Seismic data quality considerations - seafloor versus towed streamer recording

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Abstract

Seabed data acquisition methods offer a number of inherent advantages over towed streamer data. These advantages can lead to improvements in shallow resolution, deep data imaging, signal-to-noise ratio and spectral content, as well as more effective 3D illumination and undershooting through efficient wide-azimuth data acquisition.

Introduction

Demand for improved oil recovery from reservoirs has led to rising expectations for seismic data quality: better illumination, better resolution, better repeatability, better well ties, more reliable amplitudes etc. In the marine environment, towed streamer technology remains the most common acquisition method, and techniques such as “under and over” to improve bandwidth and WAZ multi-vessel acquisition for subsalt exploration have provided impressive results. However these techniques have added cost and complexity to traditionally “simple” towed streamer operations. Recent developments in seafloor seismic have delivered significant improvements in image quality. Furthermore, the cost differential between towed streamer and seafloor seismic has narrowed considerably. In this paper, we will show the results of an investigation into the relative value of four inherent differences between towed streamer and seafloor seismic. The differences considered here are (1) sensor type and performance (2) Signal to noise improvements (3) PZ summation and (4) geometry.

Sensor Type and Performance

Modern OBC systems use 3-C MEMS accelerometers combined with hydrophone pressure sensor. The MEMS accelerometer offers several advantages compared with the conventional moving coil geophone OBC sensors:

• Wide bandwidth to resolve reservoir detail. Amplitude response flat 0-500Hz

• High vector fidelity

• Direct digital output at the sensor

• Provides information about the sensor tilt against vertical axis by use of the DC component of gravity.

The hydrophone component used in OBC recording has different characteristics to that used in streamer recording. The total filter response is a combination of the sensor, the analog instrumentation filter and the digital instrumentation filter. For steamer acquisition this results in deficient recording in the sub 10 Hz range (figure 8a), whereas OBC recording is faithful down to 1Hz and only limited by the environmental noise floor. The amplitude spectra of the impulse responses of the total field filters are shown in Figure 1. From these spectra, at 5.0 Hertz, the streamer data has seven dB more attenuation, and at 2.0 Hertz, it has 21 dB more attenuation than the OBC data. Considering the amplitude of the deep reflection data, attenuating the low-frequency data during the recording process will reduce the effective signal-to-noise ratio of the recorded data.

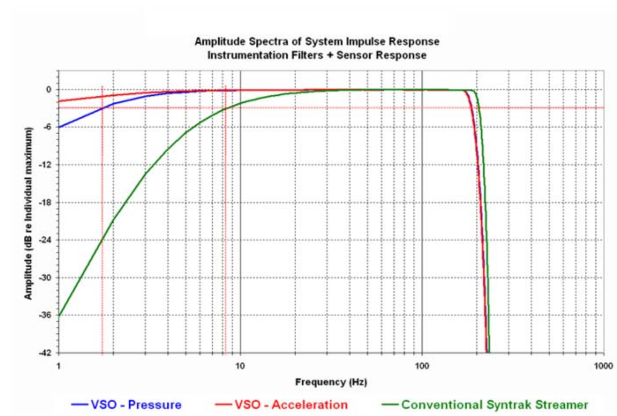

***Figure 1**. Amplitude spectra for impulse responses (OBC and streamer)*

Signal to noise ratio

Towed streamers are susceptible to a number of noise mechanisms, including turbulent flow across the cable, swell noise from the sea surface, and various modes of noise propagated along the cable, including bulge waves and cable jerk. These different factors result in increased noise levels when compared with seabed recordings (figure 2). These noise mechanisms are usually attenuated through the use of arrays, but these arrays cannot eliminate all the noise, and can result in some loss of high frequency signal. In comparison seabed recording offers a much quieter environment. Typically the ambient noise levels in the frequency range 3 – 80Hz will be somewhere between 0.5-2.0 microbar and in some cases, such as deepwater environment, the ambient noise levels will be less than the instrument noise. Of particular importance is the reduced level of low frequency environmental noise. This low frequency noise decreases with increasing water depth such that surface swell noise is only a concern in shallow water. The end result is that recovery of source signals is possible down to 1Hz. This has major implications for imaging, particularly for deep targets where the loss of high frequencies is considerable. These low frequencies inherent in seabed recording can play a major role in resolving some of the deep targets that are becoming increasingly important in frontier areas.

