Collaboratory for the Study of Earthquake Predictability

First Results of the Regional Earthquake Likelihood Models Experiment

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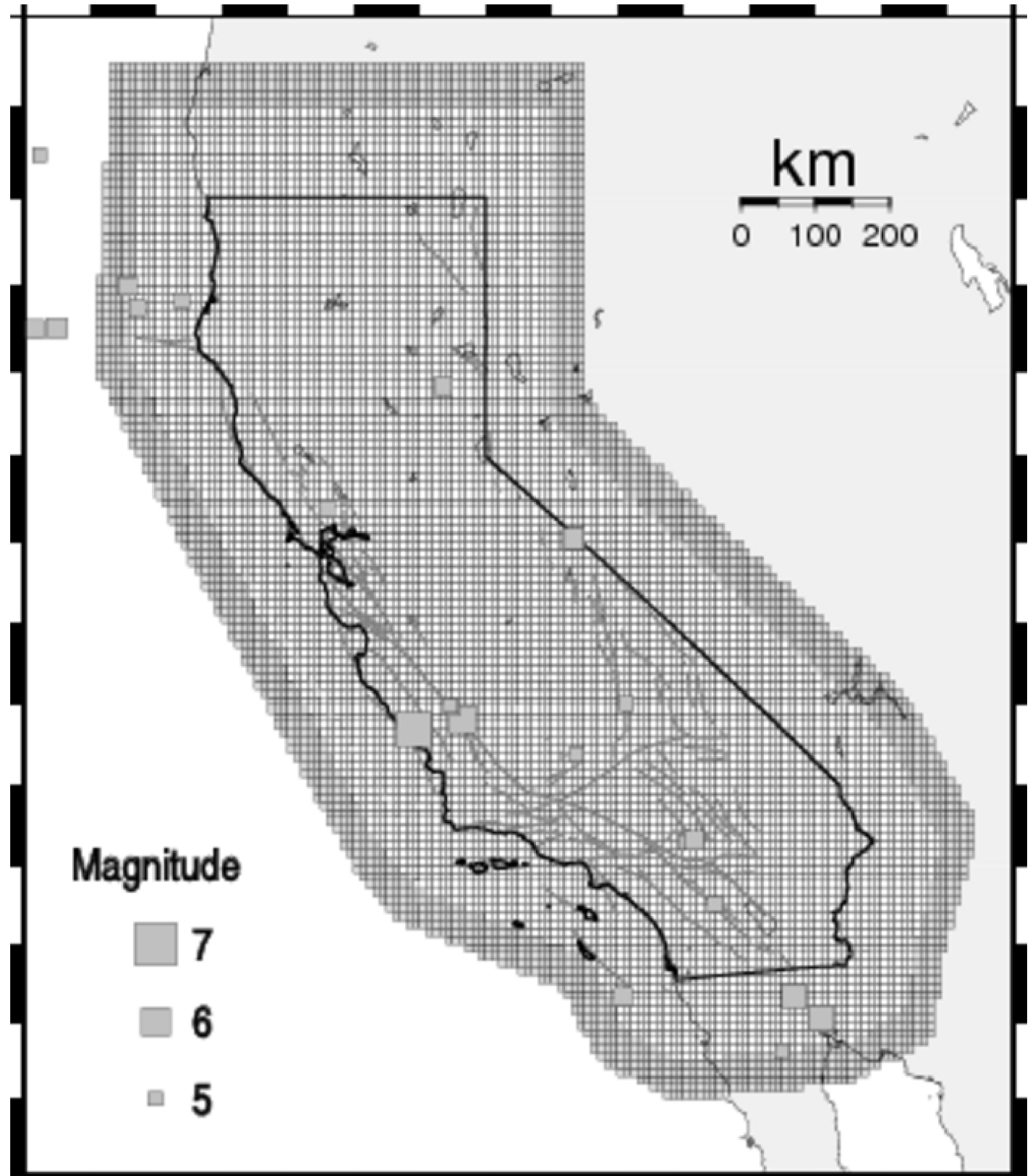
Rules

Classes
- 5-year mainshock
- 5-year main-/aftershock

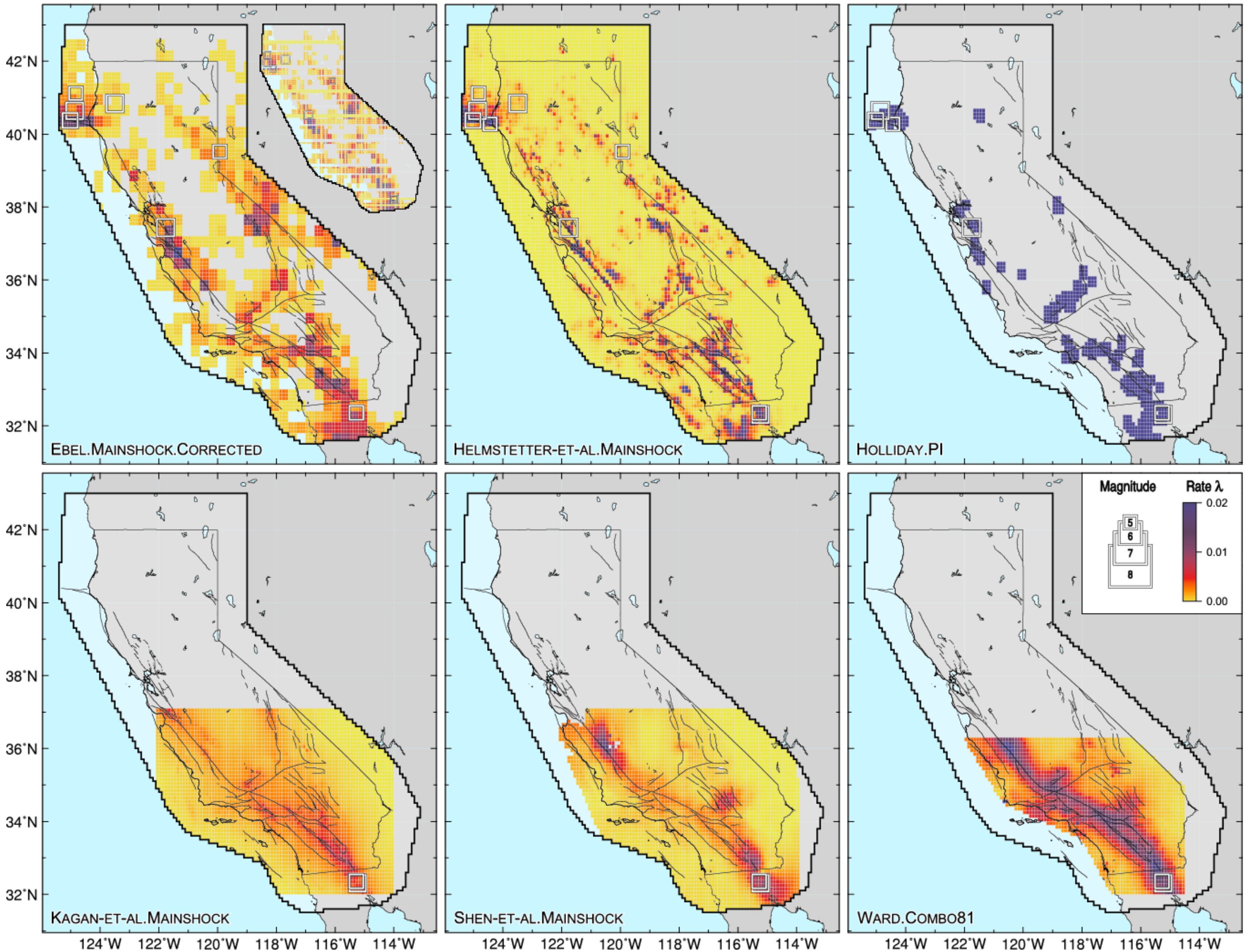
Forecast
- 0.1x0.1 degree bins
- Rates for M5-9 (0.1 step)
- Masking possible

