ZDR Calibration

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Vertical Pointing Technique for ZDR Bias Estimation
Vertical Pointing Technique

**ISSUES**
- How many revolutions to integrate?
- Ground clutter in sidelobes
- Receiver saturation
- Wetting of radome

**Limitation**
- Only can only execute when there is light rain over the radar (deep snow storms can be used)
- This makes it very difficult to document Zdr variability over long time periods with good temporal resolution.
Typical Thresholds used for VP Analysis

- **Min height** = 2.0 km to avoid differential T/R limiter characteristics
- **Delta height** = 0.5 km – analyze echoes in layers
- **LDR** < -20.0 dB (if available) to eliminate most wet ice (bright band)
- **\( \text{rhohv} \)** > 0.96 to ensure valid weather return
- **SNR** between 15 and 70 dB - avoid areas subject to noise power corrections, and to keep receiver from becoming saturated

We compute the measured ZDR bias in layers, starting just above the range at which the T/R limiters have recovered fully. We examine the results for each layer, ensuring that we have sufficient measurements for an accurate result.
Transmitter/Receiver Limiters have a time-delay response

Therefore we need to avoid data in this region, since the T/R limiters are in recovery mode for gates close to the radar.
## Example of vertical pointing results table – S-Pol

**Vertical-pointing ZDR calibration**

Start time: 2015/05/23 14:27:26   End time : 2015/05/23 14:47:16

- **n samples**: 128
- **n complete rotations**: 15
- **min snr (dB)**: 15
- **max snr (dB)**: 70
- **min vel (m/s)**: -100
- **max vel (m/s)**: 100
- **min rhohv**: 0.95
- **max ldr**: -20
- **zdr_n_sdev**: 2
- **min ht for stats (km)**: 2.5
- **max ht for stats (km)**: 10
- **mean ZDRm (dB)**: -0.239319
- **sdev ZDRm (dB)**: 0.0204313

<table>
<thead>
<tr>
<th>Ht</th>
<th>npts</th>
<th>snr</th>
<th>dBZ</th>
<th>vel</th>
<th>zdr_m</th>
<th>ldrh</th>
<th>ldrv</th>
<th>rhohv</th>
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<td>-0.6</td>
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<td>-24.018</td>
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<td>25.190</td>
<td>-3.064</td>
<td>-0.3</td>
<td>-0.238</td>
<td>-22.147</td>
<td>-23.169</td>
<td>0.989</td>
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</tbody>
</table>
ZDR Histograms, S-Pol MASCRAF, 25 Feb. 2015

21:48
Mean = .001 dB

21:51
Mean = -.025 dB

22:16
Mean = -.012 dB

22:19
Mean = -.009 dB
Vertical Pointing Uncertainty

- How to define this?
- Single 360 degree scans?
- Averages of 360 degree scans, say 5?
- Need substantial sequential time series of VP measurements – this is not commonly done.
- Calibration is usually a secondary issue and scientists want to move on and gather meteorological data
Demonstrated uncertainty of the VP Method

- 23 May 2007, S-Pol, Marshall, Colorado
- 90 x 360 degree revolutions of the antenna (about 1 minute per revolution)

$2\sigma$ uncertainty of 0.0142dB
Demonstrated variability of ZDR bias from VP method, during PECAN

14:03 to 14:53 UTC, 2015/07/02, S-POL

Standard deviation of the differences of the magenta curve and the red or green curves gives a $2\sigma$ uncertainty of 0.03 dB
Scanning the Sun for ZDR Calibration

Routine solar scans have 3 main purposes:

- To check the antenna pointing alignment
- To compute the ZDR bias in the receiver components
- To check the reflectivity calibration and/or the receiver gain stability.
Scanning the sun provides information on the receive path from the antenna to the digital receiver.
The sun is a non-polarized radiation source at radar wavelengths

It is recommended to scan the sun with the transmitter radiating, to keep the components (e.g. circulators) at operating temperature.

Solar radiation is sensed equally by all gates

Close gates are contaminated by side-lobe clutter if transmitter is on

Use far gates for sun-scan analysis
Scanning and analysis computations are performed on a grid centered on the sun.

