Anomalous Seismicity and AMR Preceding the 2001 and 2002 Calexico Mexico Earthquakes

Charles G. Sammis[(1)], David D. Bowman[(1,2)] and Geoffrey King[(3)]

(1) Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089-0740, USA (e-mail: sammis@earth.usc.edu; phone:+1 213-740-5836). (2) Now at: Department of Geological Sciences, California State University at Fullerton, Fullerton, CA 92834-6850 (e-mail: dbowman@fullerton.edu; Phone: +1 714-278-5436).
(3) Laboratoire de Tectonique et Mécanique de la Lithosphère, Institut de Physique du Globe de Paris, 4, place Jussieu, 75252 Paris cedex 05, France.

Introduction

Many large earthquakes are preceded by a regional increase in seismic energy release. This phenomenon, called “accelerating moment release” (AMR), is due primarily to an increase in the number of intermediate-size events and occurs within a distance R of the mainshock that scales with magnitude. AMR been observed before large earthquakes in many locations (see summary by Jaumé and Sykes [6]).

All of these observations are “postdictions” in the sense that the location of the main event was known and used as the center of the search pattern. The challenge is to use AMR in a predictive mode. On approach has been to use a circle of radius R (corresponding to a prescribed magnitude M in the scaling relation describe below) to search a grid for accelerating activity [see 8, 9, 5, 11]. Another approach is to search each element of a grid for activity that currently exceeds its long-term average. Figure 1 shows such a grid search recently published by Rundle et al. [10]. This paper is interesting because it postdicted several large events (marked by triangles on the figure), but especially because, subsequent to its acceptance for publication, a moderate M=5.2 event occurred in an area of anomalously high activity in northern Baja California near Calexico, Mexico. In this paper we explore this event using the full AMR analysis to see if the anomalous activity detected by Rundle et al. [10] is consistent with the AMR hypothesis.

AMR preceding the 2002 Calexico Earthquake

The M_w=5.7 Calexico earthquake, shown as the star in Fig 1, occurred on February 2: 2002 about 29 miles south of Calexico, Mexico along the eastern flank of the Sierra Cucap in Baja California. It was preceded on December 8, 2001 by a similar M_w=5.7 earthquake t the southeast (just south of the map in Fig.1). In our analysis we treat both earthquakes as double event and consider any precursory activity to apply to the pair. We first analyz precursory regional seismicity using the optimal circle method described in Bowman e al.[1]. We then apply a more sophisticated stress recovery method recently developed b Bowman and King [2, 3].

The optimal circle method

In this approach, the cumulative Benioff strain is calculated for seismicity with sequence of circles of increasing radius *R*. For each circle the cumulative Benioff strain i fit to a straight line and to a time to failure equation of the form

$$\varepsilon(t) = A + B(t_c - t)^m \tag{1}$$

where cumulative Benioff strain at time *t* defined as

$$\varepsilon(t) = \sum_{i=1}^{N(t)} \left[E_i(t)\right]^{1/2} \tag{2}$$

t_c is the time of the event, m=0.3, and *A* and *B* are adjustable parameters. A fit parameter ξ is defined as the ratio of the sum of the squared residuals from the fit of equation (1) to the sum of the squared residuals from the linear fit. Figure 2 shows this parameter as a function of the analysis radius *R* for the 2002 Calexico event.

