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Prestack Data Enhancement Using Local Traveltime Approximation

V. Buzlukov* (Opera), R. Baina (Opera) & E. Landa (Opera)

SUMMARY

The quality of recorded seismic data depends on many factors such as complexity of the subsurface, strong noise level, the topography of the earth s surface, near surface inhomogeneities etc. We propose to use a local common offset (CO) approximation for traveltime stacking surface description. It allows to approximate traveltimes of reflection events in the vicinity of arbitrary ray and thus arbitrary offset. We present the general workflow and the implementation of a signal enhancement scheme.

Introduction

The quality of recorded seismic data depends on many factors such as complexity of the subsurface, strong noise level, the topography of the earth's surface, near surface inhomogeneities etc. Irregular acquisition, short maximum offsets, low CMP fold are leading to a low quality of processing and imaging of old vintage data.
The common-reflection-surface (CRS) stack and multifocusing technology based on multiparameter stacking (Jager et al., 2001, Landa et al., 1999) has been successfully applied to enhance the time imaging sections by dramatically increasing the fold of coherent summation of seismic signals. Common offset CRS technique shows good results for data regularization and interpolation too (Hoecht et al., 2009). Possibility the CRS stack method to improve the quality of 2D prestack data is presented in Baykulov and Gajewski (2009). They apply the CRS traveltime formula to compute new partially stacked supergathers, in which each trace is a result of summation of data along the CRS stacking surface. A potential weakness of this method is the use of global zero-offset CRS operators for common offset partial summation. In case of non-hyperbolic traveltime behavior of seismic events this can result in non optimal partial summation.
We propose to use a local common offset (CO) approximation for traveltime stacking surface description. It allows to approximate traveltimes of reflection events in the vicinity of arbitrary ray and thus arbitrary offset. Here, like in Hoecht et al., (2009), we interpret the CRS operator as a local second-order traveltime approximation of reflection event. We use this local description for the purpose of partial summation. The number and location of traces in the produced data can be defined filling areas of missing data and regularizing the data. The method is very robust in the presents of noise due to the fact that summation and not interpolation is performed.
We present the general workflow and the implementation of a signal enhancement scheme. The scheme was applied to produce to enhance signal to noise ratio in synthetic and real common shot and/or common-offset subsets of a 3D data sets. We refer to these subsets as common-offset clases and they built using a binning in offset.

Stacking surface

CO CRS-based partial summation works in the time domain and is based on the estimation of local kinematic attributes of the wavefield. It makes use of second-order traveltime approximation.
Figure 1 shows observed data traces (black) and a enhanced target trace (green) which is to be generated in a 3D data cube. The idea of the method is to extract local information from the existing measured traces and to use this information to construct a new, enhanced trace by coherent partial summation.
The stacking operator for a sample $\hat{t}$ on the target trace located at ($\hat{x}, \hat{y}$) is given by the following local parabolic second-order traveltime approximation:

$$\Delta t = t(\Delta x, \Delta y) - \hat{t} = b_0 \Delta x + b_1 \Delta y + a_{00} \Delta x^2 + a_{01} \Delta x \Delta y + a_{11} \Delta y^2 .$$

Here, the traveltime difference Δt describes the moveout of a reflection event relative to the investigated sample $\hat{t}$ of the target trace. The variables $\Delta x = x - \hat{x}$ and $\Delta y = y - \hat{y}$ denote the positions of the data trace relative to the target trace location. The unknown parameters b_0, b_1, are the first order, a_{00}, a_{01}, a_{11} are the second-order special traveltime derivatives.
The procedure consists of two steps. Firstly, we estimate the unknowns from the data, and, secondly, we perform a weighted stack along the estimated surface to simulate the enhanced sample of the target trace. Practically we define two different grids in the data space: the data grid and the target grid. These grids define different types of traces. The irregular data grid is defined by locations of the actually acquired data traces. The target grid is a regular grid which is chosen for traces where the enhanced wavefield suppose to be estimated.

