Global optimization of the common-offset CRS-attributes: Synthetic and field data application

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Abstract

The common-reflection-surface (CRS) stack method produces, in 2D, a zero-offset (ZO) section from multi-coverage seismic data. The ZO-CRS stacking operator is defined by hyperbolic traveltime approximation that depends on three kinematic attributes, which are determined from pre-stack data by means of an optimization processes based on the coherence measure (semblance) of the seismic signal. The ZO-CRS stack method achieved high-quality ZO stacked sections from noisy data and structurally complex media. The CRS method can also be applied for simulating any common-offset (CO) stacked section from multi-coverage data, but in this case the stacking operator called CO-CRS depends on five kinematic attributes. Those attributes have several applications; they can be used for velocity model determination, time or depth migration, for stacking PP waves and PS conversions from multicomponent data and others. The main challenge problem of the CO-CRS stack method is the determination of the five attributes from pre-stack data by means of an automatic search processes. Usually those attributes are searched for in several consecutive steps, but in this work we search the five attributes simultaneously by applying the very-fast-simulated-annealing (VSFA) global optimization algorithm. We present the preliminary results of the CO-CRS stack to simulate a CO stacked section from Marmousi and real land datasets.

Introduction

The 2D CRS stack method introduced by Müller (1998) and Jäger et al. (2001) provides a ZO stacked sections from multi-coverage seismic data, without the requirement of a priori known velocity model. In Mann (2001) the stacking velocity is used as a guide function in the automatic search processes of the CRS attributes. Several successful applications of the CRS stack method to real datasets can be find in the seismic literature, turning it into an alternative to the conventional stacking methods.

Considering a heterogeneous media, the CRS stacking operator is defined, in midpoint and half-offset coordinates, by a second-order paraxial hyperbolic reflection traveltime approximation in the vicinity of the ZO central ray (Tygel et al. (1997); Höcht et al., (1999)). In other words, the CRS stacking operator approximates ZO reflection events in the vicinity of a ZO central ray. In 2D, the so-called ZO-CRS stacking operator is parameterized by three kinematic CRS-attributes.

As a generalization of the ZO-CRS stack method it was introduced in Zhang et al., (2001) and Bergler et al., (2001) a new hyperbolic traveltime approximation, parameterized by five kinematic attributes. This traveltime approximation defines a stacking operator for simulating any CO stacked section from multi-coverage dataset. The CO-CRS stacking operator approximates finite-offset (FO) reflection events in the vicinity of a given FO central ray. This CO stacking method has been applied for stacking primary reflection of PP or SS waves or converted PS or SP waves.

In general, the CRS stack method needs the determination of the kinematic CRS-attributes from the pre-stack data through an automatic search processes based on coherence measure (semblance) of the seismic signal. This optimization problem can be solved by means of applying a multidimensional global optimization algorithm. In general, to find the global optimum is a difficult task and time consuming, and it is strongly dependent of the behavior of the objective function. For optimization of the CRS-attributes, the used objective function is the coherence measure of the seismic signals (semblance), which is a multimodal function and too expensive to be evaluated.

For the 2D CRS stack, in order to avoid the time consuming and computationally expensive global optimization, Zhang et al., (2001) determined the five CRS-CO attributes in several automatic search processes, using single well-known seismic configurations gathers. The CMP gather is used to determine two attributes; subsequently they are applied to obtain the CO stacked section by using only the CMP gathers. In the CO CMP stacked section other two attributes are determined by means of one-parametric searches. Finally, the remaining fifth parameter is determined in the CS gather. All five parameters are used for stacking the data along a full CO-CRS stacking operator, and by repeating this procedure for all samples the CO stacked section is simulated.

In this work, we present a one-step optimization scheme to determine simultaneously the CO-CRS-attributes and to simulate a CO stacked section using the full CO-CRS staking operator. As in Garabito et al., (2012), we apply the VFSA global optimization algorithm to search simultaneously for all five CO-CRS-attributes. The objectives of this work are to calibrate the VFSA algorithm to search efficiently the five attributes and to apply this approach in stacking converted reflection waves, that is, to extract from multi-coverage land data the CO stacked section of PP and PS reflections. As a preliminary result, we present a simulation of CO staked section from the Marmousi synthetic pre-stack dataset with added random noise. Finally, we apply the CO CRS stack method to simulate a CO stacked section from a real land dataset.

