

Interactive comment on “Application of bias correction methods to improve the accuracy of quantitative radar rainfall in Korea” by J.-K. Lee et al.

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Received and published: 5 February 2016

Manuscript information

Title: Application of bias correction methods to improve the accuracy of quantitative radar rainfall in Korea Authors: Jae-Kyoung Lee, Ji-Hyeon Kim, and Mi-Kyung Suk

Comments for the Anonymous referee#1

We thank the reviewer very much for reading our paper carefully and for the comments. Detailed responses to the comments are given below.

General comments The submitted paper talks about the comparison between weather
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radar data and gauge measurements in Korea. Gauge data are considered as truth. The main goal is to develop methods to correct the systematic bias, the random errors, and the range dependent bias which affects the radar rainfall estimates. The topic of the paper is one of the most discussed in radar hydrology. Several past works, such as those cited by the Authors, have already dealt with the same problem giving valuable contributions in the assessment of radar-gauge adjustment technique (see an additional reference list below for example). Even if the MFBC method (i.e. the mean field bias correction factor) is well known in the literature for many years, as well as the LGC method is the same methodology developed by Zhang et al. 2011, as mentioned by the Authors themselves, the submitted work surely gives a contribution to the aforementioned topic. In fact, the element of originality is constituted by the fact that Authors have investigated the variability of the correction factor as a function of rain type (all rainfall types, typhoon cases, Changma front, local torrential rainfall). However, the methodologies employed to correct Z bias and rainfall estimation bias were not explained in sufficient detail (I suggest Authors to introduce more references). In addition the LGC method is explained in a confused way, and Sect. 3 is poorly written. So it's my opinion that many parts of the paper should be rewritten (see specific comments and technical corrections). I also suggest to the Authors to submit the article to a revision concerning the English language. In conclusion, I believe that the manuscript is worth for publication after some major revisions.

Additional references - Sebastianelli, S., Russo, F., Napolitano, F., & Baldini, L. (2013). On precipitation measurements collected by a weather radar and a rain gauge network. *Natural Hazards and Earth System Science*, 13(3), 605-623, doi:10.5194/nhess-13-605-2013. -Villarini, G., Mandapaka, P. V., Krajewski, W. F., and Moore, R. J.: Rainfall and sampling uncertainties: A rain gauge perspective, *J. Geophys. Res.*, 113, D11102, doi:10.1029/2007JD009214, 2008a. - Villarini, G., Serinaldi, F., and Krajewski, W. F.: Modeling radar rainfall estimation uncertainties using parametric and nonparametric approaches, *Adv. Water Resour.*, 31, 1674–1686, 2008b. - Berenguer, M. and Zawadzki, I.: A study of the error covariance matrix of radar rainfall estimates in stratiform

rain, *Weather Forecast.*, 23, 1085–1101, 2008. - Berenguer, M. and Zawadzki, I.: A study of the error covariance matrix of radar rainfall estimates in stratiform rain. Part II: scale dependence, *WJ.*, Fulton R., O'Bannon, T., and Miller D.: Real-time adjustment of range-dependent biases in WSR-88D rainfall estimates due to nonuniform vertical profile of reflectivity, *J. Hydrometeorol.*, 1, 222–240, 2000 - Gorgucci, E., Scarchilli, G., and Chandrasekar V.: Calibration of radars using polarimetric techniques, *IEEE Trans. Geosci. Remote Sens.*, 30, 853-858, 1992.

Specific comments and technical corrections Comment#1 P11429, title: I would suggest: “quantitative rainfall radar estimations” instead of “quantitative radar”. Answer#1: Accepted. The title has been revised as follows

Before: “Application of bias correction methods to improve the accuracy of quantitative radar rainfall in Korea”

After: “Application of bias correction methods to improve the radar-based quantitative rainfall estimations in Korea”

Comment#2 P11430, line 1: I would say: “there are many potential sources of bias in rainfall estimation performed by a weather radar”; in fact there is only one bias that has multiple causes. Answer#2: Accepted. The manuscript has been revised as follows

Before: “There are many potential sources of the biases in the radar rainfall estimation process”

After: “There are many potential sources of the bias in rainfall estimation performed by a weather radar”

