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When More Isn't Always Better: Lessons from Multi-Variable Calibration in Hydrology

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Abstract:

Conceptual hydrological models remain widely used in operational and research hydrology due to their relative simplicity and interpretability. Traditionally, these models are calibrated using streamflow observations alone. However, as access to multiple hydrological data sources such as evapotranspiration (ET), soil moisture, and groundwater levels has increased, there is growing interest in multi-variable calibration to better constrain parameter estimates and improve internal process representation. While this approach holds promise, it also introduces challenges, particularly regarding parameter identifiability, model structural assumptions, and the handling of dependencies between variables. These issues are further compounded when advanced machine learning-based optimization methods are used in the calibration process.

This study investigates the effectiveness and limitations of multi-variable calibration in conceptual hydrological modelling using a modified version of the Australian Water Balance Model (AWBM) (Boughton, 2004). The original AWBM, which includes three surface water stores, was simplified to a single storage bucket to reduce structural complexity and increase interpretability. Additionally, the calculation of actual evapotranspiration was modified to include a new parameter, Kc, which scales potential ET. The revised model thus includes four key parameters: BFI, K, S_max, and Kc. Two controlled experiments were conducted using synthetic data generated from fixed "true" parameter values, allowing direct comparison between known inputs and calibrated outputs.

In the first experiment, the study compared single-variable and multi-variable calibration approaches using the DREAM algorithm for parameter estimation. Two versions of multi-variable calibration were tested: one assuming independence between streamflow and ET likelihoods, and another using a multivariate normal likelihood to account for dependencies among parameters and model outputs. The aim was to assess the ability of each approach to recover the original parameters and accurately predict both streamflow and actual ET. Results showed that both approaches offered distinct advantages and disadvantages, with trade-offs in parameter accuracy and predictive performance depending on how dependencies were handled.

The second experiment explored the effect of changing the order in which precipitation and evapotranspiration fluxes are applied within the water balance calculation. Both calibration strategies were repeated under alternative model formulations and evaluated at varying time steps. The differences observed between model variants suggest that even small changes in process formulation can influence calibration outcomes, especially when evaluated across different temporal scales.

Rather than promoting a single best approach, this work presents a comparative perspective on calibration strategies to inform modelers of potential outcomes under different assumptions. The findings aim to support a more informed selection of calibration methods depending on specific modelling objectives and data availability, with an emphasis on transparency and reproducibility.

REFERENCES

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