

1.5D Internal multiple prediction in the plane wave domain

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Summary

The inverse scattering series internal multiple attenuation algorithm was developed by Weglein and collaborators in the 1990s, based on the fact that internal multiples could be constructed from subevents satisfying the lower-higher-lower relationship in the pseudo-depth domain. Innanen (2012) implemented a 1.5D version of the algorithm in MATLAB and complemented the 1D version of the algorithm studied by Hernandez and Innanen (2012). We present a 1.5D MATLAB implementation of this algorithm in plane wave domain, as initially formulated by Coates and Weglein (1996) and analyzed by Nita and Weglein (2009). Compared to the application in the wavenumber-pseudo depth domain, we generate improved numerical accuracy and reduced Fourier artifacts from internal multiple prediction in the plane wave domain. Furthermore, the procedure for generating the input data is greatly simplified. We believe the plane wave domain is a promising way of posing full 2D versions of the algorithm.

Introduction

Multiple identification and removal is essential and plays an important role in seismic data processing because most imaging algorithms (some based on the Born approximation) deal correctly only with primary reflections. The inverse scattering series internal multiple attenuation algorithm (Araújo et al., 1994; Weglein et al., 1997, 1998, 2003) leverages the fact that an internal multiple can be predicted from a combination of amplitudes and arrival times of primary reflection subevents which satisfy a certain lower-higher-lower relationship in pseudo-depth. More importantly, during the processing the primaries will remain intact, and there is no seismic information from subsurface required: the algorithm is fully data-driven. The purpose of this paper is to demonstrate the application of the internal multiple attenuation algorithm in the plane wave domain to 1.5D data using a MATLAB implementation. Our plan forward is to explore the field application of this plane wave domain algorithm, making use of the fact that in tau-p no resampling procedure is required, and implement a full 2D version as well.

Theory

Consider the relation between pseudo-depth and intercept time (Nita and Weglein, 2009; Sun and Innanen, 2014), the 1.5D inverse scattering series internal multiple attenuation algorithm from the wavenumber-pseudo depth domain to the plane-wave domain.

Internal multiple prediction in 1.5D (horizontal slowness-pseudo depth domain)

The inverse scattering series internal multiples attenuation algorithm was first introduced in wavenumber-pseudo depth domain (Araújo et al., 1994; Weglein et al., 1997). It was demonstrated that the algorithm still works even though we change the variable from wavenumber to horizontal slowness. The 1.5 D algorithm in the horizontal slowness and pseudo-depth domain was first introduced by Coates and Weglein (1996), and further discussed and analyzed by Nita and Weglein (2009), can be expressed as

$$b_{3IM}(p_g, \omega) = \int_{-\infty}^{+\infty} dz e^{i2q_g z} b_1(p_g, z) \int_{-\infty}^{z-\epsilon} dz' e^{-i2q_g z'} b_1(p_g, z') \\ \times \int_{z'+\epsilon}^{+\infty} dz'' e^{i2q_g z''} b_1(p_g, z'') \quad (1)$$

Internal multiple prediction in 1.5D (plane wave domain)

Coates and Weglein (1996) proposed a plane wave version of the original algorithm (Araújo et al., 1994; Weglein et al., 1994). In it, the internal multiple attenuation term may be written explicitly in the source and receiver slowness domain as

$$b_{3IM}(p_g, \omega) = \int_{-\infty}^{+\infty} d\tau e^{i\omega\tau} b_1(p_g, \tau) \int_{-\infty}^{\tau-\epsilon} d\tau' e^{-i\omega\tau'} b_1(p_g, \tau') \\ \times \int_{\tau'+\epsilon}^{+\infty} d\tau'' e^{i\omega\tau''} b_1(p_g, \tau'') \quad (2)$$

where $p_g = p_s$ are the source and receiver horizontal slownesses (which are equal for 1.5D problems) respectively. The time variables τ , τ' and τ'' are intercept time of three events satisfied lower-higher-lower relationship.

