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Multiple attenuation using MultiFocusing technology

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Summary

The removal of multiples energy on seismic data has been a major issue on many datasets worldwide. The primary advantage of MultiFocusing (MF) is the enhancement of the signal-to-noise ratio of both stacked sections and prestack data through stacking a much larger number of traces than in conventional CMP processing. We present a modification of the MF-based approach when multiples are recognized directly in the MF attribute domain. First, they are predicted according to MF wavefront parameters and then they are subtracted using an adaptive least squares method.

The key elements of the proposed procedure are the MF attributes. We identify and predict the multiples in the MF attribute domain through interpretation of the RMS velocity and emergence angle panels, which are determined from the pre-stack data during the MF multidimensional analysis.

We then calculated the offset traveltimes for the multiples using the identified MF attributes and compute a multiple model based on the partial coherent summation of the original data along the predicted traveltime surfaces. For the final stage, we adaptively subtract the predicted multiples from the original data using a least squares adaptive subtraction procedure similar to SRME-type multiple attenuation methodology.

We presented a multiple attenuation methodology using MF applied on a real data example. The discussed procedure is valid and robust for surface-related multiples. Interbed multiples can also accurately be removed by this technology when they can be differentiated according to either RMS velocity or dip angle.

Introduction

Many of the time-domain operating methods belong to a group of techniques that can be characterized as macro-model independent methods. In particular, the MultiFocusing (MF) transformation involves stacking large super-gathers of seismic traces, each of which can span many common-midpoint (CMP) gathers. Stacking of large supergathers is made possible by the use of a generalized moveout correction. For a given source-receiver pair, in a 2-D case, this correction depends on three parameters: the wavefront curvatures of the normal wave, the normal incidence point wave, and the emergence angle of the normal ray. For each super-gather and each zero-offset time, T_0 these parameters are obtained through a coherence analysis of the moveout corrected supergather.

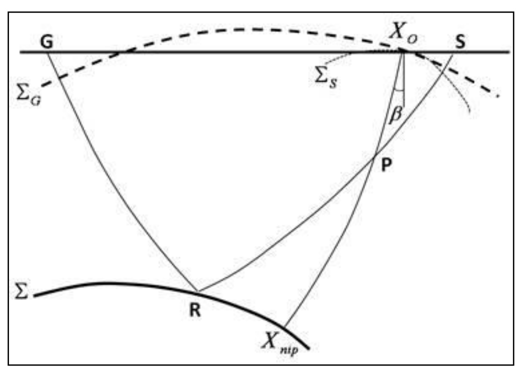

Figure 1. Ray scheme of MultiFocusing method.

The use of MultiFocusing for improved time imaging is widely published (Berkovitch et. al., 2008). At the same time, MultiFocusing can be considered as a method for wavefield analysis which reliably estimates wavefront parameters of each individual seismic event at each observation point. These wavefront parameters may have broad applications in seismic data processing and imaging.

In this paper, we present the use of the MultiFocusing technology for multiples attenuation. Multiple attenuation during data processing does not guarantee a 'multiple-free' final section. Although a great deal of effort has been invested in trying to resolve the problem of multiple-suppression (see detailed review in Weglein et. al., 2011), in cases of complex subsurface structure, the remaining multiples will be difficult to recognize, especially after the data have been migrated. In this context, methods that can recognize and attenuate residual multiples are of great importance to seismic processing and interpretation. Keydar et. al. (1998) proposed a method for multiple prediction based on the wavefront characteristics of the multiple generating primaries. These attributes can be estimated through an optimization correlation procedure similar to the one used in the MultiFocusing method. Examples of applications of this approach can be found in Keydar et. al. (1998) and Landa et. al. (1999a, 1999b).

Here we present a modification of the described MultiFocusing-based approach when multiples are recognized directly in the MultiFocusing attribute domain. First they are predicted by the MultiFocusing signal prediction algorithm and then they are subtracted using an adaptive least squares method.

Prediction and Suppression of Multiples

The proposed procedure is based on the estimation and analyses of the MultiFocusing attributes. They are determined from the prestack data in a multidimensional optimization procedure. The more accurate the MultiFocusing attributes, the better the results of the multiples attenuation. Therefore, we briefly describe the MultiFocusing method as well as physical interpretation of the MultiFocusing attributes (a detailed description of the method can be found in Berkovitch et. al., 1994, Gelchinsky et. al., 1999, Landa et. al., 2010).

