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A Quantitative Comparison of the Strain-rate and Velocity Data Measured at the Source Physics Experiment, Phase II

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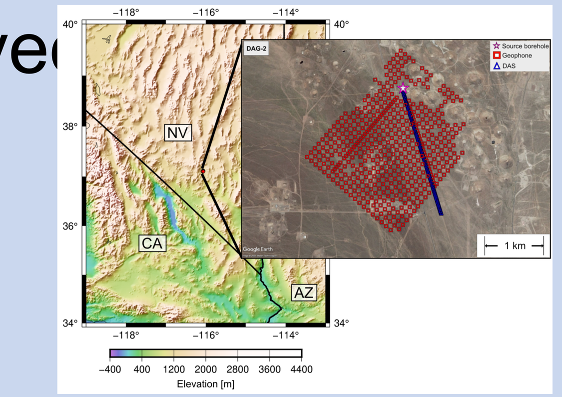
Motivation

Distributed Acoustic Sensing, DAS, is being rapidly ramped up for seismological applications. In order to have confidence that this technology can be used with our existing seismological toolkit, we need to directly compare DAS with co-located velocity instruments.

Experiment Design

This analysis focuses on a single large chemical explosion (DAG-2) deployed in a hole. A battery of tests is applied on the co-located 4.5 Hz geophones and DAS cable.



Location map of the source, geophones, and DAS at the Nevada National Security Site. The 50,000 kg source was detonated at 299 m depth. Geophones are spaced at 30-50 m whereas the DAS cable uses a gauge length of 2 m and virtual station spacing of 1 m.

Results Summary

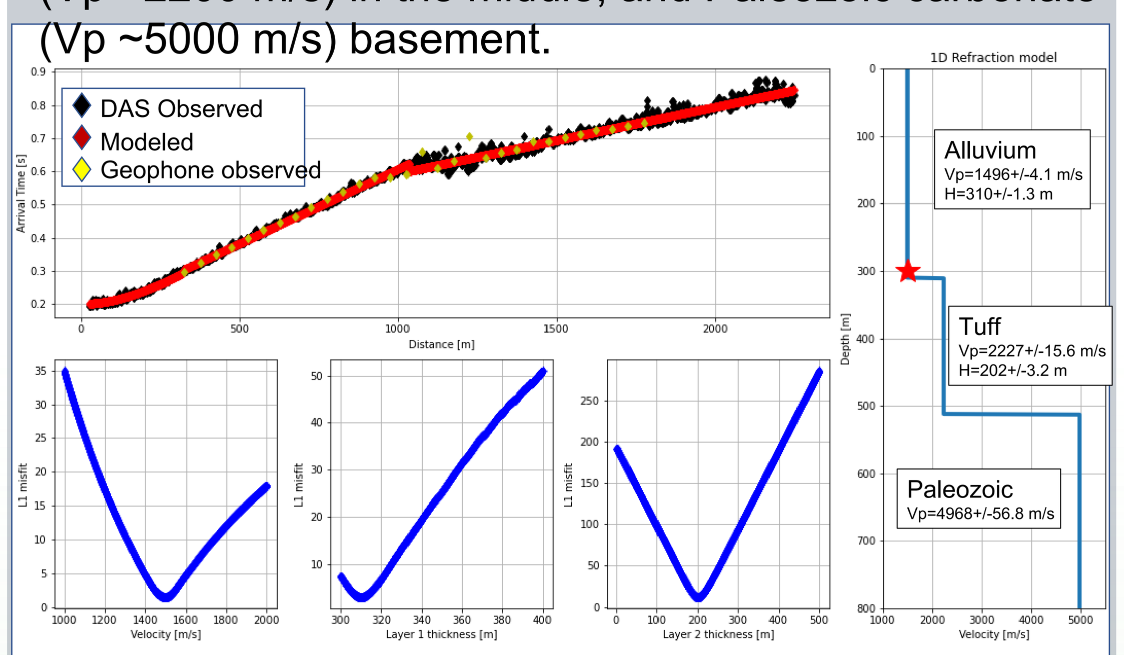
- Refraction modeling is consistent with previous models.
- Peak energy is just below 10 Hz for both datasets.
- Beamforming is consistent, but semblance is significantly more localized in slowness.
- Waveforms are consistent above ~4 Hz.

Conclusions/Take-home message

- We find that the DAS provides a significantly higher spatial resolution than the geophones.
- Conversion from strain-rate to velocity requires a high fidelity estimate of wavefield slowness.
- Analyses that are typically done in seismic data processing can be applied on DAS data with minor changes.

