Towards Distributed Acoustic Sensing as a Viable Microseismic Monitoring Tool: Results from the Field

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1. Introduction

Distributed Acoustic Sensing (DAS) has gained increasing attention in recent years as a cost-effective monitoring technique of induced seismicity. DAS exploits the naturally occurring Rayleigh backscattering of coherent laser radiation for probing the dynamic location of natural inhomogeneities in the glass structure of the optical fibre. This modulates with the impingement of incident acoustic waves and can hence record seismic events (Fig. 1).

Advantages to the use of DAS over conventional geophone arrays include:

- Low infrastructure and deployment costs.
- Vast reaches (~10s km).
- Near real-time continuous recordings.
- Simple installation of cheap, lightweight and rugged optical fibre cable.
- High sampling resolutions (e.g. <0.5m, 40kHz).
- Robustness (operational at high temperatures and pressures and in harsh chemistries).

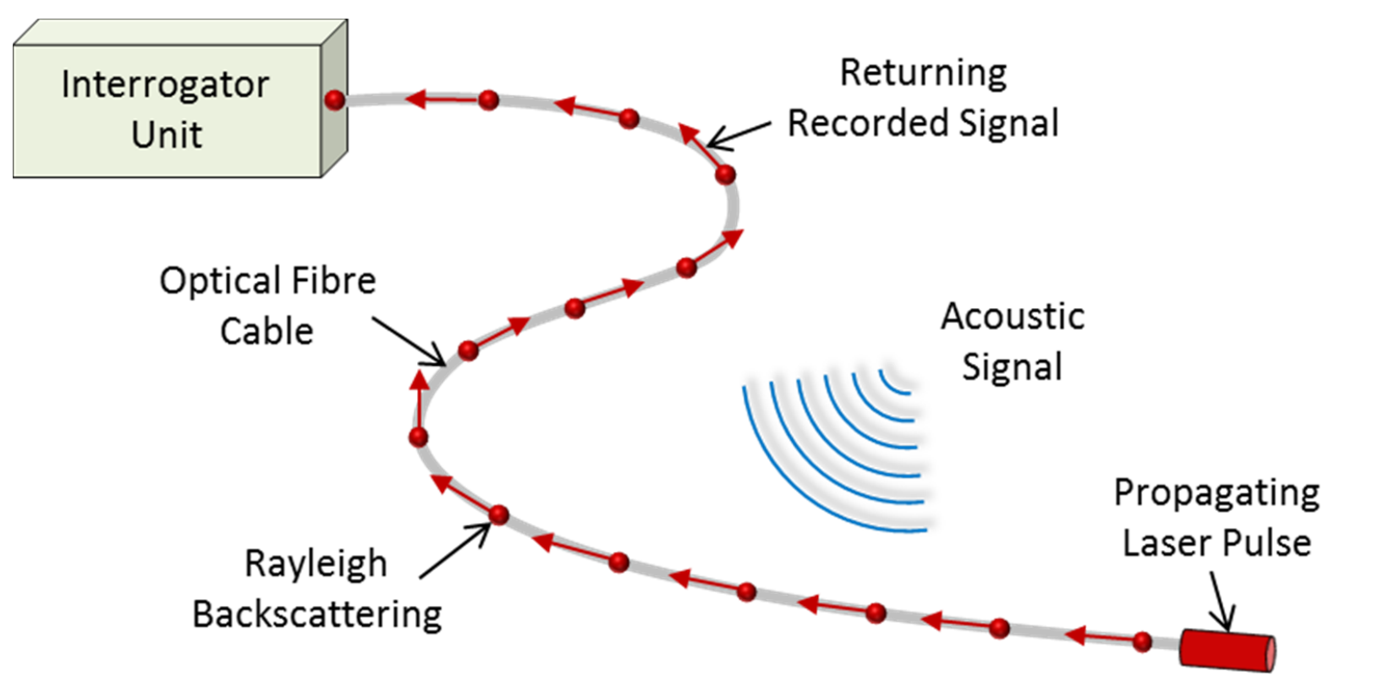


Figure 1. Cartoon of Rayleigh backscattering in an optical fibre cable.

Challenges remain that limit the usefulness of DAS however, such as high noise-floors and directional insensitivity to 'broadside' (orthogonally incident) waves. Despite this, the vast potential of DAS is of high interest to many microseismic monitoring applications but to date there has been little research into its use for monitoring induced seismicity at Carbon Capture & Storage (CCS) sites.

In this study we perform field tests using a DAS recording system developed by CMR to record man-made (sledge) hammer blows at the surface. These represent the preliminary trials in a collaborative project with the scope to monitor active CCS sites in the future.

2. Fieldwork at Norsar

- The DAS cable is laid out at the surface from the interrogator unit at point x0 through A to N (Fig. 2).
- The laser is fired with a pulse repetition rate of 40kHz (temporal sampling rate) from x0.
- The chosen time stamp between data points of 4ns gives a constant spatial sampling of ~0.4m.
- 498 channels are recorded that span the 198m of cable.
- At present we cannot constrain the absolute locations of the recording channels and hence the 498 channels are mapped to xy coordinates through interpolation along the cable.
- Hammer blows are performed at 3 locations: I, III & V.
- Data acquisitions are ~10s that cover 3 hammer blows.
- 6 geophones are installed to supplement the DAS data at locations 1-6.

