

Interactive comment on “Performance of bias correction schemes for CMORPH rainfall estimates in the Zambezi River Basin” by Webster Gumindoga et al.

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Response to Interactive comment on “Performance of bias correction schemes for CMORPH rainfall estimates in the Zambezi River Basin” by Webster Gumindoga et al.

Anonymous Referee #2

Received and published: 05 December 2017

Referee Comment

This paper investigates the use of bias correction schemes to correct satellite rainfall

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estimates in the Zambezi basin, a region in the world where data gauged rainfall is limited. With 50 million people dependent on water from this basin, having an accurate spatial and temporal representation of rainfall can help with modelling the water balance accurately which in turn can be used in studies on for example drought mitigation and risk reduction. Lacking accurate data, understanding the uncertainty within the products that are available is essential. This work applies existing methodologies to a new location. I believe this work should be published because it applies sound scientific methods and theories in a region where despite the high risk of hydrological disasters there are little models and data available. I suggest minor changes to strengthen the paper hydrological aspects of this paper.

Author Response

The authors thank the reviewer for finding merit in our manuscript. We address all comments to strengthen the manuscript.

Referee Comment

Questions posed to reviewers:

(1) Does the paper address relevant scientific questions within the scope of HESS? I believe the hydrological application of this paper is currently limited and the paper could be strengthened in this aspect.

Author's Response and changes in the manuscript

The authors have added in the results and discussion section that errors in rainfall estimates may have propagation effects in hydrological applications so bias should be assessed and corrected for to make satellite rainfall estimates (SREs) more reliable and accurate for use. We also note that the wrong detection of rainfall is a concern to hydrological application of CMORPH estimates such as shown for poor performance of CMORPH during the dry season, a finding also presented in other studies in Africa. Therefore, for monitoring the frequent droughts in the Zambezi Basin CMORPH es-

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timates should be evaluated and corrected. Correction is also advocated for heavy rainfall events (> 20 mm /day) where CMORPH detection is found to be weak, which may cause deterioration of land surface hydrological process simulation and flood forecasting.

However the much detailed hydrological application are contained in the follow-up paper by the same authors entitled: 'Hydrologic evaluation of bias corrected CMORPH rainfall estimates at the headwater catchment of the Zambezi River'

Referee Comment (2) Does the paper present novel concepts, ideas, tools, or data? This paper applies existing concepts to a new (very relevant) location.

Author's Response

We thank the reviewers for the observation.

Referee Comment

(3) Are substantial conclusions reached? This is not possible with the results, but this does not affect the quality of the conclusion.

Author's Response and changes in the manuscript

The authors have revised the conclusions section so that there is a clear match between the objectives, results and conclusions.

Referee Comment

(4) Are the scientific methods and assumptions valid and clearly outlined? Yes, although some clarification with regards to the gauged rainfall should be supplied.

Author's Response and changes in the manuscript

In section 3.1.2, the authors made clarifications on the 66 stations that were obtained from meteorological departments in Botswana, Malawi, Mozambique, Zambia and Zimbabwe that cover the study area. We have also added supplementary table that de-

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scribes the location of the rain gauge stations in the Zambezi subbasins showing the subbasin they belong to, year of data availability, % of missing gaps, station elevation and distance from large scale water bodies.

We however also note in section 3.1.3 that comparison on a point-to-pixel basis commonly has limitations of mismatch between the scales of observation and refer to studies by (Haile et al., 2013a; Haile et al., 2013b; Villarini et al., 2008). This is because the gauge provides point data while CMORPH provides pixel data.

Referee Comment

(5) Are the results sufficient to support the interpretations and conclusions? Generally yes, although conclusion should be caveated with regards to the limited gauged rainfall data and the expected misrepresentation spatially due to this.

Author's Response

We have mentioned in the conclusions that the overall performance is affected among other things by the sparse and irregular distributed rain gauges (described in item (4) above) in the Zambezi Basin. Rain gauge networks often have low density with stations that are not evenly distributed particularly in the North and North-Western part of the Basin.

Referee Comment

(6) Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? Yes, with exception of how the gauged rainfall was constructed.

Author's Response

We revisited the description and made improvements in section 3.1.2 on gauge data.

