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Supporting offshore CCS pilot scale injection with Spot Seismic

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Extended Abstract for CCUS conference, Houston

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Title: Supporting offshore CCS pilot scale injection with Spot Seismic – The Greensand pilot

Abstract:

The Greensand project aims to convert depleted oil fields in the Siri Canyon offshore Denmark into long-term CO2 storage. This study demonstrates a cost-effective, light-focused seismic monitoring method using 16 receiver nodal locations and 7 source positions. Monthly acquisitions provided insights into the CO2 plume and refined the injection model.

The results from three different time-lapse monitoring periods showed clear 4D signals at the reservoir level, confirming the CO2 plume extension and the capability of Spot Seismic to detect subtle amounts of CO2. The findings also helped refine the injection location along the horizontal well. This innovative approach enhances the safety and efficiency of CO2 storage, offering a scalable solution for future CCS projects.

Introduction

CCS economy is different from O&G, and nimble cost effective approach are in need to match the economical requirement of CO2 storage surveillance. On top of cost, safety and societal acceptability are essential drivers for CCS to be at scale.

Several CCS operators consider spot seismic an attractive monitoring solution including Carbon Safe projects. From an economic, operational, and environmental perspective, a single source–single receiver position per spot enables more frequent and agile monitoring strategies for CCS.

In this article, we present how a light acquisition layout, consisting of 16 receiver nodal locations and 7 source positions (Ollivier et al., 2023), acquired by a 600 cui seismic source, enabled frequent acquisitions (monthly) to better understand the CO2 plume and correct the injection model. The case study presented is GreenSand offshore Denmark.

Acquisition design & operational model

During the pilot CO2 injection project, spot seismic, a novel light-focused seismic monitoring method was demonstrated (Roth et al., 2023).

Instead of providing a 3D image of the subsurface around the injection well, which would have been too costly and operationally non-viable for the pilot injection, 7 areas of interest (spots) were strategically designed. These spots can be categorized into three different “families”:

- Control Spots (6 & 7): Located outside of the area of review, these spots assess the repeatability and sensitivity of the measurements.
- Calibration Spots: Located along the injection well, where we assume the CO2 will be injected.
- Conformance Spots: Positioned slightly away from the injection well to track the speed of the CO2 plume expansion as well as its limits.

To monitor these Spot in one day of operation, a design of 7 source location and 16 receivers location (for redundancy) where defined using the spot seismic methodology (Morgan et al, 2020). Once the design was set and because several Spots were close, we’ve analysed other source/receiver pair associating different sources with different recivers. The 11 additional computed Spots, -validated by the legacy data quality check- are called Spot of opportunity and are shown in Figure 1 using white dots with dark lines.

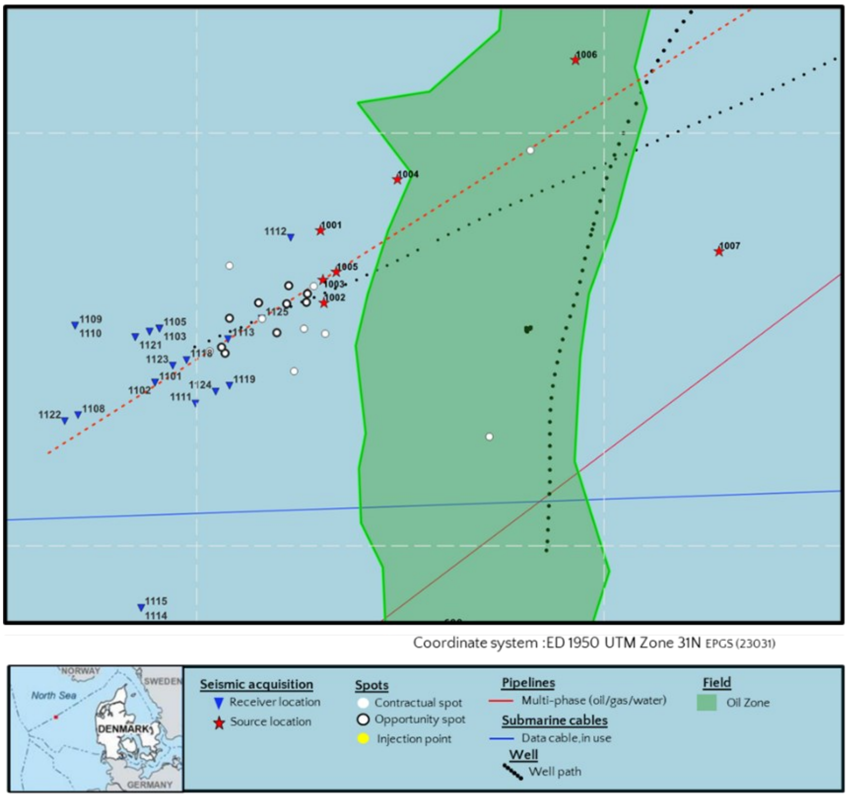

Figure 1- Acquisition design with Spots & Spots of opportunity

At each of the 16 receiver locations, Ocean Bottom Nodes (OBN) were semi-permanently laid out for 3 months to maximize repeatability. The containerized source was rigged on a Greensand supply vessel thereby decreasing significantly the cost of operation.

