	Reviewer	**Author reply**
General	Dear authors, please find attached a PDF with detailled comments. I see the paper, with its focus on the buffering role of glaciers on streamflow in the 2022 extreme event, as important and meaningful contribution to a wide audience. The paper is well-structured and provides a huge and comprehensive amount of information across the Switzerland and a wide set of variables and plots are already well-thought and presented. Nevertheless, I think the manuscript could be further improved and clarified, not only content-wise but also language-wise. I had the impression that some descriptions and explanations of the plots could be improved and are rather vague or not precise enough making it hard to get an idea to which of the many details in the plots the authors are referring to. This facilitates misinterpretation and the mixing of numbers.	We are glad to hear the reviewer recognizes this manuscript as an important contribution to a wide audience and we thank the reviewer for the positive feedback on the structure and comprehensiveness of the paper and its analyses. We take the feedback on improving the clarity, both content- and language-wise onboard, to avoid misinterpretation and the mixing of numbers. We thank the reviewer very much for pointing out the various instances where improvements are needed. We reply below to each of the major comments, and added where needed the comments of the annotated pdf.
Methodological clarifications	Some major methodological clarifications that are necessary for the readability and comprehensibility (especially the glacier mass balance interpolation and adjustment). A flowchart like Fig. S2 is highly needed in the main text for the flow of the paper.	Please see our various replies below. We will add a flowchart figure (see Figure R1) to the main manuscript explaining the various steps for the glacier mass balance interpolation procedure.
More focus on hydro-meteorological conditions of 2022	Stronger focus on the hydro-meteorological conditions (also better represented in the main text rather than in the appendix) with some spatially-distributed water balance anomaly information.	We will summarize the hydro-meteorological information of the SI and add it to the introduction to increase this focus. The glaciological and hydrological conditions are the subject of this paper and are presented in the results. We will emphasize the information on the development of the precipitation deficits and the discharge deficits over the year. The water balance anomaly information is already included in Figure 3 and we would like to keep this figure as it is, as it directly shows with the size of the bars how this compensation role of glaciers work. We will add the spatial version (maps) of the water balance anomalies in the SI (please see these new figures at the end of this reply).
	More emphasis on the methodological & dataset decisions and thus the error term provided in the context of the glacier compensation introduction	We will add more information on how we assembled the data for all 88 catchments by including a table with an overview of all the

		data and will clarify in the methods and discussion what the error term means.
	Weaknesses in the presentation of 5.4	We will split 5.4 in three sub-sections, where the first section focuses on the long-term perspective, the second one specifically on the comparison of 2003 and 2022, and the third one on the changing sensitivity.
	Recommendations for extensions/replacements	Thank you for pointing these out – we reply to them here below.

PDF REMARKS

	Reviewer	Author reply
Abstract	"In contrast the relative contribution of glacier melt to streamflow stayed constant.." → Also compared to the other extreme years, meaning other hydrological droughts still had less streamflow reductions compared to 22?	Yes, indeed. For brevity we cannot repeat "compared to other extreme years", but will change into "stayed *rather* constant" to highlight the contrast and dependence on the previous sentence more.
	"Comparing 2022 to 2003 – the most comparable recent extreme summer- shows a declining glacier meltwater supply for 55% of the catchments during summer and 36% during July, despite more intense melt, with the difference in summer/July reflecting the extremeness of the melt conditions, counterbalancing the reduction in glacier area." I think this sentence would highly benefit to split it into 2. Besides, I would recommend saying "Compared to 2022, 2003 that has been the most recent comparable/similar...". Moreover, I would recommend making the "more intense melt" part could benefit by adding again that specific (per unit area) rates are meant (at least this is how I understand it), otherwise it reads very contra-intuitive with the 55% decrease and might confuse readers.	The numbers are 2022 based not 2003 → we will simplify the sentence by leaving the explanation of why less catchments in July out: *Comparing 2022 to 2003-the most comparable recent extreme summer- shows a declining glacier meltwater supply for 55% (36%) of the catchments during summer (July), despite more intense specific melt in 2022.*
Introduction	I of course agree that the vast majority of studies (which is indirectly stated when reading the remaining Introduction), the authors should add a paragraph that focus on the actual topic of the manuscript: buffering capacities/roles of glaciers in extreme years, which is missing at the current stage. However, there is definitely related literature.	We will add some more references to the paragraph before that discussed the role of glaciers in extreme years
	Drought term never properly introduced, and are you talking about meteorological drought or hydrological drought. Suggestion to make a section on hydro-meteorological conditions and providing maps with color coding	We will add a drought definition in the introduction ("a sustained and regionally extensive period of below normal water availability"). We talk both about meteorological and hydrological drought.

