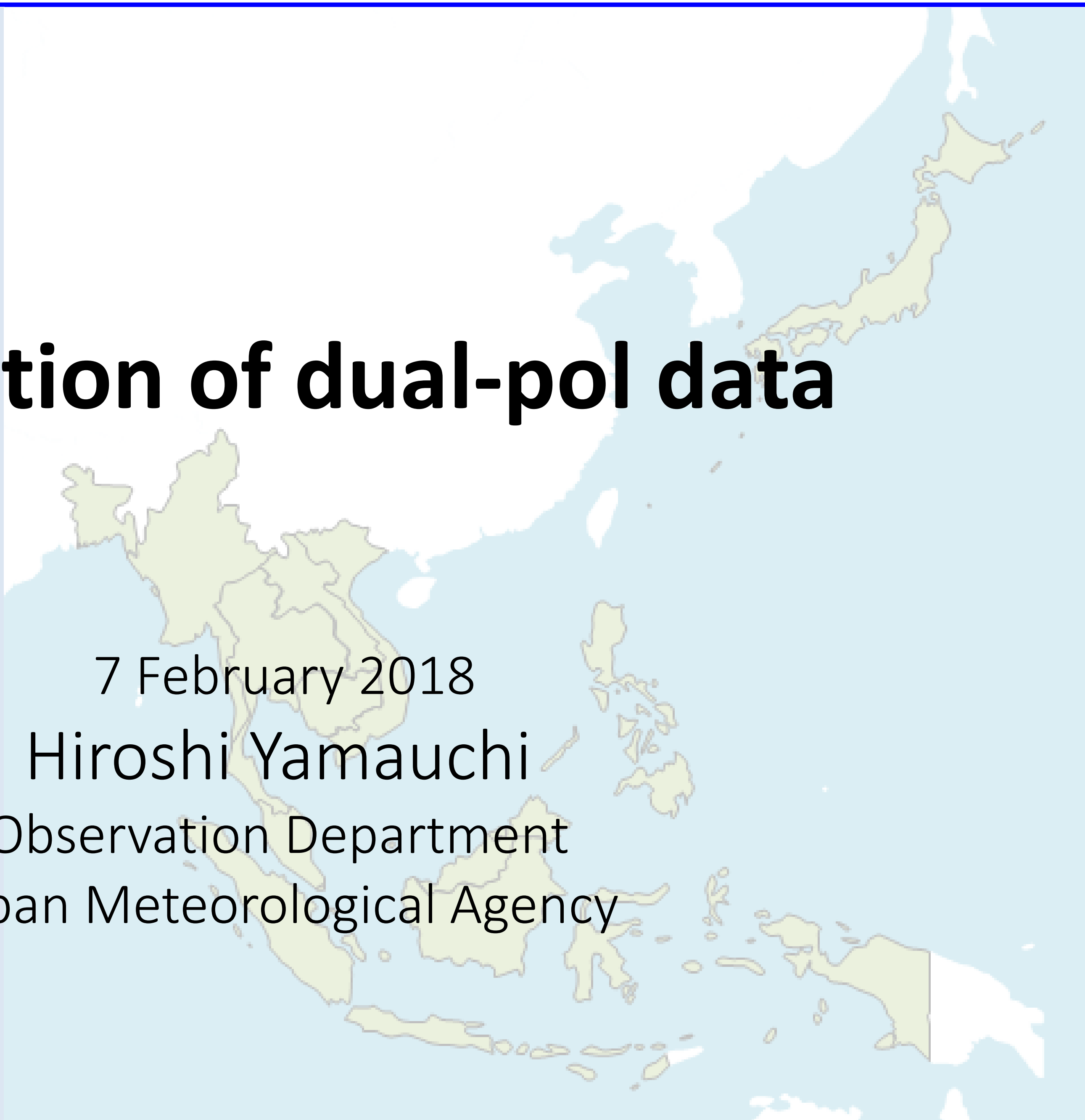

Calibration of dual-pol data

7 February 2018

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Observation Department

Japan Meteorological Agency

Contents

- Required accuracy for dual-pol
- Calibration of Z (absolute calibration)
- Calibration of Zdr and Φdp
- ρhv correction to mitigate effect of noise

Required accuracy for dual-pol

Error = random error + systematic error (bias)

- Bias of Z ← ±1 (dB)
- Bias of Z_{DR} ← ±0.1~0.2 (dB) ← very high accuracy!!

