Annual Report to the Southern California Earthquake Center: Progress During 2005

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Virtual California Simulations. There are major differences between the simulation-based forecasts that we have produced during this year and the statistical forecasts given by the Working Group on California Earthquake Probabilities. In a paper published this year [1], we considered the problem of determining the probability distribution of inter-event times, rather than assuming them. The distribution of event intervals can be obtained directly from simulations, which include the physics of fault interactions and frictional physics. Since both methods use the same database for mean fault slip on fault segments, they give approximately equal mean inter-event times. The major difference between the two methods lies in the way in which inter-event times and probabilities for joint failure of multiple segments are computed. In our simulation approach, these times and probabilities come from the modeling of fault interactions through the inclusion of basic dynamical processes in a topologically realistic model. In the WGCEP statistical approach, times and probabilities are embedded in the choice of an applicable probability distribution function, as well as choices associated with a variety of other statistical weighting factors describing joint probabilities for multi-segment events.

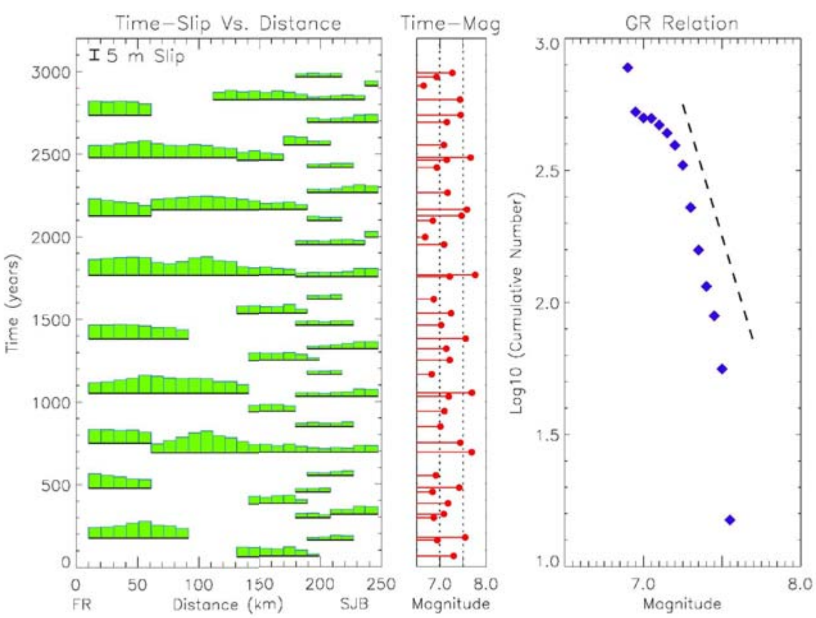

Fig. 1. Illustration of simulated earthquakes on the "San Francisco section" of the San Andreas fault from Fort Ross (FR) south to San Juan Bautista (SJB). In the left panel, the slip is given as a function of the distance along the fault for each earthquake over a 3000 year period. The center panel shows the corresponding moment magnitude of each of the simulated earthquakes. The right panel gives the cumulative frequency-magnitude distribution during the entire 40,000 year simulation. The dashed line has a slope (b-value) of 1. See ref. [1].

In our work summarized in [1-4], we found two main conclusions, 1) that the probability distribution characterizing the failure of multiple fault segments in Virtual California is of the Weibull type, rather than the Brownian passage time (BPT) or Log-normal (LN) type now assumed by the WGCEP group, and 2) that forecasts can be made about the probability of large earthquakes using simulation based methods. Our general approach is analogous to the simulations used to forecast the weather. An example of the type of statement that can be made about the seismic hazard is: "There exists a 5% chance of an earthquake with magnitude $m \geq 7.0$ occurring on the San Andreas fault near San Francisco prior to 2009 and 55% chance by 2054". The practical use of statements like this for hazard estimation using numerical simulations must of course be validated and extended in an ongoing process by more computations and observations. We plan to continue to work with the RELM group on this problem.

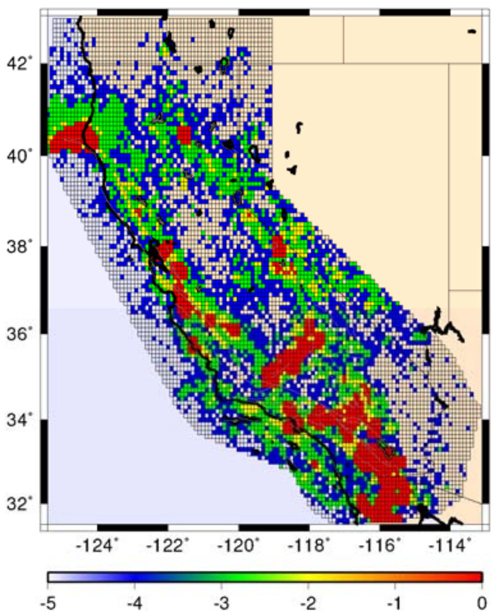

Figure 2. Continuous probability forecast map for California region RELM contest. Non-normalized Probabilities for occurrence during a 5 year period beginning September 1, 2005 are shown.

