# Chapter I:

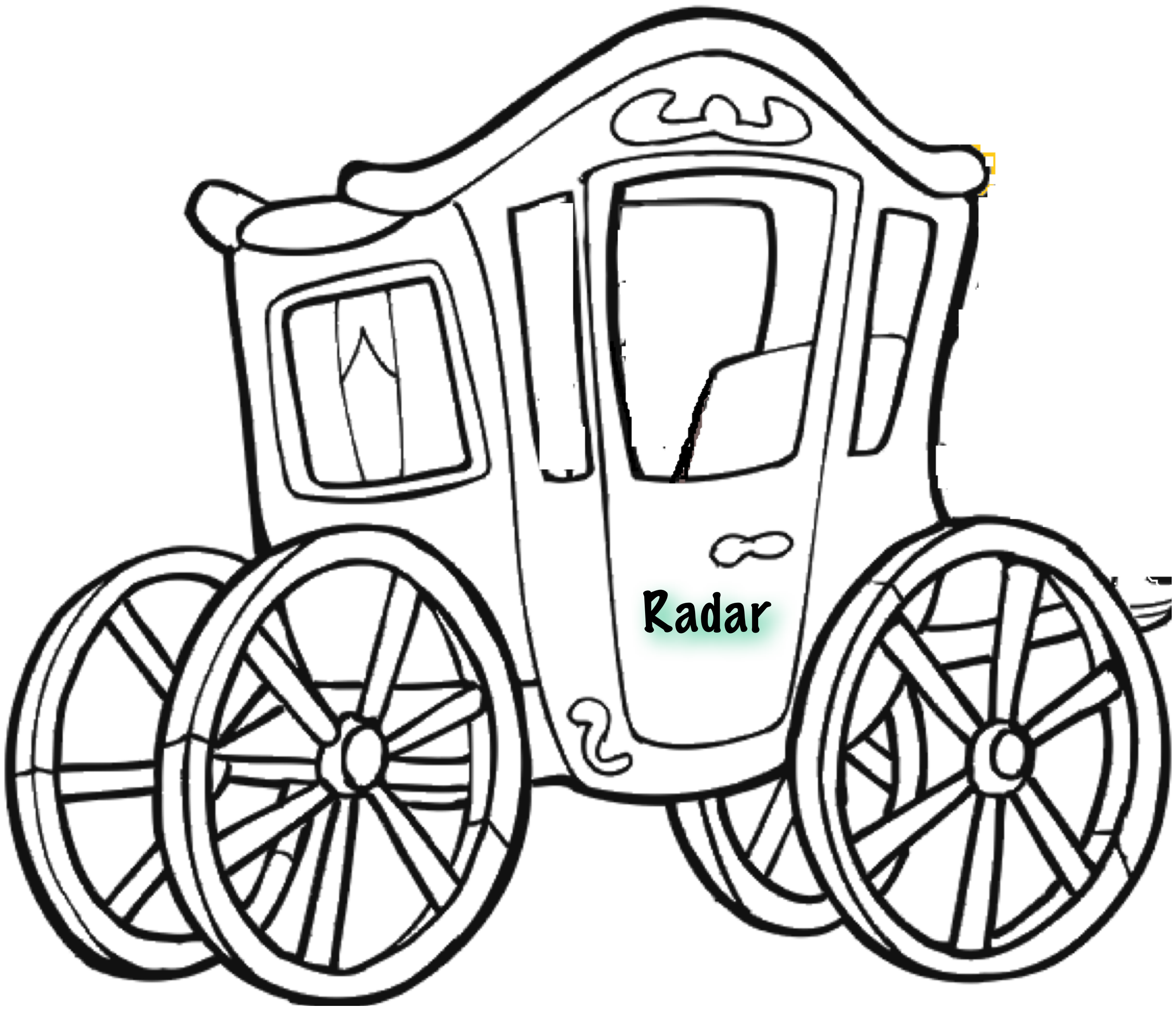
# What do you need in order to have Radar QPE

Radars
Infrastructure to operate then effectively

The more sophisticated are the radars the more sophisticated must be the infrastructure

People, not machines, are the key element

# Absolute requirements for effective radar operations



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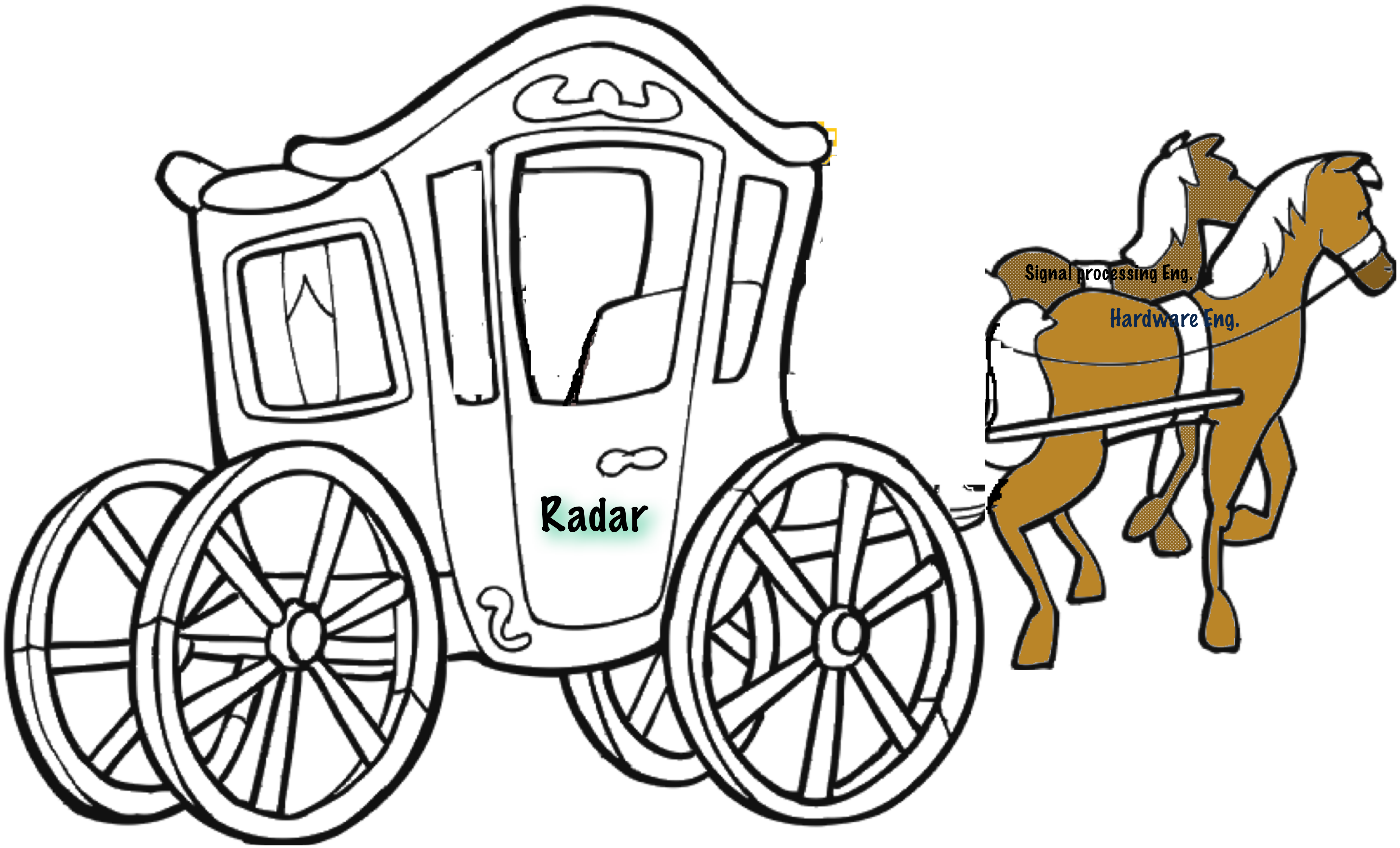

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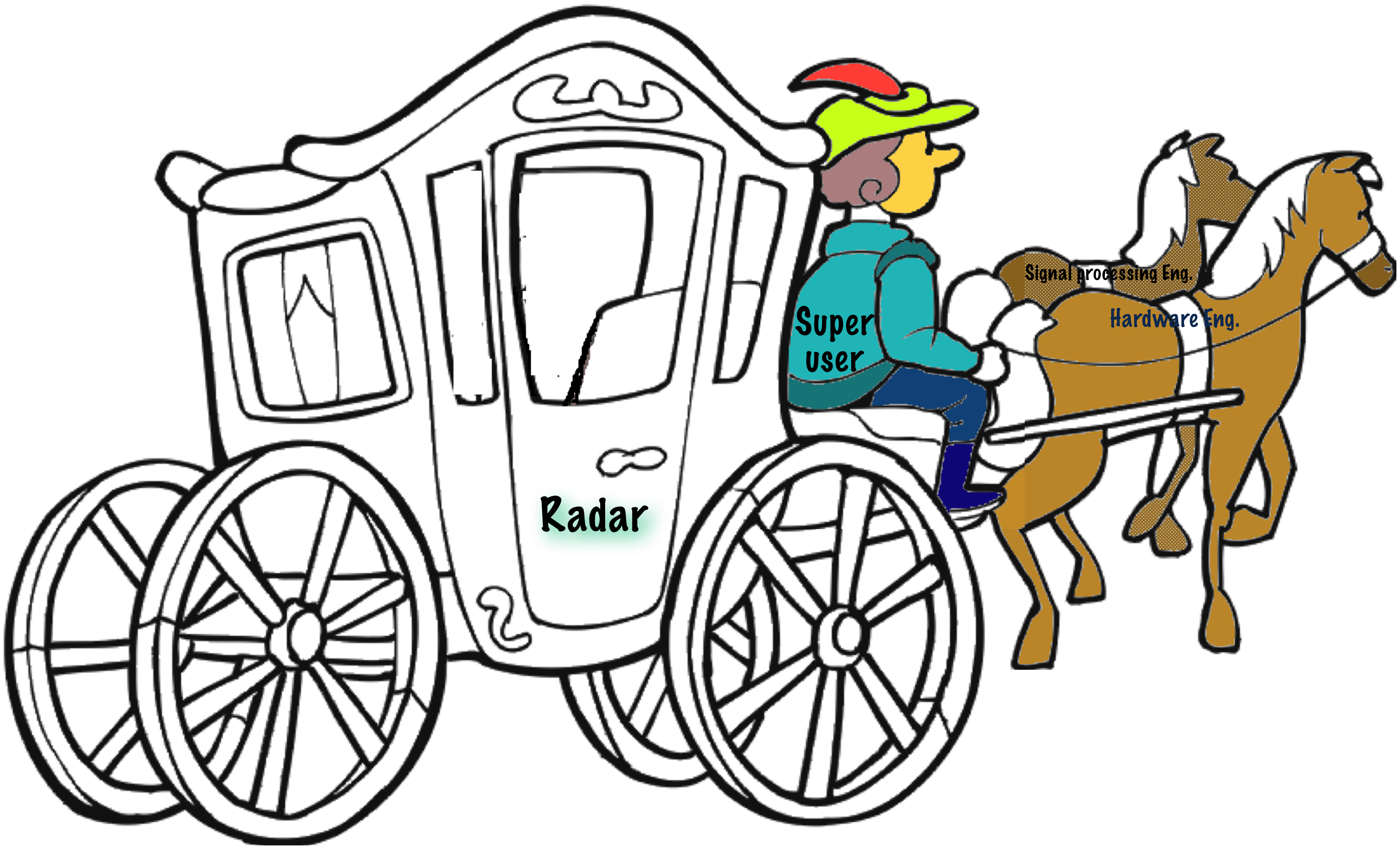

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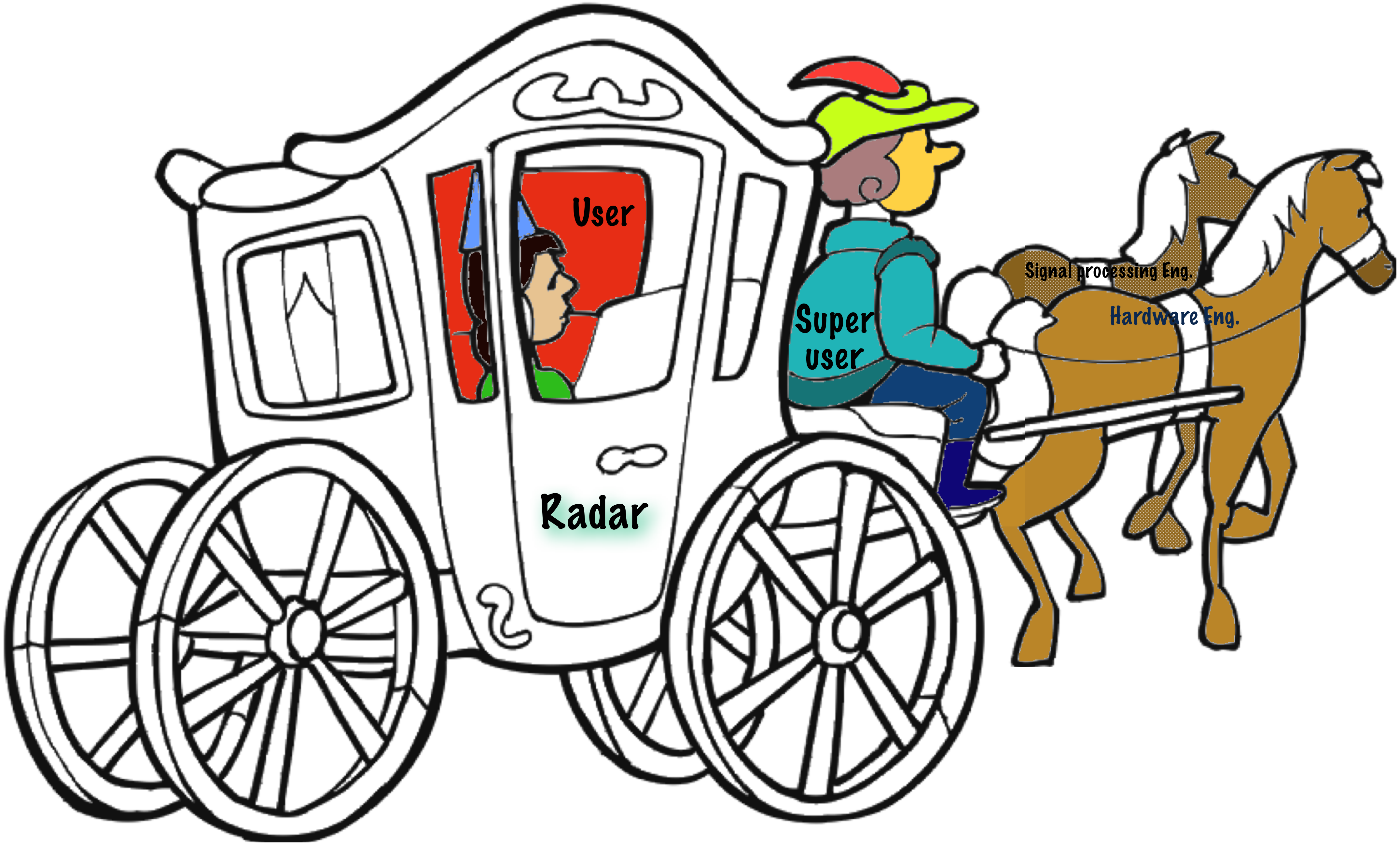

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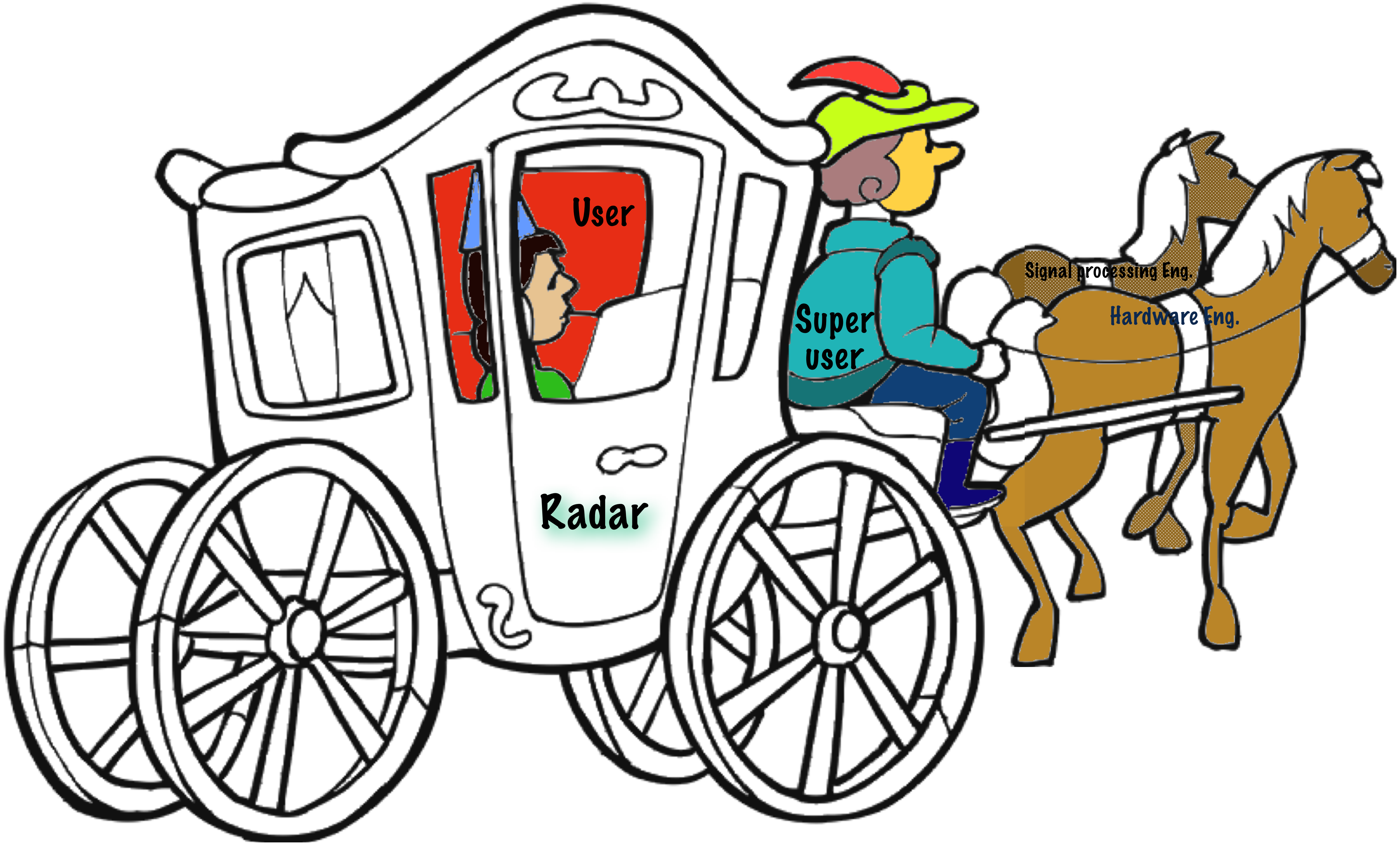



The engineers can be external, but the Super-User, the user that understands data quality, monitors data regularly and has a common language with the engineers, must be in-house.

# Radar derived QPE

## Which one of the following statements is true?

There exists a close relationship between radar reflectivity and precipitation intensity.

Consequently it is straightforward to provide frequently updated QPE maps from radar data.

Radar does not measure precipitation intensity but a loosely related parameter, radar reflectivity, at a certain height above ground, where targets other than rain may be present .

To obtain QPE from this measurement is a very difficult task.

# Radar derived QPE

This statement is true as long as QPE stands for Qualitative Precipitation Estimate.

**In many instances this is the most valuable radar product.**

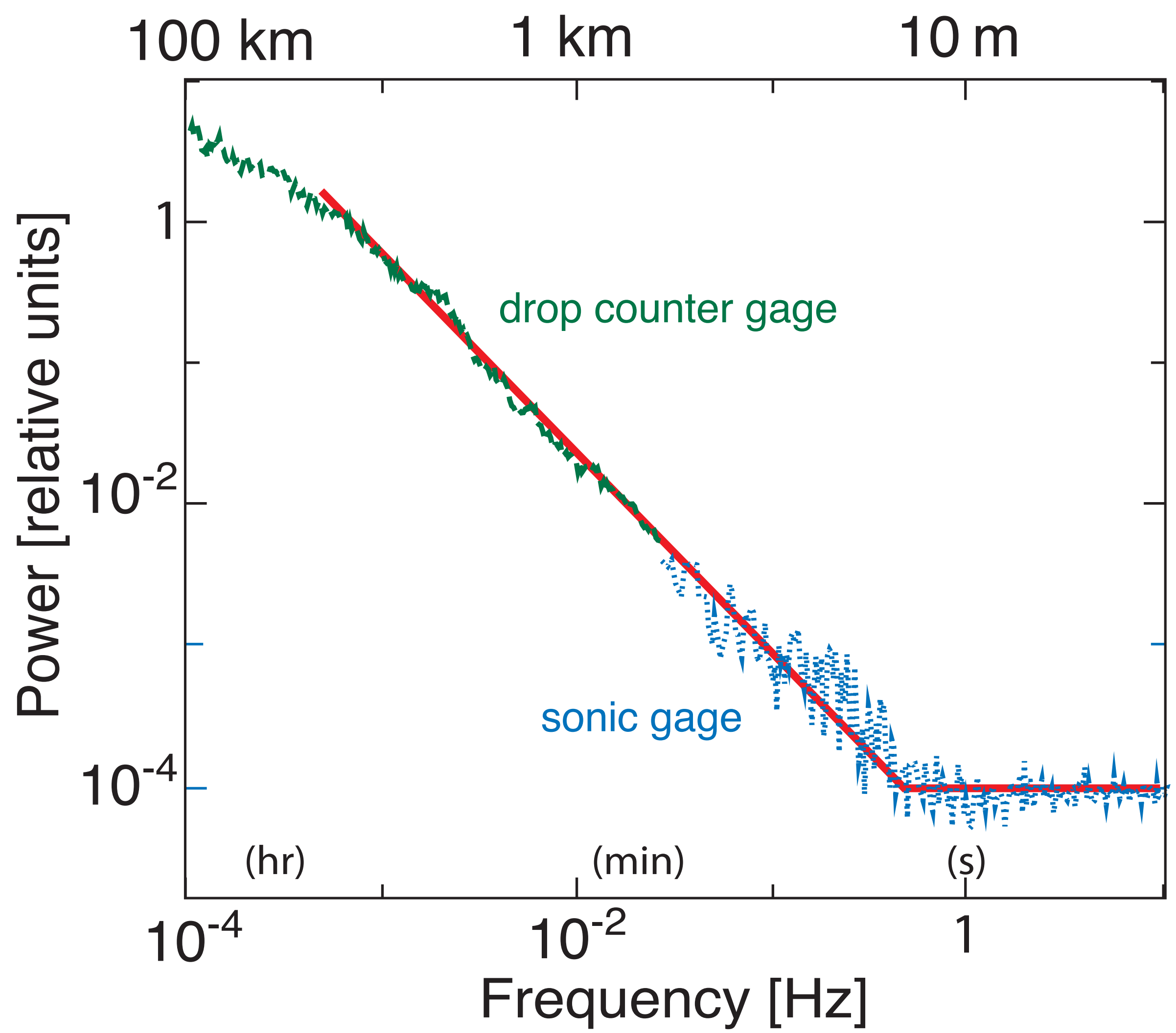
It is this product that originates the large number of hits on the radar-image web page and often justifies weather radar deployment.

Radar derived Quantitative Precipitation Estimates requires more expensive radars, careful radar maintenance and sophisticated software.

This lecture will outline the steps necessary to derive the QPE product.

We must first understand the phenomenon we want to measure

# What is to be measured?
## Variability at all scales




Rain has variability at all time-space scales down to a few meters and few seconds. Rain intensity has all the characteristics of a random correlated process.

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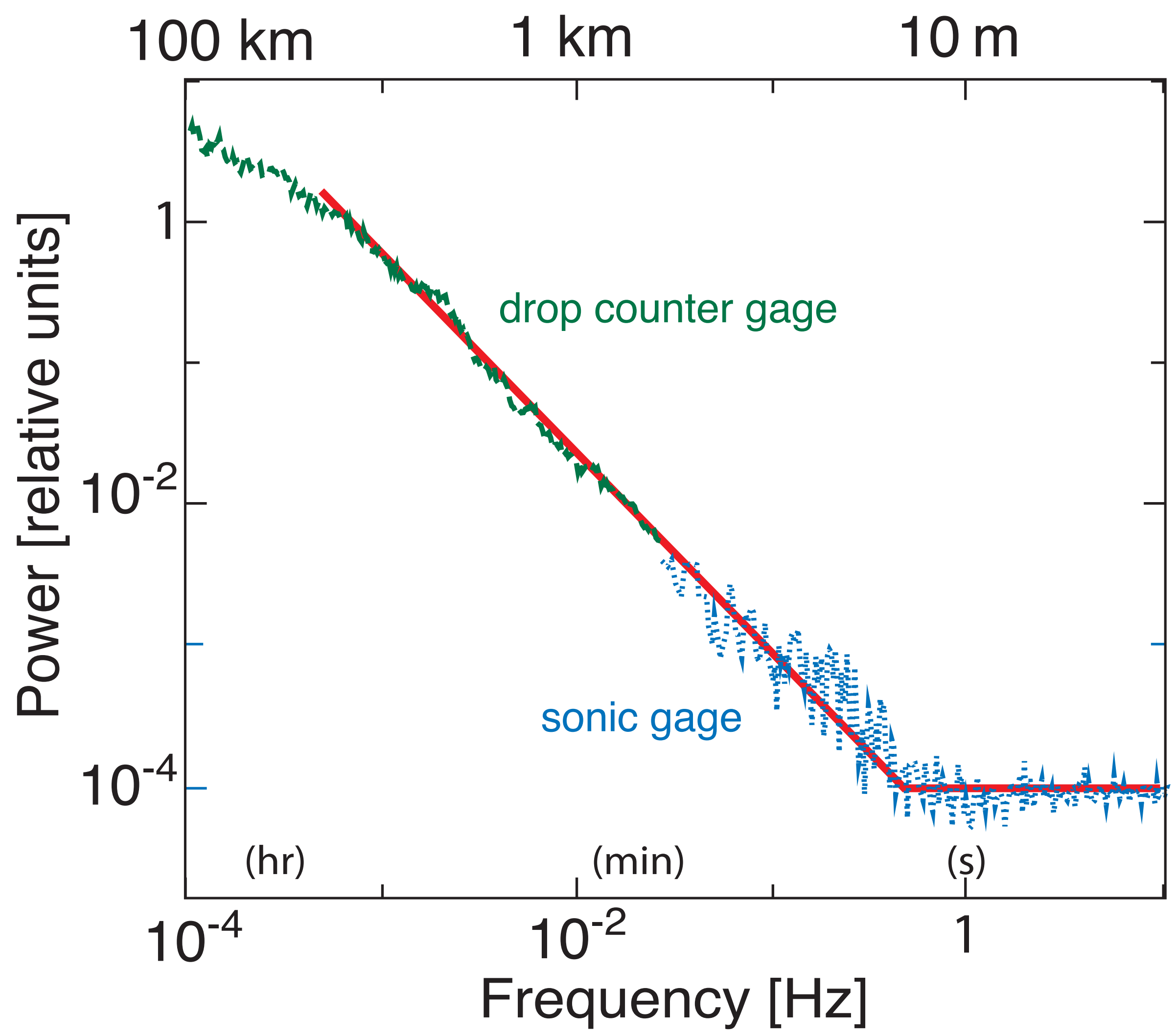


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May be gages are not so good after all !!

