Response to Reviewer #2

We thank Reviewer #2 for her/his time and feedback on the manuscript. We note that there is a number of confusions/misunderstandings most likely originating from misinterpretation of the paper objectives, which we have more clearly identified in the introduction of the revised manuscript. The reviewer's comments are in black and our response is in blue.

Being a "physically-based" hydrologist interested in signatures as indicators of catchment functional behaviour, but not a specialist at all of regionalization and statistics, I read the paper with interest, expecting to learn more about this topic. The objective of the paper is to propose a methodology for selecting the relevant regionalized signatures for calibrating a rainfall runoff model on an ungauged catchment.

Authors' reply: The objective of our paper is to assess the importance of accounting for dependencies in regionalized information when predicting streamflow in ungauged catchments. However, we do not attempt to analyze how to select specific sets of relevant regionalized signatures. To clarify the objective of the paper more clearly to the reader, we have expanded the text in the introduction that previously read on page 5393, lines 7-13, of the original manuscript:

"(…) we introduce and test a method that considers multiple regionalized signatures, explicitly accounting for the signature error correlations. By formally accounting for the error covariance, we hypothesize that accuracy of flow predictions will generally improve and a greater number of signatures can usefully be included without introducing avoidable bias related to the duplication of information. The objective is thus to explore how to get fuller value out of a set of regionalized information than has been achieved in past applications."

to now state in the revised manuscript:

"(…) we introduce and test a method that considers multiple regionalized signatures, explicitly accounting for the signature error correlations. By formally accounting for the error covariance, we hypothesize that accuracy of flow predictions will generally improve and a greater number of signatures can usefully be included without introducing avoidable bias related to the duplication of information. This should allow the modeler to use all signatures available without having to select, on a more or less subjective basis, the most relevant (independent) signatures. The objective is thus to explore how to get fuller value out of a set of regionalized information than has been achieved in past applications."

In general, I found the paper quite difficult to read and understand, especially Sec 3/Results and the corresponding Figures. The Bayesian methodology developed looks mathematically sounded (I am not a specialist).

Authors' reply: We address the specific reviewer's points on the paper clarity below as they arise.

My main comments would be on the testing protocol:

- the regionalization model used in this study is not described in detail (2.3.1), and, from the information given, looks quite simplistic. Simple regression laws are fitted to physical attributes of the catchments (we don't even know which ones). Moreover, using blindly the data of 83 catchments to estimate regionalized signatures on the 84th looks like a very rough method. This regionalization model is not evaluated, although it certainly conditions the final results.

Authors' reply: The regionalization models used were not shown in the manuscript, but the reader is referred to previous publications (Almeida et al., 2012, and Almeida, 2014) where this information

can be found. The quality of the regionalization models is shown in Figure 1 in the manuscript, and further references in the text are provided that give a detailed description of the derivation and respective quality of the models. We believe that this is sufficient information to allow the reader to follow-up should they be curious about the regionalization model that we have chosen, and we instead focus our discussion on the errors associated with these models. Lastly, leave-one-out (i.e. using the data of 83 catchments to estimate regionalized signatures in the 84th) is a standard practice in hydrological science when evaluating the performance of methods to predict streamflow in ungauged catchments (e.g. Kokkonen et al., 2003; Merz and Blöschl, 2004; Parajka et al., 2005; Goswami et al., 2007; Shu and Ouarda, 2012) and, therefore, is an appropriate technique to apply in our study.

- the selection of signatures is quite limited and basic (only 5 really classical signatures on runoff). I'm not sure that much can be concluded on the relevant number of signatures / relevant signatures using such a small sample. I understand that the objective of the paper is to present the methodology, but the application example is also important to convince readers that the methodology is useful.

Authors' reply: We agree that the application example is important to convince reader that the method is useful. This is a fundamental reason why we chose a subset of signatures that both cover a wide range of different qualities of regionalized information, and also have variability in the degree of signature error correlation. This reasoning for our choice of signatures is discussed on page 5397, lines 23-24, and page 5398, lines 1-2, where we state: "This specific subset of signatures is selected to cover a wide range of different qualities of regionalized information, and also to ensure that some signature errors are largely uncorrelated, whilst others are strongly correlated (see also Sect. 3.1)."