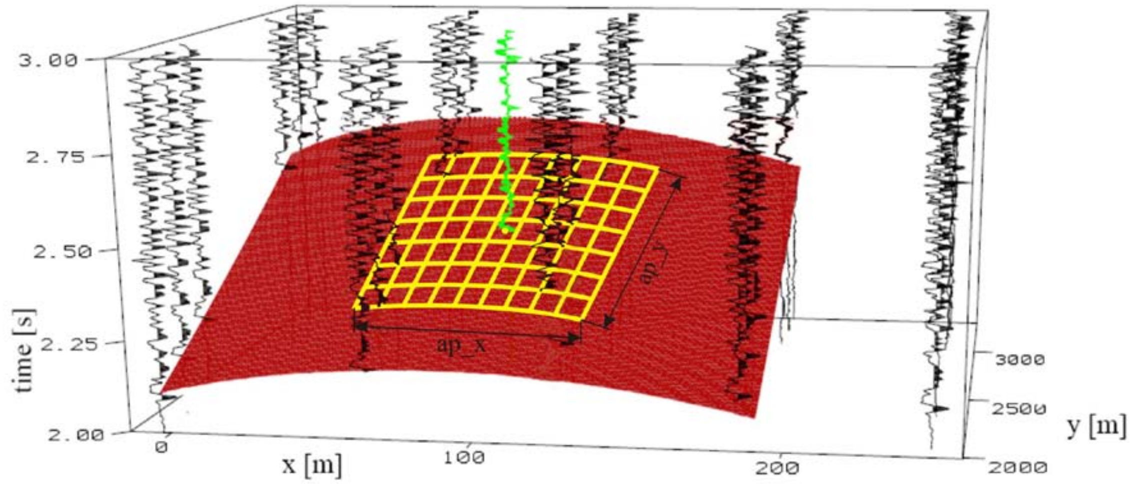

Figure 1. Signal enhancement in a 3D data space: the data traces are shown in black; the target trace is shown in green; the stacking operator for one sample is shown in red. The output target grid and summation aperture is shown in yellow.

In the first step, we estimate parameters b_0, b_1 and a_{00}, a_{01}, a_{11}. These five parameters have to be estimated for each sample of the data traces. The ideal solution of simultaneous five-parameter estimation is computationally too expensive. To search the parameters we use the strategy described Hoecht et al. (2009) which is: simultaneous two-parameter estimation in first bin direction (b_0, a_{00}), then in second bin direction (b_1, a_{01}) and lastly one-parameter estimation along surface (a_{11}).
In the second step, we define apertures for partial summation (ap_x and ap_y in Figure1). For each sample we construct operator and compute its intersection point with target trace. The amplitudes of the data traces are summed along the operator and assigned to the sample of a target trace. Because several operators can contribute to a target sample, the sum of the individual operator contributions is normalized by the number of contributing operators. The partial stack enhances the quality of the output data increasing signal to noise ratio.

Results

We demonstrate the advantages and potential of signal enhancement procedure on synthetic and real data sets.
Cassis is a 2D acoustic Born-modeled synthetic data set. This is a Marmousi-like model with channel structures in the deeper sections (Figure 2). To simulate 3D case we replicate the line in y direction. Strong amount of random noise was added to the data. Signal enhancement procedure consisted in two steps: parameter estimation for each parameter trace on each common offset section, and then partial stacks at the desired positions using the estimated parameters.

