Extension of internal multiple prediction: 1.5D to 2D in double plane wave domain

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Abstract

Internal multiple (IM) can be constructed by primary events based on inverse scattering series (ISS) algorithm. More benefits can be achieved in plane wave domain, such as improved numerical accuracy, no dipping artifacts, and less computing time. In view of that, the plane wave domain ISS algorithm can be considered as a promising way to eliminate internal multiples on land data, even for a full 2D case. 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. In addition to that, $\tau - p_s - p_g$ transform is introduced to make it possible that transfering 1.5D to 2D using ISS internal multiple attenuation algorithm. A simple synthetic 2D case is applied to 2D internal multiple prediction and preliminary achievements of internal multiple prediction exemplified that more relevant and practical benefits can be provided by the double plane wave domain 2D ISS algorithm.

Introduction

Internal multiple attenuation is still 'a Gordian knot' in seismic processing, especially on land data, for all that much considerable progress have been made. 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) and was further implemented by Berkhout and Verschuur (2005) to attenuate internal multiples by considering internal multiples as the suppositional surface-related multiples. 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.

Inverse scattering series (ISS) indicated that all possible internal multiples can be reconstructed by primary events (Weglein et al. 1997), and the algorithm is full data driven, which means no subsurface information required and all internal multiples generator will be treated in a stepwise and automatic way (Weglein et al. 1997; Verschuur and Berkhout 2005). Hernandez and Innanen (2012) implemented ISS algorithm on poststack dataset. 1.5D tests was carried out by Pan and Innanen (2013, 2015) on synthetic, physical modeling dataset in wavenumber pseudo-depth domain. In previous posts, by further analyzing the monotonicity conditions of ISS algorithm, we presented the plane wave domain ISS algorithm with several advantages: improved numerical accuracy, no dipping artifacts, and constant searching parameter (Coates et al. 1996; Nita and Weglein, 2009; 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. And consider the complexity of land dataset, 2D internal multiples attenuation is presented with double $\tau - p_s - p_g$ transform. Some preliminary predictions are achieved and those results demonstrate that more potential and practical benefits can be achieved using the inverse scattering series in the coupled plane wave domain.

1.5D case of IM prediction

The P-wave sonic log of well 12-27, recorded at Hussar by CREWES, was resampled with 2m interval and shown in Figure 1 (left). A multi-thin-layer velocity model was created using resampled P-wave sonic log (Figure 1, middle). Analogously, Hussar synthetic will be generated using finite difference with four absorbing boundaries. (Figure 1, right). The $\tau - p$ transform was performed (Figure 2, left), and then the input data of plane wave domain ISS algorithm was obtained by multiplying the factor $-2iq_s$, which is shown in Figure 2, middle. And 1.5D plane wave domain ISS algorithm was performed to predict all possible internal multiples.

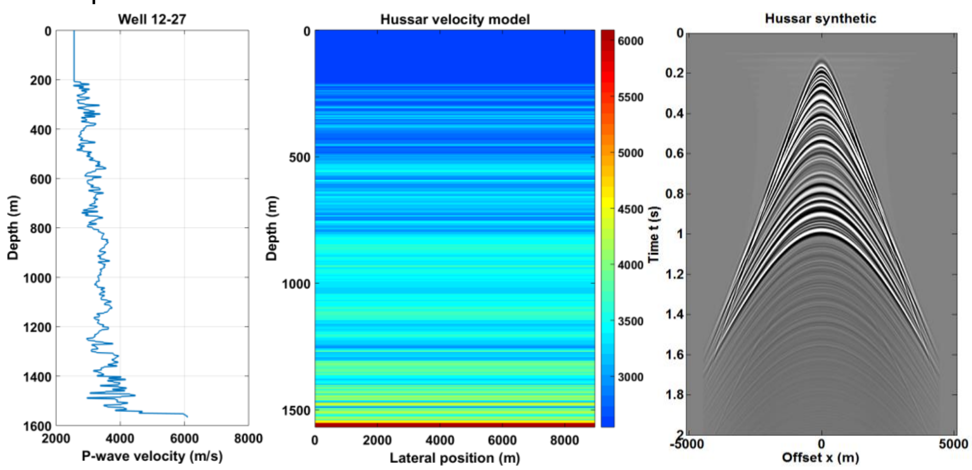

FIG. 1. Sampled well-log of P-wave velocity, synthetic velocity model, and synthetic dataset

