Authors' responds:
HESS-2017-85: Xu et al., Numerical modeling and sensitivity analysis of seawater intrusion in a dual-permeability coastal karst aquifer with conduit networks, Hydrol. Earth Syst. Sci. Discuss.,

Anonymous Referee #1
Received and published: 19 April 2017
In the submitted paper Xu et al. apply local and global sensitivity analysis on a density driven distributed model (SEAWAT) to simulate a coastal aquifer I Florida (US). They use the knowledge of previous studies to define the boundary conditions and initial parameter sets of the model. Then they apply a local sensitivity analysis on the 11 model parameters in respect to various output variables of the simulated matrix and conduit systems. The same analysis is repeated with a global sensitivity analysis method (Morris) to account for interactions among the model parameters. The parameter describing the salinity at the submarine spring outlet was found to be most sensitive but also the parameters describing the conduit properties were found to influence both the conduit and the matrix behaviour. The results of the more elaborate global sensitivity analysis scheme differ for several model parameters indicating that parameter interactions have to be considered. Finally, the authors use the simulations obtained by the sensitivity analysis to conclude about the sensitivity of the karst system to external changes and about the most gaining observations concerning model parameter identification.

The paper tackles a very interesting field of research, which is the evaluation of distributed models via sensitivity analysis. The authors clearly show that such analysis provides valuable understanding of the model and system and they also highlight that the choice of the sensitivity analysis method has strong impact on the results and conclusions. For those reasons I definitely recommend this paper for publication in Hydrology and Earth System Sciences. However, some weaknesses have to be removed first:

Response: Thanks for the positive evaluation of our work, and we agree that a revision is necessary to improve the quality of the manuscript for publication in HESS. Below are our responses to address the review comments. We would like to further revise the manuscript after the editor makes a decision on this paper.

1. The paper is much too long. In their last paragraph of the conclusions (and also in the abstract) the authors clearly state the main outcomes of their research. However, within the body of the manuscript, they lose themselves in details to often.

Response: We agree that it is necessary to reduce the manuscript length. We plan to shorten the introduction section and to remove the redundancy in the result section. The main outcomes of this study will be highlighted in the conclusion part and throughout the manuscript.

2. The usage of two sensitivity analysis schemes provides a lot of insights into their differences. However, the authors do not explain why they actually compare them. For many modellers the interaction among parameters is an accepted fact. So for the sake of focus and length of the

manuscript: Is it really necessary including the local sensitivity analysis? If not, delete. If yes, provide more explanation why.

Response: We believe it is still necessary to include the local sensitivity analysis in the paper, since it presents the parameter sensitivities in the maximum seawater intrusion case, in which seawater intrudes significantly inland. The authors and readers have special interests in understanding the seawater intrusion under such particular scenario. In addition, local sensitivity study is cheap in computational, and easy to compute.

Comparing the results of local/global sensitivity analysis may help us understand: (1) whether the parameter correlation affect the identification of important parameters, (2) whether the nonlinearity of the model affect the identification of important parameters. The parameter correlation and nonlinear significantly affect the results of sensitivity analysis, as we see different ranking of important model parameters. Therefore, we need pay special attention to these issues when we conduct model calibration and/or uncertainty analysis.

3. Some more links between the model setup and field observations/previous work is necessary. It is clear that a lot of previous work was done at the study site. But sometimes it would be helpful providing some summarizing information in addition to the reference to the previous studies.

Response: We thank the reviewer for this suggestion, and will add a more detailed introduction of model setup with its connection to previous studies in this area. We will also add a brief summary of the implications from previous modeling studies in the model setup section. With respect to previous work on sensitivity analysis, Shoemaker et al. (2004) is the only paper that we are aware of for parameter sensitivities in seawater intrusion, although there are several studies about parameter sensitivities and uncertainty quantification in karst aquifer. We plan to include these literatures in this paper during the revision.

4. The elaboration of Morris's method has to be improved.

Response: We will refine the elaboration of Morris' method with an improved introduction.

5. A clear discussion relating these results to the result of other is missing.

Response: We don't fully understand the reviewer's question. If the reviewer wants us to compare this study with other studies, however, there is no other studies ever addressed the same issue before. In previous answers, we also answered that a more detailed discussion of the previous studies on sensitivity analysis (Shoemaker et al. 2004) will be included in the revised manuscript.

6. No state of the art of sensitivity analysis is missing (and no comparison to other sensitivity analysis studies with lumped of distributed approaches in karst).

Response: We are only aware of several papers on sensitivity analysis for karst aquifers, and will compare the previous studies with this study, although the researches focus on different site and scientific questions. The meaning and benefits of sensitivity analysis of this and other researches will be highlighted in the introduction and conclusion parts to better present the overall objectives of this study.

