Multi survey matching of marine towed streamer data using a broadband workflow: a shallow water offshore Gabon case study.

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Summary

The presence of source and receiver ghost notches limit the useable bandwidth of marine towed-streamer data. In multi-survey processing, different acquisition configurations (i.e., variable source and receiver tow depths) can lead to variability in the notch period between the surveys. This complicates survey matching. Here we use source and receiver deghosting as part of a workflow to aid the matching of surveys with differing source and receiver tow depths. The data is from offshore Gabon.

Introduction

Matching of seismic data assumes that the Earth’s surface and subsurface response is constant for all surveys at a given point in space. Survey matching addresses variables associated with the acquisition setup of multiple input surveys. The main variables to correct are the source signature (the wavelet that we convolve with the earth reflectivity), the recording instruments and the ghosts that are created as a result of towing with different source and receiver depths. Noise in the data should not play a role assuming we have pre-conditioned the data suitably.

Matching of conventional zero-phased marine seismic data in its simplest form generally involves a frequency invariant time shift, phase rotation and amplitude correction. While this method often works well for conventional data (i.e, non-deghosted data with similar source and receiver depths) it breaks down when ghost notches (and their associated phase effects) are positioned at notably different frequencies for each survey. The two datasets we match are a shallow tow (4 m source 6 m cable) and deep tow (6 m source 12 m cable), providing an ideal case study for the matching scheme proposed in this paper.

We present a two-step approach to matching that involves deghosting of both datasets followed by a least squares match to account for source signature variations and receiver sensitivity.

Deghosting

Up-going seismic waves are reflected downward at the sea surface with a negative reflection coefficient of near -1 depending on the sea surface state. For a given depth beneath the sea surface these up and down going waves destructively interfere to leave notches in the power spectrum, while constructive interference at half the notch frequency creates a peak. These notches maybe calculated by dividing any integer by the ghost delay time in seconds (assuming a vertical ray path). The shallow and deep tow surveys’ receiver ghost notches alone (shallow = 128Hz, Deep = 64Hz) alter the frequency content of the recorded data significantly between surveys.

Several methods have been proposed and used to remove the ghost response from seismic data, including several acquisition based solutions (e.g. Posthumus 1993, Carlson, 2007, Soubaras, 2010).

Here we use a processing solution capable of removing source and receiver ghost components from the two flat streamer datasets. The methodology we employ (Zhou 2012, O’Driscoll, 2013) de-ghosts the data prior to migration by generating a stable, data-derived operator.

Matching

By removing the effects of the ghost we have a power spectrum that represents the Earth response (assuming there is no multiple or noise in the data), with a dominance of low frequency energy. This dominance is a result of the Earth’s attenuation and preferential loss of high frequencies with increasing travel-time, which may be accounted for by calculating a suitable Inverse-Q field or value (e.g. Kjartansson, 1979).

For matching purposes, following deghosting we may assume that the earth response and associated power spectra of both datasets would be the same, ignoring differences as a result of the acquisition.

In practice, acquisition systems play a huge role in the matching process, mostly as a result of source signature and receiver sensitivity. Regardless of deghosting, we must also address the acquisition element, including corrections for phase, time and amplitude components. We may apply a single bulk value for each component or, in the case of this example, a least-squares matching scheme. Using a short 1D filter, least squares adaptive matching allows us to effectively account for residual phase, amplitude and timing mis-ties between the two surveys. We use L2 – norm subtraction to suitably derive a shaping filter to match the shallow to deep tow data (e.g. Guitton, 2004).
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Figure 1: Pre-migration near offset stacks of a) deep tow before deghosting, b) deep tow after deghosting, c) deep tow zoom before deghosting and d) deep tow zoom after deghosting. Deghosted zoom shows removal of ghost energy which presents as sidelobes on the zero phased data (arrows). Deep tow data has more low frequency content than the shallow tow prior to deghosting.

