Utilising map based process QC attributes to optimise 3D seismic processing flows offshore Nigeria.

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Summary

Using attributes enhances the QC of seismic data processing. These attributes can be derived in a manner that captures the characteristics of particular processing steps. The use of process specific QC attributes generated for two key stages in pre-migration flows, deblending and deghosting, is demonstrated over a 3D survey, acquired offshore Nigeria. A deblending attribute based on amplitude continuity reveals a variation in the process performance with varying water depth. Two attributes are used to QC source and receiver side deghosting, one based on wavelet width and another expressing frequency content as an RGB display. Both highlight deficiencies in the deghosting process due to uncertainties in cable depth headers. These attributes capture aspects of the data processing not apparent from visual inspection of the data alone.

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Introduction

Monitoring data integrity throughout a seismic processing sequence is essential to the success of a project and for the requirements of optimal reservoir characterisation. For this purpose, quality control, QC, is a vital part of seismic data processing. This can take the form of visual inspection of key aspects of the data in various domains, however, across large datasets this can be time consuming and often misses important aspects of data quality. Extracting suitable attributes provides a means to enhance the QC process. Attributes such as RMS, bandwidth and signal to noise are readily employed and can be extended to introduce the concept of quantitative quality control, QQC, (Araman & Paternoster, 2014). This improves the QC process by allowing for key attributes to be monitored statistically and mapped over the course of the processing sequence. Another approach is to derive attributes specific to particular processing stages. These attributes are constructed to capture the key property of the process in question. We refer to this approach as process QC and in this paper we demonstrate the use of process specific QC attributes for two key stages in pre-migration flows: deblending and deghosting.

The application of the process QCs is demonstrated on the Awele Multiclient 3D dataset which was acquired offshore Nigeria in 2023/24. It will be seen that use of these attributes adds value to the QC process and captures aspects of the data processing that may not be apparent from visual inspection of the data alone. The Awele survey comprised ~11,500 km^2 of 3D seismic. The survey was shot with 10 single-sensor streamers of 10 km length at 150 m separation with a group interval of 12.5 m. Continuous recording was employed with a triple source configuration firing at 18.75 m intervals. The three sources were towed at a depth of 7 m with nominal streamer depths of 12 m.

Deblending QC attribute: amplitude continuity

The shot spacing resulted in a nominal shot interval of 9 seconds with a dither of approximately 500 ms. With a combed record length of 14 seconds, blended interference existed from the previous, N-1, and subsequent, N+1, shots.

The data were deblended using an inversion scheme (Sun et al., 2022). Such inversion schemes are widely used and have proven to be highly successful in addressing the deblending problem. However perfect deblending is difficult to achieve and some residual blended energy may remain. Also, sub optimal deblending can misappropriate noise as signal which can lead to a loss of signal in the deblended result. A QC attribute was developed to assess the performance of the deblending process and designed to capture whether residual remained or if signal leakage occurred. Figure 1 shows examples of the deblending results and describes the derivation of the attribute. The scheme is based on the normalised difference in RMS amplitudes measured above and below the N+1 region of a shot record. This measure is based on the assumption of amplitude continuity in the underlying signal across the N+1 overlap region. The attribute is expressed such that positive values tending to +1 may indicate overlapping shot residuals. Negative values tending to -1 can indicate a loss of signal. An attribute value close to zero suggests optimal deblending.

Figure 2 shows the amplitude continuity attribute calculated and mapped for every shot over a subset of the Awele project before and after the deblending process with histograms showing the distributions. Before deblending a distribution close to +1 is seen. After deblending the values shift towards 0. However, it is clear there is a variation in the values ranging from the Southwest of the survey (where the attribute becomes negative but is close to 0) to the Northeast (where values tend to be still quite positive). This is seen in the multimodal distribution of the attribute after deblending. A bathymetry map of the survey showed a trend from deep to shallow water running roughly Southwest to Northeast. This indicates that the deblending has worked optimally in the deep-water area whilst some remnant noise remains in the shallower water regions. A cross plot of the attribute with water depth is also shown in Figure 2. This shows a clear trend of increased residual noise with decreasing water depth. This result is not obvious when visually inspecting the deblend results of Figure 1 demonstrating the value of attribute-based QC. In these areas as identified by the amplitude continuity attribute, the residual overlap noise can be addressed by extending the inversion to further iterations.

