Evaluating HD weathering surveys and surface seismic with DAS in a sand dune environment

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Summary

Surface seismic on land demands more significant trace density with finer sampling to address imaging and near-surface challenges. It becomes challenging to meet these requirements with conventional point sensors. Distributed Acoustic Sensing (DAS) offers a potentially more attractive alternative with less cost, provided the directivity challenge can be solved. DAS also opens new horizons to deliver multiscale data in the form of "shallow", "deep", and "FWI" surveys leveraging acquisition with the same fixed cables. While DAS offers multiscale data at no extra cost, conventional point sensors would require separate receiver layouts to achieve them. We present a field trial evaluating HD weathering surveys and surface seismic with DAS in a sand dune environment. Focusing on the directivity challenge, we evaluate four different omnidirectional cables with varying wrapping angles and compare them to 3C geophones and straight DAS cables. We further evaluate three different source types considered for various applications. Field trial provides comprehensive datasets for assessing the initial performance of DAS cables in sand dune environments for surface seismic with DAS.

Introduction

Surface seismic in a desert environment requires higher acquisition density to completely resolve imaging challenges. Prestack data quality is challenging with small arrays and especially single sensors. Strong vertical and lateral velocity variation in near surface is a major culprit. Energetic near-surface arrivals blanket weak reflections. Scattering in the near surface further breaks down reflections themselves (Bakulin et al., 2020b). Finer sampling is needed for both goals: reconstruct the detailed near-surface velocity and provide enough traces to cancel out the effect of energetic complex organized noise during imaging. Bakulin et al (2020a) put forward a detailed use case for seismic using Distributed Acoustic Sensing (DAS). DAS can provide unprecedented flexibility for inline sampling to vary from ~ 1m to tens of meters. In addition, DAS being a small natural array, can provide better data quality than point sensors that suffer from scattering and require pre-processing or stacking even for first breaks to become useable (Khalil and Gulunay, 2011; Bakulin et al., 2019a). To fully assess the benefits of seismic DAS recording and contrast it against conventional geophones, we conduct a focused field trial to assess both High-Definition (HD) weathering surveys for near surface and surface seismic with DAS. Since conventional DAS cables placed on the surface have predominantly horizontal directivity, we assess multiple prototype omnidirectional DAS cables allowing us to record reflected data robustly.

Field trial

A field trial was conducted in Western Australia. The test site in a sand dune environment was selected to replicate seismic acquisition and challenges of a desert environment. Specifically, two main features were of interest. First, to replicate trenching and coupling of DAS cable in the sand. Second, replicate typical prestack gathers from a desert environment dominated by energetic near-surface arrivals

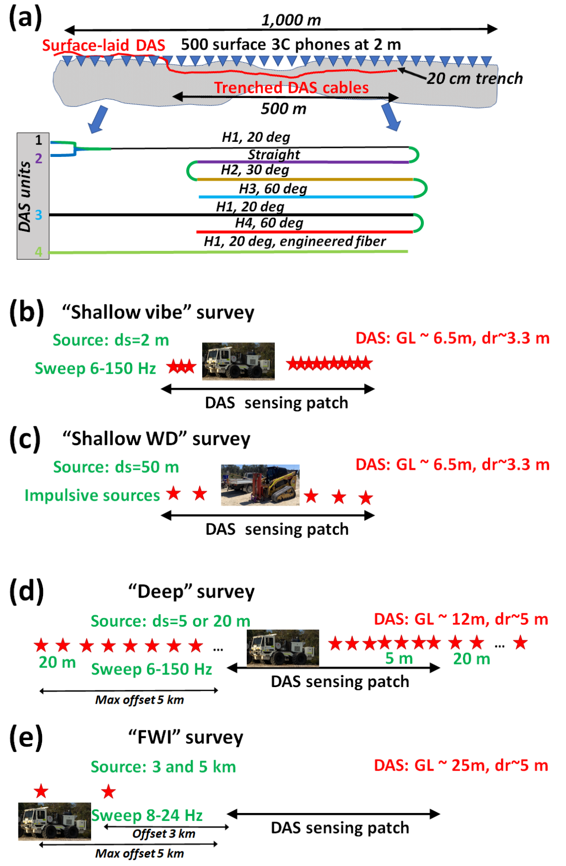

Figure 1: (a) Sensor layout geometry inside 2D sensing patch with surface geophones, trenched, and surface DAS cables. The bottom panel shows four DAS strings composed from daisy-chained fibers from five DAS cables: one straight and three helically wound. (b) "Shallow vibe" survey; (c) "Shallow WD" survey; (d) "Deep" survey; (d) "FWI" survey.

with a low apparent velocity that mask weak reflections (Bakulin et al., 2020b, 2021).

