9B.5 METHODS FOR IDENTIFYING SYSTEMATIC DIFFERENTIAL REFLECTIVITY ($Z_{DR}$) BIASES ON THE OPERATIONAL WSR-88D NETWORK

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Goal

Improve performance of dual polarization quantitative precipitation estimates (QPE) by reducing absolute systematic $Z_{DR}$ bias.

Note: Absolute $Z_{DR}$ bias of 0.1 to 0.2 dB produces a 10 - 30% QPE error!
Objectives

1. Develop automated observational methods that evaluate the performance of the current WSR-88D system $Z_{DR}$ calibration method

2. Present fleet-wide statistics from the observational methods

3. Combine these methods to isolate & correct sources of biases
Observational Methods to Identify Total Systematic $Z_{DR}$ Biases

Data collected on targets with intrinsic $Z_{DR} = 0$

- Stratiform: $Z_{DR}^* = 0$ dB
  - *After correction applied (developed by A. Ryzhkov)*
- Boundary Layer Discontinuity
- Dry: $Z_{DR} = 0$ dB
  - Moist

Light Precipitation

Bragg scatter
Observational Methods are Automated with Operational Scanning Strategies

Level II data

Data Filters

Statistical Filters

Systematic $Z_{dr}$ Bias Estimate

Step 1

Step 2
Observational Methods to Identify Total Systematic $Z_{DR}$ Biases

Data collected on targets with intrinsic $Z_{DR} = 0$

- Stratiform
  - $Z_{DR}^* = 0$ dB
  - *After correction applied (developed by A. Ryzhkov)

- Boundary Layer Discontinuity

- Dry
  - $Z_{DR} = 0$ dB

- Moist

- Light Precipitation

- Bragg scatter
Caribou, ME (KCBW)

Systematic $Z_{DR}$ Bias
- Light Precip (Conv)
- Light Precip (Strat)
Antenna bias changed manually based on calibration guidance

Antenna bias reset to previous value

Systematic $Z_{DR}$ Bias

- Light Precip (Conv or Strat)
Fleet-wide Systematic $Z_{DR}$ Biases (based on Light Precip. Method)

82 Sites

100 Sites

116 Sites

129 Sites
Light Precipitation Estimated Biases

July 2013

| \(|\Delta_{\text{precip}}|\) |
|-----------------|
| < = 0.1 dB   | Green  |
| 0.1 to 0.2 dB | Yellow |
| > 0.2 dB      | Red    |

No Data = NaN
Observational Methods to Identify Total Systematic $Z_{DR}$ Biases

Data collected on targets with intrinsic $Z_{DR} = 0$

- **Light Precipitation**: $Z_{DR}^* = 0$ dB
  - *After correction applied (developed by A. Ryzhkov)*

- **Boundary Layer Discontinuity**
  - **Moist**: $Z_{DR} = 0$ dB
  - **Dry**: $Z_{DR} = 0$ dB

- **Bragg scatter**
Bragg Scatter Example – Little Rock, AR
KLZK, 12 May 2013, 15:43Z, 3.5° Elev.

Rings at ~15 and 25 km

Correlation Coefficient > 0.98

Reflectivity < 10 dBZ

Differential Phase ≅ Initial system \( \Phi_{DP} \approx 25° \)

Differential Reflectivity ≅ 0 dB

9B Polarimetric Radar - Data Quality / Calibration
Little Rock, AR (KLZK)
15-16 UTC  22 May 2013
Median = 0.94, Mode = 0.75

Difference from 0 is systematic ZDR bias
Little Rock, AR (KLZK)

Systematic $Z_{DR}$ Bias
- Light Precip (Conv)
- Light Precip (Strat)
- Bragg Scatter

Month/Day

$Z_{DR}$ (dB)

03/31 04/05 04/10 04/15 04/20 04/25 05/01 05/06 05/11 05/16 05/21 05/26 06/01 06/06 06/11 06/16 06/21 06/26 07/01 07/06 07/11 07/16 07/21 07/26 08/01 08/06 08/11 08/16

9B Polarimetric Radar - Data Quality / Calibration
Bragg Scatter Histogram

Raleigh, NC (KRAX)
16-17 UTC 25 May 2013
Median = -0.50, Mode = -0.50

Difference from 0 is systematic ZDR bias

Note: Mode and Median are equal
Raleigh, NC (KRAX)

Systematic $Z_{DR}$ Bias
- Light Precip (Conv)
- Light Precip (Strat)
- Bragg Scatter

Dual polarization components replaced & full calibration done
Systematic $Z_{DR}$ Bias

- Light Precip (Conv)
- Light Precip (Strat)
- Bragg Scatter
Summary

1. The light precipitation method indicates that 56-59% of cases (54-58% of sites) have a $Z_{DR}$ bias within ±0.2 dB for April-July 2013.

