Multi-azimuth and offset directional strain tensor results recorded on an experimental directional DAS sensor

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ABSTRACT

An experimental 10x10 m Directional DAS Sensor (DDS, also known as the Pretzel) was buried at a depth of 2 m at Carbon Management Canada's Newell County Facility (formerly known as the Containment and Monitoring Institute's Field Research Station, or CaMI.FRS), near Brooks Alberta in 2018. We recorded 549 VP on the sensor as part of the Snowflake2 survey that was acquired in 2022. The data were processed 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 We plotted time slices of the results as colour-coded quiver plots in map form where the base of the quivers are located at VP-DDS mid-point locations and have observed circular wavefronts propagating with an apparent direction from the DDS towards far offsets. The results presented in this report constitute a better, and certainly more complete, proof of concept demonstration of the DDS than was previously possible.

INTRODUCTION

An experimental 10x10 m Directional DAS Sensor (DDS, also known as the Pretzel) was buried at a depth of 2 m at Carbon Management Canada's Newell County Facility (formerly known as the Containment and Monitoring Institute's Field Research Station, or CaMI.FRS), near Brooks Alberta in 2018 (Innanen et al., 2018, 2019a, 2019b). The sensor consists of two horizontal squares, with one square rotated approximately forty-five degrees relative to the other square. Straight fiber traverses the first square twice, then the second square twice, followed by helically wound fiber along the same route. Initial testing consisted of recording four Vibe Points (VP) with a maximum offset of 63 m from the centre of the DDS at two different azimuths (Figure 1) on the sensor and comparing to surface geophone data converted from velocity to strain-rate (Hall and Innanen, 2019; Hall et al., 2020a, 2020b). Hall et al. (2020, 2021a, 2021b) proposed a method of using directional strain-rate traces from the DDS to estimate time-series of strain-rate-tensors and applied it to a single period of ground-roll (~40 ms) recorded on straight and helical fiber in the DDS as well as surface geophones, after applying corrections to better approximate a point receiver.

In 2022, the DDS was added to the end of a permanent 5 km fiber loop at the Facility, and 549 VP with a maximum offset of 550 m from the center of the DDS and azimuths from 0 to 360 degrees at 15-degree increments were recorded as part of a 3D vertical seismic profile (VSP) monitor survey known as Snowflake2 (Figure 2; Innanen et al., This volume). This report show data from Snowflake2 source lines 1-13 shot with an Inova AHV-4 vibrator using a 2-150 Hz linear sweep over 20 seconds, with 2 sweeps per VP. Of particular interest is the observation on both the 2018 and the 2022 DDS data that the polarity of DAS traces does not flip when the direction laser light travels down the fiber relative to the ground is reversed. This observation is important for the development of smaller directional sensors (eg. Hall et al., This volume).

