Appendix M: Empirical Estimation of Regional Time Variation in Seismicity Rates

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USGS Open File Report 2007-1437M
CGS Special Report 203M
SCEC Contribution #1138M
Version 1.0

2008

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U.S. Geological Survey

California Department of Conservation
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Suggested citation:
Felzer, K. R. 2008, Empirical estimation of regional time variation in seismicity rates, *Appendix M in* The Uniform California Earthquake Rupture Forecast, version 2 (UCERF 2): U.S. Geological Survey Open-File Report 2007-1437M and California Geological Survey Special Report 203M, 19 p. [http://pubs.usgs.gov/of/2007/1437/m/].

Appendix M: Empirical Estimation of Regional Time Variation in Seismicity Rates

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August 14, 2007

1 Introduction

As discussed in Appendix I, seismicity rates in many parts of California over the recent past have been different than the estimated long term average calculated from the combined instrumental and historical catalogs. This is most likely because earthquakes tend to cluster in time and space. Seismicity rate variation has been especially noted in the literature for the San Francisco Bay Area, where the relative quiescence over the last 80 to 100 years in comparison to the preceding 50 years has long been a topic of publication (Willis 1924; Ellsworth et al. 1981; Harris and Simpson 1998; Bakun 1999; Stein 1999). The purpose of this appendix is to use the most recent parts of the earthquake catalog given in Appendix H to make an empirical projection of regional seismicity rates that we expect over the short term, and to compare these to the estimated long term averages.

Precedent for catalog-based empirical short term seismicity rate estimates was set by the Working Group on California Earthquake Probabilities 2002 (WGCEP 2002) which worked only on the San Francisco Bay Area (SFBA). WGCEP 2002 first tried to model the region's observed seismicity quiescence as the result of a stress shadow imposed by the 1906 San Francisco earthquake, using models that applied static stress decreases to both elastic and visco-elastic media. None of the models used, however, were successful in matching the duration and nature of the observed quiescence. The group therefore also used an empirical model (Reasenberg et al. 2003) based on the concept that ”the seismicity in the near future.... will (in the absence of a major stress-changing event) be similar to that in the recent past”. This model fits well with the general observation that regional seismicity rates tend not to change drastically over short periods of time unless there are significant stress altering events.

The empirical SFBA seismicity rate was calculated by the 2002 WGCEP in ten different ways (models A through J). The ten models were then averaged together with equal weight to produce the final time variable seismicity rate projection. The first four models, A though D, consisted of taking mean seismicity rates over different time periods and magnitude ranges. Specifically, these were the mean rate of $M \geq 3.0$ earthquakes from 1942-1998 (Model A), the mean rate of $M \geq 3.0$ earthquakes from 1984-1998 (Model B), the mean rate of $M \geq 5.5$ earthquakes from 1906-2000 (Model C), and the mean rate of $M \geq 5.5$ earthquakes from 1979-2000 (Model D). Model C was started in 1906 because of the potential influence of the 1906 earthquake. Model A, on the other hand, was started in 1942 to coincide with the initiation of the Northern California Seismic Network. 1979 and 1984 were chosen as additional starting times because they were perceived to be when the SFBA seismicity rate started increasing in the $M \geq 5.5$ and $M \geq 3.0$ magnitude ranges, respectively. Choosing measurement time periods to start at times of known higher seismicity rate is potentially problematic, however, because unless there is a strong theoretical reason to believe that the higher rate is not random, the results will be biased. Nonetheless, significant upgrades to the statewide seismic network, and to processing of the data, did occur in the 1970s and early 1980s, and 1984 is a good date to represent the beginning of the improved catalog. Thus in the current analysis we preserve the 1984 cutoff (Model C), but do not use the 1979 cutoff (Model D). We also extend all rate measurements through 2006, the end of our current catalog (see Appendix H), and we use completeness magnitudes taken from Appendix I that change with time and region. The use of variable completeness magnitudes allows for overall higher accuracy but also a somewhat more complicated seismicity rate computation, which is described in further detail below.

