Surface Related Multiple Attenuation on Sigsbee2B Dataset

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Summary

This paper compares two different approaches to attenuate surface related multiples, i.e., the minimum energy wavelet extraction and the adaptive subtraction with 1D matching filter. Results on Sigsbee2B synthetic data are illustrated to demonstrate the effectiveness of both methods.

Introduction

Surface related multiple attenuation (SRMA) has become a viable method for multiple suppression especially in complex structure where conventional methods may fail. Wave-equation based SRMA approaches generally work in a two-step fashion. In a data driven approach, surface related multiples are first predicted through convolution and integration of seismic data without any prior information about subsurface structures. The predicted multiples are then used to attenuate surface multiples recorded in seismic data. There are several approaches to subtract multiples from the seismic data, such as minimum energy wavelet extraction (Verschuur, 1992; Berkhout 1997), 1D matching filter (Berkhout, 1997), 2D matching filters (Wang, 2003), pattern recognition (Spitz, 1999), prediction error filters (Guitton, 2003). Abma (2002) compared some of these subtraction methods.

In this paper, we describe two implementations of multiple attenuation, i.e., the minimum energy wavelet extraction and the 1D matching filter, and then evaluate them on the Sigsbee2B dataset.

Multiple Predictions

Given surface reflection coefficients and source wavelet, multiple-free data can be obtained by convolution and integration of seismic data (Verschuur, et. al., 1992):

$$P_0 = P + AP^2 + A^2P^3 + A^3P^4 + \cdots \qquad (1)$$

where P is the seismic data in frequency domain; P_0 is the multiple-free data, and

$A = -R/S(\omega)$

with R representing surface reflection coefficients and $S(\omega)$ the seismic source wavelet. The right hand side of equation (1) shows the Taylor expansion of the de-multiple operator. Since the source wavelet $S(\omega)$ is usually unknown, what is actually computed are the Taylor terms ($P^2, P^3, P^4, \ldots$). In general, N'th order Taylor term P^n is computed by convolution and summation between the input data P and lower order Taylor term P^{n-1}.

Minimum Energy Wavelet Extraction

Based on the assumption that after multiple removal, the total energy in the seismic data is minimum, the source wavelet in Equation (1) can be extracted by minimizing the following cost function in a least square sense (Berkhout, 1997)

$$E(S(\omega)) = \sum_{s,r} \left| P + AP^2 + A^2P^3 + A^3P^4 + \cdots \right|^2 . \qquad (2)$$

The integration is over source and receiver coordinates. Once obtained, $S(\omega)$ is plugged into Equation (1) to obtain multiple free seismic data. The estimation of $S(\omega)$ is carried out iteratively. The iteration stops when the residual energy in Equation (2) reaches its minimum. To obtain optimal extraction of source wavelet, several Taylor terms (four terms in this example) need to be computed.

Adaptive Subtraction with 1D Matching Filter

1D matching filter is the most simple and also the most criticized adaptive subtraction approach. Since the first Taylor term P^2 computed in Equation (1) contains all orders of surface related multiples, it can be used as a multiple model to subtract multiples recorded in seismic data P. This approach is called model driven approach (Berkhout, 1998). Compared with recorded multiples, the modeled multiple events ($M = P^2$) have about the same traveltimes but different amplitudes and wavelet shapes, due to the convolution and summation. A 1D matching filter can be applied to the multiple model M before it is subtracted from the data. The matching filter is found by minimizing the following cost function

$$E(f) = \sum_{t} \left| p - f * M \right|^2 , \qquad (3)$$

where M is the multiple model used, f is the 1D matching filter and $*$ denotes time convolution. The summation is over a time window.

The 1D matching filter has been criticized for its inability to handle correctly the travel time, amplitude and wavelet mismatches between the predicted and the recorded multiples. To overcome these difficulties, the amplitudes of the predicted multiple traces have to be scaled down to the same amplitude level of multiples recorded in seismic data traces prior to the estimation of matching filters.

Sigsbee2B Data Results

The Sigsbee2B dataset contains two sets of synthetic data, one with free surface multiples (FS) and one with no free surface multiples (NFS). The data with no free surface multiples (NFS) is used as benchmark to evaluate and compare multiple attenuation algorithms.

Figure 1 shows the prestack depth migrations of Sigsbee2B data before and after multiple attenuation. Figure 1a shows the migration image before multiple attenuation, and Figure 1b is the migration image from data with no free surface related multiples. Figure 1c is the migration image after minimum energy wavelet extraction with four Taylor terms. The first order water bottom multiples showing at 22.5 kft on the left and at 12 kft on the right in Figure 1a are eliminated. Other multiple images in the sub-salt area are also attenuated, giving an image that closely resembles the multiple-free image in Figure 1b. Figure 1d shows the migration image after adaptive subtraction with 1D matching filtering. It eliminated the water bottom multiples at the cost of some primary events being slightly weakened. It also leaves more residual multiple energy underneath the salt body, compared with that of wavelet extraction.