■CIMO GUIDE

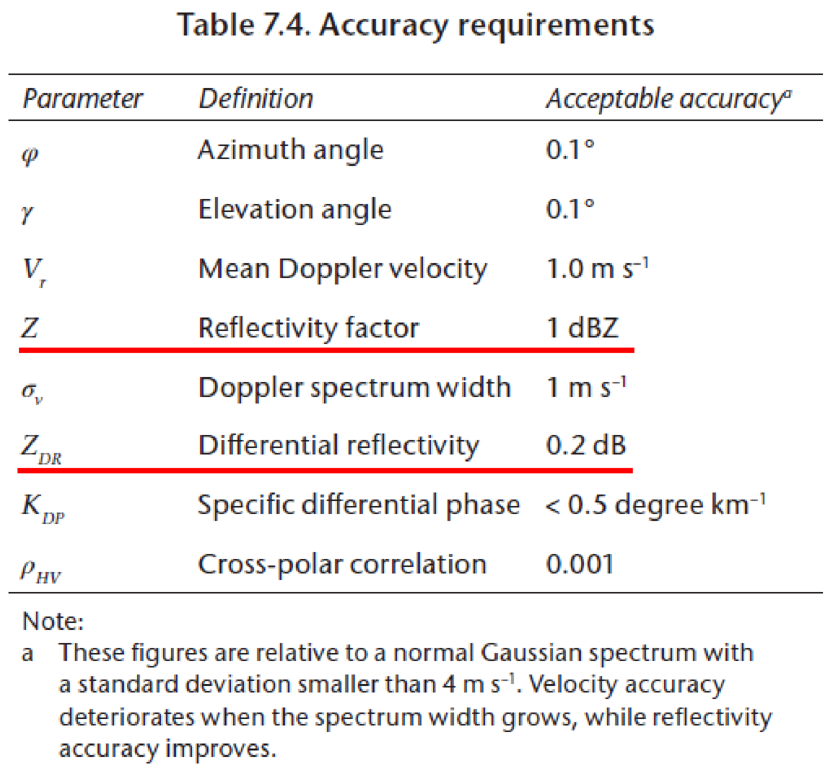


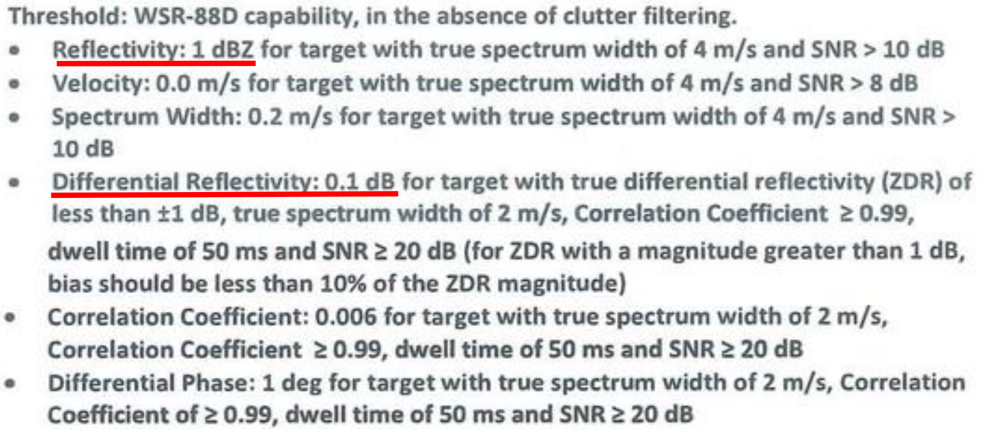
Table 7.4. Accuracy requirements

Parameter	Definition	Acceptable accuracy[a]
φ	Azimuth angle	0.1°
γ	Elevation angle	0.1°
V_r	Mean Doppler velocity	1.0 m s^{-1}
Z	Reflectivity factor	1 dBZ
σ_v	Doppler spectrum width	1 m s^{-1}
Z_{DR}	Differential reflectivity	0.2 dB
K_{DP}	Specific differential phase	< 0.5 degree km^{-1}
ρ_{HV}	Cross-polar correlation	0.001

Note:

a These figures are relative to a normal Gaussian spectrum with a standard deviation smaller than 4 m s^{-1}. Velocity accuracy deteriorates when the spectrum width grows, while reflectivity accuracy improves.

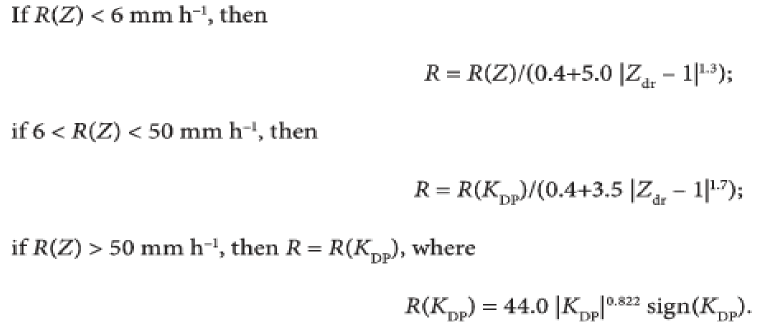
■NOAA/National Weather Service Radar Functional Requirements (2015)



Threshold: WSR-88D capability, in the absence of clutter filtering.

- Reflectivity: 1 dBZ for target with true spectrum width of 4 m/s and SNR > 10 dB
- Velocity: 0.0 m/s for target with true spectrum width of 4 m/s and SNR > 8 dB
- Spectrum Width: 0.2 m/s for target with true spectrum width of 4 m/s and SNR > 10 dB
- Differential Reflectivity: 0.1 dB for target with true differential reflectivity (ZDR) of less than ±1 dB, true spectrum width of 2 m/s, Correlation Coefficient ≥ 0.99, dwell time of 50 ms and SNR ≥ 20 dB (for ZDR with a magnitude greater than 1 dB, bias should be less than 10% of the ZDR magnitude)
- Correlation Coefficient: 0.006 for target with true spectrum width of 2 m/s, Correlation Coefficient ≥ 0.99, dwell time of 50 ms and SNR ≥ 20 dB
- Differential Phase: 1 deg for target with true spectrum width of 2 m/s, Correlation Coefficient of ≥ 0.99, dwell time of 50 ms and SNR ≥ 20 dB

■NEXRAD (Ryzhkov et al. 2005)



