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# Distributed Acoustic Sensing vs. Geophone Accelerometer Measurements

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## Summary

Distributed acoustic sensing (DAS) acquisition holds the promise of disrupting borehole seismic acquisition with significant gains in cost and efficiency. Prior to deploying DAS technology in the field with conventional geophone tools, a comprehensive experiment was performed to understand and benchmark the measurement against conventional measurements. A near-offset VSP survey was acquired using conventional Geophone Accelerometer and DAS sensors. Theoretical relationship between the measurements was confirmed with field observations by using the DAS-to-Velocity transform. DAS strain measurement is axial strain along the fiber scaled by a normalized sinc function in the spatial frequency domain. The effect of the normalized sinc function is reversed using a gauge length correction scheme in the spatial frequency domain. Axial strain is equivalent to particle velocity field scaled by slowness. This amplitude effect is corrected in the FK domain. A robust match is shown between the two measurements.

## Introduction

Distributed acoustic sensing (DAS) is being extensively used in borehole seismic acquisition. DAS allows dense measurements along the length of the fibre while taking minimal acquisition time. Seismic source activation can be sensed across the entire length of the fibre. Relative to the conventional geophone, the fibre is not actively coupled and has lower sensitivity. To circumvent this limitation, a larger number of shots are required to create a complementary dataset across the entire well trajectory. This has resulted in significant gains in acquisition efficiency over conventional geophone acquisition (Borland et al., 2016). Large volumes of data generated by DAS has sparked great interest in comparing the measurement with conventional geophone measurements. In this paper, we develop a deeper understanding of the DAS measurement and compare it to geophone accelerometer (GAC) measurements in the same well.

## Data Acquisition

To make a complete comparison, a high-density vertical seismic profile (VSP) survey in an exploratory well in the northern zone of Colombia (Lower Magdalena Valley Basin) was acquired using DAS, as well as GAC measurements in the same well. The primary objective of the survey was to determine an accurate time-depth-velocity profile for well-tie analysis. The DAS acquisition was performed during a logging descent preceding the GAC descent. Several authors (Kimura et al., 2017; Martinez et al., 2020; Useche et al., 2020) have shown that VSP data can be acquired with any logging descent by using a hybrid cable that contains the fibre, thereby eliminating the need for an independent VSP descent. In this case, the VSP descent with GAC sensors was also performed to generate a comprehensive comparison of DAS and GAC datasets.

DAS and GAC datasets were acquired with a vibroseis source generating a linear 6-96 Hz, 12 s long sweep. The GAC data used 5 good shots to stack receiver stations at 15 m spacing, while the DAS data stacked 75 shots at ~5 m receiver spacing. Gauge length used for DAS acquisition was 20 m. Operational times for GAC and DAS acquisition were 14 and 1 hour, respectively. Figure 1 displays the stacked VSP data from GAC and DAS measurements. DAS data is richer in lower frequencies and it also shows a 90° phase advance as compared to the GAC data.

