# Interactive comment on "Comparison of TRMM, MPEG and CFSR rainfall estimation with the ground observed data for the Lake Tana Basin, Ethiopia" by A. W. Worqlul et al.

**Response to Anonymous Referee #2**

The comments of referee 2 are excellent and appreciated. The original contributions should be acknowledged. We apologize for not spending the time to find these original publications. At the other hand, partially to our own defense, the ultimate acceptance of original work by the research community is that the research has become so commonly used and the source is not cited anymore. For example who cites the original publication of Darcy? However this is reference is ancient and the current standard references for satellite rainfall estimates are not even 20 years old in this revised manuscript we have looked up the original publications. All other comments have been great aid in improving the manuscript. Since they are diverse and affect various parts of the manuscript, we will address them individually.

In the section below, we repeat the comment and then have our response immediately below it. In addition, where appropriate, we indicate how the text is changed.

**GENERAL COMMENTS**

This study compares three satellite rainfall estimation methods, TRMM 3B42, MPEG, and CFSR, with rain gauge data over the Lake Tana Basin in Ethiopia during 2010. The authors find that MPEG, despite consistent underestimation, performed best, followed by CFSR and lastly TRMM 3B42.

The references are inadequate in several places. In particular, facts that have been known for decades are sometimes cited with a reference from 2012 or so. The TRMM 3B42 algorithm (in the main text and Appendix A2) is referenced via a 2010 paper that studied its performance in certain regions, instead of listing the appropriate citations:

Huffman, G.J., Adler, R.F., Bolvin, D.T., and Nelkin, E.J.: The TRMM Multi-satellite Precipitation Analysis (TMPA). Chapter 1 in Satellite Applications for Surface Hydrology, F. Hossain and M. Gebremichael, Eds., Springer Verlag, ISBN: 978-90-481-2914-0, 3-22, 2010.

Huffman, G.J., Adler, R.F., Bolvin, D.T., Gu, G., Nelkin, E.J., Bowman, K.P., Hong, Y., Stocker, E.F., and Wolff, D.B.: The TRMM Multi-satellite Precipitation Analysis: quasiglobal, multi-year, combined-sensor precipitation estimates at fine scale. J. Hydrometeor., 8(1), 38-55, 2007.

**RESPONSE:**

The following references are included in the main text and Appendix A2 which is now part of the main text as recommended by Referee #1.

In the Appendix A2, Huffman et al., 2007 is added).

Huffman et al., 2007 is also included in the main text as seen below in the introduction part on page 8015 line 26 to 28:

It is one of the major water balance component of the global water budget. Although the spatial and temporal variability of precipitation is important, unless large numbers of rain gauge stations are available, capturing variability is difficult (Chaubey et al., 1999;Pardo-Igúzquiza, 1998).

The growing availability of high-resolution (and near real time) satellite rainfall products can help hydrologists to obtain more accurate precipitation data, particularly in developing countries and remote locations where weather radars are absent and conventional rain gauges are sparse(Creutin and Borga, 2003;Kidd, 2001).

Passive Microwave (PM) and Thermal Infrared (TIR) sensors are the most widely used channels of the electromagnetic spectrum for satellite rainfall estimation (Huffman et al., 2007;Negri et al., 1984;Joyce et al., 2004;Kidd et al., 2003).

One of the limitations with a TIR sensor is that it only uses the top cloud temperature from which the depth of the cloud is inferred (Todd et al., 2001) and also underestimates warm rain and misidentifies cirrus clouds as raining (Dinku et al., 2011). Microwave sensors utilize a more direct way of retrieving precipitation from satellite; they gather information about the rain rather than the cloud (Todd et al., 2001). The absorption of microwave radiation by liquid water and its scattering by ice particles can be related to rainfall over ocean and over land (Ferraro, 1997).

**COMMENT:**

The appropriate CFSR Version 2 reference, if this is the version used in this study, is:

Saha, S., and Coauthors: The NCEP Climate Forecast System Version 2. J. Climate, 27, 2185-2208, 2014; doi: http://dx.doi.org/10.1175/JCLI-D-12-00823.1.

**RESPONSE:**

In the Appendix A3 the citation (Saha et al., 2010) is substituted by (Saha et al., 2014) on page 8027 line 6 to 8.

The CFSR was designed and executed as a global, high-resolution coupled atmosphere–ocean–land surface–sea ice system to provide the best estimate of the state of these coupled domains for the study period (Saha et al., 2014).

**COMMENT:**

The paper is generally well-written, but the English could be improved by review from a native speaker.

I reviewed the original manuscript without consulting the posted comments from and authors' reply to Reviewer 1, in order not to be influenced by their discussion. Additional comments after consulting that discussion will be listed at the end of the "Specific Comments" section and indicated as such.

**RESPONSE:**

RESPONSE: We have revised the manuscript for the English revision by a native speaker.

**SPECIFIC COMMENTS**

**COMMENT 1:**

TRMM is the name of the mission. The precipitation product is 3B42, also known as TMPA (TRMM Multi-satellite Precipitation Analysis). The title of this paper should cite it as either "TRMM 3B42", as is done in the referenced Dinku (2011) and Ouma (2012) papers, or as "TMPA", but certainly not just "TRMM". If you do not wish to change the labeling in all the figures and the text, I suggest that when you first mention 3B42 in the Abstract and in the Introduction, you should specify "TRMM 3B42 (hereafter, simply "TRMM")."

**RESPONSE:**

We have changed the title and the introduction according to the suggestion of referee 2. The title is now:

"Comparison of Rainfall Estimations by TRMM 3B42, MPEG and CFSR with Ground Observed Data for the Lake Tana Basin in Ethiopia**"**

In the introdiction we have changed the sentence as follows:

"In this study, a satellite estimated rainfall by TRMM (hereafter, simply "TRMM"), MPEG and CFSR are validated by comparing the estimates with the ground observation rainfall data in the Lake Tana Basin, Ethiopia"

**COMMENT 2:**

Because Fig. 4c shows that 3B42 is essentially unbiased overall, the last sentence of the abstract should mention this. I suggest replacing the last sentence with something like "The Bias indicated that 3B42 was, on average, unbiased, whereas MPEG consistently underestimated the observed rainfall, and CFSR often produced large overestimates."

