[GC]Spectral Decomposition Methods: Applicability and Limitations*

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General Statement

The previous three Geophysical Corner articles have focused on the spectral decomposition of seismic data, describing some of the methods and their applications (Search and Discovery Articles #41260, #41272, and #41273).

This month we add another one on the same topic, showing the comparative performance of some of the methods commonly available in the interactive interpretation software packages. Each of these methods has its own applicability and limitations, and the choice of a particular method also could depend on the end objective.

Methods with Example

The most basic and perhaps the simplest method is the traditional Fourier transform method, also known as the short-window discrete Fourier transform (SWDFT) method. As the name implies, when using a fixed time window the seismic data is transformed into the frequency domain, and the output spectral amplitudes and phase volumes are visualized at different frequencies. The choice of the time window has a bearing on the frequency, temporal and spatial resolution of the output data. A shorter time window could result in a reduced frequency resolution on the output and vice-versa.

Figure 1a shows a comparison of stratal slices from the input seismic data volume from western Canada and the equivalent slices at 55 Hz from the SWDFT spectral decomposition method using a time window of 30 ms (Figure 1b) and 60 ms (Figure 1c). The stratal slices were chosen 24 ms below a marker seismic reflector close to 960 ms on seismic data processed with 5-D interpolation used to regularize offsets and azimuths.

The shape of time window also is important. Careful tapering (rounding the edges) avoids artifacts called the Gibbs phenomenon. The "smoothest" taper would be to use a truncated Gaussian window; this particular implementation of the SWDFT is named the Gabor transform, after its originator. A common pitfall for the SWDFT is to use an analysis window that is smaller than the period of interest, such that Gibbs artifacts dominate the result. A fixed window will include more cycles of a higher frequency than of a lower frequency sinusoid, suggesting that one could design the window length to be proportional to the period. This construct gives rise to the continuous wavelet transform (CWT).

In Figure 1d we show a 55 Hz spectral magnitude display, using CWT equivalent to the previous stratal slices – and notice the superior definition of the channel morphology. If in turn, the window is a Gaussian whose standard deviation is the period being analyzed, we obtain (omitting a few key mathematical details) the S-transform. This choice avoids picking a window that is too small.

One can implement these transforms in two ways:

- By simply cross correlating the seismic trace with a suite of complex band-limited wavelets.

- By applying a suite of band pass filters to the data and then computing the square root of the energy under a sliding window.

In general, the S-transform yields better temporal resolution than the SWDWT, especially at higher frequencies (Figure 1e). By construction, the CWT and S-transforms produce lower temporal resolution at lower frequencies. The continuous wavelet packet-like transform (CWPT) method overcomes this limitation by dividing the window into sub-windows but keeping the same central frequency. This makes it somewhat flexible and in the process displays higher resolution. This can be seen in Figure 1f, where it resolves the channel morphology better than the SWDFT and the CWT displays in Figures 1b, 1c and 1d.

In the CWT spectral decomposition method when the spectral magnitude display is sought at a given frequency – at, say, 55 Hz – it usually produces the averaged spectral amplitude response from the neighboring frequencies 50 Hz to 60 Hz. Time frequency continuous wavelet transform (TFCWT) spectral decomposition method overcomes this averaging by producing the desired spectral magnitude at the desired central frequency within the given time window.

In doing so, it results in producing a higher time-frequency resolution than the SWDFT or the CWT methods – notice this on the display in Figure 1g. It is computationally intensive, and so takes longer to run.

Disscussion

The wide choice of algorithms can be quite confusing. As is often the case, no algorithm is always best. If the objective is to measure the number of geologic cycles per unit time, we suggest stratal (i.e. proportional) slicing the seismic data between two picked horizons, and then applying the SWDFT with a window equal to the number of slices. In this case the cyclicity would be a geologic cyclicity, say of progradation and retrogradation along a shelf margin vs. a much quieter and lower “frequency” basinal area.

The algorithm that shows the most “geology” is not necessarily the best. Longer window algorithms like the SWDFT will often cause more vertical mixing of stratigraphy, providing images with “more channels” than a shorter window S transform. While these channels exist in the data, they may be more properly associated with shallower or deeper horizons than the one being examined.

Conclusions

Different spectral decomposition methods provide an effective way of examining the seismic response of stratigraphic geologic features in terms of spectral components and so help in the interpretation. Each of the methods described above have their own advantages and limitations.

The user is expected to understand these characteristics of the methods before making their application. We hope this article helps provide some insight into this aspect.

