

**A review of some powerful noise elimination techniques for Land Processing,**  
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**Introduction**

Raw seismic data are often dominated by noise. Both coherent and incoherent noise are inherent to, and a pervasive problem of, seismic data. To facilitate proper interpretation and analysis of the relevant structure in the subsurface, the elimination of this noise is essential. Noise attenuation challenges have kept the oil and gas industry, and in particular the seismic data processing professionals, busy for many years. We have come a long way. However, the total elimination of this noise remains an elusive goal.

Coherent noise such as ghosts, reverberations, multiples, direct arrivals, ground roll, etc., may be thought of as organized signals (in some domain) that appear in our seismic records together with the true seismic signal produced by primary reflectors. Incoherent noise includes random/ambient noise, swell noise, power line noise, traffic noise, spikes or noise bursts of undefined origin on single traces and noise from pipelines, pump jacks or other production equipment. The general (intuitive) definition of incoherent noise is one that shows no “spatial or temporal structure”.

Can we use the properties of specific noise types to eliminate them? One of the most interesting observations made early on in the seismic processing industry was that coherent noise, or signal, in one domain may become incoherent in another. Signal and noise that may appear inextricably tangled can be “separated” by transforming to a new domain. This produces one of the mantras of noise elimination techniques, “Find a domain wherein signal and noise separate.”

Many coherent noises are associated with real physical phenomena, which contain valuable information about the subsurface. In the past, most of the effort has been directed at eliminating this noise with no concern for the information lost. However, there is a new paradigm shift to try to extract the remaining pieces of information contained in these bothersome but real events.

A distinction must be made as to the nature of noise based on whether the data is marine, transition, or land. This presentation will concentrate on land data and describe some of the noise elimination techniques used.

**Linear Noise**

This noise appears whenever there is seismic energy travelling along or near the surface of the earth. Such noise appears as linear (compared to hyperbolic or parabolic) and often with a different amplitude and frequency content than the surrounding signal. These characteristics are exploited to create a transform wherein signal “separates” from noise.

**The Wavelet Transform (WTF)**

Based on the Discrete Orthogonal Wavelet Transform, (Daubechies 1992), it is possible to decompose the seismic signal into different “scales” where signal and certain noises may be effectively separated/isolated. Subsequent muting of the noise is easily achieved in the WTF domain operating only on the “scales” where the offending noise appears. After muting, the inverse transform is applied to return the data to its original space-time domain. Figure 1 depicts the Daubechies wavelet and its spectrum. Figure 2 depicts an X-T ensemble and selected components or “scales” of the wavelet transform. Figure 3 shows a portion of a 3D shot gather before and after WTF filtering and the attenuated noise (Deighan *et al*).

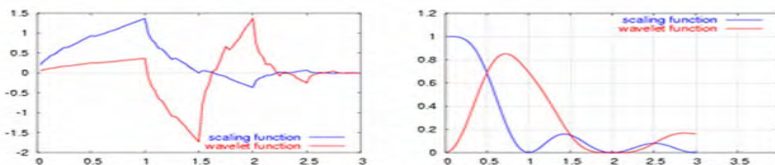


Figure 1: Daubechies Wavelet and Spectrum.

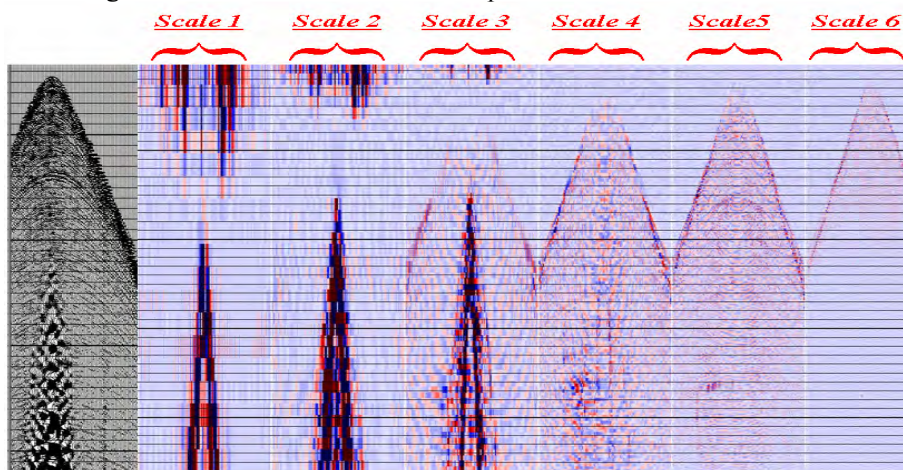


Figure 2: Shot gather and its WTF. Note the strong linear noise in the “Large Scale” region.

