

A complex SVD-polarization filter for ground-roll attenuation on multicomponent data

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Summary

Single sensor MEMS type (multicomponent) data offer the potential for improved data quality, simplified field operations, reduced sensitivity to tilt and greater dynamic range, as compared to conventional coiled geophones (Gibson et al, 2003, Behr et al, submitted to CSEG Convention and Ronen et al, submitted to CSEG Convention). However, the majority of geophysicists in the exploration industry still have concerns about ground roll in the absence of receiver arrays. By their very nature, multicomponent (3C/9C) datasets provide information on the full wave-field and therefore offer new full wave-field solutions for the ground roll problem. Here we introduce a time-domain 3C complex SVD (Singular Value Decomposition) polarization filter that is optimized to remove most ground roll energy, whilst preserving the reflected energy. We use synthetics and real data to test our polarization filters performance on both prestack (shot) and poststack (final stacks) data. Finally, vertical-component stacks from two polarization filters with different design length are compared to a control stack with no ground roll attenuation and a shot domain f-k filtered stack. We found that our polarization filter provides the best quality stacks.

Introduction

In many cases, the success of a land survey partially depends on ground roll suppression and the recovery of low frequency reflections. These considerations have traditionally driven survey design and data processing. The traditional approaches to attenuate ground roll include the use of source and receiver arrays, the stack array method (Anstey, 1986), or filtering in the frequency, f-k, τ -p, or wavelet domains. Here we focus on the ground roll problem for (3D) multicomponent data. The manner in which these data are acquired often prevents the use of many traditional attenuation techniques. The use of source and receiver arrays becomes especially impractical for 3D surveys, and more generally, intra- and inter-array S-wave statics can not be neglected. The tight restrictions the stack array method puts on fold and CDP bin population are often not met (Anstey, 1986). Contrary to this, multicomponent data also provide the geophysicist with the opportunity to apply powerful ground roll attenuation methods. One such method that uses full wave-field information is polarization filtering.

The polarization filter we present here combines previous efforts by Franco and Musacchio (2001) and Liu (1999) with the concept of complex polarization analysis (Vidale 1986). Complex SVD decomposes the data into its elliptically polarized components and is better suited to deal with ground roll than real SVD where linear polarizations are assumed. The filter can be tuned by a number of parameters, which include an offset dependant filter application region, the application frequency bandwidth and the filter design window (Figure 1). This sliding design window is the part of data that is used to derive the polarization filter. The ground roll estimate is obtained by applying the time and offset dependant filter to the central 3C sample of the relevant design window. The window has three parameters: (1) length, in time or number of samples, (2) width, in number of neighboring recording stations that are included, (3) the offset dependent linear moveout correction applied to data from the different 3C stations.

Figure 1: Polarization filter parameters: 1, gray lines mark the filter application region; 2, in this example, ground roll is estimated from the 50 Hz low pass filtered data; 3, the filter design window is defined by a length in time, a width in number of stations and a linear moveout correction between those stations. Although not shown on the figure, it is implied that all parameters apply equally to data from inline and crossline components.

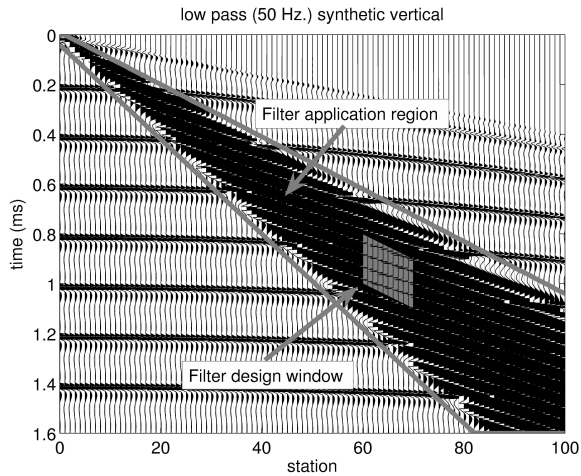


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Filter theory

Our adaptive 3C complex filter in matrix notation is:

$$\mathbf{D}_f = \text{Re}\langle \mathbf{D} - \mathbf{D}_{lp} \mathbf{F}(t) \mathbf{S} \rangle \quad \text{with} \quad \mathbf{S} = \begin{bmatrix} \dots & 0 & 1 & 0 & 0 & 0 & \dots \\ \dots & 0 & 0 & 1 & 0 & 0 & \dots \\ \dots & 0 & 0 & 0 & 1 & 0 & \dots \end{bmatrix}. \quad (1)$$

