Reply to review comments Referee #2

We would like to thank the reviewer for her/his extensive review of our manuscript in the HESS-category 'Cutting-edge case studies' and the sound topics brought forward. To a certain extent we agree with the statement that the study area is not as data scarce as presented. In this reply we explain why actual data scarcity still was a serious issue for us in this study. It even set limitations for the bias correction approaches that could be selected. Here we also want to emphasize that as hydrologists we are forced to use the data that have been provided in a project, that are available for a reasonable price or ideally datasets that are open source. See also our comments to the remark where the use of the Indian Meteorological Department (IMD) dataset is mentioned for the first time (page 2). In the following sections we reply (in italics) to all of the reviewers comments (cited):

General comments

"In this paper, the authors perform a climate change analysis for the Brahmani-Baitarani river basin in India. For this purpose, the authors use three GCMs. Further, because of absence of reliable long historic meteorological data in the study area, they use two easy to implement bias correction approaches. The authors conclude that in general the south west monsoon rainfall, number of wet days and number of days with heavy rain are projected to increase over the study area. However, the authors also state that the APHRODITE dataset which is considered as the observed meteorological dataset underestimates the number of "heavy rain" events when compared to observed data of Central Water Commission (CWC) rain gauge stations and that this will affect the reliability of future climate change projections for precipitation."

> *Indeed our analysis indicated that the heavy rain events are underestimated by the APHRODITE dataset. For the estimation of future changes the Delta Change (DC) and Linear Scaling (LS) methods have been applied to the same slightly biased dataset – we agree that it is therefore likely that the absolute quantification of heavy rain events will also be biased in the future projections. Yet, the relative changes are expected to be of the same order of magnitude.*
>
> *To check this we applied the DC-multipliers of the three GCMs for 2045s and 2085s to the CWC station observations and compared the relative changes. The statistics of mean seasonal rainfall, number of wet days (WD), and the number of days with light and moderate rain (LRD, MRD) in general show a similar direction and order of magnitude. The change statistics of the number of days with heavy rain (HRD) show no clear direction.*

"The topic is very relevant and such a study is especially useful for developing countries like India where data availability is always scarce. However, the current version of the manuscript neither makes any contribution in terms of the use of advanced state-of-art techniques nor does it provide any new insight for the study area. Therefore, in my opinion, the manuscript in its present state does not make a significant contribution to justify its publication. I therefore would suggest a couple of major revisions to improve the manuscript."

> *We agree with the reviewer that we did not apply advanced state-of-the-art techniques for bias correction. The two-fold reason for that approach is discussed in the above reply. To the knowledge of the authors no dedicated study of the impacts of climate change on rainfall in the Brahmani-Baitarani River basin has been published in peer-reviewed international journals. The manuscript therefore provides additional insight for that specific region in India. This region is of special interest because it encompasses both coastal and mountainous areas that in this specific case show a mixed response to climate change. We will add the following sentence on the specific spatial focus of this study to the introduction:*
>
> > "This basin is interesting because it encompasses both coastal and mountainous areas that will likely show a mixed response to climate change" (P4L5).
>
> *Additionally, as a cutting-edge case study the manuscript shows what choices one has to deal with when carrying out this type of climate change assessment studies, e.g. when some data is just not available to the researchers.*

Most peer-reviewed papers on advanced down-scaling and bias-correction methods address the ideal situation where long historic observational records are available, yet in reality these data may not be present. As reviewer 1 suggested we have read the recent paper of Rajczak et al. (2015). We do appreciate the idea of spatially transferring bias-correction functions. However, Rajczak et al. already mention the limitations for spatial heterogeneous variables such as precipitation especially when the reference datasets are short. For the derivation of representative transfer functions the calibration is ideally based on long-term data records, this to include the natural variability sufficiently with anomalous wet and dry periods. Rajczak et al. (2015) suggest the use of a climatological representative period of at least 20 years. Within their study they show that by using only a limited number of years, for the calibration of a Quantile Mapping transfer function, large biases in absolute monthly precipitation amounts can be obtained.

This confirms the statements we made that an advanced method such as quantile mapping cannot be applied in our situation since we do not have rain gauge observed data and GCM data that overlap in time and the observational records only have a limited length. Differences in duration curves may as well occur due to trends in precipitation or incomplete inclusion of natural variability. We add the following comment to the manuscript (P8L3):

> "For the derivation of representative transfer functions for the Quantile Mapping approach the calibration is usually based on long-term data records, ideally more than 20 years, this to include the natural variability sufficiently with anomalous wet and dry periods (Rajczak et al., 2015). Using only a limited number of (overlapping) years, which would be the case if we use the CWC gauge data as reference, can result in large biases in absolute monthly rainfall amounts. When working with non-overlapping periods, an additional difference can be introduced by trends in rainfall time-series and according to Goswami et al. (2012) there has been an increasing trend in both frequency and intensity of heavy rain events over Central India of 10% per decade since 1950. Moreover the Quantile Mapping method requires reliable CDFs of reference rainfall and from the comparison between the APHRODITE dataset and station observations (Rana et al., 2014) we know that large biases in rainfall extremes exist indicating that the APHRODITE dataset cannot be used as reference for Quantile Mapping."

