Ground Roll Removal and Signal Preservation by Cascading SVD Polarization Filters with Localized Fk-Filters

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Introduction

The attenuation of surface wave energy, ground roll or Rayleigh waves in particular, is a challenging problem on many land datasets. Moreover, the current drive within the industry towards single sensor data acquisition, systems be it single component (1C) or multi component (3C), obviates the traditional benefit of receiver arrays for surface wave reduction. Single sensor acquisition systems are preferred over receiver array systems in areas where higher frequency content of the signal is demanded. 3C systems require single sensor acquisitions to avoid problems with array misalignments and S-wave statics.

Ground roll can be attenuated using a range of tools like f-k filters, fx deconvolution, slant stacking, polarization filtering and even band pass filtering. The reality is that many of these techniques often fail to sufficiently improve the data quality within the ground roll bandwidth (≈ 0-25 Hz.). This can happen due to a variety of reasons like inadequate geometries, aliasing, or backscattered and 'badly behaving' ground roll. Many processing flows in which true amplitude recovery is secondary to obtaining a good image therefore include one or more passes of a band-limited and time-dependant amplitude scaling to downscale 'bursts' of high-energy noise. The downscaled residual ground roll noise will typically reappear after deconvolution, thus requiring a second pass of noise attenuation and/or spectral balancing. The end result is that not much usable low-frequency signal remains within the ground roll cone and that the amplitude properties of the remaining signal are unreliable.

This work presents the successful implementation of a cascaded processing flow that removes ground roll energy whilst preserving the underlying low frequency reflected signal. This flow combines polarization filtering and localized fk-filtering to remove the ground roll from the vertical component of a 2D 3C line. The flow excludes any form of adaptive amplitude scaling and aims to preserve true signal amplitudes.

The polarization filter that is used in this study is described in De Meersman et al. (2005). It models the noise by adaptively fitting an ellipse to the 3C hodograms (3C particle motion). This is done using a sliding-window, complex-numbered SVD where the data window contains the analytic signal of a number of neighbouring 3C stations. The data from neighbouring stations is included to help constrain the waveform of the ground roll estimate. An approximate ground roll moveout correction is applied within the window and relative to the station that is being filtered. The filter operates in three stages: (1) adaptively estimate the first 3C eigen-image, (2) detect the ground roll and zero any part of the 3C eigen-image that is not identified as noise and (3) deduct the resulting noise estimate from the raw data to obtain the filtered 3C data. The polarization filter is cascaded with a proprietary filter known as ‘Coherent Noise Attenuation’ (CNA). This localized least squares fk-filter is implemented in the fx domain and allows for irregular spatial sampling.

This cascaded approach allows us to benefit from the strengths of both filters whilst avoiding their weaknesses. The polarization filter models the ground roll by least squares fitting an ellipse to the 3C signal within a sliding window. This allows for relatively fast changes in amplitude and phase, which is an advantage when different ground roll modes interfere or when dealing with backscattered energy. There is, however, the danger of using too short data windows which results in over fitting the data and hence the removal of reflected signal. The CNA filter uses apparent velocity to separate the signal from the noise. It performs well when the ground roll and reflected signal reside in separated apparent velocity regions, but it is less effective when handling backscattered, dispersive and interfering noise.

