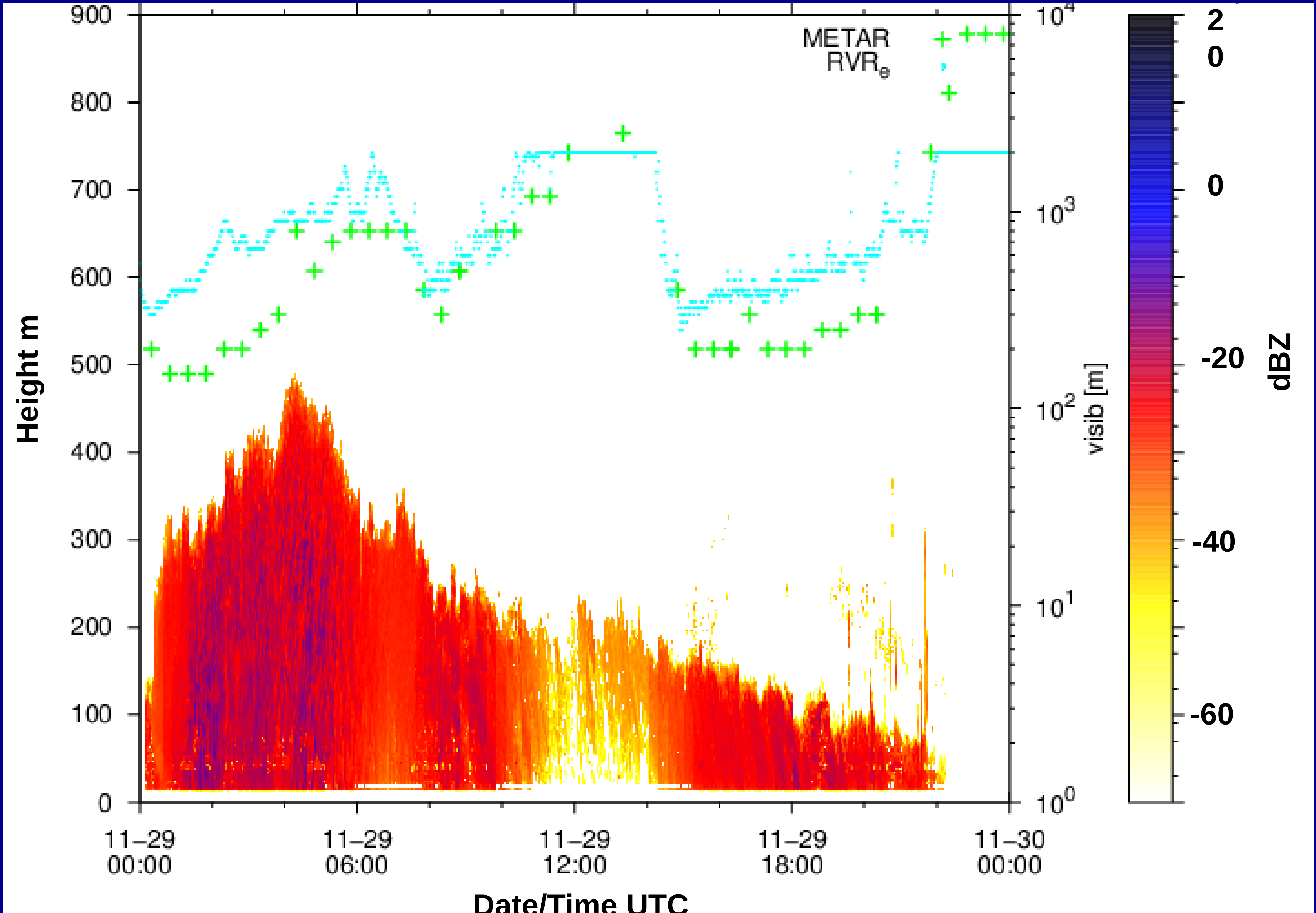
Height projection → SNR at given height at 5° elevation by ~ 18 dB smaller than at 45°



