1.5D internal multiple prediction in MATLAB

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Introduction

We present a 1.5D MATLAB implementation of the inverse scattering series internal multiple prediction algorithm developed by Weglein and collaborators in the 1990s.

We discuss the transformation of the data from the space and time domain to those of wavenumber and pseudo-depth, and the subsequent prediction operation, and illustrate the procedure with a synthetic example.

Our plan forward is to apply with the 1.5D algorithm the methods developed by Hernandez for the 1D algorithm (in this report), which involve stepping from synthetic, to laboratory, and finally to land data.

The algorithm of Weglein and Araujo I: input

The procedure for generating the input to the prediction algorithm is much the same as that by which a constant velocity Stolt migration is carried out. We begin with a data set measured over intervals in lateral source location x_s, lateral receiver location x_g, and time t. The data are Fourier transformed over all three of these coordinates:

$$d(x_g, x_s, t) \rightarrow D(k_g, k_s, \omega). \quad (1)$$

and a change of variables is made from ω to k_z:

$$D(k_g, k_s, \omega) \rightarrow D(k_g, k_s, k_z), \quad (2)$$

where $k_z = q_g + q_s$ and

$$q_g = \frac{\omega}{c_0}\sqrt{1 - \frac{k_g^2 c_0^2}{\omega^2}},\ q_s = \frac{\omega}{c_0}\sqrt{1 - \frac{k_s^2 c_0^2}{\omega^2}}. \quad (3)$$

The data are scaled by $-i2q_s$, forming

$$B_1(k_g, k_s, k_z) = (-i2q_s)\, D(k_g, k_s, k_z), \quad (4)$$

and B_1 is, finally, inverse Fourier transformed over k_z, appearing in the wavenumber-pseudodepth domain as

$$B_1(k_g, k_s, k_z) \rightarrow b_1(k_g, k_s, z). \quad (5)$$

The quantity $b_1(k_g, k_s, z)$ is the input to the prediction algorithm.

The algorithm of Weglein and Araujo II: prediction

The prediction algorithm in 2D is then

$$\text{PRED}(k_g, k_s, \omega) = \left(\frac{1}{2\pi}\right)^2 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} dk_1 dk_2 \times \Gamma(k_g, k_1, k_2, k_s|\epsilon), \quad (6)$$

where

$$\Gamma = \int_{-\infty}^{\infty} dz e^{i(q_g+q_1)z} b_1(k_g, k_1, z) \int_{-\infty}^{z-\epsilon} dz' e^{-i(q_1+q_2)z'} b_1(k_1, k_2, z') \times \int_{z'+\epsilon}^{\infty} dz'' e^{i(q_2+q_s)z''} b_1(k_2, k_s, z''), \quad (7)$$

and the q_X are vertical wave numbers associated with the various lateral wave numbers and the reference velocity c_0. In 1.5D the wavenumbers are integrated over analytically and the algorithm is significantly simpler:

$$\text{PRED}(k_g, \omega) = \int_{-\infty}^{\infty} dz e^{ik_z z} b_1(k_g, z) \int_{-\infty}^{z-\epsilon} dz' e^{-ik_z z'} b_1(k_g, z') \times \int_{z'+\epsilon}^{\infty} dz'' e^{ik_z z''} b_1(k_g, z'') \quad (8)$$

where $k_z = 2q_g$.

Data requirements

We assume the availability of a single split-spread shot record of input data with direct arrivals muted (halt muting at offsets where the direct wave begins to interfere with reflections). Deconvolution and deghosting are a useful preprocessing step; if the internal multiples are resolvable in the data without these steps, they may be avoided (we will not deconvolve our synthetic data later in this paper), though this will lead to a more involved subtraction problem subsequently.

Two interface model

In Figure 1. we illustrate a simple two interface model which we will use to test the internal multiple predictions.

