Performance assessment and benchmarking of a conceptually coupled groundwater - surface-water model

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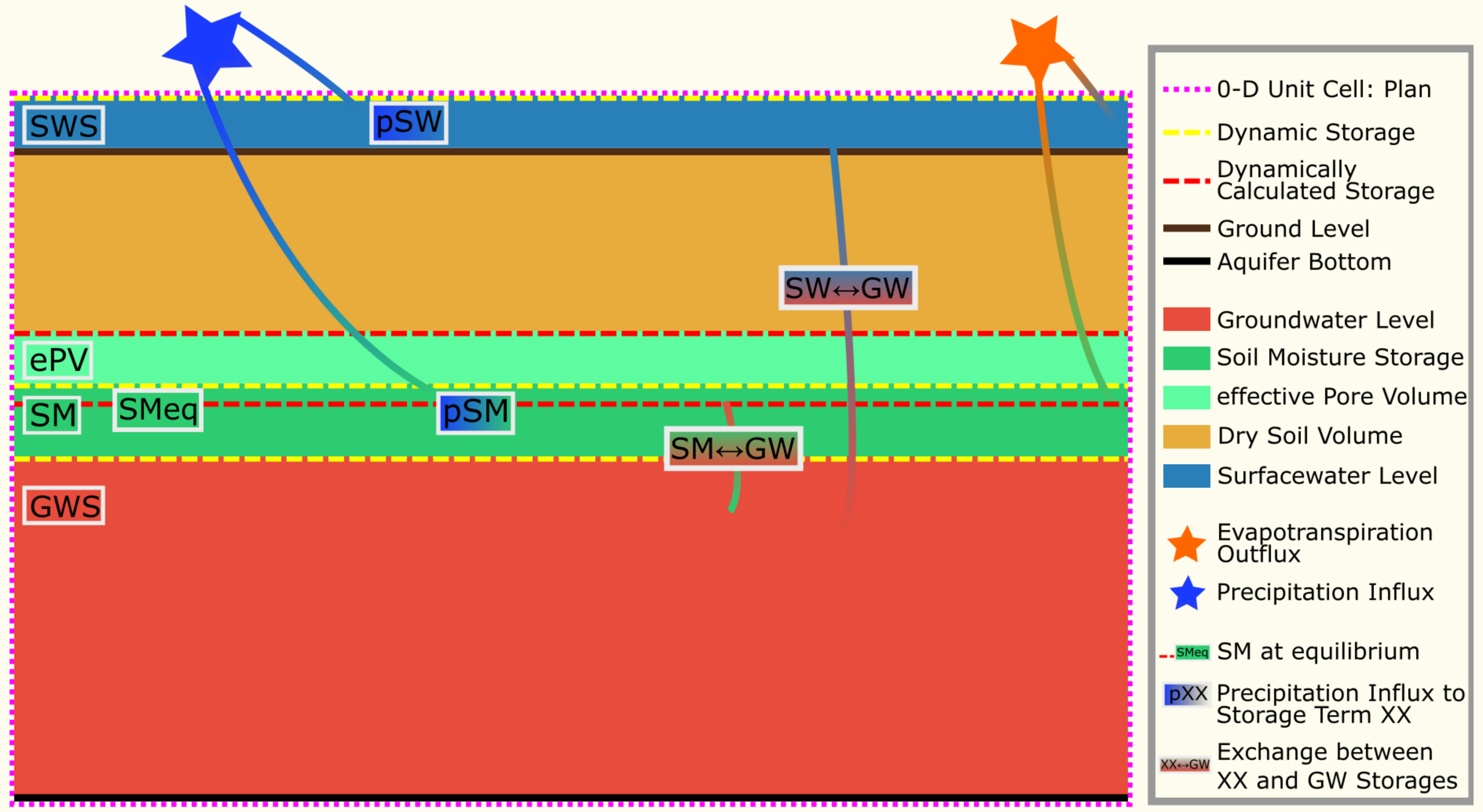
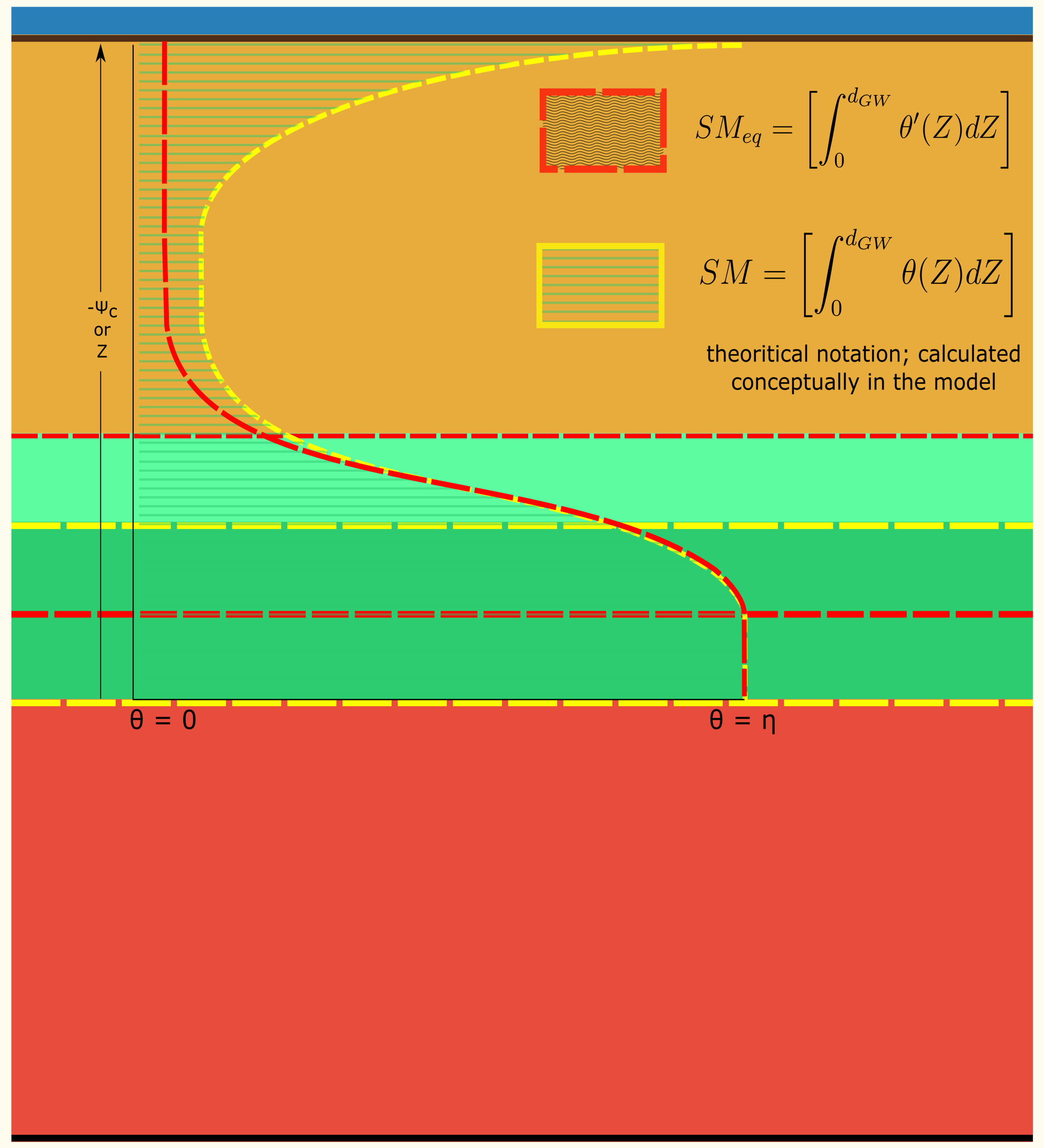
GWSWEX: the Conceptual Unsaturated Zone (UZ) Model



