Authors Comment (AC)
On the Referee Comments (RC) #1 C5207

We thank the Anonymous Referee #1 for the positive comments and constructive suggestions, which helped improve the manuscript. Item-by-item replies are inserted in blue, whereas the Referee comments are in black.

1) p. 11146, line 13-17: The matching between rain gauge and TRMM-PR (or other satellite derived estimates) in space and time introduces uncertainties not only linked to the sparse sampling, but also due to the different type of measurements made by groundbased instruments (such as rain gauges) and by spaceborne observations. It should always be taken into account that temporal range of the spaceborne MW sensor measurements is not really "instantaneous", and it refers to the cloud volume where the rainfall originates. The relationship between the measurement and the surface precipitation is highly dependent on the type of cloud (spatial extension, homogeneity, microphysical structure, precipitation regime, etc.). The rain gauges, on the other hand, measure directly the precipitation near the surface, and the result is based on integration over time. I would suggest to add some more comments on this regard, specifying that the challenge in the validation of satellite-derived estimate is also the temporal matching between the different dataset, linked to the type of measurements available from the different instruments.

The point is well taken. Comments regarding the temporal matching will be added to P. 11146, line 13-17: "Nevertheless, matching the observations from raingauges and TRMM PR at the nominal pixel scale (~5 km) in space and time introduces uncertainties due to differences in the measurement control-volume, generally referred to as representativeness error (i.e. Porcù et al., 2014), which is further aggravated due to sparse spatial sampling and topographic variations: raingauges report near-surface point rainfall rate while satellite estimates correspond to a cloud volume-averaged rainfall rate, which is also highly dependent on the precipitation system, cloud physics and morphology, and associated rainfall (e.g. Pratt and Barros, 2010; Habib and Krajewski, 2011). However, this discrepancy can be alleviated by using an optimal integration time interval for gauge observations (Wang and Wolff, 2010; Pratt and Barros 2009) as it is done in this manuscript (see Section 2). Despite these challenges, comparisons with ground reference gauges constitute a critical component in evaluating the accuracy of the PR estimates of surface precipitation, reflectivity and rain rate."

2) P. 11147 line 5-14: I would suggest to add a reference to the work by Porcù et al. (2014) where the error associated to temporal and spatial sampling of rain gauges in the validation of satellite-derived precipitation estimates is analyzed and evaluated. Some of their conclusions are relevant to the study presented here, such as the choice of the time interval for integration of rain gauges measurements to be compared to a pixel-scale precipitation measurement.
Please, clarify the meaning of the following sentence (line 8-9): "the gauge rain rates are integrated and temporally averaged over a range of time-scales (10–60 min) centered at the time of overpass" Do you integrate in time over 10-60 minutes time and then average in space (meaning that all rain gauge integrated precipitation values falling within each PR pixel are averaged to obtain a mean value to be associated to the PR estimate, as for example it seems to be the case for the results shown in Fig. 4)? Or else there is no averaging made within each PR pixel? What does "temporally averaged means"? Is it a total average over all temporally

integrated rainfall values? It is not clear how the spatial association between each PR pixel and the rain gauges falling within that pixel is made.

Please clarify the meaning of the following sentence (line 9-13): "When multiple gauges exist in same pixel, the PR measurements are paired separately with different raingauges, hereafter referred to as point-to-pixel comparisons, to increase the sample size and avoid ambiguity associated with the spatial representativeness of the gauges within the pixel." Is this an alternative procedure to the one described above (line 8-9)? It is not clear if you choose randomly gauges within the PR pixels or if you select all rain gauges falling within one pixel. How does this point-to-pixel comparison relate to the averaging and integration mentioned above?

We thank the Referee for providing this reference. The paper above will be added as a reference in Line 13-17 (P. 11146). As for Line 8-9, it means that the gauge measurements are integrated over 10-60 minutes time scales and then converted to an hourly rain rate (mm/hr). "Temporally averaged" simply means dividing the accumulated rain amount over the time interval (τ) by (τ/60), which is consistent with Equation (13) in Porcù et al. (2014). The "point-to-pixel comparisons" mentioned in Line 9-13 are only used in contingency tables and statistical skill scores (discussed in Section 2.3.1) to evaluate the satellite rainfall detectability. As stated in P. 11147 line 1-3, the paired gauges are not randomly chosen, but are within the corresponding PR pixels. To account for the spatial representativeness, the gauge rain rates within each PR pixel are averaged to a mean value for the pixel and compared to the PR estimate in the quantitative analysis in Section 2.3.2 (described in P. 11149 line 7-10) and thereafter.

