THREE-DIMENSIONAL DISTRIBUTED ACOUSTIC SENSING TO MONITOR GEOTHERMAL FIELDS

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Introduction

Local geothermal energy operators in the **Munich area** (Germany) are interested in the capabilities of Distributed Acoustic Sensing (DAS) for routine monitoring of the operated hydrothermal system – the porous Malm reservoir.

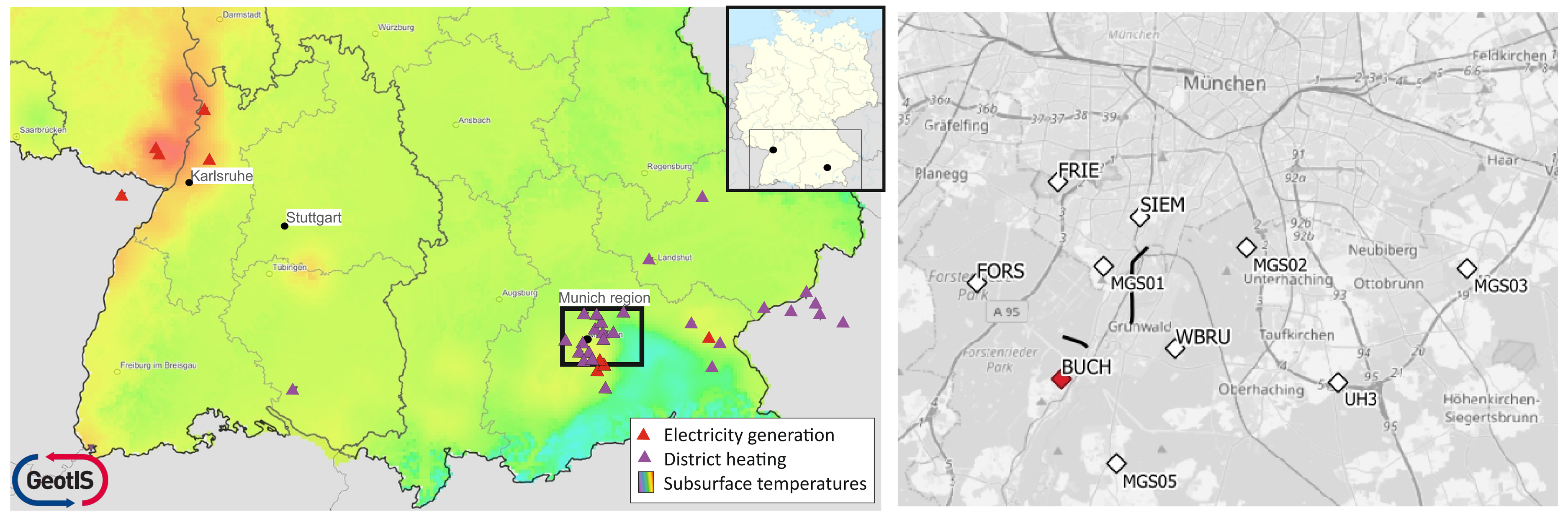
DAS measurements were conducted **on a dedicated infrastructure** in the Munich region, in an urban setting, with the prime objective of **monitoring locally induced seismicity within a 10km radius.** The study covers a range of passive seismic monitoring tasks and explores its capabilities for the monitoring of subsurface properties. We present:

→ the design of the station, giving access to three dimentional sensing capabilities,

→ the processing capabilities, for the location of seismic sources and the estimation of source properties (moment magnitude, stress-drop) from DAS strain-rate data,

→ the validation of the precessing results, which are compared to measurements from the more standard local seismometer network, and the evaluation of converted DAS data.