Hotspot Maps. During this period, we developed and extended the hotspot map techniques we introduced for intermediate-term earthquake forecasting Pattern Informatics (PI) and Relative Intensity (RI) methods. We continued to monitor the success of the maps in real time, we extended the methods to other seismically active geographic regions, including Japan, world-wide, and Taiwan, and we developed new means of statistically evaluating the quality of the forecasts, comparing our PI method to our RI method [6-16]. These methods are based on *Relative* (or *Receiver*) *Operating Characteristic* diagrams for binary forecasts using decision thresholds, very similar to methods used in binary tornado, El Nino, hurricane, and climate foreasting. We have also participated in an evaluation of our methods by the California Earthquake Prediction Evaluation Council on September 20, 2005. Recall that the RI map represents regions where the average intensity of seismic activity for magnitudes M ≥ 3 (for California; M ≥ 5 world-wide) is highest, whereas the PI map represents areas where the averaged squared change in intensity of events having M ≥ 3 (for California; M ≥ 5 world-wide) over a ~10 year period is largest. Recall that both methods forecast the likely locations of M ≥ 5 events (for California; M ≥ 7 world-wide) over the succeeding 10 years. We have also found a

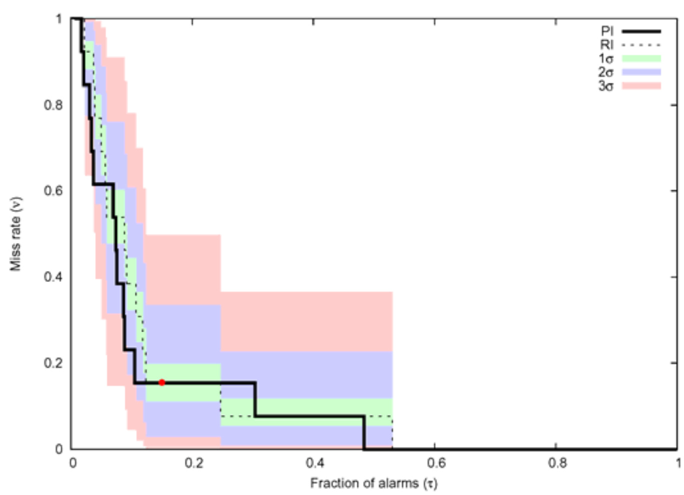

Figure 3. Statistical test of improvement of PI map over RI map, a plot of miss rate against fraction of map area covered by alarms. Dark stepped line is PI, dashed stepped line is RI. Colored stepped lines represent the confidence intervals relative to the RI map for 1 standard deviation (1σ = green), 2 standard deviations (2σ = blue) and 3 standard deviations (3σ = red). Red dot represents the decision threshold (in hotspot area as a fraction of the total mapped area) of the original PI map published in [17]. Method from J. Zechar and T. Jordan

means to modify our hotspot map method so that we could participate in the RELM "contest" on earthquake forecasting, by combining our basic methods and using the Gutenberg-Richter Magnitude frequency relation to produce a forecast map with continuous probabilities. This new map is amenable to testing by a likelihood ratio test developed by the RELM group. A caveat is that likelihood tests are plagued by known, serious defects. We are therefore working with J. Zechar and T. Jordan on new methods of testing our basic hotspot maps using Molchan-type error diagrams, plotting miss rates against fraction of alarms to estimate the confidence level at which the PI map outperforms the RI map. In Figure 2, we show the new continuous probability map [15]. In Figure 3, we show the evaluation of our original PI map against our original RI map using the Molchan-type error analysis. On this figure, a red hotspot is counted as a successful prediction if the epicenter of a significant earthquake ($M \geq 5$) lands in the Moore neighborhood of a red hotspot. It can be seen that the PI map outperforms the RI map by as much as 2 standard deviations (2σ).

Theory. Over the last year we have concentrated on understanding the physics of fault systems underlying forecasting large events. We have pursued this study via simple models, the physics that governs their evolution and the relation between the physics of the models and the physics of the fault systems.

We have made progress in several areas.

1. In order to develop an understanding of the fault system physics from models we have continued our study of the relation between various types of models. To that end we have done an extensive study of the Burridge-Knopoff(BK) model with long range springs and a velocity weakened friction force to determine if the statistical distribution of events differs from the one obtained from the cellular automaton version of the same model. The friction force contains a parameter α that determines the rate of the velocity weakening.(The larger α, the slower the weakening) We found that for small α the BK model was virtually identical to the CA models whereas for large α there was a much smaller scaling region and more characteristic events. This work was accepted for publication in Physical Review Letters[18]. A longer paper is in preparation.[19] These results also indicate the importance of getting the friction law right when modeling faults and fault systems.

2. We have examined the CA version of the BK model for precursors of large events. These were found and can be related to the PI and RI techniques. This paper is in preparation[20]

3. We have examined the nucleation process in systems with elastic forces. The reason for this study is that in the CA version of the BK model the largest events were triggered by nucleation. We found that the nucleation process was non-classical and had a structure that might provide some insight into the relation between the nature of the precursory activity and the size of an event.[21]

4. We are studying various fault systems world wide for ergodic behavior and the link between ergodicity and forecastibility. The results are currently being prepared for publication.[22]

Papers acknowledging SCEC grant

J.B. Rundle, D.L. Turcotte and P.B. Rundle, The future role of numerical simulations in RELM forecasts, *Seism. Res. Lett*., in review (2005). (SCEC contribution number 940)

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