

**On-Fault Parameters and Fault Connectivity Control Synthetic Earthquake
Catalogs and 30-Year Rupture Probabilities in RSQSim Simulations of the Eastern
San Francisco Bay Area**

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Key Points:

1. RSQSim simulations of the California East Bay can produce earthquake probabilities consistent with UCERF3.
2. RSQSim catalogs are sensitive to fault connectivity, friction and coseismic weakening assumptions.
3. Mismatched recurrence at paleoseismic sites warrants caution in RSQSim usage.

Abstract:

The faults in the Eastern San Francisco Bay Area in California have long been known as a source of seismic hazard. This potential for large earthquakes, paired with high population density and economic activity leads to high seismic risk in the Bay Area. In this study we utilize the physics-based earthquake simulator RSQSim to generate synthetic earthquake catalogs for the San Francisco East Bay. We run a suite of models with different fault connectivity and on-fault parameters. We compare the model catalogs with UCERF3 probabilities and paleoseismic data. We find that initial on-fault assumptions of friction, weakening and connectivity shape the resultant catalogs. Firstly, we find that all our catalogs have b-values greater than 1, with models with uniform velocity-weakening and strong coseismic weakening having the lowest b-values (~ 1.4). The b-values are higher ($1.5\sim 1.8$) for models with velocity-neutral and velocity-strengthening patches. However, if only fitting Mw 5 and greater, all model b-values fall within ~ 1.0 - 1.2 . Secondly, we observe connected faults leading to more multi-segment slip events for the Hayward and Calaveras faults. We also observe good agreement between the RSQSim models and the UCERF3 Time-Independent and Time-Dependent probabilities of Mw 6.7 or greater events on the Hayward and Calaveras faults, within the maximum and minimum probability bounds. Models without velocity-strengthening yield time-independent 30-year probabilities of 22.4-28.9% for the Hayward and 13.3-20.5% for the Calaveras and time-dependent probabilities of 17.3-42.2% and 12.5-25.3% respectively. Finally, we compare model results to the mean recurrence intervals at three paleoseismic sites using a Welch's t-test. For all but three models (all of which have uniform velocity-weakening friction) we can reject the equality

of the mean recurrence rate between the paleoseismic data at Tyson Lagoon and the model catalog at the 95% confidence level, motivating future work exploring the full spectrum of fault slip.

Introduction:

The greater San Francisco Bay Area in California is positioned on the major transform plate boundary between the Pacific and North American Plate. This region accommodates 37-39 mm/yr of plate motion across multiple fault strands and is partitioned between faults on the western side of the bay and faults on the eastern side (d'Alessio et al., 2005). On the western side, the San Andreas fault accommodates roughly 21-25 mm/yr (Savage et al., 1999; Segall, 2002; Dawson et al., 2013; Field et al., 2014, 2015). On the eastern side of the bay the story is more complex, and slip is partitioned among multiple interconnected faults, some of which have substantial creeping sections (Bürgmann et al., 2000; Funning et al. 2007; Harris, 2017). One such fault is the Hayward fault, which has a slip rate of 8-10 mm/yr (Lienkaemper et al., 1991; Lienkaemper & Borchardt, 1996; Evans et al., 2012) and has significant creep in the shallow portion of the fault (Lienkaemper et al., 1991; Schmidt et al., 2005) and in some locations has creep extending down to 7-8 km (Lienkaemper et al., 2012; Chaussard et al., 2015). South of its junction with the Hayward fault, the Calaveras fault accommodates a 13-17 mm/yr of displacement, declining to 3-7 mm/yr north of the junction (Manaker et al., 2003, d'Alessio et al., 2005). There is substantial shallow and deep creep along the entirety of this fault. Other East Bay faults that are included in this study are the Rodgers Creek fault, which is the northern extension of the Hayward fault,

the West Napa Fault which hosted the 2014 Mw 6.0 South Napa earthquake (Wei et al., 2015; Brooks et al., 2017) and the Franklin Fault which is a connector between the West Napa and Calaveras faults in the Statewide California Earthquake Center's Community Fault Model version 7 (SCEC CFM7) (Plesch et al., 2024). We elect to exclude the San Andreas fault, which is on the western side of the bay, as it would increase the computational costs and is outside our geographic scope of interest. We also elect to not include the Concord-Green Valley and Greenville fault zones as these do not directly connect to the other five faults in our study.

The complex active faulting in the East Bay and the high population density is a recipe for high seismic risk in the area. One way to probe the seismic risk in the east bay is to look in the past. Paleoseismic sites in the region trace the surface rupturing earthquake history at certain locations along the faults. Fault trenching at El Cerrito (referred to in this study as Mira Vista) along the northern Hayward fault (yellow star in Figure 1) conducted by Lienkaemper et al. (1999) revealed 4 surface rupturing paleoevents and three additional possible events which occurred between 355 B.C. and 1776 A.D. and taking into account uncertainties they bound the average recurrence interval at this location to have a minimum of 270 years and a maximum of 710 years. At a trench along the southern Hayward fault near Tyson Lagoon (yellow star in Figure 1) Lienkaemper et al. (2002, 2010) identified 12 surface rupturing events spanning back ~2000 years, the most recent correlating to the 1868 Mw 6.8 event (Bakun, 1999). At this southern location the mean recurrence in the whole ~2000 year period is 161 ± 65 yrs but is 130 ± 40 yrs for earthquakes in the past 500 years, both of which are significantly shorter than in the north. Paleoseismic studies at Leyden Creek along the

Calaveras fault (yellow star in Figure 1) have revealed 5-6 surface rupturing events in the past 2500 yrs, with an average recurrence between 250-850 yrs. (Kelson et al., 1996). These paleoseismic studies yield valuable insight into the earthquake history and average recurrence intervals at specific locations along a fault which in turn can be used to infer future seismic behavior. However, these studies are limited in their spatial and temporal extent.

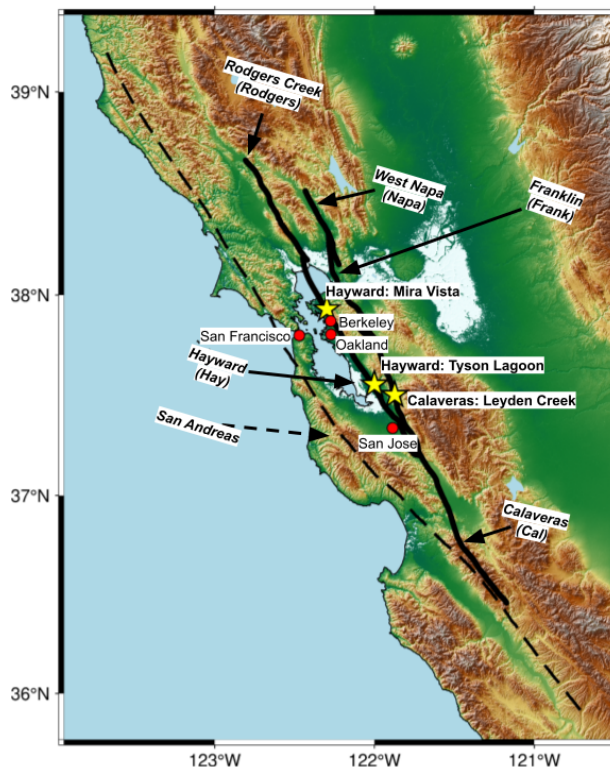


Figure 1: Map of the San Francisco Bay Area. Solid black lines are faults used in this study from the SCEC CFM7 (Plesch et al., 2024), labeled with bolded-italicized text, text in parenthesis denotes the abbreviated name for each section used throughout the study. The San Andreas fault, not used in the models, is shown as a dashed black line. Yellow stars labelled with bolded text are paleoseismic locations and red dots denote locations of several cities.

A geographic map of the San Francisco Bay Area displaying regional fault lines and key locations. Major faults used in the study are drawn as solid black lines, labelled in a bold italic font with its abbreviation in parentheses. The San Andreas fault trace is shown as a dashed black line not used in this study. Red dots mark the location of several major cities in the region. Specific paleoseismic sites are shown as labelled yellow star.

Others have utilized statistical and probabilistic methods to look at future probabilities of large earthquakes on these faults. Several of these probabilistic studies have projected that the Hayward and Calaveras faults are the two most probable faults to host a Mw 6.7 or greater earthquake in the Bay Area in the near future. Uniform California Earthquake Rupture Forecast V3 (UCERF3) Time-Independent model (TI), yields 30-year probability range of Mw 6.7 or greater event occurring on the Hayward and Calaveras faults as ~9-36% and ~8-36% respectively, with a preferred probability of ~22% on the Hayward and 18% on the Calaveras (Field et al., 2014). The 2014 Working Group on California Earthquake Probabilities (Aagaard et al., 2016) and the UCERF3 Time-Dependent model (Field et al., 2015) suggest there is a ~32% chance of a Mw 6.7 or greater occurring along the Hayward fault and a ~25% chance of occurrence along the Calaveras fault before 2043; with uncertainties putting the UCERF3 probability range for the Hayward at 15-56% and 10-54% for the Calaveras.

In addition to purely statistical models, physics-based earthquake simulators (Tullis et al., 2012a, b; Richards-Dinger & Dieterich 2012) have been utilized for seismic hazard modeling on larger scales. Shaw et al. (2018) utilized RSQSim to conduct a California wide physics-based earthquake simulation and compared the resultant statistics of the simulated catalog to UCERF3 and found good agreement. In this study we take a similar approach and use RSQSim to model earthquakes specifically on

interconnected five fault segments within the California East Bay and compare the results to paleoseismic records and statistical models, with implications for the use of physics-based models in earthquake hazard forecasting. We build upon the Shaw et al. (2018) framework and highlight sensitivities of the model results to initial input parameters and frictional assumptions and expand on some strengths and shortcomings of the models. We run models for two different geometries, one where the faults are connected at depth (Chaussard et al., 2015; Watt et al., 2016; Plesch et al., 2024), referred to as “Connected” and a model where the faults are not connected, referred to as “Disconnected”. For each geometry we run five models with differing on-fault frictional and weakening assumptions. We find that the initial assumptions about connectivity have a first order impact on the simulated catalogs, with the Connected models yielding larger, multisegmented events compared to the Disconnected models. In addition, under certain assumptions, RSQSim models are consistent with both the UCERF3 time-dependent and time-independent earthquake probabilities for large earthquakes (Mw 6.7 or greater). However, the paleoseismic data are more difficult to reproduce and most of our models do not capture the historic recurrence rate at Tyson Lagoon. The models do produce behaviors more consistent with paleoseismic behavior at Mira Vista and Leyden Creek.

