First De-ghost Depth Migrated 4D Signal on Akpo Field: From Acquisition to Innovative Processing Adaptations and Impact.

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Abstract

For close to a decade, seismic monitoring campaigns over the Akpo Field have been quite successful in impacting infill well development and reservoir management decisions. In 2018, a dedicated low-cost seismic monitor survey was acquired while achieving high repeatability metrics (lower dS+dR) in both the obstructed and the non-obstructed parts of the field. This was made possible with real-time iterative fold and repeatability acquisition QCs between vessel offshore and onshore site.

Prior to 2018, 4D seismic has been utilized rather qualitatively relying on narrow bandwidth time-migrated 4D signal. With the 2018 survey, a 4D seismic processing flow was innovatively adapted to de-ghost the 4D signal after the main de-multiple flow and then depth-migrate the 4D signal using a prior TTI PSDM velocity model after just one update of tomography. The combined results of the carefully executed 4D seismic acquisition survey and specialized non-conventional processing techniques has resulted in the first ever de-ghosted, larger bandwidth, depth-migrated 4D signal on the Akpo Field.

Initial results show that the 4D signal thus obtained is better resolved, more coherent with geology and more laterally continuous. This has increased confidence in the robustness of the 4D seismic in impacting infill drilling as well as permitting a more quantitative use of the 4D signal for model history-matching and dynamic model update for better forecasting of remaining field reserves in the maturing field.

Akpo field is operated by Total Upstream Nigeria Limited (TUPNI) on behalf of NNPC, SAPETRO, PETROBRAS and CNOOC.

Introduction

The Akpo field, operated by TUPNI, is located deep offshore, Nigeria and is 200km south of Port-Harcourt. The water depth varies from 1200m to 1500m and the reservoirs are turbidite channel complexes and lobes of Miocene age, containing under saturated critical fluids. Figure 1 shows the location of Akpo field relative to other big fields in the Niger Delta basin.

Since the first oil in 2009, previous monitor surveys acquired include Monitor 1 (M1) in 2011, Monitor 2 (M2) in 2015 and the very recent Monitor 3 (M3) in 2018. The baseline seismic was acquired in 1998 while the undershoot baseline seismic was acquired in 2009 covering the area with fixed surface installations (Akpo FPSO & Offloading Buoy).

After 10 years of production, the Akpo field has recorded great successes with 4D monitor surveys. For example, the M2 facilitated the identification of un-swept areas leading to infill drilling opportunities. The M3 processing was in two phases, the fast track and the full processing, the full processing of the M3 was carried out using a de-ghosted depth migrated approach, with the aim of pushing the fast track volumes (which was a 4D conventional PSTM delivered four months after the last shot point of the M3 2018 acquisition) to yield better results.

With these additional processing steps included, we were able to:

- Achieve bandwidth extension targeted at improving the low frequencies and enabling sharper and more continuous 4D signal;
- Increasing the 4D signal to noise ratio;
- Improving the lateral positioning and focusing of the 4D signal with one pass of velocity update and;
- Optimize the global matching between the three monitors, which was one of the feedbacks from the inversion team, in order to get better results from the 4D inversion.

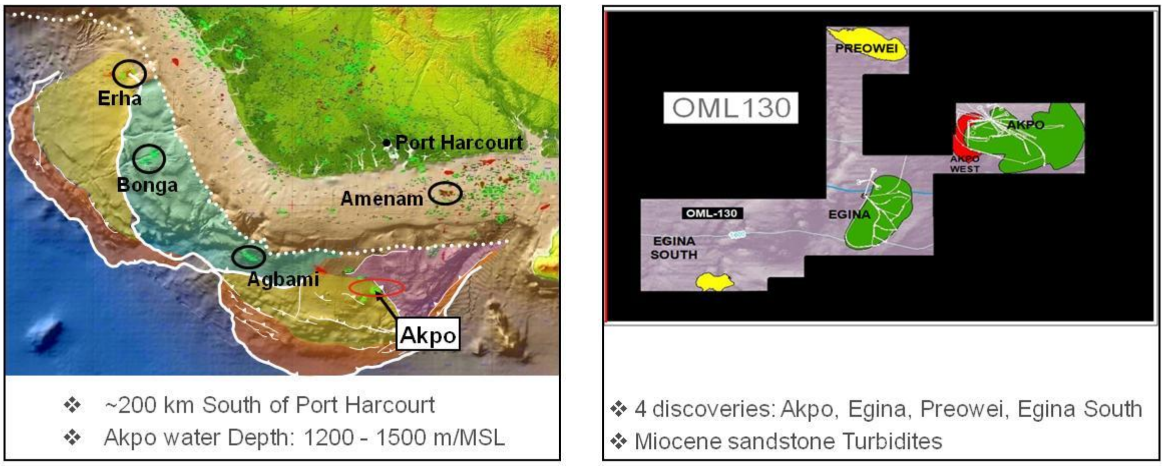

Figure 1: Regional location of Akpo field

Objectives & Challenges

The main geophysical challenge was to use an optimized workflow to extract a sharp and accurate 4D signature with a minimal turnaround time. The asset objectives of the 4D seismic were for reservoir monitoring & management; identifying infill opportunities, bypassed zones and as a guide for potential well intervention.

