

The effect of deghosting on the 4D response: Usan field, Nigeria.

Piero Agnisola*, Ross O'Driscoll, Philip G. Smith (ION), Dez Chu, (ExxonMobil Houston), Essiet E. Assiak, (Esso E&P Nigeria), Charles Ugwueze, Paula Ukerun, (Bulwark Services)

Summary

In this study we present the benefits of removing the source and receiver ghosts early in the 4-D processing sequence. Results from running a test in parallel comparing deghosted with a non-deghosted dataset clearly demonstrate that deghosting is a significant aid to improved 4-D interpretation at the reservoir interval.

The time-lapse surveys used in this deghosting test were acquired in 2012 and 2014, over the Usan field, offshore Nigeria, using near identical acquisition parameters, which resulted in good repeatability and 4-D fold of coverage.

Introduction

In time-lapse (4-D) seismic experiments, repeated surveys are typically designed such as to minimise differences in acquisition. This includes repeating source and receiver positions and aligning equipment response and towing configuration. While many of these differences can be minimised with good survey planning, equipment calibration and QC in the field, there will be some residual mismatch which must be compensated for in processing (Johnston, 2013).

The ghost response has a major impact on the recorded spectrum of a seismic dataset (Laws and Kragh, 2002). Constructive interference between the ghost and primary creates amplitude peaks in the frequency spectrum. Destructive interference causes notches in the amplitude spectrum at multiples of the inverse of the ghost period, suppressing these frequencies to tens of decibels below the peak frequency. In addition, the ghosts lead to sudden phase changes at frequencies corresponding to the notches in the amplitude spectrum. As the ghost response is dependent on arrival angle, both the amplitude and phase response of the data changes with arrival angle.

The benefits of deghosting to 4-D data have been studied in the literature, for example Furre and Eiken (2014) and Loh et al. (2014). Charrier et al. (2012) describe how the frequency content of 4-D surveys can have a significant effect on the seismic repeatability. The dominant frequency of a dataset can influence many of the seismic attributes which are used to quantify repeatability. Lecerf (2015) propose using CNRMSd which provides a weighting to compensate for different dominant frequencies.

From these studies we would expect two significant benefits from applying deghosting to a 4-D project. Firstly any small difference in the wavelet ghosts due to subtle variations in receiver or source depths can be removed, thus making survey matching easier (Payne, 2015). Secondly a broadband, zero phase dataset may allow more stable 4-D attributes to be extracted at all arrival angles.

In this paper we present the benefits of removing the source and receiver ghosts early in 4-D processing. Results from running a test in parallel with a non-deghosted dataset demonstrate deghosting is a significant aid to improved 4-D interpretation at the reservoir interval.

Method

The time-lapse surveys used in this deghosting test were acquired in 2012 and 2014, over the Usan field, offshore Nigeria. The near identical acquisition parameters, summarised in Table 1, resulted in good repeatability and 4-D fold of cover.

Year of survey	2012, 2014.	Cable separation	50m with a 20% fan
Source depth	5m	Nominal fold	80
Number of cables	12 (2012), 10 (2014)	Nominal near offset	150m
Cable length	6000m	Acquired bin size	12.5m x 6.25m
Cable depth	6m	No. Channels	480 groups

Table 1: Acquisition parameters for the time-lapse surveys.

A nominal 6m receiver depth, with a +/- 0.5 metre tolerance gives a potential ghost notch frequency range of 117Hz to 137Hz. This near 20Hz range of notch frequencies means a potential 10Hz range of peak frequencies.

The processing flow is summarised in Table 2 and key steps which made the most significant improvements in repeatability are discussed below. Broadband deghosting was applied to the data after denoise in order to create a stable data-adaptive deghosting operator. This operator corrects for both the source and receiver ghosts. Different operators were designed for surveys M1 and M2 in a shallow design window where signal to noise was high. A stable deghosting operator was derived and its phase and amplitude validated (see Figure 1).

