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Hydrology and Earth System Sciences
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Discussions



# *Interactive comment on* "A Robust calibration/validation protocol of a hydrological model using hidden Markov states" *by* Etienne Guilpart et al.

**Etienne Guilpart et al.**

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We highly appreciate your time and effort in conducting a thorough review of our manuscript. Please find below our responses (your comments are in bold, our responses in normal font, and proposed changes to the manuscript in italic).

**In this study, it is interesting to apply the HMM to find hidden states in a method for identifying hydro-climatic condition of data used to calibrate/validate hydrological model. It is expected that the method of identifying annual hydro-**

**climatic states by generating hidden state sequences through HMM will be more systematic and useful. However, to improve the completeness of this paper, several supplements are needed as follows:**

**(1) Apart from the comparison between the Petitt's test and the HMM, it is necessary to present a comparative analysis of whether the climate classification sequence identified by the HMM reflects temporal variations in other meteorological data or land use. For example, it would be possible to present any changes in land use or to state whether the temporal behavior of the dry index from annual rainfall and reference evapotraspiration over the same period is similar to the sequence of climatic state identified by the HMM.**

We agree that river discharges are the result of hydrological processes taking place upstream and are influenced by changes in precipitation, land use, etc. Anthropogenic changes may indeed alter the flow regime and hence influence an HMM-derived classification which would no longer rely solely on natural factors. However, that anthropogenic influence can be removed so that the analysis is done on naturalized flows, something fairly standard in time series analysis but also in process-based hydrological modelling.

The overall goal of this paper is to highlight the relevance of combining HMMs classifications with the differential split-sample test to assess the robustness of a hydrological model to be used in climate change studies, i.e. to generate hydrologic projections from contrasted climate ones. So, the emphasis is on changes in physical processes rather than human-induced ones. The Senegal River basin is only used as a case study to illustrate the proposed method to test the robustness of a hydrological model. For that river basin, most of the runoff and headwaters of two of the three sub-basins (Daka Saidou, Oualia) are located in the Fouta Djallon, a sparsely populated plateau where vegetation cover is relatively stable (Descroix et al, 2020), anthropogenic impacts on runoff seem to be negligible (Faty, 2017) or not even mentioned in the updated Senegal River monography (Bader et al, 2014) and in the River Basin Master Plan (OMVS, 2011). The areas mainly concerned with massive land-use conversions are located downstream of Bakel, a region not considered in our analysis. For the third sub-basin, river discharges at the outlet were naturalized by Bader et al. (2014) after removing the influence of the Manantali dam on the flow regime. In this study, the term “robustness” refers to the ability of the hydrological model to perform well under contrasted hydro-climatic conditions. This definition is coherent with the so-called robust decision-making framework that is often advocated to handle the deep uncertainty attached to climate change (Lempert et al., 2006). In other words, we do not seek the "best" model (with the best fit) but a model that performs reasonably well under different conditions.

Also, we propose replacing the second to last paragraph in the introduction with:

*In this article, we combine a classification obtained by an HMM with the differential split-sample testing framework. The goal is to improve the robustness of the calibration/validation of a hydrological model, which is a prerequisite to climate change impact assessment. The term "robustness" refers to the ability of the hydrological model to perform well under contrasted hydro-climatic conditions. This definition is coherent with the so-called robust decision-making framework that is often advocated to handle the deep uncertainty attached to climate change (Lempert et al., 2006). This is illustrated using the Senegal River Basin (SRB) as a case study. Headwaters in the SRB are still largely natural areas (Descroix et al, 2020; Faty, 2017) and the flow regime in the upper part of the basin exhibits regime-shifting behavior with departures from the inter-annual average over extended periods of time (Faye et al. (2015); Paturel et al. (2004); Dacosta et al. (2002). These characteristics makes the SRB an*





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*interesting case study to illustrate the split-sample testing framework with hydrologic sequences identified from an HMM.*

We propose replacing the abstract with:

*The impacts of climate and land-use changes make the stationary assumption in hydrology obsolete. Moreover, there is still considerable uncertainty regarding the future evolution of the Earth's climate and the extent of the alteration of flow regimes. In that context, it is crucial to assess the performance of a hydrologic model over a wide range of climates and their corresponding hydrologic conditions. In this paper, numerous, contrasted, climate sequences identified by a Hidden Markov Model (HMM) are used in a differential split-sample testing framework to assess the robustness of a hydrologic model. The split-sample test based on an HMM classification is implemented on the time series of monthly river discharges in the upper Senegal River Basin in West Africa, a region characterized by the presence of low-frequency climate signals. A comparison with the results obtained using classical rupture tests shows that the diversity of hydrologic sequences identified using the HMM can help assessing the robustness of the hydrologic model.*

**(2) The three sub-basin are all located within one same basin. So their flow data show similar temporal behavior with different scale. This makes it difficult to generalize the results of this study. Moreover they show same dramatic changes in climatic conditions. This is rather thought to make it difficult to show the advantages of the proposed method in this study.**

This paper shows how an HMM classification can be used within the differential split-sample testing framework to assess the robustness of hydrological models under shifting flow regimes. The Senegal River, for which the presence of low-frequency climate signals has already been discussed in the literature (Ardoin-Bardin, 2004; Bodian et al, 2014, Descroix et al, 2015), is used as a case study. The results presented in this paper are therefore specific to the case study and cannot be generalized. However, the idea of using an HMM to identify contrasted subsequences of streamflows to feed a differential split sample test is relevant for other rivers exhibiting a regime shifting behavior. We will modify the abstract and the introduction to better explain the novelty of the approach and the specific contributions associated with the case study (see previous comment).

**In the abstract section, the authors mentioned that the results show that when the time series of river discharges does not exhibit a clear climate trend, or when it has multiple change points, classical rupture tests are useless and HMM classification is a viable alternative as long as the climate sub-sequences are long enough. However, the results in section 5 do not adequately explain this. The results show that Pettitt's test is still on of the appropriate tools. Perhaps an addition of another time series (basin) should be considered that clearly illustrates the difference between methods.**

Section 5 only focuses on the 1940-1998 period, which displays clear subsequences for each sub-basin. To further demonstrate the relevance of the HMM classification, we analyzed two shorter 26-years periods (1945-1971 and 1972-1998) which are presented in the Supplementary Materials section. We initially decided to put that analysis in the Supplementary Materials section because we thought it might distract the attention from the main objective of the paper, which is combining differential split sample tests with HHM-based classifications. However, based on the reviewer's comment, we will reconsider that decision and move the corresponding analysis to the main text.

**(3) The ultimate goal in hydrological modeling would be to obtain a better fit. The HMM's theoretical advantages of more granular and continuous identification is understood, but the results do not seem to support it. The authors noted in Section 5.2 that the HMM could lead to better model performances than the Pettitt's test, but it is difficult to accept the argument that the HMM is a better way with the values provided in Table 3. I think each method has similar NSE (KGE) values. A clearer rationale or explanation is needed for this part.**

The goal of this paper is not to obtain a better fit but to "assess the performance of a hydrologic model over a wide range of climates and their corresponding hydrologic conditions" (Line 4). So, the idea is not to improve the calibration of a hydrological model but to determine if the performances of that particular model measured on different, preferably contrasted, subsequences of streamflows are similar or not. That robustness is key when the hydrological model must be used in climate change studies with diverging climate projections. This point will be clarified (see our proposed changes in our response to comment 1).

**(4) The sentence for the length of data mentioned in section 6 is not the result of this paper. It was only cited from other paper and no substantive analysis was performed to support this conclusion. A minimal analysis needs to be performed to apply the claims of existing studies to the method proposed in this study.**

That sentence refers to material provided in the Supplementary Materials section of the paper. As indicated above, we are keen to bring that material back to the main text and further discuss the issues associated with the minimum length of data.

**(5) Please check some typos. ex. Check the isohyets range on the Bakel basin (Table 1). ex. Check T3HMMnor in Climate segments (Figure 4).**

We particularly appreciate your careful reading, and we will proofread all the paper to check for the mentioned mistakes and for any other mistakes.

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