Source distance and source effort on DAS data

Kevin W. Hall, Don C. Lawton, Tom Daley[1], Barry Freifeld[1] and Paul Cook[1]

ABSTRACT

Vibroseis and weight-drop sources were recorded on looped vertical seismic profile and surface fibre optic lines using distributed acoustic sensing (DAS) at the Containment and Monitoring Institute (CaMI) Field Research Site (FRS) in Newell County, Alberta. This report examines the effects of source distance and source effort on DAS data.

INTRODUCTION

Field Research Site

The Containment and Monitoring Institute (CaMI) Field Research Site (FRS) has three 350 m deep vertical boreholes on the well lease (Figure 1). A CO_2 injection well is located at the center of the study area. The injection well has optical fibre in it, but the fibre is not connected to anything at this time. A geophysics observation well is located 20 m southwest of the injection well. The geophysics well contains straight and helical optical fibre in addition to permanent 3C geophones. A geochemistry well is located 40 m to the northeast of the injection well. The geochemistry well contains straight optical fibre and stainless-steel tubing with a sampling port at reservoir level (~300 m). A south-west to north-east oriented one km long trench of approximately one metre depth is centred southwest of the geophysics well and contains straight and helical optical fibre as well as permanent electrodes for repeated electrical resistivity tomography (ERT) surveys.

Borehole and trench fibre are connected in a continuous loop of about 5 km in length in the following order, 1) helical fibre to bottom of geophysics well and back, 2) straight fibre to bottom of geophysics well and back, 3) straight fibre to bottom of geochemistry well and back, 4) straight fibre to north end of trench, 5) helical fibre the length of the trench from north to south, and 6) straight fibre from the south end of the trench back to the well lease. Three junction boxes on wooden posts for fibre splices are present on the ground, one at each end of the trench and one at the geophysics well.

Seismic acquisition

Three seismic surveys were conducted at the FRS in 2017 that were recorded on optical fibre. Figure 1 shows May and July vibe point (VP) locations for source lines 13 (parallel to trench), 15 (perpendicular to trench) and 21 (north-south). Lines 13 and 21 have a nominal 20 m VP spacing and line 15 was acquired with 10 m spacing. October data is shown by (Hardeman et al., 2017). The University of Calgary's IVI EnviroVibe was used as the primary source with anywhere from 2 to 16 sweeps per VP. The sweep used was a 10-150 Hz linear sweep over 16 s with a 3 s listen time. Five additional source points (SP) were acquired with a nitrogen-spring weight-drop trailer at the corners of a 100 m square centred on the injection well (orange triangles; Figure 1) and at the closest VP (May VP 159) to the geophysics observation well. Weight-drop source points were repeated twice,

[1] Lawrence Berkeley National Laboratory

and upon inspection, will need to be repeated many more times to achieve the same quality as a single Vibe sweep on the DAS data (not shown).

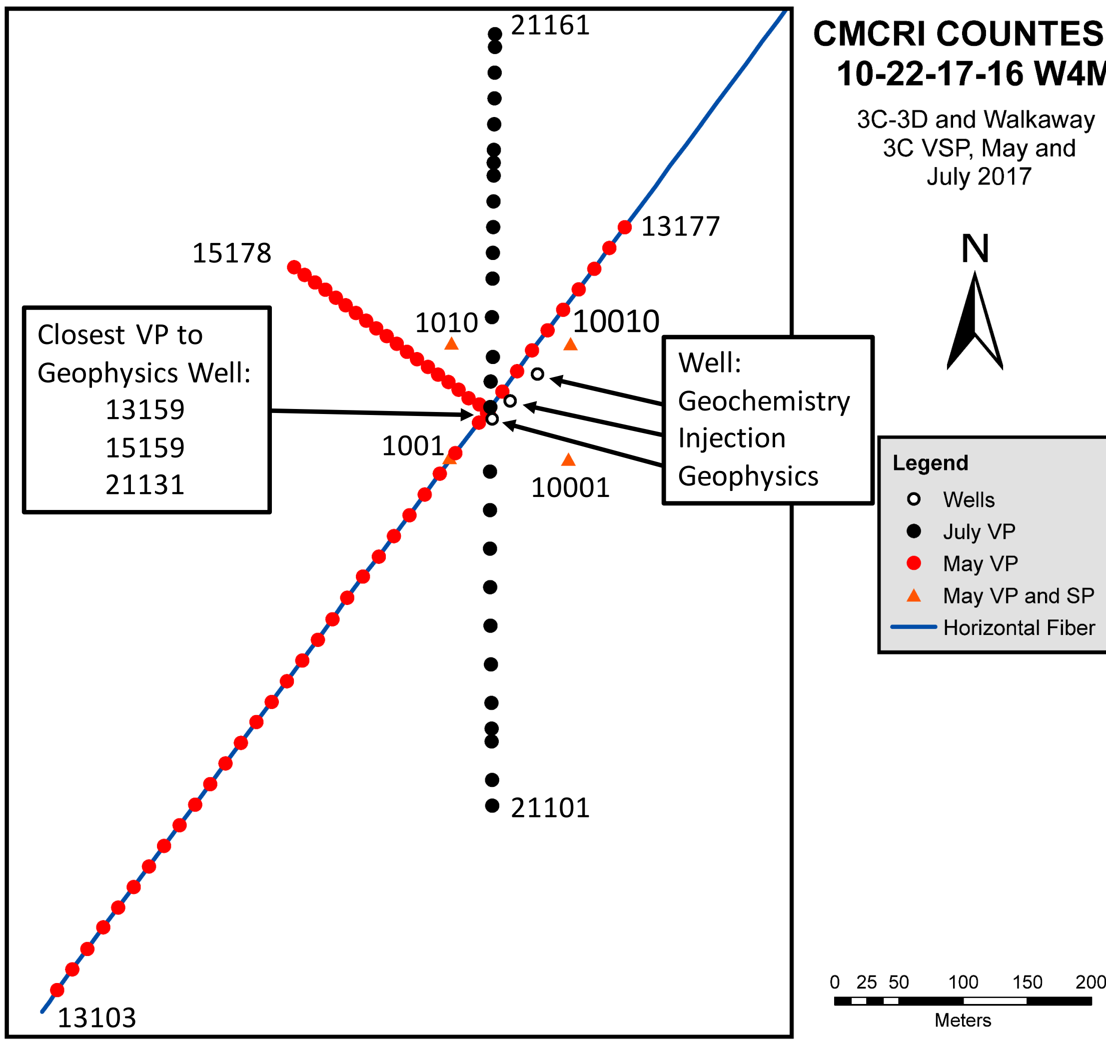

Figure 1. Location of May and July 2017 source points relative to injection and observation wells at the CaMI FRS site near Brooks, Alberta.

DAS data were acquired using a first generation Silixa iDAS interrogator with 10 m gauge length and 25 cm channel spacing (Table 1). For uncorrelated data, this results in a 1.4 Gb (3 s listen) or 1.5 Gb (4 s listen) SEG-Y file per sweep at a 1 ms sample rate (Table 2). Total size of uncorrelated data on disk is 546 Gb for 376 sweeps.