The next two WGCEP 2002 empirical models, models E and F, were based on the assumptions that the SFBA seismicity rate was increasing linearly. The two models made different empirical estimates for the speed of the increase, and then projected over the forecast time period (which, for WGCEP 2002, was until 2031). At the time it seemed reasonable to assume that SFBA seismicity rates might be undergoing a long term increase because the rates had been higher from 1979 at least through 1989, even though they appeared to be decreasing again by the year 2000. In fact, since 2000 the rate of seismicity has again been relatively low. In our extended San Francisco metropolitan region (see below), we estimate that the average seismicity rate from 1979–1997 was almost twice that from 1906–1979, but seismicity in 1997–2006 returned to 1906-1979 levels. Given this, we do not see justification for modeling the seismicity rate in SFBA as linearly increasing. We also find no evidence for assuming continuously increasing rates in any other region of California.

The final four WGCEP 2002 empirical models (G through J) were based on the assumption of the existence of a seismicity cycle, in which seismicity rates plummet after large earthquakes (presumably after the end of the aftershock sequence ?) and then gradually rise again until the next great event (Ellsworth et al. 1981; Bufe and Varnes 1993; Jaume and Sykes 1996). Models G through J represent two different assumptions of the SFBA earthquake cycle length and alternate assumptions of linear and exponential increasing trends. The idea of a seismicity rate cycle has long enticed seismologists, but has yet to be proven by data. Like a large number of other ideas it has been used to post-dict a number of earthquakes, but never to reliably predict them. Foreshock studies, which show that at least 50% of large earthquakes are preceded by foreshocks (Abercrombie and Mori 1996; Reasenberg 1999; Felzer et al. 2004), demonstrate that large earthquakes are indeed more likely to occur when seismicity rates are higher, but most foreshock sequences are short and do not accelerate, and so they do not represent the long term secular rate increases postulated by the seismic cycle models. Given this we chose not to use models G through J in our analysis.

In summary, then, our empirical model incorporates Models A through C of the WGCEP 2002 empirical model, which comprise mean seismicity rates calculated from 1906, 1942, and 1984, respectively. Following WGCEP 2002 precedent we weight each of these rates equally to get the final summary rate, but all calculated values are provided in this report so that different weights may also be assigned if warranted. More details are given in the following section.

2 Method

As described in the introduction we empirically estimate short term California seismicity rates by averaging together (with equal weights) average seismicity rates calculated from the 1906-2006, 1942-2006, and 1984-2006 catalogs. The years 1942 and 1984 represent points of improvement in the seismic network and catalog; the latter time periods may also represent current seismicity rates more accurately than the full 1906-2006 time period.

We make these short term seismicity rate calculations for each of the 8 California regions specified in Appendix I and illustrated in Figure 1. These regions were designated based on relatively uniform internal population and instrumentation coverage such that uniform catalog minimum magnitude of completeness thresholds could be assigned throughout each region for different periods of time. The appropriate completeness thresholds were determined from population (for the pre-instrumental era) and seismic instrument densities, with the sensitivity of each instrument and population center determined from empirical statistical tests. The method and resulting completeness thresholds are provided in detail in Appendix I. In addition to the absolute short term rates we also estimate the fractional change between the short and long term rates.

Appendix I provides details on correcting the catalog for magnitude errors and rounding. All of the calculations that we do here include these corrections. Appendix I also details three different methods that may be used to calculate seismicity rates given that the catalog's magnitude of completeness changes with time. All three of these methods are used in Appendix I, but the preferred method, and the only one used here, is the averaged Weichert calculation. This calculation uses the method of Weichert (1980), but instead of applying it to the entire time period at once it applies it separately to sub-time periods when these sub-time periods have sharp differences in completeness magnitudes. The rates calculated for each period are then averaged together with weights proportional to the amount of time that each covers. The reason for doing the calculation in this manner is that the straight Weichert method assumes that the seismicity rate is constant in time and thus assigns weights to different parts of the catalog only as a function of their completeness thresholds. If magnitude completeness thresholds decrease greatly with time, as is the case in the California catalog, then the results will be very heavily weighted by the most recent data, and the calculated long term and recent short term rates become virtually indistinguishable. If we wish to allow for the possibility that the long and short term rates are different, however, then the historic and older parts of the instrumental catalog must be given more weight despite their high magnitude completeness thresholds. This is accomplished by the averaged Weichert calculation. As in Appendix I we set our time periods for the averaged Weichert calculation to 1850-1932, 1932-1997, and 1997-2006 since significant statewide improvements in earthquake detection occurred in1932 and 1997.

