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Hydrology and Earth System Sciences
Discussions

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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The authors investigate changes in mean and extreme precipitation in Bangladesh for five different forcing scenarios. They divide Bangladesh in four regions and analyse the magnitude of events with different return times. They find increases in pre-monsoon and monsoon precipitation due to higher global mean temperatures but also due to a decrease in aerosols. While the paper is clear in scope and the analysis in principle straightforward, it needs more work, especially the text. As crucial information is missing from the methods section I can only recommend publication of the paper after

major revisions.

We thank for the constructive comments from the anonymous Reviewer 2. We have carefully revised the manuscript to incorporate necessary amendments as per suggestions. Responses to the Referee Comments 2 (RC2) are presented in the following Author's Comments 2 (AC2):

General and Technical Comments ## Text

RC2: The text could profit from more work. Some sections seem rather long; while others miss some essential information (see below). Also, there are numerous small mistakes that give the impression of sloppy proofreading. The conclusions, on the other hand are very well written and concise.

AC2: Thank you for your careful review. We have revised the text as per suggestions and corrected the identified errors in the text.

RC2: It is very hard to really pin down, but I had the impression that some information is repeated over and over again, see e.g. my comment concerning the abbreviations below. Another example is the first two sentences in your introduction - they are different but they basically say the same. Of course, sometimes it is good to repeat things (e.g. in the conclusions), I felt it rather hindered the flow while reading.

AC2: We have aimed at avoiding repetitions in the manuscript as good as possible now.

RC2: When you use the word significant do you mean 'statistically significant' or large? Significant is a reserved word – please only use it if you conducted a statistical test!

AC2: We mean statistically significant here. For all risk ratios, we also have calculated the associated error bars (using bootstrapping) to know whether the results are statistically significant or not.

RC2: Similarly, you have to be careful when using the word 'risk'. Risk is often formal-

ized as the combination of exposure and vulnerability to weather and climate events. Therefore please check if 'probability' of 'magnitude' would be more appropriate.

AC2: We are aware that 'risk' is often defined as the product of vulnerability and exposure. However, in the probabilistic event attribution, 'risk' is indicative of the range of hazards. According to UNFCCC, "Climate related risks are created by a range of hazards. Some are slow in their onset (such as changes in temperature and precipitation leading to droughts, or agricultural losses), while others happen more suddenly (such as tropical storms and floods)." [Source: https://unfccc.int/topics/resilience/resources/climate-related-risks-and-extreme-events]. In the abstract, to avoid any possibility of misinterpretation, we have explained clearly what the term 'risk' means in this study.

RC2: You introduce abbreviations for the simulations, but you often refer to the simulations by the full name; e.g. on P6: L11 (twice); L15, L16, L21; L30 (twice). There are many more examples throughout the manuscript.

AC2: Apologies for the irregularity. The model simulations are now uniformly denoted throughout the manuscript.

RC2: What is the abbreviation for the simulation with current-day GHGs and pre-industrial aerosols? GHGonly? GHG? GHG only? AR? All of them are used throughout the manuscript. Be consistent! Also make sure that it can be differentiated from the abbreviation for greenhouse gas (GHG).

AC2: Apologies again for such inconsistency. In this model ensemble, anthropogenic aerosols are reduced to pre-industrial levels, and so, the GHGs (at current concentrations) act as the main forcing. Hence this model ensemble consists of ACT GHGs with reduced anthropogenic aerosols (levels of the natural aerosols are unchanged). To keep this uniform throughout the manuscript, this model ensemble is now called 'GHG-only'.

Methods

RC2: You should explicitly write why you use different time periods for your two observational datasets.

AC2: At the time of analysing data for this study, APHRODITE was only available until 2007; while, CPC was available for the period of 2006-2015. Fortunately, this observation data is recently updated up till 2015. Therefore, we have updated our analysis with same period for all model and observation data sets.

RC2: You use bi-linear interpolation to regrid your data. For the future I would recommend to use a conservative remapping scheme to make sure the precipitation amount is conserved.