We still begin with the data set $d(x_g, x_s, t)$ which is $\tau - p$ transformed over all three coordinates:

$$d(x_g, x_s, t) \rightarrow D(p_g, p_s, \tau). \quad (3)$$

Then, a Fourier transform are applied from τ to ω ,

$$D(p_g, p_s, \tau) \rightarrow D_1(p_g, p_s, \omega). \quad (4)$$

Third, the data are scaled by $-2iq_s$,

$$B_1(p_g, p_s, \omega) = (-2iq_s) D_1(p_g, p_s, \omega). \quad (5)$$

Finally, an inverse Fourier transform are used to calculate the input data $b_1(p_g, p_s, z)$,

$$B_1(p_g, p_s, \omega) \rightarrow b_1(p_g, p_s, \tau). \quad (6)$$

An inverse Fourier transform and a $\tau - p$ transform will be applied after the application the algorithm.

Synthetic Example

Construction of the input data

In order to compare with the algorithm in wavenumber-pseudo depth domain, we make use of the simple two-interface model used by Innanen (2012) to test the internal multiple prediction in Figure 1a. In Figure 1b a single shot record of data is illustrated. The raw seismic data is created using the CREWES acoustic finite difference function `afd_shotrec.m`, with all four boundaries set as “absorbing” to suppress the creation of free-surface multiples (Innanen, 2012). The zero offset travel times of two primaries are indicated in yellow and two internal multiples zero offset travel times are indicated in red. Our objective is to use the primaries as sub events to predict these two internal multiples at all offsets.

In Figure 2a the input data is illustrated for the horizontal slowness-pseudo depth algorithm using the procedure. For the plane wave domain algorithm, the input data are generated using the steps stated as Eq. (1)-(2). Both of them are applied to test the algorithm in the horizontal slowness-pseudo depth domain and the plane wave domain, respectively.

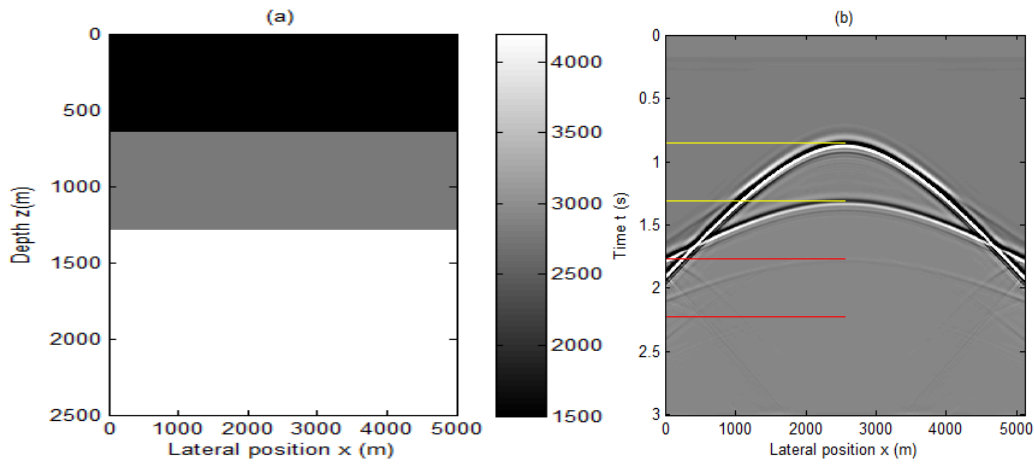


FIG. 1. Synthetic model and data acquired to test 1.5D internal multiple prediction algorithm. (a) Layered two interfaces model to generate the synthetic data. (b) Synthetic data calculated using synthetic model in Figure 1a. Primary zero offset travel times are indicated in red and multiple zero offset travel times are indicated in yellow.

