Distributed Acoustic Sensing for Seismic Monitoring: A Geothermal Case Study in Switzerland

Introduction

The GeoCogen Eclépens geothermal project by Swiss Geo Energy (SGE), in collaboration with the Swiss Federal Office for Energy (SFOE), is targeting both deep and shallow geothermal targets in the region of Eclépens in Vaud, Switzerland. The 3D seismic exploration campaign carried out in the Fall of 2023 covers a survey area of 104 km^2 and is traversed by 16 km of fiber optical (FO) cable (Figure 1). This unique opportunity was used to test the potential of Distributed Acoustic Sensing (DAS) methods for passive seismic monitoring in geothermal exploration endeavours. The innovative methodology offers an alternative to conventional geophones and offers a high degree of continuous spatial sampling (Shatalin et al., 2021). The following DAS study is the first of its kind in Switzerland and offers insight into the use of such technology in the geothermal industry. In this study, we assess the quality of acquired DAS data using preinstalled telecommunication FO cables and determine its sensitivity to microseismic events for future continuous monitoring.

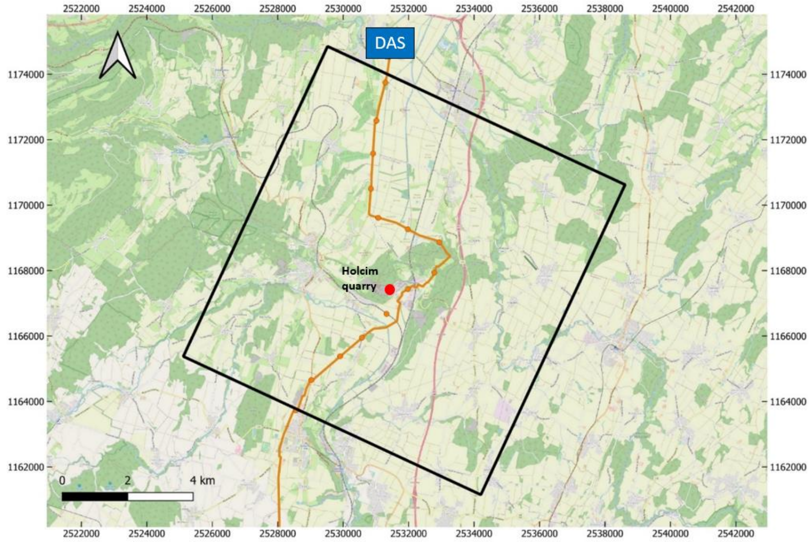

Figure 1 *GeoCogen 3D survey area with FO cable path (orange). The red dot corresponds to the quarry and the orange dots to horizontal geophones in place along the cable during the survey.*

Method and Theory

The DAS system measures strain-induced phase changes in backscattered laser pulses down a fiber optic cable caused by subsurface acoustic wave propagation (Hartog, 2017). Single component strain rates inline with cable orientation are calculated, allowing for wavefront characterization over a wide range of frequencies. Such data has proven to produce similar results to geophones (Shatalin et al., 2021). The methodology allows for continuous signal sampling and high spatial resolution, particularly suiting it for passive continuous seismic monitoring (Hudson et al., 2021).

In the following study, the DAS interrogator is located to the North of the GeoCogen survey area in Orbe (VD) and connects to the FO cable, which crosses the survey area along a curved trajectory oriented approximately north-south. The FO cable is buried underground (~ 3 m) in a casing and follows a gas pipeline conduit; however, the exact cable conditions in the casing are largely unknown. The DAS acquisition parameters were tested and calibrated to achieve the best quality in the recorded strain data. These include the time sampling rate, the spatial sampling rate, and the gauge length (GL). The GL defines the window over which the signal phase change is considered to calculate the strain rate and can be considered as the spatial resolution along the FO cable (Hartog, 2017). The GeoCogen Eclépens DAS study used a time sampling of 2 ms, a spatial sampling of 2.5 m, and a GL of 10 m.

