Processing of DAS and geophone VSP data from the CaMI Field Research Station, Newell County, Alberta

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Summary

As part of on-going seismic monitoring at the CaMI Field Research Station, vertical seismic profiles are being recorded unto a 24-level permanent downhole 3-component geophone array as well as helical wound and straight optical fibre for Distributed Acoustic Sensing (DAS). Advances over previous processing include smoothing DAS first break picks, application of both a median and FK filter to separate and enhance the upgoing energy, and careful assessment of shot statics based on minimizing the error between observed and computed first break travel-times. The velocity model for the VSP CDP transform for offset shots was determined initially from well-log data and the zero-offset DAS data, and then updated through matching computed and observed moveout for walkaway sources. Having the very near-surface velocities available from DAS data enabled a very robust 1-D velocity model to be established, which also improved VSP-CDP transforms of the borehole geophone data. The final VSP-CDP stack enabled excellent imaging up to nearly 100 m from the VSP well for the DAS data and 64 m for the geophone data. After deconvolution, the processed geophone and DAS data correlate very well.

Method

The CaMI Field Research Station (FRS) is located approximately 200 km southeast of Calgary in the Newell County. It is focused on the development of new continuous and discrete subsurface and surface monitoring technologies, including DAS. Earlier processing of data from this site has been reported by Gordon et al., (2017, 2018) following developments in DAS VSP surveys by Mateeva et al. (2014). The new processing described in this paper was undertaken with the objective of developing a detailed velocity model that will be the basis of future DAS and geophone data processing for time-lapse surveys.

At the CaMI.FRS, the geophones and fibre are all cemented behind the casing in a 350 m deep observation well and the fibre is also laid out in a loop including the two observation wells at the site as well as in a 1.1 km long trench in which the fibre is buried at a depth of 1.25 m (Figure 1). The source for the VSP survey was an Envirovibe with a sweep of 10 – 150 Hz over 16 s. Data used for this paper were recorded from 14 source points with offsets from 9 m to 199 m from the VSP well. DAS traces were recorded with a 10 m gauge length with an output trace interval of 0.25 m to a maximum depth of 338 m in the well.

Results

The stacked and correlated DAS data followed a standard initial processing flow consisting of a median filter to separate the upgoing and down-going energy. Figure 2a shows the separated down-going energy for a near-offset source point, including both P-wave and S-wave energy; Figure 2b shows the upgoing P-wave energy after additional FK filtering. Good quality reflections are evident over the full depth range of the fibre.

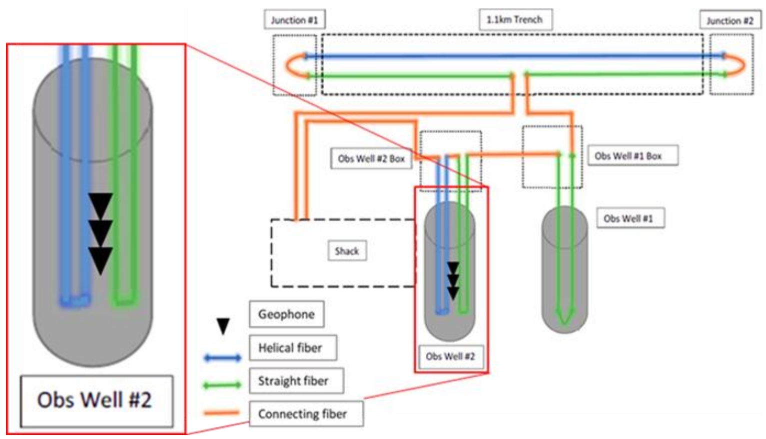

FIG. 1. Layout of fibre at the CaMI Field Research Station. This paper focusses on data collected with the straight fibre in Observation Well #2.

