Improving pre-stack land data using smart supergrouping

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Summary

3D land seismic data acquired in arid environments is often challenging for data processing and interpretation, due to low signal-to-noise ratio and the presence of various types of noise. Traditionally, large source and receiver arrays have been utilized for noise suppression and signal enhancement. A trend in modern seismic data acquisition is to reduce the size of the source and receiver arrays, aiming to record broadband signals for imaging and inversion purposes. For many processing steps and velocity model building, achieving good pre-stack signal-to-noise ratio may be more important. We propose a simple but effective supergrouping technique that significantly enhances pre-stack data quality. We demonstrate our approach on two 3D onshore datasets from Saudi Arabia.

Introduction

Land seismic data from a desert environment generally has poor signal-to-noise ratio (SNR) (Robertson and Al-Husseini, 1982). Modern seismic acquisition is trending toward recording a higher number of channels with smaller arrays of sources and receivers. In Saudi Arabia, this means acquiring huge data volumes of significantly lower pre-stack data quality. Naturally, every processing step that relies on pre-stack information becomes more challenging if applied to raw data with low SNR. In the past, large source and receiver arrays were utilized to improve SNR. While their popularity in acquisition has reduced, processing approaches that compensate for decreased data quality are lagging behind. Conventional group forming may help up to a certain limit but often requires too fine spatial sampling. In this study, we propose a method of enhancing the quality of conventional 3D land pre-stack data using a supergrouping technique that combines elements of grouping and stacking. With increased emphasis on low frequencies and proliferation of hierarchical techniques (applied from progressively low to high frequencies) from statics to velocity model building, we expect that adaptive supergrouping may fill the missing gap for different frequency bands. Supergrouping builds on a foundation of the group forming, but goes beyond to deal with large source/receiver intervals, using simple assumptions and smart summation techniques that prove to work well for field data of different complexity. In this paper, we briefly describe the methodology and illustrate it with examples using two 3D field datasets.

Method

Algorithm

At the highest level of abstraction, our method is similar to conventional group forming (Figure 1). It operates on 3D field data that may have significant geometry irregularities. In addition, the input data itself can have been recorded with source/receiver arrays. As such we call our method supergrouping. For these reasons pre-conditioning of the data is not trivial, as it may require individual adjustments for every super group as well as some simple regularization. Supergroups can be implemented in the source domain, receiver domain or a combination. As such, super group type and geometry has to be specified. In this study, we focus on supergroups formed using adjacent shots. We apply it to cases when output geometry is identical to the input, although regular coarser geometry may be acceptable for steps such as velocity model building. As such this could be thought as a sliding spatial window outputting results into a “central” shot from the supergroup aperture. Stacking itself can be achieved with the following two different options.

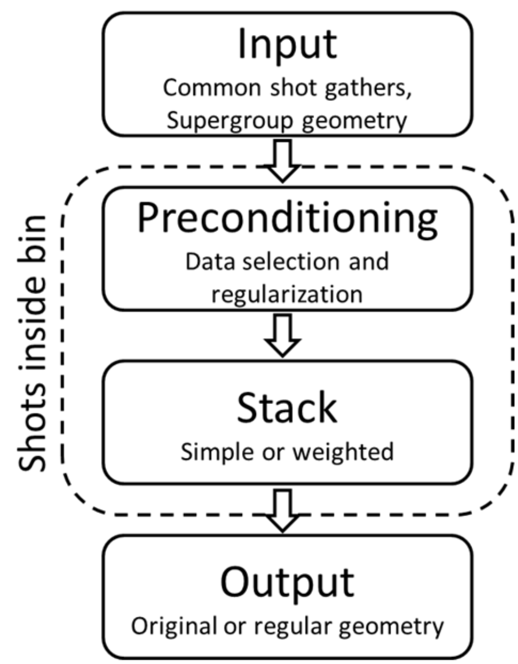

Figure 1: Simple flow for supergrouping on a source side.

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Simple stack

For shot-based supergroup, a simple stack denotes summing neighboring common shot gathers. The selection and summation process may differ from conventional group forming. In a typical case of orthogonal 3D land shooting geometry, source sampling along the source line is smaller than the distance between source lines. For this reason, we first stack data in crossline direction (with finer source sampling) forming traditional source group (works well for groundroll suppression). In contrast, in the inline direction (with coarser source sampling), we cannot use direct summing and instead employ so called common-offset stack with an appropriate trace selection beforehand. While such an approach is robust and fast, it obviously relies on the assumption of a 1D subsurface and as such may blur shallow reflections at near offsets since time shifts between traces due to near-surface lateral variations are ignored.

