A simple program for attenuation of source-generated linear noise in 3D seismic data

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Summary

Researchers have devoted significant effort to the attenuation of coherent seismic noise generated by artificial seismic sources because this type of noise often obscures the relatively weak backscattered energy of reflections. The characteristic shared by all source-generated coherent noise modes presented in 2D data is that their event arrival times appear as a linear function of the straight-line distance from source to receiver. Therefore, most coherent noise attenuation algorithms are actually designed for removing linear noise in a 2D data set. In this paper, we present a simple program that can use any 2D linear noise attenuation algorithm on 3D receiver lines where source points and receivers are not collinear along a relatively straight line.

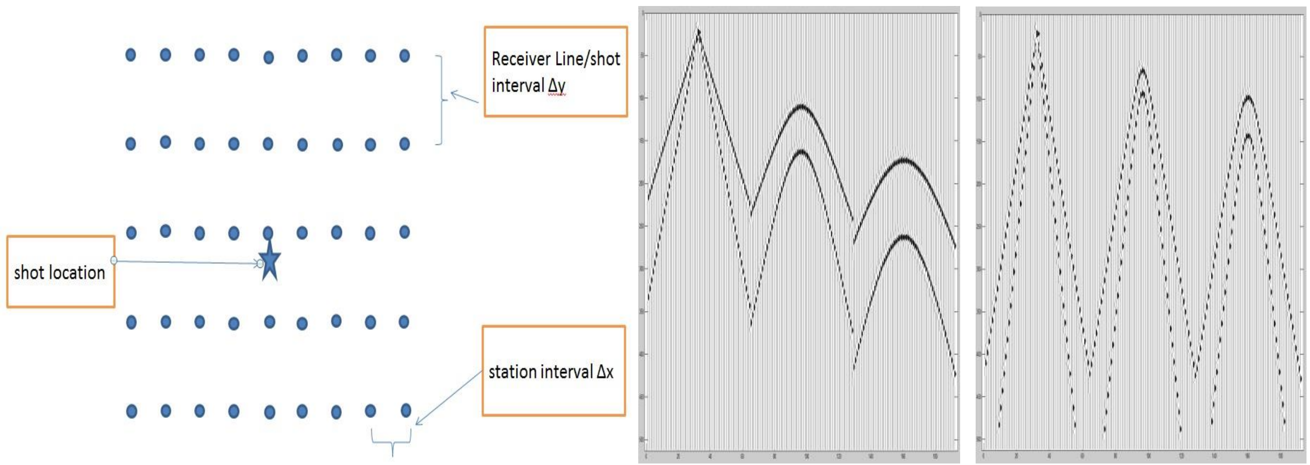
Introduction

Because exploration seismic sources are located near the earth's surface, they generate surface-coupled modes, such as Rayleigh waves, or ground-roll, which appear as coherent "noise" in seismic data. Due to geometry spread mechanics, these coherent noises are not only stronger than most reflection energy near the source, but also their relative strength dies out less rapidly with distance from the source than that of reflected energies. Thus, it is important to attenuate the coherent noise on seismic records before attempting to image the backscattered seismic energy (i.e., reflections).
One characteristic shared by all coherent noise modes is the fact that their event arrival times are nearly a linear function of the straight-line distance from source to receiver, e.g., ground roll, which makes the noise easily distinguishable from reflected energies and therefore makes the noise vulnerable to attenuation. Thus, methods involving linear noise attenuation have been developed (e.g., Henley, 2014; Ventosa et al., 2011). For trace gathers from 2D seismic surveys, with sources and receivers essentially collinear along the surface, each mode of source-generated noise appears indeed as a linear event in the space of spatial and time coordinates, the slope of which is determined by an apparent velocity. With the assumption that the reflections do not significantly share the same apparent velocity as noise events, the coherent noise can be separated from reflected events in some transfer domain and, therefore, the noise can be filtered, e.g., using an f-k domain fan filter (Askari and Siahkoohi, 2008). When we consider source-generated noise in 3D, however, we soon realize that, although the noise arrivals themselves are still linear with source-receiver offset distance, if we consider an arbitrary receiver line gather as a natural subset of a conventional 3D source gather, the offsets between source and receiver are distributed hyperbolically (except for a receiver line gather containing the source position or aligned with it). Therefore, existing linear noise techniques cannot be applied. From typical 3D acquisition geometry for one source point, the wave fronts of source-generated coherent noise present as concentric circles, and a cone filter in the f-k domain can be applied, e.g., Bakshi and Saxena (2013). However, because the distribution of offsets in a 3D source gather is usually far from uniform, this cone filter may suffer from an aliasing problem when the sample interval is large along one of the coordinate directions, e.g., the receiver line interval. Applying algorithms of linear noise attenuation to some sorted subset, for example, azimuthally sorted data; from a 3D data set is an alternative procedure (e.g., Gaiser, 1995). The sorted data are projected onto a 2D line and, except for nonuniformity of the source-receiver offset spacing, the coherent noise appears as linear events. However, for the azimuth in a direction near the direction that is

