Modeling and analysis of Distributed Acoustic Sensing (DAS) data in Geothermal Environments

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Abstract

In recent years, interest in Distributed Acoustic Sensing (DAS) technology has surged, especially in microseismic monitoring within borehole installations. DAS, with its superior spatial sampling compared to traditional seismological technologies like geophones or seismometers, offers detailed seismic wavefield information. However, standard microseismic data analysis faces limitations with DAS systems' sub-meter inter-sensor spacing. To address this, we propose a semblance-based seismic event detection method leveraging DAS's high spatial sampling. Despite widespread DAS adoption, questions persist about its self-noise compared to traditional systems and how ambient noise recorded by DAS diminishes with depth. Our study characterizes noise in DAS data from borehole installations, specifically at the FORGE site in Utah, USA. PSD Analysis evaluates depth-dependent noise reduction and its temporal variations.

Keywords

Distributed Acoustic Sensing, Microseismic Monitoring, Semblance, Power Spectral Density, Frontier Observatory for Research in Geothermal Energy

Introduction

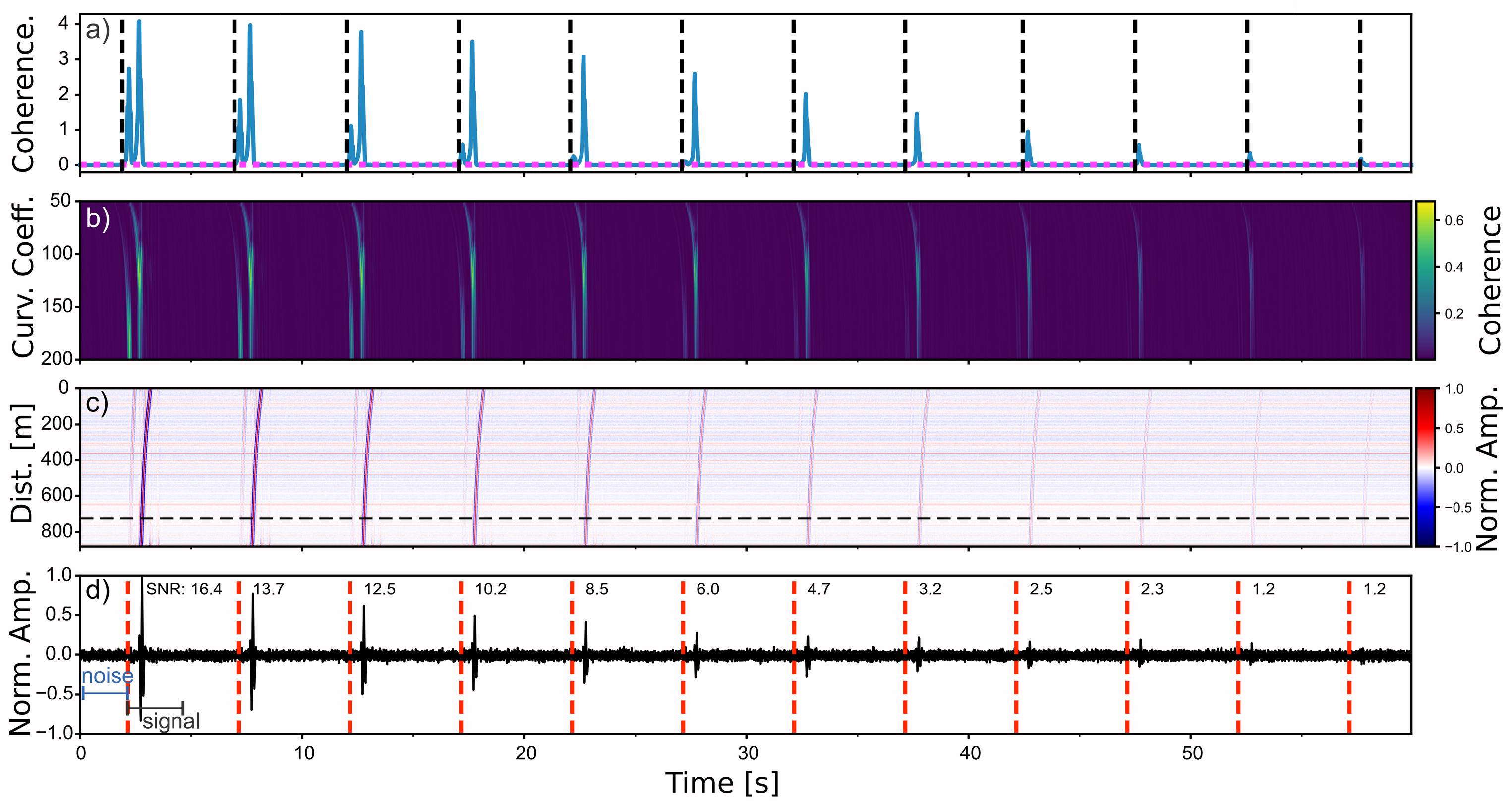
Distributed Acoustic Sensing (DAS) allows to turn fiber optics such as conventional telecommunication or engineered cables into a dense array of seismometers (i.e. a seismic antenna) that can samples the seismic wavefield (almost) continuously for several kilometers. A DAS system consists of an **Interrogator** and **Fiber-optic cable**.

