Reference Number: hess-2014-156

RESPONSE TO THE FIRST REVIEWER'S COMMENTS

We are grateful to Reviewer #1 for his/her helpful and insightful comments. The provided comments have contributed substantially to improving the manuscript. Accordingly, we have made significant efforts to revise the manuscript, with the details being explained as follows.

Point #1

COMMENT: *The paper is well organised but the writing need to be improved substantially (English editing) for publication in HESS.*

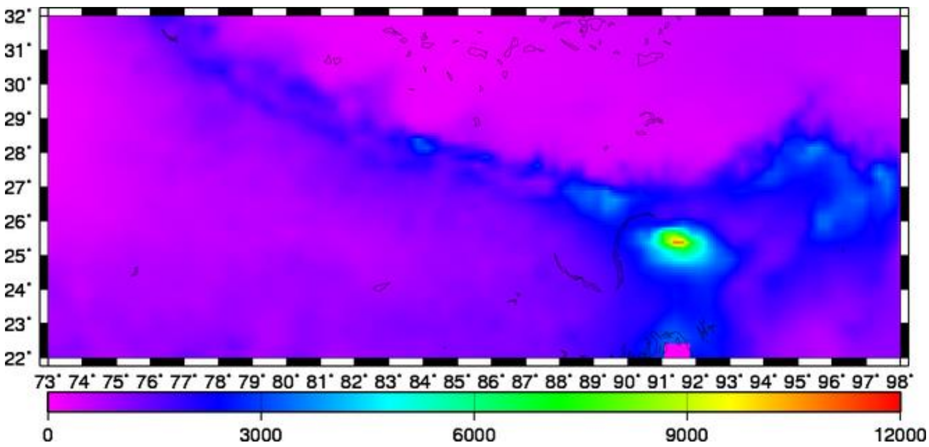
RESPONSE: We are grateful to the Reviewer for his/her concerns. Accordingly, we have revised text to improve writing quality.

Point #2

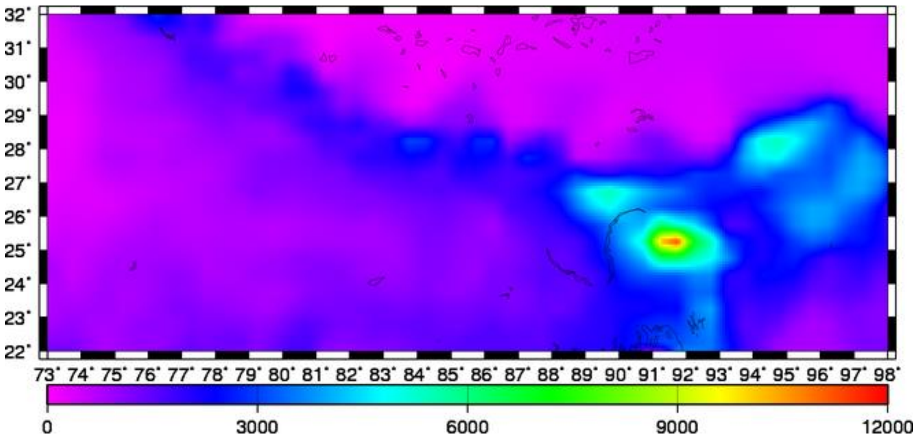
COMMENT: *The authors have used WFD forcing data when there are a number of publications which show that the APHRODITE reanalysis data is the best available climate data for this region.*

RESPONSE: Thanks for the comments. We do agree with the Reviewer that the APHRODITE precipitation dataset is the best available dataset. However, the required climate forcing data for running H08 include seven metrological variables: precipitation, specific humidity, air temperature, surface pressure, wind speed, downward shortwave radiation and downward long-wave radiation. The WFD dataset provides all of these seven forcing variables, but the APHRODITE only provides precipitation and temperature. Following the Reviewer's comments, we have re-simulated H08 by using the APHRODITE precipitation and temperature data. We found the simulation using APHRODITE precipitation and temperature data does not give better simulation results than the simulation using WFD.

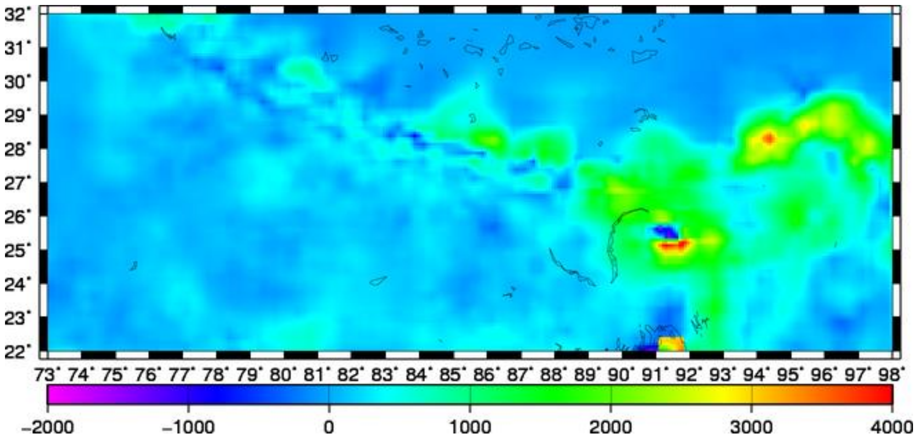
Spatial distribution of annual (1988) precipitation of the WFD and the APHRODITE over entire GBM basin and difference between two data are shown below:



APHRODITE (mm year^{-1})



WFD (mm year^{-1})

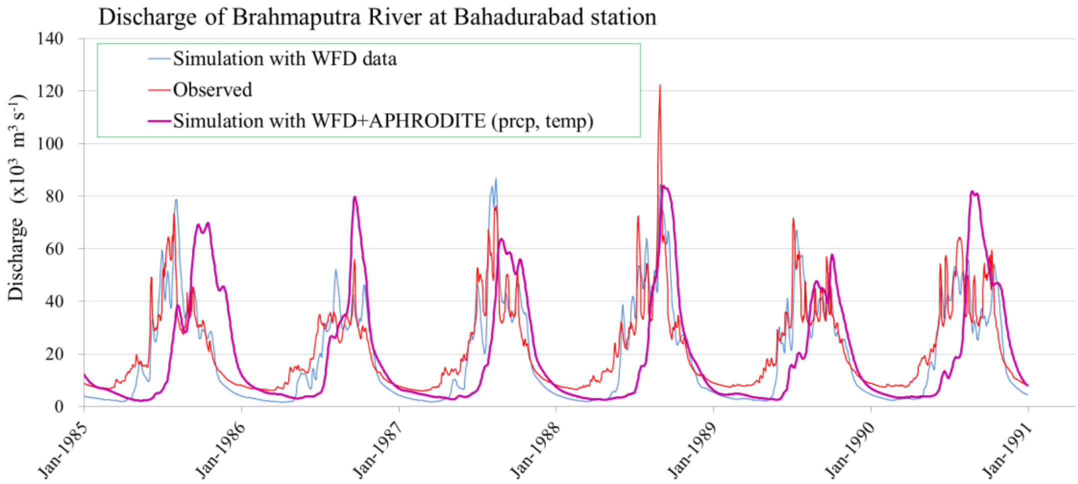


WFD - APHRODITE (mm year^{-1})

Result obtained from two different simulations (1988) using the APHRODITE and the WFD precipitation data (unit: mm $year^{-1}$)

		Rainfall	Snowfall	Total runoff	ET
APHRODITE	Entire GBM	1 171	27	664	524
	Brahmaputra	1 252	9	852	424
	Ganges	959	27	442	537
WFD	Entire GBM	1 555	27	1 034	538
	Brahmaputra	1 819	16	1 430	426
	Ganges	1 178	18	627	565

Time series plot of simulated discharge using both (i) complete dataset from the WFD and (ii) combination of precipitation and temperature data from the APHRODITE dataset and other metrological variables from the WFD is shown below:



Point #3

COMMENT: *I have a major issue with the way the authors have used bias correction for the GCM rainfall. The authors state that the GCM does okay for pre and post monsoon as well as for the drier winter months but it underestimates the monsoon high rainfall. The bias (underestimation) when compared to WFD rainfall is due to this underestimation by MRI for monsoon high rainfall events. But the authors apply an annual scaling factor (multiplier) which will push up all the rainfall throughout the year by a small amount instead of only the monsoon high events. This will lead to underestimation of monsoon high rainfall and eventually high runoff events as evident from Figure 6 a and b. The authors should be adjusting (bias correcting) different rainfall amounts based on seasons differently to overcome this issue.*

RESPONSE: We fully agree with the Reviewer's comment. We much appreciate the Reviewer's suggestion. Accordingly, we have corrected the bias of GCM data based on the monthly scaling factor (multiplier) instead of using the previous annual scaling factor. We have revised all our modelling results accordingly. Also, we have revised the text in the Introduction as follows:

> In order to be consistent with the historical data, the monthly correction factor (i.e. the ratio between the basin-scale long-term monthly mean precipitation of the WFD data and that of the MRI data for each month) for each basin is applied to the MRI-AGCM3.2S precipitation forcing data.

