The limits of seismic resolution and pitfalls in bandwidth extension algorithms

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1. Summary

Most rules of thumb on vertical resolution are based on the resolving power of the dominant frequency of an otherwise broad band wavelet. In this paper, we examine three algorithms designed to increase the limit or at least quantify vertical seismic resolution: spectral balancing, bandwidth extension and the Hölder exponent. We find that spectral balancing provides a useful, but limited improvement of seismic resolution. Although bandwidth extension attempts to resolve beds below tuning frequencies by extending the magnitude spectrum, the corresponding phase spectrum interference patterns are not properly unraveled. Events that were previously resolved appear sharper, while those that were not are now corrupted. The goal of the Hölder exponent is to use the shape of the magnitude spectrum to characterize the underlying reflectivity as being blocky, spikey, or smooth. However, the Hölder exponent suffers from the same limitations of other spectral decomposition techniques in the presence of tuning.

2. Methodology and results

We illustrate the limits of resolution using a simple wedge model (Figure 1). We created three wedges based on the types defined by Chung and Lawton (1995) and further developed by Tirado (2004), Portniaguine and Castagna (2004 and 2005), Chopra et al. (2006), Puryear and Castagna (2008); and Chopra et al. (2009) (Figure 2). The top wedge exhibits Type III, the middle wedge a Type II and the bottom wedge a Type I coefficient pairs that represent the mixed, even and odd components, respectively.

Spectral balancing

A collection of seismograms is said to be spectrally balanced if they have been filtered in such a way that they exhibit the same amplitude spectrum (Tufekčić et al, 1981).

Figure 3 displays the application of spectral balancing to wedge models from Figure 1. Small side lobes can be observed at the different interfaces, which can also be explained by looking at the shape of the extracted wavelet in Figure 3b.

