Node on Node, Highly Repeatable Acquisition for Reservoir Monitoring, Bonga Field Offshore Nigeria

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ABSTRACT

The Bonga field, located in deep water offshore Nigeria, has been producing since November 2005. Reservoir monitoring based on 4D time-lapse streamer seismic surveys was first implemented in 2008, bringing tremendous value in understanding fluid movements and sweep efficiency. However, the poor repeatability of the streamer surveys under the Bonga floating production storage and offloading (FPSO) facility, impedes the interpretability of the 4D results on the up-dip reservoir compartments. To enable 4D interpretation over the full reservoir area, Shell Nigeria Exploration and Production Company acquired in 2010 the first deep-water ocean-bottom node (OBN) survey in Nigeria to provide a 4D baseline and subsequently acquired in 2018 the monitor OBN survey. This case study illustrates the highly repeatable character of the OBN acquisition in an area with numerous production infrastructures. We review the inherent sources of non-repeatability associated with environmental change and describe the tailored OBN 4D processing and imaging applied simultaneously to the 2010 and 2018 surveys. The 4D attributes show excellent repeatability with normalized root mean square values around 5% and minimum 4D noise, both away from and under the Bonga FPSO, thus allowing monitoring the up-dip reservoir. The Bonga field's first OBN 4D survey demonstrates the excellent repeatability of this acquisition technique, even in an obstructed area. The project established 4D OBN processing workflows that delivered, in-country and in the required time frame, valuable high-resolution information on the reservoir changes.

Keywords: OBN, 4D, Time-lapse, Node Acquisition, Reservoir Monitoring and Repeatability.

INTRODUCTION

The Bonga field, located in the deep-water offshore Niger Delta was discovered by Shell Nigeria Exploration and Production Company (SNEPCO) in 1995. Production started in late 2005, including water injection to maintain pressure as part of the development plan. To optimize and monitor the Bonga field's production over the years, 4D seismic monitoring was implemented at an early stage. In this study, we discuss the workflow and result of the third 4D seismic monitoring project executed in-country over the Bonga field. The first 4D seismic survey was performed in 2008 and the second in 2012 (Quadt *et al.,* 2013; Effiom *et al.,* 2014). Both the 2008 and 2012 acquisitions utilized towed-streamer acquisition technology and, while bringing tremendous value in understanding fluid movement and sweep efficiency, they suffer from challenges in streamer positioning repeatability and from acquisition gaps around the floating platform storage and offloading (FPSO) facility, altering the 4D interpretability of the up-dip reservoir compartments. These challenges remain despite the 2012 survey utilizing steerable streamer and dedicated infrastructure undershooting techniques. Hence, to optimize acquisition repeatability and overcome the surface and subsurface access limitation, SNEPCO acquired in 2010 an ocean-bottom node (OBN) survey as the 4D baseline and, in 2018, the monitor OBN survey to enable accurate and reliable 4D interpretation over the full extent of the reservoir.

We review the characteristics of this first node-on-node seismic monitoring project over the Bonga field in terms of acquisition methods to minimize the non-repeatable variables during OBN processing and the new 4D results. We demonstrate that, with established OBN-specific processing algorithms and associated 4D QCs, we can deliver within the required five-month time frame, a high-quality 4D result to enable accurate interpretation of reservoir changes over the full reservoir extent.

METHODOLOGY

SURVEY DESCRIPTION

The Bonga field is located around 120 km offshore the Nigeria coast with water depths ranging from 800 m to

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1200 m. The field consists of several stacked, channelized reservoirs of Upper to Middle Miocene turbidite sands. Oil production is sustained through pressure maintenance by water flooding. Therefore, reservoir continuity is one of the main uncertainties affecting production performance (Detomo and Quadt 2011). For this first 4D OBN program, SNEPCO contracted Seabird Geophysical to acquire the two OBN surveys in 2010 and 2018. The 2010 acquisition utilized 1010 four-component autonomous nodes and 300,000 air-gun shots. In 2018, the survey utilized 1034 nodes and 303,000 air-gun shots. The extents of the two surveys differ in response to 3D image needs; however, they fully overlap on the core 4D area. Bonga's surface infrastructure (FPSO facility and associated single-point mooring system and their subsurface extensions) had virtually no impact on the sea floor node location deployment, which was achieved using remotely operated vehicles (ROVs), and a very limited impact on the source coverage (Figure 1).