AC2: Thank you for the suggestion. We have checked ACT precipitation data over Bangladesh in this regard. As per figure AC2.a, we can argue that changing the method from bilinear interpolation to conservative has no effect on the high intensity precipitation events.

RC2: The description of the model simulations is very long and overly detailed. I recommend to shorten it.

AC2: We have tried to make this part shorter by avoiding repeating ensemble information.

RC2: On the other hand, I miss a description of your statistical analysis, which makes it difficult to assess it. In particular I need the following questions answered:

RC2: How do you calculate the return time?

AC2: "Return time" of an event, also known as the "return period" is the likelihood of an event occurring, defined by a particular variable exceeding a certain threshold during a given time interval. For a variable X, if the threshold level is xT, then an extreme event occurs when $X \geq xT$ Now, if p is the probability of occurrence of an extreme event, then

Return Period = T = 1/p, or, p(X $\geq$ xT) = 1/T. For instance, a “1 in 10 year event” is an event with a 10% chance of occurring. On the contrary, the rarest event is a “1 in 1000 year event”, with a 0.1% chance of occurring in a given year.

RC2: How do you calculate the uncertainty of the return time?

AC2: The uncertainty of the return period is calculated using bootstrapping. The time series is resampled a 1000 times and what we present are the 95% confidence intervals. We note that structural model uncertainty (such as parameter sensitivity) is not included in our uncertainty estimate.

RC2: For the RR, do you assume an Extreme Value distribution? If not how is the probability calculated?

AC2: In case of the model results, we have large enough an ensemble to calculate the probabilities of occurrence (P) of the event in question explicitly by means of the different forcing scenarios. For example, suppose a 200 mm/day precipitation event has a ’P’ACT of 50 years and a ’P’NAT of 100 years. The resulting change of probability of that event would simply be a doubling (RR= 2) due to the change in forcing.

RC2: How do you calculate the uncertainty of RR?

AC2: To calculate the upper and lower limits of the uncertainty of RR we have used the following formula (error propagation model for independent contributors): Upper limit of RR uncertainty = rootsquare of (a2 + c2); and Lower limit of RR uncertainty = rootsquare of (b2 + d2) Where, a = upper limit of uncertainty of ’P’ACT, b = lower limit of uncertainty of ’P’ACT, c = upper limit of uncertainty of ’P’NAT, d = lower limit of uncertainty of ’P’NAT.

RC2: Do you consider all days or only days with rainfall larger a threshold? This is particularly relevant for MAM.

AC2: We are considering all days while calculating the return periods. In this way, we can look at low intensity rainfall events with minimum return period of 1 year, and also

high intensity rainfall events with up to 980 years return period. However, we focused on rainfall events with high return periods that are relevant for impacts and adaptation planning (e.g., 10-100 year events).

RC2: Given that you have data from 98 * 10 years, should your maximum return time not be at 980 years instead of 1000 as in Figure 6?

AC2: The maximum return period is at 980 years. The coloured dots in the figure end at that point but the scale ends at 1000 years. Due to very little difference between them (in comparison to the total length of the scale), it is not clearly visible.

RC2: Similarly, when analysing the two wettest/ driest years should you not end at 196 years instead of 200?

AC2: Yes, you are right. This ends at 196 years not 200 years.

RC2: You might want to mention that you look at SPI in the methods.

AC2: SPI calculation method is now added to the supplementary material of the manuscript.

Results

RC2: The two observational datasets show quite some differences. Do you have a guess if this is due to the different periods they span, or would they also be different covering the same periods? How different are they during the two overlapping years?

AC2: The discrepancy between the two observation data sets is due to different periods that they spanned. We have now used the same time period for both data sets because APHRODITE is recently updated and this data version covered up till 2015. Figure AC2.b demonstrates the improvement in the results; by comparing the old and updated versions of the annual cycles. In the right panels we can see, that the two observation data sets are in better agreement. The model biases are also reduced as a consequence of comparison between the model and observation data spanning the

same time period.

