Differential Reflectivity Calibration for the Euskalmet Weather Radar

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Abstract: The following document shows how the differential reflectivity –Z_{DR}– was monitored and calibrated for the dual-polarized weather radar property of the Basque Country Meteorological Agency –Euskalmet–. The techniques that were used and their constraints are presented as well as the results and the conclusions reached.

Keywords: weather radar, differential reflectivity, calibration

1. INTRODUCTION

Differential reflectivity (Z_{DR}) data provide very valuable information, especially when combined with reflectivity (Z) data. Since Z_{DR} is a polarimetric variable very sensitive to system failures or changes (V. N. Bringi and V. Chandrasekar, 2001), all radar operators monitor it and calibrate it if necessary.

Biased data observed by the radar operator during the monitoring routines, for instance the daily sun signature monitoring (Figure 1), led it to ask for a calibration of Z_{DR} (M. Maruri et al. 2012).

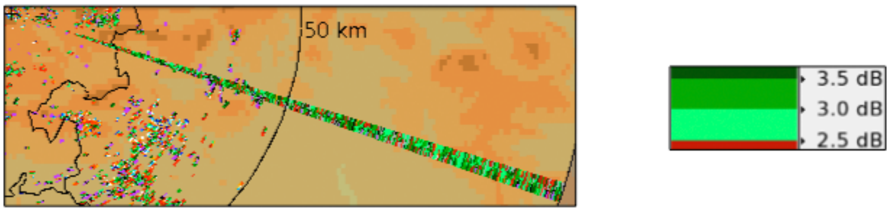

Figure 1: Sun signature – Z_{DR} bias

Two techniques based on the use of natural scatterers such as precipitation were selected because of their reliability and economic constraints. One consists in using data collected at vertical incidence in light rain (E. Gorgucci et al. 1999) while the other one takes advantage of the fact that Z_{DR} decreases with increasing elevation due to increasing view angle (R. Bechini et al. 2008).

In this work, a selection of case studies was made among data collected in 2012 and 2013. Afterwards, all of them were statistically treated and plotted using the tools that were programmed in order to analyse the information and draw conclusions using only the convenient cases for each method. The calculated offset bias was applied using the radar maintenance and control software so the operator of the radar could test it.

During the work some additional requirements were found to properly perform the calibration. These are presented, as well as two instances (one previous to the adjustment and another one subsequent to it) of the same weather event in order to show the enhancement achieved.

2. DESCRIPTION OF THE WEATHER RADAR SYSTEM

The C-band weather radar owned by Euskalmet, a Gematronik METEOR 1500-C, is sited at 1221.2 m high on top of Mount Kapildui (Basque Country, Spain) (J.A. Aranda et al. 2006). This particular model, which features Doppler and polarimetric (SHV) capabilities, is also capable of operating at elevation angles up to 89 degrees.

The task currently scheduled consists in 4 scans every 10 minutes (Table 1), 2 of which are volume scans and 2 are elevation scans. Sometimes an additional azimuth scan is performed at 89 degrees elevation for research and calibration purposes.

Table 1: Current scan strategy

Scan geometry	Range	Range resolution	Elevation angles	Principal moments
Volume	300 km	1000 m	4 within [0º-2.5º]	Z, Z_{DR}
Volume	100 km	250 m	15 within [-0.5º-35º]	Z, Z_{DR}, V, W
Elevation	100 km	250 m	0.3º steps [-1º-50º]	Z, Z_{DR}, V, W
Elevation	100 km	250 m	0.3º steps [-1º-50º]	Z, Z_{DR}, V, W
Azimuth	25 km	250 m	1 at 89º	Z, Z_{DR}

Z_{DR} mean values of the sun signature (I. Holleman et al. 2010) are compared daily as an operational monitoring tool, both at sunrise and sunset. Other calibration routines such as *Zero Check* (ZC) every hour and *Single Point Calibration* (SPC) every 24 hours are executed. The ZC calibration is used to remove the high variable environmental noise signal, whereas the SPC adjusts the transfer function of the receiver.