Data
- ANSS Catalog
- 1 month delay

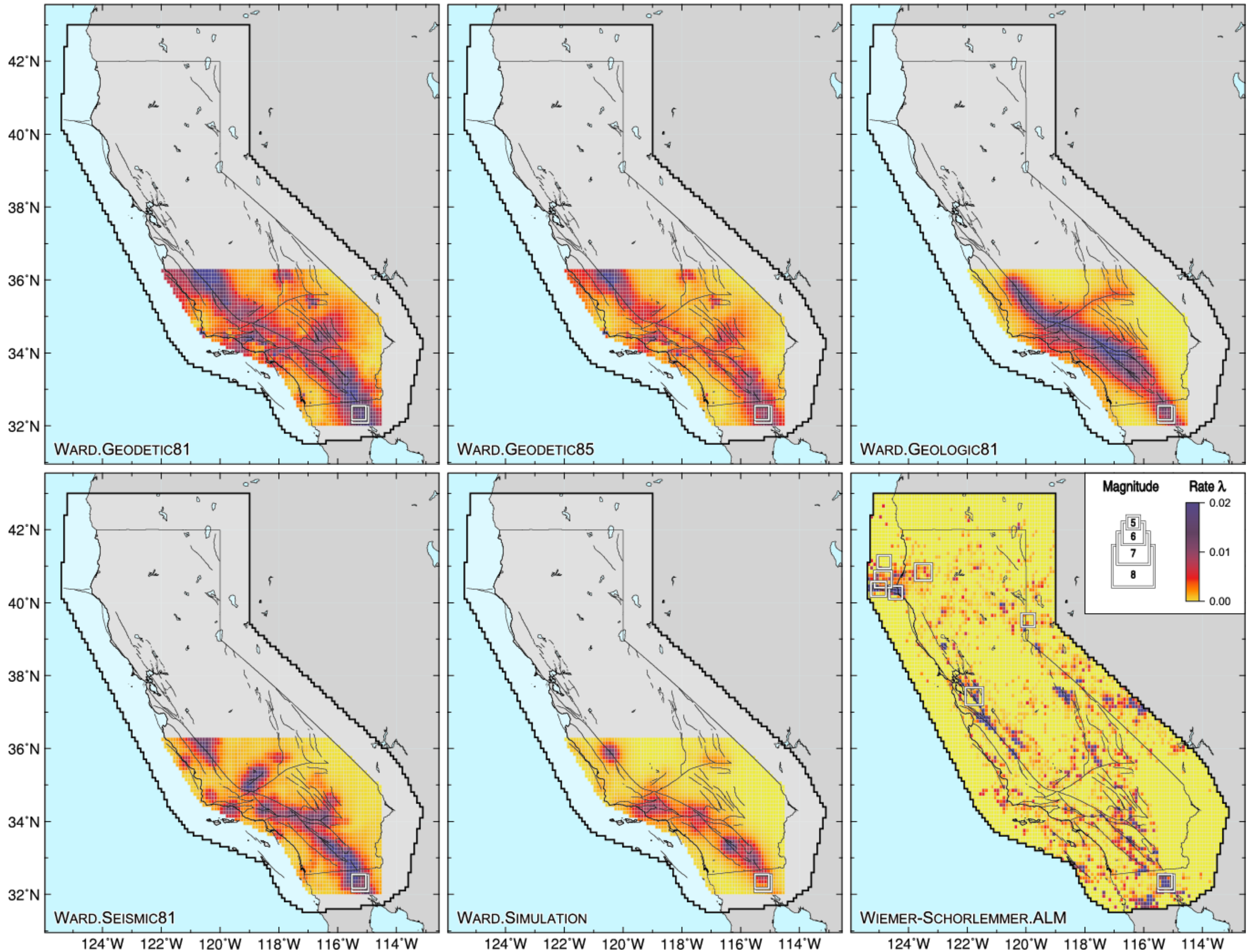
Test
- L-, N-, R-Test



RELM Mainshock Models

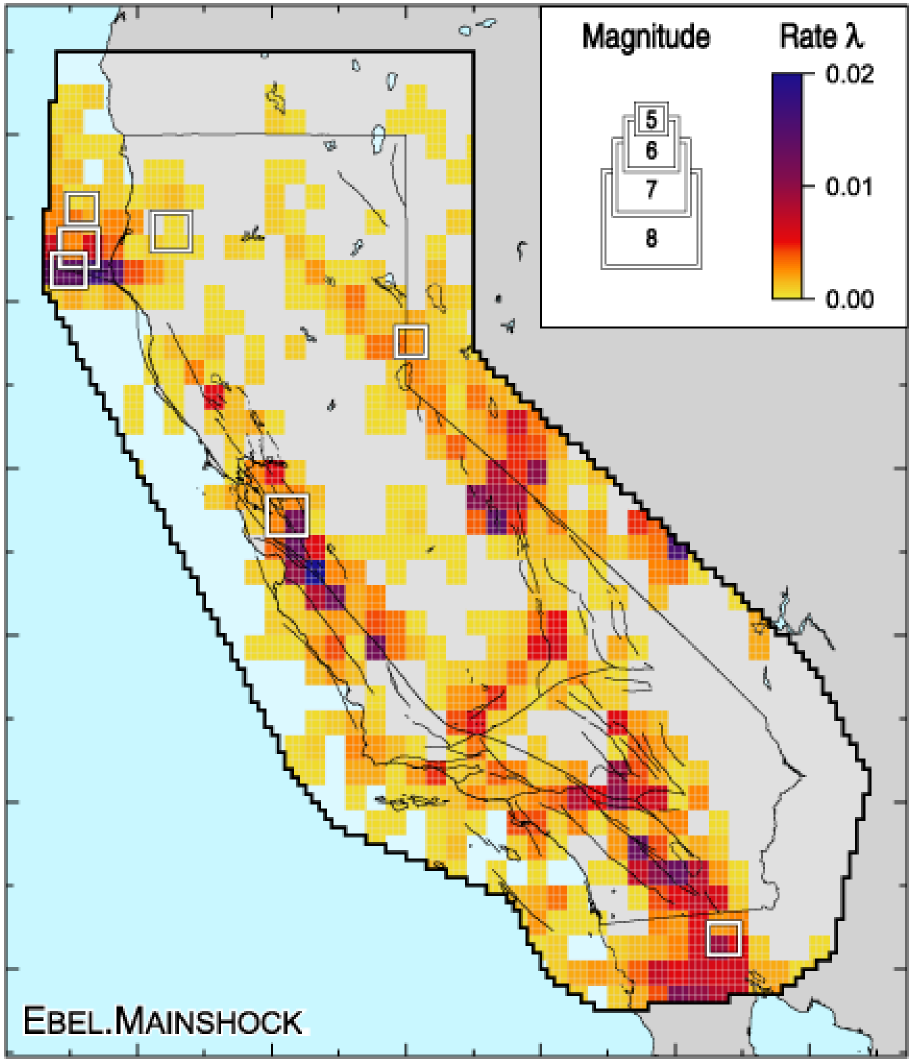


RELM Mainshock Models



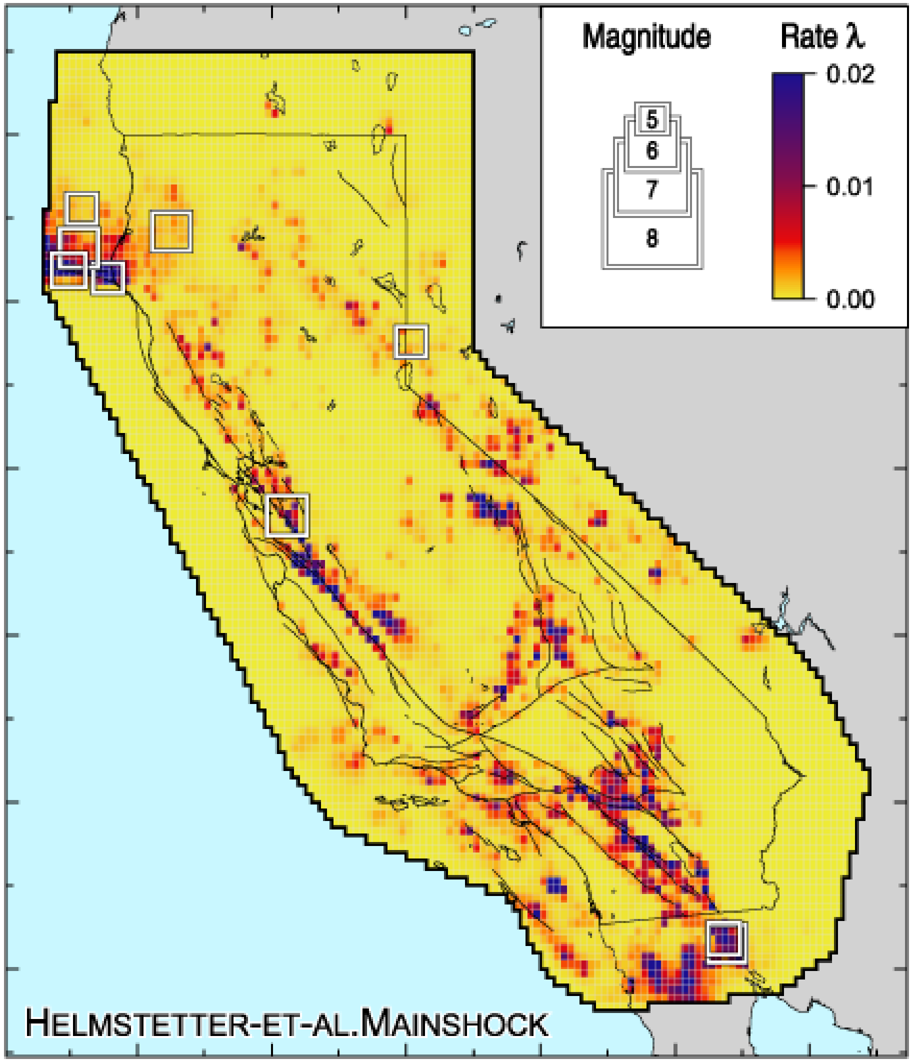
Ebel

- Decluster 1932-2004 catalog
- Determine average 5 yr rate of M5+ events in 3°x3° cells
- Use Gutenberg-Richter relation to extrapolate



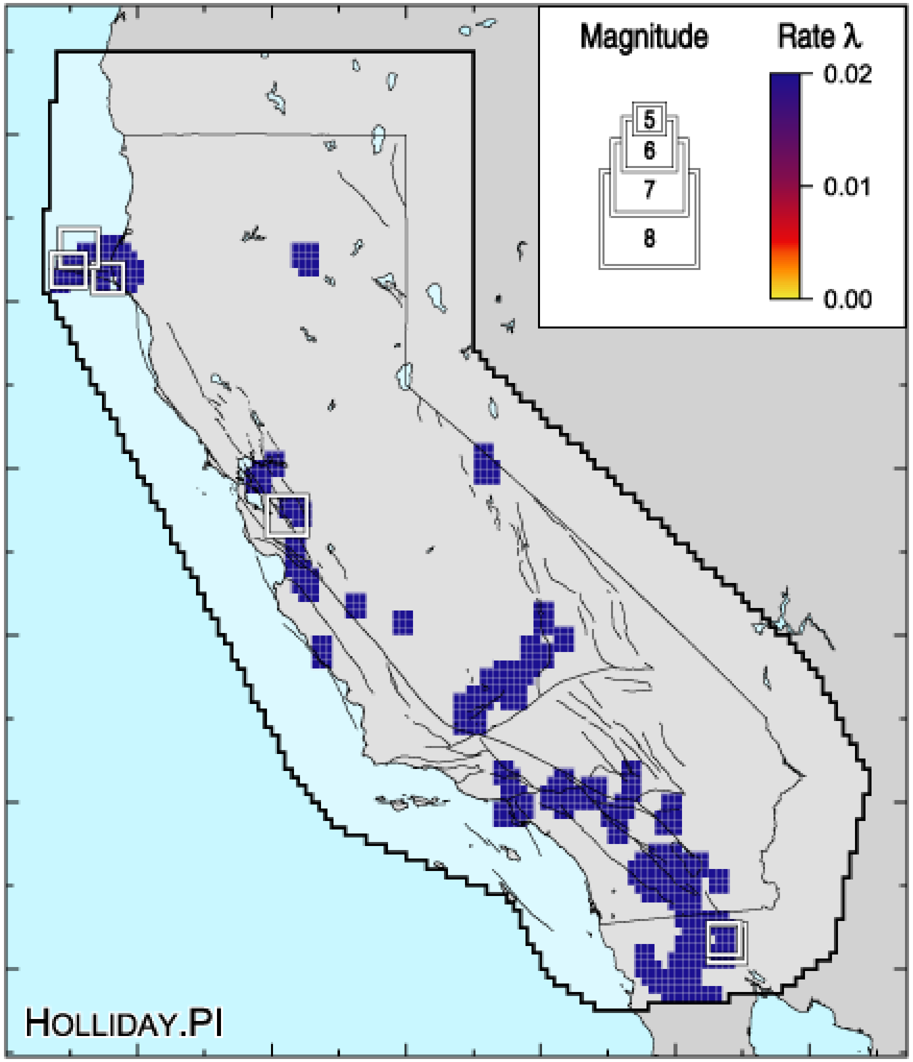
Helmstetter et al.

- Power-law smoothing of M2+ events
- Bandwidth is density-dependent and optimized
- Account for spatially-varying M_c



Holliday

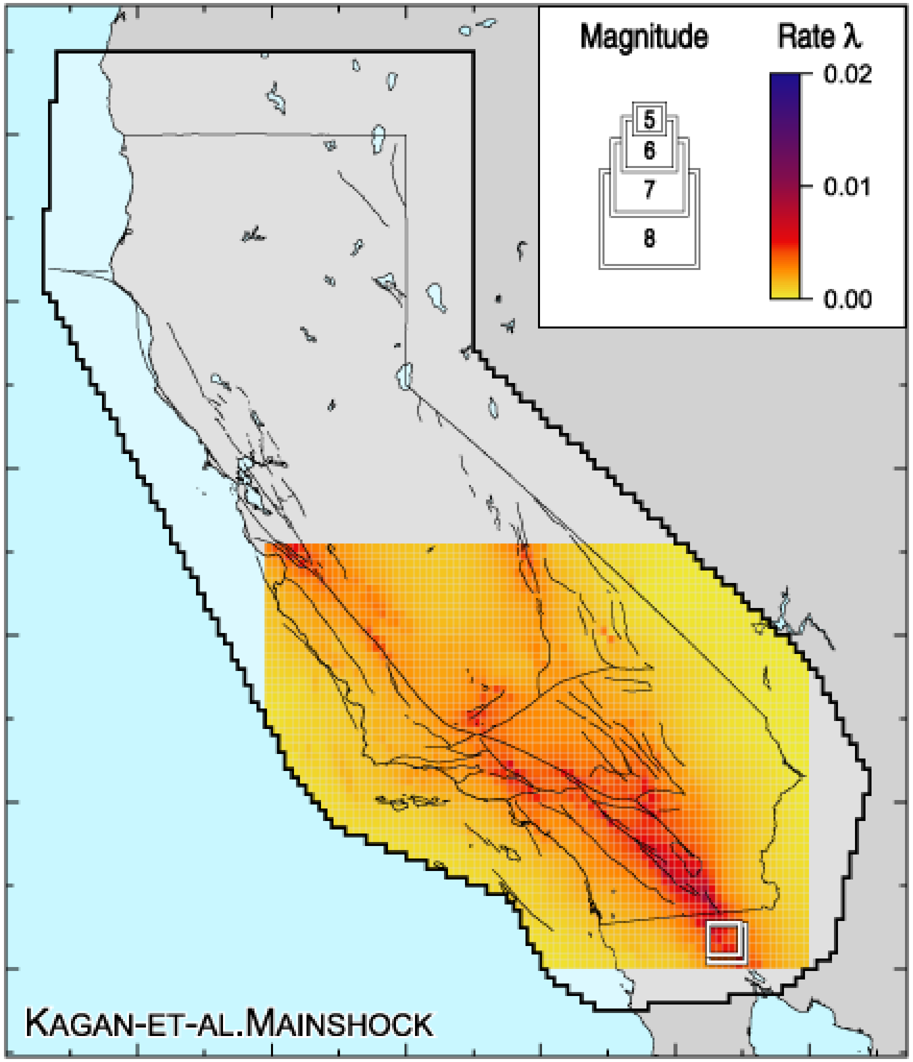
- Search for recent changes in seismicity of each cell relative to long-term behavior
- Activation and quiescence
- One variant of the Pattern Informatics method



Kagan et al.

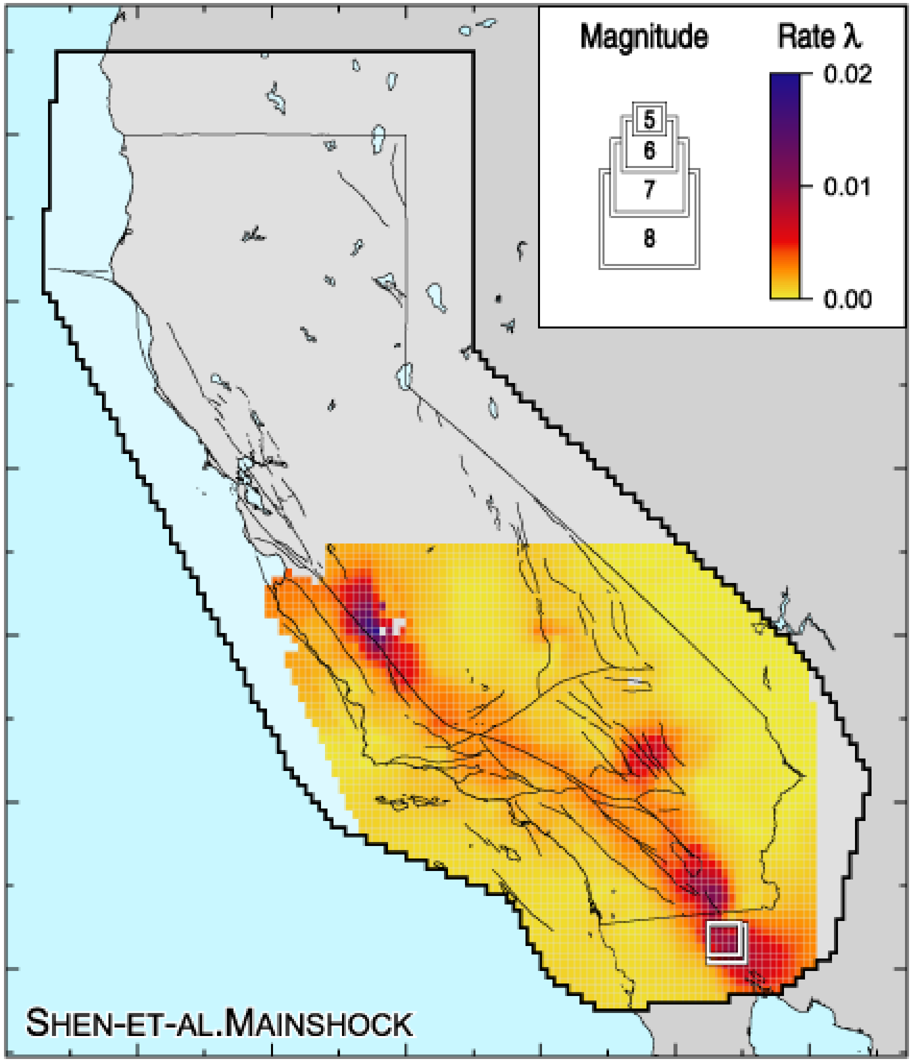
- Smooths large events in southern California since 1800

