Joint Demultiple with Modelled Water-Layer and Subsurface Reflectivity Model Augmented by Separated Wavefield Imaging

Eric Camarda, Cesar Ricardez, Fernando Nunes, David Cavalin, Richard Huang, Alex Cruz, Khaled Abdelaziz, Junyong Chang, Sangwon Ham* (*TGS) Christina Tapia, Maddie Bishop, Nigel Hicks (Arena Energy)*

Summary

Removing both short-period and long-period multiples from complex seismic data acquired in very shallow water requires the pragmatic application of a suite of demultiple tools. In this paper we show an example of water bottom demultiple, which was performed on a shallow water OBS survey with an average receiver depth of 20m. A dual model approach was utilized for multiple subtraction, using both a modelled water-layer and wave equation multiple model. Importantly, separated wavefield imaging technology is used to create a shallow section image which is the key to obtaining a good result in the wave-equation demultiple model creation. Special care is taken to preserve low frequency energy in the subtraction process.

Theory

In this study we use a combined approach using both a modelled water layer and wave-equation demultiple. The modelled water-layer demultiple (MWD) model is derived from convolving the input data with a Green's function at the water bottom, modeling the additional bounces through the water layer. The MWD model is derived purely from the input data. The wave-equation demultiple model is derived by performing wave equation analysis on a shallow section produced with separated wavefield-imaging. The separated wavefield-imaging algorithm utilizes multiple energy to image shallow reflections, including the water bottom, which are post-critical for primary reflections (Valenciano *et al.*, 2014). An image generated using separated wavefield-imaging down to 1km depth is used to generate the wave-equation demultiple model.

The MWD and wave-equation demultiple multiple models are observed to be kinematically very similar, which is encouraging since two independent methods arrive at similar solutions. The MWD model is richer in lower frequencies while the wave-equation demultiple model contains more high frequency details. It is observed that including the wave-equation demultiple model in addition to the MWD model in the adaptive subtraction removes more high frequency multiple energy than just subtracting the MWD model alone. Figure 1 demonstrates that both approaches model similar energies, but the wave-equation demultiple approach models long period in addition to short period multiples. Given this it is sensible that also including the wave-equation demultiple model will take out more energy in the demultiple process. The advantages of a dual multiple model approach have been noted previously (Yao *et al.*, 2025). The lower end of the spectrum looks similar with either the MWD-only or MWD-plus-wave-equation demultiple approach. Given this dichotomy, low frequency subtraction (below 15Hz) is done with the MWD model only while higher the higher frequencies utilize a simultaneous adaptive subtraction of both the MWD and wave-equation demultiple models.

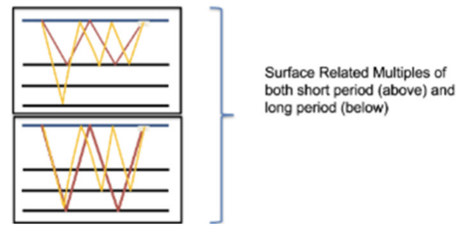

Figure 1: Diagram demonstrating both short and long period multiples. The MWD method models only short period multiples, while the wave-equation demultiple method models short and long period multiples

Methodology

Initial tests of adaptive subtraction at all frequencies yielded unsatisfactory results on the low end of the spectrum, with unexpected phase rotations of the multiple models upon adaptation to the input data. An investigation with a synthetic data case, where a re-datum is performed of a deepwater OBN node to a water depth similar to ones encountered in this survey, allows separation of the known primaries and multiples fields. Examining the overall amplitudes of the synthetic primaries-only field vs the primaries-plus-multiples fields shows that the primaries-only field is higher in amplitude at the lower frequencies (<12Hz). This is due to multiple energy interfering with primary energy at the low frequencies, causing a tuning effect.

Given this demonstrated tuning effect at the low frequencies, it is reasonable to expect that low frequency data will be higher in amplitude after multiple subtraction. This violates the core assumption of least-squares adaptive subtraction process, which assumes input data will be lower in amplitude at each event after subtracting the multiple model. To accommodate this, data are split into two frequency bands via 12-16Hz high-cut and low-cut filters, wherein the lower band matches only the MWD model to the input data with a single value amplitude scalar, and the upper band matches the MWD and wave-equation demultiple models to the input data with simultaneous least-squares adaptive subtraction. Data are reintegrated after both bands have undergone multiple model subtraction.

Examples

Figure 2 shows the synthetic data case where the data containing primaries only is higher in overall amplitude than the data containing primaries + multiples at the low end. This demonstrates the necessity of assuring the low frequencies are overall boosted in amplitude after multiple subtraction instead of diminished.

