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2D SEISMIC DATA DE-GHOSTING, WESTERN OFFSHORE PROVINCE, EGYPT

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طريقة لإزالة الخيال الانعكاسي وتأثيره على بيانات المسح السيزمى ثنائى الأبعاد بالمنطقة الغربية البحرية فى مصر

الخلاصة: يتناول هذا البحث تقنية استخدام المرشحات لإزالة الخيال الإنعكاسي واستعادة الترددات المنخفضة والعالية لبيانات المسح السيزمى البحرى فى المنطقة الغربية لمصر، ومنذ عام ١٩٩٩ أجرى العديد من المسوح السيزمية ثنائية الأبعاد بهدف استكشاف البنية الجيولوجية بالمنطقة والعثور على خزانات حاملة للهيدروكربون ولكنها فى أغلبها كانت ذات جودة متدنية.

ولما كان الخيال الانعكاسى ذا تأثير سلبى على البيانات السيزمية المسجلة فقد كان لزاما التخلص من هذا التأثير أو على الأقل تقليصه، ومن هنا اتبعنا منهجية فى هذا البحث لتحقيق الهدف وتحسين جودة البيانات المسجلة لاستخدامها عند اجراء أى مسح سيزمى بحرى مستقبلاً.

ABSTRACT: *In marine seismic acquisitions, a major deteriorating effect on resolution is caused by ghost reflections. Sensors towed at depth within a water column record not only the desired up-going wavefield reflected from geological formations, but also its reflections from the sea surface known as down-going wavefield, or seismic ghost. This generates notches in the spectrum of the measured wavefield, reducing significantly the usable bandwidth and accordingly the resolution of the seismic data. Recently, the removal of the ghost ('de-ghosting') has attracted increasing attention with the aim of obtaining more broadband data.*

In this paper, 2D spatially variant de-ghosting filtering technique is used to eliminate the ghost effect and recover the lost lower and higher frequency data for marine-towed streamer data in the Western Offshore Province, Egypt. Since 1999, many 2D surveys using conventional acquisition have been carried out across the Western offshore Province, Egypt. Nevertheless the hydrocarbon prospectivity in the area was very challenging, because most of the available old 2D seismic data were of poor quality. One of the major imaging challenges in the area was the limited bandwidth and resolution due to the effect of the ghost. The methodology used in this paper demonstrates its effectiveness and versatility to be used for any vintage and new marine streamer seismic data.

INTRODUCTION

The Western Offshore Province, Egypt, (Figure 1) has received an increased international interest in the last few years as it represents the unexplored part of Eastern Mediterranean region which has a very high hydrocarbon potentiality. Discoveries in offshore Egypt, Palestine and Cyprus have revealed huge reservoirs, which has increased the eagerness to understand the subsurface of the study area.

Western Offshore Egyptian Province is part of the Eastern Mediterranean Basin and covers the north-eastern corner of the African continental shelf. It is bounded by a passive margin to the east "Levant Margin" and a subduction zone to the north and northwest "Mediterranean Ridge". It is also bounded from the south by the Mediterranean shore line northern the Western Desert of Egypt and Libyan border from the west. There are many challenges in imaging the subsurface of the study area; one of the main challenges is to obtain a broader seismic bandwidth and a higher resolution beneath the salt.

Broadening the seismic bandwidth has recently become a very intensive effort by the marine seismic industry. Different techniques from acquisition, processing, to hybrid approaches, have emerged over the past few years, made the elimination or mitigation of the ghost effect practical, and shown the benefit of improving the seismic resolution for exploration and production needs (Carlson, 2007; Soubaras, 2010 and Zhou et. al., 2012).

Techniques using non-conventional acquisition and hybrid approaches require new acquisition and thus significant investment. On the other hand, using a processing based approach can be an alternative solution because it can improve the resolution of existing conventional streamer data which are abundant and also new deep-towed constant depth streamer data which has better lower frequency but also has lower ghost frequency "ghost notches" (Yu, 2014).