- Includes spatial anisotropy, extending the event along the presumed fault



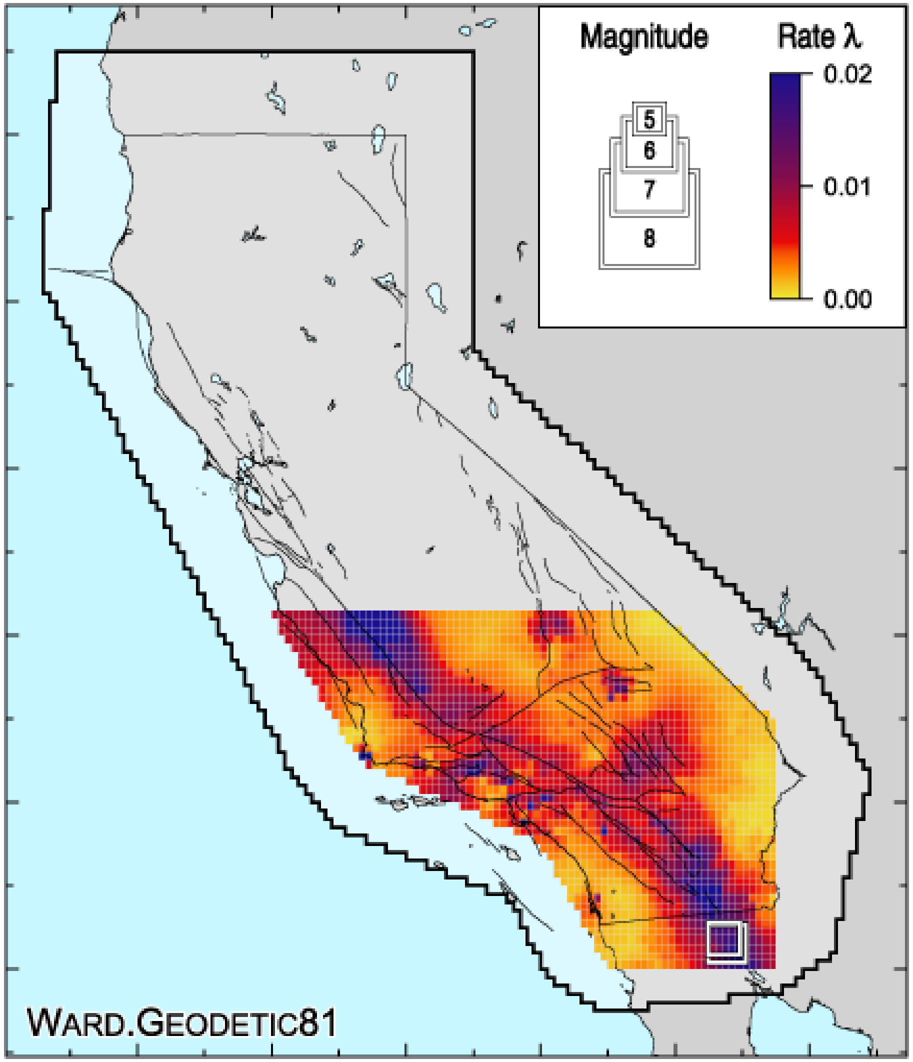
Shen

- Uses GPS data
- Assumes seismicity rate is proportional to horizontal maximum shear strain rate
- Uses tapered Gutenberg-Richter relation for extrapolation



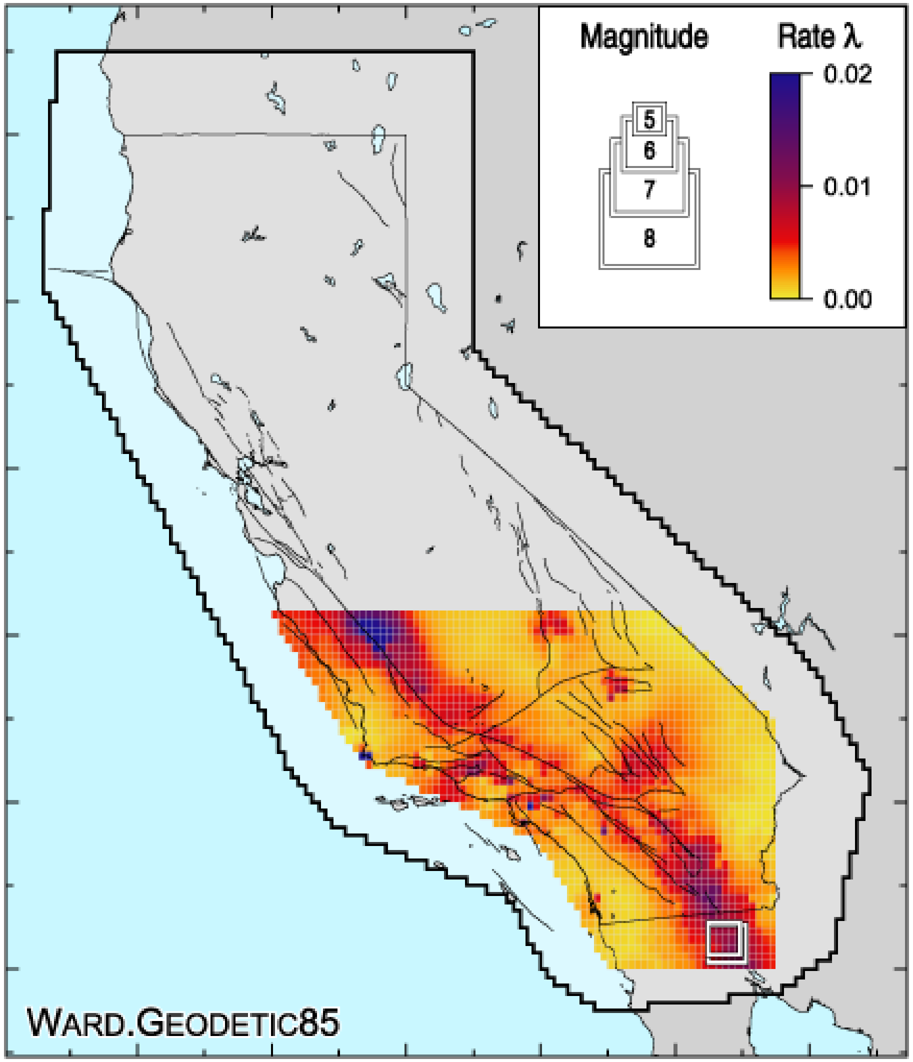
Ward [Geodetic81]

- Uses larger GPS dataset
- Slight variation on mapping strain rate to seismicity rate
- Assumes maximum magnitude $M_{max} = 8.1$



Ward [Geodetic85]

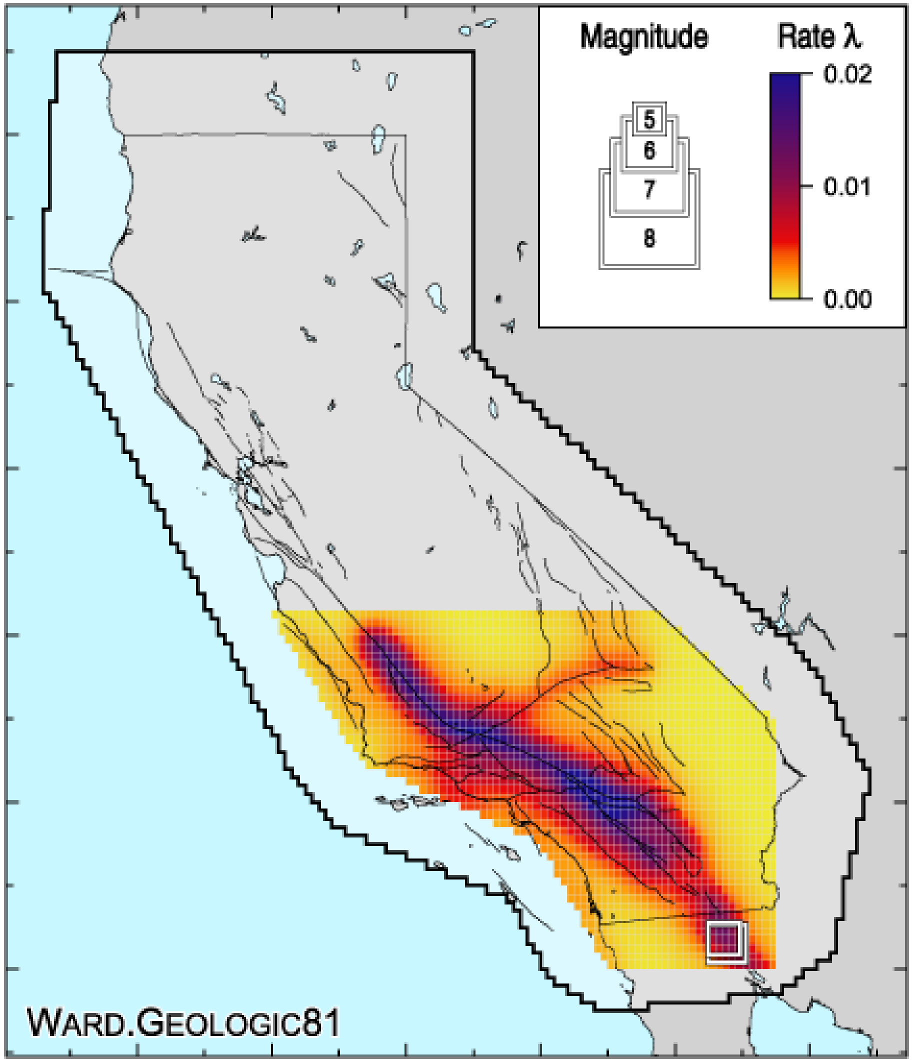
– Same as previous, except assuming $M_{max} = 8.5$



Ward [Geologic81]

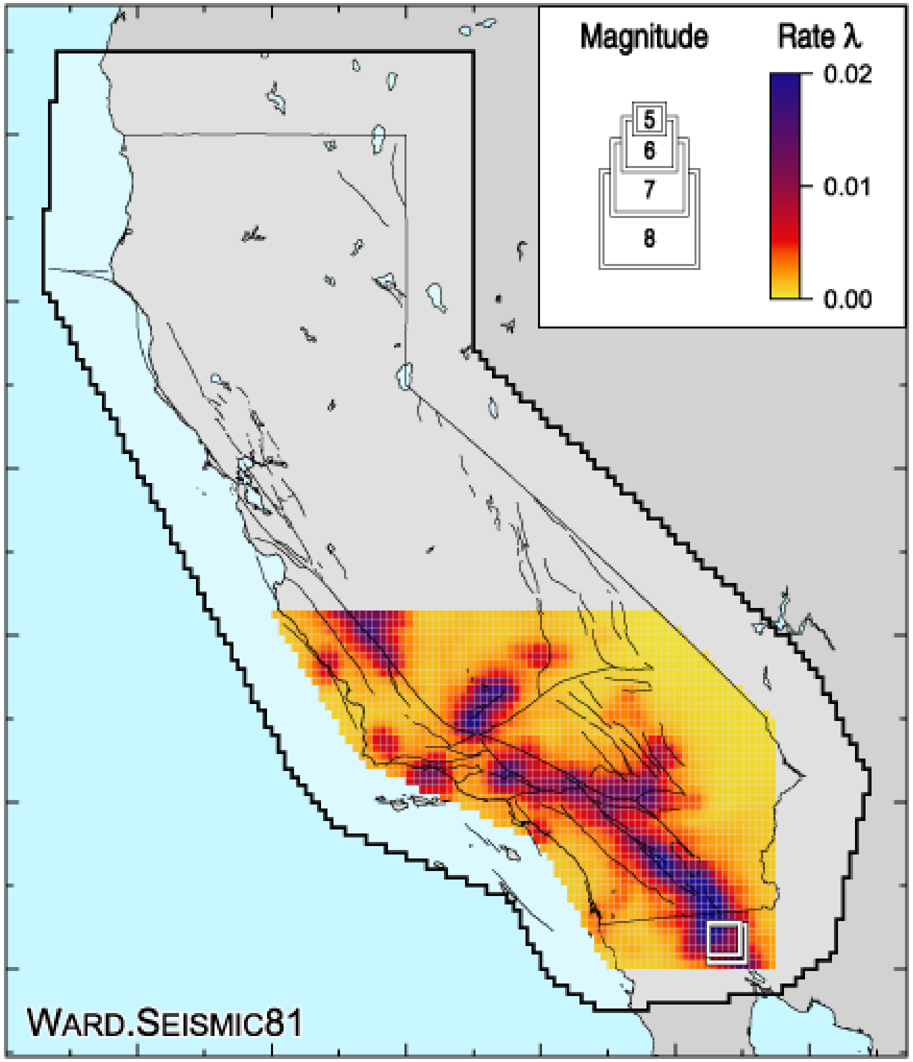
– Uses geologic data

– Maps slip rates to smoothed moment rate density, then to seismicity rate



Ward [Seismic81]

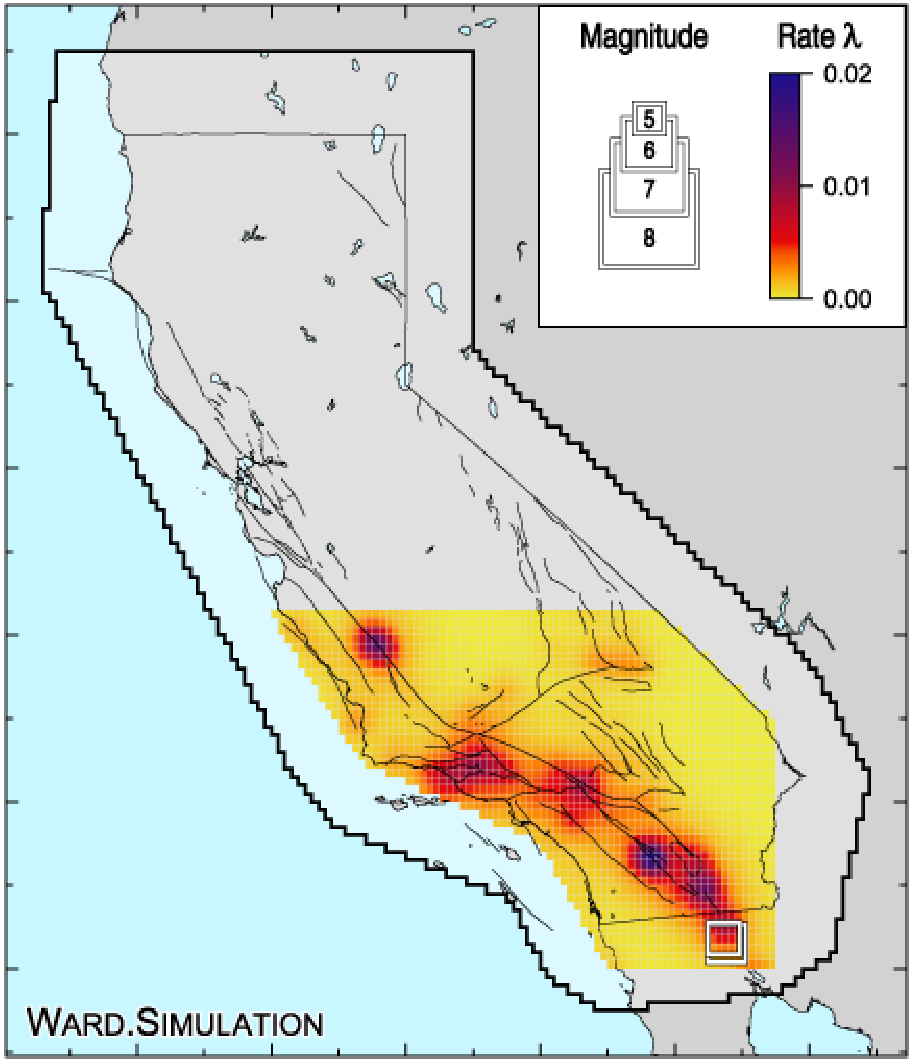
- Smooths large events since 1850



Ward [Simulation]

