Calibrating Operational Radar by Dual-Polar Self-Consistency

Rob Thompson & Anthony Illingworth
Department of Meteorology
University of Reading

And thanks to the Met Office

1. How Accurately Do We Need Z?

- Calibrating radar is of critical importance if we are to estimate the rainfall accurately and without significant bias.

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

Calibrating Z to ±1dB for R to 0.6dB (15%)

Z to ±0.5dB for R to 0.3dB (~ 7%)

- Absolute calibration is difficult, but essential.
- But If the hardware doesn't change and transmitted power is monitored the calibration should be stable.

2. Comparing Radar to Disdrometer

University of Reading

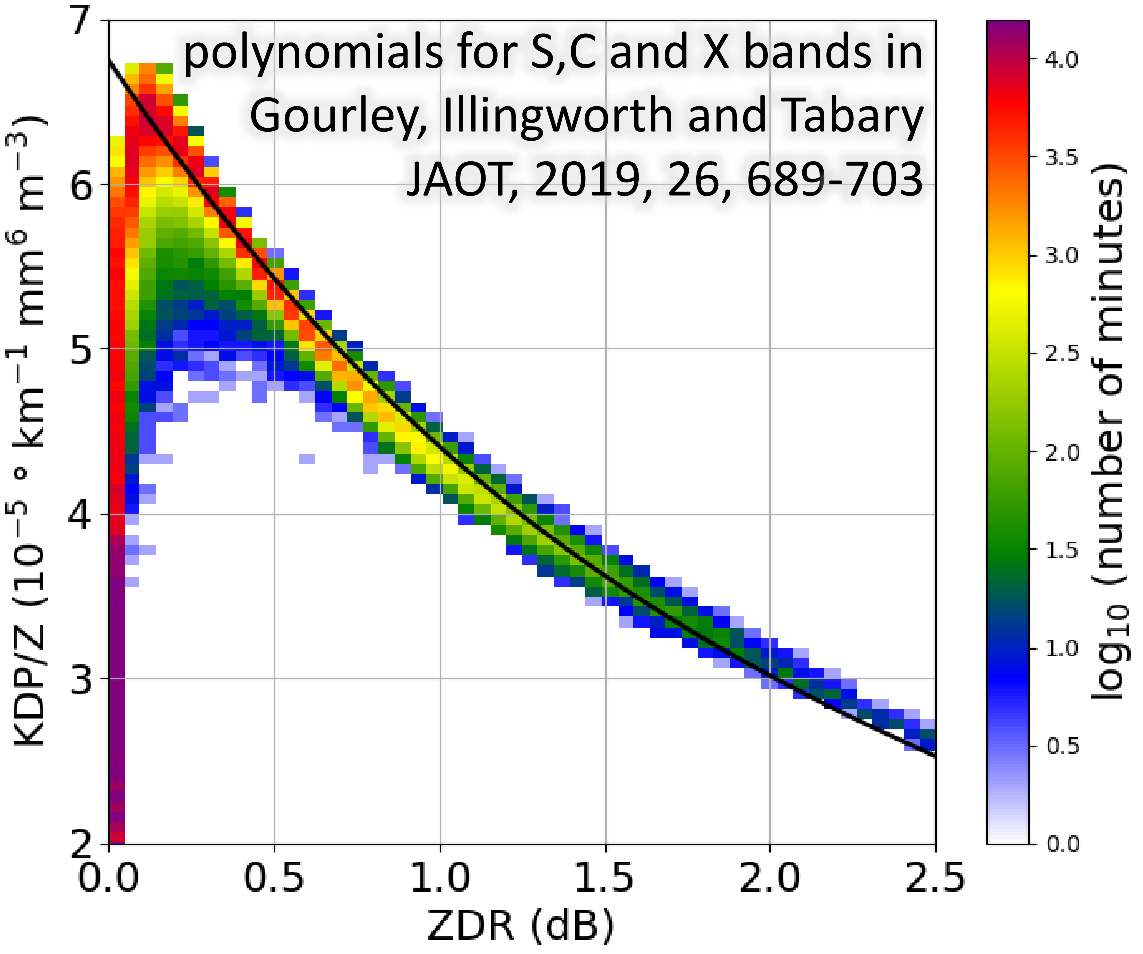
- Compare each scan (5 minutes) 600m radar pixel above disdrometer.
- Radar pixel is 19km range and 700m above the disdrometer.
- Only include very high quality scans (ρ_{hv} limit to avoid any clutter)

- But there's a scan-scan random error of 3dB (wind drift, representativity etc.)
- Can take months for enough hits to converge with sufficient accuracy.

- 2 years continuous monitoring showed hardware stable to better than 1dB… resulted in a +2dB change to whole UK network in Dec. 2019.
- Not practical to have calibrated disdrometer for every radar.

3. Naturally occurring rain has a unique relationship between K_{DP}/Z and Z_{DR} by chance

- 12 years of rainfall each minute from a disdrometer.
- Colour scale is the log of the occurrence.
- For a given value of Z_{DR} the value of K_{DP}/Z varies by less than 5%
- So adjust the calibration of Z so all the data lie on the black line?



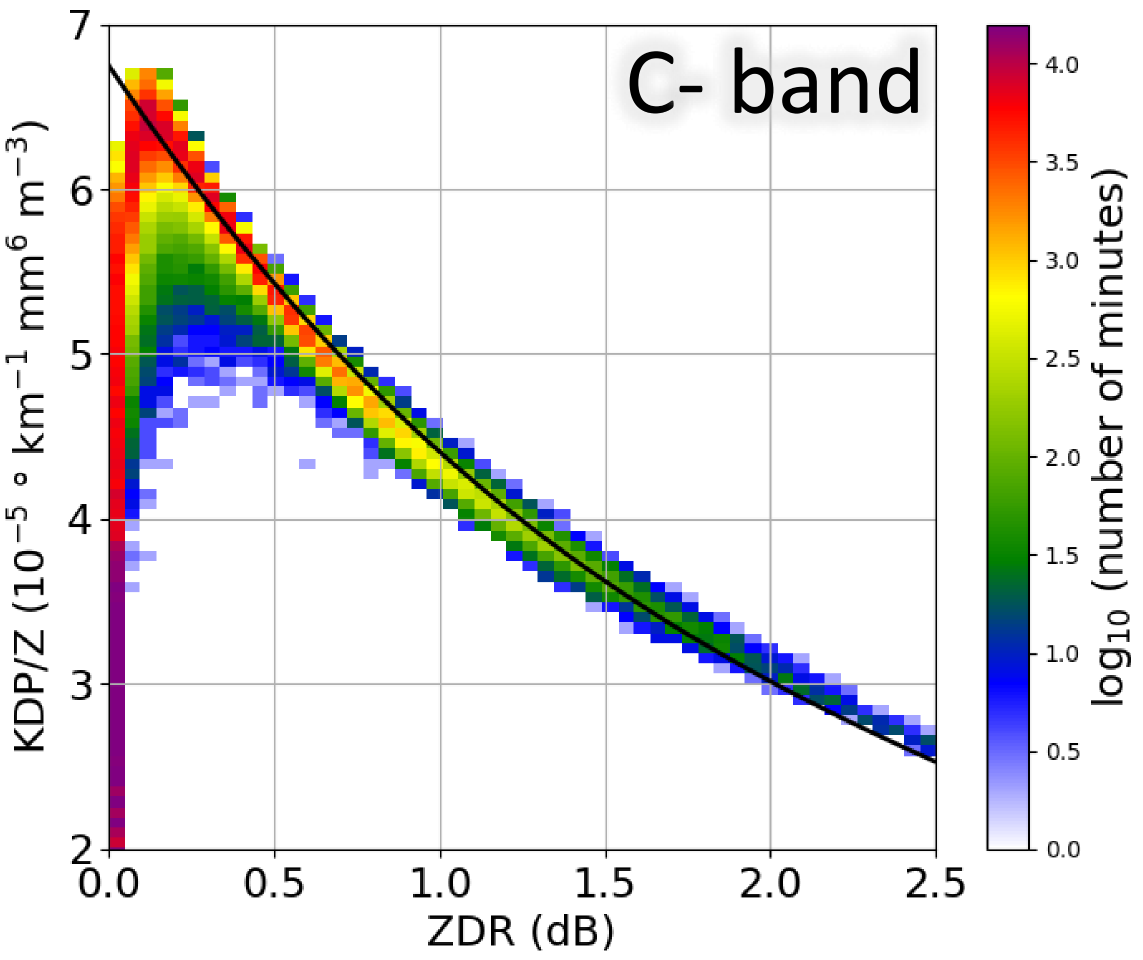
3. Naturally occurring rain has a unique relationship between K_{DP}/Z and Z_{DR} by chance

