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Constraining a Distributed Hydrologic Model Using Process Constraints derived from a Catchment Perceptual Model

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The increased availability of spatial datasets and hydrological monitoring techniques improves the potential to apply distributed hydrologic models robustly to simulate catchment systems. However, distributed catchment modelling remains problematic for several reasons, including the miss-match between the scale of process equations and observations, and the scale at which equations (and parameters) are applied at the model grid resolution. A key problem is that when equations are solved over a distributed grid of the catchment system, models contain a considerable number of distributed parameters, and therefore degrees of freedom, that need to be constrained through calibration. Often computational limitations alone prohibit a full search of the multidimensional parameter space. However, even when possible, insufficient data results in model parameter and/or structural equifinality. Calibration approaches therefore attempt to reduce the dimensions of parameter space to constrain model behaviour, typically by fixing, lumping or relating model parameters in some way when calibrating the model to time-series of response data. An alternative approach to help reduce the space of feasible models has been applied to lumped and semi-distributed models, where additional, often semi-qualitative information is used to constrain the internal states and fluxes of the model, which in turn help to identify feasible sets of model structures and parameters. Such process constraints have not been widely applied to distributed hydrological models, despite the fact that distributed models make more predictions of distributed states and fluxes that can potentially be constrained.
This paper presents a methodology for deriving process and parameter constraints through development of a perceptual model for a given catchment system, which can then be applied in distributed model calibration and sensitivity analysis to constrain feasible parameter and model structural space. We argue that the perceptual model of a catchment – a set of perceptions codified in some lingual, pictorial, mathematical or symbolic form that represents a current state of understanding about a catchment system – should be derived independently from any modelling exercise. Such a perceptual model should be constructed hierarchically in space and time, and contain constraints on our understanding of the magnitude of stores and fluxes in the system at different scales – typically in the form of inequalities or intervals. Such information can then be applied to constrain model behaviour, depending on the mapping between process constraints and model states. We derive a perceptual model of the Plynlimon catchment (UK), and investigate the ability of different process and parameter constraints derived from the perceptual model, based on different levels of data availability, to constrain the Penn State Integrated Hydrologic Modeling System (PIHM) when applied to the catchment.