Results from a 3D field trial with a seismic acquisition and processing method based on continuous wavefields

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Summary

This paper describes the acquisition setup and results from a field trial conducted with a novel marine seismic acquisition and processing methodology that utilizes continuous wavefields. Compared to a conventional survey previously acquired in the same location, both the peak sound pressure and sound exposure levels were reduced significantly. The lateral sampling was improved and trace density increased without loss of acquisition efficiency. The imaging results of the field trial data show deep penetration equivalent to the conventional data despite the significantly lowered source output.

Introduction

In summer 2018, PGS acquired a small 3D data set offshore Brazil with a novel seismic acquisition and processing method that makes use of continuous wavefields on the source and receiver side (Hegna et al., 2018a). The survey had a size of about 25 km length and 5 km width. The data was acquired on top of a previous survey with a conventional dual-source setup such that a comparison can be made. The survey location is shown in Figure 1.

The continuous wavefields method treats both the recorded wavefield on the receiver side and the emitted wavefield on the source side as continuous wavefields. Seismic data recorded continuously for typically the length of a sail line is treated at once over the full time length. On the source side, the emitted wavefield is also treated in a continuous fashion. The method and its potential benefits have been described in Hegna et al. (2018b) and Klüver et al. (2018b).

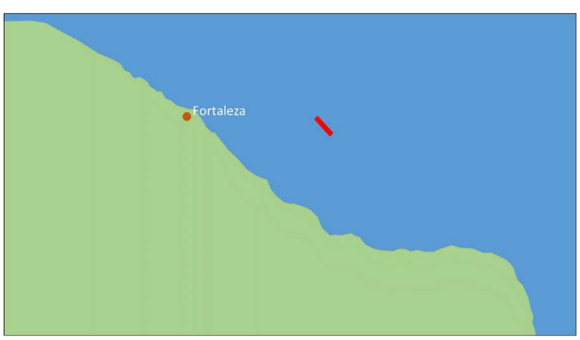

Figure 1: Location of the field test in the northern part of Brazil offshore Fortaleza.

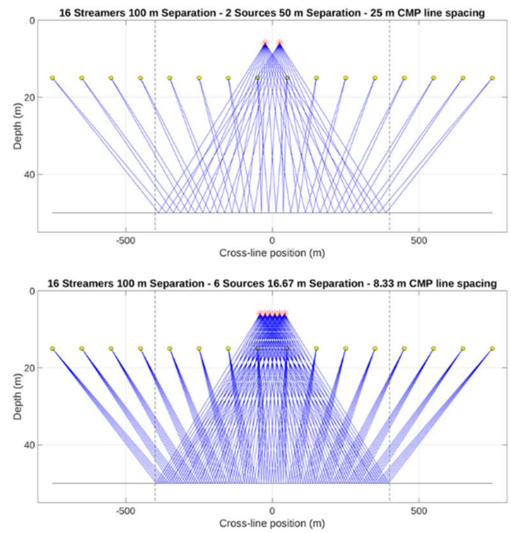

Figure 2: Source and streamer configurations for the conventional dual-source survey (top) and the field test (bottom).

In this paper, we describe the field trial setup, describe acquisition efficiency gains and sampling improvements, and show processing results obtained so far.

Acquisition geometry and efficiency

The field test was acquired with the same spread of 16 streamers spaced 100 m apart as the conventional survey. Six strings of air-guns were deployed 16.67 m apart in a central cross-line position in front of the streamer spread. Each string was equipped with six air-guns of three different volumes which are actuated in a sequence to generate a continuous source wavefield which approaches the properties of band-limited white noise (Klüver et al., 2018a). In the conventional survey two 4130 cu. in. source arrays were operated in flip-flop mode with 25 m shot point interval (50 m per source).

The continuous wavefields method generated a common receiver gather in each crossline position of the six strings of air-guns for each inline position, resulting in a hexa-source setup. This gives 96 CMP lines per sail line with a nominal crossline bin size of 8.33 m compared to 32 CMP lines spaced 25 m apart with the conventional setup. The continuous source wavefield can output band-limited point sources anywhere along the source trajectories. With 12.5 m spacing between the band limited point sources along the source trajectories for all six strings with air-guns, this

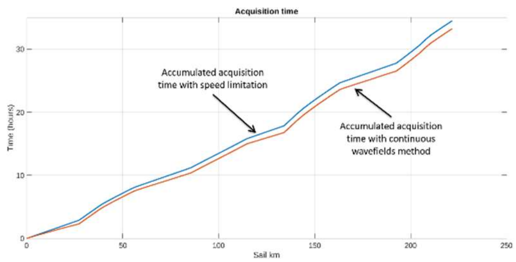

Figure 3: Accumulated acquisition time with speed limitation (blue) and with the continuopus wavefields method (red).

results in twelve times more data than in the comparison data set and yields improved lateral sampling both inline and cross-line. The increased trace density and improved lateral sampling is achieved without loss of acquisition efficiency. The acquisition setups are summarized in Figure 2.