As in Appendix I we do our rate calculations here for both the full and declustered catalogs, and with both the best fit Gutenberg-Richter b values and the lowest and highest b values consistent with the 98% confidence range. The b value is used both in the rounding and magnitude error corrections and in the Weichert rate calculation. It can also be used together with the average annual rate of $M \geq 5.0$ earthquakes provided in this report to project the rate of earthquakes above other magnitude cutoffs. A detailed discussion of how b affects the magnitude corrections and Weichert calculation is given in Appendix I. Our long term rates are also calculated with and without model corrections for the possibility that earthquakes as large as M 8.3 may occur (with very low frequency) in California, as discussed in Appendix I.

3 Results

The results of the rate calculations are given in a series of tables below. Regional rates calculated separately for the 1906-2006, 1942-2006, and 1984-2006 time periods are given first, for the full catalog with a b value of 1.0 (Table 1), the full catalog with the 98% confidence limit b values of 0.91 and 1.13 (Tables 2 and 3), the declustered catalog with a b value of 0.8, (Table 4) and the declustered catalog with b values of 0.72 and 0.98 (Table 5 and 6). We solve for the estimated current regional seismicity rates by averaging the 1906-2006, 1942-2006, and 1984-2006 values (Table 7). For comparison we then provide regional long term rates for the full and declustered catalogs, corrected and not corrected for the possibility of occasional earthquakes in California as large as M 8.3 (Table 8 and 9). Finally we provide our best estimate and error bars on the ratio between the current and long term seismicity rates in each region (Table 10). Our best estimates for this ratio in the San Francisco area is 0.42 ± 0.11 (98% confidence interval) for the full catalog, and 0.57 ± 0.25 for the declustered catalog if we assume $M_{max} = 8.3$ for the long term rates. Likewise if we make this M_{max} assumption for the Los Angeles area (which includes metropolitan San Diego) we estimate a ratio of 0.60 ± 0.27 for the full catalog and 0.55 ± 0.29 for the declustered catalog. If we do not make the M_{max} assumption but instead base the long term rate fully on the 1850-2006 catalog, we obtain ratios of 0.46 ± 0.13 and 0.63 ± 0.21 for the full and declustered catalogs, respectively, for the San Francisco area, and ratios of 0.66 ± 0.33 and 0.6 ± 0.33 for the full and declustered catalogs for the Los Angeles area. For comparison with previous calculations we have that a seismicity rate ratio of 0.57 was calculated for the San Francisco Bay Area by the 2002 Working Group (WGCEP 2002), which is within the range of our calculations. For the entire state considered as a whole we get ratios of 0.74 ± 0.46 and 0.8 ± 0.33 for the full and declustered catalogs, respectively, with the $M_{max} = 8.3$ correction and 0.82 ± 0.34 and 0.88 ± 0.31 for the full and declustered catalogs without the correction.

4 Discussion

There are several items in the results that merit extra discussion. First we address two technical issues. One is that it can be seen by comparing Tables 8 and 1 that the errors are larger for calculations over 1850-2006 than for over shorter time periods. Although seemingly counter-intuitive this is because the longer time periods have historical and early instrumental data with high magnitude completeness thresholds. The high completeness threshold means few useable earthquakes, and thus rate estimations with high errors when errors from the historical catalog part of the catalog are propagated through the calculation. The 1984-2006 rates tend to have slightly higher errors than the 1942-2006 rates simply because the catalog duration is shorter and the magnitude completeness threshold is not dramatically different between the two time periods.

Another technical issue is that in some regions the historical magnitude of completeness threshold is so high and the local seismicity rate so low that historical seismicity rates cannot be calculated at all. This is true for both the Mojave desert region and the Northeast region of the state, for which no seismicity rate can be reliably determined before the Southern California Seismic Network became fully operational in 1932. For these areas only 1942-2006 and 1984-2006 rates are calculated. From these rates we calculate empirical absolute short term rates, but we cannot calculate a fractional change in rate from the long term average. So that these regions are not completely neglected we do include them in all of the "whole state" calculations, with the caveat that because their completeness thresholds are so high, their inclusion may cause the estimated whole state rates to come out too low. The Mojave, for example, has a completeness threshold above M 7.3 until 1870 and above M 7.0 until 1880 (see Appendix I). Therefore while the region may have had a reasonable M 6–7 seismicity rate from 1850-1880, its rate is recorded as zero for that period since it failed to produce any $M \geq 7.0$ earthquakes over this time. Thus the high magnitude threshold in this region could end up artificially pulling down the statewide rate estimate.

