Improved quality for common focusing point data regularization

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Summary

The data driven 3D true azimuth Common Focusing Point (CFP) data regularization technique is a multi-dimensional data regularization tool. It can be used as a general tool to merge multiple surveys pre-stack, including, for example, orthogonal Wide Azimuth (WAZ) surveys, different Narrow Azimuth (NAZ) surveys, or a combination of the two. Some technical details that address how to improve output data quality, such as intermediate computation grid size and aperture, are discussed.

Introduction

Many new acquisition technologies have been developed to improve the subsurface image. One such example is provided by the Kepler and Justice orthogonal WAZ surveys acquired by TGS in the Gulf Mexico in 2010. These two orthogonal WAZ surveys provide an efficient way to obtain close to full azimuth data over an existing WAZ area; in turn giving a significant uplift in the subsalt image (Figure 1).

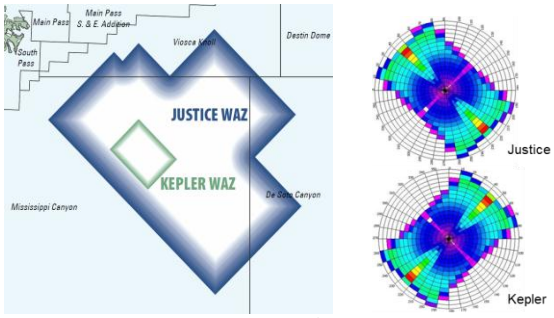

Figure 1: Map shows the location of the Justice and Kepler WAZ surveys on the left. The corresponding surface azimuth coverage is shown on the right.

For certain potential prospect areas, many surveys have been acquired over time, each with a different survey geometry. In cases like these, how to merge the different surveys before imaging becomes an important question.

One possible solution to pre-stack multi-survey merging is multi-dimensional data interpolation. 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), anti-leakage Fourier transform (Xu et al., 2005) and minimum weighted norm inversion (Liu and Sacchi, 2004).

Cai et al. (2011) proposed the CFP-based data driven redatuming data regularization approach; and used the merging of the two orthogonal WAZ surveys just described as an example to demonstrate the effectiveness of this technique. In this paper, we first review the basic idea of the CFP redatuming algorithm; then use orthogonal WAZ merging as an example to discuss some technical details that can impact the final output data quality. Finally, we will briefly show one application of this technique as a general data regularization tool to improve migration quality.

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 sources and receivers are located. It has been used as a tool to remove the near surface overburden imprint on seismic data (Berryhill, 1979, 1984; Shtivelman and Canning, 1988; Hindriks and Verschuur, 2001; Schneider, 1978; Alkhalifah and Bagaini, 2006).

The CFP technique was first 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 could be 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. To preserve the azimuth information for each of the receivers, we define the aperture as a rectangle whose long axis is parallel to the azimuth between the output source and receiver (red rectangle in Figure 2). Each receiver will have its own aperture definition. Each aperture is binned onto a calculation grid. For bins where there is more than one trace available, we choose the one that has the closest defined attribute (azimuth, inline, crossline, offset, etc. are used to calculate the desired attribute).

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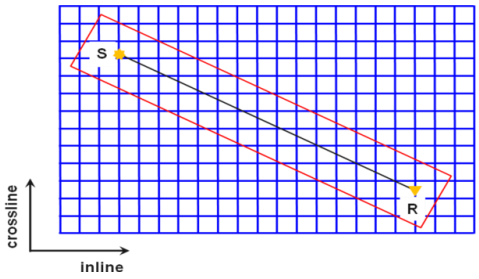

Figure 2: The aperture is defined differently for each receiver. For output source-receiver (S-R), the aperture is defined as the red rectangle. Then aperture is divided into calculation grids (blue) which are oriented along the inline and crossline directions.

The only external information the algorithm needs is the velocity model between the survey surface and redatuming subsurface. For marine surveys, if we define the redatuming subsurface in water, then the water RMS velocity can be used and the algorithm becomes almost a data driven approach.

The CFP data regularization in practice

First of all, the phase and amplitude of the different surveys to be merged needs to be matched. Next the data from all input surveys are used to build one contribution table, used for CFP data regularization. Then the data regularization step itself is performed. There are three main steps to CFP based redatuming data regularization:

1. Define the CFP focal point on a user defined redatuming surface. Define the output shot locations and their survey geometry.
2. Construct CFP shot gathers, with regularized shots on the redatuming surface at desired shot locations; while the regularized receivers for corresponding shots are located at the desired output locations on the surface.
3. 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.