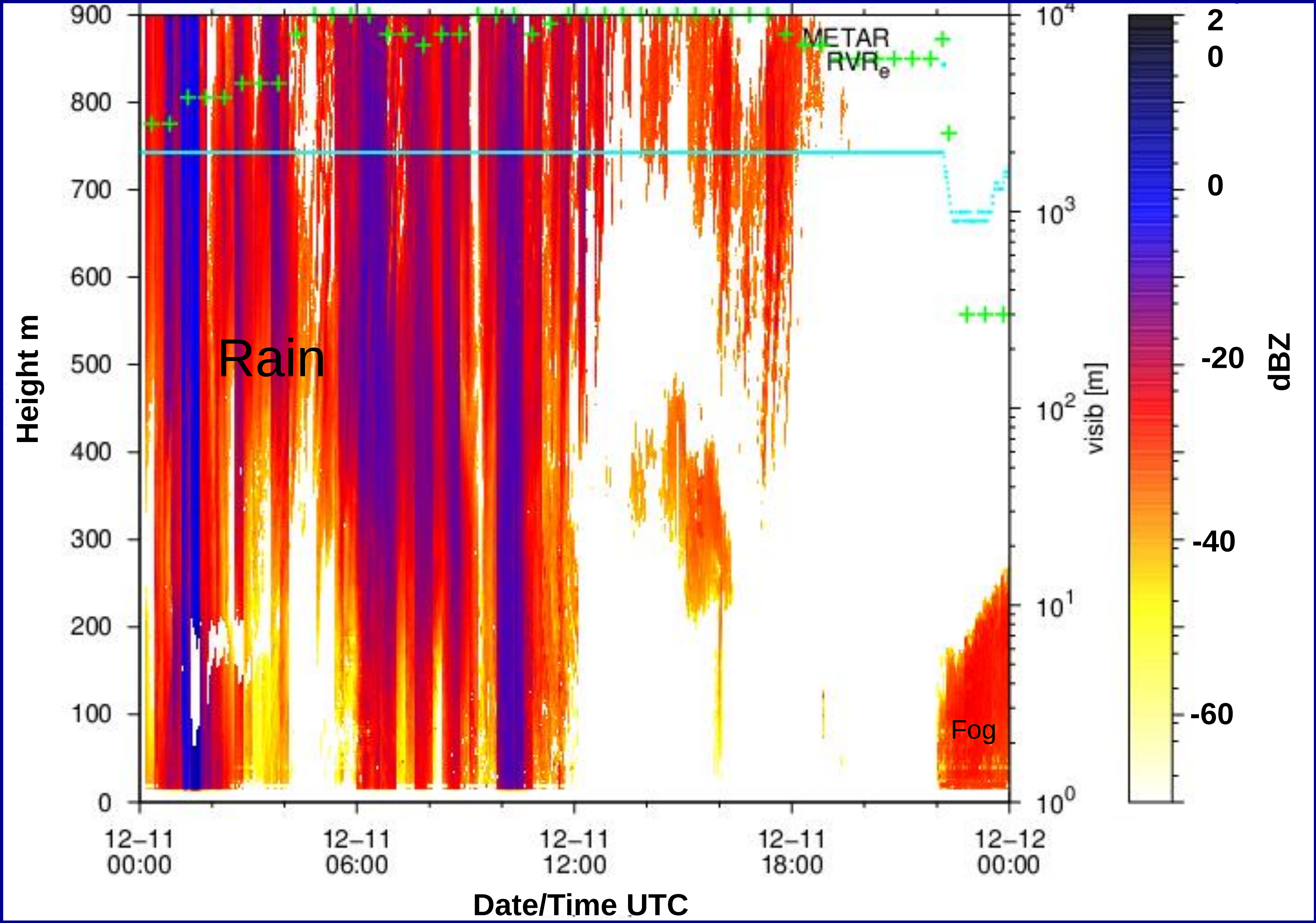
Equivalent Radar Reflectivity Factor Ze of Hydrometeors 09:00 19.11.2011 - 10:59 19.11.2011 Airport Munich
Height km
2.5
2.0
1.5
1.0
0.5
0.0
09:00
09:15
09:30
09:45
10:00
10:14
10:29
10:44
10:59
Time UT
dBZ
0
-20
-40
-60
ROCK ANTENNE: Moosinning Richtung Nordwesten 19.11.2011 11:08:04
ROCK ANTENNE: Moosinning Richtung Nordwesten 19.11.2011 11:18:04
Ceilometer 200 – 325 ft; visibility sensor airport intrumentation1200 – 2000 m



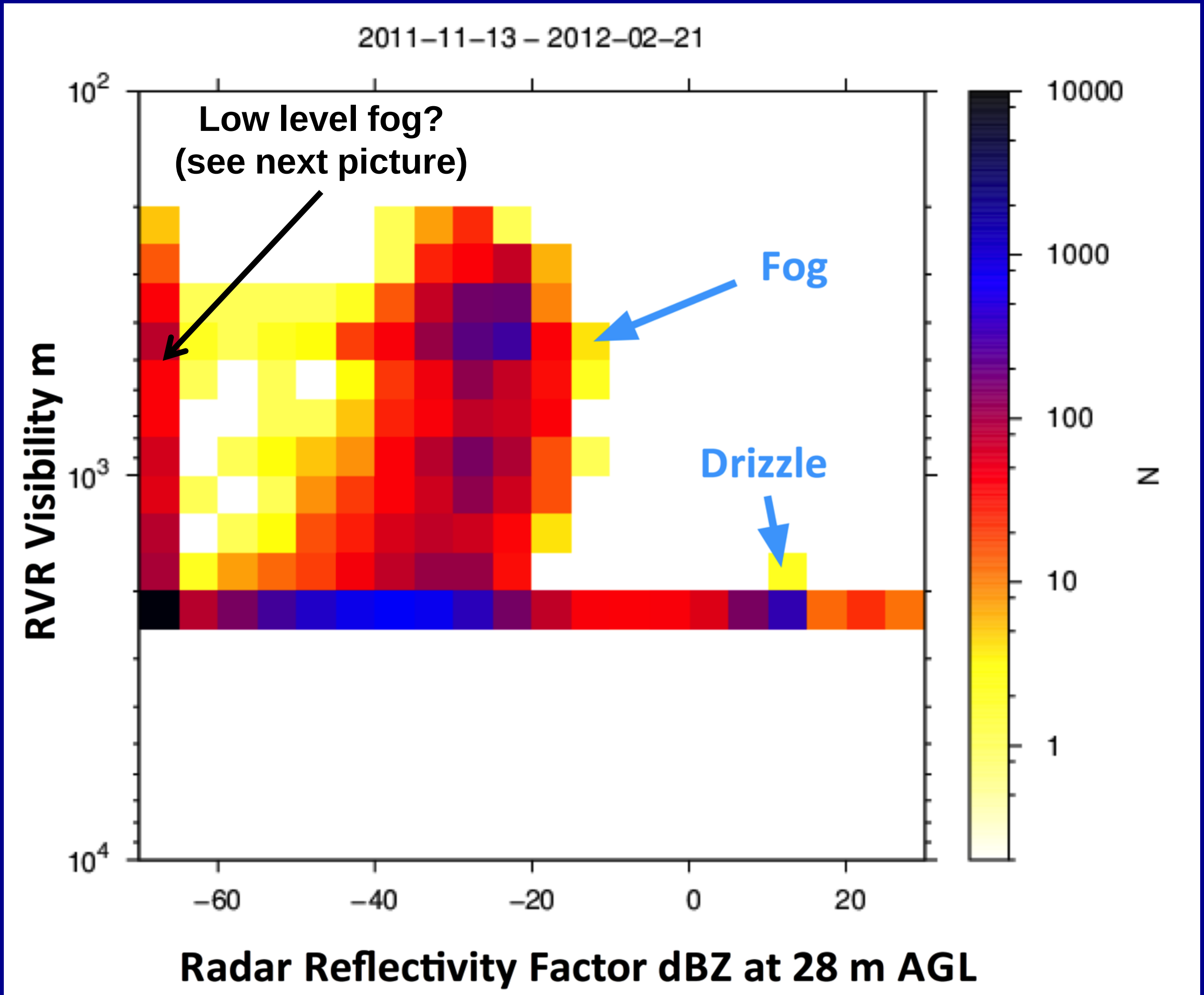
900
800
700
600
500
400
300
200
100
0
Height m
METAR
RVR$_e$
10^4
10^3
10^2
10^1
10^0
visib [m]
11–25 00:00
11–25 06:00
11–25 12:00
11–25 18:00
11–26 00:00
Date/Time UTC
2
0
0
-20
-40
-60
dBZ



