Freedom Wide-Azimuth Processing and Imaging, a case history study of WAZ imaging in Mississippi Canyon, Gulf of Mexico

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Summary

Wide-azimuth (WAZ) data is the most significant advance to have occurred in seismic acquisition and processing since the introduction of 3D seismic in the early 1980's. Along with the promise of better subsurface images free of multiples came some unique processing challenges, as well as a new layer of complexity added to processes also found in conventional narrow-azimuth (NAZ) sequences.

Here we present an overview of three key steps in a wide-azimuth processing flow, using a wide-azimuth data set jointly owned by TGS and WesternGeco in Mississippi Canyon: the Freedom WAZ survey. Data regularization is used to prepare the data for multiple attenuation and imaging; 3D multiple attenuation techniques are used to remove multiple energy, in particular complex multiples beneath salt; and a suite of high-end migration algorithms are used to create the final image of the subsurface.

Introduction

Early forward modeling experiments demonstrated that significant improvements in imaging and multiple attenuation were possible with wide-azimuth data (Regone, 2006; VerWest & Lin, 2007). Initial field data trials quickly followed using ocean-bottom nodes (Ross & Beaudoin, 2006) and streamer data acquired with a range of acquisition scenarios (e.g. Corcoran et al, 2007; Howard & Moldoveanu, 2006; Moldoveanu & Egan, 2007; Threadgold et al, 2006). The results from these surveys confirmed the modeling results, but they also raised some interesting questions about the optimum processing sequence for WAZ data (e.g. Michell et al, 2006). As more data has been acquired the initial promise of better imaging and reduced multiple content has not been fulfilled every time. Behind the scenes, geophysicists have been working hard to understand the processing best-practices that will extract the maximum amount of uplift from wide-azimuth data (Fromyr et al, 2008). New ways to visualize and QC the data have been developed. Existing processing techniques and algorithms have been redesigned and updated.

In this paper we review three of these techniques: data regularization, multiple attenuation and RTM imaging. The examples are taken from the TGS/WesternGeco Freedom wide-azimuth streamer survey currently being acquired in the Mississippi Canyon and Atwater Valley areas of the Gulf of Mexico. All the processing examples shown in this paper are the work of TGS-Nopec on a subset of the Freedom WAZ data.

Visualization & QC

Wide-azimuth acquisition creates larger data volumes carrying more information than conventional narrow-azimuth streamer data. In order to ensure that all of this new information is used detailed QC is essential. This QC requires new ways of viewing the data and its attributes.

The 'supershot' is a unit of data that arises naturally out of the way wide-azimuth data is acquired. Within one supershot all the shots fired at a common surface location are collected together. Each supershot can be thought of as a 3D cube of data (Fig. 1). It forms the basic input unit to a number of subsequent processing steps including regularization, multiple attenuation and imaging.

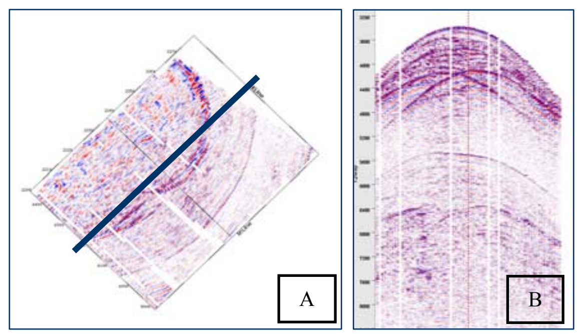

Figure 1 (a) Timeslice & (b) crossline through a supershot.

A supershot is formed by collecting a number of actual shots whose locations are near the center of a supershot location. For the Freedom WAZ survey, a total of 8 physical shots form a supershot. Fig. 2 shows one way to visualize supershot formation. The QC display allows the geophysicist to ensure that supershots have been built correctly and to assess the likely impact of cable feathering and other external factors on their integrity.

The azimuth distribution within a CDP gather has an impact on a number of processing steps, including, Radon multiple attenuation and Kirchhoff depth migration. On-the-fly display of 'spider diagrams' (Fig. 6) is a way to visual the distribution of offset and azimuth within a gather, allowing the geophysicist to determine appropriate multiple attenuation, regularization, or decimation schemes.

