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Reverse Time Migration of Multiples with OBN Data

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SUMMARY

Reverse Time Migration of Multiples (RTMM) was adapted for OBN data. Using synthetic and field data examples from deep water Gulf of Mexico, we demonstrate the benefits of OBN RTMM, which include image extension, better top of salt imaging, and better illumination of subsalt areas.

Introduction

Recorded seismic data contain both primary and multiples. Both carry subsurface information, but multiples have one or more extra bounces at the water surface or in the subsurface. Traditional migrations use the primaries to form an image of the reflectors, whereas multiples in the input can create noise or even false images. However, because multiples may provide additional information, they might also be used to image the subsurface reflectors. Wave-equation migration algorithms, such as reverse time migration (RTM) and one-way wave-equation migration, can be extended to use multiples alongside primary signal.

Our multiple migration method uses a pseudo-surface source, which is the primary signal recorded at all receivers. Illumination comes from all of the receivers instead of the single source point used in the primary migration. With this change, multiple migration can provide denser subsurface sampling, a wider illumination angle range, and greater near angle illumination. Using the multiple wavefield for imaging improves illumination (Berkhout and Verschuur 1994; Liu *et al*. 2010; Lu *et al*. 2011). The reverse time migration of multiples (RTMM) algorithm can provide a better water bottom image for shallow-water streamer data because of its increased near-angle illumination power below the critical angle (Yang *et al*. 2013). When applied to a wide azimuth (WAZ) data set in deep water Gulf of Mexico (GoM), RTMM proved it can deliver a better image at some poorly-illuminated subsalt areas once the cross-talk noise from the different orders of multiples is attenuated (Yang *et al*. 2013).

However, the illumination benefit of the multiples can be limited in conventional streamer data (WAZ or narrow azimuth) for two reasons. First, without full azimuth (FAZ) coverage and large offset recording, the multiples' pseudo-surface source may not be fully recorded. Second, when viewing the surface coverage of an entire WAZ or NAZ survey, the shots are usually densely spaced and cover the entire survey area. Although the illumination effect of the multiple wavefield can be significant for a swath of streamer data, the effect on the entire survey is limited. On the other hand, ocean bottom node (OBN) acquisitions use a FAZ configuration that has a very large shot coverage and a very small receiver coverage. Therefore, the illumination effect of the multiple wavefield on OBN data can be significant.

In recent years, using OBN data for imaging complex structures (e.g., subsalt imaging in GoM) have gained popularity because this acquisition configuration provides richer low frequency data, longer offsets, higher signal-to-noise ratios, and FAZ coverage. OBN data are also ideal for time-lapse monitoring of producing reservoirs because of the excellent repeatability of source and receiver positions (Boelle, 2012). However, because of the high acquisition cost of OBN surveys, the receiver nodes are usually sparsely placed on the sea floor and cover only a small area. As a result, the image provided by OBN primary reflection data is often limited to the small area covered by the nodes. In this case, applying migrations of multiples to OBN data may extend the value of OBN data by exploiting the increased illumination power of the multiple wavefield.

Using synthetic and field data examples, we demonstrate the benefits of OBN RTMM, which include image extension, better top of salt imaging, and better illumination of subsalt areas.

RTMM with OBN geometry

Adapting RTMM to OBN geometry is fairly straightforward. Figure 1 illustrates the OBN down-going wavefield primary migration and RTMM. OBN migration is usually performed in the common receiver domain. In OBN down-going mirror RTM, the source wavelet is forward propagated from the mirrored source location, and down-going primaries are backward propagated from all receivers' locations at the free surface to form an image. In the case of migrating multiples in the OBN down-going wavefield, we forward propagate the recorded down-going primary wavefield from all the receiver locations at the free surface and backward propagate the recorded multiple wavefield from all the receiver locations at the same free surface. Applying the imaging condition to both forward and backward wavefields correctly images subsurface reflectors. Similarly in RTMM, we assume that no further downward reflections happen during the wave propagation. Therefore, only forward propagated down-going primary and backward propagated down-going first order multiples can create the correct image. With full azimuth coverage and a large fold, OBN data not only records a more complete multiple wavefield at the surface, which is ideal for multiple migration, but it also provides a strong stacking power to suppress the cross-talk noise.