RC2: What is the point of using the two lowest and highest years? It basically says 'during a wet year the magnitude of a 1 in X year's event is larger than during an average year', which is a relatively trivial result. Also, these results are barely used / described in the results sections. My proposition would be to either remove this entirely, or move it to the appendix. This would help to clean up the figures and/ or reduce the amount of required subplots.

AC2: The use of two wettest and driest years explains how much natural variability of sea surface temperatures (SSTs) contributes to the variability of rainfall intensities over this study area. These are two pairs of individual years with the wettest and driest conditions amongst all model years of ACT ensemble. This model ensemble has same forcings in each year for the historical period of 2006-2015 and this means the only variability playing a role in changing the intensity of rainfall is natural variability of SSTs. This indicates that for Bangladesh natural SST variability can play a role besides the anthropogenic forcings in some cases. This would not be the same case, for example, in a European country context, where natural variability of SSTs would be very small and so it will have minimal contribution compared to other forcings. We agree that this result is not adequately discussed in the manuscript and so we are adding this in the updated version.

RC2: Evaluation is done with 5-day precipitation but return time plots and RR in the main text are with 1-day precipitation – why is that?

AC2: For model evaluation, 5-day running mean precipitation based annual cycles only smooths out the variability of daily data based annual cycles (not shown) – the overall model evaluation result remains the same. For brevity, we only put the 5-day precipitation based annual cycles in the manuscript. For RRs, we have looked at both 1- and 5-day precipitation events considering their potential to cause flash floods or, landslides. We have presented 1-day precipitation based RRs in the main text because (i)

this illustrates the highest variability of the daily precipitation extremes that are probable due to different forcings (ii) daily extreme precipitation events can have sudden and severe impacts on society by affecting agriculture, transport, industry and ecosystem services. The results for 5-day precipitation events are presented at the supplementary materials.

RC2: You sometimes talk about a linear rainfall response. What do you mean with linear? How can you know it's linear (as you have only 5 data points)?

AC2: By linear response, we meant steady and gradual increase in the climate change impact on rainfall from one forcing scenario to another due the warming effects starting from NAT to ACT, ACT to HAPPI 1.5 and HAPPI 1.5 to HAPPI 2.0. But we see a non-linear response during JJAS (in Fig. 3) which involves a drying effect from pre-industrial to present climate (Fig. 3a), followed by a large wetting effect from present-day climate to 1.5 degrees warmer world (Fig. 3b) but then again a small wetting effect from 1.5 to 2.0 degrees warmer worlds (Fig. 3c). If we consider the GHG-only scenario, we can explain this non-linear effect, as it demonstrates the extent of aerosol-related rainfall suppression (Fig. 3d). The "data points" are the result of hundreds of model simulations, i.e. they are robust as far as our weather@home model setup is concerned. They might differ amongst models, but since the other HAPPI models do not provide a GHG-only scenario, we can only infer causality of potential non-linear changes between the warming scenarios from weather@home.

RC2 General Comments on Figures

RC2: I had to rasterize the Figures in order to print them. Not sure what the problem is but - please make sure this does not happen for the final paper. However, even in your original pdf the figures are all blurry and don't have a good quality, this makes them very difficult to analyse. Please save them as *.pdf and ensure fonts are embedded.

AC2: Apologies for the difficulties that you have faced. Most of the figures are redone to have good quality with high resolution.

RC2: Avoid mixing green and red in the figures.

AC2: Thank you, this point is noted.

RC2: The text (labels, legend) is generally too small.

AC2: Labels, legends are now larger where possible.

RC2: The captions are very long and describe results. Please make them shorter and move all results to the main text.

AC2: The captions are made reasonably shorter by moving some texts to main results section.

RC2: The naming of simulations is inconsistent in the legend/ labels. E.g. in Figure 1 you call it 'HadRM3P ACT' but 'HAPPI 2.0'. I recommend removing 'HadRM3P'. In Figure 2 and 3 it is called present instead of ACT. In Figure 4 you introduce a new abbreviation!

