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Enhancing Challenging Prestack Data Using Local Summation Approaches

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Summary

For high-channel count and single-sensor seismic data many processing steps requiring estimation of prestack parameters become more challenging due to the low signal-to-noise ratio of the data. Conventional processing algorithms involve estimation of velocities, statics and surface consistent scalars and operators, and need good prestack data quality, which is rarely the case for land seismic data acquired in arid desert environments of Saudi Arabia with a complex near surface. We present two methods for prestack seismic signal enhancement based on mixing neighboring traces. The first method called supergrouping performs local summation of traces using a global normal moveout correction to align reflected signal. The second approach, called nonlinear beamforming (NLBF), is a data-driven procedure to estimate local moveout directly from the data. We demonstrate the signal enhancement ability of these procedures on synthetic and challenging land seismic data from Saudi Arabia.

Introduction

Land seismic data from desert environments suffer from severe contamination originating from complex near-surface scattering. Naturally, every processing step relying on prestack data becomes very challenging to execute. In the past, large source and receiver arrays were employed in the field to suppress surface waves and backscattered noise, so that reflections can be recorded with reasonable signal-to-noise ratio (SNR). Modern seismic acquisition is steadily moving to finer spatial sampling using smaller field arrays or point sources and receivers, while typical distances between shot and receivers remain relatively large. Theoretically, we get better sampling of signal and noise and expect to achieve improved imaging results. In practice, for regions with a complex near surface such as Saudi Arabia we obtain hundreds of terabytes of data with low SNR. Traditional land seismic data processing cannot compensate for the loss of signals, making it very difficult to obtain a reliable estimation of prestack parameters, such as velocities, deconvolution operators, statics, and surface-consistent scalars. Proper estimation of these parameters is a prerequisite for any further processing. Promising results of enhancement of very challenging data were obtained recently by supergrouping of neighboring traces (Bakulin et al., 2016). While this approach is robust and fast, it assumes summation is done along global hyperbolic normal moveout (NMO) and, as such, can be applied in areas with relatively simple geological structure. A more sophisticated approach called nonlinear beam forming (NLBF) is based on estimation of actual local moveout directly from the data followed by stacking along estimated trajectories (Bakulin et al., 2017). NLBF consists of two steps: estimation of the unknown coefficients (prestack kinematic attributes) using semblance optimization and weighted summation of seismic events along the estimated surfaces similar to CRS or multifocusing techniques (Baykulov and Gajewski, 2009; Berkovitch et al., 2011; Buzlukov and Landa, 2013). In this study we demonstrate supergrouping and nonlinear beamforming on synthetic and challenging land seismic data from the Saudi Arabia.

Supergrouping

The main idea of supergrouping is based on local summation of nearby traces to enhance SNR. It is very similar to conventional group forming, which is typically done during data acquisition; however, there are some differences. Supergrouping is typically applied to data already acquired with field arrays justifying the title. Since there is no practical way to introduce any kinematic corrections in the field, conventional shot/receiver groups require very fine sampling. The spatial sampling of modern high-channel count data or single sensor usually remains significantly larger than what is required for field array forming. Figure 1 shows a typical example of modern high-channel acquisition for 3D seismic data in Saudi Arabia. One can see that even best sampling along shot and receiver lines still exceeds what is necessary for field arrays, whereas distances between lines remain large due to cost of acquisition. This creates a challenge for seismic processing that can no longer rely on large field arrays or conventional group forming. Denser 3D data opens new opportunities. Bakulin et al. (2016) showed that supergrouping allows enhancement of the reflected signal and obtains more reliable estimates of prestack parameters from enhanced data (velocities, deconvolution operator, statics) and, finally, gives a much better image in comparison with conventional single-sensor processing.