**RESPONSE:**

Thank you, we replaced the sentence as recommended. The final part of the abstract reads now

"Similarly, the areal comparison indicated a better performance for both MPEG and CFSR data in capturing the pattern and amount of rainfall. MPEG and CFSR also have a lower RMSE compared to the TRMM 3B42 satellite rainfall. The Bias indicated that 3B42 was, on average, unbiased, whereas MPEG consistently underestimated the observed rainfall, and CFSR often produced large overestimates"

**COMMENT 3:**

It would be helpful to state something about the quality of the gauge network. How well is it maintained? Is the data quality and availability roughly the same at all 38 stations?

**RESPONSE:**

We included the following statement under data availability section 1.2.

"Thirty eight stations remained that have continuous daily rainfall data for the selected study period (2010). Of these 38, there are seven stations classified as Class 1 (synoptic stations where all meteorological parameters are measured every one hour). Majority of the Seventeen stations are Class 3 (Ordinary stations) where only rainfall, maximum and minimum temperature are collected on daily basis. The remaining fourteen stations are Class 4 only daily rainfall amounts are recorded."

**COMMENT 4:**

In conjunction with Fig. 1, it would be especially helpful to depict or describe the differences in spatial resolution amongst the three satellite products, in particular in relation to the distribution of the gauges. How often do multiple gauges fall within the same grid box for each of the three products?

**RESPONSE:**

Fig. 1 has been modified to include TRMM and CFSR grids. In addition the locations of the available and selected stations are shown. Finally a scale bar is added. .

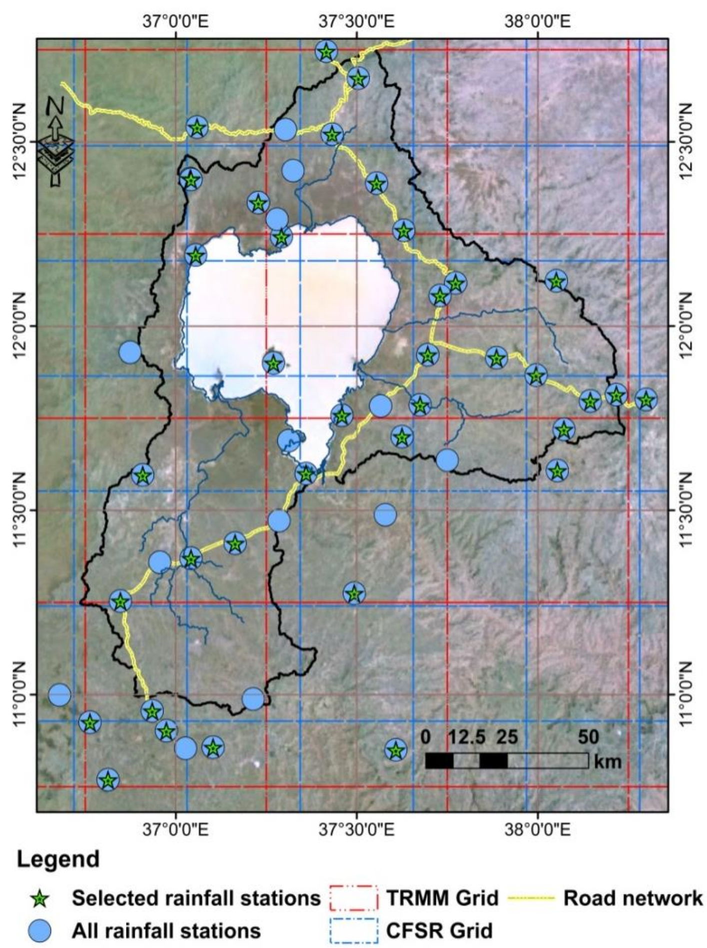


Figure 1: Lake Tana watershed, showing the TRMM and CFSR Grids and the location of the available and selected rainfall stations (Google Earth map as background).

**p. 8014**

**COMMENT 5:**

line 23 – there must be some source for this value; please provide it.

**RESPONSE:**

We have accepted your comments and included the reference.

Precipitation is a major component of the water cycle and is responsible for depositing approximately 505,000 $km^3$ (or on the average 990 mm) of the fresh water on the planet (Ramakrishna and Nasreen, 2013).

**COMMENT 6:**

line 26: Sharma et al. (2012) may be one appropriate reference, but the point you are addressing has been well-known to the community for many years before this. After all, you cite WMO (1994) as a standard in mountainous regions. Therefore, there must be papers from 1994 or earlier that can be cited.

**RESPONSE:**

We have included papers from 1990.

Although the spatial and temporal variability of precipitation is important, unless large numbers of rain gauge stations are available, capturing variability is difficult (Chaubey et al., 1999;Pardo-Igúzquiza, 1998).

**COMMENT 7:**

Similarly, nearly all of the citations in the paragraph spanning pages 8015-8016 are much too recent, as these facts have been known since the 1990's or even late 1980's.

**RESPONSE:**

The following references are changed to after your comment

It is one of the major water balance component of the global water budget. Although the spatial and temporal variability of precipitation is important, unless large numbers of rain gauge stations are available, capturing variability is difficult (Chaubey et al., 1999;Pardo-Igúzquiza, 1998).

The growing availability of high-resolution (and near real time) satellite rainfall products can help hydrologists to obtain more accurate precipitation data, particularly in developing countries and remote locations where weather radars are absent and conventional rain gauges are sparse(Creutin and Borga, 2003;Kidd, 2001).

Passive Microwave (PM) and Thermal Infrared (TIR) sensors are the most widely used channels of the electromagnetic spectrum for satellite rainfall estimation (Huffman et al., 2007;Negri et al., 1984;Joyce et al., 2004;Kidd et al., 2003).

One of the limitations with a TIR sensor is that it only uses the top cloud temperature from which the depth of the cloud is inferred (Todd et al., 2001) and also underestimates warm rain and misidentifies cirrus clouds as raining (Dinku et al., 2011). Microwave sensors utilize a more direct way of retrieving precipitation from satellite; they gather information about the rain rather than the cloud (Todd et al., 2001). The absorption of microwave radiation by liquid water and its scattering by ice particles can be related to rainfall over ocean and over land (Ferraro, 1997).

**p. 8021**

**COMMENT 8:**

line 1: It is inappropriate to cite a reference for the Bias calculation when none has been cited for R-Squared or RMSE. If citations are necessary, they should be mathematical reference works.