AC2: Removed HadRM3P, its only ACT now. We have now used uniform names throughout the manuscript for the different forcing scenarios. ACT, NAT, GHG-only, HAPPI 1.5 and HAPPI 2.0 are used for present-day actual; pre-industrial natural; present-day GHG (with pre-industrial levels of anthropogenic aerosols); and additional global warming since pre-industrial period by 1.5 and 2.0 degrees, respectively.

RC2: In the same category: sometimes it is called MAM and sometimes pre-monsoon

AC2: Now they are kept uniform throughout the manuscript.

RC2 Specific Comments on Figures

RC2: Figure 1: Annual -> seasonal

AC2: Amended as per suggestion.

RC2: Figures 2 and 3: I recommend to change the title to '(ACT - NAT) / NAT', '(HAPPI1.5 – ACT) / ACT', etc. so it is absolutely clear what you are doing.

AC2: Percent change (PC) is calculated as: PC actual relative to natural = {(ACT-NAT)/ACT} $\times$ 100. We have added a paragraph explaining how PC is calculated in the supplementary material. Therefore, we are not changing the figure caption.

RC2: The maps in the top row look a bit distorted – do you use a projection for the map plot?

AC2: The maps are produced again with high resolution and without any distortion. We show here one updated figure (Fig. AC2 c) for MAM PC maps to show the improvements.

RC2: Why is it only 'approximately' the sub-regions? Remove approximately. AC2: Removed

Figure 6: 'sub-regions of 1 and 2' -> remove of AC2: Removed

RC2: Figures 10 and 11: Please use a logarithmic y-axis so that the plot is symmetric with respect to 1. Remove the bars, the RR is not really something that starts a 0. Reverse the order of the bars, start with the 1 in 10 year event.

AC2: We have now used a logarithmic y-axis. After using a logarithmic y-axis, the issue of starting from 0 is solved. The order of the bars is reversed starting from 10 in 100-year event. See the updated figures AC2. d, & e).

RC2 Minor Comments

RC2: P1 L11: the future

AC2: Amended

RC2: P1 L15: risk -> probability

AC2: We want to keep the term as it is. To avoid any possibility of misinterpretation, we have explained clearly what the term 'risk' means in this study.

RC2: P1 L16: 2C global warming

AC2: We want to keep it as it is because this is an opening statement and so it can be applicable for 1, 2, 3 or even 4 degrees warmer conditions. But we have only focused on the Paris Agreement temperature targets.

RC2: P1 L20: risk -> probability or magnitude

AC2: We want to keep the term as it is. To avoid any possibility of misinterpretation, we have now explained clearly what the term 'risk' means in this study.

RC2: P1 L23: in terms : : : impact. -> remove, you do not look at impacts

AC2: By impacts we meant climate change impacts on the probabilities of extreme rainfall events. We have modified the line as "Climate change impacts on the probabilities of extreme rainfall events are found during both pre-monsoon and monsoon seasons, but the level of impacts are spatially variable across the country."

RC2: P1 L25: GHG abbreviation not introduced

AC2: GHG abbreviation is now introduced.

RC2: P2 L12: Is it really an increasing trend – do you mean a positive trend?

AC2: We meant a positive trend. This line is now changed to "The frequencies of observed high-intensity rainfall events are increasing in the recent years."

RC2: P2 L14: names -> name

AC2: Corrected

RC2: P2 L15: Currently the sentence reads as if the "low-lying areas" damaged the rice.

AC2: Modified the line as "Consequently, vast areas of Haors (local name for low-land wetlands) and low-lying areas were inundated and most of the nearly-harvestable 'Boro' paddy crop (a local high yielding variety of paddy) was damaged (Nirapad, 2017)."

RC2: P2 L15: Should that be "Boro (...) and paddy crops"? Or is should it be "Boro paddy crops (...)"?

AC2: It should be Boro paddy crop (. . . .), see the above response.