Figure 2 shows zoom views for the area under the salt. Without SRMA, the reflectors and faults under the salt body are blurred by the multiple images (Figure 2a). Both the minimum energy wavelet extraction (Figure 2c) and the 1D matching filter (Figure 2d) eliminated the multiple images. While the 1D matching filter leaves slightly more residual multiple energy.

The results show that these two approaches can produce multiple attenuated images that pretty are close to the image obtained from data with no free surface multiple.

Conclusions

The sigsbee2B data results showed that, the minimum energy wavelet extraction can successfully attenuate free surface related multiples present in the Sigsbee2B data. However, it requires more Taylor terms to be computed and consequently more CPU time. On the other hand, the 1D matching filter also attenuates most multiple energy but leave slightly more residual multiple energy compared with the minimum energy wavelet extraction approach. This method uses only one Taylor term in the multiple prediction stage and therefore substantially save CPU times. It requires experience to tune up the lengths of design windows and matching filters for optimal multiple attenuation and primary preservation.

References

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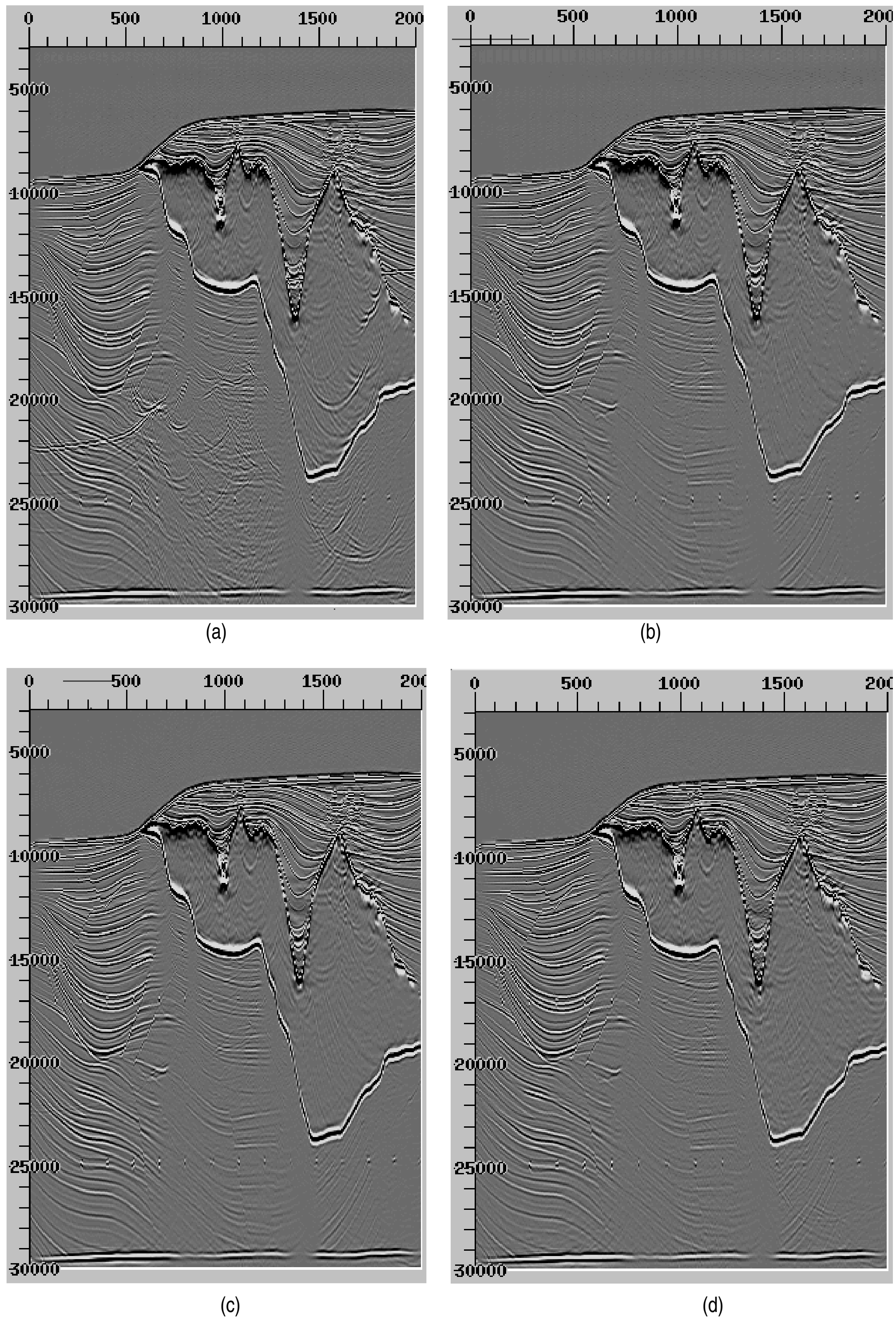

Figure 1: Prestack depth migrations of Sigsbee2B data. (a), before multiple attenuation; (b) from data with no free surface multiple; (c), minimum energy wavelet extraction with four Taylor terms; and (d), 1D matching filter.

