Joint multiple predictions in SRME with combined Orthogonal WAZ surveys: case study

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Summary

Data driven 3D true azimuth surface related multiple elimination (SRME) is a proven technique for removing surface related multiples in both narrow-azimuth (NAZ) and wide-azimuth (WAZ) surveys. The success of SRME depends on good spatial sampling of the data. However, in WAZ surveys data is often poorly sampled in space. Combining orthogonal WAZ surveys improves the SRME multiple prediction quality by increasing the effective surface sampling of the input data. The results of applying this technique to dual WAZ surveys in the Gulf of Mexico are shown.

Introduction

Using the 3D surface related multiple elimination (SRME) algorithm developed by Berkhout and Verschuur, 1997, multiples for a given target trace may be predicted by the convolution of a multidimensional shot and receiver gather. The output of this convolution, termed a multiple-contribution gather (MCG), is stacked to create a prediction trace, which is adaptively subtracted from the data.

However, the prerequisite for this method: dense shot and receiver sampling is not met for most marine 3D acquisition, which is typically acquired to generate dense coverage in surface midpoint coordinates – shot and receiver sampling, especially in the crossline direction, can be very sparse. Several techniques have been developed to address this issue (Aaron et al. 2008, Dragoset et al. 2008). Cai et al. (2010) propose true azimuth multiple elimination (TAME).

Theory

In practise TAME predicts the multiples by convolving input data traces within a user defined aperture:

$$M = \sum_{aperture} F \cdot D \otimes D$$

Here D is the input data and F is a filter to correct the phase and amplitude distortion caused by sparse spatial sampling and the directivity of the source signature of the input data. For TAME, the aperture is defined along and perpendicular to the source receiver-azimuth for each target trace. The aperture is divided into a calculation grid oriented along the inline and crossline directions. For each node of the calculation grid, if there is more than one trace available, the trace that most closely matches the attributes (offset, azimuth) of the target trace will be chosen. 1D regularization using normal moveout (NMO) is used to correct the remaining difference between the actual and desired offset of the selected traces. This process will be repeated until all grid nodes in the aperture have been visited. Finally all the output traces from convolutions are stacked to generate the multiple contribution gather for the target trace.

TAME overcomes the limitations of sparse marine acquisition. However, for wide-azimuth (WAZ) acquisition the crossline shot and receiver sampling is significantly larger than for narrow azimuth data. This reduced sampling has critical implications for the prediction of multiples on the near and near-mid offset ranges. This increases the load that has to be carried by the 1D NMO regularization. Aaron et al. 2011 have shown the negative effects this can have on the multiple event prediction.

It is therefore reasonable to increase the surface sampling prior to computing the MCGs in order to minimize the work done by 1D NMO regularization. This can be done in a number of ways: shot interpolation (to reduce the offset spacing), cable interpolation (Cai et al. 2009), or regularization techniques such as antileakage Fourier transform (ALFT). In addition, underlying NAZ data may be used. Finally, orthogonal WAZ surveys may be utilized to increase the effective surface sampling (Yu et al. 2013). Each method has distinct advantages and disadvantages. In practice several approaches may be combined.

Here we describe the use of orthogonal WAZ surveys to enhance the surface offset and azimuth sampling in order to predict more accurate multiple models.

In addition, 3D FKxKy cable interpolation in the shot domain was applied (Cai et al, 2009). Cable interpolation can partially compensate for the acquisition imperfections of the receiver spacing. A significant advantage of cable interpolation is that azimuth information is naturally preserved for the inserted new cables. However, cable interpolation does not recover data in areas of poor coverage due to cable feather or surface obstructions. Hence in these areas 1D regularization will be required potentially leading to an incorrect model being predicted.