RC2: P2 L16: Which dataset is this?

AC2: It is NASA's Integrated Multi-satellitE Retrievals for Global Precipitation Measurement, GPM (IMERG) data. We have now mentioned this in the manuscript.

RC2: P2 L25: remove 'multi'. Also I would recommend to rewrite this sentence.

AC2: 'multi' is removed and the sentence is re-written as follows: "According to global climate model (GCM) ensemble based study, By 2090, the north-western part of Bangladesh would experience nearly 9% and 18% increase in the pre-monsoon (Mar-May) and monsoon (Jun-Sep) mean rainfall respectively (Kumar et al., 2014)".

RC2: P2 L25: for the northwestern part of

AC2: This part is edited, see the above response.

RC2: P2 L27: the high resolution

AC2: Amended

RC2: P2 L28: in the global

AC2: Amended RC2: P2 L31: north-eastern

AC2: Amended

RC2: P2 L34: remove 'of'

AC2: Removed 'parts of'

RC2: P2 L35: Even if they did not calculate RRs other studies did look at the influence of anthropogenic climate change -> please reformulate

AC2: By the influence of anthropogenic climate change, we meant the human impacts on climate change due to past GHG emissions (since pre-industrial period). This attribution experiment is done by comparing probabilities of occurrences of events crossing a predefined threshold in (i) present-day climate and (ii) a hypothetical natural climate with pre-industrial levels of GHGs in the atmosphere. This is certainly not done in Kumar et al., (2014), Caesar et al., (2015), and Nowreen et al., (2015). For clarity, we have changed the line as "...; explained whether or not anthropogenic climate change played a role in changing the probabilities of those projected future rainfall events; . . ...."

RC2: P2 L41: runs -> simulations

AC2: Amended as per suggestion.

RC2: P2 L41: remove 'the'

AC2: Removed

RC2: P3 L4-L5: also : : : warning: I don't understand what you mean here.

AC2: These observation data sets are also used in another paper of the authors. We have removed this line to avoid confusion.

RC2: P3 L10: remove 'here'

AC2: Removed

RC2: P3 L11-L14: I recommend to move this sentence to the methods. AC2: Agreed and moved to method section.

RC2: P3 L18: 2.2 -> 3.1

AC2: Corrected, thank you for pointing this out.

RC2: P3 L20: You did not mention Section 3.2

AC2: Section 3.2 is now mentioned.

RC2: P3 L27: remove the second 'observational'

AC2: Removed

RC2: P3 L30: remove 'grids'

AC2: Removed, this line is rewritten as "APHRODITE is a high-resolution daily gridded rainfall data set for Asia (V1901, available for 1998-2015); created primarily with data obtained from a rain-gauge-observation network."

RC2: P3 L31: in Table S1

AC2: Corrected

RC2: P3 L39: Move the reference behind 'program'.

AC2: Moved as per suggestion

RC2: P3 L41: remove 'of'

AC2: Removed

RC2: P4 L2: remove 'the model'

AC2: Removed

RC2: P4 L5: GHG was introduced before

AC2: It is 'GHG-only' not 'GHG'.

RC2: P4 L6-L9: This belongs in the Results Section.

AC2: Moved to Result section

RC2: P4 L10: remove 'the'

AC2: Removed

RC2: P4 L27: one third

AC2: Amended as per suggestion.

RC2: P4 L29: remove ‘world’

AC2: Removed

RC2: P4 L31: hereinafter?

AC2: Removed hereinafter

RC2: P4: Formula (i) and (ii): These are unnecessary.

AC2: Removed

RC2: P4 L39: force -> forcing

AC2: Amended as per suggestion.

RC2: P4 L41: the other GCMs -> other GCMs

AC2: Amended as per suggestion.

RC2: P5 L5 and L6: I would write this as 3x30x10x98 and 4x30x10x98. In addition, make a remark that all months have 30 days in the used model.

AC2: Agreed and rewritten as per suggestion.

