Noise attenuation for Common Hydrophone Gathers

Gary C. Aldunate e Flor A. Vivas.

This paper was prepared for presentation at the 9th International Congress of The Brazilian Geophysical Society held in Salvador, Brazil, 11-14 September 2005.

Abstract

This work shows how the noise present in 2-D prestack marine data sorted in Common Hydrophone Gathers (CHG) can be attenuated via FX deconvolution. Three ways to solve the Hermitian Toeplitz matrix in the FX deconvolution codes were tested and compared as well.

The unitary complex prediction Wiener filter FX, is calculated directly from LU decomposition and iteratively by Levinson and Gradient Conjugated recursion, in frequency-space domain. FX filtering in the CHG domain can avoid the muting of noisy traces in the edition process.

Introduction

Noise present in marine seismic data in Common Shot Gathers (CSG), presents for every hydrophone a different kind of noise as seen in Figure 1. For very noisy traces the usual solution in the edition process is muting it, instead of that we see that every kind of noise is equal for a particular hydrophone in all the CSG, so sorting it in Common Hydrophone Gathers (CHG) we observe a coherent noise for every gather as seen in Figure 2, some gathers more noisy than others. So every hydrophone has a particular noise that we can filter with FX deconvolution.

The FX prediction technique was introduced by Canales (1984) and further developed by Gulunay (1986), based on Treitel's complex series prediction work (Treitel, 1974). This technique divides the two-dimensional filtering problem into many one-dimensional filtering problems in space, one for each frequency. The name that Gulunay used for this process was FXDECON, which stood for frequency-space domain predictive deconvolution, in Theodoro (1997), the program Sufxdecon (Sesmic Unix, 2005) was implemented in this way, we introduce alternative solutions to the matrix problem.

FX deconvolution as usually applied, attenuate random noise in the spatial direction of stacked CMP section with small dips, (Yilmaz, 2001). In the CMP section the reflector information is linearly predictable in a space window with few traces and the non predictable energy corresponds to the noise. FX deconvolution calculates a filter for every frequency and every window with typical length of five to ten traces, guarantees the reflector coherence (Theodoro, 1997). In the CHG instead, it is the noise associated to the recorder instrument (hydrophone) that appears as a spatial coherent noise independent of time. Using a unitary prediction model $\mathbf{D}(x_i,\omega)$ of order N for a sample $\mathbf{D}(x_i,\omega)$ from samples $\mathbf{D}(x_{i-1},\omega),\mathbf{D}(x_{i-2},\omega),\cdots,\mathbf{D}(x_{i-N},\omega)$ and taking into account a predictable component (Porsani, 2004), in this case corresponds to the noise $\eta(x_i,\omega)$, can be obtained for the filter; then the prediction error $\mathbf{e}(x_i,\omega)$ that corresponds to the reflectors information is:

$$\mathbf{e}(x_i,\omega)=\mathbf{D}(x_i,\omega)-\widetilde{\mathbf{D}}(x_i,\omega)$$

where $\widetilde{\mathbf{D}}(x_i,\omega)=\eta(x_i,\omega)$. As the noise in CHG domain, presents a high spatial coherence, the space window to calculate the FX filter can be greater than the conventionally used and only one filter can be applied for each CHG.

The complex Wiener filter N can be obtained without complex arithmetic transforming the complex system in a real system of size 2N and using LU decomposition with a cost of $(2N)^3$ operations, (Claerbout, 1985) . The complex Levinson recursion has cost of N^2 operations, being efficient computacionally. And the Gradient Conjugate recursion costs N^2+2N operations. These three kinds of solving the Hermitian Toeplitz matrix were tested in FX deconvolution to filter real noisy marine data.

Spatial prediction filter

Let's represent a CHG as $\mathbf{D}(x,t)$, applying a time Fourier transform we get $\mathbf{D}(x,\omega)$. For every frequency ω we define a complex vector $\mathbf{D}_\omega=\mathbf{D}(x_i,\omega)$, with $i=0,\cdots,M$ in the x direction, where M is the window size for filter application. The unitary Wiener complex prediction filter N, $F_N=F_j, j=1,\cdots,N$; corresponds to a solution of normal equation system (Abma and Claerbout, 1995):