If $R(Z) < 6$ mm h^{-1}, then

$$R = R(Z)/(0.4+5.0\,|Z_{dr} - 1|^{1.3});$$

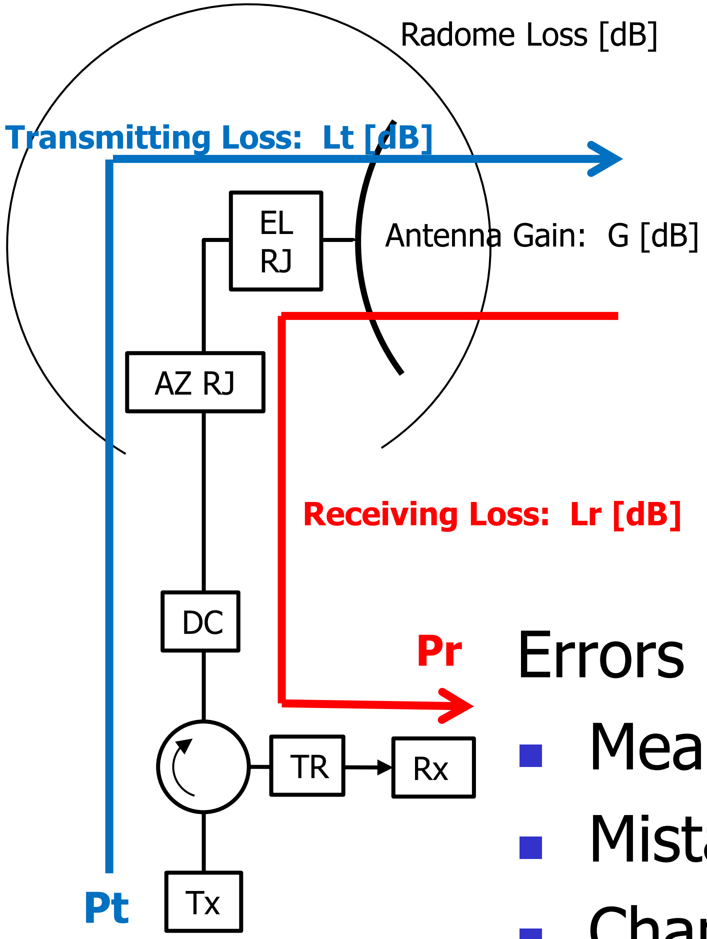
if $6 < R(Z) < 50$ mm h^{-1}, then

$$R = R(K_{DP})/(0.4+3.5\,|Z_{dr} - 1|^{1.7});$$

if $R(Z) > 50$ mm h^{-1}, then $R = R(K_{DP})$, where

$$R(K_{DP}) = 44.0\,|K_{DP}|^{0.822}\,\mathrm{sign}(K_{DP}).$$

Causes of Z bias



Radome Loss [dB]

Transmitting Loss: Lt [dB]

EL RJ

Antenna Gain: G [dB]

AZ RJ

Receiving Loss: Lr [dB]

DC

Pr

TR

Rx

Pt

Tx

Radar equation

$$P_r = \frac{\pi^3 \cdot c}{2^{10}\log_e 2}\cdot\frac{P_t\cdot\tau\cdot G^2\cdot Lt\cdot Lr\cdot\theta\cdot\phi}{\lambda^2}\cdot\frac{1}{r^2}\left|\frac{\varepsilon-1}{\varepsilon+2}\right|^2 Z$$

$$\Downarrow$$

$$Z = \frac{2^{10}\log_e 2}{\pi^3\cdot c}\cdot\boxed{\frac{\lambda^2}{P_t\cdot\tau\cdot G^2\cdot Lt\cdot Lr\cdot\theta\cdot\phi}}\cdot r^2\left|\frac{\varepsilon+1}{\varepsilon-2}\right|^2\boxed{P_r}$$

Errors in hardware parameters cause bias in Z.

- Measurement errors of hardware parameters
- Mistakes in setting of radar parameters
- Changes with age

Calibration of Z is called “absolute calibration.”

