Multiple removal strategy for deep and shallow water

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Abstract

This paper discusses the removal strategy of surface-related multiples in marine situation with different water depths. Multiples can make interpretation of primary target structures very difficult if they have not been removed from the recorded data in a very early stage. Therefore it is important to define strategies for optimal attenuation of surface-related multiples in various environments.

Surface-related multiple elimination (SRME) has been applied very successfully to various marine datasets, but is known to have difficulties with shallow water environment, due to the fact that missing near offsets cannot be reconstructed in a reliable manner. Therefore, a combined methodology with multi-gate predictive deconvolution (MGPD) is suggested to cover all application areas. Examples on synthetic and field data are shown to support this strategy.

Introduction

The method of surface-related multiple elimination (SRME) (Verschuur et al., 1992), which is being used widely in the industry nowadays, can handle any subsurface geology (provided a 2D limitation in practice) and is capable of removing various types of surface multiples at the same time, because each event in the seismic data act as a predictor of a certain type of surface multiples. This method is based on a data-driven approach using multi-channel autoconvolutions to predict multiples from the recorded data and especially provides good multiple estimates for long period multiples.

Multiple removal: deep and shallow water

The surface-related multiple elimination (SRME) method is known to have difficulties with the short period multiples that for example occur in shallow water environments. A precondition for successful multiple estimation using this method is an accurate near-offset interpolation.

In shallow water environments, the water layer reverberations cause relative short period multiples. The other surface-related multiples are of large period, and this creates a mixed period problem. Also the missing near offset gap is large compared to the water depth and this means that there are large missing illumination angles. Furthermore, the source wavelet is not allowed to be of a longer duration than the two-way travel time through the water, otherwise the involved adaptive subtraction step becomes instable. To cope with the shallow water problems, the method of multi-gate prediction deconvolution (MGPD) (Alá'i and Verschuur, 2004) showed an effective way to estimate different types and different orders of multiples with small and medium period. Actually, the multi-gate predictive deconvolution (MGPD) is a simplified manner to mimic the effects of the industry standard method of surface-related multiple elimination (SRME).

Note that when this would be applied in the Radon domain, there is a similarity with the REMUL method from Lokshtanov (1999), which also uses multiple gates in order to predict water reverberations.

Moreover, the deconvolution method for handling the shallow water layer reverberations can be well combined with SRME to address the longer period multiples, according to the following strategy:

- Remove the direct wave and apply a FK filter to remove the post-critical water layer reverberations;
- Apply a multi-gate deconvolution to remove the shallow reflector reverberations;
- Mute the top part of the data including the shallow multiple generating primaries;
- Apply SRME on the remainder of the data to remove the remaining longer period multiples.

In this way all types of multiples are addressed in a cascaded manner, without mixing the different multiple types.

Data examples

The attenuation of multiples for deep water and shallow water is being illustrated with synthetic data and field data recorded in the Arabian Gulf.
In the synthetic data example, two versions of a horizontally layered 7-reflector model have been used: one with a deep and one with a shallow water layer.

Figure 1a shows a shot gather simulated with a deep water layer with all multiples included and the data after surface-related multiple elimination (SRME) is depicted in Figure 1b. The true primaries are shown in Figure 1c. To mimic a more realistic situation, some near-offsets have been omitted (see Figure 1d). Using this gather as input to the SRME, it can be observed that the result after SRME is far from being correct (see arrow for the strong multiple that has not been attenuated correctly because of the missing near-offsets). The true primaries are shown in Figure 1f. Figures 1g-1i show the data after near-offset interpolation, using the parabolic Radon transform (Kabir and Verschuur, 1995), the results of multiple attenuation and the true primaries, respectively. Note that a close to perfect multiple removal result is obtained again.

In Figures 2a-2c it is demonstrated that in principle the SRME method works equally well in the case of shallow water. Figure 2a shows a similar input data as Figure 1a, with the difference that the first two reflectors have been put at shallower depth. The result after applying SRME (Figure 2b) is close to the ideal output (Figure 2c). However, in practice the input data suffers from missing near offsets and contamination and possibly the contamination of near offsets by the direct wave. Figure 2d displays the more practical input data with 200 meters near offsets gap. Without any near offsets restoration, SRME hardly has an effect on the input data, as shown in Figure 2e: all multiples are still visible. By using again the parabolic Radon-based near offset reconstruction method (Figure 2g), SRME is able to reduce the multiples somewhat, but the result is far from satisfactory compared to the true output (Figure 2i). Thus, an imperfect input data yields imperfect results. Furthermore, note that the larger part of the surface multiple relies on the small offset part of the shallow primaries. Thus, it can be concluded that the SRME method relies on a good near offset interpolation and that this creates a severe limitation for shallow water data.

