Within and Between-Events Variability of Strong-Velocity Pulses

Ming-Hsuan Yen[1,2], Kuo-Fong Ma[3,4,5], Fabrice Cotton[1,2], Yen-Yu Lin[3,4], and Ya-Ting Lee[3]

[1] GFZ German Research Centre for Geosciences, Germany; [2] Institute of Geosciences, University of Potsdam, Germany;
[3] Earthquake-Disaster & Risk Evaluation and Management, E-DREaM, Center, National Central University, Taiwan;
[4] Department of Earth Sciences, National Central University, Taiwan; [5] Institute of Earth Sciences, Academia Sinica, Taiwan

Introduction

Near-fault ground motions with strong pulses bring significant damage to nearby structures. The period and the amplitude of the strong-velocity pulses are then especially critical for structural engineering and seismic hazard assessment. Several studies revealed that the pulse periods scaled with earthquake sizes and proposed empirical relationships between pulse periods and earthquake magnitudes (Somerville, 2003; Shahi and Baker, 2011, 2014). The scaling of pulse periods show large within and between-events variabilities (Fig. 1). These pulse periods variabilities are still poorly understood.

In this study, we investigate the variability of pulses and analyze the physical factors controlling this variability through new data analysis but also simulations. We analyze four earthquakes in Taiwan and Japan and perform simulations using a simple FK method. In the classification of pulses, we perform the automated procedure (wavelet analysis) of Shahi and Baker (2014) to extract and characterize the strongest pulses.

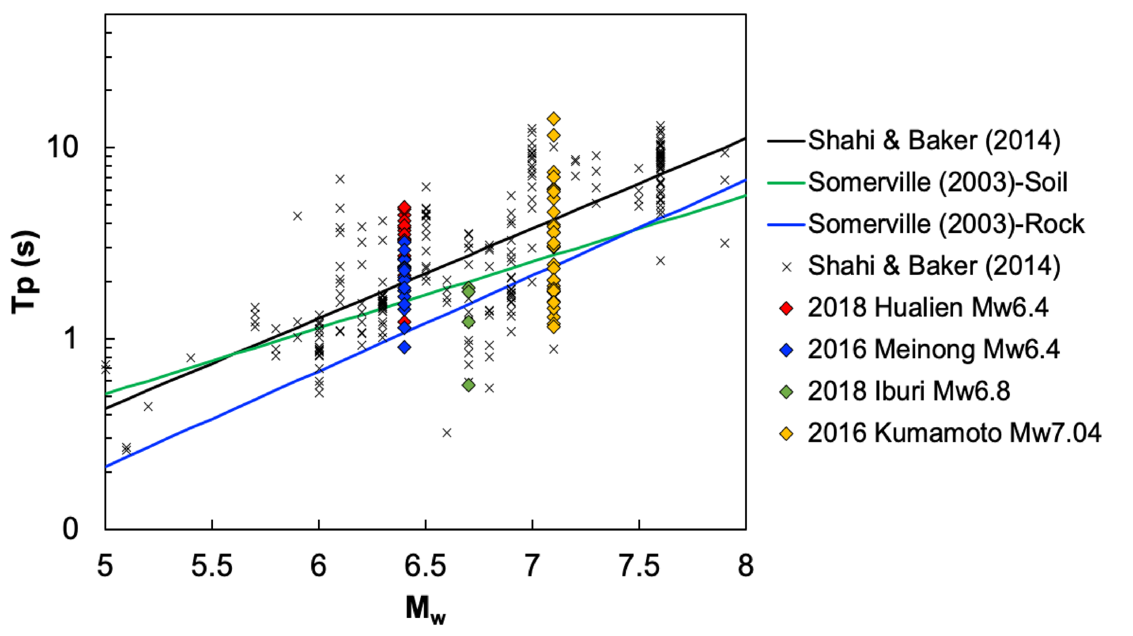


Fig.1. Value of the pulse period, Tp, as a function of earthquake moment magnitudes.

