Internal multiple prediction in the tau-p domain: 1.5D synthetic results

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ABSTRACT

Internal multiples on land data can be predicted in an efficient way using inverse scattering series approach, and more elegant results could be achieved in plane wave domain than in wavenumber-pseudo depth domain. With a view to the feasibility of this algorithm on land data with thin layers and large offset, we carried out a complex model using Hussar well-log, and implemented 1.5D algorithm with a constant epsilon value in plane wave domain. All internal multiples were delicately predicted with a straightforward muting or cosine taper.

INTRODUCTION

Internal multiple elimination is still 'a Gordian knot', for all that much considerable progress have been made recently. Several innovative technologies have been developed, but most of methods have been only successfully applied in marine dataset. Internal multiple attenuation on land data continues to be a grand challenge because of its unique characteristics such as noise, statics and coupling (Luo et al. 2011). 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. However, both of those two strategies require superabundant user actions and extensive knowledge of multiple-generating boundaries (Verschuur & Berkhout, 2005), which are not appropriate in all practical situations. The inverse scattering series algorithm treats all possible internal multiple-generators in a stepwise and automatic way (Weglein et al. 1997; Verschuur & Berkhout 2005).

Hernandez and Innanen (2012) implemented the inverse scattering series algorithm on poststack land dataset. After that Pan and Innanen (2013, 2015) carried out a 1.5D test on synthetic, physical modeling dataset in wavenumber pseudo-depth domain on the basis of the version proposed by Innanen (2012). In previous posts, we analyzed the relationship between pseudo-depth and intercept time on the foundation of Coates et al. (1996) and Nita and Weglein (2009), and presented a 1.5D inverse scattering approach in the plane wave domain with improved numerical accuracy and reduced Fourier artifacts (Sun & Innanen, 2014, 2015). To give an eye for the feasibility of inverse scattering series on land data with thin layers and large offset, the plane wave domain algorithm will be applied on a complex synthetic land data generated with a sonic log, which was collected by CREWES at Hussar, Alberta (Isaac & Margrave 2011) .

HUSSAR SYNTHETIC

To study the low frequency content of seismic data, CREWES carried out an experimental low-frequency seismic shoot line at Hussar, Alberta in September, 2011.

The seismic line was 4.5km runs NE-SW with across or close to 5 wells (Figure 1), i.e., 5-27, 12-27, 14-27, 1-34, and 14-35 (Margrave et al. 2012).

In this experiment, well 12-27 was chosen which includes P-wave sonic, S-wave sonic, density log, and Gamma ray log. Here, only P-wave sonic log (Figure 2) was applied to obtained a velocity model and generated synthetic datasets. In next section, to examine the capacity of the predicted algorithm for thin-layer cases, P-wave velocity of well 12-27 will be blocked with different intervals to created complex synthetic datasets in large offset.

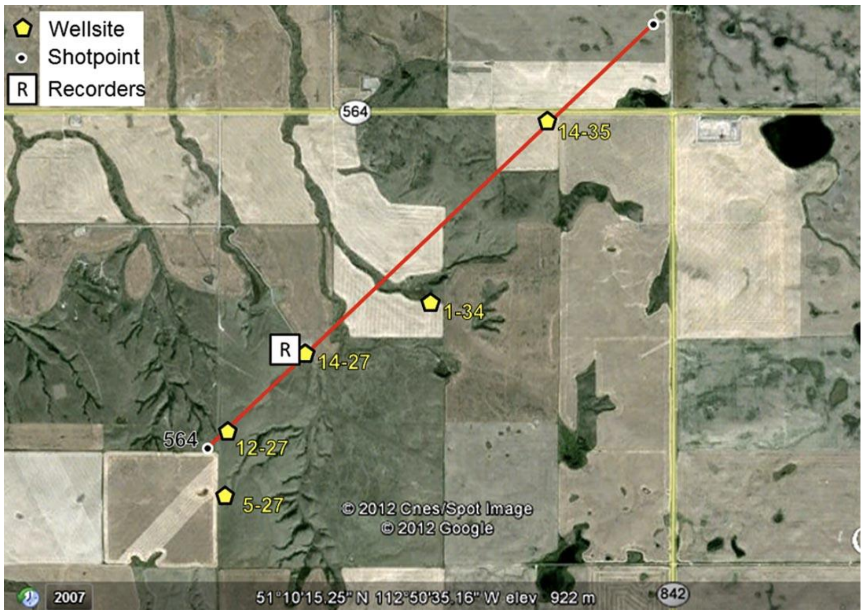

FIG. 1. The location of Hussar seismic line and 5 wells (Margrave et al. 2012)

