Dear Editor and Reviewers:

First, we would like to thank the editor and reviewers for their helpful comments and suggestions, which improved the quality of our manuscript. We agree with most of the concerns raised by the reviewers and have therefore modified the manuscript according to the reviewers' comments and suggestions. Newly added and modified text is highlighted in yellow in the revised manuscript, and our point-by-point responses to the reviewers' comments are provided below. We hope that the revised manuscript is now suitable for publication in Hydrology and Earth System Sciences.

Reply to Reviewer (#1)'s Comments:

This manuscript highlights the projection of hydroclimatic extremes in the Asia monsoon region under global warming. The authors have comprehensively examined seventeen indices using the best five GCMs over different climatic zones in Asia. However, I feel substantial work to be done to improve the paper. Hence, I request an editor to give more time for the revision of the article. I would love to review the revised draft, and the authors can find my major and minor comments/suggestions below:

► We appreciate the reviewer's feedback and helpful comments. Kindly find our detailed response to each comment below.

Major:

1. No robust finding is coming out from the abstract. It contains a few lines of introduction, method, and overall results. The abstract has to be crisp, short, and quantitative with results.

► We have revised the abstract considering the reviewer's comment.

: The influences of global warming have contributed to changes in hydroclimatic extremes, which are more complicated at the regional scale. To reduce the potential risk of extremes under future climate, assessing the change of extreme climate events is important, especially in Asia due to various different climates features and seasonal variability. Here, the changes in hydroclimatic extremes are assessed over the Asian monsoon region under global mean temperature warming targets of 1.5 and 2.0 ℃ above preindustrial levels based on representative concentration pathways (RCP) 4.5 and 8.5. Analyses of the subregions classified using regional climate characteristics are performed based on the multimodel ensemble mean (MME) of five bias-corrected global climate models (GCMs). For runoff extremes, the hydrologic responses to 1.5 and 2.0 ℃ global warming targets are simulated based on the variable infiltration capacity (VIC) model. The temperature extremes show significant change patterns over all climate zones. As the globe warms, increasing warm extremes (fewer than 45 days) and decreasing cold extremes (fewer than 32 days) occur more frequently over Asia with strong robustness. Moreover, changes in precipitation and runoff averages (and low runoff extremes) show change patterns with large spatial variations featuring weak robustness based on intermodel agreement. Additionally, global warming is expected to significantly intensify maximum precipitation extremes (usually exceeding a 10 % increase in intensity under 2.0 ℃ of warming) in all climate zones. Regardless of regional climate characteristics and RCPs, this behavior is expected to be enhanced under the 2.0 ℃ (compared with the 1.5 ℃) warming scenario and increase the likelihood of flood risk (up to 10 %). Additionally, the spatial extent and magnitude of the runoff change patterns are modulated by those of the precipitation change patterns. More importantly, an extra 0.5 ℃ of global warming under 2 RCPs will amplify the change patterns of hydroclimatic extremes with strong robustness, especially in cold (and polar) climate zones. The results of this study clearly demonstrate the changes patterns in regional hydroclimatic extremes (e.g., temperature and high precipitation) under warmer conditions over Asia and confirm that hydroclimatic sensitivities differ based on regional climate characteristics.

2. What are the major scientific questions of study?

▶ Thank you for this comment. The major scientific question of this study is to examine how hydroclimatic extremes respond differently in regions with unique climate features under global warming of 1.5 and 2.0 ℃. We provide this text in "Section 1. Introduction".

: Because the impacts of global temperature increases impact each region separately due to the changes in regional climate features, the hydroclimatic changes in response to global warming reflect unique regional responses. Hence, global warming leads to changes in regional hydroclimatic extremes according to regional sensitivities, which remain uncertain. Therefore, the main purposes of this study are to examine the potential impacts of regional climate on hydroclimatic extremes under different global warming conditions and to investigate the regional-scale sensitivity of individual hydroclimatic variables to increases in the global mean temperature with diverse climate features.

3. How the selection of GCMs varies for the different climatic zone? And what are RMSE and SSC range to assign a score from -1, 0, 1? Why is the score given based on MME not against observed? MME comparison may induce bias, and I recommend to re-calculate GCMs performance (calculate Pbias) against observed data for each climatic zone. To see selections of GCMs remain the same for all climatic zone or not? Also, I would like to see selected five GCMs performance against observed data from the 2006-2019 period.

▶ The selection of GCMs is the same within the study area (i.e., the Asian monsoon region) regardless of the climate zone because we select the best-performing GCMs to simulate the spatial patterns of Asian climate features compared with observations. We have clarified this point in the revised manuscript.

: Reliable climate change scenarios, which are derived from the selected GCMs, are important sources for estimating the impacts of global warming on hydroclimatic (e.g., temperature, precipitation, and runoff) extremes. Here, the method for selecting GCMs suggested by Kim et al. (2020) is employed while focusing on their performance in simulating the spatial patterns of observed climate features in Asia because the regional climate is affected by physical climate system processes that occur over large spatial scales (e.g., from the planetary scale to the synoptic scale and mesoscale). For the future projections, the selected GCMs are applied to the entire domain regardless of the climate zone.

▶ For the second comment, the RMSE and SCC criteria used to assign scores for the 12 individual climate variables range from 0.0 (specific humidity) to 409.9 (geopotential height) for RMSE and from 0.37 (geopotential height) to 0.94 (near-surface air mean temperature) for SCC. This shows the large variability among the climate variables because the values of the criteria depend strongly on the modeling uncertainty existing in the simulation of individual climate variables.

▶ Here, we apply the MME-based scoring rule to exclude the low-performing GCMs and select the best-performing GCMs based on the relative concept. The individual GCM performance in this rule is judged by comparison with the MME performance, where the MME is considered the score under the assumption that the MME is similar to the observed data compared with each GCM (Xu et al., 2020;

Tegegne et al., 2020). Moreover, the scoring rule based on observed data can be used to determine the rank of the GCMs; however, this rule does not provide the information needed to screen the GCMs. We clarified why we apply the MME-based scoring rule in the revised manuscript as follows:

: Next, we apply the MME-based scoring rule for the section of GCMs (Nyunt et al., 2012) to exclude low-performing GCMs and select only the best-performing GCMs by using a relative concept because the scoring rule based on the observed data does not provide the information needed to screen the GCMs. Therefore, the individual GCM statistics (i.e., the SCC and RMSE) are judged by comparison with the MME statistic. The value of MME statistics are considered as criteria to give a score to each GCM under the assumption that the MME is similar to the observed data compared with the output from only one GCM (Xu et al., 2020; Tegegne et al., 2020).

▶ Also, the root mean square error (RMSE) and spatial correlation coefficient (SCC) between each GCM simulation field and observed data field are used in this study to examine the GCM performance in simulating the observed spatial climate features. Of course, the GCM performance can be evaluated from the Pbias, but we applied the RMSE statistic instead of Pbias to measure the error between the simulation and observation. Since the RMSE and SCC are commonly used to validate GCM simulations (IPCC, 2007; McSweenet et al., 2015), we hope this approach is acceptable. We clarified the explanation of the GCM selection approach in the revised manuscript.

: The spatial correlation coefficient (SCC) and root mean square error (RMSE) between the historical simulation field derived from each GCM and the observed field are calculated for each of the twelve relevant variables over the Asian monsoon region, as these statistics are commonly used to examine the performance of GCMs in the simulation of observed spatial climate features (IPCC, 2013; McSweeney et al., 2015).

▶ And, the selected GCMs are employed for all climatic zones as suggested in the response of the first comment.

▶ For the final comment, we understand the concern regarding the validation of the GCMs raised by the reviewer. However, the future simulation period of the AR5 GCM started in 2006 based on representative concentration pathway (RCP) scenarios. Although the RCPs are consistent with a wide range of possible changes in future anthropogenic GHG emissions, the RCPs are obviously different from the real world. Since it is difficult to directly compare the selected GCM simulations with observations for the 2006-2019 period, we validated the selected GCMs with the observed data (e.g., mean and maximum values) from a historical period (1976-2005), as shown in Figure 3 for precipitation, Figure S5 for temperature, and Figure S6 for runoff.

: The validation results of the MME compared with the OBS for the minimum (and maximum) temperature are illustrated in Figure S5. The MME outputs of minimum and maximum temperature are very similar to the OBS temperature patterns. In addition, the simulated runoff based on the MME and OBS are compared due to the lack of measured runoff data (Figure S6). The MME results show reasonable historical simulations with implications for the reliability of the climatological and hydrological responses to the climate forcing derived from the MME.

