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Water-layer free-surface multiple attenuation in complex seabed scenarios: Case study from offshore Canada

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Summary

We present a formal description of a true-azimuth 3D deterministic water-layer demultiple method, demonstrated in a transition seafloor depth with severe dip and complex geological features in a towed streamer survey from offshore Canada. The key step in this workflow is a multidimensional convolution framework between two input datasets – field recorded data and Green function of the water reflection. We aim to show in this work that a complete modeling of water-layer multiples (receiver side, source side and the correction term) is crucial to obtain an accurate and effective multiple attenuation outcome.

Introduction

Surface multiple attenuation is a required processing step in typical industry-standard marine seismic projects. This step is commonly done with 3D SRME, a data-driven method that predicts surface-related multiples, followed by adaptive subtraction (Verschuur, 2012). The 3D SRME method performs well when sampling and data conditioning requirements are met (Dragoset et al., 2010). However, this method faces several challenges in shallow water environment where the seafloor depth is smaller than the nearest source-to-receiver offset acquired in the data. Reconstruction of seismic traces at the nearest offset and adaptive subtraction are the main limitations when using 3D SRME in shallow water areas with depths less than about 200m (Kostov et al., 2015).

Methods based on wavefield extrapolation and removal of multiples in shallow water surveys (Lokshtanov, 2001; Moore and Bisley, 2006; Verschuur, 2012; Wang et al., 2014) specifically focus in addressing free-surface multiples that experienced bounces at the water-layer. Figure 1 provides an overview of different classes of free-surface multiples. Wavefield extrapolation methods model free-surface multiples that has experienced a bounce in the water-layer on the shot or receiver side ($\mathrm{M}_{\mathrm{WLM}}$), notated in Figure 1.

Moore and Bisley (2006) proposed a method for attenuation of $\mathrm{M}_{\mathrm{WLM}}$ multiples using a reduced number of wavefield extrapolations. This approach, referred as DWD (Deterministic Water-layer Demultiple), works under the assumption of shallow-water with relatively flat seafloor topography. We apply a variation of the DWD workflow without the simple seafloor topography assumption. This implementation is called general DWD (GDWD) and provides true-azimuth 3D prediction of $\mathrm{M}_{\mathrm{WLM}}$ multiples. This workflow is applicable to any streamer data and can be complemented with other prediction methods for attenuation of remaining free-surface multiples. Remaining free-surface multiples can be addressed using general surface multiple prediction (GSMP), a particular implementation of 3D SRME (Moore and Dragoset, 2008).

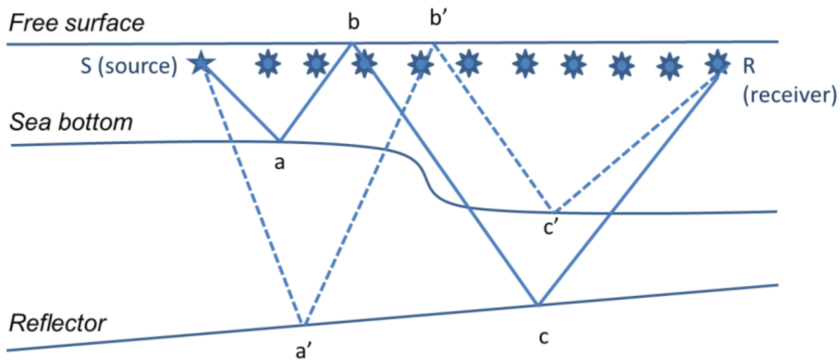

Figure 1: First-order free surface multiples that include an upward reflection on the water bottom (M_{WLM}) can be grouped depending on whether the reflection occurs on the source side (continuous line) or receiver side (dashed line).

Theory and/or Method

The GDWD starts with the principle of wavefield extrapolation of common-shot or common-receiver data through the water-layer to predict M_{WLM} multiples (Figure 1). The workflow employs a Green function of the water reflection based on a water-layer model to perform the prediction. The wavefield extrapolation of a common shot gather with a Green function of the water-layer (W_R) produces a model of multiples that have experienced a water bottom reflection at the receiver side (M_R). In the same way, a source side water-layer multiple model (M_S) is obtained by combining the common receiver gathers with a Green function (W_S). This is summarized by (Kostov et al., 2015)

$$M_R = W_R * D \text{ and } M_S = W_S * D, \quad (1)$$

with symbol * denoting multidimensional convolution in space and time (Verschuur, 2012). A correction term is proposed by Lokshtanov (2001) to avoid double prediction of multiples present in both receiver and source side models. The final water-layer surface-related multiple model (M_{WLM}) is expressed as

$$M_{WLM} = M_R + M_S - W_R * D * W_S - D_W * W_S, \quad (2)$$

where D_W is used for the water bottom primary.

