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Methodology Utilizing Continuous Source and Receiver Wavefields – a 3D Case Study

T. Klüver[1]*, S. Hegna[1], J. Lima[1]

[1] Petroleum Geo-Services

Summary

In summer 2018, PGS acquired a survey offshore Brazil using an acquisition and processing method based on continuous wavefields on top of a survey that had been previously acquired using a conventional dual-source setup. In this paper, we compare processing results obtained with the continuous wavefield method to results obtained from the conventional comparison data. The denser spatial sampling obtained with the continuous wavefield method provides improved spatial resolution in the images and permits proper anti-alias protection of the input to migration. Equivalent penetration is obtained in both surveys even though significantly less energy has been emitted with the continuous wavefield methodology.

Introduction

Recently, Hegna et al. (2018a) reported on a novel seismic acquisition and processing methodology that treats the wavefields on both the source and the receiver side as continuous wavefields. 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 impact of marine seismic surveys, and to potentially improve acquisition efficiency whilst maintaining or improving spatial sampling. Klüver et al. (2018a) illustrated the method using real data examples from a 2D test. The potential benefits and the processing methodology have been further described in Hegna et al. (2018b) and Klüver et al. (2018b).

In summer 2018, PGS acquired a survey offshore Brazil using the continuous wavefield method on top of a survey that had been previously acquired using a conventional dual-source setup. Initial results of that survey, including significantly reduced peak sound pressure and sound exposure levels, have been reported in Hegna et al. (2018c). In this paper, we compare the imaging results obtained with the continuous wavefield method to results obtained from the conventional comparison data.

Methodology

The acquisition and processing methodology is based on continuous source and receiver wavefields. A continuous source wavefield is generated in the field by densely triggering individual air-guns with randomized time intervals, i.e., spreading source energy out in time instead of triggering large air-gun arrays at fairly large and fixed spatial intervals. The wavefield on the receiver side is recorded continuously for as long as it takes to acquire a sail-line.

In June 2018, PGS acquired a small survey of about 25 km length and 5 km width on top of a larger survey acquired using a conventional dual-source setup to test and validate the continuous wavefield acquisition and processing methodology. The survey took place in the Northern part of Brazil offshore Fortaleza and consisted of eight sail-lines. Figure 1 shows the acquisition configuration for both surveys. The same spread of 16 dual-sensor streamers spaced 100 m apart was deployed. The conventional dual-source acquisition had two 4130 cu in air-gun arrays deployed with a separation of 50 m, resulting in 32 CMP lines spaced 25 m apart in the cross-line direction. With the continuous wavefield methodology, a receiver gather is generated for each air-gun string deployed in the field. The six strings in this survey have been spaced 16.67 m apart resulting in a natural cross-line CMP spacing of 8.33 m. Both surveys have a natural in-line bin size of 6.25 m. The flip-flop shooting pattern of the conventional acquisition has a nominal shot point interval of 25 m yielding an in-line shot spacing of 50 m along individual source lines with only one source present in every inline position. The continuous source wavefield allows us to choose the trace spacing along the individual source lines in processing; it is no longer an acquisition parameter. The trace spacing has been chosen to be 12.5 m with all six sources present in every inline position. This means that spatial sampling has been improved both in-line and cross-line and the number of traces has been increased by a factor of twelve compared to the conventional dual-source survey. This has been achieved without loss of acquisition efficiency since the same sub-surface coverage per sail-line has been achieved in both surveys.

The pre-processing sequence for both data sets is summarized in Table 1. Whereas all processing steps for the conventional data have been performed on individual records, the pre-processing of the data acquired in the test survey is conducted on continuous data. For the continuous wavefield methodology, the effect of the source wavefield and the source ghost is deconvolved from the data using a multi-dimensional deconvolution operator in the common receiver domain including anti-alias protection of the resulting common receiver gathers. The conventional dual-source data have a traditional designature flow applied with source directivity compensation. Source side deghosting has been applied in the shot domain due to poor sampling of common receiver gathers.