Methods:

RSQSim Framework

In this study we utilize the 3D boundary element code RSQSim (Dieterich, 1995; Dieterich & Richards-Dinger, 2010; Richards-Dinger & Dieterich, 2012). RSQSim

models the earthquake cycle on discretized faults by implementing three major components: (1) the fault elements are governed by a rate-and-state friction law (Dieterich, 1979, 1981; Ruina, 1983; Linker and Dieterich, 1992) (2) the stressing rate of each element is the sum of a far field “tectonic” rate and the near field stressing from adjacent slipping elements, (3) in a velocity-weakening regime each element can be in 1 of 3 distinct states: Healing (State 0), Nucleation (State 1) or Rupture (State 2). This simplifies the problem and allows for quick analytical solutions for the timing of events. However, if there are any velocity-strengthening patches ($a-b > 1$), an additional state is introduced, State3, in which creeping, patches continuously stress other elements in the model, this greatly reduces the efficiency by 2-3 orders of magnitude. In RSQSim, the friction (τ^{fric}) is governed by a rate and state constitutive relation (eq1):

$$(eq.1) \quad \tau^{fric} = \sigma[\mu_0 + a \ln\left(\frac{V}{V_0}\right) + b \ln\left(\frac{\theta V_0}{D_c}\right)]$$

Where σ is the normal stress, μ_0 is the reference frictional value, V is the slip velocity, V_0 is the reference slip velocity, D_c is the critical slip-weakening distance, a and b are the rate and state coefficients and θ is the state variable. In RSQSim the state variable evolves following a stress-dependent aging law (eq.2) (Linker & Dieterich, 1992) where α (set to 0.25 in this study) scales the sensitivity of the state variable evolution to changes in normal stress and stressing rate $\dot{\sigma}$.

$$(eq.2) \quad \dot{\theta} = 1 - \frac{\theta V}{D_c} - \alpha \frac{\theta \dot{\sigma}}{b \sigma}$$

As mentioned, RSQSim assigns discrete states (not to be confused with the state variable in the friction law) to each element in the model. By implementing discrete states for each element, the earthquake cycle problem can be reduced to solving for changes in element state. Initially all elements are in state 0 (Healing), where the shear stress is below the failure stress, in this case the stressing rate is equal to the constant tectonic loading rate and the aging law is reduced to eq. 3:

$$(eq. 3) \quad \dot{\theta} = 1 - \alpha \frac{\theta \dot{\sigma}}{b\sigma}$$

This yields an analytic solution for time to failure for each element, allowing RSQSim to update all elements to their respective stress states at the time to failure of the first element. Once an element has a shear stress greater than the failure stress it transitions to RSQSim state 1 (Nucleation) where the aging law becomes (eq4)

$$(eq. 4) \quad \dot{\theta} = -\frac{\theta V}{D_c} - \alpha \frac{\theta \dot{\sigma}}{b\sigma}$$

This leads to accelerated slip speed of the element, however in this step stress is not transferred to adjacent elements. The element then transitions to RSQSim state 2 (Rupture) where it slips at a prescribed speed of 1 m/s, in this state the slipping patch transfers stress to nearby elements. In addition, during the Nucleation and Rupture states, to approximate the stress concentration at the rupture front that is present in fully

dynamic models (Andrews, 1976; Barall, 2009, Harris et al., 2009, Harris et al., 2018), RSQSim lowers the a coefficient of neighboring patches by a factor (f_a) to promote rupture propagation. Overall, the state based updating through analytical solutions for time to failure allows for the modeling of earthquakes across thousand-to-million-year time scales.

The efficiency of the RSQSim framework in the velocity-weakening regime has led to its implementation in studying the seismic hazard in various locations such as California (Shaw et al., 2018), Turkey (Chartier et al., 2021), New Zealand (Shaw et al., 2022; Niroula et al., 2025), Taiwan (Hsu & Wu, 2025) and Spain (Gómez-Novell et al., 2025). In addition, there has been an increased desire to implement RSQSim (and other physics-based simulators) into national hazard models for both the United States (Field et al., 2014, 2015; Field et al., 2024) and New Zealand (Niroula et al., 2025; Williams et al., 2025).

Implementation for the East Bay

We generate two different triangular fault meshes for a system composed of 5 major fault segments from the SCEC CFM V7 (Plesch et al., 2024) (Figure 1): the Hayward (Hay), Calaveras (Cal), Rodgers Creek (Rodgers), Franklin (Frank) and the Napa (Napa) faults. The first fault mesh has all the fault segments connected, meaning there is no spacing between the elements at fault intersections (models with this geometry will be referred to as Connected) and in the other geometry the fault segments are not connected and do not intersect each other (models with this geometry

will be referred to as Disconnected). Since the faults are primarily vertical to sub vertical (Plesch et al., 2024), for each fault mesh, we simplify the domain by taking the surface traces from the CFM V7 and project them vertically down to a locking depth of 15 km and then discretize them into 500 m triangular elements using the Gmsh python package (Geuzaine & Remacle, 2009) for a total of ~685,000 elements. Using this element size allows us to resolve a minimum magnitude for our catalogs at around Mw 3-4, however it significantly increases the computation time. We recognize that this is a simplification of the fault system and does not capture the variations in fault depth and dip in this region, which may lead to larger Mmax in the modelled catalog. However, the implementation of different frictional assumptions at depth, effectively influences the seismogenic zone within the models.

For each fault segment we assign a slip-rate based on an aggregate of previous studies in the region (Lienkaemper et al., 1991; Schwartz et al., 1992; Lienkaemper & Borchardt, 1996; Kelson et al., 1996; d'Alessio et al., 2005; Wesling & Hanson, 2008; Evans et al., 2012; Dawson et al., 2013; Hatem et al., 2021). Due to the inherent uncertainty in slip rate measurements and variability between published rates, we opt to represent each fault's slip rate as a preferred whole mm/yr rate. If no geologic sliprates are available (such is the case for the Napa and Franklin) we utilize estimates from hazard maps (Wesling & Hanson, 2008). The slip rates used in this study are Hayward: 9 mm/yr, Calaveras: (5 mm/yr on the northern part, 15 mm/yr on the southern part), Rodgers Creek: 7 mm/yr, Napa: 2 mm/yr, Franklin: 2 mm/yr. It is important to note that this leads to differences between our initial slip rates and those explicitly used in UCERF3 which arise from deformation models and inversions (Parsons et al., 2013).

For example, the slip rates used in UCERF3 for the Napa and Franklin faults are 1 mm/yr and 0.01 mm/yr respectively. However, given the range presented in studies indicating preferred rate of 1-3 mm/yr (Cao et al., 2003, Wesling & Hanson, 2008) and the connectivity of these two faults (Catchings et al., 2016) we assign a value of 2 mm/yr for both. Once these slip rates are assigned, we follow a hybrid loading scheme to reduce stress concentrations at the edge of the fault model domain (Shaw et al., 2018; Shaw, 2019).

For each element within the fault system we also assign rate-and-state frictional constants a , b , D_c , μ_0 and the RSQSim weakening factor f_a . Table 1 lists each model run and the corresponding parameter values. For the Variable Friction and Creeping models, the a and b parameters are assigned based on known locations of creep along the faults in the East Bay (described in more detail in the model descriptions). For each model (except the creeping model) we run the simulation for 25,000 years and in the analysis, we ignore the events that occur during the spin-up time (Shaw et al., 2018; Niyogi et al., 2025) which for this study is ~5000 years.

Table 1: List of the different RSQSim models and corresponding input parameters.

Model Name	a	b (max)	b (min)	D_c (m)	μ_0	f_a
Uniform	0.01	0.015	0.015	1e-5	0.6	0.10
Variable Friction	0.01	0.015	0.011	1e-5	0.6	0.10
Creeping	0.01	0.015	0.008	1e-5	0.6	0.10
Uniform low f_a	0.01	0.015	0.015	1e-5	0.6	0.05
Variable Friction low f_a	0.01	0.015	0.011	1e-5	0.6	0.05

Model Descriptions:

Here we explain in detail the similarities and differences between the models.

The following input parameters are held constant across all models (except for the

Creeping Model): initial normal stress is 100 MPa, initial shear stress is 60 MPa, the rate-state coefficient a is 0.01, the reference frictional value is 0.6 and the critical slip distance is $1e-5$ m. One of the main differences between the models is the frictional behavior on elements, Figure 2 shows the friction $a-b$ value for each model along the entire fault system.

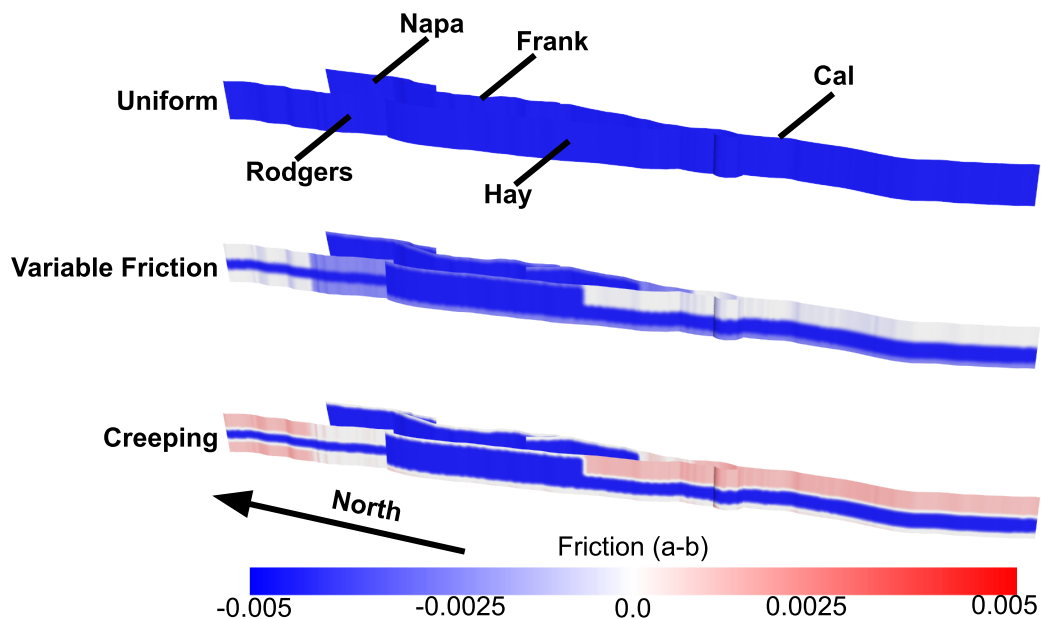


Figure 2: On-fault friction for each model with the fault segments labeled. Blue colors indicate velocity-weakening and red colors indicate velocity-strengthening.

