Broadband Processing of Marine Streamer Seismic Data

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Introduction

The vast majority of marine seismic data are acquired with conventional towed streamer cables which are equipped only with hydrophones and are all towed essentially at the same constant depth for any single survey. The receiver ghost zeros out the spectral response of the recorded data at notch frequencies equal to any integer divided by the ghost delay time, limiting both the top end of the usable spectrum as well as attenuating the low frequency response. The source ghost has a similar effect. The combined effect of the ghosts results in greatly reduced resolution in the subsurface image. A conventional "solution" for this problem is to tow the sources and streamers shallow (at less than 7m of depth below the surface) to obtain higher frequencies, at the expense of attenuating low frequencies and exposing the sensors to a noisier environment near the sea surface.

There are currently several acquisition methods that can mitigate or remove the effects of the ghosts and obtain broadband seismic images (Carlson, 2007, Posthumus, 1993, Soubaras, 2010). These methods require non conventional data acquisition, either with streamers equipped with multi-component sensors, or with streamers configured in unconventional geometries such as over-and-under or slanted configurations. Such methods are not applicable to conventional streamer data.

An effective broadband processing method based on a new de-ghosting technique have been developed. It can remove most of the ghost effects from conventional streamer data. (In this paper, The method is refressed as WiBand.) This method is designed to address both the amplitude attenuation and the phase distortion introduced by the ghosts to obtain nearly flat spectral response in the typical range of 4Hz to 150Hz, as well as a compact, well focused seismic wavelet. In order to validate the method, we evaluate the phase reconstruction fidelity of our algorithm by comparing the WiBand result from a deep tow data with the non-deghosted processing result from a shallow tow data over the same area.

Methods and Results

De-ghosting methods

Up-going seismic waves are reflected downward by the sea surface with near -1 reflection coefficient. At any given depth below the surface, the up and down going waves interfere destructively at certain frequencies, producing notches in the power spectrum of the data recorded at that depth. There have been many attempts at solving this problem (Robertsson, 2002). A standard operator for removing the receiver ghost is an x-y-t domain pseudo-differential operator, $D = \left(1 + r\,e^{2iz\sqrt{\omega^2/c^2 - k_x^2 - k_y^2}}\right)^{-1}$.

This operator is to be applied to shot records. Here, r is the surface reflection coefficient; c is the near surface sound velocity; and z is the receiver depth. This operator is typically applied in the f-k or f-p domains. However, stable application of this operator is very difficult due to its near singularity, the variability of r and z, and the difficulty of transforming streamer data into f-k or f-p domain without pronounced end point artefacts. For instance, when the streamer depth varies up to +/-1m, this operator is no longer stationary along the cable, and additional corrections analogous to phase-shift-plus-interpolation migration are required. Furthermore, because the operator is nonlinear in the key parameters r and z, obtaining these parameters directly from the input data requires effective nonlinear optimization methods and carefully selected objective functions (Baan, 2008, Mo, 2009). Nevertheless, the advantage that the operator is described by a very small set of variables makes such nonlinear problems solvable. Typically, only a 2D version of this operator can be applied.

Another line of attack on the de-ghosting problem uses variations of traditional blind deconvolution methods (Zhang, 2011). In order to overcome the mixed phase nature of ghosted data, the L2-norm objective function of standard Weiner-Robinson deconvolution must be replaced with non-quadrilinear measures. A subtle difficulty with this approach is that, the convolutional operators required are very long as expressed in the time domain, so a direct time domain approach to solve the nonlinear optimization problem faces the issue of too many of degrees of freedom. This problem can be removed if the de-convolution operator is expressed as an infinite-impulse-response filter defined by a small number of coefficients. This approach also requires special techniques to extend its application to earth models that are not one-dimensional.

The WiBand workflow combines the strengths of these two types of de-ghosting approaches, and data-adaptively derives the most stable operator to remove the effects of the source and receiver ghosts from the data prior to migration. It is not a data creation method, but a method to recover the signal weakened by the ghosts, and relies on the presence of usable signal at the ghost frequencies in the raw data.

Figure 1 compares a standard processing result with a WiBand result from a Polarcus offshore Gabon dataset with a streamer towed at 15m below sea surface. The receiver ghost notch associated with this depth is about 50Hz, and in the standard processing flow a high-cut filter was applied to remove energy above 55Hz from the data. No high-cut filtering was applied in the WiBand processing flow. It is