METAR
RVR_e
Height m
visib [m]
dBZ
Date/Time UTC
11–29 00:00
11–29 06:00
11–29 12:00
11–29 18:00
11–30 00:00
900
800
700
600
500
400
300
200
100
0
10^4
10^3
10^2
10^1
10^0
2
0
0
-20
-40
-60

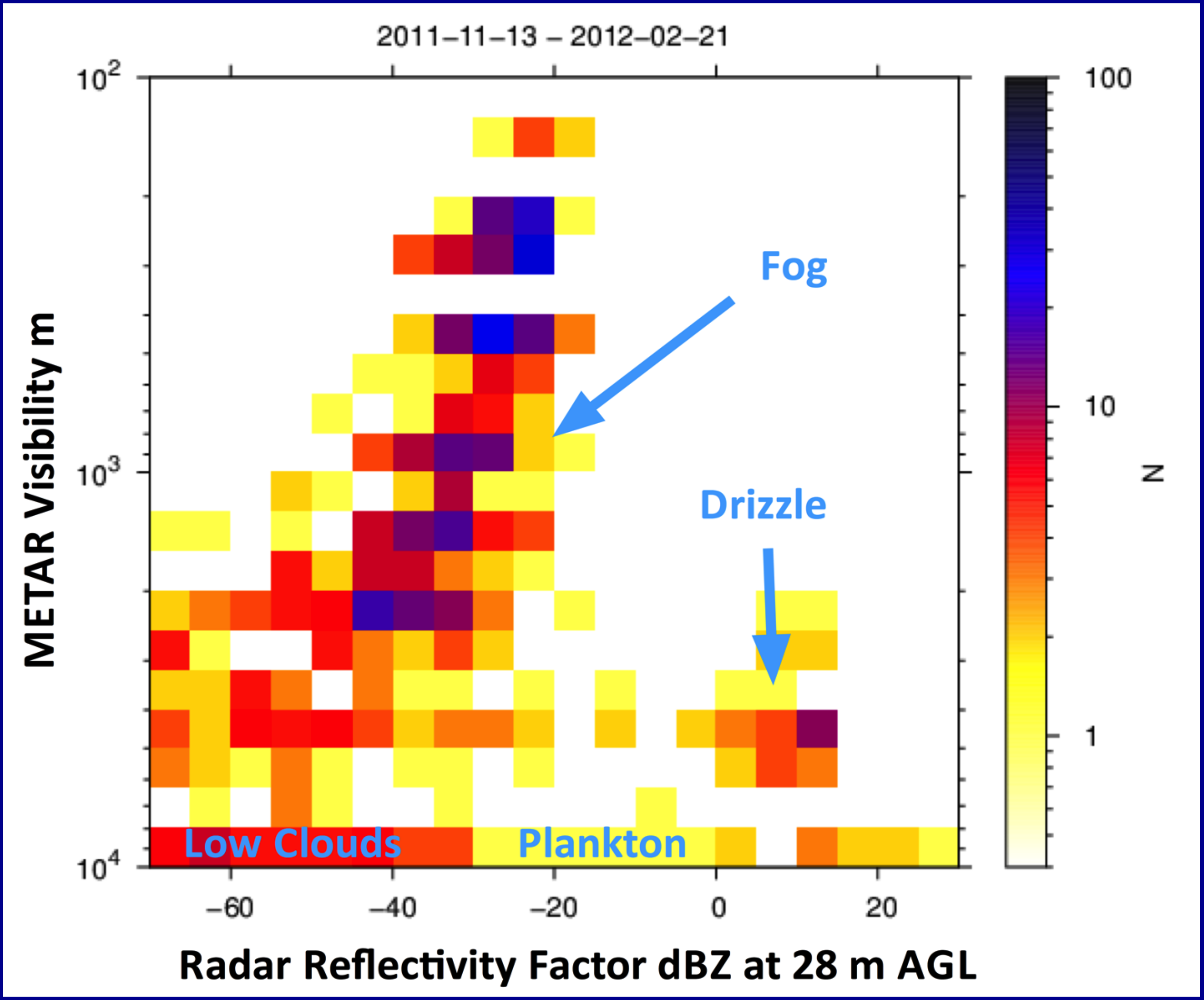

Height m
900
800
700
600
500
400
300
200
100
0
Rain
Fog
METAR
RVRe
12–11 00:00
12–11 06:00
12–11 12:00
12–11 18:00
12–12 00:00
Date/Time UTC
visib [m]
10^4
10^3
10^2
10^1
10^0
2
0
0
-20
-40
-60
dBZ

Scatter plot showing data of all 17 days: Radar Reflectivity ←→ RVR Visibility



The RVR visibility instrument is mounted at 2 m AGL / radar height is 28 m
Systematic difference in the fog intensity at such different heights
(the same plot with radar range at 16 m looks similar)

