geoconvention 2018
Calgary • Canada • May 7-11

Effect of source effort and source distance on DAS data at CaMI.FRS, Newell County, Alberta

Kevin W. Hall[1], Don C. Lawton[2], Thomas M. Daley[3], Barry M. Freifeld[3] and Paul Cook[3]

[1]CREWES, University of Calgary, [2]CREWES/CaMI, University of Calgary and [3]Lawrence Berkeley National Laboratory

Summary

Vibroseis and weight-drop sources were recorded on looped borehole and surface fibre optic lines using distributed acoustic sensing (DAS) at the Containment and Monitoring Institute (CaMI) CO_2 injection Field Research Site (FRS) in Newell County, Alberta. This abstract examines the effects of source distance and source effort on DAS data recorded on vertical and horizontal optical fibres.

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 optical fibre and an experimental helically-wound fibre cable 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 fibres are connected in a continuous loop of about 5 km 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.

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. The University of Calgary's IVI EnviroVibe was used as the primary source with anywhere from 2 to 16 sweeps per VP. The sweep was 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, 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.

DAS data were acquired using a Silixa iDAS interrogator with 10 m gauge length and 25 cm channel spacing yielding 20,000 traces per sweep. 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 after down-sampling to a 1 ms sample rate. Total size of uncorrelated data on disk is 546 Gb for 376 sweeps.

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.

Method

All sweeps for a given VP were vertically-stacked and correlated from single to 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 to calculate something like the signal-to-noise ratio to generate a single number per source gather which can then be quickly plotted to provide quality control (QC) plots for our field data. The speed with which this can be done is critical for the large data volumes we are expecting once permanent continuous sources become operational at the FRS. Rietsch (1980), 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.

To reduce computation time we have opted to instead calculate the signal-plus-noise-to-noise ratio:

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

where *(signal+noise)* represents trace amplitudes with no attempt to estimate signal amplitudes, 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 for large data volumes, this calculation takes much less time than the Vibroseis correlation step. Without proof, SNNR is expected to be proportional to SNR. Testing with Brooks DAS data using 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 s static 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 window results in graphs that were qualitatively less smooth. 1.5, 2.0, 2.5 and 3.0 s windows give results with identical trends as the 1.0 s window, but smaller values for SNNR (not shown).

Examples

Figure 2 shows SNNR calculated for almost every sweep recorded in May and July, colour-coded by location of the straight fibre. Three VPs had anomalous (much higher than the local trend) SNNR values, which turn out to be a mismatch between GPS time-of-shot and VP number, and have been excluded from this plot. SNNR is horizontally asymptotic with increasing VP distance from the fibre.

SNNR values were unexpectedly higher for the July data than for the May data. Upon inspection, the July data are qualitatively (visually) better than the May data. This could be due to near-surface ground conditions, as the ground was wet in May but very hard and dry in July. DAS acquisition parameters may also have affected signal levels. Results from helical fibre data are similar to straight fibre, but SNNR values are lower. In general, helical fibre data is noisier than straight fibre data, particularly close to the surface in the geophysics well.

Figure 3 shows single-vertical-fold DAS data recorded on straight fibre in the geophysics well, for the VPs closest to 0, 50, 100, 150 and 200 m from the well for the July survey. Note that the data is displayed with an AGC, but SNNR was calculated using correlated data with no gain. 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 source offsets from the wells.

DAS is most sensitive to changes in strain parallel to the axis of the fibre, with Silixa's iDAS recording strain-rate (Daley, et al, 2016), so the trench data represent our worst-case scenario (broad-side incidence for vertical motion) for fibre data. We do not expect to record waves with purely vertical particle motion on the horizontal straight fibre in the trench, and in fact we mostly recorded ground-roll, however, low-amplitude P-P reflections can be recovered from the trench data after noise-removal and deconvolution. SNNR drops off rapidly as the Vibe moves horizontally away from the trench, and by 200 m ground-roll is largely invisible. Compare this to vertical fibre in the wells, where we can still see faint P-P reflections with the Vibe 200 m from the wells (Figure 3).

