Stolt deconvolution, a fast and effective method for deep water OBN multiple attenuation

Introduction

In deep water OBN surveys, we often keep the downgoing data after wavefield separation due to its superior illumination thanks to mirror migration. The deeper the survey, the larger the difference in illumination between the upgoing and downgoing wavefields. Regardless of the type of the wavefield separation used, the downgoing wavefield always has a stronger content of free surface multiples than the upgoing wavefield and therefore multiple attenuation techniques are necessary.

Several techniques exist for multiple attenuation in OBN. Convolutional techniques like MWD (Model-based Water-layer Demultiple,Wang et al 2011) and SRME (Surface Related Multiple Elimination, Verschuur et al, 1992) are among these methods. They are effective at predicting complex multiples but require additional data not available in the node itself. MWD can only predict WB related multiples and requires accurate bathymetry. However, the predictions are full bandwidth and these multiples are the strongest to be removed. SRME in OBN will require additional data from towed streamer acquisition due to the challenges in redatuming OBN data's receiver depth to the free surface. It's usually not challenging to find existing towed streamer data from the same location of the OBN survey, though. SRME predictions have limited bandwidth due to the squaring of the wavelet in the convolutional process, however, all free surface multiples are predicted. Because of these complimentary features, often both MWD and SRME are used to predict multiples in deep water OBN surveys followed by simultaneous least squares adaptive subtraction.

There is also a group of deconvolutional techniques that only use data from within the node itself to make multiple predictions, most commonly in FKK or TauPxPy domains. One of the better known techniques that has been used for years in the industry is TauP deconvolution. Thanks to the shot sampling available for each node, 3D implementation of this technique is feasible in OBN datasets. The idea behind TauPxPy deconvolution is that XT domain data gets transformed to a domain where different dips corresponding to different plane waves get mapped to different regions where multiple periodicity is better organized. Predictive deconvolution then assumes that true reflectivity is random and anything periodic will be organized energy in the autocorrelation which will be attenuated depending on its location relative to the zero-lag. This restriction distance is often called the gap and it's related to the depth of the seabed. Larger gap values make this process safer since Earth's reflectivity is not truly random.

The Stolt domain and deconvolution

We will refer to Stolt domain as the forward 3D time migrated image using constant water velocity. It's a lossless transform for all events faster than water velocity and it's fast because it uses simple operators in the FKK domain. It will collapse most primary and multiple energy to near zero offset. For flat water bottom (WB), the free surface WB related multiples can be predicted very accurately by simply shifting the data by two times the WB travel time at offset zero. Deviations from flat WB and the existence of other non-WB free surface multiples complicate the relationship between the primary and multiple energy. We propose to compute a three dimensional operator F(x',y',t') in the Stolt domain to minimize the following cost function:

$$J = ||D(x',y',t') - F(x',y',t')*D(x',y',t'-2*rec\_z/w_{vel})||^2 \qquad (1)$$

with receiver depth rec_z and water velocity w_{vel}, where D(x'y't') = Stolt[D(x,y,t)] is the input data in the Stolt domain. Then the multiple prediction M becomes:

$$M(x,y,t) = Stolt^{-1}[F(x',y',t')*D(x',y',t'-2*rec\_z/w_{vel})] \qquad (2)$$

This multiple model can be directly subtracted in the (x,y,t) domain or could be adapted using traditional L2 energy minimization techniques.