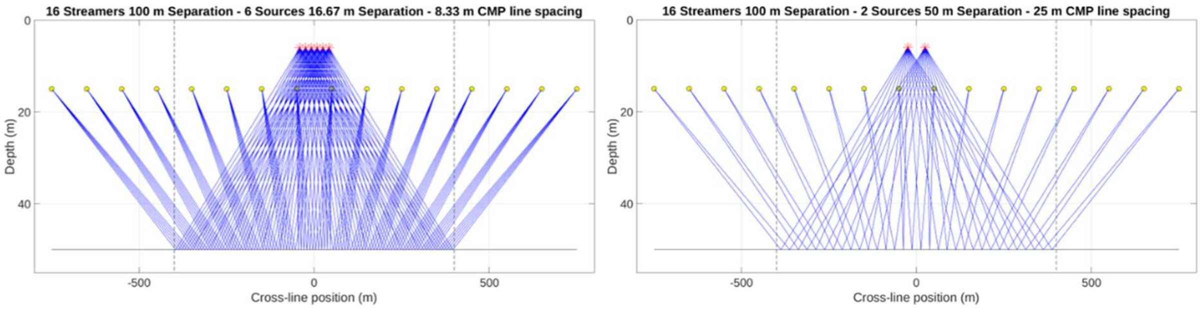

Figure 1 *Continuous wavefield (left) and conventional dual-source (right) source and streamer setup. Yellow dots represent streamer locations, red stars represent air-gun strings, and blue lines are ray paths connecting sources and receivers through a sub-surface reflection point.*

Processing continuous wavefield data	Record-based processing of conventional dual source data
Removal of acquisition system related filtering effects	Noise attenuation
Resampling to 4 ms	Receiver side wavefield separation, sensor response matching
Noise attenuation	Source side deghosting
Receiver motion correction	Designature and source directivity compensation, removal of acquisition system related filtering effects
Receiver side wavefield separation	Resampling to 4 ms
Source wavefield deconvolution including deghosting	Receiver motion correction

Table 1 *Summary of pre-processing sequences.*

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 time migration.

Results

Figure 2 shows 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 emittedby the continuous source, 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 3 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 centre of the data displayed in Figure 3.

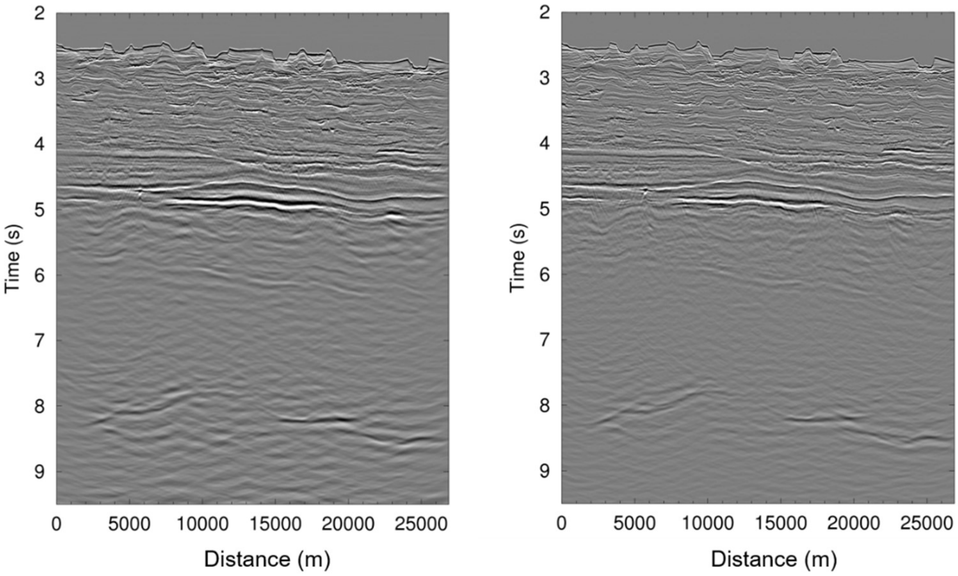

Figure 2 *An inline section from the continuous wavefield test data (left) and the conventional comparison data (right).*