A more important issue, and one that can be readily observed from Table 10, is that in all regions in which we can calculate a contemporary vs. long term seismicity rate we observe that the current seismicity rate is less than the long term average. It is true that many of the rate change errors are also very high, but nonetheless the rate decrease pattern is consistent. Assuming that this is not a simple error of overestimated magnitudes or underestimated magnitude errors in the historic part of the catalog, the latter of which in particular is quite possible (please see Appendix H), this may indicate some sort of statewide correlation in seismicity rates, perhaps as a result of earthquake interactions. The veracity of the rate decrease is supported by the observation that the largest earthquakes to occur throughout the state – the M 7.9 1857 Ft. Tejon Earthquake, the M 7.6 1872 Owens Valley earthquake, and the M 7.8 1906 San Francisco earthquake – all occurred during the historic era. These earthquakes drive up the historic (1850-1932) seismicity rates in both the full and declustered catalogs, and any recorded associated foreshocks and aftershocks would be expected to increase the rates further in the historic full catalog, as well as to some extent in the historic declustered catalog, since no declustering algorithm is 100% effective. Since 1932 the only $M \geq 7.5$ event has been the 1952 M 7.5 Kern County earthquake.

Another point that needs to be emphasized is that, as noted by Reasenberg et al. (2003) and quoted above, our empirical estimates of the short term seismicity rate hold only in the absence of any significant stress changing events. Such an event could be a large earthquake or even several moderate earthquakes. In volcanic regions of the state movements of magma or gases or full eruptions could also cause significant local seismicity rate disruptions.

Should a large earthquake occur outside of a volcanic region the expected short term seismicity rate could be quickly modified using the known statistical behavior of aftershock sequences (e.g. Reasenberg and Jones (1989), Felzer et al. (2003), Helmstetter et al. (2006) and Felzer and Brodsky (2006)). Initial infrastructure for this is already in place in the form of twenty-four hour aftershock shaking forecast maps currently produced on a daily basis by the U.S. Geological Survey and posted at http://pasadena.wr.usgs.gov/step/ (Gerstenberger et al. 2005). Further efforts on more long term official aftershock forecasts could be pursued in the future if deemed appropriate.

Acknowledgements We thank Y. Kagan and W. Bakun for reviews of this appendix and A. Felzer for editing the manuscript.

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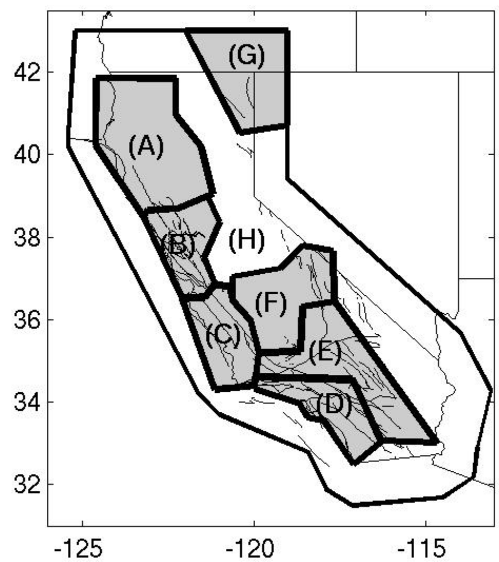

Figure 1: The map gives the different regions (shaded in gray) for which regional short term and long term rates are calculated. Starting from the north the regions are (A) the North region, (B) the San Francisco region, (C) the Central Coast Region, (D) the Los Angeles region, (E) the Mojave region, (F) the Mid region, and (G) the Northeast region. The rest of the area (H) is processed as the "rest of the state". Boundaries of these regions come from Appendix I, where they were set to enclose areas of similar catalog magnitude completeness thresholds. Similarity of completeness threshold greatly aids in accurate rate calculation within a region. The magnitude of completeness is primarily determined by population (pre-1932) and instrumental (post-1932) density (see Appendix I).

