Adaptive Marchenko multiple removal on Arabian Gulf OBC data

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Introduction

The subsurface of the Arabian Gulf contains carbonates, anhydrites and clastics that form a sequence of many thin layers with strong impedance contrasts. As a result, the higher order internal multiples are of importance due to the sheer number of generation possibilities and contribute to a complex wavefield that interferes with the primary response. The Marchenko equation-based methodology is well-suited to predict such a complex wavefield because it does not require the identification of individual multiple generators as opposed to other de-multiple methods. The resulting inverse problem solves for a complete inverse transmission response v^+ of the overburden (direct wave and multiple coda), which can be used to predict overburden borne reverberations. These can then be subtracted directly from the original data.

In all, we propose a wave-equation-based and data-driven approach that requires a careful preparation of the data. In theory, the method predicts multiples with the correct amplitude and phase. In practice, due to imperfections in the acquired data and preprocessing minor differences between the multiples in the data and their predictions are present. Therefore, we use a mild adaptive filter to compensate for these amplitude and phase differences. We will demonstrate that the aforementioned complex interference pattern can be predicted and subtracted from OBC data acquired in a shallow marine environment in the Arabian Gulf using our adaptive Marchenko multiple removal method.

Proposed method

We combine the approaches from van der Neut and Wapenaar (2016) and Staring et al. (2018) to exploit the advantages of both. The former authors propose a method to predict internal multiples without redatuming. They retrieve a nested series expansion of an inverse transmission generator v^+ and a type of upgoing wavefield U^- without receiver-side multiples and primaries from the overburden: $v^+ = \sum_{j=0}^{N} v_j^+ = \sum_{j=0}^{N} (\theta_1 R^* \theta_1 R)^j \, \delta$ and $U^- = \sum_{i=0}^{M} U_i^- = \theta_2 R \, v^+$. Here, R and R^* are operators that represent a convolution and a correlation with the reflection response, θ_1 and θ_2 are mutes, and v_0^+ is a band-limited spatio-temporal delta function. Next, one could perform a multidimensional deconvolution of the upgoing wavefield U^- with the downgoing wavefield U^+ to remove all overburden interactions. Instead, following Staring et al. (2018), we propose a more straight-forward approach by convolving the upgoing wavefield U^- with an inverse transmission generator v^+: $U^{-+} = U^- * v^+ \approx U_0^- + \alpha(U_1^- + U_0^- * v_1^+ + U_1^- * v_1^+ + \cdots) \equiv U_0^- + \alpha \sum_{k=1} U_k^{-+}$. The resulting wavefield U^{-+} does not contain any internal multiples generated in the overburden. Note that later arriving multiples (which would be imaged deeper) generated by interactions between the target area and the overburden are not removed by this convolution. The first term U_0^- is the muted reflection response, while later terms U_k^{-+} contain predictions of internal multiples. A single adaptive filter α is used to compensate for unavoidable amplitude and phase differences.

Application

Marchenko multiple prediction, as outlined above, requires a sufficiently dense grid (to avoid aliasing) of co-located dipole sources and monopole receivers (much like SRME and IME). In addition, the reflection response should be de-noised and be free of ghosts and surface-related multiples. Throughout these preprocessing steps, it is very important to take care of amplitude fidelity and consistency, since individual terms in $\sum_{k=1} U_k^{-+}$ are summed without any weighting. After regularization and high-cut filtering of the Arabian Gulf OBC data, we obtained a 2D line of unaliased data at 25 m spacing. Lastly, in a shallow marine setting, the removal of surface-related multiples and the source de-signature are the main challenges. The Robust EPSI method fits the desired workflow very well, not only because it addresses both issues simultaneously (Belonosov et al., 2019), but also because it produces a reflection response R that serves as a suitable input for our proposed Marchenko method.

Since the subsurface of the Arabian Gulf generates a highly complex interference pattern, we cannot speak of predicting individual events or orders of events, but rather of obtaining corrections for amplitude and phase to U^{-+}.