Increased Repeatability in Acquisition

In 4D processing, to detect changes in the reservoir, good repeatability of acquisition parameters is key to achieving good 4D results (Johnson 2013). However, getting the right match between surveys can be challenging given that the circumstances surrounding the previous acquisition will differ, with changes in factors such as ocean currents, temperature, tides and surface obstructions on the field. To mitigate this, it is highly recommended to have steerable streamers (to maintain source tracks and streamers on pre-plot), and also to have real time current data and a 4D in-field acquisition specialist onboard for optimal line planning. In order to reduce the impact of the listed factors, infills are designed and acquired so as to improve on 4D repeatability in areas of low fold. The baseline and the monitor surveys on Akpo field, apart from M1, involved single and dual vessel operations. The constraints of the fixed surface obstructions, Akpo FPSO & Offloading Buoy with about 2 km of separation between them as shown in Figure 2, led to an innovative design, which is the use of a push-pull asymmetric streamer configuration which enabled the acquisition of the 5200m far offset with reduced number of streamers and streamer length (the initial recording spread is therefore roughly divided by four due to HSE related risk in the obstructed area). This acquisition technique was used for the first time on Akpo field and in Nigeria in 2009.

The single vessel operation consisted of a spread of 8 streamers, each of 5200 m length and separated by 100 m, while the dual vessel operation consisted of four streamers, each of 2600m length and separated by 100m. In order to acquire the same offsets range and CDP lines comparable to the single vessel mode, it is necessary to navigate four times (two times in push and two times in pull) to acquire same data. The pull mode involves the source vessel leading the streamer vessel by 2600m for acquisition of long offsets (from 2600 to 5200m) while the push mode involves the source vessel lagging the streamer vessel by 350m for acquisition of the short offsets (from 350 to 2600m). The undershoot of the FPSO and the offloading buoy, and acquisition of the lines in between the obstructions (Figure 2), are facilitated using this acquisition push-pull method (Figure 3).