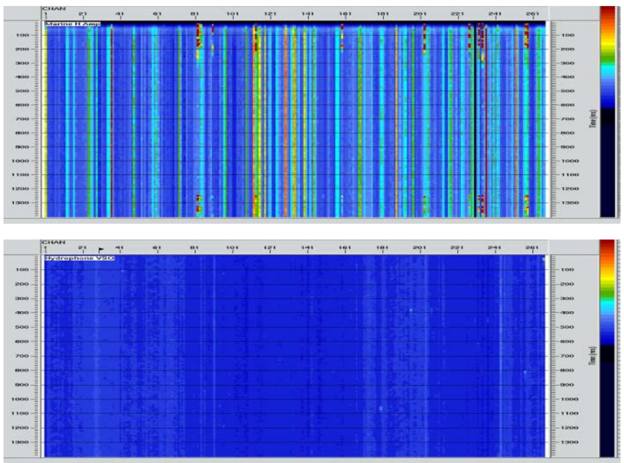

***Figure 2**. Noise levels on example streamer system versus OBC (Scale set to 30µbar max on both displays).*

Furthermore stationary receivers, as used in seabed recording, are inherently quieter. Moving receivers can introduce undesirable data smearing and Doppler shift effects. Seafloor data is not subject to these noise mechanisms, and can thus be acquired using true point receiver sensors, enabling improved high frequency response, while still achieving improved signal to noise ratio.

PZ Summation

A pressure phone in water is subject to spectral notching due to the free surface ghost. The positions of the notches in the frequency spectrum are governed by cable depth. For typical towed marine surveys, the first and second notches impinge on the useful seismic frequency range. The first notch is always at zero Hertz and the second obeys the formula $f=V_w/D$ (where V_w = water velocity and D= cable depth).

For an ocean bottom hydrophone the notching obeys similar rules except D is now water depth. However, the accompanying Velocity (or Acceleration) phone, measures particle motion in a particular direction (vertical in this case). Due to the sign of the down-going wave with respect to this directivity sensor, notches are out of phase with those observed on the hydrophones. Summation of the two components in the appropriate ratio will result in flatter spectrum and broader bandwidth (figure 7). Also in certain hard water bottom conditions it has been observed that vertical geophone data alone contains less reverberation energy and has a high signal to noise ratio than streamer data acquired in the same location (Stewart et al, 2007).

Multiples and reverberations from both the source and receiver side also introduce spectral notching. Their characteristics are similar to the hydrophone response. Again, when appropriate ratios are selected, the PZ summation process allows the opportunity to suppress multiples (Barr and Sanders, 1989).

Flexible Geometry

The more flexible geometry available to seabed crews offers a number of geophysical advantages:-

• Longer offsets. Long offsets are important for deep structural imaging, high angles required for deep AVA analysis, velocity model building sensitivity and refraction analysis. Towed marine surveys are subject to physical cable length limits. OBC surveys have no such limits.

• Positioning accuracy. Receiver positioning accuracy has improved considerably over the past 10 years. Acoustic and first break pick positioning techniques are routinely used in OBC acquisition. This provides two independent measurements which can be used in a hybrid method to drive the receiver co-ordinates. In water depths >50m comparisons between each method, acoustic versus first break pick, show that derived co-ordinates match very closely, with ranges less than 1m (figure 3). Dedicated software programs use the acoustic and first break arrival times to compute the receiver co-ordinates using a non-linear parametric least squares estimation, in which the positions of shots are held fixed. OBC receiver co-ordinates are routinely derived with an absolute accuracy of <3m with 95% confidence level.

