1.5D internal multiple prediction: physical modelling results

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ABSTRCT

Inverse scattering series algorithm has been verified theoretically as a wise way to eliminate internal multiples both for marine and land datasets. In this paper, we presented internal multiple predictions in plane wave domain using inverse scattering series on synthetic and physical modeling data generated in marine environment. Beyond that, the influences of wavelet reverberation are also discussed. The relevant and pragmatic benefits are exemplified by those results using plane wave domain inverse scattering algorithm.

INTRODUCTION

There are few obstacles of seismic processing remain to be solved, multiple elimination is one of them. Multiples can be identified as two major classes, surface-related multiple and interbred multiple, in the light of the influence of free-surface. Surface-related multiples can be successfully eliminated as its periodic appearance in $\tau - p$ domain and many innovative technologies have been developed. Taner (1980) and Treitel et al., (1982) demonstrated predictive deconvolution can be applied to remove surface-related multiples based on its periodic property. Verschuur (1991) proposed an inverse approach for multiple attenuation using the feedback model and a similar method was described by Weglein et al. (1997) on the strength of inverse scattering series. Liu et al., (2000) presented surface-related multiple attenuation on 2D case in the plane wave domain using the invariant embedding technique. Berkhout and Verschuur (2005, 2006) derived a multiple attenuation method using inverse data processing and Ma et al., (2009) implemented this algorithm in plane wave domain.

However, internal multiple attenuation continues to be a big challenge though much considerable progress have been made recently. A boundary-related/layer-related approach was demonstrated by Kelamis et al. (2002) to remove internal multiples in the poststack data and CMP domains. Berkhout and Verschuur (2005) proposed a way to attenuate internal multiples by considering internal multiples as the suppositional surface-related multiples through the layer-related or boundary-related approach in common-focus-point (CFP) domain. The common defect of those two approaches is that both of them require superabundant user actions and extensive knowledge of multiple-generating boundaries (Verschuur & Berkhout, 2005). Inverse scattering series algorithm can be applied to reconstruct all possible internal multiple by those events satisfying lower-higher-lower relationship in an automatic way (Weglein et al. 1997).

Inverse scattering series approach has been studied and implemented on poststack, synthetic and physical modelling data in wavenumber-pseudo depth domain (Innanen, 2012; Hernandez and Wong, 2012; Pan and Innanen, 2013, 2015). Based on the foundation of Coates et al. (1996) and Nita and Weglein (2009), Sun and Innanen (2014, 2015) further analyzed the relationship between pseudo-depth and intercept time, and demonstrated the inverse scattering series algorithm in plane wave domain with more accuracy predicted results. To examine the capacity of plane wave domain inverse scattering algorithm on physical modelling data, we presented the internal multiple predictions under marine environment using inverse scattering series in plane wave domain. And the effects of wavelet are also discussed.

PHYSICAL MODELING EXPERIMENT

In this experiment, the physical modeling data was provided by CREWES, and the same dataset was implemented by Pan (2015) in wavenumber pseudo-depth domain. A five-layer model was built using water, polyvinyl chloride (PVC), aluminum and Plexiglas, and the schematic diagram and parameters are shown in Figure 1. The materials of this physical modeling experiment provide a perfect situation to collect a marine dataset. To eliminate ghost, data are collected in a fixed configuration, with source and all receivers positioned 20m below water surface, receivers located in a fixed step-size of 25m. A 2ms sample rate and 20-100Hz frequency range for source were applied into acquisition system.

