

## Improving Low Frequency Information from 10Hz Geophone data

*Pulak Kumar Bera\*, Pramesh Kumar Satapathy, ONGC*

### Abstract

The recording of low frequency seismic data and its preservation during processing is very important. The low frequencies suffer less attenuation during propagation and carries faithful geological information from the deeper zones of the earth. Low frequencies are required to be preserved for imaging sediments below basalt as most of the high frequencies are attenuated or lost within basalt layers. This paper elaborates two methodologies – application of inverse filter and matching filter to enhance spectra by recovering low frequency content in conventional 10 Hz geophone data and subsequent comparisons of the spectra of 10 Hz geophone data with that of 4.5 Hz geophone data. Present study shows that low frequency component enhancement in 10 Hz geophone data is possible by applying filters derived from the geophone response wavelets. Conversion of 10Hz geophone data equivalent to 4.5 Hz geophone data was carried out and applied on land datasets. Both the methods ensure the effective recovery of low frequency in the data acquired with 10Hz geophone.

**Key words: Geophone response function, Natural frequency, Inverse Filter, Match filter**

### Introduction

The extension of recording bandwidth to the upper frequencies has been the main focus since many years in the pursuit of higher resolution. The most common geophones used have natural frequency of 10Hz providing a flat response proportional to ground velocity above this frequency and a response roll-off below 10 Hz is about 12 dB/Octave. Extending bandwidth on the high end of the spectrum is not the only way to improve resolution. Adding an octave or two on the low end may serve the purpose as well. The purpose of this study is to present methods to recover the low frequency part of the data recorded with 10Hz geophone. Here, the data used for the study was acquired with 10Hz geophone and methods are proposed to recover the low frequency equivalent to data acquired with 4.5Hz.

### Methodology

The methodology proposed here is based on the design of filters from response functions wavelets of both 10Hz and 4.5Hz geophones. The low frequency content in the data acquired with 10 Hz geophone has been boosted by two methods: (a) Application of Match Filter and (b) Inverse filtering.

#### a. Match filter application

A match filter is a simple convolution filter that is designed on the amplitude and phase spectra difference between two traces. The operator when

applied will make the target trace ‘match’ the reference trace. Matching filter was derived from the geophone response function wavelet. The response function wavelet is estimated from the amplitude and phase spectra of the response function of 10Hz and 4.5Hz geophones. Matching filter operator for conversion of 10Hz data to 4.5Hz equivalent is designed from response function wavelets; this filter is applied to data acquired with 10Hz geophone.

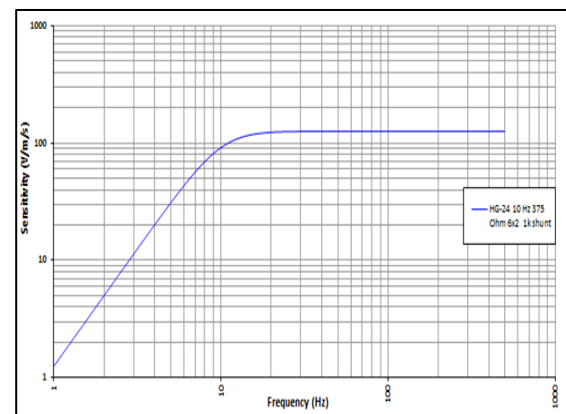


Fig. 1a: The response function of 10Hz geophone

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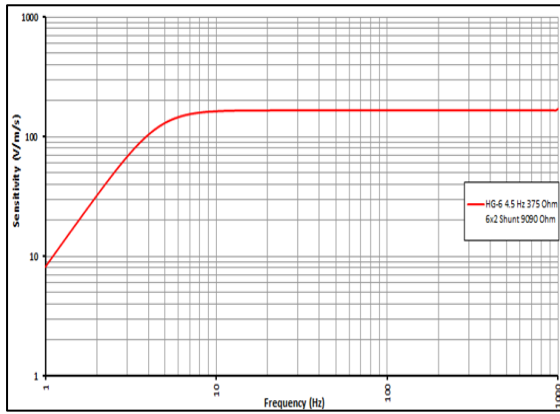


