RMS Repeatability Ratio (RRR) Improvement of Time-Lapse Seismic datasets through Global Statics Corrections in CODD Field, Onshore Niger Delta

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ABSTRACT

An attempt has been made here to develop and implement a methodology for statics correction of time-lapse differences in reflection arrival times of time-lapse prestack seismic data. The method is called global statics correction (GSC). This is necessitated due to the difficulties encountered during the processing of the time-lapse 3D land seismic data. These difficulties are to a large extent attributed to changes in near-surface velocities which cause differences in reflection arrival times with attendant detrimental impact on time-lapse seismic imaging. The GSC method is compared with single vintage statics solution (conventional method) and presented for onshore Niger delta. The GSC method included cross-correlation of the traces acquired at the same locations but during different campaigns and calculation of the prestack time shifts between the surveys. The time shifts are decomposed in a surface-consistent manner, which yields static corrections that tie the monitor data to the baseline data. While both workflows demonstrated their capability to improve similarity between the time-lapse datasets, it is shown that the GSC approach reduces 4D noise more effectively than separate statics corrections and improves the RMS repeatability ratio further.

Key words: Time-lapse, Statics, Cross-correlation

INTRODUCTION

In the processing of reflection seismic data, static corrections are applied on a trace-by-trace basis to compensate for the effects of surface elevation variations, near surface weathering layer velocity and thickness variations. Statics refer to time shifts that are caused by shallow velocity variations and topographical changes. They are commonly corrected by assigning time corrections to the respective shot and receiver positions in two steps (Dahl-Jensen, 1989): Firstly, refraction static corrections consisting of a correction for elevation and a correction for variations in refracted wave traveltimes (Lawton, 1989) and secondly, residual static corrections to take care of the remaining variations by shifting the traces in the normal moveout corrected CDP gathers, e.g., by maximizing the stack power (Ronen and Claerbout, 1985). The main objective of static corrections is to calculate reflection arrival times representing a survey consisting of a flat plane (datum) on which all arrival times are no longer affected by low near surface velocities or a weathering layer (Cox, 1999). These corrections remove a significant part of the traveltime distortions from the data — specifically, long-wavelength anomalies. Nevertheless, these corrections usually do not account for rapid changes in elevation, the base of weathering, and weathering velocity. Removal of near-surface distortions on reflection times associated with deeper reflectors is routinely done by lowering the shots and receivers along vertical ray-paths from the surface to a datum below the weathering layer. The positioning of shots and receivers to a datum along vertical raypaths amounts to static time corrections in a surface-consistent manner.

Time-lapse seismic methods have undergone considerable development in the past decades. Several case studies have demonstrated that 4D seismic surveying can play an important role in hydrocarbon reservoir characterization and monitoring (e.g. Landrø et al., 1999, Lumley, 2001). Most reported surveys were conducted for production monitoring of offshore reservoirs. Only a minority of the publications deal with onshore surveys. One of the biggest challenges in onshore time-lapse seismic data processing is compensating for the effects of the near-surface conditions. This is usually faced in a vintage-dependent sense because changes in statics due to changes in the near-surface conditions are known to be first-order contributors to time-lapse noise (Kragh and Christie, 2002). Considerable changes in the statics of repeated onshore seismic surveys can occur due to precipitation-related changes in soil moisture and in the groundwater table. Accurate static correction is an essential prerequisite for quantitative time-lapse interpretation methods that are based on time shifts (Landrø and Stammeijer, 2004; Chadwick et al., 2012).

In processing of this onshore Niger delta time-lapse seismic data, two different approaches of refraction and residual static corrections have been used to enhance the stack coherency of the individual dataset vintages, yielding varying degrees of improvement in RMS Repeatability Ratio (RRR) time-lapse measurement metrics.

The first approach (termed here as the conventional method) builds a 2-layer velocity model for respective vintages of the time-lapse datasets, estimates statics solutions per survey and applies each model to the respective datasets in a parallel processing sequence. The second approach (termed here as global method) combines both the baseline and monitor datasets, harmonized the input offsets, builds a common near-surface model which is used to estimate a global statics solution and applied to the individual time-lapse surveys. These time shifts were first decomposed in a surface-consistent manner, with the source and receiver terms applied to align each monitor survey with the baseline. The global method was found to yield considerable improvement in time-lapse repeatability metrics over the conventional method.

The main reason for this is the general inability of refraction static corrections to provide sufficiently accurate velocity models of the weathered layer, which is due to 2 factors. First, the inherent band limitation of seismic data and low signal-to-noise ratio (S/N). This makes a reliable first-break determination in many cases impossible for the baseline dataset. Second, the solution to refraction static problems can be nonunique (Palmer, 2010a; 2010b).

LOCATION AND GEOLOGY OF AREA OF STUDY

The CODD Field, shown Figure 1, is located 25 km SW of Port Harcourt 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 (Figure 1) 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).