The seven source locations were shot approximately 50 times each in dynamic positioning (static), achieving a 1.5 m position accuracy from one vintage to another and allowing temporal stack of data to increase signal to noise ratio. The acquisition of Monitor 2 in February 2023 lasted less than one day. Data were processed using a dedicated processing sequence (Mari et al., 2024) increasing further the repeatability to up to 10% NRMS on some antennas.

Results, Observations:

All 18 spots were acquired on three different time-lapse monitoring periods on 3 months, before injection and after 4000tons of CO2 and 8000tons of CO_2.

Figure 2 shows the detection results achieved on 3 different Spots: A control Spot (7), A Spot showing no detection (2) and a Spot showing a clear detection at monitor 1 & 2 at reservoir level (27).

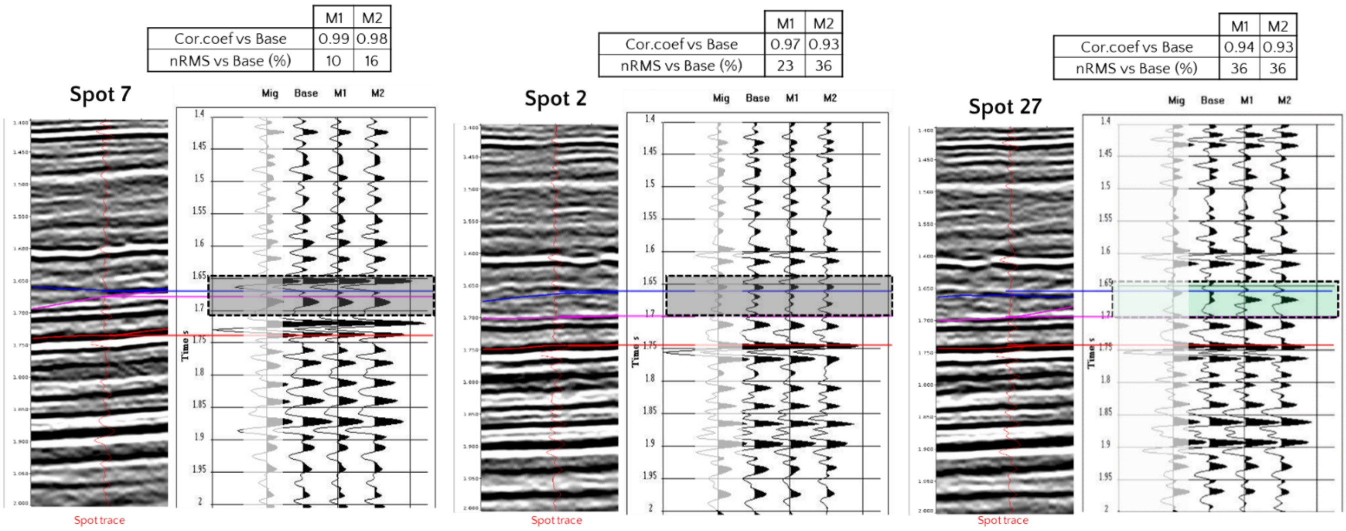

Figure 2- Detection results on Spot 7, 2 & 27. The reservoir interval in highlighted

The analysis of the first monitor results showed a clear 4D signal at the reservoir level on several spots. These effects were still visible on the second monitor, with an increasing number of spots showing a 4D signal. Figure 3 shows a “top view” of the detection results of each Spots, overlaying the modeled CO_2 plume for 4000 tons of CO_2 and 8000tons.

