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Interactive comment on "The effects of climatic anomalies on low flows in Switzerland" *by* Marius G. Floriancic et al.

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We thank Referee 2 for the constructive feedback. We appreciate the suggested improvements and will address them in our revised version. Below we list our response (in bold) to the reviewer's comment *(in italic)*.

In this work, the authors assess how anomalies in precipitation and potential evapotranspiration shape occurrence and magnitude of annual low flows for 380 Swiss catchments comparing preceding precipitation and evapotranspiration for different periods to the annual minimum flow. After an initial analysis of annual low flows, the authors decided to focus on summer low flows for the rest of the analysis. The paper is clearly outlined and easy to read. I agree with reviewer 1 that I particularly like Figure 6 illus-

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trating the increasing role of PET during development of extreme low flows. However, different to reviewer 1 I have some major comments that I find important to address before publishing:

Thank you. Below we address the comments point-by-point.

Major comments:
Summer and winter low flows
After an initial analysis of annual low flows, the authors decided to focus on summer low flows for the rest of the analysis. This analysis takes relatively much of the full paper both in text and in Figures (1, 2 and 4). While I agree that it is important to differ between summer and winter low flows particularly when analyzing the drivers, I do not see that the results of general occurrence are new (e.g. Smakhtin 2001 and references therein, Fiala et al. 2010 and basically all runoff regime literature for Switzerland in particular e.g., Weingartner and Aschwanden, 1992) nor that they deserve this weight in the article. I suggest to minimize this to the introduction refereeing to the relevant references and remove Figure 1 and focus in Figure 2 on only the summer events or split in to summer and winter low flows at the beginning and then assess both for winter how snow (or precipitation and temperature) shapes low flow occurrence and magnitude and for summer how precipitation and evapotranspiration shape low flow occurrence and magnitude

We will improve the introduction of summer vs. winter low flows and include further literature as outlined by Referee 2. While we agree that there are contributions pointing out the general occurrence of winter and summer low flows, we consider it valuable to show that the occurrence of summer vs. winter low flows can be related to elevation (1200m, Fig. 1) and that the differences of summer vs. winter low flows are also detectable when analyzing the climate anomalies (Fig. 2a and b). We furthermore use Fig. 2a and b to argue why we relate summer low

flows to precipitation / PET anomalies, and expect these relations to hold for a wide range of low-elevation catchments

More focus on the shaping
Instead of counting and presenting summer and winter low flows representing the annual low flow, I think it would be more interesting to try to add on the shaping of the low flows caused by precipitation and evapotranspiration. For instance, in addition to correlation between precipitation and PET separately on extreme or less extreme low flows it would be interesting to look at their combined effect. And then how much of the combined effect could be attributed to precipitation and to PET. This would allow a better relative quantification and really add to the values of this study.

We emphasize that Fig. 3 and Fig. 6 are studying the combined effects of P and PET on low flows already. In the revision we will try to make the partitioning of the effects of the two drivers more explicit, for example by multivariate regression between the low-flow magnitude (anomaly) and the two climatic driver anomalies. We agree with the reviewer that it is interesting to quantify the relative roles of P and PET for low flow generation.

Choice of summer months
The authors focus at extreme low flows and the preceding conditions and chose 2003, 2011, 2015 and 2018 as the relevant years. The drought in 2011 was finished for most catchments before July, I urge the authors to look into the data and if so, adjust the analysis by either treating 2011 differently, i.e. not considering it a summer but a spring low flow and or change the analysis period for all years that was defined by the authors Jul-Nov.

We agree that the drought in 2011 is predominantly occurring in spring throughout the Swiss catchments (i.e. only 143 of 380 catchments have their low flows in

July through November in 2011). We choose the 6-month period July-November because most low flows occur during this period. However, in some cases low flows do occur outside of this window (e.g., 2011). When we calculate the statistics of the main figures that use the 6 month window (e.g. Fig. 2 cd, 3, etc.) the results do not change significantly because our chosen period captures almost all low flows. In the revised version we will more clearly acknowledge that not all low flows are captured by this window, but also that this choice does not affect the results significantly.

Terminology
There is a seamless transition from "drought" to "low flow" and mixed use of "droughts" and "deficits" while the citations support both. I find this mix critical since already deficit (even when regularly/seasonally occurring) causes low flows but meteorological droughts are larger deficits than normal, i.e. the regularly/seasonally occurring deficit. Please, revise the introduction to distinguish clearly between these. This would help the reader in the analysis that follows.

In the revised version we will better distinguish between drought, deficit and low flow. In short, we will minimize the use of the term (and references to) drought, since low flows are not necessarily droughts.

Likewise, the authors use often only the term "low flow" when actually referring to "extreme low flow". This can result in wrong statements (e.g. L72 "low flows are exceptional flow conditions" or L186 "triples the chance of an annual low flow"). And I would ask the authors to revise and correct the usage throughout the manuscript.

In the revision we will be clearer when we refer to a (typical) low flow versus an extreme low flow. In addition, we will be clearer what we mean when we use

“extreme”, since not being explicit about this can lead to misinterpretation (e.g. L72).

Mixed results and discussion section
In my opinion results and discussion should be separated. This allows to focus on the results. Only then what we can learn from the results and where we might to be a bit more careful, then also relate and compare to what was done elsewhere and where limitations and possibilities lay. In the present form the manuscript mixes these aspects and is more difficult to search for s specific result /argument this way.

We understand that separating discussion and results may in many cases be a good choice. However, we tried both options in preparing the manuscript and found the chosen option to work best, because it is easiest for the reader to see the connection between the results and their interpretation. In the revision, we will go through the entire manuscript to ensure it is as clear as possible.

