Responses to Referee #2:

We greatly appreciate the reviewer for his/her valuable comments and feedback on our study.

We have substantially revised the manuscript to address the criticisms, and the main revisions are summarized below:

(1) Reviewer 1 made a major comment about the weakness of using only two synthetic climate scenarios and indicated that the scenarios are too simple without considering climate variables. To address this comment, we have totally changed the alternative scenarios used in this study. The number of different scenarios has increased from 2 to 6, and they are all now generated from real climate data. The generation procedure for the new scenarios can be described as follows: the annual weather data from 1998 to 2013 were first collected and divided into multiple dry and wet seasons. Then, these seasons were sorted according to their total precipitation values, and they were divided into six different groups representing six climate scenarios from wet to dry (three for the dry season and three for the wet season). The mean and standard deviation values of the different climate variables (e.g., precipitation, maximum temperature) for each group were further calculated using their daily climate data. Finally, we generated random daily climate data for each climate scenario based on these mean and standard deviation values using the normal distribution.

(2) Reviewer 1 raised a question on the generation of model uncertainty. In the revised manuscript, to address the comment, we have changed the uncertainty of the model from with/without the overland flow module to that associated with three plausible aquifer models. This revision adds physical meaning to model uncertainty because when establishing the hydrological model for the research area, the thicknesses of the different aquifers were uncertain and can be described by different conceptual models. According to Pellertier et al. (2016), the thickness of the soil and unconsolidated rocky material exceeded the maximum value in their model (50 m) in the central Amazon region; therefore, we built three aquifer models considering different thicknesses for the unconfined and confined

aquifers: (1) 100 m and 200 m, (2) 50 m and 250 m, and (3) 250 m and 50 m, respectively.

(3) Both reviewers commented about deficiencies in terms of the results and deep discussion, especially the absence of physical interpretation. To solve this problem, we have totally revised the uncertainty sources, including all uncertain inputs of scenarios, models, and parameters, used in this study. The generation of new climate scenarios and plausible models has been described above, and the parametric uncertainty has also been totally revised. One new uncertain parameter, which is the length of the flow path for runoff contribution to the overland flow domain, has been added. The six parameters were further divided into three groups: vadose zone parameters, groundwater parameters, and the overland flow parameter. A new set of subdivided parametric sensitivity indices was further calculated for each parameter group. To implement the sensitivity analysis, we have performed a more physical and practical interpretation of the model parameters and structures. To estimate the subdivided parametric sensitivity indices, we implemented the Latin hypercube sampling method and binning method with the hierarchical sensitivity analysis method for the first time. The new sensitivity analysis results can provide more detailed information on the importance of different uncertainty sources for modelers. The size of the parameter samples was also increased from 100 to 600. Therefore, the total number of simulations increased from $2\times2\times100=400$ to $6\times3\times600=10{,}800$.

(4) Both reviewers commented on the equal weights (probabilities) used for the alternative scenarios and models. To address the comment, we have added a section to the revised manuscript to discuss the new sensitivity analysis results using different weight values for the scenarios and models.

(5) Reviewer 2 commented on the description of the governing equations for the PAWS model. To address this comment, we have added an appendix to describe the governing equations and parameters of PAWS in detail.

General Evaluation

The topic is interesting and relevant for the scope of HESS. However, the paper does not clarify if there are new significant results achieved and the innovations are not clear. In particular hierarchical global sensitivity analysis was already implemented by Dai & Ye (2015), several applications are reported in literature (see for example Dai et al., 2017; Dai et al., 2019) and the new contribution with this paper to the technique remains unclear. The suggestion is a deeper analysis of the work and therefore it should be completely reviewed.

Response

We thank the reviewer for the positive evaluation of this manuscript and constructive comments. To provide a better physical interpretation and deeper analysis of this study, we have completely revised the uncertainty framework and uncertain inputs, as we described in the summary of the main revisions. We also implemented a new sensitivity analysis method and bin algorithm to estimate the sensitivity indices for new parameter groups. All the sensitivity analysis results and discussion of this study have been totally revised and updated accordingly.

In terms of emphasizing the innovation of this research, in the revised manuscript, we have added text to highlight the new methodology and algorithm used as follows:

"We also improved the hierarchical sensitivity analysis methodology by introducing new parameter groups into the uncertainty framework and implementing new algorithms to make the assessment of global sensitivity analysis for large-scale PBHMs computationally affordable. This study is the first to implement a comprehensive hierarchical sensitivity analysis method in relation to a complex and large-scale PBHM."

"A new set of subdivided parametric sensitivity indices was first defined to provide more detailed information for parametric sensitivities. Because of the high complexity and dimensionality of this model, the highly efficient parameter sampling method of Latin

hypercube sampling (LHS) and a binning method were applied to estimate the sensitivity indices. We also investigated the effects of prior weights on the climate scenarios and numerical models."

