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# Comparison of Spectral Enhancement Techniques Applied to Post Stack Data

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## SUMMARY

Spectral enhancement is a technique for selectively boosting portions of the seismic signal with distinguishable frequency content. It is often applied to seismic data in order to boost the high frequency content of the data, which can be masked by underlying low frequency signal. The practical application is to improve the vertical resolution of events thereby improving interpretability. Here we compare three different methods of spectral enhancement that are regularly applied to 3D post stack seismic data. We are particularly interested in the effectiveness of each technique in enhancing real signal in the data, as well as the efficiency of each process at this task.

## Introduction

Spectral enhancement is a technique for selectively boosting portions of the seismic signal with distinguishable frequency content. It is often applied to seismic data in order to boost the high frequency content of the data, which can be masked by underlying low frequency signal. The practical application is to improve the vertical resolution of events thereby improving interpretability. Here we compare three different methods of spectral enhancement that are regularly applied to 3D post stack seismic data. We are particularly interested in the effectiveness of each technique in enhancing real signal in the data, as well as the efficiency of each process at this task.

## Method

Here we compare three different approaches for isolating and enhancing frequency, with particular focus on wavelet methods with different time and frequency resolution. Two of the methods are based on bandpass filtering the data through convolution of Gabor wavelets with different scales while the third method uses the trace derivative (curvature) to increase frequency content. To provide a comparison between different methods, spectra have been computed for each method at a key interval using fast Fourier transform (fft) averaged over a number of traces and statistical measures are computed from each spectrum (see Widess, 1982; Barnes, 1993 for spectral measurements). Measures of average frequency are based on the distribution of power and energy over the frequency spectrum and they include mean, median, mode and RMS frequency. Measures of bandwidth of the spectral distribution include standard deviation, interquartile range and spectral width at 50% peak power. Statistics based on spectral power can be erroneous if the fft spectrum is notched, whereas measurements based on energy may be misleading if there is inclusion of data below the noise floor, therefore comparison of multiple measurements is preferred.

### *Derivative (trace curvature) method*

The first and second derivatives of the seismic trace were computed in the trace direction. In order that the derivative function has the correct peak and trough alignment with the input reflectivity it is phase rotated (1st derivative by 90° and the 2nd derivative by 180°). The process of differentiation has the effect of fully resolving doublets (Figure 1a), increasing the mean frequency of the data, thereby enhancing high frequencies and suppressing low frequencies. To ensure that the low frequency content is maintained the phase rotated derivative function is summed with the input reflectivity data.

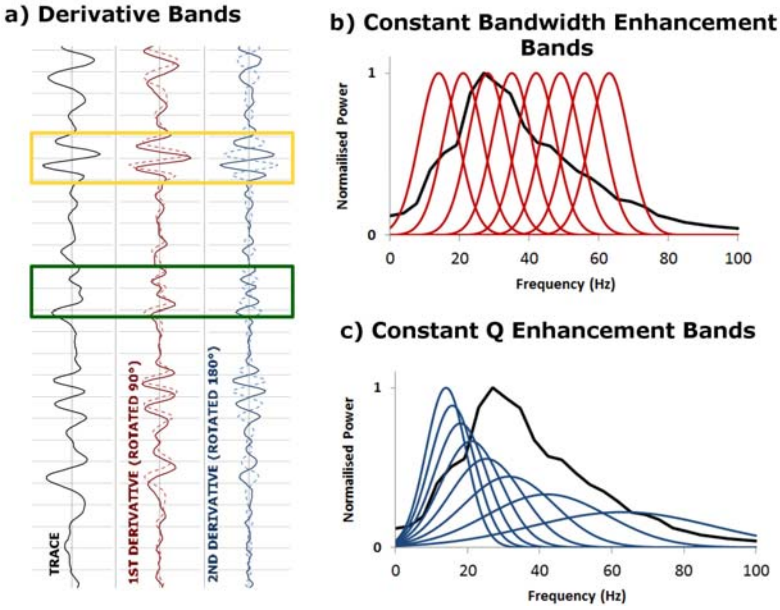
### *Constant bandwidth narrow-band enhancement*

This method involved decomposing the seismic signal into a number of narrow frequency bands through bandpass filtering with a Gabor wavelet. For the constant bandwidth enhancement the scale of the Gabor wavelet is varied to maintain uniform bandwidth of decomposition bands with increasing central frequency (Figure 1b). A spectral enhanced reconstruction of the seismic signal can be made by summing the individual bands with modified weightings, thus manipulating the frequency-power distribution. The narrow bandwidth equates to a good frequency localisation, therefore it is useful for isolating discrete frequencies; for instance, acquisition noise or processing artefacts. For this reason the narrow bands are extremely useful for spectral whitening because they provide a lot of scope for spectral reshaping. It is usual for uniform frequency spacing to be used between bands in order that the resolution is maintained across the whole spectrum. The high frequency localisation comes at a cost to resolution in the time domain and this trade-off can be attributed to uncertainty principle. Reduced temporal resolution at higher frequency often manifests as 'ringing', which is multiple oscillations about peak or trough centre.