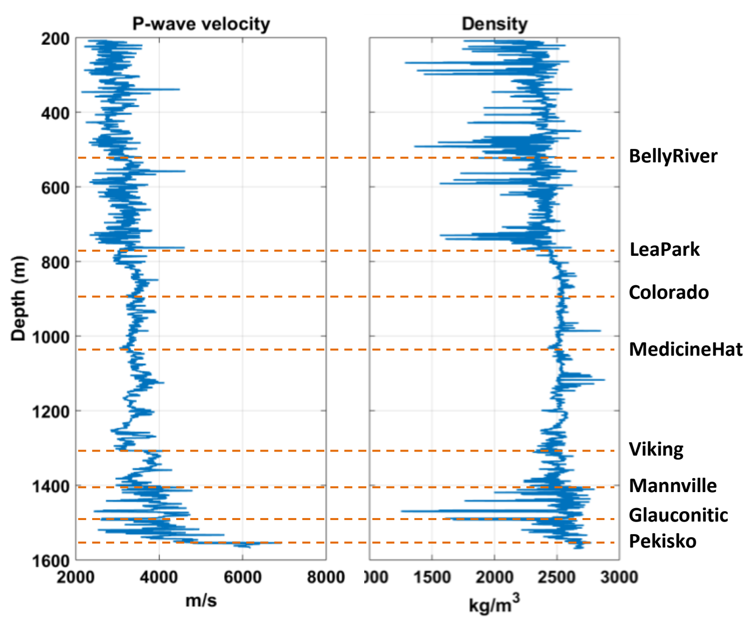

FIG. 2. P-wave velocity of well 12-27 and geological markers

EXPERIMENT

Here, P-wave sonic log was first blocked in 100m intervals to build a multi-layered velocity model and a synthetic dataset was generated using finite difference method with four absorbing boundaries. Therefore, only primaries and internal multiples are included in the synthetic land dataset. After that, the plane wave inverse scattering series algorithm is implemented to predict all internal multiples.

The difference of second case is that P-wave sonic log to create velocity model is non-blocked and only sampled by 2m interval. As a consequence, plenty of thin layers are generated as the velocity is gradually varied. That will give us a great opportunity to inspect how well this algorithm on extremely thin-layer case is.

Hussar synthetic with 100m blocked well-log

Figure 3 shows the P-wave velocity of well 12-27 and blocked P-wave sonic log with 100m interval. The velocity from surface to 200m is considered as a constant which is 2563m/s.

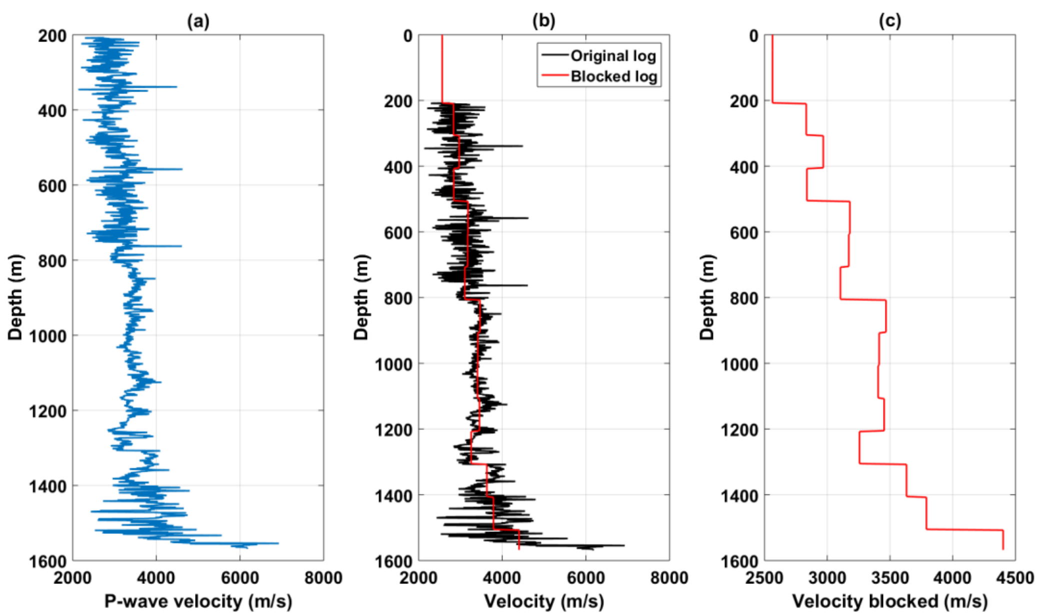

FIG. 3. Sonic log of P-wave and blocked sonic log with 100m interval

A synthetic multi-layered velocity model was created using the blocked P-wave sonic log (Figure 3c) and shown in Figure 4. The velocity model will be applied with finite difference method *afd_shotrec* from CREWES toolbox to generate a shot record, which is indicated in Figure 5a. In Figure 5b, Hussar synthetic dataset is shown in the $\tau - p$ domain.