# And rain intensity does not averages out easily !!

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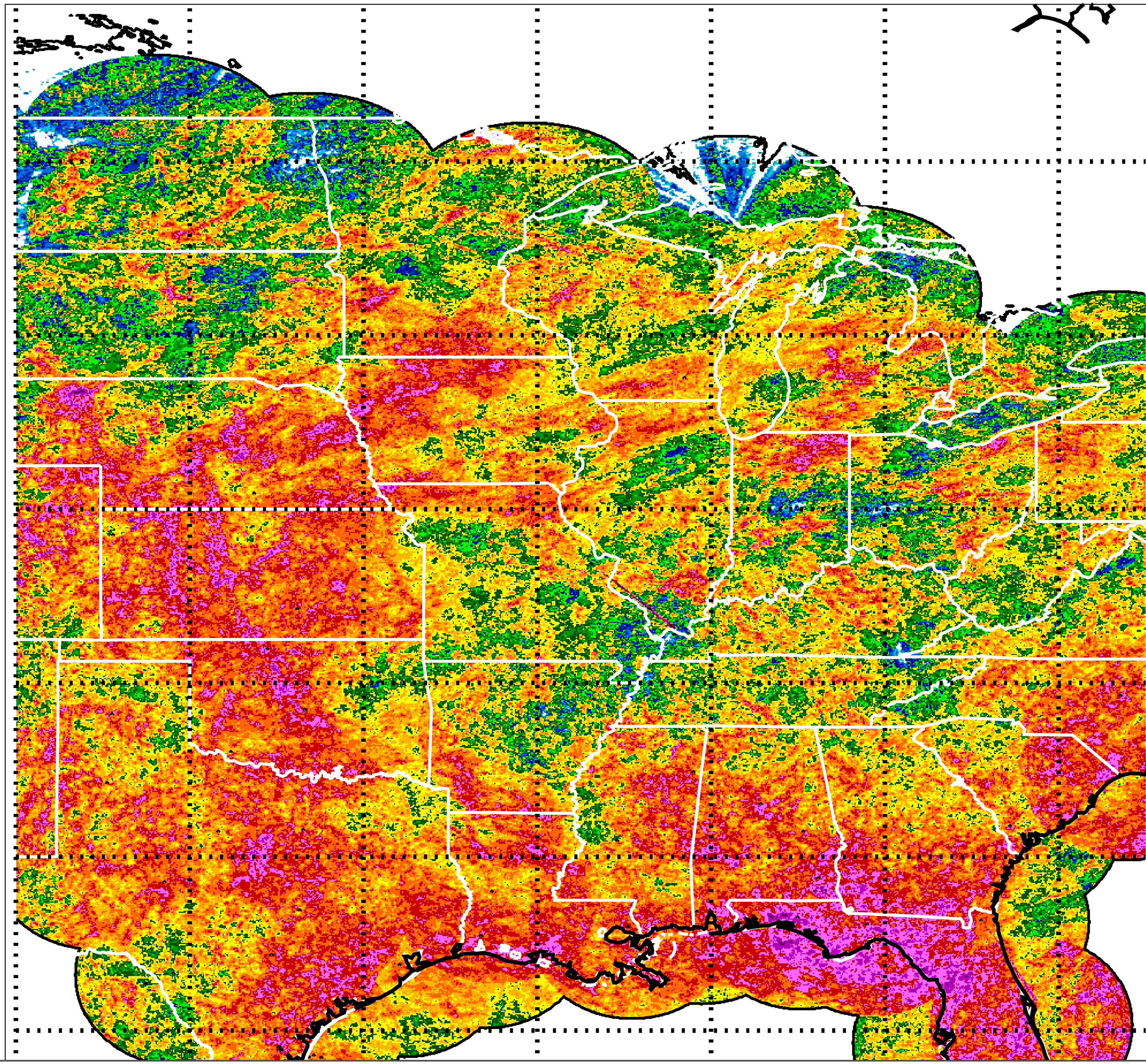
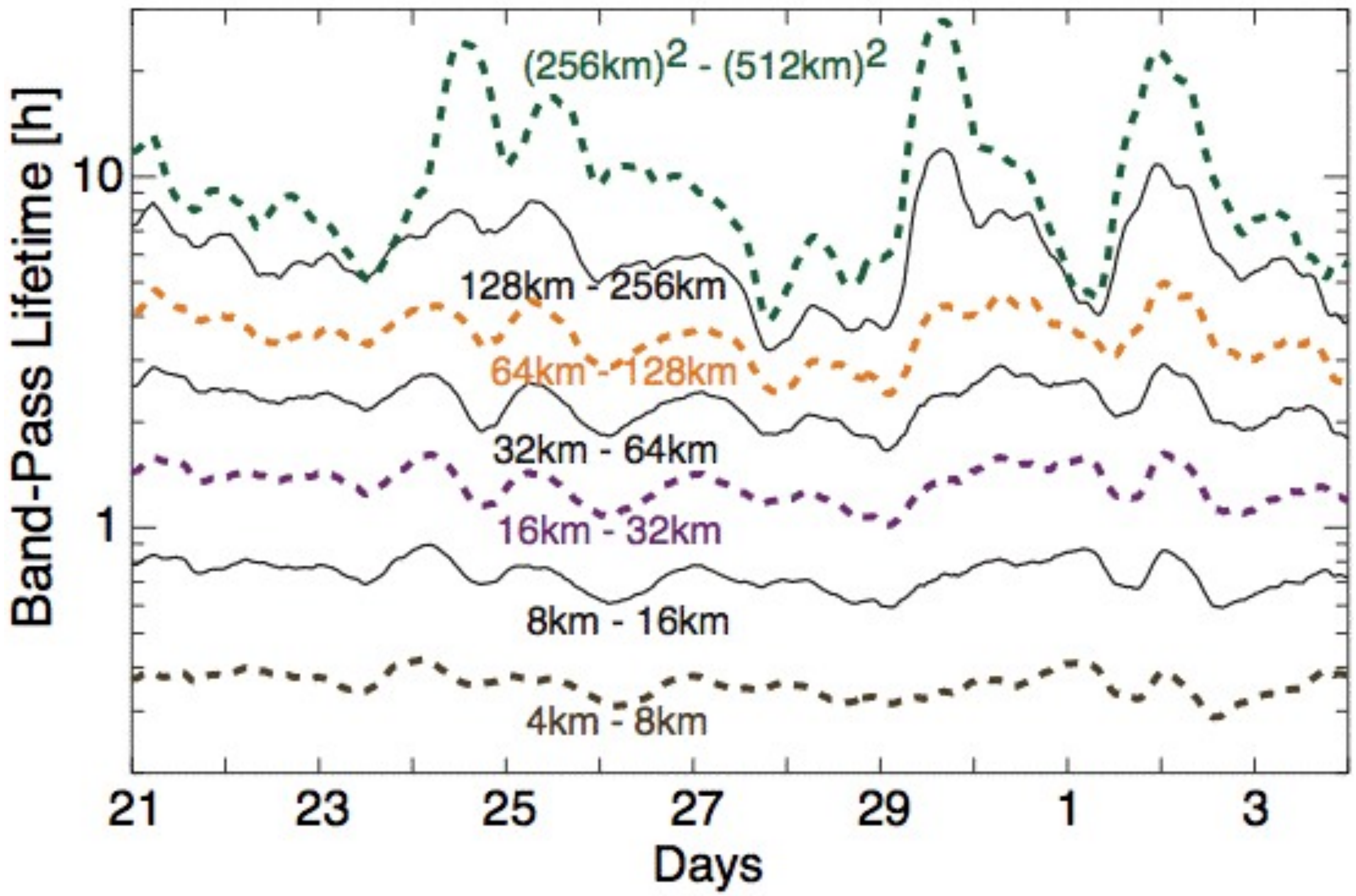
Avg. reflectivity [dBZ] - August 1996



# What is to be measured?
## Scale dependence of predictability



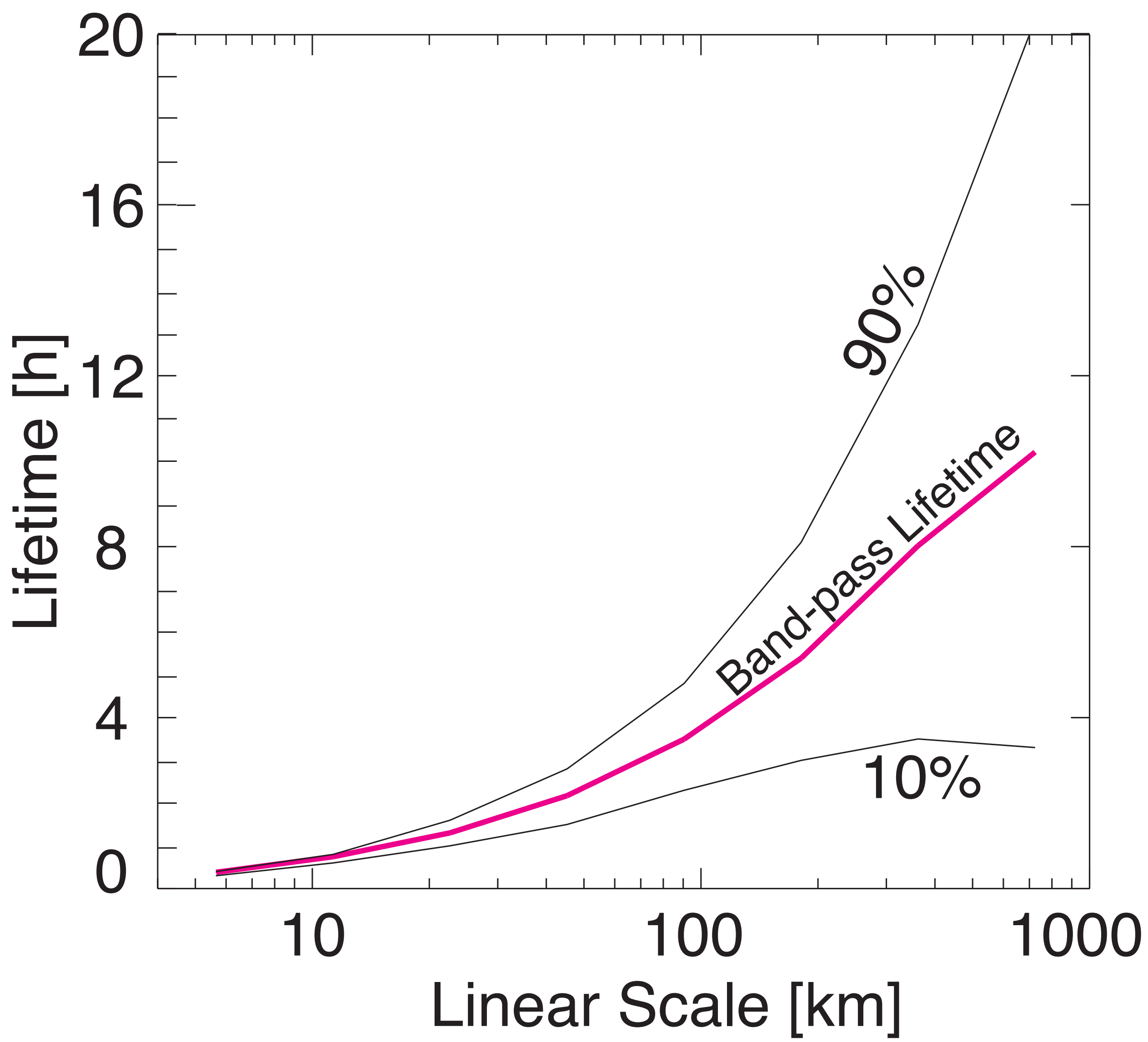

Small scales are perishable, their lifetime is short.

The smaller the scale the less variability in their lifetime.

Scales of the order of a few kilometres have a lifetime of few minutes;
by the time you observe them they have changed.

# What is to be measured?
## Scale dependence of predictability

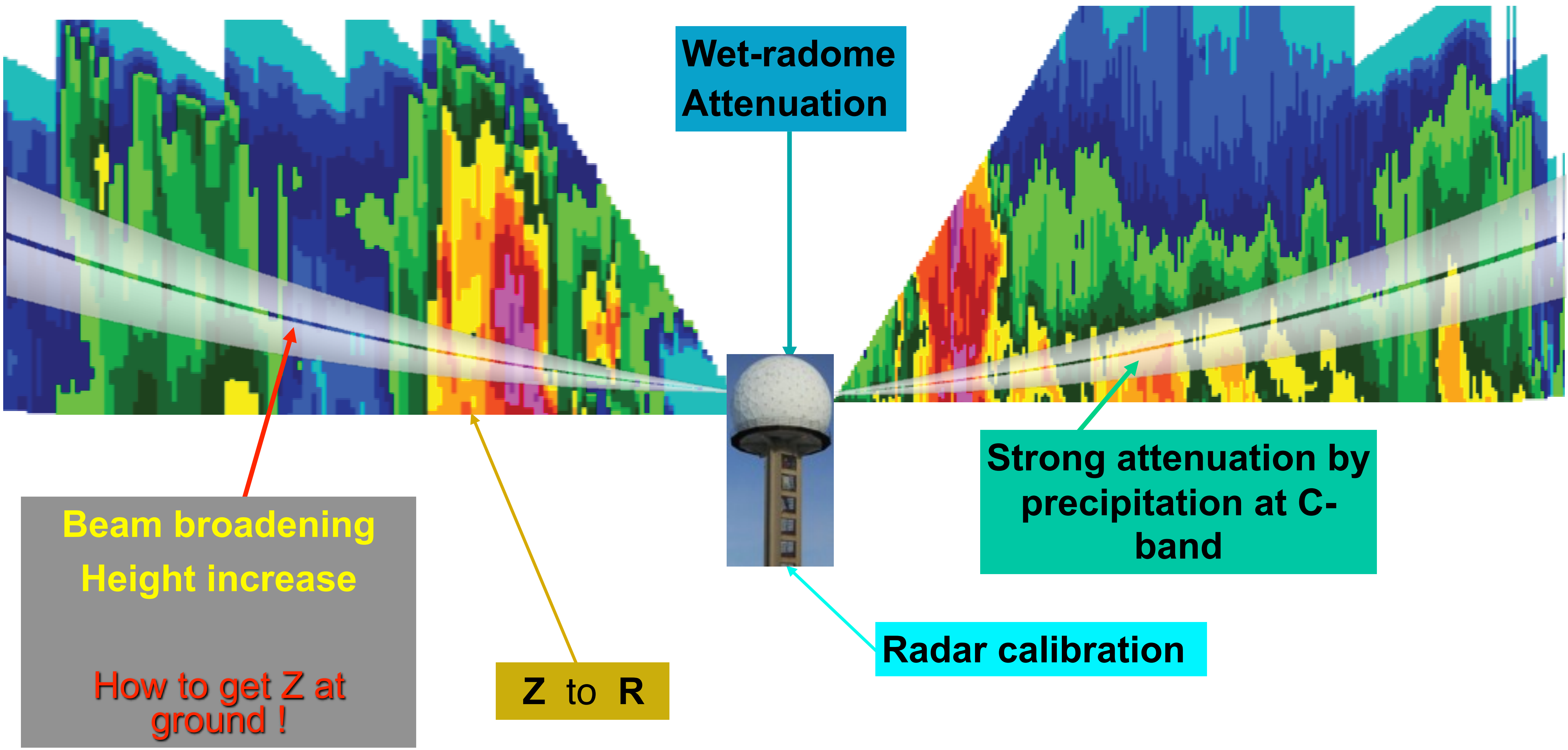
Average from a large data base




From incomplete observations (radar) it is not possible to predict the evolution of small scales. The question: can numerical models do it?

# Considerations necessary to derive a radar QPE product

Target identification | Removal of contaminations | Compensation for beam blockage



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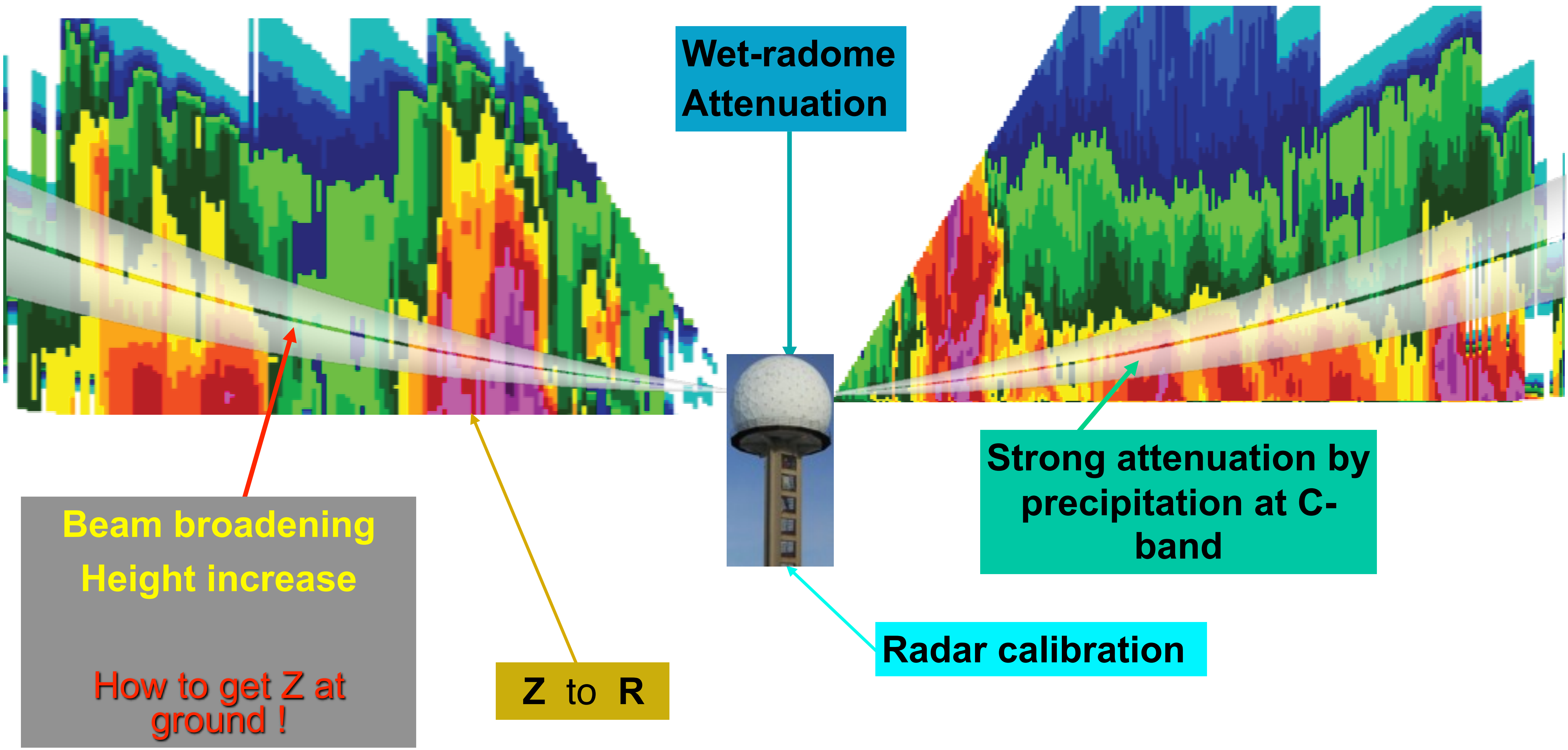
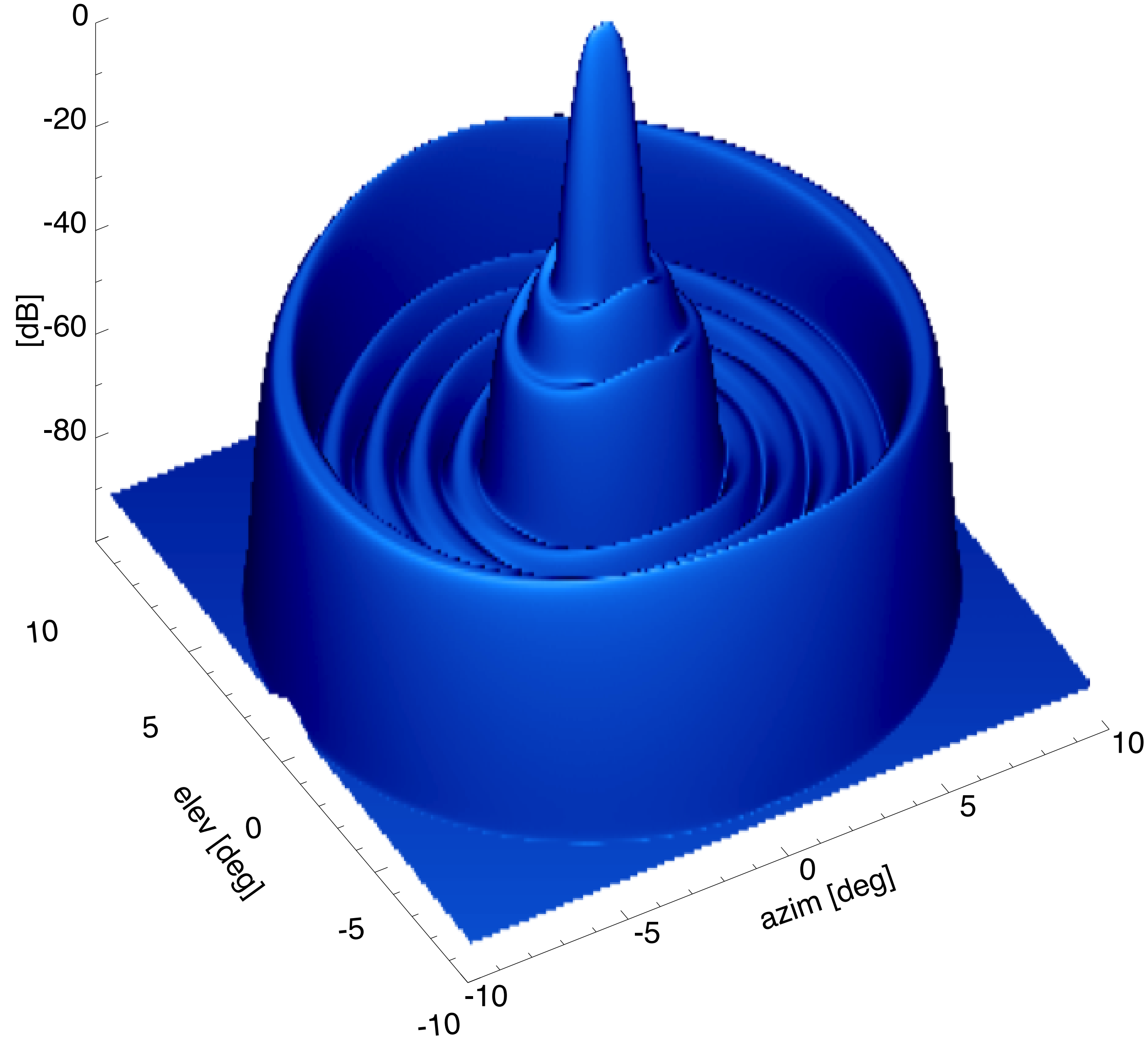


# Beam broadening

## The transmitted power within the radar beam depends on the quality of the antenna and the mounting of the horn

A typical distribution of transmitted power **(radar beam)** in space.



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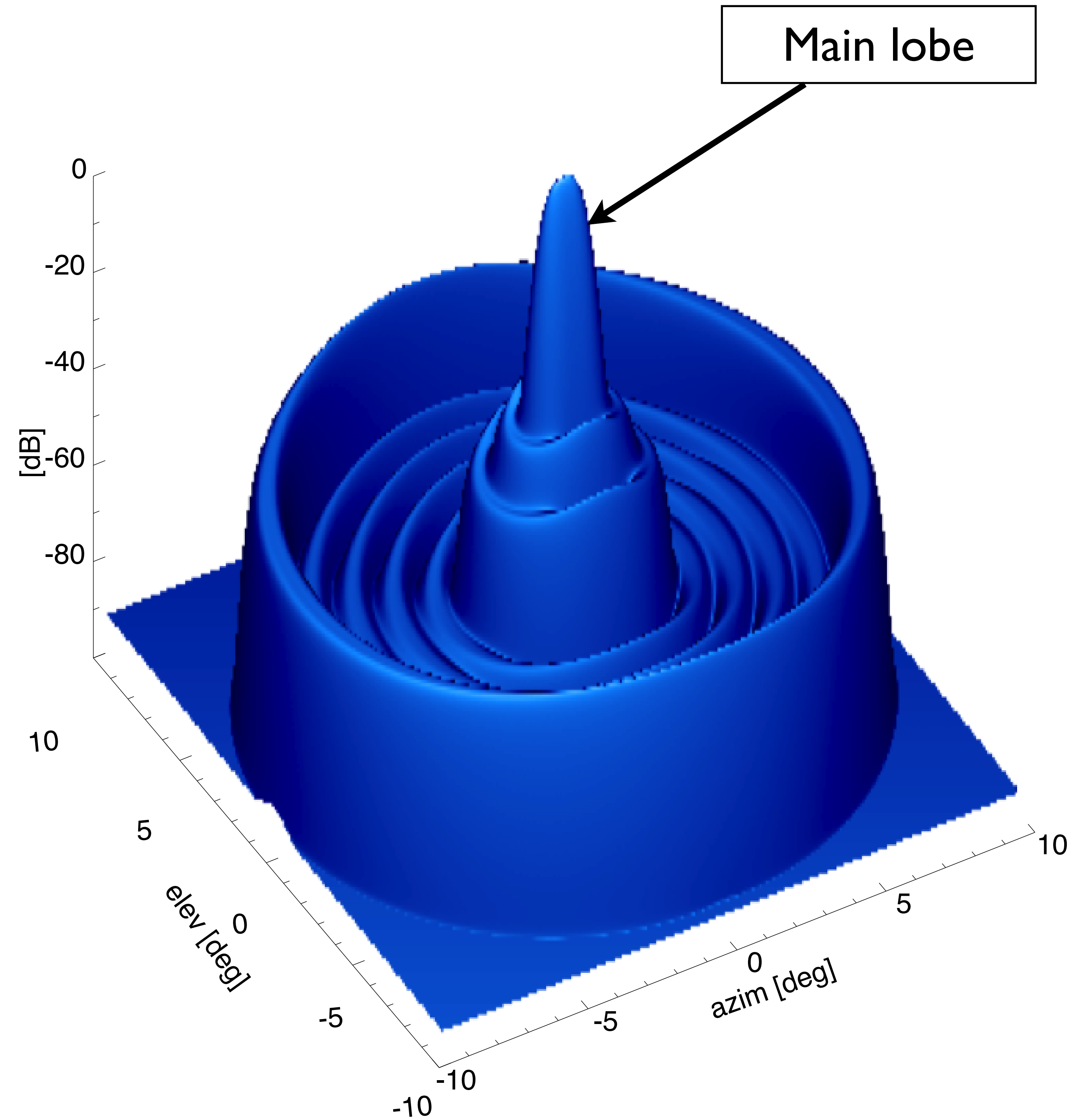

