Anti-Multiple Processing on offshore Brazil Deep Water Seismic Data Using 3D Surface-Related Multiple Modeling.

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Abstract

Marine seismic data acquired over sea floors made of submarine canyons are characterized by the presence of extremely complicated patterns in the shape of the reflected multiple energy. Despite the fact that data-driven SRME techniques do not require any *a priori* knowledge of the subsurface (reflectivity, structures and velocities), it is sometimes difficult in 3D to perform the reconstruction of the missing data or the missing multiple contributions needed when applying this technique, as the method theoretically requires a shot location at each receiver location. In the following instead, we present a model-based surface-related multiple modeling technique (SRMM), which is free from any constraint relating to shot position (including OBC) and distribution, which was applied on marine seismic data acquired offshore Brazil over a series of deep submarine canyons.

Introduction

When dealing with rough sea floors, some multiple reflections can result in unexpected shapes, which are difficult to characterize and identify. Multiple generation "squares" (at least for first order multiples) the degree of complexity of the reverberated reflected energy, and, in general, there is no domain, neither time, depth, nor pre or post migrated, in which multiples and primaries can be simplified simultaneously. Conventional separation methods based on multiple periodicity or residual move-out will fail, and it is therefore necessary to predict deterministically the multiples in 3D to ensure proper denoising of the seismic data.

SRME technology, (Vershuur and Berkhout, 1997, Biersteker, 2001) led to an elegant and efficient, purely data-based multiple modeling technique. The main advantage is that SRME 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. 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.

The first solution to this problem requires the use of existing data only, and then extrapolation of the available multiple contributions. The second solution requires interpolation of the input data, thus creating the missing streamers and shot lines for the required convolutional process. Model-based modeling techniques may require interpolation between streamers, but not between sources.

Instead of interpolating, the first proposed solution consists in extrapolating the available multiple contributions, as proposed by Van Deden and Verschuur (2001), without any interpolation in the input data. Missed crossline contributions can then be extrapolated by using a parametric inversion assuming constant-velocity hyperbolic curvatures in the search for the Fresnel zones of the sparse crossline contributions. The method is recommended for situations where crossline structures vary gently. Moore and Dragoset (2004) have shown some examples of fully computed crossline contribution panels where it was clear that the pattern of those contributions was rather irregular and clearly not hyperbolic. Nevertheless, the method can work in rather complex situations as shown by Van Borselen et al. (2004).

The second solution for SRME implementation in 3D involves interpolation of the pre-stack input data. The regularization through the application of DMO and inverse DMO offers a suitable solution as proposed and implemented by Baumstein and Hadidi (2004) or Matson et al. (2004). Other authors prefer the use of statistical or pure signal processing methods. Thus, Lin et al. (2004) used the Fourier transform-based method from Xu et al. (2004), while Hokstad and Sollie (2004) preferred parabolic sparse inversion in the angular frequency domain either for interpolating the data itself or for interpolating the available multiple contributions.

3D Surface-Related Multiple Modeling (SRMM)

The alternative to data-based SRME techniques lies in the family of model-based prediction methods. Recently, Kabir et al. (2004) demonstrated a wavefield extrapolation-based demultiple method which opens out to 3D the technique proposed by Wiggins (1999) for targeting the elimination of water bottom multiples and peg-legs. Interpolation between receiver lines is necessary for building an areal antenna, but not interpolation between sources.
Continuing with model-based prediction methods, the surface-related multiple modeling technique (SRMM) presented here consists in using the pre-stack demigration of a migrated volume and subsequently simulating the reverberations of primary energy within this

volume. It assumes that the migrated section is a reliable representation of the actual subsurface reflectivity. The principle of SRMM is intuitively obvious, but we can verify that it relates to the same implicit relationship between primaries and multiples as SRME:

$$D = (I - s^{-1} * P)^{-1} * P \ . \qquad (1)$$

where D are the data and P the primaries, and thus M = D - P. The symbol `*´ stands for a multidimensional surface-consistent convolution operator, and, s^{-1} the inverse wavelet or wavelets. This expression can be expanded in the Neumann series:

$$D = \left[\sum_{n=0}^{\infty} (s^{-1} P)^{n} \right] P \qquad (2)$$

and then developed:

$$D = P + (s^{-1} * P)^{1} * P + (s^{-1} * P)^{2} * P + \ldots \qquad (3)$$

$$= P + M_1 + M_2 + \ldots$$

$$= P + \mathbf{SRMM}$$

Each term in the series from equation (3) in fact describes the operations involved in SRMM: from primaries, generated or recorded, it is necessary to iterate the previous result with a primaries generator tool.

By comparison, SRME convolution of the data with the primaries immediately provides all order multiples with the right kinematics, while in the first stage of SRMM, the demigration leads to the primaries model (figure 1a). The second iteration consists in reintroducing previous primaries as sources for a new modeling, thus leading to the first-order multiples (figures 1b). These correspond to the second term of the Neumann series, and more iterations lead to higher order multiples (figure 1c).
It is also possible to skip this cyclic procedure if the deconvolved and regularized shot records are available, by interpolating between streamers. In this case, the shot record can be used as an areal source in the modeling procedure (figure 1d and figure 2). As long as the primary modeling into a multiple-free migrated section is reliable, then again:

$$M = s^{-1} * D * P \ . \qquad (4)$$

The input for the demigration procedure consists of a migrated section, either time or depth, a velocity macro-model and the data trace coordinates for the shotpoint in question. The ringing of the primaries and multiples through the target volume is modelled using the one-way wave equation. The method therefore handles well the problems of cable feathering, as there is a propagated wavefield all along the acquisition surface. The OBC case geometry is also easily handled as the sources (common receiver) can be placed anywhere.

The need for a preliminary input migrated section may have been regarded as prohibitory not so long ago. But the new fact is that pre-stack migration (or even post-stack for easy cases) is nowadays almost the basic processing sequence for any project. Pre-stack migration programs are designed for working with massive PC clusters, allowing for flexibility and very fast turnaround. Velocity analysis has also evolved considerably, and we can rely on dense automated picking. The sharpness of the migrated image will be crucial in determining the capability to generate diffractions, but conventional migration illumination sizes allow for good definition of subsurface detail.

Real Data Examples

Experience of the application of SRMM to real data includes cases such as Gulf of Mexcio (GOM) data, North Sea and offshore Angola examples. Among the North Sea real data cases, Ormen-Lange dataset (Kleemeyer et al., 2003), is a good example, illustrating the advantages of this technique for modeling multiples from a complex seafloor and its neighboring reflectors. In those cases, the reduced extension of the main multiples generator (sea bottom and close reflectors), means very realistic results can be obtained by using a constant velocity macromodel for the wavefield propagation.

For GOM data, rapid changes in propagation velocities resulting from shallow salt structures have shown that the constant velocity assumption prevents an accurate prediction of top or base salt peg-legs when the initial primaries needed in the SRMM process are obtained by demigration. In such cases, the alternative technique using regularized input shot records as areal source in the demigration procedure will be preferred. The data preprocessing is heavier when using this kind of technique, as it is necessary to interpolate the input shot gathers crossline (between cables). It is also necessary to extrapolate the data toward zero offset, using RNMO, and even further by using the source and receiver reciprocity principle (figure 2).

Despite these additional difficulties, we selected this methodology for processing a marine dataset recorded offshore Brazil, in order to benefit from its greater robustness with respect to the propagation velocities. The crossline section from the migrated seismic block shown in figure 3 illustrates the complexity and roughness of the sea floor from this dataset processed with 3D SRMM. It is a submarine canyon environment where the bathymetry varies from 200 to 2000 meter depth inline. These results will be shown in the presentation.

