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Comment on hess-2021-331

Anonymous Referee #1

Referee comment on "Quantifying pluriannual hydrological memory with Catchment Forgetting Curves" by Alban de Lavenne et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-331-RC1, 2021

Review of "Quantifying pluriannual hydrological memory with Catchment Forgetting Curves."

This paper aims at better understanding how catchments' runoff response depends on the climate of the years preceding. The paper introduces a method to quantify these effects and applies this method to a large set of French and Swedish catchments. The results indicate that memory effects appear limited ("approximately 80% of the Swedish catchments and 89% of the French catchments showed no significant pluriannual memory"). Still, the catchments that do show memory appear to be more groundwater-dominated (in France), and the memory increases with aridity (both in France and Sweden). From this, it is concluded that there is a "need to account for catchment memory to produce meaningful and geographically coherent elasticity indices."

Overall this study addresses a relevant topic, potentially suitable for HESS, and investigates this across a large spatial domain (several hundreds of catchments). Yet, at present, there are several things that need to be resolved. The main issues are:

- The main result that elasticity values are underestimated using a normal approach seems questionable. Eq. 1 quantifies how Q/P of year X varies with P/E_o of year X. These numbers are both hopefully of a similar sign typically. If the same is quantified using Eq. 2, the P/E_o values originate from multiple years, thereby having values that will often differ in sign from Q/P of year X. Since their combined weight (that is sum(omega_i)=1) is still 1, the associated elasticity value needs to be higher yield a similar effect of P/E_o on Q/P. A difference between epsilon_2 and epsilon_1 would therefore have little to do with physics, but rather (partly) arises from a mathematical artifact. This seems supported by the fact that even in catchments with no significant memory the epsilon_2 still typically very strongly exceeds epsilon_1.
- **It is unclear how it is possible that so often a particular year's aridity explains that year's runoff ratio so poorly. Is this because the paper does not make use of water years, but calendar years instead?**

- **The writing is at times unclear. I made many detailed comments below, but those are not necessarily comprehensive in resolving all issues.**

Detailed comments

Abstract: I think the relevance of the study would become a lot clearer by starting the abstract by introducing the problem that this paper addresses (e.g. a knowledge gap, or a paradigm that is challenged), rather than just stating what has been done.

L2: it is a "precipitation – runoff" relationship as many catchments will also experience snow.

L2: For clarity: rather than saying "focusing on" just describe what elasticity actually expresses.

L4: since "humidity" can refer to several hydrological conditions, I'd more accurately introduce this concept.

L5: make "distribution" plural to indicate that each CFC has its own parameterization.

L5: rather than say that a gamma distribution is used, provide some context of why a gamma distribution is used (e.g. it fits the data?).

L7: what are: "powerful aquifers"?

L7: "a long memory" can be made more specific and thereby more informative.

L8: state how aridity matters rather than that it matters.

L8: I am unsure what "appears to be one of the main drivers" really means here. Please rephrase it to be more accurate of how it matters.

L8-9: "Our work underlines the need to account for catchment memory in order to produce meaningful and geographically coherent elasticity indices." Sounds like a nice conclusion but it does not seem to reflect that >80% of the catchments have no significant memory effect… This should be discussed in the abstract.

L15-16: I think a reference or two would not be inappropriate here.

L20: "will" seems redundant.

L21-24: I find it hard to fathom the statement "To make this discussion of a complex matter simple, we start with a first-order simplifying assumption: We hypothesize that a catchment may have both a short-term and a long-term memory (see e.g., Risbey and Entekhabi, 1996; McDonnell, 2017); we consider the short-term memory to be seasonal, and will not address it in this paper in order to focus on the long-term (pluriannual) memory effects.". To me, this statement is unclear (how are seasonal and longer-term memory really separate?), it is not clear why the assumption you make can be made (because it is not explained), and the reference seems off (why refer to a paper about water ages, when the quantity you're interested in are quantities of water?).

L26: "its variability" in space, in time, or both? Please specify.

L28-29: I find it hard agree with the statement "is obviously a function of catchment storage capacity (in groundwater aquifers, wetlands, lakes or glaciers)". It is not the

"capacity" that matters, but rather the "storage amounts" which are largely independent of "capacity". For example, there is a lot of storage capacity in the pores of Sahara sand, but only if these pores are filled (or not) will influence whether it has an influence on memory.

