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AMPLITUDE CALIBRATION FOR DISTRIBUTED ACOUSTIC SENSING

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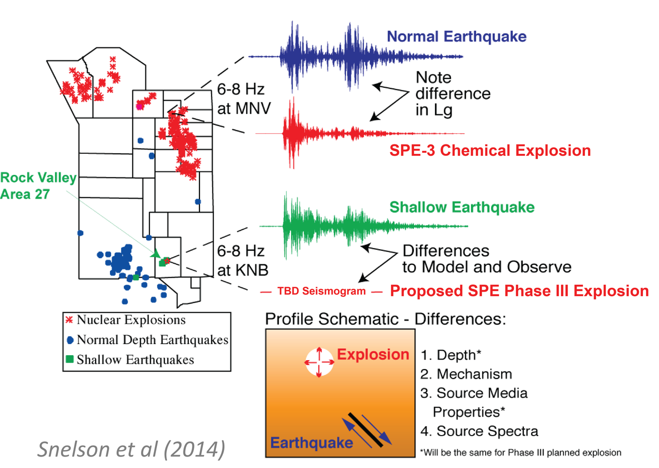
Abstract

Distributed Acoustic Sensing data is increasingly used to characterize near-source and far-field signatures of anthropogenic and natural sources. However, conversion from strain rate to particle velocity can be challenging in environments where near-field elastic properties and fiber coupling affect the recorded DAS signal. Calibrated signal amplitudes are critical for wavefield modeling efforts and quantitative interpretation of DAS data. We compare amplitudes of controlled-source signals, ambient noise, explosions, and earthquakes recorded on co-located fiber optic and nodal instrumentation and discuss optimal approaches for converting strain rate to ground motion. Variations in fiber geometry, emplacement, and signal frequency are analyzed to derive transfer functions between fiber and geophone data for different fiber arrays and source types. We show that while empirical relations for converting strain rate to acceleration are useful as a first order approximation, using a gradiometry-derived strain rate provides a more useful comparison. These results will inform future applications where well-calibrated amplitudes are required. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

Source Physics Experiment (SPE) Rock Valley Direct Comparison



Snelson et al (2014)

Motivation

1. While we can discriminate between earthquakes and explosions down to very small amplitudes, there are still issues with deep and or small local events.
2. There are still problems with the ratio between surface wave magnitude and body wave magnitude.
3. Explosion surface waves remain poorly predictable.
4. What is the smallest event we can apply moment tensor analysis?
5. Improve our understanding or seismic event aftershocks.

Why DAS calibration?

Deriving velocity and/or acceleration is required for source characterization efforts and other amplitude based analyses, including yield and magnitude.

Relating strain rate to acceleration

DAS strain rate ($\dot{\varepsilon}$) data can be related to apparent phase velocity (c) using the equations in Wang et al (2018) and Lindsey et al (2020):

$$\ddot{u} = \dot{\varepsilon} \times c$$

where $\ddot{u}$ is the acceleration and $\dot{\varepsilon}$ is the strain rate → this only requires knowledge of apparent phase velocity c

$$\dot{u} = \varepsilon \times c$$

where $\dot{u}$ is velocity and ε is the strain → this requires to integrate from strain rate to strain and compare to velocity

Alternatively, one can derive velocity (m/s) from strain rate (nm/m/s) by:

- Converting from nm/m/s to m/m/s for units consistency

nm/m/s = 10−9 m/m/s

- Integrate the strain rate ($\dot{\varepsilon}$) with respect to the spatial coordinate x to find particle velocity v

$$v(x) = \int \dot{\varepsilon}\, dx = \dot{\varepsilon} \cdot L$$

where L is fiber distance and $\dot{\varepsilon} = \frac{\partial v}{\partial x}$ = strain rate, v is the particle velocity and x is the spatial coordinate along the fiber

