Annual Report, 2002
SOUTHERN CALIFORNIA EARTHQUAKE CENTER

Title of Project: Methods for evaluating and testing earthquake potential in and around California

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My SCEC funded research in 2002 dealt with continuing efforts to improve and deploy various classes of earthquake potential/earthquake likelihood models for areas in and around California in support of the RELM program. In particular, I am constructing four different and largely stand alone methods to estimate earthquake potential -– one based purely on geodesy, one based purely on geology, one based purely on historical seismicity, and one based on computer simulations of earthquakes on the fault system of California. Each of these models was revisited in 2002, updated and improved. All of the figures in this report are new for 2002 and I've highlighted the newest developments. Much of the material in this report also appears in my 2003 SCEC proposal to continue this work.

I. Geodetic Hazard Models

Technical description.

1) Compile a GPS velocity map for the California/Nevada region. I employ existing GPS site velocities from the SCEC Crustal Motion Map2 and the SOPAC/SCIGN network.

2) Invert GPS site velocities into geodetic strain (Figure 1, upper left) rate and rotation rates using a variable sized smoothing window.

3) Convert geodetic strain rate into maps of geodetic moment rate density using Kostrov's formula and an assumed seismogenic thickness.

4) Translate the mapped moment rate density into earthquake rate density (Figure 1, top right and lower left) using a Gutenberg-Richter relation with given b-value and M_{max}.

Required Information: (1) GPS site positions, horizontal velocities and errors. (2) A map of seismogenic thickness. (3) A b-value and M_{max}.

Advantages: (1) Being purely strain rate based, geodetic models are 'clean' with few subjective constraints. (2) The maps have well defined error bounds, and (3) Wide geographical coverage even where little fault information is known. (4) Geodetic strain rates vary with time, so hazards mapped from them better represent the next 30-years than do geological methods.

Drawbacks: (1) Mapping of geodetic strain to seismic strain is not unique. (2) Some strain may be aseismic or non-tectonic. (3) Geographic patterns of instantaneous strain may not reflect patterns of seismic moment release over the long term. (4) Rates of large earthquakes must be extrapolated from rates of small ones.

2002 CHANGES: The geodetic potential map employs the newest SOPAC GPS data and awaits release of SCEC Crustal Motion Map3 which should be available in 2003. New color scheme has been developed for use in all the maps.

II. Geological Hazard Models

<u>Technical description.</u>

1) Turn small patches of each fault into moment rate sources, using known fault slip rates and down-dip extent.

2) Smooth the moment rate of these sources into maps of moment rate density. This step merges the earthquake potential of adjacent faults, accounts for potential location uncertainties and makes a fault based estimate into a grid based estimate.

3) Translate the mapped moment rate density into earthquake rate density (Figure 2). Ultimately, for well-known faults, this distribution could be based on actual rupture mode statistics. Currently, I use the Gutenberg-Richter relation with given b-value and M_{max}.

