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Time-frequency Analysis of Georgia Earthquake (25 December 2012)

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SUMMARY

Seismic waves that observed in earthquake records are non-stationary typical. To better understand the structure of the seismic signals, not only is enough to examine changes at time domain, also frequency domain is shows a component characteristics of the signal important. Therefore in recent years, different time-frequency analysis methods are used extensively. Time-Frequency analysis is suitable for non-stationary signal analysis and processing. Time-frequency analysis contains a signal in both time domain and frequency domain at the same time. In this study we applied and compared a linear and a quadratic two different time-frequency analysis methods short-time Fourier transform and Wigner-Ville distribution in December 25, 2012 Georgia earthquake record. As a result of this study, short-time Fourier transform method gave better results than the Wigner-Ville distribution.

Introduction

Commonly used signal analysis methods based on the Fourier analysis cannot demonstrate basic characteristic of the time and frequency locality of the non-stationary signal. The Fourier analysis is converts to frequency domain from a signal time domain. However, this method does not give information about the frequency values, which correspond to the time periods. Time-Frequency Analysis (TFA) includes time information for the frequencies. TFA is one dimensional signal into a two-dimensional function of time and frequency, and show how the spectral content of the signal changes with time. TFA has been used extensively in seismic data processing and interpretation and suitable for non- stationary signal analysis. Seismic waves that observed in earthquake records distinctive non-stationary typical. Therefore, recent decades researchers have been applied to time-frequency analysis of seismic data their studies (Demetriu and Trandafir, 2003; Fan and Dong, 2009; Liu et al, 2011).
In this study, we used a linear and a quadratic time-frequency analysis methods which are short -time Fourier transform (STFT) and Wigner-Ville distribution (WVD), respectively and determined the advantages of each other these method's features.

Data and Method

Traditionally, standard methods of seismic signal analysis have been used for interpretation. The most common of these methods are analysis in time-domain and analysis in frequency-domain, Fourier analysis. Recently other methods of signal analysis have been developed and although their basic principles have been established many years ago, only the evolutions of personal computers allow its current use (Saldana, 2008). These methods are analysis in time-frequency domain and analysis in time-scale domain.
The most commonly used method has been the Fourier analysis. It reveals the frequency content of any signal by decomposing it into sinusoids of different frequency. Fourier analysis converts a signal from the time domain to the frequency domain. However, this method does not give information about the frequency values, which correspond to the time periods.
The Time-Frequency Analysis (TFA) method transforms a one-dimensional signal into a two-dimensional function of time and frequency, and illustrates how the spectral content of the signal changes with time. TFA indicate changes in signal frequency content over time by combining time-frequency functions (Cohen 1989). Several types of TFA have been developed and used. The time-frequency distributions consist of two categories. These categories are classed linear distributions and quadratic distributions (Cohen, 1995, Hlawatsch and Boundreaux-Bartels, 1992). The difference between linear and quadratic methods is that the linear transform can be inverted to reconstruct the time signal. Thus, the linear transform is suitable for signal processing, such as noise reduction and time-varying filtering. On the other hand, the quadratic methods describe the energy distribution of a signal in the time-frequency domain, which is useful to analyze, classify, and detect features of the signal. We used a short-time Fourier transform (STFT) which is a linear time-frequency analysis and a Wigner-Ville Distribution (WVD) which is a quadratic time-frequency analysis.
The basic concept in STFT method is to divide the signal into small segments of the same width and perform Fourier analysis on each of them to get the frequencies present in each segment (Cohen, 1995). The amplitude distribution is define by STFT through the linear integral,

$$STFT_x(t,f) = \int_{-\infty}^{\infty} x(\tau).h(\tau - t).e^{-i2\pi f\tau} dt$$

STFT is the local spectrum of signal x (t) around time t, selected by localization window h(t).

WVD is computed by correlating the time signal with a modified version of the time signal itself, but does not estimate time waveform into segments. This distribution satisfies large number of desirable mathematical properties. The WVD is always real valued, it preserves time and frequency shifts. WVD of a signal f is given by (Carmona et al. 1998),

$$W_f(b,w) = \int f(b+\frac{\tau}{2}) f^*(b-\frac{\tau}{2}) e^{-\theta wt} dt$$

where b is a time variable, w is a frequency variable, and * denotes complex conjugate.

Time- Frequency Analysis of Georgia Earthquake

In this study, we used December 25, 2012 Georgia earthquake record (Mw=5.4, depth is 2 km) to examine time, frequency and time-frequency analysis. We selected five seismic station records. These stations are; Batumi (BATM), Aydıntepe (BAYT), Çayeli (CHOM), Kislovodsk (KIV) and Tbilisi (TBLG). Figure 1 shows the location coast of Georgia earthquake and used records seismic stations. The earthquake records are obtained Bogaziçi University Kandilli Observatory Earthquake Research Institute (KOERI) and Karadeniz Technical University (KTU). We examined Fourier analysis for frequency domain and two dimensional TFA. Using the same earthquake records, the two-dimensional TFA methods STFT and WVD was compared. Some of the following results were obtained using the time- frequency toolbox developed in Matlab (Auger et al., 1996).