Acknowledgements

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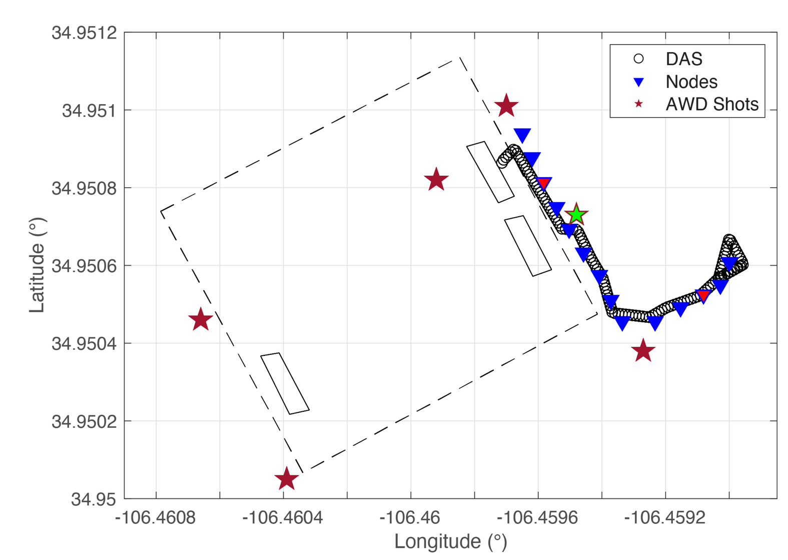
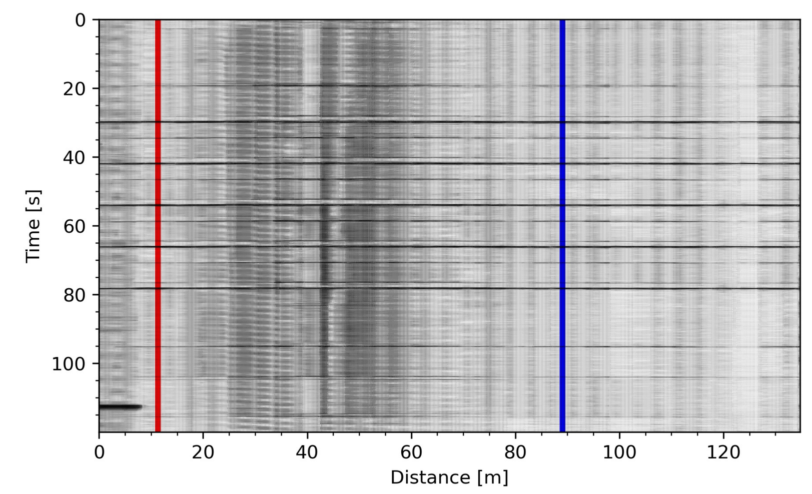
Facility for Acceptance, Calibration and testing (FACT)

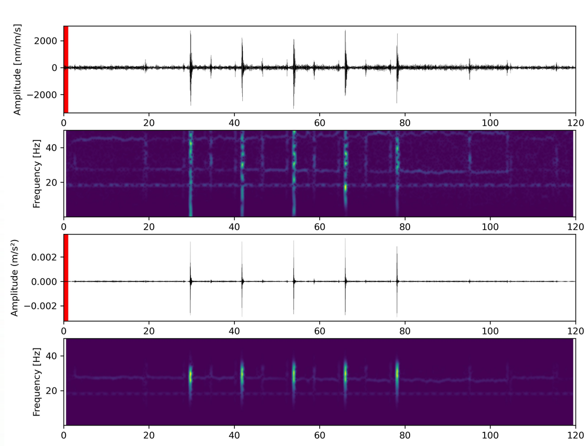


DAS (circles) and co-located nodes (triangles) data deployed at SNL FACT site. We recorded 8 AWD source locations (red stars), background noise, and other sources. Below we present data from shot S8 for co-located nodes and DAS channels. DAS data was acquired at 100 Hz, with a channel spacing of 0.25 meters. Node data was recorded at 500 Hz but resampled to match DAS sampling frequency.

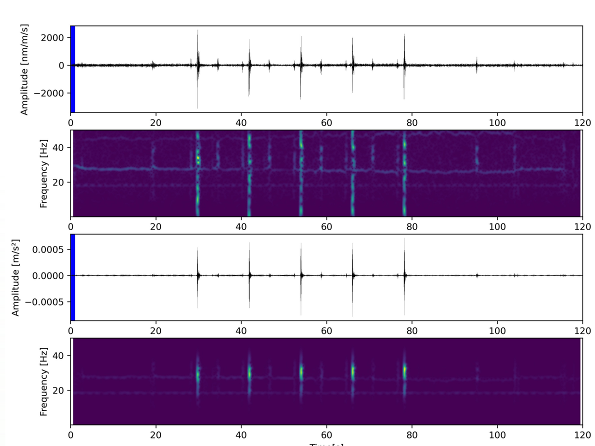


DAS record section along distance (540 channels) showing energy arriving from 5 AWD shots generated at one location, between 20 s and 80 s. Amplitudes are in units of nanostrain rate (nm/m/s). Red and blue lines mark locations of two co-located nodes (top panel).