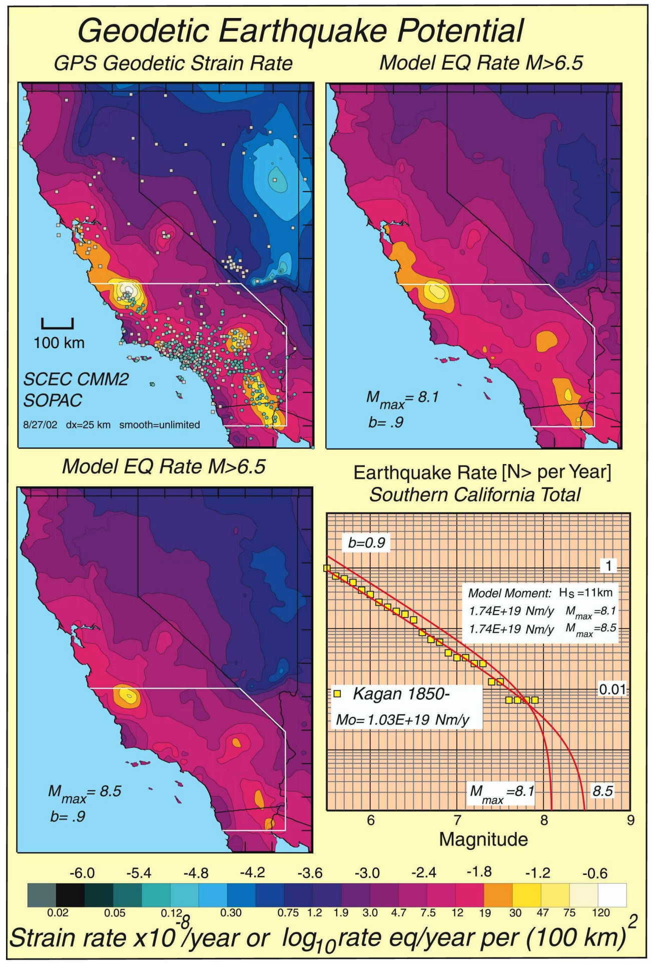

Figure 1. Geodetic earthquake potential models for $M_{>}$=6.5 assuming b=-0.9 and M_{max}=8.1 (top right) or 8.5 (lower left). The geodetic strain rate is mapped in the upper left panel. Note that the *geodetic moment rate* of 1.74 x 10^{19} Nm/y exceeds the 1850-2000 *seismic moment rate* of 1.03 x 10^{19} Nm/y. Because moment is conserved, the choice of M_{max} has an effect of about a factor of two on most earthquake rates (lower right). M_{max}=8.5 fits the historical earthquake rates fairly well.

<u>Required Information</u>: (1) Maps of fault traces with a resolution of a km or two. (2) Orientation of the faults. (3) Down dip seismogenic depth. (4) Slip Rates. (5) Rupture mode statistics if known, otherwise a M_{max} and b-value for the Gutenberg-Richter relation.

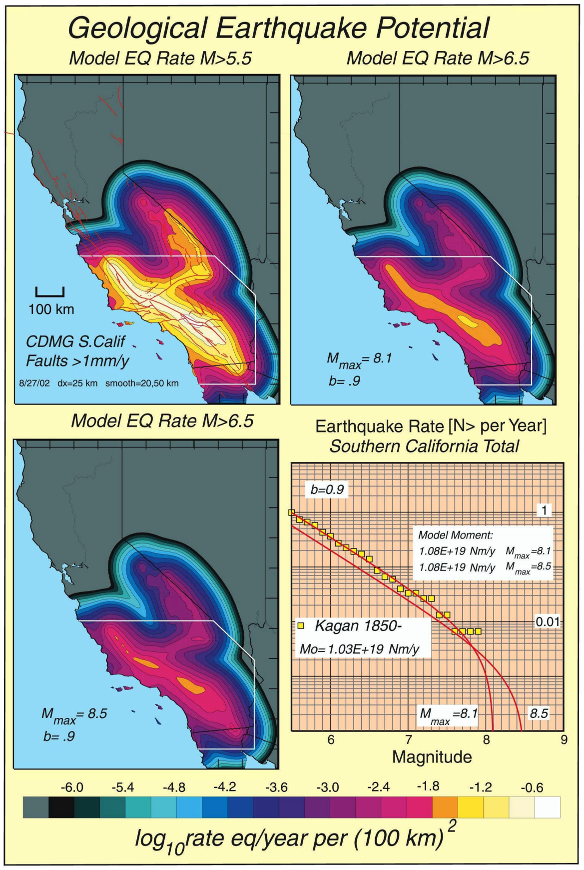

Figure 2. Geological earthquake potential models for $M_>$=5.5 and 6.5 assuming b=-0.9 and M_{max}=8.1 (top row) or 8.5 (lower left). Note that the long-term *geological moment rate* of 1.08 x 10^{19} Nm/y is close to the 1850-2000 *seismic moment rate* of 1.03 x 10^{19} Nm/y. Because moment is conserved, the choice of M_{max} has an effect of about a factor of two on most earthquake rates (lower right). M_{max}=8.1 fits the historical earthquake rates fairly well.

Advantages: (1) Earthquake potential falls near known faults. (2) Gives proper account to well constrained fault slip rate information and to historically quiet faults. (3) Conforms well with traditional approaches to earthquake hazard. (4) Maps fault-based hazard to grid-based hazard.

Drawbacks: (1) Geologists will never be able to specify every fault location and slip rate. (2) Does not necessarily reproduce historical earthquake rates. (3) Rates of large earthquakes must be extrapolated from rates of small ones. (4) No obvious means to include time dependence.