For optimum repeatability, the two surveys shared the same acquisition configuration, with the OBN receiver layout on the sea floor based on a 412.5-m stagger grid and a 37.5-m shot grid. For both surveys, the shooting direction was east-west and the source characteristics were identical — the same tow depth, array configuration, gun type and gun volumes. Seven hundred and seventy-six common receiver locations were selected for the 4D processing with a common 6-km shot patch radius around each of them. From the acquisition side, as observed in other case studies (Craft *et al.,* 2016; Stopin *et al.,* 2011), Bonga's OBN surveys show an excellent repeatability of the receiver and source positions, which is essential for a successful 4D project. Analysis of the positioning difference between common OBN receivers (Figure 2) gives an average of 2 m, illustrating the accuracy of OBN receiver positioning using ROV technology.

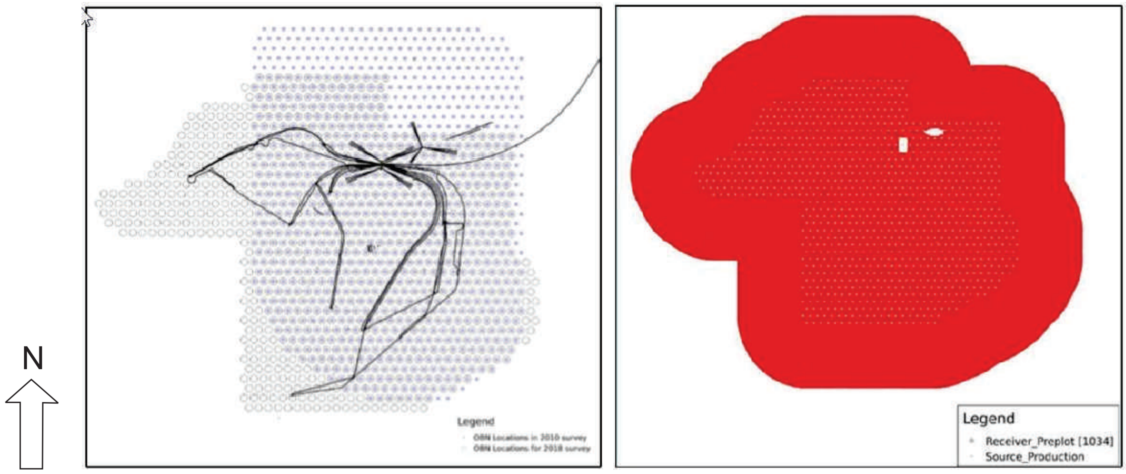

Figure 1 (left): OBN receiver layout, circle 2010 survey, dot 2018 survey and rigth) 2018 Bonga source coverage.

OBN 4D processing

The processing objective for the 4D seismic data was to produce concurrently high-resolution depth-migrated

