Efficient Broadband Marine Acquisition and Processing for Improved Resolution and Deep Imaging

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Summary

We present a new method for broadband marine acquisition and processing. A 3D shallow towed-streamer 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 will 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. 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 6m and two deeper streamers (below shallow streamers 2 and 5) towed at a depth of 20m.

Introduction

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.

Method

In a new method presented here, we propose the use of shallow towed streamers together with a smaller number of deeper streamers. 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 smaller 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 low-pass filter) from streamers at these same 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-to-noise 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. We can combine the low-frequency 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 (Özdemir et al., 2008) 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.

Figure 2 illustrates that data can be sampled in a sparse manner for low frequencies. We use a single shallow-tow-depth dataset from a North Sea survey. In this example, we processed the data below 20 Hz using a crossline streamer separation of 300 m. Data above 20 Hz were processed with the acquired streamer separation of 100 m. The two data streams were then merged to a single image. We used interpolation in the common-offset crossline domain to regularize the low-frequency data to the same grid as the high-frequency data. The left panel shows the full-bandwidth processed data (an inline stack is given as an example). The centre panel shows the reconstructed image where the data below 20 Hz were first decimated to a 300 m streamer separation. This mimics our sparse-under acquisition method. The right panel shows the difference (which only contains energy below 20 Hz). We note that, in a real sparse-under acquisition, the deep streamers would be in a quieter environment (in this example, all streamers were at 7 m depth) so we would expect less residual error from high-wavenumber noise.

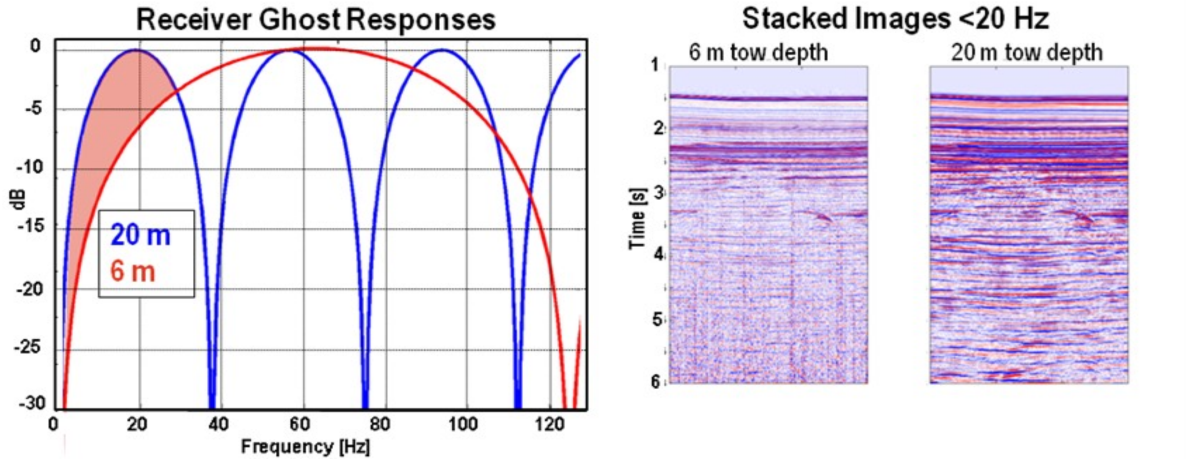

Figure 1: Example of shallow and deep-tow hydrophone ghost responses (left) and stacked images obtained (right). The ghost responses on the left show the improved signal from the deeper streamer below ~30 Hz (shaded red). The images on the right show examples of stacked data, displaying only data after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