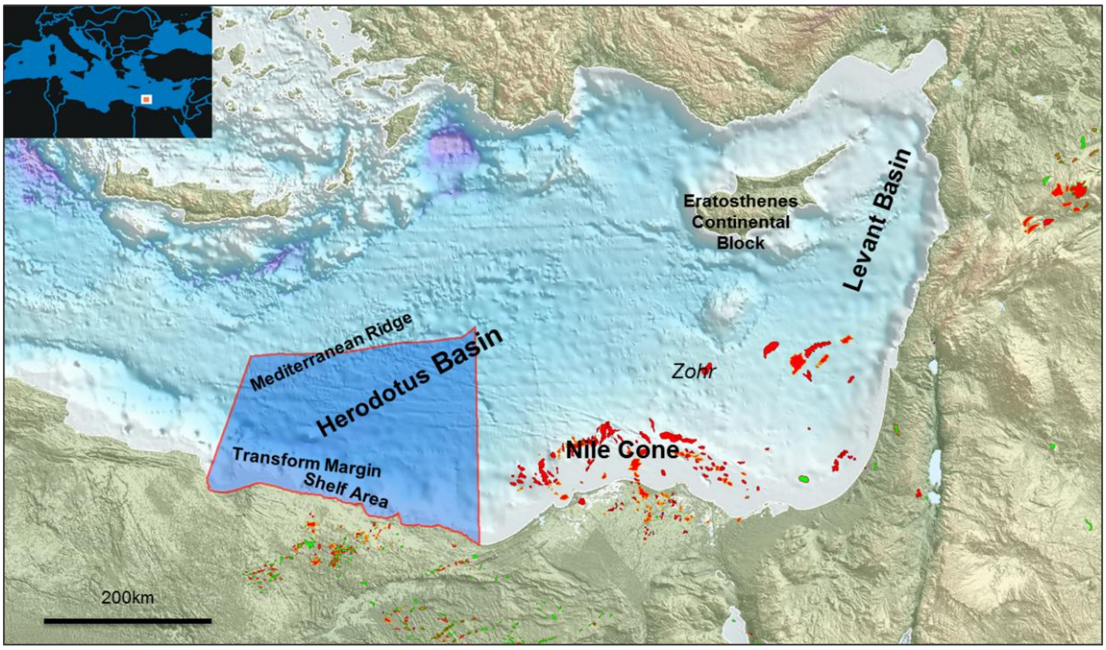

Figure 1: Location Map of the study area.

This paper proposes simple and fast technique to effectively remove the ghost based on processing solutions. These solutions usually treat the ghost effect as an inverse problem that can be solved by computing an inverse operator to remove (de-convolve) the ghosts from the data.

The proposed solution to eliminate the ghosts from the seismic data is to use a cascaded approach of 2D receiver de-ghosting followed by a 2D source de-ghosting. The de-ghosting technique is validated by all the required QCs to assess de-ghosting effectiveness. This work has been done on a pre-migration data directly after removing the loud noise that means it must be applied upfront on the processing sequence to increases its usefulness and robustness.

Background

In marine seismic data acquisition, seismic streamers contain sensors to detect the wavefields initiated by the seismic source and reflected from subsurface layers. After the reflected wave reaches the streamer cable, the waves continue to propagate to the water / air interface at the water surface, from which the wave is reflected downwards, and is again detected by the hydrophones in the streamer cable. The water surface is a good reflector and its reflection coefficient is nearly unity in magnitude and is negative in sign for pressure signals. The waves reflected at the surface are thus be phase-shifted 180 degrees relative to the upwardly propagating waves. The downwardly propagating wave recorded by the receivers is commonly referred to as the surface reflection or the "ghost" signal (Riyanti, 2018).

The configuration of the standard marine acquisition geometry with source and receiver below the sea surface, will setup two types of ghost, Receiver ghost and Source ghost. The seismic bandwidth and resolution of conventional marine streamer data suffers from this source and receiver ghosts, which lead to the recording of four seismic events for every impedance contrast and manifest itself as a notches in the amplitude spectra whilst leading to phase change of the data with polarity reversal occurring at the notch frequency, caused by the interference between primaries and ghosts, furthermore there is a complex constructive and destructive interference between all primaries, multiples, and ghosts (Figure 2).

The physics of sinusoidal wave propagation states that when two waves have the same wavelength, destructive interference (cancellation) occurs when they arrive exactly 180^{o} out of phase. Because the reflection coefficient at the surface is negative, the downgoing reflected wave experience 180^{o} phase shift relative to the direct wave (Evans, 1997). However, the reflected waves experience a further phase shift because of the additional distance, 2d that it travels relative to the direct wave. If destructive interference is to occur, that distance must be an integral number of wavelengths. That is, destructive interference occurs when 2d= nλ, where n= 0, 1, 2….. Since λ= v/ f, the notch frequencies where destructive interference is experienced (for vertical travel path) are given by

