Merging multiple surveys before imaging

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Summary

We present a redatuming data regularization technique based on a 3D true azimuth Common Focusing Point (CFP) technique. It can effectively merge different surveys including orthogonal Wide Azimuth (WAZ) surveys. We applied the technique to merge two orthogonal WAZ surveys, TGS Justice and Kepler, to provide a single and improved image.

Introduction

In order to further improve the subsurface illumination, two WAZ surveys (TGS Kepler and Justice) overlying each other with orthogonal acquisition were acquired in the Gulf of Mexico. Two orthogonal WAZ surveys provide an efficient way to obtain close to full azimuth data on an existing WAZ area; in turn giving a significant uplift in the subsalt image (Figure 1).

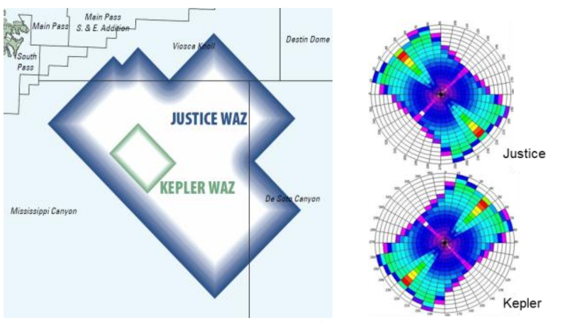

Figure 1: Map shows the location of the Justice and Kepler WAZ surveys on the left. The corresponding surface azimuth coverage is shown on the right.

To better understand the benefits of merging the two surveys, a finite difference modeling program with input reflectivity (Figure 2D) and Tilted Transverse Isotropy (TTI) models derived from field data was used to generate a synthetic data set; followed by TTI Reverse Time Migration (RTM). The synthetic RTM image shows that the survey orientation produces different subsalt illumination. The Justice acquisition (Figure 2A) synthetic RTM image (Figure 2E) provides better continuity for subsalt events (arrows); while the Kepler acquisition (Figure 2B) synthetic RTM image (Figure 2F) gives clear sediment truncation against the base of salt (blue circled area). The RTM image of the merged shots (Figure 2G) provides the best of both worlds. These synthetic examples clearly demonstrated the benefit for merging two orthogonal WAZ surveys before migration.

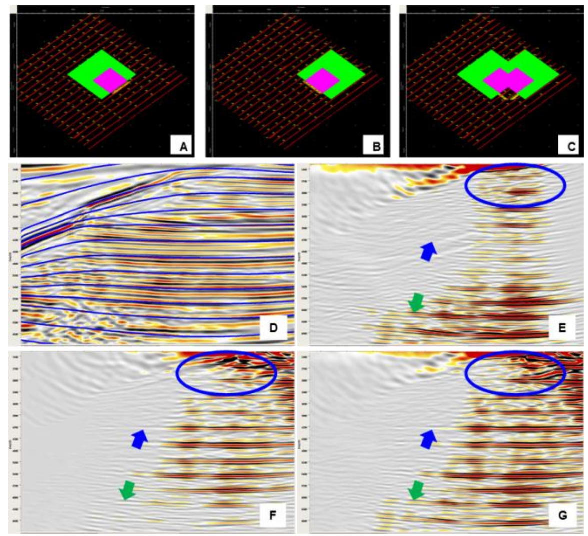

Figure 2: Synthetic examples. (A) to (C) The shot geometry simulates Justice, Kepler, and the merged survey. (D) Reflectivity (blue curves) model used for forward modeling. (E) One shot RTM image for Justice survey synthetic data. (F) One shot RTM image for Kepler survey synthetic data. (G) One shot RTM image for merged shot.

In order to merge two orthogonal WAZ surveys before imaging, multi-dimensional data interpolation is one possible solution. Most multi-dimensional data interpolation algorithms are implemented in the Fourier domain. The common methods include least-square Fourier reconstruction (Hindriks and Duijindam, 2000; Cai et al., 2009; Jin, 2010), antileakage Fourier transform (Xu et al., 2005) and minimum weighted norm inversion (Liu and Sacchi, 2004).

We propose an alternative solution that combines the CFP technique with the redatuming concept as a data regularization technique. A benefit of the downward wavefield continuation is that the gaps in the acquisition at the surface are naturally healed; in turn the input data condition for data regularization will be improved compared to the surface acquisition. By merging the surveys before imaging, we can obtain denser shot point spacing (from 150x600m and 600x150m shot intervals to a combined 150x150m shot interval), thus reducing the data aliasing before migration. Combining two WAZs (or any multiple surveys) into a single survey with richer azimuth coverage, we will be able to provide a unique and improved subsurface image, rather than a few images each migrated with individual survey.

