Reply to the Reviewers' comments

Key:

Review comment.

Response.

> "Quotation from revised paper."

Reply to Reviewer #1

SUMMARY:

This paper looks at the lagged seasonal correlations between the average river flow in antecedent months and, on one side, peak flow for the High Flow Season (HFS), and on the other hand, average flow for the Low Flow Season (LFS). It also looks at what are the possible physical drivers that could explain these correlations. The study is carried out using a large sample of European rivers. It also shows a real-case application of the findings to flood frequency estimation

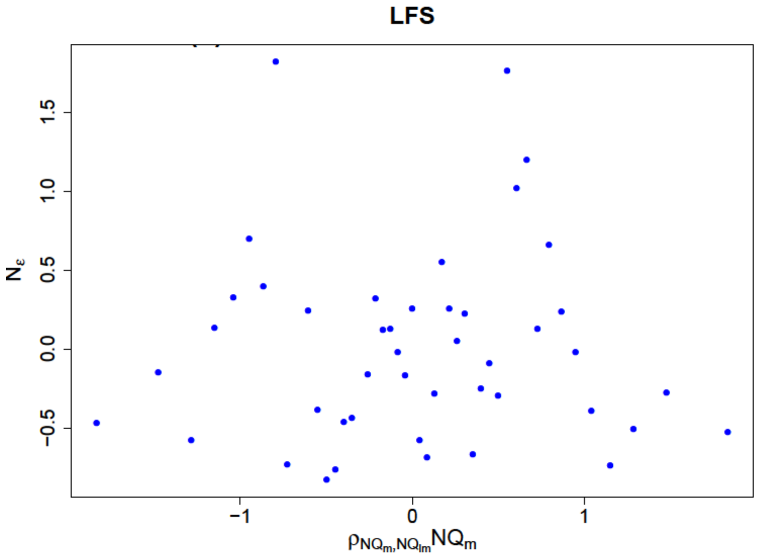
GENERAL COMMENTS:

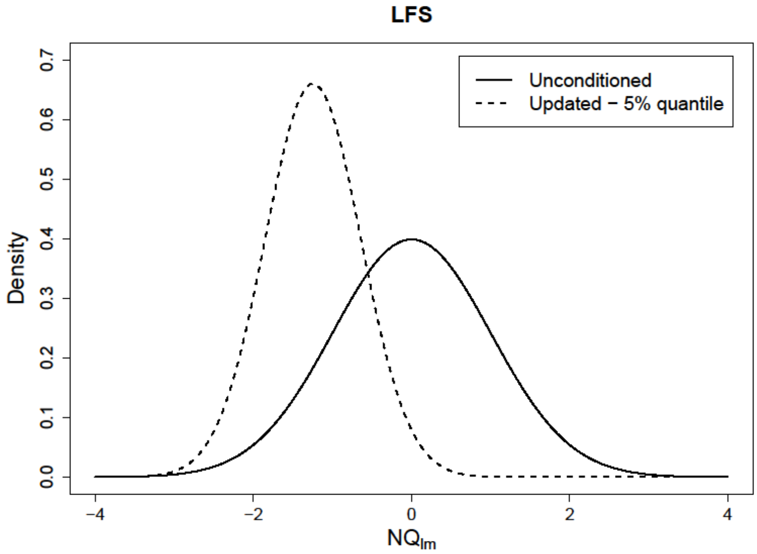
The paper is well-written, clear, interesting and attempts more systematically than previous study to attribute the observed correlations to physical drivers. The methods used are adequate and robust, assumptions are being verified. Overall, it contributes to the advance of science in the field, and my recommendation would therefore be for publication.

We gratefully thank the Reviewer for the very positive evaluation of our work and for recommending publication. We are also thankful for the constructive comments, the corrections and suggestions provided which will certainly help improve the manuscript. These are discussed below.

However, I have a couple of comments for suggested improvement: 1) My major comment is that, although the whole manuscript looks at both high flows and low flows, and analyses both in detail, the practical example at the end is only for high flows. I think a similar case study for low flows is missing there. If there is a really good reason for only giving an application example for high flows, the motivation for this should be clearly explained.

We thank the Reviewer for this comment. Certainly, the application for LFS is also of great importance and we agree that it would be a useful addition to the paper. Some modifications are required in order to apply the methodology for the case of updating the distribution of average flow in LFS. Following the Reviewer's suggestion, in the revised version, we will present this application too and discuss it as follows. In order to update the distribution for the average flow in LFS, the already identified average flow in the pre-LFS period will serve as the explanatory variable. A linear model will be adopted in the Gaussian space in the same manner as for the HFS model. For the case study, we will update the low flow distribution upon the hypothetical occurrence of a mean flow in the pre-LFS month equal to its lower 5% sample quantile. The updated distribution in the non-Gaussian space could be modelled by any adequate distribution exhibiting good fit. Among the Gamma, the Weibull and the lognormal distributions, which are typical candidates for average flows, the lognormal distribution was found to exhibit the best fit for the river in question. The above information along with the equations describing the new linear model for the LFS will be included in Section 2.3 which will be renamed to "Technical experiment: Real-time updating of the frequency distributions for high and low flows". In Section 7, we will include the following plots for the LFS case study alongside the existing plots for the Oise River. In order to maintain the brevity of the manuscript, we will drop the second HFS application for the Torsebro River in the revised version.