3. Z_{DR} CALIBRATION TECHNIQUES

As mentioned above, in this work two different Z_{DR} calibration techniques were implemented: vertical pointing and Z_{DR} variation with elevation angle. Each one requires data gathered under certain circumstances in order to generate accurate results. These are presented below together with an explanation of how each technique works.

3.1. Vertical pointing

Vertical pointing is the most widely accepted technique for Z_{DR} bias determination. It consists in using Z_{DR} measurements collected at vertical incidence in light rain, rotating the antenna 360º to reduce the influence of any azimuth dependency of Z_{DR} (E. Gorgucci et al. 1999; R. Bechini et al. 2007). Under these conditions, the mean value of Z_{DR} in precipitation is expected to be 0 dB because of the hydrometeor symmetry (Figure 2).

Many operational radars can not operate at vertical incidence because of mechanical constraints (A. V. Ryzhkov et al. 2005). However, although the default scan strategy performed by the Euskalmet weather radar does not include any zenith scan, some of them were executed to carry out this work. Apart from that, there can be other difficulties:

- No rain at the radar
- Wetting of the radome
- Receiver saturation if the rain is too heavy

Horizontal reflectivity data collected at the same time spans as Z_{DR} data was used to facilitate the location of the precipitation. This helped to choose the case studies best suited to accomplish the calibration of Z_{DR} using this technique.

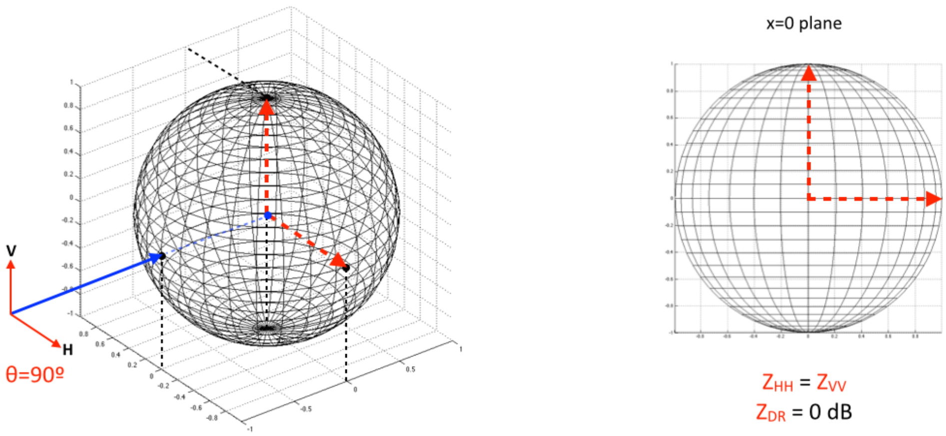

Figure 2: Model of a raindrop in light rain

3.2. Z_{DR} variation with elevation angle

This Z_{DR} calibration method relies on the assumption that this polarimetric variable decreases with increasing elevation due to increasing view angle (Figure 3). The average observed profile should fit the corresponding theoretical curve given by V. N. Bringi and V. Chandrasekar, 2001; A. V. Ryzhkov et al. 2005:

$$Z_{dr}(\theta)=\frac{Z_{dr}(0)}{\left(Z_{dr}(0)^{1/2}\sin^2\theta+\cos^2\theta\right)^2} \quad \text{Eq. 1}$$

where Z_{dr} is the differential reflectivity in linear scale and Θ is the elevation angle in radians.

Although this technique does not present any mechanical constraint, some other considerations must be taken into account for the results to be reliable:

- The microphysical profile below the bright band must be uniform (R. Bechini et al. 2007)
- The precipitation should be in the surroundings of the radar (up to 10 km)
- The freezing level and the thickness of the melting layer
- The height at which the radar is installed