- I don't understand the interest of using synthetic data. It seems to me that rather than simplifying the problem, it does bring more complexity to it: the model is first calibrated on the observed time series for each catchment, thus model structure and observational errors are still there.

Authors' reply: The uncertainty introduced by inter-signature error correlation can be masked by other sources of uncertainty, namely model structure and observational errors. Therefore, we chose to use synthetic data in order to better understand and evaluate the sensitivity of our results to the regionalization quality and the regionalization errors' correlations (page 5396, lines 13-14).

To generate the synthetic streamflow time series, the rainfall-runoff model is in fact first calibrated on the observed time series for each catchment. The parameter set with the best NSE is taken to generate a 'perfect model' streamflow time series, as stated in section 2.2.3. This time series is thereafter used as if it was the 'observed' streamflow. This way, we can be sure that there is no model structure or observational errors.

- Section 3 is really difficult to understand. The main focus seems to be on the comparison of synthetic / observed data, and the initial focus (selecting the relevant regionalized signatures) is lost. The Figures are incomprehensible.

Authors' reply: As discussed in our reply to the reviewer's previous comment, the focus of our paper is on accounting for dependencies in regionalized information and not on selecting relevant regionalized signatures. The motivation behind the selection of a specific subset of signatures is covered in section 2.3.2 (page 5397, lines 23-24, and page 5398, lines 1-2) where we explain that the specific subset of signatures is selected to cover a wide range of different qualities of regionalized information, and also to ensure that signatures have variability in the degree of signature error correlation.

With regard to the reviewer's comment about the figures in Section 3, further information about the point of confusion would be required in order to make meaningful changes that can improve the interoperability of these images.

- Finally the authors seem to obtain quite disappointing results, and cannot conclude much from the study. Potential additional developments are widely discussed in Sec 3.4. Before that, maybe it would be worth revisiting and/or discussing the testing protocol, that may be inadequate.

Authors' reply: We disagree with the reviewer that the results are disappointing. We believe that the results shown in this study make a number of meaningful and relevant contributions to the literature. First, we show that, unless correlations are very strong, disregarding these correlations does not introduce large errors into regionalized estimates of streamflow. Disregarding inter-signature errors correlation is common practice in the literature, but our study is the first to demonstrate clearly the impact of this assumption on regionalization performance. For regionalization practitioners, this is a positive result as it shows that streamflow can be predicted even though knowledge about information dependencies typically is very limited. Second, we propose a method that is useful when multiple signatures are used simultaneously to condition a rainfall-runoff model. A key innovation of this method is the ability to incorporate larger sets of signatures in the model conditioning process, without the need to worry about double-counting of information or the degree of uncertainty in signature estimates. Furthermore, this method also helps to avoid subjective decisions about the removal of possibly nonindependent information.

Finally on the form of the paper:

- The paper is really focussed on the mathematics (especially from Sec 3); it could be nice not forgetting readers who are not specialists

Authors' reply: We keep the math as simple as possible - a reader is given three equations (1)-(3) in the main body of the paper, where eqs. (1) and (2) represent Bayes' law, and eq. (3) is a ration of two probability density functions, called Bayes factor. The most complicated eqs. (1) and (2) commonly appear in papers on Bayesian methods in HESS and other high-impact hydrological journals, and indeed require some mathematics knowledge.

- In section 2, information is mixed up along the paragraphs: for example the regionalization technique is described partly p 5393 (in 2.1), p 5395 (in 2.2.2), and 5397 (in 2.3.1). I could be worth restructuring this part a bit.

Authors' reply: The Bayesian method for signature assimilation is described in Section 2.1. Two important parts of it is the prior distribution used, which is described in subsection 2.2.1, and the likelihood function, which is described in subsection 2.2.2. Section 2.3.1 describes the case study used to apply the regionalization method. We believe it is a logical way to present the material, and it is unclear how the reviewer would like the section to be restructured.

References

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