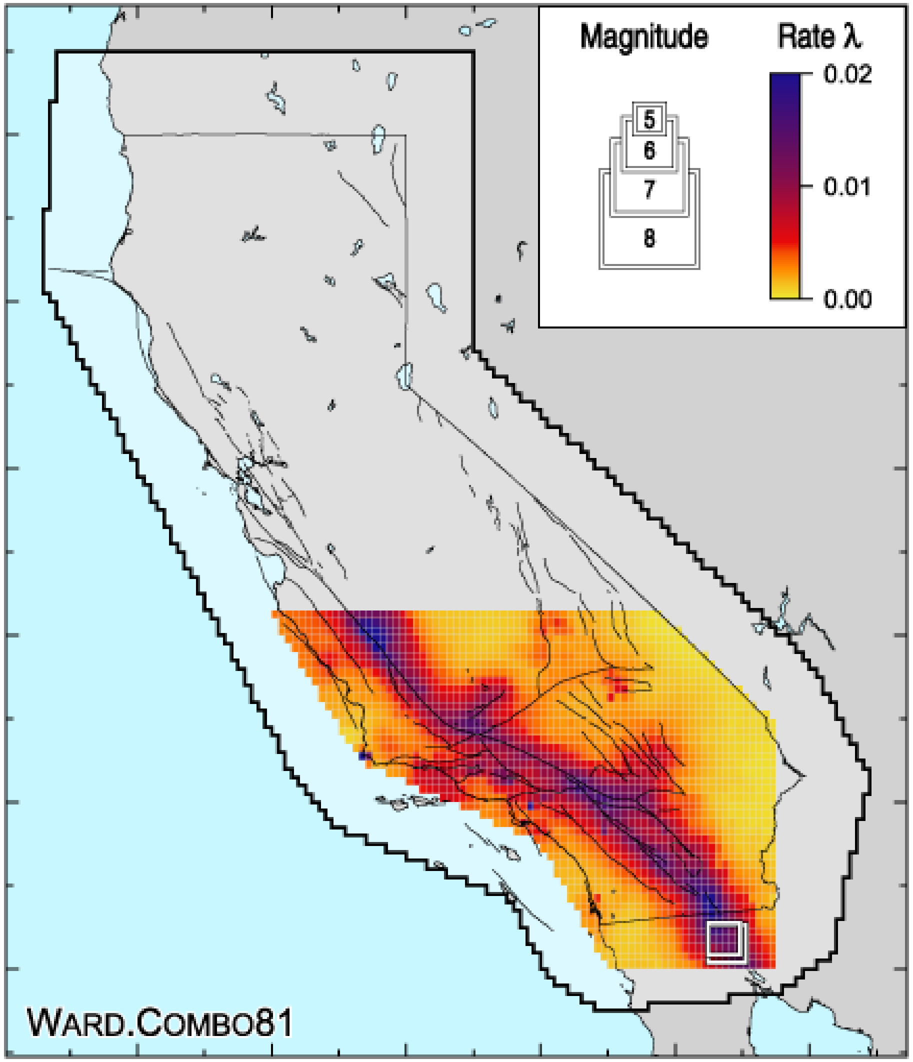
– Derived from “physics-based” simulations of velocity-weakening friction on a prescribed fault network

– One variant of the ALLCAL earthquake simulator



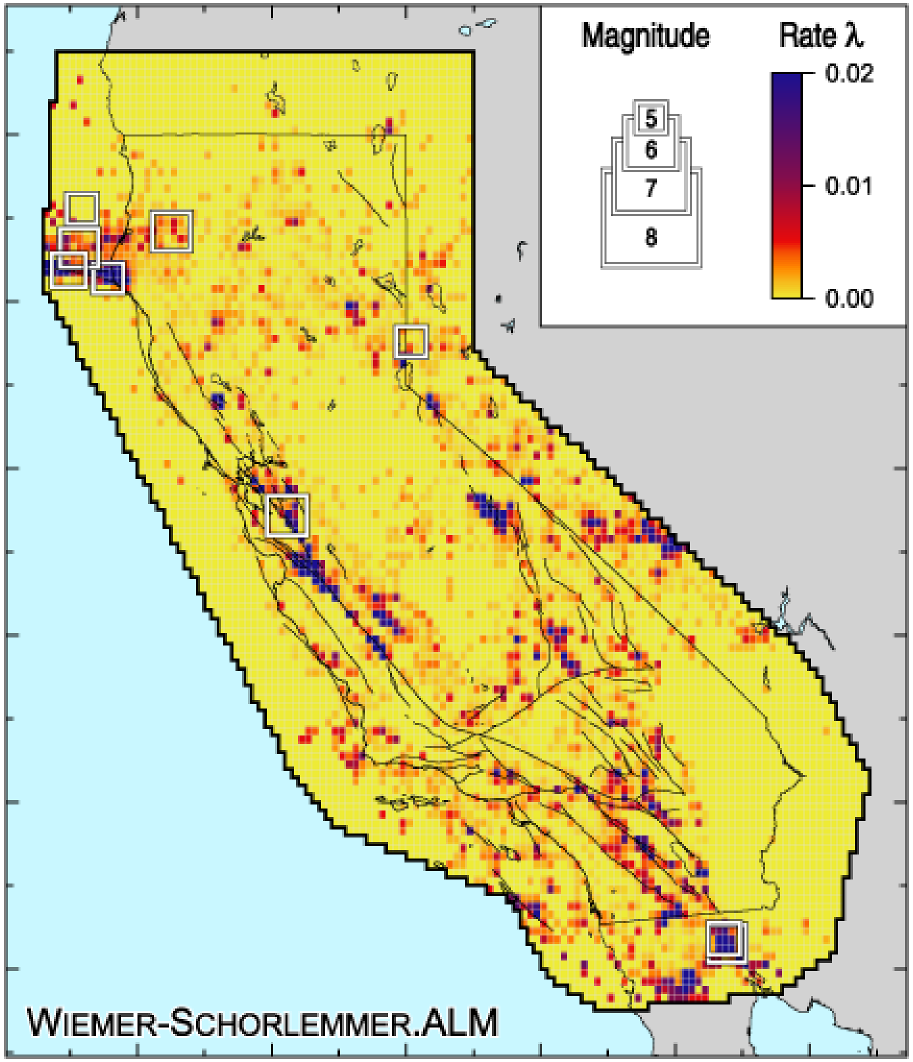
Ward [Combo81]

– Average of Ward's forecasts



Wiemer & Schorlemmer

- Estimates Gutenberg-Richter *a*- and *b*-values in every cell
- Variations in these parameters are assumed to indicate presence of asperities



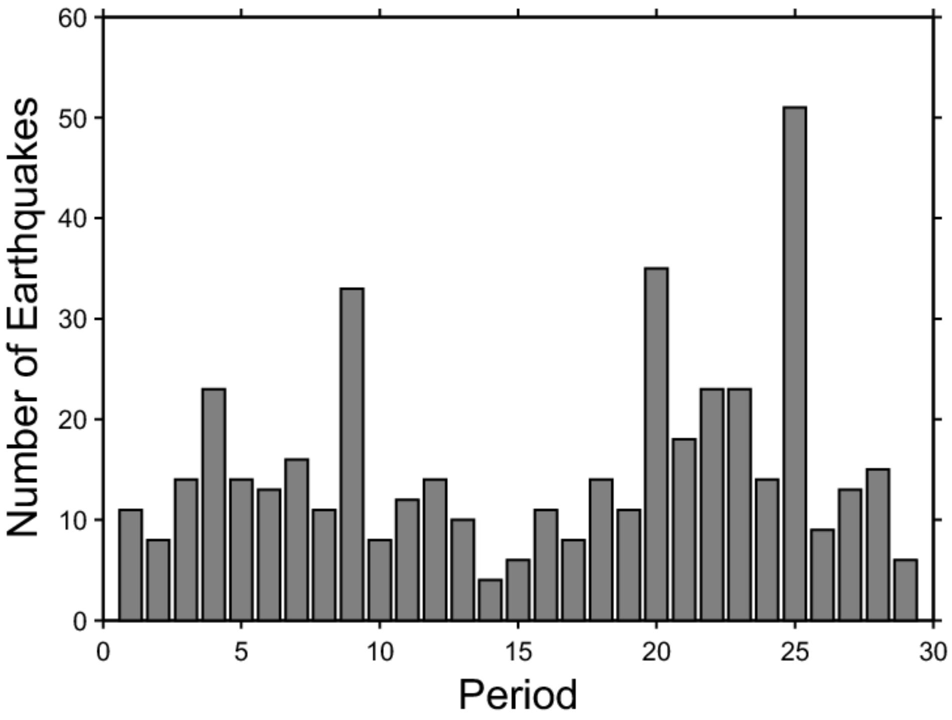
Target Earthquakes (2.5 Years)

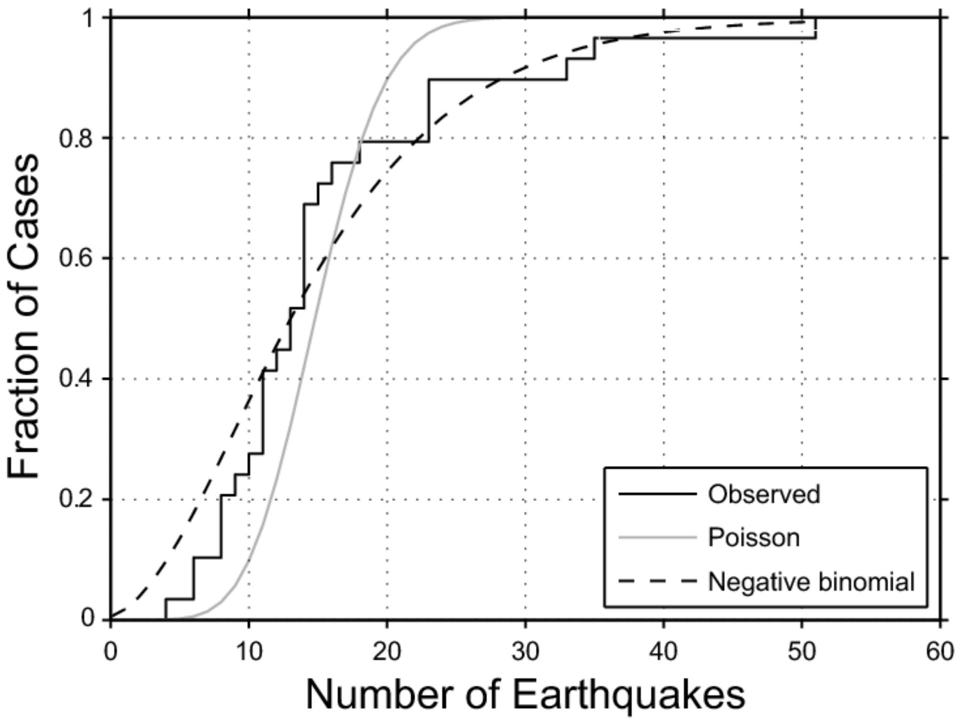
No.	Origin Time (UTC)	Latitude	Longitude	M_w	P_{I}
1	24 May 2006, 4:20	32.31	-115.23	5.37	0.24
2	19 Jul 2006, 11:41	40.28	-124.43	5.00	1.00
3	26 Feb 2007, 12:19	40.64	-124.87	5.40	1.00
4	9 May 2007, 7:50	40.37	-125.02	5.20	1.00
5	25 Jun 2007, 2:32	41.12	-124.82	5.00	1.00
6	31 Oct 2007, 3:04	37.43	-121.77	5.45	1.00
7	9 Feb 2008, 7:12	32.36	-115.28	5.10	0.04
8	11 Feb 2008, 18:29	32.33	-115.26	5.10	0.96
9	12 Feb 2008, 4:32	32.45	-115.32	4.97	0.11
10	19 Feb 2008, 22:41	32.43	-115.31	5.01	0.26
11	30 Apr 2008, 3:03	40.84	-123.50	5.40	1.00

Target Earthquakes (2.5 Years)

– We compared earthquake rates (1 January 1932 - 30 June 2004)

– Low activity (not significantly)





Mainshock Models

– L-, N-Tests for consistency of forecasts with observation

Model	γ	δ
EBEL.MAINSHOCK	[**0.017**]	0.631
HELMSTETTER-ET-AL.MAINSHOCK	0.604	0.511
HOLLIDAY.PI	0.954	0.050
KAGAN-ET-AL.MAINSHOCK	0.730	0.285
SHEN-ET-AL.MAINSHOCK	0.667	0.400
WARD.COMBO81	0.966	0.041
WARD.GEODETIC81	0.997	[**0.007**]
WARD.GEODETIC85	0.854	0.173
WARD.GEOLOGIC81	0.922	0.082
WARD.SEISMIC81	0.893	0.102
WARD.SIMULATION	0.146	0.682
WIEMER-SCHORLEMMER.ALM	0.473	0.361