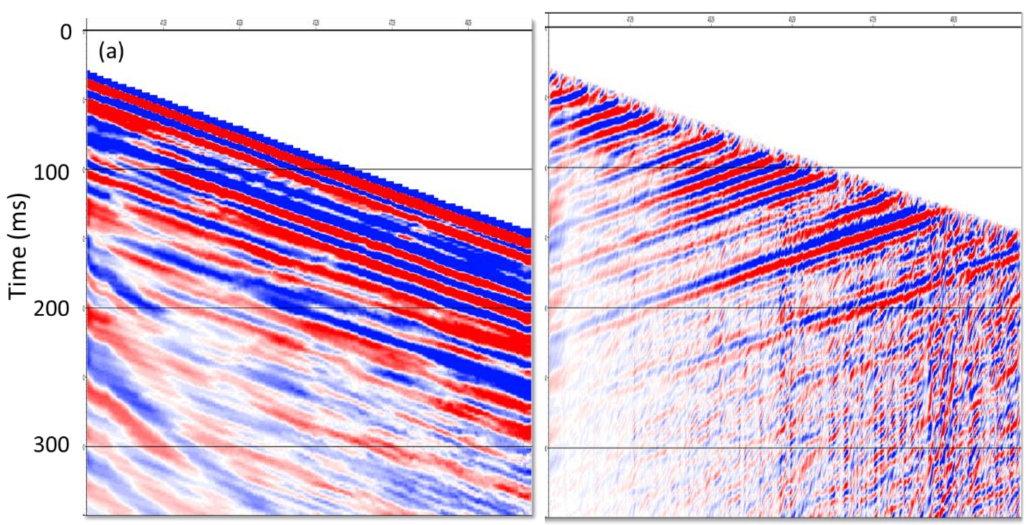

FIG 2. Near offset separated down-going (a) and upgoing (b) wavefields after application of median and FK filters.

Following wavefield separation, the down-going P-wave first arrivals were used to design the deconvolution operator to apply to the upgoing wavefield. The up/down deconvolution used a 300 ms operator using a window from 80 ms to 880 ms after flattening the data with first breaks to 100 ms before the up/down deconvolution and restoring the original timing afterwards. In addition, source statics were computed. A velocity inversion was performed allowing anisotropy to be estimated in 3 shallow layers to minimise the travel time differences between the velocity model predictions and the actual first arrival times, this procedure yields residual, or relative shot statics to properly align the energy from shots with different offsets.

For processing the walkaway records, a detailed velocity model first had to be constructed. Initially drift corrections were applied to match sonic velocities with zero-offset first arrival travel times. The sonic velocities are more densely sampled and erratic than those from the DAS first arrivals and help get the average level in the correct place. A shallow velocity model was inserted for the weathering layer with a rapid build up to the velocities in the consolidated layer. To ensure a stable velocity model the velocities from the DAS first arrivals were blocked into 7 layers. Figure 3a shows the final velocity model which was developed by minimizing the error between the observed and computed first arrival travel times. An example of a near-offset NMO-corrected gather is displayed in Figure 3b and shows that the reflections are all flattened.

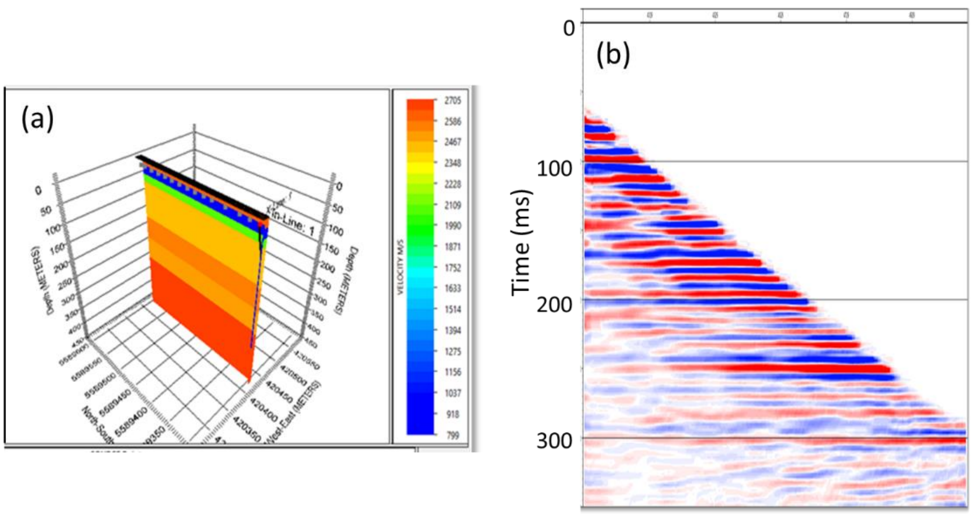

FIG 3. (a) Final velocity model after minimising errors between observed and computed first arrival times for all offset shots; (b) Flattened up-going energy after median filter, FK filter, shot statics, deconvolution and normal moveout corrections applied.

