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EVALUATION OF PASSIVE SOURCE DAS METHODS ON AN EXPLOSIVE SOURCE

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Take-home message

- Conversion to ground motion with Euler's method only holds for the passage of plane waves.
  - Frequency-wavenumber integration works in more general cases.
- High spatial resolution/channel count makes DAS ideal for array processing and ML based denoising.

Objective

The past 10 years have seen a significant increase in the utilization of Distributed Acoustic Sensing (DAS) for passive source seismology. The technology is more developed in the energy industry where time-lapse characterization has important ramifications for safety and production. Explosion seismology falls into a gap between the two where methodologies developed for passive sources can be applied to controlled source studies. Here, we evaluate a handful of passive source methods applied to short-offset recordings of explosions.

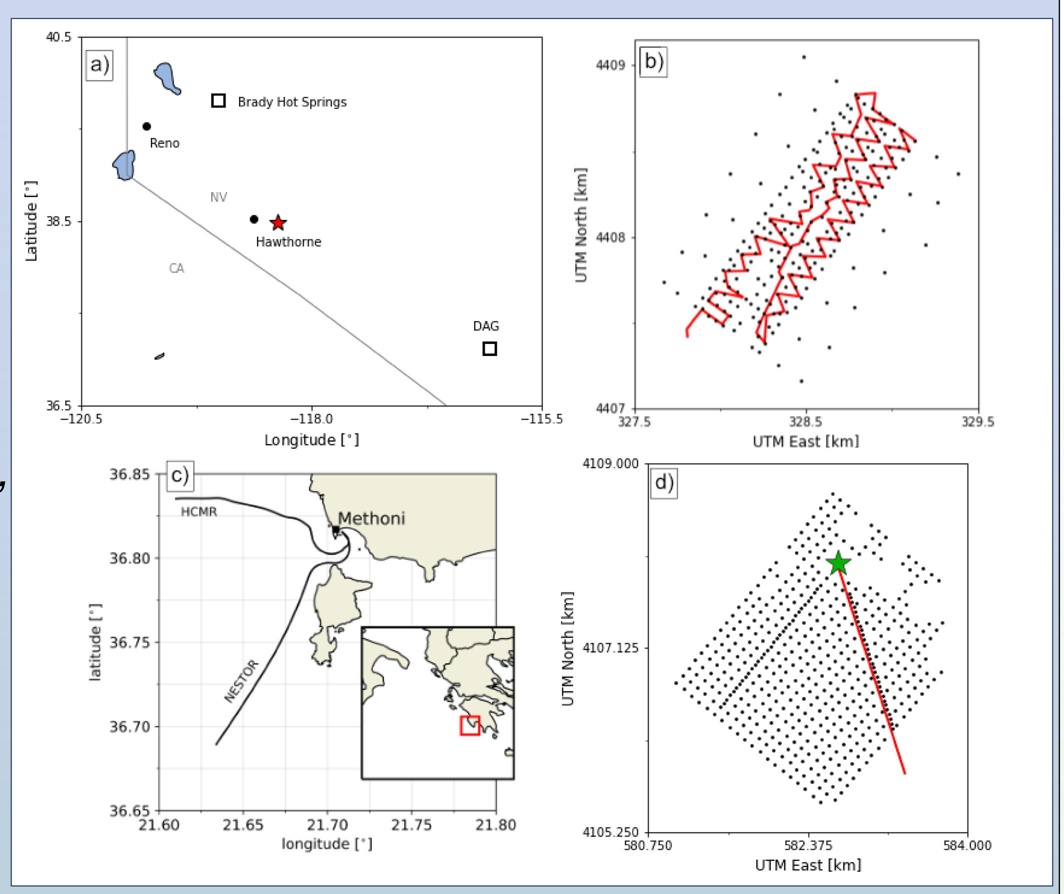
Data

Arrays: Porotomo at **Brady Hot Springs**, NV; Dry Alluvium Geology **(DAG)**, Mercury, NV, part of the Source Physics Experiment; HCMR and NESTOR off-shore from Methoni, **Greece**.