And we have revised the last line of Section 2.4 as follows:

> Therefore, the bias of MRI-AGCM3.2S's precipitation dataset has been corrected by multiplying using monthly correction coefficient (ratio between basin averaged long term monthly mean precipitation from WFD and that from MRI for each month) for each GBM basins.

Figure 5 (former Figure 6) presents the hydrograph comparisons for both the calibration and validation period using the WFD forcing dataset. We have revised the caption of Figure 5 (former Figure 6) as follows:

> Figure 5. (a)-(c) Hydrographs (both calibration and validation period) (d) mean monthly (1980-2001) discharge at outlet of three basins using the WFD forcing dataset. Nash–Sutcliffe efficiency (NSE), percent bias (PBIAS), relative Root-Mean Square Error (RRMSE), correlation coefficient (cc) and coefficient of determination (R2) for both calibration and validation period are noted at each sub-plot.

Point #4

COMMENT: *Page 5756 top paragraph: Having worked in this region for a long time, I do not agree that the authors should be ignoring crop growth (as most of the area is under agriculture) and reservoir operations components of the HO8 model. This is a major shortcoming of this analysis. And later on in the paper when the model simulations are poor, the authors speculate that this is due to ignoring these components. They should be switching on the components and show whether they can explain the processes.*

RESPONSE: Thanks for the comments. We have improved our model simulation. Now we have found that our results agreed satisfactorily with observed data. However, we are not ignoring the crop growth process. The rationale here is to run the crop growth model (CGM) and reservoir model (ReM), we need to complete the land surface model (LSM) and river models (RiM) beforehand because the output of LSM and RiM becomes the input of CGM and ReM. In this paper, we are not neglecting the human activities, but we are now just first focusing on the natural part of the basin. Moreover, we have compared our simulation result with the results of Biemans et al. (2013) who explicitly considered crop production and water use in this basin. The following table shows comparison of mean discharge at Bahadurabad station, the outlet of Brahmaputra basin:

Mean discharge at Bahadurabad (outlet of Brahmaputra) (1986-1991) (m^3 s^{-1})			
Our simulation result	Global Runoff Data Centre (GRDC)	Observed (rating equation)	Biemas et al. (2013)
23 299	23 719	22 767	20 947

Biemans, H., Speelman, L. H., Ludwig, F., Moors, E. J., Wiltshire, A. J., Kumar, P., Gerten, D., and Kabat, P. (2013). Future water resources for food production in five South Asian river basins and potential for adaptation — A modeling study, Science of The Total Environment, 468–469, Supplement, S117-S131, http://dx.doi.org/10.1016/j.scitotenv.2013.05.092.

Point #5

COMMENT: *'Soil moisture is expressed as a single-layer bucket which is 15 cm deep for all soils and vegetation types'. This is surely not valid for this region.*

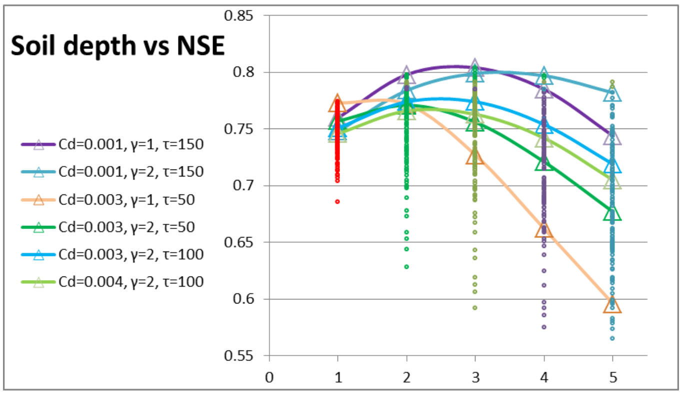
RESPONSE: Thanks for the comments. What we meant that our model assumes "a 15-cm deep single-layer bucket" is that the water holding capacity of soil is set to be 150 mm, which is the commonly specified value in the global land surface model simulations since the original pioneering work of the bucket model developed by Professor Manabe in 1969.

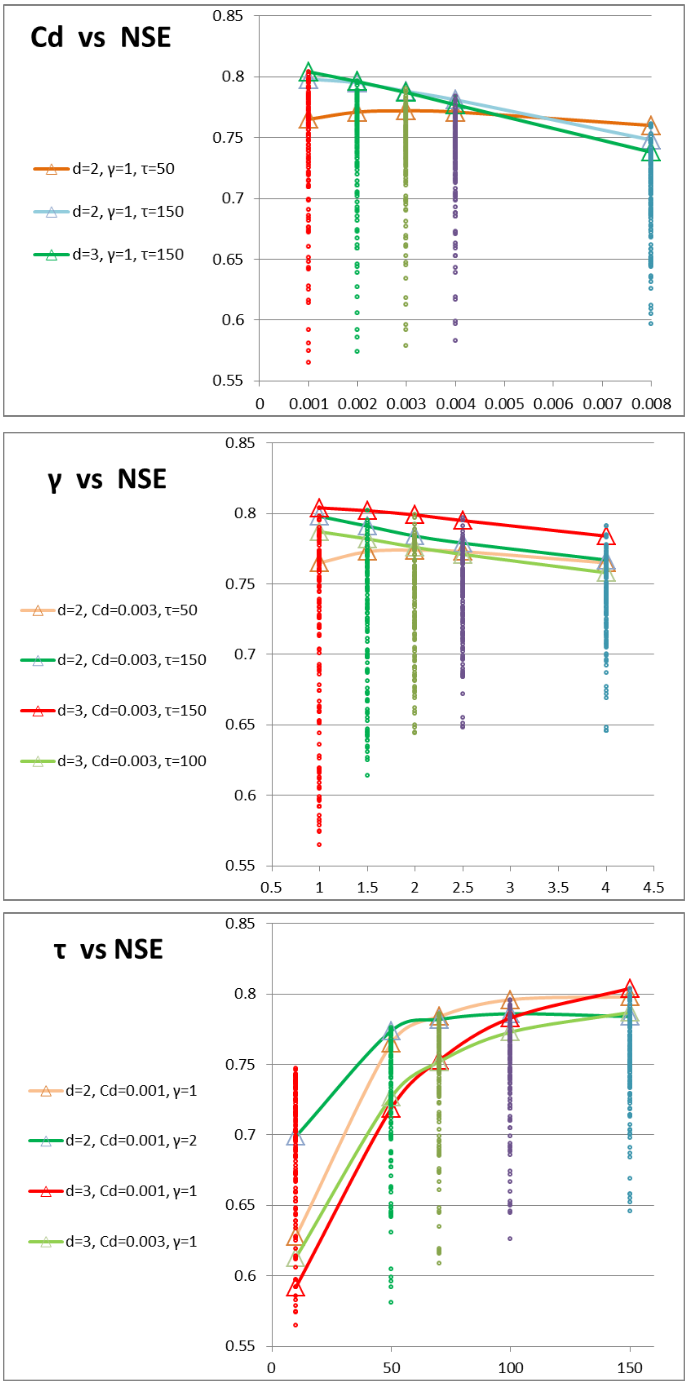
Point #6

COMMENT: *Section 3.1 Parameter sensitivity: The analysis the authors have undertaken is not really Monte Carlo as they are just sampling 5 random seeds for the entire parameter distribution. The five points picked can be all away from the optimum.*

RESPONSE: Thanks for the comments. Five parameter values were chosen for each calibration parameter within their respective feasible physical ranges, then in total 625 simulations were conducted considering the extensive combinations from these parameter spaces and based on that the optimal parameters were determined. We agree with the Reviewer that the method we used in this study is not the same as the Monte Carlo simulation since we did not consider/analyse the statistical distributions of either parameter values or the simulation results. Therefore, we revise the wording "the Monte Carlo simulation" into "the parameter-sampling simulation" throughout the entire manuscript.

As regarding the identification of optimal parameter values, the following plots of the evaluation of model simulations in terms of Nash–Sutcliffe efficiency (NSE) to each calibration parameter suggest that there is little possibility of escaping from the optimum, given the fact that all parameters must lie within their respective feasible ranges.