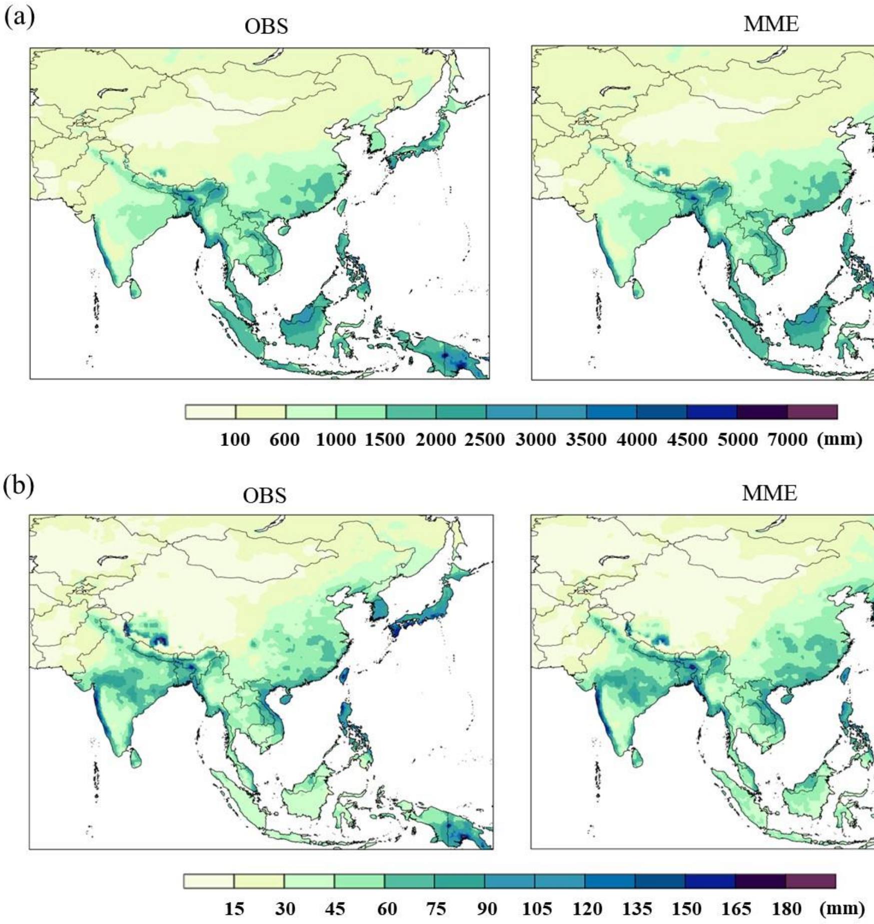

Figure 3: Spatial distributions of the (a) annual mean precipitation (PANN) and (b) annual maximum precipitation (PX1D) for the historical period (1976-2005) in the Asian monsoon region derived from observations and the MME of bias-corrected outputs from the five GCMs.

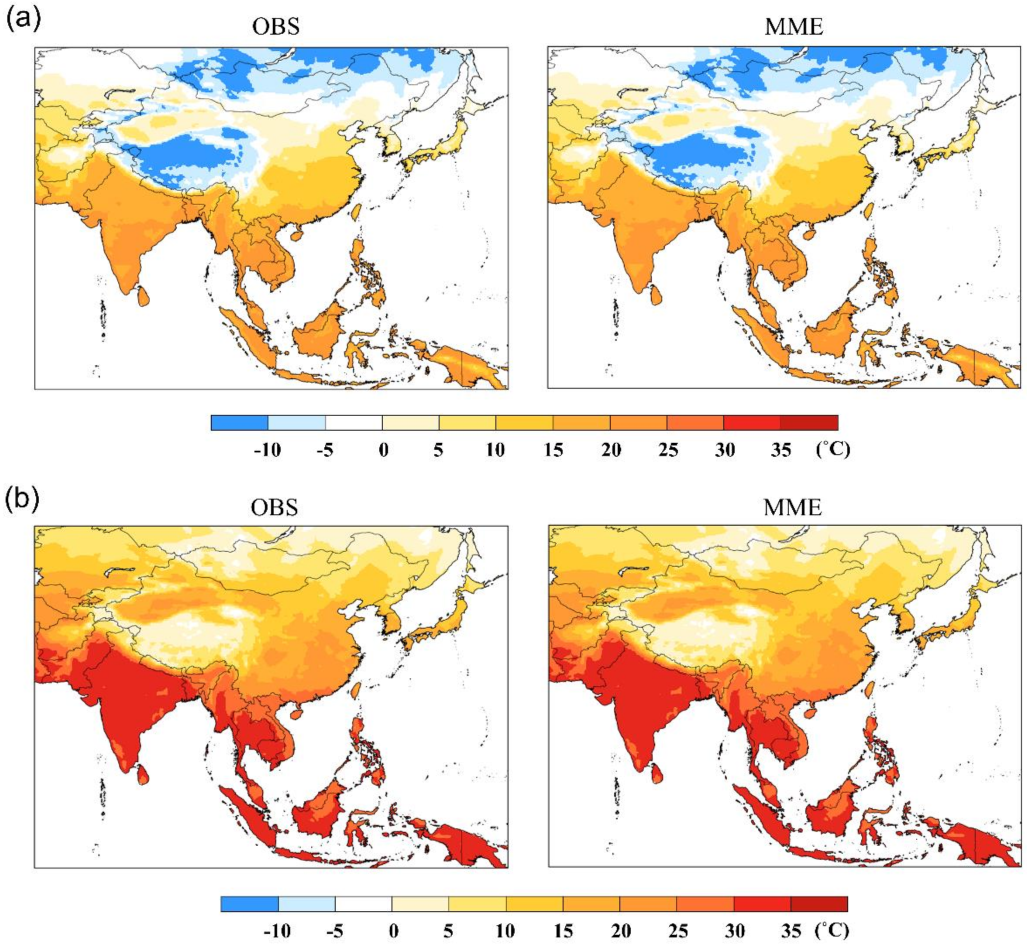

Figure S5: Spatial distributions of the (a) annual minimum temperature (unit: °C) and (b) annual maximum temperature (unit: °C) for the historical period (1976-2005) in the Asian monsoon region. OBS and MME denote the values obtained from the observational temperature dataset and the MME of bias-corrected outputs from the five GCMs, respectively.

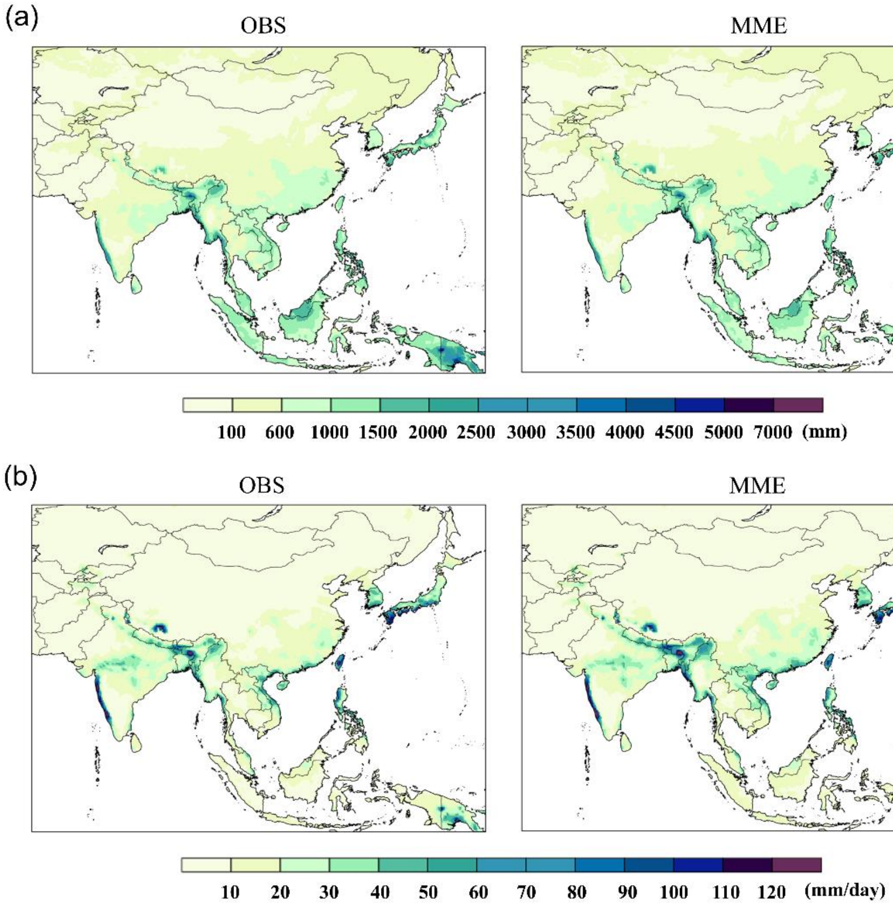

Figure S6: Spatial distributions of the (a) annual mean runoff (unit: mm) and (b) daily maximum runoff (unit: mm/day) for the historical period (1976-2005) in the Asian monsoon region. OBS denotes the simulated runoff from the VIC model fed by observational precipitation data (i.e., APHRODITE). MME denotes the simulated runoff from the VIC model fed by the MME of the bias-corrected outputs from the five GCMs.

4. Why is bias correction applied after the selection of reference period for individual GCMs? How bias corrections affect the 1.5 and 2 ℃ central years for reference?

