Enhancing 3D SRME to Stop Complex Continental Shelf Slope Topography Obscuring the Seismic Signal

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SUMMARY

Continental shelf slopes are associated with deep erosional canyons that in general form perpendicular to depth contours, but we acquire strike of the water bottom in order to minimise HSE risk from streamer tangles and maximise coverage. This choice results in poor sampling of the complex multiples and rapid lateral near surface velocity changes, leading to many scales of distortion in the seismic image. We developed enhancements to 3D surface related multiple elimination (SRME) that combine the kinematics of 3D SRME and high resolution radon transforms to improve the subtraction of multiples. The increased signal to noise in conjunction with iterative wavelet shift tomography and pre-stack depth migration improves the imaging of potential exploration targets. Examples of using these techniques are shown from the processing of 31,000 km2 3D seismic over continental shelf slopes in Tanzania, Kenya and Uruguay.

Introduction

Continental shelf slopes are associated with deep erosional canyons that in general form perpendicular to depth contours, as shown in Figure 1. In contrast ocean currents on many continental shelf slopes run parallel to the depth contours. This creates a survey planning problem because to minimise HSSE risk from streamer tangles and maximise coverage it is advantageous to acquire in the direction of these currents. However, this acquisition direction being parallel to the strike of the water bottom, is often perceived to compromise velocity analysis and demultiple – since it does not allow the recording of a larger aperture of multiple contributions along the well sampled streamer. Such topography also results in lateral velocity contrasts and complex multiples. To resolve the velocity complexities travel time tomography is required, but the multiples significantly reduce signal-to-noise making it difficult to pick accurate travel times. In this abstract we show how improved demultiple enabled tomography and pre-stack depth migration (PreSDM) to work effectively.

We have developed enhancements to 3D surface related multiple elimination (SRME) that we have used in the processing of 31,000 km^2 of 3D seismic in the last three years over continental shelf slopes in Tanzania, Kenya and Uruguay. These enhancements to 3D SRME processing have allowed us to negate this narrow azimuth streamer acquisition planning problem and acquire data perpendicular to the slope dip. The enhanced demultiple gathers also provide more suitable input into the PreSDM velocity model building, which is required to provide realistic geometries under rugose water bottom topography.

Previous publications (Aaron et al., 2010) have shown how multiple contributions can be calculated with reasonable accuracy within the limits of the data acquired. We build on top of these efforts by improving the subtraction using a combination of those improved multiple model timings, high resolution radon transforms and simultaneous subtraction of several multiple models. We recognise that the inaccuracies of the multiple prediction change with frequency and that this is mostly seen in the variable wavelet mismatch with changing offset. This is mostly due to the lack of accurate source signature in the 3D SRME calculation (Verschuur et al., 1992) and the vertical arrival assumption in the source de-signature, but also partly due to the smaller proportion of acquired crossline aperture with increasing offset that is inherent in narrow azimuth acquisition.