Sources:

Earthquakes:
- M4.1 near Hawthorne, NV
- 26 pre-cut events recorded off-shore *(used for replication, not presented here)*

Explosions:
- DAG-2: 51 tons @ 300 m depth
- DAG-3: 1 ton @ 150 m depth



Location maps for (a) Nevada, (b) Brady Hot Springs, (c) Greece, and (d) DAG

Conversion between strain-rate and ground motion

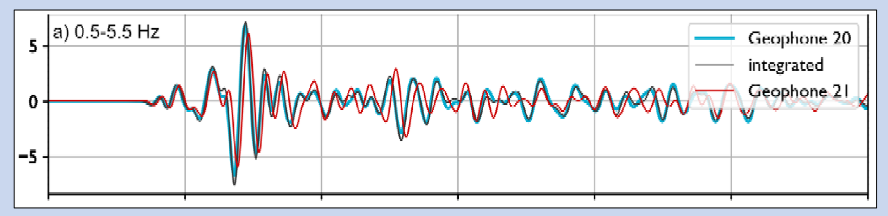
Euler's method: step-wise integration

$$\dot{\varepsilon}_{DAS}(x,t) = \frac{\dot{u}\left(x+\frac{L}{2},t\right) - \dot{u}\left(x-\frac{L}{2},t\right)}{L}$$

$$\dot{u}(x,t) = \dot{u}(x_{ref},t) + \dot{\varepsilon}(x;x_{ref},t)\Delta x$$

$$\dot{\varepsilon}(x;x_{ref},t)\Delta x = L\sum_{i=1}^{n}\dot{\varepsilon}(x_{ref}+iL;x_{ref}+(i-1)L,t)$$

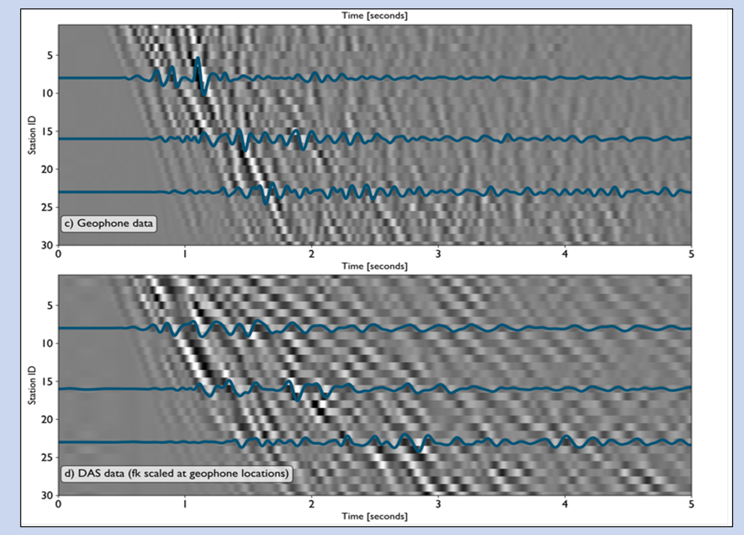
This method operates by adding DAS recorded strain-rate signals to a geophone anchor point. The waveform changes don't capture the phase shift of a near-source recording.



(above) Result of Euler's method between two geophones.

Frequency-wavenumber integration

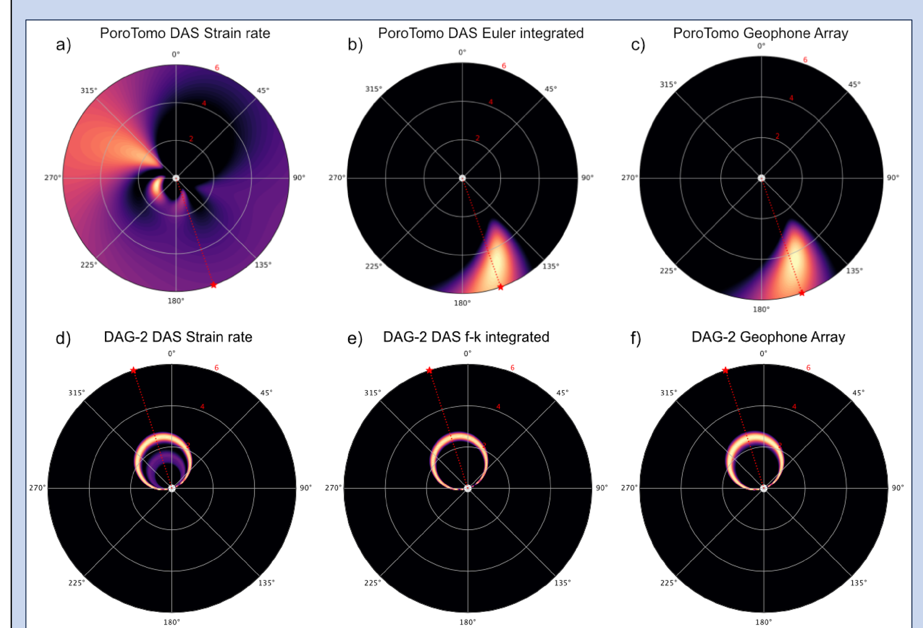
$$\dot{u}(x,k,\omega) = \pm(k/\omega)\,\varepsilon(x,k,\omega)$$



