Continuous wavefields methodology – A field trial in the Potiguar Aracati area, Brazil

Jostein Lima*, Stian Hegna and Tilman Klüver, PGS

This paper was prepared for presentation during the 16th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 19-22 August 2019.

Abstract

In summer 2018 a test survey was acquired offshore Brazil using a novel method based on continuous wavefields on top of a survey that had been previously acquired using a conventional dual source setup. The novel acquisition and processing method is called "eSeismic". In this paper, we describe the differences between the continuous wavefield method and the conventional method in terms of how the data sets were acquired, the environmental footprint of the seismic sources that were used, and the processing methods applied to the data sets. Finally we discuss the results obtained after 3D migration.

Introduction

Recently a novel seismic acquisition and processing method utilizing continuous wavefields on both the source and the receiver side to extract the response of the earth was introduced in HEGNA et al. (2018) and KLÜVER et al. (2018). With modern continuous recording systems, seismic data recorded continuously can be treated over the full time-length, typically the length of a sail-line, at once. The emitted wavefield on the source side is also treated as a continuous wavefield. The motivation behind the method is reducing the environmental footprint of marine seismic surveys, and to potentially improve acquisition efficiency whilst maintaining or improving spatial sampling.

In June 2018, a small test survey of about 25 km length and 5 km width was acquired on top of a larger survey acquired using a conventional dual source setup to test and validate the continuous wavefields acquisition and processing methodology. The survey took place in the Northern part of Brazil offshore Fortaleza in the Potiguar Aracati area (see Figure 1), and consisted of eight sail-lines.

In this paper we explain the acquisition configurations used for the field trial and for the comparison data set, show the differences in sound pressure levels and sound exposure levels between the conventional source array and the wavefield emitted during the field test, describe some of the differences in the processing of the data sets, and finally discuss the results after imaging.

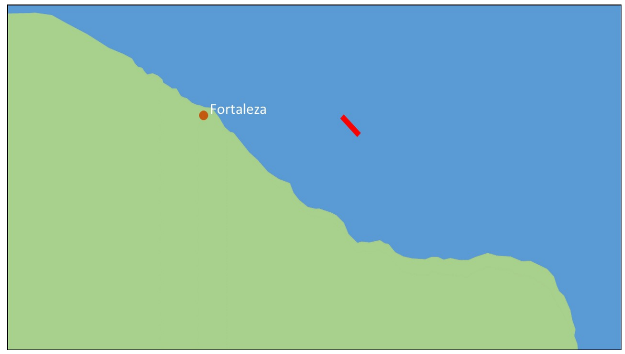

Figure 1 – *Map illustrating the survey area of the field trial in the Potiguar Aracati area. The outline of the survey is highlighted as a red polygon.*

Acquisition configurations

With today's recording systems on seismic vessels, data are typically recorded continuously for the length of a sail line. With the continuous wavefields method, data recorded over the length of an entire sail line is treated continuously during pre-processing.

The continuous wavefields method allows for a source that is constantly emitting energy while moving. There is no concept of minimum listening time or 'shot points'. The desired continuous source wavefield to be used with this method would be white noise. In order to generate a continuous source wavefield that is approaching the properties of white noise using existing equipment on-board marine seismic vessels, individual air-guns can be triggered with very short randomized time intervals in a near-continuous manner generating a continuous wavefield. The test survey was acquired in this fashion. The configuration of the strings with air-guns is illustrated in Figure 2. The cross-line separation between the strings was 16.7m.