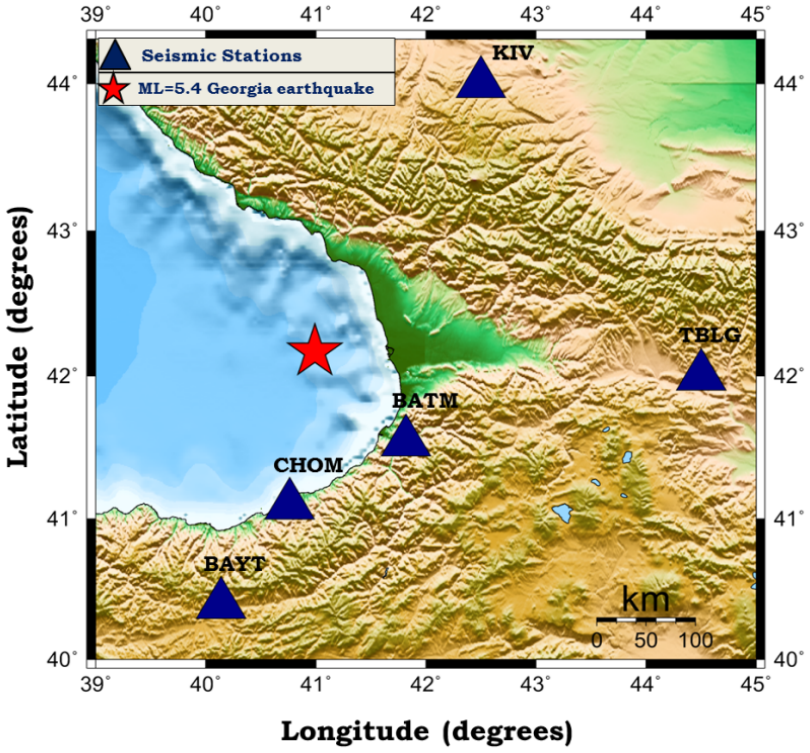

Figure 1 *Map of the coast of Georgia earthquake and recorded seismic stations.*

Batumi (BATM) station record in Georgia earthquake time, frequency and time-frequency analysis with STFT are shown in figure 2 (a) and the time-frequency analysis with WVD in figure 2 (b). In this station, maximum energy released around 16 s in the time domain and between 2-6 Hz in the frequency domain.