Comment#3 P11430, lines 1-6: you wrote: “This study classified the biases from the rainfall estimation process into the reflectivity measurement bias and the rainfall estimation bias by the Quantitative Precipitation Estimation (QPE) model and also conducted the bias correction methods to improve the accuracy of the Radar-AWS Rainrate (RAR) calculation system operated by the Korea Meteorological Administration (KMA).” The

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sentence is too long, please rephrase. I suggest writing: “This study classifies the rainfall estimation process overall bias into the reflectivity measurement bias (Z bias) and the rainfall estimation bias (R bias). It also conducted the bias correction methods to improve the accuracy of the Radar-AWS Rainrate (RAR) calculation system assessed by the Korea Meteorological Administration (KMA). The rainfall is estimated by a Quantitative Precipitation Estimation (QPE) model.” Answer#3: Accepted. The manuscript has been revised as follows.

Before: “This study classified the biases from the rainfall estimation process into the reflectivity measurement bias and the rainfall estimation bias by the Quantitative Precipitation Estimation (QPE) model and also conducted the bias correction methods to improve the accuracy of the Radar-AWS Rainrate (RAR) calculation system operated by the Korea Meteorological Administration (KMA).”

After: “This study classified the rainfall estimation process overall bias into the reflectivity measurement bias (Z-bias) and the rainfall bias (R-bias) estimated by the Quantitative Precipitation Estimation (QPE) model. It is also conducted the bias correction methods to improve the accuracy of the Radar-AWS Rainrate (RAR) calculation system operated by the Korea Meteorological Administration (KMA).”

Comment#4 P11430, lines 7-8: I suggest to write: ” for the Z bias occurred when a weather radar measures the reflectivity this study : : :” (a weather radar measures the reflectivity, not the rainfall). Answer#4: Accepted. The manuscript has been revised as follows.

Before: “In the Z-bias correction for the reflectivity biases occurred by measuring the rainfalls, this study utilized the bias correction algorithm.”

After: “This study utilized a bias correction algorithm to correct the Z-bias occurred when a weather radar measures the reflectivity”

Comment#5 P11430, line 8: please replace “the bias” with “a bias”. P11430, line

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10: please add the word “reflectivity” between the words “radar” and “corrected”. Answer#5: Accepted.

Comment#6 P11430, line 11: you wrote: please delete the words “and then”. P11430, line 13: I suggest hereafter to replace “rainfall estimation bias” with “R bias”. Answer#6: Accepted.

Comment#7 P11430, line 13: I suggest to remove “by the QPE model” because it has already been said. Answer#7: Accepted.

Comment#8 P11430, lines 15-18: you wrote:” For the rainfall types, although the accuracy of the Changma front and local torrential cases was slightly improved without the Z bias correction the accuracy of the typhoon cases got worse than the existing results in particular. The sentence is too long. I suggest to write “However it needs to distinguish between precipitation types. In fact the accuracy of the Changma front and the local torrential cases was slightly improved without the Z bias correction. Vice versa, the accuracy of the typhoon cases got worse than the existing results”. Answer#8: Accepted.

Comment#9 P11430, lines 18-20: the sentence is too long and it is not clear, please rephrase. I suggest to write: “Result obtained by the LGC method is better than that obtained by the MFBC method, due to the different rainfall biases applied to each grid rainfall amount in the LGC method.”. You have to define the meaning of “Z bias LGC_method” before, if you want to utilize it. Answer#9: Accepted. The manuscript has been revised as follows.

Before: “As a result of the R-bias correction, the Z-bias_LGC was especially superior to the MFBC method because the different rainfall biases were applied to each grid rainfall amount in the LGC method.”

After: “In R-bias correction methods, result obtained by the LGC method with Z-bias correction was especially superior to that obtained by the MFBC method, due to the

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different rainfall bias applied to each grid rainfall amount in the LGC method.”

Comment#10 P11430, lines 20-23: the sentence is not clear, what did you mean? Perhaps you meant to say that the results are more accurate if you correct first Z bias and then R bias with the LGC method, especially for the typhoon case? Please rephrase. Answer#10: Accepted. The manuscript has been revised as follows.

