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Repeatability analysis for continuous seismic monitoring with the surface geophone array and the permanent rotary sources: CO2CRC Otway Stage 2C

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Abstract

In the CO2CRC Otway Project, seismic monitoring has evolved from traditional campaign based seismic acquisition towards techniques using continuous seismic acquisition based on permanently deployed sources and receivers. Permanent reservoir monitoring facilitates assurance of safe CO_2 storage, while reducing the cost and the environmental impact of geophysical surveillance. Two Surface Orbital Vibrators were deployed in late 2015 to test their capability as permanent sources. After the optimisation of the SOV design in 2016, the existing buried geophone array was utilised to record continuously for several months. In this study, we analyse the data and outline a methodology for data processing. Promising seismic repeatability is obtained that validates the long-term applicability of the SOVs.

Keywords: permanent reservoir monitoring, surface orbital vibrators, repeatability

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1. Introduction

Time-lapse (TL) seismic monitoring of injected CO_2 has been a key research area at the CO2CRC Research Facility. The survey geometry, near-surface conditions, overburden complexity and ambient-noise are the main factors that affect seismic repeatability. A number of developments have addressed some of these factors. To optimise the receiver side of the surveys, a buried geophone array was deployed during Stage 2C of the Otway Project [6]. In order to track the plume evolution, this array was utilised to monitor the effect of injecting CO_2 into the saline aquifer in ~5kT intervals at a depth of 1500 m. In total five 3D surveys were conducted using conventional vibroseis, including baseline and four repeat monitor surveys [4]. Additionally, on the source side, we deployed two Surface Orbital Vibrators (SOVs) close to the CRC-2 and Naylor-1 wells for the appraisal of an alternative source that could be permanently deployed at the Otway site [1]. The utilization of SOVs provide the following benefits: reduced environmental footprint and cost savings. Also, improved ground coupling of the source would further

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increase the repeatability of the TL seismic signal. In order to evaluate the long-term applicability of SOVs, we analyse the data, tailor the data processing, and analyse the repeatability of the surveys for the detection of TL signal. The layout of the permanent receiver array along with SOVs are displayed in Figure 1.

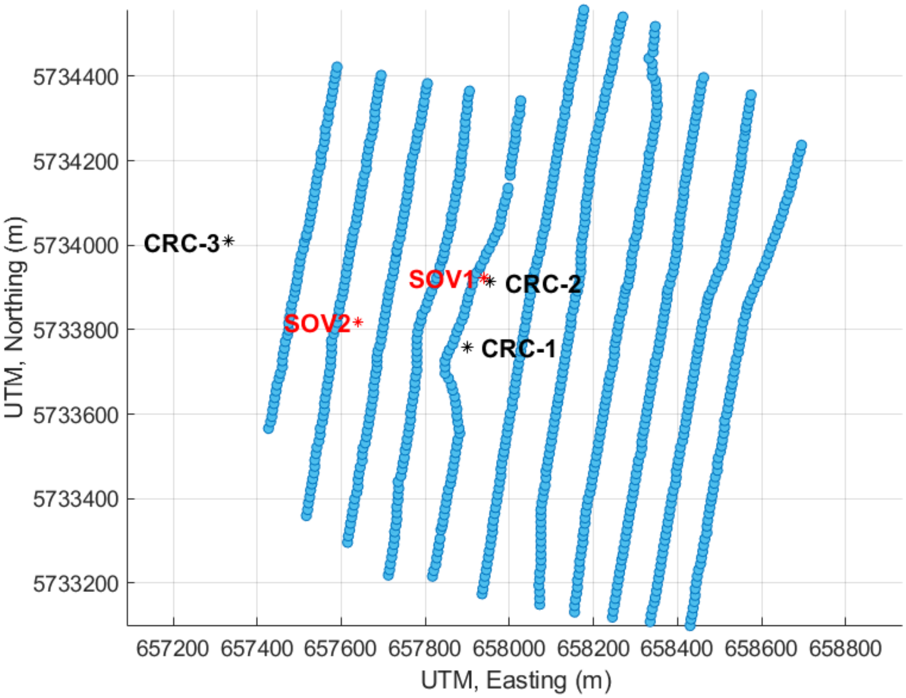

Fig. 1. Acquisition layout of the permanent geophone array (blue dots), the two permanent SOVs (in red), and the wells (CRC 1, 2 and 3 in black).