Fig. 1b: The response function of 4.5 Hz geophone

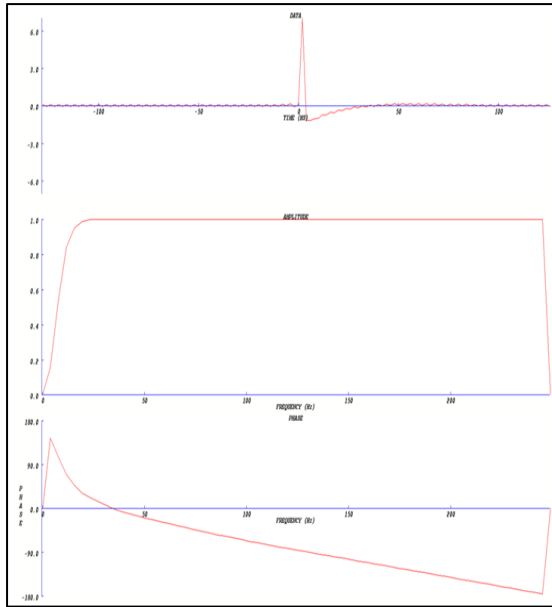


Fig.2a: Amplitude and Phase spectra of 10 Hz geophone response function wavelet

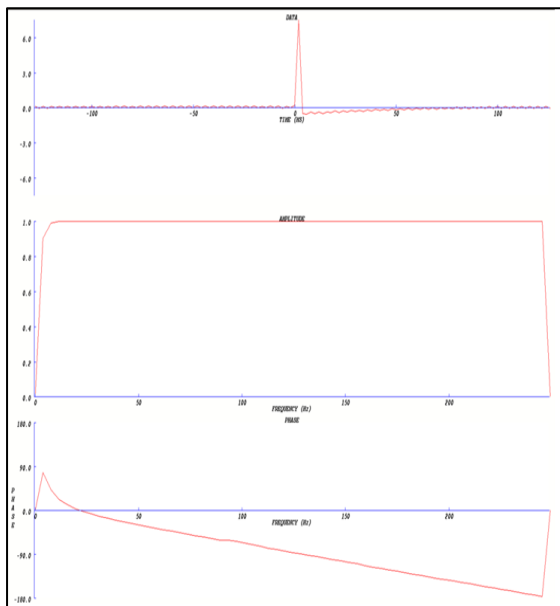


Fig.2b: Amplitude and Phase spectra of 4.5 Hz geophone response function wavelet

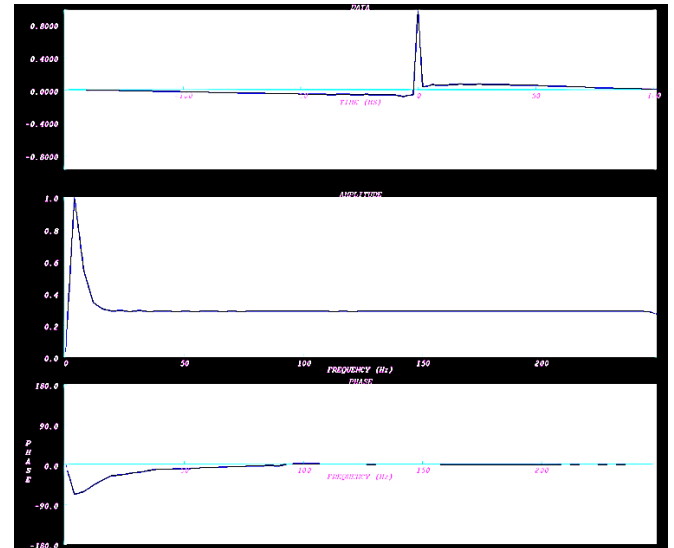


Fig. 3: Matching filter from 10Hz and 4.5Hz response function wavelets (top), corresponding amplitude (middle) and phase (bottom) spectra

**b. Inverse filter application**

The low frequency enhancement may be done by designing an inverse filter with the characteristics of the inverse of the 10 Hz geophone response. It has been assumed that geophone response roll-off is 12 dB/Octave and may be approximated by a Second Order, Minimum Phase, Butterworth filter. Minimum phase inverse equivalent was extracted from the 10 Hz geophone response. Then, the inverse filter was convolved with the data acquired with 10Hz geophone.

