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Slob, E.C.; Zhang, L.

DOI
10.3997/2214-4609.202012142

Publication date
2020

Document Version
Final published version

Published in
82nd EAGE Conference & Exhibition 2020

WS15_05

Marchenko Multiple Elimination

E. Slob[1]*, L. Zhang[1]

[1] Delft University of Technology

Summary

Marchenko methods compute a focusing function for a receiver at the acquisition surface and a virtual source in the subsurface. Computing the focusing function requires subsurface information. The method has been modified to operate at the acquisition surface. The focusing function becomes a fundamental wave field as known since many decades. These can be computed from the up- and down-going parts of the data without any subsurface information. The up- and down-going parts can be obtained from up-down decomposition, or from up-down decomposition of the data followed by free surface multiple removal and wavelet deconvolution. The primary reflection dataset is obtained from applying the fundamental wave field to the data, or directly from the up-going part of the fundamental wave field. In the first option, the obtained primary reflections are the same as in the data, with all transmission effects and possibly the source ghost and source wavelet. In the second option, the obtained dataset is a primary reflection impulse response where the amplitudes have been compensated for transmission effects.

Introduction

Marchenko focusing (Broggini et al., 2011; Wapenaar et al., 2011) was introduced to create a Green's function for a physical receiver at the acquisition surface and a virtual source inside a heterogeneous medium. It requires subsurface information. In the overburden removal scheme of van der Neut and Wapenaar (2016) the need for subsurface information is reduced by projecting the focusing functions back to the surface. This idea led to Marchenko multiple elimination schemes that come with or without correction for transmission effects (Zhang and Staring, 2018; Zhang et al., 2019). No subsurface information or adaptive subtraction is necessary to eliminate all multiples, because the time truncation is taken as a free and independent parameter.

Corrections for transmission effects requires deconvolution if the projected Green's functions are used. Slob et al. (2014) showed in 1D that the transmission effects can be eliminated by choosing a unit impulse as the initial down-going part of the focusing function. The associated wave field is known as the fundamental wave field and the idea can be traced back to Kunetz and d'Erceville (1962). We give an overview of the method applied to data after various levels of pre-processing, from up-down decomposition to pre-processed data after free surface multiple removal and source wavelet deconvolution.

Brief review of Marchenko Multiple Elimination

The initial part of the down-going focusing function was collapsed to a delta-function at the acquisition level in van der Neut and Wapenaar (2016) to remove the effect of the overburden from the reflection data. This reduced need for model information to requiring only a truncation time that depends on the source-receiver pair and a chosen depth level. Zhang and Staring (2018) showed that truncations times can be used independent of source-receiver pair and a chosen depth level. This made the truncation time a free parameter that can be used across the whole dataset. With this introduction the Marchenko multiple elimination scheme does not require any subsurface information. The primary reflections that are retrieved from the reflection response can be collected in a new dataset, where they occur at their physical two-way travel time and with their physical amplitude including transmission effects. This is the Marchenko multiple elimination (MME) scheme.

The up- and down-going parts of the fundamental wave field are computed from the up- and down-going parts of the data as

$$\int_{\partial\mathbb{D}_0} [p^+(\mathbf{x}'_0,\mathbf{x},t) * h^-(\mathbf{x},\mathbf{x}''_0,t,\tau) - p^-(\mathbf{x}'_0,\mathbf{x},t) * h^+(\mathbf{x},\mathbf{x}''_0,t,\tau)]\mathrm{d}\mathbf{x} = p^-(\mathbf{x}'_0,\mathbf{x}''_0,t), \tag{1}$$

$$\int_{\partial\mathbb{D}_0} [p^+(\mathbf{x}'_0,\mathbf{x},-t) * h^+(\mathbf{x},\mathbf{x}''_0,t,\tau) - p^-(\mathbf{x}'_0,\mathbf{x},-t) * h^-(\mathbf{x},\mathbf{x}''_0,t,\tau)]\mathrm{d}\mathbf{x} = 0, \tag{2}$$

for $0 < t < \tau$. In these equations the up- and down-going parts of the acoustic pressure and the fundamental wave field are denoted $p^\pm(\mathbf{x}'_0,\mathbf{x},t), h^\pm(\mathbf{x},\mathbf{x}''_0,t,\tau)$ where the plus- and minus-signs indicate down- and up-going parts, respectively, t is time, τ is truncation time and $*$ indicates temporal convolution. The position vectors denote the receiver and source locations, e.g., in the right-hand side of equation (1) they are given by $\mathbf{x}'_0, \mathbf{x}''_0$, respectively and $\mathbf{x}$ is the coordinate vector for all sources at the acquisition surface $\partial\mathbb{D}_0$. Once h^+ is known, we retrieve the time sample for the primary reflection dataset p_t as

$$p_t(\mathbf{x}'_0,\mathbf{x}''_0,\tau) = p^-(\mathbf{x}'_0,\mathbf{x}''_0,\tau) + \int_{\partial\mathbb{D}_0} [p^-(\mathbf{x}'_0,\mathbf{x},t) * h^+(\mathbf{x},\mathbf{x}''_0,t,\tau) - p^+(\mathbf{x}'_0,\mathbf{x},t) * h^-(\mathbf{x},\mathbf{x}''_0,t,\tau)]\mathrm{d}\mathbf{x}|_{t=\tau}, \tag{3}$$