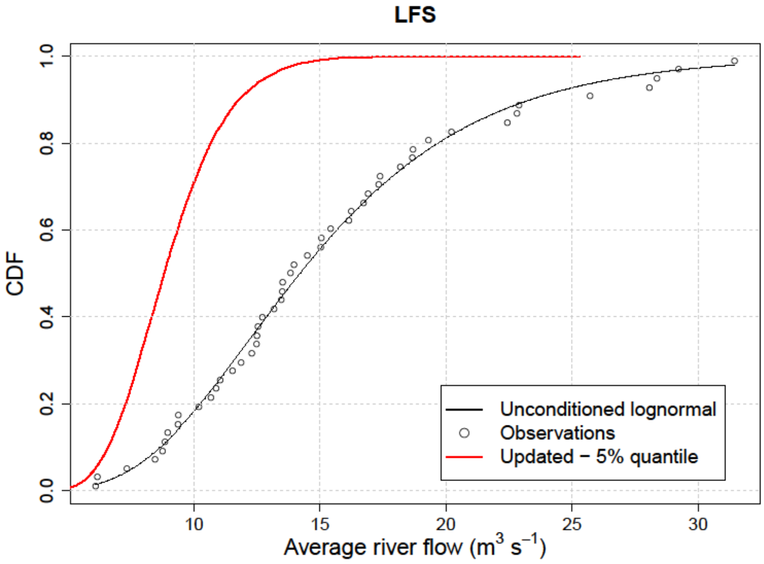


Figure 15. Conditioning the frequency distribution for low flows for the Oise River. Plots of the residuals of the linear regression given by Eq. (2). Probability distribution of the unconditioned normalized average low flows NQ_{lm} (solid line) and the normalized average low flows NQ_{lm} conditioned on the occurrence of the lower 5% quantile (dotted line). Cumulative distribution function of the unconditioned average low flows Q_{lm} (black line) and the average low flows Q_{lm} conditioned on the occurrence of the lower 5% quantile (red line) and modelled by the lognormal distribution.

Section 2.2 is too long. It would help readability to have a few sub-sections in here. Suggestion of subsections below (could be different, this is just a suggestion): 2.2.1. Correlation analysis 2.2.2. Analysis of physical drivers a) Drivers (catchment descriptors, geological descriptors, climatic descriptors) b) Principal Component Analysis

We thank the Reviewer for this suggestion. We agree and we will adopt the proposed subsections.

MINOR COMMENTS:

Abstract:

line 43: change “in real-world cases” to “in two real-world cases”: otherwise it is misleading and it sounds like you’ve done this to all the 224 catchments

Thanks, we will correct the wording accordingly in the revised version.

1. Introduction:

Line 63-66: Note that the persistence method described by Svensson (2016) that you cite here, has been used operationally in the production of the UK Hydrological Outlook since 2013 (see Prudhomme et al., 2017)

Reference: Christel Prudhomme, Jamie Hannaford, Shaun Harrigan, David Boorman, Jeff Knight, Victoria Bell, Christopher Jackson, Cecilia Svensson, Simon Parry, Nuria Bachiller-Jareno, Helen Davies, Richard Davis, Jonathan Mackay, Andrew McKenzie, Alison Rudd, Katie Smith, John Bloomfield, RobWard & Alan Jenkins (2017) Hydrological Outlook UK: an operational streamflow and groundwater level forecasting system C2 at monthly to seasonal time scales, Hydrological Sciences Journal, 62:16, 2753-2768, DOI: 10.1080/02626667.2017.1395032

We thank the Reviewer for bringing to our attention this important application. We will include this reference in the revised version.

2. Methodology

Section 2.2: see comment earlier in general comments regarding splitting this section

Thanks, we will address this issue as discussed above.

Line 127: change "in terms of catchment, climatic and geological descriptors" to "in terms of catchment, geological and climatic descriptors", because that is the order in which you list them later in the text.

Thanks, we will change this.

Line 128-130: add altitude to the list of catchment descriptors (as you present it after percentages of lakes and glaciers).

Thanks, this will be added.

Line 139: replace "baseflow index" with "BI"

Thanks, we will change it.