Results

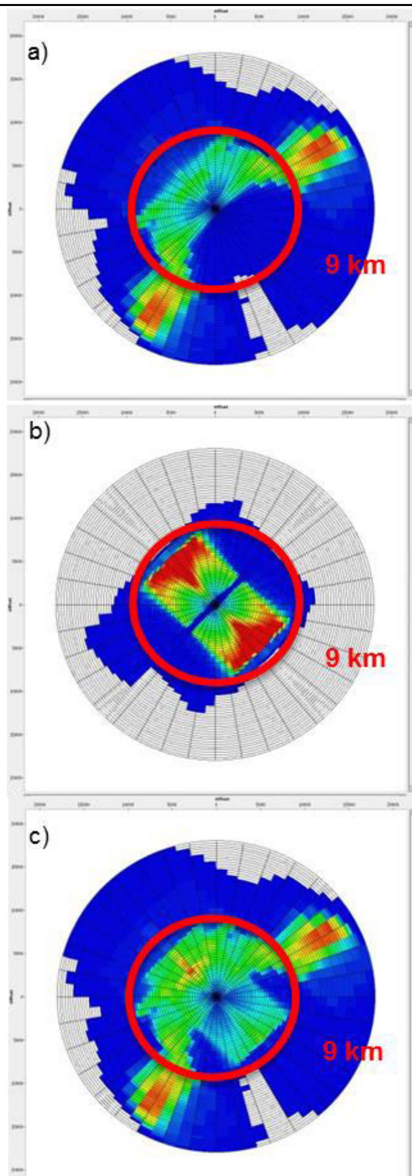

Figure1: (a) Rose diagram of Declaration WAZ survey without reciprocity (staggered acquisition-shooting direction NE-SW); (b) Rose diagram of Justice WAZ survey (shooting direction NW-SE); and (c) combined Rose diagram of the Declaration and Justice WAZ surveys. The Red circles indicate offset distribution up to 9 km.

The Declaration and Justice 3D WAZ surveys are located in the Mississippi Canyon and Viosca Knoll protraction areas of the central Gulf of Mexico with a water bottom ranging from 100 ms to 3300 ms two-way time (TWT). The Declaration 3D WAZ survey was acquired in 2014-2015 and was acquired along a (northeast to southwest) shooting direction, orthogonal to the existing Justice WAZ survey (northwest to southeast) acquired in 2010.

The Declaration WAZ survey was acquired using a modified version of CGG's StagSeis acquisition technique and utilized 2 streamer vessels and 5 source vessels. The maximum inline offset is 16000 m and the maximum crossline offset 4800 m. The Justice WAZ survey was acquired with 2 streamer vessels and 4 source vessels. The maximum inline offset is 7500 m and the crossline offset 4140 m. The shot line spacing of 600 m is common between two surveys.

Figure 1 shows the rose diagrams of (offset-azimuth distribution) for the Declaration WAZ (northeast to southwest) and Justice WAZ surveys (northwest to southeast). The Declaration survey configuration provides ultralong offsets (up to 16 km) which can help improve the illumination of deep targets in eastern Mississippi Canyon in the Gulf of Mexico. Combining both orthogonal wide azimuth surveys (Figures 1a and 1b) provides full azimuth coverage up to 9 km. This additional coverage improves the multiple predictions in complex geological areas.

The preprocessing flow consisted of multidomain denoise with maximum preserving low frequency data. After denoise, the data were debubbled. deghosting, using adaptive window-based deghosting (Zhang et al, 2016), was followed by zero phasing and shot and channel amplitude correction. Water column statics were applied to minimize the effect of water velocity variation due to temperature and salinity.

A fast track volume was created without deghosting and using only the Declaration WAZ survey for the multiple predictions. The main processing included deghosting and combined both WAZ surveys for the TAME multiple prediction step. Prior to the joint multiple model prediction amplitude, phase and timing attributes were matched between the two surveys

Figure 2a-c show the TAME results using a single WAZ survey (fast track) and that from combining the two orthogonal WAZ surveys. Figure 2a shows a CDP gather before TAME. Figure 2b shows the same gather after TAME with single WAZ survey model generation and 2c after TAME with the combined WAZ surveys.

The middle panel shows residual multiples at near to mid offsets. The multiple model for the data shown in Figure 2b are predicted using a single WAZ survey (Declaration WAZ only). The shot line spacing of 600 m requires a significant differential normal moveout correction for residual offset differences between the selected and target traces. Timing errors introduced by the 1D regularization will appear in the multiple contribution gather (MCG) and lead to an incorrect multiple model when the MCG is stacked. The rightmost panel in Figure 2 shows the result from combining two orthogonal WAZ surveys for multiple model building. The improved spatial sampling minimizes the extent of the 1D regularization leading to a higher fidelity multiple model. The effect of this increased fidelity is evident in Figure 2c where the 3D SRME results with combined orthogonal WAZ surveys show better multiple event removal.

