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EVALUATION OF PASSIVE SOURCE DAS METHODS ON THE SOURCE PHYSICS EXPERIMENT (SPE) PHASE II

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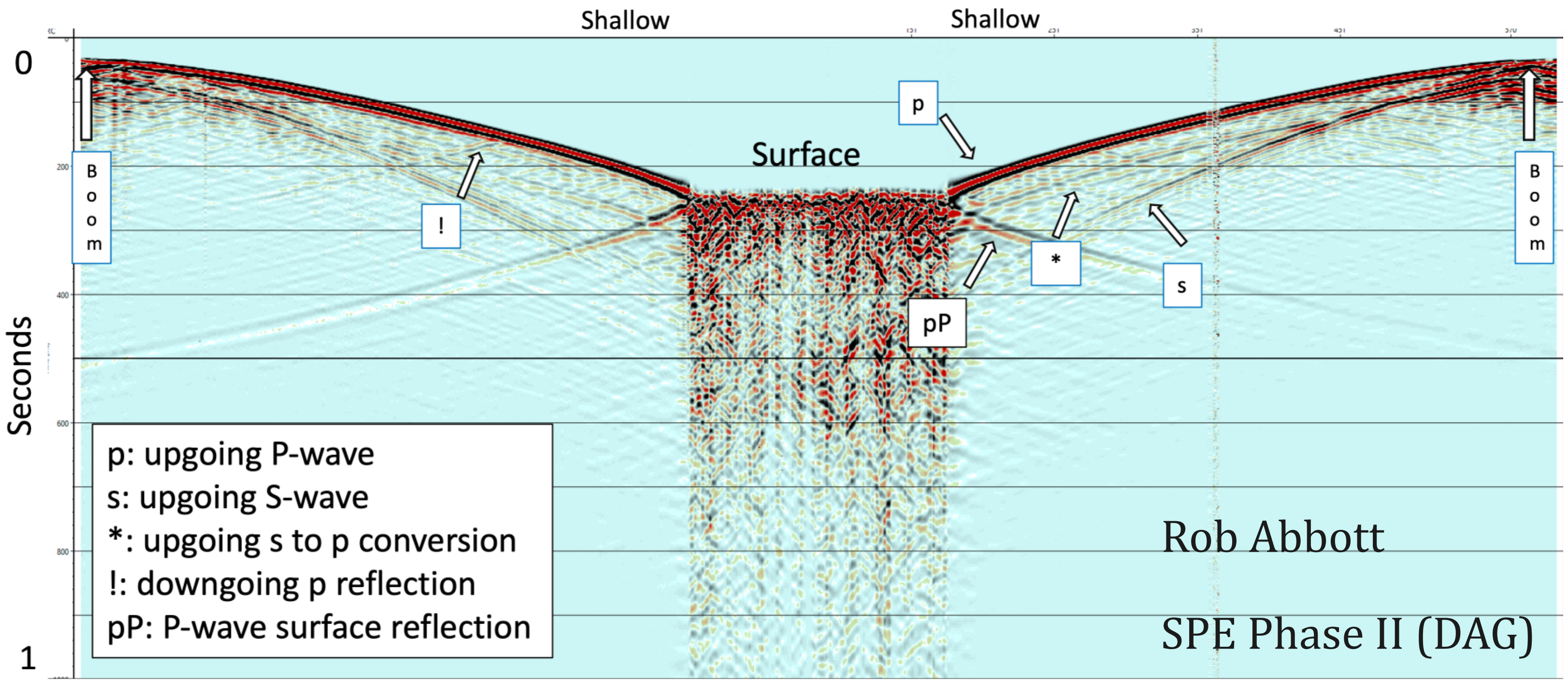
MOTIVATION

Recent advances applied to passive source signals (primarily earthquakes) recorded by DAS show potential for a step function improvement in characterizing the seismic wavefield.

Chemical explosion sources provide a source of seismic energy that is comparable, but distinctly different from earthquakes, volcanoes, or non-explosive anthropogenic sources.

How do we reproduce geophone signals and take advantage of the array nature of DAS for underground explosion monitoring?



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COMPARISON OF STRAIN-RATE TO GROUND MOTION SYSTEM

EULER INTEGRATION

Ground motion for a given point in time and space can be estimated by integrating the strain from a reference point.

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

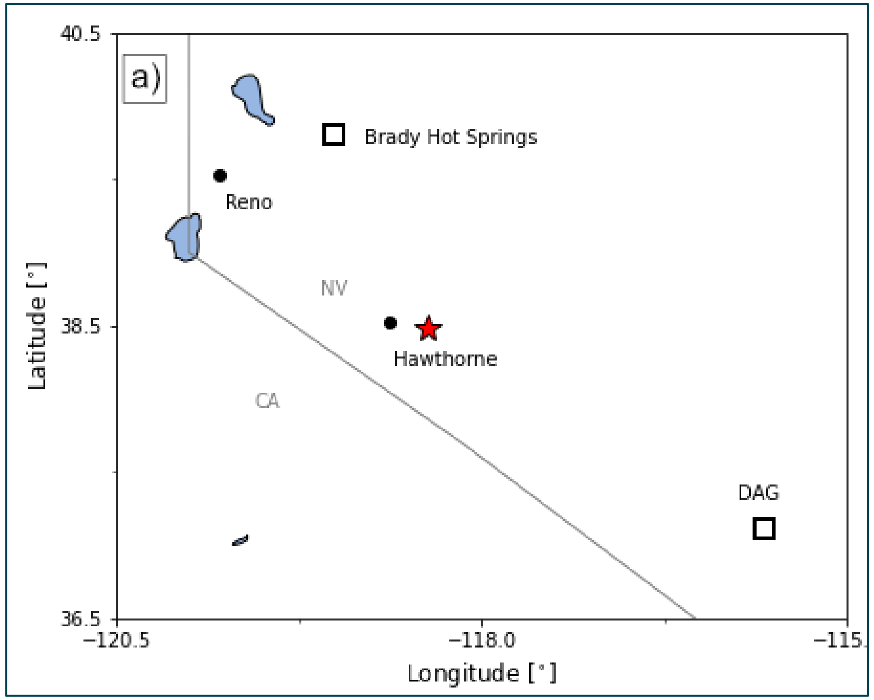
$$\dot{\varepsilon}_{DAS}(x,t) = \frac{\dot{u}(x+\frac{L}{2},t) - \dot{u}(x-\frac{L}{2},t)}{L}$$