**RESPONSE:**

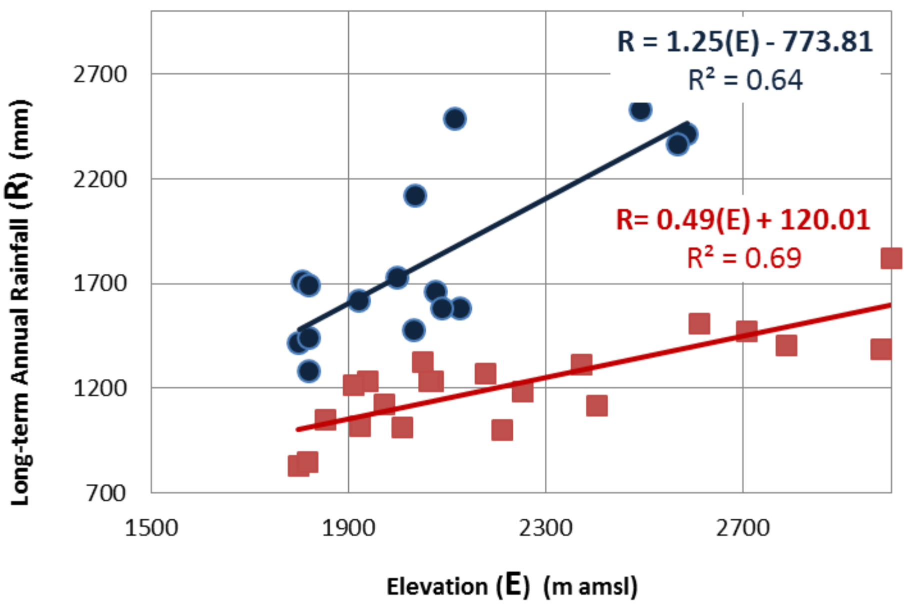
We agree that it is not required to put the references for these commonly used statistics. Consequently we removed the citation of Bias.

**COMMENT 9:**

line 12: How is the increase 125 mm per 100 m elevation if the slope is 1.41?

**RESPONSE:**

This comment refers to Fig. 3. In this figure, the X-axis is Rainfall and Y-axis is Elevation. In order to obtain the numbers mentioned in the manuscript (50mm and 125mm), Elevation should be on the X-axis and Rainfall on the Y-axis. In this case the slope is the reciprocal which is 1/1.41= 0.49 and 1/0.51 =1.25. This indicates that for a 100 m increase, rainfall will increase by 50 mm and 125 mm respectively. The figure below is included for your reference:



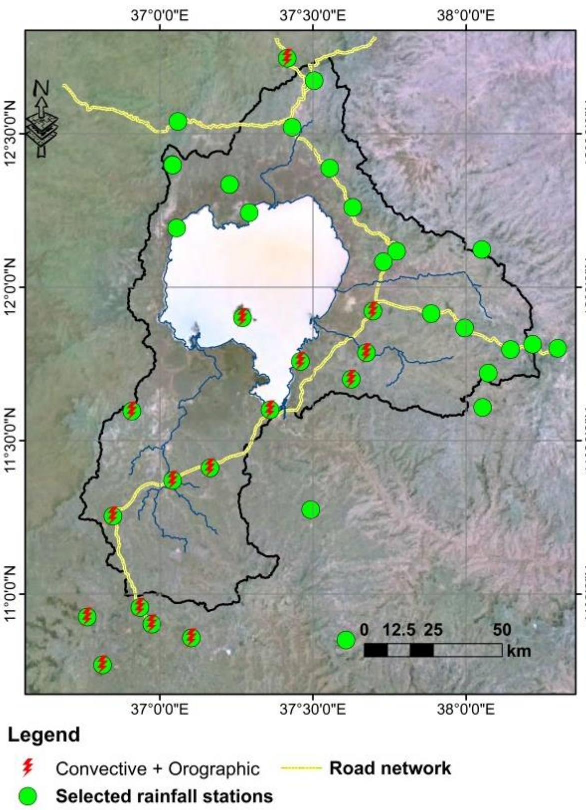

**COMMENT 10:**

lines 13-15: How did you stratify the data points into categories, particularly for the stations that fall in between the two best-fit lines? It would be very helpful to depict the sites on a map similar to Fig. 1, but plotted as rectangles and circles, in order to see whether each group of stations is clustered together geographically or in some spatially-coherent pattern. This could potentially support or disprove your contention that one cluster is convective only and the other is convective + orographic. Actually, you do this for the convective points in Fig. 6, much later in the paper.

**RESPONSE:**

The two linear relationships were optimized by a backward removal technique (page 8018 line 21 – 25). In this technique: first all of the stations were used to feet a linear model with $R^2$ of 0.1083, then using the linear equation Y = 0.3922 X + 630.0 residuals were calculated then the weakest independent variable or the station with a maximum residuals are removed and classified as group two after which the regression is recalculated. This procedure is done many times to get a maximum $R^2$ value.

Figure 1 shows all of the stations (51) and selected stations (38). The Thiessen Polygon interpolation (Fig. 6) is done for likely convective stations. The stations likely affected by convective + orographic are located in the Gilgel Abay basin (around 50 % of them) and in the proximity of eastern part of the lake see Figure below, this map is not included in the manuscript.




**p. 8022**

**COMMENT 11:**

line 1: I do not see Yismala station depicted in Fig. 4. Perhaps this is the missing station (see Technical Comments for Fig. 4)?

**RESPONSE:**

Thanks, we have included Yismala station in Fig. 4 a, b and c. Figure 4 a, b and c are copied below.

**p. 8023**

**COMMENT 12:**

lines 13-14: The number of stations specified within each watershed does not appear to correspond with Fig. 6. Perhaps I am misunderstanding, but for example, the Thiessen polygon for Gilgel Abbay watershed in Fig. 6 shows no stations within the blue boundary.

**RESPONSE:**

We apologize for the quality of the picture in the manuscript. On the original very high resolution map is attached. Actually the number of station likely affected by convective rainfall, areal influence interpolated by Thiessen Polygon method indicated the same number of stations specified on the document. Even though the stations are outside the watershed, by

Thiessen Polygon interpolation technique the nearby stations Adet and FeresBet have areal influence. Though some of the stations have a very small weight and difficult to see them on the figure. I have attached the map.

