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Permeability Estimation from Tracer Circulation Tests using the Ensemble Kalman Filter - the Soultz-sous-Forêts case

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Information on the distribution of permeability at depth is of primary concern in geothermal reservoir engineering. As part of the joint MeProRisk project various inversion methods have been adopted to infer the 3D permeability distribution. Here we present the results using an Ensemble Kalman filtering (EnKF) technique applied to observations of chemical tracer circulation tests. Firstly we studied a purely synthetic test case with different numbers of production wells to investigate the performance of the method. Secondly we applied the method to the 2005 tracer circulation test performed between the injection borehole GPK3 and the two production boreholes GPK2 and GPK4 at the European Enhanced Geothermal System (EGS) test site at Soultz-sous-Forêts, France. This experiment showed that GPK2 and GPK3 are well connected, presumably by a pre-existing natural fault system, which is missed by GPK4.

In our study the geothermal system is modelled by the code Shemat_suite which solves the coupled transient equations for groundwater flow, heat transport, and transport of chemical tracers in a porous rock matrix. These equations are expressed in a finite volume notation for rectangular grids and solved with a Picard iteration method for transient problems. The injection and production of fluid in the drill holes are implemented by an equivalent volume source. However, a well model taking into account the near-well behaviour of the flow is currently being tested.

The Kalman Filter is essentially a sequential assimilation procedure which compares observation to observation predicted by a numerical simulator and adjusts system variables of the simulator according to the error statistic assuming Gaussian error distribution. For the EnKF the error statistic is obtained from the mean and variance of a number of realisations. We use the concentration of the chemical tracer with time at the production wells as observation data and the permeability distribution as the system variable to be adjusted. During the sequential assimilation the information obtained at the single wells is propagated in the numerical simulation by the dynamic of the system.

For the synthetic test case we assume a pumping experiment and well spacing according to the conditions at Soultz. The permeability field is estimated in an ellipsoidal area containing the three wells. We use the synthetic case to investigate various filter parameters (damping, system noise, data noise) and their effect on the permeability estimate and resolution. We also assume a variable number of passive observation points additionally to the three active well points to study the spatial resolution of the filter procedure.

With information of only two production wells as for the Soultz case no detail spatial information is possible. However, with the EnKF assimilation a permeability field is obtained which can fit the chemical tracer concentration at GPK3 very well. It is not able to predict the behaviour of the tracer concentration at GPK4 correctly, though the values are in the observed range. The permeability in most of the reservoir is on the order of 10^{-15} m^2, between GPK2 and GPK3 a good connection exists with a mean permeability on the order of 10^{-13} m^2, while a barrier exists to GPK4.