Calibration of dual-pol data

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Required accuracy for dual-pol

Error = random error + systematic error (bias)

- Bias of \( Z \) \( \leq \pm 1 \) (dB)
- Bias of \( Z_{DR} \) \( \leq \pm 0.1 \sim 0.2 \) (dB) \( \leftarrow \) very high accuracy!!

**CIMO GUIDE**

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<td>( \varphi )</td>
<td>Azimuth angle</td>
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<td>( \tau )</td>
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<td>0.1°</td>
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<tr>
<td>( V_r )</td>
<td>Mean Doppler velocity</td>
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<td>( Z )</td>
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**NOAA/National Weather Service Radar Functional Requirements (2015)**

- **Threshold:** WSR-88D capability, in the absence of clutter filtering.
  - Reflectivity: 1 dB 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 \( \pm 1 \) dB, true spectrum width of 2 m/s, Correlation Coefficient \( \geq 0.99 \), dwell time of 50 ms and SNR \( \geq 20 \) 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 \( \geq 0.99 \), dwell time of 50 ms and SNR \( \geq 20 \) dB
  - Differential Phase: 1 deg for target with true spectrum width of 2 m/s, Correlation Coefficient \( \geq 0.99 \), dwell time of 50 ms and SNR \( \geq 20 \) dB

**NEXRAD (Ryzhkov et al. 2005)**

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

\[
R = \frac{R(Z)}{(0.4 + 5.0 |Z_{dr} - 1|)^3};
\]

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

\[
R = \frac{R(K_{DP})}{(0.4 + 3.5 |Z_{dr} - 1|)^7};
\]

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

\[
R(K_{DP}) = 44.0 |K_{DP}|^{0.822} \text{ sign}(K_{DP});
\]
Causes of Z bias

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.”

Radar equation

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

\[ Z = \frac{2^{10} \log_e 2}{\pi^3 c} \cdot \frac{\lambda^2}{P_t \cdot \tau \cdot G^2 \cdot L_t \cdot L_r \cdot \theta \cdot \phi} \cdot r^2 \left| \frac{\varepsilon + 1}{\varepsilon - 2} \right|^2 P_r \]
Calibration of Z

- 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

1. Measurement of transmitting loss

   radome

   CA \leftarrow \text{known}  
   \text{(Loss, Atte, Gain)}

   DC \rightarrow FWD \rightarrow \text{Spectrum Analyzer} \rightarrow \text{PrB}

   Pt = PrA + CA + Lt

   \Rightarrow Pt = PrB + LB

   Lt = PrA - PrB + CA - LB

   known / measurable

2. Measurement of receiving loss

   radome

   CA \leftarrow \text{known}  
   \text{(Loss, Atte, Gain)}

   Pt

   Signal Generator

   Pt = PrA + CA + Lr

   \Rightarrow Pt = PrB + LB

   Lr = PrA - PrB + CA - LB

   known / measurable
Using Disdrometer

Both radar and disdrometer observe $Z$

Reflectivity $Z$ [dBJ]

Courtesy of Mr. Umehara
Using rain-gauges

- Assuming Z-R relations (B, $\beta$)
- 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

$$A = \frac{1}{N} \sum_{i=1}^{N} G_i = \frac{1}{N} \sum_{i=1}^{N} R_i$$

Bias correction

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

Using rain-gauges

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

After correction

\[ R = \left( \frac{Z_{\text{corr}}}{B} \right)^{\frac{1}{\beta}} \]
Causes of Zdr and $\Phi_{dp}$ 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 $\Phi_{dp}$ bias.
Calibration of Zdr and $\Phi_{dp}$

- Using metal sphere
- Bird-bath scan (PPI scan at $\text{el}=90^\circ$)
- 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 $Z_{DR}$ bias and $\Phi_{dp}$ bias
- $Z_{DR}$ and $\Phi_{dp}$ must be zero

$Z_{DR} \text{ EL} = 90 \text{ deg}$

Stratiform rain

Azimuthal-mean

Range (km)

0 5 10 15 20 25 30 35 40

Azimuth (deg)

0 50 100 150 200 250 300 350

Range (km)

0 1 2 3 4 5

$Z_{DR}$ (dB)

-5 -4 -3 -2 -1 0 1 2 3 4 5

360°

Courtesy of Mr. Umehara
ρ_{hv} correction to mitigate effect of noise

$$\rho_{hv} = \frac{|R_{0hv}|}{(R_{0hh} R_{0vv})^{1/2}}$$

Where,

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

Auto correlation for H signal

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

Auto correlation for V signal

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

Cross correlation between H and V

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

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 $Z_{dr}$ and $\Phi_{dp}$
- $\rho_{hv}$ correction is needed to mitigate effect of noise
- More information will be available via DWD HP of Weather Radar Calibration & Monitoring workshop 2017