

Surface Related Multiple Attenuation: A Case Study from MBA Basin, East Coast of India

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Summary

In a marine environment, strong contamination from surface multiples is one of the major problems in imaging sub-surface structures. The surface related multiple attenuation (SRMA) technique has been effective in attenuating the multiples in complex geological areas. Surface-related multiple attenuation consists of two steps. The first step is the prediction of the multiples from the data. The second step is the adaptive subtraction of the predicted multiples from the data. This method is purely data driven and does not require any a priori knowledge of the subsurface velocity, while accounting for the full complexity of the earth. A comprehensive case study has been demonstrated using data of MBA basin unveiling effectiveness of this 3D SRMA technique for multiple attenuation.

Introduction

Complex 3D multiples are a pervasive problem affecting data sets from a variety of geographic areas. 3D surface related multiple attenuation (SRMA) is a powerful method capable of attenuating a large class of even the most complex 3D multiples. 3D-SRMA does not make any assumptions about the subsurface velocity and is a data-driven procedure. The main advantage is that SRMA can be implemented as a fully data-driven technology. There is no need for picking or velocity analysis, and it can be used in the earliest stages of the data processing chain. Unlike other methods of multiple attenuation, SRMA does not rely on assumptions or knowledge about the subsurface, nor does it use event properties to discriminate between multiples and primaries. The main drawback of this kind of technique is that it ideally requires one shot location for each receiver position, and this is not the case for most 3D acquisition geometries. 3D SRMA can target multiples with very little differential moveout, such as peg-leg multiples, diffracted, 3D multiples and multiple energy residing on the near offset traces without severely affecting the primaries. The parabolic radon demultiple method works well at mid to long offsets but has its limitations on near offsets. For complex and rugged water-bottom 3D SRMA based multiple removal techniques provide much better results.

3D SRMA is implemented in two steps. In first step multiples are modeled using convolution and in second step this model is adaptively subtracted from the original seismic data containing primary and multiple events.



Figure 1: Location map of the area

Theory of SRMA

Surface-related multiples include all multiples except those generated by totally internal reflections. They are typically the strongest multiple events present in the seismic data and therefore need to be removed from prestack gathers prior to any further imaging process. Surface-related multiples are classified into different orders depending on how many times they are reflected back from the free surface. A multiple event is called first-order surface multiple if it is reflected only once at the free surface; while a second-order multiple is reflected twice at the free surface. In general, an Nth order multiple gets reflected N times at the free surface. The SRMA technology is designed to attenuate these multiples in a two-step fashion. During the first step, surface-related multiples are predicted kinematically. The predicted multiples have about the same travel times as the

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multiples recorded in seismic data but different amplitudes and wavelet shapes.

In the second step, the surface-related multiples present in the seismic data are attenuated using predicted multiples. The method assumes that sources and receivers have the same spatial sampling interval and they are located at the same stations at the free surface.

This method does not require distinctive move out differences between the primaries and multiples, and does not require any prior knowledge of the subsurface structure, such as velocities. The seismic data itself can be used to predict the surface-related multiples. According to the theory by Verschuur, the multiple prediction operator can be expanded into a Taylor series. In the frequency domain, the Taylor expansion can be expressed as

$$P_0 = P - \{R/S(w)\} [P]^2 + \{R/S(w)\}^2 [P]^3 + \{R/S(w)\}^3 [P]^4 + \dots \\ = T_0 + T_1 + T_2 + T_3 + \dots$$

Where matrix P is the input seismic data and matrix P₀ represents multiple-free data. One column of P represents one common shot gather for a given frequency; while one row of P represents one common receiver gather. R is the reflection coefficient at the free surface. S (w) is the source wavelet and is a function of frequency. Since the source signature is usually unknown, it is set to a spike in SRMA, and R is also set to 1. Setting to a spike results in wavelet distortion in predicted multiple events. The effect of the source wavelet will be accounted for by finding matching filters that transform the wavelet of predicted multiples into that of the recorded multiples.

In the Taylor expansion, the terms T₀, T₁, T₂ and T₃ are corresponding Taylor terms. Each term in the Taylor series contains multiples starting from a certain order. They are obtained by multiplying the data matrix P with lower order Taylor term. The zeroth order Taylor term T₀=P in the expansion is the input seismic data itself containing both the primaries and multiples of various orders.

