Optical fibre dataset registration

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ABSTRACT

The Containment and Monitoring Institute (CaMI) Field Research Site (FRS) has three wells on the lease, referred to here (from SW-NE) as the geophysics, injection and geochemistry wells. Borehole and trenched optical fibres are connected in a continuous loop of ~5 km length in the following order: 1) helical in geophysics well, 2) straight fibre in geophysics well, 3) straight fibre in geochemistry well, 4) straight fibre from geophysics well to south end of trench, 5) helical fibre for entire length of trench and 6) straight fibre from the north end of the trench back to the geophysics well. Since we know the trace spacing for each survey, we can assign coordinates to traces once we know the position of any given trace. Tap tests in above ground junction boxes can be spread over as many as 100 traces due to gauge length effects and are not precise enough for this purpose. High-amplitude noise observed at above ground junction boxes also spreads across variable numbers of data traces, depending upon source distance from the junction box. Separation of continuous loop data into discrete datasets has been performed by running a modified STA/LTA algorithm on the fourth power of the sum of the absolute value of uncorrelated trace amplitudes to locate the edges of junction box noise, which also gives us a starting point for determining trace location. Figure 1 shows a correlated record with 0.75 m trace spacing muted using STA/LTA results for all source gathers in this example.

For borehole registration we have calculated least-squares hyperbolic fits to first-break picks to determine which is the deepest trace in each well. Tests of this process give a result with a standard deviation of one trace for straight fibre and three traces for helical fibre for a survey acquired with 0.25 m trace spacing and 10 m gauge length.

INTRODUCTION

The Containment and Monitoring Institute (CaMI) Field Research Site (FRS) has three vertical wells on the lease. Borehole and trenched optical fibres are connected in a continuous loop of approximately 5 km length in the following order: 1) classroom trailer to geophysics well, 2) experimental helically-wound fibre to bottom of geophysics well and back to surface, 3) straight fibre to bottom of geophysics well (observation well 2) and back to surface, 4) straight fibre to bottom of geochemistry well (observation well 1) and back to surface, 5) straight fibre to south end of ~1.1 km long and ~1 m deep trench, 6) experimental helically-wound fibre from south to north in the trench, and 7) straight fibre from the north end of the trench back to geophysics well (Figure 1).

Fibre exits the ground at four junction boxes; J.Obs1 near the geochemistry well, J.Obs2 near the geophysics well, J.South at the south end of the trench and J.North at the north end of the trench. Table 1 shows the results of tap tests conducted by Paul Cook in May of 2017, where zero metres refers to the end of the fibre in the classroom trailer. Note that the zero metre end of the fibre is being shortened as successive users cut off existing connectors and splice on new connectors of various types, and recent work has been done with the interrogator plugged into the opposite end of the loop, which includes a ~5 km spool of fibre sitting on a bookshelf in the classroom trailer before traversing the described fibre loop in reverse order.

