Macro-model independent migration to zero offset (CRS-MZO)

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Abstract

The Common-Reflection-Surface (CRS) stack is a well-established time imaging method that provides high quality stacks of three or two-dimensional seismic data, and important kinematic wavefield attributes, i.e. the emergence angle of the normal reflection ray, and also the radii of curvatures of the normal incidence point (NIP) and of the normal (N) waves. In the present work, we adapt the CRS stack approach for a situation of diffraction points. The obtained formalism is called Common-Diffraction-Surface (CDS) stack operator, which is successfully used to migrate multi-coverage seismic data to zero-offset sections (MZO) without knowledge of a macro-model. Like CRS method the CDS stack is defined by a second order (hyperbolic) paraxial traveltime approximation that depends on two wavefield attributes: The emergence angle of the normal ray and the radius of curvature of the NIP wave. Because the CDS stack operator depends on the kinematic wave attributes obtained from the CRS stack, only few additional computational efforts are necessaries to build the MZO sections. The so-called CRS-MZO approach presented in this paper is successfully applied to the 2-D Marmousi synthetic seismic data.

Introduction

The 2-D CRS method was presented for the first time by Müller (1998) and Müller (1999), as an alternative seismic stack process to the conventional Common-Midpoint and Dip-Moveout (CMP/DMO) method. By the 2-D CRS stack, it is simulated a zero-offset (ZO) seismic section without knowledge of a macro-velocity model. We can also obtain four panels with three kinematic wavefield attributes (CRS parameters) and the semblance values.

The three CRS parameters are the emergence of the reflection normal ray β_o, and the radii of curvatures of the NIP and N waves R_{NIP} and R_N, respectively. In order to determine the CRS parameter, Müller (1998) used a parameter search strategy by which the initial three CRS parameters are estimated by one-parametric search performed on CMP and ZO stacked sections. The final search of the CRS parameters is done in the multi-coverage data domain by using the Nelder-Mead optimization algorithm. Other contributions in the development of optimization strategies for estimating the CRS parameters can be found in Birgin et al. (1999), Mann (2001), Jäger et al. (2001), and Garabito et al. (2001).

In this paper, we present a macro-model independent MZO that is based on a special case of the CRS stack, so-called CRS-MZO approach. For that, the CRS hyperbolic paraxial traveltime approximation is tailored for a situation of diffraction points giving as result the CDS stack formalism. By using the CDS stack we develop a new migration to zero offset (CRS-MZO) method to simulate ZO (stacked) sections from multi-coverage seismic data. The 2-D CRS-MZO approach depends on two CRS parameters: the emergence angle of the normal ray β_0, and the radius of curvature R_{NIP}, of the NIP wave. We employ a simulated annealing (SA) algorithm (see, e.g., Kirkpatrick et al. 1983; Corana et al. 1987) as a global optimization scheme to estimate the two CRS parameters β_o and R_{NIP} from the multi-coverage seismic data at each sample point of the ZO section. As result of the CRS-MZO process we have a simulated ZO section, and three panels with the maximum coherence values, emergence angles β_0, and radius of curvature R_{NIP}, respectively.

Method

CRS stack traveltime approximations

The 2-D CRS stacking surface can be derived by means of paraxial ray theory (Schleicher et al. (1993)). It approximates the finite-offset reflection traveltime in the vicinity of a fixed normal ray, generally called central ray. That ray is specified by its emergence point, $x_0\beta_0$, called the central point and generally taken as a certain CMP along the seismic profile. The two-way traveltime of the ZO central ray that pertains to x_0 is denoted t_0. A given point, $P_0 = (x_0, t_0)$, in the output ZO section is constructed by stacking along the following CRS traveltime surface (Tygel et al., 1997)

$$t^2(x_m, h) = \left[t_0 + \frac{2\sin\beta_0}{v_0}(x_m - x_0)\right]^2 + \frac{2t_0\cos\beta_0}{v_0}\left[\frac{(x_m - x_0)^2}{R_N} + \frac{h^2}{R_{NIP}}\right]. \quad (1)$$

As indicated above, x_0 and t_0 denote the emergence point of the normal ray on the seismic line, the central point, and its ZO traveltime, respectively; x_m and h are midpoint and half-offset coordinates: $x_m = (x_s + x_r)/2$ and $h = (x_s - x_r)/2$, where x_s and x_r are the coordinates of the source and receiver along a straight line profile in the acquisition surface.

