Dear editors and reviewers:

On behalf of my co-authors, thank you very much for your attention to our paper “Regional difference in runoff regimes and changes in the Yarlung Zangbo river basin”. My co-authors and I think that all the comments are valuable and very helpful for us to improve the manuscript. We have carefully revised the manuscript according to the reviewers’ comments.

We hope this manuscript will satisfy the requirement of the Hydrology and Earth System Sciences.

Best regards

He Sun

REVIEWER COMMENTS:

Reviewer #2: This study presents modeling results of the hydrological regime in subbasins of the YZ basin from 1971 to 2020. The authors compare the variations in runoff components and their change trends across the subbasins. I have a couple of concerns regarding the motivation, methodology, and discussion, which the authors may consider for further improvement of their work:

The authors should reduce the number of self-citations in the introduction and discussion sections. The frequency of citing works published by their own group is too high in the text. It would be more appropriate to include a wide range of peer research from other groups in the same study area. Citing research findings from other groups can provide more robust evidence for their statements.

Reply:

Thanks for the comments. We have reduced the number of self-citations, and cited some research findings from other groups in the revision.

The authors need to provide more evidence or references to support their claims about the novelty of this work (lines 133-138). They should explain why spatially varied runoff regimes are important and novel compared to previous studies. Additionally, they should clarify why model validation using an observational hydrometeorological network is considered new. It would also be helpful to explain the novelty of using their own precipitation dataset for model running.

Reply:

We introduce several novel components which may advance our understanding of the YZ hydrology:

(1) "The analysis uncovers spatially varying runoff regimes and changes across six sub-basins of the YZ basin, associated with heterogeneous surface characteristics." Previous relevant studies in the YZ mostly focused on the region above Nuxia (NX) hydrological station (Chen et al., 2017; Cuo et al., 2019; Su et al., 2016; Zhang et al., 2013; Zhao et al., 2019; Cui et al., 2023; Gu et al., 2023), but few studies have been conducted in the downstream region between the NX and Pasighat outlet (NX-BXK), which accounts for about 65% of total glacier areas and 52% of total runoff in the YZ, mostly due to the lack of hydrometeorological observations.

(2) "A basin-wide observational hydrometeorology network is used to validate glacier-hydrological model to

quantify runoff processes under climate-cryosphere changes." Most studies only validate hydrological models using streamflow observations, yet realistic runoff simulations at the catchment outlet cannot guarantee reasonable simulation results (Zhao et al., 2019) because of the compensation between precipitation-induced runoff and glacier runoff. We have collected precipitation observations at 280 gauges, streamflow observations at eight hydrological stations, glacier mass balance observations at two sites, and satellite-based glacier and snow cover area estimates in the YZ basin. These constitute a basin-wide observation dataset enabling us to validate hydrological models, and reveal runoff regimes and flow changes in the YZ basin.

(3) "A comprehensive long-term precipitation dataset with a high spatiotemporal resolution (Sun et al., 2022) is used to improve the accuracy of precipitation estimates and hydrological simulations in this high-altitude basin." The daily precipitation data with a spatial resolution of 10×10 km for 1961–2020 were corrected from the newly released fifth-generation reanalysis (ERA5) precipitation of the European Centre for Medium-Range Weather Forecasts (ECMWF) based on 580 rain gauges in the monsoon-dominated TP region and the machine learning algorithm. The developed precipitation data set was evaluated at a point scale by comparing it with gauge observations, and has been inversely evaluated by the hydrological model.

We expect these findings will provide a basic framework to study cryospheric basin hydrological cycles in the TP with complex terrain and climate controls and limited observations, and assist policy-makers and water managers in adopting strategies based on a solid scientific understanding." We have made these points clear in the revised text.

It is necessary to include a methodology section to provide more details on how the change trend of runoff was tested, how the change point of 1997-1998 was identified, and how the change trends were attributed.

Reply:

The change trend of runoff was calculated by a linear regression.

"Cuo et al. (2019) examined the precipitation and streamflow mutations by the Mann-Kendall analysis in the YZ basin, and suggested that precipitation shows no mutation while streamflow mutates in 1997 at NX hydrological station." Therefore, we separated the simulation time period based on the year 1998. We have made these points clear in the revised text (Lines 362–364).

