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Fourier Domain Regularization 5D and More

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Summary

Global multi-dimensional regularization has become a widely used tool in seismic data processing. Many advantages of regularization in the Fourier domain come with some serious problems. In this paper we consider the intrinsic properties of the Fourier transform to identify problems and limitations of the method.

Practical and efficient iterative multi-dimensional regularization technique is used to overcome the strategic pitfalls of the Fourier transform. The results of application on different 2D and 3D data sets are discussed.

Finally we show how the same multi-dimensional Fourier regularization technique can be used as a random and coherent noise suppressor.

Introduction

Converting seismic data into frequency-wave number or multi-dimensional wave number domain is a natural tool for data regularization. However its efficiency comes with some serious problems usually characterized as "spectral leakage". A clear understanding of what causes such phenomena will help us to develop an improved tool to perform interpolation, multi-dimensional regularization, noise suppression as well as any other operation in frequency or frequency-wave number domain in a meaningful way.

Method

To perform a regularization of prestack seismic data we create a new desired regular grid filled with the available input data, positioned at the nearest grid node and with zero data at all other locations. Gridded data (traces) are first converted into the frequency domain and then into the multi-dimensional wave number domain. This final spectrum is a result of the convolution of the full data spectrum with the Fourier transform of the sampling operator. The spectrum distortion is also known as spectrum "leakage", which means that each original spectrum component affects others and components with stronger amplitudes have more impact especially on nearest components. Figure 1 shows the distortion of the spectrum caused by gap and upsampling. Two main problems arise: spectrum "repetition", caused by upsampling operator and amplitude distortion caused by the gap. We have to keep in mind, that there is always some amplitude distortion caused by zero padding in time and space.

These problems should be dealt with simultaneously during the regularization process.

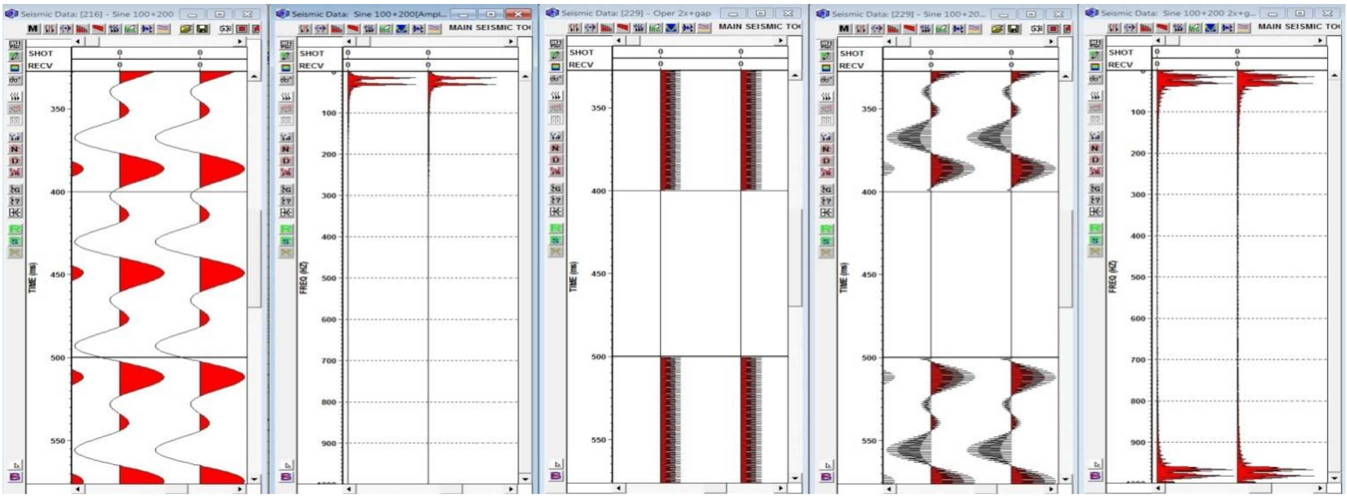

Figure 1: time series, spectrum, sampling operator, time series and spectrum after operator application