University of Reading

- 12 years of rainfall each minute from a disdrometer.
- Colour scale is the log of the occurrence.
- For a given value of Z_{DR} the value of K_{DP}/Z varies by less than 5%
- So adjust the calibration of Z so all the data lie on the black line?

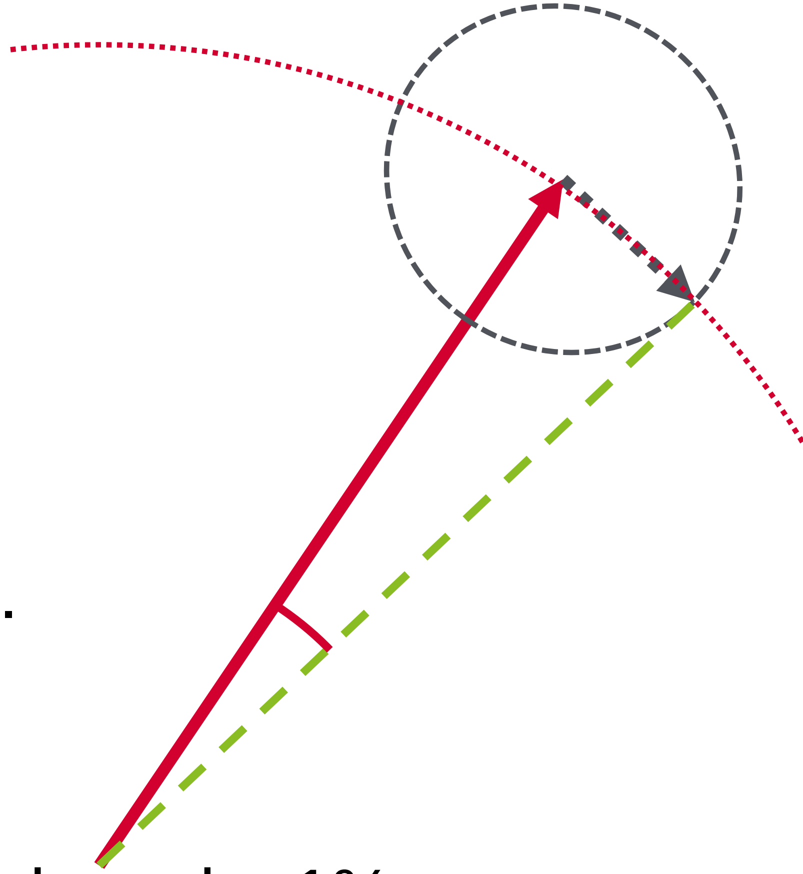
NO! NO! NO!

- FOR OPERATIONAL RADARS Φ_{DP} HAS A NOISE OF ABOUT 1 OR 2 DEGREES SO K_{DP} , the differential of Φ_{DP}, IS VERY NOISY!
- Need to integrate Φ_{DP} along a ray and adjust Z so the total phase change agrees with observations.



4. Why Avoiding Clutter is So Important

University of Reading



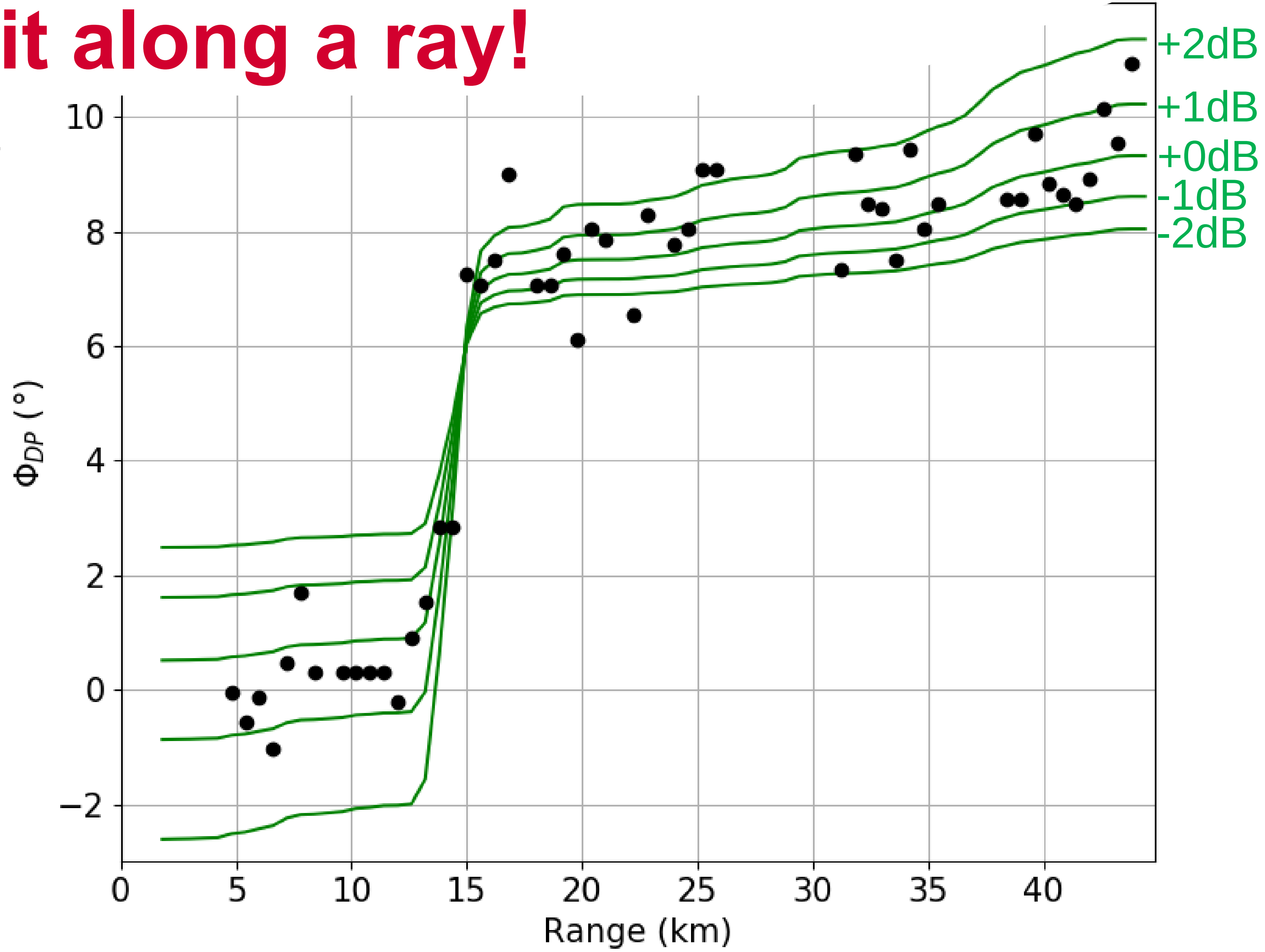
- Polarisation parameters data quality is fundamental!
- Suppose rain Z = 20dBZ = 100 (linear)
- Now have ground clutter 20dB below the rain signal
- Z goes from 100 to 101 (so increase of just 0.04dB)
- Z_{DR} may also change by 0.04dB
- BUT… Z is intensity, amplitude of clutter is 10% of rain.