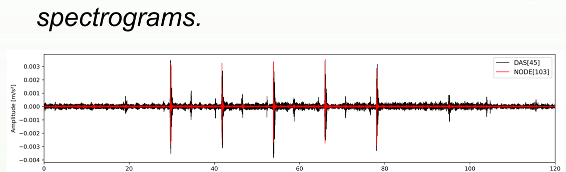
SNL AWD provides a unique source, capable to impart energy to the ground at both 90˚ and 45˚, for both compressional and shear energy.



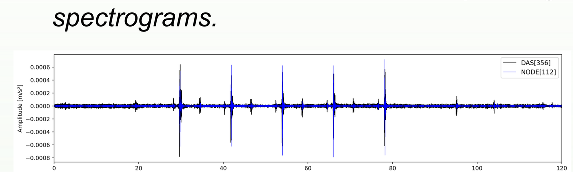
Time domain data showing 5 AWD shots recorded on DAS channel #45 (11.25 m) and the co-located node, and the corresponding spectrograms.



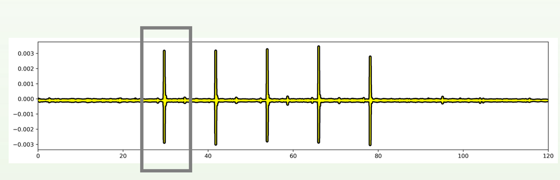
Time domain data showing 5 AWD shots recorded on DAS channel #356 (89 m) and the co-located node, and the corresponding spectrograms.



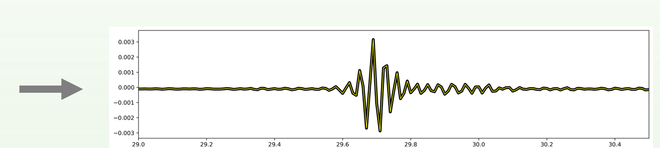
Scaled DAS data (m/s^2) to co-located node data (m/s^2) using apparent velocity, location 1



Scaled DAS data (m/s^2) to co-located node data (m/s^2) using apparent velocity, location 2

