7th International Conference & Exposition
on Petroleum Geophysics

"HYDERABAD 2008"

P - 278

Source - and Receiver-Side Deghosting in OBC Surveys

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Summary

The pursuit for better marine seismic data quality must contend with the phenomenon of ghosting. Wavefield separation techniques can do this. But in order to perform full deghosting, the challenge at both the source side and the receiver side must be addressed. The specific implementation of wavefield separation does not need to be the same for each case. So for Ocean Bottom Cable surveys, standard dual-sensor recording can enable the wavefield separation to be performed at the receiver side and deployment of over/under airgun arrays can enable the same at the source side. Such a strategy was employed in the field trials presented here. Penetration to deeper targets was the most significant benefit that was observed. This was followed by overall improvements in the signal-to-noise ratio and resolution.

Introduction

One of the high-profile challenges over the last few years in various parts of the world has been to improve the quality of marine seismic data for the purposes of characterizing deep gas reservoirs. One of the major factors influencing that quality is the ghosting that occurs in the water layer.

Ghosting at the receiver is addressed in Ocean Bottom Cable programs by using dual-sensor recording. This is possible because the dual-sensor data enable wavefield separation to be performed. However, the problem that has remained in such surveys is how to address the ghosting that takes place at the source. In this regard, previous *towed-streamer* tests with which the authors had been involved (Moldoveanu et al., 2007) showed that the process of wavefield separation could be implemented for source deghosting too when the source arrays were towed in an over/under fashion. So that provided the fuel for the suite of field experiments that will be discussed here. These tests were acquired in January 2005, but the results were not widely shared in public until now.

Strategy

The confusion caused by ghosting results when the signal-rich upgoing wavefield is interfered with by the downgoing wavefield that is scattered from the air-water interface. What we would like to do is determine the two wavefields separately. And then, unless we want to execute an up/down deconvolution procedure for multiple suppression, we discard the downgoing one. We can do this determination algebraically. But since we have two unknowns (the upwave and the downwave), we need two independent equations.

At the receiver side in OBC surveys we get those two equations from the simultaneous independent measurements of the pressure field and the particle velocity field. At the source side, if we rely on source-receiver reciprocity, we can mimic the acquisition of two independent measurements too. In that case both "measurements" are of the pressure field, but the independence of the linear equations comes from the fact that the "measurements" are made at *two different* depths.

Table 1 lists pertinent details of the acquisition experiments. Figure 1 gives the general strategy in pictorial form. The two source arrays were towed inline at depths of

6 m and 11 m respectively. The separation between the two was 37.5 m. In the subset of tests that are featured in this abstract, the source arrays were not fired simultaneously. Instead, the procedure was to fire the lead array, and then when the trailing array arrived at the same x,y position, it was fired. This inline flip-flop process feigned the desired "over/under" source geometry.

Of course source-side measurements were not actually taken. In order to mimic the over/under measurement strategy, the data were re-sorted into receiver gathers and then the wavefield separation equations were solved. As mentioned above, the source-receiver reciprocity principle is what allows this mathematical slight-of-hand to be implemented.

Expectations

The technical justifications for investing in the field tests were based on three anticipated benefits. Those expectations were that,

- the overall signal-to-noise ratio would be improved
- the "penetration" to deeper targets would be enhanced, and
- the resolution in the processed image would be more crisp.

Discussions of why we expected these benefits would be obtained will be interleaved in the next few sections with discussions of actual test results. For the sake of brevity, the focus will be on the source-side deghosting comparisons. That is, all of the displays presented will already have had the receiver-side deghosting performed.

Signal-to-noise ratio

The process of solving the over/under simultaneous equations for the upgoing wavefield is actually one of combining the over data and under data using frequency-dependent complex weights. In other words, it is a *stacking* process. So by virtue of that stack, we would expect the signal-to-noise ratio to improve. That is, we would expect the signal-to-noise ratio of the computed upgoing wavefield to be better than that of the individual over and under data sets. This is indeed what is observed in the receiver records that are displayed in Figure 2. Of special note is the nature of the low-frequency content.

There are several factors that come into play at low frequencies. Three of the key ones are listed here.

