Geophysical Research Abstracts
Vol. 16, EGU2014-5018, 2014
EGU General Assembly 2014

Bottom-up or top-down? Introducing constraints might be a way forward

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Lumped conceptual and distributed physically based models are the two endpoints of the modeling spectrum in many environmental systems models, ranging from simplicity to complexity. These two approaches are characterized by their very own advantages and limitations. In hydrology, physically based models are typically applied under the assumptions that (a) the spatial resolution and the complexity of the model is warranted by the available data, and (b) the catchment response is a mere aggregation of small-scale processes. However, these two fundamental assumptions are violated in many cases. As a result, not only the predictive power but also the hydrological insights that these models provide can be limited. In the case of conceptual models, parameter values are typically specified through a process of calibration that seeks to match the model runoff simulations to observed hydrographs. Expert knowledge can be brought to bear implicitly, by the prior specification of parameter ranges that define the feasible parameter space. There have been various strategies proposed to find “better parameter sets” by introducing regularization, regionalization, multi–objective and multi-response calibration of hydrological models.

Although the above-mentioned strategies have demonstrated that incorporation of expert and a priori knowledge can help improve the realism of models, no systematic strategy has been presented in the literature for constraining the model parameters to be consistent with the (sometimes) patchy understanding of a modeler regarding how the real system might work. Part of the difficulty in doing this is that expert knowledge may not always consist of explicitly quantifiable relationships between physical system characteristics and model parameters; rather, it may consist of conceptual understanding about consistency relationships that must exist between various model parameter or behavioral relationships that must exist among model state variables and/or fluxes. For example, the geology of a given catchment may suggest that the catchment response during intense rainfall events is characterized by a slow responding groundwater component accompanied by fast responding Hortonian overland flow. In such a situation, any model results that imply that peak flows are composed of a strong groundwater response should be discarded or given lower importance. Such information can act as a constraint on the set of feasible model behaviors, and thus help to limit the feasible extent of the model parameter space, resulting in reduced parameter and predictive uncertainty.

Here, we present a “constraint-based” strategy for constraining the feasible parameter space of a conceptual model, based on relational constraints inferred from expert knowledge regarding plausible catchment behavior. The approach is applicable to both lumped/semi-distributed and spatially distributed catchment models. The constraints can be based on any information obtained from field observations at various scales, and be applied to the model while bringing to bear sound hydrological reasoning (rather than simple extrapolation) applied to the findings at the points scale.