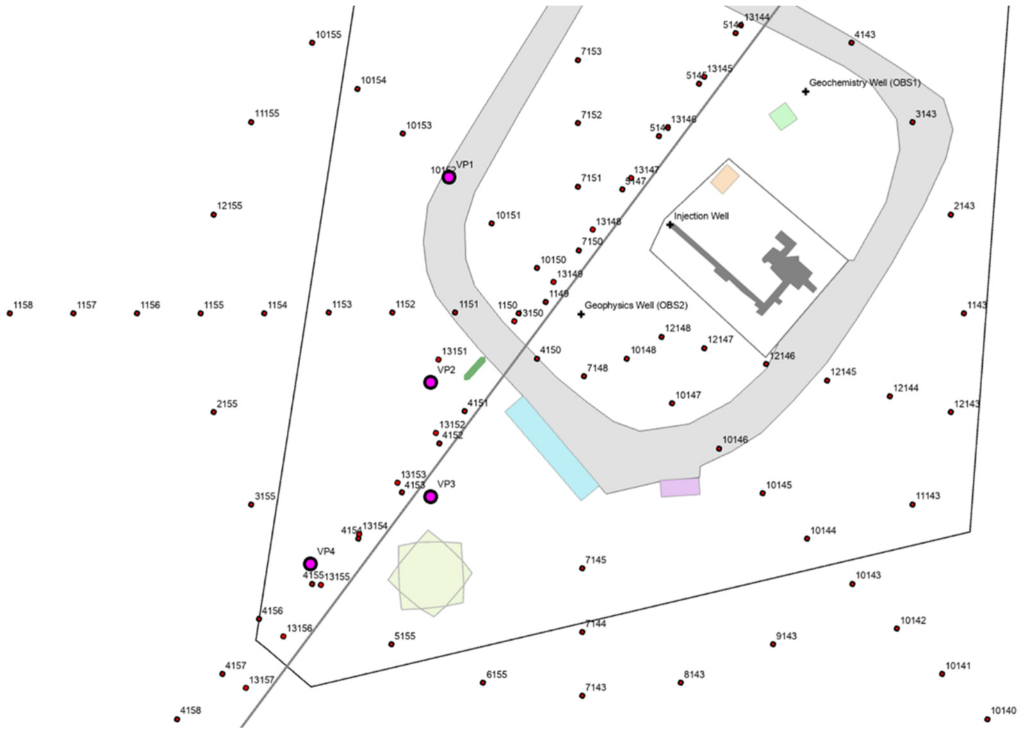


FIG. 1. Map showing the well lease with the DDS (Green), VP1-VP4 (magenta) that were acquired for initial testing of the DDS, and Snowflake2 VP (red dots) at a nominal 10 m VP spacing.

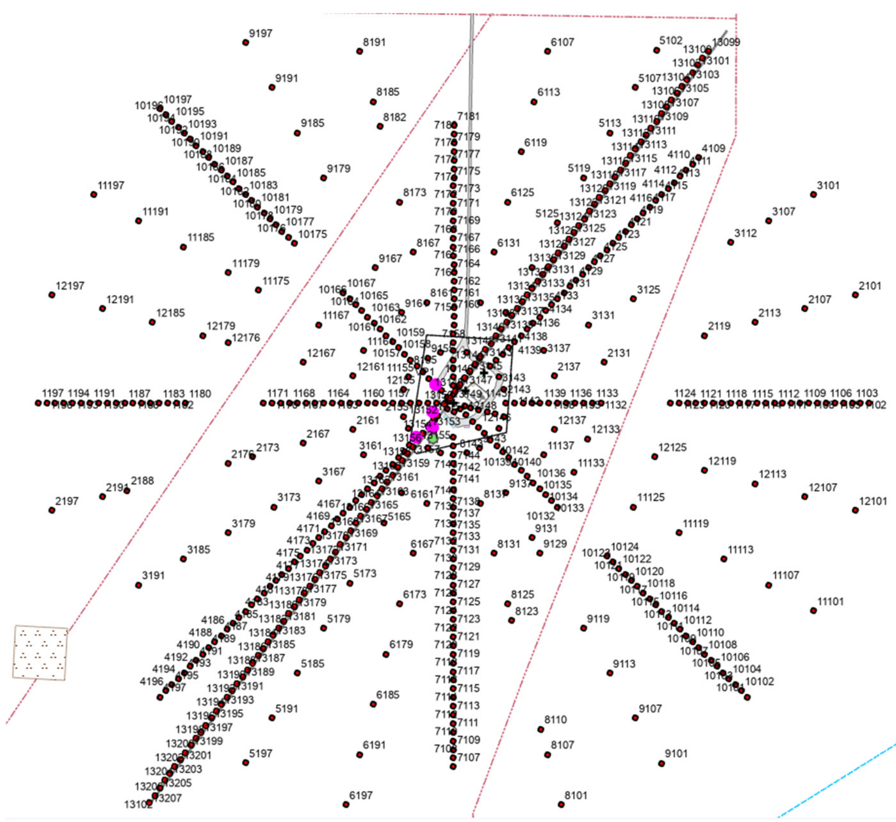


FIG. 2. Map showing the well lease with the DDS (Green), VP1-VP4 (magenta) that were acquired for initial testing of the DDS and Snowflake2 VP (red dots) at a nominal 10 m VP spacing.