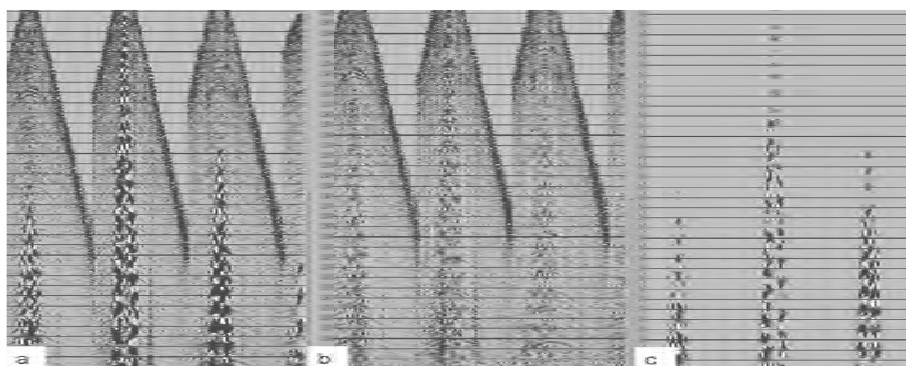


Figure 3: Shot Gathers a) before, b) after c) difference showing what was removed.

Note that although WTF has eliminated a significant amount of the noise, remnant noise often requires additional noise elimination via other methodologies. In a production workflow, a cascade of several different filter types is applied to achieve more complete rejection of the noise. The next filter is described below.

### Time Frequency Domain (TFD)

TFD (original algorithm courtesy of BP) does sample wise median thresholding within frequency subbands in  $(t-\omega)$  space. Each ensemble is transformed into this space using a Short Time Fourier Transform (STFT). This approach separates the amplitude and phase components for each subband. Anomalous spectral amplitudes within a subband are replaced with the median of the surrounding samples. Inverse transform returns the noise rejected data to the X-T domain. Figure 4 shows the data after the application of WTF+TFD in a “cascaded” fashion.

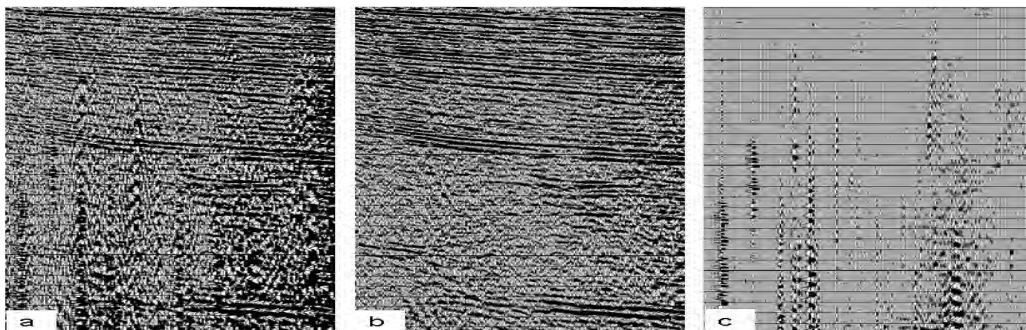


Figure 4: a) Raw Stack Section and b) after WTF and TFD filtering and c) Difference.

### Hybrid Gathers Technology

Hybrid gather sorting is applicable to 3D land, transition zone and OBC datasets having intersecting source and receiver line geometries (Thomas *et al*). These gathers are the result of sorting the pre-stack data into a hybrid cross-spread domain by selected traces from a subset of receiver lines that intersect an individual source line. This type of ensemble forms a pseudo shot whose effective “source position” lies at the intersecting point of the source and receiver lines. A hybrid gather will be formed at each intersection in the 3D survey. The advantage of such a sort is the unraveling of signal and noise that is highly aliased in a traditional domain. Hybrid sorting improves sampling in the cross-receiver-line direction and facilitates removal of aliased coherent and random noise using true 3D techniques.

Cross-line sorting allows 3D volumes of data to be constructed using pre-stack data from brick or cross-spread acquisitions. Once in the hybrid domain, processes such as true 3D linear radon are much more effective because of the regularization of the sampling and reduction of aliased noise effects. The technique is particularly effective for wide angle geometries likely to appear in wide azimuth acquisition.

Figure 5 shows the hybrid gather formation, a “traditional” crossline and a “hybrid” crossline. While significantly aliased in the traditional crossline ensemble, strong linear noise is readily apparent in the hybrid crossline. This noise may now be effectively attacked using true 3D filtering techniques.

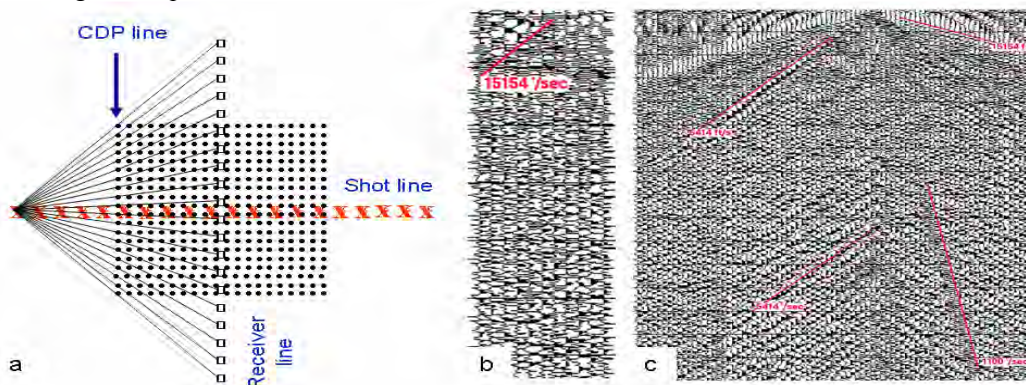


Figure 5: a) Hybrid Gather, b) Traditional Crossline, c) Hybrid Crossline.

