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1.5D internal multiple prediction on physical modeling data

Pan Pan, Kris Innanen and Joe Wong*
CREWES, University of Calgary

Summary

Multiple attenuation is a key aspect of seismic data processing, with the completeness of multiple removal often significantly affecting final image results. In this paper, we analyze 1.5D internal multiple prediction on physical modeling data simulating a 2D marine seismic survey designed to generate significant internal multiples. We examine a 1.5D (i.e., pre-stack data over a layered geology) implementation of the inverse scattering series internal multiple prediction. The results show good agreement of predictions compared against synthetic data and physical modeling data. We discuss the selection of the integral limit parameter ϵ and the influence of free-surface multiples. We also demonstrate that the beginning and ending integration points of frequencies, wavenumbers, and pseudo-depths in the code can be optimally chosen to reduce computational burden.

Introduction

There are two advantages of the inverse scattering series internal multiple prediction method. First, this algorithm does not require any subsurface information. Secondly, first-order internal multiples are predicted with accurate times and approximate amplitudes. Internal multiple events are usually considered to be coherent noise in the seismic data. However, in many cases, internal multiples interfere with primary reflections, and removal of internal multiples without compromising primaries is very challenging in these cases. Reshef et al. (2003) pointed out that the prediction itself can be the final output, which is useful as an interpretation tool for identification only. Whether we decide to subtract them or not, the ability to identify internal multiples amongst primaries is still a technological necessity (Hernandez and Innanen, 2014).

The purpose of this paper is to examine the response of the 1.5D internal multiple prediction algorithm as implemented in MATLAB on physical modeling data, and seek out an approach which can reduce computational burden and support interpretation. The data we used are designed to be strongly contaminated with internal multiples.

Seismic physical modeling provides scaled simulations of real world scenarios, the benefits of which are controlled acquisition geometry and physical model properties (Lawton et al., 1998). Physical modeling of seismic surveys has been conducted at the University of Calgary Seismic Physical Modeling Facility since 1985. Data are written into SEGY files, and gathers of seismograms can be read directly by processing packages such as ProMax (Wong et al., 2009a). Additional details regarding the modeling systems are described by Lawton et al. (1989), and Wong et al. (2009a, 2009b).

Internal multiple prediction

The formula for 1.5D internal multiple prediction (Weglein et al., 1997; 2003) is

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

where $k_z = 2q_g$ and the $q_g = \frac{\omega}{c_0}\sqrt{1 - \frac{k_g^2 c_0^2}{\omega^2}}$ is the vertical wavenumber associated with the lateral wavenumber k_g, the reference velocity c_0 and the temporal frequency ω. The quantity b_1 is the input to the prediction algorithm.

The prediction process is applied to the physical modeling data after pre-processing. The SEGY file of physical modeling data was loaded into the prediction algorithm. The data are transformed from the space/time domain to the wavenumber/pseudo-depth domain to create the input $b_1(k_g, z)$. The quantity $z = c_0 * t/2$ is the pseudo-depth defined in terms of reference P-wave velocity c_0 and vertical travel time t. After the construction of the input, the 1.5D algorithm, which can be thought of as a sequence of 1D internal multiple predictions, one per output k_g value, is run. An ϵ value, whose practical importance was first pointed out by Coates and Weglein (1996) is chosen based on the width of the wavelet. Effects of various ϵ values have been described in Pan and Innanen (2014). Here we determine the optimal ϵ value to be 80 sample points. We also created a numerical finite-difference acoustic model using the same parameters as our physical model. We set the boundary conditions to be absorbing for all sides, which means there are no free-surface multiples in the synthetic data.