The first order Taylor term T₁= -{R/S (w)} P x P contains the first-order multiples and all other higher-order multiples except any primary reflection. The second order Taylor term T₂ in the Taylor expansion contains second-order and higher order multiples only.

Each Taylor term is computed through summations of cross convolutions between input seismic traces and lower order Taylor terms that are already computed. The input seismic data, when convolved with itself, or expansion contains second-order and higher order multiples only. It can be noted that the Nth order Taylor term in the expansion contains not only the Nth order multiples, but also all possible higher order multiples. The input seismic data, when convolved with itself, predicts the first order Taylor term, which contains multiples only. In the 3D SRMA application, only the first-order Taylor term is computed.

Methodology

Navigation merged raw shot gathers were taken as input data. Band pass filter was applied to remove swell noise. Data was CDP sorted before subjecting to 3D SRMA module for prediction of surface generated multiples.

Initial Velocity Model Building

Stacking velocity was picked on CDP sorted data. Initial stacking velocity model was created using Constrained Velocity Inversion (CVI) application. This application enables to create a smoothed and structurally credible velocity volume. From closed grid picking of vertical functions as input, stacking velocity volume was created.

Input Data Preparation

Multiple prediction in 3D SRMA is based on the correlation of pairs of traces over the possible multiple generation locations. This is a data driven process and for best results require regular input data. That is hardly ever possible in real cases. Therefore, SRMA will utilize the nearest shot(s)/receiver(s) using residual moveout to compensate for the distances. A velocity volume used in the residual moveout applications is one of the inputs to this process.

The following steps should be followed to make the data suitable for input to SRMA.

Removal of Direct Waves and Ghosts

The direct wave needs to be muted before SRMA; otherwise, the convolution of direct waves with primary reflection events and multiple reflection events may produce unwanted events in the multiple model. These unwanted events are unrealistic. They do not exist in the original input and will be added into the final results as coherent noise after multiple subtraction; therefore, they need to be removed. Ideally, input data should only contain primaries and surface related multiples.

Deghosting

If the guns and receivers are several meters below the free surface, they will produce ghost events. SRMA process does not predict ghost events so they need to be removed prior to SRMA.

Source and Receiver Depth Correction

SRMA requires that both the sources and the receivers are at the free surface where multiple reflections take place. If the sources and the receivers are several meters below the free surface, a static correction must be applied to move

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them to the free surface. This can be done by calculating and applying a bulk time shift to the traces. The time shift corresponds to the source depth and the receiver depth. If this correction is not applied, predicted multiple events will have time shifts. Multiple attenuation deploying 3D SRMA was executed in following two steps

- Prediction of surface related multiple models
- Adaptive subtraction and filtering of multiple model from input seismic data.

Prediction of surface related multiple models

For prediction of multiples suitable aperture is necessary. Aperture is the main parameter which governs the time taken by SRMA process. For optimisation of this parameter test jobs were run with 4km, 6km and 8km inline apertures. It was found that 6km is optimal in terms of quality and execution time.

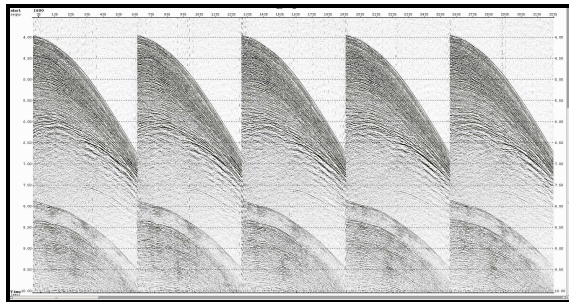


Figure 2: Representative input shot gathers showing water bottom multiples.

According to the theory of surface multiple attenuation, surface related multiples can be kinematically predicted by 2D surface integration of the convolution of prestack seismic traces at possible surface multiple reflection locations. 3D SRMA requires dense source and receiver distributions in both inline and cross line directions. If such acquisition is available, SRMA utilizes these traces. In most marine surveys, dense source distribution is not found. Therefore, the process requires selecting the "most suitable" trace from the available traces.

SRMA uses the existing data along with residual move out application to form the surface integration over possible multiple location.

Adaptive subtraction and filtering of multiple model from input seismic data.

