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Using strain tensor measurements to locate and characterize subsurface heterogeneities

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In order to better assess and monitor complex geomechanical systems, we have developed a parallelized stochastic optimization framework capable of characterizing the geometry and physical parameters of geologic structures in the subsurface. Using pumping operations to stress the poroelastic medium, we are able to observe the geomechanical response using borehole strainmeters in concert with pressure transducers, extensometers, and tiltmeters.

Given a specified injection schedule and model of the subsurface, a partial differential equation solver couples the groundwater flow and elastic deformation equations to estimate geomechanical signals (e.g. pressure, strain, tilt and displacement) at each sensor location. Stochastic optimization algorithms are then used to iteratively generate a large number of geomechanical models, and a high performance cluster computer efficiently evaluates these computationally expensive models in parallel. The set of model predictions are then compared to measured datasets, and used to identify the set of models that explain the data. Parameter uncertainties and tradeoff relationships are examined, and used to inform further iterations until the parameter space has been adequately explored.

We have found that synthetic geomechanical measurements taken from a target formation, either from a nearby observation well or the injection well itself, can be used to accurately and efficiently estimate the physical properties of that formation. We also observe that measurements taken in an overlying confining unit can be used to estimate the properties of the deeper target aquifer. Taking advantage of the parameter sensitivity we observe in the confining unit can significantly mitigate drilling and installation costs as well as reduce the risk of puncturing the target aquifer. Preliminary analysis of field data also indicates that strain tensor data can be used to locate and characterize a high-permeability lens within the target formation.

We have demonstrated that measurements of the strain tensor in relatively shallow boreholes can be informative about geologic structures and geomechanical processes in the deeper subsurface, particularly when taken in combination with other borehole instruments such as tilt and pressure. Our next goals will be to relax our regularization of the inverse problem, allowing the consideration of more complex heterogeneous structures. We will also investigate the information value of this data when coupled with more dynamic systems including thermal or chemical processes.