Review of manuscript: amt-2016-52

Title: Improved Analysis Of Solar Signals for Differential Reflectivity Monitoring
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GENERAL COMMENTS

This manuscript reviews and improves several aspects of the methodology that uses solar hits found in operational scans for daily monitoring of the calibration of the weather radar differential reflectivity (ZDR) bias in reception. The main achievements are the proposal of a procedure to improve the accuracy of the power and differential reflectivity estimated for the solar hits and that the authors provide solid arguments supporting a separate fit to solar hits' power in each channel, in contrast to a direct fit to solar ZDR data. The authors also give good guidelines about how to interpret the solar ZDR bias results in comparison to zenith ZDR measurements in rain in order to identify potential inconsistencies in the transmitter or gain losses. I believe that this work is of interest for the weather radar community and fits well within the scope of AMT journal. Comments, questions and suggestions to be considered by the authors are listed in the following.

SPECIFIC COMMENTS

- Eq. (1) given in P.3 is valid when the calibration reflectivities $dBZ_0^{H,V}$ are available for both channels. In this case both radar constants C_H and C_V are known - note that the radar constants C_H and C_V include antenna parameters and transmission losses regarding their respective polarisations.
  However, often the radar processor only allows for a single calibration reflectivity and the differential reflectivity offset, dBZ_0^H and ZDR_0 (e.g. Z_{dr}^{rain}), for instance. In this second case, a single radar constant is used for the two channels (e.g. C_H) and the differences between radar constants are accounted for in the ZDR_0 calibration. If the measurands available are Z_H and Z_{dr} and only C_H is known (the difference $C_H - C_V$ is accounted in the calibration ZDR_0), P_H can be calculated from Eq. (1) but it is not possible to calculate P_V. Instead the following quantity can be calculated:

  $$P_V - (C_H - C_V) = P_H - Z_{dr} = Z_H - Z_{dr} - C_H - f(r)$$

  Therefore, Eq.(12) also holds valid for this case and it is not correct to say that $C_H = C_V$ (P.7, L.8). In this case, separate fits would mean fitting P_H and $P_V - (C_H - C_V)$ but the difference between the peak powers would still give an estimate of the differential receiver bias.

  I think that these two cases need to be more explained and the procedure to follow in the two fitting approaches (direct Z_{dr} fit and separate H/V fit) explicitly described for each case.

- If I am not mistaken, the $\hat{Z}_{dr}$ value corresponding to perfect antenna-sun alignment estimated from the fit has a slightly different interpretation depending on wether Z_H and Z_V are separately available with their own calibration reflectivities (Frech, 2013) or wether Z_H and Z_{dr} are available (Holleman et al., 2010a) together with the calibration dBZ_0^H and ZDR_0. In the first case, $\hat{Z}_{dr}$ carries information about the differential sensitivity (i.e. differences in noise figure between channels) while in the second case $\hat{Z}_{dr}$ gives information (except for the ZDR_0 calibration value) about the bias of the linear depolarisation ratio or differential receiver bias. I have tried to prove this in the Appendix at the end of this document.

- **P.7, Eqs.(15)-(16):** Since the squint angle is studied in an upcoming section, it is important to mention that these equations are derived assuming that the pointing biases are equal for both polarisations. Also Eqs.(10)-(11); the parameters $B_{\phi,\theta}$ give the position of the minimum/maximum/saddle point of the surface but represent the biases only under the aforementioned assumption.

- **P.6-7, Section 3.3:** I suggest that this section is reordered for clarity and rigour; it should start with Eq.(12) to arrive at Eq.(8), since the latter model is the result of subtracting the two paraboloid surfaces. Then, Equation sets (9)-(11) and (13)-(16) could be joined in a single set. Having Eqs.(13)-(14) before the sentence in lines 18-19 would also be helpful. In addition, the first paragraph of the section may be moved after the mathematical derivation so that is easier to understand the qualitative description of the left panel in Figure 2.