Region	1906-2006	1942-2006	1984-2006
(A) North	0.40 ± 0.26	0.36 ± 0.11	0.46 ± 0.17
(B) San Francisco	0.40 ± 0.11	0.37 ± 0.05	0.46 ± 0.09
(C) Central Coast	$0.39, -0.19^{*}, +0.4$	0.25 ± 0.04	0.32 ± 0.08
(D) Los Angeles	0.57 ± 0.22	0.36 ± 0.05	0.50 ± 0.09
(E) Mojave	–	1.34 ± 0.10	1.75 ± 0.18
(F) Mid	0.31 ± 0.04	0.43 ± 0.05	0.56 ± 0.10
(G) Northeast	–	0.02 ± 0.02	0.01 ± 0.02
(H) Rest of state	2.67 ± 1.71	2.37 ± 0.45	1.87 ± 0.52
Whole State	5.66 ± 1.79	5.48 ± 0.49	5.92 ± 0.61

Table 1: Regional rates, given in average number of $M \geq 5$ earthquakes/year, measured over different time periods for the full (not declustered) catalog. The letters given before the region names correspond to the letters printed in the given region in Figure 1. Magnitude rounding and errors are corrected for, and the averaged Weichert seismicity rate calculation is performed (see text), using $b = 1$. Errors are given at 98% confidence. In this table, and those that follow, most errors are estimated using the Weichert routine. Errors with asterisk, however, were estimated directly from the Poissonian distribution since the mean was too small/error too large for the Gaussian approximation to the Poissonian to be appropriate. We also note that the regional and whole state rates are calculated independently. Since there is slight variability each time the rate calculation is done due to randomness in the magnitude rounding correction routine (see Appendix I) this means that the given regional rates may not always sum precisely to the whole state rate. The Mojave and Northeast rates are not provided individually for 1906-2006 because the pre-1942 errors for these regions are very high due to high catalog magnitude completeness thresholds. The Mojave and Northeast regions are included in the 1906-2006 whole state rate, however with the caveat that the very high completeness thresholds in these regions may cause the whole state rate to come out low. The whole state rate without these regions may, of course, be readily calculated by summing the appropriate rows.

Region	1906-2006	1942-2006	1984-2006
(A) North	0.40 ± 0.22	0.39 ± 0.12	0.51 ± 0.18
(B) San Francisco	0.45 ± 0.11	0.45 ± 0.06	0.57 ± 0.11
(C) Central Coast	$0.38, -0.20^{*}, +0.30$	0.30 ± 0.05	0.39 ± 0.09
(D) Los Angeles	0.61 ± 0.20	0.44 ± 0.06	0.62 ± 0.12
(E) Mojave	–	1.62 ± 0.12	2.14 ± 0.22
(F) Mid	0.37 ± 0.05	0.53 ± 0.07	0.69 ± 0.12
(G) Northeast	–	0.02 ± 0.03	0.02 ± 0.02
(H) Rest of state	2.37 ± 1.17	2.36 ± 0.44	2.00 ± 0.52
Whole State	5.7 ± 1.26	6.11 ± 0.49	6.94 ± 0.64

Table 2: Regional rates, given in average number of $M \geq 5$ earthquakes/year, measured over different time periods for the full (not declustered) catalog. Magnitude rounding and errors are corrected for, and the averaged Weichert seismicity rate calculation is performed (see text), using $b = 0.91$. Errors are given at 98% confidence. The Mojave and Northeast rates are not provided individually for 1906-2006 because the pre-1942 errors for these regions are very high due to high catalog magnitude completeness thresholds. The Mojave and Northeast regions are included in the 1906-2006 whole state rate, however with the caveat that the very high completeness thresholds in these regions may cause the whole state rate to come out low. The whole state rate without these regions may, of course, be readily calculated by summing the appropriate rows.

Region	1906-2006	1942-2006	1984-2006
(A) North	0.42 ± 0.35	0.32 ± 0.10	0.39 ± 0.15
(B) San Francisco	0.35 ± 0.12	0.27 ± 0.04	0.34 ± 0.07
(C) Central Coast	$0.43, -0.20^{*}, +0.58$	0.18 ± 0.03	0.24 ± 0.06
(D) Los Angeles	0.54 ± 0.27	0.26 ± 0.03	0.37 ± 0.07
(E) Mojave	–	1.01 ± 0.08	1.31 ± 0.14
(F) Mid	0.23 ± 0.03	0.32 ± 0.04	0.41 ± 0.07
(G) Northeast	–	0.01 ± 0.02	0.01 ± 0.01
(H) Rest of state	3.36 ± 2.99	2.39 ± 0.47	1.73 ± 0.54
Whole State	6.03 ± 3.09	4.78 ± 0.49	4.80 ± 0.59

