Supported by tetfund

COMPARING f-k FILTERING AND BANDPASS FILTERING IN GROUNDROLL ATTENUATION OF A LAND SEISMIC DATA – THE D-10 DATASET CASE STUDY

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Received: May 18, 2020 **Accepted:** September 20, 2020

Abstract: This work aims to present a comparison between the f-k and bandpass filtering methods in reducing ground roll energy in a land seismic dataset. The f-k filter used is based on the 2-D Fourier transform of the input data in the t-x domain. A triangular-shaped f-k filter was incorporated as the reject-band which is then applied to areas where the ground rolls are located without affecting the signal in the same area. The f-k filter attenuates the ground roll using the differences between noise and signal in two aspects: frequency and amplitude, with the data outside the window still intact. However in the bandpass filtering, the band pass filter of truncation frequencies of 5-15-55-65 Hz (10-60 Hz) was used to attenuate the ground roll, and this eliminates low-frequency reflection signals which contribute to the character of reflection events which are very important in inversion for acoustic impedance and advanced seismic processing. This analysis is applied to the D-10 dataset, which demonstrates a successful performance using this comparison.

Keywords: f-k filter, bandpass filter, 2-D transform, groundroll, D-10 dataset, attenuation

Introduction

The attenuation of source generated coherent noise like groundroll can be a challenging problem for land data where groundroll often exhibit complex behaviour with multiple propagation modes, high amplitude, and relatively low frequency. Seismic land data are often contaminated by coherent noise that mask the reflections needed to properly construct an accurate subsurface image. The noises usually consist of groundroll and other coherent noises (Almedia *et al*., 2015). Groundroll is a persistent problem in seismic processing of land data, and a number of techniques have been developed to attenuate it (Liu *et al.*, 2009; Henley, 2003; Strobbia *et al*., 2011; Lu *et al*., 2006; Duncan and Beresford, 1993; Boas *et al*., 2015; Duan and Fu, 2001).

In this work, two methods of attenuating groundroll is presented; this is based on the characteristic low-frequency and high amplitude of the groundroll.

The f-k filtering technique is based on the 2-D Fourier transform from the t-x to the f-k domain, since the field record is sampled in time and space, it can be represented by a 2-D transform from the t-x domain to the f-k domain. Because data are sampled in both time and space, data outside a plane that is between $-k_n$ and $+k_n$ in the wave number direction and between 0 and f in the frequency direction is called the F-K plane, as illustrated in Figure 1 (Gadallah and Fisher, 2005).

Band-pass filtering is a common way of attenuating ground rolls in land seismic data because of the low-frequency property of ground rolls. The band-pass filtering usually means frequency filtering, when data are filtered, the input amplitude spectrum is multiplied by the filter amplitude response. Thus, the idea of the band-pass filtering is to reduce or attenuate frequency components where noise dominates over signal (Chen *et al*., 2015). The bandpass filter attenuates frequencies below its low cut-off frequency and above its high cut-off frequency (The difference between these two cut-off frequencies is the pass band).

The D-10 seismic dataset has a usable reflection energy confined to a bandwidth of approximately 20 to 50 Hz, with a dominant frequency around 30-40 Hz. The main objective of this work is to compare both filtering methods in determining its effectiveness in ground roll attenuation combined with an excellent signal preservation.

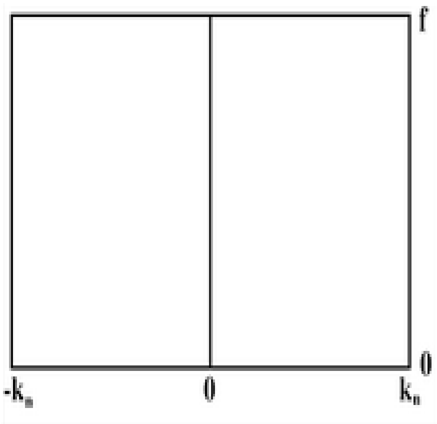

Fig. 1: The f-k plane

Materials and Methods

Theory

F-K filtering and 2-D Fourier transform

F-K filtering can be useful in discriminating against noise and enhancing signal based on a criterion that can be distinguished from trace to trace, such as dip or apparent velocity. The 2-D Fourier transform is the basis for this analysis (Yilmaz, 2005). Frequency (number of cycles per unit time) is the Fourier dual for the time variable. However, a seismic wave field is also a function of space, the Fourier dual of space is the wave number or spatial frequency (number of cycles per unit distance).