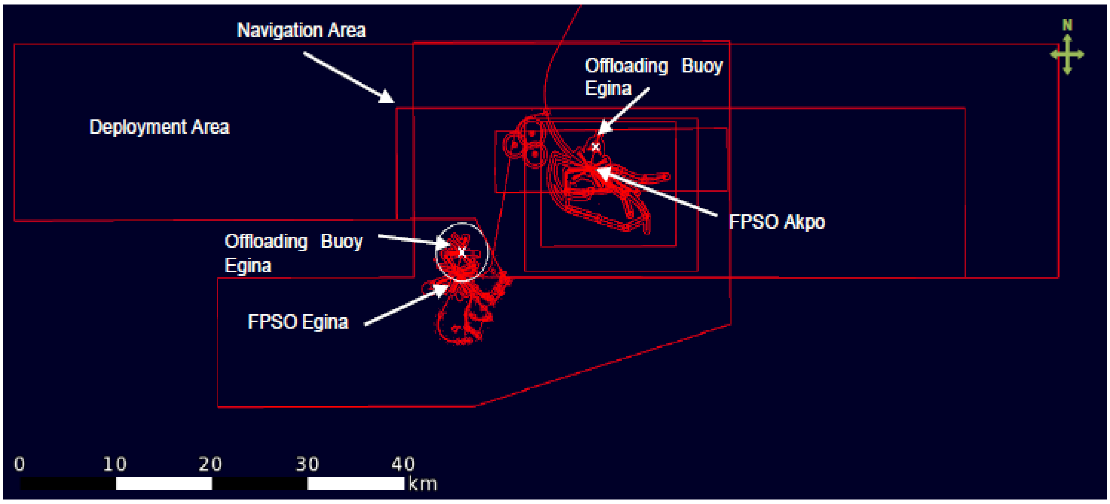

Figure 2: Survey Layout and Obstructions

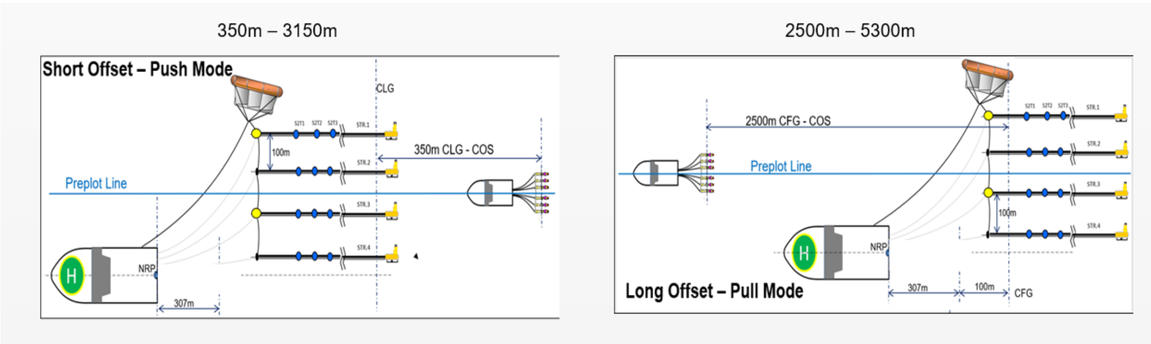

Figure 3: Configuration showing Dual Vessel configurations during Akpo 4DM3. Long offset – Pull Mode (Right) and the Short offset – Push mode (Left)

For the M3 acquisition, the pre-plot was the post-plot of M2 (prime & infill lines) with slight smoothening. Steerable streamers, near real time current data and optimal line planning by a 4D in-field acquisition specialist aided in obtaining very good dataset with medium to high level of 4D repeatability and coverage (Figures 4, 5). There was an additional constraint on the SW part of the survey area – the Egina OLT Buoy installation where 3 km exclusion zone was agreed. This affected the Run-in & Run-out in that area and consequently, the coverage without any detrimental impact on 4D signal at the reservoir level. There was a significant cost savings on the M3 survey due to better management, optimization and contractual conditions than for M2 in 2015. Lastly, the survey was completed safely without any significant or high potential HSE or Security incident and this was achieved in record time.

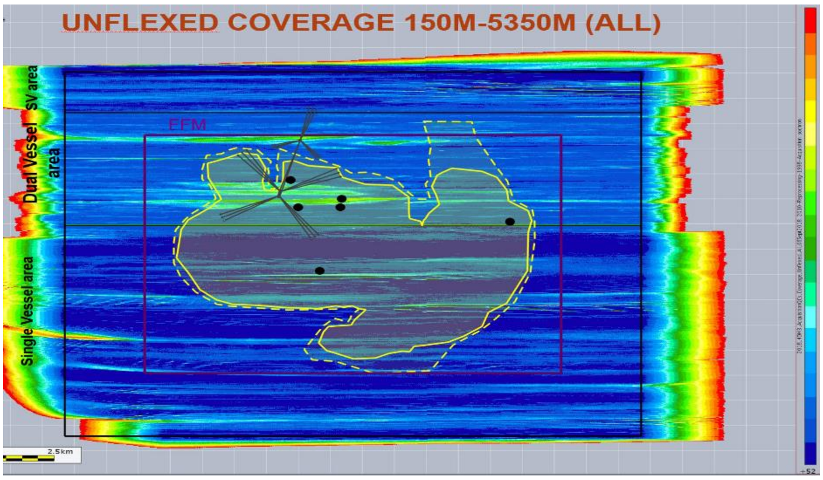

Figure 4: Unflexed coverage (150m – 5350m). Full fold achieved in both the single and dual vessel areas.

