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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Hierarchical Sensitivity Analysis for Large-scale Process-based Hydrological Modeling with Application in an Amazonian Watershed" *by* Haifan Liu et al.

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We appreciate the reviewer for his/her valuable comments and feedback on our study. We believe these comments will greatly improve this research.

General Evaluation 1

The authors did a lot of work, but I think the writing needs a great improvement to highlight their work. The current writing reads more like a report rather than a scientific paper. The scientific motivation is not very clear to me.

Response

We appreciate the reviewer's evaluation of this manuscript and constructive comments. We will totally revise this paper, especially the abstract, introduction, discussions and conclusions sections. The contents of these sections will be reorganized and partially rewritten in order to highlight and emphasize our research motivation and goals: to develop a new tool and demonstrate its implementation to a pilot example for comprehensive global sensitivity analysis of large-scale hydrological modelling.

General Evaluation 2

The authors said the aim of this work is to provide a pilot example of comprehensive global sensitivity analysis for large-scale PBHMs, then what lessons can the audience learn from this pilot example? Please provide a detailed discussion.

Response

We will add more discussions about our findings for this comprehensive global sensitivity analysis in the revised manuscript. In general, we would like to discuss three key insights we learnt from this study results. First, it is necessary to implement such a comprehensive global sensitivity analysis method which considers more than parametric uncertainty for the large-scale PBHMs since the sensitivity analysis results showed that other sources of uncertainty (e.g., climate scenario and model uncertainties) are essential as well for model predictions. Second, using the new improved hierarchical sensitivity analysis method with the capability of flexibly combining different uncertain factors together is a computational affordable and useful way to identify the most important physical process for the large-scale complex PBHMs. By categorizing and combining these uncertainty sources into different processes and placing them in a proper layer of a hierarchical uncertainty framework, this advanced hierarchical sensitivity analysis method can largely reduce the initially unaffordable computational cost of global sensitivity analysis of PBHMs and useful sensitivity indices can be provided to measure the importance of different model uncertain inputs in the physical process viewpoint. And we also discovered certain patterns for the sensitivity analysis results

of this study case. Although these patterns may not be universally correct, they still can provide useful insights for other modelers with similar cases and models. We will add more contents related to these points in the discussions and conclusions sections.

General Evaluation 3

In the introduction, please highlight the objective, contribution and novelty of this work, and justify its significance.

Response

We will totally rewrite the introduction section with different logical flow and new content. After modification, the purpose, contribution and novelty of this research will be more highlighted. We will point out the main purpose and contribution of this work is to develop and demonstrate a new comprehensive global sensitivity analysis method for large-scale complex hydrological models with considering various types of uncertainty sources and physical processes. The novelty of our work includes the implementation of comprehensive global sensitivity analysis for the large-scale complex PBHMs using affordable computational cost. And the new flexible hierarchical uncertainty framework and sensitivity index system also provide modelers novel capability of analysing sensitivity in the physical process viewpoint and estimating accurate importance for further subdivided parametric uncertainty.

General Evaluation 4

I think the authors need pay more attention to the writing. The logic is not very clear and sometimes the conclusive sentences pop out without justification.

Response

To improve the presentation of this study, we will revise the manuscript substantially to make sure that the logic flows smoothly and also avoid making any conclusions without any justification. The abstract, introduction, and conclusions sections will be totally rewritten. And we will hire professional editor for revising the grammar.

Comment 1

The grammar of the title is not right.

Response

We will revise the title following professional English language editor's suggestions.

Comment 2

I think the abstract needs to be rewritten. Right now, it reads like a report instead of a scientific paper. I did not see a scientific motivation but a description of what the authors did.

Response

We will rewrite the abstract. The basic scientific motivation of this work will be highlighted as to develop a new computational affordable tool for comprehensive global sensitivity analysis of large-scale complex PBHMs with considering various uncertainty sources and physical processes.

Comment 3

I think the logic of the introduction needs an improvement.

Response

We will rewrite the introduction and the basic logic of this part has been rearranged as: 1. Introduce the background of the PBHM model and the importance of sensitivity analysis of the PBHM model. 2. Present an overview of traditional sensitivity analysis methods. 3. Present the challenges encountered in the analysis of PBHMs using traditional sensitivity analysis methods. 4. State the purpose and contribution of this research with highlighting the novelty of our method. 5. Provide an overview of the structure of this paper.