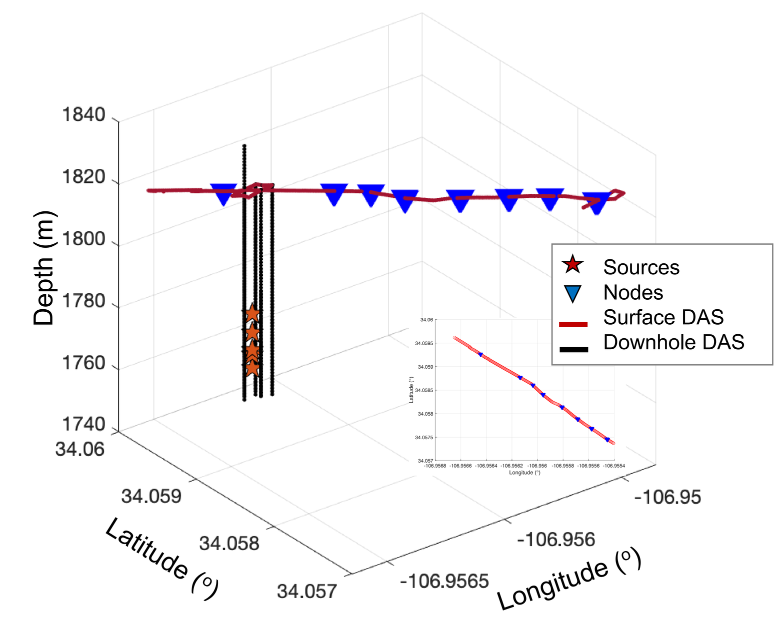


Direct scale of fiber data (m/s^2) to nodal radial component (m/s^2), location 1

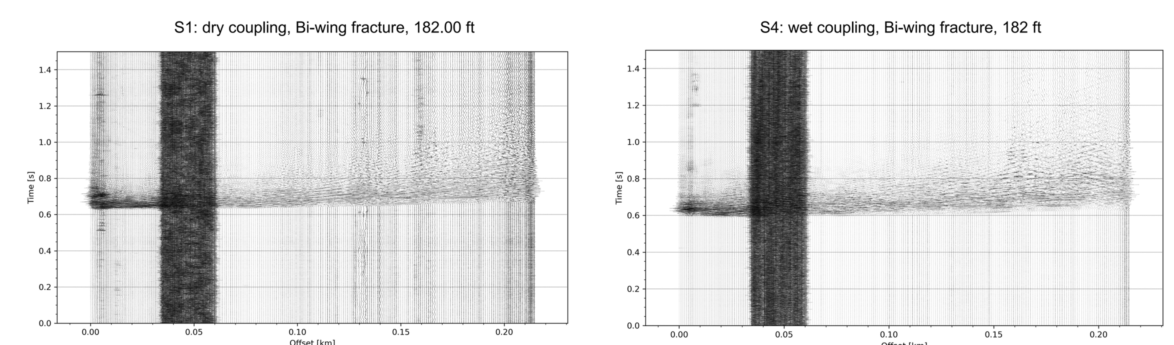


Shot 1 of 5 - Direct scale of fiber data (m/s^2) to nodal radial component (m/s^2), location 1

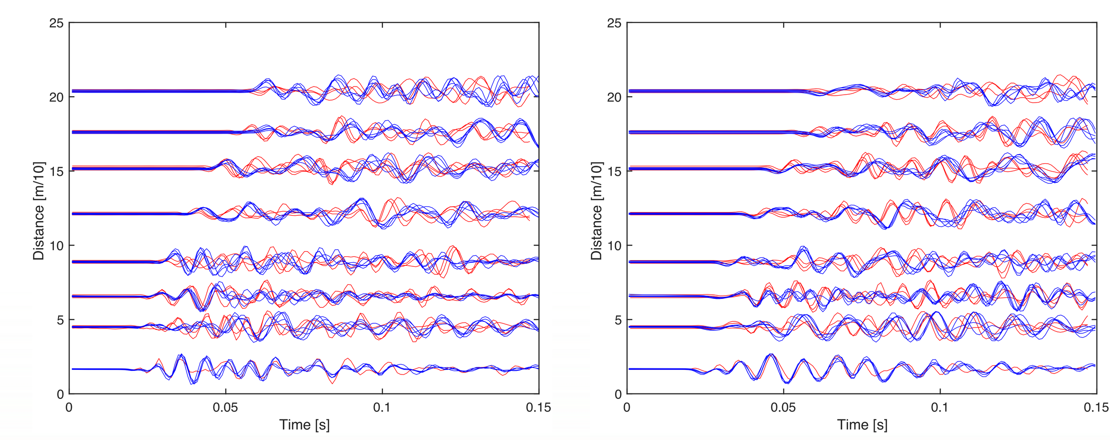
Blue Canyon Dome (BCD) EMRTC



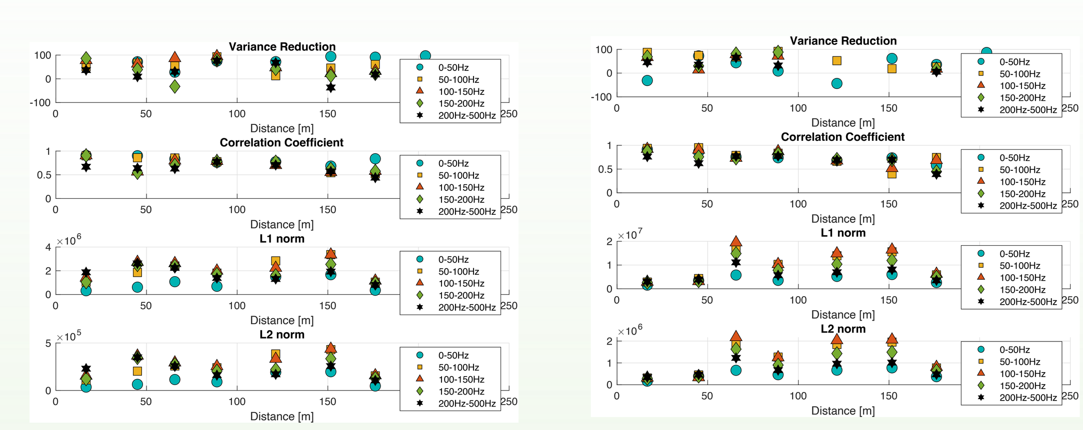
Station locations: DAS channels (red), seismic nodes (inverted blue triangles), and DAS channels within the observatory boreholes (vertical black dots). Red stars show source locations. Inset shows DAS channels and nodes used below.