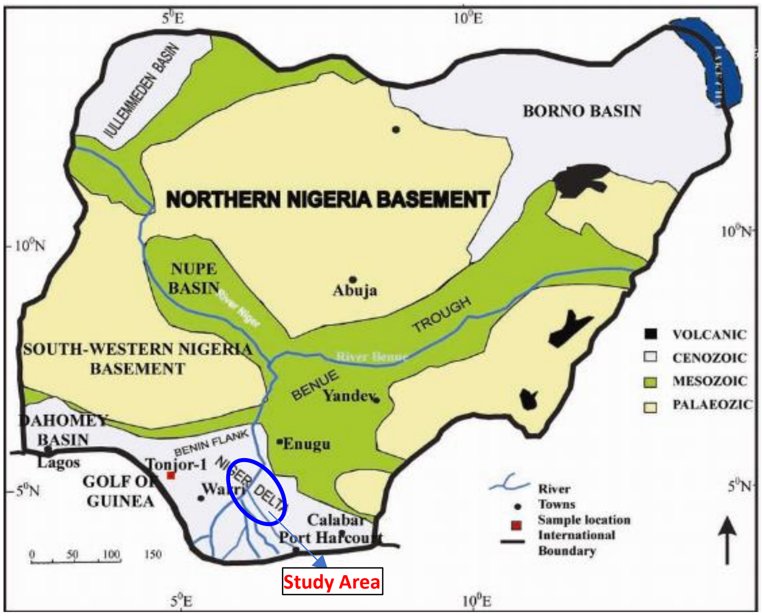

Figure 1: Map of Nigeria showing the study area (Source: Reijers *et al*. (1997))

DATA AVAILABILITY AND SUITABILITY

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 further complicating the 4D processing work. 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.

Seismic data quality for both survey vintages is fair. The monitor survey has better data quality including better fold and longer offsets. Better signal-to-noise ratio is observed in the monitor brute stack over the base brute stack. This is due to better acquisition parameters deployed in the more recent monitor survey. There was a fair amount of noise present in all data sets, particularly in Base survey. High-energy, narrow-band, time-localized noise is also prevalent in both surveys.

METHODOLOGY

Statics correction is a key impacting step in time-lapse processing as it provides a means to correct for overburden effects. Refraction technique utilizes the travel-times of critically refracted seismic energy to compute the depth and velocity structure of near-surface layers (Palmer, 1981). This method can indirectly estimate intercept time and bedrock velocity using the first arrival times and uses this to estimate a shallow velocity and depth model at all locations within the survey area.

The first step in refraction statics derivation was picking the first breaks from the seismic data (Base and Monitor) - on linear moveout corrected shot gathers using a refractor velocity of 1750m/s. First break blanking was done using initial mute function and the model attribute card of distance-time pairs. As there is a river channel across the survey area, river corrections were applied to the first break picks and the seismic data before application of the calculated refraction statics. The effect of these corrections was for the airgun sources to be lowered to the water bottom (i.e., ZSHT [shot depth] to water bottom), and for the hydrophone receivers assumed at water level to be lowered to the real hydrophone depth (i.e., ZREC [receiver depth] to real hydrophone depth). Effort is made here to explain differences in strategy between the conventional statics correction workflow and the global statics solution workflow.

The conventional workflow used individual first break picks for base and monitor surveys to solve for and apply statics corrections respectively using different models. The workflow employed is listed below.

1) First break picking

2) QC of picks in time-offset domain and building initial velocity model
3) Tomographic inversion
4) Model QC and Datum Selection
5) Statics derivation

The process started first with extensive testing of various first break picking parameters (travel times from source to receiver via the base of the weathering layer) and first breaks automatically picked. The process of picking the first breaks was done with a lot of care and QC because the picks are not always exactly on the actual first break of the traces. Erroneous picks could translate to inaccurate statics solution. It is preferred to have a null pick than to have a wrong pick since the values of the first arrival for the null pick can be estimated using surrounding picks as a guide.

The reciprocal error was checked, and the wrong picks were edited until the shot misfit was brought down to as low as reasonably practicable (in this case, 15ms). The picks were then displayed together in shot offsets and bad picks were manually cropped out and a new traveltime file was created from which the initial velocity model was built from. Using the traveltime file and the initial velocity model that was built, first arrival traveltime tomography was performed. Fifteen (15) iterations resulted in RMS misfit of about 16ms. This process was followed by defining the intermediate and the floating datum for statics calculation and also to examine the raypaths associated with the near-surface model. Each datum was carefully smoothed to remove jitters. After QC'ing, the short-wavelength statics and the long-wavelength statics were calculated using the traveltime tomography and with the knowledge of the weathering layer velocity.

The computed statics was exported as total statics to final datum which had both the shot and the receiver components of the statics. The replacement velocity used for the application was 1750m/s. This value is gotten by taking the average velocity along the intermediate datum. The weathering layer effect was therefore compensated for by replacing the unconsolidated layer medium with a constant refractor velocity (replacement velocity) of 1750m/s.

The only major difference between the conventional and the global refraction statics solution workflow is that for the later, after picking first arrivals for each survey, all picks (from both the base and monitor datasets) were merged into one single file and the offsets limited to a maximum of 1600 m for consistency in input data offsets for both the base and monitor datasets, to derive and apply shot and receiver statics as calculated using a single near surface velocity depth model as described above.

