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# Reduction of depth uncertainties using common offset RTM (COR) Gathers

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## Summary

Subsalt velocity estimation has presented significant challenges in the past. Ray based methods suffer from poor S/N ratios that results from sparse ray coverage beneath salt bodies. The use of common offset RTM gathers (COR) has been shown to decrease uncertainties in subsalt residual moveout estimation, which can more reliably be used by tomographic algorithms to invert for more accurate velocity estimations.  Furthermore COR gathers have been shown to improve salt velocity estimations in areas with sediment inclusions.  Better ties to well information (sonic logs, formation markers) have validated the improved resultant velocity models.

## Introduction

Generation of reliable velocity updates below salt has traditionally been a challenging task. Prestack Kirchhoff depth migration (or other ray based algorithms) have most commonly been used to produce CIP gathers used for tomographic inversion. The large velocity gradient between the salt and sediment interface tends to yield sparse ray coverage in subsalt regions. The CIP gathers produced in these areas show quite a substantial decrease in signal/noise ratio when compared to sediment areas not influenced by salt.

The poor signal in the CIP gathers in the subsalt results in unreliable residual moveout estimates. The quality of a tomographic update is strongly dependant upon a quality of the residual moveout measurements that are input into the inversion algorithm. Hence the poor S/N in the subsalt regions results in significant uncertainties in the inverted subsalt velocity model

Signal degradation below salt in the final migrated image has similarly provided challenges for structural interpretation of the final stack images in Kirchhoff migrations. This challenge has driven the adoption of multi-arrival wavefield methods to improve the structural interpretability in these regions. RTM algorithms in particular have become the standard imaging tool in areas with strong velocity contrasts. Hence it would seem pragmatic to attempt to make use of RTM for velocity model updating in areas of poor ray illumination.

Leveraging wavefield methods for use in velocity updating has presented their own challenges. Different approaches to using the RTM engine to derive subsalt velocity updates have been implemented. Among these methods are: the generation of RTM angles gathers (Yoon 2011), generation of RTM image offset gathers, as well as velocity scanning simulations such as DIT scans (Wang 2008). While these methods often result in better updates than using Kirchhoff gathers, they present a different set of challenges.

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. Furthermore COR gathers, in conjunction with a structurally constrained tomography, such as IG Tomography (Hilburn 2014), can be used to invert for “dirty salt” updates.

At first glance, generation of COR gathers can be compute intensive, however with some code modification, as well as practical parameter choices, COR gathers can be quite cost effective.

## Method

The generation of common offset RTM gathers (COR) is conceptually straightforward.

Shot gathers are subdivided into N shots of limited and non-overlapping offset ranges. The number N would control the number of offset traces generated for a CIP gather after migration. Each of the N sub-shots would be migrated separately. As in normal RTM migration, after imaging step, all of the sub-shots 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 sub-shot. Migration of all the shots in the survey with this limited offset range would result in a common offset stack volume.

This procedure would be repeated for each of the N limited offset ranges. The resultant common offset volumes could 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.

RTM runtime is directly proportional to the number of shots to be migrated. At first glance it would appear to be a very compute intensive method to generate gathers for use in deriving a tomographic velocity update. Generating a 30-fold gather would cost 30 times a normal RTM iteration. Such a cost increase would probably not be feasible for a typical project.

However, there are some operational efficiencies, as well as some algorithmic modifications that can be leveraged.

Since all of the sub-shots generated from the same input shot have the same source location, code modifications could be made to reuse the forward propagated source wavefield. Only the receiver wavefield for each sub-shot would have to be recalculated before cross-correlation with the source wavefield.

In sediment areas without strong velocity gradients, Kirchhoff gathers are generally quite suitable for velocity model building. COR gathers would only be necessary in the more complex subsalt areas of the dataset.

Perhaps most importantly, high frequencies would typically not be required for establishing a residual moveout trend that is used to drive a tomographic update. Furthermore, since in the subsalt region high frequencies typically do not penetrate beneath salt bodies due to scattering and transmission losses, high frequencies are not required for sub-salt imaging.

The ability to specify a lower maximum frequency in the RTM migration will lead to dramatically decreased runtimes. 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 4th power of frequency, so the ability to limit the maximum frequency is a major factor that makes COR gathers computationally feasible.

Finally, for the subsalt gathers, angular sampling is quite limited, due to the strong velocity gradients at the salt interface. To adequately describe the sub-salt residual curvature in most instances would not require a significant number of offsets (it would be important to sample the gathers out to the farthest offset). For this study only twenty offset traces were generated to span the 8km maximum offset from the input shots.

