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Hydrology and Earth System Sciences Discussions

Interactive comment on "Sensitivity analysis of Takagi-Sugeno-Kang rainfall-runoff fuzzy models" *by* A. P. Jacquin and A. Y. Shamseldin

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We would like convey our appreciation to the Editor Dr. Erwin Zehe and the anonymous referees for their constructive criticisms, which have helped us to improve the quality of the manuscript. The details on how their remarks are addressed in the revised paper are given in the discussion below. The chronological order of publication of the referees' comments in HESSD is used.

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I. Reply to Referee 3

This is an interesting topic on the continuously growing topic of applying sensitivity analysis to hydrological models. The topic is appropriate for publication in HESS. The paper is generally good and interesting, but a few aspects are missing, which I discuss below. I think addressing these points would significantly improve the manuscript.

1. P.1968: The first sentence of the introduction is too simplistic a view of the calibration problem. There are clearly other problems such as model structural uncertainty, errors in input and output data etc. that cause problems during calibration. It is not just the parameters!

Response: We agree in that there are other issues causing problems during model calibration. In that sentence, we were referring to those related with the parametric structure of the model only. This point is clarified in the revised manuscript (Introduction, 1st paragraph).

2. Table 3: The authors should add an explanation of the meaning of the parameters into the table to make it easier for readers not familiar with the models to follow the paper.

Response: Parameter descriptions have been added to Table 3.

3. P. 1981: It seems to me that the measures R2 and REP should be correlated, which would have an impact on the results and conclusions. Did the authors check for this?

Response: The measure R2 is very sensitive to the errors in the high flow region, which is the zone of the hydrograph that the measure REP is concerned with. There is effectively a strong correlation between both measures of model performance, with high R2 associated with low REP values. Thus, it is not surprising that parameter sensitivities of R2 and REP are similar. This point was mentioned in section 5.1 of the original manuscript (P. 1985, line 1), but this discussion is further expanded in the revised manuscript (section 5.1, 1st paragraph).

4. P. 1983: A better reference for MCAT is Wagener and Kollat (2007, Environmental

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Modelling and Software).

Response: Reference changed in revised manuscript.

5. P. 1984: The authors just show a single plot of the RSA results. However, since they use a subjective interpretation of these plots (which is fine in general), it would be good to see more results in order to understand how the authors interpret the plots. I suggest that the authors add more RSA plots and more depth on this discussion.

Response: A plot showing the results of RSA method when applied to the model TSK2.5 is added (Fig. 2). In section 5.1, these results are compared with those shown in Fig.1, corresponding to model TSK1.5.

6. P. 1985: I do not agree with the authors; statement that the RSA method only presents the first-order sensitivity of the model parameters without interactions. This is not correct. The RSA approach actually (implicitly) considers parameter interactions since it allows for all the parameters to vary simultaneously. It is this similar to the total sensitivity calculated in Sobol. However, the RSA approach has a strong tendency to have sensitivity results to be dominated by a few parameters. The interaction is important though since non-sensitivity of parameters in the RSA approach can be caused by strong interactions with parameters! The authors could easily check this by varying pairs of parameters only and by looking at the resulting response surface plots.

Response: Even though the results of the RSA method are based on simultaneous variations of all the parameters, it ultimately relies on the analysis of univariate probability distributions. Even though the RSA approach can implicitly account for some kinds of interaction structures, this is not the general situation as several types of interaction effects are obscured by a comparison of univariate probability distributions (see e.g. Saltelli et al., 2008). As pointed out by Referee 3, the non-sensitivity shown by some parameters may be due to the fact that they affect the model output mainly through interactions. It is in this sense that the sensitivity results of the RSA method are related with the first-order effects rather than with the total effects of Sobol's method,

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because the first-order effects only account for the effect of univariate changes of the parameters whereas the total effects indicate the overall importance of the parameters, including the effect of interactions. This limitation can be partially overcome by analysing bivariate covariance structures, as proposed by the referee. However, this approach is such that it only shows bivariate interactions, while higher order interaction effects are not be revealed (Saltelli et al., 2008).

This comment of Referee 3 is incorporated in the revised manuscript by reformulating the discussion of the RSA method in section 2.2.1 (2nd paragraph). In addition to this, the parts of the manuscript discussing RSA have been modified in order to acknowledge the fact that some kinds of interactions can be accounted for by RSA (e.g: section 5.2.1, 1st paragraph; Conclusions, first paragraph).

7. The authors never mention the actual performance of their model in representing the different watersheds. This is important though since sensitivity analysis is only meaningful if the model is a good representation of the watershed input-output behavior. It would be good to add a Nash Sutcliffe Efficiency for example.

Response: We think that sensitivity analysis is useful even if a model's goodness of fit is poor, as there may be cases where some model is the only one available or applicable. Calibrating the model parameters in order to obtain the best possible estimates of the real system's response is mandatory, even if these estimates are known to have serious deficiencies. The information provided by sensitivity analysis can be incorporated to the process of model calibration.

In any case, table 1 summarizes the efficiency values R2 of the models TSK1.5 and TSK2.5, which vary from case to case. We are not including this table in the revised manuscript, as it is already too long and there are other issues raised by the referees that we would like to address.

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Table 1. Efficiency values of the fuzzy models TSK1 5 and TSK2.5.

Catchment.....R2calib*.....R2verif*

Sunkosi-1

TSK1.5.....0.88.....0.84

TSK2.5.....0.93.....0.91

Yanbian

TSK1.5.....0.79.....0.75

TSK2.5.....0.84.....0.79

Shiquan-3

TSK1.5.....0.88.....0.77

TSK2.5.....0.84.....0.36

Brosna

TSK1.5.....0.42.....0.49

TSK2.5.....0.79.....0.87

Bird Creek

TSK1.5.....0.87.....0.13

TSK2.5.....0.70.....-0.61

Wollombi Brook

TSK1.5.....0.89.....0.73

TSK2.5.....0.83.....-0.26

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*Values taken from the study by Jacquin y Shamseldin (2006).