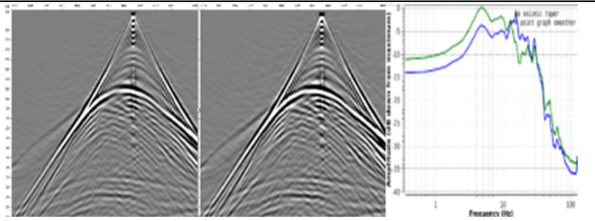

Figure 2: synthetic case shows higher overall amplitude after demultiple (middle) than before (left) below 15Hz. Amplitude spectra (right) shows before (blue) and after (green) demultiple. Note the green curve is above the blue curve below 10H

Examination of the demultiple input data vs the two multiple models, along with a single model (MWD) subtraction using least squares adaption at all frequencies, and a dual model (MWD and wave-equation demultiple) subtraction using amplitude scaling matching at the low and least squares adaption at the high frequencies, shows good agreement between the MWD and wave-equation demultiple models, and that the dual model subtraction takes out slightly more multiple energy than the single model subtraction (figure 3).

Spectral analysis of the input data after undergoing single model, single frequency adaptive subtraction vs dual model split frequency subtraction shows how allowing adaptive subtraction to operate at all frequencies reduces amplitude at the low-end vs allowing only amplitude scaling at the low frequencies increases amplitude at the low end (figure 4).

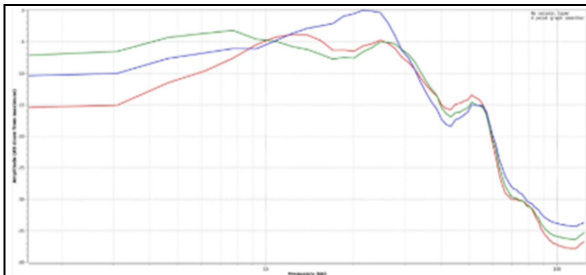

Figure 4: Input data (blue), output of adaptive subtraction at all frequencies (red) and of amplitude scaling at low and adaptive subtraction at high frequencies (green). Note the green curve is above the blue curve while the red curve is below it below 10Hz

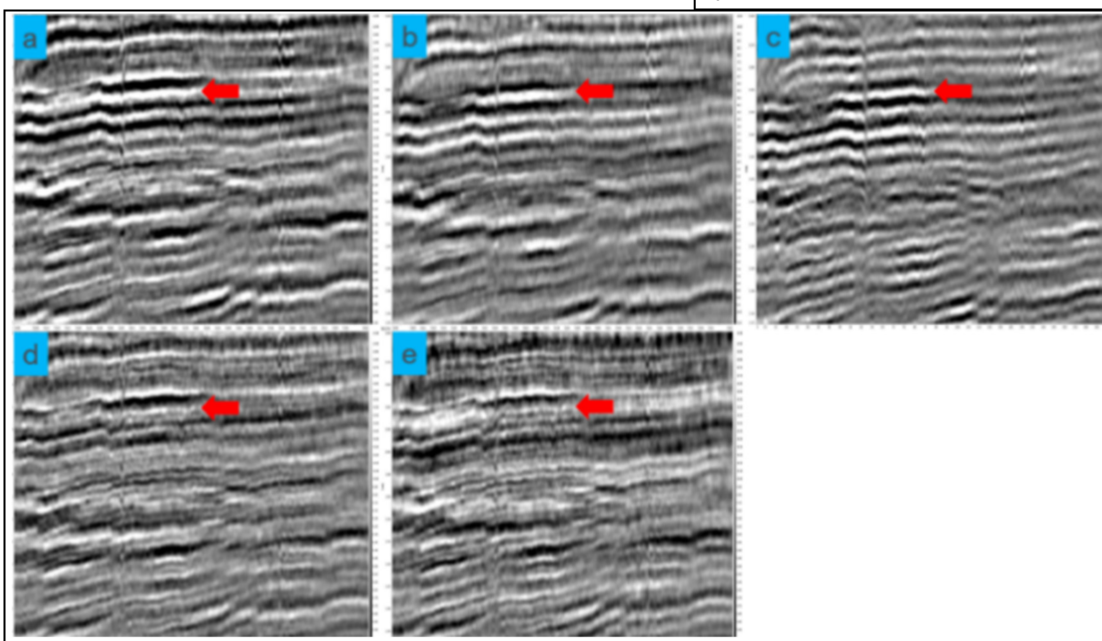

Figure 3: From top left to bottom right, (a) demultiple input, (b) MWD model, (c) wave-equation demultiple model, (d) MWD model only subtraction, (e) MWD+wave-equation demultiple model subtraction. Red arrows denote a multiple event that is modelled and attenuated after subtraction