2002 CHANGES: The geological potential map is currently upgrading to include all faults slipping at rates >1/4 mm/y. There are over 5,500 km of faults in southern California that meet that criterion including all those in the Eastern California Shear zone. A new multi-scale smoothing was employed to smooth some potential over the whole southern California region, yet still concentrate hazard near faults. Output from the geological model was the first to be included in Ned Field's web-based hazard application.

III. Seismic Hazard Models

Technical description.

1) Smooth catalog epicenters into earthquake rate density down to a minimum magnitude M_{min} where significant geographic coverage can be obtained, but not so low that catalog completeness becomes an issue.

2) Rescale the smoothed rates to reproduce $N_>(M_{min})$ for the region of interest.

3) Extrapolate earthquake rates at M_{min} to higher magnitudes using a Gutenberg-Richter relation with given b-value and M_{max} (Figure 3).

Required Information: (1) Catalog of earthquake locations, dates and magnitudes. (2) Good estimate of catalog completeness level (minimum magnitude) versus catalog length.

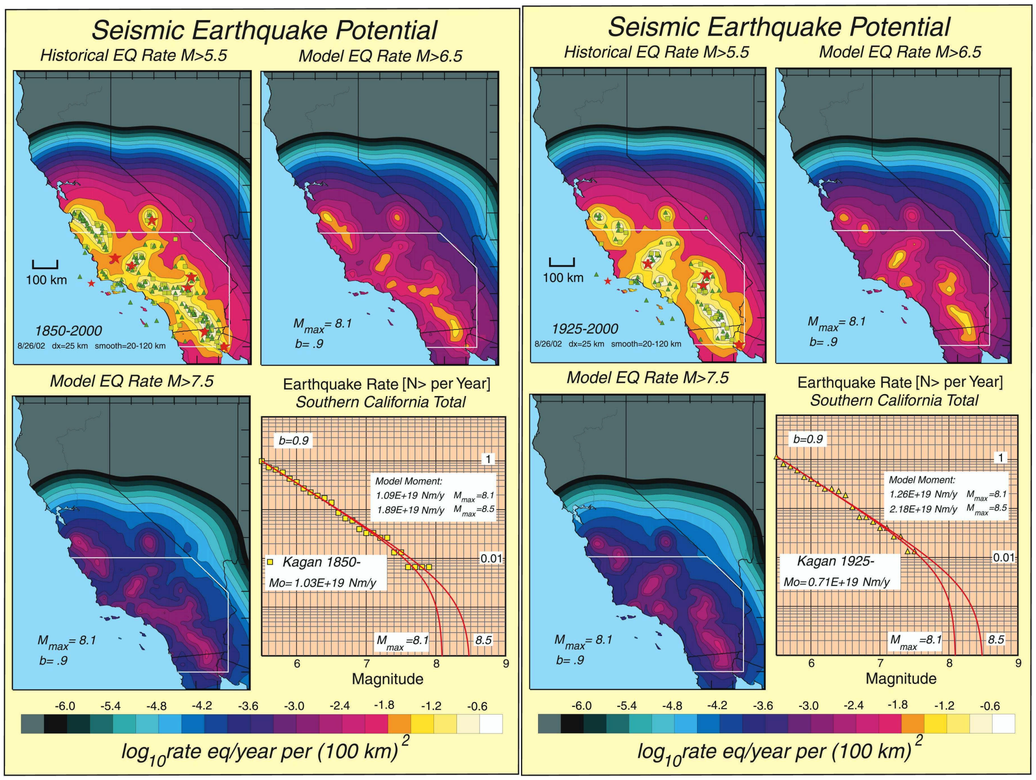

Figure 3. Seismic earthquake potential models for $M_>$=5.5, 6.5 and 7.5 assuming M_{min}=5.5, b=-0.9 and M_{max}=8.1. The figures use Kagan's earthquake catalog in the interval 1850-2000 (left) and 1925-2000 (right). Unlike the shorter catalog, the longer catalog is not complete to M=5.5 -- still, the better geographic sampling of seismicity in the longer catalog seems to more than compensate. Because $N_>(M_{min})$ is conserved, the choice of M_{max} has little effect on the rates of all but great earthquakes (lower right panels).