The data was acquired in a region with strong currents. In a conventional survey, the seismic vessel is sometimes forced to slow down to enable a sufficiently long listening time between consecutive activations of the source arrays. There is no listening time required in the continuous wavefields method as the source is continuously emitting energy. Consequently, the seismic vessel does not need to slow down which yields an efficiency gain. Figure 3 shows the accumulated acquisition time from the test survey in comparison to the equivalent curve if the vessel had to slow down to enable 10 s listening time. The survey would have taken ~7% more time to acquire with such a vessel speed limitation.

The continuous source wavefield is generated by densely triggering individual air-guns with randomized time intervals. The source energy is spread out in time which leads to a significant reduction in peak sound pressure levels

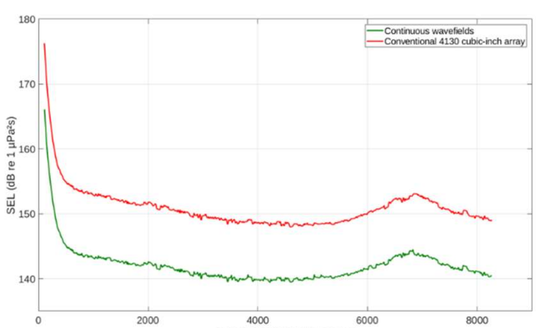

Figure 4: The SEL (integrated over 10.5 s) with the continuous wavefields method (gree) is about 8-9 dB below the SEL for the conventional dual-source survey with 4130 cu. in. source arrays (red).

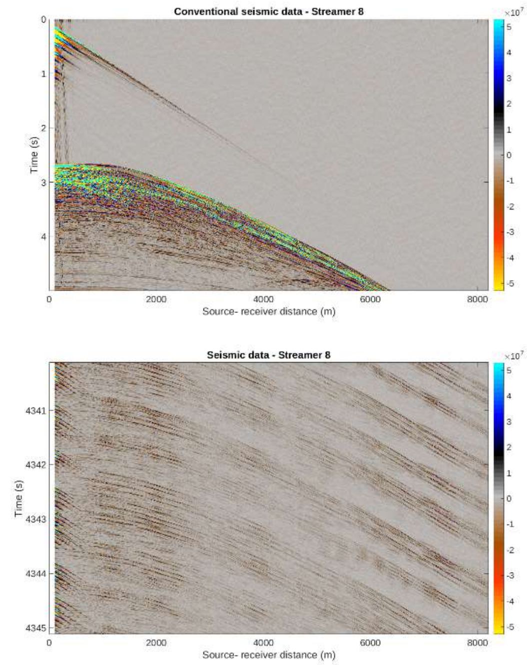

Figure 5: A shot record from the conventional survey (top) and a portion of the continuous record from the field test data. Both data are approximately in the same location.

(SPL). Compared to the conventional reference survey, where two 4130 cu. in. air-gun arrays were operated, the peak SPL was lowered by 20-22 dB (evident in the reduced amplitudes of Figure 5). The sound exposure level (SEL) was also reduced. When integrating over 10.5 s, a reduction of 8-9 dB has been achieved, as plotted in Figure 4.

Processing results

The pre-stack data recorded with the continuous wavefields method looks very different compared to the data from the conventional survey. Figure 5 illustrates the difference showing a five second portion of a continuous record acquired by triggering individual air-guns with short randomized time intervals and a five second portion of a shot record from the conventional survey using 4130 cu. in. source arrays. Both data are displayed with the same color range covering -5e^7 to 5e^7 micro-Pascal.