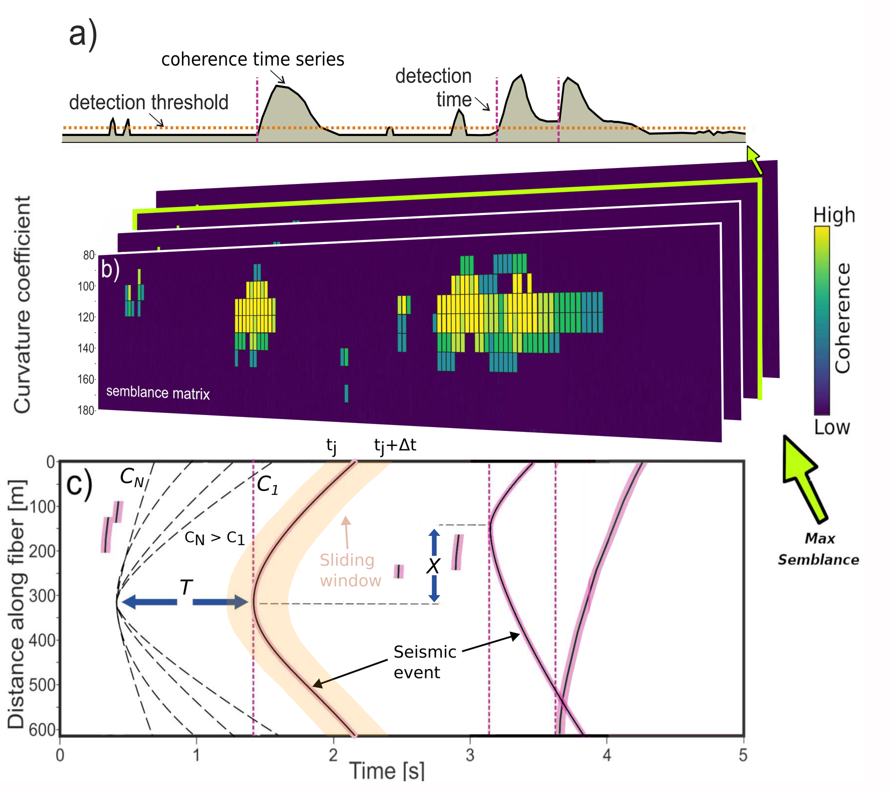
DAS Systems utilize **backscattering**, a phenomenon where a wave encounters a reflective body much smaller than its dominant wavelength. In fiber optics, backscattering occurs when a light pulse interacts with points of different refractive index, such as artificially included impurities in the fiber.