Prior to conducting these surveys, we had no idea how many sweeps per vibe point would be required, or what VP distance from the fiber is too far at this site. It was determined by qualitative visual inspection of the May data that we could not move the Vibe much more than 300 m away from the geophysics well for a walk-away VSP, and the July source line was therefore shortened. Given the potentially very large datasets that can be generated by DAS, it would be good to have some quantitative measure of data quality that can be quickly calculated for each gather.

This report examines the effect of varying the source distance from the straight fiber in the geophysics well, geochemistry well and trench, as well as the effect of increasing vertical fold.

Table 1. Optical fibre parameters.

DAS, straight fibre		
Channel spacing	25.0	cm
Gauge length	10.0	m
Geophysics well channel range	3817-6385	
Geophysics well total channels	2569	
Geophysics well fibre length in	642.3	m
Geochemistry well channel range	6963-9298	
Geochemistry well total channels	2336	
Geochemistry well fibre length in	584.0	m
Trench channel range	12076-9819,19297-17200	
Trench total channels	4356	
Trench fibre length	1089.0	m

Table 2. SEG-Y file sizes for correlated and uncorrelated data

Line	Correlated	nTraces	nSamples	nFiles	Gather FileSize (Gb)	Total FileSize (Gb)
13	FALSE	20000	20000	114	1.5	170.4
15	FALSE	20000	20000	40	1.5	59.8
21	FALSE	20000	19000	222	1.4	315.3
13	TRUE	20000	1001	38	0.2	8.7
15	TRUE	20000	1001	20	0.2	4.6
21	TRUE	20000	1001	27	0.2	6.2

METHOD

All sweeps for a given VP were vertically-stacked and correlated from single to the maximum available vertical fold. Lines 15 and 13 had 2 and 3 sweeps per VP, respectively. Line 21 had 6 sweeps per VP on the southern half, 10 sweeps per VP on the northern half, and 16 sweeps at VP 132 which is located about 10 m north of the geophysics well.

We propose calculating something like the signal-to-noise ratio to generate a single number per VP which can then be plotted to quickly provide quality control (QC) plots for field data. Signal-to-Noise Ratio (SNR) in decibels may be calculated using the formula:

$$SNR = 10log10\left(\frac{\sum signal^2}{\sum noise^2}\right), \tag{1}$$

where *signal* is an estimate of signal amplitudes contained in our seismic data and *noise* is an estimate of noise amplitudes in the same data. Rietsch (1980), for example, details methods to estimate *signal* and *noise* for each trace in a gather of at least three traces. Signal estimation involves auto-correlations of a given trace with all other traces in the gather, and noise estimation involves subtracting all other traces in the gather from a given trace. The assumptions here are that signal is identical on adjacent traces and noise is not coherent. DAS data with 25 cm trace spacing should come reasonably close to satisfying the first assumption.

Given time limitations and the volume of data generated in a DAS survey, we have opted to instead calculate the Signal+Noise-to-Noise Ratio:

$$SNNR = 10log10\left(\frac{\sum(signal+noise)^2}{\sum noise^2}\right), \quad (2)$$

where *(signal+noise)* represents our seismic amplitudes with no modification, and the *noise* estimate for a given trace is provided by subtracting a single adjacent trace. This calculation quickly provides a single number per trace or a single number per gather. More importantly, this calculation takes much less time than the Vibroseis correlation step for 20,000 traces. Without proof, SNNR is expected to be proportional to SNR. This idea was tested trace by trace on a three-component geophone source gather, and the SNNR numbers highlighted the Vibe location on each component, bad channels, and the transitions between vertical and horizontal components (not shown).

Testing with Brooks DAS data using 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 s time windows starting at time-zero have shown that the best results are obtained using a 1.0 s time window for the SNNR calculation. A 0.5 s windows results in graphs that were qualitatively less smooth. 1.5, 2.0, 2.5 and 3.0 s windows give results with the identical trends as the 1.0 s window, but with smaller values for SNNR (not shown).

EFFECT OF SOURCE DISTANCE FROM FIBRE

Figure 2 shows SNNR calculated for almost every sweep recorded in May and July, colour-coded by location of the fibre. Three VPs are anomalous, as discussed below, and have been excluded. SNNR is horizontally asymptotic with increasing VP distance from the fibre. SNNR values are higher for the July data than for the May data. This could be due to near-surface ground conditions, where the ground was wet in May as compared to very hard and dry in July. IT is also possible that the interrogator was operated with a higher gain setting in July.

Figure 3 to Figure 8 show single-vertical-fold DAS data recorded on straight fibre for the geophysics well, geochemistry well and trench for the VPs closest to 0, 50, 100, 150 and 200 m from the fibre for each source line. It is immediately apparent that the higher SNNR values calculated for source line 21 (July) relative to source lines 13 and 15 (May) are entirely justified. Note that the data is displayed with an AGC, but SNNR was calculated using un-gained data. In general, reflections can be seen on the well data out to 200 m, but not much past 300 m. Direct arrivals in the well data show evidence of turning-rays at larger offsets from the wells.

Fibre is sensitive to changes in strain parallel to the axis of the fibre, so we do not necessarily expect to see vertical component data on horizontal fibre in the trench. In fact,

Figure 7 and Figure 8 show that fibre in the trench has mostly recorded ground-roll. Amplitudes drop off rapidly as the Vibe moves horizontally away from the trench, and by 200 m are largely invisible. Compare this to the vertical fibre in the wells, where we can still see faint P-P reflections with the Vibe 200 m from the wells. Isaac and Lawton (2017) show that reflections can be recovered from the trench data after noise-removal and deconvolution.

Horizontal noise bands appear in the data for the VPs closest to the well or trench. These VPs are close to the fibre junction box at the geophysics well, and the noise is likely due to the Vibe the wooden post, junction box and fibre in the junction box.

The SNNR value for the VP at 184 m from the trench on source line is anomalously high (red, Figure 8). This is the furthest VP from the trench on line 21, so we should not see any source noise on it (cf. Figure 7). This I evidence that SNNR can be used to identify bad source gathers or possible geometry issues.

