Deep water OBC 4D Acquisition

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This paper was prepared for presentation during the 12th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 15-18, 2011.

Abstract

Seabed seismic acquisition is increasingly being used to obtain high quality images in areas where conventional streamer methods are viewed as inadequate. In the Campos Basin eight OBC surveys have been acquired over the past two years. The complex infrastructure environment in the Campos Basin requires detailed pre-survey planning to ensure that adequate coverage and 4D positioning repeatability is maintained around obstructions.

Introduction

There is a growing need to characterize and monitor deep water reservoirs. In shallower water areas such as the North Sea enhanced seismic acquisition techniques such as full azimuth HDOBC are providing better images and reservoir attributes. It seems logical that these techniques should also be used for dynamic imaging, particularly in the deep water environment with high costs associated with drilling. A key question is whether the impressive results from the North Sea seabed reservoir monitoring programs can be emulated in the deep water environment. Retrievable OBC has proven capability up to 2000m water depth, however despite these advances there has been limited uptake in 4D acquisition with only one deep water OBC monitor survey acquired thus far. More recently industry attention has focused on emerging nodal technology with the potential for deep water 4D monitoring. Despite good imaging results in complex structural settings, there is an increasing body of evidence showing that the receiver density of current nodal acquisition is insufficient for reservoir monitoring (Boelle 2005, Bouska 2008). The cost considerations associated with dense seabed receiver deployment indicate that OBC has distinct advantage over ROV based node technology.

Deep water OBC: Campos Basin

Since 2004 there have been more than ten 3D field scale OBC surveys acquired in water depths exceeding 500m. The majority of the surveys have been acquired in the Campos Basin including the Roncador 3D 4C survey in water depths 1600m-1860m. Although the total receiver area of Roncador was only 45km^2 the survey is significant in setting the benchmark for OBC deep water capability. Furthermore, the number of stations deployed (6240) is still significantly higher than any node survey acquired in similar water depths. Another important outcome from the Roncador survey was that it demonstrated that OBC could be deployed remarkably close to pre-plot, even in 2000m water depth with strong currents. Post positioning analysis showed the average receiver landed 1.7 m inline and 6.1m crossline from the preplot location (Cafarelli et al, 2006).

Over the past two years the deep water OBC experience has continued in the Campos Basin. During this period the OBC technique has continued to provide a high level of positioning repeatability. As the water depth increasing the receiver deployment technique becomes more difficult, however even at 1000m the average x-line distance from pre-plot is 15m. When plotting the average distance from pre-plot versus water depth over the entire 1800km^2 program it can be seen that OBC provides a very high level of positioning repeatability (figure 1). OBC 4D has also shown to have good levels of positioning repeatability when using monitor pre-plots. Despite these impressive results there is room for improvement, particularly when compared with the deployment results from a recent 4D shallow water survey (figure 2).

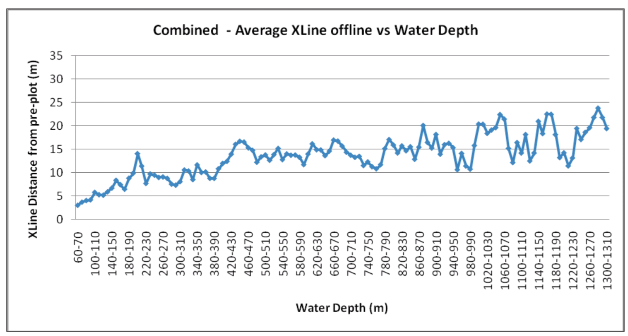

Figure 1. Average receiver distance from pre-plot vs water depth for seven different surveys acquired in the Campos Basin.

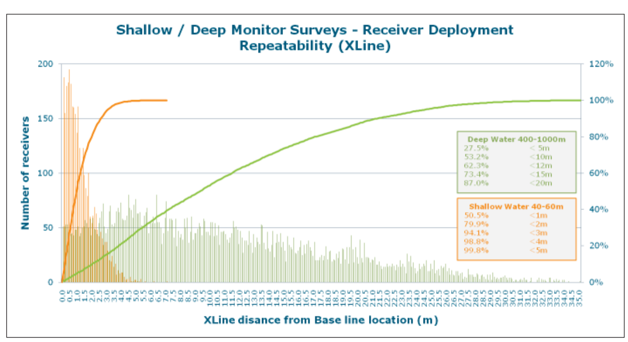

Figure 2. Number of receivers vs radial distance from pre-plot for 4D monitor 100km^2 survey in shallow water (orange) compared against the deep water monitor in the Campos Basin (green).