Mainshock Models

– R-Test for comparative testing of the consistent models

Model	0	1	2	3	4	5	6	7	8	9
0 HELMSTETTER-ET-AL.MAINSHOCK	—	[**1.000**]	[**1.000**]	[**0.999**]	[**1.000**]	[**1.000**]	[**1.000**]	[**1.000**]	[**1.000**]	[**1.000**]
1 HOLLIDAY.PI	0.708	—	0.973	0.864	0.449	0.826	0.749	0.438	[**1.000**]	0.559
2 KAGAN-ET-AL.MAINSHOCK	0.738	[**0.013**]	—	0.030	0.799	0.672	0.812	0.518	[**1.000**]	0.635
3 SHEN-ET-AL.MAINSHOCK	0.328	[**0.003**]	[**0.000**]	—	[**0.990**]	[**1.000**]	[**0.991**]	0.964	[**1.000**]	0.766
4 WARD.COMBO81	0.868	[**0.003**]	0.085	0.626	—	0.759	0.836	0.254	[**1.000**]	0.062
5 WARD.GEODETIC85	0.868	[**0.009**]	0.076	[**0.994**]	0.217	—	0.934	0.612	[**1.000**]	0.059
6 WARD.GEOLOGIC81	0.704	[**0.007**]	0.045	0.450	0.174	0.104	—	0.729	[**1.000**]	0.164
7 WARD.SEISMIC81	0.798	[**0.003**]	[**0.008**]	0.314	[**0.025**]	0.042	[**0.024**]	—	[**1.000**]	0.138
8 WARD.SIMULATION	0.943	0.185	0.858	0.956	0.518	0.636	0.611	0.689	—	0.053
9 WIEMER-SCHORLEMMER.ALM	0.367	[**0.000**]	[**0.000**]	[**0.001**]	[**0.000**]	[**0.000**]	[**0.000**]	[**0.000**]	[**0.000**]	—

Mainshock Models

- R-Test for comparative testing of the consistent models

Model	0	1	2	3	4	5	6	7	8	9
0 HELMSTETTER-ET-AL.MAINSHOCK	—	[**1.000**]	[**1.000**]	[**0.999**]	[**1.000**]	[**1.000**]	[**1.000**]	[**1.000**]	[**1.000**]	[**1.000**]
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Mainshock Models

– R-Test for comparative testing of the consistent models

Model	0	1	2	3	4	5	6	7	8	9
0 Helmstetter-et-al.Mainshock	—	[**1.000**]	[**1.000**]	[**0.999**]	[**1.000**]	[**1.000**]	[**1.000**]	[**1.000**]	[**1.000**]	[**1.000**]
1 Holliday.PI	0.708	—	0.973	0.864	0.449	0.826	0.749	0.438	[**1.000**]	0.559
2 Kagan-et-al.Mainshock	0.738	[**0.013**]	—	0.030	0.799	0.672	0.812	0.518	[**1.000**]	0.635
3 Shen-et-al.Mainshock	0.328	[**0.003**]	[**0.000**]	—	[**0.990**]	[**1.000**]	[**0.991**]	0.964	[**1.000**]	0.766
4 Ward.Combo81	0.868	[**0.003**]	0.085	0.626	—	0.759	0.836	0.254	[**1.000**]	0.062
5 Ward.Geodetic85	0.868	[**0.009**]	0.076	[**0.994**]	0.217	—	0.934	0.612	[**1.000**]	0.059
6 Ward.Geologic81	0.704	[**0.007**]	0.045	0.450	0.174	0.104	—	0.729	[**1.000**]	0.164
7 Ward.Seismic81	0.798	[**0.003**]	[**0.008**]	0.314	[**0.025**]	0.042	[**0.024**]	—	[**1.000**]	0.138
8 Ward.Simulation	0.943	0.185	0.858	0.956	0.518	0.636	0.611	0.689	—	0.053
9 Wiemer-Schorlemmer.ALM	0.367	[**0.000**]	[**0.000**]	[**0.001**]	[**0.000**]	[**0.000**]	[**0.000**]	[**0.000**]	[**0.000**]	—

Mainshock Models

– R-Test for comparative testing of the consistent models

Model	0	1	2	3	4	5	6	7	8	9
0 HELMSTETTER-ET-AL.MAINSHOCK	—	[1.000]	[1.000]	[0.999]	[1.000]	[1.000]	[1.000]	[1.000]	[1.000]	[1.000]
1 HOLLIDAY.PI	0.708	—	0.973	0.864	0.449	0.826	0.749	0.438	[1.000]	0.559
2 KAGAN-ET-AL.MAINSHOCK	0.738	[0.013]	—	0.030	0.799	0.672	0.812	0.518	[1.000]	0.635
3 SHEN-ET-AL.MAINSHOCK	0.328	[0.003]	[0.000]	—	[0.990]	[1.000]	[0.991]	0.964	[1.000]	0.766
4 WARD.COMBO81	0.868	[0.003]	0.085	0.626	—	0.759	0.836	0.254	[1.000]	0.062
5 WARD.GEODETIC85	0.868	[0.009]	0.076	[0.994]	0.217	—	0.934	0.612	[1.000]	0.059
6 WARD.GEOLOGIC81	0.704	[0.007]	0.045	0.450	0.174	0.104	—	0.729	[1.000]	0.164
7 WARD.SEISMIC81	0.798	[0.003]	[0.008]	0.314	[0.025]	0.042	[0.024]	—	[1.000]	0.138
8 WARD.SIMULATION	0.943	0.185	0.858	0.956	0.518	0.636	0.611	0.689	—	0.053
9 WIEMER-SCHORLEMMER.ALM	0.367	[0.000]	[0.000]	[0.001]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	—

Mainshock/Aftershock Models

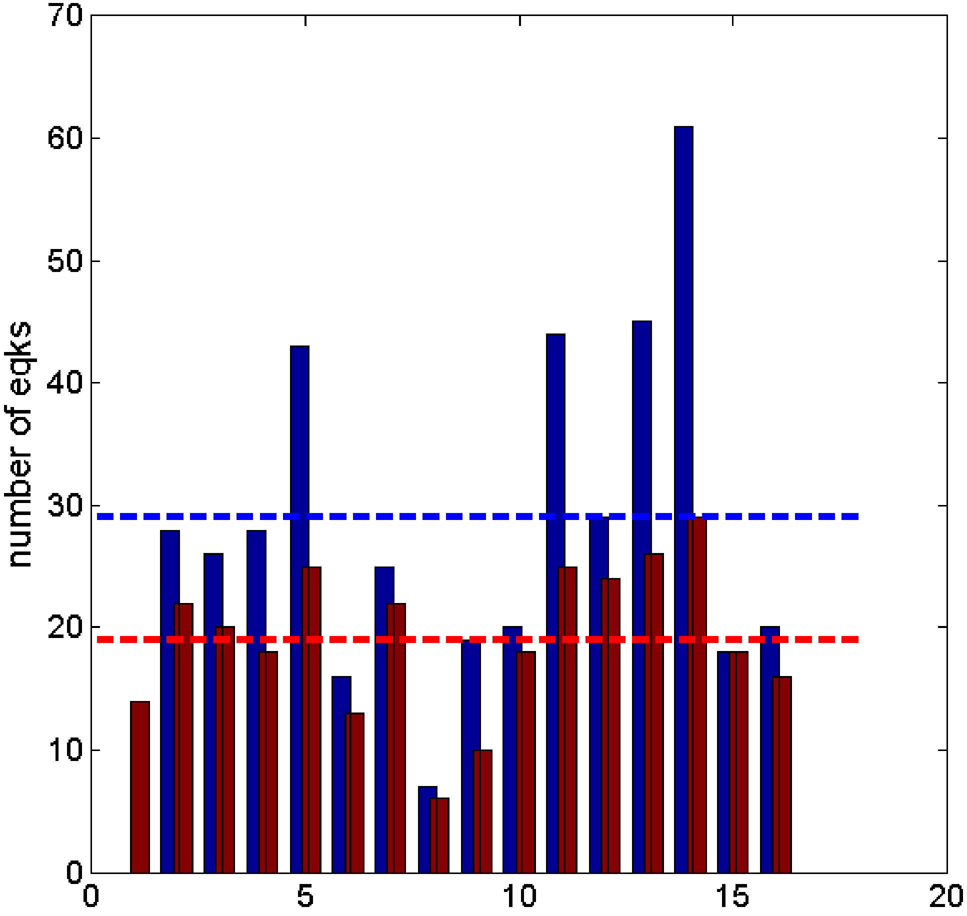
Model	γ	δ
Bird-Liu.Neokinema	1.000	[**0.000**]
Ebel.Aftershock	1.000	[**0.000**]
Helmstetter-et-al.Aftershock	0.976	0.035
Kagan-et-al.Aftershock	0.894	0.100
Shen-et-al.Aftershock	0.891	0.145

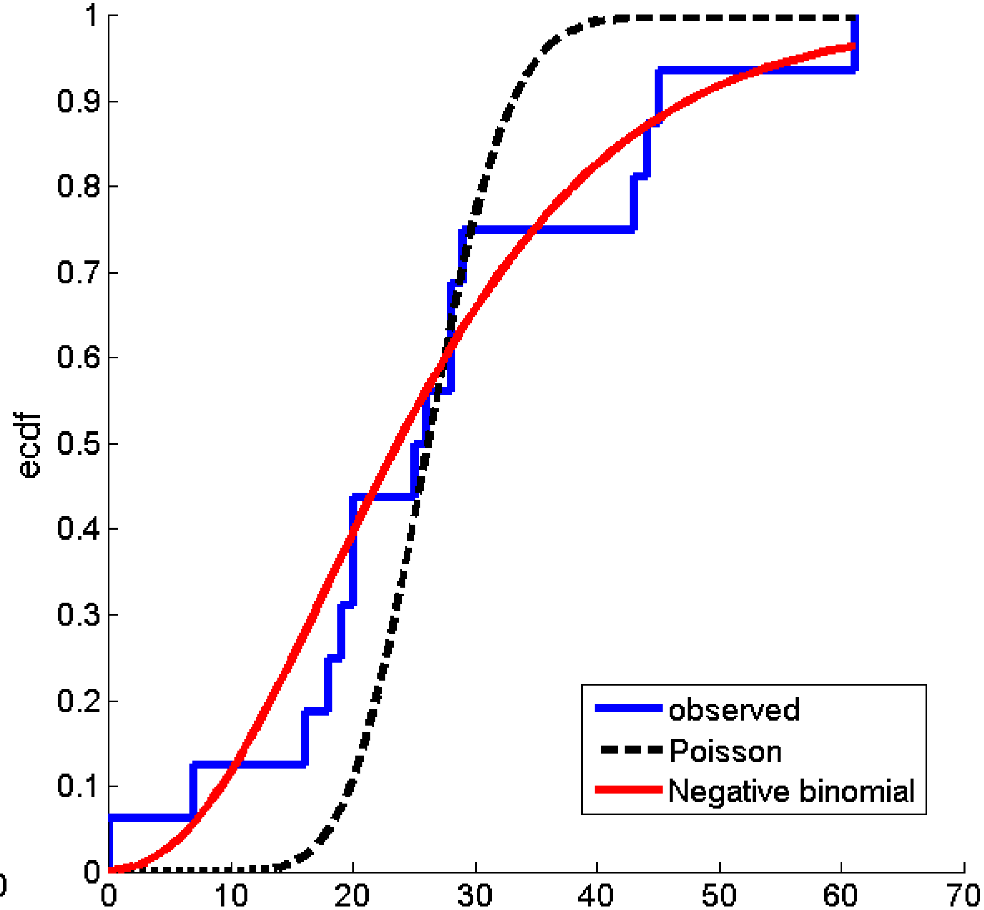
Model	0	1	2
0 Helmstetter-et-al.Aftershock	—	[**1.000**]	[**1.000**]
1 Kagan-et-al.Aftershock	0.334	—	0.087
2 Shen-et-al.Aftershock	0.112	[**0.002**]	—

Target Earthquakes (4.5 Years)

No.	Origin Time (UTC)	Latitude	Longitude	M_{ANSS}
1	**24 May 2006, 04:20**	**32.31**	**-115.23**	**5.37**
2	**19 Jul 2006, 11:41**	**40.28**	**-124.43**	**5.00**
3	**26 Feb 2007, 12:19**	**40.64**	**-124.87**	**5.40**
4	**09 May 2007, 07:50**	**40.37**	**-125.02**	**5.20**
5	**25 Jun 2007, 02:32**	**41.12**	**-124.82**	**5.00**
6	**31 Oct 2007, 03:04**	**37.43**	**-121.77**	**5.45**
7	**09 Feb 2008, 07:12**	**32.36**	**-115.28**	**5.10**
8	11 Feb 2008, 18:29	32.33	-115.26	5.10
9	12 Feb 2008, 04:32	32.45	-115.32	4.97
10	19 Feb 2008, 22:41	32.43	-115.31	5.01
11	**26 Apr 2008, 06:40**	**39.53**	**-119.93**	**5.00**
12	**30 Apr 2008, 03:03**	**40.84**	**-123.50**	**5.40**
13	**29 Jul 2008, 18:42**	**33.95**	**-117.76**	**5.39**
14	**20 Nov 2008, 19:23**	**32.33**	**-115.33**	**4.98**
15	**06 Dec 2008, 04:18**	**34.81**	**-116.42**	**5.06**
16	**19 Sep 2009, 22:55**	**32.37**	**-115.26**	**5.08**
17	**01 Oct 2009, 10:01**	**36.39**	**-117.86**	**5.00**
18	**03 Oct 2009, 01:16**	**36.39**	**-117.86**	**5.19**
19	**30 Dec 2009, 18:48**	**32.46**	**-115.19**	**5.80**
20	**10 Jan 2010, 00:27**	**40.65**	**-124.69**	**6.50**
21	**04 Feb 2010, 20:20**	**40.41**	**-124.96**	**5.88**
22	**04 Apr 2010, 22:40**	**32.26**	**-115.29**	**7.20**
23	04 Apr 2010, 22:50	32.10	-115.05	5.51
24	04 Apr 2010, 23:15	32.30	-115.26	5.43
25	04 Apr 2010, 23:25	32.25	-115.30	5.38
26	05 Apr 2010, 00:07	32.02	-115.02	5.32
27	05 Apr 2010, 03:15	32.63	-115.81	4.97
28	08 Apr 2010, 16:44	32.22	-115.28	5.29
29	15 Jun 2010, 04:26	32.70	-115.92	5.72