Weighted stack

To improve the alignment at 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 frequency domain. We formulate the stacking procedure as a frequency-domain beam-forming problem. To estimate the optimal stacking weights, we perform a discrete Fourier transform over time for each CSG in the super group and construct 2D frequency panels F_i, $i = 1,..,N_{shots}$. Simple stack of the panels provides us some preliminary information about the signal. Each panel is represented as a complex-valued 2D matrix. Then eigenimage decomposition of the panels is computed using SVD analysis (Trickett, 2003). We assume that desired signal components are associated with the elder singular values, whereas noise components correspond to the smaller singular values. Using this decomposition, signal covariance COV_S and noise covariance COV_N matrices are estimated. Simple stacked panels for each frequency, F_{Stack}, are also used to construct covariance matrixes to constrain the weights.

The optimal stacking weights are elements of the first eigenvector of the matrix: $D = [COV_N^{-1} COV_S]$, i.e., $\vec{W}$ = 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 additional noise suppression in each stacked frequency panel using a Karhunen–Loève filter. This procedure delivers an enhanced single-frequency panel for a shot supergroup that could be input to a frequency-domain full-waveform inversion, or an array of processed frequency panels can be converted back to the time-domain for further processing.

3D Field Data Examples

We demonstrate benefits of the proposed approach on two real 3D land datasets from Saudi Arabia acquired with typical orthogonal acquisition geometry (Vermeer, 2005).

The first dataset is from a good data quality area. It has been acquired using a nonlinear 2 to 90 Hz sweep. The surface conditions in this area are relatively simple with smooth low relief east-west topographic variations (Figure 2a). Therefore the source and receiver layouts are quite regular. The inline and crossline sampling for receiver groups is 50 and 250 meters, respectively. Shot groups are spaced at 250 and 50 meters in inline and crossline directions, respectively. Receiver group size consists of 5 x 5 geophones covering 50 x 50 m, whereas each source group comprises three vibrators oriented in the crossline direction with a 12.5 m interval. This data has relatively good SNR (Figure 3a).

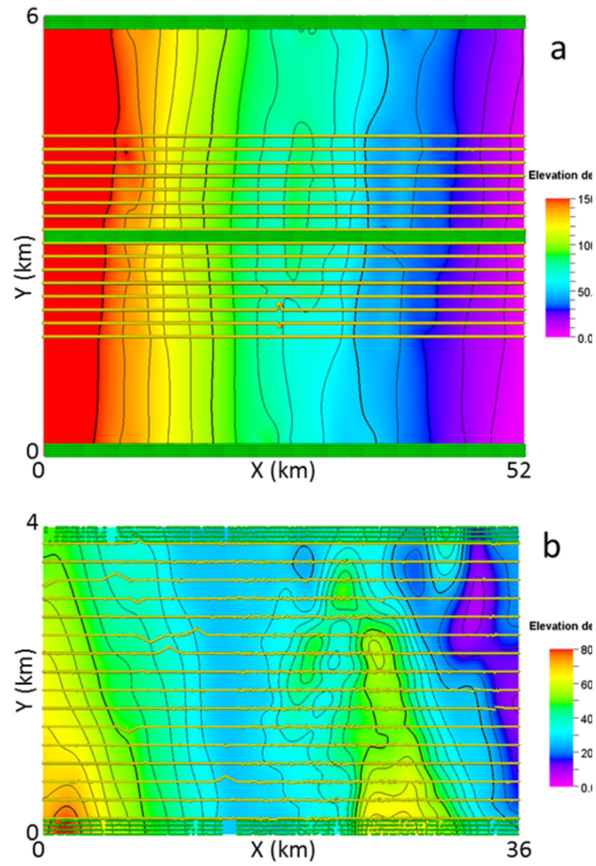

Figure 2: Geometry layout and surface condition comparison for first (top) and second (bottom) field datasets. Green and yellow dots correspond to the source and receiver positions, respectively. Top geometry is regular and topography smoothly varying from west to east. Geometry of the second dataset is irregular with many missing shots and crooked receiver lines. Surface topography has rapid variations in some areas.

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The second dataset is an example of very challenging data with extremely poor SNR and represents legacy data acquired with a narrowband linear sweep of 8 to 80 Hz. The source and receiver layouts are quite irregular due to rapid topography variations (Figure 2b) and various surface obstructions. Receiver groups comprise 6 x 12 geophones over 55 x 55 m, every 60 meters in the inline direction and 240 meters in the crossline direction. Source groups are every 60 m crossline and every 120 m inline. Due to the complex surface and near-surface conditions this data has very low SNR and has little visible signal on pre-stack gathers (Figure 5a).

