Hydrol. Earth Syst. Sci. Discuss., 12, C1606–C1614, 2015
www.hydrol-earth-syst-sci-discuss.net/12/C1606/2015/

Hydrology and Earth System Sciences
Discussions

Interactive comment on "Temporal parameter sensitivity guided verification of process dynamics" *by* M. Pfannerstill et al.

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Received and published: 19 May 2015

We thank Shervan Gharari for giving us several very helpful suggestions of how to improve the submitted paper significantly. Considering the provided remarks, we conclude that the most relevant shortcomings of the current version of our manuscript comprise two aspects. The first aspect deals with descriptions of how the temporal dynamics of parameter sensitivity are used to verify our modified model. Here, we see in particular the need to distinguish between the two TEDPAS methods (TEDPASsingle, TEDPASall) as a central point of our verification framework. The second aspect refers to the imprecise definitions of specific terms that lead to confusion. In the following, we will carefully consider these aspects by answering the raised questions step by step

and we will specify our ideas how we intend to improve the current manuscript.

Shervan Gharari 1 - In the entire paper I didn't see any explanation on how the authors calculated sensitivity. Please elaborate on that.

Answer 1: The core idea of this manuscript is to use the temporal dynamics of parameter sensitivity (TEDPAS) to analyse the proper reproduction of processes of a modified model component (here: groundwater). To calculate the temporal parameter sensitivity, we use the Fourier Amplitude Sensitivity Test (FAST) which is described in detail by Reusser et al. (2011) and provided by the R-package FAST by Reusser (2012). In our manuscript, we provide the core idea of FAST and the most important methodical aspects. For further details, we refer to the initial FAST study by Reusser et al. (2011). Since this current manuscript deals with the application of this method and does not focus on the development of this method, chapter 2.1 "TEDPAS methods" (1734/10) gives a general overview for the general idea of TEDPAS and application examples. Within this chapter, the underlying assumptions of TEDPAS are described and it is shown how the sensitivity is calculated. In TEDPAS, the partial variance is calculated for each parameter as demonstrated in Eq. 1 (1735/9).
For our study, the sensitivity analysis is applied with the parameters that are described together with their defined ranges (1758, Table 1). At the end of Chapter 3.2 the general model setup is defined: We choose a warm-up period from 1997 to 2000 and the sensitivity analysis was performed for the hydrological years of 2001 to 2004 (1739/21-23).
By referring to the key paper of Reusser et al. (2011) and by providing a short description of the TEDPAS method, we think that the sensitivity analysis method is understandable according to its role in our overall approach.

Shervan Gharari 2a - What hypothesis do the authors try to verify with the SWAT model? To me it looks as if they are trying to verify the assumptions which the model is actually based on. The model does essentially what we ask the model to do and nothing more.

Answer 2a: We are thankful for bringing this point to our attention. Considering our methodical approach, we realise that the way of describing the core ideas is not as precise as we aimed for. Thus, we will clarify it in the revised version of this manuscript as described in the next paragraphs.
In TEDPASsingle we analyse if the model modification (of the groundwater module) leads to model parameter behaviour that is consistent with our intention while changing the model structure. To achieve this, we use a methodical approach of a temporal parameter sensitivity analysis. The analysis of TEDPASsingle aims to verify the appropriate temporal dynamic of parameter sensitivity. In this way, we make sure that our idea of model modification is implemented according to our expectations. Consequently, the referee is totally right by stating that TEDPASsingle is used to test if the model is able to meet our expected parameter behaviour.
In contrast, the idea of TEDPASall, which is fundamentally different to TEDPASsingle, is obviously not clearly explained in the current manuscript. The core idea of TEDPASall is to use observations and process knowledge of the catchment to verify the processes that are simulated by the model. Hypotheses are derived from observations and knowledge about the processes within the catchment. To derive these hypotheses, we looked at former studies in the catchment and benefit from these experiences in addition to own experiences from field studies. These hypotheses about process occurrence are compared with the simulated process occurrence. In this way, we make use of catchment information (observed processes) to verify proper model behaviour (simulated processes).
To summarise, we think that the difference between TEDPASsingle and TEDPASall was not clearly enough emphasised. This is in particular the case for TEDPASall. Thus, we like to propose a way how to improve this shortcoming of the current manuscript.