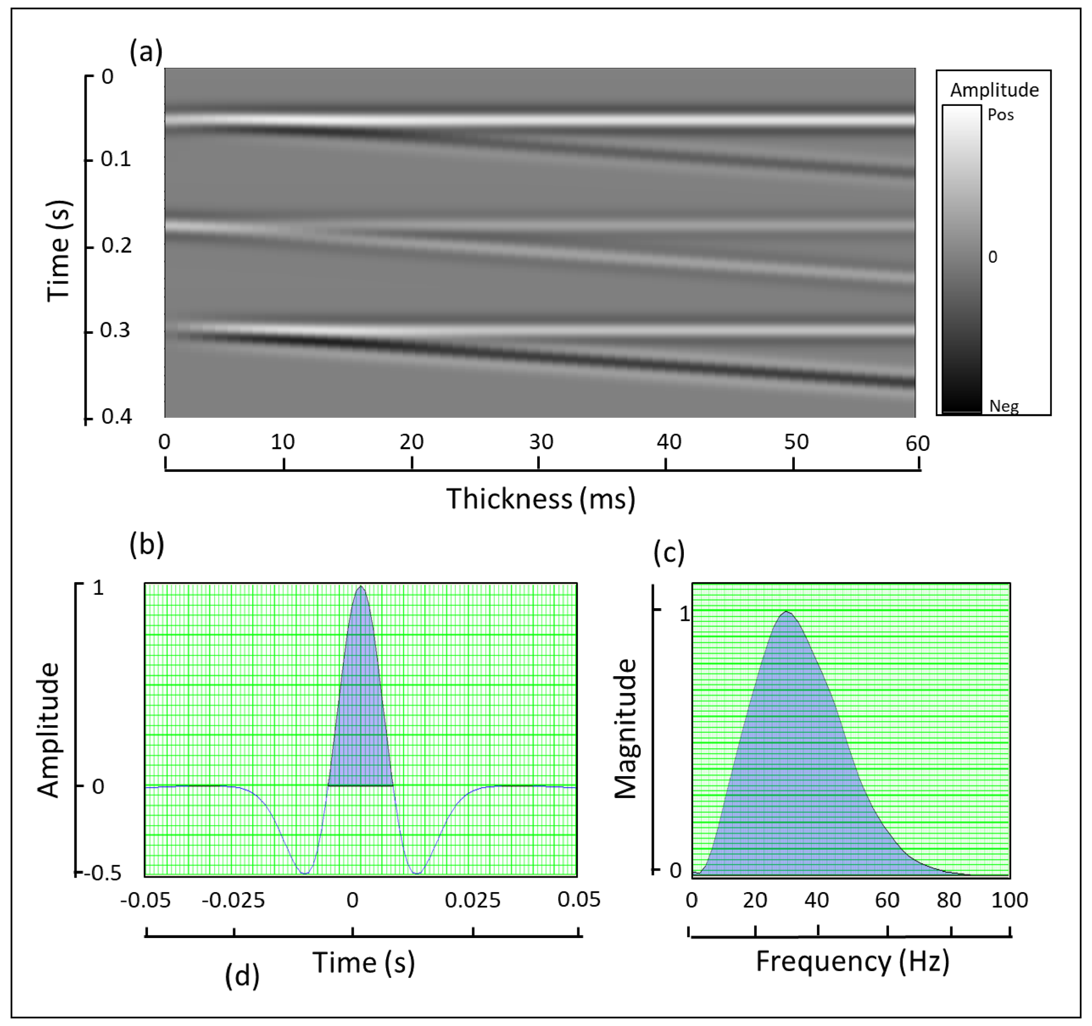

Figure 1. (a) Simple wedge models convolved with a (b) 30 Hz peak frequency Ricker wavelet and (c) it corresponding frequency spectrum. (Top of (a)) the Type III (Mix component); (middle of (a)) the Type II (even component); and (bottom of (a)) the Type I (odd component) wedges, according to Chung and Lawton (1995) and Chopra et al. (2006).

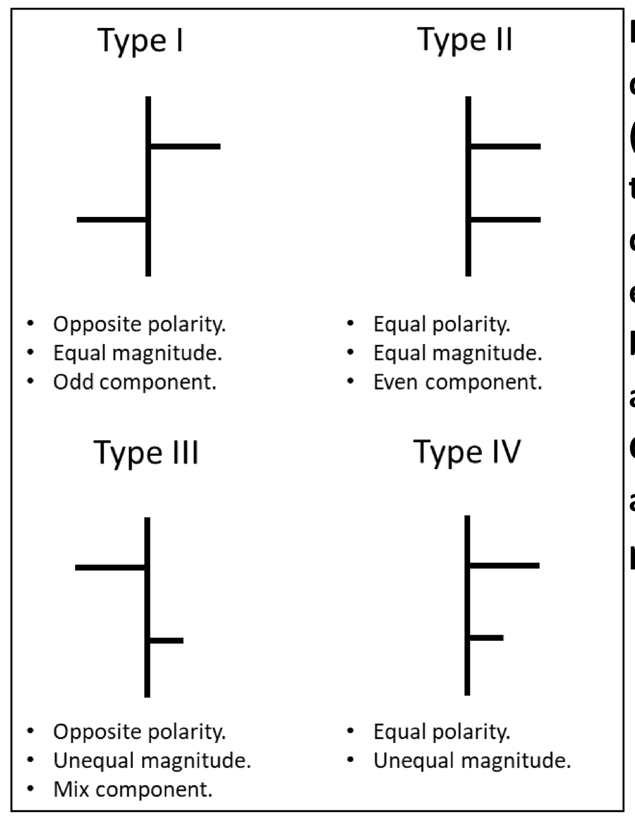

Figure 2. Reflectivity types as defined by Chung and Lawton (1995). This concept was further developed for reflectivity decomposition in odd and even components, as defined by Tirado (2004); Portniaguine and Castagna (2004 and 2005); Chopra et al. (2006); Puryear and Castagna (2008); and Chopra et al. (2009).

Bandwidth extension

We decompose the three wedge models into their spectral components through the implementation of a Continuous Wavelet Transform to evaluate the feasibility of increasing the seismic resolution by using this technology.

