Simulation Based Earthquake Forecasting with RSQSim

Jacqui Gilchrist

Tom Jordan (USC/SCEC), Jim Dieterich (UCR), Keith Richards-Dinger (UCR), Bruce Shaw (Columbia), and Kevin Milner (USC/SCEC)

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Main Objectives

- Develop a physics-based forecasting model for earthquake rupture in California
  - Produce a suite of catalogs (~50) to investigate the epistemic uncertainty in the physical parameters used in the simulations.
    - One million years of simulated time
    - Several million M4-M8 events
    - Varied simulation parameters and fault models
  - Compare with other models (UCERF3) to see what we can learn from the differences.
RSQSim: Rate-State earthquake Simulator
(Dieterich & Richards-Dinger, 2010; Richards-Dinger & Dieterich, 2012)

- **Multi-cycle earthquake simulations (full cycle model)**
  - Interseismic period -> nucleation and rupture propagation

- **Long catalogs**
  - Tens of thousands to millions of years with millions of events

- **Complicated model geometry**
  - 3D fault geometry; rectangular or triangular boundary elements

- **Different types of fault slip**
  - Earthquakes, slow slip events, continuous creep, and afterslip

- **Physics based**
  - Rate- and State-dependent friction

- **Foreshocks, aftershocks, and earthquake sequences**

- **Efficient algorithm**
  - Event driven time steps
  - Quasi-dynamic rupture propagation

(Dieterich & Richards-Dinger, 2010; Richards-Dinger & Dieterich, 2012)
California Earthquake Forecasting Models

Simulator-based UCERF

- UCERF3 long-term
- UCERF3 short-term
- UCERF2
- NSHM

Reid renewal

Omori-Utsu clustering

long-term renewal models

“medium-term gap”

short-term clustering models

Century Decade Year Month Week Day

Anticipation Time
Use of simulations for long-term assessment of earthquake probabilities

Components of the Uniform California Earthquake Rupture Forecast

- **Fault Models**: Specifies the spatial geometry of larger, more active faults.
- **Deformation Models**: Provides fault slip rates used to calculate seismic moment release.
- **Earthquake-Rate Models**: Gives the long-term rate of all possible damaging earthquakes throughout a region.
- **Probability Models**: Gives the probability that each earthquake in the given Earthquake Rate Model will occur during a specified time span.

Inputs to simulations: Use tuned earthquake simulations to generate earthquake rate models.
RSQSim Calibration

- Develop a model that generates an earthquake catalog that matches observed California seismicity as closely as possible.
- The UCERF3 data set is used for calibration, and cross-validation of the model, as well as specification of fault geometry.
  - Fault Model
  - Long-Term Slip Rates
  - Recurrence Intervals
Calibration: Faults & Long-term Slip Rates

- Fault geometry and geologic slip rates from UCERF3
- High-resolution Model
  - 260,000+, 1 km², triangular patches
  - ~M4-M8 events
Simulation Parameters

- **Rate- and State-friction Parameters**
  - $a$, $b$, and $Dc$ (rate and state coefficients, and the critical slip distance)

- **Other Model Parameters**
  - $\tau$ and $\sigma$ (shear and normal stresses)
  - Earthquake slip rate

- **Adding heterogeneity of parameters**
  - Vary $a$, $b$, and $\sigma$ with depth
  - Adding deep creeping segments
Parameter Sensitivity Tests

Recurrence of M7+ Events in CA

<table>
<thead>
<tr>
<th>Normal Stress (MPa)</th>
<th>Mean Recurrence Time (years)</th>
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</thead>
<tbody>
<tr>
<td>100</td>
<td>9</td>
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<tr>
<td>120</td>
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<td>180</td>
<td>13</td>
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<tr>
<td>200</td>
<td>14</td>
</tr>
</tbody>
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- UCERF3 MRI
- RSQSim Catalogs

RSQSim Catalogs *(b−a = 0.005)*

* (Normal Stress = 100, b = 0.015)
Calibration: Mean Recurrence Intervals

- MRI’s are calibrated by making adjustments to the normal stress.
- UCERF3 subsection MRI’s

\[
\text{Stress Adjustment Factor} = \frac{\text{UCERF3 MRI}}{\text{RSQSIm MRI}}
\]
Result From Two MRI Calibration Rounds

SSAF Pallett Creek

Frequency

dt

RSQSim MRI
Paleoseismic MRI
UCERF3 MRI
Result From Two MRI Calibration Rounds

Calaveras–North

Frequency

0 5 10 15

dt

0 500 1000 1500 2000 2500

RSQSim MRI  
Paleoseismic MRI  
UCERF3 MRI
Result From Two MRI Calibration Rounds

NSAF Santa Cruz

- RSQSim MRI
- Paleoseismic MRI
- UCERF3 MRI

Frequency

0 20 40 60 80 100 120

0 50 100 150 200 250

dt
Mojave M7 Scenario

- Magnitude 7 on the San Andreas Fault in the Mojave is followed by another Magnitude 7 within a week.
Event # 1: $M = 7.1$ (Nucleated on SanAndreas(MojaveS), Subsection11)
Mojave M7 Scenario

Event # 2: $M = 7$ (Nucleated on SanAndreas(SanBernardinoN), Subsection 1)

$dt = 34$ minutes

Garlock Fault

San Andreas Fault
Mojave M7 Scenario

Event # 2: $M = 7$ (Nucleated on SanAndreas(SanBernardinoN),Subsection1)

$dt = 34$ minutes

Probability of a magnitude 7 or greater earthquake anywhere in California, **within 1 week** following a magnitude 7 on the San Andreas in the Mojave:

UCERF3 = 4.5%  
RSQSim = 5.6%
Conclusions

• Using RSQSim to develop a physics-based forecasting model for earthquakes in California.

• Initial calibration and validation tests are promising (but we still have some work to do on the model).

• Initial results illustrate how rupture simulators might assist forecasters in understanding the hazards due to multi-event sequences and complex faulting.
Thank you!