$$\mathbf{RF}=\mathbf{G}, \tag{1}$$

where $\mathbf{R}$ is the Hermitian Toeplitz matrix of autocorrelation coefficients $\mathbf{r}_i$ from data $\mathbf{D}(x,\omega)$, $\mathbf{F}$ is the filter and $\mathbf{G}$ the conjugated autocorrelation coefficients $\mathbf{r}^*_{i+1}$. The equation (1) can be written in real matricial form as:

$$\begin{pmatrix} R_r & -R_i \\ R_i & R_r \end{pmatrix}\begin{pmatrix} F_r \\ F_i \end{pmatrix}=\begin{pmatrix} G_r \\ G_i \end{pmatrix}, \tag{2}$$

the LU direct method solves this real matrix system, equation (2), the iterative methods, Levinson and CG recursion, solve the complex matrix system equation (1). These little differences in the way to solve this matrix are reflected in the time domain results, as it will be seen.

The FX deconvolution algorithm can be summarized in the next steps:

- Time Fourier transform over every CHG
    - Hermitian Toeplitz resolution problem: LU, Levinson, CG.
    - Filtering in frequency (ω) domain.
- Inverse time Fourier transform

Application on NIC marine data

The NIC data was acquired in the sea of Nicaragua, it's a 2-D seismic line with 659 CSG with 50 m shot spacing every gather has 240 hydrophones with 25 m receiver spacing, with 1501 samples at every 4 ms per trace. The first CSG is shown in Figure 1, where we detect clearly different noise traces per hydrophone (in the usual process very noisy traces are muted).

Sorting in CHG, Figure 2, we confirm that every receiver has associated a particular coherent noise; each CHG then, has it's own noise that differs from other gathers, some with low noise and other ones very noisy, but in every CHG the noise is coherent, as we see for the selected CHG-10 test bed indicated by rows in Figure 3(a), the first trace of this gather is shown by rows in Figure 1, where the high noise spatial coherence is visible, it's interesting to observe that the noise is the same for the entire trace not only in the water portion but in the reflectors area too, that is present in all the recorder time. It's very important to mention that we dont pass any kind of frequency filter, amplitude corrections, mute or other kind of seismic pre-process, because this would destroy or modify the original coherent noise.

Sorted the data in CHG we apply the FX filters. In Figure 3(b) we present the result of FX LU filter where all the noise present in the CHG was attenuated and present a clean section. We improved the resolution of this one, and the reflectors appears visible without the presence of noise. Note this specially below 4 seconds. The difference between the original data CHG-10 (Figure 1) and the section after FX LU filtering (Figure 5), are the noise that was subtracted. Almost similar results, with few differences, we observe with the FX Levinson filter Figure 3(c), and with the FX CG filter Figure 3(d) this last one attenuates all noise correponding to water media but in the reflectors still remains some kind of noise visible below 5 seconds. The FX Levinson filter has the better computational performance.

Although the matricial problem is the same, the precision to solve it is somewhat different for the three tested methods, we observe this in the amplitude analysis envelope before and after filtering for a trace, where the original amplitude is presented in Figure 5(a). Observe the interesting preserved amplitudes (with few differences) corresponding to reflectors below 3 seconds in Figures 5(b) and 5(c), FX LU and Levinson filters, respectively; the water noise part is well attenuated. The same behavior is not seen for FX CG filter where the water noise is highly attenuated and the amplitude reflectors are well preserved too, but are seen in different scale, Figure 5(d).

Finally, after filtering, we can sort the CHG into CSG data. Figure 6 shows the result of FX LU filtering in CSG corresponding to first NIC CSG, comparing with Figure 1 we see that all noise was reduced and the reflectors are now clean. From this filtered data we can start the usual seismic process.

Conclusions

Coherent noise present in Common Hydrophone Gathers can be attenuated via FX deconvolution, and it works as an alternative to the traditional mute of noisy traces avoiding the lost of information. Levinson recursion has shown computationally efficient to solve Hermitian Toeplitz systems, reducing the filtering process time and keeping the same quality image than LU FX filter. CG FX filter attenuate coherent noise present in water media but can destroy some reflectors in depth.

Acknowledgements

The authors would like to thank to Brazilian government funding agencies CAPES, Universidade Federal da Bahia CPGG, for the financial support. Flor thaks to Universidad de Pamplona (Colombia).

Referências Bibliográficas

Abma, R. and Claerbout, J. (1995) Lateral prediction for noise attenuation by t-x and f-x techniques, Geophysics, **60**, 1887-1896.

