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Moment Tensor Solution in Time Frequency Domain

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INTRODUCTION

One popular solution is determining the source parameters via Centroid Moment Tensor (CMT) inversion. The CMT usually shows a brief image of the source processes of earthquakes at the time of faulting. Several codes are available for point/extended source parameters inversion in regional and teleseismic distances. These methods only use one band for the source study. Therefor frequency, an algorithm that can consider the time and frequency domain at the same time has not been presented for CMT inversion yet

METHODS/DATA

This study presents a new method and algorithm based on an extension of Dreger and Helmberger (1991) and Minson and Dreger (2008) for CMT inversion that combines efficient time-frequency decomposition and automatic data processing. We use an interpreted high-level programming language (python) in the Wavelet Domain Moment Tensor (WDMT) inversion package.

The data import is easy with WDMT for available database formats. The WDMT code imports the input data using the Obspy library. It makes it easy to access several databases without conversions. Alongside reading the data, several algorithms check the quality of data so as gaps, the number of samples, noise level, and amplitude saturation. The user can limit the distance and azimuth of stations before the processing.

START

RESULTS

We first show the advantage of the proposed algorithm on synthetic tests. We generate the synthetic seismograms for an arbitrary faulting system. Then the algorithm tries to solve the CMT inversion for noise-free and noisy data. Finally, the CMT is recovered for a pre-studied event in southern Iran.

CONCLUSION

The package WDMT presented here allows an easy application of the point-source method of Dreger and Helmberger (1991) and Minson and Dreger (2008) in the wavelet domain, thus the method can be used for all frequency content.

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Introduction

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An accurate and reliable estimation of the source parameters of earthquakes is essential for hazard assessment, tsunami warning, understanding the tectonic process of the region, and tomography. One popular solution is determining the source parameters via Centroid Moment Tensor (CMT) inversion. Today broadband instruments are installed densely and used regularly in seismic networks. Therefore, several approaches are also developed to access the CMT solutions in regional distances. These methods also use a narrow frequency band of the broadband waveform (Zhao et al,1994; Sokos and Zahradnik, 2008; Donner et al, 2020). The GFs and synthetic seismograms can be synthesized by discerning the origin time and hypocenter location of earthquakes. Therefore, we can produce more accurate GFs and synthetic seismograms by defining a complete earth model and accurate location. Several codes are available for point/extended source parameters inversion in regional to teleseismic distances (Sokos and Zahradnik,2008; Kikuchi and Kanamori.1991. Dreger and Helmberger, 1991). These methods only use one frequency band for the source study. The incompleteness of the earth model is also considered with time-shifting to align the arrival phases. Templeton et al. (2008) introduced an algorithm that accounts for the spectral and temporal variation known as cut and paste (CAP). CAP divides the seismograms into five windows based on arrival phases and the type of waves. It solves the time-shifting problem (solves the model problem) but it does not take into account the complete waveform spectral. Therefore, an algorithm that can consider the time and frequency domain at the same time has not been presented for CMT inversion yet. The idea of time-frequency decomposition can solve time-shifting and the frequency problem simultaneously. It enables us to compare the results in multiple time and frequency windows. Ji et al. (2002) shows that wavelet transform is an appropriate time-frequency decomposition method for studying the complexity of sources. A wavelet transform can decompose any signal into translations and scales (corresponding to time-shifting and frequency window). That means we can use both the temporal and spectral characteristics of seismograms in inversion. That means the proposed package can retrieve the point-source moment tensor in a multi-channel time-frequency domain efficiently. This paper aims to show the accuracy and efficiency of the new semi-automatic WDMT inversion algorithm in the time-frequency domain.

