Integration geoConvention 2013 geoscience engineering partnership

Prestack signal enhancement by non-hyperbolic MultiFocusing

Evgeny Landa*, OPERA, Pau, France
evgeny.landa@univ-pau.fr ,
Alex Berkovitch, Geomage, Modi'in, Israel
alex@geomage.com
and
Kostya Deev, Geomage, Modi'in, Israel
kostya@geomage.com

Abstract

MultiFocusing technology can dramatically improve the quality of seismic imaging especially in cases of low fold data, poor signal- to- noise ratio and sparse 3D acquisition. At the same time, local parameters of the observed wavefield in prestack seismic records are of great interest for many seismic applications such as signal enhancement, velocity model building etc. We propose to employ the MultiFocusing idea to achieve this goal. A local common offset MultiFocusing approximation for traveltime stacking surface description is used. It allows accurately approximate traveltimes of seismic events in the vicinity of arbitrary offset. We present a signal enhancement scheme and demonstrate its efficiency.

Introduction

Time imaging usually constitutes a key first step in the seismic imaging workflow. For these reason, improving the quality of time imaging is a focus of intensive research. MultiFocusing (MF) is a method with the potential to greatly improve the quality of time imaging.

In contrast to the procedures of CMP-based methods, in the MF approach proposed by Berkovitch et al. (1994) and described in Berkovitch et al. (2008) and Landa et al., 2010, each zero-offset trace is constructed by stacking traces that need not belong to the same CMP gather but, rather, whose sources and receivers are within the limits of a certain aperture in the vicinity of the central (imaging) point. The size of such an aperture is determined by the size of the first Fresnel zone. The number of traces falling in this zone can significantly exceed the number of traces belonging to one CMP gather. This allows a considerable increase in the signal-to-noise ratio for the target reflection. Since the traces being stacked no longer belong to the same CMP gather, this procedure requires a more general moveout correction than the one used in conventional CMP stacking. For a given source-receiver pair, the MultiFocusing moveout equation is based on the spherical approximation of the reflection event's wavefront near the observation surface. The moveout correction expressed by the zero-offset MultiFocusing (ZOMF) formula is, in 2D case, a three-parameter surface which accurately approximates the actual traveltime in the vicinity of the imaging point. The three parameters are: the emergence angle of the normal ray β and the radii of curvature Rcre and Rcee of the two fundamental wavefronts, namely, normal incident point and normal waves respectively. One of the main limitations of the ZOMF method is a quasi-hyperbolic approximation for travel-time surfaces. The operator in this case is constructed around a zero-offset ray and, in principle, is valid for short offsets. The idea of using accurate traveltime approximation for prestack signal enhancement is not new. Both MultiFocusing and common reflection surface stack (CRS) can be used for this purpose (Baykulov and Gajewski, 2009, Buzlukov et al., 2010). But the global, quasi-hyperbolic zero-offset operator used in these methods limits the efficiency of this application for cases of complex geology and/or strong lateral velocity variations. In these cases, the traveltimes of seismic events become non-hyperbolic and MF/CRS zero-offset operator approximation starts to be inaccurate. Similar effects can be caused by anisotropy or large offsets. The proposed COMF procedure is free of this limitation due to a local character of the new common-offset correction and separate processing for each desired offset.

In this paper, we introduce a generalization of the ZOMF correction for the arbitrary offset case. We refer to this new time correction as common-offset MultiFocusing (COMF). There are a number of possible applications of the COMF such as non-hyperbolic time imaging, prestack signal enhancement, AVA, velocity model building etc. We illustrate prestack signal enhancement in case of non-hyperbolic arrival traveltimes for reflected events.

Common-offset MultiFocusing correction

One of the main limitations of the ZOMF method is a hyperbolic approximation for actual travel-time surfaces. To increase the accuracy of the MF approximation and to take into account non-hyperbolicity of the traveltime surfaces, we introduce a local MF time correction for an arbitrary non-zero-offset trace. Figure 1 illustrates schematically the new method.

