Th P4 10

# Shallow Water Multiple Elimination (SWME) on Broadband Data

Y. Zhai (TGS Geophysical Company), S. Sen (TGS Geophysical Company), Z. Liu (TGS Geophysical Company), J. Sheng (TGS Geophysical Company), B. Wang (TGS Geophysical Company), C. Zhan (TGS Geophysical Company), N. Hokanson* (TGS Geophysical Company), S. Laha (TGS Geophysical Company) & L. Zhang (TGS Geophysical Company)

## SUMMARY

Surface Related Multiple Elimination (SRME) has been approved to be an effective demultiple tool for marine data processing. However, it breaks down when applied to shallow water data mainly because 1) missing or contaminated near-offsets lead to inaccurate multiple models; 2) the cross-talk of short-period multiples deteriorate the matching filter during the adaptive subtraction; 3) the spectrum of the multiple model is distorted by the extra source signature.

This paper proposes a new approach that combines a model-based method and a conventional SRME to serve the means of shallow water multiple elimination (SWME). The advantages include: 1) replacing the water-bottom Green's functions with broadband wavelets predicts the correct amplitudes of the multiples; 2) limiting the aperture of the Green's functions to the distance where the critical reflection occurs suppresses the artefacts in the multiple model and lowers the cost; 3) Simultaneously subtracting both the receiver- and source- side water-bottom multiples significantly improves the efficiency; 4) a following SRME helps remove the residual non-water-bottom multiples. A broadband 2D line offshore Santos, Brazil is tested with the proposed approach. It has prominently outperformed the legacy processing that used SRME and Tau-P deconvolution years ago.

## Introduction

The data-driven surface-related multiple elimination (SRME) method has been widely used since the pioneering work of Berkhout *et al.* (1992). Most attractively, this method requires no prior information of the subsurface, i.e. the velocity structure, or reflectivity. It is effective to attenuate water-bottom-related multiples (WBRM). Although, problems have been encountered for shallow water situations because the wavefield reconstruction to near offsets is inaccurate. When offset approaches the distance where critical reflection occurs, the NMO-based extrapolation distorts the primaries, or introduces unwanted energies, such as refractions. The wavelet stretch is severe, too.

Another difficulty occurs in the subtraction stage. The crosstalk caused by multiple and multiple convolution is negligible for deep water, but severe for shallow water because the predicted multiples are of very short period. Since several orders of multiples are present in the same operating window, many iterations are often needed to balance the biased amplitude and/or phase (Berkhout and Verschuur, 1997). Additionally, convolving the data with itself is easy to implement but introduces an additional source signature. This changes the spectrum of the multiple model from the input data, degrading the adaptive subtraction.

Many efforts have been made to overcome the disadvantages of the SRME on shallow water. Predictive deconvolution can effectively remove the short period water-bottom multiples (Hung and Bisley, 2010). However, it attenuates all events with the period close to the water layer, including the primaries and interbed multiples. Deterministic demultiple methods design an operator to predict water layer multiples from the data (Moore *et al.*, 2006). It predicts the amplitude accurately, but struggles with the complex water bottom due to the inaccurate model derived from the auto-correlation. Lopez and Verschuur (2014) proposed an inversion-based SRME algorithm to avoid the multiple subtraction from the data. Whereas, the primaries are estimated with the corresponding multiples to explain the data directly. However, the cost could be significantly high.

Model-based methods can handle the near-offset issue properly with limited prior information, i.e. the Green's functions of the water bottom (Wang, *et al.*, 2011). We propose a new approach that combines the model-based method with the conventional SRME to attenuate multiples of broadband data. The proposed shallow-water multiple-elimination (SWME) approach predicts the multiple model accurately by using a broadband wavelet and proper aperture. We limit the offset of the Green's functions so that post-critical energies are not convolved. This ensures the resulting multiple model is free of artefacts, and very importantly, significantly reduces the cost. Two multiple models from both source- and receiver- sides are adaptively subtracted from the input data with an enhanced hybrid subtraction method, such that no high-order multiple term is solved explicitly. After the WBRM is removed, a conventional SRME is followed to remove residual surface-related multiples.