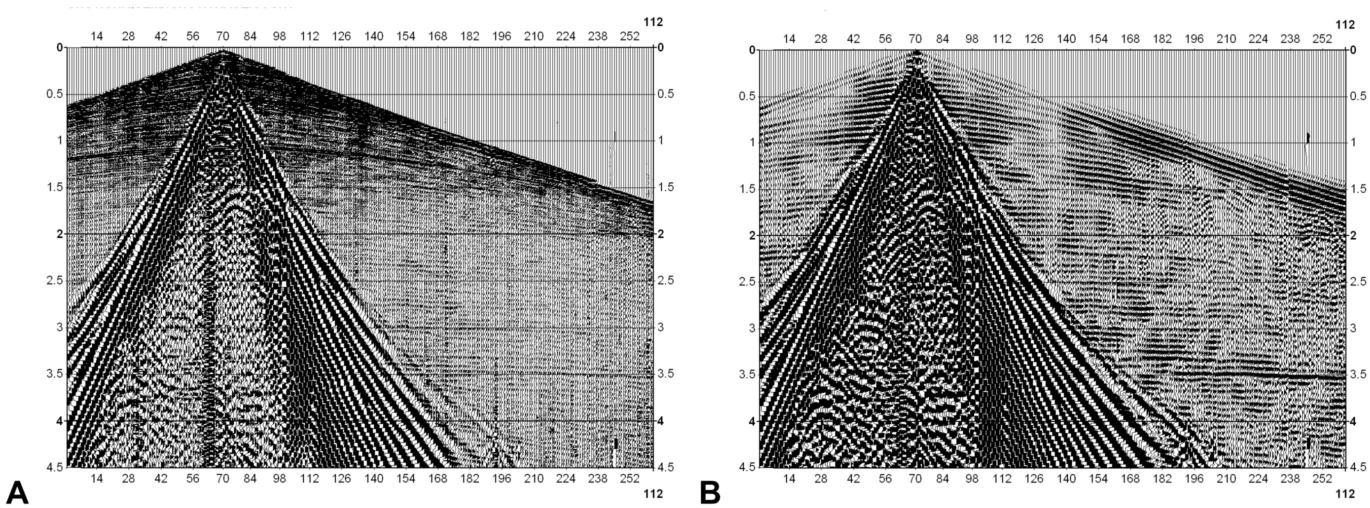

Figure 1. (A) Vertical component raw data shot gather example after spherical divergence correction. (B) Same data example after application of a lowpass filter with corner frequencies of 15 and 20 Hz and a constant gain increase. There is abundant low frequency signal visible outside the ground roll cone, but none inside.

Dataset

The 2D-3C line we use for testing was shot in 1995 in Eastern Hungary. The approximate station interval is 15 meters with an average of 260 stations per shot. This dataset was selected mainly for the reasons summarized below:

1. Good data quality with reflections that are clearly visible on the raw shot gathers (Figure 1).
2. High energy surface wave noise that is approximately 40 dB higher energy than the underlying reflected signal (Figure 2A and 2B).
3. The ground roll consists of pure mode energy as well as scattered energy and covers the 0-20 Hz bandwidth.

4. The higher ground roll frequencies are spatially aliased.

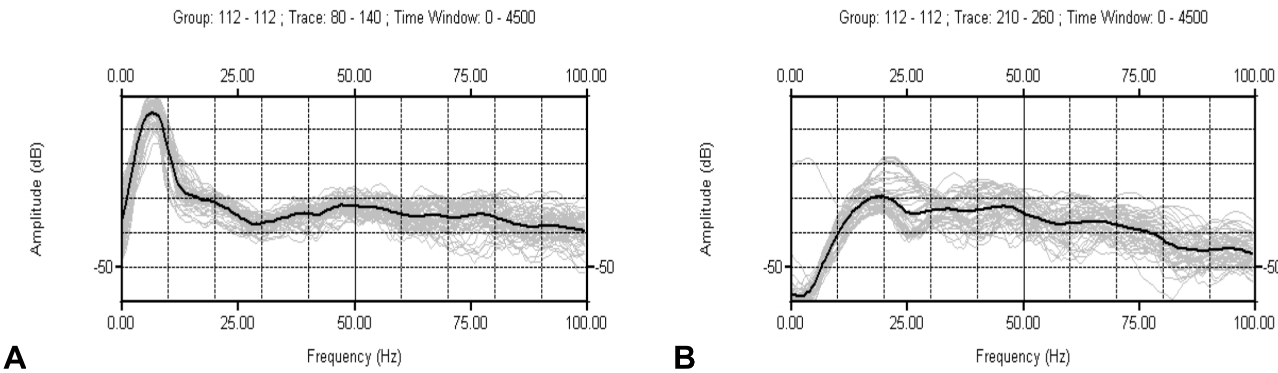

Figure 2. Amplitude spectra (in dB) for 60 near offset traces (A) and 50 far offset traces (B). The spectra of individual traces are plotted in grey and the average spectrum is plotted in black. The average spectrum of the near offset traces shows a 30 dB, 7 Hz ground roll peak relative to amplitudes in the 25-50 Hz band. On the average spectrum for the far offset traces we have a 10 dB trough at 7 Hz and relative to the 25-50 Hz band. This indicates that the signal-to-noise ratio in the ground roll bandwidth (0-20Hz) is approximately 40 dB down.