8. Tables 5-8 contain the results, but are very difficult to analyze without spending a lot of time on them. There must be better ways to help the reader by adding visual aids! For example, why not highlight highly sensitivity parameters by making the background gray, or by making them bold. It is important for the reader to see patterns in the tables and the authors should help the reader to do so easily!

Response: This suggestion was incorporated in the manuscript (see tables 5-8 and 1st paragraph of section 5.2).

9. There was a recent paper by van Werkhoven et al. (2008, Water Resources Research) that showed a tremendous variability in sensitivities across different watersheds. It would be very interesting if the authors could discuss their results in the context of this research to see whether this result has general validity.

Response: See Conclusions of the revised manuscript (2nd paragraph).

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II. Reply to Referee 2

The paper presents a global sensitivity study of parameters of a fuzzy rule-based rainfall-runoff model developed by the authors. The authors implement a Regional Sensitivity Analysis and Sobol’s variance decomposition to analyse the sensitivity of the model to its parameters. The paper is written well and the results are interesting. I have some comments that I feel the authors need to address to make some points clearer. Specific Comments

1. Page 1985, lines 3-6: It is not clear why R2 emphasizes the model errors in the high flow zone. It gives equal weights to the model errors across the entire spectrum of the flow. The similarity of the parameter sensitivity with respect to the two measures of performance could probably be due to a systematic over or underestimation of the high flows by the model and that a large proportion of the errors is in the high flow zones.

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Could you clarify this point?

Response: Please refer to response to comment 3 by Referee 3.

2. It is also indicated in the first two lines on page 1987 that no sensitivity to some of the model parameters was noted when REVF was used as a measure of performance. It would be good if the authors tried to interpret this in terms of the model performance.

Response: In the case of the fuzzy model TSK1.5, it was observed that the antecedent spreads have a moderate importance in determining the model performance, with respect to the measures R2 and REP. This situation indicates that, variations in the spreads of the antecedent fuzzy sets have some impact in the discharge estimates and, thus, in the model errors. However, these changes in the model errors are relatively small in magnitude, as revealed moderate total effects associated with the measures R2 and REP. By contrast, the performance measure REVF showed a modest sensitivity to changes in the parameters . This sensitivity pattern reveals that the changes in the model errors nearly compensate in average.

3. Pages 1985-86, section 5.2.1: Wouldn't it make more sense to compare the results of the Regional Sensitivity Analysis with the results reported in Tables 7 and 8 instead of those in Tables 5 and 6? I understand that sampling of the model parameters in the RSA method was performed by randomly varying all the model parameters. Therefore, one can not separately evaluate the sensitivity to a single parameter without its interaction with the other parameters.

Response: Please refer to response to comment 6 by Referee 3.

4. What cut-off points are used to categorize sensitivities as high, moderate, etc in tables 5-8? The authors sometimes categorize values as high as 0.18 as depicting insensitive case while they also declare values much lower than this value as non-negligible (page 1986, line 4).

Response: Cut-off points are given in section 5.2 (1st paragraph) of the revised

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manuscript.

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III. Reply to Referee 1

I fully agree with the anonymous referees #2 and #3 (especially the latter).The paper is very important regarding the ongoing debate about the applicability and prognostic ability of hydrological models. Therefore, a profound sensitivity analysis is absolutely necessary for model evaluation. However, additionally to the comments of referees #2 and #3 the authors should consider the following remarks. This would be worthwhile because the reader likes to get the main features more easily. So, my additional remarks are:

1. P. 1969, line 16ff: Because it is very important to choose data which are informative/representative, the authors should explain/show their data and catchments in the chapter 4.1.

Response: The data sets used in this study are further explained in section 4.1 of the revised manuscript.

2. P. 1973, line 20. This equation needs more explanation. There might be a mistake in V12...p -> V1,2,...p

Response: This notation has been changed to V1,2,...p, as suggested by Referee 1.

3. Chapter 3: The indices of the equations have to be checked (sometimes the index m is used in minor or in capital writing). The difference between h and ha must be explained (equation 14 and 15).

Response: The index m is used to indicate the mth rule of a fuzzy model and the symbol M is used for the total number of rules (sentences before equation 5 and equation 9, respectively). The notation haj is used for the pulse response ordinates of the auxiliary SLM (sentence below equation 15). The notation hj,m represents the pulse response

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ordinates of the mth rule of fuzzy models TSK1.5 and TSK2.5 (section 3.2, penultimate paragraph).

4. The symbols in Fig.1 are not consistent with the text. Suggestion: Add a list of symbols!

Response: Symbols in Fig.1 have been changed for compatibility with the text.

5. Chapter 5: Was the RSA method additionally applied to the verification data?

Response: The RSA method was applied to the verification data as well. This is mentioned in the revised manuscript (section 5.1, 2nd paragraph.

6. P. 1986, line 2ff: What are the criteria for "sensitive" and "very sensitive"?

Response: Classification of parameters as sensitive (S) or very sensitive (VD) by the RSA method was made through (subjective) visual analysis of plots such as those in Fig. 1 and Fig. 2.

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References

Jacquin, A.P. and Shamseldin, A.Y.: Development of rainfall-runoff models using Takagi-Sugeno-Kang fuzzy inference systems, J. Hydrol., 329, 154-173, 2006.

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., Saisana, M. and Tarantola, S.: Global Sensitivity Analysis: The Primer, John Wiley & Sons, Chichester, 292 pp., 2008.

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