

# Abstract

Ensemble kalman filter (EnKF) has proven to be a powerful inverse method for the characterization of hydraulic conductivities, which works well for non-linear state equation and Gaussian-distributed parameters. It is computationally more efficient than other inverse methods; however, it is still time-consuming. This thesis addresses two issues, how to speed up the EnKF through code parallelization and how to properly address the problem of characterizing non-Gaussian hydraulic conductivity fields. It is organized in four parts.

The first part deals with the the parallelization of the ensemble Kalman filter (EnKF) algorithm in the context of hydraulic conductivity characterization using transient piezometric head data. The EnKF consists of two steps, forecast and analysis, and both steps have potential to be parallelized. In the forecast step, due to the Monte Carlo nature of the EnKF, the most straightforward way for parallelization is at the realization level, where each member of the ensemble is sent to a different processor. While in the analysis step, the computations of the covariances are distributed between the different processors. The results of speedup and efficiency show that the parallelized EnKF can significantly reduce the computation time, especially for a large number of ensemble realizations.

The second part describes an application of the localized normal-score EnKF with covariance inflation in a heterogenous bimodal hydraulic conductivity field. The objective is to demonstrate the power of transient piezometric head for the characterization of the spatial variability of a channelized bimodal hydraulic conductivity field, where the only existing prior information about conductivity is its univariate marginal distribution. Besides, covariance localization and covariance inflation are used to overcome the appearance of spurious correlations and the underestimation of the final uncertainty by the NS-EnKF. Covariance localization eliminates the effect of spurious correlations between state variables and parameters by constraining the correlation range of the empirical covariance. Covariance inflation is a technique used to avoid filter inbreeding by inflating the empirical covariance. The results show the importance of covariance localization and covariance inflation to reduce filter inbreeding.

The third part investigates the inverse method proposed by (Hu et al., 2013) and proposes an improved version. Unlike the idea of (Hu et al., 2013),

which uses the EnKF to directly update uncorrelated uniform random fields (those used to draw from the local conditional marginal distributions in sequential simulation), the new version propose working on correlated uniform random fields, more precisely the same uniform random field used in probability field simulation (Froidevaux, 1993). The comparison of both versions shows that the new proposed one is much better than the original in order to capture the main patterns of conductivity and in reducing uncertainty.

The fourth and last part proposes a new stochastic inverse method named inverse sequential simulation (iSS). The iSS is a breed of sequential simulation and the normal-score ensemble Kalman filter. The new approach applies the ensemble concept to generate realizations by sequential simulation using the experimental non-stationary cross-covariance between conductivities and piezometric heads computed on an ensemble of realizations. We use the normal-score transformation to ensure marginal Gaussian distribution. And then, we apply standard multivariate sequential Gaussian conditional simulation to generate conductivity realizations conditioned to both conductivity and piezometric data. The benchmark against the NS-EnKF shows that the iSS is capable of generating inverse-conditioned non-Gaussian realizations with similar quality for both approaches.