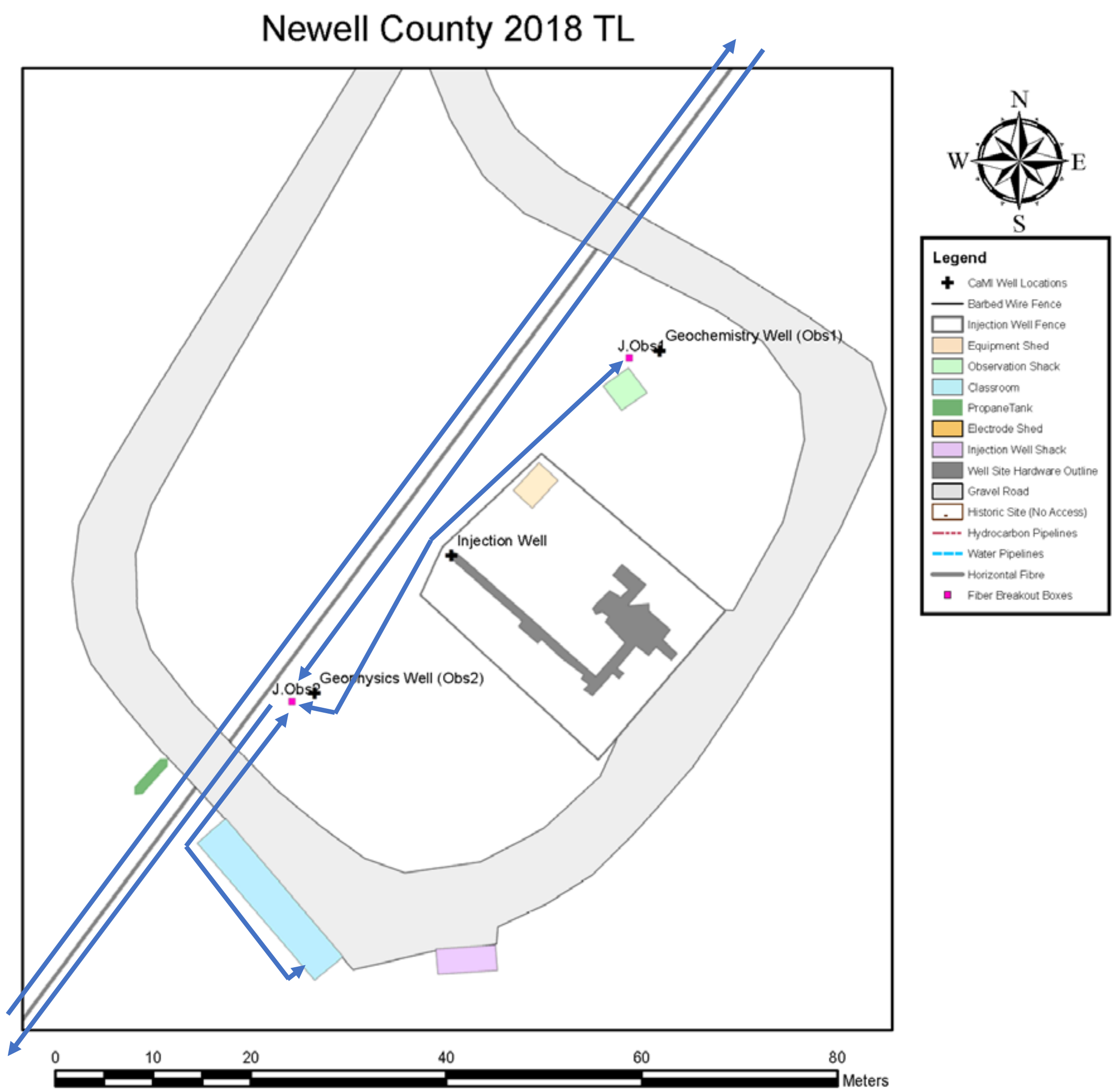

FIG. 1. Wellsite map showing locations of the classroom (light blue), the geophysics and geochemistry wells (black plusses), fibre junction boxes J.Obs1 and J.Obs2 (magenta squares), the trench (dark grey line), and approximate underground fibre routing (dark blue arrows).

While it is important to know where a given field seismic trace is located for processing, this information is not necessarily easily available for fibre-optic data. For example, at the CaMI.FRS, it is not precisely known what depth the fibre reached in the geophysics and geochemistry wells. Nor is the length of fibre in the trench, the amount of fibre present in each junction box, the length of the run between the classroom trailer and the Geophysics well, or the length of the run between the Geophysics well and the Geochemistry well precisely known. The trench itself is referred to as a horizontal trench but follows topography, which can vary on the order of a metre over the length of the trench, and exits the trench at each end in a sloping pipe We have GPS data for junction box locations, but no GPS for fibre position and elevation within the trench. In addition, it has recently come to light that the geophysics well may have a slight deviation from the vertical (Hall et al., 2018).

Table 1. Tap test results from May 2017 courtesy of Paul Cook. Distances are measured from end of fibre in the classroom trailer.

Junction Box	Fibre Location	Fibre	Distance (m)	Distance (m)	Range (m)
J.Obs2	Geophysics Well	Helical begins	50.79	67.63	16.84
J.Obs2	Geophysics Well	Helical to straight	815.99	837.94	21.95
J.Obs2	Geophysics Well	Straight ends	1524.28	1541.12	16.84
J.Obs1	Geochemistry Well	Straight begins	1590.64	1613.86	23.22
J.Obs1	Geochemistry Well	Straight ends	2298.92	2320.36	21.44
J.Obs2	Trench	Start of straight	2370.9	2387.75	16.85
J.South	Trench	Straight to Helical	2971.73	2988.58	16.85
J.North	Trench	Helical to Straight	4241.54	4259.15	17.61
J.Obs2	Trench	Straight ends	4794.64	4819.66	25.02

The good news is that we do know the nominal trace spacing for each survey that has been conducted, so it should be possible to assign trace locations in a general sense, once we know where a given trace is located, for example, the deepest trace in a well, or the closest trace to a seismic source. GPS data exists for surface locations of permanent electrodes in the trench, so interpolated trench elevations may be assigned assuming a constant trench depth. Sampling on straight and helical fibre occurs along the axis of the fibre, which means that traces recorded on helical fibre are spatially closer together than those recorded on straight fibre, which will also need to be considered when assigning a geometry.

METHOD

Tap-tests in junction boxes appear on 17-25 traces at 1 m sampling (68-100 trace at 0.25 m sampling) and may not be precise enough to non-ambiguously assign a trace location on the fibre data (Table 1). If a well has permanent geophones with known depths, it is possible to register the fibre dataset using the geophone data (Gordon 2017, 2018). However, many wells, including the geochemistry well at the FRS, have fibre but no geophones.

High-amplitude noise is observed on uncorrelated source gathers where fibre exits the ground to splices in junction boxes. Due to gauge length effects, this noise smears across variable numbers of data traces depending on source distance. Similarly, source noise smears onto the generally noisy traces when the source is close to a junction box. To separate data from the continuous loop into various downhole and trench datasets, we have attempted STA/LTA picking of the sum of the squares of trace amplitudes. These results could also be used as a starting point for assigning x, y, and z coordinates to traces. We have also used least-squares hyperbolic fitting to first-break pick on the borehole dataset to determine the location of the deepest trace in well. Once picked, this can also be used as a starting point for geometry assignment. A similar method could also be used for the trench data; however, direct arrivals are difficult to pick due to fibre broadside insensitivity, and source-generated noise is inconsistent, difficult to pick, and asymmetric (not shown).