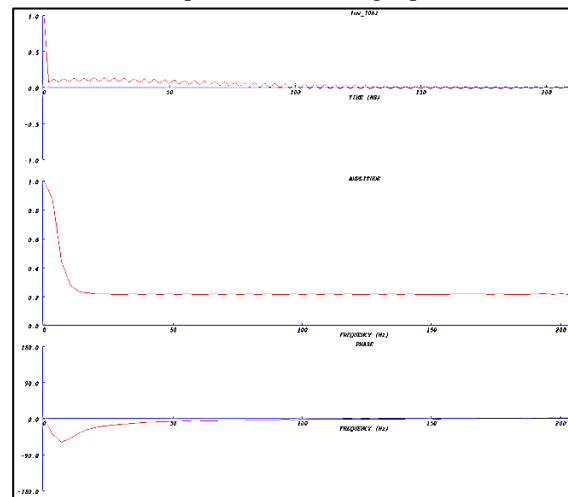


Fig. 4: Inverse filter (top), amplitude (middle) and phase (bottom) spectra

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Results

Two filters described above have are applied on raw shot gathers (Fig.5). The raw shot gathers (Fig. 6, 7) along with spectra (Fig. 8, 9) are shown below after convolving with geophone matching and inverse filters to retain low frequency. The raw offset domain gathers at long offsets after and before filter application are shown in Figures 10, 11, 12. From the average amplitude spectra, it is found that dominant low frequency in 10 Hz. Geophone data is around 4-5 Hz. A band pass filter (1-2-4-8 Hz) has been applied in records following filters in both the cases to reduce boosted DC levels in the filtering process. Enhancement of low frequency content in the 10 Hz geophone data has been done by two methodologies as discussed above. Raw stacks and their spectra are generated for comparison.

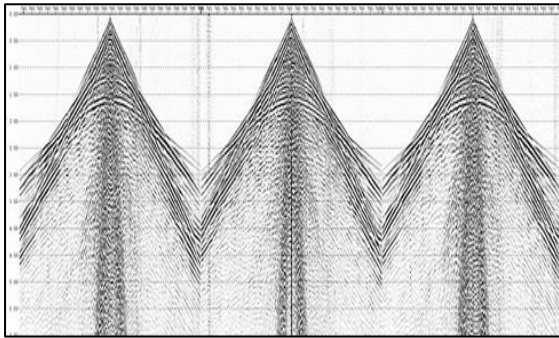


Fig.5: Raw shot gather acquired with 10Hz geophone

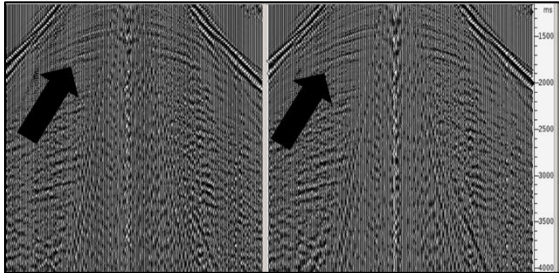


Fig.6: Raw shot after matching filter (left) and after inverse filter (right) at shallow

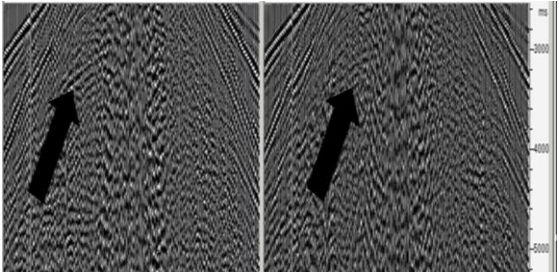


Fig.7: Raw shot at deep after matching filter (left) and after inverse filter (right)

