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Selective-input Adaptation of Model-based Water-layer Demultiple

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SUMMARY

Model-based water-layer demultiple (MWD) is an effective method for attenuating water-layer-related multiples (WLRMs), especially in shallow water environments. Regular 3D MWD uses regularized common-offset cubes for both shot- and receiver-side multiples. We propose a selective-input adaptation of regular 3D MWD workflow that uses both regularized shot gathers and regularized common-offset cubes as input and prioritizes the data selected for model prediction; data are selected first from regularized shot gathers and then from regularized cubes. Using field data, we demonstrate that this selective-input MWD removes more multiples than regular MWD, especially for high-order multiple reverberations.

Introduction

The success of surface-related multiple elimination (SRME) (Berkhout 1982; Verschuur et al. 1992; Biersteker 2001) in shallow water data is limited due to missing near-offset data and the low quality of water-layer primary reflections in the recorded data (Verschuur 2006). In shallow water, water-layer primary reflections often arrive at large propagation angles and thus are contaminated by other waves arriving at similar travel times, such as direct waves, head waves, and refracted waves. Applying SRME in this case is difficult because SRME depends highly on the recorded water-layer primary reflections to predict water-layer-related multiples (WLRMs). In addition, the cross-talk among multiples and the double source wavelets from the auto-convolution of the recorded data distort the amplitude and spectrum of SRME multiple models (Wang et al. 2011, 2014). This makes the subsequent adaptive subtraction (Verschuur et al. 1992) more difficult, especially for low- and high-frequency multiples.

Model-based water-layer demultiple (MWD) is an effective supplement for SRME for shallow water multiple attenuation (Wang et al. 2011, 2014). Unlike SRME, which convolves the recorded data with the recorded data, MWD convolves the recorded data with the modelled Green's function from the water-bottom model. The success of MWD comes from (1) eliminating the cross-talk among multiples, (2) preserving the amplitude spectrum of the input seismic data, and (3) relaxing the dependency on high quality water-layer primary reflections (crucial for SRME). Like many other demultiple methods, MWD can be performed in a 2D fashion using regularized one-gun-and-one-cable shot gathers as input data. We found that 2D MWD removes most of the WLRMs at near cables if the water-bottom is not highly complex. However, in areas where WLRMs have strong 3D effects, 3D MWD is required, which uses regularized common-offset cubes as input. Figure 1 shows an example from a far cable where the shallow multiples have strong 3D effects. The blue circles show that 3D MWD (Figure 1c) better removes those shallow multiples compared to 2D MWD (Figure 1b). Nonetheless, 3D MWD sometimes leaves more high-order residual multiple reverberations (Figure 1, blue arrows). We found this is because the prediction of high-order multiple reverberations requires high-level data consistency in both inline and crossline directions for 3D demultiple methods.

We propose a selective-input adaptation of regular 3D MWD workflow to combine the benefit of 2D MWD and regular 3D MWD (hereafter called selective-input MWD). Selective-input MWD uses both regularized shot gathers and regularized common-offset cubes as input. When a particular trace is needed for the multiple prediction of one particular trace, it uses a trace first from regularized shot gathers and then from regularized common-offset cubes. This selective-input adaptation facilitates better prediction performance for high-order multiple reverberations.