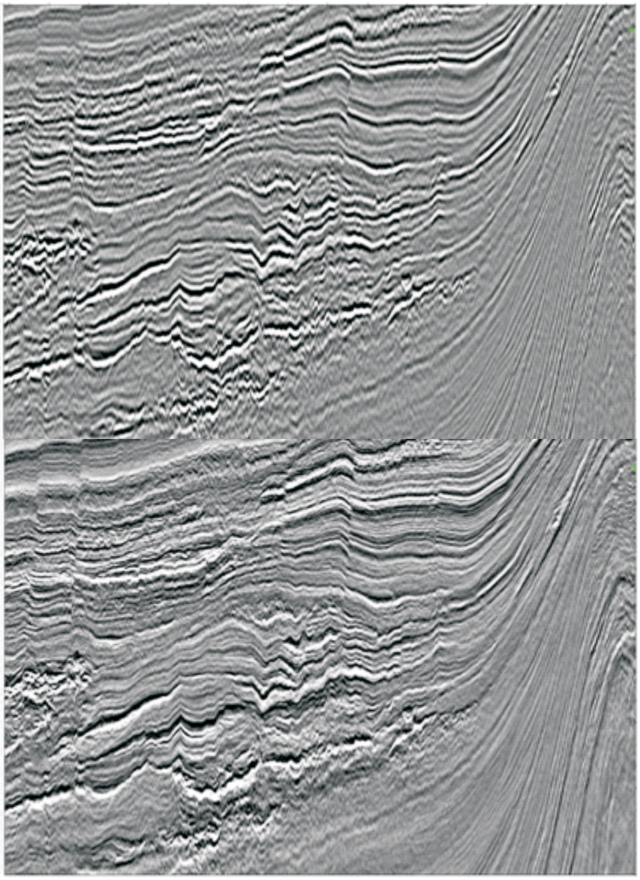

Fig. 1 : Standard 4ms PSTM image (top) and WiBand 2ms PSTM image. Data is acquired with streamer towed at depth of 15m. Data courtesy of Polarcus and Ophir.

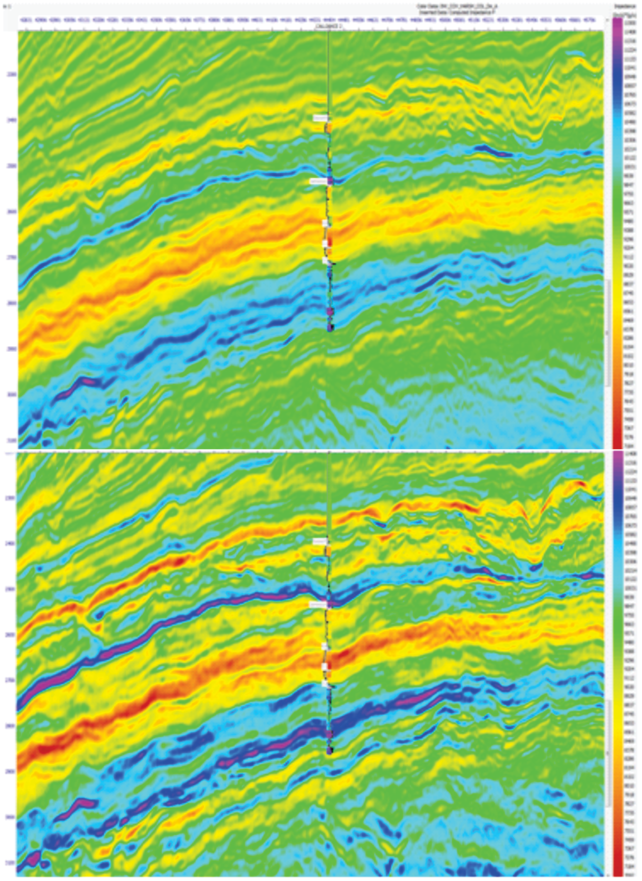

Fig. 2 : Acoustic impedance (AI) inverted from standard (top) and WiBand images, with well-derived AI curve superimposed. Data courtesy of Searcher Seismic.

apparent from this comparison that the WiBand flow has managed to greatly enhance the resolution of the image. Both low and high frequency signals have been greatly enhanced, and many structural details invisible in the standard product are well resolved in the WiBand image.

Figure 2 shows a comparison between two acoustic inversion results, one derived from a standard processing product, one from a WiBand processing product. A common log-derived background model is used in the inversion, and a common colormap is used in the displays. This Searcher Seismic data line is from the Australian northwest continental shelf and goes through the Calliance II well. It was acquired with a streamer towed at 7m depth. In the WiBand-derived result, better contrast is observed between low and high impedance layers and these contrasts correlate well with the log-derived curve at the well location. This uplift over the standard processing result can be attributed to the enhanced low frequency response of the de-ghosted data. The logged section is about 2sec below water bottom. Here, the high frequency limit is determined by overburden seismic absorption, hence de-ghosting brings limited high-frequency extension.

Conclusions

It is believed that a processing-based broadband solution can provide an effective alternative to the acquisition-and-processing based solutions that require non-conventional streamer acquisitions. A processing-based solution can be applied to existing conventional streamer data to extract the maximum value out of the data. Much of our current datasets have been processed through workflows that start with a resampling to 3 or 4ms, and contain high-cut filters that remove most of the energy above the first order receiver ghost notch frequency. It has been We have demonstrated that there is a great amount of information present in the raw data that is lost through such standard processing flows, and that such information can be retained and utilized through a new type of workflow that can carefully preserves all the signal and properly compensates for the effects of the ghosts.

Present method can also be seen in the context of new acquisition and remove the constraints on receiver depth posed by the requirements for high frequency signal. Since the ghost notch can be effectively filled, a new acquisition no longer has to have the receivers shallow in order to record frequencies above, say, 90Hz. Rather the acquisition parameters can now be chosen to both improve operational efficiency and optimize signal-to-noise ratio over the whole desired frequency band by considering factors such as the avoidance of swell noise and avoiding positioning the ghost notch at a dominant frequencies of streamer-borne noises.

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