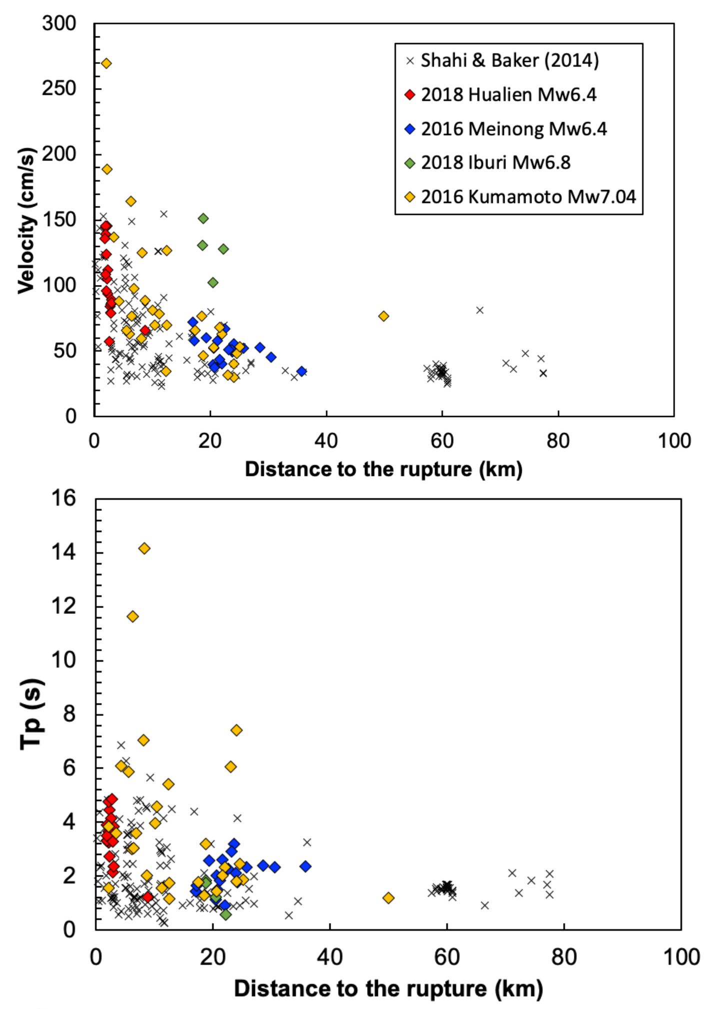


Fig.2. Scaling of (a) pulse velocity and (b) pulse period Tp according to the distance to the rupture. The data of Shahi and Baker (2014) are shown for earthquakes magnitudes between 5.0 and 6.9.