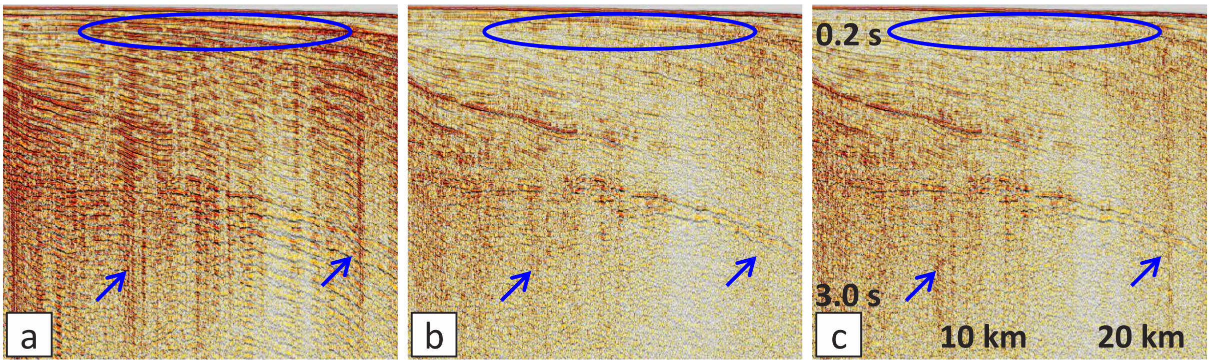

***Figure 1** Near-offset section of a far cable data set (a) before demultiple, (b) after 2D MWD, and (c) after 3D MWD. Fewer shallow multiples (blue circles) are removed by 2D MWD because those multiples have strong 3D effects. Fewer multiple reverberations (blue arrows) are removed by 3D MWD due to some inconsistency in the multiple contribution gather in both inline and crossline directions (Figure 2).*

Method

The multiple models between a source point $\boldsymbol{s}$ and receiver point $\boldsymbol{r}$ can be obtained from the convolution of recorded data D and the Green's function G (Wang et al., 2011):

$$M(\omega;\boldsymbol{s},\boldsymbol{r}) = \int [D(\omega;\boldsymbol{s},\boldsymbol{x})G(\omega;\boldsymbol{x},\boldsymbol{r}) + G(\omega;\boldsymbol{s},\boldsymbol{x})D(\omega;\boldsymbol{x},\boldsymbol{r})]d\boldsymbol{x}, \tag{1}$$

where ω is the angular frequency and $\boldsymbol{x}$ is a bounce point at surface within the integration aperture. The first term in Equation 1 is the receiver-side multiple, which convolves the shot gather (shot side) with the Green's function (receiver side); the second term is the shot-side multiple, which convolves the receiver gather (receiver side) with the Green's function (shot side). MWD predicts only the WLRMs, thus the Green's function needed for MWD can be calculated from a predefined water bottom model.

While most marine towed-streamer acquisitions offer a good sampling of shot gathers, the sampling of receiver gathers is often very poor due to the coarse shot sampling. Therefore, for regular 3D MWD, we chose to bin the input data into common-offset cubes followed by common-offset regularization to fill in holes. Figure 2 shows the multiple contribution gather (MCG) for regular 3D MWD using regularized cubes as input. Each trace in the MCG is the convolution of the recorded data with the Green's function for the possible reflection point $\boldsymbol{x}$ in Equation 1 (i.e., DG or GD**)**, which are then summed to give the multiple model. Figures 2a and 2b show the time slice at 700 ms for shot- and receiver-side contribution, respectively. Figure 2c shows a receiver-side inline section marked by the blue line in Figure 2b. The MCG for regular 3D MWD shows some incoherency in both inline and crossline directions because of the

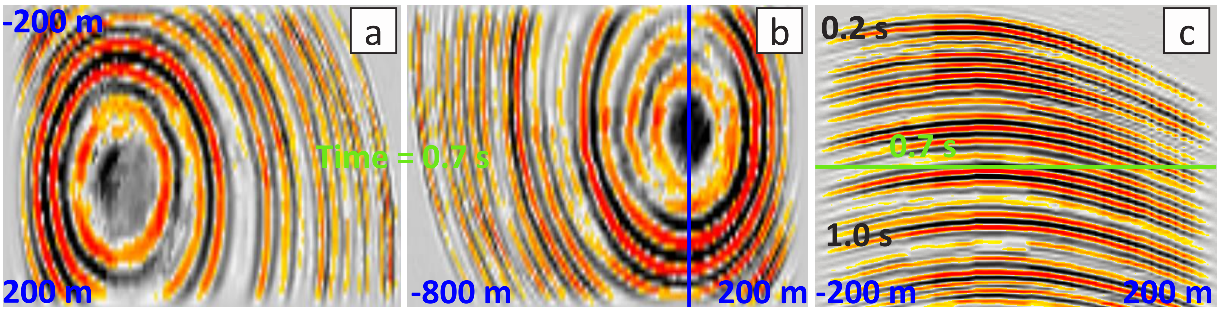

Figure 2 *Multiple contribution gather for regular MWD: Time slices at 700 ms for (a) shot-side, (b) receiver-side, and (c) inline sections for receiver side; the blue line shows the location of the inline section, and the green line shows the time for the time slice.*

