Interactive comment on "Calibration of radar differential reflectivity using quasi-vertical profiles". Response to Anonymous Referee 2

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October 9, 2021

We thank the reviewer for the detailed, positive remarks that surely will help us to improve the work. The answers to the questions are given below in blue with the proposed modifications to the paper.

This study proposes an operational method to estimate a systematic bias of radar differential reflectivity (Zdr) using quasi-vertical profiles (QVP). The authors compared the results of the proposed QVP method with those derived from vertical profiles (VP) and disdrometer data for one year period of 2018. They concluded that the new approach is consistent with the traditional method and is operationally applicable.

I think that this study is very important for radar quantitative precipitation estimation (QPE) based on polarimetric variables. However, I see a limitation of this study for an operational application. After reading the manuscript carefully, I found that the QVP method requires a disdrometer-derived Zdr bias for light rain (e.g., 0.18 dB). This is a challenge where there is no disdrometer near radar sites. Additionally, using the disdrometer data in the QVP procedure (e.g., Zdr correction) affects an independent evaluation based on Zdr derived from the disdrometer data (e.g., Fig. 10). My detailed comments are provided below.

We thank the reviewer for raising these important points. Indeed, the method requires a disdrometer-derived Zdr bias in light rain. However, this value can be computed using measured or simulated DSDs. In the paper we used measured DSDs, but the results are the same if simulated DSDs are used (see replies to points 1 and 2 below and Figure 1 in this document). The second point is about using the same disdrometer data set to compute the Zdr bias in light rain and to validate the results. It is fair to say that the validation of the method is performed not only in light rain, but also in moderate and heavy rain. However, to address this issue, we have now simulated a wide range of DSDs expected in real storms in order to compute the Zdr bias in light rain and we used the measured DSDs to validate the method (see reply to point 2 below).

Major comments:

1. Title is misleading

   Just looking at the title, I started reading the manuscript with high hope to see how the QVP method can estimate a Zdr bias. However, it turns out that the method needs a reference Zdr value simulated from disdrometer measurements. This is a limitation for the operational estimation for most radar sites, particularly in the United States. I think that the author should include "disdrometer data" in the title.

   We believe there is no need to include "disdrometer data" in the title of the manuscript. The proposed method can be applied even if disdrometer observations are not available. We originally computed the Zdr bias in light rain using measured DSDs, but this bias can also be calculated using simulated DSDs. The results show that the simulated value is *consistent with the value obtained using measured DSDs (see reply to point 2). Therefore, the proposed Z_{DR} bias in light rain can be extrapolated to other radar sites.*

2. Independent evaluation
   Part of evaluation in this study is not independent. The disdrometer data used in the QVP procedure were also used in the evaluation (e.g., Figs. 10 and 11).

   To address this issue, we simulated a wide range of DSDs using the range of parameters described in Bringi and Chandrasekar (2001) expected in real storm events:

$$10^3 \leq N_w \leq 10^5 \ [mm^{-1}m^{-3}]$$
$$0.5 \leq D_0 \leq 2.5 \ [mm]$$
$$-1 \leq \mu \leq 5$$
$$R \leq 300 \ [mm \ h^{-1}]$$

   We randomly generated 10,000 sets of DSD parameters (Nw, D_0 and μ) uniform-distributed within the ranges defined above. Equation 3 from the paper was used to simulate the DSDs, which were used as input to a T-matrix scattering model to compute Z_H and Z_{DR}. The scattering simulations were performed using the same assumptions as described in the manuscript: (i) the raindrop shape model from Thurai et al. (2007) (their Eq. 2 for $D > 1.5$ mm, their Eq. 3 for $0.7 <= D <= 1.5$ mm, spherical raindrops otherwise); (ii) no canting angle distribution; (iii) maximum diameter for the integration fixed to $3D_0$; (iv) temperature of $10°$ C, radar wavelength of 5.3 cm and elevation angle of $0°$. The results are shown in Figure 1, which depicts the theoretical variation of Z_{DR} versus Z_H. We computed the Zdr bias in light rain and this gives a value of $\overline{Z_{DR}} = 0.18dB$ for $Z_H < 20$ dBZ, which is consistent with the result obtained using measured DSDs.

3. Zh- Zdr dependence
   There is no Zh- Zdr dependence demonstrated in the manuscript. I think that the authors took simple averages of Zdr values conditioned on Zh values (0-20 dBZ) at each different disdrometer location.

   The Zh- Zdr dependence is shown in Figure 1, which is also consistent with previous studies (see Bechini et al. (2008); Bringi et al. (2006); Giangrande and Ryzhkov (2005); Ryzhkov et al. (2005) for instance.). See also reply to point 2.

4. Discussion section
   The discussion section seems to be the summary of this study. Most of the paragraphs are summaries of the results presented in the figures described in the previous sections. I would like to see actual discussions e.g., regarding any challenges or limitations (or sensitive factors) that can affect the accuracy of QVP method. Additionally, there is no "outlook" in the last section.
   Agreed. We will improve this section in the revised version of the manuscript taking into account the reviewer's suggestions.