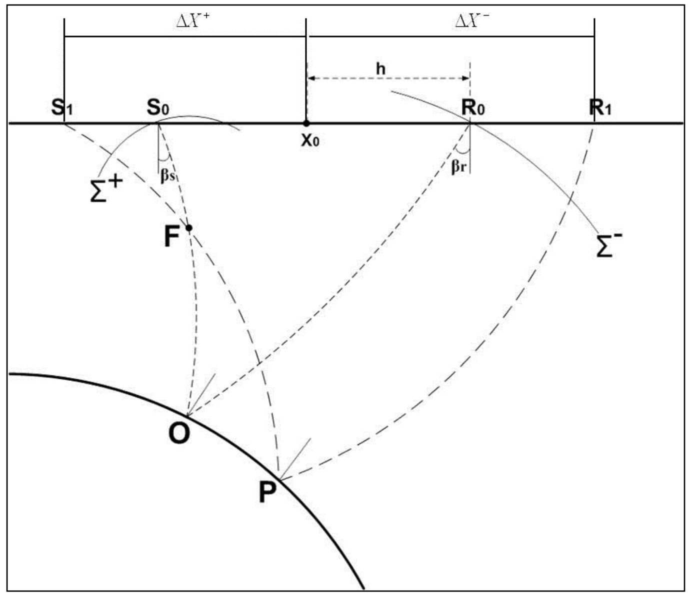

Figure 1. Schematic representation of the common-offset multifocusing.

A ray which we call central starts at the surface point S_0, and the emergent angle β_s to the vertical. This ray hits the reflector at the point, O, and returns back to the surface point R_0 and the emergence angle β_r. This pair of rays belongs to a CMP point located at X_0 and half offset h. A paraxial ray starts from an arbitrary source S_1 located at distance ΔX^+ from the middle point X_0, crosses the central ray S_0O at point F and arrives at receiver R_1 located at distance ΔX^- after reflecting at point P. Wavefront parameters, namely, curvatures and emergence angles for different waves propagating along the rays, can be computed using dynamic ray-theory fundamental solutions (Červený et al., 2001).

Let us consider two fictitious wavefronts: Σ^+ emitting from the point F upward to the surface, and Σ^- emitting from the point F downward, reflected at the reflector and emerging at the point R_1. These two fictitious wavefronts are characterized by two radii of curvatures R^+ and R^-. The common-offset Multifocusing (COMF) establishes connection between two fictitious waves Σ^+ and Σ^- and dynamic parameters of the common offset ray S_0OR_0, namely, radii of curvature of the common shot R_s, common receiver R_r and geometrical spreading function L. The travel time correction Δt in this case can be written as:

$$\Delta t = \frac{\sqrt{(R^+)^2 + 2\sin\beta_s R^+ \Delta X^+ + (\Delta X^+)^2} - R^+}{V_0} + \frac{\sqrt{(R^-)^2 - 2\sin\beta_r R^- \Delta X^- + (\Delta X^-)^2} - R^-}{V_0}.$$

where V_0 is a near surface velocity, and

$$R^+ = \frac{1+\sigma}{\dfrac{1}{R_1^+} + \dfrac{\sigma}{R_2^+}}, \qquad R^- = \frac{1-\sigma}{\dfrac{1}{R_1^-} - \dfrac{\sigma}{R_2^-}}$$

$$\frac{1}{R_1^+} = \frac{1}{2L} + \frac{1}{R_s}, \qquad \frac{1}{R_2^+} = -\frac{1}{2L} + \frac{1}{R_s}$$

$$\frac{1}{R_1^-} = \frac{1}{2L} + \frac{1}{R_r}, \qquad \frac{1}{R_2^-} = -\frac{1}{2L} + \frac{1}{R_r}$$

and focusing parameter σ can be derived solving the following system of equations

$$\Delta X^+ = \frac{(1+\sigma)}{\cos\beta_s} Y + \frac{\sin\beta_s}{\cos^2\beta_s}(1+\sigma)\left(\frac{1}{R_1^+} + \frac{\sigma}{R_2^+}\right)^2 Y^2$$

$$\Delta X^- = \frac{(1-\sigma)}{\cos\beta_r} Y + \frac{\sin\beta^-}{\cos^2\beta_r}(1-\sigma)\left(\frac{1}{R_1^-} - \frac{\sigma}{R_2^-}\right)^2 Y^2$$

where *Y* is the so-called asymmetrical coefficient.

The travel time correction for arbitrary surface CMP position and offset *h* (Figure 1) is a function of observation geometry, near surface velocity and 5 unknown parameters: β_s, β_r, R_s, R_r, L.

COMF traveltime formulas provide an adequate representation of arrival times for a ray pair with arbitrary source-receiver configuration. The COMF correction formula is remarkably accurate even for strongly curved reflectors. The moveout correction is an appropriate basis for the common-offset stacking procedure, as it can align seismic events in a vicinity of an arbitrary central ray. Implementation of the COMF method is technically challenging because it requires defining five moveout parameters in 2D for each time sample of the common-offset image. Estimation of optimal parameters consists of calculating a correlation measure (e.g., semblance) as a function of unknown parameters, and choosing an appropriate correlation maximum. The parameters are estimated for each imaging point, for each offset and for each time sample. It is important to note that the described procedure is applied locally within a small vicinity of each seismic trace and does not require global full offset approximation. In this way, we avoid hyperbolic or quasi-hyperbolic approximation for traveltime curves/surfaces as it is usually required in many conventional time imaging procedures such as CMP, PSTM, ZOMF, etc. Output of the COMF is partially stacked common-offset sections and optimal wavefront parameters (emergency angles and curvatures).