Minor comments:
L25-27 Remove this sentence for the abstract

This sentence may sound trivial but is needed for the logical flow of argument in the sentence following it. Therefore, we prefer to keep this sentence. We will consider reformulating the abstract to improve its clarity.

L40/41 is “landscape” only including surface features? Maybe use rather catchment properties”.

We use landscape because we thought it would make clear that it does not include all catchment properties (such as its climatic conditions). Landscapes

extend into the subsurface; this is implied in our statement in line 40, but we will now explicitly add this in the revision.

L72 this statement is not correct they occur every year. Make clear that it is about extreme low flows here!

In the revision we will choose more precise wording which reflects that the low flows we are studying are "annual extremes" and not every annual extreme is necessarily an extreme in the long-term record.

L92-94 a summary table (maybe only in the supplementary material) would be helpful

We will include a table in the supplementary material; the data for all catchments will be made available through the "open access" platform of the ETH library.

L121 1200m asl, why this threshold? Why not a range?

We use a threshold to split the dataset into two groups (below 1200m asl and above 1200m asl). This threshold accurately reflects what type of low flow (seasonality) is expected within this dataset. We do not see how using a range would improve this observation.

L130 remove "However, this remains to be tested".

OK.

L147-150 For these low flows, people are usually prepared. Here it would be interesting how much more extreme are others. If it was due to a lack of precipitation, the signal should be visible in spring melt.

We agree that such winter precipitation deficits can have effects on flows later in the snowmelt season, and will likely be visible in the data. However, the aim of this paper was not to explore all these hydrological connections, but rather focus only on the climatic conditions leading to the lowest flow in the year. This remains an interesting suggestion for further research.

L154 "suggesting. . ." could be also formulated that lower elevation Swiss catchments could be representative sample for global summer low flow? (and maybe not even global but for humid regions with seasons?); This part would better fit in the introduction or methodology/catchment section.

We put this statement here because we discuss our results and their implication here. Making this statement in the introduction is leapfrogging ahead, because we have not characterized the seasonality of Swiss low flows at that stage.

L161 altitudinal variation in 30-day anomalies: could that be influenced by catchment size? A large catchment might not react on such an anomaly a small catchment not anymore if the driving anomaly is at the beginning of the period.

We tested if catchment size affected the altitudinal variation. While such effects can be expected, no clear signal was found, probably because the catchments are relatively small (< 519km^2, with a median of 74km^2). We will discuss this in the revised paper.

L174 "substantial site to site variability" can this be quantified?

To clarify what this variability refers to, we now explicitly refer to Fig. 2c and 2d for the reader to look at the spread. We also add the range in the text.

L181 can these 8L189-196 These results are not surprising (the authors refer even to studies that found the same) but nicely illustrated and supported by the data. However, it would add to the value of this study to quantify the contribution of precipitation and evapotranspiration.

We agree that these results are maybe not surprising, as they have been shown for individual cases (as referenced earlier in the paper). Our work improves past studies by (a) providing a large dataset which shows the variability and consistency in low flow-climate relations among basins; (b) quantifying the effect of duration of the climatic anomalies required to generate the extreme low flow events; and (c) separating the effects of precipitation and PET. We believe this provides a more robust picture of otherwise intuitive relations.

L189-196 Consider also to compare to Stahl et al. 2010

We will put our results in context of the findings of Stahl et al. 2010.

L196-197 delete sentence

It is unclear to us why this sentence should be deleted.

L203-204 it is possible to avoid that by the study design (see also my major comment on seasonal split)

We agree that it is possible to select data such that only the drier years are kept. However, that is not the purpose of our study. We rather discuss that not all annual low flows are created equal.

L222-228 that depends on how one looks at the drought: is the same scale as in the references used? The effect was also found in low flows but maybe not in the metric "annual low flow", again distinguish between drought and low flows (see also major comment on terminology above) Figure 4: Looking at the figure makes me wonder how/if the regulated catchments might influence the pattern presented. Could that be picked up in the discussion?

We will change this in the text, to clearly distinguish between "droughts" and "low flows". We will discuss the influence of flow regulation on low flow timing in the revised manuscript.

L241 How brief since the study is about anomalies?

We will remove this.

Technical comments

While I find that active voice generally a good choice, I would avoid starting every sentence with "we" (e.g. 2.1 but also elsewhere), please revise.

We will consider how to reduce the prevalence of sentences beginning with "we" (although they are usually the most compact, clear and direct way of expressing things).

L22 "dry years saw" please rephrase

We will change this.

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L28 redundant, delete either “could” or “potentially”

We will delete “could”.

L44 “(PET)” -> “, PET”

We will change this.

L44 remove “should” and “usually”

We will delete “should” and “usually”.

L46 remove “made”; split sentence: “: : :to a catchment. Hence a sustained: : :”

We will change it accordingly.

L49 Make a new paragraph

Ok.

L64 “smaller” = “lower”?

We will change this.

L66 “comes” -> “occurs”; remove “the” before summer and before winter

We will change this.

L79 “useful” = “suitable”?

We will change this.

L94 “quantified” -> “estimated”

Ok.

L100 “years whose lowest annual flows were much” -> “years with lowest annual flows much”

We will change this.

L103 “low flows” -> “extreme low flows”

We will change this.

L224 remove “the” before summer and before winter

We will change this.

L238 “more strongly” -> “higher” (also in L244)

We will change this.

L259-262 rephrase to make more concise

We will rephrase this sentence.

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