► Thank you for this comment. We applied the bias correction method after the determination of both the reference period (i.e., corresponding to 0.48 ℃) and two future periods (i.e., corresponding to 1.5 and 2 ℃) for each GCM. The purpose of applying a statistical bias correction is to reproduce regional (or local)-scale climate information based on large-scale climate information (i.e., GCM outputs) and observed regional features from climate impact studies, while the reference period and future periods for individual GCMs are defined by identifying global mean temperature responses to global warming targets. Since each period is taken based on the increment in the globally averaged temperature above the PI level, bias corrections are not necessary for this process and do not affect it. We added a flowchart (Figure 2) for the climate change scenario to guide the readers, and we have clarified this explanation in the manuscript.

: 2.3 Methodology

Figure 2 presents a flowchart of the entire procedure used in the study. To simulate the climate during both historical and future periods, climate projections forced by historical and representative concentration pathways (RCPs) 4.5 and 8.5 are selected. The five of the raw GCMs of the Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2012) are selected by applying a unique evaluation procedure (Kim et al., 2020). Then, a reference 30-year period and two future 30-year periods of individual GCM projections are defined under warming targets of 0.48, 1.5 and 2.0 ℃ above PI levels (1861-1890) based on a time sampling method. Then, these daily forcing data (e.g., precipitation, maximum temperature, and minimum temperature) are extracted from the five selected GCM projections and then statistically bias-corrected using the quantile mapping method. The bias-corrected GCMs are used as meteorological forcings to run the variable infiltration capacity (VIC) hydrological model. The future changes in the hydroclimatic mean and extremes corresponding to the conditions at warming targets of 1.5 and 2.0 ℃ are spatially analyzed according to the identified subregions based on climate zones. We focus on the hydroclimatic extreme responses to temperature, precipitation, and runoff variations under global warming targets (i.e., 1.5 and 2.0 ℃) using extreme indices. A more detailed description of each procedure is provided in section 2.4, section 2.5, and section 2.6.

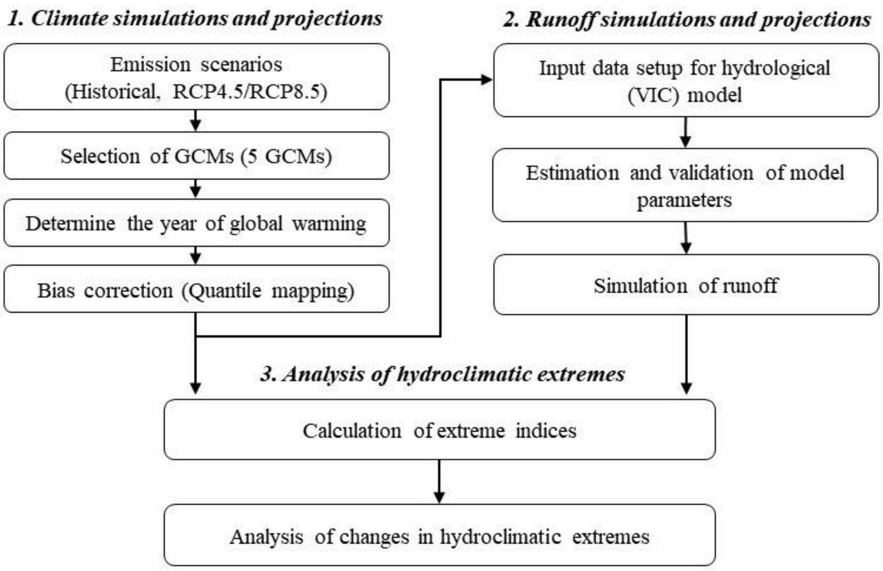

Figure 2: Flowchart of the entire procedure used in this study.

5. How APHRODITE and University of Washington data could perform against CERA-20C reanalysis?

► We collected the observational meteorological dataset considering the data availability for long-term records and the time scale. For the meteorological inputs for the VIC model, we preferentially collected daily observational data (i.e., daily precipitation from APHRODITE and daily minimum and maximum temperatures from the University of Washington). The remaining climate variables were obtained from the CERA-20C reanalysis on a monthly basis due to the limited availability of data. We have clarified this point in the revised manuscript.

: Observational meteorological datasets are required as input variables to the hydrological model on a daily time scale and for validating the performance of the GCM simulations on a monthly time scale. We select the meteorological datasets considering the availability of long-term records and their time scales. To run the hydrological simulations (1950-2005), we collect precipitation data from the Asian Precipitation Highly Resolved Observational Data Integration Toward Evaluation of Water Resources (APHRODITE) product (Yatagai et al., 2012), and the maximum and minimum temperature data and wind speed data are obtained from gridded forcing datasets provided by the University of Washington (Adam and Lettenmaier, 2003; Adam et al., 2006). To evaluate the performance of the GCM simulations, the reanalysis data for the remaining climate variables are obtained from the Coupled European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis system-20C (CERA-20C) (Laloyaux et al., 2018) on a monthly basis due to the limited availability of data. These observational datasets including the reanalysis data (hereafter “OBS”), are gridded at a 0.5° spatial resolution and interpolated to the same grid system as the GCMs.

6. Make a similar plot (Figure 2) using observed and MME data for temperature and simulated runoff. You can keep those in the supplemental material.

► Thank you for this comment. We have added Figures S5 for temperature and S6 for runoff (as shown above) to the Supplementary Material and revised the manuscript (see response to the final comment No. 3)

7. The figure’s quality is poor.

► We upgraded the figures to high quality (600 dpi).

Minor:

- Line 25: “increased the frequency and intensity of natural disasters” Give citations.

► We have added citations.

: The climate system in this region has changed as a result of global warming, and consequently, the frequency and intensity of natural disasters related to climate (e.g., heatwaves, heavy precipitation, and floods) have increased (Thomas et al., 2013; IPCC, 2013; Thomas et al., 2014; Thomas et al., 2015).

- Line 71-77: I recommend to keep these in data and method sectionsâ˘A ˇTno need to brief in the introduction.

► We have attempted to make the text more concise in the Introduction

: In this study, we assess the changes in climate (and hydroclimatic) extremes corresponding to the warming targets of 1.5 and 2.0 °C with a focus on the broad continental-scale climate zones of the Asian monsoon region (Figure 1), as delineated by Bae et al. (2013). Since climate extreme events are an inherent climate component, we classify the subregions in the

Asian monsoon region considering regional climate characteristics to understand the change behaviors of climate (and hydroclimatic) extremes under global warming. To consider the reliability of future projections, we present the results based on the multimodel ensemble mean (MME) derived from five selected GCM projections, including intermodal agreement. This study provides scientific information for policy makers to identify regional patterns of the changes in extremes and thereby recognize the impacts of anthropogenically induced warming.

And, we have suggested detailed information in the Materials and methodology section (section 2.2~2.6).

- Line 81: "As far as we know, relatively few studies" Give citations.

► We have added citations.

: To the best of our knowledge, relatively few studies have examined the impacts of global warming on extreme hydroclimatic variable-related responses considering the regional climate in Asia (Liu et al., 2019; Kim et al., 2020; Zhao et al., 2020).

- Line 120-123: How to relate 1.5-2.0 ℃ global warming with the RCP4.5 scenario? The small description of this will help the reader to understand the process.

► This comment is well taken. As the reviewer and editor suggested, we have implemented an additional RCP (i.e., RCP8.5); we have analyzed the results of changes in hydroclimatic extremes under 1.5 and 2 °C of global warming based on two different RCPs in the revise paper (i.e., RCP4.5 and RCP8.5). In this regard, we have added an explanation as follows:

: Our focus is to understand the changes in extreme hydroclimatic conditions under global warming environments of 1.5 and 2.0 ℃. The timing to reach specific warming levels for individual GCMs depends on the representative concentration pathway because future projections are forced by these scenarios. The temperature response to different RCPs varies, and therefore, the increasing trend and slope of the global mean temperature differ. Here, the analysis is based on RCP4.5 and RCP8.5, which are commonly considered for realistic future projections. RCP4.5 is a stabilized emission scenario with radiative forcing of approximately 4.5 W/m2 in the year 2100, and this value is never exceeded (Thomson et al., 2011; Van Vuuren et al., 2011). This scenario assumes that emission mitigation policies are implemented to limit emissions and radiative forcing. On the other hand, RCP8.5 is a very high emission scenario with radiative forcing of approximately 8.5 W/m2 in the year 2100. Although the global warming process under RCP4.5, which is based on a medium-low GHG emission pathway is relatively slow compared to higher GHG emissions (e.g., RCP8.5), many studies have suggested that the global warming climate under RCP4.5 exerts impacts on hydroclimatic phenomena (Chen et al., 2017; Donnelly et al., 2017; Kim et al., 2020). However, global warming impacts under different RCPs on the regional changes of hydroclimatic extremes are not simple. In this regard, the results based on two RCPs (RCP4.5 and RCP8.5) can provide useful information for identifying the impacts of global warming on hydroclimatic extremes from those expected under different RCPs. This implies the need for minimum mitigation strategies as well as adaptation plans according to the global warming induced by GHG emissions, even those under the relatively low-impact RCPs (e.g., RCP4.5).

- Line 136: What is a central year for reference for MME at 0.48, 1.5, and 2℃?