Conclusion

By using pre-stack demigration of a migrated volume and subsequently simulating the reverberations of primary energy within this volume, it is possible to perform 3D Surface-Related Multiple Modeling. The method may require a previous velocity macro-model when dealing with deep multiple generators, but simpler assumptions can be used when dealing with shallower multiple generators. A reflectivity model is compulsory. It should not be a blocky one, but the migrated section itself. Of course, a rich and well defined migrated section will allow the building of very detailed multiple models. As a result of the use of the wave equation demigration algorithm, the method has a large CPU time consumption, and when regularized input shot records are not available, higher order multiples have to be explicitly calculated, thus requiring more computing time for each multiple order. The main strength of this method is that there are no constraints on the acquisition geometry. It can handle cable feathering and can process OBC acquisition geometries as well. When the primaries are computed within the same process, there are light data transfer flows as the pre-stack data are not needed in this case, only the trace headers and migrated section. This makes SRMM well suited to parallel implementation on pc cluster architecture.

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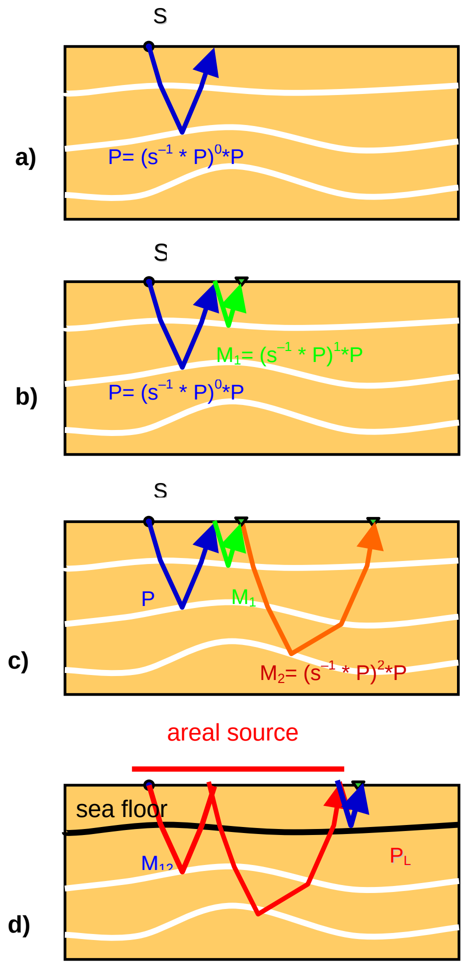

Figure 1: **a)** When a regularized input shot record is not available, SRMM requires simulation of each bounce in the multiple generation process, starting as here with the primary modeling. **b)** The primaries reaching the surface have to be reinjected into the model as an areal source record to illuminate the migrated section, and thus model the first order multiples. **c)** This process has to be repeated to model each multiple order, unless the recorded real data is regularized and injected into the model. **d)** Once the input shot record can be regularized, it can be used as an areal shot record for injection into the model. When using a thin reflectivity model (sea floor vicinity) at least the receiver side peg-legs can be accurately modeled.