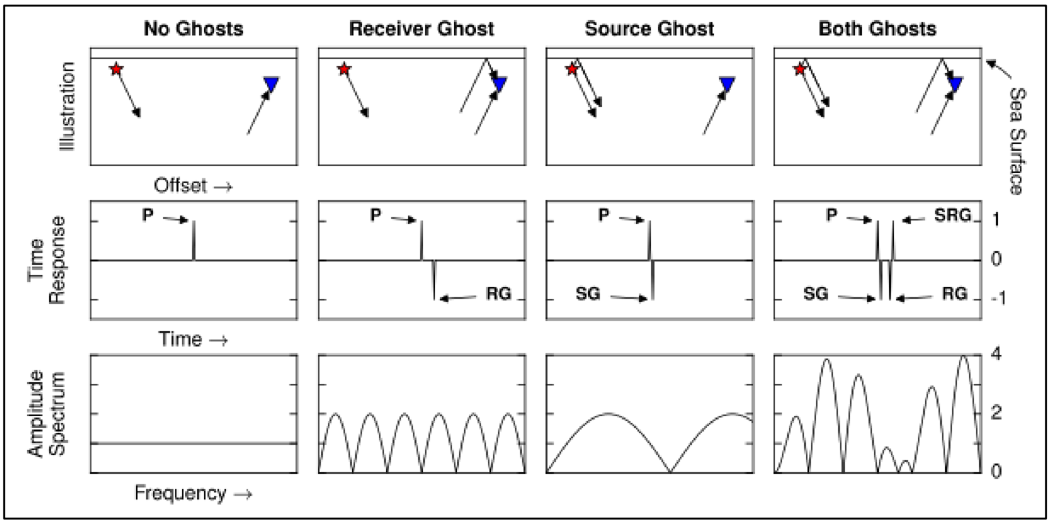

Figure 2: illustration of source-and receiver ghost effects. P, RG, SG and SRG denote primary, Receiver-, Source- and Source-Receiver ghost (after Schuberth , 2015).

$$f = \frac{nv}{2d} \quad , n = 0,1,2 \dots\dots$$

Where, v is the water velocity and d is the receiver depth. The first non-zero frequency notch (v/2d) has historically been the limit of usable seismic bandwidth. To increase high-frequency content, one needs to move the cable shallower (smaller d). However, this may result in stronger swell noise and a deeper notch at zero Hz, and thus is destructive the low-frequency signals, in many geologic setting such as subsalt plays, are extremely important.

For non-vertical travel paths, the delay between the original and ghost wavefields is angle-dependent, causing the frequencies at which destructive or constructive summation occurs to change with the takeoff angle of energy from the source.

GEOLOGIC SETTINGS

The study area (Western offshore province, Egypt) covers very large part of the Egyptian Mediterranean "approximately 46%". It comprises different basins and consequently different thicknesses of the stratigraphic column in these different basins and even within each basin itself. The Egyptian margin is characterized by a mixed carbonate-siliciclastic sedimentation from Paleozoic to Cenozoic the onshore Western Desert may contain Palaeozoic sediments as old as Cambrian (Azab, 2014). A major unconformity separates the Mesozoic from the Palaeozoic with Permo-Triassic sediments being absent.

The main tectonic and stratigraphic events which shaped offshore Egypt and control its hydrocarbon prospectively are linked to the history of the opening of the Neo-Tethys ocean which most probably has started in the Permian-Triassic and dominated with left-lateral, trans-tensional movements of the African Plate relative to the Eurasian Plate giving rise to continental block rifting followed by ocean spreading into the early Cretaceous. The opening of the Neo-Tethys to the north of the Egyptian margin allowed the development of a wide Jurassic to Cretaceous carbonate platform attached to the continental system in the south from Western Desert to Sinai. This platform was frequently invaded by terrigenous sediments sourced from the south in the Western Desert area, from Permian to early Jurassic. The Western Desert and the onshore Nile Delta contains sediments deposited in a continental depositional environment (PGS Internal Report).

The evolution of the general Eastern Mediterranean Basin encompasses three major stages; rifting/extension, passive margin development and foreland basin development (Figure 3) (Tassy et al., 2015).

The period of rifting lasts from the Triassic to the mid-Jurassic and spreading during the upper Jurassic and the lower Cretaceous. This event resulted in the separation, along a set of transform faults broadly oriented NNW-SSE. After rifting finished a thick (around 4 to 5 km) carbonate platform developed on the offshore Cyprus, as it did on the Levant margin. Two basins were also formed:

- The Levantine basin containing a thick infill of essentially deep water sediments (around 12 km) with probably some oceanic crust indicated by a positive Bouguer gravity anomaly in its axis.
- The Herodotus basin with an oceanic crust and a very thick sedimentary section (12 to 15 km) (Montadert, 2014).

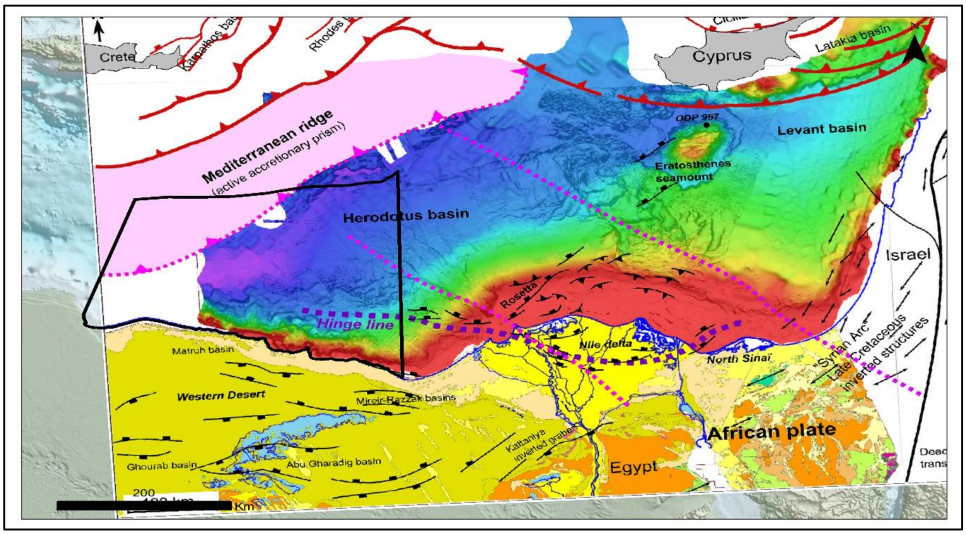

Figure 3: Structural map of the present-day East Mediterranean (after Tassy et al., 2015).

