

# ***Interactive comment on “Risks of seasonal extreme rainfall events in Bangladesh under 1.5 and 2.0 degrees’ warmer worlds – How anthropogenic aerosols change the story” by Ruksana H. Rimi et al.***

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Received and published: 2 July 2019

We thank for the constructive comments from the anonymous Reviewer 1. We have carefully revised the manuscript to incorporate necessary amendments as per suggestions. Responses to the Referee Comments 1(RC1) are presented in the following paragraph in the Author’s Comments 1(AC1):

Introduction

RC1: The introduction provides a general background on the research topic with clearly

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stated objectives and research question. The author divided whole Bangladesh into four sub-regions (page 3, line11-14) to evaluate the risk of extreme rainfall events. Are there other specific reasons for to divide into four seasons like climatological variation or any other previous study used these sub-regions.

AC1: These 4 sub-regions of Bangladesh and the different seasons are used for a reason. The three wet seasons with substantial climatological variations include: pre-monsoon (during Mar-Apr-May; MAM), monsoon (during Jun-Jul-Aug; JJA) and post-monsoon (Sep-Oct-Nov; SON). Little or no rain occurs in winter (during Dec-Jan-Feb; DJF). This dry winter season is excluded from our analysis because we are interested in wet extremes. Any MAM extreme rainfall events are known to cause flash floods and substantial crop damage (Ahmed et al., 2017). Bangladesh receives more than 75% of the annual total rainfall during JJAS (Shahid, 2010). An extreme rainfall event in this period can therefore cause wide-spread flooding and landslide eventually leading to loss of lives and livelihoods. A high impact SON rainfall event may be associated with the coastal floods that occur due to storm surges or tidal effects along the northern part of Bay of Bengal (Hossain, 1998). Considering both meteorological hazards and potential impacts, we have looked at extreme rainfall events of pre-monsoon and monsoon seasons and excluded the post-monsoon season. The same 4 sub-regions are used in Rimi et al., (2019) where, we evaluate the model's performance in simulating extreme events (see Fig. AC1.a). We believe that the pre-evaluated model simulations over the same 4 sub-regions provide confidence in analyzing the extreme rainfall events under different forcing scenarios.

RC1: A standalone Figure of Bangladesh including the four sub-regions could be useful with mean seasonal rainfall.

AC1: Because a standalone figure of Bangladesh including the four sub-regions with mean seasonal rainfall has already been shown in Rimi et al., 2019 (see Fig AC1.b); we are not using the same kind of figure in this paper. Nevertheless, the sub-regions are indicated in panel e of Fig 2 & 3 of this manuscript.

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RC1: Line 16 page 2 – In June 2017, heavy rainfall killed at least 156 people (needs a citation).

AC1: The following citation is added for this information: Paul, R. and Hussain, Z.: Landslide, floods kill 156 in Bangladesh, India; toll could rise, Reuters, 14th June [online] Available from: <https://uk.reuters.com/article/uk-bangladesh-landslides/landslide-floods-kill-156-in-bangladesh-india-toll-could-rise-idUKKBN1950AG>, 2017.

Data and Methods Model setup and experiment design

RC1: The wettest and driest years are not well presented in the Table S2. Is it range of years or individual year? Classification of wet years and dry is not clearly mentioned. It has been mentioned that spatiotemporal average of rainfall has been used here. Is there any threshold for the classification of wet period and dry period? In Bangladesh flooding years are considered as wet year during monsoon. This needs to be made clear.