A 6 deg x 4 deg 'box scan' is set up centered on the sun. Antenna speed 1 deg/sec. Grid resolution 0.2 degrees.
Example of Sun Scan – KOUN NEXRAD radar, 2012/12/25

KOUN, H channel, noise corrected power (dBm)  
KOUN, V channel, noise corrected power (dBm)
Example of Sun Scan – KOUN NEXRAD radar, 2012/12/25

Phase difference H-V (deg)

H-V cross correlation coefficient
Pattern is caused by struts.
The mean ZDR bias, for the receiver system, is computed from the ZDR pattern within the 1 degree circle centered on the sun.
Sunscan docs and code on-line at GitHub

You can find the SunCal code and documentation on-line at GitHub:


- sunscan_ael_v1.1_20161201.pdf – Algorithm description for NEXRAD
- sunscan_nexrad.c, sunscan_nexrad.h – C code for NEXRAD algorithm
Estimating $S_1S_2 = ZDR \times 2$

- Correct for sun movement
- Correct for elevation angle distortion
- Subtract noise power
- Grid data (0.1 X 0.1 deg.)
- Scan the sun slowly: 1 deg./s
- Integrate $S_1S_2$ over about 1 deg. solid angle
- Solar disk: about 0.53 deg. diameter
- S-Pol antenna beam width: 0.93 deg.
On S-Pol at 2809 MHz, the H (left) and V (right) patterns are somewhat distorted. What we find is that this distortion is dependent on frequency. The receive frequency was slewed from 2700 to 2873 MHz in steps of 3 MHz. Center frequency of the horn is 2809 MHz, ~150in focal length, 18dB taper.
As the power patterns change so do the H/V correlation patterns. On the left is a poor pattern with high correlation coefficients at the strut locations (S-Pol has 4 struts). On the right is an optimal pattern with low correlation coefficients throughout.
As the power patterns change so do the receiver ZDR patterns. This plot shows the S-Pol S1S2 fields, which are effectively ZDR * 2. On the left is a poor pattern with high gradients, caused by dissimilar H and V patterns. On the right is an optimal pattern which is smooth with low gradients.
S1S2
2798MHz
S1S2 2799MHz
S1S2
2800MHz
S1S2
2801MHz
S1S2
2804MHz
S1S2
2805MHz
Consider again the distorted patterns for H and V channels.
We compute 2 asymmetry metrics

(1) **The Axis Zdr Difference statistic**: we estimate the mean ZDR for a line through the sun centroid, extending out by 1 degree each way along the elevation axis, and similarly in the azimuth axis. We then compute the difference between these two values. This quantity is quite sensitive to the distortion in the power patterns.

(2) **Aspect Ratio Difference**: we compute the aspect ratio, in elevation vs azimuth, for the H and V patterns independently. We then take the difference between the aspect ratios for the H and V channels.
Relative Shape of the H and V (Zdr) Solar Patterns cycles with frequency every 40 MHz or so.
Dry Snow Technique for ZDR Bias Estimation
Estimating ZDR Bias from Dry Snow

- **Mean-offset method**: Zittel et al. (2014) shows how the returns from snow can are used for routine monitoring of the ZDR bias in the NEXRAD radar network. The HCA is used to classify the echoes. The mean ZDR in snow is computed. An offset of -0.2 dB is applied from the mean to estimate the ZDR bias.

- **Percentile method**: here we describe a similar method which differs as follows: (a) the NCAR Particle ID (PID) algorithm is used instead of the NEXRAD HCA, and (b) a selected percentile in the observed distribution of ZDR in the snow region is used instead of the offset mean of 0.2.

- We compare these methods by applying them to data sets from PECAN (Kansas 2015 – midwest plains) and DYNAMO (Maldives 2011 - maritime).

- We use data from the NCAR S-Pol radar, and make use of the vertical pointing mode to determine the ZDR system bias.
ZDR from Snow vs. the Rain and Bragg methods

- Utilizing Bragg echoes is attractive since these have an inherent ZDR of 0 dB.

- However, Bragg is unlikely to be available for C and X band radars.

- ZDR in rain has a higher variability than in snow and Bragg, so the rain method is inherently less accurate.

- Also, light rain close to the radar occurs relatively infrequently in some locations.

- Dry snow regions are available in both convective and stratiform situations, so they occur relatively frequently.

- And since snow occurs higher in the atmosphere than rain, we can get cases at longer range.
Convective RHI from PECAN field project

Reflectivity of an RHI through a convective storm observed by the NCAR S-Pol radar at McCracken, Kansas during PECAN
June 26 2015
This figure shows some of the regions used by various methods designed to find the ZDR bias. Bragg echoes have ZDR values close to 0. In rain and dry snow, the mean ZDR values are above 0 by “known” amounts, so these regions can be used by making a suitable correction.
Identifying the snow regions

- We run the NCAR Particle ID (PID) algorithm, and apply the analysis to the gates identified as ‘Dry Snow, ID=10’.