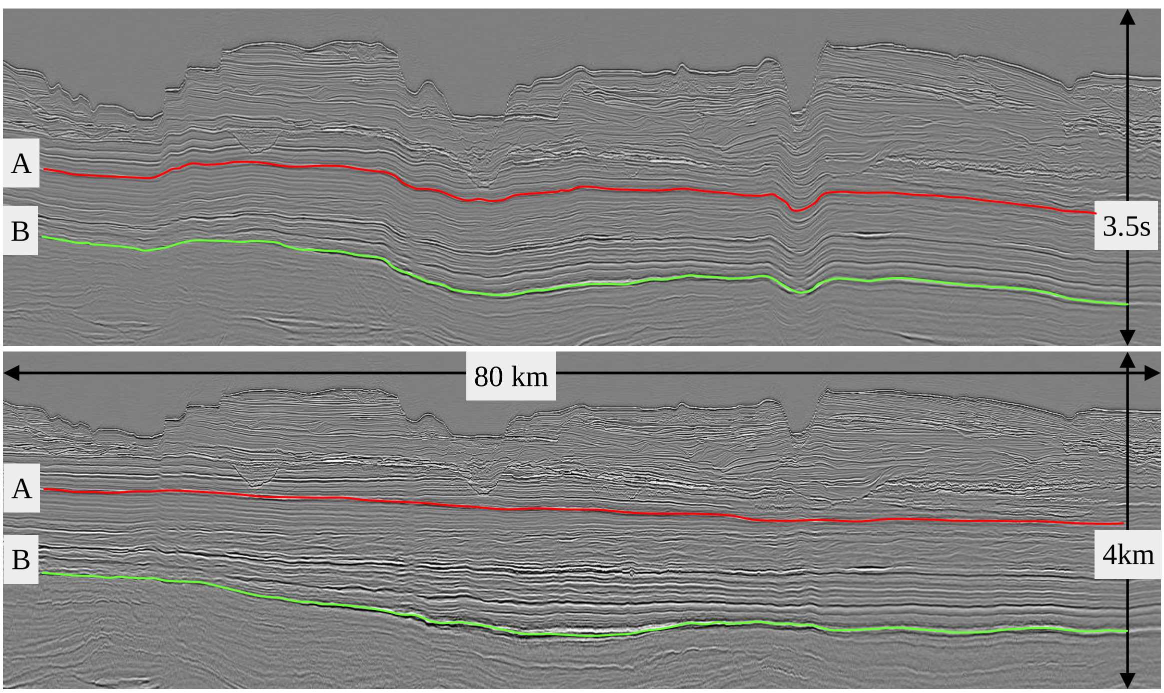

Figure 1 *Top – Pre-stack time migration result showing complex water bottom and many scales of distortion on reflectors A and B. Bottom – Comparable pre-stack depth migration showing that the distortion on reflectors A and B have been reduced. Note the overall geometry of reflectors A or B were not part of any constraint in the tomography.*

We observe in our experience (Figure 2 and 5), that 3D SRME produces robust timings of predicted multiple events, but increasingly poor amplitude and phase match between multiple model and observed data with increasing offset. The widely used method to correct for this change in accuracy of the multiple predictions with offset is to use a smoothly varying adaptive subtraction - a matching filter derived through a least squares minimisation scheme of residual amplitudes. However, as shown in Figure 2 this fails to adequately match the change in phase and frequency with offset.