CO CRS traveltime

For 2D, Zhang et al. (2001) introduce a hyperbolic traveltime approximation for paraxial rays related to a finite-offset central ray. Figure 1 shows the paraxial ray and central ray. The hyperbolic formula calculates the primary reflection traveltime for any source-receiver positions ($\bar{x}_S$, $\bar{x}_G$) in the vicinity of known finite-offset reflected central ray (x_S , x_G). It reads

$$
\begin{aligned}
T^2(\Delta x_m, \Delta h) = {} & \left[t_0 + \left(\frac{sen\,\beta_G}{v_G} + \frac{sen\,\beta_S}{v_S} \right) \Delta x_m + \left(\frac{sen\,\beta_G}{v_G} - \frac{sen\,\beta_S}{v_S} \right) \Delta h \right]^2 \\
& + t_0 \left[(4K_1 - 3K_3) \frac{cos^2\,\beta_G}{v_G} - K_2 \frac{cos^2\,\beta_S}{v_S} \right] \Delta x_m^2 \\
& + t_0 \left[K_3 \frac{cos^2\,\beta_G}{v_G} - K_2 \frac{cos^2\,\beta_S}{v_S} \right] \Delta h^2 \\
& + 2t_0 \left[K_3 \frac{cos^2\,\beta_G}{v_G} + K_2 \frac{cos^2\,\beta_S}{v_S} \right] \Delta h \Delta x_m
\end{aligned} \tag{1}
$$

where $\Delta x_m = x_m - x_0$ and $\Delta h = h - h_0$ are the midpoint and half-offset displacements, respectively. The midpoint coordinates $x_0 = (x_G + x_S)/2$ and $x_m = (\bar{x}_G + \bar{x}_S)/2$ and half-offset coordinates $h_0 = (x_G - x_S)/2$ and $h = (\bar{x}_G - \bar{x}_S)/2$ are related to the central ray and paraxial rays, respectively. Related to the central ray are also the velocities v_S at the source position and v_G at the receiver position. The quantity t_0 is the reflection traveltime of the finite-offset central ray. The angles β_S and β_G are between the normal to the surface and the central ray at the source and receiver locations, respectively. The quantities K_1, K_2 and K_3 are wavefront curvatures associated with the central ray, which are computed at the source and the receiver positions. The last five parameters, called CO-CRS-attributes, are generally unknown and they need to be determined from pre-stack data.

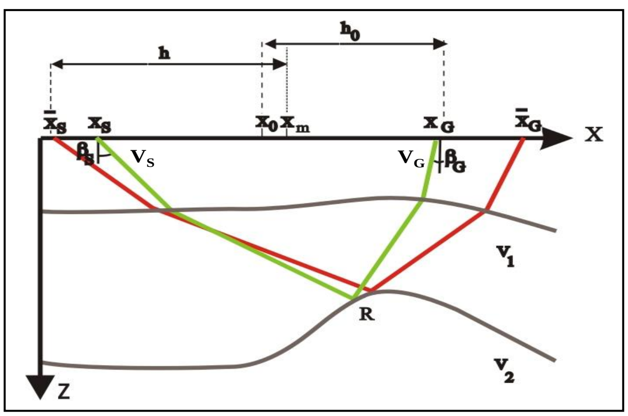

Figure 1. Ray paths for the central and paraxial rays for a synthetic model with constant velocity layers with curved and smooth interfaces.

Global optimization of the CO CRS-attributes

For simulating a staked CO section from multicoverage data using the traveltime approximation (1), it is necessary to determine the five kinematic CO-CRS-attributes (K_1, K_2, K_3, β_S and β_G) for each sample point, $P_0(x_0, h_0, t_0)$, of the section to be simulated. Thus equation (1) defines the full stacking surface in the midpoint and half-offset domain, and the seismic amplitudes need to be summed along this stacking surface.