EGSs, artificial geothermal reservoirs with high-temperature dry rock formations, use hydraulic stimulations, injecting fluid at high pressure to create a fracture network for heat excange. However, **induced seismicity** remains a concern (Grigoli et al., 2018). To tackle this, the U.S. Department of Energy initiated the **FORGE** experiment in Utah, focusing on developing microseismic monitoring methods for induced seismicity in geothermal environments (Lellouch et al., 2021).

Methods: *Semblance*

$$S(T,X,C)=\frac{\sum_{j=1}^{N}\left(\sum_{i=1}^{M}A(t_{ij})\right)^2}{M\sum_{j=1}^{N}\sum_{i=1}^{M}A(t_{ij})^2} \quad \text{with} \quad t_{ij}=t_i(T,X,C)+j\mathrm{d}t$$





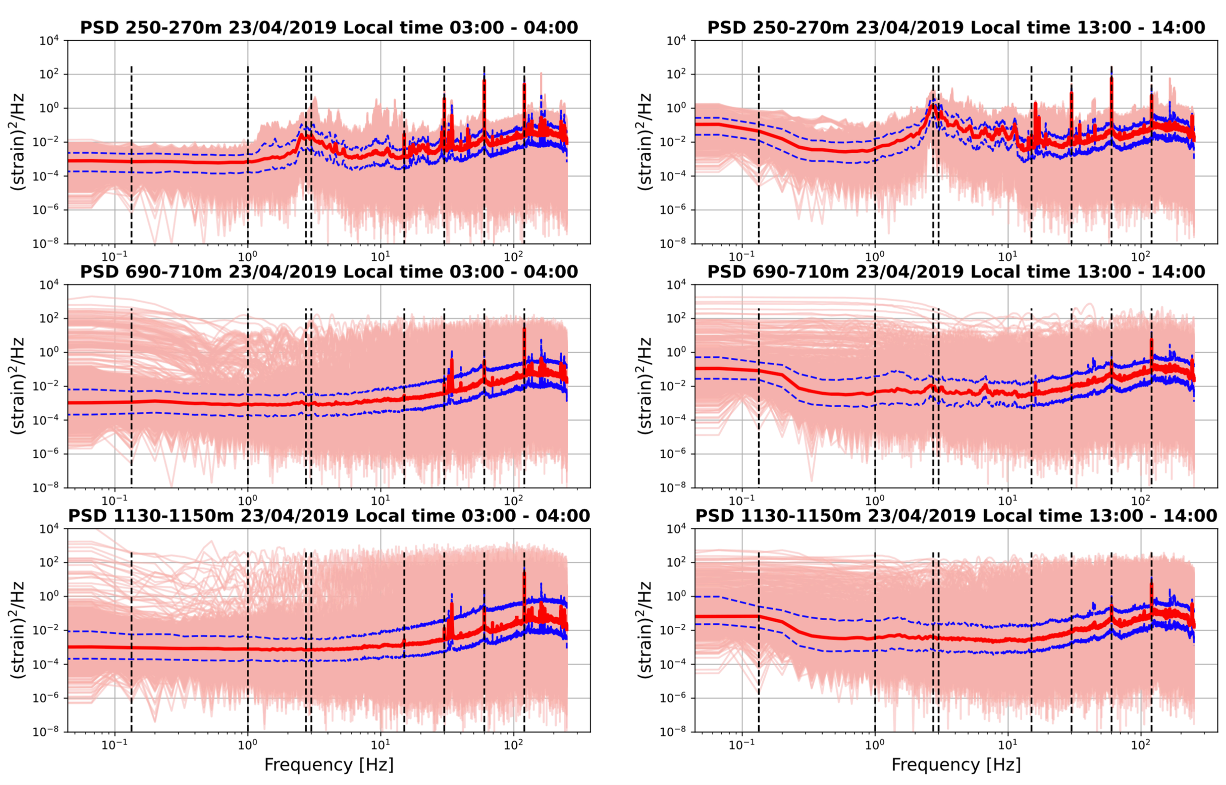
a) represents the coherence time series, which overcomes the detection threshold in the presence of energy signal.

b) shows a volume of 2D semblance matrices resulting from the scanning of the waveform coherence along geometrical hyperbolic shapes.

c) illustrates the range of geometrical hyperbolas at each X and T used to measure the waveform coherence along a finite-width data window.