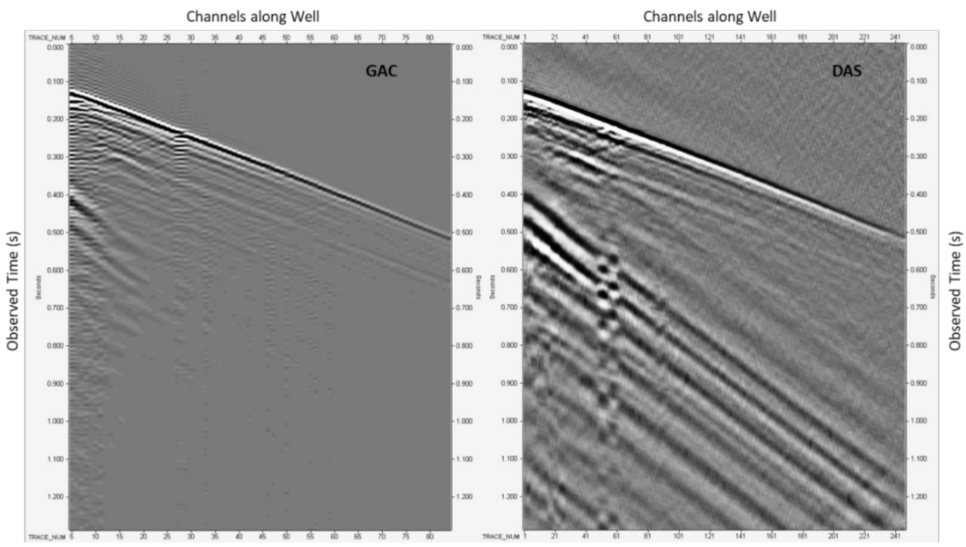


***Figure 1*** *Stacked VSP data from GAC (left) and DAS (right) acquisition is displayed across well depth (horizontal axis) and observed time (vertical axis). Direct arrivals, reflected arrivals, as well as converted waves are visible. Note the differences in frequency and phase of the GAC and DAS measurements. Depth interval of the data along the well is ~1200 m.*

## Theory

Sayed et al. (2020) have shown that the DAS measurement is the axial strain along the fibre scaled by a normalized *sinc* function in the spatial frequency domain as given in equation 1 (Sayed et al., 2020, equation 3),

$$\varepsilon_{zz}^{DAS}(z,t) = sinc_{\pi}(sL)\, \varepsilon_{zz} \quad (1)$$

where, $\varepsilon_{zz}^{DAS}$ is the DAS strain measurement, $\varepsilon_{zz}$ is the axial strain, $z$ is depth along the fiber, and $L$ is the gauge length.

The normalized sinc function corresponding to a gauge length of 20 m is shown in Figure 2. The sinc function becomes zero when its argument ($sL$) is an integer.

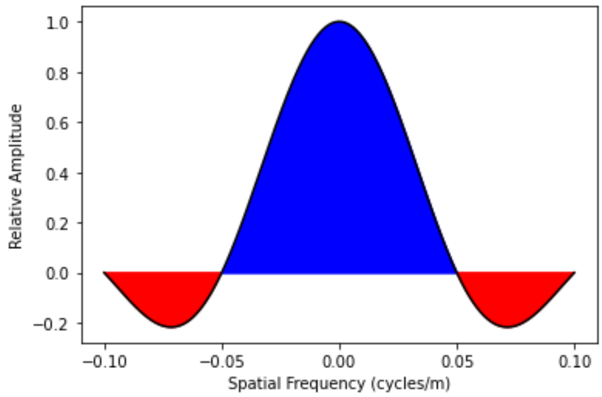


***Figure 2*** *Amplitude response of a normalized sinc function corresponding to a 20 m gauge length. The positive lobe of the sinc function is highlighted in blue, and the negative lobe is highlighted in red.*

Scaling in the spatial frequency domain with a *sinc* function has significant implications. The temporal spectra of each event are scaled differentially based on their slope or apparent velocity as the temporal frequency of an event is related to the spatial frequency by the its apparent velocity. Such variations can also lead to errors in Q estimation using the spectral ratios method. Further, the amplitudes of higher spatial frequencies are scaled down. This results in the faster events being damped relative to the slower waves.

## Data Processing

To compare the GAC and DAS measurements both are converted to velocity. A sensor transform is applied to convert the GAC measurement to velocity. We utilize the DAS to velocity transform as described by Sayed et al. (2020) to convert the DAS measurement to velocity. The transform is divided into two steps. The first step corrects the spectra by applying gauge length corrections corresponding to the normalized sinc function in the spatial frequency domain to yield axial strain. The second step converts axial strain to velocity. This can be done in multiple domains: 1) in the XT domain by integrating along depth and differentiating along time, 2) in the FK domain by scaling the FK spectra by an *f*/*s* factor, or 3) in the *tau-p* domain by scaling the data by a 1/*p* factor.