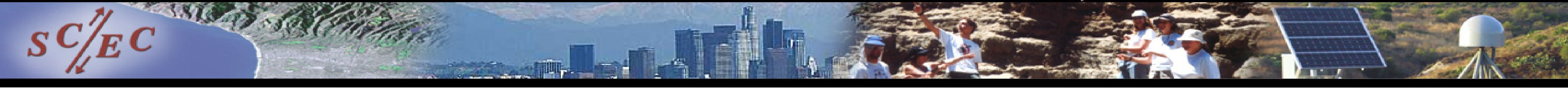
Target Earthquakes (4.5 Years)





Mainshock Models

Model	γ	κ	δ		ζ
EBEL.MAINSHOCK	[**0.010**]	0.389	0.394	0.697	[**0.000**]
HELMSTETTER-ET-AL.MAINSHOCK	0.478	0.265	0.5325	0.559	0.340
HOLLIDAY.PI	0.987	0.130	0.992	[**0.015**]	[**0.000**]
KAGAN-ET-AL.MAINSHOCK	0.591	0.278	0.636	0.485	0.801
SHEN-ET-AL.MAINSHOCK	0.444	0.272	0.468	0.655	0.842
WARD.COMBO81	0.988	0.190	0.995	[**0.012**]	0.804
WARD.GEODETIC81	1.000	0.197	1.000	[**0.001**]	0.772
WARD.GEODETIC85	0.917	0.195	0.933	0.120	0.795
WARD.GEOLOGIC81	0.960	0.186	0.982	0.0377	0.267
WARD.SEISMIC81	0.960	0.164	0.973	0.0530	0.656
WARD.SIMULATION	0.117	0.070	0.357	0.767	0.324
WIEMER-SCHORLEMMER.ALM	0.331	0.514	0.724	0.356	[**0.000**]



Lessons learned

- Difficulties in R-Test interpretation
  - Development of improved tests: T-Test, W-Test
- Account for negative binomial distribution in new forecasts
- Focus on time-dependent models

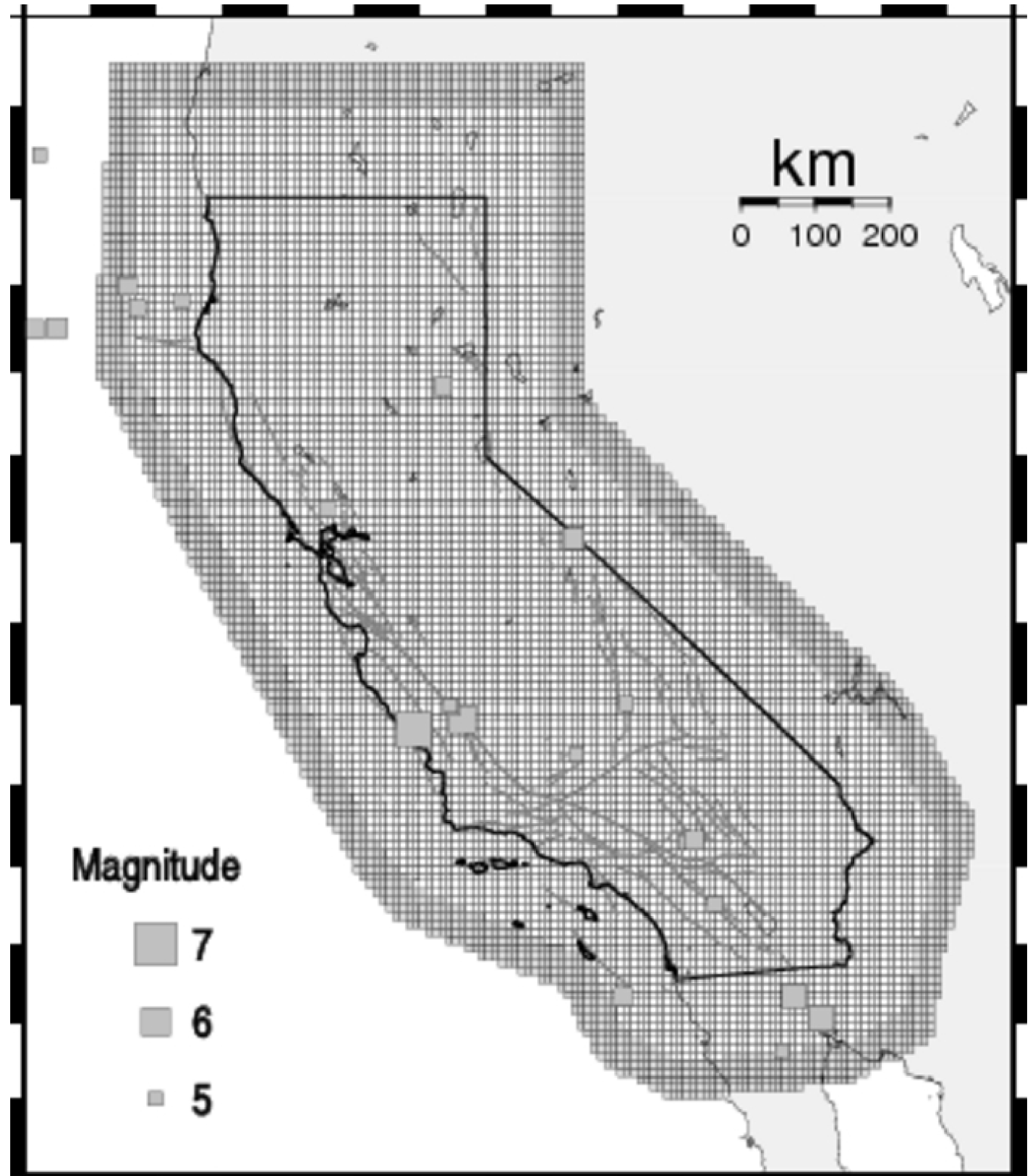
1-Day Models

Classes
- 1-day main-/aftershock

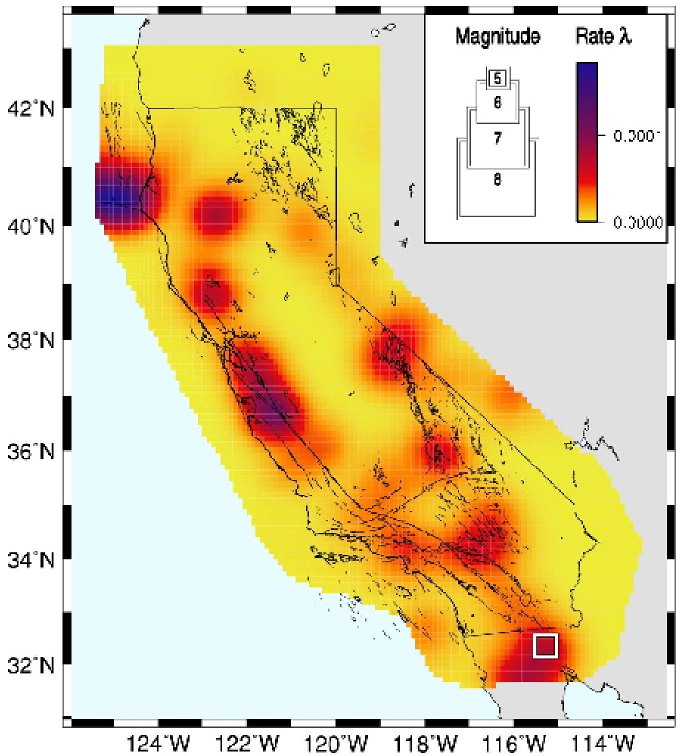
Forecast
- 0.1x0.1 degree bins
- Rates for M4-9 (0.1 step)
- Masking possible

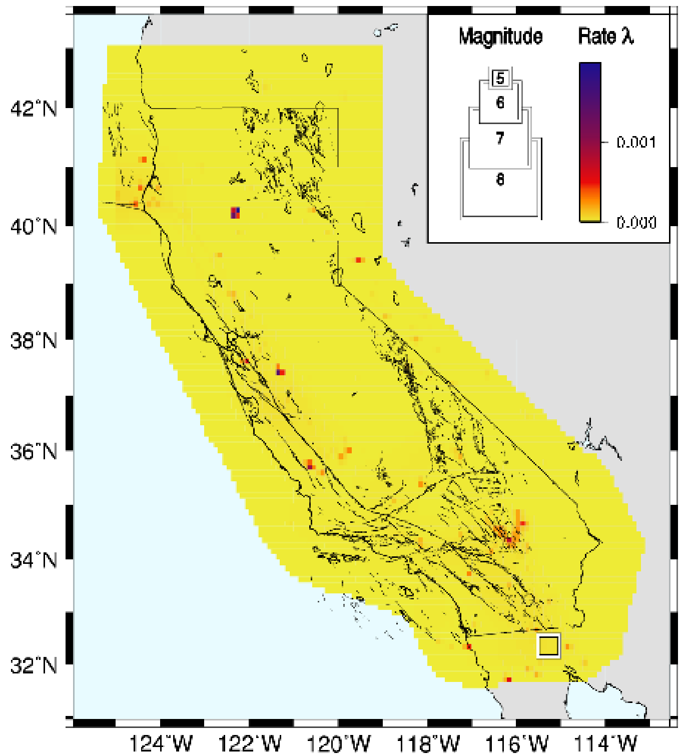
Data
- ANSS Catalog
- 1 month delay

Test
- L-, N-, R-Test

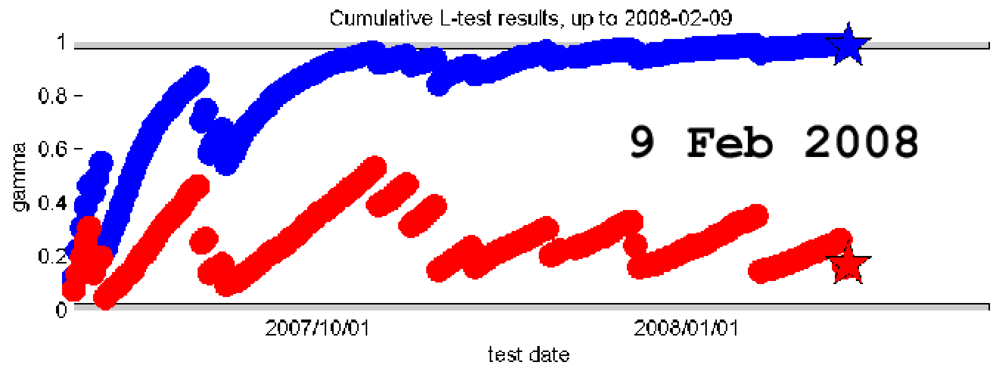


Results – Baja Swarm



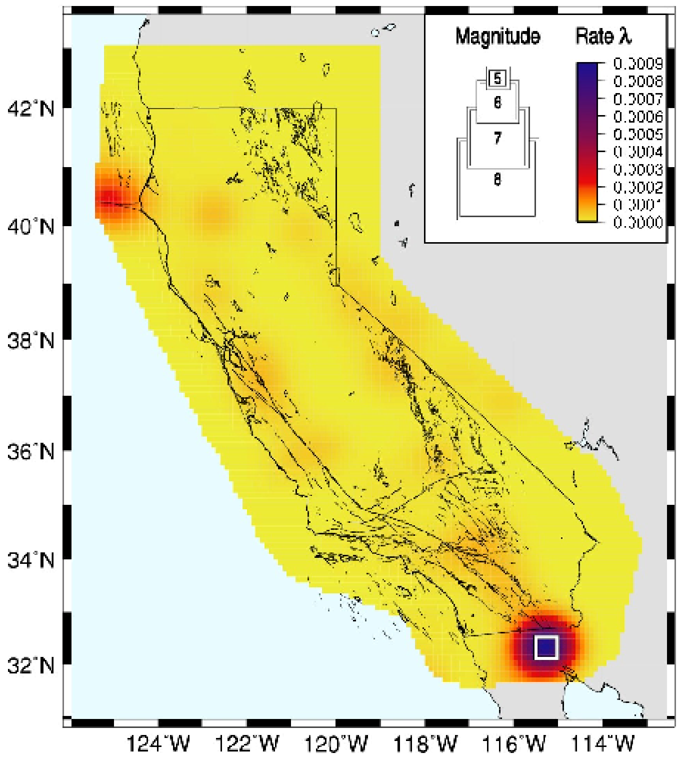


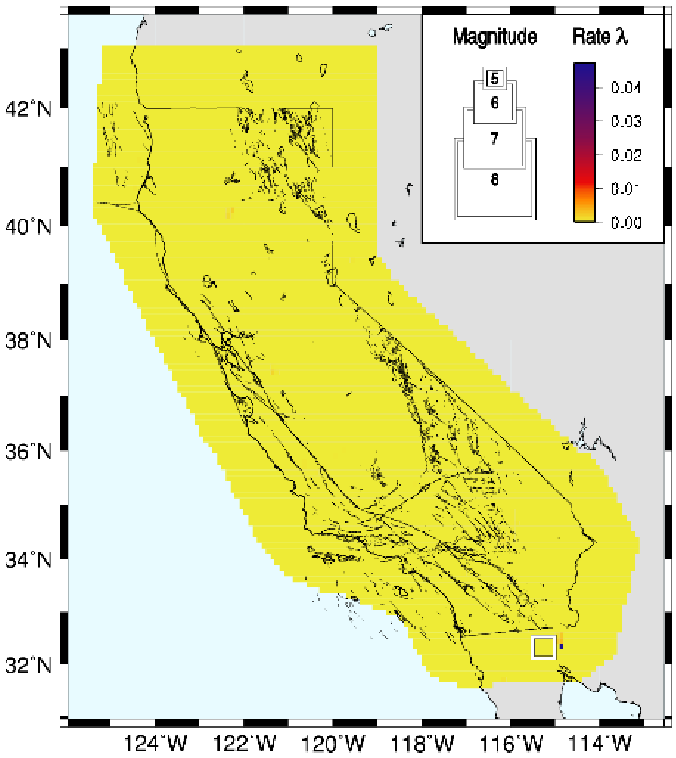
ETAS



STEP

Results – Baja Swarm





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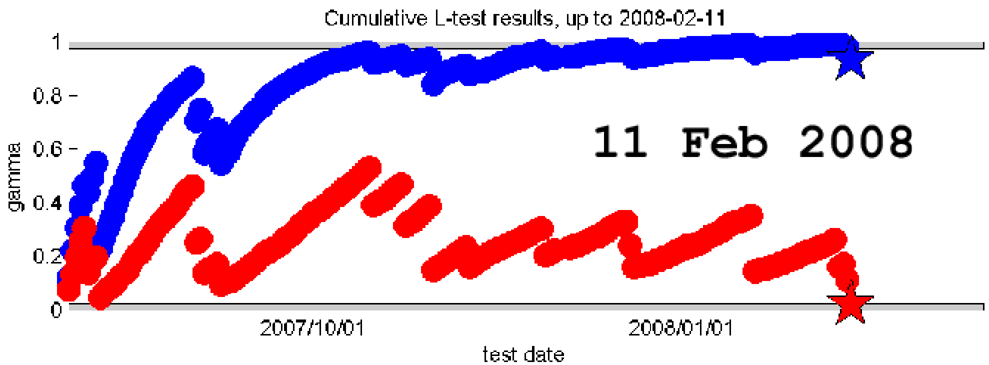

