Accounting for sea surface variation in deghosting – a novel approach applied to a 3D dataset offshore west Africa

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Summary

The ghosting effect of towed marine seismic data is controlled by the acquisition geometry and the sea state. Deterministic methods of deghosting typically require accurate depth information for every receiver along the length of the streamer within decimetres. Any minor inaccuracy in this information can lead to characteristic ringing through application of the deghosting operator in the wrong frequency. In practice neither the sea surface is flat nor do the receivers remain at their nominal depths; measurements themselves are sparser and generally interpolated. The position of the receiver-ghost notch frequency is dynamic, varying for every receiver in every shot gather which is augmented in higher sea states.

Here we describe an approach of differential deghosting applied to a 3D dataset offshore west Africa. Firstly, the receiver ghost notch is isolated from the *f-x* spectra of the precritical water bottom reflection for every shot and a search of minimum amplitude is performed around the calculated value from the recorded measurements. Based upon these estimates we move or 'reghost' the notch either to the measured value in the trace headers or to a corresponding nominal depth. By applying this step we demonstrate that the variability in the sea surface is accounted for and a significant improvement made in subsequent full deghosting.

Introduction

Deterministic methods for deghosting marine seismic data assume we know both the source and receiver depths, reflection coefficients and account for the ghost variation with incident angle. If the sea surface is flat acting as a 'perfect mirror' these assumptions can be valid but rarely this is true. As shown in Figure 1, the position of the receiver ghost notch is dynamic from shot to shot and along the streamer itself. This high level of dynamicity results in the random diversification of the receiver ghost notch frequency for any given angle of incidence.

By applying deterministic deghosting only we can recover the amplitude within the receiver ghost notch for any given angle prestack, yet a phase discrepancy may still occur from receiver to receiver. This may only become apparent when the data is stacked, manifesting itself as a 'residual notch'. The cartoon in Figure 2 demonstrates this effect whereby the streamer itself is generally well behaved but the sea surface is varying. Only by compensating for this variation can all events be summed constructively to avoid a residual receiver ghost notch effect post stack (Figure 3).

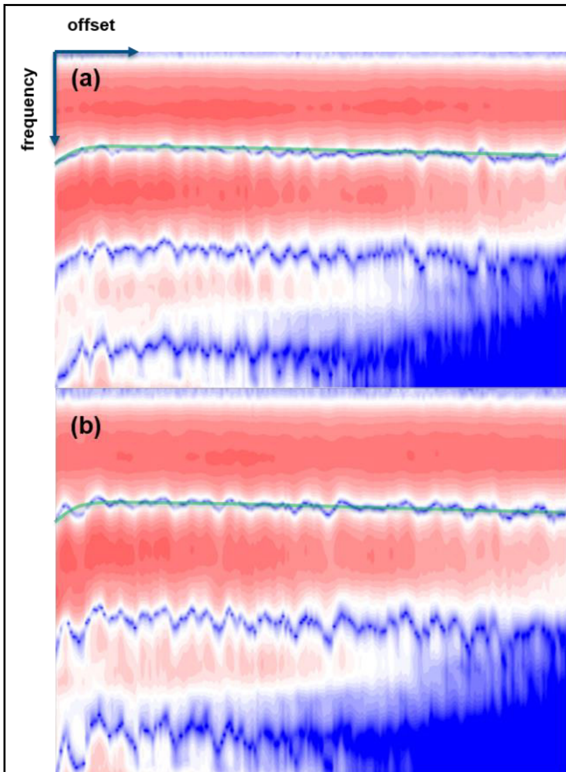

Figure 1: a) *f-x* spectra of traces from a shot gather acquired at an assumed nominal depth, obtained after the water-bottom event is isolated and NMO corrected. The calculated receiver depth from measurement is shown by the green line. b) *f-x* spectra of an adjacent shot gather showing the dynamic variation due to the sea surface.

Raw hydrophone data towed relatively deep (15 m) from a Geostreamer 3D survey offshore west Africa is used through extraction of the *f-x* spectra of the water bottom reflection; subsequently a search is performed. This allows differential receiver deghosting in a semideterministic manner removing both variations in the sea surface and the streamer depth improving the result.