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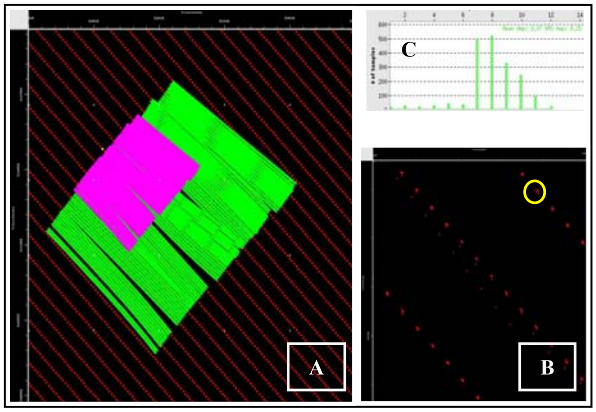

Figure 2: QC of supershot creation (a) streamer geometry, (b) shot distribution & (c) supershot fold.

Pre-Processing

Initial pre-processing steps: noise removal, bubble attenuation etc., have much in common with narrow-azimuth processing. We will not go into these processes in more detail in this paper, except to note that some steps, among them, zero-phasing and water-column statics, need to be modified to take into account the additional crossline offsets present in the data.

Regularization

Supershots form the basic processing unit for much of the wide-azimuth processing flow. The first step in data regularization is to combine individual sequences together into lines of supershots. With the Freedom wide-azimuth survey shooting geometry one supershot has a receiver array that is roughly square (7.2km x 8.3km). In a perfect world the supershot would consist of a regular array of receivers; however, cable feathering, cable and gun dropouts and infill give rise to holes as well as areas of duplicate coverage (fig. 1 & fig 2).

Regularization within a supershot involves solving a linear inverse equation in the F-Kx-Ky domain. Further details of this technique can be found in Cai et al, 2009. Regularization can be implemented in two ways.

Firstly, regularization is used to improve the receiver sampling in preparation for 3D SRME or wave-field extrapolation (WFE) multiple attenuation. Fig. 3(a) shows three additional cables interpolated between pairs of original cables. This reduces the cable spacing from 120m down to 30m and reduces aliased noise in both the WFE and 3D SRME models. In addition to cable interpolation near offset extrapolation is also important for 3D SRME and WFE; especially for the infill of crossline near offsets. Depending on the acquisition geometry, these offsets can be missing from some wide-azimuth data.

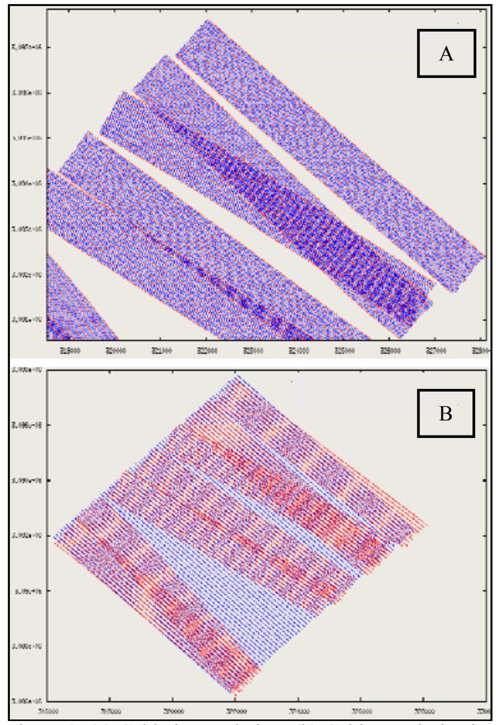

Figure 3: (a) Cable interpolation; (b) Cable regularization

Secondly, regularization can be used to interpolate data where there is no receiver coverage and regularize data where duplicate receivers or irregular coverage exists due to cable feathering. Used in this way it provides a completely regularized supershot that can be used as input to RTM, for example (Fig. 3(b)).

Multiple Attenuation

Despite the early promise that the additional crossline offsets in wide-azimuth data would do away with the need for multiple attenuation experience has shown that multiple attenuation is still required in practice. Furthermore, in the presence of large crossline offsets conventional approaches, such as Radon, are problematical and 2D techniques, such as 2D SRME, are ruled out.

3D multiple removal schemes must bear most of the weight of multiple attenuation on wide-azimuth data. There are two main approaches for 3D multiple prediction: data driven 3D SRME and model based wavefield extrapolation techniques (WFE).

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Data-driven techniques have traditionally been used in both narrow- and wide-azimuth processing to create a 3D prediction of surface related multiples. The 3D SRME shown here is a true-azimuth fully data-driven convolution-based approach, that utilizes high-fidelity regularization routines (see above) to reduce aliasing (see Cai et. al, 2009 for more information). Fig. 4 shows an example of stacked data with and without 3D SRME.