- This will add 5.7° of random noise in Φ_{DP} .
- If the clutter is just noise in H and V (uncorrelated) ρ_{HV} drops by 1%

  e.g. That means ρ_{hv} falls from 0.99 to 0.98.
- Avoid low ρ_{hv}, weight Φ_{DP} using ρ_{hv} to maximise use of the cleanest pixels.

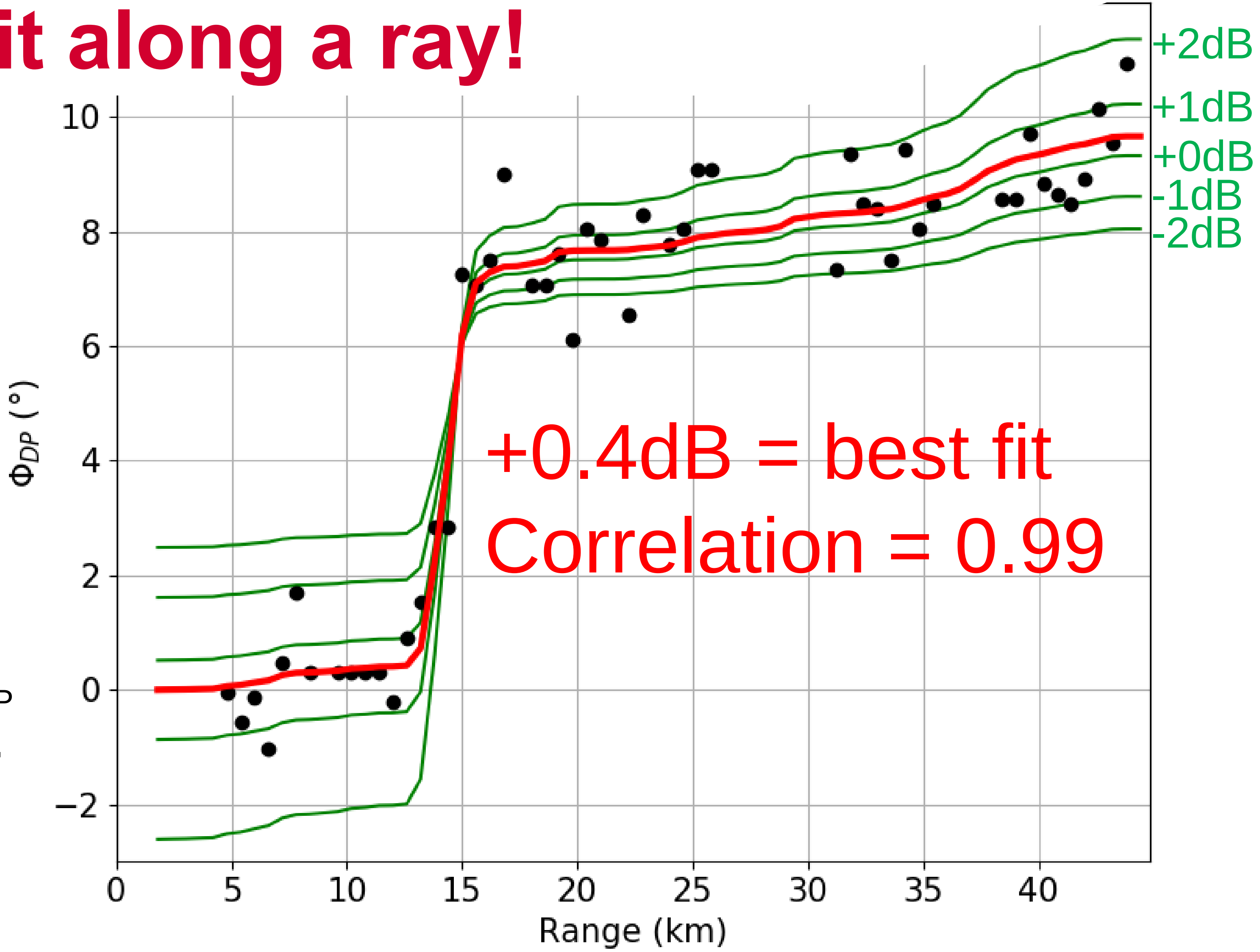
5. Instead of differentiating a noisy Φ_{DP} integrate it along a ray!

- Adjust the Z calibration until best fit of Φ_{DP} along a ray agrees with the observed change in Φ_{DP}.
- Individual values of Φ_{DP} have scatter around the best fit.
- Each green line represents a change in calibration of 1dB.



5. Instead of differentiating a noisy Φ_{DP} integrate it along a ray!

- Adjust the Z calibration until best fit of Φ_{DP} along a ray agrees with the observed change in Φ_{DP}.
- Individual values of Φ_{DP} have scatter around the best fit.
- Each green line represents a change in calibration of 1dB.
- Adjust the calibration of Z to minimise the cost function of the scatter of each, ρ_{hv} weighted, Φ_{DP} around the theoretical green line.
- Correlation between the weighted observations and best fit gives quality of the fit.

