Ghost effect analysis and bootstrap deghosting application on marine streamer data

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Abstract

Demand for broadband seismic data is rising. In this paper, we analyze the effect of the source and receiver ghosts on the wavelet, spectrum, and AVA. We also demonstrate how the bandwidth of constant-depth streamer data can be broadened with a bootstrap deghosting approach in the pre-migration stage. We use two constant-depth streamer examples from the Gulf of Mexico to show the benefits of bootstrap deghosting on restoring the bandwidth and reducing side lobes.

Introduction

Conventionally, marine seismic data are acquired with all the streamers towed at a constant depth. It is commonly known how both the low and high frequencies of the acquired data are limited by ghost notches. Our industry generally accepts that a broad bandwidth spectrum in seismic data is important for both seismic imaging and interpretation. Lower frequencies provide better penetration into the deep section and reduce side lobes of the wavelet for easier structural interpretation, velocity analysis and reservoir inversion; higher frequencies sharpen the central peak of the wavelet for thin bed differentiation. In response to these needs, several new acquisition methods have been developed to acquire broadband seismic data in the last few years; examples include dual-sensor streamers (Carlson et al., 2007), over-under streamers (Özdemir et al., 2008) and variable-depth streamers (Soubaras, 2010).

While the utilization of broadband acquisition is rapidly increasing, there is still much constant-depth streamer data in use for hydrocarbon exploration. Deghosting constant-depth streamer data and broadening its bandwidth to approximate that of a broadband acquisition will be beneficial. Wang and Peng (2012) proposed a pre-migration deghosting method using a bootstrap approach. The main steps of the bootstrap deghosting are as follows:

1. Input the data in shot order
2. Create a mirror NMO corrected shot gather from the original shot gather using 1D ray-tracing based normal moveout correction
3. Jointly invert the original and mirror shot gathers to derive an initial ghost filter through a least squares process
4. Iterate using a bootstrap approach and the original data to refine the initial ghost filter to account for time shift, noise, and receiver depth uncertainty
5. Apply the inverse of the resulting ghost filter on the original shot gather to obtain a ghost-free output

This method does not require accurate angle estimation and is suitable for both 2D and 3D data regardless of shot and receiver sampling. It derives ghost delays from data optimization, and thus does not require accurate receiver or shot depth. Inherently, it can be used for streamer data with either a constant- or variable-depth profile.

In this paper, we analyze the effect of the ghost on the wavelet, spectrum and amplitude, and then demonstrate the benefits of bootstrap deghosting on pre-migration data. We use two constant-depth streamer examples from the Gulf of Mexico to show the benefits of deghosting on restoring the bandwidth and reducing side lobes.

Analysis on ghost effect

Traditional processing techniques work well at frequencies below the first receiver ghost notch. Deghosting is the technique to reduce this limitation and broaden the usable frequency range.

To understand the effect of deghosting, we first need to study the response of the ghost on seismic data. Ghost arrival delay time increases as shot or receiver depth increases. Shallow-towed streamer data has a relatively broad bandwidth lacking low frequencies. Deeper-towed streamer data, which is usually used for wide azimuth (WAZ) acquisition, gains more energy in the low frequency end but creates the first ghost notch at a lower frequency. The ghost arrival delay time also decreases as incidence angle increases. For the same event, as offset increases, the ghost delay time decreases, thus the ghost notch moves to higher frequencies. Deeper events, in general, have smaller incidence angles than shallow events; consequently, they have less ghost delay variation and relatively lower notch frequencies. In summary, ghost delay time is spatial and time variant in seismic data. 1D filters can be used to broaden the bandwidth assuming a constant ghost delay. This can result in wavelet distortion at large angles, such as shallow far offsets. Deghosting according to different ghost delays is expected to produce better results.

Due to absorption of the subsurface, only shallow seismic data contains high frequency signal and deep data is typically recorded with only low frequencies. Figure 1 shows the ghost effect on shallow and deep events in both time and frequency domains, with a Q value of 250. Shallow primary data has a broad bandwidth. By adding the ghost, the spectrum becomes narrower since the ghost notch frequency is within the primary bandwidth. For the deeper event, the peak frequency of the data is around 6Hz due to absorption. This peak frequency is shifted to 40Hz by including the ghost effect; therefore, the data appears higher frequency with the ghost. Based on this analysis, we can expect that the proper deghosting would restore the data spectrum by broadening both low and high frequencies in the shallow data and shifting the peak to lower frequency in the deep data.