True azimuth CFP redatuming data regularization

Redatuming is referred to as an upward or downward continuation of seismic data, the purpose of which is to redefine the reference surface on which the source and receivers appear to be located. It has been used as a tool to remove the near surface overburden imprint on the seismic data (Berryhill, 1979, 1984; Shtivelman and Canning, 1988; Hindriks and Verschuur, 2001, Schneider, 1978, Alkhalifah and Bagaini, 2006).

The CFP technique was introduced by Berkhout (1997) and Thorbecke (1997). A common receiver CFP gather represents focused data with one receiver in the subsurface and all sources at the surface (or vice versa for a common source gather). The CFP focusing operator is calculated by forward modeling to calculate the response at the surface from a point source at the subsurface focal point location. Using this focusing operator, a CFP gather for focusing at the focal point is constructed by a time-domain convolution between the traces of the focusing operator and the traces in the shot record.

To construct a 3D CFP gather, time-domain convolution needs to be applied for all the traces within a user defined aperture.

$$M = \sum_{aperture} F \bullet C \otimes D$$

where C is the CFP focusing operator, D is the input data, and F is the filter to correct the phase and amplitude distortion caused by sparse spatial sampling and aliasing of the input data. To gain efficiency, the convolution is normally performed in the frequency domain for a user defined frequency range.

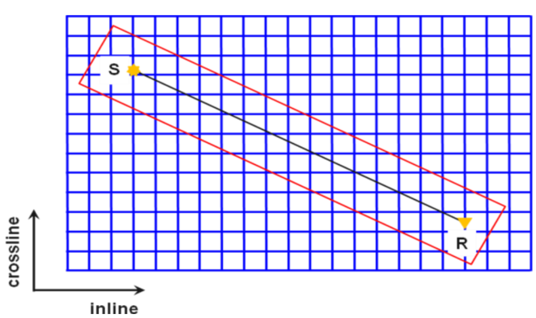

Figure 3: The aperture is defined differently for each receiver. For output source-receiver (S-R), the aperture is defined as the red rectangle. Then aperture is divided into calculation (blue) grids which are along the inline and crossline.

To preserve the azimuth information for each of the receivers, we define the aperture along the azimuth between the output source and receiver and perpendicular to the azimuth (red rectangle in Figure 3). In turn, every receiver will have its own aperture definition. Each aperture is divided into small calculation grids. For each of the calculation grids, if there is more than one trace available, we will choose the one that has the closest defined attribute (azimuth, inline, crossline, offset, etc. are used to calculate the desired attribute).

The generated convolved traces volume is called a CFP contribution gather (CCG). Stacking a CCG produces one target output trace. The aperture of the CCG should cover the contribution of the Fresnel zone. Intuitively, the aperture should cover all the vertices of the events (Figure 4). It is a useful tool for aperture definition.

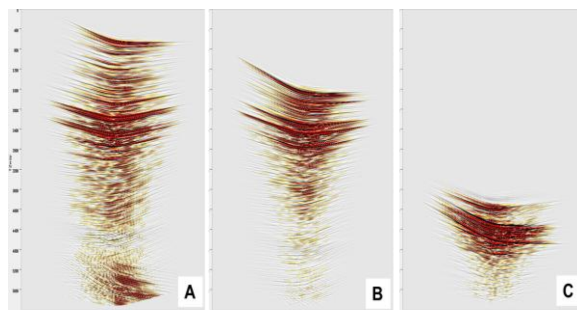

Figure 4: CFP contribution gathers for extended Marmousi model (Figure 5): near offset trace (A), middle offset trace (B), and far offset trace (C).

To illustrate and also check the validity of this technique, we use a modified Marmousi model as test case. Figure 5 is the velocity model, with 400 meter water depth. The black surface is the surface at the original source and receiver depth. The magenta surface is the target redatuming surface. The velocity contrast is used to generate the events.

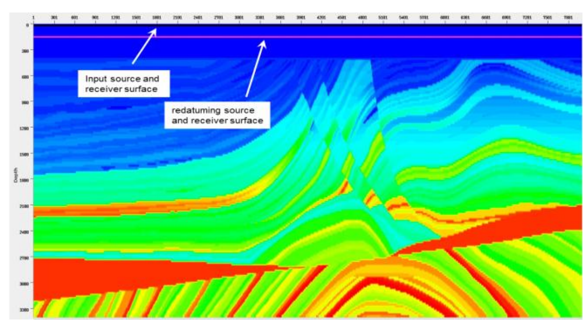

Figure 5: Velocity model for synthetic dataset.