Author's changes in the manuscript

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Section 3.1.2 now reads: ‘. . . .The rainfall is measured as a vertical depth of water accumulated on a flat level surface. All the stations are standard type raingauges with a graduated measuring cylinder whose units of measurement is mm/day. . . .’
. . . . Stations are irregularly distributed across the vast basin and are located at elevations between 3 m to 1575 m. The minimum, maximum and average distance between the rain gauges is 3.5 km (Zumbo in Mozambique-Kanyemba in Zimbabwe), 1570 km (Mwinilunga in Zambia-Marromeu in Mozambique) and 565 km respectively. The rain gauged network has density of 1 station per 24.000 km². The network is most dense in the Shire River sub-basin in Malawi (1 station per 7.500 km²) and very sparse in Tete sub-basin in Mozambique (1 station per 16.000 km²). The Cuando/Chobo sub-basin has no rain gauges at all.’

Referee Comment

(7) Do the authors give proper credit to related work and clearly indicate their own new/original contribution? Yes

Author’s Response

We thank the reviewers for the observation

Referee Comment

(8) Does the title clearly reflect the contents of the paper? Yes Author’s Response

We thank the reviewers for the observation

Referee Comment Yes (9) Does the abstract provide a concise and complete summary? Yes

Author’s Response We thank the reviewers for the observation

Referee Comment

(10) Is the overall presentation well-structured and clear? Yes

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Author’s Response We thank the reviewers for the observation

Referee Comment

(11) Is the language fluent and precise? Yes

Author’s Response We thank the reviewers for the observation

Referee Comment (12) Are mathematical formulae, symbols, abbreviations, and units correctly defined and used? Yes

Author’s Response We thank the reviewers for the observation

Referee Comment

(13) Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? Yes, please see comments below.

Author’s Response Specific comments have been attended to.

Referee Comment

(14) Are the number and quality of references appropriate? Yes

Author’s response We thank the reviewers for the observation

Referee Comment

(15) Is the amount and quality of supplementary material appropriate? Not applicable.

GENERAL COMMENTS

Referee Comment Topographical relationship and distance to lake relationship to bias not found. More details are required with regards to the used gauged data and in which category the gauges are locations e.g. are there an equal amount of gauges in all of the categories? Also the sensitivity of the method to the amount of gauged data should be discussed, perhaps if there were a few more gauges a relationship could be found.

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Author Response and changes in the manuscript

Section 3.2 has been extended to explain the number of raingauges in each distance zone. The stations are not evenly distributed in the 4 distance zones. We note that the majority of the stations (47 %) lie in the > 100 km distance from large scale open water bodies whilst only less than 1 % are in the < 10 km zone.

The authors have carried out a sensitivity analysis on varying the amount of raingauges in each of the 3 elevation zones and the 4 distance zones. This procedure involves withholding gauges at a time and calculating the bias field without these particular gauges. Reductions of number of raingauges by 25%, 50 % and 100% respectively were tested by eliminating those stations contributing to low R2 through a scatter. Findings indicates that the 25 % reduction in the number of raingauges gives an improved relationship between elevation and bias whilst a 50 % reduction gives an improved relationship between the distance from open water bodies and bias. As such the above raingauges with improved relationship are selected for further use and explanations contained in section 3.2: Elevation and distance from lake open water bodies the Zambezi basin.

Results show an established relationship between topography and satellite rainfall error. This confirm to findings by Habib et al. (2012) who showed that bias in CMORPH is dependent on topography and latitude across the catchment of the Nile basin.

Referee Comment

Discussion paper should be named as a caveat. Especially as the Elevation zone bias correction method performs well this conclusion requires more justification to be convincing or it needs to be changed/'mellowed'.

Author's Response and changes in the manuscript

The authors have modified the conclusion to accommodate the good performance of the elevation zone bias. This is more so in the found improved relationship between distance from open water bodies and bias. However it should be noted that the linear

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baas correction scheme (STB) that considers space and time variation of SRE bias, is found more effective in reducing rainfall bias in the basin than the EZ which does not consider the spatial variability in rainfall. This indicates that the temporal aspect of SRE bias is more important than the spatial aspect of bias in the Zambezi Basin.

