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Identifying dominant hydrological processes: development of the Hierarchical Mixture of Experts architecture

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Choosing the best model in a hydrologic modelling exercise has always been a difficult task. This difficulty can be amplified by the various uncertainties associated with the modelling process. Evidence exists of the catchment responding differently under different conditions so that relying on a single model with a rigid modelling structure can lead to significant inaccuracies and biases, particularly when used for prediction.

To form a better prediction of catchment behaviour than would be provided by a single model, a model can be approximated through the combination of a number of different model structures. Each model is adopted at a given time with a probability that depends on the current hydrologic state of the catchment. This framework is known as a Hierarchical Mixture of Experts (HME). HME models provide an improvement of simple combinations of models, by allowing the way that model predictions are combined to depend on predictor variables. Models are then combined depending on catchment conditions as summarized by the predictor variables. In this way, HME models are dynamically specified, with model structure (and complexity) depending on relevant antecedent conditions. This study builds on previous work, in which the HME architecture is introduced and applied to a range of catchments across Australia. This application illustrates that catchments may be modeled as a mix of several distinct “states”, where the catchment will respond differently depending on the current catchment conditions. The study is motivated by the fact that multiple catchment states exist and are well addressed by the HME architecture, hence there is a desire to apply the method for prediction.

The challenge in applying the HME framework to catchments for predictive purposes lies in determining how to calculate which model should be selected depending on the state of the catchment. Estimating the probability of selecting each component model is central to the effectiveness of the proposed HME framework. Estimating this probability is reliant on choosing appropriate variables to characterise the catchment state, and a mathematical function that can relate the predictor value to the dominant model. An intuitive choice for the predictors used to estimate this probability is the antecedent soil moisture state, which may be represented as the modelled surface water storage or the preceding rainfall. The choice of predictor, however, needs to be made through an elaborate comparison that considers the various mechanisms that could lead to a "switch" in the flow generation process.

In this study, the usefulness of different predictors and gating functions is investigated, the predictors including the catchment's antecedent moisture storage, incident rainfall over specified periods of time and the preceding trend of switching between models. More complex choices for the gating function involving nonlinear or nonparametric functional terms are illustrated. Our conclusions are based on selected case studies where the true model configuration was known and HME and non-HME model architectures evaluated for their predictive performances on such systems.