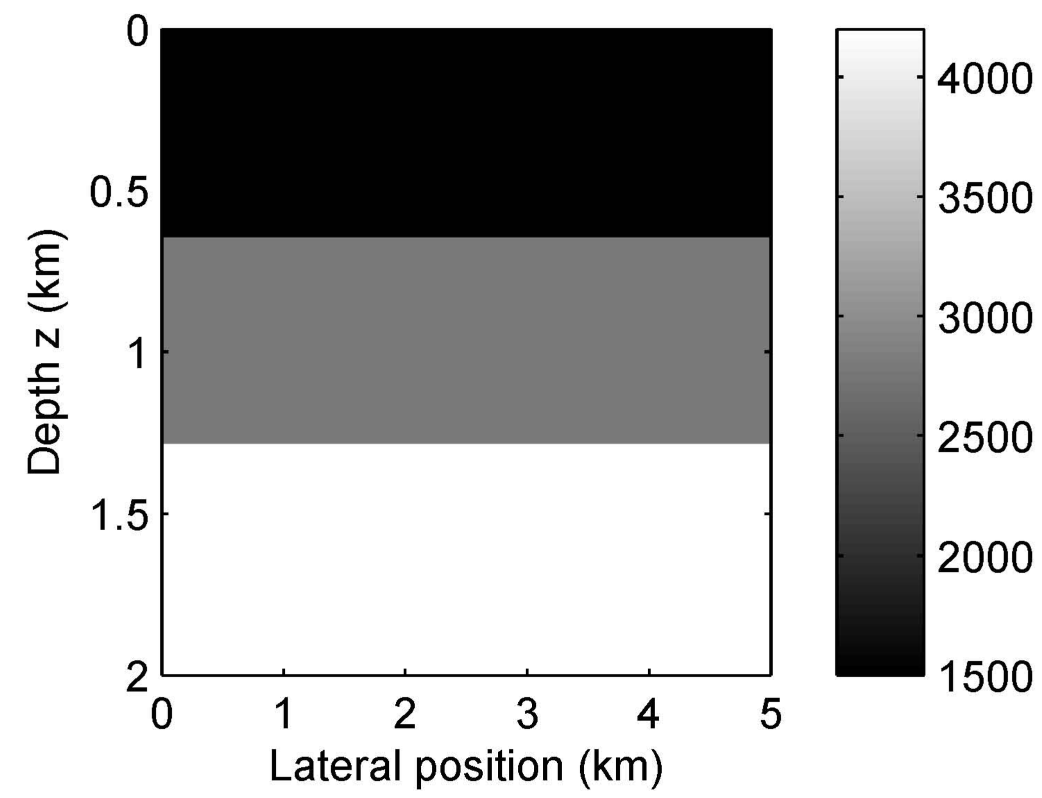

Figure: 1. A two-interface layered acoustic medium model with impedance contrasts suitable for generation of internal multiples.

Synthetic data

In Figures 2a-b a single shot record of data is illustrated. The data are 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.

In Figure 2a we pay particular attention to the two primaries, whose zero offset travel imes are indicated in yellow.

In Figure 2b we pay attention rather to the two internal multiples that (while dim) are visible in the data.

The zero offset travel times of these events are indicated in red. Our objective is to use the primaries as subevents to predict these two multiples at all offsets.

