

SC #1

This paper uses the most recent climate projections combined with a sophisticated downscaling approach known as quantile mapping, to develop predictions of changes to the flow regime under three climate change scenarios for 93 catchments in Switzerland. In addition to quantifying mean annual and seasonal changes in runoff, this paper investigates changes in seasonality (i.e. changes in the timing of flows) as well as providing estimations for the time of emergence, and how the time of emergence is expected to change in time. This paper contributes to an important facet of climate change research and provides valuable insights towards climate change adaptation policies and management strategies. With the continual improvement of climate change models, it is critical that research towards understanding changes to the flow regime under future climate scenarios is implemented with the most current climate change models. In general, this paper serves that purpose and provides novel insights towards furthering our understanding of how the flow regime is expected to change in the future. However, there are several components of this paper that undermine its ability to effectively communicate these findings, and below are my suggestions on ways that the paper could be improved, all of which are meant to be constructive.

Reply: Thank you very much for your thorough review. We very much appreciate this very helpful and improving review.

This review is structured as follows:

1. QUESTIONS POSED BY THE HESS REVIEW CRITERIA ARE ADDRESSED.
2. SUGGESTIONS CORRESPONDING TO SPECIFIC SECTIONS OF THE PAPER.
3. ISSUES OF GRAMMAR AND PHRASING.

1. HESS review criteria

Questions 1-3. Does the paper address relevant scientific questions within the scope of HESS? Does the paper present novel concepts, ideas, tools, or data? Are substantial conclusions reached?

The questions posed within this research paper, namely how climate change will affect the flow regime in a variety of hydroclimate regions in Switzerland, are within the scope of HESS. Although the research questions posed in this paper are not novel, and similar analyses have been done on the topic, this paper uses the most current climate change projections and a more sophisticated method for downscaling the coarse climate model output. For these reasons, the data obtained from this study can be considered a relevant and novel contribution to the area of research.

Furthermore, the authors were able to determine not only how the flow regime is expected to change in the future, but also quantify how changes to the flow regime will differ under various warming scenarios.

Reply: We are glad to read that you think that our study is relevant.

Question 4. Are the scientific methods and assumptions valid and clearly outlined?

The scientific methods are clearly outlined in the methods section however, the section headers are quite vague and could be more informative (discussed fully in question 10). Several assumptions could be explained in more detail, for example, why the decision to use 90% as the criteria to determine direction changes of temperature in simulations, and 66% for the change in seasonal and

yearly mean of emergence time? It is also assumed that the three RCP's correspond to the three warming levels (+1.5°C, +2°C, and +3°C), but isn't explicitly stated in the text.

Reply: *Thank you for your comment. We will extend the description of methods. The 90% refer to the model agreement on the sign of change. This means that 90% of the models show either positive or negative changes in the runoff indicator (not in temperature). We chose these thresholds following the IPCC terminology where 90% refers to "very likely" and 66% to "likely".*

Additionally, an explanation on the choice to use the mean elevation as a metric for comparing between catchments, rather than a metric that would better represent the variability of elevations between catchments could be valuable. Since the catchments used in your study cover a wide range of sizes (14-1700 km²) and elevations (476- 2700 masl), wouldn't using mean elevation as a basis of comparison run the risk of comparing large catchments that may have a significant area in both high and low elevations (but their mean would be a mid-elevation), with smaller mid elevation catchments (that do not have any high or low elevation components)? If this was an issue then perhaps a different metric should be used which more accurately captures the variability of catchment elevations. If this was not a concern, then it should be addressed and explained how the inability to account for variability in elevations among catchments did not influence the outcomes of this study.

Reply: *A previous study by Koeplin et al. (2012) showed that the catchment response to climate change can be directly linked to the mean altitude. Therefore, we chose mean altitude of the catchment to show the elevation dependence of our results. We will add this point and the issues that you raised to the discussion of the results.*

Köplin, N., Schädler, B., Viviroli, D., & Weingartner, R. (2012). Relating climate change signals and physiographic catchment properties to clustered hydrological response types. Hydrology and Earth System Sciences, 16(7), 2267-2283.

The uncertainties associated with this study are only briefly discussed at the end of the discussion and more detail is required in order for the reader to determine whether or not the findings are justifiable, provided the associated uncertainties.