2. Surface Orbital Vibes and Field Data

In land seismic monitoring surveys, conventional seismic sources are often criticized for the high environmental footprint. Utilizing vibroseis trucks can reduce consistency in positioning, which introduces detrimental effects during TL processing. The ground coupling, as well as the cost and footprint issues, could be easily avoided with the utilization of point sources that are expected to provide a significant improvement on TL seismic repeatability. In this study, point-vibrating SOV sources, which distribute source energy over an extended time through the rotation of two eccentric weights using common AC induction motors, were operated for several months to generate a seismic signal to be recorded with the existing buried geophones. The initial appraisal of the signal content and the repeatability of the SOV data were demonstrated in [2] and [3]. Prior to the CO_2 injection in late 2015 and after fixing a flaw in the foundation designs, the initial SOV data was acquired. However, the continuous acquisition of seismic data utilising both SOVs officially commenced in mid-February 2016 with the first 10 days of continuous data being used as the baseline. Data acquisition continued for 107 days with breaks to allow for the acquisition of conventional monitor surveys. Firstly, we analyse sweep signals of both SOVs. Due to the location of the SOVs, offset coverage and the plume evolution direction, we focus on SOV2 for the tailored processing. The recorded source signature differs for sweeps generated by clock-wise and counter-clockwise rotation of the SOV2. After analysis and visual quality control, we proceed with the CW, which data appeared less affected by surface waves.

3. Data Processing

To prepare the SOV data for processing and to improve the signal-to-noise ratio, we generate daily stacks using sweeps recorded over two hours. Continuous weather data acquisition complements the SOV data analysis, specifically taking into account the near surface conditions. We perform careful quality control of the daily stacks with respect to variations in temperature, rainfall and wind both on shot and receiver domains to carry out an initial assessment of the repeatability. [5] demonstrated advancements to the TL seismic processing flows in order to more accurately image the TL signal of the plume in both baseline and monitor surveys. These processing advancements were carried out on data that was initially acquired with conventional vibroseis sources paired with the same buried geophone array. Upon quality control of SOV data, these flows are then utilised to guide the SOV data processing. Figure 2 shows daily stacked shot gather of SOV 2 data prepared for the data processing.

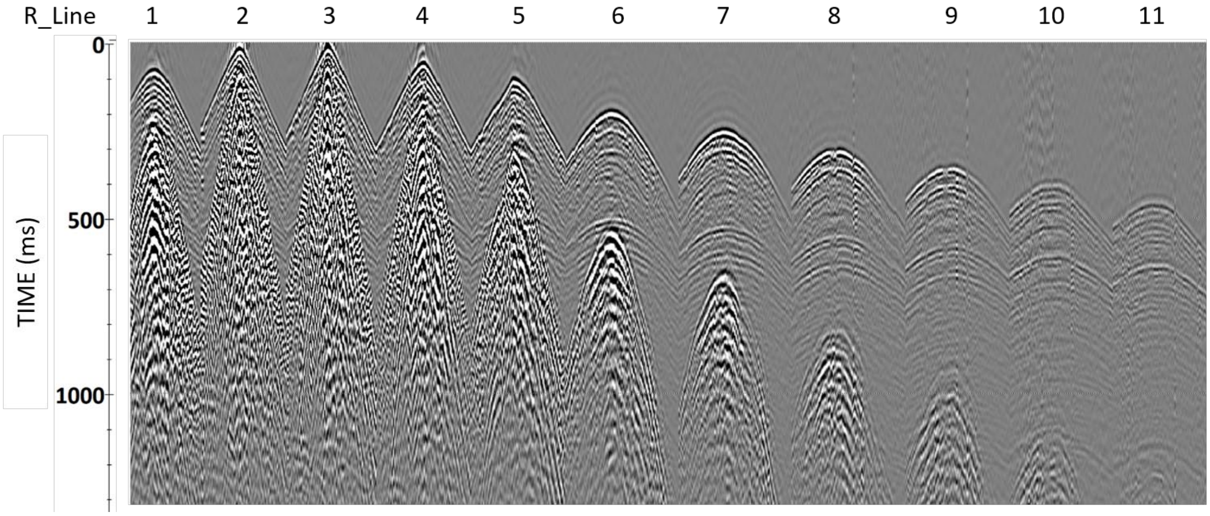

Fig. 2. SOV 2 data day stacked shot gather

The ground roll, specifically in late autumn, has a significant detrimental effect on the data. During the pre-processing of SOV data, to avoid this adverse effect, a special effort is made on testing ground roll removal techniques and cross-equalisation of the source wavelet before producing the difference seismograms. After ground roll removal and cross equalisation we first generate a baseline (shot/day gather) by stacking the first few days of data acquired from mid-February 2016. The phase and amplitude differences as well as the time shifts between the baseline and the day stacks are calculated for all traces in a 600 ms time window above the reservoir level, which starts below the first arrivals to around 1 s. The majority of the amplitudes provide a correlation percentage of 70 – 100 % with the time shifts ranging from -1ms to 1ms. Following this, a zero-phase spiking deconvolution, amplitude compensation, a bandpass filter and radon filter were applied to the data. Figure 3 displays the SOV2 baseline and last week of March 2016 1 week stacked data for the detection of the plumes seismic signal. Shot domain migration techniques are also tested. Although we managed to recover major known reflections in the SOV seismic sections, the seismic signal from the plume could not be retrieved.

