2003 Annual Report

**Testing Models for Accelerating Seismicity**

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The primary objective of last year's project was to see if we could use small events to distinguish between four hypotheses for the origin of the accelerated seismic moment release (AMR) observe before many large earthquakes. These are: 1) the damage mechanics model (Ben-Zion and Lyakhovsky, 2002), 2) the critical point model (Sornette and Sammis, 1995), 3) the stress recovery model (King and Bowman, 2002), and 4) the generalized "ETAS" type aftershock model (Helmstetter et al., 2002).

The motivation was that the AMR signal is primarily due to an increase in intermediate sized events. Because there are not many of these, the statistical significance of the observations is low – particularly their spatial distribution that might distinguish between the four models. The hope was that the myriad of smaller events also carries a signal that might have enough statistical weight to make a distinction.

There is a more fundamental issue here that lies behind these studies and the work proposed this year. The question is whether the crust has a "memory" of past events. The first three models implicitly assume that there is a state of the crust in which large events are more likely while the fourth assumes that an event changes the probability of the subsequent events of all sizes in a way which does not take past history into account. Hence, any evidence that the "state of the crust" is a meaningful concept and that it changes with time is relevant to this argument.

Two graduate students worked on this project, Shoshana Levin and Youlin Chen. Both finished their Ph.D. work this fall and their results from this study formed a significant part of each thesis. Both students focused on the ten years of seismicity preceding the 1992 M=7.3 Landers earthquake, since this the largest recent event with the lowest magnitude of completeness for its precursory catalog. This event had a strong AMR signal with an optimal radius of 125 km. (Bowman et al., 1998; Bowman and King, 2001).

Ms. Levin compiled a catalog of 32,610 fault plane solutions and moment tensors for events down to magnitude 0. She then used the method developed by Kostrov (1974) to convert these into a regional strain field, which she compared with the strain field predicted by the King and Bowman (2002) stress accumulation model (Fig.1). This predicted pre-Landers strain field she calculated using the "backslip" method in which the fault displacements that occurred during Landers were reversed to find the strain field that existed at the time of the event. She obtained a positive correlation between the strain orientations implied by the small earthquakes and that predicted by the stress accumulation model. This correlation was optimal when a background tectonic stress of 5-30 bars was superimposed on the backslip field. She also observed that the median distance of yearly moment release decreased with time up to the Landers event as predicted by the stress recovery model, but that the effect was not limited to the active lobes predicted by that model. We are currently condensing her thesis "Using Small Events to Measure the Evolution of the Strain and Stress Fields Before the 1992 Landers California Earthquake" into a publication.

