Assimilation of surface displacement data into reservoir models for improved characterization and monitoring of geological carbon dioxide storage sites

Marc A. Hesse\textsuperscript{1,2} and Georg Stadler\textsuperscript{2}

\textsuperscript{1}Department of Geological Sciences, University of Texas at Austin
\textsuperscript{2}Institute of Computational Engineering and Sciences, University of Texas at Austin

Abstract

The In Salah project has shown that carbon dioxide (CO\textsubscript{2}) injection into deep saline aquifers leads to measurable and transient deformation of the surface. Therefore, high-accuracy, high-resolution, and high-frequency time-series measurements of surface deformation with PS-InSAR and GPS are a promising monitoring tool for geological CO\textsubscript{2} storage. These measurements can be integrated with other observations (well pressures, flow rates, downhole stress and strain meters, micro-seismic observations) to extract quantitative information about the properties of the reservoir as well as the evolution of the pressure distribution in the subsurface. This data integration requires a coupled hydrogeophysical inversion for the reservoir parameters, based on a fully coupled geomechanical and hydrological process model.

We use a fully coupled hydrogeophysical inversion of surface deformation and hydrological data to constrain the permeability field in a linear poroelastic model. The inverse problem is formulated in a Bayesian inference framework, in which we study the posterior probability density function, which combines prior information on the parameters with information from measurement data. To compute the maximum a posterior (MAP) point of this distribution, the squared norm of the misfit between model prediction and observed surface deformation as well as hydrological data is minimized under the constraint given by the poroelastic equations. The resulting least-squares optimization problem is solved using an inexact Newton method based on derivatives computed efficiently through adjoint poroelastic equations. In several cases studied so far, surface deformation data contains significant additional information about the permeability field and will improve monitoring the pressure distribution in the subsurface.

However, despite the success of this type of monitoring at the In Salah project, it is not clear under which circumstances surface deformation monitoring provides relevant information. Therefore, we propose a parameter study that identifies the parameter space where surface deformation monitoring is likely to be successful. However, even the simplest model for hydro-geomechanical coupling, linear poroelasticity, has a large number of parameters. Therefore we propose the identification of the minimal number of dimensionless governing parameters for injection from a single well into a single horizontal layer. We will explore the effect of these parameters on our ability to reconstruct the lateral variations in the permeability distribution of the storage aquifer. This will lead to the identification of the parameter regime under which surface deformation monitoring is able to add significant information about the reservoir.

These results will provide guidance for the permitting process and the design of the monitoring strategy at potential field sites. Currently only surface deformation measurements and 4D seismic monitoring yield spatially distributed information about flow in the reservoir that is necessary to direct more localized monitoring techniques. However, surface deformation monitoring is substantially less expensive than 4D seismic monitoring with the temporal frequency needed to detect a leak in time to avoid significant leakage. Therefore, the feasibility of surface deformation monitoring at a specific storage site may have a significant impact on the cost of monitoring and hence the feasibility of a geological storage project.