An inverse method to measure thickness and volume of a thin CO_2 layer at the Sleipner Field, North Sea

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At the Sleipner Carbon Capture and Storage Project, CO_2 extracted from produced natural gas is being injected at approximately 1000 m depth into a pristine saline aquifer to reduce anthropogenic CO_2 emissions into the atmosphere. The storage reservoir is a highly porous sandstone and is 250 m thick in the injection region, sub-divided by 1 m thick shale layers at intervals of about 30 m.

Monitoring of injected CO_2 is primarily achieved through time-lapse three-dimensional seismic reflection surveys. Previous studies have shown that injected CO_2 is trapped in nine distinct thin layers within the reservoir. Whilst seismic reflection images obtained from the time-lapse surveys are adequate to measure changes in lateral extent of these layers through time, measuring the volume of CO_2 trapped within each layer has proved difficult. These layers are generally too thin to be resolved by direct measurement of the separation between reflections from the top and bottom of each CO_2 filled layer.

Here we present an inverse method to measure the thickness of thin CO_2-saturated layers by exploiting the repeatability of the time-lapse seismic data. Our approach combines measurements of reflection amplitude from the top of the CO_2 layer with measurements of relative changes in two-way-travel-time to the same reflection between time-lapse surveys to give unique estimates of CO_2-layer thickness. A series of synthetic forward models, to which varying levels of ambient noise is added, are used to test the robustness of our inverse method and quantify uncertainties in these measurements.

This method is applied to the uppermost layer at Sleipner, Layer 9, and the uncertainties in these measurements is quantified. By measuring CO_2-layer thickness on all time-lapse surveys, temporal changes in the volume of CO_2 in layer 9 can be calculated. The volume of CO_2 in Layer 9 is observed to be growing at a rate that is found to be quadratic in time, despite an approximately constant injection rate at the base of the reservoir. The relationship between the thickness of CO_2 and topography of the structural trap for layer 9 is also explored, and potential CO_2 migration pathways through the aquifer are identified.