Calibration of Z

Radar Calibration Spheres | ce

www.centurymetalspinning.com/radar-calibration-spheres/

630.595.3900

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RFQ FOR CALIBRATION SPHERES

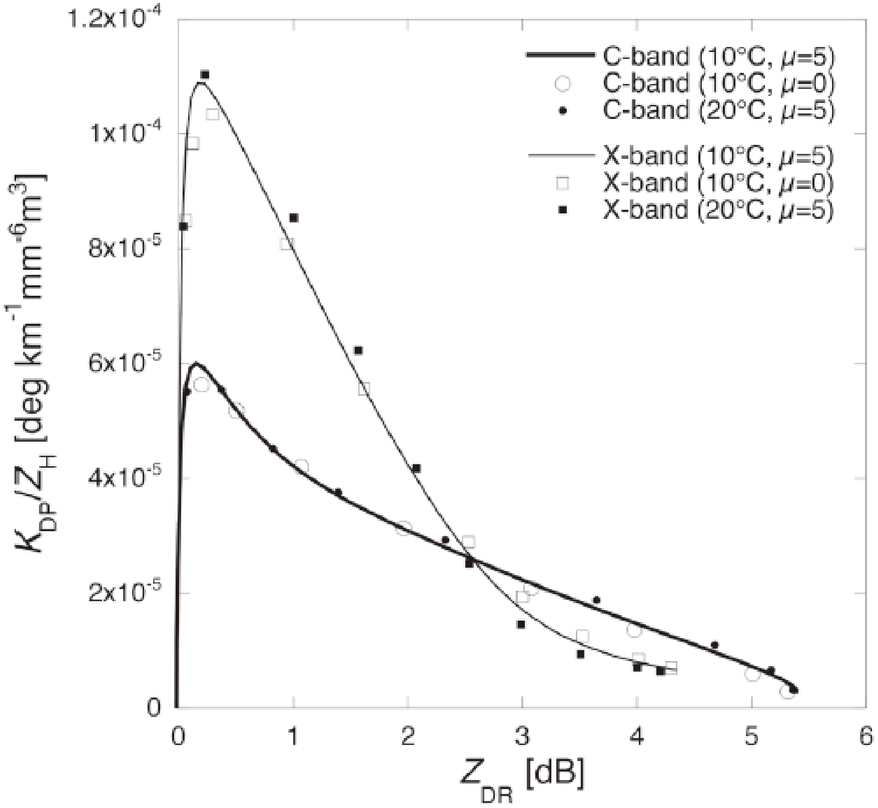
RADAR CALIBRATION SPHERES

2" to 36" Diameter

63 micro inch finish

Mirror Finish

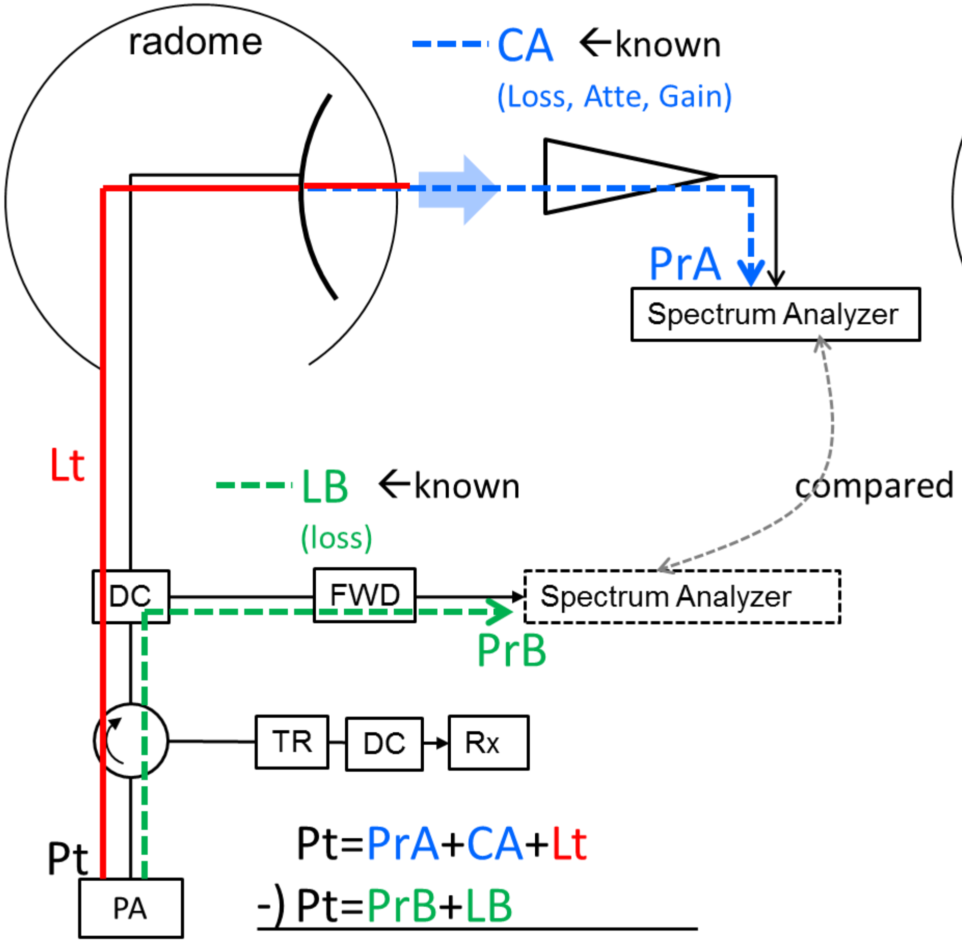
- Using metal sphere
- Using external receiver and transmitter
- Using disdrometer
- Using rain-gauges
- Self-consistency



Adachi et al. 2015: Estimation of Raindrop Size Distribution and Rainfall Rate from Polarimetric Radar Measurements at Attenuating Frequency Based on the Self-Consistency Principle

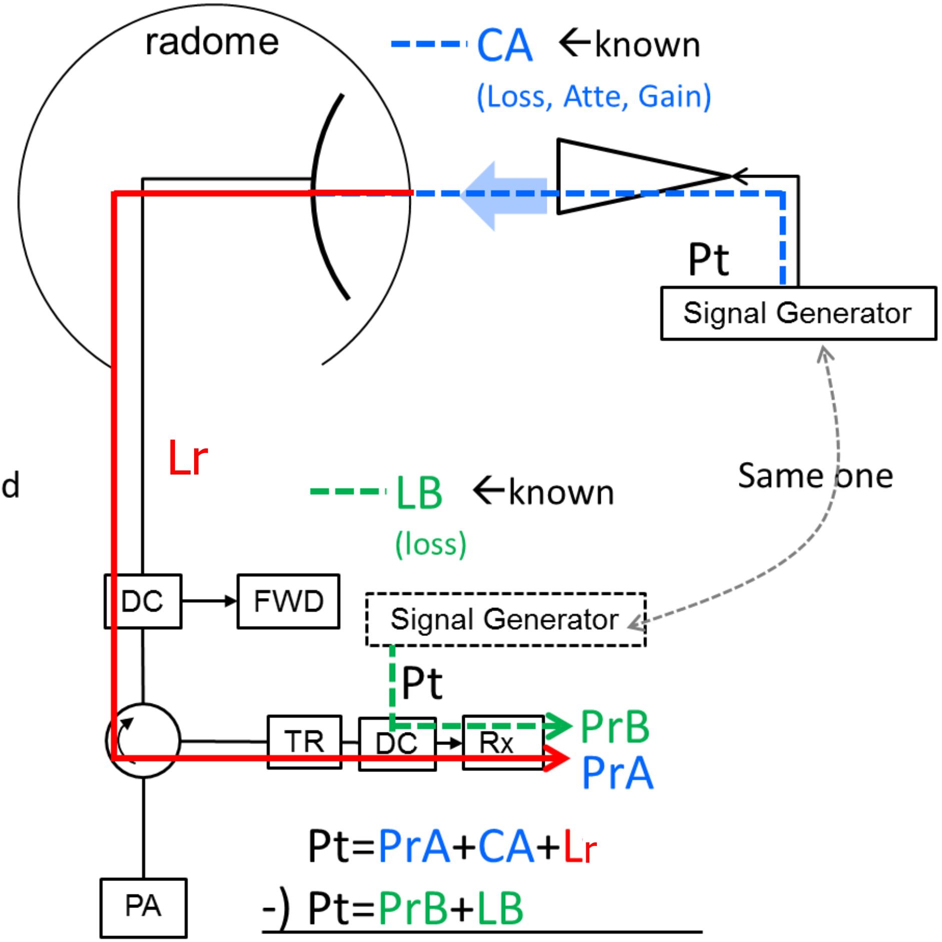
Using External Receiver and Transmitter

①Measurement of transmitting loss



$$\begin{array}{rl} & Pt=PrA+CA+Lt \\ -) & Pt=PrB+LB \\ \hline & Lt=\underbrace{PrA-PrB+CA-LB}_{\text{known / measurable}} \end{array}$$