perpendicular to a receiver line, the aliasing problem may still affect the attenuation result. Moreover, irregular offset intervals may lead to an overly complicated algorithm.

In this paper, we present a simple program that can easily apply linear noise attenuation algorithms to each receiver line of a 3D dataset. Our program is based on the fact that surface coupled noise depends on a near-surface wave propagating velocity that is nearly symmetric around the source location. Therefore, when the data are optimally sorted in offset order, the surface coupled noise is indeed presented as linear noise. The procedure of our data sorting can be compared to azimuthally segmented gathers (e.g., Gaiser, 1995), but with variable azimuth angle, and the corresponding projected 2D line contains a regular offset interval, which is computationally more efficient. Instead of processing 3D data in azimuthal bands, we process the data receiver line by receiver line, and traces in each line combine optimally (both far and near azimuth). This makes our program both flexible to use and efficient for attenuating the noise. Furthermore, processing sorted data with overlapping windows means our program can take account of waveform dispersion. The validation of our program will be demonstrated by a real data example.

A synthetic data example

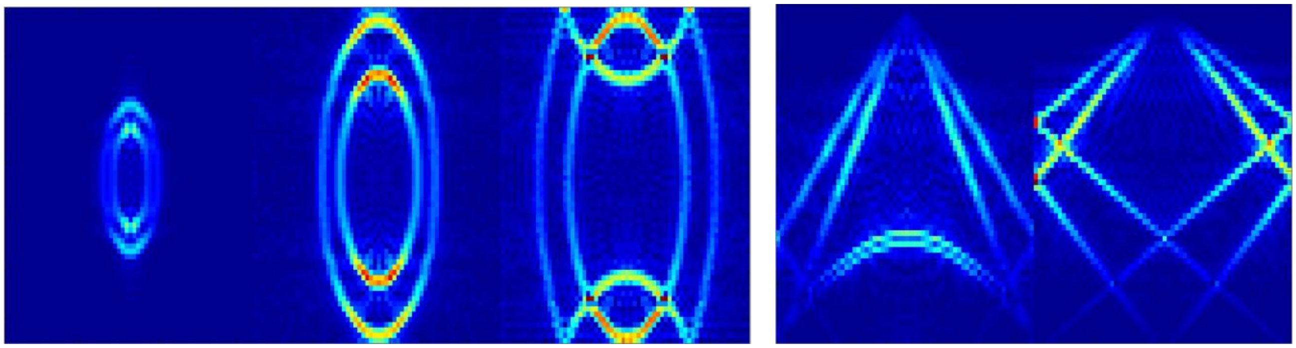


(a) (b) (c)

Figure 1: (a) 3D geometry; (b) seismograms of receiver line gathers; (c) seismograms of cross-receiver line gathers.

Figure 1a shows a 3D geometry for synthetic data, where the receiver line interval is two times the station interval, i.e., $\Delta y=2\Delta x$. The gathers of the synthetic seismograms of receiver lines and those of cross-receiver lines are shown in figures 1b and figure 1c. The first gather in both figures 1b and 1c indicates the lines nearest to the shot location. Figure 2a shows frequency slices (from low to high) of the kx-ky spectrum, and figure 2b shows the intersection of the f-kx and f-ky spectra along the first gathers in figures 1b and 1c, respectively.

From figure 2, we can conclude that when aliased energy is present, unless some interpolation or regularization is applied, an f-k cone filter has difficulty in removing the coherent noise and the aliased noise due to the fact that the receiver line interval can spread aliased coherent noise to all azimuth directions. However, if the spectrum is calculated for each receiver line separately, such a spread of aliased energy may not happen; see, for example, figure 3, which shows the f-kx for the first gather in figure 1b. Therefore, selecting data based on azimuthally segmented gathers may be a good choice for removing linear noise. Figure 4 gives a chart for azimuthally segmented gathering, in which a pseudo 2d shot gather is formed via projection onto a straight line located in the center of the azimuthal fan.