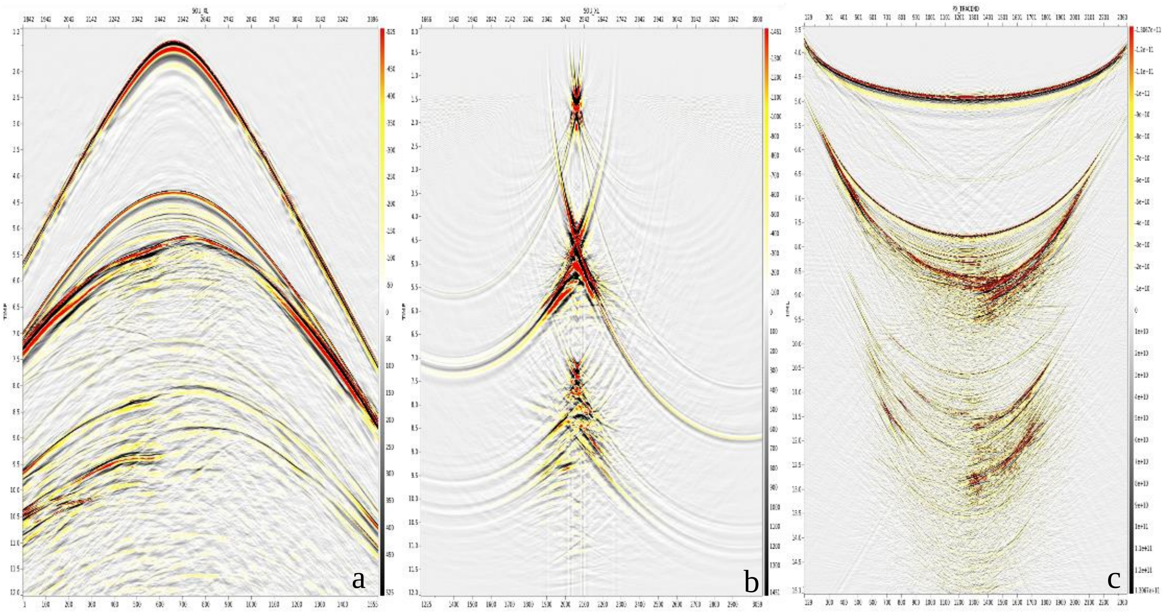

Figure 1: (a)XT, (b)Stolt and (c)TauP domains

Figure 1 shows a comparison of a gather in 3 domains: XYT, Stolt, and TauPxPy. Similar to XT domain, in TauPxPy domain the multiples converge in time with the corresponding primaries in far offsets. In other words, the window between primaries and multiples gets smaller as offset increases. In the context of predictive deconvolution, this implies the need for smaller gaps to predict far offset multiples, making deconvolution riskier at those offsets. Nevertheless, in Stolt domain we see that primary and multiple events are "focused" near offset zero, which makes the separation between primaries and multiples somewhat consistent and no small gap is needed to predict far offset multiples. However, near and far offset energy is now mixed together and we have increased the complexity of the operator needed to accurately predict multiples in this domain. We now rely on the inversion process in (1) to produce the necessary complex filter for accurate multiple prediction, but the separation between primary and multiple should make the deconvolution safer for the primaries.

Application of Stolt deconvolution on Brazil deep water OBN dataset

We tested the proposed method on a Brazil deep water OBN dataset. Wavefield Separation below the seabed was performed using adaptive PZ summation in 3D curvelet domain to produce the input downgoing wavefield dataset used in this test. While matching P and Z in the curvelet domain optimizes obliquity correction, shear wave denoise, local calibration and wavefield separation in one single step, the resulting downgoing wavefield contains both receiver side ghost and free surface multiples. Using mirror migration makes the first WB multiple useful for imaging with enhanced shallow illumination, however, one must take care of the second and third order free surface multiples.

To illustrate the effect of the deconvolution filter in equations (1) and (2), we first show the resulting multiple prediction if we allow the filter to be equal to 1 simply, corresponding to a WB only free surfacemultiple prediction. It's inaccurate because we use only single water bottom two-way time value implicitly assuming flat WB. Inaccuracies due to the dip in the WB reflector can be observed in the far offsets. We show input and multiple predictions in both XT and Stolt domains, and include MWD prediction for comparison. MWD takes into consideration WB variation seen at every receiver and uses those depths to calculate the time delays in the neighboring traces used for the prediction. It relies on accurate bathymetry which is typically not an issue. Figure 2 shows this comparison in both XT and Stolt domains.