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., 2019, 2020a, 2020b). 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 or two traces from each side of the DDS that are uncontaminated by gauge length effects. The 10x10 m DDS can be more reasonably considered to be a point receiver at greater offsets (max 550 m) than were previously recorded. 38 VP were identified where a line drawn between the VP and the center of the DDS is normal to two 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 (Figure 3) 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 4).

RESULTS

Matlab code for reducing the eight-component data from the DDS to a time-series of directional tensors (Hall et al. 2020, 2021a, 2021b) was converted to a Python script, purely to learn how to call Python from Schlumberger Vista. The results for VP 1101 (E-W source line of the Snowflake2 survey) are shown on the right side of Figure 4. Figure 5 shows receiver gathers for each directional tensor trace, where traces are sorted by the absolute value of the source-DDS offset. Subtle differences between components can be observed in the direct arrivals and ground-roll but are difficult to interpret at this scale.

The question now becomes how to effectively display the results for all VP. 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 6). Map co-ordinates have been arbitrarily rotated fifteen degrees counter-clockwise 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). Time-slices at 0.2 s and 0.5 s (yellow lines; Figure 5) are shown as quiver plots in Figure 6 and appear to show circular wavefronts centered on the DDS.

Animating Figure 6 sample by sample clearly shows circular wavefronts that appear to propagate from the DDS towards the sources (see the presentation for this report). This apparent directionality is purely because it takes less time for energy to reach the DDS from closer sources, and the manner in which we have chosen to plot the data.