Power Spectral Density Analysis

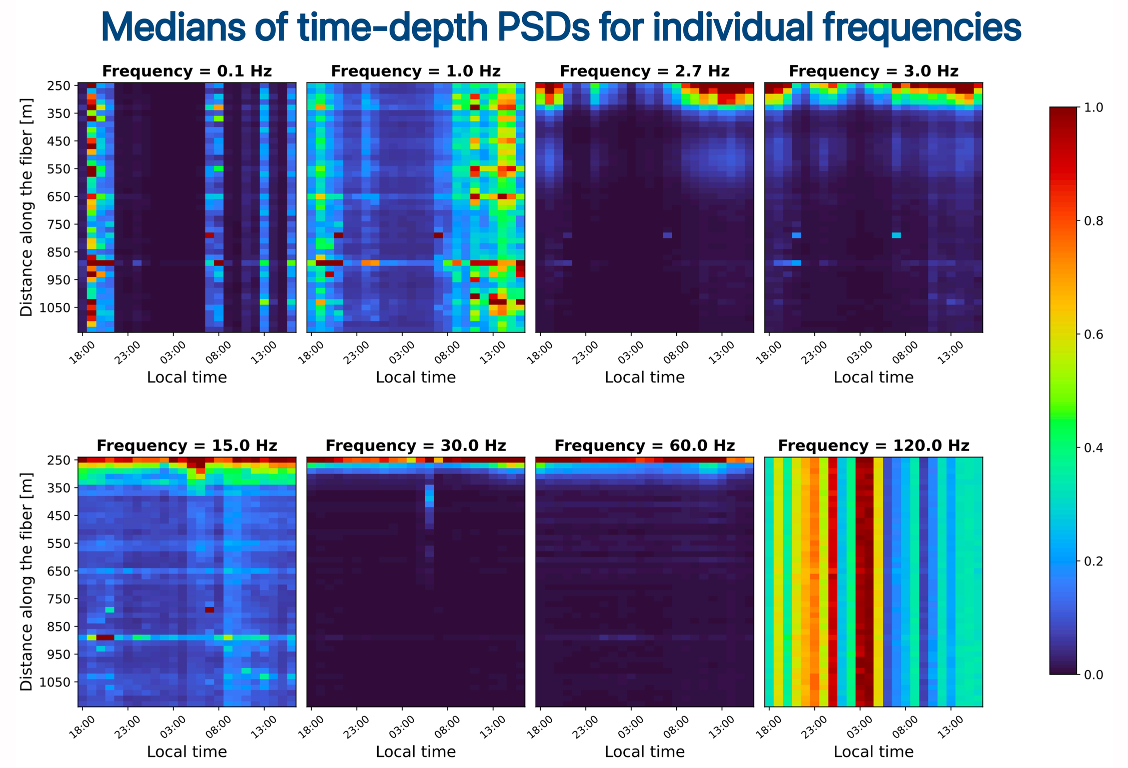
$$Y_k=\frac{Y(f_k,T_r)}{\Delta t} \qquad P_k=\frac{2\Delta t}{N}|Y_k|^2$$