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

Reference ground velocity

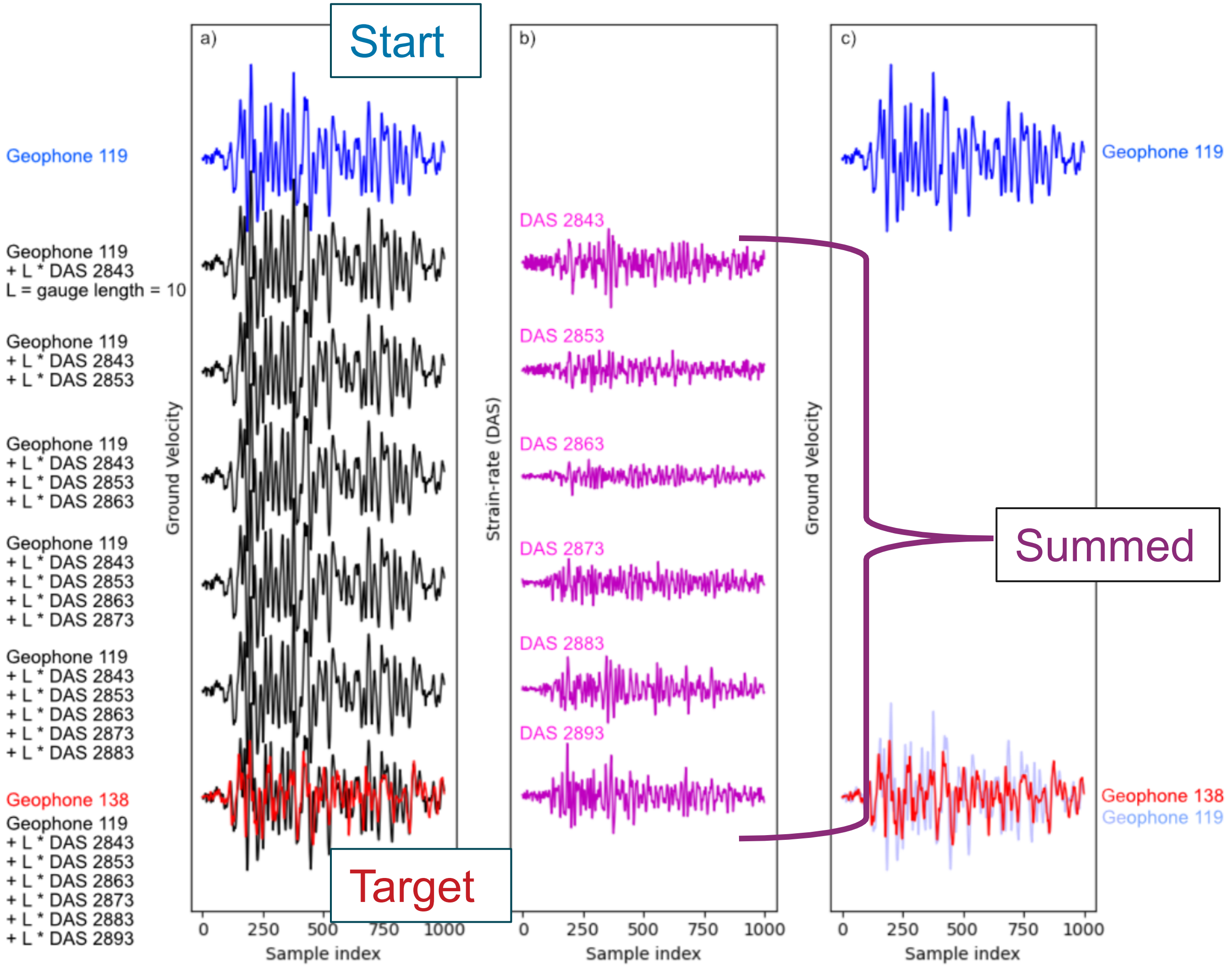
Integrated ground strain-rate

Bakku, 2015, *PhD Thesis, MIT*

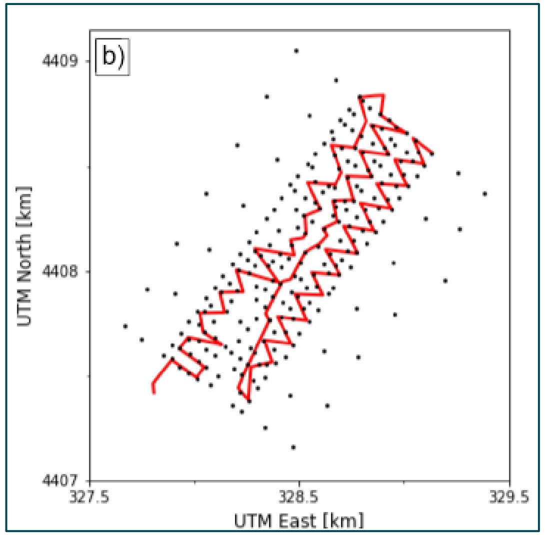


x = spatial coordinate, t = temporal coordinate, u = displacement, epsilon = strain, L = Gauge length

EULER INTEGRATION APPLIED TO POROTOMO



Small differences between reference geophones can be inferred from summation of strain-rate signals.



Porritt and Stanciu, *SAND Report*, OSTI

Wang et al., 2018, *Geophys J. Int.*

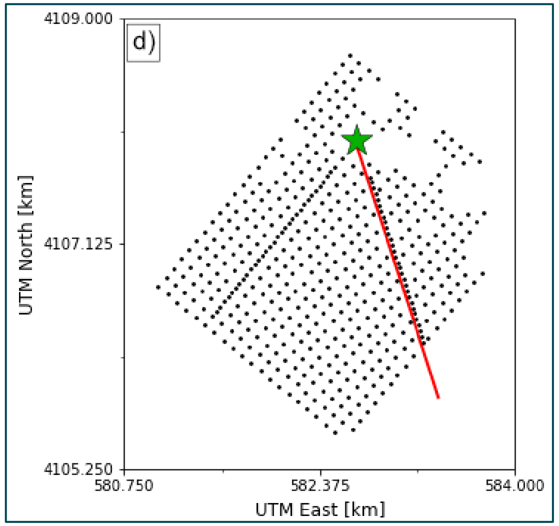
Van den Ende and Ampuero, 2021, *Solid Earth*