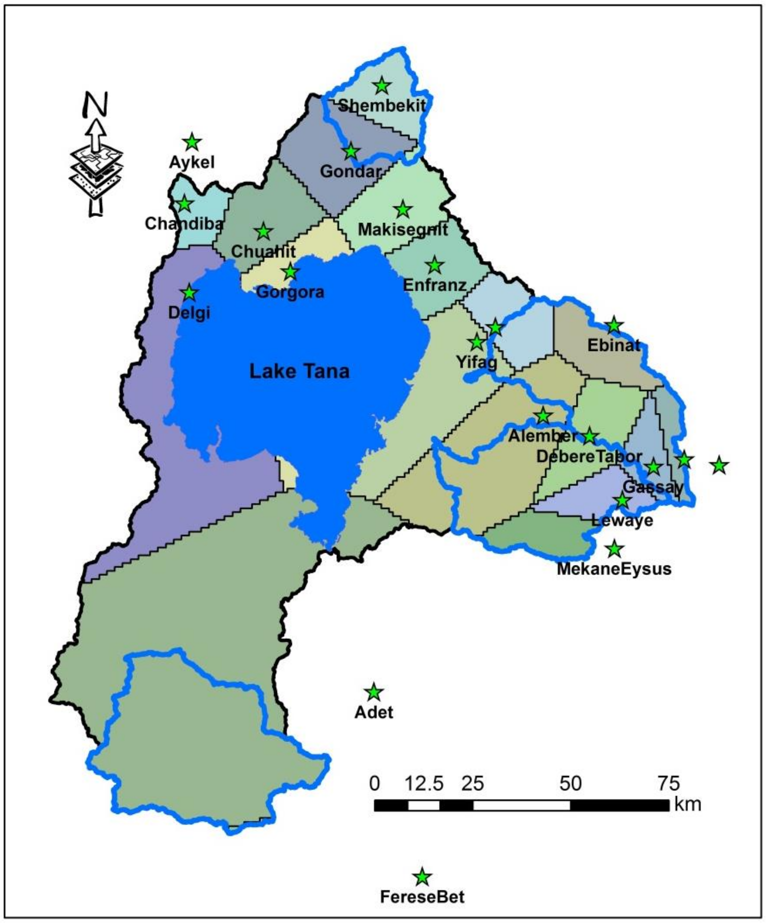



Figure 7: Thiessen Polygon of stations likely affected by convective rainfall in the Lake Tana Basin. The green stars represent the rainfall stations likely affected by convective rainfall alone.

**COMMENT 13:**

p. 8023-24: It would be helpful to include a figure similar to Fig. 7, but for Bias. Values of Bias within +/-5% for two of the four basins for CFSR and within +/-10% for 3B42 for three of the four basins seem like excellent results, yet your text de-emphasizes this in favor of proposing scaling factors for the consistently-underestimating MPEG.

**RESPONSE:**

We agree and a figure showing the areal bias is included.

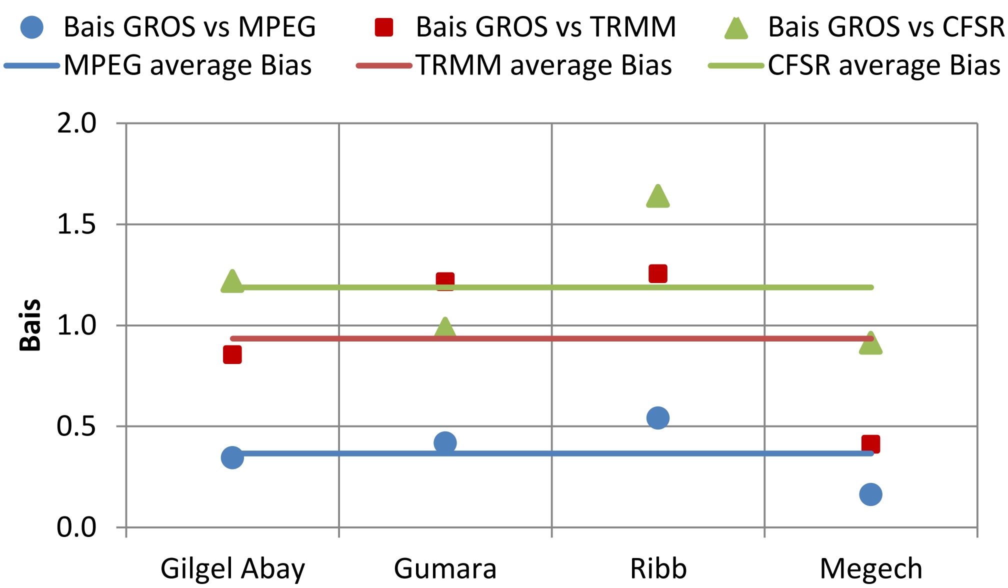



Figure 9: Bias of areal ground observed rainfall versus satellite rainfall estimate for the major river basins in the Lake Tana.

**COMMENT 14:**

p. 8024, lines 23-24: words like "inconsistent" and "not consistent" make it sound like both the CFSR and 3B42 do a bad job with respect to Bias ratio, when in fact it is better to have such results (as long as the values do not deviate too far from 1.0) than to have a consistent (i.e., systematic) underestimation, as MPEG does.

**RESPONSE:**

The rainfall estimate from TRMM 3B42 on average for the 38 station the Bias is close to 1 (0.93) with a Standard Deviation (STDV) of 0.3. But, if we see R-square of TRMM 3B42 it is very small with average R-square value of 0.07 and STDV of 0.09, which indicates 3B42 is weak in capturing the temporal pattern of observed rainfall. CFSR on the average captures the pattern well with R-square value of 0.86 and STDV of 0.09, average Bias for CFSR data is 1.25 with a STDV of 0.66, this indicates that CFSR is not consistently on capturing the observed rainfall. MPEG captures the pattern of observed rainfall with average R-square value of 0.78 and STDV of 0.14, and has average value of Bias of 0.43 with a relatively smaller minimum STDV compared to 3B42 and CFSR data of 0.15.

So, TRMM 3B42 has on average a very good Bias but fails to capture the pattern and CFSR captured well the pattern but with a higher Bias which will make both of them difficult to calibrate by a simple scaling factor. But on the other hand MPEG with a higher R-square value and with a consistent underestimation with a smaller STDV makes it easy to do rainfall bias correction. For example, I just used excel function solver and tried to optimize the bias by a correction factor. What I found was for a correction factor of 2.27; the average bias will be one with a STDV of 0.38 for the same R-square of 0.78.

**COMMENT 15:**

p. 8025, lines 6-7: this conclusion seems unnecessarily harsh given that 3B42 was unbiased overall (Fig. 4c), whereas MPEG consistently produced underestimates, and CFSR often produced large, sometimes more than a factor of two, overestimates.

