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Increasing Resolution with a New Method for Efficient Broadband Marine Acquisition and Processing

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Summary

We present a new method for broadband marine acquisition and processing. A 3D shallow towedstreamer spread is deployed, designed to optimize the mid- and high-frequency parts of the bandwidth. In addition, data are simultaneously acquired from a small number of deeper towed streamers. The depth of these deeper streamers is optimized for the low frequencies such that the combined overall bandwidth is enhanced. Because the deep streamers only provide the low-frequency part of the bandwidth, we can more sparsely sample these data enabling efficient acquisition scenarios as fewer streamers are required. A 3D case study using this new acquisition method was acquired off the NW Shelf of Australia. The streamer spread consisted of six shallow streamers towed at a depth of 6 m and two deeper streamers (below shallow streamers 2 and 5) towed at a depth of 20 m. The resulting data exhibit both high resolution and deep penetration for subsalt and sub-basalt imaging, for example. In addition, inversion for acoustic impedance, imaging, and velocity model building, also benefit from the broadband result. Data acquired in this way are more robust to poor weather conditions than conventionally acquired data.

Introduction

We present a new method for broadband marine acquisition and processing. A 3D shallow towedstreamer spread is deployed, designed to optimize the mid- and high-frequency parts of the bandwidth. In addition, data are simultaneously acquired from a small number of deeper towed streamers. The depth of these deeper streamers is optimized for the low frequencies such that the combined overall bandwidth is enhanced. Because the deep streamers are only going to provide the low-frequency part of the bandwidth, we can more sparsely sample these data enabling efficient acquisition scenarios as fewer streamers are required. The data are combined in processing, optimizing the signal-to-noise ratio over the entire bandwidth. The resulting data exhibit both high resolution and deep penetration, for subsalt and sub-basalt imaging, for example. In addition, inversion for acoustic impedance, imaging, and velocity model building, also benefit from the broadband result. Data acquired in this way are also more robust to poor weather conditions than conventionally acquired data. Data for a 3D case study using this new acquisition method were acquired off the NW Shelf of Australia. The streamer spread consisted of six shallow streamers towed at a depth of 6 m and two deeper streamers (below shallow streamers 2 and 5) towed at a depth of 20 m. A novel over/under source design was also used to bias source output toward low frequencies and further enhance the low-frequency signal-to-noise ratio of the acquired data.

Method

The effect of the free-surface ghost in marine seismic acquisition is well understood. Shallow towing favours the higher frequencies at the expense of attenuating the low frequencies, while deeper towing favours the lower frequencies, at the expense of attenuating frequencies within the seismic bandwidth. Compensating for the ghost effect has been the subject of geophysical research for many years and two successful solutions have been developed on the receiver side. These are over/under acquisition, where streamers are towed as vertically aligned pairs (Hill et al., 2006) and the use of additional velocity measurements in the streamer, where pressure and velocity measurements are combined to achieve the deghosting step (Long et al., 2008). The over/under method requires twice

as many streamers to cover the same spread aperture, with a corresponding decrease in acquisition efficiency. The dual measurement approach requires new hardware and can suffer from high levels of noise at low frequencies in the velocity measurements, rendering them unusable below a cut-off frequency where the method reduces to a deep-tow pressure measurement. The zero frequency notch is present in both solutions, but both solutions considerably enhance the low-frequency content compared to standard shallow towed spreads. In a new method presented here, we propose the use of shallow towed streamers together with a smaller number of deeper streamers.
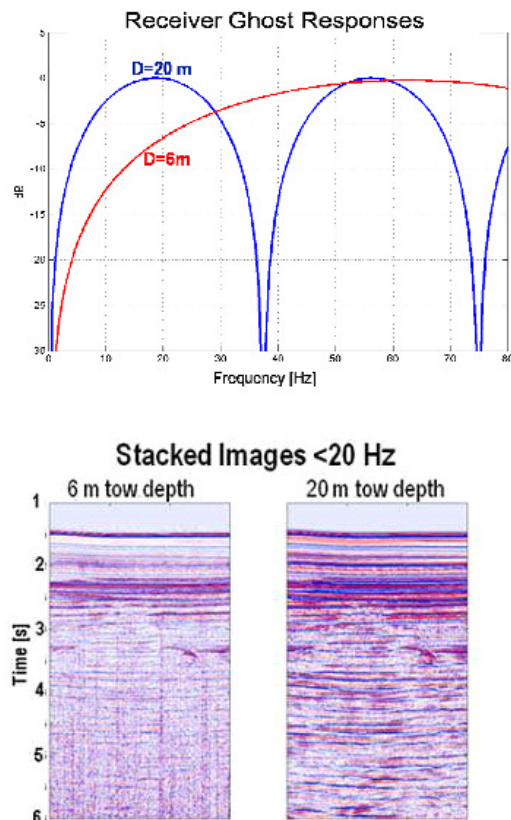

Figure 1. Example of shallow and deep-tow hydrophone ghost responses (left) and stacked images obtained (right). The ghost responses on the left show the improved signal from the deeper streamer below ~30 Hz (shaded red). The images on the right show examples of stacked data, displaying only data after applying a 20-Hz low-pass filter.

