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Towards improving the Pareto frontier in environmental models using multi-dataset calibrations coupled with metaheuristic methods

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Environmental models, such as hydrological models or water quality models, are incorporate numerical algorithms that describe either empirically or physical-based the large variety of natural processes that govern the flow of water (or other variables) and its components. The purposes of these models range from improving our understanding of the principles of hydrological processes at a catchment scale to making predictions about how anthropogenic activities will influence future water resources. To be applicable, these models require calibration with observed output data, which is most often streamflow for hydrological models. Yet, the complex nature of hydrological processes, on the one hand, and the limited observed data to inform model parameters, on the other hand, evoke the unavoidable equifinality issue in the calibration of these models. This equifinality issue is expressed with the presence of several optimal model parameters that have different values but lead to similar model performance. One way of dealing with this issue is through providing a parameter ensemble with optimal solutions instead of a single parameter set, reported often as parametric model uncertainty.

However, this equifinality issue is far from being solved, as also highlighted by one of 23 Unsolved Problems in Hydrology (UPH). This is particularly the case if more variables than only streamflow are of interest. Our hypothesis is that using more than one dataset for calibrating any environmental model helps reducing the equifinality issue during model calibration and thus improves the identifiability of model parameters. In this review-based study, we present recent examples of hydrological (and water quality) models from literature that have been calibrated within a multiple dataset framework to reduce the equifinality issue. We demonstrate that a multi-dataset calibration yields a better model performance regardless of the complexity of the model. Finally, we show that coupling a multi-dataset model calibration with metaheuristics (such as Monte Carlo or Genetic Algorithm) can help reducing the equifinality of model parameters and improving the Pareto frontier. At the bottom of this study, we outline how such a multi-dataset calibration can lead to better model predictions and how it can help emerging water resources problems due to an emerging climate crisis.

This work contributes to one of the seven major themes of 23 UPH, i.e., Modelling methods. It

paths a way forward towards reducing parameter uncertainty in hydrological predictions (UPH question #20) and thus towards improving modelling of hydrologic responses in the extrapolation phase, i.e., under changed catchment conditions (UPH question #19).