RC2: P5 L15: presented -> present

AC2: Amended as per suggestion.

RC2: P5 L15: This sentence does not make sense, please rewrite.

AC2: Rewritten as “In order to quantify changes in the probability of occurrence of extreme rainfall event, we use Risk Ratio (RR), which is calculated as RR = Pf / Pcf (NAS, 2016). Here Pf denotes the probability of the event in factual climate including climate change (ACT, HAPPI 1.5 and HAPPI 2.0) and Pcf denotes the probability of an event of the same magnitude in a counterfactual climate without anthropogenic climate

change (NAT).”

RC2: P5 L17: the probability

AC2: Amended as per suggestion.

RC2: P5 L17: remove ‘scenarios’

AC2: Removed

RC2: P5 L18: an event of the same magnitude

AC2: Amended as per suggestion.

RC2: P5 L18-L20: Abbreviations!

AC2: Rewritten

RC2: P5 L26 and L34: annual -> seasonal

AC2: Amended as per suggestion.

RC2: P5 L35: dataset it is compared with and sub-regions. -> dataset and the sub-region.

AC2: Amended as per suggestion.

RC2: P5 L36: at -> in

AC2: Amended as per suggestion.

RC2: P5 L36: There is no way to know if the bias is the same for the different scenarios! This is an assumption. It’s ok to make the assumption, but ‘note’ is not the appropriate word here.

AC2: Removed the word ‘note’ and rewritten the sentence as “The bias is apparently present in all model scenarios; hence it is unlikely to affect the comparison between model scenarios”.

RC2: P6 L2: Significant?

AC2: Here ‘significant’ meant important.

RC2: P6 L6: although they suggest

AC2: Amended as per suggestion.

RC2: P6 L28-L29: Did you show this somewhere in your paper? Do you have a reference for this?

AC2: We refer to Bollasina at al. (2011) and Zhao et al. (2019) for more theoretical background and model support for our conjecture (which we do not further analyse as it is beyond the scope of this paper) that circulatory changes may have caused the non-linear rainfall percent-change in northern India with warming.

RC2: P6 L34-L35: Is that global or local warming?

AC2: It is global, not local warming. We are looking at global warming effects on regional/local weather events.

RC2: P6 41: Significant?

AC2: Changed ‘significant impacts’ to ‘major impacts’.

RC2: P7 L4: remove ‘and hence efficiently masked’

AC2: Removed

RC2: P7 L6: SPI: abbreviation not introduced

AC2: Now it is introduced.

RC2: P7 L15: in all -> in almost all

AC2: Amended as per suggestion

RC2: P7 L36: frequencies of occurrence -> magnitude

AC2: Amended as per suggestion

References:

Bollasina, M.A., Ming, Y. and Ramaswamy, V.: Anthropogenic Aerosols and the Weakening of the South Asian Summer Monsoon, Science 334 (6055), 502-505, doi: 10.1126/science.1204994, 2011.

Zhao, A.D., Stevenson, D.S. and Bollasina, M.A., The role of anthropogenic aerosols in future precipitation extremes over the Asian Monsoon Region, Climate Dynamics 52:6257-6278, doi: 10.1007/s00382-018-4514-7, 2019

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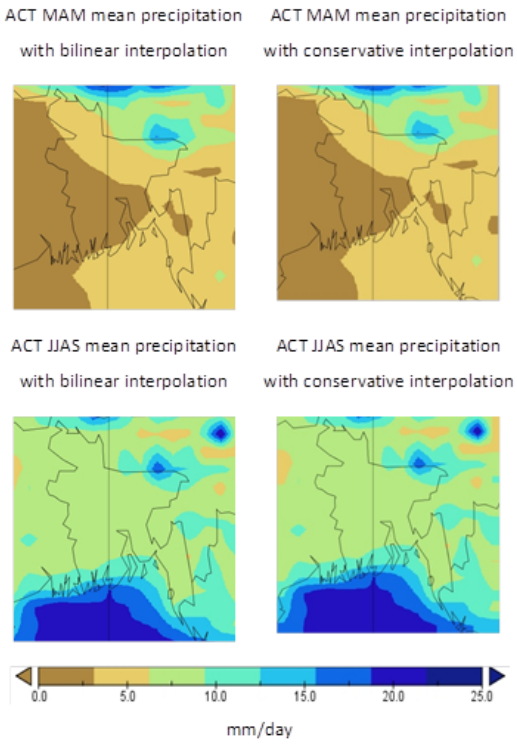