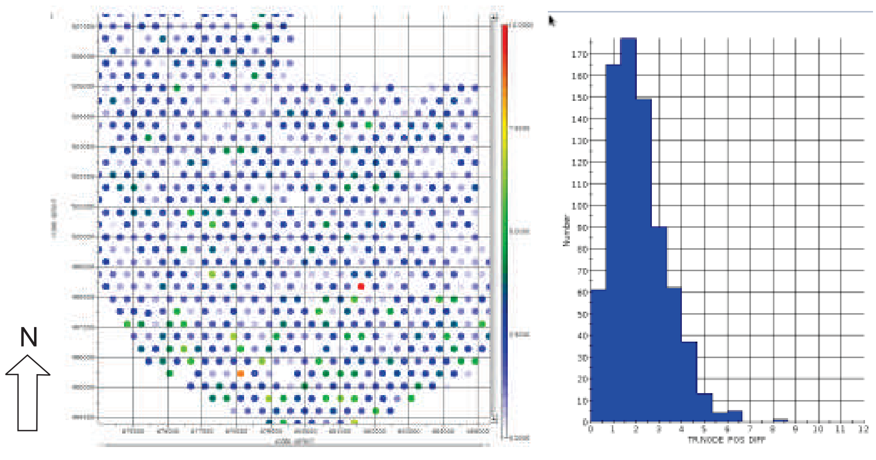

Figure 2: Receiver position difference between base and monitor surveys; average value of 2 m.

images from the 2010 and 2018 OBN surveys and, subsequently, subtract the 2010 survey from the 2018 survey to obtain an accurate 4D difference volume. An optimum 4D difference image should contain information associated with reservoir change only, the rest being considered as 4D noise. To achieve our goal, we used established OBN-specific workflows to process the raw OBN measurements (P & Z) into a downgoing wavefield through acquisition QC, water-column correction, noise attenuation, PZ calibration, angular designature, wavefield separation, and multiple attenuation (Kristiansen *et al.,* 2014) ready for imaging with a mirror migration. Throughout applying these processes, sources of 4D noise associated with the non- repeatable variables of our seismic experiment must be understood, QC'ed and corrected for preimaging.

The main sources of non-repeatability in 4D projects are the receiver and source positioning, the shot-to-shot variability, environmental noise, and the ever-changing state of the water column. For deep-water OBN 4D projects, as seen above (Figure 2), the repeatability receiver position is high and of less concern. The source positions are regularized to a common grid prior to wavefield separation and the gun variability is addressed through a shot- by- shot designature process. Environmental noise is limited as the receivers reside in a relatively deep-water environment, far from sources of noise such as swell and currents, and residual noise is addressed with early-stage noise attenuation processes. The Z vertical component tends to be contaminated by significant shear-wave leakage that requires careful attenuation, as slight variations in the receiver positioning and sea floor coupling make the shear noise non-repeatable and a too-severe attenuation could alter the 4D signal information. We use the X & Y components for shear-wave noise modelling and subtraction. Z to Z variations linked to variations in sea floor coupling are minimized during the node-by-node PZ calibration.

Autonomous nodes are affected by clock drift; however, the 2018 survey was acquired using a node that has an atomic clock, and correction was applied onboard with no residual corrections required. For the 2010 survey, linear and residual clock drift was applied onboard; however, analyzing the transit time in the water column from direct arrivals and of the residual clock drift values showed an unrealistic source acquisition pattern. Furthermore, travel time inversion of the direct arrival picks could not explain the water velocity profile from external Sippican's bathymetric measurement (Figure 3).

Therefore, the 2010 residual clock drift corrections were backed off from the data prior to starting the water velocity correction step. In a deep-water environment, the change in water column state is reported to be the main source of non-repeatability for OBN 4D surveys, especially when using the downgoing wavefield that encounters three legs in the water column (L'Heureux and Gherasim 2015). Our observations for the Bonga 4D OBN surveys were consistent with this. The changes in the water column state are associated with changes in tide height and changes in the acoustic characteristic of the water column from the seasonal variation of temperature and salinity and, potentially, from fresh water or loop currents. Tide and seasonal variation effects are shot-consistent and accumulate during the wavefield propagation, requiring a dynamic correction to make the seismic data appear as recorded with the stable water column of the velocity model used for the migration step (Mackay and Fried 2002).

