Considering rupture directivity in selecting ground motion ensembles for seismic response analysis in the near-fault region

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1. Background and Objective

Selecting appropriate ground motion ensembles is a key step in assessing the seismic performance of engineered systems through time-domain seismic response analyses. While physics-based simulation of ground motions can directly incorporate rupture directivity effects, empirical approaches for ground motion prediction and selecting as-recorded motions representative of such predictions can provide necessary tools to constrain and validate the simulation techniques. Moreover, ground motion selection is needed to extract a practically small number of ground motions from the simulated time series to be used in seismic performance assessment process. Recent developments in earthquake rupture forecast models and ground motion prediction equations (GMPEs) provide the engineering community with advanced empirical models to consider physical processes such as rupture directivity in seismic hazard calculations. This study presents an example application of such models to assess the seismic hazard in the near-fault region and subsequently select ground motion ensembles that appropriately represent the target hazard.

2. Considering the occurrence of forward directivity pulses in seismic hazard analysis

Conventional GMPEs do not explicitly account for the characteristics of near-fault ground motions such as velocity pulses. A rigorous approach to address this problem is the direct consideration of the near-fault characteristics in the development of GMPEs which requires improvements in the existing directivity models. The method used in this study to account for directivity effects in ground motion prediction is based on Shahi and Baker (2011). This approach is a surrogate for future GMPEs which will explicitly address the effect of directivity pulses in a rigorous manner instead of using post hoc correction models. Another important aspect in considering directivity effects in seismic hazard analysis is the uncertainty in the rupture hypocentre location. This is addressed in this study by considering multiple possible locations for the hypocentre along the strike and dip directions for each rupture.

Figure 1 illustrates percentiles of the predicted SA ordinates for a $M_w = 7$, $R_{rup} = 5$ km scenario rupture with $V_{s30} = 400$ m/s based on the Boore and Atkinson (2008) GMPE, with and without explicit modification for directivity effects. Note the increase in the target SA for the range of vibration periods consistent with the pulse period distribution predicted for the corresponding rupture (i.e., $T = 2 - 7s$).

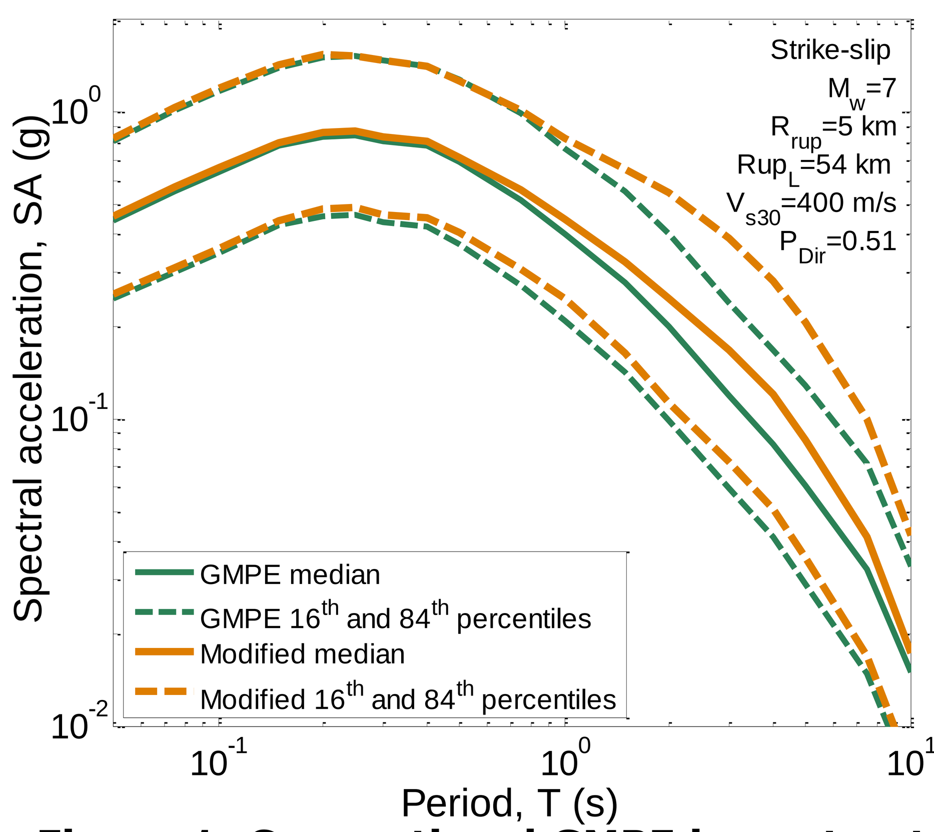

Figure 1: Conventional GMPE in contrast to directivity-included prediction

3. Scenario-based ground motion selection

Figure 2a illustrates the SA ordinates of the selected ground motions for the $M_w = 7$, $R_{rup} = 5$ km scenario rupture and their corresponding 16th, 50th, and 84th percentiles. As shown by the similarity of the target distribution and selected ensemble percentiles, the selected records appropriately represent the target SA hazard.