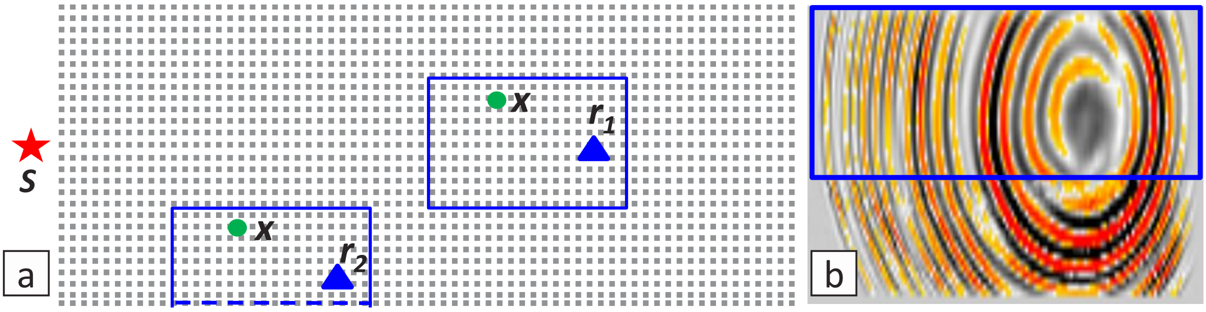

Figure 3 *Receiver-side multiples using shot gather convolving with Green's function: (a) a regularized shot gather. The red star marks the shot location, and grey dots mark the receiver locations (missing near offsets can be borrowed from adjacent shots). The blue triangles represent a near cable receiver and far cable receiver for multiple prediction, respectively. The green dots are the integration points. (b) Time-slice at 700 ms for receiver-side MCG of a far cable receiver using regularized cubes and regularized shot gather as input. The blue box marks the contribution from the same shot gather while the area outside the box is the contribution from regularized cubes.*

mixture of contributions from different shots and/or different saillines. The incoherent events in the MCG will cause artefacts in the multiple model when summed together, which is especially harmful for high-order multiple reverberations.

Because 2D MWD often better removes high-order multiple reverberations compared to 3D MWD, and 2D MWD uses regularized one-gun-and-one-cable shot gathers as input, we checked the possibility of utilizing regularized one-gun-and-all-cables shot gathers to help regular 3D MWD. Figure 3a shows a regularized shot gather. For a receiver at near cables, the regularized shot gather provides all the data needed for the aperture integration (the upper box) if the required aperture is not so large. However, for a receiver at far cables, the data needed for the aperture integration is truncated (the lower box). This truncation of data causes problems when the multiple bounce points are outside the shot gather area due to strong 3D effects. Our solution is to combine data from regularized cubes if a needed trace is unavailable in the regularized shot gather. In addition, it is preferable to use regularized cubes to obtain corresponding receiver gathers for shot-side multiples. Thus, our new selective-input MWD uses both regularized shot gathers and regularized cubes as input and selects a trace first from regularized shot gathers and then from regularized cubes.

Figure 3b shows a receiver-side MCG of selective-input MWD for a trace at far cables. Compared to the receiver-side MCG of regular MWD in Figure 2b, the contribution in the blue box is more coherent because the contributing traces are from the same regularized shot gather, whereas the contribution outside the blue box is still less coherent because the contributing traces are from different shots and/or different sail lines.

Data example

We tested the advantages of selective-input MWD using a field data set from Nova Scotia. In Figure 4a, the blue arrows highlight two multiple reverberations in the input data. Both regular MWD and selective-input MWD predict the multiple reverberations. However, careful examination reveals that regular MWD

