Comment 1:

This article calibrates a sophisticated hydrological model with diverse datasets in a large basin in the Tibetan plateau and then uses the model to understand sensitivity of hydrological fluxes to possible changes in temperature and precipitation. The entire calibration exercise is very interesting, as it is done with varied dataset (streamflow, snow coverage, glacier mass balance, and stable water isotopes). By calibrating across these datasets, it is assumed that the model parameters closely mimic the underlying hydrologic processes. The article then does climate perturbation studies and predicts that temperature increase changes internal water flux partitioning within the catchment with limited changes in absolute amount of streamflow, whereas precipitation changes has a significant impact on streamflow amounts (and not on flux partitioning). The article also highlights certain interesting threshold processes occurring in this region, where a small increase in temperature may lead to decrease in streamflow whereas a larger increase in temperature increases streamflow due to enhanced glacial melt. Additionally, there are lots of other small interesting results within the article which might be very relevant to researchers working in this region.

The flow of the article is well drafted and it explains modeling and results reasonably well. I have a few suggestions to further improve the article and a few questions regarding the model application.

Response:

Thank you very much for your appreciation. We will revise the manuscript thoroughly according to your comments. We have finished some necessary calculations and figure redrawing works, and we will present them in response to the corresponding comments below.

Comment 2:

A key advantage of using a hydrologic model is that it allows estimating uncertainty within the modeling result. However, the article does a very poor job in describing uncertainties in model outputs. Except in Figure 5(a, d), uncertainty in model outputs have not been described in text or in figures. For e.g. in Table 4, change in CP days (<2 days in the most extreme scenario) have been inferred which might be deceiving unless the uncertainty bounds introduced by natural climate variability is taken into account. It is quite possible that the day of peak runoff varying by 2 days can be explained by natural variability. To ensure the robustness of these results, I suggest adding uncertainty to most plots and do statistical significance tests. I have pointed this out findings in my more detailed comments below. My general suggestion will be to introduce uncertainty bounds in every figure (wherever feasible) and include statistical significance of any future results (e.g. runoff decrease of 20%under a given scenario at what significance level?). This will make the discussions more robust.

Response:

Thank you very much for your suggestion. The model uncertainty is indeed an important issue for runoff projection and sensitivity analysis. A common method to estimate the uncertainty in runoff projection studies is to adopt the output of multiple general circulation models (GCM) to drive the model and provide the uncertainty range of results produced by different GCM product (e.g., Lutz et al., 2014; Cui et al., 2023). However, in this study, the model was driven by only one dataset (i.e., perturbing the historical temperature/precipitation by a certain degree) in each scenario, thus the uncertainty range cannot be produced in a similar way. Actually, the bounds in Figure 5a-d do not refer to the uncertainty, but the range of interannual variability, to show the conditions in relatively wet/dry years. Based on the above considerations, **we will adopt the standard deviation of annual variables (runoff, contribution of runoff components, CP/CR) to represent the uncertainties introduced by natural climate variability. In addition, we have conducted the t-Test of paired two samples for these variables in the baseline and perturbed temperature/precipitation scenarios, and found that all the changes are statistically significant except for CP in some scenarios.** We will add these results in the revised manuscript.

Comment 3:

One key limitation in the model calibration is that the calibration period uses the entire period of collected hydrometeorological data, and there is no proper validation period. In a way, the article replaces time with space, where calibration is done over time and validation is done scantly over space. Please provide a justification for this calibration scheme, and why hasn't the model been calibrated and validated in a conventional way?

Response:

Thank you very much for pointing out this limitation. The main reason for such calibration scheme was the large basin area. In our previous studies in this region (Nan et al., 2021, 2022), we found that the model performance during validation period was highly correlated with that of calibration period, which was partly due to the strong linearity of precipitation-discharge relation in the large basin. But the model performance at internal stations had a large uncertainty when the discharge at outlet station was simulated well. Consequently, we did not divide the simulation period into calibration and validation period, but only used the discharge data of internal stations to validate the model. We will justify these in the revised manuscript.

Comment 4:

The hydrological model consistently underestimates peak streamflow across sites (only exception is 2008 period of Figure 3f). This suggests that the model has a consistent bias which hasn't been adequately discussed in the article. Please provide more context to this, why this bias exists and what should be done to remove this bias.

Response:

Thank you very much for pointing out this shortage of streamflow simulation. The major difficulty of hydrological simulation in this region is the uncertainty in precipitation input data. The Tibetan Plateau is a typical data scarce region, especially in high elevation regions, making the precipitation product poorly validated by station precipitation data (Li et al., 2021). Previous studies indicated high precipitation in some high elevation regions based on (e.g., Jiang et al., 2022), which was however not integrated in the gridded precipitation dataset. Results also showed that most precipitation products performed poorly on accurately capturing the amount of specific precipitation events (Xu et al., 2017), which had important influence on the simulations of peak flow. **Consequently, the underestimations of peak streamflow could be attributed to the underestimated precipitation, especially for the source region with high elevation.** Further correction on the precipitation product based on more station data could be helpful to remove this bias. Nonetheless, our results showed that the annual runoff and seasonality were reproduced relatively well for most stations, and our study did not focus on the sensitivity of flood processes. Thus we believe that the sensitivity analysis results are mostly meaningful. We will add these context in the revised manuscript.