The effect of deghosting on the 4D response

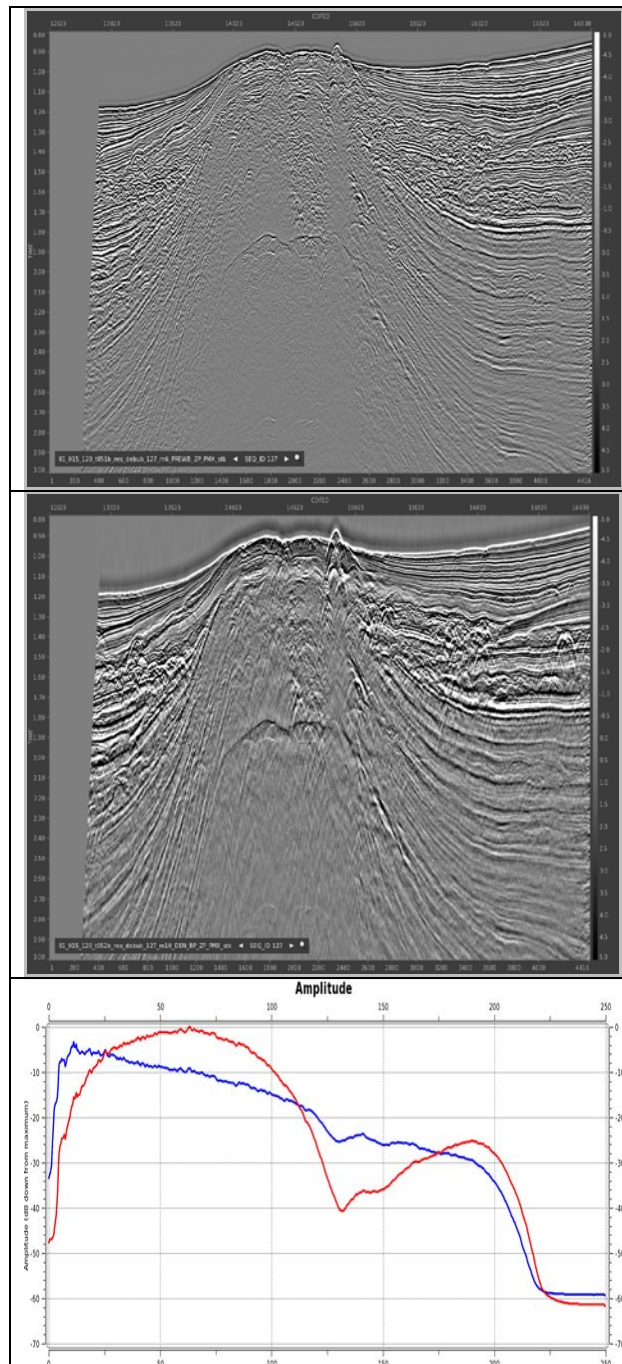


Figure 1: Results of deghosting monitor dataset M1. Top left: Stack without deghosting. Top right: Deghosted stack. Bottom: Comparison of amplitude spectra: red= conventional; blue= deghosted.

The operator was applied in the Stolt migrated shot domain (migrated at water velocity) to correct for the angle dependence of the ghost period. As seen in Figure 2, the effect on the 4-D difference is significant.

- 1 SEG-Y Input, 2 Denoise, 3 Debubble,
- 4 Zero Phasing (with/without deghosting),
- 5 Local Footprint, 6 Receiver motion correction,
- 7 Tidal Statics, 8 Cold Water Statics,
- 9 Global Survey Matching ,
- 10 3-DSRME,
- 11 Phase Q,
- 12 4-D Time Destriping ,
- 13 Global Footprint Correction,
- 14 4-D Binning,
- 15 Regularisation
- 16 Radon demultiple, 17 Dealiasing,
- 18 Survey Matching Correction,
- 19 PreSDM,
- 20 RMO correction,
- 21 FXY deconvolution,
- 22 Stack, 23 TVF

Table 2. Key steps in the time-lapse processing flow

Application of tidal and cold-water statics resulted in large convergence of the 4-D QC attributes for both deghosted and non-deghosted workflows. Global matching filters had a more dramatic effect on the non-deghosted workflow, which we attribute to the effect the ghosts have on the data.