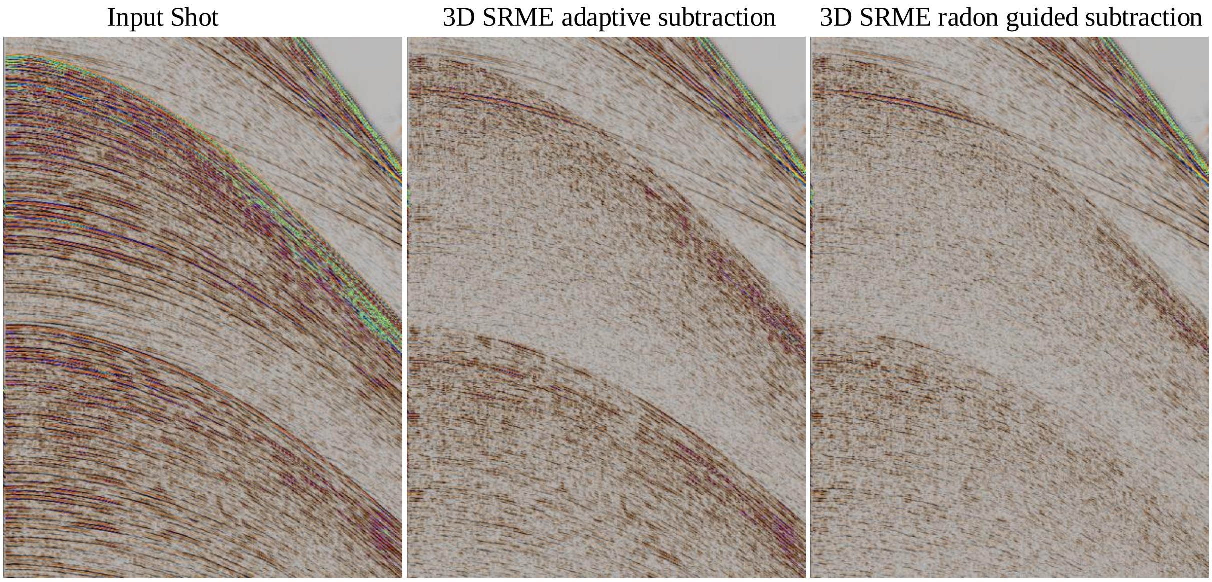

Figure 2 *A shot showing the improvement in removing the multiple using the radon guided method, particularly at mid and far offsets and on the second order multiple.*

To improve upon this we took inspiration from a curvelet domain matching scheme (Herrmann et al., 2008) which uses the sparseness in the curvelet domain to make a more robust match of the multiple model to the multiple in the input data. Unfortunately, the curvelet transform has not been widely implemented by industry. We therefore use a high resolution radon transform and the kinematics of the 3D SRME multiple model to produce a more accurate multiple model at mid and far offsets. We then use a least squares scheme to select the optimal multiple estimate from either the original adapted multiple model or the radon guided adaption multiple model, which provides a significantly improved demultiple result as shown in Figures 2 and 6.

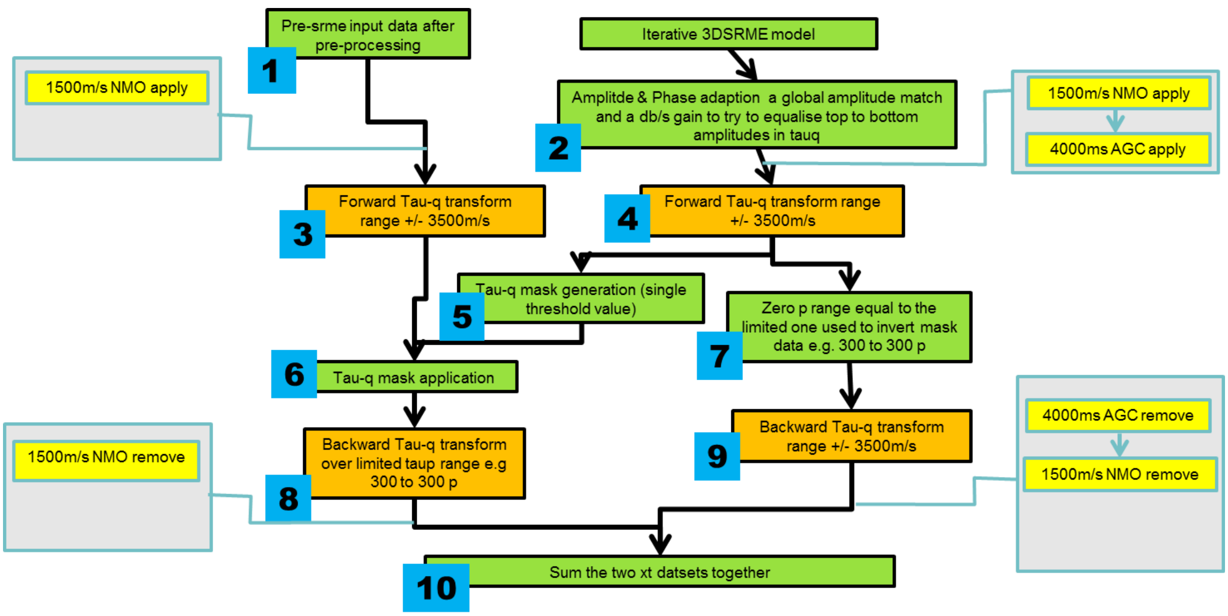

Figure 3 *Flowchart showing the initial stages of the radon guided matching method.*