The normalized sinc function is inverted to compute the gauge-length correction factors. The correction factors are applied as gains to the spatial frequencies and are tapered outside the signal range. The gauge-length corrected DAS wavefield shows a sharper first arrival indicating spectral recovery (Figure 3). As the spectrum is corrected appropriately for each slope, such data is ready to be used as input to Q estimation.

The conversion to velocity is also performed in the FK domain. The FK spectra are scaled by the *f*/*s* factor to compute the velocity field. The scaling field is applied to the axial strain in FK domain to produce the DAS-transformed-Velocity (DtV) wavefield. DtV compares well with GAC velocity field in phase and sharpness of the first arrivals (Figure 4). Furthermore, the faster direct arrivals are relatively amplified to the slower waves that are not as prominent as compared to the raw stacked DAS (Figure 1).

The field data example validates phase relationships indicated by theoretical and synthetic studies (Sayed et al., 2020) between the raw DAS measurement, velocity measurement, and acceleration measurement. Raw DAS measurement is 90° and 180° out of phase with acceleration and velocity measurements. This relationship guides the travel-time picking on DAS data.

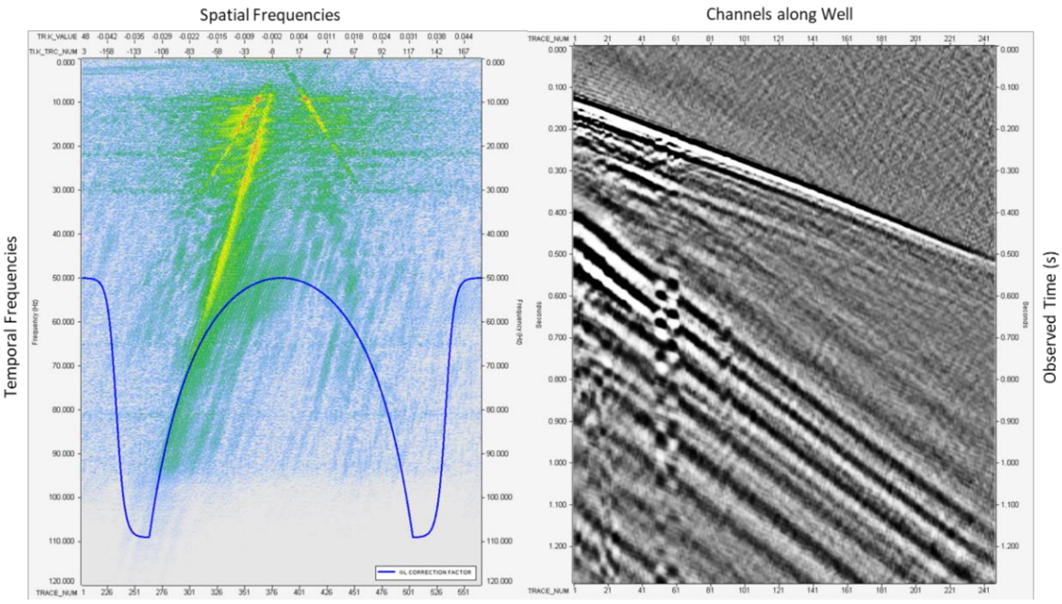


***Figure 3*** *The FK spectrum of the stacked DAS (left) and axial strain (right) are displayed. The gauge-length correction factors are overlain on the FK spectrum in blue.*