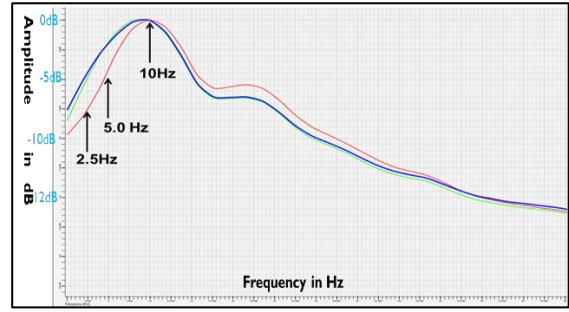


Fig.8: Amplitude spectra; red curve (raw shot), green (after matching filter) and blue (after inverse filter)

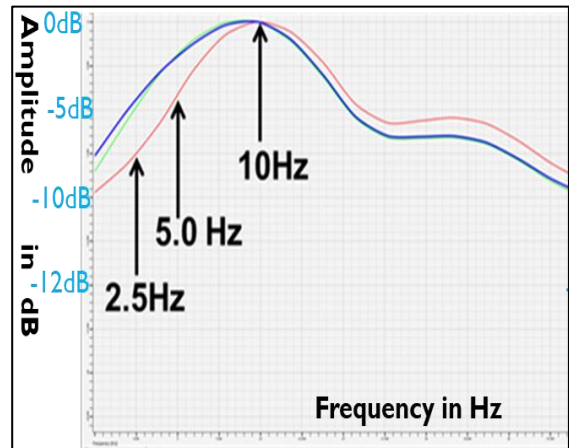


Fig. 9a: Spectra in Fig. 8 zoomed up to 30Hz

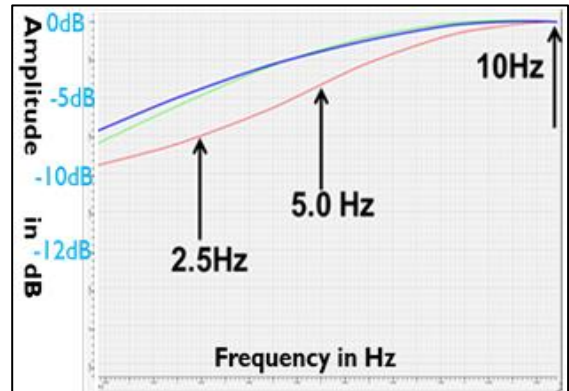


Fig. 9b: Spectra in Fig. 8 zoomed up to 10Hz  
The two methodologies described above works better to recover the low frequency part of the data. The dB level change at lower frequencies with respect to the original data acquired with 10Hz geophone is tabled below (Table 1).

Freq. (Hz)	dB level in raw gather	dB level after matching filter	dB level after inverse filter
2.5	-7.5 dB	-5dB	-4.5dB
5	-4.5dB	-2.0dB	-2.0dB
10	0dB	0dB	0dB

Table 1: Comparison of amplitude level

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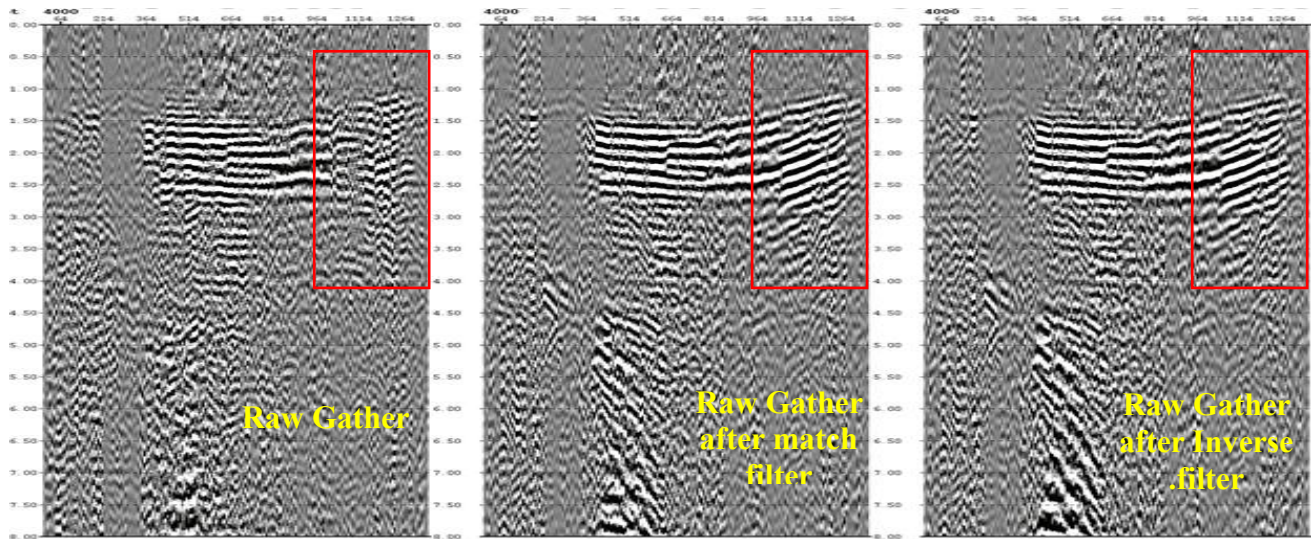


