

# Do we need elastic internal de-multiple offshore Middle East, or will acoustic Marchenko suffice?

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## INTRODUCTION AND PROBLEM STATEMENT

In the Middle East, dense layering with strong elastic contrasts generate internal multiples leading to undesired, highly complex interference patterns. Marchenko-equation-based de-multiple methods (e.g. van der Neut and Wapenaar, 2016) are particularly well suited for this situation. By formulating an inverse problem, they retrieve an inverse transmission  $v^+$  (see Fig. 1c) through the entire overburden (as opposed to identifying individual multiple generators). Subsequently, the solution is used to retrieve a target reflection response  $R_{Target}$  that is scattering-free in the overburden (see cartoon in Fig. 1a). This method relies on accurate data preprocessing such as wavelet estimation, elimination of surface-related multiples and near surface effects. These requirements are challenging for land seismics but can be handled for streamer data (see submission to this workshop by Staring et al.).

The elastic extension of Marchenko de-multiple depends on two assumptions, which can be easily violated: (a) All components of the reflection response are required to predict all (converted) multiples. Nevertheless, in a marine setting (streamer data), shear wave source- or receiver-components of the elastic reflection response ( $R_{ps}$ ,  $R_{sp}$  and  $R_{ss}$ ) are absent, only the acoustic component  $R_{pp}$  is measurable. (b) The temporal ordering of primaries must agree with the reflector ordering in depth. However, the P- and S-wave propagation speed differences enable target-related P-primaries to outpace overburden-related S-primaries (Reinicke et al., 2019), which ultimately convert to P-waves in the water layer. It is believed that these two conditions are also required by other existing data-driven elastic internal de-multiple methods (e.g. elastic extension of Jakubowicz, 1998; Sun and Innanen, 2019).

Due to these unsolved theoretical challenges, a strategy is to use acoustic theory and treat elastic  $R_{pp}$  data as if it were an acoustic reflection response  $R_{ac}$ , but is that sufficiently accurate? On the one hand, due to the nearly horizontal layering of the Middle Eastern geology, elastic effects may be negligible for short-offsets because they vanish at zero-incidence and only appear gradually with increasing angle of incidence. In addition, S-wave conversions, leading to steep events, can be partially attenuated by  $f$ - $k$  filtering during preprocessing. On the other hand, the Marchenko method will treat "non-acoustic" effects, such as P-S-P conversions, as if they were acoustic. If these assumptions hold, acoustic Marchenko de-multiple, using elastic  $R_{pp}$  data, may be sufficient for structural imaging, which mainly relies on stationary points, but naturally falls short for AVO analysis.

To verify the aforementioned conjecture, we build a complex synthetic Middle East model inspired by regional well-logs (P- and S-wave velocities as well as density from log data), accounting for a gentle regional dip, varying layer thicknesses and introducing minor faults, riverbeds as well as small relief structures (see Figs. 1a-b). From this model we can obtain an acoustic reflection response  $R_{ac}$  (S-wave velocity  $c_s = 0$ ) as well as elastic  $R_{pp}$  data ( $c_s \neq 0$ ). In this controlled experiment we demonstrate not only that the Marchenko method attenuates nearly all internal multiples but also that acoustic Marchenko with elastic  $R_{pp}$  data performs very well in close-to 1.5D media, using prestack Kirchhoff depth migrated (PSKDM) images as a benchmark.

## SCATTERING RELATIONS AND DE-MULTIPLE RESULTS

The acoustic workflow in reverse order consists of an Amundsen (2001) deconvolution of auxiliary fields  $U^\pm$  to obtain the response  $R_{Target}$ , and a Marchenko inversion for the inverse transmission  $v^+$  through the overburden,

$$U^- = R_{Target}U^+, \quad U^+ = -R_{ac}(\Theta[R_{ac}v^+])^* + v^{+*}, \quad U^- = R_{ac}v^+ - \Theta[R_{ac}v^+], \quad v^+ = \Theta[R_{ac}^* \Theta[R_{ac}v^+]] + \delta(x). \quad (1)$$

Here,  $\delta(x)$  is a spatial delta function and integrals in  $x$ - $f$  coordinates are hidden (for details see van der Neut and Wapenaar, 2016). All outputs can be obtained from (i) the input data  $R_{ac}$  and (ii) the mute  $\Theta$  (shown in Fig. 1c) which is based on a single time horizon.

