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Advancing Explosion Monitoring with Distributed Acoustic Sensing: Insights from the NORFOX Fibre Array

Alan F. Baird, Andreas Wuestefeld, Andreas Köhler, Ben Dando

NORSAR, Gunnar Randers Vei 15, N-2007 Kjeller, Norway
alan.baird@norsar.no

INTRODUCTION AND MAIN RESULTS

The NORFOX DAS array in southern Norway (5 arms, ~3 km aperture) complements the co-located NORES seismic array. DAS records P, S, and acoustic phases from earthquakes, explosions, and thunderstorms. Beamforming with directivity weighting significantly improves resolution for SH waves, while incoherent methods (e.g. STA/LTA) enable robust detection of complex events.

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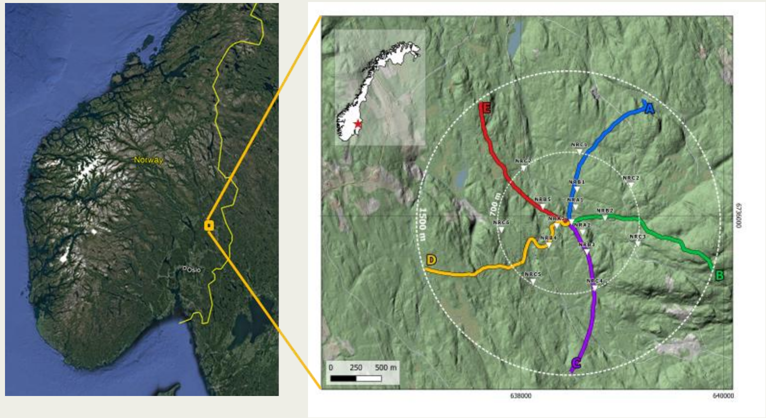
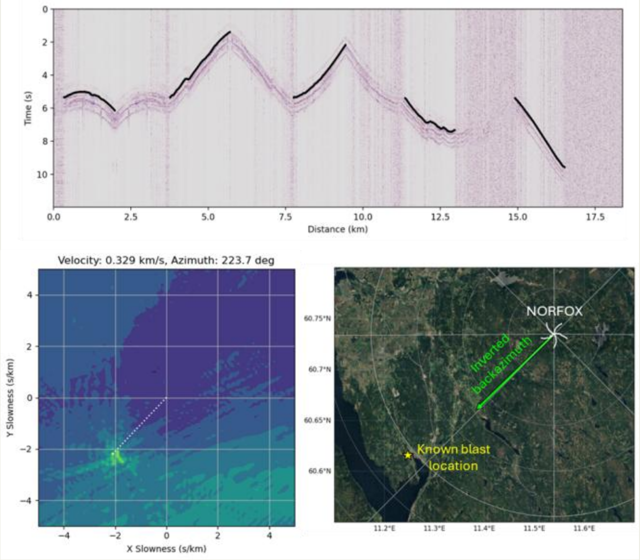
Introduction



The NORFOX DAS array (5 arms, ~3 km aperture) is co-located with the NORES seismometer array (white triangles) in southern Norway. This setup provides a unique testbed to compare fibre-optic sensing with traditional seismometers for regional event monitoring.

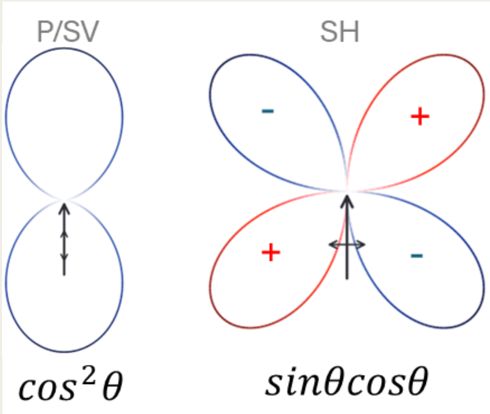
Array processing of acoustic wave

The figure to the right shows: Top – DAS recording of acoustic arrivals from a nearby construction blast with best-fitting arrival times overlaid; the mirrored sawtooth pattern reflects the outgoing and return fibres of each arm. Bottom – FK analysis (left) identifies slowness and backazimuth, matching the known blast location on the map (right).