Canales, L.I. (1984) Random noise reduction, 54th Ann. Internat. Mtg., Soc. Expl. Geophys., 525-527.

Claerbout, J. F. (1985) Fundamentals of geophysical data processing: Blackwell Scientific.

Gulunay, N. (1986) FXDECON and complex Wiener prediction filter, 56th Ann. Internat. Mtg., Soc. Expl. Geophys., 279-281.

Porsani, M. (2004) Aulas de Processamento de Dados Sísimicos I-II.

Seismic Unix (2005) Free seismic processing package version 38.5, Colorado School of Mines.

Theodoro, C. E. (1994) Sufxdecon, CWP.

Treitel, S. (1974) The complex wiener filter: Geophysics, **39**, 169-173.

Yilmaz, O. (2001) Seismic data analysis, Society of Exploration Geophysicists, Tulsa.

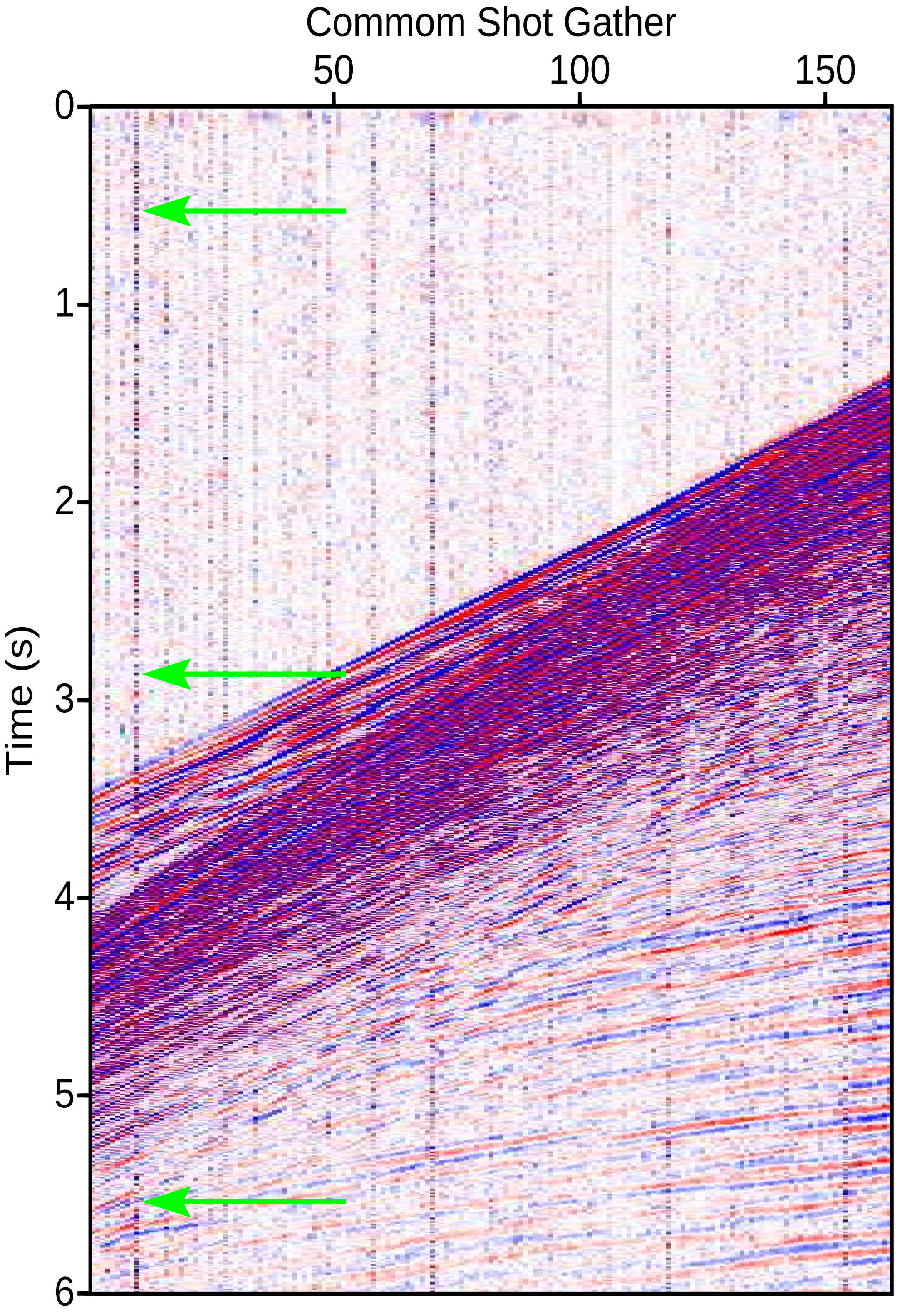

Figura 1: First CSG of NIC data showing some noisy traces, the noisy trace corresponding to hydrophone number 10 is marked.