To improve clarity, Line 13-17 (P. 11146) will be revised as follows: "To determine whether there is an optimal time-scale that reconciles the nearly instantaneous (point in time) satellite-based areal rainfall estimates (pixel scale) with raingauge observations (point in space) with different measurement resolution (TB size), the gauge rain rates are integrated over a range of time-scales (10–60 min) centered at the time of overpass and spatially averaged at the PR pixel scale. For the satellite detectability evaluation (contingency tables and statistical skill scores), point-to-pixel comparisons will be applied to increase the sample size and avoid ambiguity associated with the spatial representativeness of the gauges within the pixel. When multiple gauges exist in same pixel, the PR measurements are paired separately with different raingauges"

3) p. 1149 line 21-26: The underestimation can be attributed also to the fact that, to my understanding, no spatial averaging of 10 min integrated rainfall values from the rain gauges falling within each PR pixel is made (see point 2) in this review). If that is the case, please provide an explanation of why the spatial averaging is not applied, and possible implication on the results, especially for heavy rain rates.

Why are results in Fig. 4 shown for the 10 min integration interval? Please, provide an explanation (I believe it is because the error bias is minimum at 10 min, as stated in Section 3.1) and a short discussion of how the PDF differ for average rain gauge rates computed at 20 min, 30 min and 60 min.

As explained in the response to point 2, spatial averaging is applied in all quantitative analysis starting from Section 2.3.2 (Figure 4). As stated in P. 11150 line 14-19, a sensitivity analysis of bias was performed to obtain an optimal integration time scale for gauges with different measurement resolution (descried in P. 11143 line 1-5): 10-min for RG0XX and RG1XX, 30-

min for RG3XX. This reflects the differences in the sampling resolution for the different types of raingauges. For illustration, Figure Add1 shows histograms of rain rates at different integration timescales: 10, 20, 30, 60-min. Overall, satellite estimates agree well with the 10-min gauge integration in lower (0-1 mm/hr) and high (30-40 mm/hr) rainfall intensity while intermediate (2-7mm/hr) rain rates are consistent with high integration timescales of 20, 30, 60-min, in particular 30-min.

4) Section 3.3. The discussion of Fig. 8 is quite complex, as the figure itself. I would suggest adding a short paragraph at the end of Section 3.3 summarizing the most relevant findings from the analysis of Fig. 8.

The Referee's comment is well taken. The following summary will be added to the end of Section 3.3 (P. 11155, line 16). "Overall, steeper positive gradients in reflectivity are displayed in OVR cases at lower levels, while the decreasing trend with height shown in UND and FA possibly indicates light rainfall evaporation before reaching the ground. The high cloud tops in UND can be potentially linked to warm rain with embedded convection, resulting in heavy rainfall events."

Tables:
Table 2: Section b) in the Table 2 should be titled "near-nadir cases" according to the caption.

The title will be added in Table 2 (b).

Figures:
Please, enlarge all Figures, in particular Fig. 8, 9, 10 and 11.

We agree with the Referee. A note has already been sent to the publisher. The figures will be enlarged in the final revised version, but it is not possible to do so in the published discussion paper.

Fig. 5b: Please, show to which class the third sector in the scatter plot (without label) correspond (according to the classification provided in Table 4).

The unity line is not there for separating classes and will be removed to avoid confusion.

Fig. 8: The figure is very complex, and it is very hard to read. This figure should be enlarged to at least half a page. I would suggest modifying the figure to make it more readable, and simplify the plots. Please, indicate "UND", "OVR" and "FA" on top of each column, and "stratiform with BB", "stratiform without BB", and "convective" on the left of each row. The red marks and the blue boxes are hard to see. Enlargement could be enough to make them more readable. The two horizontal lines "whiskers" could be eliminated from the figure, as they are not essential to the discussion. You could keep the outliers (red marks) specifying that they represent points falling out of the +/- 1.5 IQR.

Figure 8 will be modified as suggested with the exception that we would like to keep the two horizontal lines "whiskers", indicating variability outside the upper and lower quartiles.

Enlargement will be done in the final revised version to make them more readable. We regret this problem with the figure size. We did not realize initially that the figures would be so reduced in size.

Fig. 9: It is not clear how the track of the TRMM PR overpass shown is related to the cross sections in Fig. 10, 11, and 12 (latitude here goes roughly from 34N to 36.3N, a much larger interval than the one corresponding to the black lines in Fig. 9). My suggestion for Fig. 9 is that the TRMM PR overpass could be shown as two parallel lines delimiting the whole swath over the region shown. The line within the swath corresponding to the cross section for each event should also be shown in each image. The border of the region of study (the Pigeon River basin) could appear on the radar map as reference as well.

Figure 9 will be modified as suggested. Thank you.

Fig. 10: Label c) is missing on last four panels. The black arrow and the colored asterisks are hard to read. Please, enlarge the figure. Each panel should be at least as large as in Fig. 12.

The label will be added to Figure 10.

Fig. 11: The black arrow and the colored asterisks are hard to read. Please, enlarge the figure. Each panel should be at least as large as in Fig. 12.

As stated earlier, the figures will be enlarged in the final revised version.

Technical corrections:
Please, use either “rain gauges” or “raingauges” throughout the manuscript.

Thanks for pointing it out. “rain gauges” will be replaced with “raingauges”.

p. 11148 line 3: Please change “In V7 (see Table 2a), …” in “The results for all rain gauges (see Table 2a) for V7 show…”.

This will be changed. Thank you.

p. 11148 line 10-11: Please, specify “Overall, V7 exhibits slightly better detection skill *than V6*…”.

