An Alternate Method for Earthquake Source Characterization through Empirical Mode Decomposition and Spectral Analysis of Strong-Motion Records

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Abstract

The occurrence of a large number of earthquakes in the inter and intraplate settings of the Japan Trench leads to ruptures with varying frequencies. To capture the temporal distribution of energy and their ranges of frequencies, we have used the Intrinsic Mode Functions (IMFs) derived from the vertical components of the strong-motion records. Here we present an "energy release function", which is yet another way of representing frequency-dependent energy release. Without the assumptions of the area of slip and elastic moduli, this provides a new representation of the energy released at the source. Choice of the appropriate IMF and thus the range of frequencies representing the source was based on the best fitting teleseismic model for the same earthquake. We analysed the strong-motion records for three earthquakes (all in the magnitude range of 7.1 to 7.3), representing interplate, intraplate, and intraslab settings and used borehole data from the KiK-net. These were the Miyagi 2005 (Interplate), Tohoku 2011 (Intraslab), and Honshu 2012 (intraplate). We used the Hilbert-Huang Transform, a combination of Empirical Mode Decomposition (EMD) and Hilbert Transform (HT) to develop the spectra for vertical components of each of these earthquakes. A combination of the IMFs within the frequency band (0.1 to 3 Hz) that mostly represent the frequency range used for teleseismic source inversion (0.01 to 2 Hz) was used to develop the spectra in each case. The shape of the spectra generally mimics that of the moment rate function. Where the moment-rate function follows a single pulse, the spectrum is able to generate its shape, and the sub-events are represented through independent pulses of energy. We believe that the representation of an earthquake source based on its frequency content and temporal pattern has important applications in predicting the shaking effects of an earthquake.

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1. Introduction

- Occurrence of a large number of earthquakes along the Japan Trench leads to ruptures with varying frequencies.
- Energy release is traditionally represented using the moment rate function (MRF), from teleseismic models.
- We use strong-motion data to obtain an "energy release function" that represents frequency-dependent energy release.