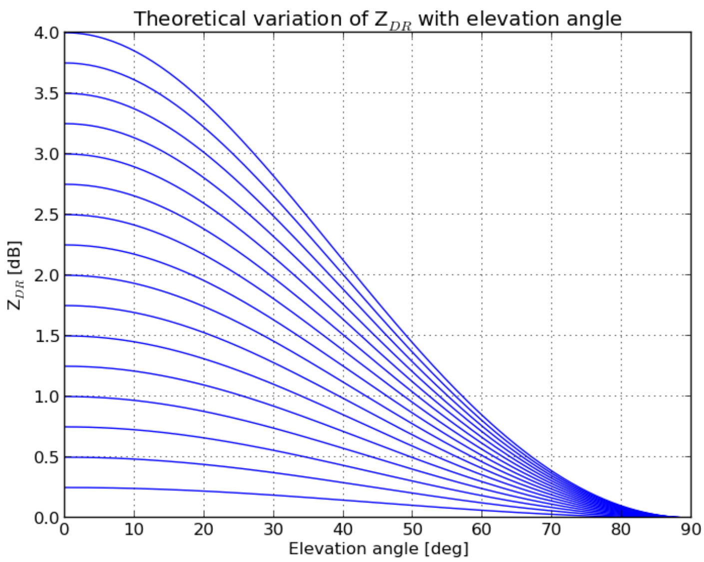

Figure 3: Z_{DR} variation with elevation angle - Example of theoretical curves

The reason of all these requirements is that Z_{DR} profiles must be obtained from enough data below the bright band to stay in the rain medium.

4. RESULTS AND DISCUSSION

A lot of case studies were analysed to guarantee that the estimated mean of Z_{DR} does not change as a function of any other reason different from the system bias. Below these lines there is a representative example of each of the calibration methods applied.

4.1. Vertical pointing

First of all, it is necessary to identify whether the precipitation above the radar is light rain or not. To do so, graphs like those in Figure 4 were made as a first approximation. In the image on the left it is shown Z_H raw data, which helps to locate the volume where the rain is, whereas in the figure on the right it is shown Z_{DR} raw data. Using this kind of charts it is easy to discard useless case studies.

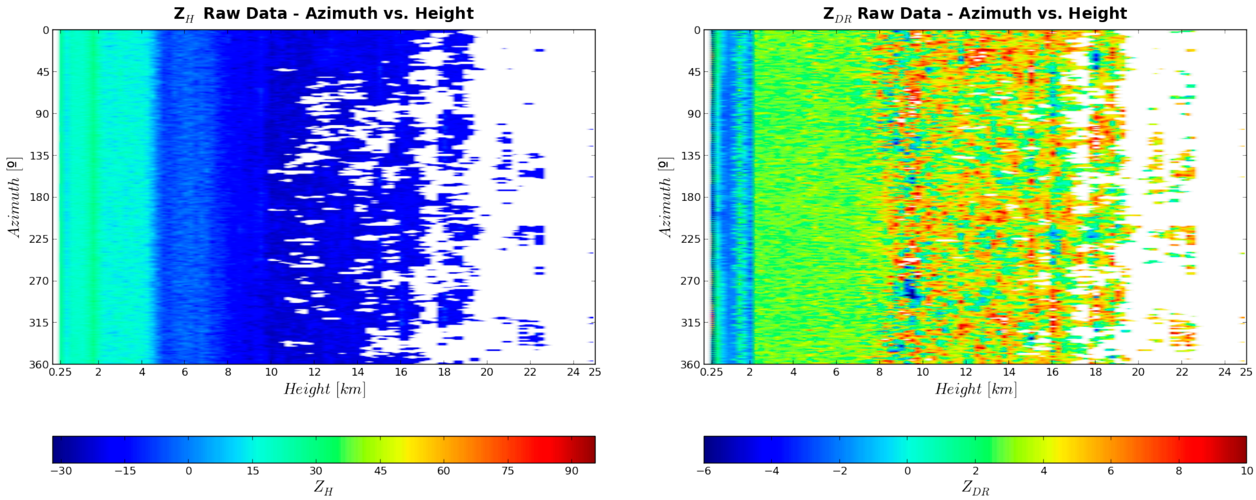

Figure 4: Z_H and Z_{DR} raw data – Azimuth vs. Height

However, they do not provide enough visual information about the data distribution as the box plots below do (Figure 5). In addition to the information given by the box plot itself, the mean value of Z_{DR} is calculated using only the data in the volume mentioned before, between the heights selected (in this case from 3 to 4.5 km high), where both Z_H and Z_{DR} have to be fairly uniform.