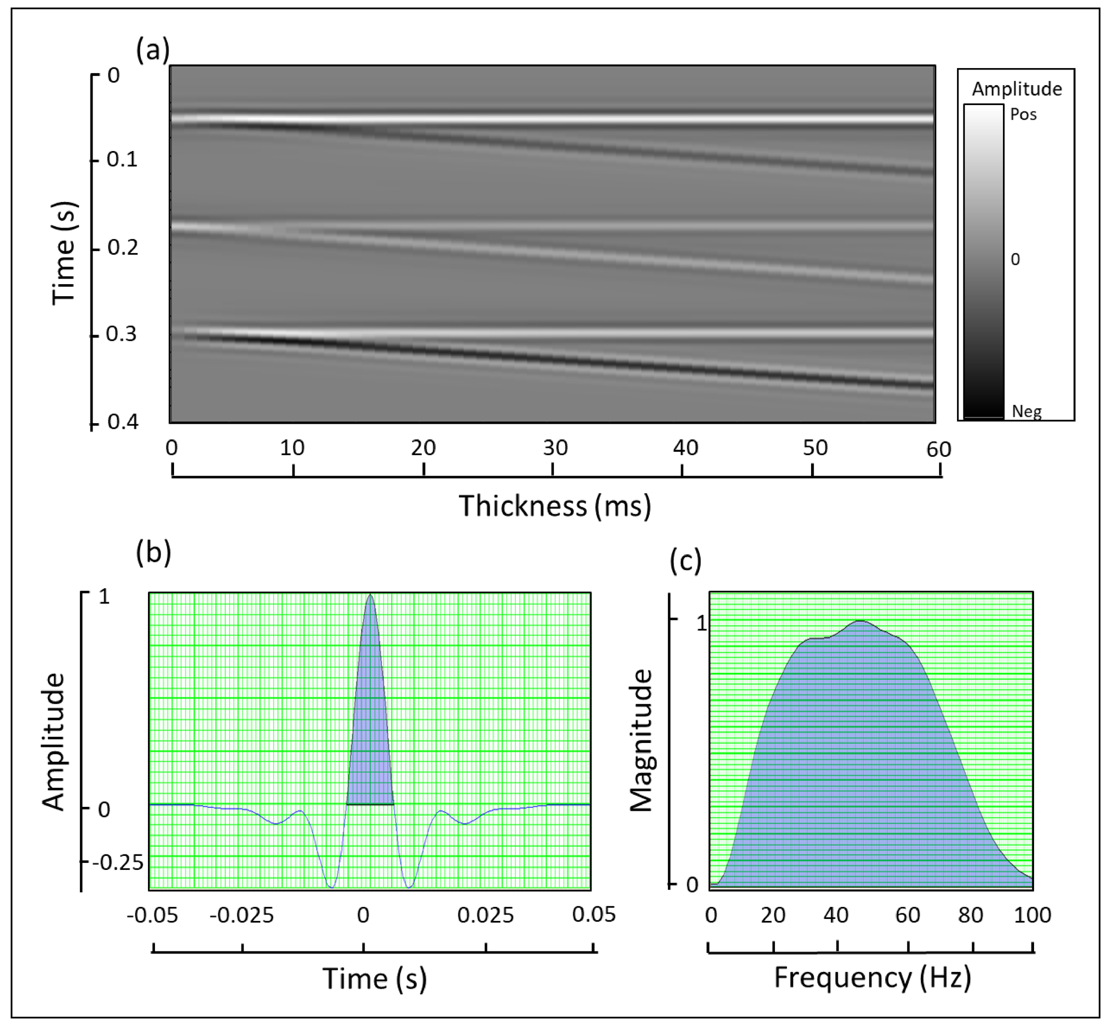

Figure 3. (a) Simple wedge models after spectral balancing with the (b) extracted wavelet for the entire line and its (c) corresponding magnitude spectrum.

Hölder exponent

Li and Liner (2008) developed a method to detect singularities in acoustic impedance profiles from seismic reflection data through the utilization of amplitude, phase and frequency integration in what they term the "Hölder" attribute.

Figure 5 displays a hypothetical acoustic impedance profile and the calculated Hölder exponent response, along with the seismic trace that generates it. Sub-seismic events are not properly imaged, as can be seen from the lower portion of the Hölder exponent trace. Furthermore, Figure 6 displays spectral magnitudes computed from seismic trace on Figure 5c. Since the Hölder exponent denotes the evolution of magnitudes across all frequencies, special consideration need to be taken not to allow higher frequencies response to dominate Hölder exponent trace.