Table 3: Regional rates, given in average number of $M \geq 5$ earthquakes/year, measured over different time periods for the full (not declustered) catalog. Magnitude rounding and errors are corrected for, and the averaged Weichert seismicity rate calculation is performed (see text), using $b = 1.13$. Errors are given at 98% confidence. The Mojave and Northeast rates are not provided individually for 1906-2006 because the pre-1942 errors for these regions are very high due to high catalog magnitude completeness thresholds. The Mojave and Northeast regions are included in the 1906-2006 whole state rate, however with the caveat that the very high completeness thresholds in these regions may cause the whole state rate to come out low. The whole state rate without these regions may, of course, be readily calculated by summing the appropriate rows.

Region	1906-2006	1942-2006	1984-2006
(A) North	0.29 ± 0.17	0.28 ± 0.10	0.34 ± 0.15
(B) San Francisco	0.27 ± 0.08	0.28 ± 0.05	0.31 ± 0.09
(C) Central Coast	0.28 ± 0.22	0.22 ± 0.05	0.21 ± 0.08
(D) Los Angeles	0.35 ± 0.16	0.22 ± 0.05	0.24 ± 0.08
(E) Mojave	–	0.47 ± 0.07	0.53 ± 0.12
(F) Mid	0.15 ± 0.03	0.20 ± 0.05	0.26 ± 0.08
(G) Northeast	–	0.02 ± 0.03	0.01 ± 0.01
(H) Rest of state	1.41 ± 0.74	1.37 ± 0.32	1.18 ± 0.37
Whole State	3.1 ± 0.81	3.05 ± 0.36	3.06 ± 0.45

Table 4: Regional rates, given in average number of $M \geq 5$ earthquakes/year, measured over different time periods for the declustered catalog. Magnitude rounding and errors are corrected for, and the averaged Weichert seismicity rate calculation is performed (see text), using the best fit b value of 0.8, Errors are given at 98% confidence. The Mojave and Northeast rates are not provided individually for 1906-2006 because the pre-1942 errors for these regions are very high due to high catalog magnitude completeness thresholds. The Mojave and Northeast regions are included in the 1906-2006 whole state rate, however with the caveat that the very high completeness thresholds in these regions may cause the whole state rate to come out low. The whole state rate without these regions may, of course, be readily calculated by summing the appropriate rows.

Region	1906-2006	1942-2006	1984-2006
(A) North	0.29 ± 0.15	0.30 ± 0.11	0.38 ± 0.16
(B) San Francisco	0.31 ± 0.08	0.34 ± 0.06	0.37 ± 0.11
(C) Central Coast	0.29 ± 0.18	0.26 ± 0.06	0.25 ± 0.09
(D) Los Angeles	0.36 ± 0.15	0.26 ± 0.06	0.29 ± 0.10
(E) Mojave	–	0.56 ± 0.09	0.63 ± 0.15
(F) Mid	0.18 ± 0.04	0.24 ± 0.05	0.32 ± 0.10
(G) Northeast	–	0.02 ± 0.03	0.01 ± 0.02
(H) Rest of state	1.30 ± 0.54	1.38 ± 0.32	1.29 ± 0.37
Whole State	3.13 ± 0.62	3.35 ± 0.36	3.53 ± 0.48

Table 5: Regional rates, given in average number of $M \geq 5$ earthquakes/year, measured over different time periods for the declustered catalog. Magnitude rounding and errors are corrected for, and the averaged Weichert seismicity rate calculation is performed (see text), using the lower 98% confidence b value of 0.72. Errors are given at 98% confidence. The Mojave and Northeast rates are not provided individually for 1906-2006 because the pre-1942 errors for these regions are very high due to high catalog magnitude completeness thresholds. The Mojave and Northeast regions are included in the 1906-2006 whole state rate, however with the caveat that the very high completeness thresholds in these regions may cause the whole state rate to come out low. The whole state rate without these regions may, of course, be readily calculated by summing the appropriate rows.