Before: “For the rainfall types, the results of the Z-bias_LGC showed that the rainfall estimates for all types was more accurate than only the Z-bias and, especially, the outcomes in the typhoon cases was vastly superior to the others.”

After: “For the rainfall types, results obtained by the LGC method with Z-bias correction in all types were more accurate than that obtained by only the Z-bias correction. Especially, the “results in the typhoon were vastly superior to the other types.”

Comment#11 P11431, line 1: I would replace “they play” with “playing”. P11431, line 2: I would remove “process of calculating”. Answer#11: Accepted.

Comment#12 P11431, line 3: what did you mean saying “radar data”? Perhaps you meant radar estimates of rain? Please specify. P11431, line 5: I would remove “and” before the words “quality controls”. Answer#12: Accepted.

Comment#13 P11431, lines 5-6: I believe that Z-R relationship parameter estimation as well as QPE model structures are sources of errors that don’t lead to a systematic bias but they lead to random errors (see below). Answer#13: Accepted.

Comment#14 P11431, lines 8-9: I would change “because one of major reasons is” in “due to the fact”. Answer#14: Accepted.

Comment#15 P11431, line 10: I would change “measured radar variables” in “radar measurables”. Answer#15: Accepted.

Comment#16 P11431, line 12: I suggest the Authors to refer to a Z bias and to an R bias hereafter. Answer#16: Authors defined Z-bias and R-bias in the end of Introduc-

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tion.

Comment#17 P11431, lines 11-14: I suggest the Authors to distinguish between the systematic bias (due to the lack of radar hardware calibration) and the others errors. The systematic bias occurs whenever a radar makes a reflectivity measure and it is not dependent by both the spatial location of the sampling volume and the point in time when the measurement of reflectivity is made. Systematic bias (Villarini et al., 2008b) is not due to the loss of power which occurs when the signal propagates across the atmosphere, or when the radar beam is blocked by the ground, to the amount of backscattered power due to the ground detection, and to the increase in height with range of the sample volume. Beam-blocking, attenuation, ground clutter, and radar beam propagation geometry are sources of range-dependent bias (or error), whereas the choice of the relationship between Z and R is the sources of a random error, as mentioned by the Authors. In particular, temporal and spatial sampling errors are due to the radar beam propagation geometry, as detailed by Villarini et al., 2008a; Berenguer and Zawadzki, 2008, and Berenguer and Zawadzki, 2009. You can find an explanation of the different sources of error (such as systematic bias, random error, and range-dependent bias) in Sebastianelli et al., 2013 in which a gauge-adjustment technique is applied to define an adjustment factor to correct the radar range dependent error in comparison with rain gauges. Answer#17: Accepted. References you mentioned help to define errors from the rain estimates.

Comment#18 P11431, lines 11-14: Authors may specify whether the radar errors which are discussed are evaluated with respect to raingauges' measures or other. Answer#18: Accepted.

Comment#19 P11431, lines 11-14: I suggest to add the following references: - Sebastianelli, S., Russo, F., Napolitano, F., & Baldini, L. (2013). On precipitation measurements collected by a weather radar and a rain gauge network. *Natural Hazards and Earth System Science*, 13(3), 605-623, doi:10.5194/nhess-13-605-2013. - Villarini, G., Mandapaka, P. V., Krajewski, W. F., and Moore, R. J.: Rainfall and

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sampling uncertainties: A rain gauge perspective, *J. Geophys. Res.*, 113, D11102, doi:10.1029/2007JD009214, 2008a. - Villarini, G., Serinaldi, F., and Krajewski, W. F.: Modeling radar rainfall estimation uncertainties using parametric and nonparametric approaches, *Adv. Water Resour.*, 31, 1674–1686, 2008b. - Berenguer, M. and Zawadzki, I.: A study of the error covariance matrix of radar rainfall estimates in stratiform rain, *Weather Forecast.*, 23, 1085–1101, 2008. - Berenguer, M. and Zawadzki, I.: A study of the error covariance matrix of radar rainfall estimates in stratiform rain. Part II: scale dependence, *Weather Forecast.*, 24, 800–811, 2009. Answer#18: Accepted. I added the references you mentioned.