Next, we will go over each of the steps and study the related technical and practical details.

The redatuming surface can be defined in either the upward or downward direction with respect to the acquisition surface. A benefit of the downward redatuming subsurface is that gaps in the acquisition at the surface are naturally healed by the downward wavefield continuation; in turn the input data condition for data regularization will be improved compared to the surface acquisition; which looses the algorithm implicit assumption. The redatuming depth is determined by two factors, the CFP operator shape and CFP aperture. Figure 3A shows that, for a small redatuming depth, the CFP operator is very steep, which, in turn, requires a finer surface survey sampling to prevent aliasing. Since we are constrained by the acquisition shot and receiver spacing, we have to redatum the data deeper than a certain depth. Figure 3B shows some possible surface trace locations for the case of a flat reflector at depth Z. The aperture is given by the source and receiver offset plus an additional variable *x:*

$$x = \frac{H}{2Z - H} offset$$

where H is the redatuming depth, Z is the flat reflector depth and *offset* is the shot and receiver distance. So for the same reflector, the deeper the redatuming depth (larger H), the bigger the aperture (x + *offset*) that will be needed – which, turn will require a greater computation time. The optimum redatuming depth is really a compromise between these two factors. After testing different redatuming depths, 150 m water depth was chosen for the Kepler and Justice merged surveys.

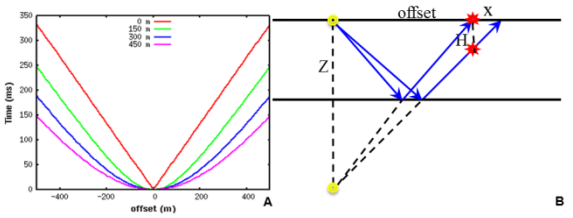

Figure 3: Diagram to show the redatuming depth determination. (A) The CFP operator kinematic with different redatuming depth. (B) CFP aperture definition related to redatuming depth.

When we redatum the surface data downward, the shot and receiver spacing need to be dense enough to adequately sample the downward wavefield propagation. Considering that the Kepler and Justice surveys are orthogonal, and have 150 m x 600 m and 600 m x 150 m shot intervals, respectively (Figure 4A), regularized shots were output at a 150 m x 150 m shot interval (Figure 4B). As a result the CFP data regularization outputs four times more data than the original combined input.

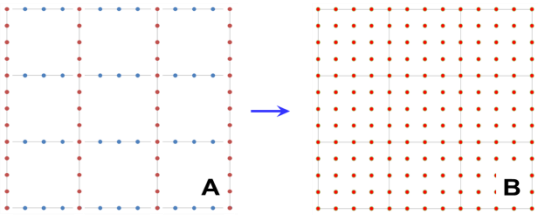

Figure 4: After shot regularization, the shot spacing changes from 150mx600m and 600mx150m (A) to 150mx150m shot spacing (B).

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The regularized receiver location for each shot is shown in Figure 5B. It is designed to sample the full azimuth information contained in the original orthogonal WAZ surveys (Figure 5A).

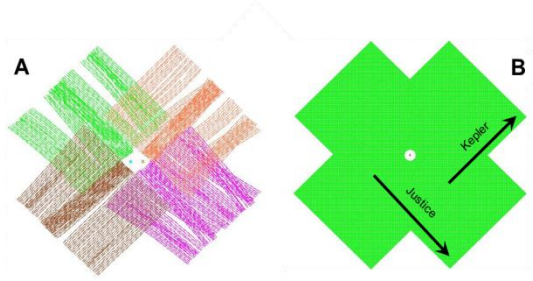

Figure 5: Shot geometry. (A) The supershots drawn in brown and orange are Kepler's supershot. The supershots drawn in green and magenta are Justice's supershot. (B) Merged Justice and Kepler's regularized shot.

The intermediate computation grid size becomes a critical parameter in order to avoid spatial aliasing of events. Figure 6 shows the CFP regularization output for different intermediate grid sizes. We can see in general, the finer the grid size, the less the aliasing (the aliasing is better seen in the blue circles). In addition, both CPU time and disk requirement are proportional to the number of intermediate grid (inversely proportional to the grid size).