**RESPONSE:**

We rewrote the conclusions as follows:

This study evaluated EUMETSAT's MPEF Multi-Sensor Precipitation Estimate-Geostationary (MPEG), Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis TRMM 3B42 data version 7 and Climate Forecast System Reanalysis (CFSR) rainfall estimation, using 38 ground rainfall observation stations in and around the Lake Tana Basin for 2010. Two approaches were used in the evaluation: the precipitation of the point gauged data was compared to satellite predicted rainfall for the grid in which the rainfall station was located; and all satellite grid based prediction was compared with the areal interpolated observed rainfall stations that were only influenced by convective rainfall. The performance of MPEG and CFSR satellite rainfall estimates both for point to grid and areal comparison was better than the TRMM satellite rainfall amounts. Although the MPEG satellite rainfall underestimated consistently the ground observed rainfall by an average of 60%, it captured the rainfall pattern well. CFSR satellite rainfall also captured the observed rainfall pattern but it overestimated for some and underestimated for the other stations. TRMM rainfall was not consistent in estimating the ground rainfall observation for both point to grid and areal comparison and didn't capture the observed rainfall pattern at all.

The ground observation data indicated 86% of the annual rainfall to occur from June to September and the MPEG and CFSR indicated approximately the same percentage. The TRMM indicated only 30% of the annual rainfall to occur during the rainy season June to September. Based on the study period for the study area, MPEG has performed better in capturing the spatial and temporal pattern of observed rainfall. The result suggested that there should be a further calibration for the TRMM 3B42 rainfall product to capture the temporal variation of rainfall and MPEG can be easily calibrated by a correction factor to capture the observed rainfall.

**COMMENT 16:**

1. Appendix A2, line 2: GPM was launched in February 2014.

**RESPONSE:**

We corrected the expression.

The successor GPM is launched in February 2014, with advanced radar and passive microwave sensors and will provide continuous precipitation estimates for the next years to come.

**Technical Comments**

**Comment 1:**

Abstract, line 14: TRMM is misspelled.

**RESPONSE:**

We corrected the spelling.

..while TRMM explained only 17% of the variation.

**Comment 2:**

**p. 8015,**

line 1: Replace "Though" with "However".

**RESPONSE:**

We corrected the expression.

However, ground based rainfall observation station networks are often unevenly and sparsely distributed in developing countries...

**Comment 3:**

line 6: (WMO, 1994) is cited but not listed in the References.

**RESPONSE:**

We included the reference.

WMO: World Meteorological Organization, Guide to Hydrological Practices: : Data Acquisition and Processing, Analysis, Forecasting and other Applications. WMO-No. 168., WMO, Geneva, 770, 1994.

**Comment 4:**

line 7: "gauge" is misspelled. [: : :now I see this was addressed in response to reviewer 1.]

**RESPONSE:**

We  corrected spelling and the expression.
The poor coverage introduces large uncertainties in rainfall distribution estimation and will evidently undermine the dependability of hydrologic models used in simulating flow (both low flows and floods), sediment load and nutrient fluxes (Kaba et al., 2014).

**p. 8016,**

**Comment 5:**

line 14: the meaning is not clear.

**RESPONSE:**

We  modified the expression:

In this study, a satellite estimated rainfall by TRMM 3B42 (hereafter, simply "TRMM"), MPEG and CFSR are validated by comparing the estimates with the ground observation rainfall data in the Lake Tana Basin, Ethiopia.

**Comment 6:**

lines 20-24: the meaning is not clear.

**RESPONSE:**

We modified our expression:

This study validates satellite rainfall products in two ways: comparing satellite gridded rainfall data to point observation data and second by comparing satellite areal rainfall estimates to areal ground observed rainfall interpolated by Thiessen Polygon method for the major sub-basins of Lake Tana.

**Comment 7:**

p. 8017, lines 7-10 should be deleted (redundant).

**RESPONSE:**

We removed the text.

**Comment 8:**

p. 8018, lines 4-6 should be deleted (redundant).

**RESPONSE:**

We removed the text.

**Comment 9:**

p. 8019, lines 8-9 can be deleted, because this is obvious.

**RESPONSE:**

We removed the text.

**Comment 10:**

p. 8021, line 10: I suggest replacing "trends" with "relationships", since trends suggests a pattern over time.

**RESPONSE:**

We replaced the word.
Two clear relationships can be observed; the first one shows a 50 mm of rainfall increase for every 100 m elevation increase and...

**Comment 11:**

p. 8022, line 3: swap the order to say "Shembekit and Gassay".

**RESPONSE:**

We corrected the order.
The CFSR has a coefficient of determination ranging from 0.63 to 0.99 for Shembekit and Gassay respectively, ...

**Comment 12:**

lines 25-27 should be deleted (redundant).

**RESPONSE:**

We removed the text.

**Comment 13:**

p. 8023, top paragraph (from Section 3.1): I understand what you are saying about the influence of orography, but the English needs some cleaning up, especially for the last sentence. Also, the references listed are fine but should again be supplemented by older references that have found similar results.

**RESPONSE:**

We modified the expression:

This is quite reasonable, because orographic lifting of the moist air will lead to precipitation while the cloud top temperature is still relatively warm. Satellite rainfall products may not detect the rainfall from the warm clouds as the cloud-top temperature would be too warm for TIR thresholds (Dinku et al., 2008), and there will not be much ice aloft to be determined by PM sensors. But, both sensors can detect the rainfall from the deep convection (Tsidu, 2012).

**Comment 14:**

p. 8023, line 12: Replace "there" with "their".

**RESPONSE:**

We corrected the expression.
Stations likely affected by convective rainfall are interpolated using a Thiessen Polygon method and their weights on areal rainfall for the major watersheds is determined (Fig. 7).

**Comment 15:**

line 16: Fig. 7, not Fig. 9 (which doesn't exist).

**RESPONSE:**

The figure label is corrected. The figure is now labeled as Fig. 8. We have added a new figure showing the spatial distribution of annual rainfall estimate for MPEG, CFSR and TRMM data after Referee 1 comment.

Fig. 8 shows the correlation and RMSE of areal Ground Rainfall Observation Station (GROS) versus MPEG, areal GROS versus TRMM and areal GROS versus CFSR for the major river basins of Lake Tana.

**Comment 16:**

p. 8024, lines 5-7: The meaning is not clear.

**RESPONSE:**

We modified our expression:

Thus, the consistence Bias with an excellent correlation for MPEG rainfall estimate, there is a possibility to use scaling factors for the rainfall Bias correction.

**Comment 17:**

Appendix A1, line 20: presumably you mean SSMIS rather than SSM/I?