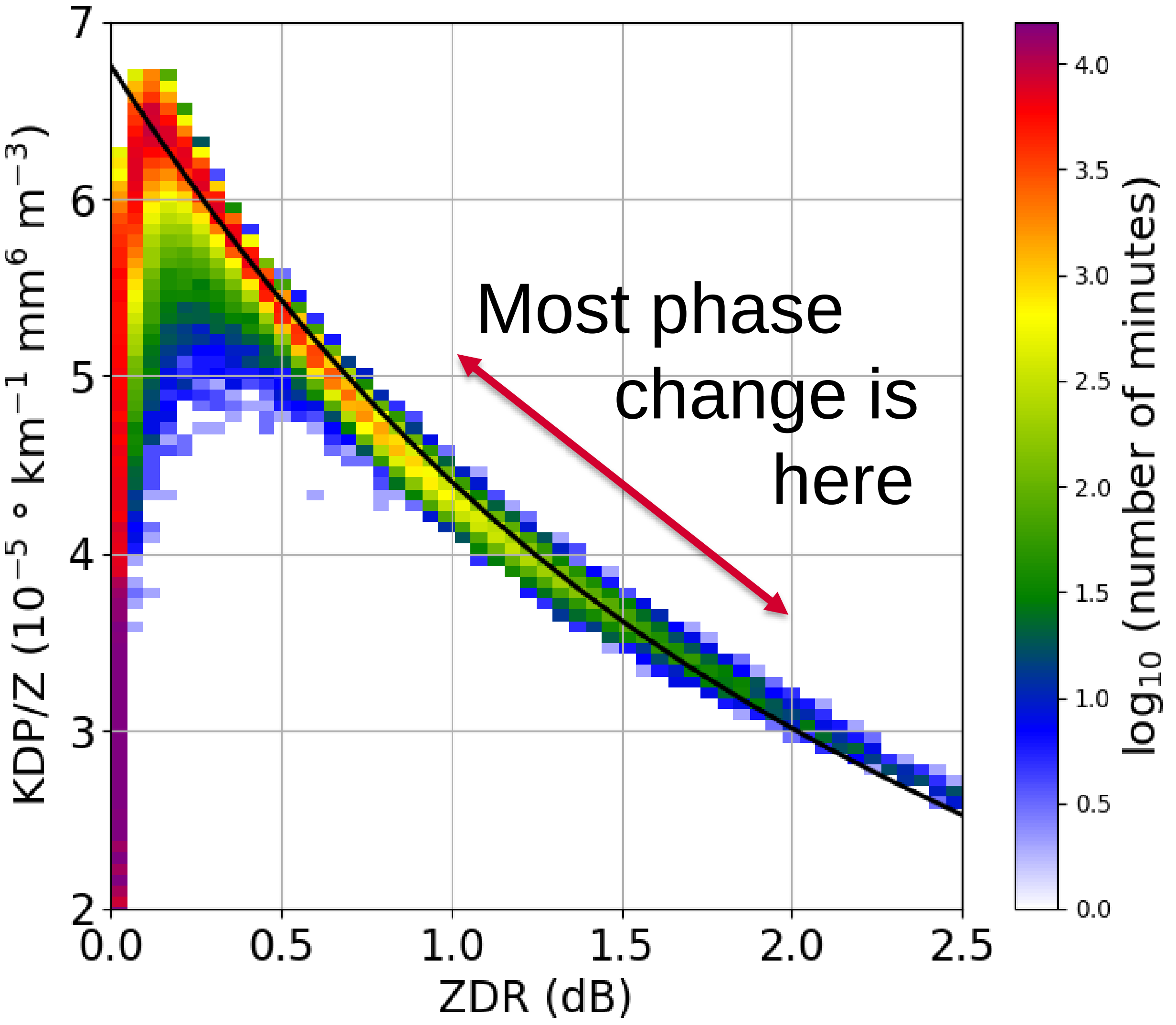


6. How Accurate Do We Need Z_{DR}?

University of Reading

- Calibration of Z_{DR} is potentially problematic (see workshop session 8)

- Majority of observed phase shift occurs where Z_{DR} between 1 and 2 dB
- Slope of the K_{DP}/Z curve suggests a change of about 7% Φ_{DP} for a 0.2 dB change in Z_{DR}.
- Tests show that introducing an artificial bias in Z_{DR} of 0.2dB changes derived calibration by only about 0.3dBZ.



7. Calibrating Operational Radars

University of Reading

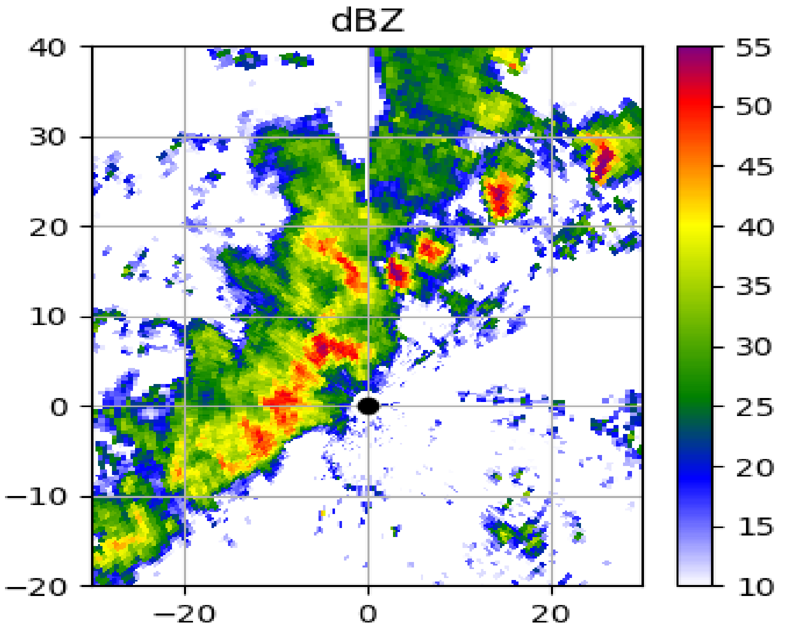
- Must be sure that only rain is the target – ρ_{hv} weighting.
- In summer avoid hail – so limit max Z to 50dBZ.
- Use rain in the range up to ~45km to avoid beam filling problems
- Avoid significant rain over the radar
  - a wet radome will attenuate and produce an apparent change in calibration.
- During winter time, avoid bright band & less heavy rain.
  - Fewer opportunities for calibration.
- UK rain max ρ_{hv}>0.996 – but high Z_{DR} rain has ρ_{hv} of 0.98, lower ρ_{hv} if cluttered.

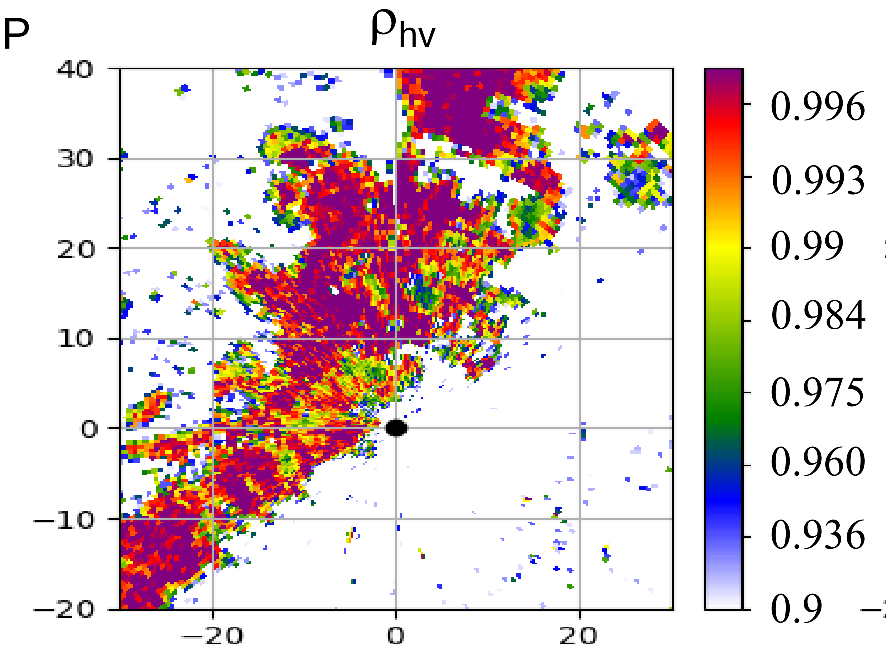
- ONLY ACCEPT RAYS WITH >0.95 CORRELATION BETWEEN OBSERVED AND THEORETICAL Φ_{DP} AND WITH LARGE Φ_{DP} SHIFT RELATIVE TO ITS NOISE.

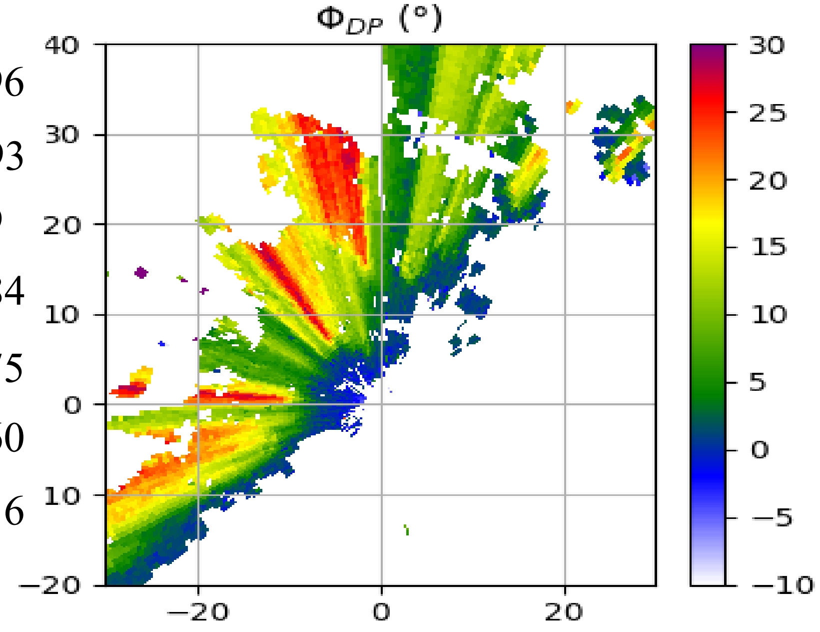
8. Example of 28 July 2021

- Band of convection approaching the Dean Hill radar
- Not yet raining at the radome (no radome attenuation)
- Well under bright band
- Many rays with enough Φ_{DP}
- ρ_{hv}> is high if good SNR,

  0.996 in light rain.