5. Physical interpretation of correlation

Line 365: typo: replace "20-cathcment" with "20-catchment"

Thank you for the careful review, we will correct it.

8. Discussion and Conclusions

Line 456: typo: replace "There" with "Their" or "These"

Thanks, we will correct this too.

Reply to Reviewer #2

Recommendation:

This is a very interesting paper, investigating the drivers of seasonal streamflow correlation for both high and low flows, using a wide range of physical drivers including catchment, geological and climatic descriptors. The paper is very well structured, easy to follow, concise and clear throughout with a well explained methodology and clear contribution to the field. Limitations and assumptions are also discussed well. I would recommend this paper for publication subject to minor revisions based on the comments below.

We are grateful to the Reviewer for providing very positive remarks on the contribution and quality of our work and for recommending publication. We also wish to thank her/him for all the thoughtful suggestions and comments provided which will certainly help improve the manuscript and highlight its contribution. These are discussed below.

General Comments:

1. It may be apt to mention that this analysis is for Europe, in the title of the paper

Thank you for this suggestion. We will change the title of the paper accordingly.

2. I agree with reviewer 1 that the readability of section 2.2 would improve if it were split into subsections

Thank you for this suggestion. We agree as well and we will adopt Reviewer's 1 suggestion on that.

3. It is not clear from the methods or from section 7 why you are doing this technical experiment and what you hope to gain from it. There is a brief explanation of this in the abstract, and it would be beneficial to further describe what the purpose of this experiment is within the manuscript.

Thank you for the comment. The technical experiment is meant to highlight the practical applicability of the proposed method, besides its importance for improving the physical understanding of river memory. Providing more reliable flood estimates is a fundamental hydrological task and we want to provide a relevant case study showing how the identified correlation explicitly serves such a purpose. Following the Reviewer's suggestion, in the revised version, we will elaborate on the purpose of the technical experiment and extend the relevant discussion on the main body of the manuscript as well. We will also extend the technical experiment to include the low flows distribution updating as well and discuss its practical relevance.

4. Again, I agree with reviewer 1 that I was expecting to a case study / technical experiment for low flows as well, and would like to see this included in the revised manuscript as it would certainly be of interest.

Thank you for the comment. Indeed, this is a very important application too. In the revised version, we will include the relevant case study discussed above.

5. While I find the discussion to be thorough, with comparison to the literature and interesting points made, the conclusions seem to be very rushed and do not do the paper justice. I would recommend including a separate conclusions section and expanding significantly on this, including for example the wider implications of your work, how the findings could be applied and used, what further work could be done from this, etc. The conclusions imply that all of your results agree with the literature that was already out there, when in fact I believe this paper has done more than this. This is also the first time data assimilation is mentioned so there is no context here. It would also be interesting to further mention section 7 as an example of use.

We sincerely thank the Reviewer for the suggestions on how to improve the conclusions in order to better convey the research findings of this work. We will include a separate conclusions section and discuss areas of practical applicability as well as directions for further research. We also agree with mentioning section 7 as an example of use and in this section, we will also introduce the data assimilation concept.

6. There are a lot of figures included in this manuscript - is it necessary to include all of these, or could some of them be provided in supplementary material for further interest? Some are barely discussed in the paper, for example 15a,b,c,d.

We thank the Reviewer for this comment. We will consider the possibility to include some of these figures as supplementary material in the revised version.

– Minor Comments and Clarifications:

Line 33-34: it should be mentioned that the study covers 6 countries in Europe, the abstract implies that the whole of Europe is included

We thank the Reviewer for this remark. We will include this.

Line 78: Remove "in fact"

Thanks, it will be removed.

Lines 87-89: This is repetitive of information stated just above

Thanks, it will be removed.

Line 105: "employed" is used a lot in this paragraph - maybe just use "used"?

Thanks for the suggestion, we will adopt it.

Line 110-111: Why do you not take into account the minor HFS after identifying it? This could be interesting to discuss; but at least should be justified.

We thank the Reviewer for this comment. Actually, we are interested in exploring the river memory for the purpose of predicting high flows and low flows and therefore we are interested in the most extreme seasons. Exploring the memory for the minor HFS may be interesting for reservoir management or water resources management, but in our opinion would not add much for the purpose of analyzing the probability of occurrence of the most relevant flows. Besides, minor high-flow seasons characterized by low or moderate significance were only detected in a few rivers in Austria and Sweden (section 4.1), and therefore, we consider a minor HFS analysis to be more relevant in other regions of the world where bimodal flood regimes are more prominent, as shown by the analysis of Lee et al. (2015). We will add these considerations in the discussion section of the revised manuscript.

Line 123: Why do you look for correlation with mean flow in the previous months? This is fine, but the reason should be included.