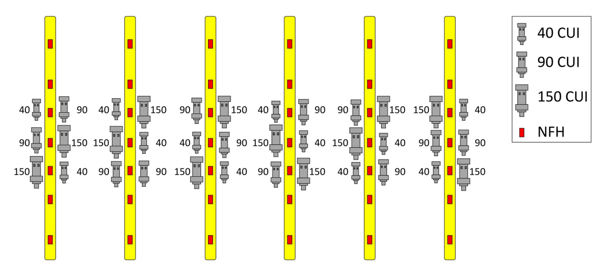

Figure 2 - *Six strings with 40, 90 and 150 cubic-inch air-guns on each.*

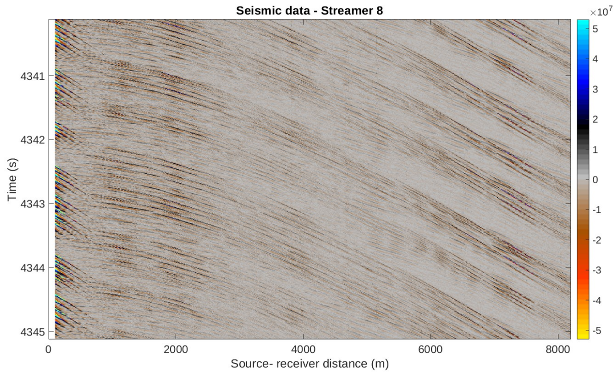

***Figure 3 –** Five second portion of a continuous record acquired with the continuous wavefields method by triggering individual air-guns with short randomized time intervals. Colors range from -5e7 to 5e7 micro-Pascal.*

The comparison survey was acquired with standard dual 4130 cubic-inch source arrays. The cross-line distance between the two sources was 50 m, and the shot-point interval was 50 m for each source (25m flip-flop).

The streamer configuration was the same for the test survey and the comparison data. Both were acquired with 16 streamers and 100 m separation. Figure 3 and 4 show portions of raw recorded hydrophone data from the test survey (Figure 3) and the comparison data (Figure 4) illustrating the difference between the acquired data with the conventional marine seismic method and the continuous wavefields method.

The continuous source wavefield emitted with the new method allows to choose the trace spacing in the common receiver gathers output from the source deconvolution step in processing. The locations of the output traces can be anywhere along the trajectories where source elements have been located during the acquisition. For the test survey acquired in Brazil, we chose to output band-limited point sources every 12.5 m in the inline direction, which is the same as the receiver spacing along the streamers. The six strings with air-guns, each emitting a continuous or near-continuous wavefield, allowed us to output six common receiver gathers per stationary receiver position, one in each cross-line position of the strings. This hexa-source and 16 streamer configuration resulted in 96 CMP lines per sail line with a cross-line spacing of 8.33 m. With the conventional configuration used for the comparison data set, 32 CMP lines were acquired per sail line with a cross-line spacing of 25 m. A front/tail view illustrating the increased cross-line sampling is shown in Figure 5.

Environmental footprint

One of the main benefits with the continuous wavefields method is reduced environmental footprint of marine seismic sources. The sound pressure levels are reduced by activating one air-gun at a time, compared to conventional marine seismic sources where several air-guns are activated simultaneously in tuned arrays. The difference in amplitudes can be seen in Figure 3 and 4.

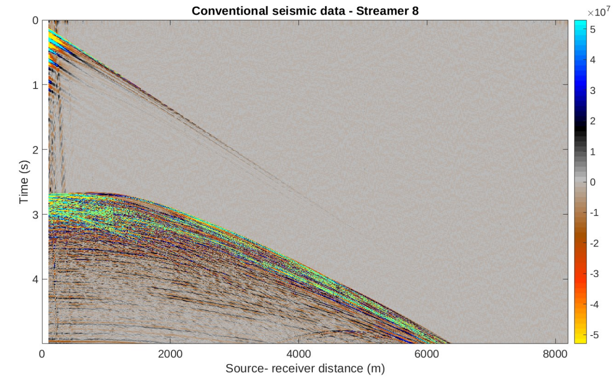

***Figure 4 –** Five second portion of a shot record acquired with a conventional dual source configuration using 4130 cubic-inch source arrays. Colors range from -5e7 to 5e7 micro-Pascal. The data are recorded by the same vessel, same streamer and approximately the same location as in Figure 3.*