MultiFocusing method

Let us first consider acquisition on a curved surface (Figure 1). The central ray starts at X_0 with an angle β to the vertical. It hits the reflector Σ at the normal incidence point X_{nip}, and returns to X_0. A paraxial ray from the source, *S* intersects the central ray at *P,* hits the reflector Σ at *R* and arrives back at the surface at the receiver location *G*. These two rays define fictitious focusing waves initiated at point *P*, namely, the upgoing wave front Σ_S, and the wavefront downgoing from point *P*, reflected by the reflector Σ, and emerging again at point X_0 with the wave front Σ_G. The traveltime difference between the paraxial ray *SRG* and the central ray $X_0\ X_{nip}\ X_0$ (MultiFocusing moveout) can be written as

$$\Delta\tau = \Delta\tau^{+} + \Delta\tau^{-}$$

Where

$$\Delta\tau^{\pm} = \frac{\sqrt{(R^{\pm})^2 + 2R^{\pm}\Delta X^{\pm}\sin\beta + \Delta X^{\pm 2}} - R^{\pm}}{V_0}$$

Here

$$R^{\pm} = \frac{1 \pm \sigma}{\frac{1}{R_{CEE}} \pm \frac{\sigma}{R_{CRE}}}$$

And σ is the so-called focusing parameter given by

$$\sigma = \frac{\Delta X^+ - \Delta X^-}{\Delta X^+ + \Delta X^- + 2\frac{\Delta X^+ \Delta X^-}{R_{CRE}}\sin\beta};$$

In the above equations, ΔX^+ and ΔX^- are the source and receiver offsets for a given ray with respect to the central ray, $R^{\pm}$ are the radii of curvature of the fictitious wave fronts Σ_S and Σ_G in the vertical plane, respectively, and v_0 is the near surface velocity which is assumed known and constant along the observation line.

Finally, R_{cee} and R_{CRE} denote the radii of curvature of the two fundamental wave fronts corresponding to the normal (CEE) wave and normal-incidence-point (CRE) wave, respectively. The CRE wave front is formed by a point source placed at the point where the zero-offset ray emitted from the central point hits the reflector. The wavefront of the CEE wavefront is formed by normal rays emitted by different points on the reflector (like in an "exploding reflector" scenario).

Most publications on MultiFocusing are mainly focused on the increased fold and the improved quality of the MultiFocusing section. However, MultiFocusing can obtain an increased number of wavefield parameters as compared to a conventional stacking velocity analysis. In fact the MultiFocusing parameters estimation can be considered as MultiFocusing transforms and can provide not only optimal wavefront parameters but also full distribution of these parameters in the parameter domain when semblance value plays the role of a probability function.

Multiples suppression with MultiFocusing attributes

A method for the identification and removal of multiples using wavefront characteristics was introduced by Keydar et al. (1998) and Landa et al. (1999). Their approach is the target-oriented 'Predict and Subtract' attenuation method, of which the objective is to remove multiples of any type (surface related, interbed or peg-leg). The multiples prediction algorithm is based on a simple but powerful concept: the timing of any multiple consists of segments that are primaries. To predict arrival time for a particular multiple, one should understand the segments of the multiple generating primaries. These segments should satisfy a so-called “multiples condition”: emergence angles of the upgoing and downgoing segments are identical. This condition is used to determine arrival times for multiple events, which are just simple arithmetic sums of the primary segments. Practically, this procedure requests the accurate estimation of emergence angles for primary-reflected events, which generate multiples for all source-receiver pairs along the seismic line and finding those traces that satisfy the multiples condition.

MultiFocusing can be used for this purpose because it efficiently estimates emergence angles for the normal ray and wavefront curvatures. After multiple times are predicted they can be subtracted in the parabolic $\tau - p$ domain (Landa et. al., 1999).

Alternatively, multiply prediction can be done directly in the domain of the MultiFocusing parameters. In many cases, the emergence of the angle β and radii of curvature R_{CRE} may be sufficiently different for primary and multiple reflections.

In this work, we chose to model the multiples using information obtained in the MultiFocusing transform domain. Instead of modeling multiples by inverse MultiFocusing transform as is done in other technologies, we compute a multiple model by using a prestack signal enhancement algorithm (Berkovich et. al., 2011).

The idea is to apply the MultiFocusing traveltime formula to compute new partially stacked traces, when each trace is the result of the summation of data along the MultiFocusing stacking surface. Prestack traveltimes of the multiples are calculated with the help of the MultiFocusing attributes of the identified multiples. The resulting traces should be located at the positions of the original ones for subsequent

subtraction. The algorithm for multiples modelling can be described as follows: according to estimated MultiFocusing parameters corresponding to multiple events, the partial MultiFocusing stack calculates a stacking surface around a specified CMP- offset location and performs the summation of data along that surface. The result of summation is assigned to the same CMP, offset, and time coordinates.
Repeating this procedure for all desired points generates a new gather that is the MultiFocusing-enhanced multiples model. Later this gather can be subtracted from the original gather by a least square adaptive subtraction method similar to how it is done in the SRME type multiples attenuation.