Next, we will discuss ghost impact on amplitude. With the interference of the ghost, the amplitude of the wavelet can be attenuated or boosted based on the ghost delay time and bandwidth of the data. This can create complications for amplitude variation with angle (AVA) analysis (Zhang et al., 2012). Figure 2 shows AVA on synthetic data with constant reflectivity. With a full bandwidth signal (100Hz), amplitude increases at first but then decreases as the angle increases due to the effect of the ghost (red curve in Figure 2a). By excluding the notch frequency with a high cut filter, the AVA curve becomes simpler, but the slope varies with bandwidth. With an 80Hz high cut filter, we obtain a reasonably correct AVA curve. With higher or lower bandwidth, we will over- or under-estimate the actual AVA response. Figure 2b shows the AVA response of the data with different high cut filters after bootstrap deghosting. Deghosting recovers the amplitude distortion and produces the correct AVA, which will make AVA analysis more reliable.

Application of bootstrap deghosting on real data

We perform bootstrap pre-migration deghosting on a narrow azimuth (NAZ) dataset and a wide azimuth (WAZ) dataset from the Gulf of Mexico to show the effect of bootstrap deghosting and demonstrate the benefit of ghost free data. In the first example, we apply bootstrap deghosting to a NAZ dataset covering approximately 5 OCS blocks around the Diana field in the East Breaks area. This dataset has a constant shot depth of 7m and a constant receiver depth of 9m. We performed Kirchhoff migration on the data with and without deghosting with an existing VTI velocity model. In our second example, we selected a WAZ dataset from the Garden Banks area. This dataset has a constant shot depth of 10m and a constant receiver depth of 15m. We applied a similar processing flow as in the NAZ example. A 25Hz RTM was also performed to evaluate the subsalt image. The following figures show the effect of deghosting from these two examples.

The migration results from the first example show that the bootstrap deghosting reduces the side lobes of the wavelet and makes the geologic structure easier to interpret (marked in Figures 3a-3d). The amplitude spectra (Figures 3e and 3f) demonstrate how the deghosting has broadened the bandwidth. The spectrum in the deep window after deghosting has stronger low frequencies and, as expected, peaks at a very low frequency due to the absorption of the earth.

The RTM results from Garden Banks (Figures 4a and 4b) show cleaner subsalt images (circled) and reduced side lobes (arrows) with pre-migration deghosting. By reducing the side lobes, bootstrap deghosting can significantly reduce far offset stretch. Figures 4c and 4d show a migrated common image gather with and without pre-migration deghosting. The stretching at far offsets (Figure 4c) distorts event curvature and can lead to velocity errors in tomographic inversion.

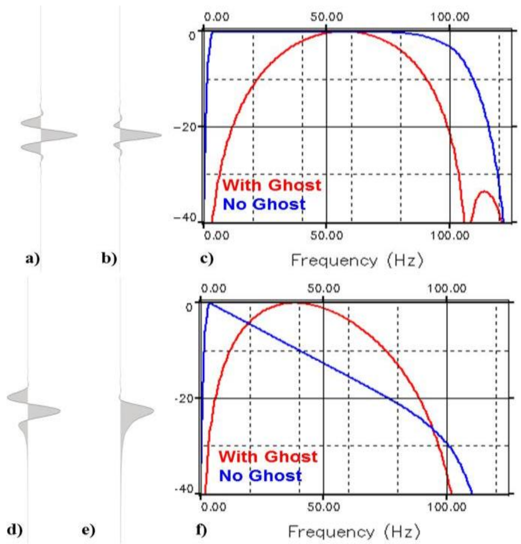

Figure 1: Synthetic shallow event (a) without ghost, (b) with ghost and (c) spectrum. Synthetic deep event (d) without ghost, (e) with ghost and (f) spectrum. For both examples a Q value of 250 was used.

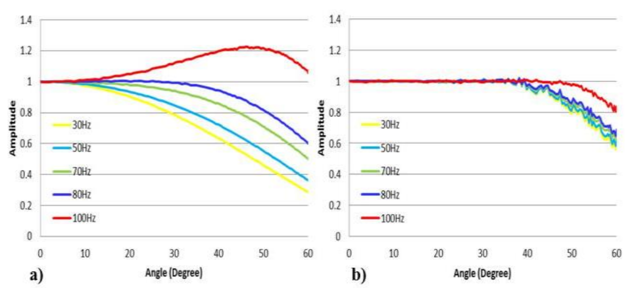

Figure 2: (a) AVA response with different high cut filters, (b) the AVA response of deghosted data. Shot/receiver depth is 6m/7m.

A 1D deghosting operator can broaden bandwidth with less cost than bootstrap deghosting. To verify the effect of a 1D filter and the differences with bootstrap deghosting, we design a 1D filter by matching the raw near offset data to the near offset data after bootstrap deghosting, and then apply it to all offsets for comparison. The 1D filter works well on near offsets (by design) but degrades as offset increases. The 1D filter creates a lot of ringing on far offsets because it ignores variations of the ghost-time delay. Meanwhile, bootstrap deghosting is still effective on far offsets (Figure 5).