## Method

Theoretically, the multiples can be generated by convolving the input data with the subsurface reflectivity (Verschuur *et al.*, 1992). Wang *et al.* (2011) proposed a model-based method that uses the Green's functions of water-bottom primaries instead of the data itself as the conventional SRME does:

$$M = D\,G \qquad (1)$$

where M is the multiples, D is the data, G is the Green's functions which contain the predefined water-bottom information, e.g. water-layer velocity and depth. This method avoids using primaries that contain an extra source signature, thus it can preserve the spectrum of the input data. The cross-talk issue is also solved because no M * M operation is performed during the convolution. Yang and Hung (2013) proposed a hybrid technique, taking advantage of the predictive deconvolution method, and ultimately adding more information to the Green's functions. In practice, the contribution from both source- and receiver- sides must be included to solve equation (1). Therefore, the complete WBRM can be represented as:

M(s,r) = G(s,s') D(s',r) (source) + D(s,r') G(r',r) (receiver) - G(s,s') D(s',r') G(r',r) (common term) (2)

where s and r are source and receiver locations, s' and r' are bouncing points at the surface as shown in figure 1. Because both 1st and 2nd terms at the right hand side include the same high-order term, it must be subtracted to avoid crosstalk. Figure 2 is synthetic data that illustrates 1st (b) and 2nd terms (c) of equation (2). It is clearly shown that b) and c) share the same high-order term, especially in the deep portion. The two models are identical when the subsurface is perfectly flat.

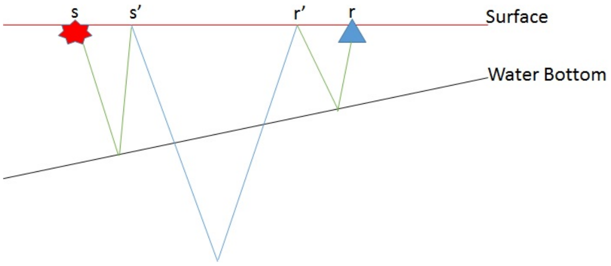


***Figure 1*** *Ray paths describing the water-bottom-related multiples. In green is water-bottom bounce of the source side (ss') and receiver side (rr').*

One issue when solving equation (2) is that calculating G might be expensive on broadband data which has been widely acquired and processed (Tang *et al*., 2014). In practice, we model G within limited frequency band and replace the source signature with a very broadband wavelet. Postcritical events dominate the far-offset wavefield of shallow-water data, yet have negligible contribution to the true multiple model. Therefore, we calculate the distance where the critical reflection occurs based on the water depth and velocity contrast at the water bottom. We then limit the offset of G during the convolution to obtain an artefact-free multiple model with reduced cost.

Another issue, potentially more severe for 3D than 2D, is that calculating the 3rd term in equation (2) involves an additional loop. To avoid this we propose an enhanced hybrid subtraction method that removes several multiple models from the input data simultaneously. Weights are first calculated based on their similarities to the input data. The weighted summation is then calculated to generate a "new" multiple model. Different than Mei and Zou (2010), the subtraction would favour the one with the minimum residual after the adaptive subtraction out of the three models (Cai, *et al*., 2009). This procedure is repeated until a certain satisfactory level is reached. Finally, a conventional SRME is applied to remove residual non-water-bottom-related multiples.

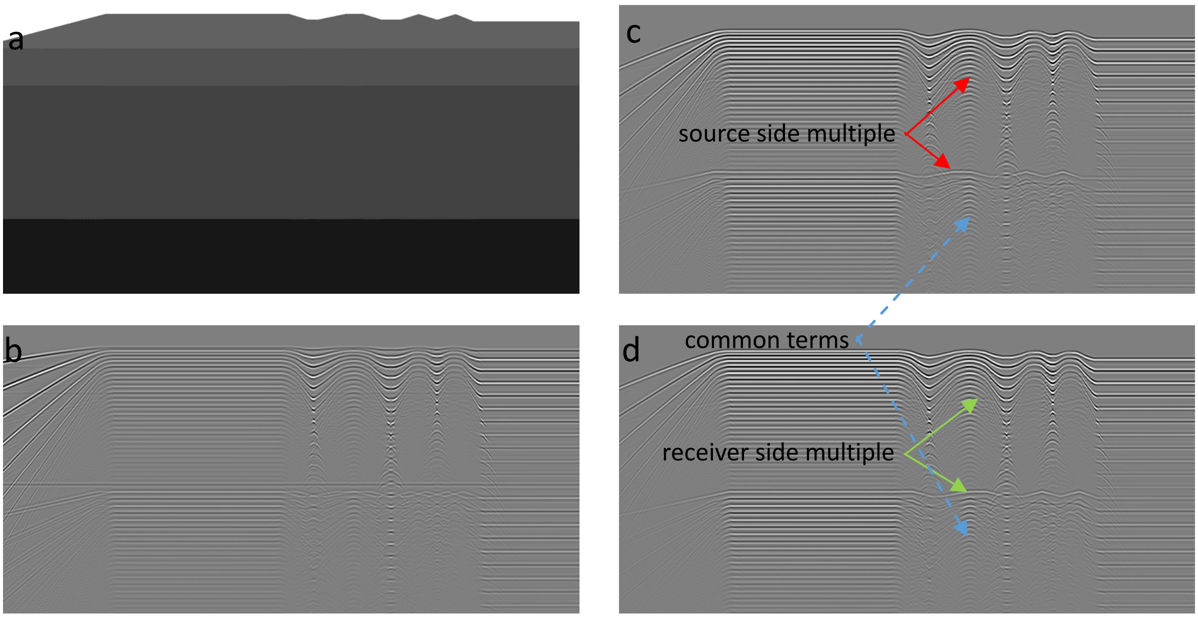


***Figure 2*** *Velocity structure a), input data b), source side multiples c) and receiver side multiples d). Note that source- and receiver- side multiples share the same high-order terms.*

