High-resolution Geostatistical Inversion of the Transient Richards Equation

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Abstract: The vadose zone and the complex physical processes in it play a vital role in our understanding of the environment. The production of most food is directly or indirectly linked to the growth of organic matter sustained by subsurface flow. For a reliable assessment of the influence of natural and anthropogenic changes to such a coupled system detailed knowledge about the flow patterns and dynamics is important, but the high spatial variability of subsurface hydraulic parameters makes reliable predictions about flow patterns difficult. Direct measurement of these properties is not possible, making indirect observations through dependent quantities and parameter estimation a necessity.

The geostatistical approach characterizes these hydraulic parameters without predetermined zonation. The parameter fields are treated as stochastic processes, optionally incorporating a priori information in the probability distribution. Maximizing the likelihood of the parameters with regard to the given observations yields a parameter estimate with high spatial resolution.

This approach naturally leads to nonlinear least squares optimization problems that may theoretically be solved using standard techniques. However, the accurate numerical representation of the Richards equation neccesitates high spatio-temporal resolution and therefore a large number of parameters, while time series of observed physical quantities typically lead to many data points to invert. This high dimensionality in both the parameter and observation space makes standard techniques unfeasible.

We present an extension of one of these existing inversion methods, developed for stationary flow in confined aquifers, to instationary flow regimes in partially saturated porous media. Our approach uses a Conjugate Gradients scheme preconditioned with the prior covariance matrix to avoid both multiplications with its inverse and the explicit assembly of the sensitivity matrix. Instead, one combined adjoint model run is used for all observations at once. As the computing time of our approach is largely independent of the number of measurements used for inversion, the presented method can be applied to large data sets.

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