4D Harmonization of Non-Dedicated Time-Lapse Datasets - The CODD Field, Onshore Niger Delta Case Study

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ABSTRACT

The application of time-lapse seismic method for reservoir monitoring in onshore Niger Delta oilfields has been faced with some challenges due to environmental changes resulting from urbanization and industrial growth. These changes have posed great difficulties in acquisition of 4D seismic data in the Niger Delta. Combined with renewed exploration interest, repeat surveys usually have different acquisition geometries thereby creating geometrical repeatability problems.

This has been recognized as a major source of 4D noise. In the time-lapse processing of CODD field onshore Niger Delta base and monitor datasets which were acquired with different geometries and systems, we tested two methods of 4D binning with the goal of improving spatial repeatability while maintaining time-lapse signal. By identifying trace pairs that are close to each other and subsequent processing of these pairs, differences in acquisition between vintages is reduced and 4D processing is improved. The NRMS metrics was employed to qualify 4D data quality improvement.

Key words: Time-lapse, Binning, Repeatability, Geometry

Introduction

For several reasons, the application of time-lapse seismic technology as a tool for oil and gas field redevelopment in Onshore Niger Delta, to enable accurate assessment of by-passed and remaining hydrocarbon has been faced with some challenges. This has significantly reduced the success recorded for land 4D seismic method. Some of them are discussed here.

In carrying out time-lapse surveys, different acquisition instruments and parameters are usually deployed to properly cover the entire prospect and go even deeper than the previous depth attained in the initial 3D survey to accommodate fresh exploration objectives. These different acquisition instruments have different impulse responses that often impact on recorded seismic data. In considering the repeatability of the 4D seismic survey, the same factors as in previous 3D surveys such as hole depth, shot depth, receiver positions and patterns involving geophones and hydrophones, source types and positions, should be used for the 4D survey design. However, it is now necessary to improve the quality of successive 3D data set during the 4D seismic acquisition, especially in the deep layers by increasing fold coverage and the number of active channels.

Urbanization and industrial growth cause environmental changes which have made 3D repeat or 4D seismic surveys hugely challenging, both technically and operationally. New pipelines crossing the 3D seismic lines of baseline survey and springing up of new buildings in a previously surveyed area surely affect array geometry and pose the problem of repeating the base survey acquisition geometry. The resultant effect is that of too many offsetting acquisition stations which reduces spread control and the ability to repeat previous acquisitions, and the minimization of artifacts caused by differences in acquisition.

Even though multi-vintage surveys are mostly conducted under a common survey design (the common bin size, common source and receiver geometry, and common azimuth and so on), discrepancies in each survey geometry are inevitable in field surveys. 4D harmonization is usually applied in time-lapse processing for the reduction of the differences.

Broadly applied, 4D harmonization includes all efforts and processes applied from time-lapse seismic survey to processing of multi-vintage datasets to improve the repeatability of timelapse survey geometries and improve trace-to-trace similarities. However, in this paper 4D harmonization is considered and confined within the context of 4D binning which re-grids and re-aligns multi-vintage datasets to enhance repeatability.

In practice, there are several ways to calculate repeatability. We can calculate geometrical repeatability during acquisition. For each common mid-point bin, we can compare all base and monitor traces with similar offset and calculate the difference between the source (Delta Source) and receiver (Delta Receiver) positions. The combined attribute (Delta Source + Delta Receiver) is a good indicator of the ultimate 4D data quality. During acquisition the traffic light system can be used to identify problem areas and possible reshoots (where Delta Source + Delta Receiver is more than a defined threshold).

Another way to calculate geometrical repeatability in the field is to use a shot-based method. Here we find the nearest base and monitor source and calculate the difference in inline and cross position.

Furthermore, there ways to measure repeatability on seismic data. Many different metrics are used, but the most used in the industry is NRMS (Normalised RMS). NRMS is calculated from RMS amplitudes measured in a window. The RMS from the difference is normalised by the average of the base and monitor. In the case of good repeatability there will be little 4D noise in the difference window and the NRMS will be low. Other attributes are Predictibility, and SDR Total's (Signal Distortion Ratio – Cantillo 2011).

