Ground-roll attenuation based on SVD filtering

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SUMMARY

We present a singular value decomposition (SVD) filtering method for attenuation of the ground roll. Before the SVD computation, the normal move-out (NMO) correction is applied to the seismograms, with the purpose of flattening the reflections. SVD is performed on a small number of traces in a sliding window. The output trace is the central trace of the first few eigenimages. These contains mostly horizontally aligned signals, and other noise in the data will be suppressed. The new method preserves the character and frequency content of the horizontal reflections and attenuates all other type of events. We illustrate the method using land seismic data of the Tacutu basin, located in the north-east part of Brazil. The results show that the proposed method is effective and is able to reveal reflections masked by the ground-roll.

INTRODUCTION

Ground roll is a particular type of Rayleigh wave and has high amplitude, low frequency, and low velocity, being the main type of coherent noise in land seismic surveys. Ground roll is also dispersive and normally overwhelms the desired reflected signal. Because of its dispersive nature, ground-roll masks the shallow reflections, at short offsets, and deep reflections, at long offsets (Claerbout, 1983; Saatilar and Canitez, 1988; Henley, 2003).

Various new methods to filter ground roll have been proposed in recent years. Deighan and Watts (1997) proposed the use of wavelets which does not assume that the signal is stationary. Liu (1999) and Montagne et al. (2006) proposed the use of the Karhunen-Loève transform to estimate and subtract the ground roll from the common-shot gathers. SVD is a coherency-based technique that provides both signal enhancement and noise suppression. It has been implemented in a variety of seismic applications (Freire and Ulrych, 1988) Kendal et al. (2005) proposed a SVD-polarization filter for ground roll attenuation on multicomponent data. Tyapkin et al. (2003) proposed to use the data alignment method of Liu (1999) to make the coherent noise horizontally aligned in one or more time sections of a common shot gather. Chiu and Howell (2008) proposed a method that uses SVD to compute eigenimages that represent coherent noise in a localized time-space windows. Yarham and Herrmann (2006) proposed a two stage method of identifying and removing ground roll using the curvelet transform. Karli et al. (2008) proposed the use a Wiener filter in the estimation of ground roll via a reference noise such as a linear (or nonlinear) sweep signal. Melo et al. (2009) presents a filtering method for the ground-roll attenuation that uses a 2-D time-derivative filter.

In this paper we present a SVD filtering method for the ground-roll attenuation. First, NMO correction is applied to the seismograms, with the purpose of flattening the reflections. Next, SVD analysis is performed on a small number of traces in a sliding window along the x-axis. The filtered output trace is the center trace of the first few eigenimages. This preserves the amplitude and character of horizontal events and attenuates all other events. We illustrate the method using land seismic data of the Tacutu basin, located in the north-est part of Brazil.

SVD FILTERING

We consider a real data set $d(t,x_n)$, $t=1,\ldots,N_t, n=1,\ldots,N_x$, where the primary reflections have been corrected for NMO so that they are horizontally aligned along the x-axis. In order to enhance coherent signals along the x-axis we perform a local SVD analysis of a sub-set of the data $d(t,x_n), n=n_0-M,\ldots,n_0,\ldots,n_0+M$. This can be expressed by SVD as (Golub and van Loan, 1996).

$$\mathbf{d} = \mathbf{U}\begin{bmatrix}\Sigma \\ 0\end{bmatrix}\mathbf{V}^T \tag{1}$$

where $\Sigma = diag\{\sigma_1,\ldots,\sigma_{2M+1}\}$ which $\sigma_1 \geq \ldots \geq \sigma_{2M+1} \geq 0$. The matrices $\mathbf{U}$ of dimensions $N_t \times N_t$ and $\mathbf{V}$ of dimensions $(2M+1)\times(2M+1)$ are unitary such that $\mathbf{U}^{-1} = \mathbf{U}^T$ and $\mathbf{V}^{-1} = \mathbf{V}^T$. On component form this is

$$d(t,x_j) = \sum_{k=1}^{2M+1} \sigma_k u_k(t) v_k(x_j) \tag{2}$$

where $j = -M+n_0,\ldots,M+n_0$. The filtered data output contains only the first K eigenimages of the central trace

$$\bar{d}(t,x_{n_0}) = \sum_{k=1}^{K} \sigma_k u_k(t) v_k(x_{n_0})\,. \tag{3}$$

This operation is performed on all the input data with a step of one trace on space position. In each step a new SVD is performed and the output is computed as in equation (3). At the start and end of the data, the first and last $M+1$ traces in the sum of the first K eigenimages are used as output. The result is a filtered data set $\bar{d}(t,x_n)$ of the same dimension as the input data set where energy which is not coherent in the x-direction has been attenuated. Both the character and amplitude of the horizontal events are well preserved as they are represented by the first eigenimages which have the largest energy.