► Thank you for this comment. The central year, which is the median year during the 30-year period, is the first year in which the 30-year running temperature anomaly surpasses the target temperature compared to the PI level. The target temperatures in this study for the 30-year reference and future periods are 0.48 °C and 1.5 and 2 °C. We have clarified this point in the revised manuscript as follows:

: In this process, the individual 30-year periods and their central years (i.e., the median year of each period) are determined based on the temperature anomalies relative to the temperature of the PI period. All five GCMs reach specific warming levels in their central years and in the 30-year reference and future periods under both RCP4.5 and RCP8.5 (Table 3 and Figure S1). Because the individual GCMs simulate the climate based on their own physical climate system processes, the warming phases of the GCMs are different even under the same emissions forcing. In this study, the central year of each period is the first year in which the 30-year running temperature anomaly surpasses the target temperature above the temperature of the PI period. The temperature anomalies targeted in this study are 0.48 °C for the reference period and 1.5 and 2 °C for the two future periods.

- *Line 137-138: How come the central year of PI is 1895? When your PI period is 1861-1890? Please check.*

► The correct central year of the PI period (1861-1890) is 1875. We revised this point in the manuscript.

: Unlike the temperature taken from the central year of the PI period (1875), the temperature anomalies are calculated for the entire period.

- *Line: 155: provide the full name of VIC.*

► We added the full definition of VIC.

: The bias-corrected GCMs are used as meteorological forcings to run the variable infiltration capacity (VIC) hydrological model.

- *Keep observational datasets section after section 2.1*

► We have reorganized the contents and revised the manuscript.

- *Line 197: what are the reference period and two future periods? Is it for individual GCM or MME? Please clear to avoid confusion.*

► Thank you for this comment. The reference period and two future periods indicate the periods corresponding to warming targets of 0.48 °C and 1.5 °C (and 2.0 °C) for the individual GCMs. We clarify this point in the revised manuscript as follows:

: For the changes in temperature extremes, the numbers of tropical days (TR), frost days (FD), warm nights (TN90P), and cold nights (TN10P) are calculated using daily minimum temperature data during the reference period and two future periods for each selected GCM, as shown in Table 3.

- *Table 4: Also, provide a source of indices (e.g., minimum temperature, maximum temperature, precipitation, and runoff) in another column.*

► We provided the sources of the indices in the 4th column of Table 4.

Table 4: Definitions of the hydroclimatic extreme indices using minimum temperature (denoted by TN), maximum temperature (denoted by TX), precipitation (denoted by PR), and runoff data, where ‘i’ and ‘j’ represent the month and year, respectively.

Index name (label)	Index definition	Unit	Source of indices
Tropical nights (TR)	The number of days when TNij > 20 ℃	Days	Minimum temperature
Frost days (FD)	The number of days when TNij < 0 ℃	Days	
Warm nights (TN90P)	The number of days when TNij > TNref90; here, TNref90 is the calendar day 90th percentile centered on a 5-day window for the reference period of individual GCMs	Days	
Cold nights (TN10P)	The number of days when TNij < TNref10; here, TNref10 is the calendar day 10th percentile centered on a 5-day window for the reference period of individual GCMs	Days	
Summer days (SU)	The number of days when TXij > 25 ℃	Days	Maximum temperature
Ice days (ID)	The number of days when TXij < 0 ℃	Days	
Warm days (TX90P)	The number of days when TXij > TXref90; here, TXref90 is the calendar day 90th percentile centered on a 5-day window for the reference period of individual GCMs	Days	
Cold days (TX10P)	The number of days when TXij < TXref10; here, TXref10 is the calendar day 10th percentile centered on a 5-day window for the reference period of individual GCMs	Days	
Very wet day precipitation (P95)	The total precipitation when PRij exceeds the 95th percentile of the wet day precipitation in the reference period of individual GCMs	Mm	Precipitation
Extreme wet day precipitation (P99)	The total precipitation when PRij exceeds the 99th percentile of the wet day precipitation in the reference period of individual GCMs	Mm	
Annual maximum precipitation (PX1D)	The maximum 1-day precipitation	Mm	
Maximum 2-day precipitation (PX2D)	The maximum consecutive 2-day precipitation	Mm	
Maximum 3-day precipitation (PX3D)	The maximum consecutive 3-day precipitation	Mm	
Maximum 5-day precipitation (PX5D)	The maximum consecutive 5-day precipitation	Mm	
Minimum 7-day runoff (DWF07)	The minimum consecutive 7-day runoff	Mm	Runoff
Minimum 30-day runoff (DWF30)	The minimum consecutive 30-day runoff	Mm	
Annual maximum runoff (MDF)	The maximum daily runoff	Mm	

- Section 3.1: Is climatic zone classification is based on observed data? And which year? Also, mention which observation reanalysis or APHRODITE and University Washington data?

► We have clarified this point in the revised manuscript as follows:

: The climate zones over the Asian monsoon region in this study are classified based on long-term (30-year; 1976-2005) observation datasets (i.e., precipitation from APHRODITE; minimum and maximum temperatures from the University of Washington).

- Line 219: "the bias-corrected GCMs are validated" Justify this result for temperature as well.

► Thank you for this comment. We have shown the validation results of the bias-corrected GCMs for temperature in Figure S5, and we have revised the manuscript accordingly (see response to the final comment No. 3)

References (Added)

Liu, J., Xu, H., Luo, J.J. and Deng, J.: Distinctive Evolutions of Eurasian Warming and Extreme Events Before and After Global Warming Would Stabilize at 1.5 °C, Earth's Future, 7, 151-161, 2019.

McSweeney, C.F. Jones, R.G., Lee, R.W. and Rowell, D.P: Selecting CMIP5 GCMs for downscaling over multiple regions, Climate Dynamics, 44, 3237-3260, 2015.

Tegegne, G., Melesse, A.M. and Worqlul, A.W.: Development of multi-model ensemble approach for enhanced assessment of impacts of climate change on climate extremes, Science of The Total Environment, 704, 12321-12330, https://doi.org/10.1016/j.scitotenv.2019.135357, 2020.Yatagai, A., Kamiguchi, K., Arakawa, O., Hamada, A., Yasutomi, N. and Kitoh, A.: APHRODITE: Constracting a Long-Term Daily Gridded Precipitation Dataset for Asia Based on a Dense Network of Rain Gauges, Bulletin of the American Meteorological Society, 93, 1401-1415. https://doi:10.1175/BAMS-D-11-00122.1, 2012.

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Thomas, V., Albert, J.R.G., and Hepburn, C.: Contributors to the frequency of intense climate disasters in Asia-Pacific countries, Climatic Change, 126, 381-398, https://doi.org/10.1007/s10584-014-1232-y, 2014.

Thomas, V., and Lopez, R.: Global increase in Climate-Related Disasters, ADB Economics Working Paper Series No. 466, Asian Development Bank, Philippines, 38 pp., 2015.

Xu, Y., Gao, X. and Giorgi, F.J.: Upgrades to the reliability ensemble averaging method for producing probabilistic climate-change projections, Climate Res., 41, 2375-2385, 2010.

Zhao, Y., Li, Z., Cai, S. and Wang, H.: Characteristics of extreme precipitation and runoff in the Xijiang River Basin at global warming of 1.5 °C and 2 °C, Natural Hazards, 101, 669-688, 2020.

Reply to Reviewer (#2)'s Comments:

The manuscript presents an analysis of likely changes in future temperature, precipitation, and runoff extremes over different climatic regions of Asia. Climate projections are obtained from a suite of climate models and a hydrologic model is used to translate climate to runoff. While the manuscript addresses a topic of relevance to the journal, it has several major shortcomings that prohibit readers from interpreting the results and gauging their reliability. These are listed below:

► We appreciate the reviewer's feedback and helpful comments. Kindly find our detailed response to each comment below.