I think these corrections can all be done within the frame of moderate revisions. Please find some more specific comments in the attached and commented pdf.

Response: We thank the reviewer for the detailed comments, and will address them during the revision.

Anonymous Referee #2
The paper by Xu et al. presents the analysis of results with using local and global sensitivity analysis and different scenarios on a karst coastal aquifer system with seawater intrusion. The topic is potentially very interesting but to be useful to the reader, the paper needs significant improvements. The main concern is about the overall goal of the study. The abstract concentrate mainly on the comparison between local and global sensitivity results, but then a significant portion of the paper deals with scenarios.

From a first reading, it is not clear the purpose of developing all these scenarios and how this connects to the previous sensitivity analysis. From my understanding, the scenarios are developed based on the most sensitive parameters and are expected to show how changes in those parameters can affect the results, but this needs to be more clearly explained.

Response: The reviewer is right about the purpose of having the scenarios in the sensitivity analysis. Based on the sensitivity analysis results, we set up the scenarios by changing the important parameters. The physical meanings of the changing parameters indicate either sea level, precipitation discharge or the length of drought period. For example, the extent of seawater intrusion is quantitatively measured in the scenarios of various sea levels. Although hydraulic conductivity is relatively an important parameter as well, the scenarios of various K are not simulated since it is a constant in a specified study site without change with time. We will attach a clearer explanation in the revised manuscript.

I have serious concerns about how the local sensitivity results are presented: the analysis lacks completely the presentation of the parameter correlation coefficients which are provided as output by UCODE, but are not presented here. CSS without parameter correlation coefficients is not informative and needs to be combined to the correlation analysis.

Response: We respectfully disagree with the reviewer for several reasons. First of all, our local sensitivity analysis is based on CSS, which was defined in Section 2.1 of the manuscript. In addition, if we are not mistaken, CSS does not consider parameter correlation but data correlation. Taking equation (2) of our manuscript (equation 4.5 of the book of Hill and Tiedeman cited in the manuscript), the covariance matric, omega, is for data, not for

parameters. In fact, the conventional local sensitivity analysis (e.g., the one used in UCODE and also in this study) does not address parameter correlation. This was part of the reason of conductivity the Morris-based global sensitivity analysis.

Furthermore, there is not good explanation of which observations are used in this analysis. There should be heads and salinity field observations, but it is not clear how many, where and mostly which is the weight which is applied to each observation.

Response: When conducting sensitivity analysis, we do not need to have "field observations". We only need to know which "model simulations" are sensitivity to which parameters. We can have many model simulations. Very little head and salinity observations can be used in this analysis, since it is extremely difficult to collect water samples or install sensors in the subsurface karst conduits (100 meter deep). Xu et al. (2016) summarized the existed field observations within the conduit system. However, these measurements are far inland and not applicable to be used for model calibration in this study.

How are the local sensitivity analysis results used to build the simulations for global sensitivity analysis? Are the same parameters included in both the analyses? Which are the key additional information that we are getting from this double analysis? Often local sensitivity results can be used to discriminate which parameters should be included in the global sensitivity analysis, but this does not seem to be the case in this paper. The two analyses seem to be performed exactly on the same set of parameters.

Response: We did not use the local sensitivity results to build the simulations for global sensitivity analysis. Both the local and global sensitivity analyses evaluate the same parameters. However, the global analysis evaluates parameters within a certain range, while the local analysis only evaluates the specified parameter values. The key additional information in global sensitivity analysis is the assessments of parameter sensitivities within the range and the parameter interaction/correlation with each other.

The introduction is too long and does not get exactly to the point of the paper. Sensitivity analysis and calibration of similar models have already been performed and it would be good to point out where. The discussion of the sensitivity analysis results and of the different scenarios should be organized and made more concise. There are also some inconsistencies with the parameter names that should be checked. My suggestion would be to develop a summary table with all the results for both sensitivity and again for the scenarios to help the reader understanding which are the key findings of this analysis.

Response: We thank the reviewer for the excellent suggestion. We will shorten the introduction, link this research with previous sensitivity studies in karst, and highlight the overall objective of this study. The result and discussion parts will be re-written and re-organized. A summary table with the itemized major findings in this study is a good idea to proceed.

Some more specific comments include:
l.48-49: are the parameters mentioned here calibrated parameters?

Response: These are the parameters and boundary conditions adjusted in the scenarios simulations. All the parameters of aquifer characteristics are calibrated.

l. 132: Which are the issues with VDFST-CFP? Why cannot be used in this case? Without explanation it is not clear why this other method should be mentioned.