Strong-Velocity Pulses from Observations

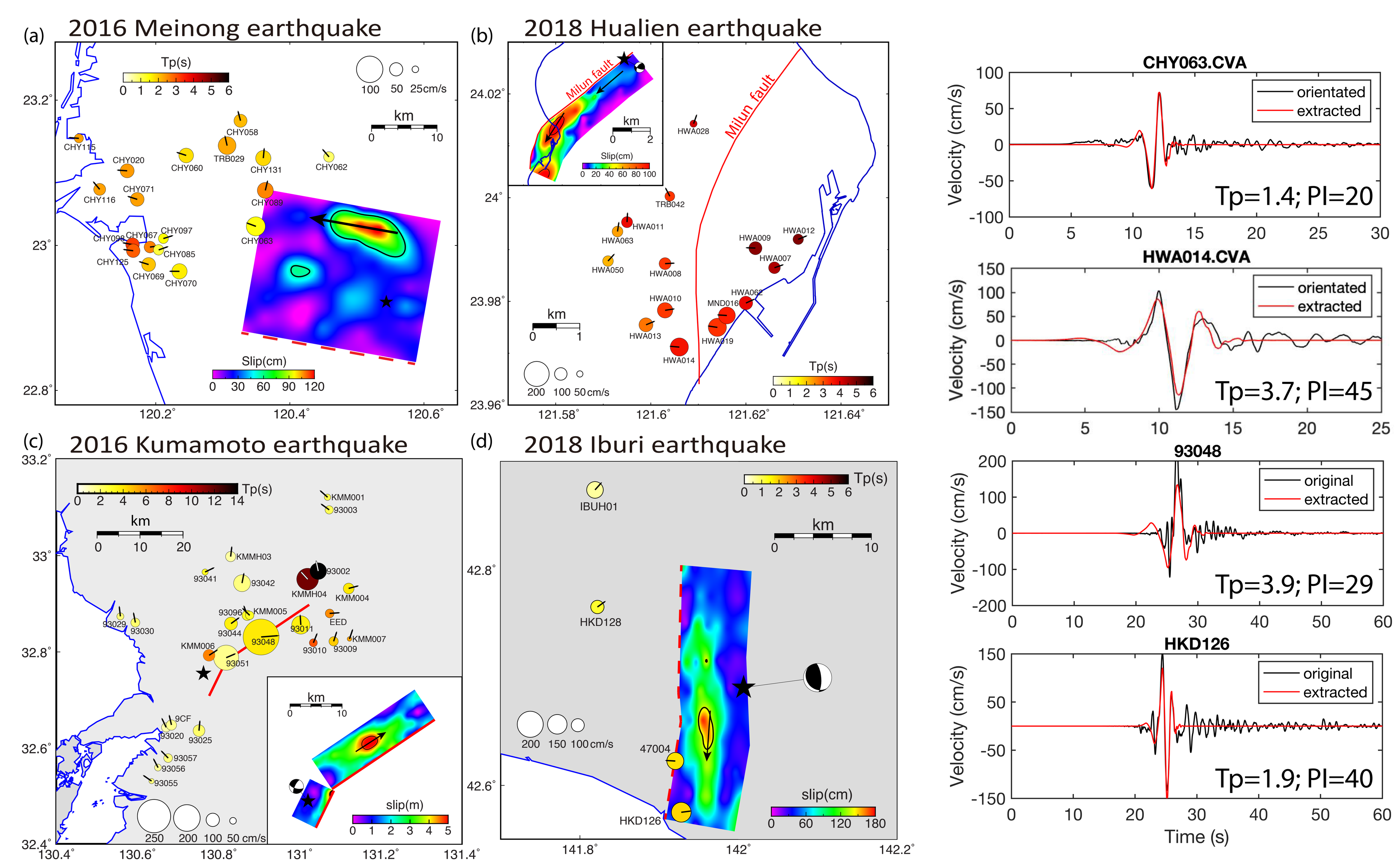
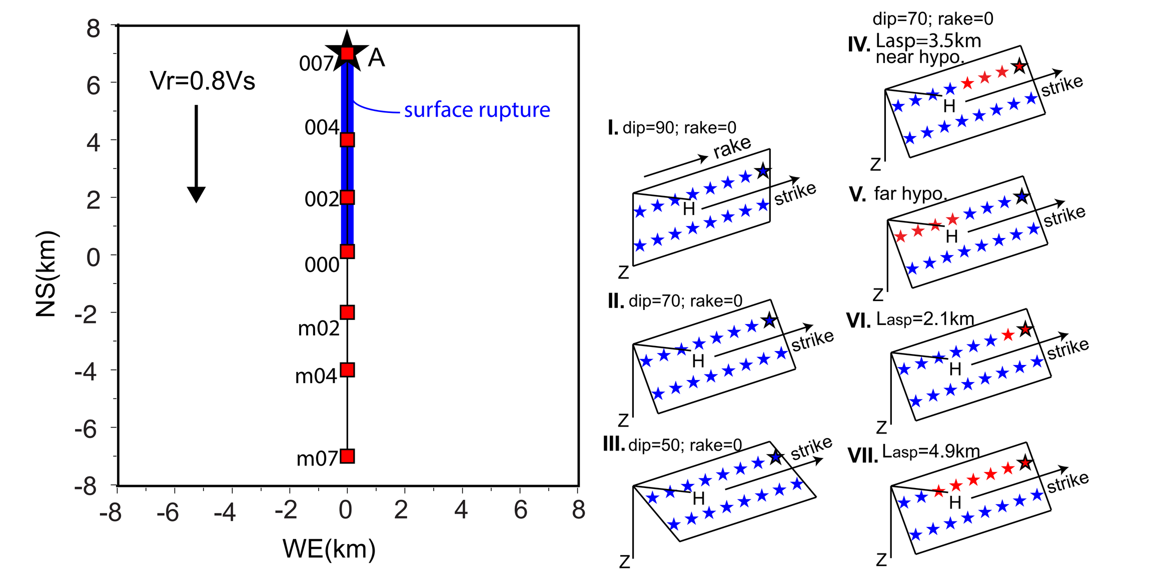


Fig.3. Waveforms of largest pulses in each earthquake and distributions of strong-velocity pulses. Arrows on the circle represent the orientation of strongest pulses. The slip distributions of (a) and (b) are referred to the inversion results of Lee et al. (2016; 2019), and (c) and (d) are referred to the inversion results of Asano and Iwata (2016; 2019).

