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Estimating seismic velocity and thickness of a CO2 layer in the Sleipner plume

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Thin layers of CO_2 in the Sleipner injection plume produce strong reflections on seismic data but determining layer properties, such as thickness and velocity, remains challenging. At Sleipner, the $C0_2$ is injected into the Utsira sand and the plume is imaged as a series of sub-horizontal reflections representing thin layers of CO_2 trapped beneath intra-reservoir mudstones. In this contribution we examine the possibility of combining spectral decomposition and direct reflectivity measurements to assess the thickness and velocity of a thin layer of dense-phase CO_2 in a quantitative manner.

Initial analysis focuses on detecting the leading edge of the advancing CO_2. Synthetic models, designed to represent thin layer spreading in the Sleipner plume, are utilised to establish the accuracy with which the leading edge can be imaged. Once the limitations of the imaging are determined, a spectral decomposition algorithm based on the Smoothed Pseudo Wigner-Ville Distribution enables single frequency slices to be extracted with sufficient frequency and temporal resolution to provide diagnostic spectral information on individual CO_2 layers. The method offers improved resolution over a short time window in comparison to the windowed Fourier transform and the continuous wavelet transform. The accuracy of the technique is assessed using a synthetic wedge model prior to application of the algorithm to the topmost layer of CO_2 in the plume.

Useful energy above 100 Hz in the high resolution Sleipner data set allows layers with thin temporal thicknesses to be studied and investigation reveals strong evidence of thin layer tuning effects. Analysis of tuning frequencies suggests that temporal thicknesses of individual layers can be derived with an accuracy of 1 to 2 ms.

Independent assessment of the thickness of the top layer of the Sleipner plume enables the subsequent calculation of the layer velocity. This study has calculated layer velocities of around 1550 ms^{-1} which are somewhat higher than the values expected from the rock physics (of approximately 1430 ms^{-1}). It is noted that the current range of uncertainty is significant. An alternative approach to determine layer velocity is also undertaken in locations where the top and base reflections from the upper CO_2 layer are imaged explicitly. Here, where the temporal thickness of the CO_2 layer exceeds the tuning thickness, direct measurements of the layers top and base reflectivity are made. Utilising previous work which assessed the acoustic impedance of the virgin sand and caprock prior to injection, calculation of a layer velocity of approximately 1470 ms^{-1} is possible. This value provides closer agreement with the layer velocities expected from the rock physics.