A comparative study of different DAS vendors data

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ABSTRACT

Distributed acoustic sensing is a technology with a high potential for seismic monitoring. Apart from the optical fibre, that is the sensing element and replaces the traditional geophone, the other part of this system is the interrogator that transforms the back-scattered light from the fibre into a digital seismic signal. The fibre is usually installed permanently but the interrogator is interchangeable, not only by newer and more sophisticated models, but by different vendors' models. We compare distributed acoustic sensing data obtained at the same locations, with the same sources and optical fibre, and almost at the same frame time, but generated by interrogators from three different vendors, at the Containment and Monitoring Institute Field Research Station in Alberta, Canada. We confront these datasets before and after conditioning, and also against vertically oriented geophone data. We found that after some data conditioning, all vendors agree in wave character at the early times, however, at later times there are delays in the events arrivals that depend on the trace depth.

INTRODUCTION

The Containment and Monitoring Field Research Station, CaMI-FRS, is a research facility located near Brooks in Alberta, Canada (Lawton et al., 2015). Figure 1 shows the location and satellite image of CaMI-FRS. It has a surface area close to 1 square km. At least 400 tons of CO_2 are being injected annually within a 5 years operation plan. Several monitoring technologies have been deployed there and are actively being tested (Lawton et al., 2017).

Among these technologies, there is a 5km loop of optical fibre that goes 1m depth through a 1km trench and down two 340m depth boreholes several times. This optical fibre is used as the sensing element of a Distributed Acoustic Sensing (DAS) system. The other part of the DAS system is the interrogator, that is interchangeable and is in charge to send light pulses through the fibre and transform any back-scattered light in a digital seismic signal. The back-scattered light changes due to the passage of a seismic wave and this change can be transformed by the interrogator into a digital signal proportional to the strain or strain rate sensed by the fibre (Hartog, 2018).

It is reported that interrogators have an internal interferometer with different path lengths in order to produce the interference pattern from the light backscattered from two fibre sections separated by a gauge length (Hartog, 2018). But apart from this, it is not publicly known what else is inside commercial interrogators or how they calculate the strain based in the interference pattern.

Some details can be found in different patents, but even in that case it is not sure that an interrogator device is based on a specific patent or has some non documented enhancements. All this can make the DAS response very dependent on the interrogator. For time lapse seismic applications this is a crucial factor because the signal can change in time due

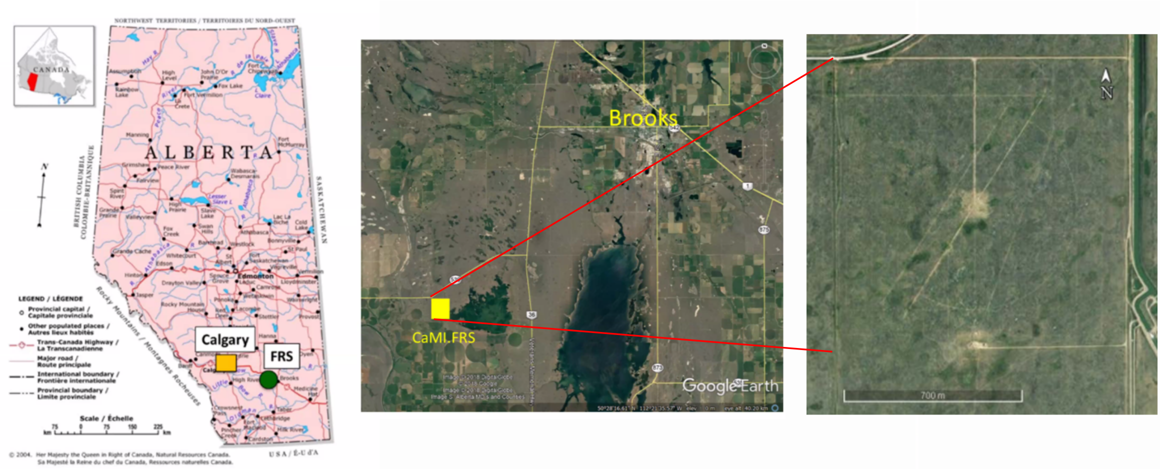

FIG. 1. Containment and Monitoring Institute Field Research Station (CaMI-FRS) location and satellite views. It is located in the South of Alberta, Canada (left part), near Brooks (middle). It has an area close to 1 square km with CO_2 injection facilities in the middle and monitoring technologies (right). From Natural Resources Canada and Google Maps.

to a change of interrogator, and not only due to the more important reservoir properties.

In this report we compare VSP data recorded by three different interrogators at CaMI-FRS. In order to make the comparisons significant, we used VSP gathers acquired with the same fibre. at the same place, with the same source and in most cases, in the same frame of time. We also compare the corresponding geophone data.

In the following section we describe the DAS data, then we do an initial exploration of this data. Next, we do some conditioning on the DAS data to mitigate of unwanted noise. Finally, we compare gathers and individual traces.

FIELD DATA

Description

The DAS data to compare comes from two vertical seismic profile (VSP) gathers at CaMI-FRS. We use DAS data from three different vendors and that means, different DAS interrogators, but the same DAS fibre infrastructure. Our aim is to compare DAS data from these three vendors acquired at the same location, in the same time frame and with the same source. We accomplished all of this with one exception.

Table 1 shows the two sets of gathers used in the comparison. The first set is composed of one geophone and two DAS vendors data. DAS vendors are going to be called *Vendor 1* and *Vendor 2* hereafter. This three gathers are from the same location, namely, shot point 130 from line 23, and were acquired in October of 2017. The source was the same, an Envirovibe with a linear sweep of 20 seconds from 10 to 150Hz. The geophones were oriented vertically.

Vendor	Line	Acquisition time	Shot Point
Geophone	23	October 2017	130
Vendor 1	23	October 2017	130
Vendor 2	23	October 2017	130
Geophone	21	October 2017	131
Vendor 1	21	October 2017	131
Vendor 3	21	February 2018	131

Table 1. List of vertical seismic profile (VSP) shot gathers used in the comparison. They are divided in two sets according to their similarity. The first set is from shot point 130 of line 21 acquired in October of 2017. There are geophone data and two DAS vendors data labelled *Vendor 1* and *Vendor 2*. The second set is from shot point 131 of line 23. Only the geophone and the DAS *Vendor 1* were acquired at the same time frame, October of 2017. The other gather, from the *Vendor 3*, in this set was taken in February of 2018. Note that *Vendor 1* in both sets refers to the same DAS provider. The sources were, in all cases, an Envirovibe with a linear sweep of 20s between 10 and 150Hz. Figure 2 shows the well and shot point locations.

The second set is also composed of three gathers, with one geophone and two DAS vendors data. The differences with respect to the first set are that the location is shot point 131 from line 21, that one of the DAS vendors is different, *Vendor 3* from now on, and that the VSP gather from this vendor was acquired in February of 2018. The source was the same used for the first set and the geophone were also oriented vertically. Note that the *Vendor 1* in both sets refers to the same DAS provider.

