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Velocity analysis of Primaries-only Seismic Reflection Data

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Abstract

A range of seismic processing methods are based on the Born approximation. When multiply scattered waves are present in the data they can cause errors and artefacts. While predicting and the removing multiples by subtraction has been investigated widely, Meles et al. (2016) present a method to construct data containing only primaries from acoustic reflection data without subtracting multiples. Here, the approach has been applied to a synthetic data set and successfully extracted primaries-only data. We use these data in a simple velocity analysis workflow to see if the result is improved if the data is really consistent with the Born approximation.

Method

The Green's function between two sources can be approximated by integrating the in- and outgoing components of the Green's function over a closed boundary around one of the sources (Wapenaar and Fokkema, 2006). Meles et al. (2016) postulate that convolution of a direct wave from the surface with a primary reflection and subsequent integration along a virtual receiver line in the subsurface will yield the Green's function of a primary reflection between the two points at the Earth's surface. To this end, they assume that at any point along a virtual receiver line the first downgoing arrival will be a direct wave from the surface (G^+_D) and the first upgoing arrival (G^-_F) will be a primary reflection from the first reflector below the virtual receiver line (Fig.1).

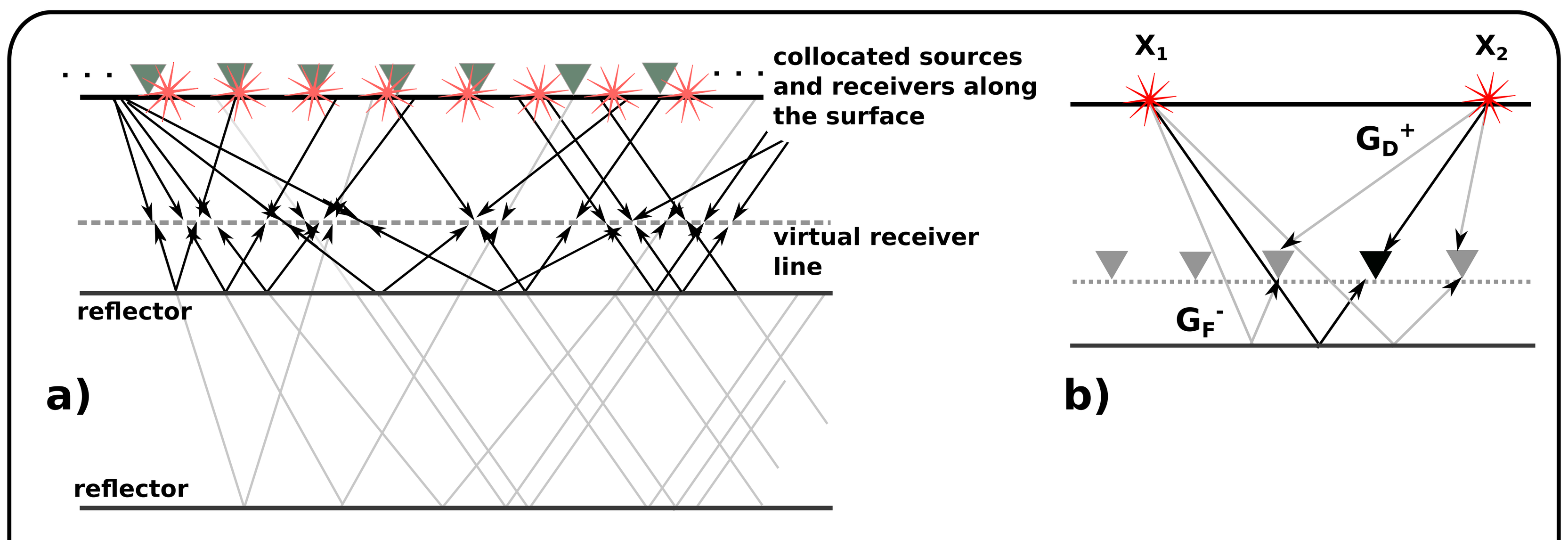

Fig. 1 a) Wavefield decomposed into up- and downgoing component at a virtual receiver line (dashed grey line). The first upgoing and first downgoing arrivals (black arrows) are picked along a virtual receiver line and used for reconstruction of the first primary.
b) The stationary points (black triangle) along the virtual receiver line (dashed grey line) have to be sampled for the primary to be reconstructed (grey triangles = non-stationary points).

Their frequency domain formula for a primary reflection G_P between two source points x_1 and x_2 at the surface is

$$G_P(x_1, x_1) \approx \int_S \frac{2i\omega}{v(x)\rho(x)} \{G_F^-(x,x_2)G_D^+(x,x_1) + G_D^+(x,x_2)G_F^-(x,x_1)\}\, dS$$

Here, v is the medium velocity, ρ is the density and ω is the frequency. The up- and downgoing wavefield are calculated by Marchenko redatuming of the reflection response measured at the surface (van der Neut et al., 2015).

