Application of Extinction Theorem Deghosting Method on Ocean Bottom Data

Jingfeng Zhang and Arthur B. Weglein,*
M-OSRP, Physics Dept., University of Houston

Summary

As one of the pre-requisites for multiple removal, imaging and inversion, the effectiveness of deghosting affects the performance of the followed operations. Extinction Theorem based deghosting method has been successfully applied on towed streamer data by Zhang and Weglein (2005b). In that paper, the deghosted data was then processed using inverse scattering series (ISS) free surface multiple removal (FSMR) algorithm and it was shown that using deghosted data and with given source wavelet, that the ISS FSMR can predict the free surface multiples accurately both in time and amplitude. Thus, the ISS FSMR algorithm with appropriate wavelet and deghosting directly predicts and subtracts the free surface multiples without the need of adaptive subtraction. In practice, this will mitigate the need for adaptive subtraction; and its sometimes harmful application that can run at cross purposes to the underlying strength of the ISS FSMR method. In this paper, we apply the same deghosting algorithm on ocean bottom data. With source wavelet available, only pressure measurements have been used in the process of deghosting and this avoids the need for the troublesome vertical velocity measurements. The deghosting results agree very well with the exact results calculated using the Cagniard-de Hoop method.

Introduction

In seismic exploration, a common sequence of data processing is source wavelet estimation, deghosting, free surface multiple removal, internal multiple removal, imaging and inversion. This sequence of processing steps is like a chain of tasks in the sense that the performance of the later operations could be affected by the former ones. As one of the pre-requisites for imaging and inversion, deghosting has received more and more attention recently. Part of the reason is that more and/or better information are expected to extract from the data at every processing stage (free surface multiple removal, imaging and inversion). Deghosting could affect (sometimes critically) the performance of the above mentioned procedures. For example, deghosting is one of the pre-requisites for free surface multiple removal. Using adaptive subtraction, there are many situations that free surface multiple removal algorithm works well without deghosting. But for complex media case, where severe overlapping can happen between primaries and multiples and adaptive subtraction have a difficult time, better prediction of multiples is very important and can be achieved using deghosted data. Also, ghost effects are angle dependent and thus, inversion such as AVO could be affected by ghost events. For some recently developed processing techinques such as imaging with reference medium velocity (e.g., Weglein et al., 2000, Shaw et al., 2003, Liu et al., 2005 and Innanen, 2005) and nonlinear inversion (Zhang and Weglein, 2005a) , deghosting is a crucial step since those algorithms assume the data is fully deghosted and put a very high bar on the data quality.

The deghosting algorithm we derived is based on Green's/Extinction theorem and is firstly given by Weglein et. al. (2002). We tested it on towed streamer data last year (Zhang and Weglein, 2005b) and get very good deghosting results. The dehosted data was then put into the ISS FSMR algorithm (Carvalho, 1992 and Weglein et al., 1997 and 2003) and accurate prediction of free surface multiples is obtained. Then the free surface multiples in the data were eliminated through a trivial subtraction instead of adaptive subtraction.

This year we test its application on ocean bottom data. Unlike towed streamer case, point receivers are usually used on ocean bottom. So we don't need to test the receiver array effect. The deghosted results are compared with the exact one which is calculated by Cagniard-de Hoop method. Very good results are also obtained. We will not show the ISS FSMR results in this paper. But we would like to point out that the direct application of some surface multiple method (e.g., Verschuur, 1991) on ocean bottom data will cause some problem since the predicted free surface multiple will not have the correct arrival time, unless a separate data extrapolation has been performed on the seismic data in advance. The details will be discussed in the following.

In the next section, a brief review of the deghosting theory has been provided. The numerical tests and acknowledgements are given after that.

Theory

Motivations and different methods about deghosting have been extensively discussed in literature (e.g., Schneider, 1964; Robertsson and Kragh, 2002; Weglein et al., 2002 and Amundsen et al., 2005). The deghosting method we used in this paper is firstly provided in Weglein et al., (2002). The receiver side deghosting formula is:

$$P^{\mathrm{up}}(\mathbf{r},\mathbf{r}_s,\omega) = \int_{MS} \Big(P(\mathbf{r}',\mathbf{r}_s,\omega)\frac{\partial G_0^+(\mathbf{r},\mathbf{r}',\omega)}{\partial z'}$$

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[1] 617 Science & Research Bldg 1, Houston, TX 77204-5005

$$-G_0^+(\mathbf{r},\mathbf{r}',\omega)\frac{\partial P(\mathbf{r}',\mathbf{r}_s,\omega)}{\partial z'}\Big)d\mathbf{S}' \qquad (1)$$

