Prestack and poststack wave-equation based demultiple: a case study of its impact on subsalt interpretation

Gregg Barker, August Lau, Apache; Jian Mao, Dhananjay Tiwari and Satyakee Sen, TGS*

Summary

In depth migration for marine seismic data, the water-layer related multiples will cause severe artifacts in migration images, sometimes misguiding interpretation. For a deep-water case, we always use surface related multiple elimination (SRME) to suppress the multiples. In recent years, the shallow water multiple elimination (SWME) method is also developed for tackling multiples where the water bottom is relatively shallow (<100m). Furthermore, poststack wave-equation based multiple prediction and subtraction methodology can be utilized to remove residual multiples. In this study, we applied SWME on the original shot gathers followed by the depth migration, using the demultipled data for input. After stacking, we also applied the wave-equation based poststack multiple prediction and subtraction on the stacked image. Comparing the results before and after multiple removals, we can see dramatic improvement in the subsalt area.

Introduction

One of the major challenges for subsalt imaging in the Gulf of Mexico is the poor signal-to-noise ratio and the lack of signal content in the lower frequencies. For deeper prospecting, the application of sophisticated demultiple techniques is thus very important as the signal to noise ratio in subsalt areas is inherently poor. It is crucial that the primary seismic signal is well preserved and relatively free from interfering multiples so that subtle subsalt geologic information can be properly imaged. In this case study, we have used Shallow water multiple elimination (SWME) in the prestack domain, followed by a wave equation based post-stack demultiple with the end goal of trying to improve the quality and reliability of the migrated image in a subsalt prospect area for the interpreter. We will show that the improved quality of the image leads to significant improvements in the interpretation process for the subsalt prospect. In the following sections we first give a brief description of the demultiple workflow that was used and then we show the resulting improvements in the interpretation of the subsalt prospect that was achieved.

Prestack SWME

Data-driven surface-related multiple elimination (SRME) method proposed by Berkhout et al. (1997), along with its 3D implementation (Moore et al., 2004) has been widely used in seismic processing to suppress surface related multiples. However, conventional SRME (2D as well as 3D) has severe difficulties in dealing with a shallow water environment due to the short period nature of the water bottom multiples. For such shallow water environments, in deeper areas the problem with the multiple model is even more severe. This leads to poor attenuation of water-bottom related multiples, which in turn leads to difficulty in interpreting subsalt prospects with a high degree of confidence. In recent years, model-based methods have been proposed to handle such shallow water situations (Wang, et al., 2011). TGS showed that such a model-based method combined with conventional SRME can be used as an effective tool to attenuate multiples in broadband data (Zhai et al., 2015). The proposed shallow-water multiple-elimination (SWME) approach predicts the multiple model accurately by using a broadband wavelet for the Green's function of the water-bottom and enforces adequate aperture control on the Green's function as well. Such aperture control (based on the critical angle of the water bottom reflection) is key to obtain a clean and artefacts free multiple model by reducing contributions from spurious post-critical water bottom reflections to the convolution process. In this study, the SWME workflow is applied on the prestack data. Then demultipled data is passed to depth migration engine. The comparison of the depth migration images before and after SWME is shown in latter section.

Poststack Wave-equation based multiple modeling

TGS also have a methodology for predicting and removing multiples in the post-migration depth domain (Wang et al., 2011). This technique is based on wave-equation wavefield extrapolation (WFE) and is applied in the post-stack domain with a consistent predicted multiple model in depth domain. Compared with the prestack demultiple method, poststack based WFE is much more efficient. In addition, the post-stack WFE is insensitive to velocity model errors, since the reflectivity model is kinematically consistent with the zero-offset image. Therefore the zero-offset demigration is a kind of kinematic reversal of the migration, and cancelling out the errors. With a multiple model in depth for comparison, the interpreter can use it to guide the interpretation by staying on the primary signal. Based on the predicted multiple model, we also use adaptive subtraction to remove the leftover multiple residuals on the poststack image.