Figure 1a shows sensor layout geometry. Multiple fiber-optic cables are all placed inside the 500-m long trench. Five different cables were evaluated:

- Standard telecom cable, loose tube with 11-degree pitch (six single-mode cores) – usually referred to as a straight DAS cable;
- H1, tactical tight-buffered helical cable with three single-mode and one engineered fiber, wrapping angle < 20 degrees;
- H2, loose tube helical 30-degree cable (two single-mode fibers);
- H3, tight-buffered tube helical 60-degree (two single-mode fibers);
- H4, loose tube helical 60-degree (one single-mode fiber).

Four cables have multiple fibers allowing simultaneous interrogation with different DAS units. As a result, various short cables were daisy-chained to optimize recording, as shown in Figure 1a, forming four distinct DAS strings that could be recorded simultaneously. Each shooting run employed four different DAS units generating seven different versions of data (seven distinct fibers on Figure 1a) corresponding to different interrogator-cable/fiber configurations.

The following goals we set for the field trial:
• Evaluate several omnidirectional DAS cables for reflection seismic and select the best one for further trials (sandy test site representative of the desert environment);
• Evaluate various DAS recording systems for surface seismic applications;
• Evaluate shallow trenching/coupling methods for various DAS cables;
• Evaluate High-Definition weathering surveys with DAS (super-dense sampling with < 1 m) and various sources;
• Evaluate surface seismic with DAS (vibroseis, max offset 5 km).

In this study, we describe the details of the field acquisition and show representative data without any processing.

Sensor instrumentation and deployment

DAS cables require adequate coupling to the ground to measure a seismic signal. Previous studies have shown that shallow trenching provides good coupling (Alajmi et at, 2019, Bakulin et al., 2017). In principle, DAS data can be recorded without trenching; however, data quality deteriorates (Nap et al., 2020) and becomes susceptible to wind noise (Bona et al, 2021). Therefore, we opted for a relatively shallow ~20-cm trench. We also had some cable segments on the surface to verify the effect of trenching (Figure 1a).

Figure 2 shows the key steps of the sensor placement. First, a 500-m long trench was prepared (Figure 2a). Then, five cables were deployed side by side (Figure 2b). Finally, the trench was closed, and 3C geophones were deployed by the side of the trench (Figure 2c). In the future, cable plowing machines can automatically trench cables in a single step without opening the trench (Bakulnt et al., 2019), similar to how it is currently done with telecommunications cables.

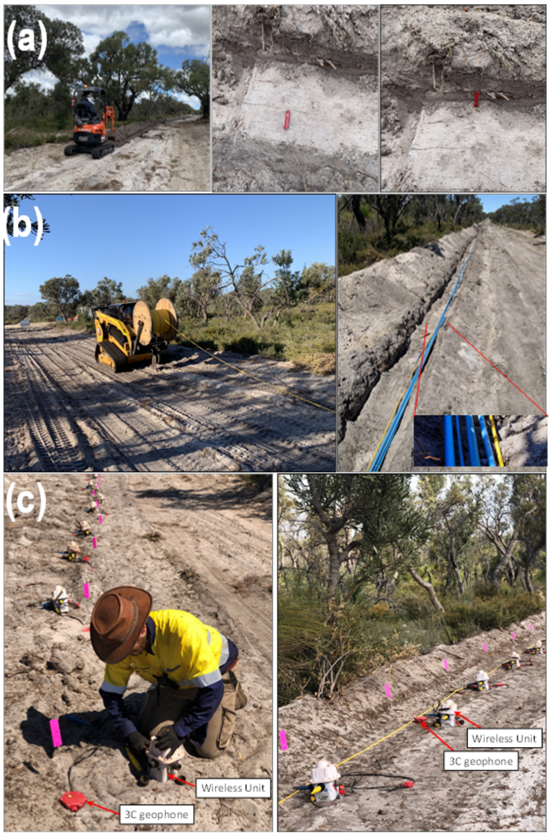

Figure 2: Sensor deployment: (a) opening of the trench; (b) deployment of the DAS cables; (c) placement of 3C geophones (nodes) alongside the trenched fiber-optic cables.

