Velocity analysis using surface-seismic primaries-only data obtained without removing multiples

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Velocity analysis using surface-seismic primaries-only data obtained without removing multiples

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Summary

Introduction

A number of seismic processing methods, including velocity analysis (Sheriff and Geldart, 1999), make the assumption that recorded waves are primaries - that they have scattered only once (the Born approximation). Multiples then represent a source of coherent noise and must be suppressed to avoid artefacts. There are different approaches to mitigate free surface multiples (see Dragoset et al. (2010) for an overview), but internal multiples still pose a problem and usually cannot be removed without high computational cost or knowledge of the medium.
Recently, Marchenko redatuming has been developed to image a medium in the presence of internal multiples (Wapenaar et al., 2014). Using Marchenko redatuming in combination with convolutional interferometry, Meles et al. (2016) have developed a method which allows the construction of a primaries-only data set from existing seismic reflection data and an initial velocity model. The method was proposed for the acoustic case and appears to be robust with respect to even huge inaccuracies in the employed velocity model.
In this paper we investigate the impact of such primaries-only data on a simple velocity analysis workflow, as opposed to using the full data set with multiples. We use semblance analysis (Sheriff and Geldart, 1999) and compare the results obtained with three different data sets: the full reflection data with multiples, primaries data calculated with prior knowledge of the subsurface, and primaries data calculated with an entirely incorrect constant velocity model. We then use the velocity models that we construct to perform reverse time migration (RTM) of each of the data sets. We find that the velocities found are robust with respect to errors in the initial model used for Marchenko redatuming, and the method produces good results if non-hyperbolic moveout effects are avoided.

Method

To extract primaries-only data we combine acoustic Marchenko redatuming with convolutional interferometry as presented by Meles et al. (2016). Marchenko redatuming permits us to calculate Green's functions of the up and downgoing wavefield at an arbitrary point x in the subsurface, given the reflection response of collocated sources and receivers at the surface, and an estimate of the direct wave from the surface to the virtual receiver position (Fig. 1). To calculate the primaries-only data, the up and downgoing wavefields are calculated at a horizontal virtual receiver line. At each receiver, the downgoing direct wave is convolved with the first upgoing wave, which is assumed to be the first wave reflected from an underlying interface (Fig. 2).

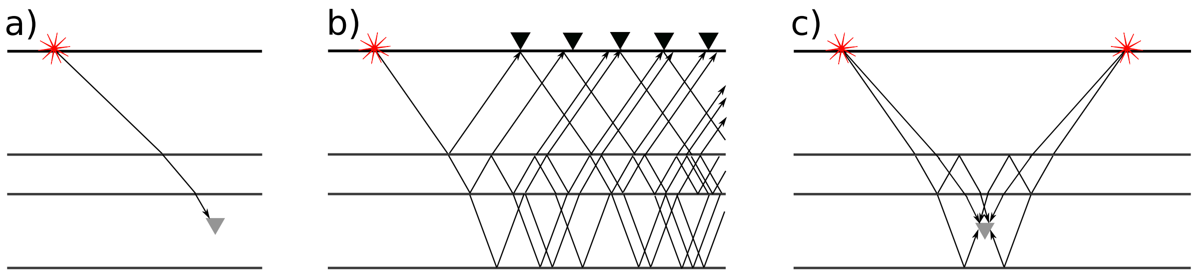


Figure 1: Input [a) and b)] and result [c)] of Marchenko redatuming. *a)* direct wave from surface source (star) to virtual receivers (triangle), *b)* reflection response recorded at the surface, *c)* up and downgoing wavefield as recorded at virtual receiver.

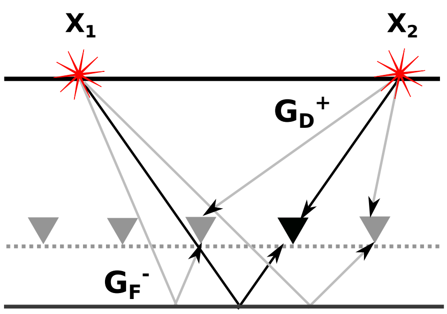


Figure 2: Green's functions of the direct wave, $\mathbf{G}_D^+$, and the first upgoing wave, $\mathbf{G}_F^-$, from surface sources to a virtual receiver line (grey/black triangles). The main contribution to the integral in equation 1 comes from around the stationary point indicated by a black triangle.