Fig. 1. AC 2a: Comparison between two interpolation methods applied for seasonal mean precipitation during JJAS and MAM over Bangladesh.

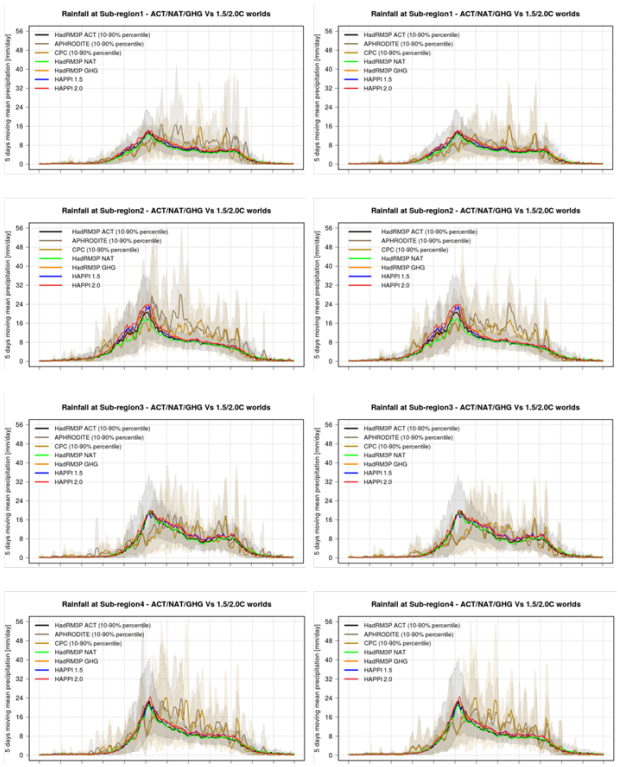

Fig. 2. AC 2b: Comparison between old and updated versions of annual cycles of 5-day precipitation over the four sub-regions of Bangladesh.

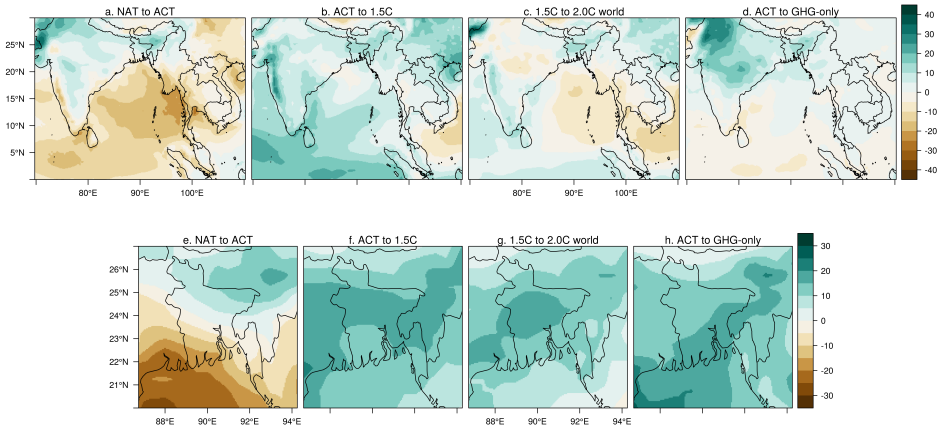

Fig. 3. AC 2c: Percentage change (PC) in the MAM seasonal mean rainfall between different forcing scenarios.

