Reply to the Reviewer's Comments:

First, we would like to thank the Reviewer for his/her valuable comments which helped us to improve the manuscript.

The Reviewer's comments are addressed below:

A note on the General comment*:*

Note, to our knowledge, the pixel-by-pixel interpolation method of bias factors that we introduced in this paper does not exist in the literature. *A pixel-by-pixel spatial interpolation of bias factors in the interpolation method is carried out using Eq.(7). It is a modified version of the method of ensembles without employing the ensembles. The method of interpolation is included by the authors to show the improvements in Root Mean Squared Errors (RMSE), Absolute bias and correlation coefficients are not only based on the results of accounting for spatial variation. Therefore, the method of interpolation was incorporated in order to evaluate the importance of imposing ensembles on bias factors.*

(The above italic paragraph is included on P8924, L9).

MAJOR COMMENTS:

1) **Comment: On p. 8928, L. 14-16, it reads: "For cases, I, IV and V the method of ensembles improved the absolute bias in the original estimation better than the rest of the methods." However, according to Table 2, bias correction by interpolation seems to perform better than the original method in 4 out of the 5 cases while ensemble method performed better only in 3 cases. Moreover, bias adjustment by interpolation performs better than bias adjustment by ensembles in 4 out of the 5 cases. Also, according to Figs 5-8, rainfall amounts upon interpolation more closely agree with that of ST-IV than upon applying mean ensembles. All this needs to be state, and conclusions should be revised.**

Responses: Concerning the disagreement between the result section and Table 2: We agree that the statement on P.8928, L. 14-16 ("For cases, I, IV and V the method of

ensembles improved the absolute bias in the original estimation better than the rest of the methods“) and results in Table 2 appear to show some inconsistency. That is because it was stated before the implementation of the ‘interpolation method’. We recognize that this is confusing. However, based on the reviewer’s recommendation, the paragraph on P8928, L4-L18 is revised as the follows:

In terms of RMSE, the performances of the methods of mean and maximum ratio correction methods are comparable. RMSE before and after bias correction using the method of mean and maximum ratios are the same. On the other hand, the method of ensembles has improved the RMSE between the original satellite rainfall estimation and ST-IV by 8, 25, 17, 54 and 37.2 percent in cases I, II, III, IV and V respectively. Similarly, the interpolation method has also improved the RMSE by 25.6, -4, 4, 54.4 and 35.3 percent in cases-I, II, III, IV and V respectively. The mean ratio bias correction method improved the absolute bias in the original estimation better than the other bias correction methods in cases III and V. For cases-I and -II the interpolation method improved the absolute bias in the original estimation better than the rest of the methods, whereas the method of ensembles worked better in case-IV than the rest of the methods (Table 2). Regarding correlation coefficient, even though both the method of ensembles and the interpolation method have consistently improved the correlation coefficients significantly, the method of ensembles outperformed all the methods (Table 2).

Based on the reviewer’s recommendation part of the summary and conclusion (P8931, L11-21) is revised as:

When it is compared with the methods of the ratio of mean, interpolation and maximum ratio, the proposed method in this paper (method of ensembles) outperform the rest in terms of improving RMSE and correlation coefficients. The method produced a correlation coefficient of 90% in one case while the other methods did not show much improvement in the satellite product. The method of ensembles, the mean ratio method and interpolation method improved the Absolute bias in 1, 2 and 2-cases respectively. Finally, a time series for four randomly picked pixels were checked before and after bias correction. Results show the proposed method and the interpolation method significantly reduced the discrepancies in the time series. Even if the rainy hours were treated

separately, the interpolation and method and the method of ensembles produced results that emulate as if they were from the same time-series analysis. This implies that our method is robust and can be applied for independent rainy hours by calculating the required parameters at hourly levels.

Note that, the intention behind presenting RMSE, Absolute Bias and Correlation Coefficients enables one to choose his/her criteria. Under certain circumstances, one may prefer RMSE, while others may choose Correlation Coefficients. It is very difficult to reach a conclusion about the performances only on the basis of Absolute bias (the mean ratio and the interpolation method performed best in 2 and 2 cases respectively, while the method of ensembles performed best in 1-case). Our recommendation was more based on the RMSE and correlation coefficients, and we suggested in favor of the method of ensembles.

Regarding Figs. 5-8, the following more explanatory italic statements are included on P8929, L30:

In Fig. 5, it is shown that the method of ensembles performed better than the method of interpolation (the method of interpolation suggests better estimation for 6 hours, whereas the method of ensembles made better estimations for 8 hrs). Similarly, in Fig. 6, the method of interpolation shows a better estimation than the method of ensembles. In Fig. 7, both methods are more or less comparable, whereas in Fig. 8, the method of interpolation follows the ST-IV more closely than the rest of the methods.

2) **<u>Comment:</u> In Summary and conclusions on p. 8932 first line it reads: "The major results of this work suggest that satellite intensity biases can be corrected using radar products. . ." This assumes ground based radar products such as ST-IV are better than the satellite products. This assumption, which might not be true, must be stated in the Summary and conclusions section.**

<u>Response:</u> Based on the Reviewer's recommendation, we revised the statement in the paper as follows: *"The major results of this work suggest that satellite intensity biases can be corrected using radar products, assuming that ground-based radar products such as ST-IV is more accurate than satellite products, which may not be universally true."*

OTHER COMMENTS:

3) **Comment: P8915, L13: "Second, satellite IR products are the only sources of rainfall observation. . ." Perhaps a major source is more appropriate term.**
Response: Based on the Reviewer's recommendation *"major"* is used instead of "only".