2. The Bragg scatter method is a viable alternative to the light precipitation method.

3. The light precipitation or Bragg scatter method, when combined with the sunspike method (not shown but described in paper) and data logs, can isolate component problems.
Challenges

1. Reduce the variance of $Z_{DR}$ biases across the WSR-88D fleet
   a) Maintenance procedures (barn door vs. mouse hole)
   b) Hardware limitations (connectors, antenna positional accuracy)

2. Refine observational methods
   a) We know our methods do not provide estimates within 0.1 dB reliably
   b) Many observations required to establish bias
   c) Large changes to bias seen quickly; trends require many observations to discern

3. Geographical / climatological limitations
Thank you – Questions?
Backup Slides
**$Z_{DR}$ Calibration Equations**

**Total Systematic $Z_{DR}$ Bias**

- Receive Path Bias
  - $\Delta_{total} = \Delta_R + \Delta_T$
- Transmit Path Bias
  - $\Delta_R = r_x^{bias} + a_n^{bias}$
  - $\Delta_T = t_x^{bias} + a_n^{bias}$

**Methods for estimating $\Delta_{total}$**

- **Current engineering method ($\Delta_{cal}$) – realtime adjustment**
  - Ideally $\Delta_{cal} = \Delta_{total}$
- **Observational (volume scans)**
  - Light Precipitation ($\Delta_{precip}$)
  - Bragg scatter ($\Delta_{Bragg}$)

**Estimating $\Delta_R$**

- **Sunspikes**
  - $Z_{DR}_{sunspike} = Z_{DR}_{Level2} + \Delta_{cal} = r_x^{bias} + a_n^{bias} = \Delta_R$
### Light Precip Data Filters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCP</td>
<td>11, 12, 121, 211, 212, 221, 31, 32</td>
</tr>
<tr>
<td>Elevations</td>
<td>&gt; 1.0°</td>
</tr>
<tr>
<td>Range</td>
<td>&gt; 20 km</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>19.0 to 30.5 dBZ, 2 dB Steps</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>CC &gt; 0.98</td>
</tr>
<tr>
<td>Melting Layer</td>
<td>1 km below ML Height</td>
</tr>
<tr>
<td>Signal-to-Noise Ratio</td>
<td>S/N &gt; 20 dB</td>
</tr>
<tr>
<td>Adjusted Median $Z_{DR}$</td>
<td>&gt; 200 bins / step*</td>
</tr>
<tr>
<td>Average $Z_{DR}$</td>
<td>Adjusted Median per category</td>
</tr>
<tr>
<td>Volumes Averaged</td>
<td>12</td>
</tr>
</tbody>
</table>

*Adjusted Median $Z_{DR}$

<table>
<thead>
<tr>
<th>Z (dBZ)</th>
<th>20</th>
<th>22</th>
<th>24</th>
<th>26</th>
<th>28</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZDR (dB)</td>
<td>0.23</td>
<td>0.27</td>
<td>0.32</td>
<td>0.38</td>
<td>0.46</td>
<td>0.55</td>
</tr>
</tbody>
</table>
## Additional Data Filters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Drop Contamination Test</td>
<td>&lt; 40 bins with 40 dBZ or higher above melting level</td>
</tr>
<tr>
<td>Stratiform Test</td>
<td></td>
</tr>
<tr>
<td>Weak Reflectivity</td>
<td>10 to 30 dBZ</td>
</tr>
<tr>
<td>Strong Reflectivity</td>
<td>&gt; 30 dBZ</td>
</tr>
<tr>
<td>Signal-to-Noise Ratio</td>
<td>&gt; 20 dB</td>
</tr>
<tr>
<td>Ratio weak to total reflectivity bins (x100)</td>
<td>80%</td>
</tr>
<tr>
<td>Duration per Plotted Point</td>
<td>Median over 3 hrs</td>
</tr>
</tbody>
</table>
Bragg Scatter Data Filters for $Z_{DR}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCP</td>
<td>21,32</td>
</tr>
<tr>
<td>Elevations</td>
<td>2.5° &amp; above (batch modes)</td>
</tr>
<tr>
<td>Range</td>
<td>10 to 100 km</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>-32 &lt; Z &lt; 10 dBZ</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>0.98 &lt; CC &lt; 1.05</td>
</tr>
<tr>
<td>Velocity</td>
<td>$V &lt; -2$ or $V &gt; 2$ m s$^{-1}$</td>
</tr>
<tr>
<td>Spectrum Width</td>
<td>$W &gt; 0$ m s$^{-1}$</td>
</tr>
<tr>
<td>Signal-to-Noise Ratio</td>
<td>0 &lt; S/N &lt; 15 dB</td>
</tr>
<tr>
<td>Differential Phase</td>
<td>$25^\circ &lt; \Phi_{dp} &lt; 35^\circ$</td>
</tr>
<tr>
<td>1 Hour Histogram</td>
<td>$\geq 35,000$ bins</td>
</tr>
<tr>
<td>Yule-Kendall Index</td>
<td>$\leq 0.1$</td>
</tr>
<tr>
<td>Symmetry Test</td>
<td></td>
</tr>
</tbody>
</table>
Using Sunspikes in Level II Data to Monitor $Z_{dr}$ Bias