With 4D trace selection (4D binning), we wish to select only repeatable traces for further processing. It is a process by which pairs of traces between two vintages are compared for each bin on a common grid with respect to geometry and/or seismic repeatability. Whatever criterion is chosen (and in general use is made of several), we simultaneously populate a specific bin in both surveys using traces that exhibit the greatest similarity, immediately taking a significant step in reducing acquisition differences where possible.

Location and Geology of Area of Study

The CODD Field, is located 25 km SW of Port Harcourt, Nigeria, on Latitude: 4°26'56.5" (4.449°) North, and Longitude: 7°5'1.8" (7.0838°) East. It covers an area of about 200 Km^2 in the Niger Delta. The Niger Delta is situated in the Gulf of Guinea and extends throughout the Niger Delta Province as defined by Klett et al. (1997). From the Eocene to the present, the delta has prograded south-westward, forming depobelts that represent the most active portion of the delta at each stage of its development (Doust and Omatsola, 1990). The stratigraphic sequence of the Niger Delta comprises three broad lithostratigraphic units namely, (1) A continental shallow massive sand sequence – the Benin Formation (2) A coastal marine sequence of alternating sands and shales – the Agbada Formation and (3) A basal marine shale unit- the Akata Formation. The sand percentage in the Akata formation is generally less than 30%. The Agbada Formation consists of alternating sand and shales representing sediments of the transitional environment. The sand percentage within the Agbada Formation varies from 30 to 70%. The Benin Formation is characterized by high sand percentage (70–100%) and forms the top layer of the Niger Delta depositional sequence (Obaje, 2009). The massive sands were deposited in continental environment. The sediments of the Niger Delta span a period of 54.6 million years (Adesida et al., 1997).

Acquisition Geometry

As indicated earlier, the survey covers an approximate area of 200 Km2. Although categorized as onshore, the area is a mixed terrain of land, river channels and swamp. This also had a bearing in acquisition geometries and systems, thus making the 4D processing work more challenging. The first 3D survey, called the Base, was acquired with SN368 recording instrument in 1987 with a fold of 12 while a non-dedicated repeat 3-D survey, called the Monitor, was acquired with a 408UL recording instrument in 2002 with a fold of 48.

The basic geometry used to acquire the land portion of the Base 3D survey is Off End (swath type), bin size of 25m x 25m, 6 receiver lines with spacing of 350m with total active channels of 480. Source line spacing is 500m while receiver and shot points spacing are 50m respectively. The basic geometry used to acquire the water portion of the Base 3D survey is Cross spread, bin size of 25m x 25m, 6 receiver lines with spacing of 400m and total active channels of 96. Source line spacing is 100m while receiver and shot points spacing are 50m respectively.

The basic geometry used to acquire the land portion of the Monitor 3D survey is Off End (swath type), bin size of 25m x 25m, 6 receiver lines with spacing of 350m with total active channels of 960. Source line spacing is 500m while receiver and shot points spacing are 50m respectively. The basic geometry used to acquire the water portion of the Monitor 3D survey is Cross spread, bin size of 25m x 25m, 6 receiver lines with spacing of 400m and total active channels of 384. Source line spacing is 100m while receiver and shot points spacing are 50m respectively.

Acquisition and Trace Pair Depopulation

Due to 3D requirements aimed at the deeper targets, urbanisation and the presence of infrastructure it was not possible to acquire an exact repeat of the base CODD 1987 survey. The difference in the acquisition geometry was resolved by reducing the number of channels per line in the monitor survey (160) had to be reduced to the 80 channels per receiver line (RL) in the base survey by rejecting the first and last 40 receivers in each receiver line acquired in the monitor survey (Figure 1)

Despite the decimation by acquisition geometry, there was still needed to do a 4D (base, monitor) pair decimation in a panel based on a minimum distance criterion. This step helped achieve a comparable base and monitor fold maps compared to what the fold maps were before depopulation/decimation (Figures 2 -5).

At the binning stage, traces were selected which minimized the sum of source and receiver location differences to ensure that additional effort during acquisition was not compromised in processing.