Dealing with P/S directivity effects

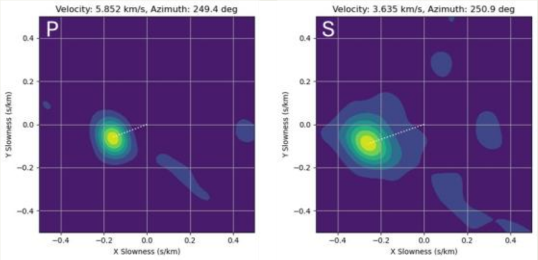
DAS is a directional sensor, measuring only strain parallel to the fibre. Sensitivity is set by projection of propagation and polarization vectors onto the fibre axis, giving different responses for P, SV and SH waves and shown in figure to the right. Neglecting these variations can degrade beamforming performance.



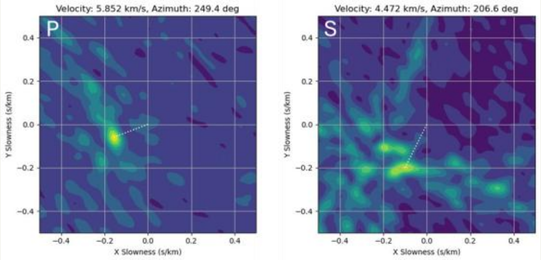
Figures to the right: FK analysis of P (left) and SH (right) arrivals from a construction blast. Shown are the seismometer array (top), unweighted DAS array (middle), and DAS with phase-directivity weighting (bottom). P waves are well resolved in both DAS cases, while SH waves improve significantly with weighting, which corrects polarity reversals that would otherwise cause destructive stacking.