Reply: *True, we will extend the discussion on the uncertainties.*

Question 5. Are the results sufficient to support the interpretations and conclusions?

The results are sufficient to support the interpretations and conclusions in this study, however if possible the authors should consider including quantitative rather than relative changes for some of their results. For example, in section 4.2 consider including the quantitative differences in both the changes in the timing and magnitude of the peak runoff, rather than simply stating that "runoff decreases strongly in the summer months and less strongly in the autumn months". Based on figure 5 it appears that the changes in timing and magnitude could be expressed more specifically, instead of only mentioning relative changes.

Reply: *Thank you for this comment. We will try to incorporate a more quantitative language.*

Although provided the specificity of the climate change projections to Switzerland, it could be useful to discuss a broader applicability of the findings from this study. Would these findings also apply to other snow dominated and glaciated catchments around the world? Or other countries with a range of hydroclimate regimes like Switzerland?

Reply: *We will add a statement on the applicability of our results to other regions and compare our results with the pertinent literature.*

Question 6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)?

Although admittedly I am not familiar with this type of analysis, I believe that the description of the experiment is sufficient to allow for reproducibility by other scientists.

Question 7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution?

Proper credit is provided to related work and it is clearly differentiated from original contributions.

Question 8. Does the title clearly reflect the contents of the paper?

The title adequately reflects the contents of the paper, however it is vague and could include greater detail without becoming too long. Seeing that what sets this paper apart from previous research is the use of an up to date climate model and a more sophisticated downscaling approach, these details could be included in the title, both to represent the contents of the paper more accurately and better captivate readers. Additionally, including that the paper investigates a variety of hydroclimate regimes may increase the appeal to a broader audience (those outside of Switzerland).

Reply: Thank you for your suggestion regarding the title. We propose to change the title to “Future changes and time of emergence for pluvial to glacial runoff regimes in Switzerland based on the newest transient hydrological scenarios”.

Question 9. Does the abstract provide a concise and complete summary?

The abstract provides a complete summary of the paper, however including some minor details could improve the clarity of the abstract. For example, a brief explanation of the concept of “time of emergence”, like was done in the first sentence of section 3.2, would make it more applicable to a broader audience. Additionally, when discussing the changes of average relative runoff, it would be good to include the reference point of this change (from the reference period discussed in section 3.2?).

The examples provided in regard to impacts from changing runoff regimes are mainly industry based. Perhaps it would be good to mention environmental impacts and flood/drought concerns as well? The same applies to the introduction, where only economic impacts are discussed as being affected: “sectors such as agriculture, fishery, hydropower generation, and tourism.”

Reply: We will add a brief explanation of the concept of time of emergence and add a statement on the ecological impacts. A companion paper (<https://doi.org/10.5194/hess-2020-667>) discusses climate change impacts of moderate extremes for Switzerland.

Question 10. Is the overall presentation well-structured and clear?

In general, the paper is well structured and for the most part follows a logical flow. However, the sub-section headers are very vague and, in my opinion, do not provide enough detail to adequately represent the contents of each sub-section. For example, instead of “Changes in runoff regimes” for section 3.2 it could be something like “Criteria for determining changes in runoff regimes” or even “Interpreting changes in runoff regimes”. Section 3.3 titled “Changes with increasing global mean temperatures”, should specify what changes you are referring to. Similarly, for sub-sections 4.1 and 4.2, titled “Seasonal and yearly mean changes” and “Changes in the runoff regime” respectively, it is unclear which changes are being referred to. An alternative option for the section 4.2 header could be to specify that the section illustrates the changes in the runoff for each of the six representative hydroclimate regimes.

It is also difficult to draw the connection from the sub-sections in the methods, to the sub-sections in the results, which I believe is largely due to the vagueness of the sub-section titles. Maybe re-ordering or renaming some of these headers will provide a more logical flow to the paper. Perhaps making sub-section 4.2 the first sub-section in the results section will better represent the order of operations proposed in the methods section.

Reply: *Thank you for this suggestion. We will try to make the headers of the sections more precise and informative.*

Question 11. Is the language fluent and precise?