Multiple models generated during the prediction is merged with input seismic CMP gathers file. Later this merged file is used as input to module for adaptive subtraction. The least squares matching filter is designed such that the

residual energy between the data traces and the filtered multiple traces is minimized in a selected 2D window. In other words, the filtered multiples will match the recorded multiples as closely as possible, in terms of travel times, amplitudes and wavelet shapes. This should result in the optimal attenuation of the multiples. The output generated are CMP gathers in which the original input data traces with multiples removed and primaries preserved are present.

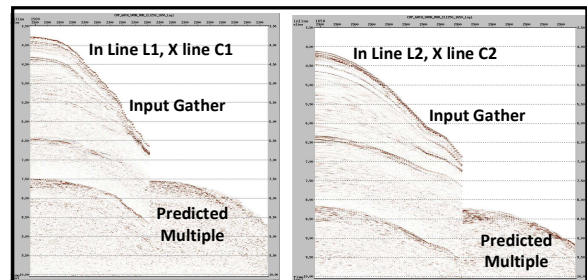


Figure 3: Representative CMP gathers merged with SRMA model along in line L1 and L2 from the cross line C1 and C2 respectively.

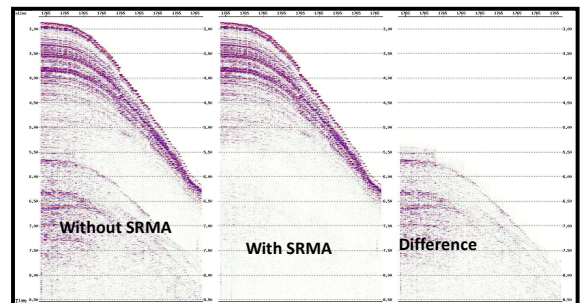


Figure 4: A representative CMP gather showing effect of SRMA adopted from in line L1

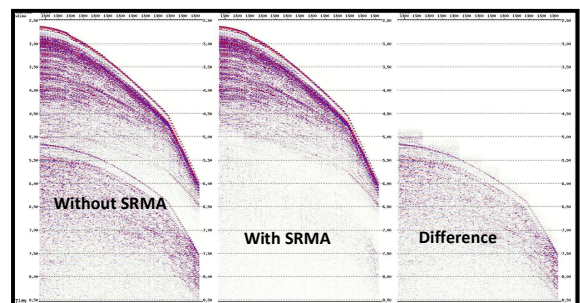


Figure 5: A representative CMP gather showing effect of SRMA adopted from in line L2

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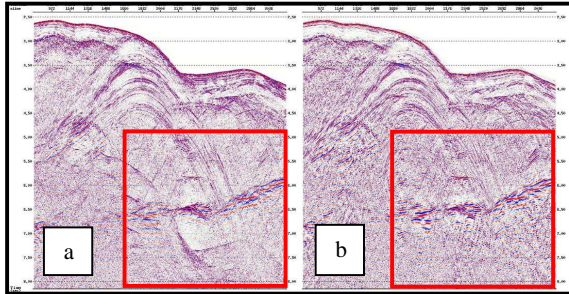


Figure 6: Comparison of stack section before (a) and after 3D SRMA (b) along in line L1

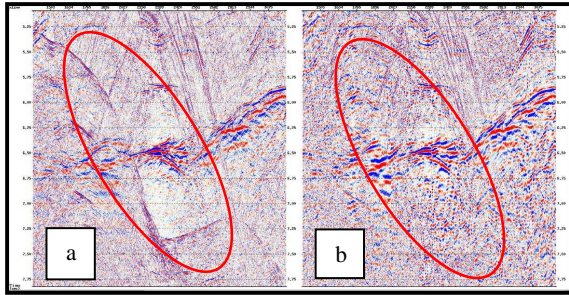


Figure 7: Comparison of stack section before (a) and after 3D SRMA (b) along in line L1 (zoomed)

Area of study

The area under study lies in MBA basin situated in east coast of India. The major part of the block falls within the Fore-arc setting and minor part in volcanic arc. The said block is located east of Little Andaman Islands. A number of medium sized anticlines were developed within probable Miocene sequence near the junction of inner and outer fore arc. The Bathymetry ranges between 1950 m to 4100 m and there is abrupt change in water bottom depth in NW part of 3D area.