Comment#19 P11432, lines 9-10: I would change “the bias of radar estimation” in “the radar estimation bias”. Answer#19: Accepted.

Comment#20 P11432, lines 13-14: I would change “the bias by the QPE model” in “the bias which affects the rainfall estimation by the QPE model (R bias)”. Answer#20: Accepted.

Comment#21 P11432, lines 14-15: it's my opinion that the sentence “because the measurement and estimation procedures of rainfall play and important roles to the accuracy of weather radar rainfall” is not necessary, so I suggest the Authors to remove it. Answer#21: Accepted.

Comment#22 P11432, line 16: what the Authors define as Z bias is an overall error which includes the systematic bias, and the range-dependent bias due to beam-blocking, attenuation, ground clutter, and radar beam propagation geometry. It's correct? Answer#22: In this manuscript, Z-bias is defined as the only reflectivity measurement bias which occurs while using weather radar hardware systems to detect precipitation. Therefore, Z-bias can include the systematic bias and the range-dependent bias. Z-bias is calculated difference between the reflectivity of the reference radar and that of the target radar in Section 2.3.

Comment#23 P11432, line 19: concerning the random error due to the parameter of

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the Z-R relationship I suggest the Authors to add the following reference: Seo, D. J., Breidenbach, J., Fulton R., O'Bannon, T., and Miller D.: Real-time adjustment of range-dependent biases in WSR-88D rainfall estimates due to nonuniform vertical profile of reflectivity, *J. Hydrometeorol.*, 1, 222–240, 2000, in which the difference between the range-dependent bias and the mean field bias (due to both the random error related to Z-R relationship parameter and the lack of radar hardware calibration) is explained. Answer#23: Accepted.

Comment#24 P11432, lines 20-21: in Section 2 both the correction methods of Z bias and R bias are described. Answer#24: Accepted.

Comment#25 P11432, lines 21-23: the sentence is poorly written, I suggest to write: "Section 3 shows effects of methods used to correct Z and R bias on the rainfall estimation performed by the QPE model". In addition I recommend the Authors to summarize here methods utilized to correct Z bias and R bias, as already done in the abstract. Answer#25: Accepted.

Comment#26 P11433, lines 7-10: I suggest to write "The Bislan: : : was installed: : : and was selected: : :". Answer#26: Accepted.

Comment#27 P11433, line 13: please replace "has" with "consists of". P11433, line 16: please replace "a reference" with "that reference". Answer#27: Accepted.

Comment#28 P11433, line 21: I would suggest to replace "a scan range of maximum 200 km" with "a scanning circle of 200 km radius". P11433, line 22: I would change "the radars" in "radars". Answer#28: Accepted.

Comment#29 P11433, lines 22-25: the sentence is too long, could you split it? Answer#29: Accepted.

Comment#30 P11434, line 8: I would change "the parameters of the Z–R relationship" in "the Z–R relationship parameters"; in addition please delete "in real time" because it is mentioned after. Answer#30: Accepted.

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Comment#31 P11435, line 20: rain rate. Answer#31: Accepted.

Comment#32 P11435, line 24: I would change "the measured reflectivity of the reference radar and the target radar" in "the reflectivity measured by the reference radar and that measured by the target radar". Answer#32: Accepted.

Comment#33 P11436, lines 4-8: I suggest the Authors to add the following reference: Gorgucci, E., Scarchilli, G., and Chandrasekar V.: Calibration of radars using polarimetric techniques, *IEEE Trans. Geosci. Remote Sens.*, 30, 853-858, 1992. Answer#33: Accepted.

Comment#34 P11437, line 2: I would replace "adjacent" with "close". P11437, lines 8-9: how it is estimated the attenuation? You used the differential propagation phase shift pattern? Could you add a reference for the used methodology? P11437, line 10: what's the methodology followed to estimate CAPPis? You're followed Sinclair and Pegram (2005)? Could you add a reference for the used methodology? Answer#34: Weather Radar Center in the Korea Meteorological Administration developed the methodology for Z-bias calculation of single-polarization radar using a dual-polarization radar (reference radar). The procedures of the attenuation and CAPPis estimation are described in the reference, Korea Meteorology Administration (2011).