The 2-D Fourier transform of a 2-D function, such as a wave field $P(x,t)$ is given by

$$P(k,f) = \iint P(x,t)\exp(ikx - ift)dxdt \qquad (1)$$

The function $P(x,t)$ can be reconstructed from $P(k,f)$ by the 2-D inverse Fourier transform:

$$P(x,t) = \iint P(k,f)\exp(-ikx + ift)dkdf \qquad (2)$$

The integral given by equation (1) is evaluated in two steps. First, by Fourier transforming in *t*,

$$P(x,f) = \int P(x,t)\exp(-ift)\,dt \qquad (3a)$$

Then by Fourier transforming in *x*, and this gives the 2-D Fourier transform

$$P(k,f) = \int P(x,f)\exp(ikx)\,dx \qquad (3b)$$

Band-pass filtering

In setting up a band-pass filter, it is always necessary to avoid superimposing the amplitude spectra of the output data, with the actual spectrum having a ringy character, and this is known as the Gibbs phenomenon (Claerbout, 1976). This ringing is undesirable, since some frequencies in the passband are amplified, while others are attenuated. This Gibbs phenomenon can be avoided by defining the passband as a trapezoid, making the output amplitude spectra to be in closer agreement with the filter operator. The trapezoidal filter is specified by four corner frequencies (f_1, f_2, f_3, and f_4) and a filter length. Fig. 2 shows a pass-band filter response and defines the corner frequencies. The responses are 0 at f_1 and f_4, and 1 at f_2 and f_3. From the vertical symmetry of the response, the frequencies at which the response is ½ are $\frac{f_1+f_2}{2}$ and $\frac{f_3+f_4}{2}$. These two frequencies determine the filter pass band (Gadallah and Fisher, 2005).

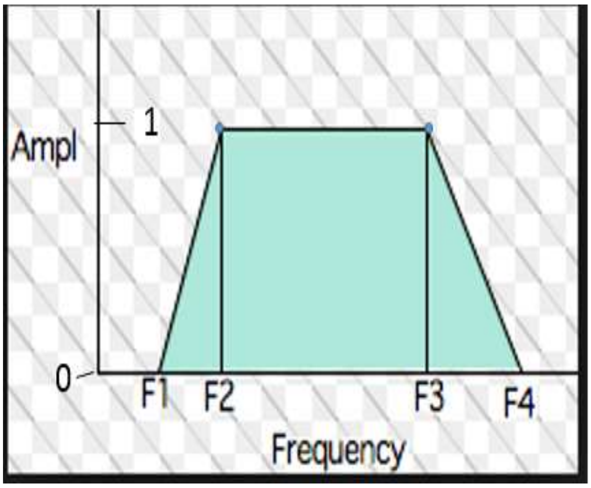

Fig. 2: Band-pass filter response and corner frequencies

Band-pass and f-k filter- D-10 dataset

A 1.9 GB raw seismic data acquired by The Shell Petroleum and Development Company (SPDC), Portharcourt, Nigeria was used for this study. The data was initially acquired in a SEG Dformat but reformatted to a SEG Y format to accommodate newer seismic processing software. A resampling was done on the SEG Y data with a sample interval of 4 ms. A 100-125 Hz high cut and anti-alias filter was also applied. The seismic processing software: Vista 2D-3D (version 12.0) was used for this analysis.