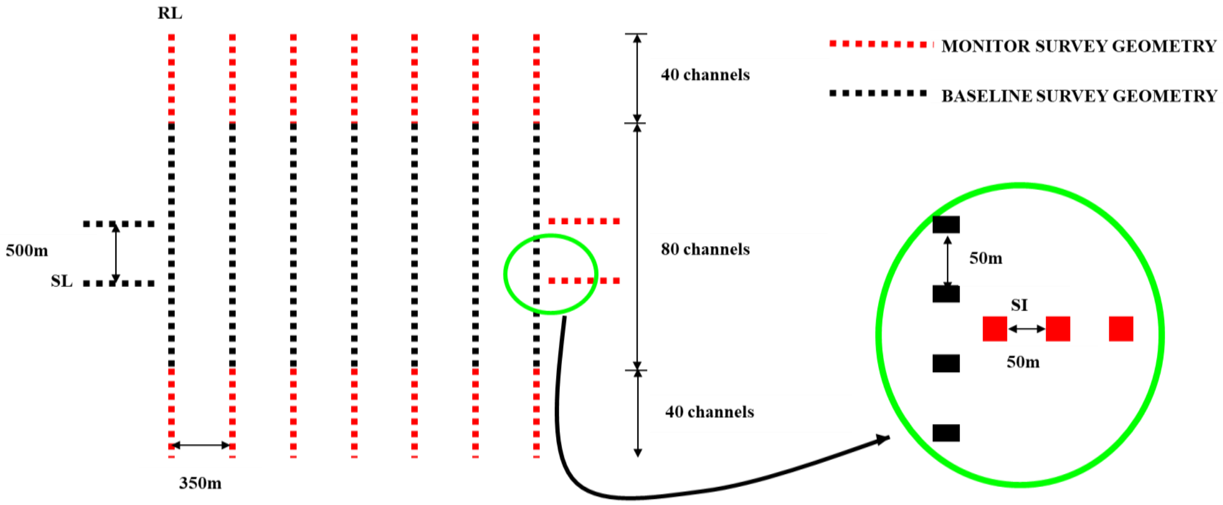

Figure 1: Base and Monitor surveys acquisition geometries

Data Selection and Equalization

Both base and monitor surveys have different dimensions in inline (IBLSEQ), crossline (IBPSEQ), shot-receiver offsets (XDIST), azimuth and fold or multiplicity. To improve repeatability (trace similarity), 4D data was selected for further processing. For 4D binning, base and monitor seismic datasets were simultaneously analyzed for the selection of optimum traces, which best satisfies a criterion (such as minimum distance between midpoint, bin-center or azimuth), guaranteeing equivalency between the time lapse datasets. Traditionally, equivalency is measured as sum or average of the distances between sources and receivers. However, the equivalency is also evaluated by computing the most similar mid-point location, offset, source or receiver location or azimuth (Helgerud *et al.*, 2011)

For the first method tested, up until this point, we had used all seismic traces available including the 3D and 4D flagged traces from the monitor surveys. A large amount of testing was dedicated to determining the best way to select the 4D data sets that were continuing in the processing flow. Original intention was to make use of the information in the headers to select the 4D data sets from base and monitor surveys. It soon became apparent that this 'base' case was not to be trusted due to lack of confidence in the header information. This approached was abandoned as a result and the 'Muerz' method (using cross-correlation coefficients) was applied.

The second method tested was the Sequential 4D Selection (S4DS) method, which uses geometrical constraints (selects pairs within a bin IBLSEQ/IBPSEQ based on closest shot distance) to select the 4D traces. This S4DS method was finally chosen to be the best solution for this field to provide better results in terms of multiplicity, offset and azimuth harmonization when compared with the Muerz method results.

Results

Figures 2 and 3 show the prior and outcome of using the Murez method respectively, focusing on achieving similarity using only the fold dimension of the base and monitor datasets.

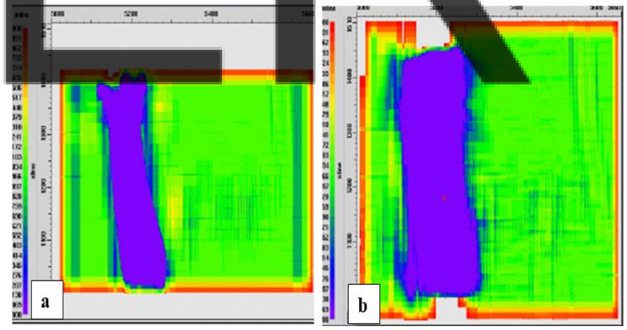

Figure 2: Multiplicity maps of base (a) and monitor (b) before 4D harmonization using Murez method