Besides that, after several analyses it was concluded that this calibration technique works better when the mean value of Z_H is in the interval from 10 to 30 dBZ, which corresponds to an interval from 0.15 mmh^{-1} to 2.7 mmh^{-1} for rainfall rate (according to the Marshall-Palmer z-R relationship).

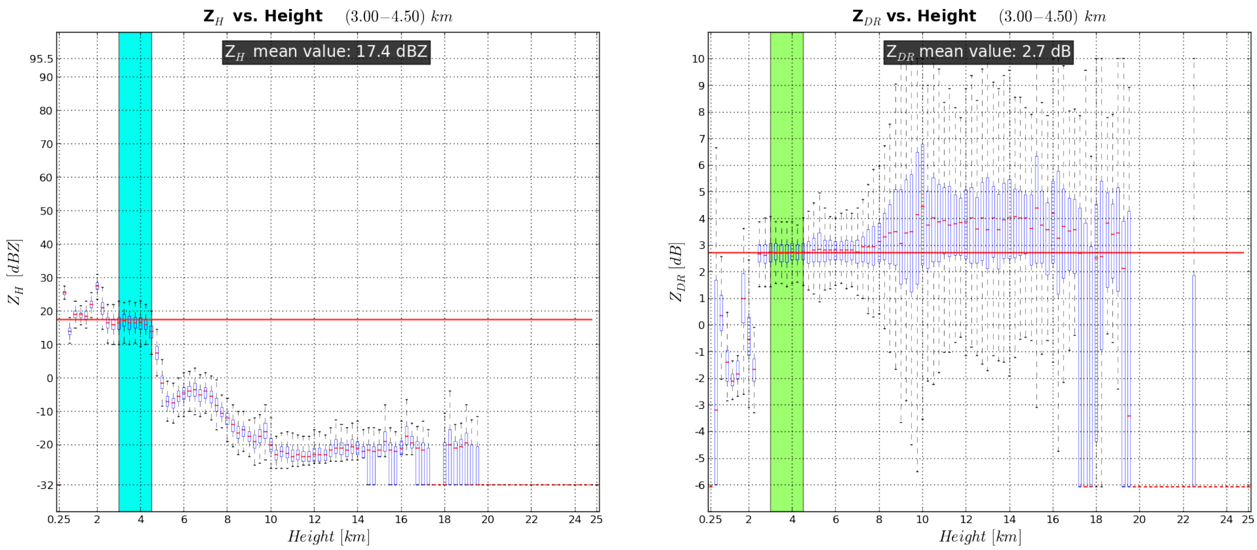

Figure 5: Z_H and Z_{DR} data distribution

Finally the following charts show a histogram of the selected data along with a red line that shows an estimation of the probability density function (PDF) in each case, using a non-parametric way of estimation called kernel-density estimation (KDE). In this example a bias of Z_{DR} of 2.7 ± 0.5 dB was estimated.