		More specifically the paper analyzes how glaciers can alleviate the propagation from meteorological to hydrological drought. Thus, the term “drought” encompasses the situation in Switzerland in 2022 where it was extremely dry due to a lack of snowfall in winter, rainfall in summer, impacting streamflow and glacier melt. As indicated before, we will summarize the hydro-meteorological conditions of 2022 in the introduction and will provide maps of the water balance anomalies in the SI (to avoid overlap with information already shown in Figure 3).
	What I am additional missing in the introduction (with respect to what I have said before already) is to provide context for some previous extreme yers in the Alps. I believe that there might be studies that evaluated extreme conditions and especially some of the years later chosen by the authors?	In the revised version, we will add more references on previous extreme years (in the alps) in the introduction.
Hydrological, Meteorological and cryosphereic data	Add basin area to table 1	Thank you, we will add this to the table.
	Figure 1 – add a legend for the basin colors	We will add a legend for the basins and changed the color of the glacier outlines on the map.
Methods	Add a flowchart for the methodology (glacier part) or a table with an overview of all the data	See the reply above. We will add a table with all the data in section 3 and add a flowchart in the methods section to better illustrate the glacier mass balance interpolation procedure.
	Explain reason for 2011-2020 reference period for the glacier interpolation method	We understand the confusion between this shorter glacier reference period and the longer general reference period used in this study. Or even with the 1980-2010 period used in the glacier interpolation procedure. Whereas the reference period used in the study (1991-2020) was used as a climatological baseline, another period was needed for deriving the glacier mass balance as the data for most glaciers does not cover this full 30 year period. Thus this 10yr (2011-2020) reference period was chosen to optimize the number of glaciers for which their measurement period covers this period. We will clarify this in the manuscript.
	Why where actual values and not anomalies used for the winter mass balance extrapolation?	There are two reasons for this decision: 1) absolute winter mass balances are assumed to vary less in space than annual mass balances as this is purely the accumulation term without glacier dynamics involved. 2) For long-term average winter mass balance, no glacier-

		specific information is available as for the annual scale (based on geodetic surveys). Therefore, using anomalies is not possible for the winter mass balance term. In the revised paper, we will include the above explanation.
	Literature or proof from the data why higher glaciers receive less accumulation?	The relation between median glacier elevation and precipitation is directly given by the dependence of air temperature on elevation: We can assume that temperature at a given elevation throughout Switzerland is similar. A glacier with a high median elevation thus must be characterised by less precipitation as melt rates are smaller (lower average temperature). This has already been shown e.g. by Ohmura et al. (1992) and is also shown by plotting observed winter mass balance data of Swiss glaciers against their elevation (see Figure R2 below) In the revised paper, we will add this explanation and the corresponding reference.
	Correction of anomalies to Bgeod is not clear	We will add a few more references to refer to the procedure, and add more explanation. In short, the geodetic mass balances provide a long-term mass balance signal for every single glacier which represents the most accurate available information. The annual measurements are crucial though for providing the year-to-year variability. So we use the measurements for extracting the variability (the anomalies), and superimpose this on the long-term mean mass balance.
	More info needed for the optimization of the daily mass balance model	We will add an explanation to the text that the daily mass balance model is calibrated each year to fit the various seasonal mass balance observations (winter probings and summer/annual ablation). Each of these two processes (accumulation and ablation) have their own corresponding parameters that are adjusted. Input for the model is meteorological data from a nearby meteorological station.
	Explain the meaning of “L”	“L” is the Level of compensation, and indicates how much the extra amount of glacier melt could compensate for the lack of precipitation and extra evapotranspiraiton. It represents the ratio between the surplus and the deficits and is expressed as percentage. This will be clarified in the manuscript.
	Better explain the error term	We will clarify in the methods part what the error term means. In essence, it is a value that is needed to close the water balance. What causes the error (or non-closing water balance term) is more difficult to indicate. This is discussed in the discussion part.

