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Reservoir-scale transdimensional fracture network inversion

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Aquifer systems in fractured rocks are dominated by the geometry of the discrete features, as they provide the main pathways for flow and transport. Characterization of these systems are challenging, due to their high level of heterogeneity. Existing modelling approaches often average over the fractures approximating the aquifer with equivalent porous media. This approximation, however, eliminates the possibility of localizing dominant discrete aquifer features, the main hydraulically active fractures that plays a key role in transport processes.

A more realistic approach would be the use of discrete fracture networks (DFNs). DFN models are realistic representations of the fractured media, where the flow and transport is restricted into the fractures. For the use of DFN models, however, the number of fractures (the number of model parameters) has to be set at the start of the inversion, although in real cases this number is unknown. We resolve this problem by using a transdimensional inversion methodology that varies the number of parameters during the inversion process. Transdimensional inversion of DFN models has been successfully used to interpret tomographic experiments in hydrogeology. In such data-rich examples, this methodology was able to identify the dominant structures and the main transport trajectories of fractured aquifers.

In this research we apply a similar inversion method to characterize a geothermal reservoir at the Waiwera site, New Zealand. The Waiwera geothermal reservoir is a shallow hydrothermal system formed by the mixing of fresh, geothermal and marine water. The flow system is governed by the tilted and stratified sandstone, which is intersected by two high inclination fault zones. This complex system forms a steady-state temperature anomaly, with a non-symmetric shape. The site is an ideal subject to test new inversion methodologies, as it is well studied, and a large amount of information is available. Existing models mainly used the continuity approach to represent the aquifer, neglecting the effect of local discrete features, faults and discontinuities.

In contrast to the tomography applications, this study only uses steady-state borehole temperature profiles – with significantly less data. This is mitigated by using the available geological information to constrain the DFN geometry, mainly by fixing the location of the known faults at the site. We use the reversible-jump Markov Chain Monte Carlo (rjMCMC), which is well-established and widely used for transdimensional inversion. rjMCMC is an iterative algorithm that allows one to introduce or to remove model parameters during the inversion process. We use the transdimensional DFN inversion to provide a better fit to the measured borehole temperature profiles than previous models were able to, and to reveal the discrete aquifer features (faults and layers) that play a key role in forming the shape of the observed temperature anomaly.