Conclusions and discussion

In this paper, we discussed the ghost effect and observed the following: 1) Ghost delay is time and space variant, hence deghosting that can accommodate the variation is better than a 1D filter; 2) The ghost impact on spectrum is not only related to ghost delay time, but is also influenced by the bandwidth of the primary event. Proper deghosting would broaden both low and high frequencies for high frequency events, mostly in shallow data, and tilt the peak frequency towards a lower frequency in deep low frequency data; 3) The presence of the ghost also complicates amplitude vs. angle due to the ghost delay and frequency variation in the data. Deghosting recovers the amplitude distortion and produces correct AVA, which will make AVA analysis more reliable.

We presented the results of bootstrap deghosting on constant-depth streamer data from the Gulf of Mexico. The results show that the bootstrap deghosting approach is robust and can be used for both NAZ and WAZ 3D surveys. The deghosting process restores the bandwidth and reduces side lobes, thereby improving the interpretability of geologic features. Additionally, deghosting produces cleaner and undistorted common image gathers, which can lead to improved velocity estimation and reservoir inversion. Bootstrap deghosting also has its own limitations. Since it is data driven, strong noise contamination can reduce the reliability of the deghosting filter. Also, the effectiveness of the bootstrap method can be compromised when a large variation of ghost delay times is present in the same time window.

Overall, we demonstrate the importance of deghosting and the effectiveness of the bootstrap deghosting method on constant-depth streamer NAZ or WAZ data sets in the Gulf of Mexico. However, high noise levels near notch frequencies in constant-depth streamer data would limit the deghosting effect of this method. More benefits may be obtained from a true broadband acquisition solution (Rebert et al., 2012).

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References

Carlson, D.A., Long, W., Tobti., H., Tenghamn, R., and Lunde, N., 2007, Increased resolution and penetration from a towed dual-sensor streamer: First Break, 25, 71-77.

Özdemir, A.K., Caprioli, P., Özebek, A., Kragh, E., and Robertsson, J.A., 2008, Optimized deghosting of over/under towed-streamer data in the presence of noise: The Leading Edge, 27, 190.

Rebert, T., Sablon, R., Vidal, N., Charrier, P., and Soubaras, R., 2012, Improving pre-salt imaging with variable-depth streamer data, 82nd Annual Meeting, SEG, Expanded Abstracts.

Soubaras, R., 2010, Deghosting by joint deconvolution of a migration and a mirror migration: 80th Annual Meeting, SEG, Expanded Abstracts, 3406–3410.

Wang, P., and Peng, C., 2012, Premigration deghosting for marine streamer data using a bootstrap approach, 82nd Annual Meeting, SEG, Expanded Abstracts.

Zhang, Y., Roberts, G., and Khalil, A., 2012, Compensating for source and receiver ghost effects in reverse time migration, 82nd Annual Meeting, SEG, Expanded Abstracts.

