Responses to Referee #3:

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

Major Comment 1

The overall motivation should be improved. It should not be "there lacked of research utlilizing quantitative and representative global sensitivity analysis" (line 59-61). I mean yes this is a gap but the primary objective should be to understand uncertainty sources and provide insights to physical processes that control ET and baseflow.

Response

We thank the reviewer for the valuable insights on the purpose of the study. We will improve the motivation such as "to discover and understand the different types of uncertainty sources of PBHMs and to further provide modelers insights of dominant physical processes that control hydrologic fluxes such as ET and baseflow etc.".

Major Comment 2

Section 2.2 should be greatly shortened, or moved to Supporting Information. It's way too long right now.

Response

We will shorten the Section 2.2 to highlight methodological improvements of the hierarchical sensitivity analysis in this study. And we are going to move the main equations of the hierarchical sensitivity analysis method to the appendix.

Major Comment 3

Conversely, some figures deserve more discussion, e.g., Figure 7 – I do not think it is the thickness right under the river cells, it's about overall thickness and how much water from the watershed concentrates to the channels. This hypothesis can be tested; Figure 9 – headwater vs stem river cells. Figure 11 – not really discussed much.

How the authors came up with the six climate scenarios are not described. How could you have these different scenarios?

Response

We will add more discussions about figures, especially Figures 7, 9, 11. We agree with the reviewer that in Figure 7, the sensitivity index for aquifer thickness is about the average aquifer thickness for the whole watershed, rather than the thickness 'right' under the river cells. This is because the volume of groundwater to the river takes into account the contribution of overall watershed grids. We will replace the relevant expressions in the manuscript. As for the Figure 9, we will add more discussions about the difference between headwater and stem river cells. In general, according to this figure, in headwater cells, aquifer thicknesses are usually the most important uncertainties; in stem river cells, model parameters are usually the most important uncertainties. We will expand our discussion of Figure 11 to specifically analyse the effects of three subdivided groups of parameters on ET and Q_G.

We present the generation of six climate scenarios in Section 2.4 (Page 11, Line 276-282). In general, we generated six climate scenarios based on statistical information 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, we sorted the different wet and dry seasons according to their total precipitation values during the whole season. Next, we divided these wet and dry seasons into three different groups representing six climate scenarios from wet to dry. The mean and standard deviation of the values of the different climate variables (e.g., precipitation, maximum temperature) for each group were calculated using the daily data. Finally, we generated random daily weather data for each climate scenario based on these mean and standard deviation data using a normal distribution. We will add these details in the revised manuscript.

Major Comment 4

Figure 4 is a big mess. A cleaner representation such as a boxplot is required.

Response

We will replace this figure to better exhibit the great uncertainty of the model simulation results.

Major Comment 5

The authors need to tone down the description of the hourly sensitivity especially around

night. There may be many assumptions baked into how daily precipitation is disaggregated into hourly which influenced these results. I doubt how robust this is.

Response

We understand that assumptions about averaging daily precipitation data to hourly data may affect the results. We will pay more attention to the interpretation when describing the hourly results.

Major Comment 6

Although not required, it will be nice to demonstrate the results for a year rather than 180 days. The annual cycle tells us more things.

Response

We agree with the reviewer on this point. However, we believe it may be unnecessary because we focused on the wet and dry seasons in the Amazon area for the climate conditions. And different climate scenarios with length of a half year were generated to represent alternative situations of these two seasons. Furthermore, the computational cost is too high for us if we used one year for simulation time. One annual cycle would be a good choice for this type of hydrological model cases, we will try to construct different annual climate scenarios in the future study.

Major Comment 7

The soil thickness should not be called "numerical model" uncertainty, but "subsurface stratigraphy".

Response

We believe the reviewer is talking about different confined and unconfined aquifer thicknesses. We understand the confusion of reviewer, but we believe the different thicknesses of distinct types of aquifers indeed lead to different conceptual hydrological models and represent a form of model uncertainty. We have used similar concept (different thicknesses for material A and B underground) for the model uncertainty in the previous work (Dai et al., 2017). We will create other forms of model uncertainty especially using different mathematical models (i.e. different governing equations) in our future research.

