The impact of broadband acquisition and processing on imaging Brazil's deep water Campos basin

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Summary

The Campos basin offshore Brazil has proven to be a challenging area for seismic imaging, because of its complex geology and deep pre-salt targets. By providing an improved low-frequency response and a broader usable bandwidth, seismic data recorded using variable-depth streamer acquisition appears to be an appropriate and promising solution for oil and gas exploration offshore Brazil. We show the comparison between images obtained using conventional flat tow streamer data with and without de-ghosting applied, as well as the impact of broadband variable-depth towed streamer acquisition in combination with de-ghosting. Furthermore, the impact of increasing the maximum offset and azimuth on the image quality of variable-depth streamer data is shown, as well as that of TTI anisotropic depth imaging. As such we demonstrate how new acquisition technology combined with advanced processing techniques is beneficial to post- and pre-salt imaging in the Campos basin.

Introduction

The Campos basin is one of several key basins for the production of hydrocarbons in offshore Brazil. Since the first well was drilled in the seventies, it has been continuously developed and as a result a significant infrastructure for the production of oil is now in place in the shallow-water part of the basin. The basin, situated 250km East of Rio de Janeiro, is a challenging area for seismic imaging because of its complex geology and deep pre-salt targets. Post-salt sediment deposits are anisotropic and heterogeneous with sharply varying thicknesses and can have volcanic intrusions. The presence of high velocity (> 5000 m/s) carbonates just above the salt further challenges illumination, while the complex and diverse salt bodies overlying the pre-salt targets attenuate the seismic signal making imaging even more difficult. Nevertheless, the deep-water area usually provides seismic data of high quality**.** Recent post and pre-salt discoveries in the deep-water part of the basin have increased demand for seismic exploration in this area.

Ghost Wavefield Elimination (GWE) (or de-ghosting) removes the imprint of the ghosts on the spectrum and helps recover the broadband nature of the data recorded. In this way it improves the resolution of the seismic image. Variable-depth towed streamers (Soubaras, 2010) are known to allow improved recording of both low and high frequencies due to the diversity of the notches for different offsets (and azimuths).

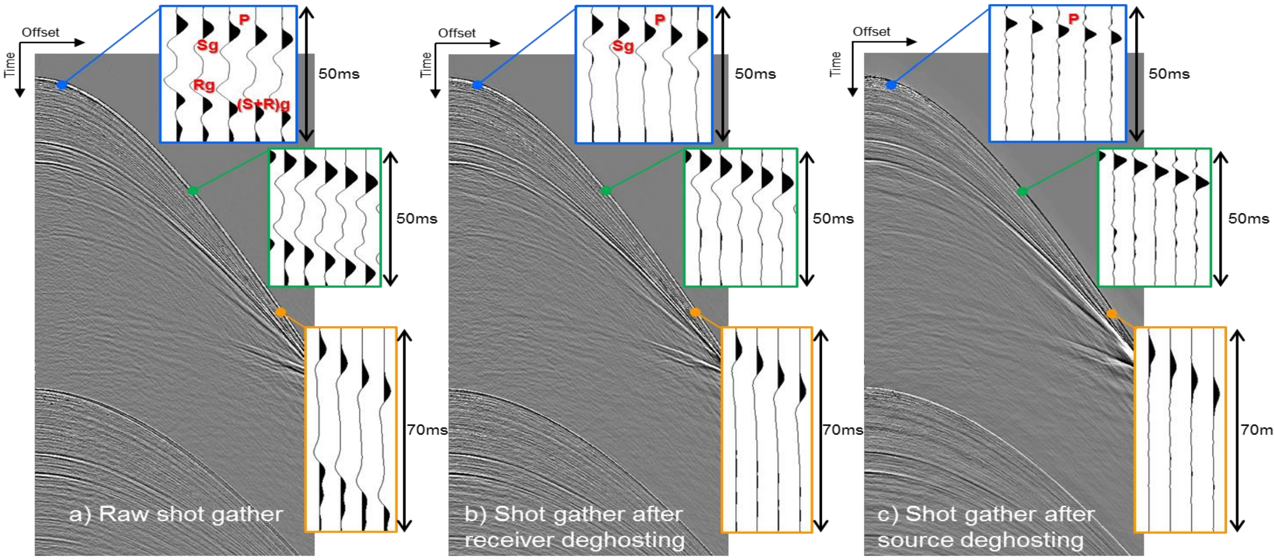

Figure 1. Shot gathers before and after receiver and source GWE. For each shot, the seismic water bottom event is zoomed for the near, mid, and far channels (in wiggle display). Notice only the water bottom primary event is left after GWE.