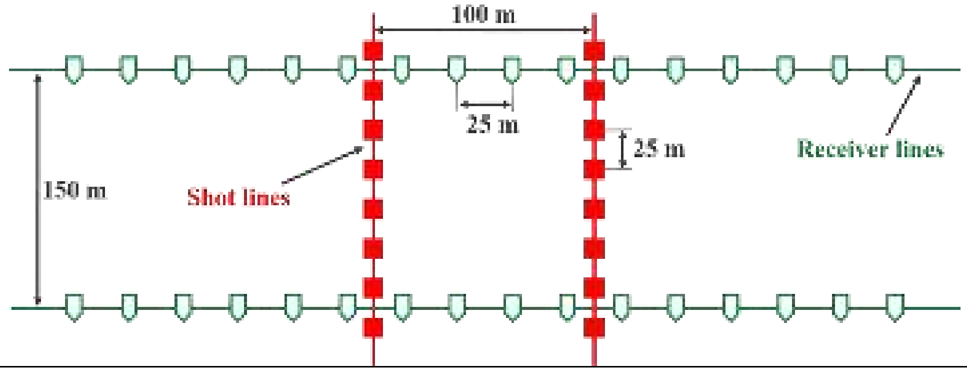

Figure 1: *An example of typical modern 3D high-channel acquisition geometry.*

Application of NMO corrections prior to supergrouping allows us to handle larger spatial separation between traces. In the presence of a complex near surface or subsurface, the assumption of global NMO may break down. To overcome this problem, we consider an NLBF approach that can estimate actual local moveouts directly from the data.

Nonlinear beamforming

NLBF can be described as a delay and sum approach and can be written as follows:

$$u(x_0, y_0, t_0) = \sum_{(x,y)\in B_0} w(x, y)u(x, y, t_0 + \Delta t(x, y)), \qquad (1)$$

where $u(x, y, t)$ represents a seismic trace with coordinates x and y. The coordinates of the output trace after the beamforming procedure are given by x_0, y_0. The summation is done over local region B_0 around the output trace in the x-y domain along trajectory with moveout $\Delta t(x, y)$. Here we assume that the travel-time surfaces can be locally approximated by a second order surface as follows:

$$\Delta t = t(x, y) - t_0(x_0, y_0) = A(x - x_0) + B(y - y_0) + C(x - x_0)(y - y_0) + D(x - x_0)^2 + E(y - y_0)^2, \quad (2)$$

where parameters A, B, C, D, E are unknown beamforming parameters that are estimated using coherency analysis. Due to the computational demand of simultaneous estimation of five parameters we follow a similar approach to Hoecht et al. (2009) and first perform a two-parameter scan for A and D, followed by another scan for B and E. Finally, we fix these four coefficients and search for an optimal value of C. The summation is done using an operator-oriented approach (Hoecht et al., 2009; Bakulin et al., 2017).

Synthetic tests

To validate performance of the local summation we compare depth migrated images using synthetic data generated for the Sigsbee model with different summation apertures. Local data summation was done in the CMP-offset domain. Figures 2a and 2b show a comparison of Kirchhoff depth migrated data after supergrouping and NLBF for a stacking aperture 100 ft. One can see that for such relatively small aperture we do not observe much difference between seismic images. In contrast, larger apertures (500 ft) used in supergrouping result in significant smearing of both faults and dipping structures, whereas NLBF images remain largely unaffected with some smearing of the faults only. For the models with a simpler subsurface these distortions are expected to be much less.

Real data tests

NLBF is demonstrated using a challenging 2D seismic data from Saudi Arabia. Shot and receiver spacing is 30 m. Data was acquired using 72-geophone groups and five-vibrator source arrays. Figure 3a shows fully processed common-midpoint (CMP) data. Despite use of large field arrays, reflected signal is almost invisible on processed gathers. Since the target structure is relatively simple, this area is probably characterized by an extreme level of small- and medium-scale near surface scattering dominating the records. Enhancement of the data using NLBF was done in the CMP-offset domain. Summation and operator apertures were chosen to be 600 m in both common-midpoint and common-offset directions. An aperture of 1200 m was used to estimate prestack kinematic parameters A, B, C, D, E.

We applied global NMO corrections prior to enhancement to minimize the possible dip and curvature ranges for searching the coherent seismic events. This allows to reduce calculation time of the most time-consuming estimation procedure. Figure 3b shows the results of the enhancement after NLBF. One can see that NLBF gives significant uplift in the data quality and velocity semblance panels (Figures 3c and 3d). The corresponding stacked sections are shown in Figure 4 using the original stacking velocity. We observe smaller improvements of the stacked sections despite large differences in data quality before stack. Further improvements in stack require applying Enhance-Estimate-Image approach (Bakulin and Erickson, 2017) involving deriving new velocities and other prestack parameters using the enhanced data and iterative imaging with new parameters. This will be reported in future studies.