1. **Ghost Theory**

   All source ghosts contain a notch at zero Hz. By definition, this means the amount of signal that can be recorded at low frequencies is limited. (Unfortunately, the same cannot necessarily be said for noise. That is, ghosting does not necessarily limit the amount of low-frequency noise that is recorded because mechanisms associated with the generation of such noise do not typically involve ghosted raypaths). Anyhow, the width of a ghost notch is smaller for deep tow depths than for shallow ones; and happily, the wavefield separation process reduces that width further. So the expectation was that the 6-m data would contain the least amount low-frequency signal, the 11-m data would contain more, and the upwave data would contain the most.

2. **Hydrostatic Pressure**

   The hydrostatic pressure at the depth of an airgun array influences the performance of that array. (For example, the periods of airgun bubbles depend on the depths of the bubbles). This is something of an equalizer. Consequently, spectra of the modeled source signatures that were generated in the survey design study showed that the wealth of very low-frequency signal in our 11-m case was not expected to be quite as superior with respect to the 6-m case as otherwise predicted by ghost theory alone.

3. **Phone Responses**

   The sensitivity of the receivers at low frequencies is also very important in dictating how much low-frequency data are actually written to tape. In these experiments SM4 geophones and P700 hydrophones were used. The amplitude spectra of the responses published by the manufacturers are the same at low frequencies. The sensitivities drop off significantly below 10 Hz. At least in this case, the loss of sensitivity was expected to be the same for signal and noise alike.

Inspection of the Figure-2 records did indeed reveal that the signal content at low frequencies was worst in the 6-m example, middle-of-the-road in the 11-m example, and clearly the best in the upwave example. In fact, in light of the equalizing effects that were expected from point #2 and #3 mentioned above, the large extent to which the low-frequency signal was boosted in the upwave record was something of a pleasant surprise.

Penetration

Because seismic energy is lost to frictional heat at a slower rate when frequencies are low, an obvious potential benefit of greater low-frequency content is the appearance of deeper penetration of the seismic waves. Consequently it was expected that the 11-m source data would exhibit greater penetration than the 6-m data, and that the upwave result would show the best penetration of all. This is indeed what was observed not only in the records shown earlier, but also in the stacks of the prestack time migrated data (PSTM) shown in Figure 3. In fact, the results of wavefield separation are quite dramatic.

Resolution

In addition to the low-frequency advances discussed above, the upwave section was expected to demonstrate improvement in higher temporal (and spatial) frequencies too because ghost notches all across the frequency axis would be filled – not just the one at zero Hz. However, modeling analyses predicted that this improvement would not necessarily be pronounced in the deep section because extensive frictional heat loss would rob the data of the higher frequencies there. In general, these predictions were found to be true. Figure 4 compares the shallow PSTM data from the 6-m case vs. the upwave data. The removal of ghosted legs leads to a markedly clearer upwave section.

Conclusions

Full deghosting of seabed data is possible by augmenting the standard dual-sensor recording operation with the addition of the over/under source technique. Results of field trials in the South Timablier area of the Gulf of Mexico were that penetration was the most significant benefit obtained, followed by overall signal-to-noise improvement, and then resolution enhancement.

References

Moldoveanu, N., Combee, L., Egan, M., Hampson, G., Sydora, L., and Abriel, W., 2007, Over/Under towed streamer acquisition: A method to extend seismic bandwidth to both higher and lower frequencies: The Leading Edge, 26, 41-58.

Acknowledgements

The authors would like to thank WesternGeco for its continued support of investing in field trials to find new exploration solutions. We would also specifically like to acknowledge the very good work done by the Geosupport Team, the OBC-1 Crew, Houston Data Processing Center, and our colleagues in the Integrated Solutions Group.

Location	Gulf of Mexico
Date	January 2005
Type	Syntron 4C
Water Depths	35m to 91m
Geometry	2D
Line Length	42km
Record Length	14s
Receiver Interval	50m
Source Interval	37.5m
Source Depth	6m & 11m
Max DP Offset	12500m

