Response Letter

The value of ASCAT soil moisture and MODIS snow cover data for calibrating a conceptual hydrologic model

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In the following document, we reproduce all the comments of the Referees in italic characters followed by our responses.

Response to referee #1

The authors calibrated a conceptual hydrological model by using ASCAT soil moisture and MODIS snow cover data jointly or separately, and improvements of related variants have been achieved in varying degrees. The efficiency improvement was also analyzed under different scenarios and catchment attributes. Overall, the results seem convincing and the study is valuable for related research. However, there are several issues that still exist and need to be clarified further as indicated in the following.

> We want to thank the reviewer for her/his positive, helpful and insightful comments on the manuscript.

First, the manuscript needs further editorial work to improve the paragraph structure and some vague expressions. A single sentence definitely cannot be a paragraph (e.g., line 286), and a paragraph should not be too long or too short. In addition, please pay attention to vague expressions in this manuscript, such as line 84 " to compare the multiple objective calibration to soil moisture and runoff to three different calibration variants", which is really confusing. There are other similar sentences, so I hope the authors make a thorough change to improve the clarity of the manuscript.

> Thank you for this comment. In response to this comment, we have checked the manuscript and tried to improve the clarity of presentation and length of paragraphs. We made numerous edits to improve the clarity of presentation. For example, the break line on l. 286 has been removed, or long sentences (asm e.g. on l.84) have been simplified.

Another major issue in this manuscript is that conclusions in the Results section can be presented in a more straightforward way. At its current form, the conclusions are over detailed and have too many numbers, which do not have much value. It is hard for the readers to get the key messages from the authors. Furthermore, the figures and tables contain too much information (e.g., Fig5-6, Table 7-8), also leading to the difficulty in deriving the key information. So please make more concise and clearer conclusions, and improve the presentation of all figures and tables to make sure the key messages stand out.

In response to this comment, we have reduced the number of variables showed in Figures 5 and 6. The variables which do not have significant correlation have been moved to a new Figure, which was moved to the Supplement. We have also moved the Tables 7 and 8 to the Supplement.

Technically I have a couple of comments that might be useful for improving this study and manuscript:

L45-46 This sentence does not have an obvious relationship with the context and needs further description.

> The study of Nijzink et al. (2018) belongs to studies evaluating the value of the combination of different products for constraining hydrologic models. This study shows that the combination of different soil moisture satellite products can help to constrain not only soil but also snow model parameters. In response to this comment, we have revised the sentence as follows: "For example, Nijzink et al. (2018) demonstrated that constraining hydrologic models profited from an increased number of data sources. Interestingly, the use of different soil moisture products had a positive impact on the identifiability of not only soil but also snow model parameters."

L68-69 Then how well does the ASCAT soil moisture perform in Austria compared to other soil moisture products? Is it the best one? Have you had a chance to look at ESA CCI soil moisture product that blends a variety of passive and active microwave soil moisture products and seems to be more widely used.

> The ASCAT product used in this research is the same product which is used as the active product in CCI. The study of Dorigo et al. (2017) demonstrated the quality of the active CCI product over temperate climates such as Austria. This is demonstrated in the blending weights used for the combined product, which are based on triple colocation analysis. Over Austria, the active product has the largest weight, close to 1 (Figure 2). Considering that the spatial sampling of the CCI dataset is 0.25deg, whereas the ASCAT product has a sampling of 12.5km we chose to use the improved ASCAT product in this research. In addition, we have improved the algorithm of the ASCAT product to perform better over Austria. Among other algorithm changes, improved vegetation parameters have been applied as described in Pfeil et al. 2018. In this paper, the authors also showed that the ASCAT, AMSR-2 and SMAP soil moisture products perform similarly well over a temperate climate agricultural catchment.

> In response to this comment, we added below in the discussion:

"The ASCAT product used in this research is the same product which is used as the active product in the ESA-CCI. The study of Dorigo et al. (2017) demonstrated the quality of the active ESA-CCI product over temperate climates such as Austria. Considering that the spatial sampling of the ESA-CCI dataset is 0.25 degree, whereas the ASCAT product has a sampling of 12.5 km, the ASCAT product was chosen to be applied in this study. In addition, the algorithm of the ASCAT product which improved vegetation parameters performed better over Austria (Pfeil et al., 2018)."

L71 "The launch of the Sentinel-1 series provides observations at a high spatial resolution of x20 m". Can you clarify this further? Even though with higher spatial resolution using radars, does Sentinel-1 have sufficient spatial coverage to implement research like yours?