The spatial DAS sampling, separation between adjacent traces, is 0.25m for Vendor 1, 0.6667m for Vendor 2 and 1.0254m for Vendor 3. All DAS datasets go from the surface to an approximate depth of 345m. On the other hand, geophones are located from 191m to 306m every 5m. Four of the 24 geophone channels were muted because they only contained noise.

Figure 2 shows the VSP shot gather locations at CaMI-FRS. The geophysics well, where the optical fibre and geophones used to acquire all the data that appears in table 1 are installed, is close to the centre. Walkaway VSP lines 21, from North to South, and 23, from West to East, are also displayed on the left part of this figure. The right part is a magnification around the geophysics well. The two shot points used in the acquisition of the data mentioned in table 1 are also marked, shot point 130 on line 23 and shot point 131 on line 21. Distances from them to the well head position are less than 10m, making the datasets practically zero offset.

Initial exploration

Figure 3 shows the geophone and the two DAS vendors, 1 and 2, data from shot point 130 in line 23. As mentioned before, geophone data only goes from 191 to 306m depth. The three gathers have a t^2 amplitude recovery in depth for visualization purposes. It is very noticeable a checkerboard low frequency noise in the DAS datasets. Also, Vendor 2 gather have the opposite polarity of Vendor 1. From now on, the Vendor 2 gather will appear with the opposite polarity. It is also apparent the difference in character between geophone and DAS first arrivals.

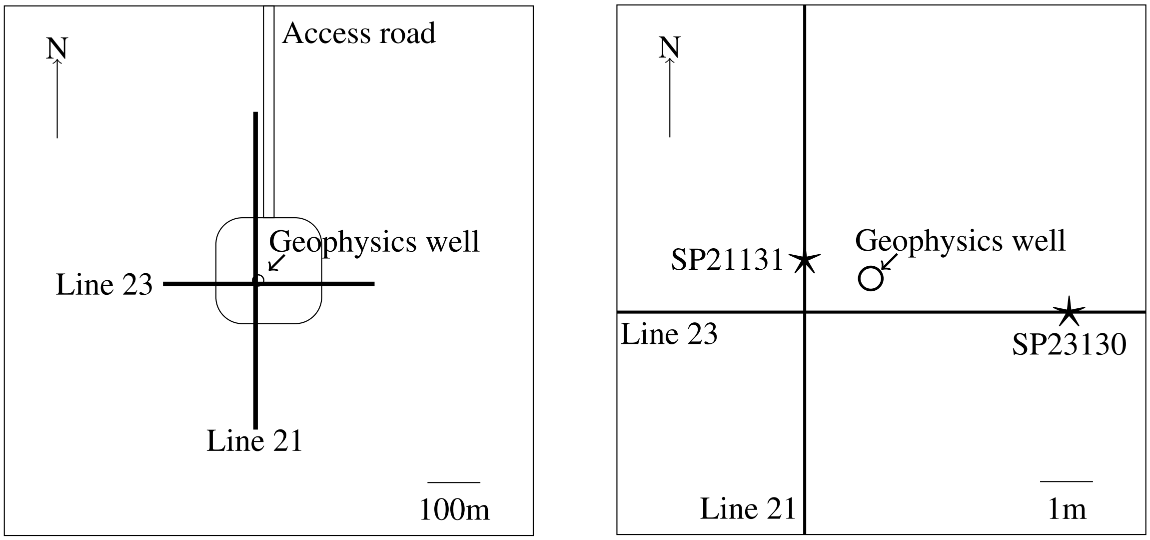

FIG. 2. Survey map showing the location of the walkaway VSP gathers used in the DAS comparison. The left part shows the geophysics well and the VSP walkaway lines 23 and 21 at CaMI-FRS. On the right, the map is magnified around the geophysics well showing the locations of shot point 131 on line 21 and shot point 130 on line 23.

Similarly, Figure 4 shows the geophone and the DAS Vendors 1 and 3 data from shot point 131 in line 21. They have the same t^2 amplitude recovery along the depth axis that was applied to the first set of gathers. A checkerboard low frequency noise is also pervasive in the DAS gathers. Something different is the frequency difference between the first arrivals of both DAS datasets, that makes downgoing events in the Vendor 3 gather look wider. The geophone first arrivals are also different in character.

Data conditioning

Our first concern is the checkerboard low frequency noise that contaminates the DAS datasets. In Figure 5 we explore the frequency spectra of the six shot gathers. Below 50Hz, three peaks are evident in most spectra. These frequency zones are possible locations of the checkerboard noise. Also, a zone with relative low amplitudes above 100Hz is apparent in some of the frequency spectra. The speckle noise that appears in the gathers of figures 3 and 4 can be located in this band.

Using Vendor 1 gather from shot point 130 of line 23 we test three possible low cuts to filter the checkerboard noise. The three peaks below 50Hz in some amplitude spectra of Figure 5 suggest testing low cuts at 20, 35 and 50Hz. The filtering is done using a Butterworth filter with 6 poles (Claerbout, 1992).

Figure 6 shows the filtering tests results. As before, a t^2 gain was applied in depth. The checkerboard noise is still present when 20Hz and 30HZ low cut filters were used, while the 50Hz low cut filter removed this noise.

The results of applying the 50Hz low cut filter to the first set of gathers appear in Figure 7. The checkerboard low frequency noise was suppressed. We also applied this filter to the