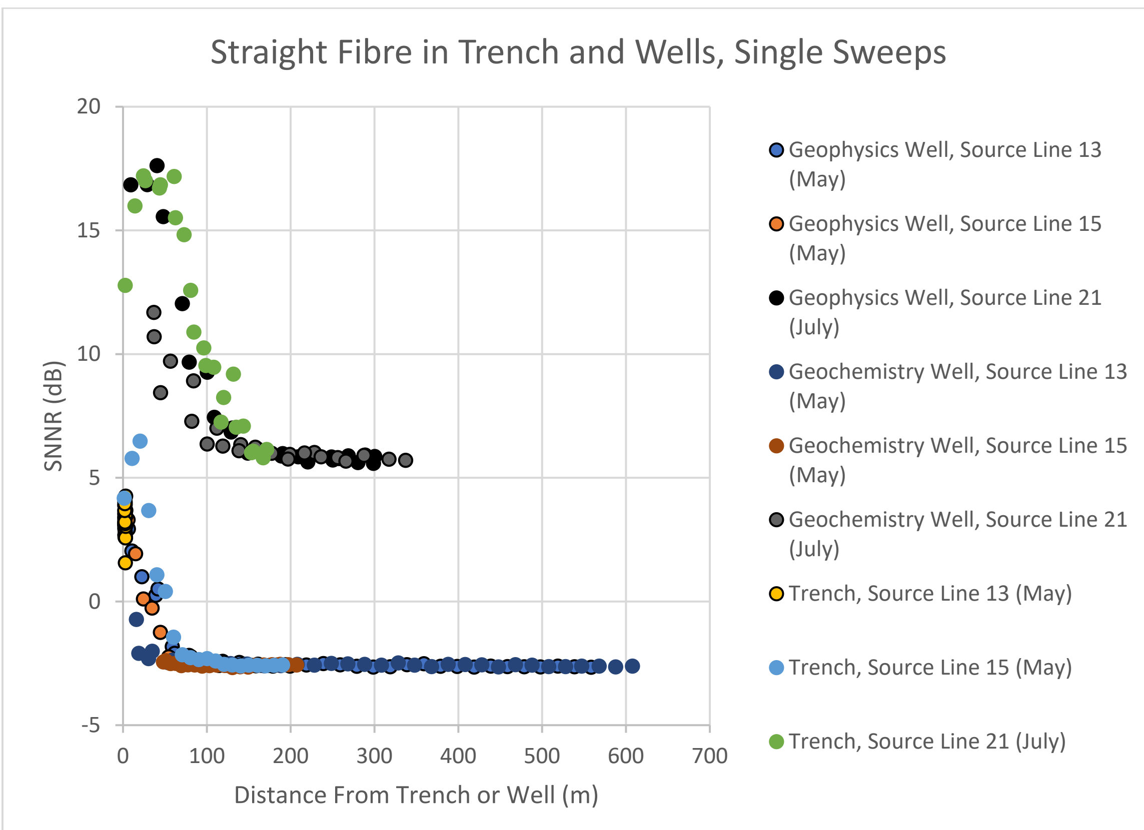

Figure 2. SNNR calculated for single-fold correlated gathers for all data recorded on straight fibre.

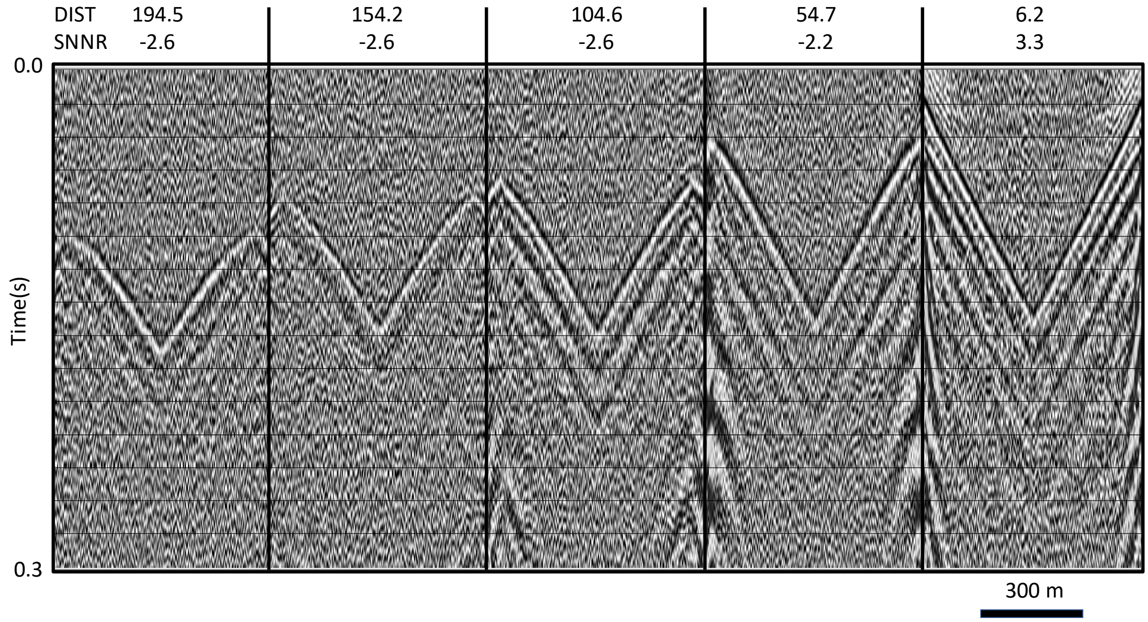

Figure 3. Source line 15 correlated single sweeps recorded on straight fibre in geophysics well with 10 ms AGC for display. Source distance from well decreases from left to right.

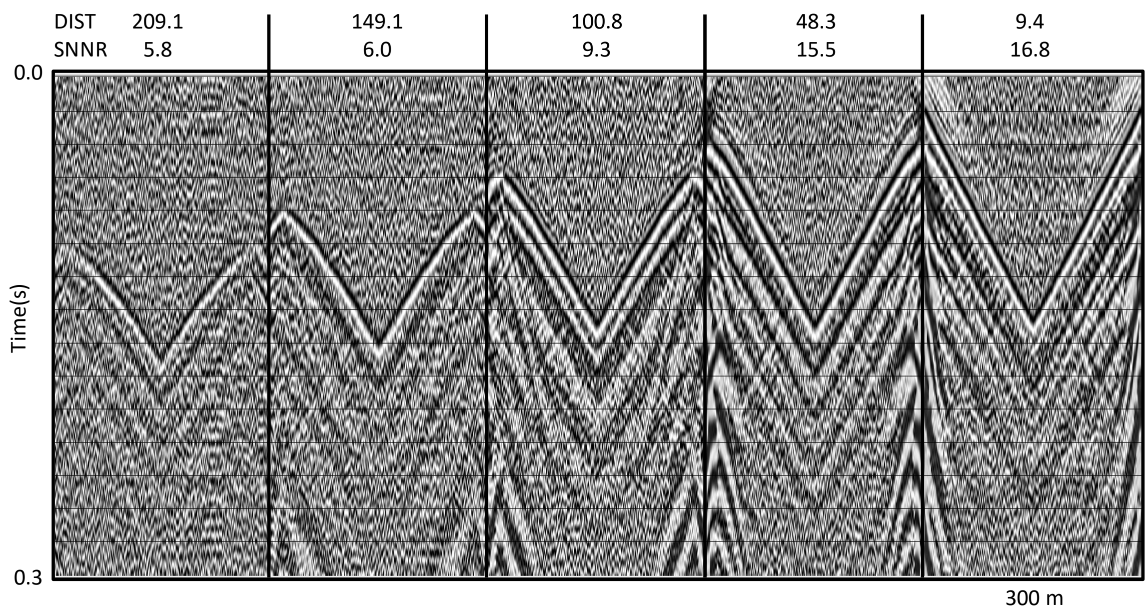

Figure 4. Source line 21 correlated single sweeps recorded on straight fibre in geophysics well with 10 ms AGC for display. Source distance from well decreases from left to right.

