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Rapid-repeat time-lapse seismic monitoring of CO_2 injection

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Summary

In 2019 CREWES researchers carried out a VSP-type seismic experiment to seek rapid (hour-scale) variations in seismic waveforms propagating through a plume of CO_2 being injected into the 300m formation at the CaMI-FRS in Newell County AB. We carried out a 160hr set of repeated seismic shots taken during an injection cycle. Strong repeatability was observed in the waveforms generated with the Vibroseis source, which was fixed with pad down throughout, and sensed with permanent 3C geophones cemented behind casing in the CaMI geophysics well. On this backdrop, we identified several spectral variations which appear and then vanish over the course of the experiment. The changes exceed empirically established error bars significantly. There is a tendency for lower frequencies to decay (and then relax) and higher frequencies tend to boost (and then relax). In 2020 and beyond we will continue this analysis, as it is suggestive of useful modes of monitoring of fluid injection. Our findings are in broad agreement with at least two other independent time-lapse experiments focusing on short term variations (Nakatsukasa et al., 2017; Byerley et al., 2018; Innanen et al., 2019).

Experiment

The experiment involved placing the University of Calgary EnviroVibe Source at a fixed point, lowering the pad, and leaving it there with pad down over the course of 160hrs, repeating sweeps throughout. Just after the baseline data were acquired, the injection well was pressured up, commencing injection. After several hours, the pump was pressured down and the system was allowed to lapse back to a quiet state. By the end of the 160hr program the pressure had returned to its pre-injection level. A total of 203 shots were taken, in 14 clusters, with 5-29 shots taken in rapid succession within each cluster. The EnviroVibe was programmed with a linear 10-150Hz sweep. The sensors were 3C geode geophones cemented behind casing. A visual inspection of the data was carried out after the experiment and 6 representative levels were selected based on overall data quality. Of these, the deepest was at approximately 275m; the shallowest was at 230m.

Processing

Our approach was to do a bare minimum of processing, because while we had some idea that variability would be identified, it was unclear what form it would appear in. With that in mind, we corrected several polarity reversals, and normalized each trace to its maximum value prior to Fourier transform. The latter step took the place of any candidate normalization of the spectra (e.g., transformation to *db down*), and would allow us to avoid choosing a particular frequency at which to enforce agreement between spectra.

Significant Transients

We observed several changes on this backdrop of accurate repeatability and controlled injection timeline. We divide these phenomena into transient and non-transient groups, with the latter

corresponding to changes which appear and then remain, and with the former corresponding to changes which tracked with changes in reservoir pressure and vanished as it relaxed. In this presentation we will show an illustrative example of a transient change. In Figure 1, the variation of the peak amplitude spectrum of a sensor placed about 25m above the injection zone is plotted; and a clear transient signal is noted.

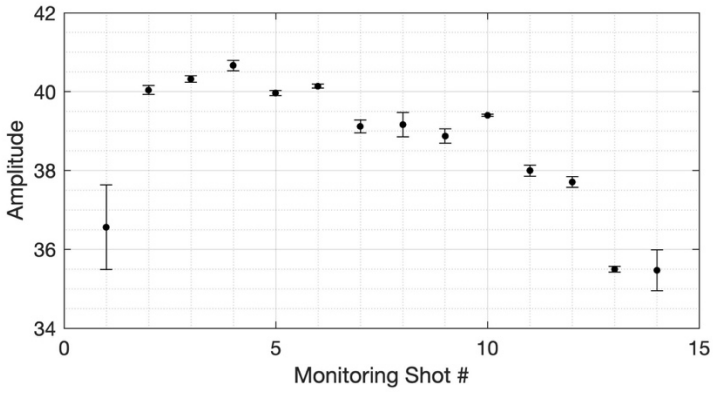

FIG 1: The maximum value of the amplitude spectrum of the vertical component of the geophone at roughly 275m depth, about 25m above the injection location, was extracted and plotted at each of the 14 monitoring points during the 160hr experiment. Error bars are standard deviations derived from the repeated shots at each monitoring point.

In our presentation we correlate this with injection data, principally pressure at the injection point.

Conclusions

There appear to be readily discernible short duration changes to a seismic waveform as it propagates through injection plumes, even ones (such as this) which are small compared to the wavelength. Although the mechanism has not yet been determined, the possibility that such variations could support novel injection monitoring strategies motivate continued analysis, and expansion of the attempt to capture and understand these waveform variations.

Acknowledgements

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