During the late Cretaceous this opening was substituted by the convergence between Africa and Eurasia, roughly N-S oriented this formed the Cyprus arc, over thrusted on the older structural elements from northern Arabia to Turkey (Antalya) through the island of Cyprus (Montadert, 2014). Syrian Arc compression during the Santonian reactivated syn-normal faults as well as resultant uplift and erosion onshore. Localized shortening and uplift continued intermittently into the Palaeogene (Tari et al., 2012).

Beginning in the late Eocene-early Oligocene, an important change in the tectonic regime occurred in connection with the beginning of the separation of Arabia from Africa and this had significant structural and sedimentary consequences.

During the Oligocene-Miocene, anticlines were formed in the Levantine basin. The prospectively of these has been proven by the Noble Energy gas discovery of Tamar (Israel). This tectonic change allowed the input of large volumes of clastic sediment into the eastern Mediterranean. It produced the Nile delta and associated deep sea fan with its variety of potential reservoirs (Montadert, 2014).

During the latest Miocene, and in common with the rest of the Mediterranean area, very thick Messinian evaporites were deposited in the basinal areas of the eastern Mediterranean: the Levantine and Herodotus basins. Erosion of the Egyptian margin during the Messinian sea level drop generated low-stand deltas into the saline Messinian Herodotus basin. The study area comprises a relatively narrow shelf area followed by a narrow transform margin belt and a deep sedimentary basin towards the north (the Herodotus Basin).

METHODOLOGY

For marine seismic acquisition with hydrophone streamer, the up-coming primary reflections and down-going reflections or ghosts from the sea free surface interfere with each other destructively at certain frequencies manifested as spectral notches that are determined mainly by the source and receiver depth, water velocity, and free surface reflectivity. This ghost effect is a well-known problem and tackled since early marine seismic surveys using a normal incident ray approach (Lindsey, 1960).

The notch frequency can be determined at any angle of incidence by:

$$Fn = (Vw) / (2 \times Depth) * \cos(Ø)$$

Where Fn is the notch frequency for either the source or the receiver, Vw is the speed of sound in water, Depth is either source or receiver depth, Ø is the angle between the incident ray and the normal to the surface.

The ghosts G(Kz)can be formulated in frequency domain as;

$$G(K_x, K_y, K_z, Z) = 1 - r_0 \exp(2iK_zZ)$$

Where $K_z = \sqrt{\frac{w^2}{v_w^2} - K_x^2 - K_{xy}^2}$ is the vertical wave number, r_0 is the free surface reflection coefficient, K_x and K_y are the horizontal wavenumbers, $\boldsymbol{\omega}=2\pi f$ is the circular frequency.

So theoretically de-ghosting can be performed by applying the inverse filter

$$D(K_x, K_y, K_z, Z) = 1 / G(K_x, K_y, K_z, Z)$$

The de-ghosting operator can be described as,

$$D(K_x, K_y, K_z, Z) = 1 / ((1 - r_0 \exp(2iK_z Z))$$

Different processing methods have been published and shown certain degree of success from model driven, data driven, to hybrid methods in different domains and dimensions. The proposed de-ghosting technique here uses Wave-equation methods based on pressure-only recordings can be derived assuming that the sea-surface is perfectly flat, and that the sea surface acts as a perfect mirror, i.e. it has a reflectivity coefficient of R=-1. Using Rayleigh's reciprocity theorem, an equation can be derived that computes a de-ghosted pressure wave field from the measured scattered pressure wave field through a multiplication of a spectral operator that collapses the primary reflections and their ghosts (together a dipole recording) into a de-ghosted, monopole recording. The equation takes the following form:

$$\bar{P}^{deghost}\,(js\alpha_1, js\alpha_2, x_3|x^S, S) = \frac{\exp(S\Gamma x_3)}{2\,\sinh(S\Gamma x_3^R)}\,\bar{P}^{sct}(js\alpha_1, js\alpha_2, x_3^R|\,x^S, S),$$

In which $\bar{P}^{\,deghost}$: denote the de-ghosted pressure wave field in the frequency domain

$\bar{P}^{sct}$: denote the measured scattered pressure wave field in the frequency domain

x_3^R : denote the constant Receiver depth

x^S : is the vectorial position of the source

S : is the Laplace frequency parameter and

Where $\Gamma_k = j\sqrt{\frac{\omega^2}{c^2} - k_x^2 - k_y^2}$

The proper de-ghosting means that the ghost has been removed correctly without boosting the noise in the notch frequency range and provide a useful broadband data to the quantitative and qualitative inversion considering the fact that the data in the notch frequency range is not recorded.