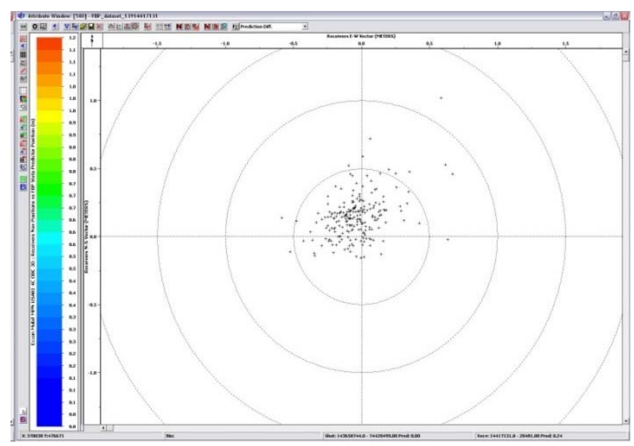

***Figure 3**. Receiver location prediction uses first break times and compares against acoustic positions. Bullseye shows range from acoustic to first break calculated position (inner bullseye radius = 0.5m)*

Receiver positioning for towed streamer acquisition has also improved considerably by the use of a full acoustic network. This means that receiver locations (or group centers) can be positioned with an accuracy of 3 - 5 meters. However obviously the receivers are moving and co-ordinates are registered at shot fire time which of course could be some distance from the receiver location at the end of the record cycle. The accuracy of the navigation data assignment is therefore limited by the tow speed and record time.

• Positioning repeatability. Seabed seismic sensors are steered into position using autonomous acoustic transponders attached to the cable. During cable layout these transponders are interrogated from the vessel and layout adjusted to ensure baseline positions are matched closely. Recent 4D OBC surveys have shown that baseline receiver positions can be matched closely even in the presence of strong currents (figure 4). This example 4D survey acquired in 2007 comprised of 3358 receiver stations in water depths of 42-55 meters. Post processing analysis on the entire survey showed the average distance from baseline was 2.2 meters with a standard deviation of 1.2m. This high level of deployment repeatability will result in reduced nRMS levels that are necessary for time lapse reservoir monitoring. Seabed receiver deployment technology has improved steadily over the past 15 years; this trend will likely continue in order to match the demand for high levels of repeatability.

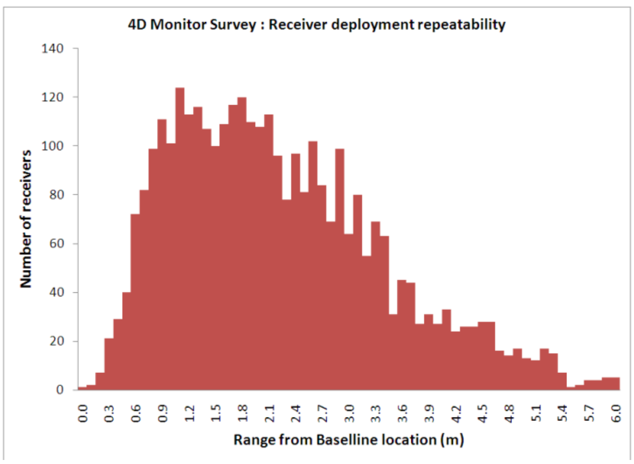

***Figure 4**. Example of repeatability possible in OBC acquisition. Water depths 40-56 meters.*

• Near offsets. Invariably, most towed marine surveys suffer from lack of near trace offsets. This lowers near surface resolution. OBC surveys allow true zero offset acquisition. This also allows a vertical incidence test analysis which can be used to accurately calculate the seabed reflectivity and appropriate dual sensor summation scalars.

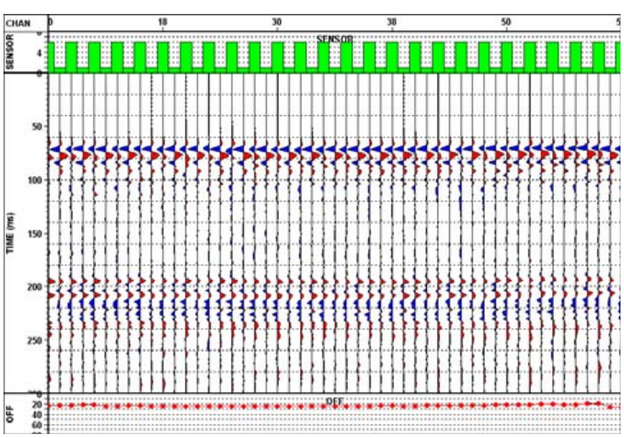

***Figure 5**. Vertical incidence test. Interleaved pressure and vertical component near offset traces with appropriate scaling and polarity reversal.*

• Fixed receiver geometry offers the capability to acquire a survey with full offset/azimuth distribution (figure 6).