Note that terms in equation (2) involve at least five wavefield extrapolations (in form of multidimensional convolutions). In GDWD these terms are grouped in a different way to reduce the number convolutional operations. Terms in equation (2) can be reduced combining, the terms M_S and $D_W * W_S$. The term $W_R * D * W_S$ is also simplified by an approximation based $M_S * W_S$ followed by a linear filter operation.

$$M_{WLM} = M_R + [(D - D_W) * W_S - f * M_R * W_S], \quad (3)$$

where f in equation (3) is a linear filter indicating that the combined source and receiver side multiples $M_R * W_S$ are being removed by adaptive subtraction from the data. The resultant model M_{WLM} is removed by the field data by adaptive subtraction from the field data. The adaptive subtraction derives a linear matching operator that best fits the multiples present in the recorded data in a least-square sense.

Examples

We applied the GDWD workflow to a 3D survey located offshore Newfoundland, Canada. This 3D towed marine survey consists of 1600 km2 acquired with a source array at 8 m depth. The receiver configuration consists of 12 streamers, each 7.05 km long, separated by 100 m (maximum 150m with feathering) in the crossline direction and nearest channel at 168 m. The main goal of this survey is to improve the overall multiple attenuation workflow between the base Tertiary level (~3.4 s TWT) down to approximately 6.0 s TWT. Seafloor topography is quite complex, varying from ~440 m down to ~2400 m with a steep escarpment in the northeast direction.

Shallow water multiple attenuation is one of the major challenges in this survey. Strong reverberations coming from the water-layer and peg-leg from the base Tertiary event, combined with diffracted multiples generated at the glacial boulders just beneath the seabed are the main coherent noise contamination over the target zone. Interpretation and inversion are inviable if an effective 3D multiple attenuation approach is not in place. The application of the GDWD workflow started with the true-azimuth 3D multiple model prediction. The Green's function of the water reflection was computed via three-dimensional wavefield extrapolation through a water-layer model, later used to compute the receiver and source side model, as described in Equations 1 and 3. The correction term was computed and adaptively filtered and removed from the source side model. The water-layer multiple model $\mathrm{M}_{\mathrm{WLM}}$ was then subtracted from the field data using a least-square simultaneous subtraction approach, where matching filters were computed for the receiver and corrected source side models to better remove the predicted water-layer surface multiples.

Figure 2 shows a time image section before attenuation of multiples (Figure 2a), after GDWD application (Figure 2b), and their difference (Figure 5c). Water-layer surface multiples are well attenuated after GDWD image (Figure 2b), clearly showing events that were previously hindered by the strong reverberation. The difference image (Figure 2c) shows no evidence of primary events being subtracted from the field data. Similarly, the same behavior is visible when looking at common imaging point gathers (CIP) in Figure 3. Strong under corrected events (multiples) contaminates primaries throughout the CIP gather (Figure 3a). All these events were severely attenuated after GDWD (Figure 3b), and their difference (Figure 3c), again, shows no evidence of primary leakage after adaptive subtraction.

Conclusions

We presented a workflow for prediction of water-layer surface multiples using a true-azmuth multidimensional convolution framework to derive accurate models. The workflow foundation is based on the computation of general wavefield extrapolation operators capable of modeling water-layer source and receiver side bounces, interacting with seafloor of complex geometry.

The GDWD method is illustrated using a towed streamer survey from offshore Canada. We are capable to successfully predict and subtract water-layer surface multiples from a complex seafloor environment, with strong multiples contaminating the target zone. The overall seismic and image improvement after GDWD is noticeable throughout the whole section, where the strong multiple interference is attenuated. Albeit the resultant multiple model is kinematically correct, adaptive matching filters are computed and applied to correct for events not anticipated in the workflow, such as effects due to source directivity, noise and residual ghost effects.