Sources

Three different source types used in the trial are shown in Figure 3:

1. 26,000 lbs seismic vibrator;
2. Large weight drop built of 720 kg concrete breaker;
3. Small 45 kg accelerated weight drop.

While vibrator is a workhorse of current acquisition, a smaller weight drop source could be a competitive candidate for “Shallow” surveys (Figure 1b,c). Specifically for Near-Surface High-Definition weathering surveys, weight drops may be more fit-for-purpose in terms of cost, operational simplicity, and reduced shot-generated and correlation noise.

Multiscale DAS acquisition

The concept of surface seismic with DAS may offer these key advantages (Bakulin et al., 2020a):

Figure 3: Seismic sources used in the trial: (a) 26,000 lb vibroseis; (b) smaller sources for HD weathering surveys: left – small 45 kg accelerated weight drop; right – large 720 kg weight drop.

- Massive channel count with cheaper per channel cost than point sensors;
- Uncompromised inline sampling;
- Flexible multiscale recording suitable for looking “shallow” and “deep” as well generating “FWI velocity survey” with dedicated low-frequency arrays;
- Completely broadband nature of the DAS sensor.

We have explored the following four surveys in this trial, each addressing a specific application.

“Shallow vibe” survey. Such an acquisition (Figure 1b) with small gauge length (GL) and densest channel spacing unlocks near-surface characterization with finely-sampled tomography, reflection-based methods, surface-wave inversion, elastic FWI, etc. – all harvesting benefits of unaliased data (Bakulin et al., 2020a). Minimum GL of 6.5 m was employed, whereas channel spacing was 1-3 m. Similarly, source spacing was reduced to 2 m. Besides, shot locations are restricted only to along the DAS trench.

“Shallow weight-drop” survey. Such a test generated a decimated alternative of the same shallow survey but utilizing smaller impulsive sources (Figure 1c). Weight drop was often used for Low-Velocity Layer (LVL) survey, measuring the weathering characteristics at close spatial sampling along a seismic line (Roy, 1995; Cox, 1999).

“Deep” survey. Such acquisition (Figure 1d) with a longer gauge length (i.e., larger array) and the moderate spacing would be a proxy for conventional data targeting deep reflections. Shortest GL rises to 10 m, while typical channel spacing increases to 5 m (with some systems still recording at less than 1 m samplings). Bakulin et al. (2020a) explained that most DAS systems record data at finer intrinsic sampling but output supergrouped data when larger channel spacing is specified. Likewise, for the “deep” surveys shot spacing increases to 5 m above the trench and 20 m outside the trench. In addition, offsets up to 5 km away from the trench are explored (Figure 1d).

“FWI” survey. Since DAS is a broadband sensor recording all the way to static strain, one way to leverage DAS for a low-frequency FWI survey is to resort to an even larger GL creating a low-frequency receiver with improved sensitivity (Bakulin et al., 2020a). GL of up to 25 m is explored, whereas source sweep is restricted to 8-24 Hz, further focusing energy in the band of interest. This test was limited and recorded only two offsets at 3 and 5 km away from the edge of the trench (Figure 1e).

Data overview

Figure 4 shows examples of selected shot gathers. Detailed analysis is outside of the scope of this work and will be reported in separate publications. Figure 4a,b shows recordings with two coiled helical cables and contrasts them to vertical geophone data (Figure 4c). All gathers confirm the high complexity of the wavefield dominated by energetic near-surface arrivals. A very slow and dispersive groundroll populating the inner noise cone is well recorded by both geophones and DAS. In general, reflections are overwhelmed by strong near-surface arrivals. While all gathers register the same vibroseis shot, there is an observable difference in the clarity of the first arrivals. Early waveforms are crisp on geophone data and easy to pick (Figure 4c, yellow arrows). They are also visible on the H4 cable with 60-degree wrapping (Figure 4b). However, first arrivals have reduced signal-to-noise ratio on H1 cable, suggesting perhaps weaker signal. Similar observations can be made focusing on reflected events. While reflections in the desert environment are usually well hidden behind near-surface arrivals, one reflected event can be seen without processing on H4 cable and geophones (Figure 4b,c, green arrows). However, this event is not readily observed on