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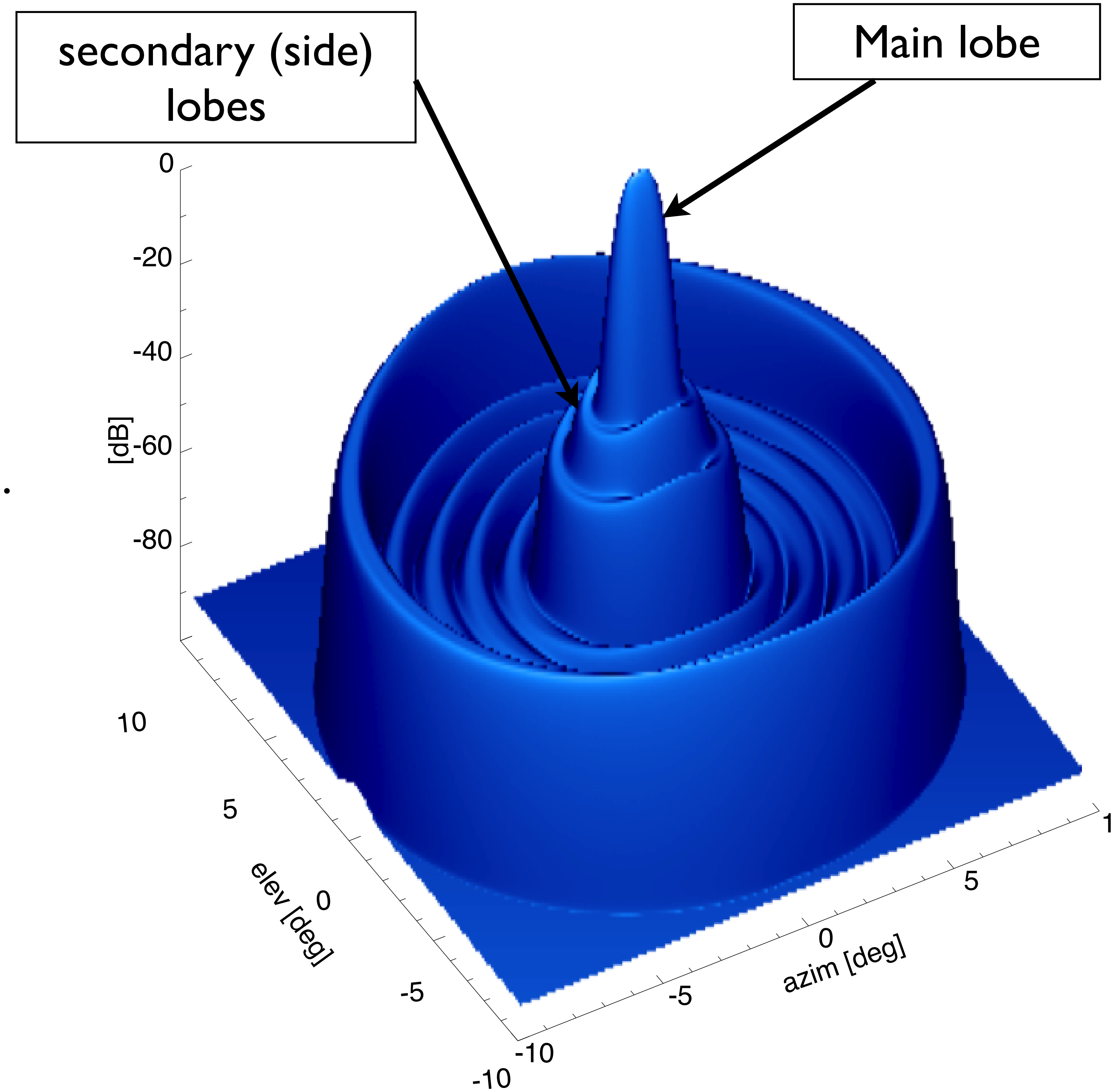
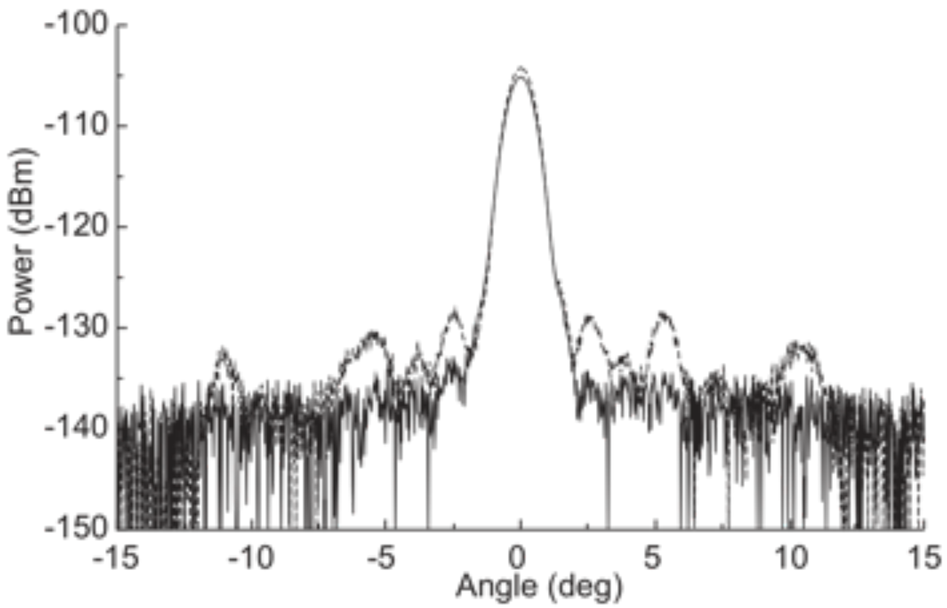
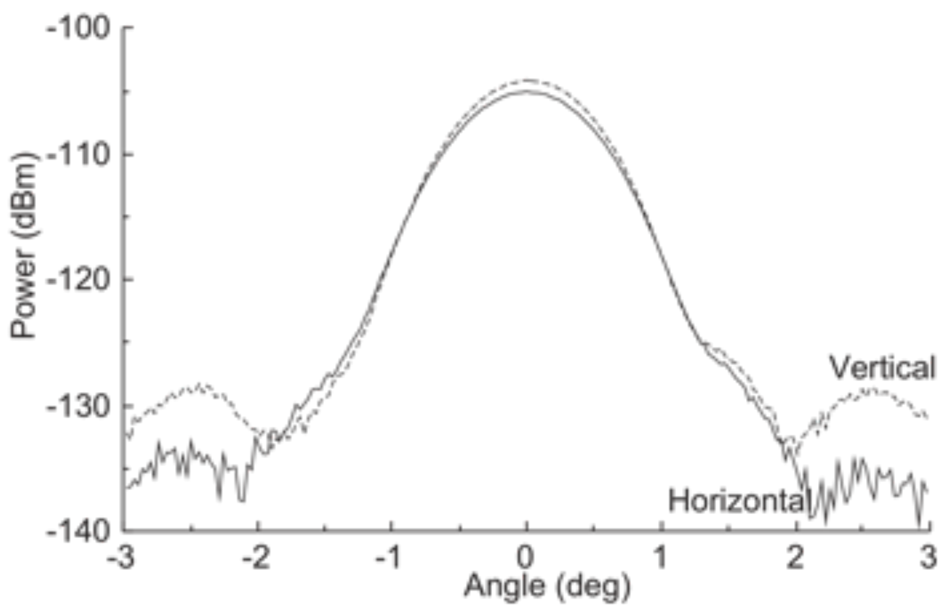
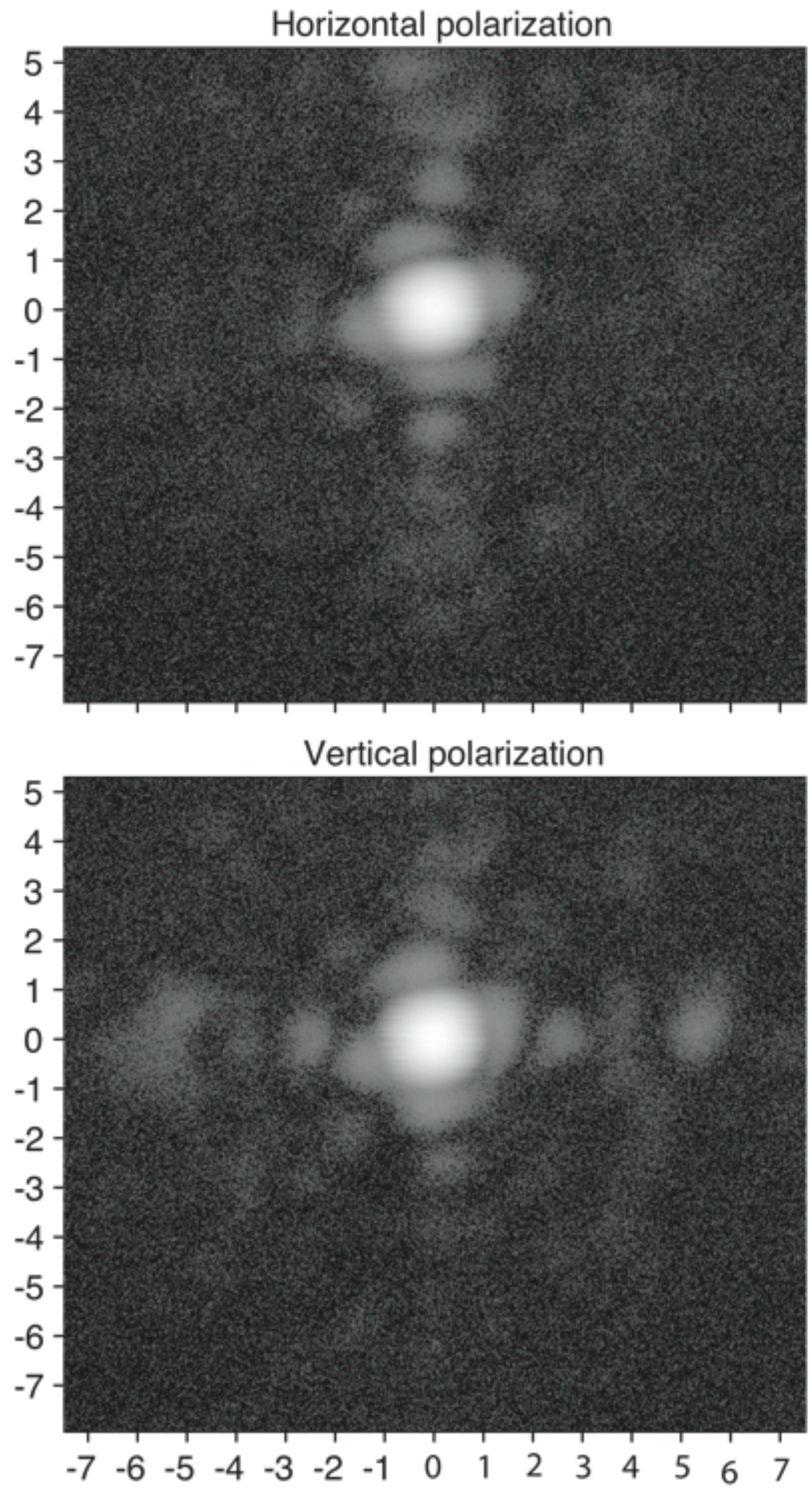


# Real beam pattern
## from scanning the sun




Apparent beam patterns along the horizontal plane



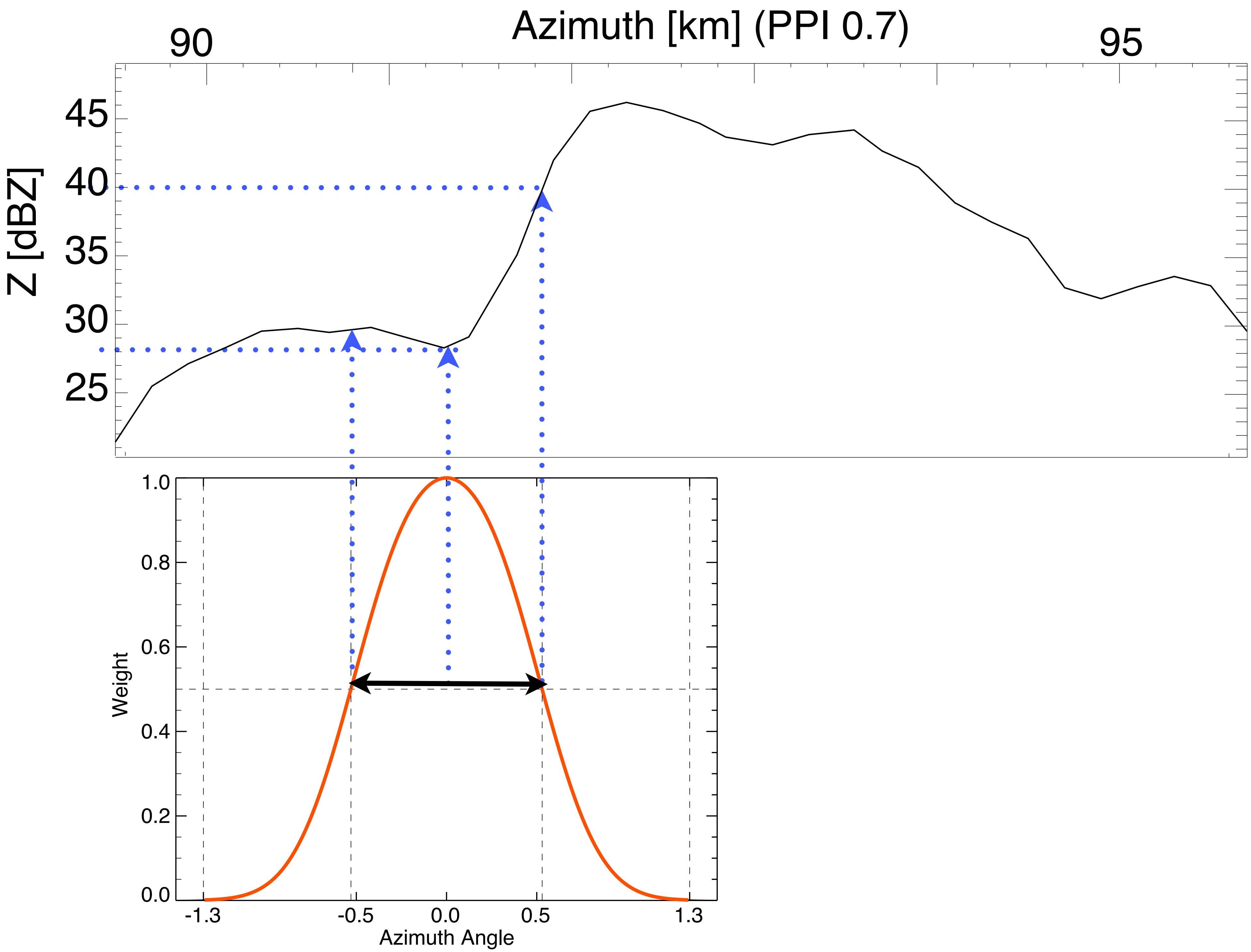
# Beam broadening is a source of complex representativity errors. It limits the resolution of quantitative measurement to several beamwidths

Measured reflectivity is the convolution between the distribution of energy within the radar beam and the spatially variable reflectivity. In range, azimuth and elevation coordinates:

$$Z_m = W(r\vartheta, r\alpha) * Z(r, \vartheta, \alpha)$$

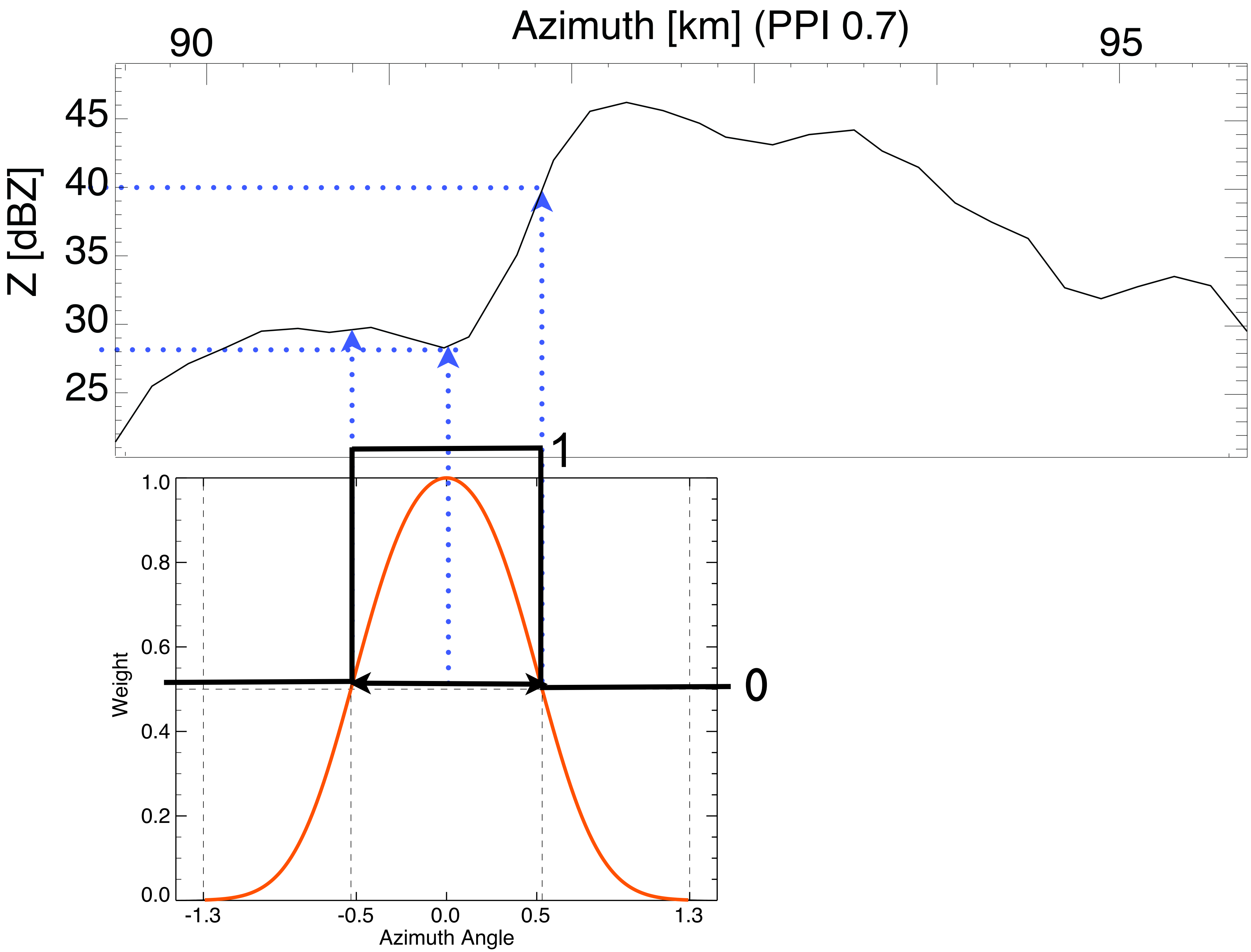
With reflectivity gradients of 20-30 dB/km, quite common, the effect of this convolution is to render the interpretation of the measurements ambiguous: is it the average reflectivity within the beam? (no), the value at the centre? (no). These errors can be considered as position errors or as biases.

# Beam broadening; representativity error




The contribution from the 40 dBZ is weighted by 0.5.
Hence, it is 5 times stronger than contribution from 28 dBZ .

# Beam broadening; representativity error

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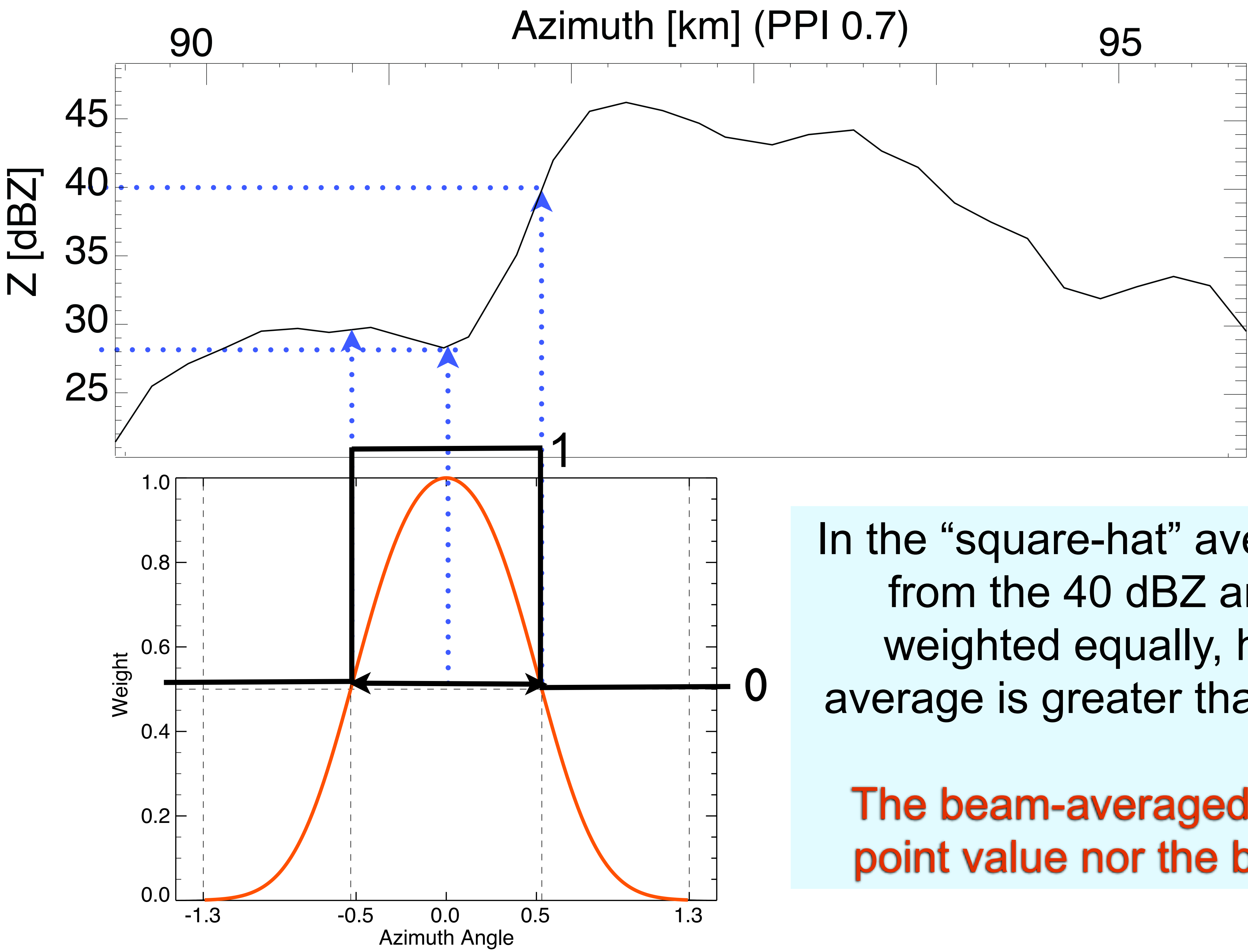


In the "square-hat" average the contribution from the 40 dBZ and the 28 dBZ are weighted equally, hence, the uniform average is greater than the beam average.

**The beam-averaged value is neither the point value nor the beam-width average**

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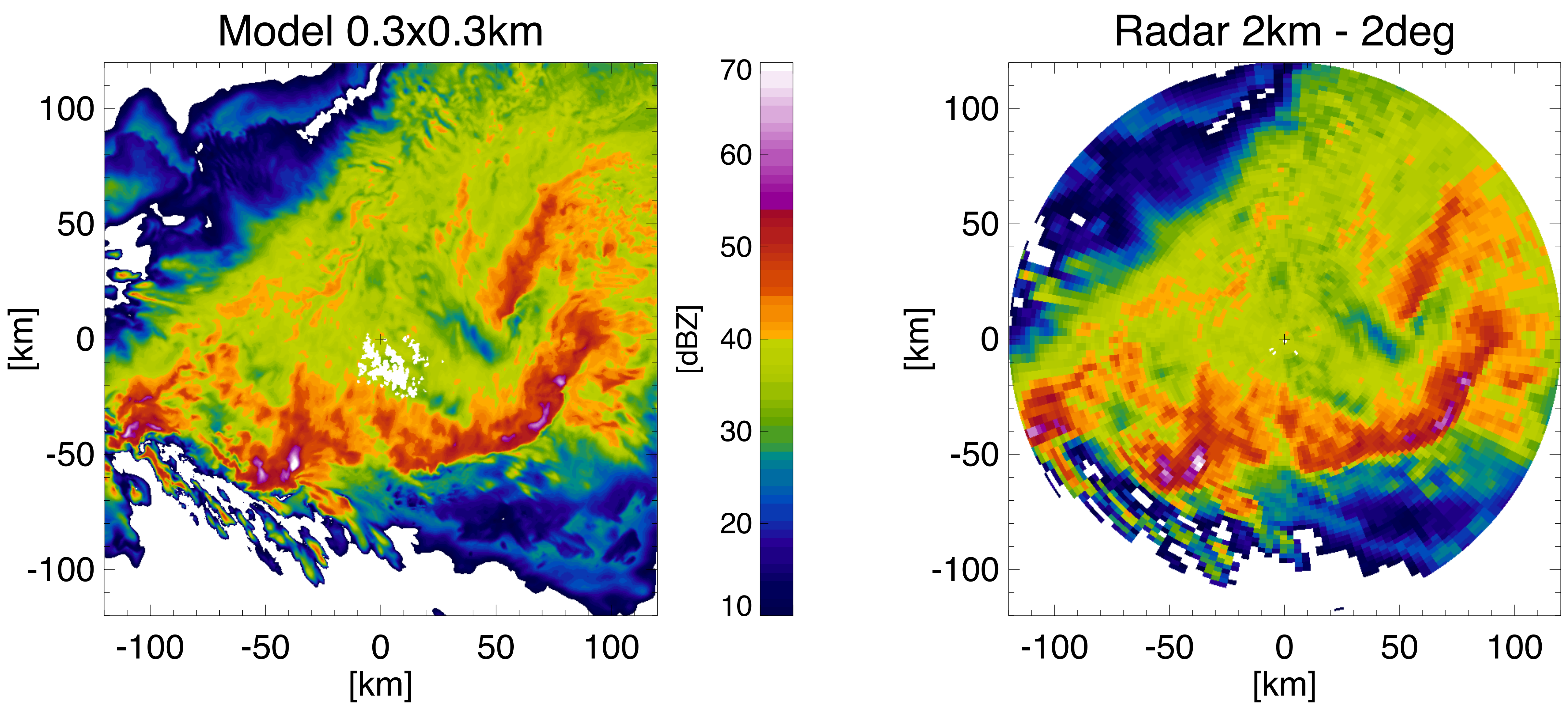
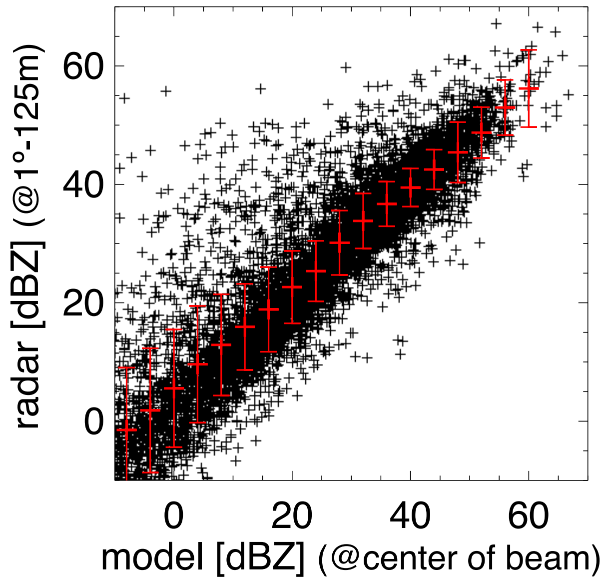
# A radar simulator




Derived by convolution of a gaussian beam with the model output

# Representativity error




Representativity errors of radar measurements are due to the shape of the radar beam coupled with the fine structure of rain fields, which have variability at all scales.

These errors are important.
They are diminished only by averaging in azimuth over a few beam-widths.

From the point of view of quantitative measurements the resolution of radar data must be taken as a few beam-widths.