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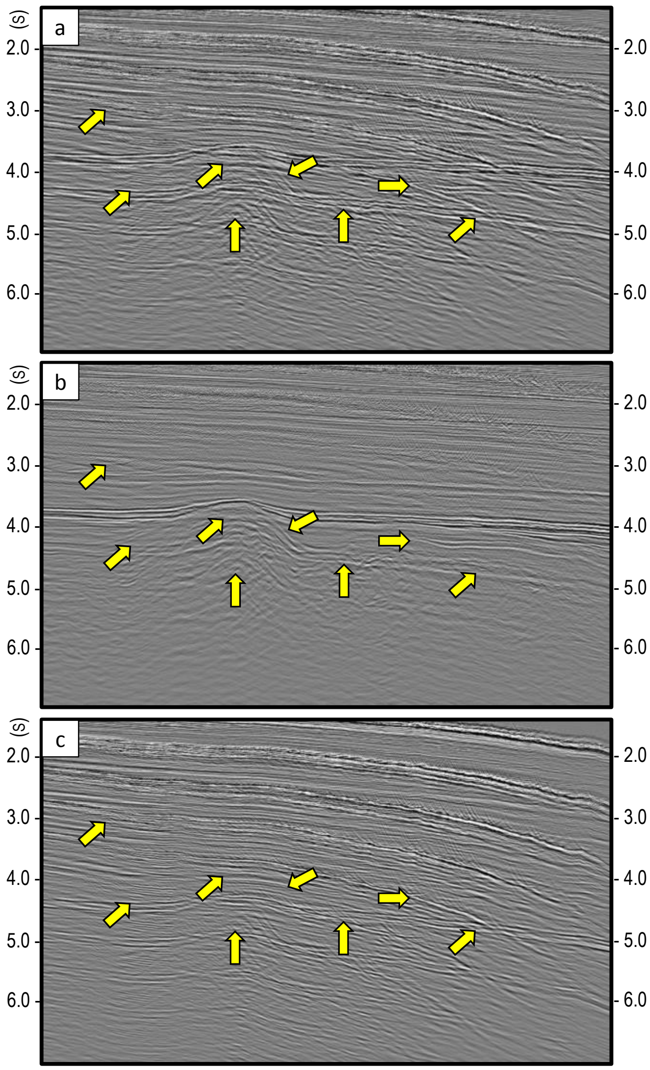

Figure 2: Kirchhoff pre-stack time image section a) before GDWD, b) after GDWD and c) their difference. Strong water-layer multiples were successfully attenuated revealing weak primaries at the target zone, (highlighted by the yellow arrows) previously masked in (a) due the seismic multiple interference.

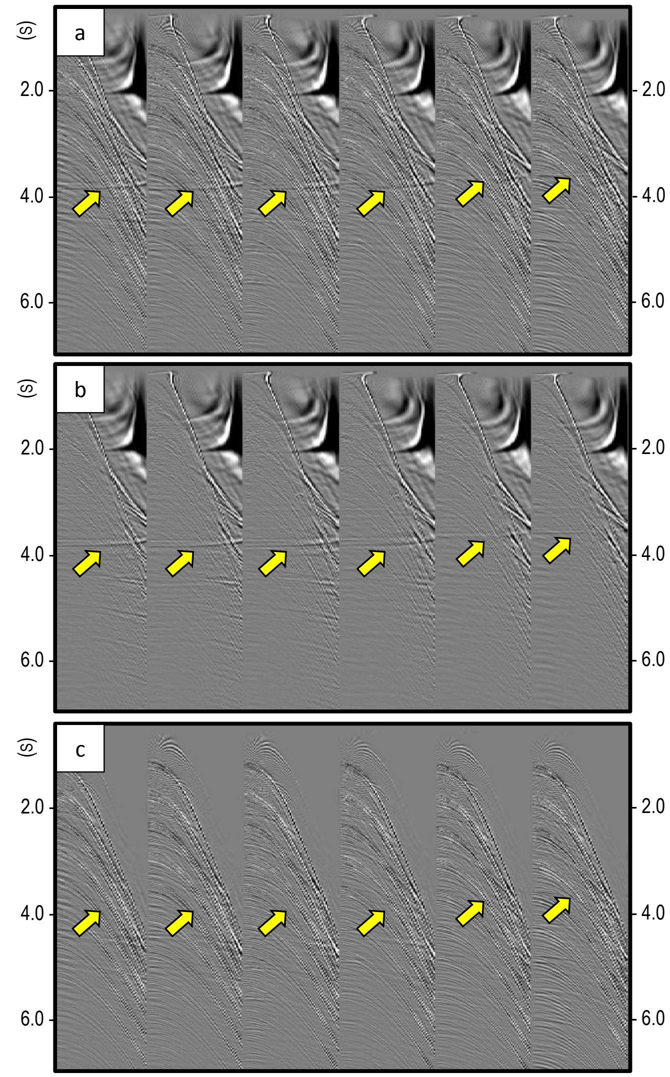

Figure 3: Kirchhoff pre-stack time common image point gathers (CIP) a) before GDWD, b) after GDWD and c) their difference. Water-layer multiples appear as a strong under corrected events and were successfully attenuated from the recorded data. Yellow arrows highlight that key primary was not attenuated after adaptive subtraction.

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