Comment 4

Line 47-50, I found this last sentence is confusing. SA “becomes” important? Limited resources?

Response

We understand the reviewer’s confusion. We will revise this sentence and add more references. The sentence will be revised as: “Uncertainty is inevitable and important in numerical modelling (Saltelli and Sobol, 1995; Neuman, 2003; Saltelli et al., 2000, 2010; Neuman, 2003; Lu et al., 2012; Song et al., 2015; Razavi and Gupta, 2015, 2016; Neuman, 2003; Rojas et al., 2010) , especially for the highly complex PBHMs considering various physical processes. Therefor the sensitivity analysis which can identify the most influential sources of uncertainty is a useful tool for both modelers and managers. The resources can be preferentially used to reduce the most important uncertainties (e.g., obtaining new data for more accurate boundary conditions) and thus most efficiently improve the model calibration and prediction processes.

Comment 5

Line 59, this sentence is confusing. “Using” large-scale PBHMs? Why the computational cost is high?

Response

We will rewrite this sentence as “there is still a lack of research of quantitative and comprehensive global sensitivity analysis for large-scale PBHMs”. There are generally two main reasons for the high computational cost of global sensitivity analysis of a large-scale PBHM: the high complexity of model itself and the high standard of global sensitivity analysis. A PBHM usually has a very large number of parameters and multiple high-order nonlinear governing equations. These facts combining with a large-scale model domain cause the running of a PBHM itself is already very computationally expensive. For the sensitivity analysis, comparing with the local sensitivity analysis which can only provide results valid in certain range of parameter values (e.g., the derivative

of model prediction with respect to parameter A at certain value point can be a measurement of A’s local sensitivity at this point), the global sensitivity analysis is more comprehensive because its results are valid for the whole range of parameter value. To achieve this goal, the methods of global sensitivity analysis are all relatively computationally expensive (e.g., the Morris method and variance-based method both use complex sampling techniques) and their computational cost grows exponentially with number of parameters. Therefore, the implementation of global sensitivity analysis for a PBHM leads to extremely high computational cost considering we have to run a large number of simulations for a complex PBHM using different parameter samples. We will state these clearly in the revised manuscript.

Comment 6

Please justify why the authors chose the PAWS model as the pilot example.

Response

The main reason for choosing PAWS as the pilot example of PBHMs is that, compared with other PBHMs, PAWS is a comprehensive and representative large-scale hydrological model which can be applied to large catchments and long-time frames by efficiently coupling both surface and subsurface hydrological processes (Shen and Phanikumar, 2010). And the complexity and parameter dimensionality of PAWS are high enough to test and demonstrate our new global sensitivity analysis method. Furthermore, PAWS has been applied to the studying watershed previously and it was capable of simulating multiple key variables of hydrological states and fluxes at different spatiotemporal scales and presented good model performance comparing to various ground and satellite observation data (Niu et al., 2017). This previous model application provides solid base for our uncertainty identification and sensitivity analysis study. We will add these reasons for choosing PAWS in the introduction section.

Comment 7

It seems that the authors have some methodology development on the basis of their previous work. Please highlight these contributions and novelty, and justify that this new development is necessary for the complex and large-scale model sensitivity analysis.

Response

We do have a new methodology development based on the previous work: the further decomposition and quantification for the subdivided parametric uncertainties. This new technique defines a new set of sensitivity indices and allows modelers to analysing the importance of a physical process only involves partial model parameters. The implement of this new method is necessary because the main weakness of our previous methodology is it considers all parameters together as one single process. This simple strategy may be adequate for a groundwater modelling case, but it cannot provide detailed information for a PBHM which includes multiple hydrological processes. We will revise the introduction to highlight this contribution and novelty, then justify the necessity of this new development.

Comment 8

Line 221, why 600 samples?

Response

We understand the confusion of reviewer. First, based on the experiences of previous research cases (Emery et al., 2016; Dai et al., 2019), we believe 600 is an adequate parameter sample size for our test case considering the model domain and number of uncertain parameters. Second, because of the high computational cost, 600 parameter samples are the maximum size we can afford. After combining model uncertainty and climate scenario uncertainty, we need to conduct a total of $600\times3\times6$=10,800 simulations for the PBHM. The pure simulation time without analysing data is already very time consuming even using the best high-performance computing (HPC) platform we have.