- We apply the constraints below when identifying the regions of dry snow.

<table>
<thead>
<tr>
<th>Field</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID</td>
<td>Ice / dry snow</td>
</tr>
<tr>
<td>SNR</td>
<td>10 to 50 dB</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>0 to 30 dB</td>
</tr>
<tr>
<td>Max Phidp accumulation</td>
<td>10 degrees</td>
</tr>
<tr>
<td>Temperature</td>
<td>-5 C to -50 C</td>
</tr>
<tr>
<td>KDP</td>
<td>&lt; 0.6 deg/km</td>
</tr>
<tr>
<td>VEL</td>
<td>&lt; -1.5 or &gt; 1.5 (to avoid clutter contamination)</td>
</tr>
<tr>
<td>RHOHV (not noise corrected)</td>
<td>&gt; 0.98</td>
</tr>
<tr>
<td>Elevation angle</td>
<td>&lt; 25 degrees</td>
</tr>
<tr>
<td>Calibrated ZDR</td>
<td>&lt; 0.75 dB</td>
</tr>
<tr>
<td>Min number of ice points in volume for valid analysis</td>
<td>1000</td>
</tr>
</tbody>
</table>
ZDR for Convective RHI from PECAN project

We can compute the observed distribution of ZDR in the various regions depicted above. In this study we concentrate on the snow region.
Distribution of ZDR in Dry Snow, PECAN

Blue lines: show the fit for a normal distribution. In red are the mean observed ZDR, and the (ZDR mean – 0.15) values. In black are the 5th, 15th and 25th percentiles.

We need to select a percentile that effectively estimates the ZDR bias.

For dry snow/aggregates, ZDR ranges from -1dB to 1.4dB. Thus, in dry snow regions, ZDR will be negative in places and positive in others, but the distribution of ZDR values will span 0 dB.

The region of dry snow must contain sufficient samples for the assumed ZDR distribution shape to be well approximated.
ZDR bias for PECAN, 15 June through 16 July, 2015

Through experimentation with the PECAN data it was found that the 15th percentile provides a good match between the observed distribution in snow and the vertical pointing results.

This figure shows the observed, and corrected, ZDR bias for the PECAN field project.

Shown in yellow are the results from the vertical pointing scans.

The blue icons show the ZDR values for the 15th percentile in the distribution.

The red icons show the results after correcting for the bias and temperature (discussed later).

Top panel: volume by volume results. Bottom panel: daily means
Blue: measured ZDR bias from 15th percentile in ZDR distribution
Yellow: vertical pointing results
Red: ZDR corrected for bias and temperature
ZDR bias for PECAN, 15 June through 16 July, 2015

In order to compare the offset-mean and percentile methods, this figure shows the 15th percentile of the ZDR distribution, in dark blue, overlaid on the (mean – 0.15dB) values for the offset-mean method, in light blue.

The 0.15 dB offset was determined experimentally to give good agreement with the vertical pointing results, which are shown in yellow.

The lower panel shows that (a) the percentile and offset-mean methods produce similar results and (b) the percentile method appears to have less variability than the offset-mean method.

Blue: measured ZDR bias from 15th percentile in ZDR distribution
Light blue: mean – 0.15 dB
Yellow: vertical pointing results.
Distribution of ZDR in Dry Snow, DYNAMO

The distribution for DYNAMO is less close to normal that the distribution for PECAN.

It was found experimentally that a 5th percentile provided the best results for the percentile method, and an offset of -0.25 dB gave the best results for the offset-mean method.

These compare to the 15th percentile and offset of -0.15 dB for PECAN.

These differences indicate that the methods may require different tuning from one regional environment to another.

Blue lines: show the fit for a normal distribution.
In red are the mean observed ZDR, and the (ZDR mean – 0.25) values.
In black are the 5th, 15th and 25th percentiles.
The 5th percentile produces a good estimate for the bias.
ZDR bias for DYNAMO, 1 October 2011 - 16 January 2012

This figure shows the observed, and corrected, ZDR bias for the DYNAMO field project.

Shown in yellow are the vertical pointing results.

The blue icons show the ZDR values for the 5th percentile in the distribution.

The red icons show the results after correcting for the bias.

The red triangles in the lower panel demonstrate that the percentile method can correct the ZDR with little variability over time.