Receiver Ghost Elimination Data Example

It is the process in which we compensate for the effect of the receiver ghost on conventional streamer data. The traditional source signature used is a convolution of:

Source signature = SGF * gs * gr * R

Where, SGF is the ghost-free source signature, gs is the source ghost, gr is the receiver ghost and R is the instrument filter.

Traditional zero-phasing de-signature compensates for the ghost phase effects but not the amplitude and assumes vertical propagation only i.e. a 1-D sense .In the paper, the receiver ghosts are treated in a 2-D sense by taking account of the emergence angle. The solution is deterministic using the measured Receiver depth. De-ghosting is applied in the Laplace domain with stabilization factors (both in amplitude and phase) in order to control the process at the notches frequency.

Receiver de-ghosting workflow applies the inverse operator of the receiver ghost in order to remove the effects the receiver ghost has on the phase and amplitude of the data. It is also uses pole suppression which aims at removing zeros from the ghost operators and the obliquity function such that these operators become stable under inversion.

Raw shot gather in t-x acquired with a streamer depth of 9 m and a source depth of 7 m (Figure 4), which

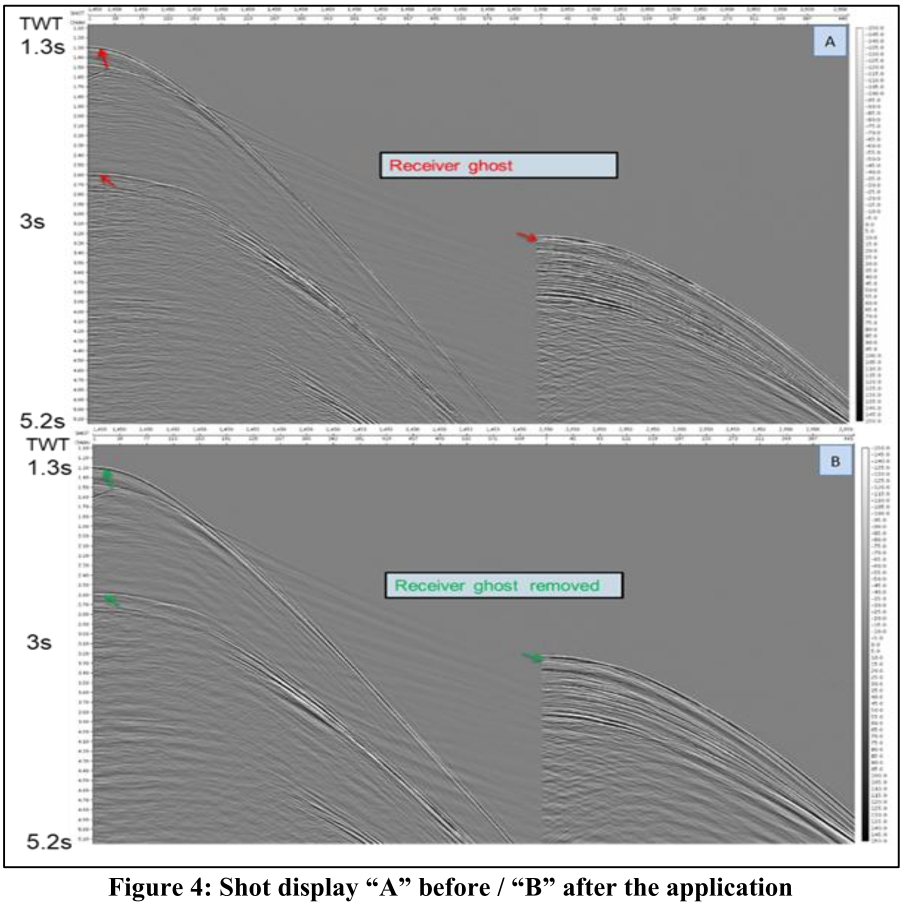

Figure 4: Shot display "A" before / "B" after the application of the Receiver de-ghosting workflow.

show how the receiver ghost has been effectively removed.

Also the Near channel display (common offset) (Figure 5) shows that the receiver ghost has been effectively removed.

Amplitude spectra extracted from the data (Figure 6), shows the successful retrieval of the energy at the vicinity of the receive notch after the application of the receiver deghosting.