At each iteration, only those spectrum components bigger than a specified threshold are selected and accumulated in the output spectrum. After inverse wave number Fourier transform, the resulting grid of traces is first reduced to only the original trace positions. Those “original position” traces are then subtracted from the input. Thus by subtracting the strongest components, we reduce the strongest distortion of weaker components. The new input traces will next be forward transformed ready for the next iteration. The threshold is reduced at each step of the procedure. To prevent data aliasing especially if substantial upsampling is the objective, the search area of the spectrum is truncated at the current values of the maximum wave numbers in all directions. Thus the iterations first concentrate on high amplitude data near small wave numbers while maximum wave numbers are being changed with each iteration. Figure 2 shows output spectrum changes during iterations

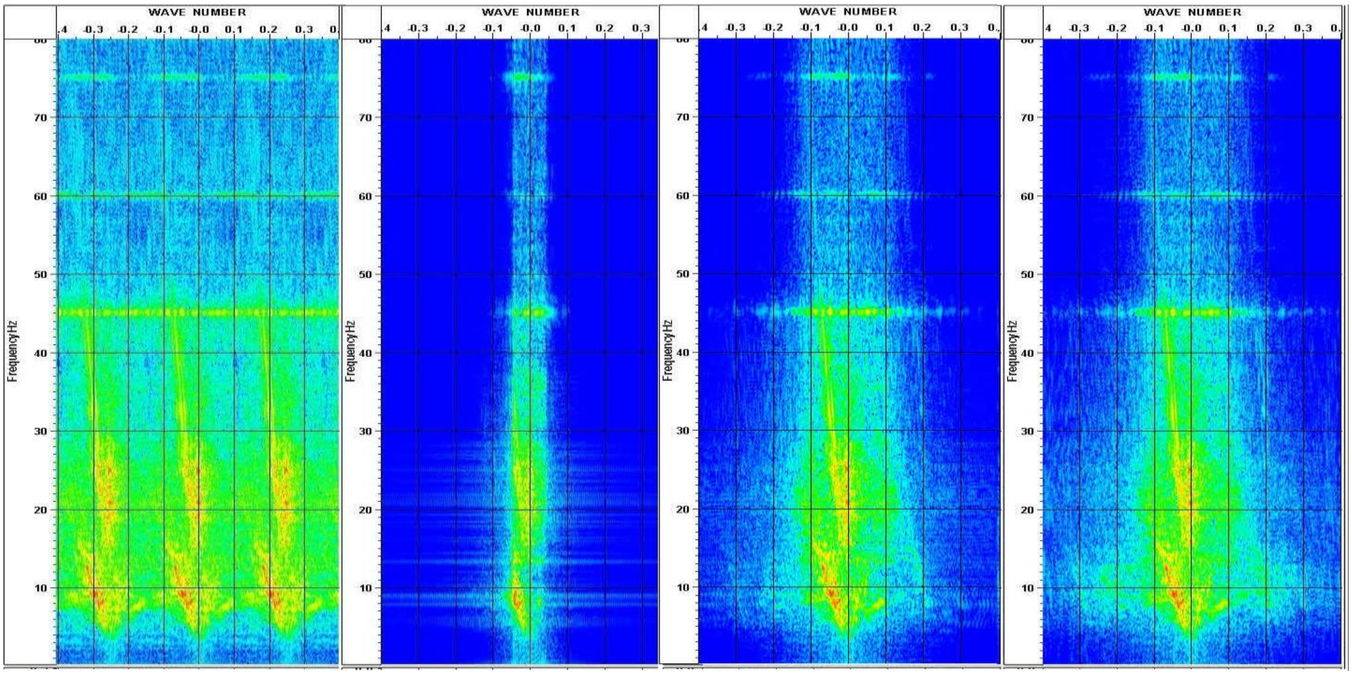

Figure 2: FK spectrum: 0 iterations, 25 iterations, 75 iterations, 100 iterations

Examples: 5D Regularization

The results of the proposed method are shown on two 3D real datasets. Figures 3 and 4 show the regularization of a very sparse survey. Figure 5 shows PSTM results before and after 3 times upsampling..