Enhanced seismic gathers

The signal enhancement procedure consists of two steps: parameter estimation for each defined trace on each common offset section, and then, according to the estimated parameters, the partial stack calculates a stacking time surface around a specified surface location and performs summation of data along that surface. The result of the summation is assigned to the same surface location, offset, and time coordinates. Repeating this procedure for all desired points generates a new gather that is called the COMF enhanced gather.

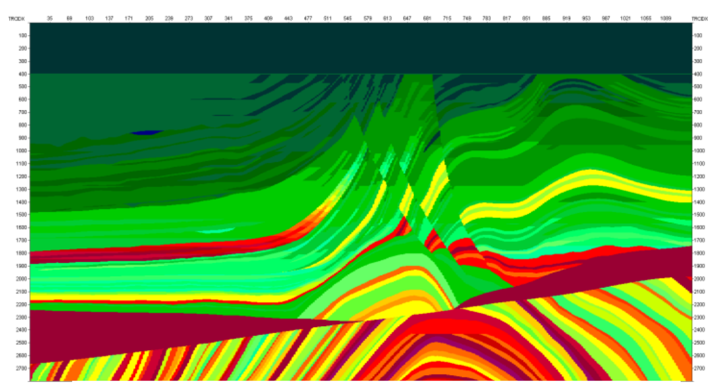

Figure 2a. Synthetic Marmousi-type model.

Figure 2b illustrates a synthetic CMP gather computed for a Marmousi-type model shown in Figure 2a. Seismic events at about 2.5-3.5 sec are characterized by strong non-hyperbolic arrivals due to a strong velocity anomaly in the model. Figure 3a shows the same CMP gather after applying zero-offset MF signal enhancement when the enhancing operator was estimated using zero-offset MF approach. As it was expected, a non-hyperbolic part of the events was deteriorated by non coherent summation along hyperbolic operator defined by ZOMF. Figure 3b shows the gather after applying COMF signal enhancement. A partial stacking operator was developed through estimation of five parameters for each CMP position, each offset value and each time sample. Aperture for estimation was 125m in CMP direction and 250m in offset direction. The resulting gather shows perfect reconstruction of the non-hyperbolic part of the gather.

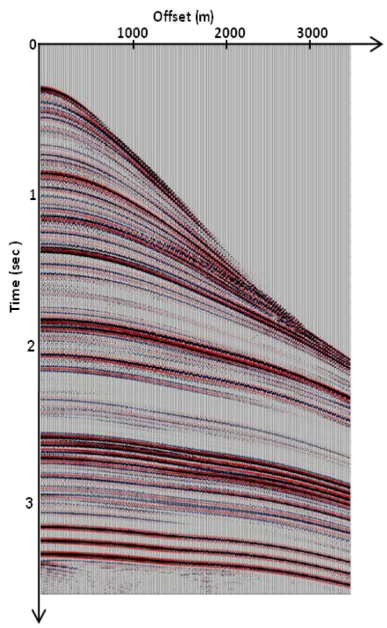

Figure 2b. Original CMP gather. Strongly non-hyperbolic in the deep part

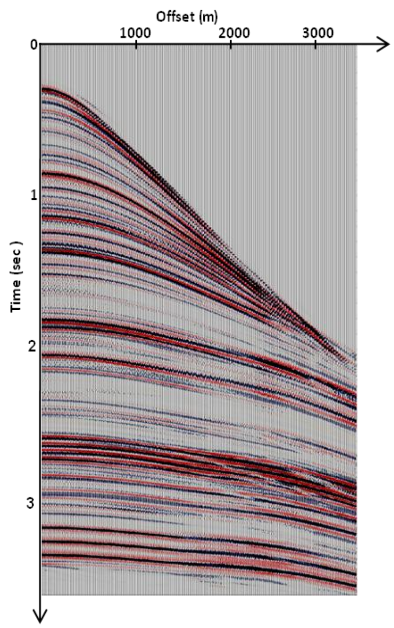

Figure 3a. The same CMP gather as shown in Fig. 2b after ZOMF signal enhancement. Events in the deep part are deteriorated.