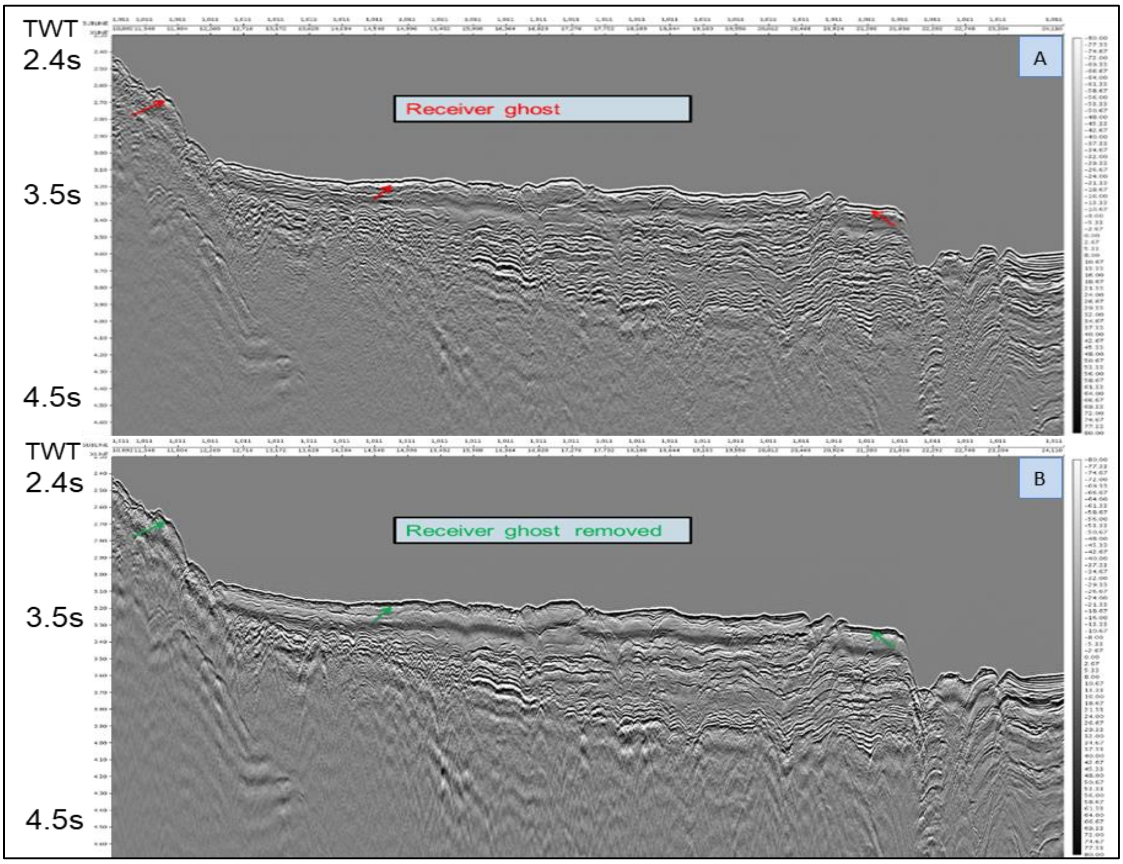

Figure 5: Near channel display channel 5 "A" before / "B" after the application of the Receiver de-ghosting workflow.

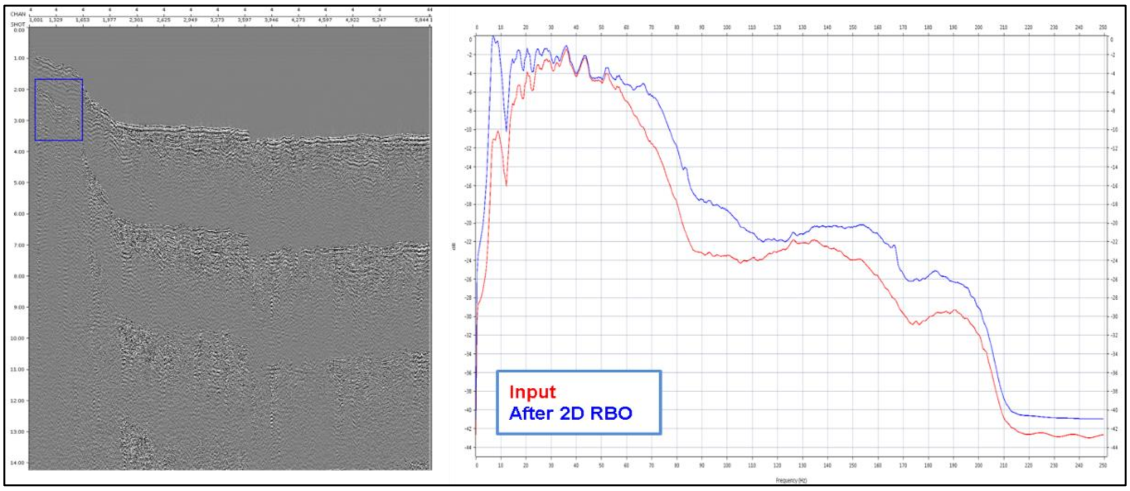

Figure 6: Amplitude Spectrum before / after the application of the Receiver de-ghosting workflow.