Comment 1

Line 82, Michigan state –> Michigan or the state of Michigan. A relevant citation for this paragraph: Ji et al., 2019, 10.1029/2018WR023897

Response

We appreciate the reviewer to point this out and provide this reference. We would modify "Michigan state" to "Michigan" and include this reference in our manuscript.

Comment 2

Line 126. the model tool –> the modeling tool.

Response

Yes, we will revise this phrase.

Comment 3

Line 122, drainage network was formed –> formed.

Response

Yes, we will revise this phrase.

Comment 3

Line 287-292 paragraph-Brunke et al. 2016 is relevant to discuss 10.1175/JCLI-D-15-0307.1.

Response

We thank the reviewer for this reference. We will add this reference into our manuscript.

Comment 4

Line 307– on what machine did you run these many simulations and how much time did it take?

Response

In the case of parallel calculations using High Performance Computing (13 cores of Xeon 2.8G CPU), the average time spent on a single simulation was 2.8 minutes. 10,800 simulations took 3 weeks. We will add related descriptions in the revised manuscript.

Comment 5

Line 323 –> has little influence on spatially-averaged ET. (I believe for different cells it has a more prominent impact).

Response

Yes. The time-averaged ET result shows that the thickness of aquifers has different effects on different grid cells. We will revise these sentences to more accurately describe the results.

Comment 6

Line 326 –> temporally dependent –>time-dependent.

Response

Yes, we will revise this.

Comment 7

Line 331 "greatly decreasing"?? awkward phrasing.

Response

We will revise this phrase to “significantly decreased”.

Comment 8

Line 356 – accumulation over time? Maybe also due to seasonality? We don’t know for sure.

Response

Yes, there may not be only one explanation for this result. We will pay attention to our tone, and thus elaborate on the various possibilities for producing this result.

Comment 9

Line 354 – river flow always occurs hours later than the rainfall process — what if the rainfall isn't large enough to trigger a response?

Response

The original text refers to that considering the Q_G results, the sensitivity indices of the climate scenario always reach their maximum values around 1:00 am. We think that the reason of this pattern may be the exchange process between groundwater and river water always happens several hours later than the rainfall process, and the exchange volume always reaches its peak at around 1:00 am in the night. We believe if there was not enough rainfall to trigger the exchange of groundwater and rivers, this pattern of sensitivity analysis results would cease to exist.

However, we believe that since the Amazon region receives a lot of rainfall, and we considered a total of six climate scenarios in this study, there is always more than one climate scenarios in which rainfall can trigger the exchange of groundwater and rivers.

Comment 10

Line 347-348– circular logic and tautology.

Response

We will revise this sentence as: "***Groundwater has been demonstrated by previous research to be crucial for soil moisture in the Amazon region (Miguez-Macho and Fan, 2012b). Meanwhile, it also exerts a significant buffering effect on maintaining evapotranspiration during dry seasons (Miguez-Macho and Fan, 2012a; Pokhrel et al., 2014). The model PAWS uses the output Q_G to quantify the variation of groundwater volumes and measure the interaction process between groundwater and rivers. It is essential to implement sensitivity analysis to investigate which factor is most influential to this groundwater exchange process.***" in the revised manuscript. We will add some descriptions in the method section to explain why we chose Q_G as the output of interest.

References

Dai, H., X. Chen, M. Ye, X. Song, and J. M. Zachara: A geostatisticsinformed hierarchical sensitivity analysis method for complex groundwater flow and transport modeling, Water Resour. Res., 53, doi:10.1002/2016WR019756, 2017.

Miguez-Macho, G., and Fan, Y.: The role of groundwater in the Amazon water cycle: 1. Influence on seasonal streamflow, flooding and wetlands, Journal of Geophysical Research: Atmospheres, 117, 10.1029/2012jd017539, 2012a.

Miguez-Macho, G., and Fan, Y.: The role of groundwater in the Amazon water cycle: 2. Influence on seasonal soil moisture and evapotranspiration, Journal of Geophysical Research: Atmospheres, 117, 10.1029/2012jd017540, 2012b.

Pokhrel, Y. N., Fan, Y., and Miguez-Macho, G.: Potential hydrologic changes in the Amazon by the end of the 21st century and the groundwater buffer, Environ Res Lett, 9, 084004, 10.1088/1748-9326/9/8/084004, 2014.