Strong-Velocity Pulses from Simulations

The rupture initiates at the edge of the fault and propagates with a constant rupture velocity (2.4 cm/s, 0.8 times the S-wave velocity). The rupture area is equal to 7x5 km² and the magnitude of the simulated cases sets as Mw 6.0. To analyze the impact of the asperity on pulse properties, we implemented a simple asperity with an associated magnitude of Mw 5.8 in four simulations cases. Since the pulses were found in earthquakes with different mechanisms, we also tested the impact of various fault dip angles with homogeneous slip distributions.



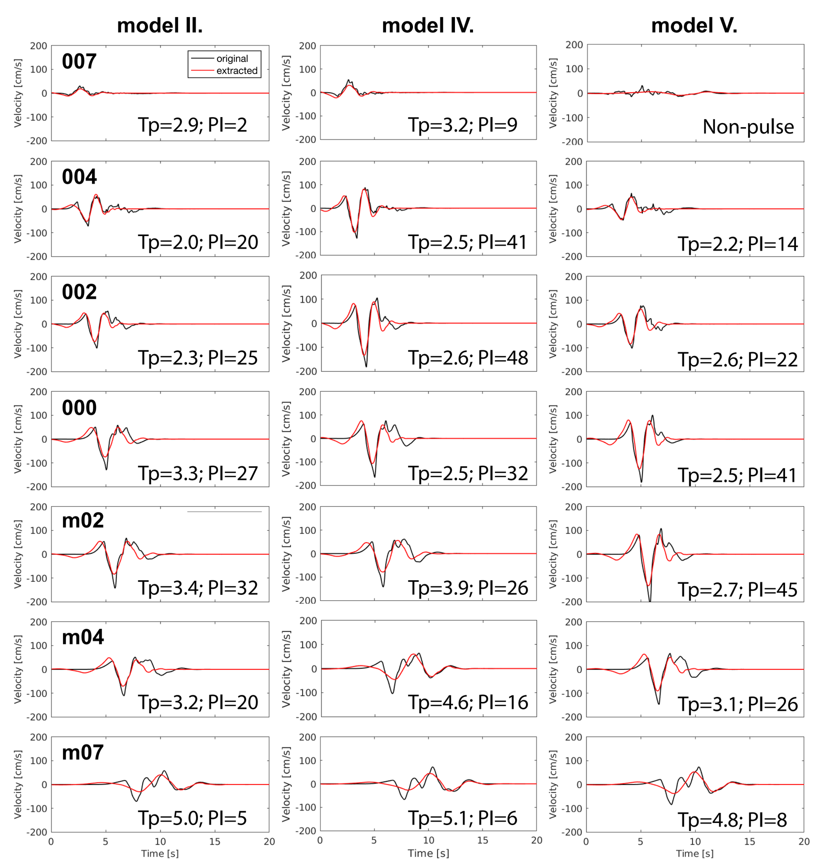


Fig.4. Simulations setting. Squares represent the stations showing waveforms. Stars with frame in fault view indicate the initial rupture point. Red stars are asperities. Blue stars are the subevents with background slips.

Fig.5. Examples of the original ground-motions and extracted pulses. The PI indicates the reliability level of extracted pulses.

