Author response to reviewer's comments

On behalf of myself and the co-authors, I take the opportunity to thank the anonymous reviewers for their constructive comments, questions and suggestions. We have responded to all questions and comments, as discussed below. Most of the given comments and suggestions were relevant, and we have updated the manuscript accordingly. We think the quality and readability of the paper have improved significantly compared to the previous version.

Reviewer #2

General comment

The manuscript focuses on evaluating of different satellite rainfall products in the Tekeze-Atbara Basin, Ethiopia. It is interesting to see a validation study of satellite data in the hydrologically remote part of the world where there is limited data for understanding the climate and hydrology. However the structure of the paper is not easy and clear and the results are not clearly discussed. There are also many type errors. I see many spacing errors between words. On the abstract section alone I have seen more than 10 errors. I have indicated those errors as minor comments. Those errors are too many to list them in my review; I hope the authors will spend some time to correct those errors. With this and other concerns I have indicated below I cannot recommend to accept the paper for publication.

Response: The authors would like to thank the anonymous reviewer for his/her detailed review of our manuscript. We have responded to all comments as given below. We would like to apologies for the spaces between the words, which actually happened during transferring the file to Pdf.

Specific comments:

Abstract

1. The authors indicated that they have evaluated the performance of the products at various spatial and temporal scale. However, in the abstract Line 26 to 28, the spatial and temporal scale of the evaluation is not indicated.

Response: We have added a description of spatial (point, sub-basin, basin) and temporal (daily, monthly and seasonal) scales to the manuscript in p1 of L28-30.

2. The abstract should be rewritten to summarize the evaluation result at the multiple temporal and spatial scale. The authors indicated that they have done evaluated the 8

products at various temporal (daily, monthly, seasonal) and spatial (point, sub-basin, basin) scales. However, they did not indicated clearly which products worked at what scale.

Response: We have now modified the abstract to show details of the performance, at the different spatial and temporal scales in paragraph 2 and 3.

Introduction

3. Page 2: The statement from 23 to 28 needs a reference.

Response: We have included references (Jiang *et al.*, 2012, Guo & Liu, 2016; Dinku *et al*., 2007; Haile *et al*., 2010; Dembele *et al*., 2016) p 3 Line 2 to 3.

4. The authors indicated that tomography as a key factor influencing microclimates in the basin (Page 3 line 32 -33). However, Figure 2b which indicate the relationship between elevation and annual average rainfall doesn't capture the effect of topography. That relationship between rainfall and topography as indicated in this figure is insignificant. What are the author's claming that the topography is a key factor?

Response: We agree with the reviewer that Fig.2b does not show a clear pattern of annual rainfall against the elevation of the station. This contrasts with other basins, where the literature shows that rainfall increases with elevation due to the orographic uplifts (Moreno et al., 2014; Worqlul et al., 2014). However, this pattern is not uniform in the T-A Basin. The annual rainfall increases with elevation in the southern and southwestern parts, while it reduces with elevation in most other parts of the basin. This is shown in Fig. 2a and Fig, 2b: the annual rainfall increases with elevation for some stations and decreases for other stations. This non-uniform pattern is attributed to the complex local topography of the Tekezze-Atbara basin, and seasonal movements of the ITCZ, which influence the microclimate of this basin significantly (Kiros et al., 2016). When the rain-bearing winds reach the basin, their direction is modified by the local topography forcing the release of moisture in the lower areas before they reach the top of mountains. This creates more intense and shorter duration convective rainfall events in the lowlands where warm and moist airflows encounter the mountain foothill (Van der Ent et al., 2010). This shows that topography in the basin plays an important role in moisture cycling either by blocking or capturing moving air masses.

5. Figure 2b disproves the stament on page 4 line 18 and 19.

Response: see explanation of point 4 above.

6. The rainfall products were not described very well. As the authors indicated satellite rainfall products quality can be affected by the algorithms used. The authors should discuss the different algorithms and platforms used by those products. What part of the electromagnetic spectrum was used? Are they polar orbiting, or sun synchronized satellites

or a geostationary satellites are used? The description of the different products on page 6 and 7 should address this.

Response: Although these products have been widely applied and documented in the literature, we have improved the description of satellite products as the space may allow in section 2.2.2. More references for detailed information are also included under each product.

7. Page 6 line 21: the autors describe CMORPH product as having a very high spatial and temporal resolution however in the summary table (Table 1) this product doesn't prove to be at a higher resolution compared to others such as CHIRP and ARC and others?

Response: This has been rectified to "The CMORPH product produces global rainfall is also a product from NOAA-CPC"

8. Page 7 line 4. TRMM 3B42V7 is not a latest version

Response: Corrected to "The TRMM product (3B42V7) was developed by the National Aeronautics and Space Administration (NASA)".

9. Table 1 should indicate that the temporal resolution for TRMM3B42V7 should be 3hr. And the product TRMM3B42 should be referred as TMPA-3B42 (Huffman et al., 2010; Prakash et al., 2013; Vrieling et al., 2010).