The most fundamental equation in the filtering procedure for seismic data processing is given as;

$$Seismicdata = Signal + Noise \qquad (4)$$

Where in this case, the signal is the primary reflections, while the noise is the ground-roll energy

Bandpass filtering is commonly performed in the frequency domain; the choice of the bandpass filter is mainly to attenuate low frequency noise like ground roll and some high frequency ambient noise. From the field data in Fig. 3, ground-roll energy is observed to dominate the data. Ground roll is a type of dispersive waveform that propagates along the surface and is characterised by low-frequency and large-amplitude (Yilmaz, 2005). These characteristics are evident from the amplitude spectra in Fig. 3. The spectra consist of the reflection signal (red line) and the ground-roll noise (yellow line). Although the ground-roll noise is of lower frequency compared to the signal, it is evident that there is much overlap between the frequency bands of the signal and the noise; this explains the existence of the low-amplitude component in Fig. 3. The useable seismic reflection energy of the D-10 dataset is confined between 20 and 50 Hz, with the dominant frequency around 30 Hz as shown in the amplitude spectrum of Fig. 6. Therefore, a low-cut bandpass filter of corner frequencies of 5-15-55-65 (10-60 Hz) was designed to suppress the ground-roll noise and some low-frequency component of the signal.

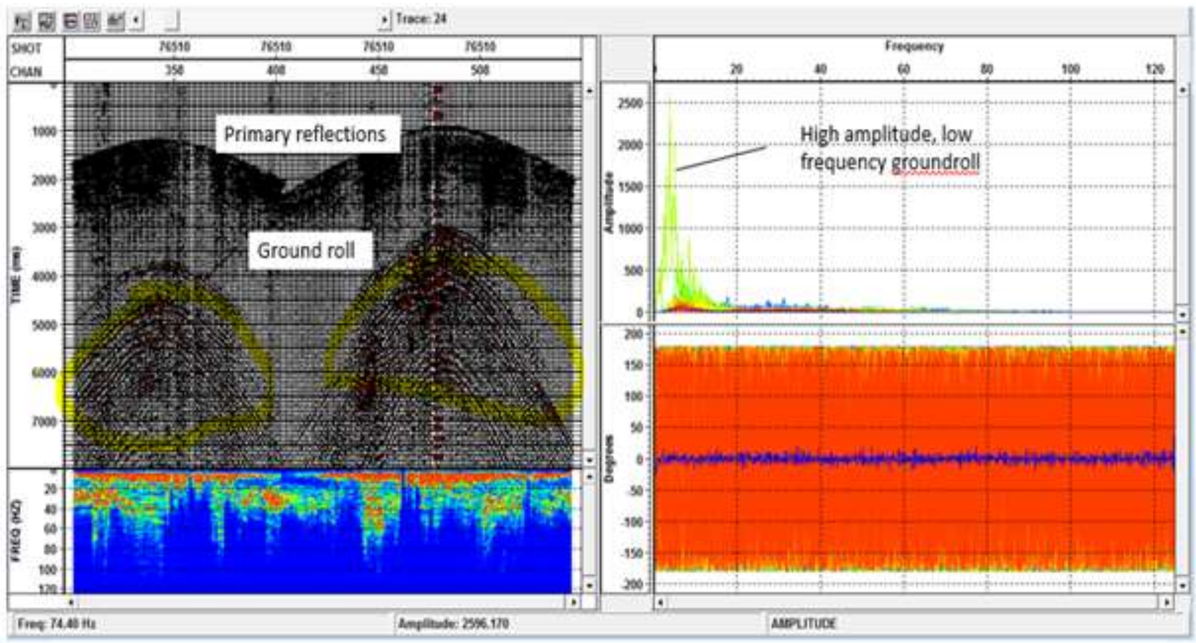

Fig. 3: Raw field data with amplitude spectrum characterising low frequency high amplitude ground roll