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For our example, we needed to use tens of terms ($m = n = 20$) before their contributions became negligible. In contrast, Staring et al. (2018) only needed two terms to remove internal multiples from a target area in deep-water Brazil. In the Arabian Gulf, we predicted a complex wavefield of internal multiples, after which a mild adaptive filter (filter length of 5 samples, windows of 100 samples by 25 traces, L2 minimization) was used to subtract it from the reflection response. Figure 1 shows migrated images of the input and the result of internal multiple removal and their amplitude spectra. The spectra show that the removed interference pattern mainly had low frequencies, which seems to be a property of this particular medium. The result seems to have a more broadband character, indicating an enhanced resolution. In the RTM images, conflicting seismic events have been resolved, leading to improved visibility of known horizons (see the green circles). Note that the overburden has been removed, but that sources and receivers still reside at the surface. In addition, the images suggest that there are faulted structures that were not seen before (see the red circles). We remark that the results obtained in this field study are supported by synthetic detailed controlled experiments (Reinicke et al., who also submitted to this workshop, and Elison et al., 2019).

Conclusion

We have applied a Marchenko multiple removal method on shallow water OBC data of the Arabian Gulf. The internal multiples that were predicted and adaptively subtracted fit the expectations of a complex interference pattern, thus demonstrating the complexity of the multiple problem in this geological setting and the potential of the method.

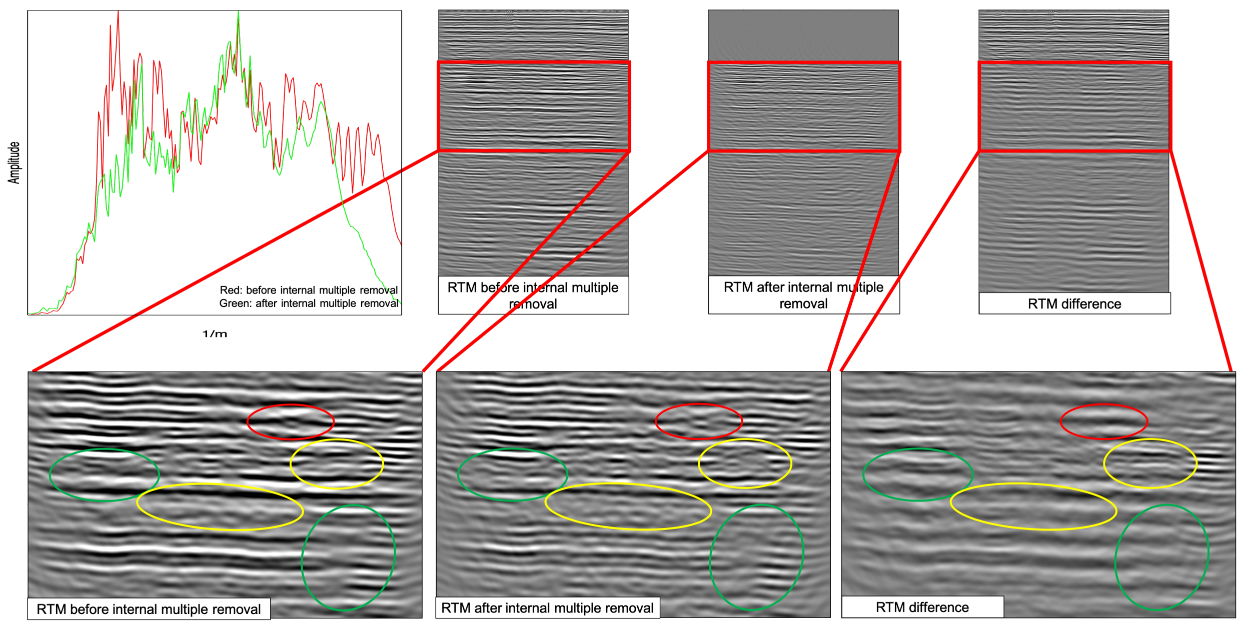

Figure 1: Top left: amplitude spectra of RTM images before and after internal multiple removal, top right: RTM images before and after multiple removal and the difference; bottom: zoom of the RTM in the upper right. The yellow circles indicate a significant reduction of multiple energy; the green circles indicate an increased resolution of reflectors after removal of monochromatic interbed multiples; and the red circle indicates a better definition of faulty structures.

References

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