The CFP based redatuming data regularization is implemented by:

- Defining the CFP focal point on a user defined surface as the redatuming surface (magenta surface in Figure 5).
- Defining regularized output shot locations and their survey geometry considering the original survey.
- Constructing CFP shot gathers, with regularized shots that are located on the redatuming surface at desired shot locations; while the regularized receivers for corresponding shots are located at the desired output locations on the original surface (Figure 6B).
- Perform the CFP transform on each of the receivers to move the regularized receiver down. This time we put the focusing points on the redatuming surface, and right underneath the current receiver surface location (Figure 6C).

A comparison between a shot gather redatumed to a depth of 150 m (Figure 6C) and a modeled shot gather with both shot and receivers at 150 m depth (Figure 6D), shows that this technique can provide a high-fidelity data regularization solution.

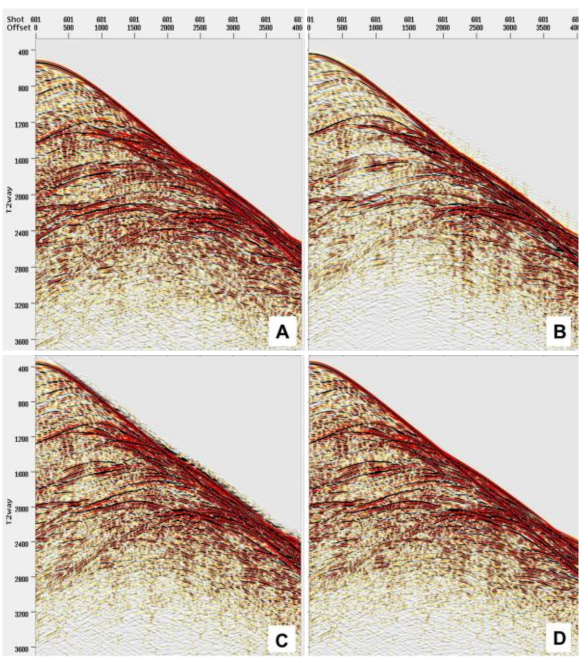

Figure 6: Synthesis. (A) Original shot gather at 20m depth. (B) Redatuming shot to 150m depth. (C) Redatuming both shot and receivers to 150m depth. (D) Synthetic data with shot and receivers are at 150m depth.

Merge two orthogonal WAZ surveys

From the previous equation, we can see that the CFP gather construction is a data driven approach. But the velocity between the surface and redatuming reference surface is needed to construct the focusing operator.

For data regularization purposes, the redatuming surface was selected as a surface with constant depth inside the water; and water RMS velocity was used. In turn the velocities used for the CFP focusing operator are very close to the true velocities.

Considering that the Kepler and Justice surveys are orthogonal, and have 150x600m and 600x150m shot intervals respectively, we designed the output regularized shots at 150x150m shot interval. The regularized receiver location for each shot is shown in Figure 7B and is designed to catch the full azimuth information contained in the original two orthogonal WAZ surveys (Figure 7A). One of the interpolated shot and its input examples is shown in Figure 8.

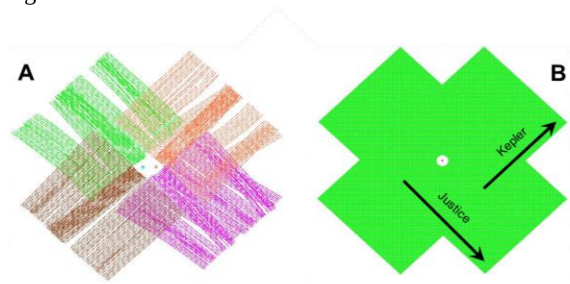

Figure 7: Shot geometry. (A) The supershots drawn in brown and orange color are Kepler's supershot. The supershots drawn in green and magenta color are Justice's supershot. (B) Merged Justice and Kepler's regularized shot.

Three RTMs were run to test the effectiveness of the redatuming data regularization technique. Two of three RTMs were run, one each for the Justice and Kepler surveys, respectively. A third RTM was run on the merged data sets from the redatuming data regularization step. The models and RTM parameters were exactly the same in each case; the only difference between the three runs were the input data sets. Next, we simply summed Justice's RTM image with Kepler's RTM image as shown in Figure 9A. Compared with the RTM image from redatuming data regularization (Figure 9B), we can see there are some uplifts. A benefit of using denser data coverage for each individual shot within the migration aperture is that the redatuming image shows more high frequency for shallow structures (blue arrows). For the subsalt area where the merged shot benefited from better azimuth coverage for each individual shot; less RTM illumination compensation is needed for this RTM image. In turn, the artificial migration swing noise was suppressed; subsalt events become more continuous (circled area), and sediment truncations against the base of salt are better imaged (green arrows). Since RTM is a wave equation based migration, the increased trace count within an individual shot does not impact the RTM run time. Of course, an increase in the total number of shots will increase the overall cost.