In this study, residual statics was executed to improve on the refraction statics solution, as there was still some unresolved residual short wavelength statics left in the data after refraction statics. This is the derivation and application of SURFACE CONSISTENT residual statics. Variations in the thickness and the velocity of near-surface low-velocity layers often cause considerable variations in reflection times within bins. This results in non-alignment of traces prior to stack and would result in stacks with poor signal-to-noise (S/N) ratio and spurious lateral variations in seismic reflection character. The corrections for the variations in the near-surface layers are assumed to be time-invariant (static) and surface-consistent, i.e., all traces generated at one shot station or recorded at one receiver station are assumed to require the same shot or receiver static correction. Reflection times were picked, and picks inverted to estimate surface consistent shot and receiver static corrections.

Prior to the residual statics computation process, velocity analysis was executed on the input common mid-point (CMP) sorted data with the RMS or effective velocity model updated in an iterative manner after each residual statics update.

To compensate for 3D acquisition’s inherent coarse grid which causes a lack in sequential ordering of multiplicity, crossline and inline bins were combined optimally in the picking panel in order to guarantee trace coupling in statics calculation. This also ensures that the results are due to geology, since bins are summed, and we do not expect geology to remain the same. It will prevent ‘zero solutions’ which results in jitters on the stacks. The data was sorted to provide a continuous wrap around at the inline ends. The number of bins smashed in each direction is a function of the acquisition parameters for each survey.

Two approaches were attempted. The first (conventional method) approach involves the use of super-bins. To calculate the superbin of a survey (base or monitor), with receiver line spacing of 350m and shot line spacing of 500m having point spacing of 50m. Receiver line spacing/ receiver point spacing and shot line spacing/ shot point spacing = 350/50m and 500/50m= 7:10. Finally, we pick the lowest numbers that can divide 7 and 10 with a remainder (2 and 3 respectively). So, the super bin in the inline / crossline direction will be 2x3.

The second approach (global solution method) involves the use of 2x2 overlapping bins irrespective of the acquisition geometry. Also, the bin numbering, for both methods, is recalculated and sorted to achieve a continuous wrap around at the inline ends (i.e., the last bin number of the first inline will continue with the last bin number of the next inline and then moving upwards). This is to avoid jumps in the picked times from panel to panel at the end of the line caused by inline sorting of the data. Within each panel each trace was correlated with both a reference trace and its 20 nearest neighbors. The reference trace was constructed from the stacked traces of the previous picking panel with their time picks applied. The picking gate was 2000 ms long and centered around 2000 ms.

RESULTS AND DISCUSSION

The refraction statics corrections were applied to both the baseline and monitor datasets after derivation using the conventional and global workflows. The ranges of statics and impact on datasets were closely observed and analyzed. Figures 5A & 5B are plots of base survey receiver statics solutions which ranged from -112 ms to 22 ms and from -40 ms to 30 ms for the conventional workflow and global statics correction workflow respectively. The base survey shot statics range from -58 ms to 30 ms and from -31 ms to 30 ms for the conventional workflow and the global solution workflow respectively. This is shown in Figures 6A & 6B.

Likewise, in the monitor survey, Figures 7A & 7B show that receiver statics range from -43 ms to 7 ms and from -41 ms to 10 ms for the conventional workflow and global solution workflow respectively. The shot statics range from -39 ms to 32 ms and from -41 ms to 32 ms for the conventional workflow and global solution workflow respectively as captured in Figures 8A & 8B. Comparing these values with the shot and receiver elevation maps indicated reasonable agreement. However, it was observed that the absolute range of statics values derived using the conventional workflow were larger in most cases and included more outliers when compared to those derived with the global workflow for base sure while the ranges are comparable for the monitor survey (see Table 1).