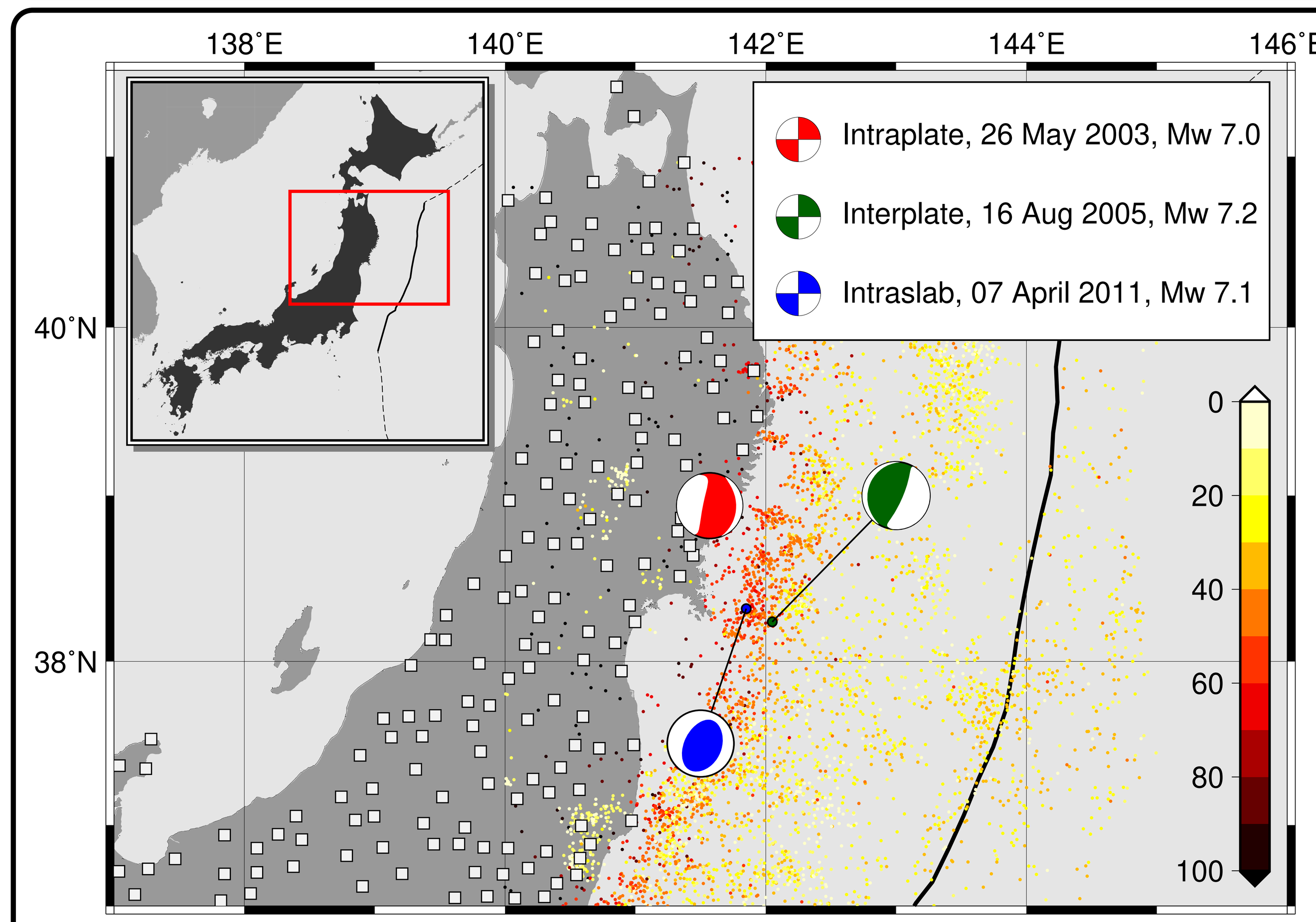


Figure 1: Earthquakes used in this study (focal mechanisms), background seismicity (circles), and KiK-net stations (squares).

