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SPARSE passive monitoring of large-scale CO_2 storage sites

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Summary

One of the significant challenges for large-scale CO_2 storage operations is the high cost associated with conventional long-term geophysical monitoring. Operators must demonstrate that the stored CO_2 remains securely contained, necessitating decades of monitoring during the operational phase and post-injection.

This has triggered the development of sparse, low-cost geophysical monitoring approaches that may be based on sparsely distributed "nodes" located on the sea floor or on land, e.g., in the ACT4 SPARSE project. The nodes can be equipped to acquire both active and passive data, such as seismic, EM, gravity, sea floor deformation, etc. The focus of sparse monitoring is to establish conformance between model predictions and observed data during the CO_2 injection. For long-term low-cost monitoring, passive monitoring methods may be particularly suited, as no active sources are required on or around the data acquisition nodes, reducing cost for operation and maintenance as well as minimizing the impact on the environment.

Within the SPARSE project we investigate if and how passive seismic monitoring methods (e.g., using teleseismic data) can be used optimally as a part of sparse monitoring systems. In this paper we present first results of a feasibility study that investigates if teleseismic data can be used for CO_2 monitoring.

Theory / Method / Workflow

We investigate the use of low-frequency passive data from teleseismic events, for sparse node-based monitoring.

Teleseismic earthquakes occur regularly, e.g., at plate boundaries, and may be used for 4D analysis, provided that repeating events with comparable waveforms can be identified and the data are sufficiently sensitive to small amounts of CO_2 in the subsurface.

Initial numerical modeling of the WIFF effect of CO_2 on low-frequency (1-5 Hz) teleseismic data showed a clear effect of the presence of CO_2 on spectral amplitudes. In addition, it has been shown that changing gas saturation may have a visible influence on the amplitude spectrum of low frequency waves from seismic noise (e.g., Frehner et al., 2007, Saenger et al., 2008, and Kremer et al., 2024).

To explore if repeating events can be observed, we analyzed teleseismic events from Japan, Alaska, and South America, recorded at seismological broadband stations near the Aquistore CO_2 storage site in Canada. These stations were unaffected by CO_2 and served as reference stations. Several similar events could successfully be identified between 2014 and 2024 (Figure 1).

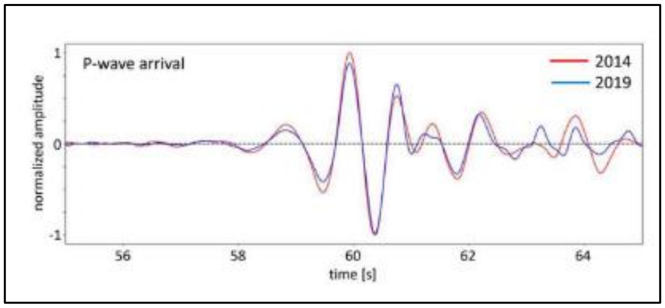

Figure 1: Example of repeating events.

In a second step, the identified events were analyzed at five permanent stations at the Aquistore site. Our initial analysis focused on spectral changes over time at Aquistore compared to the stable reference stations. We examined different spectral attributes, such as v/h ratios and 4D spectral ratios.

The examples in Figure 2 show spectral ratios within a narrow 0.75 to 1.3 Hz window where the noise level was low. The spectral ratios are given for the reference stations (EPLO) and the available Aquistore stations (SV1- SV5). The Figure on the left shows the spectral ratios for two events that occurred only few days apart so that no change of the CO_2 distribution is expected. The spectral ratios of the Aquistore stations are mostly constant and comparable to the one at the reference station (EPLO). The plot on the right shows an example where the first event occurred in 2015 and the second one in 2022. Unfortunately, only one Aquistore station was available for both events. While the spectral ratios for the reference station are similar to the previous example, the one at Aquistore (SV2) shows a clear reduction of the spectral ratios around 1Hz.

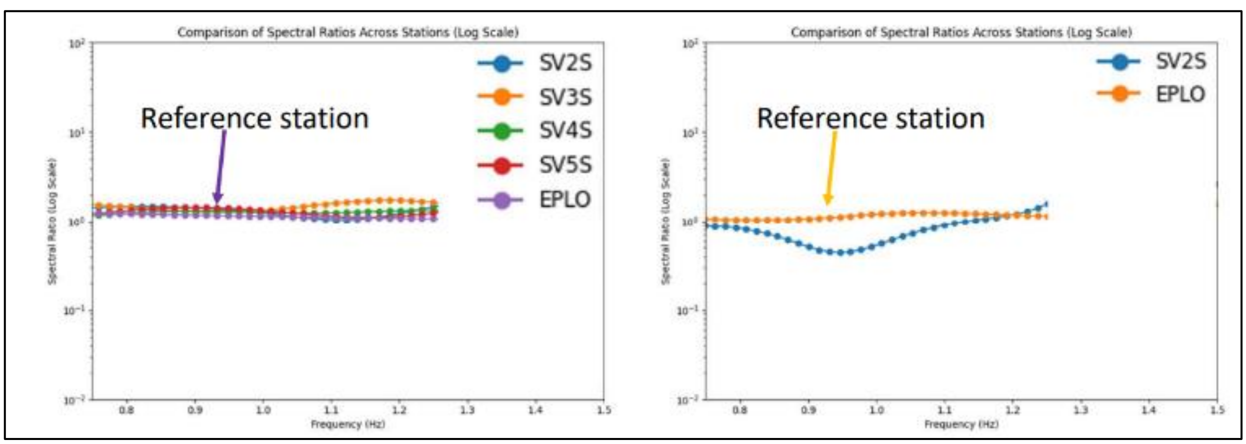

Figure 2: Example results for Aquistore site. Spectral ratios of first arrival data of two events observed within few days (no change) on the left. Spectral ratios of an event in 2015 and one in 2022.

During the data analysis it was observed that while the noise level was generally low at the reference stations, it was rather variable at the Aquistore site and data with high noise levels were excluded from further analysis. While the first results look promising, further analysis is required to investigate any potential influence of remaining noise, and the sensitivity of the method to small amounts of CO_2.

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