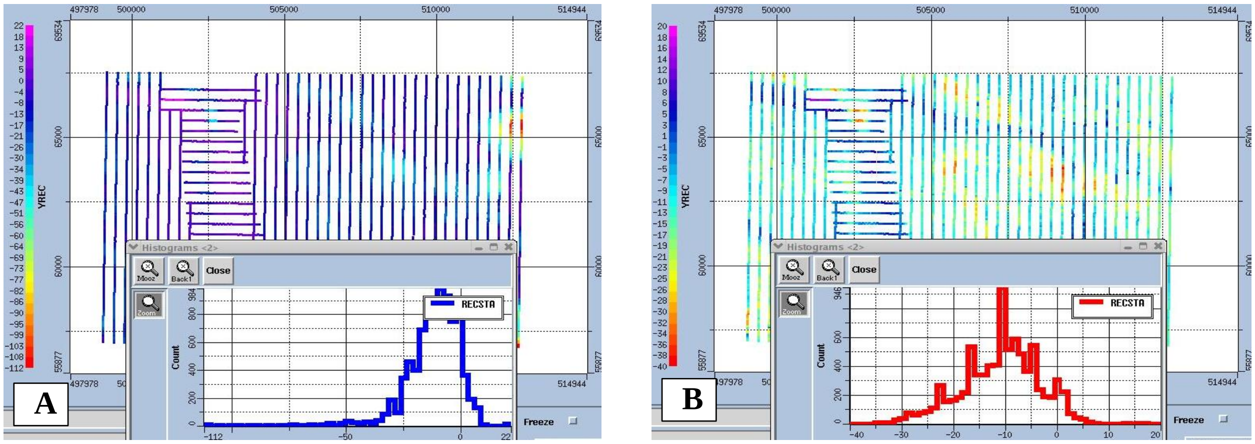

Figure 5: Base receiver statics (A) Conventional workflow and (B) GSC workflow

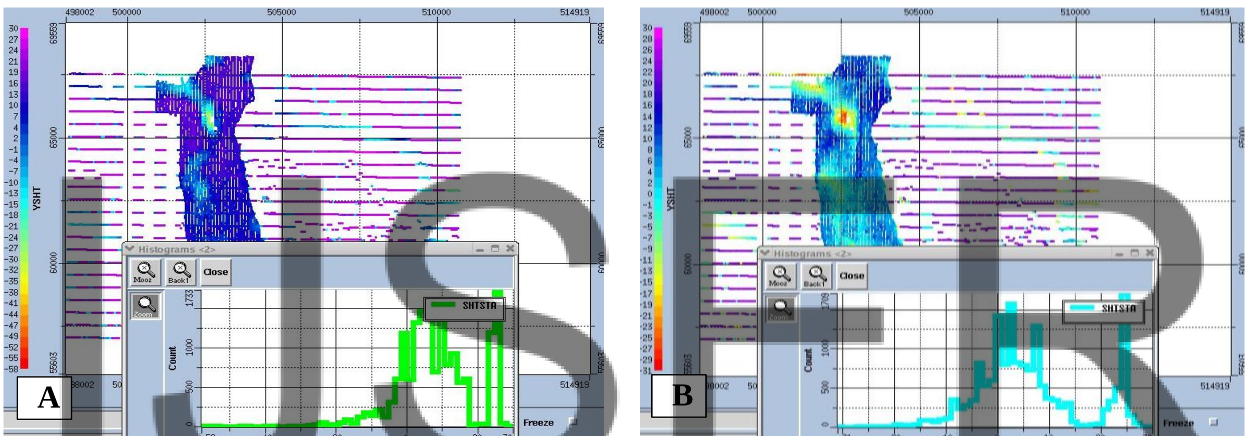

Figure 6: Base shot statics (A) Conventional workflow and (B) GSC workflow

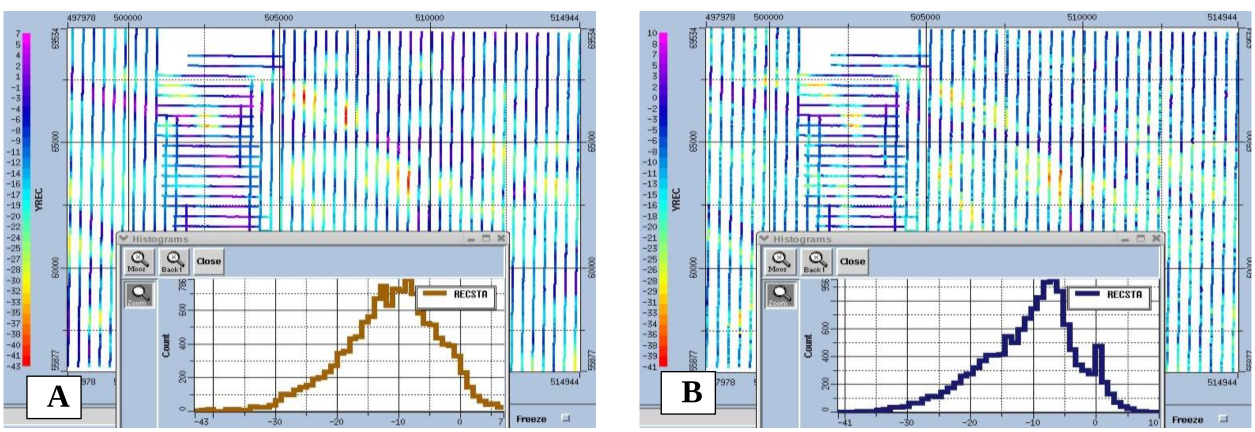

Figure 7: Monitor receiver statics (A) Conventional workflow and (B) GSC workflow