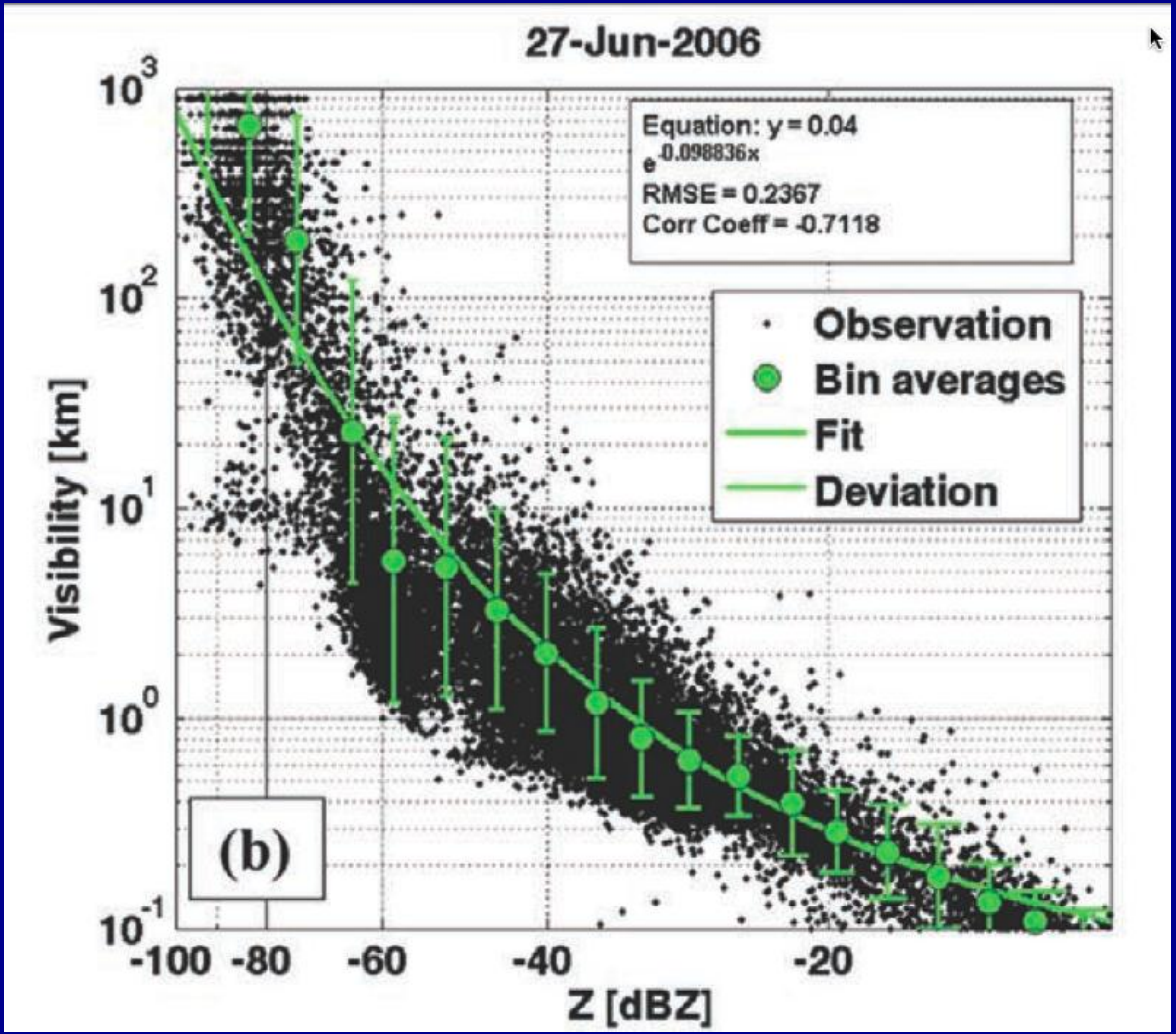
Scatter plot showing data of 17 days : Radar Reflectivity ←→ METAR Visibility (observers)



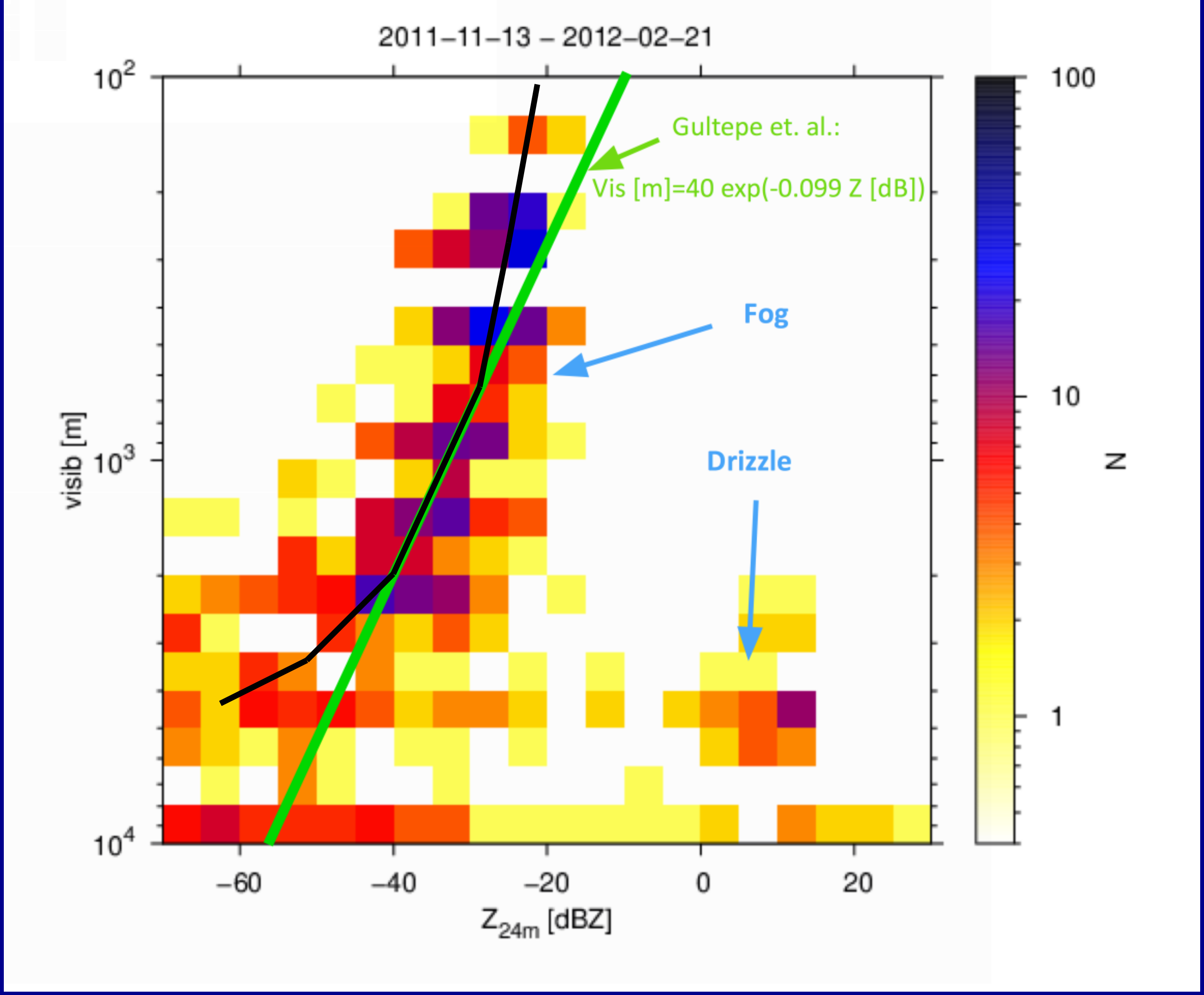
Both measurements represent about the same height range but different locations (2 km)
Less data as METAR visibilities are available only twice per hour

