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Estimating Aquifer Parameters Using the Ensemble Kalman Filter Applied to Tomographic Hydraulic and Tracer Experiments

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The performance of groundwater flow and solute transport models depends to a large extent on the resolution at which aquifer heterogeneity is resolved. To estimate aquifer parameters at a high resolution, a large amount of data is needed. However, data availability is often limited by experimental costs and technical complexities. The evolution of modern measurement techniques has fostered the development of field tests with tomographic layout, allowing the aquifer to be stressed in different directions. While hydraulic tomography with multi-level pumping tests has repeatedly been applied at the field scale, tracer tomography with multiple multi-level tracer tests lag mainly due to technical limitations. We developed an experimental method to perform solute-tracer tomography at the field scale. In contrast to the few reported applications of tracer tomography, in which heat was used as a tracer, the experimental setup developed in this work was designed to use fluorescein as a conservative tracer. We applied the method in the shallow alluvial aquifer at the Hydrogeological Research Site Lauswiesen in Southern Germany to collect hydraulic- and tracer-tomographic data sets. To estimate the spatially distributed hydraulic conductivity of the aquifer, we analyzed the collected data set with the ensemble Kalman filter, coupled to a three-dimensional groundwater flow and solute transport model. The efficiency of the filter allows describing aquifer heterogeneity at a high resolution while keeping reasonable computational costs. We tested the filter in a synthetic study and used the filter settings with the best performance in the estimation of aquifer parameters from the real field data. The synthetic study showed that applying the ensemble Kalman filter to combined data from both hydraulic and tracer tomographic experiments considerably reduces uncertainty and improves predictions of flow and solute transport models. The estimated parameter fields retrieved some fine-scale details of the reference field. Inversion results based on real hydraulic and concentration data agreed with earlier descriptions of the aquifer at the site. Transport simulations were, however, affected by numerical dispersion. Also we did not consider as porosity and dispersivity as spatial fields, thus estimating only effective uniform values. To reduce numerical dispersion, efficient methods to optimize the grid resolution while reducing matrix dimensions would be required. This study narrows the gap between numerical studies and field applications for high-resolution aquifer characterization, showing the potential of combining the ensemble Kalman filter with data collected from hydraulic and solute tracer tomographic experiments.