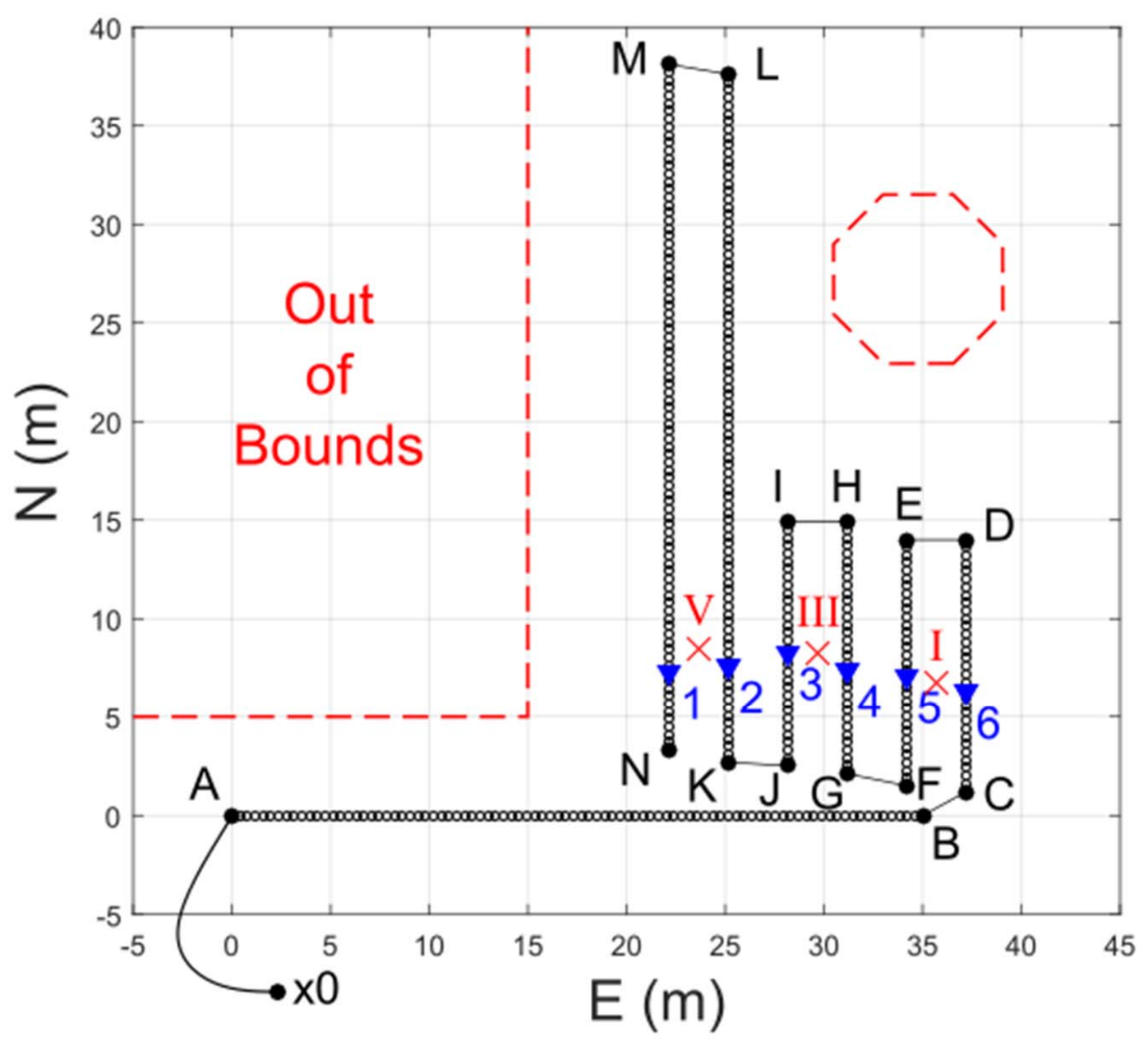


Figure 2. The cable and sampling points (black), geophones (blue) and hammer blow (red) locations.

3. Data Processing

Our data processing routine follows:

- Data are decimated temporally from 40kHz to 10kHz with an anti-aliasing filter.
  - N.B. We observe that applying the anti-aliasing filter as a part of the decimation process improves data quality and SNRs in comparison to recording at lower rates (downsampling).
- Traces are detrended and the mean is removed.
- A 1% cosine taper and a 3rd order band-pass Butterworth filter between 20 and 200Hz are applied (Figs. 3 & 4).