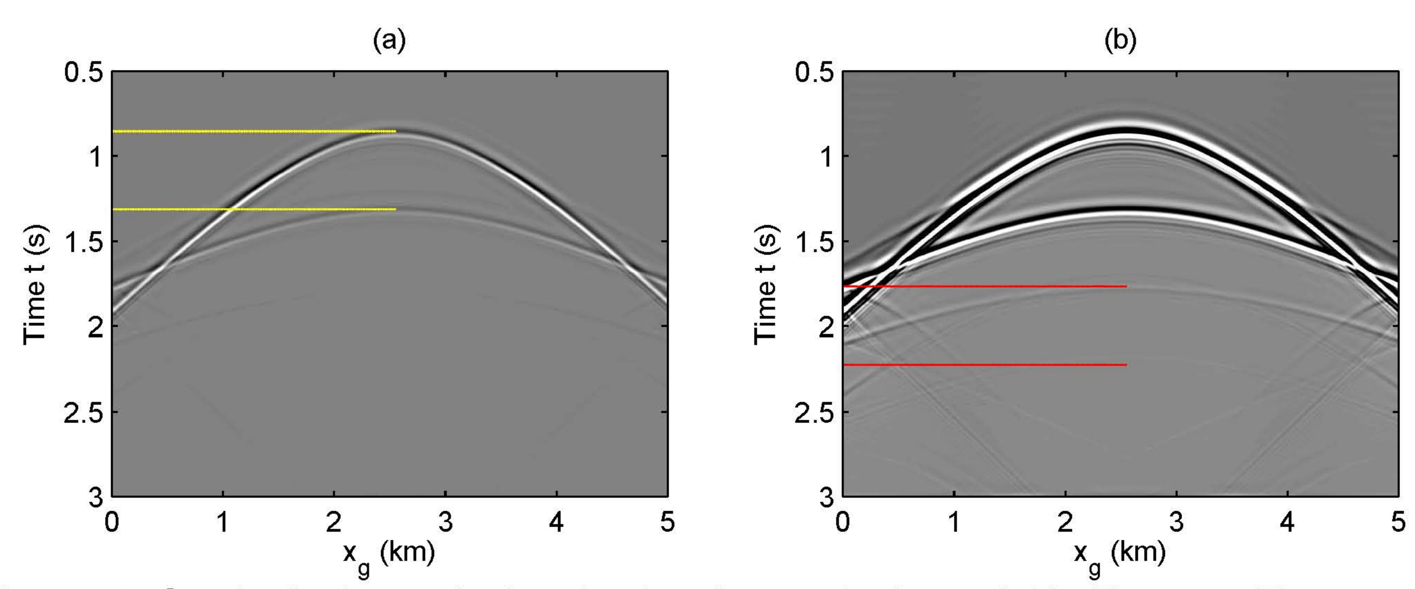

Figure: 2. Synthetic data calculated using the synthetic model in Figure 1. The CREWES code *afd_shotrec.m* was used to create the data. (a) Primary zero offset travel times are indicated in red. (b) Multiple zero offset travel times are indicated in yellow.

Algorithm input

In Figure 3 we illustrate the construction of the core input to the prediction algorithm, $b_1(k_g, z)$. Note it is constructed for positive k_g values only—later through conjugate symmetry the negative wavenumbers are filled. Although difficult to interpret, at low k_g the arrival times of the two primaries are visible.

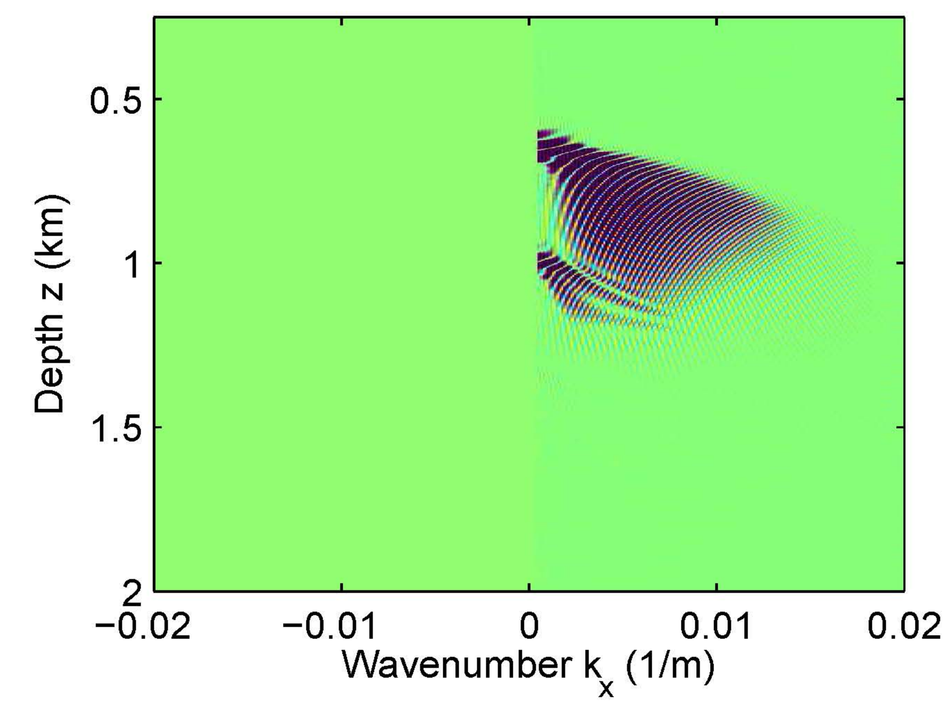

Figure: The algorithm input $b_1(k_g, z)$ is generated using the input data and the single reference velocity c_0.

