Multiple attenuation using 3D SRME with targeted demigration

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Summary

Surface-related multiple elimination (SRME) is an effective and widely used tool for the attenuation of multiple energy in marine seismic data. However, removing multiples with SRME is still challenging in geologically complex areas, and we often observe residual multiples in such settings. Residual multiples can be caused by poor sampling of near offsets, low signal-to-noise ratio (S/N), and cross-talk among different orders of multiples. To remove strong residual multiples, we propose a targeted SRME flow where we demigrate the generators of the strongest residual multiples and predict an SRME model with demigrated data as input. We present applications of this method on two field data examples in the deepwater Gulf of Mexico, where the targeted residual multiples are effectively attenuated.

Introduction

Most migration techniques are based on a single scattering assumption, which requires multiple attenuation in preprocessing steps. Surface-related multiples are a category of multiples involving an extra reflection at the air-water interface. They can be predicted using 3D SRME, which involves 3D convolution of primary reflections with the full recorded data, including primaries and multiples, followed by a deconvolution of the source signature (Verschuur et al., 1992). In practice, the primary reflections are unknown, so the SRME flow uses a full-data-to-full-data convolution to generate the multiple model (hereafter, called data-to-data SRME).

Although the data-to-data convolution introduces cross-talk between different orders of multiples that causes overestimation of higher-order multiple amplitudes, 3D SRME workflows have been widely adopted and proven to be both efficient and effective. Because of reduced cross-talk, a second round of primary-to-data or primary-to-primary SRME using the data-to-data SRME output may be useful to further attenuate multiple energy.

In the Gulf of Mexico, subsalt images are generally severely contaminated by multiples associated with strong shallow reflectors, including water bottom (WB), top of salt (TOS), and base of salt (BOS). In this study, strong WB-BOS peg-leg residual multiples were observed in the subsalt (Figures 1a, 1b). A second-round primary-to-primary SRME was performed to attenuate the residual first-order multiples. However, the WB-BOS peg-leg residual multiples persisted (Figure 1c).

Conventional SRME limitations

To better understand the reason for the residual multiples, we investigated the limitations of our SRME flow. From this point forward, we denote the data-to-data followed by primary-to-primary SRME flow as conventional SRME.

Conventional SRME predicts the multiple model by convolving traces within a spatial prediction aperture known as a multiple contribution gather (MCG). This requires that lower-order reflections have been well recorded in the data used for convolution. However, this is not always the case with real data, where the nearest-offset data, which are important for multiple prediction, are sometimes missing or of poor quality. In addition, surface and internal multiples, diffractions, noise, and other strong events can overpower the generator of some multiples.

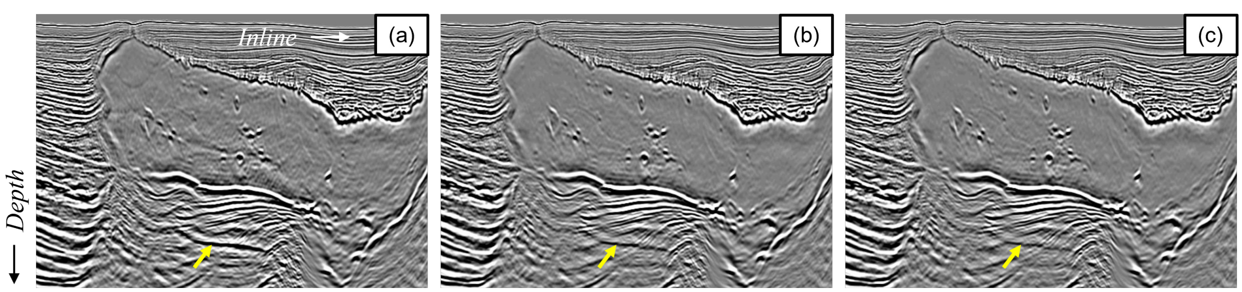

Figure 1: 15 Hz RTM stack (a) before SRME, (b) after data-to-data SRME, and (c) after second-round primary-to-primary SRME. The residual multiple is approximately 7 km below the water surface.

Even though the BOS is a very strong reflector, it is still difficult to observe in real pre-migration data (Figure 2a). We generated forward-modeled data by solving the acoustic wave equation using an 8 Hz FWI model (Figure 2b). Compared to real data, these wave equation forward-modeled data were free of noise. They also have fewer diffractions due to missing details in the velocity used for modeling. A hint of the BOS can be seen at middle offsets (green arrow), but the event is still hard to observe at the near offsets due to interference from surface multiples, internal multiples, and other primary events (blue arrow). Next, we generated demigrated data following the Born approximation, where the background velocity model was from FWI and the reflectivity model was taken from the RTM image (Figure 2c). In the demigrated data, the BOS was very prominent across the entire offset range because of the much-reduced multiple interference. In the end, we isolated the BOS in the RTM image for a targeted BOS demigration. For this case, there was no interference from other events, and therefore, the modeled BOS showed the best coherence from near to far offsets (Figure 2d).