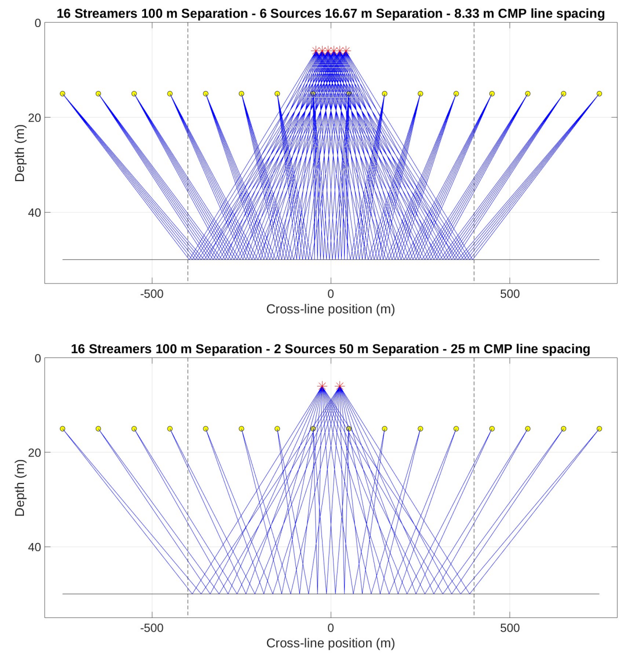

***Figure 5 –** Continuous wavefields method (top) and conventional dual source (bottom) source and streamer setup. Yellow dots represent streamer locations, red stars represent air-gun strings, and blue lines are ray paths connecting sources and receivers through a sub-surface reflection point.*

In order to quantify the differences in peak sound pressure levels (SPL) and sound exposure levels (SEL), the amplitudes in the raw recorded hydrophone data have been converted into micro-Pascal. The SEL computed from the raw hydrophone data have been normalized to the same integration length of 10.5 seconds for both the test data and the comparison data. The differences in peak SPL between the data acquired with continuous wavefields and the comparison data acquired with conventional sources is shown in Figure 6.

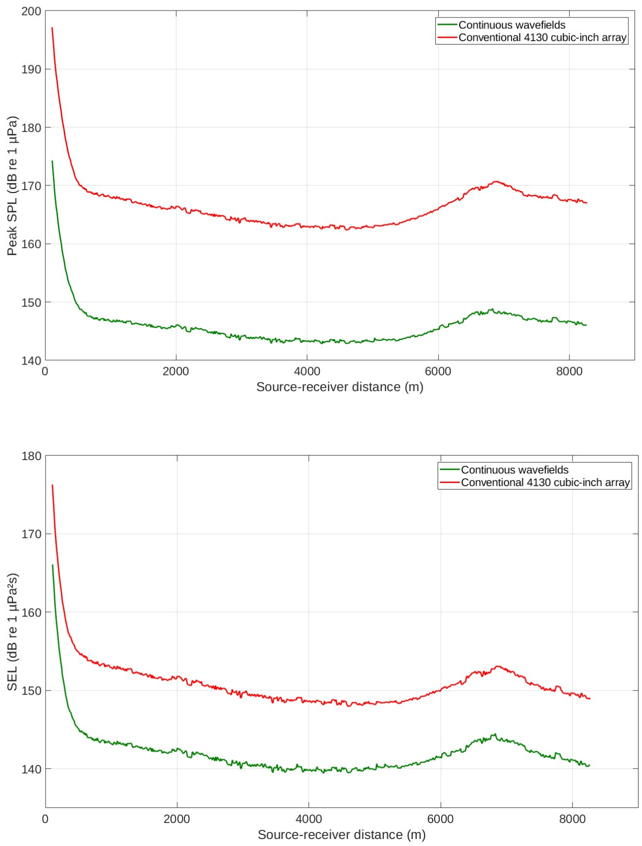

Figure 6 - *Top: Peak SPL computed from the data acquired with the continuous wavefields method (green curve) and with a conventional source array (red curve). Bottom: SEL with a 10.5 seconds integration length computed from the data acquired with the continuous wavefields method (green curve) and with a conventional source array (red curve).*

In general the peak SPL is reduced by 20-22 dB with continuous wavefields, whereas the SEL is reduced with 8-9 dB. For source-receiver distances larger than approximately 500 m, the SEL values for test data are in the range between 140 and 145 dB, whereas for the conventional data the SEL values are in the range between 148 and 153 dB.

Processing method

The processing of data acquired with continuous source and receiver wavefields follows the flowchart shown in Figure 7. The first step in the processing sequence corrects for analogue filtering effects in the data. The different analogue filter responses of pressure and particle motion measurements in multisensor streamers are deconvolved from the data, and the particle motion recordings are converted to the pressure equivalent. The continuous records were re-sampled to 4 milliseconds temporal sampling rate.

Following this, noise attenuation was applied to the pressure and particle motion measurements. The methods used are specifically designed to take advantage of the long record length when dealing with a continuous seismic record from one sail-line at once.