Region	1906-2006	1942-2006	1984-2006
(A) North	0.30 ± 0.25	0.24 ± 0.09	0.26 ± 0.12
(B) San Francisco	0.21 ± 0.08	0.19 ± 0.04	0.20 ± 0.06
(C) Central Coast	$0.30, -0.20^*, +0.37$	0.15 ± 0.03	0.14 ± 0.05
(D) Los Angeles	0.35 ± 0.22	0.14 ± 0.03	0.16 ± 0.05
(E) Mojave	–	0.32 ± 0.05	0.36 ± 0.08
(F) Mid	0.10 ± 0.02	0.13 ± 0.03	0.17 ± 0.06
(G) Northeast	–	0.01 ± 0.02	0.005 ± 0.01
(H) Rest of state	1.85 ± 1.56	1.37 ± 0.34	0.99 ± 0.37
Whole State	3.13 ± 0.62	3.36 ± 0.36	3.53 ± 0.48

Table 6: Regional rates, given in average number of $M \geq 5$ earthquakes/year, measured over different time periods for the declustered catalog. Magnitude rounding and errors are corrected for, and the averaged Weichert seismicity rate calculation is performed (see text), using the upper 98% confidence b value of 0.98. Errors are given at 98% confidence. The Mojave and Northeast rates are not provided individually for 1906-2006 because the pre-1942 errors for these regions are very high due to high catalog magnitude completeness thresholds. The Mojave and Northeast regions are included in the 1906-2006 whole state rate, however with the caveat that the very high completeness thresholds in these regions may cause the whole state rate to come out low. The whole state rate without these regions may, of course, be readily calculated by summing the appropriate rows.

Region	Full catalog rate	Declustered catalog rate
(A) North	0.41 ± 0.11 (0.0008)	0.30 ± 0.08 (0.006)
(B) San Francisco	0.41 ± 0.05 (0.0019)	0.29 ± 0.04 (0.0014)
(C) Central Coast	$0.32, -0.07^{*}, +0.14$ (0.0014)	0.23 ± 0.08 (0.001)
(D) Los Angeles	0.48 ± 0.08 (0.0025)	0.27 ± 0.06 (0.0014)
(E) Mojave	1.55 ± 0.10 (0.0044)	0.50 ± 0.07 (0.0014)
(F) Mid	0.43 ± 0.04 (0.0015)	0.20 ± 0.03 (0.0007)
(G) Northeast	0.01 ± 0.01 (tiny)	0.01 ± 0.01 (tiny)
(H) Rest of state	2.30 ± 0.61 (0.0008)	1.32 ± 0.29 (0.0005)
Whole State	5.67 ± 0.65 (0.0012)	3.07 ± 0.33 (0.0007)

Table 7: Best estimate current regional seismicity rates, given in average number of $M \geq 5$ earthquakes/year. Calculated by averaging together the 1906-2006, 1942-2006, and 1984-2006 rates. Calculations are done for the full and declustered catalogs, with the best fitting b values of 1.0 and 0.8, respectively. Numbers given in parenthesis after each value is the earthquake rate expressed as per 100 km^2 of region area. Note that rates for the Mojave and Northeastern regions are calculated from post 1942 earthquakes only due to highly incomplete catalogs at earlier times. The whole state rates, however, do include Mojave Northeastern region rate contributions, with the caveat that this may cause the wholee state rates to come out low (please see previous table captions). Errors are given at the 98% confidence levels.

Region	Long term rate	Long term rate/100 km^2	Long term rate with $M_{max} = 8.3$
(A) North	0.52 ± 0.40	0.001	0.58 ± 0.40
(B) San Francisco	0.89 ± 0.23	0.0042	0.97 ± 0.23
(C) Central Coast	$0.50, -0.34^*, +0.54$	0.0022	$0.55, -0.34^*, +0.54$
(D) Los Angeles	0.73 ± 0.34	0.0038	0.80 ± 0.34
(E) Mojave	–	–	–
(F) Mid	0.67 ± 0.48	0.0024	0.74 ± 0.48
(G) Northeast	–	–	–
(H) Rest of state	$2.99, -1.45^*, +2.57$	0.001	$3.29, -1.45^*, +2.57$
Whole State	6.93 ± 2.75	0.0015	7.62 ± 3.0

Table 8: Regional long term rate estimates for the full (non-declustered) catalog, given in the average number of $M \geq 5.0$ earthquakes/year. The first column of values provides rates calculated directly from the 1850-2006 catalog. The second column gives the same rate, but per 100 km^2 contained within the region. Values in the second column contain a multiplicative correction for the estimated increase in the full region long term rate if earthquakes as large as M 8.3 may occur within California (details given in Appendix I). Because we cannot rule out the possibility of M 8.3 earthquakes we take the values in the third column as our preferred rates. Magnitude rounding and error corrections and the averaged Weichert seismicity rate calculation is done with the full catalog best fit b value of 1.0. Errors are given at 98% confidence. Long term rates are not calculated for the Mojave and Northeast regions because of lack of a good long term catalog, however these regions are included in the statewide long term rate calculation.

