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Enhancing 3D Broadband Land Seismic Data with Smart Super Groups for Processing and FWI

D. Neklyudov* (Institute of Petroleum Geology & Geophysics SB RAS), A. Bakulin (EXPEC ARC, Geophysics Technology, Saudi Aramco), M. Dmitriev (EXPEC ARC, Geophysics Technology, Saudi Aramco) & P. Golikov (EXPEC ARC, Geophysics Technology, Saudi Aramco)

SUMMARY

Land seismic data in Saudi Arabia is always challenging thus hindering any technique relying on pre-stack information such as for instance full-waveform inversion (FWI). While many sophisticated algorithms for noise removal exist, the greatest power remains with final stack for imaging. We show how power of stacking can be harvested to enhance raw broadband 3D land data for various pre-stack applications using smart super grouping. We design large super groups both in inline and crossline directions and devise smart stacking procedures adapted to variable spatial sampling in each direction. We demonstrate on synthetic data that at low frequencies (< 8Hz) reflections and diving waves are identical on point-source and super-group data. On real 3D broadband data, super grouping greatly enhances signal-to-noise ratio and produces data ready for FWI starting from lowest sweep frequency. Advanced stacking with complex data-driven weights can also enhance high-frequency reflection data for processing and imaging. We illustrate both of these points by applying smart shot-based super groups on a 3D seismic dataset from Saudi Arabia acquired with broadband sweep 2-90 Hz.

Introduction

Land seismic data from desert environment is generally of poor quality. As such, any techniques relying on pre-stack data require specialized heavy pre-processing often of a custom nature. Full-waveform inversion (FWI) is one such approach that relies on ability to measure pre-stack signals of interest that can be fit with a rather simple subsurface model. Due to hierarchical nature, FWI success often hinges on ability to reliably extract low-frequency information starting from 1.5-2 Hz. This task is quite challenging for conventionally acquired land broadband data. Baeten *et al* (2013) presented an example of 2D land data that was carefully pre-processed for FWI with elaborate multi-step flow to preserve and highlight pre-stack signals at low frequencies. In this study, we aim at enhancing 3D broadband land data and take a different approach with a simpler implementation. We employ areal super groups of vibrators and receivers that allow enhancing signals of interests. While in one (better sampled) spatial direction this may be considered as classic group forming, in another direction (with sparser sampling) we have to employ a common-offset summation to enhance signals. Super groups produce greatly enhanced low-frequency data almost ready for FWI and require little additional processing. Super groups also prove useful at much higher frequencies provided smart weighted stacking is applied instead of simple stacking valid at low frequencies. We demonstrate effect of smart super grouping using 3D broadband land dataset of moderate complexity from Saudi Arabia.

Method

We focus on a typical 3D orthogonal land acquisition geometry that is currently used in Saudi Arabia. The receivers listening to each shot are densely sampled along parallel receiver lines, whereas shots are densely sampled along parallel shot lines that are orthogonal to receivers (Vermeer *et al*., 2005). We illustrate the concept using 3D broadband dataset from Eastern province of Saudi Arabia. Receivers are sampled at 50 m along receiver lines and 250 m in perpendicular direction (Figure 1).

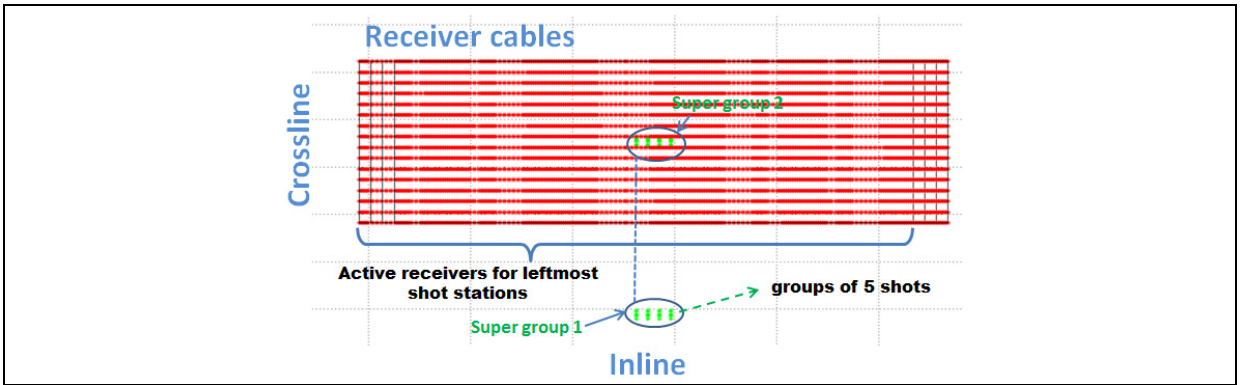

Figure 1 *Example of shot super group applied to real data. Inline direction – stack of common-offset traces from four shot lines (1,000 m). Crossline direction – grouping of five shot stations.*