The simultaneous determination of the five CO-CRS-attributes is accomplished through a multidimensional global optimization algorithm using as objective function a coherence measure (semblance) of the pre-stack seismic data. We use the VFSA algorithm (Ingber, 1989) to search simultaneously for the five parameters or attributes. For the optimization tests we used the Marmousi synthetic dataset (Burgeois, et al., 1991). For a given sample point on the CO section (offset 1000m) to be simulated, we ran several times the VFSA algorithm in order to calibrate the optimization parameters. The display in Figure 2 shows the performance of the VFSA algorithm in searching the global minimum. We can see that the minimization process is relatively slow and the optimum five parameters are reached after a relatively large number of evaluations of the objective function.

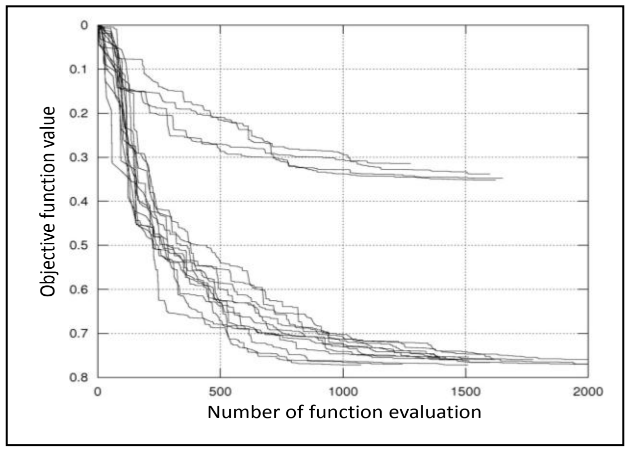

Figure 2. Performance of the VFSA algorithm applied to the determination of the five CO CRS attributes from synthetic Marmousi dataset.

Application of the CO CRS stack method

We apply the one-step global optimization scheme presented before for simulating a complete CO stacked section from the Marmousi pre-stack dataset. Before the application of the CO CRS stack, random noise with signal-to-noise ratio of 7 was added to the whole pre-stack data. Figure 3 shows the modeled synthetic CO section (offset 1000m) with random noise added. We simulated using the CO CRS stack method the same CO of 1000m from whole dataset and the result is presented in the Figure 4. This CO stacked section reveals a great signal enhancement, with overall more clearly defined reflection events.

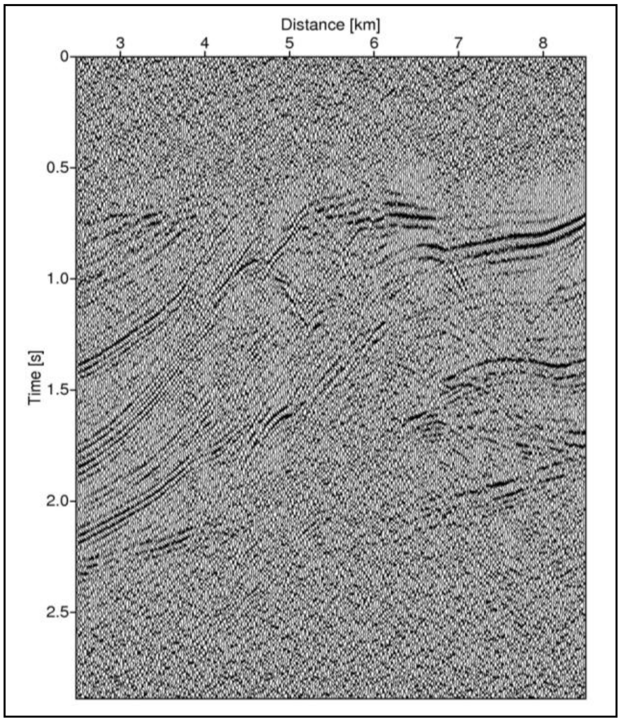

Figure 3. Synthetic CO section of 1000m of the Marmousi dataset with random noise added. The signal-to-noise ratio is low in the middle and lower parts.