1 - Context and Station Layout



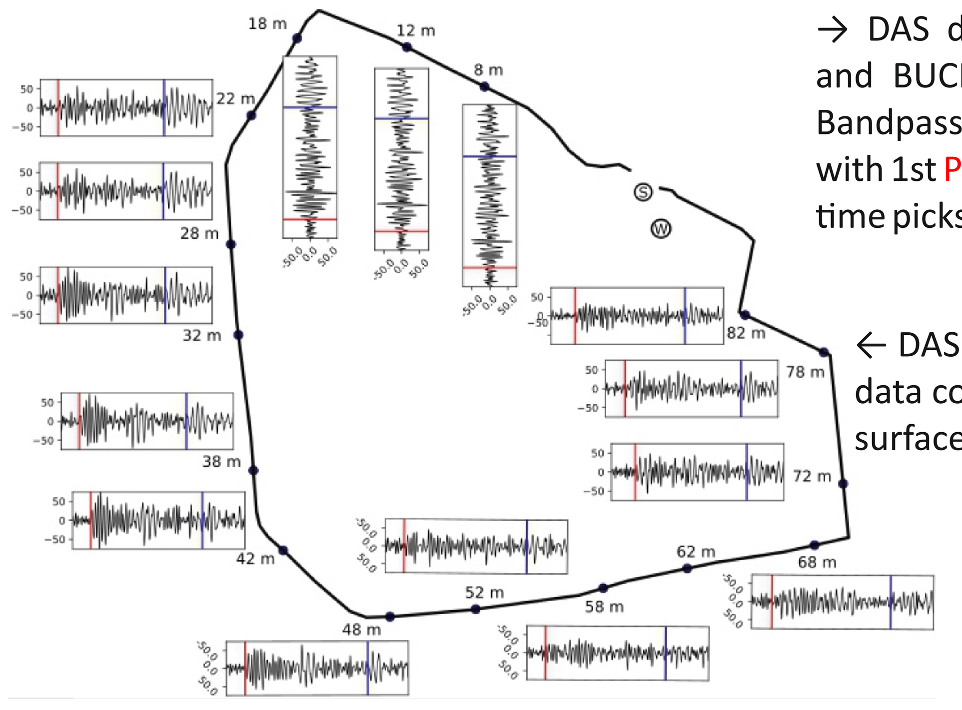
WHERE: Municipality of Buchenhain, south of Munich, in the Molasse Basin

WHAT: A monitoring station (♦) using DAS on a fiber-optic cable with 3D-layout: trenched on surface *and* installed in a monitoring well + reference 3-C broadband seismometer (BUCH). Complements existing seismometer network (♢)

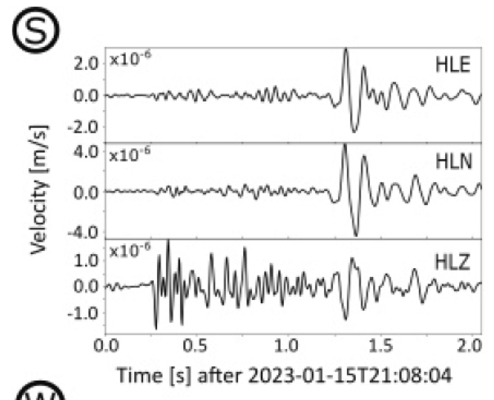
WHEN: Running continuously from March 2021 to end of 2024, with downtimes for hardware updates

2 - Dataset

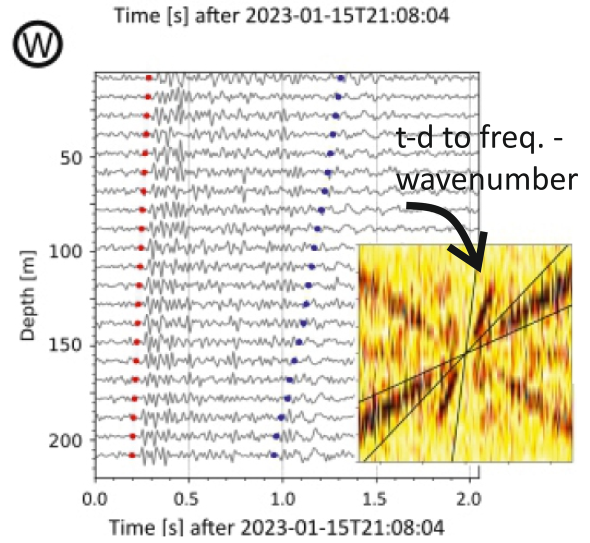
Processing capabilities demonstrated for **Mw 0.5** event on **2023-01-15**



→ DAS data from well (W) and BUCH seismometer (S) Bandpass (B.P.) btw 5-50 Hz, with 1st P- and S- wave arrival time picks



← DAS strain-rate (SR) data collected around surface loop (B.P. filtered)