Objectives

Wavelet transform and inversion

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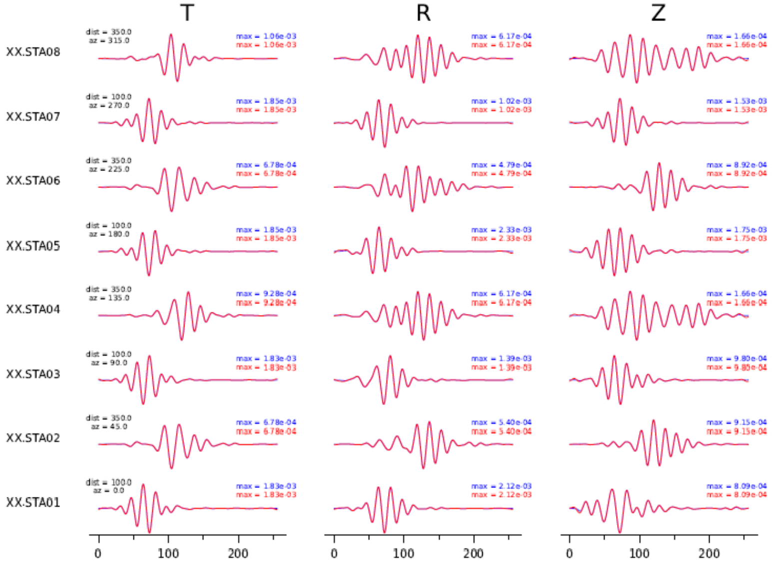
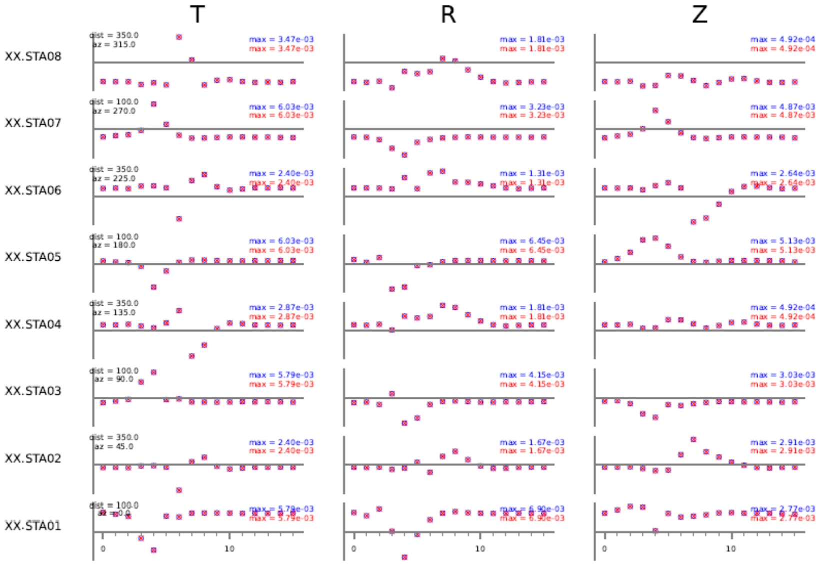
The first step in CMT inversion is aligning Greens function and seismograms via correlation. This step is an essential procedure to shift data and align the seismic phases for inverting the correct part of data. Then the WDMT applies ODW transform to the green's function and data.
The wavelet coefficients of each trace are saved in a matrix-based format. The inversion retrieves the CMT solution at each scale iteratively. By minimizing the L2 norm error function, we fit observed and synthetic data. The package is planned to invert the data in two regular methods; the deviatoric method (usually used for planner faulting) and the full moment tensor inversion (regularly implemented in explosive events, volcanic earthquakes and nuclear test ban). Then the results are decomposed to pure Double Couple (DC), deviatoric (CLVD), isotropic (ISO) parts. The MT is usually shown with focal mechanisms. Finally, synthetic seismograms are calculated by retrieved MT and are compared to the original data. This step run for each wavelet scale and results are saved in text format for future control. The code also saves comparison results in the wavelet and time-domain graphically in a PDF file.