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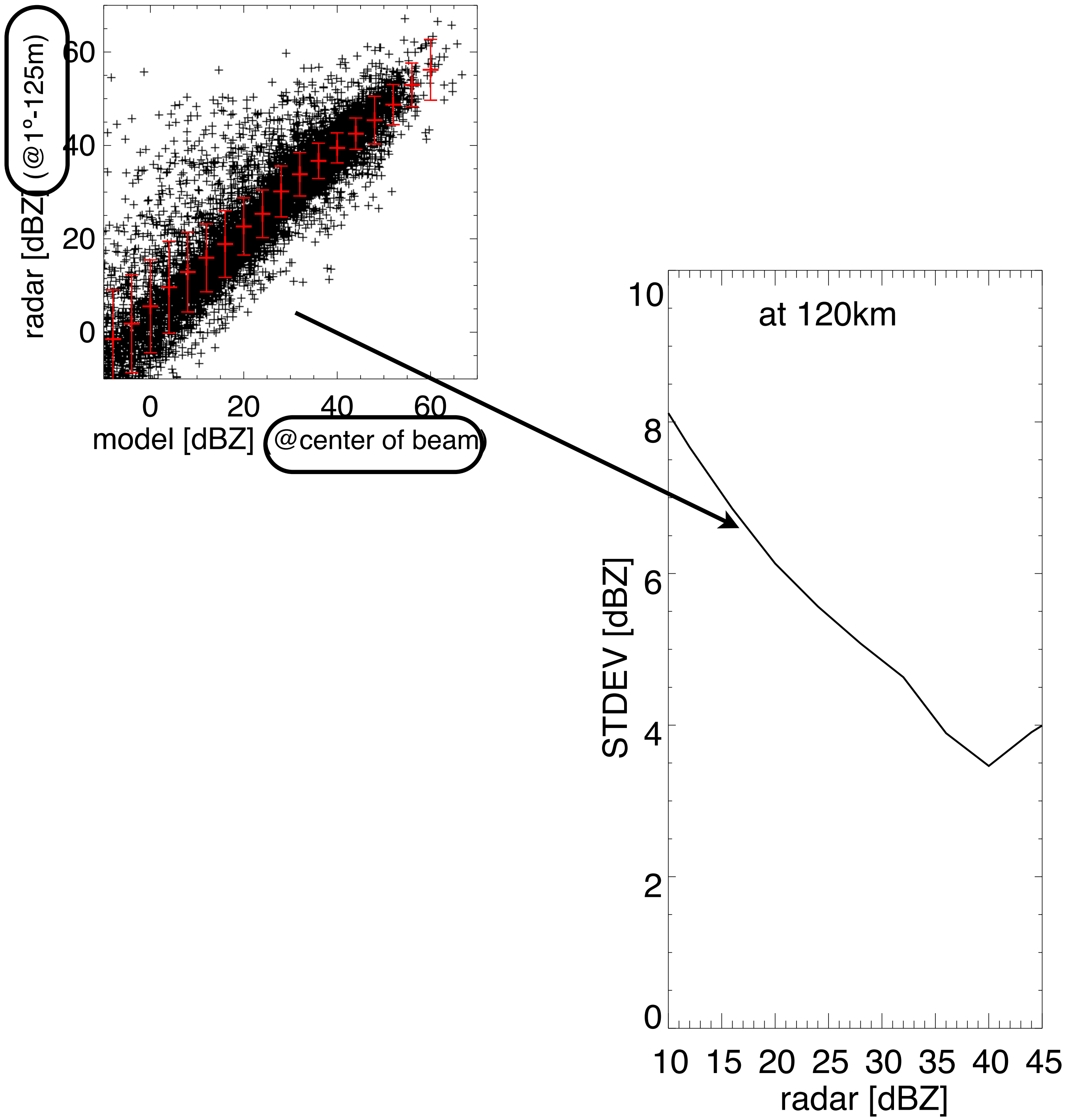


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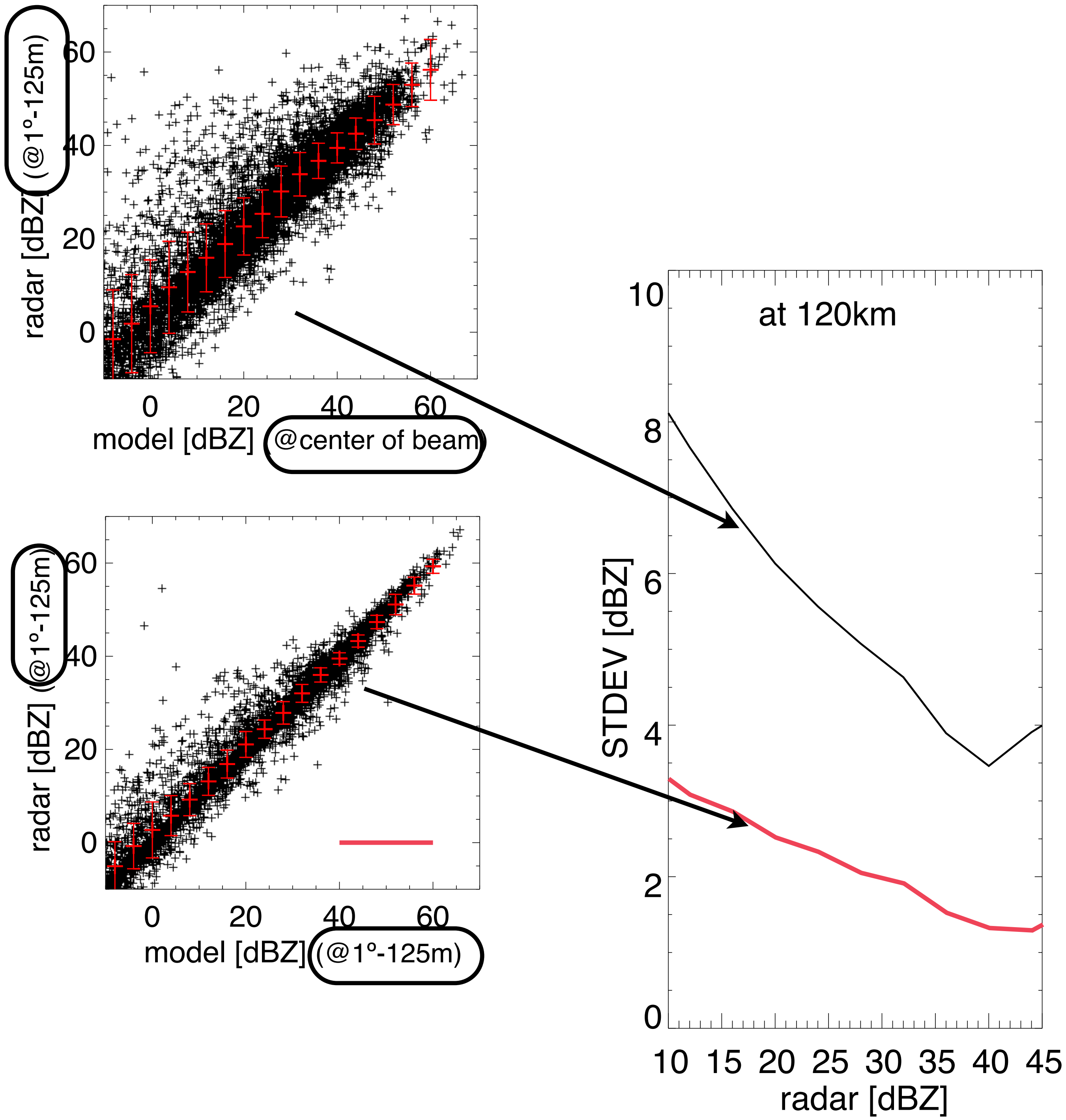


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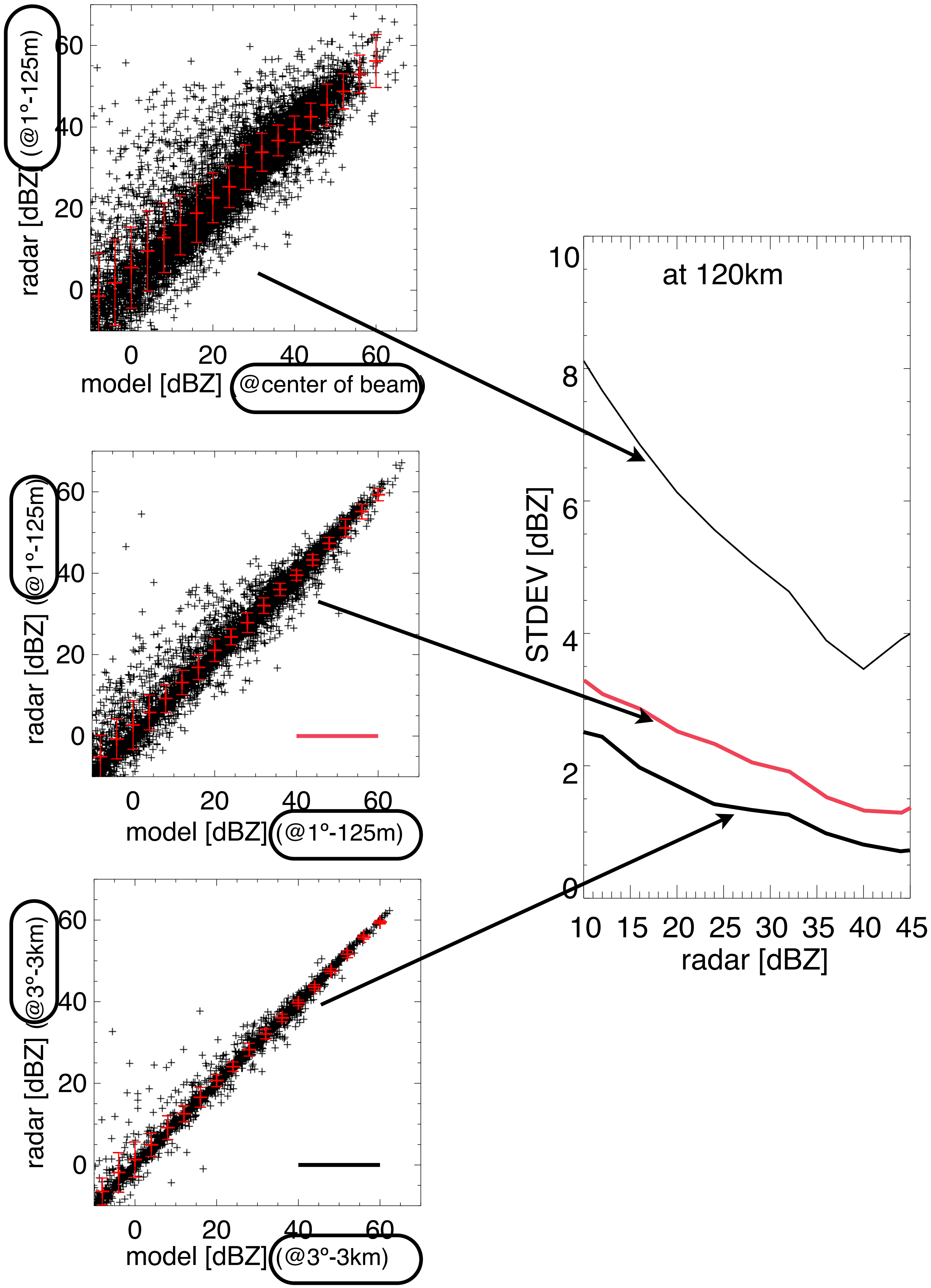


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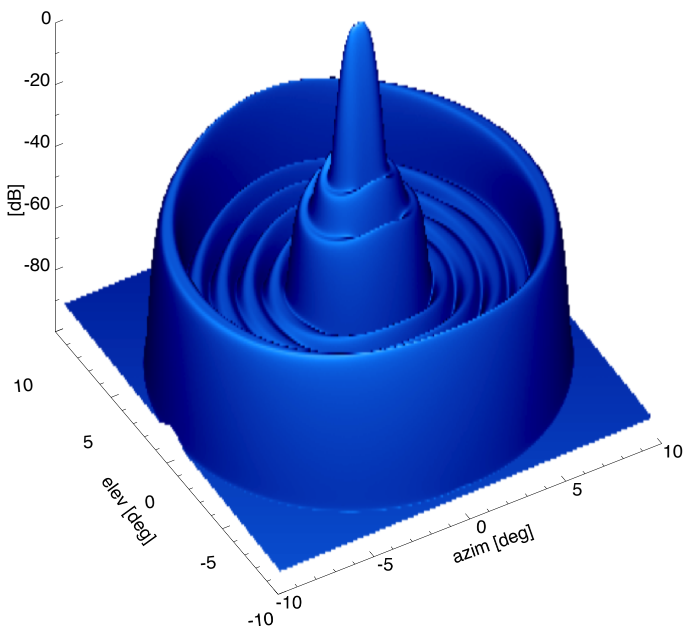
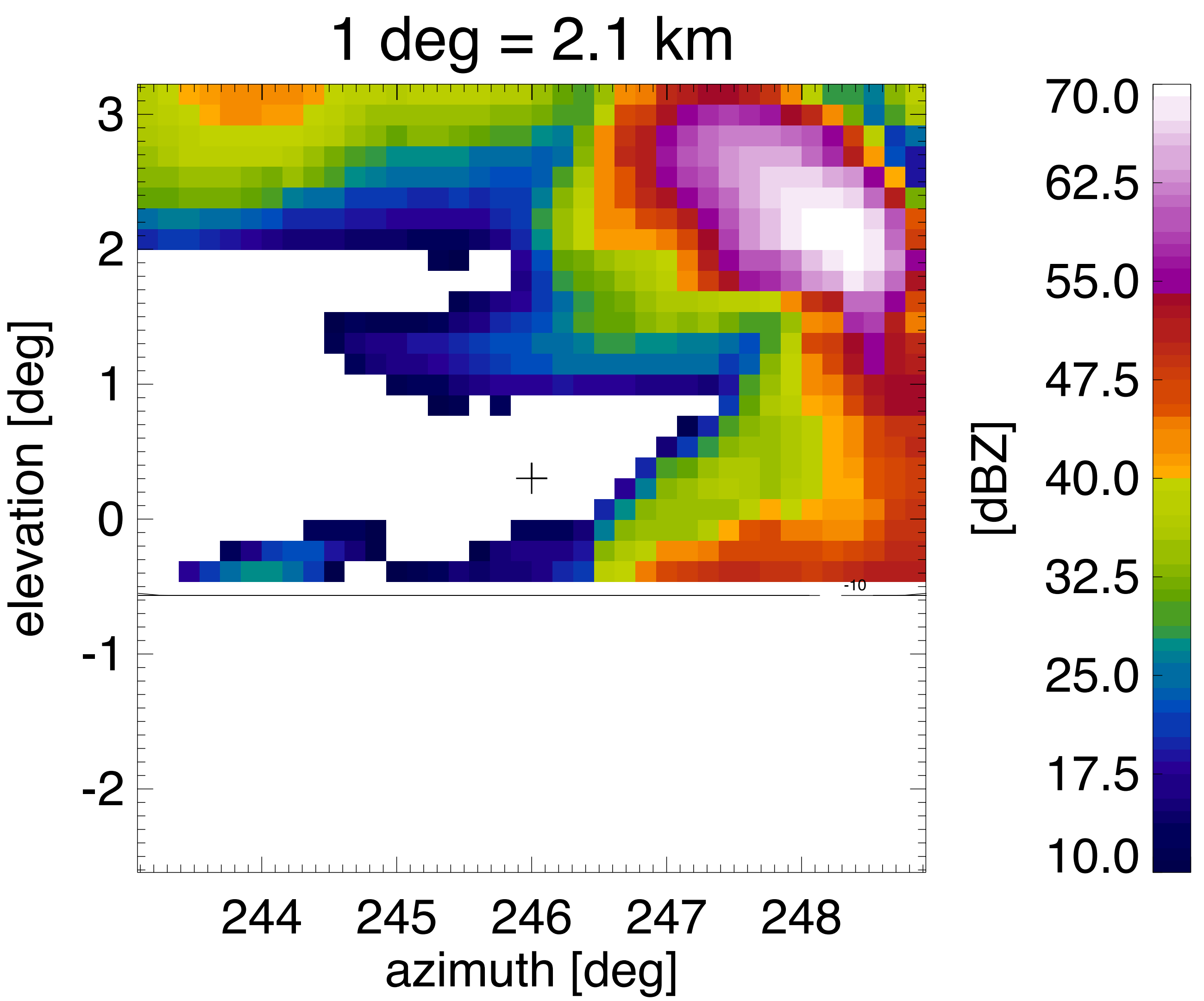
# Effects of side-lobes



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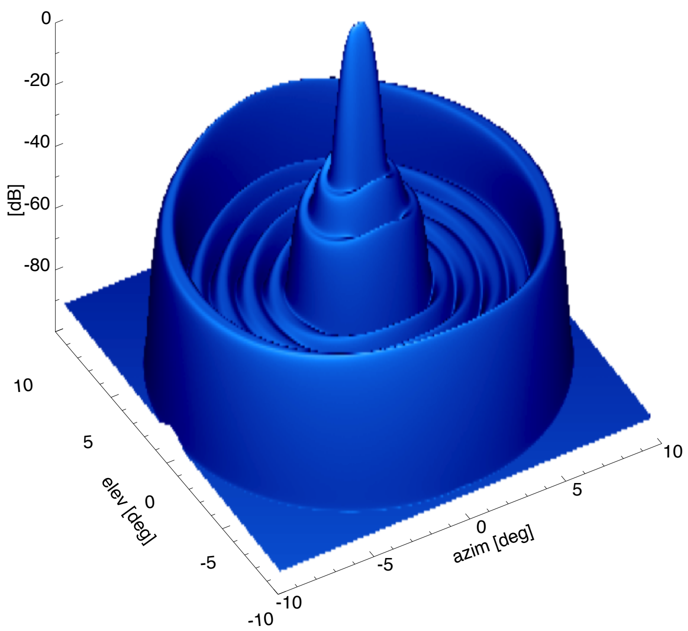


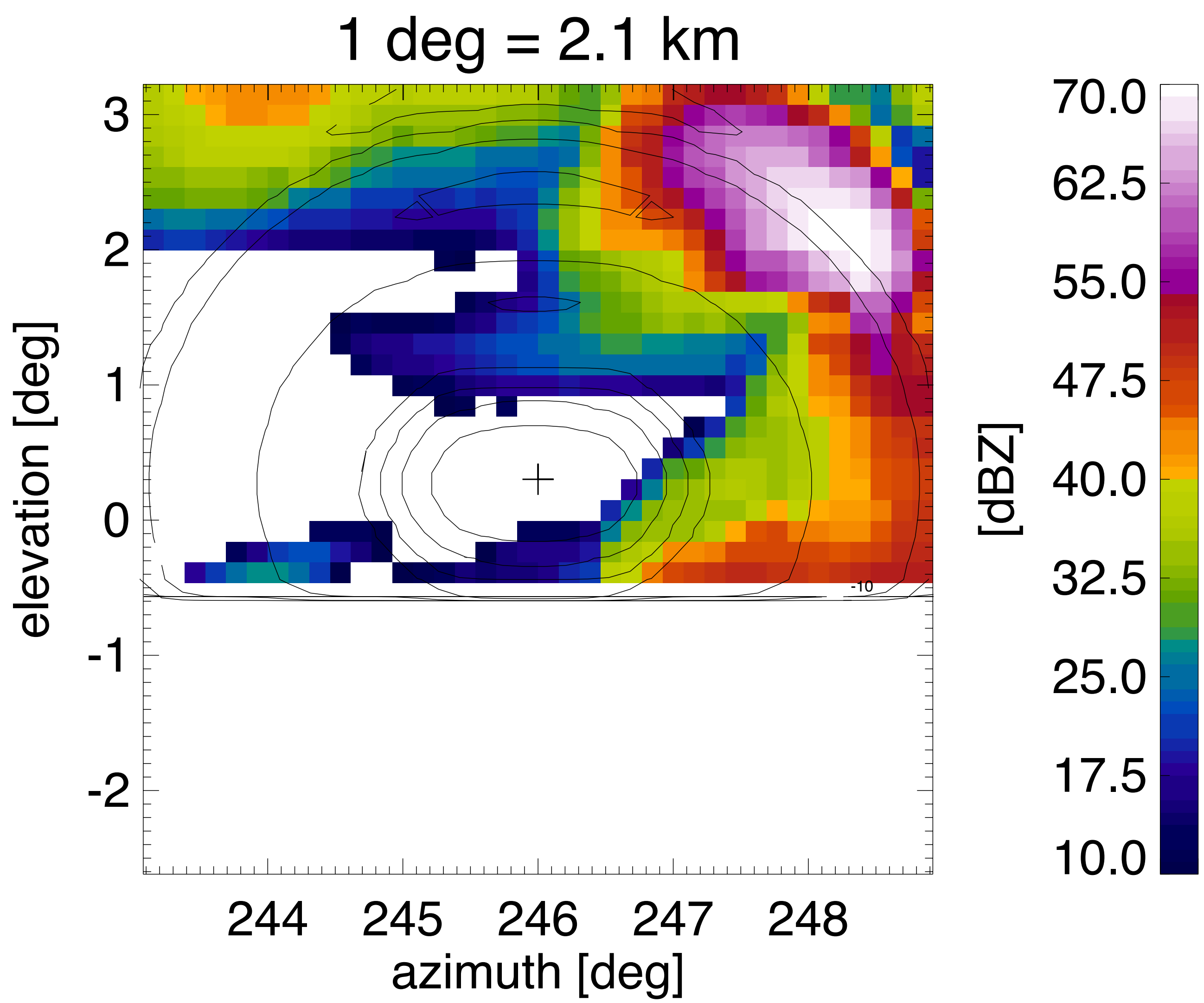

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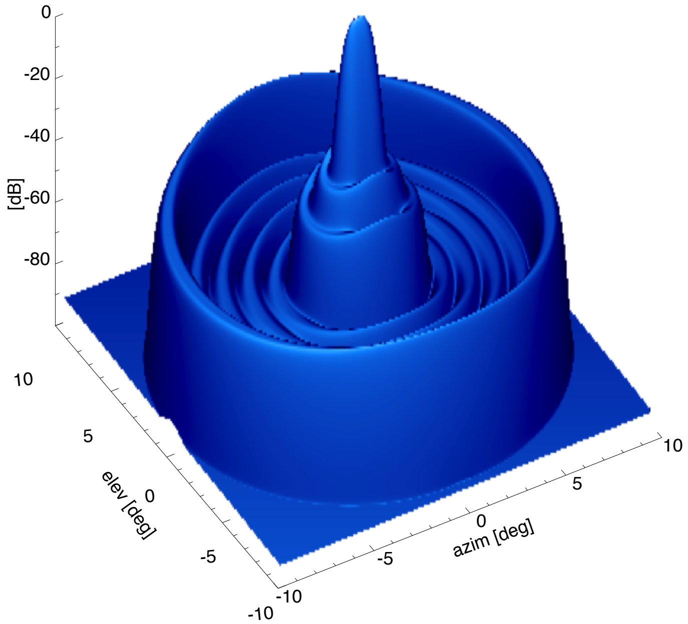


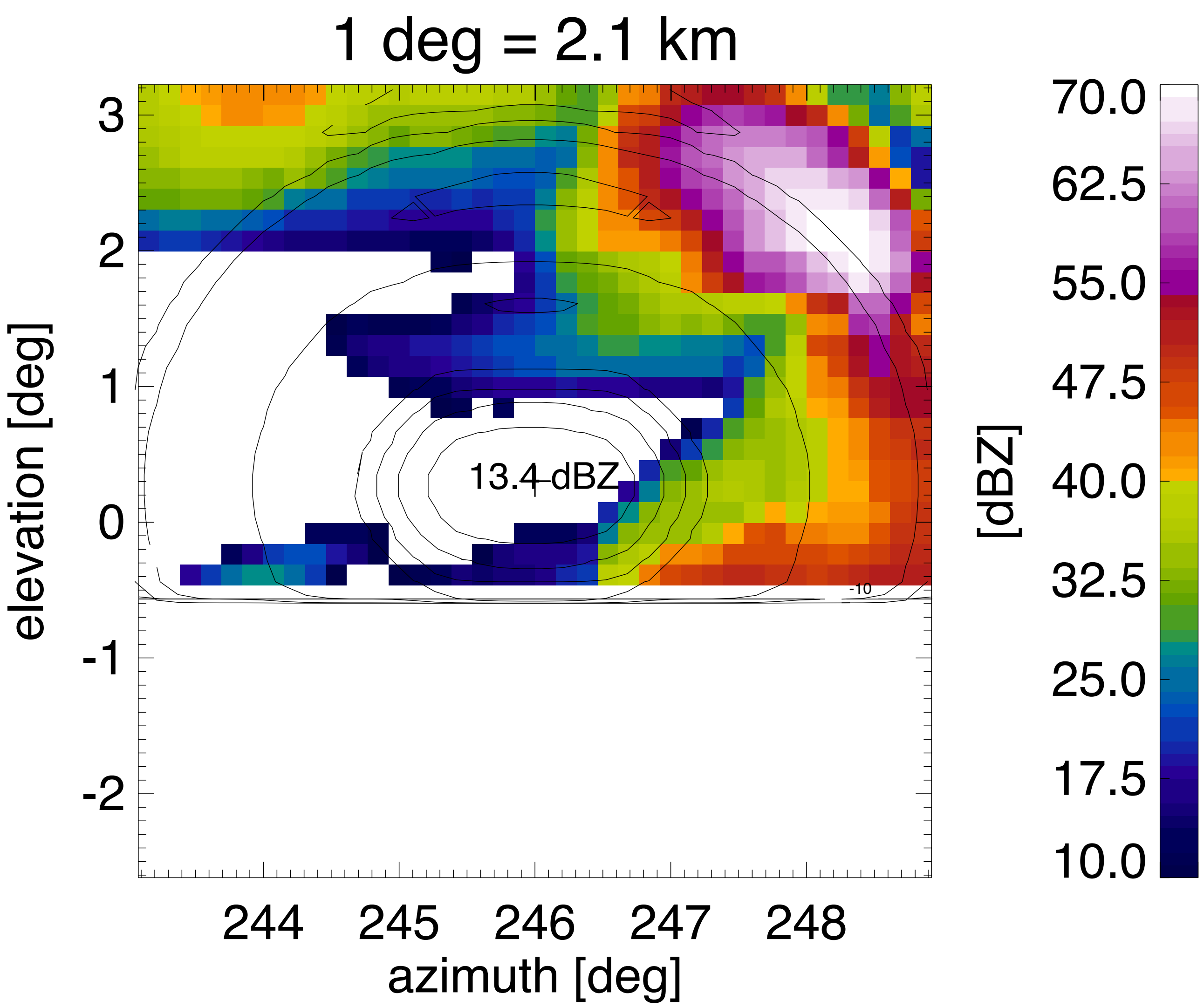

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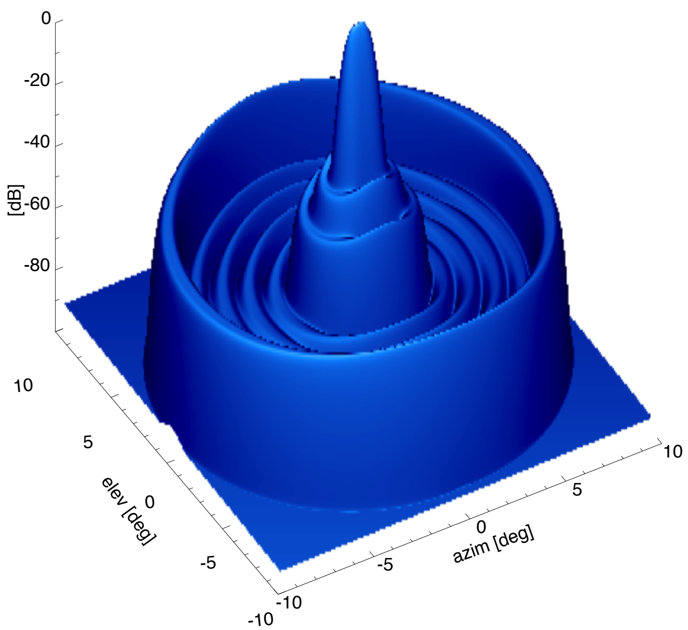
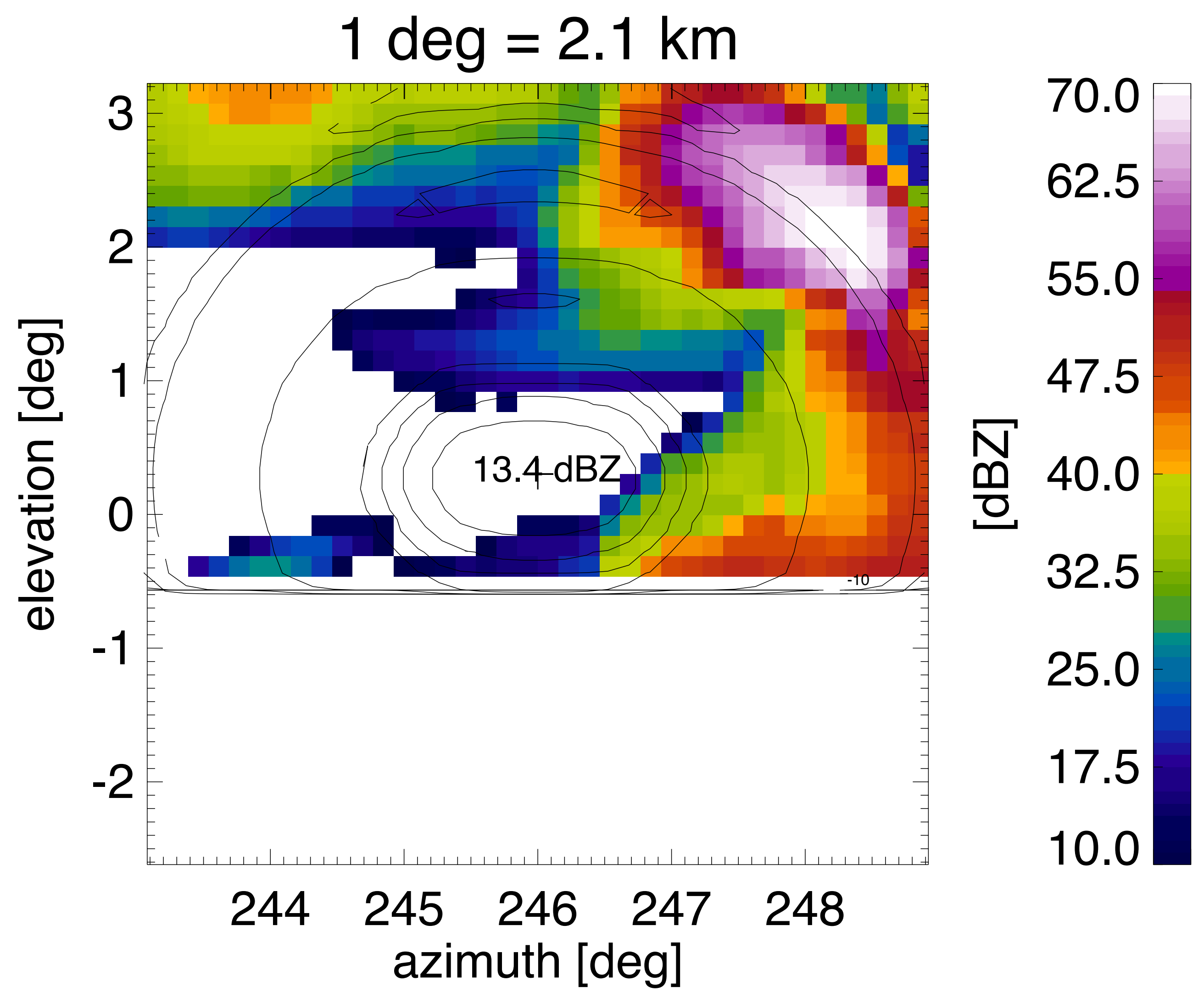
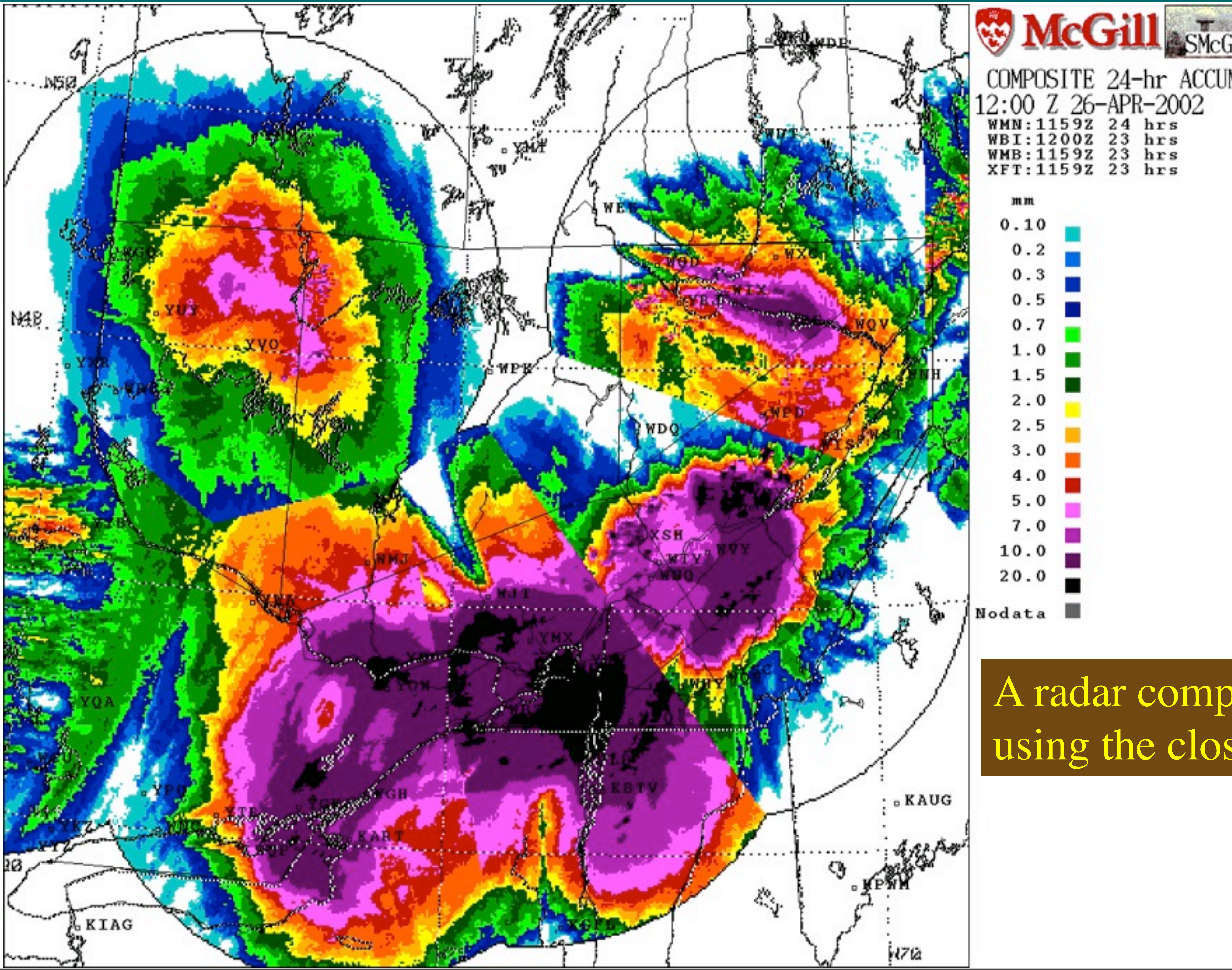