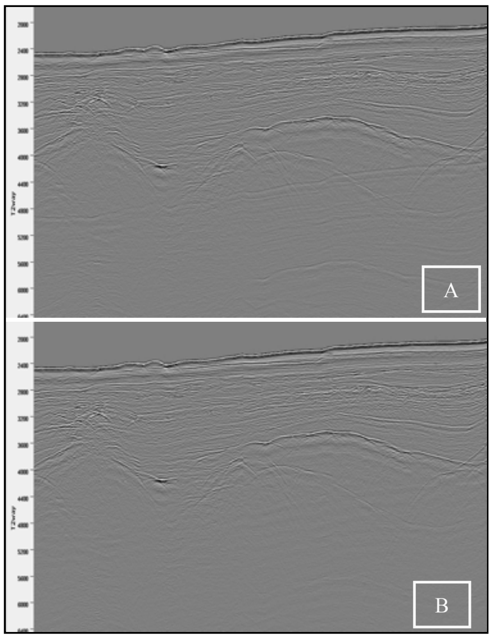

Figure 4: Stacked data without (a) and with (b) 3D SRME.

Wavefield extrapolation multiple attenuation (WFE) techniques provide an alternative to data-driven approaches. Since they work shot-by-shot they are particularly well suited for wide-azimuth data, in which the receiver density is higher and the shot density lower than for conventional narrow-azimuth acquisition.

The WFE technique shown here is a shot-based process that extrapolates a surface shot record down to a target depth and back to the surface. In one pass it generates a 3D prediction of all surface related multiples. A high resolution depth migration is used to generate the reflectivity model. Once the multiples are modeled, an adaptive subtraction process is applied to remove the modeled multiples from the original shot record. Fig. 5 shows stacked data with and without WFE.

In certain cases the strengths of the 3D SRME and WFE techniques complement one another. In these cases an uplift can be achieved by combining the two models together. Both models are input into the adaptive subtraction step and for each adaptation window the model that has the highest correlation to the multiples in the data is selected.

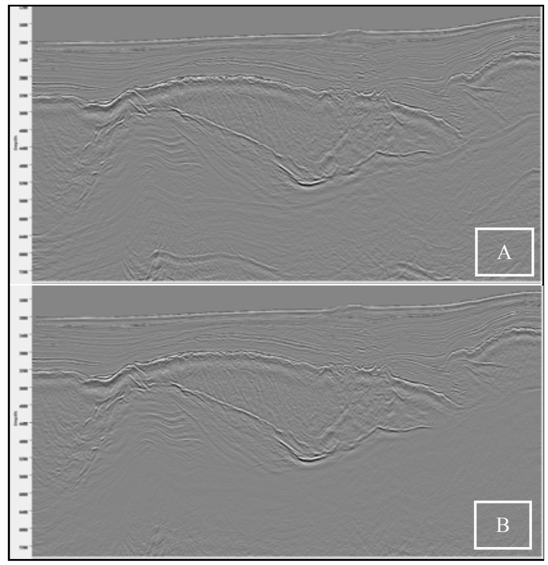

Figure 5: 2D PreSTM data without (a) and with (b) WFE.

Radon based multiple attenuation techniques are a standard part of most narrow azimuth processing flows. Their use on wide-azimuth data is more problematical. Data gathered into 3D CMP gathers contain a high degree of 'jitter' arising through the combination of a number of different sequences of varying source-receiver azimuths into one CMP (Fig. 6(b)). In contrast to this, CMP gathers built from source-receiver pairs have a limited azimuth range and so reduced 'jitter'; but they can suffer from low fold and a limited offset range at large crossline offsets (Fig. 6(a)). They can also exhibit anomalous apparent velocities (Levin, 1971). One way to avoid the shortcomings of both approaches is to apply Radon multiple attenuation to 3D CMP gathers sorted into regularized azimuth sectors.

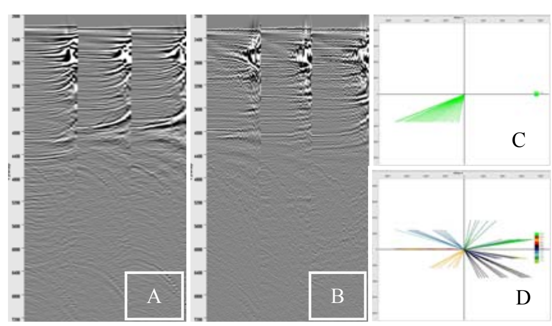

Figure 6: (a) CMP gathers from a common source-receiver pair; (b) 3D CMP gathers; (c) Offset azimuth distribution for (a); (d) offset-azimuth distribution for (b).