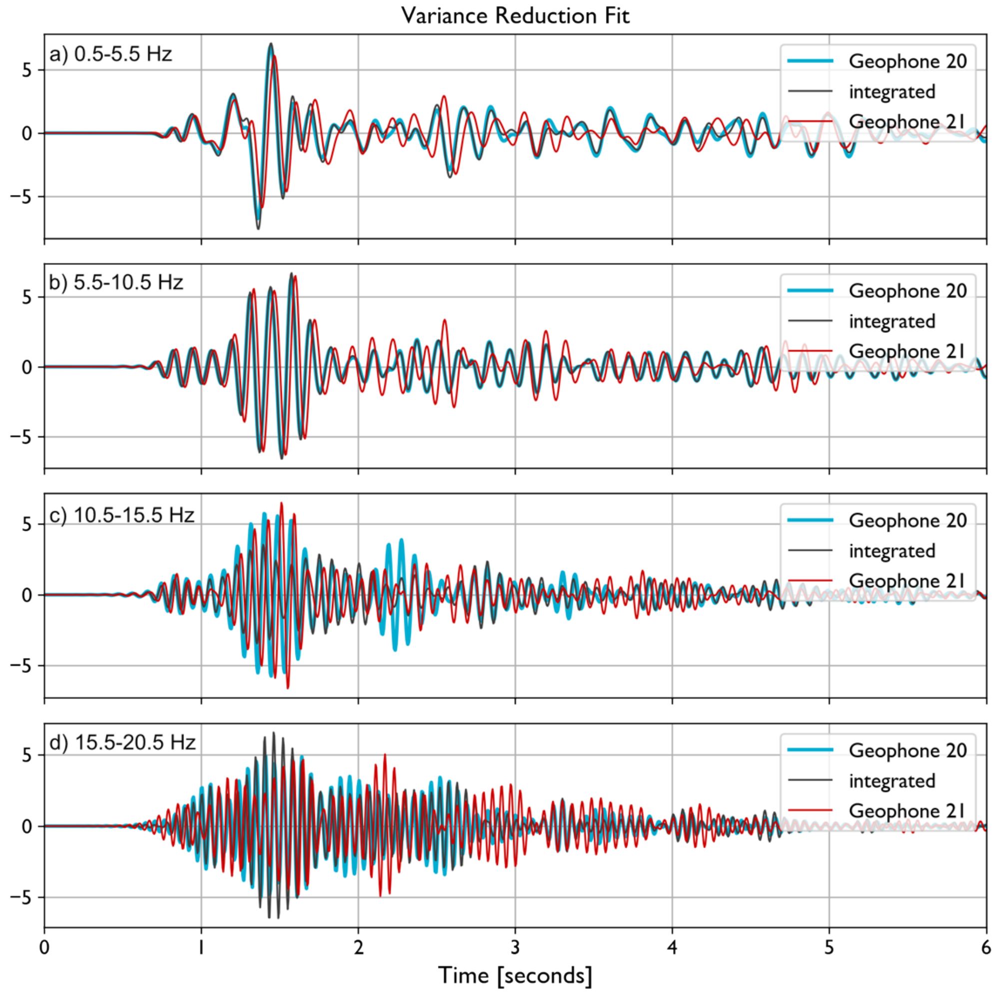
EULER INTEGRATION APPLIED TO DAG

Porritt and Stanciu, *SAND Report*, OSTI

Visually, appears ok at less than 10 Hz, but phase shift is apparent at higher frequencies.

We consider the conversion ***not applicable*** because ***1) the region has high scattering*** and ***2) the short offset is inconsistent with a passing plane wave.***





Increasing frequency band

F-K INTEGRATION

Porritt and Stanciu, *SAND Report*, OSTI

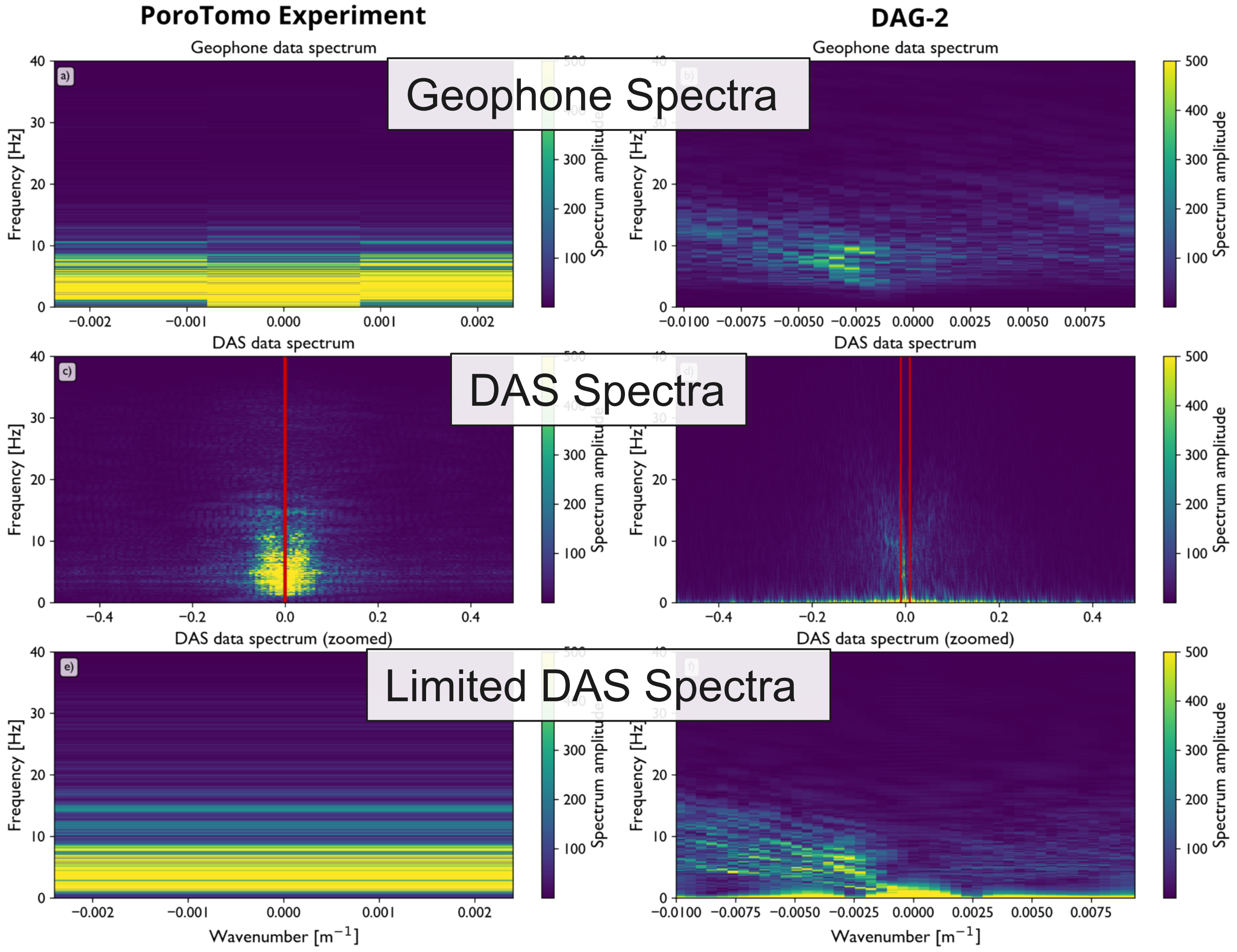
Scales the strain by the phase velocity.