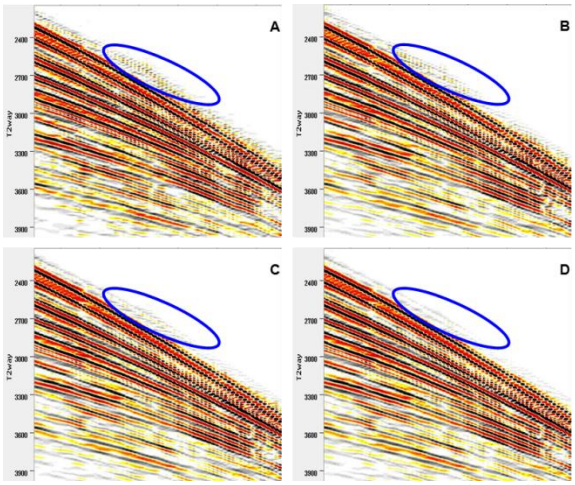

Figure 6: CFP redatuming data regularization for different intermediate receiver grid sizes: 17.5m (A); 15.0m (B); 12.5m(C); and 10.0m (D). Notice the aliasing noise within the blue circles.

Similar to migration algorithms and SRME, the aperture is a critical parameter to capture all the events for each shot-receiver pair. All the convolved traces within the aperture are 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 7). It is a useful tool for aperture definition.

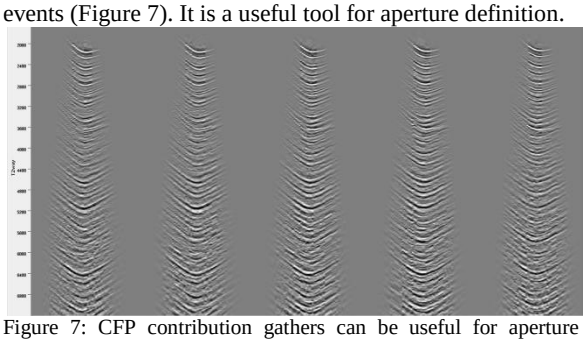

Figure 7: CFP contribution gathers can be useful for aperture definition.

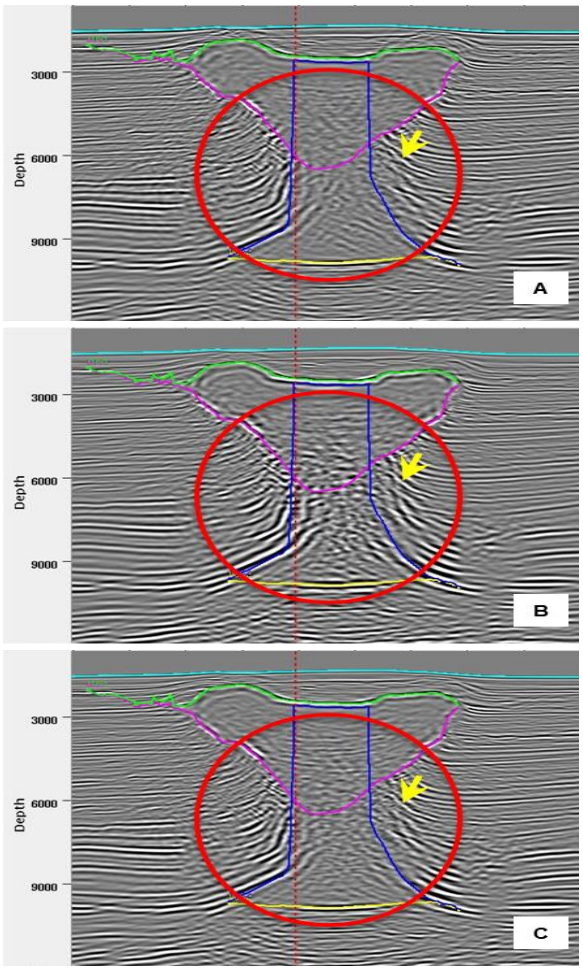

Figure 8: (A) The RTM image of weighted summing Kepler and Justice Surveys' RTM images. (B) The RTM image for redatuming data regularization input with large aperture. (C) The RTM image for redatuming data regularization input with small aperture.

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We found that a large aperture is particularly important in order to capture the steep-dip events. This conclusion is demonstrated by the RTM comparison in the following discussion.