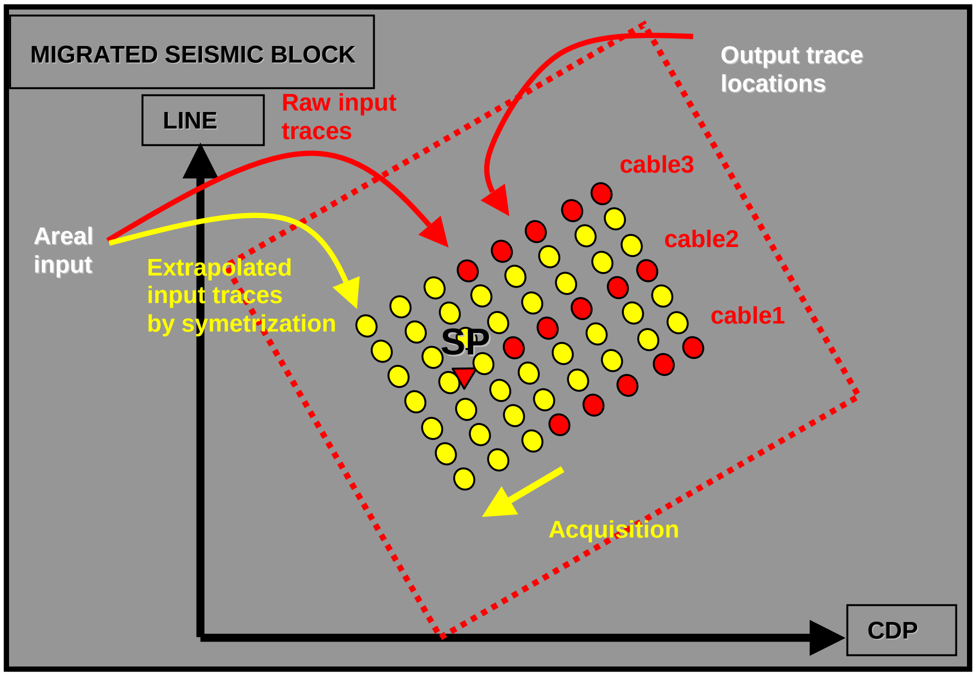

Figure 2 : The areal source record propagated into the migrated section is built by interpolating between streamers (f-x or RNMO), and by extrapolating the data ahead of the initial recording array (using the reciprocity theorem).

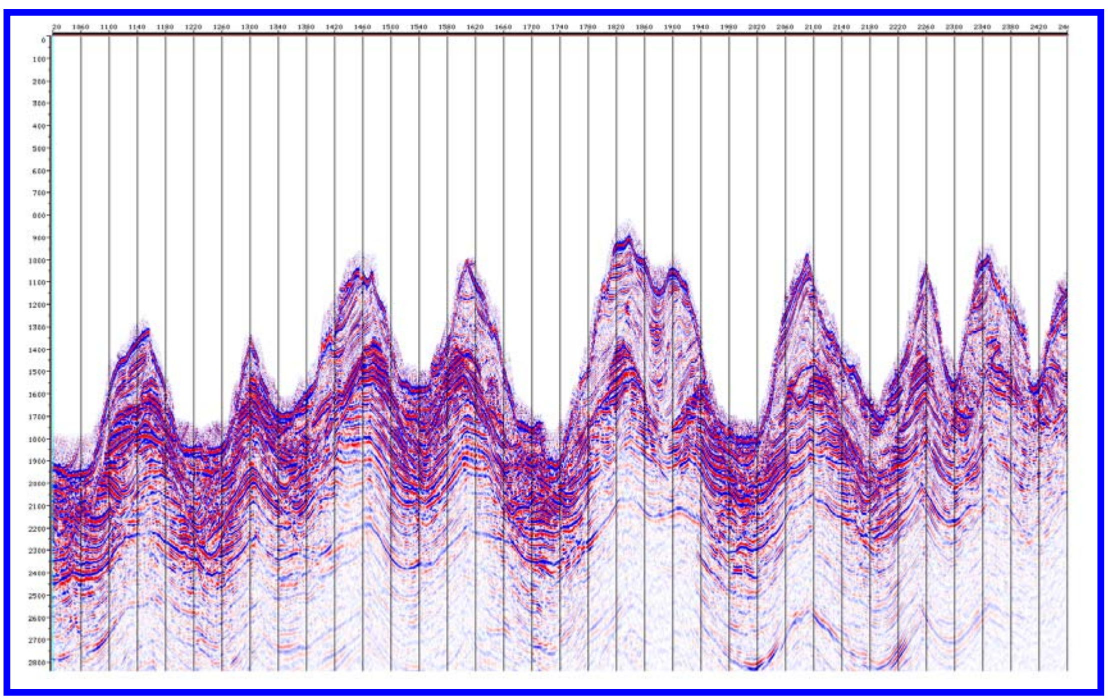

Figure 3 : This crossline section from the migrated seismic block illustrates the complexity and roughness of the sea floor from this Brazilian dataset processed with 3D SRMM. It is a submarine canyon environment where the bathymetry varies from 200 to 2000 meter depth inline.