where the time integral is evaluated for $t = \tau$. Note that when only up-down decomposition is done to the measured data (Amundsen, 2001), the retrieved primary reflections dataset contains the source-receiver ghost and the source-time signature. When the dataset is fully processed, the down-going field is an impulse, $p^+(\mathbf{x}'_0,\mathbf{x},t) = \delta(x'_0 - x, y'_0 - y, t)$, and the up-going field is the subsurface impulse reflection response, $p^-(\mathbf{x}'_0,\mathbf{x}''_0,t) = R(\mathbf{x}'_0,\mathbf{x}''_0,t)$. In that case, $p_t = R_t$ denotes the primary reflections dataset as in Zhang and Staring (2018). The associated dataset of primary reflections with compensation for transmission effects is obtained from the up-going part of the fundamental wave field as $R_r(\mathbf{x}'_0,\mathbf{x}''_0,\tau) = h^-(\mathbf{x}'_0,\mathbf{x}''_0,t \uparrow \tau)$ (Zhang and Slob, 2019). Independent of what type of data is used, the fundamental wave field is a band-limited impulse response.

Example of Marchenko multiple elimination

The reflection responses, for the velocity and density models including a free surface shown in Figure 1, are computed for 601 source positions and 601 receiver positions for each source. A 20 Hz Ricker wavelet is used as the source time signature and is assumed to be known when we compute the fundamental wave field and the resulting dataset containing only primary reflections. The middle and right columns of Figure 1 show the central shot gather of the modelled reflection response (middle) and the retrieved primaries dataset (right). In the modelled response in the left graph, red arrows point at the free-surface and internal multiple reflection events that are present in the data. We can see that these events are absent in the filtered response as shown in the right graph. To compute the result in the right graph 10 iterations were used in the solution of equations (1) and (2).

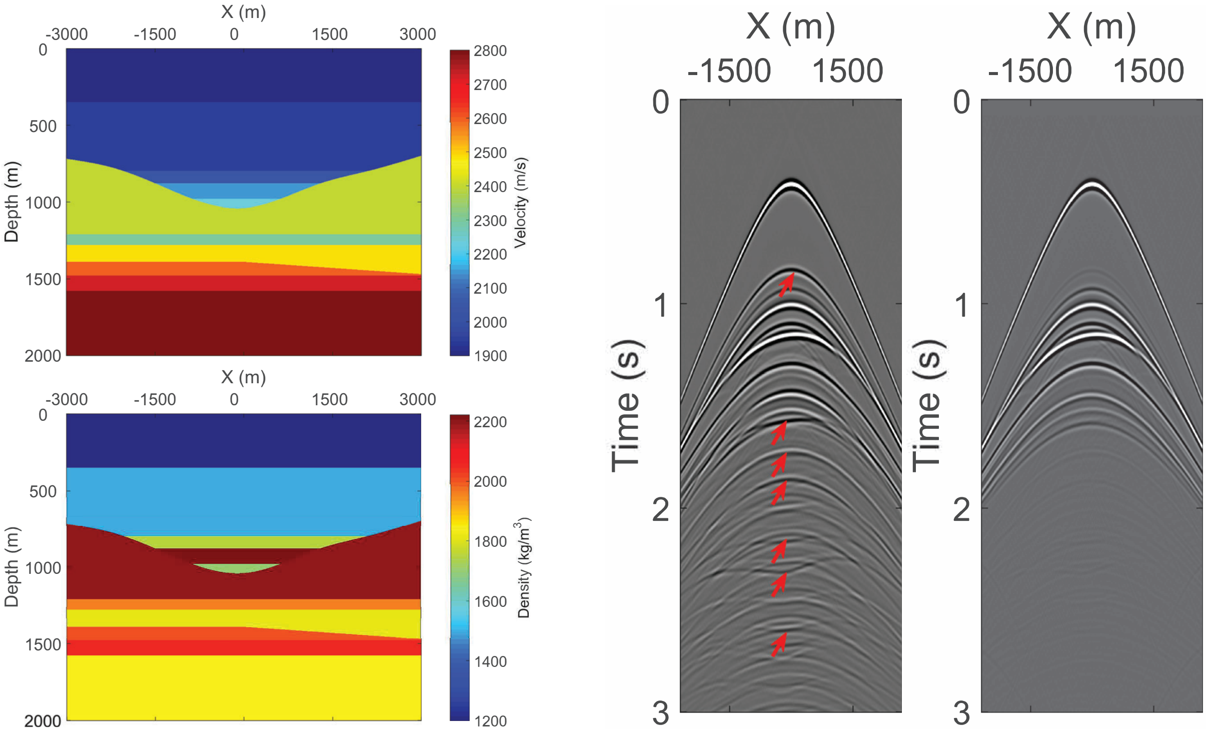

Figure 1 *Subsurface velocity (top left) and density (bottom left) models, the central shot gather before (middle column) and after (right column) multiple elimination.*

Conclusions

We have shown that MME retrieves primaries from data that can have free-surface and internal multiples. In the marine case MME produces a dataset containing only primary reflections, but the source ghost is not removed. This is because no redatuming takes place and the primary refections are the same as present in the original dataset. This scheme removes only multiples from the data.

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