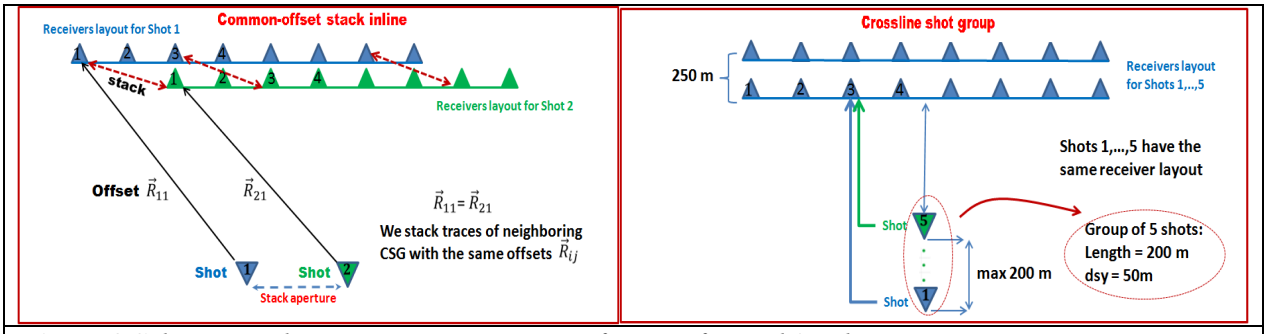

Figure 2 *Schemes explaining smart super group forming for real 3D dataset.*

Likewise, sources are sampled at 50 m along source lines (orthogonal to receivers) and 250 m in perpendicular direction. Broadband nonlinear sweep 2-90 Hz is employed. For each shot station there are a fixed number of laid receiver lines and active channels.

First, we select a geometry of an areal super group. Once the super group is defined, we consider two methods to enhance signal-to-noise ratio: 1) simple stack of the individual shot gathers forming the super group; 2) advanced weighted stack of the shot gathers from the super group. The second approach provides proper phase shifts for each frequency component of the data so that higher frequencies are better preserved during stacking. For the dataset at hand, the super group is mainly governed by the shot side and the simple stack is implemented as follows: 1) parallel to shot lines: 3-5 vibrator positions with 50 m sampling (100-200 m) are grouped together to suppress arrivals with low apparent velocity and enhance reflections and diving waves that have relatively high apparent velocity; 2) perpendicular to shot lines, we take 3-5 shot lines with 250 m sampling (500-1,000 m) and apply stacking of common-offset traces from neighboring shot stations (Figure 2). This approach seems to work well for mild to moderate lateral velocity variations. Numerical experiments with synthetic data demonstrate that a simple stack does not distort desired signals at low frequencies (up to 6-8 Hz) even for models with complex near-surface velocity variations.

To improve the signal quality for higher frequencies we introduce a weighted stack with special amplitude and phase corrections for each frequency component of different common-shot gathers (CSG) in a super group. The stack is applied in the temporal frequency domain. We formulate the stacking procedure as a frequency-domain beam-forming problem. First, we perform a temporal discrete Fourier transform for each CSG in the super group and construct 2D frequency panels F_i, $i = 1,.., N_{shots}$. Each panel is represented as complex-valued 2D matrix. Then signal covariance COV_S and noise covariance COV_N matrices are estimated using Karhunen–Loève filtering (K-L filter) or eigenimage decomposition filtering (Trickett, 2003) of the frequency panels F_i. We assume that desired signal components are associated with the elder singular values whereas noise components correspond to the smaller singular values. The optimal weights are elements of the first eigenvector of the matrix: $D = [COV_N^{-1} COV_S]$, i.e. $\vec{W} = \text{Principal Component}[D]$ (Monzingo and Miller, 1980, Panea and Drijkoningen, 2008). After computing optimal complex weights, we stack the original frequency panels with the corresponding weights: $F_W = \sum_{shots} W_i F_i$. Finally, we perform an additional noise suppression in each stacked frequency panel using a K-L filter. This procedure delivers enhanced single-frequency panel for a shot super group that could be direct input to the frequency-domain FWI, or an array of processed frequency panels can be converted back to the time domain for further processing.

To demonstrate that both simple and weighted stacks do not distort desired low-frequency signals for a wide class of velocity models, we calculated synthetic seismograms for the 3D SEG/EAGE model using 3D acquisition geometry form the field data. Figure 3 shows a comparison of the 6 Hz frequency panels for the collocated point source and super group obtained with simple and weighted stacks of 20 CSGs. We can clearly see that smart super grouping does not distort the signals at low frequencies, except in the small vicinity of the shot. Extensive acoustic modelling suggests that even in models with strong lateral variations, we do not observe significant distortions at the low frequencies (up to 6-8 Hz). As such, the FWI of the super group and point source data delivers identical subsurface models. While synthetic tests with super groups demonstrate little distortions of the signals, when we apply them to real data, our main goal is to suppress noise.