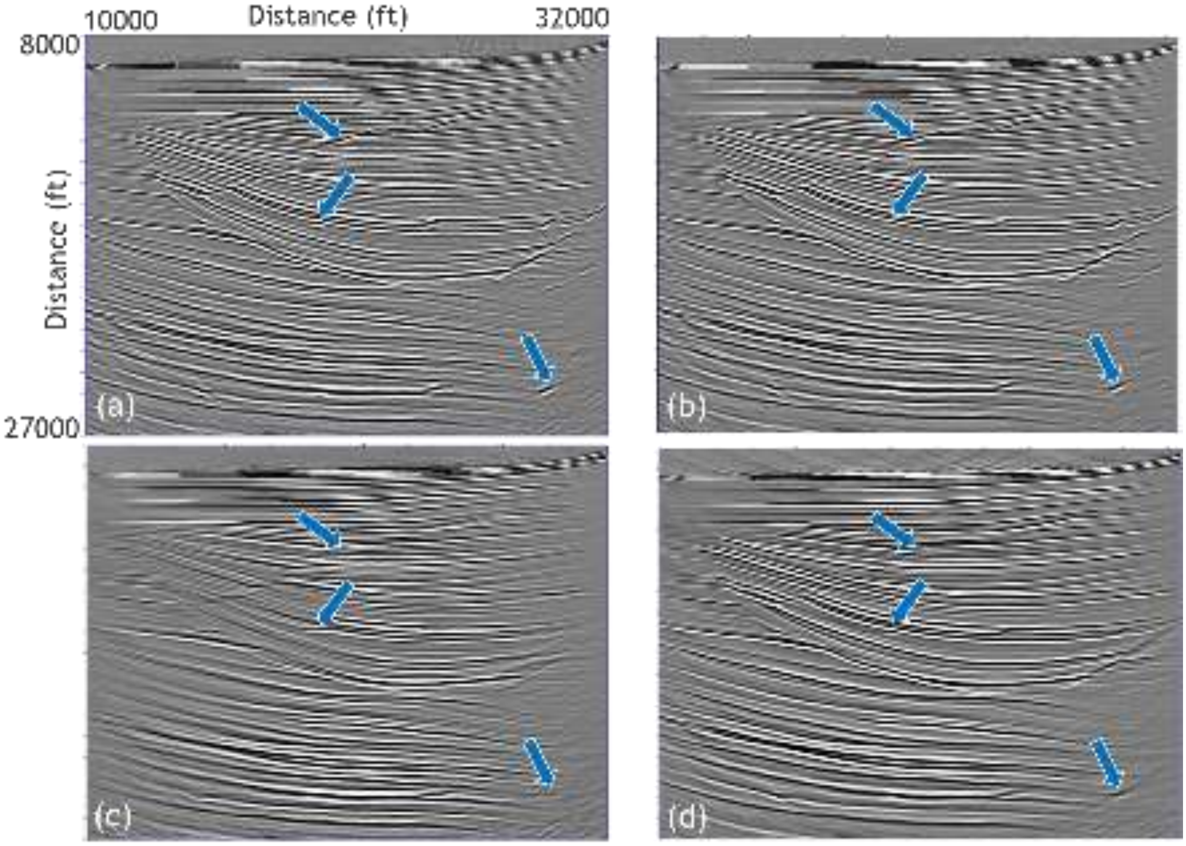

Figure 2: *Depth-migrated images using the true Sigsbee model for different stacking apertures: (a) supergrouping 100 ft, (b) NLBF 100 ft, (c) supergrouping 500 ft, and (d) NLBF 500 ft.*

