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It's the parameters, stupid! Moving beyond multi-model and multi-physics approaches to characterize and reduce predictive uncertainty in process-based hydrological models

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Multi-model and multi-physics approaches are a popular tool in environmental modelling, with many studies focusing on optimally combining output from multiple model simulations to reduce predictive errors and better characterize predictive uncertainty. However, a careful and systematic analysis of different hydrological models reveals that individual models are simply small permutations of a master modeling template, and inter-model differences are overwhelmed by uncertainty in the choice of the parameter values in the model equations. Furthermore, inter-model differences do not explicitly represent the uncertainty in modeling a given process, leading to many situations where different models provide the wrong results for the same reasons. In other cases, the available morphological data does not support the very fine spatial discretization of the landscape that typifies many modern applications of process-based models. To make the uncertainty characterization problem worse, the uncertain parameter values in process-based models are often fixed (hard-coded), and the models lack the agility necessary to represent the tremendous heterogeneity in natural systems.

This presentation summarizes results from a systematic analysis of uncertainty in process-based hydrological models, where we explicitly analyze the myriad of subjective decisions made throughout both the model development and parameter estimation process. Results show that much of the uncertainty is aleatory in nature – given a "complete" representation of dominant hydrologic processes, uncertainty in process parameterizations can be represented using an ensemble of model parameters. Epistemic uncertainty associated with process interactions and scaling behavior is still important, and these uncertainties can be represented using an ensemble of different spatial configurations. Finally, uncertainty in forcing data can be represented using ensemble methods for spatial meteorological analysis. Our systematic approach of quantifying the individual sources of uncertainty (inputs, parameters, and structure) allows us to understand how the different sources of uncertainty propagate through to the system-scale response, and avoids the impossible challenge of untangling uncertainty estimates from inverse methods. More generally, our approach helps identify critical needs for model development and improves the operational applicability of process-based hydrological models.