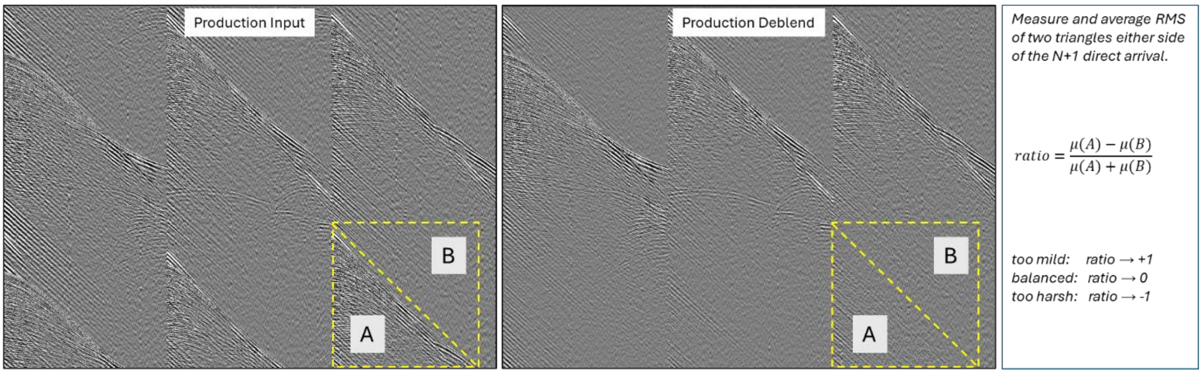

Figure 1 *Deblending results and description of amplitude continuity QC attribute.*

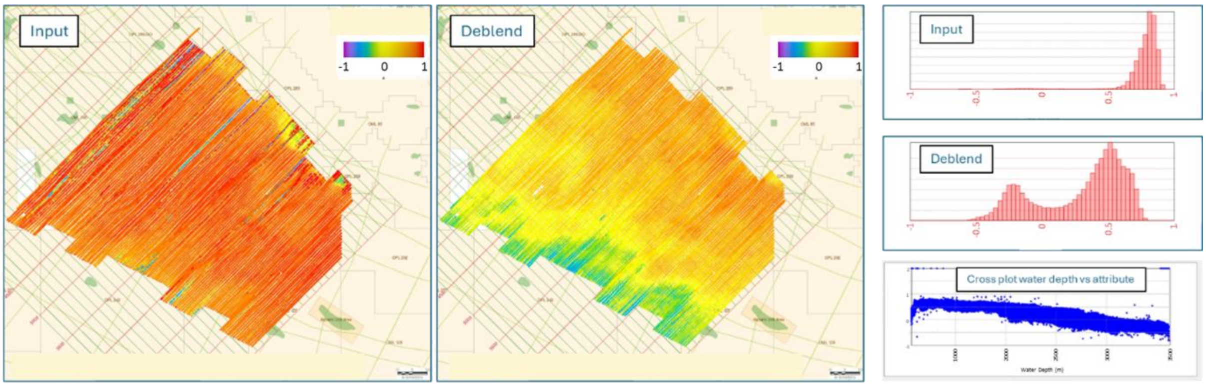

Figure 2 *The deblending QC RMS ratio attribute mapped over a subset of the Awele Survey before & after deblending with corresponding distributions. A cross plot of the attribute after deblending against water depth is also shown.*

Deghosting QC attributes: Wavelet width and RGB map QC

A 3D sparse Tau-p inversion method (Seher et al., 2021) was used to perform both source and receiver side deghosting. Acquisition supplied receiver depths were used to initially guide the process. Two methods were derived to QC the deghosted results.