It is important to note that OBC data has also been acquired in highly obstructed areas (figure 3 & 4). Despite the difficulty in deploying cables around anchor chains and other underwater infrastructure the OBC method is capable of providing the required coverage in the deep water environment. Working in this environment requires careful onshore and in-field planning to decide upon the most suitable location to deploy cables close to obstructions. Deviations due to seabed obstructions are inevitable, however additional receivers lays and undershooting can be planned to ensure adequate coverage. Noise sources such as pipelines can result in a number of unusable channels but the high receiver density of the OBC method generally means that this does not result in a coverage hole during QC processing. The OBC situation contrasts markedly with nodal based system. Node based acquisition cannot monitor the noise in real time and this combined with the sparse receiver method leaves the potential for significant coverage holes around obstructions.

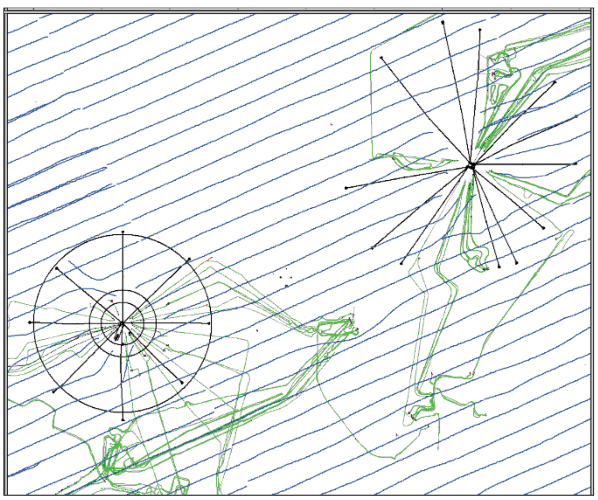

Figure 3. Receiver deployment around deepwater FPSO and semi-sub in water depths up to 1100m. Blue lines show the post plot receiver positions. These have nominal receiver line separation of 300m. The semi-sub anchor chains have a touch down radius of 500m

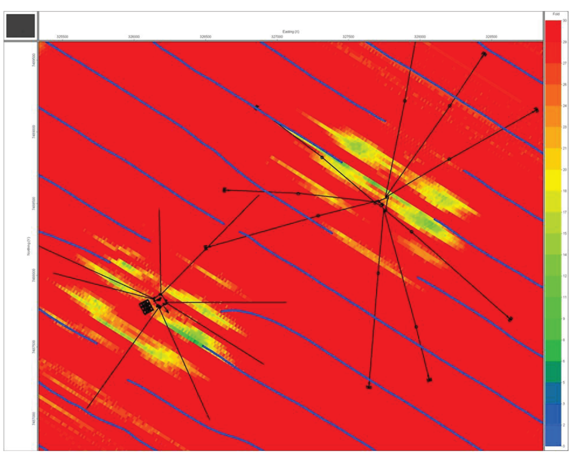

Figure 4. Near offset coverage (0-1500m) around obstructed area. Nominal receiver line (shown in blue) separation of 400m. Red colour represents 30 fold of coverage.

4D OBC Monitor Acquisition: Campos Basin case

Time lapse streamer seismic has been successful in areas of the Campos basin, however there are problems associated with acquisition repeatability. The density of obstructions in areas such as the Marlim complex and strong currents can create difficulty in matching baseline acquisition. In these areas the differences in data coverage between baseline and monitor streamer surveys has resulted in low repeatability. The analysis of the repeatability effects lead to the question on whether seabed seismic, with higher levels of repeatability but also higher costs, would be more suitable for obstructed oil fields such as those found in the Campos Basin (Aguiar Jr, 2007). The end result has been a dramatic increase in the number of OBC surveys acquired in the most obstructed areas of the Campos Basin. Since the beginning of 2009 there have been nine OBC seismic surveys acquired. The primary driver for data acquisition has been the need to obtain good baseline datasets for 4D monitoring purposes. There has also been one OBC on OBC monitor survey acquired and this will be the topic of the remainder of this section.