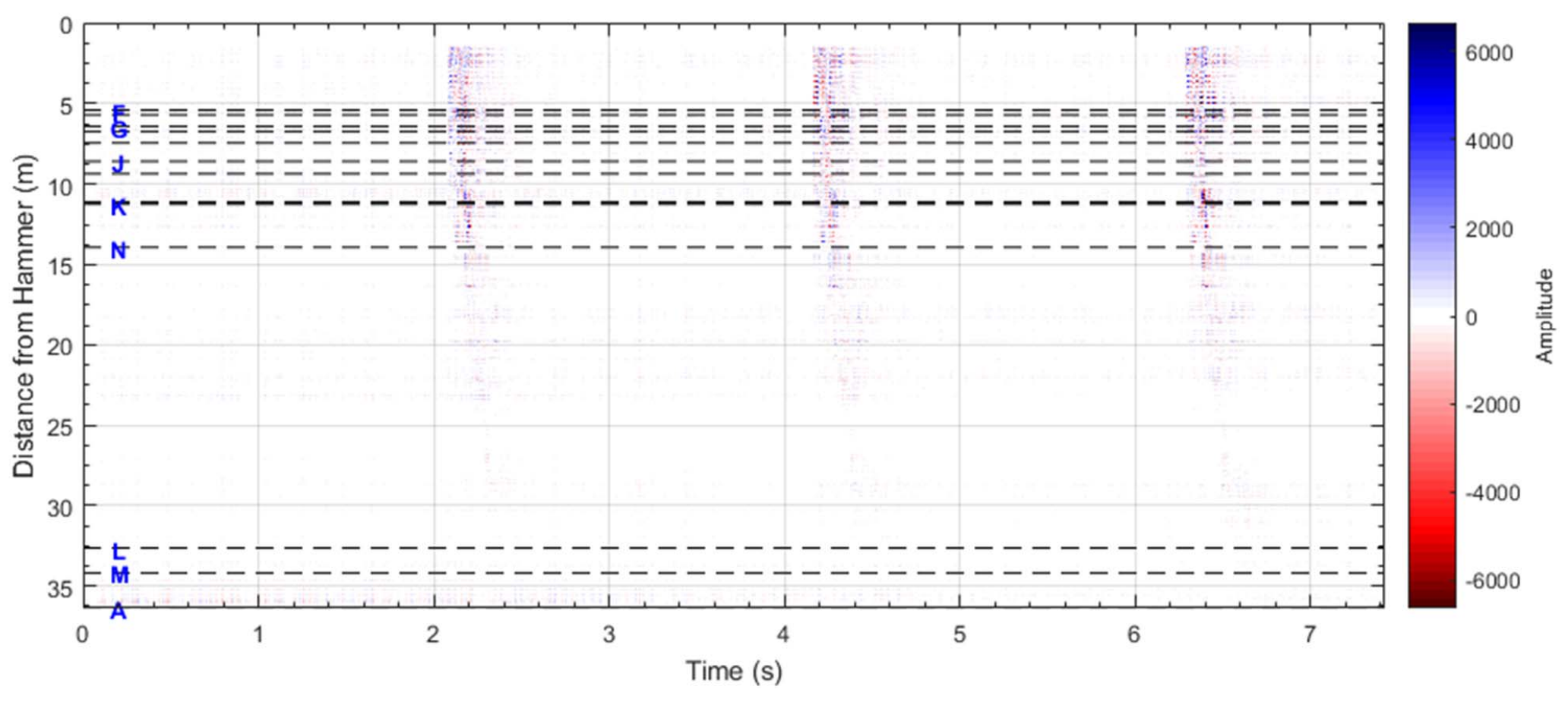


Figure 3. Common shot gather of 3 hammer blows at location I. The cable corners A-N are dashed lines.

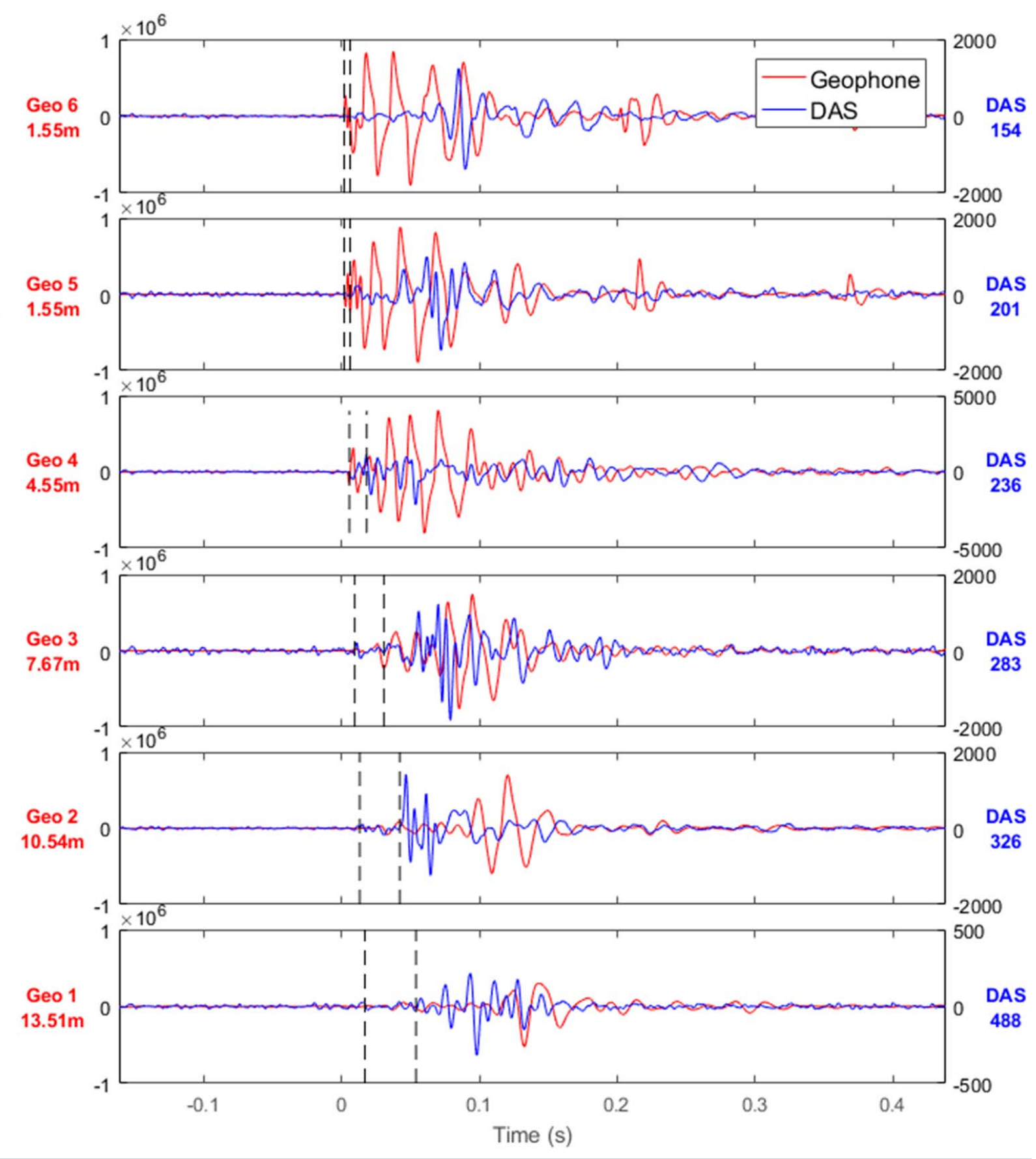


Figure 4. Move-out of seismic arrivals from I, across 6 geophones (red) and the 6 closest DAS channels (blue). Arrivals with move-out velocities of 250 and 800m/s are also marked. →

4. Signal-to-Noise Ratios (SNRs)

SNRs are calculated in the time (Fig. 5) and frequency (Figs. 6 & 7) domains for geophone and DAS recordings.