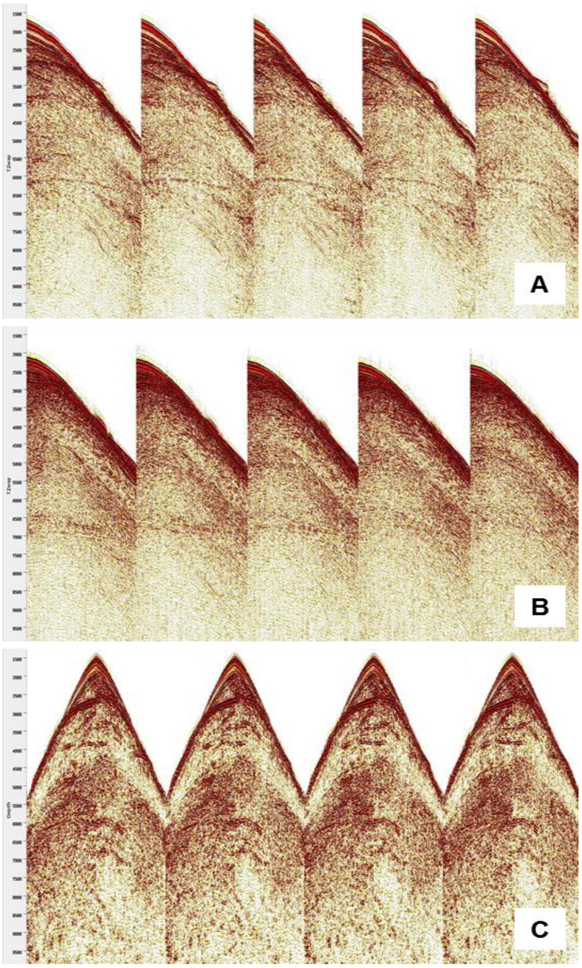

Figure 8: (A) Justice's shot. (B) Kepler's shot. (C) Merged two orthogonal WAZs shot by redatuming data regularization.

Conclusions

A 3D redatuming data regularization algorithm based on a CFP technique is presented. It has been successfully applied to merge two orthogonal WAZ surveys. The designed output can effectively utilize the full azimuth coverage from the original two orthogonal WAZ surveys. Better surface data coverage that results from this data regularization technique, compared to the coverage from each individual shot, also improves the RTM image.

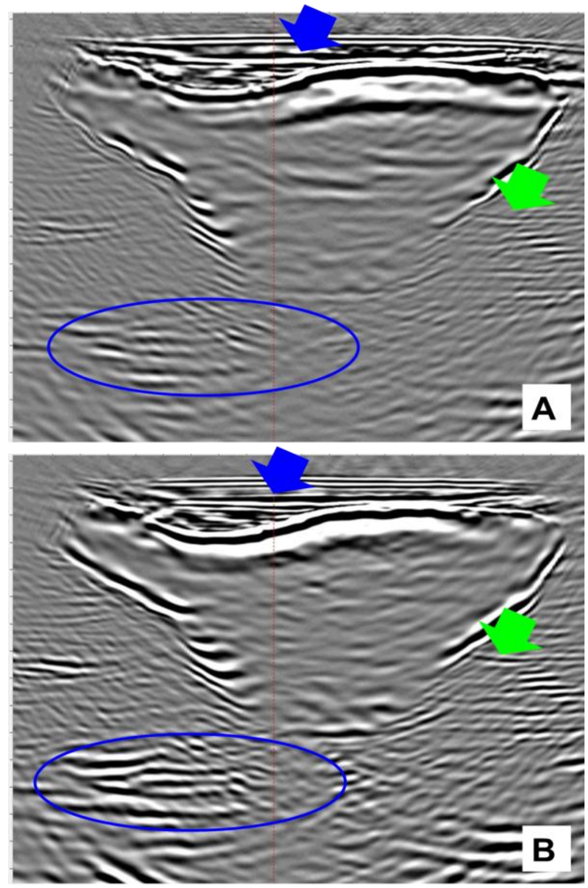

Figure 9: (A) The RTM image of summing Kepler and Justice surveys' RTM images. (B) The RTM image for redatuming data regularization input.

Acknowledgments

The authors would like to thank Bin Wang, Zhiming Li, Xuening Ma and Terry Hart for their discussion, advice and support during this project. We thank Roy Camp and Cristina Reta-Tang for their support and for the data and model preparation; and Laurie Geiger and Simon Baldock for proof-reading. We thank the management of TGS for permission to publish this paper.

EDITED REFERENCES

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