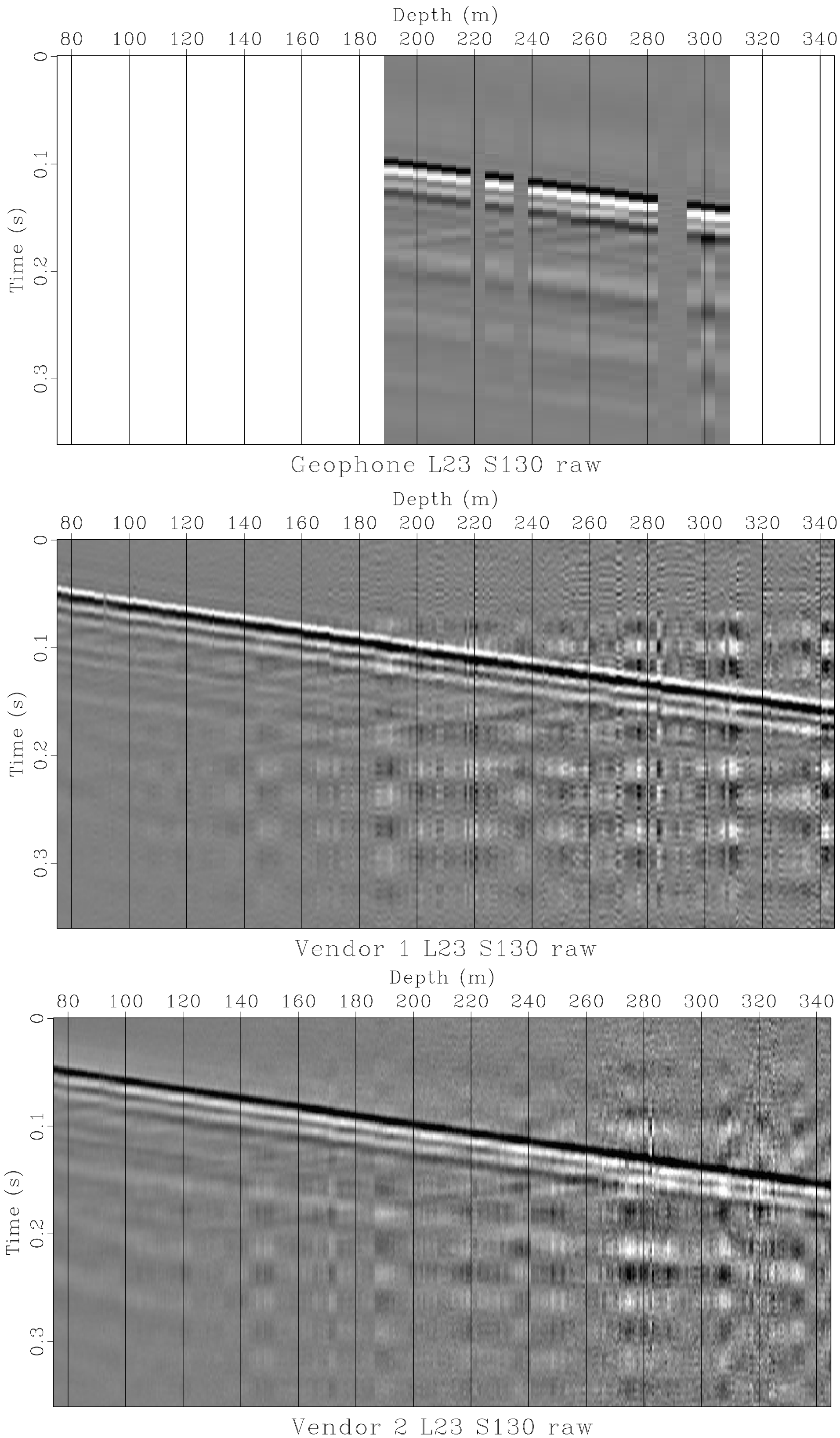

FIG. 3. Line 23 shot point 130 raw data from geophone, at the top, DAS Vendor 1, at the middle and DAS Vendor 2 at the bottom. The datasets contain only a t^2 amplitude correction along the depth axis. Notice that data from Vendor 2 has the opposite polarity of the other two datasets. Also notice the checkerboard low frequency noise in the DAS gathers, and the different character of the geophone first arrivals with respect to the DAS ones.

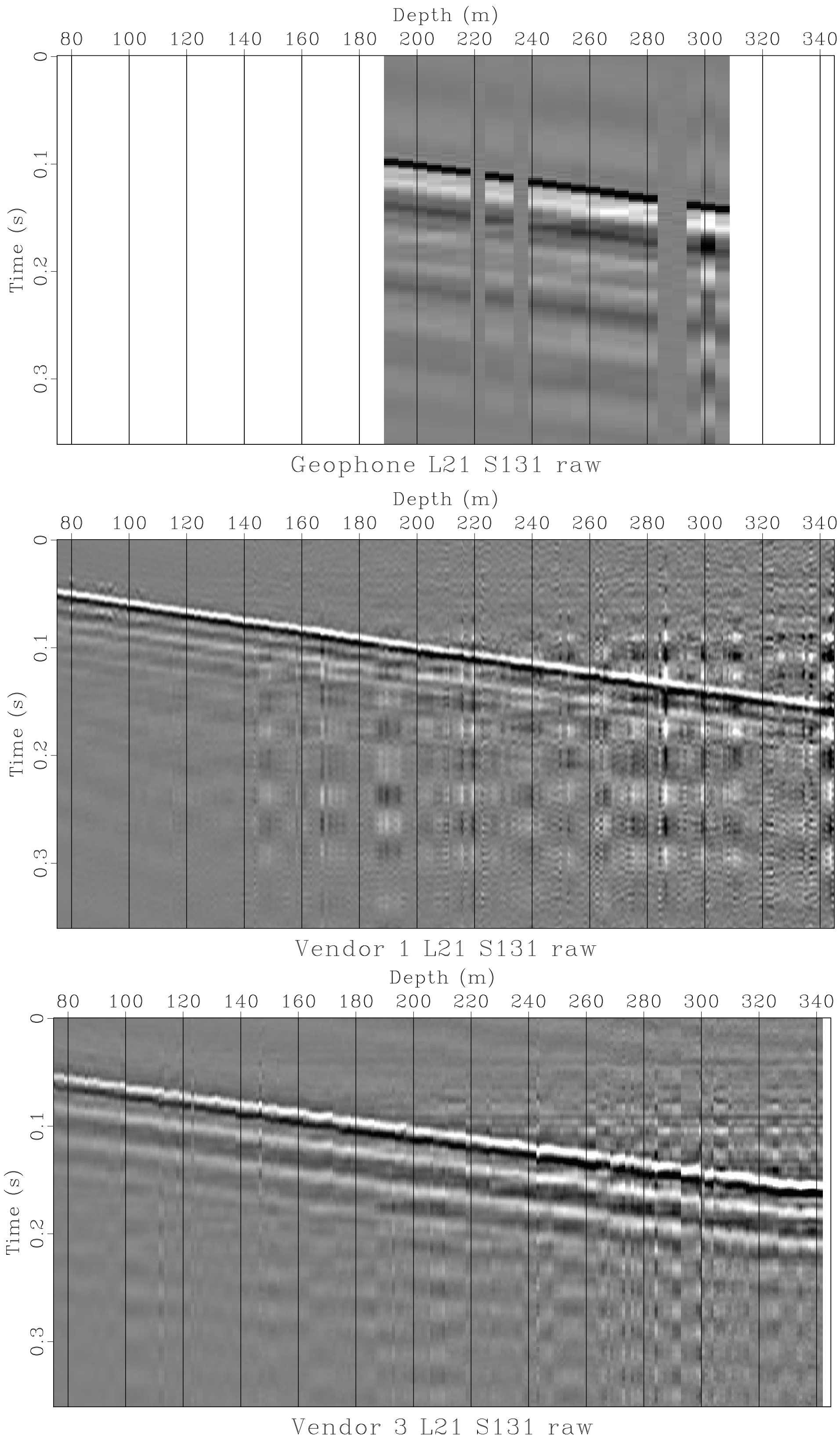

FIG. 4. Line 21 shot point 131 raw data from geophone, on the top, DAS Vendor 1, on the middle, and DAS Vendor 3 on the bottom. The datasets contain a t^2 amplitude correction along the depth axis. Notice that data from Vendor 3 has different first arrivals shape that data from Vendor 1. Also notice the checkerboard low frequency noise in the DAS gathers, and the very different character of the geophone first arrivals with respect to the DAS ones.

