Using spectrograms, scalograms and multi-tapers to analyze earthquake data

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ABSTRACT

In this study I have used certain signal processing techniques, like interpreting spectrograms, scalograms and multi-taper deconvolution methods to analyze earthquake records. I have been working on analyzing the ground motions of a recent M6.6 earthquake that occurred in the island of Crete in Greece in May 2020. The low shaking intensity is disproportionate for the earthquake's magnitude. Such behavior is common to 'Domain-A' or tsunami earthquakes according to Lay *et al.* (2012). However, low ground motion onshore Crete (and areas on the back-arc) from such an event could also be a property of the path the earthquake signal traverses. Local shallow subduction zone structure and its high attenuation (due to the overlying thick accretionary wedge) could also explain the low ground motions. In order to establish the attenuation of the crustal structure, I want to use the dispersion curves for surface waves generated from spectrograms and perform a surface wave inversion to look at the subsurface properties. The study also does a comparative analysis of spectrograms and scalograms to look at frequency domain characteristics of earthquake recordings. Finally, a multi-taper deconvolution method was used to calculate relative source time functions(RSTF) of an event, which can be extended to study source properties of the numerous small earthquakes in the region.

Introduction

According to conceptual models of the depth-varying properties of megathrust earthquakes (Lay *et al.* (2012)), "tsunami earthquakes" rupture the shallow-most (<10–15 km) seismogenic region of a subduction zone (Domain A) with large fault slip to the seafloor. In contrast, the majority of similarly sized earth- quakes rupture the plate interface at greater depth within Domains B and C. Domain A is characterized by very compliant (Bilek and Lay (1999)), fluid-rich rocks with predominantly velocity strengthening frictional properties (Faulkner *et al.* (2011)) that rarely lead to coseismic rupture.

Our goal is to study the seismic history of the island of Crete in tandem with the recent M6.6 earthquake to account for the odd variability of ground-motions. Preliminary intensity measure calculations for this area, has hinted towards a strongly attenuating crustal structure in the region. Looking at frequency-domain characteristics of earthquake recordings and using that information to infer subsurface elastic and density properties is a way to affirm the attenuation factor of the area. This study uses spectrograms to zoom into the surface wave part of earthquake recordings and look for trends in increasing frequency characteristics with amplitude and get an idea of the dispersion curve.

The study also focuses on the earthquake recordings at multiple scales by using a Continuous Wavelet Transform and interpret the results in the form of a scalogram. A scalogram illustrates how signal activity within a range of time-scales evolves over time. The scalogram is constructed by evaluating the correlation between a signal and wavelets with different scales, and then plotting how the correlation with each wavelet varies over time. Looking at the scalogram plots is another way of looking at the frequency domain characteristics of earthquake recordings.

The relative source–time function (RSTF) method is used to estimate the source properties of earthquakes in an effort to determine if there are systematic variations in the source parameters of these earthquakes (e.g., stress drop, rupture complexity, and rupture directivity) with the tectonic setting. This study envisions the use of this technique to look at small yet similar clusters of earthquakes to look at their source properties.

Here in this study, we look at five large earthquakes, $M_w > 6.5$, on which these signal processing techniques are applied.

Data

We used vertical component seismic records for earthquakes recorded by the FDSN and IRIS networks in the period 2005 to 2020. Seismic waveforms were a mixture of EHZ, HHZ and BHZ channels. Due to limit on the number of figures that could be used in this paper, all figures and examples discussed are with reference to the Tohoku 2011 earthquake recording from the seismic station with station code WET and network code GR.

Methodology

Before analyzing data for frequency domain characteristics, all data must conform to some pre-processing techniques. Once, we have the origin time information for earthquakes, we use ObsPy to query and download the data for a window length of 4 hours centred around the P-arrival time. The data once downloaded is decovoluted from its response, detrended linearly, demeaned resampled if necessary to 50Hz.

0.1 Spectrograms

A spectrogram displays signal strength over time at the various frequencies present in a waveform. Spectrograms can be two-dimensional graphs with a third variable represented by color, or three-dimensional graphs with a fourth color variable. To generate a spectrogram, a time-domain signal is divided into shorter segments of equal length. Then, the Fast Fourier Transform (FFT) is applied to each segment. The spectrogram is a plot of the spectrum on each segment. The “Frame Count” parameter determines the number of FFTs used to create the spectrogram and, in result, the amount of the overall time signal that is split into independent FFTs. The Hanning window is applied to each segment, and the amount of overlap of each segment is specified with number of overlap points set at 128.