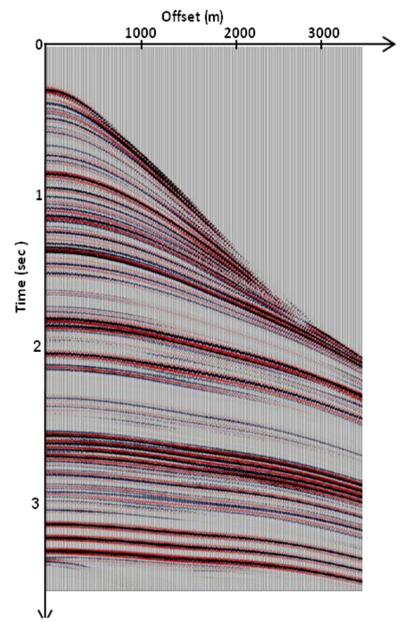

Figure 3b. The same CMP gather as shown in Fig. 2b after COMF signal enhancement. Deep events are perfectly reconstructed.

To illustrate correctness and efficiency of our procedure we performed prestack depth migration using original data with random noise added and both sets of the enhanced gathers for the true velocity model.

Figure 4a shows the PSDM result using the original gathers. Figure 4b is a depth section obtained from gathers enhanced by the zero-offset MF operator and Figure 4c illustrates the PSDM section using the COMF operator. As it was expected, differences between the two images appear at places where the arrival traveltimes on the original gathers are strongly non-hyperbolic.

Conclusions

Common-offset MultiFocusing provides an efficient way for model independent prestack signal enhancement which can improve imaging in cases of low signal to noise ratio and non-hyperbolic movouts. The method is based on a local MultiFocusing approximation for locally coherent seismic events and allows, for each trace and each time sample, an accurate estimation of the wavefront parameters (curvatures, geometrical spreading and emergence angles in shot and receiver domains). We have presented and illustrated prestack signal enhancement

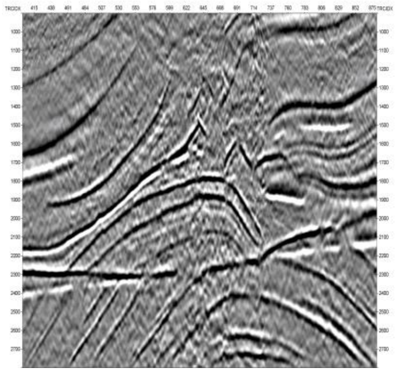

Figure 4a. PSDM image obtained from the original gathers with random noise.

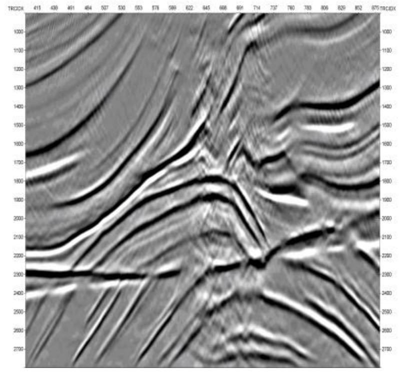

Figure 4b. PSDM image obtained from the ZOMF enhanced gathers. Places of non-hyperbolic traveltime surfaces are deteriorated.

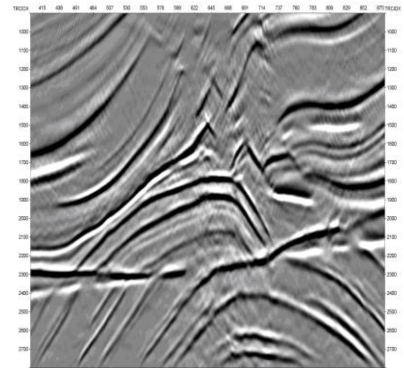

Figure 4c. PSDM image obtained from the COMF enhanced gathers. The image is very close to the correct one shown in figure 4a.

References

Baykulov, M. and Gajewski, D. [2009] Prestack seismic data enhancement with partial common-reflection-surface (CRS) stack, Geophysics, 74, V49-V58.

Berkovitch, A., Gelchinsky, B., and Keydar, S. [1994] Basic Formula for MultiFocusing Stack. *56th EAGE Conference and Exhibition*. Expanded Abstracts.

Berkovitch, A., Belfer, I., and Landa, E. [2008] Multifocusing as a method of improving subsurface imaging, The Leading Edge, 2, 250-256.

Buzlukov, V, Baina, R, and Landa. [2010] Prestack Data Enhancement Using Local Traveltime Approximation. *72nd EAGE Conference and Exhibition ,* Extended abstract

Červený, V. [2001] Seismic ray theory. Cambridge University Press.

Landa E., Keydar, S., and Moser, T.J. [2010] MultiFocusing revisited - inhomogeneous media and curved interfaces. Geophysical Prospecting, 58, 925–938.