Figure 6 displays the results of the computed Hölder exponent on wedges from Figure 1. It can help to assess potential exploration or development targets where high values are located. However, similarly to spectral decomposition methods, it suffers from the same limitations arising from tuning thicknesses and frequencies.

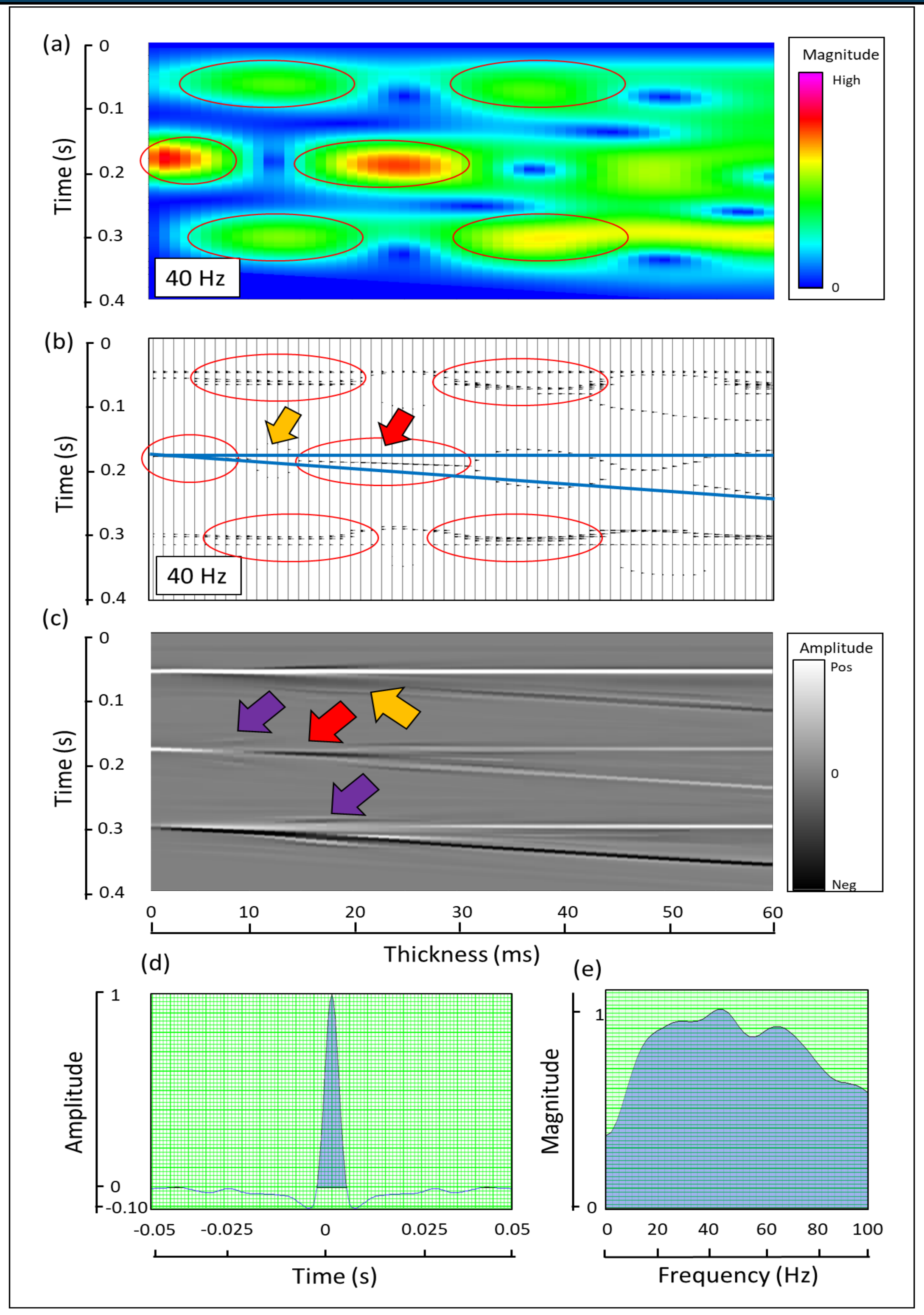

Figure 4. (a) Spectral magnitude components and (b) spectral ridge components for wedge models in Figure 1 the 40 Hz component. Red ellipses indicate tuning amplitudes where resolution of events becomes challenging. . Red arrows indicate a mislocation of events due to interference patterns. Maximum constructive interference simulates the presence of only one wavelet, which is all that ridges