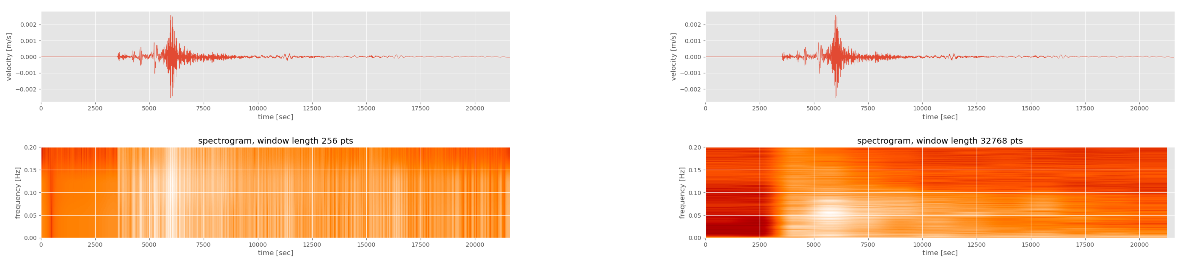

Figure 1. Effect of changing the NFFT of spectrograms. Uncertainty principle

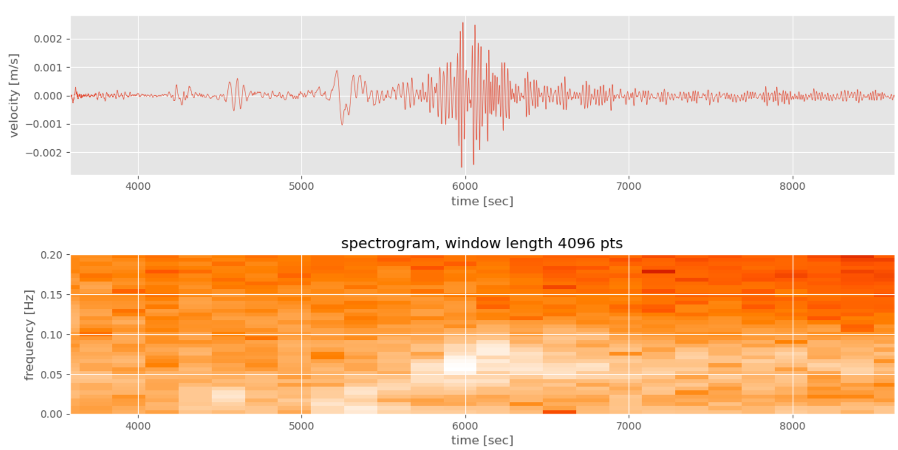

Figure 2. A curve from lower to higher frequencies. This is the dispersion of the surface waves.

Figure 1 shows the effect of the uncertainty principle with changing the number of sample points from low to high. We can see vertical lines with NFFT = 256 and thus can only determine the moment in time where high amplitudes are to expect. We cannot say at which frequencies these high amplitudes occur. When we increase the number of sample points it is vice versa. We now see horizontal lines, i.e. we can clearly define the frequencies but not the moments in time, at which they occur. By increasing the number of samples for the FFT to produce the spectrogram and keeping the time length of the signal constant, we have decreased Δf and thus increase the resolution in the frequency-domain. Figure 2, shows how the highest amplitudes change their frequencies. We obtain a curve from lower to higher frequencies. This is the dispersion of the surface waves.

0.2 Scalograms

Non-stationary signals are frequently encountered in a variety of engineering fields. The inability of conventional Fourier analysis to preserve the time dependence and describe the evolutionary spectral characteristics of non-stationary processes requires tools which allow time and frequency localization beyond customary Fourier analysis (Gurley and Kareem (1999), Kareem *et al.* (1993)).