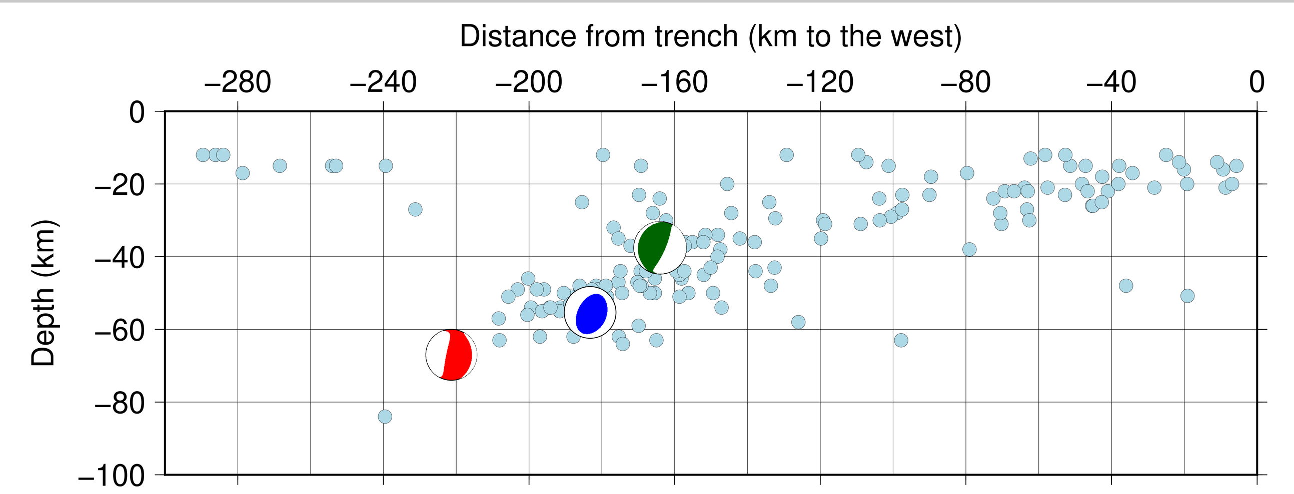
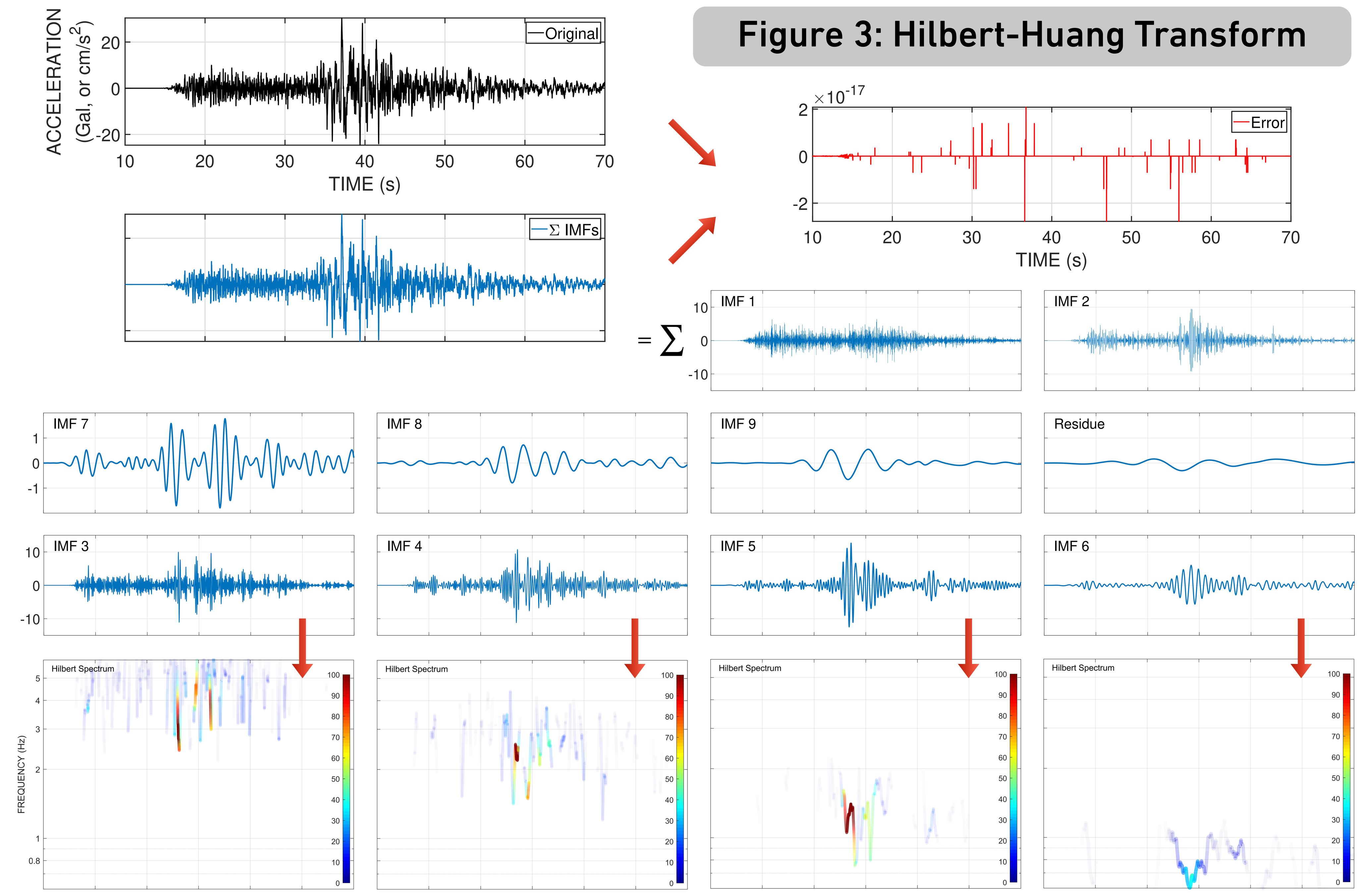


Figure 2: Cross-section showing the subduction of the Pacific slab beneath Japan and the trend of earthquakes. Blue and green beach balls represent the Tohoku (2011) and Miyagi (2005) earthquakes.

2. Methodology

- Hilbert-Huang Transform (HHT) is used to develop spectra that capture the temporal distribution of energy and ranges of frequencies. HHT is a combination of Empirical Mode Decomposition (EMD) to derive Intrinsic Mode Functions (IMFs) and Hilbert Spectral Analysis (HSA).
- A combination of IMFs within the frequency band (0.1 to 3 Hz) used; mostly represents the teleseismic source inversion (0.01 to 2 Hz).
- Hilbert Transform gives instantaneous frequencies as functions of time and resolves energy release at finer scale.