In traditional over/under acquisition both over and under streamers are towed at depth and in pairs. A key difference here is that we propose the use of a shallow tow depth for the upper spread, which is designed to optimize the mid and upper frequencies in the survey. A number of deeper streamers are then placed at a depth to optimize the low frequencies only. Combining the two data sets provides broadband data with good signal-to-noise ratio at both the high and low ends of the spectrum. A second key point is that, because we are only going to use the low frequencies from the deeper streamers, we can sample these data more sparsely. i.e., we only need a small number of deeper streamers. This allows for efficient 3D acquisition. Figure 1 shows a 2D example of this shallow and deep tow idea for depths of 6 m and 20 m. The left panel shows the vertical incidence hydrophone ghost notches and the right panel shows stacked images (displaying only the data after applying a 20-Hz lowpass filter) from streamers at these depths. The ghost responses show, in theory, why we might want to choose these depths to optimize the signal strength over a broad bandwidth, and the right panel shows, in practice, the increased signal-tonoise ratio we get from the deep tow for these low frequencies

Processing

The challenge in processing these data is integration

of the differently sampled low- and high frequency data. Figure 2 shows an example, using 3D synthetic data, of one method that we can use to do this. An inline shot record from a single streamer is presented from a "9-over 3-under" sparse acquisition scenario (shown in the insert). The data are actually processed in the crossline vertical shot domain (every trace shown here is generated from the full crossline streamer set of 12 traces) by applying a weighted Fourier interpolation algorithm to reconstruct the data at a given shallow level (shown in green on the insert). The weights are adjusted based on the signal-to-noise ratio of the input data points. The signal-to-noise ratio after integration of the data (central panel) is considerably improved because the deeper streamers are, in this synthetic example, noise free. As an alternative processing scheme, we can combine the lowfrequency data from the deep streamers with their shallow streamer counterparts (treating them as sparse over/under pairs). This can be achieved using an optimized weighted deghosting scheme, or, by simply redatuming the low-frequency data to the shallow level after application of an appropriate deghosting operator. Interpolation of the

redatumed low-frequency data can then be performed in the common-offset crossline domain to regularize the low-frequency data to the same grid as the high- frequency data from the shallow streamers. Residual errors will be due to a combination of interpolation error (not all wavenumbers are correctly sampled) and high wavenumber noise in the data. The latter should be small as the streamers are towed deep and therefore in a relatively low-noise environment. Other processing routes can be envisaged, such as regularization of the low frequency data prior to redatuming/combination with the shallow streamer data.

3D case study

Data for a sparse under case study were acquired off the NW Shelf of Australia during December of 2008. Six shallow streamers were towed at a depth of 6 m with two additional deep streamers, deployed under streamers 2 and 5, at a depth of 20 m.

A novel over/under source design was also used to strengthen the source output in the low frequencies and further enhance the low-frequency signal-to- noise ratio of the acquired data. Figure 3 shows 2D brute stacks from the first phase of the acquisition. The upper panel is the shallow streamer at 6-m depth and the lower panel is the combined result including data from the deep streamers below ~30 Hz. A considerable enhancement in the low frequencies is clear. This is about 10 dB as shown in the spectral comparison in the insert. We now plan to process the full 3D data set and quantify the low-frequency uplift of the technique

