

Attenuating 2D Noise in a 3D World

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Summary

Coherent seismic wave modes generated by artificial seismic sources are almost always present on seismic reflection data recorded on land. Because they obscure the relatively weak backscattered energy, or reflections, that we actually seek, we often devote significant effort to attenuation or removal of these modes. Many methods have been tested and implemented, both in data acquisition and processing, for the removal of source-generated coherent noise, some of them quite effective.

Most coherent noise attenuation techniques are designed to be applied to 2D data, with source points and receivers collinear along a relatively straight surface survey profile. We consider some issues involved in adapting 2D noise attenuation techniques to the increasingly common 3D surveys of today. We demonstrate on real data a method for attenuating coherent noise from a 3D source gather using 2D radial trace filtering.

Introduction

The objective of exploration reflection seismology is to create useful images of the subsurface of the earth from elastic wave energy backscattered from layer interfaces and other impedance discontinuities deep in the earth. Although we prefer to observe only the body wave energy transmitted from our artificial sources into the earth and reflected or diffracted from its structural features, our transducers unavoidably detect other wave propagation modes as well. Chief among these are so-called source-generated coherent wave modes. Because our artificial seismic sources are nearly always located at or near the earth's surface, they inevitably excite not only downgoing body waves, but various kinds of direct, refracted, and waveguide modes in the near-surface layers, acoustic waves travelling in the air above the surface, and surface-coupled modes like Rayleigh Waves, or ground-roll. Depending on the velocity structure of the near-surface, more energy from the source may propagate as coherent "noise" modes than as useful downgoing waves. Furthermore, because these modes travel along or parallel to the surface (approximately 2-dimensional), their amplitude diminishes with the reciprocal of the distance from the source ($1/r$), whereas the body waves we use for imaging radiate their energy into the earth's volume (3-dimensional) and diminish with the square of the reciprocal distance ($1/r^2$). So, not only is coherent noise stronger than most reflection energy near the source, but its relative strength dies out less rapidly with distance (or travel time) from the source. Thus it is often important to significantly attenuate coherent noise on seismic records before attempting to image the backscattered seismic energy.

One characteristic shared by all coherent noise modes, which makes them vulnerable to attenuation, is the fact that their event arrival times are always a linear function of the straight-line distance from source to receiver, hence the alternate term "linear noise" often applied to them. Indeed, for trace gathers from 2D seismic surveys, with sources and receivers essentially collinear along the surface, each source-generated

noise appears as a linear event with some “apparent velocity” determined by the slope of the event with respect to the spatial and time coordinates of the particular trace gather. Since the traces in most source or receiver gathers are (more or less) regularly spaced in source-receiver offset, such gathers readily lend themselves to various multi-trace processing schemes for estimating and removing linear noises, often based on the apparent velocity of noise events relative to reflection events. One of the most commonly used methods relies on the f-k (2D Fourier) transform to separate noise events, by velocity, from underlying reflection events, assuming that the reflections do not significantly share the same apparent velocity as noise events. While a method like f-k filtering is often effective on 2D data sets, the input data traces must be uniformly spaced in source-receiver offset distance in order to satisfy the requirements of the Discrete Fourier Transform upon which it is based.

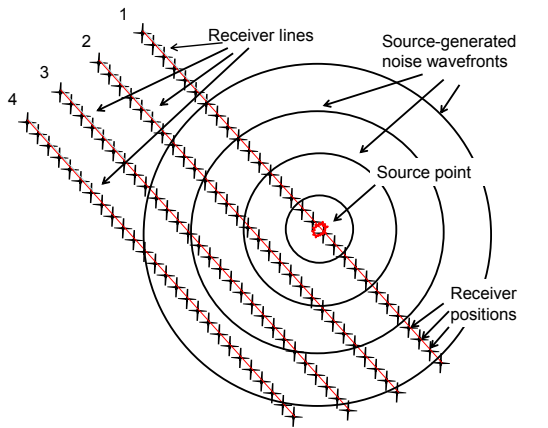
When we consider source-generated noises in 3D, however, we soon realize that, while the noise arrivals themselves are still linear with source-receiver offset distance, the distribution of offsets in a typical 3D source gather is far from uniform. If we consider an arbitrary receiver line gather as a natural subset of a conventional 3D source gather, we find that source-receiver offsets are distributed hyperbolically, except for a receiver line gather containing the source position, or aligned with it. Figure 1 shows a schematic of typical 3D acquisition geometry for one source point, with concentric circles representing the wavefronts of source-generated noise. Figure 2 shows the corresponding arrival time patterns for those wavefronts, as a consequence of the distribution of source-receiver distances for each receiver line gather. The only uniformly spaced arrival times are associated with the receiver line containing the source position.