Comment 5:

L201-203: How different is glacier meltwater isotopes from snowmelt isotopes, and how have these two been differentiated within the tracer module of the model?

Response:

The isotope composition of glacier meltwater is very steady, because the glacier is formed by the precipitation within past hundreds of years and updated slowly. On the contrary, the snow is updated quickly in each year as indicated by the intra-annual variation of snow cover area. In the tracer module, the isotope composition of glacier meltwater was assumed as a constant value, which was lower than the average precipitation isotope to reflect the fractionation effect during melting process. The isotope composition of snowmelt was updated based on the water and isotope mass balance of the snowpack, similar with other water storages. We will illustrate it in the revised manuscript.

Comment 6:

In the mathematical equations, a lot of variables are depicted by small words (like PET). I will suggest using a single alphabet for a variable, in-line with proper mathematical convention. Please address this in all the equations.

Response:

Many thanks for your suggestion. We will adopt single alphabets to represent variables in the equations.

Comment 7:

Figure 4. Looking at difference between Y-axis of Fig 4a and 4d, its clear that annual runoff is not significantly impacted by increasing temperature. Is the conclusion about reduction in annual runoff in different temperature scenarios statistically significant?

Response:

Many thanks for your comments. We have conducted the t-Test of paired two samples for annual runoff and the reduction in different temperature scenarios is statistically significant, although the decreasing rate is small. We will add this in the revised manuscript.

Comment 8:

Figure 5. One interesting takeaway from the figure is that precipitation increase has a disproportionate impact on summer month runoff whereas temperature increase has higher impact on winter runoff. This is a very interesting result as it suggests winter baseflow is more influenced by temperature changes. This should be highlighted in the text.

Response:

Many thanks for your high evaluation on this result. We will highlight it more in the revised manuscript.

Comment 9:

L366-367: concentration ratio and concentration period have not been defined in the text. Please define them

Response:

Many thanks for your suggestion. We will add the definitions of equations of CR and CP.

Comment 10:

L369-372: Was CP decrease of 2 days statistically significant?

Response:

Thank you very much for your question. We have conducted the t-Test of paired two samples for CR and CP. We found that the change of CR is significant at significance level of 0.01 in all scenarios, but the change of CP is insignificant in some scenarios. In specific, the decrease in CP for the warming of 1°C is insignificant at the level of 0.01 ($p=0.014$), but significant in higher warming scenarios. The changes of CP in two reducing precipitation scenarios are significant, but is insignificant in two scenarios with increasing precipitation ($p=0.02$ and 0.12 for 110% P and 120% P, respectively). We will add these results in the revised manuscript.

Comment 11:

L380-383: if subsurface runoff is 70%, rainfall runoff 20%, glacial melt runoff 10% and snowmelt runoff 5%, then where is the remaining 5% water flux? I suggest using uncertainty bounds (or standard deviation values) with these fluxes to solve these issues

Response:

Many thanks for your comments. This is an inaccurate description of the results. The contributions of subsurface runoff, rainfall runoff, glacier melt runoff and snowmelt runoff in annual runoff are 67.8%, 21.6%, 7.4% and 3.2%, respectively. We will describe them more accurately in the revised manuscript, and add the standard deviation of this proportion.

Comment 12:

L404-408: I don't understand the discussion around proportion of three other components. Also these values look very very small to make meaningful conclusions. Please include error bands around these values

Response:

I am sorry to make you confused about this. Here we are just reporting the changing rate of the components' contribution with the changing precipitation. We will add the standard deviation of these annual values in the revised manuscript.

Comment 13:

L453-457: This is a very interesting result, it highlights the most dynamic regions within the basin, which can keep shifting between energy vs water limited stages. Have past studies identified such regions? If yes, please mention them in discussions. Also, please highlight this part in the abstract and conclusions part.

Response:

Many thanks for your high evaluation on this result. As far as we know, there are no past studies identifying such regions. The past studies in this region focused on the hydrological responses either at the large basin scale (e.g., the whole YTR basin) or at the sub-catchment scale (e.g., the Lhasa River basin), but did not explore the spatial pattern of catchment scale hydrological characteristics within the whole basin, thus cannot identify the particularity of such regions.

Comment 14:

L478-479: Please show the other figures with insignificant correlations in the supplementary material

Response:

Many thanks for your suggestion. We will add them in the revised manuscript.

Comment 15:

L488-489: How can glacier coverage be higher in warmer regions? Shouldn't the presence of glaciers be more in colder places?

