Appendix Q—The Empirical Model

By K.R. Felzer[1]

Introduction

I investigated whether there are regions in California that are currently experiencing seismicity rates that are lower than their long-term average. Seismicity rates sometimes drop regionally for prolonged periods of time, a phenomena known as stress shadowing when it is linked casually to a large earthquake (for example, Harris and Simpson, 1998; Toda and Stein, 2007). There is also the potential for rate increases over time, but because of recording incompleteness in the early part of the catalog, it is not possible to robustly document increases. However, most rate increases that have been observed in the instrumental record have been linked to aftershock sequences, swarms, volcanic activity, or anthropogenic activity.

Method

The earliest written earthquake data for California comes from the 1769 to 1838 Mission era, but this data is difficult to associate with precise magnitudes and locations. There is a data gap from 1838 to 1849, and then an increase in written information when the Gold Rush brought population and newspapers to California. The 1850–2011 catalog is used here as a representation of the "long-term" seismicity rate in California and the modern, dense instrumentation era, from 1984 to 2011, and as the representation of current seismicity. Because 1850–2011 is a relatively short period on the scale of California seismic time, more accurate results could theoretically be obtained by comparing current seismicity with long-term seismicity models derived from Global Positioning System (GPS) and geologic data. At this time, however, these longer-term models are not precise enough in space for use in this investigation, and they are handicapped by the unknown degree to which observed deformation is aseismic. Thus, the existing catalog is used with the caveat that it may not represent true long-term seismicity in all locations across the State. The spatially variable long-term rates across the State are modeled by smoothing $M \geq 5.5$ earthquakes that occurred from 1850 to 2011. The catalog is not uniformly complete to this magnitude across the time period, but the existence of rate decreases (as opposed to rate increases, as stated above) may be robustly determined even with an incomplete initial catalog, although the true rate decrease may be more extreme than that measured. I attempted to remove aftershocks by using the declustering algorithm of Gardner and Knopoff (1974), which has been traditionally used in seismic-hazard mapping. If aftershocks are not removed, rate decreases will automatically appear wherever active aftershock sequences are decaying or have decayed within the older part of the catalog. The Gardner and Knopoff (1974) algorithm has proved to be a reasonable declustering method; however, no declustering algorithm is perfect, and it is to be expected that some amount of the rate decreases measured are due to aftershock decay.

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[1]U.S. Geological Survey.

Results

The 1850–2011 $M \geq 5.5$ earthquakes were smoothed using the protocol by Helmstetter and others (2007) with a Gaussian kernel and $n=2$, meaning that the smoothing constant for each earthquake is the distance to its nearest neighbor (for method details, see Helmstetter and others, (2007; fig. Q1). The value of n used here is smaller than that used for the smoothed seismicity model, which is based on $M \geq 2.5$ earthquakes, because the $M \geq 5.5$ earthquakes are further apart from each other. For the modern era, $M \geq 4.7$ earthquakes were used, which provided the same total number of earthquakes as the 1850–2011 catalog and thus smoothing that is on a similar scale. The smoothed 1984–2011 map is given in figure Q2. The measured ratios between the two smoothed maps, given at 0.1 by 0.1 degree grid points, are shown in figure Q3.

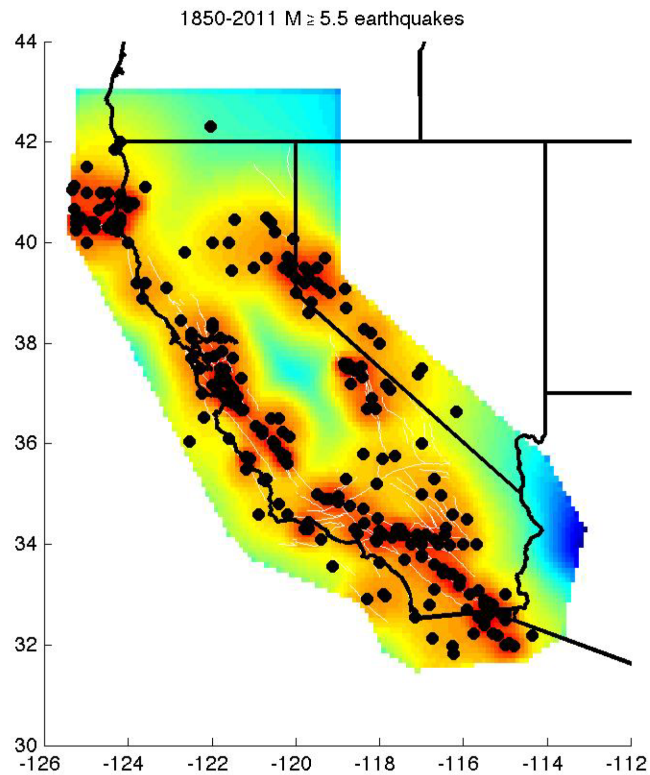

Figure Q1. Map showing smoothed *M*≥5.5 seismicity for earthquakes occurring from 1850 to 2011 in California. Earthquake locations are indicated by black dots.