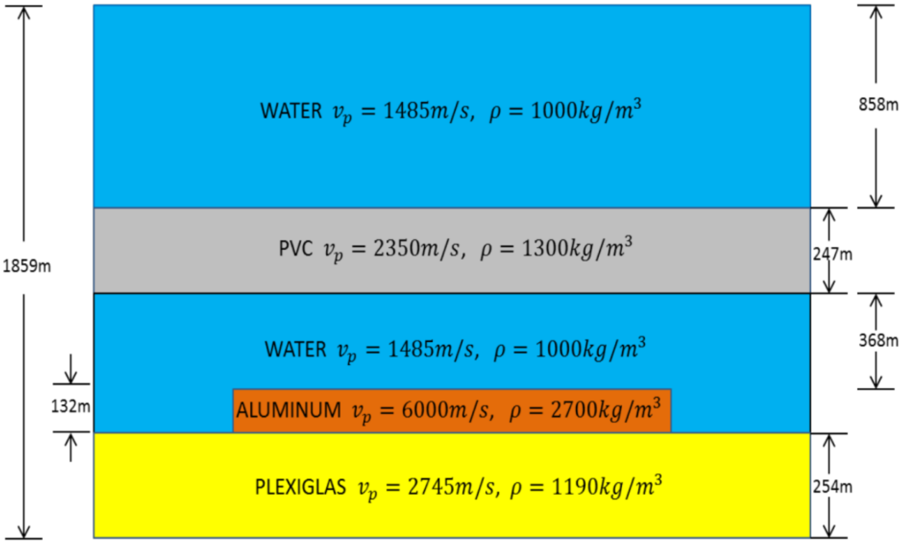

FIG. 1. The schematic diagram of the physical modelling experiment (Pan, 2015)

After gather collected, a basic seismic processing flow was applied before internal multiple prediction, such as top muting for removing direct wave, a bandpass filter of 10-20-70-90 for suppressing noises, spiking deconvolution and AGC. To discuss the effect of wavelet reverberation in multiple predictions, plane wave domain inverse scattering will also be implemented on the dataset without spiking deconvolution. The dataset before and after spiking deconvolution of operator length 80ms, and operator taper in 30ms, were shown in Figure 2 and 3 respectively.

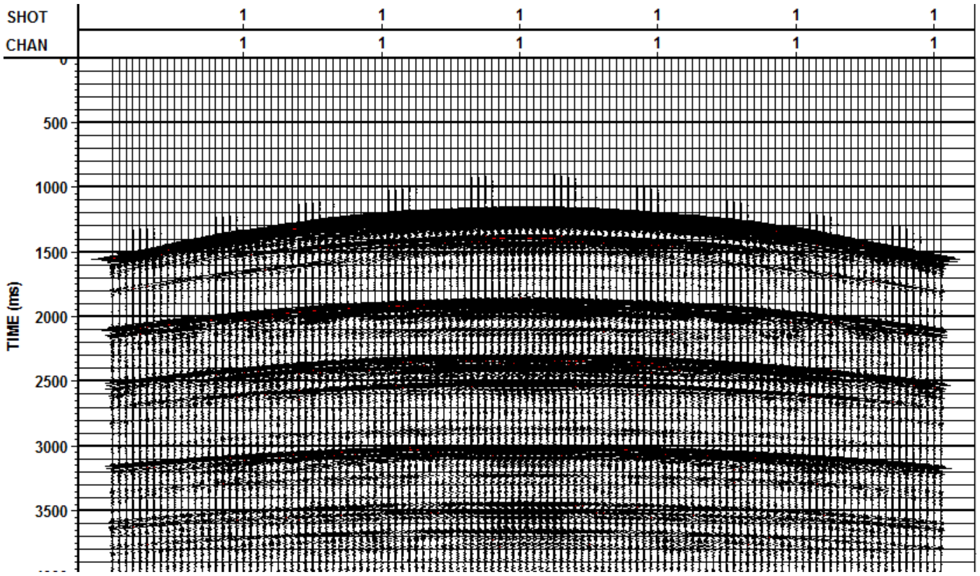

FIG. 2. Physical modelling data after top muting, AGC and bandpass filter of 10-20-70-90 Hz.

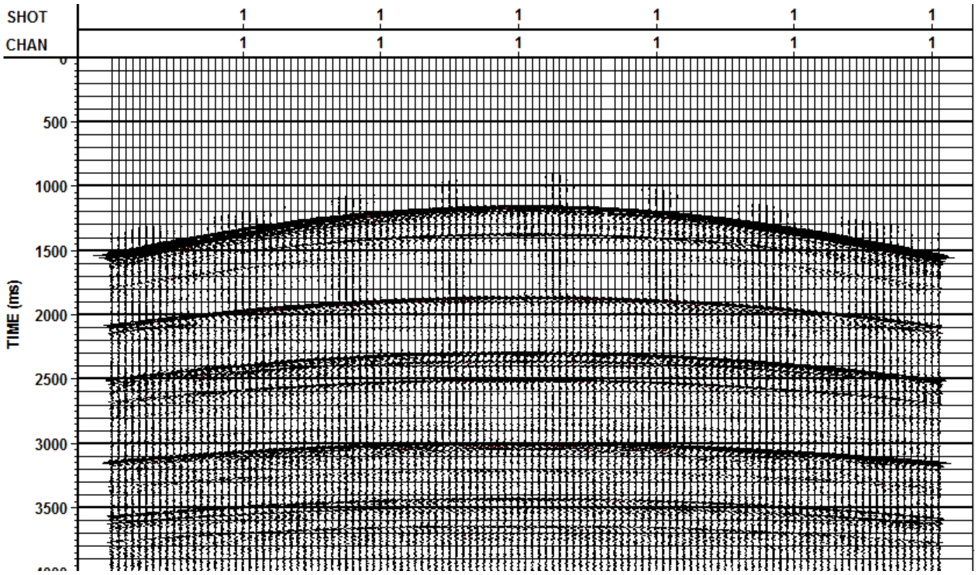

FIG. 3. Physical modelling data after direct muting, AGC, bandpass filter of 10-20-70-90 Hz, and spiking deconvolution of operator length 80ms.

