

## Responses to the comments of Reviewer 1

We are very thankful to anonymous Reviewer 1 for his or her time to review the article and provide valuable comments. We will address these in the revised manuscript and accordingly our responses to each comment are given below. We mark our replies in blue font, while original reviewer comments are presented in black font.

### General comments

Some parts of the manuscript require a revision to avoid repetitive ideas and improve discourse flow, as some parts of the text are rather disconnected.

Response: We will address any repetition issues in the revised version of the manuscript, as well as addressing the flow of the text.

In addition, the authors should explain better the rationale behind each of the analysis described in the manuscript.

Response: We will look to improve the rationale for each part of the analysis and make sure each part is fully justified.

Besides the structure of the manuscript, I missed a more detailed analysis of the meteorological situation leading to localised short-duration rainfall events, which are key for rapid rise floods according to the manuscript's conclusions. Have the authors considered which mesoscale or local-scale atmospheric factors contribute to these intense rainfall events? If not, are they aware of any study that analyses this aspect for the events considered here (or others of similar nature)?

Response: Localised short-duration rainfall in the region is particularly related to synoptic events such as monsoon depressions or (weaker) low-pressure systems passing from the Bay of Bengal and tending northwards across the coast. These systems are also affected by the position and strength of the monsoon trough. We have provided a short description in Section 2.2 of the movement of the monsoon trough and the role of depressions or low-pressure systems embedded within:

“Monsoon heavy rainfall in the Brahmaputra basin is associated with the movement of the eastern end of the monsoon trough to the Assam region, producing break

monsoon conditions over central India and active conditions around the Himalayan foothills (Fig. S2), often with a monsoon depression originating from the Bay of Bengal, which recurves northwards over the Brahmaputra basin i.e. Bangladesh and Assam (Dhar and Nandargi, 2003; Dhar and Nandargi, 2000; Nandargi and Dhar, 2011).”

The trough itself undergoes control by at the larger scale by the boreal summer intraseasonal oscillation (BSISO), e.g., implied by the northward movement of the trough towards the Himalayan foothills during (Indian) monsoon breaks in Krishnamurthy and Shukla (2007). We have already undertaken an analysis of the influence of BSISO events on the short-duration rainfall events which lead to flooding in 5.1.1, not finding any clear link. However, we have not undertaken any direct analysis of mesoscale features, and note from the literature that such an analysis would only likely represent such features in high resolution models e.g. Vellore et al. (2014).

In the revised version of the manuscript we will also add a short section to the discussion to consider other studies that have looked at mesoscale features, for example, noting that the interaction of orography with mesoscale features such as southward-intruding mid-latitude westerly troughs on the subtropical westerly Jetstream that can increase precipitation totals over the Brahmaputra basin (Vellore et al., 2014).

Moreover, it gives the impression that the 33-year data is not fully exploited. Some of the analyses shown in the manuscript could be extended to other years to better highlight the differences between the selected years, when exceptional floods occurred, and the rest. This is only done for some drivers, but not for all, which can be confusing for readers.

Response: While the figures in the paper largely focus on the three distinct flood types, Table 2 is used to look at additional examples and counter examples from the full 33 year record. Nevertheless, we agree that this approach could be better described, and so we will include some introductory paragraphs at the start of Section 4 to address this and justify the approach taken.

## Specific comments

**Abstract (L26-27):** Does the last sentence refer to the drivers analysed in this study or to sedimentation and morphological changes? If it is the latter, I suggest removing this sentence, as this aspect is not investigated in this study nor anything related to climate change. In this case, I would replace this sentence by a new one that summarises the main conclusions of the manuscript.

Response: We have removed the reference to Climate Change, but don't see an issue with the comment on geomorphological changes. We show that the recent high water levels are not also observed in the discharge measurements. This means that geomorphological changes are influencing the water level, not hydrometeorological factors, and therefore addressing this is of critical importance for flood forecasting and early warning.

**Introduction:** I recommend modifying its structure. I think it would be more appropriate to start with more general aspects of flooding in the area before introducing the details regarding the most devastating cases. In addition, the whole section should be carefully revised to avoid repetitive ideas (e.g., L37-38 and L46-47) and provide a coherent text that focuses on the most relevant aspects that will be discussed in the following sections.

Response: We will revise the introduction accordingly, avoiding repetition while maintaining a logical order.

**L36:** I suggest moving Fig. S1 to the main manuscript.

Response: We will move S1 into the main manuscript.

**L59-61:** Why are these factors chosen?

“we analyse antecedent conditions (Blöschl et al., 2013; Carter and Steinschneider, 2018; Schröter et al., 2015), large-scale atmospheric and ocean anomalies (Paeth et al., 2011) and extreme statistics of precipitation and river flow (Schröter et al., 2015).”