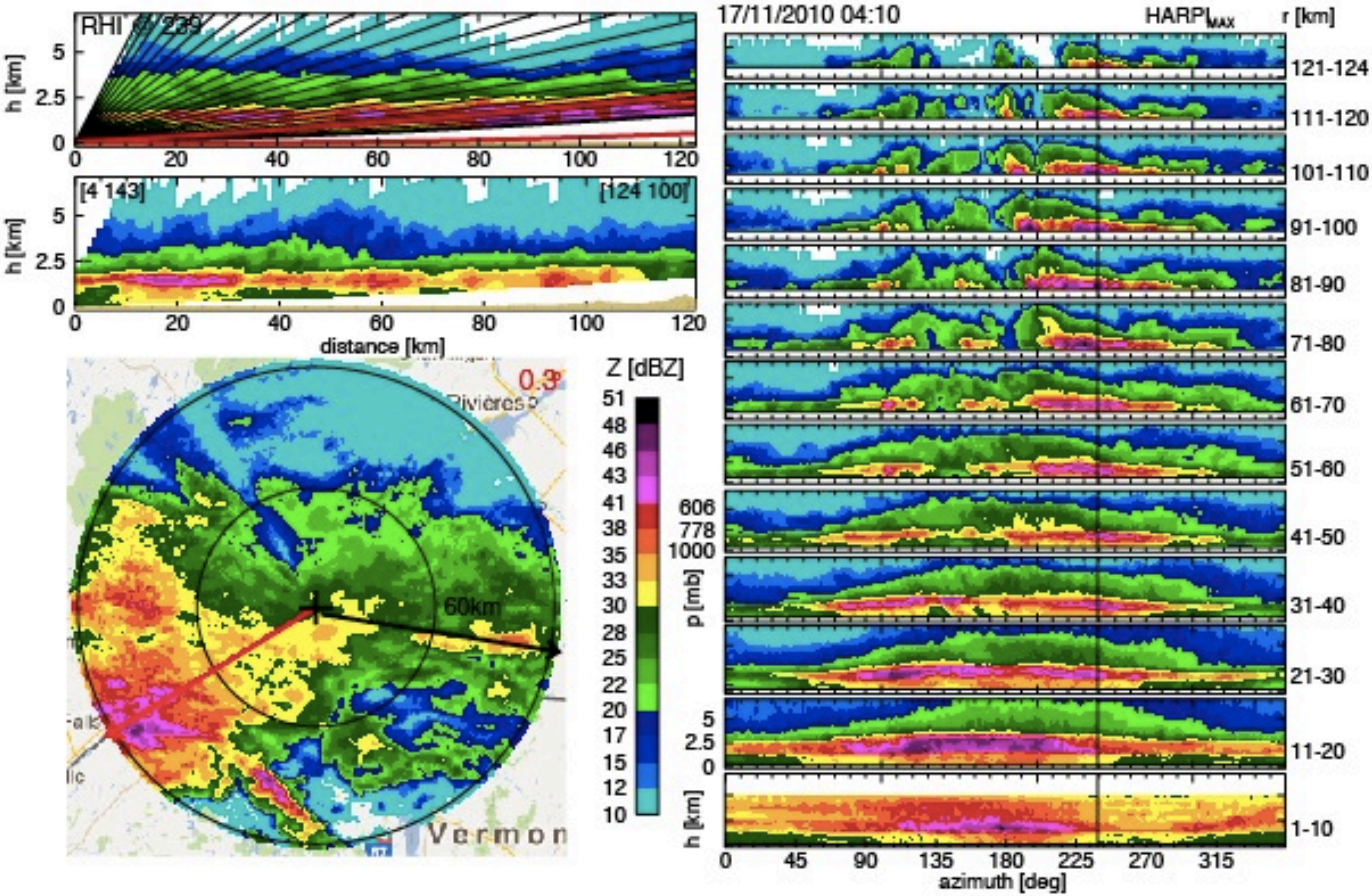

The effect of side-lobes is most evident on the top height of convection

# Calibration




A radar composite using the closest data!

# Extrapolation to ground



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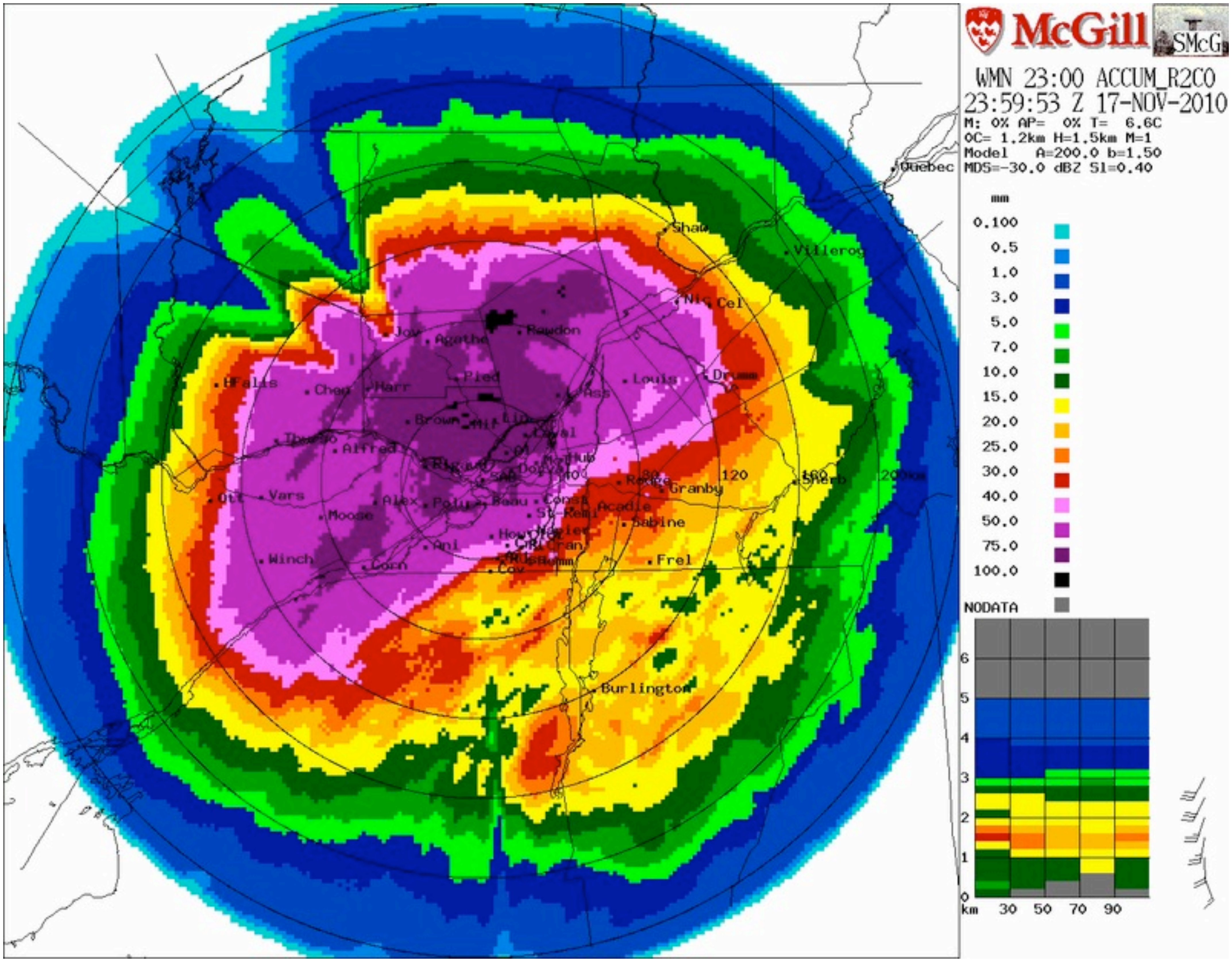

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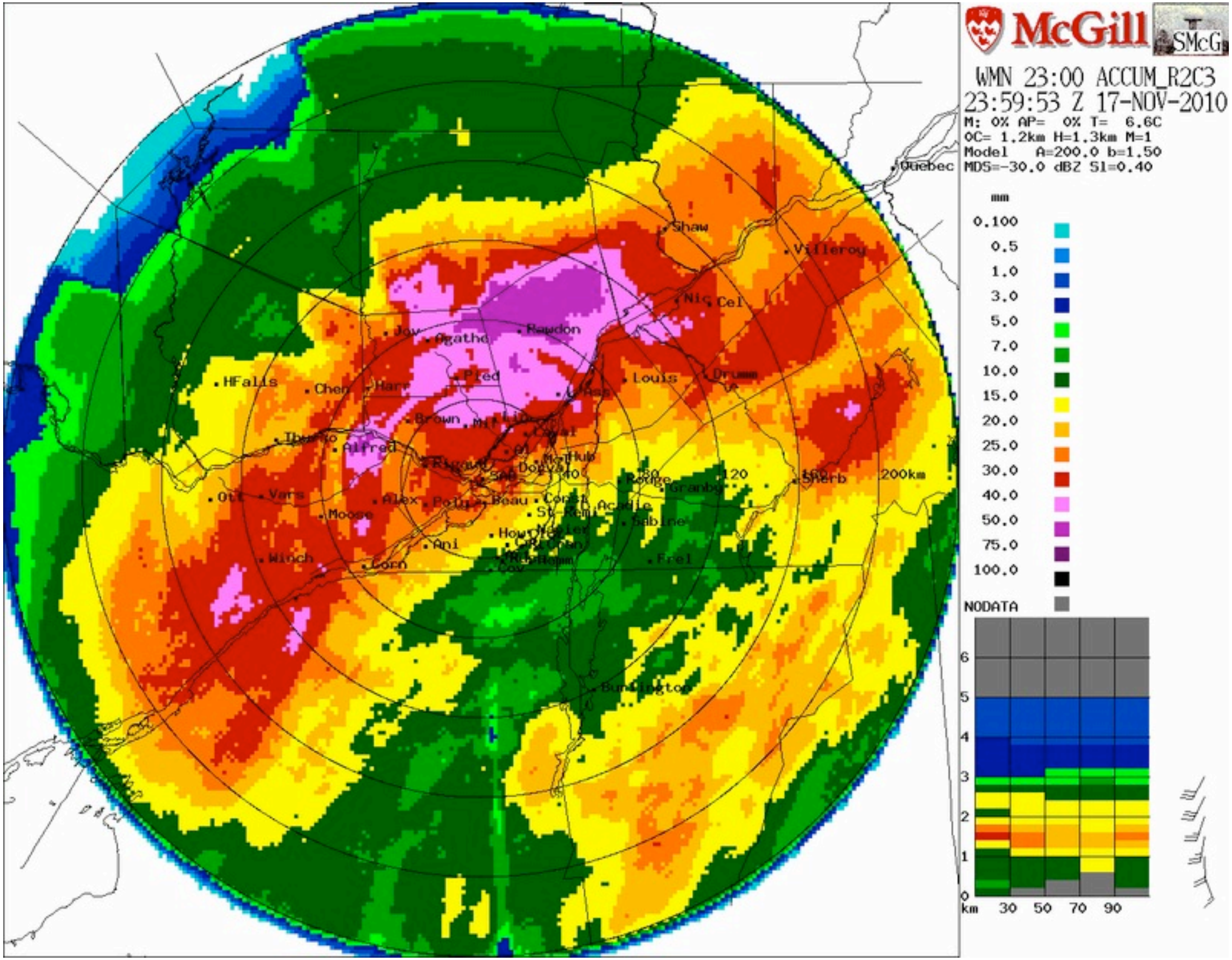

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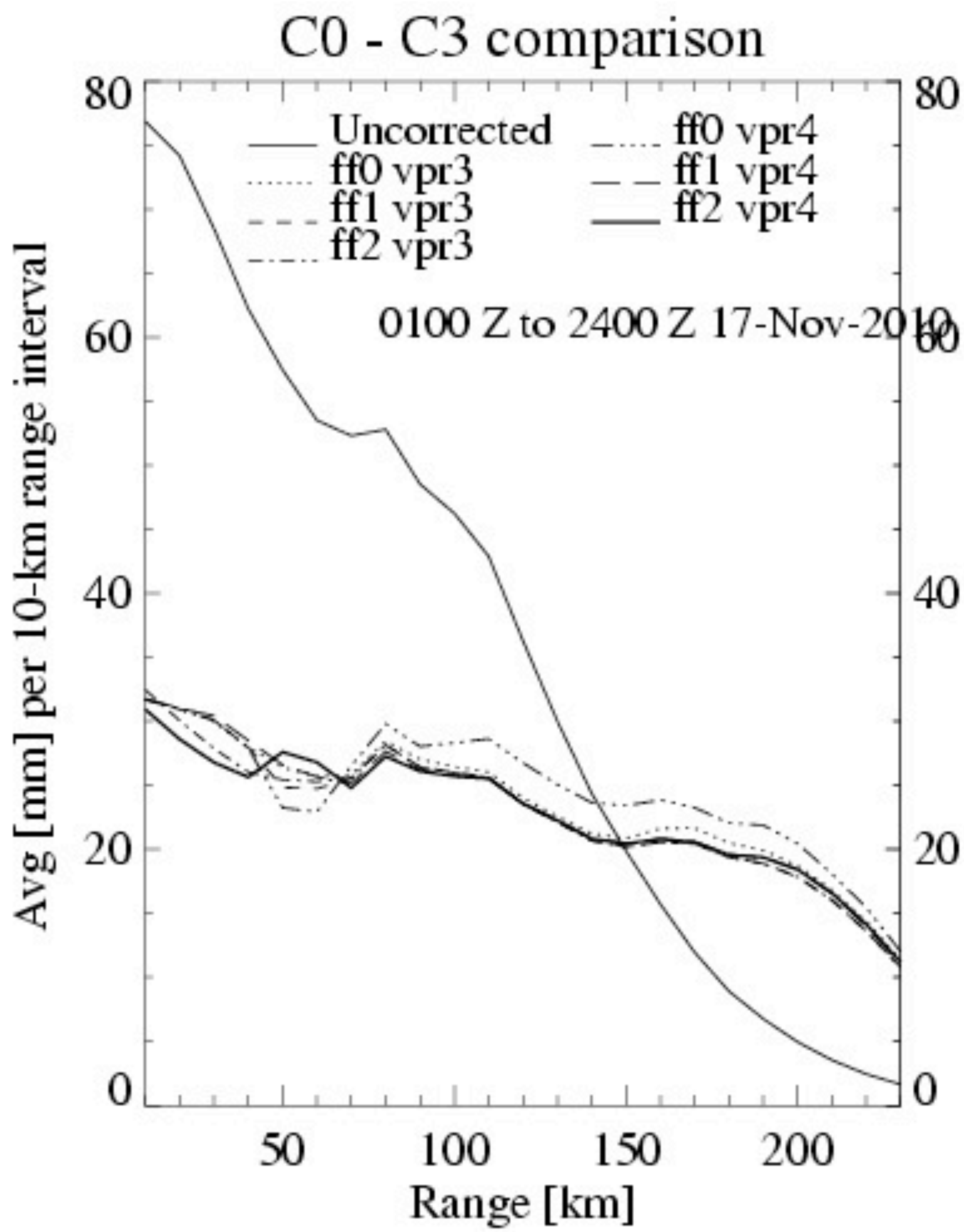
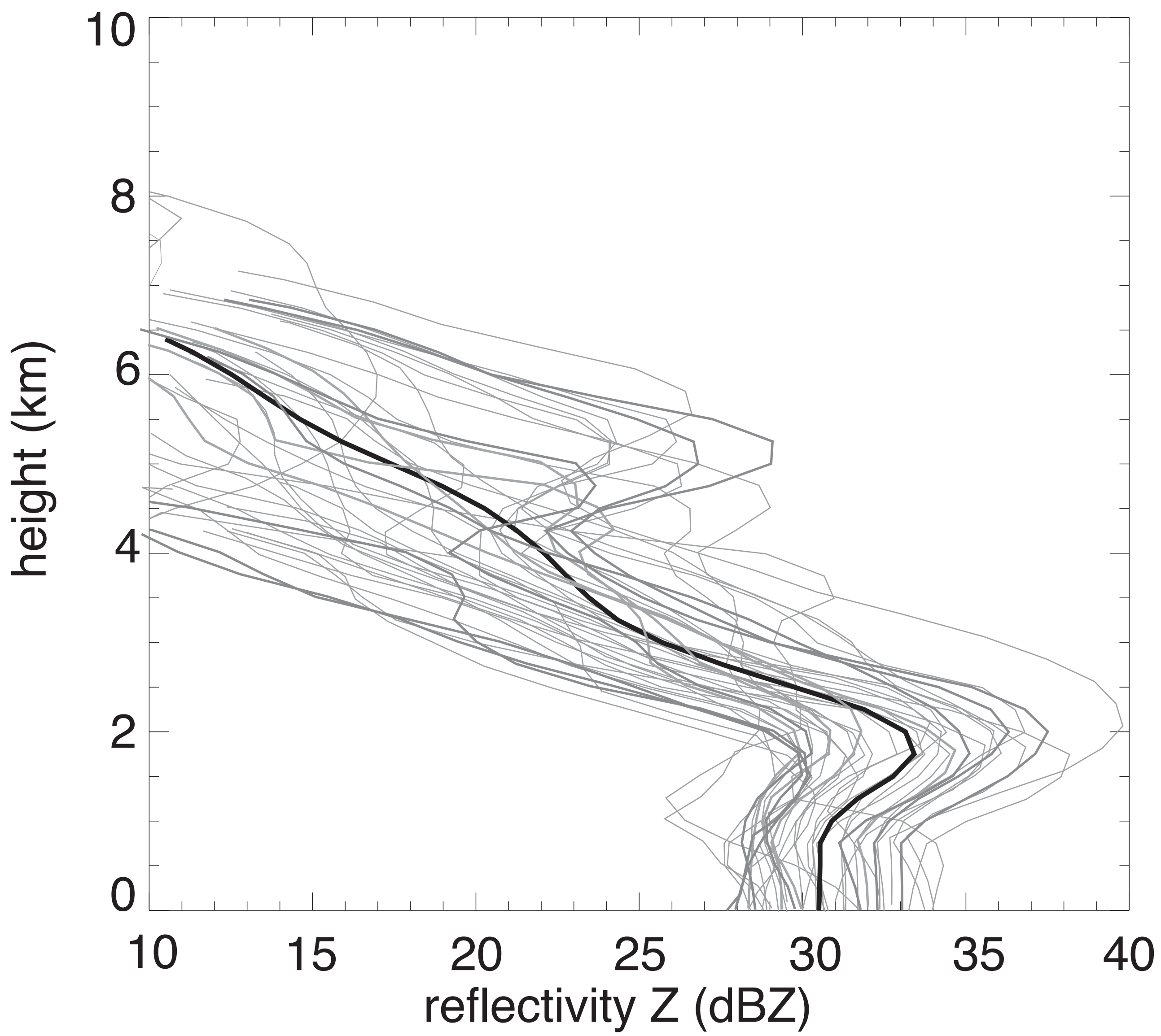
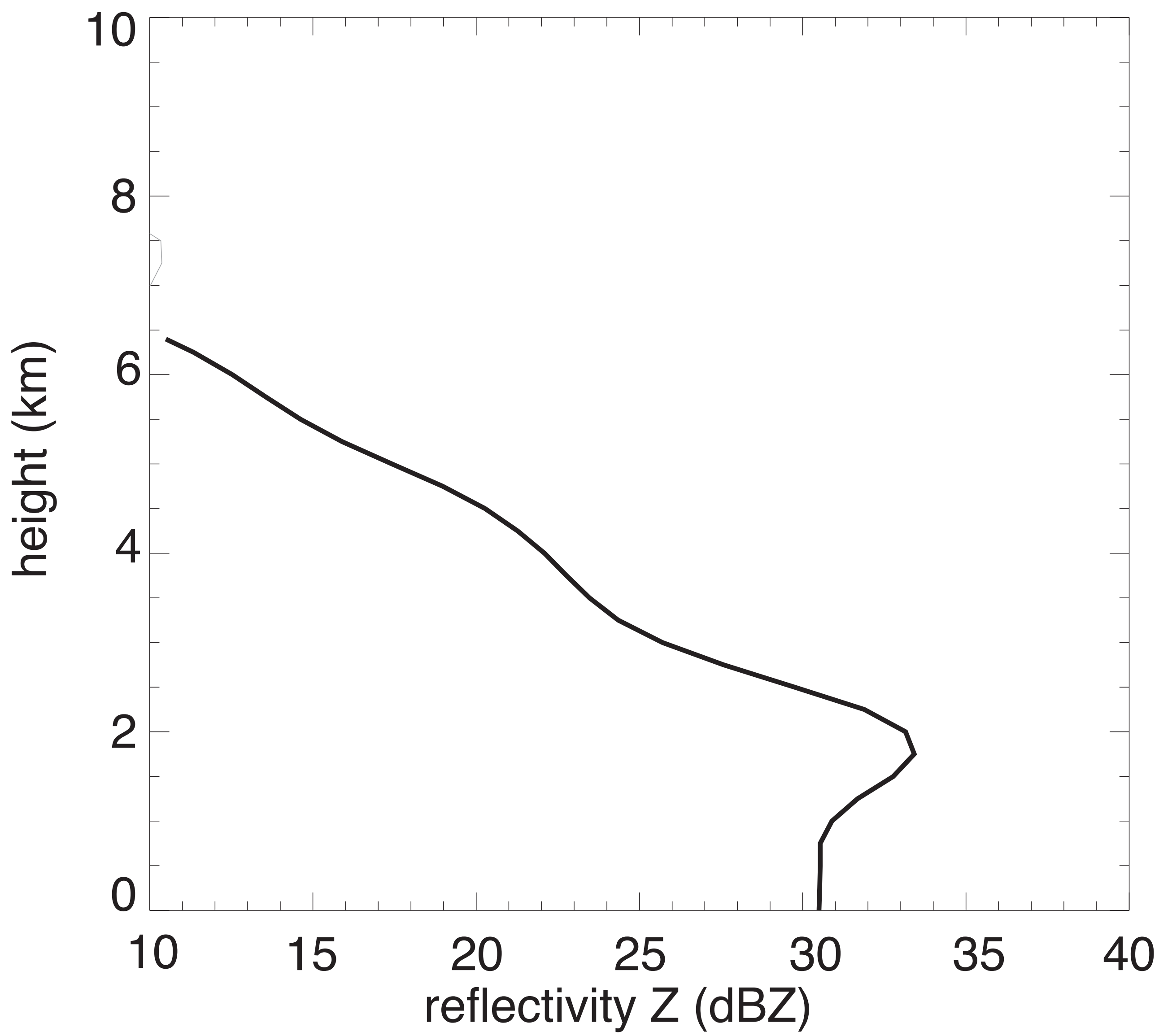


# Height increase (the effect of beam broadening will be considered later)

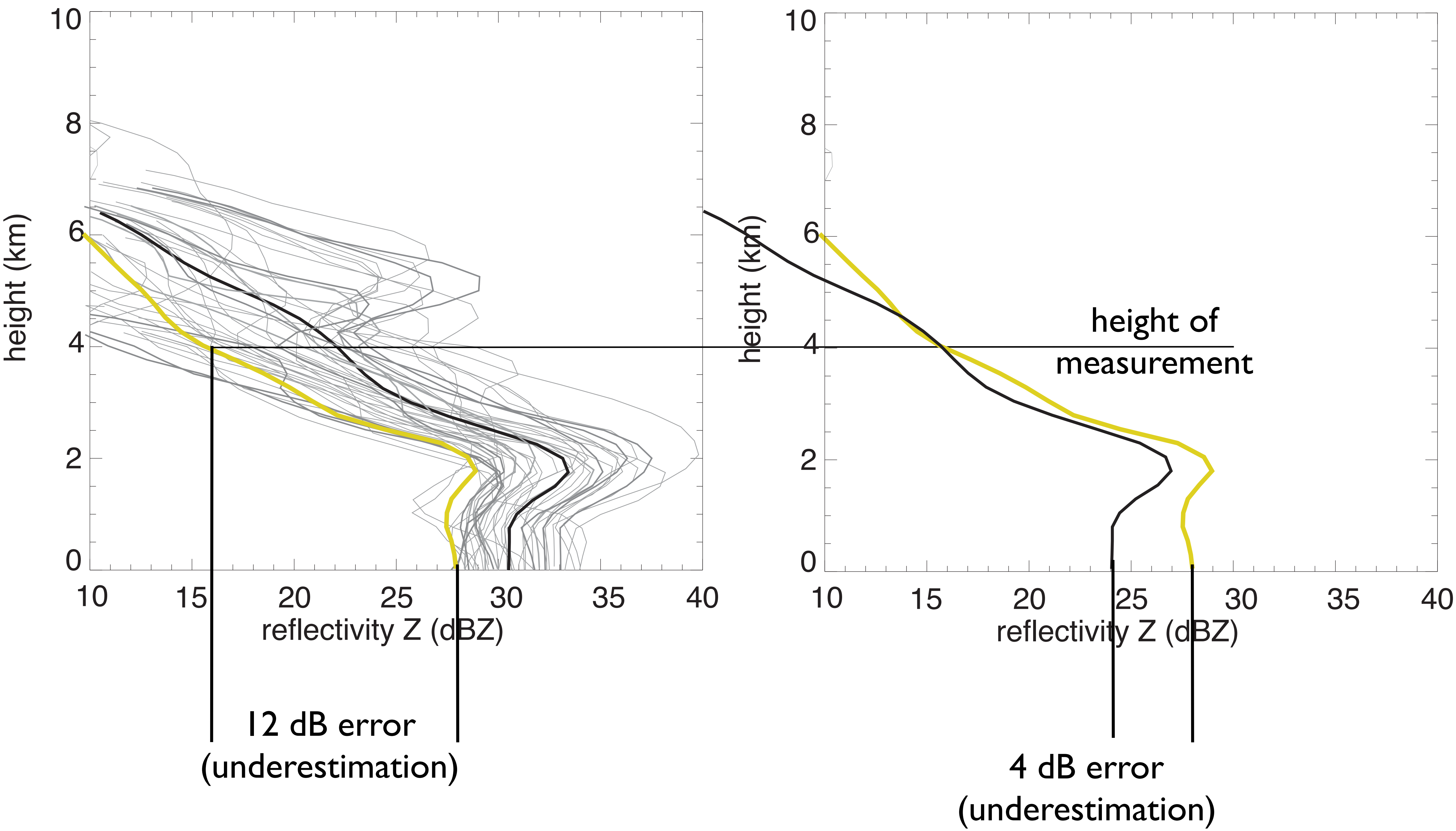



Observed vertical profiles of reflectivity (VPRs) at a short range in a particular radar image.
Note the randomness around the mean of these samples of the VPR.