- **P.8, Fig.4:** The median estimate (red) and the mean estimate (green) lines overlap but their corresponding window upper and lower widths are not at the same distance from each other. There seems to be an inconsistence in the green lines drawn for the mean.

- **P.9, L.8-9:** I could not find the solar hit rejection explained in sentence "In addition solar hits with standard deviation ..." in the references given at the beginning of the paragraph. Do you apply it for the present work only? If so, maybe it should be explained or this sentence should be placed later in the section. Also, what is approximately the standard deviation expected for a solar hit?

- **P.9, L.11-12:** Just a "picky" comment: the method of removing outliers using the fit curve as reference may fail also when there is a single outlier but "badly located" so that it alone biases the fit curve. This is implied in the sentence just afterwards "The results are further improved ..." but may be interesting to mention it explicitly.

- **P.10, L.26:** For clarity, this sentence may be extended to explain that, after the estimation of the width and the filtering, the mean value for ranges > 50 km is computed.

- **P.10, L.28-30:** Another reason to use a fixed width may be that at low elevations there might be too few (or none, depending on the maximum range) range bins at high altitudes available for estimation of the filtering window width.

- **P.10, L.30:** Could you give a value for the fixed window width recommended for filtering (e.g. the one estimated using data at high altitudes in the analysis in Fig. 4)?

- **P.9-10, Section 4.1:** I think it would be interesting to provide further evidence on how the proposed filtering increases the number and quality of the solar hits, to support what is stated in P.2 L.15-16. For example, are the fit estimates more stable or the RMSE of the fit lower when applying the proposed quality control? This is somewhat accomplished in P.14, L.2-6 but comparisons of the number of hits and standard deviation for the same dataset before and after the quality control may be desirable.

- **P.11, L.7-9:** I think the 3-parameter fit with fixed pointing may give biased results if there is a significant squint angle (from the reasoning in the comment above for P.7, Eqs.(15)-(16)).

- **P.11, L.12:** In this sentence it is not clear which methods are compared. The first method described (the one used in Holleman et al. (2010a)) is not analysed. Maybe this should be explicitly mentioned in case the reader expects to find it among the methods compared in Fig. 6.

- **P.12, L.5-6:** The sentence "For surfaces ... is one of the fit parameters" is a very good point and hints to a very strong argument to support the separate fit for the horizontal and vertical channels. Even if it is further discussed in the conclusions, I think it would be beneficial to put more stress in this reasoning at this point of the manuscript. The case described (constant surface) corresponds to an extreme case of ill-conditioning of the inverse problem in Eq.(8) (there are more parameters in the model than needed to explain the observations). This example also indicates that fitting Eq.(8) is not an appropriate methodology for routine usage, since the well-conditioning of the problem depends on the magnitude of the differences between the horizontal and vertical widths, which may change in time and from radar to radar.

- **P.11-14, Section 4.2:** Could you specify which measurands were available for the calculations in this section?
- **P.15, L.16-17:** If I am getting it right, assumed that the antenna gains are correct and that the bias corresponds to inaccurate transmitter losses, then this bias is systematic for the reflectivity values and should not affect the estimation of the pointing errors or the squint angle.