Referee Comment

Taylor diagrams, I have not come across these before and find them difficult to understand. I understand the benefit of showing 3 performance scores on one plot, perhaps when you introduce them you can try and clarify by using a simple diagram, showing where the perfect model would sit and what it means when the results are located up/down/sideways from this perfect point. Author's Response

We have made more detailed clarification in the interpretation of the Taylor diagram.

Author's changes in the manuscript

In the methods section '3.6. Assessment through Taylor diagram' we have included a clearer explanation on how the Taylor Diagram is interpreted. In addition, in the results section where each Taylor diagram is appearing we are referring to a supplementary file (Appendices) that summarizes and gives the absolute values of the 3 performance scores (Pearson's product-moment correlation coefficient (R), root mean square difference (E), and the ratio of variances on a 2-D plot) used to develop the Taylor diagram. As such the Taylor diagrams in Figure 3 and Figure 6 are accompanied by Appendices 2 and 3 respectively.

Referee Comment

Strengthen link to hydrology by doing for example comparing cumulative rainfall volumes over the time period of a drought (or take the dry seasons) of the different methods. This quick analysis would give an indication of the uncertainty of the methods and the impact this would have for the volumes of water in any type of water balance analysis, which is essential for hydrological applications. A comparison to spatial rain-

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fall derived from gauges isn't necessarily required to get an indication of the range of uncertainty of the methods.

Author Response and changes in the manuscript

The authors have strengthened the link to hydrology by expanding section 5.1.1 which provides seasonal influences on CMORPH bias correction. Table 1 gives 'estimated ratio' of cumulative rainfall volumes (1998-2013) for the five different bias correction schemes against the gauge estimates but grouped into dry (April-Sept) and wet (Oct-March) seasons. We believe this analysis is important for water balance assessment as also alluded to by the reviewer. Overall, the STB, PT and EZ methods are more effective in reducing the bias in the cumulative rainfall volumes in the two seasons and can thus be used for water balance assessment in the basin.

Referee Comment

Discussion is missing. This is another opportunity to link to hydrology and perhaps list your next steps.

Author's Response and changes in the manuscript

The authors have strengthened the discussion section. Our next steps as mentioned in the manuscript are to evaluate application of CMORPH SREs for hydrologic modelling in the Zambezi basin by the REW model. This by selecting the two best bias correction schemes: STB and EZ. Through these results we aim to evaluate how the performance of REW model used for streamflow predictions is affected when bias corrected and uncorrected.

Referee Comment

Is there any gauged flow data? Especially in regions where gauge rainfall in scarce, gauged flow can really help with verifying rainfall data.

Author's Response

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We appreciate the reviewers for the comment and suggestion. However runoff modelling is not part of this paper but will be done in the paper on 'Hydrologic evaluation of bias corrected CMORPH rainfall estimates at the headwater catchment of the Zambezi River' as already alluded to.

Referee Comment

Will you next test the performance of these methods using a hydrological model?

Author's Response

Yes, the authors are working on a manuscript on 'Hydrologic evaluation of bias corrected CMORPH rainfall estimates at the headwater catchment of the Zambezi River'

Referee Comment

Figure 1, use differences in colours and symbols for the gauges to indicate in which height and distance category they fall.

Author's Response

We thank the reviewer for the observation.

Author's changes in the manuscript

Figure 1 has been improved to include different colours of the raingauges according to the 3 elevation zones. However we could not differentiate the colours again for the distance zones since this would make Figure 1 unreadable. The contours on the map of Euclidian distance (km) from large open water bodies helps to illustrate the message that would have been shown by the different colours.

Referee Comment

Section 3.1.2, expand on which stations were omitted and add how many station per height and distance category were used. Include length of available time series. Consider using a table.

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Author's Response and changes in the manuscript

We have included a table under supplementary data that shows the rain gauge stations in the Zambezi subbasins showing x and y location, subbasin they belong to, year of data availability, % of missing gaps, station elevation and distance from large open water bodies. After screening, 6 stations with suspicious time series were removed and these are not show in the supplementary table to reduce length of manuscript. Stations are affected by data gaps but the remaining 60 stations are of sufficiently long duration to serve the objectives of this study.

Section 3.1.2 has been modified according to the reviewer suggestion.