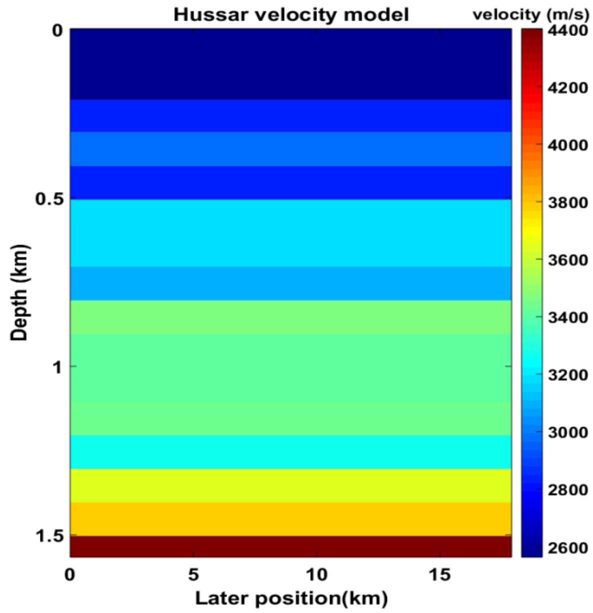

FIG. 4. Hussar velocity model using blocked log with 100m interval

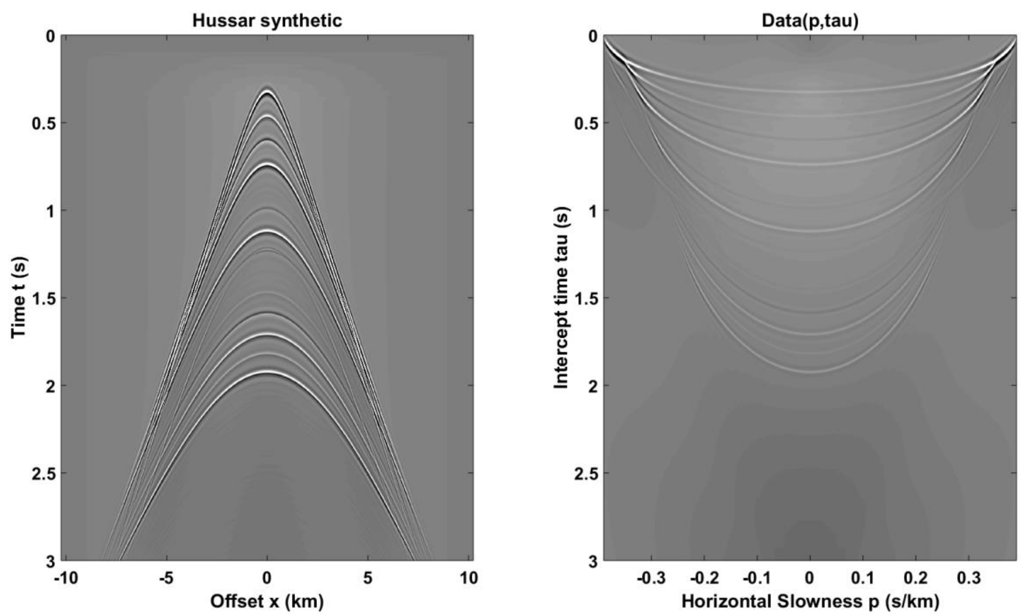

FIG. 5. Hussar synthetic data and $\tau - p$ transformed result

Following the procedure we declared before (Sun & Innanen, 2014, 2015), the input $b1(p,\tau)$ of inverse scattering series algorithm in plane wave domain are obtained and shown in Figure 6. The epsilon value can be determined as the bandwidth of one event by zooming in the input data. With an eye at the zoomed in input, a bit artifacts can be identified in large horizontal slowness range, which is caused by the defective absorbing boundary condition and the unstable of $\tau - p$ transform. The impacts will be included in the result because those artifacts are right in the horizontal slowness range of the algorithm. Setting that aside for a moment, we looked into the comparison of synthetic and input dataset in details. The trace at zero-offset was extracted from Hussar synthetic and the input was stacked over all horizontal slowness, which was represented in Figure 7.

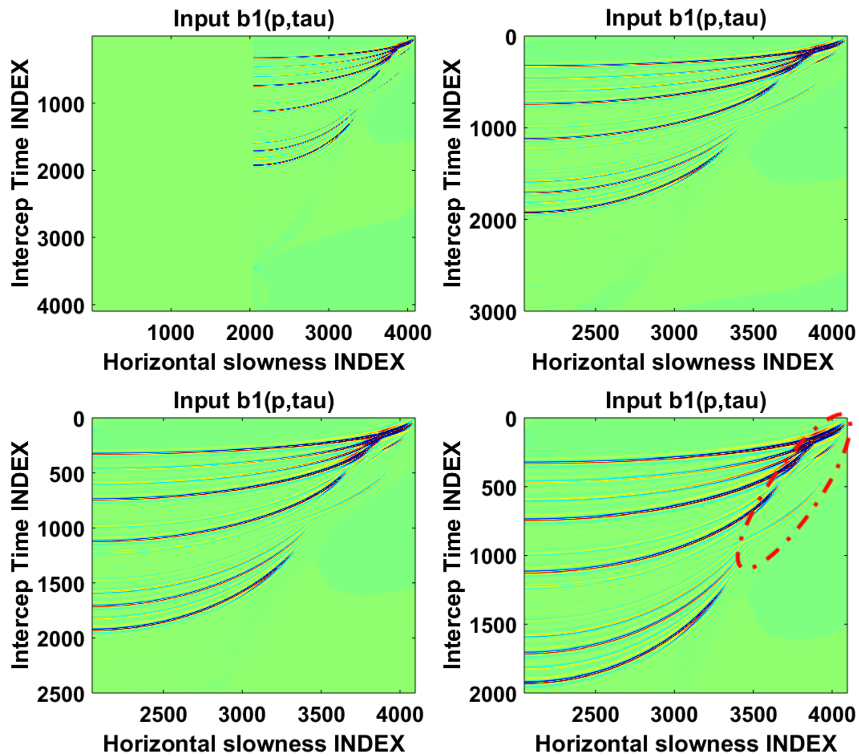

FIG. 6. Input $b1(p,\tau)$ for plane wave domain inverse scattering series algorithm