The elastic extension of Eq. (1) replaces scalar wavefields by matrices to account for all wavefield components. For sufficiently weak mode coupling, the off-diagonal matrix elements become negligible, simplifying the elastic scheme to an acoustic one. For streamer data, however, only the PP matrix element is non-zero, which leaves the elastic inverse transmission  $v^+$  undefined. Further, because of P- and S-wave speed differences, the mute  $\Theta$  is now defined for each elastic wavefield component separately. The elastic extension of the right-most expression in Eq. (1) remains exact only if assumption (b), about temporal ordering, holds. Otherwise, the retrieved  $v^+$  will be erroneous, and so will be

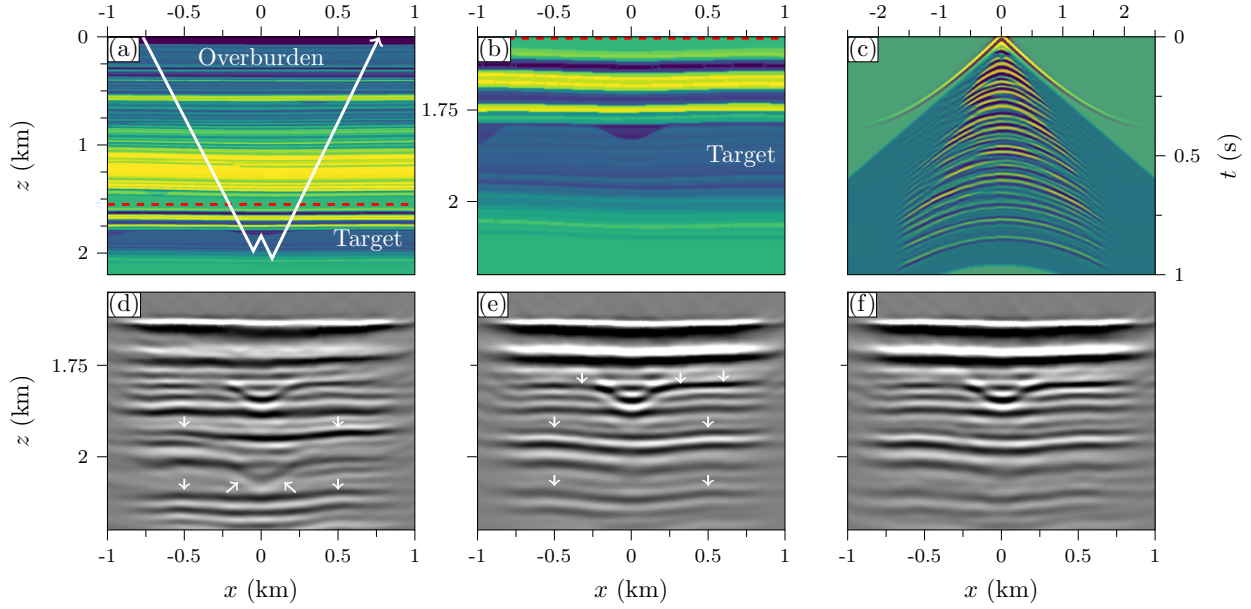


Figure 1: (a-b) Structural model and close-up of the target, dashed red line separating the overburden from the target. (c) Marchenko solution  $v^+$  retrieved from the acoustic reflection response  $R_{ac}$  and mute  $\Theta$  depicted by black shadow. (d-f) PSKDM images.

the fields  $U^\pm$  and  $R_{Target}$ .

Considering these challenges, we analyze whether the close-to 1.5D medium combined with the advantages of the Marchenko method alleviates the need for elastic internal de-multiple. For this test, we consider the model in Fig. 1a and retrieve PSKDM images of the target (depicted in Fig. 1b) using three different reflection responses as input: (i) The reflection response  $R_{ac}$ , the response  $R_{Target}$  derived from Eq. (1) using (ii)  $R_{ac}$  and (iii)  $R_{pp}$  instead of  $R_{ac}$ . The respective images (see Figs. 1d-f) show that the Marchenko method removes most of the multiple-related artefacts (indicated by the arrows in Fig. 1d), improves continuity and reveals previously unseen reflectors (see arrows in Fig. 1e). Further, acoustic Marchenko de-multiple with  $R_{ac}$  and  $R_{pp}$  data leads to nearly identical images (compare Figs. 1e and f).

## CONCLUSION AND ACKNOWLEDGEMENTS

Despite the model complexity, e.g. leading to short-period multiples, near-to-all internal multiples could be attenuated without adaptive subtraction. We conclude that acoustic Marchenko de-multiple with elastic  $R_{pp}$  data may be sufficient for structural imaging of close-to 1.5D media, demonstrating its relevance offshore Middle East.

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