Internal Multiple Removal in Offshore Brazil Seismic Data Using the Inverse Scattering Series

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Abstract

The inverse scattering series methods to attenuate multiples were applied to field marine seismic data provided by Petrobras. The available data are from offshore Brazil and display complex geology with salt domes and salt layers, making processing a hard task. Many multiple events are observed, some of them at the target depth. The observed multiples remain in the data even though several other methods of multiple attenuation had been tested. Therefore, this dataset is considered a challenge to new multiple attenuation methods. First, the dataset was reprocessed to meet the requirements of the inverse scattering series methods. Then, these methods were applied and improvement is clear when observing the internal multiple attenuation results.

Introduction

Multiple reflections are considered noise as long as they do not contribute to imaging or inversion when traditional imaging methods are employed. In addition, multiples can make the interpretation of the final result harder as they can be mistaken for primaries or obscure the desired signal. In this work we discuss and employ the method based on the inverse scattering series (ISS) to attenuate free surface and internal multiples. The method was applied to a 2D offshore seismic dataset that displays complex geology with salt domes and salt layers of complicate stratification. Figure 1 shows a stacked seismic section of the data provided. The free surface multiples are very strong and can be identified by a repetition of the shallow events in the deep part of the section. Additionally, the salt layers have high reflection coefficients and the generated internal multiples are strong when compared with the weak signal below salt. The ISS technique will be applied to the data as we try to remove both free surface and internal multiples. In this situation, the advantages of the method may be explored. The method is data-driven so that no interpretation on the complex geology, particularly on the salt layers, is necessary. In addition, no *a priori* information is required besides the seismic dataset itself. Finally, the requisites of the method, that data must be free of ghosts and the wavelet predicted, can be accomplished by

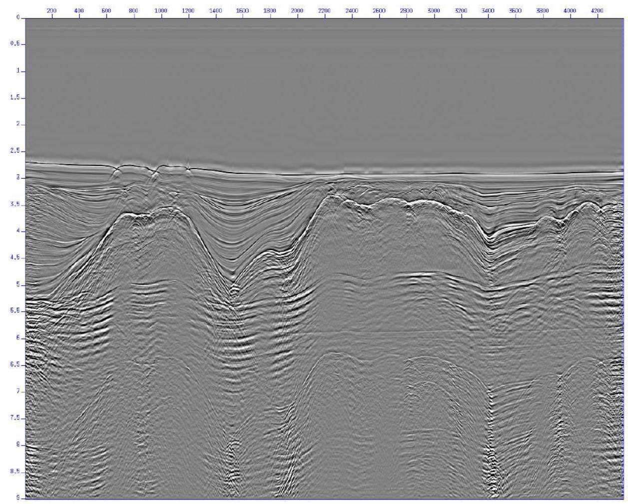

Figure 1: seismic section showing a portion of the stacked data. Salt domes and salt layers are indicated. All multiples are present since no multiple attenuation method was applied. Image provided by Petrobras with no scales available.

Petrobras.

Theory

Many methods can be employed to attenuate multiples, each of them holding advantages and disadvantages according to the situation. The main advantages of the ISS methods lie on the fact that no interpretation on the complex multiple generators, velocity fields or modeling is necessary. Only the seismic data are required to generate the multiple model that is later used to remove multiples by some adaptive subtraction. Some disadvantages include the requisite of special processing and the high computational cost of the internal multiple algorithm.

The method is derived from a scattering subseries. Such series are obtained when the wave propagation problem is addressed from a scattering point of view. In other words, instead of reflectors we work with scattering points. According to this picture, the seismic sources generate an incident field and the seismic dataset corresponds to the field scattered by earth and measured on a surface. The subsurface properties are then in some way contained in the earth scattering potential. Hence, our effort is to obtain the earth scattering potential which is a complicated inverse problem (as opposed to the forward problem which computes the field in the earth using as input the incident field and the earth scattering potential). In principle, if the scattering potential is completely computed as a series expansion, the full inversion problem is solved and all interesting properties can be obtained. However, the series approach shows us that the complete inversion solution cannot be obtained with seismic data only. In addition, the entire series is very complicated and convergence problems usually occur. Hence, the problem is addressed as processing steps, each of them carried out by a subseries of the original series that performs a specific task on the seismic data. In this work only the subseries that perform multiple attenuation are employed. These steps are special since they are model-independent and no *a priori* information is required (multiples can be predicted from the seismic dataset itself).