We apply source side supergrouping and utilize both simple and weighted stack options for both raw and preprocessed datasets. The results are shown in Figures 3 to 6. Each plot has input data (right panel) and results of simple and weighted stacks (central and right panels, respectively). Red arrows on the plots mark the main reflections. AGC was applied for all panels for display purposes.

The first dataset from a good area has visible reflections (red arrows in Figure 3a) but their amplitude is almost at the same level as noise especially for shallow (~1.25 s) and deep (~2.5 s) part. Application of smart supergroup 5 x 5 with the supershot aperture of 250 x 1250 m, significantly improves SNR and makes both shallow and deep reflections more crisp (Figure 3b and 3c). As expected, weighted stacking does better job at near offsets by reducing blurring effect.

After applying conventional preprocessing the first dataset shows improved quality with most of the linear noise suppressed (Figure 4a). Simple stacking reinforces reflections and weighted stack improve SNR even further (Figure 4b and 4c). Similar to previous example weighted stack slightly improves signal at near offsets.

The second dataset from a challenging area has such a poor SNR that no reflections are visible on pre-stack gathers (Figure 5a). As such it is quite difficult to come up with any model of signal and noise for further processing. By using a supergroup of 4 x 7 shots with an aperture of 420 x 840 m, we greatly improve S/N ratio making reflections visible and ready for analysis (Figure 5b and 5c). In this case simple stack does slightly better job because weighted stack highlights similarity in data and is more sensitive to the noise nature.

The conventional processing flow aimed to suppress various noises, has a hard time with such a data (Figure 6a) while supergrouping substantially improves S/N ratio across all offsets including long ones (Figure 6b and 6c). Weighted stack in this case seems to work better for shallow reflections. It is interesting to compare a conventionally processed second dataset (Figure 6a) with supergrouping applied to raw data (Figure 5b and 5c). One can observe that this simple procedure that requires little input seems to produce pre-stack data of better quality compared to more conventional preprocessing. While supergrouped may result in some lateral smoothing, we believe it is fit-for-purpose for early processing stages where enhancing pre-stack signal is critical.

Conclusions

We presented a supergrouping method designed to improve pre-stack data quality for challenging 3D land datasets. It can be of value for both raw as well as data preprocessed for imaging. It goes beyond conventional group forming and can be used with large source/receiver sampling that conventional group forming cannot handle. It operates on original group-formed 3D data and does not require regular geometry. Such an approach can be of help for many processing stages. For poor quality data, it can help identifying obscured target reflections and create a signal model. We have presented an example of a dataset where few reflections can be identified without supergrouping. It may also enhance SNR for first break picking and velocity analysis or tomographic reconstructions. Supergrouping with variable aperture also reduces data volume, while at the same time improving pre-stack data quality. As a result we can improve turnaround time and design more efficient processing flows. Even for already preprocessed data, there may be room for smart supergrouping with smaller apertures for further improvement of SNR for imaging and inversion.

We outline two possible stacking options: simple stack and smart weighted stack. Simple stack is a combination of grouping and common-offset stacking that has an advantage in speed and computation cost. It may blur near-offset and shallow reflections and can be utilized when higher frequencies and near offset information are not so important. Smart weighted stack employs a similar procedure but with data-driven complex weights that enhance similarity between individual data panels. Therefore it has a better chance to correct for intra-group statics, align higher frequency data better and reduce blurring effects.

We conclude that smart supergrouping shows a significant improvement in data quality and will certainly help further data processing and velocity analysis.

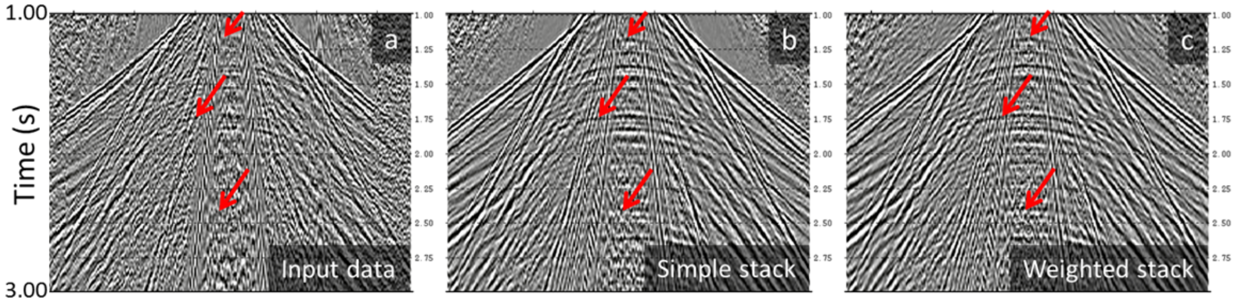

Figure 3. Near cable shot gather comparison for raw first dataset. Both stack methods highlight main reflectors (shown by red arrows), however weighted stack does slightly better job at near offsets for both shallow and deep reflections.