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Differential deghosting method

An approach is taken with the assumption that the receiver depths are known, either recorded in acquisition or estimated based on a stochastic search (e.g. Masoomzadeh *et al*., 2013; Hardwick *et al*., 2014). In the latter case we refine the nominal depth by deghosting many times in order to improve the result. This search finds the most appropriate set of parameters, which include depths and frequency-dependent reflection coefficients assessing the autocorrelation for minimum energy. Whilst some of the sea state variation may be ‘absorbed’ by this step we can remove the effect of the sea surface entirely by applying static shifts in the frequency domain.

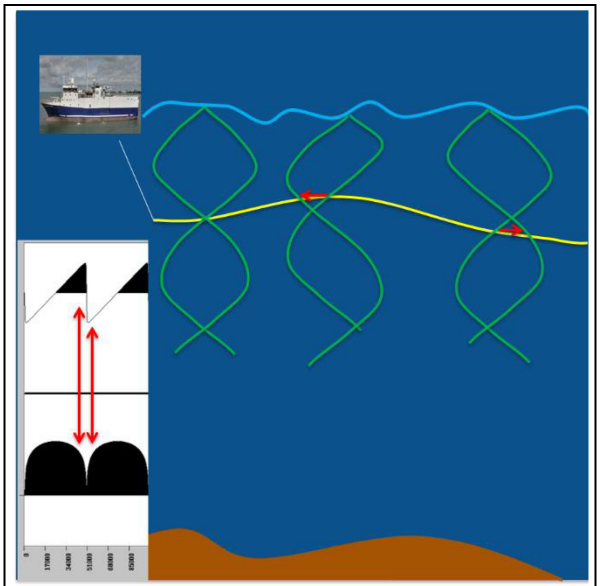

Figure 2: Phase variation due to streamer depth and sea state. In certain receivers perfect cancellation occurs whilst not in others. Inset shows the reversal of phase expected in the receiver ghost notch position.

The measured depths, refined by stochastic searching, are ‘shifted’ to their nominal depths – moving to the idealised acquisition with both a flat streamer and flat sea surface in this instance. This is demonstrated in Figure 4. At the same time we account for the gun-cable static correction in all angles to redatum the data to mean sea level.

This ‘reghosting’ exercise then allows standard deghosting techniques for a flat streamer acquisition in the tau-*p* domain where the ghost delay is consistent for any given slowness trace. For a deliberately shaped slanted or curved cable we can still use this method to adjust the receiver ghost notches to their idealised position and a flat sea surface beforehand, although the details of the deghosting algorithm may differ.

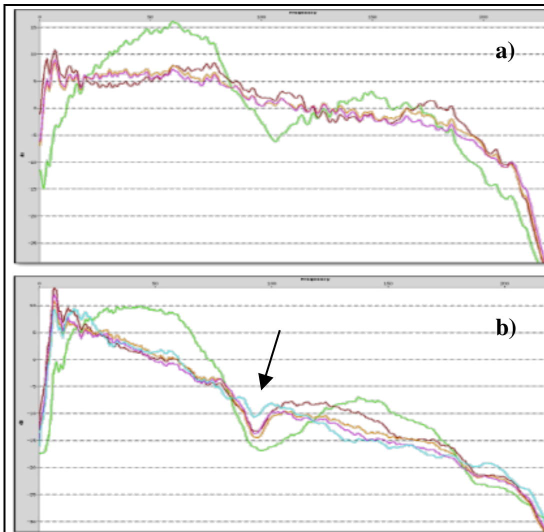

Figure 3: Average amplitude spectra before (green) and after deghosting: a) before stack, b) after stack. Amplitude loss is observed around a frequency at which the maximum phase discrepancy occurs. This effect is more observable around the seabed event, where the stacking velocity is closer to the water velocity.

Results

Figure 5 shows an example shot gather from offshore west Africa. Highlighted is the receiver ghost which has a footprint of the sea surface undulation. Assuming a flat streamer geometry and constant ghost delay time, the deghosting operator fails to completely remove the effect, leaving a residual (Figure 5(b)). Through application of differential deghosting, that includes redatuming, searching and reposition of the receiver ghost notch prior to standard deghosting, the result is significantly improved (Figure 5(c)). The disruption caused by localised phase issues are also resolved when the data is stacked (Figure 6).