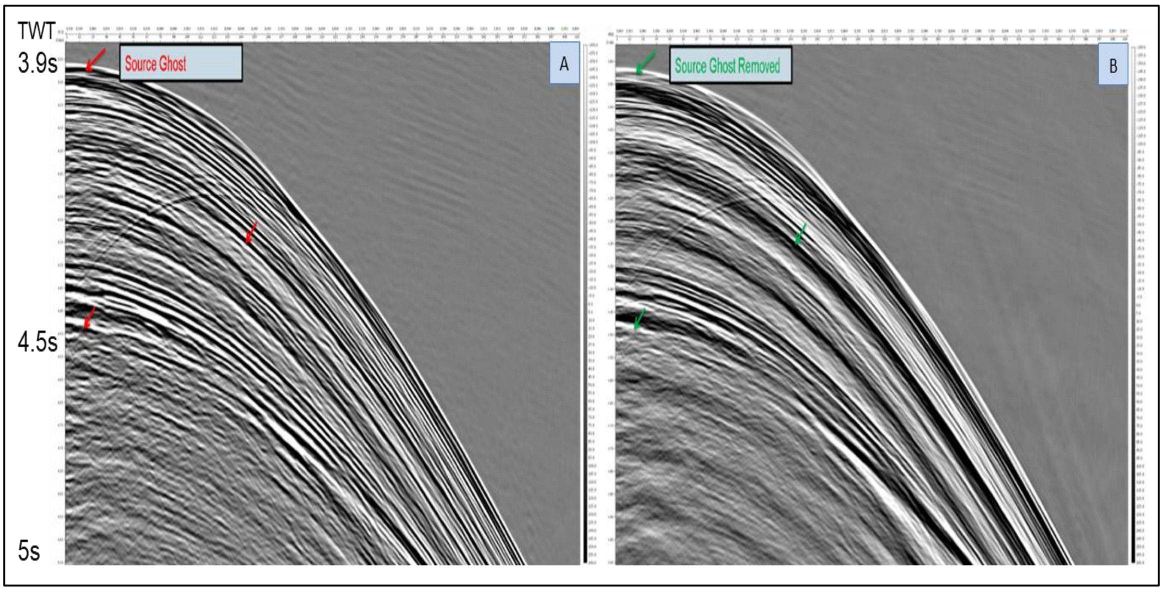

Figure 7: Shot display “A” before / “B” after the application of the Source de-ghosting workflow.

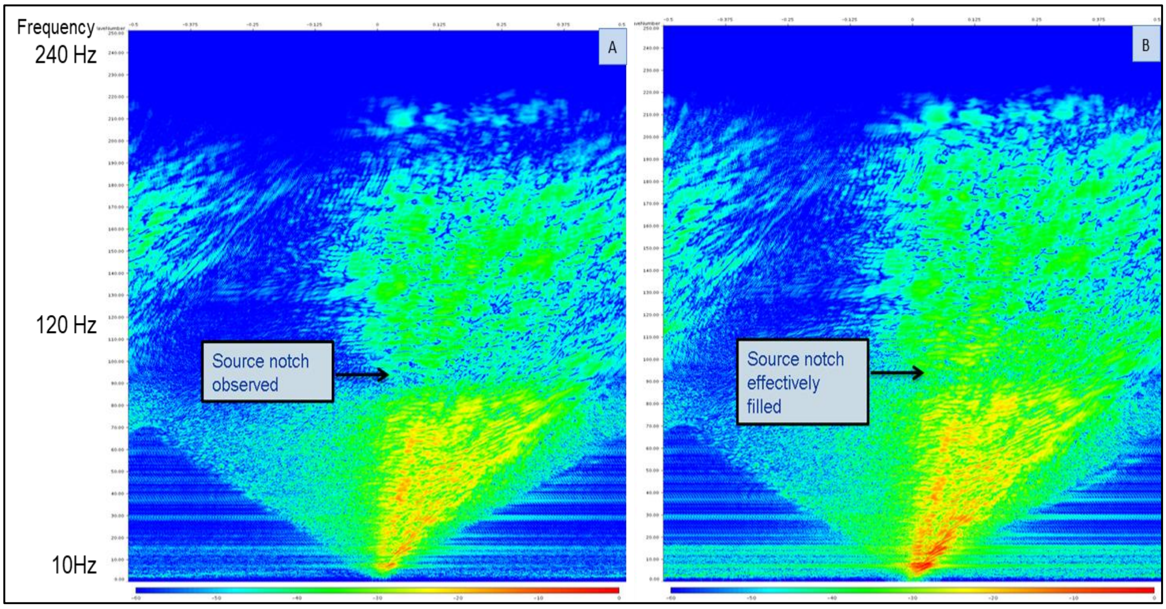

Figure 8: F-K spectrum “A” before / “B” after the application of the Source de-ghosting workflow.