Time Domain

- 0.2s time windows are taken around the signal and noise.
- The average power of these windows (P_S & P_N) are taken:

$$P_S = \frac{1}{N}\sum_{k=0}^{N-1} |s(k)|^2.$$

- SNR is calculated as:

$$\mathrm{SNR} = 10\log_{10}\left(\frac{P_S - P_N}{P_N}\right).$$

Frequency Domain

- At each DAS channel/geophone, amplitude spectra of the unfiltered signal and time windows are computed.
- Signal spectra are divided by the noise spectra.

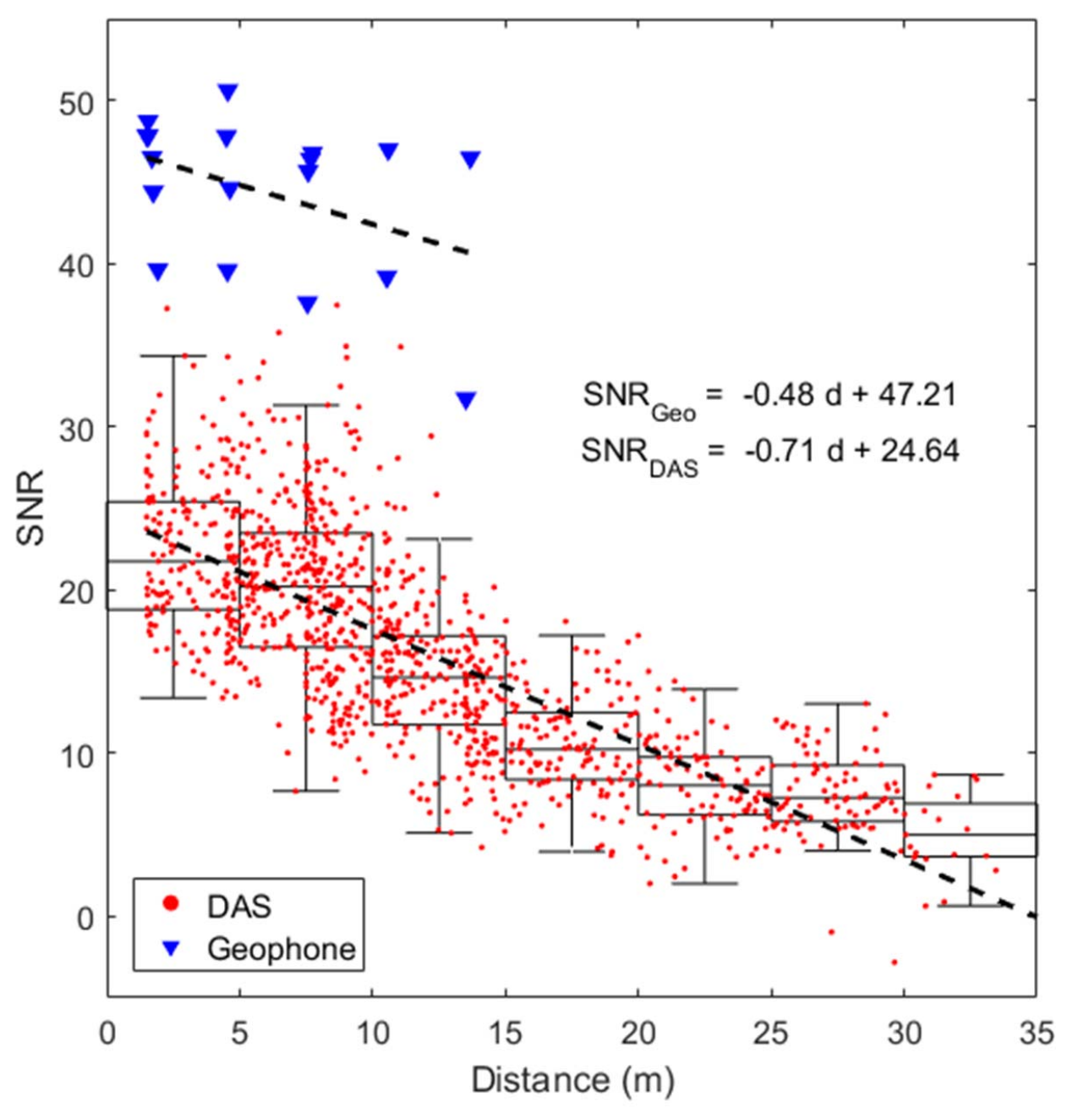
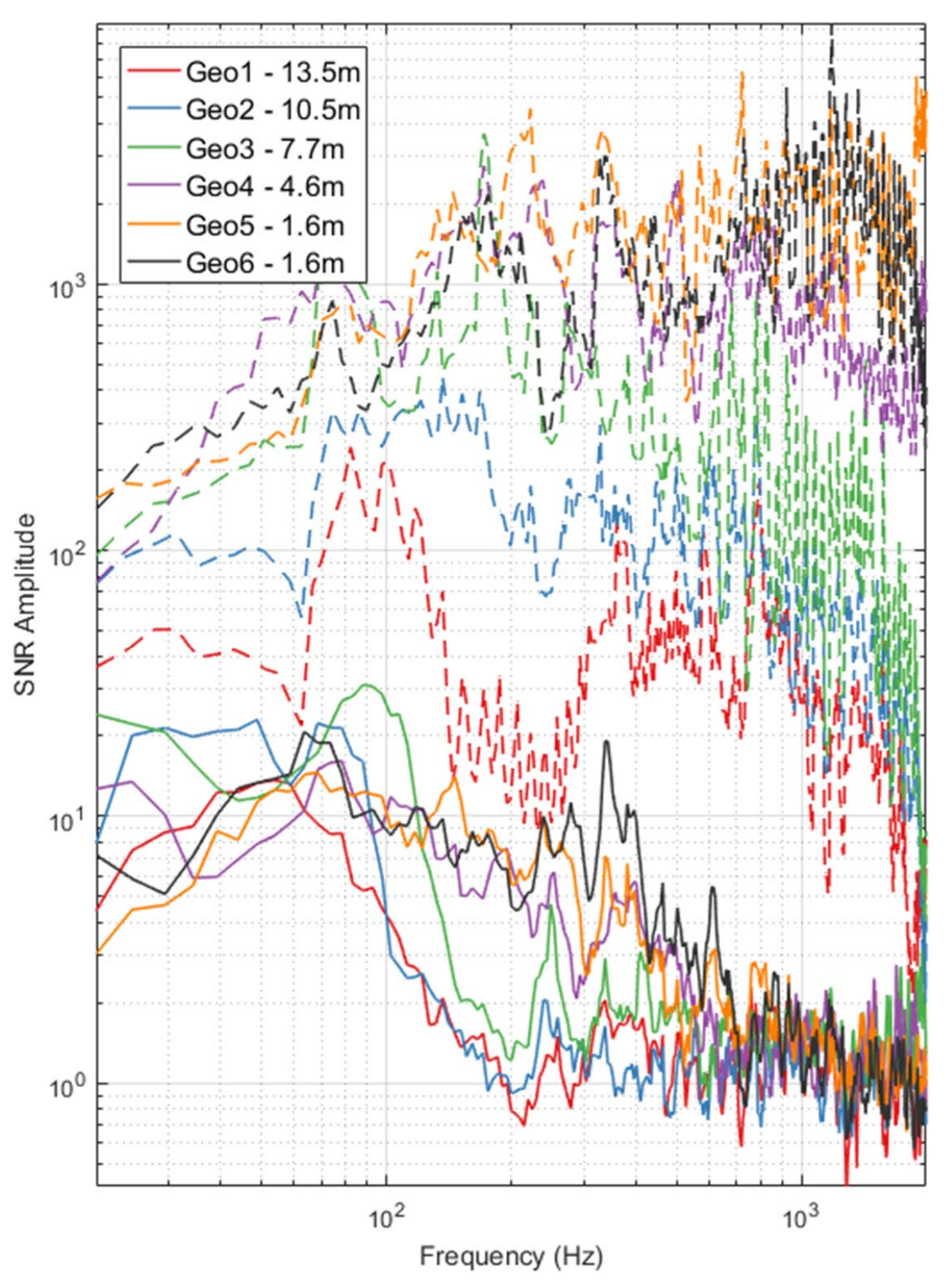
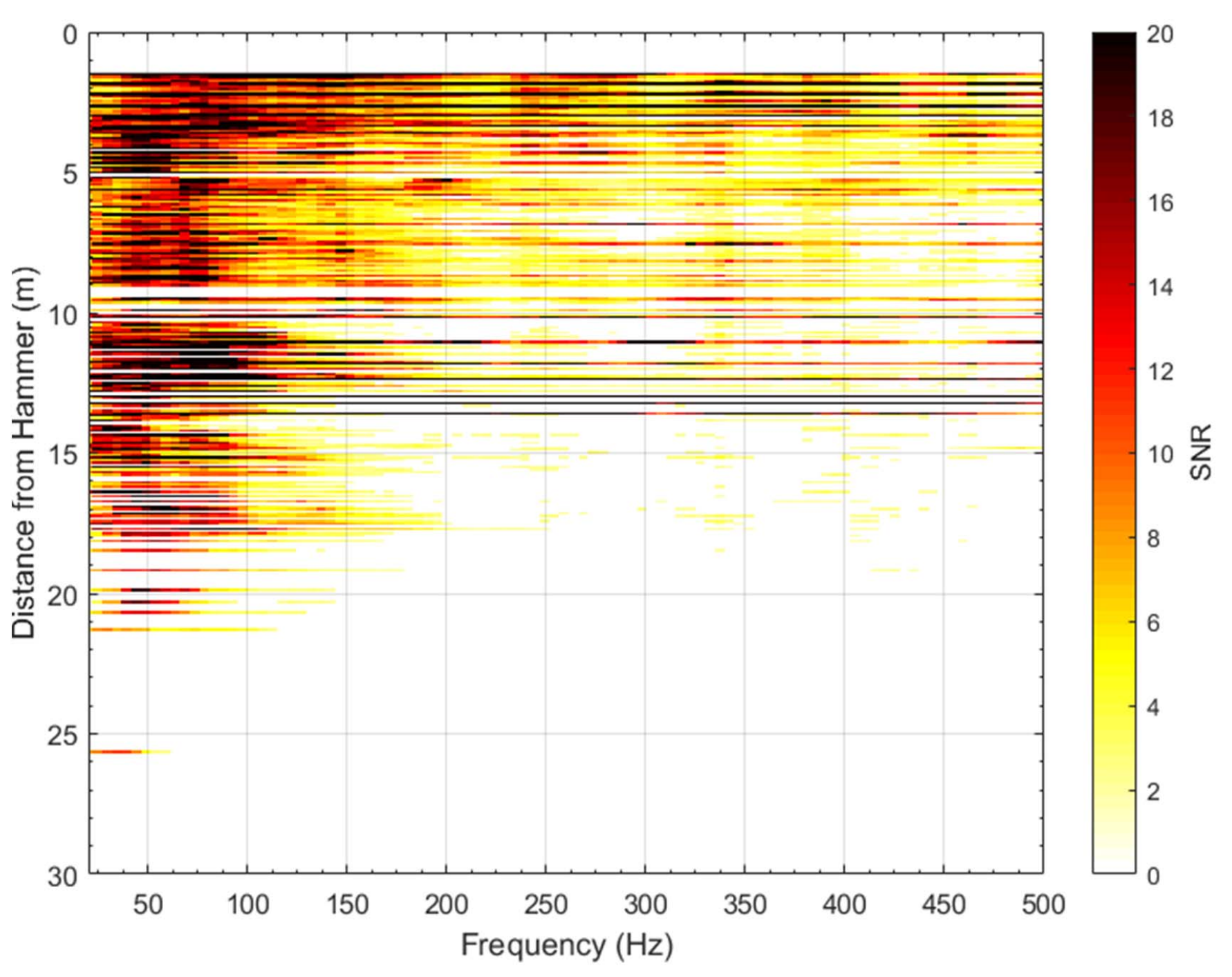


