Annual Report: Collaborative Research – Emergent Modes on Earthquake Fault Systems

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Over the past year we have made significant progress in four areas of significance. They are; forecasting, the physics of fault systems, properties of models and theory.

<u>Forecasting (Southern California Data):</u> We have improved our Pattern Informatics (PI) forecasting technique and updated our forecast through 2002. Our success rate has been encouraging (see Figure 1). In addition it appears from the data that the medium size earthquakes are the predictors for the large events as postulated in previous work (Tiampo et al., 2002a; Tiampo et al., 2002b, under previous SCEC/RELM grant).

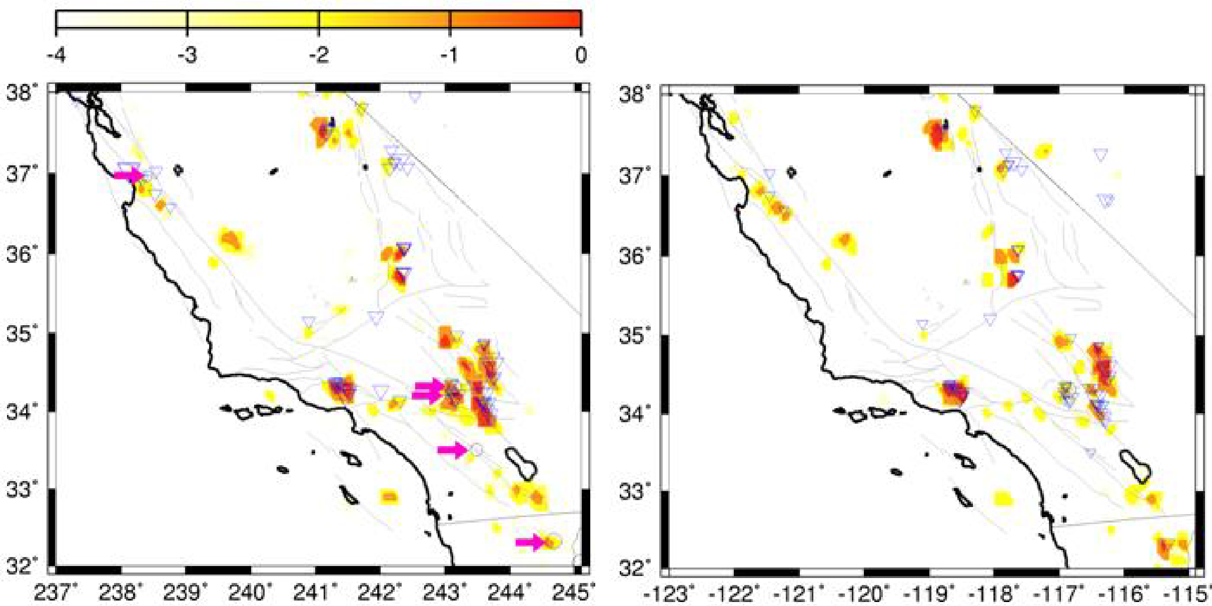

Figure 1: PI index for 1999-1989 (left) and 2002-1992

In addition, we developed a technique for identifying the upcoming rupture dimension, and, by extension, the total moment release, of an upcoming event in southern California, as shown in Figure 2. Here we show the PI index for ever-growing regions around the upcoming Coalinga event (no seismic data is used here for 1983 or later). The picture on the left shows the PI index calculated only around the upcoming anomaly, while the middle and right pictures show the same calculation, but for larger regions. The PI index is a constant value for the colored region on the right, and characterizes the Coalinga mainshock and aftershock region entirely. As rupture dimension can be directly related to seismic moment release, this technique can apparently be used to predict the total magnitude of a future earthquake, including its major aftershocks. This work will be submitted to the upcoming special issue on RELM in BSSA.

Earthquake Fault Systems Physics: We have made significant progress in understanding one of the basic statistical parameters of mean field models of earthquake faults, ergodicity, and applied it to the southern California fault system seismicity. This work is in press (Tiampo et al 2003a, 2003b). Using the idea of a metric (Thirumalai and Mountain 1993) we compared the temporal average of the number of events per unit area to the spatial average of the same quantity in the Southern California Fault System (SCFS). We found that the difference between these two averages approached zero as a function of time (Tiampo et al 2003a) However, the approach to zero is not fit by a single function of the form D/t as required for ergodicity.(Thirumalai and Mountain 1993).

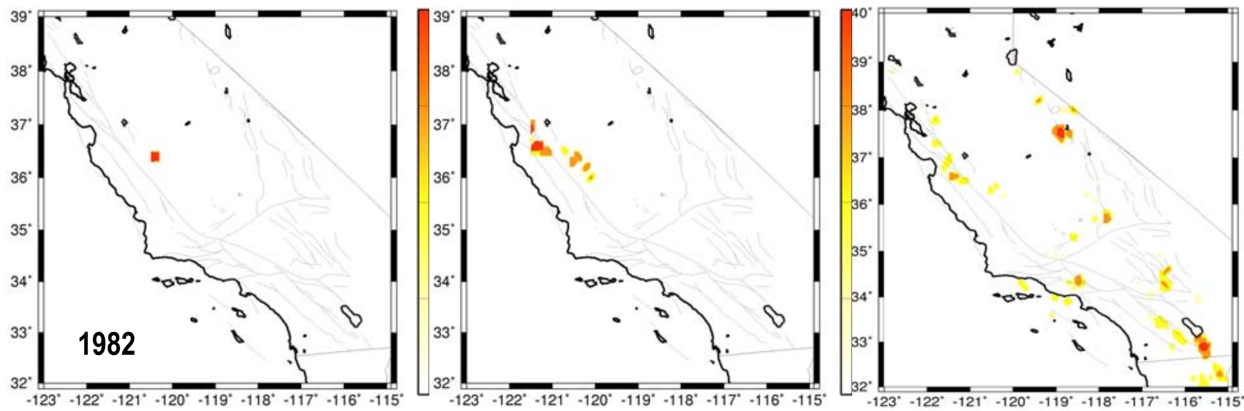

Figure 2: PI index for the region around the 1983 Coalinga earthquake, calculated for increasing region size, from left to right.

