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Application of spectral decomposition to estimate the thickness of a CO2 layer in a growing plume at Sleipner, North Sea

G. A. Williams (1) and R. A. Chadwick (2)
(1) British Geological Survey (gwil@bgs.ac.uk), (2) British Geological Survey (rach@bgs.ac.uk)

CO2 produced at the Sleipner gas field is being injected into the Utsira Sand, a regional saline aquifer. Time-lapse seismic surveys have been acquired in 1999, 2001, 2004 and 2006 in order to monitor the growth of the plume. The plume is imaged as a sequence of high amplitude sub-horizontal reflectors within the aquifer; the reflections are thought to represent tuned responses from thin layers of CO2 trapped beneath intra-reservoir mudstone baffles.

Spectral decomposition of seismic data can be used to map temporal bed thickness across a 3D seismic survey. Conventional techniques employ the Short Time Fourier Transform (STFT) using an appropriate window function to localise the frequency spectrum of the seismic trace. The resulting power spectrum represents a combination of the seismic wavelet and local thin bed effects. Time-frequency decomposition (TFD) using the STFT suffers from resolution problems: a wide analysis window gives good frequency resolution, but poor time localisation, while a narrow window localises the spectrum in time but provides poor frequency resolution. In order to overcome these limitations other time-frequency representations have been developed, these broadly fall into 2 categories: quadratic and wavelet transforms.

A small analysis window is required to isolate reflections from individual CO2 layers in the Sleipner seismic data. Consequently this study explores the potential of a quadratic transform (the Wigner-Ville Distribution or WVD) and the Stockwell Transform (a pseudo-wavelet transform which preserves phase information) to quantify tuning in the top-most layer of the CO2 plume. TFD of a synthetic wedge model suggest that both techniques can be used to investigate tuning effects in the seismic data. The WVD in particular offers excellent time-frequency resolution, however cross-terms inherent in the quadratic formulation make interpretation difficult. Applying a smoothing kernel in the time-frequency plane to produce a reduced interference distribution (or pseudo WVD) can reduce the effect of these artefacts.

Preliminary analysis of the Sleipner datasets shows strong frequency tuning effects and indicates that quantitative temporal-thickness mapping is practicable. Correlating temporal-thicknesses with depth-thicknesses derived by other methods provides additional constraints on layer velocities.