STA/LTA results for a single Vibe Point

Figure 2 shows an uncorrelated source gather acquired with a 0.75 m trace spacing and 10 m gauge length. Extremely high amplitudes at the start and end of the fibre loop where the fibre is present inside the classroom trailer were observed and arbitrarily muted. Traces with high amplitude noise at all junction box locations are visible even at this scale. A graph of a trace-by-trace sum of the absolute values of amplitudes results in peaks at each junction box location, the sides of which can be steepened by taking them to the nth power, where the n=4 has been settled upon experimentally. Thresholding the STA/LTA results followed by a further trace-window threshold gives us trace locations for the edges of zones of high amplitude traces in the junction boxes. Figure 4 shows trace mutes applied to Figure 2 based on the red dots shown in Figure 3.

In more detail: the red circles in Figure 3 marking potential junction box edges were calculated using the following algorithm and parameters:

1) Run STA/LTA on sum(abs(traces))^4 [power of 4 to steepen slopes]
    a. STA window = 3 traces
    b. LTA window = 7000 traces
2) Threshold result; keep trace indices for STA/LTA > 0.4
3) Determine trace windows for junction boxes
    a. Calculate number of traces between answers from (2)
    b. Drop trace index if distance to next is less than 100 traces

STA/LTA results for all source points

Unfortunately, the parameters chosen for STA/LTA in the previous section do not necessarily work for all source points (VPs). Figure 5 shows the result of the using the parameters used to generate Figure 3 for 172 VP, with one VP per row. Black represents a one (keep the trace), and grey represents a zero (discard the trace).

Dropping the STA/LTA threshold from 0.4 to 0.001 gives the results shown in Figure 6. Apart from source noise effects, this threshold works better everywhere but for the geophysics well helical data. This is due to near surface noise that has previously been observed on this portion of the fibre loop (Hall et al., 2017). Muting peaks on the helical fibre trace sum interpreted to be associated with this near-surface noise before STA/LTA yields a better result for the 0.001 threshold (not shown).

Figure 7 shows the trace-by-trace sum of trace the results in Figure 6 after muting noisy helical data and re-running the STA/LTA. Source noise and gauge length effects may now be dealt with thresholding the graph in Figure 7. In this case an arbitrary threshold at 75% of all shots was used to determine trace windows for data separation. This answer does not significantly differ from a threshold set at 25% of all shots. Data exclusion zones narrow below 25% of shots due to junction box noise smearing onto data traces and widen above 75% due to data smearing into junction box noise.

Figure 8 shows the result of applying our automatically determined trace mutes to a correlated source gather and illustrates the difficulty of manually interpreting the location of these windows. As mentioned above, we may now use these trace windows as a starting point to begin to assign a geometry to the individual datasets.

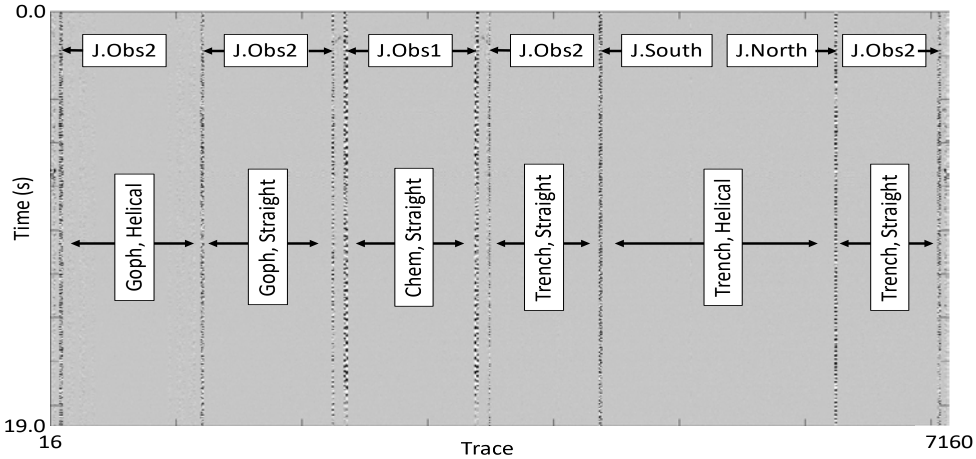

FIG. 2. Uncorrelated data for a single sweep.