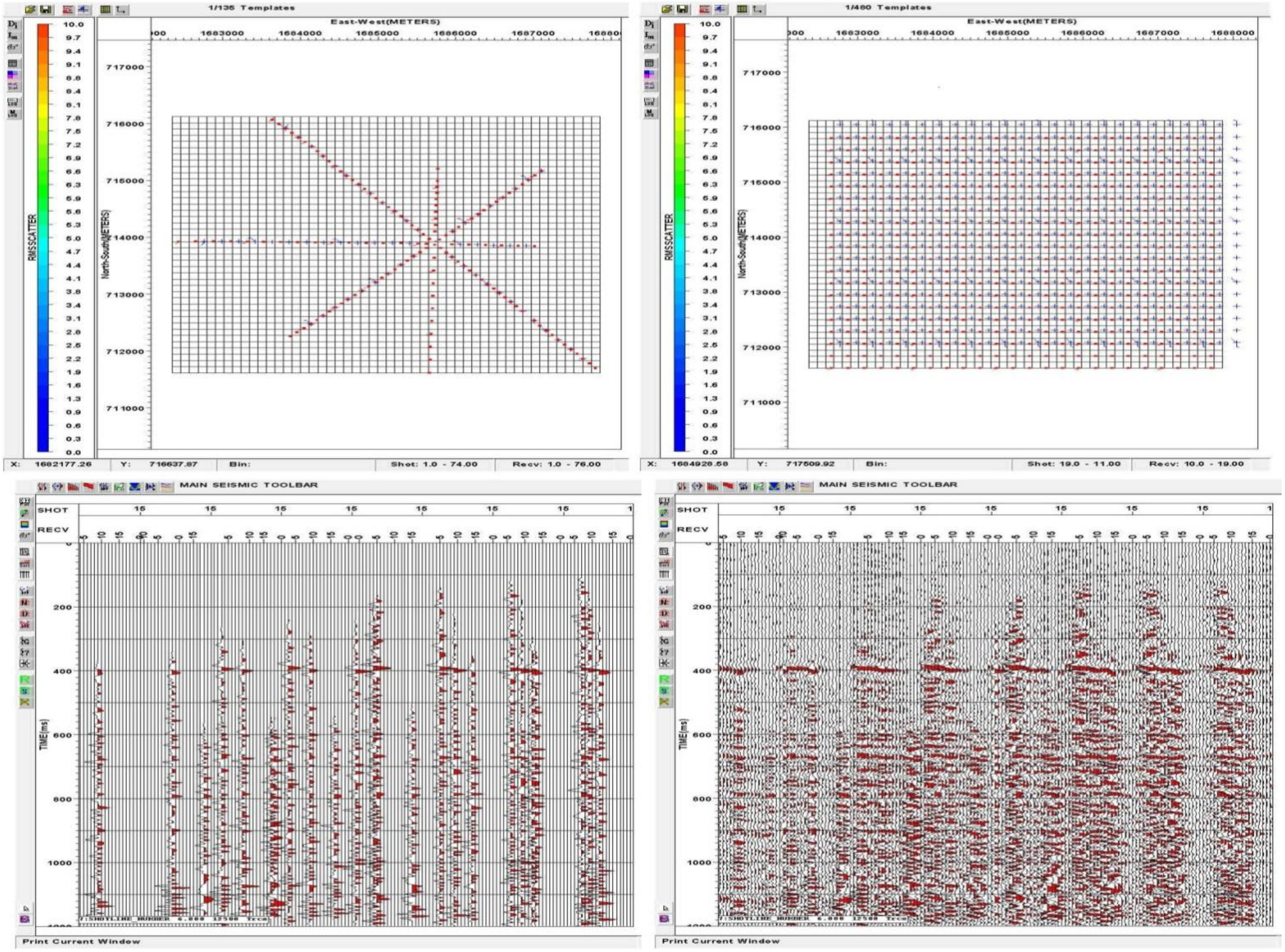

Figure 3: Geometry and prestack data before and after 5D Regularization

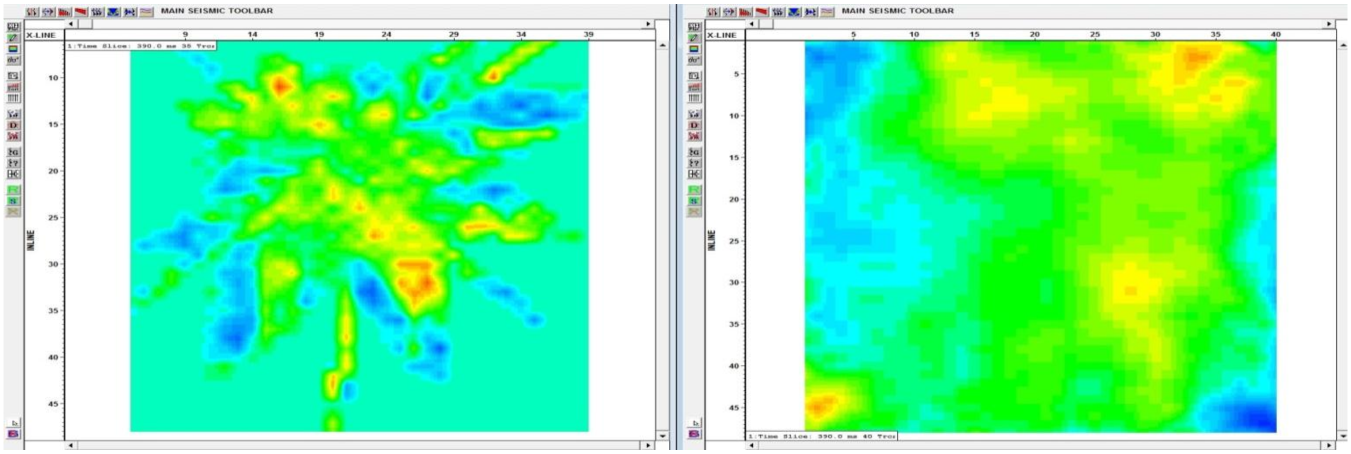

Figure 4: Time slice before and after 5D Regularization

The data in Figure 5 had a considerable amount of diffracted energy before PSTM. Clearly this diffracted energy was correctly interpolated as shown by the PSTM result after interpolation

