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Interferometric OBC Surface Related Multiple Attenuation

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SUMMARY

Surface-related multiples in Ocean Bottom Cable (OBC) data cannot be removed by directly applying standard SRME, which requires sources and receivers that are surface consistent. The ray paths needed for a complete surface-multiple prediction can be achieved by combining streamer and OBC data. The combination allows fully data driven SRME to be extended to OBC data. However, streamer data is not always available.

In this paper, we demonstrate that the required data to predict surface-related multiples in OBC data can be constructed using inter-source and inter-receiver interferometry, and the multiples can then be predicted similarly as in SRME. The work flow does not require knowing any subsurface information.

Key words: SRME, Multiple, OBC, Interferometry

INTRODUCTION

OBC acquisition is extensively used in shallow water and transition zone areas; it is generally superior to towed streamer acquisition, in part due to the use of dual-component or four-component sensors. The hydrophone and geophone measurements are usually processed by calibrating the geophone component to the hydrophone component with a matching filter then summing the two in a process known as PZ summation. The summation can attenuate receiver-side ghosts (Soubaras, 1996), therefore the output of PZ summation should be free of receiver-side ghosts, but retain peg-leg and other multiples. However, conventional multiple removal methods for OBC data are mostly based on a simple flat model of the water-bottom, such as gapped de-convolution or up-down de-convolution (Jiao, 1998).

Jin et al. (2012) extended the Model-based Water-layer Demultiple (MWD) from streamer data to attenuate OBC multiples. The MWD method convolves modelled Green's functions with OBC data to model both source-side and receiver-side multiples. It is essentially an extrapolation of the wave-field through the water layer. The method specifically targets water-layer related multiples and requires accurate water bottom information in the modelling process.

Surface Related Multiple Elimination (SRME) is fully data driven and has been very successful for suppressing free surface multiples in marine towed streamer data. With the help of streamer data covering the same region, each OBC receiver gather can be combined with a corresponding surface shot record, which will act as Huygens' sources to predict surface multiples in the OBC gather (Verschuur, 1999). This approach is a natural extension to SRME and requires no subsurface information. However, the requirement of corresponding streamer data has limited its applications. Ma et al. (2010) proposed a method of using a modified version of SRME that uses OBC data only. The method predicts all the surface multiples utilizing shot gather convolution of OBC data only. It involves, however, three to five primary traces to construct one multiple trace, thus leading to high computational costs and significant wavelet distortion in the model.

Seismic interferometry refers to the principle of generating new seismic responses by cross-correlating observations at different receiver locations. No assumption is made with respect to the diffusivity of the wave-field (Wapenaar et al., 2006). The cross-correlation and summation leads to the Green's function that corresponds to what would be observed at one of those receiver locations if there was an impulsive source at the other location (Schuster et al., 2003, Wapenaar et al., 2004). In this paper, we demonstrate that the additional data required to predict surface-related multiples for OBC data can be constructed from inter-source and inter-receiver interferometry without any knowledge of subsurface information, and the surface-related multiples in OBC data can then be predicted in a similar way as in SRME.

METHOD AND THEORY

The difficulty in applying SRME on OBC surveys is due to the asymmetric ray paths of OBC data, which results in a lack of sources at receiver positions and/or a lack of receivers at source positions. Thus, the ray paths of surface-related multiples cannot be constructed from primaries as in streamer data, where both sources and receivers are close to the sea surface (Ikelle, 1999). However, the interferometry method, which cross-correlates two recordings of wave-fields at two receiver positions, can lead to the Green's function that would be observed at one of these receiver positions as if there was an impulsive source at the other location, but without any prerequisite knowledge of the subsurface.

The basis theory of seismic interferometry can be illustrated as in Figure 1(a). Assume there are two sources X_A and X_B, if the response between sources X_A and X_B is desired while no receiver can be put on either of them, the seismic response can be reconstructed using the following equation as described by Wapenaar et al. (2006):

$$2\Re\{G(X_A,X_B)\} = \oint_{\partial D} \big(G^*(X_A,X)\partial_i G(X_B,X) - \partial_i G^*(X_A,X)G(X_B,X)\big) n_i d^2x$$

where $\Re$ denotes the real part, G is Green's function, ρ is density, n is normal direction of boundary, j represents $\sqrt{-1}$ and ω is frequency; G* is complex conjugate of G; while X and D denote the locations and enclosed boundary. The equation is actually an integration of the cross-correlation of all scattering wavefield contributions along arbitrary boundary ∂D that encloses X_A and X_B. The medium inside or outside the boundary can be arbitrarily inhomogeneous. Wapenaar (2004) gave an illustration of a single scatterer in half plane as shown in Figure 1(b), and Figure 1(c) shows the cross-correlation between the two receivers X_A and X_B, where t_{AB} is the travel time along $X_A - X_D - X_B$. Interferometry provides us with an impluse response between X_A and X_B without actually firing a source at either X_A or X_B.