Synthetic multiple modeling

To analyze the field area, we first built a synthetic reflectivity model from the real model to identify the multiple problem. Figure 1(a) shows the velocity model

DOI http://dx.doi.org/10.1190/segam2015-5910437.1

which is a 2D section selected from our real model. Figure 1(b) is the reflectivity model (pseudo image) which is built based on the interpreted salt body and horizons. By using WFE, we first demigrate the reflectivity image from depth domain to time domain. Figure 2(a) is the demigrated zero-offset time data. This data is used in an additional WFE to model the multiples bounced from the water bottom, which is shown in Figure 2(b). Then we remigrate the primaries and multiples back to depth domain. Figure 3 demonstrates the remigrated primary and multiple image. From the image, we can notice that the events generated from multiples are much noisier than primaries and more swings show up. These fake events can mislead the interpreter, which is shown in the zoomed image in figure 4. The interpreter may pick false base of salt and false fault/bust. This synthetic study can help us have more understanding of the behaviour of multiples in the real dataset.

In Figures 1, 2, and 3 we showed how the first order multiple model is created and how the multiples interfere with the interpretability of a simple reflectivity model. Even with the simple and smooth water bottom the multiples can appear as false structural and stratigraphic anomalies in the data (Figure 3). A more complex water bottom would make the multiple image even worse. Much of the original mapping in this area has been contaminated by mapping on multiples and their migration swings. Using the combination of the pre-stack SWME plus post-stack wave equation modeling (WFE) to attack any remaining multiple energy, we can have greatly improved our primary image below the salt, which will be shown in next section.