Assumption: Sun is unpolarized

$Z_{dr_{true}} = 0 \text{ dB}$

Receiver and Antenna (Ant) Bias Only
No Transmit Path (Tx)

$$Z_{\text{meas}} = Z_{\text{intrinsic}} + r_{\text{bias}} + a_{\text{nt bias}}$$
Sunspike: KOKX 13 Dec 2012, 21:11Z

Reflectivity (dBZ)
-32 to 25 dBZ
S/N 10 to 15 dB

Differential Phase (deg)
Random values
0-360 deg

Correlation Coefficient (/100)
< 0.30

Differential Reflectivity (dB)
± 2 dB about central value

9B Polarimetric Radar - Data Quality / Calibration
## Sunspike Data Filters for $Z_{DR}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCP</td>
<td>31,32</td>
</tr>
<tr>
<td>Elevations</td>
<td>1.5°, 2.5° (surveillance cut)</td>
</tr>
<tr>
<td>Range</td>
<td>20 to 460 km</td>
</tr>
<tr>
<td>Signal-to-noise Ratio</td>
<td>$&gt; 10 \text{ dB} &amp; &lt; 15 \text{ dB}$</td>
</tr>
<tr>
<td>Bin Count</td>
<td>$&gt; 1000$</td>
</tr>
<tr>
<td>Volume Scans</td>
<td>3 closest to target elevations morning &amp; evening</td>
</tr>
<tr>
<td>Radial</td>
<td>Best positional match</td>
</tr>
</tbody>
</table>
Upton, NY (KOKX) Sunspike Time Series
March 31, 2013 to August 13, 2013

* = $ZDR_{L2sunspike} + \Delta_{cal}$

$= r_{bias} + ant_{bias} = \Delta R_{derived}$

$\circ = \Delta R_{system} = r_{sysbias} + ant_{sysbias}$

$\Delta R_{derived} \approx \Delta R_{system}$

Derived Rx Path Bias (Red Stars), Baron Rx Path Bias (Red Circles)

Sunspike
$Z_{DR}$ Median
= -0.024
Sunspike / Antenna - Δazm vs. Δelev
KOKX March 31, 2013 to August 13, 2013

Sunspike Z_{DR} Median = -0.024
KOKX $Z_{DR}$ vs. Range (2 to 100 km)

Solar Azimuth = 245.58°
Solar Elevation = 1.56°
Radial Azimuthal Center = 245.75°
KOKX $Z_{DR}$ vs. Range (2 to 100 km)
13 Dec 2012, 21:12:08Z, Elev 1.5°, VCP 32

Solar Azimuth = 237.46°
Solar Elevation = 1.44°
Radial Azimuthal Center = 237.25°
Site Sun Spike
$Z_{dr}$ Median = 0.015375

Upper 50th (Black Upside Down Triangle), Median (Black Dot), Lower 50th (Blue Circle)
Actual Rx Path Bias (Red Stars), Baron Rx Path Bias (Red Circles)
Contributions to System $Z_{DR}$ Bias

Total System Bias = Rx Path Bias + Tx Path Bias

\[ \Delta Rx = r_{x_{bias}} + a_{nt_{bias}} \] (Rx Path Bias)

\[ \Delta Tx = t_{x_{bias}} + a_{nt_{bias}} \] (Tx Path Bias)

<table>
<thead>
<tr>
<th>Component in the system ZDR offset</th>
<th>Parameter</th>
<th>How it is measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCB [ r_{x_{bias}} ]</td>
<td>$H_{pow}$, $V_{pow}$</td>
<td>Routine receive measurements using CW calibrated signals</td>
</tr>
<tr>
<td></td>
<td>$R_{293}$, $R_{294}$</td>
<td>Factory measured</td>
</tr>
<tr>
<td></td>
<td>$R_{297}$</td>
<td>Cross-and-straight measurements</td>
</tr>
<tr>
<td>TXB [ t_{x_{bias}} ]</td>
<td>$H_{ps}$, $V_{ps}$</td>
<td>Routine power sense measurements</td>
</tr>
<tr>
<td></td>
<td>$R_{295}$, $R_{296}$</td>
<td>Factory measured</td>
</tr>
<tr>
<td></td>
<td>$R_{298}$</td>
<td>Cross-and-straight measurements</td>
</tr>
<tr>
<td>SMB [ a_{nt_{bias}} ]</td>
<td>$P_{sh}$, $P_{sv}$</td>
<td>Suncheck measurements</td>
</tr>
<tr>
<td></td>
<td>RCB</td>
<td>See the first table entry</td>
</tr>
</tbody>
</table>

Melnikov and Zrnic (2013 MOU Report)