Z-Vis relation gained from measured Drop Size Distributions (DSD)

Gultepe et al. (2008)   green fit: Vis [m] = 40 exp(-0.099 Z [dBZ])



Same scatter plot as above (dBZ ←→ METAR Visibility) including Gultepe's fit



Gultepe: Vis [m] ~= 40 exp(-0.099 Z [dBZ]) (green line)

Maybe closer to: *Vis* [m] ~= −92 *Z* [dBZ] – 1800 (black line)

Taking into account that Gultepe's and our approach are very different the agreement is good.

Lidar/Radar method for estimating visibility

It would be ideal for such scatter plots: co-located Z and Vis measurements

The Klett algorithm using only lidar data does not work in fog.

Due to extinction the ceilometer signal decays faster with height than the radar signal.

$$Z \sim \frac{1}{R^2} \int N(R,D) D^6 dD$$

Radar signal intensity (no extinction by fog at such small ranges)

$$\beta \sim \frac{O(R)}{R^2} \int N(R,D) D^2 dD \; \exp\left\{-2 \int_0^R \alpha(\zeta) d\zeta\right\}$$

Ceilometer signal intensity
Extinction term has a strong impact

$$\frac{\beta(R_2)/Z(R_2)}{\beta(R_1)/Z(R_1)} \cong \exp(-2(R_2 - R_1)\alpha(R))$$

$$\frac{\text{Ceilometer-Radar-Ratio}(Z_2)}{\text{Ceilometer-Radar-Ratio}(Z_1)} \rightarrow \alpha$$

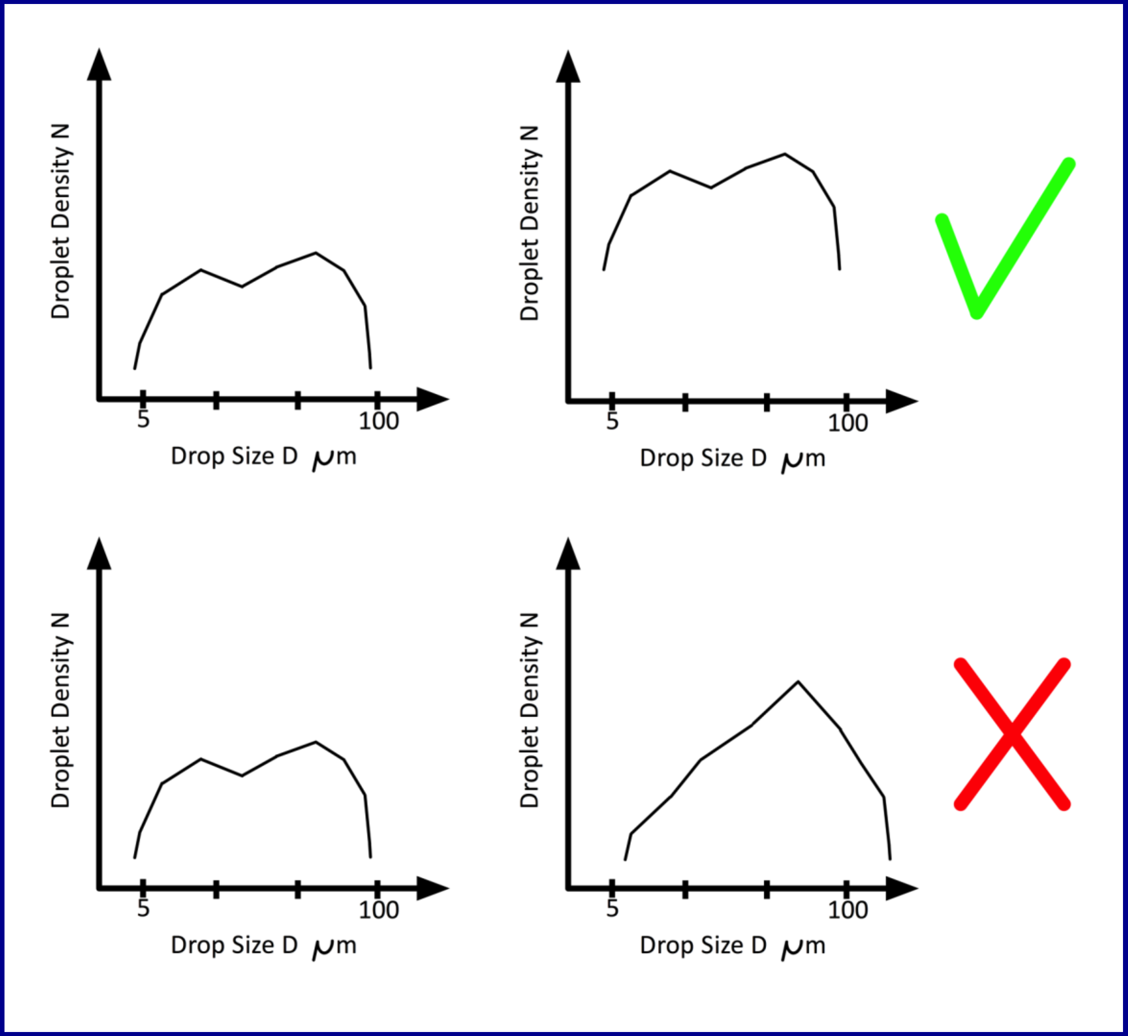
(Beam overlap factor O neglected)

