Ground Roll Suppression Using the Radial-Wavelet Transform

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Abstract

The Radial Transform rearrange the amplitudes of the seismic data, from the distance-time domain to the angle-time domain. Linear events in the distance-time domain tend to be sampled as a vertical event in the angle-time domain, while the reflections maintain its original shape. The Wavelet Transform decomposes the original shot-gather into different sub-bands, whose coefficients are differently oriented. Therefore, vertical events, like the ground roll, are isolated from the horizontal events (reflection). This paper proposes a method for ground roll suppression based on the joint implementation of these two transforms, named the Radial-Wavelet Transform.

Introduction

The ground roll is a dispersive linear noise, with low frequency, low velocity and high amplitude, that occurs frequently in land-based seismic acquisitions. This kind of noise tends to hide the reflections of the data, lowering the signal/noise ratio, making the velocity analysis more difficult and reducing the quality of the stacked section.

The Wavelet Transform, as shown in Almeida and Porsani, 2012 and Matos and Osorio, 2002, can be used to decompose the seismic data into different bands, effectively segregating the ground roll from the signal of interest. However, in order to obtain an adequate seismic image which reflects the sub-surface, it's necessary to apply the wavelet transform after normal move-out correction in order to preserve the shallower reflections (Almeida, 2013).

The Radial Transform, in Ottolini, 1979, was used in Seismic Migration and Imaging, for separating upgoing and downgoing waves. In the seismic processing it is used to transform the seismic data from the distance-time domain (XT) to the angle-time (RT), making linear events show as vertical events, and conserving the horizontal events (Henley, 1999). This makes the ground roll appear as a straight vertical event, placed in a smaller band in the middle of the image, making the processing more effective. As observed in Manenti et. al., 2011, it's not necessary to apply the normal move-out correction before the filtering while in the RT domain, even in methods that rely in the horizontal coherence of adjacent traces.

This paper proposes a method based on the implementation of both transforms, eliminating the need to use the normal move-out correction before the filtering and successfully isolating the ground roll from the signal of interest.

The Radial Transform

The Radial Transform (RT) is a simple amplitude rearrangement of the seismic data $S(x,t)$, usually placed in the distance-time domain (XT), to the angle-time or velocity-time domain (RT). This method requires a focus, with coordinate (x_0,t_0), that will be the origin of the angles of the RT. This process can be described as equation (1) (Henley, 1999):

$$\mathbf{R}\{S(x,t)\} = S'(v,t') \Rightarrow \mathbf{R}^{-1}\{S'(v,t')\} = S(x,t) \qquad (1)$$

The parameters t' and v are described in (2) as:

$$t' = t - t_0 \, , \, v = \frac{x - x_0}{t - t_0}. \qquad (2)$$

Although the focus can be placed anywhere in the seismogram, for the processing it's usually best placed on the virtual source of the data.

For rearranging the amplitudes of the data, some sort of interpolation is necessary. Manenti et. al., 2011, used the method described in equation (3), that could transform the data back and forth, with minimal loss of signal.

$$\tilde{A} = w_1 A_1 + w_2 A_2 \rightarrow w_i = \frac{{d_i}^{-2}}{{d_1}^{-2} + {d_2}^{-2}}, \qquad (3)$$

where d_1 and d_2 are the distance from the desired position to the sample, along the x-axis.

The Wavelet Transform

The wavelet transform (WT) uses compactly supported functions, denominated wavelets, in order to represent a given signal. By making the wavelet dilate or contract, the wavelet transform allows one to observe the signal at multiple resolution windows (Daubechies, 1992). This approach makes it more suitable to represent and analyze non-stationary signals, such as the seismic traces.

In it's discrete bi-dimensional form, the wavelet transform uses filter banks composed by a low-pass and a high-pass filter in order to decompose an image into various levels, according to the Multiresolution Analysis (Mallat, 1989). The decomposition procedure involves the convolution between the filter and the signal followed by a down-sampling operation. To obtain the reconstructed signal, it's sufficient to reverse the flow, using the appropriate filters.