Three fault system diagrams illustrating the distribution of on-fault friction properties for each frictional model. The spatial variation of rate-and-state friction behavior is represented through a continuous red-blue color map on the fault planes. Regions colored in shades of blue indicate velocity-weakening frictional behavior. Conversely, regions colored in shades of red indicate velocity-strengthening behavior. There is an arrow to denote the northern direction and labels on each major fault.

Uniform model:

In this model the frictional properties along the fault are uniform and velocity-weakening, $a-b$ is held constant across the entire fault system at -0.005 . The weakening factor f_a on all fault elements is the standard value of 0.10 often used in RSQSim simulations (Richards-Dinger & Dieterich, 2012, Shaw et al., 2018).

Variable Friction Model:

In this model all the fault elements are still velocity-weakening, but there are variations in $a-b$ along strike and dip based coarsely on previous studies in the region. In the model the most negative $a-b$ value is -0.005 for fully locked patches and the least negative value is -0.001 for patches that are in areas of known creep. Across all faults we reduce $a-b$ in the upper 1 km and the lower 2 km. For the Hayward fault we assign friction based on areas highlighted as creeping or locked in Chaussard et al., 2015. The Calaveras fault also has prevalent observed creeping regions (Chaussard et al., 2015; Xu et al., 2018; Li et al., 2023). For the Rodgers Creek fault we assign friction based on observations from Funning et al. (2007) and Xu et al. (2018). For the Napa fault we utilize the results from a dynamic inversion of the coseismic and postseismic slip during the 2014 Mw 6.0 event (Premus et al., 2022). For the Franklin fault we only implement the reduced weakening in the upper and lower regions which are the same across all faults.

Creeping model

In this model we take the same areas identified as creeping in the Variable Friction Model and make them velocity-strengthening; while keeping all other elements in the model velocity-weakening. In RSQSim implementing creeping patches greatly reduces the efficiency, because the stress from creeping patches needs to be calculated on top of the background tectonic stress during steady state. In essence, these creeping patches are in State 3 and stress on adjacent patches is calculated in a similar manner as if the element was in state 2 (Rupture). This increases the computational time by 2-3 orders of magnitude, so we are unable to run the model for as long as the other models. To generate a long enough catalog for the creeping model, we take the heterogeneous on-fault stress conditions of the Uniform model after the first 5000 years spin-up time and use those as initial conditions in this model and generate a 4000-year catalog. We then remove the largest event which occurs right at model start up, in essence this allows us to utilize the entire catalog without having to remove any events from spin-up time.

Uniform low_fa Model:

This model has the same frictional parameters as the Uniform model, the only difference being we lower the fa parameter from 0.10 to 0.05. Lowering this parameter increases the weakening of surrounding fault elements when an element is in State 2, this makes it easier for rupture to propagate and would be analogous to a larger stress concentration ahead of the rupture front in a dynamic model.

Variable Friction low_fa Model:

This model is the same as the Variable Friction model, but with a f_a value of 0.05 instead of 0.1.

Results:

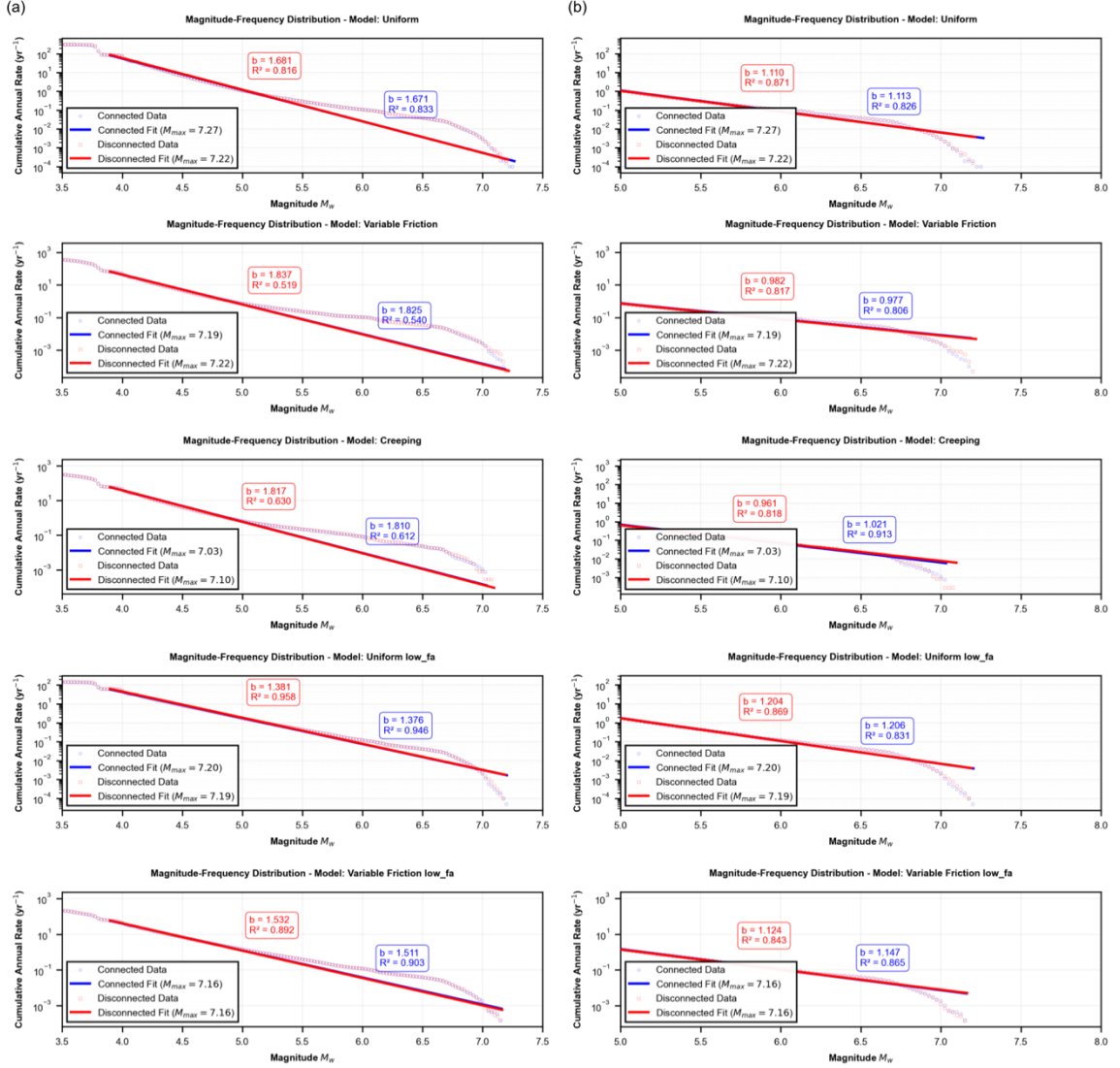
Magnitude Frequency:

For each model we remove the events that fall within the spin-up time (5000 years for every model except the creeping ones). For each model catalog we plot the cumulative number of events and fit the magnitude-frequency distribution to a Gutenberg-Richter law using a maximum likelihood estimate (Aki, 1965), with two fitting ranges: one including single-element Mw 3-4 events and one fitting Mw 5 and above, as this is what is typically reported in other RSQSim studies (Shaw et al., 2022; Hsu & Wu, 2025). Figure 3a shows the magnitude-frequency plots for each model fit with M_{min} of 3.9, which is the largest magnitude point of maximum curvature across all models, with the Connected geometries shown in blue and the Disconnected geometries shown in red. For this fitting, the GR law b-estimates are all greater than 1, indicating that we have a large number of smaller magnitude events dominating the fit. Within these fits, we see that the lowest b values are associated with the Uniform low_ f_a models; 1.376 and 1.381 for the Connected and Disconnected models respectively. In general we see that increased weakening (lower f_a values) leads to a reduction in the b-value: for example for the Connected geometry the Uniform model has a b-value of 1.671 and the Uniform low_ f_a model has a b-value of 1.376. A similar reduction in b-value is seen in comparing the Variable Friction (1.825) and the Variable Friction low_ f_a (1.511) models. In addition, the inclusion of velocity-neutral and velocity-strengthening patches

increases the b value: with the Variable and Creeping models having values of 1.825 and 1.810 and the Uniform velocity-weakening model having a value of 1.671 (for the Connected models). Regardless of the initial conditions, fitting to the small single-element ruptures yields b -values higher than 1. However, when we fit the catalogs only using Mw 5 and greater events, similar to other RSQSim studies (Shaw et al., 2022; Hsu & Wu, 2025), we see b -values much closer to 1. Figure 3b, shows the magnitude frequency distribution for Mw 5 and greater events. We see large reductions in the b -values: for the Connected geometry, the Uniform model b -value drops from 1.671 to 1.113, for the Variable Friction it drops from 1.825 to 0.977 and the Creeping model b -value drops from 1.810 to 1.021.

Across all models we see some similar behaviors, for example we see a bump in the magnitude-frequency distribution that is indicative of characteristic earthquake behavior (Schwartz & Coppersmith, 1984; Wesnousky, 1994; Ellsworth, 1995). We also see that in the Connected models, more events cause slip on adjacent faults in comparison to the Disconnected models. Figure 4 shows the comparison of events Mw 6.5 or greater where slip is constrained to a single segment vs multiple fault segments. The higher prevalence of slip across multi segments on the Hayward, Calaveras and Rodgers Creek in the Connected models and the rarity of it in the Disconnected model is consistent with previous studies which show that rupture propagation across geometric discontinuities in RSQSim is rarer than in fully dynamic models (Kroll et al., 2023). However, this is not observed along the Franklin and Napa faults. These faults form a 1.5 km wide, leasing stepover with substantial overlap (~ 3 km), which is within a consistent range for rupture jumping stepovers in RSQSim (Kroll et al., 2023). In

362 addition, we observe that increased weakening (lower f_a) leads to an increase in
363 multisegmented ruptures.