Response:

Many thanks for your correction. We made a mistake here and will correct it in the revised manuscript.

Comment 16:

Figure 10: This is a useful figure but I think change in runoff is very low in T+5 scenario (maybe bulk of points lie between -10% to 10%). What is the uncertainty range of simulation of runoff?

Response:

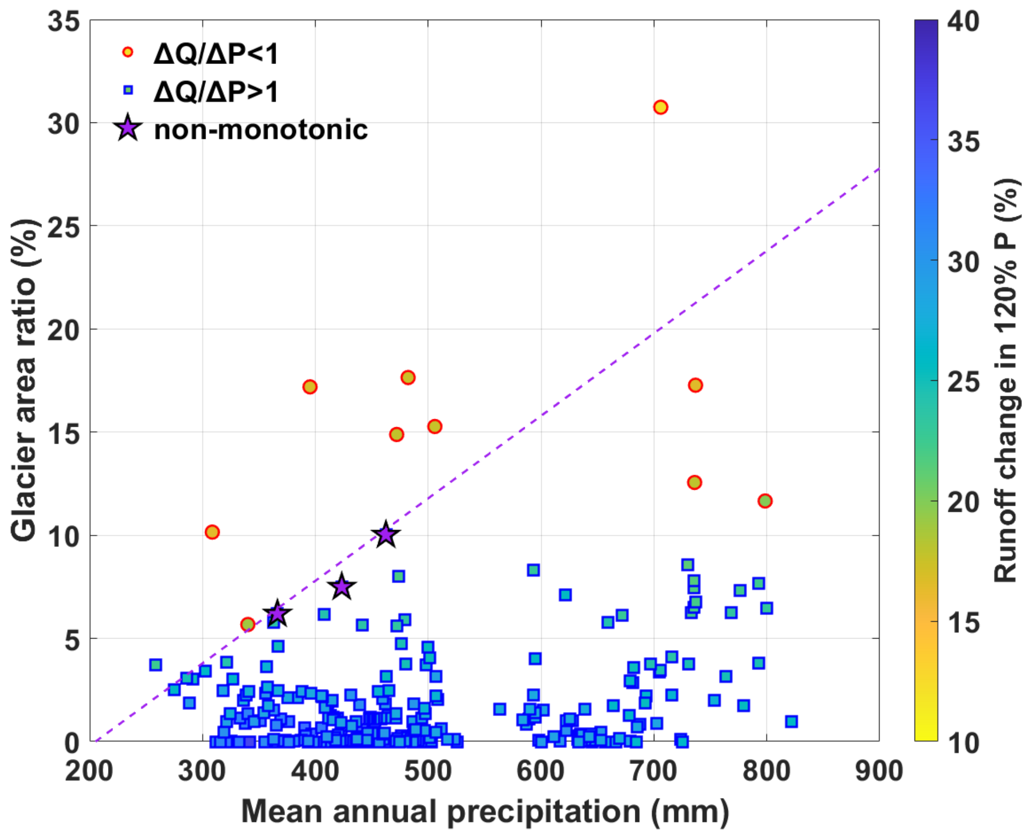
Many thanks for your comment. The runoff change in response to warming temperature is indeed very low in most regions, but the change could be rather significant in regions with large glacier area ratio or large precipitation. We have calculated the statistical significance of runoff change in each REW. We find that the runoff change in response to perturbed precipitation is significant in all REWs, but things are different for warming temperature scenarios. The runoff change in response to increasing temperature is insignificant (at significance level of 0.01) in about 26% and 15% area of the basin for warming of 1°C and 5°C, respectively. The statistical significance in response to warming temperature is related to the runoff change magnitude and the drainage area. We will describe these results in the revised manuscript, and provide the related figures in the supplementary materials.

Comment 17:

Figure 10: I suggest reproducing this sort of a figure for increasing precipitation scenario. In the text, it was mentioned that in certain areas streamflow increased by >10% if precipitation increased by 10% and in certain areas streamflow increased by <10% if precipitation increased by 10%. In a way, different regions are showing different streamflow elasticity. I suggest producing a figure of streamflow elasticity in increasing precipitation scenarios and highlight which areas are closest to 1, as they would likely show non-monotonic behavior i.e. shift from <1 to >1 in different precipitation. Does glacier area ratio play a pivotal role there as well?

Response:

Thank you very much for your valuable suggestion. We reproduced this figure for precipitation scenarios and found similar results (as shown in the figure below). There are some REWs shifting from $\Delta Q/\Delta P < 1$ to >1, and these REWs forms the boundary of REWs that $\Delta Q/\Delta P < 1$ and >1. However, there is little difference from the results for temperature scenarios. There are only three non-monotonic REWs, providing less confidence to the boundary line. As a result, there are some REWs lying lower than the boundary line but the streamflow changing rate is lower than that of precipitation.



Comment 18:

L542-543: Can you point to the figure which highlights this?