DATA RESULTS

The proposed method of SVD filtering was tested on the RL-5090 land seismic line. It contains 179 shots recorded at 4 ms sampling interval. There are 96 channels per shot in a split-spread geometry with offsets 2.500-150-0-150-2.500 m and 50 m between the geophones. The distance between the shots are 200 m giving a low CMP coverage of 12 fold.

SVD filtering to ground-roll attenuation

The flowchart for the data processing is shown in Fig. 1. First a standard processing sequence was applied: geometry, edit, preliminary spherical divergence correction, standard velocity analysis and NMO correction. Due to the limited CMP coverage, the data were then resorted into shot gathers before the SVD filtering was applied. In the filtering process we used a 5-trace window (M=2 in equation (1)) for the SVD analysis, and we kept the two most significant central eigentraces (K=2 in equation (3)).

The result of SVD filtering the shot gather in Fig. 2a is shown in Fig. 2b, and the residual noise is shown in Fig. 2c. The ground roll is very well separated from the horizontal events.

The original shot gather shown in Fig. 3a, is shown in Fig. 3b after f-k filtering and in Fig. 3c after SVD filtering. The SVD filter seems to have removed noise in a better way than the f-k filter.

The amplitude spectrum of each trace was computed, and the average amplitude spectrum for the three shot gathers in Fig. 2 are compared in Fig. 4. It is seen that the SVD filtering removes a substantial part, but not all, the low-frequency energy in the original gather.

The average amplitude spectrum of the three gathers in Fig. 3 are compared in Fig. 5. For high frequencies the SVD filter and the f-k filter show similar results. A large difference occurs below 10 Hz where all signal and noise energy have been removed by the f-k filter. There is substantial low-frequency energy left in the SVD filtered data.

Fig. 6 shows the velocity analysis of a supergather formed by 10 CMP gathers. The ground roll which is present in the data seriously degrades the velocity analysis. The same supergather after SVD filtering is shown in Fig. 7 together with the corresponding velocity analysis. It is seen that this velocity analysis has much better defined reflections than the one in Fig. 6.

Part of the stacked section obtained from the original data is shown in Fig. 8a. This should be compared with the stacked section shown in Fig. 8b obtained after SVD filtering the data.

CONCLUSION

We have developed a new and efficient SVD filter method which enhances horizontal events on seismic sections. The SVD filter process preserves the character and frequency content of the horizontal reflections and attenuate all other types of events. New applications and extensions for pre or post-stack seismic data, can be easily implemented. The method was successfully applied to ground roll attenuation on a land seismic data set. In particular, ground roll was virtually absent from the filtered pre-stack gathers.

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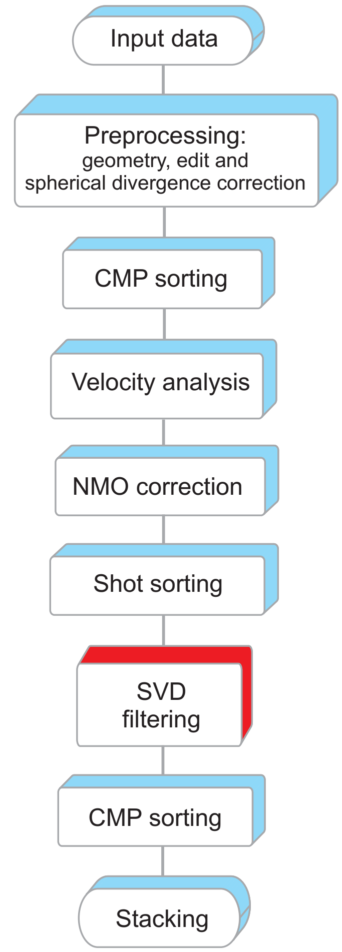

Figure 1: Flowchart for the seismic data processing.