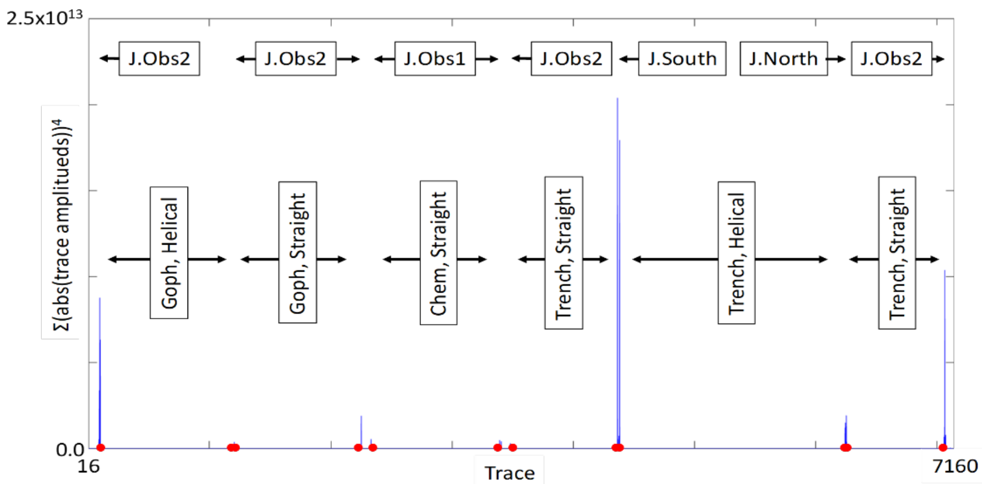

FIG. 3. Square of the sum of squared amplitudes and STA/LTA results (red dots).

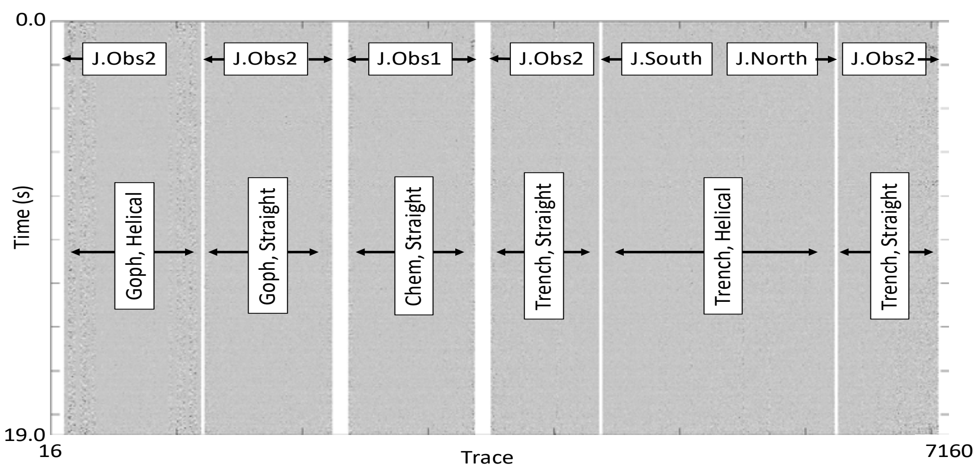

FIG.4. Trace mutes based on STA/LTA results shown in Figure 3.

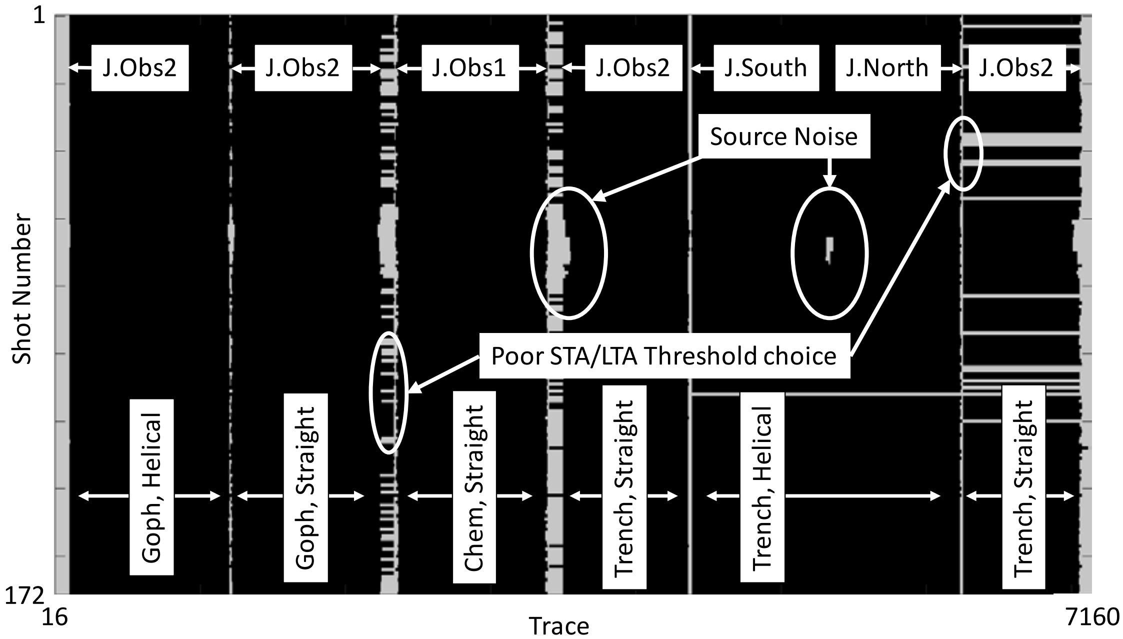

FIG. 5. STA/LTA Threshold = 0.4; Trace range threshold = 100. Black = 1 (keep trace), Grey = 0 (mute trace).