Point #7

COMMENT: *Discussion on page 5759'Figure 4 shows that: : :: : :unchanged'. I do not agree that we need to do any model simulations to find out what the authors are reporting here. Having used the model before, the model equations/formulation already tells you this and you don't need to do any model simulations.*

RESPONSE: Thanks for your comments. We agree with the Reviewer's instructions, and accordingly the Figure 4 as well as the related discussion in the text, have been totally removed in the revised manuscript.

Point #8

COMMENT: *Page 5761 - 3.2 Calibration and validation (bottom of this page 'This is likely : : :: : :..present model simulation'. This statement is factually incorrect as it is a well accepted fact that backwater effect is larger under low flow conditions than high flow conditions'.*

RESPONSE: Thanks for the comments. We do agree with the Reviewer's comments, so we have removed these sentences in the revised manuscript.

Point #9

COMMENT: *Page 5762 – 4.1 Seasonal cycle: 'Lower ET of Brahmaputra : : :..compared to other two basins'. Brahmaputra NDVI is 0.38, Ganges is 0.41 and Meghna is 0.65. The physical/hydrological explanation for the results provided by the authors is incorrect as Brahmaputra and Ganges have very close NDVI (0.38 and 0.41).*

RESPONSE: Thanks for the comments. However, the magnitude of ET depends on several other factors than NDVI. Lower ET values in the Brahmaputra basin is likely due to its cooler air temperature (Ganges: 21.7°C vs. Brahmaputra: 9.1°C) and higher elevation than that in the Ganges though these two basins have very similar NDVI. We have revised the sentences in Section 4.1 as follows:

> Lower ET of the Brahmaputra is likely due to its cooler air temperature, higher elevation and less vegetated area. The basin-averaged Normalized Difference Vegetation Index (NDVI) of the Brahmaputra is 0.38, whereas for the Ganges and Meghna, NDVI are 0.41 and 0.65, respectively (NEO, 2014).

Point #10

COMMENT: *Page 5768 – 4.5 Uncertanity in projection due to model parameter (towards the bottom of this page 'Therefore, uncertainty of future: : :: : :..). the authors are missing some key references here which sheds light on parameter usability under climate change or variable* *climate conditions. Coron, L., Andréassian, V., Perrin, C., Lerat, J., Vaze, J., Bourqui, M., Hendrickx, F. 2012. Crash testing hydrological models in contrasted climate conditions: an experiment on 216 Australian catchments, Water Resour. Res., 48, 5, doi:10.1029/2011WR011721. Vaze, J., Post, D. A., Chiew, F. H. S., Perraud, J.-M., Viney, N., Teng, J., 2010. Climate nonstationarity - Validity of calibrated rainfall-runoff models for use in climate change studies. Journal of Hydrology, Volume 394, pp. 447–457, doi:10.1016/j.jhydrol.2010.09.018.*

RESPONSE: We are grateful to the Reviewer for his/her concerns. Thanks to the Reviewer for referring these two important articles. We have referred these studies and revised text in Sec. 4.5 as follows:

> Therefore, uncertainty of future projection due to model parameter cannot be neglected (Vaze et al., 2010; Merz et al., 2011; Coron et al., 2012), which is mostly ignored in the climate change impact studies (Lespinas et al., 2014). Result obtained by Vaze et al. (2010) indicates that the model parameter can generally be used for climate impact studies when model is calibrated using more than 20 years of data and where the future mean annual rainfall is not more than 15% drier or 20% wetter than the mean annual rainfall in the model calibration period. However, Coron et al. (2012) found significant level of errors in simulations due to this uncertainty and suggested further research to improve methods to diagnose parameter transferability under a changing climate.

Point #11 (i)

COMMENT: *Page 5769 i) toward the top– 'uncertanity band for runoff is low' this is partly because you are showing total runoff and not the components (surface and subsurface);*

RESPONSE: Thanks for your comments. We do agree with the Reviewer that the uncertainty band of the two (surface and sub-surface) runoff components is not necessarily narrow although the uncertainty of the total runoff is low. The two model parameters (τ and γ) have very sensitive impacts on the flow partitioning (as shown in the Fig. 3). However, in this study we focused on estimating the future change and the associated uncertainty of the total runoff ONLY, not attempted to address the uncertainty of the simulations of two runoff components since we do not have any baseflow data available to validate this runoff partitioning.

Point #11 (ii)

COMMENT: *ii) just below the above statement' from Fig 5 it is observed that: : :..' This statement is misleading as you are looking at the 10 simulations and all of them being similar to* *each other does not imply that uncertainty is low.*

RESPONSE: Thanks for the comments. We fully agree with the Reviewer. The uncertainty of runoff is low since we calibrated our model against the observed stream discharge and we chose the optimal 10 parameter sets to estimate the uncertainty, as mentioned in Section 4.5 (line 15, page 5769).

<u>Point #11 (iii)</u>

COMMENT: *The discussion on this whole page is speculative and misleading. You are comparing results from multiple realisations of the model and all of them giving similar answer only tell that the predicted/simulated variable is insensitive to the parameter value. The real value is when you compare the simulations to observations, either on-ground or secondary such as satellite ET and soil moisture data. Page 5786 Figure 6 – a). The figure shows that the model cannot reproduce peak flows well (this is due to the fact that the bias correction method you have used underestimates peak rainfall – see comment 3 above). The model cannot reproduce the peaks in the validation period as well. Page 5769 – 7th line from top 'Lower uncertainty: : :: : :: : :could be ignored'. Your calibrated model is not able to reproduce the peak flows in calibration and validation. What confidence do you have in the model simulations for the future climate conditions.*

RESPONSE: Thanks for the comments. According to the suggestion of Reviewer we have improved our model simulations as described in Section 3.2 and also shown in Figure 5 (the former Figure 6). In this study, we have attempted to estimate the uncertainty in projection due to non-stationary model parameter. It is very common in hydrologic modelling study that calibrated model parameters are assumed as stationary over the whole span of study period. Therefore, our hypothesis was "calibrated model parameter might not be stationary over time". In other words, best model parameter set obtained from calibration in current climate might not be represented as best set in future climate. Therefore, in our study we tried to compare uncertainty in projecting different hydrologic variables through model simulation with considering 10 optimal parameter set (assuming any one set among 10 set might be represented as best set in future) while most of previous studies considered a single best parameter set.