Results and Conclusions

Figure 3A shows the results after application of an aggressive polarization filter. This filter uses a short filter window of 50 ms and removes most of the ground roll energy. Unfortunately, a significant part of the reflected energy has been attenuated as well. Figure 3B shows the resulting vertical component using a processing flow that includes multiple passes of CNA (least squares fk-filtering) and adaptive noise subtraction. The amount of ground roll energy was significantly reduced, but the filter introduces some artefacts and removes some of the reflected signal. Figure 3C shows the filtered vertical component after application of a mild polarization filter. A significant amount of ground roll energy has been removed. The remaining low frequency signal clearly contains significant amounts of preserved reflected energy as well as residual ground roll energy. Figure 3D gives the vertical section after our cascaded filter approach. This applies the localized least squares fk-filter (CNA) after the mild polarization filter in Figure 3C. Note that some aliased ground roll residual remains.

Figure 4 shows the spectra of a number of near offset traces after ground roll attenuation. We use the same traces as those in Figure 1A. Comparison of the spectra indicates we have successfully removed the 0-20 Hz ground roll noise. Moreover, the low frequency content of the filtered near offset spectra strongly resembles that of the far offset traces in Figure 1B. With the image in Figure 3D this suggests our filter approach has greatly reduced the noise within the data and done no, or little harm to the low frequency reflected energy.

Besides simplicity, the presented processing flow has the advantage that it provides significant signal-to-noise improvements at an early stage in the processing flow. Evidently this will benefit all subsequent processes that are applied to the data. Pending further testing we conclude that our approach is potentially useful for AVO compliant ground roll attenuation. The noise is modeled and directly subtracted from the raw data without using of any form of adaptive rescaling of noise and/or signal.