Reference

Cuo, L., Li, N., Liu, Z. et al., 2019. Warming and human activities induced changes in the Yarlung Tsangpo basin of the Tibetan plateau and their influences on streamflow. J. Hydrol-Reg. Stud. 25. https://doi.org/10.1016/j.ejrh.2019.100625

In the discussion, the authors should compare their results of runoff component contributions with findings from other studies. Although Table 4 is listed, it is not discussed in the text. Moreover, the authors should also compare their runoff change trend in subbasins up to the NX station with other studies.

Reply:

Thanks for the comments. We have compared our results of runoff component contributions and runoff changes in subbasins up to the NX station with other studies in the Discussion section.

"There is consistent that total runoff shows non-significant increasing trend in the NX basin (Cuo et al., 2019; Tang et al., 2019; Wang et al., 2021). Cuo et al. (2019) suggested that annual streamflow, available for longer periods, exhibits non-significant increasing trends at Rikaze, Lhasa, Yangcun and Nuxia hydrological stations. Our results was similar to existing studies in the NX basin. However, between existing research and our study, results are contradictory on runoff changes in the NX-BXK. Wang et al. (2021) suggested that total runoff showed an increasing trend of 6.4×10^8 m^3/yr during 1998–2019. However, in our study, simulated total runoff exhibited a decreasing trend of about -0.3 mm/10yr (-7.5×10^8 m^3/yr) during 1998–2020 in the sub-basin (Figure 8, Table 3). This difference between the two studies is mostly because of the trends in precipitation estimates used for the hydrological model (Figure 11). Precipitation shows increasing trends of 90 mm/10yr during 1981–2016 and 19 mm/10yr during 1998–2016 in Wang et al. (2021), compared with decreasing trends of -110.0 mm/10yr during 1981–2016 and -84.0 mm/10yr during 1998–2016 in this study. In addition, a decreasing trend of atmospheric moisture during the monsoon season in the sub-basin also partly confirms the rationality of the reconstructed precipitation used in this study as model input.

The varition of precipitation datasets for high mountains may result in large differences in meltwater contribution. For the NX basin, glacier melt contributed about 2–18% to total runoff in the existing researches (Table 4), mostly resulting from differences in forcing inputs and parameters for VIC-Glacier models. For example, with the VIC-Glacier model driven by corrected CMA data, Zhang et al. (2013) estimated a mean annual contribution of 11.6% from glacier runoff to total flow. Zhao et al. (2019) simulated glacier runoff by the VIC-Glacier model driven by interpolated CMA data, and estimated a mean annual contribution of 5.5% from glacier runoff to total flow. Less attention about the contribution of glacier runoff in the YZ basin was paid to the NX-BXK (Table 4), and large inconsistencies in glacier contributions also existed in these studies (Table 4), mostly resulting from uncertainties in forcing inputs and parameters for VIC-Glacier models. For example, Sun and Su (2020) suggested that mean annual glacier runoff contributed of about 45% to total runoff in the NX-BXK sub-basin for 1980–2000 using a hydrological model without calibration and validition due to a lack of runoff observation in the sub-basin. Based on newly collected rain gauge data, and runoff, glacier mass balance, and glacier and snow cover observations in the NX-BXK, glacier runoff is simulated by the well-validated VIC-Glacier model forced by a comprehensively reconstructed long-term precipitation dataset in this study. The contribution of glacier runoff to total runoff is updated to 19% during 1971–2020 in the NX-BXK sub-basin.

"

The conclusions section is lengthy and wordy. It would be beneficial to make it more concise and present the novel findings in a straightforward manner.

Reply:

We have reorganized the Conclusions section.

“In this study, runoff regimes, flow changes and the attribution are comprehensively investigated across six sub-basins in the YZ for 1971–2020 with a particular focus on the comparison between the NX and NX-BXK based on a newly generated precipitation dataset and the well-validated large-scale VIC-Glacier model with observed streamflow at eight hydrological stations, glacier mass balance data at two sites, and satellite-based glacier and snow cover estimates. Large regional differences in runoff regimes and flow changes in the YZ basin were observed. The main features of these differences are summarized below.

1. Regional differences in runoff regimes are presented in the YZ basin. The NX-BXK contributes 52% to total runoff at the Pasighat outlet of the YZ basin, followed by the YC-NX (25%), LS (10%), and other sub-basins (3%–6%). Although runoff generation in the entire YZ is dominated by rain-induced (59%–72%), glacier runoff plays more important roles in annual total runoff in the downstream sub-basins (16%–19%) than other sub-basins, especially in summer (23%–35%).