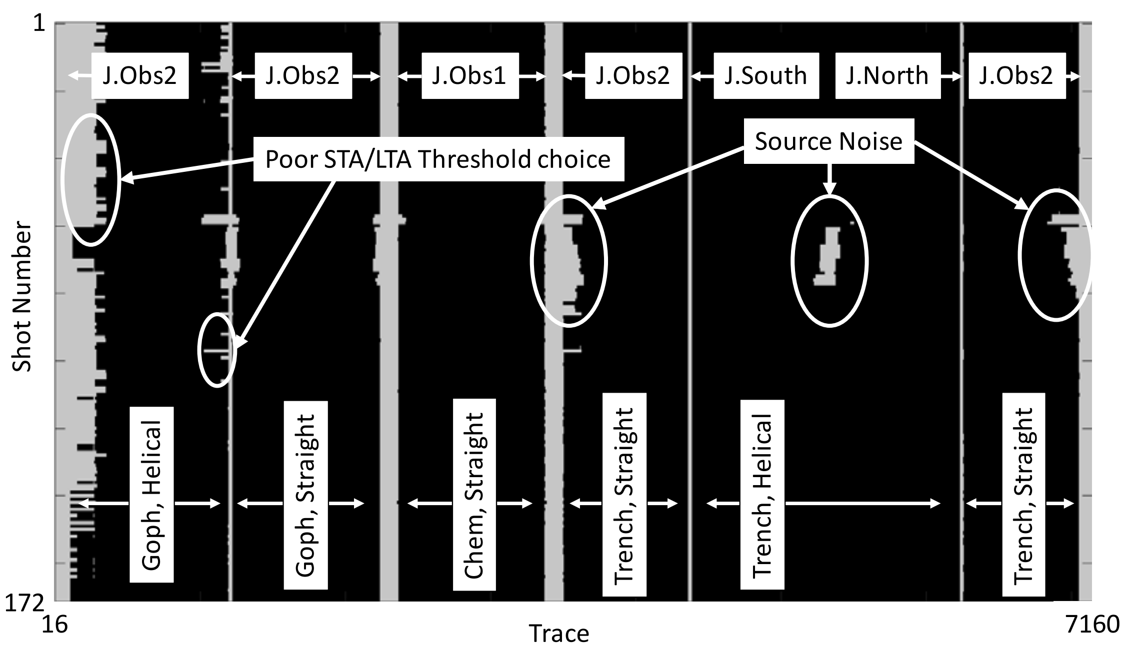

FIG. 6. STA/LTA threshold = 0.001; Trace range threshold = 100. Black = 1 (keep trace), Grey = 0 (mute trace).

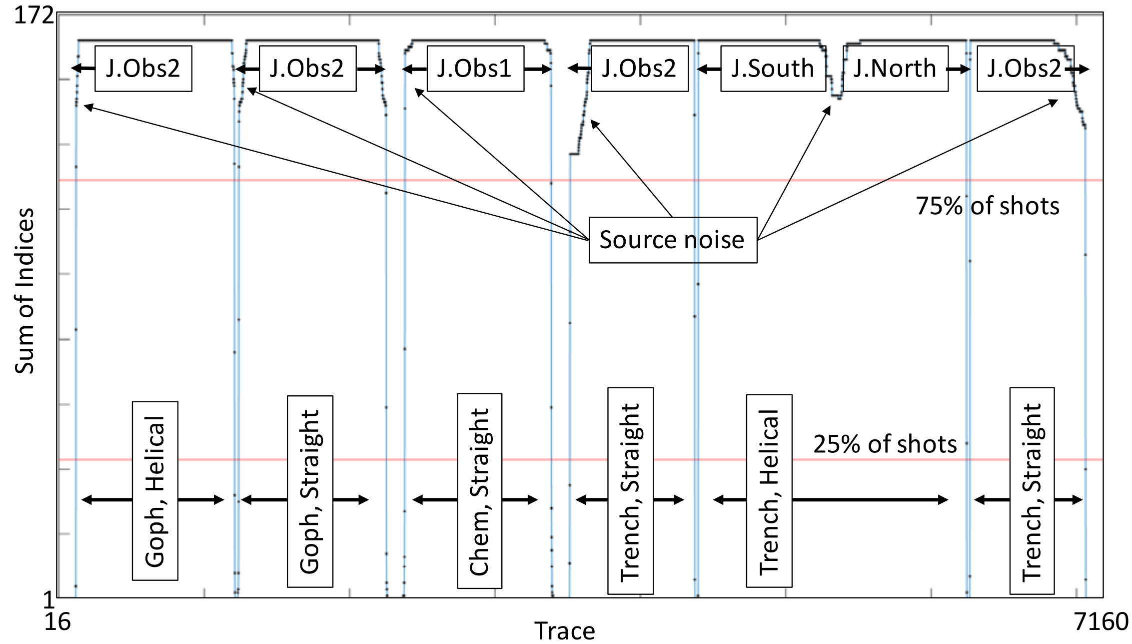

FIG. 7. remote. STA/LTA threshold = 0.001; Trace range threshold = 100. Muted Goph Helical near-surface noise before STA/LTA.

