Implementation of Monte-Carlo earthquake catalogs in probabilistic seismic hazard analysis: An application to CyberShake

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Abstract

In recent years, ground motion models used in probabilistic seismic hazard analyses (PSHA) have evolved from the traditional ground motion prediction equations (GMPEs) to ground motion simulation models. In this context, SCEC developed CyberShake, a research project that incorporates physics-based simulations using 3D wave propagation to generate ground motions that are then used in seismic hazard calculations. For a typical site in Southern California, a considerable amount of computational time and resources is required due to the significant processing requirements imposed by source-based models and by the large number of rupture variations (or scenarios). The current study proposes an efficient PSHA framework that can accurately represent the seismic hazard at a site by only considering a subset of earthquake scenarios. The proposed framework is based on a Monte Carlo simulation procedure that generates earthquake catalogs having a specified duration. In this case, ground motion time series only need to be simulated for the scenarios selected in the earthquake catalog, and hazard calculations are limited to the intensity measures of this subset of scenarios. The proposed framework is applied to a site located in Southern California, and hazard calculations are performed for a set of earthquake catalogs with different lengths. To evaluate the accuracy of the method, the resulting hazard curves are compared to the curves obtained by considering the entire set of scenarios (as currently implemented in CyberShake).

Methodology

The proposed methodology uses a Monte-Carlo simulation procedure illustrated in Figure 1 to generate an earthquake catalog over a period of $\boldsymbol{Y}$ years for a site or region of interest. The simulated catalog contains a subset of all the earthquake scenarios for the region of interest and represents one possible realization of the earthquakes that may occur in that region in $\boldsymbol{Y}$ years.

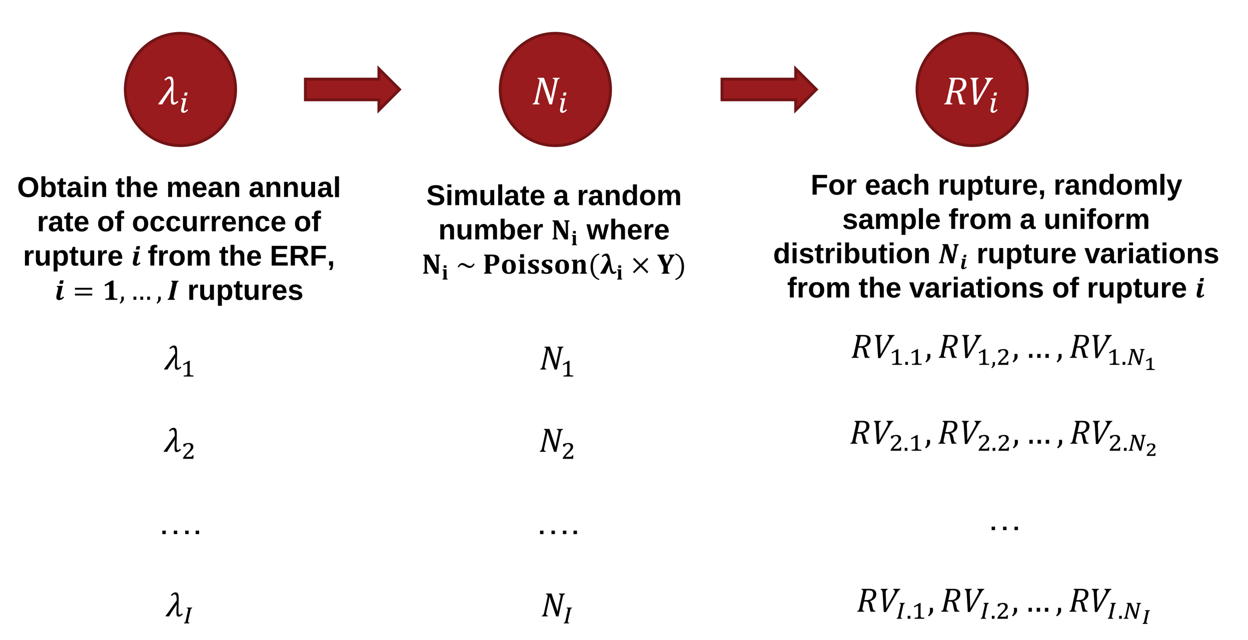

Figure 1: Monte-Carlo method for developing an earthquake catalog for a period of Y years using the same earthquake rupture forecast (ERF) as CyberShake

