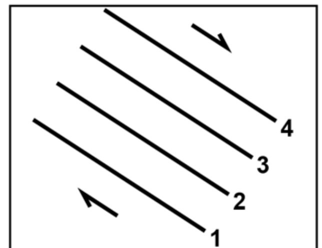
2026 SCEC Report

Initial exploration of correlated uncertainties within deformation models used for probabilistic seismic hazard assessment: towards development of a geologically informed mode

Principal investigator: James Dolan (USC), Alexandra Hatem (USGS), Kevin Milner (USGS)
Participating Graduate Student: Caje Kindred Weigandt (USC)

Research activities during reporting period and preliminary results

This project is focused on improving consideration of fault slip rate uncertainty in geologic deformation models for probabilistic seismic hazard analysis by exploration of correlated uncertainties. We began our exploration using a simple, synthetic deformation model for four parallel strike-slip faults with a total system-level slip rate of 40 ± 5 mm/yr. Our progress thus far includes successful development of a framework for both non-conditional and conditional random sampling of the slip rates of the four parallel strike slip faults from their respective marginal (i.e., individual slip rate) distributions of a multivariate (i.e., four dimensional) normal distribution under an imposed covariance matrix. The non-conditional approach produces many realizations of a single deformation model (i.e., four parallel strike slip faults with an imposed system level slip rate budget of 40 ± 5 mm/yr; Figure 1) by exploration of the full uncertainty space under the assigned covariance structure. This is particularly useful considering that the NSHM23 over-fit slip rates. The conditional approach offers this same benefit but is also capable of leveraging useful geologic observations that are not necessarily incorporated in typical seismic hazard analysis (e.g., a well constrained short term geologic slip rate).



$$35 \leq \sum_{i=1}^{4} \textit{Fault Slip Rate}_i \leq 45$$

Figure 1. Schematic representation of our synthetic deformation model of four adjacent, parallel strike slip faults with a cumulative system level slip rate of 40 ± 5 mm/yr.

Non-conditional model

To test the performance of our non-conditional model, we assume that the system level slip rate is 40 ± 5 mm/yr (Figure 1) and that the marginal distribution of each individual fault is a normal distribution with mean slip of 10 mm/yr and standard deviation of 5 mm/yr. We impose a covariance matrix on the multivariate normal distribution such that all faults are equally anti-correlated to one another with normalized covariance of –0.3. This value ensures that the imposed covariance matrix is positive definite, as required for the multivariate normal distribution.

In Figure 2, the dark gray histograms represent all of the samples obtained by this method, and the overlain white histograms represent samples that are considered valid (i.e., “accepted) on the basis of (1) having a cumulative system level slip rate of 35-45 mm yr and (2) having no faults slip below 0.001 mm/yr. The colored lines illustrate accepted scenarios. For example, in the red scenario, Faults 1, 2, and 4, exhibit slip rates of 7-8 mm/yr, while Fault 3 slips much faster at 21 mm/yr, providing a system level rate of ~43 mm/yr. The yellow scenario exhibits a similar system level rate (~43 mm/yr), but as a result of Faults 1 and 3 slipping at 4-5 mm/yr, Fault 2 slipping at 11 mm/yr, and Fault 4 slipping at 23 mm/yr. The variability among these scenarios highlights the potential capability of our model framework to produce many realizations of a single deformation model by exploring the full range of the uncertainty space.