(a) (b)

Figure 2: (a) Frequency slices of kx-ky; (b) f-kx and f-ky along the first gathers in figure 1b and figure 1c, respectively.

Because the projected traces may have an irregular offset interval, a spatial fan filter operator is used for linear noise attenuation. When the 2D line is close to the direction that is perpendicular to receiver lines (see yellow portion in figure 4), aliasing may appear. Also, an irregular offset interval makes the algorithm complicated and less efficient.

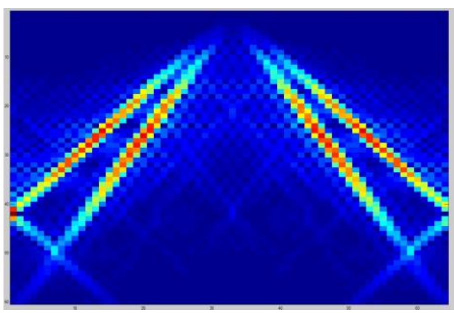


Figure 3: The f-k spectrum for receiver line near shot location

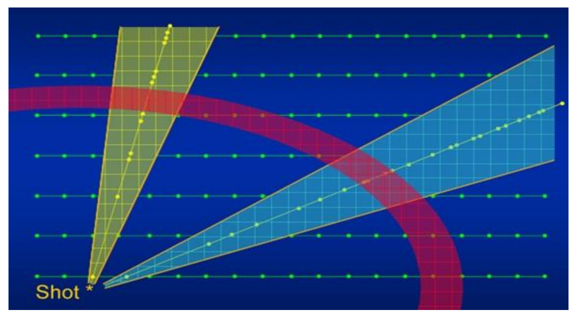


Figure 4: Pseudo 2d shot gather generation.

A simple program for 3D linear noise attenuation

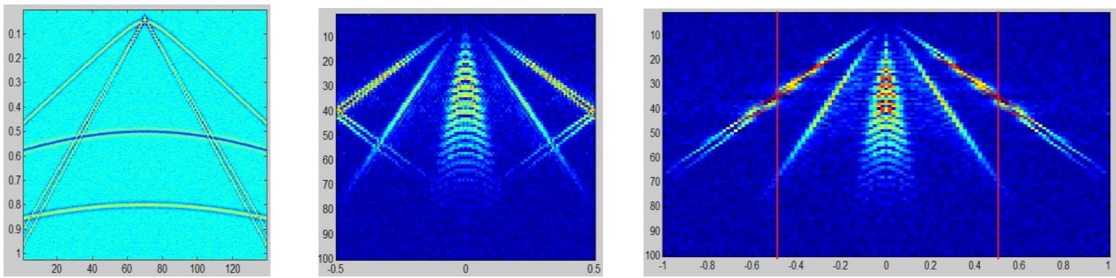
We previously observed that when we process a selected 2D line with relatively small offset interval, we obtain linear coherent events and also avoid aliased energy spreading. Based on the fact that surface coupled linear noise is symmetrically distributed around the source location due to the limited variation of near-surface velocity, we first generate a pseudo 2D line that contains offset range [min_offset, max_offset] with trace interval $\Delta <= \min(\Delta x, \Delta y)$. Then, starting from the first receiver line, we proceed to fill traces in the pseudo line based on corresponding offset, e.g., figure 2a from top to bottom. The trace filling is based on the first-come, first-served principle. After the pseudo 2D line is fully filled, we start processing.

We first apply any chosen method of linear noise attenuation (e.g., fan filter) on an overlapping windowed basis to the pseudo 2D line. Then we replace the traces of the first receiver line by the filtered samples. Now we turn our attention to the second receiver line and repeat the process. We continue with the next receiver line, and so on. Each time, the traces in the current line replace the corresponding traces that have the same offsets and stay there until next receiver line processing. Thus, any advanced 2D algorithm can be adopted for processing this 2D pseudo line, and we simply output the noise-removed traces that belong to current receiver line. We repeat the procedure until all the receiver lines are processed.