$$\frac{3}{\alpha} = Vis$$

MOR visibility: power of light beam has decayed by 13 dB

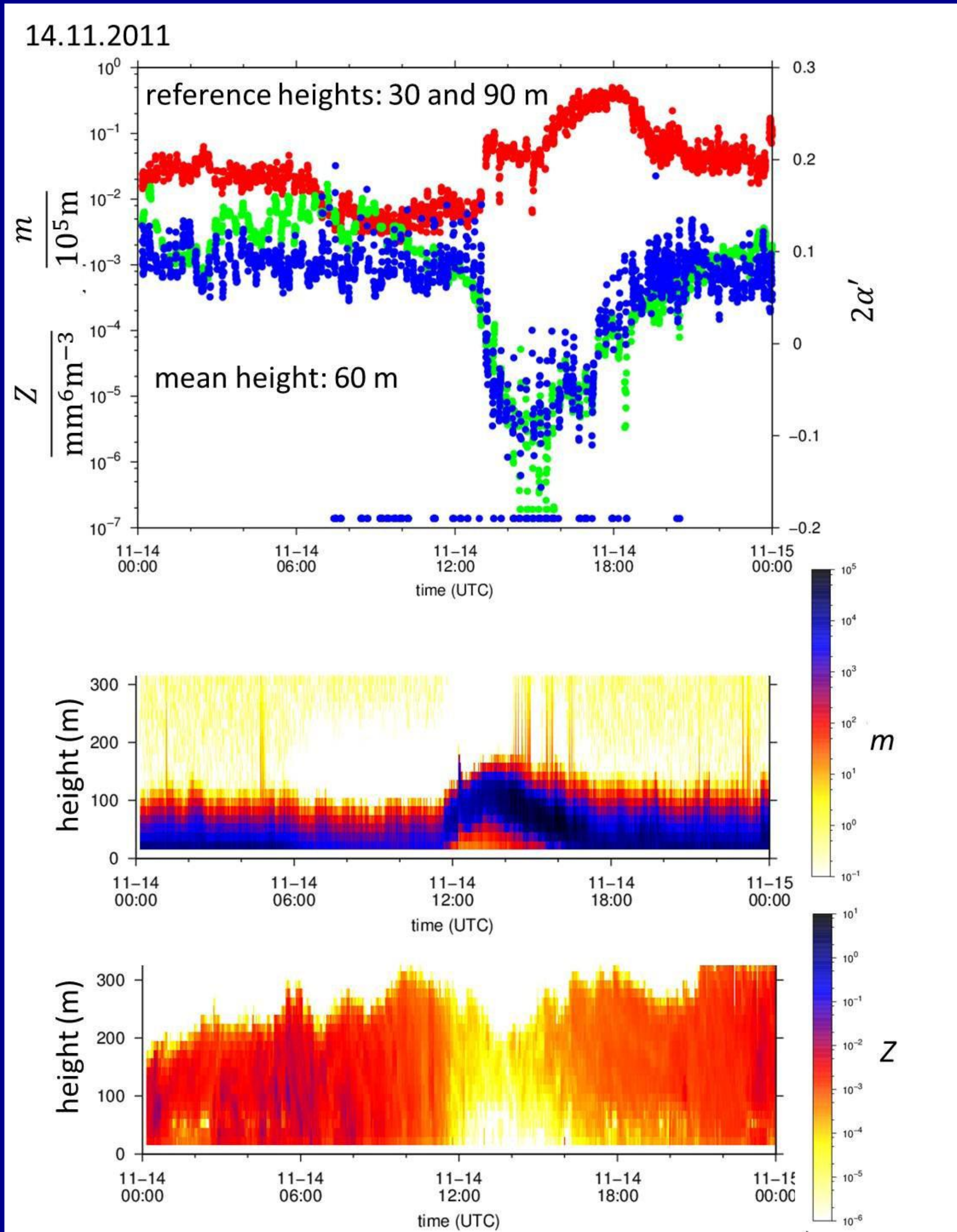
Constraint for the lidar/radar method:

This constraint only has to be fulfilled for some neighboring gates.



