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Using a coupled hydro-mechanical fault model to better understand the risk of induced seismicity in deep geothermal projects

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The changes of fluid pressures related to the injection of fluids into the deep underground, for example during geothermal energy production, can potentially reactivate faults and thus cause induced seismic events. Therefore, an important aspect in the planning and operation of such projects, in particular in densely populated regions such as the Upper Rhine Graben in Germany, is the estimation and mitigation of the induced seismic risk.

The occurrence of induced seismicity depends on a combination of hydraulic properties of the underground, mechanical and geometric parameters of the fault, and the fluid injection regime. In this study we are therefore employing a numerical model to investigate the impact of fluid pressure changes on the dynamics of the faults and the resulting seismicity. The approach combines a model of the fluid flow around a geothermal well based on a 3D finite difference discretisation of the Darcy-equation with a 2D block-slider model of a fault. The models are coupled so that the evolving pore pressure at the relevant locations of the hydraulic model is taken into account in the calculation of the stick-slip dynamics of the fault model.

Our modelling approach uses two subsequent modelling steps. Initially, the fault model is run by applying a fixed deformation rate for a given duration and without the influence of the hydraulic model in order to generate the background event statistics. Initial tests have shown that the response of the fault to hydraulic loading depends on the timing of the fluid injection relative to the seismic cycle of the fault. Therefore, multiple snapshots of the fault's stress- and displacement state are generated from the fault model. In a second step, these snapshots are then used as initial conditions in a set of coupled hydro-mechanical model runs including the effects of the fluid injection. This set of models is then compared with the background event statistics to evaluate the change in the probability of seismic events.

The event data such as location, magnitude, and source characteristics can be used as input for numerical wave propagation models. This allows the translation of seismic event statistics generated by the model into ground shaking probabilities.