Note that this is done in the 2D frequency-wavenumber domain for vector wavenumber (**k**) and angular frequency (**ω**).

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

Note that strain-rate has been time integrated to strain.

To optimize the comparison with the geophones, limit the f-k space to the wavelengths available to the geophones.



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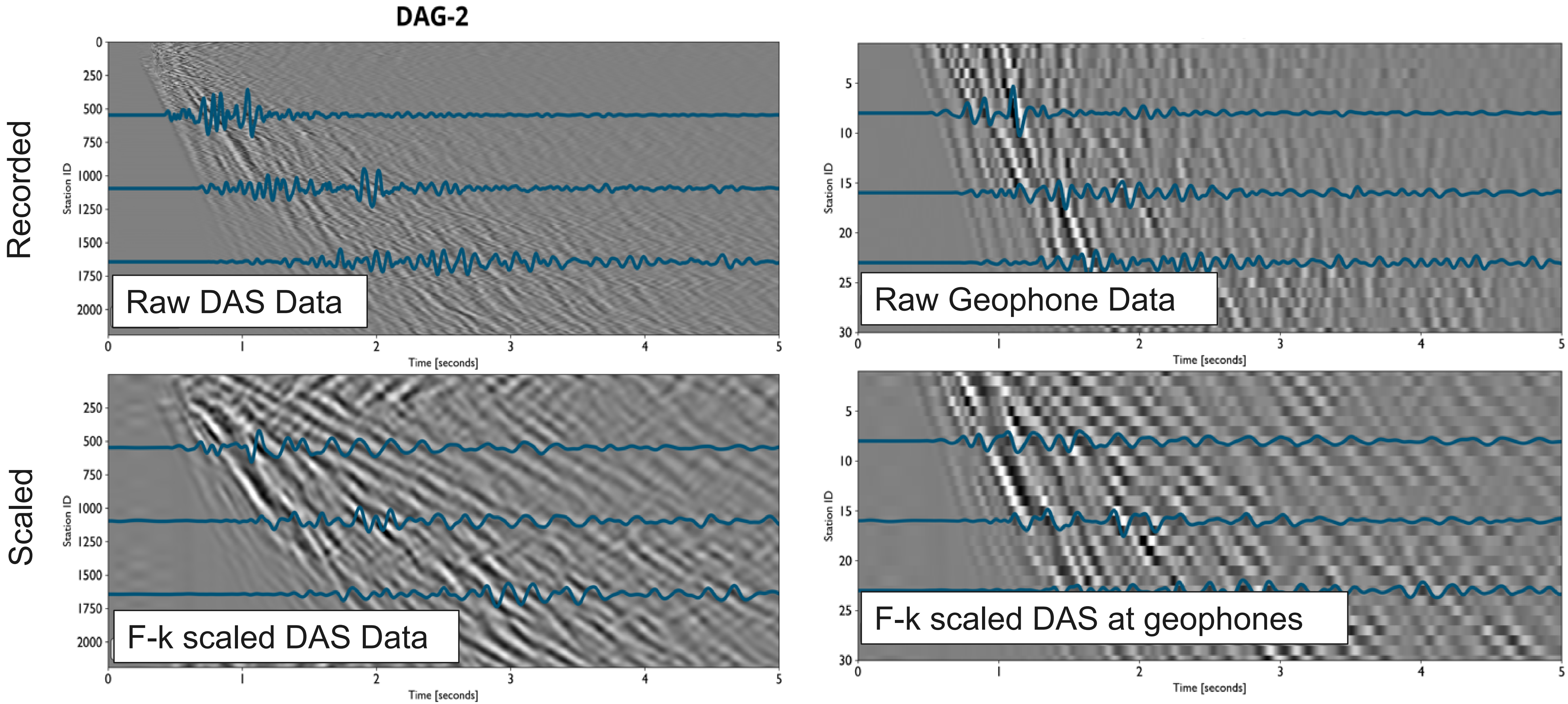
F-K INTEGRATION AT DAG

Porritt and Stanciu, *SAND Report*, OSTI



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END OF SECTION

Take home messages

- Conversion to ground motion with Euler's method only holds for the passage of plane waves.

- Frequency-wavenumber integration works in more general cases

Porritt and Stanciu, *SAND Report*, OSTI

Luckie and Porritt, *Seismica*, in revision.