Response: The temporal resolution is corrected to 3 hourly and the name TRMM 3B42V7 changed to TMPA-3B42 in the table.

10. Page 8 line 22 to 24: Why the inverse distance interpolation is selected? And what was the grid size used for interpolation this will matter since your rainfall products have a various spatial resolution? Inverse distance weighting (IDW) is a possible simple way to go but probably not the best one. There are interpolation algorithms that take into account secondary information (e.g. kriging with external drift).

Response: IDW was adopted in this study for its simple and robust technique which has been commonly applied for rainfall interpolation (e.g. Haile et al., 2010; Jiang et al., 2012; Hu et al., 2014; Worqlul et al., 2014). We agree that each techniques (e.g., IWD and Kriging) have their own advantages and disadvantages; however, the authors believe that applying kriging instead of IWD will not significantly change the results. Further clarification is added to the manuscript in p 10 Line 23 to 26.

12. The performance indicators for satellite rainfall are too simplistic. The authors should consider a categorical statistics to evaluate the effectiveness of those satellite images. Refer Haile et al. (2010). Haile, A.T., Rientjes, T., Gieske, A., Gebremichael, M., 2010. Multispectral remote sensing for rainfall detection and estimation at the source of the Blue Nile River. International Journal of Applied Earth Observation and Geoinformation, 12: S76-S82. The authors should indicate the number of incorrect and correct rain detection by

those satellite products. Why the authors include RMSE and AME is not RMSE better explanatory than AME since it gives higher weight for larger errors. Otherwise, they provide similar outputs.

Response: We agree with the reviewer that the literature shows several alternative statistical indices for performance evaluation of satellite rainfall other than RMSE and MAE. We however maintain that the most commonly used indices include Root Mean Square Error (RMSE), Percent of Bias (PBIAS), Mean Absolut Error (MAE), Mean Error (ME), and correlation coefficient (r). ThEse are used by, e.g., Meng et al. (2013), Dinku et al. (2007), Derin and Yilmaz (2014), Katsnaos et al. (2015), Jiang et al. (2012), Worqlul et al. (2014), among many others.

We agree with the reviewer that these statistical indices are simple but they are the most commonly applied and well documented in the literature as shown above.

We agree that both MAE and RMSE are used to evaluate the average magnitude of the error but RMSE gives a relatively high weight to large errors compared to MAE, implying that RMSE is more useful when large errors are particularly undesirable. The MAE is suitable to describe uniformly distributed errors while the RMSE is more appropriate if the errors are normally distributed (Chai and Draxler, 2014). Thus, evaluating the satellite products using both indices is advantageous. A more detailed explanation is added to the text document, in p 10 Line 31 to 34.

13. The reference use on page 9 line 3 Moriasi et al., 2007 is actually for a performance evaluation of simulated flow, sediment and nutrient. My question is that if you accept a PBIAS of ± 25 and R of 0.5 (which will be 0.25 R-square) as input to your hydrological model; imagine the performance of your model. I really do not agree with the performance evaluation criteria.

Response: We agree that such criteria are used to evaluate simulated streamflow, and definitely a rainfall PBIAS of 25% will lead to large uncertainty of runoff computed by hydrological models. However, we maintain that still the satellite rainfall data can be useful for applications other than accurate hydrological modelling. We have amended the text in Section 3.2.

Result

14. The authors provided a single average statistics like average PBIAS, r, RMSE and MAE for different satellite products (Page 9 line 14 and 15). The authors should discuss the range of variability of those statistics and their relation to landscape position.

Response: We agree that the range of variability is more explanatory than an average value. Although the value of each station is provided as supplementary file (S2-S5) and in Fig.3, we have added the range of statistical indices to the manuscript in Table 3 which is discussed in section 4.1. We have added the standard deviation to the tables. Their relation to the landscape is now discussed in section 4.1 of second paragraph (p11) and second paragraph in P13.

15. The discussion in line 16 page 9 is lamped. The authors should address the range of variation, standard deviation and their relation to landscape postion. Otherwise this doesn't make any sense "Similarly, r value of these products was≥ 0.5 in the majority of stations with an average value of 0.52, 0.50 and 0.50, respectively.." What does the average line representing in Figure 3 a and b? what does that implies?

Response: See point 14 above

16. The authors indicated that RMSE and MAE has showed the same trend as PBIAS and r (page 9 line 18 and 19). How is this measured?

Response: The value of RMSE and MAE also shows lower value for these products which implies obtained errors by comparing the satellite rainfall against ground measurement is smaller for CHIRPS, RFEv2 and TRMM products compared to the remaining products. The manuscript is modified accordingly.

17. This doesn't make any sense, the study is about comparing of those products with gauged data, but here they averaged the performance statistics. I guess the authors should discuss the range of performance/variability in terms of spatial and temporal scale for each products since this was indicated on the abstract section as a method (page 1 line 23 and 24).

Response: See point 14 above. We have amended the manuscript to give the range of indicators, and standard deviations. We have also discussed such variability, in section 4.1.

