

Review of Seelig et al.: Hydrological Modeling of Climate Change Impacts on Alpine Catchments: Shifting Snow Dynamics, Runoff Regimes, and the Frequency of Extremes

The study by Seelig et al. presents hydrological modelling for 5 study areas (15 nested catchments) in the Austrian Alps and several climate change scenarios in order to characterize the impacts of on hydrological regimes, with a particular attention to the role of catchment storage characteristics. It involves an impressive amount of model simulations and analyses, with results nicely synthesized in very elaborate figures (both in the main article and the supplementary material), and will doubtlessly make a worthy contribution to the literature. The challenge lies in digesting the amount of information presented to carve out the key message of the article – I often struggled with keeping track of the storyline while jumping back and forth between text, figures, and supplementary material. I therefore have a few suggestions for revisions, some of which aim at better highlighting the novelty of the article / guiding the reader, while most others are simple requests for clarifications that I believe could improve the readability of the manuscript. Thank you for the opportunity to review this interesting work, and please don't hesitate to reach out in case of questions (giulia.mazzotti@inrae.fr)

Major / general comments

1. Are rock glaciers intended to be a focus of the study?

This was a recurring question while reading the manuscript. It first came up in the introduction (a paragraph dedicated to rock glaciers but no mention of rock glaciers in the paragraph presenting the study objectives), then again in the methods (rock glacier monitoring and use for calibration is mentioned, but how exactly it is integrated in the rest of the model setup procedure remains unclear), and in the results and discussion section (all figures specifically relating to rock glaciers are in the supplement). I think explicitly clarifying whether this is a focus and better incorporating the paragraphs and analyses related to rock glaciers into the rest of the storyline would greatly help the narrative of the manuscript. I tried to comment on specific instances that relate to this issue in the line-to-line comments below (I apologize for redundancy)

2. Are rock glaciers representative of headwater catchments in general?

The high-altitude catchments chosen all have a high rock glacier coverage. It is unclear to what extent the conclusion drawn in this study would apply to headwater catchments without such a high rock glacier coverage as well; i.e., are the rock glacier areas here treated as a specific case or considered representative of high-alpine areas? This aspect could be discussed more explicitly (even just in the Conclusion section).

3. Differences between catchments vs. differences along altitudinal gradients

I have the impression that the study highlights the variability in hydrological response along altitudinal gradients within the same catchments more than the variability between catchments. However, the choice between which figures are presented in the main article and which in the supplementary material somewhat contradict this. Only Figure 4 contrasts sub-catchments between the same study areas, while all other figures of the result section present results for the five study areas (which are often redundant). To interpret the results on the variability along altitudinal gradients (and the role of rock glaciers) one has to find one's way in the numerous figures of the supporting information. This massively disrupts the reading flow. This said, I do not want to suggest removing material from the supplementary material, there is definitely value in

presenting the analysis results as comprehensively as it has been done in this case and I really commend the authors for this! But some figure choices in the main article could be revisited (e.g., make the existing figures slimmer by not showing all five catchments every time, and instead move some examples that now only figure in the supporting information to the main article). Again, I have tried to provide suggestions in the specific comments below, which may have caused some redundancy.

4. What are the implications of the methodological limitations of the study?

The study uses conceptual models that have limitations with regards to process representation. For example, a degree-day snow model may not accurately capture the snowpack response to rain-on-snow, and therefore, melt factors calibrated on current conditions may not appropriately represent future dynamics. Likewise, I think you are not accounting for changes in subsurface storage capacity as currently ice-containing rock glaciers become inactive? I think adding a paragraph on model limitations would be relevant (e.g. in 4.1?).

Minor / line-to-line comments

L71: 'Their distribution...' - I am not sure I understand what you are trying to say with this sentence, consider rephrasing.

L84ff: Considering the importance of rock glaciers in the rest of the study, I find it somewhat surprising that they aren't mentioned in this paragraph. I recommend bringing up this aspect explicitly here, this will facilitate following the storyline later.

Section 2: The description of each site is very detailed and contains interesting information, but with 5 sites the details are very hard to retain. I wonder if a more concise description could better serve the paper. In practice, this could be achieved by moving the detailed information to the supplement, and instead introducing the sites all together by referring to Table 1 (no need to repeat the numbers in the text) and better highlighting how these sites differ. But this may be personal preference...