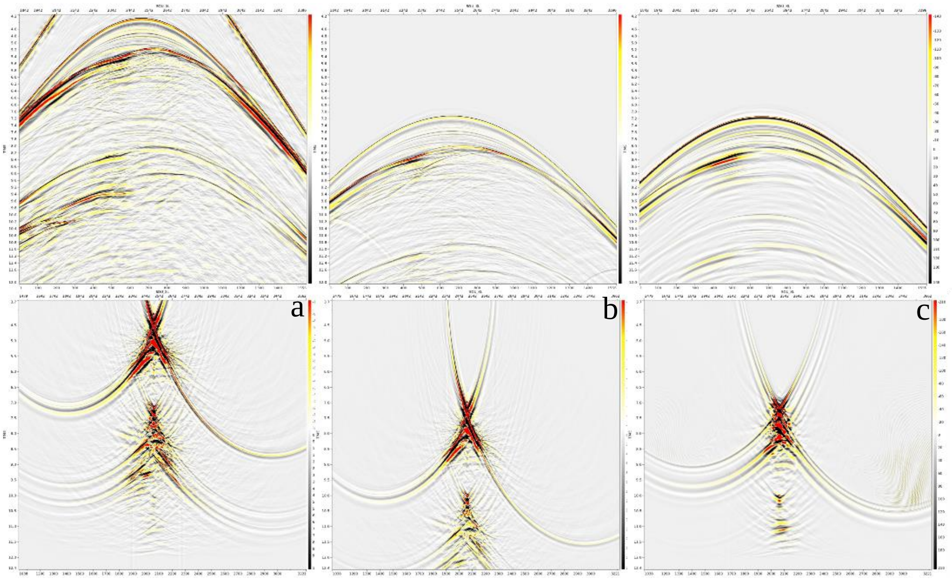

Figure 2: (a)input, (b)shifted input and (c)MWD model. XT domain at top, Stolt at bottom

Next, we allow our multidimensional filter to match the shifted version of the input to the multiple and now the resulting model is much more accurate in both Stolt and XT domains, and with full bandwidth. This time we compare with 3D SRME model which is able to accurately predict all free surface multiples including WB ones as long as auxiliary towed streamer dataset is available. The prediction's accuracy is data driven but it has limited bandwidth since it's produced by convolution of two band-limited signals. It is superior when it comes to complex multiples that require large aperture for their prediction which is the advantage of the use of auxiliary data to allow for these predictions to be modelled. Stolt deconvolution, similar to other deconvolution methods, relies only on data from the node itself which limits its ability to model complex multiple features. As we can see, the multidimensional filter obtained in the optimization process allows the model to be adjusted kinematically in far offsets and also include reflectivity information needed for predicting non-WB multiples. One can think of reflectivity as a multidimensional shift operator, where a flat WB corresponds to a flat layer of single time delay spikes. Figure 3 compares input, Stolt deconvolution and SRME models in XT and Stolt domains. Figure 4 shows Pre-stack Depth Migration stack comparison before/after Stolt deconvolution, and the noise removed.