19. Table 2: On Figure 3a I can see a PBIAS value of negative but under Table 2 the autors indicated rage of PBIAS from 0 to infinity. How do you council that?

Response: We have corrected the range value in the Table 2

20. Table 2: The authors should remember that R = 1 doesn't mean perfect, it is obvious we have to check the slope and interest of the fitted line. Eg. Y = 5x + 8 has Pearson correlation coefficient (r) of 1 but Y and X are not similar.

Response: We agree with the reviewer that it may not necessarily be perfect for the given reason. We have now removed such an explanation from the table to avoid confusion.

21. Table 3 is duplicated on Table 4. Remove Table 3

Response: They are not the same, Table 3 is the summary of average (now modified to range value) accuracy indicators from pixel-to-point monthly comparison while Table 4 shows the summary of statistical indices from aerial averaged rainfall comparisons at basin level.

Figures

22. Figure 1. Label the two figures. What does the dotted line over the DEM represent?

Response: The name of the study area was missed from the legend. We have now improved the figure to include the label. The two dotted lines in the figure represent groups of rainfall stations in the highlands (>2500 m.a.s,l) and lowlands (<2500 m.a.s.l), which is later used to compare the performance of satellite rainfall products in highlands against lowlands. The figure caption is improved to explain this.

23. Figure 2. Label the two figures and describe them independently.

Response: Figures are now labelled independently and description of each figure is given under the figure.

24. Figure 3. What does the average line representing?

Response: The average line indicated represents the average value of PBIAS and r of all products and is helpful to identify how far the value of each product deviates from the average value of all products. This is also included in the manuscript

25. Figure 4 where are those representative station located in the watershed?

Response: Indicating these stations will help readers appreciate the effect of landscapes on the performance of the satellite rainfall. The names of these stations are included in the map (Fig.1)

General comments:

Abstract: the abstract full or problem

Response: We agree with the reviewer that there were many space errors throughout the document. Space errors were created when the sources document was converted into the Pdf file during uploading. We will cross-check any possible spacing error when uploading the revised manuscript.

1. Line 21: space between rainfallproducts

Response: corrected

2. Line 26 space between thatCHIRPS, Line 26 space between TRMM,and, Line 26 space between wereable

Response: corrected in the file

2. Line 27 space between BIASand

Response: corrected

3. Line 28 space between >0.5over different

Response: corrected

4. Line 35 space between respectively.CMORPH

Response: corrected

5. Line 35 space between scale.Their

Response: corrected

6. Line 39 space between lowlandswhereas

Response: corrected

7. Line 40 space between athighland

Response: corrected

8. Line 41 space between thepixel-to-pointcomparison

Response: corrected

9. Line 42 space between showthat

Response: corrected

10. Line 42 space between scalesin

Response: corrected

11. Page 3 line 29 and 30 modify it as: with a significant elevation variation

Response: Sentences modified accordingly

12. Page 6 Line 17: sofar PM and IR are not defined. I see later in the paper they are defined.

Response: They are now defined in the first sentences and abbreviations are used in the remaining document

14. Many many errors (dailyrainfall page 9 line 10, (r)of page 9 line 11, andTables page 9

line 14, double fullstops (page 9 line 17), MAE,which line 18,

Response: Thank you very much. Such errors were clearly seen in the Pdf file, uploaded in the HESSD website. We will take care of such problems when uploading our revised manuscript.

15. Page 9: wasfurther (line 24), investigatedat, that the, correlationfor, reducedat, Forexample

Response: Space problem is now corrected

16. Page 10: madefor, correlationcoefficients, of the, season.CHIRPS,

Response: Space problem is now corrected

17. Page 11: many

Response: All space problems corrected in the document

18. Page 12: so many type errors

Response: All space problems corrected in the document

19. Page 14: ofTRMM, productshave, withsimilar, werefound, products.Bayissaet, (2017)revealed, (2007)showedthat CMORPH, etcccc

Response: We would like to thank you and all problems corrected in the document

Reference

Haile, A.T., Rientjes, T., Gieske, A., Gebremichael, M., 2010. Multispectral remote sensing for rainfall detection and estimation at the source of the Blue Nile River. International Journal of Applied Earth Observation and Geoinformation, 12: S76-S82.

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Vrieling, A., Sterk, G., de Jong, S.M., 2010. Satellite-based estimation of rainfall erosivity for Africa. Journal of hydrology, 395(3): 235-241.

Response: Thank you for the sugestions we have used these references in our document.

References

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Van der Ent, R. J., Savenije, H. H., Schaefli, B., & Steele-Dunne, S. C.: Origin and fate of atmospheric moisture over continents. *Water Resour. Re., 46*(9), W09525, 2010.

Xu R., F. Tian, L. Yang, H. Hu, H. Lu, and A. Hou.: Ground validation of GPM IMERG and TRMM 3B42V7 rainfall products over southern Tibetan Plateau based on a high-density rain gauge network, J. Geophys. Res. Atmos., 122, 2017