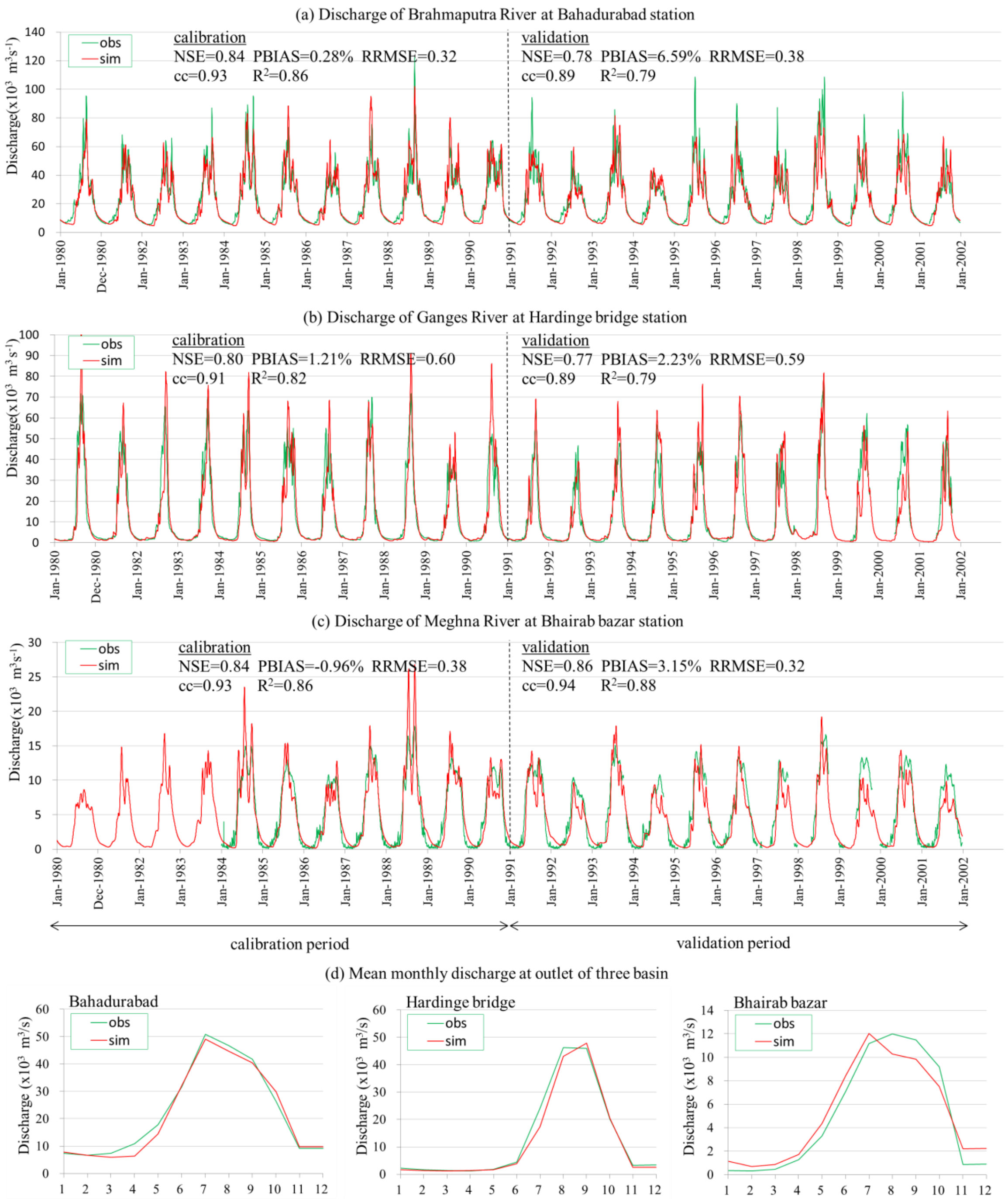


Figure 5. (a)-(c) Hydrographs (both calibration and validation period) (d) mean monthly (1980-2001) discharge at outlet of three basins using the WFD forcing dataset. Nash–Sutcliffe efficiency (NSE), percent bias (PBIAS), relative Root-Mean Square Error (RRMSE), correlation coefficient (cc) and coefficient of determination (R2) for both calibration and validation period are noted at each sub-plot.

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RESPONSE TO THE SECOND REVIEWER'S COMMENTS

We are grateful to Reviewer #2 for his/her helpful and insightful comments. The provided comments have contributed substantially to improving the manuscript. Accordingly, we have made significant efforts to revise the manuscript, with the details being explained as follows.

Specific comments

Point #1

COMMENT: *The length of time periods should correspond to the standard of 30 years applied in climate impact assessment.*

RESPONSE: Thanks for the comments. The MRI-AGCM3.2S data which we obtained from MRI to use in this study only contain three 25-year time-slice experiments: the present-day (1979–2003), near-future (2015-2039) and far-future (2075–2099) periods. After hearing Reviewer's comments back, we have asked for getting longer MRI-AGCM data, but unfortunately without success. Therefore, we have to stick to the analysis of three 25-year periods, and we do not think this will cause large differences comparing to the 30-year simulation analysis.

Point #2

COMMENT: *From the abstract should be clear, which climate scenarios were applied, before describing the final results.*

RESPONSE: We much appreciate the Reviewer's suggestion. Accordingly, we have updated the Abstract as follows:

> The impacts of climate change (considering SRES A1B scenario) not only on the runoff, but also on the basin-scale hydrology including evapotranspiration, soil moisture and net radiation have been assessed in this study through three time-slice experiments; present-day (1979–2003), near-future (2015-2039) and far-future (2075–2099) periods.

Point #3

COMMENT: *Abstract: "due to increased net radiation" and Section 4.4.6: why is the net radiation increasing? Please discuss.*

RESPONSE: Thanks for the comment. Accordingly, we have revised the Section 4.4.6 as follows:

> Figure 10g-i presents projected changes of net radiation. Net radiation is projected to be increased by more than 5% in the entire GBM basin by the end of the century. Due to increase of air temperature in future downward long-wave would be increased, which finally leads to increase of net radiation. However, in the far-future changes of net radiation are larger in dry season (Brahmaputra: 10%, Ganges: 7.8%, Meghna: 6.1%) than that in wet season (Brahmaputra: 3.6%, Ganges: 4.3%, Meghna: 4.7%). Due to projected air temperature increase in dry period is large, downward long-wave radiation would be large too, which results in larger increase of net radiation in dry period. In the near-future, changes of net radiation are quite low with 1.1% decrease in Meghna basin and almost constant through all seasons. Decrease of net radiation of Meghna in the near-future might be due to lower increase of air temperature (0.7°C) as well as decreased incoming solar radiation (not showed in figure) in this basin.

Point #4

COMMENT: *Please include a Table with main characteristics of 3 basins, like: average elevation and elevation range, average T, P, Q, major land use classes, soils, extent of water use (irrigation etc.). It would be helpful for analysis the results, e.g. in Section 4.1.*

RESPONSE: We much appreciate the Reviewer's suggestion. Accordingly, we have included the following new table (as the Table 1 in the revised manuscript) describing the major characteristics of the three GBM basins. As regarding the average temperature (T) and precipitation (P), they were already included in the Table 4 (former Table 2).

Table 1: Major characteristics of Ganges, Brahmaputra and Meghna river basin

Item	Brahmaputra	Ganges	Meghna
Origin and major properties [a]	The Brahmaputra River begins in the glaciers of the Himalayas and travels through China, Bhutan, and India before emptying into the Bay of Bengal in Bangladesh. It is	The Ganges River originates at the Gangotri glaciers in the Himalayas and it passes through Nepal, China, and India and empties into the Bay	The Meghna River is a comparatively smaller, rain-fed, and relatively flashier river that runs through a mountainous region

		snow-fed braided river and it remains a natural stream with no major hydraulic structures built along its reach.	of Bengal at Bangladesh. It is snowmelt-fed river regulated by upstream India.	in India before entering Bangladesh.
Basin area (km^2)		583 000[b] 530 000[f,g] 543 400[h]	907 000[b] 1 087 300[h] 1 000 000[c]	65 000[b] 82 000[h]
River length (km)		1 800[b] 2 900[f] 2 896[a]	2 000[b] 2 510[c] 2 500[a]	946[b]
Elevation (m a.s.l.)[e]	Range	8 ~ 7057	3 ~ 8454	-1 ~ 2579
	Average	3141	864	307
	Area below 500 m:	20%	72%	75%
	Area above 3000 m:	60%	11%	0%
Discharge ($m^3 s^{-1}$)	Station	Bahadurabad	Hardinge bridge	Bhairab bazar
	Lowest	3 430[d]	530[d]	2[d]
	Highest	102 535[d]	70 868[d]	19 900[d]
	Average	20 000[g]	11 300[d]	4 600[d]
Land use (% area)[i]	Agriculture	19%	68%	27%
	Forest	31%	11%	54%
Basin-averaged Normalized Difference Vegetation Index (NDVI)[j]		0.38	0.41	0.65
Total number of dams (both for hydropower and irrigation purpose)[k]		6	75	-

[a] Moffitt et al. (2011)

[b] Nishat and Faisal (2000)

[c] Abrams (2003)

[d] BWDB (2012)

[e] Estimated from SRTM DEM data by Lehner et al. (2006)

[f] Gain et al. (2011)

[g] Immerzeel (2008)

[h] FAO-AQUASTAT (2014)

[i] Estimated from Tateishi et al. (2014)

[j] Estimated from NEO (2014)

[k] Lehner et al. (2008)

Abrams, P. (2003). River Ganges. Retrieved 13 July 2014, from http://www.africanwater.org/ganges.htm

BWDB. (2012). Rivers of Bangladesh. Dhaka: Bangladesh Water Development Board.

FAO-AQUASTAT. (2014). Ganges-Brahmaputra-Meghna river basin Irrigation in Southern and Eastern Asia in figures –AQUASTAT Survey – 2011 (pp. 1).

Gain, A. K., Immerzeel, W. W., Sperna Weiland, F. C., & Bierkens, M. F. P. (2011). Impact of climate change on the stream flow of the lower Brahmaputra: trends in high and low flows based on discharge-weighted ensemble modelling. Hydrology and Earth System Sciences, 15(5), 1537-1545. doi: 10.5194/hess-15-1537-2011

Immerzeel, W. (2008). Historical trends and future predictions of climate variability in the Brahmaputra basin. International Journal of Climatology, 28(2), 243-254. doi: 10.1002/joc.1528

Lehner, B., R-Liermann, C., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P. et al.: High resolution mapping of the world's reservoirs and dams for sustainable river flow management. Frontiers in Ecology and the Environment. Source: GWSP Digital Water Atlas (2008). Map 81: GRanD Database (V1.0). Available online at http://atlas.gwsp.org.