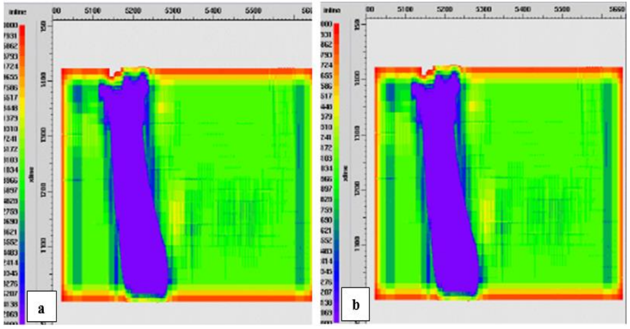

Figure 3: Multiplicity maps of base (a) and monitor (b) after 4D harmonization using Murez method

Due to different geometries and acquisition parameters as discussed earlier, the different folds of 12 for the baseline and 52 for the monitor were harmonized to a fold of 12 using the Murez method of 4D harmonization. However, the S4DS workflow used extra dimensions which included source-receiver offsets and azimuths. This 4D binning approach, harmonized the base, and monitor surveys from respective nominal fold of 12 and 52 (Figure 4), to and nominal fold of 12 for both vintages (Figure 5).

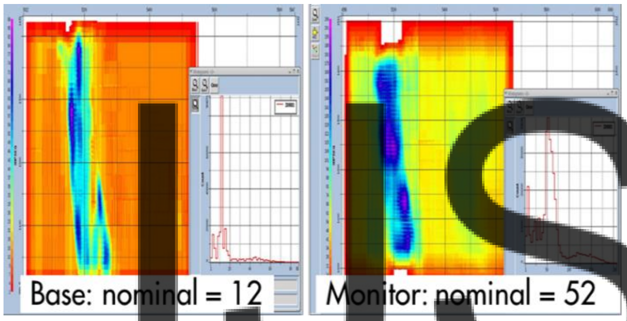

Figure 4: Fold map of Base and Monitor surveys before 4D Harmonization

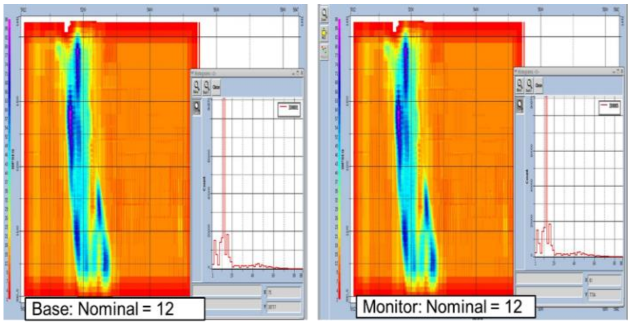

Figure 5: Fold map of Base and Monitor surveys after 4D Harmonization

The different offset ranges 180 m to 3704 m for the base and 155 m to 5291 m for monitor (Figure 6) were harmonized to offset ranges of 180 m to 3704 m for both vintages (Figure 7). An attribute of source-receiver offset difference (OFFDIF) measured for pre and post 4D harmonization showed that the offset difference between the base and monitor surveys decreased from a mode of 900m (approx.) pre-harmonization to a mode of 15m post harmonization (Figure 8).

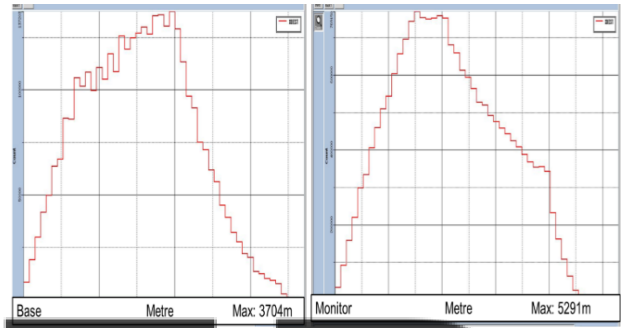

Figure 6: Offset distribution of Base and Monitor surveys before 4D Harmonization

