Summary

We show here a successful case study of applying 3D SRME for a shallow water data from West Africa. The key for successful 3D SRME is a high effort acquisition including dense source and receiver grid and a good sampling of near offsets. Careful selection of 3D SRME parameters was also critical for the successful attenuation of complex 3D multiples.

Introduction

3D Surface-Related Multiple Elimination (SRME) has been effectively used to remove multiples in datasets from deep water. Removing these multiples from shallow water data is usually much more problematic for several reasons, some acquisition-related. The 3D SRME process uses primary reflections to predict multiples. To obtain an accurate multiples prediction from 3D SRME on shallow water data requires more stringent acquisition parameters than for deep water data. Dense shot and receiver grids along both inline and crossline directions are needed to ensure that shallow primary reflections are not aliased. In addition, the distance between shot and receiver needs to be minimized to record near offsets, below the critical angle.

Once the primaries are used to create a predicted multiples model, the model is adaptively subtracted from the original data. In shallow water, the wavelet, amplitude, and dip characteristics of the primaries and the multiples are usually very similar. This makes the parameter selections in adaptive subtraction critical. The adaptive window size needs to be small enough so that both the multiples and the primaries that generated them are not included in the same window. This will maximize multiples subtractions and minimize any damage to the primaries.

This paper presents the successful application of 3D SRME to shallow water data acquired offshore West Africa. The results will show that the key components for this success are a result of the shot spacing and near offset parameter selection as well as the careful testing and selection of the adaptive subtraction parameters.

Field data and pre-processing before SRME

The field data was acquired in offshore West Africa. The water bottom depth varies in the area from about 25m to about 100m. The survey was designed to record high resolution data with flip/flop guns at a 12.5m shot interval (i.e. 25m per gun). The sail line interval in the crossline direction is 200m. By contrast, the shot interval is usually 50m to 75m within an inline and 300m to 500m along a crossline for surveys in deep water. The inline receiver interval for the survey is 12.5m, while the streamer separation is only 50m. Again, this is denser than those for a conventional marine survey which usually have a receiver grid of 12.5x100m. Furthermore, the nearest channel at the center cable is only 37m from the source, which is much smaller than the 200m to 300m typically designated for surveys in deep water. The shot and receiver configuration defines the natural bin size of 6.25x12.5m, the nominal fold of 48, and the offset range of 37m-2430m.

The prestack data went through shot-domain noise attenuation to remove different types of noise from the data, mainly swell noise and direct arrival. Special attention was given to preserve the primaries and the multiples during the noise attenuation. All of the pre-processing was surface consistent, including a shot by shot de-signature and a de-bubble filter. The water column static was done through an inversion (Xu & Pham, 2003) and the instrument datum was applied based on the acquisition definition of the gun and cable depths. Channel amplitude correction scalars were applied to correct for instrument bias between the channels.

Analysis of the acquisition geometry for SRME

Figure 1 shows the basic principle of SRME (Berkhout and Verschuur, 1997). It illustrates why a dense shot spacing and small near offsets are required. Based on the green ray paths, the source side
first bounce multiple S1R2 can be predicted by convolving the primaries S1R1 with S2R2. In order to account for all possibilities, the distance between S1 and S2 needs to be as close as the receiver interval. Ideally, the shot interval needs to be the same as the receiver interval for optimal SRME prediction. In this case, the flip/flop shot interval of 12.5m is the same as the receiver interval.

The ray path (S1R2) in red (Figure 1) indicates a water-bottom reflection just over the critical angle. Because the critical angle has been surpassed, the red ray path does not transmit energy through the water bottom. As water-bottom refracted energy is not associated with ray paths of the multiple, any offsets exceeding the critical angle would be problematic for SRME to predict lower-order water-bottom and surface-related multiples.