SGE's study aims to clarify the potential role that DAS could play in passive microseismic monitoring. To characterize DAS data quality and seismic detectability, we considered two categories of seismic sources: active-induced seismic sources and passive natural sources. The DAS system actively recorded 13,790 vibroseis sweeps (linear 5 – 85 Hz, 36 s) from the GeoCogen 3D survey. The data was correlated to the corresponding sweep and extracted along a 10 s window. Additionally, active quarry blasts were measured to simulate and characterise the DAS sensitivity to microseismic events. The DAS system also passively listened for subsurface seismicity in the region. A 1.3 magnitude earthquake was registered under Geneva Lake offshore from Saint-Prex (VD) and detected by the DAS recordings. We expect these results to qualitatively assess the response and coupling of the FO cable to induced strain.

Results

Figure 2 illustrates two extracted vibroseis sweeps at different offsets. The vibroseis sweep signal is clearly visible along the DAS recording, we observe the propagation of the signal from the shot position to either side of the FO. Different parts of the signal can be distinguished: the first break (shallow, linear, weak amplitude) and the surface waves (lower velocity, steep, high amplitudes). Such signal detectability is encouraging for the monitoring of seismicity. At 0 m offset, the signal propagates from the source point around 2 km on either side of the cable. At 500 m perpendicular offset, results reveal an already weaker fading signal extending only 1-1.5 km on either side of the cable. Our data shows that beyond 900 m offset, the signal has already been significantly dampened. These results testify to the FO cable's single-component sensitivity to strain. Vibroseis sweep signal detectability extends 2-3 km when inline with the FO cable and stops around 1 km in the perpendicular offset. A better coupling quality between the FO and the ground and additional real-time signal processing could better support detecting such small seismic events in a full range of azimuths.