1.5 s record sections of DAS data showing energy arriving from source 1 through 8 approximately at 0.6–0.8 s. Amplitudes are in nano *strain rate (nm/m/s).*

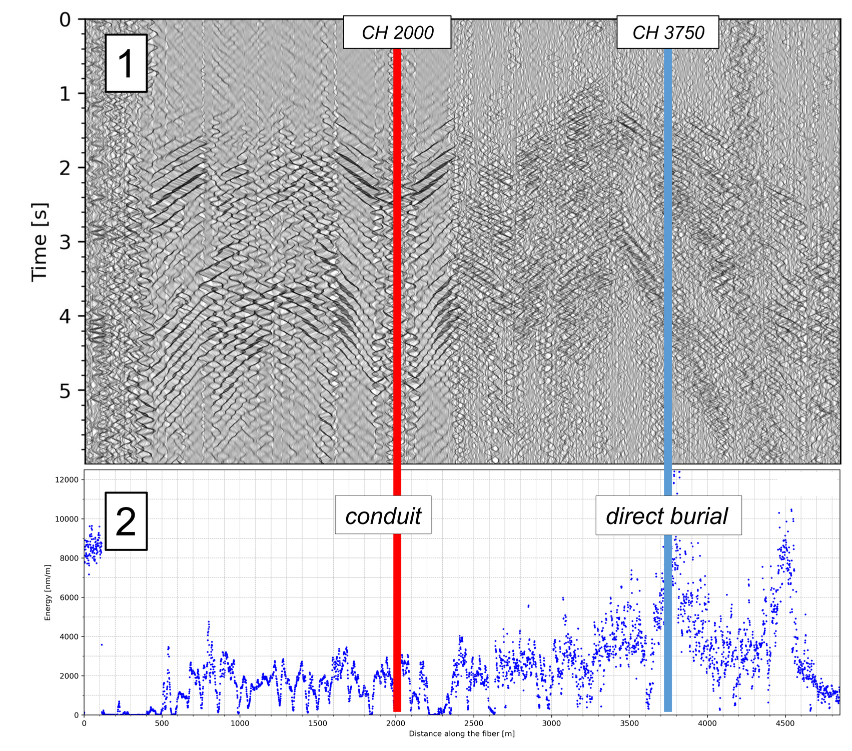


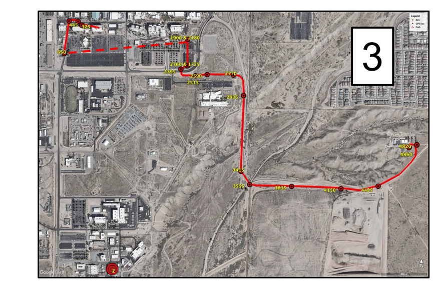
Record sections showing collocated DAS and nodes data filtered below 100 Hz for two chemical sources. Note the similarity variation in waveform and signal amplitude in the near-field versus far-field.



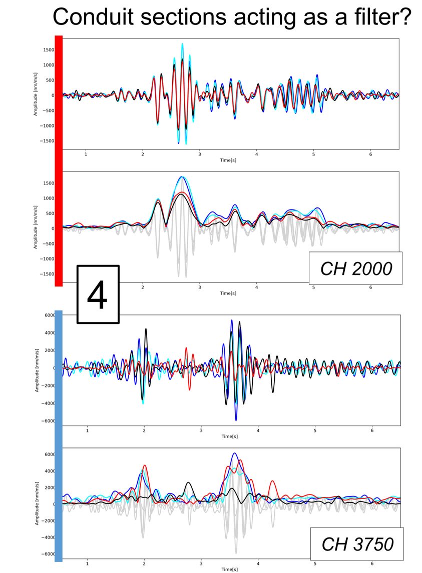
Similarity analysis for waveforms recorded by co-located DAS channels and seismic nodes. We used the horizontal node channel oriented in the direction of the source. Waveforms were aligned using dynamic time warping. The change in variance reduction and correlation coefficient is relatively consistent across different frequency bands.

Coupling and emplacement effects





Conduit sections acting as a filter?