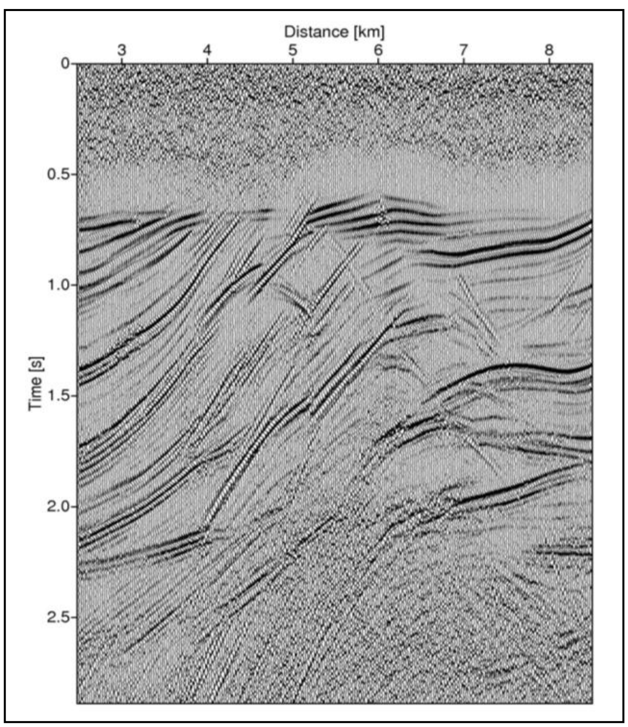

Figure 4. CO stacked section of 1000m simulated from Marmousi dataset by Appling the CO CRS stack method. This section has a high signal-to-noise ratio, with better defined reflections events.

Finally, we applied also the CO CRS stacking method to real land seismic line 50-RL-90 from the Tacutu Basin, Brazil. The data was acquired in early '80s with a low CMP fold (12 traces). The processing flow applied prior to the CO CRS stacking was the trace editing, elevation static correction, amplitude recovery, F-K filtering, spiking deconvolution, velocity analysis and residual statics. An example of the processed pre-stack data is in the Figure 5, which corresponds to a CO section of 1000 m. The result of the corresponding 1000 m CO CRS stack is shown in the Figure 6. This stacked section shows a clear signal-to-noise improvement, also all pre-stack zero traces of the original CO data were nicely interpolated by the CO CRS stacking method.

Conclusions

The optimization problem of the CO CRS stack method was solved with a one-step global optimization scheme. As preliminary validation we presented an application of the VFSA algorithm. The performance tests to search simultaneously the five CO-CRS-attributes reveal a good applicability of the VFSA algorithm to solve this optimization problem. The CO CRS stacking method was applied without using any velocity model information. The CO stacked section obtained with the CO CRS stacking method from Marmousi dataset serves as a quality control of the algorithm and demonstrates the promising potential of this stacking method in noisy datasets. This fact is confirmed by the good result obtained from the low-fold land data application. These results, again, demonstrate the high potential of the CO-CRS stack to reconstruct (regularize) pre-stack seismic data and interpolate data gaps.

As future works, the performance of the VFSA will be improved, also it will be investigated the ability of the CO CRS stack to handle converted waves from multicomponent data.

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References

Bergler, S., Duveneck, E., Höcht, G., Zhang, Y., Hubral, P., 2001a. Common-Reflection-Surface stack for common-offset: practical aspects. *63rd SEG Meeting. Extended Abstracts, P076.*

Bourgeois, A., Bouget, M., Lailly, P., Poulet, M., Ricarte, P., and Versteeg, R. (1991). Marmousi, model and data. *In: 52nd. EAEG meeting, Proceedings of the Workshop on Practical Aspects of Seismic Data Inversion, Copenhagen*, page 56.

