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Hydrology and Earth System Sciences Discussions

Interactive comment on "Hydrologic predictions in a changing environment: behavioral modeling" *by* B. Schaefli et al.

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We thank the referee for giving us another opportunity to clarify and reiterate the points made in our paper.

1. Firstly, we want to reassure the reviewer that this is indeed an opinion paper – we always intended it as such and it is only a technical glitch (with the HESS submission system) that caused this confusion. We will make sure that it is presented correctly in the revised version (if accepted).

   Nevertheless, the fact that this is an opinion paper does not absolve us of the responsibility to support our opinion through appropriate reasoning, or facts, as

the case may be, and we believe we do this already, and we will improve on this through our responses to the reviewer.

2. As the reviewer rightly points out, this opinion piece builds on the ideas earlier enunciated in Sivapalan (2005), and indeed in the subsequent and highly cited paper by McDonnell et al. (2007). The main dilemma facing hydrological modelers is the problem of "heterogeneity" and more specifically "landscape structure" – much of which is hidden, often unknown and even unknowable, except in the few places that field scientists have gone to the trouble of mapping out in considerable detail. Such mapping is not possible generally, and it is certainly not possible in ungauged basins where we often want to make predictions.

3. The thesis outlined in both Sivapalan (2005) and in McDonnell et al. (2007) is that models and modeling approaches that require us to prescribe the full heterogeneity and associated process complexity face considerable difficulties, and that we should adopt new modeling techniques that embrace and utilize their "ecosystem function" or generally "catchment function".

   This is indeed the rationale for this opinion paper, namely, that there is a need for a new generation of models that embrace "ecosystem or catchment function". The opinion paper is therefore an appeal to the hydrologic community to (i) carry out fundamental work that will discover organizing principles that underpin the "function" and (ii) build or apply models that can utilize these organizing principles as the basis of new model structures or parameterizations, or to act as constraints on model predictions.

4. While the argumentation we have followed here is not new, and mainly comes from the above two papers (and others), we have gone further than merely articulating the case for a new modeling framework based on "organizing principles", named here as "behavioral modeling", and actually present our vision as to what the new modeling framework may look like and how it could be accomplished.

HESSD

7, C4581–C4586, 2011

Interactive Comment

In the original version of the manuscript, we cited the work of Schymanski et al. (2007, 2009) but did not go into details considering that this was only an opinion paper. However, in response to the Reviewer #1 (Keith Beven, see accompanying discussion), we have now decided to give more details of that work, which, in our opinion, represents the first concrete example of "behavioral modeling" in practice (which both reviewers requested to be included in the opinion paper before it is accepted for publication).

5. The reviewer queries our use of the 'structure problem', the implication being that this has been presented before. We never claimed, and do not want to imply, that we are the first to define this problem. The reviewer mentioned Beven (2001). In fact this problem was well articulated in Sivapalan (2003) as well, neither of which we thought was necessary to cite since the idea is straightforward (in these previous references this problem was not given a name – we just called it the "structure problem"). The aim of this paper is not to define a new "structure problem" but rather use this well known "structure problem" as part of the discussion and rationale for the introduction of "behavioral modeling". However, we will now cite both Beven (2001) and Sivapalan (2003) to motivate our description of the "structure problem".

6. The reviewer claims insufficient evidence in our paper to support the assumptions we have made, and to show how the proposed theories can be useful in practice. We understand this reviewer statement to mean that (i) there are no examples of behavioral modeling in the literature and (ii) there is no evidence to indicate a modeling approach based on "organizing principles" will actually work.

   Firstly, we would readily agree that "behavioral modeling" has not yet become a mainstream activity. However, this alone should not be the reason to "do nothing", or discourage other people from articulating new ideas along these lines.

   Secondly, we hope that the reviewer might react more favorably to the example

HESSD

7, C4581–C4586, 2011

we have already cited in the original version (i.e., Schymanski et al., 2007, 2009), which we will now present in more detail, and will agree with us that a modeling approach based on "organizing principles" can actually work, and with concerted efforts in the future can work even better.

For our part, as authors of this opinion article, along with many other groups, we have recognized a fundamental problem we have in hydrological modeling, which McDonnell et al. (2007) call an "impasse", and are trying to address these problems in many ways, one of which is the search for and use of "organizing principles" in a new generation of models called "behavioral modeling".