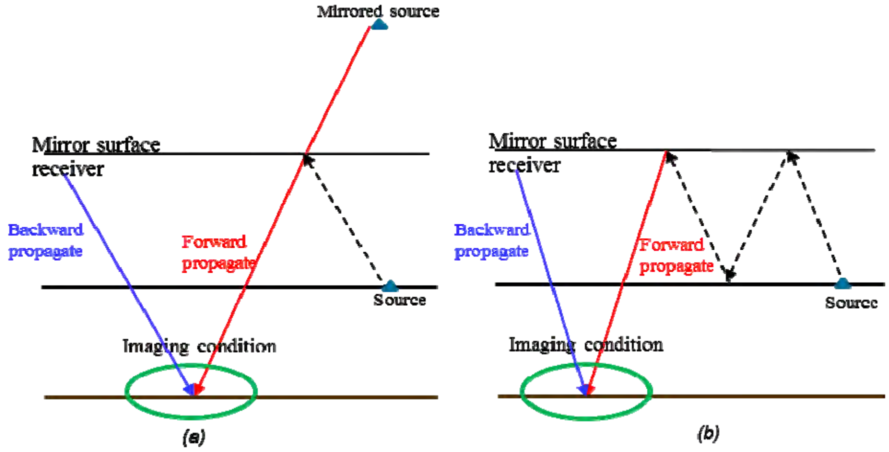

Figure 1 *(a) Ocean bottom node (OBN) down-going mirror reverse time migration (RTM). (b) OBN down-going reverse time migration of multiples (RTMM).*

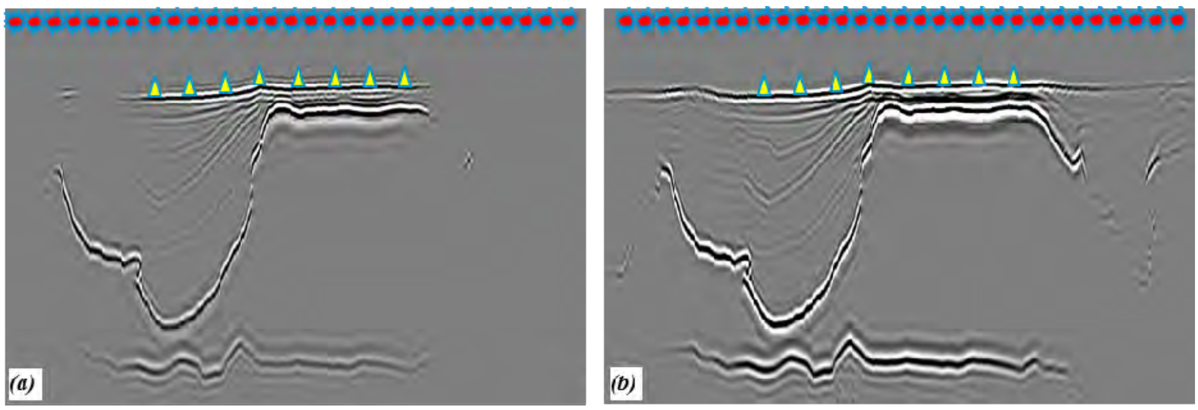

Figure 2 *Synthetic example: (a) Down-going mirror RTM. (b) Down-going RTMM.*

The comparison in Figure 1 shows the image location of RTMM is farther away from the source location, indicating that RTMM can extend the imaging area beyond that of RTM. Also, the reflection angle of RTMM is smaller than RTM, suggesting that RTMM can provide a smaller angle sampling as well as denser subsurface sampling.

Figure 2 compares OBN down-going RTM and OBN down-going RTMM from a 2D synthetic data set. OBN RTMM can extend the image to the shot coverage area, providing a wider illumination area.