Response: These papers that focus on different factors of flood drivers studies are relevant to the Brahmaputra flooding, because antecedent conditions, large-scale atmospheric and ocean anomalies influence on flood characteristics such as extremeness of floods. We will include this justification in our revised paper.

**L62:** Why are these cases analysed in more detail?

Response: Floods with different characteristics have different impacts, and therefore different implications for early warning and other flood management. As such it is important to understand the drivers of these different characteristic flood events to produce better forecasts of these impacts. We will add this justification to line 62.

**Section 3:** The beginning of this section is too abrupt. I suggest adding an introductory sentence indicating the value of each data source for this study.

Response: Thank you, we will add a short introductory sentence:

“This study for a transboundary river makes use of historical observed data available for inside Bangladesh, but for the wider river basin where datasets are not readily available the study is supplemented with alternative data sources such as reanalyses products. Details of each dataset are described in the following sections.”

**L212:** Please, add a map illustrating the Niño 3.4 region or provide some geographical references or the area.

Response: We are reluctant to add an additional figure because of the number we have already, but we will add the following which would enable replicability for any future studies:

We use monthly SST anomaly based on the monthly Extended Reconstructed Sea Surface Temperature (Huang et al., 2017) for the Niño-3.4 region (5° N to 5° S, 170° W to 120° W) available from NOAA (2020) for the period 1987–2019.

**L236-243:** The current wording of this part of the manuscript is confusing. Please, clarify what is intended to be said.

Response: We have shortened the statement in more understandable way as given below:

“Intraseasonal variation of the monsoon wet and dry spells varies with a typical lifespan of around two weeks (Krishnamurthy and Shukla, 2007). There are two distinct modes of tropical ISOs that have been linked to this intra-seasonal variability. The first, the Madden-Julian Oscillation (MJO) is an eastward-propagating mode along the equator, whereas the second, the boreal summer intraseasonal oscillation (BSISO), also gives northward-propagating bands of convection, therefore leading to variability extending into off-equatorial monsoon regions such as South Asia (Kikuchi et al., 2012; Lee et al., 2013). While the MJO has less influence at South Asian longitudes in boreal summer, it dominates from December to April (Kikuchi et al., 2012) and hence is not considered an important driver for Brahmaputra floods, which occur between June and September.”

**L250:** I propose including other years in the supplement.

Response: We will include the phase-space diagram for the BSISO during the monsoon season in other years between 1987 to 2019 in the supplementary material.

**Section 5.1:** Can mesoscale or local-scale mechanisms be analysed? (see general comments)

Response: We have responded in the general comments, above.

**Fig. 4b:** I suggest including mean JJAS rainfall for each year in this panel.

Response: We will add JJAS rainfall for each year here.

**L356:** Please, define "sweet spot".

Response: “Sweet-spot” is an informal term that has emerged from the sporting world, whereby it defines the point or area on a bat, club or racquet where it makes the most effective contact with the ball. It is now used frequently to refer to the point, location or set of conditions that would give the most effective outcome. We have checked with

colleagues that the term is translatable into Bangla, but we will adjust the sentence to be clearer:

“forming a hydrological “sweet spot” (a location where rainfall can have a more pronounced influence on river levels)”

**Section 5.1.3:** Please, add a brief introductory sentence.

Response: We will add an introductory sentence as follows:

“Next, we analysed monthly rainfall anomalies between June to September for the three flood years to understand deviations from average conditions.”

**L451:** The authors should mention some of these "other drivers".

Response: Thanks, we will add further clarification:

“In addition, the recorded high-water level in 2019 is not matched by a record in the river flow, which suggests that other non-hydrometeorological drivers such as changes to the channel morphology are also important.”

**L483:** The relevance of these "short-duration rainfall events" motivates an analysis of them (see general comments).

Response: We will refer back to the additional information we will add to section 5.1.2 here (see response to general comments).

**Section 5.2.3:** Please, add an introductory sentence indicating why is soil moisture relevant.

Response: We will add an introductory sentence as follows:

“Analysing soil moisture provides an indication of the importance of antecedent conditions as a driver of floods, as also addressed by Bloschl et al. (2013).”

**L488:** Can the data confirm that "basin-wide and frequent rainfall events maintained soil moisture" and thus, avoid saying "it is likely"?

Response: Our results confirm this statement, therefore we remove "likely."

**Section 5.2.4:** Again, add some introduction to this section.

Response: We will add introductory sentences as follows:

"Peak water level and discharge are two important variables needed to study annual flood characteristics. We investigated the trend and extremes of the annual peak in water level and river flow.

**L529:** I suggest including these values in a table.

Response: We will include these in Table 2.

**L534:** I recommend adding Fig. S6 to Fig. 10.

Response: We will add this in the revised version.

**L537-538:** The authors should give some recommendations to perform this task.

"lower than the one in 1998, despite higher water levels. The trend analysis of annual maximum water levels shows a positive trend at the 0.05 significance level (Fig. 10b). On the other hand, the trend in annual maximum discharge is not significant at the 0.05 significance level. Forecasting exceeding annual peak water level can provide valuable information to flood managers to take appropriate action to prevent overtopping embankments of the river."