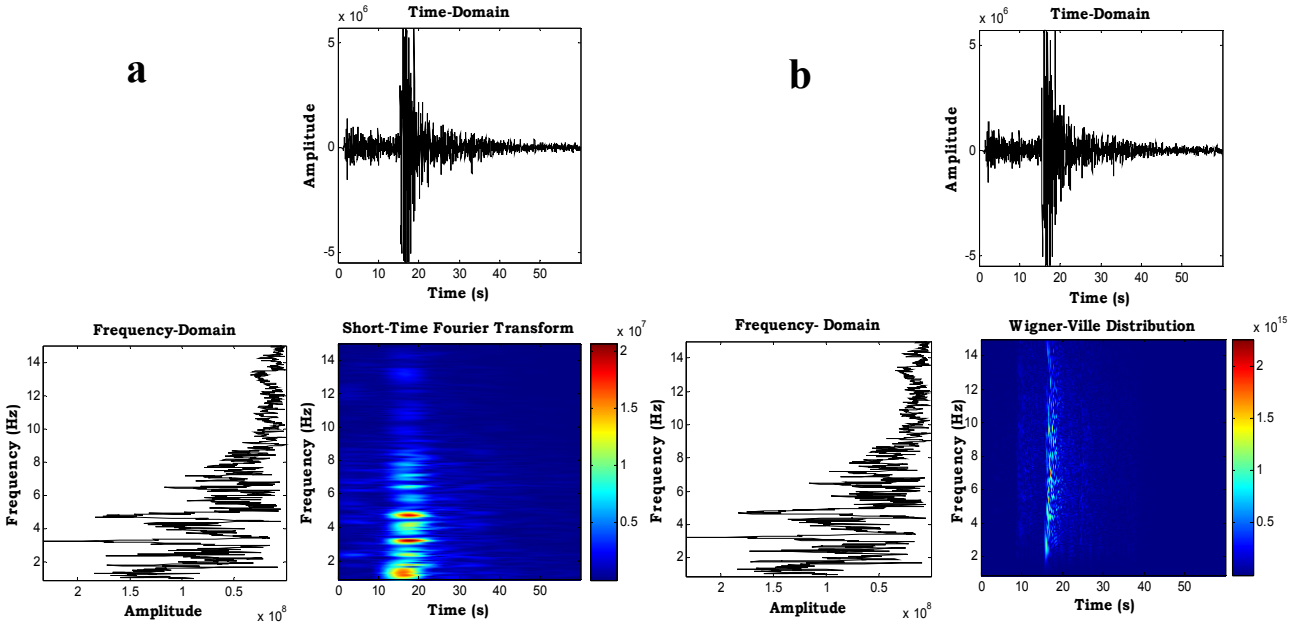

Figure 2 *Time domain, frequency domain and STFT (a) and WVD (b) representation December 25, 2012 Georgia earthquake, recorded at station Batumi (BATM).*

Aydıntepe (BAYT) station record in Georgia earthquake time, frequency and time-frequency analysis with STFT are shown in figure 3(a) and the time-frequency analysis with WVD in figure 3(b). In this station, maximum energy released around 25 s in the time domain and around 2 Hz in the frequency domain.

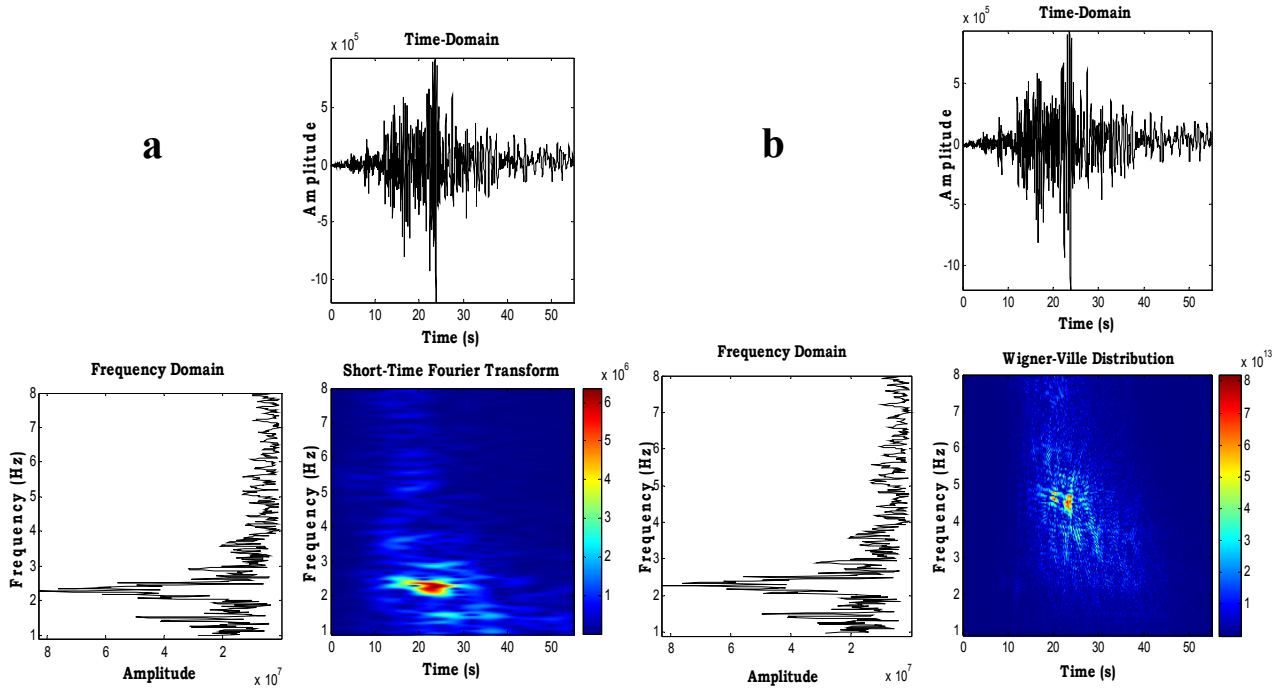

Figure 3 *Time domain, frequency domain and STFT (a) and WVD (b) representation December 25, 2012 Georgia earthquake, recorded at station Aydıntepe (BAYT).*

Conclusion

In this study we used two different time-frequency analysis method STFT and WVD in December 25, 2012 Georgia earthquake record. Characterization of the time and frequency content of the seismic waves is possible with time-frequency analysis high resolution signal processing method. Results of the analysis, maximum amplitude on time domain can be distinguished well, but maximum amplitude on frequency domain cannot be recognize. To solve this problem, different time-frequency distributions are used. STFT method both time-domain and frequency-domain has played a good role in the determination of the maximum and minimum amplitude value. WVD method has not demonstrated the location of the amplitude values exactly and also cause to slip amplitude in frequency-domain. As a result of this study, short-time Fourier transform method gave better results than the Wigner-Ville distribution.

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