Figure 10: Offset gather at 4000 m

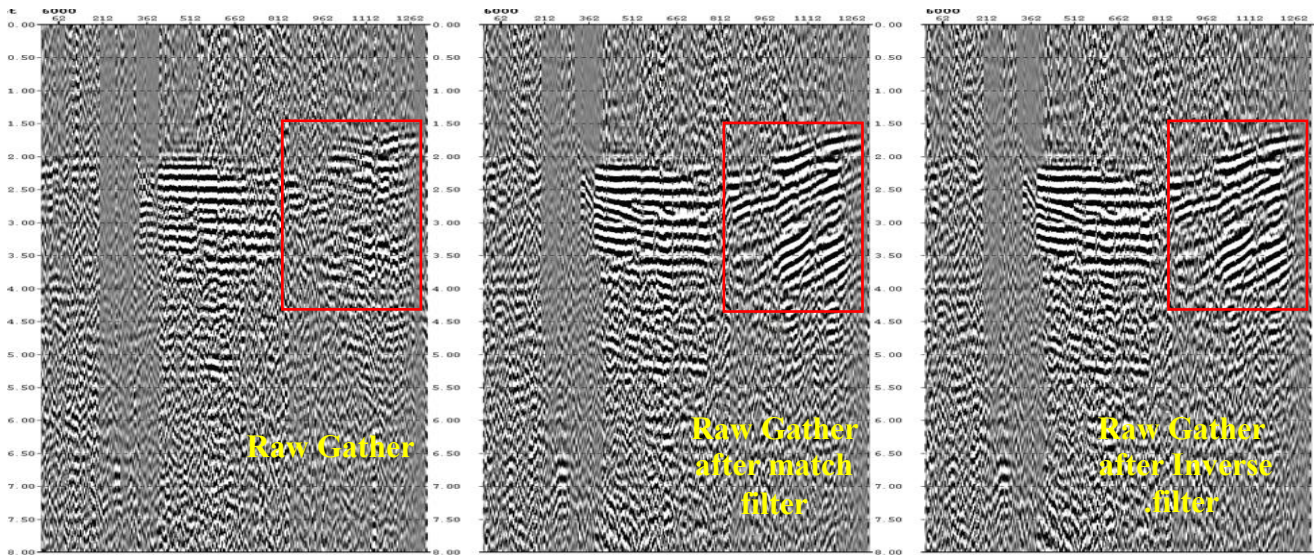


Figure 11: Offset gather at 6000 m

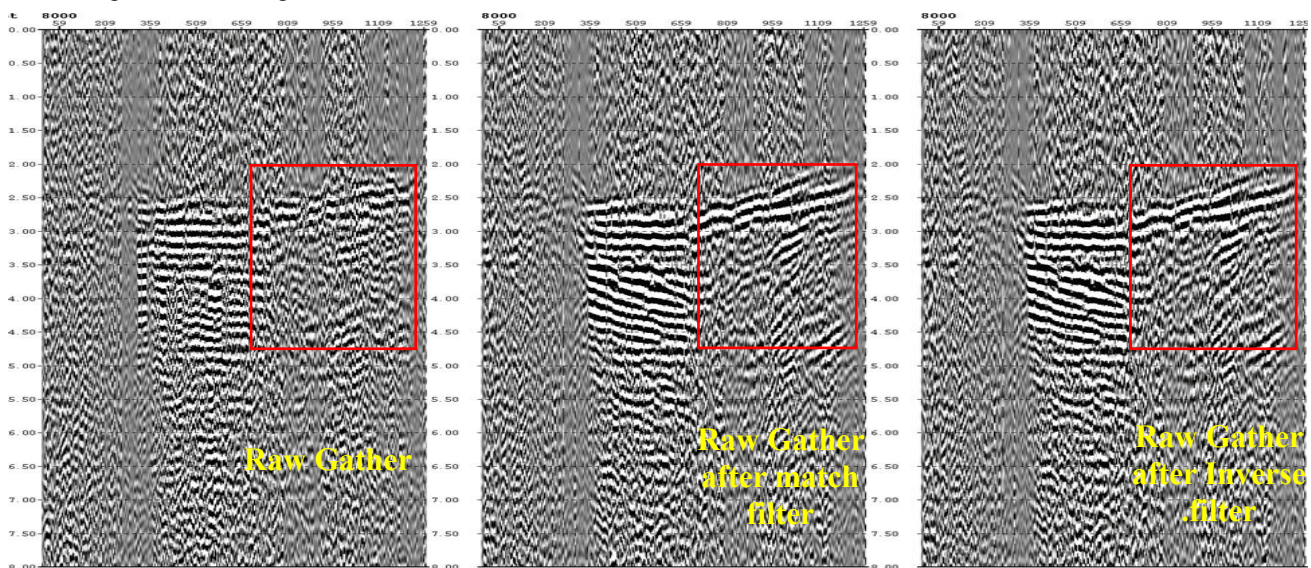