In this paper we demonstrate the benefits of variable-depth streamer acquisition and processing in the Campos basin. We compare the results obtained with conventional streamer data with and without GWE applied, variable-depth streamer data with GWE applied, and variable-depth data with longer offsets with GWE applied, and study the respective differences in image quality. Throughout this work all imaging was obtained using Kirchhoff PSDM.

The impact of GWE

Considering the high interest in seismic exploration in the Campos basin, a variable-depth streamer acquisition with 12 streamers each 8100 m long was acquired by CGG in 2014. The cable depth varied from 10 m at the near offset to 50 m at the furthest offset, while the source depth was 6 m. These data were processed using GWE to recover the broadband nature of the recorded data and effectively remove the ghosts on both the source and receiver side. Prior to GWE, a de-signature was applied using the far-field source signature modelled using the recorded near-field hydrophone (NFH) response (Ziolkowski et al., 1982). The QC of the de-signature process can be challenging prior to GWE, because the ghost effectively suppresses the low frequencies present in the source signature After GWE these low frequencies are boosted, and any residual bubble energy not properly modelled in the source signature and consequently not properly removed in the de-signature step, can show up. Therefore, usually, a residual de-bubble operator is estimated after GWE.

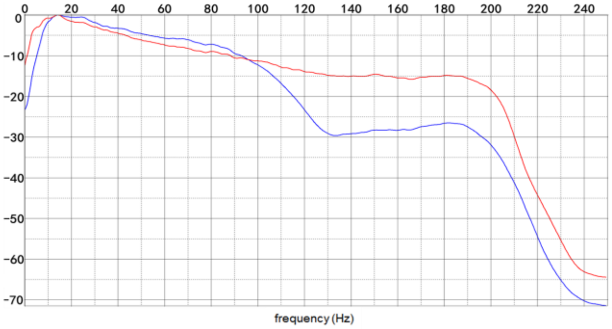

Figure 2. Amplitude spectra in dB of stacked data before (blue) and after the application of GWE (red). The spectrum of the data after GWE includes the effect of residual de-signature.

Ghost Wavefield Elimination (GWE) was introduced by Wang et al. (2013) as a method for de-ghosting the data using a bootstrap approach in the τ-p domain. This method derives ghost delays from the data and is therefore not affected by errors in either receiver or shot depths. GWE can be applied to data with either a constant or variable tow-depth (Bai et al., 2013).

Figure 1 shows the result of applying GWE both on the receiver (Figure 1b) and source side (Figure 1c). Comparing wiggle displays in Figure 1, we see that both ghosts are effectively removed. The amplitude spectra in Figure 2 of the stacked data before and after application of GWE show that the source notch around 130 Hz has been effectively removed by GWE.

Depth imaging

A conventional flat tow streamer dataset had already been acquired in 2008 with 8 4800m-long streamers in the deep-water part of the Campos basin. The cable was towed at a depth of 9 m, while the source depth was 6 m. These data were originally imaged using isotropic PSDM without any GWE applied prior to imaging (Figure 3a). In 2013 these data were reprocessed using GWE and imaged using TTI PSDM (Figure 3b). The availability of the 2014 variable-depth acquisition mentioned previously, together with the conventional streamer acquisition from 2008, allows us to compare the impact of variable-depth acquisition. We note that the 2014 data have a larger number of cables as well as a substantially longer maximum offset than the 2008 data. Therefore, the 2014 data have an increased seismic aperture and as a result a better migration illumination. Furthermore, these data were acquired at an azimuth approximately 60 degrees different from the original survey acquired in 2008, thus resulting in different subsurface illumination. In this work, all data shown after (depth) migration, have been resampled from 2ms to 4ms prior to migration. Therefore the bandwidth after migration is reduced compared to the bandwidth of the original data (see Figure 2).