Figure 4 shows comparison of the low-frequency component (2-6 Hz) of the field data before and after enhancement, using a super group with a weighted stack of 20 CSG. We obtain significant improvements of the signal and suppression of non-coherent events and shear-wave related energy. In the same Figure we also compare 2 Hz frequency panels (the lowest frequency in the sweep) before and after super grouping. We observe a dramatic improvement in the signal-to-noise ratio (not reproducible in synthetic modeling) while having a reasonable assurance that signals of interest are preserved. Smart super grouping becomes an enabler for land FWI using broadband seismic data with a weak low-frequency component.

While it is intuitive that large super groups should be effective at low frequencies, it turns out that they can also help at significantly higher frequencies as well. Figure 5 shows an example of reflection data from the same dataset now pre-processed for imaging using a standard flow. Despite elaborate noise removal, pre-stack events on a single shot gather remain heavily obscured by noise, whereas smart super grouping greatly enhances visibility and quality of reflected events. We also note that as expected, the weighted stack does a much better job at preserving and enhancing higher frequencies.

Conclusions

We have presented a simple, robust and efficient approach for enhancing pre-stack land 3D seismic data using smart super grouping. We demonstrated the process for creating shot super groups on a field dataset from Saudi Arabia with typical 3D land orthogonal geometry. Similar principles can be applied on both source and receiver domains, or combinations thereof. We presented two methods of super grouping based on simple and advanced weighted stacks. On synthetic data, we prove that both methods do not considerably distort low-frequency signals of interest, whereas on field data, we achieve significant signal-to-noise improvements that produce FWI-ready data, starting from the lowest swept frequency of 2 Hz. A weighted stack performs significantly better than a straight stack at higher frequencies, and delivers greatly enhanced reflection data that could be used for various other pre-stack applications.

Acknowledgements

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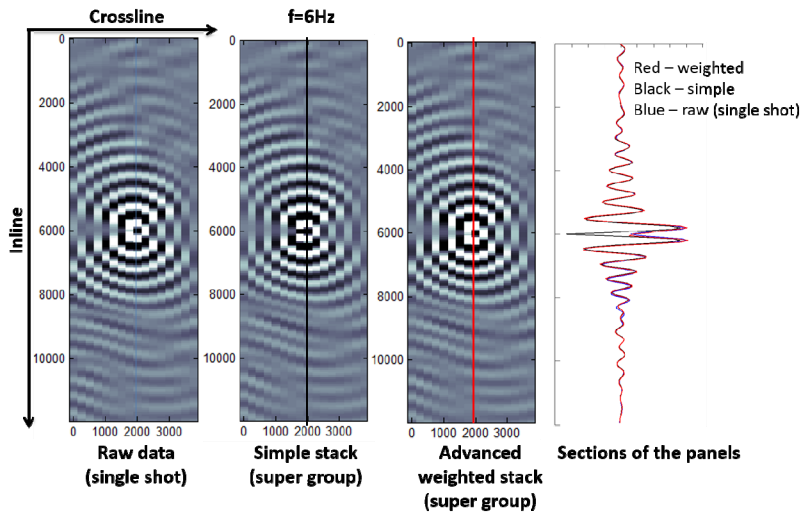

Figure 3 *Frequency panels at 6 Hz for 3D Overthrust model. Observe equivalence of point source and super group (20 CSG) data except in the vicinity of the shot.*