Here, D is a diffusion Instead one sees temporal regions where the fit is of the form D/t with different values of D, separated by regions that cannot be fit with a function of the form D/t at all. This behavior, as we have seen previously in cellular automata(CA) models (Ferguson et al 1999) of earthquake faults with long, but finite range interactions or stress transfer, is indicative of what we call punctuated ergodicity or punctuated equilibrium.

In the models we have examined the system behaves as if it were in equilibrium until a large event pushes the system out of the equilibrium state. The system then re-establishes itself in equilibrium after some time. In the models, where the range of interaction or stress transfer R is tunable, the length of time that the system is in equilibrium, (i.e. the metric can be fit by the form D/t) increases as R increases and diverges with R. (Anghel et al 2003) In the SCFS the deviation of the metric from the D/t form can, in each instance, be correlated with a large event of magnitude greater than five. Our conclusion is that like the models with finite but large R the SCFS is in a state of punctuated equilibrium or ergodicity. That is, there are time intervals in which the system can be described by an equilibrium picture, separated by large events that drive the system out of equilibrium. These results have significant implications for understanding our forecasting approach. We discuss these implications below.

Modeling: We have investigated two classes of models. One takes as its inspiration the Burridge-Knopoff BK) model. The other is what we refer to as Virtual California (VC). In the BK class of models we have investigated both the cellular automaton (CA) versions as well as the original BK model with inertia and real friction forces. In all of our investigations we use long-range forces or stress transfer. For example, in the original BK model rather than the nearest neighbor springs used by BK we have springs from each block to many other blocks.

The purpose of these investigations is to identify properties and patterns that transcend the specific class of models and may be found in real fault systems as well. An example of such a property, the punctuated equilibrium or ergodicity discussed above, was found first in the CA version of the BK models.

In the previous year we have produced several results.

a) In the long-range CA models we have looked carefully at the Gutenburg-Richter scaling and found that rather than one type of earthquake event these models have three types (Anghel et al 2003) of events that exhibit scaling. These events can be understood via the Langevin approach to these models valid in the R goes to infinity limit. (Klein et al 1997, Klein et al 2000) They can be classified as types of equilibrium fluctuations near the mean-field spinodal.

b) In these models larger (almost system size) events occur that do not scale (Anghel et al 2003) and cannot be described by the Langevin equation derived in Klein et al 1997. These are not equilibrium fluctuations but are events that drive the system out of equlibrium. In addition these events initiate a long lived pattern that provides a memory. This pattern must decay away before the system returns to equilibrium(Anghel et al 2003). Aspects of this behavior were seen in the SCFS as discussed above.

c) We have also begun to test the effect of healing time in the long range stress transfer CA models. In this case after a site has failed there is a specified waiting time before the site can support stress. If stress is transferred to a site before it heals that stress is dissipated. We note an increased frequency of large system wide events, compared to the system with instantaneous healing, with an attendant longer lasting memory. We have found, via measurements of the two-time correlation function and the metric, that the large events generate non-equilibrium behavior(Weatherly at al 2003).

d) We have begun the investigation of the original BK model with long range springs. Preliminary measurements with a velocity weakened friction force indicate punctuated ergodicity. In addition there is evidence of more than one type of scaling event as in the CA models. (Jun et al 2003)

The VC model was constructed to test the effect of real fault morphology on earthquake patterns.(Rundle et al 2002). In the past year we have developed an efficient parallel code to enable simulations with a more realistic fault distribution. (Rundle 2003). This code has a new piece of failure physics that models the effect of a dynamic stress intensity factor. With this code, we are presently working to understand the data that Tom Rockwell and Jim Dolan have developed using paleoseismic field methods. These data indicate phase locking between the faults of the Eastern Mojave Shear Zone and the Los Angeles Basin. The VC code, which has been checked and demonstrates realistic Gutenberg-Richter magnitude-frequency relations, shows some evidence to support the phase locking idea over time periods of 10,000 years or more, although the phase locking does disappear after additional time passes.

Theory: Since our models and the SCFS are in a punctuated equilibrium or ergodic state with large events that are not equilibrium fluctuations, the standard Langevin equation (Klein et al 1997) will not completely describe the system. Since we know from the calculation of the ergodicity metric and the unequal or two-time correlation function that the large events set up long lived patterns that provide a memory, we have used projection operator techniques(Zwanzig 2001) to generate a Langevin equation with a memory kernal. This approach gives us a natural description of a system out of equilibrium due to a long lived pattern generating a memory.(Klein et al 2003)

Publications :

(Publications under this grant are designated with an asterix. We will be requesting SCEC numbers for these if accepted).

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