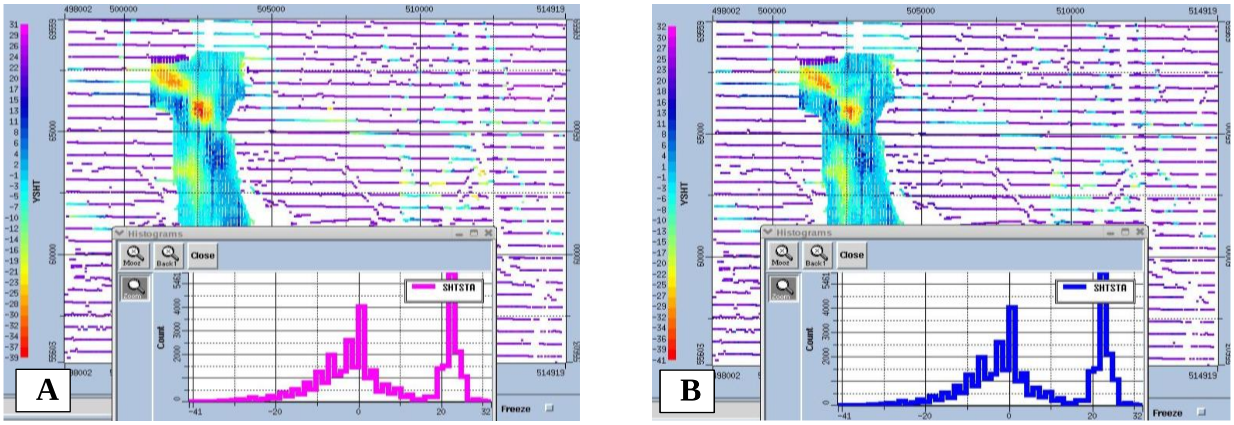

Figure 8: Monitor shot statics (A) Conventional workflow and (B) GSC workflow

Table 1: Statics values in absolute ranges

	Convetional Method	GSC Method
Base Receiver Statics (ms)	134	70
Base Shot Statics (ms)	88	61
Monitor Receiver Statics (ms)	50	51
Monitor Shot Statics (ms)	71	73

The test of the credibility of the solutions was in the resultant stack responses. A comparison of stack response before (brute stack) and after refraction statics application shows significantly improved signal-to-noise (S/N) ratio in the later over the brute stack for both the base and monitor surveys. This shows a reasonable convergence of the statics solution. Additionally, comparison of post refraction statics application using conventional workflow and global solution workflow for both vintages, shows enhanced stack response and improved signal-to-noise (S/N) ratio delivered by the global solution workflow. Figure 9 compares base stack (A) with monitor stack (B) after application of refractions statics solution derived from convectional workflow while Figure 10 compares base stack (A) with monitor stack (B) after application of refractions statics solution derived from Global workflow. In both cases the global refraction statics solution shows better events continuity and improved signal-to-noise ratio.

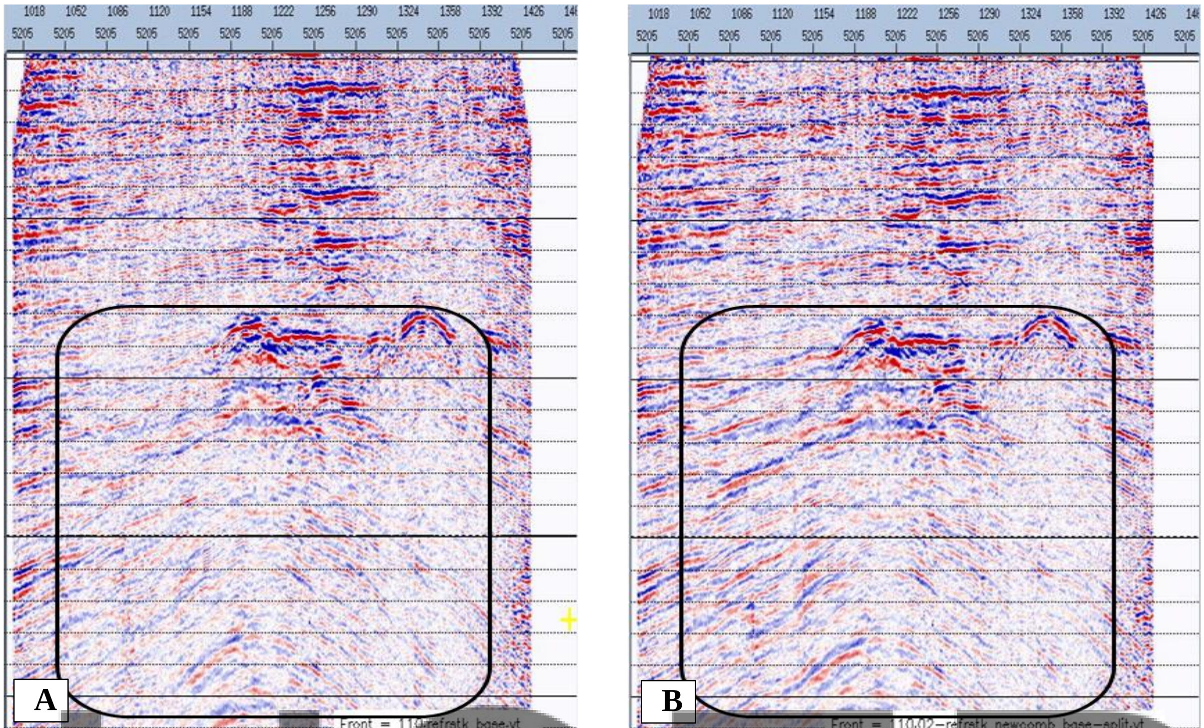

Figure 9: Results of application of refraction statics solution derived from Convectional workflow to base stack (A) and monitor stack (B)