4-D Co-binning was a critical step resulting in a significant improvement in repeatability. A hybrid trade-off of seismic repeatability metrics and geometrical repeatability metrics was tested and applied, and ensured that differences in repeatability of the input surveys were minimised.

Results

Figure 2 shows a key inline stacked seismic section for M2 with a color overlay of the difference. The deghosted result is generally less noisy with a significant improvement in continuity.

Figure 3 shows a cross section of 4-D seismic going through a reservoir compartment. Overall the 4-D difference from the deghosted seismic data is much less noisy than that from the data with ghosts and the 4-D anomaly stands out from the background more clearly on the deghosted 4-D difference (Figure 3a and Figure 3b).

The effect of deghosting on the 4D response

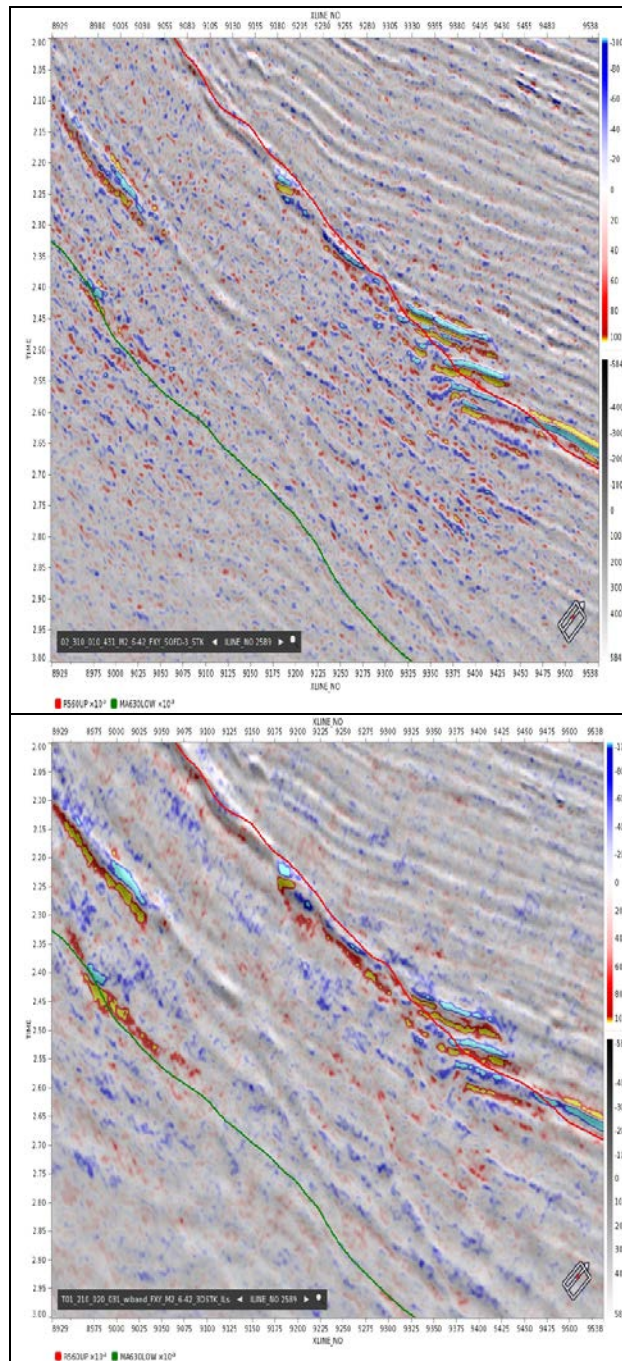


Figure 2: Final Migrated Volume Difference M1-M2 (colour) overlaying M2 (grey): without deghosting (left) and with deghosting (right). Note the clearer 4-D difference in the deghosted case and the reduction in scattered 4-D “noise”.

