Introduction

Distributed Acoustic Sensing (DAS) technology has emerged as a transformative tool for reservoir monitoring in Oil & Gas and carbon capture and storage (CCS) applications. By utilizing fiber optic cables as continuous sensors, DAS enables real-time, high-resolution monitoring of subsurface seismic activity, fluid dynamics, and reservoir performance. This document explores the applications of DAS technology in end-to-end solutions for vertical seismic profiling (VSP), microseismic monitoring, elastic Full Waveform Inversion (FWI), and comprehensive reservoir monitoring in various projects.

Method and/or Theory

- Vertical Seismic Profiling (VSP)

Vertical seismic profiling (VSP) is essential for characterizing subsurface structures and monitoring CO2 injection and storage projects. Traditional VSP surveys rely on downhole geophone arrays, which are costly and logistically challenging to deploy. DAS technology offers a cost-effective alternative by converting standard fiber optic cables into distributed sensors capable of recording seismic signals along the entire length of the cable. DAS-based VSP surveys provide enhanced spatial resolution and coverage, enabling detailed imaging of subsurface structures and accurate monitoring of CO2 plume migration and depletion within the reservoir. By leveraging existing well infrastructure, operators can deploy DAS-based VSP surveys more efficiently and cost-effectively, improving reservoir characterization and optimizing strategies.

- Microseismic Monitoring

Microseismic monitoring is crucial for assessing reservoir behavior, geomechanical stability, and CO2 injection performance in CCS projects. Traditional microseismic monitoring systems are limited by their fixed sensor locations and low spatial resolution. DAS technology addresses these limitations by offering distributed sensing capabilities along fiber optic cables installed in boreholes or on the surface. DAS-based microseismic monitoring enables real-time detection and localization of microseismic events induced by CO2 injection or reservoir stimulation, providing operators with detailed insights into reservoir response and fracture propagation dynamics (Figure 1, Nakayama *& al.*, 2024a & Nakayama *& al.*, 2024b). By integrating DAS-based microseismic monitoring into CCS workflows, operators can optimize injection strategies, assess reservoir performance, and mitigate geomechanical risks, ultimately enhancing the efficiency and safety of CCS operations.

- Elastic Full Waveform Inversion (eFWI)

Elastic Full Waveform Inversion (eFWI) is a powerful technique for plume migration monitoring in CCS projects. By utilizing DAS data, elastic FWI can generate high-resolution subsurface images, allowing for precise tracking of CO2 plume migration and distribution. This advanced imaging technique enhances the ability to detect and monitor CO2 movement within the reservoir, providing critical information for optimizing injection strategies and ensuring the long-term integrity of CCS projects (Figure 2, Yamada *& al.*, 2024).

- Comprehensive Reservoir Monitoring

In addition to VSP, microseismic monitoring, and elastic FWI, DAS technology enables comprehensive reservoir monitoring in CCS projects (Le Calvez *& al.*, 2021). By integrating DAS sensors into existing well infrastructure, operators can continuously monitor reservoir parameters such as pressure, temperature, and fluid composition in real-time. This enables early detection of potential CO2 leakage, reservoir anomalies, and geomechanical instabilities, allowing operators to take proactive measures to mitigate risks and ensure the long-term integrity of CCS projects. Furthermore, DAS-based reservoir monitoring provides valuable data for reservoir management and optimization, enabling operators to maximize recovery, CO2 storage capacity, improve injection efficiency, and achieve regulatory compliance.

