

## Introduction

Disregarding their possible use in imaging, surface multiples are primarily still dealt with by 3D SRME (convolutional and/or wave equation modelling in different ratios) despite its well-documented shortcomings related to the need for adaptive subtraction and its well-known limitations in shallow water regimes. However, where necessary, this single prediction-subtraction process can easily be augmented by other methods generating additional predictions and then used in a simultaneous multi-model subtraction method, or the process can be completely replaced by an inversion algorithm (e.g. EPSI and its variants).

When it comes to internal or interbed multiples, prediction and subtraction as a methodology (whether based on the approaches by Jacubowitz, 1998, Berkhout & Verschuur, 2005, Weglein, 1997, van Borselen, 2002 or others) has its use cases, most notably, situations with strong reflectors such as the water bottom and top of salt in offshore regimes like Brazil (e.g. Hembd et al., 2011) or onshore with anhydrate/salt reflectors in the overburden (e.g. Al Jahdhami et al., 2017). These kind of internal multiples tend to introduce (reasonably) well defined but artificial events in our depth images if not removed beforehand, which could inhibit or complicate the correct (quantitative) interpretation when they cross reflectors or areas of interest. If their removal is not feasible on the prestack data or post migration, the interpretation will still benefit from the predicted internal multiples even though the production and handling of the additional volumes requires extra time and effort.

However, there are other situations where internal multiples can obscure the primaries of interest. A package of thin layers of similar or slightly varying thicknesses will result in so much (internal) scattering that a cloud of (internal multiple) events will be generated completely obscuring (weaker) primaries from deeper reflectors as observed in a dataset acquired at or near the Arabian Peninsula. So far, all available methods fail to handle this particular case.

Therefore, any techniques introduced in the last few years are of interest, not just Marchenko based although we will limit ourselves to those here. The term Marchenko is usually associated with the possibility of properly accounting for the presence of internal multiples in the actual imaging, which is an interesting development by itself. Nevertheless, the various options of using Marchenko for the prediction of internal multiples are seen as more feasible at the moment. First, such an option will be easier to accommodate in existing production workflows. Second, any shortcomings in the acquisition or pre-processing related to the stronger assumptions Marchenko poses on its input will have an impact on its results regardless, but this will be less of a problem for the predictions as a separate intermediate product. In addition, it is not uncommon to run a dedicated multiple prediction workflow, which is separate from the main (pre-processing) workflow for imaging.

There are at least two different internal multiple prediction methods based on Marchenko. The first one (Meles et al., 2015) tries to predict multiples for the full gathers. This method, which shares some features with ISS based methods, will be used in this abstract as part of a collaboration project. The second one (van der Neut and Wapenaar, 2016) aims to predict and eliminate all multiples of an overburden defined by a given target horizon, which is less applicable in our case. Note that the latter article provides a good overview of various prediction methods and their advantages and disadvantages. In addition to these internal multiple prediction methods, other Marchenko based methods exist, which aim to predict the primaries only data (free of internal-multiples) (Meles, et al., 2016) or which aim to filter out the internal multiples from the prestack data (e.g. Slob et al., 2017).

## Method

A straightforward reflectivity-modelling scheme (e.g. Goupillaud, 1961) allows us to model the full response (primaries and internal multiples), all primaries or all internal multiples separately in order to evaluate the effectiveness of an internal multiple prediction method. Datasets for several 1D models with increasing complexity in terms of thin layering were generated and together with a corresponding smoothed velocity profile, which was reasonably correct in terms of the kinematics,

provided for blind testing of the prediction method, which is similar to the one described in (Meles et al, 2015). The general procedure works for a series of boundaries as follows:

- 1) For every point along a specific boundary, derive the up- and downgoing Green's functions between all surface locations and that point with a Marchenko scheme (Thorbecke et al., 2017),
- 2) Mute the direct waves in the downgoing and, for safety, in the upgoing Green's functions,
- 3) Convolve these up- and downgoing Green's functions for every point along the boundary,
- 4) Integrate these combinations over the boundary to predict internal multiples.

Finally, the results of all boundaries are stacked to create a single prediction of all internal multiples. For the 1.5D synthetics, the boundary or integration contour can be a vertical profile allowing prediction of all the multiples at once, which means the final stack is superfluous. The depths chosen along the profile could be regularly spaced or varied according to the, expected or observed, complexity of the subsurface or, as the depths can be processed independently, even refined further at a later stage as and when required. One advantage of the method is that the derived Green's functions can be inspected as part of a general quality assessment. Note that the amplitudes of the predictions are generally not correct due to several approximations (see Meles et al., 2015). On the other hand, the method is quite robust with regards to the accuracy of the velocities used.

