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Atmospheric Measurement Techniques Discussions

Interactive comment on "Approaches to radar reflectivity bias correction to improve rainfall estimation in Korea" *by* C.-H. You et al.

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Response to review

At first, thank you very much for referee's effort in reviewing our paper even your busy time. We revised the manuscript titled "Approached to radar reflectivity bias correction to improve rainfall estimation in Korea" that was submitted to Atmospheric Measurement Techniques. The manuscript has been revised as suggested by reviewer and we also corrected some mistakes. We would appreciate any feedback on the revisions.

Response to review by Anonymous referee #1

Primary comment 1. It is understood that the authors desire the best calibration possible for a single polarization radar (SPOL) using dual-polarimetric radar (DPOL) as

a guide. In the opinion of this reviewer, the authors do not describe the 3 calibration methodologies clearly

Author's Response:

Thank you for your comment. We added some descriptions to make more clearly for reader's easier understanding regarding with three calibration methodologies. First, we added the following sentences from line 12 to 14 on page 6 in the manuscript for the equidistance method. "Therefore, the reflectivity bias of PSN was calculated by averaging the difference of reflectivity along with the equidistance line observed from fourth elevation angle of PSN and third one of BSL." And we also added "Equidistance line" in Fig. 2 for better understanding and removed the bottom figure were removed for the simplicity. Secondly, we added some sentences for better understanding of overlapping method from 19 to 22 line on page 6 in the manuscript as follows; "The distance between two radars in east-west and north-south direction are 42 km and 64 km, respectively. The reflectivity observed from both radars at the pixels designated at the overlapping area as shown by blue rectangle in right panel of Fig. 4 were compared to calculate the ZH bias of PSN." Finally, we described the following sentences for DSD method from 29 to 31 line on page 6 in the manuscript as follows; "The difference of reflectivity observed from PSN and PARSIVEL were calculated and was then taken as a ZH bias."

2. Authors do not describe the meteorological events and data clearly.

Author's Response:

Thank you for your kind comment. We added the following sentence for describing the data used in this study more clearly from line 27 to 30 on page 3 in the manuscript. "The quality controlled ZH, ZDR, KDP measured from BSL were used to calibrate ZDR and ZH of BSL. The ZH measured from PSN were then corrected by using calibrated ZH of BSL using self-consistency method and ZH measured by PARSIVEL. The gage rainfall data were used to assess the performance of three ZH bias correction methods

for PSN which is SPOL." We also added two Figures (Figures 6 and 7) to explain the meteorological events clearly in the manuscript. We explained the events used for the study from 22 line on page 7 to 20 line on page 8 as follows; "Figure 6 shows the time series of ZH observed from BSL radar on 8 September in 2012 and 25 August in 2014. The precipitation within radar coverage on 8 September in 2012 was occurred by low pressure with the front located at northern part of Korea. The core of the precipitation systems was elongated from south to north and moved to eastward. The maximum reflectivity of the core was more than 45 dBZ and caused rainfall at the western part of radar center at 0300 LST (Fig. 6(a)), became more organized shape at the eastern part of radar center at 0400 LST (Fig. 6(c)), and moved to eastward and located out of land at 0500 LST (Fig. 6(e)) on 8 September in 2012. The precipitation system on 25 August in 2014 was caused by the low pressure located at southern part of Korea. The two strong rainfall within the radar coverage were located at south-western part of radar center with distance between 120 km and 150 km and southern part of radar center with distance between 30 km and 90 km, respectively at 1200 LST on 25 August in 2014 (Fig. 6(b)). The two convective cells moved to eastward, their strength were intensified and the area of rainfall was wider at 1300 LST (Fig. 6(d)). The two systems moved to eastward continuously, were merged together at 1400 LST (Fig. 6(f)). Figure 7 shows the time series of hourly rainfall and daily accumulation measured by a gage which recorded highest daily rainfall within radar coverage on 8 September in 2012 and 25 August in 2014. The highest daily accumulated rainfall was recorded from North Changwon (ID 255) and Geumjeong (ID 939) on each day, respectively. The daily accumulation of ID 255 was 150 mm, the maximum hourly rainfall was around 40 mm, and the duration of the rainfall was 7 hours (Fig. 7.(a)). The daily accumulation of ID 939 was around 270 mm, the maximum hourly rainfall was more than 100 mm h-1. The rainfall amount for 3 hours (1000 LST, 1400 LST, and 1500 LST) were mainly contributed to the total rainfall accumulation on 25 August in 2014 (Fig. 7(b))." We also changed Figure number in the manuscript, accordingly.