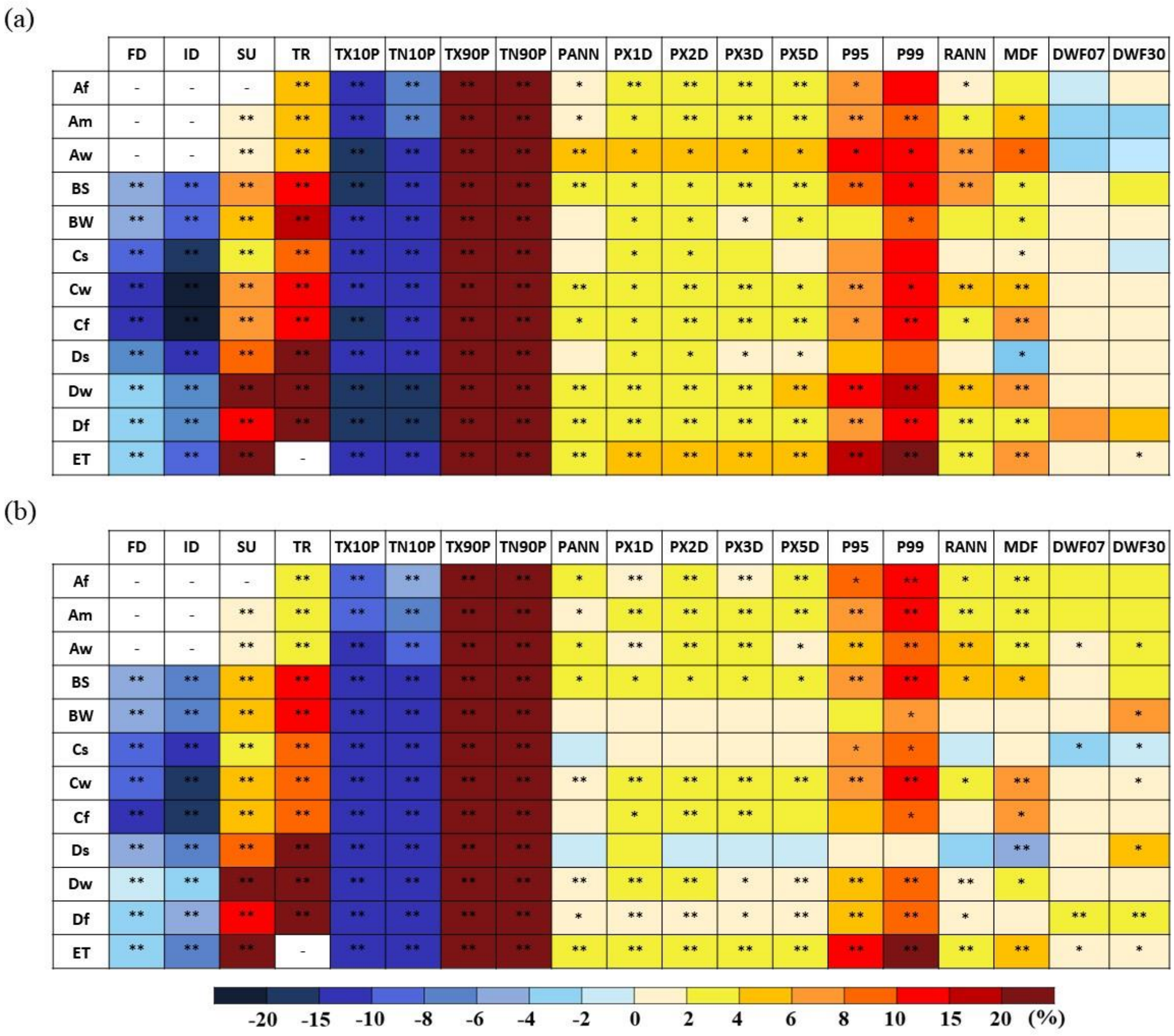
1. Novelty: There are several studies that discuss the consequences of 1.5 °C and 2.0 °C global warming on hydrology of river basins across the globe. A number of such analyses are cited in the paper but some significant research is not discussed. For example Betts et al. (2018) discuss the difference between the two global warming levels in terms of hydrologic extremes as well as food security. Similarly, Doll et al. (2018) employ two hydrologic models and an ensemble of bias corrected climate models to understand how freshwater related hazards are likely to change across the globe under the two warming levels. A number of similar studies can be found. The authors need to justify how their analysis adds value to this literature. A statistical analysis of expected changes is useful but these numbers need to be eventually translated into variables that have direct impact on society (such as food availability, flood hazard, etc.). Perhaps the authors can provide some policy relevant insights to the readers, for example, by suggesting how the adaptive measures will vary across different climate regions.

► We fully agree with your valuable suggestion. As the reviewer suggested, we have added the related text in "Introduction" and "Section 4. Discussion and conclusions" to provide an in-depth survey of relevant research on hydroclimatic responses to global warming and to emphasize the meaningful contribution of this manuscript to the literature. We suggested the needs of different adaptive measures based on unique regional responses, especially those of the hydroclimatic extremes, to an additional 0.5 °C of global warming. We clarified these points in an organized way in manuscript (line 72-86 and line 437-524).

: To the best of our knowledge, relatively few studies have examined the impacts of global warming on extreme hydroclimatic variable-related responses considering the regional climate in Asia (Liu et al., 2019; Kim et al., 2020; Zhao et al., 2020). Because the impacts of global temperature increases impact each region separately due to the changes in regional climate features, the hydroclimatic changes in response to global warming reflect unique regional responses. Hence, global warming leads to changes in regional hydroclimatic extremes according to regional sensitivities, which remain uncertain. Therefore, the main purposes of this study are to examine the potential impacts of regional climate on hydroclimatic extremes under different global warming conditions and to investigate the regional-scale sensitivity of individual hydroclimatic variables to increases in the global mean temperature with diverse climate features. In this study, we assess the changes in climate (and hydroclimatic) extremes corresponding to the warming targets of 1.5 and 2.0 °C with a focus on the broad continental-scale climate zones of the Asian monsoon region (Figure 1), as delineated by Bae et al. (2013). Since climate extreme events are an inherent climate component, we classify the subregions in the Asian monsoon region considering regional climate characteristics to understand the change behaviors of climate (and hydroclimatic) extremes under global warming. To consider the reliability of future projections, we present the results based on the multimodel ensemble mean (MME) derived from five selected GCM projections, including intermodal agreement. This study provides scientific information for policy makers to identify regional patterns of the changes in extremes and thereby recognize the impacts of anthropogenically induced warming.: Overall, the D and E zones are highly susceptible to an extra 0.5 °C of warming. These regions show significant changes in temperature extremes, high-precipitation extremes and high-runoff extremes, as depicted in Table 5. Under RCP4.5 (RCP8.5), the area-averaged cold extremes in this region are expected to decrease by -4.0 % (-2.8 %) in FD and -6.8 % (-5.2 %) in ID, while the area-averaged warm extremes are projected to vastly increase by 57.2 % (50.8 %) in SU and 80.8 % (68.3 %) in TR. Similarly, the high-precipitation extremes are projected to increase by approximately 3.3~3.6 % (1.1~1.9 %) for PX1D, PX2D, PX3D, and PX5D and approximately 10.5 % (5.6 %) and 18.7 % (9.8 %) for P95 and P99, respectively. Consequently, the high-runoff extremes (i.e., MDF) are expected to increase by 3.4 % (0.3 %) under RCP4.5 (RCP8.5), which is likely to result in a risk of more intensified flooding. In contrast, the changes in the low-runoff extremes (DWF07 and DWF30) show nonsignificant change patterns in these regions as a result of small changes under a further 0.5 °C of global warming and substantial uncertainty in the GCM projections; this finding agrees with previous results (e.g., Chen et al., 2017; Donnelly et al., 2017; Marx et al., 2018). However, the change behavior in the hydroclimatic extremes (except for the low-runoff extremes) tends to be amplified at 2.0 °C of warming compared with 1.5 °C of warming regardless of the RCP. Although substantial changes in the characteristics of the various extreme indices are found under RCP8.5, the small differences in these change patterns between the two selected RCPs are evidenced by the large changes under the 1.5 °C warming condition in comparison to RCP4.5. More importantly, under RCP8.5, global warming is likely to occur faster, and the degree of warming is much higher (e.g., above 3.0 °C of global warming) compared to RCP4.5. Our results imply the necessity for mitigation to alleviate the negative impacts of anthropogenic warming and to reduce the increased risk of hydroclimatic extremes under a far warmer climate.

: As shown in Table 5, the unique regional responses (with high significance measured by the intermodal agreement level) of an extra 0.5 °C of global warming reveal the need for different adaptive measures to expected hydroclimatic extremes. Although the vulnerability of temperature extremes will be increased in all climate zones over Asia, the frequencies of summer days and tropical nights are increased by 10 % and 20 %, respectively, in cold climate regions (D zones) under extra global warming. This temperature-related risk is likely to increase the adverse effects on human health, such as heat-related illnesses. Regarding precipitation extremes, adaptation for intensified heavy rainfall in terms of both frequency and intensity will be needed in most climate zones except for some climate regions with dry summer features (e.g., BW, Cs, and Ds). Changes in heavy rainfall amplify the risks associated with flood extremes and consequently flood damage (e.g., loss of life and economic losses). The daily maximum runoff, which is related to flood hazards, will be increased by 4~8 % in zones Cw, Cf, Dw, and ET. Therefore, both structural (e.g., flood-adaptive design for hydraulic structures) and non-structural measures (e.g., flood forecasts and measurements) are needed for flood risk management in these regions. Although the potential impacts of low-runoff extremes (e.g., minimum consecutive 7-day and 30-day runoff) show low significance in all classified climate zones under extra global warming, the low-runoff extremes are amplified by more than 10 % at 2.0 °C of global warming compared to 1.5 °C of global warming in the western parts of India and the high-latitudes (above 40° N), thus increasing the risk of water supply issues for drinking and irrigation as well as drought conditions. As the global temperature increases, regional climate change impacts hydroclimatic conditions and related aspects (e.g., human health, water supply, water-related disasters, hydraulic structures, etc.). These results suggest positive benefits of 0.5 °C less of warming in terms of hydroclimate extremes and the necessity of adaptive regional planning.

Table 5: Plots of the percentage changes (%) in the climate extreme indices in response to additional warming of 0.5 °C in the climate zones over Asia under (a) RCP4.5 and (b) RCP8.5, where '*' and '' represent significance at the 80 and 100 % levels, respectively.**



2. Methodology: There are a number of issues here:

- a. Climate data: the analysis involves a number of steps and the text is a little hard to follow in this regard. For example, to select the five GCMs, a comparison with a multimodel mean is carried out (Page 3, line 117). But why are GCMs selected on the basis of their performance w.r.t the ensemble mean? Why not directly compare the individual GCM performance with the observed data and select those that best represent the observed climate in the Asia region? It is later revealed that a bias-correction is also carried out on the climate data. Was this bias correction carried out before or after the shortlisting of the five GCMs? Overall, the sequence of methods is unclear and many methodological choices are not defended well in the text. Maybe a flowchart to guide the readers through the main steps will help.

