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Interactive comment on "Frequently used drought indices reflect different drought conditions on global scale" *by* Niko Wanders et al.

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This manuscript looks at correlations between different drought indices based on climate variables (meteorological droughts), soil moisture (soil moisture droughts) and discharge (hydrological droughts). The objective is to demonstrate that each drought index characterise quite differently drought events, between the different types, but also within each type. To reach this objective, the authors make use of a global meteorological forcing dataset and a hydrological model with a fixed parametrization (i.e. fixed catchment structure) over grid cells from the whole globe. Such a demonstration has been done for specific catchments or for single events over the last decade, so attempting to give a similar demonstration at the global scale is definitely praiseworthy. The analysis seemingly succeeds to reach this conclusion through the different figures.

There is however a central underlying hypothesis of a fixed catchment structure used

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across the whole globe, which highly restricts the range of variation of hydrological drought indices for a given climate in the analysed sample. This quite unrealistic hypothesis is first dealt with by stating that there is a negligible influence of model parametrization on hydrological drought characteristics (P329-30). This statement is based (in the manuscript) on the conclusions from a previous paper by the authors (Van Lanen et al., 2013), which actually reached completely opposite conclusions. The hypothesis is then dealt with by performing a sensitivity analysis to the model parametrization, which reaches a dubious conclusion that there is a negligible impact of changes in model parametrization on correlation between different drought indices, and therefore between e.g. purely meteorological indices and indices based on streamflow. This amounts to say that e.g. precipitation anomalies correlate to discharge anomalies in the same way in a flashy catchment and in a groundwater-fed catchment. Which is obviously not the case in reality.

These two points make this study quite shaky, and it is unfortunate because such a topic would have deserved a more rigorous treatment. I indeed totally agree on the relevance of this topic and on most of the conclusions and recommendations of this study. Better understanding the propagation of drought along the hydrological cycle is highly relevant for making drought studies more directly relevant to assess drought impacts, but there is a need to take into account catchment specificities, as highlighted recently by Van Lanen et al. (2016). The modelling set-up in the manuscript unfortunately does not allow one to put sufficient confidence on the conclusions reached. The above-mentioned issues thus prevent me recommending this manuscript for publication in Hydrology and Earth System Sciences, at least if this fixed-parametrization hypothesis is not adequately and rigorously dealt with.

I will of course welcome any online discussion with the authors on this important topic, in order to hopefully find (jointly with the authors) a way to properly reach the stated objective of the paper.

1 Main comment

The main issue of the fixed parametrization is first encountered in the “Material and methods” section. The authors refer to a previous paper where they used a similarly controlled hydrological modelling set-up with the same model at the global scale (Van Lanen et al., 2013, hereafter referred to as VL2013). They state in this paper that “*Hydrological drought is affected not only by climate, but also by catchment control, i.e., physical catchment structure (soil and groundwater system) [...]*” (p. 1725). I believe this is a quite reasonable introductory statement to the effect of catchment structure on hydrological droughts.

In this paper, the authors clearly assumed the fact that hydrological model parametrization was not fitted to catchment types across the world and build from this controlled experiment by looking mainly at the impact of climate on hydrological drought. They critically performed a sensitivity analysis to the model parametrization to look at the impact of different soils and different groundwater systems. This set-up was highly valuable to draw robust conclusions on the diversity of hydrological droughts. And their overall conclusions, recalled in the abstract, were quite clear: “*Bivariate probability distributions of drought duration and standardized deficits for combination of Köppen-Geiger climate, soil and groundwater system show that the responsiveness of the groundwater system is as important as climate for hydrological drought development*” (p. 1715).

In the results section, they comment that “*[...] the responsiveness of the groundwater system has a major impact on hydrological drought characteristics [...]*” (p. 1723). In the discussion section on the catchment control on hydrological drought, they describe in more detail the impact of different catchment structures on drought characteristics: “*Flashy hydrographs, associated with quickly responding groundwater systems, cause a high number of drought events of short durations. Hydrographs representative of slowly responding groundwater systems are rather smooth and do not show direct response to rainfall or snowmelt, i.e., the response is delayed and attenuated*”

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(p. 1726). And such conclusions are obviously valid across the world: "*Groundwater systems strongly controlled the hydrological drought characteristics of all climate types, but particularly those of the wetter A-, C- and D-climates because of higher recharge.*" (p. 1715). This conclusion was reiterated in a follow-up and more recent paper by some of the authors where they also looked at future changes in drought characteristics with a similar set-up: "*Furthermore, it was found that simulated drought characteristics are most sensitive to changes in the groundwater parametrization.*" (Wanders and Van Lanen, 2015, p. 498).