"The authors use APHRODITE data as the observed climatological rainfall dataset stating that it includes observations from over 2000 stations over India and captures the large scale features of monsoon rainfall over the Indian region well (Rajeevan and Bhate, 2008). In addition they also use observed rainfall dataset from three raingauge stations of CWC. However, for the study area, the authors could well have used a daily gridded rainfall dataset which is developed by the India Meteorological Department (IMD) (Pai et al., 2014). This is a high spatial resolution (0.25× 0.25 degree) dataset available for a long period (1901–2010) and has been developed using daily rainfall records from 6955 rain gauge stations all over India. Quite a few researchers have established that this IMD product is much more accurate than the APHRODITE dataset."

In the manuscript acknowledgements it is stated that we received funding from both the Asian Development Bank (ADB) and DFID/UKAid. The case study was carried out in cooperation with the Indian Central Water Commission (CWC) under the Technical Assistant program of the ADB. The reviewer refers to an IMD gridded data set which is indeed available. The development of that data set is discussed in Pai et al. (2014). Pai et al. (2014) describes the high spatial resolution (0.25° × 0.25°), daily gridded rainfall data set (1901-2010) as developed by IMD.
We considered using this dataset for the study. The data is not yet available free of any costs and the conditions of the Indian Meteorological Department to make this data available made it impossible for us to purchase it. IMD requests to sign for the following: "The data are meant exclusively for your own use and shall not be passed on to any other party or agency (Indian or Foreign) either in part or in full. If so needed, prior approval in writing will be taken from the

India Meteorological Department for the same. The data shall not be used for any commercial purpose or to earn consultancy fees, honoraria etc." *Because this case study was carried out as part of a consultancy-based TA-project for the ADB it was impossible for us to purchase the IMD gridded data. Our local Indian consortium partner tried as well but did not succeed. This indeed had implications for the analysis, but was beyond the researchers' control. This is the very reason why we mentioned in our manuscript that* 'data and model availability can be limited […] because political data sensitivity hampers open sharing' *(P2L9-11).*

This leaves us to check whether there is information available on the performance of APHRODITE in comparison to the IMD data set. Pai et al. (2014) compared the gridded IMD data set (i.e. IMD4) with other previous IMD gridded data sets and the APHRODITE data set. The comparison suggests that "the climatological and variability features of rainfall over India derived from IMD4 were comparable with the existing gridded daily rainfall data sets." The all mean annual rainfall and SW Monsoon rainfall in IMD4 was found approx. 13% and 11% respectively wetter than in APHRODITE, with a 0.95 correlation coefficient for both assessments. We include the following:

"Additionally, and similar to the findings when comparing CWC gauge rainfall to APHRODITE, Pai et al. (2014) concluded IMD4 to be approximately 13% and 11% wetter in mean annual rainfall and SW monsoon rainfall than the APHRODITE gridded rainfall." (P12: Section 3.1)

Prakash et al. (2014) have shown that APHRODITE and GPCC performed best among four gridded rain gauge-based land-only rainfall products which all are open available (CPC, CRU, GPCC, and APHRODITE) when compared with IMD generated gridded rainfall data. Hence, the gridded APHRODITE rainfall data set was the best open available data set to us.

We add a comment to the manuscript on the availability of the IMD gridded data set and the findings of Prakash et al. (2014) to the introduction.

"The Indian Meteorological Department has developed a daily gridded rainfall data set (1901-2010) in high spatial resolution of 0.25° × 0.25° (Pai et al., 2014). This would have been the ideal dataset for the analyses in this study as it contains data from 6955 gauges over India and covers the period 1901-2100. Yet, due to restrictive conditions set by IMD this data set could not be purchased and applied in this study. We therefore used the APHRODITE dataset. Pai et al. (2014) showed the comparability of the APHRODITE data set regarding the climatological and rainfall variability over all India. Prakash et al. (2014) listed APHRODITE together with Global Precipitation Climatology Center (GPCC) product as the best performing among 4 rain gauge-based land-only rainfall data sets when compared to the IMD gridded data set." (P4L13)

"In addition, station rainfall data for the study area is also available from IMD. There are quite a few raingauge stations in the study area (in addition to the three raingauge stations of CWC) for which daily rainfall data for 25 to 30 years are available from IMD. The authors may consider using these datasets. Thus, the study area is not as data scarce as has been made out to be by the authors. "

We agree with the reviewer that these raingauge stations exist. During the study we asked IMD to provide this dataset. IMD provided us a quote for an average of 100 USD/year/raingauge. With e.g 10 raingauges and 30 year of data that would have cost ~30KUS$. Unfortunately, limited available financial resources did not allow purchasing the datasets that we as hydrologists would have wanted to use. We acknowledge the fact that we should mention the data availability - meaning not the actual data presence but rather the possibility to use the data within the project - better in our manuscript. Unfortunately, this is reality in many projects

We add a comment to the manuscript on the availability of the IMD raingauge data in the method section.