In extremes, ringing can cause unrealistic events to appear in the enhancement band in the location of side lobes in the original data and care must be taken to avoid these unwanted effects. In addition to the problem of multiple harmonic or ‘ringing’ events appearing, a small break in a single reflector (possibly noise) may manifest as multiple breaks in the high frequency – low bandwidth response, which could be misinterpreted as a fault or structural boundary. It is a good idea to minimise the risk of any noise related effects by improving reflector continuity through noise cancellation prior to enhancement. Ringing and aliasing are avoided by honouring the bandwidth and Nyquist limits of the input spectrum.

*Constant Q variable bandwidth enhancement*

This method is similar to the constant bandwidth method of enhancement in that a number of Gabor filters, convolved with the seismic data are used to produce decomposition responses that can be recombined with the original data in order to manipulate the shape of the spectral energy distribution. The key difference is that the scale of the decomposition wavelets is kept constant for different frequencies (the wavelet Q factor is proportional to the product of its power and bandwidth), which results in the bandwidth increasing with central frequency (Figure 1c). The increased bandwidth results in decreasing frequency resolution at higher frequencies which, converse to the previous method, maintains resolution in the time domain. The use of variable window transforms for spectral enhancement is described in literature elsewhere, (e.g for bandwidth extension, Smith, 2008). When applying constant Q enhancement exponential spacing between frequency bands is sufficient to maintain frequency resolution. A consequence of decomposition using high bandwidth filters at high frequencies is that it is much more difficult to isolate frequency. The transform, being a convolution method, means that a given decomposition band will preferentially boost signal of higher power within that band. Practically this results in a limit to the amount of enhancement that can be applied through a Constant Q filter.



a) Derivative Bands

b) Constant Bandwidth Enhancement Bands

c) Constant Q Enhancement Bands

a) sample trace (black), first derivative (dashed red), phase rotated first derivative (red), second derivative (dashed blue), phase rotated second derivative (blue). Events on the trace which are well resolved (highlighted yellow) are largely unchanged by the differential process whereas poorly resolved events (doublets highlighted green) are enhanced,

b) Constant bandwidth decomposition bands at uniform spacing and matched to a sample seismic spectrum.

c) Constant Q decomposition bands with increasing bandwidth and at exponential spacing, matched to a sample seismic spectrum.

***Figure 1*** *Three methods of enhancement compared in this study.*

The dataset investigated as part of this comparative study is the USDOE Teapot 3D land survey from Colorado, US. The bandwidth of the data measured at 50% power is 33Hz (from 21Hz to 54Hz). The dataset lends itself to spectral enhancement study due to the numerous closely spaced reservoir intervals which manifest as interfering events at and around seismic resolution. The data are sampled at 2ms with Nyquist of 250Hz and this ensures that aliasing effects are avoided even with very high frequency events. Initial analysis was taken over four octaves (9 to 154Hz) about the predominant frequency at 38.5Hz at 8 intervals (voices) per octave which is well beyond the useful seismic spectrum; these extremes of frequency are shown to demonstrate the breakdown of each method at these limits and the best enhancement is with bands +/- 1 octave of the predominant frequency (covering 19 to 77Hz).

## Results and Discussion

The results of the different enhancements are summarised in Figure 2. Of the three methods only the constant bandwidth method of enhancement was useful at enhancing the data to very high frequencies and narrow bands at high frequencies are necessary to produce a 'white' spectra i.e. one where the energy distribution is constant with frequency (Figure 2a). Care must be taken not to boost frequencies that are not representative of real seismic signal, and this can become evident of ringing and sub harmonics in the high frequency responses (Figure 2c). The constant Q method has an exponential decrease in the energy distribution which results in a tapered spectrum. The constant Q responses at high frequencies are relatively similar to the original, although skewed to the higher frequency – this is the consequence of the lower frequency part of this band convolving with the low frequency seismic signal and it makes it impossible to 'over-enhance' the data (Figure 2d). The derivative method honours the original spectrum such that the enhancement is very similar to the original spectrum albeit skewed to the higher frequency. Doublet events, which are unresolved events with no zero crossing (usually a target for enhancement) are transformed into full reflectors, thus increasing the vertical resolution (Figure 2b).