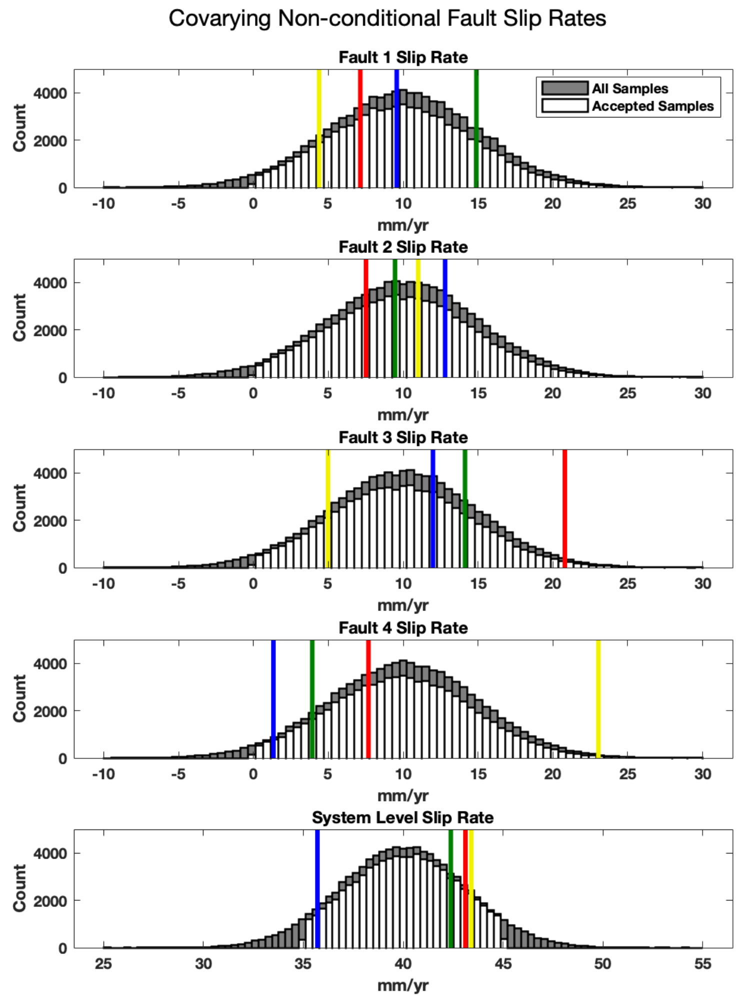


Figure 2. *Total (dark) and accepted (white) histograms resulting from non-conditional sampling of four parallel strike slip faults with slip rates represented with mean rate 10 mm/yr and standard deviation 5 mm/yr. Accepted samples are those for which (1) the total slip rate is constrained between 35-45 mm/yr and (2) no fault slips below 0.001 mm/yr. Colored lines indicate results from individual accepted sample scenarios and illustrate the capability of our non-conditional sampling framework to produce variable results from the uncertainty of a single deformation model under an imposed covariance matrix.*

Conditional Model

In similar fashion, to test the approach of our conditional model we again assume that the system level rate is 40 ± 5 mm/yr, but also that Fault 1 is slipping at a rate of 30 mm/yr in all scenarios. We sample the conditional slip rates of Faults 2-4 from the same marginal distributions as before and impose the same positive definite covariance matrix.

Figure 3 shows the conditional sample distributions (dark histograms) overlain by the accepted conditional sample distributions (white histogram). The conditional sample distributions of Faults 2-4 emerge as normal distributions with mean slip rate of ~3.33 mm/yr despite originating from the marginal distributions with mean slip rate of 10 mm/yr and standard deviation of 5 mm/yr. The colored lines in Figure 3 illustrate the variability of our accepted scenarios under conditional sampling. In the green scenario, Faults 2 and 3 exhibit extremely slow slip rates (< 1 mm/yr), while Fault 4 accommodates a majority of the slip (~10 mm/yr). In contrast, the yellow scenario highlights a case in which Faults 2-4 are all slipping between 2-7 mm/yr.

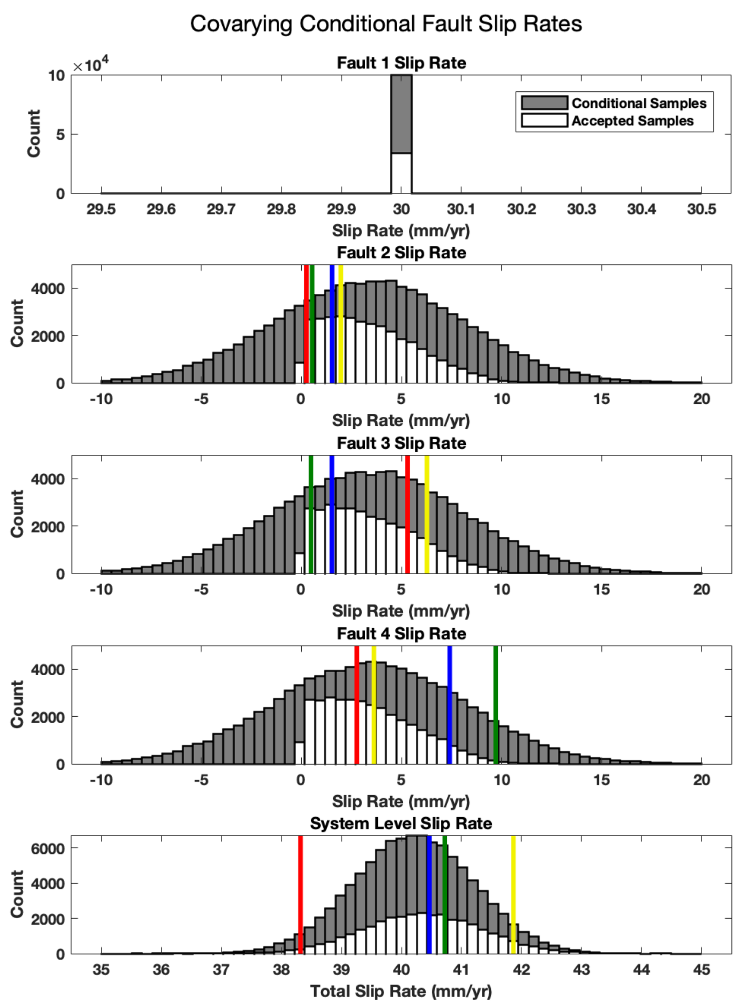


Figure 3. *Total (dark) and accepted (white) histograms resulting from conditional sampling of three parallel strike slip faults with slip rates represented with mean rate 10 mm/yr and standard deviation 5 mm/yr based on the assumption that Fault 1 is slipping at 30 mm/yr. Accepted samples are those for which (1) the total slip rate is constrained between 35-45 mm/yr and (2) no fault slips are slower than 0.001 mm/yr. Colored lines indicate results from individual accepted sample scenarios and illustrate the capability of our conditional sampling framework to produce variable results from the uncertainty of a single deformation model under an imposed covariance matrix.*

Opportunities for Training and Development

This project forms part of USC PhD student Caje Kindred Weigandt's dissertation research. Conceptualization of the sampling framework was born out of conversations among Caje and the PIs, and Caje has taken the lead role in development and implementation. He presented the work described above at the 2025 SCEC Annual Meeting, will do so again at the 2026 Seismological Society of America Annual Meeting, and continue working toward final results that will constitute a peer-reviewed publication.