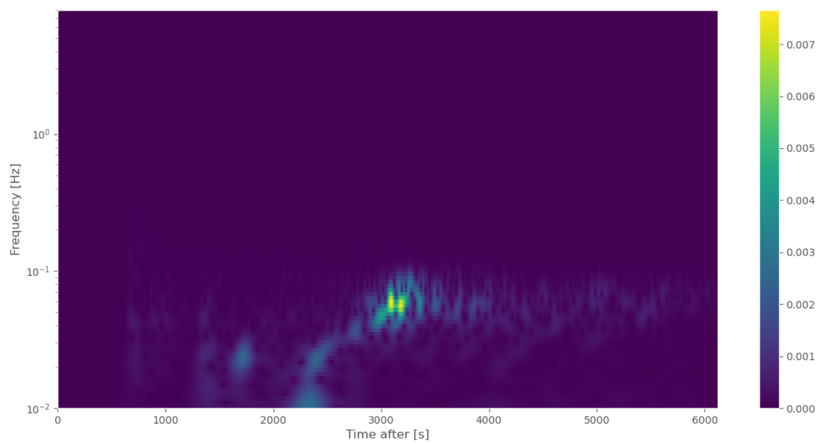

Figure 3. Continuous Wavelet Transform using the Morlet type of wavelet

Figure 3, illustrates how the scalogram demonstrates that energy (bright columnar bands) predominates in the frequency range of 0.01 to 0.1.

0.3 Multi-taper deconvolution

The primary idea of this technique is to deconvolve two time series using multitapers according to the algorithm developed by Park and Levin (2000). In this study, we use this technique to calculate the relative source time function of an earthquake. For this example, I am using seismic data from the Eastern Coalfields mining zone of India.
Relative source–time function (RSTF) method to estimate the source properties of earthquakes in an effort to determine if there are systematic variations in the source parameters of these earthquakes (e.g., stress drop, rupture complexity, and rupture directivity) with the tectonic setting Escudero and Doser (2012). In this analysis we use the empirical Greens function (EGF) technique to estimate the relative source–time functions of moderate earthquakes. This method has been used in a wide variety of situations to estimate source parameters (e.g., Mueller (1985); Mori and Frankel (1990); Hough *et al.* (1991); Ammon *et al.* (1993); Velasco *et al.* (1994)). The EGF method has both disadvantages and advantages. On the one hand, due to the necessity of finding an appropriate earthquake to be used as an EGF, the method has limited applicability. On the other hand, it can be used to determine relative source–time functions at all distance ranges and can correct for other factors such as attenuation and other path effects. The technique also provides information on rupture directivity, which aids in the identification of causative faults in a region of complex fault interactions. Figure 4 shows the relative source time function that has been calculated.

Conclusions

Through this project I want to explore the possibility of using dispersion curves generated from spectrograms to look at surface wave inversions. Surface wave inversions are a good test for looking at elastic properties, density and thickness of subsurface

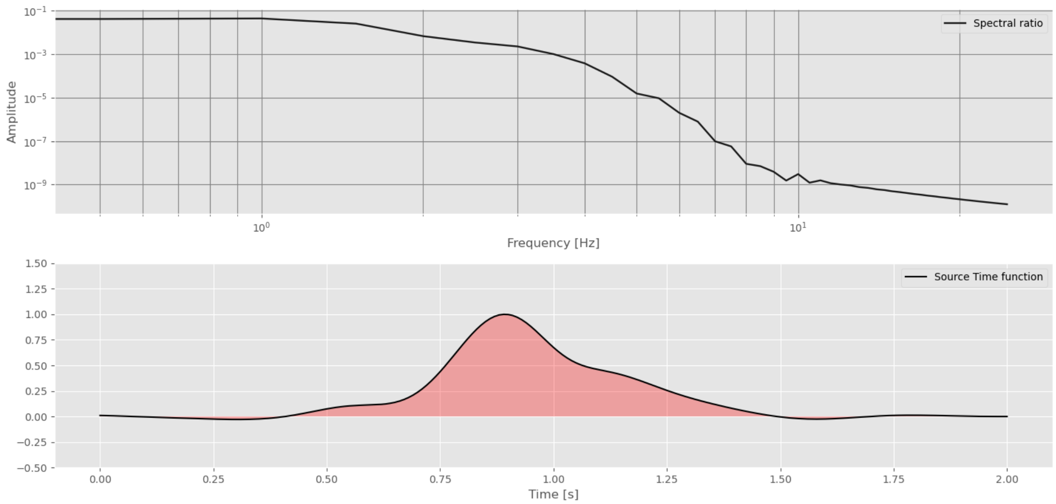

Figure 4. Spectral Ratio and RSTF of example event

layers. This in turn can be a good way of explaining attenuation in the crust. The study also xplored the difference between spectrograms and scalograms. In conclusion, although RSTF is an easy way of looking at source properties of earthquakes but is difficult finding an appropriate earthquake to be used as an EGF.

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