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Imaging

While the pre-processing, regularization and multiple attenuation schemes outlined so far are important, the single biggest uplift in wide-azimuth data comes in the imaging step through the additional illumination provided by increased azimuth coverage.

Since they provide an efficient way to take advantage of wide-azimuth acquisition's relatively sparse shot distribution, shot-based wave-equation techniques, such as WEM and RTM, are best suited to imaging wide-azimuth data. However, Kirchhoff and beam migrations are also used during the model-building phase.

Here we show a comparison of narrow-azimuth versus wide-azimuth results using Kirchhoff preSDM and a comparison of Kirchhoff versus RTM for wide-azimuth data. In all cases the model is the same and all algorithms incorporate VTI anisotropy. The wide-azimuth data has no multiple attenuation, while the narrow-azimuth data has been through a full processing sequence, including 2D SRME and Radon.

In the narrow-azimuth versus wide-azimuth example (fig. 7) the uplift from increased illumination, especially for deep sub-salt reflectors can be clearly seen.

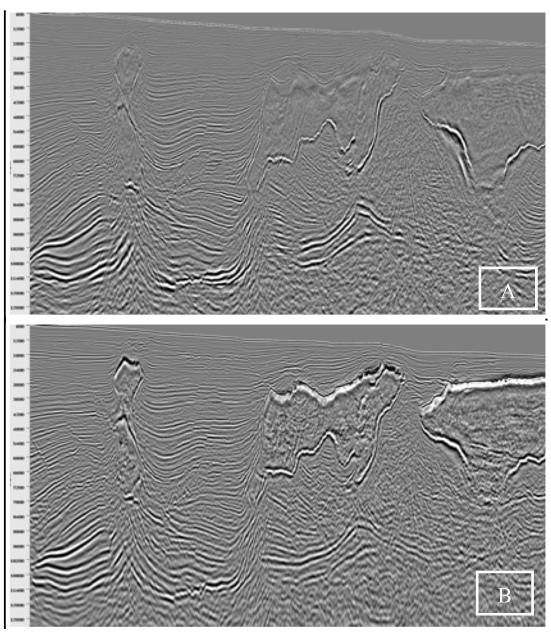

Figure 7: (a) NAZ VTI Kirchhoff preSDM (b) WAZ VTI Kirchhoff preSDM.

The Kirchhoff versus RTM example (fig. 8) shows the uplift that comes with using high-end migration algorithms in conjunction with wide-azimuth acquisition. Complex subsalt structures can be identified on the RTM data, while the superior accuracy of the algorithm has also attenuated subsalt multiples.

Conclusions

There are many new challenges associated with processing wide-azimuth data and many old challenges are cast in a new and more complex light. We have shown how high-quality images, showing the subsurface in detail hitherto unseen, can be produced through the application of processing carefully designed to take full advantage of the additional information provided by wide-azimuth data, and through the use of custom-built visualization and QC tools.

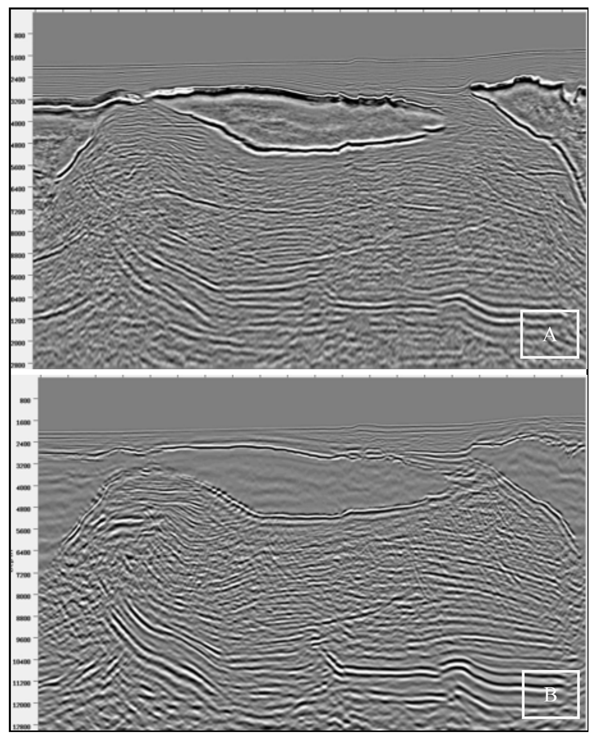

Figure 8: (a) WAZ VTI Kirchhoff preSDM; (b) WAZ VTI RTM

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