The sentences will be changed as suggested. “Overall, V7 exhibits slightly better detection skill than V6 as indicated by the higher probability of correct detection and correct rejection, and lower probability of false alarms and missed detection.”

p. 11161 line 22: “Dual-Polarization Radar” should be “Dual-frequency Precipitation Radar “ (DPR)

Thank you for pointing this out. This will be corrected.

References

Habib, Emad, and Witold F. Krajewski.: Uncertainty analysis of the TRMM ground-validation radar-rainfall products: Application to the TEFLUN-B field campaign. Journal of applied meteorology 41.5, 558-572, 2002.

Porcù, F., Milani, L., and Petracca, M.: On the uncertainties in validating satellite instantaneous rainfall estimates with raingauge operational network, Atmospheric Research, 144, 73-81, 10.1016/j.atmosres.2013.12.007, 2014.

Prat, O. P., and Barros, A. P.: Assessing satellite-based precipitation estimates in the Southern Appalachian mountains using rain gauges and TRMM PR, Advances in Geosciences, 25, 143-153, 10.5194/adgeo-25-143-2010, 2010.

Prat, O. P., and Barros, A. P.: Exploring the Transient Behavior of Z–R Relationships: Implications for Radar Rainfall Estimation, Journal of Applied Meteorology and Climatology, 48, 2127-2143, 10.1175/2009jamc2165.1, 2009.

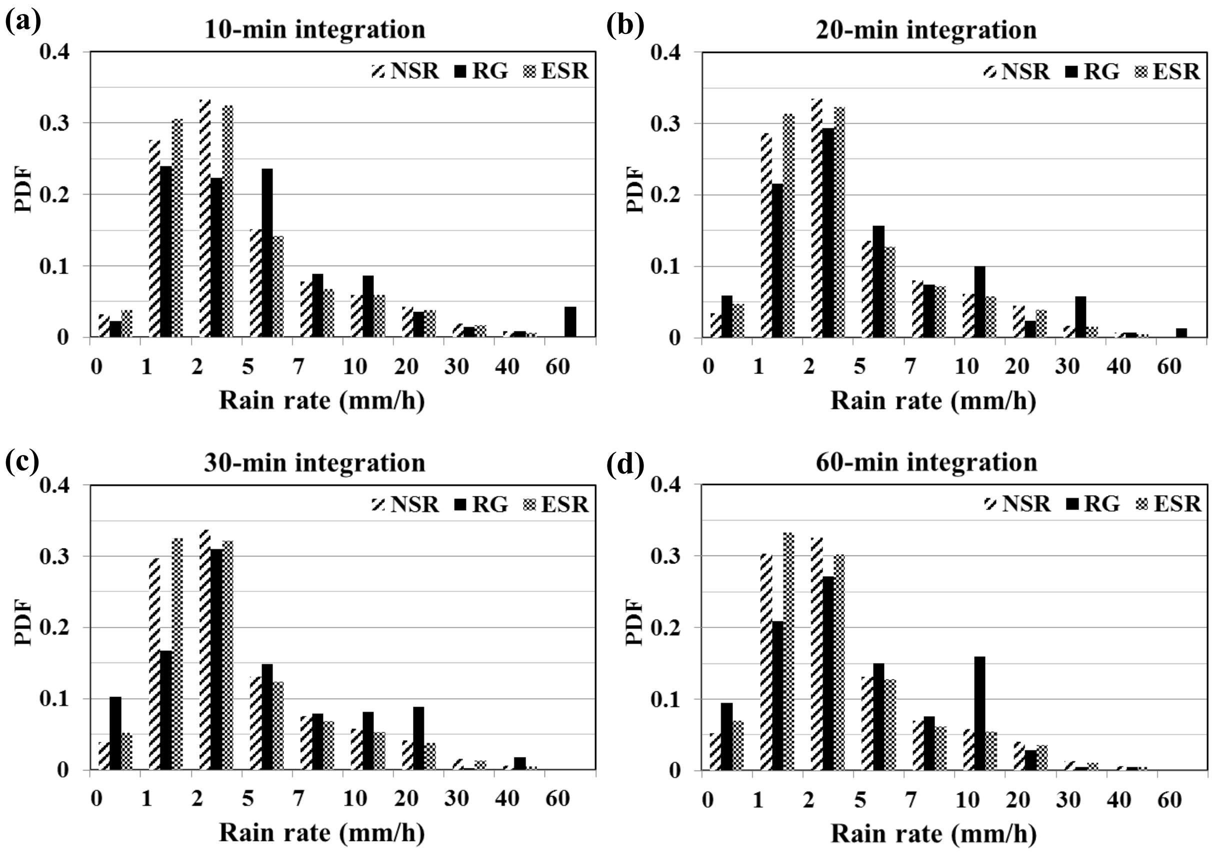

Figure Add1 Probability distribution of **non-null** TRMM 2A25 V7 surface rain rate products (ESR and NSR) and average gauge rain rates over different time scales (a: 10-min; b: 20-min; c: 30-min; d: 60-min) during the period 06/01/2008-05/31/2013.