P9.7 **OPERATIONAL POLARIMETRIC VARIABLES CALIBRATION AT METEO FRANCE : WHERE DO WE STAND ?**

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1. INTRODUCTION

In recent years polarimetry has proven to be a key technology for the improvement of the weather radar products quality. Indeed, in the near future polarimetric weather radars are going to be standard for most of the Meteorological Agencies in the world. Météo France is progressively upgrading its network since 2004, when the first polarimetric radar was installed in Trappes, near Paris. Currently 10 out of a total of 24 operational weather radars in Metropolitan France are polarimetric, 9 at C-band and 1 at S-band.

The calibration of reflectivity (Z_h) and differential reflectivity (Z_{dr}) is essential to obtain good quality radar products such as hydrometeor classification and quantitative precipitation estimation. Météo France is putting much effort in developing techniques to monitor and correct eventual biases. This paper provides an overview of the current operational techniques as well as offering some preliminary results on the self-consistency method under development to monitor the Z_h calibration bias. The paper is structured as follows: Section 2 provides an overview of the current calibration techniques, Section 3 introduces the self-consistency method, Section 4 analyses the preliminary results obtained by the method, conclusions are discussed in section 5.

2. IMPLEMENTED CALIBRATION TECHNIQUES

Bias in the differential reflectivity have two different sources : 1) The system itself, i.e. differences in transmitted power and receiver gain between the vertical and horizontal polarization channels and 2) the structures close to the radome and/or the radome itself. This last element introduces a spatial variability that must be corrected for by generating azimuth- and elevation-dependent Z_{dr} bias curves. Currently three different techniques have been implemented into the polarimetric processing chain to monitor the Z_{dr} bias.

Bias related to the system is monitored by exploiting data collected at 90° elevation (A tilt revisited every 15' in all the polarimetric radars in the network). The average Z_{dr} of each scan in which rain is present is stored, together with the number of valid gates. At 00:00 UTC, if there is a sufficient number of valid gates, a daily weighted averaged is produced. If the radar were perfectly calibrated the resultant value should be 0 dB. Any deviation from that is considered to be the inherent system bias.

Another technique meant to monitor the inherent system bias consists in observing the Z_{dr} sun signature, which should be 0 dB on average since the sun radiation is not polarized. The values of Z_{dr} in non-precipitating gates when the antenna is pointing to the sun are stored. At the end of the day the data is fed into a model which takes into account the antenna beam shape and the angular distance between the sun and the centre of the beam (See Holleman et al. 2010 for details). The difference from 0 dB is considered to be Z_{dr} bias introduced by the radar receiver chain. Fig. 1 shows an example of the annual evolution of the Z_{dr} bias inherent to the system.

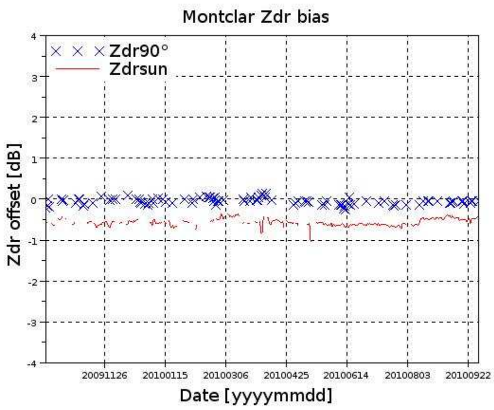

Fig. 1 Example of Z_{dr} bias system monitoring. The graph shows the Z_{dr} bias from measurements at the vertical (blue crosses) and from sun measurements (red line) obtained during 1 year (from 2009-10-07 to 2010-09-30) using the Montclar C-band polarimetric radar.

The spatial variability of Z_{dr} is monitored by observing the daily Z_{dr} average of rainfall at each azimuth and elevation with a reflectivity between 20 and 22 dBZ, which, according to electromagnetic scattering models, should be 0.2 dB if the radars were well calibrated (Gourley

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et al. 2006). In Fig. 2 an example of the annual evolution of the Z_{dr} bias azimuth curve for a particular elevation is shown.