Comparing Figures 3a and 3b, it is immediately evident that GWE provides a significant improvement in the resolution of the image. When inspecting both images more closely the impact of the anisotropic TTI migration compared to the isotropic migration can also be seen through improved focussing, especially in the pre-salt area, as well as differences in the positioning of the (dipping) reflectors. Furthermore, the sediment structures post-salt are better defined and excellent matching with the well markers is obtained. The TTI anisotropy model was constructed using the available well information.

To separate the impact of the variable-depth acquisition from the impact of the increased maximum offset, we limited the variable-depth data to the same offset as the 2008 conventional streamer data (i.e. 4800 m). The same TTI velocity model (constructed using the conventional data with GWE applied) was used for both data sets. Comparison of the 2013 and 2014 images (Figure 3b and 3c) reveals an improvement of sediment continuity in the pre-salt image, mostly due to a better illumination and overall improved signal-to-noise ratio. It is clear that the effective frequency range of the seismic image was enhanced systematically between these three processing surveys. First, in 2013, GWE enhances the relative amplitudes of the low frequencies and thus resolution (Figure 3b), and subsequently resolution is further improved through the variable-depth streamer acquisition design. Finally, Figure 3d shows the impact of the increased maximum offset and the resulting larger angular aperture. Some further improvement in signal-to-noise ratio is obtained, mostly evident in the deeper parts of the 2014 image (cf. the red arrow on Figure 3c and 3d).