Table 1: Details of the Field Experiment

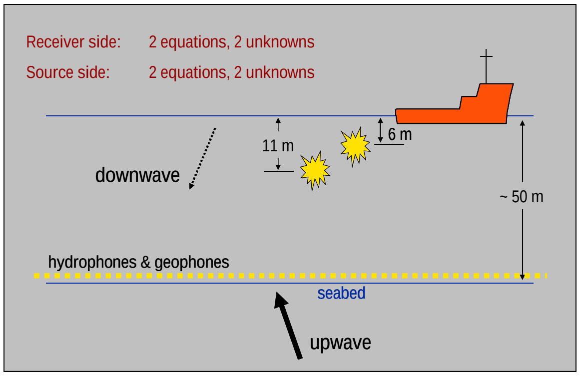

Fig 1: Description of the acquisition geometry

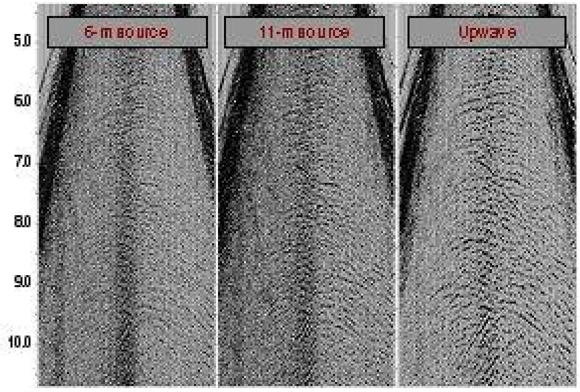

Fig 2: P-Z summed receiver records

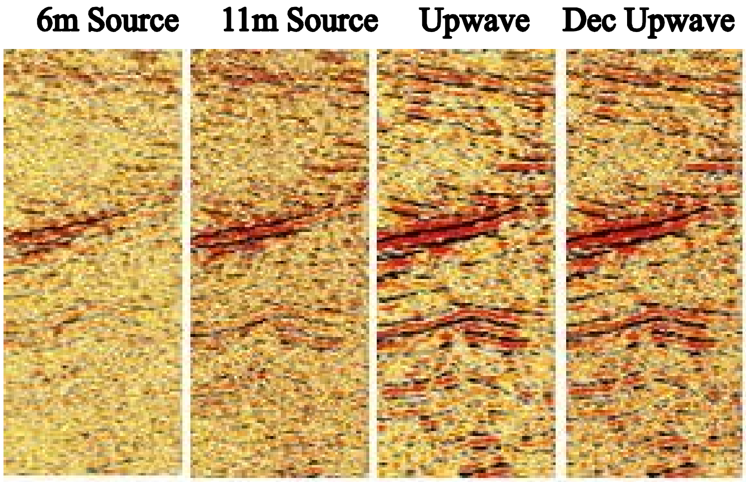
6m Source **11m Source** **Upwave** **Dec Upwave**

Fig 3: Stacks of prestack time migrated data. The time scale is from 3.9s to 8.4s TWT

NOTE: All of the 6m shots and all of the 11m shots contribute to the upgoing wavefield results shown in the third panel from the left. In order to approximate what the upwave stack would look like with an equal source effort, every other shot record was omitted from the upwave data and then the migration and subsequent stack processes were repeated. That decimated upwave display is shown on the panel in the far right. Its result is still superior to the 6m and 11m stacks, but its overall signal-to-noise ratio is commensurately worse by approx Sqrt(2) with respect to the undecimated upwave display.

6m Data **Upwave Data**

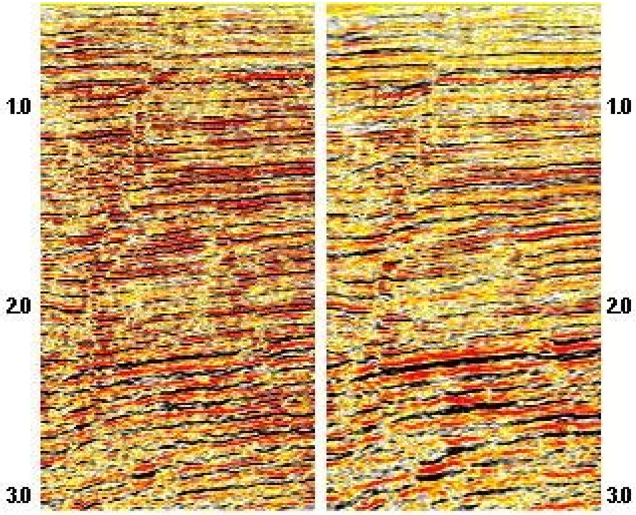

Fig 4: Stacks of prestack time migrated data