Elimination of multiples from acoustic reflection data

Slob, Evert; Zhang, Lele

Publication date
2019

Document Version
Final published version

Published in
Extended Abstracts - 16th SAGA Biennial Conference & Exhibition 2019

Citation (APA)
Slob, E., & Zhang, L. (2019). Elimination of multiples from acoustic reflection data. In *Extended Abstracts - 16th SAGA Biennial Conference & Exhibition 2019*

Elimination of multiples from acoustic reflection data

E. Slob, L. Zhang
Geoscience and Engineering,
Technische Universiteit Delft, The Netherlands
e.c.slob@tudelft.nl; l.zhang-1@tudelft.nl

BIOGRAPHY

Evert Slob, professor at TU Delft, is interested in seismic and electromagnetic fields and waves for imaging and inversion, on which he has published more than 125 journal articles and one book. He served as Editor in the SEG Board of Directors and was Editor in Chief of GEOPHYSICS during the 2013-2015 term.

Lele Zhang has an MSc from the University of the Chinese Academy of Sciences, Beijing, China and is a PhD student at TU Delft. His research interests are data-driven methods for seismic multiple elimination and imaging. He has published four journal articles.

SUMMARY

Elimination of multiples from acoustic reflection data is important to reduce the effect of their presence in velocity model building and subsequent imaging. Many processing schemes assume only primary reflection events are present in the data. Free-surface multiple elimination is an established technology, but internal multiple elimination is under development. We show that new data-driven processing methods have led to a robust multiple elimination scheme. This scheme removes free-surface and internal multiples contemporarily but can also eliminate internal multiples after free-surface multiples elimination. For each recording time instant, the method computes two filters using only the measured reflection response and an estimate of the source time signature. Once the filters are computed, they are used to filter the data up to that time instant. The result is that multiples related to reflectors with a two-way travel time less than the chosen time instant are removed from the data. This removes possible overlap with the primary reflection from the first deeper reflector. This event can be taken and stored in a new dataset. Repeating the procedure for all recording times produces the desired primaries only dataset. A numerical and a field data example show the effectiveness of the method.

Key words: multiple elimination, acoustic, processing.

INTRODUCTION

Seismic reflection data is recorded to obtain an understanding of subsurface structures that may hold natural resources of potential interest to mining or hydrocarbon companies. Subsurface characterization and imaging are usually carried out through velocity model building and migration. Routine processing schemes build velocity models from the measured data directly, but assume all reflections are primary reflections. Routine migration schemes use wavefield extrapolation operators based on the velocity model and also assume all reflections in the data are primary reflections (Weglein, 2016). This single reflection assumption can lead to errors in the velocity model and create artefacts in the image. Velocity model errors can result in incorrectly placed reflectors. The presence of multiples in the data can lead to multiples being imaged as reflectors which can be interpreted erroneously as physical reflectors.

The inverse scattering series was introduced to attenuate free-surface and internal multiples in one step and without using model information (Weglein et al., 1997). Considerable progress has been achieved in developing the method, but many questions are still open for further investigation. Free-surface multiple elimination was achieved using a minimum energy criterion (Verschuur et al., 1992), using a sparse inversion approach (van Groenestijn and Verschuur, 2009) and using a finite-difference method (Vasmel et al., 2016). Based on the ideas of Jakubowicz (1998) a scheme has been developed to attenuate internal multiples (ten Kroode, 2002, Löer et al., 2016).

Since the work of Broggini et al. (2012) several schemes have been introduced to create subsurface images without artefacts from free-surface and internal multiples (Singh et al., 2017, Ravasi, 2017). These methods require a velocity model similar to those used for routine migration schemes. Zhang and Slob (2019) avoid the need for model information by developing a multiple elimination scheme following van der Neut and Wapenaar (2016).

Here we describe the scheme to eliminate free-surface and internal multiples from the acoustic reflection response. The measured reflection response is the only input for the method. We assume for simplicity that the source time signature is known, but the method can be adapted for unknown source time signatures, similar to the approach of Ravasi (2017). We show how two filters can be computed from the reflection response without additional information. These filters are obtained in an automated unsupervised process for an arbitrarily chosen recording time instant. The scheme is not recursive. For each such recording time instant the filters exist for all times up to that recording time instant and are zero outside this time window. The corresponding equation can be evaluated for times outside this time window. The result corresponds to the reflection response but without overlap from multiples related to the overburden that have been moved into the filter. When the first time instant outside this time window corresponds to the two-way travel time of a reflector, the primary reflection is present with its physical amplitude and can be automatically obtained and stored in a new dataset.