Results	Fig. s3 say that the numbers are for 2022	Thank you for pointing that out - this will be change
	Add boxplots with abs and anomalies for the various water balance components	Figure 3 shows the relative anomalies for all basins and corresponding catchment groups with a similar level of glacierization. To provide context to what these values mean, we added the absolute values of the various water balance components in the SI. Thus the information requested here is already available and therefore another figure with very similar information will not be added. We opted for bars instead of boxplots, to immediately be able to compare the sizes of the various water balance anomalies with one another and thus see which one is most important. In a boxplot version, this would be much more difficult to grasp.
	Add color coding to figure 4	We will add the basin color coding to this Figure.
	Add boxplots for all variables for annual and summer and also for the error term, it would be a summary of Fig s6 (recommend to add to the main manuscript) and partly fig 4	Similar to the comment above, we do not see the added value of adding boxplots, while all information is already included in the manuscript. We will add a scatterplot of the error term to the SI, as this value is difficult to summarize for a group of catchments. This way, the results of Figure 4, including the error term as uncertainty bounds, will be easier to understand.
	long-term perspective would benefit from restructuring. Go more clearly row-wise or basin wise through fig 6. Also, mention the symbols you are referring to, it is not clear if the text is about the triangles or the circles or both. Some of the generalized statements might not be completely correct. It may help to make a subchapter for the detailed 2003-2022 comparison	Thank you for pointing out the need for clarification in this part. We will go better row-wise through the figure and indicate about which basins/symbols we explain in the text. We will more carefully phrase the statements and check if they are generalizable or not. We will create a subchapter for the 2003-2022 comparison, as well as for the sensitivity part.
	July 2022 – 2018 not clear	We will revise the text to better explain the connection between precipitation amounts and streamflow and what it could tell about the role of glaciers
	Meaning of rx in table 3	Yes, indeed, this indicates which rank this 7-day lowest flow of 2022 had in the full observed timeseries. We will add this to the caption.
	Figure 7 should be summarized in a boxplot? Or a table that summarizes the counting of the catchments	In addition to Figure 7, we will create a table that summarizes in how many catchments, which variable was higher/lower in 2022 than in 2003. With this table, we can shorten the corresponding text.
	Is there any chance to evaluate reservoir storage effects?	This is very difficult. Even if we were to know the amount of storage that is available in reservoirs (total storage), we have no information about how much water was actually stored in 2022, and for example 2003. This means that we do not know if more or

		less water was stored in 2022 than in 2003. For this one would need up and downstream info of reservoirs and such a set-up we don't have at the scale of Switzerland.
	Statement about fig. 5 Might be valuable to notice here then that this is true especially for glaciations ~ >10% (this seems the point of divergence between purple and orange)? Also, it reads as if the authors point to Fig 5b, if so, maybe focusing on the summer period (5c) might underline the statement even more?	Thank you for pointing this out. The 10% visibility threshold also relates to generally small contributions at low glacierizations, so that differences are more difficult to see.
	Fig 7 positive degree day	No this value is based on 0 degree and catchment average temperature, it is unrelated to any modelled DDF
	Check sentences 375 and 376 for redundancy and vagueness because of "overall" and for "specific basins"	Thank you for pointing this out. We will revise the text correspondingly.
	The sensitivity part is a little undervalued. Needs its own sub-section?	Yes, we will add an own sub-section to present and discuss the changing sensitivity.
	If I understood correctly glacierization characterization is based on the year 2016, do the authors expect this choice to affect the results?	Yes, the glacierization is based on the 2016 inventory. We understand the phrasing causes some confusion, as these glaciers, for example, may not have been in the 0.1 km2 group back in 2003. Since we used the glacier areas just to sort the sensitivity results, we do not expect a major impact on the results. The thresholds that we name in the text are meant as an order of magnitude division in glacier areas. While it is true that some glaciers may have shift groups over time, while others have not, we expect this effect to be small and the finding that larger glaciers still have a high sensitivity to such extreme years remains valid.
	It would be interesting to see how the behavior looks as function of elevation (likely similar). At least it might be interesting to add to the Supplementary Fig. S6 a row for temperature anomalies by elevation.	Elevation would be more tricky, as it is not only the median elevation of the glacier, but also the elevation range that matters. We will add the sensitivity figure against elevation (instead of glacier area) to the SI, and add a row of temperature anomalies by elevation to the SI S6 figure.
	General: add short introduction and summaries per subsection	Thank you for pointing this out. We will structure the subsections better by providing an introduction sentence at the start and a summary at the end.
	Keep everywhere the distinction between net and total meltwater volumes	We will carefully check throughout the manuscript the use of meltwater volumes and make sure that it is clear if we talk about net or total meltwater volumes.
	Figure 7 would benefit from an additional summary table that summarizes how many filled and non-filled pie pieces per variable we have.	Thank you for pointing that out - such a table will be added.
	But to be fair the Rhone seems to be driving also the overall Swiss pattern where I would evaluate the change after 1980 not very significant or in other words relatively stable (especially given the	Indeed, since the majority of the Swiss glacier volume is located in the Rhone basin, the Rhone basin also drives the overall Swiss pattern. We will add this to the sentence.