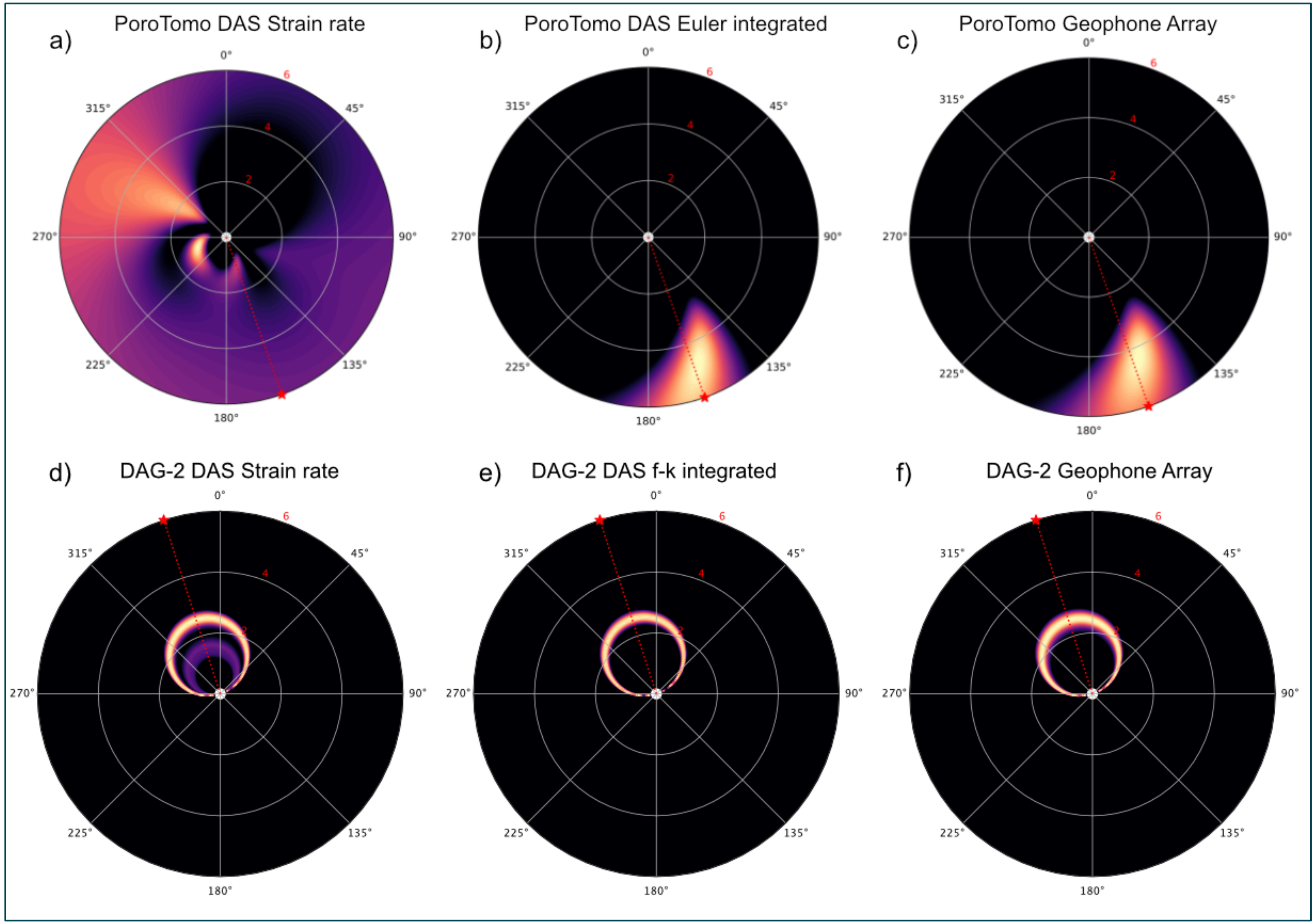
DAS AS NEXT GENERATION ARRAYS

BEAMFORMING BEFORE AND AFTER CONVERSION

Porritt and Stanciu, *SAND Report*, OSTI

Van den Ende and Ampuero show significant artifacts in beamforming (a). After conversion to ground motion, artifacts are removed (b, c).

The artifacts are relatively minor at DAG (d). After f-k integration, the final DAS slowness space matches the co-located geophones.



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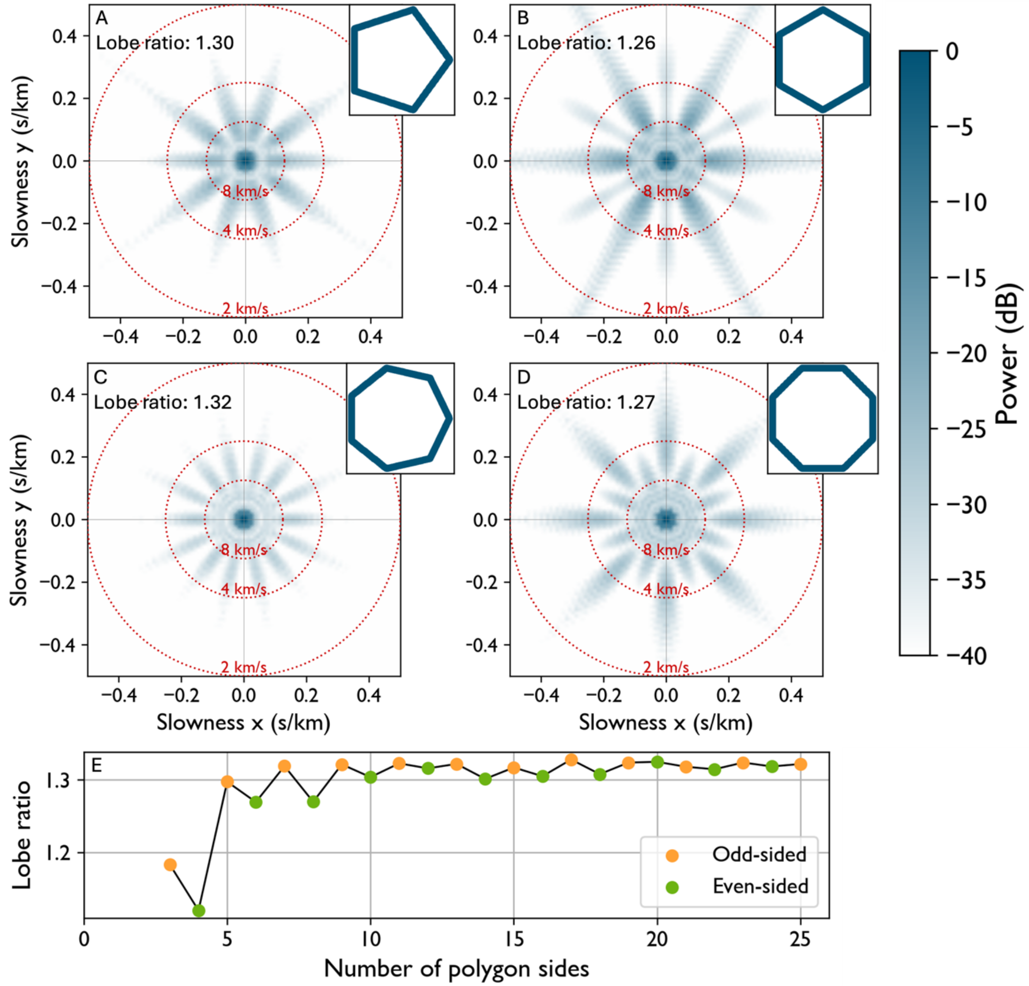
BEAMFORMING WITH POLYGONS

Logistical constraints as well as applicability of f-k integration at a variety of offsets suggest that polygonal array designs are desirable.

