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A common framework for the development and analysis of process-based hydrological models

Martyn Clark (1), Dmitri Kavetski (2), Fabrizio Fenicia (3), and Hoshin Gupta (4)

(1) NCAR Research Applications Lab, USA, (2) University of Adelaide, Australia, (3) Centre de Recherche Public - Gabriel Lippmann, Luxembourg, (4) University of Arizona, USA

Building an environmental model requires making a series of decisions regarding the appropriate representation of natural processes. While some of these decisions can already be based on well-established physical understanding, gaps in our current understanding of environmental dynamics, combined with incomplete knowledge of properties and boundary conditions of most environmental systems, make many important modeling decisions far more ambiguous. There is consequently little agreement regarding what a “correct” model structure is, especially at relatively larger spatial scales such as catchments and beyond. In current practice, faced with such a range of decisions, different modelers will generally make different modeling decisions, often on an ad hoc basis, based on their balancing of process understanding, the data available to evaluate the model, the purpose of the modeling exercise, and other considerations.

This presentation describes the application of the multiple-hypothesis methodology for developing and evaluating process-based hydrological models. Multiple-hypothesis methods provide a flexible (and extensible) approach to model development, including capabilities to 1) support multiple alternative decisions regarding process selection and representation; 2) accommodate different options for the model architecture, representing the connectivity between different model components; and 3) separate the hypothesized model equations from their solutions. Such flexibility in the selection of model architecture and components can be exploited to design various strategies for a controlled and thorough exploration of the hypothesis space, increasing the explanatory power of stringent model diagnostics that challenge both individual constituent hypotheses and the overall model architecture. Moreover, the availability of multiple modeling options improves representation of model uncertainty.

In our application of multiple hypothesis methods in hydrology we seek to provide a common framework for model development and analysis. We recognize that the majority of process-based hydrological models use the same set of physics – most models use Darcy’s Law to represent the flow of water through the soil matrix and Fourier’s Law for thermodynamics. Our numerical model uses robust solutions of the hydrology and thermodynamic governing equations as the structural core, and incorporates multiple options to represent the impact of different modeling decisions, including different methods to represent spatial variability and different parameterizations of surface fluxes and shallow groundwater. Our analysis isolates individual modeling decisions and uses orthogonal diagnostic signatures to evaluate model behavior. Application of this framework in research basins demonstrates that the combination of (1) flexibility in the numerical model and (2) comprehensive scrutiny of orthogonal signatures provides a powerful approach to identify the suitability of different modeling options and different model parameter values. We contend that this common framework has general utility, and its widespread application in both research basins and at larger spatial scales will help accelerate the development of process-based hydrologic models.