Repeating this for all necessary time instants leads to the desired dataset that contains only primary reflections at their correct two-way travel times and with their physical amplitudes. We give a numerical and a field data example to illustrate the effectiveness of this multiple elimination scheme.

METHOD

We use t for time and denote a point in space with the vector **x**, $\mathbf{x}=(x,y,z)^t$. and t in superscript means matrix transposition. The Earth surface is the acquisition surface and we assume it is a horizontal surface, indicated by ∂D_0, defined at $z_0 = 0$. The reflection coefficient of the surface is denoted r. The reflection response measured at a location $\mathbf{x}_0$ and generated by a source in x_0', is denoted $R(x_0, x_0', t)$. We define two filters, which are wavefields, denoted $h^{\pm}(x_0, x_0', t, \tau)$, where the plus-sign indicates that downgoing waves are present in the filter and the minus-sign indicates that upgoing waves are present in the filter. Following Zhang and Slob (2019) we give the relations between the reflection response and the filters for $0 < t < \tau$ and $\tau > 0$ as

$$h^-(x_0, x_0', t, \tau) = R(x_0, x_0', t) + \int_{\partial D_0} R(x_0, x_0'', t) * [h^+(x_0'', x_0', t, \tau) - rh^-(x_0'', x_0', t, \tau)] dx_0'', \tag{1}$$

$$h^+(x_0, x_0', t, \tau) = \int_{\partial D_0} R(x_0, x_0'', -t) * [h^-(x_0'', x_0', t, \tau) - rh^+(x_0'', x_0', t, \tau)] dx_0'', \tag{2}$$

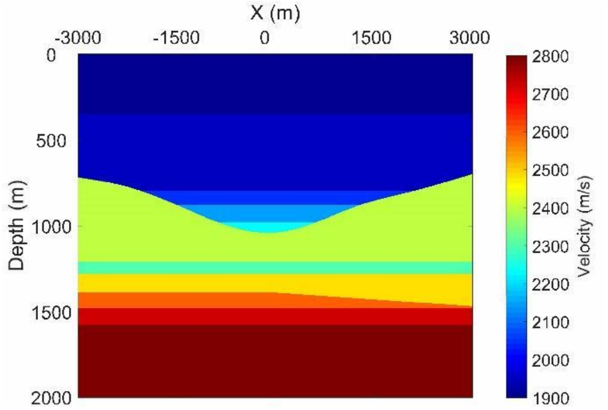
where * denotes temporal convolution. Notice that equation (1) is a convolution equation while equation (2) is a correlation equation. For every time instant τ, equations (1) and (2) are solved for the filters $h^{\pm}(x_0, x_0', t, \tau)$. When free-surface multiples are already eliminated in a pre-processing step we can take $r = 0$ and the reflection response contains only internal multiples. In case the free-surface multiples are present in the reflection response we take $r = -1$ for a pressure-free surface. We observe that in equations (1) and (2) only the reflection response and the filters occur, while τ is a free parameter. This means that the equations can be solved in a fully automated and unsupervised process. The effect of these two filtering equations is that multiples related to the part of the subsurface that has primary reflections for $t < \tau$, are moved into the filter and cannot overlap with the primary reflection at $t = \tau$. Once the filters are found for a particular value of τ, the possible primary reflection is captured and stored in the new dataset, denoted $R_t(x_0, x_0', \tau)$, as

$$R_t(x_0, x_0', \tau) = R(x_0, x_0', \tau) + \int_{\partial D_0} R(x_0, x_0'', t) * [h^+(x_0'', x_0', t, \tau) - rh^-(x_0'', x_0', t, \tau)] dx_0''|_{t=\tau}, \tag{3}$$

where the value $t = \tau$ is used as time instant for the convolution. We observe that this step also can be performed automatically without human intervention. If the outcome of equation (3) is zero at the chosen time instant, it means that no primary reflection was present in the data. If the right-hand side of equation (3) has a non-zero value at that time instant, it contains the primary reflection corresponding to a reflector whose two-way travel time is equal to that time instant. Because it is part of the original data, the primary has its physical amplitude. We refer to Zhang and Slob (2019) for a detailed derivation of these results. Before we can use equation (3) we need to know $h^{\pm}(x_0, x_0', t, \tau)$. These are found by solving equations (1) and (2) as a coupled set of equations. Equations (1) and (2) are solved with a Neumann-type iterative scheme (Wapenaar et al., 2013).