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366 Figure 3: (a) Magnitude frequency distributions for each model type comparing the Connected geometry (blue) and
367 the Disconnected geometry (red) the lines show the best fit GR law b -value for each simulation fitted with a minimum
368 magnitude of 3.9. All models have a b -value greater than 1. (b) Magnitude-frequency distributions and GR fits for
369 magnitude 5 and greater events. These fits are closer to 1, consistent with previous RSQSim studies.

370 Scatter plot and fitted line graph showing the cumulative distribution of earthquakes in each RSQSim catalog and a
371 best fit Gutenberg-Richter law line for two different minimum magnitudes, indicating that the fit is dependent on the
372 subset of catalog data examined.

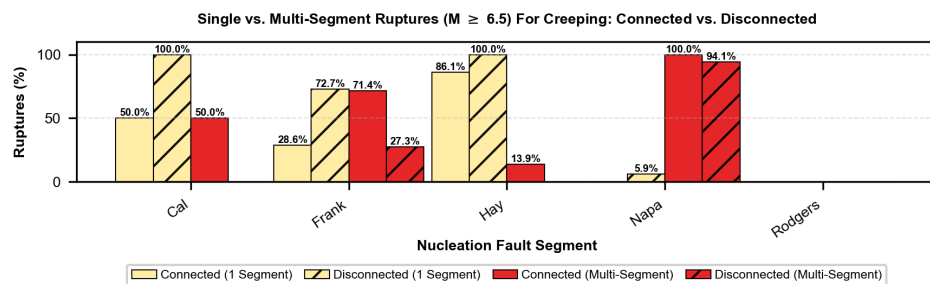
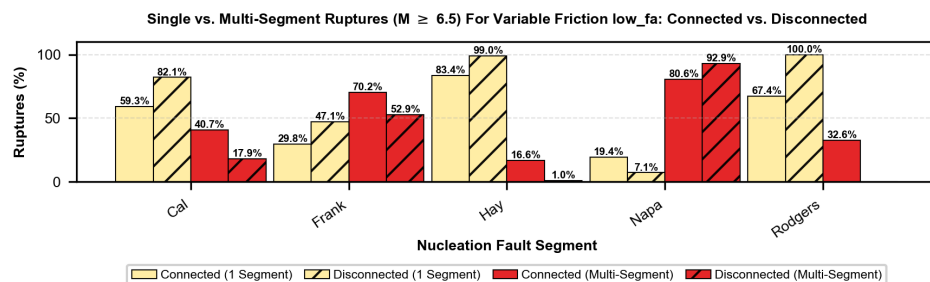
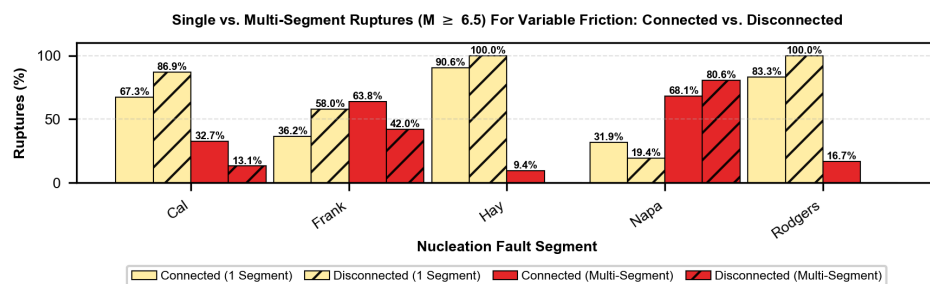
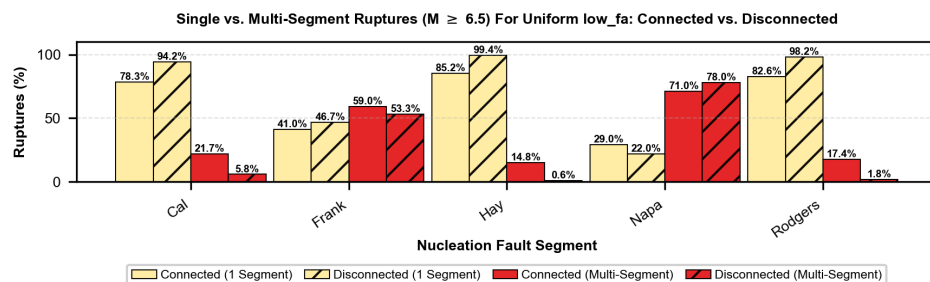
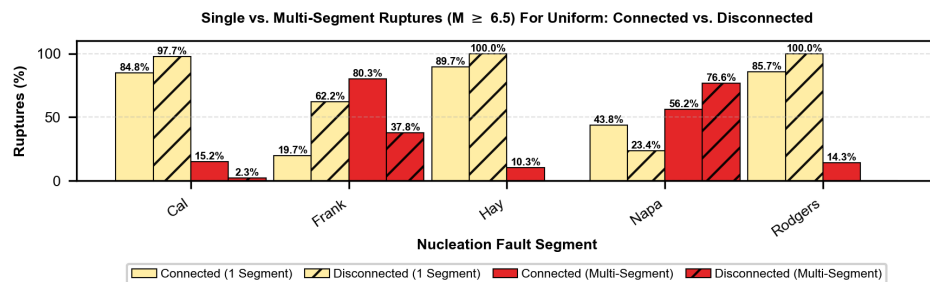


Figure 4: Bar graphs comparing the percentage of Mw 6.5 or greater single fault ruptures (yellow bars) and multi-segment ruptures (red bars) between the Connected (solid colors) and Disconnected (hashed bars) geometries for all the RSQSim models.

Bar graphs comparing the prevalence of multi-segment ruptures in the model. For each RSQSim model, each fault has vertical four vertical bars with percentages displayed above them: a solid yellow bar for single fault ruptures in the connected geometry, a hashed yellow bar for single fault ruptures in the disconnected geometry, a solid red bar for multi-fault ruptures in the connected geometry, a hashed red bar for multi-fault ruptures in the disconnected geometry. The graphs indicate that fault connectivity and enhanced weakening lead to more multi-fault ruptures.

Time-Independent and Time-Windowed Fault Participation Probabilities

In this section we look at both the time-independent and post-event time windowed individual fault participation probabilities in Mw 6.7 or greater events across the models. We define the fault participation threshold as any fault that contributes the equivalent moment of a Mw 6 (or greater) during an event. For the 30-year time-independent probability we take the Poissonian probability of each fault participating in a Mw 6.7 or greater event within a 30-year time period given its seismicity rate over the duration of the catalog minus the spin up time. In addition, we calculate a time windowed probability of a Mw 6.7 or greater event occurring on a fault segment in the RSQSim catalog within a 30-year window following participation of the fault segment in Mw 6.7 or greater event. A time windowed value higher than the Poissonian probability would indicate earthquake clustering. We then compare our fault participation rate probabilities with the summed UCERF3 Time-Independent participation probabilities for each fault segment (Field et al., 2014). Figure 5 shows the results for all the models for each geometry compared with the UCERF3 Time-Independent mean and max probabilities for each fault segments participation. It is important to note that we do not

utilize the exact slip rates for each fault that are prescribed in UCERF3, but rather a value derived from analyzing values from multiple sources (see Methods). Across all models without velocity-strengthening, we observe the highest 30-year probabilities associated with the Hayward and Calaveras faults while the Franklin, Napa and Rodgers Creek have significantly lower probabilities, which is consistent with UCERF3. In all the models without velocity-strengthening (i.e., all but the Creeping models), the Time-independent probabilities on the Hayward, Calaveras, Franklin and Napa faults are all within the UCERF3 TI upper and lower bounds; in contrast the Rodgers Creek fault is below the UCERF3 min. For the Hayward fault the Connected geometries yield time-independent probabilities in the range of 27.2-28.9% and the Disconnected geometries probabilities range from 22.4-26.6%. In addition, on the Hayward fault for both the Connected and Disconnected geometries, the time-windowed probability is lower than the time-independent probabilities but is still within ranges of 18.6-25.4%. For the Calaveras fault, the Connected models yield a time-independent probability in the range of 13.3-20.4% and the Disconnected geometries probabilities range from 15.3-20.5%, with higher probabilities associated with models with enhanced weakening. Furthermore, the Variable Friction models yield significantly lower time-windowed probabilities than the Uniform models.

Compared to all the other models (Uniform, Variable Friction, Uniform low_fa, Variable Friction low_fa), the Creeping model time-independent probabilities for both the Connected and Disconnected geometries are lower than those of the models without velocity strengthening. Intuitively this makes sense, given that creeping sections are often zones of low stress due to aseismic stress release (Kaneko et al., 2010).

421 However, with such a short run time due to the significant computational expense of
422 implementing creeping patches in RSQSim, we are hesitant to draw any definitive
423 conclusion from this observation alone.

