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Continuous Updating of Groundwater Flow Models Using Ensemble Kalman Filter

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A complete characterization of geologic formations is impractical because of spatial heterogeneity. As a result, most groundwater modelers resort to certain parameterization techniques to reduce the degrees of freedom in a distributed model parameter such as hydraulic conductivity. The zonation method, in which a spatially variable function is approximated with a piece-wise constant function, is a widely-adopted parameterization technique in practice. Groundwater models are initially calibrated with existing measurements after they are parameterized. The calibrated models can still be subject to varying degrees of uncertainty because of data limitations. The purpose of this paper is to introduce a sequential data assimilation technique [i.e., the ensemble Kalman filter (EnKF)] for continuously updating the structure and values of hydraulic conductivity zonation in a groundwater flow model based on newly available data. Our work is partly motivated by the growing popularity of environmental and ecological monitoring networks that can provide observation data continuously. The Nye County Early Warning Drilling program borehole network is one example in which new measurements are acquired periodically.

Similar to the traditional Kalman filter, EnKF involves a forecast step in which the model is run forward in time, and an assimilation step in which model states are updated to honor new observations. In contrast to the Kalman filter, EnKF is a Monte-Carlo based method in which an ensemble of model states is generated and kept up-to-date through data assimilation. In EnKF, the model state error covariance is approximated by ensemble statistics. The advantage of such a methodology is that the computational cost is dramatically reduced because a rather limited number of model states is usually sufficient for statistical convergence. This computational efficiency implies that EnKF can be applied to large-scale and non-linear problems. EnKF previously has been applied to oceanography, meteorology, and petroleum reservoir characterization. In this work, Voronoi polyhedra are used to approximate the shape of conductivity zones. The centers of Voronoi polyhedra and the zone conductivity values are part of the state variables that are updated continuously. We have found through synthetic examples that EnKF is a viable technique for simultaneously identifying the true zonation pattern and values of hydraulic conductivity. We are currently investigating the feasibility of applying EnKF to the site-scale Yucca Mountain MODFLOW model.