RESULTS

Figure 1 shows the velocity (top) and density (bottom) as a function of horizontal position and depth of the 2D numerical model that we use to generate the acoustic reflection response. The model is not based on a specific geological setting but has a sufficiently complex 2D heterogeneous structure to demonstrate that the method works for laterally varying media. The free surface is part of the model and we use the above scheme with $r = -1$. The acoustic reflection response is computed with the finite difference package of Thorbecke and Draganov (2016), which is implemented with absorbing boundary conditions on the left and right sides and in the bottom of the model, whereas the top of the model is the free surface. Sources and receivers are positioned with a spacing of 10 m on the free surface shown in Figure 1. The reflection responses are computed for 601 source positions. We use 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 filters and the resulting dataset containing only primary reflections.



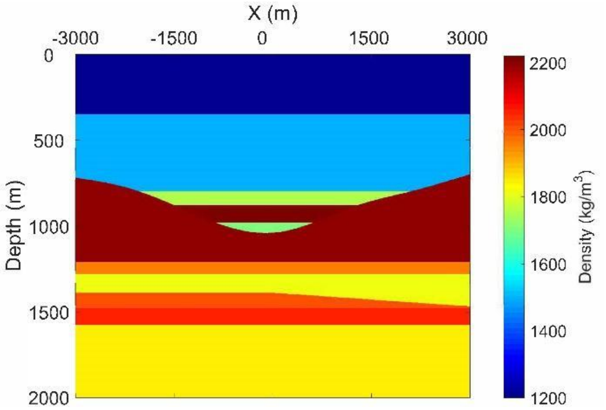


Figure 1. The velocity (top) and density (bottom) model used for seismic modelling.

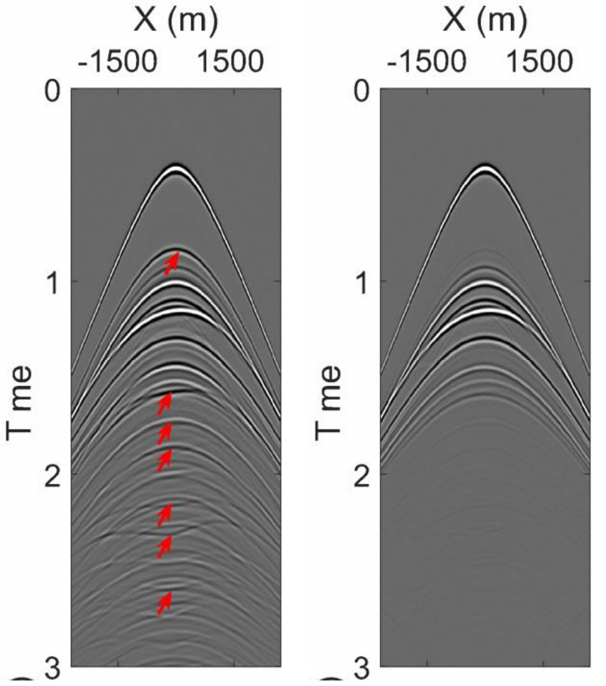


Figure 2. The shot gathers for a source at x=0 m in the model shown in Figure 1, before (left) and after (right) multiple elimination.

For the source at $x = 0$ m, Figure 2 shows the shot gather of the modelled reflection response (left) and the corresponding 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).

To demonstrate that the proposed method can be applied to reflection data acquired in the field, we show here results from a vintage marine field dataset. The data was acquired over the Vøring Basin by SAGA Petroleum A.S. (currently part of Equinor ASA) in 1994. The data was acquired in deep water with the water bottom at approximately 1.5 km. The line dataset contains 399 shot gathers with 399 receivers per shot. The source and receiver spacing is 25 m. The data has been pre-processed to remove the direct wave, a de-noising filter was applied, near offset traces were constructed using a parabolic Radon transformation method (Kabir and Verschuur, 1995), amplitude compensation was applied to facilitate the application of the 2D multiple elimination scheme, and source wavelet deconvolution was applied. All pre-processing steps have been carried out in a wave-equation consistent way such that the resulting reflection data has minimal amplitude distortions. This is crucial for any data-driven processing method, because they all rely on high-fidelity in the amplitude. We only need a single overall amplitude correction factor to apply our method. More details on the data pre-processing can be found in Davydenko and Verschuur (2018). The first free-surface reflections occur after 4 s. The target zone has reflections roughly between 2.5 s and 3.5 s where several internal multiples are present as well. For this reason, we solve equations (1) and (2) and retrieve the dataset with only primary reflections using equation (3) with $r = 0$. The solution of equations (1) and (2) is performed with an overall constant to balance the reflection data amplitude. The equations are solved without adaptive subtraction.