In contrast to the methodology currently implemented in CyberShake for hazard calculations, the proposed methodology only uses the simulations that correspond to the subset of scenarios in the simulated catalogs and is described in the steps below:

1. Simulate an earthquake catalog having a duration of $\boldsymbol{Y}$ years
2. Simulate ground motions exclusively for the scenarios sampled in the simulated catalogs
3. Calculate the intensity measure(s) of interest (e.g., $RotD50\ S_a(T), \dots$) of the obtained seismograms
4. Calculate the corresponding hazard curves

Case Study

- Site: Los Angeles Downtown (LADT) with $V_{s30} = 390\ m/s$.
- 10 Catalogs for four different catalog durations ($\boldsymbol{Y} = 20{,}000 - 50{,}000 - 200{,}000 - 500{,}000$ years) to evaluate the effect of catalog length on the accuracy of the results.

Results

Catalog Duration Y (years)	20,000	50,000	200,000	500,000
Reduction in Number of Ruptures (%)	85	75	52	33
Reduction in Number of Earthquake Scenarios (%)	100	99	97	94

Table 1: Percent reduction in the number of ruptures and scenarios in the simulated catalogs compared to the current CyberShake approach

Figure 2 compares the hazard curves from the proposed methodology to the hazard curves obtained from the current CyberShake approach, which uses the entire set of scenarios for $S_{a\ RotD50}$ at $T = 2s$.

As Y increases:

- The hazard curves from the proposed methodology converge towards the curve obtained from the current CyberShake approach
- The variability in the hazard curves from the proposed methodology decreases