The MGPD method appears to be an effective way for attenuation of multiples in shallow water environments (Alá'i and Verschuur, 2004). As mentioned above on the shallow water problems, and the mixture of different multiple periods, optimal results may be obtained by applying the MGPD methods followed by the SRME method to attenuate the larger period multiples in the deeper part of the data. Figure 3a shows the shot gather after near-offset interpolation, FK filter and mute and Figure 3b and Figure 3c show respectively the attenuation of multiples using predictive decon and SRME. Figure 3d and Figure 3e show respectively the autocorrelation before and after deconvolution.

A field data example is shown in Figure 4. This data has been recorded in the Arabian Gulf in very shallow water environments. From the experiments with the synthetic model, it can be concluded that the MGPD method is an effective way to mimic the effects of SRME by estimating different types and higher orders of multiples and by simultaneously subtracting them from the original data. This method of MGPD has been applied on a noisy shot gather containing very strong multiples (Figure 4a). The result of the MGPD method is shown in Figure 4b. The estimated noise and multiples are depicted in Figure 4c.
This field data example shows clearly the large amount and strong amplitude of the multiples and how they obscure the interpretation of the primaries.

The last example is another dataset also recorded in the Arabian Gulf. The water depth in this dataset is 60 meters. The near offset gap in this dataset is 90 meters. From the shot gather shown in Figure 5a, it can be observed that the data contains some strong post-critical water bottom reverberations. Also it can be observed that there are some missing traces and missing near-offset data. Figure 5b shows the shot gather after some preprocessing in suppression of the strong post-critical water bottom reverberations. In Figure 5b, also the missing traces have been interpolated. As mentioned above, the depth of the water in this example is 60 meters, which can be considered as being just deep enough for SRME to be applied on this shot gather. However, much attention was paid in a correct removal of the direct wave and a reliable near offset interpolation. The successful application of the SRME method is shown in Figure 5c and the estimated multiples are depicted in Figure 5d.

The corresponding stacks of this field data example are shown in Figures 6a-6c: the stack of the input data with multiples, but after preprocessing, the stack after SRME and the stack of the removed multiples, respectively. This example shows clearly that the SRME method has been applied successfully and the very large amount of multiples which are of high amplitude signal have been estimated accurately and subtracted from the original shot record.

Conclusions

The method of surface-related multiple elimination (SRME) provides good multiple estimates for *longer* period multiples and relies on a good near offset interpolation and this creates a severe limitation for shallow water data.

In shallow water environments, the water layer reverberations cause relative *shorter* period multiples. The other surface-related multiples are of large period, and this creates a mixed period problem. Therefore in shallow water environments, the multiples tend to create a complex interference pattern with the primaries.

Methods based on a long multiple period will be difficult to apply due to missing offsets. Therefore, a stategy has been proposed to use a multi-gate predictive deconvolution (MGPD) process to handle the shallow reflector reverberations, followed by a surface-related multiple elimination (SRME) procedure to address the longer period multiples.

