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Hydrology and Earth System Sciences Discussions

Interactive comment on "*HESS Opinions* "Topography driven conceptual modelling (FLEX-Topo)"" *by* H. H. G. Savenije

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About Referee # 1's comments

First of all I would like to thank the referee for his/her supportive review and valuable suggestions that will help to test the proposed approach. I fully agree with the referee that the proof of the pudding is in the eating and that we have to try and set-up an objective way of proofing 'the pudding'. Here we touch upon a fundamental problem in hydrology where an objective proof is hard to get. In catchment hydrology we always suffer from the problem that we don't know with sufficient accuracy what the exact forcing of the system was. Rainfall is highly heterogeneous in space, and point measurements can result in substantial biases. Maybe in the near future, making better use

of radar and remote sensing instruments, we shall be able to reduce these biases, but with an uncertain forcing of a model it is extremely hard to reject or accept a hypothesis. What we can do, however, is compare models. A model (hypothesis) that performs consistently better than another model (hypothesis) is most likely a better hypothesis. Although such a conclusion may be very site and case specific. So then the question is: how broad should a sample (consisting of either (i) various catchments in different climatic, geological and topographical conditions and/or (ii) various climatically different calibration and test periods) be in order to be able to draw the conclusion that one model is better than the other?

The three questions that Referee 1 raised are:

1. How will you test your ideas?
2. How will you create possibilities to falsify your ideas?
3. Will you be willing to revisit your ideas?

In view of the above, these questions apply to any hydrological study that goes beyond a pure case study application. In fact any contribution that one tries to make to enhance our understanding of how the hydrological system functions, at whatever scale, should consider these three questions. Hence the three questions apply to any hydrological paper that is worth publishing and not only to a paper who suggests a new modeling approach.

The third question is the easiest to answer. The answer is a wholehearted YES. This is not at all painful. Even if it will turn out that the original idea needs to be rejected or refined, we shall learn something in the process, and that is what matters: enhancing our understanding of how the system works. The first two questions require more words to answer. But first, for clarity, I highlight the main characteristics of the approach.

About the TopoFlex Modelling Approach

Besides uncertainty of input variables, process misrepresentations, i.e. unrealistic model structures, and related parameter identifiability, are the most important source of modeling uncertainty. Between the conflicting priorities of developing better process representations (likely leading to more complex models) and developing parsimonious models (based on as few parameters as possible and thereby improving parameter (non-) identifiability) there is little room for model improvement.

It is widely accepted that different parts of the landscape fulfill different tasks in runoff generation and the incorporation of additional information to delineate these different response units was done before (e.g. Scherrer and Naef, 2003; Uhlenbrook et al., 2004). These attempts, while valuable for gaining insights into underlying catchment processes, were of limited use for operational application as they were either incorporated in distributed, process based model structures, resulting in considerable parameter equifinality (e.g. Uhlenbrook et al., 2004) or because they simply required detailed data (e.g. soil properties) which are frequently not available (e.g. Scherrer et al., 2007; Hellebrand and van den Bos, 2008; Rosin, 2010).

The proposed approach aims at reducing these limitations by using readily available information, i.e. topography, to define different landscape units, which can then, by their perceived eco-hydrological function, be assigned different lumped, conceptual model structures. One possible and efficient tool to use topographic information is the "height-above-nearest-drainage" (HAND; Rennó et al., 2008) which allows classification of landscape units into units of different eco-hydrological function, such as riparian areas or hill slopes.

Instead of conceptualizing a given catchment with one single lumped model structure, such as for example a soil moisture module draining into two parallel linear reservoirs, the proposed method will assign different model structures to the previously identified functional hydrological units, such as riparian areas, hill slopes and plateaus. Depending on the proportions of the respective hydrological units in a catchment the modeled stream flow will then be a composite of the contributions from the individual hydrological units, represented by different model structures, routed to the stream. Or in other

words, different flow generation processes in different landscape units will be conceptualized with different model structures instead of using one single lumped model structure to represent the catchment response. The computed runoff from each model structure (or landscape unit) will then be weighed by the areas the individual landscape units occupy in a given catchment and combined to give the total streamflow.

This will result in a partially-distributed representation of reality without the need of substantially more parameters, as discussed in the manuscript. Although most of the model parameters will not be inferred from the data but will rather be calibration parameters, the potentially higher level of realism as compared to models with one single structure and the comparably low number of parameters will arguably result in more constrained, i.e. identifiable, model parameter estimates. In other words, parameters will not be more constrained by the available and incorporated topographic data themselves but rather by a better, more realistic and partially distributed representation of the different flow generation processes in the individual hydrological units.

About Model Evaluation

Regarding the evaluation of the model structures. Clearly there is no such thing as the correct or "best" model. In absolute terms, such a model most likely is not available under the given circumstances (cf. Andreassian et al., 2009). We should instead strive to develop "better" models than those available to date (Savenije, 2009). A justified question therefore is how different model structures and parameterisations can be assessed to identify "better" or more adequate models. A powerful tool to identify model improvement is multi-objective calibration. Objective functions emphasizing for example peak as well as low flow can be used to generate pareto fronts of model parameterisations (Fenicia et al., 2008). Shifts of these pareto fronts towards the origin illustrate improvements in model structures, while structures and parameterisations whose objective functions plot far from the pareto optimal solution can be rejected. Clearly, there remains a level of subjectivity in such an approach. However, in conjunction with a rigorous model crash test as suggested by Klemes (1986) and reiterated by Andreassian et al. (2009), there can be some confidence that a chosen model can adequately represent the processes in a given catchment. The mentioned model crash test involves several levels of model testing, including common split-sample tests, followed by differential split sample tests, proxy-basin tests and proxy-basin differential split sample tests (Klemes, 1986). In order to extract even more information about the adequacy of the respective models we will extend the concept of differential split sample tests. That is, instead of merely identifying some few periods of different climatic conditions for sequential model calibrating and testing, the concept of re-sampling (in a way similar to the technique of "boot-strapping") will be adopted to increase the sample sizes and therefore the information content of the tests. For example, from the available data record with length n, the model will be sequentially calibrated for one hydrological year (or any other chosen period) and thereafter the parameterisation will be tested individually for all preceding and subsequent n-1 years (or any other chosen periods). This is then repeated by calibrating the model to another hydrological year and testing it on the remaining n-1 years, until the model has been calibrated for all individual n years. Depending on the computational requirements of calibration this re-sampling framework can then even be extended to repeat the above method with different lengths of calibration and/or test periods.

In addition we shall focus model evaluation on their performance under validation circumstances and not under calibration circumstances. The ratio of the performance under calibration and the performance under validation could be an interesting indicator for the predictive uncertainty of a model. Model structures that do not perform significantly better than a bench mark or another model structure will be rejected. For the benchmark models we intend to use well established parsimonious conceptual models such as HBV (Bergström, 1992) or GR4J (Perrin et al., 2003).

The ensemble of tests will not only identify adequate model structures but will also give insight into temporal and spatial model transposability. Most importantly, it will be possible to identify under which climatic and topographic circumstances which model

structures fail, allowing us to identify weaknesses in model structures and potentially giving the modeler the possibility to adjust the model structures according to the observed weaknesses (Fenicia et al., 2008).

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