For input preparing of inverse scattering in plane wave domain, a $\tau - p$ transform provided by CREWES toolbox was applied and shown in Figure 4. There are four primaries presented (Figure 4, indicated in red at zero-offset), but only three of them can be identified because the primaries reflected by the top and the bottom of the aluminum overlapped due to the thin thickness. Therefore, those two primaries will be considered as one event in the prediction algorithm. And two surface-related multiples appeared within 3s, which are indicated in green at zero-offset in Figure 4. Also, in Figure 4, four first order internal multiples are indicated in yellow at zero-offset. In the right panel of Figure 4, data are displayed in plane wave domain, and all primary events, surface-related multiples and internal multiples are indicated in same way as before.

One of the requirements of inverse scattering attenuated algorithm is that free surface multiples have to be removed before prediction algorithm implemented. As we know, inverse scattering reconstruct the internal multiples using all primaries. In this case, all primaries are included from 0 to 2s in plane wave domain. However, all free surface multiples are presented after 2s which is totally separated from all primaries. Therefore, all free surface multiples are out of time window interest as long as only 0-2s are chosen to implement inverse scattering series in plane wave domain.

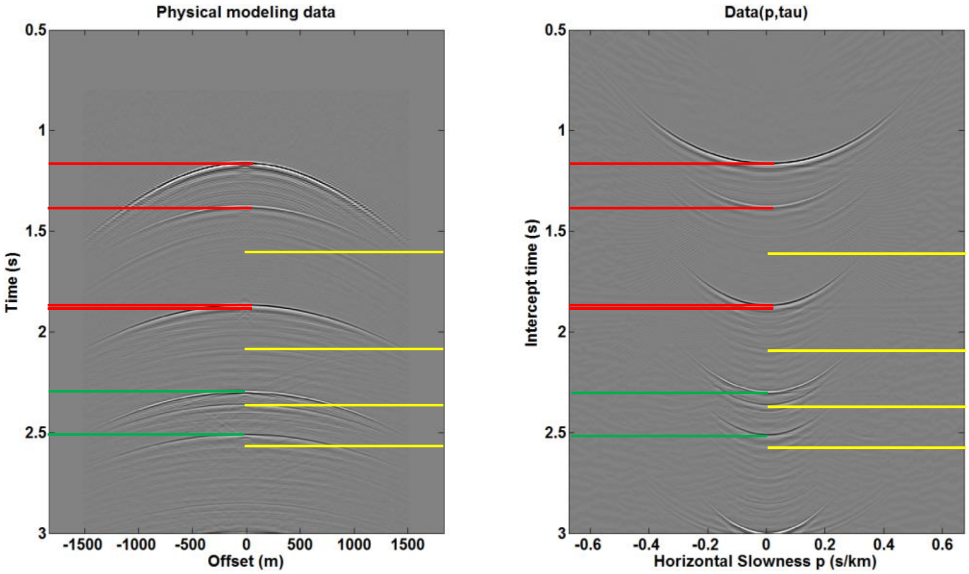

FIG.4. Physical modelling data after spiking deconvolution and its $\tau - p$ transform. At zero-offset time, all 4 primaries are indicated in red, two free surface multiples are indicated in green, and all 4 first order internal multiples are indicated in yellow.

