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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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Introduction

We thank Keith Beven for his comments and for his longstanding interest in advancing hydrological modeling in general, and especially for highlighting the importance of dealing with uncertainty in the modeling process. His comments give us an opportunity to clarify some points that perhaps we may not have articulated adequately in the manuscript.

The submitted manuscript is not a review paper, nor a technical paper, rather it is an opinion paper that sought to lay out a new framework for future modeling that is

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based on organizing principles rather than calibration strategies. It follows discussion presented in several previous articles (Sivapalan, 2005, 2009; McDonnell et al., 2007).

Having said this, we do believe that Beven's comments are unduly pessimistic about the need for and the potential of the behavioral modeling framework that we have proposed, and in some cases arise from a certain misapprehension of what we have proposed. We will attempt to identify and clarify the misunderstandings, while not dwelling on differences in opinion. We hope the juxtaposition of Keith Beven's comments and our replies will throw more light on the relevant issues involved.

Detailed Responses

The main points of Keith Beven's comments are summarized below (in italics), in each case immediately followed by our responses.

1. It is suggested that our proposed behavioral modeling framework is not so different from current modeling practice since most models already use water balance, and energy or momentum balance as constraining principles. It is suggested that the proposed modeling framework therefore runs into a circularity problem in the sense that we impose the organizing principle on the model structure and accordingly all simulations respect it.

Physical principles, such as water, energy or momentum balance, are by no means sufficient to constrain a prediction model, which explains why, classically, hydrological models are systematically calibrated on locally observed data. The organizing principles that we have proposed go beyond basic physical principles or conservation laws but are ones that reflect the co-evolution of biological, hydrological and geomorphologic processes and that impose a very different kind of constraint on predictions of acceptable models. This will be made clearer the revised manuscript.

The perceived circularity problem likely arises from our over-simplified scheme presented on p. 7791, ll 1-12. We will change this scheme to clearly distinguish between

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two different uses of optimality principles we proposed in the manuscript. One is to implement organizing principles directly in a model and test the model and the principles by comparison of model output with observations, and the other one is to use an organizing principle to separate out the behavioral models and parameterizations (i.e. the ones respecting this principle) from a set of models and parameterizations that equally reproduce the observations. These two uses have different purposes, the first being to understand which organizing principle might be at work or useful for prediction (in conjunction with real-world experiments), the second being to actually build a prediction model.

2. It is suggested that there is no convincing example of a useful organizing principle and of how behavioral modeling might actually work. All examples given in the paper have too many limitations to be useful for prediction (especially when faced by uncertainty).

Firstly, the vegetation optimality model (VOM) is an excellent example of a behavioral model (Schymanski, 2007; Schymanski et al., 2007, 2008a,b, 2009). It started off with the assumption that maximization of the net carbon profit (NCP) is an organizing principle that drives the adaptation of vegetation to its environment. To formulate a falsifiable hypothesis based on this principle, the authors had to identify some important degrees of freedom that vegetation has to adapt to its environment and their associated costs and benefits in terms of the NCP. Then, the hypothesis was formulated that the organizing principle in conjunction with the proposed degrees of freedom and their costs and benefits would allow to predict certain canopy features and CO2 fluxes at a given savanna site. The hypothesis was tested using site-specific observations and found to be falsified during the dry, but not during the wet season (Schymanski et al. 2007). This led to the conclusion that the costs for deep roots might be limiting canopy cover in the dry season. Rooting depth and the associated costs and benefits were included in an extended version of the VOM, which led to a satisfactory reproduction of the rooting depth, canopy cover dynamics and seasonal fluxes of CO2 and water vapor over several years. Clearly, the radical reduction of calibration needs by the inclusion of a proposed organizing principle resulted in a falsifiable model (Schymanski et al. 2007, 2009). From the partial falsification in the first step (Schymanski et al. 2007), the authors learned enough to construct a model with a clear potential for multivariate prediction (Schymanski et al. 2009). The utility of the max. NCP principle for reducing the need of model parameterization was also demonstrated for simulating canopy conductance (Schymanski et al. 2008a) and root water uptake (Schymanski et al. 2008b). There are several other examples we have mentioned in our manuscript. In view of Beven's comments, we will provide, in the revised manuscript, an expanded description of the VOM, and how it qualifies as a behavioral model.

Secondly, we will deal with the question of uncertainty below.

3. The most substantive of Beven's comments was concerned with the range of validity of the organizing principle approach. This concern can be broken into two parts. The first part is that our ability to model the system in such a way that the organizing principles can be observed is clouded by the uncertainties in the data used in the modeling. The second is that due to the enduring legacies of the past (such as from glaciation), human alterations and the contingencies of landscape structures in particular places, we cannot be sure that an organizing principle will be adhered to with any fidelity.

Hydrologic prediction has to face uncertainties of many kinds, including namely observational uncertainties. As under the current "data-calibration-based" modeling paradigm, it is equally possible to incorporate data uncertainties into our "organizing principle-based" behavioural modeling approach by defining a range of model outputs that count as acceptable matches with the chosen organizing principle. The width of this range is conditioned on both the uncertainties in the data and the natural variability that conditions the fidelity with which the organizing principle is held.

Li (2010) and Li and Sivapalan (2010) have followed precisely this approach to constrain distributed model predictions using the Budyko curve (deemed as an empirical organizing principle). In this case Li (2010) and Li and Sivapalan (2010) prescribe the Budyko curve with an uncertainty band. On the other hand, Dekker et al. (2010) have presented an implementation of Schymanski's VOM model where the imposition of the "maximization of net carbon profit" organizing principle is implemented while fully embracing parameter and model structure uncertainty.

We completely agree that the effects of humans on the landscape can be profound. And yet the legacy of history often remains, especially in the subsurface where our modeling uncertainties are greatest. The likely fidelity of an organizing principle in the landscape depends on the timescale required for it to be expressed, and the time since other effects (humans, glaciation) perturbed it. In the case of soil properties this may take a long time. However vegetation properties may reach some "organized" state over relatively short timescales. Thus, the timescale and legacy issues mentioned by Beven, far from invalidating our behavioral modeling approach, provide the constraints that the processes operating at faster time scales must adapt to. In this way the "frozen heterogeneity" (Kinzelbach, personal communication, 2010) makes its mark in the dynamics.

Of course, any model development framework will be sensitive to the quality of data and there is certainly no magical method that can overcome the "garbage in - garbage out" problem. In exchange, using organizing principles, i.e. the condensation of current knowledge about ecosystem behavior, to build models must be seen as a valuable step to overcome the "garbage in - reasonable things out" problem of calibrated models, which often enough give the right answer for the wrong reasons. If we develop a behavioral model which is shown not to be able to reproduce observed responses due to observational uncertainties, we can at least assert obtaining the wrong answer for the right reason.

Conclusion

In closing we reiterate that the use of organizing principles takes on added significance for making predictions in a changing world, where models conditioned on past observations of hydrologic response are no longer adequate. Surely we cannot model everything with certainty, and organizing principles offer a way to sort between the myriad possible futures, given our uncertainties (Kumar, 2007; Blöschl and Montanari, 2010). Only some futures will continue to revert to the “organized” state (over the appropriate timescales), and the others can be discarded as long as the organizing principle is deemed to hold in the future. We query as to what other way do we have to distinguish between likely and unlikely futures, apart from asking whether they are in accord with what we believe are unchanging and persistent?

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