After data processing, discussed in the next section, the first step is to apply the free surface removal subseries. Free surface multiple removal is a required step to perform the main task of internal multiple attenuation. This is because the data with free surface multiples removed are used as input to the subsequent step of internal multiple attenuation. This is a common characteristic of all ISS methods; they are performed as processing steps that use as input the previously processed data.

The free surface removal subseries computes the seismic data with free surface multiples removed as a function of the input dataset. In momentum space the series is given by

$$D'(k_g,-q_g,k_s,q_s) = \sum_{n=1}^{\infty} D'_n(k_g,-q_g,k_s,q_s) \tag{1}$$

where each series term can be obtained by

$$D'_n(k_g,-q_g,k_s,q_s) = -\pi i \int dk' q' e^{iq'(\varepsilon_s+\varepsilon_g)} D'_1(k_g,-q_g,k',q') D'_{n-1}(k',-q',k_s,q_s) \quad n=2,3,\dots \tag{2}$$

The first term is the input data and the following terms can be viewed as the multiple model. In practice, the multiple model is computed and then subtracted from the original data by an adaptive method. The algorithm was coded in C++ language by the M-OSRP group in the university of Houston. Some modifications were required to apply the code to Petrobras data.

The internal multiple attenuation series can be employed as the next step. This subseries is significantly more complicated and demands longer computer processing times to compute the multiple model. Since all computations were performed using only resources available at the University of Houston, a shorter portion of the 2D seismic line was selected as the input data. The region, discussed in the next section, was chosen to retain the complex geology and strong internal multiples issues, especially the complicated salt stratification. The main terms of the subseries are obtained by a system of equations in momentum space and pseudo-depth,

$$b_{2n+1}(k_g,k_s,q_g+q_s) = \frac{1}{(2\pi)^{2n}} \int dk_1 e^{-iq_1(\varepsilon_g-\varepsilon_s)} \times \int dz_1 e^{i(q_g+q_1)z_1} b_1(k_g,z_1,k_1) A_{2n+1}(k_1,k_s,z_1);$$

$$A_3(k_1,k_s,z_1) = \int dk_2 e^{iq_2(\varepsilon_g-\varepsilon_s)} \int_{\infty}^{z_1} dz_3 e^{-i(q_1+q_2)z_3} b_1(k_1,z_3,k_2) \times \int_{z_3}^{\infty} dz_5 e^{i(q_2+q_s)z_5} b_1(k_2,z_5,k_s);$$

$$A_{2n+1}(k_1,k_s,z_1) = \int dk_2 e^{iq_2(\varepsilon_g-\varepsilon_s)} \int_{\infty}^{z_1} dz_3 e^{-i(q_1+q_2)z_3} b_1(k_1,z_3,k_2) \times \int_{z_3}^{\infty} dz_5 e^{i(q_2+q_s)z_5} A_{2n-1}(k_2,z_5,k_s);$$

where b represents the seismic data in momentum space times a obliquity factor. Again, a multiple model can be computed and then subtracted from the input by an adaptive method.

Processing and results

A special processing was performed to meet the requirements of the ISS methods. Data deghosting was carried out in Petrobras America but the subsequent processes were applied in the University of Houston. In the university the tools used were only free software, including Seismic Unix (SU) and custom functions written in C and C++. This work provided a complete set of processing tools to prepare the field data, comprising SU flows, and custom SU (or C language) functions. For instance, the data must be Fourier transformed over source and receiver locations, demanding a regularized distribution of receiver and source points on the measurement surface. The interpolation/regularization was performed by SU flows and custom SU functions written in the university.

The processed data were used as input to the free surface removal code. Almost all data were processed and a multiple model for each shot computed. A simple adaptive subtraction, also developed in the university, was employed to remove the free surface multiples. The result after data stacking is shown in Figure 2 (compare with Figure 1). The result was considered very good although this is not the focus of the work.

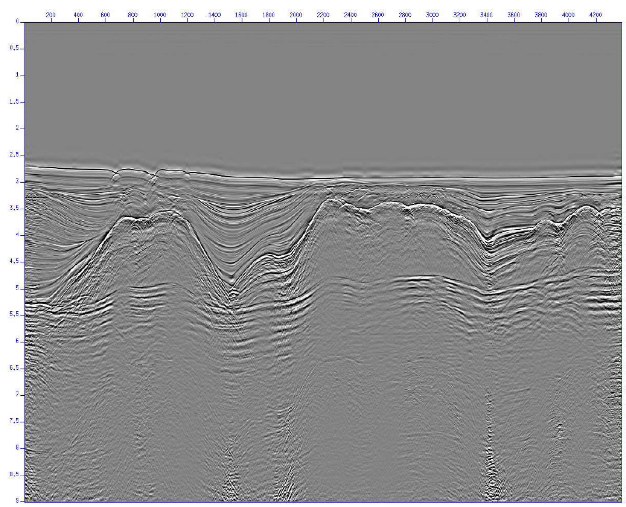

Figure 2: seismic section showing a portion of the stacked data after free surface multiple removal. The result is used as input to the internal multiple attenuation algorithm.