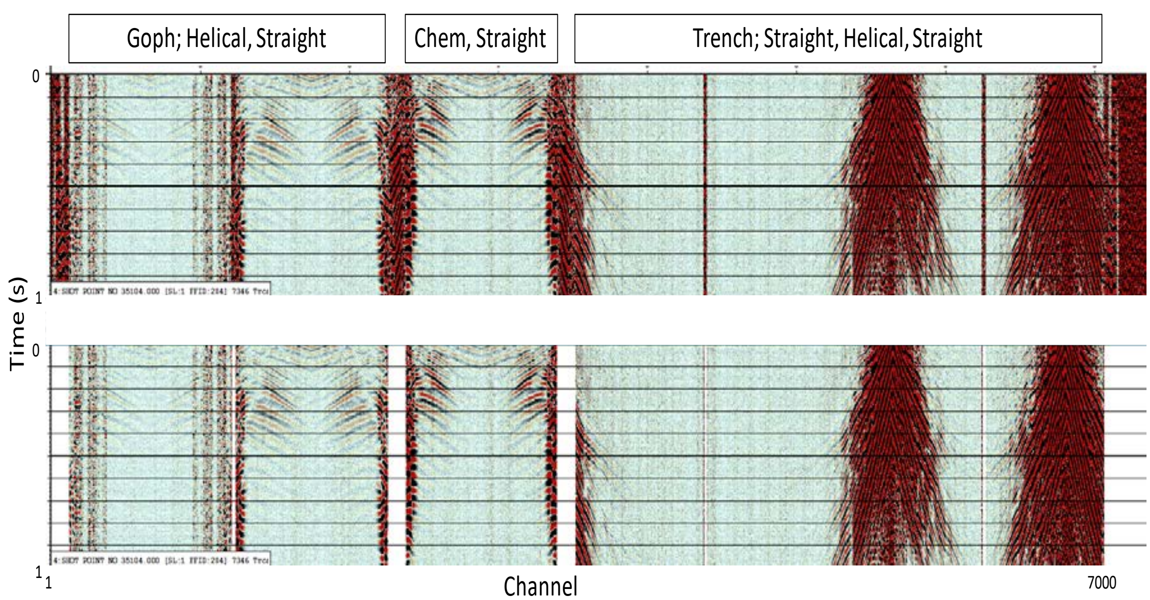

FIG. 8. Correlated data with junction box noise trace mutes calculated using a modified STA/LTA algorithm.

Deepest Fibre Trace in Well

One way to determine the depth of traces in a well is to find the deepest trace in the well and work back to the surface with the known trace spacing. This is difficult to do with a 25 cm trace spacing, as many first-break picks appear to be at essentially the same travel time. Coupled with gauge length smearing, and periodic brightening and dimming of amplitudes on helical fibre (Figure 9 and cf. Eaid, 2017). Figure 9 shows an example of first break picks for a single VP recorded on fibre in the geophysics and geochemistry wells. It is difficult to interpret where the transition from fibre in the wells to fibre above ground in junction boxes or fibre between the geophysics and geochemistry wells may be.

Figures 10-12 show first break picks across the deepest part of the well for seventeen VPs at varying offsets. For display, first-break picks have been shifted to 0.1 s. due to noise, the minimum travel time for first-break picks does not necessarily match the deepest trace in the well (difficult to see at this scale). For each VP, first-break picks have been least-squares fitted to a hyperbola, with the assumption that sediments are horizontally layered and therefore the minima of the hyperbola will coincide with the deepest trace in the well.

First-break picks on helical fibre are less consistent than on straight fibre. As a result, we obtain an answer with a larger standard deviation. The helical data have a 3-trace standard deviation or 0.65 m standard deviation, and the straight data have a 1 trace or 0.25 m standard deviation. The deepest traces in the wells for this particular survey are 2211 (geophysics well, helical fibre), 5100 (geophysics well, straight fibre) and 8136 (geochemistry well, straight fibre). These trace locations are far more precise than we could have obtained from tap tests.