Refraction

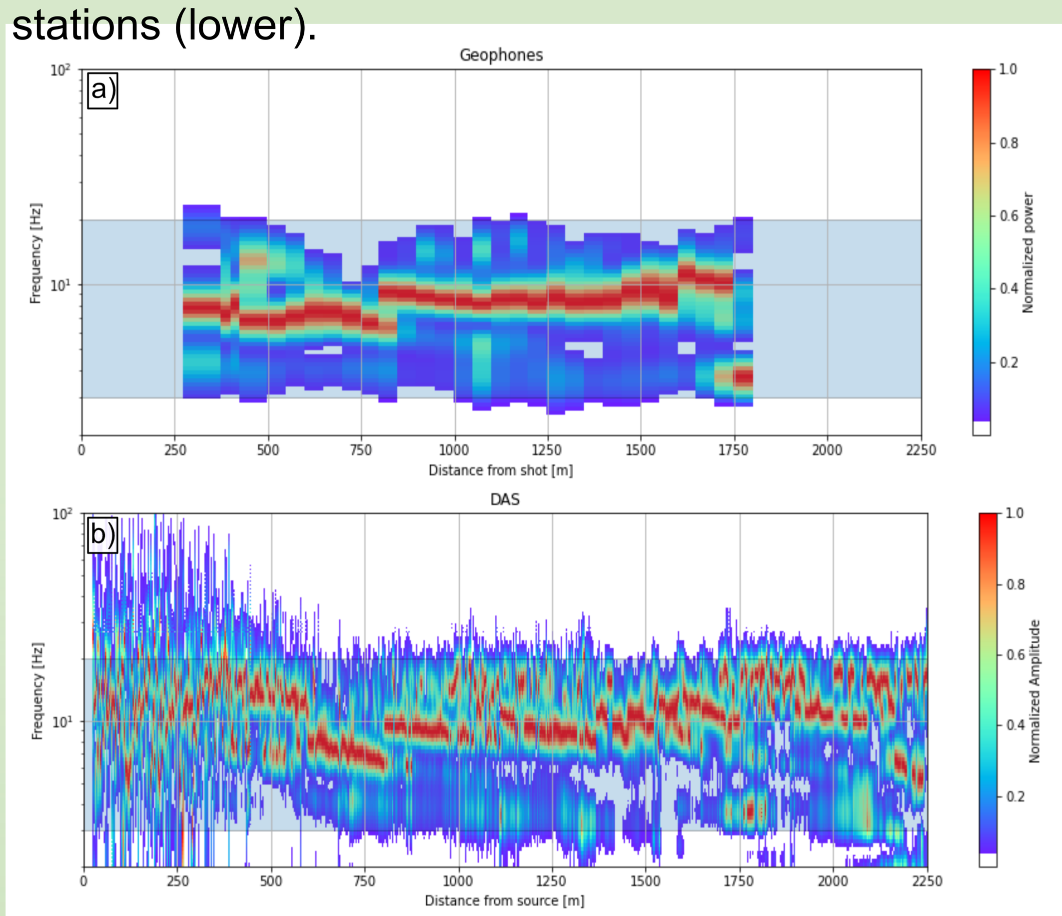
Using geometrical rays, we model the first arrivals assuming a direct upgoing ray and two refracted rays. The resulting 1D model is consistent with the Geologic Framework Model (Protho and Wagoner, 2020*) with 300 m of alluvium (Vp ~1500 m/s) on top, 200 m of tuff (Vp ~2200 m/s) in the middle, and Paleozoic carbonate (Vp ~5000 m/s) basement.



The above plots show the observed and modeled arrival times for the DAS channels and geophones. The three lower panels give the L1 misfit [seconds] for the numerically modeled upper layer wavespeed and two layer thicknesses. Lower layer wavespeeds are derived by linear regression to the straight-line portions of the arrival time curve. 1D wavespeed model on the right represents the mean and standard deviation from 1000 bootstrap realizations of the DAS arrival times.