Figure 2: Pre-migration near offset stacks of a) shallow tow before deghosting, b) shallow tow after deghosting, c) shallow tow zoom before deghosting and d) shallow tow zoom after deghosting. Deghosted zoom shows removal of ghost energy which presents as sidelobes on the zero phased data (arrows). Shallow tow data has visibly less low frequency content before deghosting. After deghosting both the shallow and deep tow datasets are visibly very similar in terms of character and frequency content.
Example

Deghosting operators were designed and applied for each survey independently following denoise and demultiple. Results of the deghosting can be seen in Figures 1, 2 and 3. The deep survey was considered first as this is the master survey to which the shallow tow was matched. The deep tow exhibits clear receiver notch behaviour at 64, 128 and 192 Hz (Figure 3a). We illustrate this with yellow and red arrows for the constructive and destructive components of the interference pattern respectively. The source notch also sits at 128 Hz explaining the extremely deep notch seen in the spectra. Figures 1a and 1b show results before and after the deghosting of the deep survey. In Figure 1b the broad bandwidth of the zero phased seismic data is clear. Side lobes of prominent events associated with the ghosts (Figure 1c) are removed (Figure 1d). Amplitude spectra also confirms a successful deghost (Figure 3a). For the shallow survey there are notches at 128 Hz and 192.5 Hz as a result of the receiver and source ghost respectively. Deghosting successfully removes the notches from the data (Figure 3b) and again broad bandwidth, deghosted seismic can be seen (Figure 2).

Comparison of the pre-broadband amplitude spectra in Figure 4a highlights the differences between the datasets that make matching especially difficult. Amplitude spectra are shown for shallow tow (blue), deep tow (red) and shallow matched to deep tow (green). Least squares matching of the shallow tow picks the notch of the deep tow very nicely, but over estimates it (Figure 4a). This shows that the merge is good in the sense that the notches are identified (a simple frequency invariant match would not have done this); however the overestimation of the notch and deterioration of frequencies on the shallow data makes this method of matching less than ideal. Following this match, truncations maybe seen in the data between the two surveys as a result of bandwidth differences and ghost energy that is independent to each survey (Figure 4a).

Following deghosting the Earth’s preferential attenuation of high frequencies can be clearly seen on both datasets. A side by side butt merge of the seismic data (following a bulk amplitude scalar applied for comparison purposes) shows both the data and spectra (Figure 4b) are very similar even before time, and (frequency dependent) phase and amplitude scaling are considered. However, whilst the amplitude spectra from 0-60 Hz show a good match, higher frequency trends diverge (Figure 4b) due to differences in source energy between surveys. A join is seen in the seismic section (Figure 4b). This bust at the boundary...
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between the shallow and deep tow is a result of timing, phase and amplitude corrections yet to be applied to the data. This is particularly notable when tracking events across the join (as highlighted by orange arrows).

To counter this, a least-squares matching scheme is used. Figure 4c shows results of the matching. We suitably derive a single shaping filter to match the shallow to deep tow data. Subtle, frequency dependent adjustments to amplitude and phase effectively match the broad-bandwidth, deghosted data, making the join between the two surveys more imperceptible, and matching the amplitude spectra effectively (Figure 4c).

Conclusions

Regardless of tow depth and survey vintage, a robust dehosting workflow in combination with a least squares matching scheme provides a simple and effective way to match data in multi-survey processing. We also have the added benefit of extending the band-width of conventional seismic data at the high and low end of the frequency spectrum.

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Figure 4: Butt merged seismic sections showing shallow tow (left) and deep tow (right) for different stages of processing and matching. Dotted line shows merge point. Amplitude spectra for each dataset is embedded for deep tow (red) and shallow tow (blue), in the case of Figure 4a we also show a spectrum (green) following matching of the shallow to deep tow data before deghosting. Figures shown are 4a) conventional data with a frequency invariant time, phase and amplitude match, b) dehosted data (shallow tow has a bulk amplitude scalar applied for indicative purposes) and c) dehosted and and least squares matched data.
EDITED REFERENCES
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