Top panel: volume by volume results. Bottom panel: daily means

Blue: measured ZDR bias from 5th percentile in ZDR distribution

Yellow: vertical pointing results

Red: ZDR corrected for estimated bias.
ZDR bias for DYNAMO, 1 October 2011 - 16 January 2012

For comparison of the offset-mean and percentile methods, this figure shows the 5th percentile of the ZDR distribution, in dark blue, overlaid on the (mean – 0.25dB) values for the offset-mean method in light blue.

As before, it can be seen that these two methods produce similar results, though the percentile method exhibits lower spread than the offset-mean method.

This is probably because the percentiles are less sensitive than the mean to a few large (positive or negative) data values.

Blue: measured ZDR bias from 55th percentile in ZDR distribution
Light blue: mean – 0.25 dB
Yellow: vertical pointing results.
Summary

- The table below shows the offsets and percentile values for each of the two methods, as determined from the results of the two field projects.

- The fact that the parameters vary significantly from one environment to another suggests that care must be taken in applying these methods in an operational setting.

<table>
<thead>
<tr>
<th>Project</th>
<th>PECAN</th>
<th>DYNAMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>USA Mid-west plains</td>
<td>Maritime</td>
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<tr>
<td>ZDR mean offset for ZDR of 0</td>
<td>-0.15 dB</td>
<td>-0.25 dB</td>
</tr>
<tr>
<td>Percentile for ZDR of 0</td>
<td>15th</td>
<td>5th</td>
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Conclusions

- The offset-mean method for ZDR bias estimation in dry snow, as described by Zittel et al., was evaluated, along with the percentile method that uses percentile values in the observed distribution of ZDR, instead of the adjusted mean.

- Both of these methods were run on data from the PECAN and DYNAMO field projects.

- The two methods were shown to produce similar results.

- However, it does appear that the results from the percentile method have less variability over time than those from the offset-mean method. This is likely because the percentile results are less sensitive to a few large values in the distribution which might bias the mean in some circumstances.
Future work on the ice method will include:

- The use of a 3-parameter function to describe the observed ZDR distribution, in order to more accurately capture the shape.

- Testing of the method on surveillance scans with an elevation angle of around 60 degrees, to test the hypothesis put forward by Ryzhkov et al. that snow observed at high elevation angles should have an intrinsic ZDR of close to 0.

- If this works, it may prove useful for the NEXRAD radars which cannot point vertically, but which can reach an elevation angle of 60 degrees.
The Bragg method can also be used. Estimated ZDR bias from ice (red) and Bragg (blue) SPOL during PECAN. Top: volume-by-volume. Bottom: daily means.
The Dependence of ZDR bias on Temperature at the Radar

The research on methods for determining ZDR bias have highlighted an interesting side issue:

that the measured ZDR bias is to some extent dependent on the temperature at the radar site.
During the course of this study, and other analyses of S-Pol ZDR data, it was noted that the observed ZDR bias is a function of the diurnal variation of temperature at the radar.

Since S-Pol has no radome, the site temperature is a good proxy for the dish temperature.

The pattern of ZDR bias results in the top panel follows that of the observed site temperature in the lower panel.
ZDR bias dependence on Site Temperature

This figure shows the observed dependence of ZDR bias on site temperature for PECAN.

A similar relationship was found when applying the cross-polar power method (Hubbert 2017).

Using this relationship, the observed ZDR values for PECAN were corrected for both ZDR bias and temperature.

Regression analysis of observed ZDR bias (from the 15th percentile) vs the site temperature
PECAN from June 16 to July 16 2015.
Time series of ZDR bias estimates from ice (green) and Bragg (blue) along with normalized site temperature (orange) – SPOL PECAN

Normalized-temp = (temp – mean) / (sdev * 10)
Time series of ZDR bias estimates from ice (green) and Bragg (blue) along with normalized site temperature (orange) – SPOL PECAN

Zoomed on period of interest

Normalized-temp = (temp – mean) / (sdev * 10)
When developing the Cross-Polar Power method for NEXRAD, we found that the SS quantity showed a diurnal cycle for KOUN.
Time series of ZDR bias estimates from ice (green) and Bragg (blue) along with normalized site temperature (orange) – KDDC PECAN

Normalized-temp = (temp – mean) / (sdev * 10)
Temperature dependence of estimated ZDR bias from ice
KDDC during PECAN
Time series of ZDR bias estimates from ice (green) and Bragg (blue) along with normalized site temperature (orange) – KDDC PECAN

Zoomed on period of interest

Normalized-temp = (temp – mean) / (sdev * 10)
Perhaps the dependence is not linear?

Comparing results from MASCRAD (winter) and PECAN (Summer) we see that the regression has a positive slope for MASCRAD and a negative slope for PECAN.