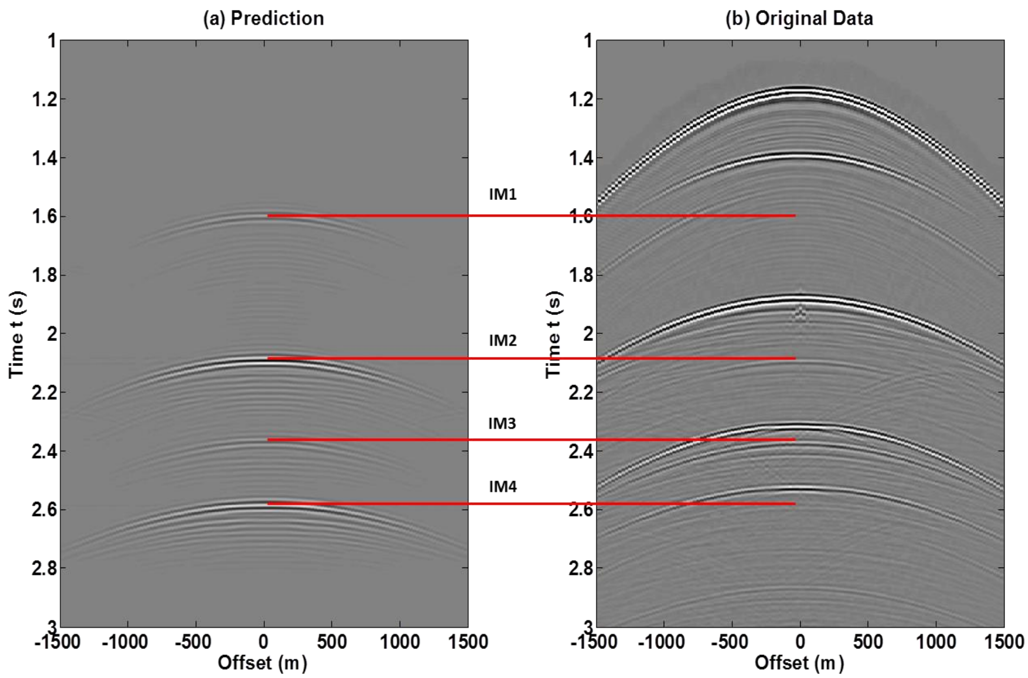

Figure 1: Comparison of prediction output with input. (a) Prediction output; (b) input data. The red lines indicate the positions of internal multiples in both input and output data.

Figure 1a is the prediction output, with its events labeled in comparison to the physical modeling data in Figure 1b. The red lines indicate the positions of internal multiples in both input and output data. The prediction and the physical modeling data are in good agreement. Artifacts in the form of near-offset oscillations from missing lateral wavenumber combinations (with some influence of the noise in the physical modeling data) are visible. The zero offset trace from this output is also examined in detail in Figure 2. The zero offset trace from the physical modeling data is plotted in Figure 2a, the prediction output in Figure 2b, and the zero offset trace from the synthetic data is plotted for comparison in Figure 2c. Even though there are some non-negligible artifacts below each predicted internal multiple, arrival times of the prediction and the synthetic data match well.

An important issue is raised by the notable absence in the prediction of internal multiples generated within the aluminum slab. The aluminum slab has a velocity of 6000m/s and a thickness of 132m which means the two reflections generated by the aluminum slab are very close to each other. Our internal multiple prediction relies on events being separated in time by at least the ϵ value, which is 80ms in this case. The two-way travel time for the top of the aluminum slab is about 1.861s and about 1.905s for the bottom, which means they are separated by 44ms. Since this is within the time interval rejected by ϵ =80ms, these two events will not be considered subevents, and the associated internal multiple will be neglected in the prediction.

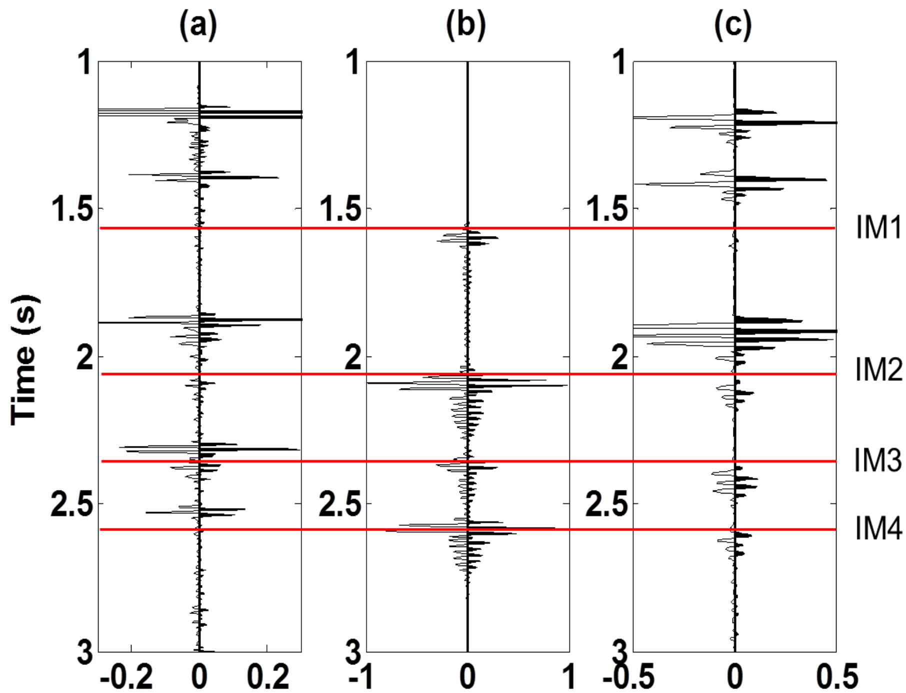

Figure 2: Detail of internal multiple predictions. (a) Input trace (zero offset trace from the physical modeling data); (b) prediction output (zero offset trace from the prediction output in Figure 1); (c) zero offset trace from synthetic data. The red lines indicate the positions of internal multiples.