Here, we compare how isolated the array response peak is for a series of polygons.

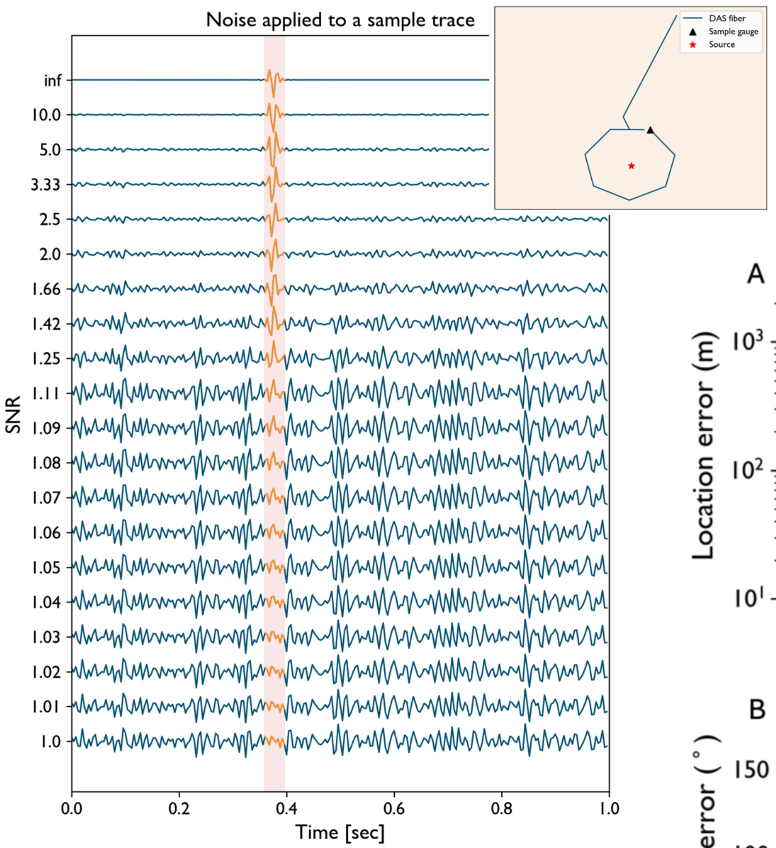
Odd-sided polygons have systematically reduced artifacts compared with even-sided polygons.

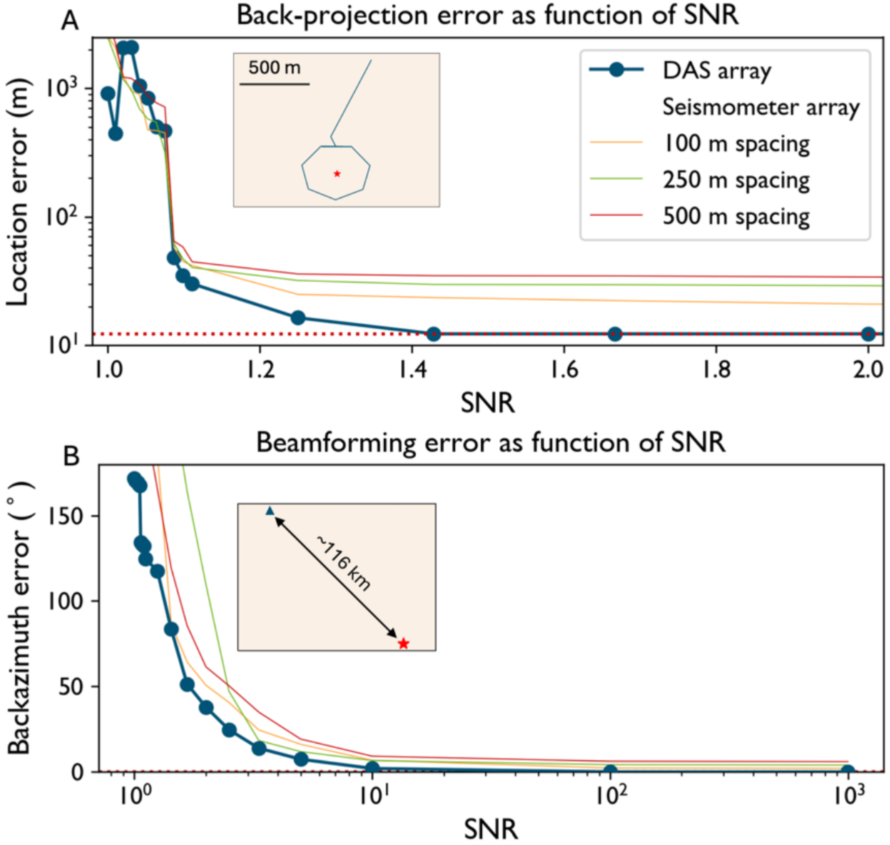
A point of diminishing returns is reached by 7 sides.



Luckie and Porritt, *Seismica*, in revision.

PERFORMANCE WITH NOISE-ADDED SYNTHETICS





Application to noise-free synthetics provides an unrealistically optimal situation.

Here we add realistic synthetic noise as a proxy for performance for variable magnitudes.

The array nature of DAS provides systematically more accurate results regardless of SNR.