Processing of the borehole geophone data followed a similar flow to that for the DAS data, except from additional data rotation steps to enable P and S upgoing wavefields to be isolated. Two trace rotations were performed. For the first rotation, the recorded horizontal components (H1 and H2) were rotated to Hmax and Hmin where the Hmax is oriented in the well-source plane and Hmin is perpendicular to the well-source plane (Hinds et al., 1996). The second rotation was then applied to the vertical component (Z) and Hmax, creating Hmax' which is oriented in the direction of the upward propagating wave front and is thus also known as the radial component. The second output of this rotation is the orthogonal component (Z'), which contains upgoing events including the reflected waves. Following the geophone data rotation, a time-variant polarization was performed to separate reflected P and S waves ensuring a clean separation at each geophone level.

For both the DAS and geophone datasets, the final processing steps for the walk-away surveys involved correcting for normal moveout and undertaking VSP-CDP transforms. The maximum source offset included in the VSP-CDP transforms was 199 m and an output trace spacing of 2 m was selected for the output images. We found that the reflections have slightly higher amplitudes and better coherence when using the DAS velocity model rather than the geophone-derived velocity model.

A comparison between the VSP-CDP stack sections from the geophone and DAS data is shown in Figure 4. There is an excellent match between the two sections even though the geophone and DAS datasets are measuring different attributes (velocity vs strain rate). We conclude that deconvolution has to some extent normalized the two measurements. However, there is a time delay of about 20 ms between the two stacks which has yet to be explained. The DAS image contains very shallow reflections due to the fibre covering the full depth of the well from the ground surface, whereas the geophone section has less vertical coverage due to the geophone aperture being limited to depths between 191 m and 306 m. The difference in depth aperture also affects the maximum offset contributing to the VSP-CDP stack, being 98 m for the DAS data, but only 64 m for the geophone data. Finally, the amplitudes of reflections in the DAS section decrease slightly with offset from the well due to the directional sensitivity of straight fibre, which decreases at higher angles incidence on the fibre.

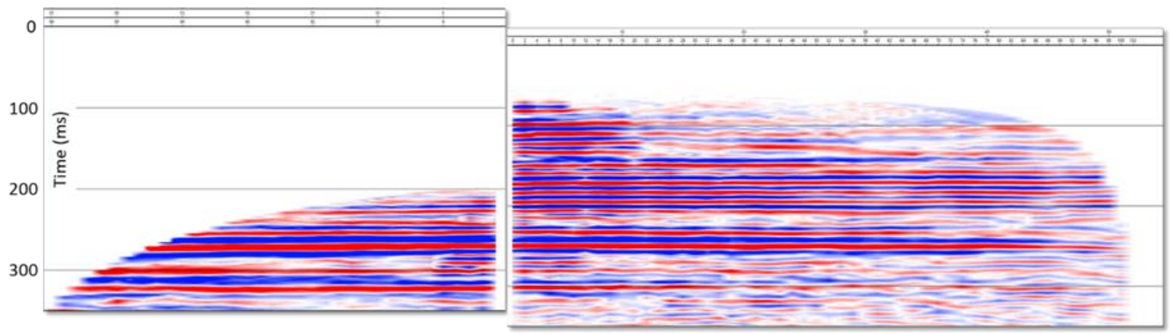

FIG. 4. VSP-CDP stacks for geophone data (left) and DAS data (right).

Discussion and conclusions

The raw DAS data perhaps does not look encouraging compared to the raw geophone data, but the resultant image is comparable at the common depth levels and extends to much shallower depths and offsets than the geophone data. The improvement through processing, using essentially identical sequences would seem to be due to the very fine spatial sampling. More care must be taken in building the velocity model for the DAS data due to this very fine sampling, and also some timing jitter that implies negative interval velocities. This latter requires some smoothing of the DAS data whilst still preserving its general character. Constructing the geophone VSP-CDP transform using the DAS velocity model results in greater continuity but should not impact event timing. It could be that the depth for the DAS cable does not quite correspond to the length along the cable but as they are tied at the deeper geophone levels this should mostly affect shallower levels rather than the overall level. Applying the residual shot statics computed through the velocity inversion procedure provided a considerable improvement in the image, several iterations of this procedure were tested. Testing and QC were performed at every step to ensure that the processes performed the task they were intended to without any harmful side effects, such as noise leaking into signal, or down-going energy leaking into up-going energy.

Acknowledgements

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