AC1: We identified the two wettest and two driest years during 2006–2015 over each of the four sub-regions of Bangladesh using ACT data. This identification process involved comparing the magnitude along with return periods of rainfall events during MAM and JJAS in each of the years throughout 2006 to 2015 (ACT model ensemble with 200 members per year used). Then a pair of wettest and driest years is used to approximately indicate the noise-to-signal ratio. For example, according to ACT model ensemble, during monsoon season at sub-region 2, the wettest years with extreme rainfall events are 2008 and 2012 (see Fig. AC1.c, the red and blue dots for individual model runs and shadings for 5-95% confidence intervals) and the driest years are 2006 and 2013 (yellow and cyan dots for individual model runs and shadings for 5-95% confidence intervals). Using the pair of these wettest and driest years from the model ensemble, we could demonstrate the plausible spread of the rainfall events within this model ensemble as a measure of noise-to-signal ratio. Because this model ensemble has same forcings in each year for the historical period of 2006-2015, the only variability

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playing a role in changing the intensity of rainfall is natural variability of sea surface temperatures (SSTs). The use of two wettest and driest years, therefore explains how much natural variability of SSTs contributes to the variability of rainfall intensities over this study area. We agree with your comment and changed the presentation of the years in the supplementary Table 2 to make it clear that they are the two individual years with either wettest or, driest conditions in a 10-year period over a specific sub-region.

### Results and Discussion Section 3.1 Model Evaluation for Five day mean rainfall

RC1: “Five day mean rainfall is used to represent the timescale responsible for river flooding as opposed to daily extremes that cause flash floods primarily in the pre-monsoon season.” Is the 5 days rainfall causes flooding or 1-day extreme rainfall causes flash flood in Bangladesh and what is the intensity of rainfall termed as extreme (what is the amount of rainfall mm/day considered as extreme value)? Citation may clear this statement.

AC1: By extreme rainfall event, we mean a high impact rainfall event (i.e., sufficient to cause flooding or landslides) with up to 100 year return period (a rare event with low frequency of occurrence). The intensity of the rainfall event can vary depending on both location and season. For example, at north-east Bangladesh, in pre-monsoon season, more than 150 mm rainfall event over a 6-day period can lead to an early flash flood (Ahmed et al., 2017). On the other hand, at south-east parts of Bangladesh, in monsoon season, more than 350 mm rainfall events over a 3-day period is enough to cause a landslide (Ali et al., 2014). Whereas, for a wide-spread river flooding e.g., the Brahmaputra River Basin flooding in August 2017, 10-day extreme rainfall event is considered (Philip et al., 2018). Considering the range from 1- to 10-day high impact rainfall events that can trigger flooding and landslides in Bangladesh, we focused on daily and 5-day events because these events can provide a typical idea about the potential risks.

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RC1: Fig.1 represents annual cycle of the four sub-regions in Bangladesh and results of the five models (ACT, NAT, GHG, HAPPI 1.5 and HAPPI 2.0) show maximum rainfall occurs in June. June to September is the monsoon month and June is the month of monsoon onset. Usually, July is the maximum rainfall month in Bangladesh. Do the results indicate any shifting of monsoon timing Due to the monsoon climate, the overall variation (inter-annual) of rainfall in JJAS months (seasonal) is not quite high? Bangladesh has almost similar pattern of monsoon precipitation in the JJAS months. Underestimation by 25-65% is quite high. The bias and uncertainty within these values is very high. The authors need to explain the reasoning for this a bit more.

AC1: No, as per observational data (APHRODITE and CPC) that are used in the annual cycles in Fig 1; there are no indications of temporal shifting of monsoon. We see an early monsoon onset in the model simulations. Such early onset of monsoon is also reported in other model based studies (e.g., in Caesar et al., 2015; Fahad et al., 2017; Janes and Bhaskaran, 2012). At the time of writing this paper, APHRODITE was only available until 2007, so we used 1998-2007 data for comparison. Recently, APHRODITE has been updated until 2015, allowing us to use 2006-2015 data for comparison (which is now same as CPC). As a result, APHRODITE and CPC observations are now in better agreement (see Fig. AC1.d) and model bias is also smaller than before (highest bias level of 65% dropped to 50%). The 25-50% underestimation of monsoon precipitation is quantified based on the model ensemble mean compared to observations. Most of the observed rainfall is found to be within the 10-90% confidence interval of the model data. Overall, the weather@home model simulates the annual cycle of rainfall with satisfactory agreement, despite the dry monsoon rainfall bias. Furthermore, Rimi et al. (2019) shows that the weather@home model gives a reasonable representation of extreme rainfall events with return periods of 50-100 years. Therefore, we are confident that these biases will not affect our risk assessments for extreme rainfall events.