Source Ghost Elimination Data Example

It is the process in which we compensate for the effect of the source ghost. The solution is deterministic using the measured source depth. De-ghosting is applied in the Laplace domain with stabilization factors (both in amplitude and phase) in order to control the process at the notches frequency. The application of Source Bandwidth Optimization “SBO” takes into account the variation in emergence/emission angle. Raw shot gather in t-x and f-k domain acquired with a streamer depth of 9 m and a source depth of 7 m (Figure 7 and Figure 8) which show how the source ghost has been effectively removed and the enrichment in the bandwidth of the data.

Also the Auto-correlation display has been used to clearly ensure that the source ghost has been remove properly (Figure 9).

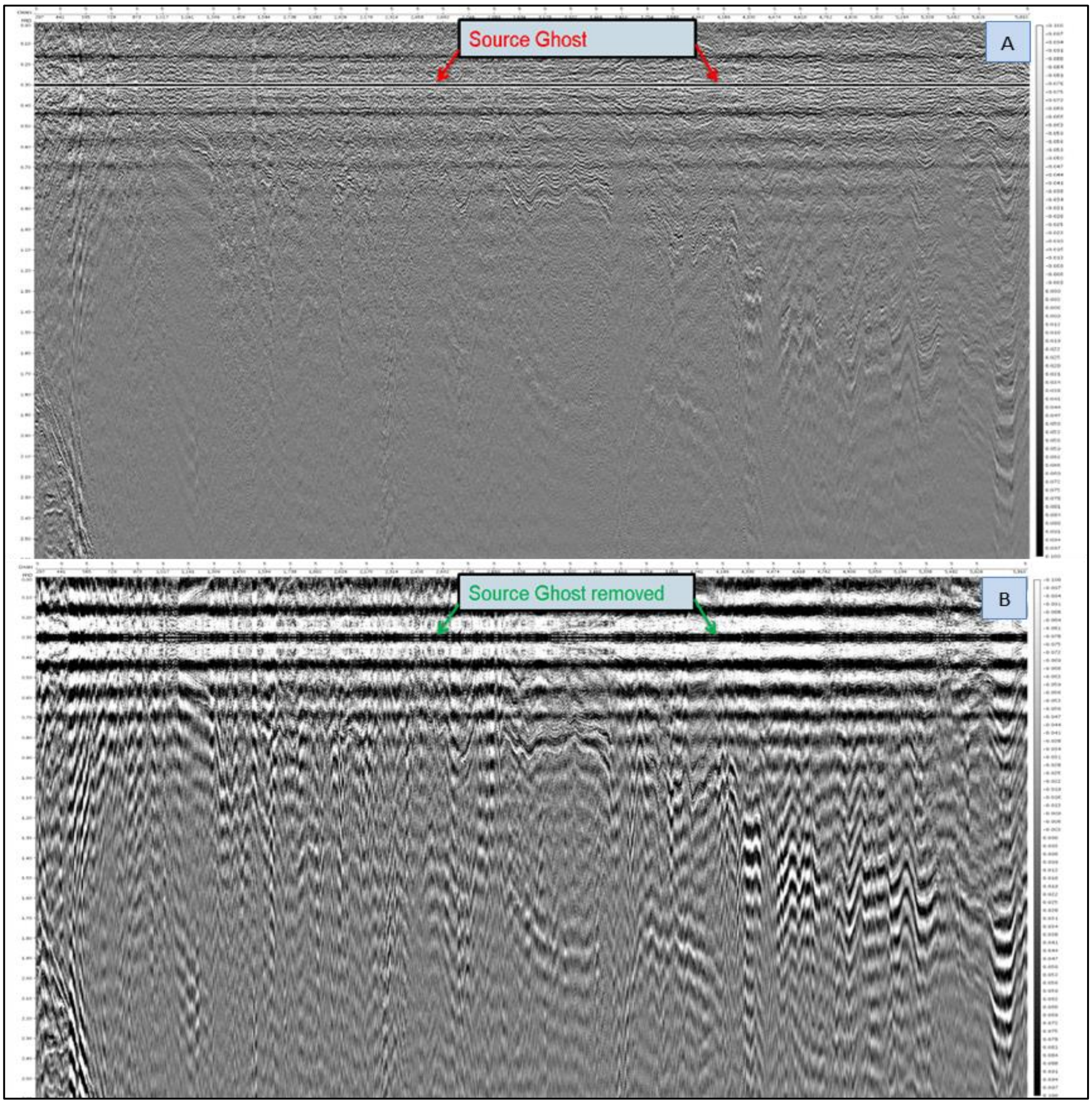

Figure 9: Auto Correlation “A” before / “B” after the application of the Source de-ghosting workflow.

CONCLUSIONS

This study demonstrates that the proposed de-ghosting workflow successfully manages to remove the ghost and its corresponding notches, recovering the lost lower and higher frequencies for the conventional streamer data acquired at constant receiver depth. Consequently, the quality of all the available old 2D data in this province is improved in terms of resolution by obtaining a broader bandwidth.

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