Acoustic Impedance Inversion Based on STHWE, Statistical and Well Log Wavelet Estimation Methods

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Abstract

Good knowledge of the propagating wavelet in seismic data is one of the fundamental criteria of seismic inversion. In this study, Short-Time Homomorphic Wavelet estimation (STHWE) as the best approach in homomorphic deconvolution, statistical wavelet estimation and using well log wavelet estimation were used to derive and compare three acoustic impedance models in one of the hydrocarbon fields in Iran. It was shown that STHWE method, as a statistical technique, provides reliable wavelet estimation and can be used as a quality control for other wavelet estimation methods.

Keywords: Wavelet estimation, short-time homomorphic deconvolution, seismic inversion.

Introduction

Nowadays, the role of acoustic impedance in static reservoir property estimation, structural analysis, and seismic stratigraphic studies is of high importance for reservoir geophysicists. Seismic inversion which combines seismic, well, reservoir and geologic data is often called secondary property due to its high correlation with static reservoir properties. Sufficient knowledge of the seismic wavelet is fundamental in seismic inversion. Model-based seismic inversion can be considered as one of the most-frequently used seismic inversion methods. The correct guess of the propagating wavelet in seismic data extremely affects its results. There are three main wavelet estimation procedures: direct measurement (deterministic), wavelet extraction based on seismic data (statistical), and wavelet extraction using both seismic and well data. Homomorphic wavelet estimation as a statistical wavelet estimation technique was first introduced in 1970's (1). Since that time, diverse approaches such as liftering (1), Log Spectral Averaging (LSA) (2) and Short-Time (3) have been investigated. All of these methods benefit from the cepstrum or logarithms of spectrum as a homomorphic system and wavelet phase estimation capability of these methods is of reputation. Despite their advantages, liftering and LSA methods could not prove themselves in real situations (Both of these methods assumed reflection series be minimum-phase. Moreover, liftering method required sparse reflectivity series whereas LSA assumed a random one which is rarely met in real situations. Herrera and Van der Baan combined liftering (3), LSA and Tribolet's (4, 5) studies to derive Short-Time Homomorphic Wavelet Estimation (STHWE) technique. In this method, several short-time traces are built by windowing a single trace using a specific overlap and taper. Log spectral average of all short-time traces is then calculated. In this situation, assuming random reflectivity series, without the need for minimum-phase assumption, the wavelet would be estimated as the Log Spectral Average of the all the short-time traces. Consider the seismic trace $s(t)$ as the convolution of the reflectivity series $r(t)$ and the propagating wavelet $w(t)$, the estimated wavelet would be:

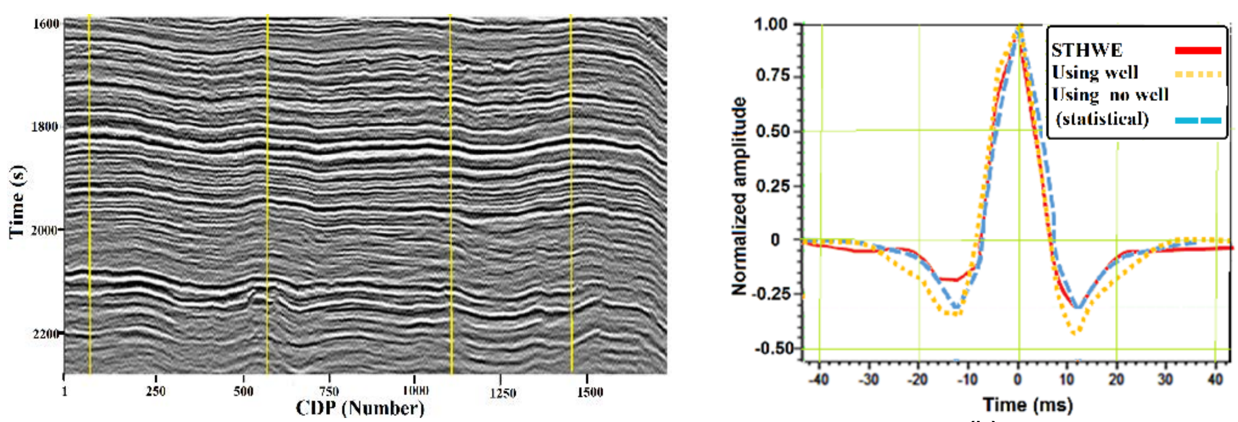
$$\hat{W_e}(f) = \frac{1}{NM}\sum_{i=1}^{N}\sum_{k=1}^{M}\hat{S}_{ik}(f) = \hat{W}(f) + \frac{1}{NM}\sum_{i=1}^{N}\sum_{k=1}^{M}\hat{R}_{ik}(f), \tag{1}$$

where: $\hat{R}(f)$, $\hat{W}(f)$, $\hat{S}(f)$ and $\hat{W_e}(f)$ are log of Fourier transform of the reflectivity, propagating wavelet, seismic trace and the estimated wavelet, respectively. *i* is the trace index, *N* traces are divided into *M* sub-traces using windowing and *k* is the index of window of length *L* which are used for computation of complex cepstrum. The estimated wavelet tends to the original wavelet since the value of $\frac{1}{NM}\sum_{i=1}^{N}\sum_{k=1}^{M}\hat{R}_{ik}(f)$ is approximately zero.

