Response to B. Guse (Referee)
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Björn Guse (BG): In this manuscript, hydrological fingerprints are introduced as target variable for a sensitivity analysis and compared with a classical approach using streamflow data for a temporally resolved sensitivity analysis. The joint benefit of both approaches is presented for several headwater catchments. As a reviewer of the first submission of this study to Hydrol. Earth Syst. Sci., I highly appreciate the large effort of the authors. The manuscript is now clearer in its objective and I have only minor comments before publication. In most of the cases, my comments are suggestions. I hope that my comments help the authors to improve the manuscript.

Simon Höllering (SH): We sincerely thank Björn Guse for reviewing also our revised manuscript. We are grateful for the thoughtful recommendations and comments which will help to further clarify and improve the presentation of the study, especially for the hints on how to emphasize the main contributions of the present study. We will gladly follow his advice when revising the manuscript. Detailed comments on the specific points are collected below.

BG: P.3, L. 12-18: Even though that it is mentioned here and also at several other places, the manuscript could benefit from mentioning your contribution to the different options in selecting target variables for a sensitivity analysis in hydrology. These are: (i) Modelled discharge, (ii) Different objective functions (Van Werkhoven et al., 2008, Yilmaz et al., 2008, Herman et al. 2013), (iii) Different hydrological variables (Massmann and Holzmann, 2015; Guse et al., 2016), (iv) Different hydrological fingerprints (this manuscript). The use of fingerprint metrics as target variables for a sensitivity analysis is the novel contribution of this manuscript in my opinion. A clear listing could help in distributing this concept in the hydrological community.

SH: Thank you for this helpful comment. We will try to rework this part of the introduction to clarify our contribution.

BG: P.5., L.7: I recommend to add some references that these metrics are often used in hydrology, since the approach depends on a reasonable selection of the fingerprint metrics. Probably it is sufficient to use studies which are already included in the reference list.

SH: Yes, good point. We will add here some references.

BG: P.5., L.30: In the study of Van Griensven, FAST is listed as a type of sensitivity analyses, but I think that no FAST application is shown in this paper. This recommended to focus the referencing on the paper with FAST results.

SH: Yes, some of the studies present only reviews, others FAST applications and results. We will modify this part to become clearer here.

BG: P.6, L.9: The referencing of seven paper for mHM seems to be a high. Are they all required to justify the selection of model parameters and their ranges?

SH: Indeed, we will select the most relevant publications at this point.

BG: P.8, L.28: You may add that 2002 was a wet year and 2003 a dry year to show that you have consider different hydrological situations in the model calibration.

SH: We added this info in the caption of Fig. 3 to explain why these periods were selected for illustration. We will see how to incorporate this in the results or discussion parts dealing with this Figure and its interpretation. In section 2.4 we will also add that the period for initial model calibration was 1997-2006.

BG: P.11, L.1-8: These results show clearly that the runoff ratio is a fingerprint metrics complementary to most of the others, while Fig.5 show similar results for several fingerprint metrics. The study might benefit from a discussion of redundant and complementary fingerprint metrics. Based on this, it is probably possible to give some recommendations about an appropriate selection of a set of fingerprint metrics as target variables in sensitivity analyses.

SH: This is a good point that might be relevant to revise/add in the discussion. We are aware that redundancy in fingerprint metrics for a specific streamflow characteristic (e.g. high flows) might be possible if several similar metrics (e.g. HPC, CV, HFD) are selected. Nevertheless, a joint, multivariate analysis with metrics of several similar but slightly different streamflow characteristics (frequency of high flow, magnitude of high flows etc.) is needed to ensure complete parameter identification for different catchments. Our results also show that results in sensitivity analysis (INDPAS) can be similar even for fingerprint metrics that characterize different streamflow characteristics (compare RTC with CV, Fig. 5), which might change with the location.

BG: P.12, L.5-12: Could you explain (based on its role in the model structure) why a soil moisture parameter is relevant both for high and low flows (but not for mid flow)? What about surface runoff or groundwater flow related parameter?

SH: The widely largest importance of the soil moisture parameter is perhaps only masked and damped during mid flows by evapotranspiration parameters. The system state probably makes a large difference during high to mid flow conditions, because of the impact of evapotranspiration on the shallow soil storage in the catchment. This is especially the case for the recession limbs after peak flow, as we also specified in the manuscript: 'TEDPAS analysis further clarified that the intermittent dominance of AspectcorrPET occurs simultaneously to the falling limbs subsequently to high flow peaks (Fig. 3c and d, g and h).
The tested parameters for surface runoff (InfilShapeFactor) and groundwater (RechargeCoeff, GeoParam) were found to be much less sensitive, although the sensitivity of the latter increases towards the low flow conditions due to their impact on baseflow (Fig. 6), which seems plausible.
Our results provide in-depth diagnostics on the model, which can hopefully support future improvements, but an in-depth analysis of the mHM model structure is beyond the scope of the paper. We will try to include this in the discussion.

