Antenna Polarization Errors and Biases in Polarimetric Variables for Simultaneous Horizontal and Vertical Transmit Radars

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You unlock this door with the key of imagination. Beyond it is another dimension: a dimension of sound, a dimension of sight, where radars transmit both H and V waves simultaneously. Assumptions are made!!

...where radar signatures aren't what they seem to be,
...where the weird and the bizarre are the norm.

You're moving into a land of both shadow and substance, of things and ideas. You've just crossed over into a zone...
Cross-Coupling of the H and V Polarized Waves

- SHV operation is based on two assumptions:
  1. The mean canting angle of precipitation in the propagation medium is zero
     - For rain this is a good assumption, but not for ice
  2. *Negligible antenna polarization errors*
     - *Is not well understood*
Transmit H and V Waves SIMULTANEOUSLY!

Just use a power splitter

- Avoid pesky ferrite switches, dual transmitters or a fast mechanical switch that are needed for fast alternating H and V transmission!
- Less expensive, less maintenance
- NEXRADs will adopt this dual polarization technique
Simultaneous H & V Transmission

Vertical Polarization

Horizontal Polarization
Modeling Radar Scatter

See Hubbert and Bringi 2003: Studies of the Polarimetric Covariance Matrix. Part II: Modeling and Polarization Errors, JTECH
Non-zero Mean Canting Angle induced Errors

- From Ryzhkov et al, 2006. KOUN Data
Data from Other Simultaneous H and V Transmit Radars

University of Alabama Huntsville, ARMOR Radar

Elev. = 10.3 deg.
Team-R X-band
TiMREX, Taiwan 2008
Modeled Zdr Bias

Due to canted ice crystals

Mean canting angle of the propagation medium

Very little differential phase needs to accumulate before significant SHV Zdr bias is observed.
Antenna Polarization Errors

- TiMREX: Terrain-influenced Monsoon Rainfall Experiment. Taiwan, May-June 2008

- Both fast alternating H&V (FHV) and simultaneous H&V (SHV) data sets gathered within minutes of each other.

First analysis of such data (to our knowledge)
S-Pol TiMREX $\phi_{dp}$

Over 100 degrees of phase shift
Fast Alternating H&V Transmit at 8.6 deg elevation  06:19:36

Reflectivity (dBZ)          Differential Reflectivity (dB)
Simultaneous H&V Transmit
at 8.6 deg elevation. 06:13:59

Reflectivity (dBZ)  Differential Reflectivity (dB)
Fast Alternating Transmit at 2.0 deg elevation

Reflectivity (dBZ)  Differential Reflectivity (dB)
Simultaneous Transmit at 2.0 deg elevation

Reflectivity (dBZ)  Differential Reflectivity (dB)
Compare SHV and FHV Zdr

For 20 dBZ < Z < 25 dBZ

<table>
<thead>
<tr>
<th>Total $\phi_{dp}$</th>
<th>Mean Zdr (dB)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>FHV</td>
</tr>
<tr>
<td>between 20 and 40 deg</td>
<td>0.17</td>
</tr>
<tr>
<td>between 40 and 70 deg</td>
<td>0.15</td>
</tr>
<tr>
<td>between 70 and 100 deg</td>
<td>-0.07</td>
</tr>
</tbody>
</table>

As $\phi_{dp}$ increases SHV data incurs positive Zdr bias
(no attenuation correction)
Power Calibration: Self-Consistency

- Compare $\phi_{dp}$ as estimated by Z, Zdr with $\phi_{dp}$ estimated directly from radar data
  - Requires approximate knowledge of DSD
  - Technique of Vivekanandan, et al., 2003 based on Gorgucci et al.
- Caveats
  - Avoid areas of hail, clutter, etc.
  - Correct for Zdr bias, first
- But also can use to detect Zdr bias
Self Consistency Technique

For rain DSDs, Kdp, Zdr and Z have a predictable relationship. In this technique, measured Zdr and Z are used to predict $\phi_{dp}$ and judge if there is any Zdr bias.

(TiMREX data)
The antenna errors can be equivalently expressed in terms of the LDR system limit, i.e., LDR measured in drizzle.

For SHV $Z_{dr} < 0.2\text{dB}$, LDR system limit $< -40\text{dB}$
Correcting S-Pol SHV Zdr

Using solar scan and LDR limit values, can calculate:

Tilt $H = 0^\circ$, $\text{ellip } H = 0.91^\circ$ and tilt $V = 90^\circ$, $\text{ellip } V = -0.69^\circ$

From the model

![Graph showing $Z_{dr}$ (dB) vs $\phi_{dp}$ (deg.) and LDR (dB) vs Principal plane (deg.)]
Corrected SHV Data

Corrected SHV data

Uncorrected SHV data
SHV $Z_{dr}$ Bias Curves

The antenna errors can be equivalently expressed in terms of the LDR system limit, i.e., LDR measured in drizzle.

Transmit linear 45 degree

Transmit Circular
KOUN Data, 30 March 2007

• Large $\phi_{dp}$ case in rain: 300 degrees!
• Reported as more “tropical” in nature (few large drops)
• No hail reports from NWS or the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS)
• Sounding data for the time period shows a moist profile through a deep layer, low vertical wind shear, and relatively low convective available potential energy (CAPE = 834 J)
KOUN Calibration

• Data from rain with less than 30 deg. accumulative $\phi_{dp}$
• Self consistency
Koun Calibrated Data

Self Consistency

Estimated Antenna Errors
KOUN Data Corrected for Antenna Errors

Self Consistency

Computed PHIDP vs Measured PHIDP
KOUN $Z_{dr}$ Versus $Z$

Uncorrected Data

Corrected Data

$\phi_{dp} < 175$ deg.

$\phi_{dp} > 175$ deg.
Physical Polarization Error Sources

- Surface error of the parabolic dish
- Blockage due to support struts and horn
- Feed horn (likely most significant)
- Radome irregularities
- Wetting of the radome
Implications

• Rainfall estimates using SHV data based on Zdr are suspect, especially for larger $\phi_{dp}$

• Differential attenuation correction, even if it is done without error, the corrected data will still contain bias due to antenna errors

  – Better to use only $\phi_{dp}$
Conclusions

• Cross Coupling between the H and V simultaneous transmitted signals can occur in ice and mixed phase regions
• All radars have imperfect antennas and therefore polarization errors
• For a radar with a -35 dB LDR limit, Zdr errors still can be from 0.15 to 0.25 dB, max. (function of $\phi_{dp}$)
• The Zdr bias is a strong function of the transmit polarization state (H-to-V phase difference).
• To minimize cross coupling the best strategy is to have an antenna with excellent isolation figure
• Using self consistency among Z, Zdr and $\phi_{dp}$, the Zdr bias can be detected in region with about 100 degrees of $\phi_{dp}$
• Differential attenuation should be corrected using $\phi_{dp}$ only

Zdr bias accumulated in rain propagates into the ice phase.
Thanks for your attention

Questions?

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Modeling, error analysis and evaluation of dual polarization variables obtained from simultaneous horizontal and vertical polarization transmit radar.
Part I: Modeling and antenna errors
Part II: Experimental data
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