Each level will contain four sub-bands, which will contain coefficients of different orientations and frequencies, depending on which dimension each filter was applied (Cohen, 1993). Figure 1 shows as schematic representation of the sub-bands in a three-level decomposition.

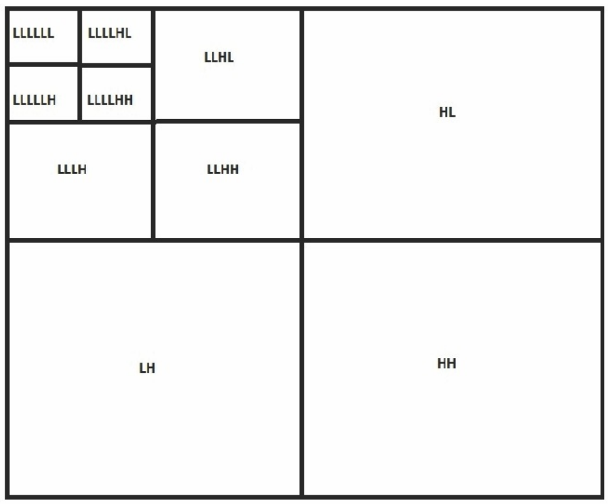

Figure 1: Sub-bands schematic representation in a three-level wavelet transform.

Radial-Wavelet Transform

As seen in Almeida, 2013, for suppressing the ground roll with the WT method, it was necessary to apply the NMO correction, in order to preserve the shallower reflections. However, the RT rearranges the seismic data, turning all linear events into vertical events. Because of its characteristic, the WT works more effectively, separating the noise from the signal of interest. Therefore, this affinity between both methods makes the Radial-Wavelet transform (RWT) more efficient for the suppression of linear events in the seismogram.

The proposed method was tested using a land-based seismic data from Line 5090 of the Tacutu basin, located in the North-East of Brazil. It contains 179 shots recorded in 1001 samples at 4 ms sampling interval. Each shot has 96 channels, in a split-spread geometry with offsets from -2500 m to -150 m and from 150 m to 2500 m and 50 m between geophones. The distance interval of shots is 200 m, and a CMP coverage of 12 fold.

The steps are described in the flowchart in Figure 5 with first the pre-processing of the data (geometry, mute and kill of noisy traces), the direct RWT, between the angles of 77 and 102 degrees, with this interval discretized in 500 angles, suppression of vertical band, inverse RWT, then sorted to CMP families. After that, NMO correction was applied to the data, followed by stacking.

Results

In the original data (Figure 7a), it was applied the direct RT, after the RT, the WT was applied, decomposing the data, once in the RT domain (Figure 7b) into four different bands; softened, vertical, diagonal and horizontal bands (Figure 8). After the decomposition, the inverse WT was applied (Figure 7c), followed by the inverse RT (Figure 7d). The RWT preserved the data's structures, as we can see in Figure 7, and signal, as seen in Figure 2. In Figure 3, the frequency spectrum of the four bands shows that the ground roll got restricted only in the vertical band, the one suppressed for the reconstruction of the data. Figure 4 and 6 show how effective the RWT is just without using the vertical band on the reconstruction of the seismogram. The super-gathers and velocity spectrum in Figure 10 show how the RWT method raised the signal/noise ratio and coherence of the data, making the velocity analysis easier. The filtering also enhanced the quality of the stacked section, in comparison with the original data, in Figure 9, with stronger and more continuous reflectors. It can also be observed in a detail scale, as in Figure 11.

Conclusions

The Radial-Wavelet Transform showed up to be a good method for filtering linear events such as the ground roll. The results obtained with the Tacutu basin data and the RWT's low computing cost make it an excellent alternative for enhancing the velocity analysis spectrum and the final stacked section.

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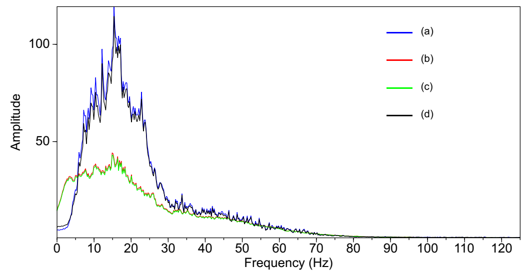

Figure 2: Frequency spectrum. Original shot-gather in (a), after direct RT in (b), after inverse WT in (c), after inverse RT in (d).