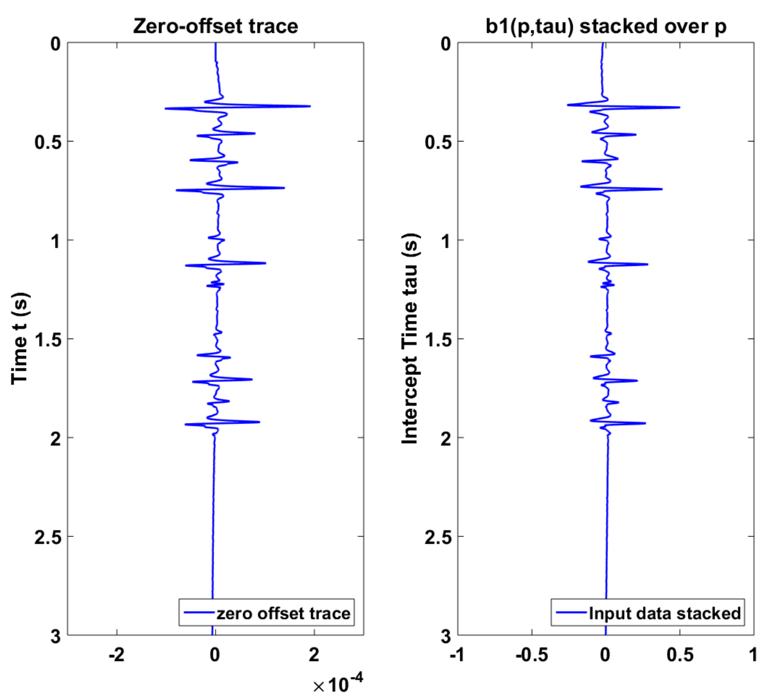

FIG. 7. Comparisons between zero-offset trace from synthetic dataset and stacked input $b1(\tau)$

After plane wave algorithm applied, internal multiples were predicted in the plane wave domain and shown in left panel of Figure 8. Final results are obtained with the inverse $\tau - p$ transform and delineated in right panel of Figure 8. It's no surprise that all internal multiples were predicted in an elegant way using inverse scattering series. However, it still has a bit defects that indicated into two straight lines of final results, which is caused by two bright spots in $\tau - p$ domain. Here, we applied a simple rectangle window in $\tau - p$ domain to mute two bright spots directly, and then transformed the prediction into $x - t$ domain.

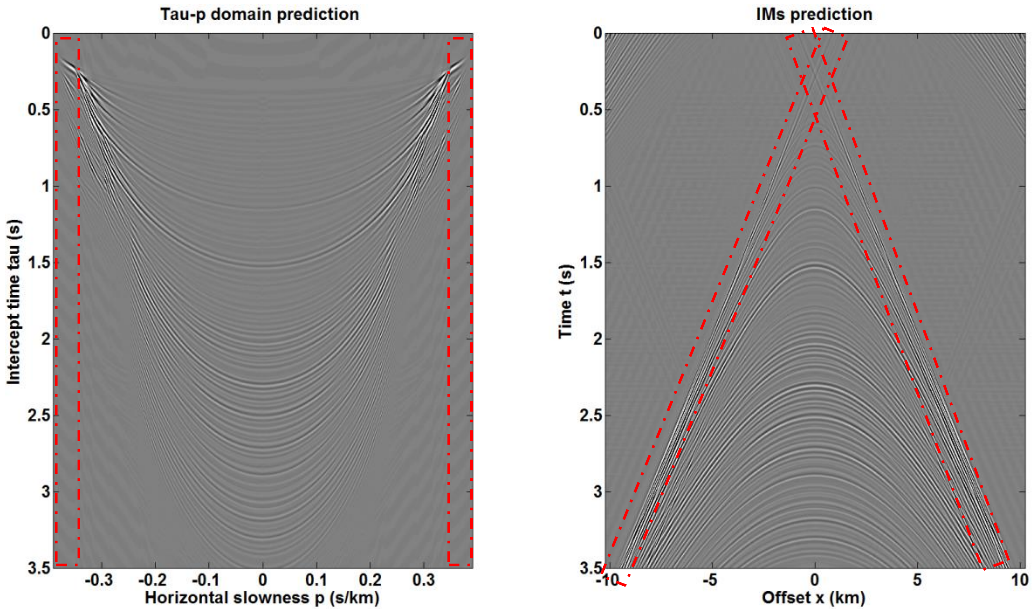

FIG. 8. Initial internal multiple predictions in $\tau - p$ domain and $x - t$ domain

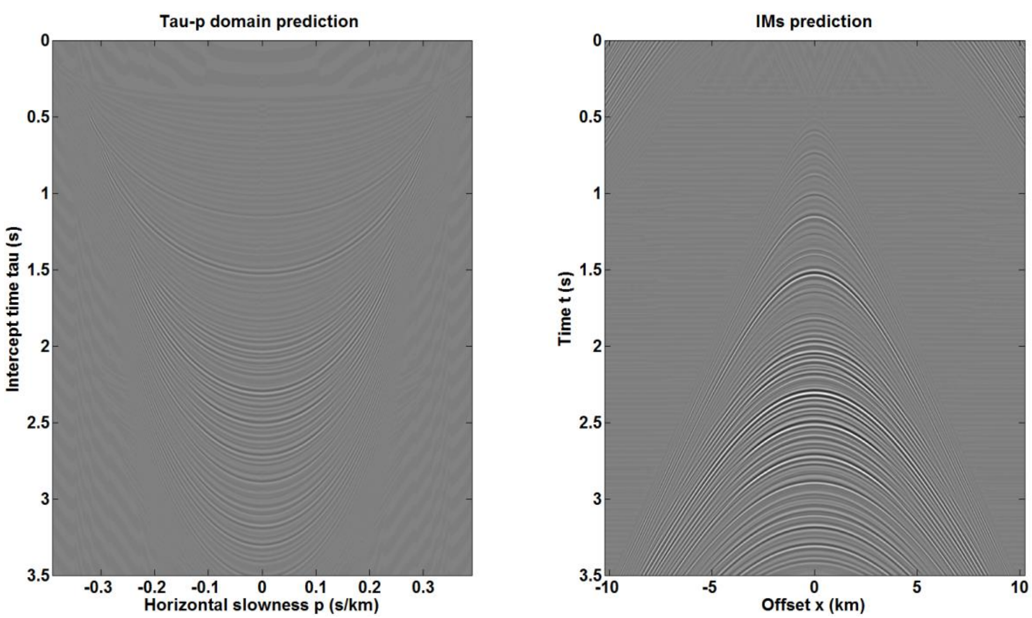

FIG. 9. Internal multiple predictions with a simple taper window applied in $\tau - p$ domain

The results after a simple muting are shown in Figure 9, and it's readily to see that two-straight-line artifacts are removed perfectly. The comparisons of Hussar synthetic, IMs prediction before and after muting are described in Figure 10.