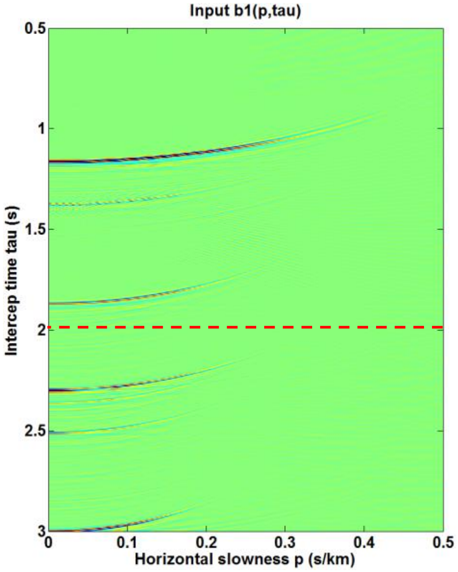

FIG. 5. Input data $b1(p, \tau)$ for plane wave domain inverse scattering series prediction

Then, the input of prediction algorithm was obtained after a factor applied. Figure 5 indicates the input data for plane wave domain inverse scattering series attenuation algorithm, and the integration-limiting parameter ϵ can be determined by the time width of one event. In Figure 6, we provide a detailed comparison between raw physical modelling data and input of plane wave inverse scattering series.

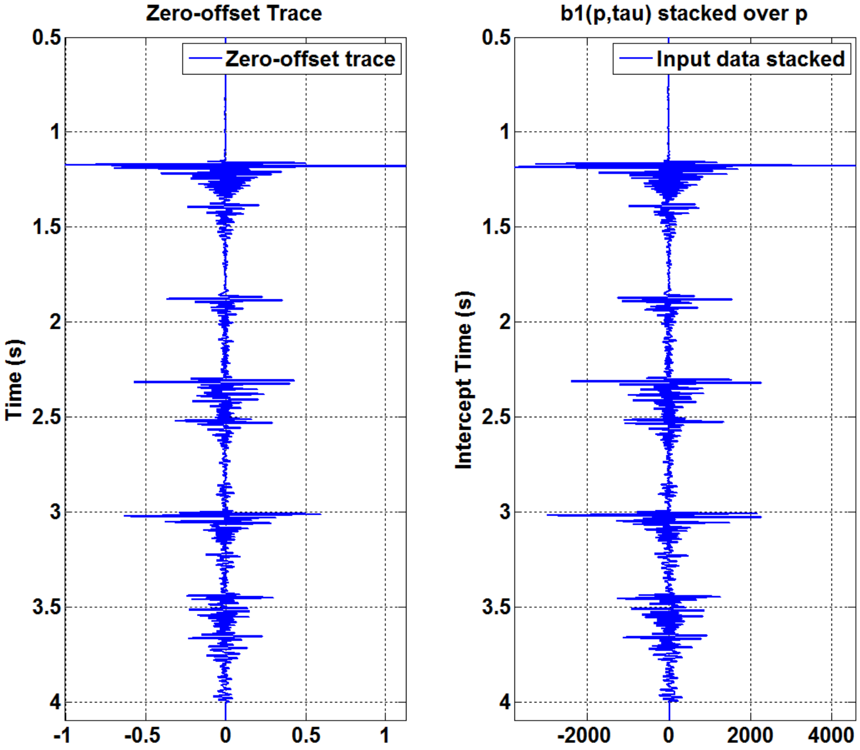

FIG. 6. Comparisons of zero-offset trace from physical modelling and stacked input $b1(\tau)$ of inverse scattering series.

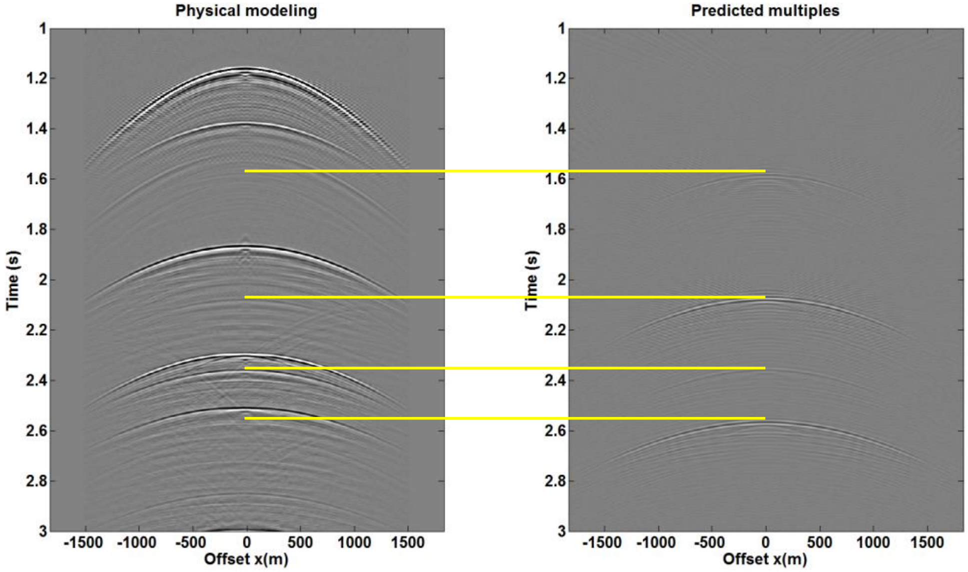

FIG. 7. Physical modelling data and predicted internal multiples using plane wave inverse scattering series algorithm. Four first order internal multiple are indicated in yellow at zero-offset.