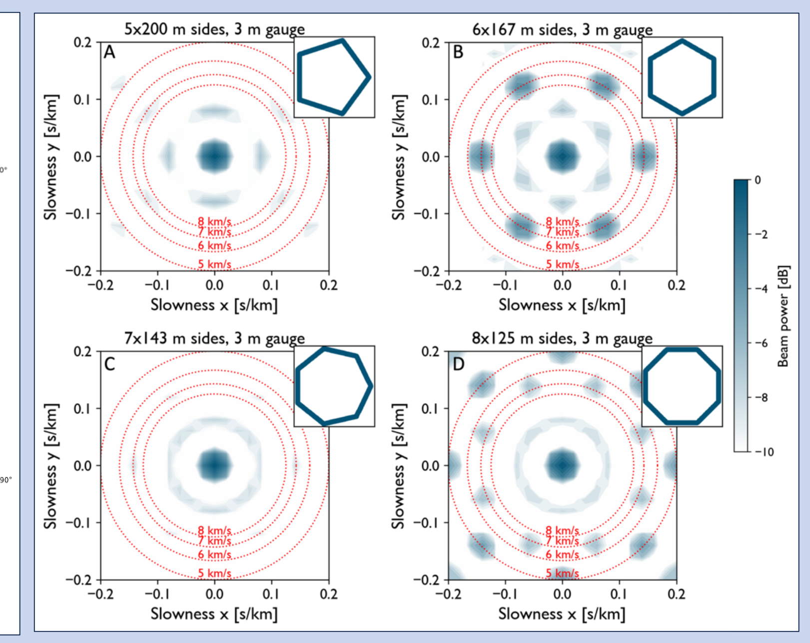
(above) Geophone record section and f-k integrated DAS record section

Take-away: Wave propagation along linear segments compare well between geophones and DAS when the frequency-wavenumber space is restricted.

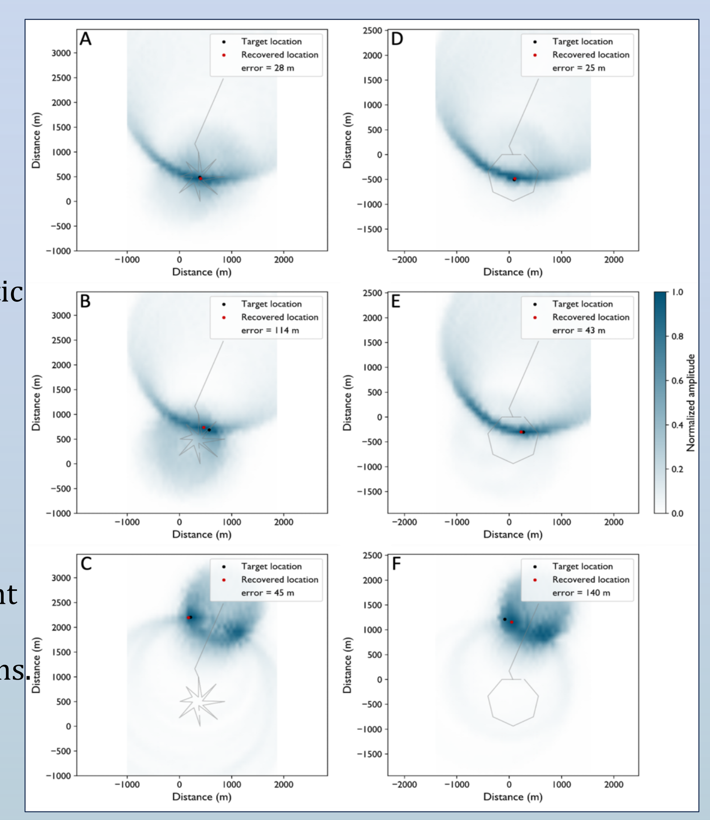
Array Analysis



(above) Beamforming result for (top row) Hawthorne event and (bottom row) DAG-2. From left, raw strain-rate, integrated to velocity, and reference geophones.



(above) Synthetic Array Response Functions for (a) pentagon, (b), hexagon, (c) heptagon, and (d) octagon.