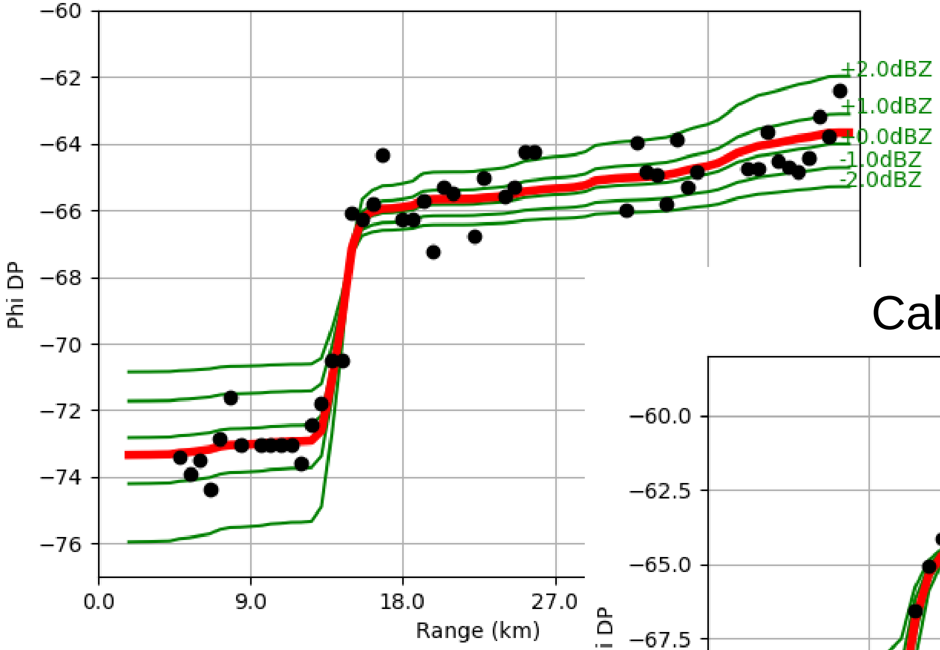


9. Examples From 28 July

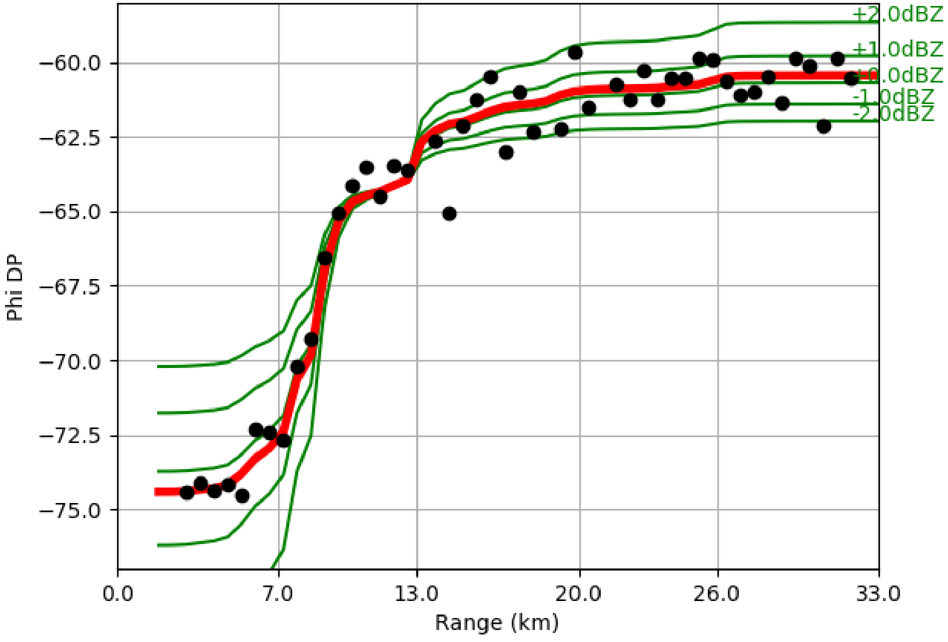
University of Reading

- Across the scan there are 48 good calibration rays
- Calibrations have a mean of 0.54dB
- Standard deviation of 0.31dB