Example

We illustrate the presented method on real data. Figure 2 shows a MultiFocusing section before conventional $\tau - p$ (Radon) multiples attenuation. The target area of this line was imaging reflections below 3000 msec. including a syncline structure at about 3250 msec. Due to strong peg-leg multiple energy at the target times, primary reflections are practically invisible. The first step in the application of the MultiFocusing-based multiples suppression method is to trace the multiple events in the MultiFocusing attribute domain according to the computed R_{CRE} and β information. Next, based on the interpreted corridor for multiples, we compute multiples model seismograms by prestack partial summation along the predicted multiple arrival surfaces (MultiFocusing prestack signal enhancement). Offset traveltimes of the multiples are calculated using the MultiFocusing attributes (emergence angles and curvatures of the wavefronts) of the identified multiples. Resulting gathers mostly contain multiples energy. In the next step we subtract these multiple enhanced gathers from the original one. Figure 3 displays a new MultiFocusing section obtained from the gathers after multiples attenuation. Primary reflections at the target area including a syncline reflection at 3250 msec. are clearly seen. Multiples are successfully attenuated.

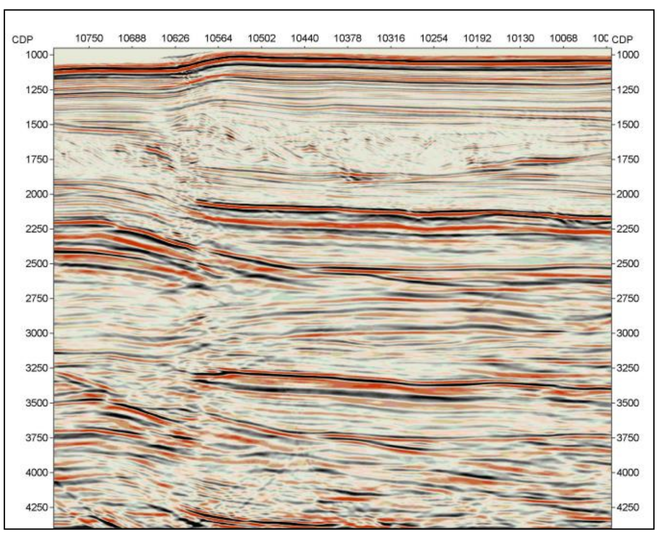

Figure 2. MultiFocusing section before multiples attenuation. Target area is below 3250 msec. Due to a strong peg-leg multiple energy primary reflections are practically invisible.

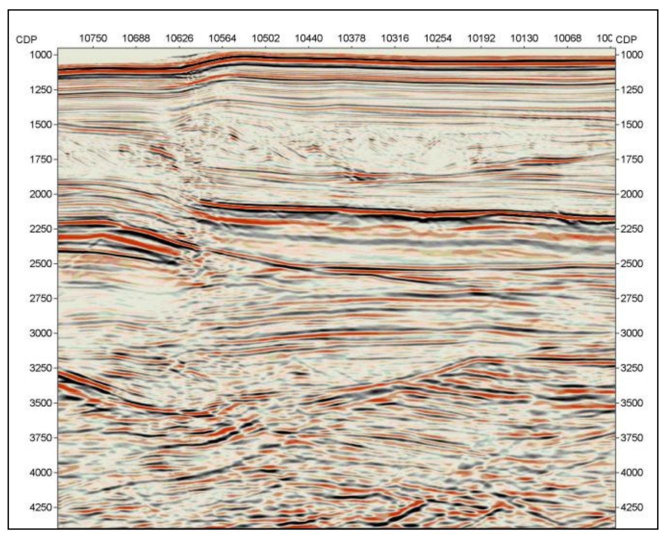

Figure 3. MultiFocusing section obtained from the gathers after multiples attenuation. Primary reflections within the target area below 3000 msec are clearly seen. Multiples are successfully attenuated.

Conclusions

We have presented an implementation of multiples attenuation which can be used within the MultiFocusing technology. The proposed procedure is valid for surface-related as well as for interbed types of multiples. It is robust and simple. It is easy to implement and it can predict all kinds of multiples defined in the MultiFocusing domain.

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