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Automated ZDR Calibration in EEC Dual-Pol Weather Radar Systems

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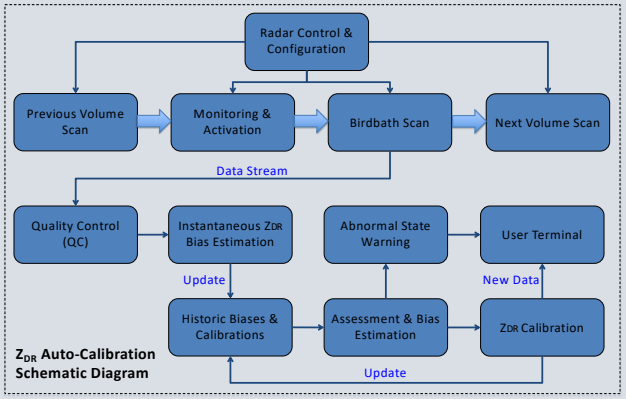
Introduction

The accurate calibration of differential reflectivity (Z_{DR}) is essential for quantitative precipitation estimations (QPE) using dual-pol weather radar data. The engineering approach may not be sufficient due to the effect of temperature variation on system gain/loss. Instead, radar-data-analysis-based methods become more popular. The measurements of ground clutter, light rain, dry aggregated snow, and Bragg scattering can be used for Z_{DR} calibration.

For accurate QPE, the Z_{DR} calibration usually requires an accuracy of 0.1 dB and needs to account for the effect of temperature variation. Moreover, an online calibration is highly desirable so that the calibration can be done frequently without impacting operations. Among all the existing Z_{DR} calibration methods, the birdbath approach has been widely accepted as a robust means for estimating Z_{DR} bias. Based on the birdbath method, Enterprise Electronics Corporation (EEC) recently developed an automated Z_{DR} calibration function in all EEC radar systems. With this function activated, the radar can monitor the Z_{DR} bias with a customized interval (from minutes to hours/days). The birdbath scan is automatically run based on the rain intensity. The light rain data with quality control can be processed in real-time for estimating the Z_{DR} bias. The historical and statistical results of Z_{DR} bias are further analyzed for determining the real-time calibration term. The whole process is completely automated and does not require any human interaction. The Z_{DR} calibration function has been tested using EEC's in-house C-band radar, installed in Enterprise, Alabama. The current study presents the testing results.



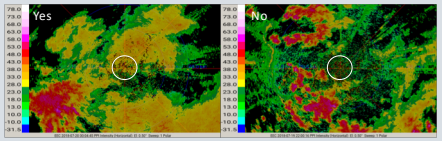
Z_{DR} Auto-Calibration Schematic Diagram

Why Birdbath Method?

- ❑ **Concept:** when the radar vertically observes light rain, the measured Z_{DR} tends to be 0 dB because the raindrop shapes tend to be spherical
- ❑ **Procedure:** Perform a PPI scan with an elevation angle of 90 degrees. Quality-control and process the Z_{DR} data over azimuth and range/height for estimating the mean Z_{DR} bias
- ❑ **Disadvantages of other popular Z_{DR} calibration methods:**
  - Engineering calibration method: instrument and measurement errors; requires radar to be offline
  - Calibration using reflector: hard to setup and repeat
  - Cross-polar power technique: affects normal radar operations
  - Clutter measurement: variation of clutter measurements at/in different time/environments
  - Bragg scattering measurement: depends on the occurrence of turbulence
  - Solar measurement: can not address the channel difference in the transmission
  - Dry aggregated snow measurement: snow model is not as accurate as small raindrop model
  - ***All these methods are inconvenient for the frequent calibration of operational radar systems***
- ❑ **Major advantages of birdbath method:**
  - **Accurate:** fully addressed the H/V channel difference in the signal paths from transmitter to receiver including the antenna
  - **Easy operation & repeat:** Can be done in real-time without affecting weather surveillance

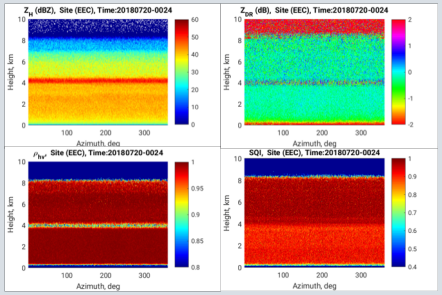
Birdbath scan activation

- Monitor radar observation at the lowest scan
- Activate the birdbath scan: precipitation signal coverage (Z>15 dBZ & ρ_{hv}>0.98) is more than 30% within the range of 10 km