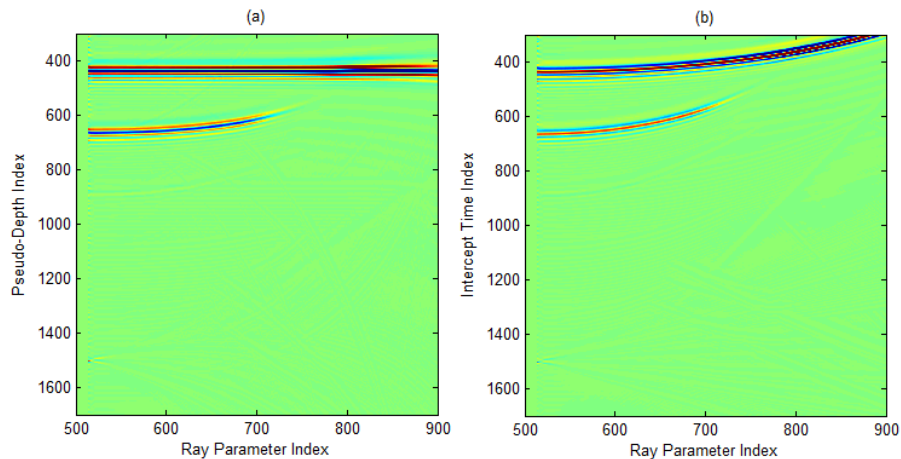


FIG. 2. The algorithm Input data is generated using procedure we discussed above. (a) The input data is generated using procedure discussed in horizontal slowness- pseudo depth domain. (b) The input data is generated using procedure discussed in plane wave domain.

Predicting internal multiples

We finally input the constructed b_1 matrix into the algorithm. The results, after a matched processing, are displayed in Figure 3. In Figure 3a the prediction, after a 2D inverse Fourier transform, is displayed with a range of visible artifacts and the zeros offset travel time are indicated in red. For horizontal slowness-pseudo depth domain the final results, which can be calculated by an inverse Fourier transform and a followed $\tau - p$ transform, are shown in Figure 3b. In Figure 3c the internal multiple prediction is displayed with better focusing and accuracy, less artifacts.

Conclusions

Compared to the wavenumber-pseudo depth algorithm, the computation cost of the algorithm in plane wave domain has been dramatically reduced. A better focusing prediction can be achieved with the internal multiple attenuation plane wave algorithm. Another advantage of the internal multiples prediction algorithm in plane wave domain is that free-surface multiples suppression with a predictive deconvolution often works better in plane wave domain. Therefore, the study of 1.5D inverse scattering series internal multiple

attenuation algorithm in plane wave domain strongly suggestive that 2D and ultimately 3D implementations in plane wave domain will bring significant technological value to the critical matter of internal /interbed multiple identification and suppression.

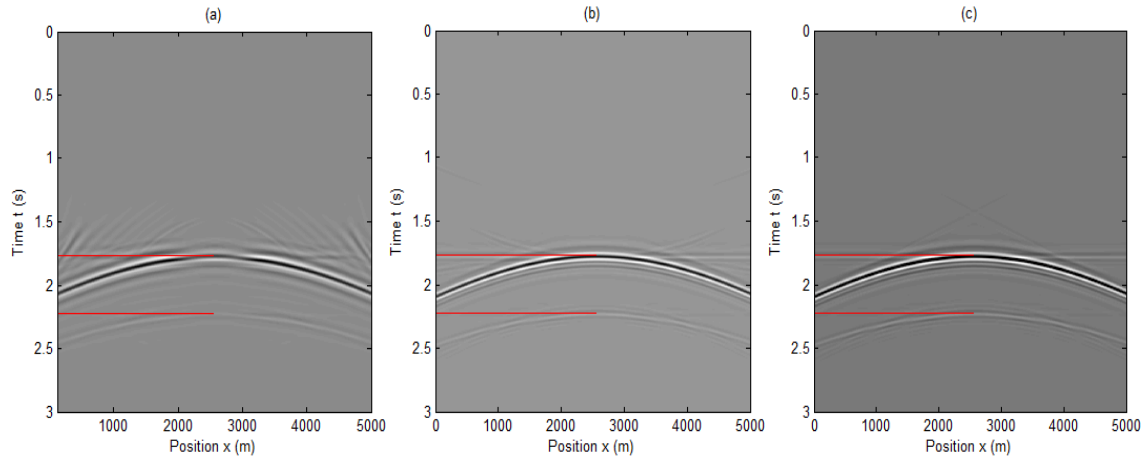


FIG. 3. The internal multiple predictions are generated using the inverse scattering series internal multiple prediction algorithm in different domains. (a) The result is predicted using the algorithm in wavenumber-pseudo depth domain (Innanen, 2012). (b) The prediction is generated using the algorithm in horizontal slowness- pseudo depth domain. (c) The outcome is created using the algorithm in plane wave domain.

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