Comparison of NORES and NORFOX beamforming

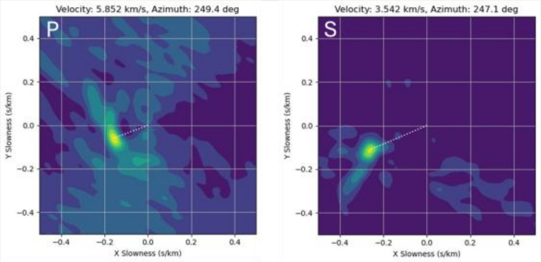
NORES seismometer array



NORFOX DAS array - unweighted



NORFOX DAS array - weighted



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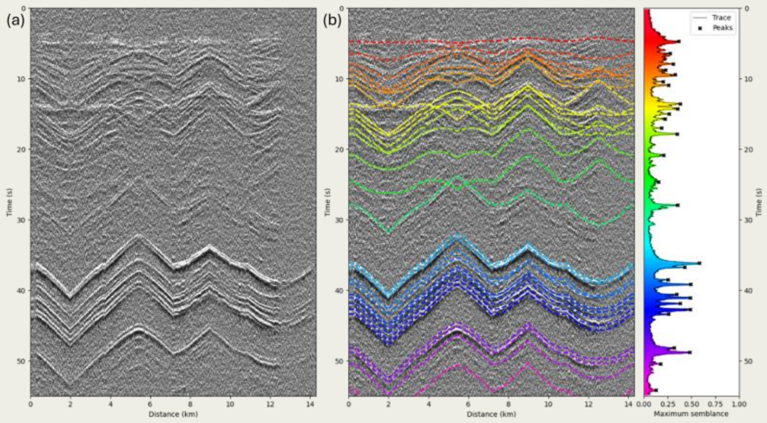
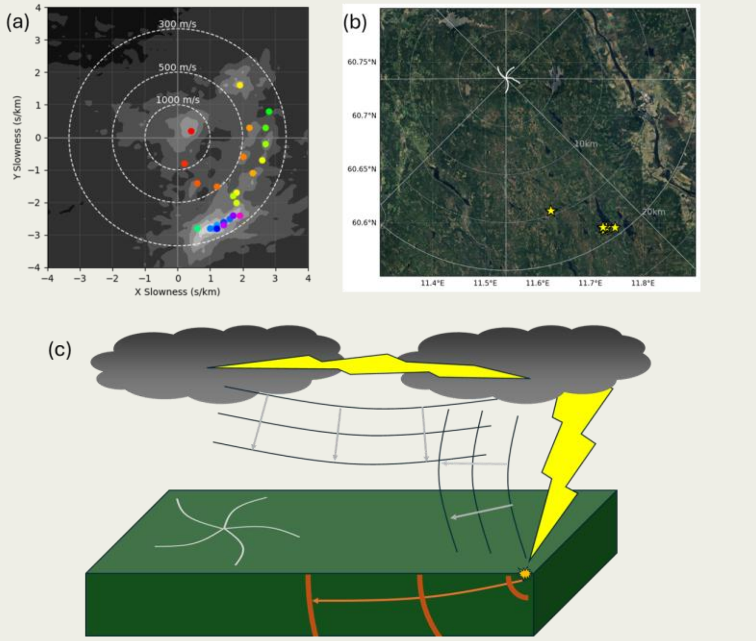
Event detection with incoherent beamforming

Incoherent beamforming uses simple characteristic functions, such as STA/LTA ratios, instead of raw waveforms. This enables detection of arrivals without the complex, phase-specific weighting corrections required in coherent beamforming using DAS.



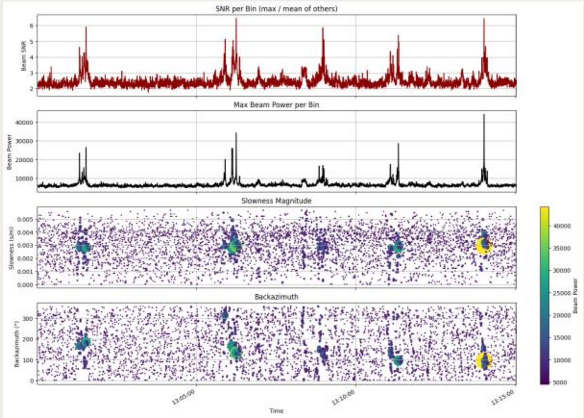
The above figure shows: (a) STA/LTA recording of thunder from a cluster of lightning strikes showing multiple complex and overlapping arrivals. (b) Same data with detected arrival times from the incoherent beamforming overlaid. Detections correspond to peaks in the maximum semblance vs. time plot (right), with colour indicating the time of arrival at the reference station at the centre of the array.

Example of thunder detections



The above figure shows: (a) Slowness grid with maximum semblance contours and detected arrivals as coloured dots. (b) Map of lightning strike locations from the Norwegian Meteorological Institute; late arrivals (blue and purple in (a)) align with expected acoustic arrivals from these sites. (c) Cartoon of lightning-generated signals: fast seismic from the strike point, horizontally propagating thunder from the bolt, and steeply downward propagating thunder from lighting branching in the clouds. These combinations may explain the diverse slownesses and backazimuths observed.

Continuous event detector



We are developing a prototype incoherent beamform detector for continuous data. The figure above shows five thunder events within 15 minutes, each with distinct backazimuths.

Conclusions

- NORFOX complements NORES with dense sampling.
- DAS detects P, S, and acoustic phases, though amplitudes are directivity-dependent.
- Weighting improves beamforming, especially for SH.
- Incoherent beamforming enables robust detection of complex sources (e.g. lightning).
- Prototype detectors show potential for real-time DAS monitoring.

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