Acquisition geometry footprints removal

Necati Gülünay, Western Geophysical

Abstract

Sparsely recorded data cause multichannel algorithms to suffer from aliasing when steeply dipping noise is present. Stacking, dip moveout (DMO) and migration, are among such processes that may produce artifacts that are known as "Geometry Footprints" or simply "Footprints". Most of the time multichannel algorithms are upgraded to handle missing data or if that fails interpolation or extrapolation of input volumes is done before applying multichannel processes. Unfortunately, there are times neither is possible and interpreters have to work with volumes which contain such footprints. At other times data which need to be interpreted in the prestack mode, like for AVO analysis, may sometimes also be degraded by the footprints.

Footprints manifest themselves as spectral peaks generated around each event in the constant frequency slices of the 3-D frequency-wavenumber transform of the data. Such footprints can be suppressed by notch filtering the spectral peaks that are produced. If data are of mild geologic complexity then it is possible to identify and suppress footprints in an almost automatic fashion.

Introduction

It is well known that sparse recording in the field causes artifacts during processing. Field recording is simply spatial digital sampling and, as in the time domain, coarse spatial sampling leads to aliasing. Aliased steeply dipping noise such as ground-roll and multiples create such artifacts. In 2-D data collection, when the source interval is equal to or larger than the receiver interval, each CMP lacks a number of offsets resulting in periodic offset patterns. A stack of such CMPs can therefore have periodic events along the CMP direction if steeply dipping noise is present. A spatially periodic phenomenon appears as spectral peaks in the wavenumber domain. This type of response is known as the CMP array response. Field arrays of 2-D data are generally tuned so as to suppress spectral peaks of the CMP array. The combination is known as the stack-array (Morse and Hildebrandt, 1989). The role of the stack-array in 2-D is to suppress events that are likely to create geometry footprints. In 3-D recording, economical considerations often lead to a lack of effective field arrays, thereby causing aliased noise to leak into the stack volumes as spatially periodic events and causing aliasing in most of the multichannel processes. Interpolation of the input data also helps to minimize artifacts caused by periodically missing data.

Sometimes, however, the 3-D data volume has still some footprints left in the data. In such cases it is well known that trace mixing or wavenumber domain filtering can be useful. The use of a frequency domain k-notch filter for 2-D data was suggested by Hampson (1994). At the same meeting, Gülünay et al. (1994) suggested the use of f-k domain k-notch filters for 3-D data volumes and proposed to determine the location of spectral peaks produced from the acquisition footprints by summing k_x-k_y amplitude spectra of data along the frequency axis and picking the location of significant maxima from the summed spectra. They applied notch filters of small extent to each frequency slice of data to minimize the artifacts. In this paper we propose an extension of the original 3-D algorithm to dipping data of mild dip.

Spatially Periodic Offset Patterns and Spatially Periodic Noise

In this section a simple 2-D example of spatially periodic offset patterns (and the resulting spectral peaks) is discussed. Let us assume, for simplicity, that the shot interval is equal to twice the detector interval. This results in a 4 CMP offset pattern. Suppose there is an event with linear moveout such as ground roll. Let us consider a temporal frequency component at frequency f. Let the moveout of the event be • T seconds (per trace moveout in the shot domain). Let k_N represent the Nyquist wavenumber (which is equal to 0.5 cycles/trace) in the f-k transform of the stack of such CMPs. Innermost traces for such CMPs are shown in Figure 1 for • T =2 ms. Here we used a 5-80 Hz zero phase wavelet sampled at 4 ms sampling interval. The stack of the CMP gathers will contain the same spatial periodic patterns, as the near trace data, except that the stack will have a different common wavelet. The f-k spectrum of the near-traces is shown in Figure 2. We see that there are four events, one at k=0 which corresponds to the flat part of the event and others at $-k_N$, $-k_N/2$ and $+k_N/2$. These events in the f-k spectrum are due to the 4-CMP periodicity in offset patterns. We observe that there is a slope in the amplitude spectrum of the artifacts (including the one at k=0) that needs explaining.