The theoretical critical angle to record water bottom primary reflections can be calculated using Snell’s law \( \frac{\sin(\theta_1)}{v_1} = \frac{\sin(\theta_2)}{v_2} \). Given a water velocity of 1500m/s, a sub-water velocity of 1650m/s, and a water depth of 30m, the maximum calculated offset below the critical angle will be at about 130m. Table 1 shows the field data near offsets distribution per cable per channel for Gun-1. As each cable represents an inline, this table shows that most of the inlines (i.e. a shot and cable pair) contain offsets below the critical angle. With sufficient near-offset traces, lower-order multiples in shallow water can be more effectively modelled and attenuated using SRME.

**SRME crossline gathers**

To examine if the data was acquired with sufficient shot and receiver density, SRME crossline gathers were generated (Lin et al, 2005) with different shot and channel spacing. Crossline gathers were constructed by summing SRME contributions along the inline direction. The prediction with the minimum travel time (apex) is the true 3D multiple model. If the data is not aliased, summing over the gathers should reveal the apex. Conversely, if the data is aliased, flat and unorganized events will appear on the crossline gather and lead to an inadequate multiples model after summation.

Figure 2A and 2B illustrate crossline gathers for offset 1,160m (middle offset) with a total aperture of 500m. Figure 2A used all the acquired data (12.5m flip/flop shot and 12.5m receiver spacing) to generate the crossline gather. Figure 2B is the result of using every other shot and channel. The results in Figure 2B are visibly worse than those in Figures 2A. Strong and prevalent aliased energy dominates the crossline gather in Figure 2B with no identifiable multiples apexes. The result in Figure 2B is not suitable for SRME unless interpolation is applied.

Based on the SRME crossline gather analysis, the inline shot spacing of 12.5m flip/flop is adequate for shallow water 3D SRME.

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**Figure 1:** Ray paths describing the basic principles of SRME. In green is the source side first bounce surface multiple. In red is a ray path just beyond critical angle.

**Table 1:** The table shows the actual offset [m] per each of the eight cables (Cb), and first nine channels (Ch) of Gun-1. The offsets which are falling below the critical angle are highlighted in yellow.
Before 3D SRME, the anti leakage Fourier Transform (Xu et al., 2005) was applied to interpolate missing near offsets at far cables, missing shots, and to compensate for cable feathering.

Crossline gathers in Figure 2 can also be used to determine the minimum and maximum aperture for 3D SRME. The minimum aperture is twice the distance from the center of the gather to the farthest multiple apex. In Figure 2, the multiples apexes are all within approximately 250m from the center. The maximum aperture is limited by the aliasing as can be clearly seen in Figure 2B. Since no obvious aliasing occurs at the far offsets, an aperture of 1,500m was chosen, ensuring a complete 3D multiples model.

**SRME model subtraction**

Once the predicted multiples model had been created, it was adaptively subtracted from the raw data (Guo, 2003). To aid the SRME algorithm in the adaption process, a matching window and a matching filter needed to be defined. In this dataset, the water bottom was flat and shallow, causing the surface-related multiples to be recorded relatively close to their respective primaries, while also exhibiting a similar character. Therefore, it was critical for the matching window to be small enough to exclude the multiple from being in the same window as its primary. Otherwise, the adaptive subtraction may have erroneously attenuated the primaries.

Figure 3 shows the seismic before and after the application of SRME (A and B respectively) as well as the predicted multiples model (C) and the surface-related multiples that were attenuated (D). Multiples within the oval in A are largely attenuated after 3D SRME as comparing to the same oval in B. The overall good timing and phase match between C and D indicates that the multiples model was predicted well and that the adaptive subtraction was effective.

**Conclusions**

Surface-related multiples in a shallow water environment can be very challenging to attenuate if data is not adequately acquired. This case study from West Africa demonstrated how a relatively dense source and receiver grid, a good sampling of near offsets, and the careful selection of the 3D SRME parameters were critical for the successful attenuation of these complex 3D multiples.

**Acknowledgments**

The authors thank Hess Corporation and CGGVeritas for permission to present this work. This paper is dedicated to the memory of Uzi Egozi.
Figure 3 A) Stack before SRME.  B) The same stack after the predicted multiples adaptive subtraction.  C) The predicted multiples model.  D) The direct difference between A) and B).

References