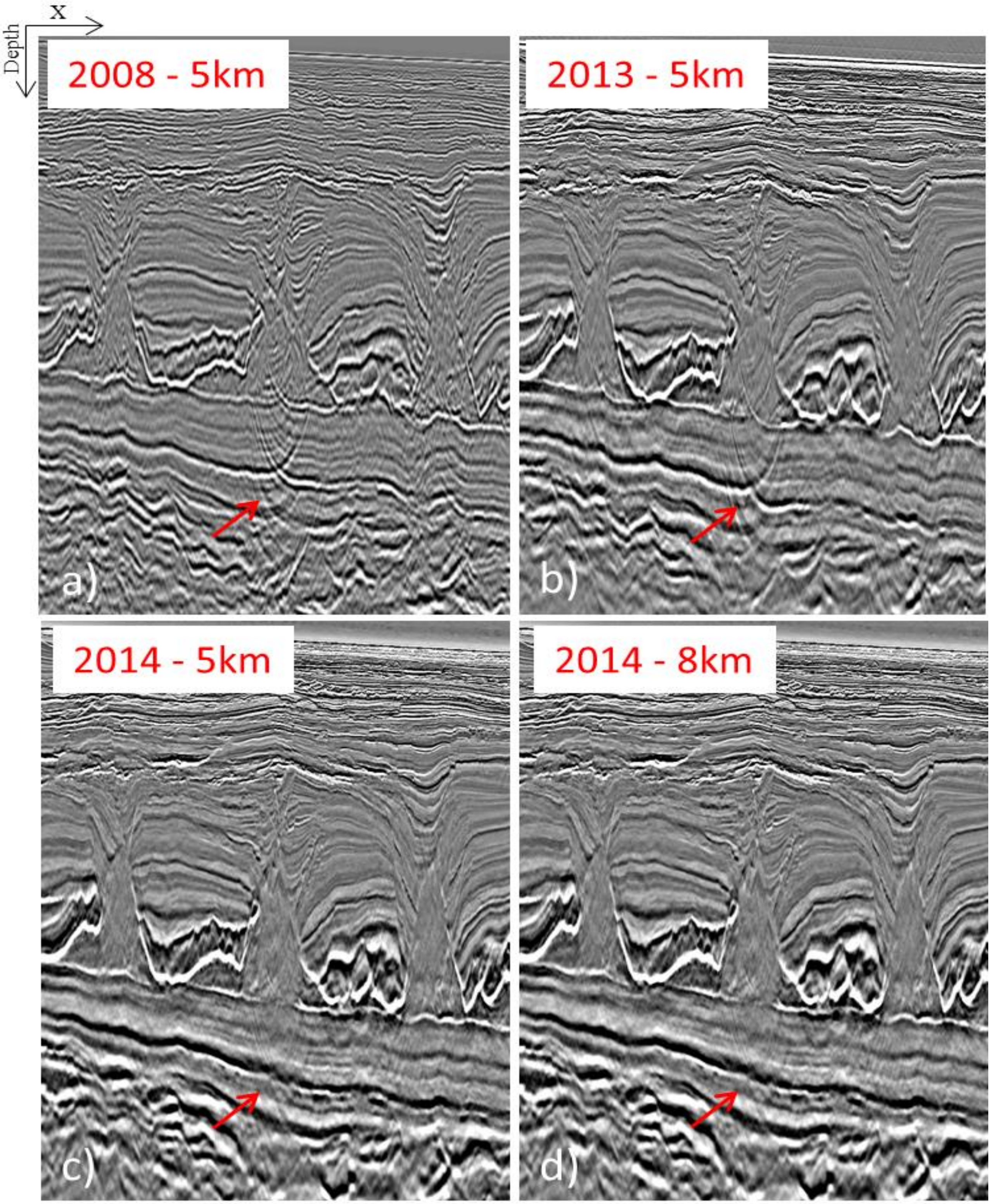

Figure 3. (a) migrated and stacked image from 2008 obtained using isotropic PSDM on the conventional streamer data with 5 km cable length , (b) TTI PSDM with GWE from 2013 on the conventional streamer data with 5 km cable length, (c) TTI PSDM with GWE on the variable-depth streamer data with 8 km cable length from 2014, but stack limited to 5 km offset and (d) TTI PSDM with GWE on the variable-depth streamer data with 8 km cable length from 2014. Notice the enhancement of the lateral continuity of the base of salt and pre-salt seismic events as well as the improved definition of the post-salt sediments (b, c).

Figure 4 shows the spectra from the images shown in Figure 3a, b and d. Clearly, applying GWE to a conventional dataset significantly increases the effective frequency range (from the green to the red curve in Figure 4). The variable-depth acquisition then even further extends the effective frequency range on both the high and low ends of the spectrum resulting in a further improvement in resolution (from the red to the blue curve). The spectrum of the image in Figure 3c (not shown), is almost identical to the spectrum of Figure 3d (the blue curve in Figure 4).

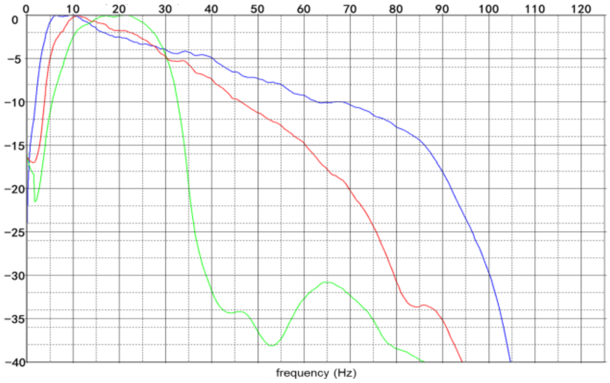

Figure 4. Amplitude spectra in dB of each of the images shown in Figures 3a (green), 3b (red) and 3d (blue). No further Q compensation was applied.

Figure 5 shows the better signal-to-noise ratio of the variable-depth-streamer acquisition data (Figures 5a-2, 5b-2 and 5c-2) when compared to conventional flat tow streamer acquisition data (Figures 5a-1, 5b-1 and 5c-1), in particular for the lower frequencies. Comparing the amplitude spectra of the conventional and broadband datasets in the post- and pre-salt regions (Figures 5d and 5e), we observe that the broadband data indeed provide improved low as well as high frequencies in both regions. In the pre-salt region, the gain in high frequencies is more subtle. In addition, we mention that the use of solid streamers in our variable-depth streamer acquisition system aids in further improving the overall signal-to-noise ratio.

Conclusions

We have presented a comparison between images in the Campos basin obtained using conventional flat tow streamer data with and without GWE applied, as well as images obtained with variable-depth streamer data. We observed substantial improved bandwidth and resolution from applying GWE to remove both the source and receiver ghosts on conventional streamer data. A further improvement in resolution was obtained by towing the streamer at variable depths and finally by increasing the cable length from 5 km to 8 km and slightly extending the azimuth range of the acquisition geometry. The bandwidth of the data is effectively extended at both the high and low frequency ends of the spectrum in both the post- and pre-salt depth regions. The increased resolution is evidenced by the improved continuity, in particular in the pre-salt targets with enriched low frequencies. TTI anisotropic PSDM further increased resolution as supported by the better defined post-salt sediment structures. Currently, the TTI velocity model is being updated as a result of the improved resolution of the 3D variable-depth streamer data, to try and further improve the overall imaging and especially the pre-salt deep events.