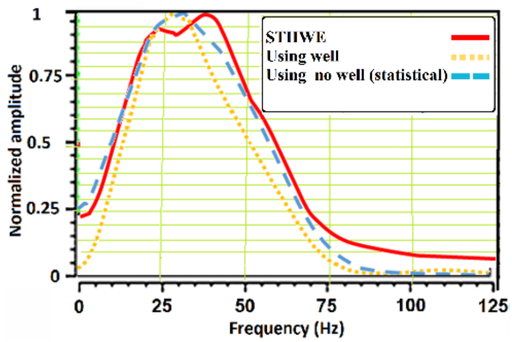
In the model-based seismic inversion, a synthetic trace is built using an initial low-frequency model from log data and the extracted wavelet and the mean squared error respect to the seismic is minimized to yield the maximum correlation to seismic data. Reliable wavelet estimation plays an important role in the quality and robustness of the inversion result. STHWE approach is superior respect to other statistical wavelet estimation methods in finding the phase spectrum of the wavelet. It can be considered as a robust wavelet estimation technique particularly in areas without any well control.

Methodology

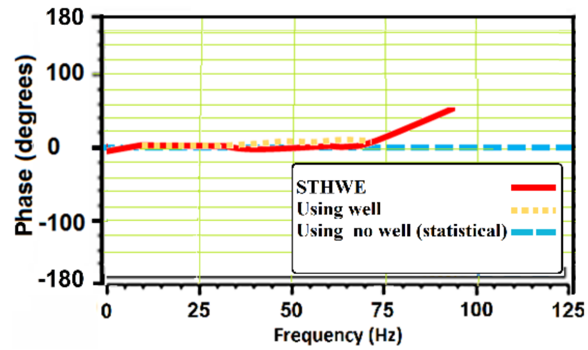
A seismic section containing 1729 traces each with 359 samples with 4ms sampling interval from one of hydrocarbon fields south of Iran has been utilized for the current study. Seismic wavelet of this dataset was estimated using three different approaches of STHWE (using MATLAB environment), statistical and using wells methods of Hampson-Russell software. Due to the wavelet shape change in data, a small portion of the seismic section from 1600 to 2200 ms was studied. In STHWE method, the window length is 30 samples (120 ms) with 96% overlap and without tapering. So, there are 322 windows in each trace with the total of 556738 windows. Figure 1 displays the seismic section, different extracted wavelets and their corresponding amplitude and phase spectra. After wavelet estimation using three different methods, post-stack model-based seismic inversion has been applied for each of these extracted wavelets separately.



(a) (b)



(c)