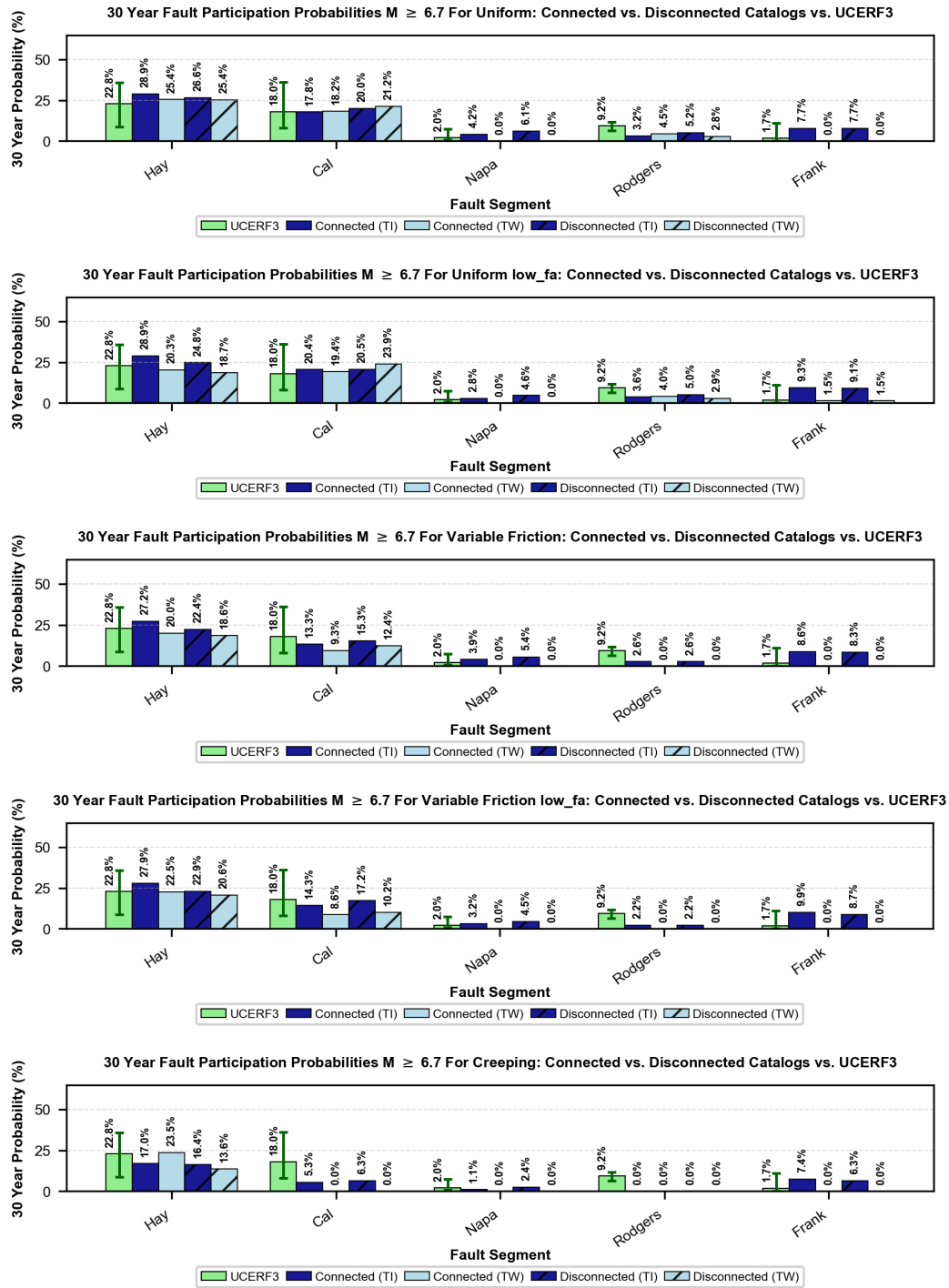


Figure 5: Comparisons of time-independent $M_w \geq 6.7$ 30-year probabilities between the model results and the UCERF3 TI mean (light green bar), with upper and lower bounds (dark green error bar). The RSQSim time-

independent results are shown in dark blue, the time windowed results are in light blue, solid bars denote the Connected geometry and hashed bars denote the Disconnected geometry. All the velocity-weakening models have TI probabilities within the UCERF3 range for the Hayward, Calaveras, Napa and Franklin faults and below the UCERF3 minimum for the Rodgers Creek fault.

Bar graphs comparing the 30 -year Time-Independent fault participation probabilities to UCERF3 for all RSQSim models. For each fault, a light green bar represents the UCERF3 mean with a dark green error bar. Beside it, clusters of blue bars show RSQSim models: dark blue for time-independent (TI), light blue for time windowed (TW), solid for Connected geometry, and hatched for Disconnected geometry. Above each bar is a printed display of the probabilities expressed as a percentage. The blue bars generally fall inside the green max and min limits for Hayward, Calaveras, Napa and Franklin, but not for the Rodgers Creek.

Time-Dependent Fault Participation Probabilities:

Here we focus on the comparisons between the RSQSim model fault participation results and the summed UCERF3 Time-Dependent fault participation probabilities using the same criteria as in the time-independent analysis. First, we take the interevent times of magnitude 6.7 or greater earthquakes on the Hayward and Calaveras faults, rank order them from shortest recurrence interval to longest and fit them to two different renewal models: a Brownian Passage Time (BPT) model (Ellsworth et al., 1999; Matthews et al., 2002; Field et al., 2015) and a Weibull distribution (Weibull, 1951; Hagiwara, 1974) (see Table 2 for the renewal model fits). Then to allow us to compare our results to UCERF3 we find the time from the last major event on each fault up until 2014. For the Hayward fault the last event was 1868 (Bakun, 1999; Lienkaemper et al., 2002; Field et al., 2014) and for the Calaveras it was 1740 (Kelson et al., 1996; Field et al., 2014) yielding us time since last events of 146

and 274 years respectively. We then find the probability of the fault participating in a Mw 6.7 or greater event in the next 30 years given the respective time since the last event by sampling our fitted renewal models at that time interval (Field et al., 2015; Field & Jordan, 2015). Figure 6 shows the RSQSim time-dependent probabilities compared to the UCERF3 TD probabilities.

Across all our models we see the Brownian Passage Time fits to the RSQSim catalogs yield a higher 30-year probability compared to Weibull fits. Another robust feature is that increased weakening (lower f_a value in RSQSim) leads to an increase in the 30-year time-dependent probabilities for all fits on both the Hayward and Calaveras faults. The Hayward BPT probabilities for the non-creeping models are all bounded within the UCERF3 max and min, with the Disconnected Variable Friction model having the lowest BPT Probability out of these models (30.6%) and the Connected Uniform low_ f_a having the highest (42.2%). For the Creeping model, the BPT probabilities fall between the UCERF3 min and mean, with a value of 30.6% for the Connected geometry and 28.4% for the Disconnected geometry. For the Weibull fits on the Hayward fault, we observe a lot more scatter, which can be directly related to different Weibull shape parameter (K) values fit to the different model catalogs. When the K value is greater than 1, the probability is near UCERF3 TD mean (Connected Uniform low_ f_a and Variable Friction low_ f_a), again this is consistent with increased weakening yielding higher probabilities of Mw 6.7 or greater events. In contrast all the other models, which have K values less than 1, yield probabilities below the UCERF3 TD mean. However, all except the Connected Creeping model are above the UCERF3 TD min probability.

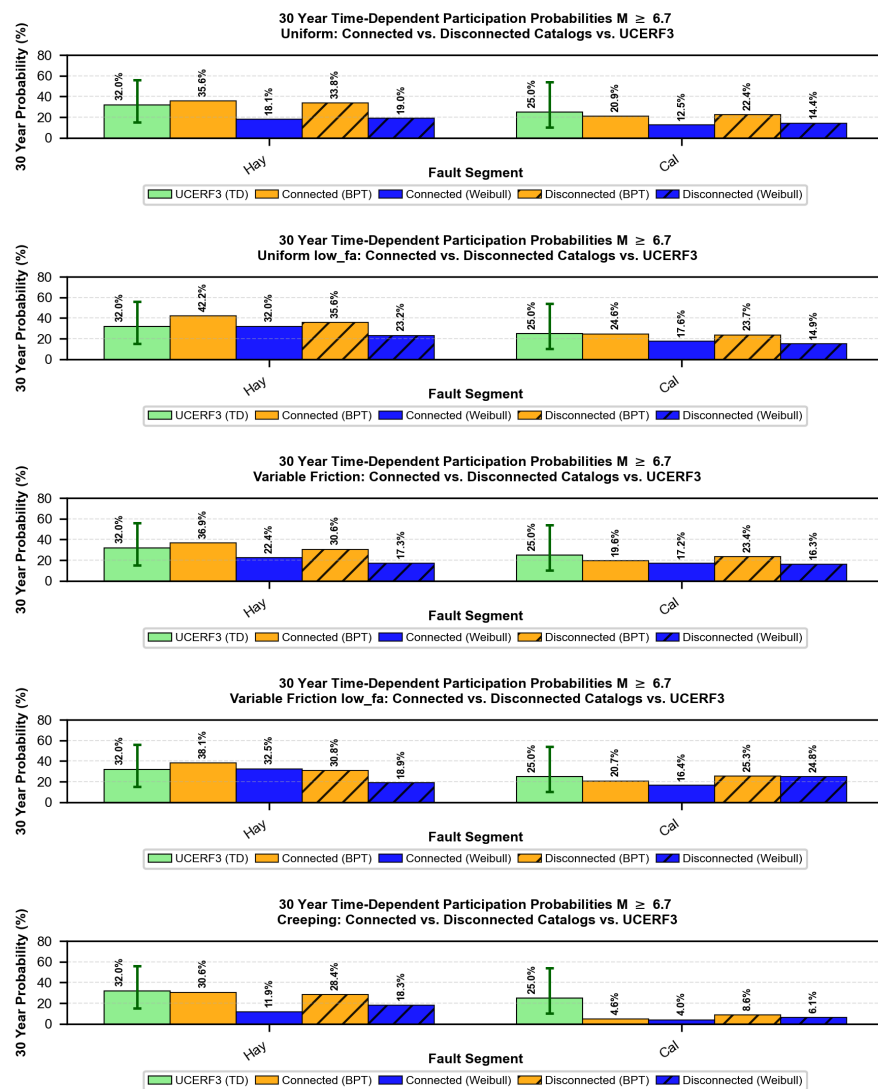
On the Calaveras fault we once again observe higher probabilities with the BPT fit than the Weibull fit across all models. However, unlike the RSQSim results for the Hayward fault, all the BPT 30-year probabilities are at or below the UCERF3 TD mean. The Disconnected Variable Friction low_fa has the highest probability of 25.3% within rounding range of the UCERF3 mean of 25%, and the lowest values are observed in the Connected Creeping model (4.6%). For the Weibull probabilities, all the values are at or below the UCERF3 mean regardless of the K value, with the highest probability of 24.8% for the Disconnected Variable Friction low_fa.

Table 2: RSQSim renewal model fits.