Region	Long term rate	Long term rate/100 km^2	Long term rate with $M_{max} = 8.3$
(A) North	0.34 ± 0.24	0.006	0.37 ± 0.24
(B) San Francisco	0.46 ± 0.14	0.0021	0.50 ± 0.20
(C) Central Coast	$0.31, -0.17^{*}, +0.28$	0.0014	$0.34, -0.17^{*}, +0.28$
(D) Los Angeles	0.45 ± 0.23	0.0023	0.49 ± 0.23
(E) Mojave	–	–	–
(F) Mid	0.30 ± 0.24	0.0011	0.33 ± 0.24
(G) Northeast	–	–	–
(H) Rest of state	$1.40, -0.5^{*}, +1.03$	0.0005	$1.54, -0.5^{*}, +1.03$
Whole State	3.48 ± 1.16	0.0007	3.82 ± 1.5

Table 9: Regional long term rate estimates for the declustered catalog, given in the average number of $M \geq 5.0$ earthquakes/year. The first column of values provides rates calculated directly from the 1850-2006 catalog. The second column gives the same values but expressed as per 100 km^2 of regional area. Values in the third column contain a multiplicative correction for the estimated increase in the long term regional rate if earthquakes as large as M 8.3 may occur within California (details given in Appendix I). Because we cannot rule out the possibility of M 8.3 earthquakes we take the values in the third column as our preferred rates. Magnitude rounding and error corrections and the averaged Weichert seismicity rate calculation is done with the full catalog best fit b value of 1.0. Errors are given at 98% confidence. Long term rates are not calculated for the Mojave or Northeastern regions because of lack of a good long term catalog. These regions are included in the whole state rate calculation, however.

Region	Raw, full cat.	Full Cat, $M_{max} = 8.3$	Raw, dec. cat	Dec. Cat, $M_{max} = 8.3$
(A) North	0.79 ± 0.64	0.71 ± 0.52	0.88 ± 0.66	0.81 ± 0.63
(B) San Francisco	0.46 ± 0.13	0.42 ± 0.11	0.63 ± 0.21	0.57 ± 0.25
(C) Central Coast	$0.64, -0.46^{*} + 0.75$	$0.58, -0.38^{*}, +0.62$	$0.74, -0.48^{*}, +0.72$	$0.69, -0.41^{*}, +0.90$
(D) Los Angeles	0.66 ± 0.33	0.60 ± 0.27	0.6 ± 0.33	0.55 ± 0.29
(E) Mojave	–	–	–	–
(F) Mid	0.64 ± 0.46	0.58 ± 0.38	0.67 ± 0.55	0.61 ± 0.45
(G) Northeast	–	–	–	–
(H) Rest of state	$0.77, -0.43^{*}, +0.69$	$0.70, -0.36^{*}, +0.58$	$0.94, -0.4^{*}, +0.72$	$0.86, -0.34^{*}, +0.61$
Whole state	0.82 ± 0.34	0.74 ± 0.46	0.88 ± 0.31	0.80 ± 0.33

Table 10: Best estimate of the ratio between current and long term seismicity rates in the different regions. The first column gives values for the full catalog, comparing raw 1850-2006 rates from Table 8 to the average short term rates from Table 7. The second column compares the short term rates to the long term rates corrected for the possibility of an M 8.3 maximum magnitude earthquake (see Table 8). The second two columns provide the same values, but for the declustered catalog, using values from Tables 7 and 9. These calculations are done with our preferred b values of 1.0 and 0.8 for the full and declustered catalogs, respectively. Errors on the fractional changes are given at the 98% confidence level and are relatively large in many areas because of the significant uncertainty associated with the historic catalog rates. Ratios are not provided for the Mojave or Northeastern regions because of lack of long term data, but these regions are included in the whole state ratio calculation.