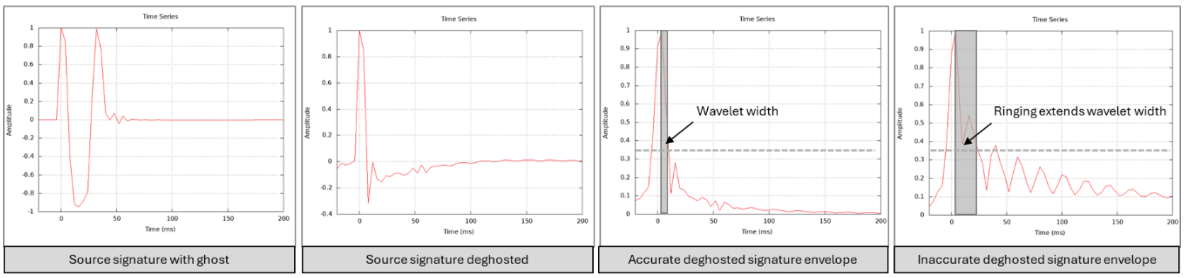

Figure 3 *Wavelet width attribute: Source signatures with ghost and deghosted signature. Envelopes of signatures after accurate and inaccurate deghosting.*

Wavelet width QC:
The first attribute used a measure of the width of the embedded wavelet. This is defined as the distance from the peak to a specified fraction of the amplitude of the trace envelope measured at a determined horizon, typically the water bottom. This width is related to the bandwidth and can vary according to geology however it is also sensitive to inaccuracies in the deghosting process that may, for example, cause ringing in the wavelet. Figure 3 shows a wavelet before and after deghosting. Also shown are the

envelopes of two wavelets after accurate and inaccurate deghosting. The resulting width calculation is indicated for these two scenarios demonstrating the principle that inaccurate deghosting will result in a larger wavelet width.

After an initial run of deghosting a 3D stack volume was created over which the wavelet width QC attribute was generated. Figure 4a shows this QC as an attribute slice after the initial deghosting with 4b showing an example crossline through the stack. Overall, a well deghosted dataset was achieved however, the wavelet width QC reveals stripes of higher values in the attribute slice. Close inspection of the crossline shows evidence of ringing in the data at specific locations (highlighted by the arrows). Further investigation of the data revealed the supplied receiver depth headers to be inaccurate for some cables and that the starting point for the inversion was too much in error. Revising these depth headers and rerunning the deghosting produced the resulting attribute analysis shown in Figure 4c with the corresponding crossline in Figure 4d. In the new results the wavelet width QC shows a consistent response across the survey giving confidence in the new results. The QC attribute shown in Figure 4a highlights where problems may exist and allows for targeted remedial efforts.

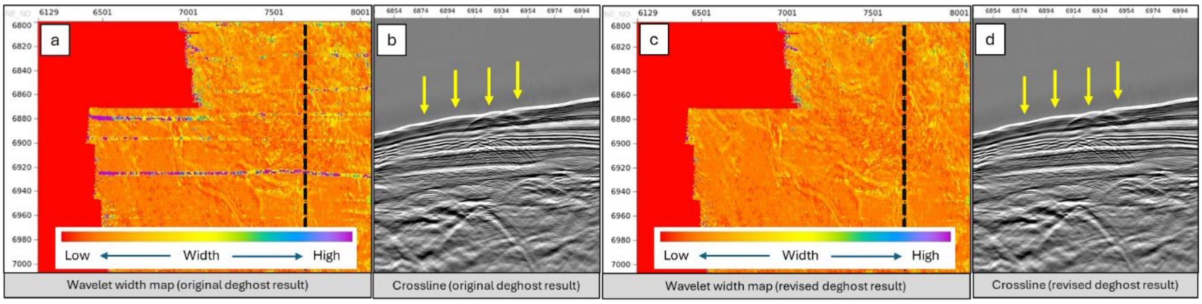

Figure 4 ***(a)*** *The wavelet width QC attribute slice over initial deghost result.* ***(b)*** *crossline through initial result.* ***(c)*** *The wavelet width QC attribute slice over revised deghost result.* ***(d)*** *crossline through revised result. Yellow arrows indicate regions of inaccurate cable depth headers.*

RGB Map QC:

An additional method relied on a frequency analysis of the data via a continuous wavelet transform expressing this as an RGB plot. Ranges of frequencies are assigned accordingly: frequencies below the expected notch (red), frequencies at the notch (green) and frequencies above the notch (blue). When combined the resulting RGB plot provides a measure of the integrity of the deghost result. When all frequencies are balanced a mostly white plot is obtained. Red or orange displays show an imbalance with low frequencies over boosted; green dominating indicates an over boosting of the notch with purple indicating a significant residual notch. Blue displays indicate an over boosting of higher frequencies.