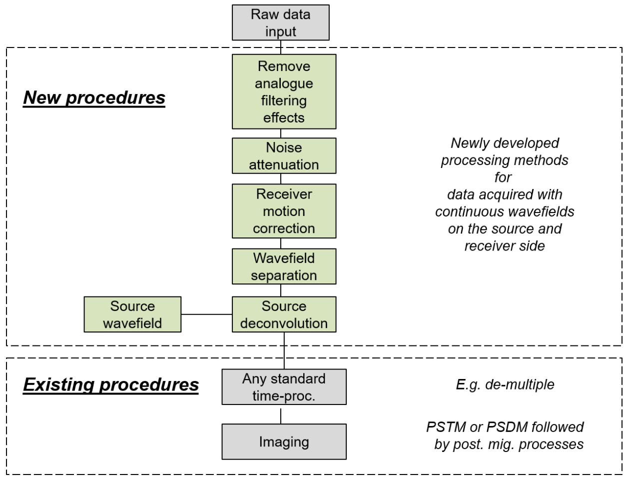

Figure 7 - *Processing flowchart. The continuously recorded input data go through several steps specific to the new methodology before processing continues with existing processing and imaging algorithms. All the new procedures are applied to continuous wavefields.*

In the next step, the continuous motion of the streamers during acquisition was corrected for using the measured navigation data.

After the receiver motion correction, the recorded pressure and particle motion data are separated into up-going and down-going parts. The methodology is as outlined in CARLSON et al. (2007), but applied to the data of one sail-line at once, not on a shot record by shot record basis. The streamer depth variations were corrected for in a redatuming step. These depth variations are handled in a continuous fashion using the measured depths available in the navigation data.

In the last step specific to the continuous wavefields method, the source wavefield is deconvolved from the stationary receiver trace using an iterative multi-dimensional deconvolution. The chosen output trace spacing in the common receiver gathers was 12.5 m. The common receiver gathers are fully anti-alias protected for the chosen output trace spacing. The chosen temporal length of the common receiver gathers was 10 seconds, and six band-limited point sources were solved for. These point sources are in the cross-line positions of the strings with air guns deployed during the acquisition of the data. An angle dependent de-ghosting was applied to the common receiver gathers to correct for the effects of the source side ghost.

The pre-processing of the conventional dual source comparison data consisted of noise attenuation, receiver side wavefield separation including sensor response matching, source side de-ghosting, designature and source directivity compensation, removal of acquisition system filtering effects, and re-sampling to a temporal sampling rate of 4 milliseconds.