The study pertains to the 150 sq. km 3D seismic data, using Surface Related Multiple Attenuation (SRMA) technology. The 81 fold 3D data was acquired using eight steamers with group interval 12.5 m and shot interval 25 m flip flop during 2013 using 648 channels per steamer. The minimum offset is 171 m and the maximum far offset is 8271 m. Record length of data is 10.0 sec. sampling interval 2.0 ms. The dimension of bin size is 6.5 x 25 m. The main objective of processing was to test effectiveness of 3D SRMA technology in a zone of 2500-8500 msec. The location map of area under study is shown in Figure 1.

Results & Discussions

Sample shot gathers have been shown in Figure 2. It is evident that these water bottom generated multiples are very strong and may result into contamination of data leading to misinterpretation by interfering with primary events. These multiples are efficiently modeled using the 3D SRMA and merged with CMP gathers containing primary and multiple both as shown in figure 3. Using this merged data set, a suitable matching filter was designed and multiple models were adoptively subtracted from the input data set resulting into multiple free CMP gathers.

Figure 4 & 5 show comparison between CMP gathers before and after multiple attenuation deploying 3D SRMA technique. Difference of these two data show that only surface related multiples have been removed while preserving the primary events.

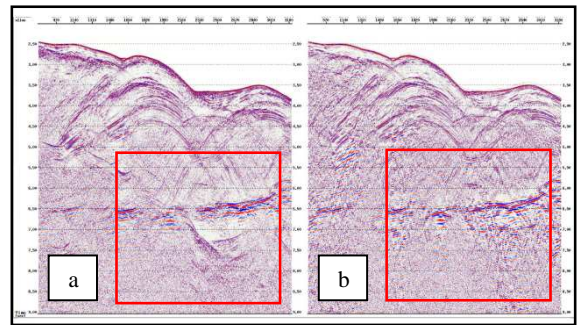


Figure 8: Comparison of stack section before (a) and after 3D SRMA (b) along in line L2

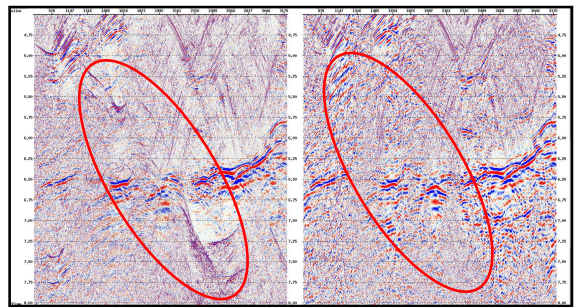


Figure 9: Comparison of stack section before (a) and after 3D SRMA (b) along in line L1 (zoomed)

Figure 6, 7, 8 & 9 illustrate comparison between stack section before and after 3D SRMA along two different inline directions. The same has been shown in figure 10 along cross line direction. It is clearly envisaged that water bottom generated multiples are effectively removed.

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Figure 11 illustrate comparison between PSTM gathers before and after application of 3D SRMA along in line direction. Looking around the near and far offset part of the gathers it is found that 3D SRMA has completely removed the surface generated multiples in near and mid offset regime only some remnant multiples are visible in far offset.

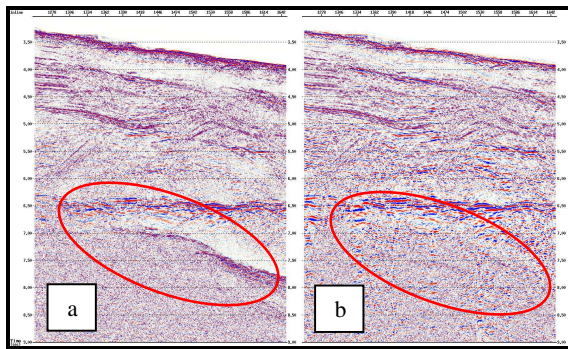


Figure 10: Comparison of stack section before (a) and after 3D SRMA (b) along cross line C1

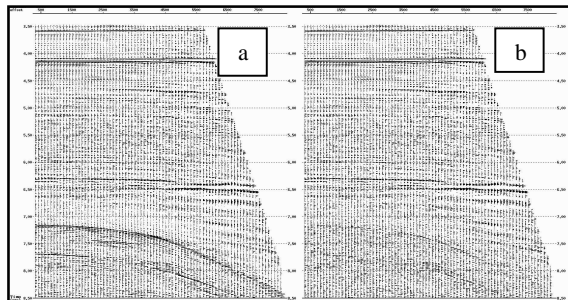


Figure 11: Comparison of PSTM gather before (a) and after 3D SRMA (b) adopted from line L2

