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Significance of temperature anomalies in heterogeneous media

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Fractured aquifers are characterized by a strong heterogeneity at multiple scales. However, flow generally takes place in a limited number of dominant fracture zones which control the transfer of fluids and solutes in the subsurface. Detection of these flowpaths, quantification of their hydraulic properties as well as their connectivity are thus major challenges. Since flow heterogeneity perturbs the natural geothermal gradient, temperature anomalies can be used to detect flowing fractures. Furthermore, we demonstrate here that temperature gradient anomalies can be inverted to estimate ambient vertical borehole flows, which are due to difference in hydraulic heads between fractures. Applying this method under single- and cross-borehole pumping conditions we show that borehole temperature anomalies can be used to estimate fracture hydraulic properties and connectivity.
Based on this finding, we propose a new temperature tomography approach, in which temperature profiles are measured under combinations of pumping conditions by changing successively pumping and observation boreholes. We develop an inverse model framework for the joint inversion of the temperature tomography data set. We tested this method on the Ploemeur fractured rock site, where three 100-meters depth well were successively pumped and logged for temperature profiles. From this data set we discuss the potential of the temperature tomography approach to reduce the non-uniqueness of the inverse problem for quantifying fracture transmissivities and connectivity.