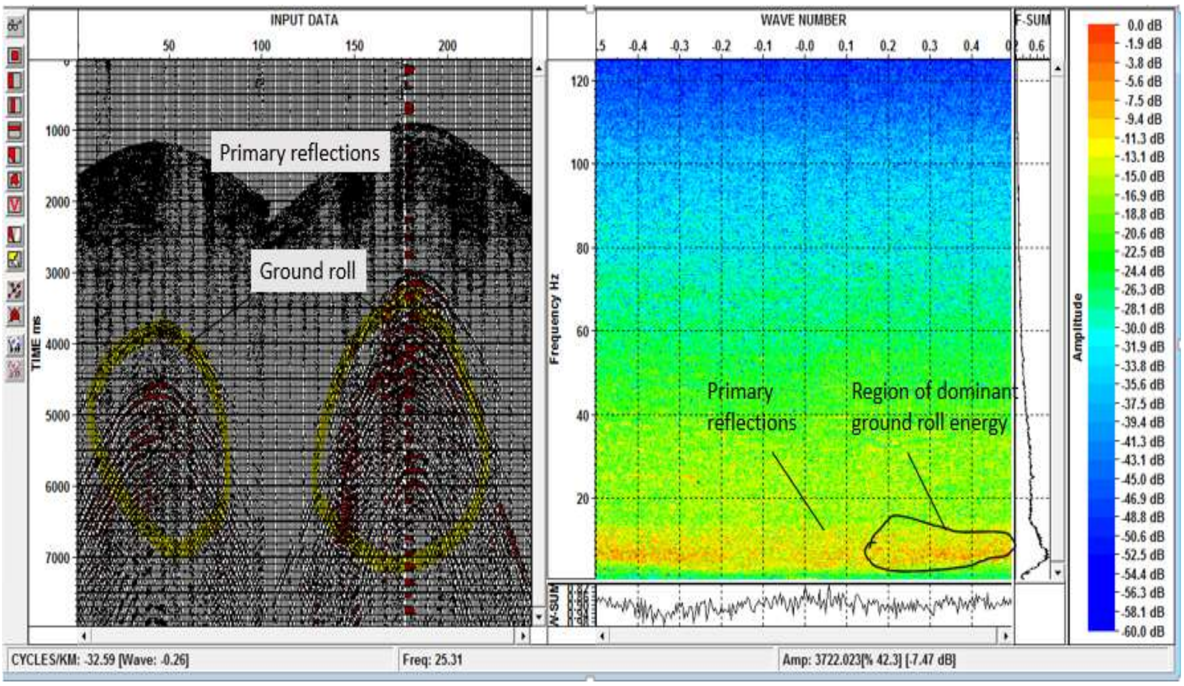

Fig. 4: Raw field data with 2-D amplitude spectrum indicating region of dominant ground roll energy