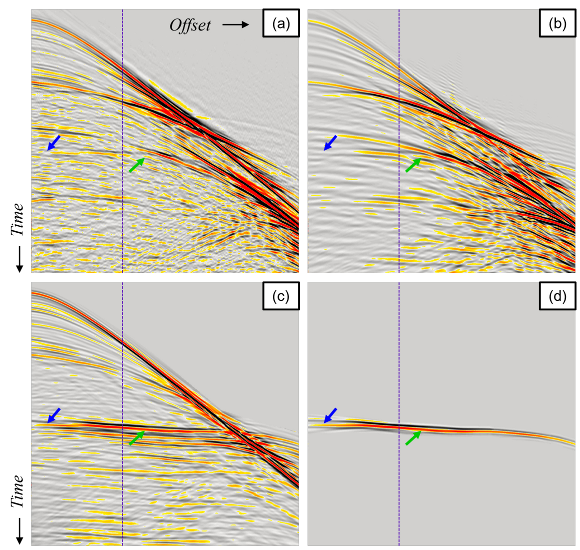

Figure 2: Shot gather after 15 Hz high-cut: (a) real data, (b) forward-modeled data, (c) demigrated full RTM stack, and (d) demigrated BOS. The dashed vertical line indicates the location of the trace whose MCG is shown in Figure 3. Blue and green arrows indicate the BOS at near and middle offsets, respectively.

These observations led to the idea of utilizing the demigrated data to improve the SRME quality. To see the impact on the convolution, we compared MCGs using real, forward-modeled, and demigrated data for a trace at around 3 km offset taken from the shot gather shown in Figure 2. The WB-BOS peg-leg event is almost impossible to see in the real data MCG (Figure 3a), and while the peak of the WB-BOS peg-leg multiple can be observed in the forward-modeled data MCG, its extent is quite localized (Figure 3b). However, the demigrated data convolution shows a coherent WB-BOS peg-leg event across the full aperture range (Figure 3c). With the targeted WB and BOS demigration, the prediction is improved further (Figure 3d). The peg-leg event is now completely isolated, and the prediction is free of contamination from any other energy. It is worth noting that for this illustration, because we show the case where WB is used on the source side and BOS is used on the receiver side, we only see one event in Figure 3d. The other combination of BOS on source side and WB on receiver side can be seen in Figure 3c (green arrow).

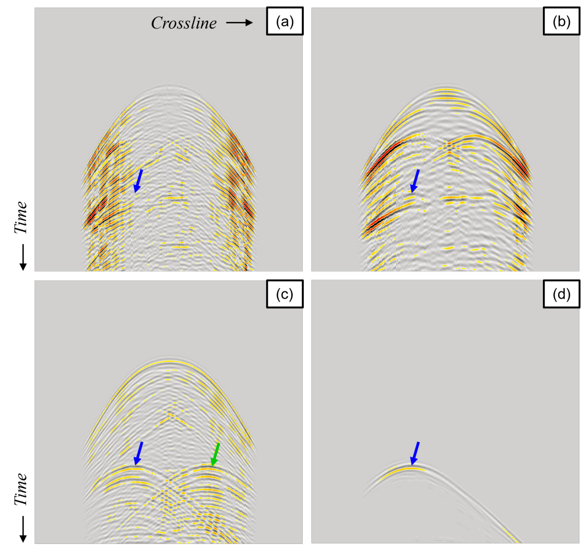

Figure 3: MCG from SRME (centered at offset 3 km) after 15 Hz high-cut for (a) data * data, (b) forward-modeled data * forward-modeled data, (c) demigrated data * demigrated data, and (d) demigrated WB * BOS, where * denotes convolution.

SRME with targeted demigration modeling

Based upon the earlier analysis, we propose a new SRME with targeted demigration. The flow is summarized in the following steps:

- identify the target multiple and its two generators,
- isolate and demigrate the generators separately from the RTM stack,
- predict the target multiple with 3D SRME – use the demigrated data from one generator on the source side with demigrated data from the other generator on the receiver side, and vice versa,
- adaptively subtract the model from the input.

Compared to conventional SRME, the two key differences in our approach are 1) demigrated data are input into the convolution instead of real data, and 2) only multiple generators are convolved to construct the predicted multiple model.

Figure 4 shows a shot gather comparison for the different SRME multiple models. Hints of the peg-leg event are visible in the real and forward-modeled data models, but it is mostly overwhelmed by other events, particularly at the near offsets (blue arrow). The WB-BOS peg-leg multiple generated from demigrated data shows higher S/N and better continuity with much-reduced or no interference from other events (Figure 4c). It is clearly visible at both middle offsets (green arrow) and near offsets (blue arrow). With the SRME model from the targeted demigration, we are able to isolate the peg-leg multiple, allowing the subtraction to focus only on the strong residual multiple (Figure 4d).