Figure 12: Offset gather at 8000 m

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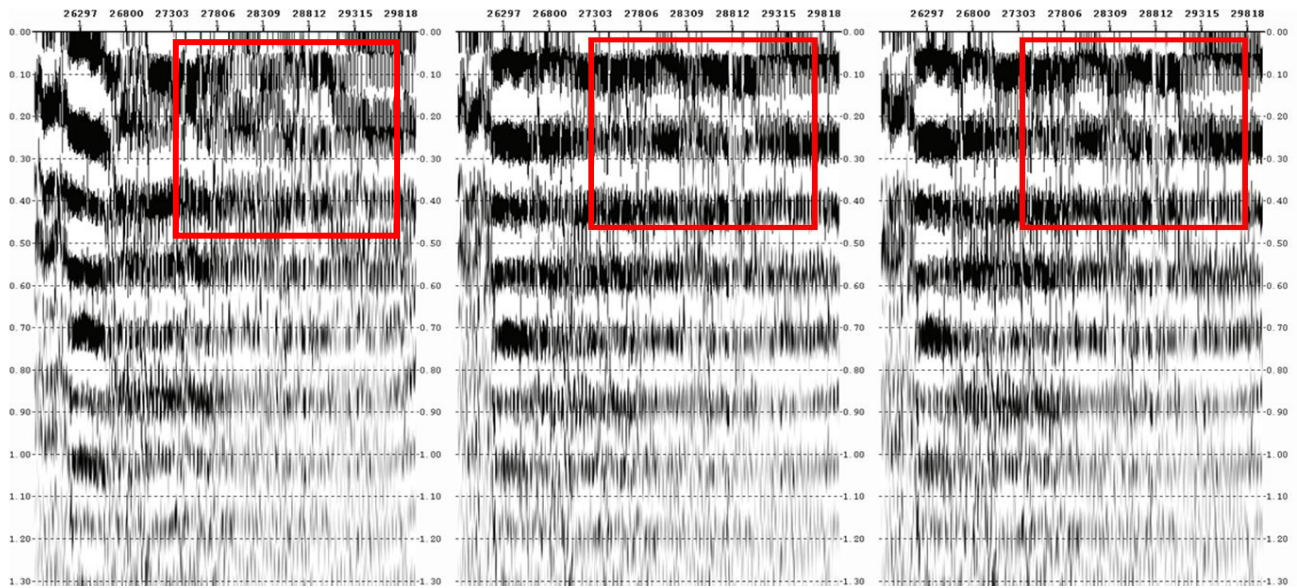


