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Thermal tracer tomography: from numerical simulation to field implementation

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Choosing heat for subsurface investigations is attractive because changes in temperature can be easily measured, and natural variations are typically slower than the timescale of the experiments. The tomographical setup expands the applicability of such tests to reconstruct the spatial distribution of hydraulic aquifer properties. A new inversion methodology is presented for thermal tracer tomography, using tracer travel times to invert the hydraulic conductivity distribution of the aquifer.
If we can assume that heat transport is driven by advection, the travel time of the thermal tracer can be related to the hydraulic parameters of the aquifer. With this assumption other thermal effects such as thermal diffusion or density driven flow appear as noise in the results. To reduce these effects the early time diagnostics of the recorded breakthrough curves are used, focusing on the fastest transport routes between the sources and receivers. The inverse problem of the experiment thus can be formulated as a classical travel time problem, and it can be solved using standard eikonal solver algorithms known from seismic or hydraulic tomography.
The method is demonstrated with a high resolution 3-D aquifer analog dataset. The generated 3-D reconstruction reveals the potential of the method, especially in finding the preferential flow paths within the aquifer. Aside from this, the developed method is computationally efficient and can provide results in a fragment of the time required for full-physics model calibration. The method is also tested under field conditions. Four heat tracer injections were performed during a three day field campaign at the Widen field site in northeast Switzerland. Pulse signals were used and the temperature evolution was measured downstream using a distributed measurement system. The preliminary results of the tomographic inversion correspond well with the findings of earlier studies from the field site imaging the same geological features as hydraulic, transport and geophysical investigations.