Lehner, B., Verdin, K., and Jarvis, A.: HydroSHEDS technical documentation, 2006.

Moffitt, C. B., Hossain, F., Adler, R. F., Yilmaz, K. K., & Pierce, H. F. (2011). Validation of a TRMM-based global Flood Detection System in Bangladesh. International Journal of Applied Earth Observation and Geoinformation, 13(2), 165-177. doi: http://dx.doi.org/10.1016/j.jag.2010.11.003

Nishat, A., & Faisal, I. M. (2000). An assessment of the Institutional Mechanism for Water Negotiations in the Ganges–Brahmaputra–Meghna system. International Negotiations(5), 289–310.

Tateishi, R., Hoan, N. T., Kobayashi, T., Alsaaideh, B., Tana, G., and Phong, D. X.: Production of Global Land Cover Data – GLCNMO2008, Journal of Geography and Geology, 6, 10.5539/jgg.v6n3p99, 2014.

Point #5

COMMENT: *Using only Nash and Sutcliffe efficiency and correlation coefficient for evaluation of model performance is not sufficient. In addition, at least one else criterion, e.g. PBIAS, should be applied. It is also recommended to compare the simulated and observed long- term average daily (or monthly) discharges for the calibration and validation periods in addition to graphs presented in Fig. 6.*

RESPONSE: We much appreciate the Reviewer's suggestion. Accordingly, we have evaluated our simulated hydrographs by the Nash–Sutcliffe efficiency (NSE), the percent bias (PBIAS), the relative Root-Mean Square Error (RRMSE), the correlation coefficient (cc) and the coefficient of determination (R^2). We have revised the manuscript (in Section 3.2) as follows:

> The obtained NSE for the calibration (validation) period is 0.84 (0.78), 0.80 (0.77), and 0.84 (0.86), while the percent bias (PBIAS) is 0.28% (6.59%), 1.21% (2.23%) and -0.96% (3.15%) for the Brahmaputra, Ganges, and Meghna basins, respectively. For all basins, the relative Root-Mean Square Error (RRMSE), the correlation coefficient (cc), and the coefficient of determination (R2) for the calibration (validation) period ranges from 0.32 to 0.60 (0.32 to 0.59), 0.91 to 0.93 (0.89 to 0.94) and 0.82 to 0.86 (0.79 to 0.88), respectively. These statistical indices suggest the model performance is overall satisfactory.

We have revised the following Figure 5 (former Figure 6) with the above important statistical indices; also, we have plotted the long-term mean monthly discharges of the three basins in this Figure.

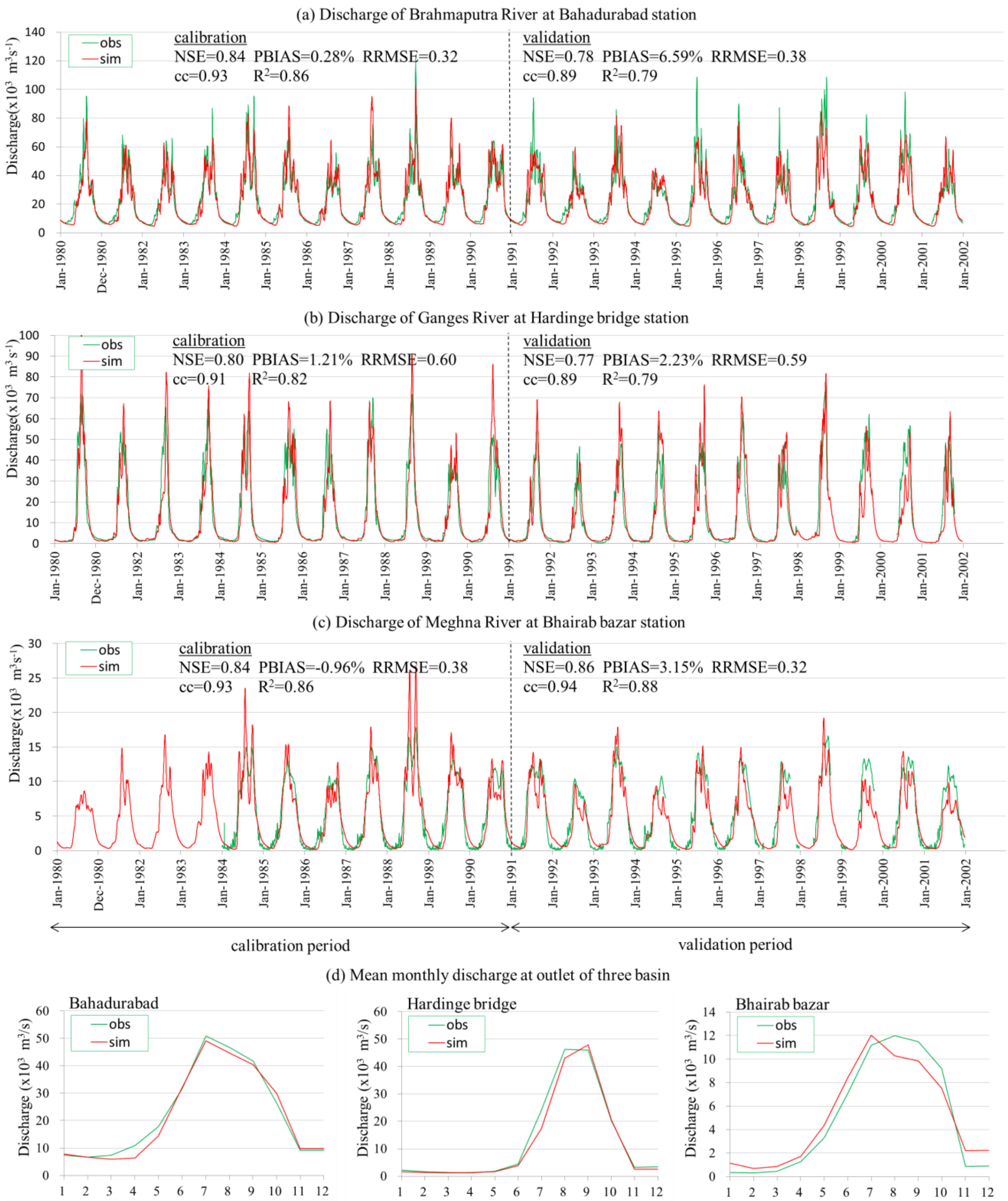

Figure 5. (a)-(c) Hydrographs (both calibration and validation period) (d) mean monthly (1980-2001) discharge at outlet of three basins using the WFD forcing dataset. Nash–Sutcliffe efficiency (NSE), percent bias (PBIAS), relative Root-Mean Square Error (RRMSE), correlation coefficient (cc) and coefficient of determination (R2) for both calibration and validation period are noted at each sub-plot.

Point #6

COMMENT: *The calibration/validation results are not fully convincing, especially for the*

Ganges. It is doubtful that water use upstream can explain the time lag in the simulated hydrograph. Besides, is water used in the Ganges to a larger extent than in the other two basins? Please clarify this point, and add some numbers to make it evident.

RESPONSE: We are grateful to the Reviewer's comment. Accordingly, we have improved our simulation by including two more calibration parameters; that is, the meandering ratio and the effective flow velocity. The statistical indices of our new simulations, as summarized in each sub-plots of Figure 5, suggest that the model performance is overall quite satisfactory.

Point #7

COMMENT: *The calibration and validation only for one gauge per basin for such large river basins is still doubtful. In section 2.2 is said: "data were mainly for the outlets". It means, there were additional data for other intermediate gauges? This would be very beneficial to include them into the calibration procedure (multi-site calibration).*

RESPONSE: Thanks for the comment. Accordingly, we have validated model simulations by comparing the simulated and observed daily streamflow at three outlets of the GBM basins. These long-term observed daily streamflow data were collected regularly by the Bangladesh Water Development Board (BWDB). Although there are other gauging stations located in Bangladesh, they are not available to us at this moment. The remaining large parts (~93%) of the basin areas located in the neighbour countries are nearly un-gauged; even the gauges exit, the data are not publicly sheared due to their geo-political constraints. However, for further validation of model simulations we have collected monthly discharge data at three upstream gauging station (Farakka, Pandu and Teesta) from the Global Runoff Data Centre (GRDC) dataset. Although the available data periods are not overlapping with our study period, we have compared the mean seasonal cycle and the mean, maximum, minimum streamflow and the corresponding standard deviation as the further model validation. As shown in the following newly added Table A1 and Figure A1 (in the Appendix A of the revised manuscript), the comparisons are reasonably well at all of these three upstream statiopns:

Appendix A: Model validation at upstream station

Table A1. Comparison between observed (data source: GRDC) and simulated discharge (m^3 s^{-1}) for Farakka of Ganges basin, Pandu and Teesta of Brahmaputra basin.