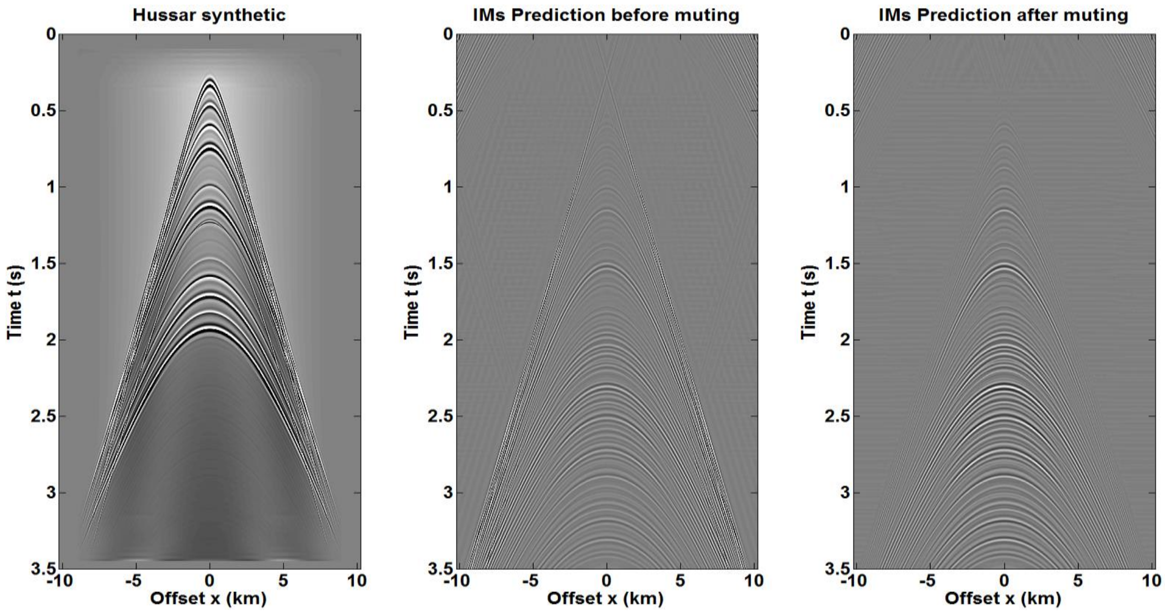

FIG. 10. Comparisons between Hussar synthetic (left), initial IM predictions (middle), and internal multiples prediction after muting (right)

Hussar synthetic with non-block well-log

The P-wave velocity of well 12-27 (Figure 2) was resampled with 2m interval, and shown in left panel of Figure 11. In the right panel of Figure 11, a multi-thin-layer velocity model was created using resampled P-wave sonic log. Analogously, Hussar synthetic will be generated using finite difference with four absorbing boundaries. However, with plenty of layers, the attenuation of wave goes faster, and only shot record within 5km are shown in Figure 12 (left). And $\tau - p$ transform dataset is calculated and indicated in right panel of Figure 12.

