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Incorporating observational errors in multivariate hydrologic model calibration: the value in known unknowns

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The latest generation of integrated hydrologic models provides new opportunities to better understand and hypothesize about the connections between hydrological, ecological and energy transfer processes across a range of scales. Parallel to this has been unprecedented growth in new technologies to observe components of Earth's biophysical system through satellite remote sensing or on-the-ground instruments. However, along with growth in available data and advanced modelling platforms comes a challenge to ensure models are representative of catchment systems and are not unrealistically confident in their predictions. Many hydrologic and ecosystem variables are measured infrequently, measured with significant error, or are measured at a scale different to their representation in a model. In fact, the modelled variable of interest is frequently not directly observed but inferred from surrogate measurements. This introduces errors in model calibration that will affect whether our models are representative of the systems we seek to understand.

In recent years, Bayesian inference has emerged as a powerful tool in the environmental modeler's toolbox, providing a convenient framework in which to model parameter and observational uncertainties. The Bayesian approach is ideal for multivariate model calibration, by defining proper prior distributions that can be considered analogous to the weighting often prescribed in traditional multi-objective calibration.

In this study, we develop a multi-objective Bayesian approach to hydrologic model inference that explicitly capitalises on a priori knowledge of observational errors to improve parameter estimation and uncertainty estimation. We introduce a novel error model, which partitions observation and model residual error according to prior knowledge of the estimated uncertainty in the calibration data. We demonstrate our approach in two case studies: an ecohydrologic model where we make use of the known uncertainty in satellite retrievals of Leaf Area Index (LAI), and a water quality model using turbidity as a proxy for Total Suspended Solids (TSS). Overall, we aim to demonstrate the need to properly account for known observational errors in proper hydrologic model calibration.