Response: VDFST-CFP is not able to hand the issue addressed in this paper, because of computational issues related to the aquifer geometry and the scale of spatial domain. The numerical model in this study is setup to study seawater intrusion in a field scale, with the real dimension and parameter values of the porous medium and the conduit in the aquifer. The current version VDFSTCFP is not able to simulate groundwater flow and solute transport within a large conduit network, because the discrete-continuum modeling method requires the cell size to be at least one order of magnitude larger than the conduit diameter. The computational cost is another constraint. For more details, please refer to Xu and Hu (2017, WRR). We will add a brief explanation in the manuscript to explain why VDFST-CFP is not applicable to this study.

L. 207: please spell out EEs

Response: EEs is the abbreviation for element effects, which was spelled out above equation (4) of the manuscript. The reviewer probably missed the spell-out.

l. 287: the goal here seems to be just performing sensitivity analysis and not calibration. But for running the scenarios, it should be clarified how the values of the parameters have been selected. After which type of calibration? Or the values calibrated in previous studies have been used?

Response: While the reviewer is correct that calibration is always performed to obtain the nominal values used for local sensitivity analysis, we want to point out that the nominal values can be selected based on literature data without conducting model calibration. This may be a limitation for the local sensitivity analysis, because it is not an easy task to selecting nominal parameter values. This problem can be resolved by conducting a global sensitivity analysis, which does not require nominal parameters values but parameter ranges (the ranges can be easily determined based on a literature review). In this study, for the local sensitivity analysis, we did not conduct model calibration, since there is no observational data available to calibrate the model, especially the simulations within the conduit network. The parameter values of aquifer properties (hydraulic conductivity, effective porosity, specific storage, and dispersion coefficient) used in this study are based on a literature review of previous modeling studies in this study area. Information on this regard was provided in section 3.1, but we will provide more detailed information to clarify in the revised manuscript.

l. 453: why the arithmetic mean of CSS?

Response: Here we mean the average of CSS values in all evaluated locations (cell #25 - #75 along the conduit/porous medium layer).

l.470: this was already said at line 455. The discussion should be more compact and better organized.

Response: We will delete the redundant sentence.

l. 568: “groundwater seepage velocity” : are these used as observations?

Response: Groundwater seepage velocity is not used as observations or model simulation in this study. We actually don’t have any observation in this study. See the answers above.

l. 610: clarify which are the field observations and how they have been weighted

Response: We will clarify in the revised manuscript that we did not use any observations for the sensitivity analysis in this paper. As explained above, sensitivity analysis does not require observations. This paragraph is talking about the implication and significance of sensitivity analysis on understanding seawater intrusion in karst aquifer. This study points out that the head and salinity field observations and numerical simulations within the conduit network are particularly important.

l. 619-621: check the English

Response: We will break this long sentence.

l. 626: the DSP package was not mentioned earlier

Response: DSP means the dispersion package in SEAWAT. We tried to deactivate the DSP package to verify that dispersion is negligible within the conduit network in this study. We will clarify this in the revised manuscript

l. 630: local sensitivity allows as well to understand interactions and correlations between parameters but it is not presented here

Response: We respectfully disagree with the review that the conventional local sensitivity analysis used in this study considers parameter interaction and correlation. Because the local sensitivity is based on the first order derivative of a model simulation with respect to a model parameter, it does not consider parameter interaction/correlation. We would appreciate, if the review could provide some references in which local sensitivity analysis address parameter interaction/correlation.

Chapter 5: how are the parameters for these scenarios defined? It would be useful

to make a stronger link between the sensitivity analysis exercise presented above and these scenarios. What is the final goal?

Response: We thank the reviewer for the excellent suggestion for linking between the sensitivity analysis and the scenarios, and this will be added in the revised manuscript. The goal of having these scenarios is to quantitatively evaluate the distance of seawater intrusion within conduit and its effects on the surrounding porous medium, under different scenarios. The distance between the shoreline and the interface of seawater and freshwater mixing is measured as the quantity for evaluating seawater intrusion.

l. 643: How “quantitatively”?

Response: Please see the answer above.

l. 684: “sensitivity analysis”: to which one do you refer? Global or local sensitivity analysis results? The distinction should be made more explicit for all the scenarios.

Response: We mean both local and global sensitivity analysis results. We will clarify this in the revised manuscript.

References:

Xu et al., 2016, Long distance seawater intrusion through a karst conduit network in the Woodville Karst Plain, Florida, Scientific Report 6, 32235.

Xu, Z. and Hu, B.X., 2017, Development of a discrete-continuum VDFST-CFP numerical model for simulating seawater intrusion to a coastal karst aquifer with a conduit system, Water Resources Research 53(1), 688-711.