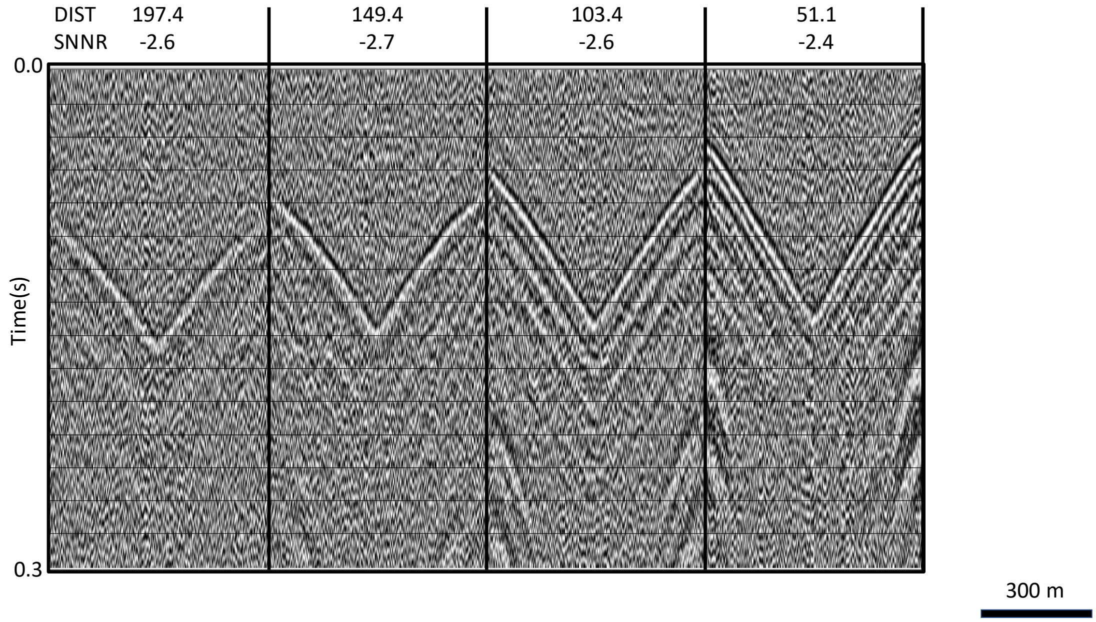

Figure 5. Source line 15 correlated single sweeps recorded on straight fibre in geochemistry well with 10 ms AGC for display. Source distance from well decreases from left to right. The closest VP to the well was 51 m for this source line.

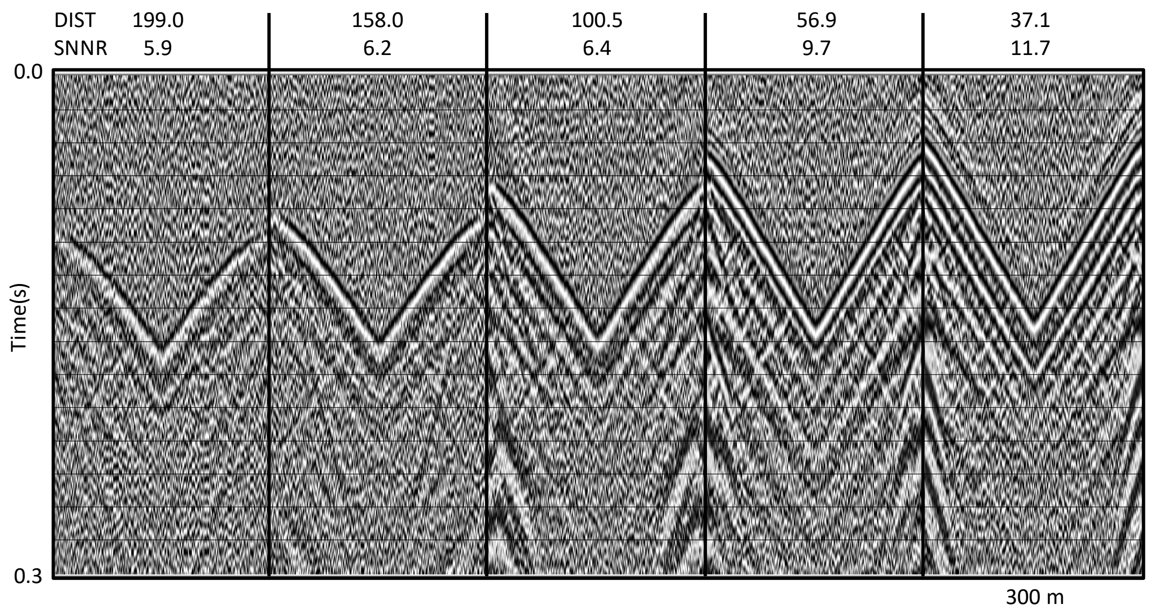

Figure 6. Source line 21 correlated single sweeps recorded on straight fibre in geochemistry well with 10 ms AGC for display. Source distance from well decreases from left to right.

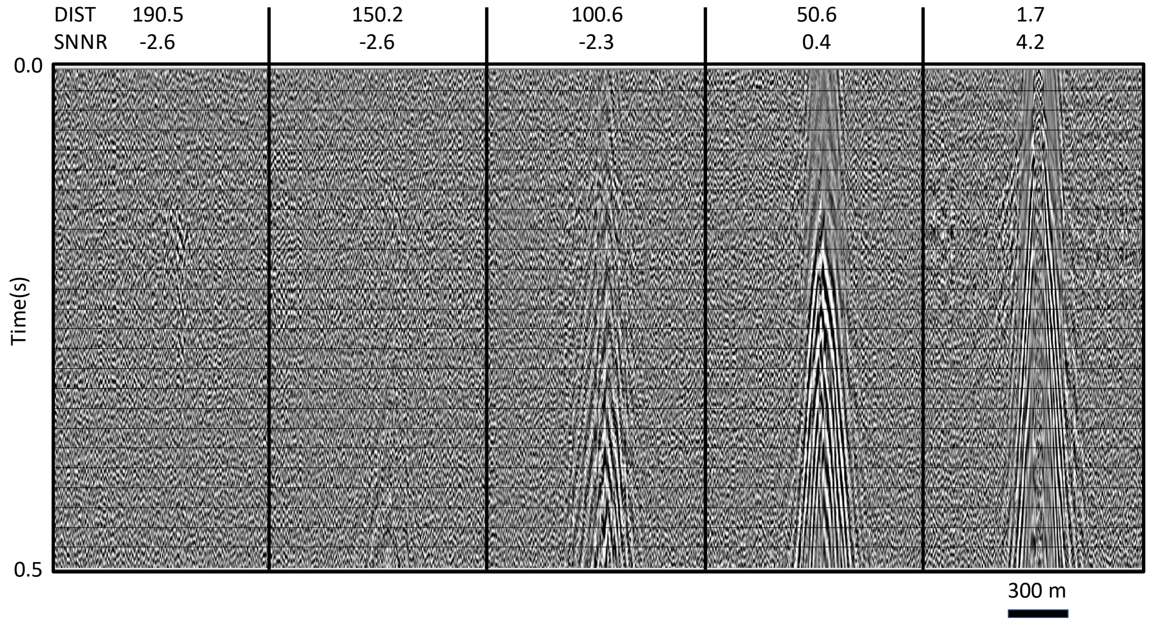

Figure 7 Source line 15 correlated single sweeps recorded on straight fibre in trench with 500 ms AGC for display. Source distance from well decreases from left to right.