► We directly evaluated the performance of each individual GCM with the observed data and selected those that best represent the observed climate in Asia. However, to select the GCMs carefully under the assumption that the MME is similar to the observed data compared with each GCM (Xu et al., 2020; Tegegne et al., 2020), the lower-performing GCMs with relatively poor statistics compared with the MME are screened. Then, only the best-performing GCMs with better MME values are selected, and the MME is used only as a means of ranking the GCM. It is difficult to determine the lower-performing GCMs without a comparison between the individual GCMs and MME values because the comparison between each GCM and the observed data does not provide the information needed to exclude the GCMs. We have clarified this point in the revised manuscript.

: The spatial correlation coefficient (SCC) and root-mean-square error (RMSE) between the historical simulation fields derived from each GCM and the observed fields are calculated for each of the twelve relevant variables over the Asian monsoon region, as these statistics are commonly used to examine the performance of GCMs in the simulation of observed spatial climate features (IPCC, 2013; McSweeney et al., 2015). Next, we apply the MME-based scoring rule for the selection of GCMs (Nyunt et al., 2012) to exclude low-performing GCMs and identify only the best-performing GCMs using a relative concept because the scoring rule based on the observed data does not provide the information needed to screen the GCMs. Therefore, the individual GCM statistics (i.e., the SCC and RMSE) are judged by comparison with the MME statistic. The MME statistics are considered as criteria to score each GCM under the assumption that the MME is similar to the observed data compared with the output from only one GCM (Xu et al., 2020; Tegegne et al., 2020).

► For the second comment, bias correction method is carried out after selected the five GCMs. Raw GCM outputs are commonly used for GCM performance evaluations because GCM outputs are necessarily fitted to the observations after a bias correction. We added an explanation of this in the revised manuscript.

: The five of the raw GCMs of the Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2012) are selected by applying a unique evaluation procedure (Kim et al., 2020). Then, a reference 30-year period and two future 30-year periods of individual GCM projections are defined under warming targets of 0.48, 1.5 and 2.0 ℃ above PI levels (1861-1890) based on a time sampling method. Then, these daily forcing data (e.g., precipitation, maximum temperature, and minimum temperature) are extracted from the five selected GCM projections and then statistically bias-corrected using the quantile mapping method. The bias-corrected GCMs are used as meteorological forcings to run the variable infiltration capacity (VIC) hydrological model.

► For the final comments, we clarified all these points and modified the manuscript (section 2.1~section 2.6) with a flowchart (Figure 2) to guide the readers through the main steps.

: 2.3 Methodology

Figure 2 presents a flowchart of the entire procedure used in the study. To simulate the climate during both historical and future periods, climate projections forced by historical and representative concentration pathways (RCPs) 4.5 and 8.5 are selected. The five of the raw GCMs of the Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2012) are selected by applying a unique evaluation procedure (Kim et al., 2020). Then, a reference 30-year period and two future 30-year periods of individual GCM projections are defined under warming targets of 0.48, 1.5 and 2.0 ℃ above PI levels (1861-1890) based on a time sampling method. Then, these daily forcing data (e.g., precipitation, maximum temperature, and minimum temperature) are extracted from the five selected GCM projections and then statistically bias-corrected using the quantile mapping method. The bias-corrected GCMs are used as meteorological forcings to run the variable infiltration capacity (VIC) hydrological model. The future changes in the hydroclimatic mean and extremes corresponding to the conditions at warming targets of 1.5 and 2.0 ℃ are spatially analyzed according to the identified subregions based on climate zones. We focus on the hydroclimatic extreme responses to temperature, precipitation, and runoff variations under global warming targets (i.e., 1.5 and 2.0 ℃) using extreme indices. A more detailed description of each procedure is provided in section 2.4, section 2.5, and section 2.6.

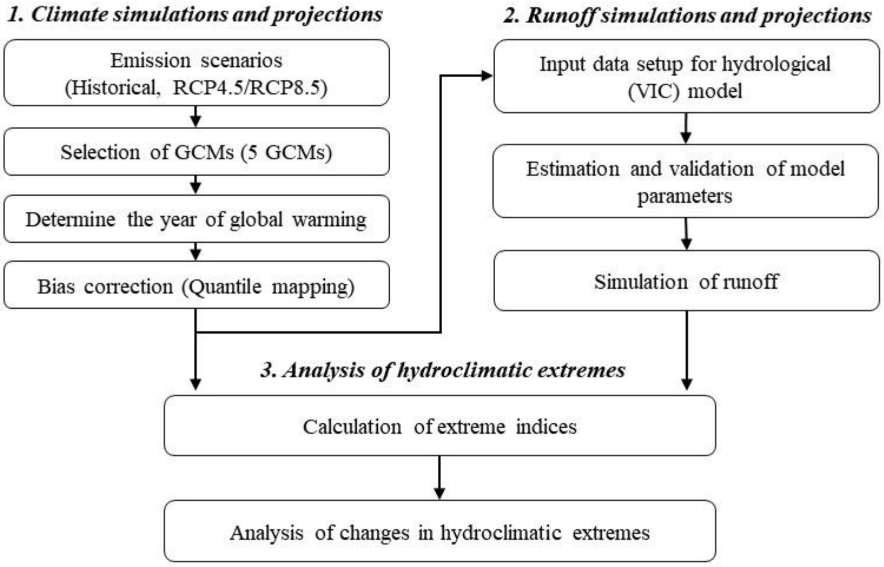


Figure 2: Flowchart of the entire procedure used in this study.

- b. Hydrologic model and runoff projections: the variable infiltration capacity model is a commonly used model to obtain continental to global scale runoff projections. However, many studies limit their analysis to understanding patterns in mean annual runoff. In this study, however, the focus is on runoff extremes, which are inherently harder to capture than a long-term mean value. However, the calibration and validation of the model are not included in the main manuscript. A regionalization approach is used to transfer parameters from gauged to ungauged sites, but how successful was this? It is important to show that the model with the regionalization scheme can capture the observed hydrologic extremes in the past. Only then, we can have some confidence regarding the reliability of the projections in the future.

► Thank you for this comment. We understand the concern raised by the reviewer. Of course, it is inherently harder to simulate long-term mean runoff extremes using a hydrologic model. However, the results can aid in understanding runoff features when observed data are not available, even though the results are limited when simulating realistic runoff extremes. We have implemented an additional validation basins (i.e., total 20 basins suggested in Figure S2 and Table S2) and added validation of simulated extreme runoff by comparing measured extreme runoff based on the monthly maximum values (suggested in Figure S4) and the limitation when discussing the simulation of runoff extremes using the VIC model (line 236-255).

: To evaluate the reliability of the runoff results, the simulated mean and extreme runoff (i.e., monthly maximum runoff) values are validated by comparing with measured data. In this study, the simulated runoff is driven by observational meteorological forcings for the historical period (1950-2005) to compare the historical runoff records obtained from the Global Runoff Data Centre (GRDC). Some parameter validation results for the VIC model in 20 river basins (Figure S2) considering the data availability of measurement records are suggested in Table S2, Figure S3 and Figure S4, and additional results can be found in a previous study (Bae et al., 2013). The simulated monthly mean runoff obtained from the VIC model using observational meteorological input data shows high temporal correlation with the observed pattern for 6 basins (See Figure S3) and the range of correlation coefficients over the 20 basins are 0.58~0.97 (See Table S2). To evaluate the accuracy of the VIC model, we also consider other quantitative statistics, such as the model efficiency (ME), root-mean-square error (RMSE), and volume error (VE), as shown in Table S2. In general, simulated runoff qualitatively and quantitatively simulates the measured runoff. Figure S4 presents the scatter plot and box-whisker diagram of measured and simulated monthly maximum runoff in the 20 basins. The assumptions used in parameter estimation and runoff analysis at the continental scale may impact the uncertainty in simulating monthly maximum runoff (See Figure S4a and Figure S4b), especially in capturing extreme runoff periods. Because it is inherently more difficult to simulate long-term mean runoff extremes using a hydrologic model, uncertainty exists between the simulated and measured extreme runoff data. Although simulated monthly maximum runoff (denoted as SIM) tends to underestimate the measured values (denoted as OBS), SIM commonly reproduces the OBS in terms of inter-quartile range (See Figure S4b) and the biases compared to variation range of OBS (See Figure S4c). The results can aid in understanding runoff features when observational data are not available, even though the results are limited when simulating realistic runoff. Overall, the validation results suggest that the VIC model is able to simulate mean and extreme runoff adequately.