Comment 9

Line 223-224, in what sense the LHS greatly reduces the required sample size compared to MC sampling? To achieve the same estimation accuracy? Please provide evidence or reference.

Response

The LHS has been one popular sampling technique to reduce computational cost and it has been proven to be more effective than conventional MC sampling method. We will provide more references to explain and exhibit the effectiveness of LHS method.

Comment 10

Line 265, when does the binning method not work? Please comment.

Response

The binning method is a rigorously derived mathematical technique designed to separating and estimating the partial variances contributed from different parameters of one LHS method sampled parameter set. Because the mathematical equations are general and rigorous, this method can be applied to any modelling case with LHS parameter samplings. However, when the samplings for different parameters are totally random and unrelated like conventional Monte Carlo simulation, the binning method is not applicable. We will add these comments in the revised manuscript.

Comment 11

Line 410, how do the authors justify the results accuracy?

Response

We intended to express that this hierarchical sensitivity analysis method is capable of estimating accurate sensitivity measurements (sensitivity index) for the importance of certain uncertainty sources. Comparing with other sensitivity analysis methods which

only provide qualitative results (e.g., ranks of importance), this variance-based quantitative global sensitivity analysis method is more accurate. It is more appropriate to replace the word “accurate” with “quantitative”. We will revise this sentence to “This study has shown that the improved hierarchical sensitivity analysis method is capable of providing quantitative and comprehensive assessment of the importance of uncertain inputs through variance decomposition. . .”

Comment 12

Line 417-419, the sentence is confusion.

Response

We will revise this sentence and collaborate with the introduction section to explain the importance of further decomposing of subdivided parametric uncertainties.

Comment 13

Line 419-420, the sentence comes out of nowhere.

Response

We will remove this sentence.

Comment 14

Line 430, “all” is a strong work, be careful of using it.

Response

We will replace “all” with "three types of common", which is more accurate.

Comment 15

Line 434, the method can largely reduce the computational cost associated with complex, large-scale hydrological models. From which aspects to reduce the cost? Does it reduce the forward simulation time? Please be specific here.

Response

We understand the confusion caused by this sentence. What we want to express here is that the improved hierarchical sensitivity analysis method largely reduces the computational cost of global sensitivity analysis for PBHMs, not the computational cost of PBHM simulation itself. In order to express more accurately, we will modify the sentence in the original text as: “this advanced hierarchical sensitivity analysis method can largely reduce the computational cost for sensitivity analysis associated with complex, large-scale hydrological models by categorizing multiple uncertainties into processes and placing them into a proper layer in a hierarchical framework” in the revised manuscript.

Comment 16

The words in Figure 2 are hard to read.

Response

We will update this figure using a higher resolution and a larger font.

References Dai, H., Chen, X., Ye, M., Song, X., Hammond, G., Hu, B., and Zachara, J. M.: Using Bayesian Networks for Sensitivity Analysis of Complex Biogeochemical Models, Water Resour Res, 55, 3541-3555, 2019. Emery, C. M., Biancamaria, S., Boone, A., Garambois, P. A., Ricci, S., Rochoux, M. C., and Decharme, B.: Temporal Variance-Based Sensitivity Analysis of the River-Routing Component of the Large-Scale Hydrological Model ISBA-TRIP: Application on the Amazon Basin, J Hydrometeorol, 17, 3007-3027, 2016. Niu, J., Shen, C. P., Chambers, J. Q., Melack, J. M., and Riley, W. J.: Interannual Variation in Hydrologic Budgets in an Amazonian Watershed with a Coupled Subsurface-Land Surface Process Model, J Hydrometeorol, 18, 2597-2617, 10.1175/Jhm-D-17-0108.1, 2017. Shen, C. P., and Phanikumar, M. S.: A process-based, distributed hydrologic model based on a large-scale method for surface-subsurface coupling, Adv Water Resour, 33, 1524-1541,

10.1016/j.advwatres.2010.09.002, 2010.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2020-87/hess-2020-87-AC1-supplement.pdf

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