Minor comments:

1. Line 4
   Maybe "light rain" instead of "rain?"
   Agreed.

2. Line 4
   Please replace "expected" with "desirable."
   Noted.

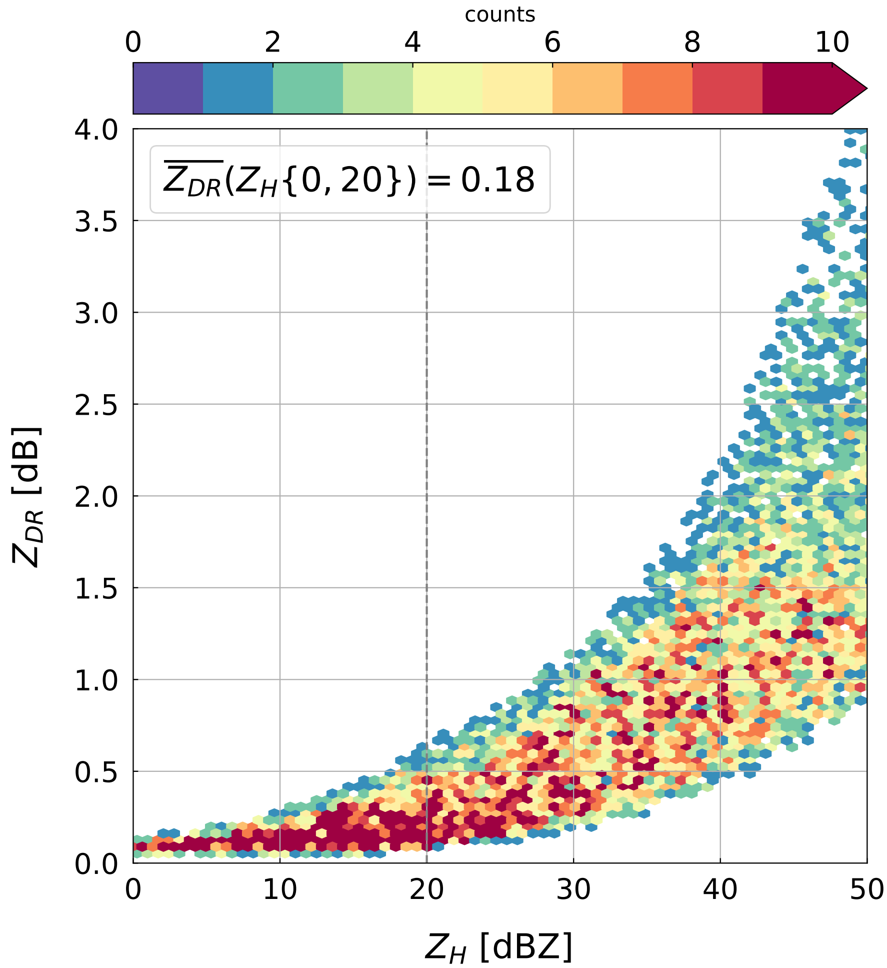

Figure 1: $Z_H - Z_{DR}$ scatterplot using simulated DSDs.

3. Line 95
   Could the author specify the elevation angle of birdbath scans? Based on "averaging azimuthally," the elevation angle is not 90 degrees.

   These are scans collected by pointing the antenna vertically (elevation angle of 90deg) while at the same time the antenna rotates around its axis (from 0 to 360 deg in azimuth). We will clarify this in the manuscript.

4. Line 169
   Why not a "solid phase?" I think that Zdr for solid phase should be reliable (for VP) if the authors avoid the melting layer (e.g., mixed phase) as seen in Fig. 2 (right).

   We agree with the reviewer. Dry snow is an excellent alternative to calibrate Z_{DR} using scans taken at vertical incidence, as demonstrated by Ferrone and Berne (2021). Furthermore, we explored the Z_{DR} values above the ML in our VPs dataset and confirmed the usability of dry-snow to compute the Z_{DR} offset. However, such hydrometeors are not a good option for calibrating Z_{DR} based on QVPs built from low elevation scans. Targeting areas above the melting layer exacerbate the beam broadening and non-uniform beam filling problems as the range increases. These circumstances complicate using dry snow or other solid phase targets to detect the Z_{DR} offset on QVPs built from 9° elevation scans. Thus, we selected *the use of light rain on both schemes to keep consistency between methods.*

5. Figure 2
   The lines indicating the ML and ML bottom are different between right and left panels.
   The individual profile shown in the right panel depicts exactly the same data as in the HTI plot. However, we agree that the lines indicating the ML in the left and right panels do not use the same thickness. We will modify these lines to be consistent in both panels.

6. Line 217
   What are “the mean dependencies?”
   This refers to the Zdr bias in light rain ($0 < Z_H < 20$ dBZ) We will clarify this in a revised version of the manuscript.

7. Line 219
   Is the value 0.18 dB supposed to dynamically change depending on different event cases in an operational situation? Otherwise, is this value static?
   We proposed this value as the intrinsic Z_{DR} value expected in light rain at ground level on measured and simulated DSD measurements. Thus, we do not expect this value to vary if the physical process leading to the light rain remains similar.

8. Line 236
   Please remove the negative sign in “-0.18 dB.”
   Noted, thanks for noting this!

9. Line 239
   Why does Zdr offset fluctuate hourly? Is it a mechanical issue?
   Previous works found hourly variations on the computed Z_{DR} offset (see Chu et al. (2019); Holleman et al. (2010), for instance). This was not the case in our datasets, where the greatest variations on the Z_{DR} offset were related to updates on the radar configuration.

10. Figure 4
    Please insert a legend for lines with different colors.
    Agreed. We will modify this figure accordingly and show all the lines in black (no colour is necessary).

11. Figure 7
    While values with VP look consistent, what is the reason of variations with the QVP method in the insets?
    Due to the inherent averaging process in the construction of the QVPs, the spatial variation of rain events could lead to QVPs that do not fully represent light rain producing some variability in the estimation of the Z_{DR} offset. We will discuss the limitations of our approach in more detail in a revised version of the manuscript.

12. Line 293
    Please replace “The top row of Figure 10” with “Figure 10(a).”
    Noted.

13. Line 344
    Please provide more details about “vague polarimetric signatures.”
    Noted. We will provide more details on this.

References

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