The same kind of operation on source side will remove the souce side ghosts. Clearly, we need both the wave field and its vertical derivative to perform deghosting. On ocean bottom, both measurements are available. However, there are several reasons not to directly use both measurements in Eq.1. The first reason is because of the different instrument response factor. On ocean bottom, the pressure/wavefield and its vertical derivative is measured by hydrophone and geophone respectively. Usually the instrument response factors of the two kinds of equipment are different. To achieve better processing result such as the integration in Eq.1, it is necessary to calibrate the two response factor which is not a easy task. The second reason is that the vertical derivative of the measurements can be inaccurate due to the loose attachment of the geophone to the ocean bottom. The last reason is that geophone measurements are ususlly very noisy. In this paper, we calculate the vertical derivative of the wavefield using the triangle relationship among the source wavelet ($A(\omega)$), wavefield (P) and its vertical derivative ($\frac{dP}{dz}$) in frequency-wavenumber domain (Weglein and Secrest, 1990 and Amundsen, 2001):

$$\begin{aligned}\frac{dP(k_x,z',x_s,z_s,\omega)}{dz} &= \frac{A(\omega)e^{ik_xx_s}(e^{-ik_zz_s}-e^{ik_zz_s})}{e^{-ik_zz'}-e^{ik_zz'}}\\ &-ik_zP(k_x,z',x_s,z_s,\omega)\frac{e^{-ik_zz'}+e^{ik_zz'}}{e^{-ik_zz'}-e^{ik_zz'}}, \qquad (2)\end{aligned}$$

where $k_z=\sqrt{k^2-k_x^2}$. The advantage of this method is that the obtained $\frac{dP}{dz}$ will naturally have the same instrument response factor as P, as long as the source wavelet ($A(\omega)$) is obtained from methods based on hydrophone measurements.

Numerical tests

The numerical tests are based on a simple 1D acoustic model. Using the Cagniard-de Hoop method, we generate synthetic data for the model in Fig.1. The source wavelet is a Ricker wavelet. The advantage of the Cagniard-de Hoop method is that we can accurately calculate any specific event we are interested in so that we can compare it with the results predicted by our deghosting algorithms.

In Fig.2, we illustrate the primary, its ghosts, and their summation. Apparently, the summation of those events look very differently from the primary. Most importantly, the receiver ghost and the source-receiver ghost arrive significantly later than the primary and its source ghost, due to the big depth of the receivers. Let's explain in detail each events in Fig.3. The direct wave (Event (a)) arrives at exactly the same time as the primary (Event (b)). The only difference is that the former one does not hit the earth while the later one hits the earth first then is recorded by the hydrophone. Similarly, the receiver ghost of the primary (Event (c)) arrives exactly at the same time as the first order free surface multiple (Event (d)) and the source-receiver ghost of the primay (Event (e)) arrives exactly at the same time as the source ghost of the first order free surface multiple (Event (f)).

If the idea of the convolution of data with itself predicts the free surface multiples is applied directly to the ocean bottom case, it is not hard to imagine that the arrival time of the predicted first order free surface multiple will be *very* different from the actual one. So a separate data extrapolation operation to move the data from ocean bottom to the free surface is needed in order to ensure the predicted free surface multipel has approximately the right arrival time. While this step is performed naturally in the inverse scattering series based free surface multiple removal method.

In the following, we will present the receiver side deghosted result for the data that contain only primary and its ghosts. The data that contains direct wave and surface multiple events will be tested in the future.

In Fig.4, the deghosting results at four offsets are compared with the exact deghosting result and the data before deghosting. After receiver side deghosting the later events has been removed while the earlier events (primary and its source ghost) are kept. The source ghost can be further removed by a source side deghosting and the test is currently underway. There are two possible reasons for the artifacts in Fig.4 (e.g., at around 0.1s in (a)). The first one is due to the spectrum division in Eq. 2 which generates some errors. The other one is the error introduced because of limited aperture in the Fourier transform over space.

Conclusions

Using an Extinction theorem based deghosting algorithm, we have performed receiver side deghosting on ocean bottom data. Instead of requiring the difficult to accurately measure vertical derivative of the wavefield, it is calculated through the triangle relationship using the source wavelet and the pressure wavefield. The results are encouraging and further data tests and comparisons are underway.

