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A comparison of Ensemble Kalman Filtering and Monte-Carlo type transient inverse modeling for mildly to strongly heterogeneous formations

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Data assimilation is of interest for the real-time modelling of dynamic groundwater systems as often measurement data are available in real-time, and management decisions might be optimized using the information from real-time models. It can also be used for the off-line calibration of transient groundwater flow models. The Ensemble Kalman filter approach is used here to update states together with internal parameters (transmissivities), by adopting an augmented state vector approach. If both states and parameters are updated, the updating is performed in two steps in order to reduce problems associated with non-linearities. The propagation of individual members by the EnKF is optimal for normally distributed state variables and linear dynamics, and expected to give worse results for non-normally distributed state variables and non-linear dynamics, as compared with an inverse algorithm that is not restricted to linear dynamics. However, the ensemble approach adopted in EnKF makes its performance more robust against deviations from normality and non-linear dynamics. The performance of EnKF is investigated in a synthetic study with a 2D transient groundwater flow model, where water is pumped from three wells and recharge rate is variable in space and time, and where (1) only transmissivity is spatially variable with σ^2_{lnT}=1.0 or (2) σ^2_{lnT}=2.7. The results were compared with transient inverse modeling by the sequential self-calibration method (SSC). For the moderately heterogeneous case (σ^2_{lnT}=1.0), EnKF gave for all comparison measures very similar results to SSC, but needed only 1 hour of CPU time (Linux PC) to generate 100 stochastic realizations, conditioned to two years of time series of hydraulic head data, whereas SSC needed two weeks.

For the strongly heterogeneous case (σ^2_{lnT}=2.7) results in terms of hydraulic head estimates, hydraulic head variances and transmissivity variances were similar, but SSC yielded significantly better estimates of logtransmissivity. Nevertheless, also EnKF was able to improve the characterization of the strongly heterogeneous transmissivity fields considerably. The calibrated logtransmissivity fields obtained with the two methods, and both for the moderately and strongly heterogeneous case, were independently tested for two different cases: (1) for two years with different time series of spatially variable recharge, and (2) for solute transport. Results were in correspondence with the conclusions mentioned before.