Basin	Ganges		Brahmaputra		Brahmaputra	
Station	Farakka		Pandu		Teesta	
Data type	observed	simulated	observed	simulated	observed	simulated

Data period (with missing)	1949-1973	1980-2001	1975-1979	1980-2001	1969-1992	1980-2001
Mean	12 037	11 399	18 818	15 868	915	920
Maximum	65 072	69 715	49 210	46 381	3 622	4 219
Minimum	1 181	414	4 367	3 693	10	122
Standard deviation	14 762	15 518	12 073	11 709	902	948

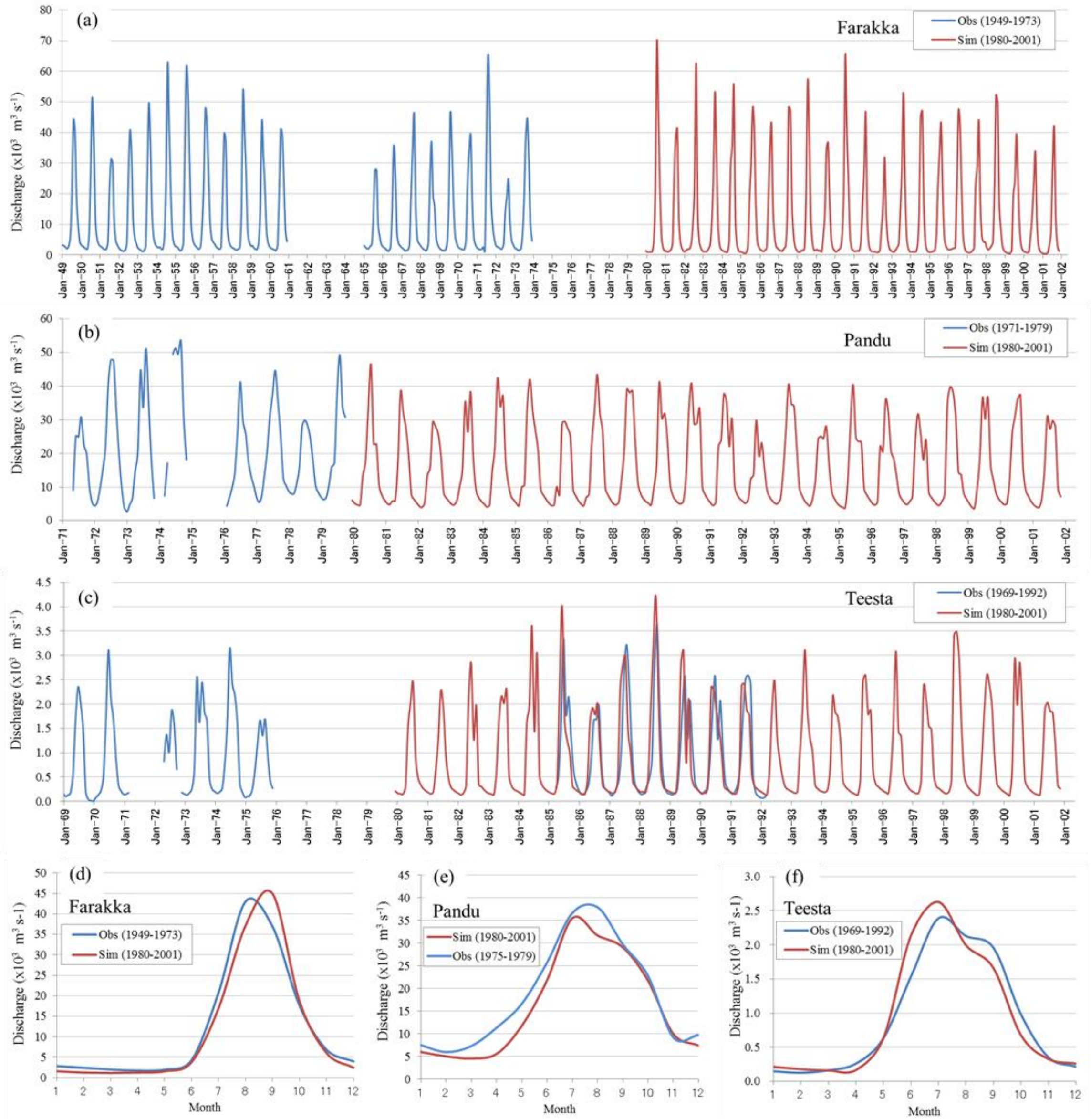

Figure A1. (a-c) Hydrographs and (d-f) mean seasonal cycles at Farakka of Ganges basin, Pundu and Teesta of Brahmaputra basin respectively both for simulated (magenta line) and observed (data source: GRDC) (blue line) data.

Also, we have revised the Figure 1 by adding the locations of the three additional up-stream validation stations. We have also added a new table (Table 3) in the manuscript which presents the basic information of the in total six validation stations.

Point #8

COMMENT: *5760: 2 sentences on lines 21-24 seems to have opposite senses: how the reduced discharge can be explained by backwater effect, and how the reduced discharge is connected with the overestimation of peaks? Besides, usually gauge stations are placed so that there is no backwater effect. Is it different in this case? If so, please clarify and add a reference.*

RESPONSE: Thanks for the comments. We do agree with the Reviewer's comment. We have removed the statement from the manuscript.

Point #9

COMMENT: *5761, l. 20-25: much lower ET in the Brahmaputra is probably mainly due to higher elevation and lower T, as vegetation in the Ganges is only slightly higher. Please check and correct.*

RESPONSE: Thanks for the comments. We fully agree with the Reviewer's comment. Accordingly, we have revised our manuscript in Section 4.1 as follows:

> Lower ET in the Brahmaputra basin is likely due to its cooler air temperature, higher elevation and less vegetated area. The basin-averaged Normalized Difference Vegetation Index (NDVI) of the Brahmaputra is 0.38, whereas for the Ganges and Meghna, NDVI are 0.41 and 0.65, respectively (NEO, 2014).

Point #10

COMMENT: *Section 4.2: statistical significance of correlation coefficients has to be evaluated as well. This would help to better analyse the results. Besides, the usual Pearson correlation may be not eligible, as some of variables are not normally distributed, and other methods could be used.*

RESPONSE: Thanks for the comments. We fully agree with the Reviewer. Accordingly, we have evaluated the statistical significance of the correlation coefficients and have revised our manuscript in the 2nd and 3rd paragraph of Section 4.1 as follows:

> Total runoff and surface runoff of Brahmaputra have stronger correlation (the correlation coefficient (cc) are 0.95 and 0.97, respectively, which are statistically significant at $p<0.05$) with precipitation than that of the other two basins. However, subsurface runoff of Brahmaputra has weaker correlation (cc=0.62, $p<0.05$) with precipitation than that of Ganges (cc=0.75, $p<0.05$) and Meghna (cc=0.77, $p<0.05$). These relationships imply that the deeper soil depths enhance the correlation between subsurface runoff and precipitation. The Meghna with a deeper root zone depth (calibrated d=5m) generates a larger amount of subsurface runoff (69% of total runoff) than the other two basins, and with stronger correlation with precipitation. Consequently, soil moisture in the Meghna basin also shows stronger correlation (cc=0.87, $p<0.05$) with precipitation than that in Brahmaputra (cc=0.77, $p<0.05$) and Ganges (cc=0.82, $p<0.05$), which is fairly reasonable since deeper soil depths buffer the short-term variations in soil moisture and enhance the relationship between precipitation and the long-term mean soil moisture.
>
> The relationships of evapotranspiration with various atmospheric variables such as radiation, air temperature, and water availability, are rather complex (Shaaban et al., 2011). Moreover, different methods for estimating the potential evapotranspiration (PET) may be a source of model parameterization uncertainty since different hydrologic models employ different methods as well as require different inputs of meteorological variables (Thompson et al., 2014). However, the ET scheme of the H08 model uses the bulk formula where the bulk transfer coefficient is used in calculating the turbulent heat fluxes (Haddeland et al., 2011). In estimating PET and hence ET, H08 uses humidity, air temperature, wind speed and radiation. Figure 7 presents the correlation of ET with different meteorological variables (precipitation, specific humidity, air temperature and net radiation) for the three basins. The ET in the Brahmaputra has a significant correlation with precipitation, air temperature, specific humidity and net radiation with the correlation coefficients (cc) range from 0.70 to 0.89 and all of which are statistically significant at $p<0.05$). The correlation of ET in the Meghna with the meteorological variables are also relatively strong (cc range from 0.61 to 0.80, $p<0.05$) except for the net radiation (cc=0.44, $p<0.05$). However, ET in the Ganges has a weak correlation with the meteorological variables (cc range from 0.29 to 0.59, $p<0.05$). A weaker correlation of ET with the meteorological variables is likely attributed to the over-estimation of actual ET in the Ganges, because the up-stream water use (which is larger in Ganges) may be incorrectly estimated as ET by the H08 model to ensure water balance.