To clarify the difference between TEDPASsingle and TEDPASall, we suggest to integrate a flowchart that clearly depicts the underlying assumptions and objectives of each method (see figure 1 attached). Furthermore, we suggest to modify the terms of each method to emphasise that one method is focused on model structure related hypotheses (TEDPASmodel) and that the other method is focused on observed hydrological processes within the catchment (TEDPAScatchment). In addition to that, we suggest to restructure the manuscript so that the verification with model-structure based hypotheses is clearly separated from the verification with catchment/observational based hypotheses.

Shervan Gharari 2b - I suggest the authors to distinguish between model assumptions and the constraints on model behavior which might come from other sources of information [such as groundwater dynamic as the authors mentioned].

Answer 2b: We hope that the previous explanation makes clear that our approach distinguishes between the verification of model based assumptions and the verification of catchment /observational assumptions. In this context, we appreciate the recommendation of using constraints such as proposed by Hrachowitz et al. (2014). However, the presented idea of this paper is focused on the general ability of a modified model to reproduce processes in a reasonable way according to the observed processes within the catchment. In contrast to constrained-based model analysis, we do not try to investigate how the model behaviour may be influenced by constraining parameter ranges while calibrating a model. We see our study more in the line of model diagnostics without focusing on the topic of model calibration.

Shervan Gharari 2c-Testing the assumptions that the models are based on is not model diagnostics in my point of view. To better understand what I mean please read my recent work (Gharari et al., 2014a,b in HESS).

Answer 2c: Referring to the last point of the comment, we would like to stress out again, that the verification of the model structure is one aspect of this framework. The other part of the presented framework focuses on the process verification, which is based on catchment-based hypotheses (in TEDPASall). In our opinion, this can be interpreted as a model diagnostic analysis. However, we are thankful for providing us additional literature which might help to explain our idea of model diagnostic with respect to other definitions of model diagnostics. As far as we interpret the mentioned findings of Gharari et al. (2014a), the presented constrained-based search algorithm shows its advantage especially in deriving realistic parameter values based on expert-knowledge of the catchment. In addition, Gharari et al. (2014b) developed a method to make use of expert-knowledge to improve the selection of parameter values in the context of spatial heterogeneity of the catchment. Both papers highlight the value of expert-knowledge integration to improve the development of hydrological models and realistic calibration. In contrast to the mentioned work, we make use of expert-knowledge in a different way. Firstly, the temporal parameter sensitivities are used to verify that the model parameters are implemented properly. Secondly, expert-knowledge of the catchment is used to compare the simulated and observed processes for model verification. Consequently, our study does not deal with constraint-based model analyses. We are unsure if the referee's intention was to integrate these two papers to point out the differences between our method and the methods that are explained in Gharari et al. (2014a) and Gharari et al. (2014b). Because of this, we kindly ask the referee to clarify if this was the intention and where this work could be considered in the current manuscript. As two sources with valuable information were mentioned we are very welcome for suggestions of where this work could be considered in the paper.

Shervan Gharari 3- I always had some problem with sensitivity analysis of model parameters! What can you say if the sensitivity of one model parameter is higher than the other; can you state that parameter is more important? You should elaborate on that. Why are you measuring the sensitivity? And how can it help? It should be justified.

