Regional Earthquake Likelihood Models (RELM)

- Collaboration between Southern California Earthquake Center (SCEC) and USGS
- To produce suite of credible source models for southern California
  - Test assumptions about earthquake nucleation and termination
  - Explore range of uncertainty in hazard and risk

Some assumptions to test

- Magnitude limited by fault length
- b-value varies spatially
- Earthquake probability increases with time since “last earthquake”
- Earthquake probability depends on estimate of Coulomb stress
  - Dislocation model of big quakes
  - Isotropic model based on smaller quakes
RELM agreements 2001

- m≥5
- 5 year test period with annual review
- 32<lat<37, -122<lon<-114
- 0.05 deg grid
- 0.1 deg magnitude bins
- Characterize earthquakes by mw, hypocenter

RELMTEST Agreements 2003

- Forecast = vector of rates: quakes per year (or day) in bins of lat, lon, mag, orientation.
- Forecasters provide numbers, not programs
- All quakes count: no distinction between foreshocks, main shocks, and aftershocks.
- Bins of 0.05 deg * 0.05 deg * 0.1 mag
- Two main "menu items:"
  - Five year forecast of m>5, no updates
  - Five year forecast of m>4, updated daily
- Special orders ok if there are multiple models, and sufficient earthquakes for test
## RELM Papers, SRL 07

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
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<tr>
<td>Petersen, Cao, Campbell, &amp; Frankel</td>
<td>Time-independent and Time-dependent Seismic Hazard Assessment for the State of California</td>
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<tr>
<td>Gerstenberger, Jones, and Wiemer</td>
<td>Short-Term Aftershock Probabilities: Case Studies in California</td>
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<tr>
<td>Ward</td>
<td>Methods for evaluating earthquake potential and likelihood in and around California</td>
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<td>Wiemer &amp; Schorlemmer</td>
<td>ALM: An Asperity-based Likelihood Model for California</td>
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<tr>
<td>Helmstetter, Kagan, &amp; Jackson</td>
<td>High-resolution time-independent forecast for M≥5 earthquakes in California</td>
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<tr>
<td>Kagan, Jackson, &amp; Rong</td>
<td>A Testable Five Year Forecast of Moderate and Large Earthquakes in Southern California Based on Smoothed Seismicity</td>
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<tr>
<td>Shen, Jackson, &amp; Kagan</td>
<td>Implications of Geodetic Strain Rate for Future Earthquakes, With a Five-Year Forecast of M5 Earthquakes in Southern California</td>
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<tr>
<td>Bird &amp; Liu</td>
<td>Seismic hazard inferred from tectonics: California</td>
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<td>Holliday, Chen, Tiampo, Rundle, Turcotte, &amp; Donnelan</td>
<td>A RELM earthquake forecast based on pattern informatics</td>
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<td>Ebel, Chambers, Kafka, and Baglivo</td>
<td>Non-Poissonian Earthquake Clustering and the Hidden Markov Model as Bases for Earthquake Forecasting in California</td>
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<td>Rhoades</td>
<td>Application of the EEPAS Model to Forecasting Earthquakes of Moderate Magnitude in Southern California</td>
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<td>Console, Murru, Catali, and Falcone</td>
<td>Real time forecasts through an earthquake clustering model constrained by the rate-and-state constitutive law: Comparison with a purely stochastic ETAS model</td>
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<tr>
<td>Field et al.</td>
<td>Overview Paper</td>
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<tr>
<td>Schorlemmer, Gerstenberger, Wiemer, &amp; Jackson</td>
<td>Earthquake Likelihood Model Testing</td>
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<tr>
<td>Schorlemmer &amp; Gerstenberger</td>
<td>RELM Testing Center</td>
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Grid for reporting RELM models: yearly rate of events for each 0.1 magnitude bin reported for 0.1 deg box centered at each grid point.

Alternative 20 year forecasts, m5.5 +

1996 NSHMP Source model, faults, characteristic eqs, smoothed seismicity.

Helmstetter et al., 2006,
Smoothed seismicity m2+
Likelihood test

<table>
<thead>
<tr>
<th>Cell</th>
<th>Region</th>
<th>Mag range</th>
<th>Ann. Expec. Rate</th>
<th>Prob 5 yr</th>
<th>Prob 1</th>
<th>Prob 2</th>
<th>Prob 3</th>
<th>Prob 4 etc</th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>4.95 - 5.95</td>
<td>0.40</td>
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<td>0.82</td>
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<td>0.02</td>
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<tr>
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<td>2</td>
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<tr>
<td>4</td>
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<td>5.95 - 6.95</td>
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<td>0.1</td>
<td>0.90</td>
<td>0.09</td>
<td>0.00</td>
<td>0.00</td>
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Likelihood = log(0.18 * 0.82 * 0.37 * 0.90)

1996 NSHMP, mainshocks only, 1981 – 2000

Helmstetter et al., 2006, mainshocks only, 1981 - 2000
Double Log Likelihood Ratio

\[ R = (L_2 - L_0) - (L_1 - L_0) \]

- \( L_1 \) = Log likelihood score for hypothetical catalog, evaluated using hypothesis 1
- \( L_0 \) = Log likelihood score for observed catalog, evaluated using hypothesis 2
- \( R = 0 \) if hypothetical catalog is observed catalog

Likelihood Ratio Test, Helmstetter et al. 06/ NSHMP 96
mainshocks only 1981 - 2000
How to interpret SS curves

- Compare two models with equal prior status: each is “null hypothesis” for the other
- Plotted so that data favoring H2 are to right, those favoring H1 are to left
- $\alpha$ is probability that H1 could look more favorable to H2 than actual data; if $\alpha$ is less than 0.05, reject H1
- $\beta$ is probability that H2 could look less favorable to H2 than actual data; if $\beta$ is less than 0.05, reject H2
- Reversibility: swapping H1 and H2 swaps $\alpha$ and $\beta$. That is $\alpha_{21} = \beta_{12}$

Likelihood Ratio Test, Helmstetter et al. 06/ NSHMP 96
mainshocks only 1981 - 2000
Conclusions and comments

• Testing is possible but not easy
  – Many investigators willing to go for it
  – Requires fairly detailed rules
  – Requires compromises (e.g., point sources)
  – All possible quakes must be assigned probability in advance

• Clustering causes big problems
  – Present tests assume Poisson behavior
  – Conditional probabilities change during experiment, requiring simulation of all possible outcomes

• Example favors smoothed seismicity over fault based model,
  – But retrospective test unfair
  – Fault-based model (NSHMP 96) not optimized for Likelihood test