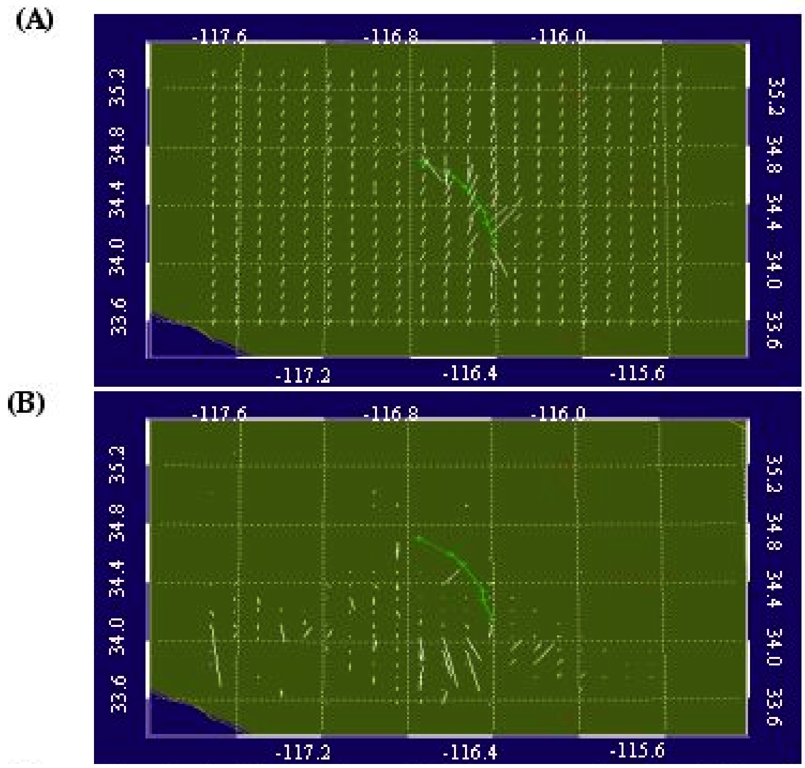


**Figure 1.** The pre-Landers model and seismicity-based strain fields mapped on a grid with 10km x10km spacing. The white bars indicate the vector of maximum horizontal shortening at each grid point. Panel (A) shows the strain field predicted by the stress accumulation model with a superimposed background tectonic loading stress of 10b. The bars are scaled by vector amplitude with the maximum set at 1/10 the hight of the map. Panel (B) shows the strain released by $1.0<M<3.99$ events between 1/1/87 and 4/22/92 (before the Joshua Tree earthquake). In (B) the bares are scaled such that the largest is 1/5 the height of the map. From Levin, Ph.D. Thesis (2003).

Mr. Chen chose the three-paper option for his Ph.D. dissertation. Two papers were on asperity mechanics and the third was related to this project:

*Chen, Y. and C.G. Sammis, Spatial and Temporal Patterns of Regional Seismicity Preceding the 1992 Landers California Earthquake, Geophysical Journal International, submitted, 2003.*

In this paper we examined clustered and declustered catalogs for ten years prior to the Landers earthquake down to the magnitude of completeness (mc=2.1). The results are summarized as follows:

1) The a-value in the Gutenberg-Richter distribution increased over all of southern California for the 10 year prior to the Landers event. For distances less than about 125 km, fluctuations in the a- and b-values are uncorrelated (see Fig.2). At a distance of about 125 km there is a sharp increase in the correlation coefficient. For distances greater than about 125km, a- and b-value are almost perfectly correlated. R=125 km is the radius found by Bowman et al., (1998) that optimized the AMR signal.

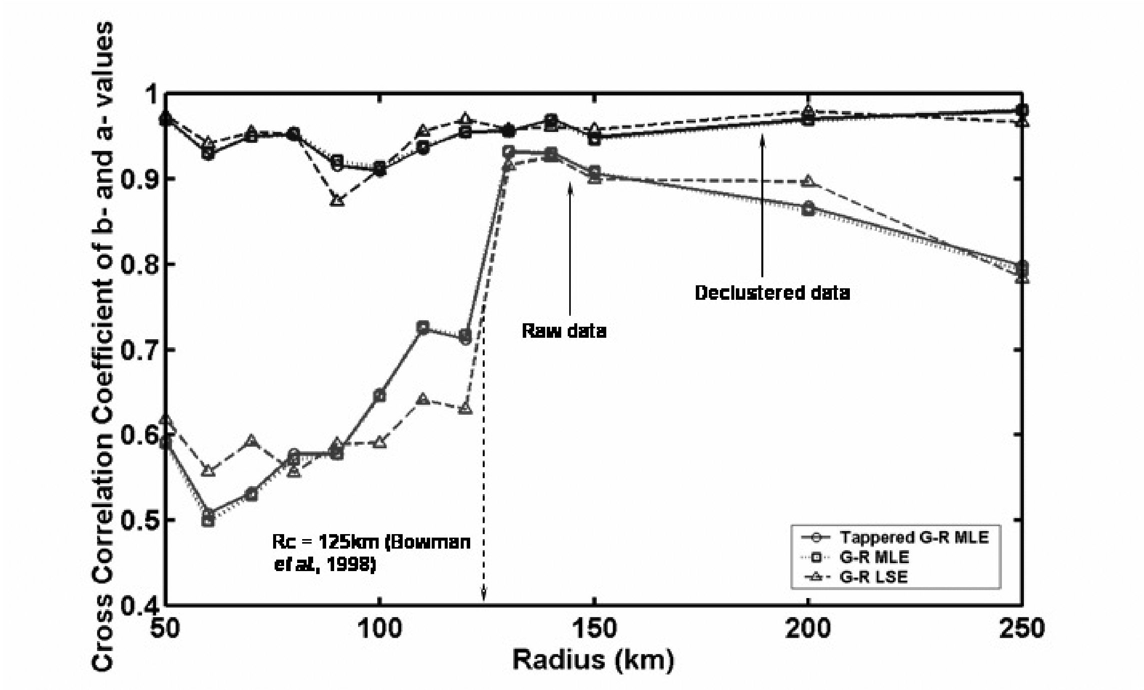


**Figure 2**. Correlation between a- and b-value as a function of region size. Note the sharp increase in correlation at about *R*=125 km. From Chen and Sammis, 2003.