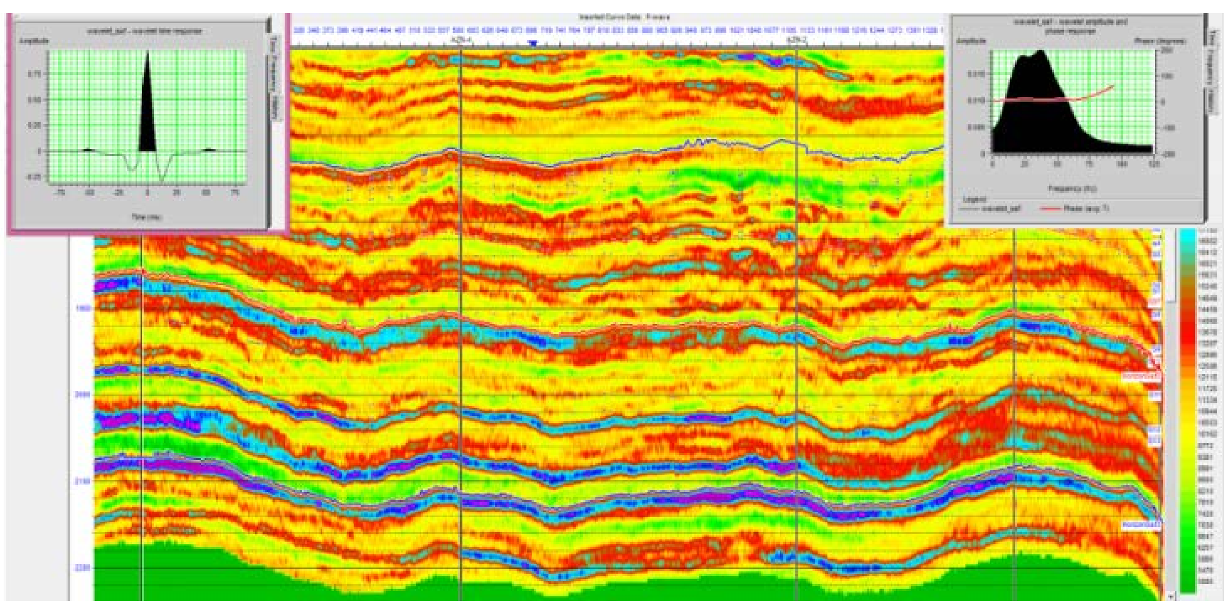


(d)

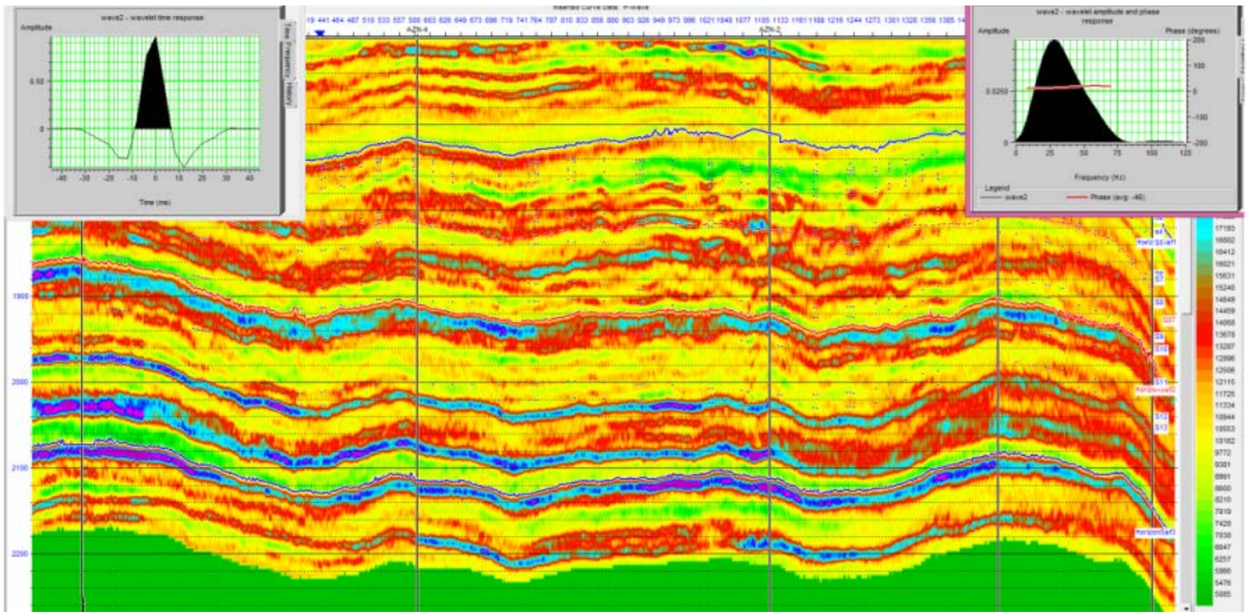
Figure 1. (a) A seismic section from one of hydrocarbon fields south of Iran. The yellow lines display the location of wells in the study area. (b) Three estimated wavelets from seismic section in (a). Red: STHWE, Yellow: using well data, Blue: the statistical approach. (c) Amplitude spectra of the three different wavelets. (d) Phase spectra of the three different wavelets.