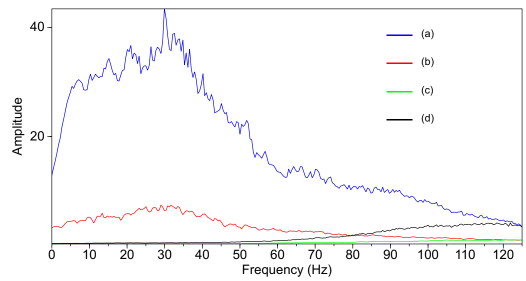

Figure 3: Frequency spectrum. Softened band in (a), vertical band in (b), diagonal band in (c), horizontal band in (d).

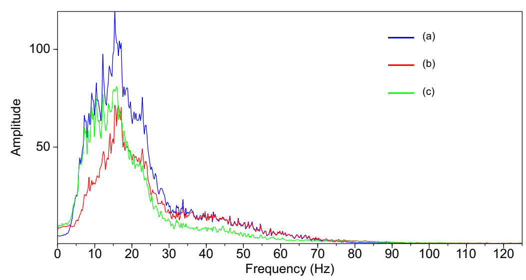

Figure 4: Frequency spectrum. Original shot-gather in (a), filtered shot-gather in (b), difference between (a) and (b) in (c).

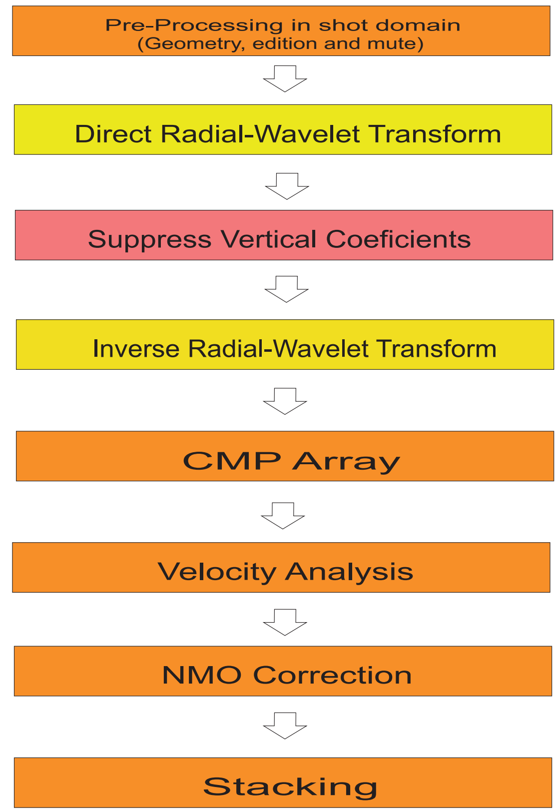

Figure 5: Flowchart of the processing made.