Answer 3: According to our explanations in the paper (1734/18-24, 1736/4-14), we analyse the dynamics of temporal parameter sensitivity. In contrast to classical sensitivity analyses, the extraction of temporal information is a focal point. We do not aim to determine, if one parameter is more important than another parameter as in classical sensitivity analyses. This decision would be indeed quite vague.
In contrast, our analysis aims to identify patterns of temporal sensitivity for individual parameters in specific discharge phases. For this, we assume that parameters with a high share on the total sensitivity have a high impact on the discharge. Based on this knowledge, two aspects can be investigated.
Firstly, we can test if the temporal dynamics of parameter sensitivity are plausible. In other words, the temporal aspect of the sensitivity and the sensitivity dynamics are important to investigate where parameters have an impact on the discharge. There should be a clear temporal pattern according to the structural integration of the model parameters. This was the intention in TEDPASsingle.
Secondly, the temporal parameter sensitivities are interpreted towards process dynamics. Assuming that the sensitivity of a parameter reflects a hydrological process, we can identify the time when a simulated process occurs. Based on expert-knowledge of hydrological processes within the catchment, we expect a specific time when a process occurs. These expectations are compared with the simulated process occurrence, which is interpreted from the temporal dynamics of parameter sensitivity. This was realised in TEDPASall.

Shervan Gharari 4 - You are suggesting TEDPAS as a model versification tool; I would like to ask how different it is from other tools such as DYNIA? Or even GLUE? Or other MCMC frameworks? [although I know they don't look at the same things]. You should be able to justify "model verification" also. What do you mean by that? If your models, hypothesis or assumptions are verified what does that mean?

Answer 4: We certainly agree that there are several approaches and tools suitable for diagnostic model analyses. In this study, we provide a new interpretation of the TEDPAS method as introduced by Reusser et al. (2011) with the aim to increase the diagnostic potential of TEDPAS.
The presented TEDPASsingle application focuses on the model structure analysis with temporal parameter sensitivities. In this study, the aim of TEDPAS is to use parameter sensitivities to analyse the general behaviour of the model and a modified model component. It does not aim to investigate uncertainty and resulting consequences for model parameter calibration which is not the general intention of TEDPAS. For this task, there are already tools and methods available that were mentioned before. Thus, in our opinion the other mentioned methods are completely different in their aim so that we do not think that our study would benefit from a comparison with well-known but different methods.
Considering the concerns of this comment how TEDPAS can be justified as a model verification tool, we suggest to integrate a more precise definition for the term of model verification when introducing it. By comparing the results of TEDPAS with observed hydrological processes within the study catchment, we can test if there is consistence between the simulated and observed hydrological processes of the catchment. If the model is able to reproduce the observed processes in a reasonable way, we assume that the model structure is suitable for the catchment. The verification may then be interpreted as a result of a diagnostic model analysis that integrated several sources of information, given by the expected model parameter behaviour and the observed hydrological processes of the catchment.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 1729, 2015.

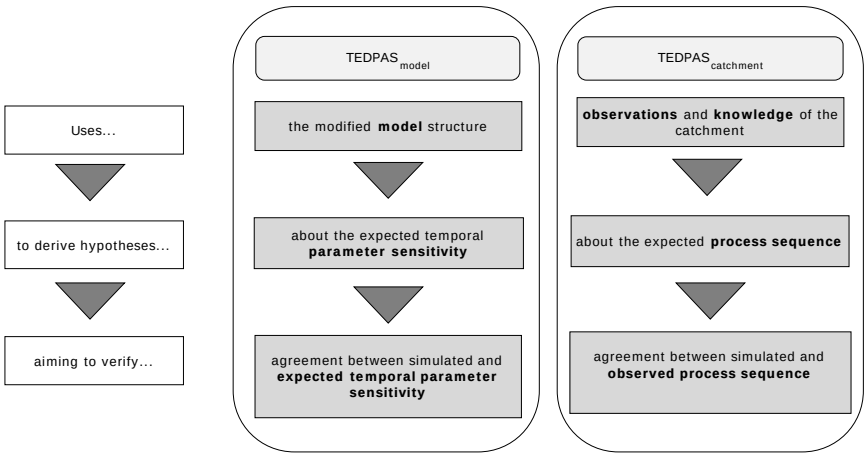

Fig. 1. Differences between model diagnostic analyses with TEPDASmodel (TEDPASsingle) and TEDPAScatchment (TEDPASall).