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Multi-component strain-tensor results from an experimental directional fibre-optic sensor

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Summary

Four Vibe Points (VP) were recorded on a 10x10m eight-sided buried experimental directional DAS sensor (DDS) at Carbon Management Canada's Newell County Facility in 2018, and the eight components of strain-rate data were used to estimate time-series of strain-rate-tensors for the DDS and surface geophones for a single cycle of the first direct ground-roll arrival across the DDS (Hall et al., 2021a, 2021b) as a proof of concept. In 2022, we were able to record 549 VP on the DDS. These VP were part of a vertical seismic profile (VSP) CO2 sequestration monitor survey (Snowflake2). Eight components of field data were used to estimate three directional strain-tensors for all the 2022 data using a simplified method, and circular wavefronts propagating with an apparent direction from the DDS towards far offsets can be observed when time-slices of the tensor results are animated in map view.

Method

The 2018 data were acquired with a 5 m gauge length, meaning that we could expect to record several traces per side of the 10x10 m DDS squares that were uninfluenced by gauge length or DDS corner effects (Hall et al., 2021a, 2021b). A least-squares numerical model to predict trace locations from the DDS was created from GPS data and the known geometry of the DDS. Traces from each side of each square were then extracted, stretched, and stacked to better approximate a point receiver prior to strain-rate tensor estimation. This process involved time-consuming interpretation steps, where the time involved was not of concern because there were only four Vibe Points. The 2022 data were acquired with a 7 m gauge length, so we can reasonably expect to have only one traces from each side of the DDS that is uncontaminated by gauge length effects. Thirty-eight VP were identified where a line drawn between the VP and the center of the DDS is normal to one of the sides of the DDS. For this case, we expect little to no energy to be recorded on the fiber due to broadside insensitivity (cf. Mateeva et al, 2012). Trace windows of nulls were interpreted for each of the VP and averaged to locate the center trace of each side of each square for the straight fiber data. The center traces were then extracted to create 8-component source gathers for the first loop of straight fiber from each of the two squares (eg. left side of Figure 1). The math used to reduce the eight-component field data from the DDS to a time-series of estimated directional tensors is detailed in previous abstracts (Hall et al. 2021a, 2021b).

Results

The results for all VP are shown on the right side of Figure 1. Subtle differences between components can be observed in the direct arrivals and ground-roll but are difficult to interpret in this display. The question now becomes how to effectively display the results. We have chosen to display color-coded (NN red; EN magenta; EE blue) quiver plots in map form, with the base of each quiver located at the mid-point between the center of the DDS and the corresponding VP location (Figure 2). Map co-ordinates have been arbitrarily rotated fifteen degrees counterclockwise around the center of the DDS so the EE, EN and NN quivers do not plot on top of each other on lines 1 (E-W source line), 4 (SW-NE source line), and 7 (N-S source line). A time-slice at 0.5 s (black line; Figure 5) is shown as quiver plots in Figure 2 and appears to show circular wavefronts centered on the DDS. Animating Figure 2 sample by sample clearly shows circular wavefronts that appear to propagate from the DDS towards the sources. This reciprocal directionality is purely because it takes less time for wavefronts to reach the DDS from closer VP, coupled with the way we have chosen to plot the data.

Discussion

We took advantage of the re-acquisition of the Snowflake VSP survey conducted in September of 2022 by acquiring all 549 of the Snowflake VP on our experimental directional DAS sensor. Processing of the data to extract traces from the center of each side of each square in the sensor to form eight component source gathers, followed by estimation of directional strain tensor traces has been successful in both Matlab and in a Python script called from Schlumberger Vista. We have plotted time slices of the results as colour-coded quiver plots in map form where the base of each quiver is located at the VP-DDS mid-point location, and have observed circular wavefronts propagating with an apparent direction from the DDS towards far offsets. In all, we feel the results presented in this report constitute a better, and certainly more complete, proof of concept demonstration of the DDS. However, it is not commercially feasible to bury 10x10 m sensors at a depth of 2 m for general seismic use., and the DDS in its current form has no vertical component information. We are looking into development of smaller multi-component fiber sensors that would be easier to bury for coupling and could additionally include a vertical component.