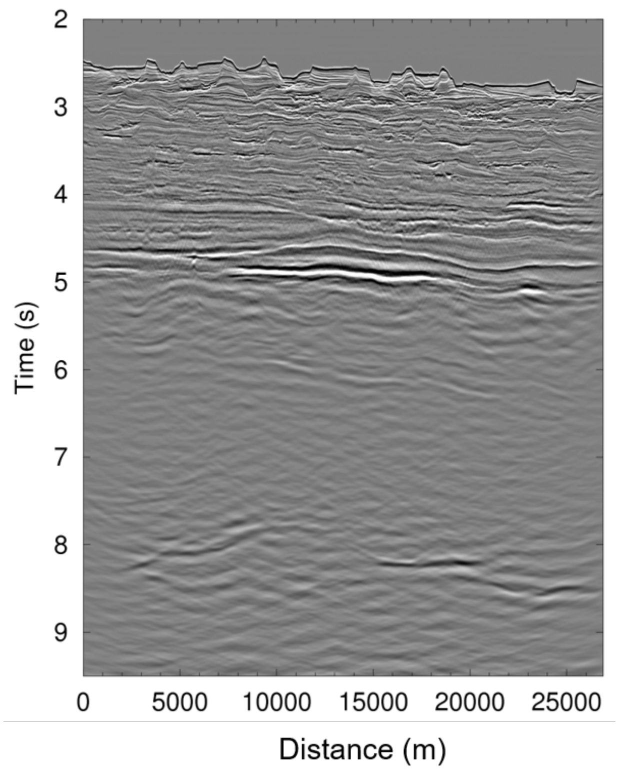

Figure 8 – *A central inline from the continuous wavefields test data.*

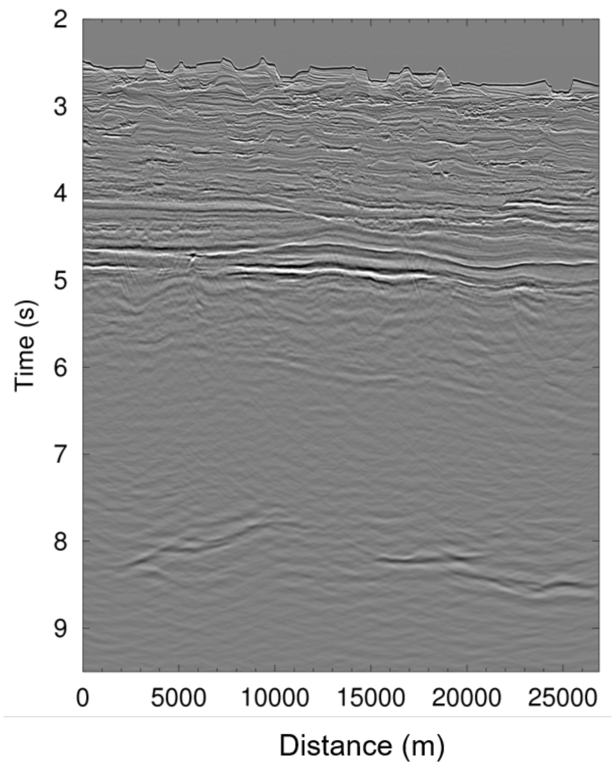

Figure 9 – *A central inline from the conventional comparison data.*

Before imaging, both data sets were regularized. The same spatial coverage as present in the data from the test survey was selected from the data of the large conventional survey and 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 in 12.5 m large offset classes. 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 then migrated to a final 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.

Results

Figures 8 and 9 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.

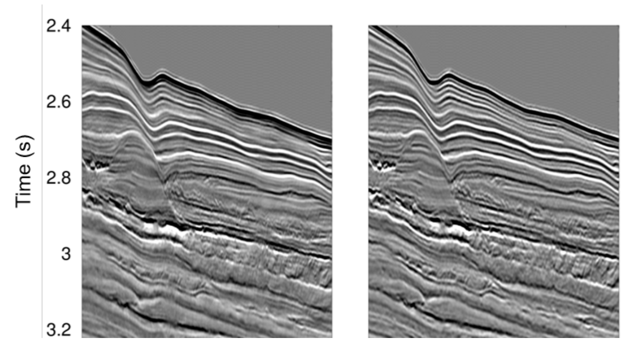

Figure 10 – *Shallow detail of a cross-line section from the continuous wavefield test data (left) and the conventional comparison data (right).*

Figure 10 shows a zoom of the shallow part below the water-bottom reflection of a cross-line section. The denser spatial sampling achieved with the new methodology results in increased resolution especially in the cross-line direction. This is most evident for the small scale features in the center of the data displayed in Figure 10.

Conclusions

A novel marine seismic acquisition and processing methodology based on continuous source and receiver wavefields has been successfully tested offshore Brazil. The data have been acquired with significantly reduced peak sound pressure and sound exposure levels compared to those generated by standard size air-gun arrays reducing the environmental footprint of marine seismic sources. Similar penetration has been achieved, despite a less energetic source wavefield compared to a conventional dual source data set acquired with standard size source arrays. The continuous wavefield methodology provides denser spatial sampling without loss of acquisition efficiency which can yield improved spatial resolution in the shallower parts of the section, and allows for improved anti-alias protection of the data.

Acknowledgments

We thank PGS for permission to publish this paper, and Equinor and The Research Council of Norway for funding the project together with PGS.

References

CARLSON, D., LONG, A., SÖLLNER, W., TABTI, H., TENGHAMN, R., LUNDE, N. Increased resolution and penetration from a towed dual sensor streamer. First Break, V. 25, p. 71–77, 2007.

HEGNA, S., KLÜVER, T., LIMA, J. Making the transition from discrete shot records to continuous wavefields - Methodology. 80th Conference and Exhibition, EAGE, Extended Abstracts, We A10 03, 2018.

KLÜVER, T., HEGNA, S., LIMA, J. Making the transition from discrete shot records to continuous wavefields – Real data application. 80th Conference and Exhibition, EAGE, Extended Abstracts, We A10 04, 2018.