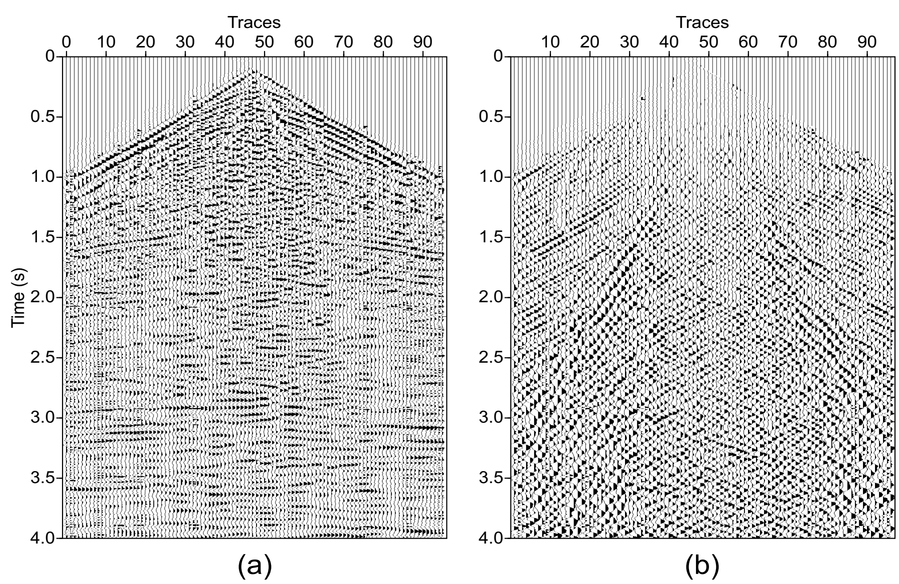

Figure 6: Filtered shotgather in (a) and difference between 7a and (a) in (b).

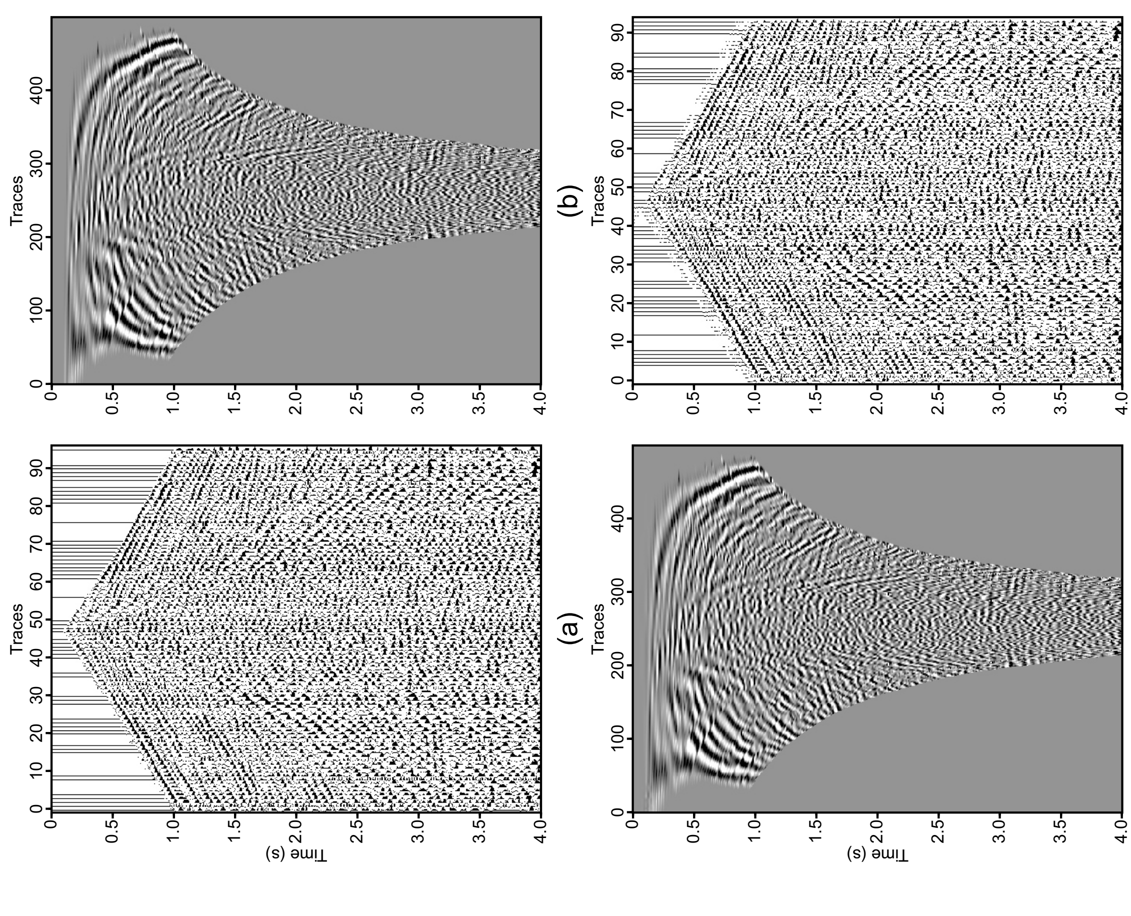

Figure 7: (a) - Original shotgather, (b) - data after the direct RT domain, (c) - data after the inverse WT, (d) - shotgather after the inverse RT.