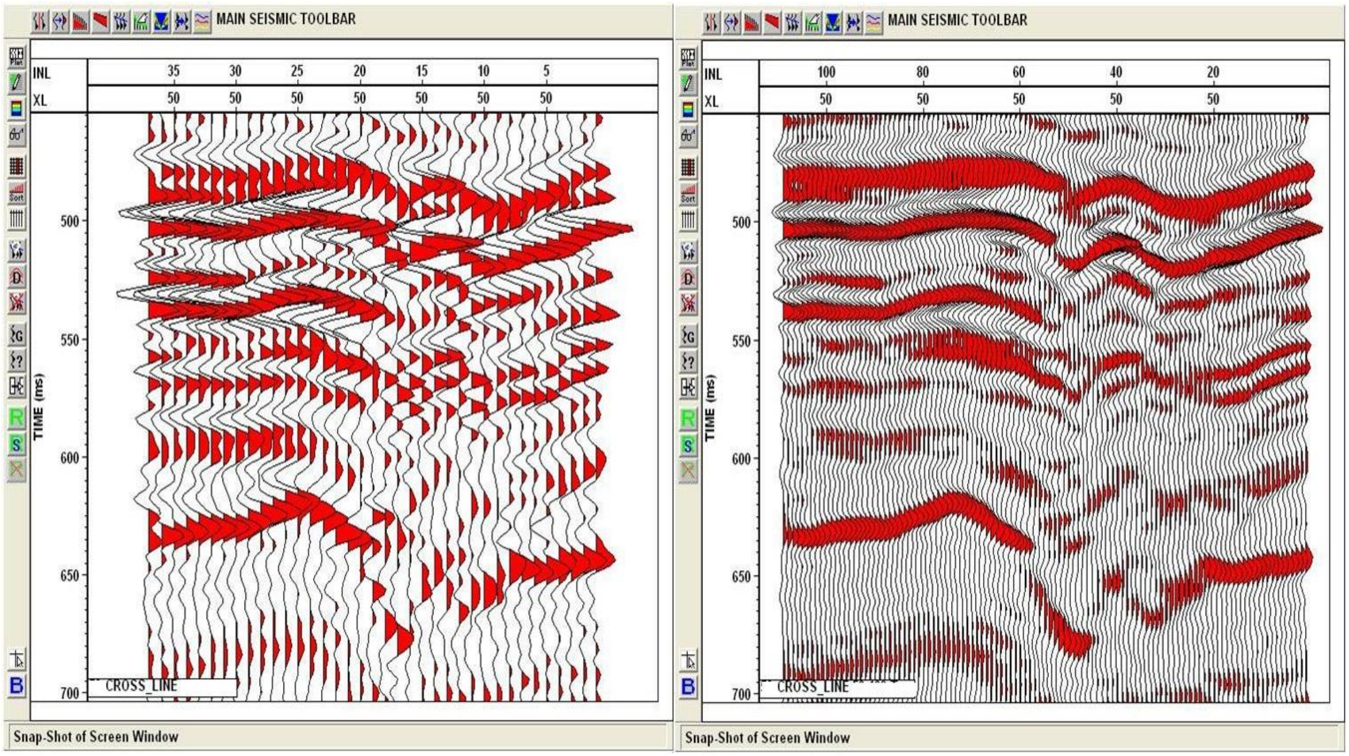

Figure 5: PSTM before and after 5D Regularization

Examples: noise attenuation

Figure 6 shows regularization as a random noise suppressor

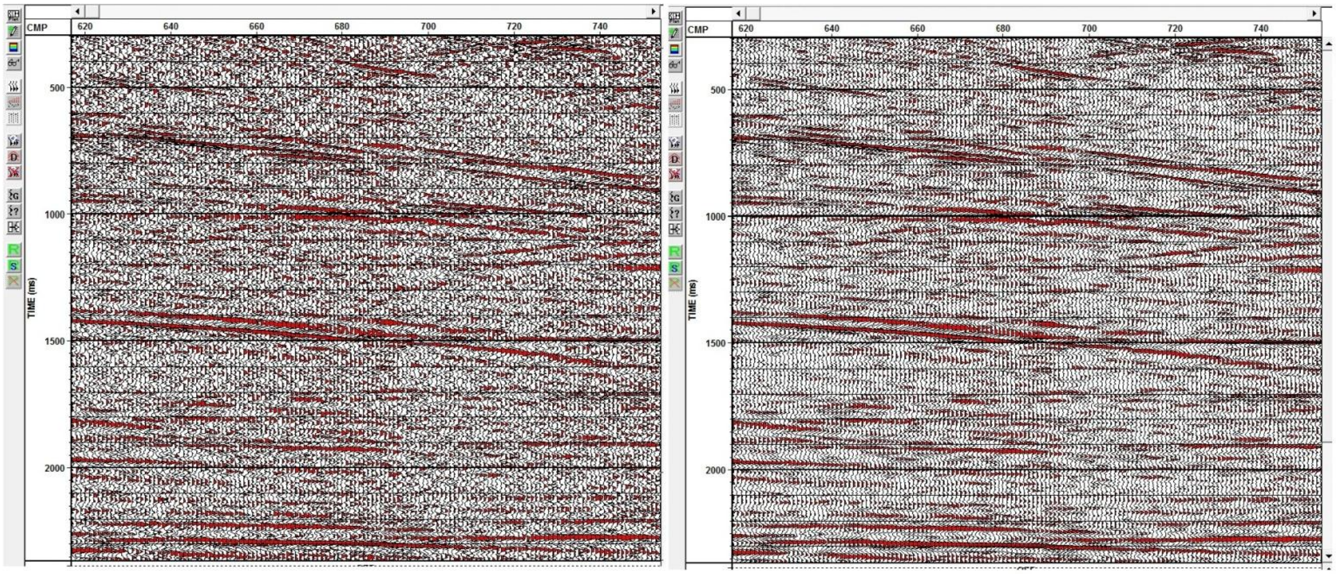

Figure 6: Before and after Random Noise Attenuation

3D noise attenuation

While random noise can be effectively attenuated during the regularization process, we developed a separate tool to address 3D linear noise based on the same technique.