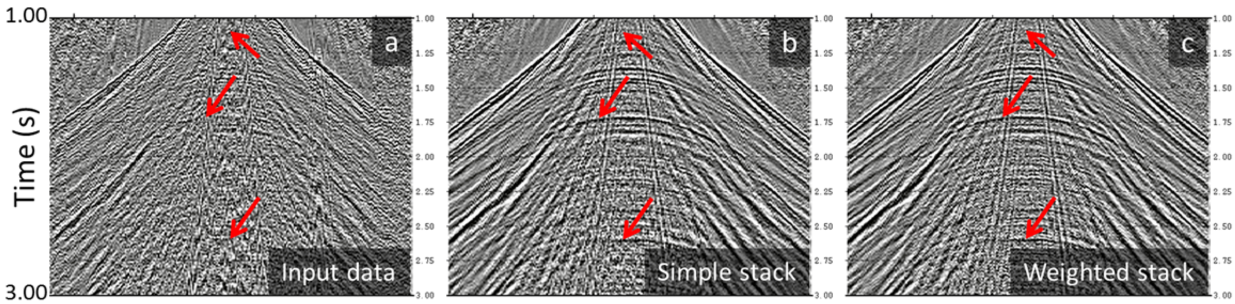

Figure 4. Near cable shot gather comparison for first dataset with conventional preprocessing. Similar to Figure 1 weighted stack slightly improves reflection continuity at near offsets for both shallow and deep reflections.

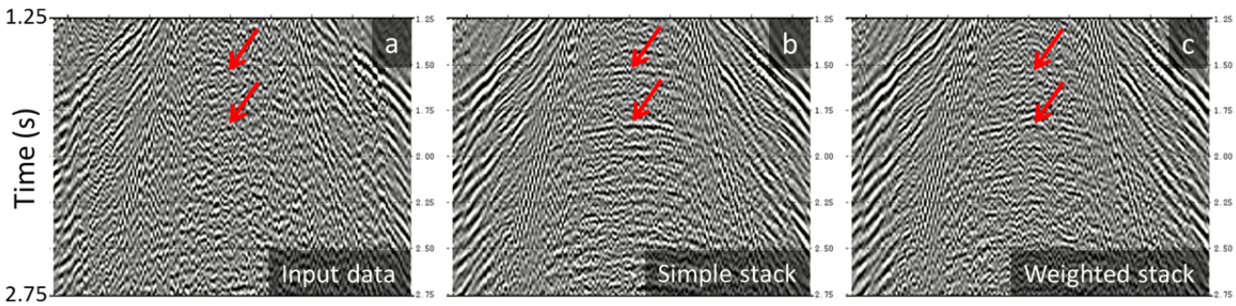

Figure 5. Near cable shot gather comparison for raw second dataset. Note very poor S/N ratio. Main reflections (shown by red arrows) are not visible at all on left panel while both stack methods bring them up. Weighted stack does slightly worse than simple stack in this case due to high sensitivity to the noise type.

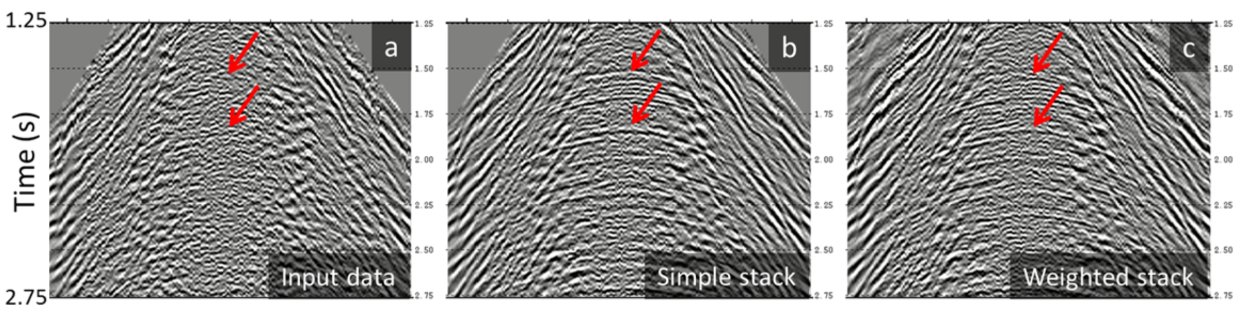

Figure 6. Near cable shot gather comparison for preprocessed processed second dataset. Signal is still almost invisible at input data panel and became clearly visible after stack. In this case weighted stack result is noisier but shows better continuity at small offsets.

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EDITED REFERENCES

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