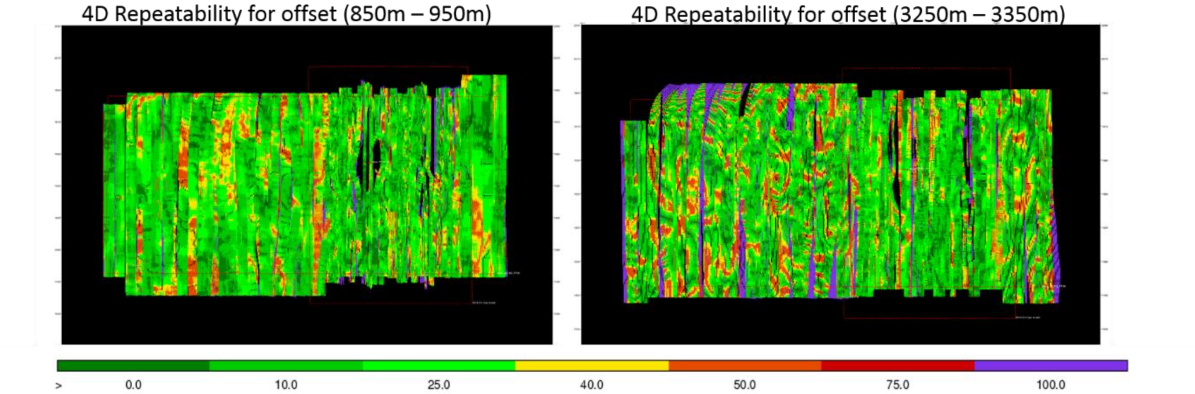

Figure 5: 4D Repeatability for Near and Far Offset

4D Processing

The 4D processing was done in two phases, the anisotropic PSTM fast track (delivered four months after the last shot-point), and the anisotropic PSDM full processing delivered six months later. The processing workflow was designed to co-process all three vintages together (Table 1), with M2 serving as the reference survey in those two separate instances. The fast track of the M3 used the regular 4D processing scope, while the full processing had additional processes such as de-ghosting and imaging, which were done for the first time on the Akpo field. Noteworthy is the fact that, the lessons learned during the fast track processing particularly for statics, matching, demultiple, destripping, 4D binning and regularization, were valuably used to optimize the full processing.

In a bid to achieve a good 4D signal, it was necessary to reduce the 4D background noise seen in the fast track. Therefore, multiple passes of denoise were applied in different domains on the co-processing of the three surveys to optimize the results. This can be seen in the 4D RMS and NRMS maps shown comparing results of the fast track and the full processing. The process of matching covered the overburden section, within the reservoir area and also in deeper sections. It was possible to closely monitor the progress of the processing with milestone 4D QCs carried out at intervals after major processing steps. Table 1 below shows the processing sequence applied to the full processing, text in red are the additional processes applied for the first time on the Akpo Field.

Table below show the processing sequence applied to both the fast track and full processing. Text in red are the addition processes applied for the full processing for the first time on the Akpo field.

INPUT NAV DATA - DESIGNATURE - DENOISE - DEMULTIPLE - AMPLITUDE DESTRIPPING - RMC - AMPLITUDE DESTRIPPING - INITIAL GLOBAL MATCHING - COLD WATER STATICS 3D SRME - DENOISE - DEGHOSTING - RESIDUAL DEBUBBLE - Q - PHASE ONLY GLOBAL FOOTPRINT REMOVAL - FREQUENCY MATCHING RESIDUAL 4D TIME & AMPLITUDE DESTRIPPING - 4D BINNING - 3D REGULARIZATION RADON DEMULTIPLE - RESIDUAL DENOISE (OFFSET) - VELOCITY MODEL BUILDING (1 UPDATE) TTI KPRESDM - RMO CORRECTION - STACK - Q - AMPLITUDE ONLY - 3D FXY DECONVOLUTION FREQUENCY MATCHING - TIME & AMPLITUDE DESTRIPPING

Table 1: Processing Sequence of Full processing Sequence (red text signifies the first time processes applied on the Akpo Field)

De-ghosting:

Conventional towed marine streamer suffers from sea surface ghost reflections, thereby compromising on signal bandwidth and limiting the resolution of seismic events and attenuation of deep signals. This can be seen as notches in the amplitude spectra as shown in Figure 6, corresponding to source and streamer depths at 5m and 8m respectively. A de-ghosting technique was used to address the above issue caused by surface ghost in order to increase the bandwidth of the data. Broadband data are well suited for 4D reservoir monitoring, for optimized recovery and decrease the interpretation uncertainty at reservoir level. Additionally, this rich low frequency solution enables accurate inversion of data, better structural & stratigraphic definitions, improved lithology, fluid prediction and serves as an optimal guide in making drilling decisions.

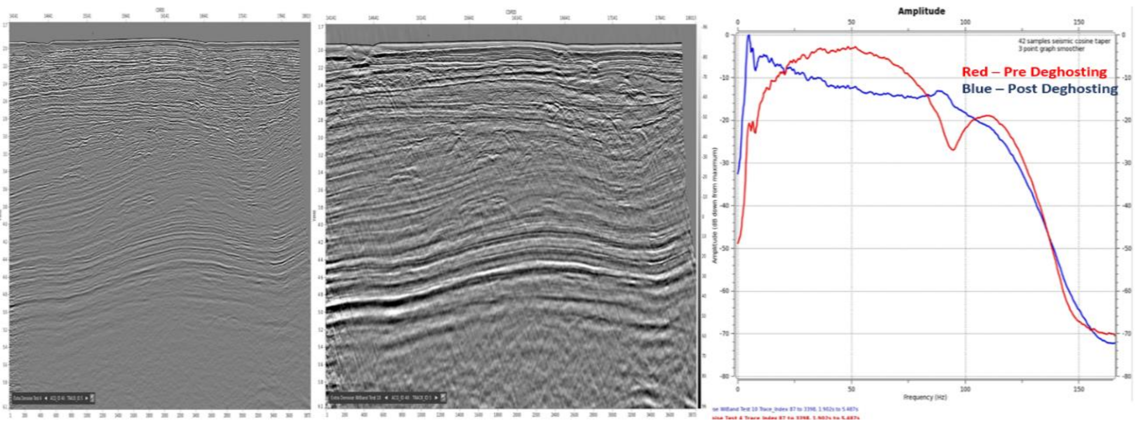

Figure 6: 2D Stack pre-deghosting (left) and post de-ghosting (middle). Amplitude spectra (right); red spectra (pre-deghosting) and blue spectra (post-deghosting)