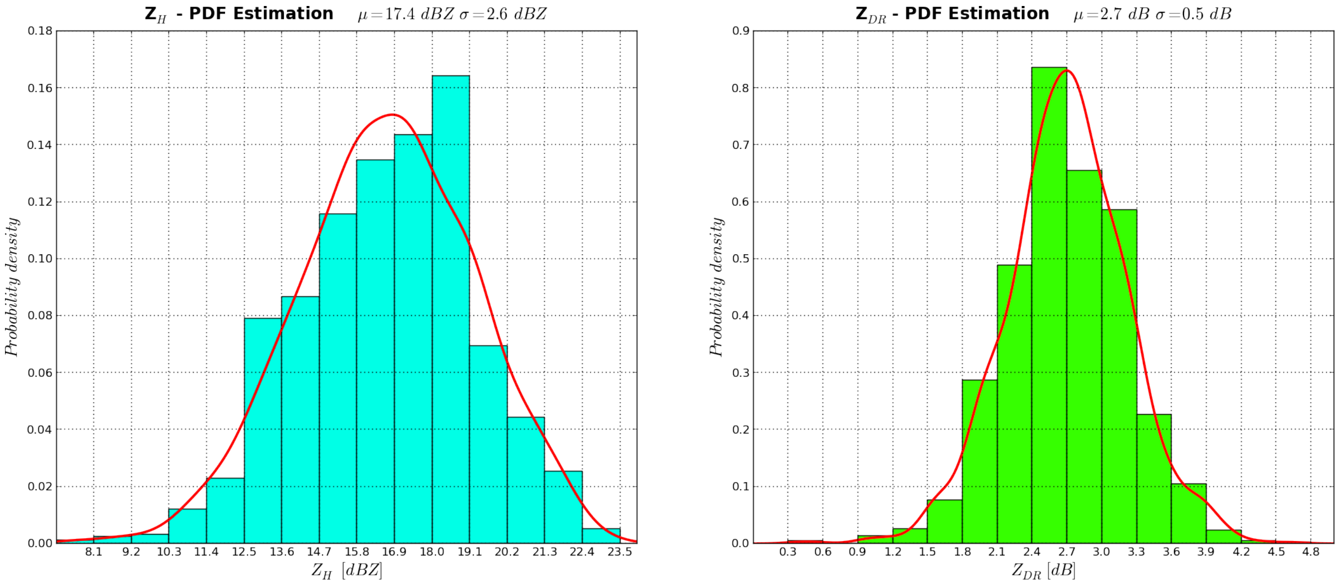

Figure 6: Probability density function

After carefully studying all the cases initially selected and considering only those most suitable for this calibration technique, a Z_{DR} bias of 2.7 ± 0.6 dB was concluded.

4.2. Z_{DR} variation with elevation angle

As opposed to the calibration methodology described before, this one is a bit more challenging given that it is necessary to consider some requirements more, including the freezing level and the thickness of the melting layer, again to find the volume where the precipitation is.

The following figure (Figure 7) is an example of the kind of results achieved. The blue dotted lines in it represent the theoretical variation of Z_{DR} with elevation angle while the red solid line with triangles represents Z_{DR} actual data from a volume defined by:

- A minimum height (0 m above the radar)
- A maximum height to stay in the rain medium considering the freeze level, the thickness of the bright band and the height at which the radar is installed
- A minimum range of no less than 2 km (depending on the case study)
- A maximum range of no more than 10 km (depending on the case study)

Apart from this, the green dotted line represents the theoretical curve best matching the actual data. The offset between this line and the red one is the estimated bias of Z_{DR}, which is of 2.69 dB in this case. After applying this offset to the original data, the bias-corrected Z_{DR} profile can be shown (the green solid line).

Since the freezing level is higher in spring and summer than in autumn and winter, it becomes easier to perform a calibration of Z_{DR} during hot seasons.

It is also advisable to use data collected in at least moderate rain. The reason is that because of the spherical shape of hydrometeors in light rain (Z_{DR} = 0 dB at any view angle), its corresponding theoretical curve is a zero slope straight line at 0 dB, sometimes making it harder to identify any possible Z_{DR} bias uniquely related to the system.

Once again, after analysing several cases and taking all this into account a Z_{DR} bias of 2.7 ± 0.1 dB was estimated.

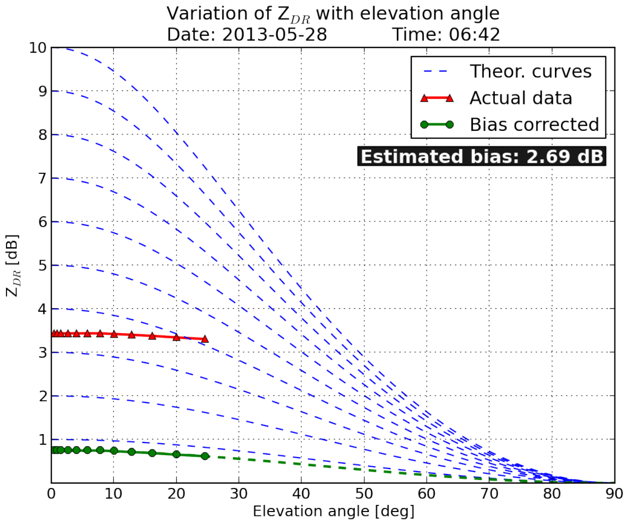

Figure 7: Variation of Z_{DR} with elevation angle - Example

5. CONCLUSION

Considering the above, a Z_{DR} offset of 2.7 dB was introduced in the system. This value is within the range 2.5 dB to 3.5 dB, initially suggested by the radar operator. After that, the monitoring routines (Figure 8) and the daily weather analysis using radar data (Figure 9) confirmed the enhancement achieved.