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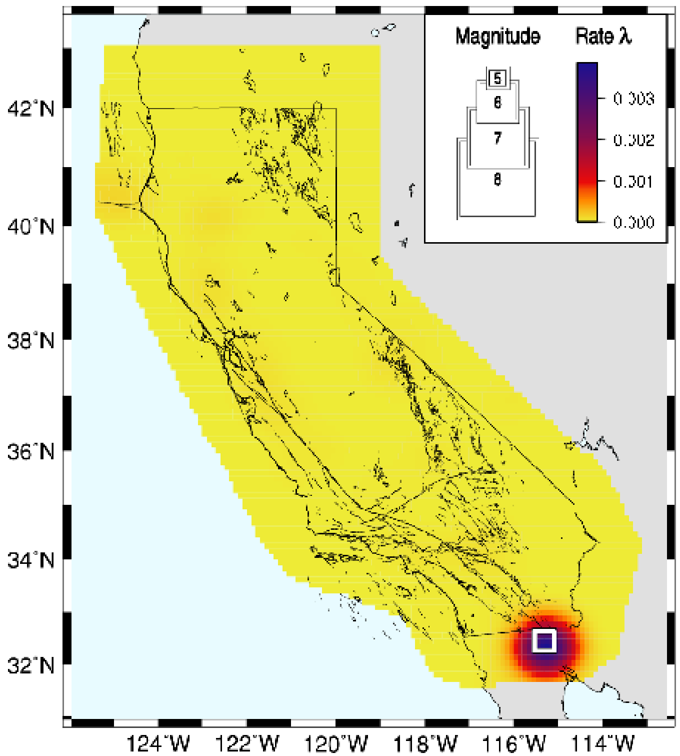

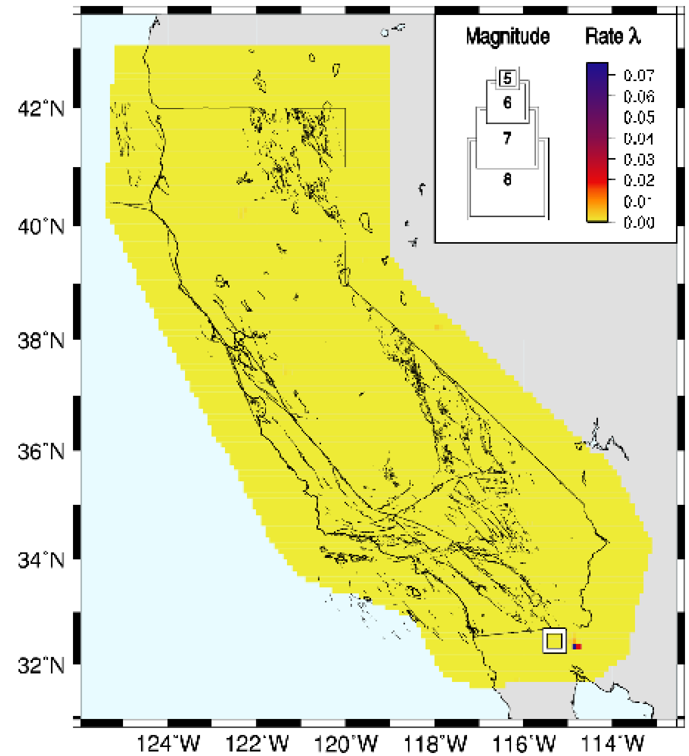

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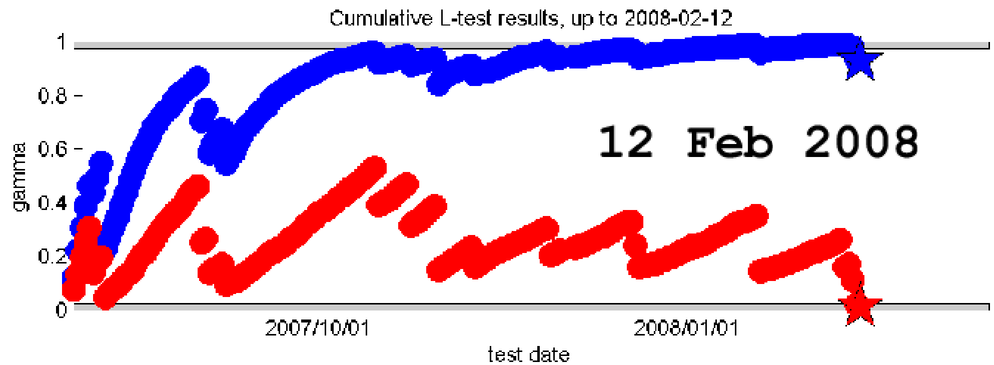

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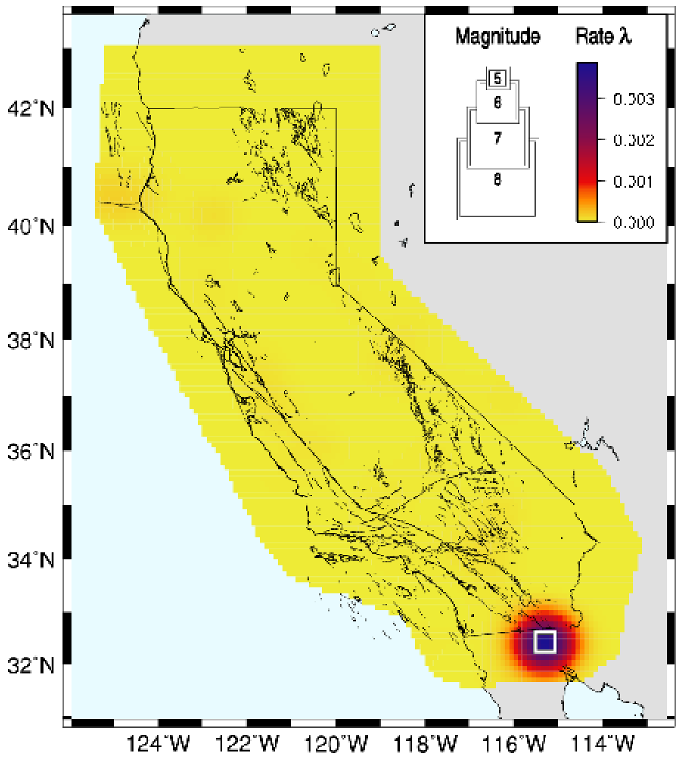

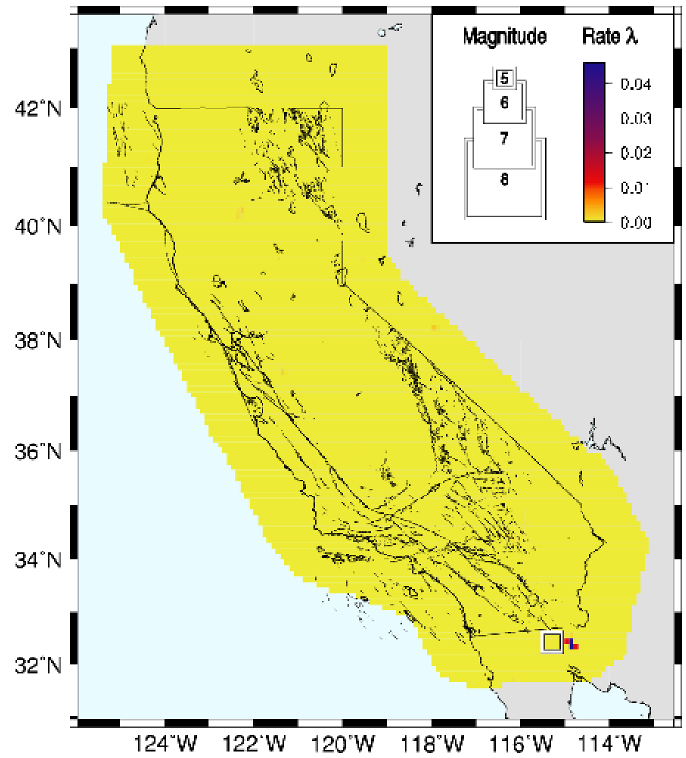

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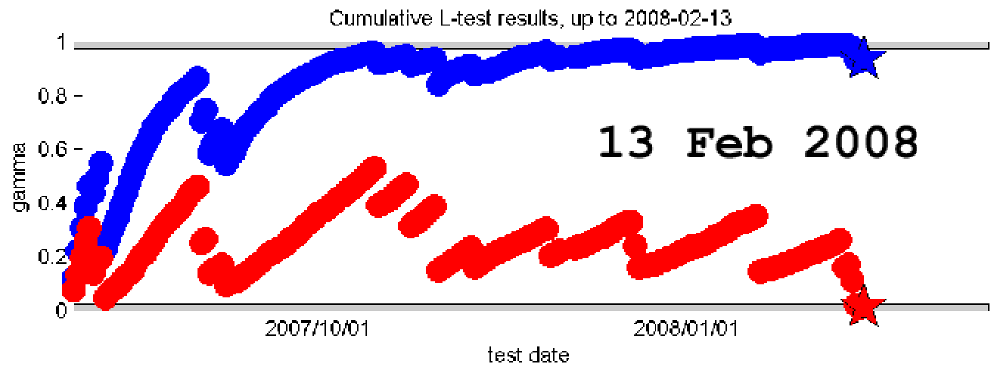

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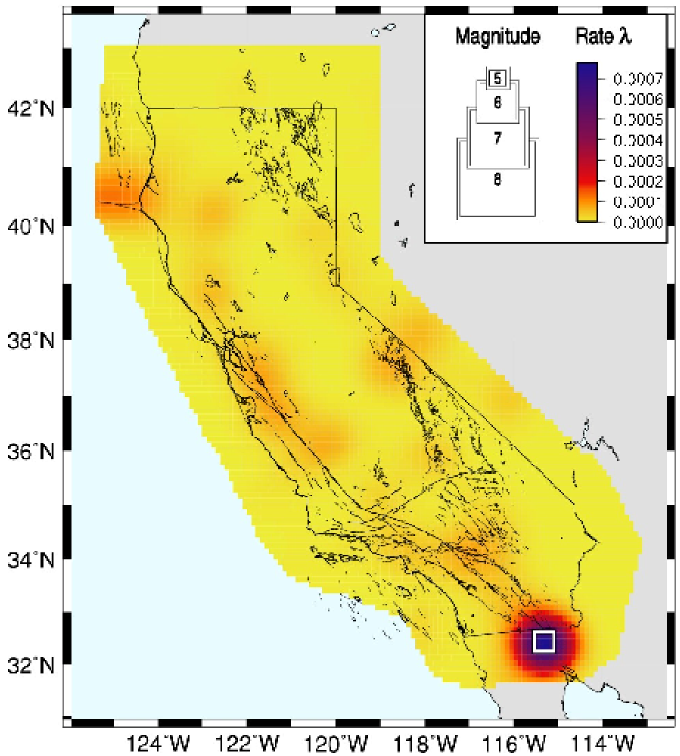