Here, \mathbf{D}_f is the t by 3 matrix in which the columns hold the filtered vertical, inline and crossline seismograms of a given 3C station. \mathbf{D} is a matrix with same dimensions as \mathbf{D}_f , but its columns now hold the unfiltered analytic signals of the vertical, inline and crossline components. These analytic signals are complex with the original seismogram as the real part and its associated Hilbert transform as the imaginary part. \mathbf{D}_{lp} is the t by 3 matrix with low-pass filtered analytic signals from the n selected neighboring 3C stations. A constant moveout correction, relative to the 3C station of interest can be applied to the different samples in \mathbf{D}_{lp} . $\mathbf{F}(t)$ is a $3n$ by $3n$ time-dependent complex filter operator and \mathbf{S} is the sparse matrix whose nonzero elements relate to the 3C station that is being filtered. The factor $(\mathbf{D}_{lp} \mathbf{F}(t) \mathbf{S})$ represents the analytic signals of the estimated ground roll. $\text{Re}\langle \rangle$ discards the imaginary part of the bracketed expression. The filter operator, $\mathbf{F}(t)$ is derived using the first eigenvector $\mathbf{v}(t)_1$ of the time-dependent data covariance matrix $\mathbf{C}(t)$. $\mathbf{C}(t)$ is calculated using the rows $\mathbf{d}(t)_{lp}$ of \mathbf{D}_{lp} for the time-window $[t-T \ t+T]$:

$$\mathbf{F}(t) = \mathbf{v}(t)_1 \mathbf{v}(t)_1^T \quad \text{and} \quad \mathbf{C}(t) = \sum_{i=t-T}^{t+T} \mathbf{d}(i)^T \mathbf{d}(i) = \sum_{j=1}^{3n} \lambda(t)_j \mathbf{v}(t)_j \mathbf{v}(t)_j^T. \quad (2)$$

Data Example

After testing our polarization filter on synthetic data with encouraging results, we moved on to a real data example (2D/3C) acquired in Eastern. The data were acquired in 2002 using dynamite sources and 3C MEMS sensors. The polarization filter is applied on raw 3C shot gathers after tilt a correction. Typically, the shot gathers are split-spread and consist of approximately 250 traces that are recorded at 15 m trace intervals. Ground roll frequencies are usually restricted to the 0-15 Hz band and peak at approximately 8 Hz. Moreover, within this band the signal-to-noise is very low and a >30 dB power difference between ground roll and signal is common. The ground roll is dispersive and spatial sampling is sufficient to avoid spatial aliasing.

A wide range of filter parameters were tested on a number of shot gathers to determine the filter that best removes ground roll while preserving the signal. Tests showed that the main parameters controlling filter performance are the frequency application bandwidth and the length and the width of the design window. The length mainly controls the amount of energy that is removed and wider filters are better at preserving reflection energy. The optimal filter parameters determined for these data were a design window of 84 ms long, 7 stations wide with a 2 ms/m moveout, and a 0-15 Hz operating band. In Figure 2, the 0-15 Hz low pass

filtered vertical and inline component of a representative shot are compared before and after the application of the polarization filter with these specifications. The signal-to-noise improvement is obvious as reflections that were previously invisible are now clearly resolvable on the gathers.

The same data were also used to generate a number of vertical component stack sections with different types of ground roll attenuation (Figure 3). The first is a control stack with no ground roll attenuation. The second is the result for a localized shot domain f-k-filter. Stack 3 and 4 are the result of two polarization filters with slightly different design length (68 ms versus 84 ms). Both filters had equal design widths of 7 stations, a moveout of 2 ms/m and were applied in the 0-15 Hz band only. Spiking deconvolution, using the same operators, was applied to all traces and all stacks were low pass filtered to permit comparison. Overall, the polarization filter produces the best stacks with more continuous reflections of increased phase stability. Both polarization filter stacks are affected by a striping that is caused by a ground roll residual left in the data. The stack from the 68 ms filter shows the least striping as this filter removed more ground roll energy. However, this shorter filter also slightly decreases reflection amplitudes. The f-k stack is affected with a random looking ground roll residual that obscures the underlying reflections more. Post-stack processing should be applied to all results, but given the nature of the residual ground roll, best results are expected for the polarization filtered stacks.