The main step concern internal multiple prediction and attenuation. According to our previous discussion, the internal multiple algorithm requires much more computational effort, both on CPU time and memory. The high cost can be explained by the complex system of integral equations that needs to be solved for each series term. The available resources in the university were not enough to process the entire 2D line of data, so that we decided to choose a portion considered significant. The selected region contains all the complex geology issues and strong internal multiples at the target depth (see Figure 3). The results can be compared for stacked sections in Figures 3 and 4, and for the nearest offset sections in Figures 5 and 6. Both results show many

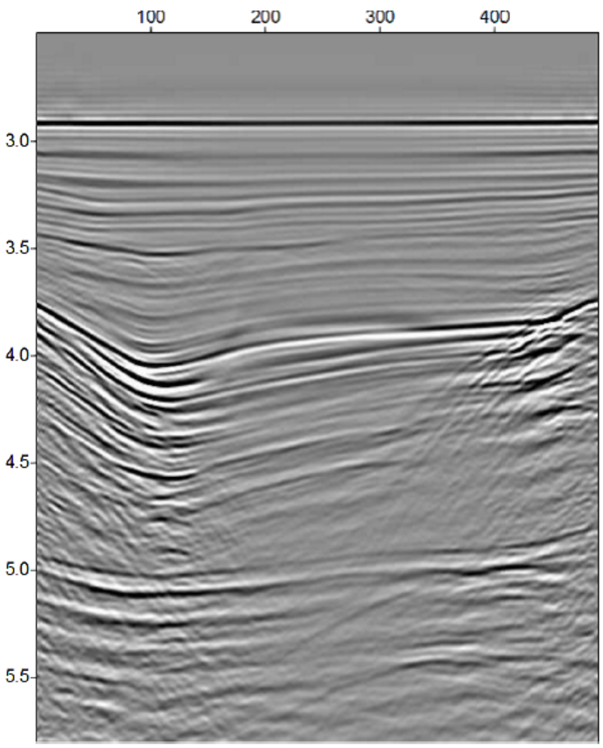

Figure 3: seismic section showing the stacked data from the portion selected as input to the internal multiple attenuation algorithm.

repeating reflectors being attenuated. Particularly, the sequence of multiples generated by the salt stratification is weakened (compare before and after results in the region below the salt flank). As usual, multiples are better observed in common offset sections, and the attenuation is very strong when comparing Figures 5 and 6. Finally, the primaries of interest below the salt may be easier identified and better processed by imaging and inversion algorithms.

Conclusions

In this work the inverse scattering series (ISS) methods for attenuating free surface and internal multiples were considered. The algorithms were applied to Brazil offshore field data, over a region of complex geology and strong multiples issues. The main advantages of the method can be exploited in this area, since the internal multiple generators are complex and cannot be mapped. The method is data-driven and no information besides the seismic dataset is required. The pre-processing required by the method was performed working mostly with free software (basically Seismic Unix and custom functions) and

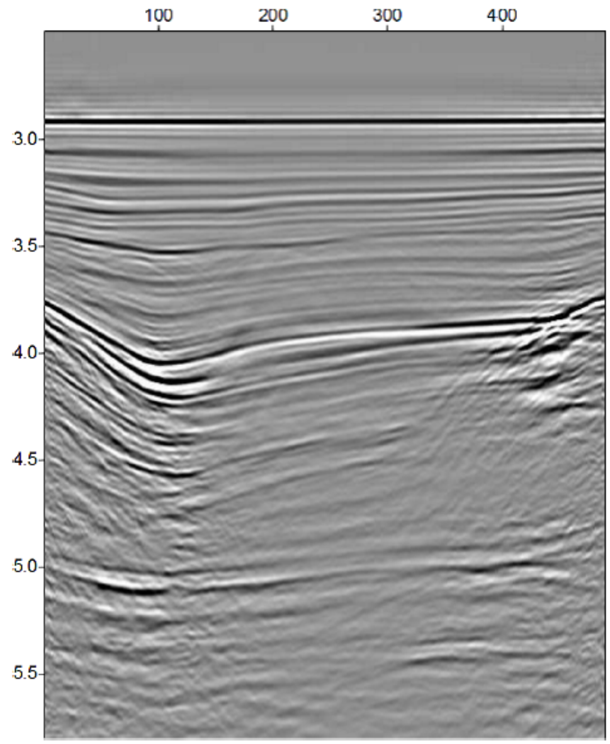

Figure 4: seismic section showing the stacked data after internal multiple attenuation. Many events associated with multiples were attenuated, particularly below the salt flank. Compare with Figure 3.