In 2010 Petrobras started 4D monitor acquisition over the Marimba field in the Campos Basin. At the time writing this is considered as the largest seabed monitor survey acquired worldwide to date. The baseline OBC dataset was acquired in 2005 using high density parameterization suitable for both time lapse studies and for converted wave imaging. The acquisition environment was challenging due to the relatively deep water (400-900m) and presence of obstructions. During the 2005 acquisition the Marimba field had a total of four mobile drilling rigs present at various times, and one permanent production rig. The obstruction situation in 2010 had changed significantly with only the production unit in place (figure 5).

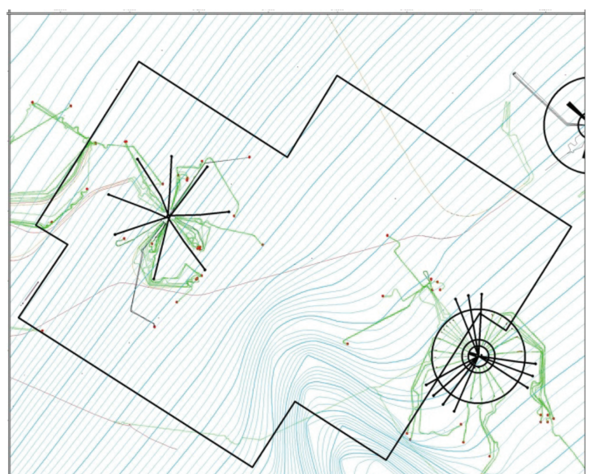

Figure 5. Marimba 4D monitory survey outline 110km^2

The Marimba 2010 acquisition required careful pre-planning in order to minimize positioning differences between the baseline and monitor dataset. Analysis of the 2005 post plot data showed there to be several issues which required attention when creating the monitor survey pre-plot. These included:

- Receiver line smoothing of baseline receiver and shot positioning

- Optimal receiver and shot positioning for coverage around obstructions

The inertial forces associated with the shooting or receiver deployment vessels mean that following a rapidly varying base line dataset can result in significant offline deviations. In these cases smoothing techniques should be used on the baseline dataset in order to minimize the positioning differences between baseline and monitor surveys (figure 6). Steering the sources or receivers along a dynamic preplot is not easy. When the source track deviates from a straight line an element of manual steering is required. The intention is to steer the sources but the steering adjustments move the vessel therefore, any adjustments made have a delayed and exaggerated effect. The result of this is that when adjusting for dynamic movements the tendency is to oversteer.

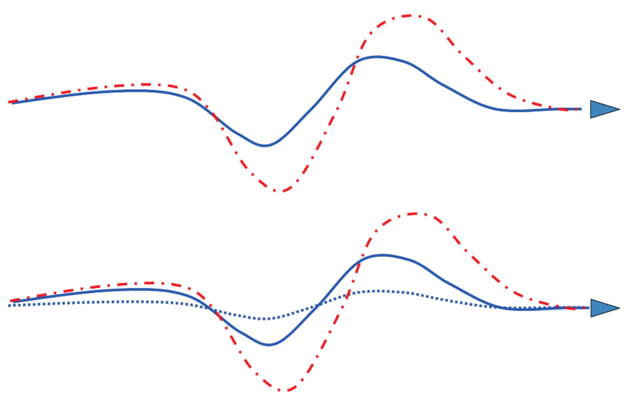

Figure 6. The effects of oversteer. The blue line represents the base line dataset. Following the baseline can result in significant oversteer (shown in red). This can be overcome by smoothing of the baseline dataset (blue dashed line).

In the North Sea the 4D approach has been to acquire OBC surveys with tight specifications on receiver deployment, typically +/-6m from pre-plot. With this level of baseline deployment accuracy it means that subsequent monitor surveys can be acquired using the straight line pre-plots. However in the case of 2005 Marimba baseline it was determined that simply following the straight line pre-plot would have resulted in significant positioning differences between base line and monitor. Based on this analysis the decision for Marimba 2010 was to smooth the baseline dataset in order to minimize these positioning differences.