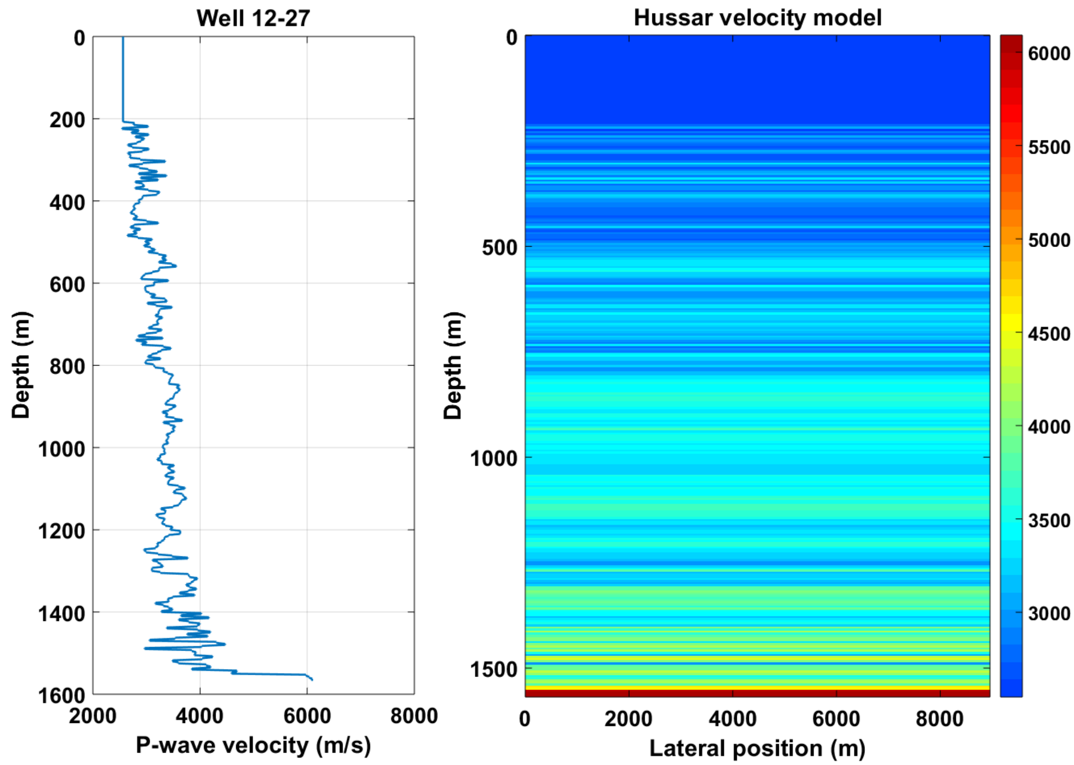

FIG. 11. Sampled well-log of P-wave velocity and synthetic velocity model

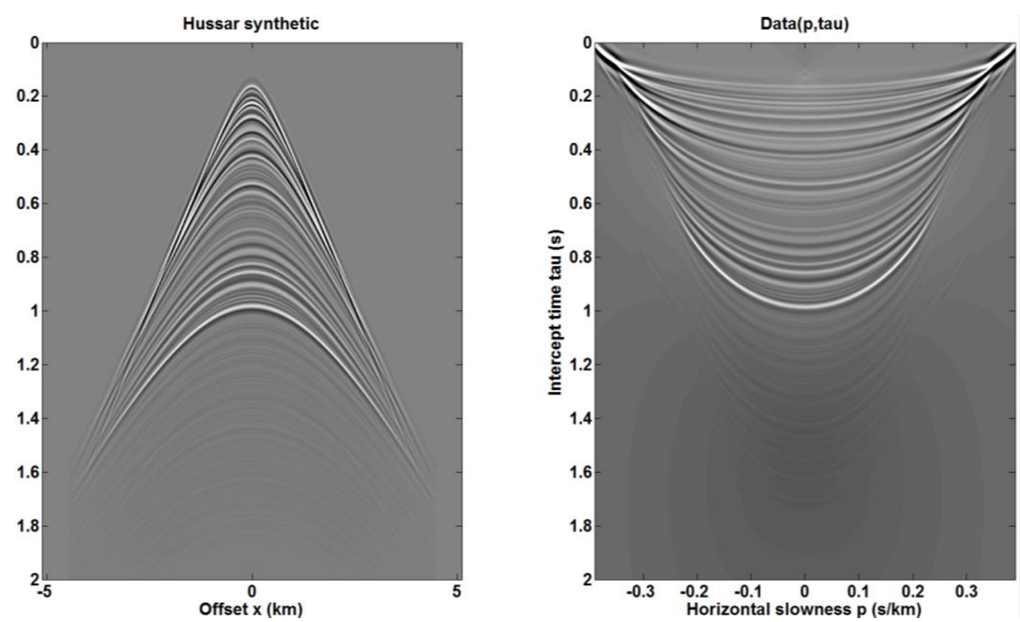

FIG. 12. Hussar synthetic data using non-block P-wave sonic log and its $\tau - p$ transform

In next step, the input of inverse scattering series in plane wave domain (Figure 13) was obtained using same method we stated before, and detailed comparisons between zero-offset trace of synthetic data and stacked input $b1(\tau)$ are shown in Figure 14. Both of them are more complicated than traces in Figure 7.

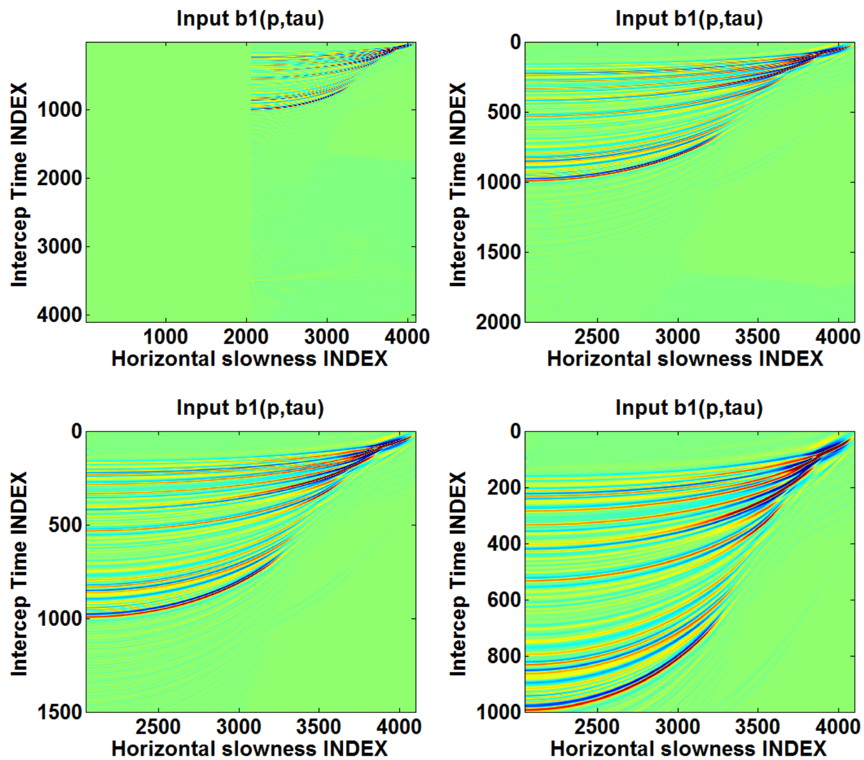

FIG. 13.Non-block input $b1(p,\tau)$ for plane wave domain inverse scattering series algorithm