2. Regional differences in annual and seasonal runoff changes are found in the YZ basin. Annual runoff generally increases (8–19 mm/10yr) during 1971–2020 in all sub-basins of the NX basin, but a significant decreasein the NX-BXK sub-basin (-9.4 mm/10yr, $p<0.05$). Total runoff trends reverse after 1998 for all the sub-basins of the YZ, with increasing trends during 1971–1997 and decreasing trends during 1998–2020. Relative to 1971–1997, mean monthly total runoff increased by 5%–22% in NX for 1998–2020, mostly due to increases in rain-induced and glacier runoff, while monthly runoff decreased by 3%–20% in NX-BXK because of decreases in precipitation-induced runoff.

3. Regional differences in extreme frequency of flood and drought are apparent in the YZ basin. The NX basin faces a considerably hazard from extreme flood, with an increasing trend of 6 days/10yr. However, more severe hydrological droughts are likely to exacer-bate ongoing water stress in the NX-BXK sub-basin. Glacier runoff shows limited roles in mitigating water shortages caused by the drought in dry seasons in the YZ basin, but it intensifies flood frequency and severity among the basins in wet season.”

Specific comments:

Line 80: "Less" - Please provide examples.

Reply:

Many studies simply focused on the region upstream of the Nuxia (NX) hydrological station, and only Wang et al. (2021) comprehensively analyzed runoff changes and components in the NX-BXK sub-basin.

Reference

Wang, Y., Wang, L., Zhou, J., Yao, T., Yang, W., Zhong, X., Liu, R., Hu, Z., Luo, L., Ye, Q., Chen, N., and Ding, H.: Vanishing glaciers at southeast Tibetan Plateau have not offset the declining runoff at Yarlung Zangbo, Geophys. Res. Lett., https://doi.org/10.1029/2021gl094651, 2021.

Line 95: Cite research from other groups.

Reply:

We have replaced by "Although many hydrological studies focus on the region upstream of the NX hydrological station (Zhang et al., 2013; Lutz et al., 2014; Zhao et al., 2019; Sun and Su, 2020; Khanal et al., 2021; Nan et al., 2021; Wang et al., 2021), regional characteristics are still unclear in the basin."

Line 105: Existing studies - cite more research from other groups.

Reply:

We have cited more research from other groups.

Line 112: Most studies - cite relevant studies in the study area. Moreover, Duethmann et al. (2014) ran their model in central Asia, which is not suitable for this study.

Reply:

We have replaced by “Zhao et al., (2019)”.

Reference

Zhao, Q., Ding, Y., Wang, J., Gao, H., Zhang, S., Zhao, C., Xu, J., Han, H., and Shangguan, D.: Projecting climate change impacts on hydrological processes on the Tibetan Plateau with model calibration against the Glacier Inventory Data and observed streamflow, J. Hydrol., 573, 60-81, https://doi.org/10.1016/j.jhydrol.2019.03.043, 2019.

Line 130: Adaptation strategies.

Reply:

We have replaced by “adaptation strategies”.

Line 221: What does "adjusted" mean?

Reply:

We have replaced by “determinate”.

Line 238: Are there references for these thresholds?

Reply:

“Here, the 95% and 5% probability of exceedance is defined as the threshold of flood and hydrological drought events (Hoang et al., 2016; Su et al., 2022)”

Reference

Hoang, L. P., Lauri, H., Kummu, M., Koponen, J., van Vliet, M. T. H., Supit, I., et al. Mekong River flow and hydrological extremes under climate change. Hydrol. Earth Syst. Sci., 20(7), 3027-3041.

https://doi.org/10.5194/hess-20-3027-2016, 2016.

Su, F., Pritchard, H. D., Yao, T., Huang, J., Ou, T., Meng, F., Sun, H., Li, Y., Xu, B., Zhu, M., and Chen, D.: Contrasting Fate of Western Third Pole's Water Resources Under 21st Century Climate Change, Earth's Future, 10, https://doi.org/10.1029/2022ef002776, 2022.

Lines 437-458: Add references from other groups.

Reply:

We have added references from other groups.

Figures 2a-b: Why not show a direct comparison between simulated and observed GMB (without normalization)? RGI is not satellite-based.

Reply:

We used normalization in this study because of strict data sharing policies.

Figures 3-6: Show results separately for the calibration and validation periods. Readers would be more interested in seeing the performance during the validation period.

Reply:

Thanks for the comments. We have provided more information about the calibration and validation processes.

"To adjust the model internal stores of energy and water from the initial condition to an equilibrium state, the VIC-Glacier model is run for the years 1961–1970 as spin-up, and the years of 1971–2020 for simulation in this study. In addition, 1971–2000 is selected as the calibration period and 2001–2015 the validation period for the VIC-Glacier model based on the observed monthly streamflow for 1971–2015.