**Field data examples**

The proposed approach has been successfully applied to a 2D survey offshore Santos Basin, Brazil. During 1999-2001, TGS acquired more than 27,840 km of 2D data at this region where the water depth varies from ~155 m to more than 2000 m. Reprocessing begins recently to take advantage of newly developed tools, e.g. Clari-Fi (bandwidth Enhancement, Masoomzadeh and Woodburn, 2014), TTI model building (Yang *et al.*, 2009), as well as the SWME. A N-S 2D line, 1535-S02A586, in the middle of the survey is tested with the SWME. As the comparison, the result of legacy processing with Tau-P deconvolution and SRME is also shown in the following session.

Figure 3 shows the Kirchhoff time migration sections of the input (top), legacy processing (middle) and the SWME (bottom). We applied the SWME to the whole survey, because it outperforms the legacy processing in the shallow water region. Likewise, the deep water and transition zone are improved with the SWME application, which is benefiting from more accurate multiple models. The blue arrow in figure 3 indicates the interbed multiples that are being attenuated by processes following the proposed flow.

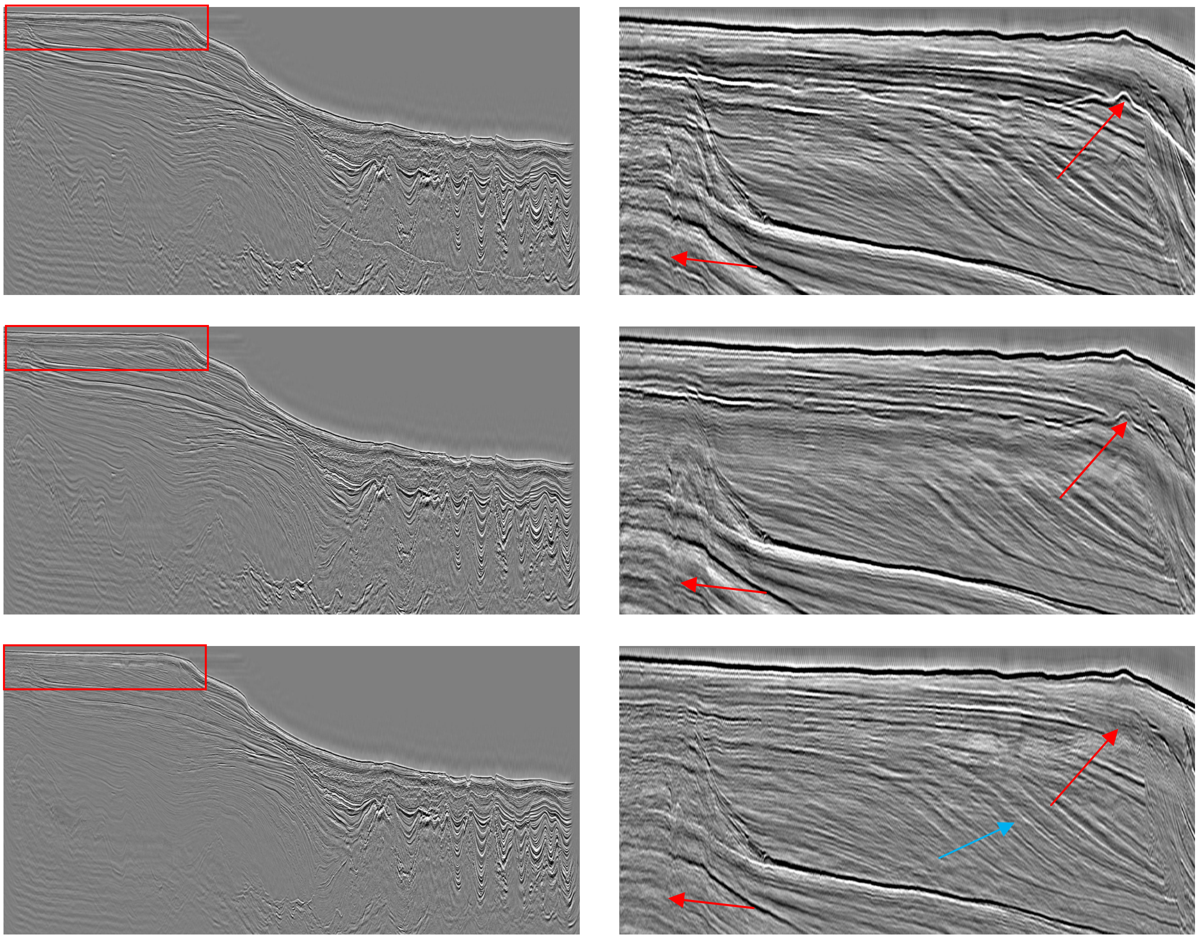

***Figure 3*** *Kirchhoff Time Migration section of Line 1535BS02A586, offshore Santos Basin. Top: input data; middle: the legacy processing with Tau-P deconvolution and SRME; bottom: the SWME. Left: whole section; right: zoom-in of the shallow water region marked by the red rectangle. Note that interbed multiples marked by the blue arrow are not the target of this approach.*

**Conclusions**

We propose a new approach that uses the model-based method to attenuate WBRM and a conventional SRME to remove residual surface-related multiples for shallow water situation. Both the source- and receiver- side multiples are modelled accurately and efficiently within a very broad frequency band. The newly developed tool coupled with enhanced hybrid subtraction, handles high-order common multiple terms, from both source- and receiver- sides at reduced cost. After the WBRM is removed, a conventional SRME removes the residual surface-related multiples that do not bounce at the water bottom. This approach (SWME) is proven to be robust and effective for shallow water demultiple purpose. We have shown that the proposed approach outperforms the tau-*p* deconvolution and SRME on a 2D test line offshore Santos Basin, Brazil.