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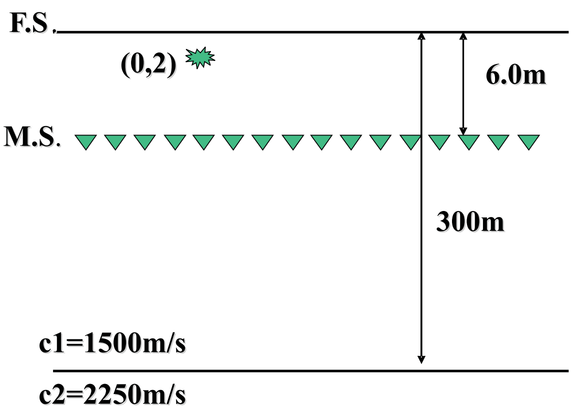

Fig. 1: One dimensional acoustic constant density medium

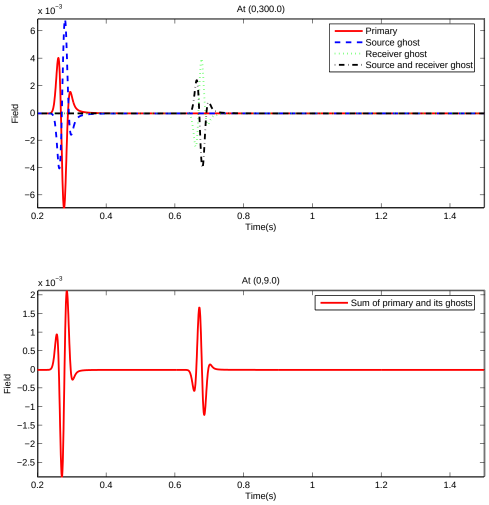

Fig. 2: Top: Each specific events; Bottom: The summation of each events

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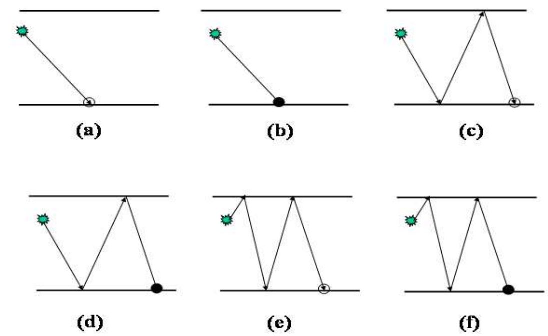
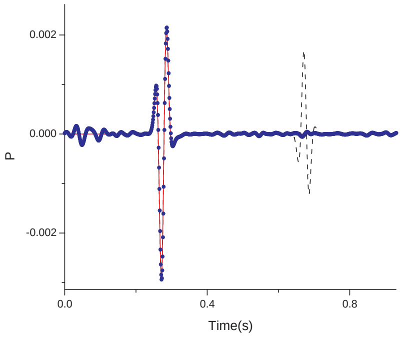
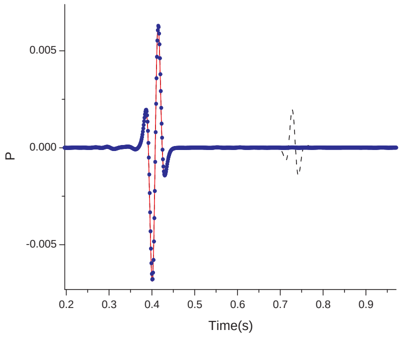


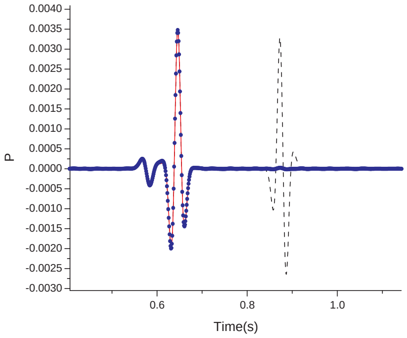
Fig. 3: Empty circle means the wave does not hit the earth and solid circle means the wave hit the earth and then reflected upward and recorded by the receiver. (a): The direct wave; (b) The primary; (c) The receiver ghost of the primary; (d) The first order free surface multiple; (e) The source-receiver ghost of the primary and (f) The source ghost of the first order free surface multiple.



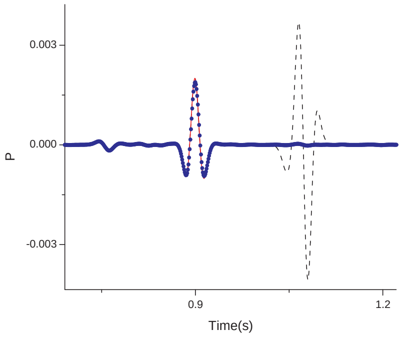
(a) At (0,298.5)



(b) At (400,298.5)



(c) At (800,298.5)



(d) At (1200,298.5)

Fig. 4: Red solid: Exact receiver side deghosted results; Blue dots: Calculated deghosting results; Black dash: Total data before deghosting

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