Linear noise in the 3D shot domain has the form of a cone in the frequency-wave number domain. Spectral leakage due to uneven spacing, missing traces and zero-padding always causes noise and signal mixing in FK domain. An iterative process is employed to isolate the signal from linear noise and prevent “leaking”.

A new regular rectangular grid is created, filled with the available input data and converted to the frequency-wave number domain. At each iteration, only those spectrum components bigger than a specified threshold are selected. To isolate the signal, while leaving the noise untouched, the threshold search area of the spectrum is limited to a cone above the maximum linear noise velocity parameter and truncated at the current values of the maximum wave numbers. Figure 7 shows the area used during this signal search.

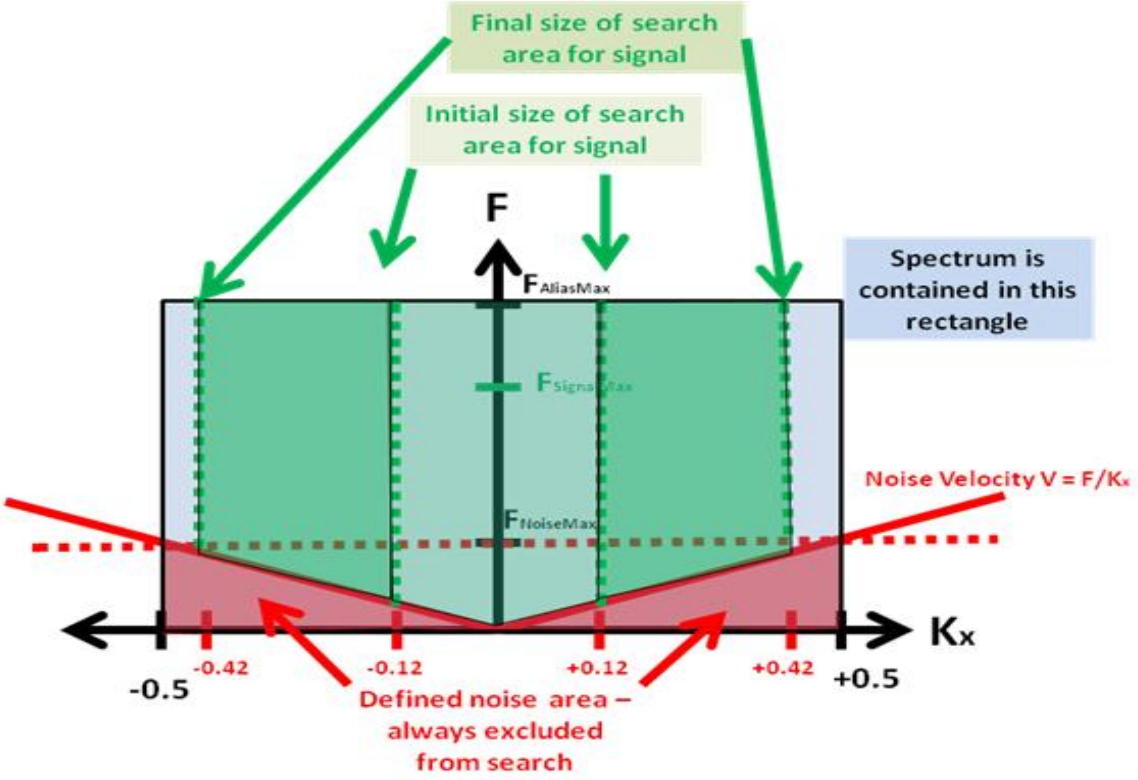

Figure 7: Linear Noise Extraction Operator

After each iteration, the threshold is reduced from the defined value to eventually reach zero at the last iteration. The maximum wave numbers in the X and Y direction are also changed in a similar fashion, according to the defined start and end values. Thus the iterations first concentrate on high amplitude high velocity signal near the frequency axis

After the iteration process is completed, the residual spectrum will contain lower frequency linear noise and also some random noise corresponding to high wave numbers.