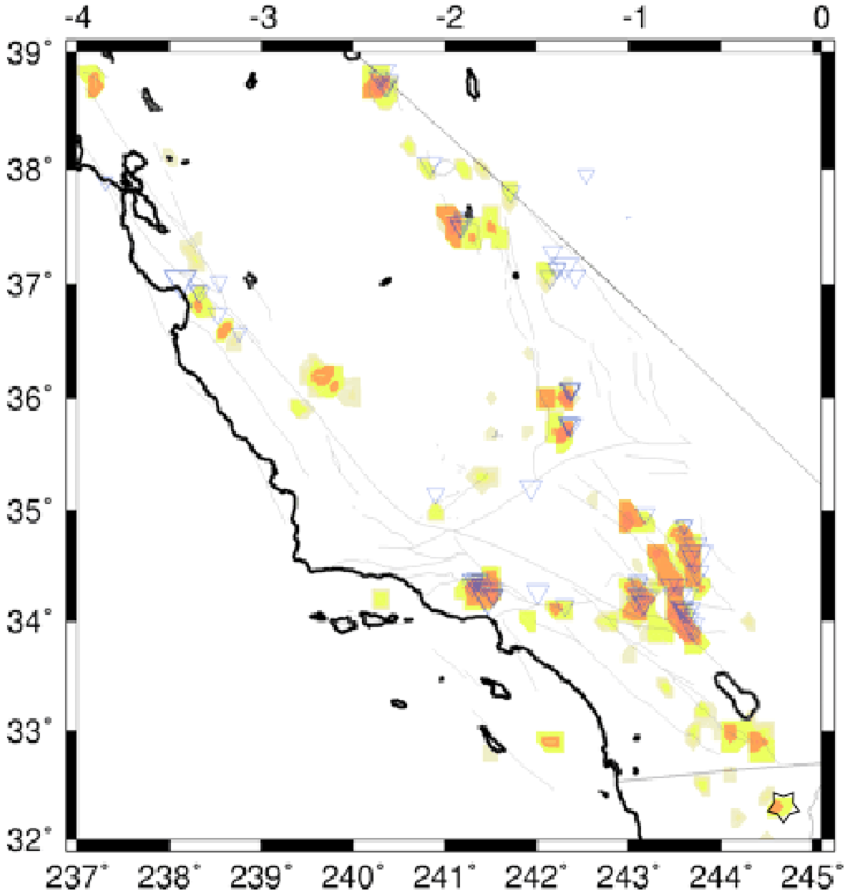

Figure 1: Shaded areas represent anomalous short-term activity relative to the long-term average. Inverted triangles are events during 1989-1999 (from Rundle et al., 2002). The star is the location of the February 22, 2002 earthquake near Calexico Mexico.

Note that the fit of equation (1) is optimal (minimum ξ) for R=60±10 km. Figure 3 shows the cumulative Benioff strain at the optimal R while Figure 4 shows that this optimal R is consistent with the scaling relations found by Bowman et al. [1] and other investigators

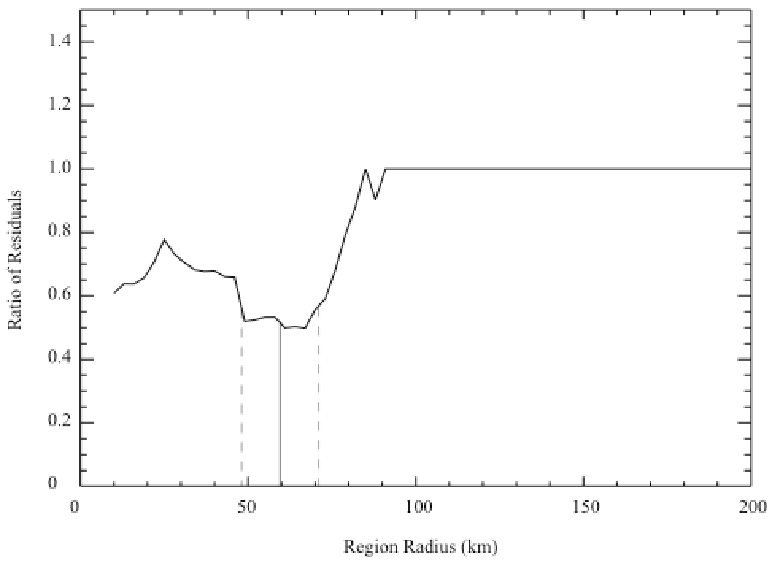

Figure 2: Ratio of the squared residuals from the fit of the cumulative Benioff strain to equation (1) to those from a linear fit to the same data as a function of the region radius R. Note that the residuals from equation (1) are a minimum for 50km<R<70km.