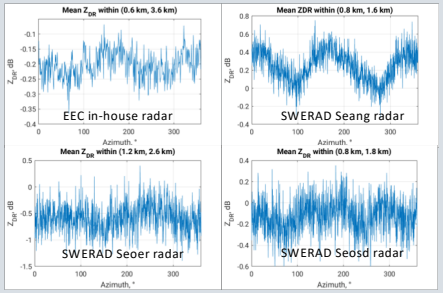
Example of birdbath scan data

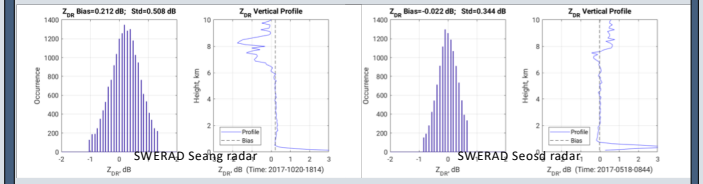
- Right figures show the vertical profiles of Z_H, Z_{DR}, ρ_{hv}, and SQI
- Rain and ice regions have high ρ_{hv} while melting layer evidently has reduced ρ_{hv}
- Dual-pol data can be used for fileting light rain data



Variational pattern of Z_{DR}

- The Z_{DR} of birdbath data has evident azimuthal variation
- The variational pattern shows periodically over azimuth
- For different rain cases, the Z_{DR} variation pattern (i.e., azimuths for peaks, valleys) tends to be similar for a specific radar
- The variation pattern might vary for different radars
- It is less likely that the Z_{DR} azimuthal variation is due to the wind effect on Z_{DR} data while antenna is pointed vertically and scanning
- It is very likely due to the coupling effect of adjacent metal structures (e.g., the lightning rod) on the antenna pattern
- Azimuthal averaging should be able to minimize its effect on Z_{DR} bias estimation





- Mean vertical profile of Z_{DR} data clearly shows the Z_{DR} bias in rain and ice regions (typically, Z_{DR} should be close to zero)
- How to estimate the Z_{DR} bias with birdbath data requires a reliable and robust signal processing

Signal Processing for Z_{DR} Bias Estimation: Three Steps of Data Filtering

1. Light rain data filtering:

- Rain region: height < bottom of melting layer
- Reflectivity: 0~30 dBZ
- ρ_{hv}>0.99
- SQI>0.8

2. Data quality control:

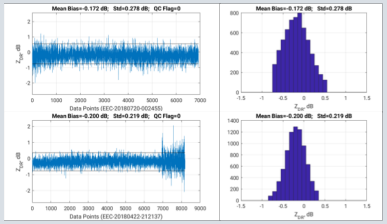
- Avoid clutter contamination: Height > threshold (depending on the location; default 0.6 km)
- Low turbulence: W<1 m/s
- Consistent H and V channels: |W-Wv|<0.1; |SQIh-SQIv|<0.05

3. Statistical assessment:

- Construct Z_{DR} histogram in terms of bins with 0.5 dB interval
- Flag insufficient data points: max@bin< 400
- Cluster data identification and removal
- 90% percentile criterion
- Flag large standard deviation

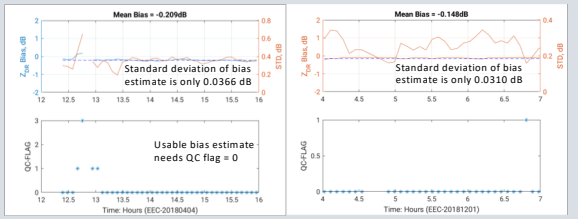
❑ Z_{DR} bias estimation with birdbath data signal processing (right figures ➔)

- *Solid lines mean 90% percentile, which is used for Z_{DR} bias estimate*
- *The standard deviation of filtered Z_{DR} is generally less than 0.4 dB*

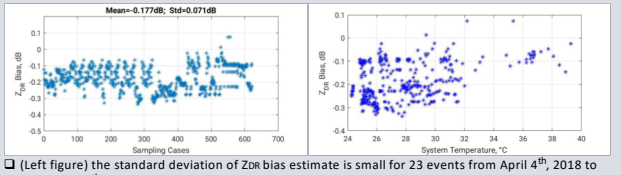


❑ Examples of estimated Z_{DR} bias during an event (figures below ➔)

- *The quality control flag helps to remove the unreliable estimate*
- *Flag=0 denotes good estimates*
- *The standard deviation of the estimated Z_{DR} bias is very small*



❑ The standard deviation of Z_{DR} bias estimate over birdbath scans is very small (e.g., 0.031 dB), implying the robust performance of birdbath method in Z_{DR} bias estimation



❑ (Left figure) the standard deviation of Z_{DR} bias estimate is small for 23 events from April 4th, 2018 to December 1st, 2018. This fact implies that the system have a good stability in H and V channels

❑ (Right figure) the Z_{DR} bias has an evident correlation with the system temperature

Conclusions

- EEC has developed the automated Z_{DR} bias estimation and calibration utility for radar operation
- The calibration can be done in real-time without affecting normal radar operation. The frequency or interval of calibration can be custom configured. Manual intervention is not necessary
- Z_{DR} bias estimate is proved robust with using the birdbath method
- EEC's in-house radar shows stable performance in H and V channels during 8 months of experiments
- The Z_{DR} bias could be related to the temperature variation
- With this new utility, the Z_{DR} bias variation can be well monitored and calibrated