The average VPR for this situation. A common procedure for extrapolation to ground is to match this profile to the measurement at the lowest measurement height.
This assumes that at far range the average VPR is the same as at short range

# Height increase



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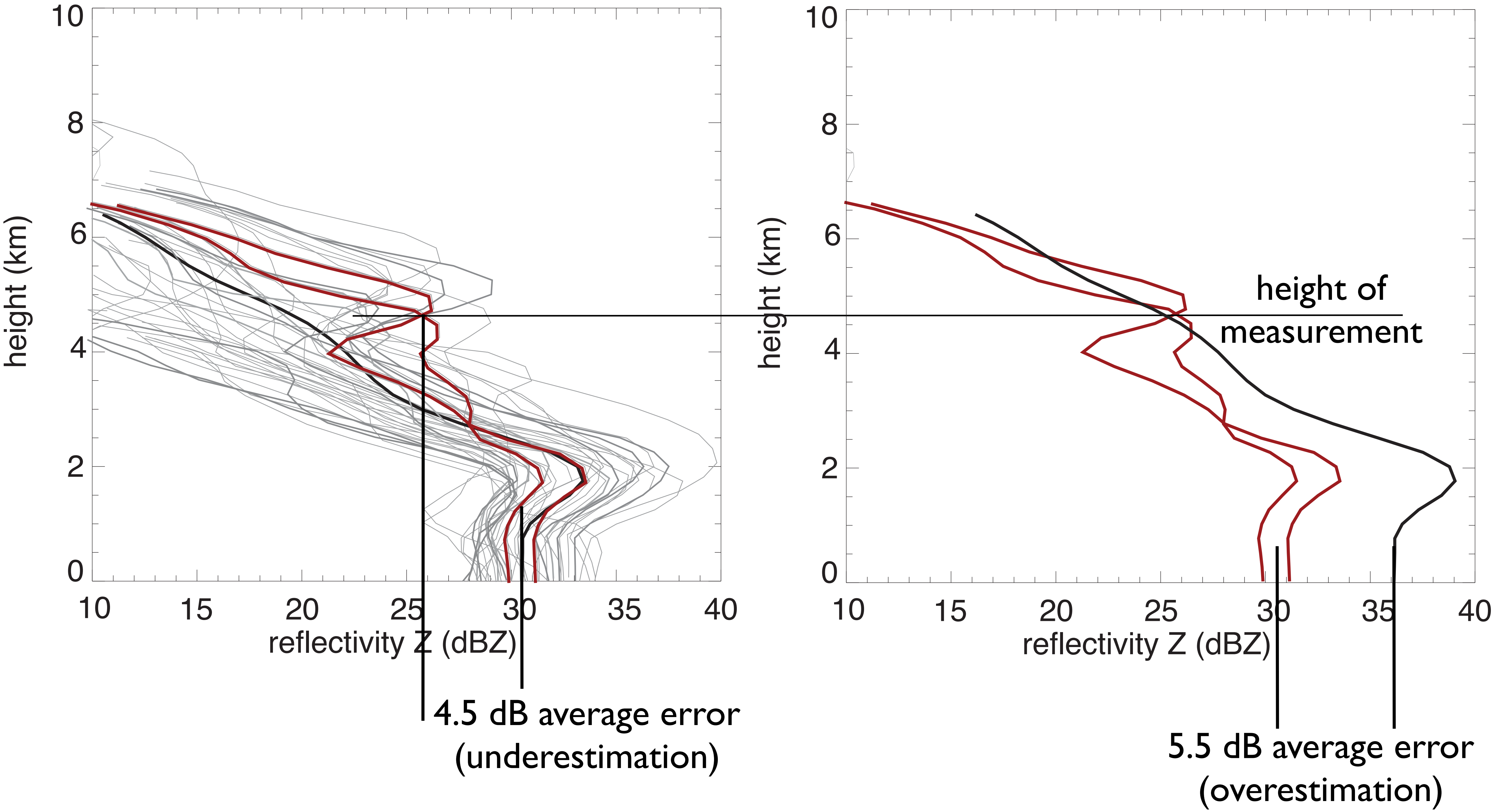

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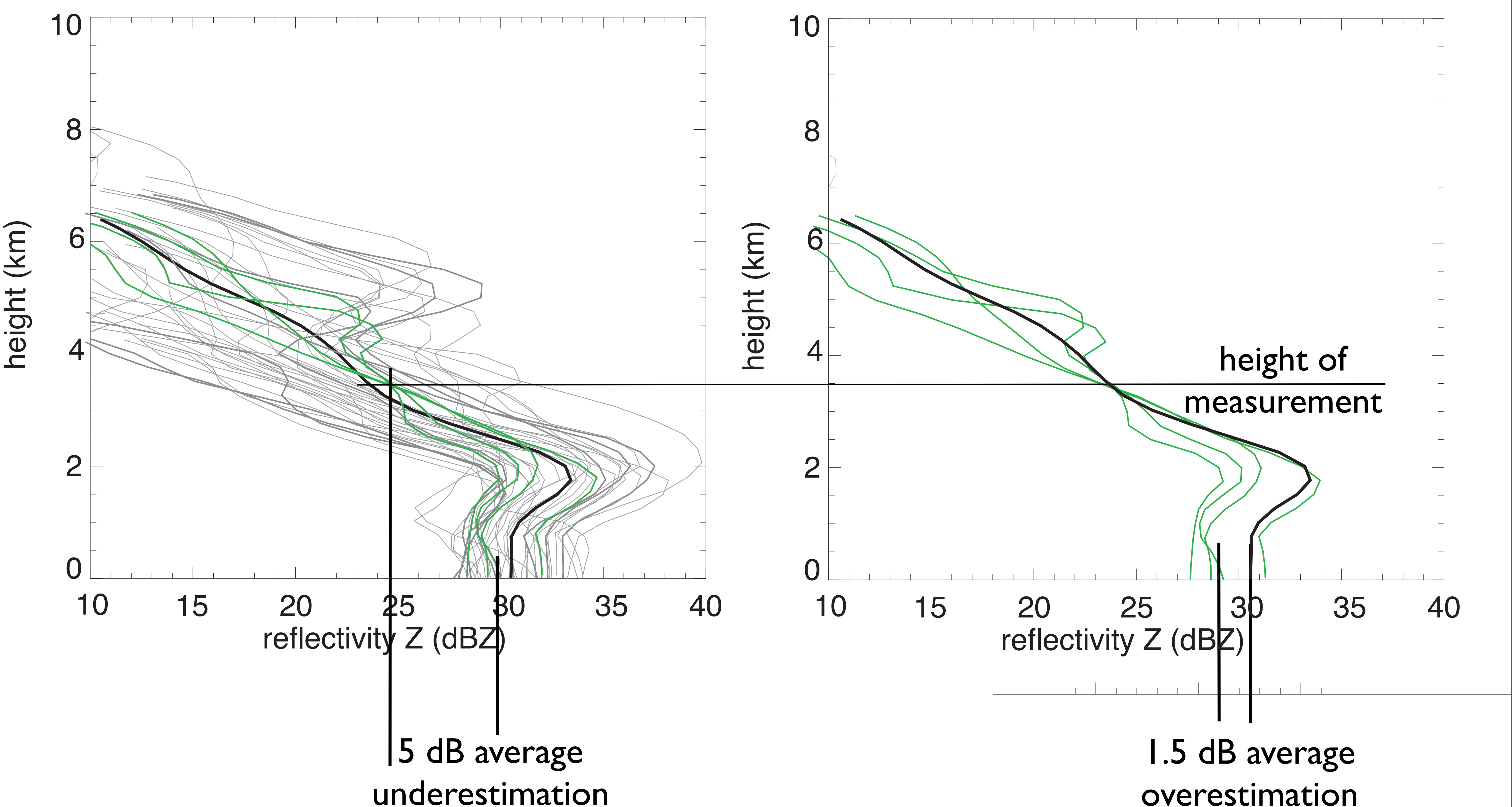

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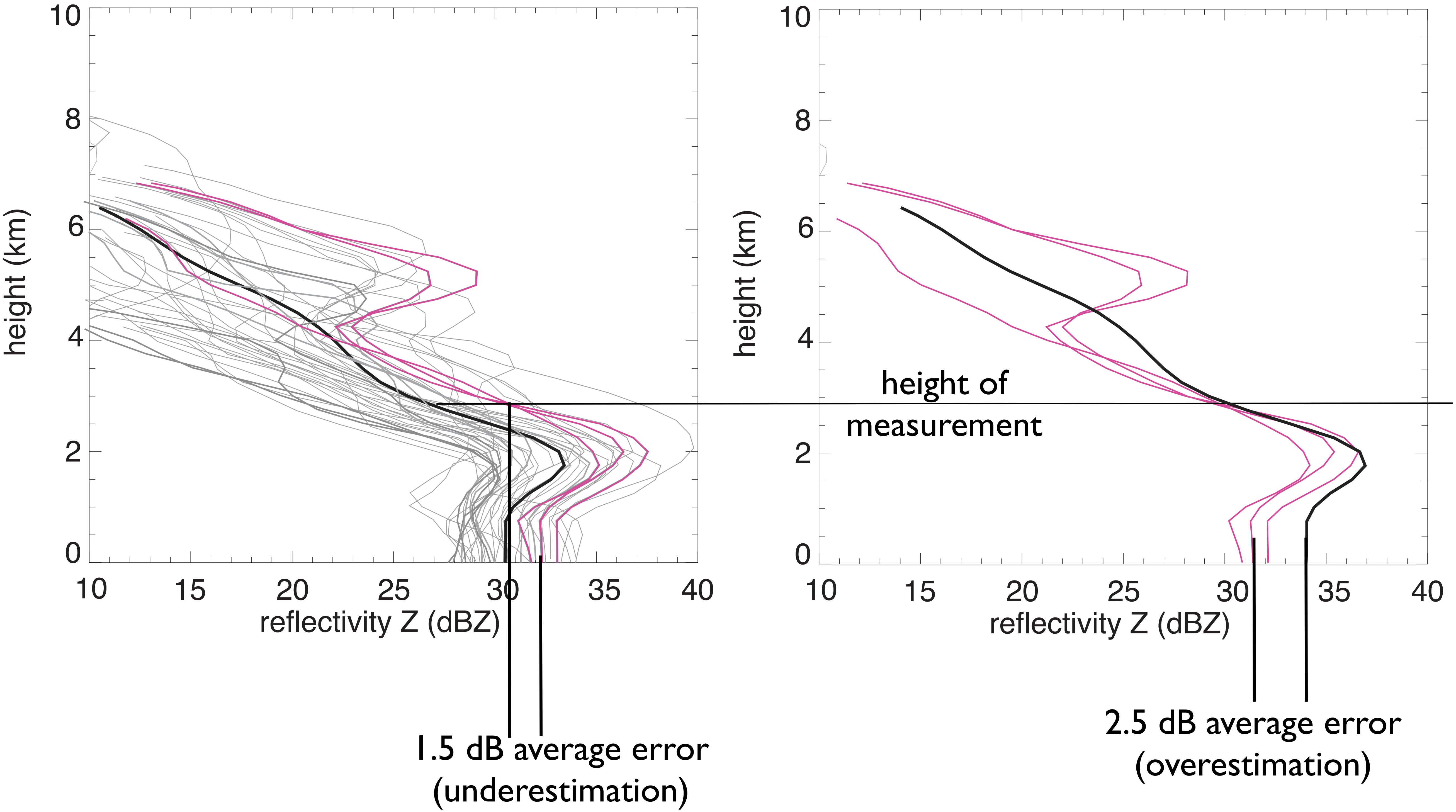

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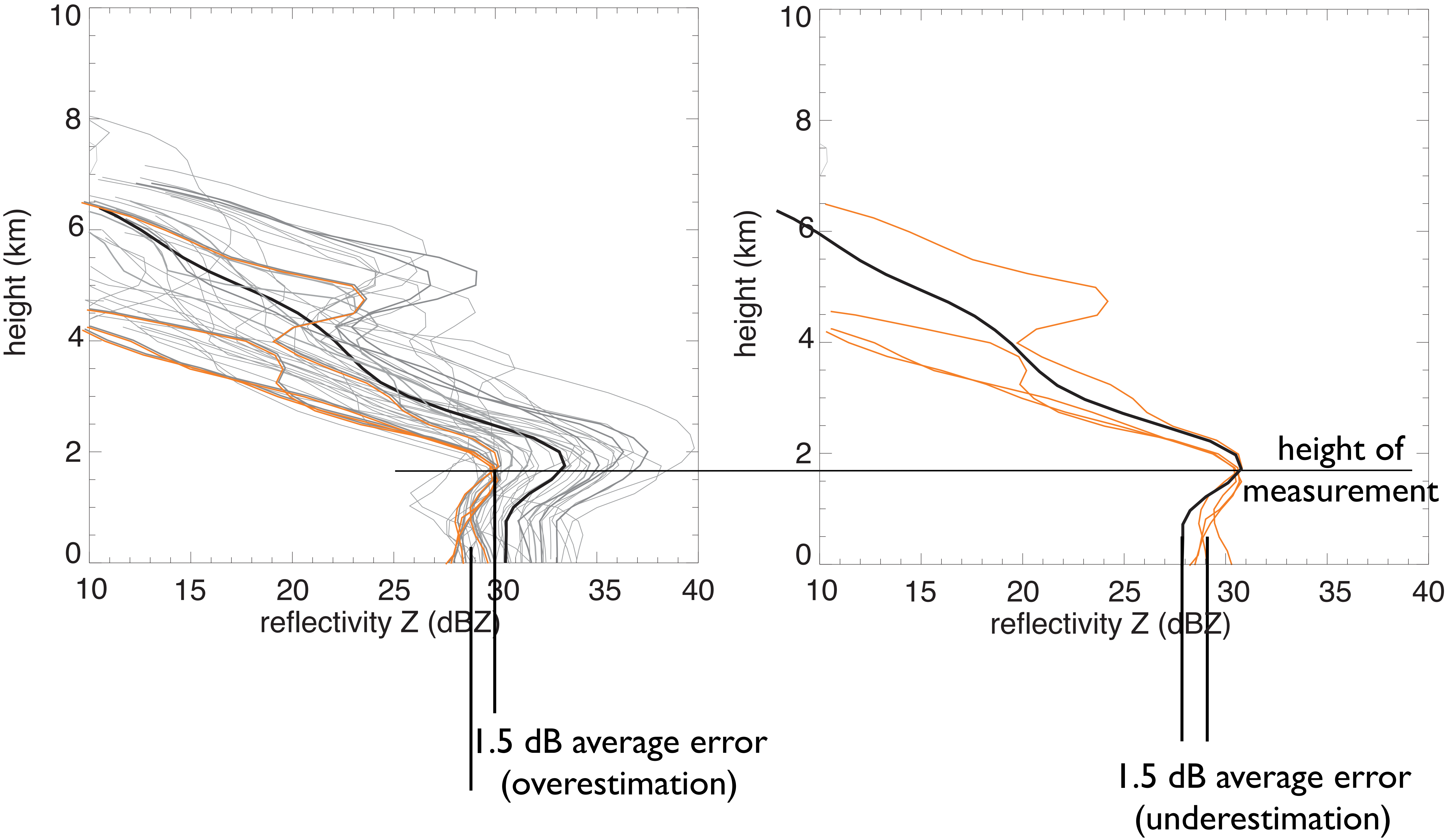

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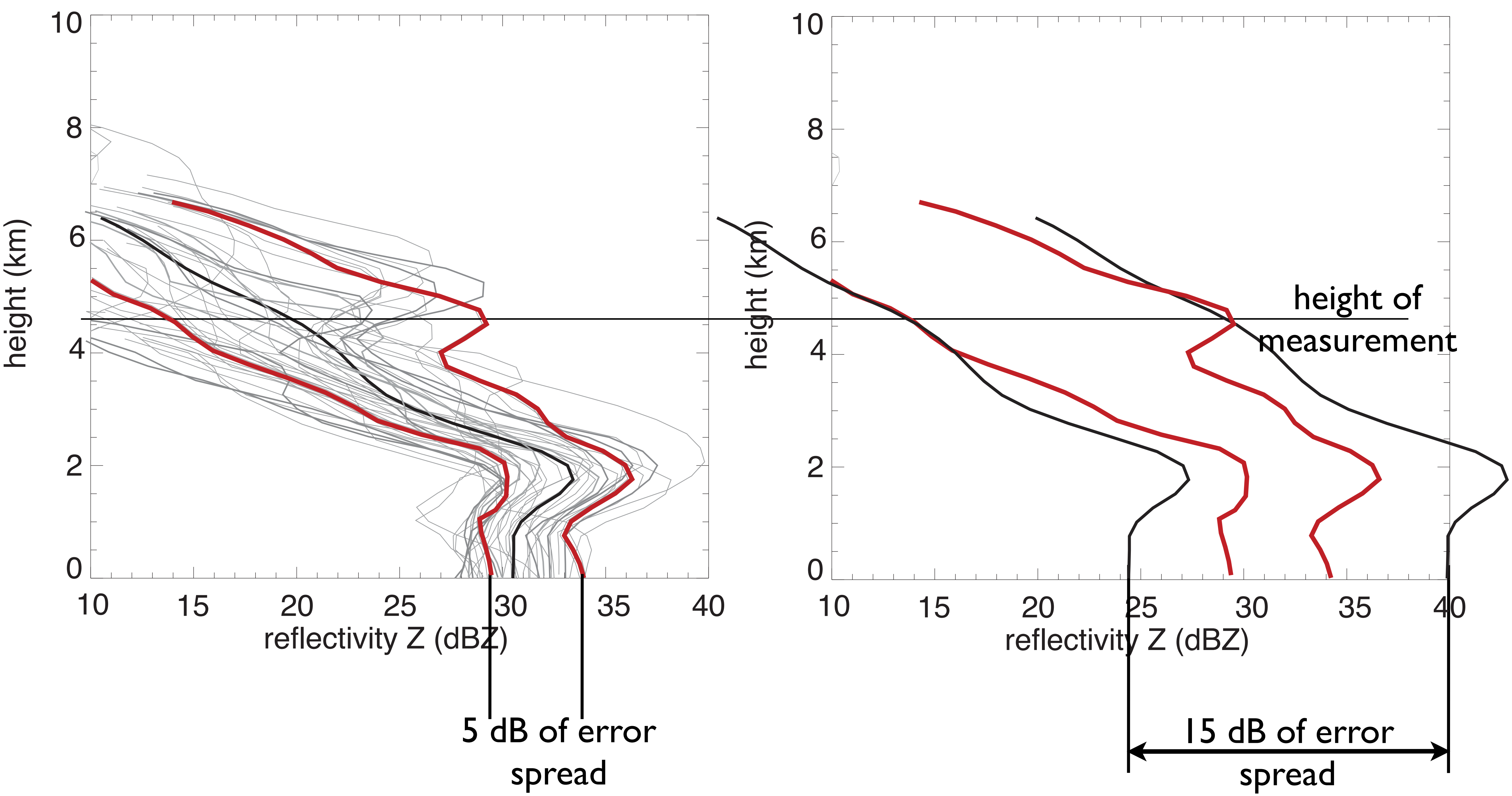

With this procedure for extrapolation to ground we eliminate the bias (assuming that the average VPR is the same at all ranges) but the texture, that is, the variability of the extrapolated values at ground, that we introduce is the one present aloft!!

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The change in reflectivity with height has a deterministic component determined by the average growth of precipitation within a given atmospheric situation.
It also has a strong stochastic component that reflects the spatial variability of the microphysical processes of precipitation growth and the 3-D advection by the winds.

With this procedure for extrapolation to ground we eliminate the bias (assuming that the average VPR is the same at all ranges) but the texture, that is, the variability of the extrapolated values at ground, that we introduce is the one present aloft!!

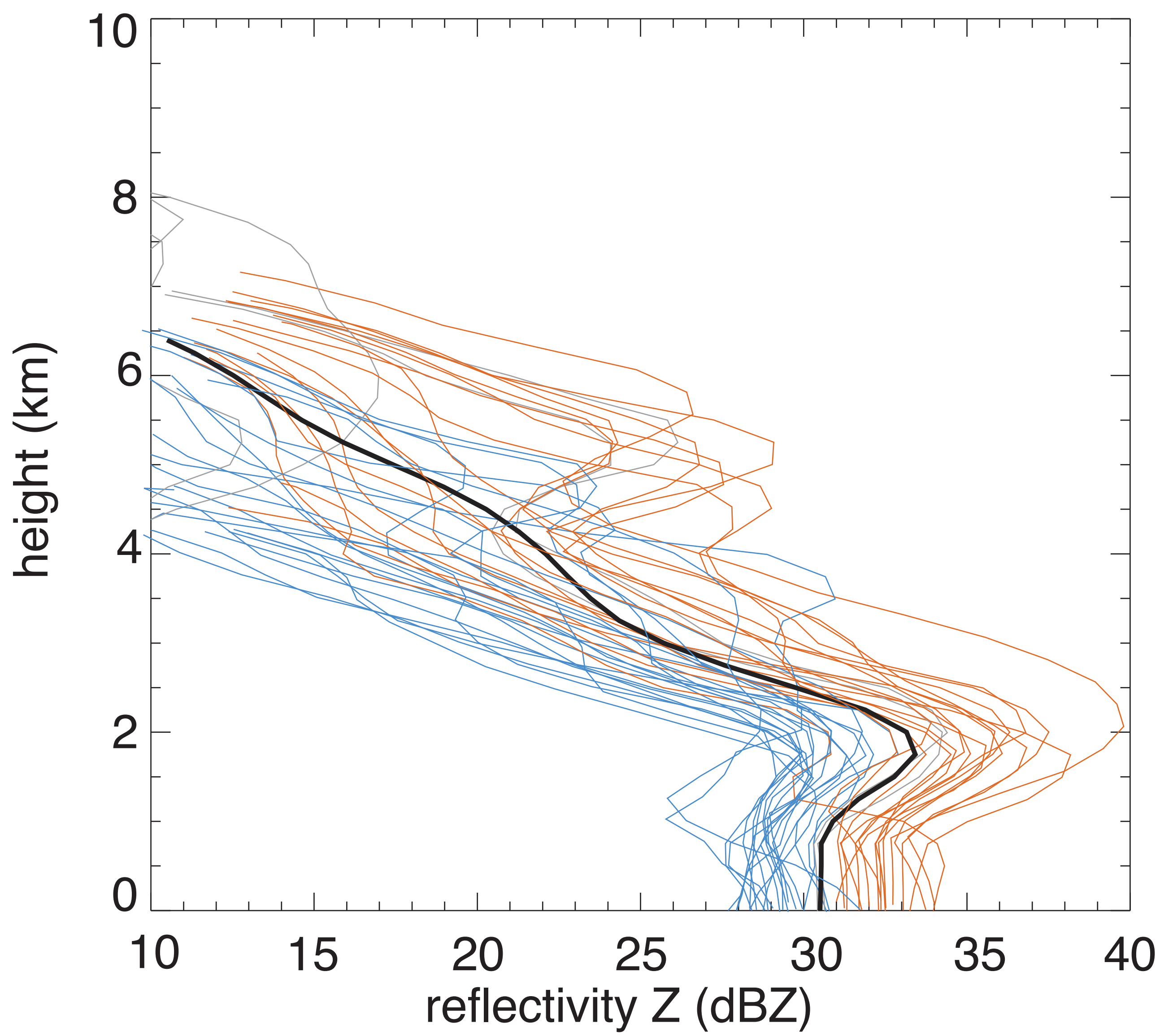
The change in reflectivity with height has a deterministic component determined by the average growth of precipitation within a given atmospheric situation.
It also has a strong stochastic component that reflects the spatial variability of the microphysical processes of precipitation growth and the 3-D advection by the winds.

The meaningful horizontal scales for the extrapolation to ground are those for which the stochastic component has been filtered out !!!

If instead of using only the measurement at the lowest elevation for the extrapolation one uses a best fit adjustment of the average VPR to measurement at all elevations the random error is decreased.

By eliminating some of the fluctuations in the sample VPR through the best fit one gets closer to the average VPR because the stochastic component if the VPR is partly filtered out.

# Is there any sense in the extrapolation?

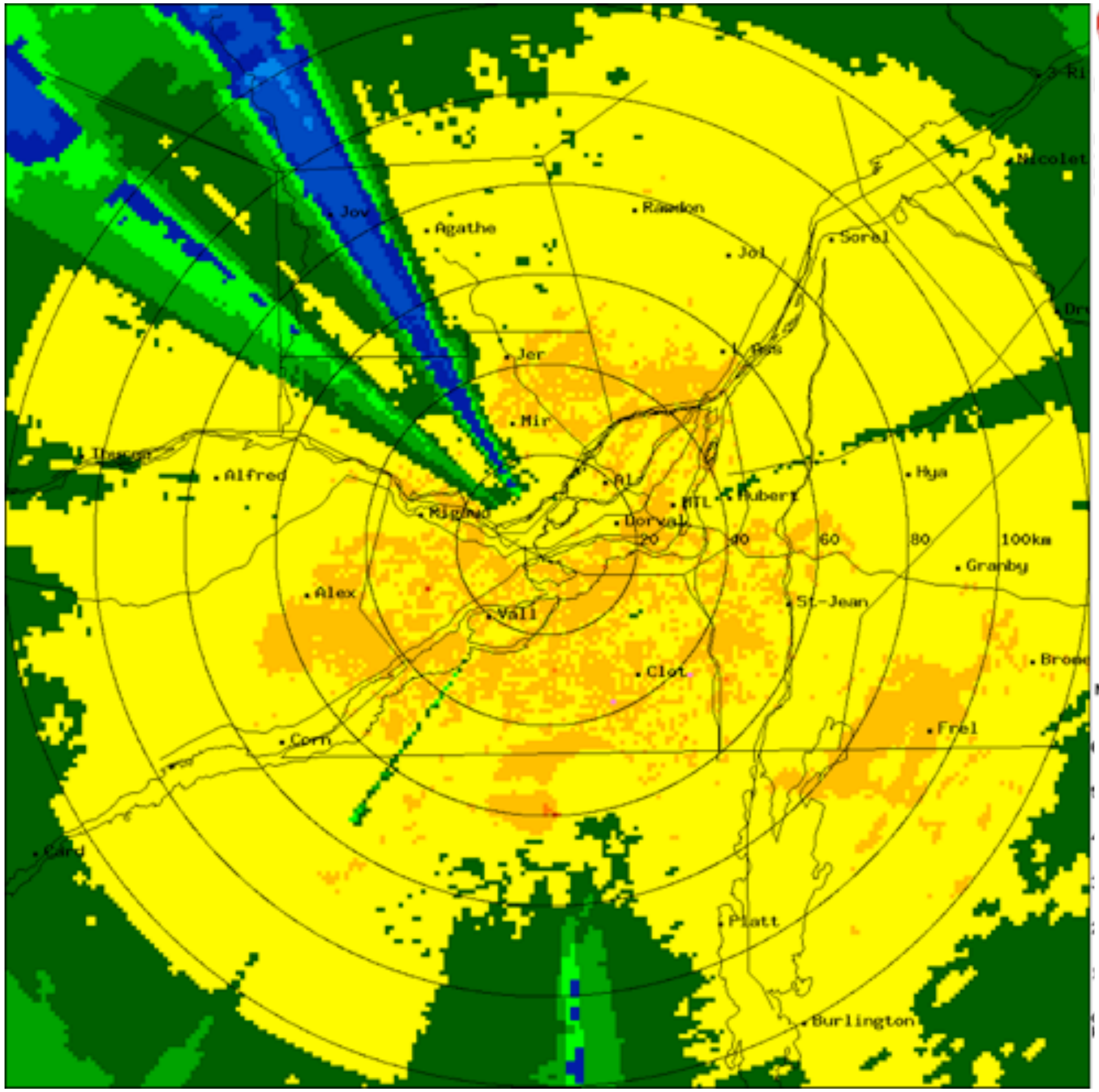



Yes: note that most of the profiles with Z>average at ground are also above average aloft (and vice-versa)

The question that needs to be answered is:
what horizontal scales must be filtered out so that the correlation between the precipitation pattern aloft well matches the pattern at ground.