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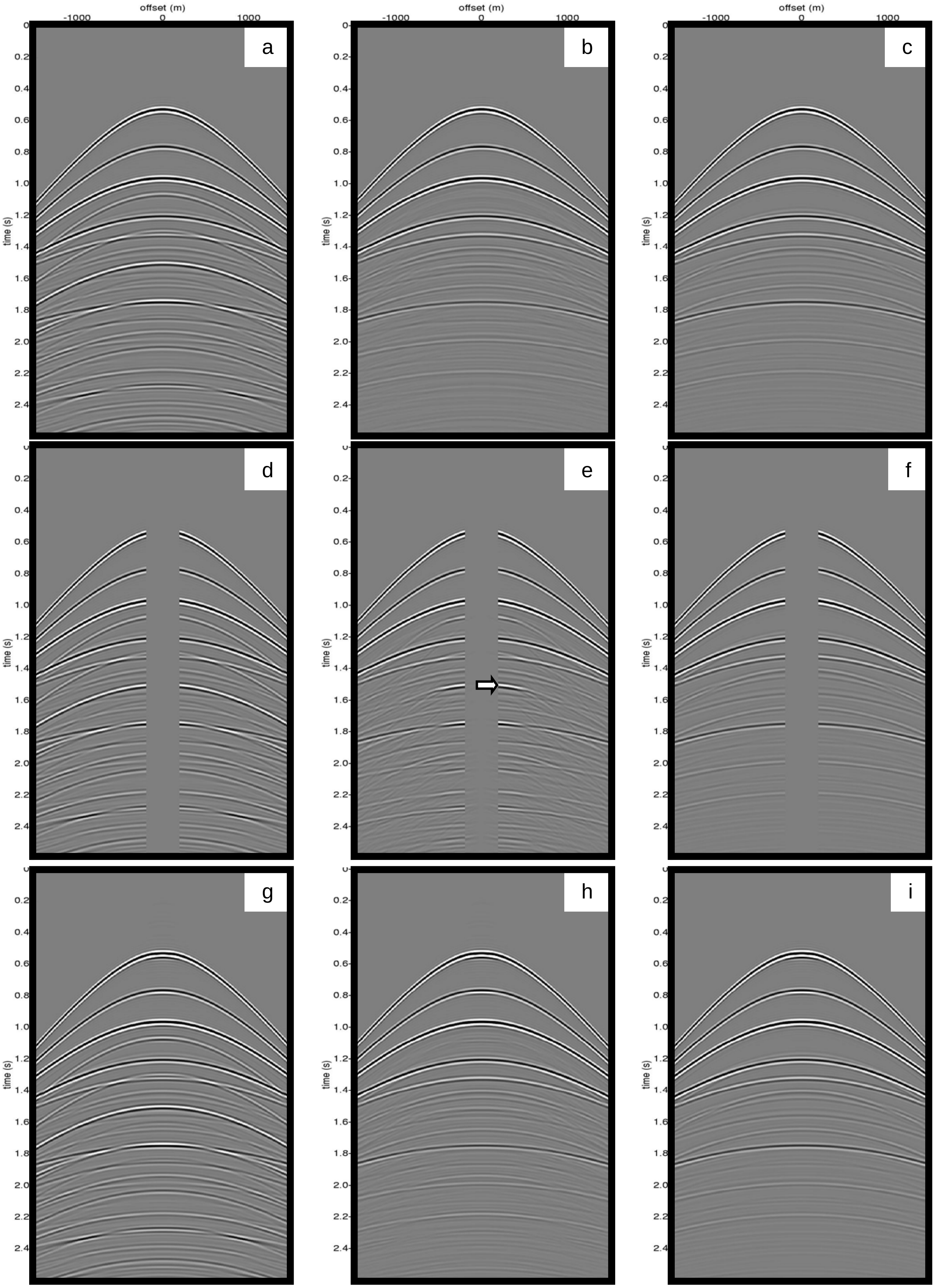


Figure 1- SRME for a 7-reflector model with deep water. a)Input data: shot record with all multiples; b)SRME output; c)ideal output, i.e. modeled primaries and internal multiples. Effect of missing near offsets: d)input data with missing near offsets; e)SRME output; f)ideal output. Results with offset restoration: g)input after near offset interpolation; h)SRME output; i)ideal output. Note that for deep water near offset interpolation can be done close to perfect, yielding satisfactory SRME results.

