Reducing subsalt velocity uncertainties using common offset RTM gathers (COR)

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Summary

Historically, deriving reliable velocity updates in subsalt regions has been problematic. Poor ray coverage below the strong salt/sediment velocity contrast leads to low signal-to-noise ratios in the offset gathers when using Kirchhoff imaging algorithms.

RTM imaging algorithms better handle the problems with illumination; however, generating useable gathers from RTM migrations has not been without its own set of challenges.

Several methods of using the RTM engine to derive subsalt velocity updates have been utilized. These methods include generation of RTM angles gathers, RTM image offset gathers and DIT scans. While these approaches often yield better updates than using Kirchhoff gathers, they have some drawbacks.

In this study we show that generation of Common Offset RTM gathers (COR gathers) addresses many of the issues encountered when using the above methods. We also demonstrate that the improved velocity model resulting when using these gathers to drive tomographic updates can better tie well velocities, and improve subsalt event continuity.

If implemented with some pragmatic parameter choices, Common Offset RTM gathers can also be cost effective.

Introduction

The study dataset for this paper is a subset of the Freedom WAZ survey located in the central Gulf of Mexico. The sediment velocities were derived using TTI Kirchhoff gathers to drive tomographic updates. Tomographic inversion has proven to be a stable and cost effective method for estimating the velocity model used in depth migration. When depth variations can be reliably measured across offsets in a migrated gather, quite high resolution models can be realized (Hilburn et al. 2014).

Tomography depends on accuracy in measuring the residual displacement along an event across an offset in a common image point (CIP) gather. In areas of poor signal, uncertainty in the depth residuals can lead to non-optimal inversion results.

Standard tomography uses PSDM Kirchhoff gathers to estimate this displacement, but Kirchhoff gathers suffer from poor ray illumination in the subsalt regions below the complex salt bodies that are commonly found in the Gulf of Mexico.

The poor ray coverage below the salt/sediment velocity contrast leads to low signal-to-noise ratios in the resulting offset gathers when using ray-based imaging algorithms.

RTM imaging algorithms better handle the problems with illumination; however, there have been complications in generating gathers suitable for tomography. Deriving the receiver propagation direction needed for the formation of RTM angle gathers is one of the main challenges. Some methods for addressing these problems have been proposed (Yoon et al. 2011), but the resulting angle gathers still tend to be somewhat noisy. Additionally, due to the limited angles that are sampled below the strong velocity contrast, it is often difficult to form enough angle traces to confidently estimate a residual moveout trend.

Other attempts to use the RTM engine for subsalt velocity estimation have been made. The DIT scanning technique (Wang et al. 2008) cross-correlates the source and receiver wavefields with different delay times to efficiently model velocity scans. While this method has been used to generate a better velocity model, this method tends to lack both spatial and temporal resolution.

The formation of RTM image offset gathers is another method of obtaining offset gathers from RTM shot migrations. In this method, the common shots are migrated and sorted into cdp and offset postmigration. Computationally this is a very efficient method of generating gathers. However, since each shot is migrated and output separately, moveout information as well as noise (head waves) gets mixed across offsets. This mixing across offset tends to make gather continuity and moveout estimation somewhat problematic.

Migration of segregated limited common offset shots, and forming offset gathers from these shots addresses most of the issues above. If implemented with care, Common Offset RTM (COR) gathers can be an efficient method of generating gathers for use in measuring the residual moveout needed for a reliable tomographic update.

Method

Conceptually it is straightforward to generate common offset RTM gathers.

Shot gathers are split into N minishot gathers each with a limited offset range. The number N would control the number of offset traces generated after migration (ie: N = fold of the gathers to be output). Each of the N minishots would be migrated separately. As in normal RTM migration, after imaging step, all of the minishots with the same offset range would be stacked together into common inline/xline bins and assigned an offset equal to the average offset of the input traces for the minishot. Following this procedure would produce a single common offset volume.

All of the resultant common offset volumes would then be sorted to common inline/xline/offset gathers to generate the final COR gathers that could then be used to derive a tomographic update.