"Several IMD rainfall gauges are present in the study area. However this data was not made available to this study."

"However, given this situation, authors have a very good scope of improving their manuscript by considering different data availability scenarios. For example the authors may consider (i) availability of only IMD station raingauge dataset, (ii) only IMD gridded rainfall dataset (iii) only APHRODITE dataset (as they have done in the present manuscript) etc. This way the authors can test which advanced bias correction technique works best under different data availability scenarios. This would be a good contribution for data scarce developing countries. "

We fully agree with the reviewer that when the IMD data would have been available to us this would have been a sound alternative scope for our manuscript. If the IMD gridded rainfall or raingauge data had been available to us, of course we would have used that data. Unfortunately, as this data was not available to us during the TA-project we cannot follow-up on the sound suggestion of the reviewer. The comment of the reviewer is exactly one of the main messages we wanted to address, how to deal with these kind of practical issues one will face during climate change assessments.

"Pai, D.S., Sridhar, L., Rajeevan, M., Sreejith, O.P., Satbhai, N.S., Mukhopadhyay, B., 2014. Development of a new high spatial resolution (0.25× 0.25) long period (1901– 2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. Mausam 65, 1–18. (ii)"

We appreciate sharing this reference and we include it in the manuscript.

"In general, the authors presented an increase/decrease or underestimation/overestimation in a given statistic. The authors should have also done checks on whether the increase/decrease or underestimation /overestimation is statistically significant."

We agree with the reviewer and have carried out t-Tests (one-tailed distribution, two-sample unequal variance for a significance level of ρ =0.05*) for each of the statistics. We add the following comments to the manuscript:*

"In general, all changes in mean monsoon rainfall derived with HadGEM2-ES and MIROC-ESM are significant (ρ =0.05 level). GFDL-CM3 shows this significance only for the changes at the end of the century (2085s). For the mountainous region changes in pre-monsoon mean rainfall are also significant at ρ=0.05 level for the long term climate projection." (Section 3.3.1 Mean seasonal rainfall)

"The changes in WD during monsoon due to climate change are significant (ρ =0.05 level) for HadGEM2-ES and MIROC-ESM, except for the DC method in the Delta region in the latter GCM. GFDL-CM3 shows a more divers pattern with only significant changes of WD in the monsoon period for the long term climate projection (2085s)." (Section 3.3.2 Number of wet days)

"There is a strong indication for the impact of climate change during monsoon on LRD, MRD, and HRD in both regions at ρ =0.05 significance level. (Section 3.3.3 Light, moderate and heavy rains)

"Also, the conclusions of the study (i.e. projected increase of SW monsoon rainfall, number of wet days and number of days with heavy rain over the study area) are more or less in line with what has been stated by previous researchers for the study area or the eastern region of India. So I do not see any new contribution here. But the reasons for such changes should be investigated and this could be a meaningful contribution."

We appreciate the reviewer for noticing the potential of our Cutting-edge case study manuscript and mentioning it as a meaningful contribution. We would like to refer to the statement made earlier that the authors are not aware of studies on climate change impact on rainfall for the Brahmani-Baitarani River basin published in peer-reviewed international journals using the CMIP5 GCM experiments.

We agree with the reviewer that many studies on climate change in India have been published, and some of them even focussing on the Brahmani River basin or the Baitarani River basin. Gosain et al. (2006) describe in Current Science a climate change impact analysis on hydrology of Indian river basins including the Brahmani River basin. A single transient climate experiment (HadRM2) has been applied. No detailed results on the Brahmani River basin are described. Islam et al. (2012) published in Water Resources Management the results of a study of streamflow response to climate change in the Brahmani River basin by a temperature and rainfall sensitivity analysis. No GCM experiments have been used. Mitra and Mishra (2014) published in the Journal of Indian Water Resources Society a hydrological impact assessment of the Baitarani River basin based on climate change sensitivity by changing the daily rainfall with ±5, 10, 15, and 20%. No GCM experiments have been used. Based on the above we conclude that for the Brahmani-Baitarani River basin this climate change assessment using data from three GCM's and considering bias-correction provides new insights. And we do believe that the manuscript is especially relevant for climate change studies focusing on change in rainfall under similar data limited conditions that occur in many parts of the world.

"Some of the important citations like Chaturvedi et al., 2012; Thrasher et al., 2012; Rana et al., 2014 are missing in the reference list."

Due to this omission in the reference list, we checked the list thoroughly. The references to Chaturvedi et al. (2012); Thrasher et al. (2012), and Rana et al. (2014) will be added to the reference list. Additionally, we found 4 references in the list not mentioned in the main text: Guhathakurta (2007), Mitchell and Jones (2005), Mitra and Mishra (2014), and Patwardhan et al (2014). We exclude these references from the final reference list.