Workflow

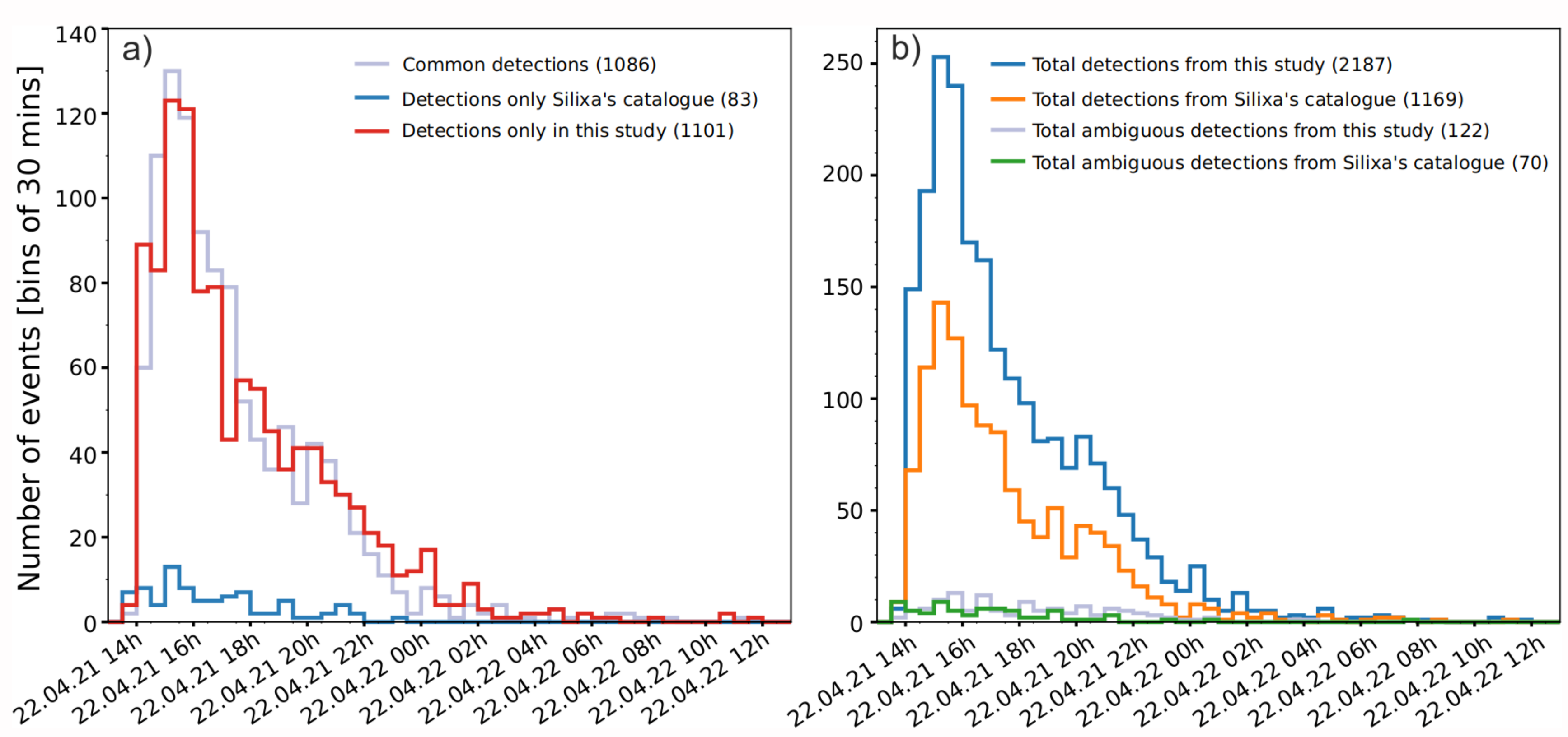
- Selection of 100 random windows of 15 seconds each for each hour of the day;
- Computation of PSDs for each channel of the DAS fiber (1150 channels);
- Division into depth intervals of 20m each;
- Computation of PSD medians for each depth interval for each hour of the day
- Analysis of noise behaviour for each frequency

