EVALUATION OF DWD RADAR CALIBRATION BASED ON COLLOCATED SPECTRAL POLARIMETRIC OBSERVATIONS FROM W-BAND CLOUD RADAR

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ROHDE & SCHWARZ
Make ideas real
CONVENTIONAL DISDROMETER-BASED CALIBRATION

Freq: C-band (5.6 GHz)
Min. Range: 1 km
Res. Vol: 15000 m³

Surface
Samp. Area: ~50cm²

High short-term uncertainty due to sampling effects:
- Spatial and temporal DSD variability
- Different sampling volumes
CONTRIBUTION OF LARGE DROPS TO C-BAND REFLECTIVITY

Normalized gamma, NL = 8000, D0 = 1.1 mm, RR = 3 mm/h, Ze ~ 30 dBZ

Normalized Cumulative Zd distribution [dBZ]

Equivolumetric drop diameter [mm]

1 dB
CONTRIBUTION OF LARGE DROPS TO C-BAND REFLECTIVITY

1 dB accuracy relies on a few drops per minute observed by a typical disdrometer (50 cm²)

0.5 dB accuracy 0.1 - 1 drop per minute

Coarse size-velocity grid
CONVENTIONAL DISDROMETER-BASED CALIBRATION

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Min. Range: 1 km
Res. Vol: **15000 m³**

Surface Samp. Area: ~**50cm²**

High short-term uncertainty due to:
- Sampling effects
- Spatial and temporal DSD variability

In order to reduce the uncertainty
- **> 20 h** averaging of *vertical* observations in stratiform rain are needed (Frech et al. 2017)

Is there a reliable reference for:
- shorter time scales
- applicable to low elevations
Sampling effects are of less importance due to:
1. Smaller distance in between
2. Smaller resolution volume relative to a weather radar
3. Longer averaging and high SNR (up to 70 dB even in low intensity rain)

Freq: W-band (94 GHz)  
Min. Range: 250 m  
Res. Vol: 140 m³  

Surface  
Samp. Area: ~50 cm²
LARGE DROPS AT 94 GHZ

Normalized gamma, NL = 8000, D0 = 1.1 mm, RR = 3 mm/h

Mie scattering $d^{-6}$

1 dB
LARGE DROPS AT 94 GHZ

Disdrometer observations are much more representative for W-band

Mean number of detected drops larger than D per min

Normalized gamma, NL = 8000, D0 = 1.1 mm, RR = 3 mm/h

Mie scattering $d^6$

1 dB
**INTERMEDIATE REFERENCE: MM-WAVELENGTH RADAR**

- Accurate calibration (Myagkov et al, 2020)
- More representative observations than a disdrometer (large particles are detected)
- Scanning unit. Profiles from operational weather radar scans can be used.
- A number of range bins can be compared

**Freq: C-band (5.6 GHz)**
- Min. Range: 1 km
- Res. Vol: 15000 m³

**Freq: W-band (94 GHz)**
- Min. Range: 250 m
- Res. Vol: 140 m³

**Problem:** How to derive the reference 5.6-GHz reflectivity for low elevation from the cloud radar?
DSD RETRIEVAL USING DOPPLER SPECTRA

![Diagram showing spectral reflectivity and radial velocity](image)

- **Precipitation**
- **Noise**

**Spectral reflectivity [dBZ/line]**

-60 to 0 dBZ/line

**Radial velocity [m/s]**

-6 to 6 m/s

Falling particles (to the radar)

Ascending particles (from the radar)
DSD RETRIEVAL USING DOPPLER SPECTRA

Uncertainties related to air motions (up/down + turbulence broadening)
Is this also applicable to slanted observations?
SLANT OBSERVATIONS

Precise correction for air motions is needed

Precipitation

Noise

Falling particles (to the radar)

Radial velocity [m/s]

Ascending particles (from the radar)

Doppler shift by air motion
WATER DROP BACKSCATTERING @ 94 GHZ

Rayleigh scattering (scatterer smaller than wavelength)

Mie oscillations (resonance effect, scatterer comparable to wavelength)
WATER DROP BACKSCATTERING @ 94 GHZ

\[ D_e = 0.2 \text{ mm} \]

\[ Z_{DR} \sim 0 \text{ dB} \]
What happens next?
WATER DROP BACKSCATTERING @ 94 GHZ

$D_e = 1.5 \text{ mm}$

$Z_{DR} < 0 \text{ dB}$

Polarimetric “oscillations”
Oscillations can be used for mitigation of air motions