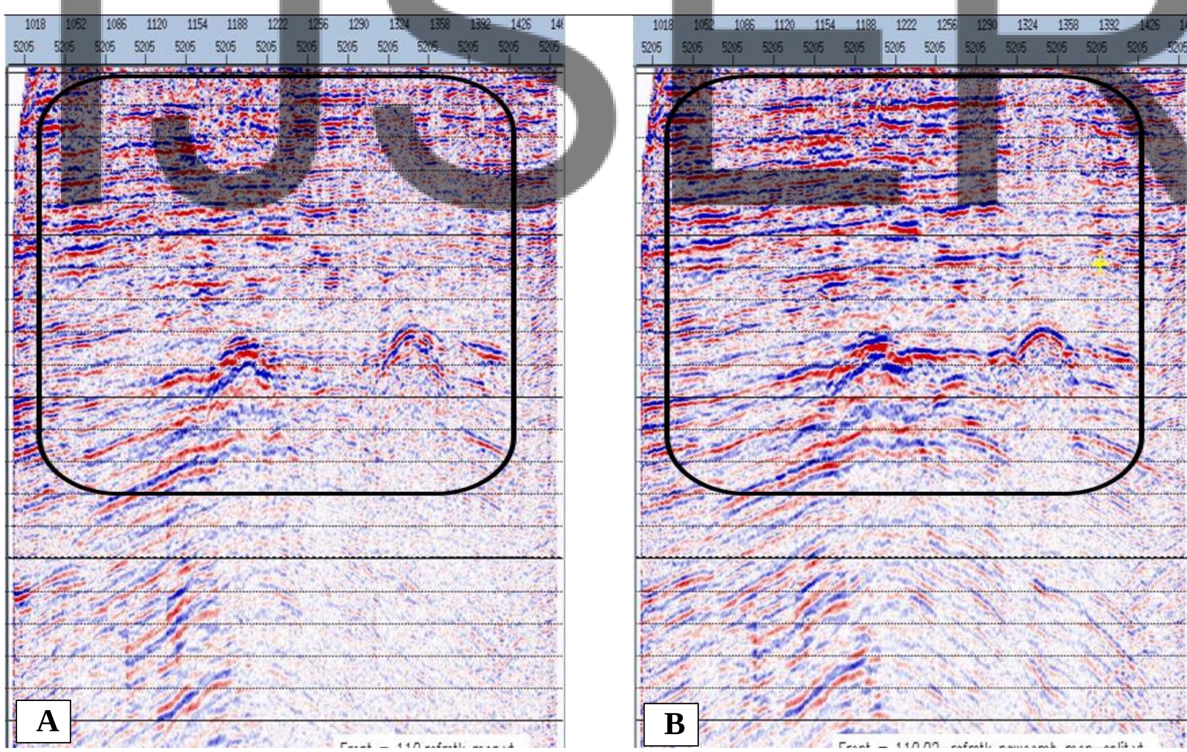

Figure 10: Results of application of refraction statics solution derived from developed GSC workflow to base stack (A) and monitor stack (B)

The results of the application of residual statics correction derived using the conventional and global solution methods to the base and monitor datasets are presented in Figures 11 and 12.