The seismic line is considered to coincide with the horizontal cartesian coordinate axis, x, along which x_s, x_r and x_0 are specified. The point $P_0(x_0, t_0)$ in the ZO section to be simulated is the output position of the stacked seismic amplitudes with formula (1).
In case the reflector element collapses into a diffractor point, the NIP and Normal wavefronts coincide. As a consequence of $R_{NIP} = R_N$, formula (1) reduces to

$$t^2(x_m, h) = \left[t_0 + \frac{2\sin\beta_0}{v_0}(x_m - x_0)\right]^2 + \frac{2t_0\cos\beta_0}{v_0}\left[\frac{(x_m - x_0)^2 + h^2}{R_{NIP}}\right]. \quad (2)$$

The traveltime approximation from equation 2, called Common-Diffraction-Surface (CDS) stack operator, was used to simultaneously estimate the two parameters β_0 and R_{NIP}, as a first step of the CRS parameter estimation strategy (Garabito et al., 2001). In this work, the pair of CRS parameters (β_0, R_{NIP}) will be refered as NIP-wave parameters.

An application of the traveltime approximation (equation 2) for pre-stack time migration, was presented in Mann et al. (2000). Garabito et al. (2006) used the same formula (equation 2) to get a pos-stack Kirchhoff type depth migration. This second-order CDS stacking surface is now used to simultaneously estimate the two parameters, β_0 and R_{NIP} , and apply a limited aperture CRS-MZO.

CRS-MZO optimization strategy and algorithm

To determine the three CRS NIP-wave parameters from prestack data, we could use a similar multi-step search strategy as proposed in Jäger et al. (2001). We use instead a simulated annealing (SA) algorithm, Corana et al. (1987), in this work to solve the two-dimensional global optimization problem to find the pair of parameters (β_0, R_{NIP}) that produce the largest coherence value. This optimization strategy uses multicoverage prestack seismic data as input and equation 2 to define the stacking surface. To start the SA algorithm, the SA algorithm uses random values generated from a priori defined intervals ($90^o \geq \beta_0 \leq +90^o$ and $0 < R_{NIP} < 1$) into which the NIP-wave parameters will be searched. As a result of this procedure, we obtain the optimized NIP-wave parameters for a given ZO point $P_0(x_0, t_0)$. Based on the described global optimization strategy to search the NIP-wave parameters, we propose a three-step algorithm to simulate a ZO section by CRS-MZO.

Step I : Parameter search

For one point $P_0(x_0, t_0)$ of the ZO section to be simulated, at least one pair of NIP-wave parameters (β_0, R_{NIP}) are searched from the multicoverage prestack seismic data of one super-bin by applying the described optimization strategy.

Step II : CDS-MO-MM stack

For one pair of NIP-wave parameters (β_0, R_{NIP}) associated to the point P_0, a multi-offset (MO) and multi-midpoint (MM) stack along the CDS traveltimes from equation 2 is applied to the prestack data of the selected super-bin.

Step III : CDS-ZO-MM demigration

For the same pair of NIP-wave parameters (β_0, R_{NIP}) associated to the point P_0, a ZO-MM demigration using the CDS traveltime approximation from equation 2 with $h = 0$ is applied on the stacked sample value, the result of step II. In order to handle events with conflicting dips at P_0, the steps II and III are repeated for all the remaining searched NIP-wave parameter pairs associated to that point. Finally, the search, the stack, and the demigration from the steps I, II, and III are repeated for all the remaining points P_0 of the ZO section until the CRS-MZO section is complete.

Synthetic data examples

To validate the performance of the CRS-MZO, we apply this approach to the well-known Marmousi synthetic dataset (Bourgeois et al., 1991). The Marmousi experiment was computed on a model with highly complex structures and tectonically realistic distribution of reflectors, and it has strong velocity gradients in both vertical and horizontal directions. Therefore, this dataset is a great challenge for any imaging method based on hyperbolic moveout.

The CRS-MZO stack proposed here is fully automatic, namely no user interaction is required. In addition, the Marmousi multicoverage data was not submitted to any pre-processing before applying the CRS-MZO approach. In Figure 1 the top section is the result of the CDS-MO-MM stack, and the middle section of same figure is the result of the complete CRS-MZO approach. After applying the complete CRS-MZO approach is improved the resolution of conflicting dips and diffractions. For reasons of comparison, we processed the Marmousi data also running conventional NMO/DMO processing (bottom section of Figure 2). By comparing the results, it is easily verified that the CRS-MZO stack resolves better strongly dipping events especially in the deeper part of the Marmousi model. The CRS-MZO application shows also clearer events in the central and shallow part of the section at places where the NMO/DMO events are generally blurred. This provides a good indication that the CRS-MZO, which in contrast to NMO/DMO is valid for general heterogeneous media can help to improve the image in tectonically complex areas.