Figure 5. Time Domain SNRs computed for DAS and geophone data at 3 shot locations.



←**Figure 6.** SNRs of 3 stacked shots at I for 6 geophones (dashed) and the 6 closest DAS channels (solid).

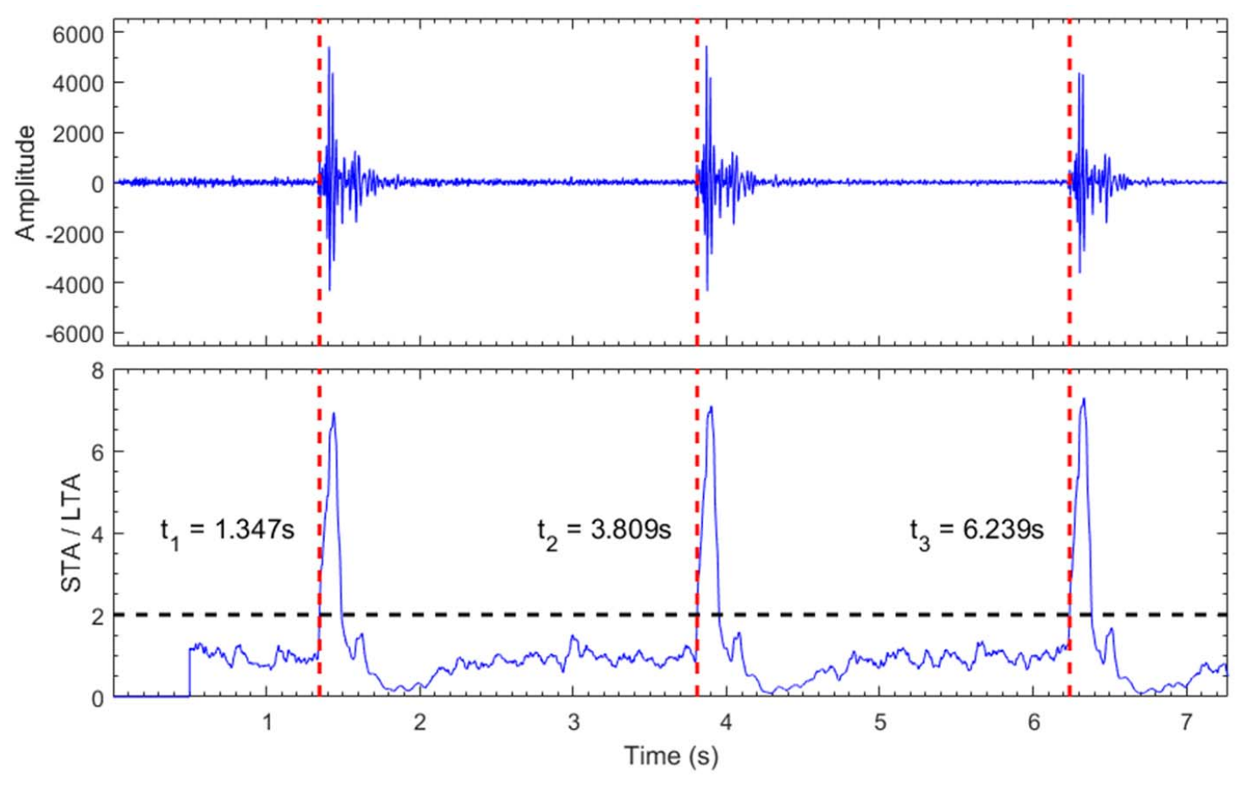
Figure 7. Along cable freq domain SNRs from I by distance. →