can detect. Orange arrow indicate a location where maximum destructive interference occurs. (c) Simple wedge models after bandwidth extension with the (d) extracted wavelet for the entire line and its (e) corresponding magnitude spectrum. red arrow indicates location where ridges merged due to tuning interference to create a false event. Purple arrows indicate location of side lobes erroneously interpreted by algorithm as location of ridges. Orange arrow indicates location where algorithm was not capable of resolving bottom layer, resulting in shadow zone within reconstructed line.

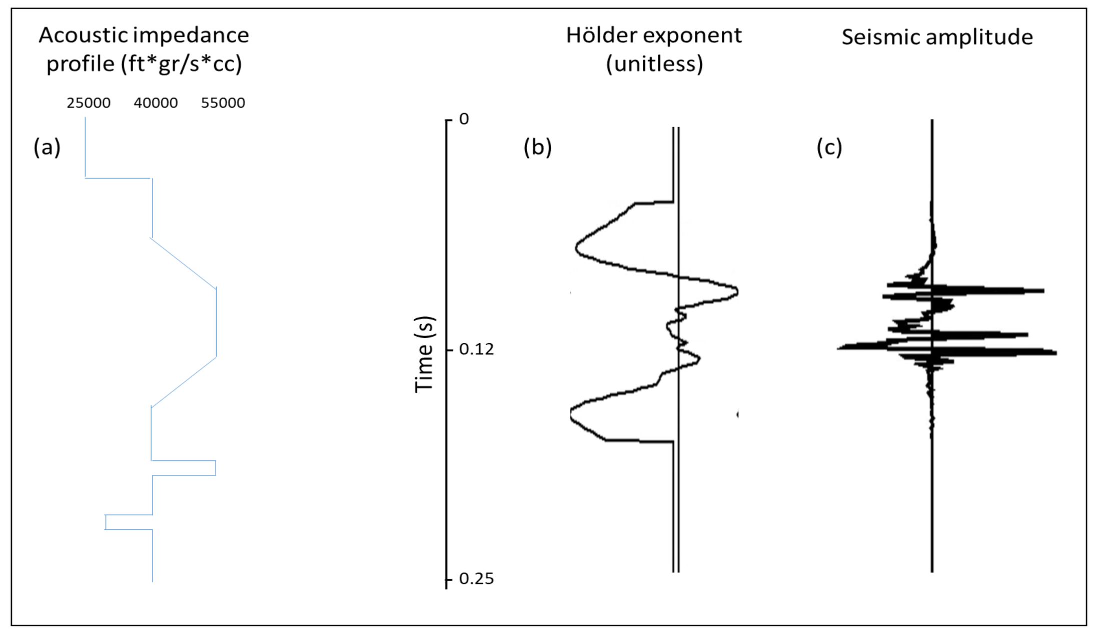

Figure 5. (a) Acoustic impedance profile modeled with its respective (b) computed Hölder exponent from a (c) seismic amplitude trace