The VIC-related model parameters (mostly B_inf and D2) are calibrated and validated with streamflow observations at eight hydrological stations across the six sub-basins. The B_inf which defines the shape of the variable infiltration capacity curve has a common range of 0–0.4 (Liang et al., 1996; Shi et al., 2008). The D2 mainly determines the moisture storage capacity in the VIC model, which has a range of 0.5–1.0 (Liang et al., 1996; Shi et al., 2008). The final values of the B_inf and D2 are usually calibrated at basin scales to match observed streamflow.

The VIC-Glacier model captures well the magnitudes and patterns of observed runoff at daily, monthly, and seasonal scales, with NSEs of 0.83 to 0.96 and RBs of less than 5.0% for the calibration period of 1971–2000 and NSEs of 0.78 to 0.92 and RBs of -8% to 2% for the validation period of 2001–2015 across the sub-basins. After the careful calibration and validation, in this study, the final values of D1, D2 and B_inf for each grid cell are set to 0.1 m, 0.8–1.5.0 m, and 0.2 across six sub-basins (Table 1), respectively. The three base flow parameters (Dsmax, Ds, Ws) and the first layer depth (D1) is adopted from Sun and Su (2020) without further calibration.”

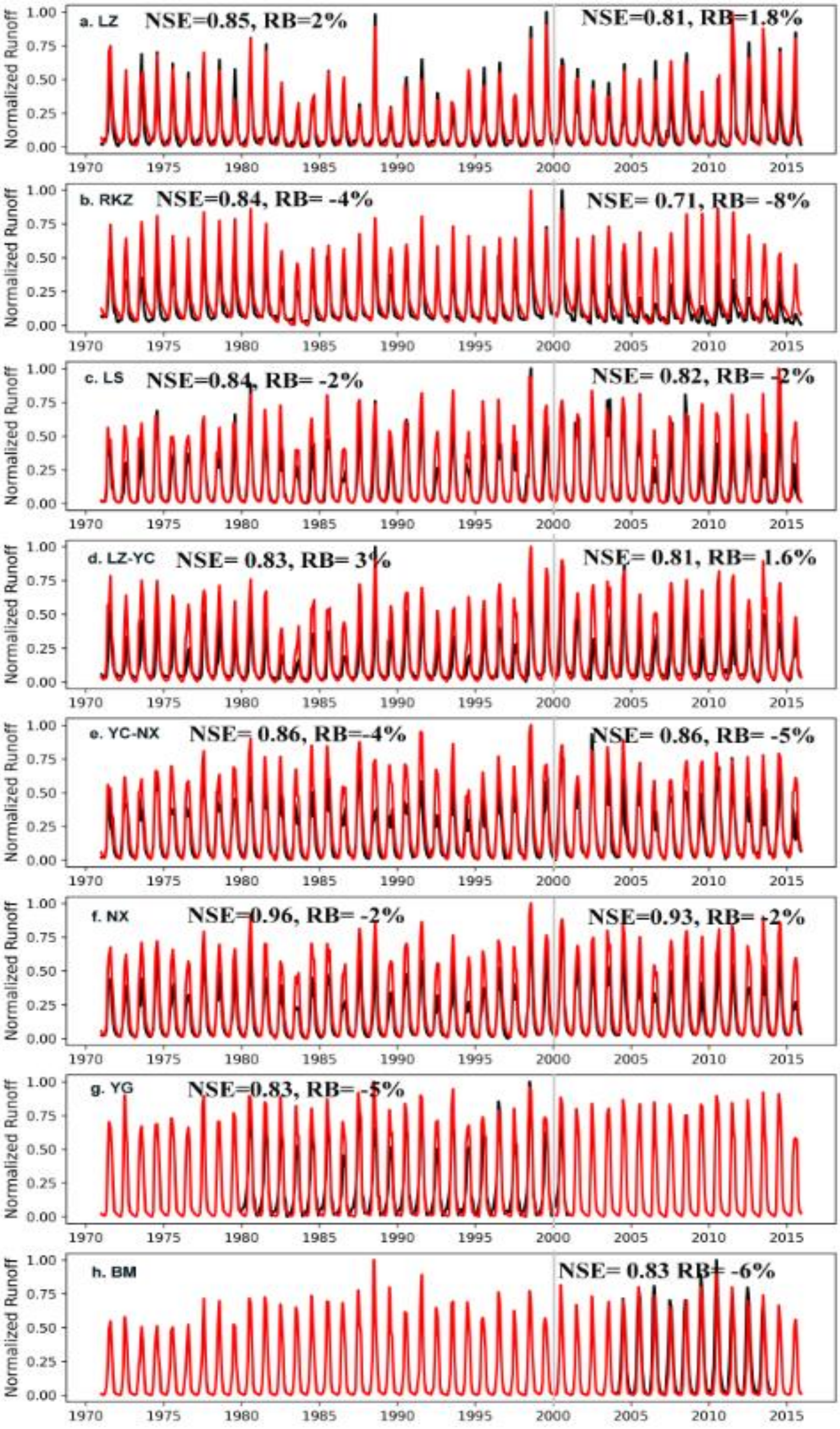

Figure S1. Monthly time series of observed and simulated runoff at eight hydrological stations in sub-basins of the YZ for 1971–2015 (1981–2000 for YG and 2004–2013 for BM).

Figure 6: How was the snow area coverage simulated in the model? Please specify in the methodology section.

Reply:

We have added it in the methodology section.