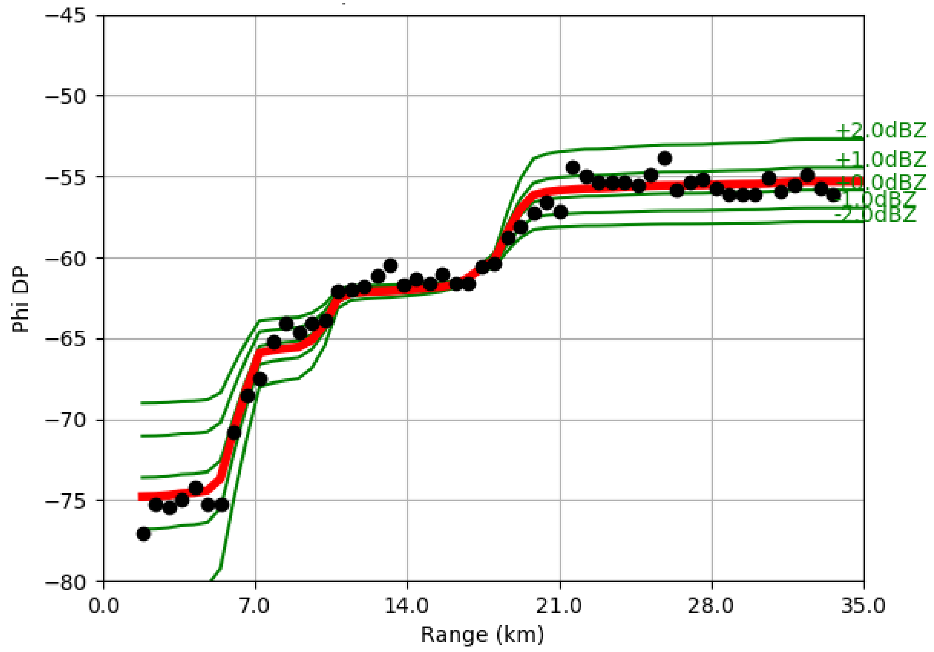
Calibration = 0.4dB



Calibration = 0.3dB



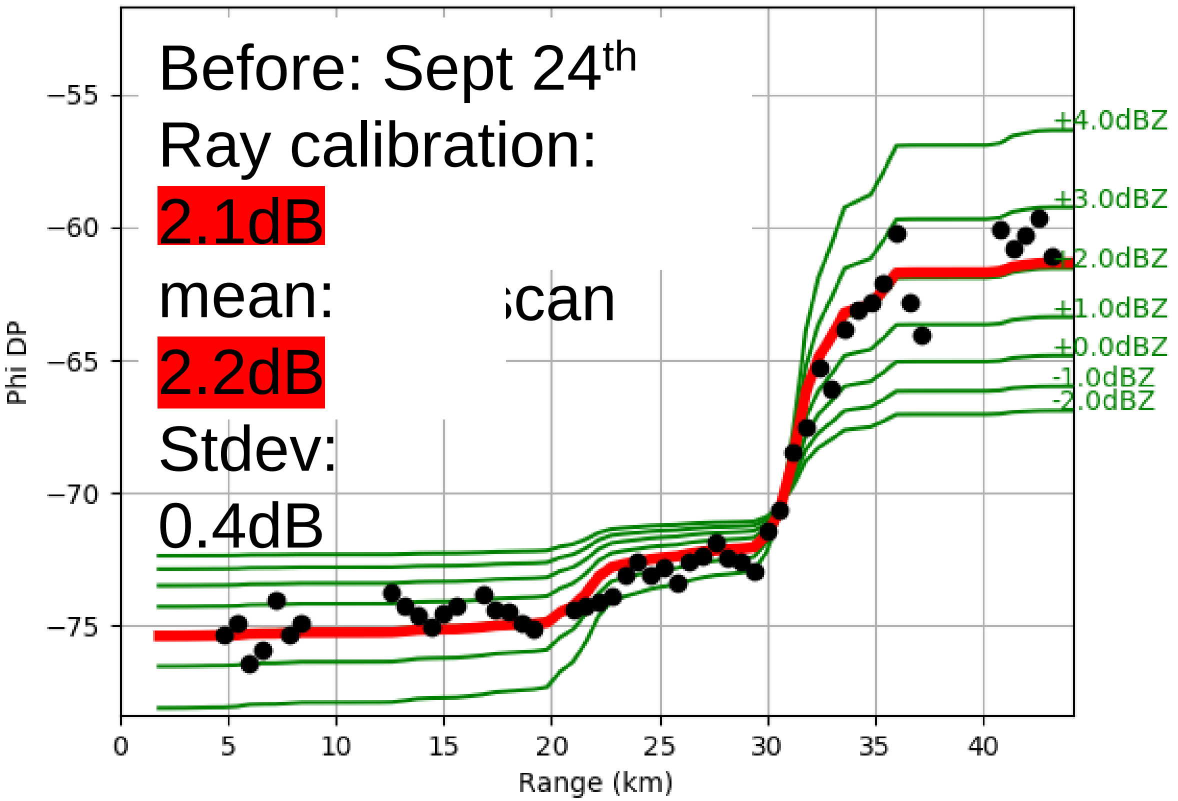
Calibration = 0.4dB

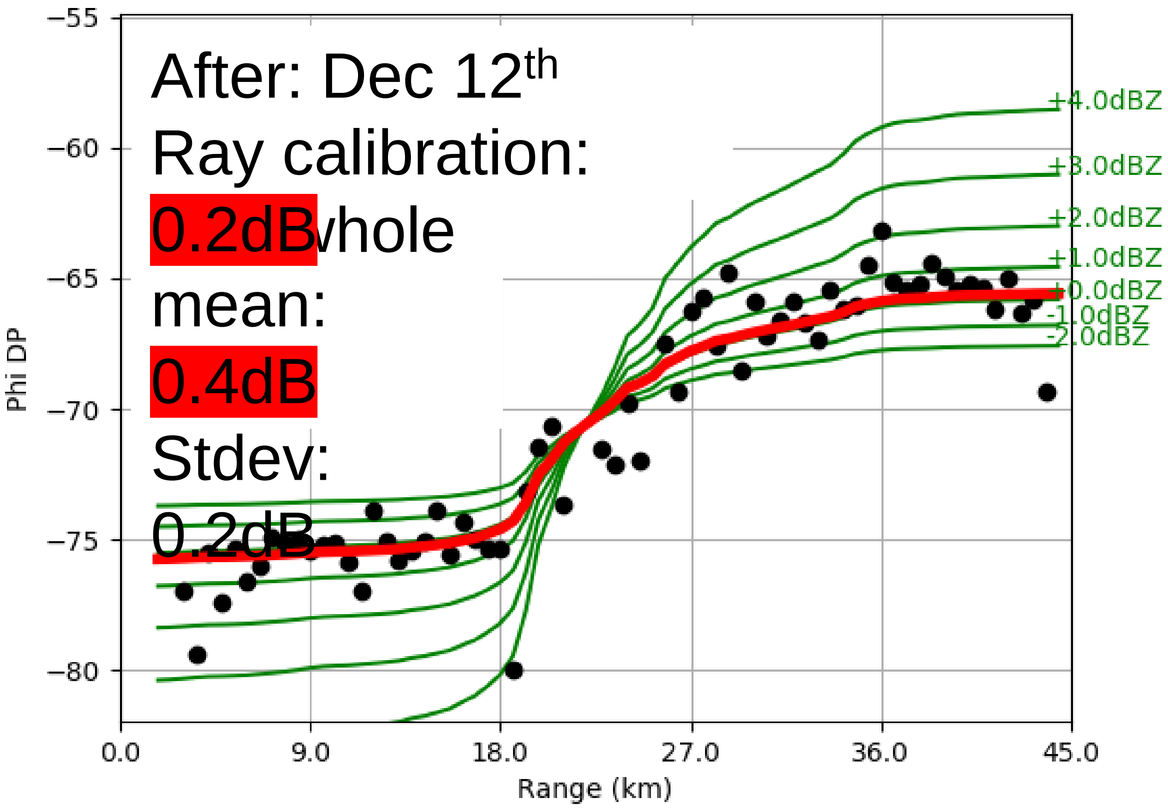


10. The 2dB change in December 2019

University of Reading

- On 9th December 2019 Radar Calibration of UK network changed by 2.0dB
- Change because disdrometer comparisons indicated 2dB miscalibration