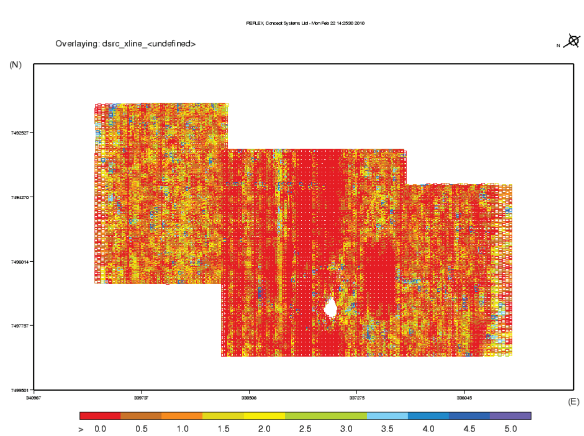

Figure 7. Differences between source positions before and after the smoothing has been applied. The areas in the centre of the survey with low crossline differences appear to be due to the averaging out of any small deviations over multiple source tracks.

The baseline shot positioning did not require a significant level of smoothing (figure 7). Outside the obstructed areas the maximum shot deviation was not more than 5m from pre-plot therefore shot positioning was not predicted to be major factor in terms of repeatability. On the other hand the receiver base line dataset required careful inspection in order to create fit for purpose pre-plots for the monitor survey. Several receiver deployments had offline greater than 15m (presumably due to strong currents) and in these cases the monitor pre-plot was created by use of a smoothing filter. There were however more extreme examples of 2005 cable redeployment (occupying same receiver stations) but with significant offline deviation during relay. In these cases there was no option but to simply follow the straight line pre-plot despite the fact that significant differences between baseline and monitor pre-plot would exist (figure 8).

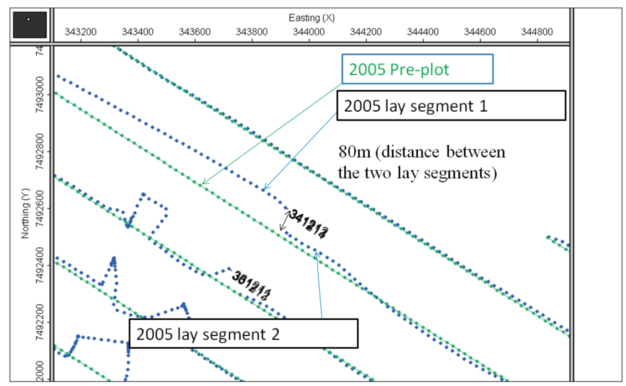

Figure 8. Base line receiver post plot vs pre-plot.

During the analysis of the 2005 dataset it was clear that following the base line receiver deployment around the production unit would not be possible. The 2005 acquisition contractor had used deployment techniques which optimised use of equipment to produce good coverage. However the type of armoured cable used for deep water and layout methodology does not allow such rapidly varying receiver locations to be followed in repeat surveys (figure 9). In this case is was decided to not attempt to match the base line positions but instead to focus on achieving good coverage whilst trying to follow the pre-plot straight line positioning. Additionally in order to build up the coverage, which could be used for downstream 4D matching techniques, it was decided to acquire dedicated undershoot lines (figure 10). This methodology for acquiring data around obstructions was also used on the other eight baseline surveys which were acquired in the Campos Basin in 2009 /2010. This acquisition approach was chosen to ensure that repeat acquisition has the opportunity to repeat the receiver locations.

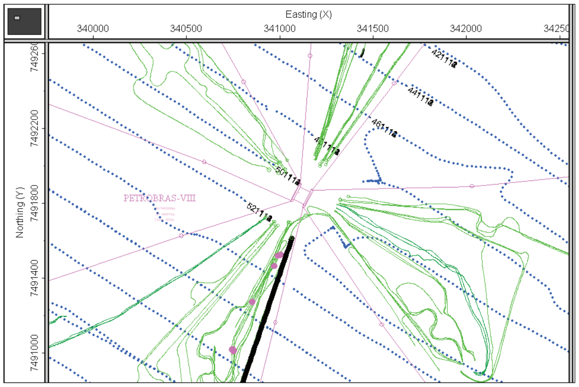

Figure 9. Baseline receiver positions around the P8 production unit.