Response:

Many thanks for your suggestion. This could be inferred from Figure 10. We will point it in the revised manuscript.

Comment 19:

L553-554: Decrease of 0.1%-3% is likely very small and not statistically significant. Can you clarify?

Response:

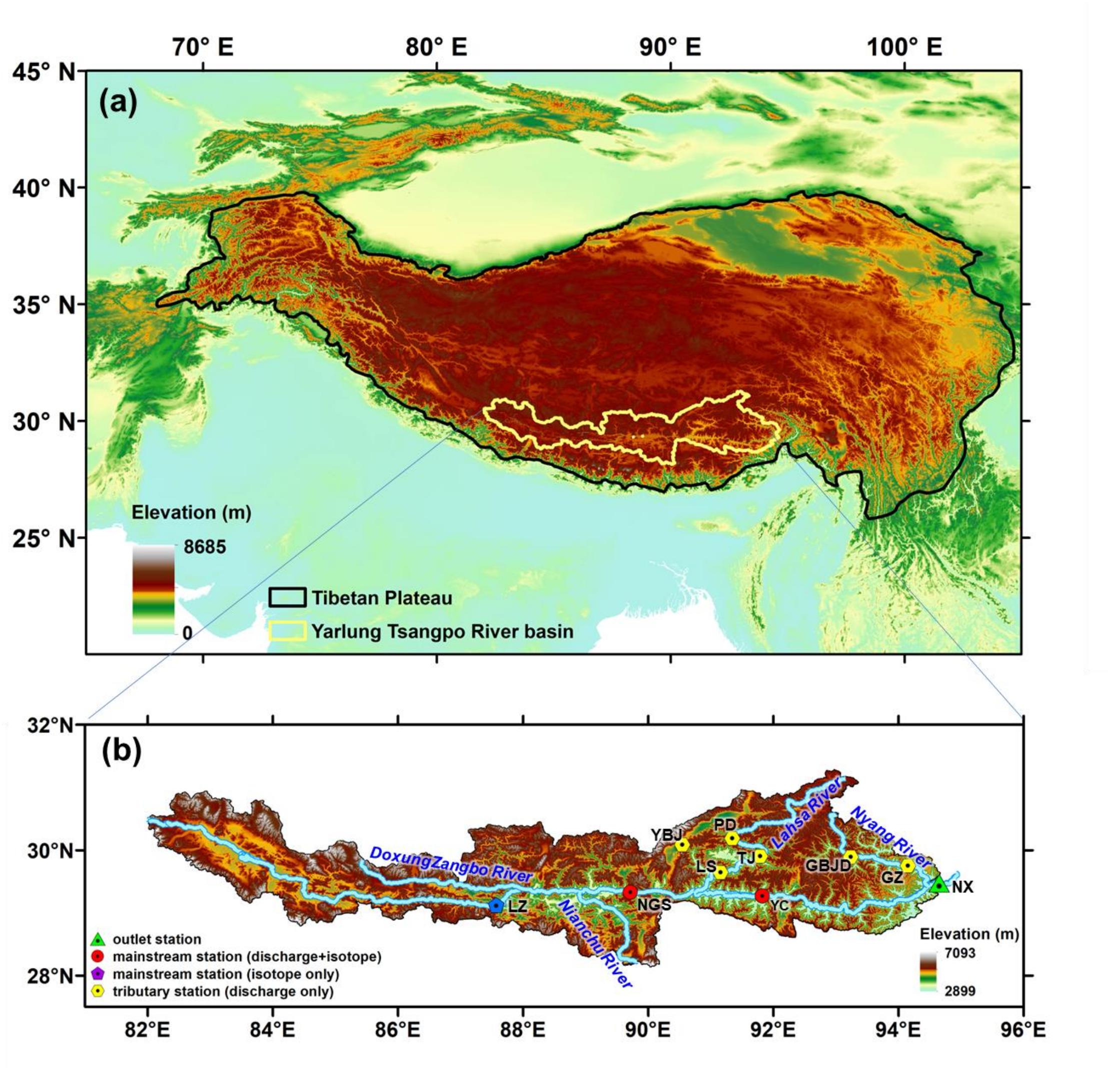
Many thanks for your question. This is the result from Cui et al. (2023) but the statistical significance was not discussed in the paper. We collect the original data from the Supplementary Information of that paper. The projected runoff change for the warming of 1.5°C in the YTR is -2.14(±4.30)%. Although the average change rate is even smaller than the standard deviation, the decreasing trend is statistically significant ($p=0.001$).