Figure 7 illustrated predicted internal multiples with a constant epsilon ($\epsilon = 170ms$) using inverse scattering series in plane wave domain. As we can see, the travel times of predictions using inverse scattering show a good agreement with raw physical modelling data. As we mentioned before, internal multiples related to the top and bottom of the aluminum cannot be separated because the constant epsilon value ($\epsilon = 170ms$) is much larger than the time difference between those two primaries ($44ms$).

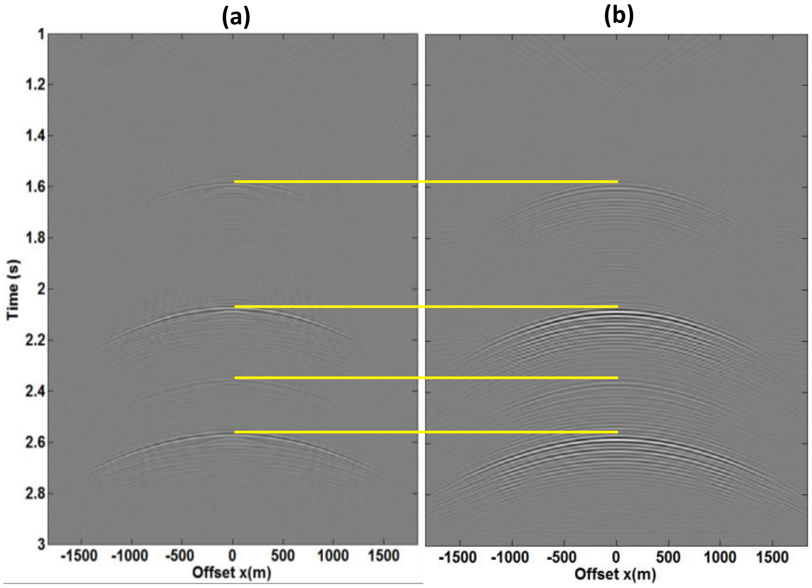

FIG. 8. Comparisons of predicted internal multiples on physical modelling data before and after spiking deconvolution. (a) shows internal multiples prediction on physical modelling with a spiking deconvolution we stated before. (b) shows internal multiples prediction on physical modelling without spiking deconvolution.

To analyze the effects of wavelet reverberation, the plane wave algorithm was also implemented with the same constant epsilon ($\epsilon = 170ms$) on the physical modelling data without spiking deconvolution (Figure 2). In Figure 8, the comparisons shows that inverse scattering series can estimate the correct travel times of internal multiples on data without deconvolution, but wavelet reverberations are also presented in the predictions which will make more difficult of adaptive subtraction. In additional to that, the wider of time bandwidth of the input will cause a larger epsilon value, and some internal multiples might be missed during the prediction. On account of that, spiking deconvolution would be suggested before the internal multiple prediction.

SYNTHETIC EXPERIMENT

In this section, to examine the capacity of this algorithm on thin layer case, we also implemented inverse scattering series on a synthetic data generated by a same velocity model. The finite difference synthetic data is shown in the left panel of Figure 9. One of differences between synthetic and physical modelling data is that events reflected by the top and the bottom of aluminum can be identified and free surface multiples are not included in synthetic data. Beyond that, the internal multiples related to the top and bottom of the aluminum can also be identified, which means two more 1st order internal multiples will presented within 3 seconds (Figure 9, indicated in yellow). The synthetic data in $\tau - p$ domain is shown in the right panel of Figure 9.