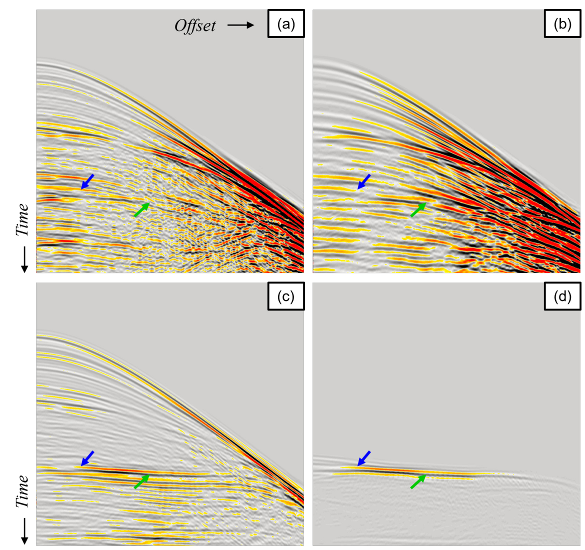

Figure 4: SRME model after 15 Hz high-cut generated from (a) data * data, (b) forward-modeled data * forward-modeled data, (c) demigrated data * demigrated data, and (d) WB * BOS using demigrated data, where * denotes convolution. Blue and green arrows indicate the WB-BOS peg-leg at near and middle offsets, respectively.

Field data application

We have applied the proposed method to a wide-azimuth (WAZ) streamer data set in deepwater Gulf of Mexico, where we target residual WB-BOS peg-leg multiples. The WAZ survey used two streamer vessels with 10 cables of 120 m cable spacing and cable lengths of 8.1 km. Prior to SRME, these data were processed using a workflow including noise attenuation and 3D joint deghost and designature.

After data-to-data and primary-to-primary SRME, strong WB-BOS peg-leg residuals were observed in several locations throughout the survey area. In areas where strong WB-BOS peg-leg residual multiples existed, we isolated and demigrated the WB and BOS from the RTM stack using the WAZ acquisition geometry. The demigration frequency was 15 Hz, because the energy beyond this frequency is weak in the time window around the WB-BOS multiple. With the same parameters as the real data, we ran the demigrated data 3D SRME.

In the time domain, the weak, low-frequency WB-BOS peg-leg residuals after conventional SRME were observed on a near-offset stack (Figure 5). Following targeted demigration SRME, the residual multiples were effectively removed. The impact become even more obvious in the depth domain, where the strong residual multiples covering the subsalt event were attenuated after targeted demigration SRME (Figure 6).

We also applied the proposed flow to a full-azimuth (FAZ), staggered streamer data set (Mandroux et al., 2013) with a maximum offset of 18 km. These FAZ data had a 9.3 km streamer length with staggered streamer boats for recording long offsets. Strong residual multiples existed after application of conventional SRME (Figures 7a, 7b), and these residual multiples compromised the subsalt structural interpretation in this complex area. Although the BOS event was not as coherent as in the WAZ data, we were still able to isolate it from the RTM image for demigration. The targeted demigration SRME successfully removed the residual multiples, improving interpretability of the subsalt events (Figure 7c).

Conclusions and discussion

We have shown that targeted demigration SRME can help attenuate strong residual multiples following a conventional SRME flow. In theory, this method can be used for any multiple mode, provided that its generators are known and are well imaged by RTM or other imaging methods. It can be easily modified to target more than one multiple by enlarging the reflectivity on either side of the convolution. If higher frequencies are required, one can instead use Kirchhoff demigration to reduce the computation cost if the accuracy is sufficient.

In this study, the real data acquisition geometry was used for the demigration but that need not be the case. The targeted events can be demigrated to a regular and denser grid with zero and near offsets, both of which can potentially improve SRME quality with additional computation cost.

Although quite effective, the proposed method has some limitations. It is computationally expensive as it requires demigration followed by another round of 3D SRME. Additionally, unlike conventional SRME, which is data driven, targeted demigration SRME relies upon the accuracy of a velocity model for demigration, and it requires the multiple generators to be known and well imaged in the migrated stack. For the deepwater Gulf of Mexico, the strongest multiple generators tend to be WB, TOS, and BOS. While this helps narrow down the search space considerably in this case, in other areas, the geology may not be as cooperative.

It is worth mentioning that one could alternatively implement our method using the ideas from Pica et al. (2005). Following this approach, the desired first-order multiple may be modeled by injecting the demigrated source-side generator as an areal source using the receiver-side generator as the reflectivity. This strategy removes the need for the surface convolution of the demigrated data, but a much denser demigrated source-side gather would likely be required to sufficiently cover the surface reflection points of the multiple.