The cost of an RTM run is directly proportional to the number of shots migrated so, at first glance this might seem like a very compute intensive method to generate gathers to feed into tomography. To generate a 30 fold gather, the cost would be 30 times a normal RTM iteration. Such a cost increase would probably beyond what could be tolerated for a typical project.

Fortunately, several operational and algorithmic efficiencies can be realized.

Since all of the minishots generated from one input shot have the same source location, code modifications could be made to reuse the forward propagated source wavefield when crosscorrelating with the receiver wavefield. This would have a throughput savings on the order of 3 fold.

As stated above, Kirchhoff gathers are generally quite suitable for suprasalt sediment velocity model building, COR gathers would only be necessary in the more complex subsalt areas of the model.

Since in the subsalt region high frequencies typically do not survive transmission through the fast salt layer, and high frequencies are not needed to define the residual displacement of events along the offset, RTM migration for the subsalt tomography purposes can be run with quite a low frequency specification.

Having lower frequency requirements can dramatically reduce the runtime for RTM migrations. Lower frequency images can be computed much more quickly since the internal propagation grids can be made to be much coarser. In general the cost of an RTM migration increases with the 4^{th} power of frequency, so the ability to limit the frequency is a major factor that make COR gathers computationally feasible.

Finally, for the subsalt events, angular sampling is quite limited. To describe a residual curvature in most instances would not require a significant number of offsets (but it would be important to sample the farthest offset). For this study only twenty offset traces were generated that spanned the entire 8 km cable length.

Data Examples

Proof of concept tests of this methodology were run using a synthetic dataset from the Sigsbee modeling effort. After verification that improved S/N ratios could be achieved with COR gathers (as compared to Kirchhoff gathers), and that residual curvature was in agreement with the input model, a field dataset from a Gulf of Mexico WAZ dataset was run.

Figure 1 shows the subsalt image gathers generated via three different methods. Kirchhoff migration was used to generate the gathers shown in Figure 1a. These gathers are quite noisy and for most of the events close to the base of salt it would be difficult to use in defining a residual moveout trend. The gathers in Figure 1b show the RTM image-offset gathers. While these gathers do have more coherent events, the moveout trend is somewhat difficult to define, especially when compared to the COR gathers in Figure 1c. Visually it can be seen that the residual moveout trend is much better defined in the COR gathers and the residual moveout seems to be more stable.

To test the potential uplift of using the COR gathers for a subsalt velocity update, both the image offset gathers and the COR gathers were used to derive a tomographic velocity update.

Figure 2 below shows the result of this work. Figure 2a shows a line with a tomography update using the image offset gathers. Figure 2b shows the line after the COR tomography update.

The COR updated image shows much improved reflector continuity and better overall coherency.

Figure 2c shows the velocity model for this line using the image offset gathers. Figure 2d shows the velocity profile after COR tomography.

The striking feature that can be seen in this profile is the dramatic slowdown of the velocities just below the salt when using the COR gathers for the update. It is not uncommon to find subsalt sonic logs that exhibit similar behavior. While image offset tomography did slow down the velocities in this region, the resultant slowdown was much smaller magnitude.
Part of the study area includes a sonic log that begins inside the salt and also samples the subsalt velocities.