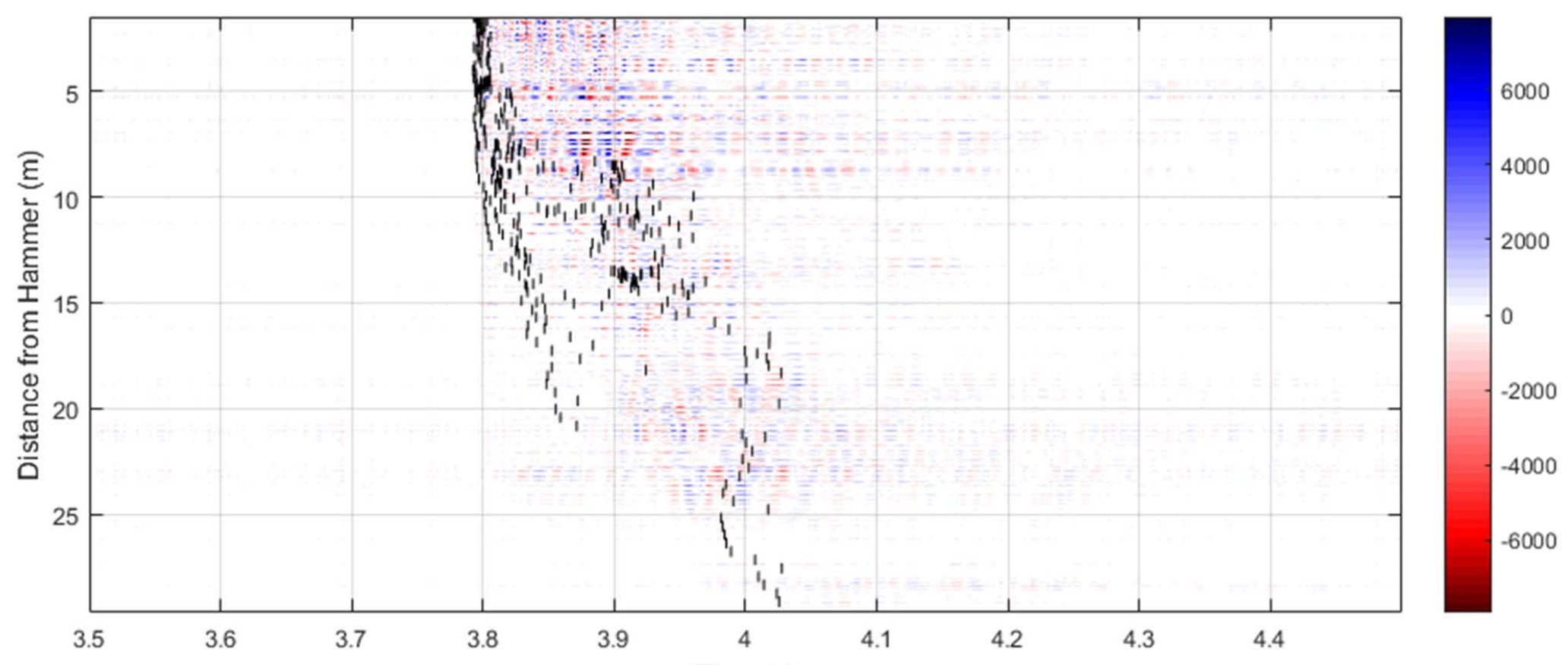


5. 2D Hammer Shot Location

- We locate the hammer shots using a 2D grid-search location algorithm with nodal spacings of 0.5m.
- Arrival picks are made automatically using an STA/LTA algorithm with STA and LTA window lengths of 0.05 and 0.5s and a trigger threshold of 2 (Figs. 8 & 9).
- Trigger outliers > 2σ of the mean arrival time of each shot are discarded.
- Triggers from a single shot are used for each location run with equal weightings.
- An equal-differential time minimisation function is applied.
- A homogenous velocity model is assumed of 250m/s.

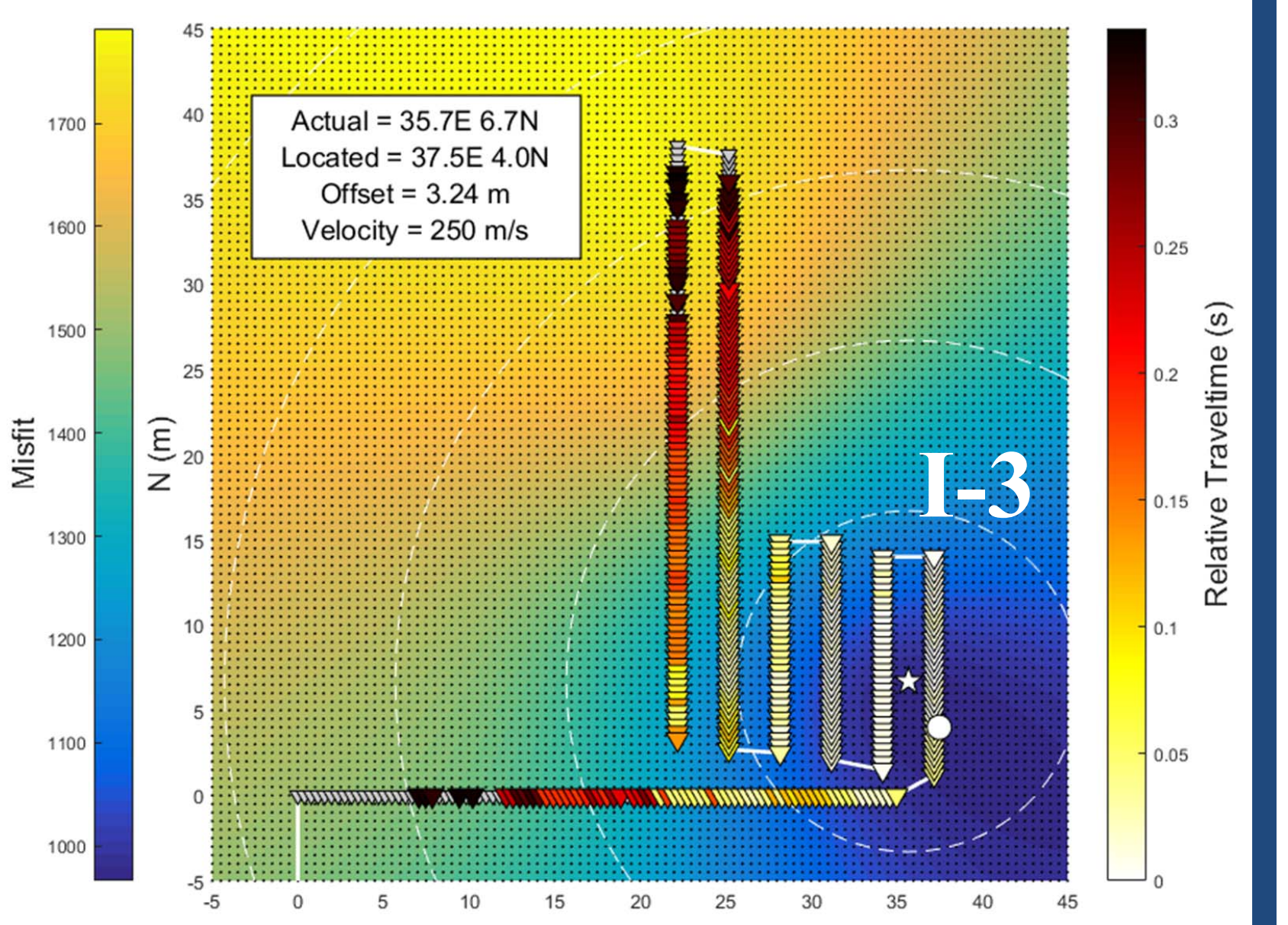
Figure 8. Example of the STA/LTA automated picking routine.