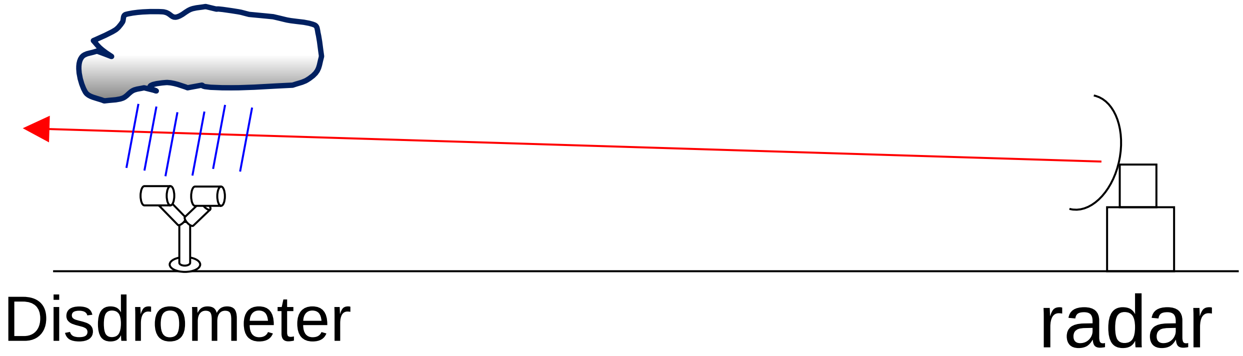
②Measurement of receiving loss

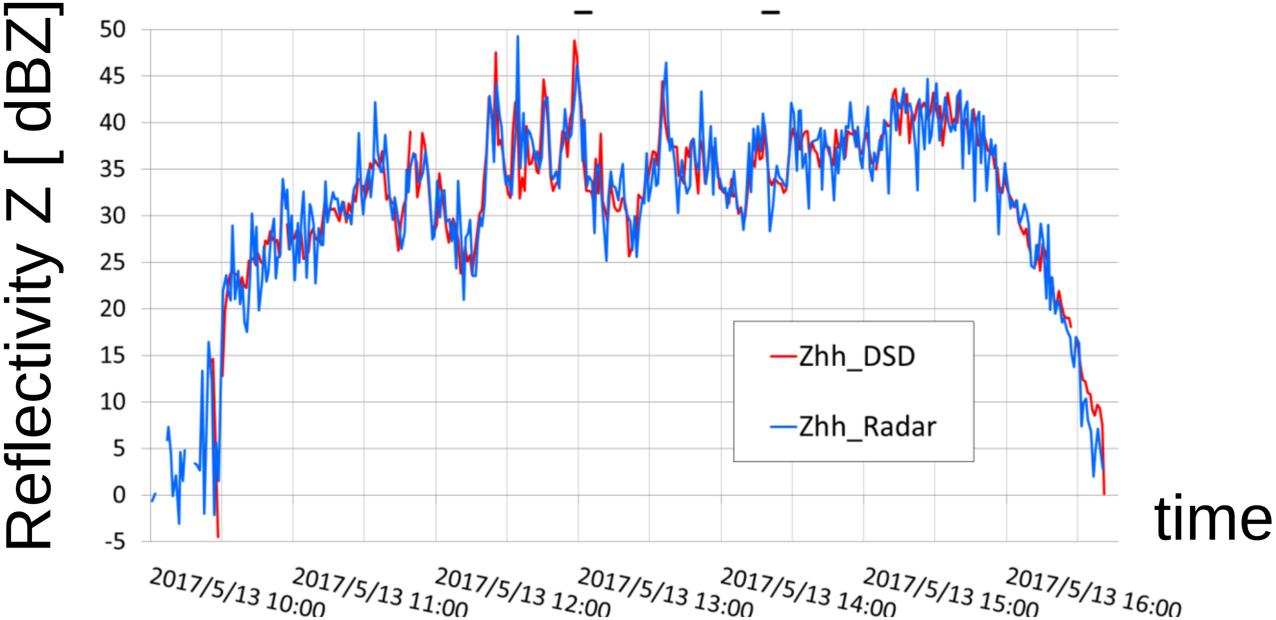


$$\begin{array}{rl} & Pt=PrA+CA+Lr \\ -) & Pt=PrB+LB \\ \hline & Lr=\underbrace{PrA-PrB+CA-LB}_{\text{known / measurable}} \end{array}$$

Using Disdrometer

Both radar and disdrometer observe Z

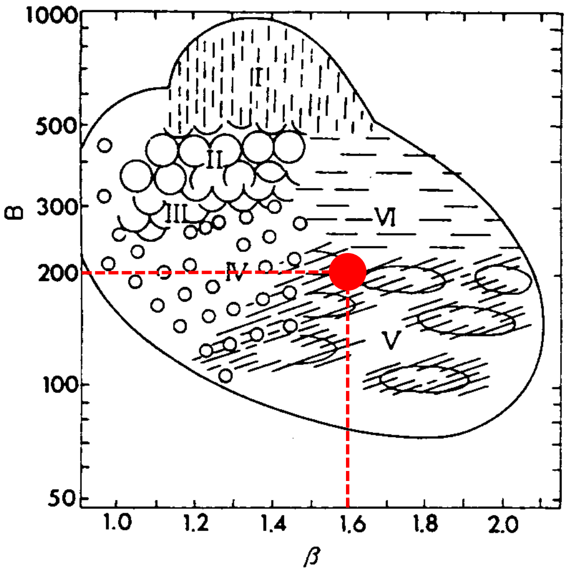




Courtesy of Mr. Umehara

Using rain-gauges

- Assuming Z-R relations (B, β)
- Derive bias as a ratio between accumulative rain-amount observed by rain-gauges and that estimated by radar.



Z-R relation

$$Z = BR^{\beta}$$

$$R = \left(\frac{Z}{B}\right)^{\frac{1}{\beta}}$$

Bias

$$A = \frac{\frac{1}{N}\sum_{i=1}^{N} \mathcal{G}_i}{\frac{1}{N}\sum_{i=1}^{N} \mathcal{R}_i}$$