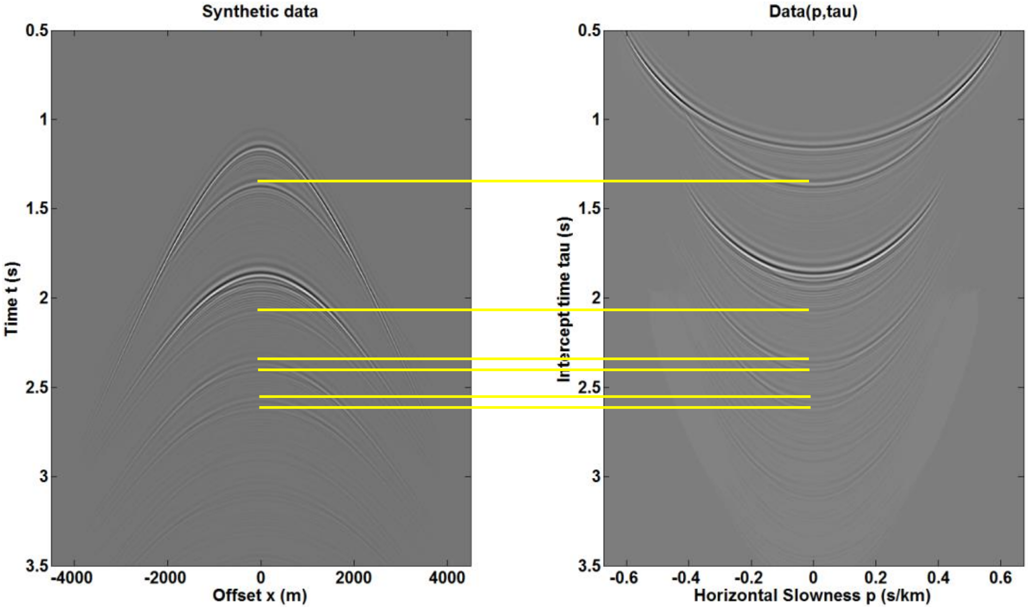

FIG. 9 Synthetic data using same velocity model in $x - t$ domain and in $\tau - p$ domain. All 1st order internal multiples are indicated in yellow at zero-offset.

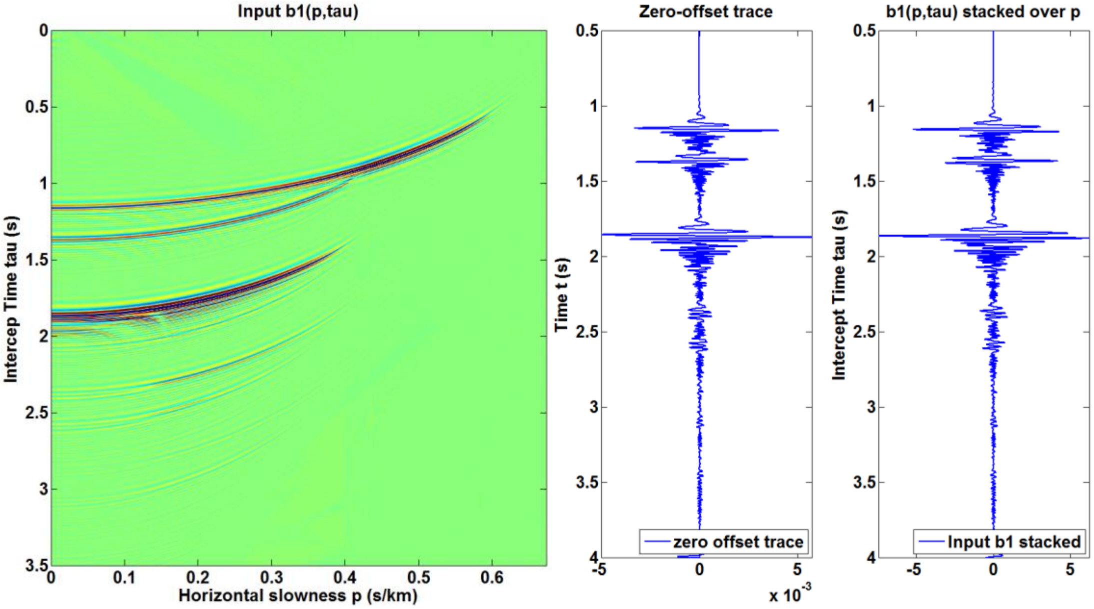

FIG. 10. Input $b1(p,\tau)$ and the comparisons between zero-offset trace and stacked $b1(\tau)$.

Similarly, input data can be obtained following the same procedure, and detailed comparisons are illustrated in Figure 10. Inverse scattering series were also presented in plane wave domain, but with a smaller constant epsilon $\epsilon = 30ms$. Predictions of internal multiple are presented in Figure 11 both in plane wave domain and offset domain. All six 1st order internal multiple we presented in Figure 9 are predicted and indicated in yellow at zero-offset in Figure 11. And an institutive comparison between synthetic data and predictions are shown in Figure 12.