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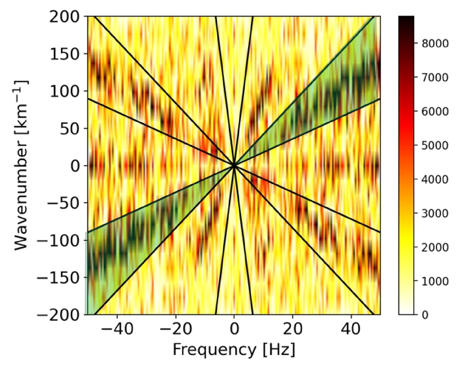
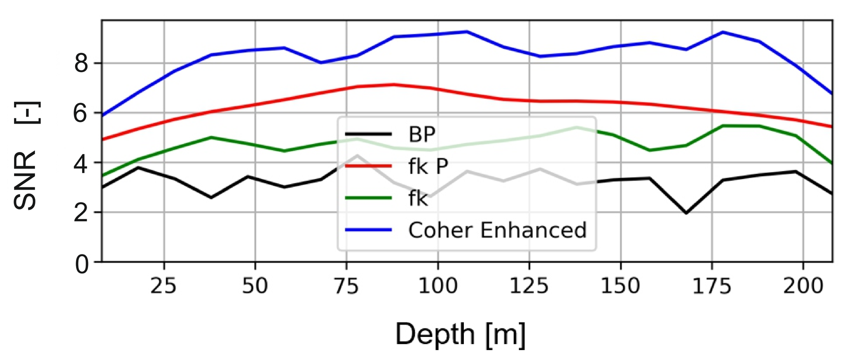
3 - Data Denoising and Spatial Coherence

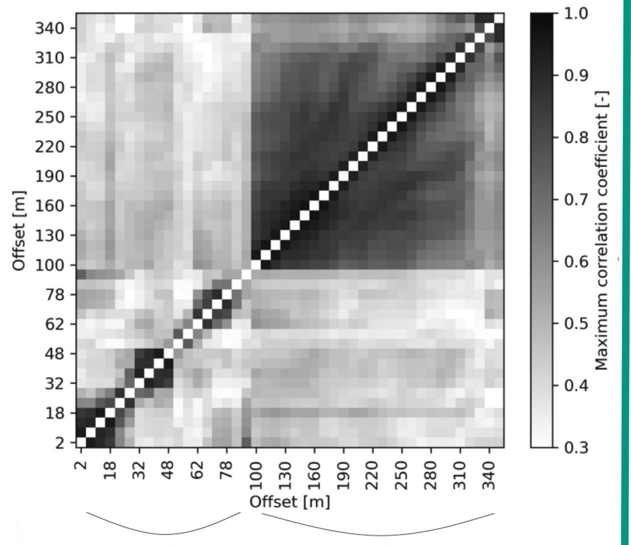
Various filtering approaches are applied to DAS data from the monitoring well:
- **BP:** bandpass filter between 5 - 50 Hz
- **f-k**: BP + isolate all upwards propagating wavefields in f-k domain
- **f-k P**: BP + isolate upwards propagating P wavefield in f-k domain
- **f-k + coher. enhancement**: f-k filtering + coherence-weighting



↑ Example: velocity filter in f-k domain focusing on P-wavefront



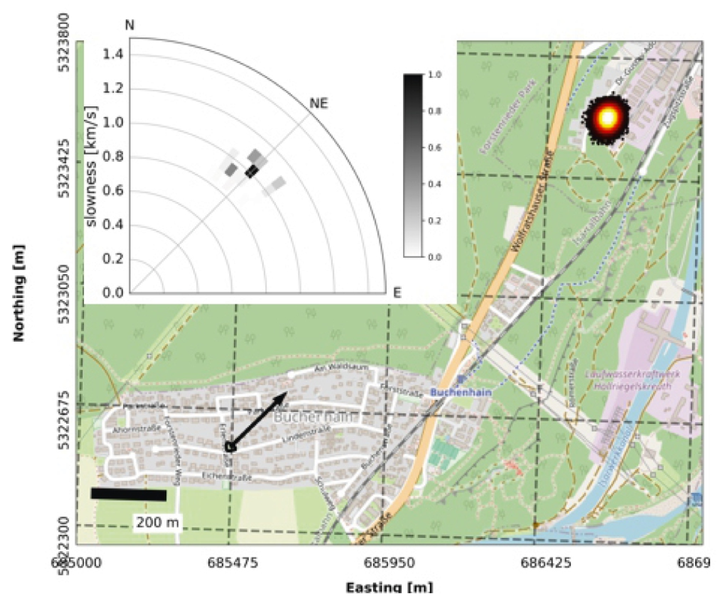
↑ Effect of filtering approaches on SNR of P-wave onset