Processing receiver lines in such a way satisfies the criteria that the traces in each receiver line are automatically associated with traces from other reciever lines that are close not only in offset but also in azimuth. During each receiver line processing, an overlapping window is applied to handle dispersion of the noise wave front. Furthermore, because now the noise to be removed is a linear event, interpolation (e.g., Spitz) may be applied to the pseudo 2D line to handle alias problems if the trace interval is large.

Example

The anti-alias 2D f-k fan filter method is used for this example and this fan filter can be explained by a synthetic data example in figure 5 (a). The F-K spectra of the synthetic data are shown in figure 5(b) and the linear noise to be removed shows aliased. We re-arrange the spectra in figure 5(b) and extend the normalized spatial spectra range from [-0.5 0.5] to [-1, 1], figure 5(c). In the new F-K spectra domain, the linear noise spectra that interference with signal spectra in figure 5(b) is now separated from signal spectra and therefore, fan filter can be applied to remove the noise spectra.



(a) (b) (c)

Figure 5. (a) synthetic data and its f-k spectra (b), (c) f-k from spatial spectra extended

Figure 6 shows an example of the 2D f-k fan filter method. The data are a cross-spread gather with station interval equal to 10 m and shot interval equal to 80 m (figure 5, top row). The noise-removed data and the actual noise to be subtracted are shown in the middle row and bottom row, respectively.

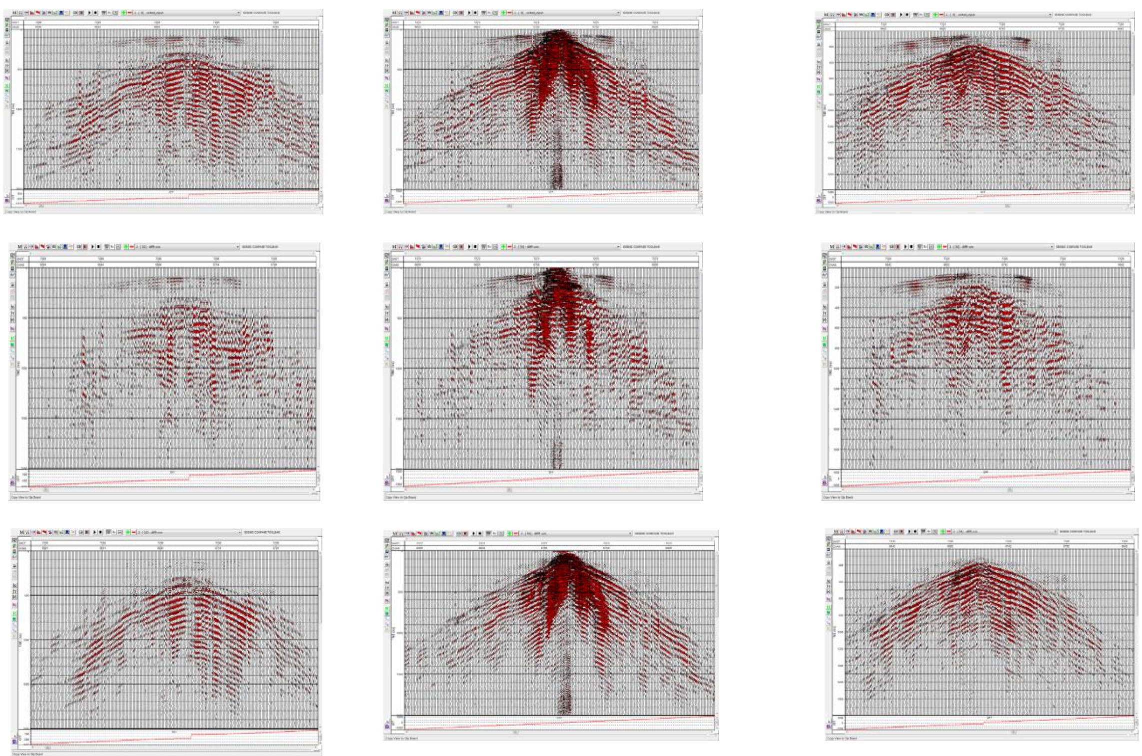


Figure 6: From top row to bottom row are raw data, noise-removed data, and removed noises.

Conclusions

We have presented a simple program for attenuating source-generated coherence noise for 3D data. The method has advantages of ease of implementation and flexibility in that any 2D algorithm can be used for 3D linear noise attenuation. The processing of the 3D data set is transposed into the processing of 2D receiver lines with regular sampling and, therefore, the program works very efficiently.

Acknowledgements

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