Low frequencies are less impacted from earth's attenuation effects and can penetrate deeper layers. Low frequency data are also beneficial for waveform and impedance inversion as richness in low frequencies allows for better constraints in inversion results. The process of deghosting will ultimately boost both the low and high frequencies as it fills in the amplitude spectra around the notch frequency locations.

It was also necessary to apply several passes of denoise in multiple domains, each handling different noise elements, both random and linear. However, for the full processing sequence, it was decided that the 3D Surface Related Multiple Elimination (SRME) de-multiple output from the fast track, will be a good starting point for the full processing, as this route will minimize the impact of the boosted residual noise after deghosting. The already zero phased data was converted back to minimum phase to adhere to the deghosting assumption of an input minimum phase wavelet. Further testing ensured neither ringing nor artefacts were introduced post application of the deghosting process. Figure 7 shows results of de-ghosting in pre-stack domain showing a boost in low frequency.

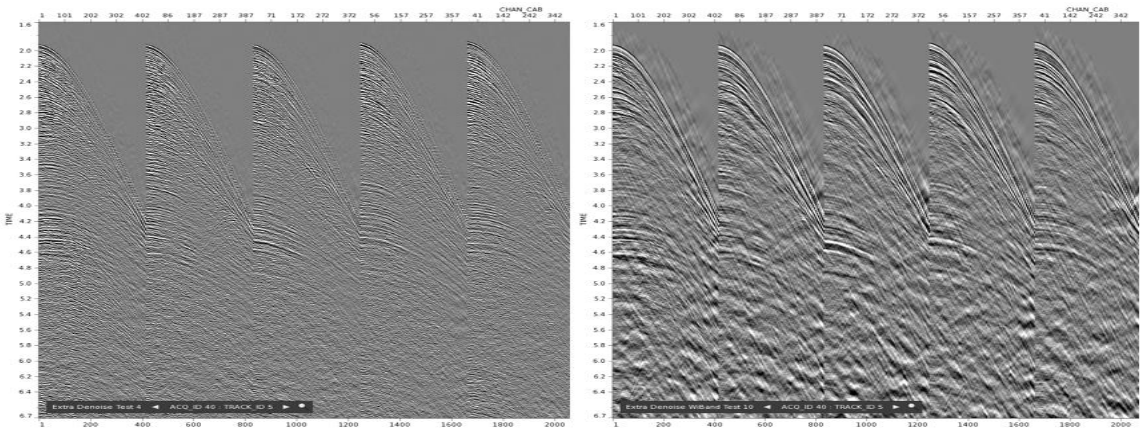

Figure 7: 2D gathers before (left) and after (right) Deghosting.

<u>Velocity Model Building</u>

In 2011, a depth velocity model was built for the Akpo field using the baseline data. This has been the reference velocity model for well placements. During the full processing of the M3, this model was updated to improve spatial positioning of structures and focusing of 4D signals. Using the newly de-ghosted datasets, one pass of velocity model update was performed, using conventional tomography in order to achieve a better stack response thus leading to sharper structural continuity of the 4D signatures, delineating flushed zones from bypassed zones.

The baseline data was selected for the tomography process. To ensure a stable automatic picking was achieved, the data was pre-conditioned in the XT domain. Gathers on a 50m x 50m grid were muted at 45 degrees to remove far offset stretch. Further cleaning of the gathers included attenuating the steeply dipping aliased multiple and eliminating high frequency noise which can interfere with the automatic picking and gridded tomography iteration process. One pass of long wavelength (800mx800mx240m) tomography was carried out to resolve the velocity variations seen in the initial (2011) model.

Depth misties analysis was done after the tomography velocity update by comparing well depth markers with seismic events. Several target lines were migrated to ensure structural consistency and that 4D effects are properly imaged. Improved gather flatness and structurally aligned signal coherency on the QC target lines indicated that the velocity model update was successful. Figure 8 shows comparison of the new velocity model and the initial model, with the DV (difference in velocity) derived from the new and the old models.