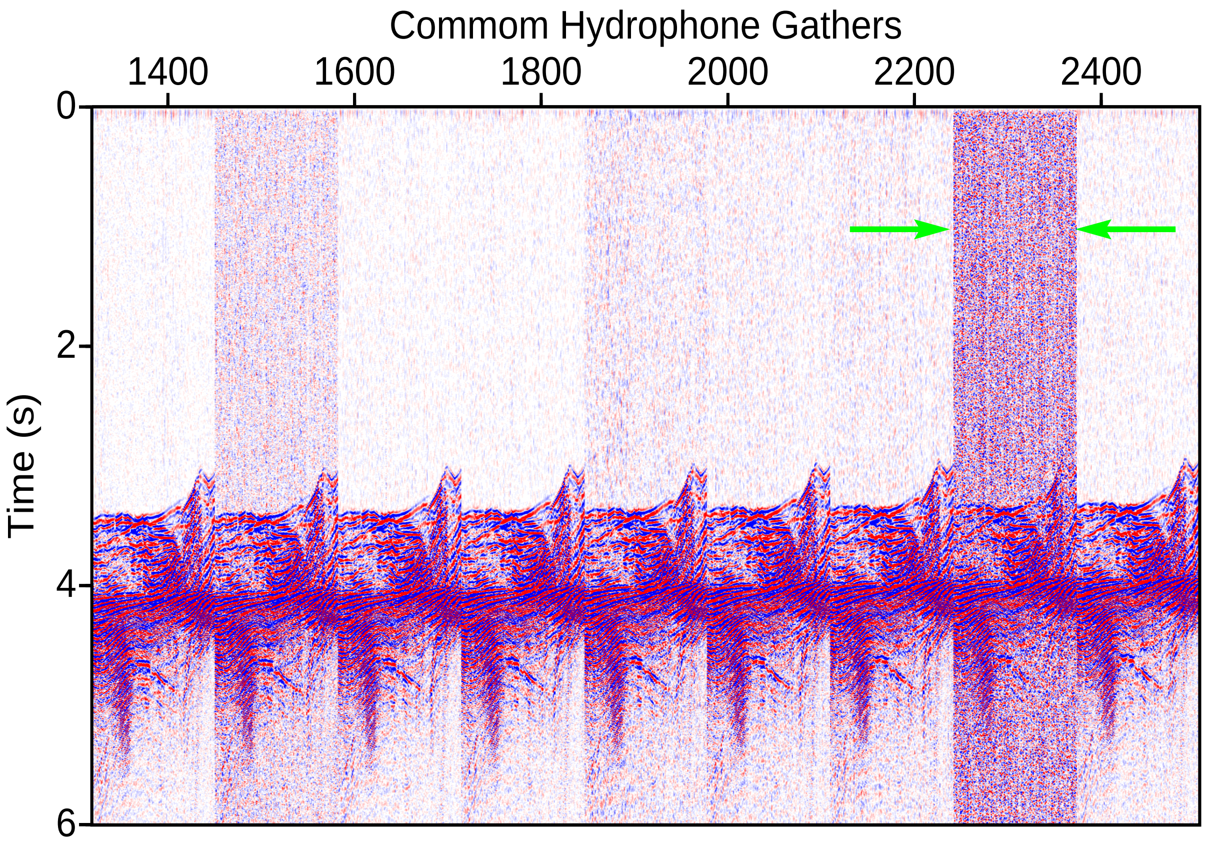

Figura 2: NIC data with 9 Commom Hydrophone Gathers showing differences in noise levels for every gather, the CHG 10 (indicated by green rows) it's selected for tests.