The GWSWEX Model is a set of manipulative equations applied on spatially agnostic compartmentalised storages that are illustrated in the figure above, that aim to quantify the in- and out- fluxes of the UZ, in order to couple groundwater (GW) and surface-water (SW) models in a modular manner while also reducing the computational expense of running an integrated hydrological model drastically.



The adjacent figure illustrates the model physics concisely, in addition to the following equations:

$$lim(t \to \infty)SM(t) = SM_{eq}$$

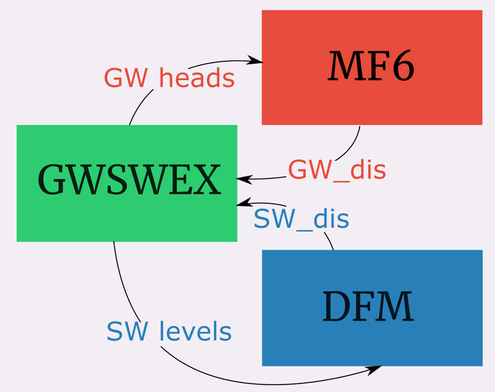
$$lim(t \to \infty)GW(t) = min((SM - SM_{eq})IC_r, k_{us}IC_r)$$

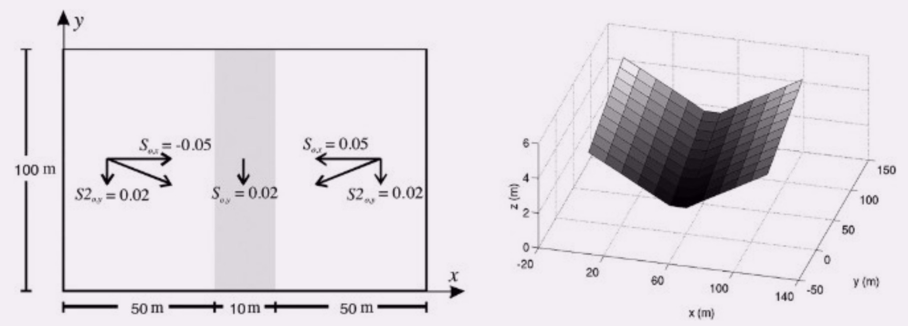
Where IC_r is the interconnectivity ratio that is essentially a counter that tracks the progression of the infiltration front and k_{us} is unsaturated hydraulic conductivity calculated using the Van Genuchten - Mualem model.

Benchmarking and Performance Assessment

To benchmark the model and analyze its performance, tests are being carried out by subjecting the coupling scheme to benchmarking tests. The results from Scenario 1 from the Tilted-V catchment case outlined in Kollet et al., 2016 is presented here. This particular case was chosen as it is a challenging, for a conceptual model nonetheless, to modell the intricate fluxes of the return flow in the formulation. The benchmarking problem, however, was not applied as-is. Due to challenges in setting the overlang flow boundary conditions as described, the boundary was left undefined. The GWSWEX model was coupled with the Delft3D-Flexible Mesh (DFM) model (Deltares, 2023) and MODFLOW 6 (MF6) with a coupling scheme as illustrated below.

In the 120h simulation period, the models exchanged information every 120s, and this was performed via the Basic Model Interface (Eric W.H. Hutton et al., 2020) and the model run-time was 245s on a desktop PC running on AMD Ryzen 7 3700X.





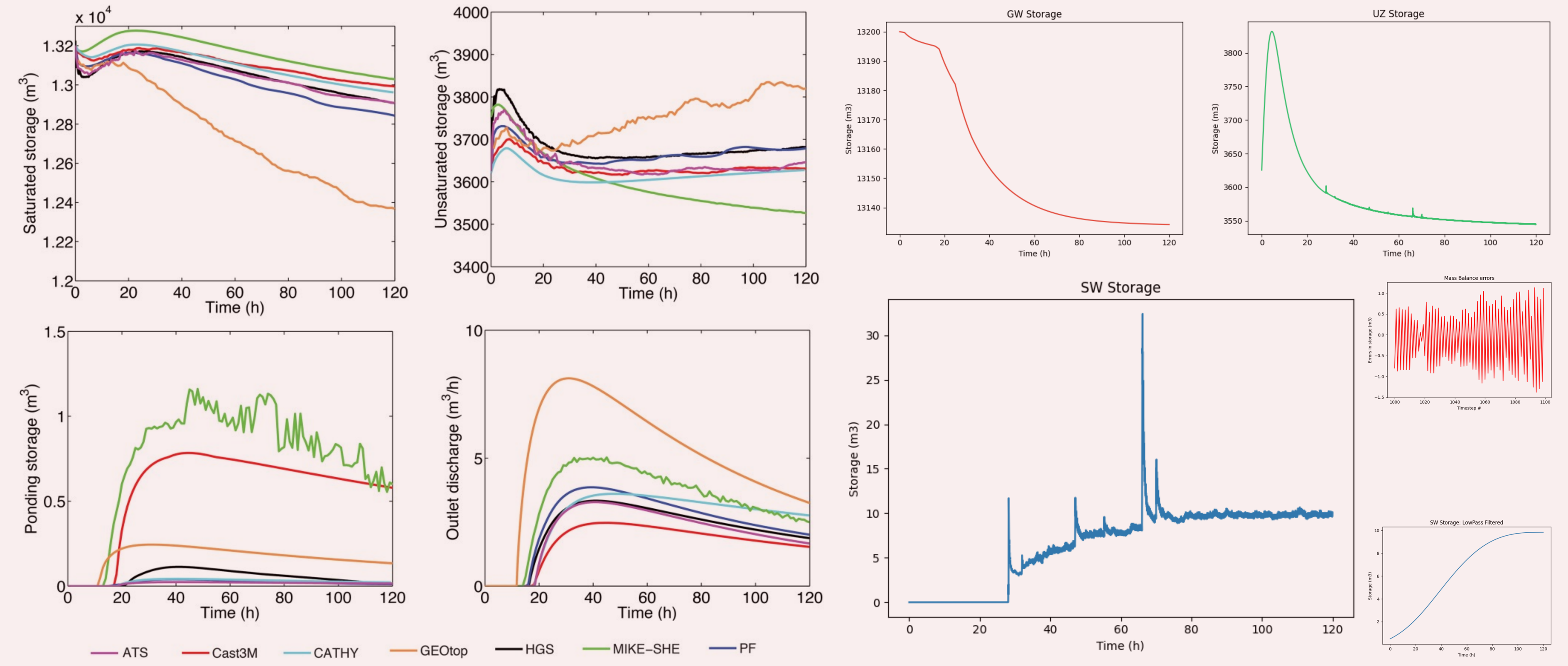
The adjacent figure illustrates the Tilted-V catchment set-up topology as defined in Kollet et al., 2016. Refer the publication for further info.