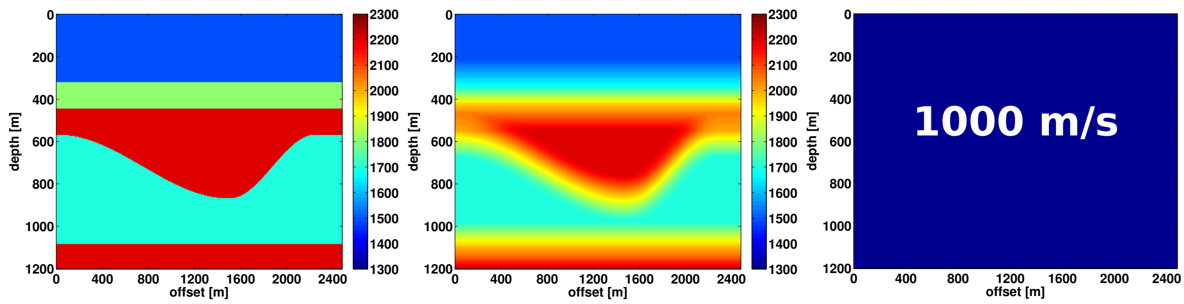
The convolution is repeated at every virtual receiver position and the results are stacked along the virtual receiver line according to:

$$G_P(x_2,x_1) \approx \int_S \frac{2j\omega}{c(x)\rho(x)} \left\{ G_F^-(x,x_2)G_D^+(x,x_1) + G_D^+(x,x_2)G_F^-(x,x_1) \right\} \tag{1}$$

Here, $G_P(x_2,x_1)$ is a primary reflection, originating from the first reflector below the virtual receiver line, between two source positions x_1,x_2 at the surface. G_D^+ is the downgoing direct wave and G_F^- is the first arrival of the upgoing Green's function. $c(x)$ and $\rho(x)$ are estimates of velocity and density at position x, and the constant $2j\omega$ comes from the Fourier transform of the equivalent time domain expression. x is the virtual receiver position and x_1,x_2 are source positions at the surface.
The position of the virtual receiver line is shifted to different depths to recover primary reflections from different interfaces. The results for each depth level are added to give a seismic gather with all primaries (for more detail see Meles et al., 2016). We then apply semblance velocity analysis to the data and compare the velocity models recovered for different types of data sets.