"The VIC snow model considers snow in several forms: ground snow pack, snow in the vegetation canopy, and snow on top of lake ice. The model has the following main features: (1) ground snow pack is quasi 2-layer; the topmost portion of the pack is considered separately for solving energy balance at pack surface. (2) considers partial snow coverage; (3) considers blowing snow sublimation.

Ground snow accumulation and melt are simulated using a two-layer energy-balance model at the snow surface, similar to that described by Anderson (1968). The snowpack is divided into two layers (a thin surface layer and the pack layer) and all the important heat and energy fluxes are considered (longwave and shortwave radiation, sensible and latent heat, convective energy). Internal energy of the snowpack is also considered. The ground heat flux is ignored (unless the frozen soil model is used). Water can be added to the snowpack as rain, snow, or drip/throughfall from the canopy. If snow is present it is assumed to completely cover the ground, thereby affecting radiation transfer and the wind profiles via increased albedo and decreased surface roughness (the snow surface roughness is used).

In every time step the model calculates the rain or snow fraction that is added to the snowpack. Then all the energy fluxes are calculated and if the energy balance is positive melt occurs. If the liquid water holding capacity of both the surface and pack layers are exceeded then the excess liquid water is immediately released as snowpack outflow. If the energy balance is negative, then the energy balance is solved by iterating on the snow surface temperature."

Figure 8: Remove the table and refine the sub-figures (colors, fonts, lines...).

Reply:

We have refined the figure 8 in the revision.