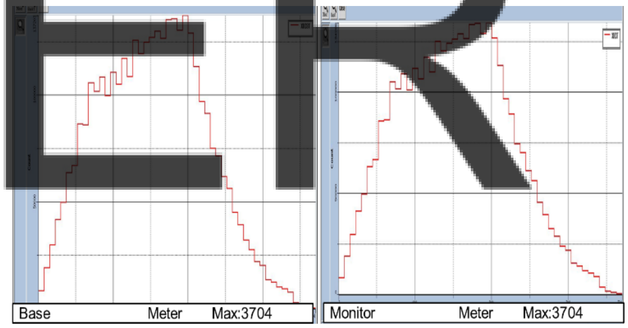

Figure 7: Offset distribution of Base and Monitor surveys after 4D Harmonization

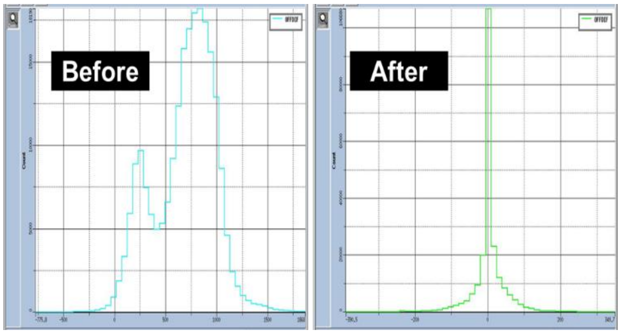

Figure 8: Offset difference between Base and Monitor surveys before and after 4D Harmonization

Post 4D harmonization using the S4DS workflow, the azimuthal difference (AZIDIF) was reduced to a mode of zero with just a few outliers (Figure 9). It is important to note that frequency bandwidth may not (and in most cases, will not, especially for non-dedicated 4D surveys) be fully aligned for both vintages post 4D harmonization. Spectral shaping of one vintage to another must be intelligently carried out.

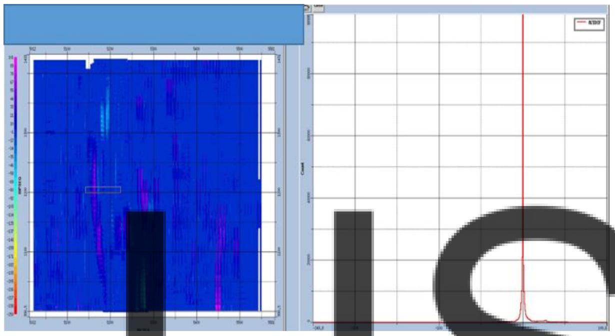

Figure 9: Azimuth difference after 4D Harmonization in Map and Histogram displays

Impact of 4D harmonization on seismic datasets

After depopulation and harmonization using seismic trace attributes, it was important to see how trace similarity is being achieved in the seismic datasets. Figure 8 shows a comparison of base and monitor datasets before 4D harmonization as described in the preceding sections. Observe the vivid differences in dimensions (Track/Bin), structure and reflection strength between the base and monitor datasets. Figures 9 and 10 show clearly on stacked seismic sections the impact of 4D harmonization in improving similarity between the two vintages.

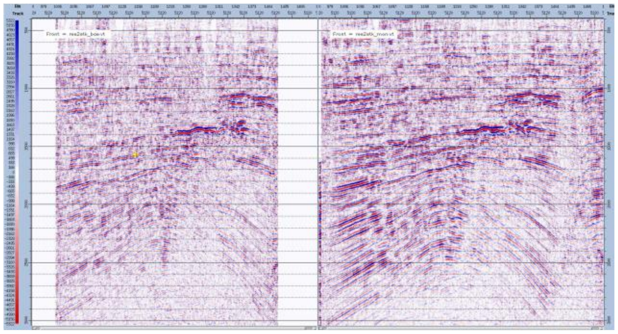

Figure 10: Inline direction comparison of base (left) and monitor (right) datasets before 4D harmonization

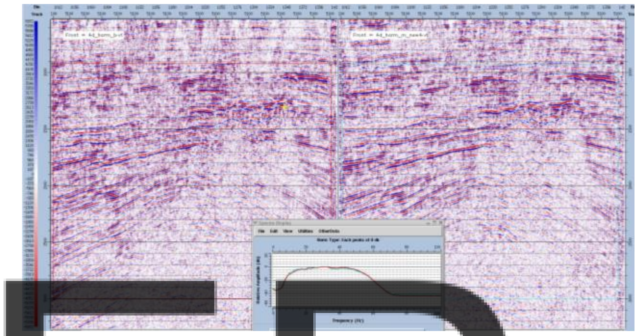

Figure 11: Inline direction comparison of base (left) and monitor datasets after 4D harmonization with spectral comparison inset