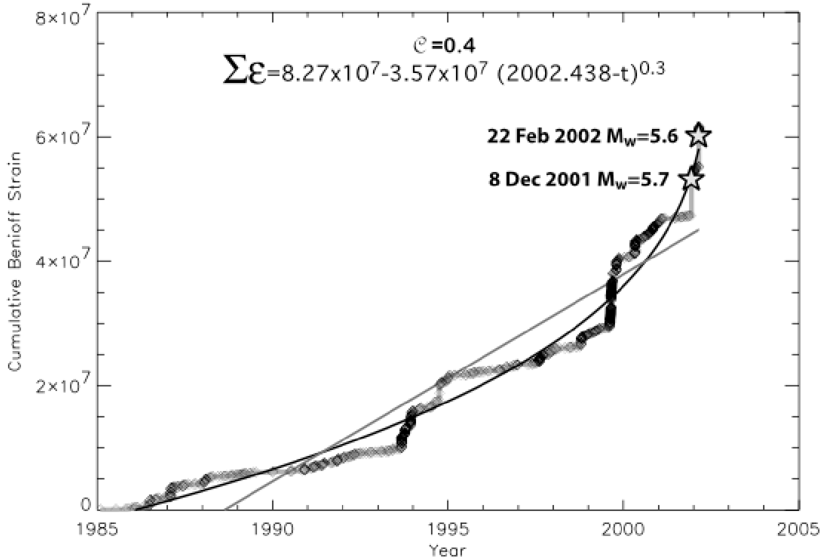

Figure 3: Cumulative Benioff strain in the optimal region R=60km. The heavy line is the fit to equation (1), the light line is the best linear fit. Stars indicate the two northern Baja California earthquakes.

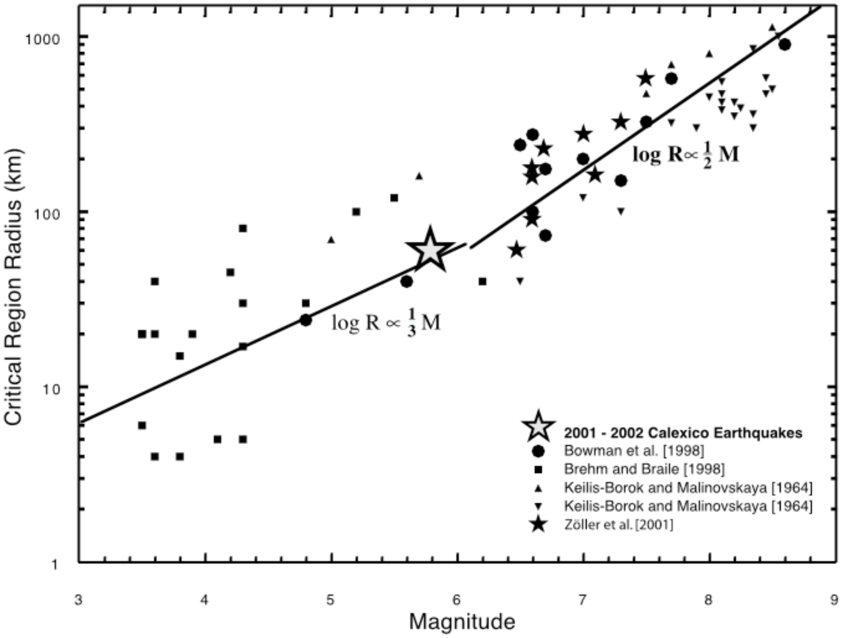

Figure 4: Scaling of optimal region radius R with magnitude. The large star shows the R=60km found here for the Calexico earthquakes, which is consistent with optimal radii estimated in other studies.

The stress recovery method

The use of a circle in the previous analysis is an arbitrary simplest first step. Bowma and King [2, 3] and King and Bowman[7] have advanced this analysis by using a simpl back-slip dislocation model to identify the areas around a known event where acceleratin moment release is expected. In these areas, the stress shadow from the previous large ever is being eroded by tectonic loading and stress transfer.

When applying this method to the Calexico earthquakes we used the fit parameter ξ t optimize two model parameters: the minimum stress contour (equivalent to R in the optima circle analysis) and the time at which the analysis begins (which was arbitrary in th optimal circle analysis). Figure 5 shows ξ as a function of minimum stress contour and sta time. Note that ξ falls below 0.4 in this analysis, significantly smaller than the minimum ξ found by the optimal circle method in Figure 2.

