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Joint inversion of crosshole GPR and temporal moments of tracer data for improved estimation of hydraulic conductivity at the aquifer scale

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Geophysical methods are widely used for aquifer characterization, but they usually fail to directly provide models of hydraulic conductivity. Here, a method is presented to jointly invert crosshole ground-penetrating radar (GPR) travel times and hydrological data to estimate the 2-D distribution of both GPR velocities and hydraulic conductivities. The hydrological data are the first temporal moments of tracer breakthrough curves measured at different depths (i.e. the mean arrival times of the tracer at the given locations). Structural resemblance between the geophysical and the hydrological model is enforced by strongly penalizing models for which the cross products of the model gradients are non-zero. The proposed method was first tested on a synthetic categorical facies model. The high resolution of the GPR velocity model markedly improves the hydraulic conductivity model by adding small-scale structures that remain unresolved by the individual inversion of the hydrological data. The method was then applied to field data acquired within a gravel aquifer located close to the Thur River, northeastern Switzerland. The hydrological data used were derived from transfer functions obtained by deconvolving groundwater electrical conductivity time series with electrical conductivity variations of the river water. These data were recorded over several years at three depth levels in three boreholes aligned along the main groundwater flow direction. The transfer functions are interpreted as breakthrough curves of a pulse injection in the river from which we retrieve the first temporal moments. These data were complemented with crosshole GPR data acquired between the three boreholes. Both the individual and joint inversion models provide a smooth hydraulic conductivity model that retrieves the same general trend as EM flowmeter data, but does not resolve small-scale variability.