In spite of the non-uniformity of their source-receiver offset spacing, for a typical 3D survey, the receiver lines capture the outgoing noise with the most coherence and least spatial aliasing, presenting the best opportunity for attenuation. Other arrangements of the input data either have much more irregular offset distributions, introduce more spatial aliasing, or destroy the coherence of noise wavefronts (see azimuthal segment gathers in Figure 3). In order to use a noise attenuation method, like f-k filtering, which employs an integral transform, the data traces for a 3D source gather must be regularized by interpolation prior to applying the f-k transform (or any filter response derived from the f-k or any other integral transform).

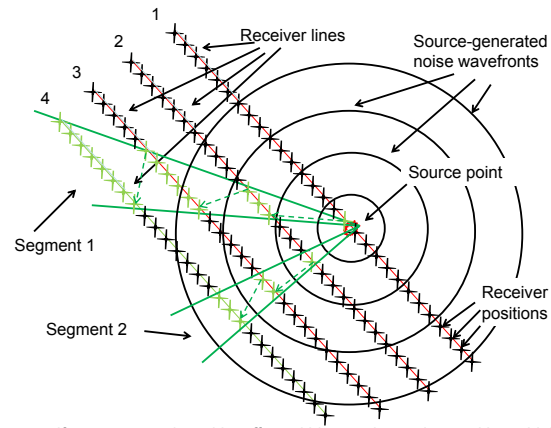
One method which does not require regularization of input trace gathers is radial trace filtering, since the radial trace (R-T) transform is a simple mapping, not an integral transform, and interpolation is intrinsic to the method. The R-T filtering method models coherent noise as the low-frequency portion of the R-T transform of a source or receiver trace gather, and subtracts the noise estimate from the original gather in the original X-T domain (Henley 1999,2003).

Details

For 2D data, coherent noise attenuation in the R-T domain requires, as input, either source or receiver gathers with the signed source-receiver offset in the trace headers. Applying the method in 3D is only slightly more complicated, primarily because the signed offset header in 3D conventionally contains only absolute offset. Hence, to apply R-T domain noise estimation and subtraction to receiver line gathers (treating them as if they are split-spread 2D source gathers), we only need to compute usable signed source-receiver offset values. The most straightforward way to do this is just to project an intersecting line from the source perpendicular to a receiver line, then force all offsets to one side of the perpendicular intersection to be negative and all offsets on the other side to be positive. Once trace headers have been modified in this manner, the receiver line gathers for each shot of a 3D survey can be filtered in the R-T domain just as if they are 2D shot gathers (albeit with non-uniform offset increment).

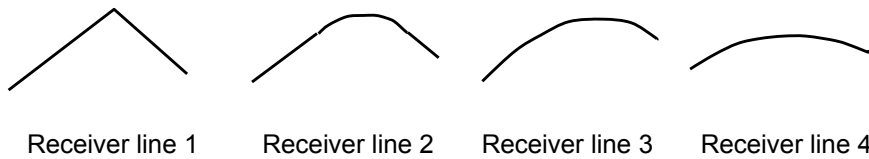


Coherent noise wavefronts and their relationship to typical 3D seismic acquisition geometry: receiver line spacing \gg receiver spacing



If traces are gathered by offset within angular wedges, either widely separated points on the wavefront are contiguous (segment 1), or offset distribution is too irregular to properly sample the wavefront (segment 2)

ent gathers have irregular offset for multi-trace filtering



Wavefront arrival times as a function of receiver station (trace spacing) along each of the receiver lines in Figure 1. Only when the source point is on a receiver line will the arrivals be linear with trace spacing; but they are **always** linear with respect to **source-receiver offset**.

Figure 2: The arrival patterns for coherent noise as seen by the various receiver lines in Figure 1. Only for receiver line 1 is the distribution of source-receiver offsets linear.

Examples

We show here two field data examples of R-T domain coherent noise attenuation. Figures 4a and 4b show two receiver line gathers for a 3D land survey. As can be seen in Figure 4a, there is considerable source-generated noise, both ground roll and first arrivals and waveguide modes. Figure 4b shows how effective R-T domain noise estimation and subtraction is on these data.

Figures 5a and 5b show another example of 3D receiver line gathers before and after R-T domain noise estimation and subtraction. In this case, the modified source-receiver offset values are plotted above the receiver line gathers to illustrate their non-linearity.