2) We used the algorithm developed by Reasenberg (1985) to identify clusters. We found that the number of clusters, the size of the clusters, and the percentage of events that belong to a cluster all increased over the ten years prior to Landers.

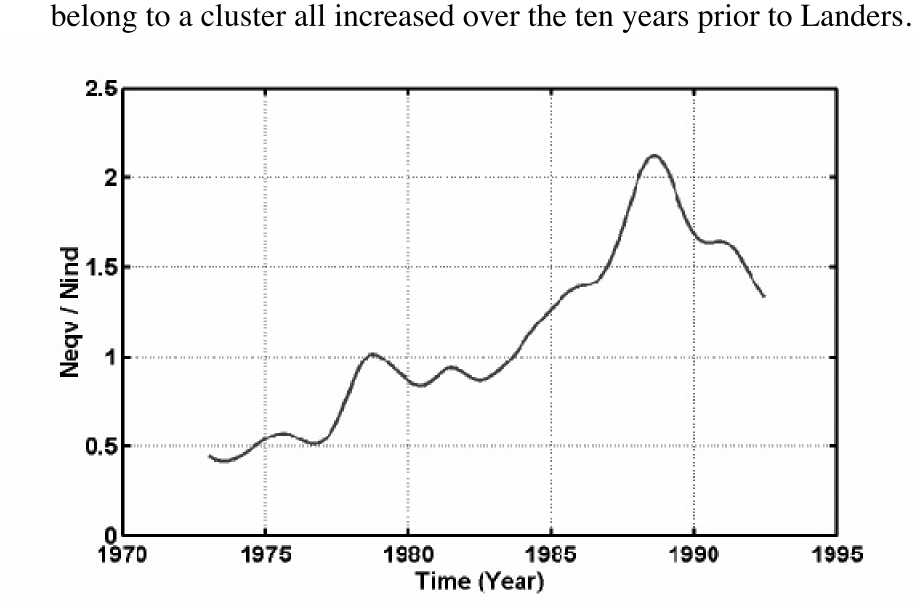


**Figure 3**. Ratio of number of clusters to number of independent events as a function of time up to the Landers earthquake. From Chen and Sammis (2003).

3) We observed a migration in the time that the accelerated moment release began. AMR first appeared at large distances from the epicenter and migrated inward with time up to the Landers event. Surprisingly, this signal was strongest for the declustered catalog, and was strongest for the "active lobes" of the stress recovery model.