Figure 3 gives an artist impression of the geological model. This model is not used in solving equations (1) and (2) and merely serves to give an impression of the geological setting. It helps understanding the seismic data shown in Figure 4. The left graph shows a shot gather for the shot position at x= 13750 m, which corresponds to the same horizontal distance in Figure 3. One shallow and three deeper internal multiples are indicated by red arrows. We don't know the ground truth related to the data measured in the field, which makes it a bit difficult to positively identify which events in the data are primary and which are multiple reflections. Davydenko and Verschuur (2018) have used a full wavefield migration technique on the same dataset. Full wavefield migration builds the velocity and reflectivity model in an iterative process that requires forward modelling. It is therefore an independent method of predicting multiples in the seismic data. If these two methods agree in identifying

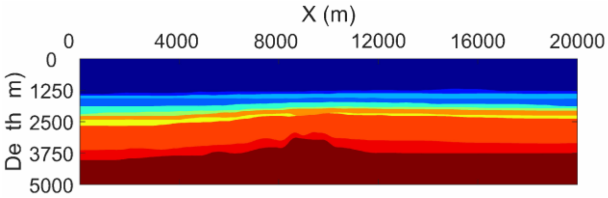


Figure 3. An artist impression of the geological model corresponding to the line of seismic data that was acquired in the Vøring Basin.

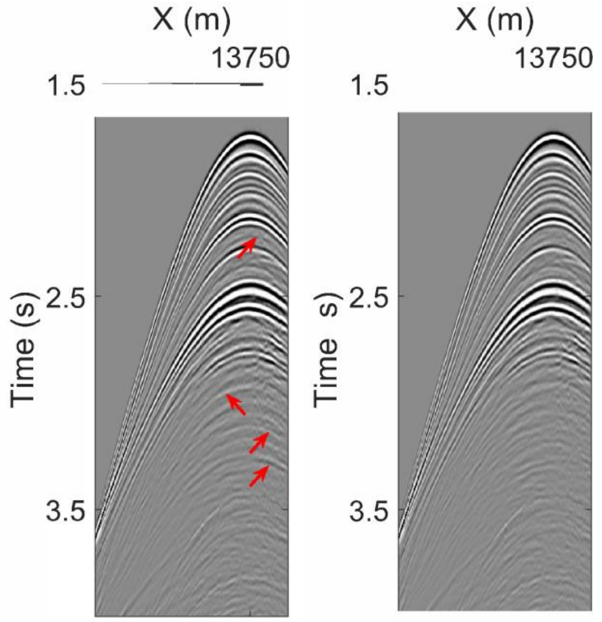


Figure 4. The shot gathers for a source at 13750 m in the virtual model shown in Figure 3, before (left) and after (right) multiple elimination.

multiples, we can have more certainty in those events being actual internal multiples than when they don't agree. That is why we feel confident that the events indicated by the red arrows are internal multiples.

The right graph of Figure 4 shows the result of our method and we can see that the shallow internal multiple has been attenuated and the deeper multiples have been removed successfully. The result shown is obtained using three iterations of our scheme. Source wavelet deconvolution is an approximate process and leaves remnants of the source signature in the data. Field data always comes with uncertainty on the absolute amplitude. The overall constant amplitude correction that was applied has not been optimized and we found that increasing the number of iterations does not improve the result. Another assumption in the method is that all wave propagation occurs in a lossless medium and the real data will most likely be affected by intrinsic loss mechanisms. We find it remarkable that in spite of these unknown amplitude uncertainties, the scheme could be implemented successfully without adaptive subtraction. We like to emphasize that adaptive subtraction has not been used, because adaptive subtraction is implemented with a minimum energy criterion. The effect is that multiple reflections that overlap with primary reflections are simply attenuated or removed together with the primary reflection.