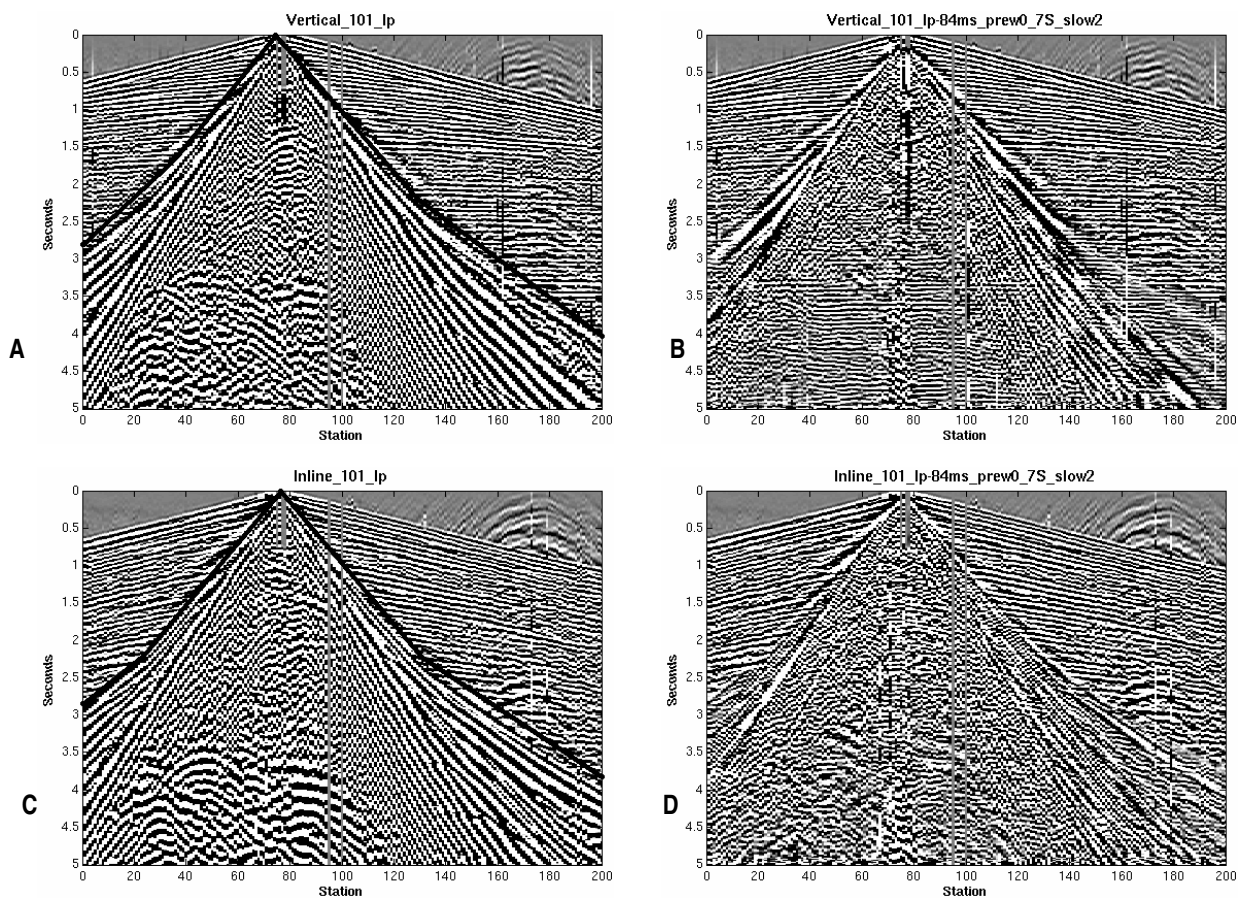


Figure 2: Raw and polarization filtered, 0-15 Hz. vertical and inline shot gathers of a representative shot gather. The filter design window is 84 ms long, 7 stations wide and has a linear moveout of 2 ms/m. The filter operates in the 0-15 Hz band. The filter is applied only on the data below the bold line that marks the start of the application region. **A:** Vertical component before filtering. **B:** Vertical component after polarization filter. **C:** Inline component before filtering. **D:** Inline component after polarization filter.