Our approach was to primarily apply deterministic corrections based on external measurements available,

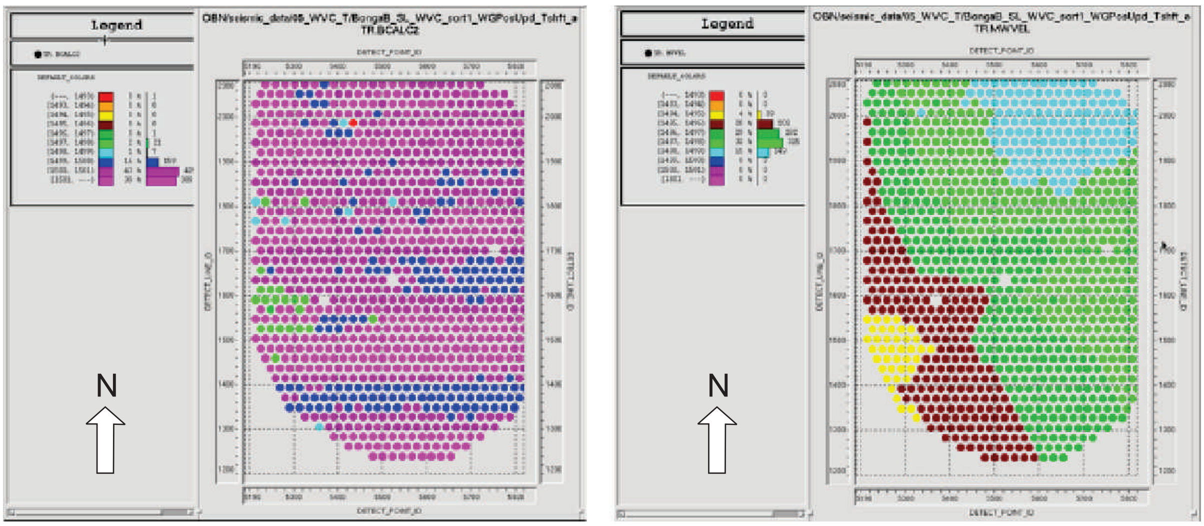

Figure 3: Base survey. Average velocity from best fit of direct arrival (left). Average velocity from SIPPICAN (right). The two are very dissimilar.

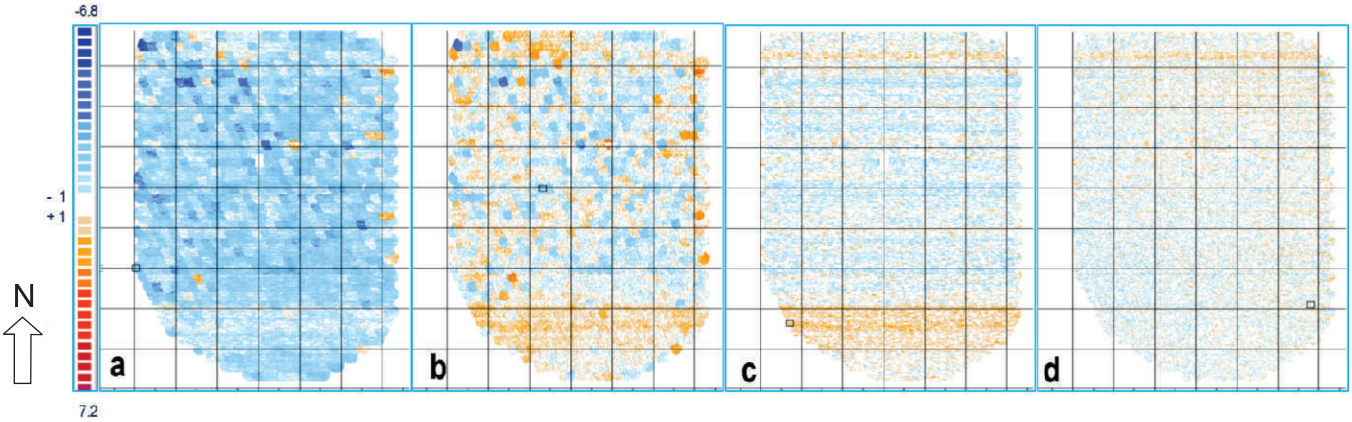

Figure 4: Residual transit-time error between picked direct arrival and modelled direct arrival, a) original, b) after tidal correction and average seasonal water velocity correction, c) & d) after traveltime inversion, c) receiver term applied, d) receiver and source term applied.