Predicting internal multiples

We finally input the constructed b_1 matrix into the prediction algorithm. The results, after a 2D inverse Fourier transform, are displayed in Figure 4. In Figure4a the prediction is displayed to match with a clipped version of the input data in 4b. The zero offset travel times and moveout patterns of the internal multiples are captured in the prediction. A range of artifacts and edge effects are visible also, which are matters of ongoing consideration.

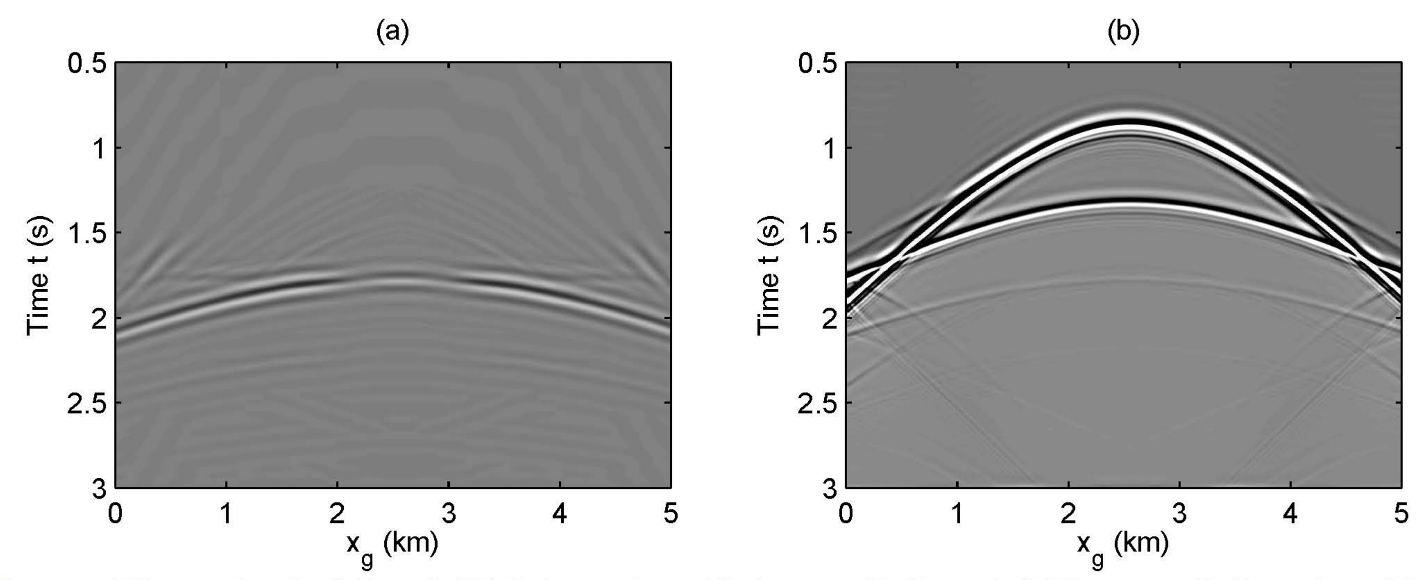

Figure: The output of the 1.5D internal multiple prediction. (a) The prediction, in which two multiples are predicted. (b) The original data with both primaries and internal multiples.

Conclusions

We implement a 1.5D MATLAB version of the inverse scattering series internal multiple algorithm developed by Weglein and collaborators in the 1990s. Our plan forward is to apply with the 1.5D algorithm the methods developed by Hernandez for the 1D algorithm (this report), which involve stepping from synthetic, to laboratory, and finally to land data.

Areas that require further study include examining the use of tapering for aperture effects, moving from a linear to a sinc interpolation scheme during the construction of b_1, and a survey of the response of the algorithm to missing traces and irregular data.

Bibliography

Please see the corresponding CREWES report for a full bibliography.