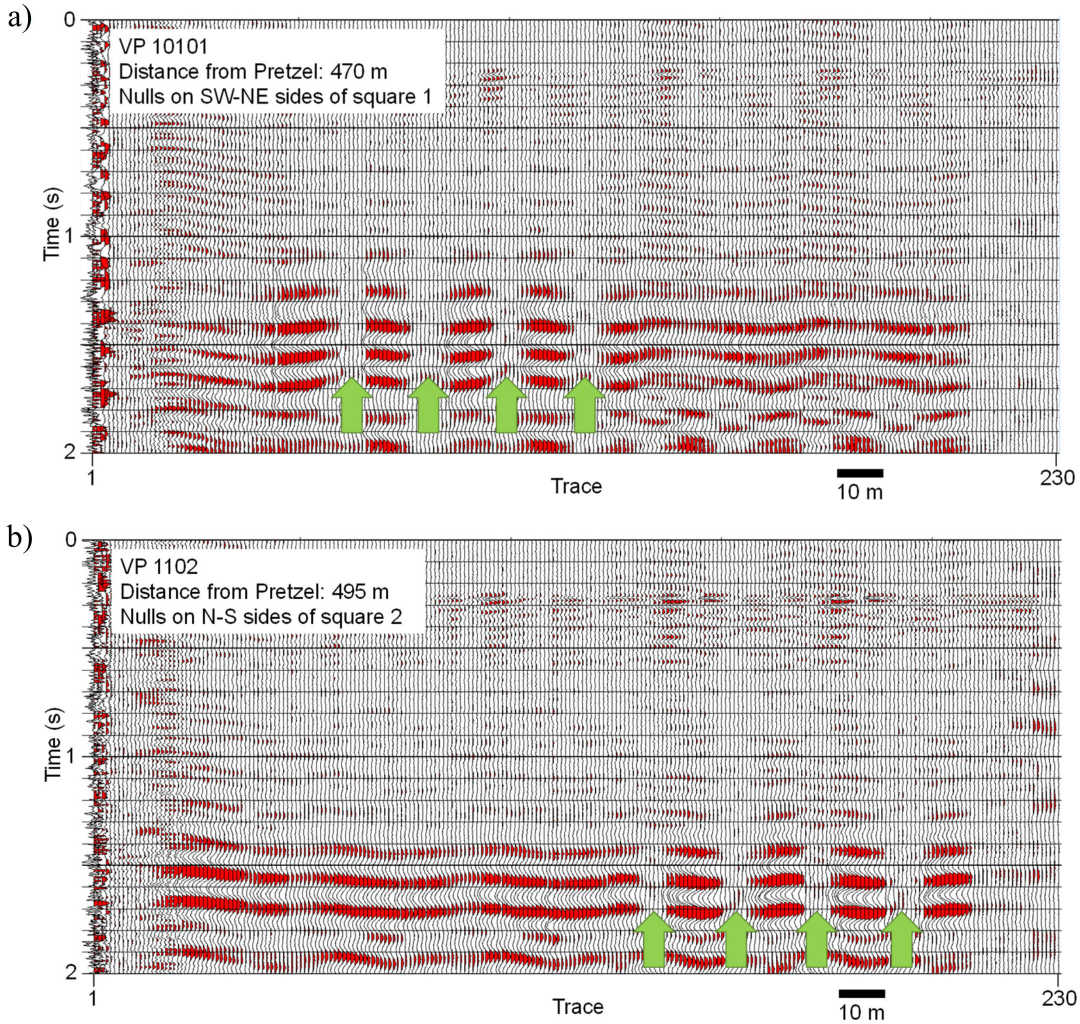


FIG. 3. Straight fiber data for VP 10101 (a) showing nulls for the two SW-NE sides of square 1 (green arrows, repeated twice) and VP 1102 (b) showing nulls for the two N-S sides of square 2.

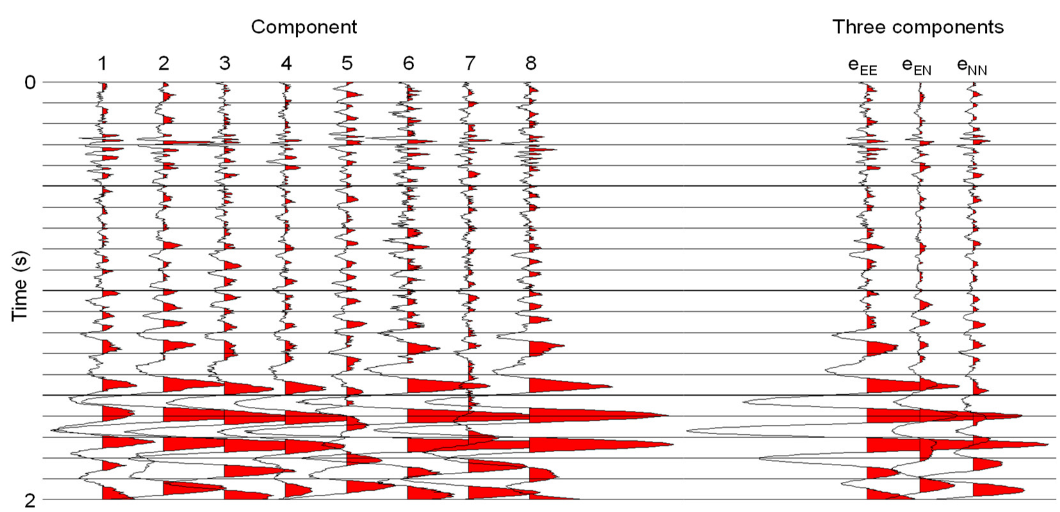


FIG. 4. VP 1101 example of reducing eight strain components to three directional components.