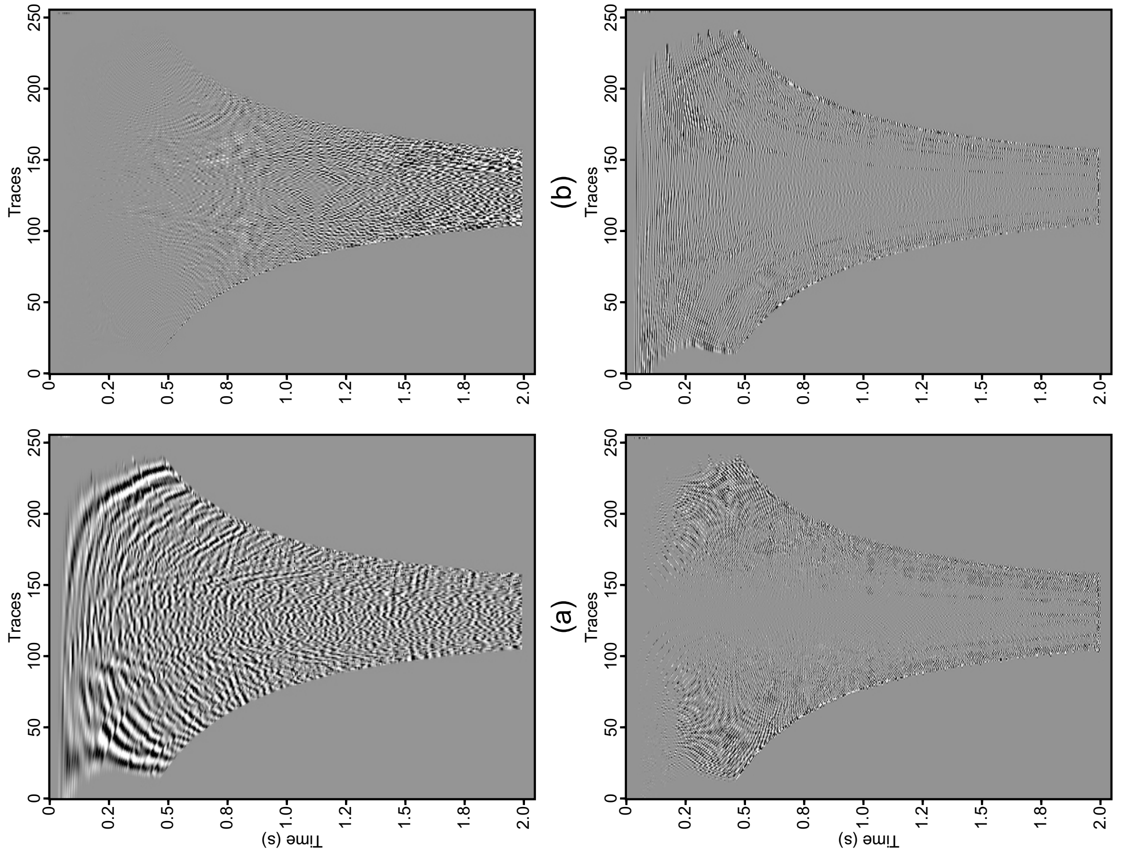

Figure 8: Data on the RWT domain: (a) - softened band, (b) - vertical band, (c) - diagonal band, (d) - horizontal band.