Results

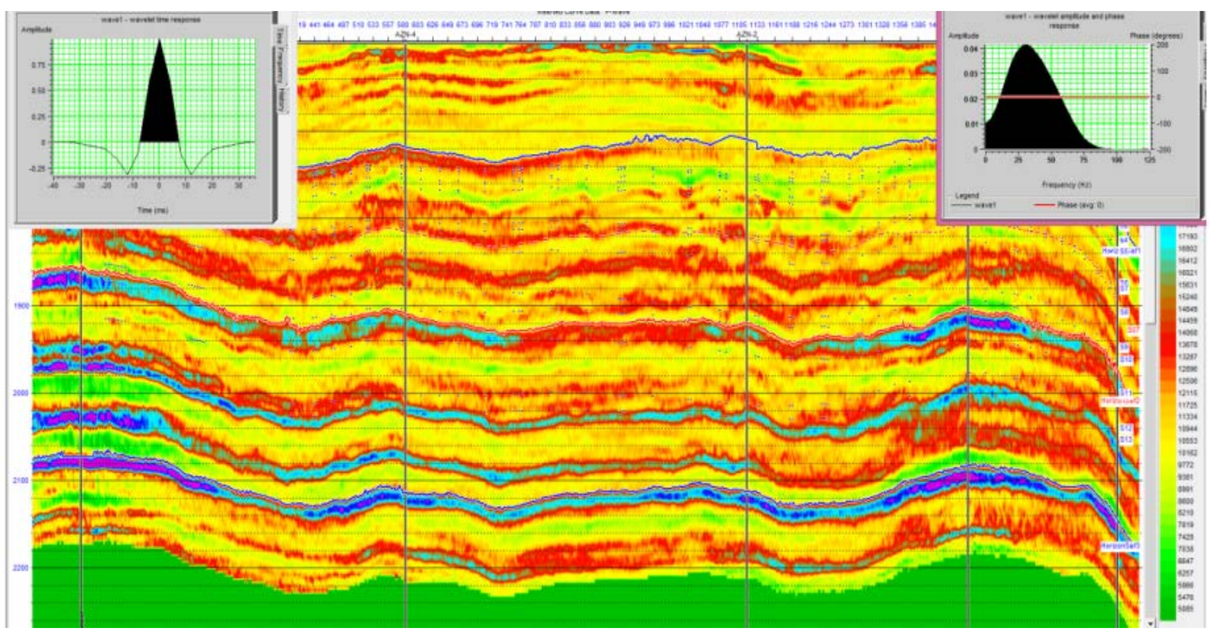
Figure 2 demonstrates the post-stack model-based inversion results using three wavelet extraction methods. The extracted wavelet in the time and frequency domains are also demonstrated in each case. Note that the inversion based on Short-Time and using well methods tend to reveal more details respect to the inversion based on the statistical wavelet estimation approach.



(a)



(b)



(c)

Figure 2. (a-c) Acoustic impedance sections using the model-based post-stack inversion with the wavelet estimated by: STHWE, well data, and statistical approaches, respectively.

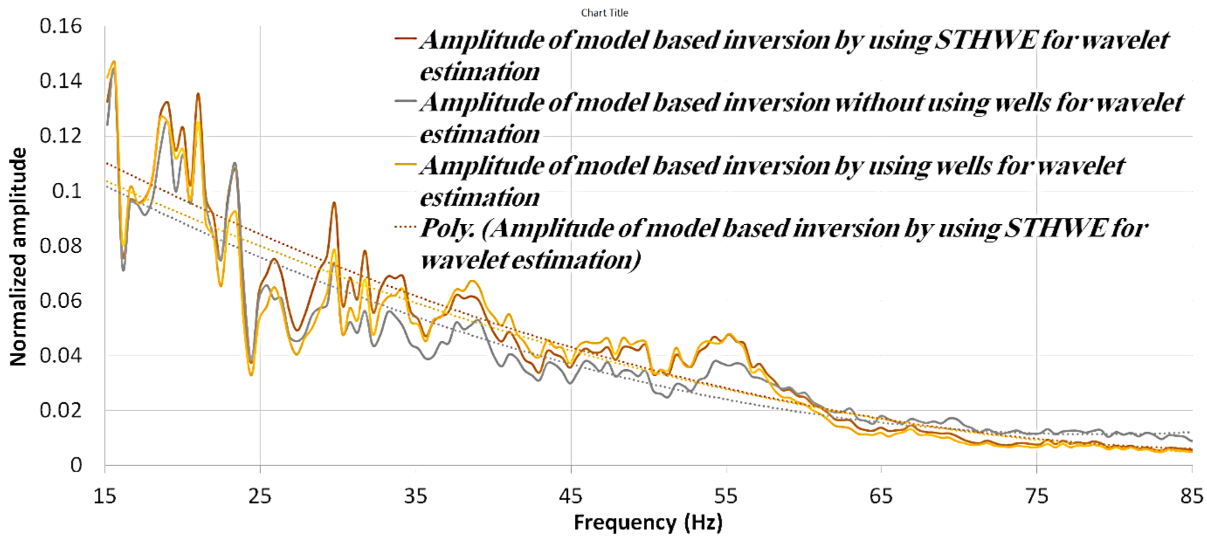


Figure 3. Demonstration of the amount of the recovered frequencies in the range 15-80 Hz. for the three approaches. Note that STHWE and using well approaches perform almost equally better than the statistical approach in recovering the frequencies.

Conclusions

A comparison of the amplitude spectrum of the seismic and inverted section reveals that the model-based inversion based on STHWE approach, and well data approach could recover frequencies equally better respect to the statistically extracted wavelet approach. STHWE as a reliable statistical wavelet estimation can be considered as an alternative approach for wavelet extraction in areas without well control.

References

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