In practical terms this means redatuming the reflection response to the virtual receiver positions, then picking and windowing of the first arrivals in the up- and downgoing wavefields at each point along a virtual receiver line. By moving the virtual receiver line throughout the medium and stacking the results, a seismogram with only primary reflections from each and every interface can be obtained.

References

Meles, G.A., Wapenaar, K. and Curtis, A., 2016. Reconstructing the primary reflections in seismic data by Marchenko redatuming and convolutional interferometry. Geophysics, **81**, Q15-Q26
van der Neut, J., Vasconcelos, I. and Wapenaar, K., 2015. On Green's function retrieval by iterative substitution of the coupled Marchenko equations. Geophysical Journal International, 203, 792-813
Wapenaar, K. and Fokkema, J., 2006. Green's function representations for seismic interferometry. Geophysics, 71, SI33-SI46

Simple Synthetic Model

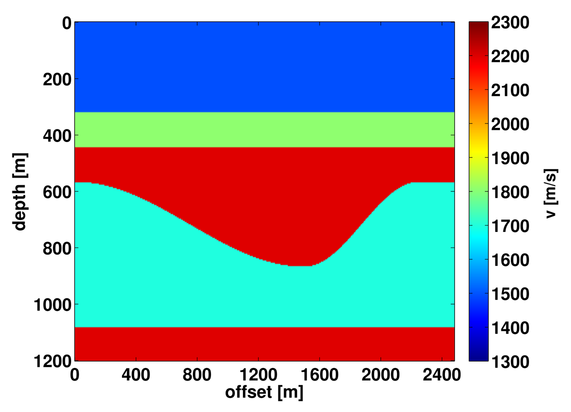

Fig. 2: V_P velocity model used to calculate synthetic data.

Acoustic synthetic data was created using collocated sources and receivers on top of a simple synthetic model (Fig. 2). The density model was a constant model with ρ = 1000 kg/m^3 There was no free surface as the Marchenko theory used here does not accommodate free surface multiples.
A smoothed version of the model was used for Marchenko redatuming.

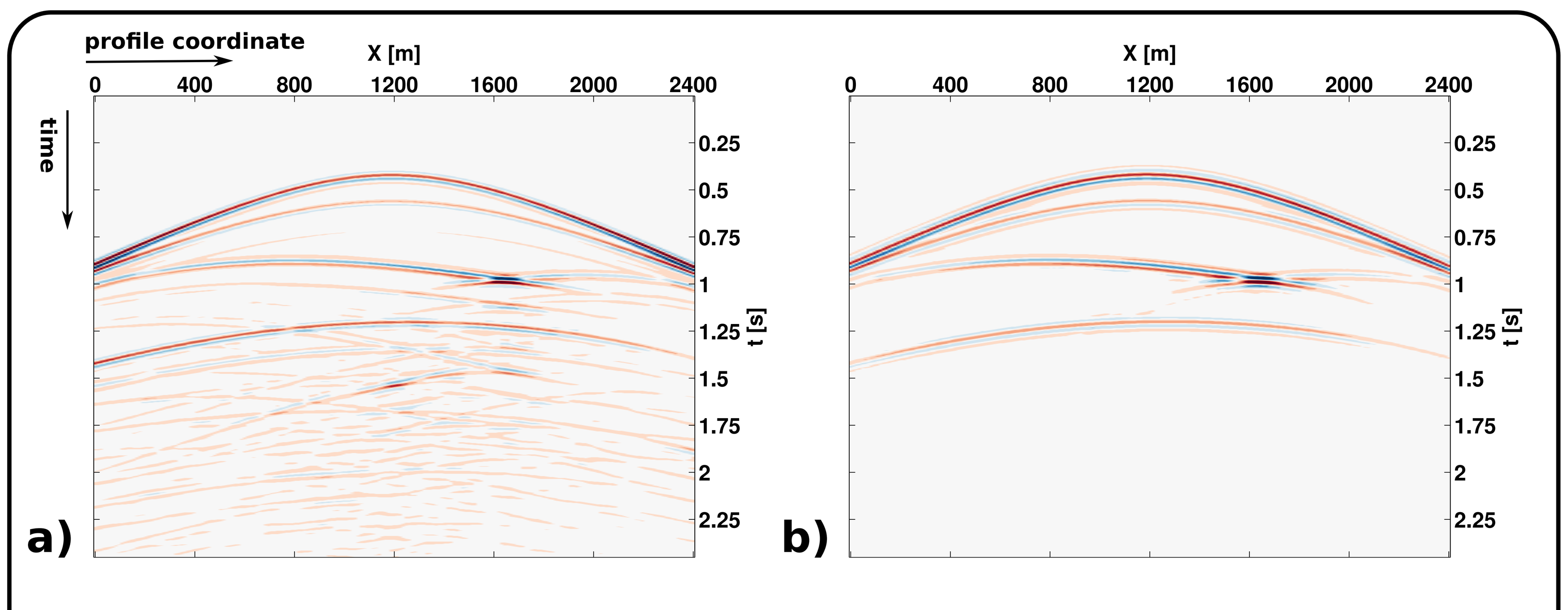

Fig. 3: Shot record from a shot in the middle of the profile (shot 100). A t^2 gain has been applied to the data. a) Full data b) Primaries only data