Conclusions

The method we describe of ‘differential deghosting’ is one where we separate out the depth effects of the sea surface and receiver-to-receiver variation in the streamer itself. The process essentially moves the data to an idealised situation where the sea surface is flat and the streamer behaves as per the acquisition specification. Through the introduction

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of this step, it allows deghosting algorithms to work correctly and avoid residual effects such as nonperfect stacking of data due to phase discrepancies in the pre-existing notch frequencies.

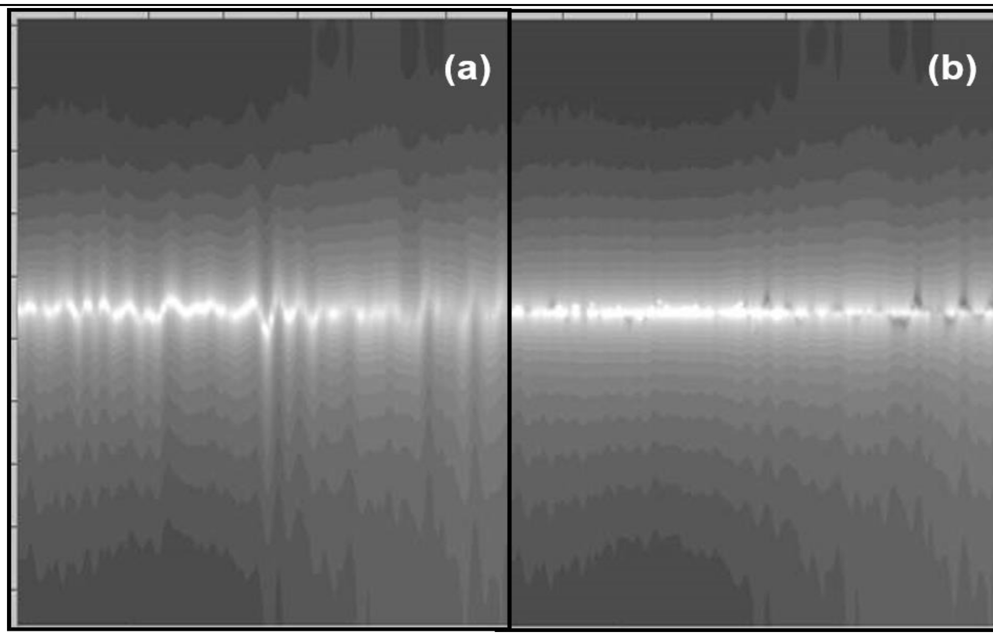

Figure 4: (a) Receiver ghost notch frequency as isolated from *f-x* spectra of the precritical reflection energy from a water bottom event showing undulation related to the sea surface. (b) After shifting to their nominal recorded receiver depths.