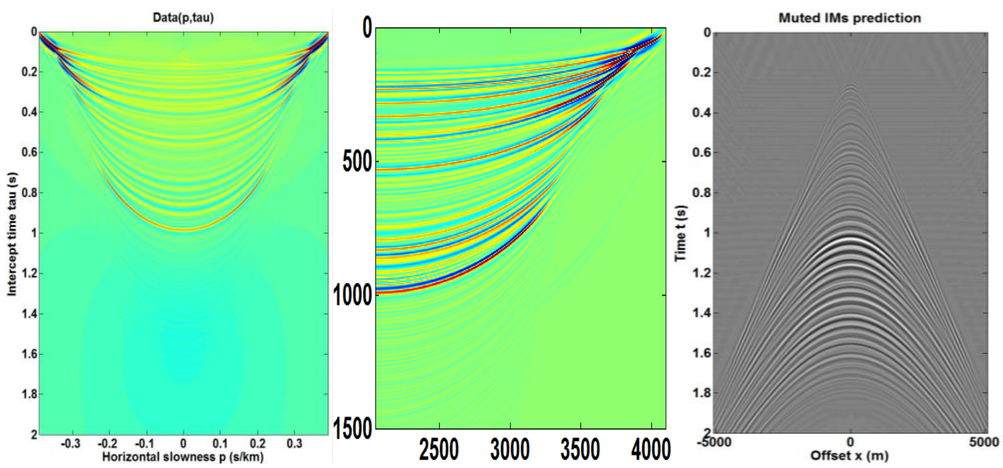

FIG. 2. Hussar synthetic data in $\tau - p$ domain (left), the input of ISS algorithm (middle), and IM prediction (right).

An elegant estimates of internal multiple was obtained, which is shown in Figure 2, right. As mentioned, the spectral of events are well focused, and no dipping artifacts or impacts of thin layer are included. Therefore, it's indubitable to say that 1.5D plane wave domain inverse scattering is an efficient and wise way to eliminate internal multiple on land dataset. To extend the 1.5D to 2D case, the 2D ISS algorithm will be recalled and double $\tau - p_s - p_g$ transform is introduced to prepare the input.

2D Inverse scattering series and double $\tau - p_s - p_g$ transform

By combining the monotonicity condition and 2D pseudo-depth domain ISS algorithm (Araujo et al. 1994) and Weglein et al., 1997), the double plane wave domain ISS algorithm can be described, which is the same one first mentioned by Coates et al. (1996),

$$
\begin{aligned}
b_{3_{IM}}\left(p_g, p_s, \omega\right) &= \frac{1}{(2\pi)^2} \iint_{-\infty}^{+\infty} dp_1 e^{-i\omega\left(\tau_{1g}-\tau_{1s}\right)} dp_2 e^{-i\omega\left(\tau_{2g}-\tau_{2s}\right)} \\
&\times \int_{-\infty}^{+\infty} d\tau e^{i\omega\tau} b_1\left(p_g, p_1, \tau\right) \int_{-\infty}^{\tau-\epsilon} d\tau' e^{-i\omega\tau'} b_1\left(p_1, p_2, \tau'\right) \int_{\tau'+\epsilon}^{+\infty} d\tau'' e^{i\omega\tau''} b_1\left(p_2, p_s, \tau''\right)
\end{aligned} \tag{3}
$$

where p_g, p_s are the source and receiver horizontal components of slowness (which are equal in 1.5D cases) respectively. The time variables τ, τ' and τ'' are intercept time of three events satisfied lower-higher-lower relationship.

In order to prepare the input data of Eq.(3), a double $\tau - p_s - p_g$ transform of the multicoverage data can be considered as the decomposition with respect to source and receiver locations simultaneously in frequency domain, which can be accomplished by the variant slant stacking with a particular phase shift applied over source and receiver respectively (Stoffa et al. 2006). Therefore, the forward double $\tau - p_s - p_g$ transform for a fixed frequency can be expressed as,

$$
D\left(p_s, p_g, \omega\right) = \iint_{-\infty}^{+\infty} d\left(x_s, x_g, \omega\right) e^{+i\omega\left(p_s x_s + p_g x_g\right)} dx_s dx_g \tag{4}
$$

with the inverse double $\tau - p_s - p_g$ transform as,

$$
d\left(x_s, x_g, \omega\right) = \iint_{-\infty}^{+\infty} D\left(p_s, p_g, \omega\right) e^{-i\omega\left(p_s x_s + p_g x_g\right)} dp_s dp_g \tag{5}
$$

where, x_s, x_g are the source and receiver location in a same coordinate. p_s, p_g are the horizontal slowness at source location and receiver location respectively.

2D case of IM prediction

To examine the capacity of the ISS algorithm in double plane wave domain, a 3-layer model including two reflectors (Figure 3a, one dipping reflector with 10^0 and one flat reflector) was used to generate the multi-shot records. And the 3D display of multi-shot is shown in Figure3b. Figure 3c indicated that 3 common shot gathers we extracted from 3D data volume. Two primary events and the 1st order internal multiple can be identified in each shot gather.