The processing methodology for the continuous wavefields method has been detailed in Hegna et al. (2018a) and Klüver et al. (2018b). It consists of a correction for analogue filtering effects, noise attenuation, receiver motion correction placing every recorded sample into the position along the line where it had been recorded with stationary receivers, and receiver side wavefield separation. The last step specific to the method is the deconvolution of the source wavefield including source side deghosting. In the source deconvolution, each receiver trace is converted into receiver gathers containing the response of the earth. A stationary receiver trace is as long as it takes to move the seismic streamer over a stationary receiver position; typically about 3500 s long for an 8000 m long streamer. A receiver gather can be generated in each crossline position where a source element has been. The spacing of the common receiver traces along the line was chosen to be 12.5 m. For each of the six source lines in a sail line, this results in one receiver gather every 12.5 along the source trajectories. The receiver gathers have been generated with 12.5 m trace spacing, and fully anti-aliased protected. The record length is no longer an acquisition parameter but can be chosen freely in processing. It was set to 15 s.

The data from the conventional dual-source survey has gone through a standard processing sequence including noise attenuation, receiver-side wavefield separation (Carlson et al., 2007), source-side deghosting, and de-signature with source array directivity compensation. In contrast to the continuous wavefields method, the source-side deghosting was performed in shot records due to coarse sampling of source positions leading to spatial aliasing in common receiver gathers. The record length was 10 s.

The improved sampling in the inline direction is demonstrated in Figure 6. The trace spacing in a common offset section from the conventional data along the trajectory of one of the two sources is 50 m. That is a factor four coarser than the inline sampling of 12.5 m achieved with the continuous wavefields method.

Before imaging, both data sets were regularized. The same spatial coverage as present in the test survey data was selected from the data of the large conventional survey. The conventional data was regularized to a 12.5 m x 12.5 m grid in 100 m offset classes. The data acquired using continuous wavefields was regularized to an 8.33 m x 8.33 m grid with 12.5 m interval between offset bins. Each offset bin contains data from only one specific offset due to the dense sampling of the band-limited point sources in the inline direction. The regularization of the test data was followed by a radial wavenumber filter to limit the wavenumber content to the spatial Nyquist wavenumber for 12.5 m trace spacing.

Both data sets were finally migrated to a 12.5 m x 12.5 m output grid using Kirchhoff pre-stack time migration. There are naturally four times as many offset planes to migrate in the test data compared to the conventional comparison data; due to the 12.5 m spacing between the band-limited point sources with the continuous wavefields method compared to the 50 m shot spacing per source in the comparison data set.

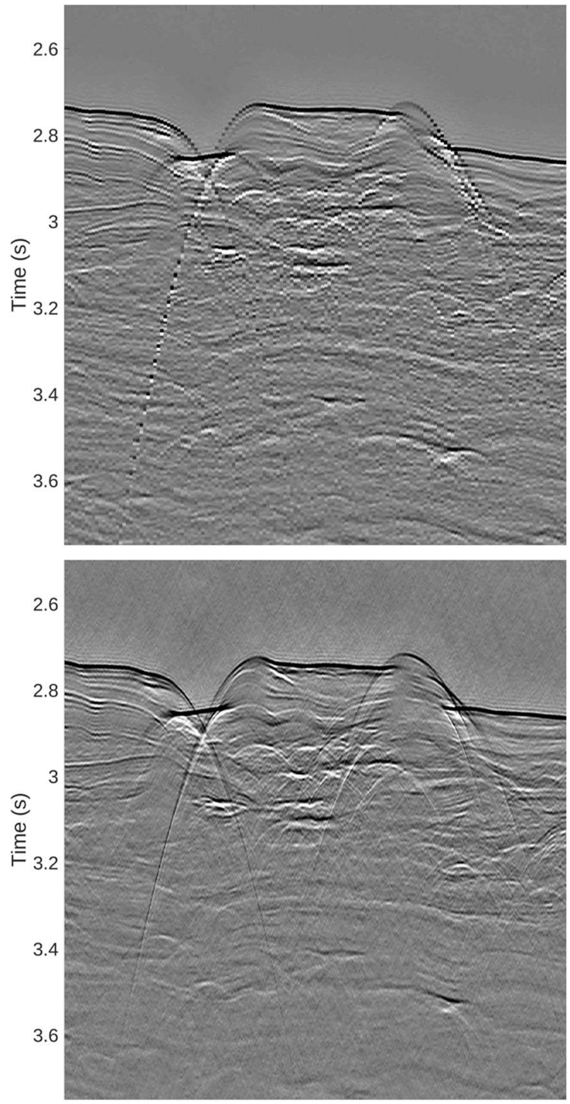

Figure 6: A common offset section for a single source line from the conventional data (top) with 50 m trace spacing, and from the continuous wavefields method (bottom) with 12.5 m trace spacing.