Section 3.2: Impact of Climate Change and Aerosol Reduction on Seasonal Mean

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## Rainfall

RC1: Provides important information regarding rainfall change due to warming 1.5°C to 2°C and aerosol impact. However, the change has been computed using model based on simulated observed data. The actual changes can be presented by using observation data (e.g., Aphrodite).

AC1: While it is definitely useful to look at the observed changes between pre-industrial and present-day rainfall, present day and future warmer (1.5 and 2.0 degrees) scenarios or the aerosol impacts; we can only do this kind of comparison using model simulated data. Because no high resolution gridded observational dataset offers the pre-industrial records and the future scenarios of 1.5 and 2.0 degrees warming. APHRODITE data was only available from 1963 to 2007 at the time of writing this paper. Recently they have updated their data up to 2015. CPC observation dataset extends from 1979-present.

Page 7 line23 -24

RC1: “While aerosol effects are consistent with other regions, the GHG induced rainfall is hampered, likely due to dynamic changes such as a delayed onset of the monsoon in response to warming”, It can be supported with other relevant studies (e.g. the variation of interannual rainfall may depend on the onset of monsoon).

AC1: While it is beyond the scope of this study to identify the exact mechanisms that lead to future changes associated with aerosol removal (or the change due to contemporary emissions for that matter), we point to the literature where this issue has been investigated in some detail already. The seminal paper by Bollasina et al. (2011), as well as more recent work by Zhao et al. (2019) are excellent resources that support our point.

3.3 Rainfall extreme: Line 40, page7 RC1: “The signal-to-noise ratio is higher in the monsoon season across all sub-regions with the lowest and highest ratio in sub-region

1 and 3, respectively (Figs. 8a & 9a)”. This statement may be needed further explanation.

AC1: This statement is rewritten as “Overall, the signal-to-noise ratio is higher across all sub-regions, during JJAS compared to that during MAM. During MAM, the highest and lowest signal-to-noise ratio is over sub-region 1 and 3, respectively (Figs. 6a & 7a). On the other hand, during JJAS, we find the highest and lowest signal-to-noise ratio is over sub-region 3 and 1, respectively (Figs. 9a & 8a). The lower the ratio, the more difficult it is to establish causality as natural variability due to ENSO or circulation anomalies is higher.”

#### References

RC1: The author referred Banglapedia, 2012 as citation in page 2 line 10. However, did not provide in the reference list.

AC1: We have now added this citation as “Banglapedia: River and Drainage system, Banglapedia- Natl. Encycl. Bangladesh [online] Available from: [http://en.banglapedia.org/index.php?title=River\\_and\\_Drainage\\_System](http://en.banglapedia.org/index.php?title=River_and_Drainage_System), 2012.” Other comments:

(a) The title of the paper says risks of seasonal extreme rainfall events and presented rainfall extreme using daily and five day mean rainfall. One day max and 5day max would be better presentation of rainfall extreme. It is also necessary to have a better description why daily and five day mean rainfall has been used.

AC1: This is because our focus is on unusual rare rainfall events with the potential to cause high impacts on the ground in pre-monsoon and monsoon seasons. We have used daily and 5-day running mean rainfall events throughout a season and then looked at events crossing a threshold (e.g. 250mm/day that can trigger floods or, landslides) with a high return period (e.g. 100 years). In particular, we have explored whether or not, and to what extent, the probability of having that same magnitude event (i.e.