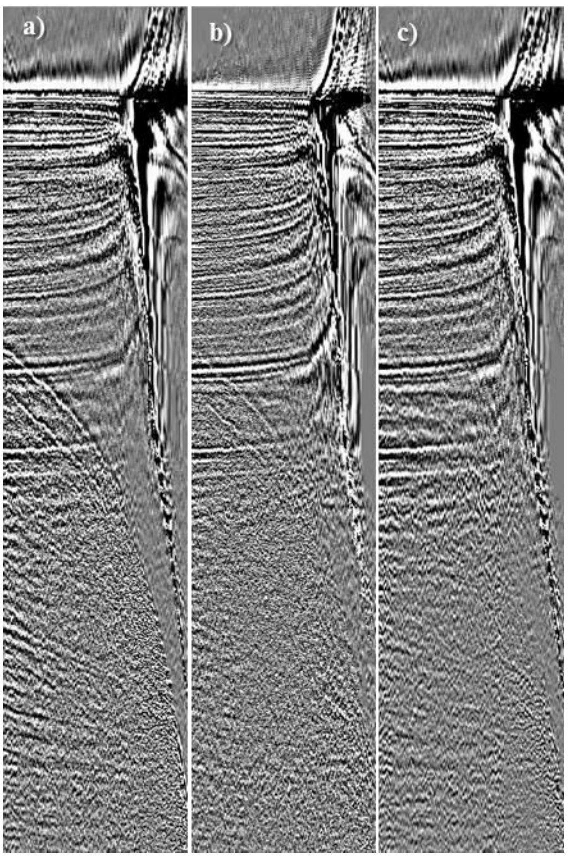

Figure 2: a) CDP gathers before 3D SRME b) CDP gathers after 3D SRME with using single survey data in multiple model prediction (Declaration WAZ only) c) CDP gathers after 3D SRME with combining two WAZ surveys in multiple model prediction (Declaration and Justice WAZ surveys)

Figure 3 compares the before 3D SRME (3a) to 3D SRME outputs that used a single WAZ survey (3b) and combined orthogonal WAZ surveys (3c). From this picture, we can see the complex geology includes very shallow rugose top of salt in this area. Figure 3b shows the 3D SRME output using only one WAZ survey data. This leaves some residual water bottom related multiples, which are marked by a yellow arrow. The primary reason for, the residual multiples, due to the sparse sampling in the crossline direction surface related multiples are aliased in the crossline direction, leading to the prediction of an inaccurate multiple model. The combination of orthogonal WAZ surveys creates a more densely sampled input data set in both inline and crossline directions, this reduces the multiple aliasing, generating a superior prediction. Figure 3c shows 3D SRME output from the combined orthogonal WAZ surveys. The results show less residual multiple than observed in the 3D SRME output for a single WAZ survey (3b).

Figure 4a-b show Kirchhoff depth migrated stack sections from the fast-track and main-track processing. The fast-track processing used an initial velocity model. Figure 4a shows the fast-track depth migration result with multiple predictions using a single WAZ survey (the Declaration survey). Residual multiples between the base of Miocene and top Jurassic geological boundaries are clearly visible. The right panel shows the main track imaging result using TAME with combined orthogonal WAZ surveys. This results in significantly less residual multiple in the data. The signal to noise ratio has been increased and reflectors between base of Miocene and top Jurassic geological boundaries are more coherent, thus making them easier to interpret.

Another benefit of reduced multiples lies in the AVO effect of the data. In the target zone, the presence of multiples distorts the AVO characteristics of the data. A better multiple removal will reduce this distortion and we would expect to be able to extract a more intrinsic AVO behavior from the data.

Conclusions

The success of 3D SRME depends on good spatial sampling of the input data. In general, WAZ surveys are often poorly sampled in space. The bigger shot line spacing requires a significant differential moveout correction for residual offset differences between the selected and target traces, which can lead to an incorrect multiple model. Combining two orthogonal WAZ surveys mitigates the offset sampling issues, which reduces load on the 1D NMO regularization, allowing more precise multiple models to be constructed. This uplift was demonstrated on a real data case using dual WAZ surveys from the Gulf of Mexico.