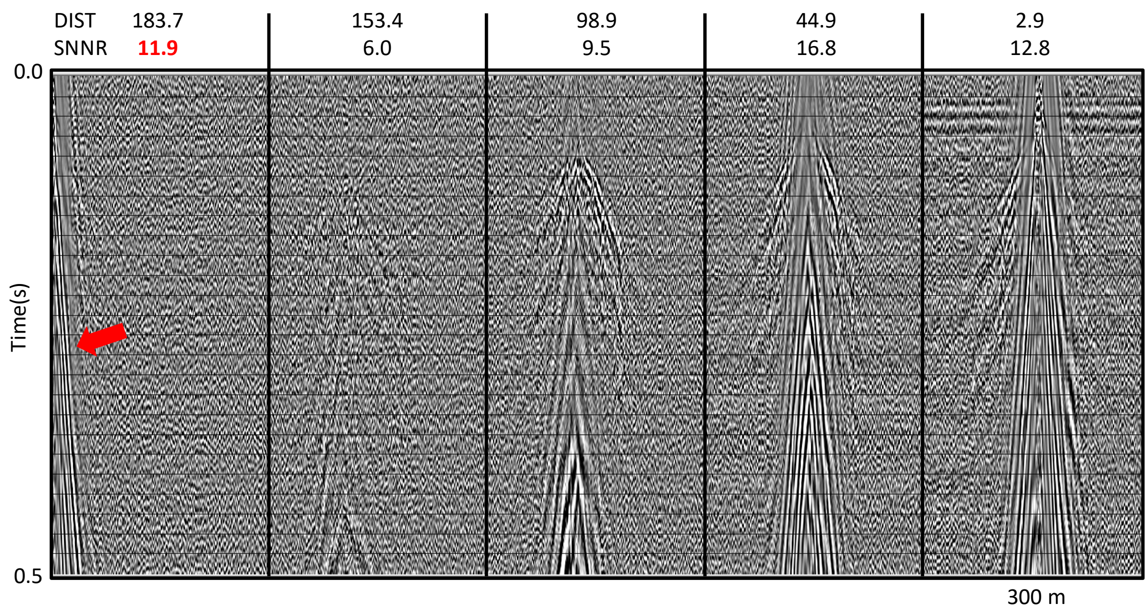

Figure 8. Source line 21 correlated single sweeps recorded on straight fibre in trench with 500 ms AGC for display. Source distance from well decreases from left to right. Red arrow highlights amplitudes that lead to an anomalous SNNR.

EFFECT OF VERTICAL FOLD

Figure 14 through Figure 19 show SNNR plotted against VP and colour-coded by source line and vertical fold. VP numbers increment by 1 every 10 m down the line so, for example, the distance from VP 160 to 170 is 100 m. Vertical red lines highlight the VP closest to the fibre. SNNR for three anomalous VPs have been excluded from these figures. After acquiring the May data, it was decided to limit July offsets to 300 m from the geophysics well. Coupled with higher SNNR calculated for the July data it made sense to plot May and July SNNR numbers on separate graphs.

The greatest improvement in SNNR appears to happen between one and two-fold, with incremental improvements all the way up to sixteen-fold. This matches qualitative visual observations. Interestingly, VPs closest to the wells have the highest SNNR in May, but there is a dip in SNNR for the July data and for the May trench data. A trace-by-trace test on geophone data showed lower SNNR on traces closest to the Vibe location (not shown), so we surmise that the SNNR decrease for VPs close to the fibre are due to source noise.

Figure 18 shows a relatively constant SNNR for VPs on line 13 (parallel to trench), and a clear improvement of SNNR with increasing fold. As seen in Figure 7 and Figure 8, SNNR drops rapidly as the Vibe moves perpendicularly away from the trench on line 15.

Figure 20 through Figure 22 show VP 21132 data for vertical-fold increasing from one to sixteen for fibre in the wells and trench. As observed in the previous section, horizontal noise bands are present throughout. Again, this is likely due to the Vibe shaking fibre in the junction box beside the geophysics well. As expected, SNNR increases with increasing vertical fold. Visually, reflections in the boreholes become higher amplitude and more continuous. Most of the improvement in these plots occur between one and four-fold, with sixteen-fold data visually appearing to be very similar to the eight-fold data. Gordon and Lawton (2017) show preliminary VSP processing results for two VPs and a comparison to the permanent geophone data from the geophysics well.

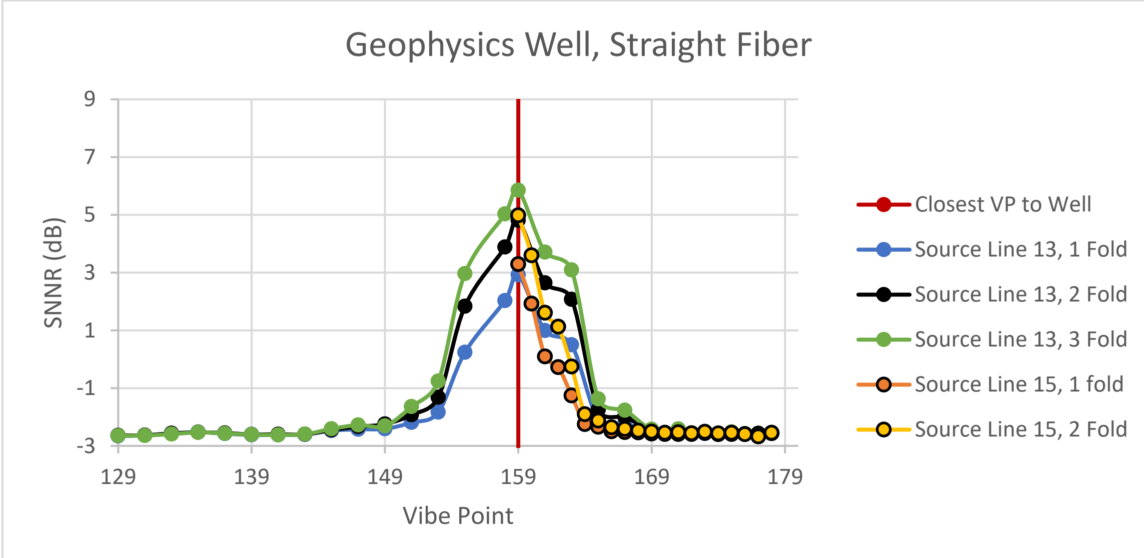

Figure 9. SNNR calculated for all stacked and correlated gathers for lines 13 and 15 recorded on straight fibre in geophysics well.