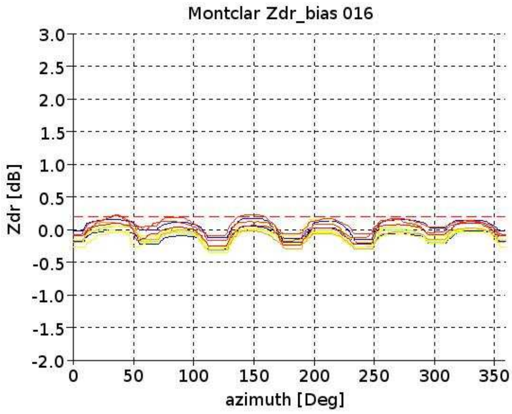

Fig. 2 Example of Z_{dr} azimuth dependent bias monitoring. The graph shows the evolution of the azimuth Z_{dr} bias of the 1.6° elevation obtained with the Montclar radar during one year (from 2009-10-07 to 2010-09-30) using the Montclar C-band polarimetric radar.

The aforementioned techniques have been operational for over a year and long-term statistics are now available. The inherent Z_{dr} bias of each polarimetric radar is largely variable, ranging from –2 dB to 2 dB. This, however, is not a major problem provided it is accounted for. What is crucial is the temporal stability of such bias. The results indicate that most of the radars in the network have a Z_{dr} stability within +/- 0.3 dB. The comparison of the results obtained from sun hits with those obtained from measurements at the vertical shows that a large portion of this instability is caused by the receiver. The analysis of the azimuth and elevation Z_{dr} bias curve show that the most important bias is introduced by the radome. The curves have a sinusoidal-like pattern centred at the Z_{dr} system bias. The pattern is fairly stable and is correlated with the type of radome.

So far the only methodology to monitor Z_h is the analysis of the sun hits performed in a similar manner as for the Z_{dr}. The results show that most of the radars in the network are stable within 1 dB. However, such methodology can only provide information of the stability of the receiver, not the transmitter and hence it is not suitable for an absolute calibration of the reflectivity.

3. THE SELF-CONSISTENCY METHOD

The technique to estimate the absolute Z_h calibration bias is described in more detail in Gourley et al. (2009). The method is based on the fact that rainfall is relatively well represented by two parameters and polarimetric radars provide more than two variables to estimate the rainfall rate: Z_h, Z_{dr} and the specific differential phase K_{dp} can thus be considered as redundant in rain. Knowing the value of two of them allows estimating the third one.

The proposed method estimates the value of K_{dp} at each valid range gate from the observed values of Z_h and Z_{dr} using relations derived from scattering modelling using the T-matrix technique. K_{dp} is then integrated in range to obtain the theoretical value of the differential phase Φ_{dp}. The relative difference between the observed and theoretical range difference in a valid segment provides the percentage of bias, i.e.:

$$C\% = \frac{\Delta\phi_{dp}^{th} - \Delta\phi_{dp}^{obs}}{\Delta\phi_{dp}^{obs}} \times 100$$

This value translates into the Z_h calibration bias in dB:

$$CdB = 10\log\left(1 + \frac{C\%}{100}\right)$$

In practice though, various phenomena may affect the performance of the method and a careful selection of the data is necessary in order to obtain meaningful results. In the first place, the self-consistency relation is exclusively valid in rain. Therefore gates contaminated with ground clutter, clear air or containing other hydrometeor types must be filtered out from the data set. Secondly, there are two phenomena related to scattering mechanisms that can affect the method, particularly at higher frequencies, such as those of the C or X-band: precipitation-induced attenuation and Mie scattering effects. The precipitation-induced attenuation can be partially corrected for since it is proportional to Φ_{dp} (See Gourley et al. 2007) but the uncertainty of the resultant corrected estimators increases. Therefore it is advisable to set a higher limit on the range of Φ_{dp}. Mie scattering effects can be avoided by setting a limit on the maximum Z_h and Z_{dr} that can be present along the ray. In the third place, in light rain, noise may affect the measured Φ_{dp}. In order to reduce its impact, a minimum Φ_{dp} increase must be set and to reduce the impact of the variance in the measurement produced by the noise a minimum segment length is necessary.

The operational implementation of the methodology has a two step approach. In the first place a theoretical Φ_{dp} field is calculated for the valid gates (i.e. Z_{dr} between 0 and 5 dB and gate classified as rain) for each scan. Secondly, for each ray in the scan, a valid segment is searched. If a segment complying with the constraints is found a Z_h bias in the segment is calculated. Once the entire scan is processed an average bias is computed and it is stored together with the number of segments used in the calculation. At the end of the day, a weighted average of the bias is computed from the valid scans.