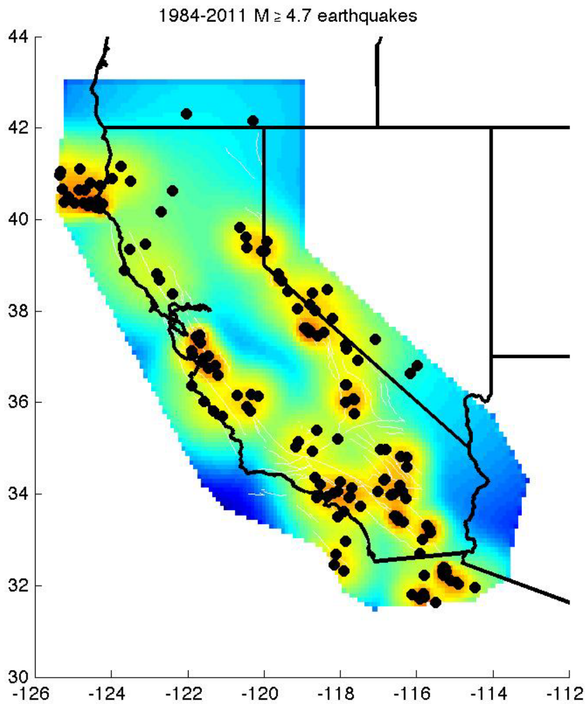

Figure Q2. Map showing smoothed *M*≥4.7 seismicity for earthquakes occurring from 1984 to 2011 in California. Earthquake locations are indicated by black dots.

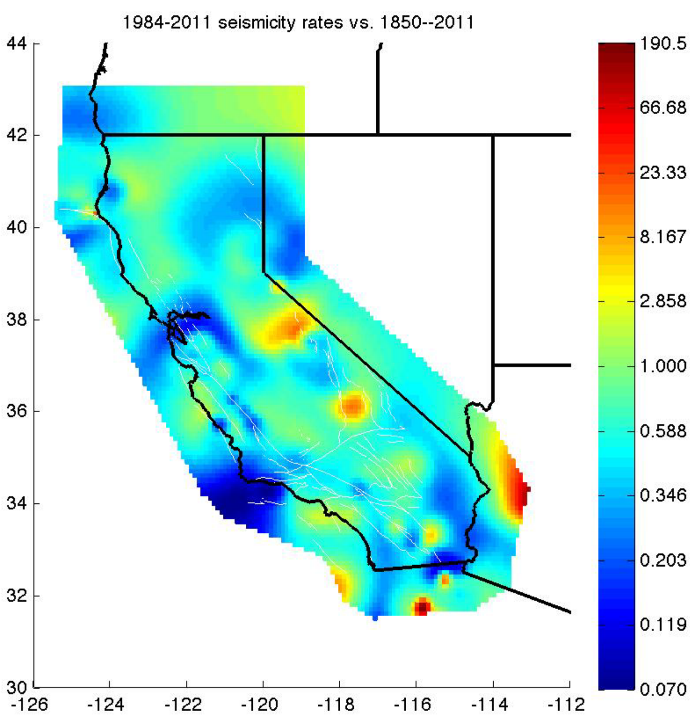

Figure Q3. Map showing ratio of smoothed seismicity rates for earthquake occurring from 1984 to 2011 and from 1850 to 2011 in California. The color bar indicates the ratio of the average number of earthquakes per year.

Seismicity is given along with the rate ratios in figure Q4, which shows that the smoothing creates artifactual areas of strong rate change where no earthquakes actually occur. There are also many mild rate changes that are unlikely to be significant. All coherent areas in which the rate change is larger than a factor of two are identified. Regions were hand-drawn around the actual earthquakes recorded in these areas in an attempt to avoid the artifacts. These hand-drawn regions are shown in figure 5, and the latitude/longitude boundaries are given in table Q1. The regions are located in the San Francisco Bay Area, the Santa Barbara area, and the Imperial Valley/Mexican border area. The number of $M \geq 5.5$ earthquakes that occurred in these areas from 1850 to 2011, and the number of $M \geq 4.0$ earthquakes that occurred in the same areas from 1984 to 2011 were counted. Uncertainty is estimated by using the Poissonian distribution to get two- tailed 95-percent confidence bounds on the true rate from the period 1984–2011. The ratio of 1984–2011 to 1850–2011 rates in these regions and the confidence bounds are given in table Q2. In all three regions, this ratio is significantly less than 1.0. As noted above, however, any attempt to decluster the catalog is unlikely to be complete. The 1850–2011 time period is short, so it cannot be ascertained as to what degree these ratios represent departures from the true long-term rates (for example, the rate over thousands of years), and it cannot be proven that there is not some muted signature of aftershock decay. Furthermore, there is no proof that the rate changes are not the result of some random process, however, the current seismicity rate in these regions is lower than what it has been historically.