Bias correction

$$Z_{corr} = \boxed{A^{-\beta}} Z$$

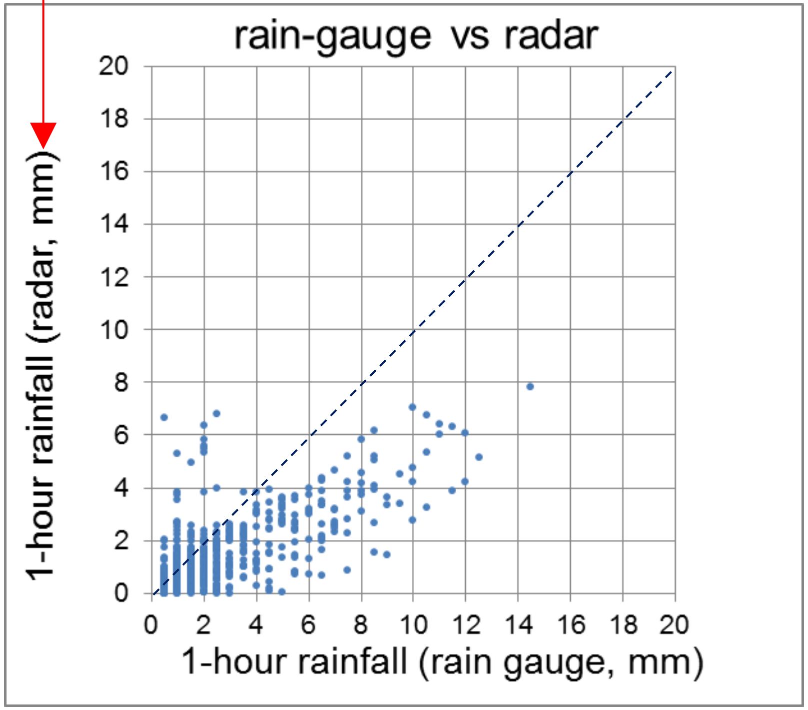
Steiner et al, 1999: Effect of bias adjustment and rain gauge data quality control on radar rain fall estimation. *Water Resour. Res.,* 35, 2487-2503.

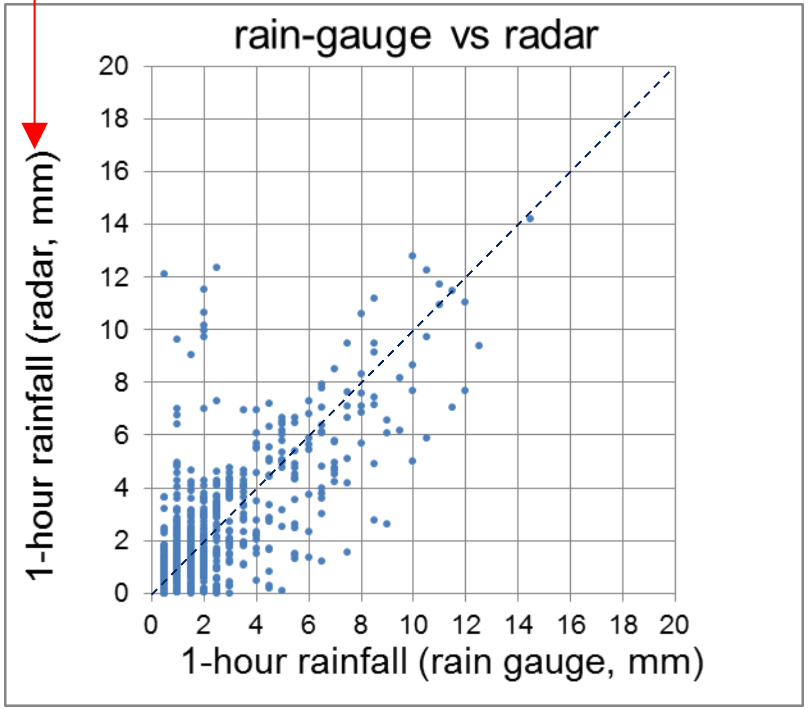
Using rain-gauges

After correction

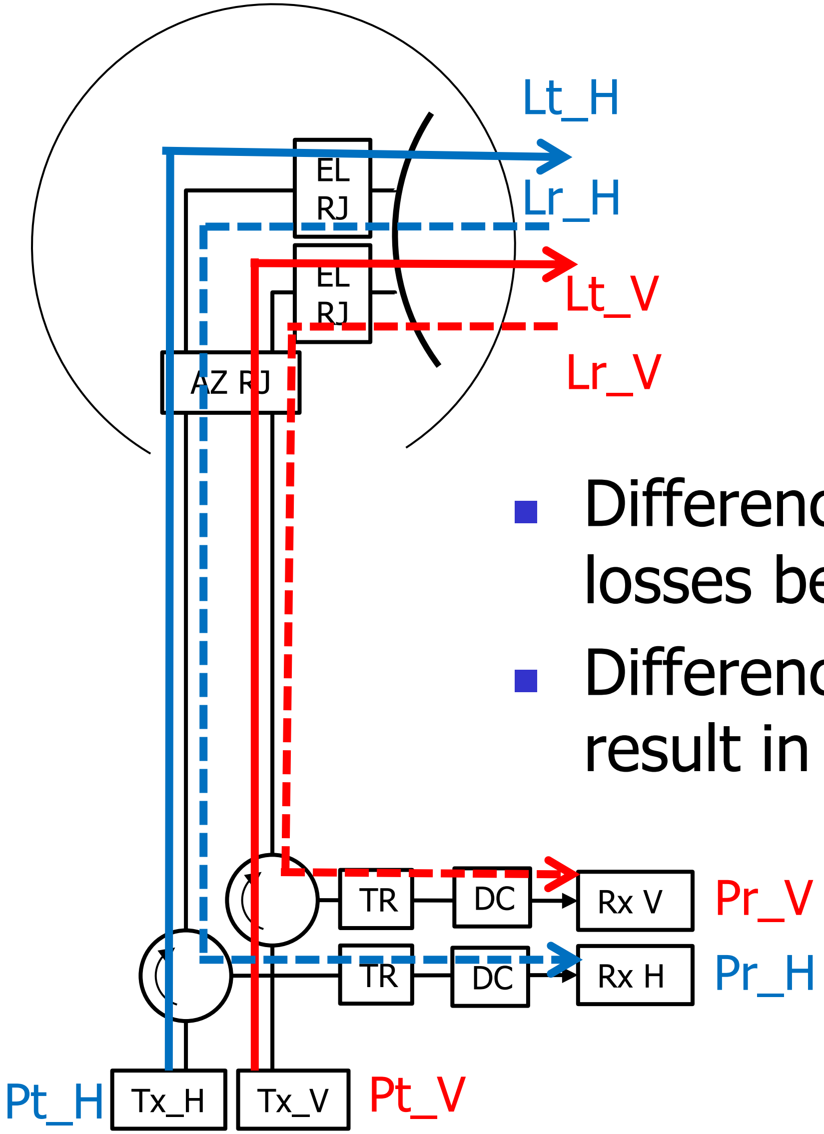
$$R = \left(\frac{Z}{B}\right)^{\frac{1}{\beta}}$$

$$R = \left(\frac{Z_{corr}}{B}\right)^{\frac{1}{\beta}}$$





Causes of Zdr and Φdp bias



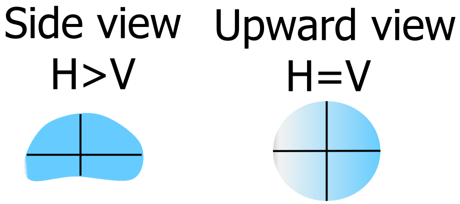
- Difference of Tx power, Rx sensitivity, losses between H and V result in Zdr bias.
- Difference of path length between H and V result in Φdp bias.