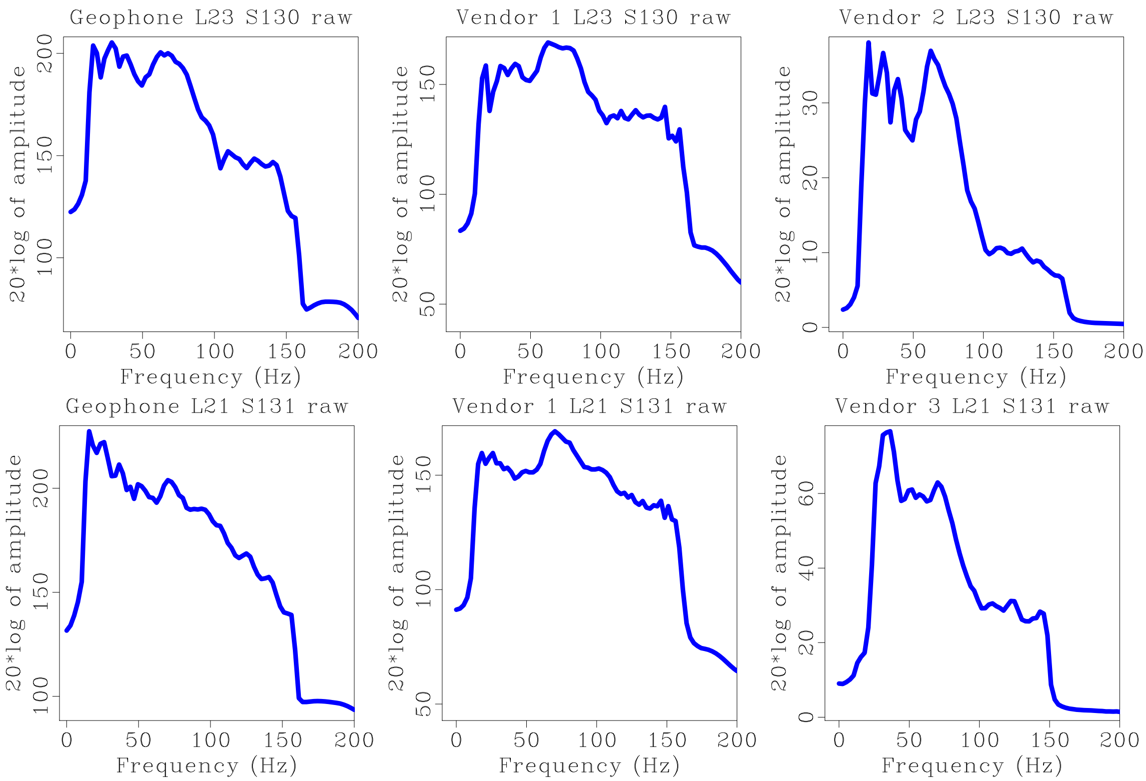

FIG. 5. Average frequency spectra of the gathers appearing in figures 3, at the top, and 4, at the bottom. They have a low frequency part below 50Hz and a high frequency part above 100Hz that could be contaminating the gathers.

geophone gather and as a result the character of the downgoing and upgoing events look more similar to the corresponding events in the DAS gathers.

The equivalent result for the second set of gathers is in Figure 8. As a result of the 50Hz low cut filter, the checkerboard low frequency noise was suppressed. One additional effect is that the low frequency character of the Vendor 3 data resembles more the character of the Vendor 1 gather. As with the other dataset, we also applied this filter to the geophone data and obtained a gather were the downgoing and upgoing events look more like the corresponding events in the DAS datasets.

The spectra of all shot gathers after the 50Hz low cut and 100Hz high cut filters appear in Figure 9. It is noticeable the resemblance between the Vendor 1 gathers and its corresponding geophone gather. Also, the spectra of vendors 2 and 3 look similar.

Individual traces comparison

Now we are going to overlay geophone and DAS traces to observe their differences in detail. We choose the traces at 191m depth, where the shallower geophone is located. The DAS depths were calibrated by calculating the maximum local cross-correlation with the pilot geophone trace.

Figure 10 shows the overlaid normalized traces of the two sets of gathers. In the case