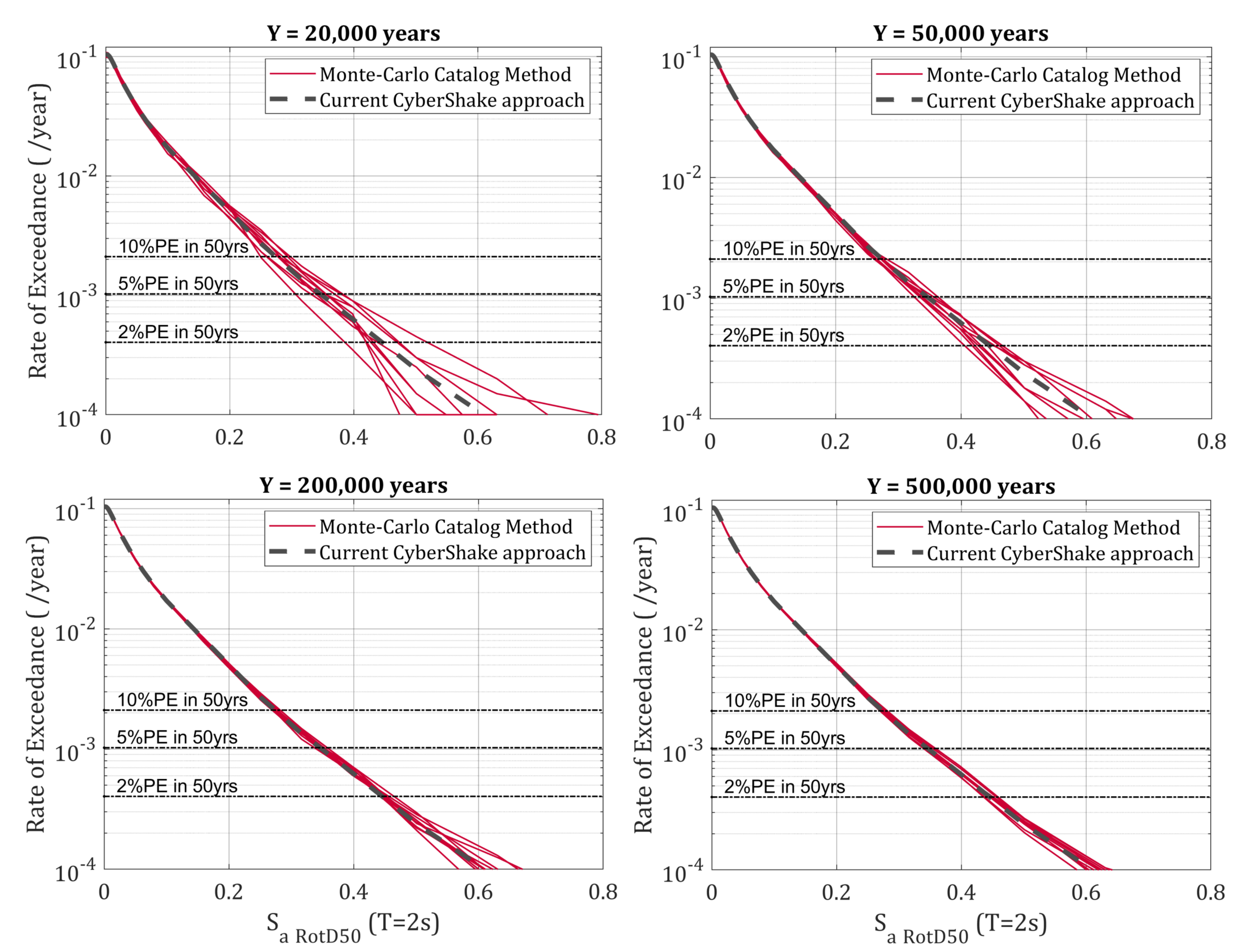

Figure 2: Comparison of $S_{a\ RotD50}$ hazard curves from the proposed methodology to curves from the current CyberShake approach at Downtown Los Angeles for $T = 2s$

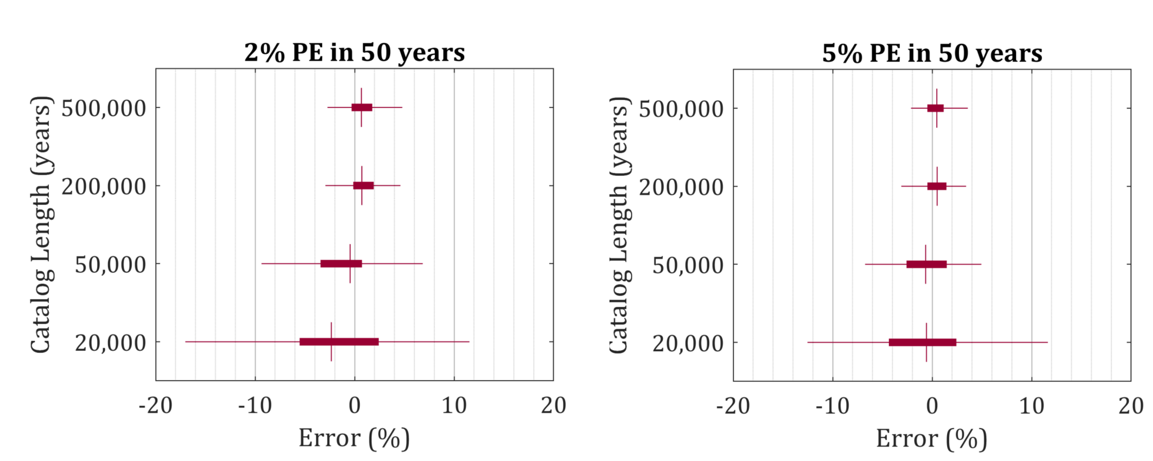

Figure 3: Boxplots of errors between annual rates of exceedance from the Monte-Carlo catalog method and the current CyberShake approach at the 2% and 5% Probability of Exceedance (PE) in 50 years hazard levels

Figure 4 compares the deaggregation of the magnitude and the closest source-to-site distance at the 5% probability of exceedance (PE) in 50 years hazard levels for $S_{a\ RotD50}$ at $T = 2s$.