Figure 2b illustrates the 5-75% significant duration, D_{s575}, distribution of the selected ground motions for two different ensembles: case 1 is selected based on SA ordinates only, whereas case 2 is selected based on considering duration and cumulative intensity measures (IMs) in the selection process. Bias in D_{s575} distribution of case 1 illustrates the importance of considering non-SA IMs in the ground motion selection process.

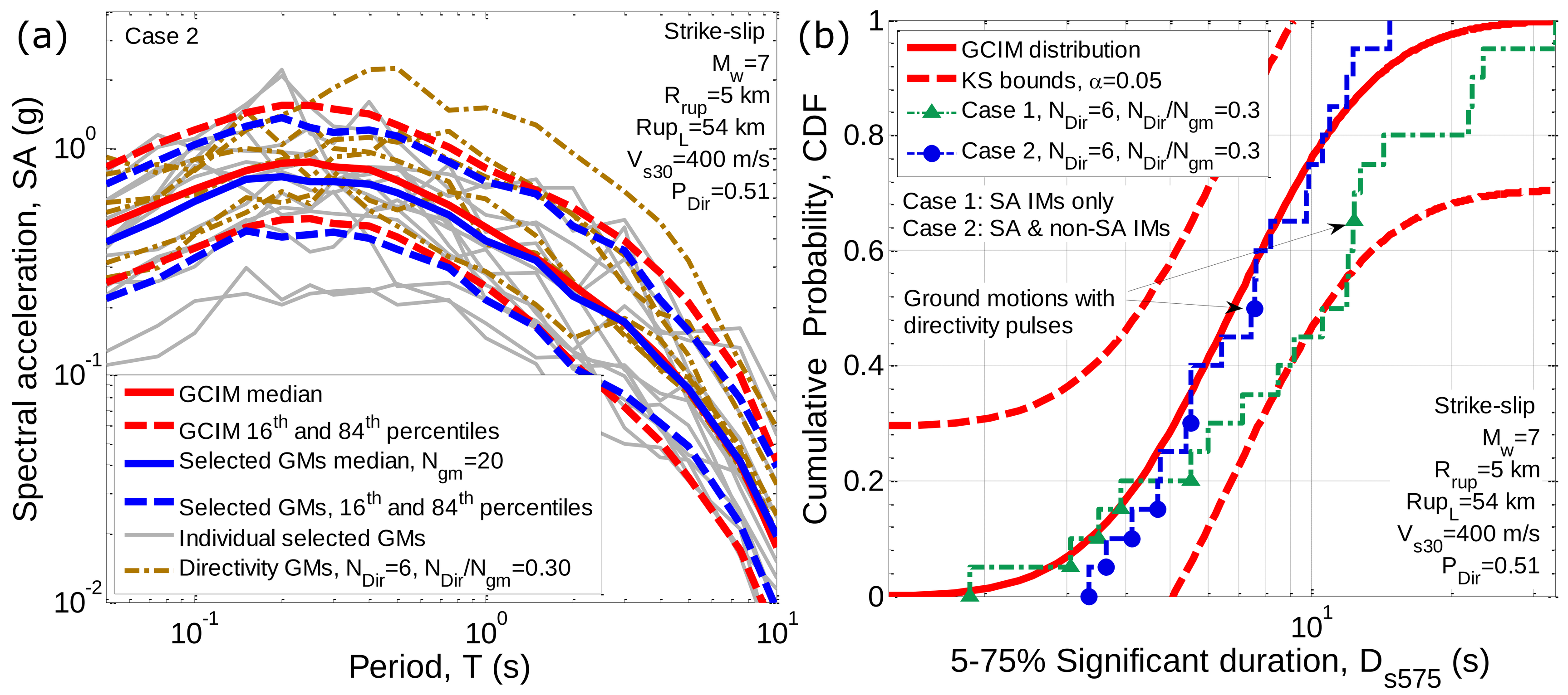

Figure 2: (a) SA ordinates of the records selected based on SA and non-SA IMs; (b) bias in significant duration of the records selected based on only SA ordinates

4. PSHA-based ground motion selection

Figure 3a-b compares the contribution of the known faults in the vicinity of Los Angeles with and without considering directivity effects for $T = 3\,s$ SA hazard with a 2% in 50 years exceedance probability. As shown, considering directivity effects increases the contribution of nearby sources, which results in a 25% and 30% increase in the ground motion level for 10% and 2% in 50 years exceedance probabilities respectively, as shown in Figure 3c.