**RESPONSE:**

Thanks for your valuable comment. There was a misprint in the paragraph; the forward slash in between the word Microwave and Imager was missing. See the correction below:

… the Special Sensor Microwave/Imager (SSM/I) instrument.

**Comment 18:**

Appendix A2, line 28: this should be SSMIS rather than SSM/I. MHS (Microwave Humidity Sounder) should also be listed.

**RESPONSE:**

We have accepted your valuable comment and included MHS (Microwave Humidity Sounder) from the list.

...TRMM microwave imager (TMI), Special Sensor Microwave/Imager (SSM/I), Advanced Microwave Sounding Unit (AMSU), MHS (Microwave Humidity Sounder) and Advanced Microwave Sounding Radiometer-Earth Observing System (AMSR-E)...

**Comment 19:**

Fig. 1: It would be helpful to have latitude/longitude labels and/or some indication of the distance in km covered by the area depicted. Of the 50 or so stations shown, can the 38 stations actually used in the study be highlighted?

**RESPONSE:**

Figure 1 is changed to show selected stations and to include the scale bar.

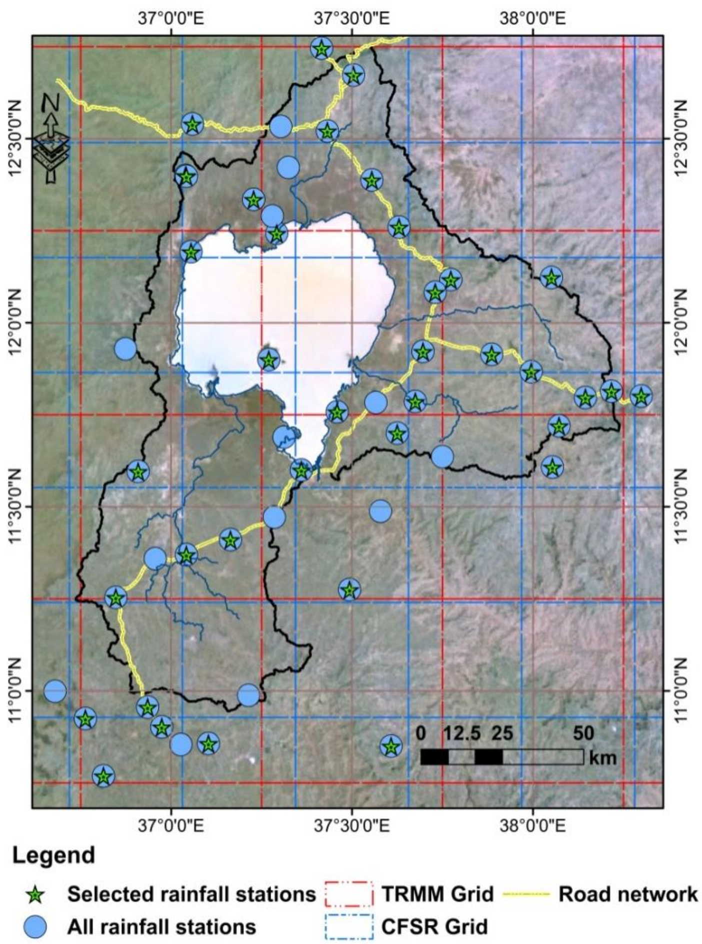



Figure 2: Lake Tana watershed, showing the TRMM and CFSR Grids and the location of the available and selected rainfall stations (Google Earth map as background).

**Comment 20:**

Fig. 3 needs an additional sentence in the caption describing the right panel. [: : :now I see this was addressed in response to reviewer 1.]

**RESPONSE:**

We have accepted your comments and improved the description after the first reviewer. The title is now

"Figure 3: (a.) Elevation verses long-term annual average rainfall relations in the Lake Tana Basin (38 stations from 1984 to 2008) and (b.) Two clear trends: first one shows a 50 mm of rainfall increase for every 100 m elevation increase and the second trend observed was a 125 mm rainfall increase for every 100 m elevation increase"

**Comment 21:**

Figs. 4 (a-c): I count 37 station names along the x-axis, not 38 (missing Yismala?). Also, "average" is misspelled in Fig. 4c. The captions are redundant. 4a can end "average R-square value"; 4b can end "Root Mean Square Error"; 4c can end "values" or "values of Bias". These captions should state that monthly values during 2010 were used.

**RESPONSE:**

We have accepted the comment and improved the caption corrected the spelling and included Yismala station in all the tables.

