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Dual States Estimation of a Subsurface Flow-Transport Coupled Model using Ensemble Kalman Filtering

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Modeling the spread of subsurface contaminants requires coupling a groundwater flow model with a contaminant transport model. Such coupling may provide accurate estimates of future subsurface hydrologic states if essential flow and contaminant data are assimilated in the model. Assuming perfect flow, an ensemble Kalman filter (EnKF) can be used for direct data assimilation into the transport model. This is, however, a crude assumption as flow models can be subject to many sources of uncertainty. If the flow is not accurately simulated, contaminant predictions will likely be inaccurate even after successive Kalman updates of the contaminant model with the data. The problem is better handled when both flow and contaminant states are concurrently estimated using the traditional joint state augmentation approach.

In this study, we introduce a dual estimation strategy for data assimilation into a one-way coupled system by treating the flow and the contaminant models separately while intertwining a pair of distinct EnKFs, one for each model. The presented strategy only deals with the estimation of state variables but it can also be used for state and parameter estimation problems. This EnKF-based dual state-state estimation procedure presents a number of novel features: (i) it allows for simultaneous estimation of both flow and contaminant states in parallel; (ii) it provides a time consistent sequential updating scheme between the two models (first flow, then transport); (iii) it simplifies the implementation of the filtering system; and (iv) it yields more stable and accurate solutions than does the standard joint approach.

We conduct synthetic experiments based on various time stepping and observation strategies to evaluate the dual EnKF approach and compare its performance with the joint state augmentation approach. Experimental results show that on average, the dual strategy could reduce the estimation error of the coupled states by 15% compared with the joint approach. Furthermore, the dual estimation is proven to be very effective computationally, recovering accurate estimates at a reasonable cost.