The reservoir in concern is mostly above the top horizon. The reservoir is segmented by a fault shown in black dashed line. 4-D seismic and production data show that the fault is a sealing fault. On the left of the fault, water saturation has increased because of water injection down dip and oil production up dip. However, the water injection has no pressure support to the producer on the left of the fault, where pressure has been drawn down. This has caused gas to come out of solution.

The extent of gas out of solution signature will help define the reservoir extent, which is obscured on the 3-D seismic because of its proximity to the salt at up dip location. The conventionally co-processed 4-D anomaly is not continuous and side lobe energy has made interpretation difficult to interpret where the gas out of solution ends, whereas the deghosted 4-D seismic clearly indicates that the reservoir continues all the way to 2180ms on the left.

The time-shift volumes for M2 relative to M1 (Figure 3c) show velocity decrease to the right of the fault and compares to the similar extent as defined by the deghosted 4-D difference for gas out of solution.

Conclusions

This project ran a time-lapse (4-D) survey through parallel deghosting and non-deghosted workflows. Slight differences in ghost periods were shown to have a major impact on seismic repeatability metrics. Deghosting was shown to significantly improve repeatability in this project resulting in better convergence of repeatability metrics than the non-deghosted result. The increased resolution and increased signal to noise of the deghosted result improved mapping of compartments and bounding faults improving understanding of fluid flow through the reservoir.

Acknowledgements

The authors would like to thank Exxon Mobil and NAPIMS for permission to show this data and ION Geophysical for permission to show this work.