3. The authors draw conclusions as to which methodology is best based on statistics

generated from a fixed ZR relationship. This approach is very misleading as a fixed ZR relationship may only be valid for a limited time/area within the event.

Author's Response:

Thank you for your comment. As reviewer's comment, there are many uncertainties of radar rainfall estimation. The variability of ZR relation is one of main source of these uncertainties. The ZR relations are different from storm to storm, precipitation types, different climatology, and so on. In this study, we would like to propose the methods for correcting ZH of SPOL which have trouble in calibration using well calibrated ZH from DPOL and PARSIVEL. And we also would like to assess the performance of three methods. One of way to understand their performance is to use the radar rainfall estimation. That is why we calculated radar rainfall estimation using corrected ZH measured by each method. For better understanding of three methods, we added the results of validations obtained by another ZR relation, Z=300R1.4 which is widely used for NEXRAD in the manuscript. We also tested another rainfall system caused by the front with indirect effect of Typhoon on 23 August in 2012 using same methods. The results are summarized in Table 1(Please refer to Figure 1). The results were similar to those of manuscript. Therefore, we assume that the radar rainfall estimation would be used for examining the performance of the three methods.

4. Figure 16 shows noticeable differences in the RMSE statistics between the two events, yet the authors do not describe why. I suspect the differences are due to the underlying meteorological differences between the two events analyzed. By analyzing other events, conclusions drawn by the same methodology may be completely different depending on the degree of validity of the fixed ZR.

Author's Response:

Thank you for your comment. As reviewer's comment, we added the following sentences from line 13 to 16 on page 11 in the manuscript. "It would be caused by the difference of total rainfall amount between two rainfall systems. The maximum total

rainfall amount for both cases were around 250 mm for 25 August and 150 mm for 8 September 2012. Another reason of the fluctuation would be the difference of radar hardware calibration error for PSN between two events. ”

5. If the authors wish to revise this paper, I respectfully suggest that the focus be on the three calibration techniques, and not on matching rain gauge data. There is not enough description of the calibration methods to fully understand what the authors are actually doing.

Author’s Response:

Thank you for your kind comment. For better understanding, we changed the Section in 2. Data and methodology as follows; 2.2 Z and ZDR bias correction of BSL, 2.3 Methodology for bias correction of PSN reflectivity. We also added the sentences as mentioned in the answer to the number 1 reviewer’s comment in the manuscript.

6. In section 2.3, the authors state that the light rain threshold of 20 dBZ<= Z <=28 dBZ was used in Ryzhkov et al 2005 and Marks et al 2011 for self-consistency calibration – this is not correct. By using such light rain, the Kdp values will not be high enough for reliable self-consistency results. No description of the self-consistency equation is provided – what equation was used, and how was it derived ?

Author’s Response:

Thank you for your comment and I am sorry to make reviewer confused. We used the threshold of 20 dBZ<= Z <=28 dBZ for ZDR bias calculation. Marks et al. (2011) used the threshold to categorize the light rain. We followed the method proposed by Ryzhkov et al. (2005) for ZH bias calculation of BSL. We also added the self-consistency method used for this study in the Sect. 2.2 of the manuscript.