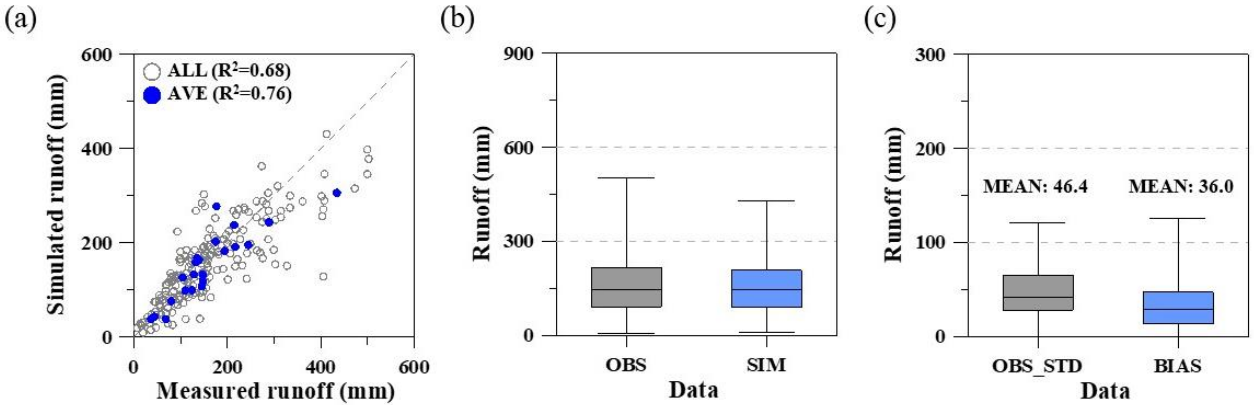


Figure S4: (a) Scatter plot of measured monthly maximum runoff and simulated monthly maximum runoff from the VIC model fed by observational meteorological input for all cases in the selected 20 basins (ALL: grey circles) and averages of all cases in each basin (AVE: blue circles) and (b) Box-whisker plot of measured monthly maximum runoff (denoted by OBS on the x-axis) and simulated monthly maximum runoff (denoted by SIM on the x-axis) in the 20 basins (unit: mm). (c) Box-whisker plot of the standard deviation of the observed monthly maximum runoff for all cases (denoted by OBS-STD on the x-axis) and the biases between OBS and SIM (denoted by BIAS on the x-axis).

▶ We added a detailed description of the applied regionalization scheme and showed the scheme in the supporting information.

: We apply the hydrological regionalization method by transferring parameters obtained from gauged regions to ungauged regions based on the assumption that two basins with analogous climate features (e.g., based on the climate zone classification) exhibit similar hydrological responses. For runoff simulations at the global scale, Nijssen et al. (2001) obtained the parameters for an ungauged basin from the estimated parameters of a gauged basin with the same temperature and precipitation features. Xie et al. (2007) and Bae et al. (2013) employed the same approach leveraging climatological similarity according to Köppen's climate classification method and suggested the applicability of this method over China and Asia, respectively. In this study, both gauged basins and ungauged basins are divided into one of the climate zones to apply the hydrological regionalization method. We examine the optimal parameters for individual climate zones that effectively simulate runoff based on the estimated parameter sets obtained from all gauged basins within each climate zone. The optimal parameters of each climate zone are then transferred to the ungauged basins belonging to the same climate zone. In our previous study, the regionalization results were verified by assuming that some gauged basins are considered ungauged basins (Bae et al., 2013), and the results support the adaptability and applicability of the VIC model to simulate runoff throughout our study area.

▶ For the final comments, we added detailed description of the validation results for VIC model including the validation of simulated mean and extreme runoff in comparison with measured extreme runoff (suggested in Table S2 and Figure S2-S4) and Table S2 Table S3 and line 236-255; (see response to first comment No. 2b)

- c. Choice of extreme indices: The choice of indices for precipitation and runoff seem counter-intuitive. The precipitation indices focus on only high precipitation events while the runoff indices focus on both high and low events. Why not include precipitation extremes that involve minimum or very low precipitation?

► We understand the concern raised by the reviewer. We set all daily precipitation amounts below 1.0 mm/day in the simulations to zero because GCMs tend to produce too little precipitation (<1 mm/day). Therefore, we did not include an analysis of the minimum or very low precipitation indices. In addition, for low precipitation extremes, although there is a duration-based concept (such as the dry spell length, which was suggested by the Expert Team on Climate Change Detection and Indices (ETCCDI)), this concept does not exactly match with low runoff events.

- d. Selection of time periods: A time sampling method is used to identify the time period of analysis for various GCMs. The authors arrive at single time period for each GCM warming level. This suggests that a spatially aggregated value of climate indices was used to identify the time periods. However, the analysis focuses on different climate regions and it is possible that each climate region reaches a global warming level in different time periods. Why was this spatial heterogeneity ignored? The same applies on the bias correction methodology, which could have been applied on each homogeneous climate region one by one. On a similar note, the climate zone classification results are presented in Line 206 onwards. Is this classification carried out using observed data or GCM data? How sensitive is the classification to the choice of climate data?

► Thank you for this comment. Of course, it is possible that each climate region does not present the same regional temperature increase as that occurring at the global scale. Therefore, globally aggregated warming targets do not necessarily mean that they can be universally acceptable because an increase in the global mean temperature does not translate into regional and local impacts in a straightforward manner (Knutti et al., 2015). In this regard, it is necessary to identify regionally emerging challenges faced by global warming targets because global warming levels above the preindustrial level are a global concept that is defined based on the globally aggregated mean temperature rather than the regional mean temperature. Based on these issues, we assessed the different regional hydroclimatic extreme climatic responses to global warming in this study.

► For the second comment, statistical bias correction (e.g., quantile mapping) methods adjust the simulated climate outputs by fitting the observed climate features. In general, the bias correction method is performed for each grid cell (or each point) data corresponding the gridded GCM outputs and observed data with the grid system. Therefore, we apply the quantile mapping method for each grid cell within the study domain.

► The climate classification is carried out using observed data for a long-term historical period (1976-2005). We clarify this point in the revised manuscript as follows:

: The climate zones over the Asian monsoon region in this study are classified based on long-term (30-year; 1976-2005) observation datasets (i.e., precipitation from APHRODITE; minimum and maximum temperatures from the University of Washington).

▶ For the final comment, the substantial differences exist among the individual observation datasets due to the analysis methodology such as the quality control of input data and spatial/temporal interpolation used in producing these simulated datasets. Therefore, the observation datasets after the data quality management process (e.g., quality control, homogeneity testing) show similar spatial features though partly with biases (Tanarhte et al., 2012). Therefore, the classification of climate zone depends on the applied climate data (e.g., data sources, data periods). For instance, a level of uncertainty in the areas occupied by different Koppen climate type is smaller than 1% using the different period historical dataset (Kalvová et al., 2003).

Kalvová, J., Halenka, T., Bezpalcová, K. et al.: Köppen Climate Types in Observed and Simulated Climates, Studia Geophysica et Geodaetica 47, 185–202, 2003

Tanarhte, M., Hadjinicolaou, P. and Lelieveld, J.: Intercomparison of temperature and precipitation data sets based on observations in the Mediterranean and the Middle, Journal of Geophysical Research, 117, 1-12, 2012

- *e. Choice of scenarios: it is not clear why RCP4.5 was chosen for the analysis when RCP6.0 and RCP8.5 are equally relevant.*

▶ Thank you for this comment. As the reviewer and editor suggested, we have implemented an additional RCP (i.e., RCP8.5); we have analyzed the results of changes in hydroclimatic extremes under 1.5 and 2 °C of global warming based on two different RCPs in the revise paper (i.e., RCP4.5 and RCP8.5). In this regard, We have clarified the reason why we selected 2 RCPs as follows:

: Our focus is to understand the changes in extreme hydroclimatic conditions under global warming environments of 1.5 and 2.0 °C. The timing to reach specific warming levels for individual GCMs depends on the representative concentration pathway because future projections are forced by these scenarios. The temperature response to different RCPs varies, and therefore, the increasing trend and slope of the global mean temperature differ. Here, the analysis is based on RCP4.5 and RCP8.5, which are commonly considered for realistic future projections. RCP4.5 is a stabilized emission scenario with radiative forcing of approximately 4.5 W/m2 in the year 2100, and this value is never exceeded (Thomson et al., 2011; Van Vuuren et al., 2011). This scenario assumes that emission mitigation policies are implemented to limit emissions and radiative forcing. On the other hand, RCP8.5 is a very high emission scenario with radiative forcing of approximately 8.5 W/m2 in the year 2100. Although the global warming process under RCP4.5, which is based on a medium-low GHG emission pathway is relatively slow compared to higher GHG emissions (e.g., RCP8.5), many studies have suggested that the global warming climate under RCP4.5 exerts impacts on hydroclimatic phenomena (Chen et al., 2017; Donnelly et al., 2017; Kim et al., 2020). However, global warming impacts under different RCPs on the regional changes of hydroclimatic extremes are not simple. In this regard, the results based on two RCPs (RCP4.5 and RCP8.5) can provide useful information for identifying the impacts of global warming on hydroclimatic extremes from those expected under different RCPs. This implies the need for minimum mitigation strategies as well as adaptation plans according to the global warming induced by GHG emissions, even those under the relatively low-impact RCPs (e.g., RCP4.5).