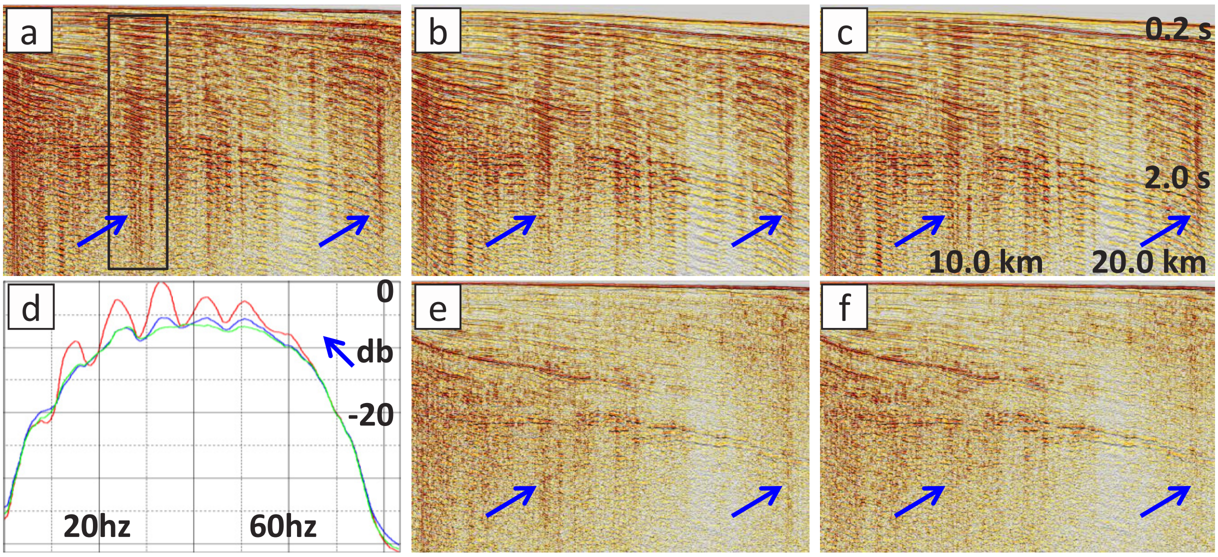

Figure 4 *Near-offset section for (a) input data, containing both primaries and all orders of multiples; (b) multiple model of regular MWD; (c) multiple model of selective-input MWD; (d) frequency spectra of input data (red), demultiple output of regular MWD (blue), and demultiple output of selective-input MWD (green); (e) demultiple output of regular MWD; and (f) demultiple output of selective-input MWD. The black box in (a) depicts the measuring region for the frequency spectra in (d). The arrows highlight the high-order multiple reverberations which is better removed by selective-input MWD.*

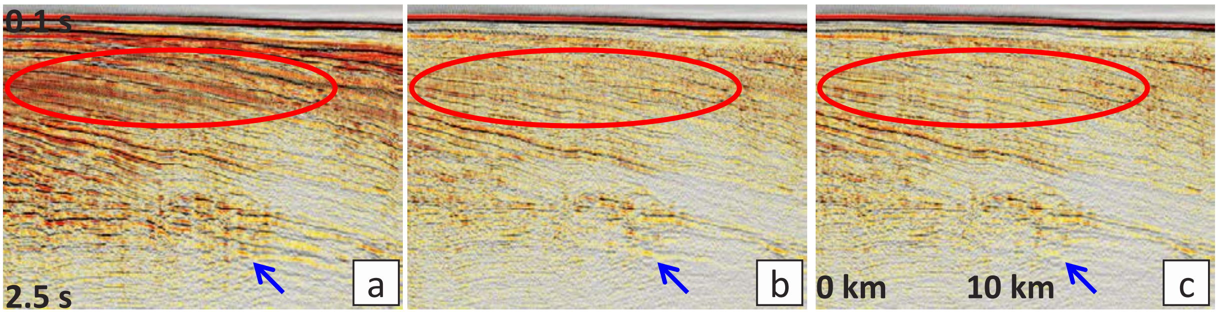

Figure 5 *Brute stack images for (a) input data, (b) demultiple output of regular MWD, and (c) demultiple output of selective-input MWD. The circles and arrows highlight the improvement of selective-input MWD over regular MWD.*

model (Figure 4b) fails to accurately predict the amplitude variation. This inaccuracy in the amplitude variation causes some residual multiples in the output (Figure 4e). In contrast, the model predicted by selective-input MWD (Figure 4c) better matches the input and thus better removes multiple reverberations (Figure 4f). The amplitude spectra comparison (Figure 4d) indicates selective-input MWD removes more multiples than regular MWD.

Figure 5 shows a comparison between regular MWD and selective-input MWD in the stack domain. In the shallow section, the demultiple output of selective-input MWD is much cleaner (red circles). Also, in the deeper section, selective-input MWD removes more peg-leg multiples (blue arrows).

Conclusions

We proposed an MWD adaptation that uses both regularized shot gathers and regularized cubes as input and prioritizes data selection first from regularized shot gathers and then from regularized cubes. Our proposed selective-input MWD improves the data coherency for receiver-side multiples compared to regular MWD. Therefore, its multiple model better matches the input data, especially for high-order multiple reverberations.

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