Figure 3: Hilbert-Huang Transform



3. Results

Shape of the spectra generally mimics the moment rate function (MRF). For energy release with a single pulse, the spectrum generates the shape of the MRF. Sub-events come out as independent pulses.

3.1. Intraslab, 2011-04-07, Mw 7.1, Lat 38.32, Long 141.85, 55.3 km

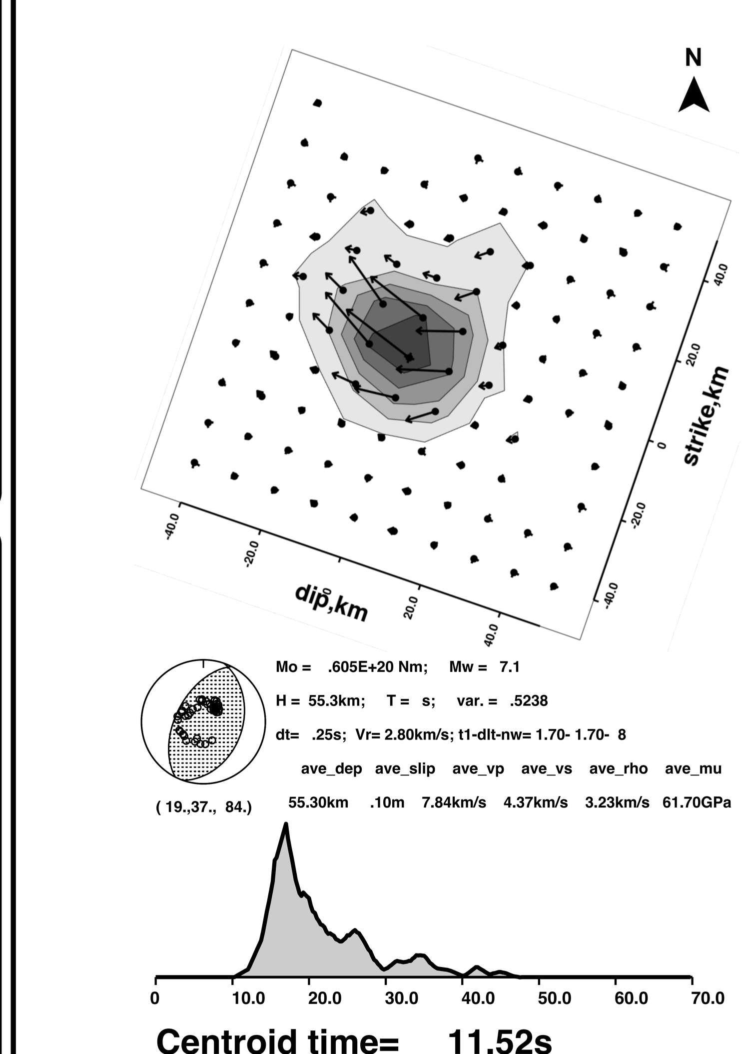


Figure 4: Waveform Modelling. Slip, focal mechanism, source parameters, and MRF.