**Acknowledgements**

The author would like to thank TGS Geophysical Company for the permission to present this work, Manhong Guo for the constructive discussions and suggestions, Eugen Besoiu and Graziella Kirtland for their effort on the data management, Cristina Reta-Tang, Jim Specht, Henrik Roende for their support on this project. We would also like to thank Connie VanSchuyver and Christopher Egger for reviewing the manuscript.

**References**

Berkhout, A.J. and Verschuur, D.J. [1997] Estimation of multiple scattering by iterative inversion, part I: theoretical considerations. *Geophysics*, **62**(5), 1586-1595.

Cai, J., Guo, M., Sen, S., Dong, S., Camp, R. and Wang, B. [2009] From SRME or wave-equation extrapolation to SRME and wave-equation extrapolation. *79th Annual International Meeting*, SEG, Expanded Abstracts, 3133-3136.

Hung, B., Yang, K.L., Zhou, J., Guo, Y.H. and Xia, Q.L. [2010] Surface multiple attenuation in seabeach-shallow water, case study on data from the Bohai Sea technique. *80th Annual International Meeting*, SEG, Expanded Abstracts, 3431-3435.

Mei, Y., and Zou, Z., [2010] A Weighted Adaptive Subtraction for Two or More Multiple Models. *80th Annual International Meeting*, SEG, Expanded Abstracts, 3488-3492.

Masoomzadeh, H. and Woodburn, N., [2013] Broadband Processing of Conventional Streamer Data – Optimized De-Ghosting in the Tau-P Domain. *76th EAGE Conference & Exhibition*, Extended Abstract, Th08.

Moore, I. and Bisley, R., [2006] Multiple attenuation in shallow-water situations. *68th EAGE Conference & Exhibition*, Extended Abstract, F18.

Lopez, G.A. and Verschuur, D.J., [2014] Closed-loop SRME – A New Direction in Surface Multiple Removal Algorithms. *76th EAGE Conference & Exhibition*, Extended Abstract, E102.

Tang, C., Convey, W., Keay, J., Yang, D., Sun, X., [2014] Rejuvenation of regional 2D in the Campos Basin, offshore Brazil through broadband processing and TTI imaging: A case study. *84th Annual International Meeting*, SEG, Expanded Abstracts, 3910-3914.

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

He, Y., Cai, J., Whiteside, W., Li, Z., Guo, M., Wang, B., Xie, J., Yoon, K. and Nessler, E., [2009] TTI/VTI anisotropy estimation by focusing analysis, Part II: Application. *79th Annual International Meeting*, SEG, Expanded Abstracts, 311-315.

Yang, K.L. And Hung, B., [2013] Shallow Water Demultiple Using Hybrid Multichannel Prediction. *75th EAGE Conference & Exhibition*, Extended Abstract, Tu14.

Verschuur, D.J., Berkhout, A.J. and Wapenaar, C.P.A., [1992] Adaptive surface-related multiple elimination. *Geophysics*, **57**(9), 1166-1177.