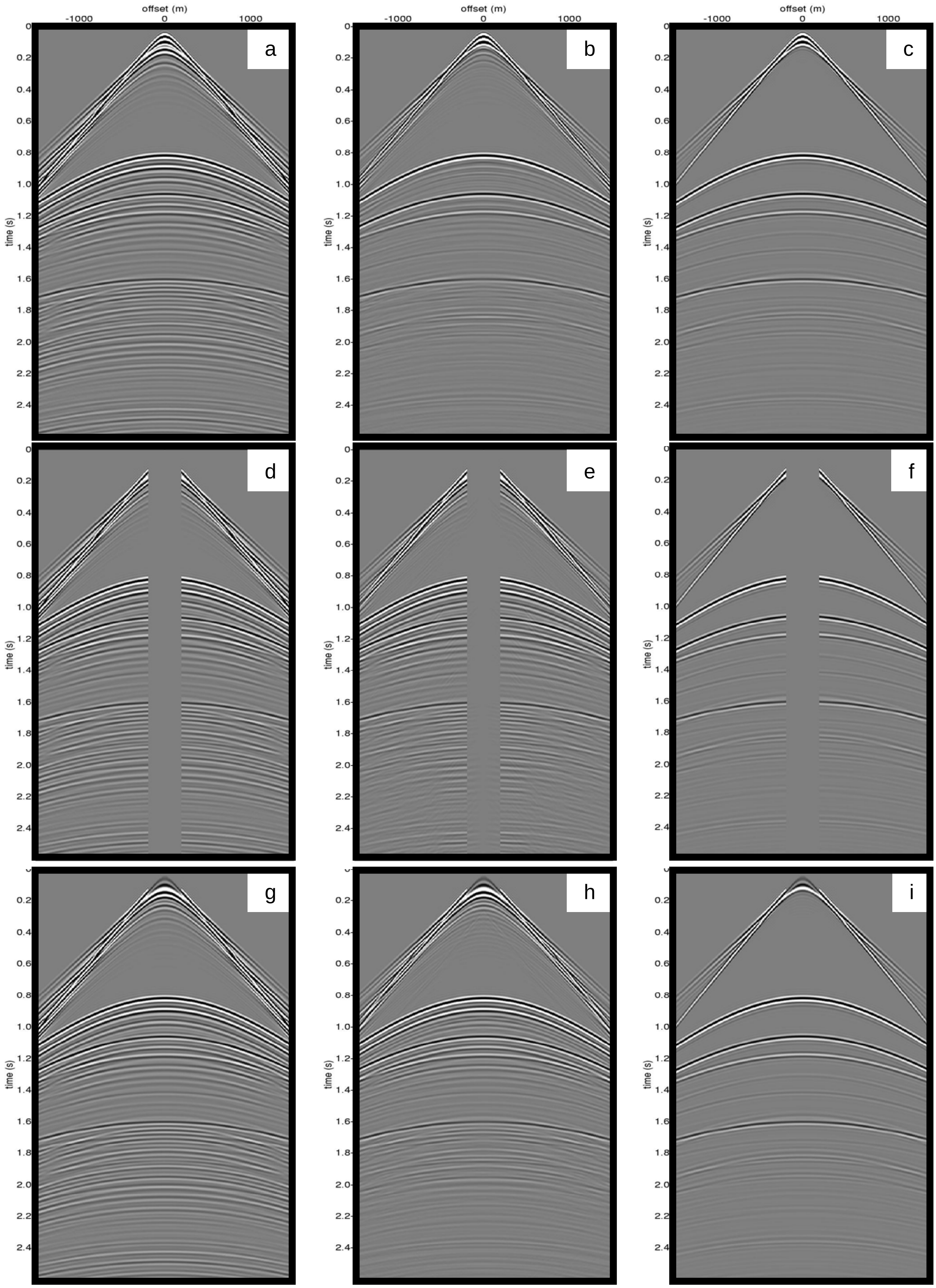
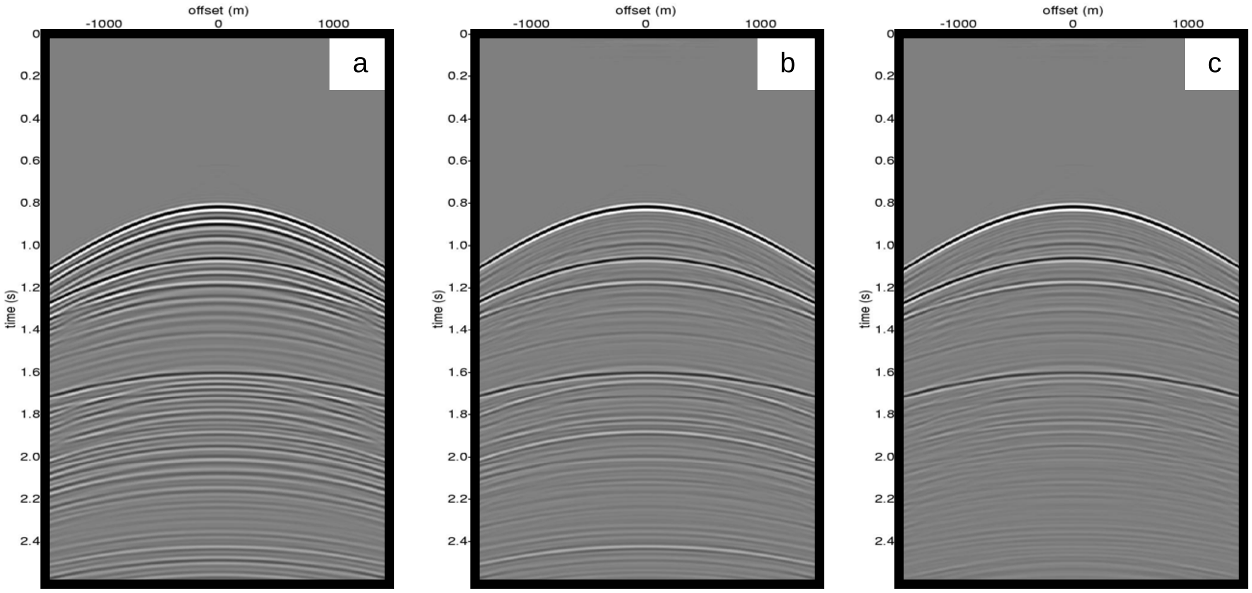