Results

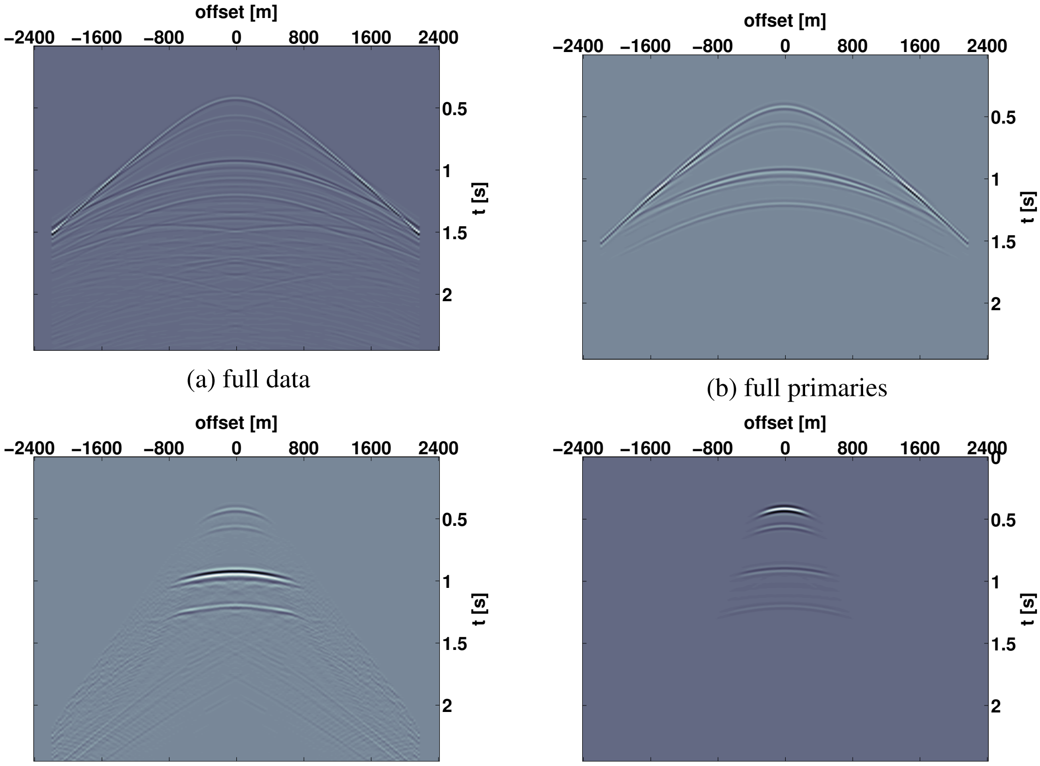
We generate seismic reflection data from an acoustic synclinal velocity model (Fig. 3a) and a constant density model ($\rho = 1000\ kgm^{-3}$). We compute synthetic surface seismic data with an finite difference time domain modelling code and a Ricker source wavelet with centre frequency 20 Hz. The profile is 2400 m long and comprises 201 collocated sources and receivers at 12 m intervals. Virtual receiver lines are placed at different depths, with 121 virtual receivers each at 20 m intervals.
For Marchenko redatuming and convolution we use the same constant density model. We test two different scenarios where we use a smoothed version of the true velocity model and a constant velocity model, respectively (Figs 3b, 3c). Note that the constant velocity model contains no prior information as velocities are too low at every point. Examples of the three data sets are shown in Fig. 4. Due to the filters applied in the Marchenko method, long offset information is missing in Fig. 4c, so we refer to these data as truncated primaries.
Semblance analysis relies on hyperbola shaped reflection curves, which is only true for short offsets. At longer offsets non-hyperbolic moveout effects lead to artefacts and errors in velocity picking. We therefore use a triangle shaped filter to cut long offsets from the full primaries data (Fig. 4d).
We apply semblance velocity analysis to the three data sets (full data, filtered primaries, and truncated primaries) and calculate velocity models from autopicked semblance maxima using Dix' formula (Fig. 5, left).



(a) true model (b) smoothed model (c) constant model

Figure 3: *a)* Velocity model used to calculate the synthetic data. *b)* and *c)* velocity models used for calculation of the primaries-only data. Density ρ constant in each model at $\rho = 1000\ kgm^{-3}$.

We use these velocity models for reverse time migration of the full data, filtered primaries and truncated primaries-only data, respectively. The images resulting from inversion of the filtered and truncated primaries-only data show none of the long wavelength artefacts normally encountered by RTM. The lower boundary of synclinal layer is best recovered when using primaries data from the constant model (Figs 5e, 5f). In the model calculated from the full data the high velocity zone extends into the underlying layer. This affects the position of the lowest reflector, which is recovered correctly in Fig. 5f and, due



(a) full data

(b) full primaries

(c) primaries from constant model

(d) filtered full primaries

Figure 4: CMP gathers described in the text for a midpoint in the middle of the profile.

to the extended high velocity layer, is too low in Fig. 5b and Fig. 5d. Apart from this, all reflectors are recovered and imaged in the correct position (Fig. 5, right side).

We attribute the absence of long wavelength artefacts in the RTM image to the absence of long offsets in the truncated reflection data. We tested this hypothesis by migrating the full primaries-only data, which has the same offset range as the full data, and found the same kind of long wavelength artefacts in the resulting RTM image as we found using the full data. Because of non-hyperbolic moveout effects the velocity model gained from semblance analysis of full data is less accurate than when the data are filtered to remove longer offsets.

Conclusions

We use primaries-only seismic reflection data in standard velocity analysis and RTM to investigate if this improves the results of such a workflow. The primaries-only data are derived from a full synthetic acoustic reflection data set using Marchenko redatuming and convolutional interferometry. We test one case where primaries-only data are calculated using a smooth version of the true velocity model, and one where a constant velocity model is used for Marchenko redatuming. We find that using this data in a simple workflow can indeed improve results compared to using the full synthetic data set. Moreover, the primaries-only derivation is robust against errors in the initial velocity model.

In the case of semblance velocity absence of long offset information in the primaries-only data can be an advantage which may not expected for other velocity analysis methods. Primaries-only data show promise in this simple case. Future research will explore the effectiveness of this approach with respect to more complex models, which are at present challenging to more standard methods.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 641943 (Art. 29.4 of the Grant Agreement). We are also grateful for the Edinburgh Interferometry Project (EIP) sponsors (ConocoPhillips, Schlumberger, Statoil and Total) for supporting this research.