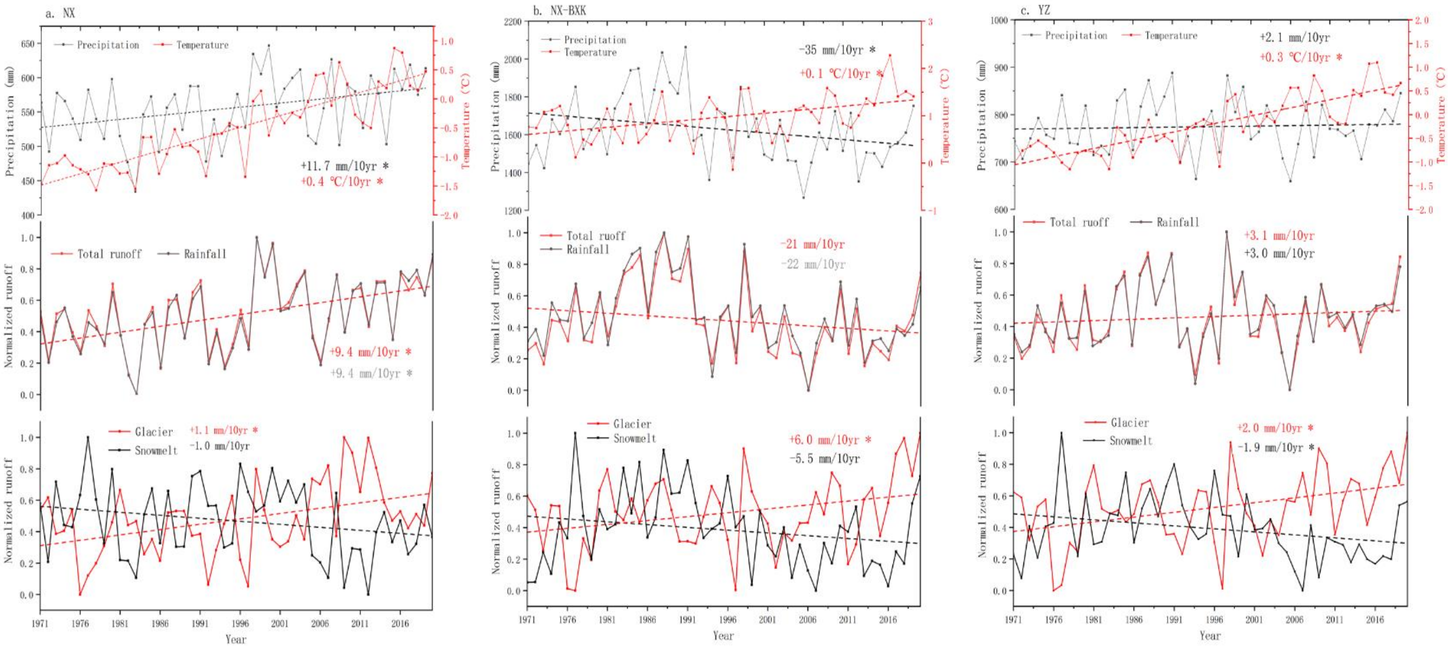

Figure 8. Annual variations of precipitation, temperature, total runoff, and three runoff components (rainfall, glacier, and snowmelt runoff) in the YZ and its sub-basins for 1971–2020, respectively. Linear trends are indicated by dashed lines, and corresponding values are also indicated. The number of each figure are calculated with actual magnitudes. Asterisks indicate the 95% significance level.

Figure 11: How was the change rate calculated? Please specify in the methodology.

Reply:

The change trend of runoff was calculated by a linear regression.

Table 1: What are the periods for snow cover area and fraction?

Reply:

It is from 2001 to 2019.

Tables 2-3: Add bottom lines for the first column.

Reply:

We have added bottom lines in the revision.

Table 3: How were the change trends tested? Please specify in the methodology.

Reply:

The change trend of runoff was calculated by a linear regression, and tested by chi-square goodness of fit.

Add a table to compare and discuss hydrological model parameters in the subbasins.

Reply:

We have added a Table, and discussed uncertainties of model parameters in hydrological simulations in the revised version.

Table 1. Characteristics of the VIC-Glacier model parameters.

		LZ	LZ-YC	RKZ	LS	YC-NX	NX-BXK
DDF (mm°C^{-1} day^{-1})	Initial range	6.5–11.0	6.5–11.0	6.5–11.0	6.5–11.0	6.5–11.0	6.5–11.0
	Final value	10.97	10.97	10.97	9.2	6.8	6.5
D1(m)	Initial range	0.05–0.10	0.05–0.10	0.05–0.10	0.05–0.10	0.05–0.10	0.05–0.10
	Final value	0.1	0.1	0.1	0.1	0.1	0.1
D2(m)	Initial range	0.5–1	0.5–1	0.5–1	0.5–1	0.5–1	0.5–1
	Final value	0.7	0.7	0.9	0.7	1	1
B_inf	Initial range	0–0.4	0–0.4	0–0.4	0–0.4	0–0.4	0–0.4
	Final value	0.2	0.2	0.2	0.2	0.2	0.2
Ds	Initial range	0.001–1	0.001–1	0.001–1	0.001–1	0.001–1	0.001–1
	Final value	0.3	0.3	0.3	0.3	0.3	0.3
Ws	Initial range	0.1–1	0.1–1	0.1–1	0.1–1	0.1–1	0.1–1
	Final value	0.9	0.9	0.9	0.9	0.9	0.9
Dsmax (mm/day)	Initial range	5–20	5–20	5–20	5–20	5–20	5–20
	Final value	10	10	10	10	10	10

“Reliable parameters are crucial for accurate runoff simulation by hydrological models. The DDF is the most sensitive parameter for degree-day glacier model (Hock, 2003). Zhang et al. (2013) studied the sensitivity of glacier melt runoff to the parameters of DDFs, suggesting that average annual glacier runoff would decrease/increase about 10% with the decrease/increase of each one unit (mm °C^{-1} day^{-1}) in DDF. In this work, the DDF parameters used in this study are derived based on observed glacier mass balance data, but intensively validations on glacier melt (e.g. observed glacier mass balance and satellite-based glacier area estimates). In addition, monthly runoff observation from eight hydrological stations are collected to further validate parameters, ensuring that the model set-up is suitable for our modelling purposes.”