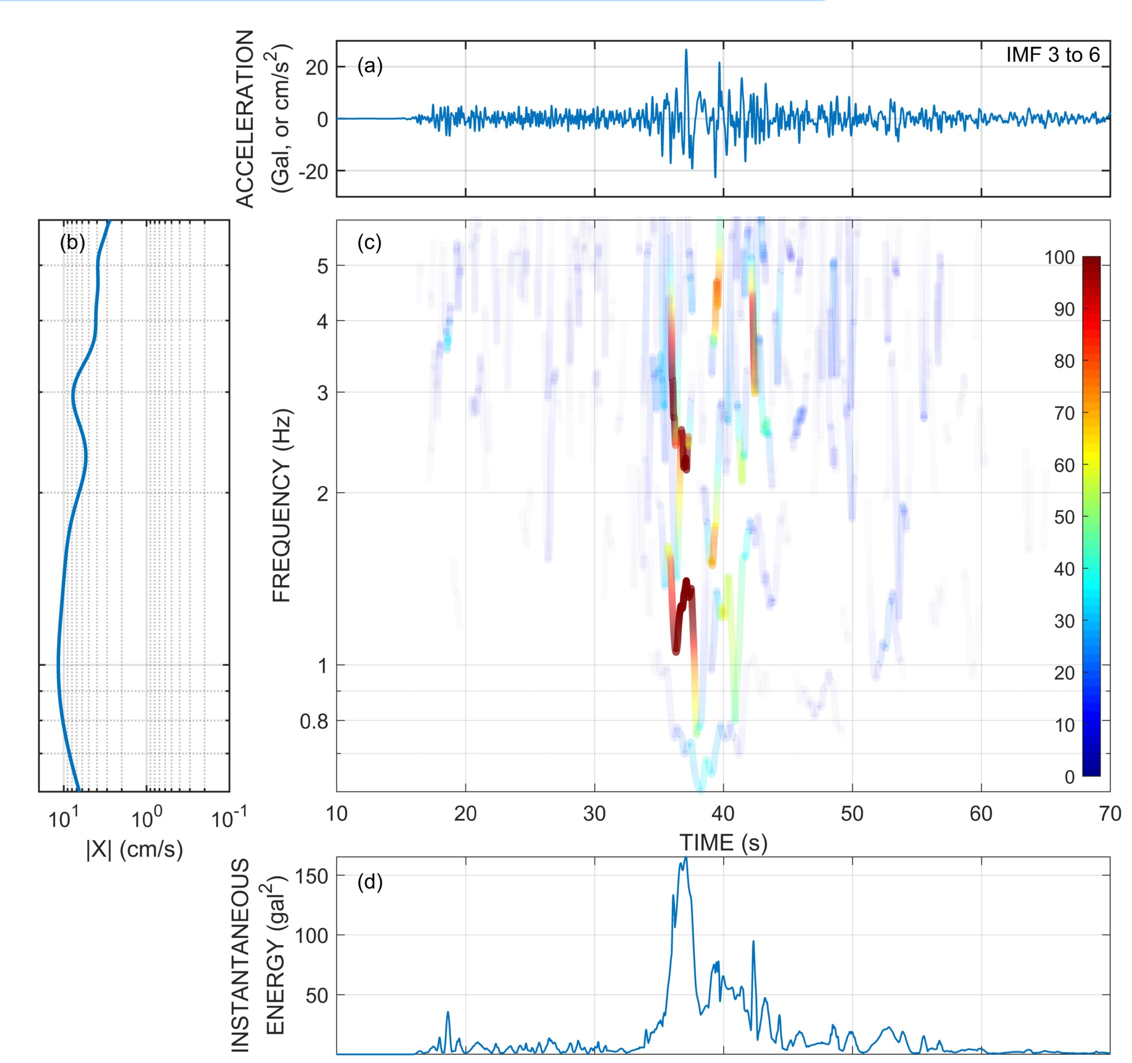


Figure 5: HHT-based (a) time, (b) frequency, (c) energy-frequency-time distribution. (d) "Energy release function"; mimics the MRF.

Sources of Data: Strong-motion data from KiK-net, Japan (NIED). Focal mechanisms, earthquake locations from GCMT. Background seismicity from ISC.