We also revised the text to emphasize its novelty:

"By implementing the hierarchical sensitivity analysis method, we aim to provide a pilot example of comprehensive global sensitivity analysis for large-scale PBHMs considering all uncertainty sources instead of only parameters and investigate the most important source of uncertainty for modeling hydrological processes in the Amazon."

Comment 1

Page 3 Line 68 - Hierarchical global sensitivity is not implemented for the first time. New aspects are related to parameter sampling technique and the general framework is applied to PAWS+CLM hydrological model for the first time. This is not explained inside the paper.

Response

We agree with the reviewer. We have revised and added some specific descriptions of the new aspects of this study in the introduction, such as

"This study is the first to implement a comprehensive hierarchical sensitivity analysis method in relation to a complex and large-scale PBHM."

"*A new set of subdivided parametric sensitivity indices was first defined to provide more detailed information for parametric sensitivities.*"

Comment 2

Page 4 Line 98 - Parameter α should have the dimension of the inverse of a length (L^{-1}) and not dimensionless. Physical meaning of the Van Genuchten parameters used for the sensitivity analysis should be reported.

Response

We thank the reviewer for pointing this out. We have revised the unit of parameter α. More descriptions of the necessity to investigate the sensitivity of Van Genuchten parameters were also added to the introduction:

"*We consider the Van Genuchten parameters α and N here because the correlation between α and N can largely affect the soil water release and infiltration processes in the vadose zone (Pan et al., 2011).*"

Comment 3

Page 7 Line 175 - Prior weights for models and scenarios may affect output results. The choice of equal weights should be motivated. An interesting point might be studying the variability of results with respect to different weights. This could be a useful tool to understand different sources of uncertainty.

Response

We thank the reviewer for pointing this out. As described in the summary of the main revisions, we have added section 3.5 to explore the influence of prior weights for the models and scenarios.

Comment 4

Page 10 Line 245 – Conductivities K have wrong measurement units.

Response

We thank the reviewer for pointing this out. We have revised the units throughout the manuscript.

Comment 5

Page 10 Line 255 – It is not clear which outputs are reported in Figure 5, if they are spatial averaged or not. Comments to Figure 5c needs a more detailed explanation (and figure reference is not 4 but 5)

Response

The original Figure 5 shows the outputs for the spatially averaged results. However, since we have completely revised the manuscript, we acquired new results and replaced this figure with Figure 4 in the revised manuscript with more detailed captions.

Comment 6

Page 11 Line 290 - An appendix with main model equations should be included for reader understanding.

Response

We thank the reviewer for the suggestion. We have added an appendix to describe the main model equations and parameters for readers to better understand the model.

Comment 7

Figure captions are too short and only acronyms of variables are reported. They should be more exhaustive.

Response

Yes, we have added more descriptions in the figure captions of the revised manuscript.

Comment 8

Formulas and indices need references.

Response

Yes, we have added references for the formulas and indices. For example, Eq. (1) and Eqs. (5)-(7).

Comment 9

Physical interpretation of results is very poor and absent in general. Substantial conclusions of the work are not highlighted. It is not clear if the hierarchical sensitivity analysis is a good tool to capture output sensitivity related to several uncertainties or not.

Response

We have completely revised the sensitivity analysis framework and results following the reviewer's comments. More physical interpretations have been added to the results since the new scenario, model, and parametric uncertain inputs have more physical meaning. The discussion and conclusion of this manuscript have also been totally revised to highlight our findings, such as

"On the basis of the results of this study, we suggest that when modelers use sophisticated hydrological simulators such as PAWS, they should pay attention to the weather variable values at approximately 12:00 noon (always the daily peak values), investigate the thickness of groundwater aquifers near rivers and adjust the parameters of the vadose zone."

We have also added descriptions of the advantages of this hierarchical sensitivity analysis method, such as

"The sensitivity analysis results can provide key information on uncertainty sources for modelers and greatly improve the model calibration and uncertainty analysis processes. By

categorizing multiple uncertainties into processes and placing them into a proper layer in a hierarchical framework, this advanced hierarchical sensitivity analysis method can largely reduce the computational cost associated with complex, large-scale hydrological models. Its combination with Latin hypercube sampling and the binning method can further decrease the computational cost."

References

Pan, F., Zhu, J., Ye, M., Pachepsky, Y. A., & Wu, Y. S. (2011). Sensitivity analysis of unsaturated flow and contaminant transport with correlated parameters. Journal of Hydrology (Amsterdam), 397(3-4), 238-249.

Pelletier, J. D., Broxton, P. D., Hazenberg, P., Zeng, X., Troch, P. A., & Niu, G. Y., et al. (2016). A gridded global data set of soil, intact regolith, and sedimentary deposit thicknesses for regional and global land surface modeling. Journal of Advances in Modeling Earth Systems, 8(1), 41-65.