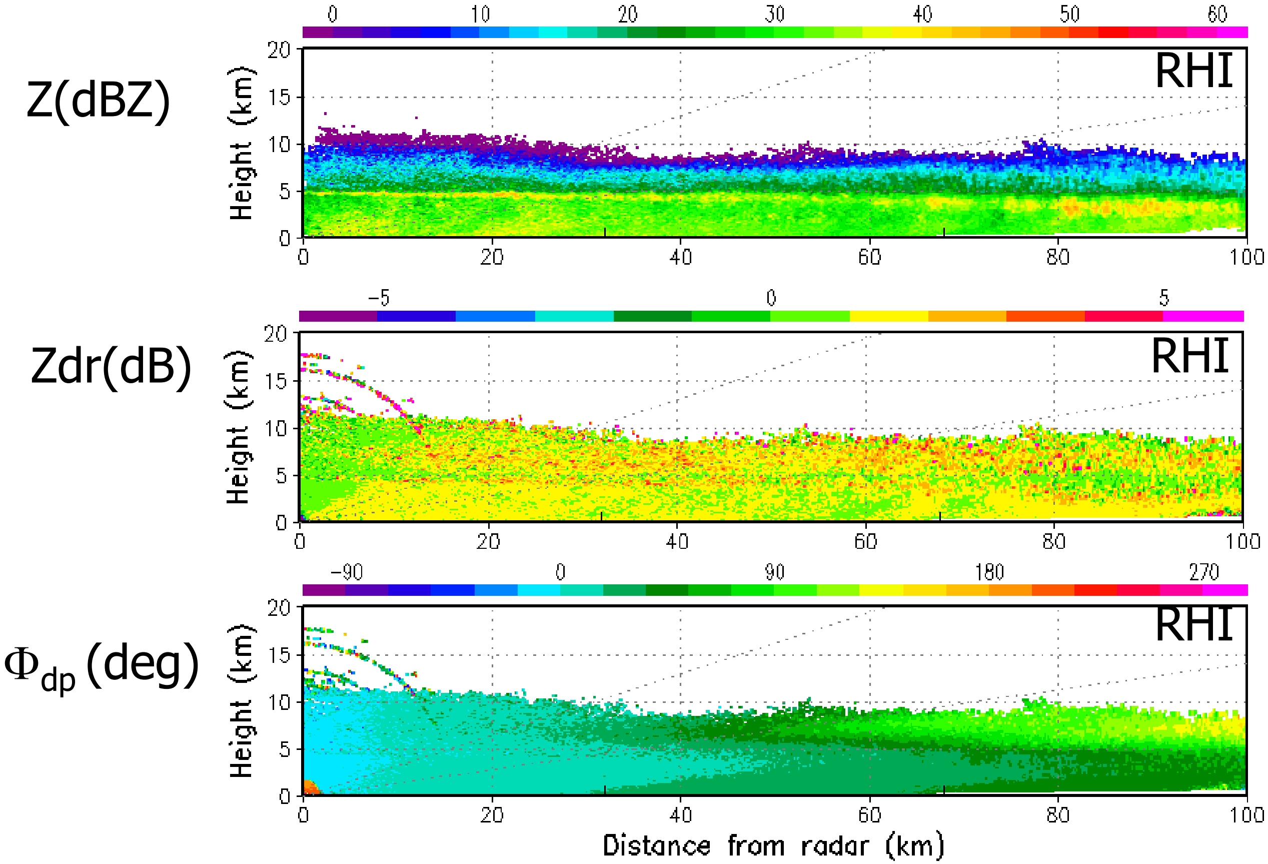
Calibration of Zdr and Φdp

- Using metal sphere
- Bird-bath scan (PPI scan at el=90°)
- Using drizzle or light rain
- Using solar signals (only for Receiver bias)

Bird-bath scan

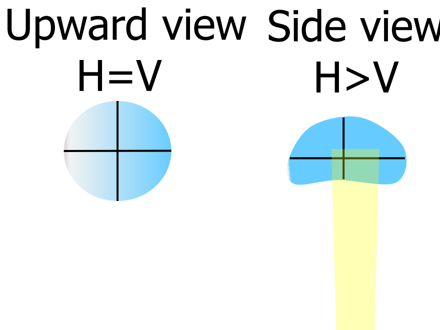
- From upward view, even a large rain drop looks circle