Catalog	Model	Fault	Mean Recurrence (years)	Standard Deviation (years)	RMSE BPT	RMSE Weibull	Weibull K Value
Uniform	Connected	Hay	87.9	68.5	0.112	0.110	0.65
		Cal	151.4	126.2	0.097	0.078	0.74
	Disconnected	Hay	96.6	74.6	0.103	0.104	0.72
		Cal	134.5	113.3	0.093	0.074	0.77
Variable Friction	Connected	Hay	94.4	67.1	0.091	0.109	0.84
		Cal	211.4	145.1	0.087	0.047	1.33
	Disconnected	Hay	118.4	86.9	0.085	0.111	0.76
		Cal	179.0	117.8	0.087	0.082	1.05
Uniform (low fa)	Connected	Hay	88.3	57.0	0.099	0.092	1.10
		Cal	130.8	102.6	0.084	0.067	0.89

Catalog	Model	Fault	Mean Recurrence (years)	Standard Deviation (years)	RMSE BPT	RMSE Weibull	Weibull K Value
	Disconnected	Hay	105.1	71.5	0.099	0.098	0.94
		Cal	130.4	106.0	0.112	0.083	0.78
Variable Friction (low f_a)	Connected	Hay	91.6	64.3	0.094	0.071	1.15
		Cal	194.0	135.7	0.050	0.059	1.14
	Disconnected	Hay	115.7	85.9	0.093	0.094	0.82
		Cal	157.9	106.2	0.073	0.041	1.35
Creeping	Connected	Hay	125.5	87.1	0.135	0.172	0.52
		Cal	520.1	200.6	0.102	0.120	2.76
	Disconnected	Hay	140.4	95.3	0.093	0.100	0.94
		Cal	467.8	314.5	0.153	0.172	1.69

484



485

486 Figure 6: Comparisons of Hayward and Calaveras fault, time-dependent $M_w \geq 6.7$ 30-year probabilities between the
 487 model results and the UCERF3 TD mean (light green bar), with upper and lower bounds (dark green error bar). We fit
 488 the RSQSim catalogs with a Brownian Passage Time (BPT) recurrence model (orange) and a Weibull Distribution
 489 (blue) for both the Connected (solid) and Disconnected (hashed) models. For all the models, the BPT probability is
 490 higher than the Weibull probability. On the Hayward fault the BPT probabilities fall within the UCERF3 bounds for all
 491 models, and on the Calaveras they are at or below the UCERF3 mean.

Bar graphs comparing the 30 -year Time-Dependent participation probabilities of the Hayward and Calaveras faults to UCERF3 for all RSQSim models. Each fault segment displays a light green bar representing the UCERF3 TD mean with a dark green error bar. Adjacent bars show RSQSim catalogs fit with recurrence models: orange bars for a Brownian Passage Time (BPT) model and blue bars for a Weibull Distribution. Solid bars denote Connected geometry, while hatched bars denote Disconnected geometry. The orange BPT bars are consistently taller than the blue Weibull bars across all models, and most bars fall within the dark green error bounds; the exceptions are the Creeping model on the Calaveras fault and its Connected Weibull fit on the Hayward fault.

Discussion:

Fault Assumptions: Geometry and on-fault parameters, and their relation to rupture propagation

From the results we observe that the connectivity of the geometry influences the how the number of faults that might slip during an earthquake in RSQSim. From Figure 4, we see that slip is observed on multiple fault segments more often in the Connected models than the Disconnected models. In addition, we generally see higher fault participation probabilities in the Connected models (Figures 5 & 6). The main reason for this is likely the lack of full dynamics. Several numerical studies have highlighted the importance of directivity, rupture speed and wave propagation in influencing rupture jumping across geometric complexities. Kame et al. (2003) and Bhat et al. (2007) both utilized dynamic rupture models to show that faster rupture velocities have increased stress concentration ahead of the rupture front which facilitates rupture through fault intersections. For fault stepovers, fully dynamic numerical models conducted by Harris & Day (1999) and Lozos et al. (2014) illustrated that lower fracture energy and higher radiated energy promotes rupture jumping at fault stepovers. Since there is no wave

propagation in RSQSim, there is no stress build up ahead of the rupture front nor is there calculated radiated energy, therefore it is more difficult for rupture to propagate across discontinuities when compared to fully dynamic models (Day et al., 1998). Kroll et al. (2023) compared results from RSQSim against results from a fully dynamic model FaultMod (Barall, 2009) for rupture across a stepover. They found that for similar on-fault initial conditions, the dynamic model was able to jump stepovers 1-2 km larger than the RSQSim model. This explains why we see fewer events on the Hayward, Calaveras and Rodgers Creek rupture multiple segments for the Disconnected geometry than we do for the Connected model. However, we still see substantial multi-fault ruptures involving the Franklin and Napa faults, because those faults form a releasing stepover with substantial overlap (~3 km) where the stepover width is less than 1.5 km.

As previously mentioned, a related RSQSim parameter that is implemented to approximate elastodynamics is the weakening parameter f_a , which is utilized to weaken adjacent fault elements around the rupture front. Although it may be difficult to see from Figure 3, when the f_a value is lowered, it leads to more moderate to large earthquakes, this is reflected in the corresponding b-values. We run one additional Uniform model with a higher f_a value of 0.15 to illustrate this point. Figure 7 shows plots for the annual rate of earthquakes binned by magnitude range for the Uniform Connected model with a low $f_a = 0.05$, the reference $f_a = 0.10$, a high $f_a = 0.15$ and the UCERF3 Time-Independent model. For the 3.5-4.0 range, the high f_a model has the highest number of events, but all the RSQSim models produce rates higher than UCERF3. This mismatch is consistent with the GR law fits in Figure 3, which indicate RSQSim is producing too many small events. In the M_w 4.5-5 to 6.5-7 bins, the low f_a model has the highest

rates, followed by the reference model and then the high f_a model. This is expected, as a lower f_a value causes increased weakening of nearby elements, which makes it easier for ruptures to propagate. In this range, the RSQSim rates are still higher than the UCERF3 mean but become bounded by the UCERF3 max as magnitude increases. However, one interesting observation is that the M_w 7+ bin does not follow this same trend and has a lower rate than UCERF3 regardless of the f_a value. This suggests that although the f_a parameter is influential in allowing smaller events to grow into larger ones, the largest events are still fundamentally determined and limited by the fault geometry in RSQSim. In addition, the increased weakening also leads to higher percentages of multi-fault ruptures; this behavior is seen in both the Uniform and Variable Friction models (Figure 4).

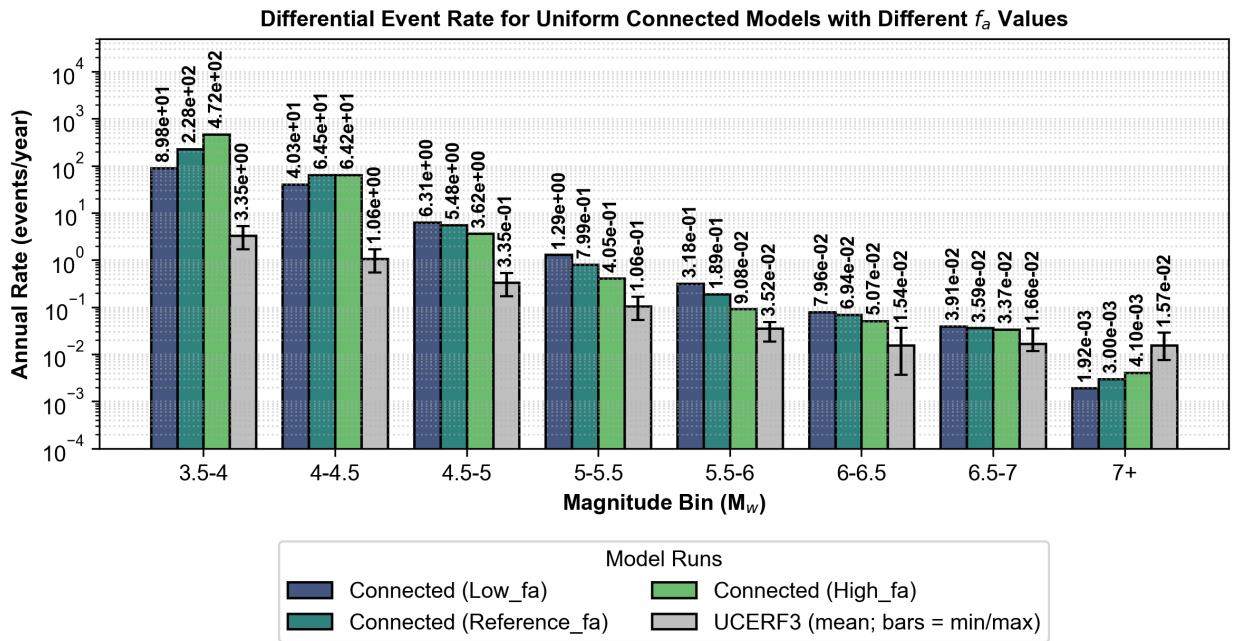


Figure 7: Differential annual event rates in half-magnitude bins for the Connected Uniform model with low ($f_a = 0.05$), reference ($f_a = 0.10$) and high ($f_a = 0.15$) f_a values, compared with the UCERF3 mean rates (grey bars; error bars denote the UCERF3 minimum and maximum). Lower f_a values result in higher

rates between Mw 4.5 and 7. The RSQSim rates exceed UCERF3 in all bins except Mw 7+, where all fa values fall below UCERF3, indicating that the largest events are limited by fault geometry.

Bar chart of differential annual earthquake rates in half-magnitude bins from Mw 3.5 to 7+ for the Connected Uniform model with three fa values and UCERF3 mean rates. Each magnitude bin has four bars: dark blue for low fa, sea green for reference fa, light green for high fa, and grey for UCERF3 with error bars marking its minimum and maximum. The printed value above each bar is its annual rate. The RSQSim bars are higher than UCERF3 in every bin except the Mw 7+ bin, where they fall below UCERF3.

The probabilities are within UCERF3 ranges, but what about the paleo record?

As shown in the results section, some of the models are able to yield earthquake probabilities that are in line with those presented in UCERF3. At first glance this is quite promising as it allows us to benchmark that the behavior arising from RSQSim simulations is within the range of error in the behavior of the currently utilized hazard model. However, as displayed in Table 2, when looking at recurrence on a fault wide scale there are high standard deviations relative to the mean recurrence; this behavior arises from elastic stress transfer from earthquakes on one section of a fault increasing the shear stress on adjacent sections (this can also be interpreted from the high time windowed probabilities in Figure 5). Therefore, it may be useful to interrogate how a single element on a fault behaves in the model and compare them to a natural benchmark, the paleo seismic record.