Sentinel-1 has global coverage, but because of the acquisition strategy, most observations are over Europe, where a temporal resolution of 1.5-4 days can be achieved. Globally the temporal resolution decreases, but the high-resolution SWI can still be obtained as the directional resampling parameters can be calculated reliably with the number of Sentinel-1 observations available.

Table 1 This table can be moved to supplement materials.

In response to this comment, we have moved this table to the supplementary.

L167-168 Were the parameters for different catchments different or the same? And how was the calibration scheme carried out? Were parameters for all catchments calibrated together or one by one?

The parameters for different catchments are different. The parameter calibration scheme was described in section 3.2. In response to this comment, we added the sentence in L211 "The procedure of model parameters calibration is carried out for each calibration variant and each catchment independently."

L253 Why was this calibration period chosen? Typically, the calibration period should include historically wet, dry and average years.

The idea was to split the period with available (overlapped) snow, soil moisture and runoff observations into two periods. The calibration period contains the year 2005, which is flood rich; also the validation period contains the year 2013, which is also flood rich.

L247-248: 0.3 seems to be a threshold value, is there any reason behind this?

This is a good question. The results are based on a large sample of catchments, so there is not a simple answer. We plan to investigate further the factors controlling the change in the efficiency in future analyses.

L272-274 So can we pick out which weight allocation has the best performance for all three components. When do these components have the same weight? The conclusion would be easier to follow with fewer numbers.

We believe that plotting individual efficiency measures will allow a more robust interpretation of results than merging (and weighting) them together, so we prefer not to change this Figure and leave it in its current form.

L279-281 What does it mean with larger regional variability? This needs to be clarified further.

In Line249-250, we illustrated the regional variability is the variability between catchments.

L283 "OSC tends to increase and the regional variability decreases for the variants involving SSC". Is there any reason behind this?

These results indicate some compensation effects of a degree-day approach when simulating both, the snow cover dynamics and snowmelt runoff. Increasing the weight to runoff (i.e. to mimic more snowmelt runoff by the model) tends, in some catchments, to be at the expense of the accuracy of snow cover mapping. There can be different factors affecting the snow model efficiency, including spatial estimation of the input, uncertainty of satellite data or simplification of the snowmelt process by the degree-day approach. The detailed analysis of such reasons goes, however, beyond the main scope of the paper.

L289-293 The time coverage of soil moisture is nearly the same in the calibration and simulation periods (four water years), then why is the performance metric smaller in the calibration period than the simulation period? And why did the snow model perform better with fewer below zero temperature days?

The reason for the first question is likely to be caused by the length for the validation is 11% (median) longer than the calibration. Secondly, but not able to be confirmed, since 2012, the second ASCAT satellite was onboard, which might improve the quality of soil moisture data.

The second question is related to the no snow condition, which is easier to be simulated for the model.

L308-311 How did you derive this conclusion? Fig. 5 only shows the correlation between model performance and changing wQ, and readers cannot obtain information about changing attributes and their impacts on model performance.

This part refers to a comparison between Fig 5, 6 and Figs S1-S4 in the Supplement which shows that the correlation between model efficiency and catchment attributes and its change with the runoff weight is similar for all calibration variants. In response to this comment, we have added following explanation: "It is obvious that for runoff weight $w_Q>=0.4$ for O_Q, $w_Q>=0.0$ for O_{SM}, and $w_Q>=0.1$ for O_{SC}, the correlations between model efficiency and catchment characteristics are similar to that for the runoff only calibration."

L390-392 What does this stand for and what is the reason behind this?

This part refers to black lines in Fig. 9. In response to this comment, we have rephrased the sentence to:

"While the inclusion of soil moisture data in the calibration mainly improves the soil moisture simulations and the inclusion of snow data improves the snow simulations, the use of both in model calibration improves both soil moisture and snow simulations to a similar extent."

Reference

Dorigo, Wouter, Wolfgang Wagner, Clement Albergel, Franziska Albrecht, Gianpaolo Balsamo, Luca Brocca, Daniel Chung, Martin Ertl, Matthias Forkel, and Alexander Gruber. 2017. "ESA CCI Soil Moisture for Improved Earth System Understanding: State-of-the Art and Future Directions." Remote Sensing of Environment 203: 185–215.

Nijzink, R. C., Almeida, S., Pechlivanidis, I. G., Capell, R., Gustafssons, D., Arheimer, B., Parajka, J., Freer, J., Han, D., Wagener, T., van Nooijen, R. R. P., Savenije, H. H. G., and Hrachowitz, M.: Constraining Conceptual Hydrological Models With Multiple Information Sources, Water Resources Research, 54, 8332-8362, https://doi.org/10.1029/2017wr021895, 2018.

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