So perhaps this is not a linear relationship?
S-Pol S1S2 measurements at the Marshall field site
April – June 2017

It appears that this is a higher-order relationship
perhaps quadratic or sinusoidal
ZDR and Z calibration checks from radar echoes, and other methods

Mike Dixon, John Hubbert
Scott Ellis, Greg Meymaris

NCAR/EOL/RSF

NEXRAD Enhancement Project
Technical Interchange Meeting
Boulder, CO
2016/06/01
Outline

- ZDR checks using ice and Bragg regions.
- Self-consistency checks using Z, ZDR and PHIDP/KDP.
- Reflectivity inter-comparison between SPOL and KDDC.
- Sun-scan and sun-spike analysis.
- Clutter analysis for monitoring.
The top two panels of the following slide summarizes the results of using solar observations and the cross-polar power ratio from clutter to estimate ZDR bias.

The third panel shows the measured transmitter power, which is stable throughout the project, varying by only 0.2 dB, in spite of the installation of a replacement trigger amplifier around June 10.

The lower panel shows the environmental temperature monitoring for both the site and components in the transmitter container.
SPOL monitoring during PECAN
ZDR calibration monitoring – sun scan analysis

- Using the powers observed during solar scans, and the solar flux observed at the Penticton observatory, we can estimate the receiver gain for each channel.

- The H receiver gain stays almost constant at 39.0 dB, and the V receiver gain at 39.35 dB, for the entire project.

- We discovered that the calibration on 2015/06/10 yielded a receiver gain of 38.2 dB for H and 38.7 dB in V, which is 0.8 dB lower than that we have estimated to be the correct receiver gain.

- As a result reflectivity was 0.8 dB too high for the period from June 10 onwards.
SPOL TRANSMIT / RECEIVE GAINS AND POWERS

Clutter scanning:

\[ P_{RHX}/P_{RVX} = (P_{TV}/P_{TH})(G_{LNAH}/G_{LNAV}) \]

\[ G_{LNAH}/G_{LNAV} = (P_{RHX}/P_{RVX})(P_{TV}/P_{TH}) \]

Sun scanning:

\[ S1 = P_{RVCO}/P_{RHCO} \quad S2 = P_{RVX} / P_{RHX} \]

\[ ZDRM Bias = (P_{RVX}/P_{RHX})(S1S2) \]
Analysis of sun scans to deduce receiver gain. Gain remains constant (within 0.2 dB) through project.
Noise monitoring
ZDR calibration using sun spike observations

- The following slide demonstrates the possibility of using routinely-observed solar spike data for ZDR calibration.

- The bottom panel shows the S1S2 ratio (from the solar rays) and the cross-polar ratio from clutter. These can be combined to estimate the ZDR bias (ZDRM).

- The advantage of this method is that it allows us to estimate ZDR bias using routine scanning.
Sun-spike analysis for ZDR bias monitoring. From beams that receive solar energy we can estimate the S1S2 ratio. We can also estimate the cross-polar ratio from clutter. Combining these gives us an estimate of ZDR bias (ZDRM).
Z and ZDR monitoring – clutter analysis

- We investigated the option of using clutter field analysis to monitor changes in Z and ZDR over the project.

- We determined the clutter field as those points at which the clutter return was persistent for over 90% of the time. No weather targets are present for that time fraction.

- We divided the targets into strong clutter (power -40 to -55 dBm) and weak targets (power -75 to -85 dBm). The -40 dBm max for strong targets was chosen to ensure the receiver was not saturated (it saturates at about -37 dBm).

- The strong targets are used to analyze clutter returns. The weak targets are used to monitor the occurrence of weather in the clutter domain.
SPOL clutter analysis. We identify persistent clutter targets close to the radar.

Median clutter power

Clutter frequency (fraction of time)
Targets are divided into two groups – weak and strong. Strong targets are used to monitor Z and ZDR over time. Weak targets are used to detect the presence of weather in the clutter domain.

Strong targets (power -55 to -40 dBm)

Weak targets (power -85 to -75 dBm)
We analyzed the clutter targets close to the radar over the course of the project. Clutter powers show considerable variability, order 5 dB, so not very helpful for power monitoring. Clutter ZDR seems pretty stable at around -1.3 dB.
We found that the variability in DBZ and ZDR from clutter is not sufficiently stable for calibration purposes.

It may be possible to use this technique for monitoring purposes, particularly to warn if the transmitter or receiver changes in a major manner.
THANK YOU