Here we focus on three surface localities in our model which correspond to three paleoseismic sites: the Mira Vista site in El Cerrito along the northern Hayward fault (Lienkaemper et al., 1999), the Tyson Lagoon site along the southern Hayward fault (Lienkaemper et al., 2002; Lienkaemper et al., 2010) and the Leyden Creek site along

the Calaveras fault (Kelson et al., 1996) (yellow stars in Figure 1). We set a lower bound of $M_w > 6$ with at least 0.10 m of slip at the surface which is consistent with natural observations (Wells & Coppersmith, 1994; Baize et al., 2020). For each paleoseismic site the data comes with some uncertainty, first for the sake of a simple comparison we define the paleo event time as the most probable time extracted from the probability density function and the inter-event times to be the timing between these event times (Figure 8a). We then calculate the mean interevent time or recurrence interval and the standard deviation of the paleoseismic events. Then for each paleo locality in our models we calculate the mean recurrence and standard deviation of the fault element closest to the surface rupturing in a M_w 6 or greater event with at least 0.10 m of slip at the surface. Given that we have different sample sizes for the paleo data and the RSQSim catalogs we conduct a Welch's t-test to investigate if the mean recurrences are statistically different. The null hypothesis is that the mean inter-event recurrence times are equal. To reject the null hypothesis at the 95% confidence level (i.e., to reject the equality of the means), the t-test p value for the model pair must be less than 0.05. P-values below 0.1 are not statistically significant but may be suggestive of a trend (Krzywinski & Altman, 2013; Andrade, 2019). Figure 8b shows the p-value for each Welch's test between recurrence of each RSQSim catalog and the paleo record at each site. At Tyson Lagoon, we can reject the equality of the means at the 95% confidence level for all but three models: the Uniform Disconnected model, the Uniform low_fa Disconnected model and the Uniform low_fa Connected model. At Mira Vista, we cannot rule out the equality of the means for any model. We also cannot reject the equality of the means at Leyden Creek for any model; the Creeping Disconnected

model does not have enough events at this location to estimate a mean recurrence interval and standard deviation.

Next, we generate 100 realizations of the interevent times from underlying paleo seismic site probability density functions. Figure 8c shows the number of the 100 realizations where the paleo and RSQSim model comparisons had a p-value less than 0.05 and the equality of mean recurrence can be rejected. The results from these 100 realizations are consistent with the single Welch's t-test. Furthermore, we do a jackknife sampling scheme to run the same analysis on subsets of the paleo-seismic data while leaving out individual events at each site (Figure 9). Even with the exclusion of events, the resultant Welch's t-tests on the sampled subsets cannot rule out the equality of mean recurrence interval between the RSQSim results and the paleoseismic data at Mira Vista and Leyden Creek. For Tyson Lagoon, most of the results still suggest that we can reject the equality of the mean between the paleo record and the RSQSim catalog, however there is some variance in the percentage of realizations that are rejected based on which event is left out. Across all Jackknife subsets, we still see that the Uniform low_fa Connected model fits the paleo record best and for many subsets there are 0% of the PDF realizations where we can reject the equality of the mean. An interesting observation is that by dropping either event 6 (which has a very broad distribution) or by dropping the next confirmed rupture, event 4, the mismatch between all RSQSim models and the paleo data drops, yielding 0-24% (event 6 dropped) and 0-41% (event 4 dropped) of realizations leading to a rejection of the equality of the means, compared to 5-100% for the full event catalog.

In general, our RSQSim results do not reproduce the paleo data at Tyson Lagoon. There may be several reasons for this mismatch. Firstly, the absence of dynamic stresses may limit the extent of some ruptures, especially the propagation through velocity-strengthening/velocity-neutral sections and across fault discontinuities. Secondly, RSQSim's discrete element states may not be able to capture the complex feedback between slip speed and fault strength in a creeping zone, Tyson Lagoon has substantial creep with rates appearing to vary over time (Lienkaemper et al., 2002; R. Bürgmann, personal communication, 2026). Furthermore, for Tyson Lagoon the best fitting model is a Uniform velocity-weakening model with enhanced weakening, which is inconsistent with the frictional behavior at that site. This also indicates that the modeling is not appropriately capturing the on-fault physics at this site. Behavior like this may be better represented within a quasi-dynamic or fully dynamic model that explicitly solves the interseismic, coseismic and postseismic stages of the earthquake, such as Sequences of Earthquakes and Aseismic Slip (SEAS) models (Erickson et al., 2020; Jiang et al., 2022).

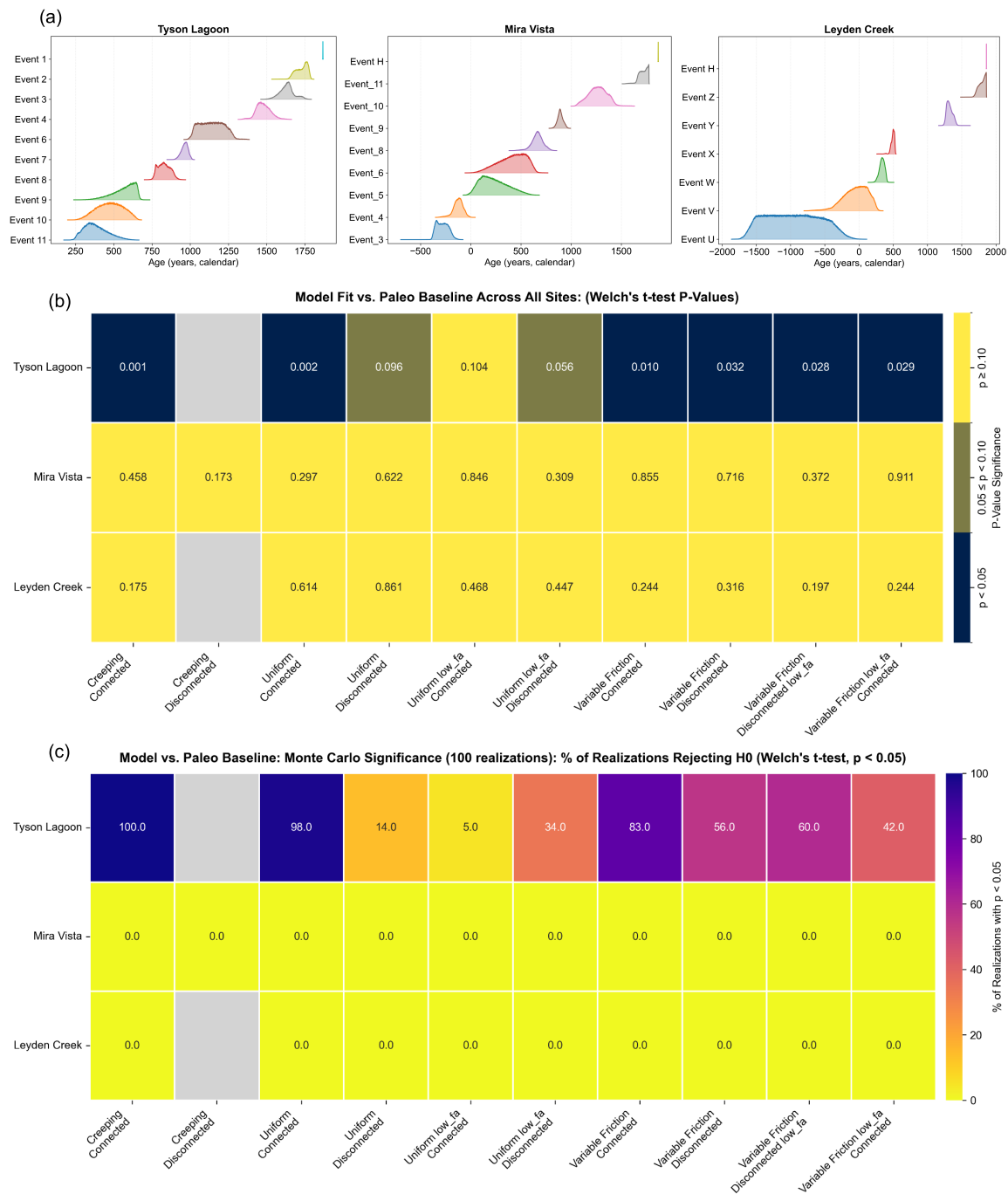


Figure 8: (a) Paleoseismic probability density functions for each of the three sites, normalized against their individual peaks (Kelson et al., 1996; Lienkaemper et al., 1999; Lienkaemper et al., 2002; Lienkaemper et al., 2010). (b) P-values for Welch's t-test across all models at each paleoseismic location. Dark blue indicates that the equality of the means can be rejected at the 95% confidence level ($p < 0.05$), olive green indicates $0.05 \leq p < 0.1$ and yellow indicates $p \geq 0.1$, for which the null hypothesis cannot be rejected. Greyed out entries indicate there aren't enough

events to gather useful statistics on recurrence intervals. (c) Results from 100 Welch's t-tests conducted between the RSQSim models and 100 realizations of the underlying paleoseismic probability density function at each site. The number in the box indicates the number of realizations in which the p-value was less than 0.05 and thus the equality of the means can be rejected.

A three-panel graphic labeled (a), (b), and (c). Panel (a) shows curves representing the Tyson Lagoon, Mira Vista and Leyden Creek paleoseismic probability density functions, each normalized to its peak. Panels (b) is a heatmap of Welch's t-test p-values comparing the mean recurrence of events between RSQSim models and the Paleo data. The heatmap is color-coded with dark blue for p-values under 0.05, olive green for 0.05 to 0.1, yellow for over 0.1, and grey for insufficient statistics. Panel (c) displays a matching grid matrix where each cell is a box containing a printed percentages where the p-value fell below 0.05 for 100 Monte Carlo realizations of the paleo PDFs, this is color-coded with a continuous yellow to purple color scale where from 0 to 100%.