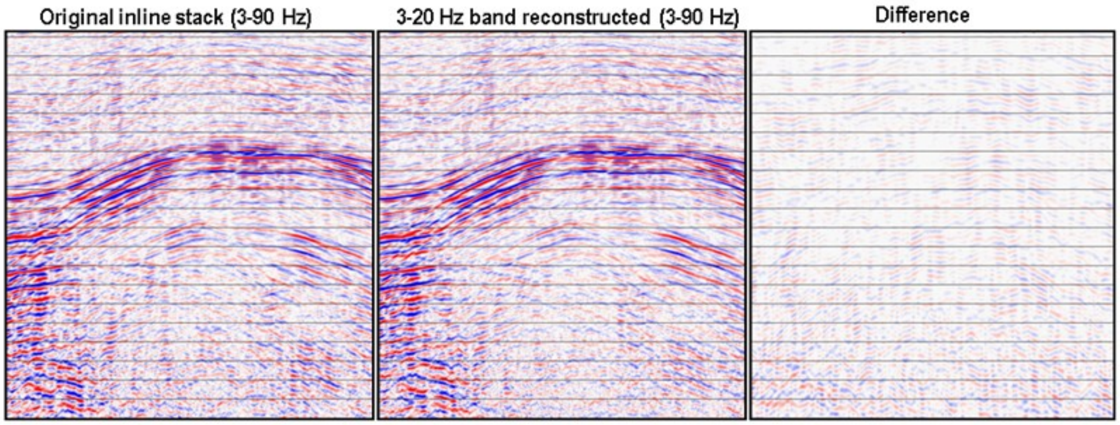

Figure 2: 3D data example using a single shallow-tow-depth acquisition as a test. The left panel shows the full-bandwidth processed data (an inline stack is given as an example). The centre panel shows the reconstructed image where the data below 20 Hz were first decimated to a 300 m streamer separation. This mimics our sparse under acquisition method. The right panel shows the difference (which only contains energy below 20 Hz).

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. Figure 3 shows representative inline images from the processed 3D migrated volume. A Kirchhoff pre-stack time migration was used. The left panel is the shallow streamer at 6 m depth and the right panel is the combined result including data from the deep streamer below ~30 Hz. A considerable enhancement in the low frequencies is clear. This is about 12 dB below 10 Hz, which can be shown from a signal-to-noise ratio analysis both in the shallow and deep part of the sections

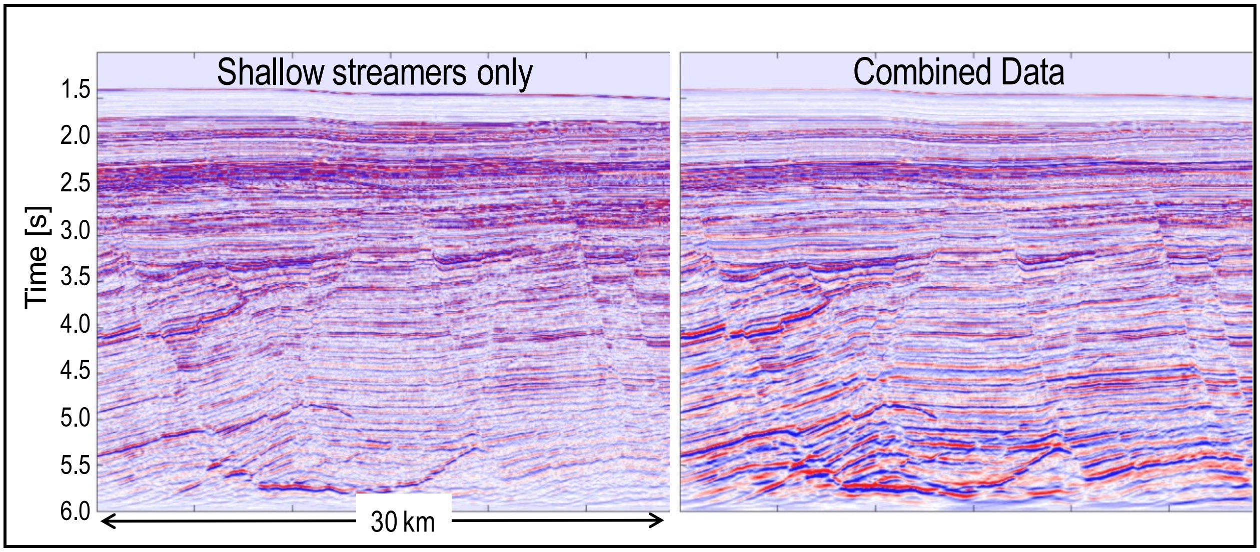

Figure 3: *Representative inline images from the 3D migrated data volume. Left: using the shallow 6 m data only. Right: from the combined 6 m and 20 m data.*

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 of deeper streamers. In a case study, the deeper streamers were towed directly beneath their shallow counterparts and the data combined to optimize the signal-to-noise ratio 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

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.

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