<u>Point #11</u>

COMMENT: *Fig. 8: were correlation coefficients calculated for all 3 periods together? ET: is it actual evapotranspiration? Please clarify this in the figure title*

RESPONSE: Yes, the correlation coefficients noted in the Fig. 7 (former Figure 8) are calculated for all the three periods together. ET is the actual evapotranspiration. We have revised the caption of Figure 7 (former Figure 8) as follows:

> Figure 7. The correlation between the monthly means of meteorological variables (WFD) and that of hydrological variables for the Brahmaputra, Ganges and Meghna basins. Three different colors represent the data in three different seasons: Black: dry/winter (November-March); Green: pre-monsoon (April-Jun); Red: monsoon (July-October). The correlation coefficient (cc) for each pair (all 3 seasons together) is noted at each sub-plot. The units are mm day^{-1} for Prec, ET, runoff , mm for SoilMoist, °C for Tair, and W m^{-2} for net radiation. All abbreviated terms here are referred to Table 2.

Point #12

COMMENT: *Section 4.4: To add a sentence in the beginning on how the changes were estimated: by comparing simulations from the scenario and reference periods driven by climate model inputs in both periods. This is important!.*

RESPONSE: We are grateful to the Reviewer's comment. Accordingly, we have added a sentence in the beginning of Section 4.4 as follows:

> The changes of the projected monthly mean have been estimated by comparing the simulated monthly mean in the future periods with that in the reference periods (1979-2003). The model is driven by the MRI-AGCM3.2S climate forcing data for both periods of H08 simulation.

Point #13

COMMENT: *Section 4.4. After the first introductory sentence Table 3, Figs. 10 and 11 should be introduced by explaining what they show. The titles of Figures 10 and 11 should state how the comparison was done: by comparing simulations from the scenario and reference periods driven by the climate model inputs in both periods. Besides, the lines for the reference period in Fig. 10 should be better distinguishable (another colour?).*

RESPONSE: Following Reviewer's suggestion, we have added a few sentences in introducing Fig. 9 (former Figure 10), Fig. 10 (former Figure 11) and Table 3 after the first introductory sentence as follows:

> The solid lines in Fig. 9 represent the monthly means of current, near-future and far-future periods of

> simulations, and the dashed lines represent the upper and lower bounds of the uncertainty bands determined from the 10 simulations which use the 10 optimal parameter sets as identified by NSE. Figure 10 plots percentage changes of projected monthly means of climatic and hydrological quantities. Table 5 presents means and percentage changes of means (annual, 6 months' mean of dry season and wet season) in tabular form.

According to Reviewer's suggestion, we have revised the caption of Fig. 9 (former Figure 9) and Fig. 10 (former Figure 11) as follows:

> Figure 9 (a1)-(f3). The mean (solid line), upper and lower bounds (dashed line) of the uncertainty band of the hydrological quantities and net radiation components for the present-day (black), near-future (green) and far-future (red) simulations as determined found from 10 simulation result with considering 10 optimal parameter set according to NSE (cu: present-day, nf: near-future, ff: far-future). Coefficient of variations (CV) for all periods (Table 4) are noted on each sub-plot.

> Figure 10 (a)-(r). Percentage changes in the monthly means of the climatic and hydrologic quantities from the present-day period to the near-future and far-future periods. The dashed lines represent the 6-month mean changes in dry season (November-April) and wet season (May-October).

To distinguish better in Fig. 9 (former Figure 10), we have revised this figure by replacing the color shading with the dashed color lines.

Point #14

COMMENT: *Conclusion: not necessary to repeat all numbers again in the Conclusion section, as they were already presented in Tables and repeated in the text above. Please formulate the results in a more general form.*

RESPONSE: We much appreciate the Reviewer's suggestion. Accordingly, we have revised the conclusion.

Technical corrections
Point #1

COMMENT: *Please check grammar. Some observed mistakes:*

5747: “results shows” (abstract);
5750: “as one of the best available global forcing dataset” -> “as one of the best available global forcing datasets”;
Section 2.1: “The WATCH Forcing Data set (WFD) (Weedon et al., 2011) are used” -> The WATCH Forcing Data set (WFD) (Weedon et al., 2011) is used”.
5755: the energy and water budget -> the energy and water budgets
5755: high temporal-resolution -> high temporal resolution
5759: “No surface runoff generated” -> “No surface runoff is generated”
5758, l. 6: less -> lower.
5758, l. 17: were fixed -> was fixed.
5759, l. 13: less -> lower.
5759, l. 15: ranges -> range
5761, l. 14: magnitude -> magnitudes
5761, l. 18: less -> lower
Section 4.1: numerous small mistakes, to be checked.
Section 4.2: numerous small mistakes, to be checked (monthly mean -> monthly means, representing -> represent, relationship -> relationships, generate -> generates, which result -> which results in, etc.)
Section 4.3: varies -> dynamics
4.4.1: century; -> century (to remove ;), 2 different scenario□2 different scenarios, which are -> which were
4.4.2 much warm -> much warmer
4.4.4. less change -> lower change
4.4.5 less -> lower
4.5, title: parameter -> parameters
4.5 “increasing complex” -> “increasing complexity of”, mistakes of singular/plural cases (e.g. 5767, l. 27), less -> lower, peak -> peak, etc.
5: 5769, l. 23: very less changes

RESPONSE: We are grateful to Reviewer for his/her enormous effort to identify these grammatical mistakes. We have corrected all these mistakes as well as similar mistakes in other places of the manuscript.

Point #2

COMMENT: *The language of the whole manuscript has to be checked by a native speaker. There are many poor and/or unclear formulations, like:*
5748: “the impact of climate change on not only the runoff”,

5748: relatively less -> relatively low
5750: "this study, a hydrologic model simulation will be calibrated"
5751: "which has been demonstrated suitable" -> "which has been demonstrated as suitable"
5751: "which benefit the analysis of their combined influences"
5751: "in most previous work" -> "in most previous works"
5754: "MRI-AGCM3.2S is based on an atmospheric climate model with a 20km grid model" – too many "models".
5754: "Climate change impacts on the south Asian climate" ???
5754: "by multiplying a correction coefficient" -> "by multiplying using a correction coefficient"
5756: "The module accumulates runoff generated by the land surface model and rout them" -> "The module accumulates runoff generated by the land surface model and routes it"
5756: "to become streamflow" -> "where it becomes streamflow" 5760: "This is likely due to that the Meghna as a tidal river .."
Section 4.3: variability of runoff and precipitation are closely similar -> inter-annual dynamics of runoff and precipitation are similar
Section 4.3: To reformulate: "Though there is no clear trend is noticed ..." Title of 4.4: Projected changes in the mean -> Projected mean changes
4.4.3: is predicted -> is projected
4.4.3: directed -> could be directed, flood -> floods
4.4.4: "It is observed in Fig. 11m–o, changes of ET in near-future are very less" please formulate in proper English
4.4.6: "Due to projected air temperature increase in dry period is large", and the rest of this sentence – please formulate in proper English
4.5: the sentence about "many parameter sets can reproduce the observations" is poor, please reformulate
4.5: "uncertainty of future projection due to model parameter should consider carefully" – please formulate in proper English
4.5, 5768, l. 23-25: "Larger uncertainty in predicting soil moisture is significant in land use management, agriculture in particular ..." – poor formulation (what does it mean: "larger uncertainty in land use management"?), please reformulate.

RESPONSE: We are grateful to Reviewer for his/her enormous effort to identify these mistakes. We have corrected all these mistakes as well as similar mistakes in other places of the manuscript.