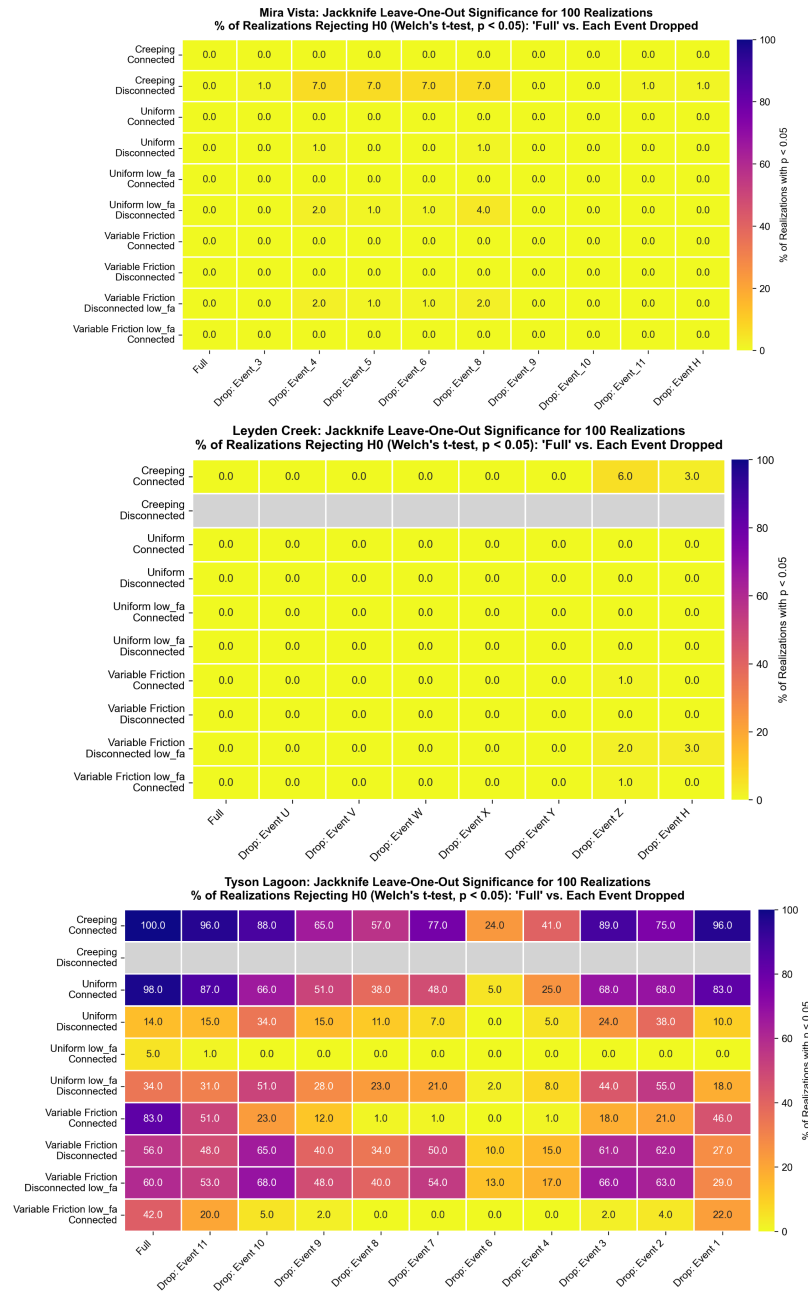


Figure 9: Results for 100 Welch's t-tests conducted between the RSQSim models and 100 realizations of the underlying paleoseismic probability density function at each site using a leave-one-out Jackknife sampling. The number in the box indicates the number of realizations in which the p-value was less than 0.05 and thus the equality of the means can be rejected. For Mira Vista and Leyden Creek, removing an event does not significantly change the t test results, however we see a reduction in the null hypothesis rejection at Tyson Lagoon with the exclusion of either Event 4 or 6.

Three heatmaps, one for each paleo site, displaying rows for RSQSim models and columns tracking individual events removed via Jackknife sampling. Each cell in the grid is a box containing a printed numerical value representing the percentage of Monte Carlo realizations with a p-value less than 0.05. The coloring and numerical values in the for the Mira Vista and Leyden Creek heatmaps are consistent across all entries. In contrast, the columns for the Tyson Lagoon site display a distinct, localized drop in percentages within columns corresponding to the exclusion of Event 4 or Event 6.

Conclusion:

In this study we utilize the long-term earthquake simulator RSQSim to generate various earthquake catalogs for the San Francisco East Bay. We find that the resultant catalogs are sensitive to the initial input assumptions. Fault connectivity can directly affect the occurrence of multi-fault ruptures within RSQSim, with Disconnected geometries hindering rupture propagation onto adjacent faults. Secondly, the internal weakening parameter (f_a) also has a significant influence on the catalog when the friction parameters a and b are comparable in size and element sizes are smaller than the typical 1.5-2.5 km elements used in other studies. When fitting the entire catalog to a Gutenberg-Richter law, a lower f_a value (stronger weakening) leads to a reduction in b -value and more $M > 5$ events. Lower f_a values also increase the ability of RSQSim ruptures to cause slip on multiple fault segments. Thirdly, the implementation of creeping patches in RSQSim greatly reduces the computational efficiency and may limit the temporal extent of the catalog.

In addition, we find that our models without creep generally agree with the 30-year time-independent and time-dependent UCERF3 probabilities for the Hayward and Calaveras faults, even though we do not explicitly use the same slip rates as UCERF3. For the Hayward fault time-independent probabilities are in the range of 22.4-28.9%. For the Calaveras fault, models yield a time-independent probability in the range of 13.3-20.5%. The Hayward Brownian Passage Time probabilities for the Disconnected and Connected geometries are 30.6-42.2%, compared to the 32% UCERF3 mean. For the Calaveras fault, the Brownian Passage Time probabilities range from 19.6-25.3%, compared to the UCERF3 mean of 25%. In general, the higher end probabilities are associated with models with increased weakening (low_fa). In the creeping models, the 28.4-30.6% BPT probability of the Hayward fault is near the UCERF3 mean; all other fits yield time-dependent probabilities near or below the UCERF3 TD minimum bound. However, although our model probabilities are bounded by the UCERF3 min and max, many of our models fail to reproduce the comparatively short recurrence at the Tyson Lagoon paleoseismic site. This signals caution in over-interpreting RSQSim results, especially in places with abundant creep. Future work could incorporate additional fault segments in the region or run dynamic SEAS models to test the effects on the produced catalogs.

Data and Resources:

All meshes were generated using Gmsh <https://gmsh.info/> (Geuzaine & Remacle, 2009). The inputs needed to run the models can be found at

DOI [10.5281/zenodo.23045666](https://doi.org/10.5281/zenodo.23045666). The simulations used the SCEC version of RSQSim (Richards-Dinger & Dieterich, 2012), which can be accessed through the Quakeworx web platform <https://quakeworx.org/>. All websites were last accessed in October 2026.

Declaration of Competing Interests:

A. Kottke is employed by Pacific Gas and Electric Company (PG&E), which supported this work through its Long-Term Seismic Program. The authors declare no other competing interests.

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Figure 1: Map of the San Francisco Bay Area. Solid black lines are faults used in this study from the SCEC CFM7 (Plesch et al., 2024), labeled with bolded-italicized text, text in parenthesis denotes the abbreviated name for each section used throughout the study. The San Andreas fault, not used in the models, is shown as a dashed black line. Yellow stars labelled with bolded text are paleoseismic locations and red dots denote locations of several cities.

Figure 2: On-fault friction for each model with the fault segments labeled. Blue colors indicate velocity-weakening and red colors indicate velocity-strengthening.

Figure 3: (a) Magnitude frequency distributions for each model type comparing the Connected geometry (blue) and the Disconnected geometry (red) the lines show the best fit GR law b -value for each simulation fitted with a minimum magnitude of 3.9. All models have a b -value greater than 1. (b) Magnitude-frequency distributions and GR fits for magnitude 5 and greater events. These fits are closer to 1, consistent with previous RSQSim studies.

Figure 4: Bar graphs comparing the percentage of M_w 6.5 or greater single fault ruptures (yellow bars) and multi-segment ruptures (red bars) between the Connected (solid colors) and Disconnected (hashed bars) geometries for all the RSQSim models.

Figure 5: Comparisons of time-independent $M_w \geq 6.7$ 30-year probabilities between the model results and the UCERF3 TI mean (light green bar), with upper and lower bounds (dark green error bar). The RSQSim time-independent results are shown in dark blue, the time windowed results are in light blue, solid bars denote the Connected geometry and hashed bars denote the Disconnected geometry. All the velocity-weakening models have TI probabilities within the UCERF3 range for the Hayward, Calaveras, Napa and Franklin faults and below the UCERF3 minimum for the Rodgers Creek fault.

Figure 6: Comparisons of Hayward and Calaveras fault, time-dependent $M_w \geq 6.7$ 30-year probabilities between the model results and the UCERF3 TD mean (light green bar), with upper and lower bounds (dark green error bar). We fit the RSQSim catalogs with a Brownian Passage Time (BPT) recurrence model (orange) and a Weibull Distribution (blue) for both the Connected (solid) and Disconnected (hashed) models. For all the models, the BPT probability is higher than the Weibull probability. On the Hayward fault the BPT probabilities fall within the UCERF3 bounds for all models, and on the Calaveras they are at or below the UCERF3 mean.

Figure 7: Differential annual event rates in half-magnitude bins for the Connected Uniform model with low (dark blue, $f_a = 0.05$), reference (sea green, $f_a = 0.10$) and high (light green, $f_a = 0.15$) f_a values, compared with the UCERF3

mean rates (grey bars; error bars denote the UCERF3 minimum and maximum). Lower f_a values result in higher rates between Mw 4.5 and 7. The RSQSim rates exceed UCERF3 in all bins except Mw 7+, where all f_a values fall below UCERF3, indicating that the largest events are limited by fault geometry.

Figure 8: (a) Paleoseismic probability density functions for each of the three sites, normalized against their individual peaks (Kelson et al., 1996; Lienkaemper et al., 1999; Lienkaemper et al., 2002; Lienkaemper et al., 2010). (b) P-values for Welch's t-test across all models at each paleoseismic location. Dark blue indicates that the equality of the means can be rejected at the 95% confidence level ($p < 0.05$), olive green indicates $0.05 \leq p < 0.1$ and yellow indicates $p \geq 0.1$, for which the null hypothesis cannot be rejected. Greyed out entries indicate there aren't enough events to gather useful statistics on recurrence intervals. (c) Results from 100 Welch's t-tests conducted between the RSQSim models and 100 realizations of the underlying paleoseismic probability density function at each site. The number in the box indicates the number of realizations in which the p-value was less than 0.05 and thus the equality of the means can be rejected.

Figure 9: Results for 100 Welch's t-tests conducted between the RSQSim models and 100 realizations of the underlying paleoseismic probability density function at each site using a leave-one-out Jackknife sampling. The number in the box indicates the number of realizations in which the p-value was less than 0.05 and thus the equality of the means can be rejected. For Mira Vista and Leyden Creek, removing an event does not significantly change the t test results, however we see a reduction in the null hypothesis rejection at Tyson Lagoon with the exclusion of either Event 4 or 6.