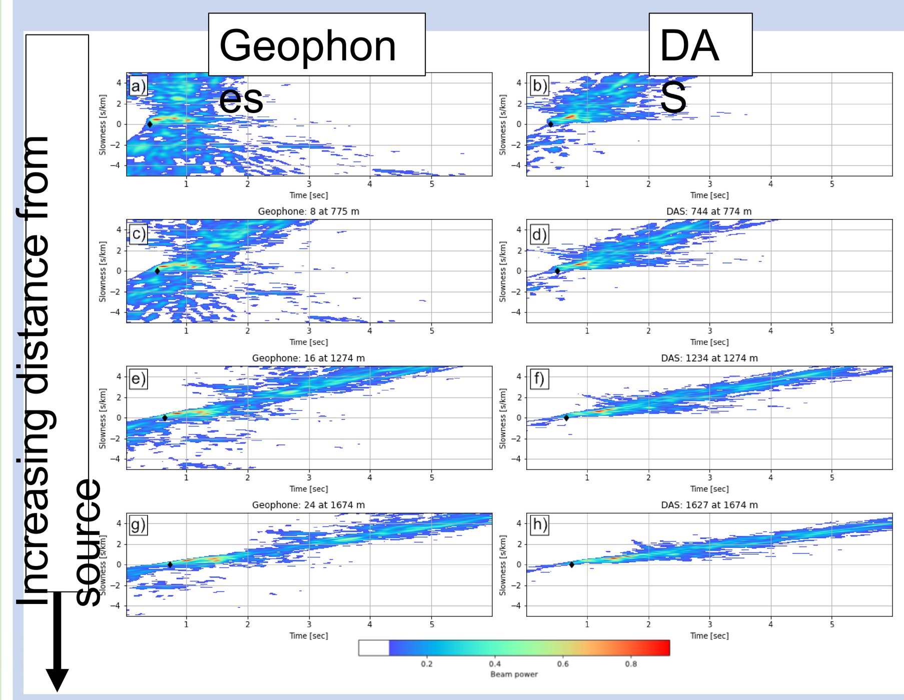
Spectra

Using the Continuous Wavelet Transform, we estimate the amplitude spectra of the direct arrival at each of the 30 geophones (top) and 2200 DAS virtual stations (lower).



The peaks in the amplitude spectra for the geophones and DAS agree that peak energy is between 5-10 Hz as observed within ~2 km of the source. Additionally, smaller-scale variations, such as a low frequency trend before 750 m offset, can be seen in both datasets.