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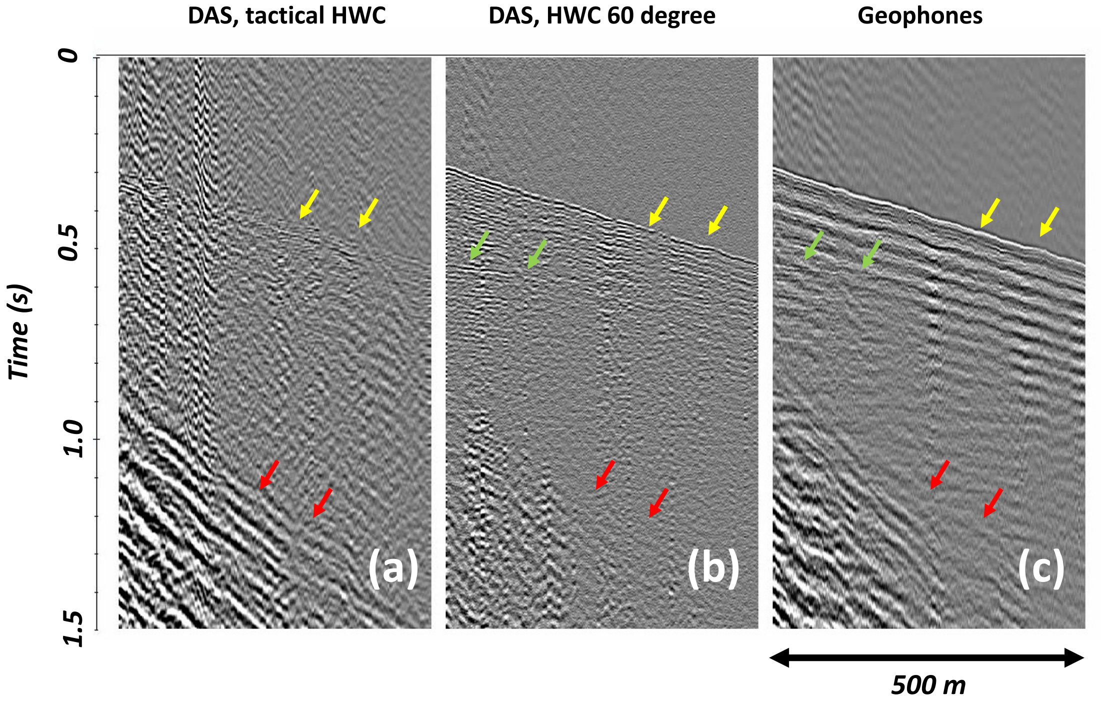

Figure 4. Vibroseis shot records obtained with two omnidirectional DAS cables and geophones: (a) H1, tactical helical (dr=~1 m); (b) H4, 60-degree helical (dr=~0.5 m); (c) vertical geophones covering the same extent as DAS (dr=2 m). Refracted arrival (yellow arrows) is clearly seen on (b) and (c). However, it remains extremely weak on (a), suggesting that a significant impact of cable design and/or fiber wrapping angle on near-vertical directivity that influence strength of the signal. Likewise, shallow reflection event (green arrows) is seen on (b) and (c), but not detectable on (a). In addition, red arrows show the reduced amplitude of near-surface arrivals on (b). All panels have the same spatial extent (~ 500 m) but differ in the number of traces caused by different spacing. In the case of DAS cables, variable sampling is caused by different wrapping angles.

the H1 cable in Figure 4a, again suggesting a weaker signal on this cable. Near-vertical ray paths are expected for first arrivals and reflections due to rapid velocity slowdown towards the surface. As a result, we interpret that the H1 cable has insufficient wrapping angle, causing less favorable directivity and sensitivity and manifesting in weaker first breaks and reflections. In addition, such a difference may also be caused by the variability of the coupling to the ground. Note that near-surface arrivals (Figure 4, red arrows), are strong on H1 cable and geophones but suppressed on H4 cable with high wrapping angle, consistent with theoretical predictions (Kuvshinov, 2016). Detailed data analysis is required to reach firmer conclusions comparing various parts of the wavefield and examining their ratios on different sensor types. We note that while recorded data replicates certain typical complications, real data from the desert environment recorded with single sensors exhibit even higher complexity (Bakulin and Silvestrov, 2021), making organized noise broken up and less coherent, whereas first breaks become challenging to pick without pre-processing (Bakulin et al., 2019).