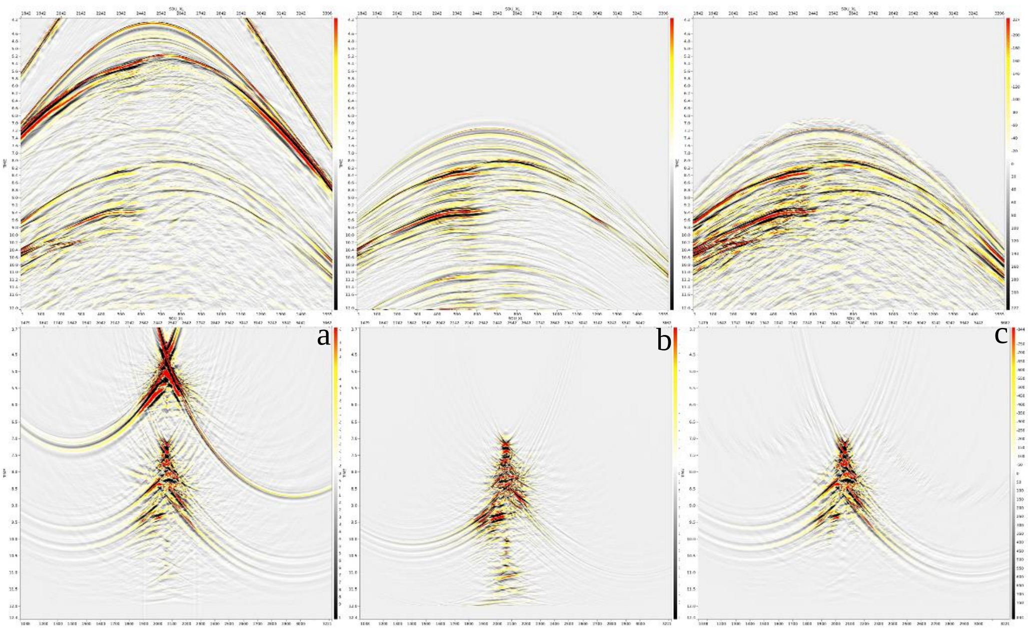

Figure 3: (a)input, (b)SRME model, (c)Stolt deconvolution model. XT domain at top, Stolt at bottom

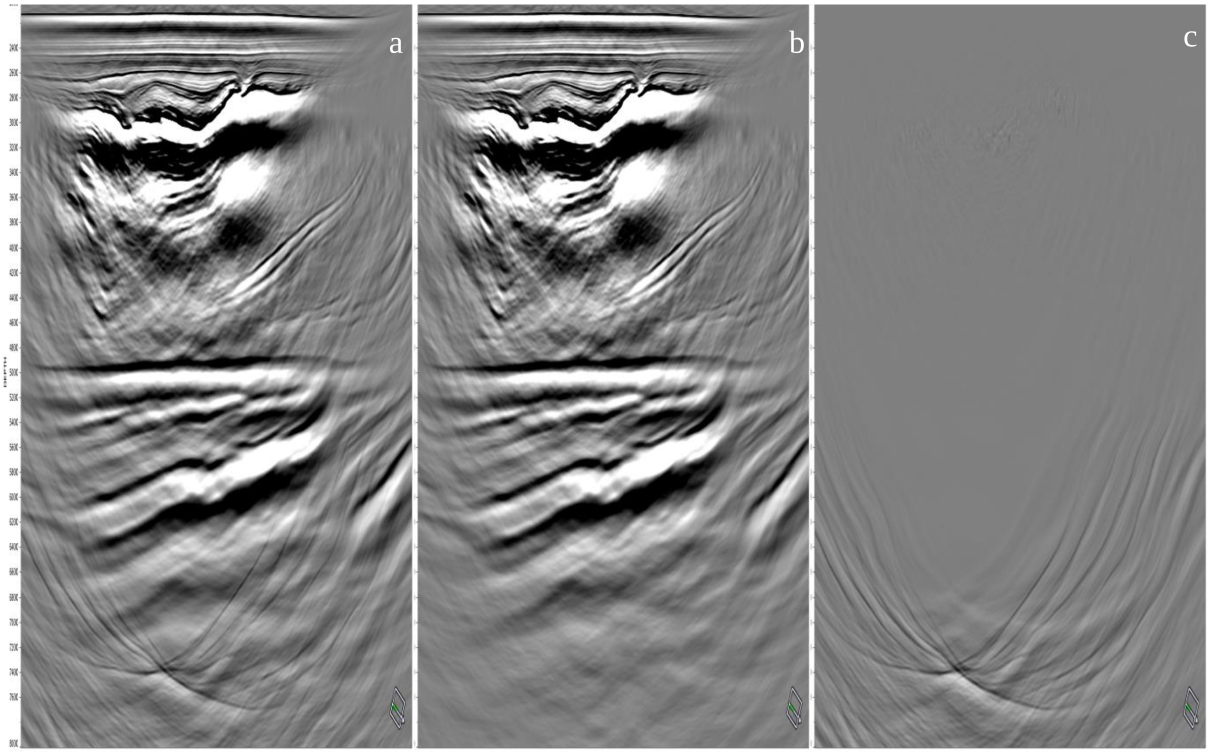

Figure 4: (a)Input PSDM stack, (b)PSDM stack after Stolt deconvolution model, (c) Difference

Conclusions

In deep water settings, where there is good separation between primaries and multiples, Stolt deconvolution can be a fast and effective method to remove multiples from OBN downgoing wavefield. Thanks to shot carpet sampling, this 3D data domain allows focusing and separation enhancement between multiples and primaries, making deconvolution safer for primaries. The multiple prediction has full bandwidth and it's accurate for all free surface multiples thanks to the complexity of the inverted filter.

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