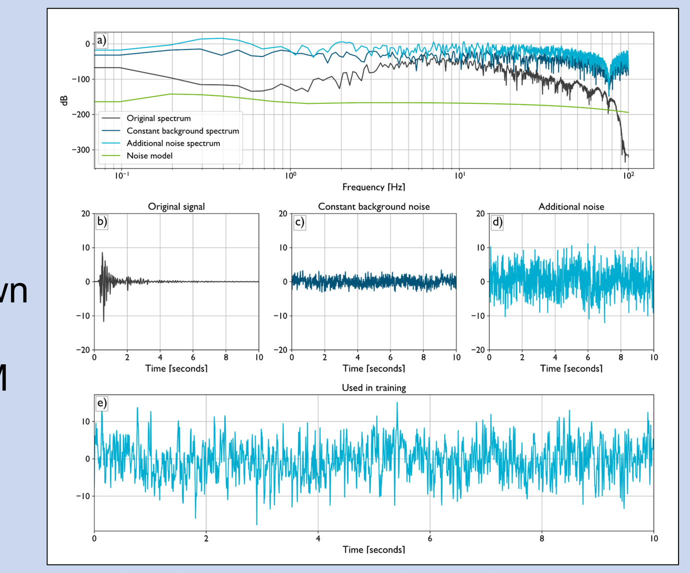
Back-projection location estimates for PyFK synthetic arrays. (left) Star-shaped antenna and (right) heptagon-shaped antenna for three different synthetic event locations.

Beamforming (upper left):
- Raw strain-rate data produces significant artifacts. Vector slowness not resolved.
- Conversion to ground motion reduces artifacts substantially.
- High SNR explosion has less artifacts than natural earthquake.

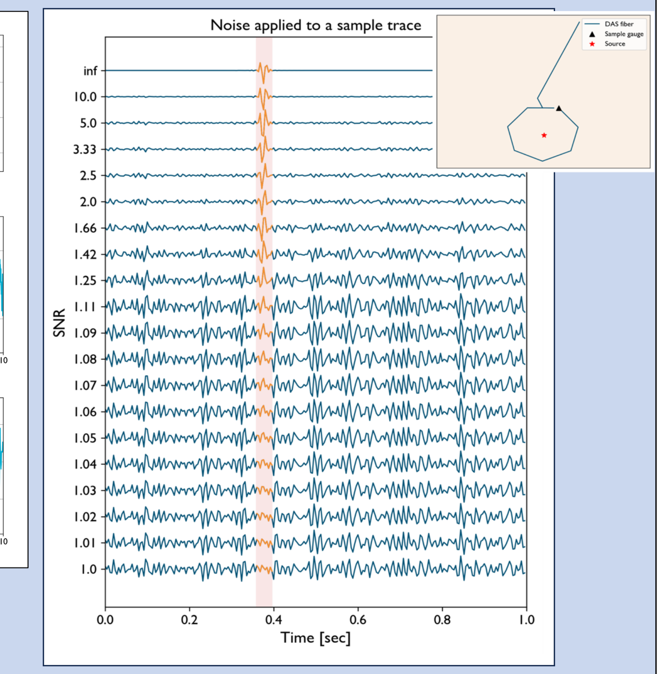
Array design:
- (upper right) Regular polygons with an odd number of sides have less artifacts.
- (left) A regular polygon tends to have better location estimates than a similarly sized array with radial arms.

Noising and denoising

Addition of noise:
- Original explosion records contain negligible noise.
- Realistic noise drawn from a distribution based on the NLNM (Peterson, 1993).
- Superimposed the spectrums for controlled SNR degradation.