Conclusions

We have presented a new method for efficient broadband marine acquisition using a single sensor, steered 3D shallow towed spread with the addition of a small number
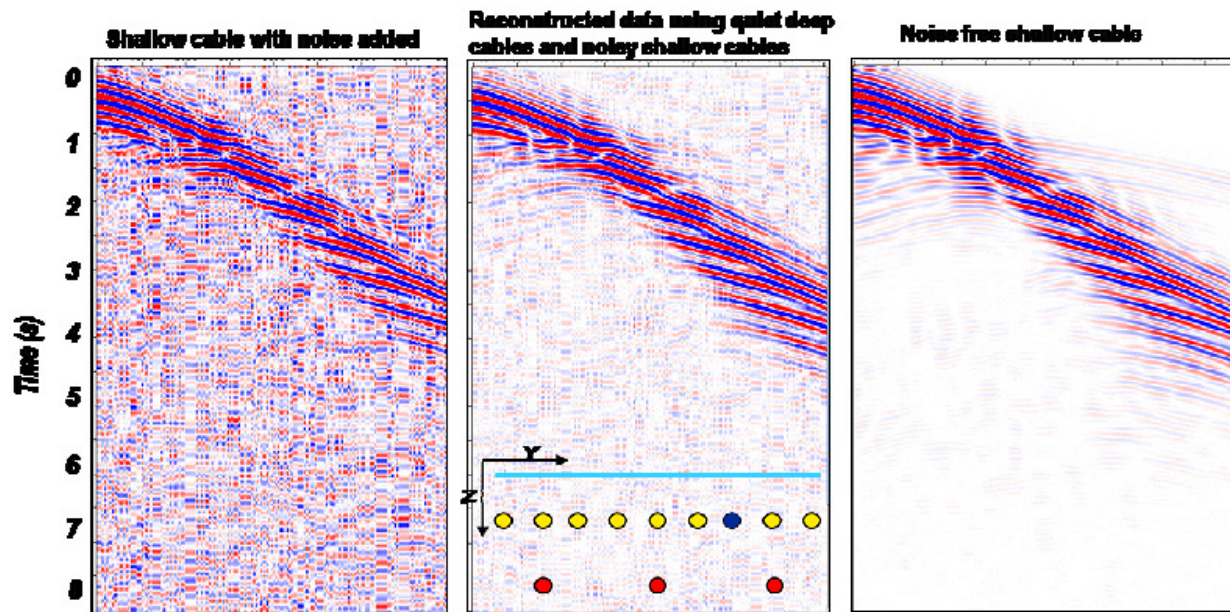

Figure 2. Synthetic example. Left: shallow streamer data (at the highlighted green position) with noise added. Right: Noise- free shallow data at the same position. Centre: Reconstructed data using all 12 streamers in the crossline vertical plane, then displayed as the same single streamer location inline. The signal-to-noise ratio is considerably improved because the deeper streamers are quieter (in this synthetic example, noise free). Note that the inset diagram is orthogonal (crossline) to the shot record display direction.

across the whole bandwidth. Enhancing the low-frequency signal of the data is a key objective for this method, and this is achieved without loss of high-frequency content. It should be noted that, according to Laws et al. (2008), it is only in the low frequencies that we lack source power in typical airgun arrays. The resulting data exhibit both high resolution and deep penetration for subsalt and sub-basalt imaging, for example.

In addition, inversion for acoustic impedance, imaging, and velocity model building, also benefit from the broadband result. Data acquired in this way are more robust to poor weather conditions than conventional acquisition.

References

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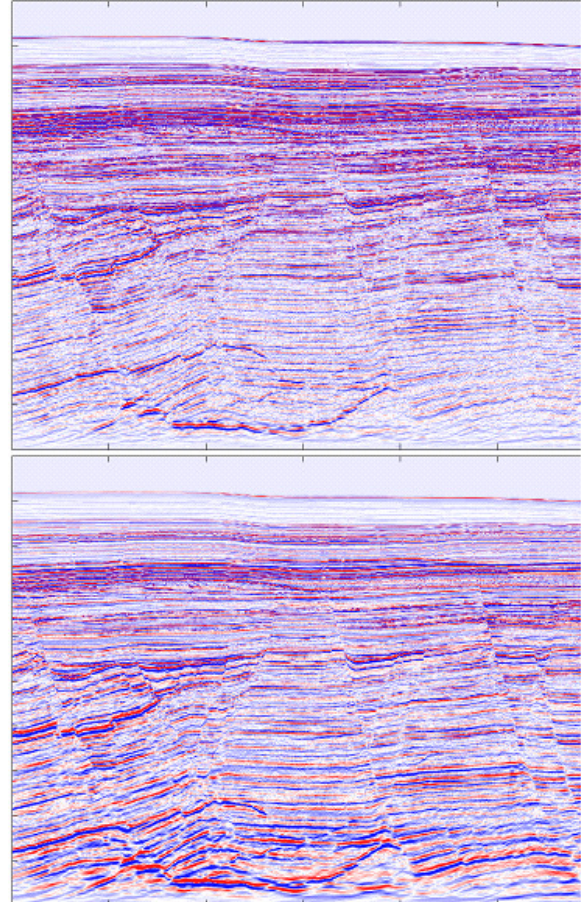
Figure 3. 3D standard processing with Kirchhoff PSDM from the 3D case study. Top: From 6-m streamers, Bottom: from combined 6-m and 20-m streamers.

Acknowledgements