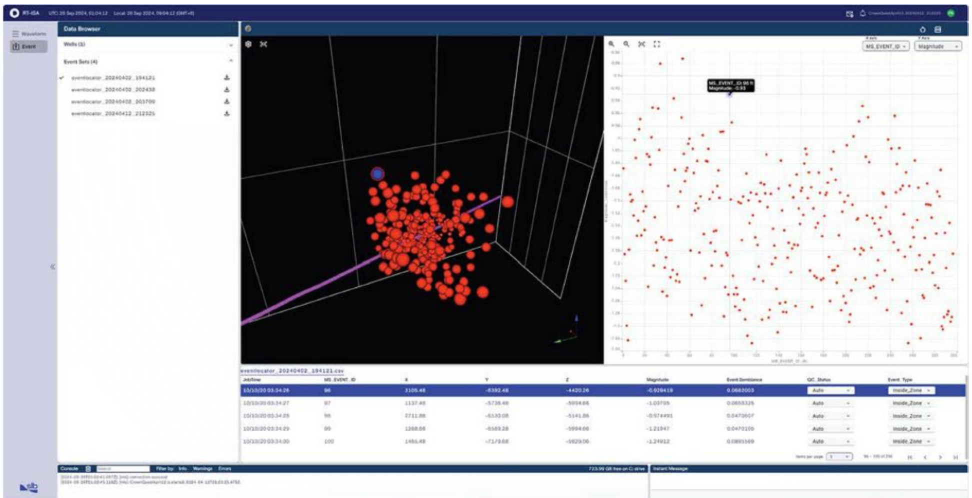

Figure 1 *Example of web interface enabling remote stakeholders to visualize real-time processing results of DAS-acquired microseismic data sets. Two- and three-dimensional displays are available with filtering capability and links to events (e.g., on the display, one event is selected in blue in 2D and 3D displays as well as in the list of events).*

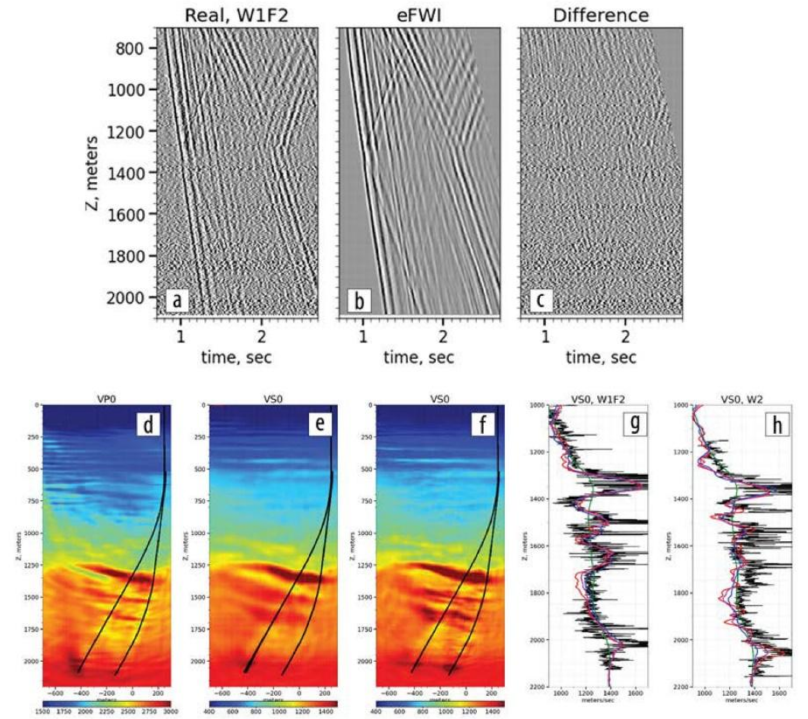

Figure 2 *eFWI results. WVSP shot gathers in the depth-time domain: (a) observed data, (b) synthetic data from eFWI, and (c) difference. The eFWI results: (d) compressional velocity tomogram (V_{P0}), (e) low-frequency shear velocity tomogram (V_{S0}), (f) high-frequency shear velocity tomogram (V_{S0}), (g) comparison of V_{S0} results extracted at the positions of Well-1 with sonic data: blue line corresponds to low-frequency result, magenta to high-frequency result at iteration 35, red to high-frequency result at iteration 75, and green to the initial model. (h) Comparison of V_{S0} results extracted at the positions of Well-2 with sonic data, with same color-coding as (g).*

Conclusions

Distributed Acoustic Sensing (DAS) technology offers comprehensive solutions for reservoir monitoring in CCS applications, including vertical seismic profiling, microseismic monitoring, elastic Full Waveform Inversion, and continuous reservoir monitoring. By leveraging fiber optic cables as distributed sensors, DAS enables cost-effective, high-resolution monitoring of subsurface seismic activity, fluid dynamics, and reservoir performance. As the industry continues to expand, DAS-based solutions are poised to play a crucial role in enhancing operational efficiency, ensuring environmental sustainability, and advancing the transition to a low-carbon future.

References

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