Methods/Data/Results(1/3)
Algorithm and implementation

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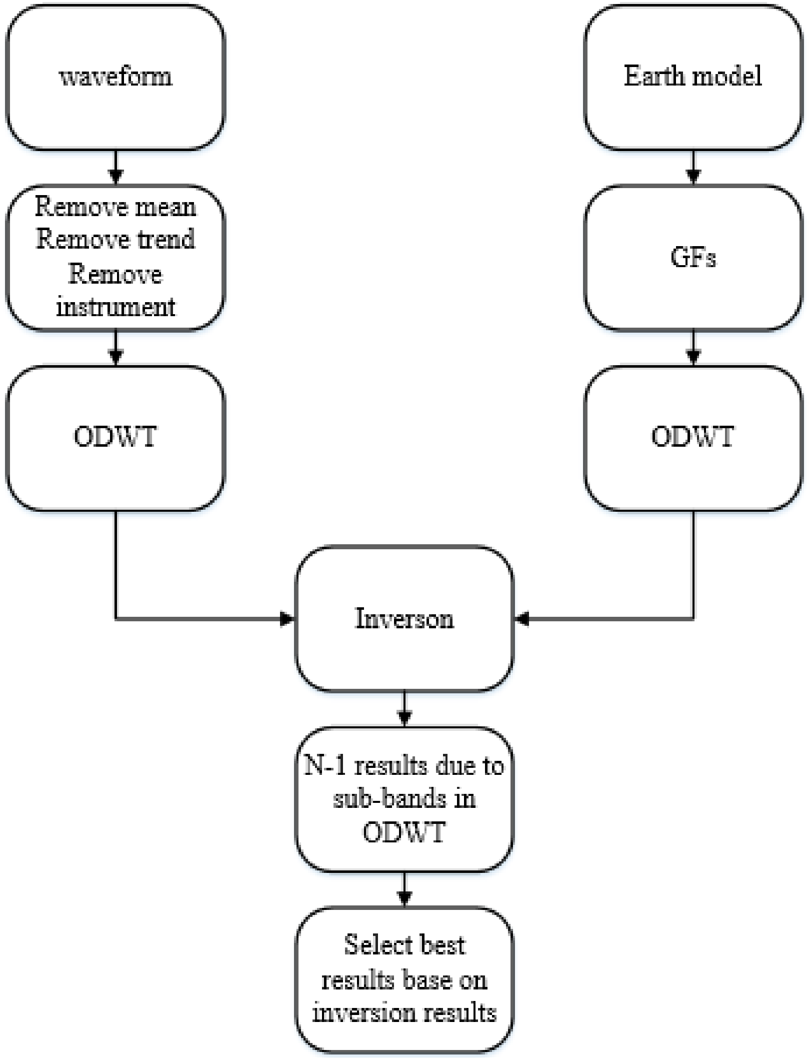
WDMT package, presented here, was written in python language. Its purpose is to retrieve the accurate and reliable CMT solution with semi-automatic data quality control and processing, Gfs calculation, wavelet transform, inversion, and high-resolution plots. We use well-prepared python libraries such as Obspy (Beyreuther et al., 2010) and pandas (The pandas development team, 2020) to interact with the seismic data and metadata. A lot of care has been taken to write the code that will be easy to handle the quality control, easy to use, accurate results, fast to run, and high-quality graphs for publications. The program is tested under Windows and Linux operating systems without any modifications and it is OS independent. The program starts with command main.py and the metadata parameters are passed to the program through switches. After running the main code following algorithms will be implemented to do a semi-automatic CMT inversion.

1. data preparation (reading, data quality control, processing),
2. Green’s functions calculation,
3. the wavelet transform and inversion,
4. plotting the results.



Methods/Data/Results(2/3)

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We first show the advantage of the proposed algorithm on synthetic tests. We generate the synthetic seismograms for an arbitrary faulting system. Then the algorithm tries to solve the CMT inversion for noise-free and noisy data. Finally, the CMT is recovered for a pre-studied event in southern Iran.