The above results are fairly well-founded, and are supported by numerous observations and modelling experiments. But in the present manuscript, one can read that "*The sensitivity analysis by Van Lanen et al. (2013) showed that hydrological drought characteristics derived from simulated discharge, did not change significantly with changes (sic) parametrization*" (P3L29-30). This is clearly contradictory to all results from VL2013 and their conclusions recalled above.

After this clearly wrong statement, the authors state that they nevertheless have performed a sensitivity study of drought indices (those based on soil moisture and discharge) to the model parametrization. This is a quite reasonable action, given the conclusions of VL2013. Results from this sensitivity analysis are given in one paragraph P11L24-32, and are summarized as: "*This clearly shows that the impact of model parametrization on the conclusions of this study is negligible*" (P11L31-32). This is based on the result that changes in correlations between indices (due to changed parametrization) is less than 0.005 (P11L31), which includes correlations between purely climatic indices and discharge-based indices. This means that for a given climate, the correlation between, let's say, SPI-6 and SRI-6 were nearly independent on the catchment structure. This is a rather surprising result (1) given the results of VL2013, but also (2) given any experience from actual data.

I therefore wanted to check whether this holds true with some actual catchment data. I focused on catchments located near Paris, in order to match the temporal pattern of the 1976 drought there that was taken in example in Figure 5. I managed to gather meteorological and hydrometric data as well as corresponding metadata for two nearby contrasted catchments in terms of groundwater systems (with respective BFI of 0.93 and 0.65), with high-quality hydrometric data, with low human influences, and not too small to be compared to the spatial resolution of the simulation from the manuscript. Their characteristics are given in Table 1.

Station	Id	S (km^2)	BFIsim	BFIobs	Cor P-Qsim	Cor P-Qobs
Essonne@Ballancourt-sur-E.	H4042010	1870	0.94	**0.93**	0.56	**0.38**
Orge@Morsant-sur-O.	H4252010	922	0.69	**0.65**	0.84	**0.83**

Table 1. Catchment characteristics.

I then computed the SPI-6 and the SRI-6 over the same period as in the manuscript: 1958-2001. The approach and code by Stagge and al. (2015) was used to compute the standardized indices, using a gamma distribution for both precipitation and discharge. Precipitation was taken from high-resolution surface reanalysis data. The SRI-6 was computed based on both the discharge observations and model outputs. Note that discharge data are available from 1964 and 1968 onwards only, which may lead to differences between the observation-based and simulation-based SRI-6, on top of the differences due to model limitations. Figure 1 at the bottom of this file shows results over the 1974-1983 period in order to be compared directly to Figure 5 in the manuscript.

This figure first shows that SPI-6 series are very similar for the two catchments, given their proximity in space (hydrometric stations are a few kilometres apart), and also very similar to the corresponding series in Figure 5 of the manuscript. It also shows that the SRI-6 series are quite different from one catchment to another, leading to quite different hydrological drought characteristics, along the lines of results from VL2013, and in contradiction with the present manuscript (P3L29-30). To paraphrase VL2013, the “*slowly responding groundwater systems are rather smooth and do not show direct*

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response to rainfall or snowmelt" (P. 1726), and the catchment with the higher BFI has indeed the SRI-6 series the least similar to the corresponding SPI6-series. This is confirmed by correlation values over the whole time series given in Table 1. Correlation values between SPI-6 and SRI-6 are 0.38 (for the higher-BFI catchment) and 0.83 (for the lower-BFI catchment). The difference (around 0.45) is much much higher than the maximum difference found by the authors: "*0.005 for all indices under study, at all locations*" (P11L31). And the impact of the model parametrization, i.e. the catchment structure, on the conclusions of the manuscript is therefore not negligible at all in this simple observational case study.

Finally, the fixed-parametrization hypothesis also serious implications for the relevance and realism of drought maps presented in Figure 3 and Figure 4. Indeed, all Africa and Europe are there considered to bear catchments with "*sandy-loam soil with an intermediate groundwater response time*" (P3L22). It also presumably supposes a permanent grassland vegetation cover, as in the default parametrization of the previous study by the authors (Van Lanen et al., 2013). This definitely leads to unrealistic drought maps for soil moisture- and discharge-derived indices, and this is clearly not acknowledged in the manuscript. Indeed, these figures are said to depict "*Drought conditions over Africa (resp. Europe) in August 1984 (resp. August 1976)*".

2 Specific comments

1. P1L5-6, "Physical indices...": There may be a transition word missing here.
2. P1L7, "We have...": This sentence may be more appropriate at the end of the abstract.
3. P2L4: The end of the physical drought cycle is actually low flows, and not only discharge anomalies. Please add it to the propagation steps.

