Intelligent Adaptive Subtraction for Multiple Attenuation

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Summary

A lot of improvements have been seen in the last decade in 3D multiple modelling techniques, such as 3D Surface Related Multiple Elimination (SRME) and 3D wavefield modelling. These processes create accurate multiple models in terms of kinematics and amplitude. The main challenge now is to improve the subtraction of multiples, with a reduction in both residual multiple and primary leakage. This paper describes a new approach for multiple adaptive subtraction, which combines different techniques (least squares filtering in the time-space domain and curvelet-based subtraction) and improves primary preservation by using true multiple adaptive subtraction. The ultimate aim is to automatically get the best subtraction according to the complexity of the geology with minimum testing for the geophysicist.

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Introduction

The current processing flow for multiple suppression consists of two steps:
The first step consists of computing the multiple models which commonly uses 3D techniques such as 3D Surface Related Multiple Elimination (Berkhout et al., 1997) and/or 3D wavefield modelling (Pica et al., 2005). These techniques are either data driven (3D SRME) or use a reflectivity model (3D wavefield modelling) and provide very good multiple models. The kinematics are generally accurate (even for dipping events from a complex water bottom) due to improved algorithms and processing flows (i.e sea state, tidal and water column statics are accounted for). Moreover the amplitudes are becoming more realistic using 3D operators to better predict the amplitude decay on multiple models. These techniques are often combined in order to obtain an optimal representation of the total multiple field.
The second step consists of subtracting the multiple models from the data in order to get a multiple free dataset. This process can be very time consuming and complex in terms of testing, parametrization and QC. A number of technologies exist for this step, such as curvelet-domain subtraction and least squares filtering (LSF) in the time-space (TX) domain. These techniques can be applied in the common channel, shot, or common mid-point domain.

The adaptive subtraction process can be a very challenging process: the different technologies need to be compared, the domain of subtraction has to be tested or is often chosen for non-geophysical reasons (same as previous project, reduce number of data sorts, etc..) and finally the different parameters such as filter length, frequency sub-bands, time and space windows have to be tested. This process becomes longer and longer and is often one of the bottlenecks for processing projects.
Tackling the problem from the user side, we tried to define the ideal processing flow that will lead to a significant turn-around time reduction for the subtraction phase.
The three main user requests were the following:

1- combine least squares filtering in TX domain with curvelet subtraction (which are the two main techniques currently used in the industry).
2- ensure full primary preservation: compromising between primary preservation and multiple attenuation is a common practice for this processing step.
3- implement a more “local” subtraction (smaller time and spatial windows).

The algorithm we propose in this paper, named iSub (intelligent Subtraction), combines the best of current technologies in order to get the most effective demultiple result in different areas of the survey regardless of the data complexity. It is a 3D process specifically designed to use the most appropriate subtraction method to remove the multiple from the data while better preserving the primary energy.

Technical description

The most widely used adaptive subtraction method is least squares filtering (LSF). LSF operates locally in the TX domain and adapts the multiple model by convolving it with a filter designed using an L2-norm minimization. LSF is an effective method, but makes the assumption that multiple and primary events are orthogonal. In Liu et al. true multiple adaptive subtraction is introduced as a modified form of the LSF method, in which the assumption of orthogonality is relaxed. In the TX domain, the true multiple adaptive subtraction described includes an automated preparation step to extract the true multiples from the data. It is an iterative process: the 1st iteration is to get a mask of the primaries, using a severe L2 adaptive subtraction for instance. Applying the primary mask on the input data allows us to perform the 2nd iteration of L2 adaptive subtraction where the raw multiples models are adapted to the real multiple only (no primary interferences). The process can be iterated until an optimum primary preservation is obtained. Therefor the adaptive subtraction is performed on the true multiples, which leads to a better subtraction of the multiple model and minimal primary leakage.

In parallel to advancements in LSF-based subtraction, the curvelet transform has also emerged as a promising tool for adaptive subtraction in recent years. Curvelets have a number of useful properties that can be leveraged for adaptive subtraction purposes: 1. Curvelets provide a sparse representation of seismic events. 2. Events of differing dip, scale or TX location will often be well separated in the curvelet domain. In Nguyen et al. [2016] a curvelet-based algorithm was proposed, in which each coefficient of the multiple model is updated (scaled and rotated, subject to both global and local constraints) to more closely match the corresponding coefficient of the total data. In Nguyen et al. [2017] it is shown that coefficient updates can be better controlled using a dip map data structure. This is another iterative process which estimates at every location the primaries' dip map (dips at each samples in the curvelet scales) and the multiples' dip map. This information is used to control the adaptation level during the subtraction. The ratio between multiple and primary dip information will control the level of scaling of the modelled coefficient to match the data before being subtracted. In other words, if the multiple dip is stronger than the primary dip, the level of adaptation is stronger, and vice-versa. By this way, the curvelet adaptation will only remove residual multiples and being ineffective in areas where there are no multiple left.