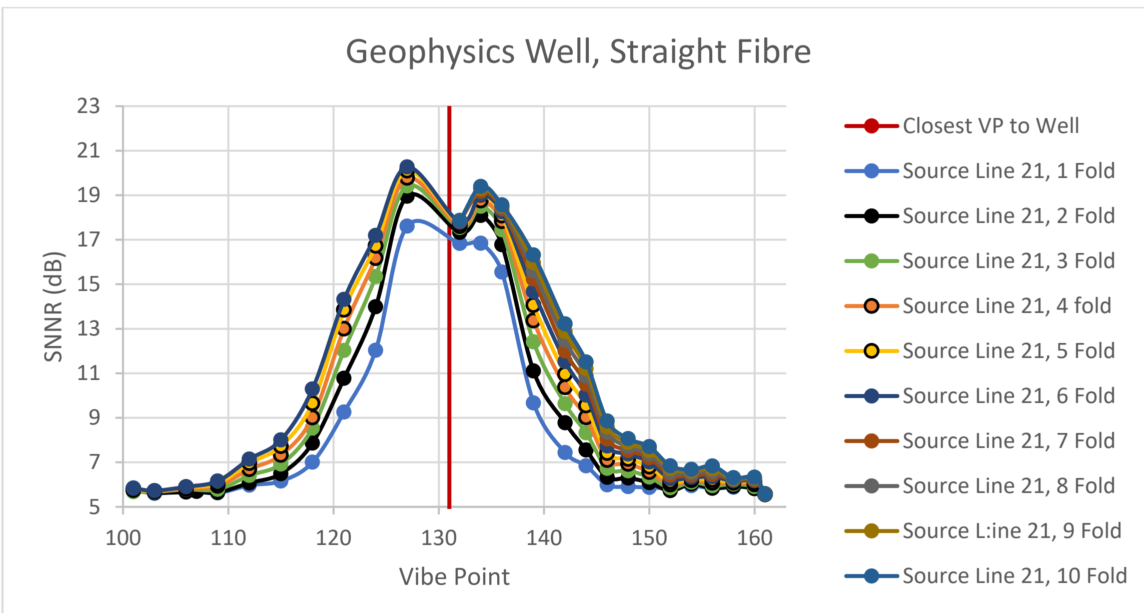

Figure 10. SNNR calculated for all stacked and correlated gathers for line 21 recorded on straight fibre in geophysics well.

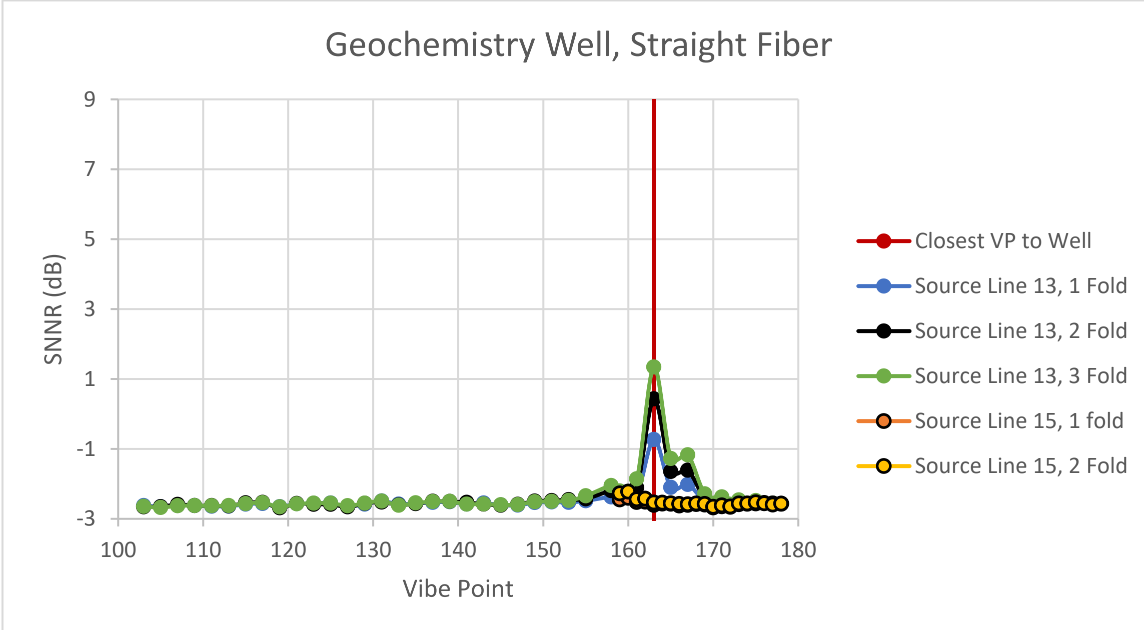

Figure 11. SNNR calculated for all stacked and correlated gathers for lines 13 and 15 recorded on straight fibre in geochemistry well.

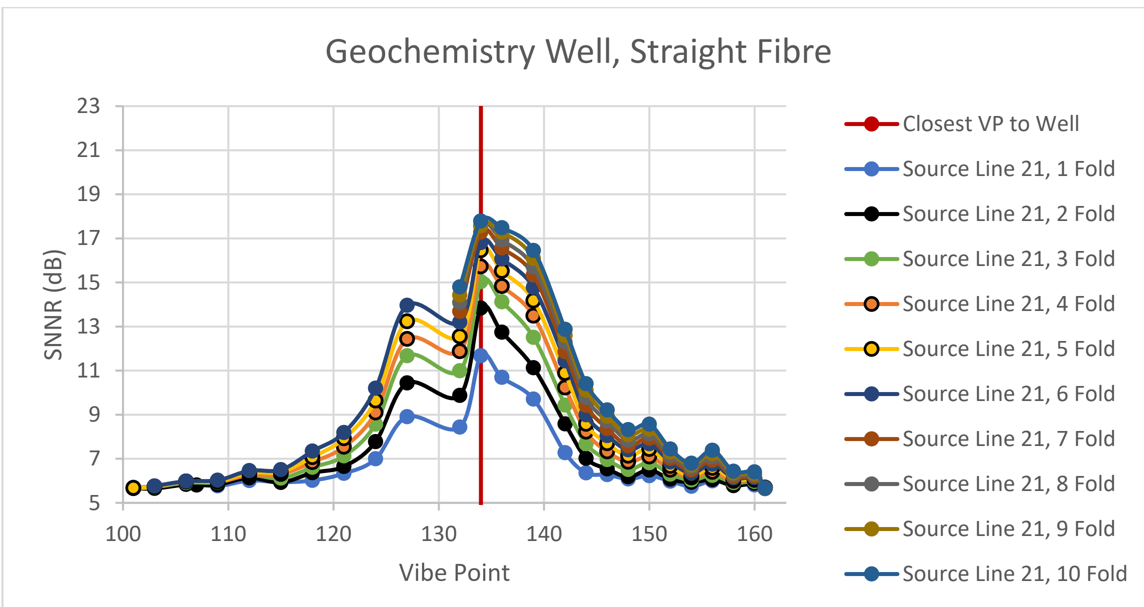

Figure 12. SNNR calculated for all stacked and correlated gathers for line 21 recorded on straight fibre in geochemistry well.