Advantages: (1) Earthquake potential concentrates near locations that actually had earthquakes. (2) Straightforward estimator. (3) Arguably a time-dependent indicator. (4) Reproduces observed seismicity rates. (5) Serves as reality check on other estimators.

Drawbacks: (1) Seismicity sample limited. Because direct predictions deteriorate for larger magnitudes, rates of large earthquakes must be extrapolated from rates of small ones.

2002 CHANGES: The seismic potential map now uses the SCEC earthquake catalog 1800-2002 complied by Kagan and Jackson. Catalog completeness length versus magnitude is now taken into consideration in the rate estimates. Because smoothing tends to smooth more earthquakes out of the southern California (white box) than it brings in, we also now rescale the "a-value" to reproduce the actual observed rate for southern California.

IV. Earthquake Simulation Hazard Models

Technical description.

1) Run several thousand year simulation on the southern California fault system using known fault slip rates with guidance provided by recurrence and slip-per-event information.

2) Smooth the computed seismicity taking into consideration the finite extent of ruptures.

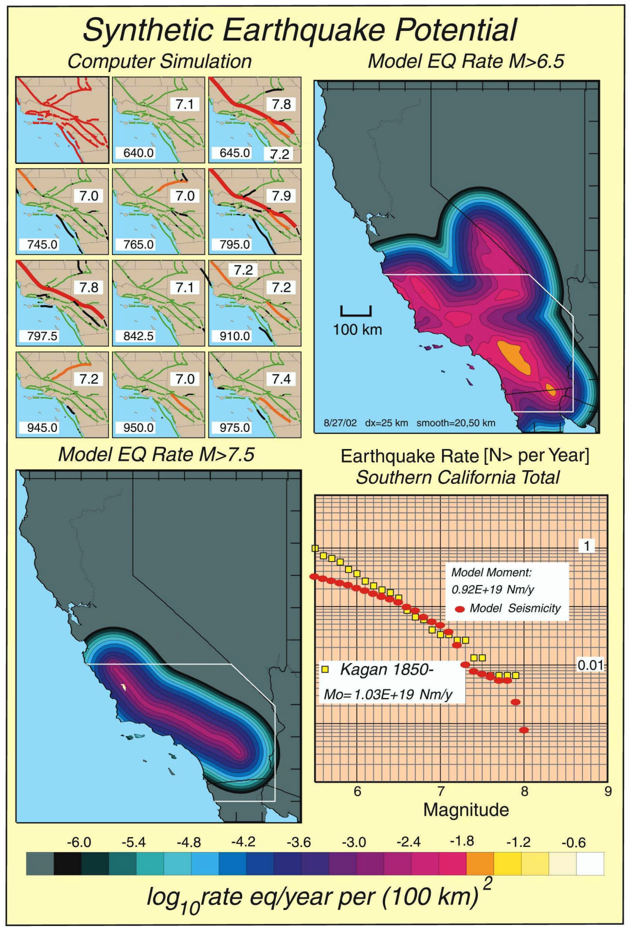

Figure 4. Synthetic earthquake potential models for $M_{>}$=6.5 (top right) and 7.5 (lower left). The computer simulation (upper left) uses the same fault catalog and slip rates as the geological models. Unlike the geological models, synthetic seismicity models **do not** employ a Gutenberg-Richter relation.

<u>Required Information</u>: (1) An earth structure and a set of faults. (2) A means to apply tectonic loading stresses to these faults between earthquakes. (3) A means to transfer stresses from fault to fault during earthquakes. (4) A means to decide when and where an earthquake should start, and how big it should grow to when it does start (fault friction law).

<u>Advantages:</u> (1) Conforms well with traditional approaches to earthquake hazard. (2) Relative earthquake rates (b-value) and M_{max} not fixed a-priori. (3) Potential to supply time-dependent statistics.

<u>Drawbacks:</u> (1) Does not necessarily reproduce historical earthquake rates. (2) Simulations are time consuming and have many parameters (strength, friction). (3) Some scientists question the results.

2002 CHANGES: The simulation potential map in Figure 4 is brand new. It had been proposed earlier but this is the first hazard map actually computed from a computer simulation. Since Figure 4 was made, the earthquake simulator has expanded to include all faults slipping at rates >1/4 mm/y. Too, in 2002 I have also begun closer collaboration with paleo-seismologists to "tune" the simulation. Better maps and animations are on the way.