RTMM field data example

We applied RTMM on an OBN field data set from the GoM. This OBN survey was acquired in a deep water area with a water depth of approximately 2 km. We used the down-going data after wavefield separation as the input data for migration. At the shallow depth slice (Figure 3), down-going mirror RTM only imaged the subsurface area beneath the node coverage (highlighted by the yellow circle), while RTMM significantly extended the imaging area outward. The RTMM image area was close to the shot coverage that has the same size as the entire output area. Figure 4 shows the inline view comparison between OBN down-going RTM and down-going RTMM. Besides the image extension from shallow depths to subsalt areas at both ends, down-going RTMM also provided a better image of the shallow, rugose top of salt in the highlighted area. This can help define a more accurate salt model.

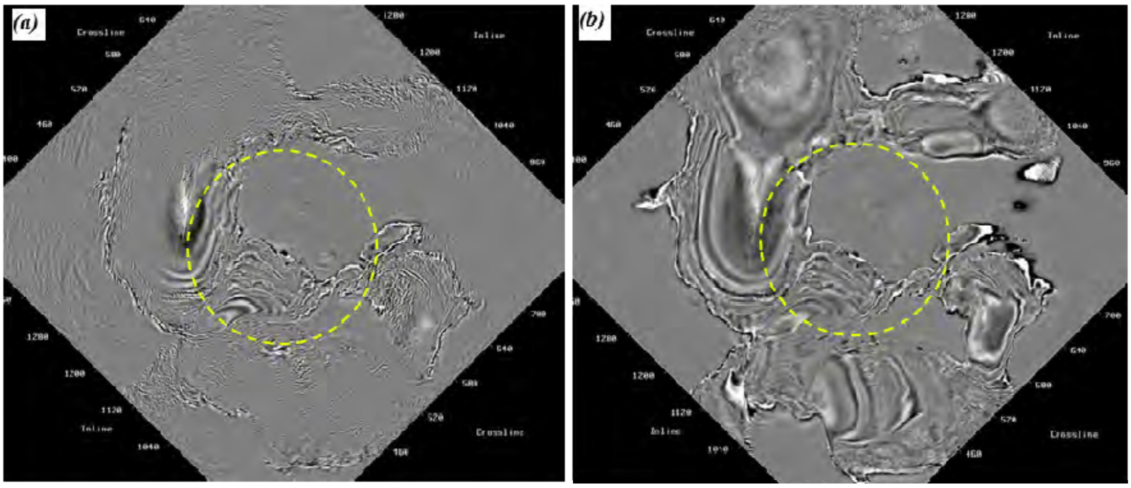

Figure 3 *Depth Slice: (a) Down-going mirror RTM. (b) Down-going RTMM.*

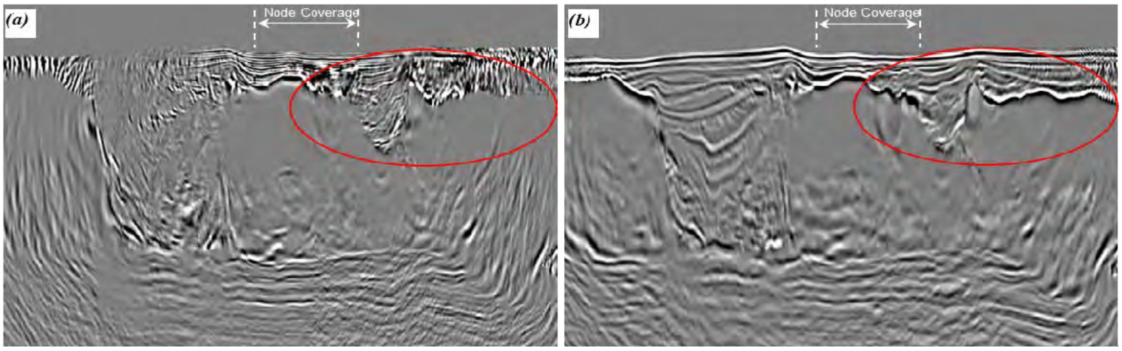

Figure 4 *Inline view: (a) Down-going mirror RTM. (b) Down-going RTMM.*

RTMM for salt model building

Defining a correct salt model is still the most critical element in subsalt imaging—even when full azimuth and long offset data are available. Due to the high velocity of salt, any small changes on the salt model can have a big impact on the subsalt image. When the salt geometry is complex, the base of salt image can be poor because of the lack of illumination. Salt interpretation in such areas is very difficult and often requires many iterations of trial and error to reach a better salt model. With improved illumination and denser subsurface sampling from the multiple wavefield, OBN RTMM can be used as a complementary image to aid salt interpretation during salt model building.