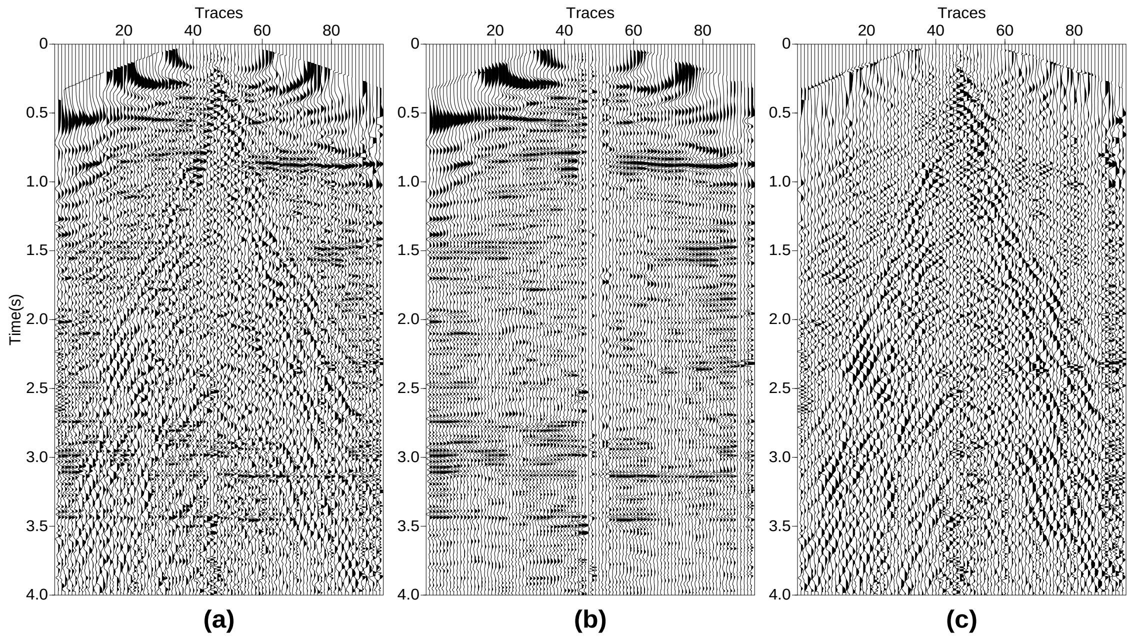

Figure 2: Signal and noise separation using SVD filtering. (a) input data, (b) output data (signal), (c) residual (noise).