## Examples

In the following examples, the direct wave, free-surface multiples and ghosts were excluded from any modelling as required for the input to the Marchenko scheme. The sampling in depth was set to 5m. The first model (Figure 1a) does not show thin layering, as its purpose is primarily to test the new codes, to help their further development and to (re)acquaint us with various practical aspects of the method. The left half of Figure 1b shows the modelled full data and the right half the corresponding internal multiples (after scaling for display). The prediction results and actual multiples are shown on the left, resp. right in Figure 1c and the corresponding zero offset traces in red resp. green in Figure 1d. All internal multiple events are very well recovered at the right times, although an additional low amplitude event appears at around 1.8s zero offset and a kind of precursor event is present. Some differences in frequency content are visible, but the overall shapes (peaks and troughs) of the events match extremely well. Note the predictions were generated up to about 40Hz with a dominant frequency of about 20Hz. The actual internal multiples were generated with a Ricker wavelet with a dominant frequency of 23Hz and were filtered down at the high end afterwards to improve these comparisons. The larger offsets do show some obvious artefacts with (near) constant dips. The extra event at 1.8s and the precursor event can be clearly distinguished as such dipping artefacts, which extend to zero offset with decreasing amplitudes. Most likely, these are some kind of aperture related effects, which do not concern us too much right now. In our experience, increasing the aperture and improving the tapering will generally mitigate these kind of effects. Nevertheless, this is still under investigation. The mismatch in relative amplitudes between predicted and actual events is as expected and would not pose a problem for an adaptive subtraction unless primaries and multiples would overlap.

The second model in Figure 1e is more interesting. This model contains a package of thin layers of varying thicknesses between 10 to 30m at around 950m depth, which creates a complex set of events. The left half of Figure 1f shows the modelled full data and the right half the corresponding internal multiples (after scaling for display). The internal multiples almost at and below 1.8s are mostly due to the presence of the last primary at 1.8s which relates to the last change in velocity at 1750m. Note that this primary does not constitute a, downward scattering, multiple generator in IME terms and hence standard IME methods would not work. The prediction results from Marchenko and the actual multiples are shown on the left, resp. right in Figure 1g and the corresponding zero offset traces in red resp. green in Figure 1h. Like in the first example, the peaks, troughs, and timings of the various

events match very well. Improved tapering here removed the dipping artefacts almost entirely. Given this is a work in progress, these results are already better than expected.

## Conclusions

Ideally, one should extract and use as much information as reasonably possible from the acquired seismic data. The research on ways to account properly for internal multiples in imaging is still ongoing and it will take some years before this can eventually become common practice. Therefore, when it comes to internal multiples, their removal would still be preferable, but even obtaining good predictions can be beneficial to any follow-up interpretation work. The predictions can be very challenging for some cases of thin layering. The initial results of the Marchenko based method so far are very promising.

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## References

- Berkhout, A. J., and D. J. Verschuur, 2005, Removal of internal multiples with the common-focus-point (CFP) approach: Part 1—Explanation of the theory: *Geophysics*, **70**, no. 3, V45–V60.
- van Borselen, R. 2002, Z-99 Fast-Track, Data-Driven Interbed Multiple Removal: A North Sea Data Example, EAGE 64th Conference & Exhibition
- Goupillaud, P., 1961, An approach to inverse filtering of near-surface layer effects from seismic records: *Geophysics*, **26**, no. 6, 754-760
- Jakubowicz, H., 1998, Wave Equation Prediction and Removal of Interbed Multiples, EAGE Expanded Abstracts
- Hemdb, J., M. Griffiths, C. Ting, and N. Chazalnoel, 2011, Application of 3D Interbed Multiple Attenuation in the Santos Basin, Brazil, EAGE Expanded abstracts
- Meles, G.A., K. Löer, M. Ravasi, A. Curtis, and C.A. da Costa Filho, 2015, Internal multiple prediction and removal using Marchenko autofocusing and seismic interferometry.
- Meles, G.A., C.P.A. Wapenaar, and A. Curtis, 2016, Reconstructing the primary reflections in seismic data by Marchenko redatuming and convolutional interferometry: *Geophysics* **81**, no. 2, Q15-Q26.
- van der Neut, J.R. and C.P.A. Wapenaar, 2016, Adaptive overburden elimination with the multi-dimensional Marchenko equation: *Geophysics*, **81**, no. 5, T265-T284.
- Slob, E., L. Zhang, and C.P.A. Wapenaar, 2017, Obtaining local reflectivity at two-way travel time by filtering acoustic reflection data, SEG extended abstracts.
- Thorbecke, J., E. Slob, J. Brackenhoff, J. van der Neut, and C.P.A. Wapenaar, 2017, Implementation of the Marchenko method: *Geophysics*, **82**, no. 6, WB29-WB45.
- Weglein, A.B., F.A. Gasparotto, P.M.Carvalho, and R.H.Stolt, 1997, An inverse scattering series method for attenuating multiples in seismic reflection data: *Geophysics*, **62**, 1975-1989
- Al Jahdhami, M., J.W. de Maag, A. Mueller, S. Rao Narhari, O. Kolawole, V. Kumar Kidambi, Al-Qadeeri, Bashar, Dashti, and Qasem, 2017, 3D surface-related and interbed multiples attenuation on 5D-interpolated OVT data from a single sensor survey in Kuwait, SEG extended abstracts.

**Figure 1 (shown on the next page)** For first example: a) blocky and smoothed velocity profiles in m/s, b) actual input (left) and internal multiples (right), c) predicted (left) and actual multiples (right), d) zero offset trace, predicted (red), actual (green), e) – h) same as to a) – d) but for second example.