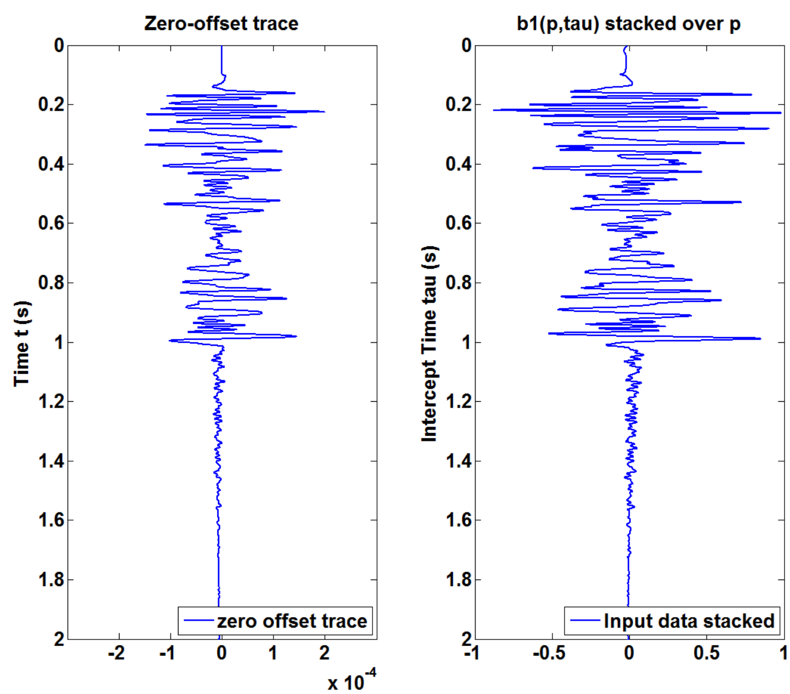

FIG. 14. Comparisons between non-block zero-offset trace and stacked input $b1(\tau)$

Initial Predicted results of internal multiple in $\tau - p$ domain and $x - t$ domain are indicated in Figure 15. Internal multiple predictions are still impressive even though two-straight-line effects appears. Here, we provide two different ways to remove the bright-spot effects in plane wave domain, directly muting and a simple cosine window.

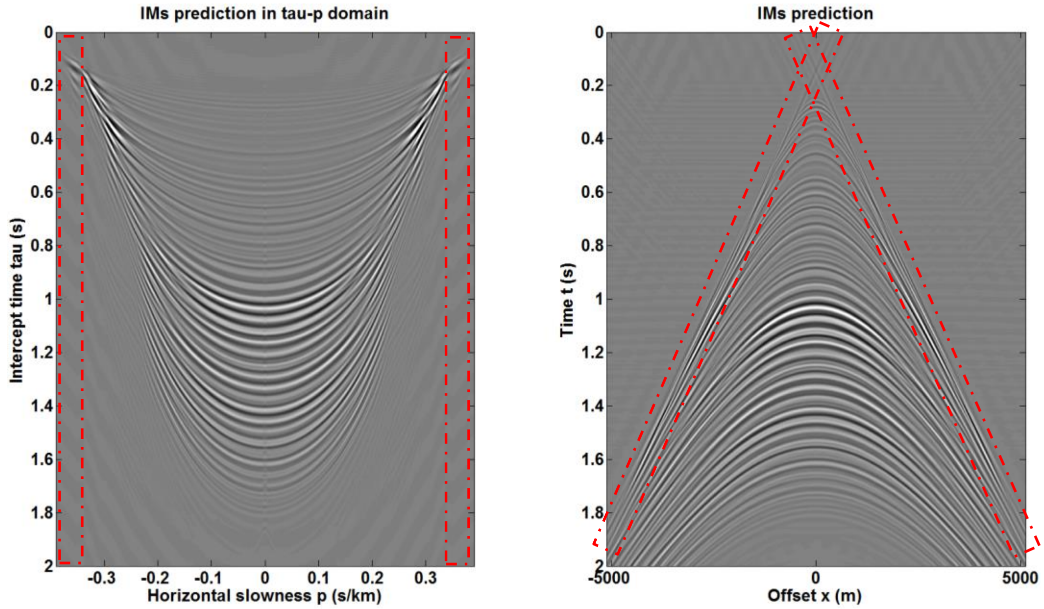

FIG. 15. Initial internal multiple predictions in $\tau - p$ domain and $x - t$ domain

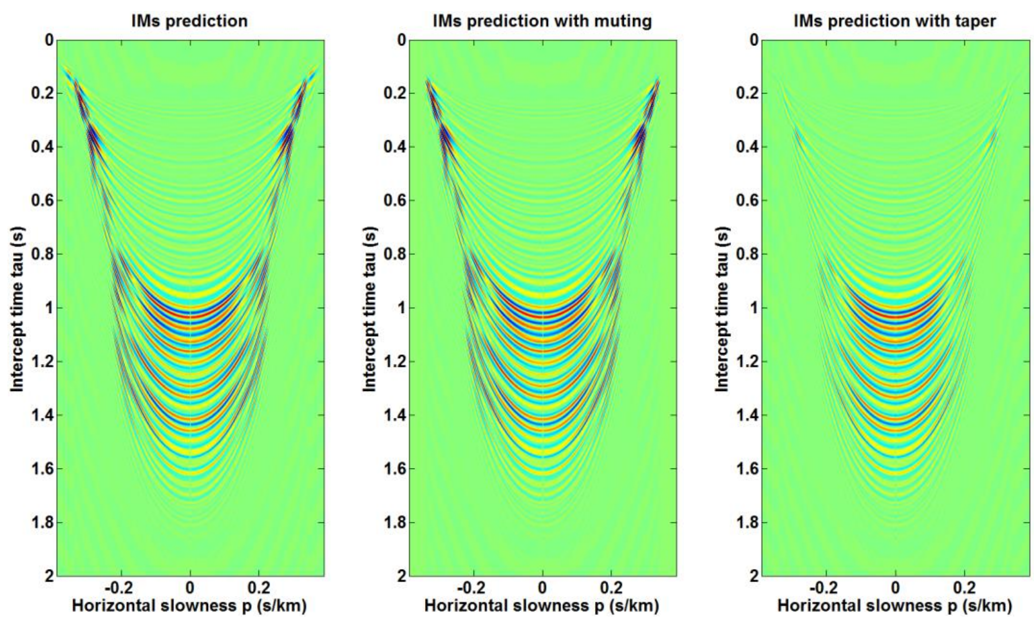

FIG. 16. Comparisons between initial predictions (left), muted predictions (middle), an predictions with taper (right) in $\tau - p$ domain