250mm/day) changes in that particular season from one forcing scenario to another (e.g. from ACT to HAPPI 1.5).

(b) Inconsistent in figure indexing spacing: In the results (e.g. Sect. 3.2) it is needed to be consistent with spacing when referencing to figures. For example, Fig.2 d and (Fig. 2d), (Figs. 8a & 8b) and (Fig. 4 a & c).

AC1: Figure indexing spacing issue has been resolved. Now this is uniformly done throughout the manuscript using Fig. 1a; Figs. 1a & b; Figs. 1a-d and Figs. 1b & 2b style.

(c) The Figure captions are too long. The author started to describe the results in some of them (e.g. Fig. 5). The results or discussion should be in text. Caption should be concise and just define what the Figure shows with the necessary information to gather information from it.

AC1: We have now moved parts of the figure captions to result and discussion section to reduce the length, and make them concise.

(d) Line 6 (page 4) – Evaluation of the model for the region was conducted by Rimi et al. (2019) and demonstrated a reasonable agreement between model results and observational datasets for extreme rainfall events. What is a reasonable agreement? Which statistical skills show general agreement (e.g.  $r^2$ , KGE). For example, 60% of stations achieved values greater than 0.6 between modelled and observed data.

AC1: We present here Fig. AC1.a adapted from Rimi et al., (2019) for reference. In Figure AC1a., the black line represents the model simulated rainfall events; while, red, blue, orange and sky-blue colours indicate APHRODITE, GPCC, CPC gridded observations and TRMM satellite data, respectively. Based on these figures, Rimi et al., (2019) reports that the pre-monsoon and monsoon extreme rainfall events with up to 100 years of return periods are adequately well captured by the model over Bangladesh when compared to APHRODITE, GPCC, CPC gridded observations and TRMM satel-

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lite data. Although the observation data sets used in that model evaluation paper had short lengths of records; by fitting a Generalized Extreme Value distribution, the authors demonstrated that the model simulated extreme events are in good agreement with the observations.

RC1: The discussion article 'Risks of seasonal extreme rainfall events in Bangladesh under 1.5 and 2.0degrees' warmer worlds – How anthropogenic aerosols change the story' by Ruksana H. Rimi et al. is very interesting focused on the extreme rainfall events due climate change particularly 1.5 and 2 degrees warmer world. This is a comprehensive analysis of future projection of multi model rainfall over several sub-region of Bangladesh. The author provides sufficient graphs and maps in the article which explained the results. The major findings of the article are related with the global warming and its implication extreme weather events for Bangladesh. Finally, I suggest that the author will consider the above comments in finalizing the script. The article is recommended to publish with minor correction.

AC1: The authors highly appreciate your careful review with constructive comments. We have updated the manuscript following most of your suggestions. In case of any disagreement, we have provided our explanation behind that. We hope that now the manuscript is ready to be accepted for publication.