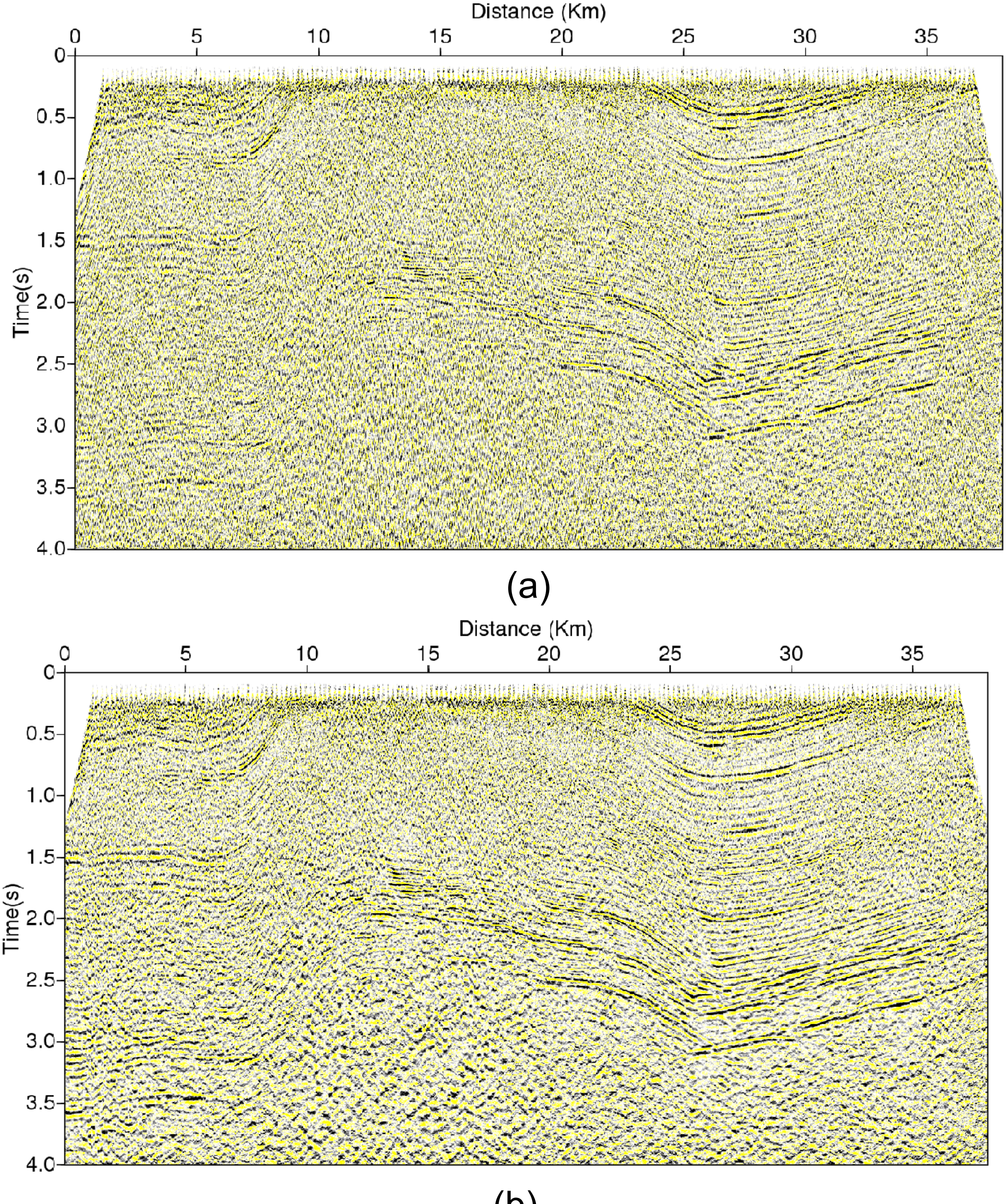

Figure 9: Original stacked section in (a) and filtered in (b).