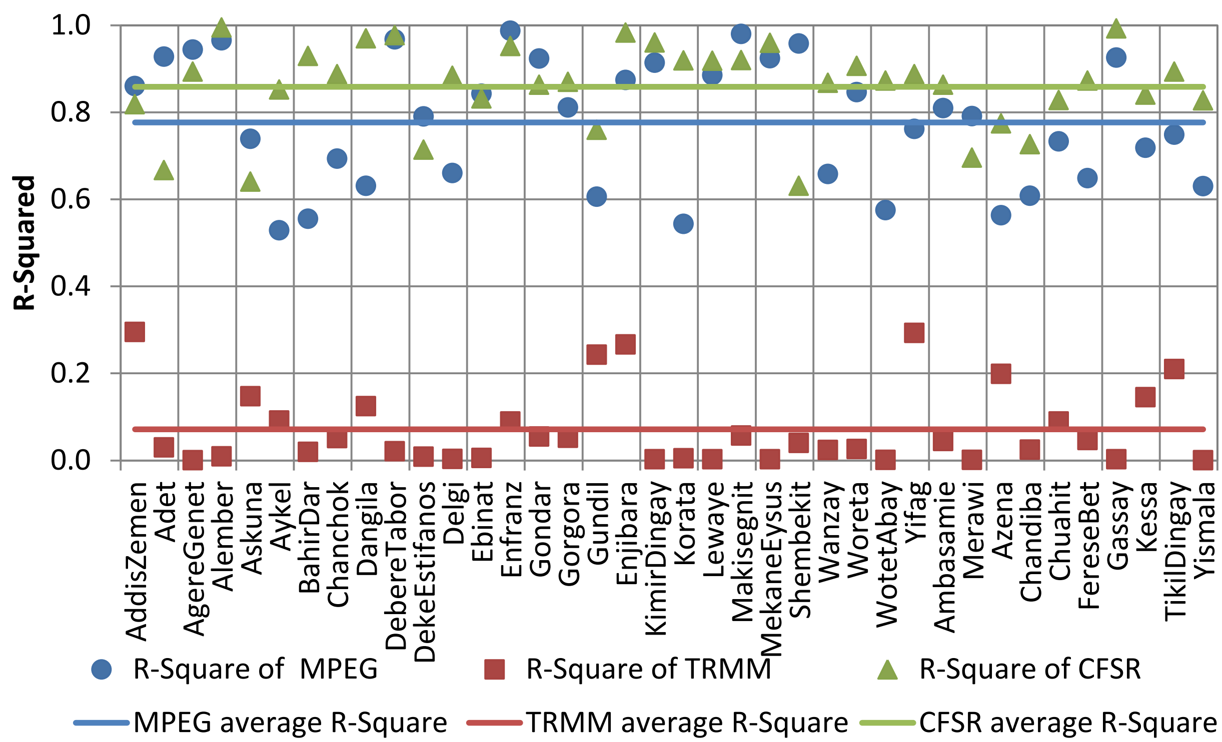



Figure 4a: R-Squared of MPEG, TRMM and CFSR compared with 38 Ground Rainfall Observation Stations (GROS) in the Lake Tana Basin.

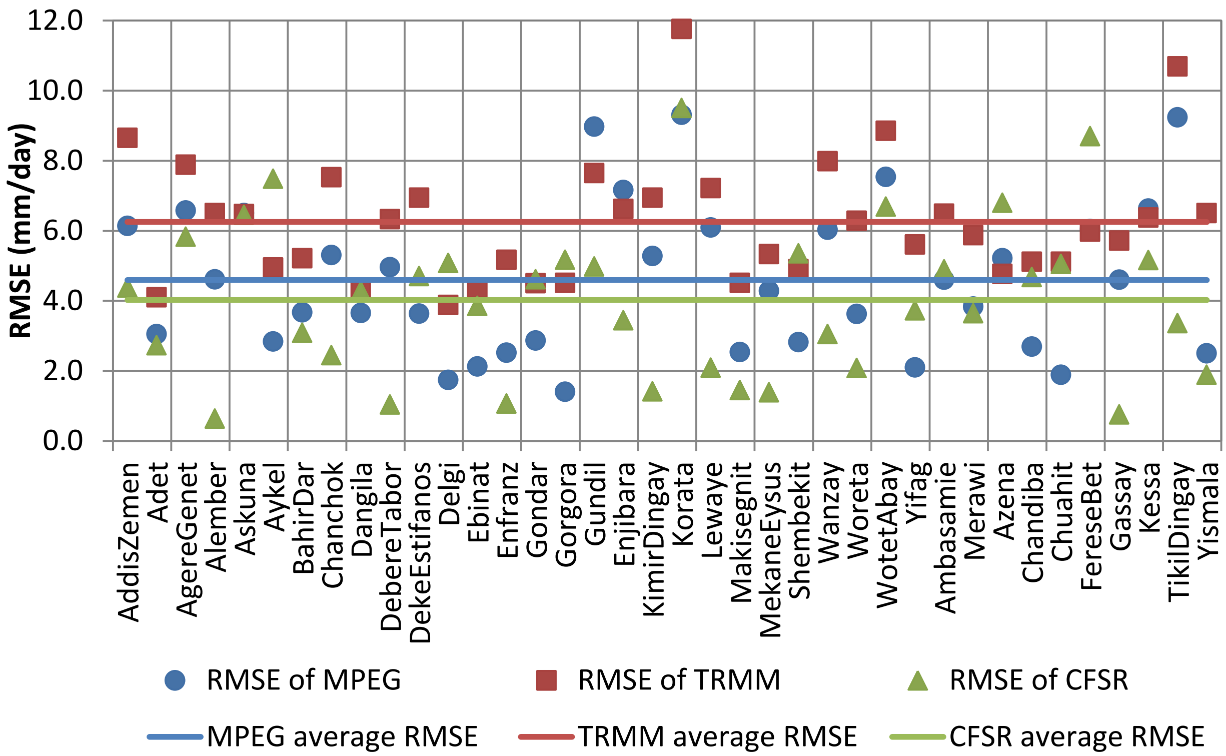



Figure 4b: RMSE of MPEG, TRMM and CFSR compared with the 38 Ground Rainfall Observation Stations (GROS) in the Lake Tana Basin.