Comment#35 P11437, lines 11-15: Have you generated pairs of radars formed by the reference radar and a radar target? The two radars are located always at the same distance in each pair? For each couples you have calculated the reflectivity differences (only into the overlap area) between the two radar measures every 500 meters, from 1.5 to 3.5 km altitude. Moreover, the Z bias seems to be independent of ground clutter and bright band. It's correct? Answer#35: Weather Radar Center in the Korea Meteorological Administration developed this methodology for the Z-bias calculation. I mentioned the reference, Korea Meteorological Administration (2011). All weather radars were located close to each other to set up equidistant pairs between the reference and target radars (refer to Figure 5). Moreover, in Korea, Z-bias is not

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mostly affected by the ground clutter and bright band from 1.5 to 3.5 km altitude.

Comment#36 P11438, lines 1-2: I would write: " : : the bias correct factor : : : is a mean field bias which is calculated as the ratio : : ." Answer#36: Accepted.

Comment#37 P11438, line 14: what the Authors define as R bias is a mean field bias (see Seo et al., 2000) consisting only of a random error (due to the Z-R relationship parameter estimation, as well as to the QPE model parameters, and to the QPE model structure), which not includes the systematic bias (which is part of the Z bias). It's correct? In addition, G and R are calculated by referring to a rainfall event, for a certain period or to a point in time? Please clarify. Answer#37: R-bias is difference between the QPE model simulations and observations. In the strict sense, because radar measurable is input data of the QPE model, R-bias includes systematic bias. However, this manuscript intended to distinguish Z-bias correction for a systematic bias and R-bias correction for a random error. In addition, Z-bias and R-bias calculated by the rainfall events, for a certain period.

Comment#38 P11439, line 3: I would change "rainfall cases that occur locally" in "local bias which affect rainfall"; in addition please add "by radar" after the words "rainfall estimates". Answer#38: Accepted.

Comment#39 P11439, line 7: I would replace "as following" with "by the following". Answer#39: Accepted.

Comment#40 P11439, line 10: what did you mean with "pixels in the radars"? Perhaps you meant "radar pixels"? Answer#40: Authors agreed with reviewer's comment.

Comment#41 P11439, line 17: r_j and g_j are rainfall amounts? How much is the length of the rainfall time series (collected by the radars and by the rain gauges)? A season? One year? A case study? Or other? Answer#41: Reviewer is correct that r_j and g_j are rainfall amounts every 10 minute (scan cycle of single-pol weather radar) for a certain rainfall case in case study.

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Comment#42 P11439, lines 5-21: this section is poorly written and therefore it is not clear. I suggest the Authors to introduce before the definition of every variable, preferably close to the related equations. For this reason, I suggest the Authors to proceed in the following order: 1) the Authors should first clarify what is D, and what rain gauges are chosen to calculate $r_{LGC,i}$. 2) the subscript i is equal to j? If it's true please utilize only a subscript. 3) $r_{LGC,i}$ is calculated for each radar pixel? For each radar pixel you consider only rain gauges which are located at a distance $d \leq D$? If $d > D$ you don't correct the radar rainfall estimate? 4) for each rain gauge you calculate $e_j = r_j - g_j$ 5) you attribute a weight w_j to the error; the weight depends on the rain gauges network density (introduce the general definition of w_j) 6) introduce the definition of $i_{A\ddot{E}Za\ddot{E}Z}$ and the definition of w_j in the case of sparse rain gauges 7) finally introduce first the equation (7) and then the equation (6) P11440, line 1: what is the name of the variable E_i ? Answer#42: 1) This manuscript defined D is the effective radius for calculating the radar rainfall bias 2) The subscript i is not equal to j. i is the number of radar pixel and j is the number of AWS. 3) $d > D$ means that a certain AWS is not located within the effective radius of a certain weather radar 4) $e_j = r_j - g_j$ is calculated for each rain gauge. 5) The weight depends on the rain gauges network density. 6) α is an impact factor whether the number of AWS is enough or not. w_j is the weight of the error in the jth AWS 7) $r_{LGC,i}$ is corrected radar rainfall using LGC method and Re,i is the weighted error. 8) Zhang et al. (2011) developed the LGC method did not name the variable E_i . I named the total error.