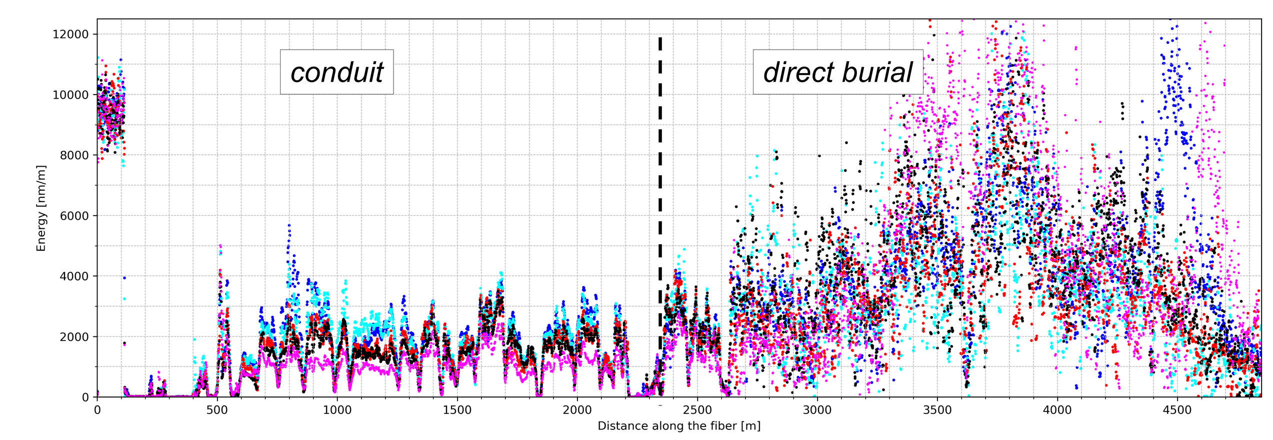


[1] Record section along fiber distance showing different amplitudes and phase arrivals across different sections of fiber.

[2] Integral of signal amplitude for each channel location.

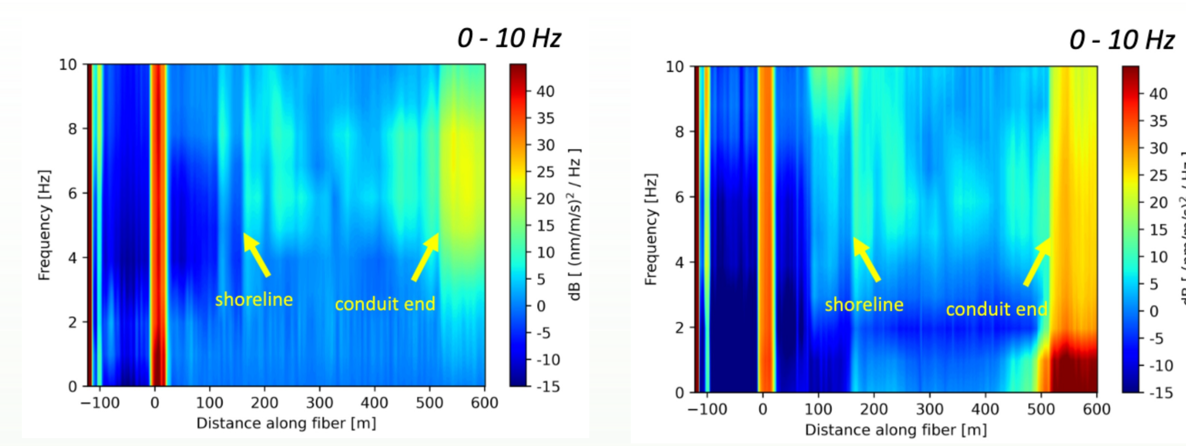
[3] Fiber location

[4] Waveforms and corresponding signal envelopes for two channel locations marked in [1]



UNDERGROUND CONDUIT
- Lower energy
- Higher coherence across channels
- 'Plate-like' coupling (conduit moves as one plate?)

DIRECT BURRIAL
- Higher energy
- Lower coherence
- 'Decoupled' channels



PSD along fiber distance for noise data collected on a submarine fiber optic. Left image shows February data collected during ice-bound conditions, and the right image shows October data collected during open water conditions. Note the signal amplitude change between the two types of environments as the fiber crosses the shore, and when it leaves the offshore end of the conduit.

Conclusions

- Simple conversion from nano strain rate to acceleration may not always be sufficient.
- A coupling factor is needed to understand fiber response.
- Environmental conditions will affect the observed amplitudes and possibly the fiber response.
- We may need to account for near- and far-field effects.

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