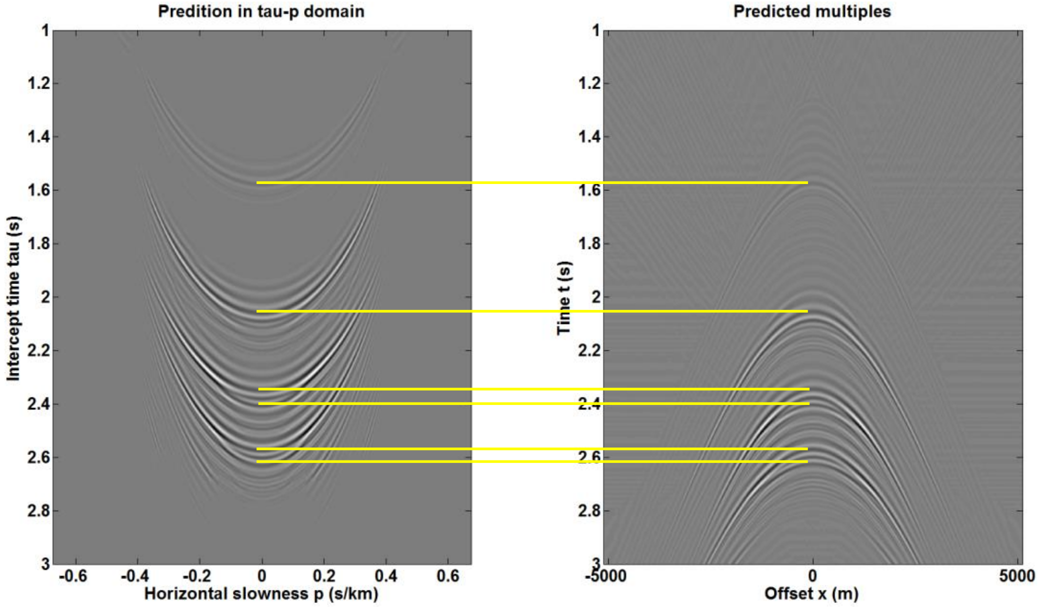

FIG. 11. Predicted internal multiples in $\tau - p$ domain and $x - t$ domain

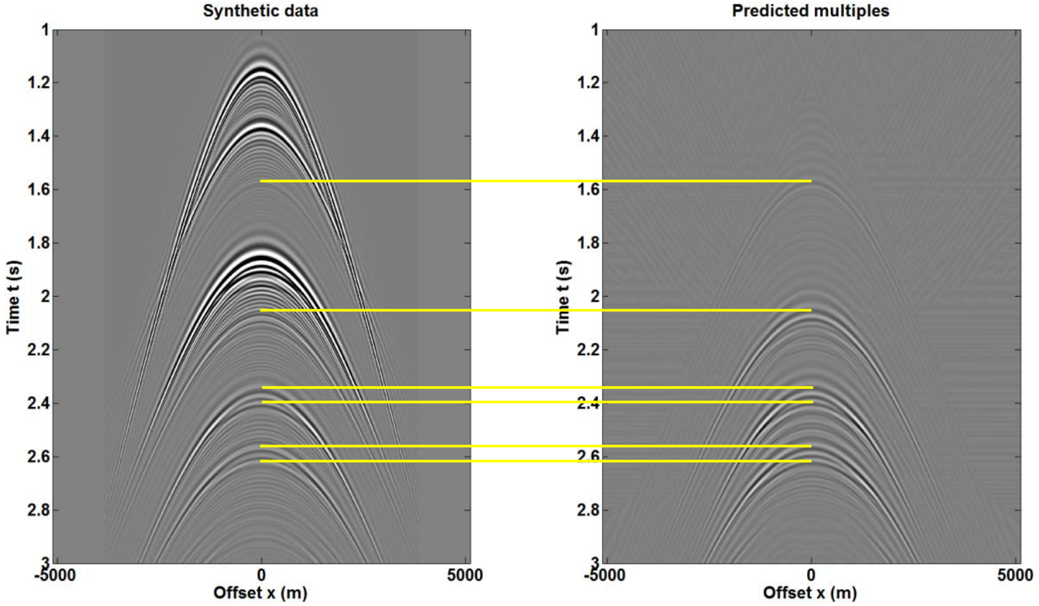

FIG. 12. Comparison of synthetic data and predicted internal multiples. All six 1st order internal multiples are indicated in yellow at zero-offset.