TECHNICAL CORRECTIONS

P.1, L.1: Suggest something like "refined" or "optimised" instead of "developed"
P.1, L.3: Suggested, for clarity, something like: "... rain and clutter contaminated gates ... "
P.1, L.4-5: I think that it is not clear to which analyses this sentence refers
P.1, L.6: "differential reflectivity offset/bias"?
P.1, L.13: Suggested: "Several methods for Z_{dr} calibration exist ..."
P.1, L.23: "normal radar operations do not need to be stopped"
P.2, L.1: Suggested: "antenna alignment information"
P.2, L.3: "introduced the on-line method for the solar"
P.2, L.6: Suggest to remove the comma after "pointing"
P.2, L.22: "where the six elevations" ? Or are there more elevations below 9° that are not scanned at single PRF?
P.2, L.22: "Every 5 minutes"
P.2, L.25: Suggest to add a comma after "For convenience"
P.2, L.24-25: Suggest to change the order of the sentence for clarity: "now two new radars have been added to the network and all radars except one are polarimetric"
P.2, L.29: Suggest to add a comma after "method"
P.3, L.1: Suggested: "increase with range"
P.4, L.5: "which is slightly"
P.4, L.5: Maybe a brief explanation here of why the distribution is wider in azimuth?
P.5, L.1-3: Suggest moving these sentences "We assume ... by the least squares method" to L.6 after "... vertical polarisations" and before "The elevation width ...", because the relation of the parameters to the widths and biases is explained afterwards.
P.5, L.5: Suggested: "... these parameters may be different ..."
P.6, L.3: Suggested: "the distribution has the form"
P.6, L.8: Lacks a space after the point
P.6, L.20: The "powers" term in this sentence may lead to confusion since Eq.(2) is a polynomial equation. Maybe something like "we can substitute the powers in Eq.(12) using Eq. (2)"
P.7-9: Suggest to structure subsection 3.4 as a separate section; e.g. one section dealing with sun calibration and the next with rain calibration.
P.8, L.10: "Because of the transient effect"
P.10, L.4: Lacks a space after the point
P.10, L.7: "devise" here instead of "device"
P.10, L.9: Suggested: "and this power together with ..."
P.10, L.17: Do you mean "rain contamination" here?
P.11, L.5: Is it Eq.(8) here?
P.14, L.3: The degree units should be dB instead
P.14, L.4: "than the 0.2 dB"
P.14, L.5: "or the 0.05 dB"
P.14, L.5: "probably due to ..."

Appendix

Solar powers at the receivers:

$$t_H = g_H^r \, p_H + N_H$$
$$t_V = g_V^r \, p_V + N_V \tag{1}$$

Calibration reflectivities:

$$dBZ_0^H = 10 \log \left(\frac{c_H \, N_H}{g_H^r} \right) = 10 \log \left(c_H \, I_0^H \right)$$
$$dBZ_0^V = 10 \log \left(\frac{c_V \, N_V}{g_V^r} \right) = 10 \log \left(c_V \, I_0^V \right) \tag{2}$$

And differential reflectivity offset:

$$ZDR_0 = 10 \log \left(\frac{g_H^r \, c_V^t}{g_V^r \, c_H^t} \right) \tag{3}$$

The radar constants include the transmission gains. The following results are derived for the Z_{dr} fit but they also apply for separate H/V fits in both cases.

case 1: Direct Z_{dr} (ZDR_0)

$$Z_{dr} = 10 \log \left(\frac{t_H - N_H}{t_V - N_V} \right) - ZDR_0$$
$$= 10 \log \left(\frac{p_H}{p_V} \right) + 10 \log \left(\frac{g_H^r}{g_V^r} \right) - ZDR_0 \tag{4}$$

Therefore, if ZDR_0 is added to the $\hat{Z}_{dr}$ fit estimate, an estimate of the linear depolarisation ratio offset (XDR) is obtained.

case 2: Z_H (dBZ_0^H) and Z_V (dBZ_0^V)

$$Z_H = 10 \log \left(\frac{t_H - N_H}{N_H} \right) + dBZ_0^H + f(r) \tag{5}$$

$$Z_V = 10 \log \left(\frac{t_V - N_V}{N_V} \right) + dBZ_0^V + f(r) \tag{6}$$

$$Z_{dr} = Z_H - Z_V = 10 \log \left(\frac{p_H}{p_V} \right) + 10 \log \left(\frac{N_V}{g_V^r} \, \frac{g_H^r}{N_H} \right) + dBZ_0^H - dBZ_0^V \tag{7}$$

$$= 10 \log \left(\frac{p_H}{p_V} \right) + 10 \log \left(\frac{I_0^V}{I_0^H} \right) + dBZ_0^H - dBZ_0^V \tag{8}$$

In this case, if calibration reflectivities and antenna gain ratio are subtracted from the $\hat{Z}_{dr}$ fit estimate, the estimate obtained is the ratio of the equivalent front-end noises $\frac{I_0^V}{I_0^H}$.