supplied tide tables for tide correction, and a correction based on the differences between the water velocity in the migration model and the water velocity measure during acquisition from SIPPICAN data. After dynamic application of these two sets of correction, direct arrival transit time differences between modelled data and picked data were inverted to source-consistent residual corrections and receiver-consistent residual corrections. The source term associated with wavefield propagation was applied dynamically. The receiver term was assumed to be associated with either residual clock drift for the 2010 survey or inaccuracy in receiver depth and were applied as static corrections (Figure 4). As the main source of non-repeatability, these water column variation corrections were extensively QC'd in a 4D sense (Figure 6). This was done in the data domain by comparing picked time and modelled time of the direct arrival and first multiple, as well in the image domain using node-based reverse time migration (RTM) mirror migration, which is very suitable for quick analysis (Figure 5), and offset vector tiles (OVT) Kirchhoff migration to evaluate the benefit of the dynamic correction with offset and ensure the OVT gather flatness at the water bottom. Post wavefield separation, simultaneous 4D, and surface-consistent amplitude corrections were derived between base and monitor surveys, but only the receiver term was applied before splitting the receiver gather in the OVT domain for Kirchhoff depth migration using a mirror model supplied by SNEPCO. Post migration, residual demultiple, residual moveout correction, and a frequency-dependent matching filter were applied to further optimize the 4D signal and reduce 4D noise.

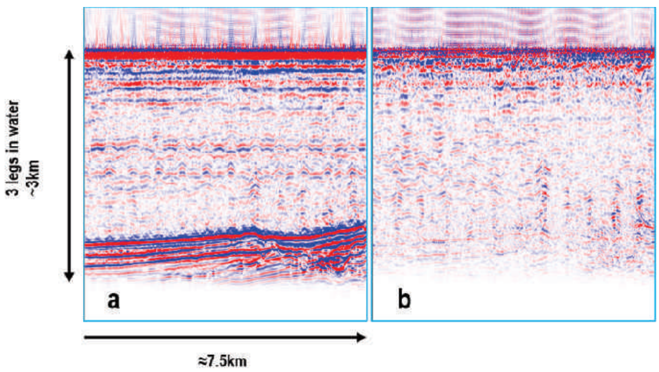

Figure 5: Transit time correction; 45-Hz RTM QC with mirror model and water flood velocity, a) base survey, b) 4D difference base minus monitor surveys after water velocity correction.

RESULTS

Figure 6 shows an example of the NRMS 4D attribute (Kragh and Christie 2001) generated for main processing steps post wavefield separation, from a global survey level view to the detail of a single receiver gather. We observed a reduction in NRMS, illustrating a better match between base and monitor surveys after each processing step. This gives confidence in the 4D compliance of our OBN processing workflow prior to imaging. Post migration, 4D attributes generated between the fully processed images show NRMS values of 5% (Figure 7), which is similar to other 4D OBN reported studies, and represents a significant improvement over the ~12% NRMS value reported (Quadt et al. 2013) on the second streamer on streamer 4D monitor study over the Bonga field. Figures 8 and 9 illustrate the low level of 4D noise and quality of the 4D signal, enabling accurate interpretation of the reservoir changes.