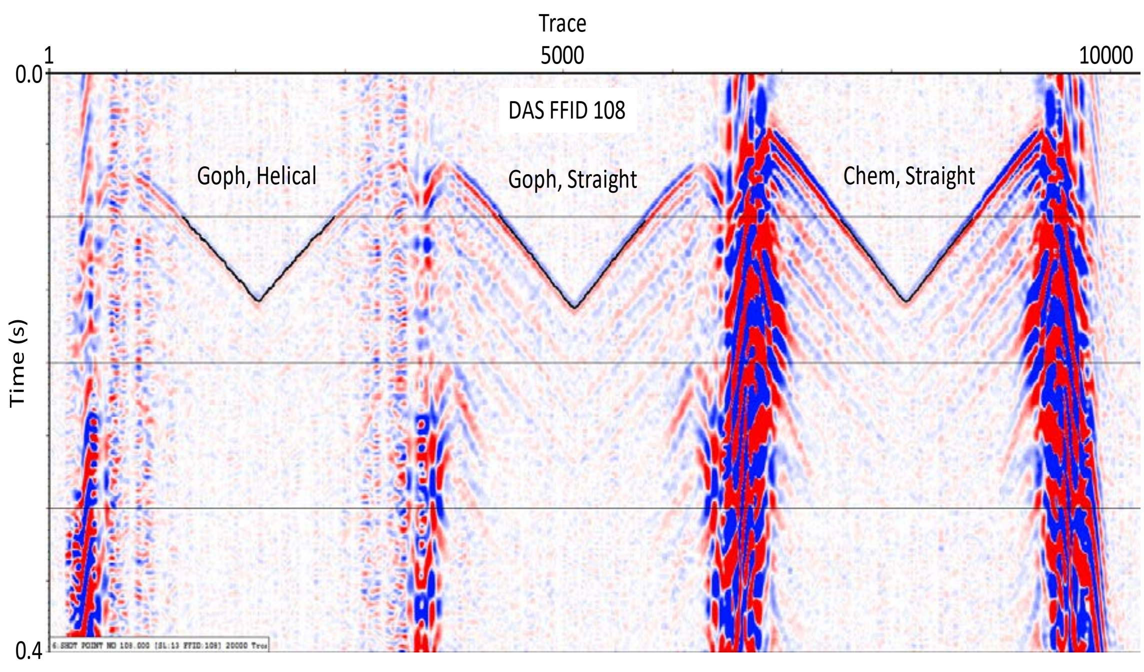

FIG. 9. Example of first break picking (black) across deepest point in each well.

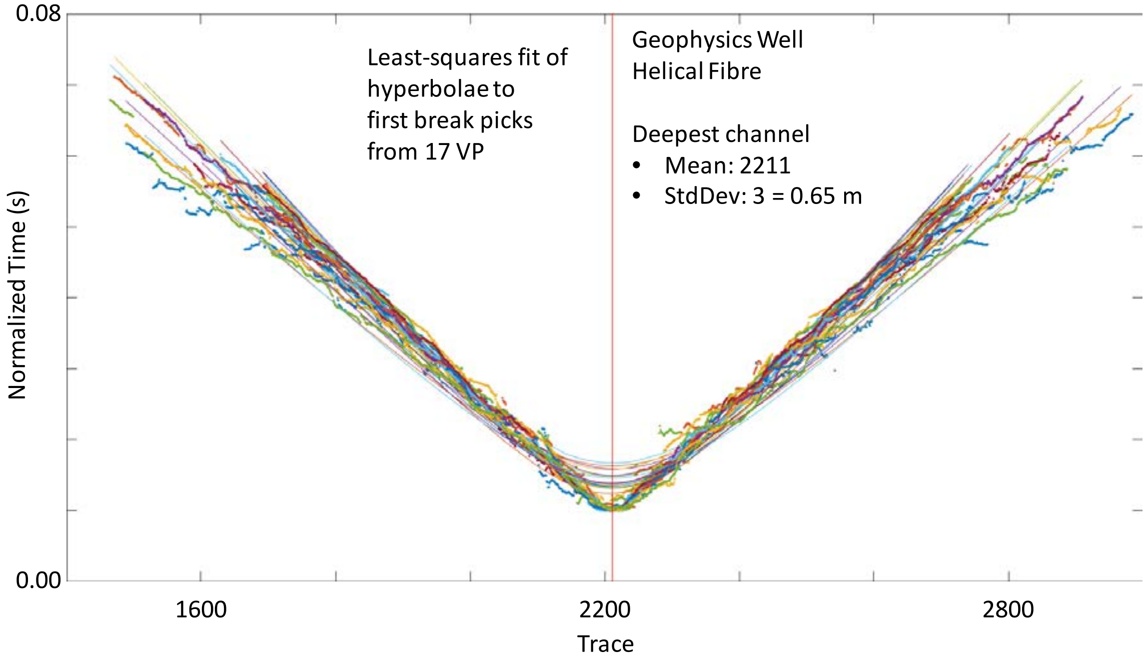

FIG. 10. Geophysics well helical fibre least-squares fit of hyperbolae to first-break picks for 17 VP. Deepest channel=2211 (vertical red line). Standard deviation = 3 traces or 0.65 m.