↑ Maximum CC coeff. between pair of channels, mixing surface (BP filtered) and well (BP+fk) sections

4 - Source Location

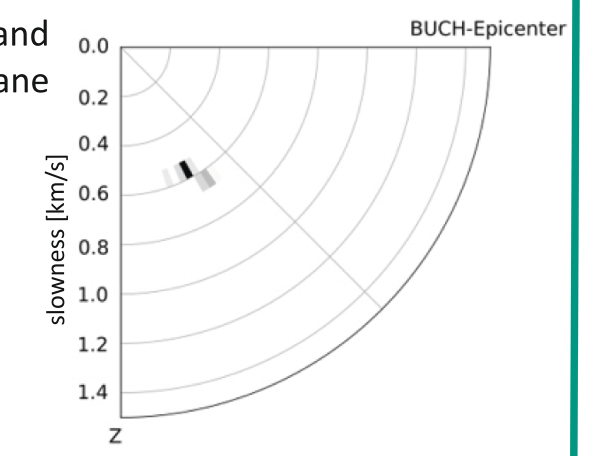
DAS-array in vertical well allows to locate a seismic event on a sphere-like surface (1D sensitivity of sensing points)
DAS-array with **3D-configuration** enables **beamforming,** leveraging multiple azimuths on surface + vertical comp. in well



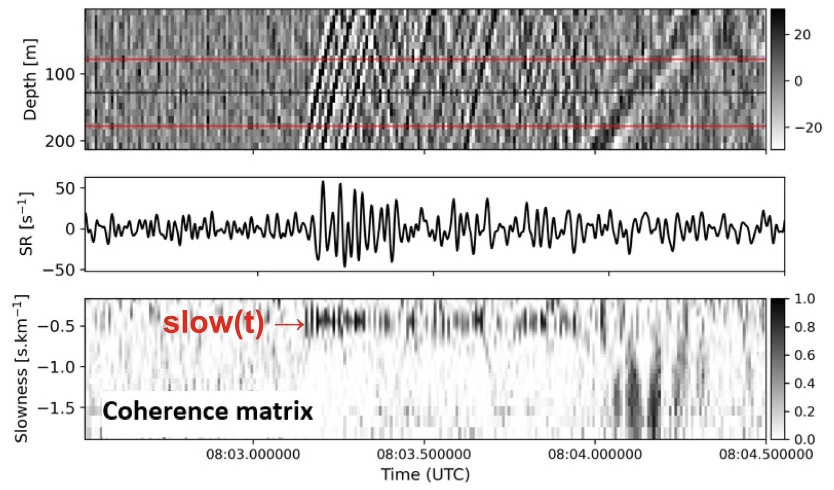
⟶ Estimation of incidence and slowness component in vertical plane

← Comparison between results from
- Surface seismometer network: 68% confidence ellipsoid from NLL
- DAS 3D array: back-azimuth and slowness vector

>> Results are in good agreement



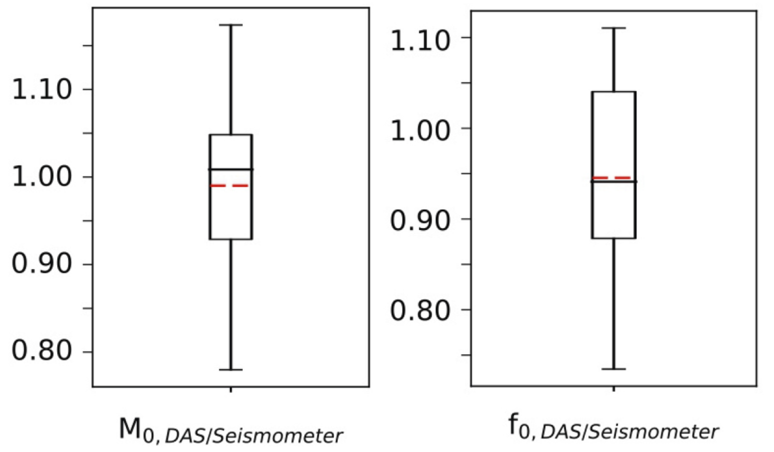
5 - Source Description



Well established methods use ground motion data, not strain-rate.
Strain-rate is converted to acceleration using following equation:
ACC (t) = SR (t) / slow (t)