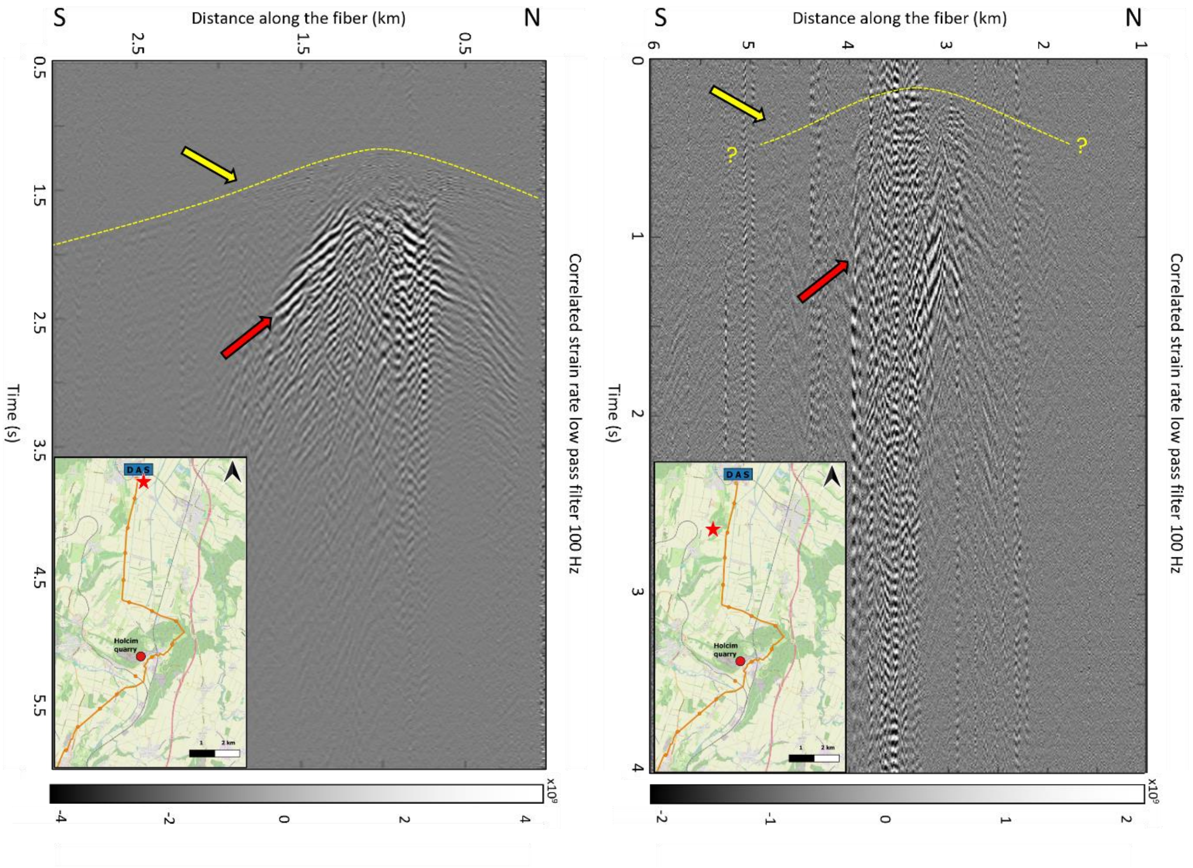

Figure 2 *DAS strain rate sections along the fiber optic cable from the correlated vibroseis sweeps. Left: the source position is near the FO cable at 0 m offset. Right: the source position is at 500 m offset from the FO cable. The red star indicates the position of the vibroseis sweep. The yellow arrow indicates the P-wave's first break, and the red arrow indicates slower surface waves.*

In addition to vibroseis sources, active quarry blasts were used to simulate the energy released during low-magnitude earthquakes (< M1) and assess the extent of detectability and the quality of the signal/noise levels along the FO cable. Figure 3 illustrates the signal and noise RMS response of the DAS data extracted along 16 km of cable after sequential dynamite blasts.

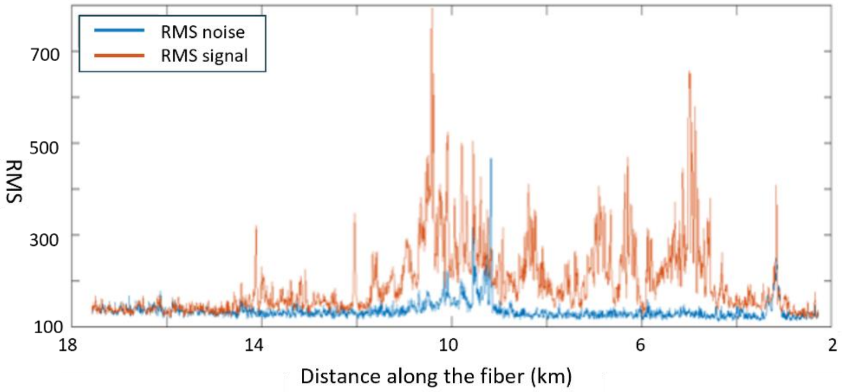

Figure 3 *RMS of the signal and noise from the DAS data of sequential dynamite blasts in the quarry.*

The detected signal from the sequential blasts is visible along all 16 km of the FO cable, suggesting sufficient sensitivity to detect seismic events of similar magnitude. In turn, the FO is also sensitive to surrounding anthropogenic activity, as shown by areas of high RMS noise, such as the industrial area at around 10 km. In these areas, some FK filtering might help denoise. The varying signal RMS also indicates possible changes in ground-coupling quality along the cable. It is still difficult to fully assess the coupling quality because the cable's disposition and burial conditions are largely unknown.

Finally, from the passive continuous seismic monitoring, the DAS system was able to detect a M1.3 earthquake near Saint-Prex 10 km from the closest FO point. The dataset is challenging as the seismic event has a small signal amplitude and large amounts of noise. Figure 4 presents the DAS recording of the earthquake after SNR enhancement (noise removal, FK filtering, spatial stacking) and calculating the short-term average/long-term average (STA/LTA) attribute with spatial smoothing.