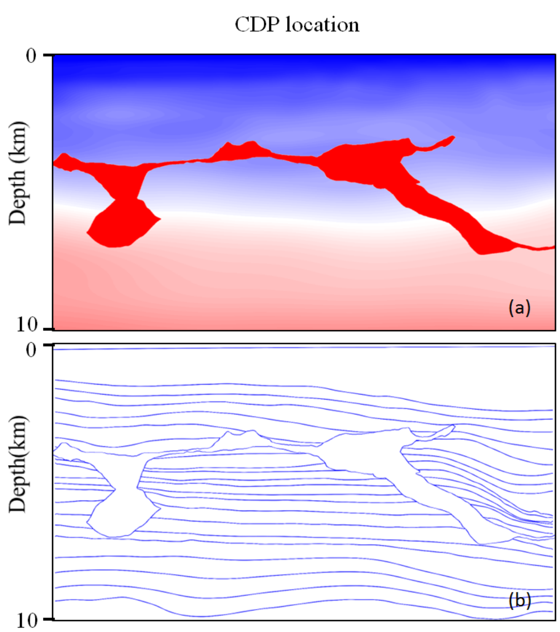


Figure 1 Synthetic model: (a) Velocity model (b) Reflectivity model

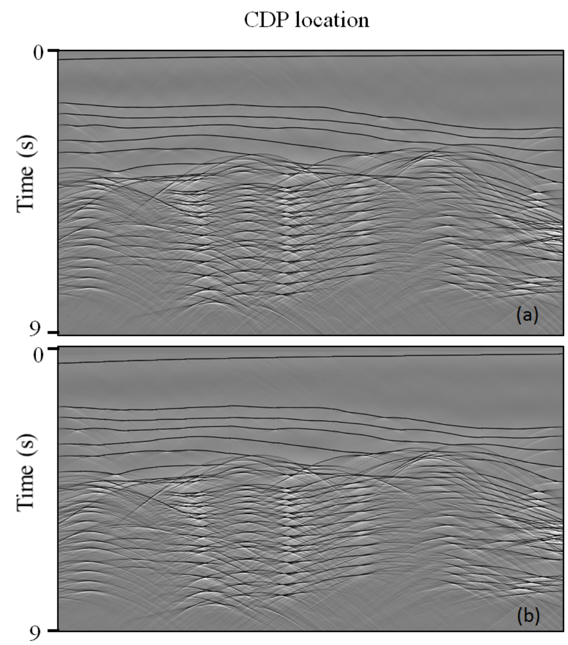


Figure 2 Demigration data with WFE: (a) Modeled primaries (b) Modeled multiples

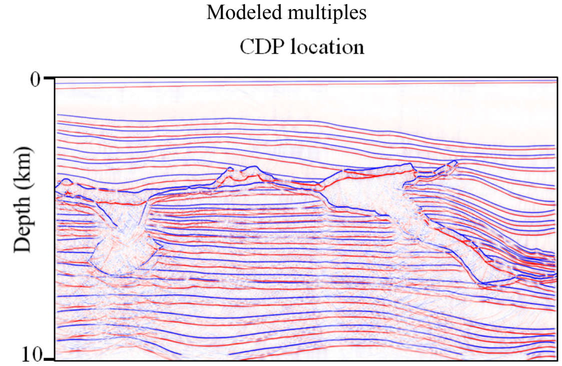


Figure 3 Remigration image of Primary + Multiple image

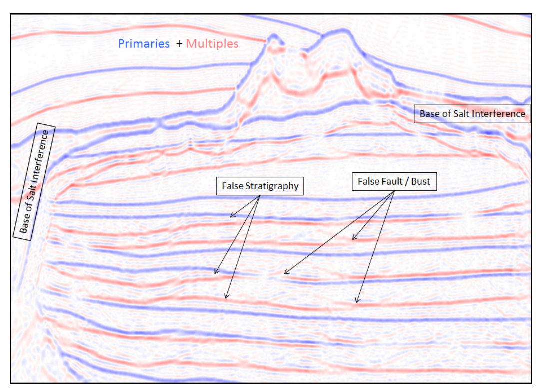


Figure 4 Interpretation on zoomed in image

DOI http://dx.doi.org/10.1190/segam2015-5910437.1

Processing of the field data

The key factors that need to be taken into account in effort to minimize the interpretation inaccuracy done on the final seismic depth migrated image are:

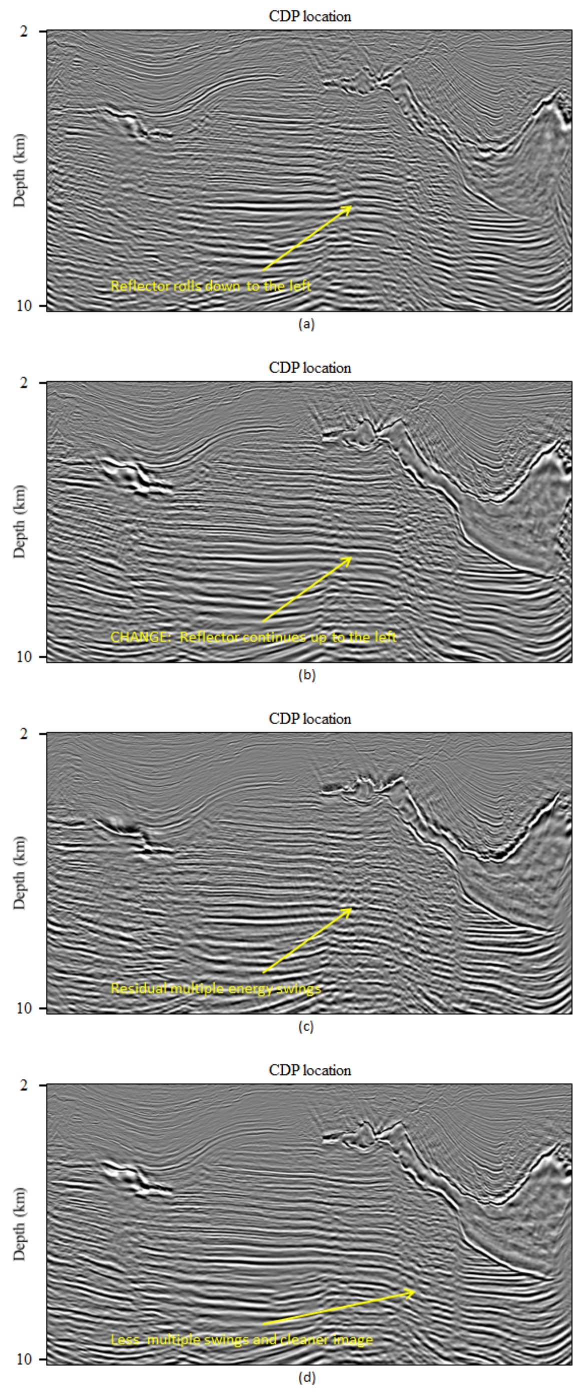
1. Good quality input data for the velocity modeling and final imaging
2. Accuracy of the velocity model
3. Post-migration image enhancement

