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Shape optimization methods locating layer interfaces in geothermal reservoirs

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Subsurface structures have a strong influence on fluid flow and heat transport in geothermal systems. We examine whether the position of an interface between two units within a geothermal system with different petrophysical properties can be detected based on measured temperature-depth profiles.

We use a shape optimization method for a level set function and combine it with the calculation of an adjoint variable on basis of the heat transport equation. The level set follows a Hamilton-Jacobi equation where the zero level set represents the position of the boundary. Starting from an initial guess, the position is iteratively adjusted during model optimization. Instead of directly computing the gradient of an objective function, we compute an adjoint temperature. The method is very efficient and requires only one forward simulation. The adjoint variable is then used in combination with the simulated temperature field to iteratively update the level set function to a new position until a shape convergence is obtained.

The method was tested to determine the interface position in a set of two-layer models with differently shaped interfaces. Specifically, we investigated how advective heat transport affects the identification of the boundary. We generated synthetic observation data of temperatures in two boreholes in the model and used this data for shape optimization. First results are encouraging as we could identify the location of simple interfaces. Furthermore, our simulations suggest that advective heat transport often helps to detect the interface better. However, challenges remain, particularly if the shape of the interface becomes too complex or the dip of a layer is very steep. Currently, we are investigating these issues in more detail, for example addressing questions of number and position of boreholes with temperature measurements required for optimal interface identification.