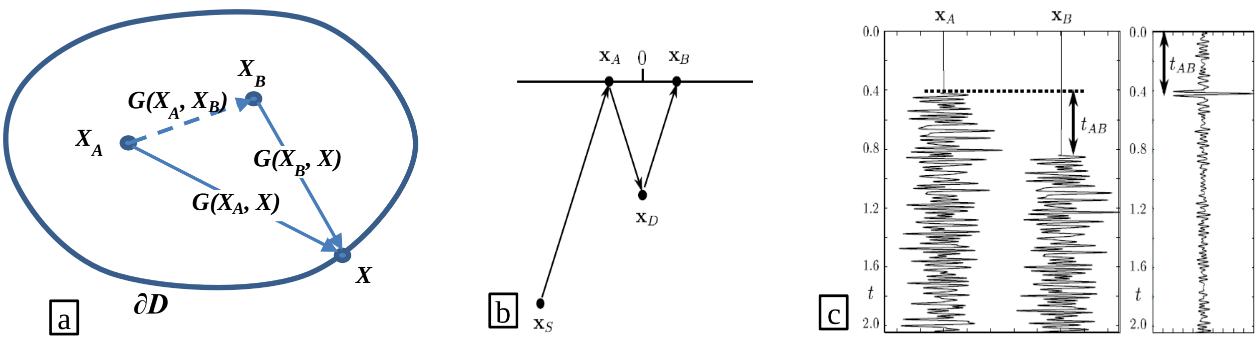

Figure 1 (a) Green's function $G(X_A,X_B)$ can be obtained by cross-correlating observations at X_A and X_B by integrating sources X along ∂D. (b) Half plane 1D illustration of random source X_S, scatter X_D, and two receivers at X_A and X_B, (c) Observations of a random source at X_A, X_B and their cross-correlation, which gives the reflection response.(Wapenaar et al. 2004, 2006)

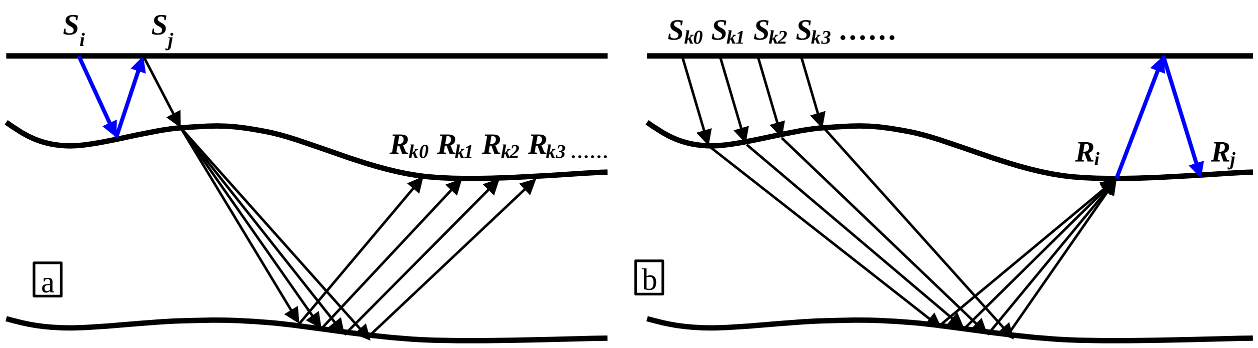

Figure 2 (a) Interferometry obtaining the Green's function S_iS_j (blue arrow) to predict OBC shot side surface related multiples (b) Receiver side illustration.

The OBC survey, as illustrated in a simple form by Figure 2, can be considered as a half plane enclosed by free surface. The additional required ray path or Green's function to predict the source side multiple, indicated by S_iS_j in Figure 2(a), and the receiver side multiple, indicated by R_iR_j in Figure 2(b), can be achieved by inter-source and inter-receiver interferometry integrating the cross-correlation of receiver points at ocean bottom indicated by R_k, or shot points at surface indicated by S_k, which have been acquired in conventional OBC surveys. Note that in Figure 2, we only plot the ray path related to the water layer for simplicity, however, the result from interferometry is as if there was an impulsive source at S_i and receiver at S_j for shot side, or source at R_i and receiver at R_j for receiver side. These ray paths are ideal components for applying SRME on OBC. Again, the constructed wavefield can include reflectors that are deeper than the water bottom.