Comment 20:

Figure 1b: The yellow color of tributary station YBJ is blending with the yellow color of the underlying DEM. Figure 2b should be redrawn and the contrast between legends and background should be increased. Its currently very hard to read

Response:

Many thanks for your suggestion. We have revised the Figure 1 as below:

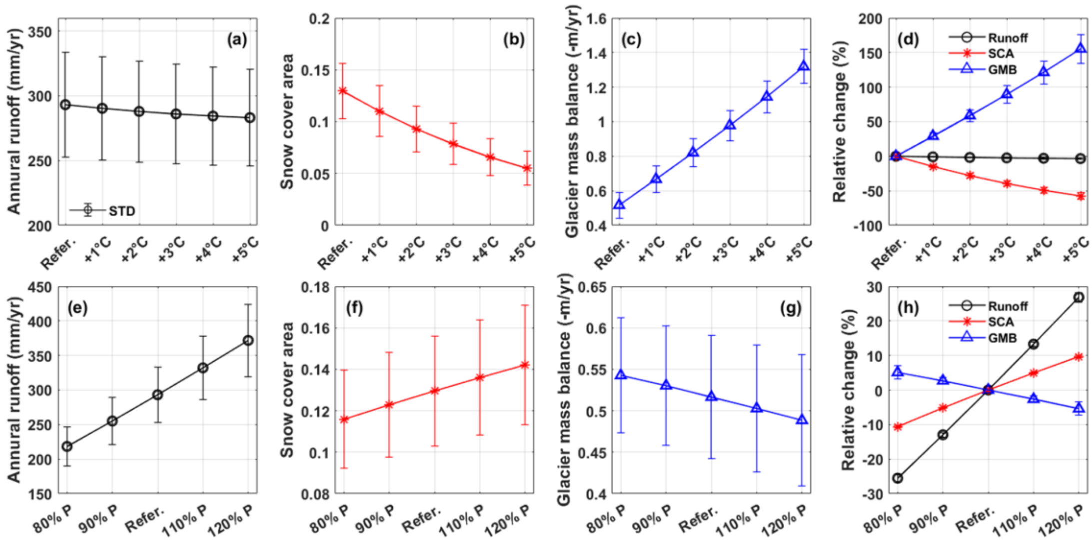


Comment 21:

Figure 4: Please describe subplots (d) and (h) in the figure description. Add error bands in all the subplots

Response:

Many thanks for your suggestion. We will add the description of subplots (d) and (h) in the revised manuscript. Figure 4 has been redrawn as below.