Horizontal noise bands appear in the DAS data for VPs close to the DAS interrogator and are visible across the entire 5 km fibre loop (eg. top of right-hand-panel, Figure 3). This noise is likely caused by the Vibe shaking the interrogator, which can have coupling through internal optical components. As expected, SNNR calculated for a given VP increases with increasing vertical fold. The greatest improvement in SNNR appears to happen between one and two-fold, with incremental improvements apparent all the way up to sixteen-fold. This matches qualitative visual observations where it was observed that most signal improvement occurs between one and five-fold, with sixteen-fold data visually appearing to be identical to eight-fold data. Visually, reflections in the boreholes become higher amplitude and more laterally continuous with increased source-effort, as expected.

Discussion and Conclusions

Distributed Acoustic Sensing (DAS) surveys generate large datasets. We propose calculating signal-plus-noise-to-noise (SNNR) for each source gather for quality control. In our testing, SNNR takes much less time to calculate than is taken to perform the Vibroseis correlation step. SNNR is higher for the May survey than for the July survey (ground conditions and/or instrument settings), and higher for straight fibre when compared to helical fibre. SNNR is horizontally asymptotic with increasing source distance and, qualitatively, we see poor to no signal in source gathers where the SNNR vs. distance graph is horizontal. SNNR values that do not match the local trend are diagnostic for geometry errors. As with signal-to-noise ratio, increased source-effort increases the value of SNNR. 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 cost of additional source effort. SNNR decreases rapidly with increasing distance from horizontal straight and helical 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.

Acknowledgements

We thank the sponsors of CREWES for continued support, CMC Research Institutes Inc. for access to the Field Research Station and the University of Calgary for operational support to CaMI through the Canada First Research Excellence Fund. We also thank the CREWES students and staff who made this field work possible by being willing to help. SeisSpace (Halliburton), was used for the seismic processing shown in this report. This work was funded by CREWES industrial sponsors and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 461179-13. Funding for LBNL was provided through the Carbon Storage Program, U.S. DOE, Assistant Secretary for Fossil Energy, Office of Clean Coal and Carbon Management, through the NETL, for the project “Core Carbon Storage and Monitoring Research” (CCSMR) under contract No. DE-AC02-05CH11231.

References

Daley, T.M., Miller, D. E., Dodds, K., Cook, P., Freifeld, B.M., 2016, Field Testing of Modular Borehole Monitoring with Simultaneous Distributed Acoustic Sensing and Geophone Vertical Seismic Profile at Citronelle, Alabama, Geophysical Prospecting, **64** (5), 1318-1334, DOI: 10.1111/1365-2478.12324.

Rietsch, E., 1980, Estimation of the signal-to-noise ratio of seismic data with an application to stacking: Geophysical Prospecting, **28**, 531-550.

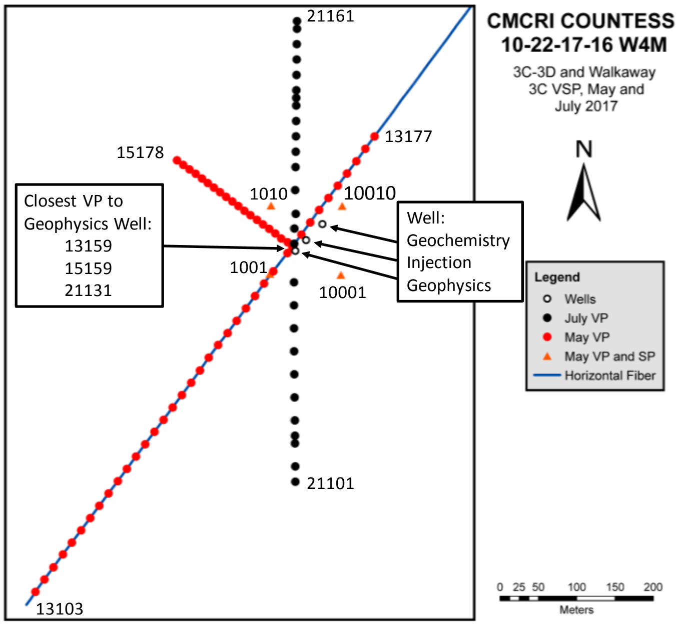

Figure 1. Location of May and July 2017 source points relative to injection and observation wells at the CaMI FRS site near Brooks, Alberta.