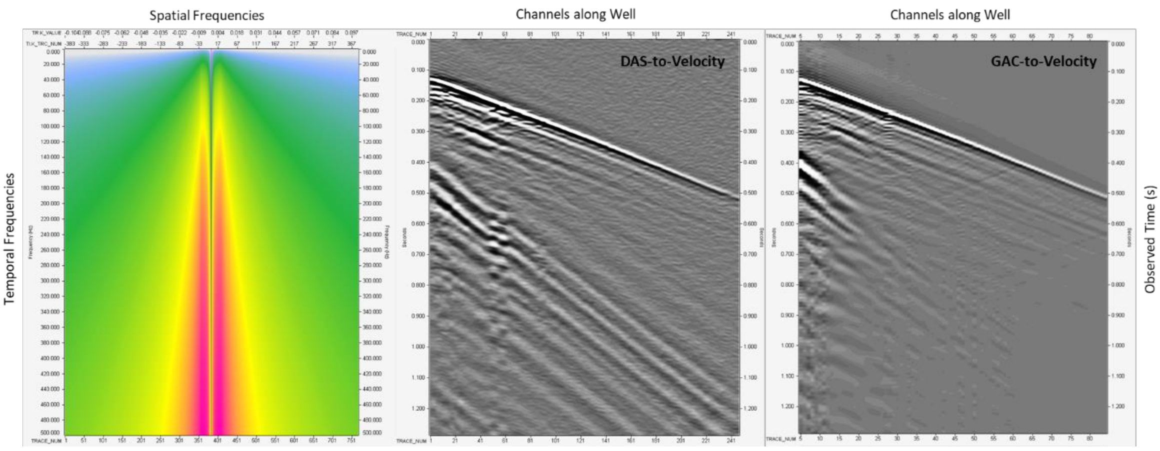


***Figure 4*** *Scaling factors for FK spectrum (left) are applied to yield DAS transformed Velocity (center). The equivalent velocity from GAC (right) compares well with DAS velocity.*

GAC and DAS transformed to velocity data were processed till final deconvolved upgoing wavefield and corridor stack using standard VSP processing techniques. The deconvolved upgoing reflections and corridor stack are shown in seismic two-way time (Figure 5). Figure 5b and 5c show a very good correlation between the corridor stack coming from the two different measurements.

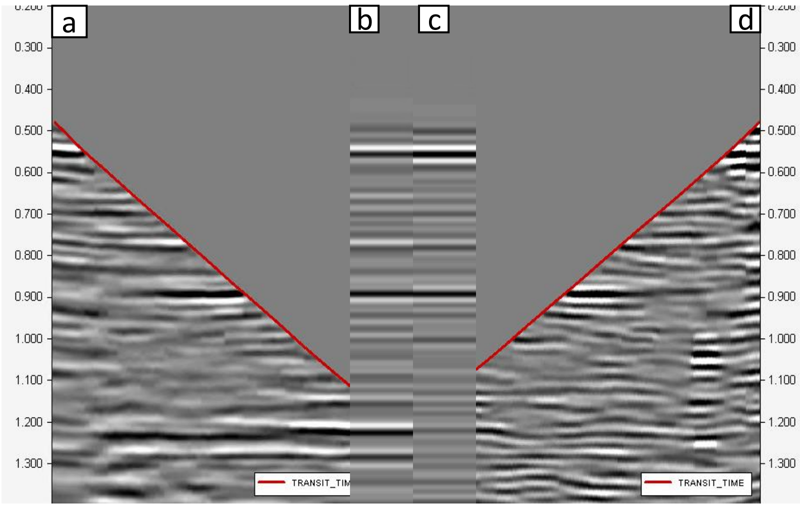


***Figure 5*** *Final deconvolved upgoing (a), corridor stack (b), displayed in two-way time generated from GAC velocity field compared with corridor stack (c) and final deconvolved upgoing in two-way time generated from DAS-transformed velocity data.*

## Conclusions

We compare distributed acoustic sensing and geophone accelerometer measurements acquired in the same well. The results confirm our understanding of the DAS measurement. The DAS-to-Velocity transform shows that, when gauge-length effect is appropriately corrected and axial strain converted to velocity, DAS-transformed-Velocity compares very well to the geophone velocity field. Corridor stack generated after processing DAS data transformed to velocity and GAC data match very well with each other. This field data example validates the methodology used in correcting the effect of gauge length and DAS-to-Velocity transformation.

## References

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