Good quality input data in terms of signal-to-noise ratio with multiple attenuation is critical for model building and final seismic depth imaging. This is especially true in the shallow-water environment, where conventional SRME suffers from accurate multiple prediction due to absent water-bottom recording at zero offset. Shallow-water multiple elimination has an advantage over the SRME as it inverts to predict the water bottom, this reduces the kinematic error of the predicted multiple model. We have used SWME as a demutiple in addition to the denoise in multidomain.

In a good signal-to-noise area, conventional tomography is suitable to optimize the velocity model. While in a moderate signal-to-noise zone, one might incorporate Delay Imaging Time (DIT) based RTM scans (Wang et al. 2009), improving the velocity subsalt. However, for deeper targets where signal to noise is poor, layer-striping RTM based velocity scans can be utilized to recover the model. For this project we have incorporated all three procedures to develop the velocity model and minimize the modeling related inaccuracy.

SWME in the prestack domain involves two major steps. First, we predict the multiple, and subsequently adaptively subtract the predicted multiple model from the input. There is always some degree of leakage in the adaptive subtraction that leaves some remnant multiple in the data. After final imaging, these residual multiples interfere with the primary reflector, which misleads interpretation. Beneath the complex subsalt final image, residual multiples may appear as faults and/or confuse reflector dip interpretation. Thus poststack enhancement by WFE multiple prediction and subtraction in image domain after the migration is very important to apply.

In this field area, we already processed in 2013. However, we found the quality of the image in sub-salt area still can be improved. And we noticed that the reason is due to the contamination of the shallow water multiples. That's why we have extra effort by using the enhanced demultiple workflow to improve the sub-salt image. The example in figure 5 is to demonstrate the effectiveness of our new demultiple workflow.



DOI http://dx.doi.org/10.1190/segam2015-5910437.1

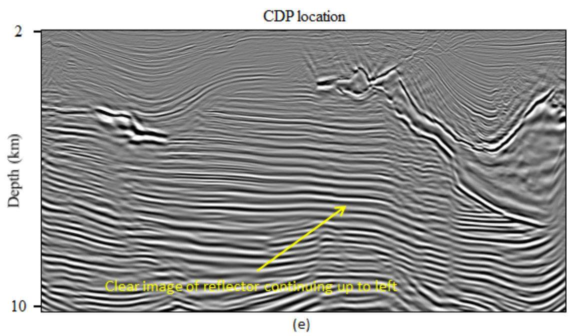


Figure 5 Depth migration images: (a) original image (b) Image after SWME (c) Modeled multiple image by WFE (d) Image after adaptive subtraction of WFE multiples (e) Image after FK

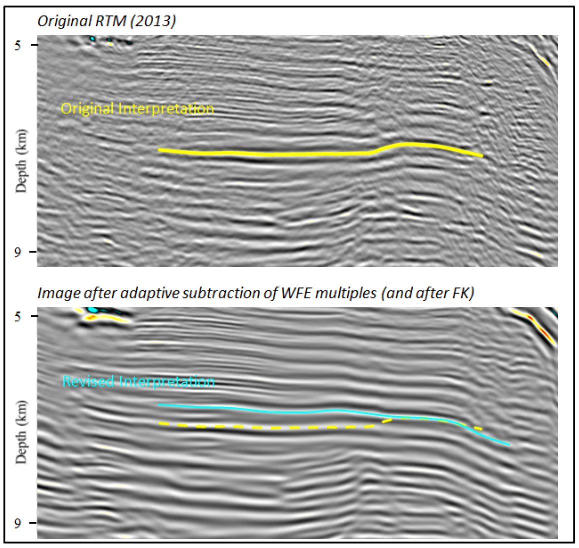


Figure 6 Comparison of before and after demultiple: (a) image before demultiple (b) Image after demultiple and postprocessing

