Energy release patterns and shaking effects of earthquakes in the Japan Trench: A Hilbert-Huang Transform approach

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Subduction zones showcase the multiplicity of earthquakes—interplate, intraplate and intraslab—with shallow, intermediate, or deep focus, associated with different energy release patterns and frequency contents. An understanding of the duration and frequencies associated with various pulses of energy is useful for damage assessment. Empirical Mode Decomposition (EMD) of strong-motion records and the application of Hilbert transform have been suggested to overcome the limitations of the Fourier spectral analysis in dealing with highly non-linear strong-motion records (Huang et al., 1998, Zhang et al., 2003). Following the same approach, we have been trying various methods of analysis using the KiK-net strong-motion records to explore the efficacy of these techniques in representing the source of the rupture, in terms of energy release and frequency distribution. Our previous studies used EMD and time-frequency analysis tools such as spectrogram, scalogram, and Hilbert spectrum, using Intrinsic Mode Functions (IMFs) of the original signals as inputs. Nishant (2019) made random picks of IMFs to represent sources by correlating the sum of the selected IMFs with the original signal but found that the results were station dependent. We selected IMFs based on their frequency content (0.1 to 3 Hz) and used their linear combinations to develop the Energy Release Functions (ERF) for individual earthquakes (Mache et al., 2019). They reported that the ability to capture the signature of the original signal using the IMFs varied between earthquakes and stations. Next, we selected stations based on the direction of rupture inferred from teleseismic waveform models. The use of appropriate combinations of individual IMFs, chosen based on the direction of slip, resulted in ERFs whose shapes compared better with the Moment Rate Functions (MRFs) obtained from the teleseismic models. To further explore the station dependence on the resolution of ERFs viz-a-viz the MRFs, we used the instrumental seismic intensity distribution maps (JMA 1996, Shabestari and Yamazaki 2001) to select the stations. We analyzed five earthquakes; two interplate (Mw 7.2 2005 Miyagi, and Mw 6.9 2008/07/19), two intraplate (Mw 7.0 2003 Sendai, and Mw 7.2 2012 Kamaishi) and one intraslab (Mw 7.1 2011 Miyagi), following the above methodologies. This abstract presents the initial results of our study, which to our knowledge, is the first of its kind and holds significant potential in understanding the spatial and temporal patterns of energy release and their associated frequencies.

On the use of IMFs based on their frequencies, we find that a linear combination of appropriate signals can lead to ERFs that compare well with their respective MRFs. The selection of stations in the direction of rupture generates better-resolved spectra. While using the seismic intensities, we find that for values three and higher, stations located along the direction of rupture propagation produce ERFs that correlate better with their respective MRFs, as observed for the 2011 Miyagi earthquake. The use of stations located along the direction of the trench also shows a good correlation. For seismic intensities lower than 3, there is a decay in the energy release and hence a poor reproduction of the ERFs. For complex ruptures (2003 Sendai, 2005 Miyagi, and 2012 Kamaishi), the ERFs are not smooth, with their energy distributed in bands of varying frequencies. It could be due to changes in slip direction or generation of sub-events, but the fact that the shapes of both the MRF and ERF are comparable adds credence to our analysis. We find that the local geology also plays an essential role in limiting the energy distribution within a frequency range, an issue that needs further exploration using more examples.

Keywords: strong-motion, spectral analysis, Hibert-Huang transform, energy release, Japan Trench, intraslab, intraplate, and interplate earthquakes