The constant bandwidth method, through the utilisation of narrow bands is very good at isolating frequency, which it makes it very useful for targeting events with a discrete frequency and when noise cancellation filters are applied to each band they can be used to target frequency specific noise. The narrowness of the filters employed, allows for the most manipulation of the spectrum; this can however result in ringing, so care must be taken when optimising the filters and band weightings. Constant Q enhancement also increases the time resolution, but it is difficult to isolate frequency specific noise and signal, especially at higher frequencies. It is difficult to over enhance using constant Q filters and therefore such an enhancement requires minimal QC of the input bandwidth threshold and noise floor. The poor frequency resolution means that it not useful for manipulating the spectrum to a specific shape. The derivative method is not useful for enhancement of low frequencies but is fast, relatively parameterless and it is difficult to over-enhance or to produce artefacts.
Knowledge of the efficacy of each method of enhancement, through resolution in time and frequency gives a better understanding of the processing workflows applied to seismic data.

## References

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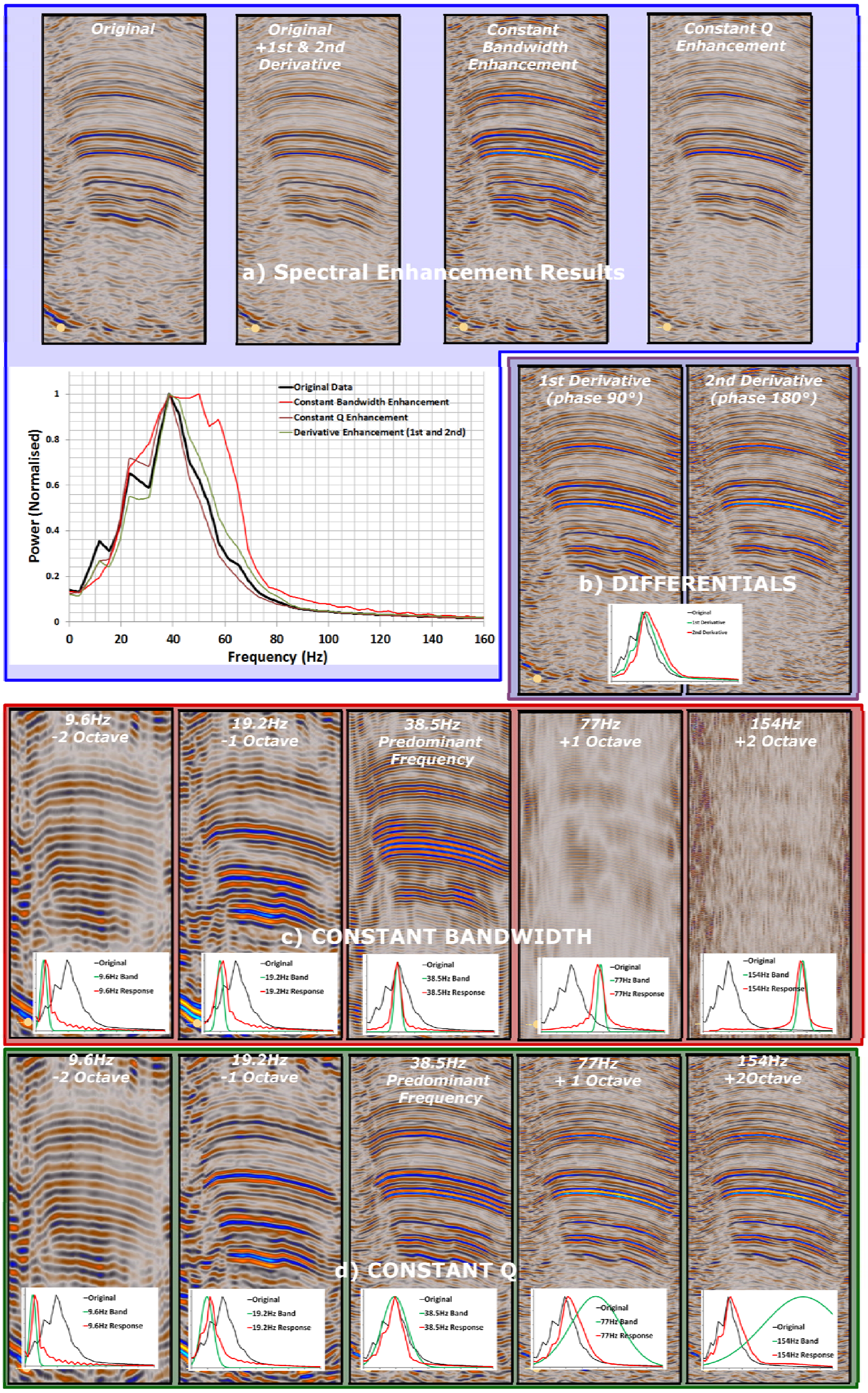

***Figure 2** a) Comparison of results and spectrum for each enhancement method (left to right) original data, derivative method, constant bandwidth and constant Q enhancement; b) first and second derivative filters that are combined with the original data as part of the enhancement process; c) example constant bandwidth responses and d) example constant Q responses covering +/-2 octaves from the predominant frequency – bands were only included +/- 1 octave in the associated enhancements.*