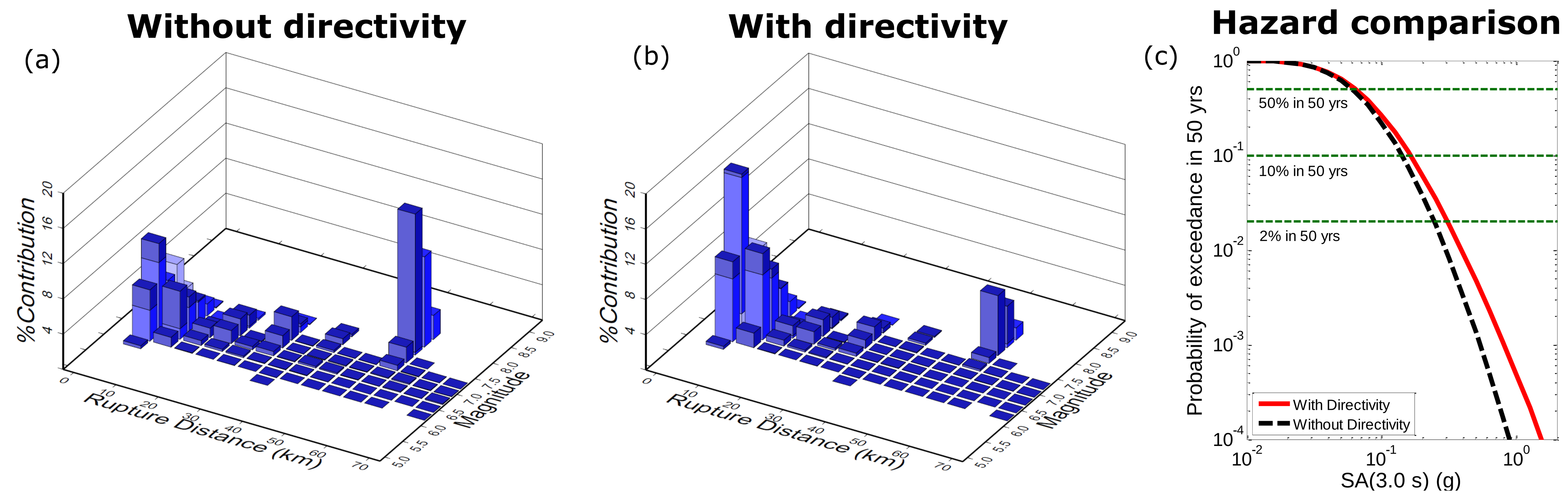

Figure 3: PSHA results for SA(3.0 s) hazard in Los Angeles for a 2% in 50 years probability of exceedance with and without rupture directivity consideration

Figure 4 presents the probability of observing forward directivity pulses (P_{Dir}) from sources close to the site. Contribution of each source to the total P_{Dir} depends on both the contribution of the source to the target hazard (see Figure 3 with directivity effects) and the corresponding source-to-site geometry.

Figure 5a presents the SA ordinates of the selected ground motions representing a 2% in 50 years exceedance probability hazard when directivity effects are considered. As shown, selected records can appropriately represent the target SA. Also, the proportion of records with directivity pulses is an appropriate representative of the predicted total P_{Dir} shown in Figure 4.

Figure 5b shows the $M_w - R_{rup}$ distribution of the selected records, illustrating their compatibility with the deaggregation results, especially for the selected records with directivity pulses.

Figure 5c compares the pulse period distribution of the selected records with the predicted distribution.