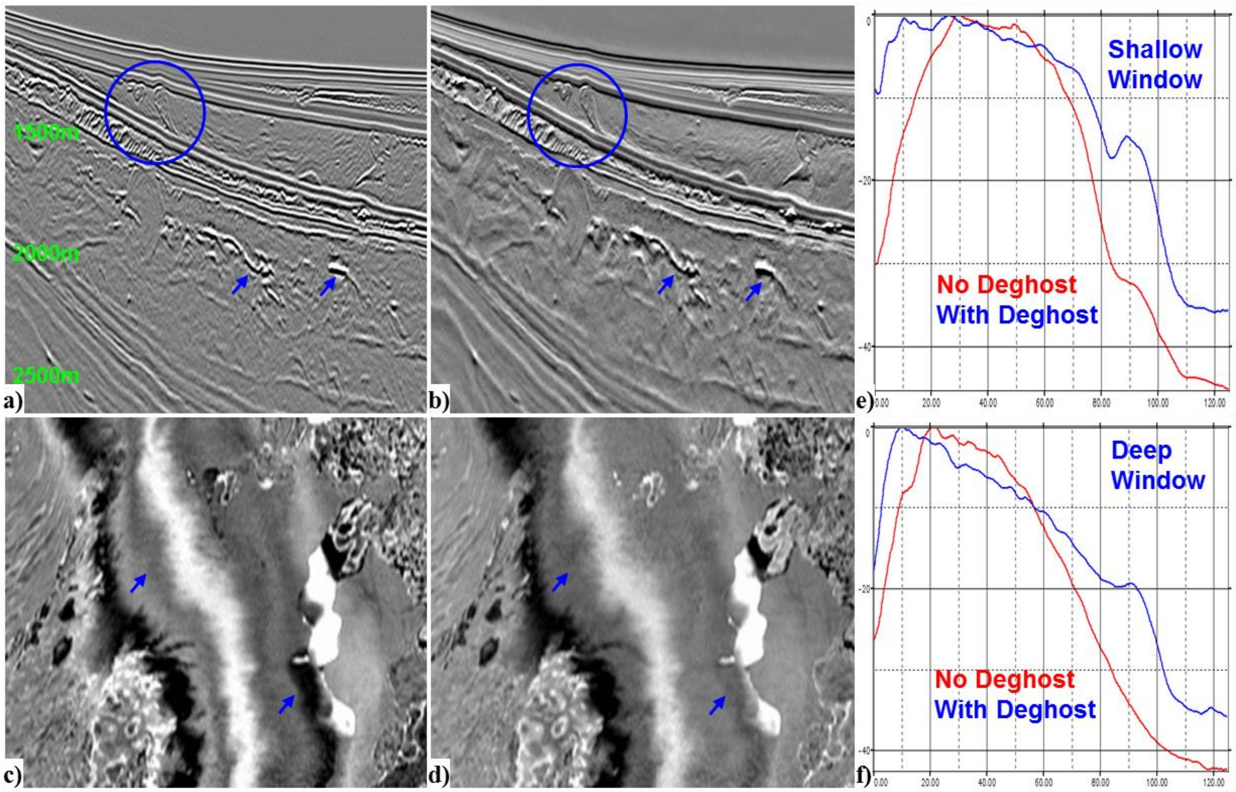

Figure 3: East Break NAZ data (a) without deghosting and (b) with deghosting. Depth slice at 1.6km (c) without deghosting and (d) with deghosting. Spectra with and without deghosting for (e) a shallow window (at 1.5km) and (f) a deep window (at 2.5km).

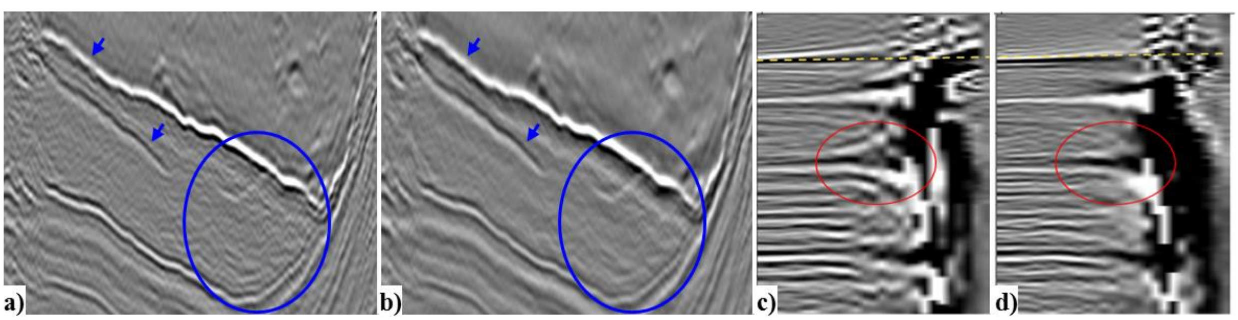

Figure 4: 25Hz RTM sub-salt image (a) without deghosting and (b) with deghosting on Garden Banks WAZ data. Kirchhoff gathers (c) without deghosting and (d) with deghosting.

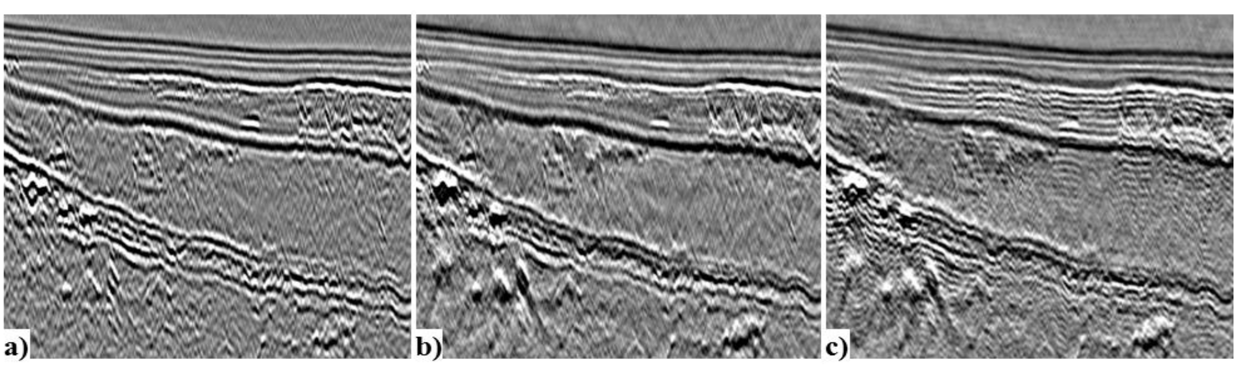

Figure 5: Offset 3470m from East Break NAZ data (a) without deghosting, (b) with bootstrap deghosting and (c) with a 1D filter.