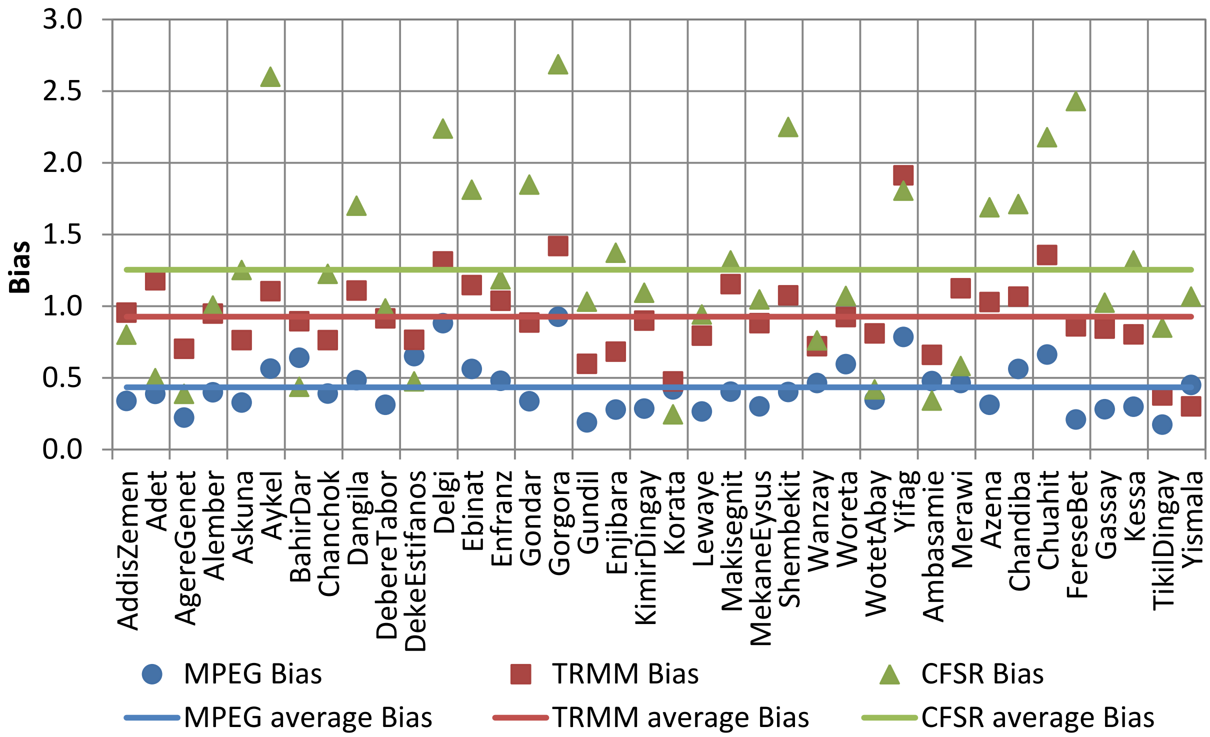


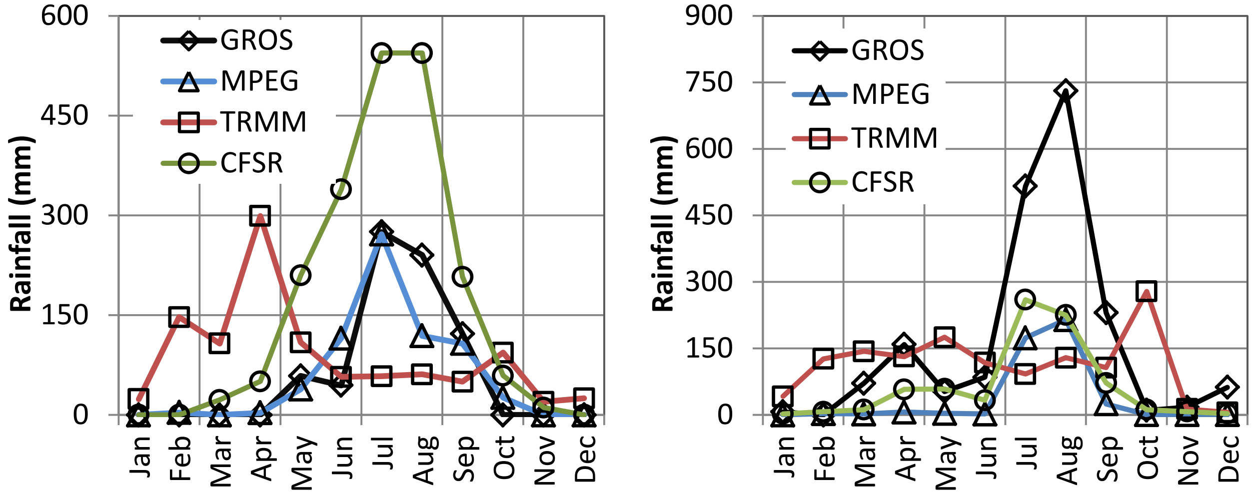

Figure 4c: Bias of MPEG, TRMM and CFSR compared with 38 Ground Rainfall Observation Stations (GROS) in the Lake Tana Basin.

**Comment 22:**

Fig. 5: Please retain the color scheme from Fig. 4. It is confusing to use the same three colors, but switch their assignments. It would also be helpful to use the same color scheme in Fig. 7, if possible.

**RESPONSE:**

We have accepted your comments and improved Figure 5.




(A) Gorgara station

(B) Agre Genet station

**FROM RESPONSE TO REVIEWER 1:**

1. New Fig. 5: “Rainfall” is misspelled in all 3 labels.

**RESPONSE:**

We have accepted your comments and corrected the spelling.

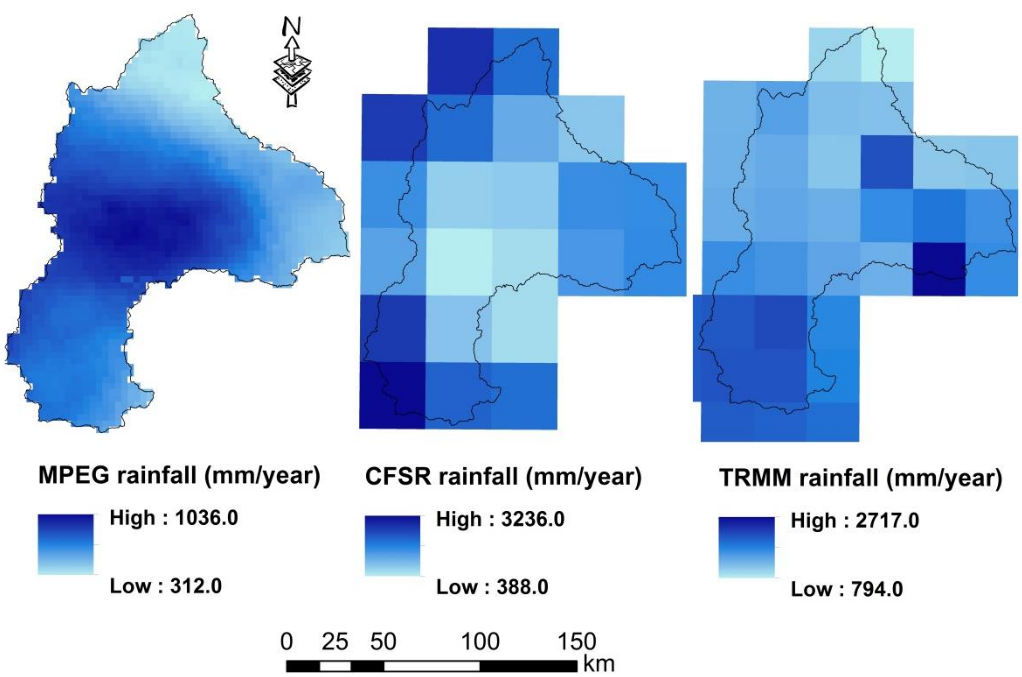


Figure 6: Spatial distribution of annual rainfall estimate for year 2010 from MPEG, CFSR and TRMM data.

2. 3B42RT is the near-real-time version of TRMM 3B42. Its latency is roughly 7 hours. Is this adequate for operations in Ethiopia?

**RESPONSE:**
Currently TRMM 3B42 data is not available at the National Meteorological Agency of Ethiopia. But, if available it will be sufficient to understand rainfall spatial and temporal variability. Ethiopian highland is under gauged as far as ground-based rainfall observation stations are concerned.

3. p. 8016, line 5: should be “utilize” instead of “utilizes”.

**RESPONSE:**
We corrected our sentence.

Microwave sensors utilize a more direct way of retrieving precipitation from satellite; they gather information about the rain rather than the cloud (Dinku et al., 2010).

We would like to express our great appreciation to you for comments on our paper

Thank you

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