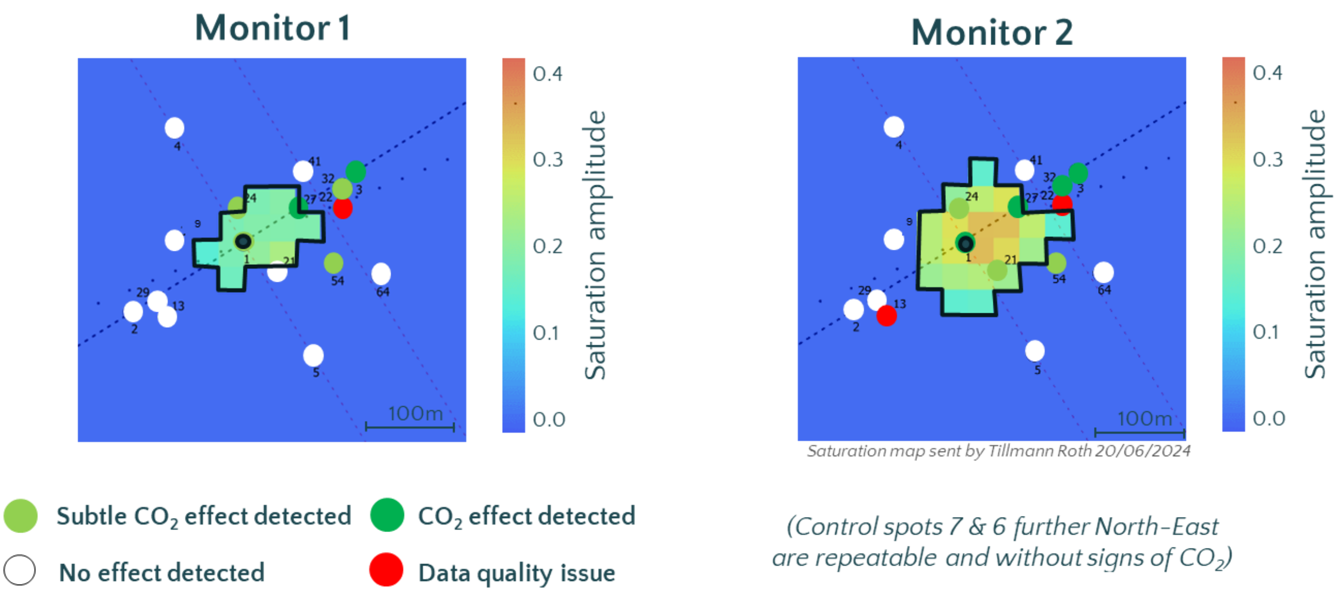

Figure 3- Top view of the modeled CO2 saturation (in color) and the spot seismic results (in white & green)

The interpretation of the results confirmed the main hypothesis of the CO_2 plume extension and the capability of spot seismic to detect subtle amount of CO_2..

The mismatch between prediction and measurement helped to refined where along the horizontal injection well the CO_2 was preferentially injected. It seems that this location is approximately 40 meters further east along the injection horizontal well as shown in figure 4.

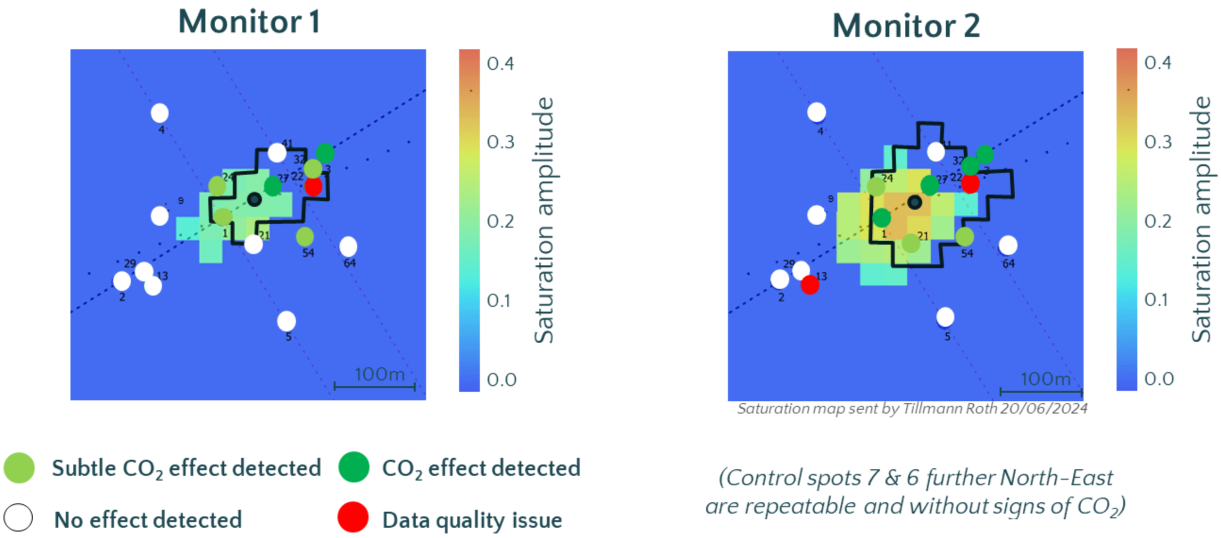

Figure 4 - Shift of the CO2 modeled plume 40m East along the injection horizontal well.

Conclusion

The Greensand project showcases a novel and effective seismic monitoring method for CO_2 storage. The use of Spot Seismic technology, with Ocean Bottom Nodes and a containerized airgun source, enabled frequent, cost-effective, and accurate monitoring.

The detection of 18 spots 7 initially designed and 11 as opportunity enabled to identify areas with clear 4D signals and helped better understand the CO_2 plume extension and refined the injection location.

Thanks to its light footprint, this innovative approach enhances the safety and efficiency of CO_2 storage, offering a scalable solution for future CCS projects.

As a way forward, the flow models need to be recomputed to test the hypothesis of a CO2 injection more toward the East.

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