Medians of time-depth PSDs for individual frequencies

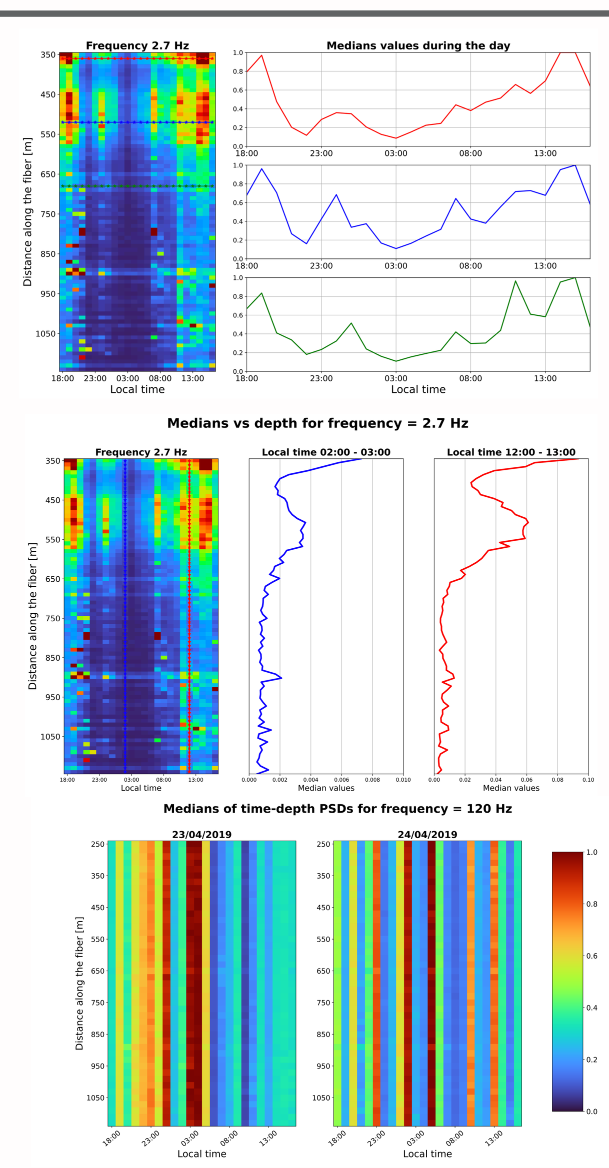


Results

Comparison between our detections and existing catalogue



Our catalogue contains 2187 microseismic events, from which 122 are classified as "false detection" (5.6 %), while the Silixa's catalogue contains 1169 microseismic events with 70 of them classified as "false detection" (6.0 %).



1) Daily noise trend clearly evident at deeper levels for low frequencies.

2) Anomalies in noise decay observed at depths between 400-600m.
Hypothesis:

- change of temperature
- change in geology
- faulting sistems

3) No correlation between the behaviour of the 120 Hz medians computed for different days.

- unpredictable electronic noise along the fiber

Conferences

National Group for Solid Earth Geophysics (GNGTS), February 2023, Bologna, Italy.
EGU General Assembly, April 2023, Vienna, Austria.
Japan Geoscience Union Meeting (JPGU), May 2023, Tokyo, Japan.
(Invited talk) Earthquake Research Institute, May 2023, Tokyo, Japan.
International Union of Geodesy and Geophysics (IUGG), July 2023, Berlin, Germany.
Seventh EAGE Borehole Geophysics Workshop (EAGE), September 2023, Milano, Italy.
AGU, December 2023, San Francisco, USA.

Publications

D.Pecci, F. Grigoli, M. De Solda, J. Porras, A. Mazzotti, E. Stucchi, R. Iannelli (2023). Modeling and Analysis of Distributed Acoustic Sensing (DAS) data in Geothermal Environments. Earth Doc, (Conference Paper)

J. Porras, D. Pecci, G. M. Bocchini, S. Gaviano, M. De Solda, K. Tuinstra, F. Lanza, A. Tognarelli, E. Stucchi and F. Grigoli A Semblance-based Microseismic Event Detector for DAS data. GJI, (accepted).

Future Research

We will thoroughly compare the data obtained with DAS with data acquired with borehole geophones in order to define possible pros and cons. We will develop an open-source tool for generating synthetic DAS events using Pyrocko software and a tool for generating synthetic DAS noise.

References

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- Lellouch A., Schultz R., Lindsey N. J., Biondi B. L., and Ellsworth W.L. (2021). Low-magnitude seismicity with a downhole distributed acoustic sensing array - Examples from the FORGE geothermal experiment, J. Geophys. Res. 126, e2020JB020462.

DESTEC Dipartimento di Ingegneria dell'Energia, dei Sistemi, del Territorio e delle Costruzioni

PON Ricerca e Innovazione 2014 - 2020