We use an arbitrary uniform station distribution and fault geometry in synthetic tests. In this event, eight stations are deployed within 350 km away from the epicenter with a considerable far-field coverage. It should be noted that a suitable station coverage is an advantage for detailed analysis. The strike, dip, and rake for the test event are 45°, 45° and 45° respectively. In the inversion, the program matches the wavelet coefficients for each scale iteratively. Therefore, we need to fit $2^j (j = 0, \ldots 8)$wavelet coefficients for each iteration. During the inversion, hypocenter depth is fixed to find the accuracy of the results. We let the inversion find the best moment tensor via the deviatoric method. The results of the noise-free test are show It completely recovers the moment tensor details in all scales and validates our algorithms. Then we add white noise (the maximum amplitude of the noise is of the maximum in data), all the results are nearly recovered in scales except at low frequencies. The main reason for low frequencies is the none time-invariant corrections (removing mean and trends) and nonlinear trend in the applied noise. At the final synthetic stage, we try to add a sine noise ($0.05A_{max}\sin[0.4\pi t]$) to all signals. The algorithm once more retrieved the moment tensor correctly at all scales except again at very long periods and the scale 6. The low frequencies again are affected by the nonlinear trend of noise. And the scale of 6 includes the noise frequency. To show the use of the package, we present the moment tensor inversion for a moderate earthquake that occurred on December 30, 2014, at 4:19 (UTC) in southern Iran (IRSC location Lat: , Lon: , Mw=5.0). The earthquake was detected and recorded by the Iranian Seismological Center (IRSC) and International Earthquake Engineering and Seismology (IIEES) permanent networks.

Comparison of results between this study result and IRSC CMT solution

	Frequency	Strike 1/2	Dip1/2	Rake1/2	Depth	Magnitude	DC %	CLVD %
This study	[0.04, 0.16]	166.9/238.6	81.0/19.0	107.3/28.1	16	5	99.3	0.7
IRSC	[0.04, 0.07]	160/205	71/26	72.132	16	5	60.7	39.3

Methods/Data/Results(3/3)

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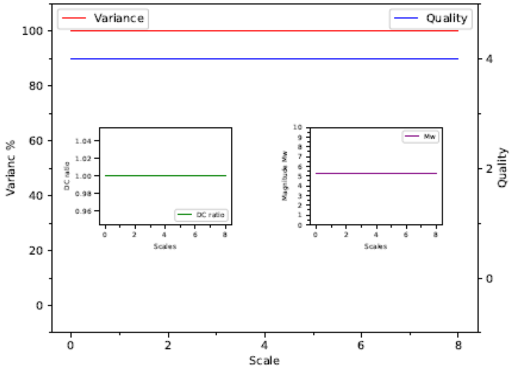
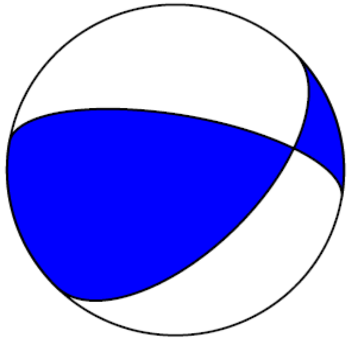
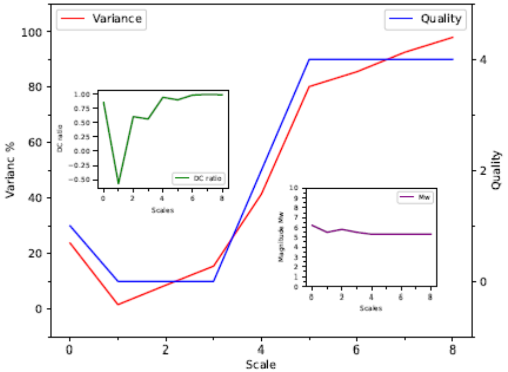
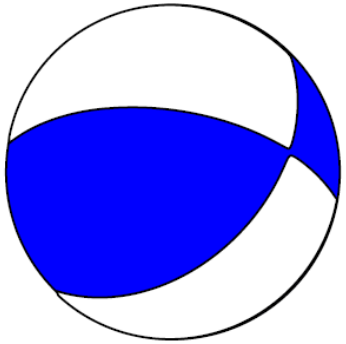
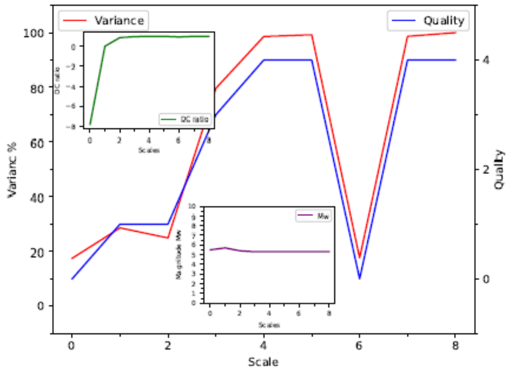
Finally, we let the program retrieve the CMT solution for all scales between $j_{min} = 4$ and $j_{max} = 8$. That means all considerable frequencies are taken part in the CMT inversion. The results show that the best solution is obtained at scale 5 with the DC=99.3% and magnitude of 5.0. In contrast comparing the results with the pre-studied CMT solution at IRSC (Hosseini et al., 2019), our algorithm uses a wider frequency band and the DC component is constrained better and the observed and synthetic seismograms are matched. The inversion time and stability of results also show that the algorithm works fine for use in automatic inversion.