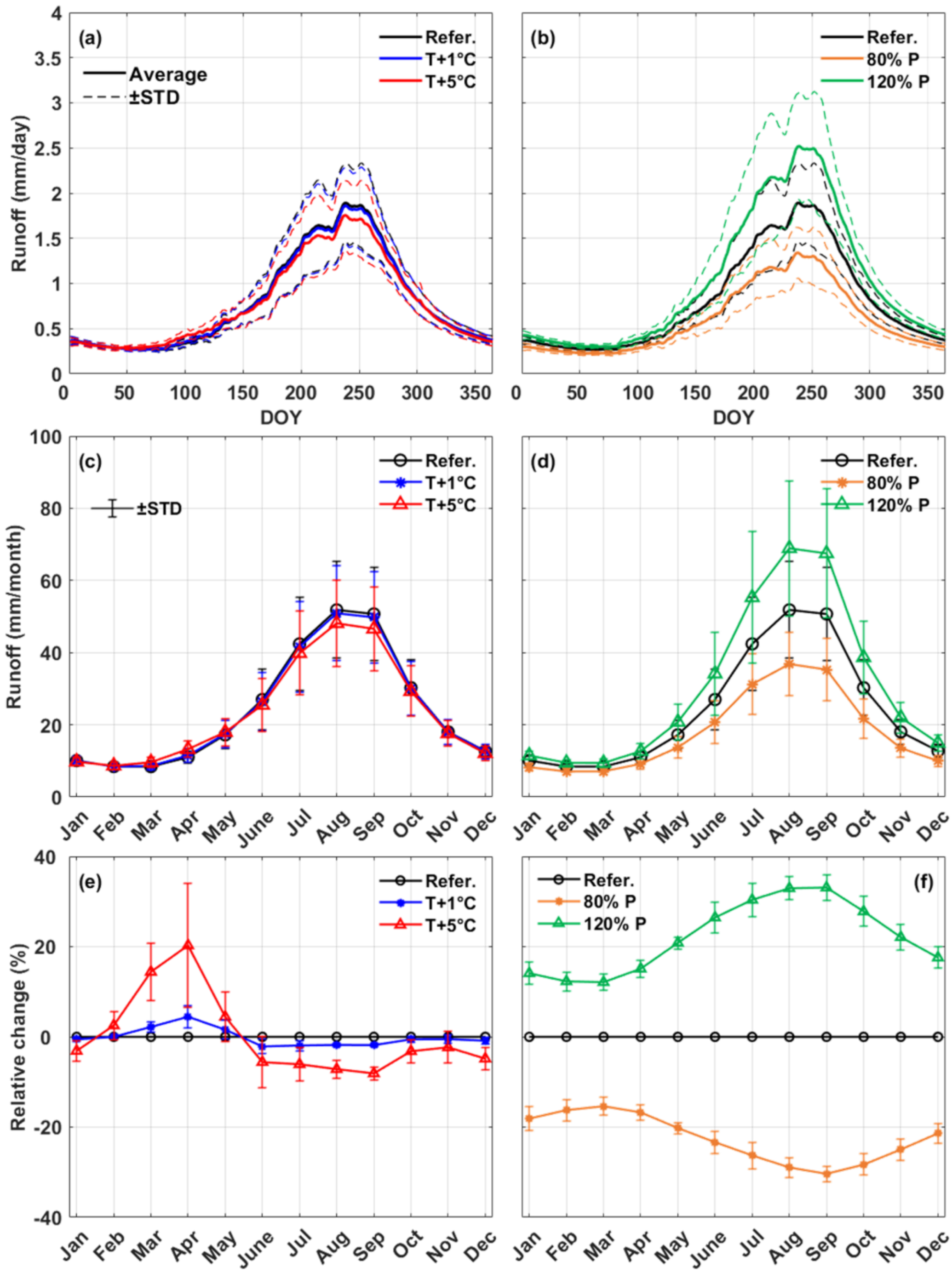


Comment 22:

Figure 5a. X-label 350 matches with "0" of subplot (b) making 350 look like 3500. Please resolve this. Also add error bands to Figure 5e and 5f

Response:

Many thanks for your suggestion. We have redrawn this Figure as below.

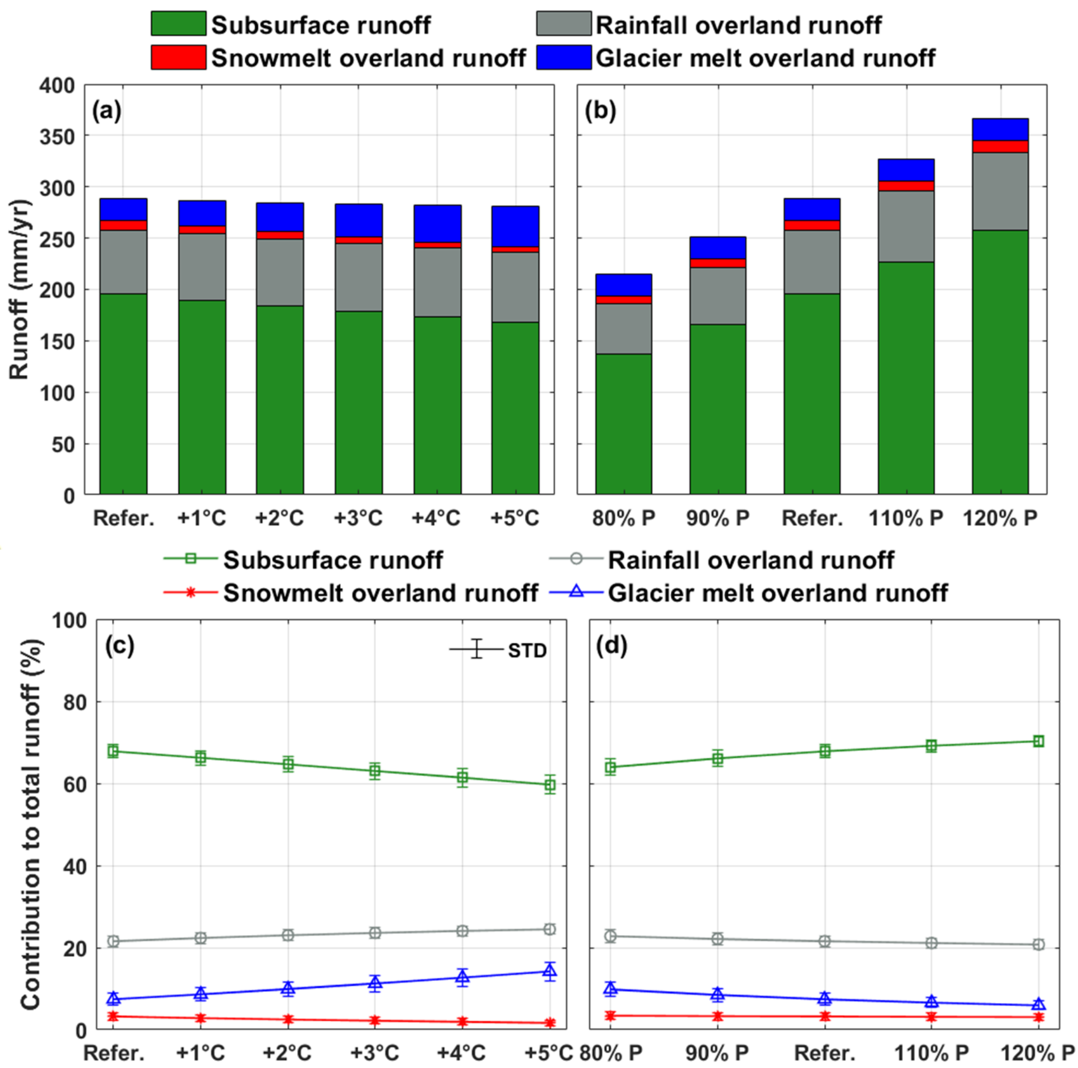


Comment 23:

Figure 6c,d: Add uncertainty bands

Response:

Many thanks for your suggestion. We have redrawn this figure as below. The interannual variations of the contributions of runoff components are small in all the scenarios, as indicated by the small STDs.