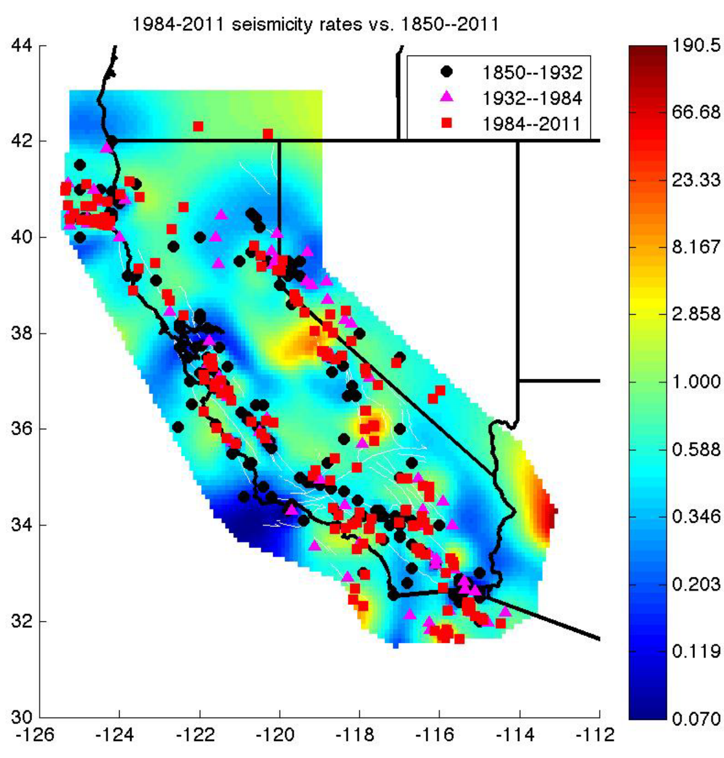

Figure Q4. Map showing ratio of seismicity rates for earthquakes occurring from 1984 to 2011 to the rate of earthquakes occurring from 1850 to 2011 in California.

Table Q1. Latitude/Longitude vertices for seismicity-rate decrease regions, California.

San Francisco Region	Santa Barbara Region	Imperial Valley Region
7.43,-122.29;	33.93,-119.3;	32.45,-114.76;
37.67,-122.6;	34.6,-121.07;	32.45,-115.44;
38.25,-122.65;	34.87.-120.34;	32.35,-115.44;
38.45,-121.88;	34.41,-119.29;	32.35, -115.76;
37.65,-121.3;	33.93,-119.30	32.73,-115.76;
37.63,-122.0;		32.74,-115.56;
37.4,-122.3		33.04,-115.56;
		33.03,-114.72;
		32.45,-114.76

Table Q2. Ratio of seismicity rates for earthquakes occurring from 1984 to 2011 to earthquakes occurring from 1850 to 2011 for three rate-decrease regions in California.

Region	1984–2011/1850–2011	95% Confidence bounds
San Francisco	0.24	0.14–0.33
Imperial Valley	0.30	0.19–0.41
Santa Barbara	0.13	0.04–0.24

The rate changes derived for the three regions are larger than those calculated in the Uniform California Earthquake Rupture Forecast, Version 2 (UCERF2; Felzer, 2008b). This size discrepancy occurs because the regions in the prior report were determined by which areas had similar levels of catalog completeness, and the regions in this investigation were drawn narrowly around areas specifically seen to demonstrate a large change in rate. The three regions designated here are given in map view in figure Q5.

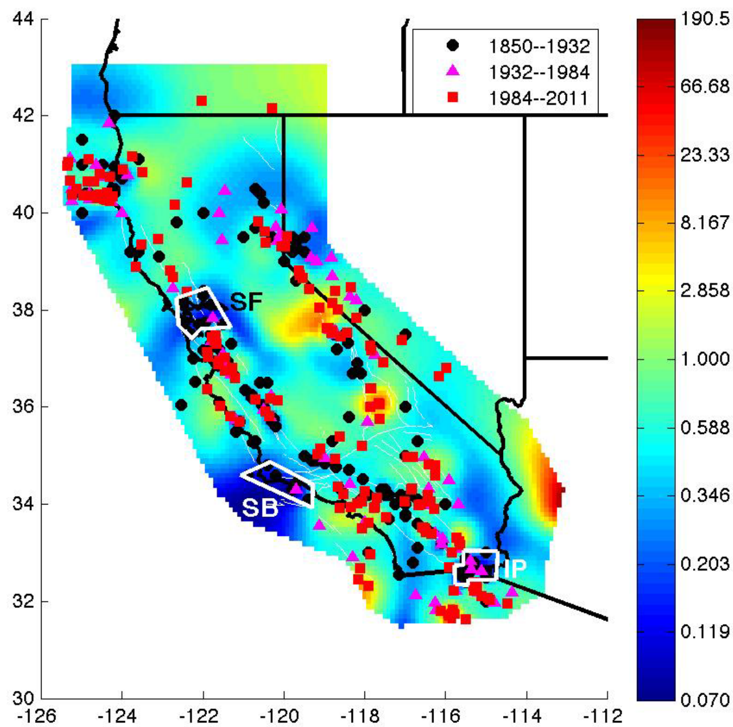

Figure Q5. Boundaries of the San Francisco, Santa Barbara, and Imperial Valley seismicity-rate decrease regions, California.

References

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