4) **Comment: P8916, L11: "US has more radar coverage than point rain-gauges." This is not clear. Perhaps you meant "US has more independent radar coverage pixels than point rain-gauges."**
Response: Based on the reviewers comment the statement is improved as *"the United States has more independent radar coverage pixels than point rain-gauges."*

5) **Comment: P8918, L21: NWS was previously defined.**
Response: based on the reviewer's comment the abbreviation is used.

6) **Comment: P8929, Eq. 1 and and Eq. 2: Rh in Eq. 1 and Eq. 2 represents a different parameter. Use different symbol.**
Response: It is corrected in the revised version.

7) **Comment: P8920, L18: "….required number of pixels with positive bias factor values." Clarify**
Responses: based on the reviewer's recommendation, the following italic paragraph is added on P8920, L18 to improve the manuscript:

From Eq. (2), bias factors can be 0 (if the radar pixel is not rainy and the corresponding satellite pixel is rainy), positive real number (if both corresponding pixels from radar-gauge and satellite are rainy), infinity (if the radar-gauge pixel is raining and the corresponding satellite pixel is not rainy (0)) or undefined (if both pixels from ST-IV and HE are not raining). To avoid any mathematical inconveniency, bias factors with positive values were considered for evaluation. We assumed that a maximum of 150 bias factors is enough for evaluation, depending on the aerial coverage of the rainy case. A Monte-

Carlo approach was used for randomly selecting the bias factors spread over the study area. In a Monte-Carlo framework, independent and identically distributed (i.i.d.) pixels in the study area are randomly chosen (Lemieux and L'Ecuyer, 2001). The process of selecting the i.i.d. bias factors is as follows: 1) To make sure a fair spread of bias factors over the study area, bias factors are calculated for all the pixels in the study area, and 150 bias factors are randomly picked regardless of their values. 2) The non positive bias factors are discarded. 3) The process of randomly picking 150 bias factors continues until we get a total of 150 positive bias factors. 4) Whenever rainy hours cover a smaller area, the process of picking up the bias factor leads to the consideration of closely located bias factors, which leads to inefficiency of the algorithm (Please see P8920, L8-L14). *In such cases, we eliminated the closely located bias factors out of the list of the 150 bias factors.*

8) **Comment: P8925, L23: "… about their optimal values by 10%, …". The parameter range in Fig. 1 span more than 10%.**

Response: This statement was meant to be "the sensitivity of the parameters was checked by running the model for a defined span (range) of values discretized at 10% of the optimum." For instance, the optimal value is 2. The sensitivity can be checked for a range of values between 1.6 and 2.4 discretized at 0.2 (10% of 2).

9) **Comment: P8926, L5: Should "greater than 7 km" be "greater than 6 km"**

Response: Based on the reviewer's recommendation, 7 km is replaced by *6 km* in the revised version.

10) **Comment: P8926, L15: Fig. 3b?**

Response: Fig. 3b is replaced by Fig. 2b in the revised version.

11) **Comment: P8926, L26: "…hourly maximum rainy pixels…"-Clarify.**

Response: The importance of this statement was to explain how bias correction using the method of maximum ratio works. In this method, a single scalar value of bias factor is calculated for each rainy hour using:

Bias factor=The maximum measured pixel rain rate for in ST-IV/The maximum measured pixel rain rate in HE.

Then bias correction for the satellite estimate is made by multiplying the HE rain field by the Bias factor calculated here.

12) **Comment: P8927, L12: Why were these events/hours chosen? Which objective criteria (if any) were used for the selection?**

Response: The hours were picked one from each rainy event listed in Table 1. Besides, we have made the maximum effort to pick cases to cover a significant range of Correlation Coefficients between the original radar-gauge and satellite rainfall estimations (-0.01 to 0.668).

13) **Comment: P8928, L21: "The right side... after... and the left side...before..."Should after/before be inversed? The same applies to Fig. 4 caption.**

Response: This is corrected for the revised version.

14) **Comment: P8928, L26: According to Table 2 "-0.13 to 0.65" should be "-0.01 to 0.67".**

Response: The statement on P8928, L24-24:" The correlation coefficient between the HE and ST-IV before bias correction ranged from −0.13 to 0.65." is replaced by *"The correlation coefficient between the HE and ST-IV before bias correction ranged from −0.01 to 0.67."*

15) **Comment: P8929, L6-L11: The lowest correlation coefficient is in September and June, not in the cold season (Feb, Dec). Should "-0.1" in L9 be –"-0.01"?**

Response: Based on the reviewer's comment, P8929, L6-L11: "At times because of the weak performance of satellite rainfall estimations in the cold season a much weaker

relationship was observed between the satellite and radar-gauge rainfall estimations with a correlation coefficient −0.1 (see Fig. 4)." is replaced by *"At times because of the performance of satellite rainfall estimations is weak, as a result, a poor relationship was observed between the satellite and radar-gauge rainfall estimations with a correlation coefficient −0.01 (see Fig. 4).*

16) **Comment: P8929, L22-L27: Delete from the text. This is clear from the figures' legend.**

Response: Based on the reviewer's recommendation, the text on P8929, L22-L27 is deleted in the revised manuscript.

17) **Comment: P8932, L9: "I" should be "We".**

Response: This is corrected based on the comment.