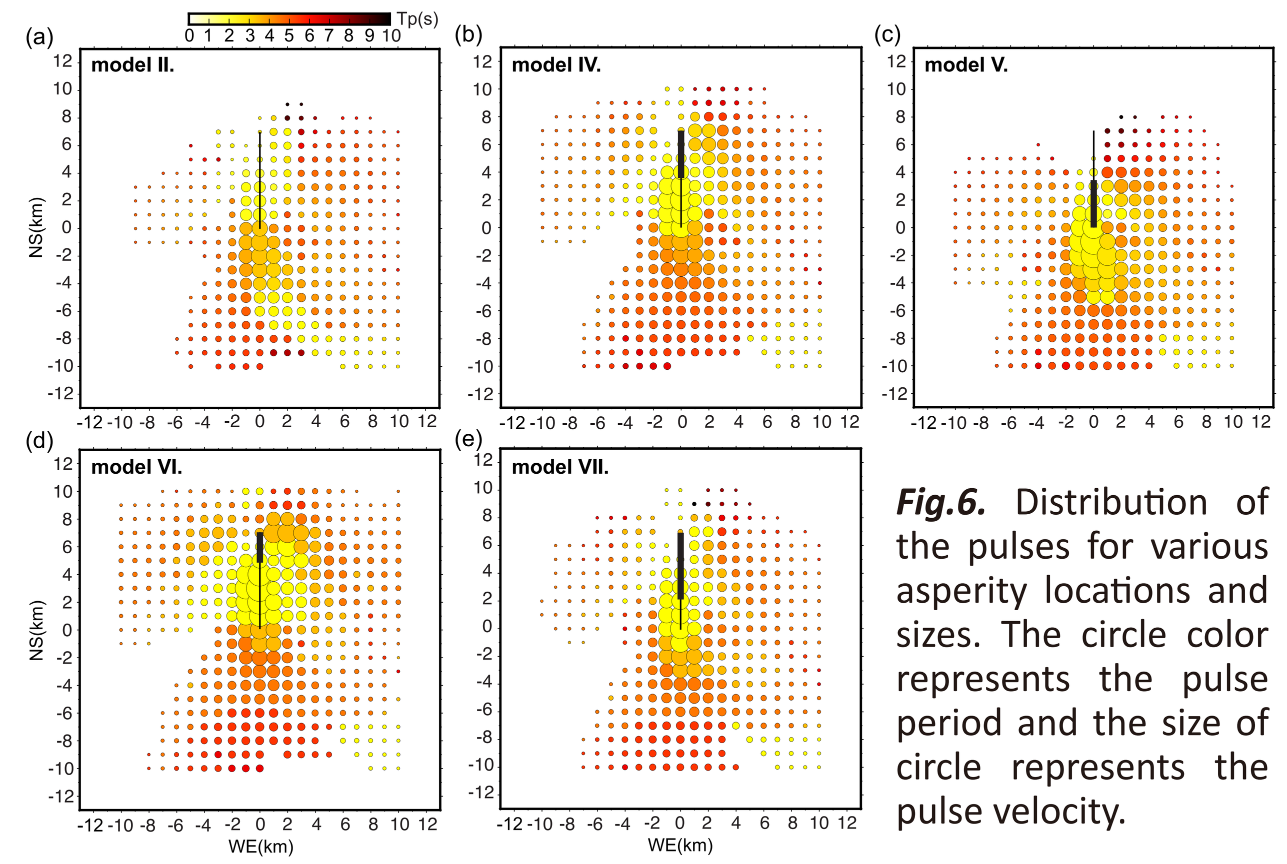


Fig.6. Distribution of the pulses for various asperity locations and sizes. The circle color represents the pulse period and the size of circle represents the pulse velocity.

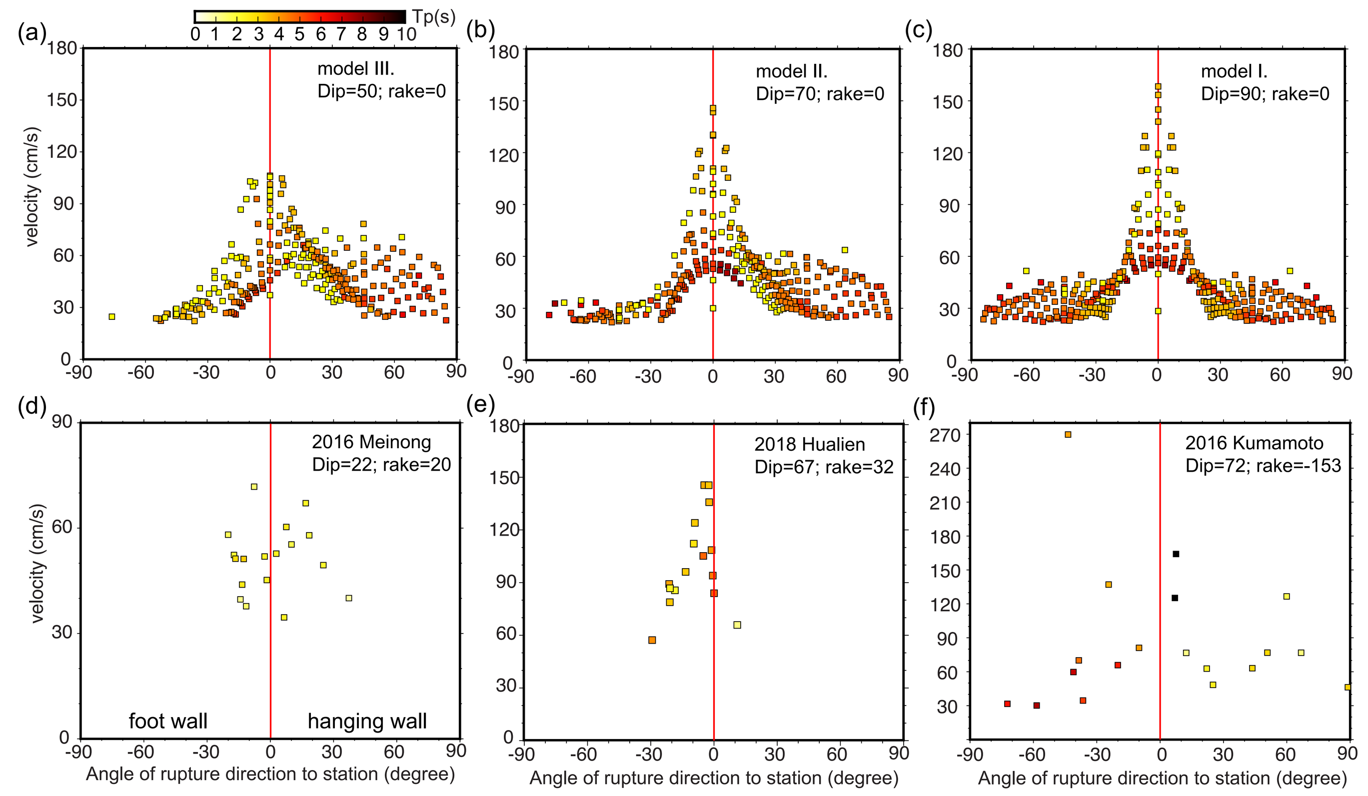
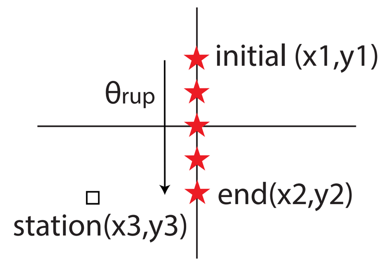