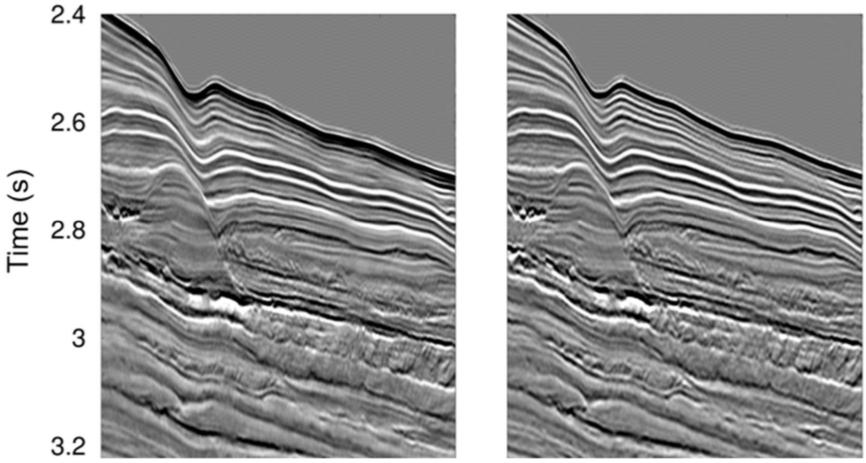

Figure 3 *Shallow detail of a cross-line section from the continuous wavefield test data (left) and the conventional comparison data (right).*

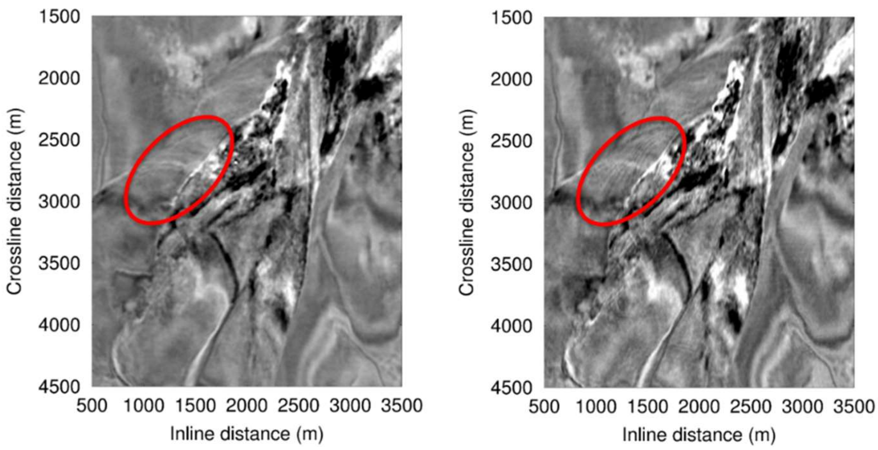

Figure 4 *Details in a shallow time slice just below the water bottom for the continuous wavefield test data (left) and the conventional comparison data (right).*

Figure 4 shows a fault plane in a shallow time slice just below the water bottom. There is clear evidence of aliased energy in the highlighted area in the conventional image. The denser spatial sampling achieved with the continuous wavefield method allows us to improve the anti-alias protection of the data input to migration. This mitigates the aliasing issue as demonstrated by the absence of aliasing effects in the image from the data acquired with the continuous wavefield methodology.

Conclusions

PGS successfully conducted a survey with a novel acquisition and processing methodology based on continuous source and receiver wavefields. 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. 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 and allows for improved anti-alias protection of the data.

Acknowledgements

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