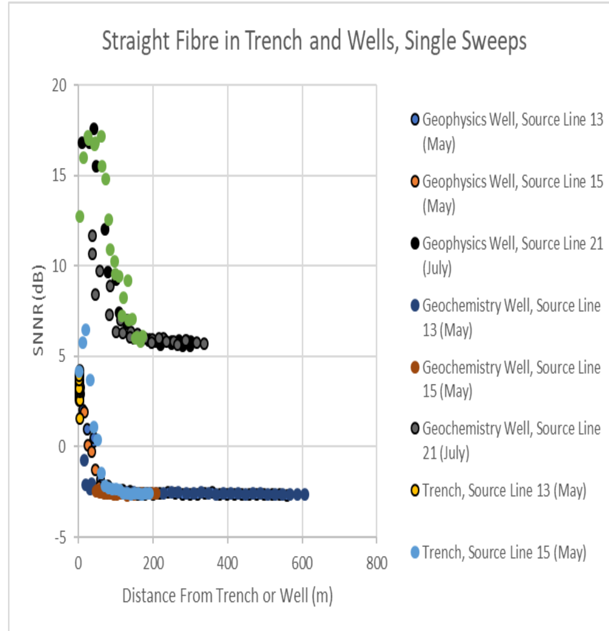

Figure 2. SNNR calculated for single-fold correlated gathers for all data recorded on straight fibre (top) and helical fibre (bottom) plotted against source distance from the fibre.

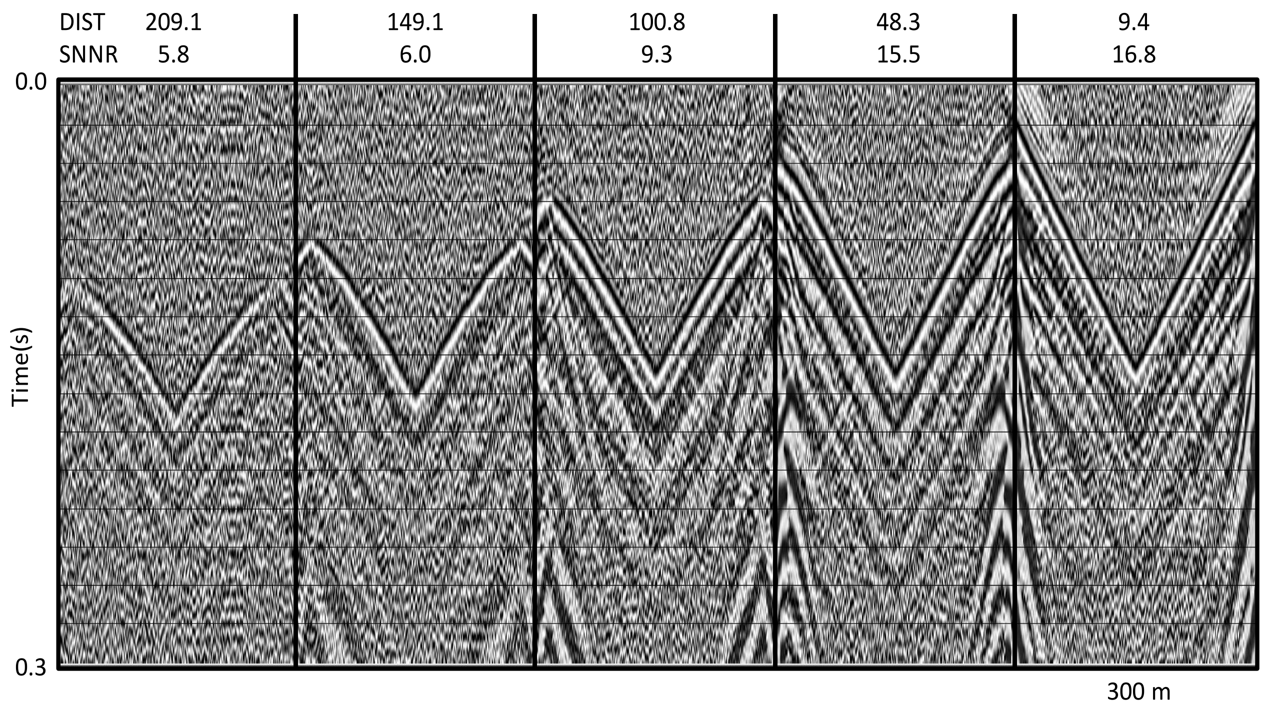

Figure 3. Source line 21 (July) correlated single sweeps recorded on straight fibre in geophysics well (black dots, Figure 1) with 10 ms AGC for display. Source distance from well decreases from left to right.