7. The reviewer queries our use of the name "behavioral modeling" for the new modeling framework, claiming that it could cause confusion. The reviewer has a point here. In fact we have debated amongst ourselves what we should call this new modeling approach. We had thought of coining the name "functional modeling", to reflect the fact that the suggested "organizing principles" underpinning the modeling framework reflect some kind of "catchment or ecosystem function."

   In the end we decided in favor of "behavioral modeling" for the same reason that the reviewer is citing, i.e., so as not to create confusion. We decided to introduce the use of "organizing principles" into existing modeling approaches, rather than start something totally new that is in competition or conflict with them.

8. One of our suggested uses of "organizing principles", i.e., to act as a constraint on model predictions, and as a way to eliminate "non-behavioral" parameter combinations, is similar in spirit to what is currently practiced in GLUE, except that in the latter case "non-behavioral" parameter sets are identified on the basis of a comparison of model predictions against observations.

   In the case of models based on "organizing principles", the model predictions are constrained by recourse to universal theoretical organizing principles (e.g.,

HESSD

7, C4581–C4586, 2011

maximization of net carbon profit, as in Schymanski et al., 2007, 2009) or regional empirical organizing principles (e.g., Budyko curve, as in Li, 2010).

In fact Keith Beven himself accepts (in the parallel discussions) that this can be easily accommodated as part of GLUE, where the word behavioral is already used with a particular meaning (i.e., parameter combinations that satisfy an empirical fitness criterion). It therefore makes a lot of sense to give the name "behavioral modeling" to the new modeling framework, because it accommodates a new fitness criterion we propose (i.e., theoretical organizing principles), and yet it is a logical and seamless extension of what is already being practiced within GLUE. As part of our response to Beven we already address the advantages of the use of organizing principles in the development of behavioral models, as opposed to mere fitting of the predictions to the observations in a given place.

9. In closing, we want to respond to the reviewer's request to the authors "to seriously reconsider their arguments, identifying issues that can justify a new contribution considering the existing literature in this respect". We believe that in this opinion paper, we have made the case for a new modeling framework focused on "function" and associated "organizing principles". We have presented it in such a way that it is a natural extension of existing modeling approaches, even while introducing new approaches to develop new model structures, and new ways to constrain model predictions, in particular in ungauged basins. Clearly, there is "no free lunch" – the new modeling framework calls for much fundamental research to discover these organizing principles. It creates a new atmosphere for the generation of "new ideas", something the reviewer emphasized in her/his comment.

Cited References

Beven, K., and J. Freer (2001). Equifinality, data assimilation, and uncertainty estimation in mechanistic modelling of complex environmental systems using the GLUE

HESSD

7, C4581–C4586, 2011

methodology. Journal of Hydrology, 249(1-4), 11-29.

Li, H.-Y. (2010). Diagnostic Analysis of Runoff Partitioning at the Catchment Scale. PhD Dissertation, Dept. of Civil and Environ. Eng., Univ. of Illinois at Urbana-Champaign. July 2010, 210p

McDonnell, J. J., Sivapalan, M., Vaché, K., Dunn, S., Grant, G., Haggerty, R., Hinz, C., Hooper, R., Kirchner, K., Roderick, M. L., Selker, J., and Weiler, M. (2007). Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology, *Water Resources Research*, 43, W07301.

Schymanski, S. J., Roderick, M. L., Sivapalan, M., Hutley, L. B., and Beringer, J. (2007). A test of the optimality approach to modelling canopy properties and CO2 uptake by natural vegetation, *Plant, Cell & Environment*, 30, 1586–1598, 2007.

Schymanski, S. J., Sivapalan, M., Roderick, M. L., Hutley, L. B., and Beringer, J. (2009). An optimality-based model of the dynamic feedbacks between natural vegetation and the water balance, *Water Resources Research*, 45, W01412, 10.1029/2008wr006841.

Sivapalan, M. (2003). Process complexity at hillslope scale, process simplicity at the watershed scale: Is there a connection? *Hydrological Processes*, 17, 1037–1041, doi: 10.1002/hyp.5109.

Sivapalan, M. (2005). Pattern, process and function: elements of a unified theory of hydrology at the catchment scale, in: Encyclopedia of Hydrological Sciences, edited by: Anderson, M. G., Wiley, Chichester, 193-220.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 7, 7779, 2010.