We use the mean flow in the previous month as a robust indicator of the 'storage' in the catchment. The mean flow is more likely to portray the condition of the catchment and its possible change with respect to a higher quantile. The latter correlation is less related to the memory properties of the catchment which are of interest here. We will include the above explanation in the revised version where specified.

Line 134: basing -> based

Thanks, we will correct the wording accordingly.

Line 155: A very brief explanation of flysch and karstic formations would be helpful for those of us with no geological background.

Thanks, we will extend the following phrases giving a brief description of the geology as follows:

> "A subset of Austrian catchments is characterized by the dominant presence of flysch, a sequence of sedimentary rocks characterized by low permeability, which is known to generate a very fast flow response."
> "Karstic catchments, characterized by the irregular presence of sinkholes and caves, are also known for having rapid response times and complex behaviour; e.g. initiating fast preferential groundwater flow and intermittent discharge via karstic springs (Ravbar, 2013; Cervi et al., 2017)."

Line 161: Remove "of" ("because of geology...")

Thanks, we will remove it.

Line 165: What type of data is this?

'Data' refers to the data described above (mean annual temperature and precipitation), which are gridded. We will clarify this further.

Line 166: What is this in km (approx.)?

10 minutes of degree equal approximately 18.55 km at the equator, i.e. the grid size is approx. 344 km^2, but as the latitude increases towards the poles, the longitude distances decrease.

Lines 164-170: You don't mention here how this relates to snow, which is discussed a lot in the results

Thanks, we will add that low mean temperature regimes are associated with snow.

Line 233: Where is this data from? is it observations? please clarify

These are daily streamflow records from gauging stations. These are provided by the institutions mentioned in the authors' affiliations and are available upon request.

Lines 242-243: Please clarify what Cfb and Dfc climatic types are

Thanks, these acronyms are defined in the legend of Figure 1. We will clarify this and reiterate the explanation in the text as well.

Lines 251: This is indeed interesting, could you expand on which rivers are regulated?

Line 257: Is the regulation really mild; what do you define as mild regulation?

We have information for the presence of such regulation for 16 of the Austrian rivers. We used the term 'mild' regulation to describe anthropogenic influences of an intensity that does not majorly alter the flow regimes. These are related to upstream regulation with very low degree of flow attenuation, hydropower operations and flow diversions to and from the basin. Indeed this is a subjective characterization given by the operators of the stations and unarguably the regulation issue requires more investigation. Unfortunately, the data that we have do not have a time reference (start, duration and end of regulation) nor does the regulation have a common starting period for all the rivers in question. A preliminary examination of these rivers did not reveal any consistent patterns worth discussing. However, because regulation is very common in European rivers, although relevant data are generally lacking (Kuentz et al. 2017) and since the possibility of human influences upstream cannot be excluded even in rivers that are formally denoted as nonregulated, we rely on the assumption of stationarity throughout the manuscript. We will include the above explanation of regulation where appropriate in the revised manuscript.

Line 287: indexes -> indices

Line 289: available for "a" few countries only.

Thanks, we will correct the wording accordingly.

Line 204: "it looks that" implies that you are unsure, maybe rephrase this

Lines 349 & 352: again, "looks" implies you are unsure

Thanks for these remarks, we will rephrase.

Line 359: "having" -> "with"

Line 378: summarize -> summarizing

Thanks, we will correct these accordingly.

Line 378: PCA analysis - analysis is included in this acronym, so reads oddly

Indeed, we will rephrase this.

Line 385: remove "majorly"

Line 391: indexes -> indices

Line 393: remove "also"

Thanks, we will adopt the above suggestions.

Line 407: add "(see sect. 2.3)" after technical experiment

Thanks, we will add this.

Line 435: "within this respect" is odd phrasing, consider rephrasing

Thanks, we will rephrase the wording.

Line 456: there -> their

Line 473: associated to higher -> associated with higher

Thanks, we will correct the wording accordingly.

Figure 2: Are the boxplots of all the gauging stations? Please clarify in the captions.

Yes they are. We will add this clarification.

Figure 8: Very nice figure, but you have red dots on top of a green map which should ideally be avoided

Figure 9: Again, a very nice figure, but it's very hard to see the yellow dots

Thank you for pointing this out, indeed this should be avoided. We will change the color of the dots.

Once again, we would like to thank the Reviewers and the Editor for the very constructive assistance.

References

Lee, D., Ward, P., and Block, P.: Defining high-flow seasons using temporal streamflow patterns from a global model, Hydrol. Earth Syst. Sci., 19, 4689-4705, https://doi.org/10.5194/hess-19-4689-2015, 2015.

Kuentz, A., Arheimer, B., Hundecha, Y., and Wagener, T.: Understanding hydrologic variability across Europe through catchment classification, Hydrol. Earth Syst. Sci., 21, 2863-2879, https://doi.org/10.5194/hess-21-2863-2017, 2017.