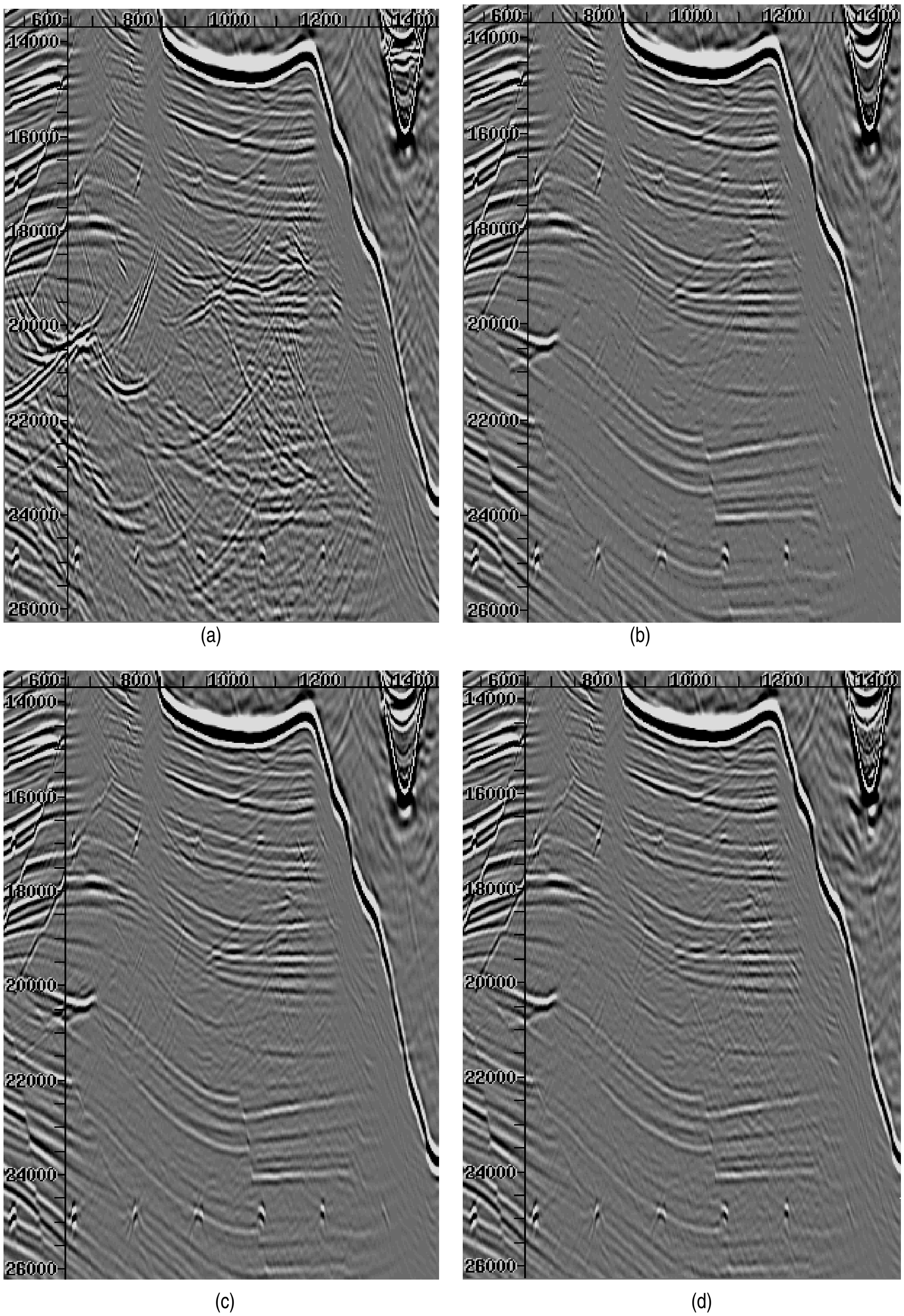

Figure 2: Zoom view of the area under salt bottom in Figure 1. (a), before multiple attenuation; (b), from data with no free surface multiple; (c) minimum energy wavelet extraction with four Taylor terms; and (d), 1D matching filtering.