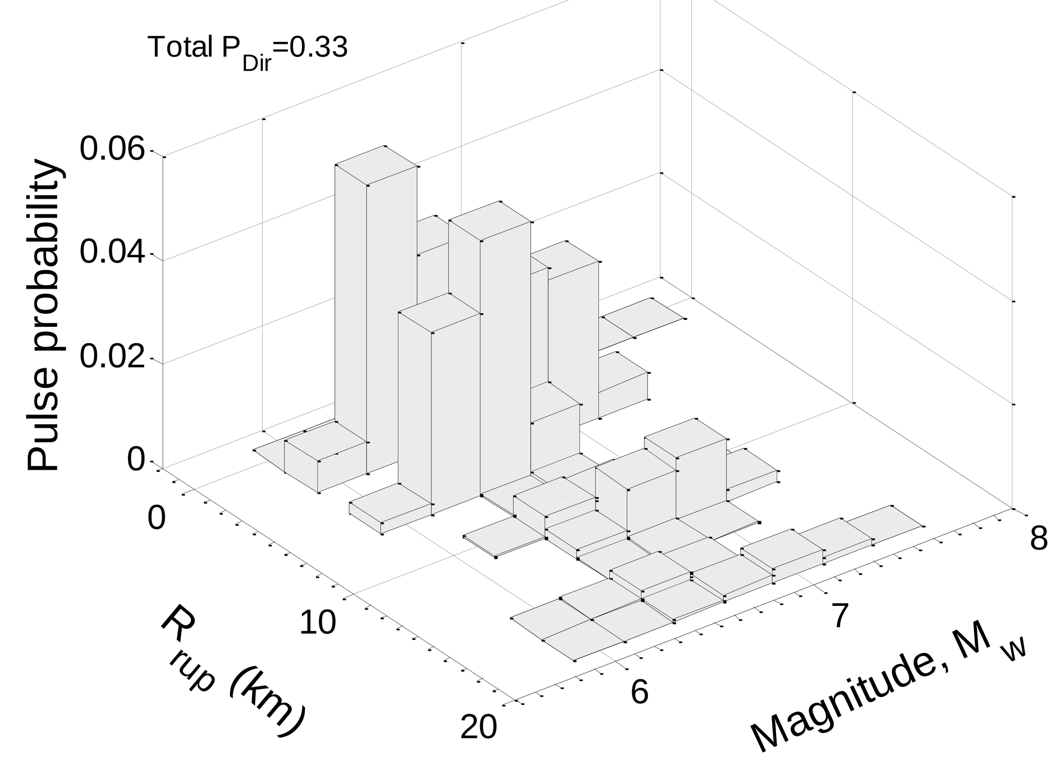

Figure 4: Probability of observing forward directivity pulses

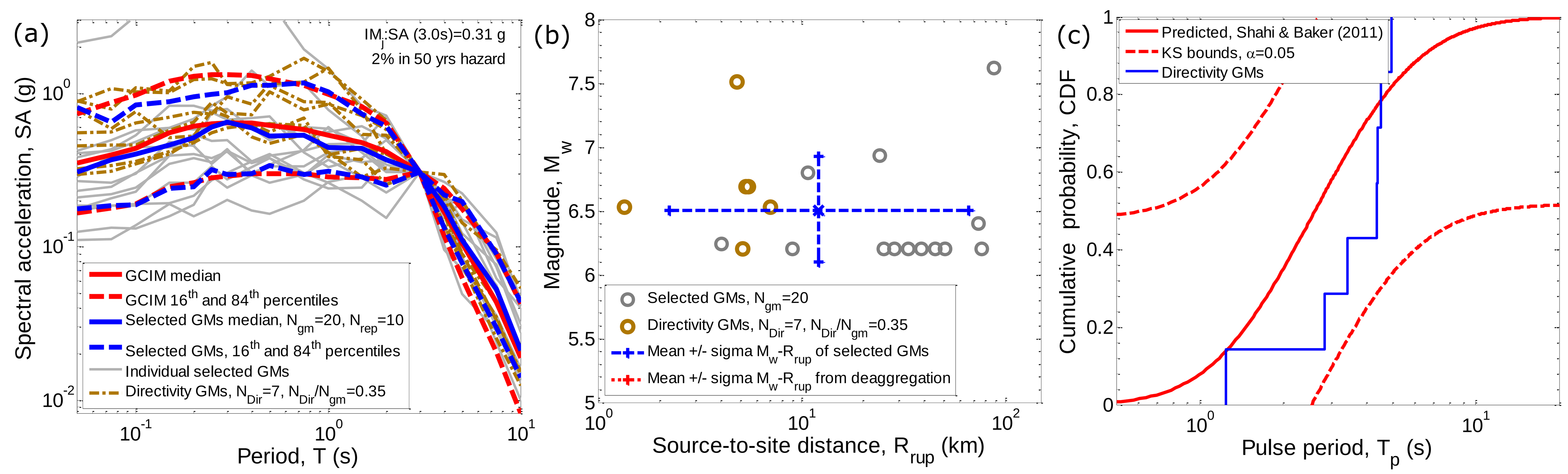

Figure 5: Properties of the selected ground motion records for the directivity-included target hazard: (a) SA ordinates; (b) $M_w - R_{rup}$ distribution; (c) pulse period distribution