It can be shown that, aside from a wavenumber independent wavelet due to stacking, the magnitude of the f-k transform of such CMP gathers is the product of a comb function

$$\delta_{k+k_N}+\delta_{k+0.5k_N}+\delta_k+\delta_{k-0.5k_N}$$

with the broad spectrum of the dipping event truncated to 4-traces

$$\frac{|\sin 4\pi(f\,\Delta T-\frac{k}{2k_N})|}{4|\sin\pi(f\,\Delta T-\frac{k}{2k_N})|}$$

This is illustrated in Figure 3 for f=0 Hz. A value of 0.5 cycles per trace along the k-axis represents a Nyquist wavenumber. The first function, a comb function, has four spikes: at $-k_N$, $-k_N/2$,0, and $+k_N/2$. The second function is a window function of a 4-trace dipping event at 0 Hz. At zero Hz the product of the two functions gives zero everywhere except at k=0. As frequency increases the location of the peak for the second function shifts due to the dip. The peak is at $k=k_N/2$ when $f=f_N$. Therefore the product of the two functions produce the slopes present in the magnitude of the f-k spectrum shown in Figure 2.

Since in this case the location (but not the magnitude) of the footprint is frequency independent it is an easy matter to sum the amplitude spectrum of each frequency slice to find the location of the artifacts automatically. An example of a summed k_x-k_y spectrum is shown in Figure 5. In this example data collection was done with a zig-zag geometry where the shot lines were at 45 degrees to the receiver lines. Therefore location of the artifacts are also in a diagonal direction in the summed spectrum. These peaks can be detected with a local maxima search algorithm and strong peaks (except the one at $k_x=k_y=0$) can be notched out. This was basically the method presented by Gülünay et al. (1994).

Spatially Periodic Noise in 3-D and in the Presence of Dips

In the examples given above it is assumed that the zero offset time of the event does not change along CMP's. Although this simple model covers many situations, it is possible to have events such as dipping multiple energy which would produce hatching on a dipping event. When an event that has hatching has also dip, then, the hatching pattern in the f-k domain is dipping as shown in Figure 4. Here I assume that the event has a 4/3 time samples per trace slope in both the x and y directions and is aliased beyond $3/4^{th}$ of the temporal Nyquist frequency. I also assume, for simplicity, a 2-trace periodicity in the inline and crossline directions. Geometry footprint related artifacts (shown in other colors than the event) follow the dip of the event (green) but only the event originates from the origin of the f-k_x-k_y volume. Here only the locations of the main event and artifacts are shown. The amplitude of the artifacts will be frequency dependent as seen in the zero dip case given above. If there is a single event with a dip then one can sum the amplitude spectra of the frequency slices after shifting (and wrapping) each spectrum in such a manner to bring the dipping event to $k_x=k_y=0$. For complex data each dipping event in a slice has to be shifted before being summed. If there are only a limited number of events in the f-k_x-k_y volume then for each event the amplitude spectra on a frequency slice can be shifted in such a way as to center the spectrum of that event to $k_x=k_y=0$. After all the shifts are completed, all the spectra are summed along the frequency axis before detection and notch filtering of the maxima. This way more than one dipping event can be considered in determining the locations of the artifacts around each event. If the location of the artifacts are known, as would be the case in a swath type 3-D shooting, then it may be desirable to specify the locations of the notches instead of detecting them. Time slices before and after this process are shown in Figure 6 and 7 for a 3D survey. Diagonal artifacts were detected and suppressed by the algorithm.

Discussion and Conclusion

In this paper an extension of a zero-dip acquisition footprint algorithm to dipping data was presented. The method assumes that artifacts occur around each dominant event in the frequency slice of the f-k_x-k_y volume and that there are only a limited number of events in the data. These assumptions can be approximated by working in small time-space gates. A 100x100 trace and 1000ms window size seems to be a satisfactory size for this purpose. It is conceivable that the algorithm may harm real events if artifact detection is not successful since f-k_x-k_y samples are zeroed at certain k_x-k_y locations at each frequency slice. For this reason difference plots are used to evaluate the nature of the energy rejected by the algorithm.

Acknowledgment

I thank my colleagues Carlos Son, John Ralph, Mike Vervalin, Ed Ferris and John Gilbert for using the new algorithm and providing feedback and John Gilbert for providing the two-time slices for field data. I thank Miles Wortham for the drafting of the figures and Western Geophysical for allowing me to present this paper.

References

Gülünay, N., Martin, F., and Martinez, R, D (1994) 3-D data acquisition artifacts removal: spot editing in the spatial-temporal frequency domain, 56th Annual Meeting of European Association of Geoscientists and Engineers, Abstracts Book, Paper H049.

Hampson, G. (1994) Relationship between wavefield sampling and coherent noise attenuation, 56th Annual Meeting of European Association of Geoscientists and Engineers, Abstracts Book, Paper H054.