3.2. Interplate, 2005-08-16, Mw 7.2, Lat 38.24, Long 142.05, 37.5 km

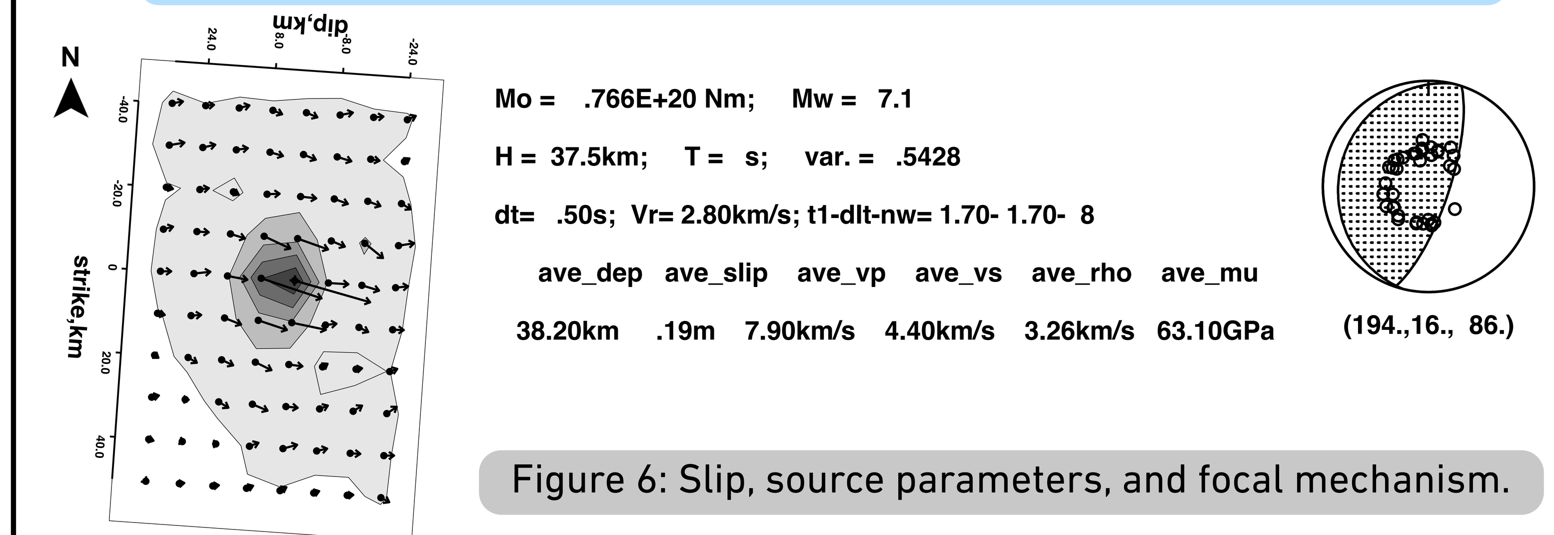


Figure 6: Slip, source parameters, and focal mechanism.

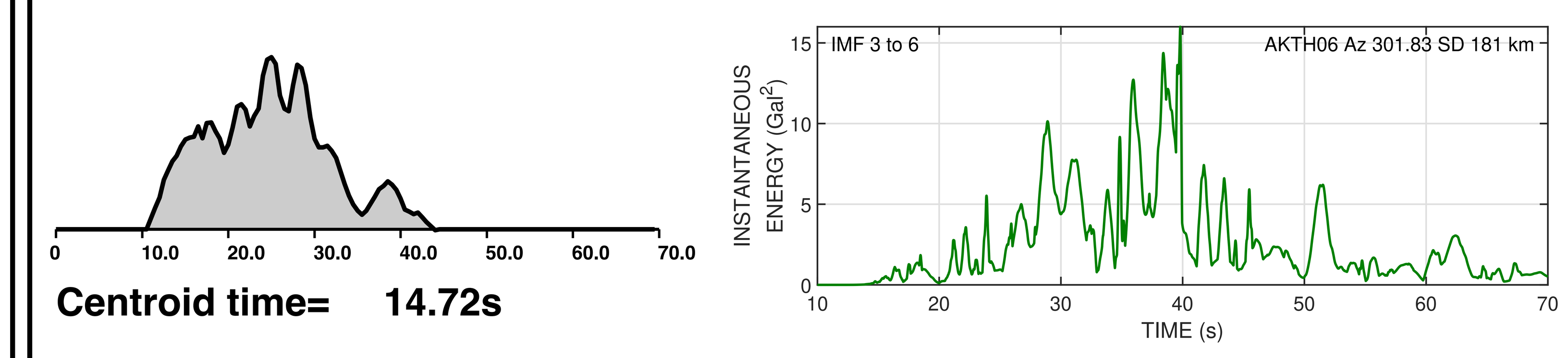


Figure 7: Moment rate function and energy release function.