CONCLUSIONS

We have shown that the reflection response can be used to filter itself and thereby remove free-surface and internal multiple reflections from acoustic data. The filtering process requires the data to be convolved and correlated with itself. After each convolution or correlation step, the result is truncated at a specific time instant that can be chosen freely. The filters have a time window from zero time to the chosen truncation time instant. Once the filters are found, we perform one more convolution at the chosen time instant and the result is either zero, when no primary reflection is present, or it is a primary reflection with its physical amplitude. We have shown that the method successfully removes free-surface and internal multiples from a computed dataset. This is under the condition that the source time signature is fully known, and no amplitude errors occur in the data. The field data example shows successful reduction of internal multiple reflections without using adaptive subtraction. We were not able to improve the result further with additional iterations, which is most likely caused by amplitude uncertainties in the data. The result agrees with the result obtained in full wavefield migration. The results in numerical and field data shown here seem to suggest that our method can be useful for seismic data processing and subsequent imaging without artefacts from multiple reflections in the data.

ACKNOWLEDGMENTS

This work of L. Zhang is part of the Open Technology Program with project number 13939, which is financed by NWO Domain Applied and Engineering Sciences. The authors thank Eric Verschuur for pre-processing of the field data and valuable discussions, and Delphi consortium and Equinor for making the field data available.

REFERENCES

Broggini, F., Snieder, R. and Wapenaar, K., 2012, Focusing the wavefield inside an unknown 1D medium: Beyond seismic interferometry: Geophysics, 77, 5, A25-A28.

Davydenko, M. and Verschuur, D.J., 2018, Including and using internal multiples in closed-loop imaging – Field data examples, Geophysics, 83, 4, R297-R305.

Jakubowicz, H., 1998, Wave equation prediction and removal of interbed multiples: 68th Annual Meeting of the Society of Exploration Geophysicists, SEG Technical Program Expanded Abstracts, 1527-1530.

Kabir, M.M.N. and Verschuur, D.J., 1995, Restoration of missing offsets by parabolic Radon-transform, Geophysical Prospecting, 43, 347-368.

Löer, K., Curtis, A. and Meles, G.A., 2016, Relating source-receiver interferometry to an inverse-scattering series to derive a new method to estimate internal multiples: Geophysics, 81, 3, Q27-Q40.

Ravasi, M., 2017, Rayleigh-Marchenko redatuming for target-oriented, true-amplitude imaging: Geophysics, 82, 6, S439-S452.

Singh, S., Snieder, R., van der Neut, J., Thorbecke, J., Slob, E.C. and Wapenaar, K., 2017, Accounting for free-surface multiples in Marchenko imaging: Geophysics, 82, 1, R19-R30.

Thorbecke, J., and Draganov, D., 2011, Finite-difference modeling experiments for seismic interferometry: Geophysics, 76, 6, H1–H18.

ten Kroode, F., 2002, Prediction of internal multiples: Wave Motion, 35, 315-338.

van der Neut, J. and Wapenaar, K., 2016, Adaptive overburden elimination with the multidimensional Marchenko equation: Geophysics, 81, 5, T265–T284.

van Groenestijn, G.J.A. and Verschuur, D.J., 2009, Estimating primaries by sparse inversion and application to near-offset data reconstruction: Geophysics, 74, 3, A23-A28.

Vasmel, M., Robertsson J.O.A. and Amundsen, L., 2016, A model-independent finite-difference method for removal of free-surface generated multiples: Geophysics, 81, 2, T79-T90.

Verschuur, D. J., Berkhout, A.J. and Wapenaar, C.P.A., 1992, Adaptive surface-related multiple elimination: Geophysics, 57, 1166-1177.

Wapenaar, K., Broggini, F., Slob, E. and Snieder, R., 2013, Three-dimensional single-sided Marchenko inverse scattering, data-driven focusing, Green's function retrieval, and their mutual relations: Physical Review Letters, 110, 084301.

Weglein, A.B., 2016, multiples: Signal or noise: Geophysics, 81, 4, V283-V302.

Weglein, A.B., Gasparotto, F.A., Carvalho, P.M. and Stolt, R.H., 1997, An inverse-scattering series method for attenuating multiples in seismic reflection data: Geophysics 62, 1975–1989.

Zhang, L., and Slob, E., 2019, Free-surface and internal multiple elimination in one step without adaptive subtraction: Geophysics, 84, 1, A7-A11.