As expected, travel times of all orders internal multiples are predicted elegantly, and more notably, the internal multiples related to the top and the bottom of aluminum can also be separated in results which means the plane wave inverse scattering internal multiple attenuated algorithm is a useful tool of internal multiple prediction on marine dataset, but also it has a good a capability for handling thin layers case.

CONCLUSION

In this paper, we implemented inverse scattering series internal multiple attenuated algorithm on physical modelling and synthetic marine dataset in plane wave domain. The physical modeling experiment indicates that this algorithm can be efficient and reliable of internal multiple prediction on real seismic marine dataset. Spiking deconvolution would be suggested before internal multiple attenuation applied. And the synthetic test demonstrates that plane wave domain algorithm has a good ability for internal multiple prediction on thin-layer case as long as thin layer can be identified in raw dataset.

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REFERENCES

Berkhout, A. J. 2006. “Seismic Processing in the Inverse Data Space.” *Geophysics* 71 (4): A29. Berkhout, A. J., and D. J. Verschuur. 2005. “Removal of Internal Multiples with the Common-Focus-Point (CFP) Approach: Part 1 — Explanation of the Theory.” *Geophysics* 70 (3): V45–60.

Coates, R T, A B Weglein, Arco Exploration, and Production Technology. 1996. “Internal Multiple Attenuation Using Inverse Scattering: Results from Prestack 1 & 2D Acoustic and Elastic Synthetics.” *SEG Abstracts*, no. 4: 1522–25.

Hernandez, M, and J Wong. 2012. “Inverse Scattering Internal Multiple Prediction on Physical Modeling Data.” *Geoconvention*, 1–4.

Innanen, Kris. 2012. “1 . 5D Internal Multiple Prediction in MATLAB.” *CREWES Research Report* 24 (2): 1–7.

Kelamis, Panos G., Kevin E. Erickson, Dirk J. Verschuur, and A. J. Berkhout. 2002. “Velocity-Independent Redatuming: A New Approach to the near-Surface Problem in Land Seismic Data Processing.” *The Leading Edge*, 730–35. doi:10.1190/1.1503185.

Liu, Faqi, Mrinal K. Sen, and Paul L. Stoffa. 2000. “Dip Selective 2-D Multiple Attenuation in the Plane-wave Domain.” *Geophysics* 65 (1): 264–74. doi:10.1190/1.1444717.

Ma, Jitao, Mrinal K. Sen, and Xiaohong Chen. 2009. “Free-Surface Multiple Attenuation Using Inverse Data Processing in the Coupled Plane-Wave Domain.” *Geophysics* 74 (4). doi:10.1190/1.3137059.

Nita, BG, and AB Weglein. 2009. “Pseudo-Depth / Intercept-Time Monotonicity Requirements in the Inverse Scattering Algorithm for Predicting Internal Multiple Reflections 1 Introduction.” *Communications in Computational ...* 5 (1): 163–82.

Pan, Pan. 2015. “1.5D Internal Multiple Prediction: An Application on Synthetic Data, Physical Modelling Data and Land Data Synthetics.” University of Calgary.

Pan, Pan, and Kris Innanen. 2013. “Numerical Analysis of 1 . 5D Internal Multiple Prediction.” *CREWES Research Reports* 25: 1–12.

Sun, Jian, and Kris Innanen. 2014. “1.5D Internal Multiple Prediction in the Plane Wave Domain.” *CREWES Research Report* 26: 1–11.

———. 2015. “1 . 5D Internal Multiple Prediction in the Plane Wave Domain.” *Geoconvention*, 1–4.

Taner, M.T. 1980. “Long Period Sea-Floor Multiples and Their Suppression.” *Geophysical Prospecting*, no. June 1975: 30–48.

Treitel, Sven, P. R. Gutowski, and D. E. Wagner. 1982. “Plane-wave Decomposition of Seismograms.” *Geophysics* 47 (10): 1375–1401. doi:10.1190/1.1441287.

Verschuur, D. J., and A. J. Berkhout. 2005. “Removal of Internal Multiples with the Common-Focus-Point (CFP) Approach: Part 2 — Application Stategies and Data Examples.” *Geophysics* 70 (3): V61–72.

Verschuur, Dirk Jacob. 1991. “Surface Related Multiple Elimination- an Inversion Approach.”

Weglein, AB, FA Gasparotto, PM Carvalho, and RH Stolt. 1997. “An Inverse-Scattering Series Method for Attenuating Multiples in Seismic Reflection Data.” *Geophysics* 62 (6): 1975–89.