<u>Point #3</u>

COMMENT: *Abstract: "evapotranspiration is predicted" is wrong, it is only projected. The word "prediction" should never be used in this context. Please check in the whole manuscript (e.g. p. 5749, 5765).*

RESPONSE: We much appreciate the Reviewer's careful review. We have replaced the word "prediction" with "projection" in the whole manuscript. The sentence in the abstract has been revised as follows:

> (c) evapotranspiration is projected to increase significantly for the entire GBM basins (Brahmaputra: +13.7%, Ganges: +7.0%, Meghna: +11.8%) due to increased net radiation (Brahmaputra: +5.7%, Ganges: +5.5%, Meghna: +5.2%) as well as warmer air temperature.

Point #4

COMMENT: *Abstract: the sentence about the "largest hydrological response" should be reformulated, as the largest hydrological response may not necessarily lead to the higher risk of flooding. Better: "the highest increase in discharge".*

RESPONSE: We have revised the sentence as follows:

> Amongst three basins, Meghna shows the highest increase in runoff which indicates higher possibility of flood occurrence in this basin.

Point #5

COMMENT: *A reference to Fig. 1 is needed in Introduction, 2nd. Paragraph.*

RESPONSE: We have referred the figure in 1st line of 2nd paragraph of Introduction as follows:

> The Ganges-Brahmaputra-Meghna (hereafter referred to as GBM) river basin with a total area of about 1.7 million km^2 (FAO-AQUASTAT, 2014; Islam et al., 2010) encompasses a number of countries including parts of China, India, Nepal, Bhutan and Bangladesh (Fig. 1).

Point #6

COMMENT: *Please correct: in Introduction: "encompasses a number of countries including China, India, ..." -> "encompasses a number of countries including parts of China and India, ...".*

RESPONSE: We have revised the sentence as follows:

> The Ganges-Brahmaputra-Meghna (hereafter referred to as GBM) river basin with a total area of about 1.7 million km^2 (FAO-AQUASTAT, 2014; Islam et al., 2010) encompasses a number of countries including parts of China, India, Nepal, Bhutan and Bangladesh (Fig. 1)

Point #7

COMMENT: *5749: why "due to the lack of calibration data"? Probably, -> "due to the lack of calibration"?*

RESPONSE: We have revised the sentence as follows:

> Although their modelling domains include the GBM basin, these global-scale simulations are not well constrained due to the lack of calibration at the basin scale.

Point #8

COMMENT: *5750: what means "well-constrained hydrologic modelling"? Please reformulate.*

RESPONSE: Thanks for the comments. Accordingly, we have replaced the term "well-constrained" with the term "well-calibrated".

.

Point #9

COMMENT: *Introduction: please subdivide the long paragraph starting "Few studies ...", and the next paragraphs in Introduction, as well as in the following Sections.*

RESPONSE: Thanks for the comments. Accordingly, we have subdivided the paragraph mentioned by the Reviewer as follows:

> Few studies have been conducted to investigate the impact of climate change on the hydrology and water resources of the GBM basins (Immerzeel, 2008;Kamal et al., 2013;Biemans et al., 2013;Gain et al., 2011;Ghosh and Dutta, 2012;Mirza and Ahmad, 2005a). In most of these studies, future streamflow is projected on the basis of linear regression between rainfall and streamflow derived from historical data

> (Immerzeel, 2008;Chowdhury and Ward, 2004;Mirza et al., 2003). Immerzeel (2008) used the multiple regression technique to predict streamflow at the Bahadurabad station (the outlet of Brahmaputra basin) under future temperature and precipitation conditions based on the statistically downscaled GCM output. However, since most of the hydrologic processes are nonlinear, they cannot be predicted accurately by using empirical regression equations derived from historical data and then extrapolating to the future conditions with the non-stationary changes. The alternative for the assessment of climate change impacts on basin-scale hydrology is by using well-calibrated hydrologic modelling, but this has rarely been conducted for the GBM basin due to the lack of data for model calibration and validation. Ghosh and Dutta (2012) applied a physically-based, macro-scale distributed hydrologic model to study the change of future flood characteristics at the Brahmaputra basin, but their study domain only focused on the regions inside India rather than the entire basin. Gain et al. (2011) estimated the future trends of the low and high flows in the lower Brahmaputra basin using outputs from a global hydrologic model forced by multiple GCM outputs (grid resolution: 0.5º). Instead of calibrating the model, the simulated future streamflow was weighted against the observations to assess the impacts due to climate change.
>
> In contrast to the above studies, in this study a hydrologic model simulation will be conducted. The calibration and validation will be based on a rarely obtained long-term (1980-2001) observed daily streamflow dataset in the GBM basin provided by the Bangladesh Water Development Board (BWDB). Relative to previous studies over the GBM basin, it is believed that the availability of this unique long-term streamflow data can lead to more precise estimation of model parameters and hence more accurate simulation of hydrological processes as well as more reliable future projection of the hydrology over the GBM basin.

However, all of the literatures introduced in the following two paragraphs are relevant; hence it is difficult to further subdivide.

Point #10

COMMENT: *Fig. 3: why is it called "climatology"??? It is a long-term average seasonal dynamics.*

RESPONSE: Thanks for the comments. Accordingly, we have revised text in manuscript (2nd paragraph of Section 3.1) as follows:

> Figure 3 plots the 11-year long-term average seasonal cycles of simulated total runoff, surface runoff and sub-surface runoff of Brahmaputra basin.

We have revised the caption of Figure 3 as follows:

> The 11-year (1980–1990) long-term average seasonal cycles of the simulated total runoff, surface runoff and sub-surface runoff (unit: mm day^{-1}) of Brahmaputra basin. Each of the five lines in each panel represents the average of 5^3 (=125) runs with one of the four calibration parameters fixed at the given value.

Point #11

COMMENT: *5759: Why "envelopes"??? What is the meaning? Maybe to reformulate?*

RESPONSE: Thanks for the comments. We have replaced the term as "uncertainty band" in the whole manuscript. For example, 1^{st} line of 7^{th} paragraph in Section 3.1 has been revised as follows:

> Figure 4 plots the uncertainty bands of the simulated discharges by using 10 optimal parameter combinations according to Nash-Sutcliffe coefficient of efficiency (NSE) (Nash and Sutcliffe, 1970).

We have revised the caption of Fig. 4 (former Figure 5) as follows:

> Figure 4. Hydrograph of simulated discharge with optimal parameter set (red line) and uncertainty band of simulated discharge with top 10 optimal parameter combinations (green shading) during calibration period (1980-1990).

Point #12

COMMENT: *5759: "for the Brahmaputra and Ganges basin": Not, for all three basins..*

RESPONSE: Yes, Figure 4 (former Figure 5) plots the uncertainty bands of the simulated discharges for all three basins. Accordingly, we have revised the sentence as follows:

> Figure 4 plots the uncertainty bands of the simulated discharges by using 10 optimal parameter combinations according to Nash-Sutcliffe coefficient of efficiency (NSE) (Nash and Sutcliffe, 1970)..

Point #13

COMMENT: *Title of section 4: Result and discussion -> Results and discussion*

RESPONSE: Thanks for the comments. Accordingly, we have revised the title as "4 Results and discussion:

Point #14

COMMENT: *5761, first sentence in 4.1: please correct, as Table 2 does not present seasonal cycles, only mean values*

RESPONSE: Thanks to Reviewer for his/her comment. We have revised the sentence as follows:

> Fig. 6 plots the 22-yr (1980-2001) mean seasonal cycles of the climatic (from WFD forcing) and hydrological (from calibrated hydrologic model simulation) quantities averaged over these three basins (yearly mean values are presented in Table 2).

Point #15

COMMENT: *5761: second sentence in 4.1 about interannual variation precipitation: "was mainly from May to September " -> "was higher from May to September".*

RESPONSE: Thanks to Reviewer for his/her comment. We have revised the sentence as follows:

> The interannual variation of precipitation in Brahmaputra and Meghna was higher from May to September (Fig. 6a,c) whereas for Ganges was from June to October.

Point #16

COMMENT: *The last sentence in 4.2 is poorly formulated ("upstream water use ... is estimated as ET"), please reformulate.*

RESPONSE: Thanks for the comments. We have revised the sentence as follows:

> Weaker correlation of ET with meteorological variables might be attributed to over-estimation of actual ET of Ganges by current model. Because upstream water use (which is larger in Ganges) is estimated as ET by this model to ensure water balance.

Point #17

COMMENT: *Section 4.3, second sentence is poor (there could be a long–term trend despite of a high inter- annual variability). Please correct.*

RESPONSE: Thanks for the comments. Accordingly, we have revised the sentence as follows:

> Long-term trend of annual variability in precipitation is not pronounced for all three basins. However, the inter-annual variability in precipitation is quite large.

Generally, we are deeply grateful to Reviewer #2 for his/her insight and careful review. His/her comments have greatly helped improve the paper.