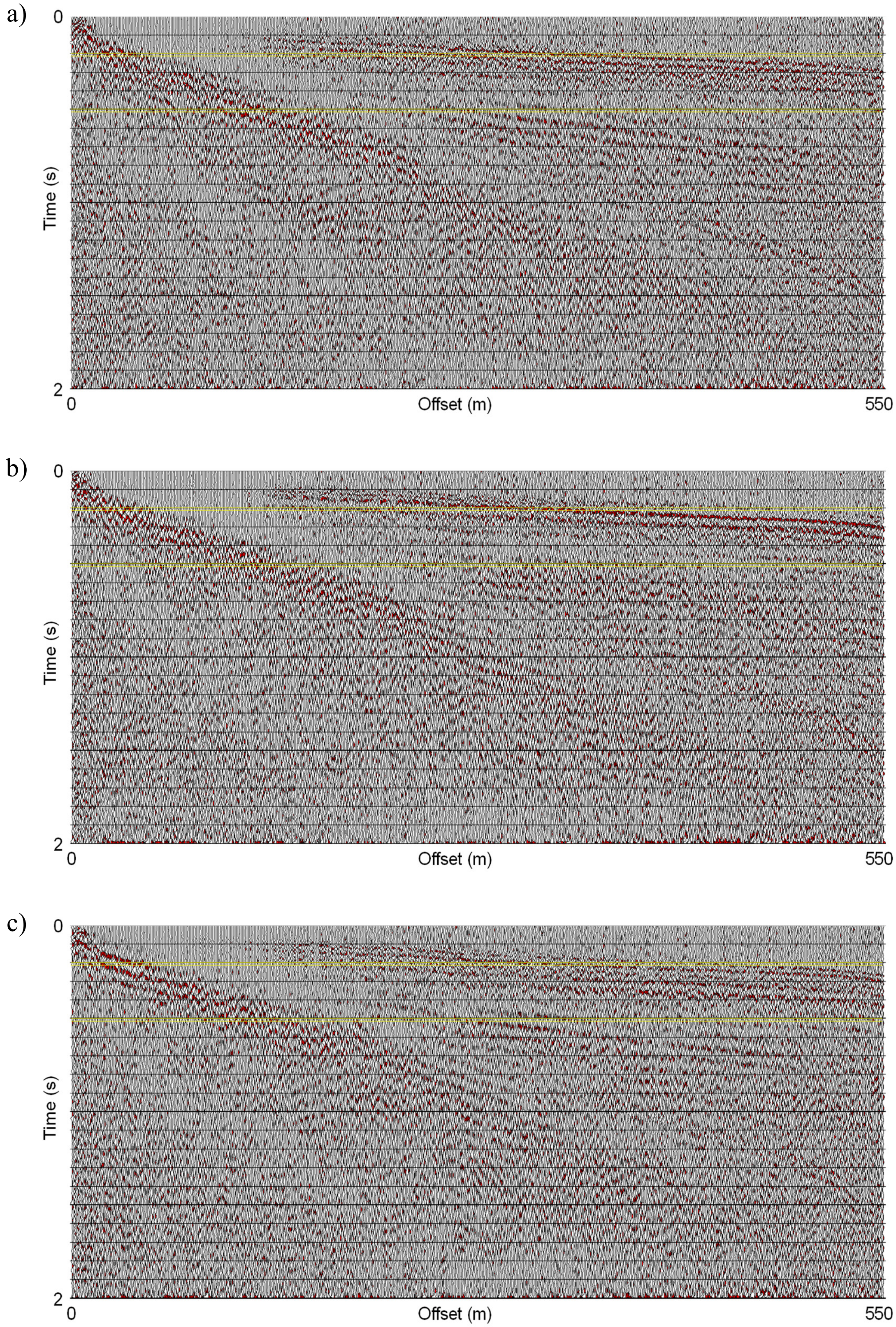
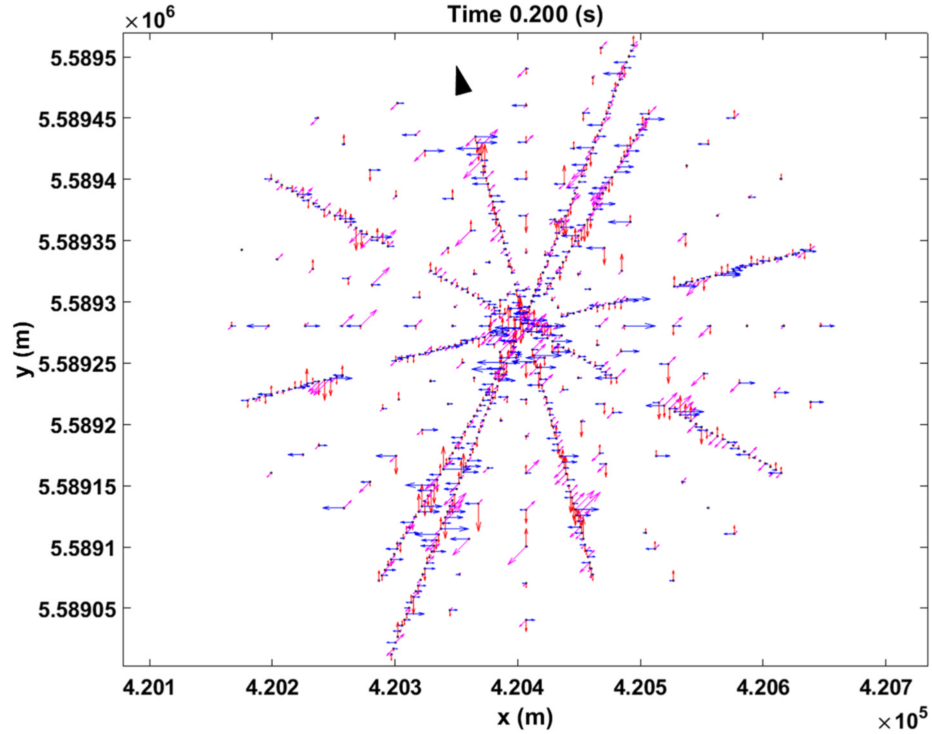


