The Greensand example: Enabling CCS surveillance using focused seismic monitoring

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Introduction

Carbon Capture & Storage (CCS) becomes unavoidable to decrease the CO_2 footprint in the atmosphere and mitigate climate change. In the Greensand Phase 2 research project co-funded by EUDP, a pilot injection of CO_2 was conducted into a depleted oilfield in the first quarter 2023. **In conjunction with the first CO_2 injection, a new geophysical monitoring approach, focused seismic monitoring (Al Khatib et al., 2021), has been applied. This spot seismic surveillance tool allows for a low environmental impact and enables a higher monitoring frequency than standard 4D seismic.**

Low cost, low impact and lean monitoring approaches are key for public acceptance and CCS projects delivery. We show that a specific survey design, operational model and processing sequence developed for spot monitoring can be used to quickly detect the CO_2 in critical locations of the subsurface. This focused seismic approach can be used to validate flow model and further increase trust and safety in CCS projects. .

Predictive Maintenance

Dynamic reservoir models are predicting storage pressure and fluid saturation evolution. These models serve as essential tools in planning underground CO_2 injection (Barros et al., 2021). Indeed, permit applications, risk assessments, and the economics of CCS projects are developed using these models. Therefore, it is crucial to **use the flow model to predict where and when we need to focus a seismic measurement** to reduce its uncertainties as part of the Measurement Monitoring and Verification (MMV) plan.

Using dynamic models' output, a differential CO_2 saturation map is built by calculating the variances between successive month-by-month models. After different smoothing and combination of differential and saturation map, a saturation intensity map of the CO_2 predicted plum is obtained (Figure 1). **The most critical areas driving the CO_2 front are automatically selected to plan focused seismic measurement**. This automated approach is also applicable to track the pressure front.

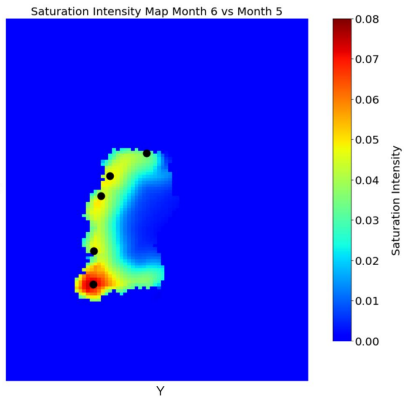

Figure 1: Saturation Intensity Map (colored background) and automatic spot positions (black dots), 5 months after injection start.

Aside of **conformance spot**, risk assessment studies will indicate **containment spot** locations crucial for potential leak assessment. A **calibration spot** is also added to the surveillance plan to calibrate the detection tool at the injection site. This injection spot monitoring and detection results are presented below.

Innovative plug & play operational model

On the operational side, by data-mining existing exploration seismic (Morgan et al., 2020), a frugal seismic acquisition design was built (Figure 2a). 15 sources and receiver antenna were used to monitor and cross validate CO_2 detection on 9 spots in the storage (Szabados et al., 2022), resulting in a low cost and low impact solution. The lightness and quickness of the system allowed for **3 seismic acquisitions of 48 hours operational time during winter 2023, in the North Sea**.

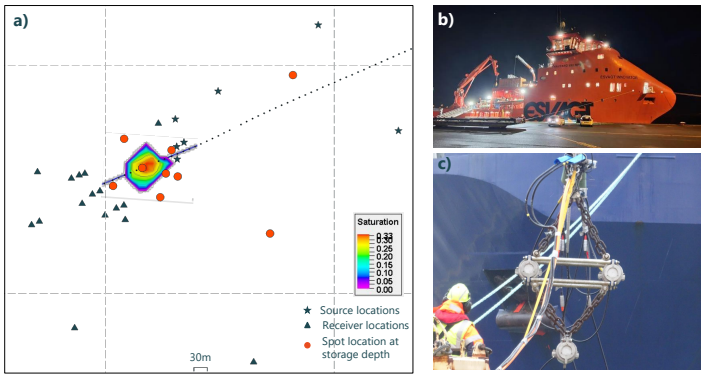

Figure 2: a) Seismic acquisition design, optimal source and receiver locations per spot monitored in the subsurface. Overlay with the simulated CO_2 saturation map after 4000 tons of CO_2 injected. b) On field available supply vessel used for few days of acquisition (dropped nodes and small static airgun). c) Tri-gun point source, total of 600 in^3.

From an equipment point of view, **a 600 in^3 tri-gun source**, containerized with all its equipment on **a standard supply vessel** was used to perform a **1-hour static shooting** at each source location (Figure 2b&c). Ocean bottom nodes were deployed and remained at sea floor level between the 3 acquisitions.

Detection results

During the acquisition, the source far field signatures are recorded for all shots to compute operators for debubbling and deghosting. Two indicators were used to assess the seismic data quality, the Normalized Root Mean Square (NRMS) and correlation coefficient giving post-processing repeatability results of around 10 to 50% NRMS. Following a processing sequence made of temporal stack and reflection waves separation (Al Khatib & Mari, 2023), a **Monitoring Spot Gather** (MSG) is obtained and presented in Figure 3a.

Figure 3b shows the variation of the attributes observed between Baseline and M2 for the spot of injection (50ms sliding window). Both indicators show anomalic values in the 1.64 – 1.69-time interval, clearly **highlighted by the Cor-NRMS coefficient** (NRMS to correlation coefficient ratio). Consequently, light monitoring at injection spot detects a significative change between January and March 2023, which is attributed to the **presence of CO_2 in the reservoir**. The result matches the expectations from simulation results (Figure 2a.).

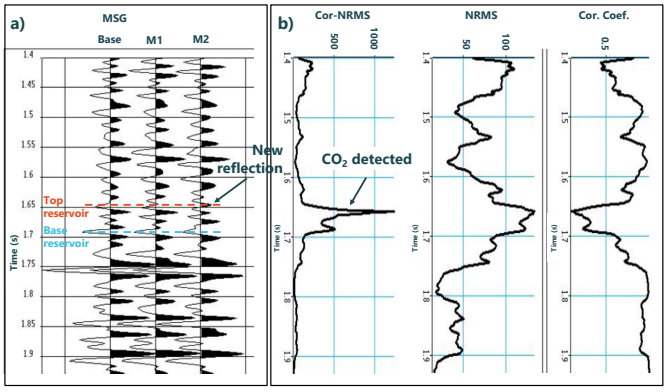

Figure 3: a) Seismic traces of base, monitor 1 and 2 after processing. b) Time-variant attributes with CO_2 detection at Spot 1 (injection spot) by Cor-NRMS attribute computed from NRMS and correlation coefficient.

Conclusion & way forward

The Project Greensand was a pilot test using focused seismic monitoring before, during, and after CO_2 injection that successfully detected 4000 tons of CO_2 at 1.8km depth. Detecting such a small amount of CO_2 indicates the great potential of this solution for saturation and pressure in fully operational projects. Follow-up research will focus on detectability assessment. As a result to this case study, it was demonstrated that **thanks to an innovative & light focused seismic technology, CCS projects can gain acceptability while increasing safety using the Predictive Maintenance approach**.

Acknowledgements

The project is funded by the Danish Energy Technology Development and Demonstration Program (EUDP) and the EU program Generation Next. Many thanks to Michael Larson & Cecilie Tang from INEOS, Tillmann Roth & Jan Grobys for their operational involvement and support and to TGS and the ESVAGT Innovator crew for carrying out the seismic acquisition.

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Funded by the European Union NextGenerationEU