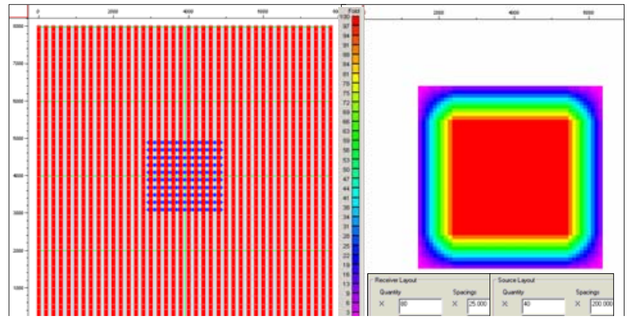

***Figure 6**. Full offset/azimuth survey.*

• Split spread. OBC surveys can be acquired with a split spread configuration. This allows several advantages in processing such as higher fold, reciprocity, refraction analysis and offer several advantages in multi-component processing

Examples

Tests have been performed in the Gulf of Mexico that demonstrate the improved low frequency response of OBC acquisition (Johnson, 2007). The main outcome from this test study was that imaging of deep targets, with associated weak signal and high frequency attenuation, can be best achieved using seabed sensors. Comparing the low frequency component of the stacked section from OBC and streamer systems, coherent events can be followed on the OBC section, however these are not evident on the streamer data (figures 8a & 8b).

Enhanced data quality has also been demonstrated by an acquisition test using both streamer and OBC technology (Walker, 2006). The line parameters were selected to allow a direct comparison between the seafloor data and streamer data acquired on the same line about two years earlier. The source was very similar, and geometry and record lengths for the OBC data were selected to allow direct comparisons between the towed streamer data and appropriate sub-sets of the OBC data. The results confirmed that OBC provides improved resolution (figures 9a & 9b) and significantly better imaging of deep targets.

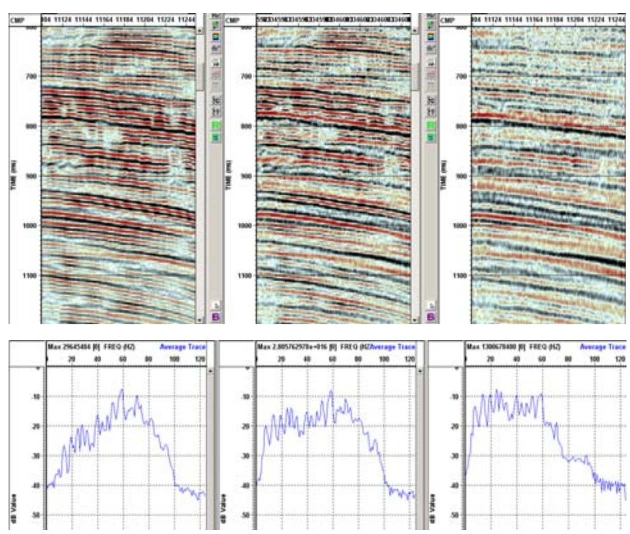

***Figure 7**. Example dual sensor summation in shallow water OBC (left HY, center dual sensor summation, right vertical component).*

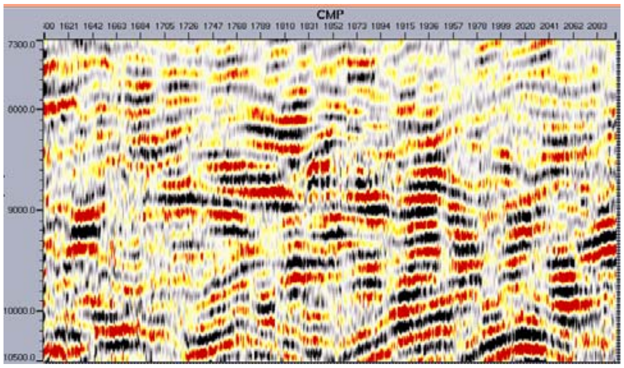

Figure 8a*. Streamer acquisition with 9Hz low pass* filter.