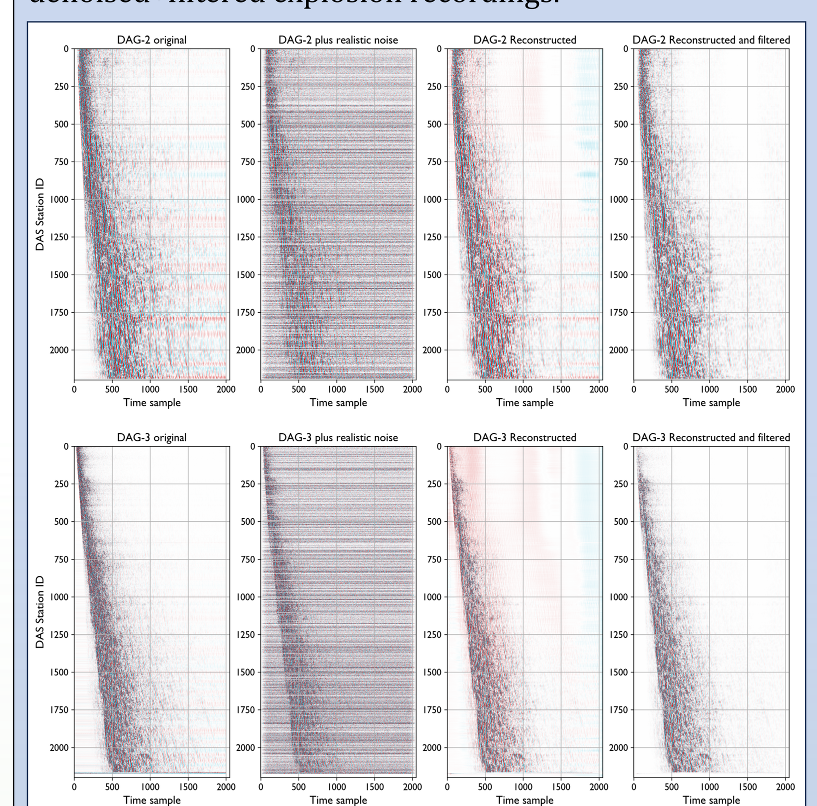
(above) Noisification of waveforms

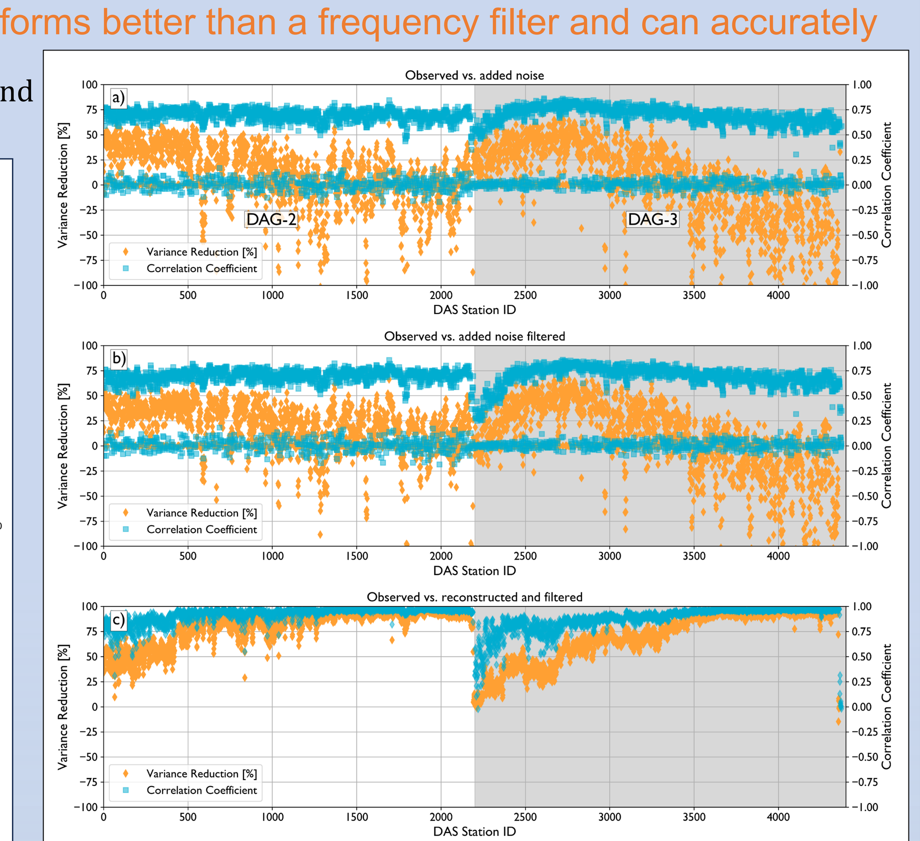


(above) Synthetic noise controlled SNR

- Noise types: coherent, incoherent, and random drop-outs.
- Denoising method: J-Invariant of van den Ende et al., 2021 (below, left).
- Quantification of Effectiveness: Variance Reduction (VR) and Cross Correlation (CC). (below, right)
- **Take-away:** array-based, ML denoising performs better than a frequency filter and can accurately reconstruct dropped-out channels

(below) Record sections of original, noisified, denoised, and denoised+filtered explosion recordings.





(above) VR and CC between original data, noisified data, filtered data, and denoised and filtered data.

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Data conversion, beamforming, and denoising results will be available in SNL Report: ***SAND2023-08140***. Array response and back-projection are included in ***Luckie and Porritt (submitted to Seismica).***

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