3. Presentation: Overall, the manuscript can gain from improvement in language. In addition, the figure clarity can be improved. The figure captions are not very descriptive and it is hard to follow what is on the figures without carefully reading the main text. Please explain all symbols and abbreviations used in the figures in the caption itself.

► The English grammar and expression have been polished by a professional agency.

► We upgraded the figures to high quality (600 dpi).

► We have thoroughly reviewed and modified the figure captions (including all symbols and abbreviations).

References (Added)

Liu, J., Xu, H., Luo, J.J. and Deng, J.: Distinctive Evolutions of Eurasian Warming and Extreme Events Before and After Global Warming Would Stabilize at 1.5 °C, Earth's Future, 7, 151-161, 2019.

McSweeney, C.F. Jones, R.G., Lee, R.W. and Rowell, D.P: Selecting CMIP5 GCMs for downscaling over multiple regions, Climate Dynamics, 44, 3237-3260, 2015.

Tegegne, G., Melesse, A.M. and Worqlul, A.W.: Development of multi-model ensemble approach for enhanced assessment of impacts of climate change on climate extremes, Science of The Total Environment, 704, 12321-12330, https://doi.org/10.1016/j.scitotenv.2019.135357, 2020.Yatagai, A., Kamiguchi, K., Arakawa, O., Hamada, A., Yasutomi, N. and Kitoh, A.: APHRODITE: Constracting a Long-Term Daily Gridded Precipitation Dataset for Asia Based on a Dense Network of Rain Gauges, Bulletin of the American Meteorological Society, 93, 1401-1415. https://doi:10.1175/BAMS-D-11-00122.1, 2012.

Thomas, V., Albert, J.R.G., and Perez, R.T.: Climate-Related Disasters in Asia and the Pacific, ADB Economics Working Paper Series No. 358, Asian Development Bank, Philippines, 38 pp., 2013.

Thomas, V., Albert, J.R.G., and Hepburn, C.: Contributors to the frequency of intense climate disasters in Asia-Pacific countries, Climatic Change, 126, 381-398, https://doi.org/10.1007/s10584-014-1232-y, 2014.

Thomas, V., and Lopez, R.: Global increase in Climate-Related Disasters, ADB Economics Working Paper Series No. 466, Asian Development Bank, Philippines, 38 pp., 2015.

Xu, Y., Gao, X. and Giorgi, F.J.: Upgrades to the reliability ensemble averaging method for producing probabilistic climate-change projections, Climate Res., 41, 2375-2385, 2010.

Zhao, Y., Li, Z., Cai, S. and Wang, H.: Characteristics of extreme precipitation and runoff in the Xijiang River Basin at global warming of 1.5 °C and 2 °C, Natural Hazards, 101, 669-688, 2020.

Reply to Editor's Comments:

Thank you for your interesting manuscript and taking part in discussion round. Two referees have carefully reviewed your paper and ranked your work from fair to good. While they concur that the overall topic is interesting - they have also pointed out number of limitations/issues. Both reviewers also kindly expressed their willingness to review the revised manuscript. I would invite you to revise the manuscript taking into account all the suggestions/comments of both reviewers into account.

► We appreciate the review's and editor's feedback and helpful comments. Kindly find our detailed response to each comment below.

As both reviewers have stated - please pay careful attention 1) to state the novelty of your study beyond what is already available in the research domain on possible consequences of 1.5 ℃ and 2.0 ℃ global warming including hydrometeorological extremes – or in words of the Reviewer #2 "to justify how their analysis adds value to this literature". 2) More careful consideration on the skill of the VIC model in simulating hydrologic extremes – employ a range of river basins in the study domain (than just six ones in Asia Monsoon region; available in the GRDC archive/other sources) to gain more confidence in overall model based assessment results. And 3) also pointed by me earlier in preliminarily round and also echoed by the Reviewer – I strongly suggest the authors to implement other RCP scenarios (6.0/8.5) – and contrast their findings with respect to that of the RCP4.5.

► Thank you for this comment. We fully agree with your valuable suggestion. We have added a discussion in "Section 4. Discussion and conclusions" to provide an in-depth survey of relevant research on hydroclimatic responses to global warming and to emphasize the meaningful contribution of this manuscript to the literature. We have suggested the need for different adaptive measures based on unique regional responses, especially those of the hydroclimatic extremes, to an additional 0.5 °C of global warming. We have also clarified these points in an organized way in the manuscript (see response to Reviewer #2 first comment)

► We understand the concern raised by the reviewer. To enhance the reliability of the runoff simulations, we have added more validation (i.e., total 20 basins suggested in Figure S2 and Table S2) of the simulated mean runoff and extreme runoff (e.g., monthly maximum values) by comparing the measured extreme runoff (Figure S4) with additional observational runoff data for river basins in the study domain. Also, we have added spatial distributions of the observation-driven runoff simulation and MME-driven runoff simulation in terms of both annual mean runoff and daily maximum runoff for the entire domain in Figure S6. Finally, we have indicated the limitations of this work when discussing the simulation of runoff extremes using the VIC model. The added text is as follows:

: To evaluate the reliability of the runoff results, the simulated mean and extreme runoff (i.e., monthly maximum runoff) values are validated by comparing with measured data. In this study, the simulated runoff is driven by observational meteorological forcings for the historical period (1950-2005) to compare the historical runoff records obtained from the Global Runoff Data Centre (GRDC). Some parameter validation results for the VIC model in 20 river basins (Figure S2) considering the data availability of measurement records are suggested in Table S2, Figure S3 and Figure S4, and additional results can be found in a previous study (Bae et al., 2013). The simulated monthly mean runoff obtained from the VIC model using observational meteorological input data shows high temporal correlation with the observed pattern for 6 basins

(See Figure S3) and the range of correlation coefficients over the 20 basins are 0.58~0.97 (See Table S2). To evaluate the accuracy of the VIC model, we also consider other quantitative statistics, such as the model efficiency (ME), root-mean-square error (RMSE), and volume error (VE), as shown in Table S2. In general, simulated runoff qualitatively and quantitatively simulates the measured runoff. Figure S4 presents the scatter plot and box-whisker diagram of measured and simulated monthly maximum runoff in the 20 basins. The assumptions used in parameter estimation and runoff analysis at the continental scale may impact the uncertainty in simulating monthly maximum runoff (See Figure S4a and Figure S4b), especially in capturing extreme runoff periods. Because it is inherently more difficult to simulate long-term mean runoff extremes using a hydrologic model, uncertainty exists between the simulated and measured extreme runoff data. Although simulated monthly maximum runoff (denoted as SIM) tends to underestimate the measured values (denoted as OBS), SIM commonly reproduces the OBS in terms of inter-quartile range (See Figure S4b) and the biases compared to variation range of OBS (See Figure S4c). The results can aid in understanding runoff features when observational data are not available, even though the results are limited when simulating realistic runoff. Overall, the validation results suggest that the VIC model is able to simulate mean and extreme runoff adequately.

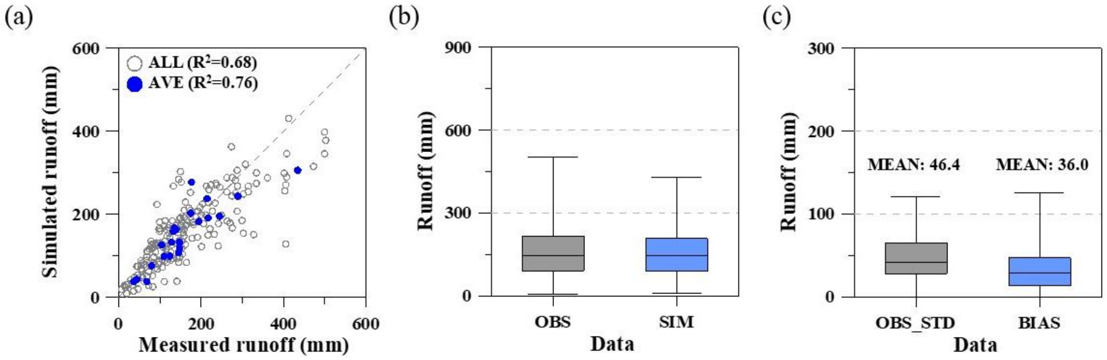


Figure S4: (a) Scatter plot of measured monthly maximum runoff and simulated monthly maximum runoff from the VIC model fed by observational meteorological input for all cases in the selected 20 basins (ALL: grey circles) and averages of all cases in each basin (AVE: blue circles) and (b) Box-whisker plot of measured monthly maximum runoff (denoted by OBS on the x-axis) and simulated monthly maximum runoff (denoted by SIM on the x-axis) in the 20 basins (unit: mm). (c) Box-whisker plot of the standard deviation of the observed monthly maximum runoff for all cases (denoted by OBS-STD on the x-axis) and the biases between OBS and SIM (denoted by BIAS on the x-axis).

► As the reviewer suggested, we have implemented an additional RCP (i.e., RCP8.5); we have analyzed the results of changes in hydroclimatic extremes under 1.5 and 2.0 °C of global warming based on two different RCPs in the revise paper (i.e., RCP4.5 and RCP8.5). Moreover, we have presented the results and these points in an organized way in manuscript (in “Section 3. Results” and “Section 4. Discussion and conclusions”).