Improved Imaging and Reservoir Characterization with Dual Sensor Streamer

Eivind Fromyr and Cyrille Reiser, PGS

Abstract

The use of collocated pressure and motion sensors allows the separation of the up- and down-going waves and thereby removal of the receiver ghost. Having access to the up- and down-going wavefields yields significant benefits for seismic data processing and imaging, and ultimately quantitative reservoir interpretation. The resulting increase in seismic bandwidth, high and low, yields improved resolution of the geological layers as well as improved accuracy in extraction of elastic attributes.

Introduction

The ghost in marine seismic recording is the result of an almost perfect reflection of the acoustic wave-field from the sea surface. Up-going waves are reflected back as down-going waves with a reversed polarity, and interfere constructively for certain frequencies and destructively for other frequencies. This phenomenon occurs both on the source side and on the receiver side. The affected frequencies depend solely on source and receiver depths. Conventional marine seismic acquisition therefore involves a trade-off between the various frequency ranges. To record high frequencies, sources and receivers have to be towed shallow, which strongly attenuates low frequencies. Conversely, a deep tow favors low frequencies at the expense of high frequencies.

Recently a dual-sensor streamer, with collocated pressure and motion sensors, has been developed (Carlson et al., 2007). Such a streamer effectively removes the receiver ghost while maintaining the efficiency of towed streamer acquisition. The uplift in bandwidth is illustrated in Figure 1. Typical towing depth for such a streamer is 15-25m.

Methods to attenuate the source ghost and thereby further increase the seismic bandwidth is subject of considerable research effort (Cambois et.al 2009)

Receiver ghost removal

Unlike the pressure sensors, the motion sensors are sensitive to the direction of propagation and this directional sensitivity coupled with measurement of pressure and velocity enables removal of the receiver ghost.

The theory behind wavefield decomposition has been described by a number of authors, e.g. Amundsen (1993) and Fokkema and van den Berg (1993). When the vertical component of the particle velocity wave-field is measured

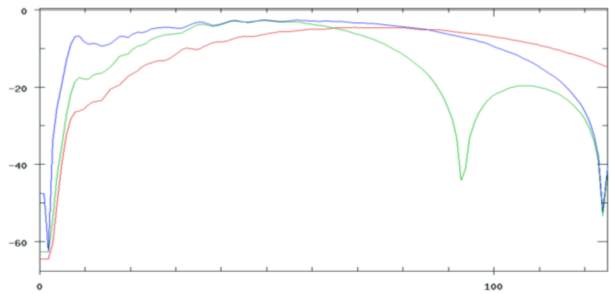


***Figure 1**: Amplitude spectra in dB for various marine configurations. Red: 4m source, 5m streamer. Green: 6m source, 8m streamer. Blue: 6m source, no receiver ghost*.

in a spatially-coincident manner with the total pressure wavefield, the two components can be used directly to decompose the total pressure and particle wavefields into their up- and down-going components. For the pressure wave-field the two components are given as:

$$P^{up} = \frac{1}{2}\left(P - FV_z\right) \quad \text{and} \quad P^{down} = \frac{1}{2}\left(P + FV_z\right) \qquad (1)$$

P is the measured total pressure wavefield, V_z is the measured vertical component of the total particle velocity wavefield, and F is an angle-dependent scaling factor. In the frequency wave-number domain, the scaling filter F is

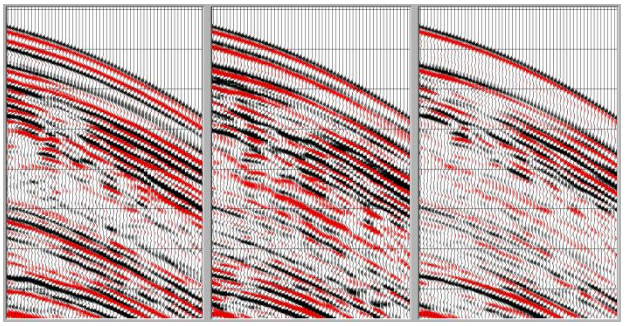
$$F(\omega, k_x, k_y) = \frac{\rho\omega}{k_z}, \quad \text{with} \quad k_z = \sqrt{\left(\frac{\omega}{v_w}\right)^2 - k_x^2 - k_y^2} \qquad (2)$$

where k_x, k_y and k_z denote the three components of the angular wave-number vector, ω denotes angular frequency, and ρ and v_w are the density of water and the acoustic wave propagation velocity in water, respectively. The scaling factor includes an angle-dependence that is required because we record only the vertical component of the particle velocity vector. Note that no assumptions are made about the sea surface state.