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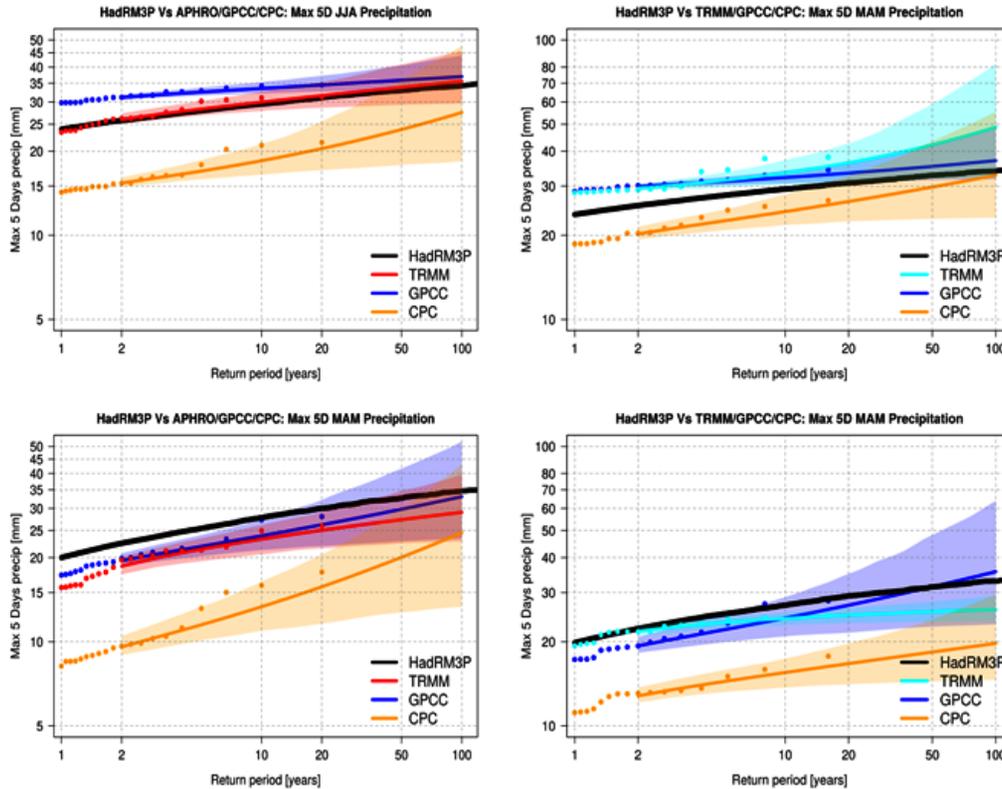
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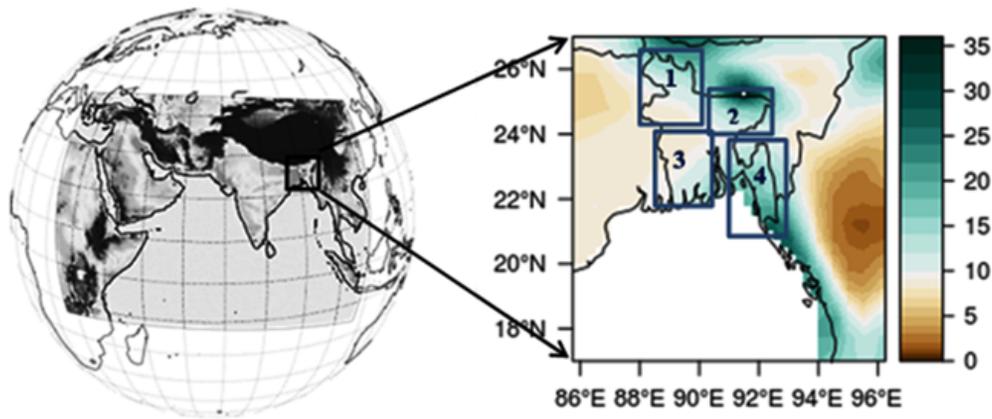


**Fig. 1.** AC1.a: Left panels show 5-day rainfall events in JJA and MAM over Bangladesh while right panels show the same but for sub-region 2.