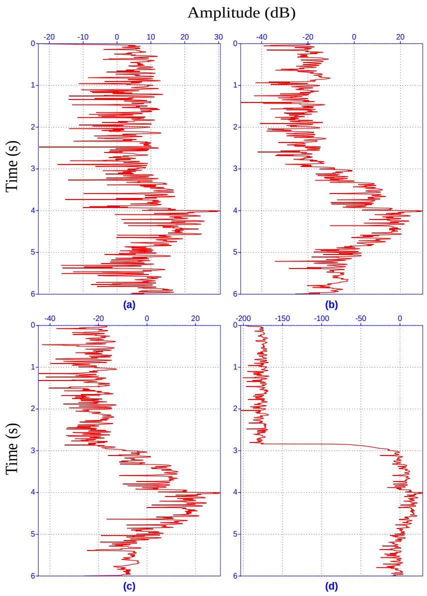

Figura 3: Amplitude envelope for the first trace in CHG-10: (a) without filter, (b) FX LU filter, (c) FX Levinson filter, and (d) FX CG filter.

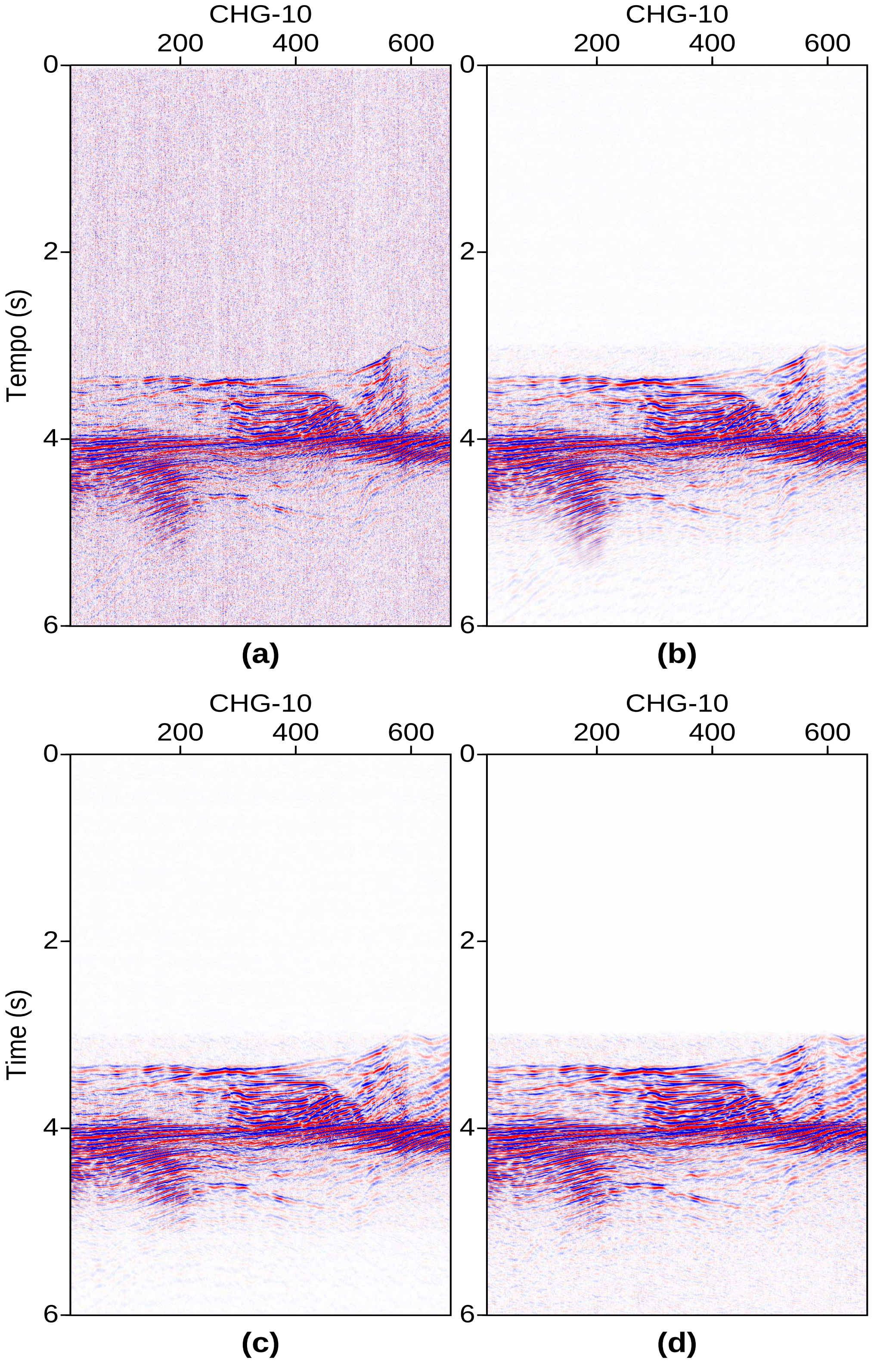

Figura 4: CHG-10 from NIC data (a) before filtering, and filtered with (b) FX LU filter, (c) FX Levinson filter, and (d) FX CG filter.