Figure 2 - SRME for a 7-reflector model in a shallow water environment. a)Input data: shot record with all multiples; b)SRME output; c)ideal output, i.e. modeled primaries and internal multiples. Effect of missing near offsets: d)input data with missing near offsets; e)SRME output; f)ideal output. Results with offset restoration: g)input after near offset interpolation; h)SRME output; i)ideal output. Note that a incorrect near offset reconstruction yields unsatisfacotry SRME results.



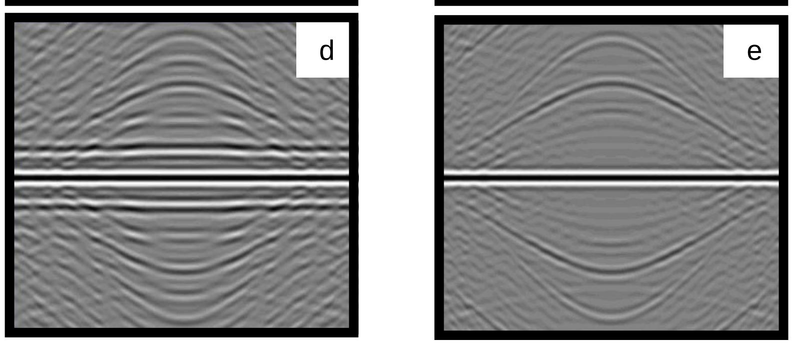


Figure 3 - Strategy for multiple removal on the shallow water data from Figure 2: a) Input data after missing offset restoration (see Figure 2g) with additional FK filter and shallow event mute; b) output of predictive deconvolution; c)output of SRME after deconvolution. The lower panels show the auto-correlation of the input data (d) and from the deconvolution result (e). Note that the predicitve deconvolution takes care of the shallow water reverberations and the SRME of the other surface multiples.