The internal multiple algorithm is designed assuming free-surface multiples have been removed (Weglein et al., 1997). Thus, the free-surface multiple events in our dataset should be expected to cause artifacts too, since the prediction algorithm will assume the free-surface multiple events to be primaries. In our case the free-surface multiples at sufficiently late times in the shot record, which means spurious predictions will not appear until times later than those we currently analyze. For this reason free-surface multiple removal, nominally a significant step in pre-processing, can be safely avoided in our study.

Analysis of the three parameters chosen in the algorithm

The 1.5D prediction algorithm contains three nested loops over lateral wavenumber, frequency, and pseudo depth. In this section, we perform an analysis of different chosen beginning and ending integration points. Beginning and ending integration points in the nested integrals can be chosen optimally to reduce computational burden (Innanen, 2012). Selecting frequencies properly not only affects computational cost but also quality of the final image. The frequencies can be chosen optimally from a simple Fourier decibel spectrum as the 30 to 80Hz range seems to contain the desired data. The rest of the data is buried in the noise.

From Figure 3 we can determine that the shallowest contribution comes from depth index 540 and last contribution primary is roughly 1020. By the same principle we chose the smallest and largest contributing wavenumber indexes to be 513 and 1024. We can choose these parameters by an iterative procedure, in which depth and wavenumber index ranges are gradually narrowed down until it reaches the points that will not destroy the final image. In Table 1 we illustrate a series of experiments that shows considerable computational savings by manipulating the parameters. We compare the final result with the first experiment, which shows a time cost savings of 114%.

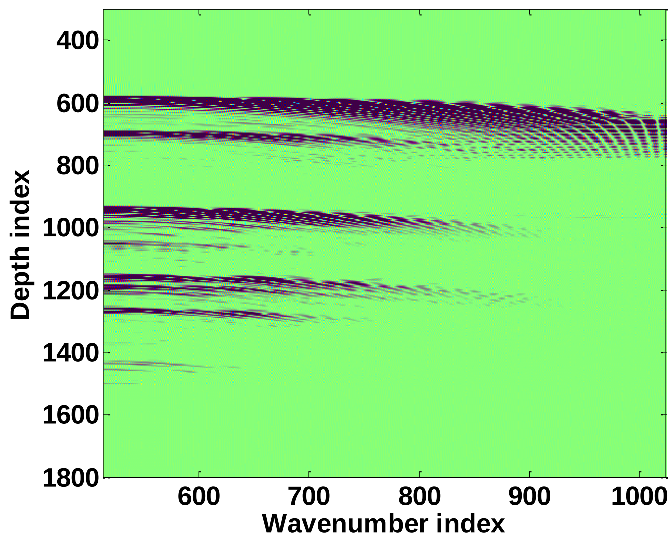

Figure 3: The algorithm input $b_1(k_g, z)$ is generated using the input data and the single reference velocity c_0.

Table 1: Time costs with different parameters chosen.

freBEG (Hz)	**freEND (Hz)**	**zBEG**	**zEND**	**kxBEG**	**kxEND**	**Time (s)**
25	80	540	1020	513	1024	1256.96
25	80	560	1015	513	1024	1189.85
25	80	560	1015	513	900	856.57
25	80	560	1015	513	800	636.24
30	80	560	1015	513	800	588.51

Conclusions

We examine a MATLAB implementation of the 1.5D version of the inverse scattering series internal multiple prediction algorithm on marine physical modeling seismic data. Prediction results show good agreement with both synthetic data and physical modeling data. The effect on the algorithm of the choice of a single ϵ value is also discussed. Even if subtraction is problematic, prediction results can lead us to obtain an "internal multiple probability map", useful for identifying both internal multiples and primaries whose amplitudes are likely to have experienced interference from them. However, it is also true that even a simple variable $\epsilon(k_g)$ may provide significantly improved prediction results permitting subtraction to proceed. Choosing the beginning and ending integration points in the nested integrals optimally leads to considerable computation savings.

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