Final predicted results with two different windows were collected and compared with initial predictions in $\tau - p$ domain, shown in Figure16. Both of two strategies can eliminated the effects of bright-spots successfully. However, the cosine taper window also attenuated the amplitude of internal multiples at large horizontal slowness. In Figure 17, we compared initial predictions, muted predictions, tapered predictions, with Hussar synthetic. As we discussed, predictions with cosine window applied also attenuated amplitudes of internal multiples at large offset.

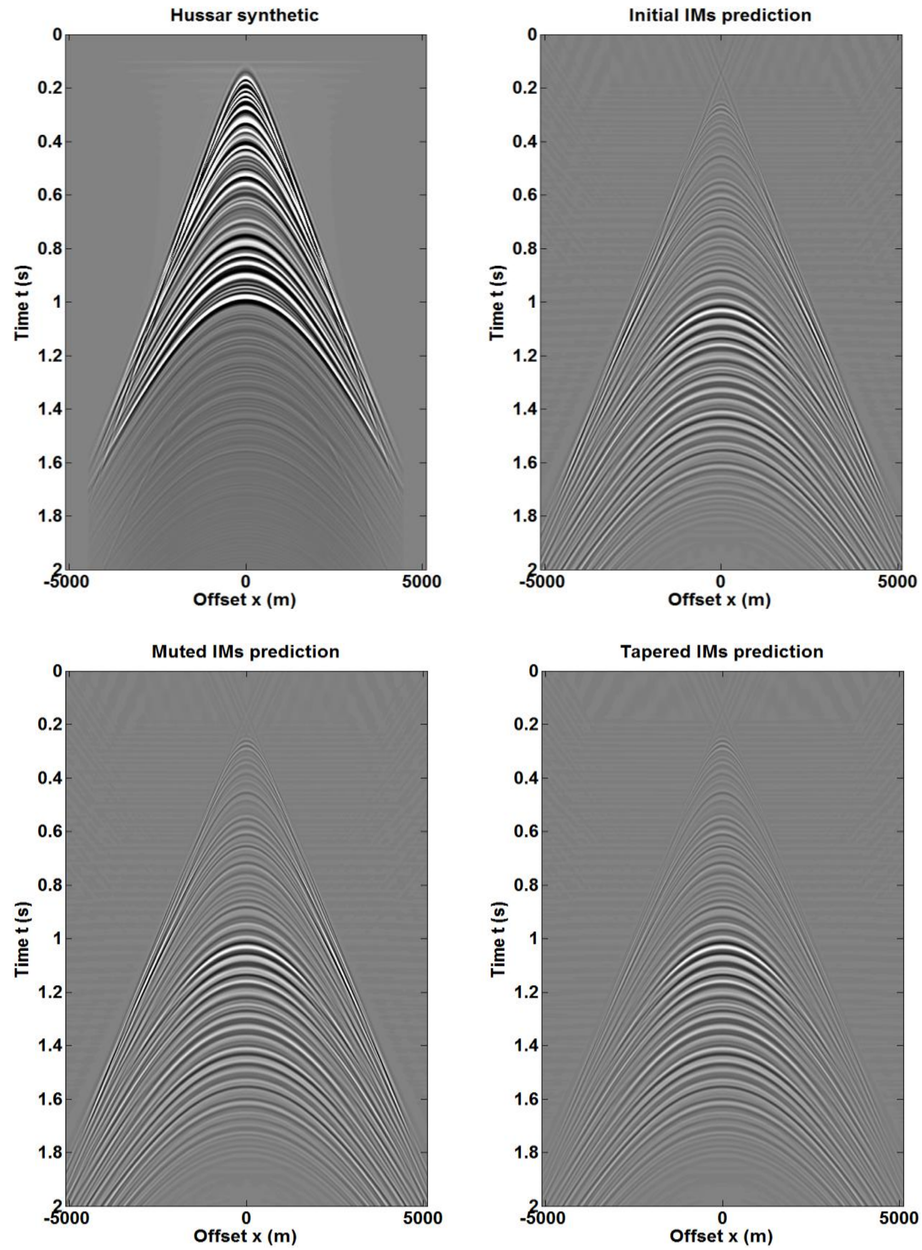

FIG. 17. Comparisons between non-block Hussar synthetic (upper left), initial IM predictions (upper right), IM predictions with muted directly (bottom left), and IM predictions with taper (bottom right).

CONCLUSION

We presented 1.5D internal multiple predictions on synthetic land dataset with multi-thin layers and large offset using inverse scattering series algorithm in plane wave domain. And two different type taper windows were suggested to remove bright-spot artifacts caused by $\tau - p$ transform. After that, a quite elegant internal multiple predicts is obtained without any large offset artifacts and impacts of thin-layer. It's indubitable to say that plane wave domain inverse scattering is an efficient and wise way to eliminate internal multiple on land dataset.

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