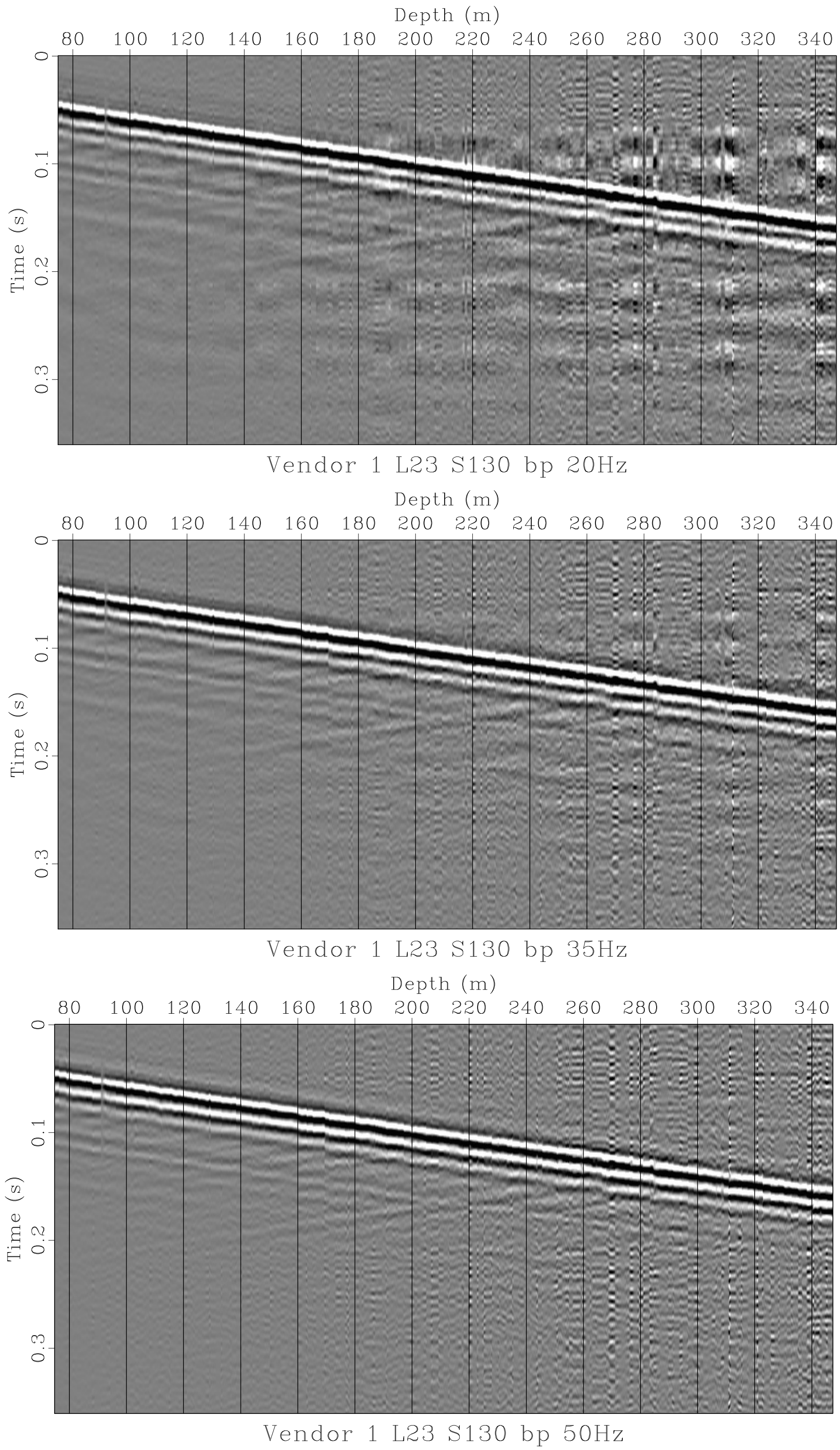

FIG. 6. Low pass filter tests on DAS gather from Vendor 1. At the top the low cut frequency is 20Hz, at the middle is 35Hz and at the bottom is 50Hz. As in the previous figures a t^2 gain was applied along the depth axis. The checkerboard noise disappears when low pass filtered with low cut frequency of 50Hz.

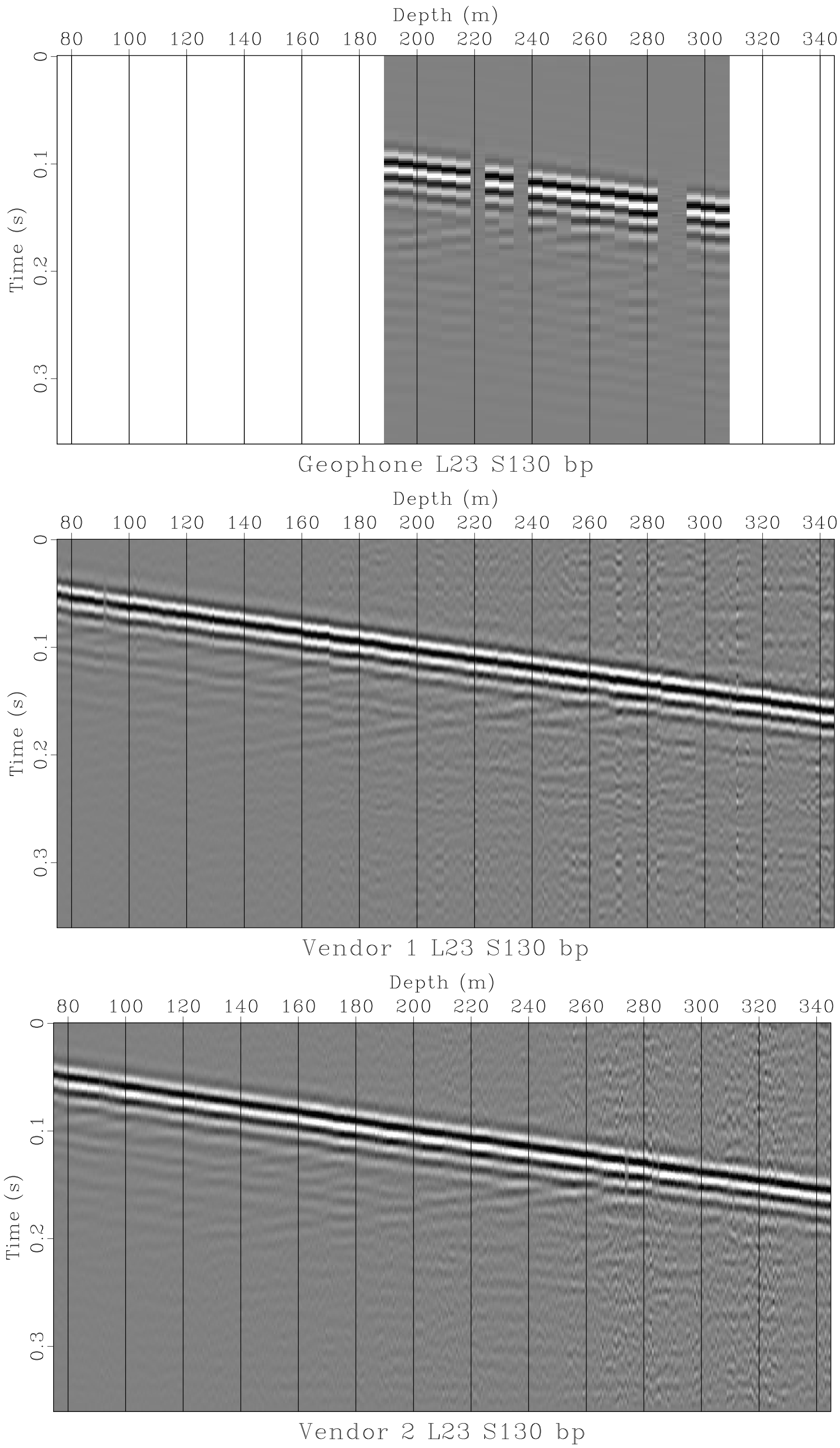

FIG. 7. Shot gathers from shot point 130 at line 23 with a 50Hz low cut filter applied. The checkerboard low frequency noise was suppressed. Also, the character of the first arrivals in the geophone data became more similar to the corresponding event in the DAS datasets. A 100Hz high cut filter was also applied to remove the speckle noise.