In practice, the particle velocity data is often heavily contaminated with low-frequency noise. To circumvent this problem, the lowest frequencies are rebuilt from the pressure record using the frequency-wave-number solution of the equation of motion (Tenghamn et al., 2007):

$$V_z(\omega, k_x, k_y \mid z_R) = -F^{-1}\left[\frac{1 + e^{-i2k_z z_R}}{1 - e^{-i2k_z z_R}}\right] P(\omega, k_x, k_y \mid z_R) \qquad (3)$$

where z_R is the receiver depth. This process assumes a flat sea surface with a constant reflection coefficient. For all practical applications a reflection coefficient of -1 can be assumed. The range of frequencies for which the recorded particle velocity data is rebuilt using equation (3) is typically limited to 20 Hz and lower. An example of a wavefield separated gather is shown in Figure 2 together with the two input gathers.



Hydrophone Velocity Sensor P-UP

Figure 2*: The input to wave-field separation: Hydrophone to the left and Velocity Sensor in the middle, and the resulting up-going wave-field to the right.*

Imaging Benefits

The up-going wave being free of the receiver ghost, no longer has a bandwidth limited by the hydrophone notch frequencies. In fact, the bandwidth is only limited by the source ghost. Due to the deeper tow it also will have a much richer content of low frequencies to improve penetration. Towing deep is also beneficial because the recording environment is quieter, and the sensors are not subject to swell noise. Thus, the low frequencies doubly benefit from increased signal amplitude and decreased noise level. Figure 3 shows a 2D example from Brazil, a comparison between a conventional acquisition with a 9m streamer depth and a dual sensor at 25m. The source is the same, a 4130 cu.in. towed at 9m. Note the improved penetration and improved deeper image for the dual sensor.

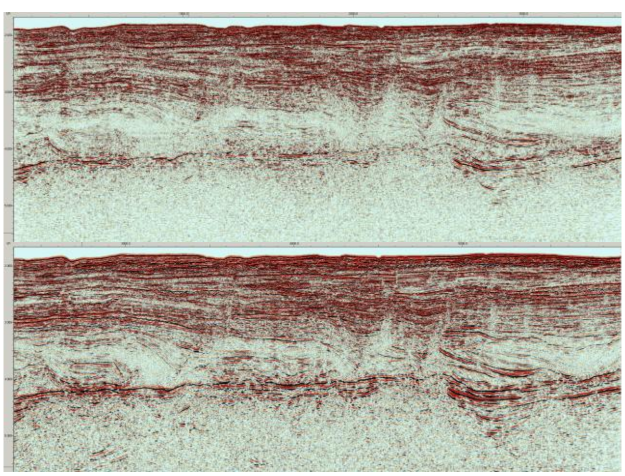


Figure 3*: Campos : Top image is a time migrated conventional line towed at 9m. Bottom image to is a dual sensor line towed at 25m. The source is identical.*

The second dual sensor example is a 3D from a North Sea. Prospects and fields of greatly varying age and depth of burial were imaged with a superior data quality at all levels. Targets described in this case study vary from very shallow Neogene channel systems through producing Paleocene sands to the Jurassic level, with the main focus on the Tertiary section. Figure 4 shows a comparison with a legacy conventional streamer 3D.