Figures 7 and 8 show a central inline section of the migrated cubes from both data sets. Both results show high resolution in the shallow part. Despite the fact that a lot less energy is emitted by the continuous source wavefield, equivalent penetration is observed in both images. The imaging result for the continuous data set contains more low frequency energy, which is explained by differences in the pre-processing sequences. No attempt has been made to match the two data sets.

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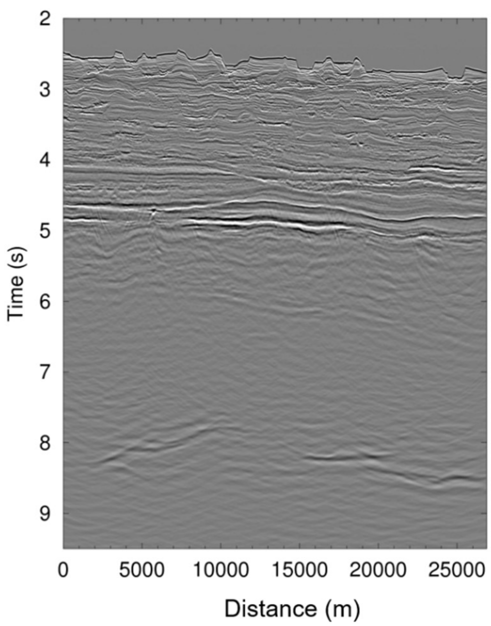

Figure 7: A central inline section of the migrated volume of the data from the conventional dual-source data.

There has been no multiple attenuation applied in the processing sequence of both data sets. Figure 9 illustrates the benefit of dense inline sampling achieved with the continuous wavefield method. The frequency wavenumber spectra are taken in a window over the first water-bottom multiple in the migrated sections shown in Figures 7 and 8 before any post-migration filtering. The dense sampling of CMP gathers in the field test data leads to destructive interference of the multiple energy when stacking the migrated offset classes. The multiple energy is spatially aliased in the conventional data and therefore does not sum destructively.

Conclusions

A successful 3D field test in offshore Brazil has been conducted using a novel marine seismic acquisition and processing methodology that uses continuous wavefields. The method allows a significant reduction in peak sound pressure and sound exposure levels without degrading deep penetration in the migrated images. The lateral sampling of the acquired data can be improved and trace density increased without loss of acquisition efficiency.

Acknowledgments

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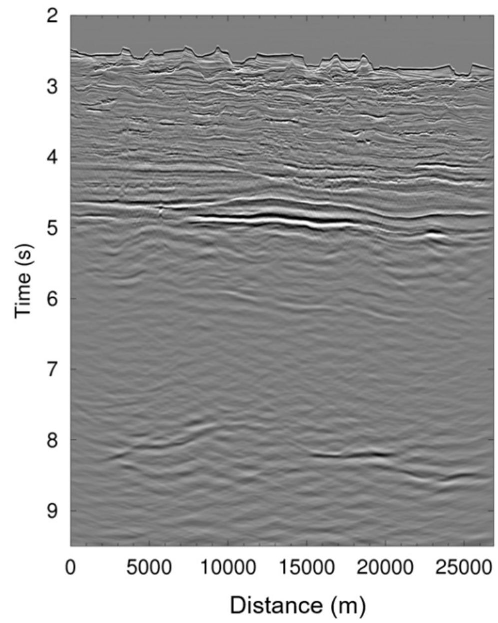

Figure 8: A central inline section of the migrated volume of the data acquired and processed with the continuous wavefields method.

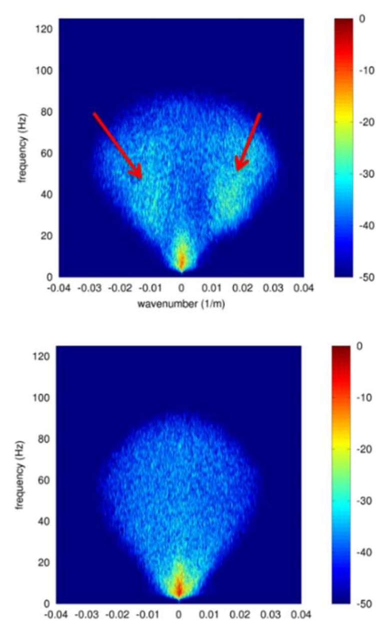

Figure 9: Frequency-wavenumber spectra in a window over the first water-bottom multiple after migration. Aliased residual multiple energy in the conventional data (upper) is highlighted with red arrows.

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