4. FIRST RESULTS

The method was tested using data from a total of 18 significant rain events from the summer of 2010 collected by 5 different C-band radars in the network. Only one elevation was used in each radar. The elevation used was the lowest possible without significant impact of partial beam blocking.

The study performed had three main objectives: assess the sensitivity of the method to the various constraints, assess the sensitivity of the method to errors in the Z_{dr} calibration and assess the impact of a wet radome on the method.

In a first analysis the data was processed using the same constraints as those found in Gourley et al. (2009). It imposed a minimum Φ_{dp} segment length of 15 km, with an increase in Φ_{dp} between 10° and 12° within the segment. Additionally it limited the distance from the radar to a maximum of 65 km to avoid the presence of the bright band in the data. The analysis showed that the conditions were too restrictive and the final number of valid segments obtained was in most cases insufficient to get meaningful results. It was therefore concluded that the conditions had to be relaxed in order to implement the technique operationally.

The first attempt was to remove the maximum distance, considering that the hydrometeor classification scheme used is mature enough to correctly identify the bright band. It resulted in a marginal increase in the number of valid segments without a degradation of the algorithm performance. Secondly, the impact of the minimum segment size was analysed. 3 different minimum segment sizes were imposed: 1km, 6 km (which is the size of the moving average filter used to smooth the observed Φ_{dp}) and 15 km. The results showed that 6 km minimum segment was a good trade off between the large number of spurious segments introduced when setting 1 km minimum segments and the lack of data due to the stringent 15 km segment.

In the second part of the study the impact of a Z_{dr} bias in the final Z_h bias estimation was analysed. In order to do that, and artificial offset of +0.2 dB and –0.2 dB, which is considered the uncertainty of our current Z_{dr} calibration techniques was set in the Z_{dr} field. The results showed that such errors had an impact in the Z_h bias of 0.5 dB, rendering the technique applicable in an operational environment. In concrete a positive Z_{dr} offset resulted in a negative contribution to the Z_h bias and a negative Z_{dr} offset resulted in a positive contribution to it.

Finally, the impact of the wet radome in the results was analysed. Wet radome is an important issue because it has been proven that a wet radome causes significant attenuation (Kurri and Huuskonen, 2008). Unlike the precipitation-induced attenuation along the path, which can be reasonably corrected for using Φ_{dp}, there are not yet mature and well established techniques to correct for it. The impact of the wet radome was analysed by observing the temporal evolution of the Z_h bias calculated at each scan and correlating it with the periods where, from the measurements at the vertical used to estimate the Z_{dr} bias, it was known that it was raining over the radar. The results show an strikingly good correlation between rainy periods and a dramatic increase in the negative Z_h bias (See the example shown in Fig. 3). Furthermore the negative bias is persistent way after the precipitation front has passed the radar, which is the time needed to dry it up. Consequently, unless radome-induced attenuation is corrected for, the affected scans must be removed from the data set, which significantly reduces the amount of valid data.

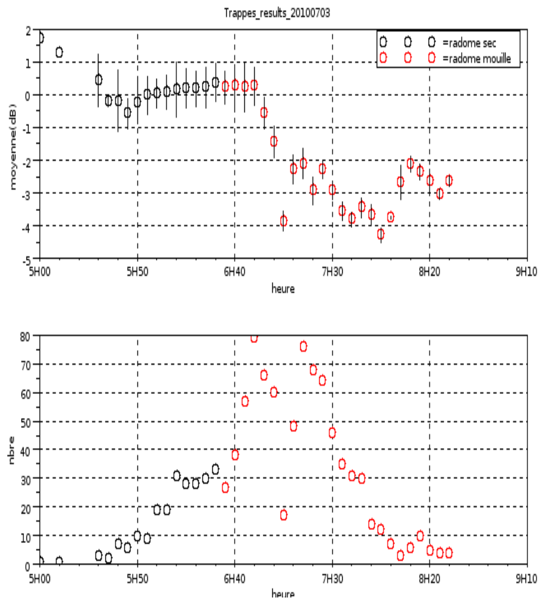

Fig. 3 Top figure: temporal evolution of the estimated Zh calibration bias. Bottom figure: number of valid segments used for the estimation. Red dots represent periods where the radome was wet.