a complete set of processing flows was implemented and is available for future application in the university. The free surface removal was not the main focus of the work, but it was considered very good. The dataset with free surface multiples removed must be used as input to the main task of internal multiple attenuation. The attenuation requires significant computer resources and we were not able to predict internal multiples for the entire dataset in the university. A representative region was selected and the results show excellent attenuation.

Many aspects of this work can be considered for future study: subtract the multiples with another (possibly improved) adaptive algorithm; work with well logs to map primaries for verification; detailed comparison with other multiple attenuation methods; improvement of the subseries for internal multiple attenuation. The latter study is purely theoretical and would serve to set up a removal series, i.e., to take into account all internal multiple removal terms and not only the first order as considered in this work. In addition, adding terms to the subseries employed here is viewed as a solution to the known problem of spurious events in the multiple prediction, although such events were not observed in this work.

References

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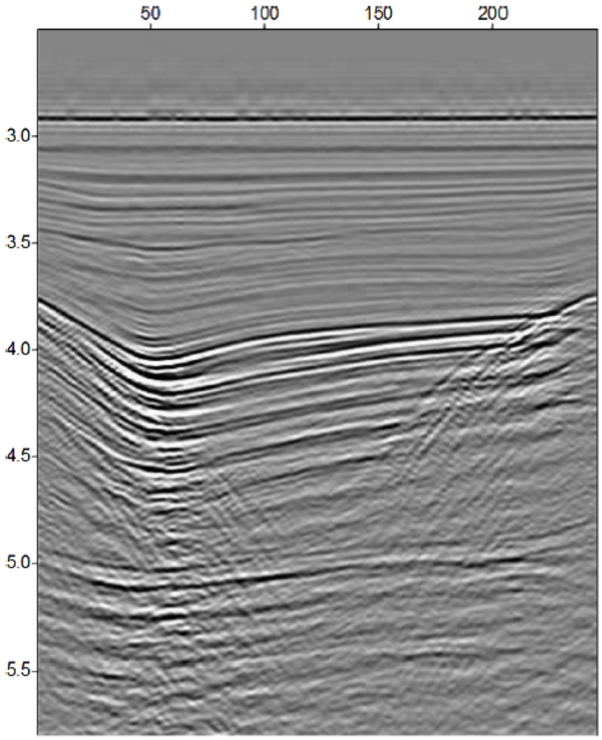

Figure 5: seismic section showing the nearest offset section (150 meters) from the portion selected as input to the internal multiple attenuation algorithm.

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Acknowledgments

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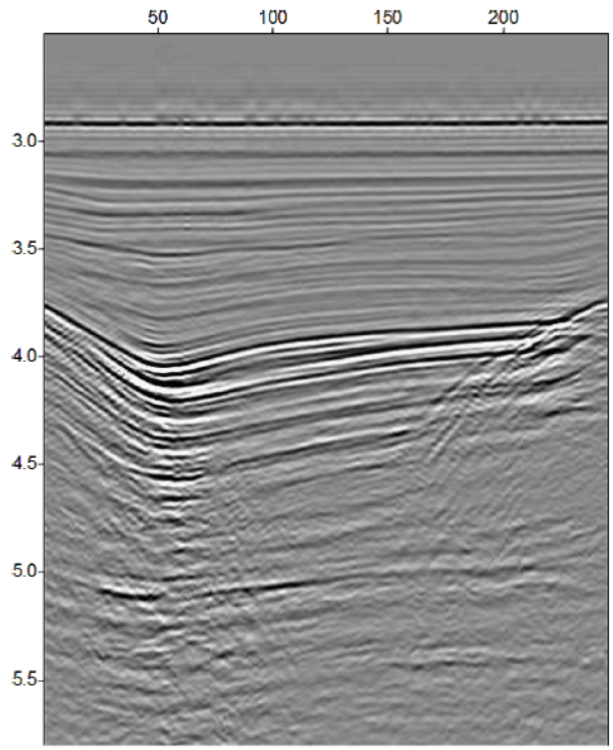

Figure 6: seismic section showing the nearest offset section (150 meters) after internal multiple attenuation. Many events associated with multiples were attenuated, particularly below the salt flank. Compare with Figure 5.