In addition to several grammatical errors (addressed in section 3), I found that some of phrasing and language used was awkward. One term that is repeated throughout the paper is “signal”, which in this paper is meant to indicate whether the change is positive or negative. In most instances, either “signal of change” or “signal direction” and in some cases “direction of change” is used. In my opinion, I find the use of the word “signal” slightly awkward in this context and typically think of it in the sense of either a strong or weak signal, rather than an indication of whether the change is positive or negative. Perhaps using “sign of change” or “direction of change” like was used in parts of the text, would help to clarify the distinction between magnitude (strong/weak) and direction (positive/negative).

The word “strong” is used many times throughout the paper (38 times to be exact) and in some cases, if possible, should be replaced by more specific language. Mentioning that A has a strong influence on B, or that A has experienced a strong increase, doesn’t provide much information to the reader without any explanation of what constitutes a strong influence or strong increase.

The terms elevation and altitude are used synonymously throughout the paper, which I think is ok, however only using one might help to clarify and improve the readability of the paper.

Reply: *The term “signal” will be replaced to “sign”. Furthermore, we will rephrase our statements to be more quantitative.*

Question 12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used?

In the methods section it might be good to specify which months are included for each season, when describing seasonal mean changes. It is evident when looking at the figures, but I think this information should also be included in the text for clarity.

There are some acronyms that are not defined in the text including RCP and the PREVAH model.

Reply: *We will implement your suggestions.*

Question 13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated?

Consider having sub-sections within section 4.1 for each season (winter, spring...) to better organize the text and make it easier to interpret differences in runoff between the seasons. This could also be applied in subsequent sections, by breaking up the text so that it is more digestible. For example, including headers to differentiate between yearly and seasonal changes or making each of the six example catchments in section 4.2 their own paragraph each with a header so that readers can more easily find information within the text.

Reply: *We will implement your suggestion.*

In section 4.1 when discussing changes in the mean runoff, it might be useful to include the results from the RCP 4.5 scenario in text because they may reveal insights towards important thresholds of change regarding an increase or decrease in runoff, which would be useful in terms of policy and management decisions. This is particularly the case in the spring where under the RCP8.5 changes were predominantly positive and under RCP2.6 some catchments shifted from positive to negative.

Reply: *Thank you for this comment. We will refer to the results of RCP4.5 in section 4.1.*

Figures:

For someone unfamiliar with Switzerland it is not obvious which country we are looking at in figure 1. It is difficult to discern where exactly we are looking in geographic space. Maybe including names of surrounding countries or different colors for surrounding countries to provide some context for the location. The figure is also missing a north arrow and perhaps an insert showing location within Europe could be useful. The figure caption should also mention that the figure is of Switzerland.

Reply: *Figure 1 will be adjusted according to your suggestions.*

In figure 2 the caption should specify what changes are being referred to (i.e. the fact that it displays changes in runoff). The same would then apply to figure 3 and figure 8.

Reply: *The caption will be adjusted according to your suggestion.*

At the end of section 4.1 (beginning from Line 186), the text describes that the RCP8.5 is represented in Figure 4a when I believe that it is meant to refer to Figure 4b. Based on this I would suggest either re-arranging the text to describe the results of RCP 2.6 first, or re-arranging the figure to have the RCP 8.5 as a) and RCP 2.6 as b).

Reply: *Figure 4 will be rearranged to display the changes for RCP8.5 in a) and for RCP2.6 in b).*

Question 14. Are the number and quality of references appropriate?

The number and quality of references are appropriate and to my knowledge there are only a few instances where potential referencing errors were made, which are addressed in section 3 of this review.

Question 15. Is the amount and quality of supplementary material appropriate?

The amount and quality of supplementary material is appropriate however, as mentioned previously, including some of the results from the RCP 4.5 may contribute to the interpretation of results from this study.

Reply: *Some results from RCP4.5 will be included in the main text. The intention to only show RCP2.6 and RCP8.5 is to show the potential range of changes. However, we agree that including some of the results for RCP4.5 in the discussion improves the interpretation of results.*

2. Suggestions relating to specific sections

Results:

- In section 4.3 consider moving the sentence describing the changes in yearly means (line 250) to follow the section of the text describing the changes in all seasons (line 253-255) then begin a new paragraph for the sentence in line 255 beginning with "Due to the definition..."

Reply: *The sentence will be moved according to your suggestion.*

Discussion:

- The first sentences in the first two paragraphs are stated as facts. Maybe these should be stated as projections?

Reply: We will reformulate these sentences to make clear that these are the results of projections.