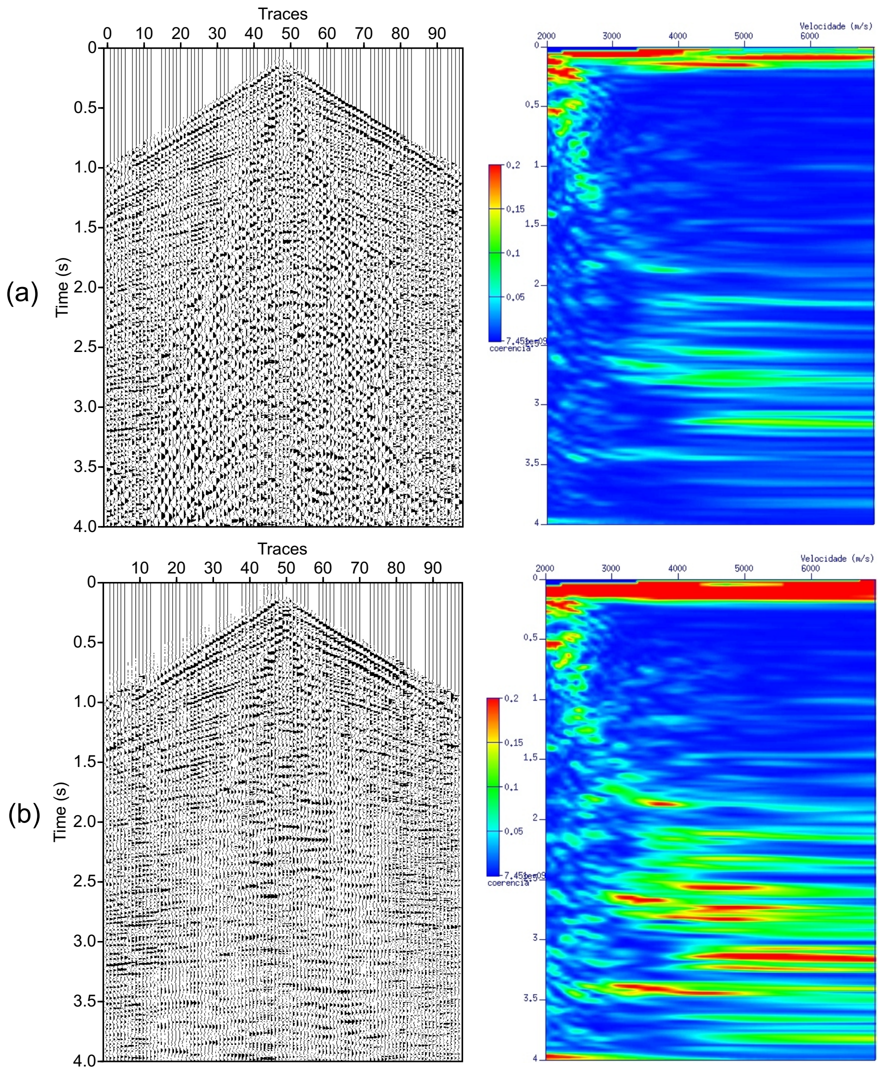

Figure 10: Original super-gather and velocity spectrum in (a) and filtered super-gather and velocity spectrum in (b).

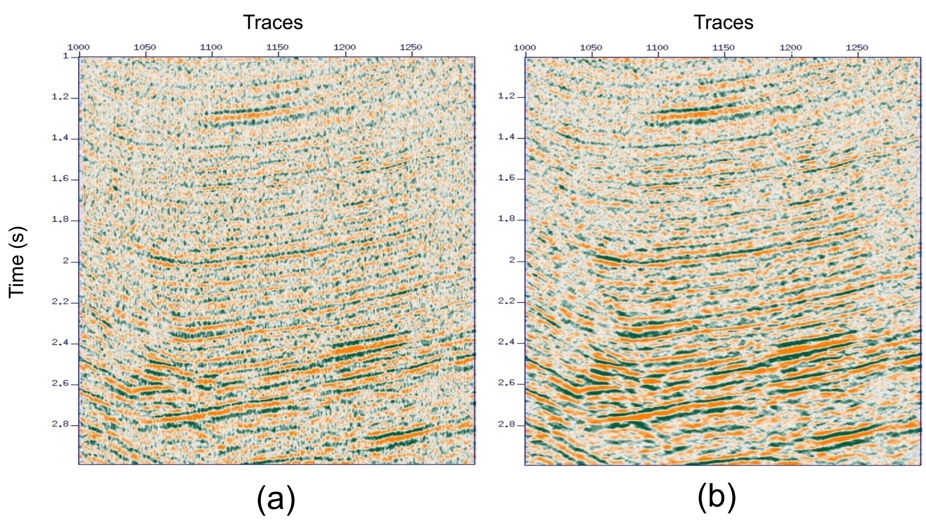

Figure 11: Detail of the stacked section; original in (a) and filtered in (b).