The start time is well defined in Figure 5 at about 1988, but the minimum stres contour at that date ranges from 0.3 bar to 0.03 bar. We chose the upper minimu (ΔCFF=0.2 bar) corresponding to a smaller effective R. Extension of the minimum to large values probably reflect the fact that there is not much contribution to the seismicity unt one gets to 0.01 bar at which point the fit degrades. The ΔCFF=0.2 bar contour is shown i Figure 6 where, except for the shape, it is seen to be roughly equivalent to R=60 km foun in the circle analysis.

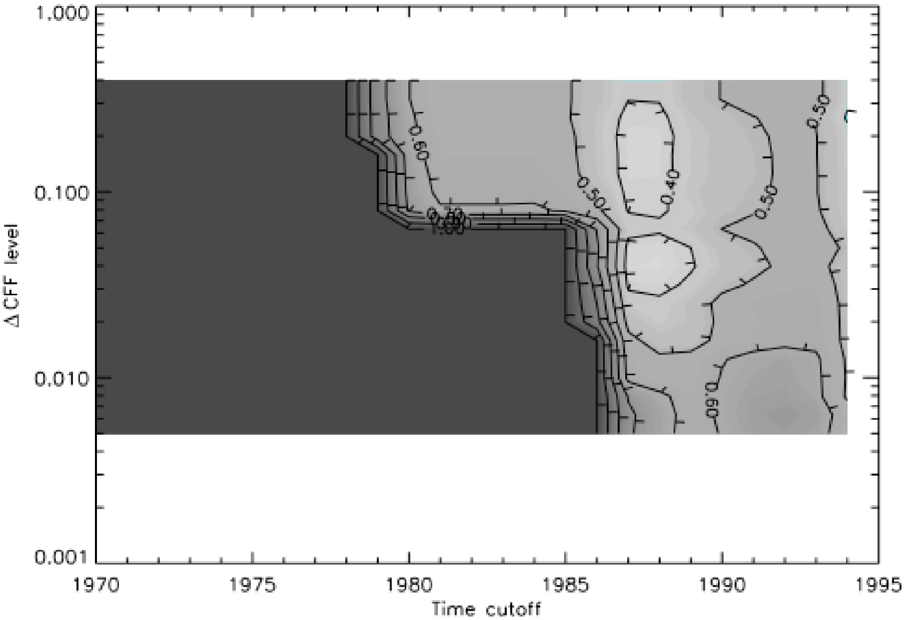

Figure 5: The value of the fit parameter ξ is contoured as a function of the minimum coulomb stress contour ΔCFF and the "time cutoff" date at which the fit is initiated. Note that the time cutoff is well constrained at about 1988. We choose the upper minimum ΔCFF=0.2 bars for reasons discussed in the text.