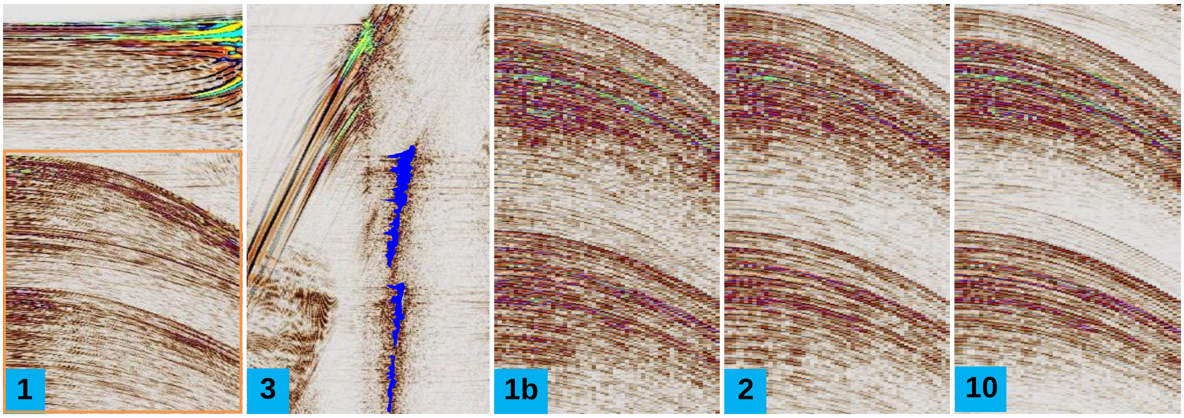

Figure 4 *Common mid-point (CMP) gathers from stages of Figure 3. 1* **-** *Pre-SRME CMP gather, 3* **-** *the radon transform of 1 with the selection mask (blue) overlain from stage 6, which covers the multiples, 1b* **-** *orange highlighted sub window of 1, 2 – standard adapted model, and 10* **-** *final radon guided multiple model.*

Method and Examples

The radon guided subtraction method improves the multiple removal at offsets approximately greater than twice the width of the streamer spread. The method is shown in Figure 3, with examples from various stages shown in Figure 4 and a description of the different stages is as follows:

- Stages 1 to 4 prepare and separately transform into radon space the recorded data which contains primaries and multiples; and the 3D SRME estimate of the multiples.
- Stages 5 to 7 then select using a local spike detection routine the high amplitudes in the radon space of the multiple model. These should correspond with the locations of just the multiples in the input data but without any transform artefacts of the primaries. We then make a binary mask from these high amplitudes and apply that mask to the input data radon space to select the multiple in the input data.
- Stages 8 to 10 then combines the output of the two inverse transforms to generate the radon guided multiple model which is shown in Figure 4.
- After stage 10 we use this radon guided multiple data and the standard least squares filtered multiple model to perform the final subtraction of multiple models from the input data. The subtraction is done using a least squares simultaneous subtraction technique after splitting all the datasets into fast and slow components relative to the water velocity. This final adaption selects the better model at any particular offset and time. In practice the standard model is only selected on the nearer offsets as this is the only area where it is effective as seen in Figure 5.

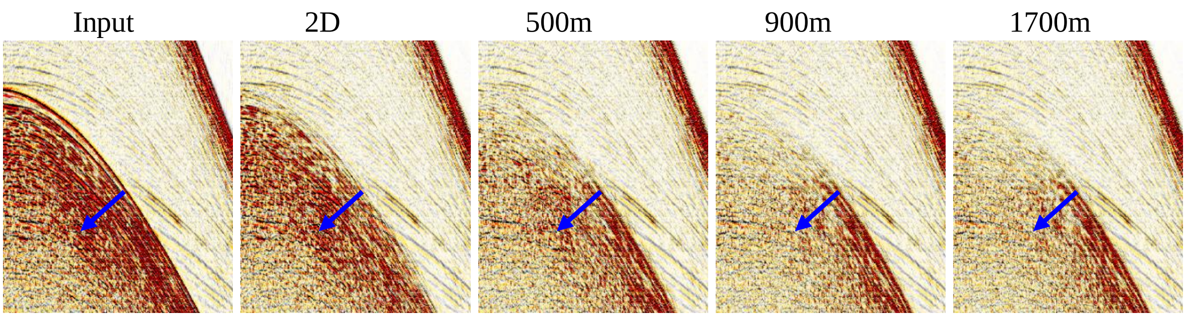

Figure 5 *A shot record comparing pre-SRME input data with post 2D SRME and post 3D SRME (increasing crossline aperture labelled and all subtractions are just least squares matching). Large crossline apertures are required to successfully reveal the primary event highlighted.*