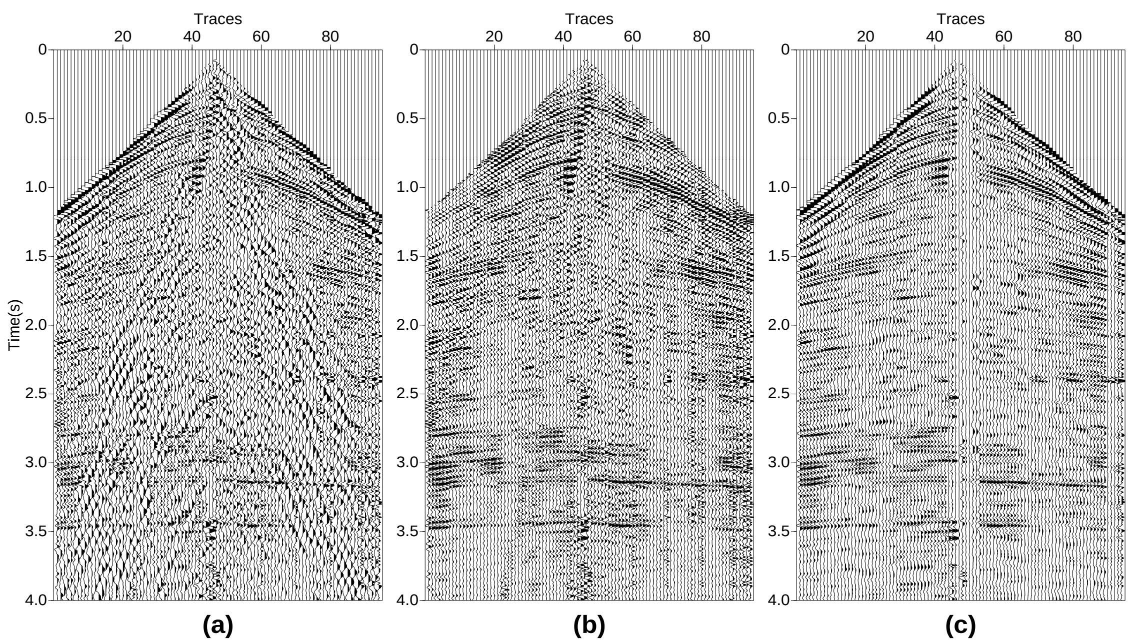

Figure 3: Comparison of SVD filtering with f-k filtering. (a) input data (b) after f-k filtering (c) after SVD filtering.

SVD filtering to ground-roll attenuation

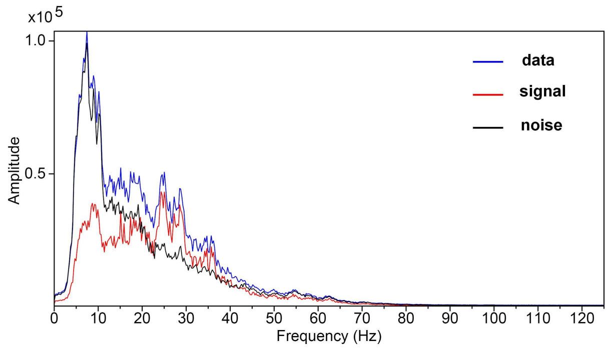

Figure 4: Average amplitude spectra of the data, signal and noise shown in figure 2.

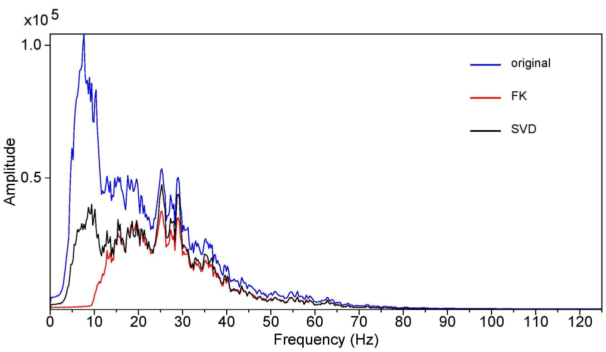

Figure 5: Average amplitude spectra of the data, f-k filtered data and SVD filtered data shown in Fig. 3.

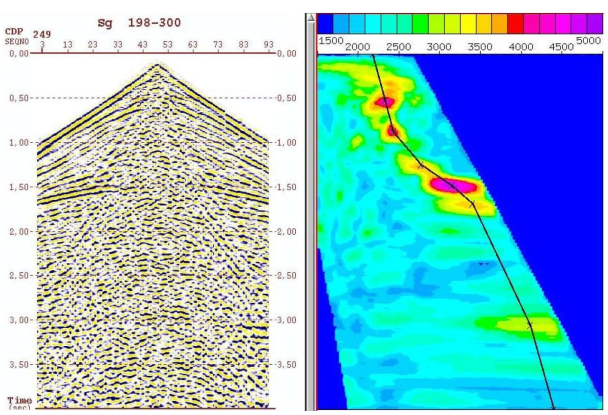

Figure 6: Input data and corresponding velocity analysis.

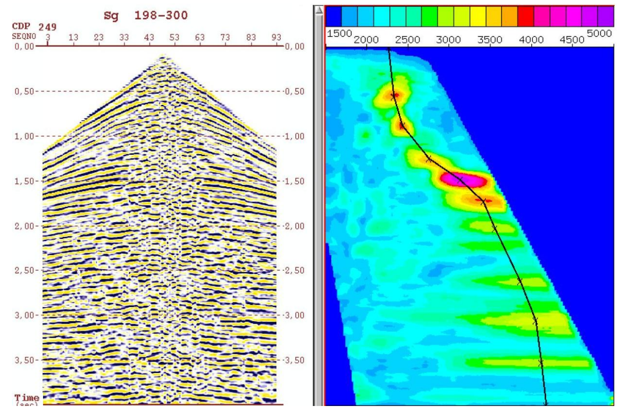

Figure 7: SVD filtered data and corresponding velocity analysis.