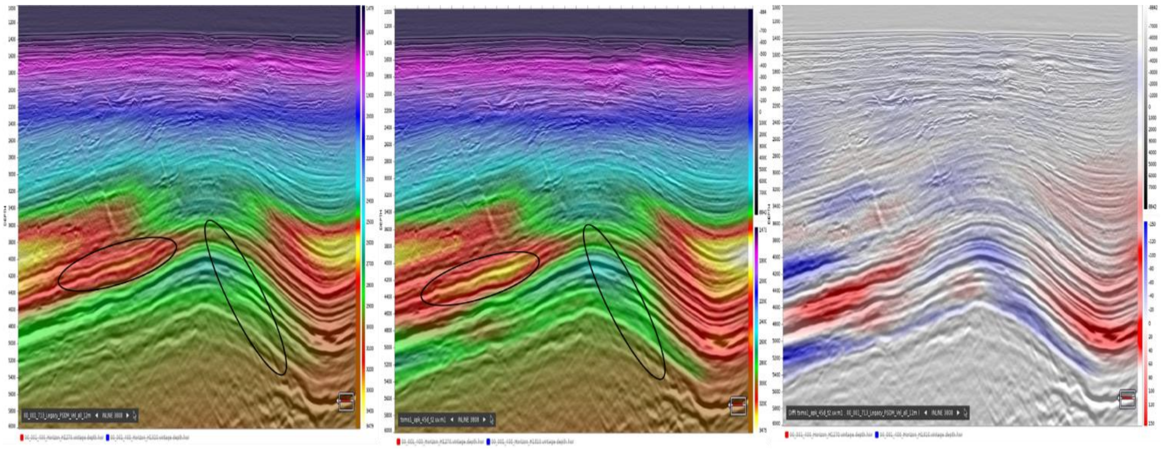

Figure 8: Structural stack overlain with velocity model: initial velocity model (left), new velocity model (middle), difference in velocity-dV (right).

Furthermore, due to the poor picks observed in the deeper section, a horizon was used to constrain the picks in the deep units to avoid introducing artefacts into the model.

After tomography inversion, a delta update was applied to maintain gather flatness and marker positions at the original depths. Depth misties carried out by the asset interpretation team on this data showed great improvement compared to misties derived from the 2011 velocity model. The improved velocity model was used for the final pre-stack depth migration on all three surveys.

Results

After the full processing, a significant impact on the qualitative and quantitative interpretation was achieved thanks to this new 4D processing approach including the addition of the de-ghosting and an update of the velocity model, needed to run an anisotropic pre-stack depth migration (PSDM). With the extra denoise steps applied in various domains, a major reduction in the 4D background noise was observed. Destripping and statics correction steps aided the convergence of time shifts (between the Base98 and M3 surveys) to the reference M2 survey, which in turn reduced the acquisition footprints and improved clarity of the 4D effects. Global matching done pre stack and post stack reduced the effects of residual 4D differences between survey pairs.

4D co-binning, using small ds+dr (repeatability between surveys) pairs between the three surveys made significant improvement with regards to the 4D NRMS (which measures the sensitivity of the repeatability metrics, with regards to the signal time shift and the signal bandwidth). It was also discovered that by limiting the ds+dr, we were able to eliminate the migration noise (feedback from fast track processing). The co-binned traces were fed into a regularization process, where small holes and empty bins (<250m) were filled, which helped to reduce migration artefacts that can arise from missing data and minimize acquisition footprints seen on the maps. Figure 9 shows a summary of the 4D NRMS progress tracked with 4D milestone QC's during the co-processing of all three surveys.