Acknowledgments

We thank CGG for permission to publish this work.

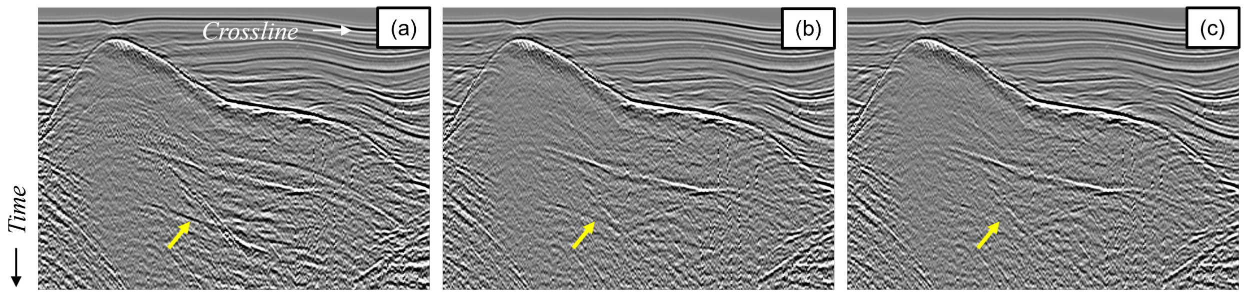

Figure 5: Time domain near-offset stack (0-3900 m, 15 Hz high-cut) (a) before conventional SRME, (b) after conventional SRME, and (c) after targeted demigration modeling SRME.

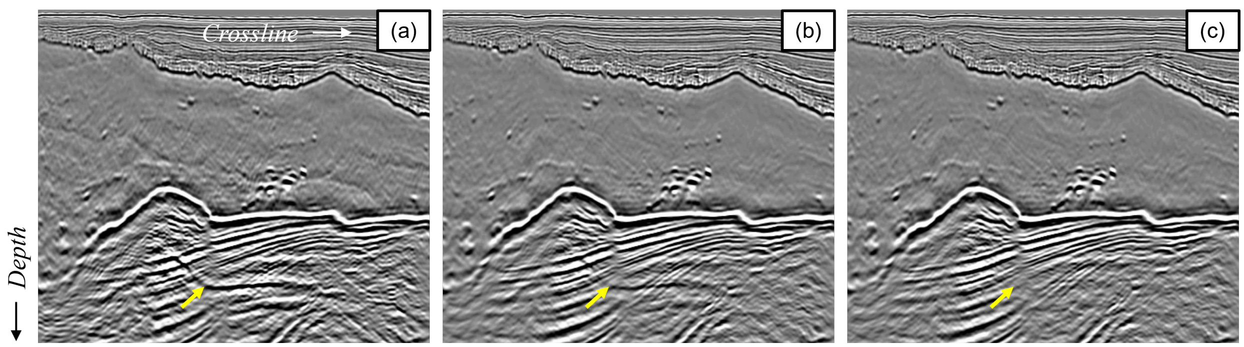

Figure 6: WAZ 15 Hz RTM stack (a) before conventional SRME, (b) after conventional SRME, and (c) after targeted demigration modeling SRME.

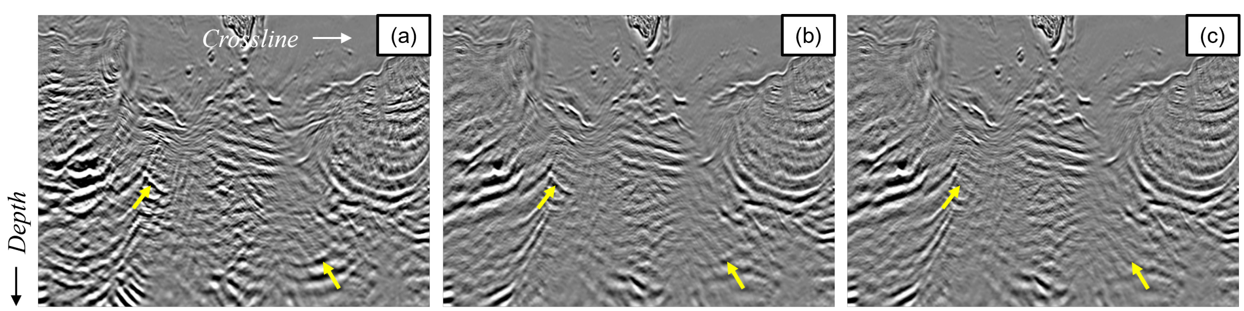

Figure 7: FAZ 15 Hz RTM stack (a) before conventional SRME, (b) after conventional SRME, and (c) after targeted demigration modeling SRME

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