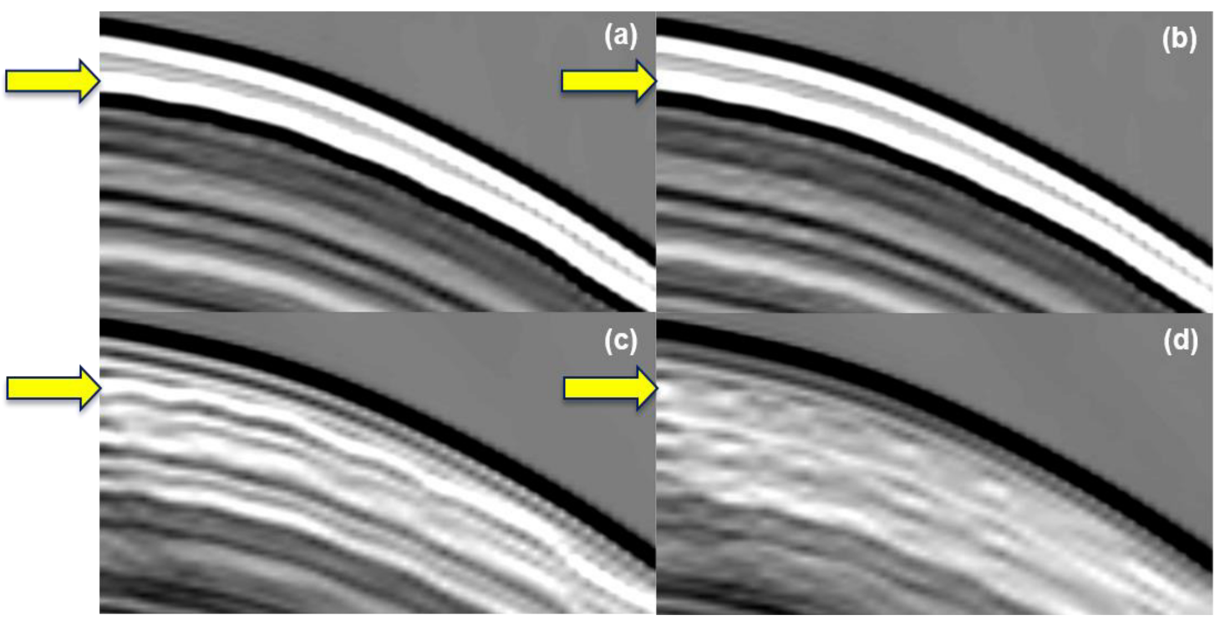

Figure 5: (a) Raw shot gather with the receiver ghost highlighted. (b) after'reghosting' to the recorded receiver depth and searching. (c) Deghosting assuming the measured depth and (d) after the 'reghosting' step. Deghosting parameters remain identical for both.

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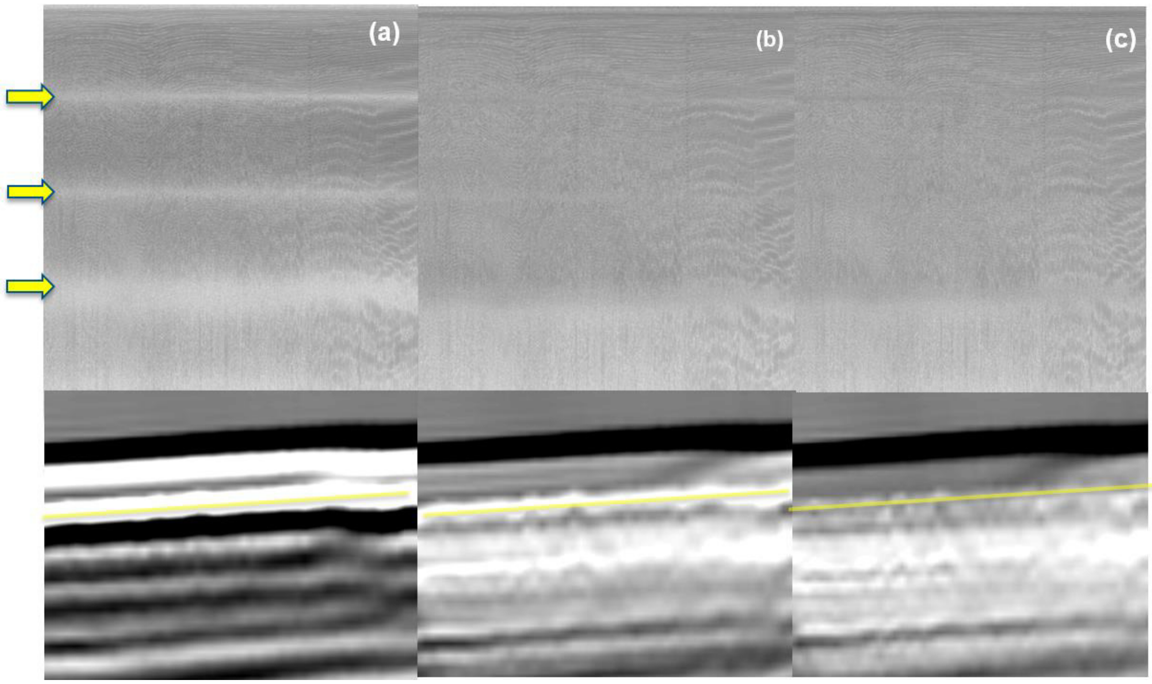

Figure 6: (a) *f-x* spectra of vertical incidence common slowness gathers before deghosting and (b) deghosted based on nominal recorded depths. (c) After differential deghosting, compensating for sea surface and streamer depth variations. A corresponding portion of stacked data is shown below for comparison with the receiver ghost highlighted in yellow. Based on nominal depths a residual ghost remains which is attenuated further with the differential deghosting method described. Note that the third receiver notch is shared with the source ghost.

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EDITED REFERENCES

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