	same level of volumes before the local high in the 80s/90s).	
	What is missing in the description of Fig. 9 currently is the interannual variability which from visual inspection seems to be much higher in the first half of the time series?	We will comment on the interannual variability of Fig. 9 in the revised version.
	L410 – a change in the overall writing quality	Thank you for pointing this out - we will put particular focus on the writing quality after L410.
	The drought terminology might be revised by the authors as extreme years (wrt temperature and precipitation) do not necessarily provide a comprehensive or differentiated drought picture.	Indeed, extreme temperatures and low precipitation do not necessarily mean drought and a heatwave. In this study we take a comprehensive approach and look at all variables important to characterize meteorological and associated hydrological drought. Since 2022 is well established as a drought over central Europe we do not think classifying the drought according to a standardized index or threshold is needed to use the term drought in this study, and accordingly, we don't think there is a need to revise the drought terminology.
	"changes in glacier surface albedo" □ and thus to local temperature variations	We prefer to stay with the albedo explanation and the effect it has on the radiation terms and the energy available for melt.
Discussion – 6.2	*In this study, 52 catchments showed a possible precipitation under-catch, which could be corrected with a multiplication factor for only 7 catchments. For the other influenced catchments, any applied correction to close the water balance may rather "correct" the human influence affects instead of the precipitation.* This is rather confusing, where do these numbers now come from and what is exactly meant with correct the human influence, please be more precise.	We will clarify this sentence by adding that these numbers come from the Methods section. We will also explain what we mean with "correcting" the human influence, by referring to the error term and its unknown source. One of the error (non-closing water balance) sources could be human influences (reservoirs, water diversions). Assuming these catchments are natural nevertheless and correcting the mismatch in the water balance by pretending it may be an undercatch in the precipitation may result in wrong interpretation of the role of precipitation in these catchments and was therefore avoided here.
	I think it would be good to provide ET (or for all vairable) maps in the appendix to get an idea on the absolute numbers across the different catchments.	We agree and therefore did already provide the absolute numbers of ET and all other variables in the supplementary information Figure 6, plotted against elevation and color coded according to main basin.
	The non-closing water balance issues could also arise from the glacier storage change estimations. Although the extrapolation procedure was carefully designed and improved in comparison to previous estimates (Huss, 2012; Cremona et al., 2023), the large variability in glacier geometries, the terrain surrounding glaciers, and local conditions make the extrapolation of measurements on only a few glaciers to 1400 glaciers a challenging task.	Since we cannot know which term causes the non-closure of the water balance in each of the 88 catchments, or if it is even caused by processes not accounted for (human influences), we rely on acknowledging the error term and discussing its potential causes. We will add more discussion on the choice of the glacier mass balance interpolation method.

	I fully agree to that and thus think that more attention should at least be given to the error term of the water balance closure/computation. Also, I think it would be beneficial to stronger support the choices of the interpolation at least by providing more references.	
	I would definitely recommend providing some maps/infos on which basins are affected.	We will add a map in the SI showing the basins that are affected and which ones can be assumed to be “natural”.
Discussion – 6.3	total meltwater, right (Table 3)?	Indeed, we referred to total meltwater and will change it accordingly
	How future extreme years may evolve thus depends on the extremeness of future conditions and the timing, determining the interval for glacier area changes. Not sure if I get this sentence right, do the authors just want to say "the status of glacier retreat"?	Yes, we will change the sentence into: “and the timing, determining the status of glacier retreat”
Conclusions	While the conclusion reads generally well, it might be improved by adding a little bit more remarks/statements on the hydro-meteorological conditions the year faced and provide thus the boundary condition for what we have seen.	Thank you for pointing the need to add more statements on the hydro-meteorological conditions in the conclusion, this will be added in the revised version.
	Do these numbers come from Fig. 3?	They come from Fig. 4
	Maybe vice versa add how many catchments in 2022 showed higher melt rates than in 2003	Yes, we will add (in numbers) that almost all catchments showed higher melt rates in 2022 than in 2003