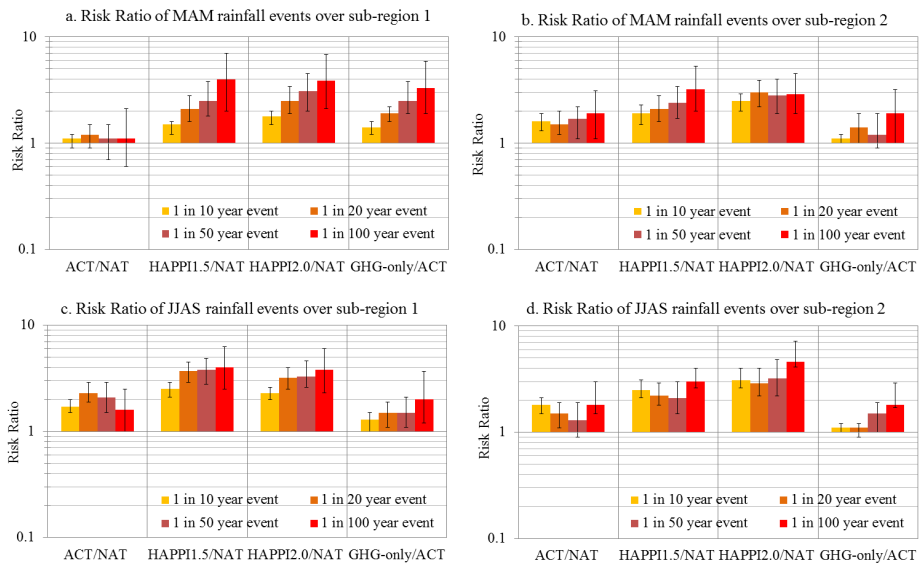

Fig. 4. AC2 d: The risk ratios of four specific rainfall events with return periods of 10, 20, 50, and 100 years between ACT/NAT, HAPPI 1.5/NAT, HAPPI 2.0/NAT and GHG-only /ACT.

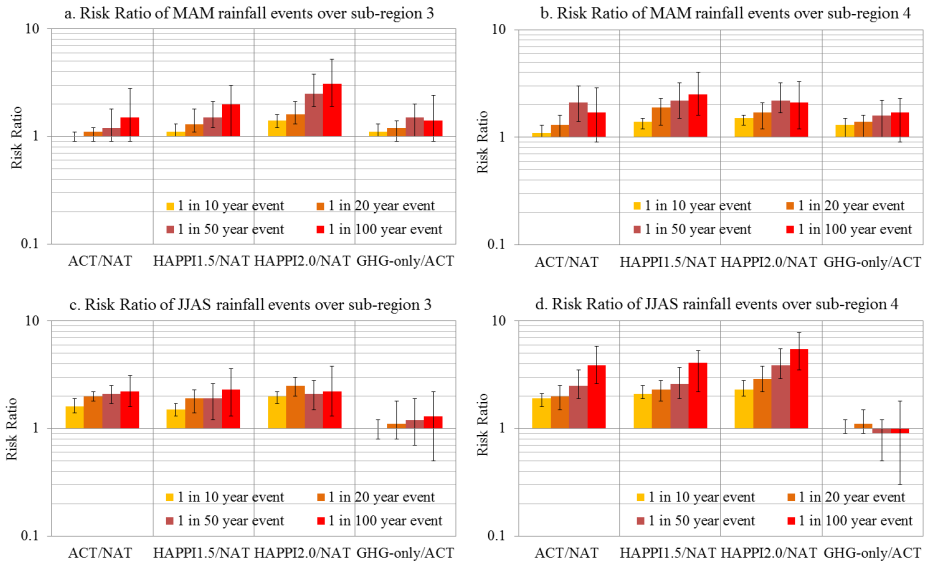

Fig. 5. AC2 e: The risk ratios of four specific rainfall events with return periods of 10, 20, 50, and 100 years between ACT/NAT, HAPPI 1.5/NAT, HAPPI 2.0/NAT and GHG-only /ACT.