geoconvention
Virtual Event
September 13 - 15
2021

Time-lapse VSP monitoring of shallow CO_2 sequestration at the CaMI Field Research Station

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Summary

Carbon Capture and Storage is considered an essential strategy for reducing global CO_2 emissions. Effective geophysical monitoring provides important risk assessment capabilities at a CCS site, and will help determine the feasibility of permanent storage of CO_2 in geologic formations. The Containment and Monitoring Institute (CaMI) operates a CO_2 sequestration experiment near Brooks, Alberta. The ongoing CO_2 injection simulates a shallow leak scenario relevant to larger-scale CO_2 sequestration projects. By May 2019, 17 tonnes of gas-phase CO_2 had been injected into a brine-saturated reservoir at a depth of 300m. The sandstone reservoir is 6m thick with 9% porosity. This was expected to produce a decrease in P-wave velocity observable in time-lapse seismic data. Walk-away vertical seismic profiles (VSP) were acquired at the CaMI Field Research Station for the purpose of monitoring of the CO_2 plume. These data were collected between 2017 and 2019 using geophones and Distributed Acoustic Sensing (DAS). The DAS repeatability suffered from using different interrogators for the baseline and monitor surveys. The CO_2 plume did not cause a strong enough anomaly in the time-lapse difference of either DAS or geophone data, relative to the background residual amplitudes. This indicates that a 17t leak is not detectable under these reservoir conditions, and the detection threshold will be established after more CO_2 is injected.

Method

CaMI's Field Research Station (FRS) allows for highly repeatable acquisition of Vertical Seismic Profiles (VSP). The observation well is located 20m from the injection well and is equipped with permanent downhole geophones and DAS fibers. Baseline surveys were shot in 2017, and the same mini-vibe source (10Hz-150Hz) and shot locations can be used for monitor surveys. Weather-related effects in the near surface led to differences in statics and source signature. DAS data had the added challenge of having used different DAS interrogators during acquisition. CO_2 saturation was expected to decrease P-wave velocity, with negligible effects on shear velocity and density (Macquet et al., 2019). For the 17t of CO_2 injected by May 2019, a ~5% decrease in P-wave velocity was expected to cause reflection and travel-time residuals of ~10%, relative to the baseline survey. This should cause a negative amplitude anomaly near the injection well with a radius of ~15m.

Typical VSP processing workflows were performed, similar to those used for previous CaMI.FRS VSP processing (Gordon, 2019, Kolkman-Quinn and Lawton, 2020). For time lapse purposes, the following key steps were included:

- After source-static corrections from ray-tracing, residual shot-static shifts between monitor and baseline gathers were determined, by cross-correlation.

- Trace-by-trace RMS normalization was applied pre-stack to mitigate amplitude differences between surveys.
- A shaping filter was applied to the monitor survey after VSP CDP mapping and stacking.
- Two standard repeatability metrics, Normalized Root-Mean-Square (NRMS) and Predictability (PRED), were calculated (Kragh and Christie, 2002).

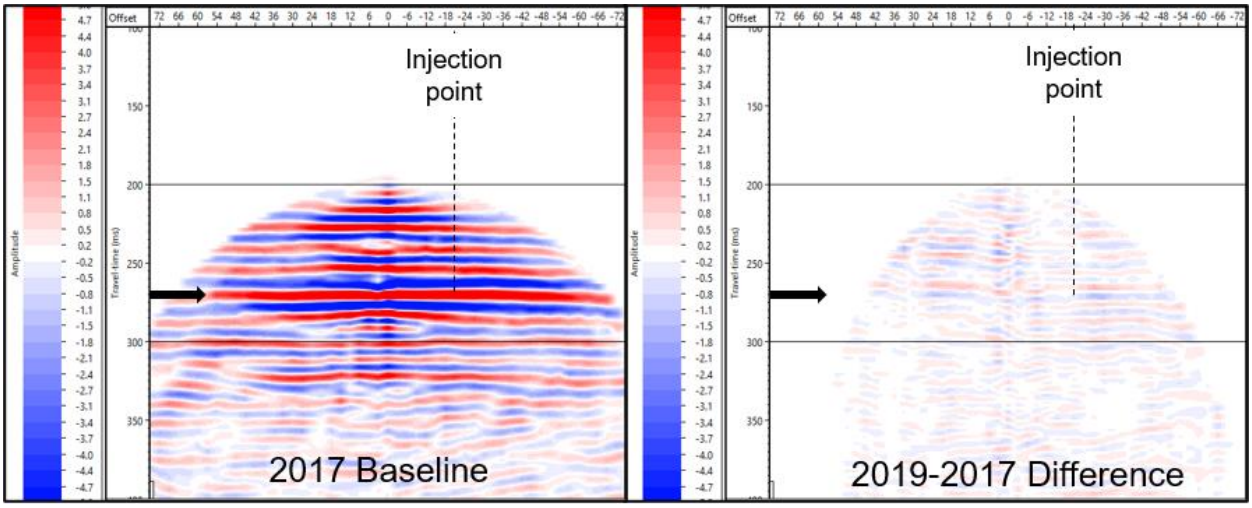

Figure 1 – Geophone VSP CDP sections from 2017 Baseline survey (left), and the time-lapse difference between 2019 monitor and 2017 baseline. The reservoir interval is indicated by the black arrow. The injection point is 20m offset from the observation well.

Results and Conclusions

In terms of reducing residual noise between surveys, the geophone data produced cleaner results than the DAS data. NRMS values of 9% have been obtained for a 20ms window around the reservoir, and 14% over the 400ms window shown in Figure 1. DAS data yielded NRMS 20%-30% higher, indicating a significantly worse match between monitor and baseline datasets. The stacked results of individual DAS VSP datasets appear at least as high quality as the geophone data. However, different DAS interrogators resulted in appreciable differences in frequency content and signal quality in the raw shot gathers. This led to greater residual amplitudes in a time-lapse difference, compared to the geophone data. Had the same interrogator been used for baseline and monitor surveys, repeatability of the DAS data would likely be more similar to the geophone data. Overcoming the differences in the DAS datasets remains a challenge.

Despite the apparent similarity between baseline and monitor data, the geophone time-lapse difference still yielded background residuals strong enough to prevent the identification of the CO_2 plume (Figure 1). The 17 tonne amount of CO_2 injected by May 2019 was relatively small, and current plans are to increase the injection rate to ~50t/year. As injection rates and amounts increase, the amplitude and time delay effects of the CO_2 will strengthen (Macquet et al., 2019), allowing for the determination of a detection threshold for the simulated leak into the 6m reservoir.

Acknowledgements

This work was funded by the industrial sponsors of the Consortium for Research in Elastic Wave Exploration Seismology (CREWES), sponsors and joint-interest subscribers of the Containment and Monitoring Institute (CaMI), and by the NSERC grants CRDPJ 461179-13 and CRDPJ 543578-19. We gratefully acknowledge continued support. The data were acquired at the Containment and Monitoring Institute Field Research Station in Newell County AB, which is part of Carbon Management Canada.

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