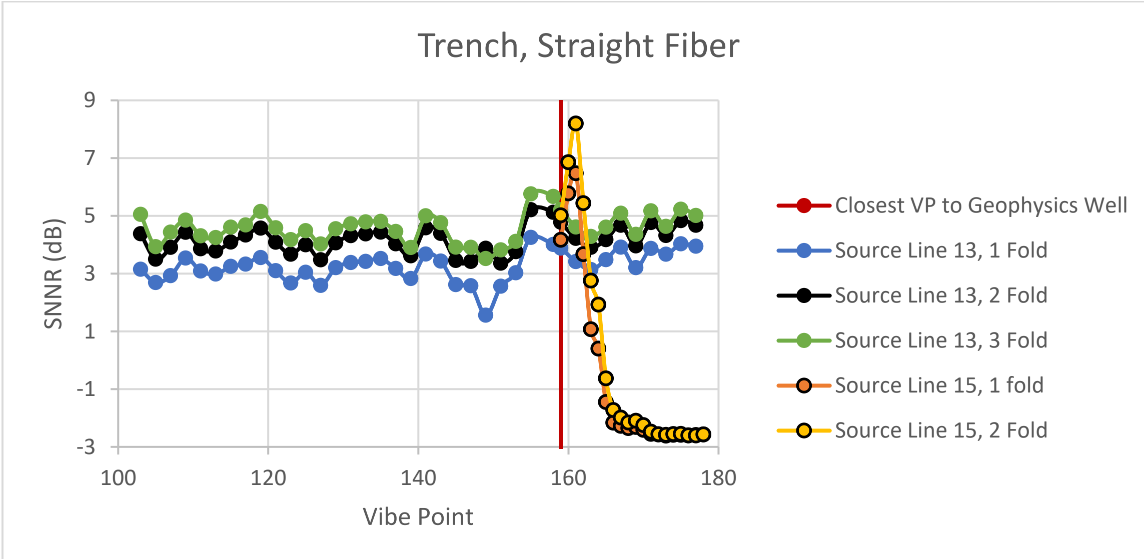

Figure 13. SNNR calculated for all stacked and correlated gathers for lines 13 and 15 recorded on straight fibre in trench.

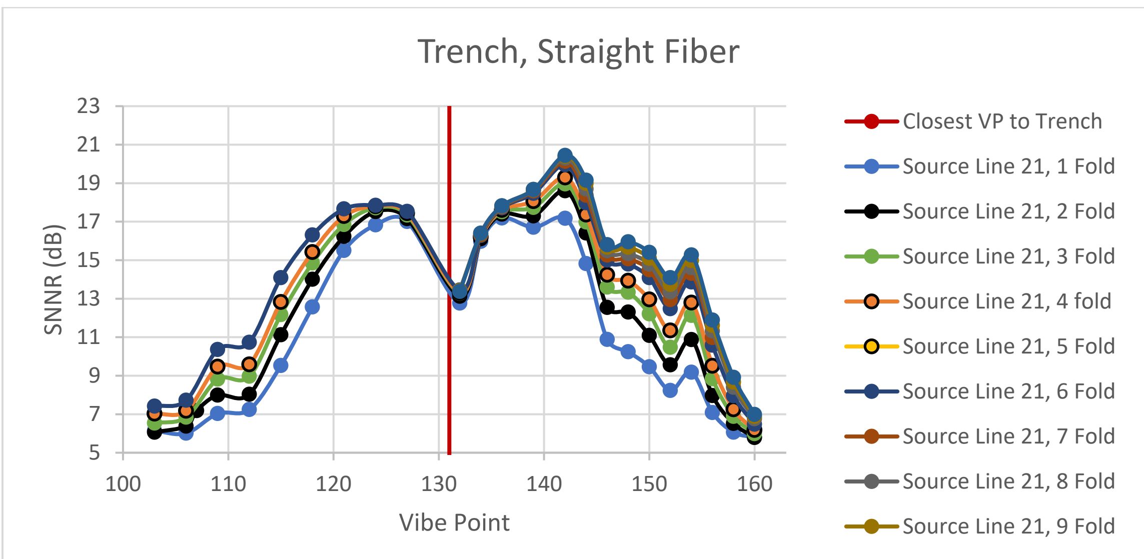

Figure 14. SNNR calculated for all stacked and correlated gathers for line 21 recorded on straight fibre in trench.

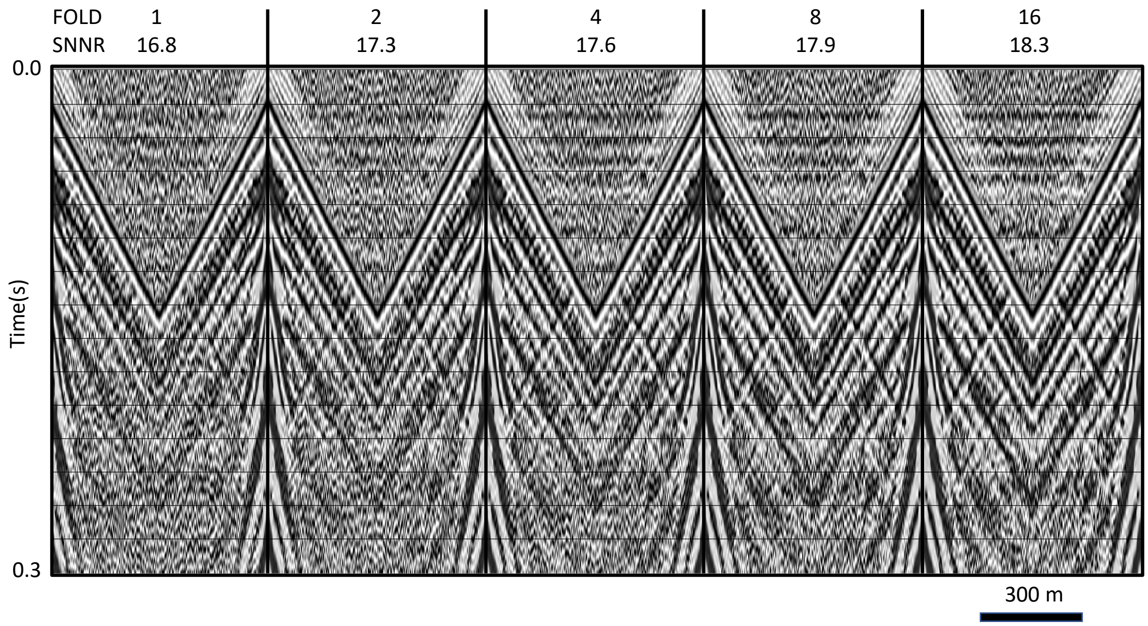

Figure 15. Source line 21, VP 132, stacked and correlated data recorded on straight fibre in geophysics well with 10 ms AGC for display. Vertical fold increases from left to right. VP is ~10 m from the well.