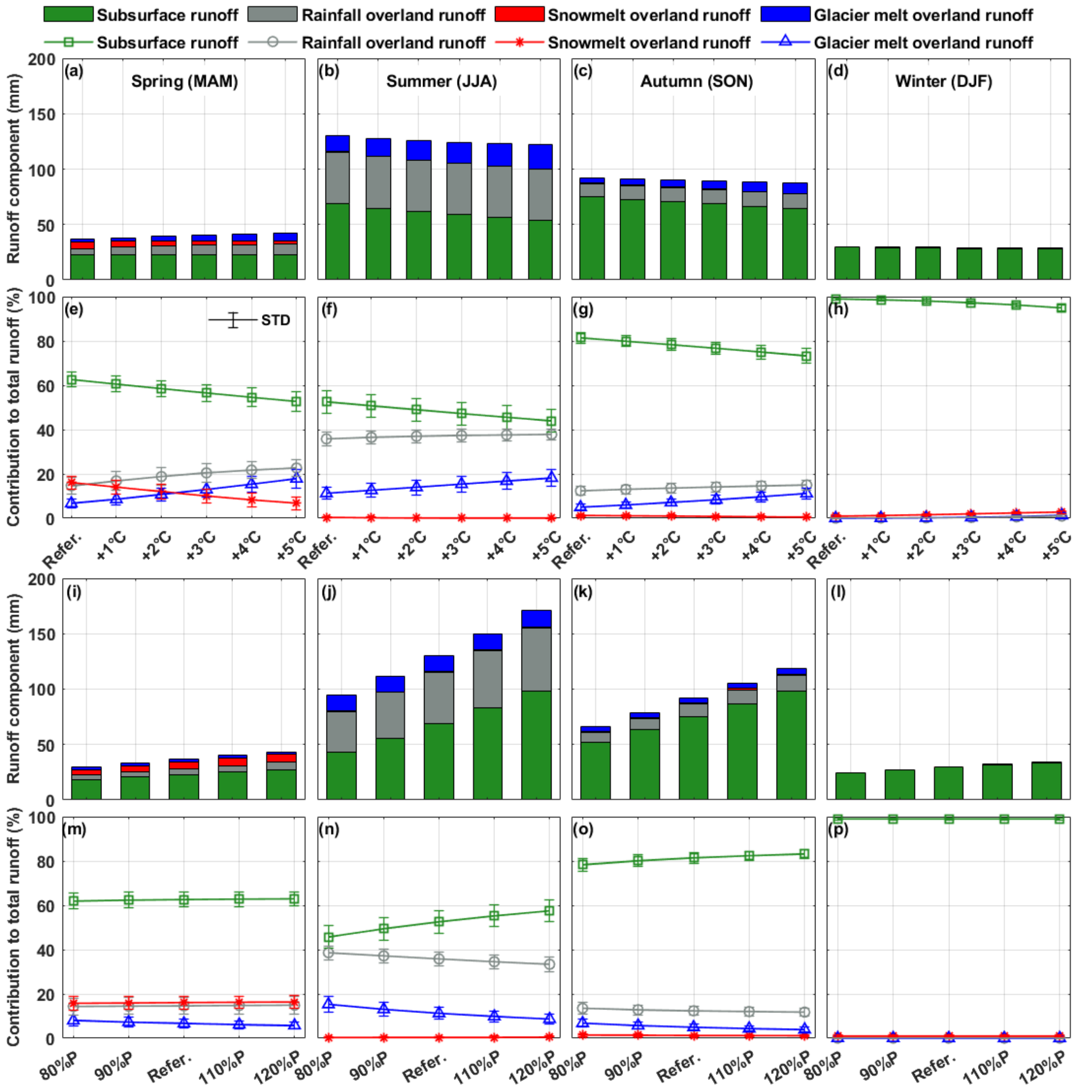


Comment 24:

Figure 7e-h, m-p: Add uncertainty bands

Response:

Many thanks for your suggestion. We have redrawn this figure as below.



Comment 25:

L16: replace exist with “existed”

Response:

Many thanks for your correction. We will change the phrase accordingly.

Comment 26:

L23: can use “multiple datasets” instead of “Datasets of multiple objectives”. It makes reading easier

Response:

Many thanks for your suggestion. We will change the phrase accordingly.