Four RTM migrations are performed using exactly the same migration parameters. The only difference is the input data and some post-migration processing. Firstly, we migrated Kepler and Justice separately (input data shown in Figure 10A and Figure 10B). Figure 8A shows coherency weighted sum results for the Kepler and Justice RTM images. Two RTMs (Figure 8B and Figure 8C) were run for different CFP regularized data (input data shown in Figure 10C). The differences between the sets of input data are the intermediate grid size (12.5 m vs. 17.5 m) and aperture (Figure 8B used CFP data created with twice the aperture used for that in Figure 8C). Comparing these four RTM images, we can see that, due to the finer grid size, the migration illumination compensation introduces less migration swings for the CFP input RTM migration, than either the individual Kepler or Justice RTMs or the coherency weighted sum RTM result. In addition, the large aperture CFP shows better steeply dipping events (yellow arrows).

Figure 9 shows another comparison between the weighted sum RTM images (Figure 9A) and the RTM images from CFP input (Figure 9B). Both the CFP RTM images (Figure 8B and Figure 9B) suggest that further detailed work on the salt model could be justified.

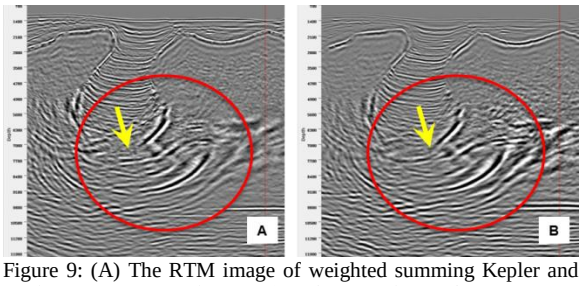

Figure 9: (A) The RTM image of weighted summing Kepler and Justice surveys' RTM images. (B) The RTM image for redatuming data regularization input. More complex salt model may be needed within the red circle area.

Conclusions

By merging surveys before imaging we can achieve a denser shot point spacing (from 150 m x 600 m and 600 m x 150 m shot intervals to a combined 150 m x 150 m shot interval), thus reducing the data aliasing before migration. By combining two WAZs (or any multiple surveys) into a single survey with richer azimuth coverage, we are able to provide a unique and improved subsurface image, rather than separate migrated images for each survey.

A finer intermediate grid size is needed to avoid aliasing. A large aperture improves the imaging of steeply dipping events. Finally, the CFP migrated image creates the possibility for a more detailed salt geometry definition.

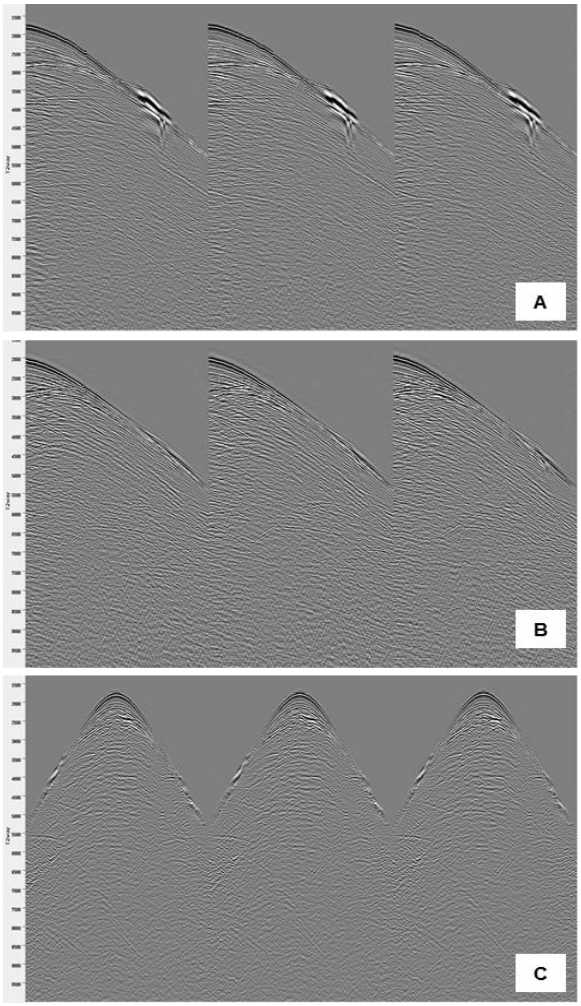

Figure 10: (A) Justice's shot. (B) Kepler's shot. (C) Merge of two orthogonal WAZ shots by redatuming data regularization.

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