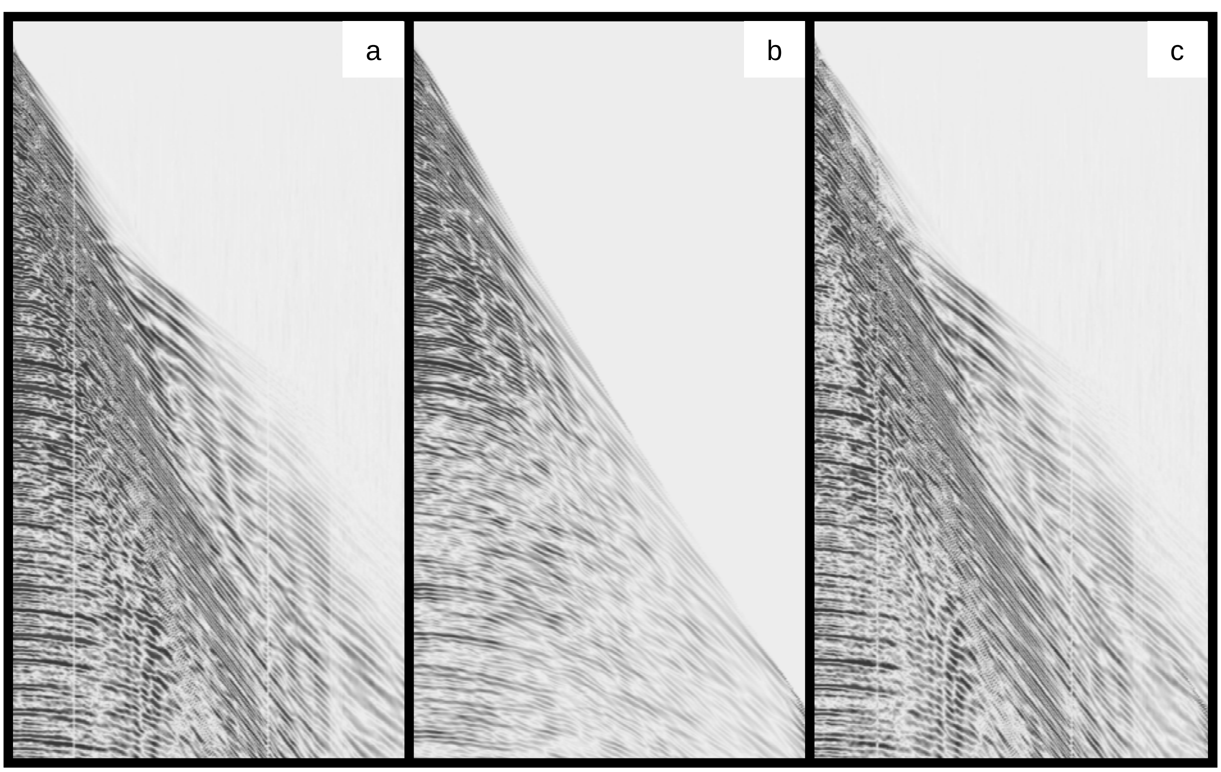


Figure 4 - Multi-gate predictive deconvolution (MGPD) applied to field data in a shallow water environment, a)raw shot record; b)shot record after MGPD and noise attenuation and c)the removed multiples and noise, i.e. difference of a) and b). Note that the MGPD results in b) reveals some primaries that were blurred by multiples in the input data