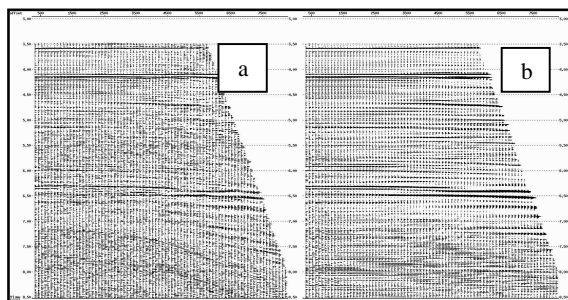


Figure 12: Comparison of PSTM gather after 3D SRMA (a) and after 3D SRMA & RADON (b) adopted from line L2.

It is very difficult to remove the near offset multiples by conventional methods, which can easily be achieved by 3D SRMA technique.

Figure 12 demonstrate a comparison between 3D SRMA applied PSTM gathers followed by RADON demultiple. It is seen that remnant multiples present in the far offset of gather have been diminished.

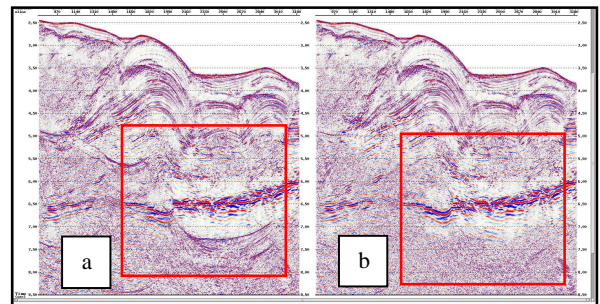


Figure 13: Comparison of PSTM stack section before (a) and after 3D SRMA (b) along in line L2

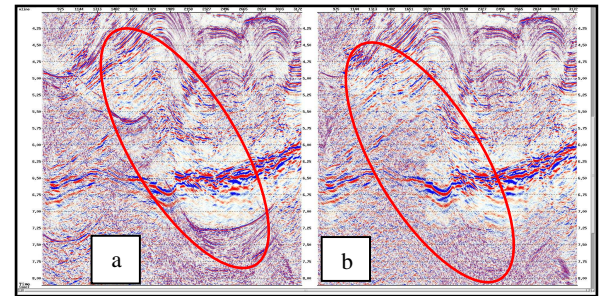


Figure 14: Comparison of PSTM stack section before (a) and after 3D SRMA (b) along in line L2 (zoomed)

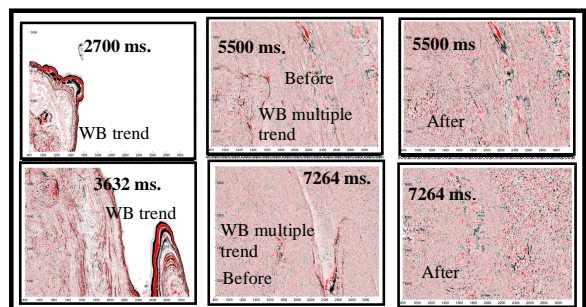


Figure 15: Comparison of time slices before and after SRMA showing water bottom and multiple trend.

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In Figures 13&14 PSTM stack section along in line direction before and after 3D SRMA have been compared. It can be concluded that seismic horizons masked by water bottom multiples have become more cleared and well interpretable after application of 3D SRMA.

In Figure 15 time slices generated through stack volume before and after 3D SRMA along with water bottom have been compared at double time of water bottom level. It is observed that the pseudo structural features generated from replication of water bottom are removed after application of 3D SRMA. This can give a lead to interpreters in delineation of sub surface structures.

Conclusions

3D SRMA is an elegant process for removal of surface related multiples in complex geological setup of marine environment. This process does not require any prior information of sub surface velocity, hence can be applied in the beginning of processing flow of seismic data conditioning. Inclusion of this process has given reasonably better seismic image and comparatively good multiple attenuated gathers at near to mid offsets. 3D SRMA can target multiples with very little differential moveout, such as peg-leg multiples, diffracted, 3D multiples and multiple energy residing on the near offset traces without severely affecting the primaries. It is necessary to supplement the process with parabolic Radon de-multiple for addressing the middle and far offset regimes. This is a computationally and I/O intensive application.

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Statement from authors:

Views expressed in this study are those of the authors only and do not reflect the official views of the company i.e. the Oil and Natural Gas Corporation Ltd.