Comment#43 P11440, lines 5-6: it is absolutely not clear the criteria adopted by the Authors to determinate b and D; how the stepwise method works? Can you add a reference? Answer#43: b and D values are determined when the MSE value is the smallest using a cross-validation scheme. The cross validation is performed by removing a rain gauge and interpolating to its location using radar-gauge errors at all the remaining rain gauges. - Reference: Zhang et al., (2011): National mosaic and multi-sensor QPE (NMQ) system. BAMS. Comment#44 P11440, line 8: n is the number of pixels? So m which is the number of rain gauges is different from n? So we have two subscripts, i and

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j? It's correct? P11440, lines 9-10: given that D is the scan range of the radars while the AWSs are rain gauges, what did you mean with the maximum range D used by all AWSs? Answer#44: n is the number of pixels and m is the number of rain gauges. And i is the number of radar pixel and j is the number of AWS. Moreover, this study used all AWSs with the maximum range D.

Comment#45 P11440, line 13: I would replace "In sequence, because" with "Since". P11440, line 16: I would change "The conditions of" in "The conditions checked by". Answer#45: Accepted.

Comment#46 P11440, line 16: I would change "in a certain AWS" in "for a certain AWS". P11440, line 17: I would change "that have" in "having". Answer#46: Accepted.

Comment#47 P11440, line 19: I would change "the center" in "location". P11441, line 1: what did you mean with thresholds? The thresholds are b and D? Answer#47: The thresholds mean 25% in (i), 90% in (ii), and 7% in (iii).

Comment#48 P11441, lines 23-26: you wrote: "In Fig. 8, after applying the Z biases to the RAR system, the accuracy of the rainfall estimates improved in the Root Mean Square Error (RMSE) and the correlation coefficient, which ranged from 7.37, 0.83, 7.21, and 0.84 mmh-1 on average, respectively." I suggest to write: " Fig. 8 shows that after applying the Z biases to the RAR system, the accuracy of the rainfall estimates improved as shown by the Root Mean Square Error (RMSE), which passed from : : : to : : : and from : : : to : : :." Answer#48: Accepted.

Comment#49 P11441, line 26: I would replace "As a result for each rainfall type" with "For each rainfall type". Answer#49: Accepted.

Comment#50 P11441, line 26: I would delete "in the RMSE". Answer#50: Accepted.

Comment#51 P11442, lines 1-3: I would write ": : : improved as showed by the RMSE which passes from: : :"; in addition the sentence is too long, please split it. Could you specify which index values in brackets refer? Answer#51: Accepted.

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Comment#52 P11442, line 4: I would write ": : : for typhoon cases decreases: : :". Answer#52: Accepted.

Comment#53 P11442, line 9: I would write ": : : in these cases: : :". Answer#53: Accepted. Comment#54 P11442, line 10: August 10, 2012. Answer#54: Accepted.

Comment#55 P11442, line 13: I would replace "It has been" with "For these reasons we proven". Answer#55: Accepted.

Comment#56 P11442, lines 17-18: please delete "Since the rainfall estimates in the RAR system were improved by the Z bias correction in Sect. 3.1" because the sentence is redundant Answer#56: Accepted.

Comment#57 P11442, line 19: please add the sentence "which results are shown in Sect. 3.1" after Z bias correction Answer#57: Accepted.

Comment#58 P11442, line 26: I would write "table 4 shows result of the two R bias correction methods in terms of the accuracy: : :." Answer#58: Accepted.

Comment#59 P11443, lines 2-4: I would write "The accuracy is improved by about 7.4% by considering RMSE values which pass from: : :." Answer#59: Accepted.

Comment#60 P11443, line 5: I would replace "In the" with "By considering the" Answer#60: Accepted.

Comment#61 P11443, lines 7-9: the sentence is poorly written; I would write "Therefore we proven that the accuracy of the radar rainfall estimates was improved with application of R bias corrections methods (applied after the Z bias correction) more than the case in which only the Z bias correction method is applied. Answer#61: Accepted.

Comment#62 P11443, line 10: please replace "superior to" with "better than", and "the reason for this is that" with "because" Answer#62: Accepted.