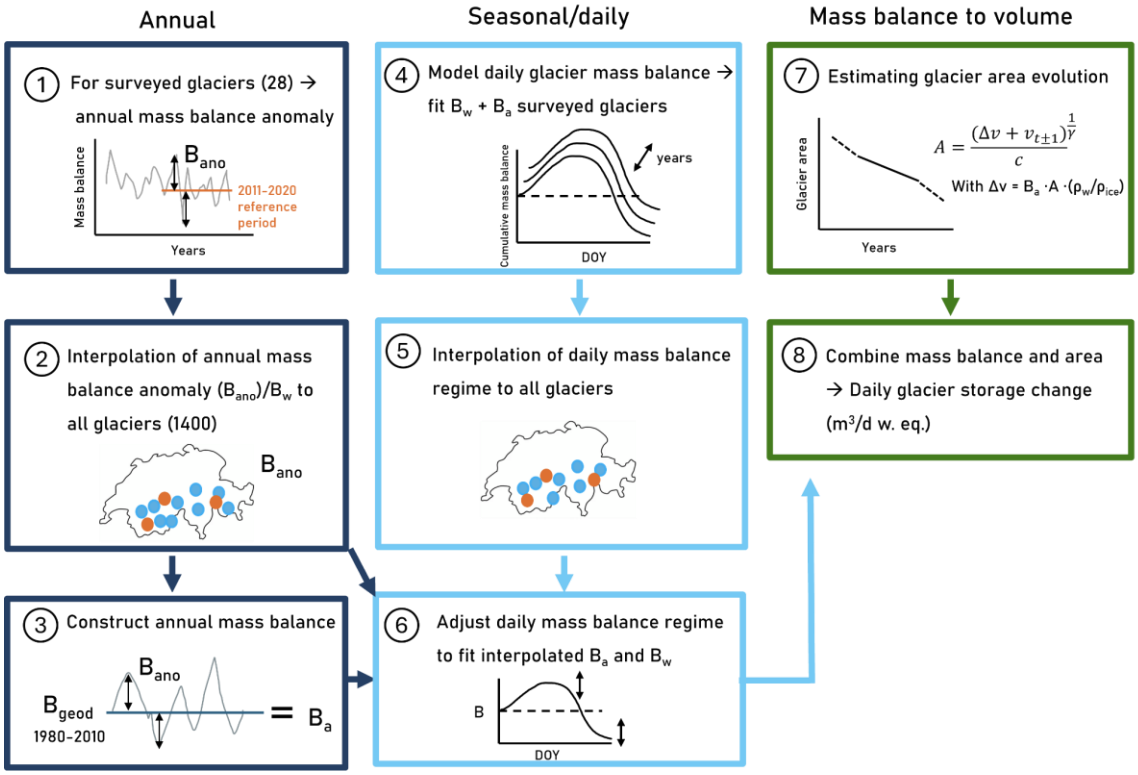

Figure R1 – Flowchart for deriving the daily glacier mass balance and glacier storage change estimates for all glaciers in Switzerland. This figure will be added in the methods part of the paper.

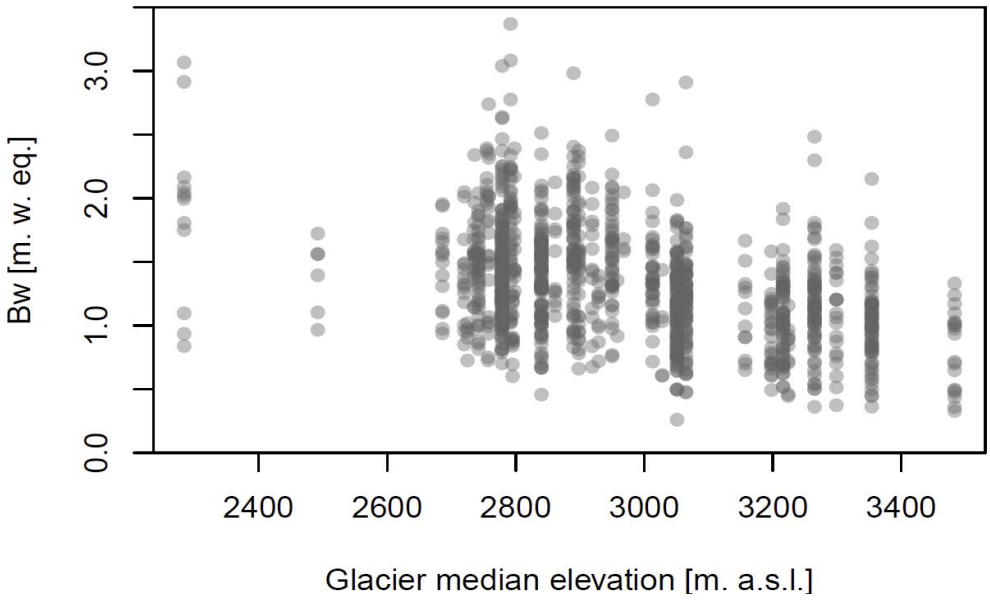

Figure R2 – Measured winter mass balance against the glacier median elevation, for all available measurements of Swiss glaciers.

References

Ohmura, A., Kasser, P., & Funk, M. (1992). Climate at the equilibrium line of glaciers. *Journal of Glaciology*, *38*(130), 397-411.