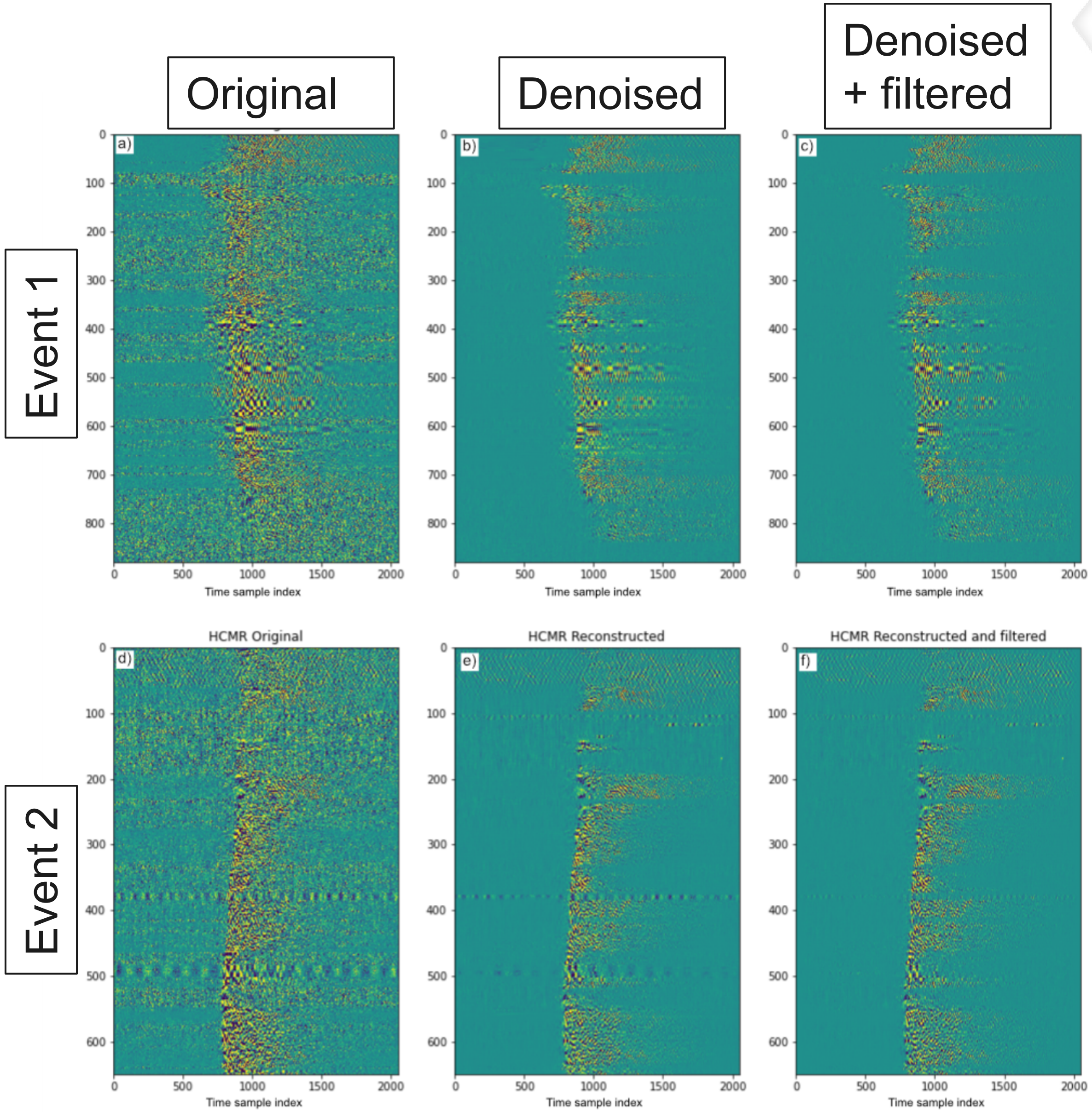
Synthetic noise generated by drawing from a distribution of amplitude spectra based on the Peterson, 1993 New High Noise Model and random perturbations to the phase spectrum.

Luckie and Porritt, *Seismica*, in revision.

DENOISING WITH J-INVARIANT

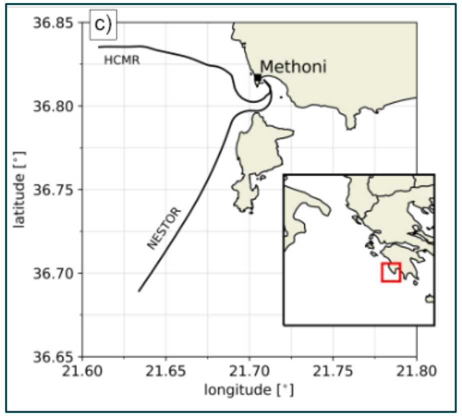
Van den Ende et al presented a method of reconstructing patterns in DAS array data to draw out transient passing signals.

Their application had impressive visual results, but as the data was collected passively on an offshore cable, the ground truth “signal” is unknown.



Van den Ende et al., 2021, *IEEE Transactions on Neural Networks and Learning Systems*,

Porritt and Stanciu, *SAND Report*, OSTI



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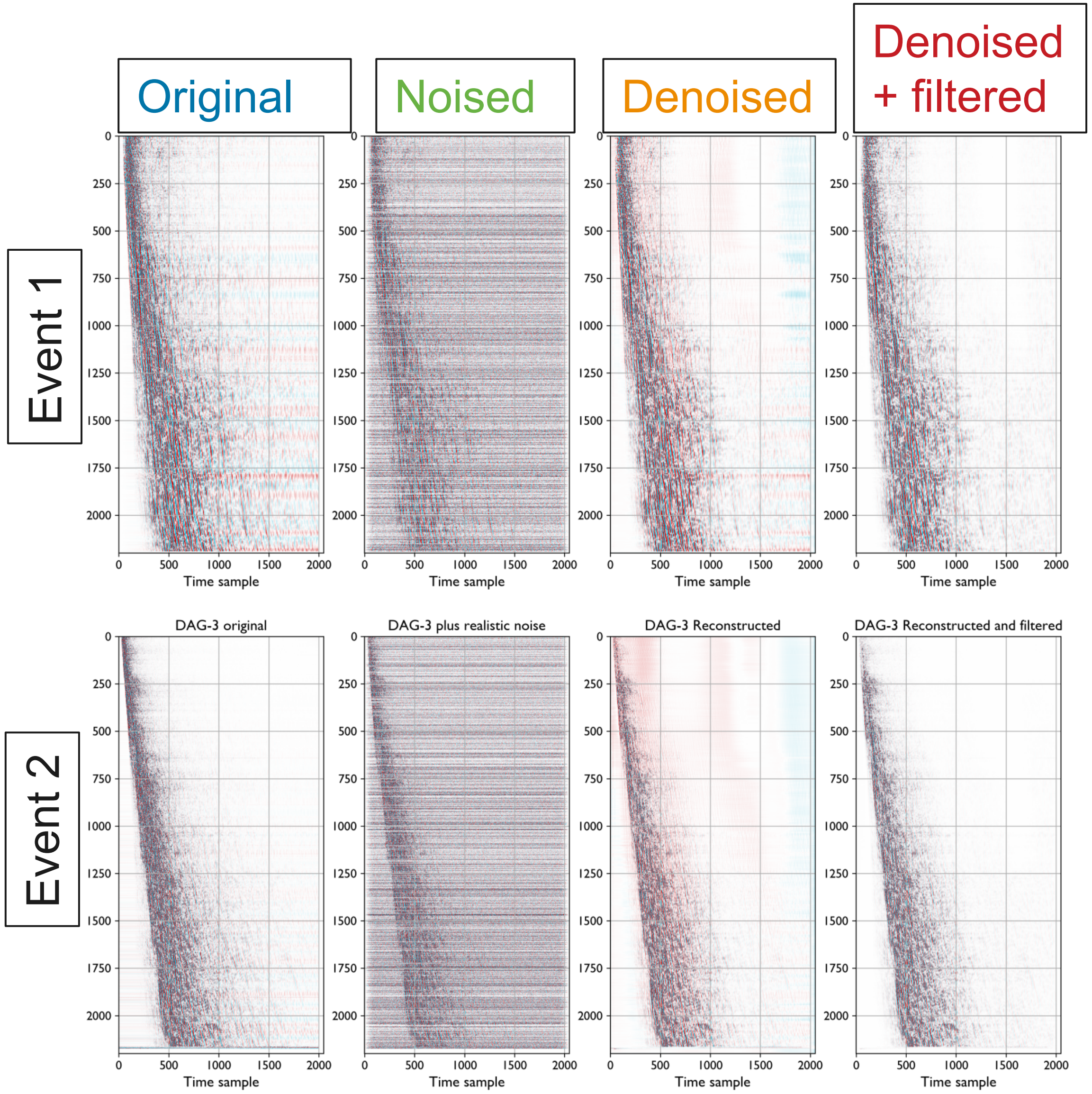
ADDITION AND REMOVAL OF NOISE FOR DAG