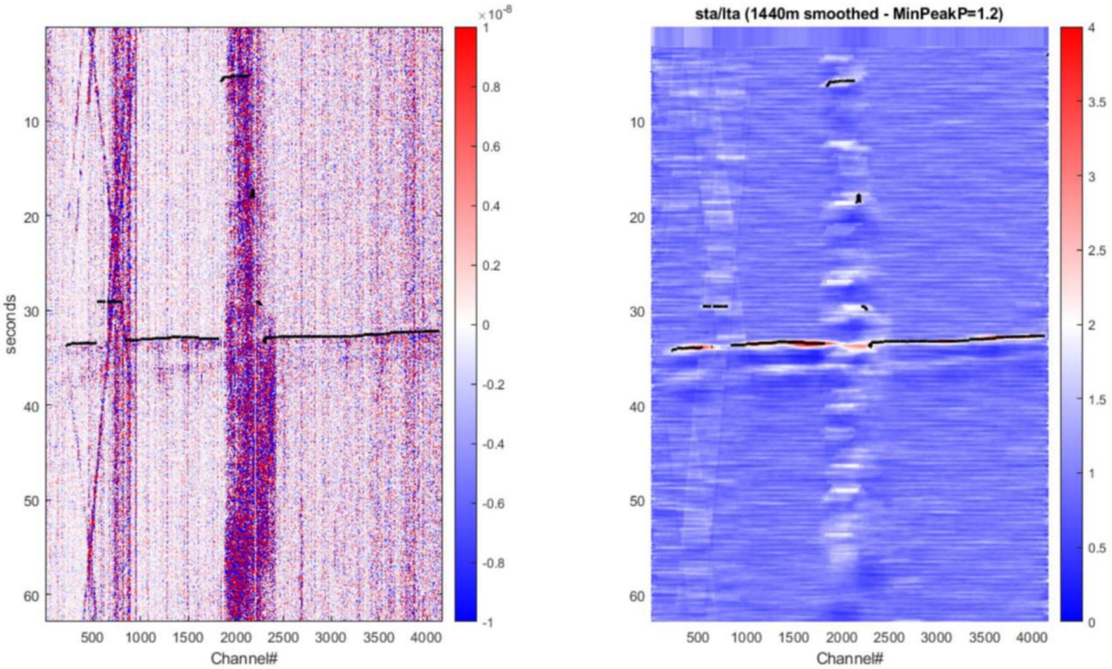

Figure 4 *Left: Earthquake DAS recording after complete processing. Right: STA/LTA attribute with 1440 m spatial smoothing aperture and peak detection with 1.2 minimum peak prominence.*

The black line highlights the earthquake energy along the FO, the detectability of such a low-magnitude event across the entire FO length is promising for the use of DAS in seismic monitoring. However, the M1.3 earthquake was first detected using the Swiss Seismological Service (SED) database and then subsequently tracked down in the DAS recordings. Automatic earthquake detection solely using DAS data is possible but challenging; it would require the exploration of the full dataset, and the application of the necessary processing is difficult in real-time. Developing such an automatic detection technology would require significant amounts of time and R&D in future studies. The DAS data collected in this study offers an excellent field data foundation for such projects.

Conclusions

The recording of active and passive seismic sources by DAS methods aimed at assessing the quality of the FO cable in place in Eclépens and determining its sensitivity to seismic events. Our active source results show the successful detection of vibroseis and quarry blasts by the FO. These results highlight the azimuthal sensitivity and susceptibility of the DAS system to noise. The passive listening successfully recorded a M1.3 earthquake across the entire fiber length, such detection highlights the promising future of the DAS methodology in seismic monitoring. At this stage, technological progress in automatic detection is required to advance further. The DAS data collected in this study offers an excellent field data foundation for such projects.

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References

Hartog, A., H. [2017] An introduction to distributed optical fiber sensors, RC Press. 440 pp.

Hudson, T. S., Baird, A. F., Kendall, J. M., Kufner, S. K., Brisbourne, A. M., Smith, A. M., ... & Clarke, A. [2021]. Distributed acoustic sensing (DAS) for natural microseismicity studies: A case study from Antarctica. Journal of Geophysical Research: Solid Earth, 126(7), e2020JB021493.

Shatalin, S., Parker, T., and Farhadiroushan, M. [2021]. High definition seismic and microseismic data acquisition using distributed and engineered fiber optic acoustic sensors. Distributed acoustic sensing in geophysics: Methods and applications, 1-32.