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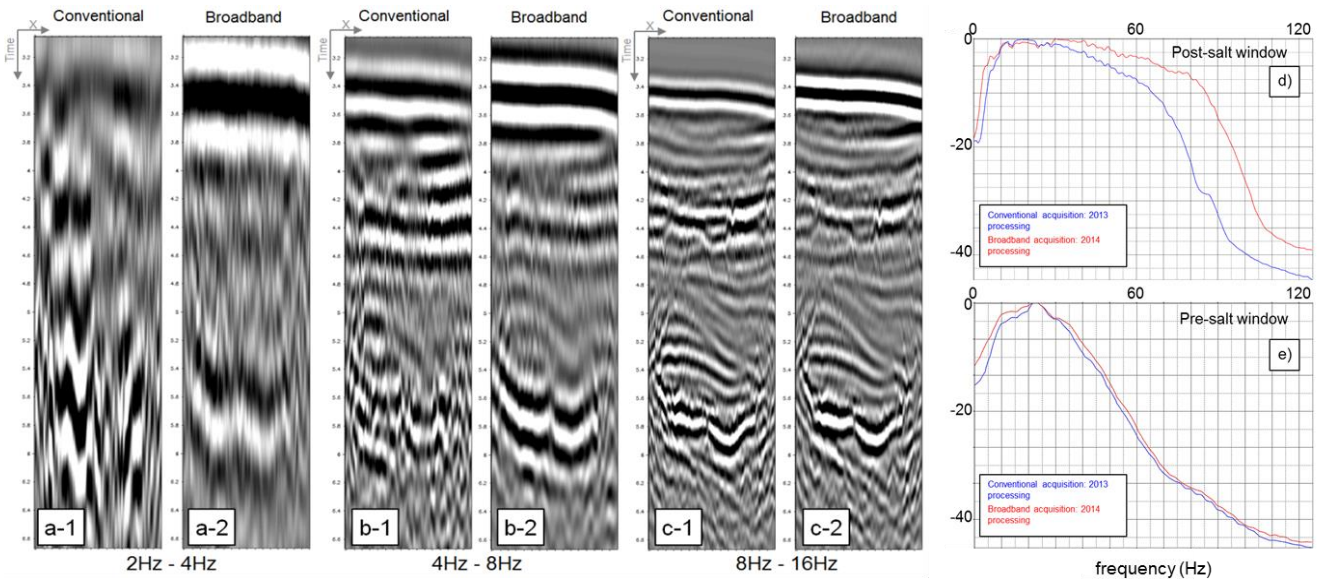

Figure 5. Left: Low frequency band-pass filtered migrated stacks from the 2013 (a-1, b-1, c-1) and 2014 processing (a-2, b-2, c-2). Right: amplitude spectra in dB of the unfiltered stacks for the 2013 (blue line) and 2014 processing (red line) for a post-salt (d) and pre-salt (e) window.

References

Bai, B., Chen, C., Yang, M., Wang, P., and Huang, Y., [2013]*, Ghost effect analysis and bootstrap de-ghosting application on marine streamer data, 75th Annual Meeting, EAGE, Expanded abstracts*.

Soubaras, R., [2010], *De-ghosting by joint de-convolution of a migration and a mirror migration: 80th Annual Meeting, SEG, Expanded Abstracts, 3406-3410.*

Tanis, M, Masclet, S., Marpeau, F., Williamson, H, Tomaz, E., Prigent, H., Douma, H., and Reinier, M., Imroving Resolution through Broadband Acquisition and Processing – A case Study in Brazil's Campos Basin, 2nd EAGE/SBGf workshop, 2014.

Wang, P., Ray, S., Peng, C., Li, L. and Poole, G., [2013], *Pre-migration de-ghosting for marine streamer data using a bootstrap approach in Tau-P domain, 83rd Annual Meeting, SEG, Expanded Abstracts.*

Ziolkowski, A., Parkes, G. E., Hatton, L., and Haugland, T., [1982], *The signature of an air gun array: computation from near-field measurements including interactions: Geophysics, **47**, 1413-1421*