To improve the multiple estimate for successive orders of multiples the 3D SRME was run iteratively (Verschuur and Berkhout, 1997). For the first iteration an aperture perpendicular to the streamer direction (crossline) of 500m was used, which was adaptively subtracted from the input data and this first result was then provided to the second iteration of 3D SRME along with the original input shots. The second iteration was calculated with a crossline aperture of 1700m as it was clear from multiple contribution gathers and shots after standard subtraction (Figure 5) that this was required to adequately calculate the multiple model.

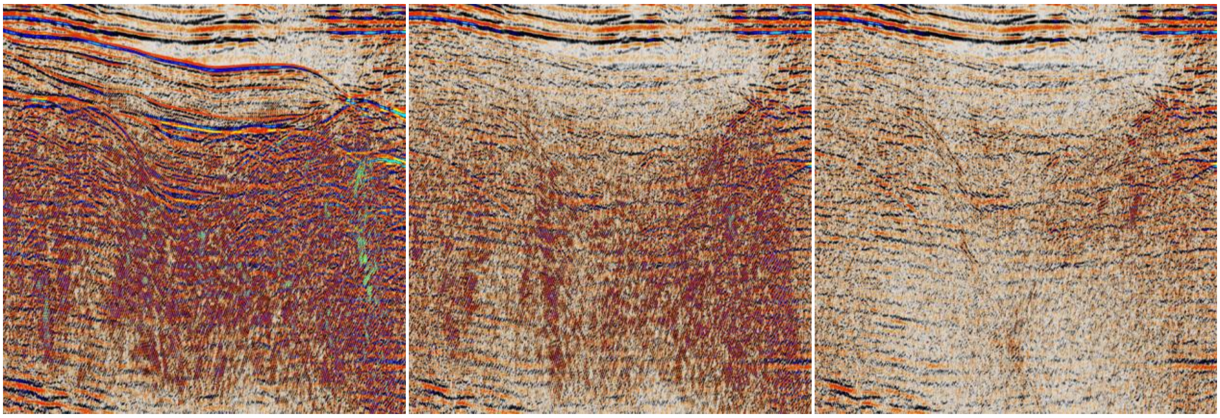

Figure 6 *Stack section showing the improvement in multiple attenuation using the radon guided method. It removed more far offset diffracted multiple whilst preserving the underlying primary data.*

To address the unapparent complexities in the velocity field that produce the distortions (Figure 1), we started with a gradient velocity field hung from the sea floor topography and performed iterative updates using wavelet shift tomography (Sherwood et al., 2011). This is based on decomposing seismic data into a regular basis of time wavelets. This was selected instead of conventional picked residual moveout gridded tomography since it avoids the reduction of the migrated gathers to just a set of discrete picks. Ensuring pick accuracy, especially in low signal to noise areas, requires time consuming manual intervention (Jones et al., 2013). In our experience this delay can be minimised by using wavelet shift tomography which produces wavelets which have invariant attributes of traveltime and dip with respect to time at its source (S) and receiver (R) locations (Sherwood et al., 2009). Each wavelet is migrated and its pre- and post-migration attributes are preserved. A residual 3D shift is estimated by correlation for each wavelet in order to align it with its neighbours. The 3D residual shifts, plus un-migrated and migrated wavelet attributes, form the input to the tomography.

Conclusions

The HSSE and technical requirements of acquisition are not always complimentary to idealised processing requirements. A radon transform based enhancement to 3D SRME adaptive subtraction has improved the attenuation of complex water bottom multiples associated with continental shelf slope canyons. The improved signal to noise after 3D SRME allowed accurate residual 3D time shift estimates and robust volumetric wavelet attribute selection. It was then possible to automatically solve for the shallow distortions in the velocity field – simply by iterative wavelet shift tomography.

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