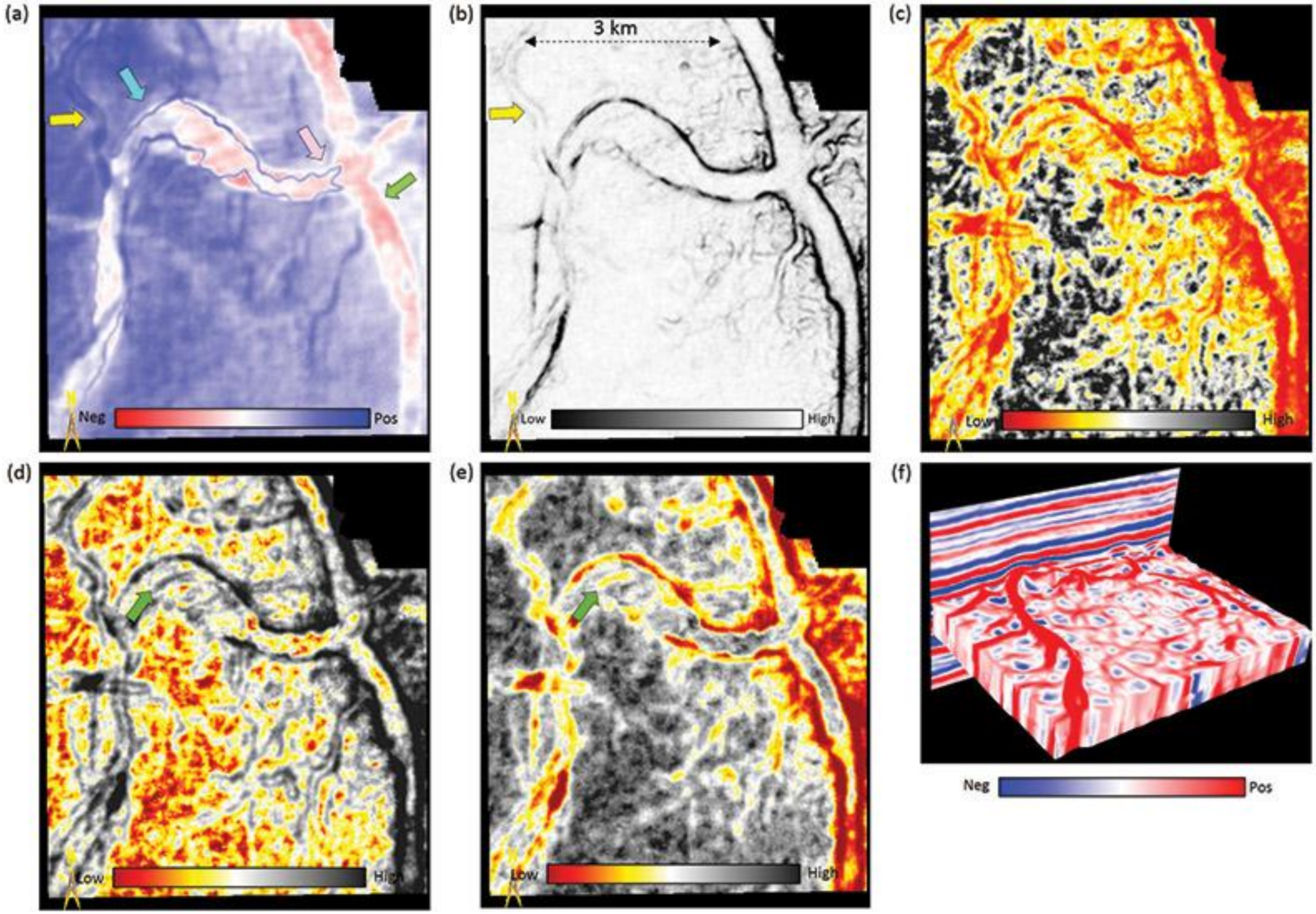

Figure 1. (a) Vertical and horizon slices through a seismic amplitude volume. The picked horizon followed a positive peak. The green arrow indicates a graben while the blue arrow indicates a channel exhibiting shallower differential compaction. Corresponding vertical and horizon slices through the 55 Hz spectral magnitude components computed using (b) a DFT in a short 30 ms window, and (c) a DFT in a longer 60 ms window. The same slices computed with a 55 Hz Morlet wavelet using (d) a CWT, (e) an S-transform, (f) a CPWT, and (g) a TCWT. As interpreters, we find (e) to provide higher lateral resolution of the high spectral magnitude distributary channel.