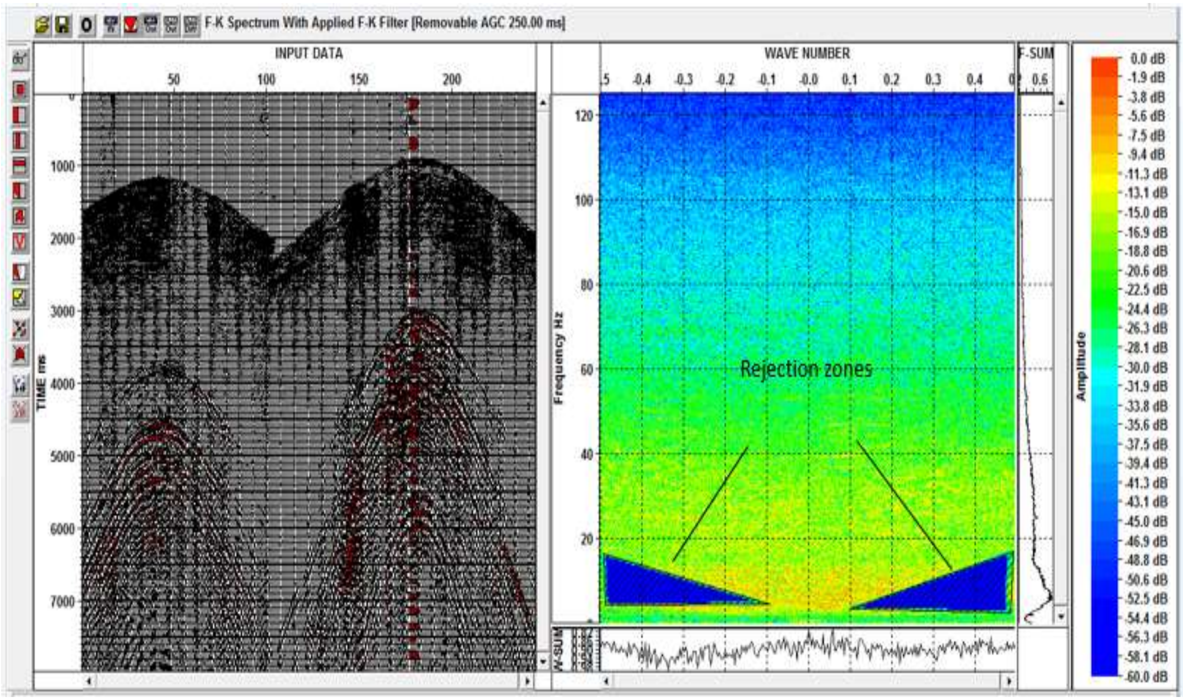

Fig. 5: Amplitude spectrum indicating f-k rejection zone

Figure 4 shows the 2-D amplitude spectrum of the field data, with the dominant reflection signals around the region k=0, with the ground roll away from it. The wave number magnitude k of the ground-roll noise is smaller than that of the reflection signal, because the apparent horizontal wavelength λ of the ground-roll noise is larger than that of the reflection signal (Huang *et al.*, 2017). In Fig. 5, a triangular-shaped filter is imposed on the f-k spectrum within which the undesired energy (ground roll) is rejected. This filter defines the 2-D reject zone in the f-k domain by setting the 2-D amplitude spectrum of the f-k filter to zero within that zone. The 2-D f-k filter is applied by multiplying its amplitude spectrum with that of the input data, and finally applying a 2-D inverse Fourier transform of the filtered data. It is worth noting that the second triangular filter on the negative k-axis is to avoid the problem of spatial aliasing (wrap around effect) in the f-k domain.

Results and Discussion

The f-k filter (Fig. 7) was designed as a triangular-shaped filter to mainly attenuate the data at low frequency and high amplitude. The filter lying within a frequency range of 4 – 16 Hz, while the wave number has a range of 0.1-0.5 cycles/km. After the application of the triangular-shaped f-k filter, it was observed that the ground roll becomes increasingly less apparent on the filtered output data in the t-x domain as shown in Fig. 8.

Pass band frequencies of 10 and 60 Hz is used for the bandpass filter and the filtering process was performed in frequency domain. In a similar manner, after applying the bandpass filter a remarkable attenuation of the ground roll energy as shown in Fig. 9 was also observed.
Both filtering techniques successfully attenuates the ground roll energy, however the bandpass filter eliminates low-frequency reflection signals which contribute to the character of reflection events and also very important in inversion for acoustic impedance and advanced stages of processing seismic data. This disadvantage is evident when comparing the amplitude spectra of both the bandpass and the f-k filtered data as shown in Fig. 10. The amplitude spectrum of the bandpass filtered data shows no amplitude event at frequency range of 0-22 Hz. However, the frequency mixing problem of bandpass filtering may achieve a successful removal of ground rolls and removing useful primary reflections.

