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

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Modeling subsurface contaminant spreading requires coupling a groundwater flow model with a contaminant transport model. This coupling may provide accurate future estimates of the subsurface hydrologic state if assisted with essential flow and contaminant data through data assimilation. Assuming perfect flow, an ensemble Kalman filter (EnKF) can be directly used for data assimilation into the transport model. This is, however, a crude assumption as flow models can be subject to many sources of uncertainties. If the flow is not accurately simulated, contaminant predictions will likely be inaccurate even after successive Kalman updates of the contaminant with the data. The problem is usually 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 this one-way coupled system by treating the flow and the contaminant models separately while intertwining a pair of distinct EnKFs, one on each model.

This EnKF-based dual states estimation suggests a number of novel features: (1) it allows for simultaneous estimation of both flow and contaminant states in parallel, (2) it provides a time consistent sequential updating scheme between the two models (first flow, then transport), (3) it simplifies the implementation of the filtering system, and (4) yields more stable and accurate solutions than the standard joint approach. Synthetic numerical experiments are carried based on various time stepping and observation strategies to evaluate the dual approach and compare its performance with the joint state augmentation approach. Experimental results show that under uncertain modeling conditions, the dual strategy could reduce the estimation error of the coupled states, on the average, 15% more than the joint approach. Furthermore, computationally the dual estimation is proven to be very effective, recovering accurate estimates at a reasonable cost.