The effect of deghosting on the 4D response

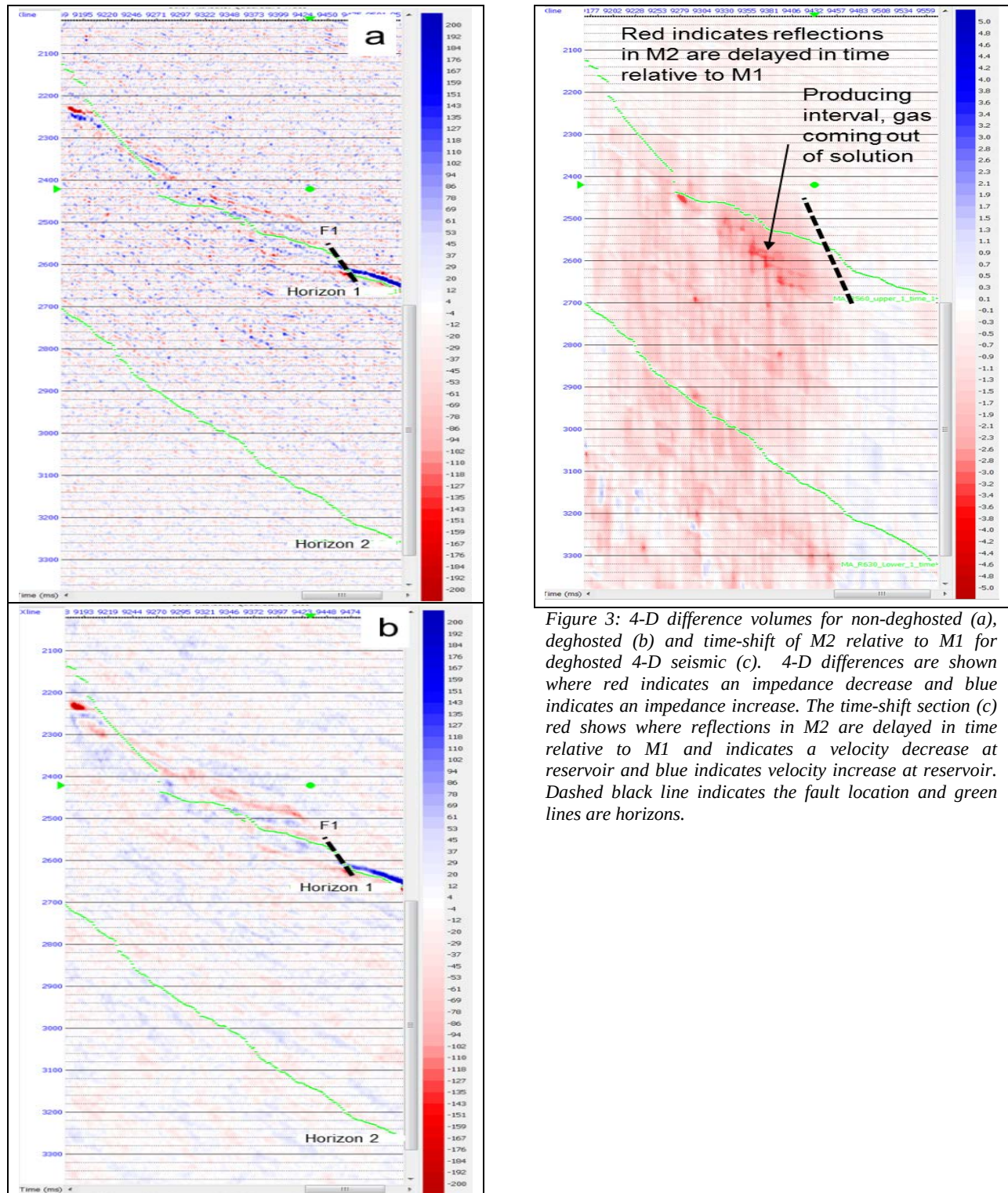


Figure 3: 4-D difference volumes for non-deghosted (a), deghosted (b) and time-shift of M2 relative to M1 for deghosted 4-D seismic (c). 4-D differences are shown where red indicates an impedance decrease and blue indicates an impedance increase. The time-shift section (c) red shows where reflections in M2 are delayed in time relative to M1 and indicates a velocity decrease at reservoir and blue indicates velocity increase at reservoir. Dashed black line indicates the fault location and green lines are horizons.

REFERENCES

- Charrier, P., Z., Yu, and T., Rebert, 2012, 4D processing between variable depth and conventional streamer data: 74th Annual International Conference and Exhibition, EAGE, Expanded Abstracts, E013, doi: <https://doi.org/10.3997/2214-4609.20149833>.
- Furre, A. K., and O., Eiken, 2014, Dual sensor streamer technology used in Sleipner CO₂ injection monitoring: *Geophysical Prospecting*, **62**, 1075–1088, doi: <https://doi.org/10.1111/1365-2478.12120>.
- Johnston, D., 2013, Distinguished instructor series: Practical applications of time-lapse seismic data: SEG.
- Laws, R., and E., Kragh, 2002, Rough seas and time-lapse seismic: *Geophysical Prospecting*, **50**, 195–208, doi: <https://doi.org/10.1046/j.1365-2478.2002.00311.x>.
- Lecerf, D., J., Burren, E., Hodges, and C., Barros, 2015, Repeatability measure for broadband 4D seismic: 85th Annual International Meeting, SEG, Expanded Abstracts, 5483–5487, doi: <https://doi.org/10.1190/segam2015-5927745.1>.
- Loh, F.C., T., Mojesky, and P., Bouloudas, 2014, Full shot and receiver deghosting for Broadband and Conventional streamer 4D studies: How close can we get?: 84th Annual International Meeting, SEG, Expanded Abstracts, 4858–4862, doi: <https://doi.org/10.1190/segam2014-1043.1>.
- Payne, N., T., Martin, J., Denly, and R., Afrazmanech, 2015, Multi survey matching of marine towed streamer data using a broadband workflow: A shallow water offshore Gabon case study: 85th Annual International Meeting, SEG, Expanded Abstracts, 5132–5136, doi: <https://doi.org/10.1190/segam2015-5896165.1>.