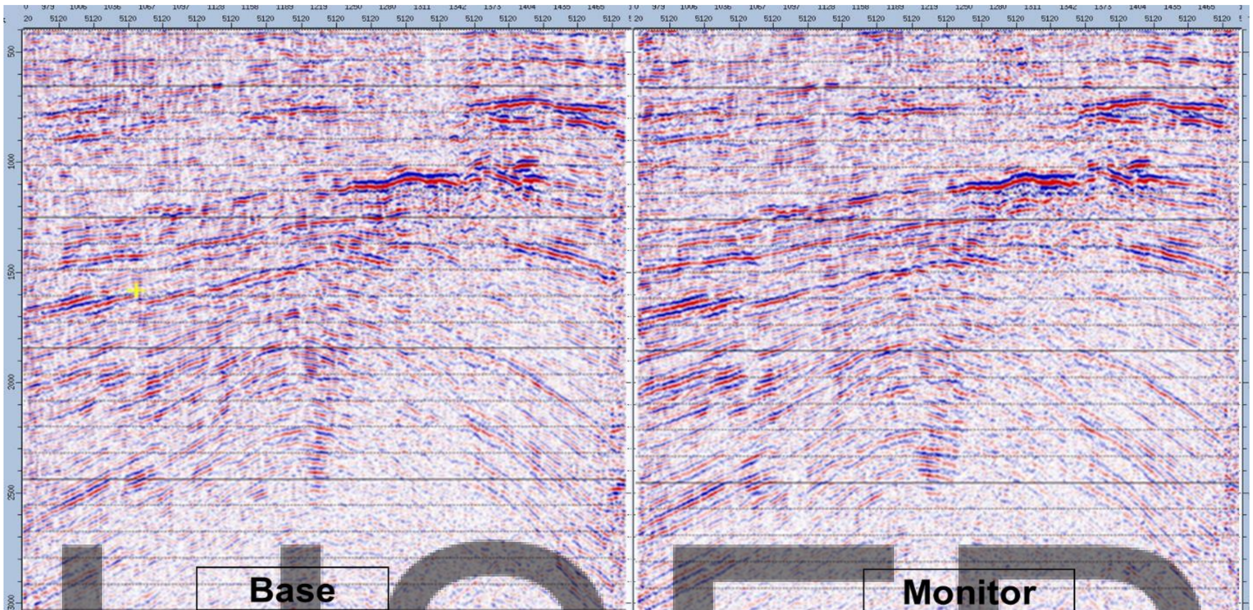

Figure 11: Comparison of base stack (left) and monitor stack (right) after application of residual statics solution derived using convectional workflow

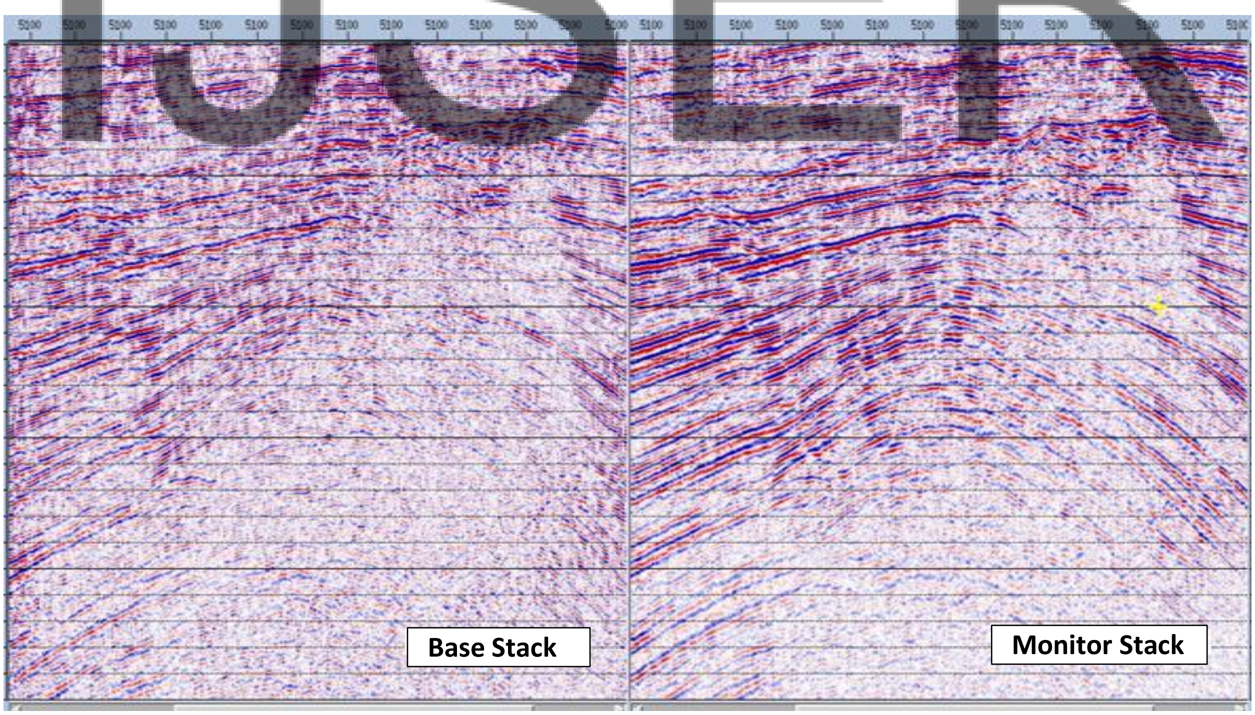

Figure 12: Comparison of base stack (left) and monitor stack (right) after application of residual statics solution derived using GSC workflow

Figure 11 shows stacks comparisons between base stack and monitor stack after application of residual statics solution derived using convectional workflow. Figure 12 shows stacks comparisons between base stack and monitor stack after application of residual statics solution derived using global solution workflow. It has been observed that the global solution workflow enhanced signal-to-noise ratio, events continuity and similarity between the base and monitor stacks better than the conventional workflow.

RMS Repeatability Ratio Measurement

The normalized root mean square (NRMS) amplitude ratio (also known as RMS Repeatability Ratio [RRR]) was used for testing the impact of the 2 workflows on improving time-lapse repeatability. Following Kragh and Christie (2002), we generated post-stack analysis of the time-lapse sections. For a baseline CDP trace, *a* and its repeat equivalent *b*, the NRMS ratio is defined as

$$NRMS\,(a,b) = 100\,\%\,\frac{2 \cdot RMS(a-b)}{RMS(a)+RMS(b)}. \qquad (1)$$

Assuming two wavelets of similar form and polarity, the NRMS equals zero. Switching the polarity of one of the wavelets corresponds to an NRMS of 200%. Therefore, 0% and 200% span the value range for NRMS ratios. The lower the NRMS the better the repeatability between the time-lapse datasets. Figures 13 and 14 present graphic views of the RRR computed after applying the different statics correction workflow. From Figure 13, RRR measurement for conventional statics workflow has a data mean of 1.08 while that for global statics workflow has a data mean of 0.91.