Velocity Analysis

We use semblance velocity analysis to construct velocity models from full and primaries-only data. The data is sorted into common midpoint gathers (CMPs) and semblance analysis is performed automatically for each gather (Fig. 4 a)). The maxima in a semblance gather are at two way travel times where a reflection was flattened into a straigt line, assuming that reflected arrival curves are hyperbolic. Multiply scattered arrivals will give maxima at the same velocity as the primary, but at longer travel-times. The maxima were picked for each semblance gather. The picks were smoothed and a velocity model was calculated using Dix velocity inversion (Fig. 4b)). Each velocity model was then used for reverse time migration of the data from which it was constructed (Fig. 4c)).

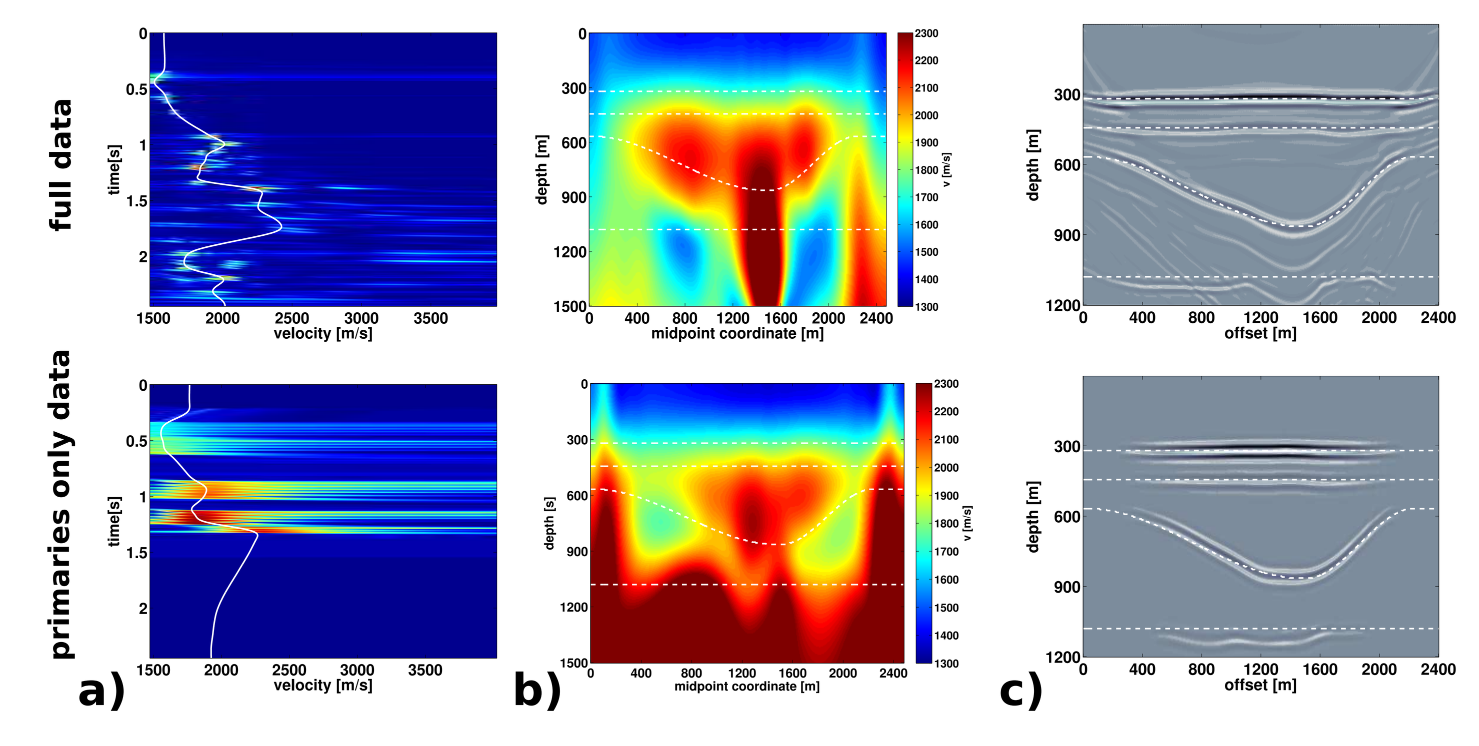

Fig. 4: a) Semblance calculated for a CMP gather in the middle of the profile with semblance picks as a white curve. b) Velocity models constructed from the smoothed picks, white dashed lines indicate true reflector positions. c) Reverse time migration result using the velocity models in b). White dashed lines indicate true reflector positions.

Next Steps

Using primaries-only data improves the results of velocity analysis and reverse time migration. The next step will be to use a more complex model to see if the improvement persists, increases or declines and to what extent. It will also show how well the method works for a more complex model geometry, up to the point where the assumption that the first arrival at a virtual receiver position follows the primary ray path breaks down.

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