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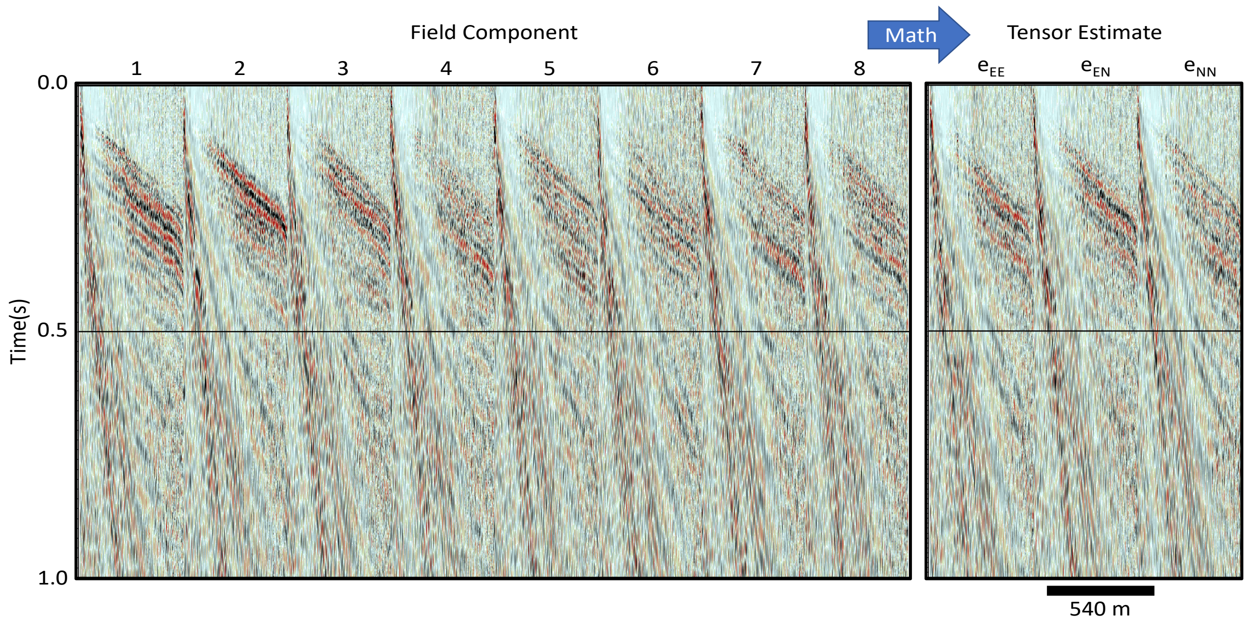

Figure 1. Eight components of field data (left) for 549 VP sorted by the absolute value of the source-DDS offset (left) and the output three component tensor estimates (right).

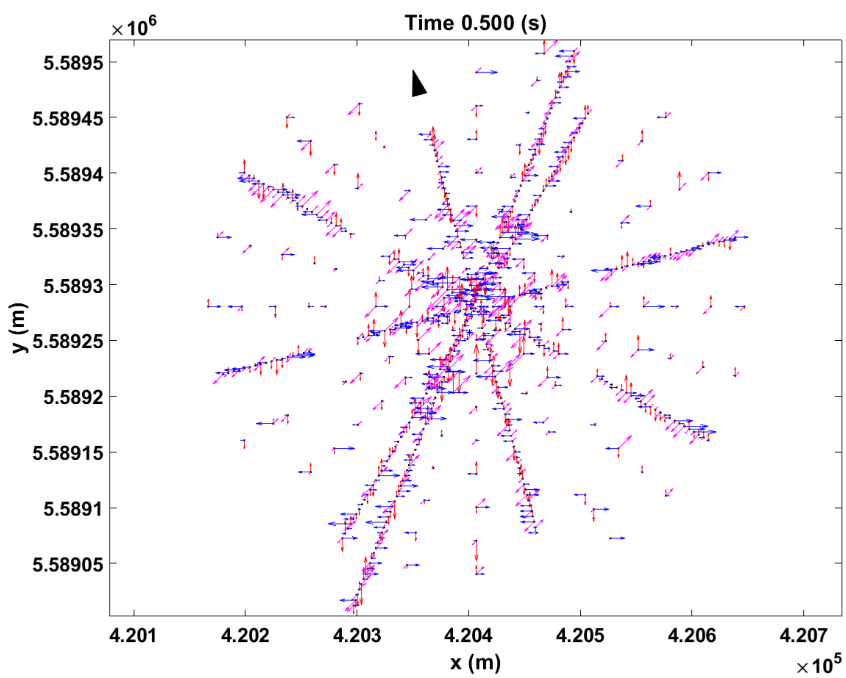

Figure 2. Matlab quiver plot for a time-slices at 0.5 s of the three component tensor estimates. The base of the quivers are located at the midpoint between each VP and the DDS. Map co-ordinates have been rotated 15 degrees counterclockwise around the DDS location for display.