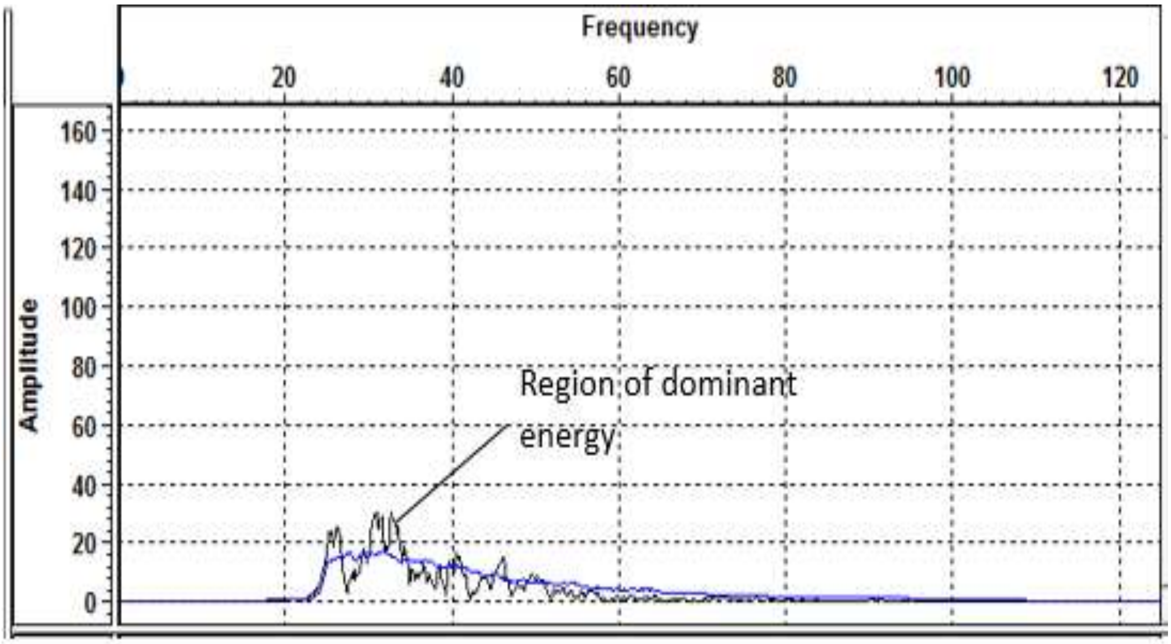

Fig. 6: Amplitude spectrum showing dominant seismic reflection energy

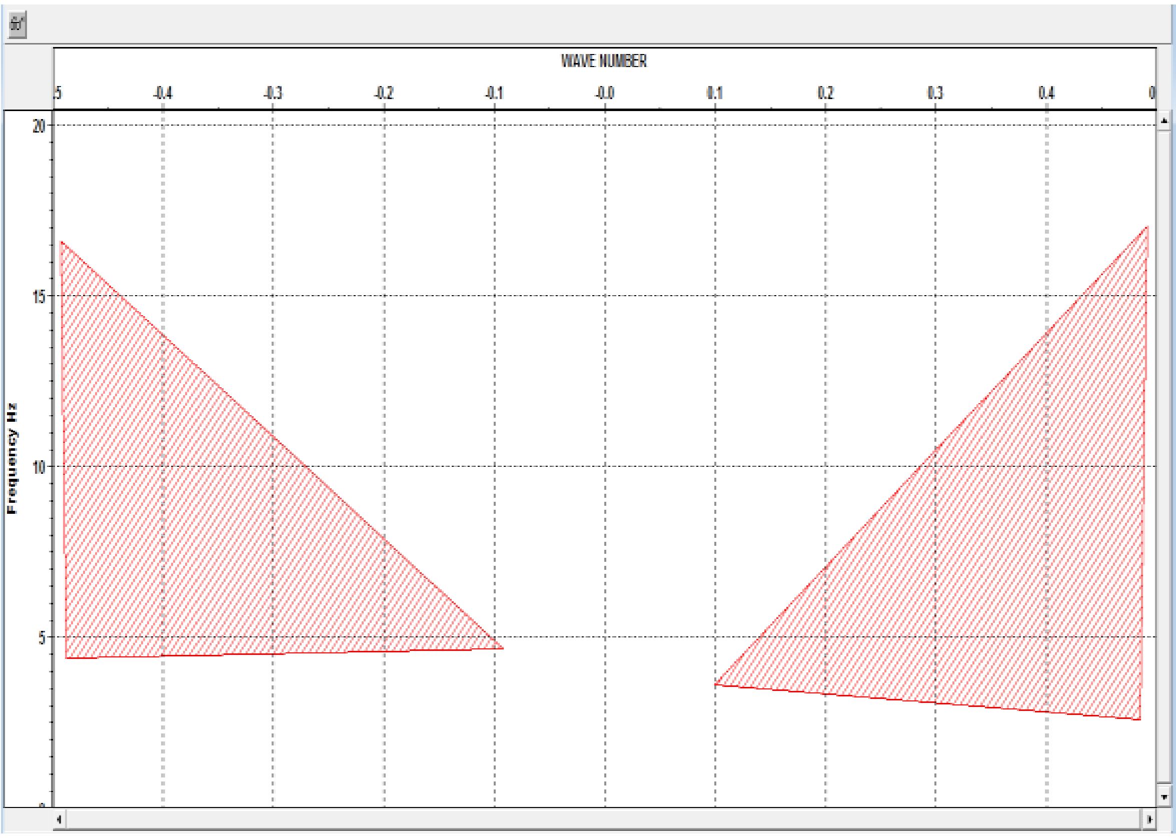

Fig. 7: Triangular-shaped f-k filter

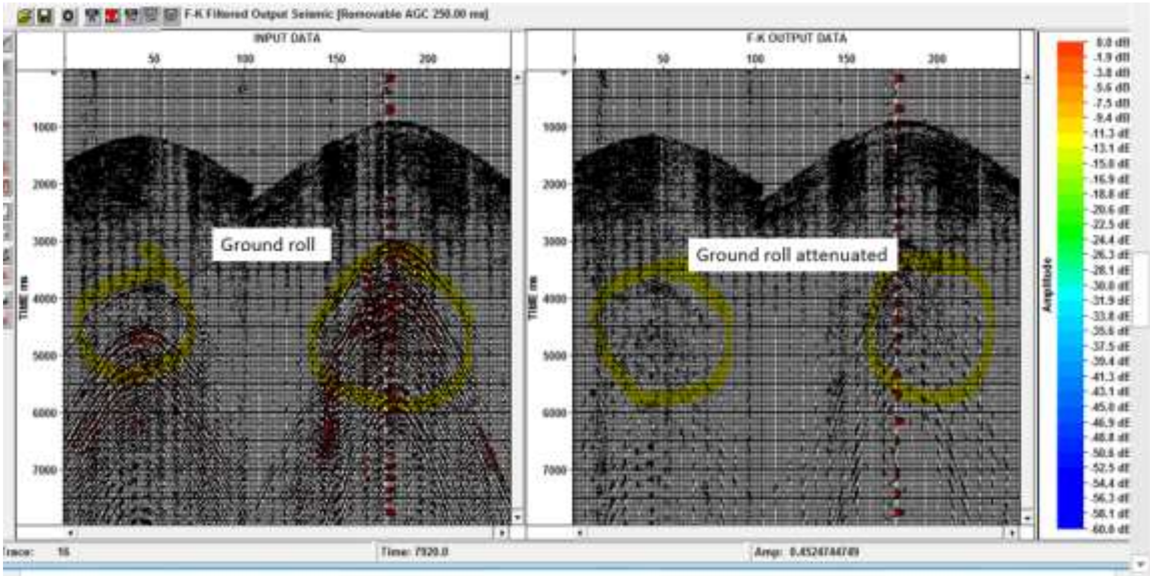

Fig. 8: Comparing the f-k filtered data with the input data in the t-x domain

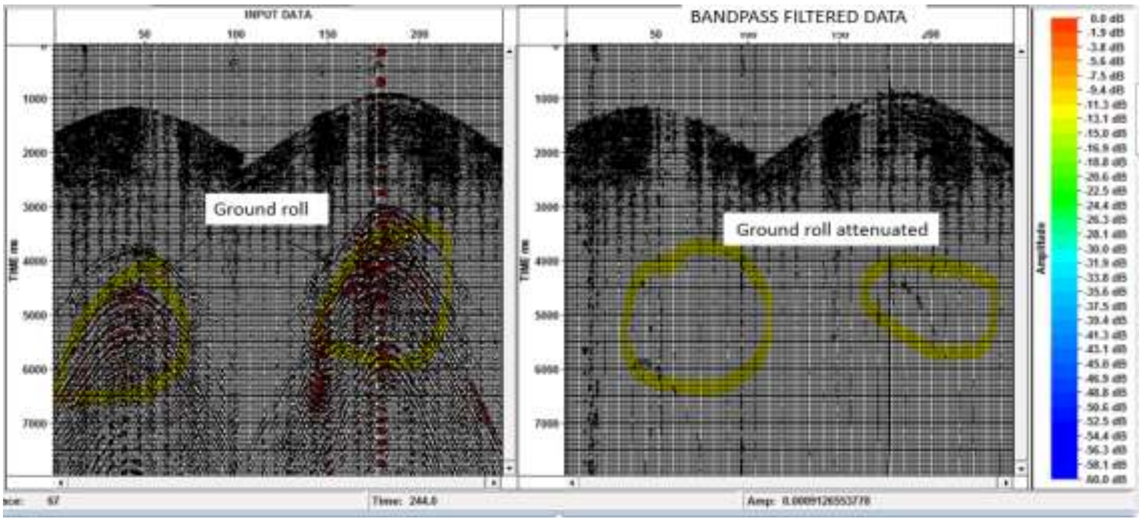

Fig. 9: Comparing the bandpass filtered data with the input data

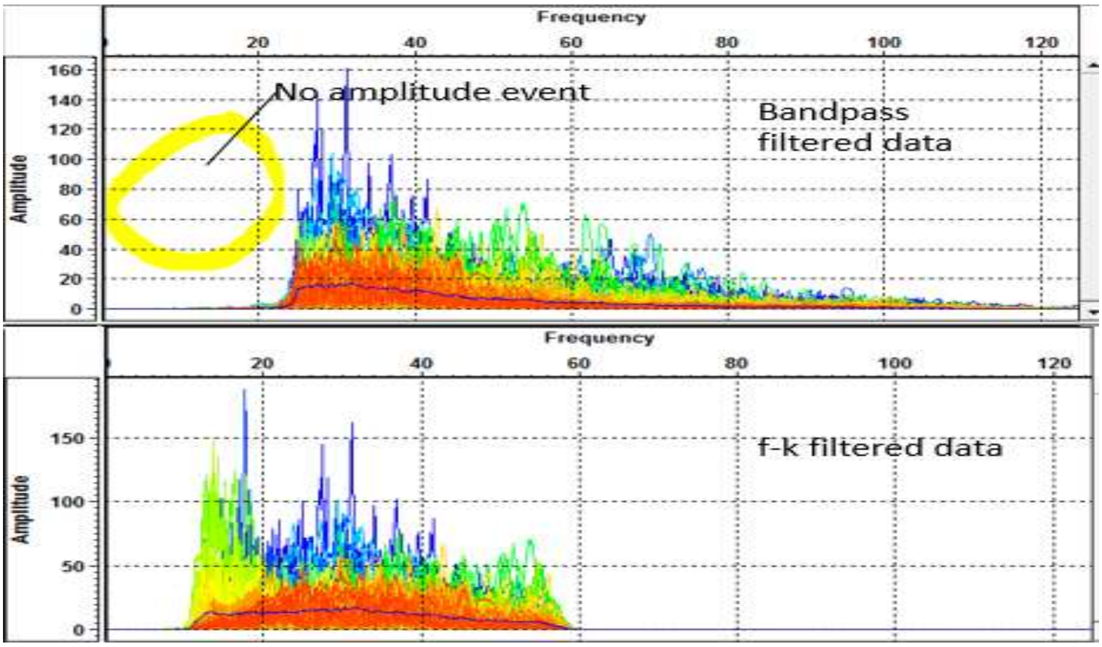

Fig. 10: Amplitude spectra of the bandpass and f-k filtered data

Conclusion

The results from the D-10 seismic dataset indicate that the f-k and bandpass filtering techniques has good ground roll attenuation characteristics, however the bandpass filter produces distortion of signals at low frequencies. In the f-k filtering, we incorporate a triangular-shaped reject-band f-k filter which is applied in a spatially and temporally varying way across seismic traces. The f-k filter is only applied to areas where the ground rolls are located and will not affect the signals that is located in the same area, thus the f-k filter attenuates the ground roll with a minimal or no distortion of the seismic signal. In conclusively therefore, results from this work has shown that multi-channel filtering processes like; frequency-wavenumber (f-k), produces a better signal-noise ratio than 1-D filtering processes like Bandpass filtering.

Acknowledgements

We wish to acknowledge Shell Petroleum and Development Company (SPDC), Port Harcourt, Nigeria for providing the data for this research work.

Conflict of Interest

Authors have declared that there is no conflict of interest reported in this work.

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