With the extra data from interferometry, it is straight forward to predict OBC multiples using SRME-type methods with cross-convolution. However, instead of combining streamer data with OBC data, here we predict both source-side and receiver-side surface-related multiples with only the acquired OBC data. In summary, taking deghosted P wave seismic data as input, our method includes the following steps.

1) Form common shot gathers and compute inter-source operators using an interferometry method,

2) Convolve the shot gathers and inter-source operator to predict source side surface multiples

3) Form common receiver gathers and compute inter-receiver operators similarly

4) Convolve the receiver gathers and inter-receiver operator to predict receiver side multiples

The multiple attenuation also involves the adaptive subtraction of predicted multiple model from input data.

SYNTHETIC DATA EXAMPLE

To verify the effectiveness of the aforementioned method, we generated a synthetic OBC survey with pressure wave only, which mimics the recording pattern used in real 2D OBC acquisition after P-Z summation. The velocity field used to generate the synthetic data has four reflectors and is shown in Figure 3(a). The dashed line indicates where the water bottom and cable were laid; the sources were positioned at the surface. Figure 3(b) shows the corresponding numerical P-wave seismic data of 5 evenly distributed shots. The four primary events are highlighted by the black arrows; all the other events are multiples.

Figure 4 shows the comparison of Green's function from interferometry of two OBC shot gathers and synthetic surface streamer data; 4(a) shows the numerical zero offset seismic section of streamer data up to one second and 4(b) shows the corresponding central shot gather. For comparison, Figure 4(c) shows the zero offset section of synthetic OBC data and 4(d) is the central shot Green's function from interferometry. The final predicted model using the aforementioned method is shown in Figure 5, it can be seen that most of the surface related multiples are kinematically well predicted.

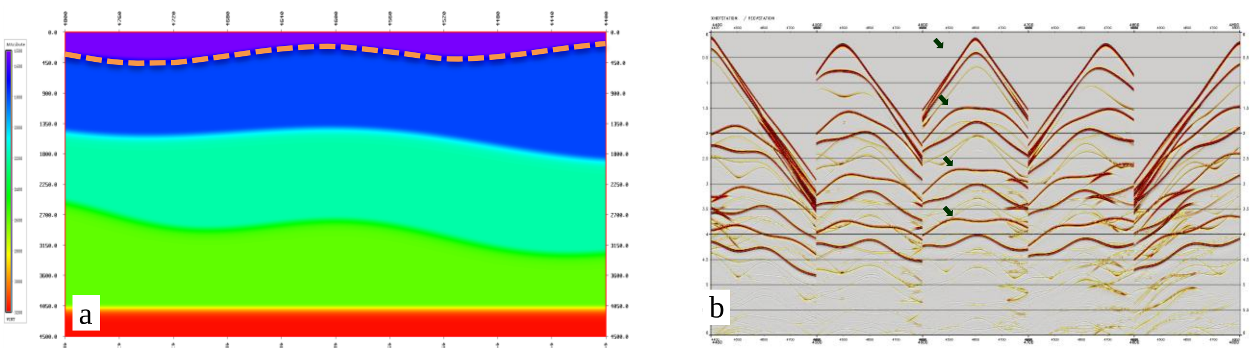

Figure 3, (a) Synthetic velocity model with four primary events; the dashed line highlights the water bottom. (b) Numerical P-wave seismic response including surface related multiples.

FIELD DATA EXAMPLE

We have successfully applied this method to an OBC survey acquired in the Bo Hai Sea, China. The water depth of the whole survey varies from 21 to 30 meters. Figure 6(a) shows a stack section that has noise removal and PZ summations applied (but before any demultiple), 6(c) shows the auto-correlation of the stack section, the ringing around the zero lag shows strong short period multiples. Figure 6(b) and 6(d) show a stack and an auto-correlation after multiple removal using our method, respectively. It can be observed that considerable peg-leg multiple energy has been attenuated which results in better defined primary events, as the interference of short period multiples on the wavelet is much reduced after the application of our interferometry demultiple method.