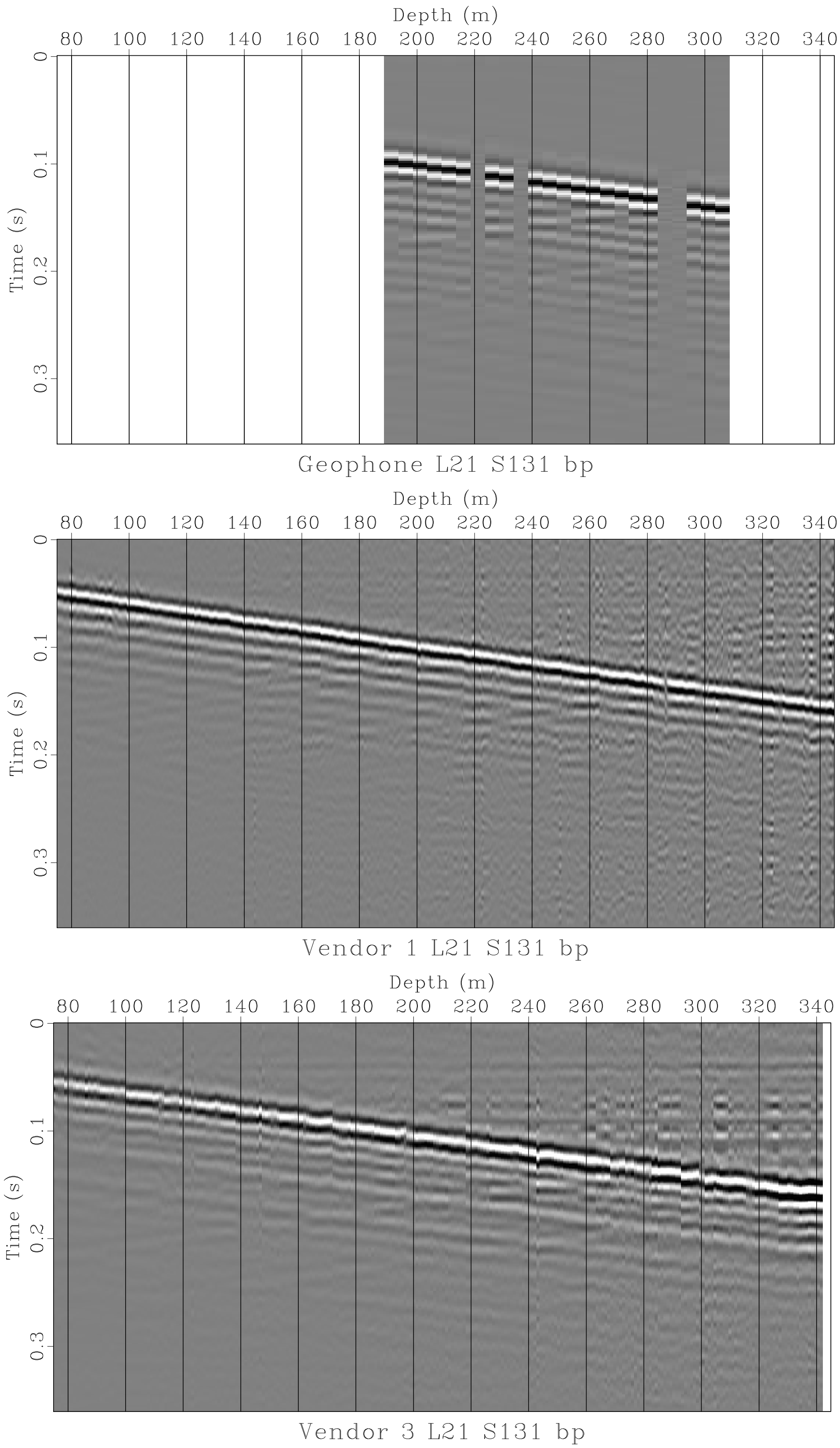

FIG. 8. Shot gathers from shot point 131 at line 21 after a 50Hz low cut filter was applied. The checkerboard noise is suppressed as a result. Also, the low frequency character noticed before in the Vendor 3 data changed to one more similar to the Vendor 1 gather. In addition, the first arrival event in the geophone gather looks closer to the corresponding event in the DAS gathers. Additionally, a 100Hz high cut filter was applied to decrease the speckle noise in the three gathers.

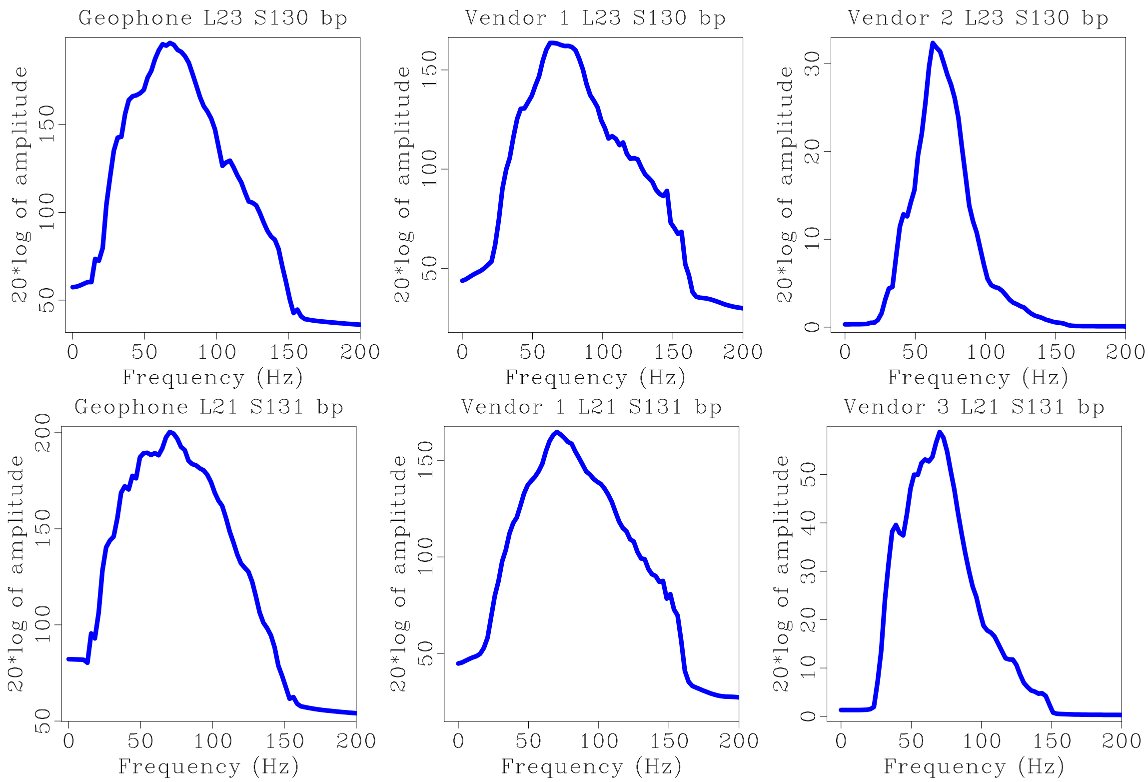

FIG. 9. Frequency spectra after the 50Hz low cut and the 100Hz high cut filtering. Vendor 1 spectrum resemble more its corresponding geophone spectrum than Vendors 2 and 3 spectra.