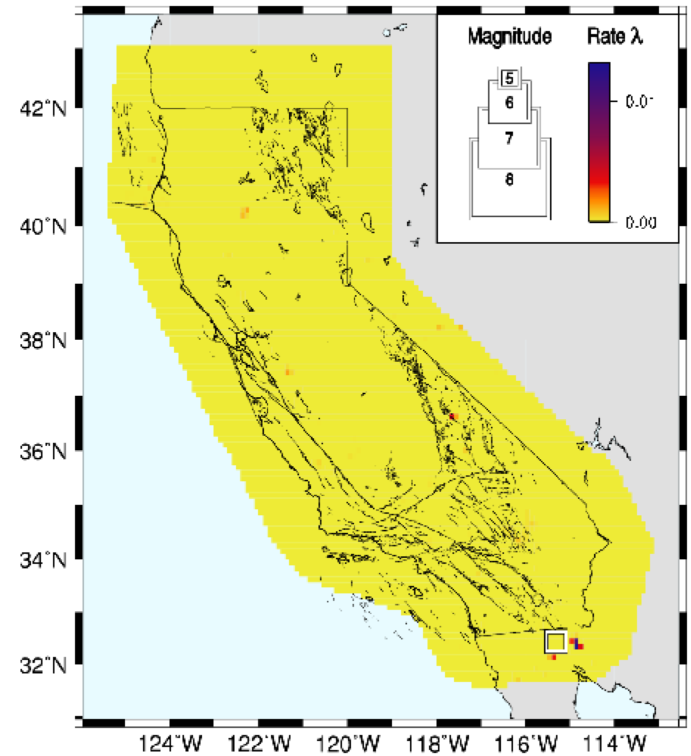

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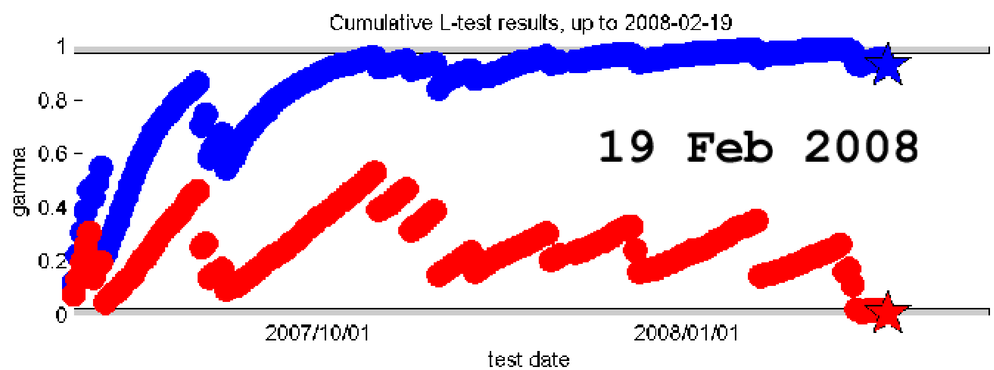

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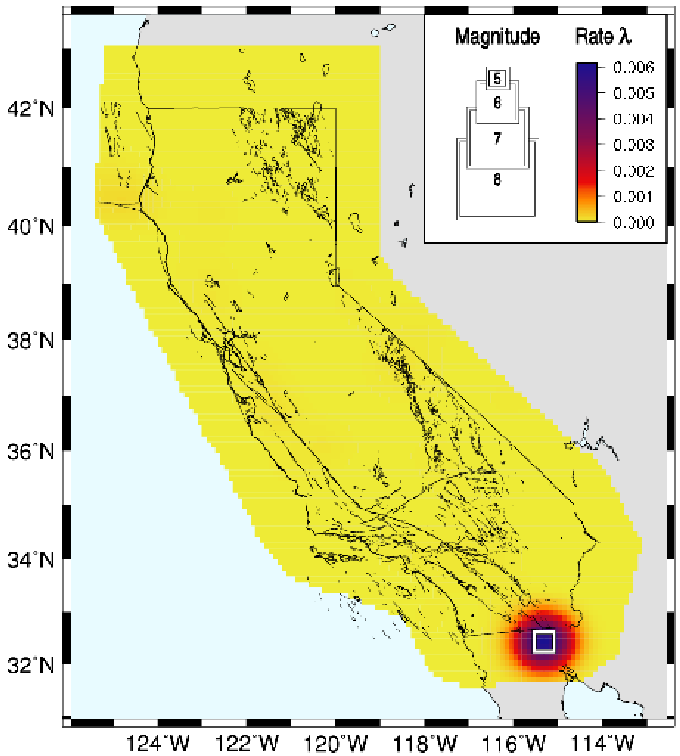

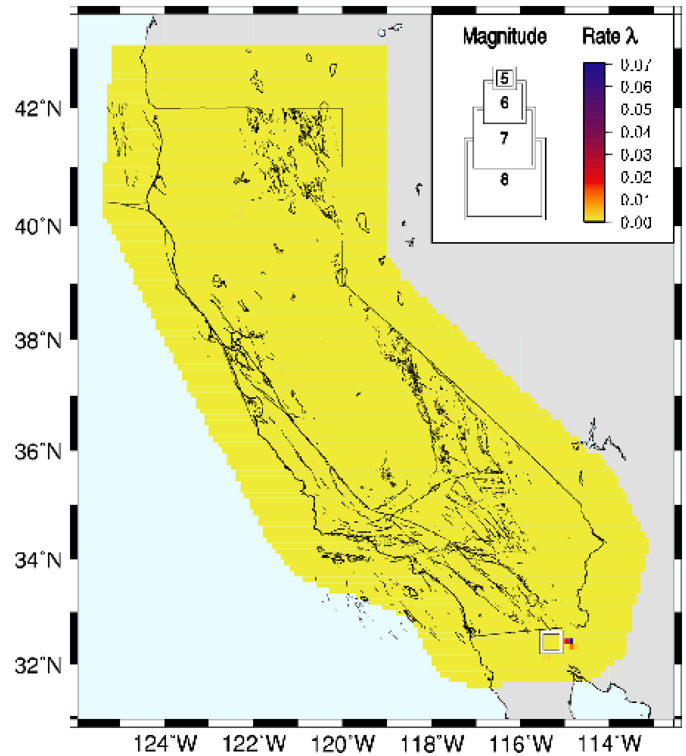

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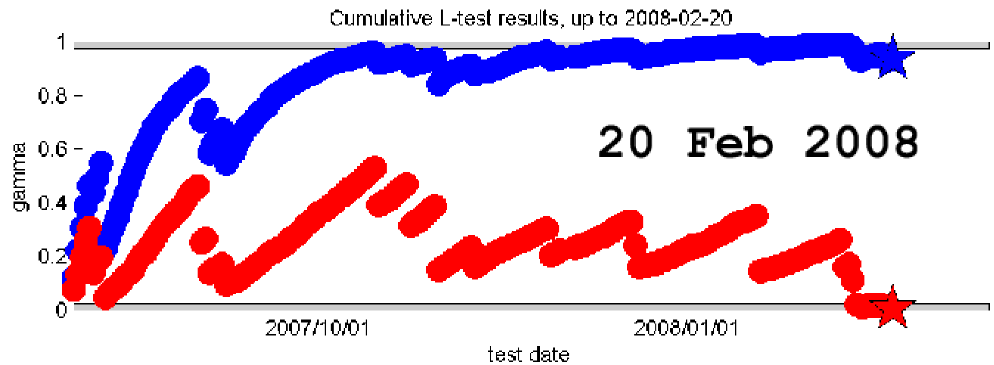
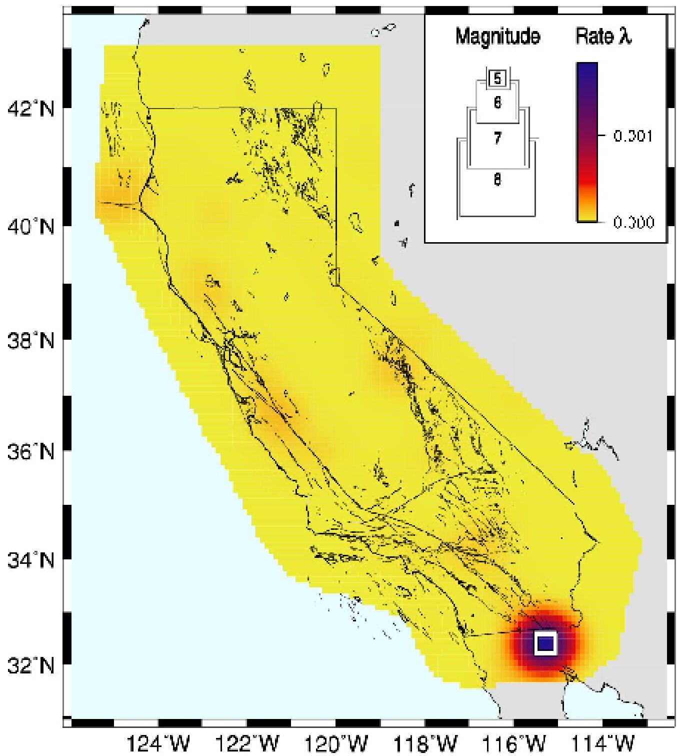
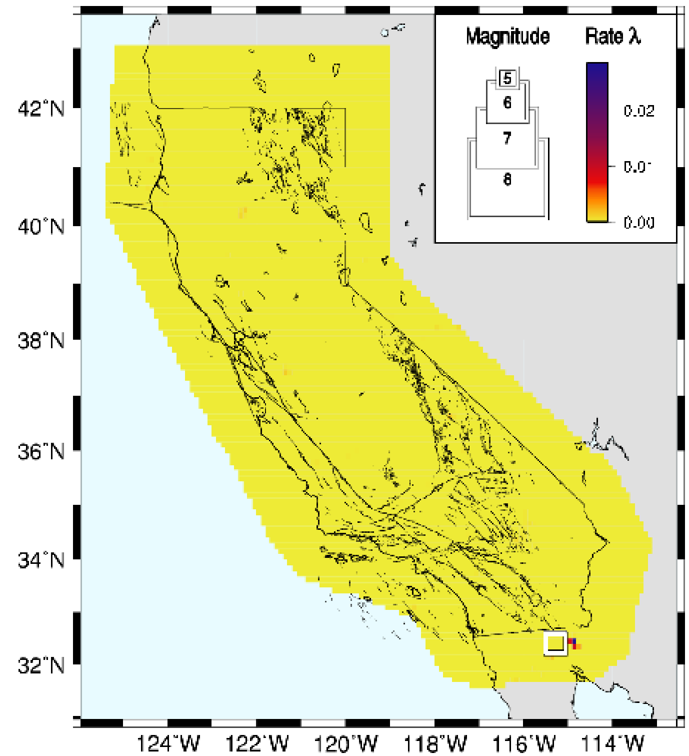


STEP

Results – Baja Swarm





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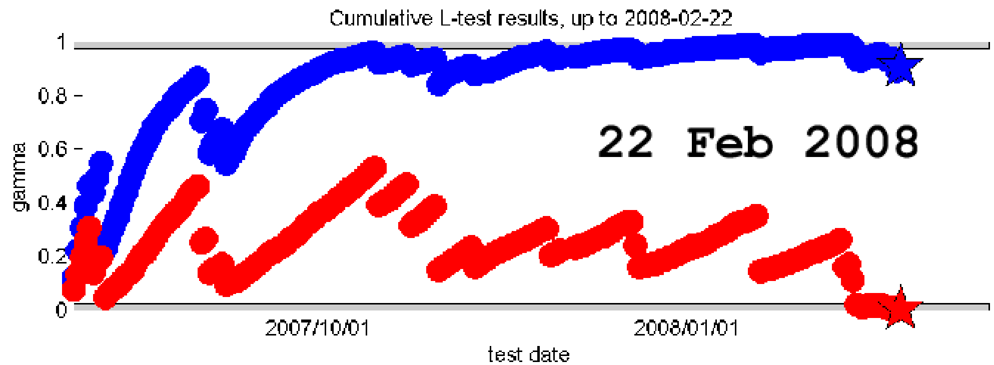

STEP

Summary

- Meaningful results within 5 years
- Smoothed-seismicity models showed best performance
- Successful standardization and consensus
- Manuscript recently published

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Pure and Applied Geophysics

First Results of the Regional Earthquake Likelihood Models Experiment

Daniel Schorlemmer,[1] J. Douglas Zechar,[1,2] Maximilian J. Werner,[3] Edward H. Field,[4] David D. Jackson,[5] Thomas H. Jordan,[1] and The RELM Working Group

Abstract—The ability to successfully predict the future behavior of a system is a strong indication that the system is well understood. Certainly many details of the earthquake system remain obscure, but several hypotheses related to earthquake occurrence and seismic hazard have been proffered, and predicting earthquake behavior is a worthy goal and demanded by society. Along these lines, one of the primary objectives of the Regional Earthquake Likelihood Models (RELM) working group was to formalize earthquake occurrence hypotheses in the form of prospective earthquake rate forecasts in California. RELM members, working in small research groups, developed more than a dozen 5-year forecasts; they also outlined a performance evaluation method and provided a conceptual description of a Testing Center in which to perform predictability experiments. Subsequently, researchers working within the Collaboratory for the Study of Earthquake Predictability (CSEP) have begun implementing Testing Centers in different locations worldwide, and the RELM predictability experiment—a truly prospective earthquake prediction effort—is underway within the U.S. branch of CSEP. The experiment, designed to compare time-invariant 5-year earthquake rate forecasts, is now approximately halfway to its completion. In this paper, we describe the models under evaluation and present, for the first time, preliminary results of this unique experiment. While these results are preliminary—the forecasts were meant for an application of 5 years—we find interesting results: most of the models are consistent with the observation and one model forecasts the distribution of earthquakes best. We discuss the observed sample of target earthquakes in the context of historical seismicity within the testing region, highlight potential pitfalls of the current tests, and suggest plans for future revisions to experiments such as this one.

Key words: Statistical seismology, earthquake predictability, earthquake statistics, earthquake forecasting and testing, seismic hazard.

1. Introduction

The Regional Earthquake Likelihood Model (RELM) working group formed in 2000 and was supported by the Southern California Earthquake Center (SCEC) and the United States Geological Survey (USGS). The group's main purpose was to improve seismic hazard assessment and to increase understanding of earthquake generation processes. Seismic hazard analysis requires two fundamental components: an earthquake forecast that describes the probabilities of earthquake occurrence in a spatio-temporal volume; and a ground-motion model that transforms each forecasted event into a site-specific estimate of ground-shaking. RELM participants focused on the former component and developed several earthquake forecast models (Bird and Liu, 2007; Console et al., 2007; Ebel et al., 2007; Gerstenberger et al., 2007; Helmstetter et al., 2007; Holliday et al., 2007; Kagan et al., 2007; Petersen et al., 2007; Rhoades, 2007; Shen et al., 2007; Ward, 2007; Wiemer and Schorlemmer, 2007). These models span a broad range of input data and methods: most are based on past seismicity, however some incorporate geodetic data and/or geological insights. See Field (2007) and the special volume of Seismological Research Letters for more details on the RELM project.

In addition to developing forecast models, RELM also explored comparative testing strategies and established a plan for conducting these tests.

The members of the RELM Working Group are listed in the Acknowledgments section.

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