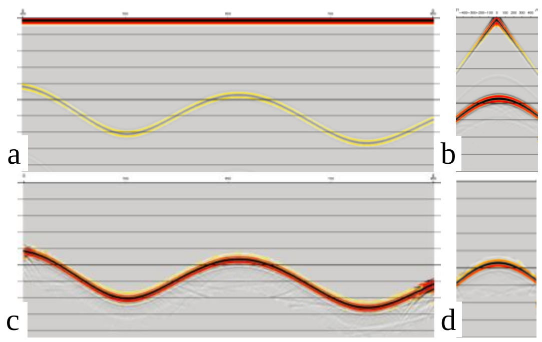

Figure 4 (a) Numerically simulated zero offset streamer data. (b) Shot gather of streamer data. (c) Zero offset section from OBC data interferometry. (d) Shot gather from interferometry.

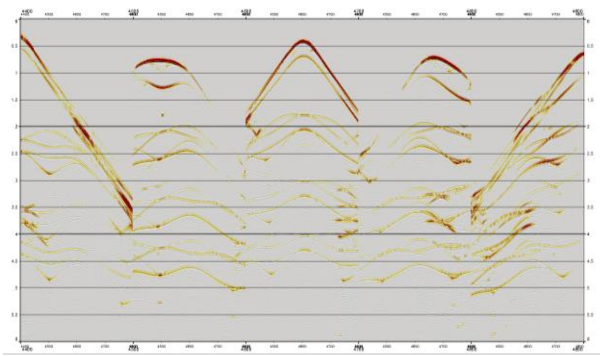

Figure 5. Predicted multiple model using OBC data only, shot and receiver side operators generated from interferometry, with prediction method similar to that in SRME by convolve data with operators.

CONCLUSIONS

We have demonstrated in this paper that, through the use of seismic interferometry, the extra ray path required to predict surface multiples in OBC surveys can be reconstructed, and both shot-side and receiver-side OBC surface multiple can be predicted. The method is fully data driven and can predict all surface-related multiples. The effectiveness of the method has been verified by synthetic and real data. However, because the method is data driven, it will be limited by the data quality and the significance of the multiple generators in the recorded data to make accurate predictions.

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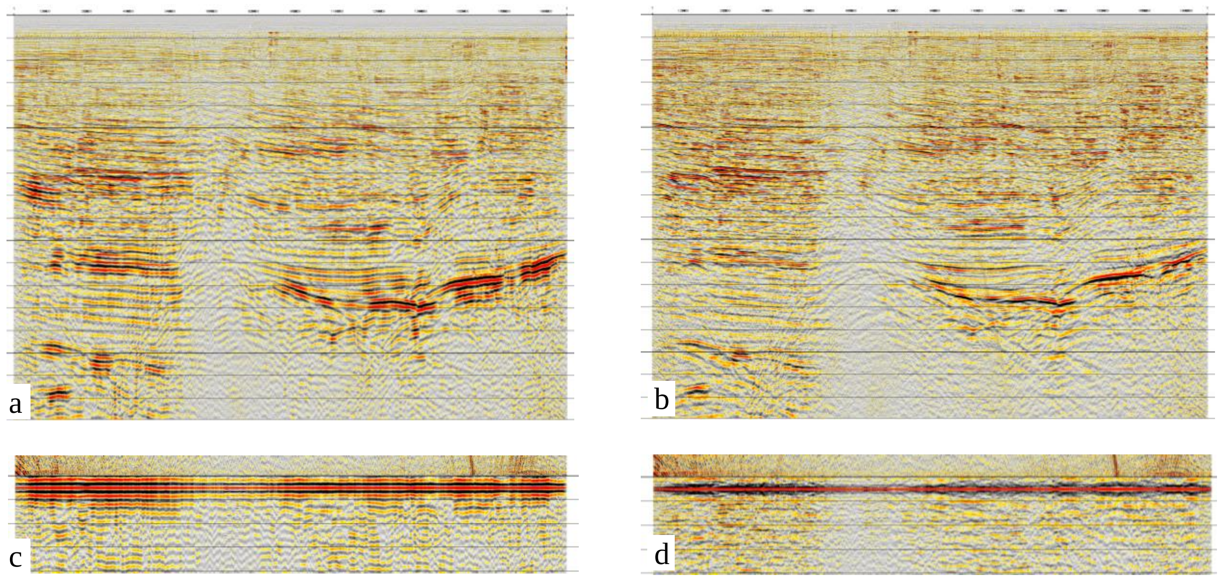

Figure 6, (a) P-wave stack after noise and ghost removal but before demultiple, (b) demultiple stack using our method, (c) autocorrelation before demultiple, (d) auto correlation after demultiple