The 3-D aspects of this domain lead to the development of true 3D implementations of filters traditionally applied in 2D such as FK and Radon. Figure 6 shows a comparison of a 2DFK

representation versus a 3D FK filtering cone. 3D Radon has a similar 3D implementation.

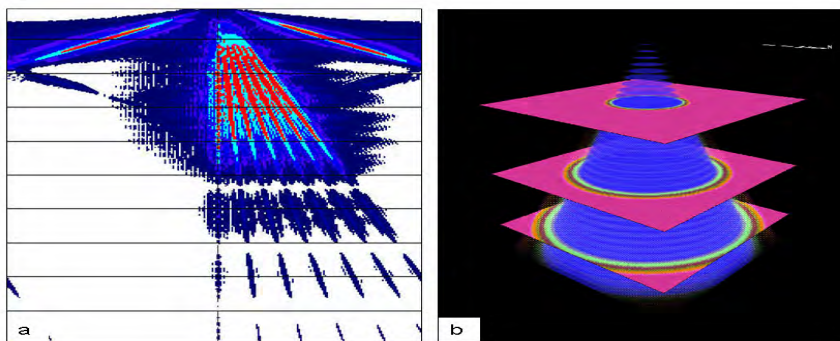


Figure 6: a) 2D FK spectrum for filter definition, b) Conical 3D FK filter mask.

Figure 7 shows the effect of hybrid domain Radon filtering on selected 3D land gathers. The workflow used was *Shots Gathers* → *Sort Hybrid Gathers* → *3D Radon Filtering* → *Sort to Shot Gathers*. Figure 8 shows how such a process affects the final migrated section.

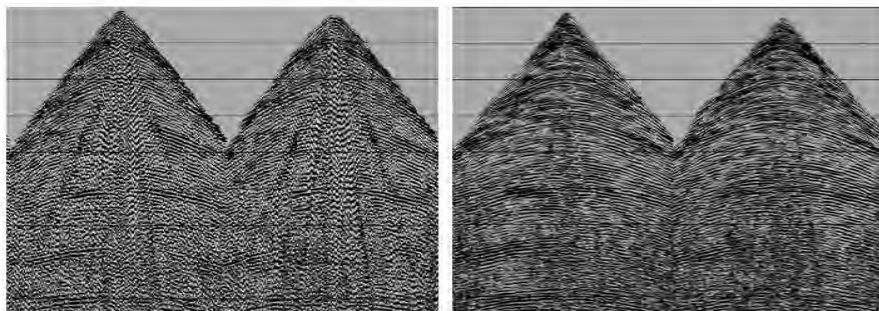


Figure 7: Shot Gathers before (left) and after (right) 3D Hybrid Domain Radon filtering.

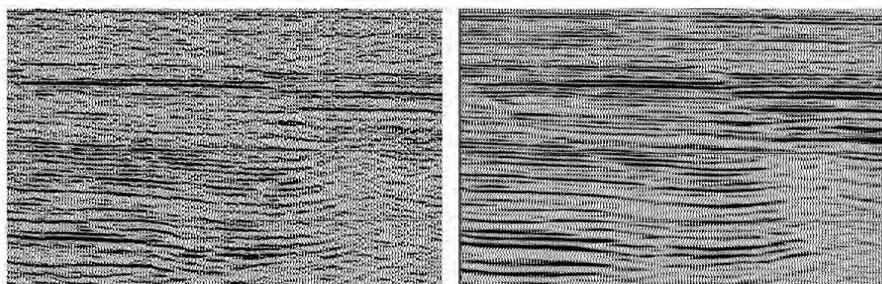


Figure 8: Migrated Data without (left) and with (right) Hybrid Gather Filtering.

## Conclusions

Coherent noises are detrimental to the identification, interpretation and evaluation of subsurface formations capable of acting as hydrocarbon reservoirs. The elimination of this noise is critical to oil and gas exploration endeavors. Several filtering techniques have been described and their power when applied to land data has been demonstrated.

It has also been shown that great additional value comes from the cascading of several filters. This cascading, when applied in a recursive way, is extremely effective at accomplishing the desired noise elimination. Three techniques were described: the Wavelet Transform Filter (WTF), the Time-Frequency Domain Filter (TFD) and the Hybrid Gather Domain. This last one is capable of unraveling and de-aliasing signals to allow the noise rejection filters to perform much more effectively on the data. Due to the true 3D nature of this sort, the need to develop true 3D filtering techniques such as 3D FK and 3D Radon was also discussed. The effectiveness of these 3D filters in the Hybrid Domain was demonstrated.



### **Acknowledgements**

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