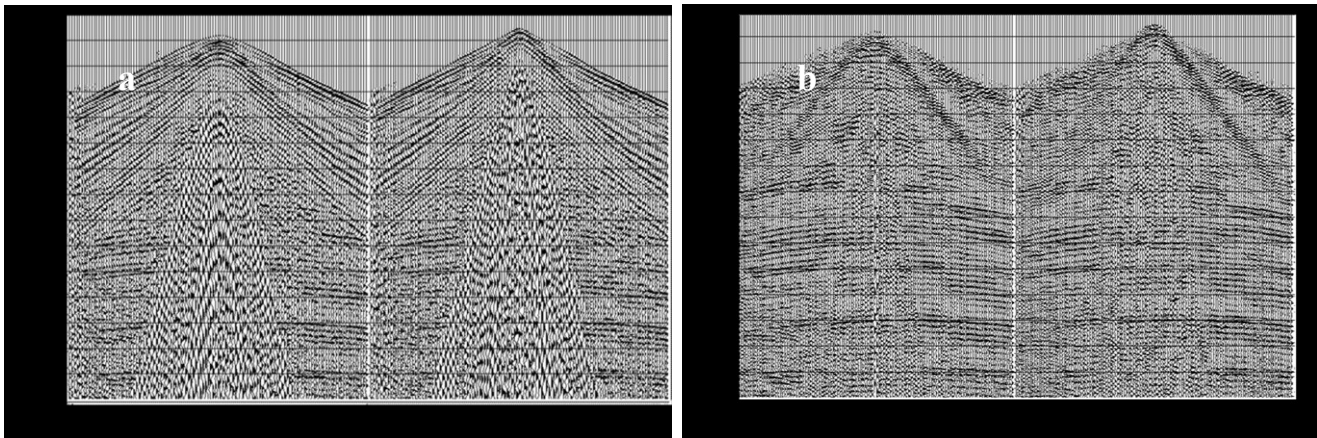
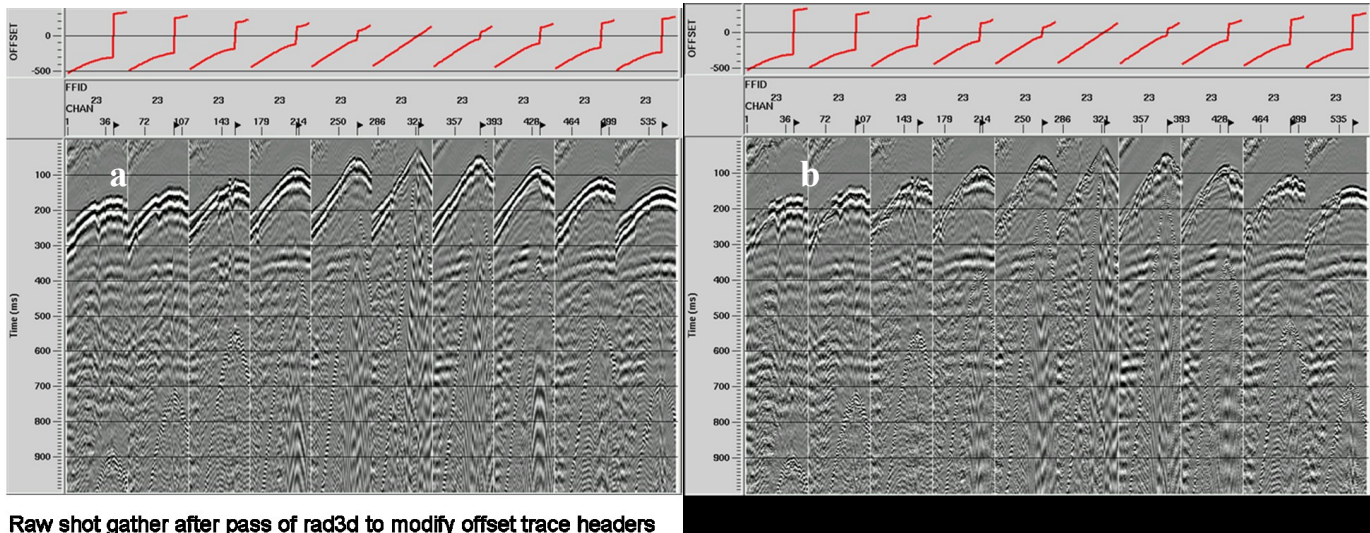


Figure 4: a.) Raw receiver line gathers. b.) Receiver line gathers from a.), after one pass of R-T noise estimation and subtraction.



Raw shot gather after pass of rad3d to modify offset trace headers

Figure 5: a.) Raw 3D receiver line gathers, with pseudo-signed offset plotted above the gathers. b.) Receiver line gathers from a.) after one pass R-T domain noise estimation and subtraction.

Conclusions

Attenuation of coherent noise for 3D surveys is more problematic than for 2D surveys, because the acquisition geometry relative to the outgoing surface wavefronts (coherent noise) complicates the spatial sampling of the wavefronts, making it non-uniform. Nevertheless, there is a technique, R-T domain noise attenuation, which can be applied directly to 3D receiver line gathers without the additional step of trace regularization required by such techniques as f-k filtering. When the noise has been adequately spatially sampled by the receiver line gathers, noise attenuation can be quite effective. If future technology leads to 3D acquisition geometries with more receivers, and finer and more regular receiver spacing, we could then consider other trace gathers for noise attenuation as well.

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References

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