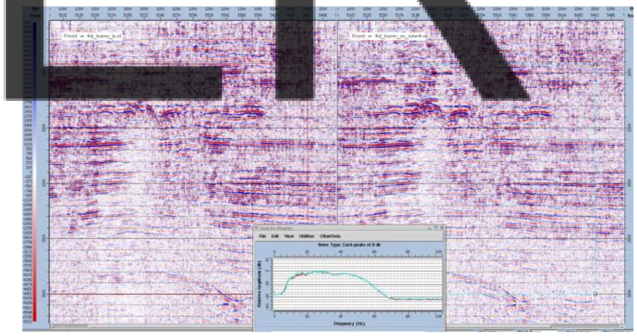

Figure 12: Crossline direction comparison of base (left) and monitor datasets after 4D harmonization with spectral comparison inset

Measuring impact of 4D harmonization using RRR (NRMS)

The benefit in terms of 4D data quality was assessed by comparing the quality attribute RRR before and after data harmonization. Figure 13 shows the respective maps and histograms of the

RRR, which was derived from the maximum cross-correlation of the stacked data at 1 second to 3 seconds. A general decrease in RRR (increase in 4D data quality) is clearly visible due to the 4D harmonization from a mode of 1.42 before to a mode of 1.1 after 4D harmonization based on the S4DS method.

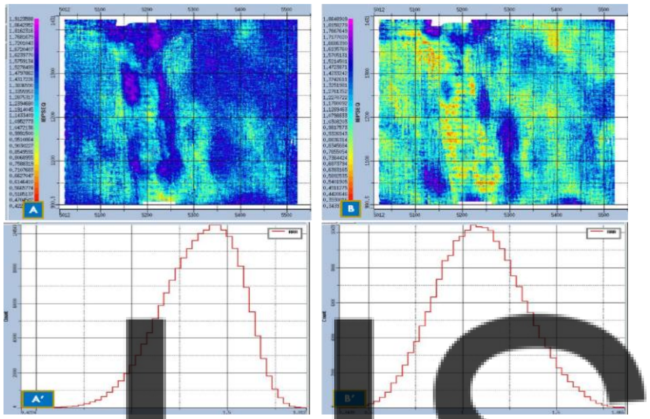

Figure 13: RRR map and histogram before (left) and after (right) 4D harmonization

Summary

With a dedicated 4D acquisition, it is relatively easy to decide on the acceptance threshold, but in cases with non-dedicated acquisition (like the CODD field), selection criteria become difficult decision. Sequential 4D Selection proved to be an adequate 4D harmonization method for the COOD field time-lapse processing work.

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References

Adesida A.A., Reijers T.J.A. and Nwajide, C.S., 1997, Sequence stratigraphic framework of the Niger-Delta. Paper presented at the AAPG international conference and exhibition, Vienna, Austria

Cantillo, J., 2011, A quantitative discussion on time-lapse repeatability and its metrics: SEG Expanded Abstracts, 30, 4160-4164.

Doust, H. & Omatsola, E. (1990). Niger Delta. In: Edwards, J. D. & Santogrossi, P. A. Editions. Divergent/Passive Margin Basins.American Association of Petroleum Geologists Memoir 48. Tulsa: American Association of Petroleum Geologists. pp. 239 – 248.

Helgerud, M.B., Miller, A.C., Johnston, D.H., Udoh, M.S., Jardine, B.G., Harris, C., and Aubuchon, N., 2011, 4D in the Deepwater Gulf of Mexico. The Leading Edge, 30, 1008–1018.

Klett TR, Ahlbrandt TS, Schmoker JW, Dolton JL (1997) Ranking of the world's oil and gas provinces by known petroleum volumes. US Geological Survey Open-File Report 97–463

Kragh, E. and Christie, P., 2002, Seismic Repeatability, Normalized RMS, and Predictability. The Leading Edge, 21, 640–647.