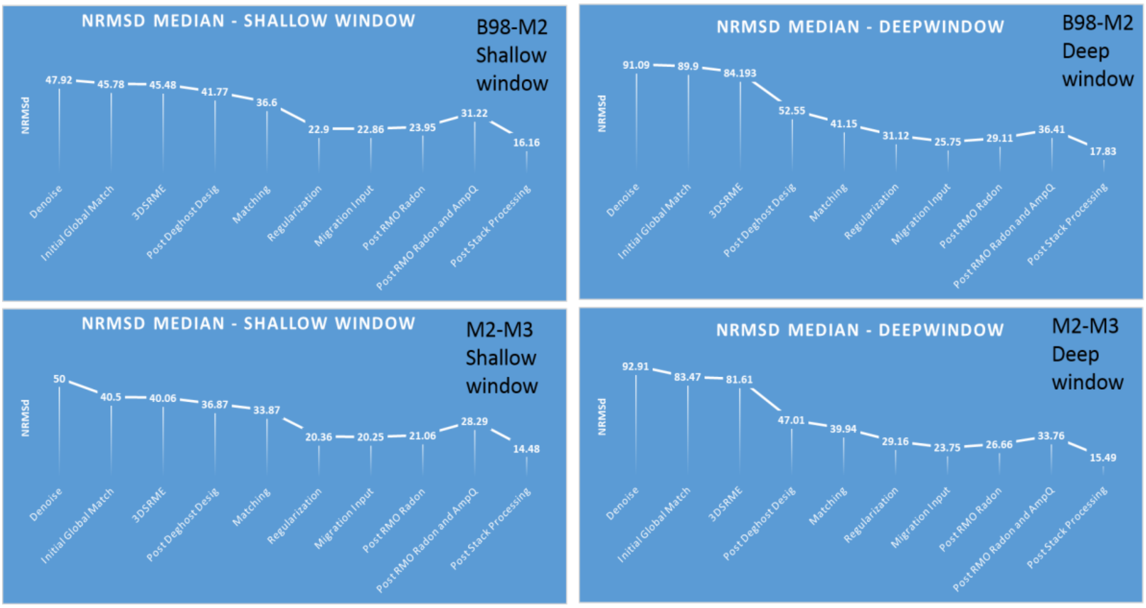

Figure 9: 4D NRMS evolution from the initial denoise to the final post stack processes applied to the data.

An anisotropic Pre-stack depth migration was run for all three surveys. This brought about further improved spatial positioning of the structures and increased focusing for more precise 4D differences. From the results below, a better focusing within the reservoir zone and better delineation of the fault structures is seen in the Akpo field. Figure 10 and 11 respectively shows maps and sections that cut across the producing reservoirs, with improvements achieved between the fast track and the full processing.

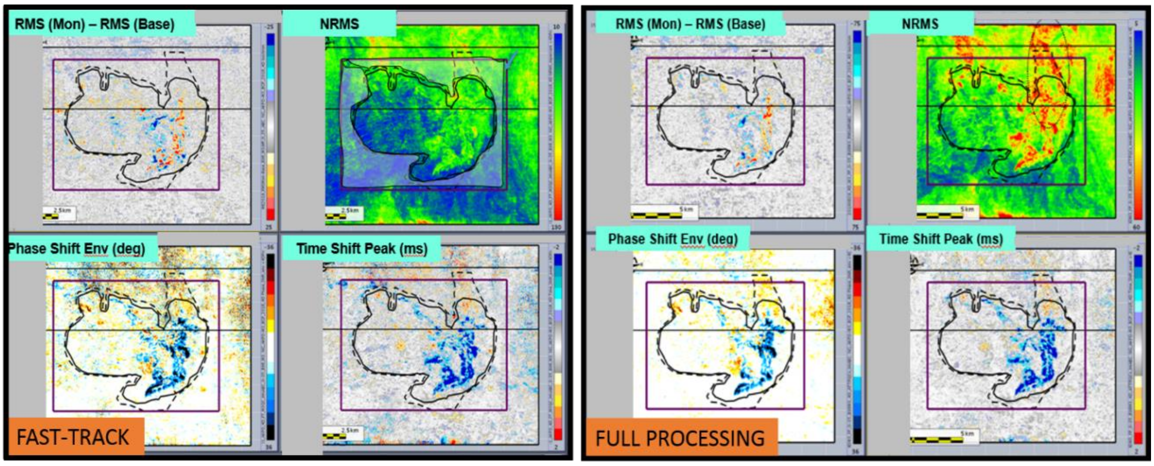

Fig 10: Qualitative differences between the FAST TRACK and FULL PROCESSING sequences in the major producing interval where activity is at its peak. *(Note the differences in scale between the fast track NRMS (10-130) and the full processing NRMS (5-60)).*