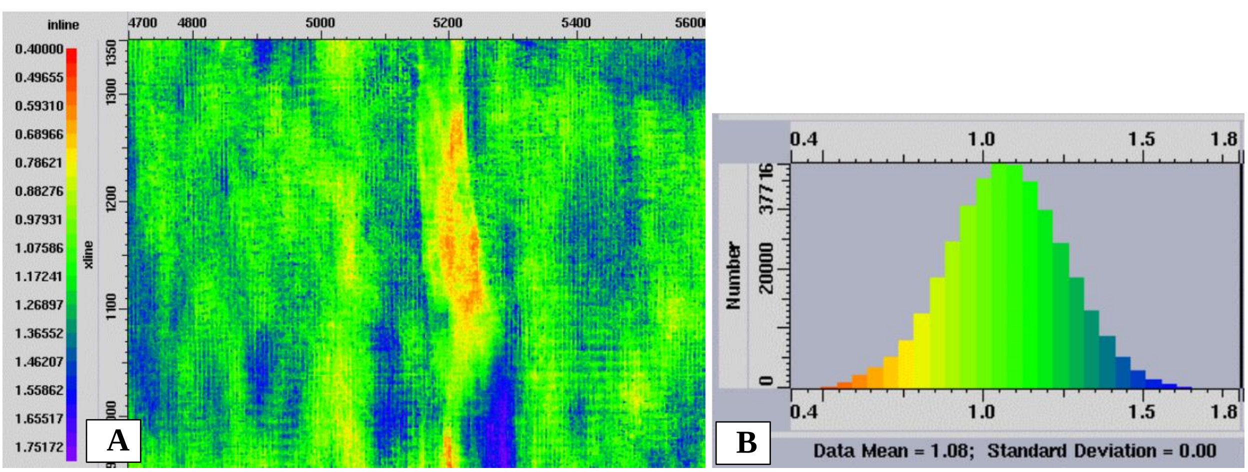

Figure 13: Map of RRR measurement for (A) conventional statics workflow and (B)adjoining histogram

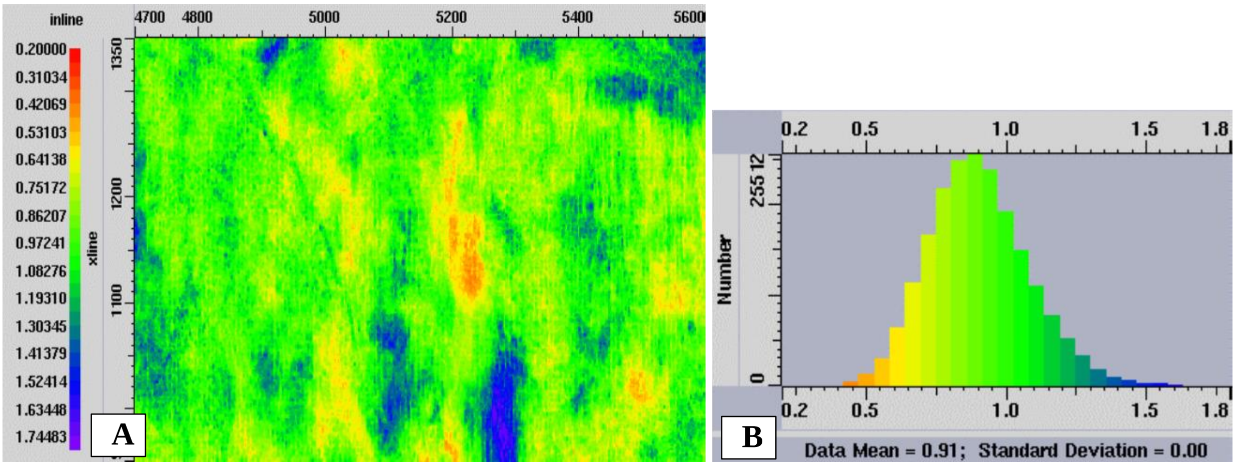

Figure 14: Map of RRR measurement for (A) global statics workflow and (B) adjoining histogram

CONCLUSION

Velocity changes in the near surface cause arrival-time differences which are known to have a detrimental impact on time-lapse seismic imaging when not accurately compensated for by static corrections. Refraction and residual static corrections, in this respect, offers only limited value when they consider only the statics for the individual time-lapse surveys. It has been shown that the global statics correction method that is focused on the accommodation of static changes between the timelapse data sets and resolving them as from one seismic dataset improves coherency of reflections and similarity of traces between the base and monitor surveys. It reduces 4D noise more effectively than the conventional static corrections. As a consequence, the RMS Repeatability Ratio (RRR) for the global statics correction (GSC) method is significantly lower than that of the conventional method.

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