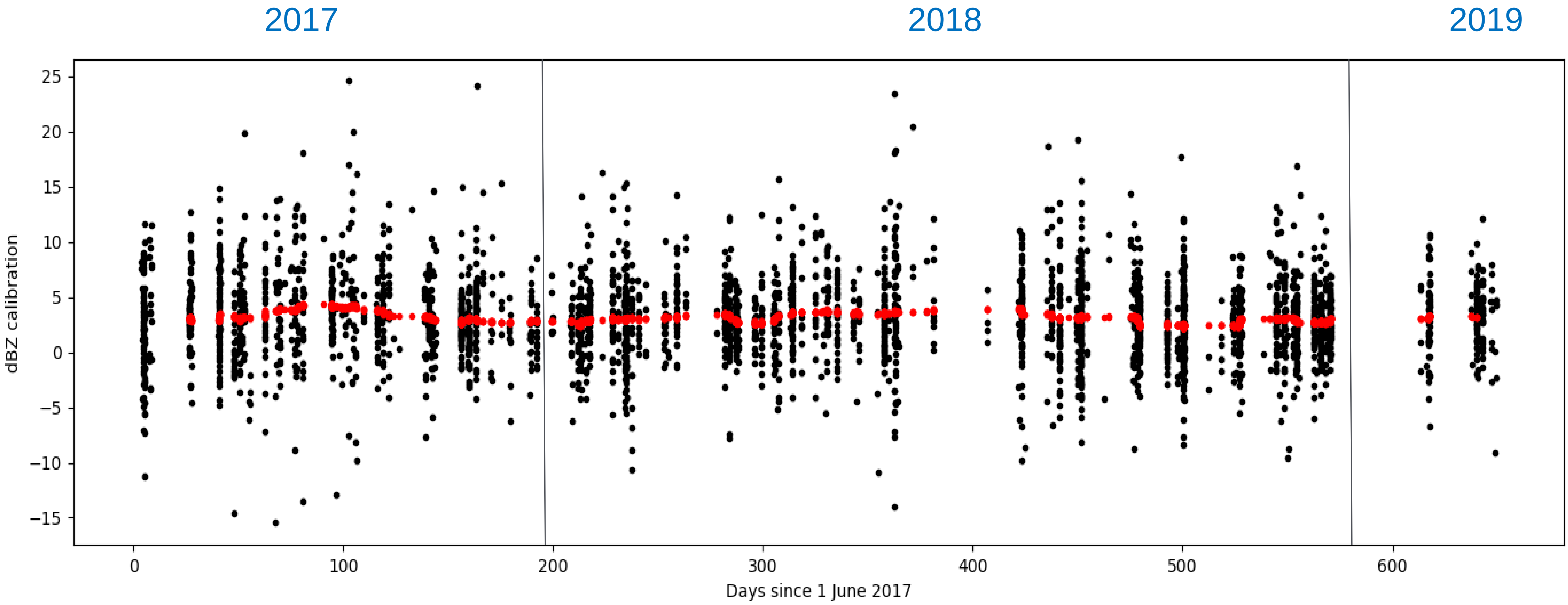
11. Summary

- Radar-Disdrometer comparison shows radars are stable over 2 years.
  - But need months to converge on a precise calibration value
  - Needs a well calibrated disdrometer for each radar
- Differential phase shift accumulation can calibrate operational radar
- Must use high quality data with high ρ_{hv} within the rain.
- Needs reasonably heavy rain within 10-40km from the radar.
- Shows consistency better than 0.5dBZ.
- Able to detect and size a known hardware calibration change.
- If no change to the hardware, the calibration remains CONSTANT.

A1. Comparing Radar to Disdrometer

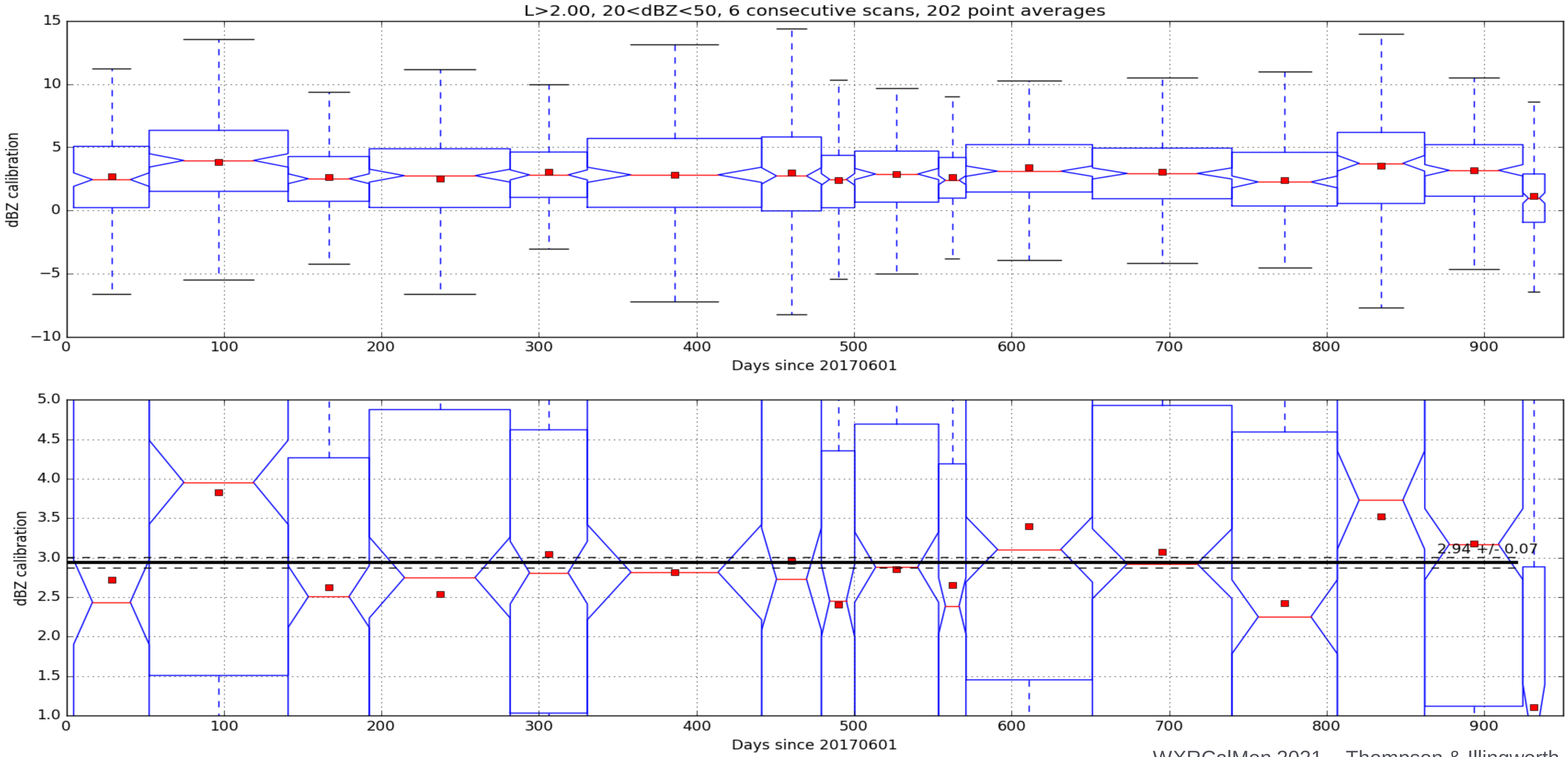
University of Reading

RED IS THE RUNNING MEAN OF 200 SCANS.