Morse, P. F. and Hildebrandt, G. F. (1989) Ground-roll suppression by the stack-array, Geophysics, 54, No. 3, p. 290-301.

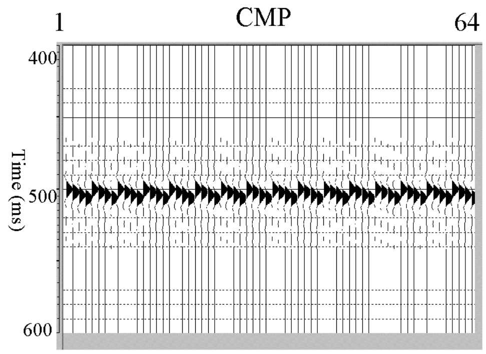

Figure 1. A spatially periodic event representing a geometry footprint resulting from a 4-CMP pattern of offset distribution. The wavelet bandwidth in 5-80 Hz, sample interval is 4 m, and time shifts for the jitter are 0, 2, 4 and 6 ms.

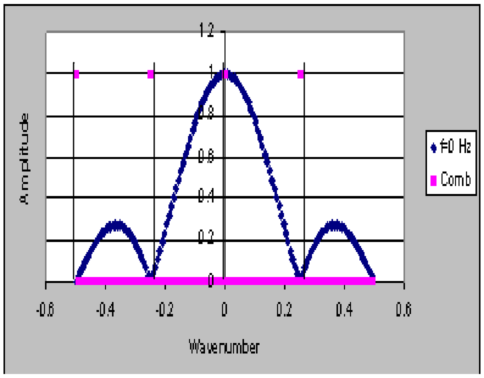

Figure 3. Comb function corresponding to a one full-trace and three empty-trace pattern and the response for a four-trace window function. Note that because of the dip on the hatching, the four-trace window function moves towards the right as temporal frequency increases. The total response is the product of the comb function with the window function leading to the amplitude variation observed in Figure 2 as frequency increases.

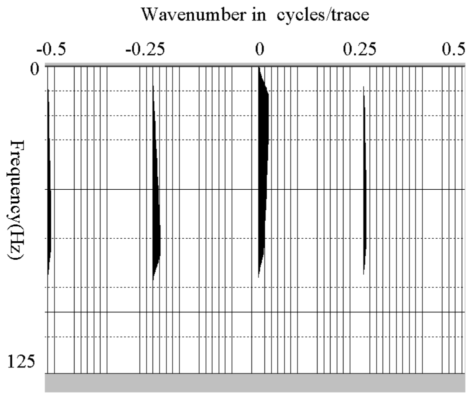

Figure 2. Magnitude of the F-K transform of Figure 1. and ½ k_N. Note that events appears at wavenumbers $-k_N$, - ½ k_N, 0

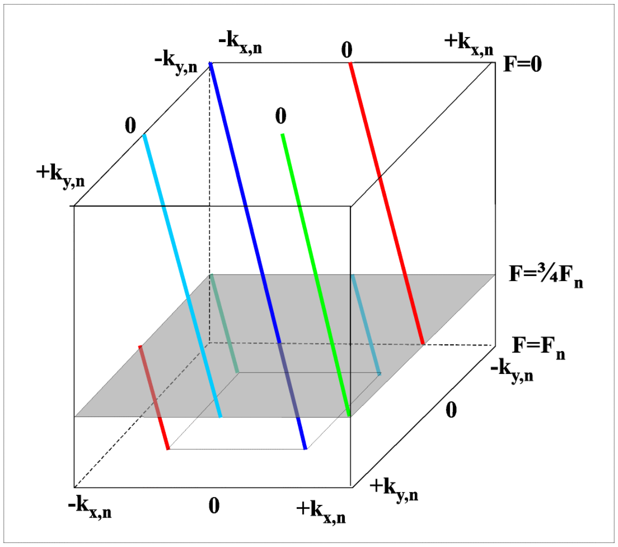

Figure 4. Location of footprint artifacts for 2 trace inline and 2 trace crossline spatial periodicity for a dipping event (in green color) with equal inline and crossline dip. Note that the event is aliased beyond three fourths of the temporal Nyquist frequency. At every frequency slice there is one event (green) and three footprints (blue, light blue and red), around it.