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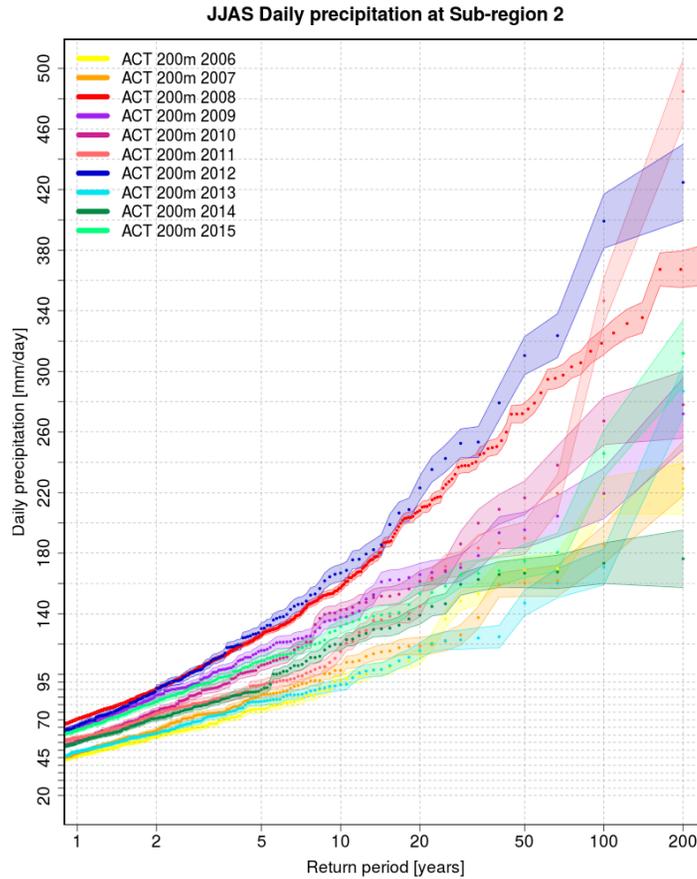


**Fig. 2.** AC1.b: Left panel shows South Asia domain of the weather@home regional climate model and right panel shows the four sub-regions of Bangladesh with APHRODITE based mean monsoon rainfall (mm/day).

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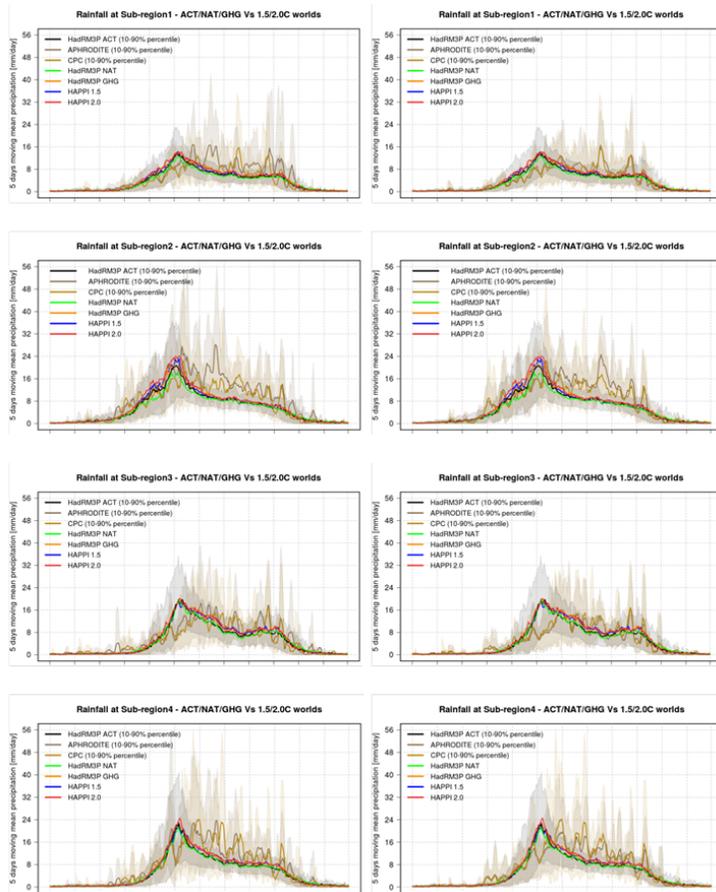


**Fig. 3.** AC1.c: Return period plots for JJAS daily precipitation over sub-region 2 in different years (2006-2015).

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**Fig. 4.** AC1.d: The left column shows the old version of the annual cycles of 5-day rainfall over the four sub-regions of Bangladesh. The right column shows the same but uses updated APHRODITE data.

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