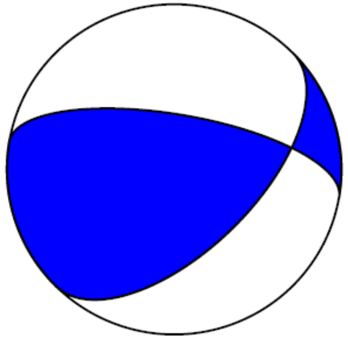












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Conclusion

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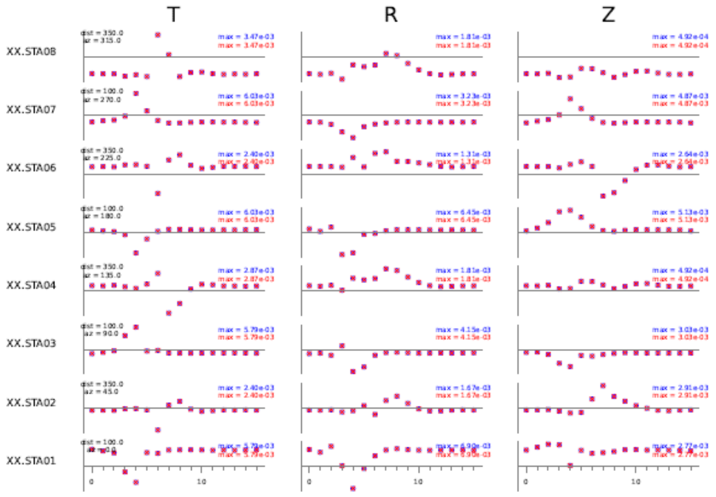

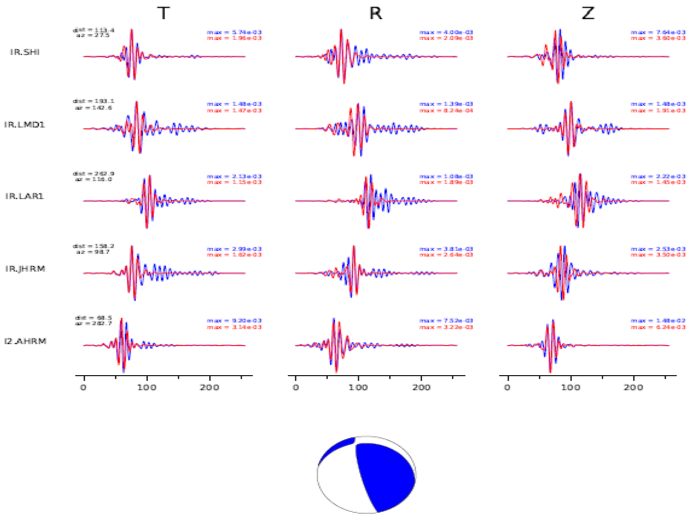

The fitting comparison between observed (blue) and synthetic (red) wavelet coefficients (scale=4). The maximum amplitude (max) for each coefficients is indicated in blue and red for real and synthetic seismograms respectively. The station name is located at the left side hand of seismograms. The azimuth (az) and distance (dist) is shown in the T component of each station. The same as part (a) but for real data test. The bottom beachball shows the final MT results for the real data test of this study.

The CMT inversion in local and regional distances is a common procedure applied to broadband seismograms worldwide, in most cases even as an automatic method. In all applications, the inversion is done for a narrow frequency band and single-point source. The package WDMT presented here allows an easy application of the point-source method in Dreger and Helmberger (1991) and Minson and Dreger (2008) in the wavelet domain, thus the method can be used for all frequency content.

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References

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