Comment#63 P11443, line 15: please replace "in the RMSE" with "in terms of RMSE" Answer#63: Accepted.

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Comment#64 P11443, line 17: I would change “in the RMSE improved over the Z bias” with “in terms of RMSE is greater than the Z bias accuracy” Answer#64: Accepted.
Comment#65 P11443, lines 18-19: please replace “where inferior to” with “are less accurate with respect to” Answer#65: Accepted.

Comment#66 P11443, lines 20-25: please check English grammar Answer#66: Accepted. The manuscript has been revised as follows.

Before: “The results of the Z-bias_LGC showed that the accuracy of the rainfall estimates for all types in the RMSE and the correlation coefficients was superior to the Z-bias and, especially, the outcomes in the typhoon cases were vastly superior to the others.”

After: “The results obtained by Z-bias_LGC showed that the accuracy of the rainfall estimates for all types by considering RMSE and the correlation coefficients was better than that obtained by only the Z-bias. Especially, the results in the typhoon were vastly superior to the other types.”

Comment#67#1 P11444, lines 4-6: sentence too long Answer#67: Accepted. The manuscript has been revised as follows.

Before: “Especially, the image of the Z-bias_LGC is similar to the AWSs and the rainfall estimates, which ranged from 40 to 50mm hr⁻¹ in the regions (indicated by black arrows in a black circle), were similar to the AWSs.”

After: “Especially, in Figure 11(d), the rainfall estimates which ranged from 40 to 50mm hr⁻¹ in the regions (indicated by black arrows in a black circle) is closer to the AWSs than others.”

Comment#68 P11444, lines 12-14: you meant that in both A and B regions the rainfall estimates are increased? Answer#68: That sentence confused reviewers. The manuscript has been revised as follows.

Before: “By contrast, in Figure 12(c) for the Z-bias_MFBC, the maximum rainfall esti-
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mates in region \hat{S}^R (which was located in the southeast of the Tembin), and in the rainfall zones from the southwest to the northeast (region \hat{S}^S) were much improved.”

After “By contrast, Figure 12(c) shows the rainfall amounts increased by the Z-bias_MFBC, especially the maximum rainfall estimates in region \hat{S}^R (which was located in the southeast of the Tembin), and the rainfall zones \hat{S}^S located from the southwest to the northeast.” Comment#69 P11444, line 15: slightly or strong? The two words have opposite meanings Answer#69: Accepted. The manuscript has been revised as follows.

Before: “However, the rainfall estimates in region \hat{S}^R were a little underestimated, and region \hat{S}^S had slightly strong rainfall amounts.”

After: “However, the rainfall estimates in region \hat{S}^R were a little underestimated, and rainfall amounts in region \hat{S}^S were more stronger than Figure 12(a).”

Comment#70 P11444, lines 18-21: please check English grammar Answer#70: Accepted. Because the sentence is repeated, that is removed.

Comment#71 P11444, lines 23-27: sentence too long Answer#71: Accepted.

Comment#72 P11445, lines 8-20: please check English grammar Answer#72: Accepted.

Comment#73 P11445, lines 21-22: I would delete “Since the rainfall estimates in the RAR system have been improved by the Z bias correction” because the sentence is redundant for me Answer#73: Accepted.

Comment#74 P11445, line 23: I would delete “For results of the rainfall estimation bias correction methods” because the sentence is redundant for me Answer#74: Accepted.

Comment#75 P11445, lines 23-27: please check English grammar Answer#75: Accepted.

Comment#76 P11445, lines 27-29: sentence too long and incomprehensible; perhaps

you meant “In fact in the MFBC method only one bias is applied to the whole area. Vice versa, in the LGC method it has a different bias for each radar pixel.” Answer#76: Accepted.

Comment#77 P11446, lines 1-12: sentences too long and redundant; please check English grammar. Answer#77: Accepted.

Comment#78 P11446, lines 12-15: not clear, what did you mean? Answer#78: Because that sentence is redundant, that is removed.

Please also note the supplement to this comment:

<http://www.atmos-meas-tech-discuss.net/8/C5312/2016/amtd-8-C5312-2016-supplement.zip>

Interactive comment on Atmos. Meas. Tech. Discuss., 8, 11429, 2015.