- A slank-stack is applied to each trace, for a set of trial slowness
- Each (t,d) sample in dataset is attributed a **coherence,** for all tested slowness values. slow(t) obtained by maximizing the coherency in slowness-time-coherence matrix
- As a byproduct, **coherence-weighting** is possible to improve SNR

← Illustration of the workflow for a trace in the well (depth = 110m)



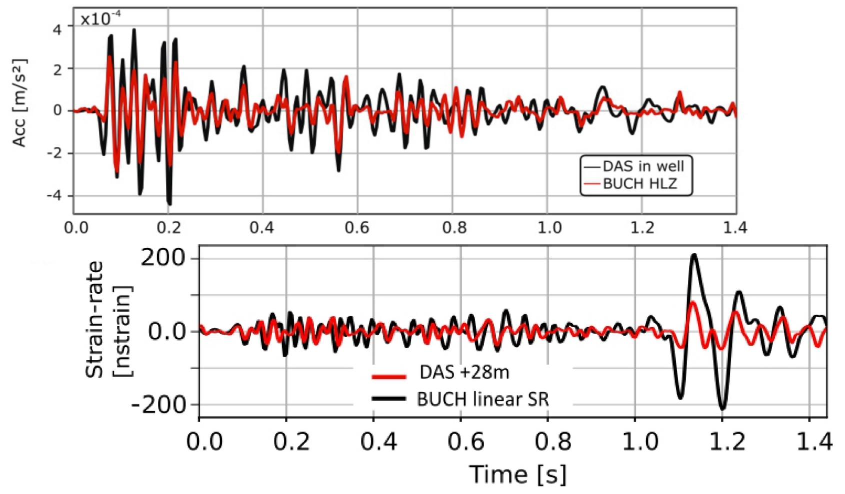
Inversion of source parameters (**moment magnitude, stress-drop**) by fitting the amplitude spectrum to source model (Anderson et al., 1984)

← Comparison of DAS-estimates with measurements from the seismometer network

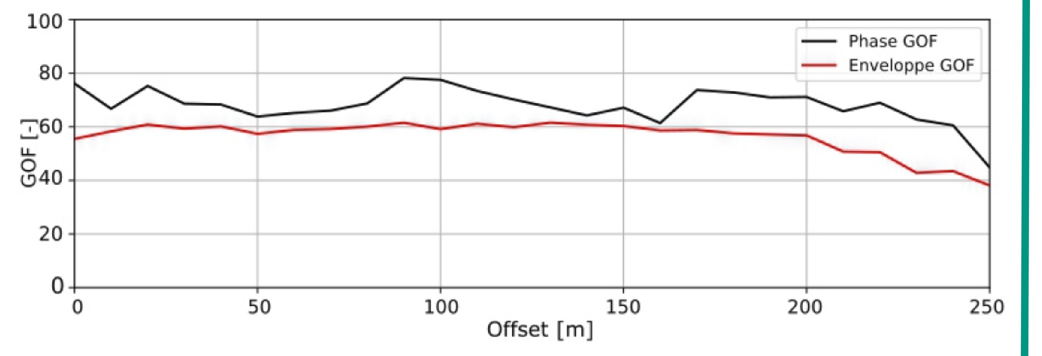
>> Estimations from seismometer network and DAS-estimates **are overall in agreement** for moment magnitude and corner frequency

6 - Comparison of Waveforms

Quantitative **waveform comparison in phase and enveloppe** using Goodness of Fit (GOF) test by Kristekova et al. (2009)
To validate the recorded strain-rate amplitudes and the conversion procedure
- **for in-well DAS channels**: after conversion from SR to ACC, comparing to BUCH HLZ
- **for surface DAS channels**: after conversion of BUCH HL* to linear strain in main recording azimuth of each gauge