Fig.7. Pulse velocities as a function of the angle between the rupture direction and stations' azimuth.

definition of the angle



$$\theta = \theta_{rup} - \theta_{sta}$$

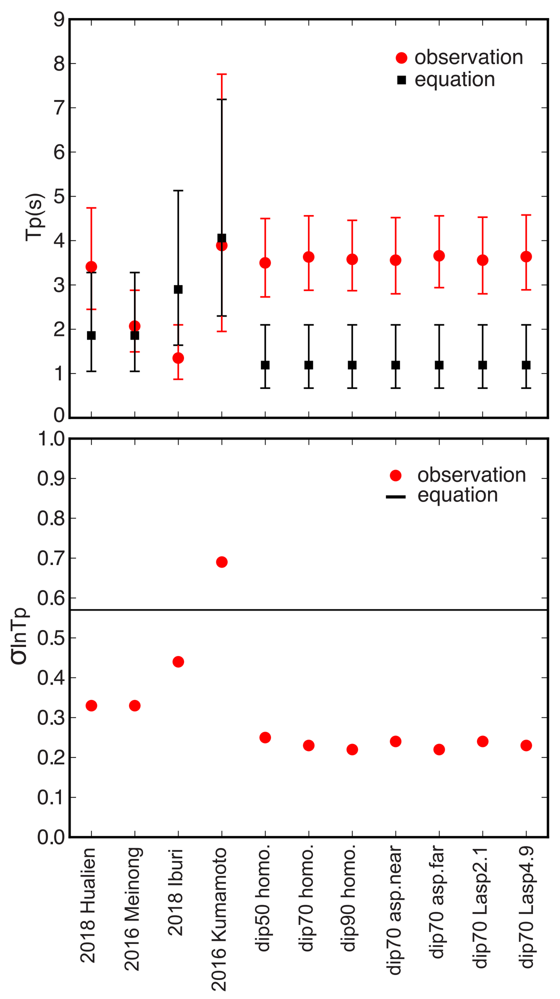
$$\theta_{rup} = \tan^{-1}\frac{y2 - y1}{x2 - x1}$$

$$\theta_{sta} = \tan^{-1}\frac{y3 - y1}{x3 - x1}$$

The Tps are sensitive to the angle of the rupture direction to the stations:
- Periods are shorter at the stations in the rupture direction
- Periods increase with the angle of the rupture direction to the stations

The pulse velocity is controlled by the asperity locations and sizes:
- Velocity increase significantly at stations near the asperity.
- Velocity are higher if the asperity is located far to the hypocenter
- Asperities with a small dimension and a higher concentration of slip (high stress-drop) would increase velocity amplitudes.