Figure 5 compares salt flood images (inline and crossline views) of OBN down-going RTM, OBN down-going RTMM, and WAZ RTM. Within the red circle, OBN RTM and RTMM provided a better image of the base of salt than WAZ RTM, which is mainly because of the FAZ illumination of OBN data. Compared to OBN RTM, OBN RTMM provided better base of salt images at the areas indicated by the blue arrows and extended the base of salt image beyond the node coverage area (highlighted by the blue circle). Therefore, RTMM can improve the value of full azimuth OBN data for salt model building. The improvements on the base of salt interpretation from OBN RTMM lead to a better salt model and potentially an improved subsalt image when compared to interpretations based on WAZ RTM and/or OBN RTM.

Conclusions and Discussion

We demonstrated that OBN RTMM can provide wider and denser subsurface illumination compared to OBN RTM; this is beneficial for seismic imaging and salt model building. Applying RTMM can help extract additional value from OBN data, thereby improving its return on investment.

Cross-talk noise is still a problem for RTMM. For deep water data, cross-talk noise can be partially attenuated by muting different orders of multiples from the input. However, this is particularly challenging in shallow-water environments. A potential solution for attenuating cross-talk is least-squares RTMM (Wong *et al*. 2014). Although OBN data provides a much higher fold and thus a stronger stacking power than WAZ data, attenuating cross-talk in RTMM remains a difficult task.

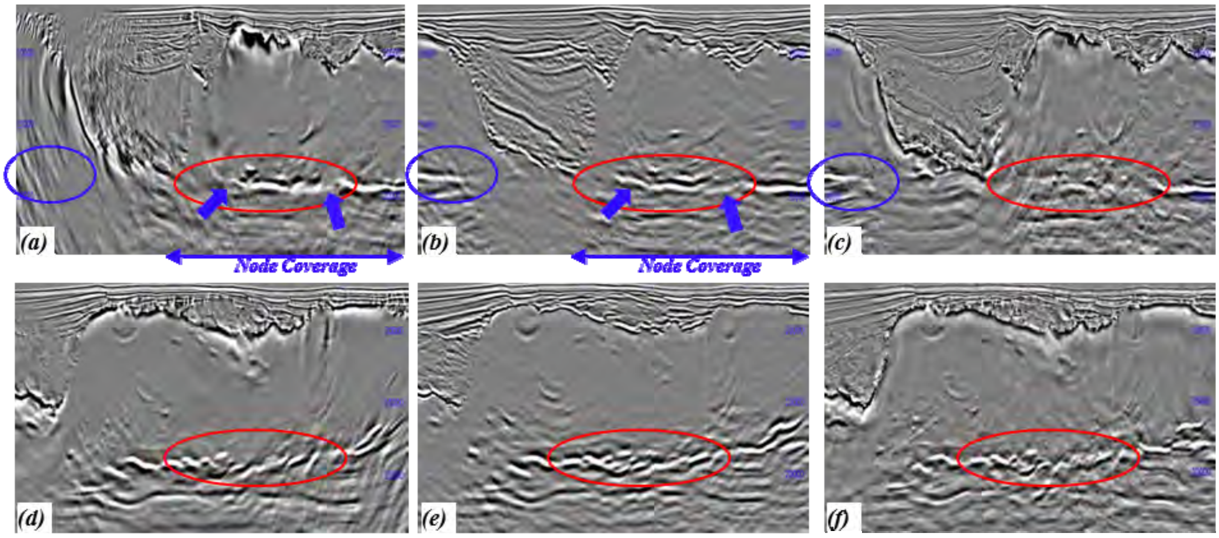

Figure 5 *Salt flood inline view: (a) OBN down-going RTM. (b) OBN RTMM. (c) Wide azimuth (WAZ) RTM. Salt flood crossline view: (d) OBN down-going RTM. (e) OBN RTMM. (f) WAZ RTM.*

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