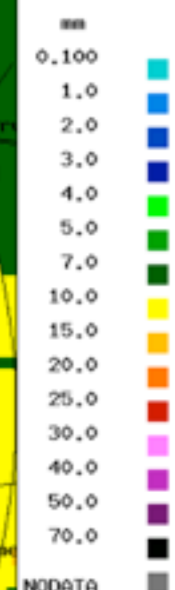
This will give the meaningful scales that are possible to retrieve when extrapolation to ground is made

# McGill blockage and residual clutter map




McGill

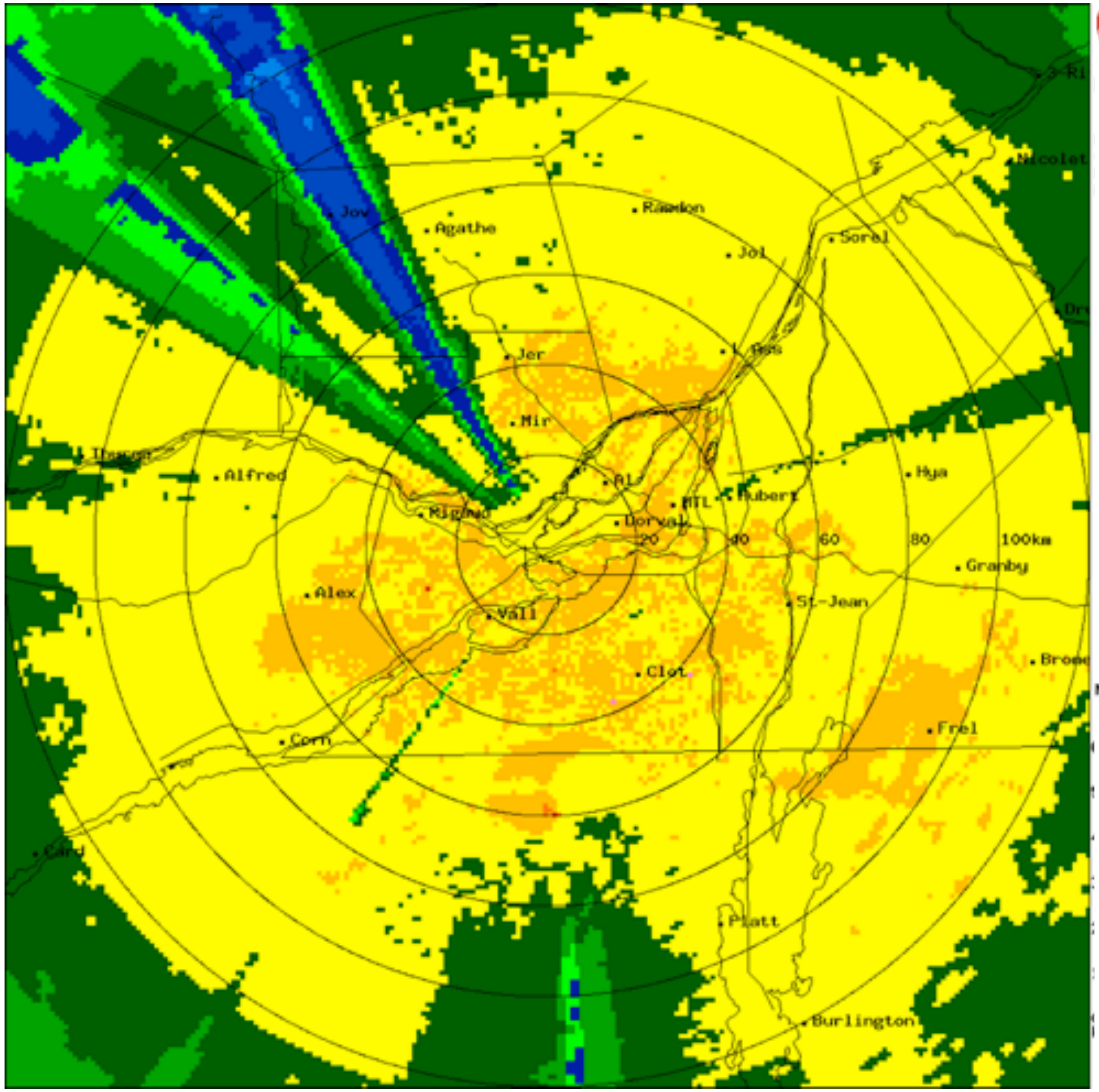
Long term average




Map of factors to be applied to correct for beam blocking

Note the residual ground clutter contamination. It is accounted for as for beam blocking

# McGill blockage and residual clutter map

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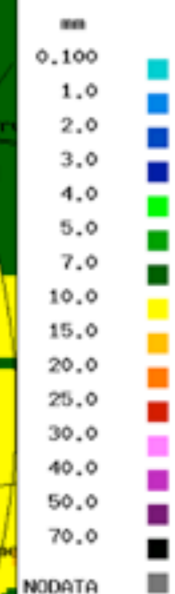


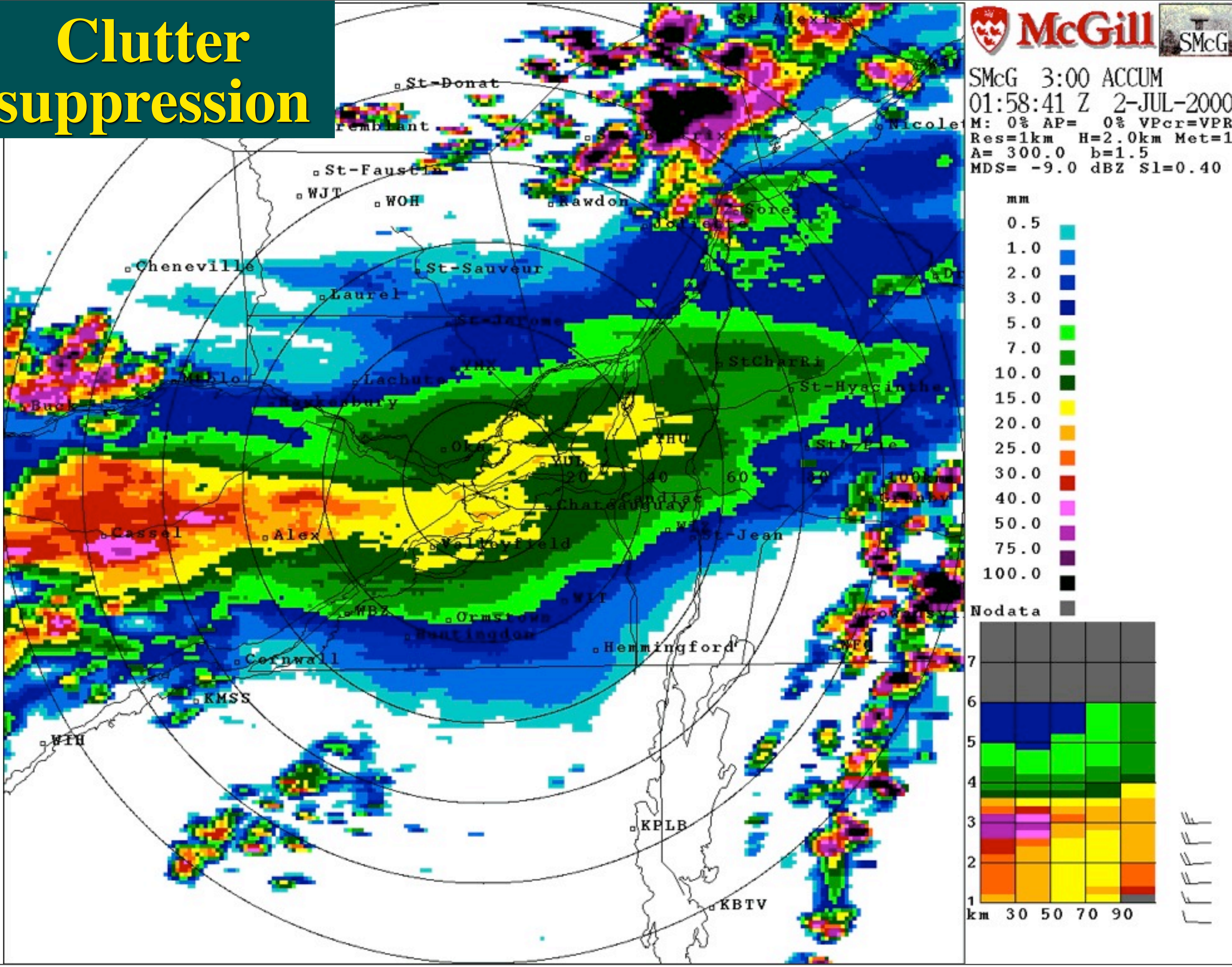

Map of factors to be applied to correct for beam blocking

Note the residual ground clutter contamination. It is accounted for as for beam blocking

McGill applies the correction factors on the Optimal Surface Precipitation (OSP) product. But it could be applied to the volume scan of reflectivity.

# Contaminations by non-meteorological targets

# Clutter suppression



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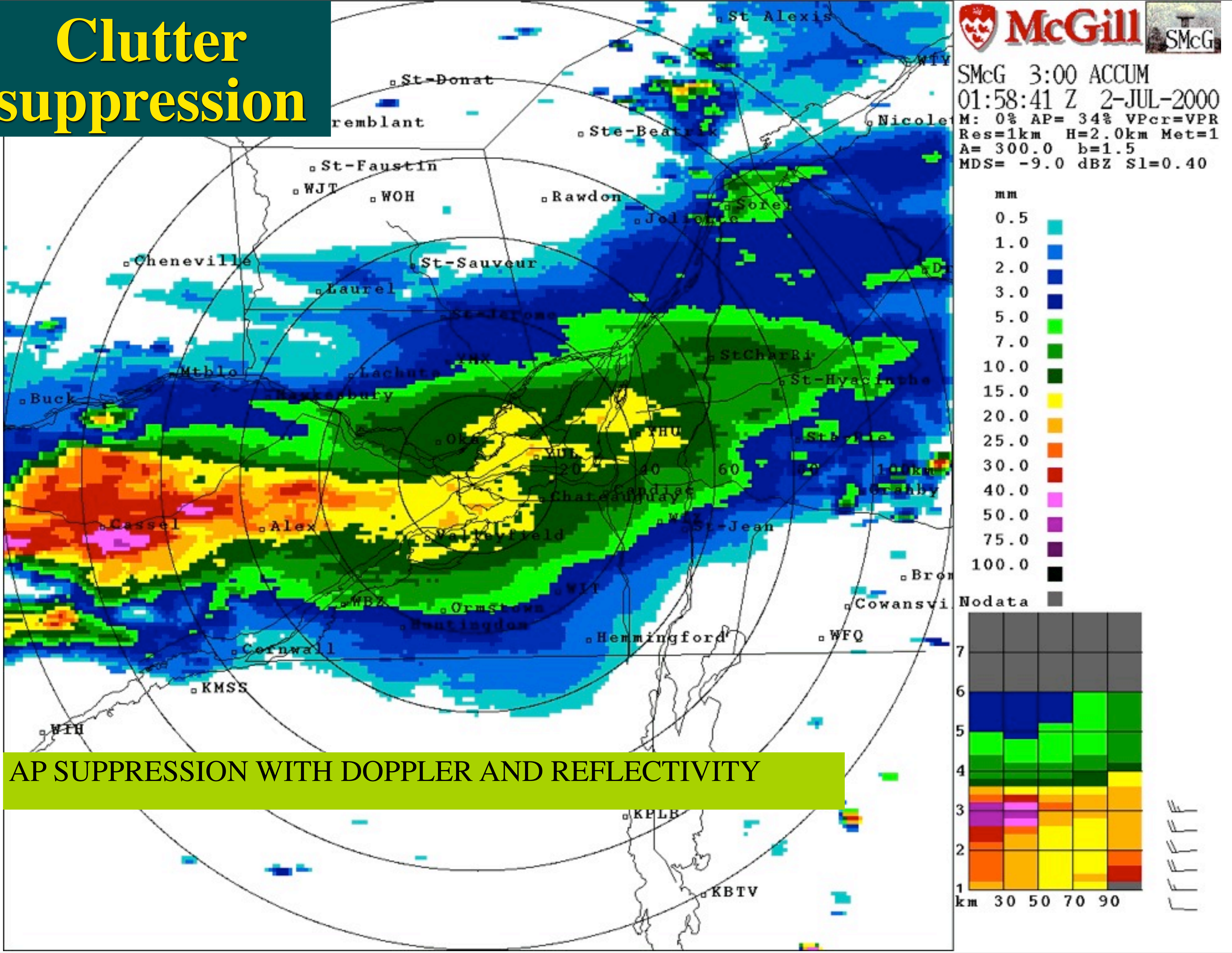
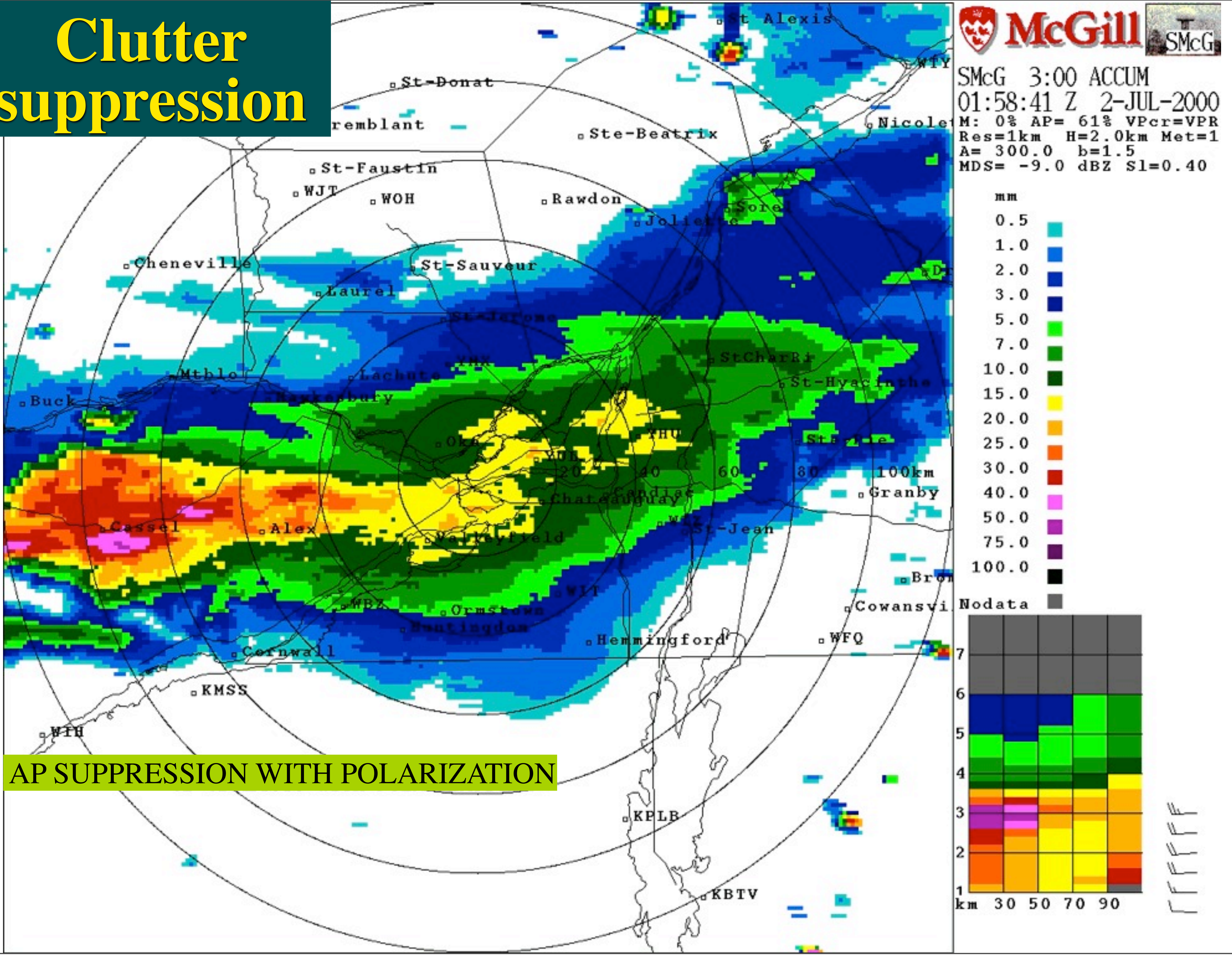



AP SUPPRESSION WITH DOPPLER AND REFLECTIVITY

# Clutter suppression



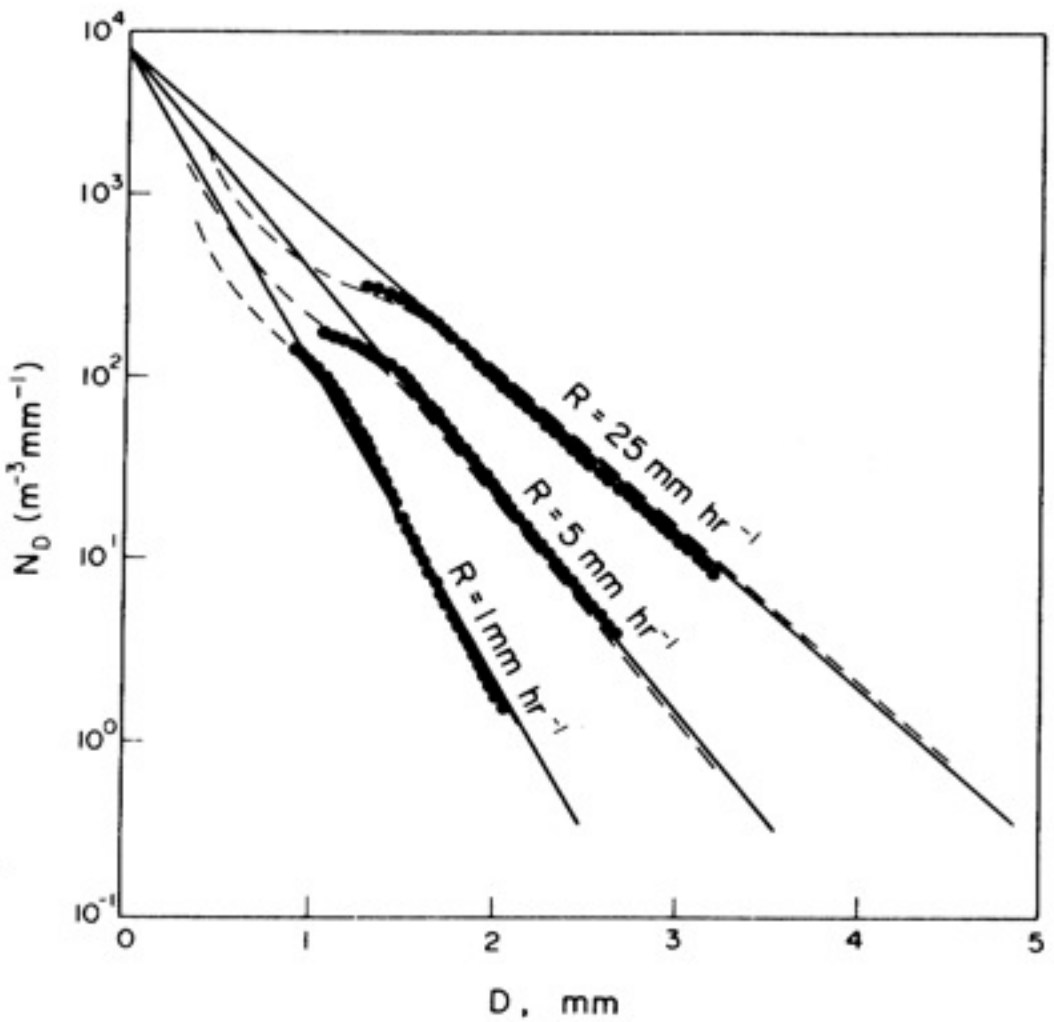

AP SUPPRESSION WITH POLARIZATION

# Finally apply the most appropriate R-Z and here is the original:

The Marshall-Palmer relationship is

$$Z = 200\,R^{1.6}$$

And it is still widely used
by all lazy users !




These DSDs where derived from a very limited sample and all DSDs within a range of intensity where averaged

In fact the Z-R relationship that is compatible with these DSDs is:

$$Z = 290\,R^{1.47}$$

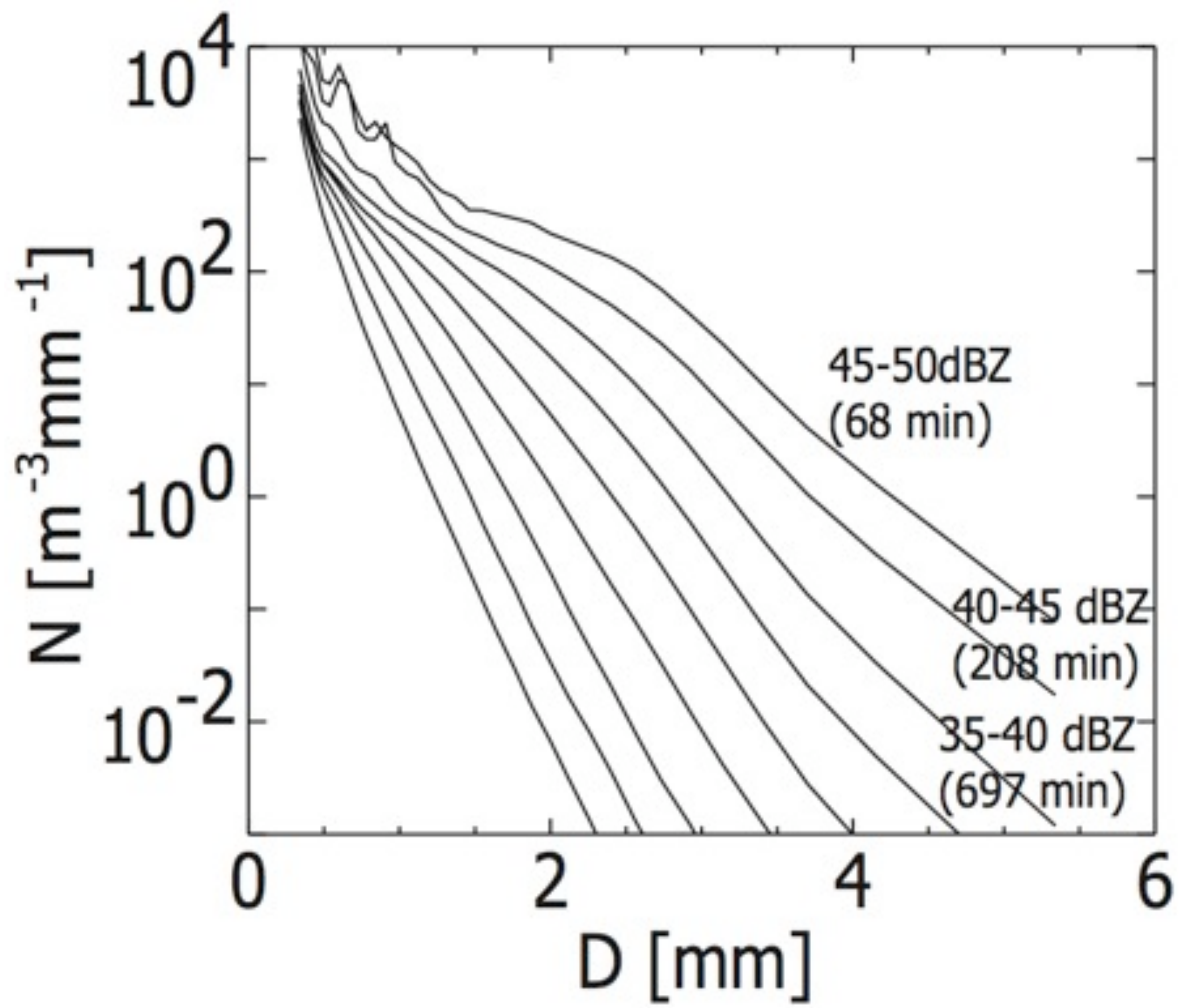
# Finally apply the most appropriate R-Z and here is the climatological:

In rain we measure

$$Z = \int_D D^6 N(D)\,dD$$

But we generally want to know

$$R = \frac{\pi}{6}\int_D D^3 V_{FALL} N(D)\,dD$$



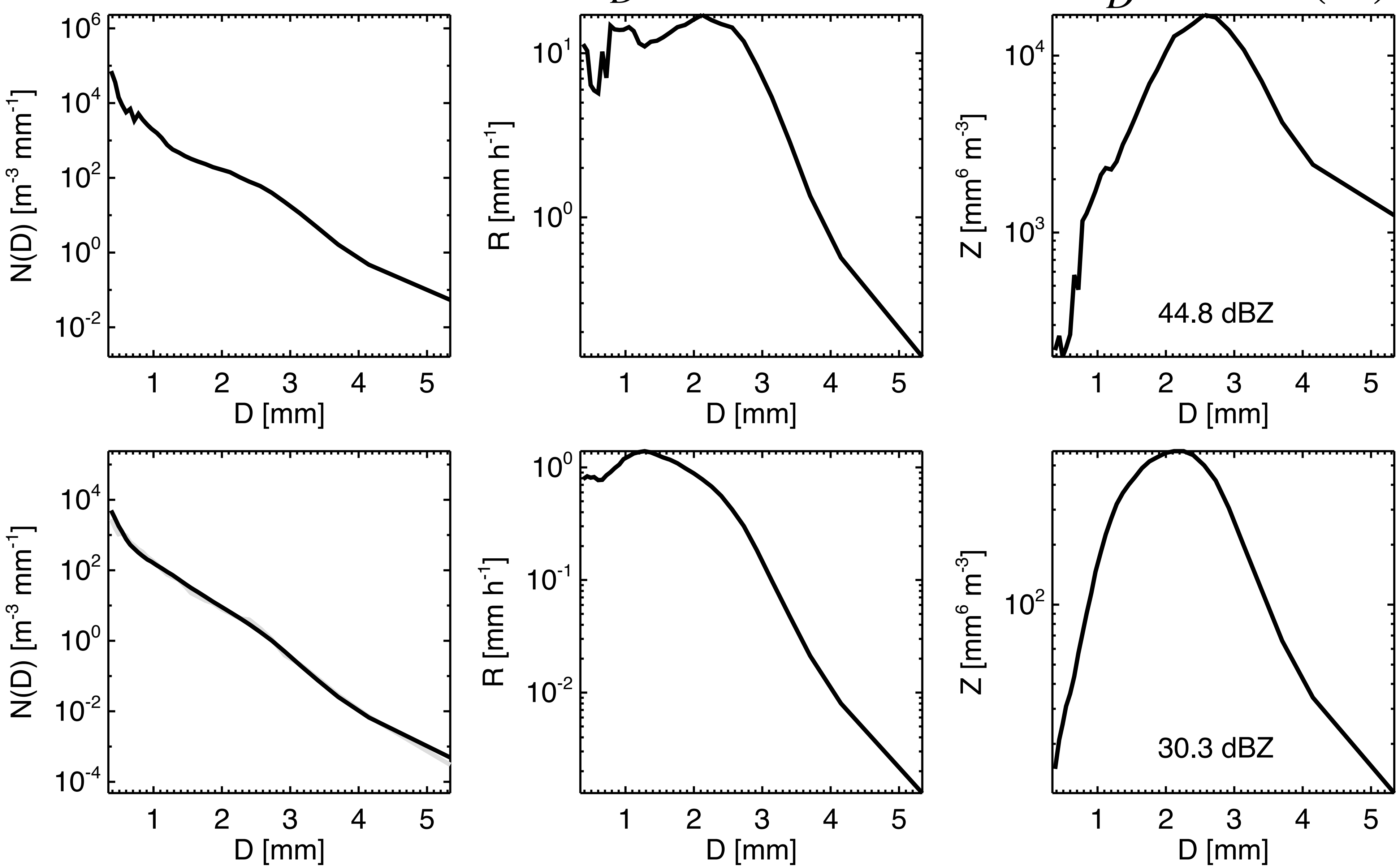

This is the physical basis for precipitation estimates by radar, assuming drop size distributions (DSDs) are known