Figure 5(a) is an inline section of the original RTM image without demultiple, which is processed in 2013. After we applied SWME, we got the image in figure 5(b). Then we use the image of SWME as reflectivity for WFE multiple prediction. Figure 5(c) is the remigrated multiple in depth domain. Finally we use adaptive subtraction to suppress the residual multiples in the poststack image, which is shown in figure 5(d). We also used FK power to enhance the signal to noise ratio of the image in figure 5(e). Compared the images before and after SWME, we see that the image quality become much higher, a lot of multiples have been removed. After WFE multiple modeling and subtraction, we get a cleaner image compared to the image with only SWME. In the subsalt area, we see some events are totally different, which leads to different interpretation.

For example, the interpretation of the section in figure 6 shows a major change in structural interpretation. The original RTM has a continuous reflector at 7000m that has an obvious structural high on the right side of the line (yellow interpretation). After SWME/WFE multiple subtractions it is clear that the primary reflector actually continues up to the right (blue interpretation). In the larger picture, the horizon picking on the original data contains cycle shifts due to multiples that force the interpreter to put in erroneous faults and compromises the confidence of the final interpretation. By getting rid of most of the multiple interference, we should alleviate most of these interpretation busts and increase confidence in the project.

Conclusions

We described our current best workflow, including SWME and WFE poststack demultiple, to tackle the multiple problem, which can greatly enhance the quality of sub-salt image. We also showed that the poststack WFE multiple modeling is very efficient and effective to model the water bottom related multiples, which can give the interpreter a quick understanding of the behavior of multiples in subsalt area. We demonstrated the effectiveness of the prestack and poststack wave-equation demultiple. The subsalt image improved a lot compared to the original result. From the results, we can see the changes of the structures in the subsalt area, which leads to different interpretation.

Acknowledgement

We thank Apache and TGS for the permission to publish this work. We also thank Zhiming Li, Bin Wang, Jean Ji, James Sheng and Zhigang Zhang for helpful discussion. We appreciate the proofreading by Connie VanSchuyver and Christopher Egger.

DOI http://dx.doi.org/10.1190/segam2015-5910437.1

EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2015 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Berkhout, A. J., and D. J. Verschuur, 1997, Estimation of multiple scattering by iterative inversion, Part I: theoretical considerations: Geophysics, **62**, 1586–1595. http://dx.doi.org/10.1190/1.1444261.

Bin, W., C. Mason, M. Guo, K. Yoon, J. Cai, J. Ji, and Z. Li, 2009, Subsalt velocity update and composite imaging using reverse-time-migration based delayed-imaging-time scan: Geophysics, **74**, no. 6, WCA159–WCA166. http://dx.doi.org/10.1190/1.3227152.

Moore, I., and B. Dragoset, 2004, Practical, 3D surface-related multiple prediction (SMP): 74st Annual International Meeting SEG Expanded Abstracts, 1249–1252.

Wang, B., J. Cai, M. Guo, C. Mason, S. Gajawada, and D. Epili, 2011, Postmigration multiple prediction and removal in depth domain: Geophysics, **76**, no. 5, WB217–WB223. http://dx.doi.org/10.1190/geo2011-0010.1.

Wang, P., H. Z. Jin, S. Xu, and Y. Zhang, 2011, Model-based water-layer demultiple: 81st Annual International Meeting, SEG, Expanded Abstracts, 3551–3555.

Verschuur, D. J., A. J. Berkhout, and C. P. A. Wapenaar, 1992, Adaptive surface-related multiple elimination: Geophysics, **57**, 1166–1177. http://dx.doi.org/10.1190/1.1443330.

Zhai, Y., S. Sen, Z. Liu, J. Sheng, B. Wang, C. Zhan, N. Hokanson, S. Laha, and L. Zhang, 2015, Shallow water multiple elimination on broadband data: EAGE. http://dx.doi.org/10.3997/2214-4609.201413391.

DOI http://dx.doi.org/10.1190/segam2015-5910437.1