7. There is not an adequate description of the Zdr calibration.

Author’s Response:

Thank you for your comment. We added the following description of ZDR calibration in the manuscript.” The assumption of ZDR is close to zero in case of the small rain drop like drizzle was chosen for this study. The ZDR observed from BSL having with reflectivity in the range of 20 dBZ to 28 dBZ for given time period were averaged. Then the averaged ZDR was taken as a ZDR bias.”

8. There is no explanation as to how reflectivity values between SPOL and DPOL are actually compared.

Author’s Response: Thank you for your comments. For the equidistance method, we extracted the reflectivity from PSN and BSL at the equidistance line as shown in Fig. 2. The averaged difference reflectivity extracted from PSN and BSL were taken as a ZH bias. For the overlapping method, we extracted the reflectivity from PSN and BSL at the overlapping area as shown in Fig. 4. The averaged difference reflectivity extracted from both radar were taken as a ZH bias. Before the comparison, the reflectivity measured from BSL were calibrated by self-consistency method. For DSD method, PSN reflectivity was averaged over a domain 13 gates by 3 degrees centered at the PARSIVEL location. Then the averaged difference reflectivity of PSN and PARSIVEL were taken as a ZH bias. We added above mentioned sentences in the manuscript.

9. Figure captions are not well described (i. e. fig 9 and 10), and lead to confusion of the reader. Large fluctuations in the reflectivity differences are not described (other than by decreased sample numbers).

Author’s Response: Thank you for your comment. We modified the captions of Fig. 9 and 10 and also described the following sentences from line 17 to line 22 on page 9. “lower bias values were occurred from 0300 LST to 0400 LST. The fluctuation also would be caused by the sudden change of microphysical characteristics of rainfall pass through the overlapping area for both radars. It would reduce the accuracy of ZH of BSL corrected by self-consistency. The radar rainfall estimation was done by using observed and corrected ZH as an input of Z-R relations.” And we also modified Figures

15 and 16 for simplicity and correction for the legend.

10. Authors are basing conclusions on rain gague rates, yet little-to-no information is provided on the gauge network. What type of rain gauges? Given that rain gauges are an accumulation instrument, how are rain rates computed.. via interpolation as in Wang et al 2008, or some other method?

Author's Response:

Thank you for your comment and I am sorry for confusion. We added the following gage information from line 5 to 6 on page 7. "The rain gages were 0.5 mm tipping-bucket type. Time resolution of gages is 1 min and data quality control was done by KMA." We did not convert gage rainfall into rain rate but we converted radar rain rate to rainfall amount. We used the accumulated rainfall amount calculated from radar and gage for the validation. We also modified "hourly rainfall" to "total accumulated rainfall amount" in the manuscript, accordingly.

11. Correcting radar calibration will improve comparisons with ground "truth" instruments. This is nothing new to the research community. If the authors wish to move forward with this paper, I respectfully suggest that the emphasis be placed on the actual calibration techniques, and not focus on potentially misleading results from a fixed ZR relationship.

Author's Response:

Thank you very much for your really kind comment. As mentioned the answer to the reviewer's comment number 3, we would like to to propose the methods for correcting ZH of SPOL which have trouble in calibration using well calibrated ZH from DPOL and PARSIVEL. And we also would like to assess the performance of three methods. One of way to understand their performance is to use the radar rainfall estimation. That is why we calculated radar rainfall estimation using corrected ZH measured by each method. Please understand our proposal.

*** Thank you very much again for your deep review and it will be of much help for better our manuscript quality.***

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/amt-2015-392/amt-2015-392-AC1-supplement.pdf

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Table 1. The RMSE, NE, and CC obtained from radar ($Z=200R^{1.6}$) and gage rainfall on 23 August in 2012

Statistics	Raw ZH	Corrected ZH		
		Equidistance	Overlapping	DSD
RMSE	62.6	45.1	27.8	49.4
NE	0.6	0.39	0.25	0.43
CC	0.85	0.82	0.83	0.76

Fig. 1.