Figure 13: Raw stack zoomed in shallow level (left), after matching filter (middle) and after inverse filter (right)

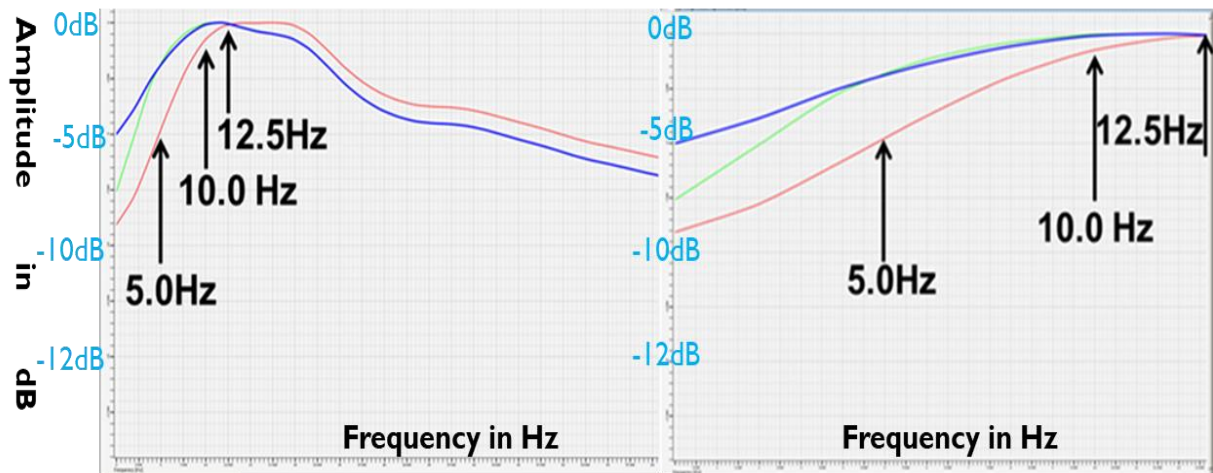


Figure 14: Amplitude spectra; red curve (raw stack), green (after matching filter) and blue (after inverse filter), right panel zoomed up to 12.5 Hz.

Freq. (Hz)	dB level in raw gather	dB level after matching filter	dB level after inverse filter
2.5	-7.5 dB	-4.5 dB	-3.5 dB
5	-5.0 dB	-2 dB	-2 dB
10	-2.5 dB	~0 dB	~0dB

Table 2: Comparison of dB level of amplitude in various raw stacks

Both filtering process discussed above are able to recover the lower frequency part of the 10Hz geophone data. The spectra of corresponding shot gathers show that there is increase in dB level of low frequency part of the data. About 2.5 to 3 dB

increase at frequency 2.5Hz and 5Hz as detailed in Table 1. The gathers at longer offsets where low frequencies are expected to be dominant, are improved in comparison to the raw data (Figures 10, 11, 12). The events in the zoomed raw stacks become clearer the strength and continuity of the events also get enhanced after filter applications (Filter 13). The event strengths and continuity in stack sections after application of matching and inverse filter has been boosted in comparison to raw stack. The comparison of spectra (Figure 14, 15) reveals that about 2.5 to 3.0 dB level increase has been noted after recovery of low frequency part from the data (Table 2).

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### Conclusion

The low frequency component of the spectrum is not available in the general processing flow of seismic data processing. The present analysis is able to establish that the recovery of the low frequency part of the data recorded with 10Hz is possible by these two methodologies. The outputs are comparable from both the methods. However, results show that the inverse filtering process from the geophone response function is having slightly better advantage in the current data sets used. The effectiveness of the methods depend on the estimation of response function wavelet from the amplitude and phase spectra. The recovery of low frequency from old 10 Hz land geophone data may help in many ways like sub-basalt imaging and merging of two datasets with different geophone natural frequencies etc.

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