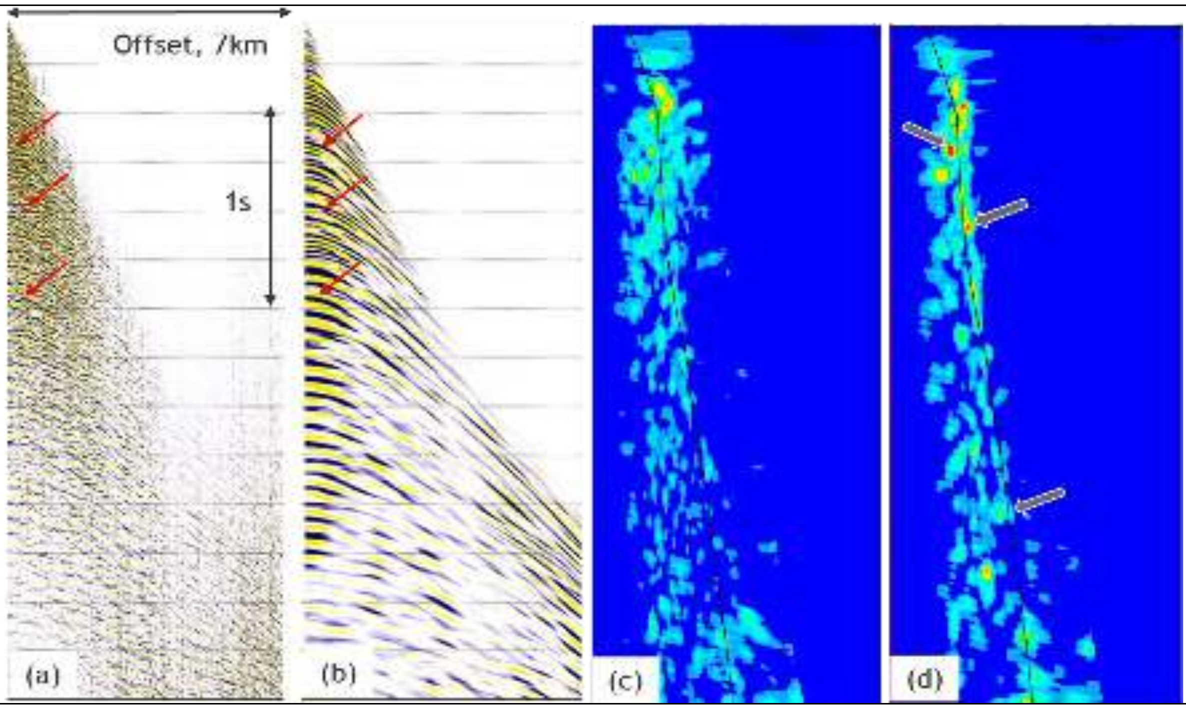

Figure 3: *Comparison of the data and velocity semblance panels before and after enhancement: (a) original CMP gather, (b) CMP gather after NLBF, (c) a velocity semblance panel for original data, and (d) a velocity semblance panel for data after NLBF.*

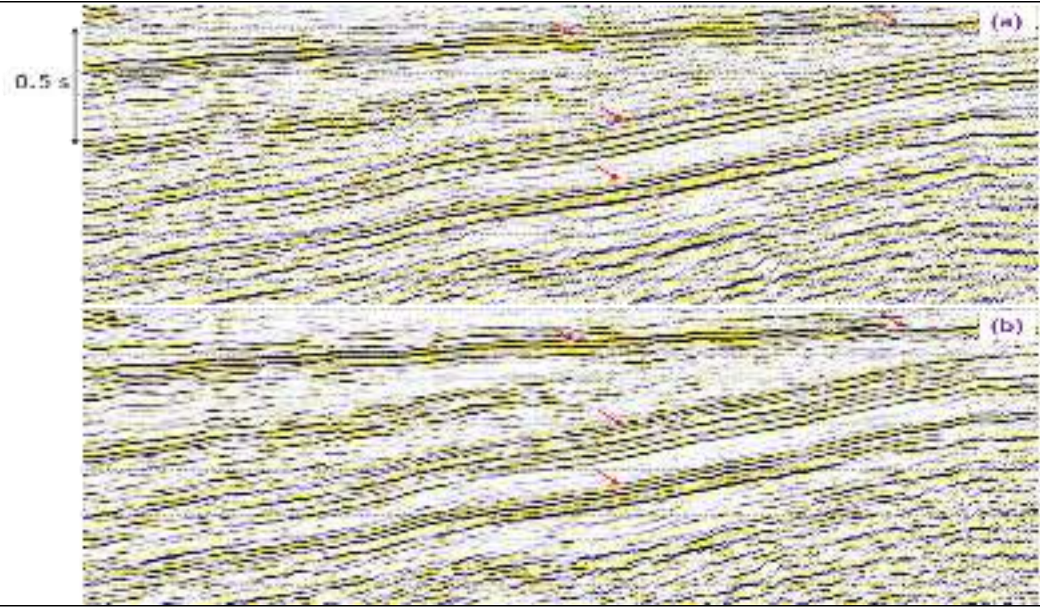

Figure 4: Stacked sections of data from Figure 3 including (a) before enhancement, and (b) after NLBF.

Conclusions

We presented supergrouping and nonlinear beam forming approaches for enhancement of prestack seismic data using local summation of the traces. Supergrouping enhances the reflected signal based on global hyperbolic NMO corrections and can be especially efficient for areas with simple geological structure. NLBF goes further and estimates actual moveout corrections directly from the data without prior knowledge of the velocities. It enables larger summation apertures resulting in stronger enhancement, although it requires significant computational power for parameter estimation and local summation of huge volumes of seismic data. Both NLBF and supergrouping allow us to greatly enhance the quality of prestack data critical for derivation of prestack parameters (velocity, deconvolution operators, statics etc.) as well as imaging. By adjusting the aperture size one can achieve different levels of enhancement for each processing step.

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