The method is multi-dimensional, multi-scale and multi-model. Multiple models are very dependent on the acquisition geometry and data quality for the data driven methods, and on the reflectivity model and the velocity field for the 3D wavefield modelling. If one of the models is not accurate, this can lead to a sub-optimal subtraction result. With the new method, iSub overcomes this type of problem by leveraging a masking technology which uses only the more accurate multiple model (the more accurate multiple model has stronger weight in the adaptive subtraction than the other ones).

To summarize, the algorithm proposed in this paper is the result of a combination and generalization of the above-mentioned methods as follows:

1. True multiple adaptive subtraction is generalized to higher dimensions, by performing the LSF design process using multi-dimensional windows that manoeuvre in the T-X_1-X_2-…-X_n domain. This means that it is no longer necessary to choose one or other domain for the subtraction. Furthermore, the windows can be more localized, whilst retaining a sufficient number of traces for stable filter estimation.
2. The curvelet coefficients as described in Nguyen et al. [2017] is used as a mechanism for deciding whether the curvelet-based adaptation can improve on the result of step 1, or conversely will cause it to deteriorate (i.e. primary leakage). It thus provides a logical data flow component that automatically chooses the best result (at coefficient level granularity) between (generalized) true multiple adaptive subtraction and curvelet-domain adaptation.

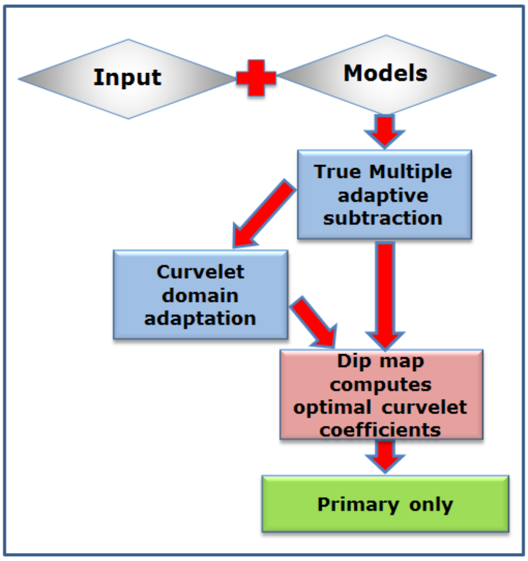

Figure 1 : *Workflow diagram showing the iSub application.*

Figure 1 is a workflow diagram describing the key steps of the iSub application. At first, the input data and multiple models are jointly used to derive masks and apply a multi-dimensional subtraction of the multiple models. Secondly, a curvelet subtraction is performed. The final and key step is to determine the optimal coefficient and keep the best of the two results.

The main achieved goals are the testing phase time reduction and to have a unique method which combines the more currently used adaptive subtraction algorithms (L2 in TX domain and curvelet). The final benefit is the 3D aspect of the method will allow to work on small windows (in time and space) and therefore getting a better multiple reduction.

Data example

In order to illustrate the benefit of the new iSub method, we choose a challenging deep water data with complex geology. 3D dual-sensor streamer acquisition in Ceara Fortaleza basin, offshore Brazil, has been selected for its very complex water bottom. Figure 2a shows the location of the survey acquired end 2015 and Figure 2b is an example of an inline showing the canyons at water bottom.

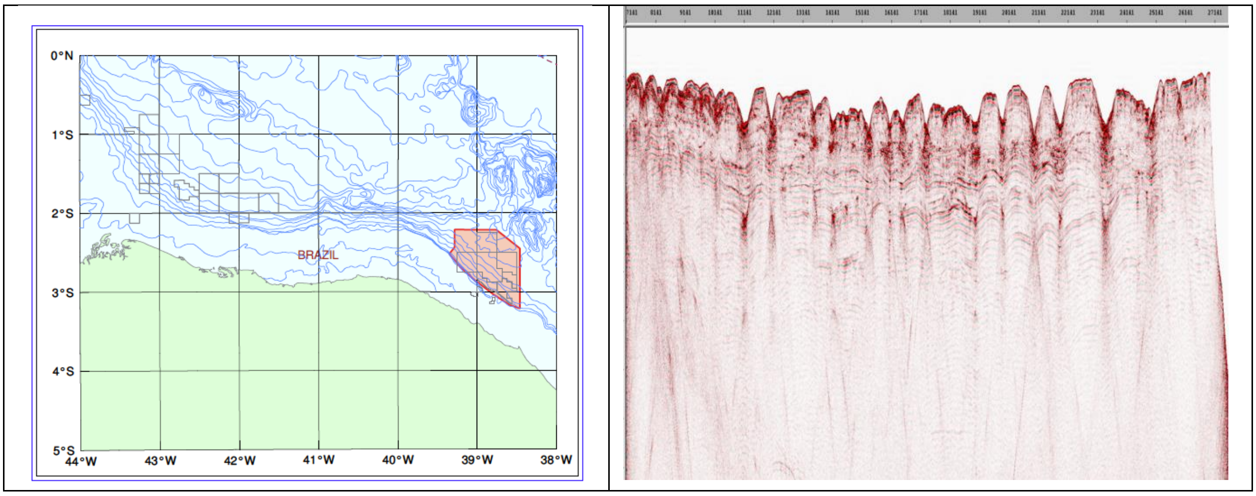

Figure 2: a, *Ceara Forteleza survey location map.* **b,** *Raw inline stack*

Figure 3 compares the results of the conventional multi-dimensional adaptive subtraction with the iSub application. It shows a zoom of the near stack (0-15^{o} angle of incidence mute) of the input data (**2a**), and the results using the conventional Least Square adaptive subtraction in the TX domain (**2b**), versus the new iSub algorithm (**2c**). The green arrows show where the new algorithm improves the subtraction in the complex multiple areas below the canyons.