The final residual spectrum therefore contains the linear shot noise we are trying to remove – and hence we simply subtract this from the original data.

Figure 8 shows the 3D linear noise subtraction results with the difference plot proving that no signal has been removed.

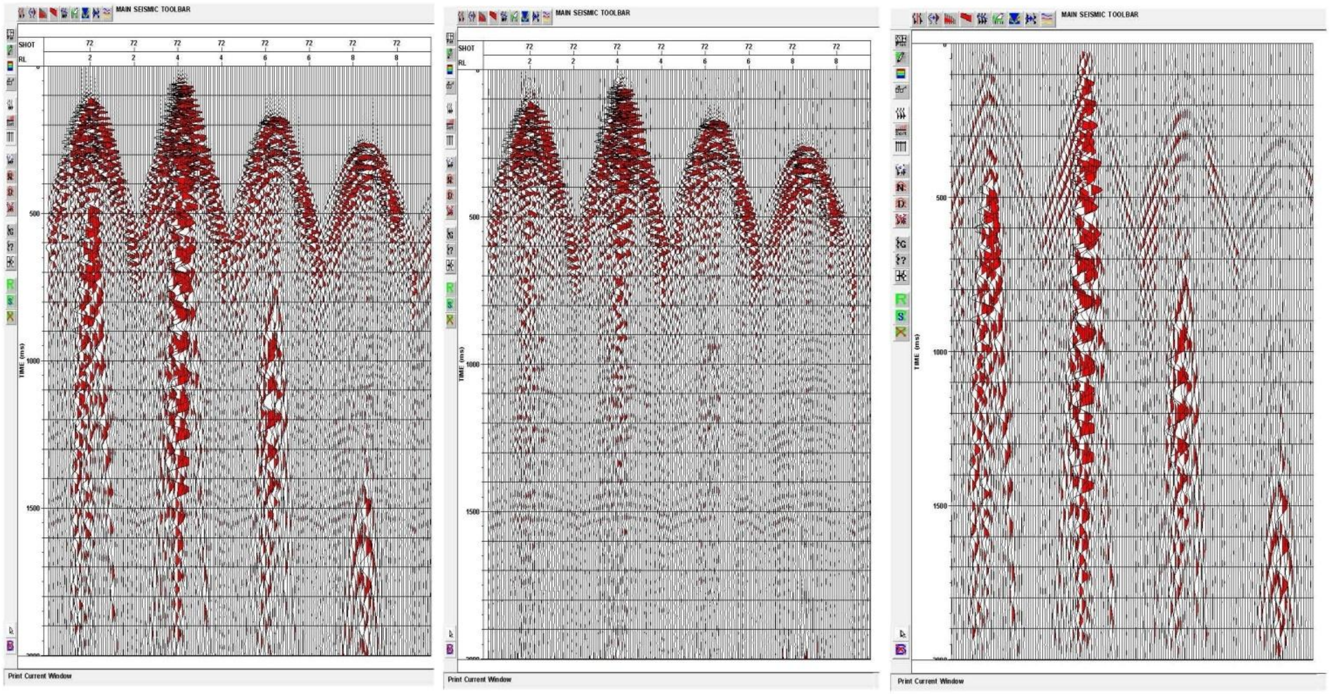

Figure 8: 3D Linear Noise Attenuation Input, Output and difference

Conclusions

With proper handling of the frequency-wave number spectrum, Fourier domain regularization has proven to be a powerful tool to interpolate extremely low populated surveys, to upsample seismic data with diffractions and dips as well as suppress random noise.

Finally, based on multi-dimensional Fourier domain regularization, an effective 3D linear noise attenuation technique has been developed.

Acknowledgements

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References and suggested reading

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