FIG. 5. Directional strain-rate receiver gathers sorted by the absolute value of source-DDS offset with AGC for display. The EE component (a), EN component (b), and NN component (c) show subtle differences at this scale. Yellow lines are shown as mapped time slices in Figure 6.

a)



b)

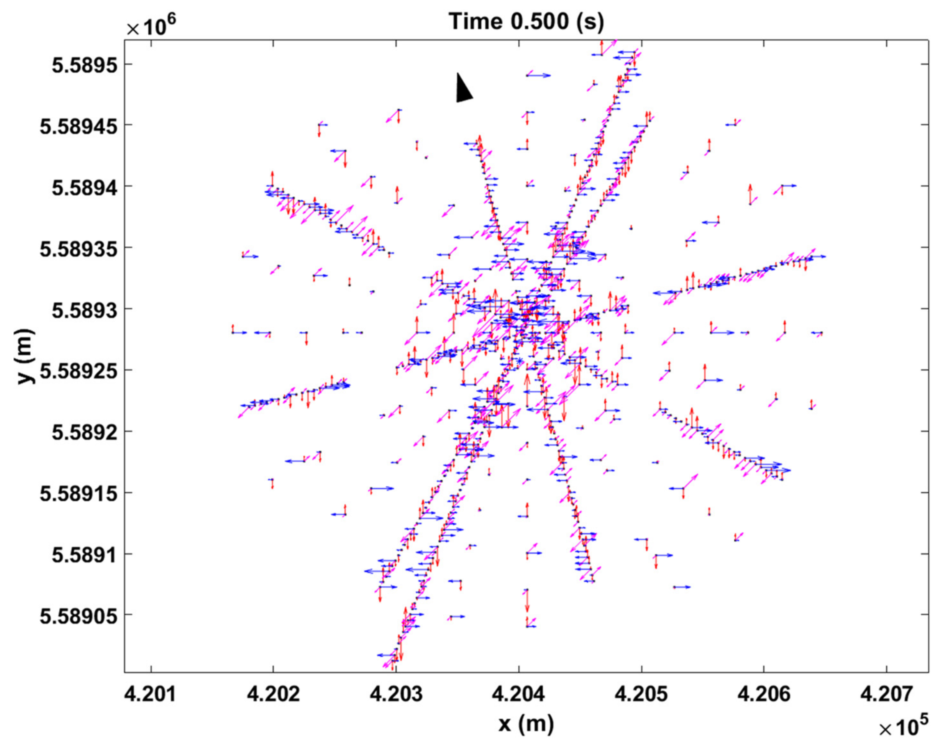


FIG. 6. Matlab quiver plot for time-slices at 0.2 s (a) and 0.5 s (b) of the directional strain traces highlighted by yellow lines in Figure 5. The base of the quivers are located at midpoint locations between each VP and the DDS. Map co-ordinates have been rotated 15 degrees counterclockwise around the DDS location for display.

DISCUSSION AND FUTURE WORK

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 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 the quivers are located at VP-DDS mid-point locations 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 (Hall and Innanen, This volume) that would be easier to bury for coupling, and could include a vertical component.

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