Using the RGB QC to analyse the initial deghost result performed with the inaccurate cable depths uncovered further insights. Figure 5a shows the RGB QC map of this deghosted data over a portion of the survey. The stripes seen in the wavelet width QC are also seen in this attribute manifesting as alternating lines of mostly orange, white and blue. The arrows indicate three inlines from each of these colour zones for which amplitude spectra are calculated. Figure 5b shows the amplitude spectrum for an inline from an orange zone of the RGB plot. For reference the spectrum of the ghosted input data from the same inline is also shown indicating the location of the notch. Within this inline it can be seen that there is an unbalanced spectrum due to an over boosting of frequencies lower than the notch suggesting a slight inaccuracy in the deghosting. Conversely Figure 5c shows the amplitude spectra from an inline through a blue region where it can be seen that the frequencies above the notch are over boosted. Figure 5d shows the spectra from an inline through a white region. The frequencies are more balanced indicating more optimal deghosting. A slight notch still exists, and this is indicated by the purple element in this region of the RGB map. It can be seen that the RGB map QC not only provides an analysis of the consistency of the deghosting process but additionally provides further information on the nature of any errors and the general quality of the result; the attribute being sensitive to whether the ghost delay is under or over calculated or the notch is over- or under-compensated.

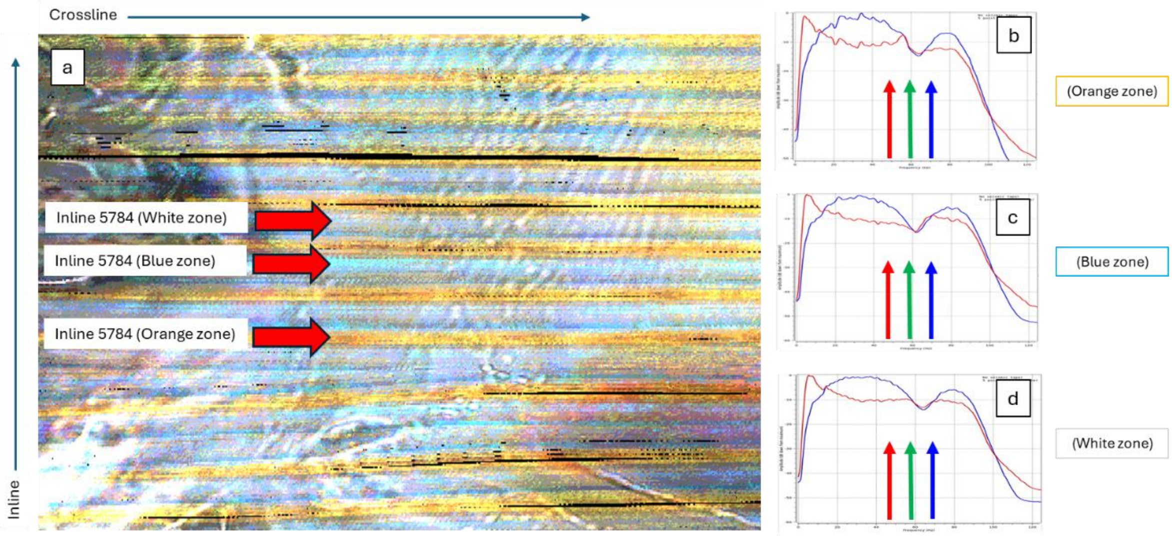

***Figure 5** Deghosting RGB attribute at water bottom: **(a)** attribute map with arrows indicating ‘orange’ ‘blue’ and ‘white’ zones, **(b)** amplitude spectra through orange zone, **(c)** amplitude spectra through blue zone, **(d)** amplitude spectra through white zone.*

Conclusions

QC of seismic data is essential throughout a processing sequence, and this can be enhanced by generating attributes designed to capture the key characteristics of specific processes. In the case of deblending, using the amplitude continuity attribute revealed the variation in the result with varying water depth. In deghosting both the wavelet width and RGB methods highlighted an inconsistency due to inaccuracies in the assumed cable depths with the latter method providing insight into the nature of these errors. The process specific attributes are able to capture these deficiencies in a more sensitive manner than straightforward measures such as RMS or visual inspection of the data. Attributes lend themselves more readily to map based and statistical analyses providing a more comprehensive and efficient QC procedure. Here we have demonstrated the benefits of process QC applied to two specific steps only, but QC schemes can be developed for other key processing stages such as denoise and demultiple.

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