The results shown on figure 3 have been obtained using identical parametrization. Figure 3d shows the amount of residual multiples removes with the new method. The uplift only comes from the new algorithm iSub which combines different subtraction techniques and primary preservation. Without additional testing, an improved reduction in residual multiples was noticed, and no difference was visible in area where the L2 adaptive subtraction was effective. Therefore the iSub method ensures that the quality of the subtraction is always better than the conventional approach.

Conclusion

The adaptive subtraction process can be very demanding for geophysicists mainly in terms of testing and choosing parameters. The new iSub application combines several innovative technologies aiming at reducing considerably the testing phase while enhancing the quality of the subtraction.
The curvelet coefficients allow combining the curvelet domain subtraction and the least square subtraction within the same application, and automatically find the best of the two algorithms. Using a

multi-dimensional, multi-scale and multi-model mechanism also enables us to get a more local subtraction.

Finally, by adapting the models to the true multiples we better preserve primary energy while improving the multiple attenuation.

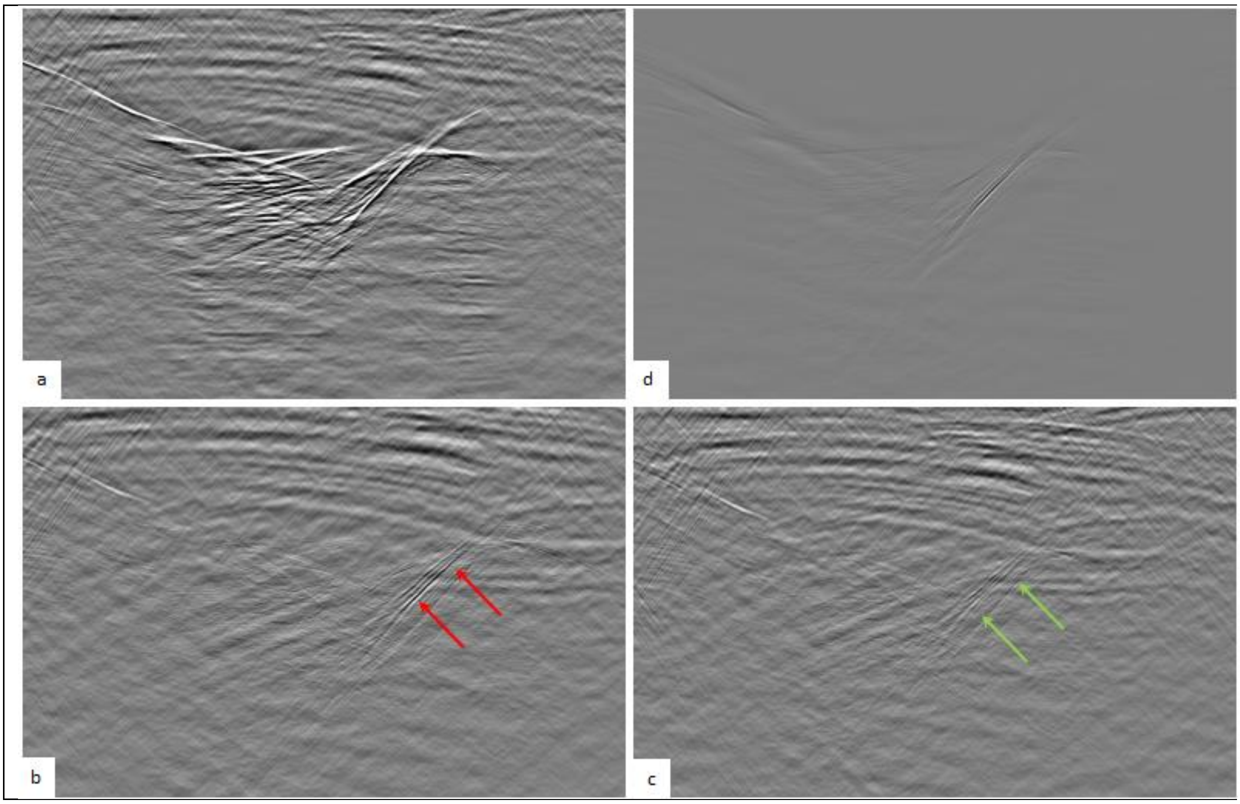

Figure 3: a, *Input near stack (*0-15° mute*).* **b,** *Near stack after standard least square TX subtraction.* **c,** *Near stack after the new intelligent subtraction using identical parametrization than figure b,* ***d****, difference between the conventional L2 adaptive subtraction and iSub.*

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