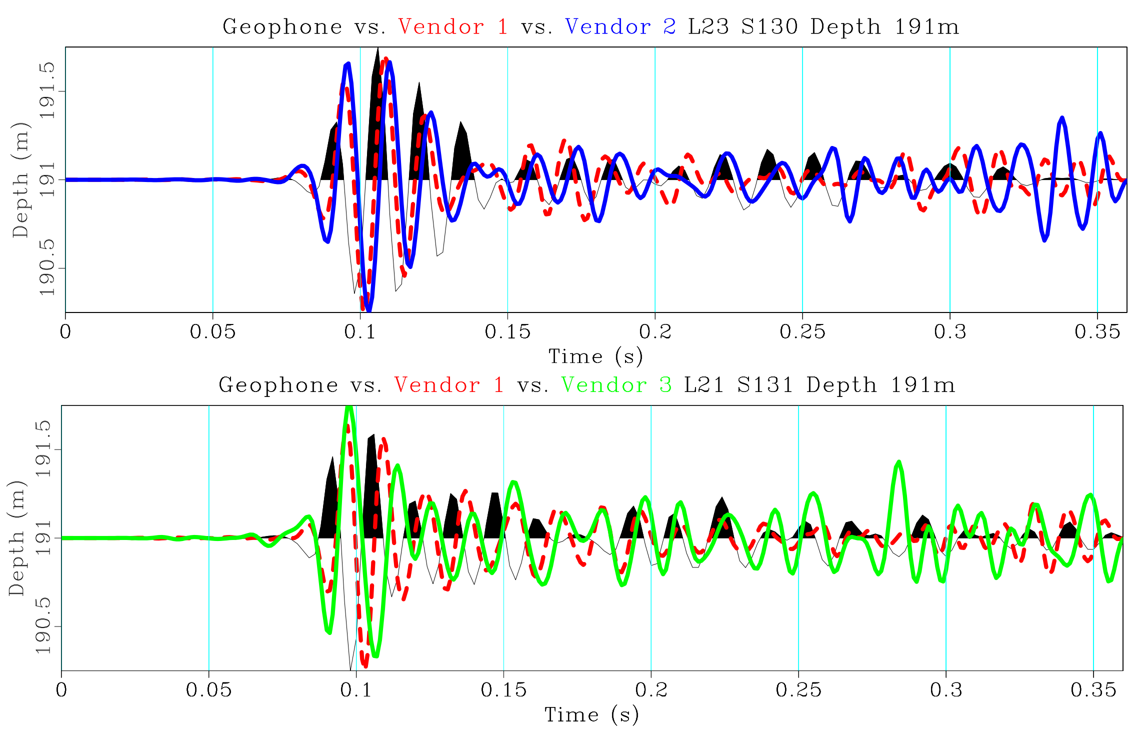

FIG. 10. Traces at 191m depth from geophone and DAS data. On the top, the shot point is the 130 from line 23 and the DAS vendors are 1 and 2. On the bottom, the shot point is the 131 from line 21 and the DAS vendors are 1 and 3.

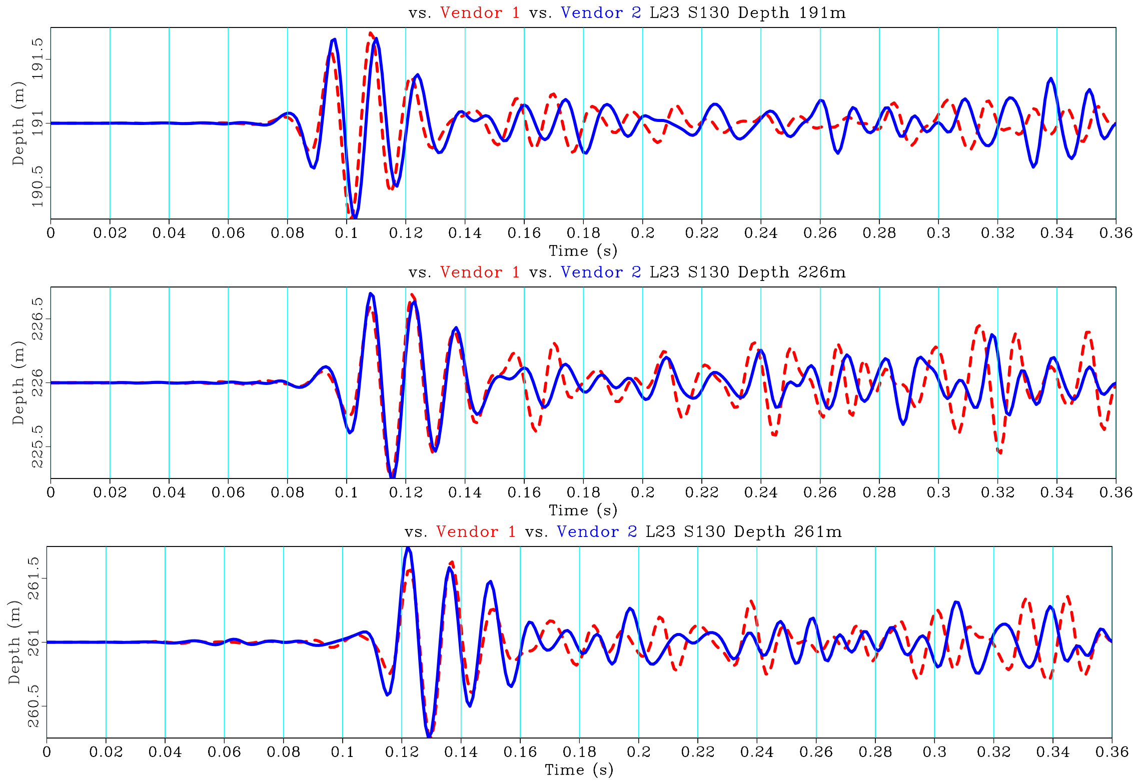

FIG. 11. Traces from vendors 1 and 2 at three different depths: 191m, 226m and 261m. All of them have a good match in the first arrival event. However, on top, Vendor 2 lags behind Vendor 1 while this situation is the opposite on the bottom.