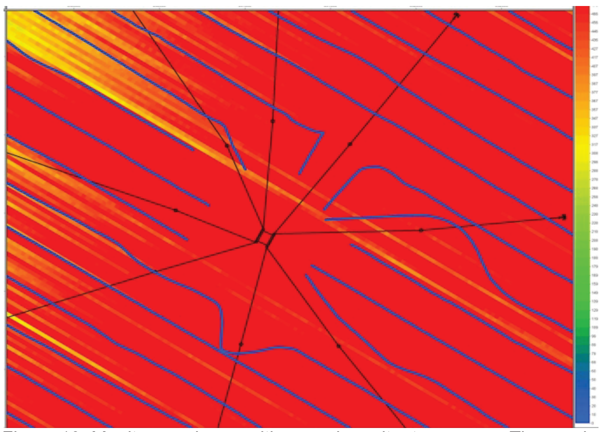

Figure 10. Monitor receiver positions and resultant coverage. The receiver line separation is 250m and red represents 480 fold points for 25m square bin

Results and discussion

During the 2010 acquisition phase there were no significant problems following the monitor pre-plots outside the obstructed areas. The post plot positions can be seen to accurately match the monitor pre-plots (figure 11). The crossline error between the recorded positions and the preplots is <25m for 92% of the receivers, with 99.4% <50m. The vast majority of occurrences where the difference exceeds 50m in the obstructed area of the field.

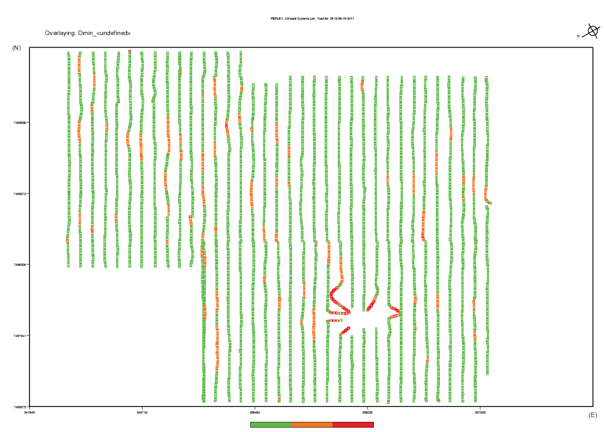

Figure 11. Post plot attribute showing radial distance from between post plot and monitor pre-plot.

Due to the complex nature of the 2005 acquisition the pre-monitor planning was viewed as essential to improving the positioning repeatability. Without the base line navigation data analysis and subsequent pre-plot modification the 2010 survey duration would likely have been prolonged due to difficulty in meeting the positioning specifications. Clearly the positioning repeatability is highly dependent on the deployment accuracy of the baseline survey, in the case Marimba 2005 a tighter specification, such as +/-10m, would have resulted in a simpler situation for repeat acquisition. The experience gained on this project should provide input for future baseline OBC acquisition in the deep water environment. This will allow the cost associated with accurate deployment to be assessed during the survey planning stage.

Of course the repeatability of shot and receiver locations is only one factor that influences the capability to measure subsurface time lapse effects. Other acquisition related issues such as wavefield sampling, source output variations, water column changes, receiver coupling effects and external noise factors are also important. These factors will be analyzed during the onshore processing of the seismic dataset.

Conclusions

OBC acquisition has proven capability in water depths up to 2000m. An increasing number of 3D OBC surveys are being acquired around complex installations in water depths up to 1500m. Despite challenges when working around subsea obstructions the OBC method provides good coverage with a high level of positioning repeatability. Based on current technology and experience it is viewed that average cable offline of less than 10m is possible even in 1500m water depth. Future acquisition with careful pre-planning and advances in deployment techniques should result in even better levels of positioning repeatability.

Acknowledgments

We would like to thank Petrobras for permission to publish this paper.

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