Response: We will change the final sentence in this paragraph as follows:

"An upward trend in water levels, but not discharge, suggests that geomorphological rather than hydrometeorological changes also have a role in flood risk. To provide skilful forecasts of flooding, the Bangladesh Flood Forecasting and Warning Centre should make sure that the bathymetry information that is incorporated within the forecasting model is regularly updated."

**L563-565:** I suggest moving this sentence to the beginning of the subsection. This kind of sentences can be used as introduction for other subsections (see previous comments).

Response: Thanks, we will do this, and make similar changes to other subsections.

**L586-588:** Please, move this sentence to the beginning of the subsection.

Response: Thanks, Lines 586-588 have been moved to the beginning, with the main channel while the Teesta did not flow above danger level (Fig. 12).

**Section 6:** As it is currently written this section is more like a summary than a discussion. In addition, the two subsections include various repetitive ideas. I suggest summarising the whole section in order to succinctly provide the most important take-home messages for readers.

Response: The Discussion summarises a detailed results section into the findings that are most significant for each of the research objectives. We are happy to merge this with the conclusions into a single 'Discussion and Conclusions' section and revise the combined new section to avoid repetition.

**L671-672:** The selected cases fall in different categories. This classification should be better explained to avoid confusion.

Response: We have changed this and the previous sentence to provide a clearer explanation:

“We structure this discussion by focussing on the top decile (tenth) of events for each flood type as well as considering possible counter examples (see Table 2). The top decile flood events by duration were in 1998, 1988 and 2017; by rate of rise were in 2017, 2019 and 1988; and by water level were in 2019, 2017 and 2016.”



**L674 onwards:** Strong La Niña seems to be a necessary but not sufficient condition for long duration floods. This idea should be emphasised.

Response: We will change this sentence to:

“However, a strong La Niña developing year may be a necessary but not sufficient condition for long duration floods; as an example, 2007 was not in the top decile by duration of flood.”

**L686-688:** Accurate forecast of heavy rainfall is extremely challenging for small scales and long lead times. The authors should clarify the spatial and temporal scales of interest and include some references indicating the feasibility of this proposal and/or its associated challenges.

Response : We will add:

“This would require skilful forecasts of 3-day rainfall totals across areas smaller than 150 km x 150 km, but even forecasts for rainfall accumulations 1 day ahead provide poor representation of the spatial pattern of intense rainfall e.g. Hasan and Islam (2018).”

**Table 2:** I recommend moving this table to the supplement.

Response: Table 2 provides an important summary of all the analysis undertaken in the paper and is referred to several times in the text, so we believe it should be kept in the main text. We note that Reviewer 2 does not provide the same recommendation.

**Section 6.2:** Climate change and disaster management perspectives: Since climate change is not considered in this study, I suggest moving this part to the conclusions as a subject to be considered for future work.

Response: We think this recommendation will be covered by the merger of the Discussions and Conclusions and associated revisions.

**L737-738:** The simultaneity of the two factors seems crucial for the development of long duration floods. This idea should be highlighted in the discussion, rather than focusing only on strong La Niña.

Response: Lines 677-682 in the Discussion already highlight this, but we will add that La Nina also influences flows in the Ganges basin (Pervez et al., 2015).

**L746-747:** All climate change discussions should be moved here (see previous comment).

Response: This recommendation will also be covered by the merger of the Discussions and Conclusions and associated revisions.

### **Technical corrections**

**L45:** Fig. 3 is cited before Fig. 2 (L115).

Response: We will adjust the ordering and make sure that figures are referenced and numbered in the order that they appear.

**L56:** I suggest "(e.g. 2017 floods). Indeed, the Bangladesh Flood Forecasting and warning Centre (FFWC) is keen to improve early warnings for these events".

Response: We will include 2007 instead of "Indeed, the Bangladesh Flood Forecasting and warning Centre (FFWC) is keen to improve early warnings for these events "

**Caption Fig. 3:** Consider a slight modification of the caption, for instance: "Dates on which water level (WL) exceeded the danger level at the Bahadurabad station on the Brahmaputra river (see Fig. 1b for location of the gauge) indicated by a coloured dot. The colour represents WL value as indicated in the legend". Please, also indicate the threshold for severe flooding.

Response: We agree with this caption change and will use it. The severe flood threshold will also be added to the caption (20.5 m water level).

**L210:** El Niño (La Niña) -> El Niño (La Niña).

Response: We will adjust the accenting as indicated.

**L215:** Please, define IPRC/SOEST.

Response: We will define IPRC/SOEST as follows:

“International Pacific Research Centre (IPRC) of School of Ocean and Earth Science and Technology (IPRC/SOEST), University of Hawaii.”

## References

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