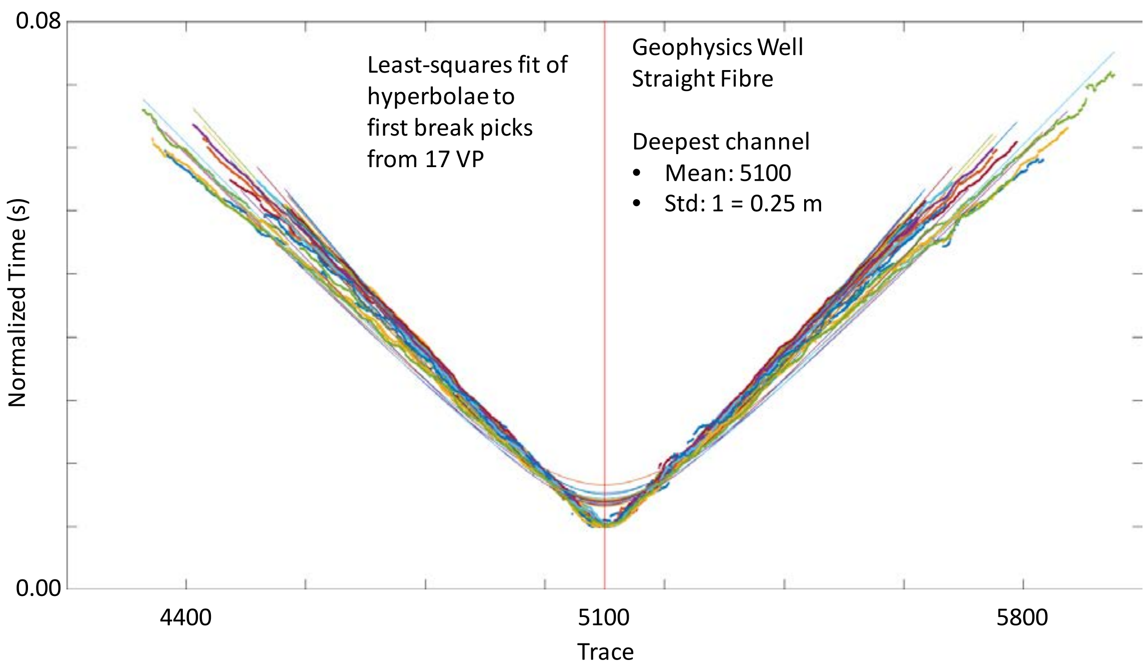

FIG. 11. Geophysics well straight fibre least-squares fit of hyperbolae to first-break picks for 17 VP. Deepest channel=5100 (vertical red line). Standard deviation = 1 trace or 0.25 m.

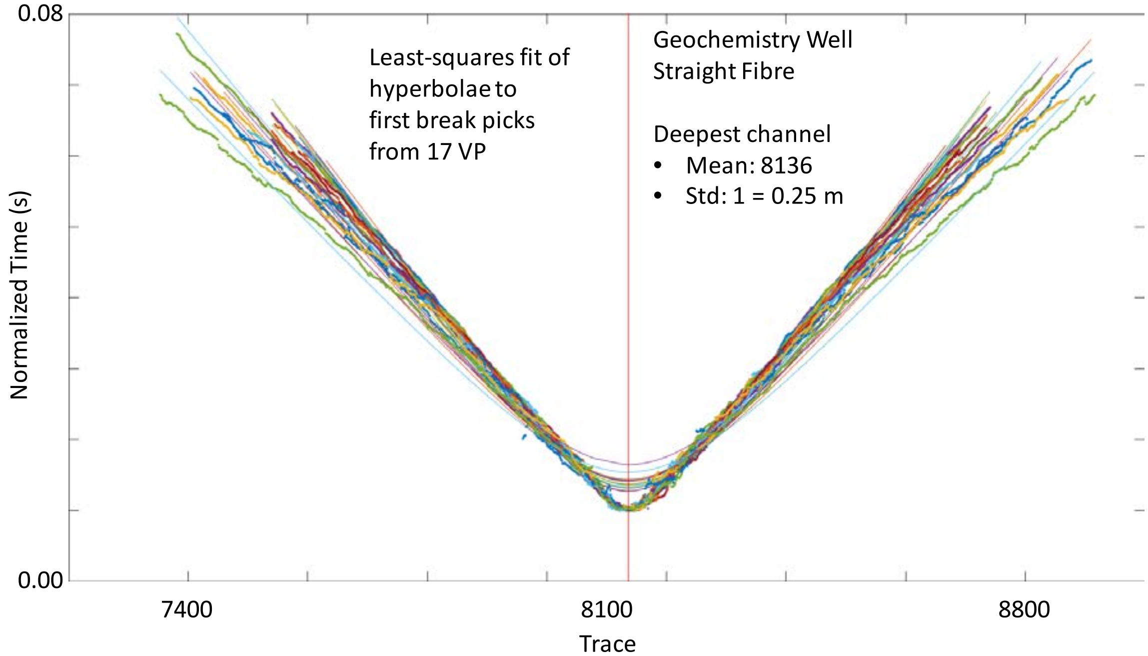

FIG. 12. Geochemistry well straight fibre least-squares fit of hyperbolae to first-break picks for 17 VP. Deepest channel=8136 (vertical red line). Standard deviation = 1 trace or 0.25 m.

DISCUSSION AND FUTURE WORK

Running a STA/LTA algorithm on the fourth power of the sum of the absolute value of uncorrelated trace amplitudes appears to be a robust method for locating the traces on a fibre loop where the fibre is above ground in junction boxes. However, some care must be taken when picking parameters for the STA/LTA, and no one set of parameters works for all junction boxes in a 5 km fibre loop. We are confident enough in our results to use them to split continuous source gathers into discrete datasets by fibre location. These results also provide a consistent starting point for assigning a geometry to the trench datasets. For borehole data we may also determine which is the deepest trace in a well, by least-squares fitting of hyperbolae to first-break picks. With seventeen Vibe Points, this method has been shown to locate the deepest trace with a standard deviation of one trace for straight fibre and 3 traces for helical fibre.

Now, we need to systematically apply this method to all of the fibre datasets that have been acquired at the CaMI.FRS and use the results combined with interpolated GPS data to assign a geometry to each discrete dataset for further processing.

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