← **Figure 9.** An example of the STA/LTA triggers determined along the cable and used in the location routine versus distance from the shot.

- The triggering algorithm works well for certain arrivals but does not capture the first-arriving energy at all channels.
- We suggest that certain picks reflect later phases to the first onsets (e.g. Fig. 4).
- Triggers are detected up to ~32m from the shot.
- We are nonetheless able to locate the hammer shots at I, III and V to 2.86-3.24, 0.82-3.89 and 2.15-2.82m of their actual locations respectively (Fig. 10).



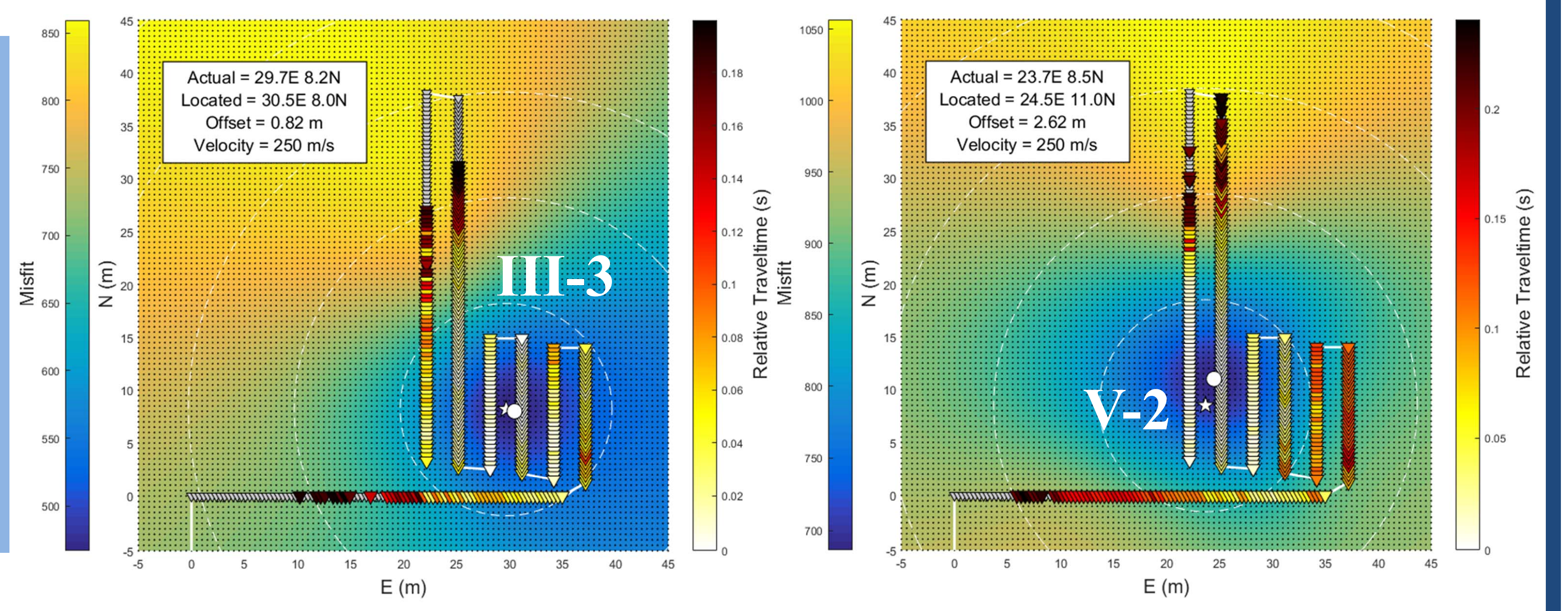


Figure 10: Results of the 2D shot locations (circles) at I, III and V (stars).→

6. Conclusions

- Coherent seismic arrivals are observed at up to 32m with frequency content up to ~500Hz.
- Signal to Noise ratios for DAS channels at a given distance are ~ $^1/_2$ those of the geophones.
- An automated STA/LTA picking algorithms is able to define reasonable seismic onsets.
- We are able to locate the hammer shots to within 3.9m of the actual source locations.
- Although using interpolation to define channel locations works sufficiently here, it is important for future work that we are able to better constrain absolute DAS channel locations in space.
- This will allow us to better constrain source locations and to investigate the sensitivity of the acoustic signal with incidence azimuth.
- These initial tests are encouraging and the project will refine the DAS recording system and the understanding of its optimum use for CCS monitoring.

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7. Outlook

Further field/lab experiments planned in 2017-2018:

- A second field trial at Norsar to test additional cable types (e.g. helical), varying interrogator parameters, longer data recordings and methods to constrain absolute channel locations.
- A laboratory borehole test at NTNU with an airgun in a water tank and/or hammer drop sources.
- Microseismic monitoring at an active CCS injection site in Canada and/or Indonesia.