Conclusions

The CRS-MZO method is introduced as a multi-offset multi-midpoint diffraction stack followed by a zero-offset demigration. The diffraction stack and demigration operators are both derived from the general CRS formula by assuming diffraction points at the endpoints of the central rays. The CRS-MZO is like the CRS stack a fully automatic time imaging method. The needed imaging parameters are searched by a one-step search approach using a global optimization scheme.

CRS-MZO is, in contrast to DMO, valid for generally heterogeneous media. The robustness of this technique in complex media is demonstrated using the Marmousi model. The CRS-MZO shows a better continuity of strongly dipping events particularly in areas of abrupt lateral velocity variation.

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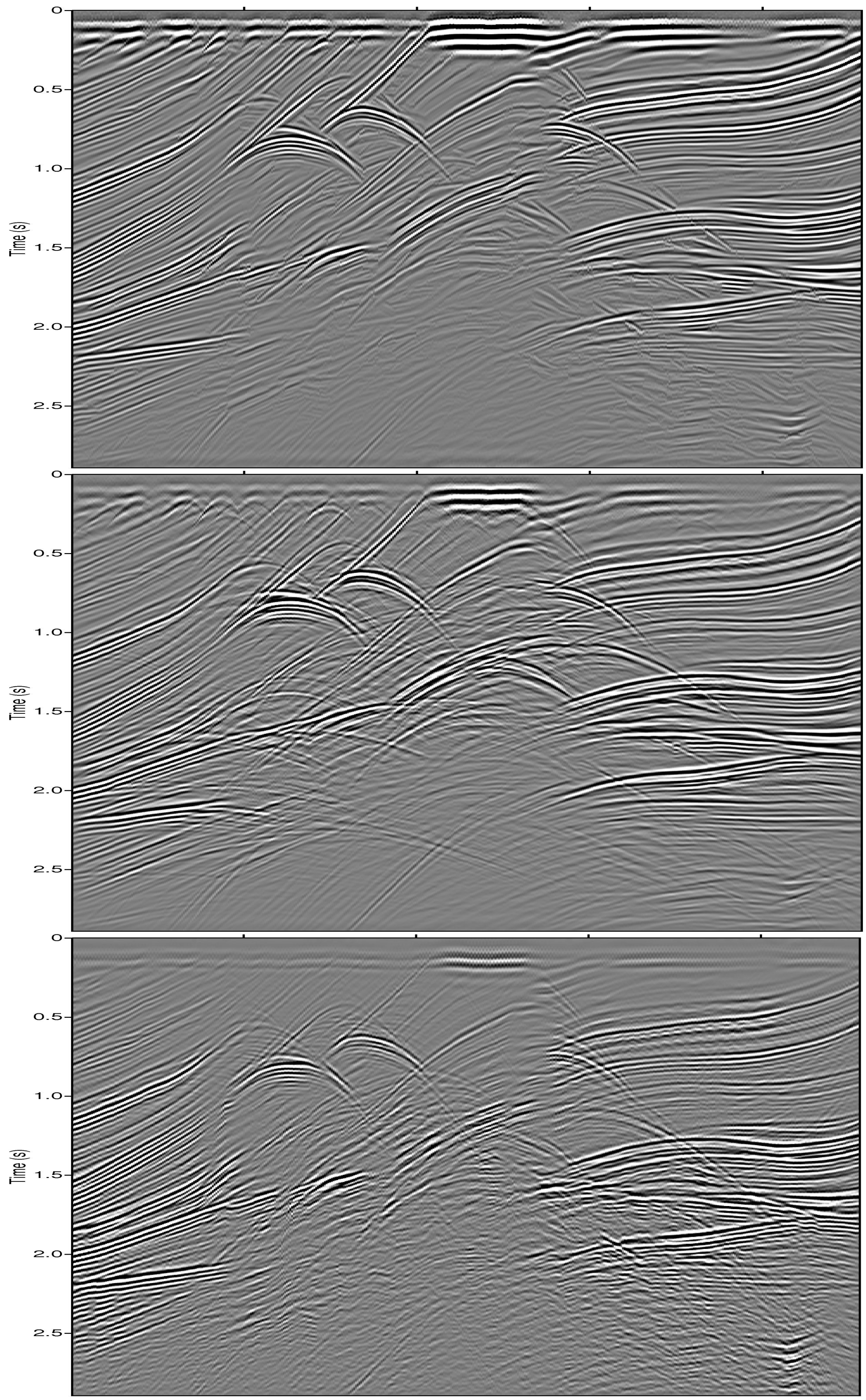

Figure 1 - *Simulated ZO sections from Marmousi dataset: Top) Result of the first step of the CRS-MZO approach. Middle) Result of the second step of the CRS-MZO approach. Bottom) Result of the NMO/DMO stack method.*