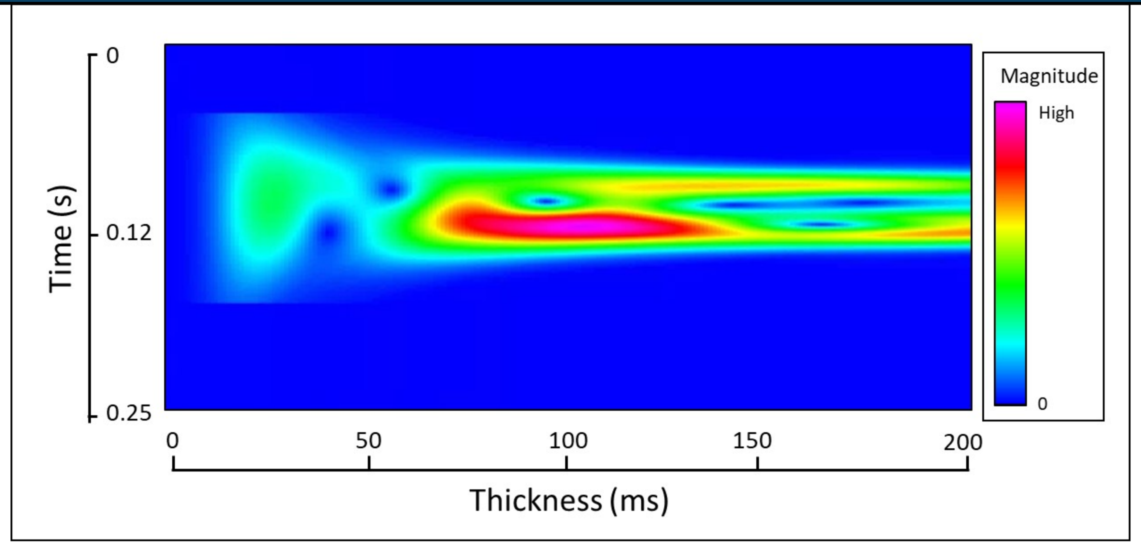

Figure 6. Spectral magnitude components corresponding to trace displayed in Figure 5c.

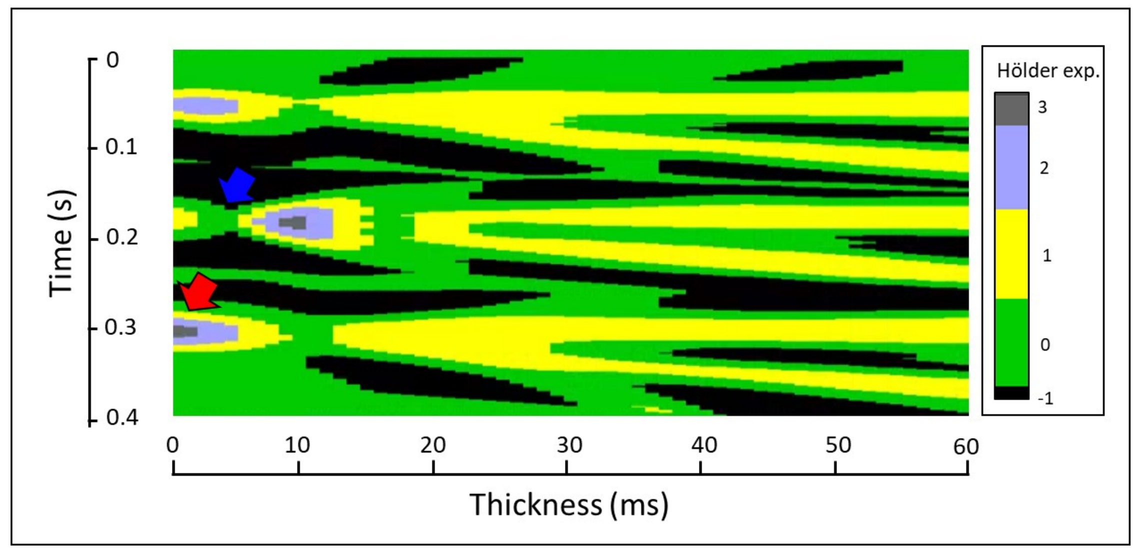

Figure 5. Hölder exponent computed on wedge models from Figure 1. Blue arrow indicates location of rapid decay of magnitudes of high frequencies, while red arrow indicates location of rapid increase of magnitudes of high frequencies.

3. Conclusions

Seismic vertical resolution below tuning thicknesses remains a very important, yet not completely understood, problem within the geosciences. Complex interference patterns prevent correctly imaging reflectors below tuning thicknesses. Phase unraveling is, perhaps, the most challenging problem to resolve, as frequency magnitudes can be determined from statistical wavelet extractions at every time sample in a seismic volume.

Of the three methods evaluated, the Continuous Wavelet Transform (CWT) Bandwidth Extension provides cosmetic improvements that may aid horizon interpretation in exploration and production endeavors, but does not improve the seismic resolution.

The Hölder exponent seismic attribute provides a means for further characterizing the impedance profile that gives rise to the seismic data. Although the Holder exponent may provide a means to discriminate between upper fining, upper coarsening, and simple blocky impedance patterns, it does not provide means for increasing seismic resolution below the tuning thicknesses.

4. References

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