Comment 27:

L38-40: I cannot understand what is being said in this line. Please rephrase

Response:

Many thanks for your comments. We will rephrase this sentence as: Some regions had a non-monotonic runoff change rate in response to climate perturbation. The GAR and mean annual precipitation (MAP) of the non-monotonic regions had a linear relation, and formed the boundary of regions with different runoff trends in the GAR-MAP plot.

Comment 28:

L81: replace “processes” with “models”

Response:

Many thanks for your correction. We will change the phrase accordingly.

Comment 29:

L97: replace “likened” with “compared”

Response:

Many thanks for your correction. We will change the phrase accordingly.

Comment 30:

L121: remove “and”. It can be better framed as “Snow, glacier, isotope data and observation ..”

Response:

Many thanks for your suggestion. We will reframe this sentence in the revised manuscript.

Comment 31:

L140: Missing unit “km2” next to 2x10^5

Response:

Many thanks for your correction. We will add the unit in the revised manuscript.

Comment 32:

L145-146: Why is the acronym of Yangjia “TJ”? It is not at all intuitive

Response:

Many thanks for your suggestion. We made a mistake and it should be Tangjia. We will correct it in the revised manuscript.

Comment 33:

Table 2: Instead of using column name as “Sample number”, use “Number of samples”. Sample number gives the impression that it’s the laboratory sample number of a collected water sample

Response:

Many thanks for your suggestion. We will change the term in the revised manuscript.

Comment 34:

Eq.6: Please move the equation to L255 as it is a continuation of that sentence

Response:

Many thanks for your suggestion. We will move equation 6 to L255.

Comment 35:

Table 4: Add error bands (or standard deviation values) in this table

Response:

Many thanks for your suggestion. We have calculated the STD values and revised the table as below.

		CR		CP (days)	
		Average	STD	Average	STD
Reference scenario		0.432	0.044	244.4	7.09
T scenario	+1°C	0.425	0.044	244.1	7.12
	+2°C	0.419	0.045	243.8	7.18
	+3°C	0.413	0.045	243.3	7.26
	+4°C	0.408	0.046	242.8	7.36
	+5°C	0.402	0.046	242.3	7.45
P scenario	80%	0.398	0.039	242.2	6.86
	90%	0.415	0.042	243.6	7.01
	110%	0.449	0.045	244.7	7.13
	120%	0.465	0.045	244.7	7.14

References

Cui, T., Li, Y., Yang, L., Nan, Y., Li, K., Tudaji, M., Hu, H., Long, D., Shahid, M., Mubeen, A., He, Z., Yong, B., Lu, H., Li, C., Ni, G., Hu, C., and Tian, F.: Non-monotonic changes in Asian Water Towers' streamflow at increasing warming levels, Nature communications, 14, 1176-1176, 10.1038/s41467-023-36804-6, 2023.

Li, K., Tian, F., Khan, M. Y. A., Xu, R., He, Z., Yang, L., Lu, H., and Ma, Y.: A high-accuracy rainfall dataset by merging multiple satellites and dense gauges over the southern Tibetan Plateau for 2014-2019 warm seasons, Earth System Science Data, 13, 5455-5467, 10.5194/essd-13-5455-2021, 2021.

Lutz, A. F., Immerzeel, W. W., Shrestha, A. B., and Bierkens, M. F. P.: Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation, Nature Climate Change, 4, 587-592, 10.1038/nclimate2237, 2014.

Nan, Y., He, Z., Tian, F., Wei, Z., and Tian, L.: Can we use precipitation isotope outputs of isotopic general circulation models to improve hydrological modeling in large mountainous catchments on the Tibetan Plateau?, Hydrology and Earth System Sciences, 25, 6151-6172, 10.5194/hess-25-6151-2021, 2021.

Nan, Y., He, Z., Tian, F., Wei, Z., and Tian, L.: Assessing the influence of water sampling strategy on the performance of tracer-aided hydrological modeling in a mountainous basin on the Tibetan Plateau, Hydrology and Earth System Sciences, 26, 4147-4167, 10.5194/hess-26-4147-2022, 2022.

Xu, R., Tian, F., Yang, L., Hu, H., Lu, H., and Hou, A.: Ground validation of GPM IMERG and TRMM 3B42V7 rainfall products over southern Tibetan Plateau based on a high-density rain gauge network, Journal of Geophysical Research-Atmospheres, 122, 910-924, 10.1002/2016jd025418, 2017.

Jiang, Y., Yang, K., Yang, H., Lu, H., Chen, Y., Zhou, X., Sun, J., Yang, Y., and Wang, Y.: Characterizing basin-scale precipitation gradients in the Third Pole region using a high-resolution atmospheric simulation-based dataset, Hydrol. Earth Syst. Sci., 26, 4587–4601, https://doi.org/10.5194/hess-26-4587-2022, 2022.