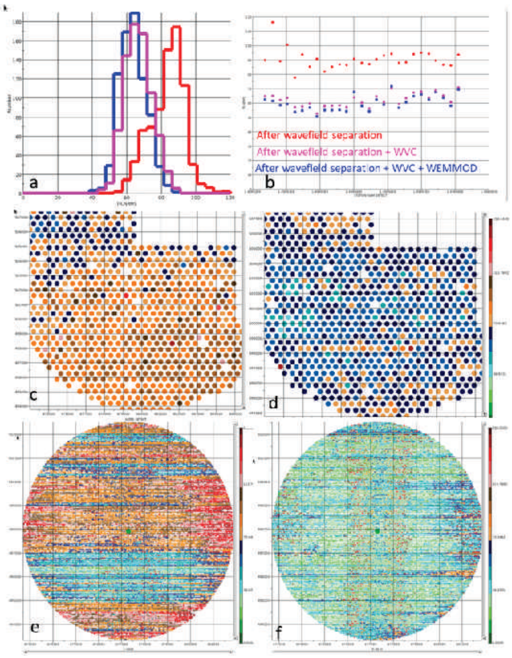

Figure 6: NRMS 4D QCs at survey level a) for a node line b), for each node c), before water velocity correction (WVC), and d) after WVC at the node level e), before WVC and f) after WVC.

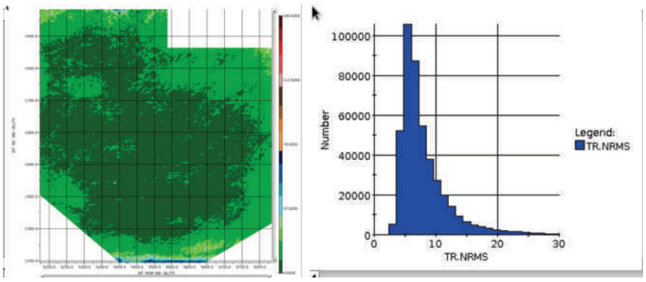

Figure 7: NRMS 4D QC, final migrated stack volume, overburden window.

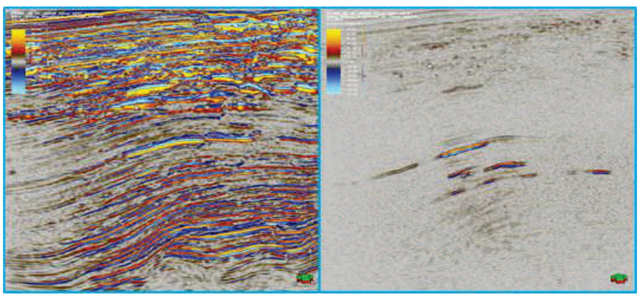

Figure 8: Inline section of the Kirchhoff depth migration for the base survey and the 4D difference volume.

SUMMARY

This study shows the highly repeatable character of the OBN acquisition over the heavily obstructed Niger Delta Bonga field. Applying an established and tailored OBN seismic processing workflow consistent with 4D

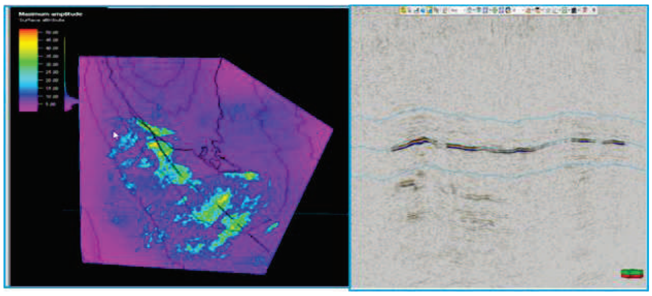

Figure 9: 4D difference from amplitude variation with offset intercept, amplitude extraction at reservoir level and random line through the reservoir.

processing objectives, together with a detailed understanding and correction of the non-repeatable variables, such as water-column variation, allowed us to deliver in the required timeframe, high-resolution 4D seismic data. These 4D seismic data were of sufficient quality to enable interpreting reservoir changes over the entire Bonga field area.

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