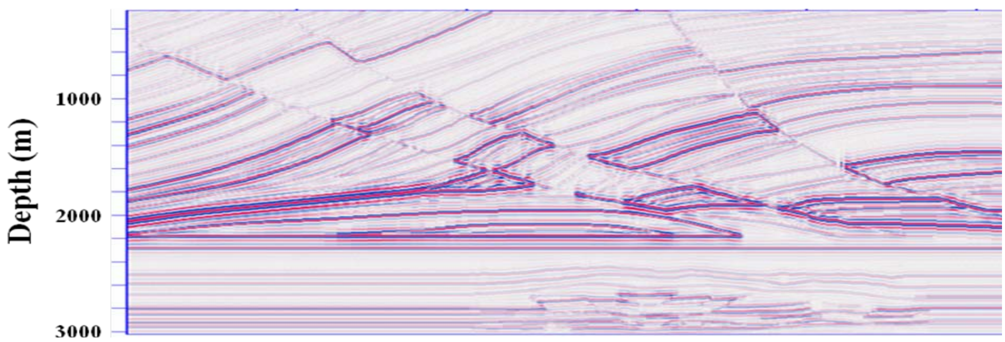

Figure 2. Synthetic model.

First we applied the proposed procedure to data without noise. Figure 3 shows one CMP gather where strong non-hyperbolicity of traveltime curves can be seen in the deeper part of the seismogram (Figure 3a). After application of the partial stack the non-hyperbolic moveouts are well preserved (Figure 3b). Figure 4a shows original input common offset section with offset equal to 1500m. After adding noise we hardly observe signals in the deeper part of the section (Figure 4b). For signal enhancement we used the following apertures: ap_x=200 m, ap_y=200 m. Figure 4c illustrates the obtained common offset section. We observe essential increase in signal to noise ratio. The resulting section preserves all structural features of the original section. Figure 5 illustrates application of the proposed method to a real 3D common offset section. Again we observe essential signal to noise enhancement.

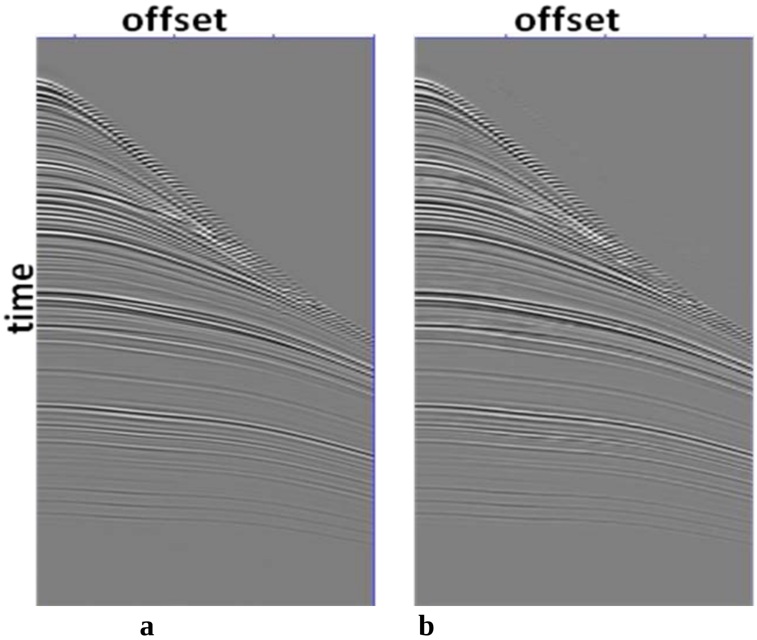

Figure 3. CMP gather before (a) and after (b) signal enhancement. Non-hyperbolic moveouts are preserved.

Conclusions

We proposed a method to enhance the quality of 3D prestack seismic data. The presented method uses second order approximation of local moveout correction and is based on partial stacks along optimal traveltime trajectories. Partial stack generated new regular gathers of higher quality. A distinction to existing methods is the use of local operators. For the procedure we use the scheme implicitly allow s the contribution of several operators for a target sample. We successfully tested the method on the synthetic and real data.