BG: P.12, L.5-12: If it helps, you might add that the result that evapotranspiration parameters are sensitive in mid flows coincides with former sensitivity studies with other hydrological models.

SH: Yes, we will check and possibly add studies.

BG: P.12, L.28: I would recommend to emphasize this statement even more. You could discuss how this result helps for model calibration in terms of parameter constraining, reduction of parameter space and appropriate target variables.

SH: Thank you, we will add some more explanation.

BG: P.13, L.1-5: Is ACT maybe less appropriate as fingerprint metric in sensitivity analysis? Also, at this point, it might be interesting to give some comments on the suitability on different fingerprint metrics.

SH: We will add here that regardless of the model parameterisation, precipitation has a large impact on the autocorrelation structure of streamflow. Thus, ACT is less informative than other metrics that depend less on the hydroclimatic boundary conditions.

BG: P.13, L.12-13: At this point, I like to remark that Ksconst control both high and low flows. Thus, it would be interesting to see how precisely this parameter can be identified. I expect also conflicting results in model calibration studies. Even though that this study is not related to model calibration, your study give insights that this conflict might occur in the calibration.

SH: Interesting remark. This would have to be tested by calibrating specifically for high and for low flow conditions. If large discrepancies in parameter values show up, an improvement of the model structure might be advisable.

BG: References: The latter "a“ is shown in smaller letters in the author list such as in P. 18, L. 28; P.20, L. 35; P. 21, L. 3.

SH: Thank you for this hint. We have corrected it.

BG: Fig. 2: The information content of this figure is relatively low. I still see a reason for including it in the manuscript. However, in the case that you have to shorten the manuscript, you may think about removing this figure.

SH: We agree with Björn Guse and would prefer to include it in the paper, because it helps to understand the essence of the FAST method.

BG: Fig. 3: For a better visualization, I recommend to show three subplots of sensitivity time series. It is very difficult to distinguish four lines in one subplot. Moreover, the blue colours are very similar. Maybe you can include the legend in the subplot (and increase the y-axis to 0.8).

SH: Thanks for this recommendation. We reworked Fig. 3 now showing three subplots of sensitivity time series including the corresponding legends in each subplot with the proposed y-axes scaling. Additionally, for this figure, as well as for Fig. 2 and 6, we modified the shade of blue for one parameter (ThetaSconst). We think by these modifications the visualization has become clearer.

BG: Fig. 4: I recommend to move the last sentence from the figure caption to the main text. An interpretation of the results belongs to the main text and not to the figure caption.

SH: We will add the information in the text. However, we consider the information on the order of importance of the parameters as helpful to interpret the figure, especially the different shapes of the curves, and would thus leave the sentence here as well.

BG: Fig. 5: This figure clearly shows that a precisely defined target variable helps to disentangle the relevance of model parameters such as in this case for AspectcorrPET. This is an important result which could be more emphasised. It is clearly shown that separate target variables are beneficial for sensitivity analyses. These could be as denoted above: Different objective functions, different hydrological variables or such as in your study different fingerprint metrics.

SH: We agree with the reviewer that this is an important result and are happy to go with the recommendation to emphasize this a bit more in the text.

BG: Fig. 6: It seems to be that due to the high differences in sensitivity it is enough to select 4-6 parameters to control the hydrological behaviour in your case. Is this a typical number of relevant model parameters using mHm (model-inherent) or a case-specific result?

SH: Hard to say. It could be specific for the type of catchment, and/or the FAST approach. Other studies (cited in the paper P.14 L.1-6) found a larger number of parameters. For our FAST studies on the Ruhr headwaters it seems a typical number of relevant parameters (also in the preliminary and earlier studies).

BG: Tab. 2: I recommend to add the meaning of "Sensitivity range“ and "Sensitivity mean“ to a table caption.

SH: We have clarified the Table caption.

BG: References:

Guse, B., M. Pfannerstill, A. Gafurov, N. Fohrer, and H. Gupta (2016): Demasking the integrated information of discharge: Advancing sensitivity analysis to consider different hydrological components and their rates of change. Water Resources Research 52, 8724-8743, doi: 10.1002/2016WR018894

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Massmann, C., and H. Holzmann (2015): Analysing the sub-processes of a conceptual rainfall-runoff model using information about the parameter sensitivity and variance, Environ. Model. Assess., 20, 41–53, doi:10.1007/s10666-014-9414-6.

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