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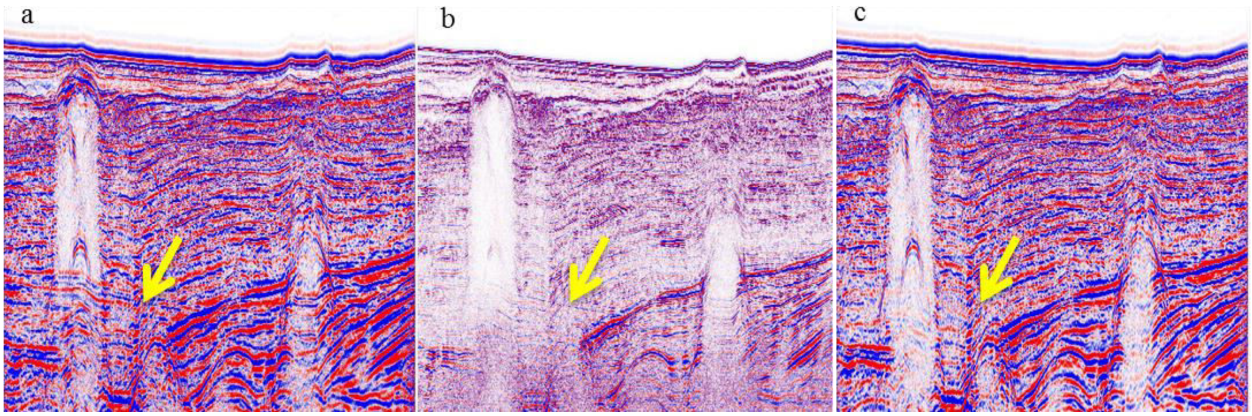

Figure 3: (a) Premigration stack before 3D SRME; (b) Fast track 3D SRME output using single WAZ survey; (c) The main track processing 3D SRME output using combined orthogonal WAZ surveys.

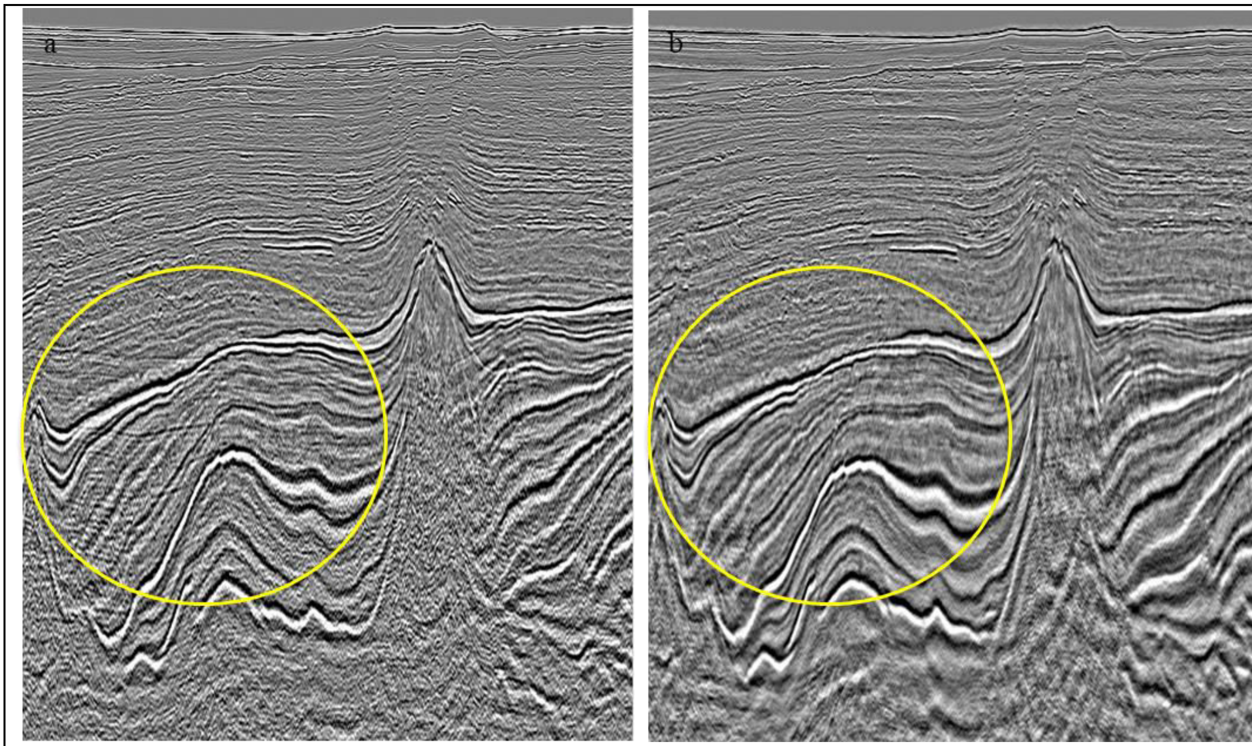

Figure 4: a) The fast track Kirchhoff depth migrated stack b) The main processing Kirchhoff depth migrated stack (intermediate product).

EDITED REFERENCES

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