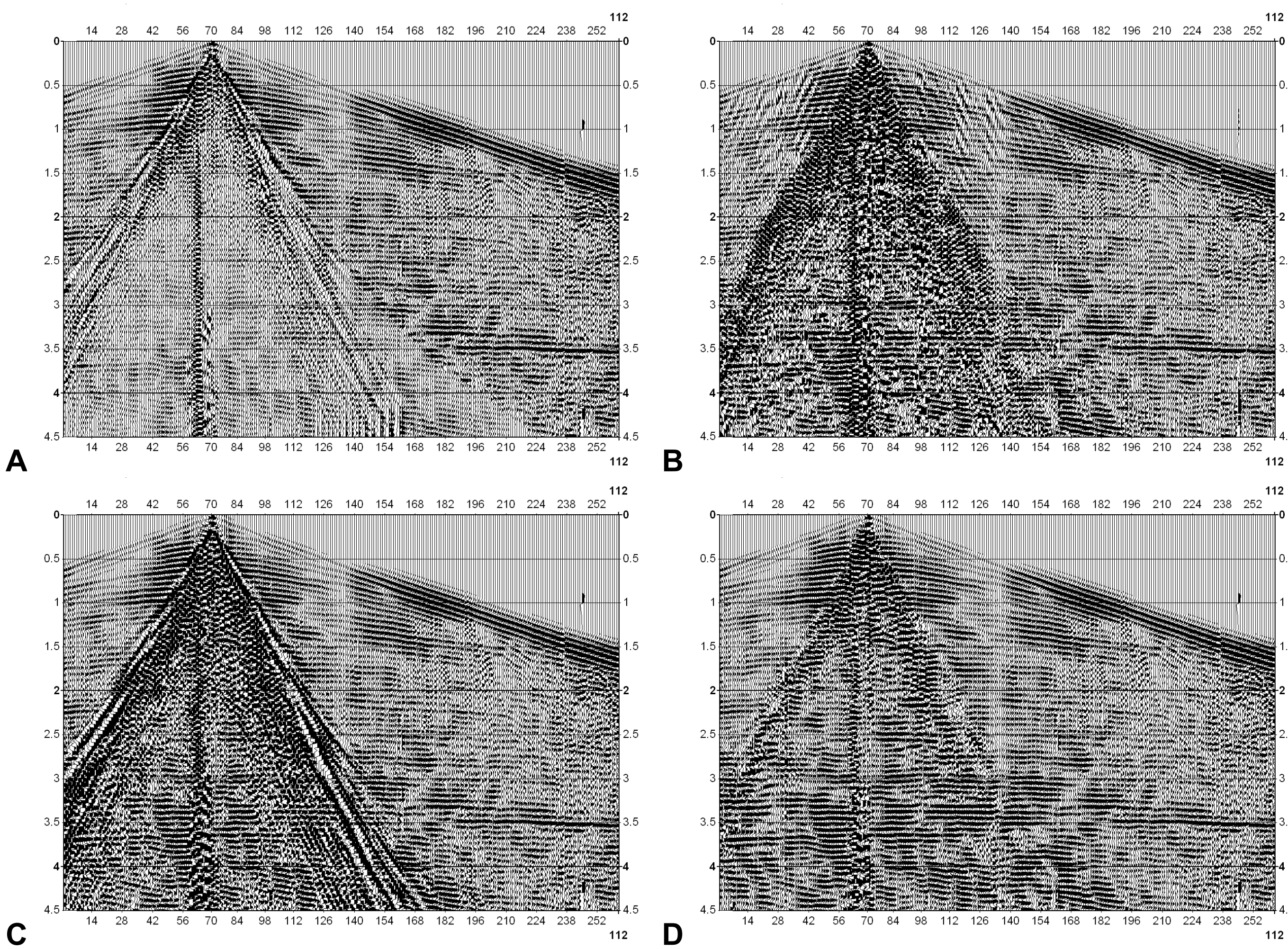

Figure 3. Vertical sections of the data in Figure 1 after ground roll filtering using different approaches. The data bandwidth is limited to that of the ground roll using a low-pass filter with corner frequencies of 15 and 20 Hz. (A) Data after aggressive polarization filtering using a 50 ms and 9 3C trace data-window. (B) Data after filtering using multiple passes of CNA (least squares localized fk-filter). (C) Data after mild polarization filtering using a 150 ms and 9 3C trace data-window. (D) Data after a mild polarization filter that is cascaded with CNA.

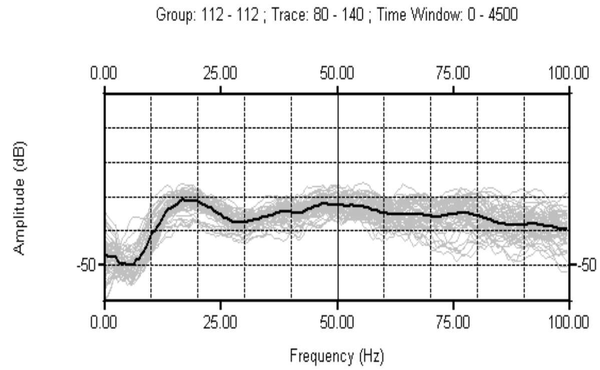

Figure 4. Amplitude spectra (in dB) for the 60 near offset traces shown in Figure 1A and after polarization filtering and CNA filtering. The noise attenuation has successfully removed the 40 dB noise peak around 7 Hz. Note the resemblance of the spectrum of the filtered near offset data with that of the unfiltered far offset traces in Figure 1B. This suggests the noise attenuation has removed no or little reflection energy in the 0-20 Hz band. Also, no high frequency energy was removed.

Acknowledgements

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References

De Meersman, K., and Kendall, R., 2005, A complex SVD-polarization filter for ground-roll attenuation on multicomponent data: EAGE Extended Abstracts, 67th Conference & Exhibition, Madrid, Spain.