As Y increases:

- The deaggregation trends become more similar to those obtained using the entire set of scenarios
- Bins with lower contribution are better captured

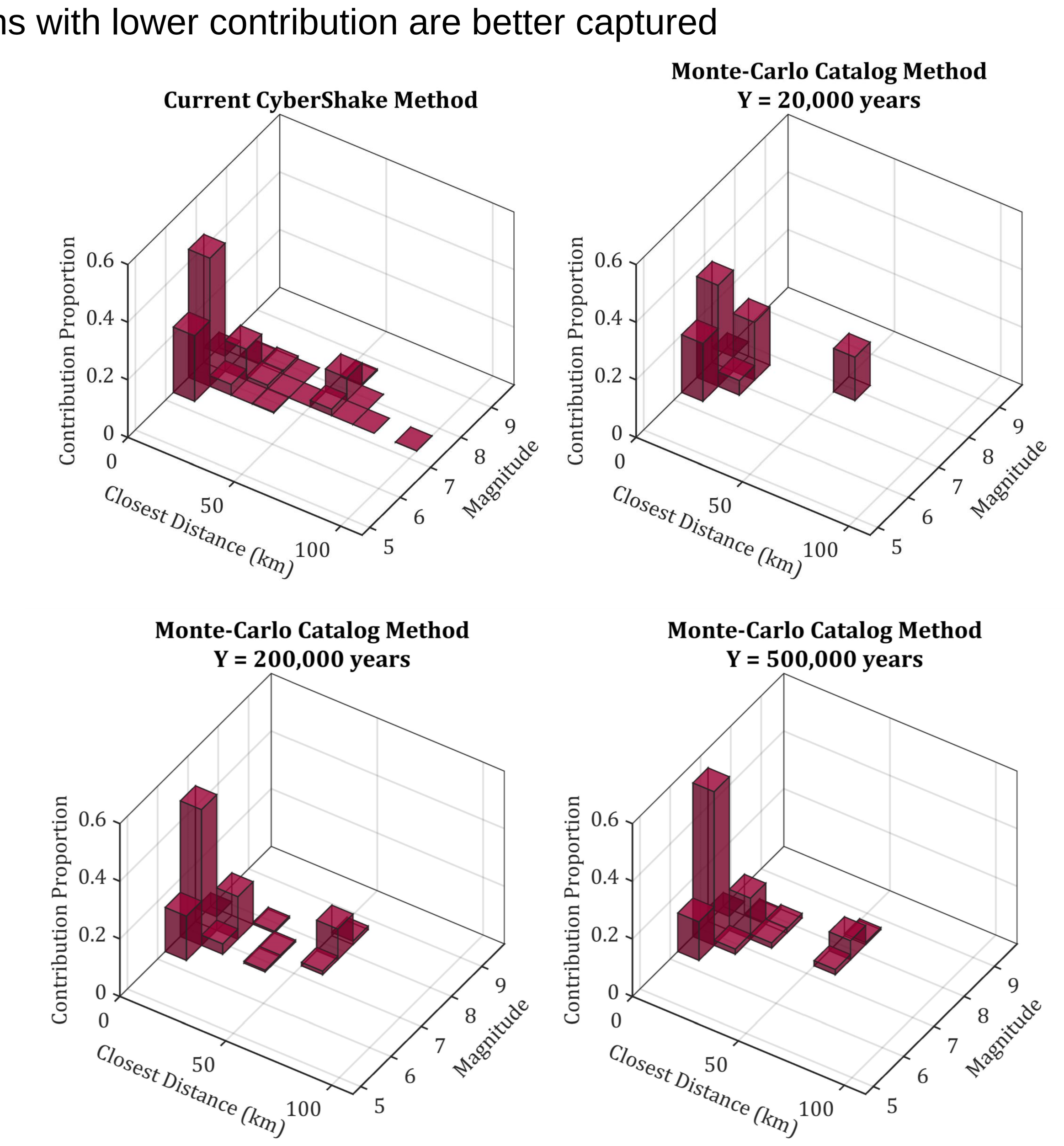

Figure 4: Magnitude-Distance disaggregation at LADT for 2s $S_a\ RotD50$ at 5% probability of exceedance in 50 years for a 500,000 years catalog

Conclusions

- The proposed methodology can result in accurate hazard curves, and the level of accuracy depends on the catalog duration Y.
- Using this methodology, the number of ground motions that need to be simulated can be reduced by 90% while still achieving an acceptable level of accuracy at the hazard levels of usual interest.
- The proposed methodology can accurately identify the most contributing scenarios. To better capture the less contributing scenarios, catalogs with longer periods should be used.

Work in progress

- The methodology is being applied to other sites exposed to basin effects and/or directivity effects to further validate the method
- The methodology is being extended to probabilistic seismic demand analyses where the response of nonlinear structures and the accuracy of demand curves are evaluated

References

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