Reducing subsalt velocity uncertainties using COR gathers

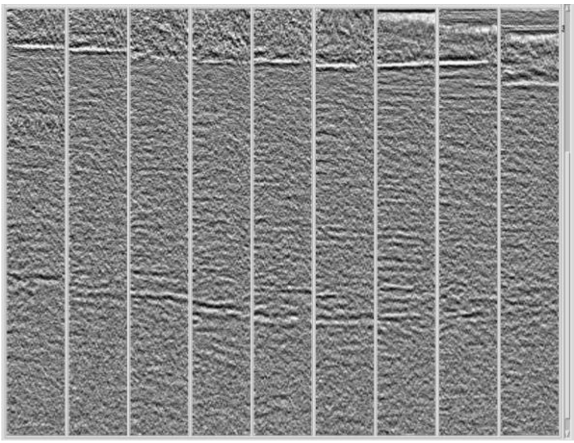

Figure 1a: Subsalt Kirchhoff gathers

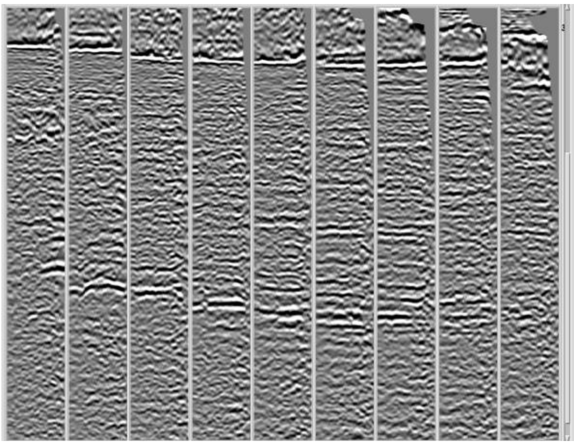

Figure 1b: Subsalt image offset gathers

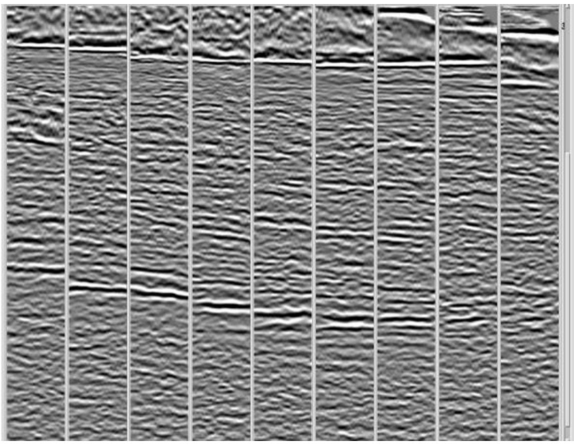

Figure 1c: Subsalt COR gathers

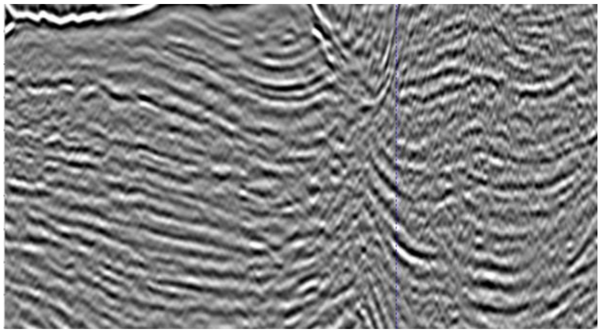

Figure 2a: Subsalt section before COR tomography

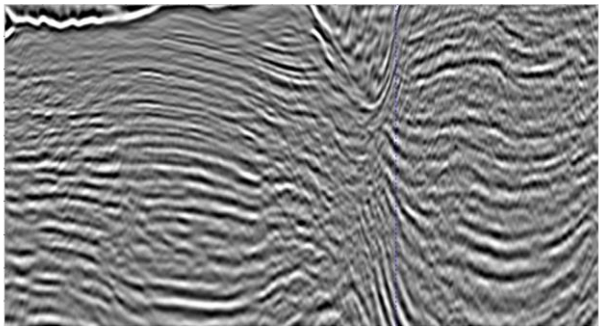

Figure 2b: Subsalt section after COR tomography

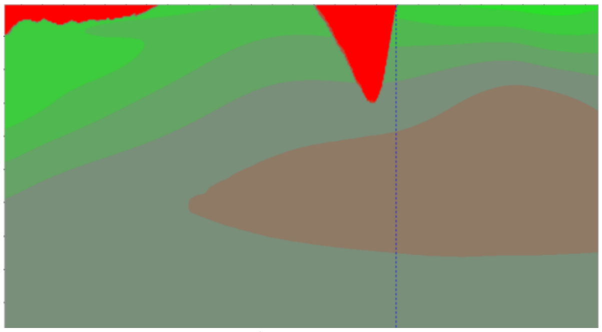

Figure 2c: Velocity model before COR tomography

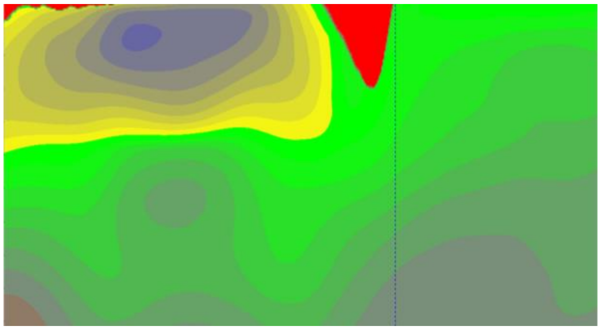

Figure 2d: Velocity model after COR tomography. Notice dramatic slowdown of velociteis in subsalt region.

Figure 4 show a comparison of the velocity field and the sonic log. The figure on the left is a plot of the starting velocity field. Just below the salt the seismic velocities were on the order of 3200 m/s. The sonic log in this area had a much slower trend that was around 2550 m/s. To