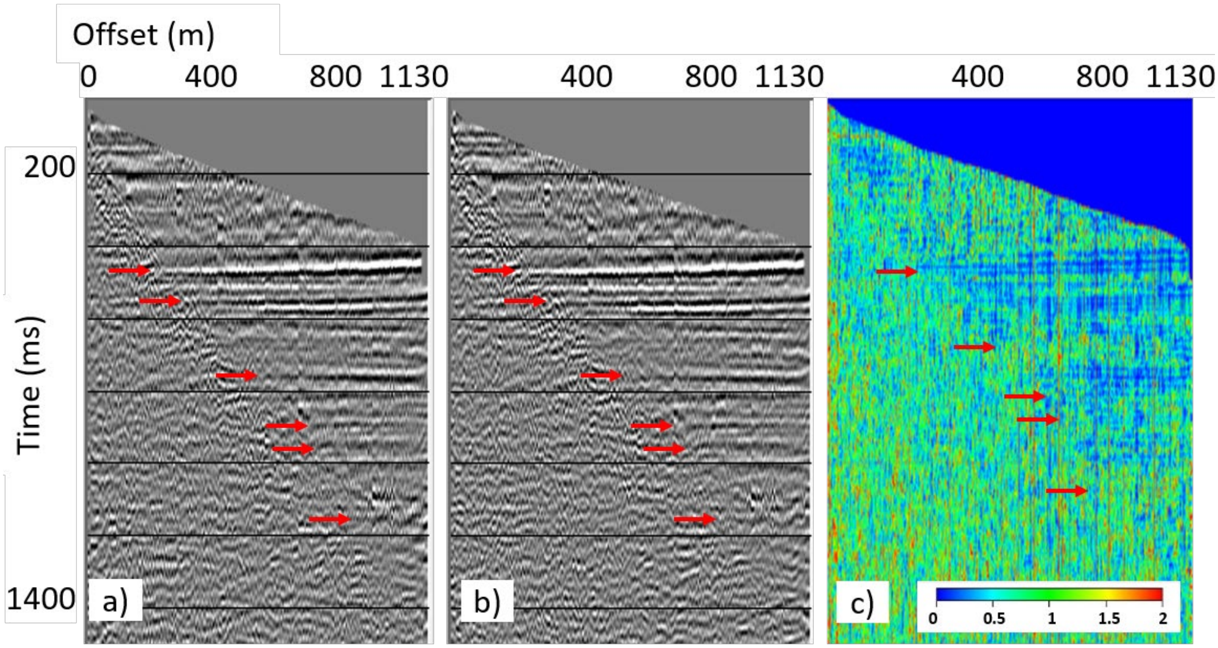

Fig. 3. a) SOV 2 Baseline shot section, a) SOV 2 last week of March 2016 shot section and c) NRMS between a) and b)

4. Repeatability

The repeatability analysis is conducted concurrently with seismic processing and the initial assessment is performed on the daily stacks with respect to near-surface conditions. While the rainy season has poor repeatability, which gradually decreases with increasing interval time (from days to months), the continuous acquisition helps to increase the repeatability of the conventional TL seismic data. Strong reflections below the first breaks for two known strong geologic interfaces are observed. Normalised Root-Mean-Square (NRMS) variations of these reflectors and first breaks showed relatively low (up to 0.2) NRMS values for the majority of the traces (Figure 3). In order to assess the general repeatability trend of the data, we display the results with regards to NRMS variation for long window NRMS calculated for the baseline. This time period was specifically chosen to capture the plume evolution from monitor 2 and monitor 3 surveys. We then asses all major data processing steps in relation to repeatability. This allows us to fine-tune the processing.

5. Conclusions

Considerable progress is made on signal-to-noise ratio of the SOV signal. As there are only two SOVs, the CMP fold is extremely small. Hence, the ability to advance the data quality through conventional data processing methods is quite limited. Therefore, the generation of day stacks allowed for the improvement in repeatability results. As expected, the effects of weather conditions on the near-surface coupling affected the data quality. Although SOVs provided sufficient repeatability for the known reflectors, deeper reflections around plume level are masked by the ground roll. This precludes robust detection of the TL signal associated with the injection of CO_2. However, complementing the experiment with the weather data, utilising conventional monitor survey processing flows as a guide, having a knowledge of geology and the plume information in the survey area and utilising NRMS analysis in various stages of the processing, allow us to tailor the data processing for SOVs. As another result, it is clarified that going further offsets with the SOVs to minimize the impact of ground roll, perhaps we would be able to improve the ability of the SOV geophone array to image the plume. The satisfactory results will create a base for the next stages in borehole permanent reservoir monitoring.

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