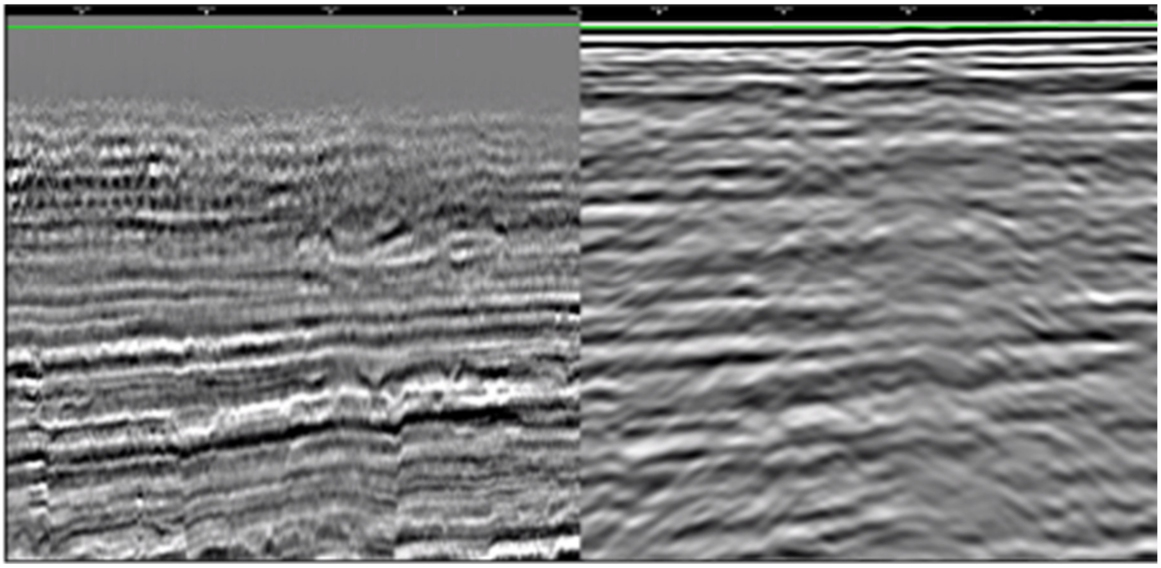

Figure 5: Kirchhoff (left) vs SWIM (right) image of the shallow section. Green curve represents the water bottom horizon

Comparing Kirchhoff imaging of primary reflections only to SWIM imaging of multiple reflections demonstrates the necessity of utilizing multiple energy in this data to image the water bottom since the water bottom reflection will be post-critical for primary reflections (figure 5). The water bottom reflection and the data immediately below it (down to 1km depth) can be used to derive a wave-equation demultiple model. Examination in depth slice view shows how sparse the shallow coverage of the RTM image is compared to the separated wavefield-image near water bottom depths (Figure 6).

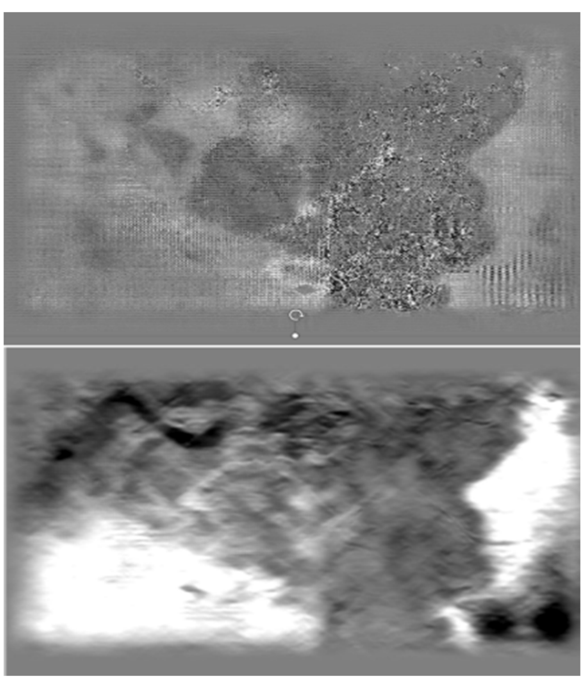

Figure 6: Depth slice at 30m of RTM (top) and SWIM (bottom) image. Note the sparsity of the RTM coverage this shallow

Conclusions

In very shallow water data, multiple energy can interfere with primary energy of the same events at the low frequencies, causing the overall amplitude to increase rather than decrease at the low end after the multiples are properly removed. Least squares adaptive subtraction may not honor this, necessitating a simpler method of matching the multiple model to the input data for the low frequencies. In this case, amplitude scaling-only was used for the low frequencies, and simultaneous least squares adaptive subtraction for the high frequencies.

Two methods of multiple model derivation were utilized. The MWD model shifted the input data by the multiple period. The wave-equation demultiple model used a shallow image derived from separated wavefield-imaging to derive a reflectivity cube.

Acknowledgements

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