It now reads as follows:

“...These are zone 1: elevation of < 250 m (total of 8 stations with mean elevation \approx 90 m and inter-gauge distance of 161 km), zone 2: elevation range of 250- 950 m (21 stations, mean elevation \approx 510 m and inter-gauge distance of 333 km) and zone 3: elevation > 950 m (31 stations, mean elevation \approx 1140 m and inter-gauge distance of 607 km). Based on rain gauge Euclidian distance to large scale water bodies, 4 arbitrary distance zones are defined. These are zone 1: < 10 km (total of 4 stations and mean distance to large scale water bodies = 5 km), zone 2: 10 - 50 km (10 stations and mean distance = 35 km), zone 3: 50 -100 km (18 stations and mean distance = 80 km) and zone 4: > 100 km (28 stations and mean distance = 275 km). . . .”

Referee Comment

Also, if spatial (gauged) rainfall was derived explain how, if it wasn't it might be helpful to state this too (if you have chosen not to, I'm assuming this is because generation spatial rainfall from point observations is ridden with uncertainties itself. You might want to add this is, because it gives insight in your understanding of the uncertainties related to your observations).

Author Response and changes in the manuscript

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We have added a new section '3.1.3. comparison of satellite derived rainfall data with rain gauge observations'

In this study, we compare rain gauge observations at point scale to CMORPH satellite derived rainfall data at pixel scale. Comparison is at daily base but also are weekly time base covering the period 1998-2013. We follow (Cohen Liechti et al., 2012;Dinku et al., 2008;Haile et al., 2014;Hughes, 2006;Tsidu, 2012;Worqlul et al., 2014) who report on point-to-pixel comparisons in African basins. We resort to point- to- pixel comparison since a comparison of spatially interpolated rainfall at pixel scale to match CMORPH pixel scale would be rather doubtful. We note from past studies that interpolation using the data from sparse and uneven distributed rain gauges often bring unreliability and uncertainty to the results (Heidinger et al. 2012, Li and Heap 2011, Tobin and Bennett 2010, Yin et al. 2008). For pixel-to-pixel comparison, there is demand for a well distributed rain gauge network that would not hamper accurate interpolation (Worqlul et al., 2014).

We however also note that comparison on a point-to-pixel basis commonly has limitations of mismatch between the scales of observation and refer to studies by (Haile et al., 2013a;Haile et al., 2013b;Villarini et al., 2008).

Referee Comment

Figure 2, analysis would be more valuable if split into two figures of wet and dry season. The author indicates that the biases are different for these two so this paper would be insightful and helpful when assessing this rainfall product for application into a hydrological model.

Author Response and changes on manuscript

Seasonal influences on bias and bias removal are addressed in section 5.1.1. So the authors have maintained Figure 2 as it is. Changes have been made on the annotation of Figure 2 to now read: The spatial variation of bias (%) estimate for gauge vs

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CMORPH daily rainfall (1998-2013) for the Zambezi Basin. The gauge based isohyets for Mean Annual Precipitation (MAP) are also shown in blue.

Our next paper is on how uncorrected and bias corrected CMORPH satellite-based rainfall estimates are evaluated for application in the Representative Elementary Watershed (REW) modelling approach in the Zambezi Basin.

Referee Comment

Figure 4, I find this figure confusing. I don't understand where the gauged, uncorrected and bias corrected are. Also, what was used to construct the mean and the max is unclear to me. This means I don't understand how you come to the conclusion about effectiveness of the schemes in section 4.3.1. Maybe this can be solved simply by having a clearer legend and adding a sentence to section 4.3.1.

Author's Response and changes on manuscript

We have replaced the radar graph with a bar graph (Figure 4) which is easier to visualise and understand. The mean is simply the arithmetic mean of the daily rainfall time series (1998-2013) for the gauge, uncorrected and bias corrected satellite rainfall. This is same approach for the maximum and the ratio of cumulative gauged sum vs CMORPH sum for the Lower, Middle and Upper Zambezi subbasins.

Referee Comment

Figures 7, I find the greys difficult to distinguish. If a black and white figure is required please consider using fills/hatching. Otherwise the colours used in Figure 8 are excellent, so perhaps reuse these.

Author's Response and changes in the manuscript

Figure 7 has been improved following recommendation by the reviewer.

Thank you for your contribution to our understanding of rainfall products available for Africa. Interactive comment on Hydrol. Earth Syst. Sci. Discuss.,

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<https://doi.org/10.5194/hess-2017-385>, 2017

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