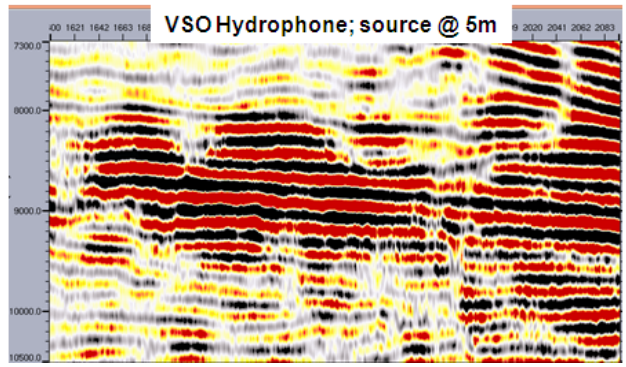

Figure 8b*. OBC acquisition with 9Hz low pass filter.*

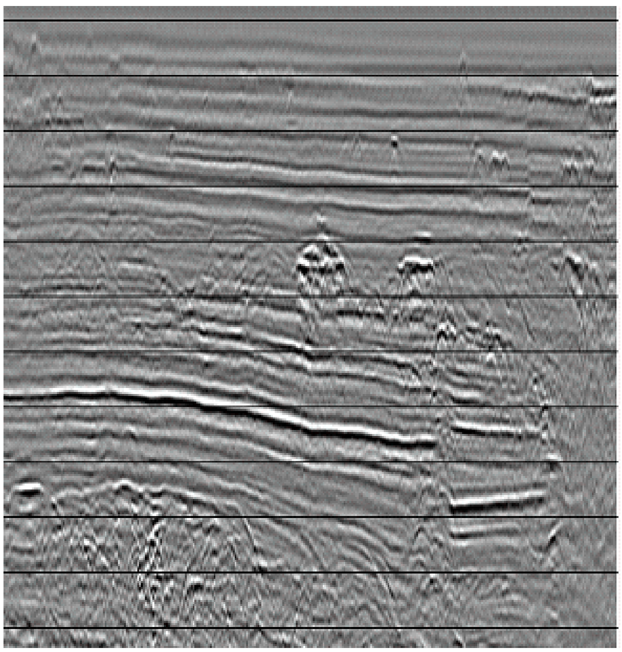

Figure 9a*. Streamer acquisition example. PSTM processing sequence identical to OBC data displayed in figure 9b (except for dual sensor summation)*

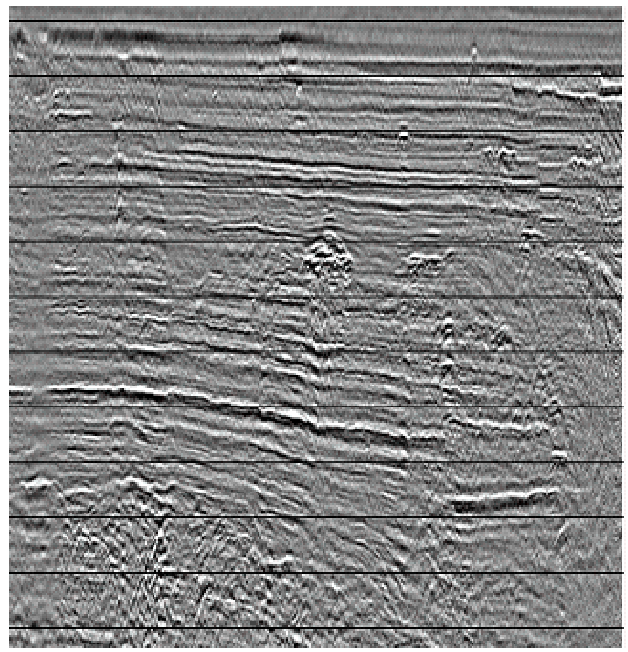

Figure 9b*. OBC acquisition example. PSTM processing sequence identical to figure 9a (except that dual sensor summation was performed).*

Conclusions

Seabed data acquisition methods offer a number of inherent advantages over towed streamer data. These advantages can lead to improvements in shallow resolution, deep data imaging, signal-to-noise ratio and spectral content, as well as more effective 3D illumination and undershooting through efficient wide-azimuth data acquisition.

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