Conclusions

We conducted a field trial to evaluate HD weathering surveys and surface seismic using DAS acquisition. A sand-dune environment with complex near-surface wavefield and strong vertical velocity gradients was explicitly selected to simulate typical challenges from a desert environment. A dense 3C geophone line with 2 m spacing was used as a reference. In DAS acquisition focus was to evaluate four different omnidirectional cables that are expected to be sensitive to vertical displacement, thus enabling registration of refracted arrivals and reflections. Omnidirectional cables are to be contrasted with straight DAS cables and benchmarked against 3C geophones. To evaluate flexible array size and spacing of DAS data, we acquired “shallow”, “deep”, and “FWI” surveys adjusting DAS acquisition parameters on the fly to address specific applications while utilizing the same trenched cable as a receiver. Finally, in addition to vibroseis, two different weight-drop sources were assessed specifically for “shallow” high-definition weathering surveys to characterize the near surface.

REFERENCES

Alajmi, M. S., R. Pevzner, T. Alkhalifah, A. N. Qadrouh, M. Almalki, and F. A. Alonaizi, 2019, Trialling distributed acoustic sensing in a sand dune environment: ASEG Extended Abstracts.

Bakulin, A., P. Golikov, R. Smith, E. Erickson, I. Silvestrov, and M. Al-Ali, 2017, Smart DAS upholes for simultaneous land near-surface characterization and subsurface imaging: The Leading Edge, **36**, 1001–1008, doi: https://doi.org/10.1190/tle36121001.1.

Bakulin, A., D. Neklyudov, and I. Silvestrov, 2020b, Prestack data enhancement with phase corrections in time- frequency domain guided by local multidimensional stacking: Geophysical Prospecting, **68**, 1811–1818, doi: https://doi.org/10.1111/1365-2478.12956.

Bakulin, A., and I. Silvestrov, 2021, Understanding acquisition and processing challenges in the desert environment through SEAM Arid and Barrett models: First International Meeting for Applied Geoscience & Energy, SEG/AAPG, Expanded Abstracts, 2824–2829, doi: https://doi.org/10.1190/segam2021-3583002.1.

Bakulin, A., I. Silvestrov, and M. Dmitriev, 2019a, Adaptive multiscale processing of challenging 3D seismic data for first-break picking, FWI and imaging: 89th Annual International Meeting, SEG, Expanded Abstracts, 3979–3984, doi: https://doi.org/10.1190/segam2019-3214616.1.

Bakulin, A., I. Silvestrov, and R. Pevzner, 2019b, Surface seismic with DAS changes land acquisition: Middle East Oil and Gas Show and Conference, SPE.

Bakulin, A., I. Silvestrov, and R. Pevzner, 2020a, Surface seismic with DAS: An emerging alternative to modern point-sensor acquisitions: The Leading Edge, **39**, 808–818, doi: https://doi.org/10.1190/tle39110808.1.

Bona, A., S. Ziramov, R. Pevzner, K. Tertyshnikov, and M. Urosevic, 2021, Distributed acoustic sensing for surface seismic: Case study from mineral exploration: 82nd Conference and Exhibition, EAGE, Extended Abstracts, doi: https://doi.org/10.3997/2214-4609.202011593.

Cox, M., 1999, Static corrections for seismic reflections surveys: SEG, 546.

Daley, T. M., B. M. Freifeld, J. Ajo-Franklin, S. Dou, R. Pevzner, V. Shulakova, S. Kashikar, D. E. Miller, J. Goetz, J. Henninges, and S. Lueth, 2013, Field testing of fiber-optic distributed acoustic sensing (DAS) for subsurface seismic monitoring: The Leading Edge, **32**, 699–706, doi: https://doi.org/10.1190/tle32060699.1.

Khalil, A., and N. Gulunay, 2011, Intra array statics (IAS) in the cross-spread domain: 73rd Conference and Exhibition, EAGE, Extended Abstracts, I037, doi: https://doi.org/10.3997/2214-4609.20149308.

Kuvshinov, B. N., 2016, Interaction of helically wound fibre-optic cables with plane seismic waves: Geophysical Prospecting, **64**, 671–688, doi: https://doi.org/10.1111/1365-2478.12303.

Nap, A., P. Edme, C. Schmelzbach, P. Paitz, and J. O. A. Robertsson, 2020, Surface seismic with distributed acoustic sensing: Is trenching worthwhile? NSG2020 26th European Meeting of Environmental and Engineering Geophysics, doi: https://doi.org/10.3997/2214-4609.202020145.

Roy, J. S., 1995, Uphole and low velocity layer (LVL) surveys, in Birddog: Springer.