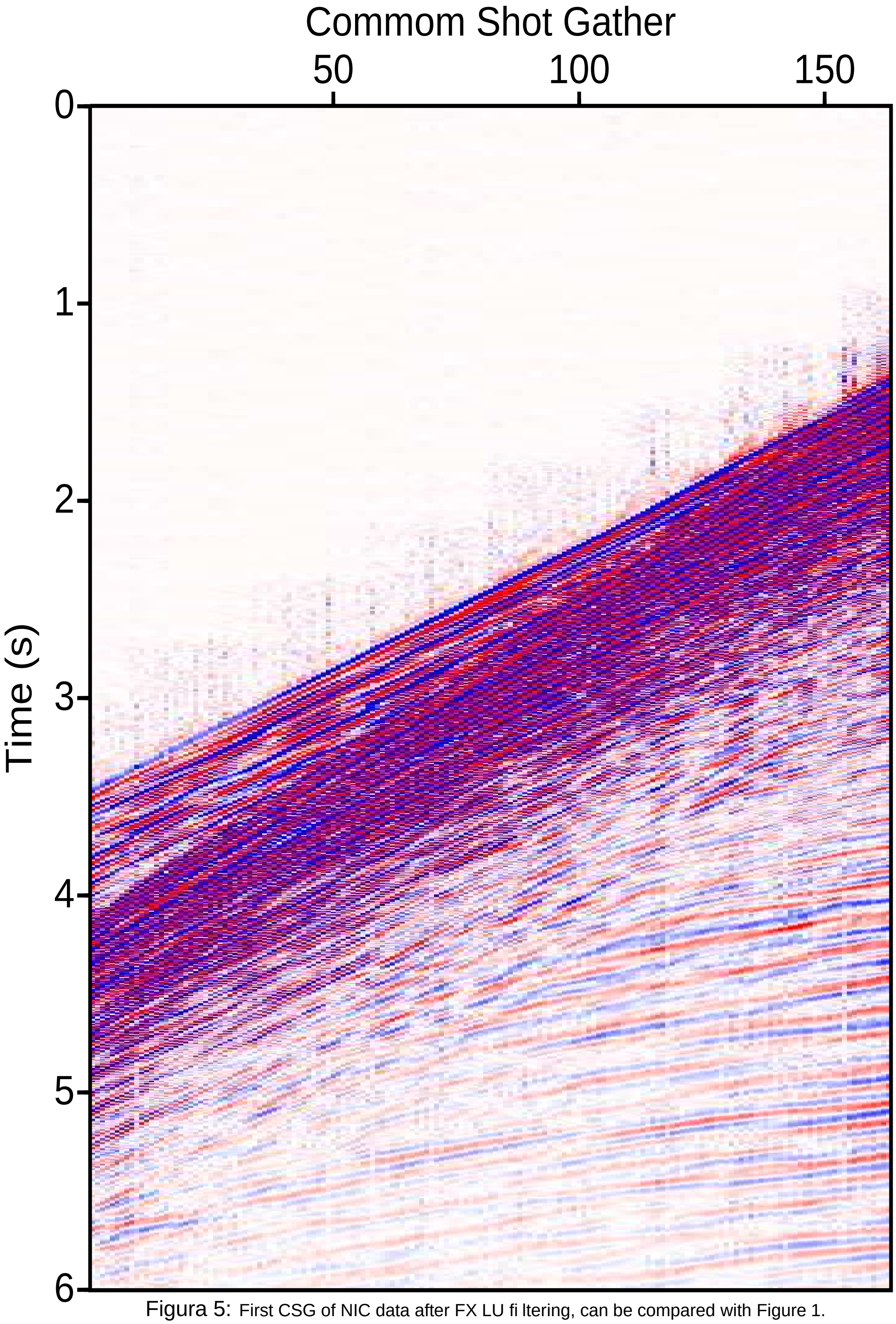

Figura 5: First CSG of NIC data after FX LU filtering, can be compared with Figure 1.