L29-30: "the originality of this paper will be in the quantification 30 of *forgetting curves* at catchment scale:". I understand that this concept is original, but I think it needs to have more context of why this concept is useful compared to current knowledge. The latter is lacking from this part of the introduction, and only is introduced later. Putting this upfront will help the reader not being confused why this study is undertaken at all.

Section 1.2. I think this clarification does not need an entire section, but should be resolved in a single sentence (or maybe two at most). Once this is resolved, I would recommend to also remove any travel time stuff from the following section(s) as this is a separate topic that is not addressed in this paper.

Section 1.3: The statement that "existing methods aiming to analyze memory either summarize the memory by a single value and/or provide an index that cannot be directly interpreted as duration" provides (in theory) a clear motivation for your study. If you also state this at the start of section 1.3 the reader will much better understand what is lacking in these pasts works (rather than concluding it in hindsight). In general, this section can be condensed.

Section 1.4 this a description of why people have reported catchment memory before, but I am unsure how this is useful (in this format) as the introduction of the paper. Can it be reframed to introduce your work, rather than mostly just listing findings? Also, I do not thing that listing flood effects or water quality affects is useful here as these topics are not addressed in your own work.

Section 1.5: this a description of what people have reported, but I am unsure how this is useful (in this format) as the introduction of the paper. Can the main findings be used to introduce your work, rather than mostly just listing findings?

I understand that the above suggestions may sound a bit arbitrary, but I think you'd do the reader (and therefore your own paper) a huge favor by having a more to the point introduction.

Section 1.6 I think the study area needs to briefly mentioned with the scope, as this defines the scope of the paper.

L158: "that are not regulated" how is this defined?

L167: "We accepted a maximum of 10% of missing data per year". OK, but what did you do with these missing data? Just calculate annual Q over fewer days?

L167: "respect"?

L168: "in order to be able to" or simply "to".

L181: are these calculated over calendar years of based on hydrological years? The latter seems more useful?

Figure 1: Can a more typical example be shown? A catchment that does not respond to its current year conditions seems like a (very strong) outlier?

Line 199: "we hypothesized (after many attempts that we cannot report here)". I have no

idea what has been done here, but to still call it a hypothesis seems like a stretch?

L200: why mention transit time distributions? Transit times distributions have nothing to do with the presented study or approach so I am unsure why mentioning them helps?

L203: What does "would not be enough" mean is this context. Please rephrase.

L216: Since there is no real reason for 75%? If you take 50% you can simply multiply alpha by beta, and choose a more typical percentage? Or, would it be possible to present a scatter plot of different percentages so it can be seen if this metric is robust?

L221: "This shows that pluriannual catchment memory is neither common nor very uncommon." Does it? Or does it suggest it's uncommon?

L244: "If larger catchments tend to have larger memory in France, this trend is not confirmed in Sweden" is unclearly formulated.

L245: earlier "humidity" was used and now "aridity"; please be consistent.

L246: "whereas the hydrological behavior under less humid climate is more variable and linked to the dynamics of long-term water storage" such an explanation might be feasible but there is no evidence supporting it. It is unclear to me whether this statement is considered a finding or speculation?

L249: "clearly identifies" use a different verb (e.g. "is associated with")

Section 3.4. I do not think this a physically meaningful comparison. Eq. 1 quantifies how Q/P of year X varies with P/E_o of year X. These numbers are both hopefully of a similar sign. If the same is quantified with Eq. 2, the P/E_o values come over multiple years, thereby having values that will often differ in sign from Q/P of year X. Since their combined weight (that is omega_i) is still 1, the associated elasticity value needs to be higher to still yield a similar effect of P/E_o on Q/P. This seems like is has nothing to do with physics, but rather arises from a mathematical artifact. This artifact seems supported by the fact that even in catchment with no signifivant memory the epsilon_2 still always exceeds epsilon_1. Maybe I get it wrong, but please convince me so in a clear manner.

Figure 9: if these two values are compared, please show them on a similar color scale. However, as stated earlier, I do not think they are comparable.

All appendices can be Supp Info?