# Finally apply the most appropriate R-Z

## The contribution to R and to Z comes from different diameters

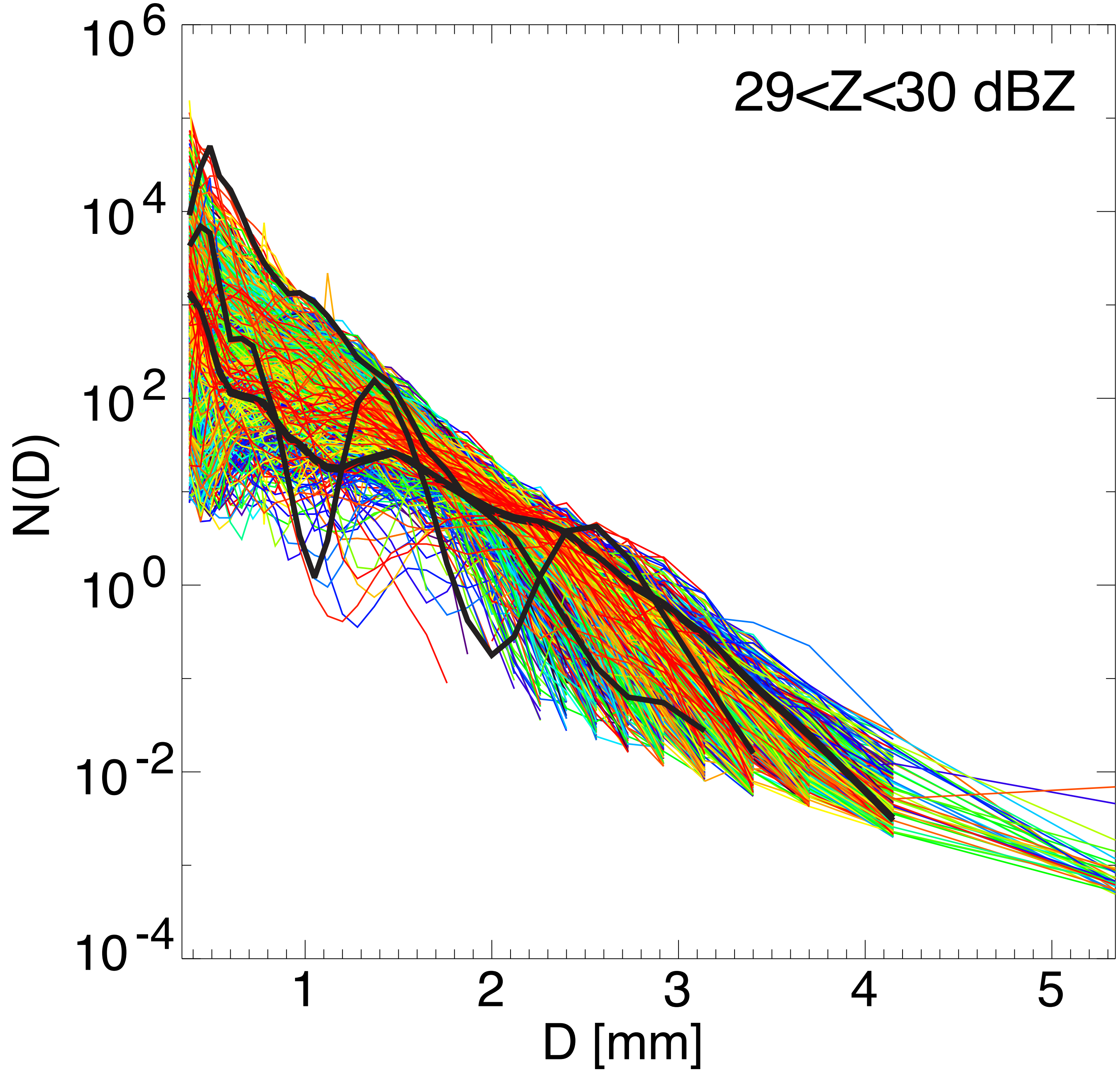
This creates uncertainties in the Z to R conversion

$$R_D = cD^{3.7}N(D) \qquad Z_D = D^6 N(D)$$

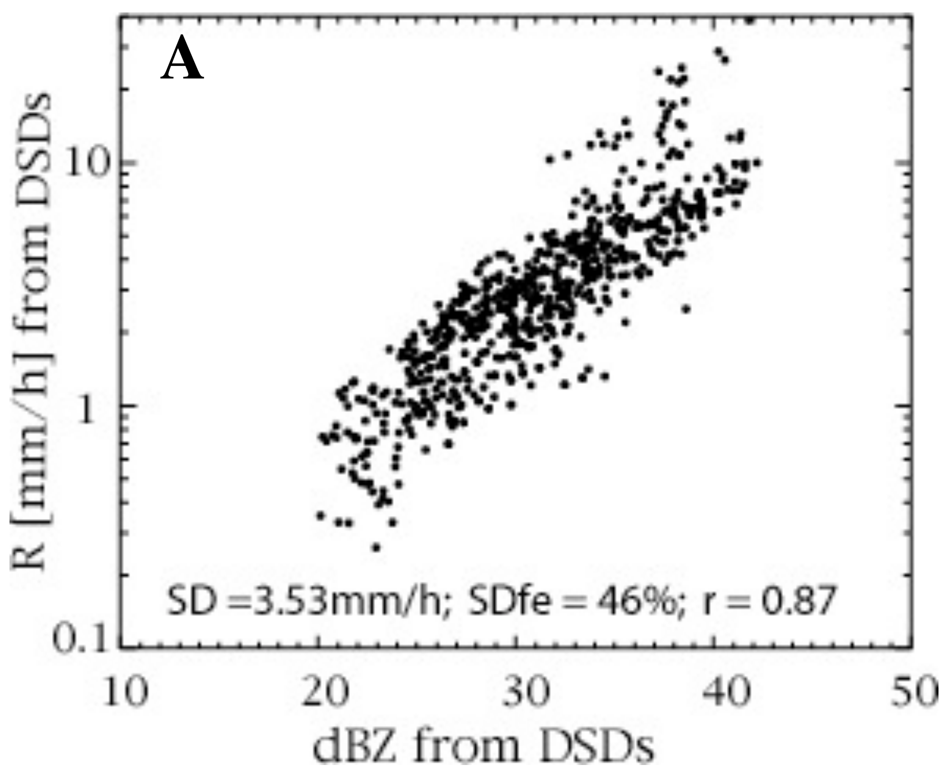


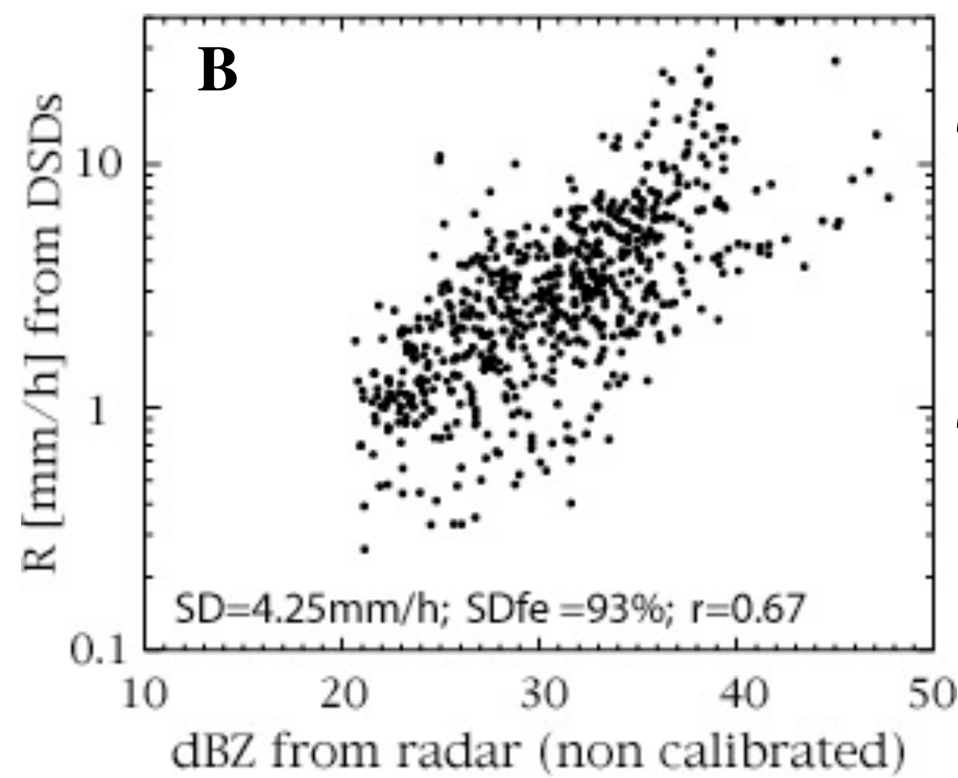
# Finally apply the most appropriate R-Z and here is a sample from a large data base:

For a given reflectivity there is a large variety of DSDs:



# Relative importance of the Variability of DSDs

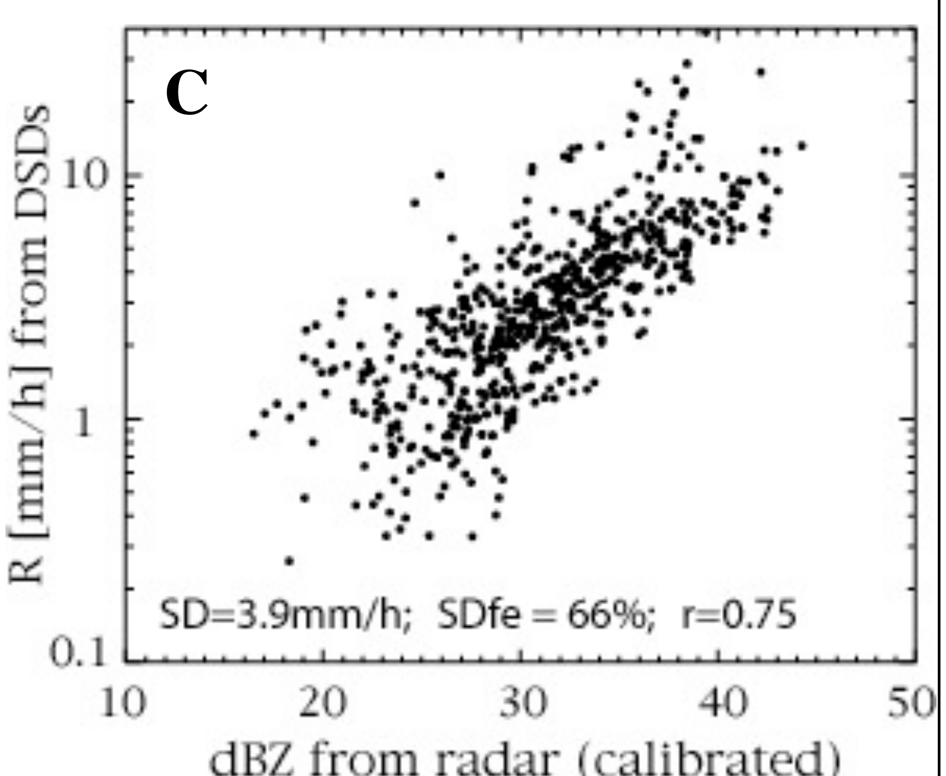



$$SD = \left[ \frac{1}{N} \sum_{N} (R - R_T)^2 \right]^{1/2}$$

$$SDfe = \left[ \frac{1}{N} \sum_{N} \left( \frac{R - R_T}{R} \right)^2 \right]^{1/2}$$

$$Z = 225 R_T^{1.6}$$



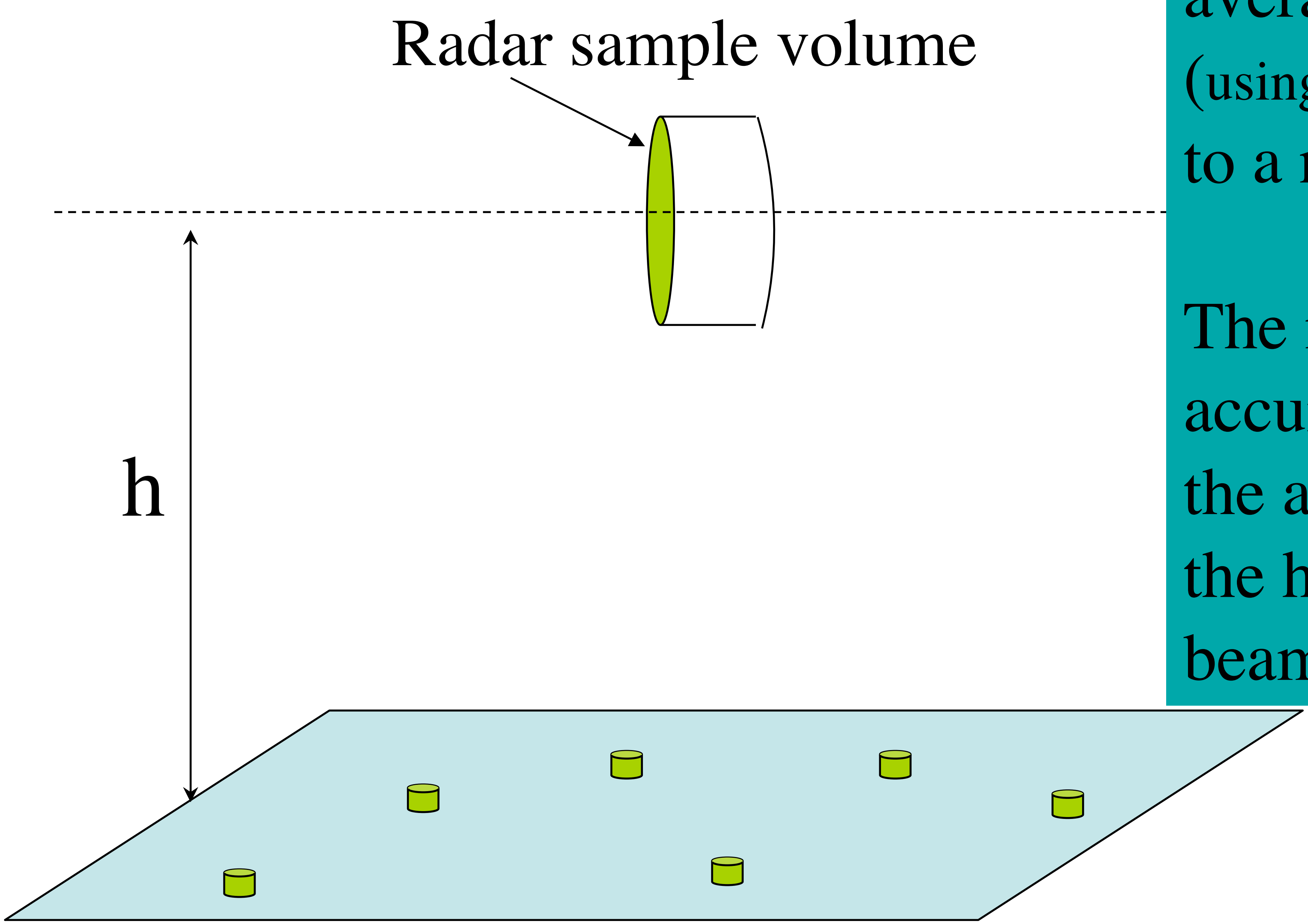

**A**- scattergram of disdrometer derived R vs. Z: reflects the uncertainty in the DSD distribution only.
**B**- same except that Z are actual radar measurements 1.5 km above the disdrometer at 30 km range: reflects all discrepancies between radar and gage measurements of rain.
**C**- as in **B** but radar is calibrated with the daily mean disdrometer reflectivity.

Beside the DSD variability the remaining scatter in **C** is due to sample volume, possible contamination (mainly side-lobe) by the melting layer and the minute-by-minute influence of the difference in height of the radar measurements (the daily average was corrected by the calibration procedure with disdrometer).

# Rain gage: THE instrument for precipitation measurements

**All others instruments allow indirect rainfall estimation only**

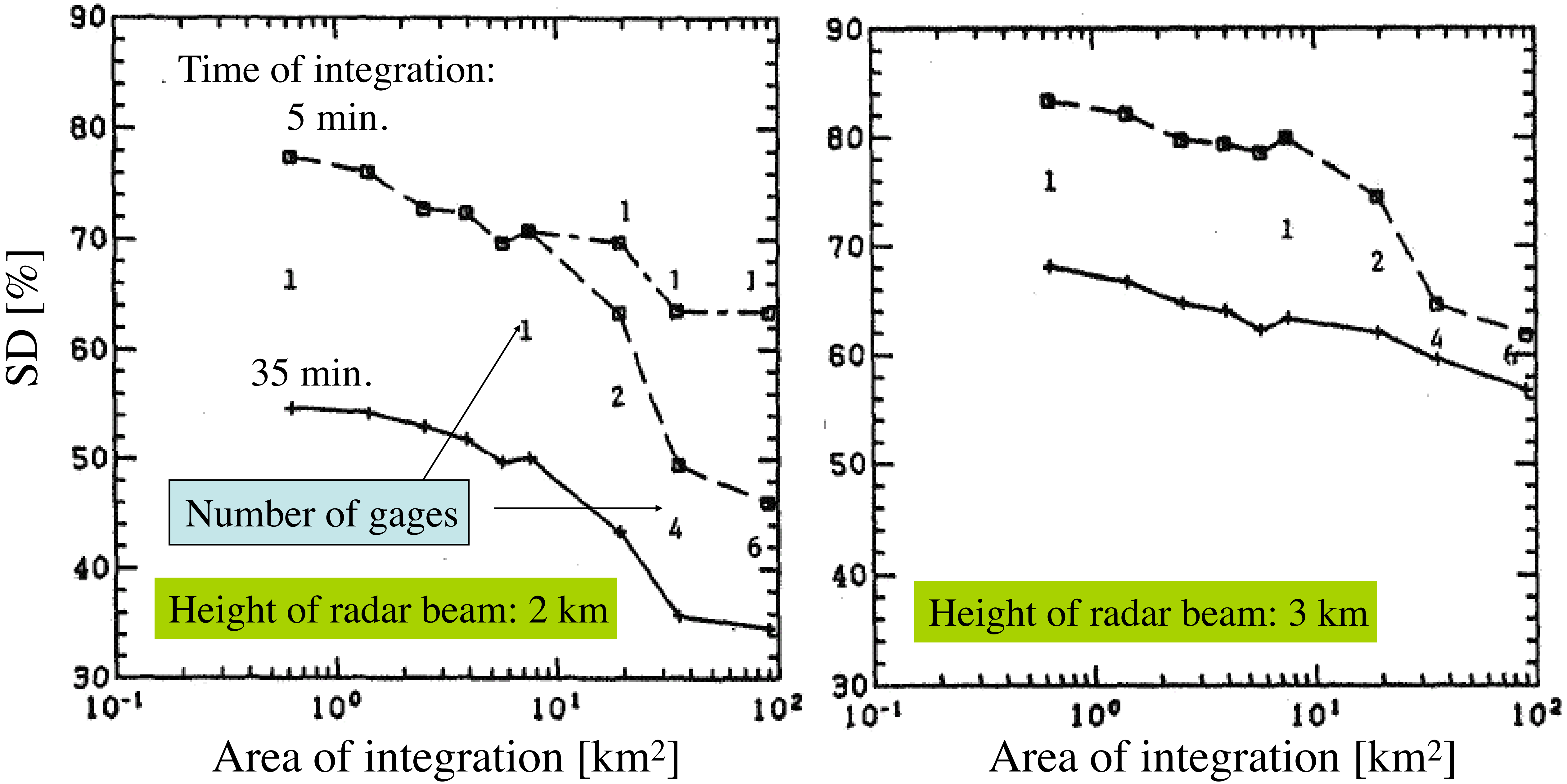
# Radar -gage comparison




We compare radar average rain rate (using $Z=200R^{1.6}$) to a number of gages.

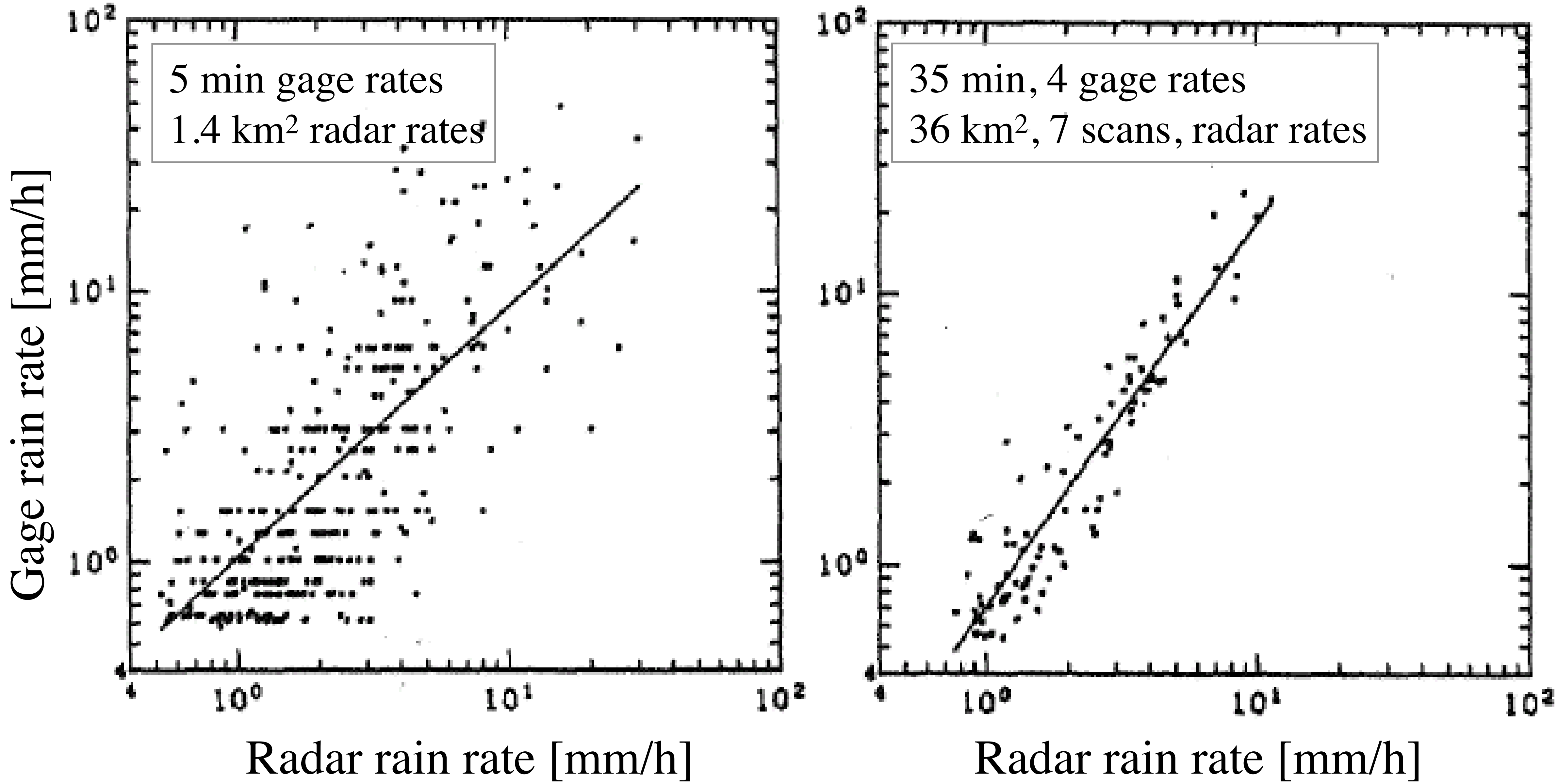
The number of gages, the accumulation time, the area of average and the height of the radar beam are all variables

# Radar -gage comparison



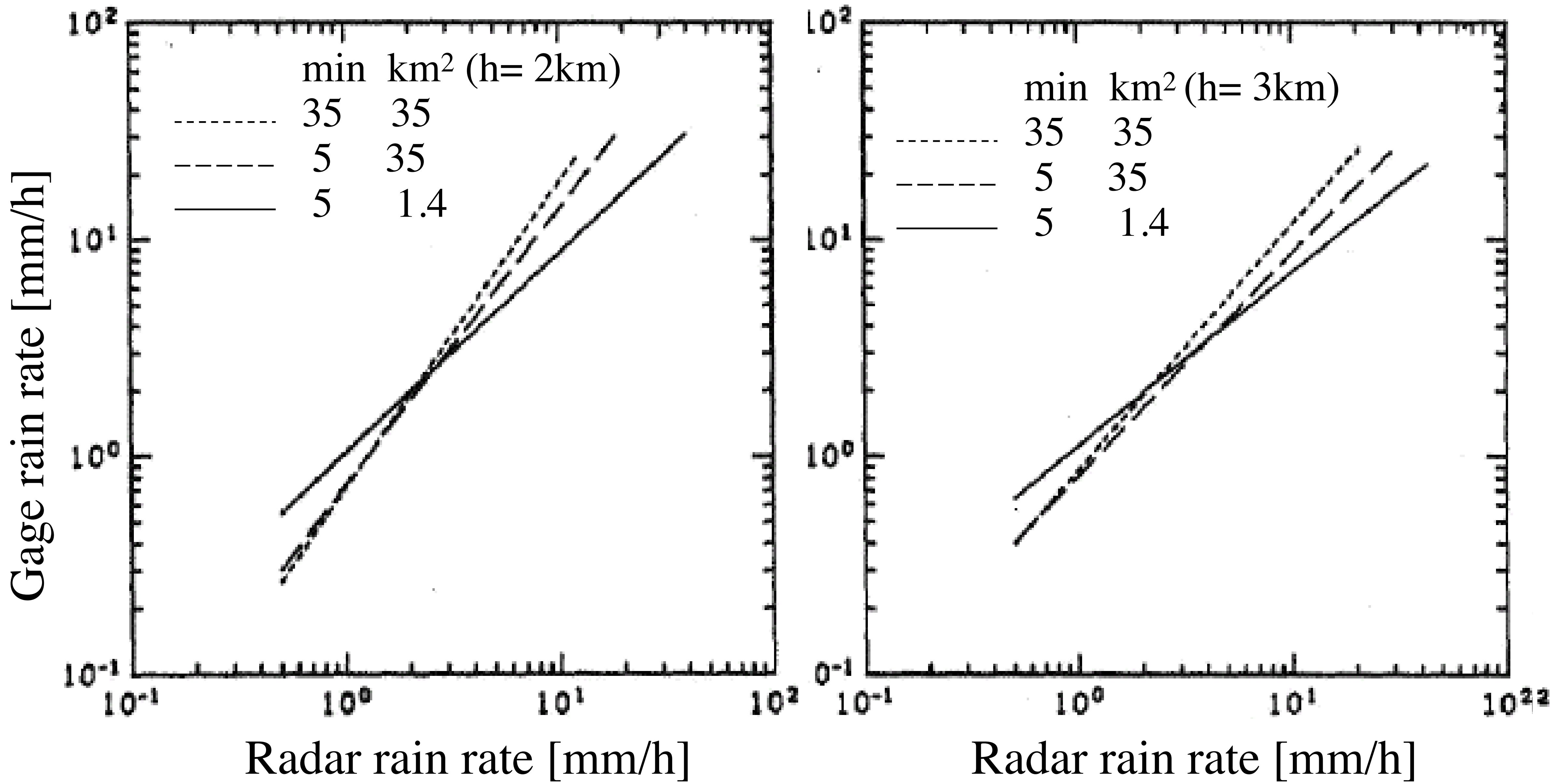

Zawadzki et al, 1986-Radar Conf

# Radar -gage comparison




Zawadzki et al, 1986-Radar Conf

# Radar -gage comparison




Zawadzki et al, 1986-Radar Conf