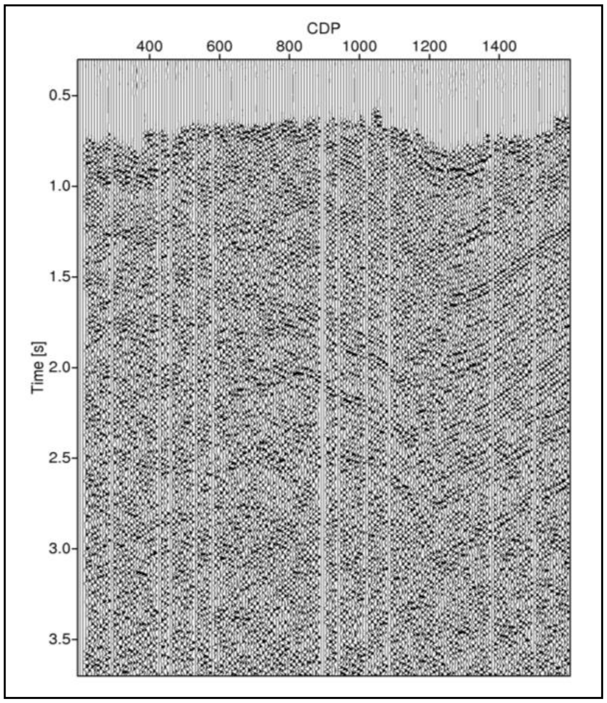

Figure 5. CO section of 1000m extracted from the real dataset of the seismic line 50-RL-90 of the Tacutu Basin, Brazil. This pre-stack data is noisy and there are several zero traces.

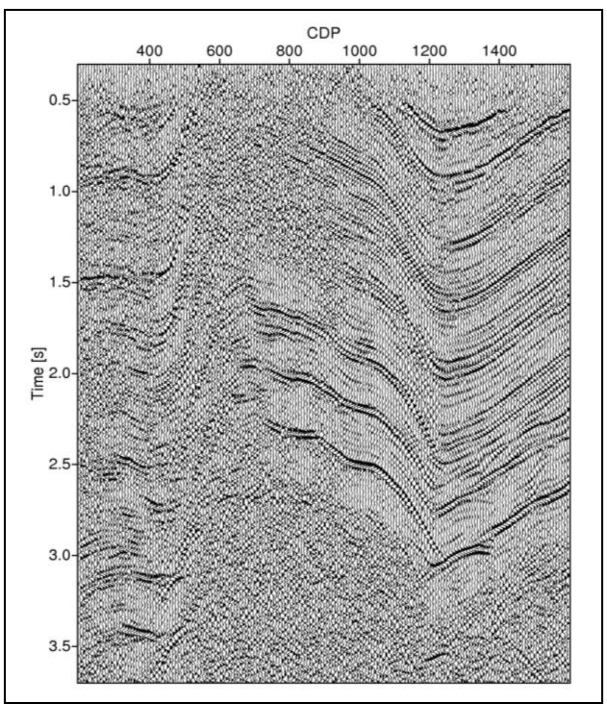

Figure 6. Simulated CO stacked section of 1000m obtained with the CO CRS stack method form the seismic line 50-RL-90 of the Tacutu Basin, Brazil. The signal-to-noise was improved and the zero traces were interpolated.

Garabito, G., Stoffa, P.L., Lucena, L.S., Cruz, J.C.R., 2012. Part I - CRS stack: Global optimization of the 2D CRS-attributes. J. Appl. Geophys, pages 92-101.

Jäger, R., Mann, J., Höcht, G., and Hubral, P. (2001). Common reflection surface stack: Image and attributes. *Geophysics*, pages 97–109.

Ingber, L. (1989). Very fast simulated re-annealing. *Math1. Comput. Modelling*, 12(9):967–973.

Mann, J. (2001). Common-reflection-surface stack and conflicting dips. *71th Annual Internat. Mtg. Soc.Expl. Geophys. Extended Abstracs.*, 13(3):262–280.

Müller, T. (1998). Common reflection surface stack versus nmo/stack and nmo/dmo/stack. *60th Mtg. Eur.Assoc. Expl. Gophys., Extended Abstracts.*

Zhang, Y., Bergler, S., Tygel, M., Hubral, P., 2001. Common-Reflection-Surface (CRS) stack for common-offset. Geophys. Prospect. 49, 709–718.