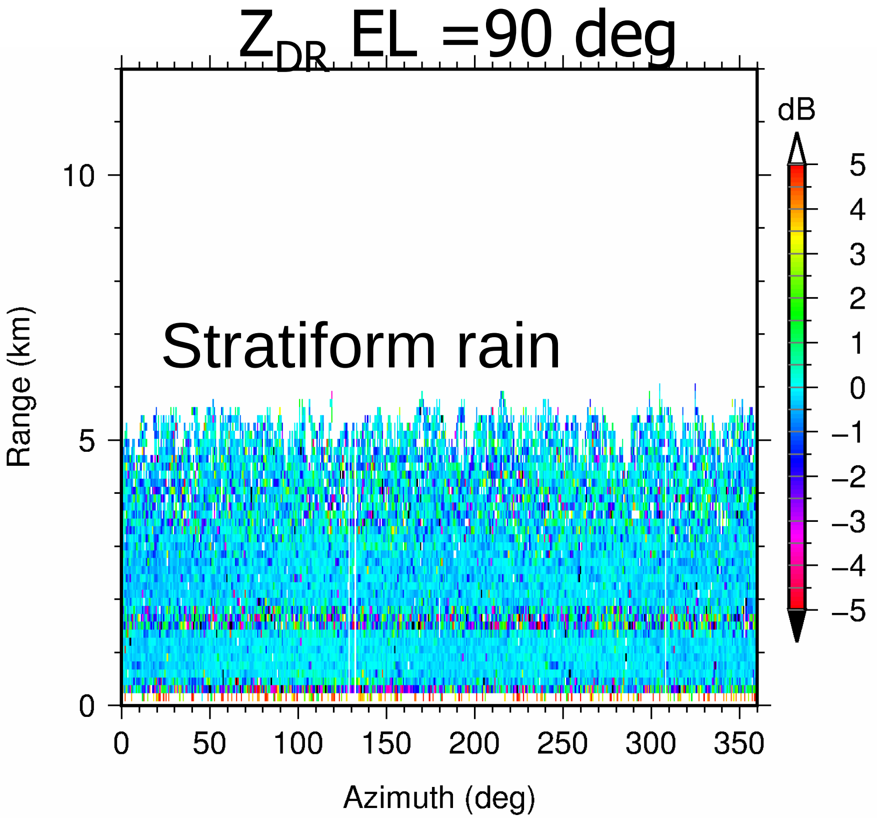


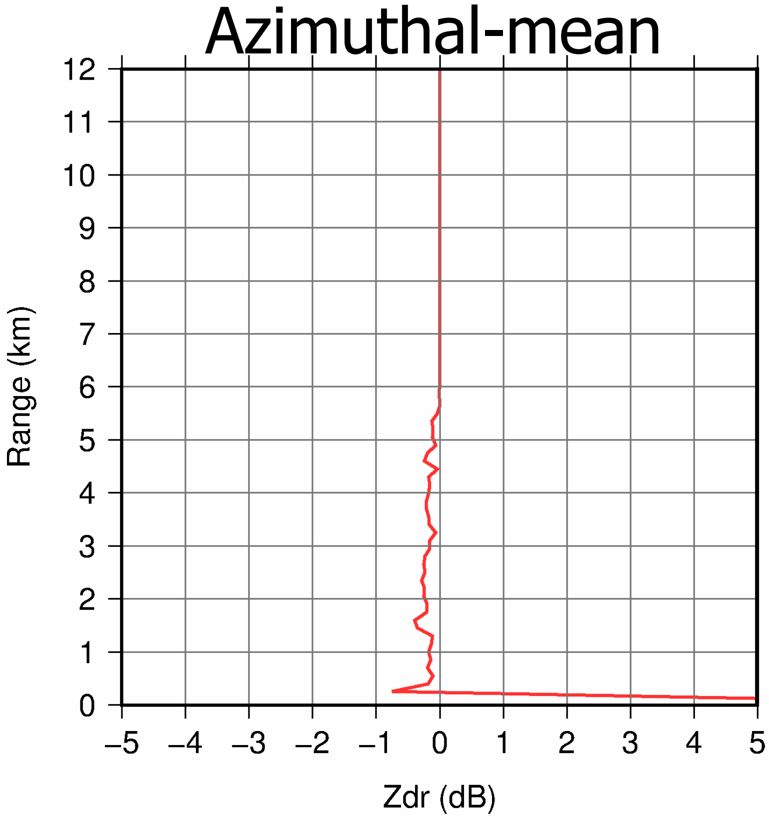


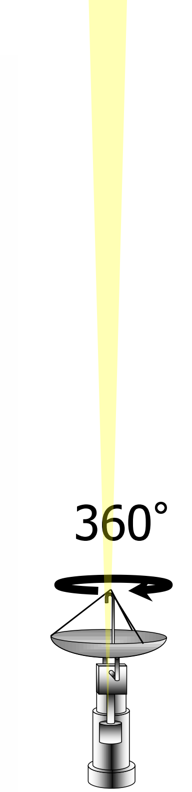
Bird-bath scan

- Useful in estimating Zdr bias and Φdp bias
- Zdr and Φdp must be zero









Courtesy of Mr. Umehara

ρhv correction to mitigate effect of noise

$$\rho_{hv} = \frac{\left|R_{0hv}\right|}{\left(R_{0hh}R_{0vv}\right)^{1/2}} \xrightarrow{\text{correction}} \rho_{hv} = \frac{\left|R_{0hv}\right|}{\left(\left(R_{0hh} - N_h\right)\left(R_{0vv} - N_v\right)\right)^{1/2}}$$

Subtract noise level

Where,

$$V_h[n] = I_h[n] + i\,Q_h[n] \quad n = 1 \ldots N$$
$$V_v[n] = I_v[n] + i\,Q_v[n] \quad n = 1 \ldots N$$

Auto correlation for H signal

$$R_{0hh} = \frac{1}{N}\sum_{n}^{N} V_h[n]V_h^*[n] = \frac{1}{N}\sum_{n}^{N}(I_h^2[n] + Q_h^2[n])$$

Auto correlation for V signal

$$R_{0vv} = \frac{1}{N}\sum_{n}^{N} V_v[n]V_v^*[n] = \frac{1}{N}\sum_{n}^{N}(I_v^2[n] + Q_v^2[n])$$

Cross correlation between H and V

$$R_{0hv} = \frac{1}{N}\sum_{n}^{N} V_v[n]V_h^*[n] = \frac{1}{N}\sum_{n}^{N}\left\{(I_h[n]I_v[n] + Q_h[n]Q_v[n]) + i(I_h[n]Q_v[n] - Q_h[n]I_v[n])\right\}$$

The method which does not depend on noise level estimation is also proposed.
Cheong et al. 2013: The impacts of multi-lag moment processor on a solid-state polarimetric weather radar

Summary

- High accuracy is needed for dual-pol data to make use of them.
- Calibration of Z (absolute calibration)
- Calibration of Zdr and Φdp
- ρhv correction is needed to mitigate effect of noise
- More information will be available via DWD HP of Weather Radar Calibration & Monitoring workshop 2017 https://www.dwd.de/EN/specialusers/research_education/seminar/2017/wxrcalmon2017/wxrcalmon_en_node.html