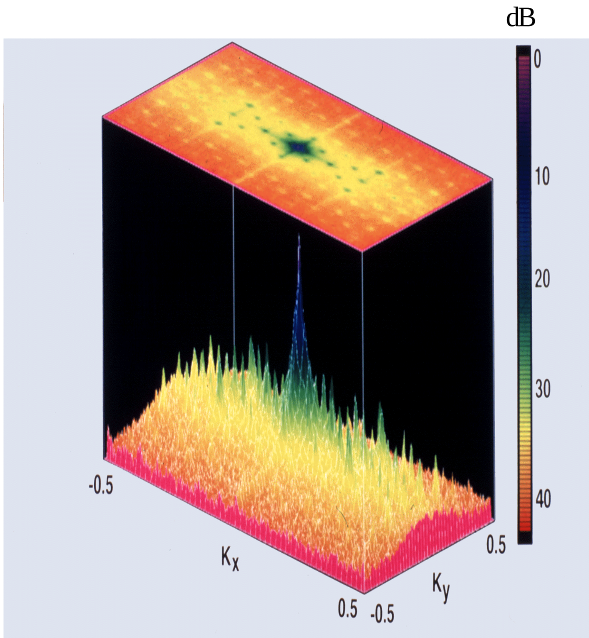

Figure 5. Average k_x-k_y spectrum of the 3-D stack volume recorded with a zig-zag (diagonal) shooting pattern. Note the diagonal location of the spectral peaks.

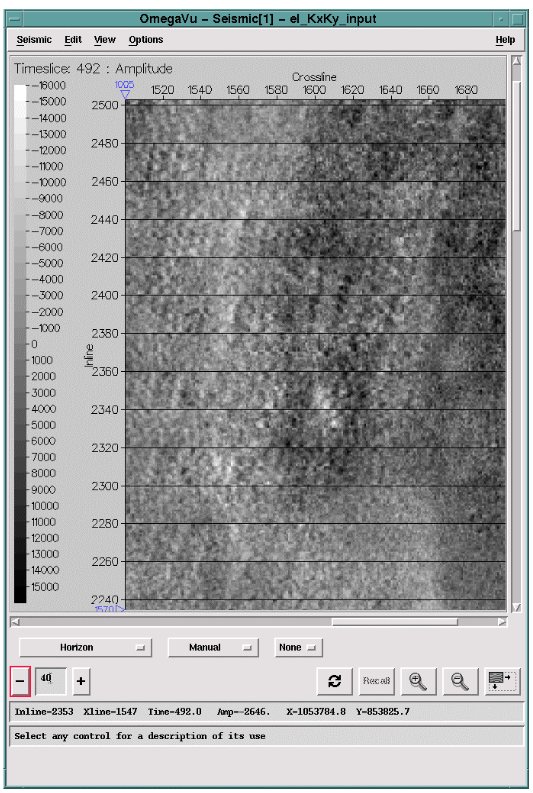

Figure 6. Input time slice from a 3-D survey.

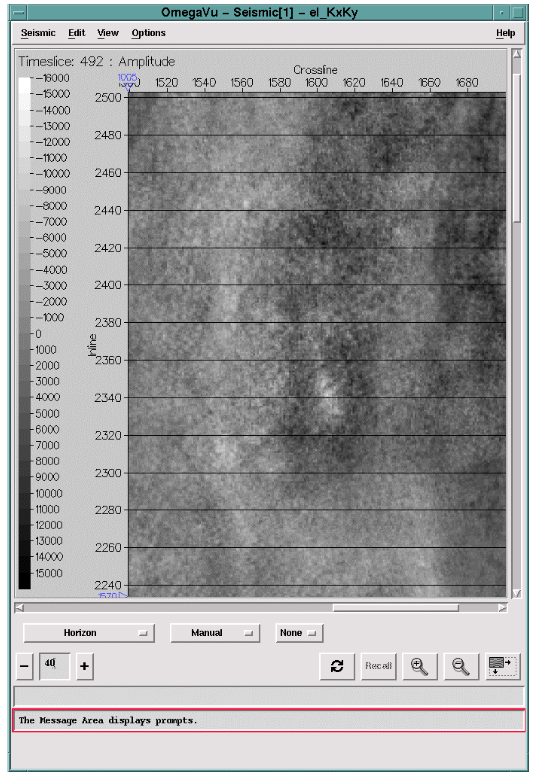

Figure 7. The slice in Figure 6 after f-k_x-k_y notch filtering.