match the sonic log , the tomographic inversion would need to reduce the velocities by about 20%. Standard tomography using the image offset gathers did drive the velocities slower, but only to around 3000 m/s.

COR tomography was better able to estimate the residual moveout which led to a much larger reduction in the seismic velocities. Indeed after COR tomography the velocities were reduced to around 2600 m/s and was a much better match to the sonic log.

Conclusions

Common Offset RTM gathers (COR) used along with existing tomographic inversion schemes can yield much improved sub-salt velocity resolution when compared to RTM image offset gathers. With some code modifications

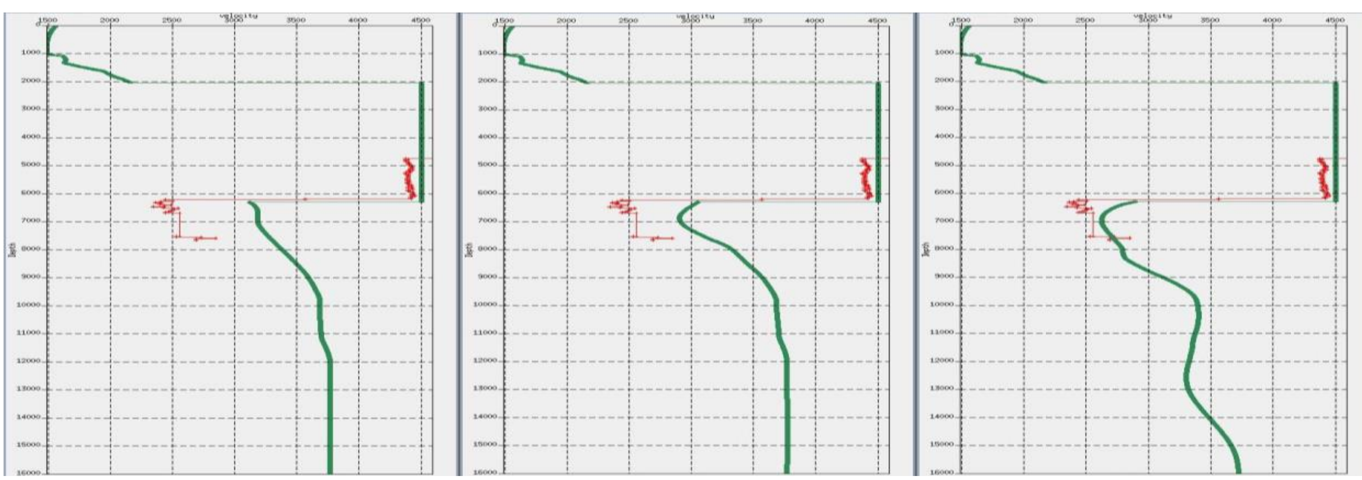

Figure 4: Green curve shows seismic velocity models. Red cure shows velocities from a sonic log. Left hand side: before tomographic update. Middle: tomographic update with image offset gather. Right: COR tomography

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