The intensity of the fog may change

But not the shape of the DSD



One Day Example Lidar/Radar method

Red: Ceilometer intensity (60 m)

Blue: Radar Reflectivity (60m)

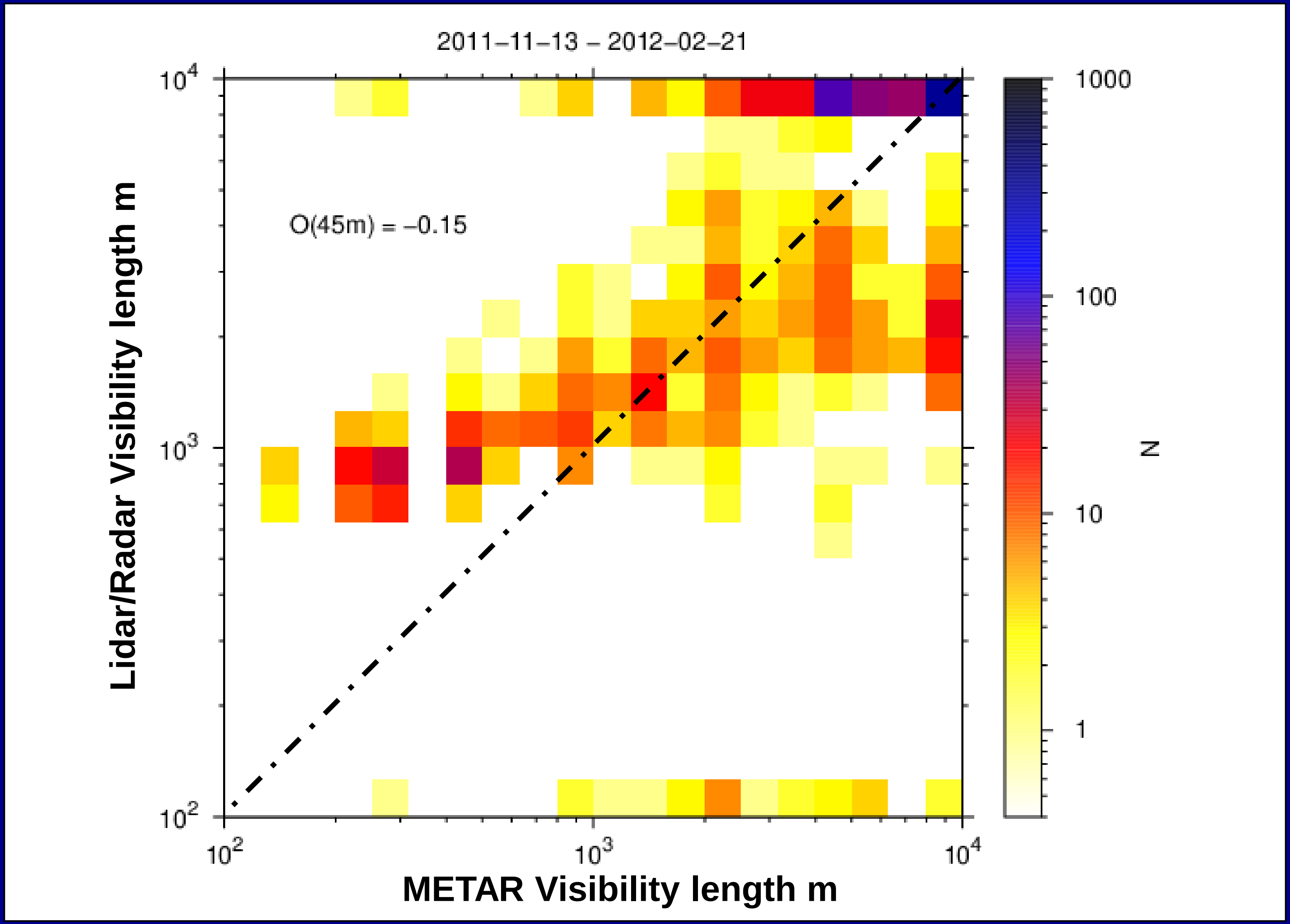
Extinction coefficient 2α

Height profiles of:

Ceilometer intensity β

Radar reflectivity factor Z

Comparison of visibilities estimated by Lidar/Radar ←→ METAR

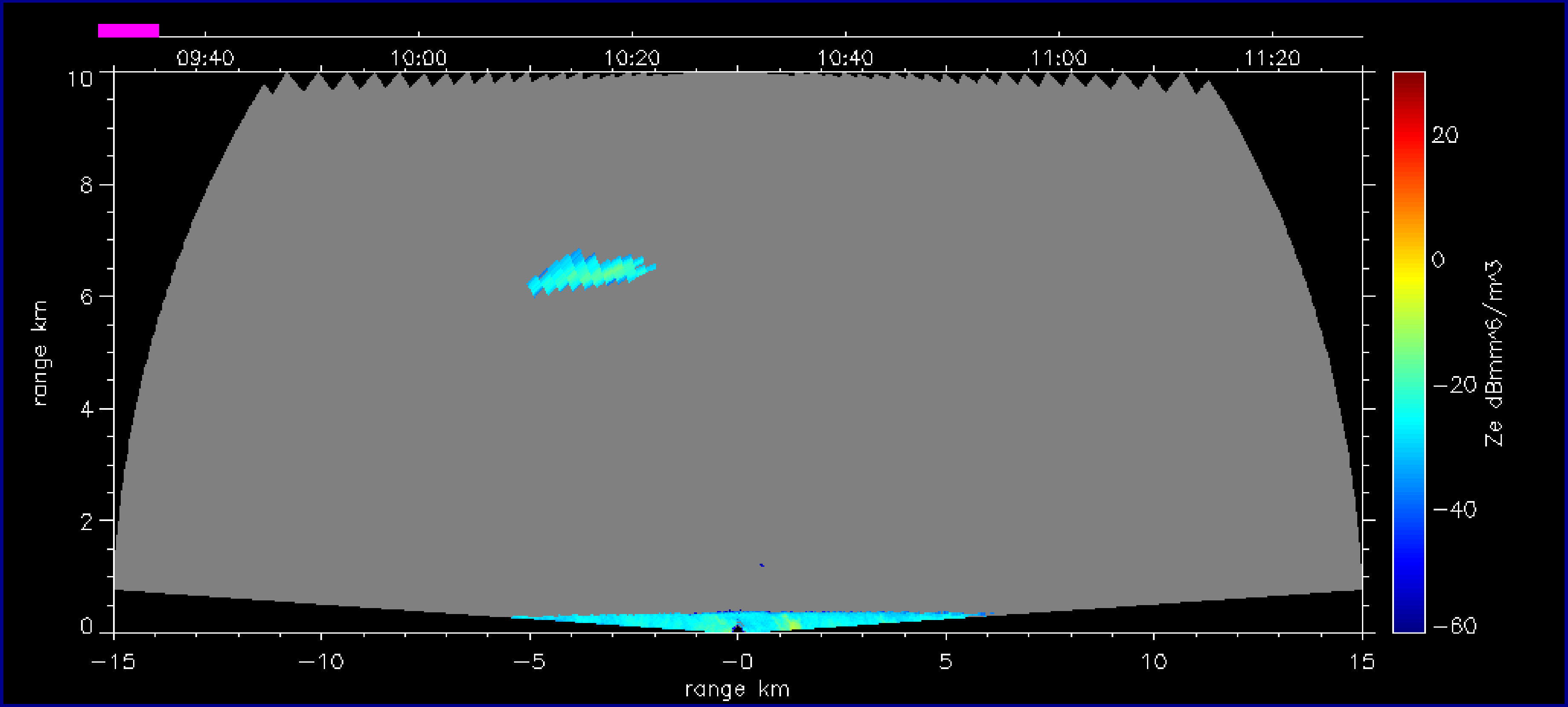


The points of this scatter plot should be centered at the diagonal. Independently of the selection of the laser beam overlapping correction O at strong for the lidar/radar method overestimates the visibility length. This is caused by multi path scattering of the optical waves. → The lidar/radar method cannot be used a reference.

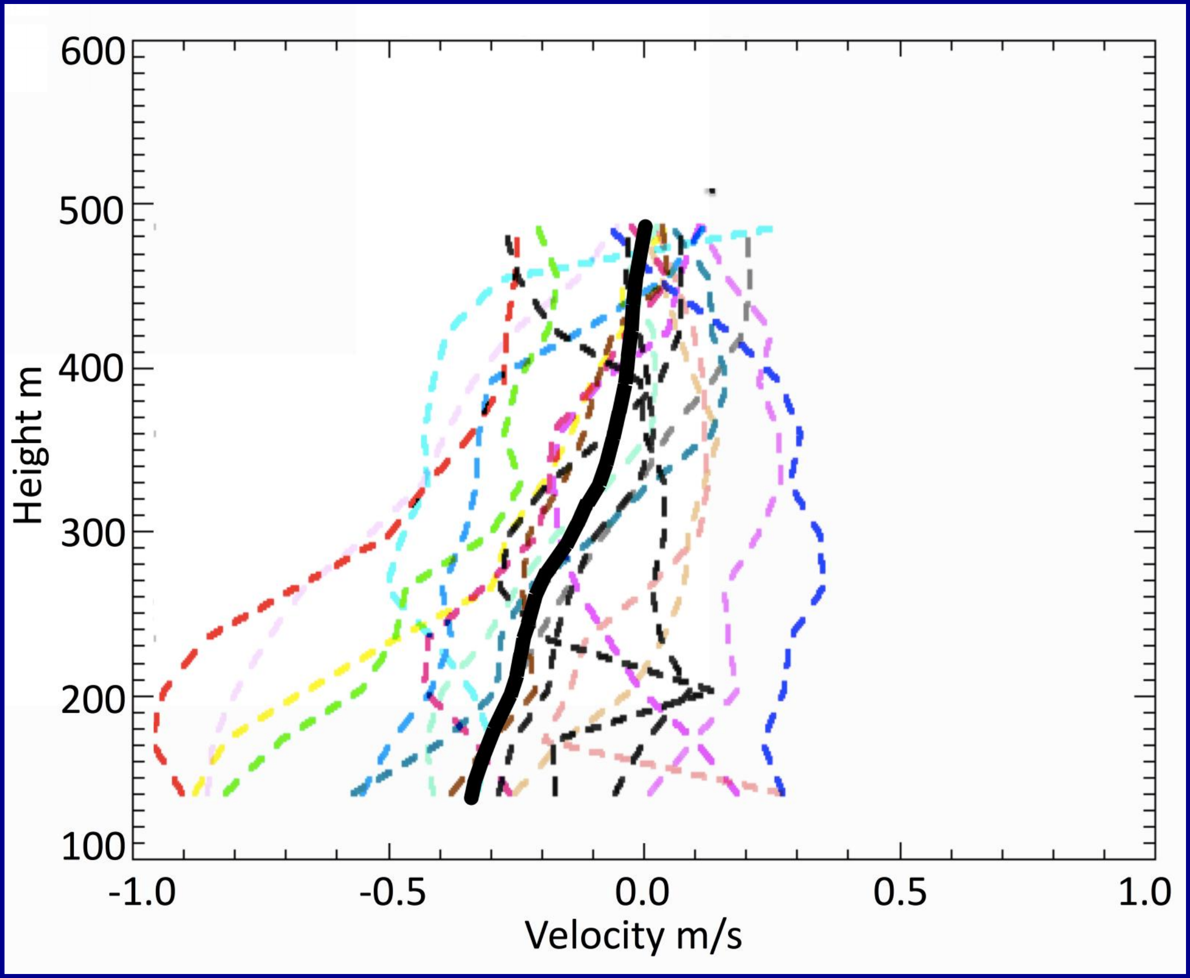
Much of the scatter is caused drizzle producing much dBZ but no so much optical extinction

Drizzle falling speeds at low altitudes can only be recognizes by RHI scans.

Maybe due to the low turbulence in fog it works better than expected.



20 RHI scans of Radar reflectivity Z captured during 2 Hours during a fog event



Vertical velocities estimated from 20 RHI scans (one hour). The black solid line is the average over the 20 profiles.

Maybe the droplet falling velocities estimated like this can be used to eliminate the signal caused by drizzle and does not affect visibility much. Like this maybe the visibility estimated from the radar data can be improved.

Conclusions:

dBZ values in the range from -60 to -20 dBZ detected by a sensitive radar give a rough estimation of the visibility. Larger dBZ values correspond to drizzle or rain, which do not affect visibility much.

More data is needed to consolidate the Z-Vis relation

Thank you

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