~5.5 m/s terminal velocity
**Variational retrieval** similar to Tridon and Battaglia, 2015 (dual frequency spectra)

- Shift due to horizontal wind
- Turbulence
- Calibration of polarimetric variables
- Attenuation by liquid
- Attenuation by gas
- Air density effects
- Error covariance matrix (Myagkov and Ori, 2021, under revision in AMTD)

Derived profiles of DSD can be used to derive expected profiles of C-band reflectivity
Cloud radar:
- Calibrated at RPG as described in Myagkov et al. 2020
- Rain mitigation system to keep cloud radar radomes dry
- Continuous observations at 30 deg elevation
- 5.5 s sampling, 30 m resolution
- Accurate leveling and pointing

Weather radar:
- Every hour the same direction for 5 min
- 25 m resolution, ~0.2 s sampling
Case study 22 Aug 2021

- 30 deg elevation
- 16:30-16:35 C-band looked to the same direction
- Stratiform precipitation
- Low turbulence
- Rain rate 2-10 mm/h
- W-band Zh ~16-18 dBZ
- Melting layer at 2.3 km
- ZDR oscillation below 1.3 km
COMPARISON: PART 1

Measured

Calculated from cloud radar
COMPARISON: PART 2

Single sample comparison
1363 profiles (5 min)
(Radar – Cloud radar)

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Offset [dB]</th>
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<tbody>
<tr>
<td>5</td>
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<tr>
<td>25</td>
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<td>50</td>
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<tr>
<td>75</td>
<td>0.3</td>
</tr>
<tr>
<td>95</td>
<td>1.0</td>
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</tbody>
</table>
COMPARISON: PART 3

Single sample (~0.2 s) comparison
Total 5 min
(Radar – Cloud radar)
COMPARISON: PART 3

Single sample (~0.2 s) comparison
Total 5 min
(Radar – Cloud radar)

1-min averaged comparison
Total ~182 h (within 3 months)
(Radar – disdrometer, Frech et al, 2017)
SUMMARY AND OUTLOOK

- Novel approach to evaluate weather radar reflectivity using a cloud radar as an intermediate reference
- Applicable to a low number of samples at elevations from 20 to 45 deg
- Reachable accuracy within ±1 dB from a few radar samples
- More data to be analyzed
THANKS FOR YOUR ATTENTION

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References:
• Evaluation of the reflectivity calibration of W-band radars based on observations in rain, Myagkov et al, 2020, AMT
• Analytic characterization of random errors in spectral dual-polarized cloud radar observations, Myagkov and Ori, 2021, AMTD (under revision)
• Monitoring the Absolute Calibration of a Polarimetric Weather Radar, Frech et al, 2017, JTECH
• Dual-frequency radar Doppler spectral retrieval of rain drop size distributions and entangled dynamics variables, Tridon and Battaglia, 2015, JGR
CLOUD RADAR EVALUATION DURING THE CAMPAIGN

![Histogram of ZThies [dBZ] vs Z94 [dBZ]](image)

- The histogram shows the occurrence of ZThies values compared to Z94 values.
- The x-axis represents the difference in dBZ between ZThies and Z94, ranging from -1 to 5.
- The y-axis represents the occurrence frequency.

The distribution indicates a higher occurrence of values close to 0 dBZ difference, with a significant peak at 0 dBZ, suggesting a closer match between the two measurements in this region.
Polarimetric oscillations for a water spheroid

~5.5 m/s terminal velocity

~5.5 m/s terminal velocity
Spectral Differential Reflectivity @ 94 GHz [dBZ]

Spectral Differential Phase @ 94 GHz [deg]

Big drops

Small drops
DSD VARIATIONAL RETRIEVAL

\[
\text{COST FUNCTION} \quad = (y - F[x])^T E^{-1} (y - F[x])
\]

State vector $\mathbf{x}$:
- Number of drops for each spectral bin
- Spectral shift due to air motions
- Spectral broadening due to turbulence

Observation vector $\mathbf{y}$:
- Reflectivity spectrum $H$
- Reflectivity spectrum $V$
- Real covariance spectrum
- Imaginary covariance spectrum

Forward model $\mathbf{F}$:
- Scattering model
- Size-shape-velocity relations
- Air motions and turbulence
- Signal-to-noise ratio

Observation error covariance matrix $\mathbf{E}$:
- Calculated as shown in Myagkov and Ori, 2021