## Examples

Figure 1 below demonstrates the problem encountered with Kirchhoff gather below salt. Figure 1a is a typical Kirchhoff PSDM image. The upper left hand side shows a typical salt feature found in the Gulf of Mexico. The yellow arrow in this figure identifies the location of the gathers shown to the right. The PSDM offset gathers that result from a ray based Kirchhoff algorithm are shown in Figure 1b. Signal/Noise ratio is quite low and it would be difficult to establish a residual moveout trend from this data. With some noise removal techniques, it might be possible to recover enough signal to make some residual curvature estimates, but the resultant tomographic update would be questionable. Figure 1c shows the COR gathers output for the same area as Figure 1b. The S/N improvement in these gathers is quite significant. Moveout trends from these COR gathers are much easier to establish without additional clean up. The improved signal here should lead to less uncertainty in the tomographic velocity update derived from these gathers.

Indeed much more reliable subsalt updates have been derived from using the COR gathers. Figure 2 compares the velocity updates obtained with Kirchhoff gathers with those obtained from COR gathers. In Figure 2a the velocity field is co-rendered with the RTM image obtained with this velocity field. The color scale used goes from cool to warm as the velocity increases from slow to fast, respectively

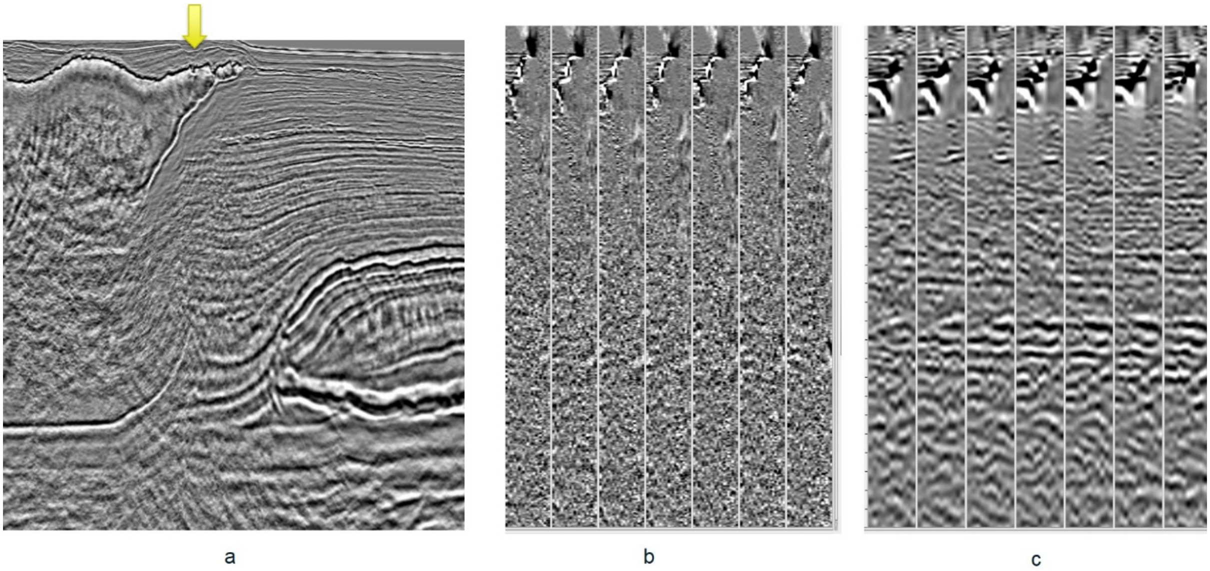

*__Figure 1__ a) PSDM Stack image b) CIP gathers generated from Kirchhoff PSDM c) CIP gathers generated from COR*