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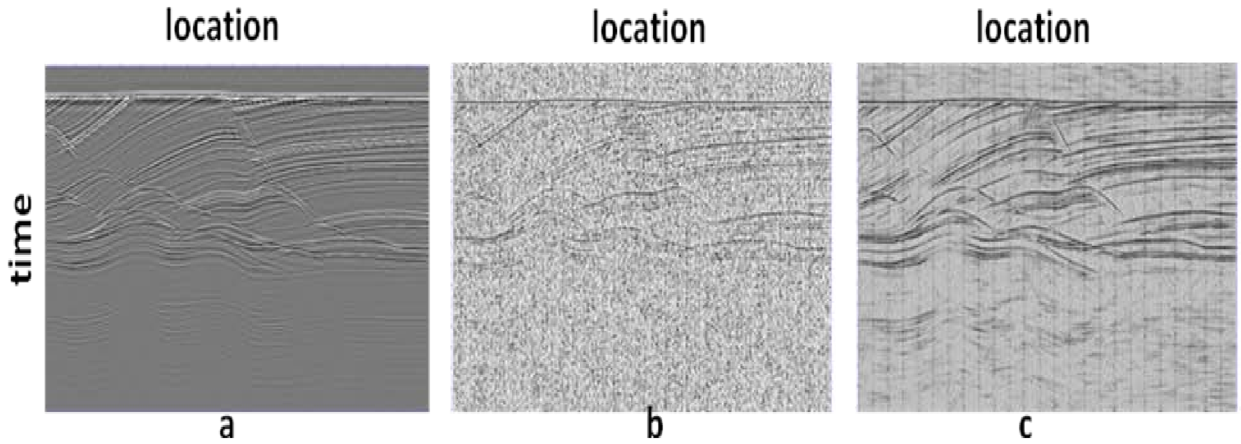

Figure 4. Common offset section: original (a), after adding noise (b) and after signal enhancement procedure.

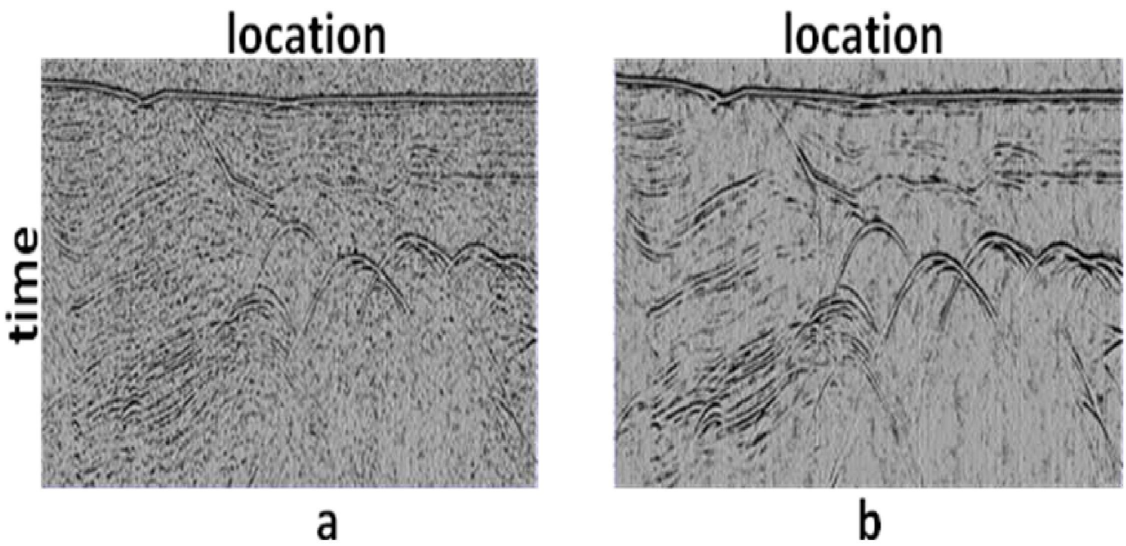

Figure 5. Real data. Common offset section before (a) and after signal enhancement.

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