One detail on the sites: since some catchments have active rock glaciers, one is left wondering if they also have glaciers – which would impact streamflow and future scenarios. I found the answer in the supplement but I would state this explicitly in the manuscript.

L103ff: 'Drainage percentages refer to...' this sentence confused me. Is 'the combined area of the rock glaciers and their contributing catchments' the same thing as the 'total area'? In that case, I would write it like that and not mention drainage percentages here. But if the drainage percentages in fact relate to something different than the total area, you should make it clearer.

L229: It is unclear what these 'five elevation bands' refer to, since afterwards it is stated that SCF is computed per grid cell. Is each basin subdivided into 5 elevation bands? Please specify.

L234: Are the projections also available on a 1x1km grid? And over one yearly cycle, or as full time series (if the latter: for which period)?

L247ff: This paragraph feels a bit out of place here – the subsequent paragraph detailing the model is a much more logical continuation. The issue is that the paragraph addresses at the same time new observational datasets (while the other observational datasets were introduced in section 3.1) and one model calibration step (while the rest of the calibration is detailed at the end of section 3.2. This leaves some open questions as to how this calibration step fits within the rest of the calibration procedure? I think the information on the rock glacier spring

monitoring should be moved to 3.1, and the entire calibration procedure should be introduced at once.

L249: 'the model parameters' – which ones?

Figure 2 could be moved to the supplement. Instead, Figure S10 would be useful in the main article.

L279: Does this mean that two KGE values are computed and weighted (Table A1 reports only one value)? Or are you using something else for the snow-covered area? Please specify. Note: the title

Figures S11 etc: These figures are great and contain a lot of very valuable information. I think though that the information on what line colors correspond to is missing. Suggest to include legends in all the subpanels of Figure S11 (for the others it's obvious that the same apply)

Appendix A: I really appreciated the effort in making the parameter calibration accessible to the reader; the only thing that remains unclear to me is how the rock glacier springs data went into this, and since it seems like a considerable effort it would be worth specifying.

Figure 3: In the seasonal plots, I struggle to distinguish between the saturated and faded colors for the area representing the uncertainty (i.e. I can't really make out which uncertainty range corresponds to which line) – consider using different colors instead?

L364: 'As evapotranspiration increases' – Is this a hypothesis, or does the data show that? I know it's not a focus of the study, but given how comprehensive the rest of the analysis is, you could consider providing these results as well if that doesn't require too much effort. I could see that being a useful reference for future studies because the subject is somewhat underexplored. * I found the data in the supplementary Figure S36. I suggest pointing the reader at this figure here already

L370ff: This paragraph is key to the paper, but I am not sure that the key message comes across. It reads as if all the nested catchments behave similarly (more buffering of CC signal downstream than upstream) – while I understand they were chosen to represent varying subsurface storage properties (not only from headwater to lowlands, but also between the headwaters of the different catchments). I therefore wonder: is the key message that the same CC impact is observed in the five catchments *DESPITE* their different properties, or are there some differences in CC impacts that can be explained by different catchment characteristics? I feel this could be elaborated on more explicitly.

Moreover, is a bit confusing that the role of rock glaciers is addressed based on Figure 4, while the results specific to the rock glacier portion of the catchment are only shown in the Supplementary Material.

Figures 6, 7, 8: If I understand the caption correctly, the three grey boxplots within each subplot should be the same? There are some cases in which they don't seem to be (e.g. third row, third column), which is confusing. If they are the same, I suggest plotting them only once to avoid confusion and leave more space for the other boxes.

L411ff: This paragraph is interesting and it's a pity that the figures supporting this conclusion are all in the Supplementary Material. Consider moving e.g. one of the panels from Figure S37 to the main article so one can follow the reasoning without having to jump back and forth between article and SM...

L466-467: Figures S39-S43 include 24 panels each – this is another place where the reader may get lost, consider presenting an example in the main article so that looking at the SM is not a necessity.

Section 4.4: Same comment as above: multiple paragraphs refer to Figures S44-48 – including some of the information presented there in the main article (and more specifically pointing to the relevant subplots) would really help the reading flow.

L565: What do you mean by ‘static baseline assumptions’?