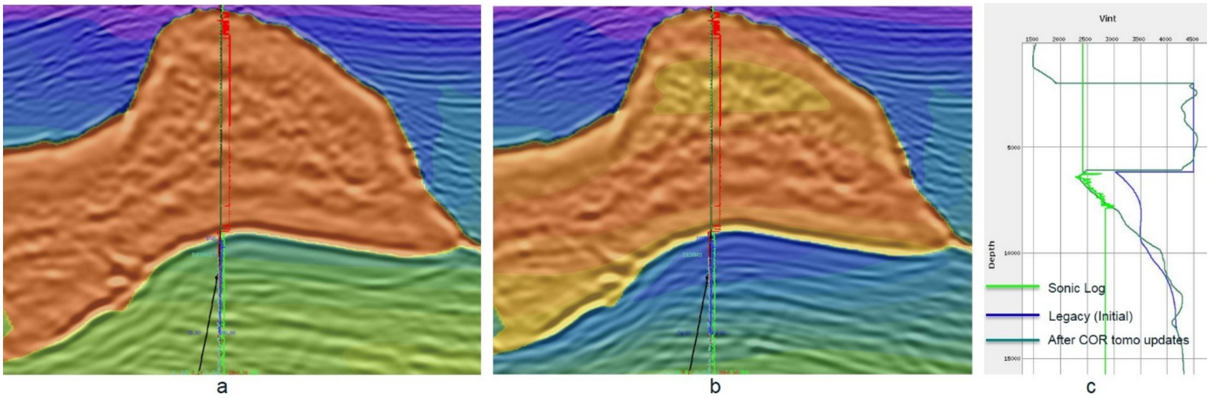

*__Figure 2__ a) RTM Stack image with initial velocity model overlaid b) RTM stack image with COR tomo updated velocity model overlaid, including dirty salt updates c) Velocity profiles of starting model, COR tomo update, and sonic log*

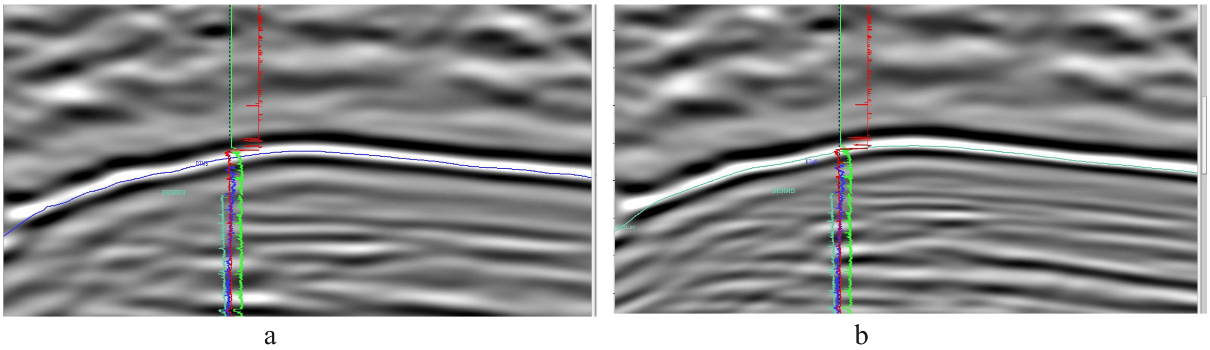

*__Figure 3__ a) Gamma Ray and Resistivity overlaid on seismic before COR tomo update b) Gamma Ray and Resistivity overlaid on seismic after COR tomo update*

Figure 2b shows the velocity update obtained from tomographic inversion using COR gathers. The resultant velocity is co-rendered with the RTM image obtained with this velocity field. The first thing to note is the dramatic slowdown in the velocities directly below salt. Overpressure is known to be characteristic of many sub-salt regimes (O'Brien 1994), so it might be geologically plausible to expect such a slowdown of the velocities coming out of salt. Also of note in this figure is that the salt velocity is no longer homogenous. The COR gathers used not only derived a subsalt update, but a velocity update within the salt. "Dirty salt", or areas of sediment inclusion are not uncommon in this area of the Gulf of Mexico. Figure 2c compares the two velocity fields with the sonic log from on the few subsalt wells in the area. The light green curve is the sonic velocity; the dark blue curve is the starting velocity. The dark green curve is the velocity field after the COR tomo update. There is much better agreement between the sonic and the COR update which gives additional validity to the update obtained. Finally, Figure 3 is a zoomed in look at the images in Figure 2. The curves shown here are the gamma ray and resistivity. The dirty subsalt update is validated by the better depth tie of the well data to the seismic at the base of salt reflector. The large kick in the gamma and resistivity logs correlate better to the depth of the base salt after the intra-salt velocity updates.

## Conclusions

Subsalt velocity estimation has presented significant challenges in the past. Ray based methods suffer from poor S/N ratios that results from sparse ray coverage beneath salt bodies. The use of common offset RTM gathers (COR) has been shown to decrease uncertainties in subsalt residual moveout estimation, which can more reliably be used by tomographic algorithms to invert for more accurate velocity estimations. Furthermore COR gathers have been shown to improve salt velocity estimations in areas with sediment inclusions. Better ties to well information (sonic logs, formation markers) have validated the improved resultant velocity models.

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