Summary

Previous passive seismic interferometry studies have used tomography to image the surface wave Green’s functions for reservoir studies (Bussat and Kugler, 2009; de Ridder and Dellinger, 2011). Here we investigate the utilization of passive seismic interferometry as a permanent, continuous, nearly real-time monitoring system. The tomographic inversion of the virtual-source data obtained by processing five days of passive seismic data recorded over the Valhall oil field in Norway demonstrates that reliable information can be obtained on subsurface velocity from passive data. Given the well-established effect of CO2 in decreasing seismic velocities, our results show that passive-seismic monitoring of CCS projects is feasible. The processing of different (overlapping) frequency bands provides velocity information at different depths in the subsurface; lower frequencies image deeper layers. CO2 plumes can thus be tracked as they move upward before they arrive at the surface and create mortal hazards. Analysis of the convergence rate of passive-data correlations towards virtual-source data with signal-to-noise ratio sufficient for tomographic inversion. The correlations converge faster for nearby receiver pairs and lower frequencies than for farther receiver pairs and higher frequencies. The convergence rate also depends on the strength of the microseism energy in the ambient seismic field. This study provides useful information on the delay that can be expected between the formation of a CO2 plume and the early warning signal provided by the passive seismic monitoring system.

Seismic interferometry aims to generate virtual-sources by correlation of seismic noise recordings (Claerbout, 1986; Wapenaar, 2004). Correlating all noise-recordings with the recording at one station generates a virtual-source gather as if that station were acting as a source:

\[ d(x_s, x_r) = r(x_s) r^*(x_r) \]

Selecting each station as virtual-source generates a full virtual seismic survey:

\[ D(x_s, x_r) = r(x_s) r^*(x_r) \]

Needs all wave-modes randomly and equally excited in space and time (energy equipartitioning).

At Valhall energy between 0.15 Hz and 2.0 Hz is dominated by interface waves; so the virtual sources only emit those waves.

How much data do we need to correlate to establish a permanent monitoring system based on ambient seismic noise tomography?

When we correlate more data, the quality of the virtual seismic sources improves.

Correlation convergence rate

In Figure 4 the correlation quality is explored as a function of time. There is a clear relationship between strength of ambient seismic field and quality of cross-correlations. However certain strong peaks in the spectrum of the ambient seismic field cause the quality of correlations to diminish, these peaks might be caused by highly directional ambient seismic noise. In Figure 5 the correlation quality is explored as a function of frequency, inter-station distance and recording length. The red contour lines do not coincide neither are parallel the the black lines, which means that the correlation quality is not linear related with recording length of the cross-correlated data. At lower frequencies and shorter inter-station distances, we achieve a 95% similarity to cross-correlating 5 days worth of data. The coherence energy is distributed (nearly) equal in all directions. As a quality factor of convergence rate, the correlation coefficient is computed between the four cross-correlations. Cross-correlating 5 days of data allows us to reliably correlate with arrival times offset by cross-correlating 5 days of data.

Figure 4: Correlation quality (correlation-coefficient between a 3 hour cross-correlating and a 5 day cross-correlation) as a function of the central time of the 3 hour cross-correlation.

Figure 5: Correlation quality (correlation-coefficient between a cross-correlating passive recordings of virtual time length made at all stations with the recording node at station 1, increasing the length of the cross-correlated passive recordings clearly improves the quality of the virtual seismic source; the background correlation fluctuations become weaker relative to the coherent energy in the ambient seismic field. This study provides useful information on the delay that can be expected between the formation of a CO2 plume and the early warning signal provided by the passive seismic monitoring system.