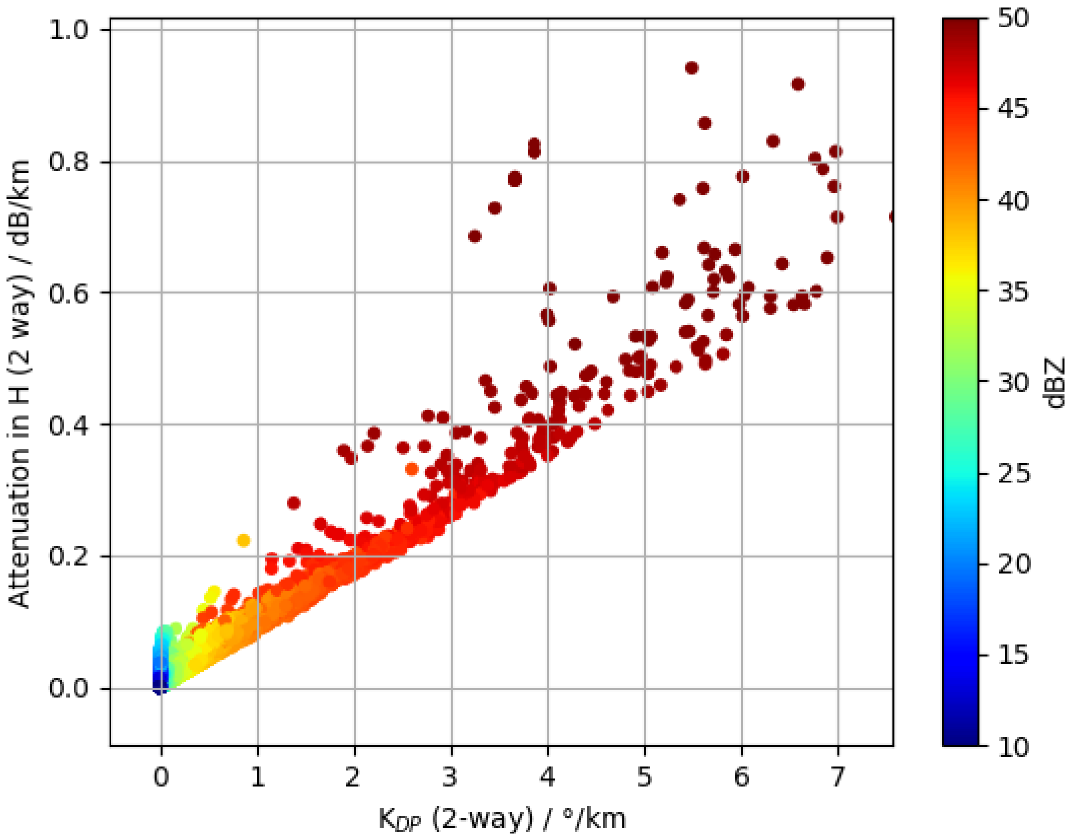
A2. Comparing Radar to Disdrometer

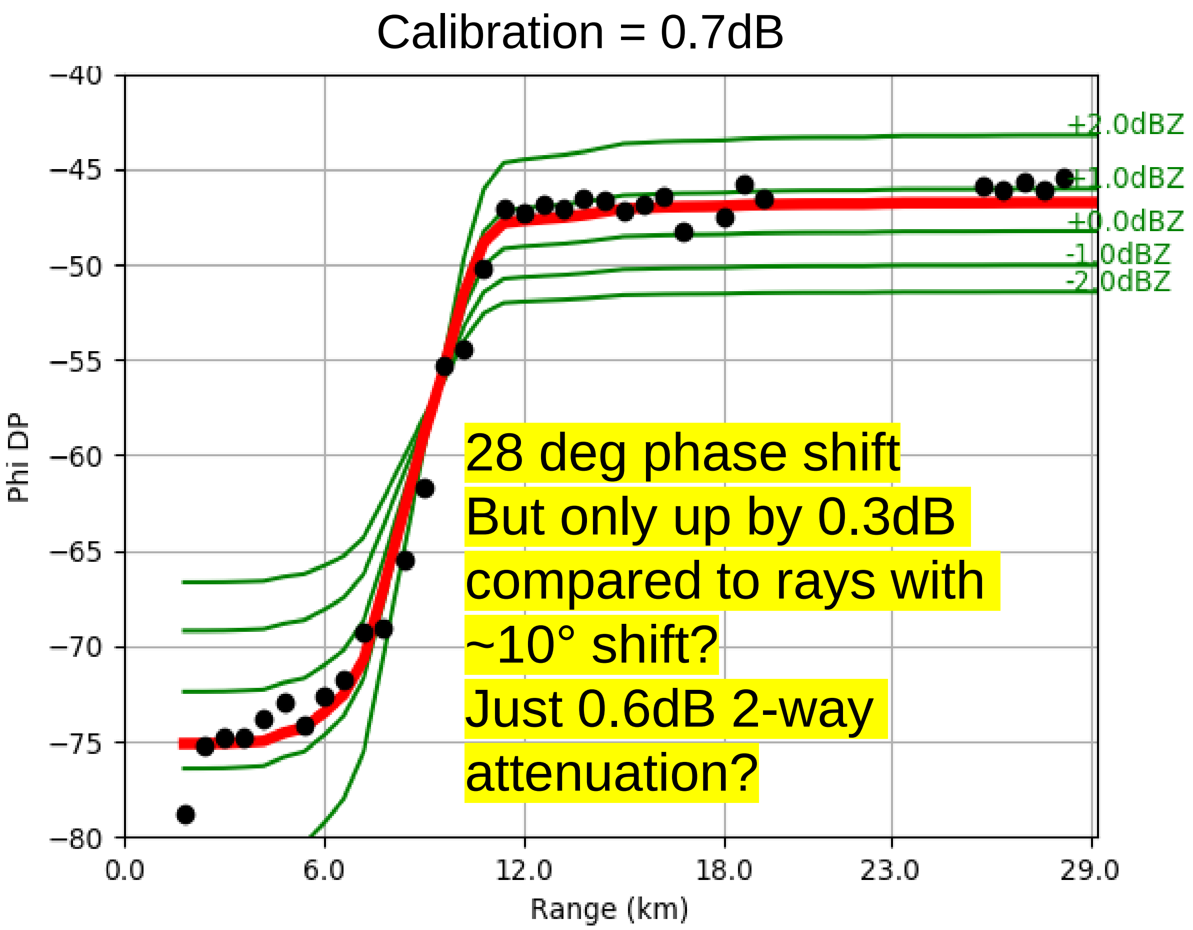
University of Reading



A3. Attenuation Along the Ray

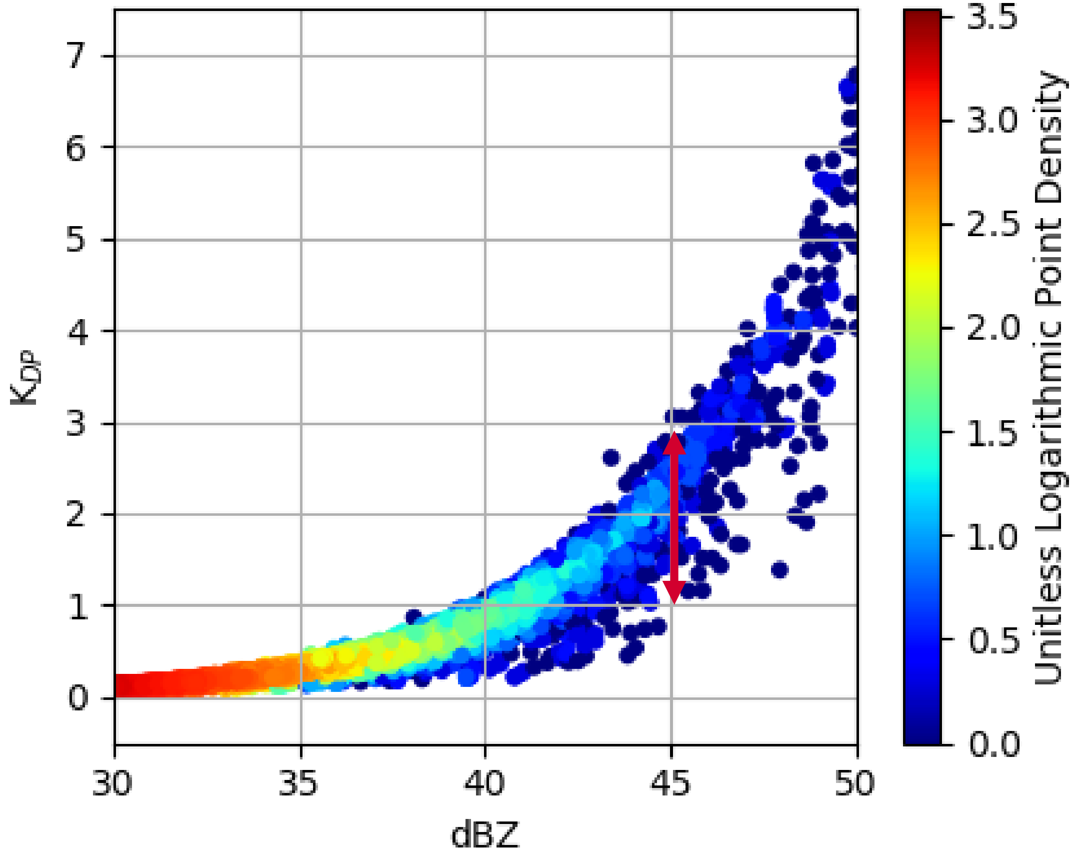
University of Reading





A4. What if no ZDR?

University of Reading



- It is possible to attempt this calibration without Z_{DR}
- But there is a lot more noise on the K_{DP} .
  - e.g. at 45dBZ, K_{DP} is 2.1, but with a 20% variation – that was just 5% when Z_{DR} was available.
- Would make the calibration much less accurate.

A5. Radome/Close Range Attenuation

- 10 Minutes after the earlier example.
- Now heavy rain at the radar – radome attenuation!
- Across the scan there are 58 good calibration rays
- Calibrations have a mean of 2.47dB (1.9dB atten.)
- Standard deviation of 0.39dB