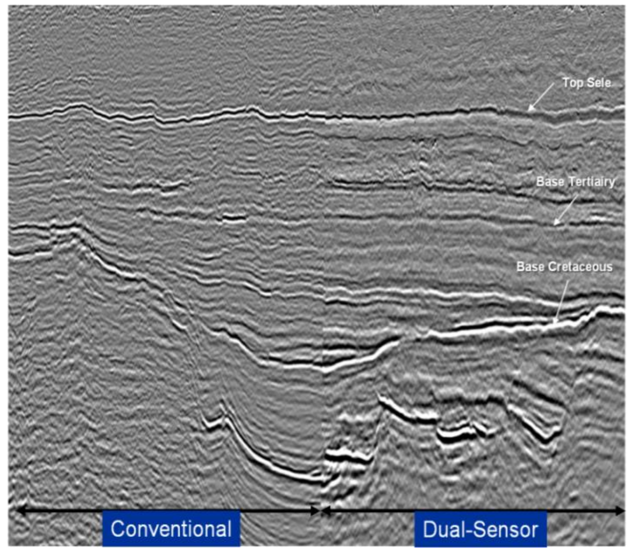


Figure 4*: The line illustrates a direct comparison between a conventional and a dual-sensor streamer acquisition over the North Viking Graben dataset. A seismic imaging improvement with the dual-sensor streamer is clearly visible throughout the section: from the Paleocene down to the Jurassic level. At the Tertiary level, below the Top Sele, the various sequences, especially the Heimdal are clearer on the dual-sensor section. At the Jurassic level the image of the tilted fault blocks is significantly improved leading to a new understanding of the area.*

Reservoir Characterization

An extensive seismic reservoir characterization study was undertaken on the 3D dual-sensor streamer dataset from the North Sea. The expectation is that the broader bandwidth will have a positive impact on extraction of elastic properties(Engelmark et.al 2010 and Reiser et.al 2010).

A pre-stack seismic inversion workflow was conducted on this dataset. Figure 5, illustrates the benefit of having extended low frequency content when extracting elastic properties. The example demonstrates that the acoustic impedance estimated through a pre-stack simultaneous inversion at Well B is nearly identical whether the well is included as a priori information in the model or not. This observation shows that our ability to predict the reservoir properties away from calibration wells is much improved due to the extended low frequency bandwidth offered by the dual-sensor streamer.

This case study has demonstrated that the broader seismic frequency bandwidth, and especially the extension at the low frequency side of the seismic amplitude spectrum, represents a key step forward in the seismic reservoir property estimation and more importantly in the lithology-fluid prediction, as the need of a priori information especially based on the well information, is considerably reduced compared with a conventional towed marine streamer acquisition. Thus, the inversion and litho-fluid prediction using this unique acquisition system has proven to depend less upon the incorporation of well data as a background model and therefore enhance the prediction of the reservoir properties away from the wells. The process is now more seismic driven as opposed to previously being model driven.

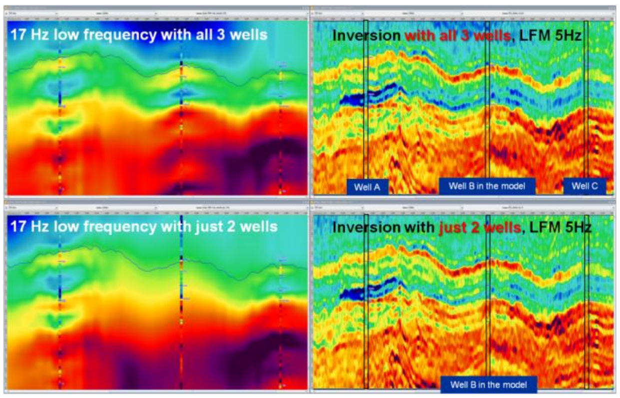


Figure 2: Comparison of two acoustic impedance results based on pre-stack seismic inversion using the dual-sensor technology and with two different initial models. The initial low frequency model in both cases was extending to 17Hz, but only the bottom 5Hz were used in the inversion process for estimating the absolute elastic properties. The results of the absolute acoustic impedance (right hand-side images) at the well locations are extremely similar using either three wells (top figure) or only wells A and C (bottom figure) in the initial model. The results at Well B are very similar, demonstrating that the reliability of the estimated reservoir properties is dramatically enhanced with the dual-sensor streamer technology.

Conclusions

Deghosting or wavefield separation for a dual sensor streamer is based on first principle science and makes no restricting assumptions. The result is a seismic data with a broader bandwidth both at the high end and the low end of the frequency spectrum. The value of dual sensor technology has been demonstrated through three case histories. We have demonstrated that the dual-sensor technology provides better seismic imaging as well as offering significant advantages in important reservoir characterization aspects. Reservoir delineation and geobodies detection are improved thanks to an increased signal to noise ratio and broader bandwidth. The extended bandwidth, especially at the low frequency side of the spectrum represents a key improvement in the lithology-fluid prediction and also on seismic reservoir property estimation. The need for a-priori information is considerably reduced by relying more on the data and less on a low frequency background model compared with a conventional seismic streamer which should notably improve the number of successful wells.

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