Wave-propagation

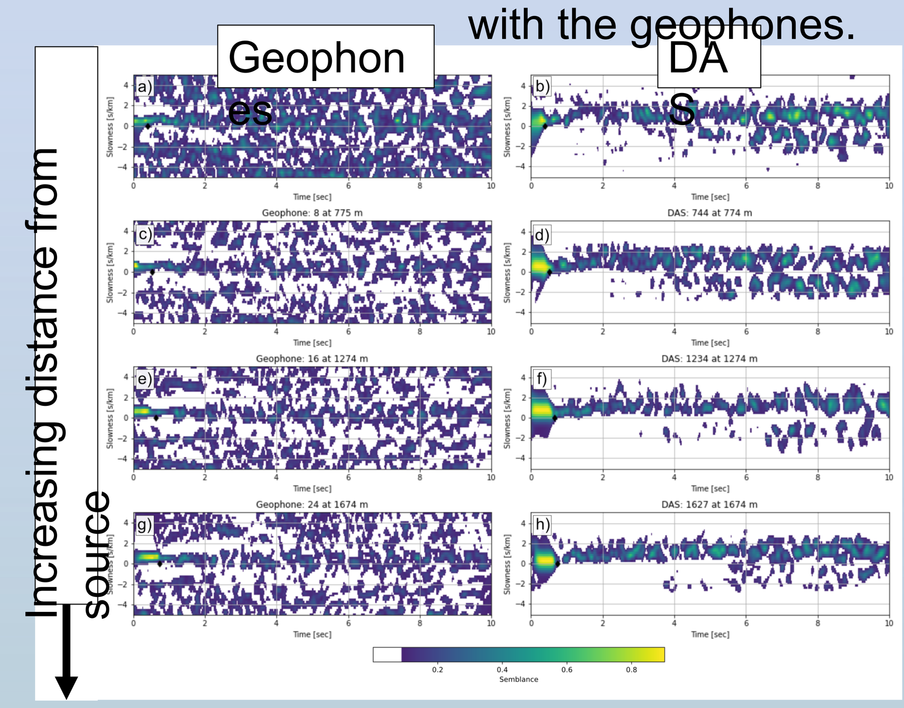


Beamforming

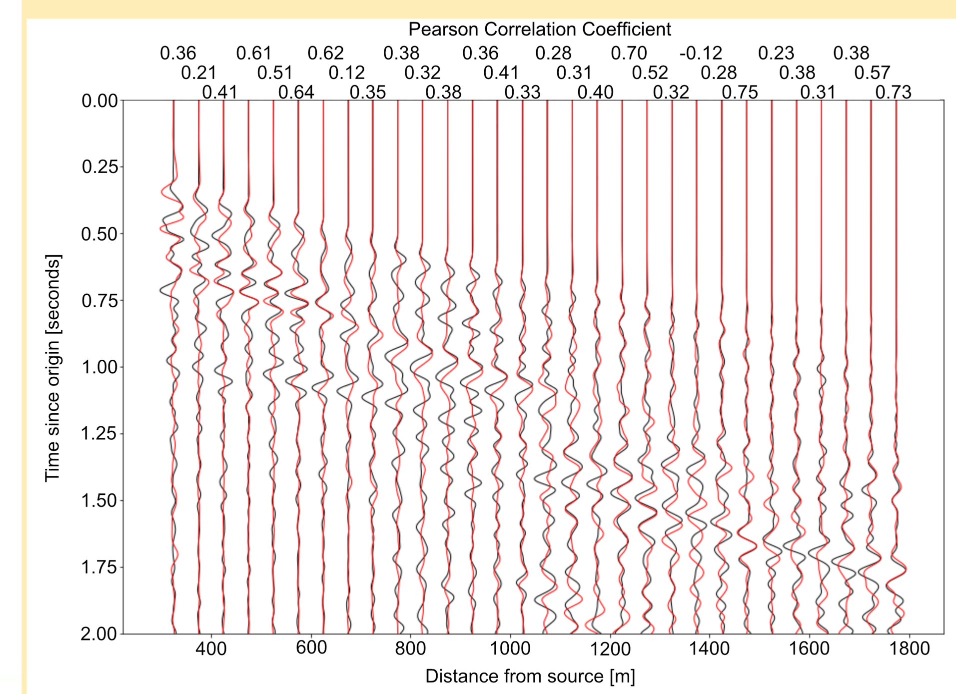
Beamforming shows the stacked amplitude for a range of vector radial slownesses. Warmer colors show alignment of seismic energy at the reference location. Geophones and DAS show similar patterns, but there is more negative slowness with the geophones.

Complex Semblance

Semblance also works by shifting and stacking, but uses the Hilbert transform to maintain phase coherency. Warmer colors indicate coherent stacking. Here, time-dependent maxima cannot clearly be seen in the geophone data, but can be identified with the DAS data.



Waveforms

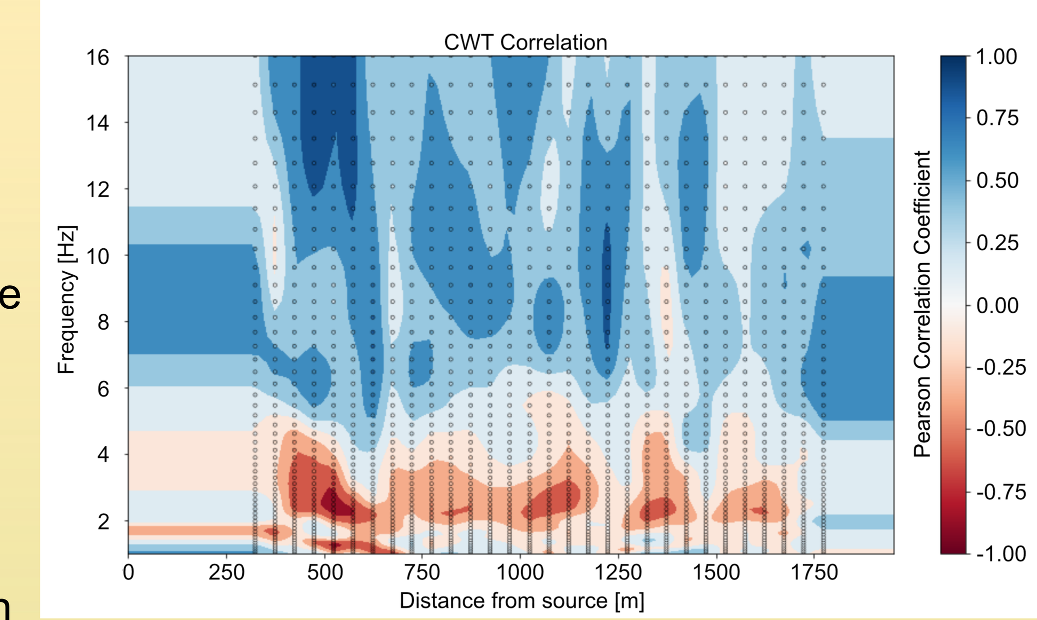


Time-Domain Similarity

Using time-dependent slowness from semblance and stacking in the wavelet-domain, we observe an average cross-correlation between the geophones (black) and DAS based velocity (red) of ~0.49. The plot to the left shows a high qualitative similarity in general and variable cross-correlation values which are generally positive.

Wavelet-Domain Similarity

Converting the waveforms into the wavelet-domain and measuring the correlation coefficient for each scale returns the frequency dependence of similarity. The plot to the right shows high correlation at frequencies above ~5 Hz. The low correlation at lower frequencies may reflect the instrument response function of the geophones.



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*Protho, L. and Wagoner, J. (2020), Geologic Framework Model for the Dry Alluvium Geology (DAG) Experiment Testbed, Nevada National Security Site.

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