At the start of each timestep, GWSWEX recieves precipitation and evapotranspiration fluxes (absent in this case) and translates it into overlandflow and infiltration which can then be prescribed as discharges to the respective models. This calculation is performed for each model element in the model domain. After the GW and SW models are solved for that timestep, the GW heads and SW levels are returned to GWSWEX and this continues iteratively. The adjacent section discussed the drawbacks of such a loose coupling method and explores potential solutions. The GWSWEX model has been written in FORTRAN with OpenMP support for computational efficiency, but provides a python wrapper for ease-of use. Acknowlidging the need to model inhomogeneous UZ conditions, a multi-layered variant of the model is currently under developement.

Kollet et al., 2016 | github: GWSWEX/tilted-v | github: GWSWEX

Follow the github repository for developements and access to the code.

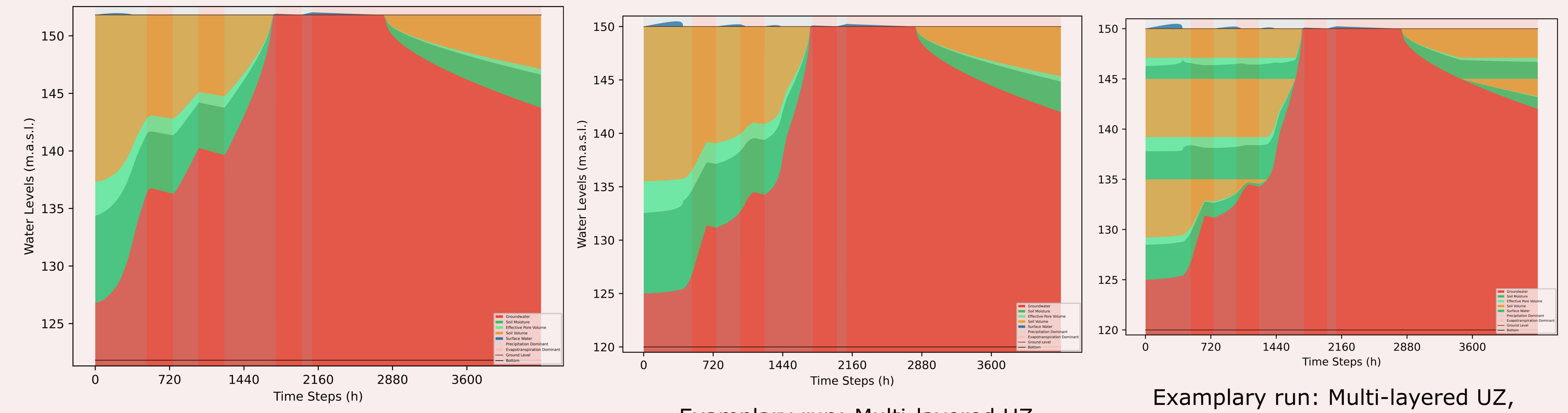
Results and Discussion



The primary disagreement in the results may be attributed to the lack of the overland flow boundary definition, thus causing persistant pounding at the outlet of the deeper end of the channel. This, in turn, results in a lower volume of GW storage being drained out. The agreement in the state of UZ storage supports this conclusion.

Apart from the aforementioned disagreement, the model itself suffers from poor mass balance with about 20% of the mass not being conserved between the storages. Here, we would like to draw your attention to the figure illustrating the SW storage and the figure illustrating the mass balance errors. The regression of rapidly generated peaks after a few time-steps and the oscillations indicate that a more robust coupling scheme is necessary to ensure convergence between the model states.

Furthermore, the GWSWEX model progresses each timestep without any information about lateral fluxes. Iteratively solving all the three models until convergence is reaches could solve this too. This is currently being investigated. Additionally, the model physics is being expanded to ba applicatble for multiple UZ layers - either with varying properties or virtual layers to simulate vertical discretization of the UZ layer in the solver, thus adding complexity to the model. The following illustrations show the difference in complexity between single and multi-layered UZ models.



Examplary run: Single-layered UZ | Examplary run: Multi-layered UZ, aggregated storage representation | Examplary run: Multi-layered UZ, individual storage representation