3.3. Intraplate, 2003-05-26, Mw 7.0, Lat 38.94, Long 141.57, 67 km

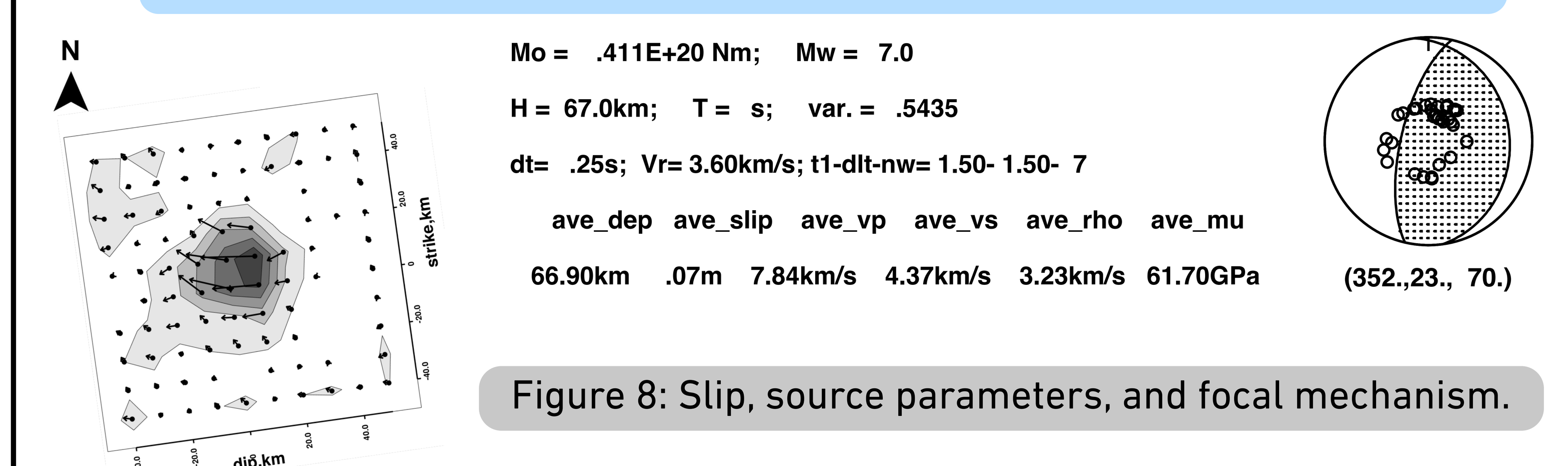


Figure 8: Slip, source parameters, and focal mechanism.

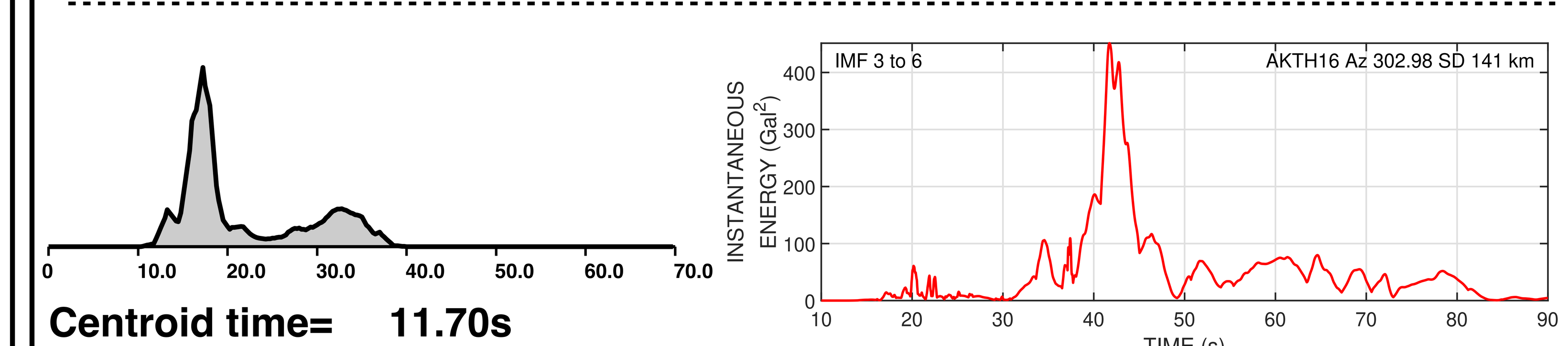


Figure 9: Moment rate function and energy release function.

4. Conclusions

- Obvious advantage of the HHT method is that it skips the assumptions of slip, elastic moduli, fault geometry, velocity models required for source modelling.
- Ability to represent an earthquake source based on its frequency content and temporal distribution could be critical for predicting shaking effects.

5. References

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