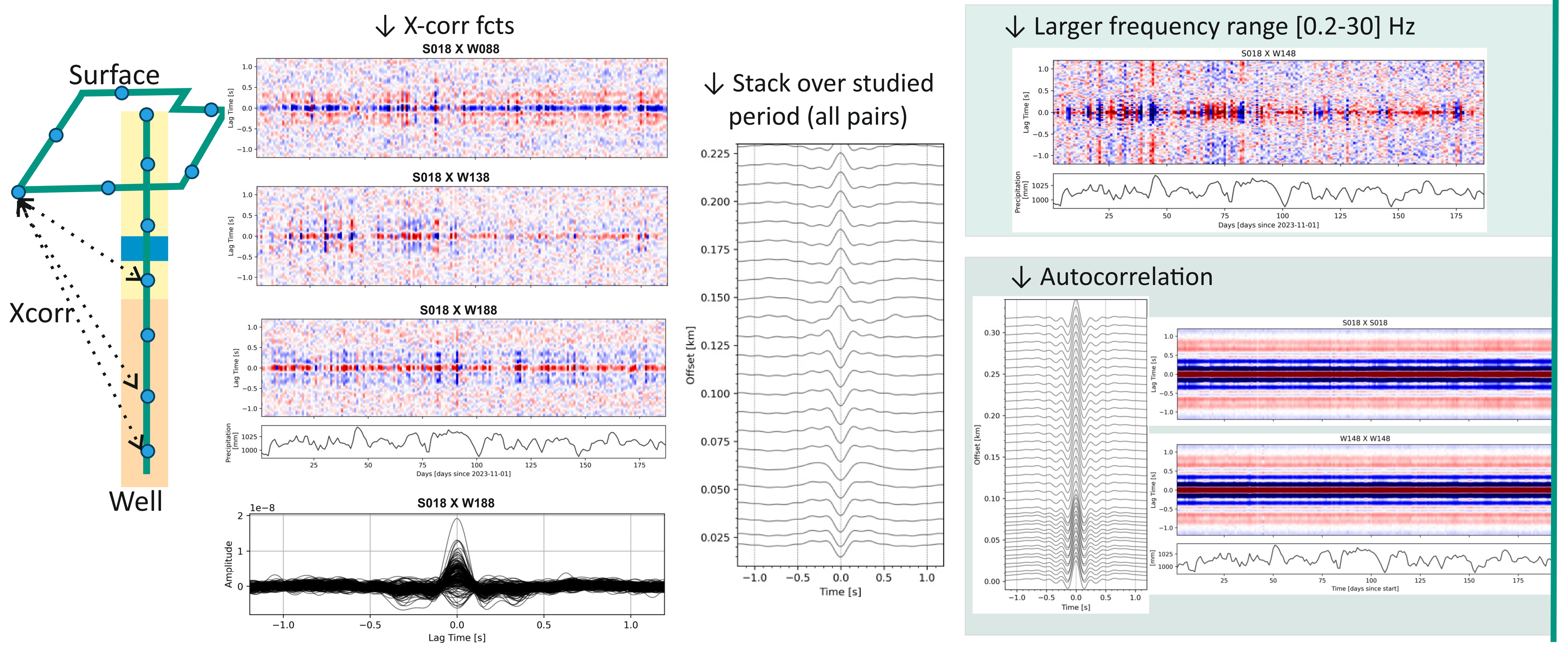
↑ Comaprison at depth of 90 m in well (top) and on loop (bottom)



↑ Evolution of GOF for enveloppe (red) and phase (black) for every channel in well, with reference BUCH HLZ

7 - Ambient Noise Interferometry

Cross-correlation of 30-min segments (no overlap) over 200 days (from 2023-11-01) between channels **in Well and on Surface**
- using MS-Noise (Lecocq et al., 2014) and standard processing (Bensen et al., 2007): detrend, taper, bandpass filter, temporal and spectral normalisation
- In addition: f-k filter (remove common-mode k=0) + data selection (only acquired during night to mitigate anthropogenic sources)
- Focus here on **frequency range [1 - 5] Hz**



Take Home messages

- The DAS-station provides a panel of seismic monitoring capabilities in urban environment from a single fiber optic cable.
- The DAS-estimates and those of the seismometer network are consistent. The station complements existing monitoring capabilities in the region. As any array, the small aperture limits its resolution, with limited sensitivity to more distant and weaker seismic events.
- The comparison of waveforms shows that DAS can capture relevant ground motion and that DAS and seismometer data are compatible in the frequency range we focus on. This opens perspective for hybrid seismic monitoring networks, mixing instruments and configurations.

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INSIDE

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