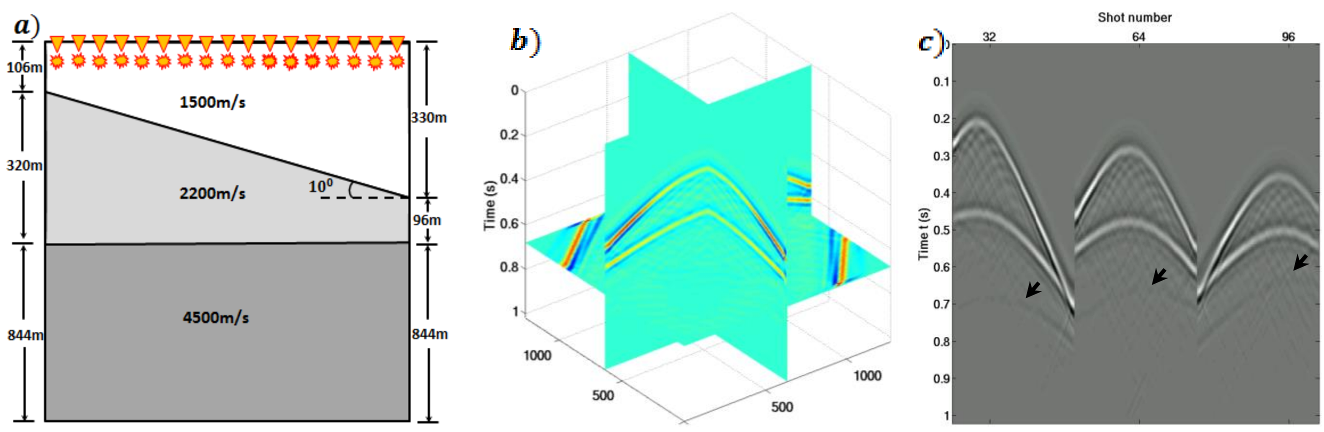

FIG. 3. a) Velocity model, b) 3D display of synthetic multi-shot records, c) Shot gathers: 310m, 630m,950m..

After double $\tau - p_s - p_g$ transform, three slices at $p_s = -0.3, 0, 0.3$ (common p_s gathers) were also extracted and shown in Figure 4a. In Figure 4b, the data matrix (p_s, p_g) at 15Hz was shown, which demonstrated that the matrix (p_s, p_g) at a fixed frequency is an antidiagonal sparse matrix. Figure 4c delineated that the common shot gathers at same location of Figure 3c, extracted from IM prediction. We can see that all possible internal multiples shown in 3 shot gathers were predicted elegantly.

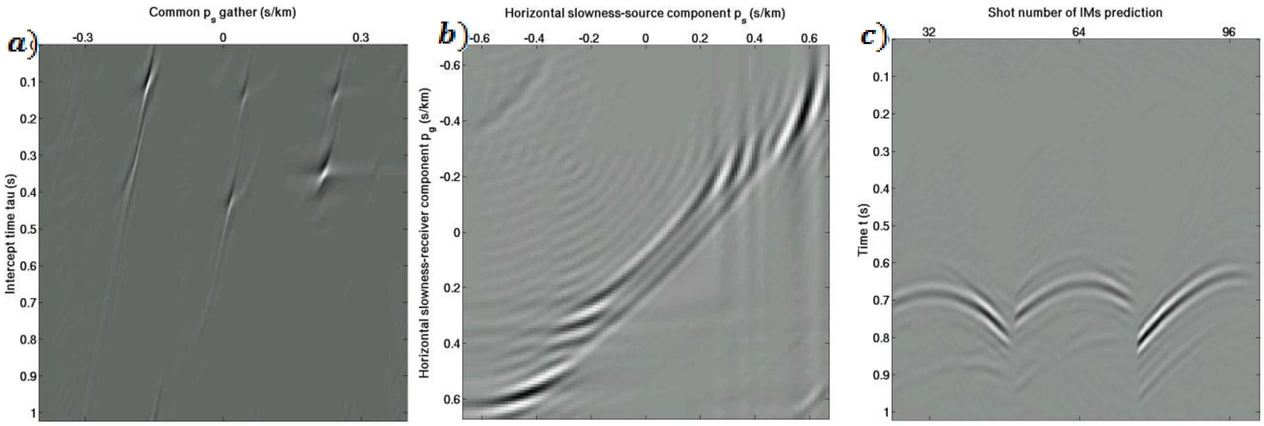

FIG. 4. a) Common p_s gathers at $p_s = -0.3, 0, 0.3$, b) 15 Hz data matrix (p_s, p_g), c) Shot gathers of IM predictions.

Conclusions

Inverse scattering series (ISS) algorithm can be applied to reconstruct all possible internal multiples. It can bring more benefits because its' full data driven property and all multiple generators will be treated in a stepwise and automatic way. We presented 1.5D internal multiple predictions on synthetic land dataset with multi-thin layers and large offset using ISS algorithm in plane wave domain. For a 2D case, the double $\tau - p_s - p_g$ transform was introduced to prepare the input of ISS algorithm. Those preliminary results exemplified that more relevant and practical profits can be provided by (double) plane wave domain ISS algorithm.

Acknowledgements

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