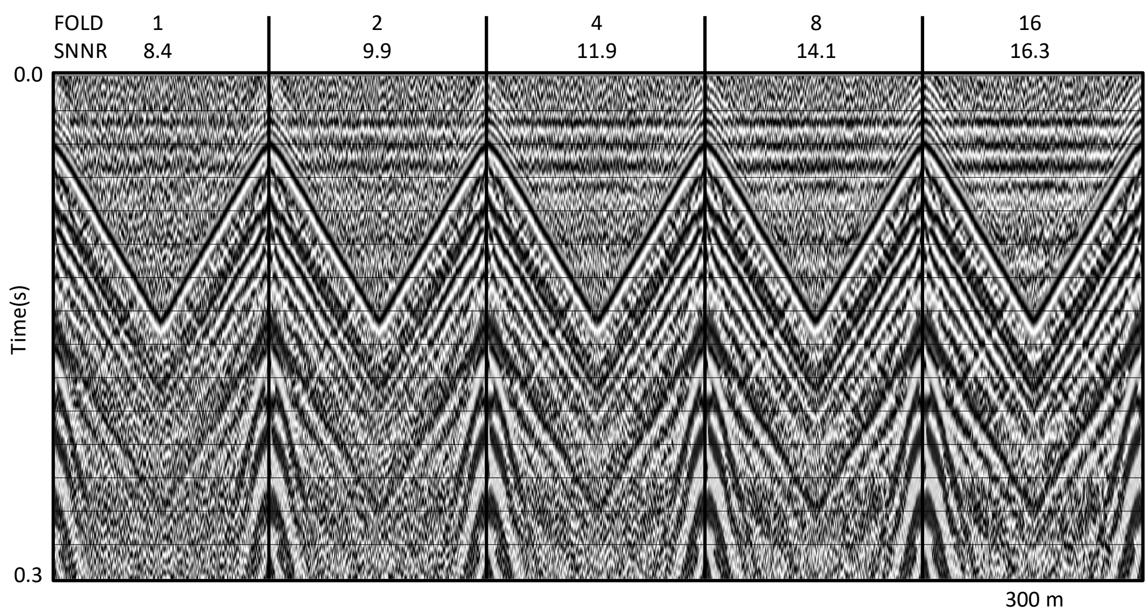

Figure 16. Source line 21, VP 132, stacked and correlated data recorded on straight fibre in geochemistry well with 10 ms AGC for display. Vertical fold increases from left to right. VP is ~40 m from the well.

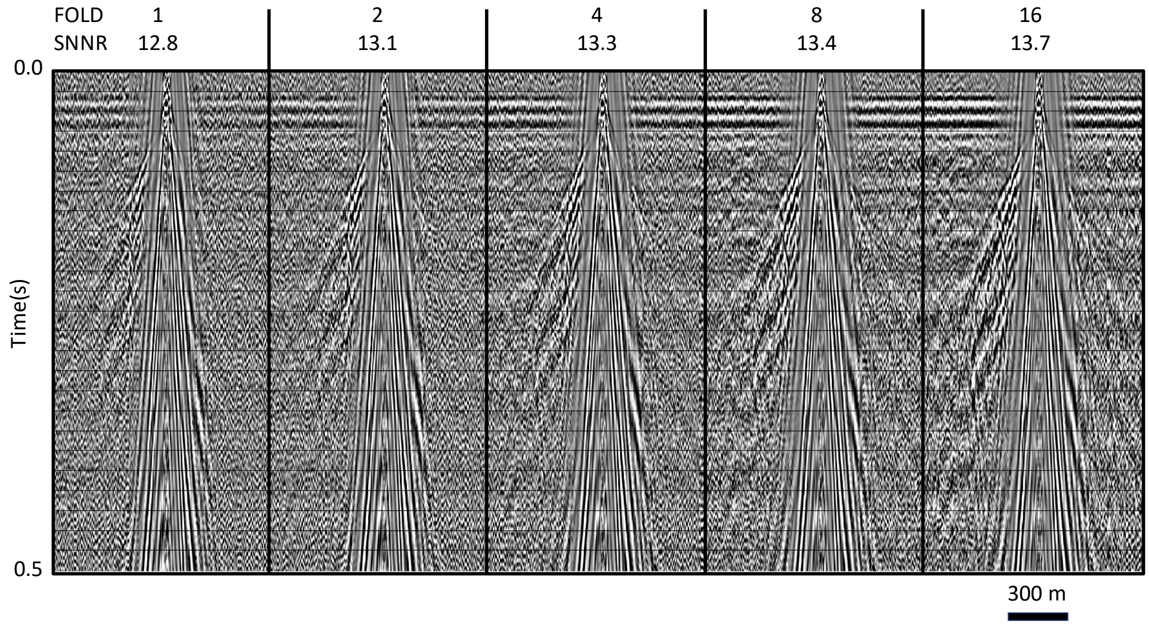

Figure 17. Source line 21, VP 132, stacked and correlated data recorded on straight fibre in trench with 500 ms AGC for display. Vertical fold increases from left to right. VP is ~2 m from the trench.

DISCUSSION AND CONCLUSIONS

Distributed Acoustic Sensing (DAS) surveys generate large datasets. Visually inspecting data stored in SEG-Y files to find bad source gathers, or to determine maximum viable source distance from the optical fibre, or to determine how many sweeps to use per Vibe Point (VP) becomes time intensive. We propose quickly calculating a single number for each gather that can help answer these questions.

The Signal+Noise-to-Noise Ratio (SNNR) is such a number, where the Signal+Noise represents unmodified seismic amplitudes and a noise estimate is provided by subtracting a single adjacent trace from the current trace. In our testing, SNNR takes much less time to calculate than is taken to perform the Vibroseis correlation step.

SNNR is generally higher for the May survey than for the July survey. This may be partly attributable to near-surface ground conditions (wet in May, hard and dry in July), but it is more likely that the DAS interrogator was operated with a higher gain setting in July.

We have shown that SNNR is diagnostic for bad source gathers. We have also shown that it is diagnostic for source distance from optical fibre, and for increasing vertical fold. SNNR is horizontally asymptotic with increasing source distance, and we do have poor to no signal where this graph is horizontal. As with signal-to-noise ratio, further processing increases the value of SNNR.

For example, we can plot SNNR against VP number (equivalent to distance) for increasing vertical fold. The most dramatic improvements are seen for up to five sweeps per VP at Brooks by visual inspection of the source gathers for one VP, and of the SNNR graph for all VPs. Incremental improvements observed between five and sixteen-fold may not be worth the additional source effort.

SNNR decreases rapidly with increasing distance from horizontal fibre and less rapidly from vertical fiber. We believe we have useable VPs up to 100 m (May) and 200 m (July) from the trench. Similarly, we have useable VPs up to 150 m (May) and 250 m (July) from the boreholes.

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