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Ensuring safe North Sea CO₂ storage: the design of robust seismic networks to enable focal mechanism analyses for stress field orientation

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Seismic monitoring plays a critical role in ensuring the safety and effectiveness of carbon capture and storage (CCS) operations, as it offers essential insights into fault stability and potential risks to storage integrity. Focal mechanism analysis provides knowledge on stress field orientation, fault slip directions, and seismic source characteristics, aiding the understanding of subsurface fault dynamics and stress changes within the reservoir. Analysing focal mechanisms of small, local earthquakes before, during and after CO₂ injection is crucial for understanding seismic response and, as a result, assessing the risk of significant future events.

Within the ACT SHARP Storage project framework, a newly compiled detailed earthquake bulletin (Kettlety et al., 2024) and waveforms collected in the North Sea region were utilised to invert for moment tensors. Proposed CO₂ storage sites in the North Sea are often located far from existing onshore seismological networks, resulting in sparse records and large azimuthal gaps, leading to significant uncertainties in earthquake parameters estimation, such as epicentre coordinates and hypocentral depth, making it very challenging to discriminate natural and induced events.

To address these limitations, we conducted a synthetic study to optimise the placement of offshore stations to improve the monitoring of CO₂ storage sites. Using the open-source Fomosto package, we modelled seismic responses from various double-couple sources and incorporated noise data from existing OBS deployments in Germany and Denmark. The results highlight optimal station configurations and strategies to enhance seismic monitoring, enabling better recovery of focal mechanisms and detecting micro-seismicity that may constitute induced seismicity or early precursors of CO₂ storage containment failure.

This study provides practical advice on designing robust seismic networks, paving the way for improved stress field knowledge and safer CCS operations in the North Sea.