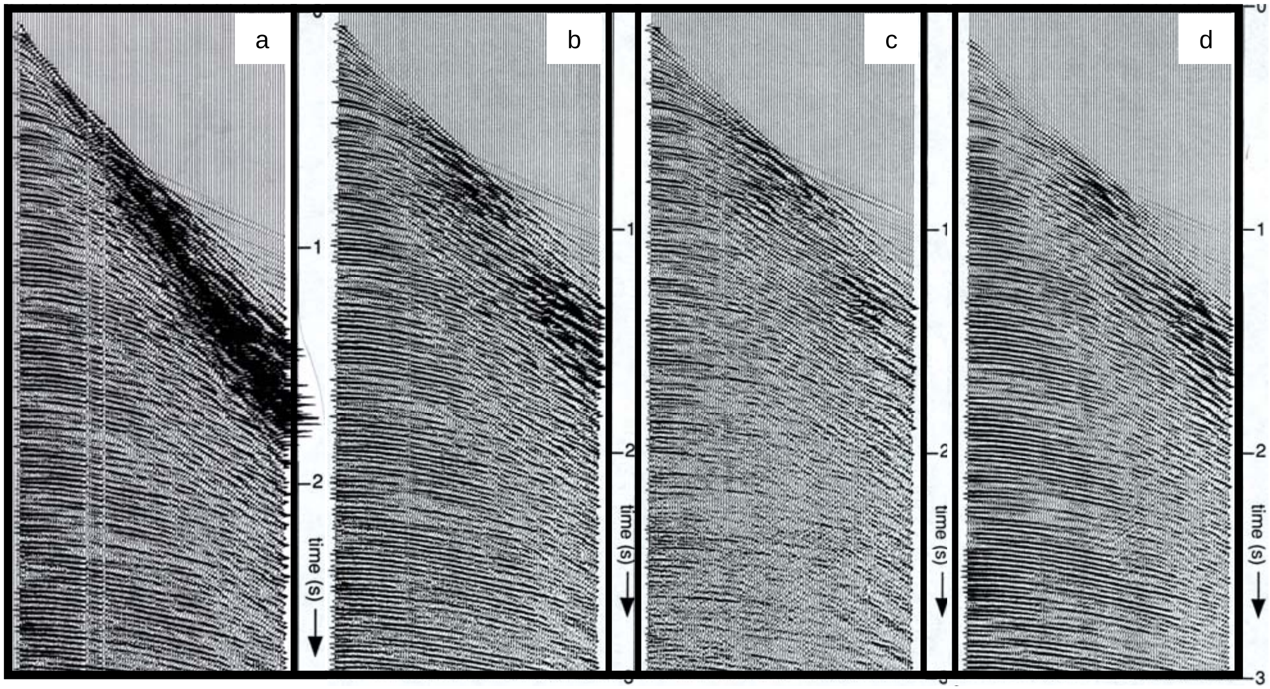


Figure 5 - SRME applied to field data in a 60 meters water depth environment. a)Raw shot record; b)shot record after preprocessing steps: FK filter and missing offset interpolation; c)shot record after SRME; d)the removed multiples, i.e. difference of b) and c). Note that the SRME result in c) reveals some primaries that were blurred by multiples in the input data.

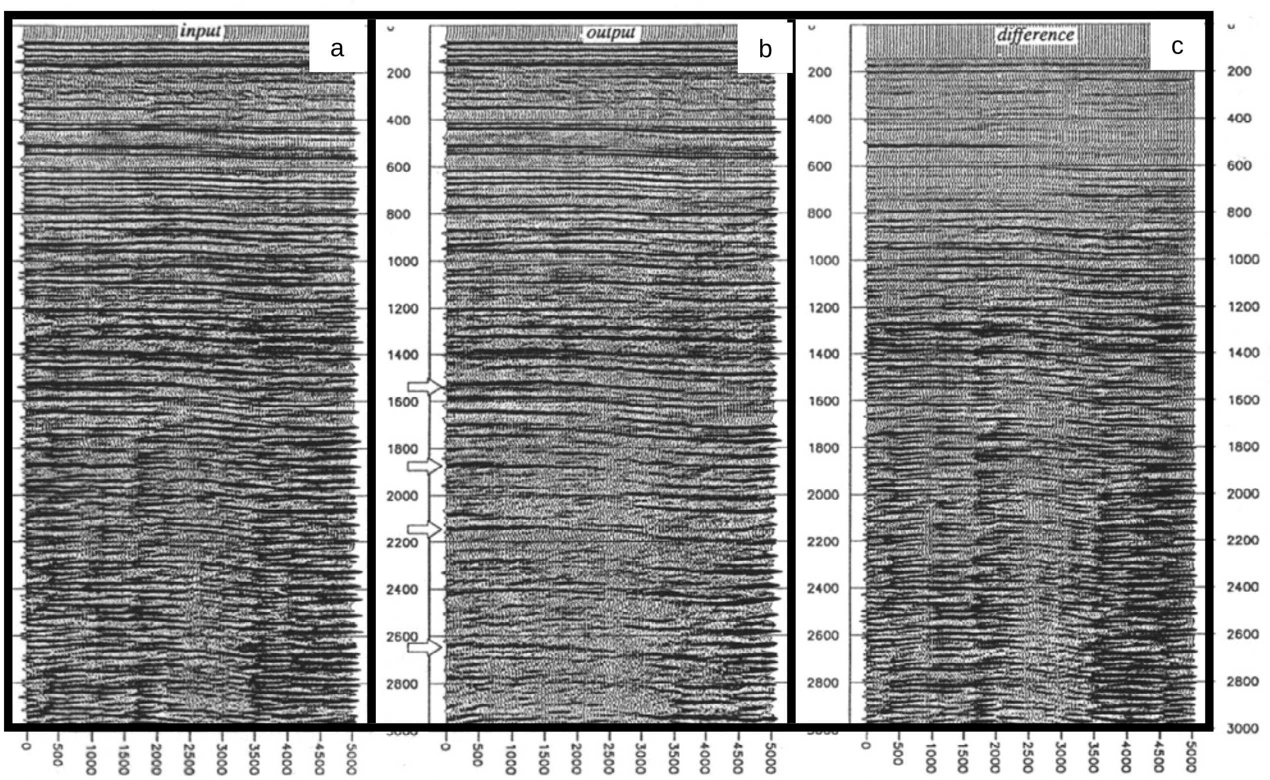


Figure 6 - Stacked section related to the field data of Figure 5. a)Stack of input data with multiples after preprocessing; b)stacked section of the data after SRME; c) the removed multiples, i.e. difference of a) and b).