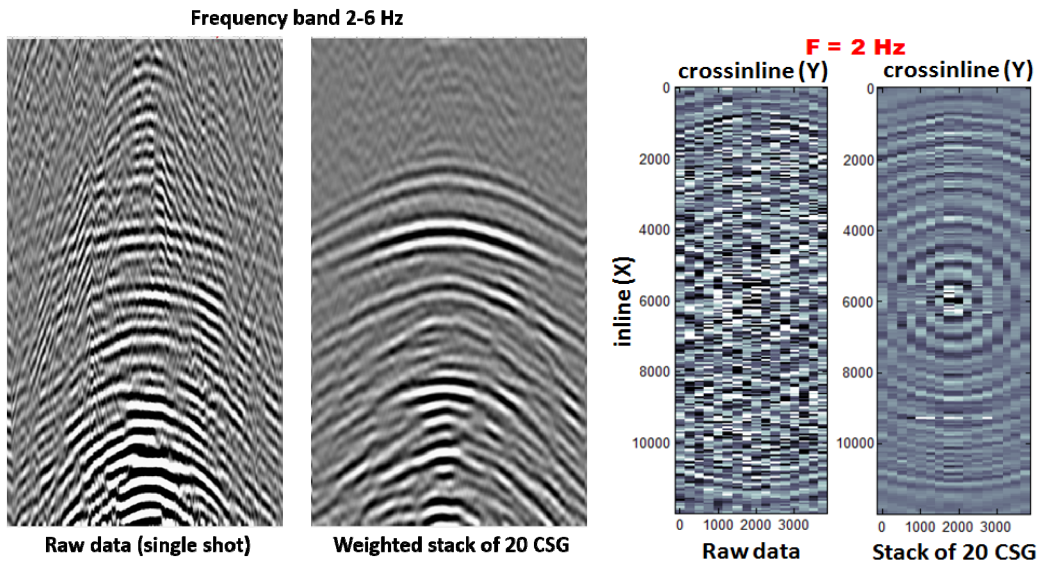

Figure 4 *Land data before and after enhancement. Left: Broadband data in time domain for an offset shot after band pass filtering (2-6 Hz); Right: 2 Hz frequency panels (real part, scaled).*

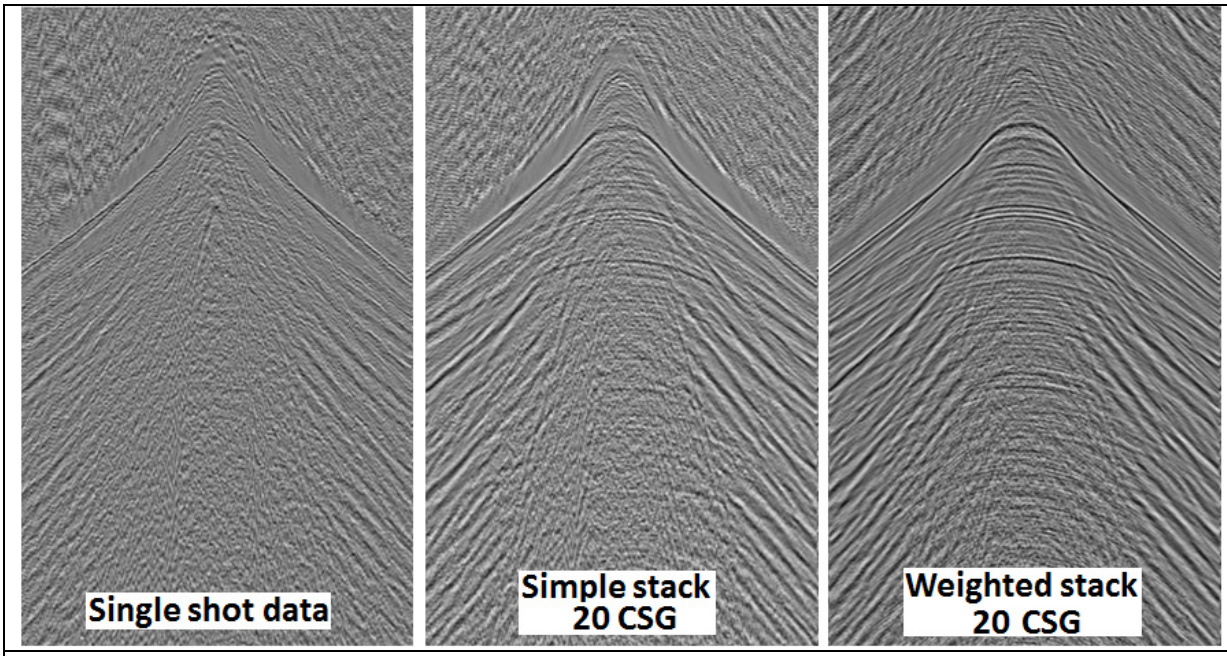

Figure 5 *Comparison of processed pre-stack reflection data ready for imaging: single shot (left);simple stack super group data (middle); weighted stack of super group data (right). Super group consisted of 20 CSG. Frequency range is 2-40Hz, 200ms AGC is applied.*

References

Guido Baeten, Jan Willem de Maag, Ren´e-Edouard Plessix, Rini Klaassen, Tahira Qureshi, Maren Kleemeyer, Fons ten Kroode and Zhang Rujie [2013] The use of low frequencies in a full-waveform inversion and impedance inversion land seismic case study. *Geophysical Prospecting*, **61**(4), 701-711.
Stewart R. Trickett [2003] F-xy eigenimage noise suppression. *Geophysics*, **68**(2), 751-759.
Monzingo, R.A. and T.W. Miller, [1980] *Introduction to adaptive arrays.* JohnWiley and Sons, Inc.
Ionelia Panea and Guy Drijkoningen, [2008] The spatial data-adaptive minimum-variance distortionless-response beamformer on seismic single-sensor data. *Geophysics*, **73**(5), Q29-Q42.
Guus Vermeer, [2005] *3-D Seismic Survey Design*. Society of Exploration Geophysics.