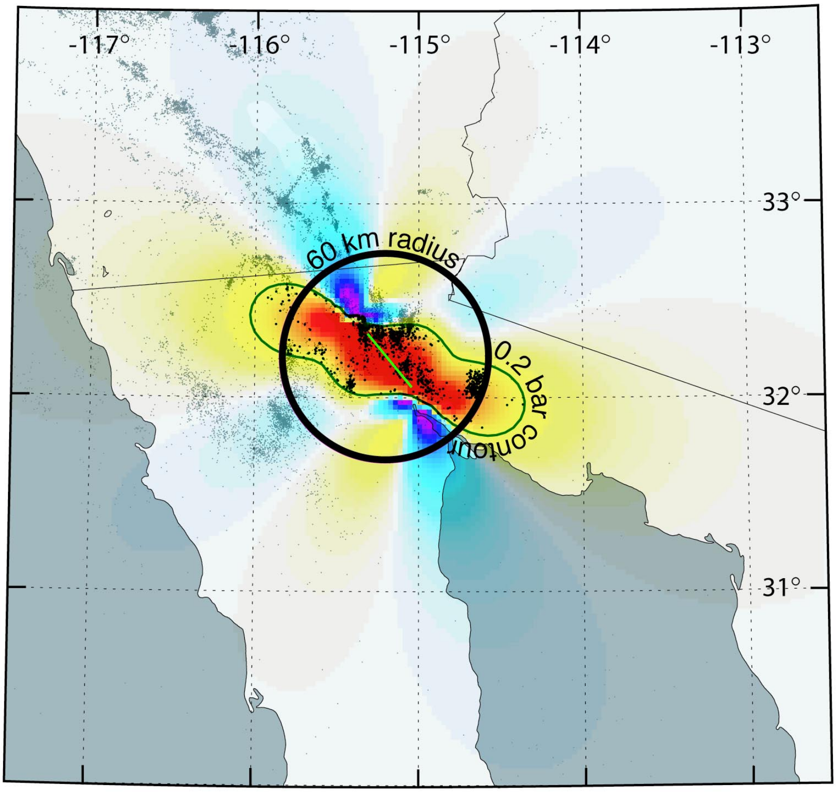

Figure 6: The optimal ΔCFF=0.2 bar stress cutoff contour found by the stress recovery method is compared with the *R*=60km radius found by the optimal circle method.

Discussion

The area of anomalous activity detected by Rundle et al. [10] preceding the 200 Calexico earthquake is indeed an example of AMR within an optimal region size consister with previous scaling studies relating *R* to magnitude. This result suggests a new approac to earthquake forecasting. The Rundle et al. [10] algorithm is first used to detect areas c anomalous activity. Within these areas, major faults are identified and potential scenari earthquakes are calculated using the Bowman-King [2, 3, 7] stress recovery methoc Finally, activity within the recovering stress lobes is used to estimate the time and size c any impending large events. It is interesting to note that the optimal radius *R* can be used i conjunction with the scaling relation (Fig. 4) to estimate the size of the impending even This offers an alterantive, and perhaps more stable, procedure than estimating size from th remaining Benioff strain in the time to failure analysis.

Acknowledgements

This research was funded by National Science Foundation grant EAR-0105405 and through Cooperative Agreements EAR-0106924 and USGS-02HQAG0008 to the Southern California Earthquake Center. This is INSU contribution number 315.

References

[1] Bowman, D. D., G. Ouillon, C. G. Sammis, A. Sornette, and D. Sornette, 1998, *An observational test of the critical earthquake concept*, J. Geophys. Res., **103**, 24,359-24,37.

[2] Bowman, D. D. and G. C. P. King, *Accelerating seismicity and stress accumulation before large earthquakes* Geophys. Res. Lett, **28**, 4039-4042, 2001a.

[3] Bowman, D. D. and G. C. P. King, *Seismicity changes before large earthquakes*, C. R. Acad. Sci. Paris, **333**, 591-599, 2001b.

[4] Brehm, D.J. and L.W. Braile, 1998, *Intermediate-term earthquake prediction using precursory events in the New Madrid seismic zone*, Bull. Seismol. Soc. Am., **88**, 564-580.

[5] Brehm, D.J. and L.W. Braile, 1999, *Intermediate-term earthquake prediction using the modified time-to-failure method in southern California*, Bull. Seismol. Soc. Am., **89**, 275-293.

[6] Jaumé, S.C. and L.R. Sykes, 1999, *Evolving towards a critical point: A review of accelerating moment/energy release prior to large and great earthquakes*, Pure Appl. Geophys., **155**, 279-306.

[7] King, G. C. P., and D. D. Bowman, 2002, *The evolution of regional seismicity between large earthquakes*, J. Geophys. Res., in press.

[8] Papazachos, C., and B. Papazachos, 2001, *Precursory accelerated Benioff strain in the Aegean area*, Annali di Geofisica, 44, 461-474.

[9] Robinson, R., 2000, *A test of the precursory accelerating moment release model on some recent New Zealand earthquakes*, Geophy. J. Int., 140, 568-576.

[10] Rundle, J.B., Tiampo, K.F., Klein, W., and J.S. Sá Martins, 2002, *Self-organization in leaky threshold systems: The influence of near-mean field dynamics and its implications for earthquakes, neurobiology, and forecasting*, Proc. Nat. Acad. Sci., 99, 2524-2521.

[11] Yang, W., D. Vere-Jones, and Li, M., 2001, *A proposed method for locating the critical region of a future earthquake using the critical earthquake concept*, J. Geophys. Res., 106, 4121-4128.

[12] Zöller, G., S. Hainzl, and J. Kurths, 2001, *Observation of growing correlation length as an indicator for critical point behavior prior to large earthquakes*, J. Geophys. Res., 106, 2167-2176.