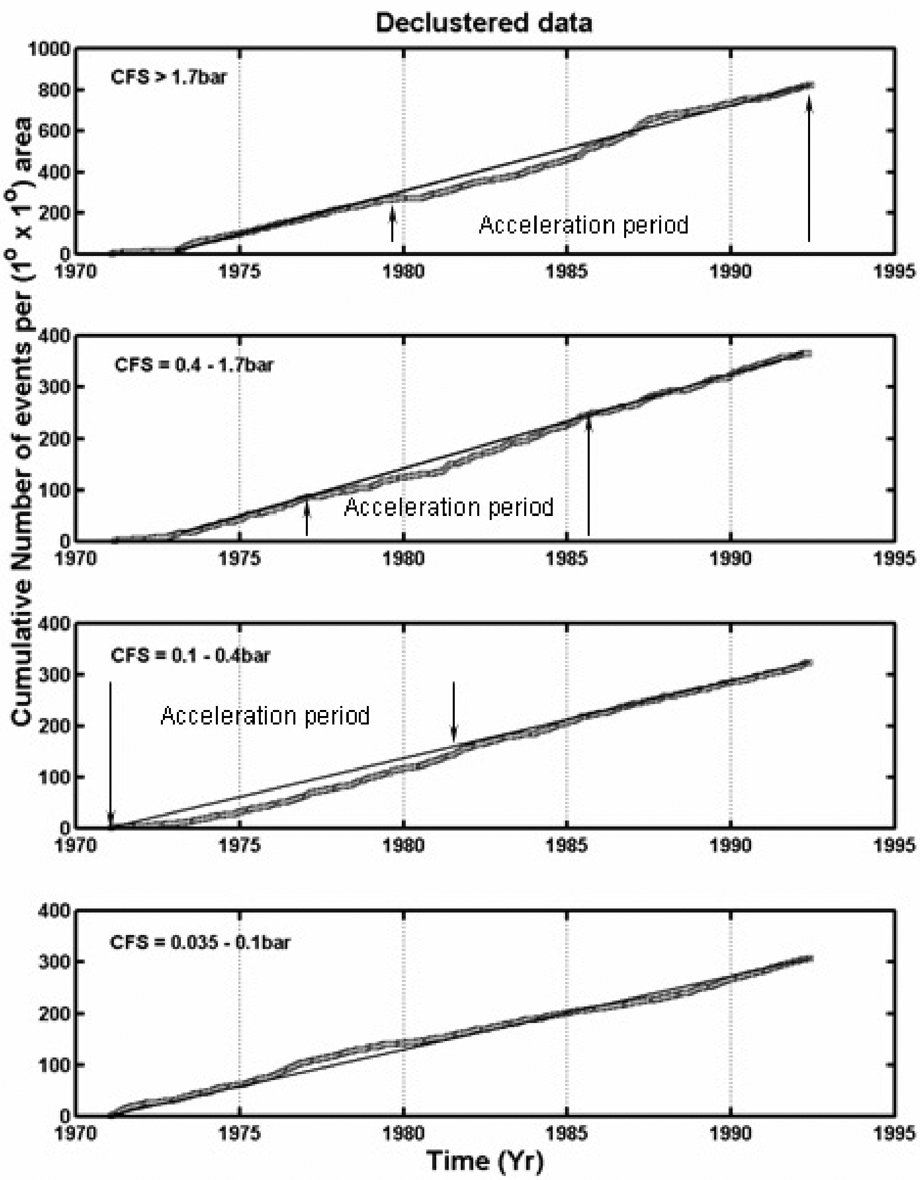


**Figure 4.** Cumulative events as a function of time in the active lobes of the stress accumulation model for the declustered catalog. Each panel shows the seismicity between the two Coulomb Failure Stress (CFS) contours specified. The regions become increasingly distant from the epicenter from the top to the bottom panel. Note that the period of acceleration begins first at distance and then moves in toward the epicenter. No Acceleration is observed between the two most distant contours in the bottom panel (equivalent to $R$>125 km.). From Chen and Sammis (2003).

*References*


Ben-Zion, Y. and V. Lyakhovsky, Accelerated seismic release and related aspect of seismicity patterns on earthquake faults, Pure appl. geophys., 159, 2385-2412, 2002.

Bowman, D.D., G. Ouillon, C.G. Sammis, A. Sornette, and D. Sornette, An observational test of the critical earthquake concept, *J . Geophys. Res.*, 103, 24,359-24,372, 1998.

Bowman, D. D., and G. C. P. King, Stress accumulation and accelerating seismicity before large earthquakes, *Geophys. Res. Lett.*, 28, 4039-4042, 2001.

Chen, Y. and C.G. Sammis, Spatial and Temporal Patterns of Regional Seismicity Preceding the 1992 Landers California Earthquake, Geophysical Journal International, submitted, 2003.

Helmstetter, A., D. Sornette, and J-R Grasso, Mainshocks are aftershocks of conditional forshocks: how do foreshock statistical properites emerge from aftershock laws?, J. Geophys. Res., in press, 2002.

King, G. C. P., and D. D. Bowman, A physical model for seismicity during the earthquake cycle: Aftershocks, quiescence, and accelerating moment release, *J. Geophys. Res.*, submitted, 2002.

Kostrov, V.V., Seismic moment and energy of earthquakes, and seismic flow of rocks, Izv. Acad. Sci., USSR, *Phys. Solid Earth*, *1*, 13-21, 1974.

Reasenberg, P.A. Second-order moment of central California seismicity, 1962-1982, J. Geophys. Res., 90, 5479-5495, 1985.

Sornette, D., and C. G. Sammis, Complex critical exponents from renormalization group theory of earthquakes: Implications for earthquake predictions, *J. Phys. I*, 5, 607-619, 1995.