5. CONCLUSION

This paper has provided an overview of the current operational calibration techniques at Météo France, as well as some insight on the first attempts to implement a method for the absolute calibration of Z_h.

The Z_{dr} calibration techniques currently implemented allow a careful monitoring of the Z_{dr} bias introduced by the receiver, the transmitter and the environment surrounding the radar (radome, etc.). The results show that Z_{dr} is stable within 0.3 dB for most of the systems in the network, close but not within the limits of 0.2 dB desired for its use in quantitative precipitation estimation.

The paper also have shown the studies carried out in order to achieve an absolute calibration of the reflectivity using the self-consistency of the polarimetric variables in rain. This first study has established the constraints that must be imposed to the data in order to get meaningful results. It has also showed that the method is relatively robust to bias in the Z_{dr} calibration. A misscalibration of 0.2 dB in Z_{dr} roughly correspond to 0.5 dB in Z_h.

The study has also highlighted the large impact of the wet radome attenuation in the results. Consequently, unless a methodology to correct for such attenuation is developed, it is recommended to remove scans suffering from wet radome from the data set. This poses some questions on the practical application of the method for temporal monitoring since there is the risk that the method provides results only for very few events. Nevertheless it must be noted that this study has been carried out using a single elevation and that the use of the entire volumetric scan (provided the effects of partial beam blocking are corrected for) can significantly increase the data set.

The study has focused on sensitivity issues but there has not yet been a rigorous quantitative validation of the methodology, which remains a difficult subject. Initial attempts to qualitatively validate the method have been performed though. In one attempt the Z_h bias have been compared with results from the sun power monitoring aforementioned and a fairly good correlation was found out, i.e. radars that had a sun power well above or well below the average had a positive or negative Z_h bias accordingly. Another qualitative validation was performed by observing the results of the Hydram factor. The Hydram factor is a parameter calculated monthly using the average of the relative differences between rain gauges and overlapping radar pixels of a selected set of data (See Cheze and Helloco, 1999, for more details). Although affected by multiple factors such parameter does provide an indication of whether the radar suffers a negative or a positive bias. The results of the self-consistency technique were in good correlation with those of the Hydram factor. It should be indicated here that direct comparison between rain gauge data and radar rainfall estimation may provide inconclusive results due to the variability of the Z-R relationship.

The conclusions of the study show promising results. It seems feasible to correct the Z_h bias within 1 dB with this technique. However, prior to its operational implementation, a systematic long term statistical analysis is necessary and robust criteria to remove scans affected by wet-radome attenuation must be produced. In the near future Météo France is going to implement the technique on a non-operational basis into some of the radars in the network in order to produce such long term statistics.

REFERENCES

Cheze J-L, Helloco F. 1999. The HYDRAM Project ot Météo France: A Quality-Based Approach for Quantitative Radar Measurements. In *Proceedings of 29th Conference on Radar Meteorology, Montréal, Canada, 12-16 July 1999.* American Meteorological Society: Boston, MA;

Gourley JJ, Tabary P, Parent du Chatelet J. 2006. Data Quality of the Meteo–France C-band Polarimetric Radar. *J. Atmos. Oceanic Technol.* 23: 1340-1356.

Gourley JJ, Tabary P, Parent du Chatelet J. 2007. Empirical Estimation of Attenuation from Differential Propagation Phase Measurements at C Band. *J. Appl. Meteor. Climatol.* 46: 306-317.

Gourley JJ, Illingworth AJ, Tabary P. 2009. Absolute calibration of radar reflectivity using redundancy of the polarization observations and implied constraints on drop shapes. *J. Atmos. Oceanic Technol.* 26: 689-703.

Holleman I, Huuskonen A, Gill R, Tabary P. 2010. Operational Monitoring of Radar Differential Reflectivity Using the Sun. *J. Atmos. Oceanic Technol.* 27: 881-887.

Kurri M, Huuskonen A. 2008. Measurements of the Transmission Loss of a Radome at Different Rain Intensities. *J. Atmos. Oceanic Technol.* 25:1590-1599.