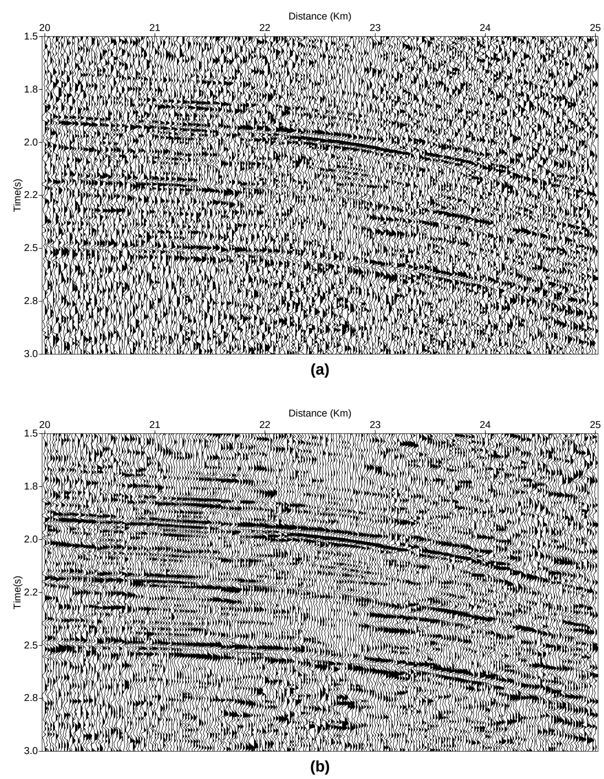

Figure 8: Details from the stacked sections: (a) original data (b) SVD filtered data.

EDITED REFERENCES

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REFERENCES

Chiu, S. K., and J. E. Howell, 2008, Attenuation of coherent noise using localized-adaptive eigenimage filter: 78th Annual International Meeting, SEG, Expanded Abstracts, 2541–2545.

Claerbout, J. F., 1983, Ground roll and radial traces: Stanford Exploration Project Report, SEP-35, 43–53.

Deighan, A. J., and D. R. Watts, 1997, Ground-roll suppression using the wavelet transform: Geophysics, **62**, 1896–1903.

Freire, S. L. M., and T. J. Ulrych, 1988, Application of singular value decomposition to vertical seismic profiling: Geophysics, **53**, 778–785.

Golub, G. H., and C. F. V. Loan, 1996, Matrix computations: Johns Hopkins University Press.

Henley, D. C., 2003, Coherent noise attenuation in the radial trace domain: Geophysics, **68**, 1408–1416.

Karsli, H., and Y. Bayrak, 2008, Ground-roll attenuation based on Wiener filtering and benefits of time-frequency imaging: The Leading Edge, **27**, 206–209.

Kendall R., S. Jin, and S. Ronen, 2005, An SVD-polarization filter for ground roll attenuation on multicomponent data: 77th Annual International Meeting, SEG, Expanded Abstracts, 928–932.

Liu, X., 1999, Ground roll suppression using the Karhunen-Loeve transform: Geophysics, **64**, 564–566.

Melo, P. E. M., M. J. Porsani, and M. G. Silva, 2009, Ground roll attenuation using a 2D time derivative filter: Geophysical Prospecting, **57**, 343–353.

Montagne, R., and G. L. Vasconcelos, 2006, Optimized suppression of coherent noise from seismic data using the Karhunen-Loève transform: Physical Review E, **74**, 1–9.

Saatçilar, R., and N. Canitez, 1988, A method of ground-roll elimination: Geophysics, **53**, 894–902.

Tyapkin, Y. K., N. Y. Marmalyevskyy, and Z. V. Gornyak, 2003, Source-generated noise attenuation using the singular value decomposition: 75th Annual International Meeting, SEG, Expanded Abstracts.

Yarham, C., U. Boeniger, and F. Herrmann, 2006, Curvelet-based ground roll removal: 76th Annual International Meeting, SEG, Expanded Abstracts, 2777–2780.