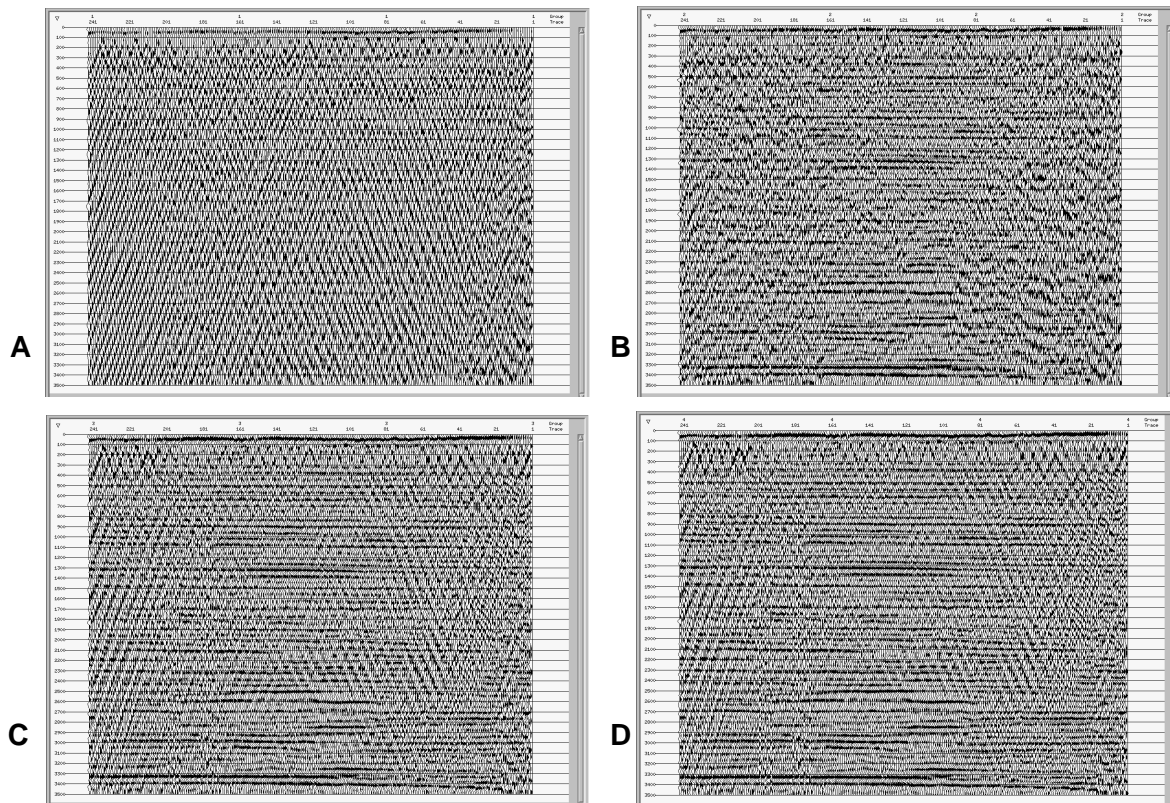


Figure 3: Vertical component stack section with different types of ground roll attenuation. All examples were generated using the same statics and spiking deconvolution operators and a 25 Hz low pass filter. **A:** Control stack with no ground roll attenuation. **B:** Stack from a localized F-K-filter. **C:** Result for a polarization filter using an 84 ms long and 7 stations wide design window and 2 ms/m moveout. **D:** Results for a polarization filter with 68 ms long and 7 stations wide design window and 2 ms/m moveout.

Conclusions

Our work demonstrates the use of complex SVD polarization filters to attenuate ground roll on 3C data. The filter takes a statistical approach to the ground roll problem and uses data from neighboring 3C stations to derive the most likely ground roll waveform for the station of interest. Using synthetic and field test data, we were able to improve signal-to-noise in the ground roll band on the vertical component by approximately 30 dB. We find that the polarization filter is, in this case, better than an f-k-filter, resolving more reflections and improving both reflection continuity and phase stability.

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