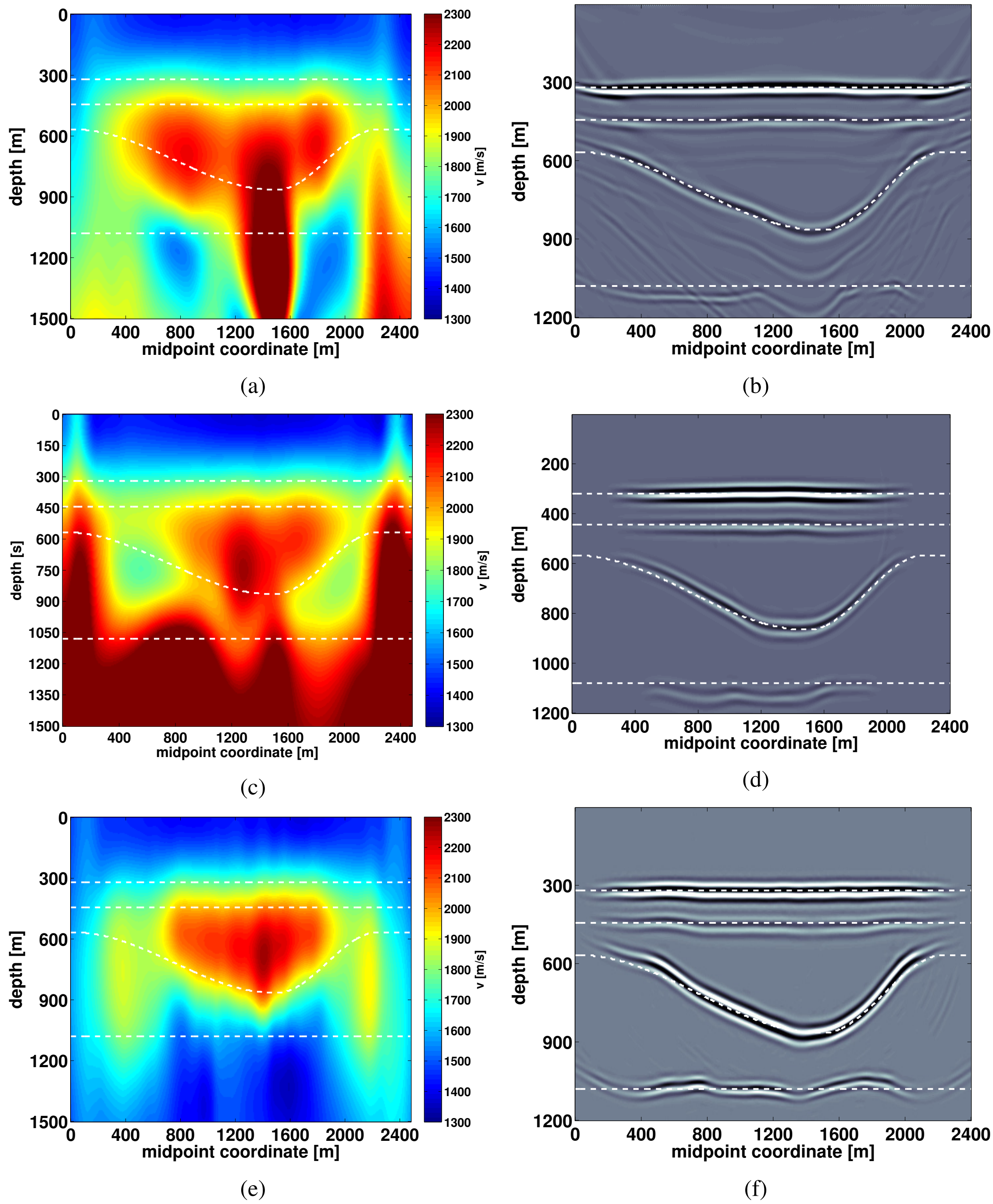

Figure 5: Velocity models (a, c, e) and corresponding Reverse Time Migration results (b, d, f) using the three different data sets in Fig 4a, c, d, respectively. White dashed lines indicate true reflector positions.

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