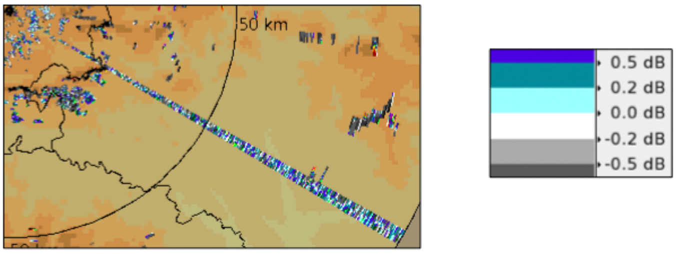

Figure 8: Sun signature – Z_{DR} bias corrected

As an example, the next pictures show two instances of the same episode of dry snow occurred in November 2013. The image on the left is the PPI prior to the adjustment and shows Z_{DR} values of about 2.5 dB to 3.5 dB. These are inconsistent with those typical ones found in the literature (-0.25 dB to 0.5 dB). On the other hand, the PPI on the right is subsequent to the adjustment, showing values of Z_{DR} between -0.5 dB and 0.5 dB, which is the expected behaviour under these meteorological conditions.

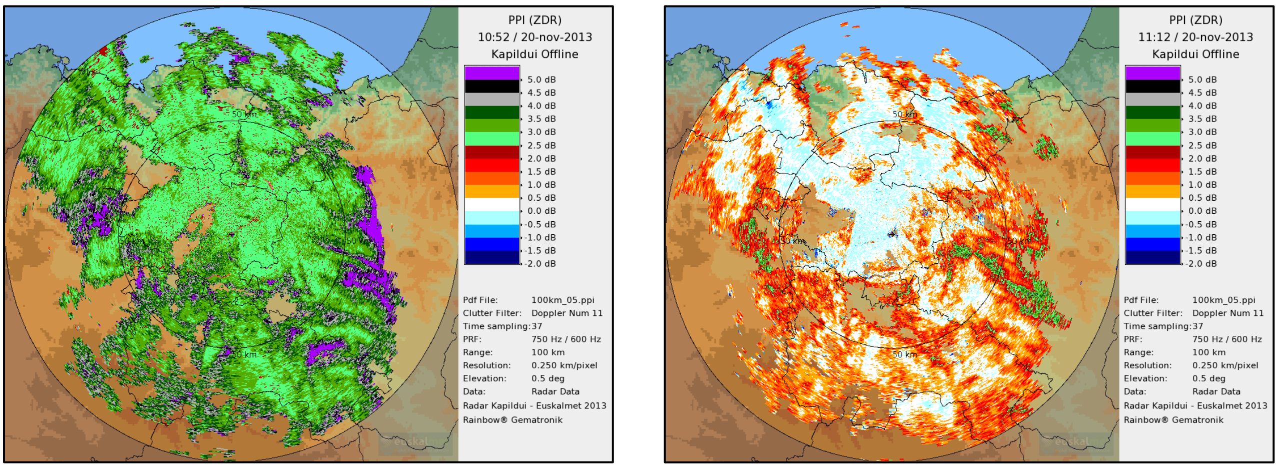

Figure 9: PPI at 0.5° elevation of Z_{DR} before and after the adjustment

Currently, any potential Z_{DR} bias is checked frequently. When the radar operator detects an unusual behaviour or if any change in the system is made, a new calibration is performed running the tools developed to make this work possible, saving time and money due to the use of radar data collected during operational routines rather than through specific calibration techniques.

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