The pulse characteristics in the near-field region for earthquakes with the same magnitude but different asperity properties are apparently various.



The observed means and standard deviation values are consistent with the one obtained by the simulations and are both smaller than the ones predicted by Shahi and Baker (2014). A lower variability for the observed values is expected since the Shahi and Baker variability is representing the combined effect of the within and between-event variability. The within-event variability may be magnitude-dependent and larger for large earthquakes. The variability of classical empirical relationships is largely controlled by the within-event variability.

Fig.9. The mean periods and the periods calculated from the equation (Shahi and Baker, 2014, equation 21), and the standard deviation of lnTp. The black line represents the standard deviation from regression (Shahi and Baker, 2014, equation 21).

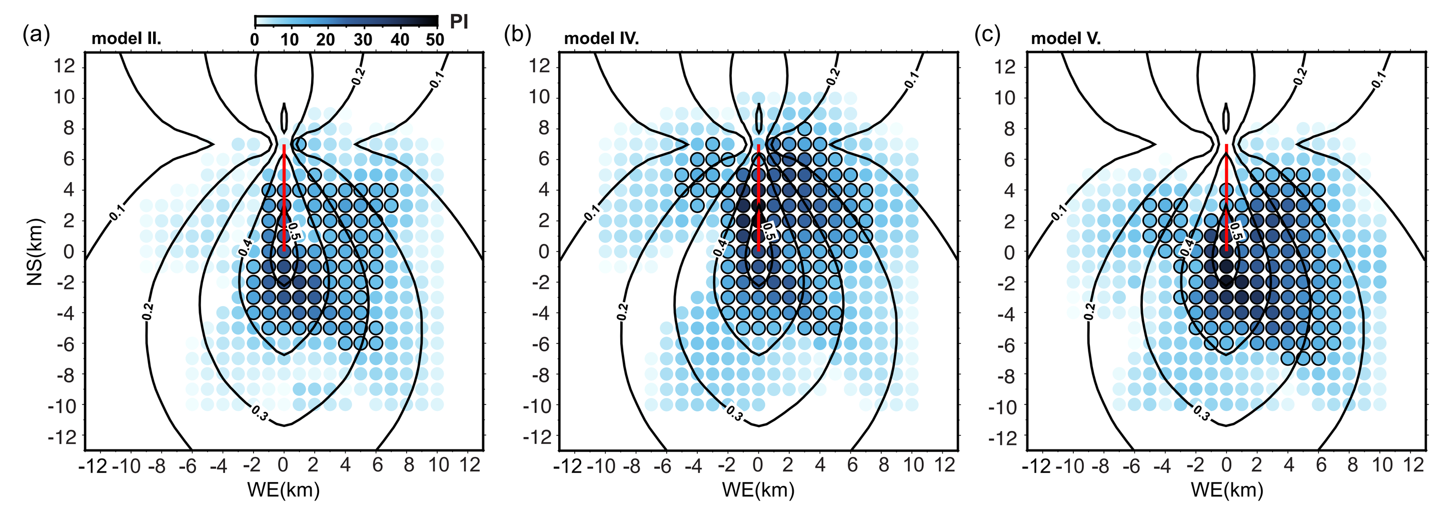


Fig.8. PI (probability of pulses) distribution of simulations for asperities cases. The contours indicate the probability of pulses (Shahi and Baker, 2014, equation 19). Circles with frame represent the pulses with PI > 10.

The PI pattern is dominated by the asperity locations. If the asperity fault strike is located on the station azimuth (forward rupture direction) and the asperity is far from the hypocenter, PI becomes larger. The asperity location also controls the occurrence of the pulse.

Fig.8 shows the Pulse model (Shahi and Baker, 2014) may overestimate the probability occurrence of pulses at moderate distances (distances larger than 10km) of moderate earthquakes.

Conclusions

New and numerous available records in the near-field clearly show the large within-event variability of pulses properties at short distances. The findings in this study reveal that the pulse characteristic may be dominated by the asperity properties.

A better understanding of the physical factors controlling the locations and properties of earthquakes asperities is then necessary to predict future pulses probability in a deterministic way. For the short term goal, engineering application will have to take into account potential large within-event variabilities of the pulse properties.

Reference