- Overall, the discussion seems to be lacking detail and implications of the findings of this study are quite vague: “This leads to the conclusion that throughout the year there will be less water available in Swiss rivers. The shift in seasonality and thus a shift in the seasonal availability of water will impact many different sectors.” Instead of simply stating that throughout the year there will be less water available in Swiss rivers, it should be highlighted, in my opinion, that the greatest reduction in runoff occurs during periods where risk of water scarcity is the highest (during summer). This could then be followed by a more detailed, but brief discussion on implications to various sectors.

Reply: Thank you for this comment. A brief discussion on the implications will be added.

3. Issues of grammar and phrasing

Reply: Thank you for your suggestions regarding grammar and phrasing in our text. We will implement your comments.

- Line 10: “...are essential for climate change adaptation...”
- Line 11: “...have a strong influence on various sectors...”
- Line 33: “...changes became have become more...”
- Line 35-37: seems like this sentence is missing a citation.
- Line 37: RCP acronym not written out fully. From line 66: “...greenhouse gas (GHG) concentration pathways: RCP2.6, RCP4.5, and RCP8.5.” If you are explaining the acronym for GHG, then RCP should be explained as well.
- Line 48: perhaps instead of “glaciated catchments” something like “glacial extent” is more representative of the climate change impact.
- Line 61: “Using quantile mapping as a downscaling approach...”
- Line 61-62: At the end of line 61 it is unclear what is meant by “partly different runoff characteristics.”? Some elaboration may be required.
- Line 62: I believe the Roessler et al. (2018) citation should actually be Keller et al. (2018). Would also be good to mention where this test catchment was located.

Reply: We are referring to the paper Roessler et al. (2019) (<https://doi.org/10.1016/j.cliser.2019.01.001>). The year of publication was wrong.

- Line 78: how do you define “medium-sized” catchments? Could be good to include the range of basin sizes used in the study here.

Reply: A range of catchment size will be given.

- Line 81: Define acronym for PREVAH model.
- Line 96: “...GCM-RCM chains...”

- Line 114: Would be good to specify what you are referring to when you mention seasonal and mean changes.
- Line 157: Instead of “stronger changes” maybe something like “stronger positive changes” or “larger increases”.
- Line 168: Similar to the suggestion above, instead of stronger changes specify that the changes are more negative in this case in mountainous catchments.
- Line 171: “...average change is across all catchments...”
- Line 192: “...elevated elevation...”
- Line 200: Again, more specific language could be used when referring to “strong changes”.
- Line 222: The type of regime is not mentioned like it is for the previous catchments
- Line 228: “...of the peaks is are less pronounced...”
- Line 245: Awkward phrasing: “Catchments without time of emergence show...” maybe instead write “...without an emergence time...” or “...without a time of emergence...”.
- Line 262: Awkward phrasing. Could be written as “However, this may lead to pre-mature detections of emergence time, that do not persist in time.”
- Line 265: “...levels are similar than to the...”
- Line 295: Negligible instead of neglectable?
- Line 278: “... patterns get become more pronounced.”
- Line 297: What is meant by “(not shown)”? Is this referring to a figure or a reference?

Reply: We apologize for the confusion. “not shown” refers to results from either CH2018 simulations (precipitation) or results from the hydrological model (evapotranspiration and snow melt) which are not explicitly presented in the paper. However, they reflect the processes leading to our results (water balance). We will clarify this in the revised version.

- Line 303: Same as line 297.

Reply: We apologize for the confusion. “not shown” refers to results from either CH2018 simulations (precipitation) or results from the hydrological model (evapotranspiration and snow melt) which are not explicitly presented in the paper. However, they reflect the processes leading to our results (water balance).

- Line 309: Instead of saying: “...glacier melt is important in early autumn today...” maybe better to say something like “...glacier melt is important in early autumn under current climate conditions...”
- Line 323: “...policy makers...”
- Line 334: In the sentence: “Strongest uncertainties in glaciated catchments...”, consider specifying why you are referring to in terms of uncertainty. Glacial extent? Glacial melt? Changes in runoff?
- Line 339: Awkward phrasing, particularly for “lacks completely”. Might also be useful to specify that the influence described is on runoff.
- Line 363: “...runoff due to the retreating glaciers...”
- Line: 374: “...strongly damped dampened but not avoided...”