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Comparison of time-lapse pressure tomography and seismic tomography for characterizing a CO_2 plume in a deep saline formation

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Geological CO_2 storage in deep saline aquifers generates CO_2 plumes. Characterizing the evolution of such plumes in the subsurface is essential for long-term monitoring and potential risk assessment. A well-established method for tracking the plume development is time-lapse cross-well seismic tomography. CO_2 saturation can be inferred indirectly from observed seismic velocity changes. Since CO_2 injection into the reservoirs also yields variations of flow properties, CO_2-induced heterogeneity can be reconstructed as well by pressure tomography based on the direct relationship between the two-phase flow properties and CO_2 saturation.

In this study, we apply pressure and seismic tomography in a time-lapse strategy, implementing the inversion prior to and after CO_2 injection. We first explore the influence of heterogeneity on pressure tomography in a synthetic two-layer model. In different scenarios, the degree of heterogeneity is modified by increasing the discrepancy of the permeability and porosity beween the two layers. Evolution of the plume is monitored by comparing the structral information derived from different diffusivity tomograms. Additionally, we employ seismic tomography to depict the plume shape in the same model by inverting the differences of seismic travel times. Velocity change is considered as an indicator for the plume. Ultimately, the final plume shape is determined by a two-dimensional joint clustering approach, combining the hydraulic and seismic tomography results. The saturation within the plume is inferred from both, the average change in velocity and the calibrated hydraulic properties within the identified plume area.

Results from both tomographic techniques indicate that their suitability for delineating CO_2 plumes is similar. However, saturation within the plume is underestimated by seismic tomography, whereas that obtained from pressure tomography is comparable to the “true” saturation. These findings show that pressure tomography has the potential to complement seismic tomography, especially for improving the prediction of CO_2 saturation.