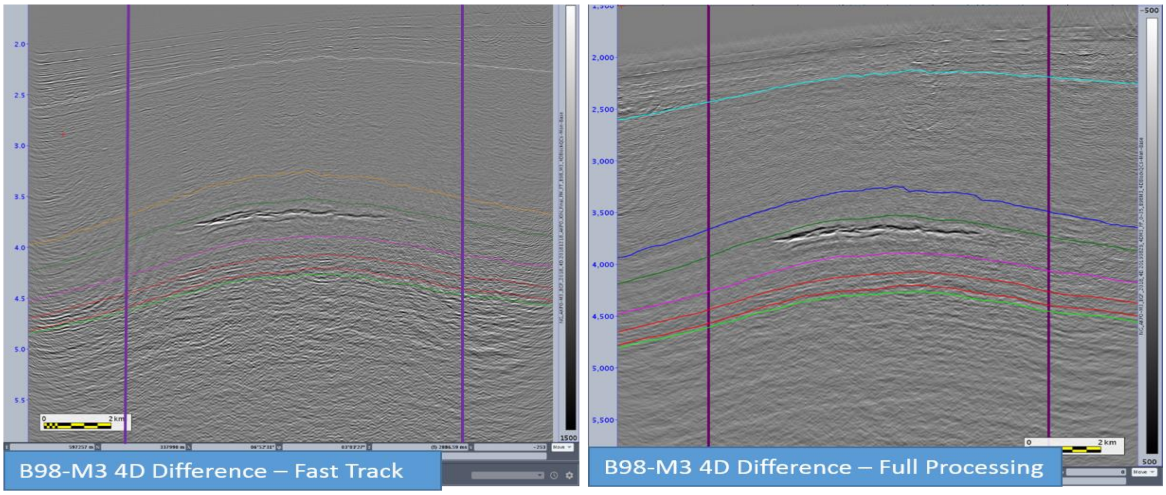

Figure 11: 4D difference of a crossline section across the Akpo field. Horizons overlaid represent overburden (between 2.5 – 3.5secs) and producing reservoirs (between 4.0 – 4.8secs). This depicts the difference seen between the anisotropic PSTM fast track on the left and the anisotropic PSDM full processing on the right. Less 4D noise on the full processing and there is better resolution. (*Note there are gain functions and scaling differences due to amplitude Q applied to the full processing)*

IMPACT

Preliminary results from 4D inversion, seen on the change in impedance, show that the fast track and the full processing have visible differences. The full processing shows better focusing and cleaner 4D signals. On the fast track, it appears what the asset thought was an over pressured zone (patches of orange) in the north east has drastically reduced (Figure 12). The obvious water anomalies seen in the west are similar, what we see as blurry in the fast track has sharper details in the full processing. Therefore, we have improved the illumination of this particular reservoir, as we see the 4D inversion gives more stable results permitting a more quantitative use of the 4D seismic data for history matching and dynamic model update, as well as confirming the location of infill wells on Akpo field.

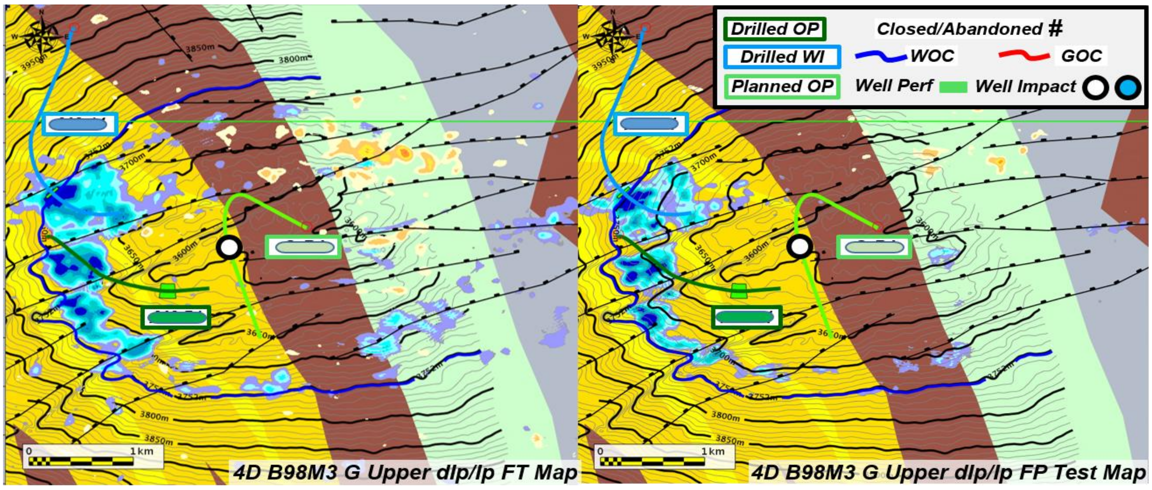

Figure 12: comparison between the Fast track (left) and full Processing (right), maps extracted are from one of the deeper reservoir levels overlain with 4D “change in impedance” between B98 and M3 over a period of 10 years.

CONCLUSION

Real time follow up of Akpo field 4D seismic acquisition and the use of steerable streamers helped to increase the much needed repeatability for a successful 4D seismic acquisition. Overall, good repeatability (ds+dr) was achieved between the M2 and the M3 even in areas with surface obstructions.

The Akpo 4D M3 processing followed two routes, the fast track processing and the full processing. For both processing routes, all three vintages B98, M2 (2015), M3 (2018) and their corresponding undershoots were co-processed together. The full processing had extra processes in the work flow such as optimizing the denoise, applying de-ghosting for bandwidth expansions and depth imaging, which was the first time for the field. With these steps, a major success has been achieved in the processing results seen on the full processing.

The velocity model update improved gather flatness and are more structurally coherent with the seismic image, most especially on the flanks. The results have confirmed with certainty that the addition of these processing steps have increased confidence in the robustness of the 4D seismic and have positively impacted infill drilling program.

Acknowledgement

The authors would like to thank the OML 130 partners – NNPC, SAPETRO, PETROBRAS, CNOOC and TOTAL for their permission to publish and present this paper. Also Bulwark-ION for processing this data in record time with good quality output, and the entire geophysics operations and Total Akpo-GSR teams for their support.

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