4. P2L9-10: Well, actually there are many examples of existing drought impact indices, e.g., the number of days with too low flows for waterborne transport, the number of days under legally-defined environmental flows, etc. This should be acknowledged in the manuscript.
5. P2L23-24: The Lincoln declaration on drought indices and the associated peer-review paper (Hayes et al., 2011) should be cited here, instead of a press release.
6. P2L24-26: It may be quite relevant to refer here to the two other international expert meetings that dealt respectively with agricultural drought (Sivakumar et al., 2011) and hydrological droughts, and to comment their respective conclusions
7. P2L27-28: Could you provide a reference (preferably peer-reviewed) for this composite index?
8. P2L29-30: Well, the very fact that this approach combines all possible drought types is also a big disadvantage because it definitively prevent the composite index to be compared to any specific drought impact. This should be acknowledged and commented in the manuscript.
9. P3L29-30: This is where the fixed-parametrization issue starts. See main comment.
10. P6L3-4: I am not sure what is meant here by “normalized”. Please make it clearer in the manuscript.
11. P6L3-5: There is very little information on the way drought indices are computed, even in the referred technical report. For example, among many others, how is done the calculation of the SPI? What is the reference period used for standardisation? What type of statistical distribution is considered? Is it the same everywhere across the globe? There are many similar questions for which answers have to be provided in the manuscript in order to assess the relevance of

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the study. Another one would concern the PDSI: it has been demonstrated that it is far from being applicable everywhere, hence the development and use of the Self-Calibrated PDSI. This should be the one index to be used here in place of the PDSI. This comment is particularly important for providing confidence in results, on top of the main comment above. I understand some descriptions (by far not complete) were removed from a first draft of the manuscript, and I believe they should definitely be in there, maybe as an appendix.

12. P6L21: There are many studies on the European 1976 drought that are more relevant and more in-depth than the cited reference, which is indeed a very short paper. Please consider providing more appropriate references.

13. P11L24-32: See main comment.

14. P12L30-P13L3: A clear distinction should be made here between the variable threshold and the fixed threshold. The latter, which considers an absolute threshold value in m3/s, is indeed much closer to drought impacts than the former, see specific comment 4. This should be acknowledged in the manuscript.

3 References

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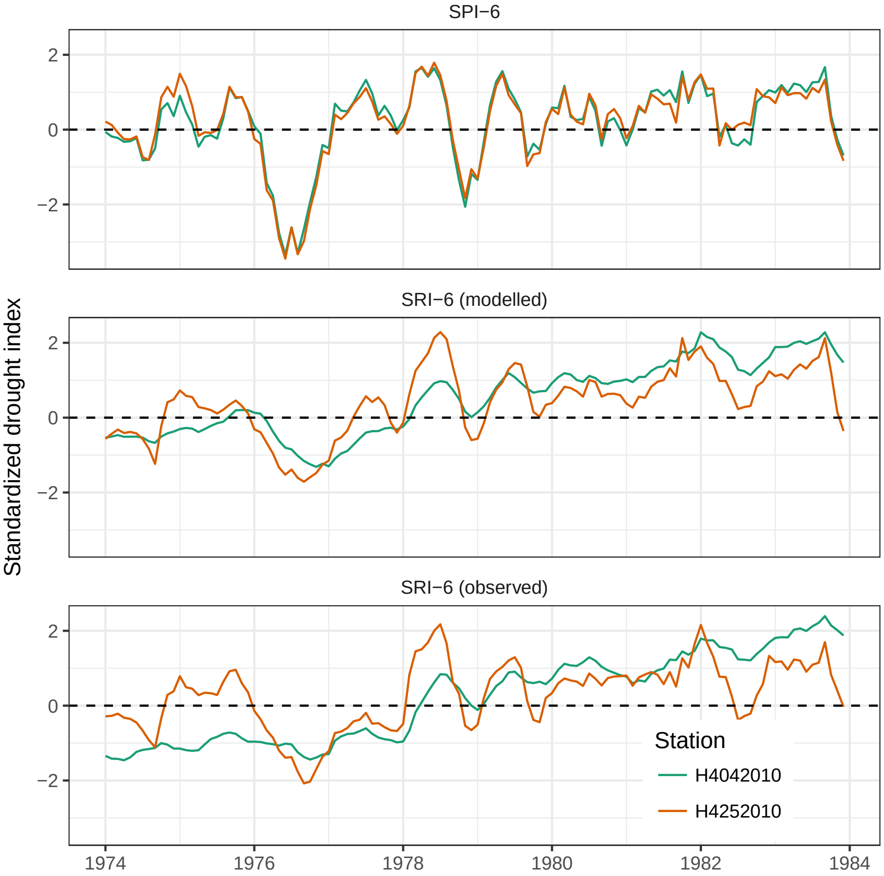

Fig. 1. Standardized drought indices time series for the two catchments over the 1974-1983 period.

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