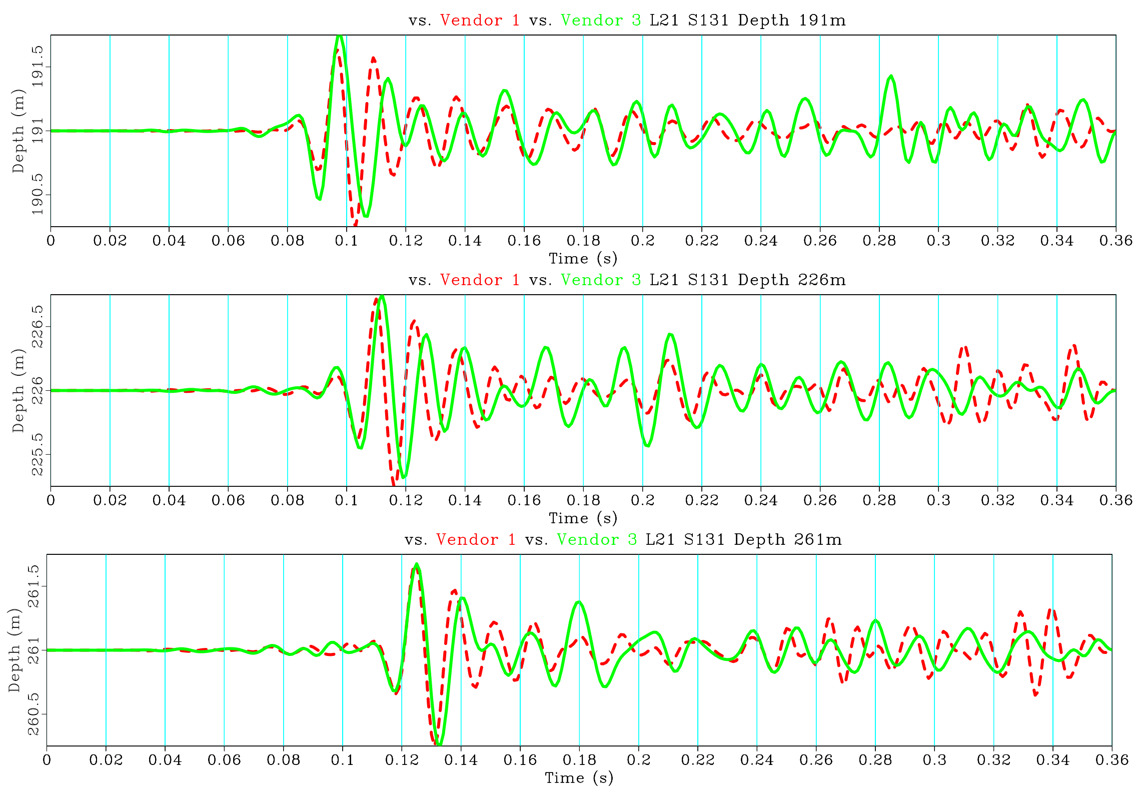

FIG. 12. Traces from vendors 1 and 3 at three different depths: 191m, 226m and 261m. In all of them Vendor 3 lags behind Vendor 1, however it synchronizes with Vendor 1 trace faster at 191m and 261m than at 226m.

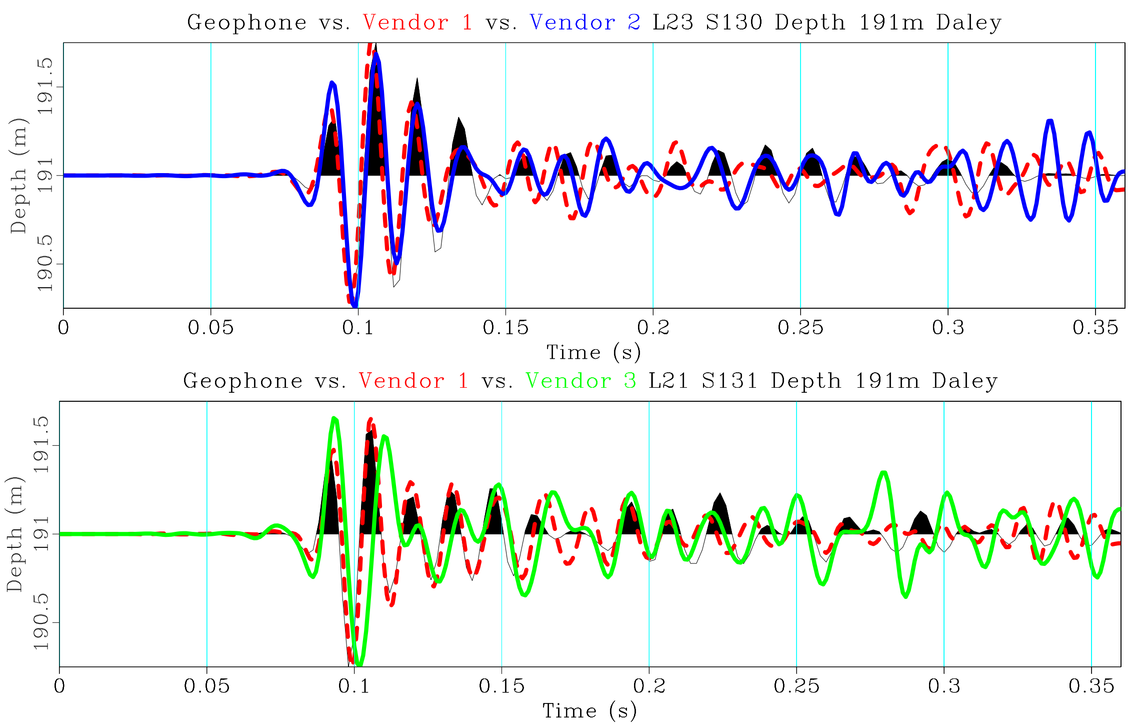

FIG. 13. Traces at 191m depth from geophone and DAS data. The Daley transform has been applied to all DAS traces (Daley et al., 2016) to make them more similar to the geophone trace.

of the first set, there is a small phase difference between Vendor 1 and Vendor 2 traces at the first arrivals. Then, the phase difference starts to increase with time. At the end, both traces are totally out of phase. With respect to the relative amplitudes they mostly agree in the first half, but towards the end, the amplitudes of the Vendor 2 trace are noticeable higher than the Vendor 1 trace.

In the case of the second set, both DAS traces start at the same time but then they go out of phase and return to be in phase three times. When they are out of phase it seems to be a small lag. The relative amplitudes coincide in the first arrival events, but is different for some events towards the end of the traces.

Figures 11 and 12 show the traces from all vendors at three different depths, 191m, 226m and 261m. On Figure 11 all the traces coincide at the first arrival event, however, the trace from Vendor 2 lags behind the trace from Vendor 1 at 191m as mentioned before. This delay is smaller at 226m, while it is the opposite, i.e., the trace from Vendor 1 lags behind the trace from Vendor 2, at 261m depth. On Figure 12 the trace from Vendor 3 always lags behind the one from Vendor 1. However, at 191m and 261m both traces synchronize after a few cycles, while at 226m they do not synchronize.

In the last comparison we applied the Daley transform to make the DAS traces more similar to the geophone trace (Daley et al., 2016). Figure 13 show the overlay traces after the Daley transform has been applied. Traces from Vendors 1 and 2 follow very close the geophone trace at the beginning, but the trace from Vendor 2 seems to follow it during more time. Trace from Vendor 3 is close to the geophone trace but lags intermittently.

DISCUSSION

Our original plan was to compare the three vendors at the same time, however, due to the lack of data from one of them, Vendor 3, in the same frame of time, we decided to split the gathers in two sets, and transitively compare Vendor 2 with Vendor 3 through Vendor 1. The effects related to the differences in timing are hard to separate from those related to different interrogator devices.

The checkerboard low frequency noise that was pervasive in the DAS gathers could have been produced by the surface operations at the CaMI-FRS injection facilities. Their filtering by eliminating frequencies below 50Hz could have been damaging for the seismic events in this band. However, we were able to make the gathers from the geophone and Vendor 3 look more like the others.

Although all traces are synchronized at the first arrival event and even share the same wavelet shape at early times, they soon begin to lag behind each other. We used cross-correlation, as mentioned before, to find the traces that match at 191m. Then, we paired traces at other depths according to the trace separation. The differences in delays between traces with depth could be related to a wrong separation between traces. This is possible when the interrogator is using the wrong fibre parameters.

It is not sure that the reverse polarity of the traces from Vendor 2 is a feature of this interrogator device or only a common mistake in the field connections, like sometimes happens in geophone surveys.

CONCLUSIONS

The three vendors DAS data showed a checkerboard low frequency noise, maybe related to the surface operations at CaMI-FRS. The filtering applied to the DAS gathers to mitigate this noise was also applied to the geophone gathers and the result was an increase in the similarity between the two types of data.

After applying a basic data conditioning, the three vendors DAS data showed similarities in the early times, but differences in phase at later times.

The phases differences vary slowly from trace to trace. This could be a registration issue related to the separation between traces.

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