Quantitative analysis of time-lapse seismic monitoring data at the Sleipner CO_2 storage operation

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The CO_2 storage operation at Sleipner in the Norwegian North Sea provides an excellent demonstration of the application of time-lapse surface seismic methods to CO_2 plume monitoring under favourable conditions. Injection commenced at Sleipner in 1996 with CO_2 separated from natural gas being injected into the Utsira Sand, a major saline aquifer of late Cenozoic age. CO_2 injection is via a near-horizontal well, at a depth of about 1012 m bsl, some 200 m below the reservoir top, at a rate approaching 1 million tonnes (Mt) per year, with more than 11 Mt currently stored.

A comprehensive time-lapse surface seismic programme has been carried out, with 3D surveys in 1994, 1999, 2001, 2002, 2004, 2006 and 2008. Key aims of the seismic monitoring are to track plume migration, demonstrate containment within the storage reservoir and provide quantitative information as a means to better understand detailed flow processes controlling development of the plume in the reservoir.

The CO_2 plume is imaged as a number of bright sub-horizontal reflections within the reservoir, growing with time. The reflections mostly comprise tuned wavelets arising from thin (mostly < 8 m thick) layers of CO_2 trapped beneath very thin intra-reservoir mudstones and the reservoir caprock. The plume is roughly 200 m high and elliptical in plan, with a major axis increasing to over 3000 m by 2008. As well as its prominent reflectivity, the plume also produces a large velocity pushdown caused by the seismic waves travelling more slowly through CO_2-saturated rock than through the virgin aquifer.

This paper summarises some of the quantitative methods that have been applied to the Sleipner time-lapse seismic datasets. These include structural analysis, model-based inversion, constrained AVO, extrema signal classification, common focus-point processing and velocity tomography.