At DAG, the large chemical explosions dominate the wavefield creating a situation with effectively no noise.

Applying our method to add synthetic noise, we are able to control how masked the signal of interest is.

These figures illustrate the original wavefield, the noise added wavefield, the reconstructed wavefield, and the result of traditional frequency filtering of the reconstructed wavefield.

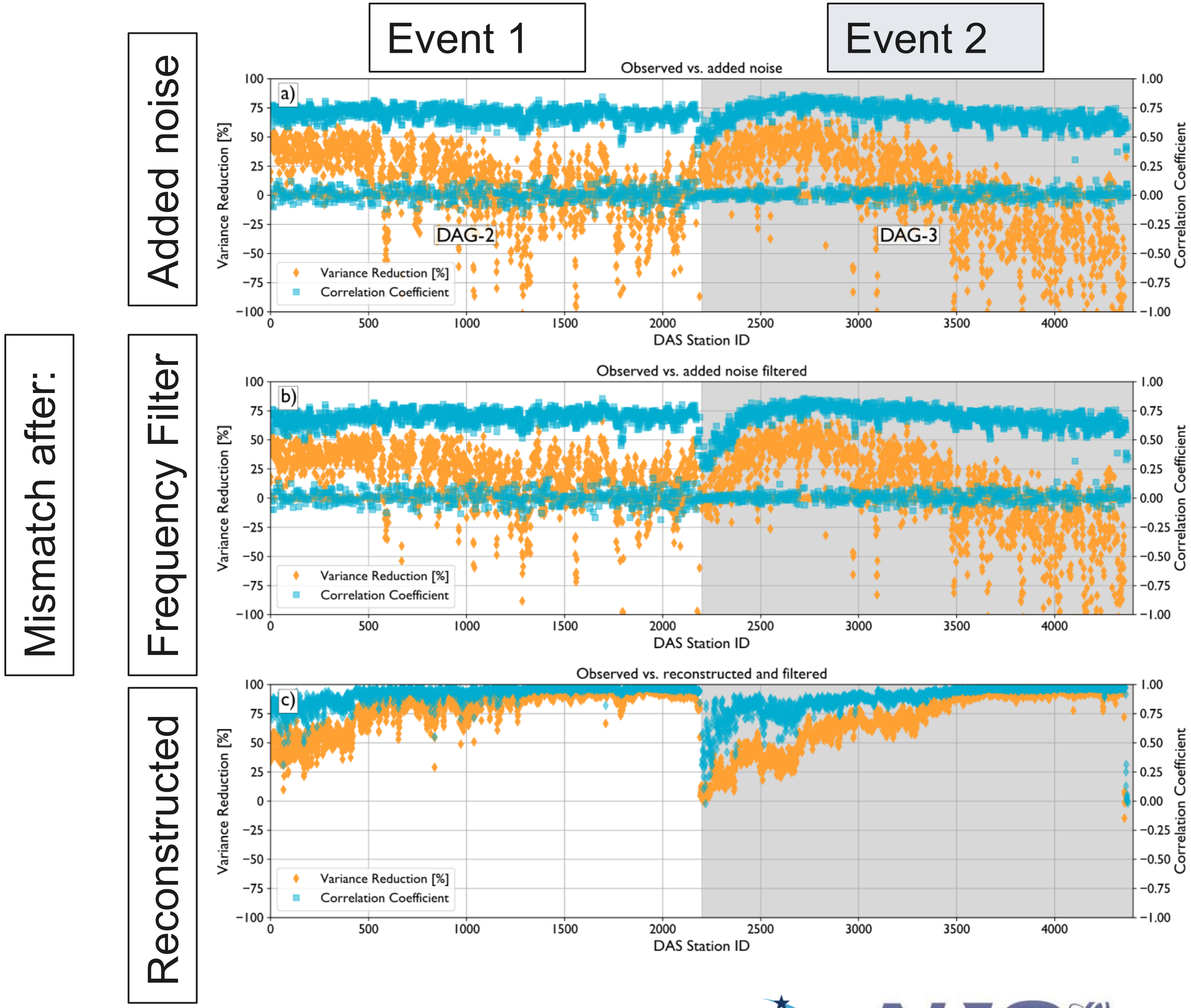
Porritt and Stanciu, *SAND Report*, OSTI

QUANTIFICATION OF DENOISING

Effectiveness of denoising is quantified by comparing the original and modified data using the Variance Reduction and Correlation Coefficient.

Traditional frequency filtering has an insignificant effect in recovering the original data.

The J-Invariant method is highly effectively at recovering the original data, event reconstructing channels that have been set to 0.



Porritt and Stanciu,
SAND Report, OSTI

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THANKS!
QUESTIONS?

- High spatial resolution/channel density makes DAS ideal for array processing and ML-based denoising.

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