Enhancing physically based and distributed hydrological model calibration through internal state variable constraints

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CC1 (https://doi.org/10.5194/egusphere-2024-3353-CC1):

The integration of internal hydrological state variables, particularly groundwater recharge, into model calibration is commendable and addresses key limitations in traditional hydrological modeling.

Thank you for the insightful comments and suggestions on our manuscript. We greatly appreciate the time and effort invested in reviewing our work. Below, we provide detailed responses to each of the comments and outline the corresponding revisions we propose to address them.

The chosen weights for the constrained Kling-Gupta efficiency (e.g., 70% KGE, 20% recharge standard deviation) appear somewhat arbitrary. A sensitivity analysis to justify these weights would enhance the study's robustness.

We acknowledge that the manuscript would benefit from a more detailed explanation of how the weights for the constrained Kling-Gupta efficiency were chosen. These values were determined through a trial-and-error approach, with the primary objective of integrating recharge in a realistic way to develop and demonstrate this novel methodology. Specifically, assigning 20% to the standard deviation of recharge and 10% to the mean recharge provided a balanced trade-off, ensuring recharge values remained realistic while maintaining acceptable KGE scores. For calibration, a weight of 4% on the recharge standard deviation was sufficient to preserve adequate recharge estimates while achieving strong KGE values.

While it is true that alternative hyperparameter values, as well as other objective functions, could have been tested, this would not have changed the core purpose of the study: to demonstrate that including a constraint on a physical process (in this case, recharge) can improve the representation of other processes. A comprehensive sensitivity analysis of these weights or objective functions is beyond the scope of this study but could be explored further in future research.

While the paper briefly mentions equifinality, a more in-depth exploration of how incorporating internal state variables addresses this challenge would strengthen the theoretical contribution.

The study is fundamentally centered on addressing equifinality by incorporating internal state variables, but we understand the need to clarify this point further. To ensure that readers fully grasp how this approach mitigates equifinality, we propose adding a clearer explanation in the introduction and discussion sections of the manuscript.

The high computational demands of the GW-RC configuration are not discussed in detail. Including a section on computational trade-offs would provide valuable insights for practitioners.

We recognize the importance of discussing the computational trade-offs associated with each configuration of the WaSiM model. As stated in response to RC2, to address this, we have enhanced Table 5 to include the computational demand for each configuration, expressed in CPU-years. This addition provides a clearer understanding of the resource requirements and allows practitioners to assess the trade-offs between model complexity and computational cost.

Data assimilation is a powerful technique widely used to integrate observations into hydrological models, improving predictions by dynamically updating model states. In this study, the authors propose an innovative calibration approach focusing on internal state variables, which aligns well with the goals of improved process representation. However, the absence of a discussion or application of data assimilation leaves an unexplored opportunity to further enhance the model's performance. then I strongly suggest to cite below papers:

"assimilation of Sentinel-based leaf area index for surface-groundwater interaction modeling in irrigation districts"

'Multivariate Assimilation of Satellite-based Leaf Area Index and Ground-based River Streamflow for Hydrological Modeling of Irrigated Watersheds using SWAT+'

This is an interesting suggestion. However, data assimilation is typically used to dynamically update model states based on real-time observations, which is not directly applicable in our study since we are developing a model for climate change impact assessment where no future observations exist. Our approach focuses on improving process representation through calibration using internal state variables, ensuring that the model remains physically consistent under different climatic conditions.

Nonetheless, we recognize the relevance of data assimilation in other hydrological modeling contexts and will consider referencing the suggested studies to acknowledge its potential applications in related fields.

Thank you once again for your constructive review.

Sincerely,

Frédéric Talbot on behalf of all authors