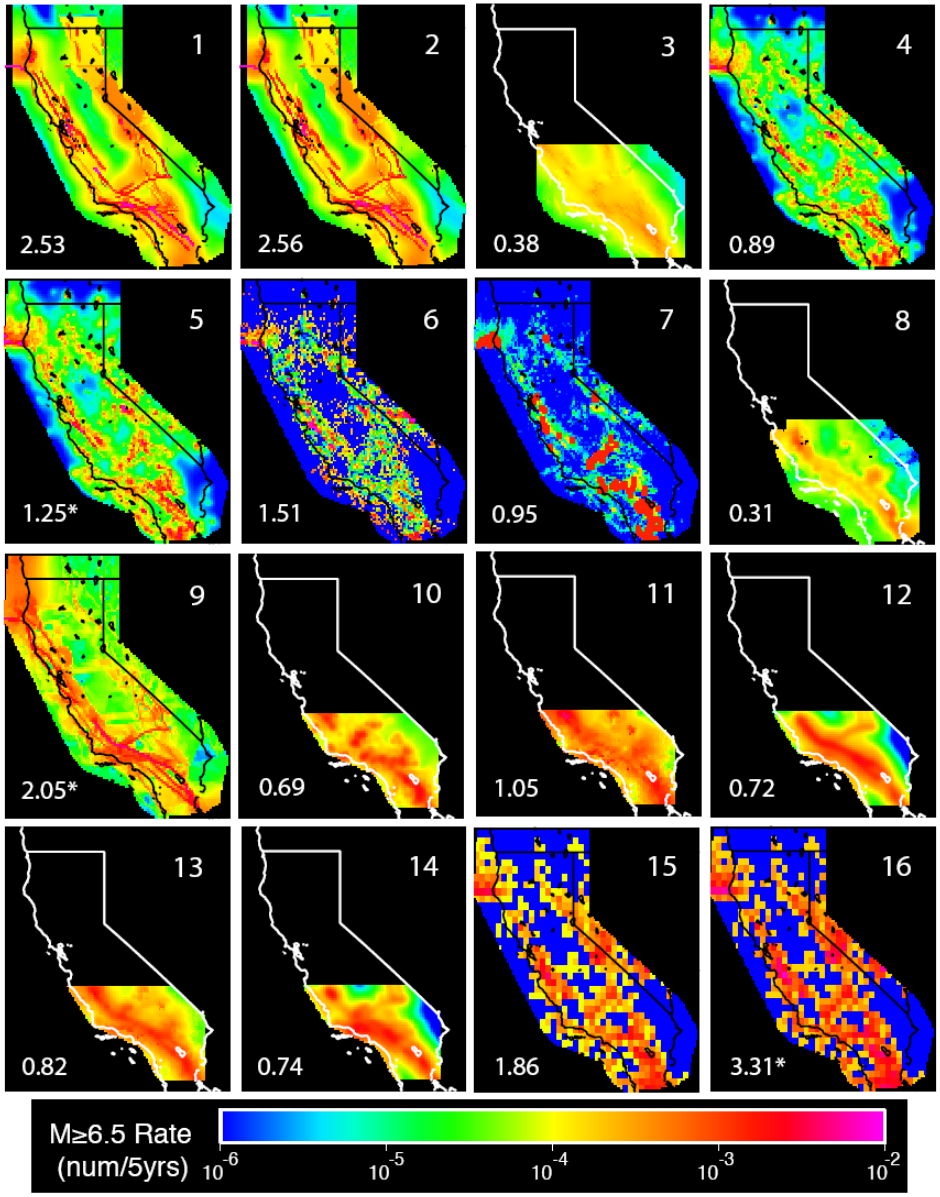


SCEC/USGS Working Group on

Regional Earthquake Likelihood Models (RELM)

5-year forecasting experiments in the California Natural Laboratory

Papers describing 19 RELMs were published in a special issue of *Seismol. Res. Lett.*, February, 2007

Half-time evaluation published by Schorlemmer et al. in *Pure Appl. Geophys.*, 2010

Full 5-year evaluation in production by Zechar et al., 2011

Collaboratory for the Study of Earthquake Predictability

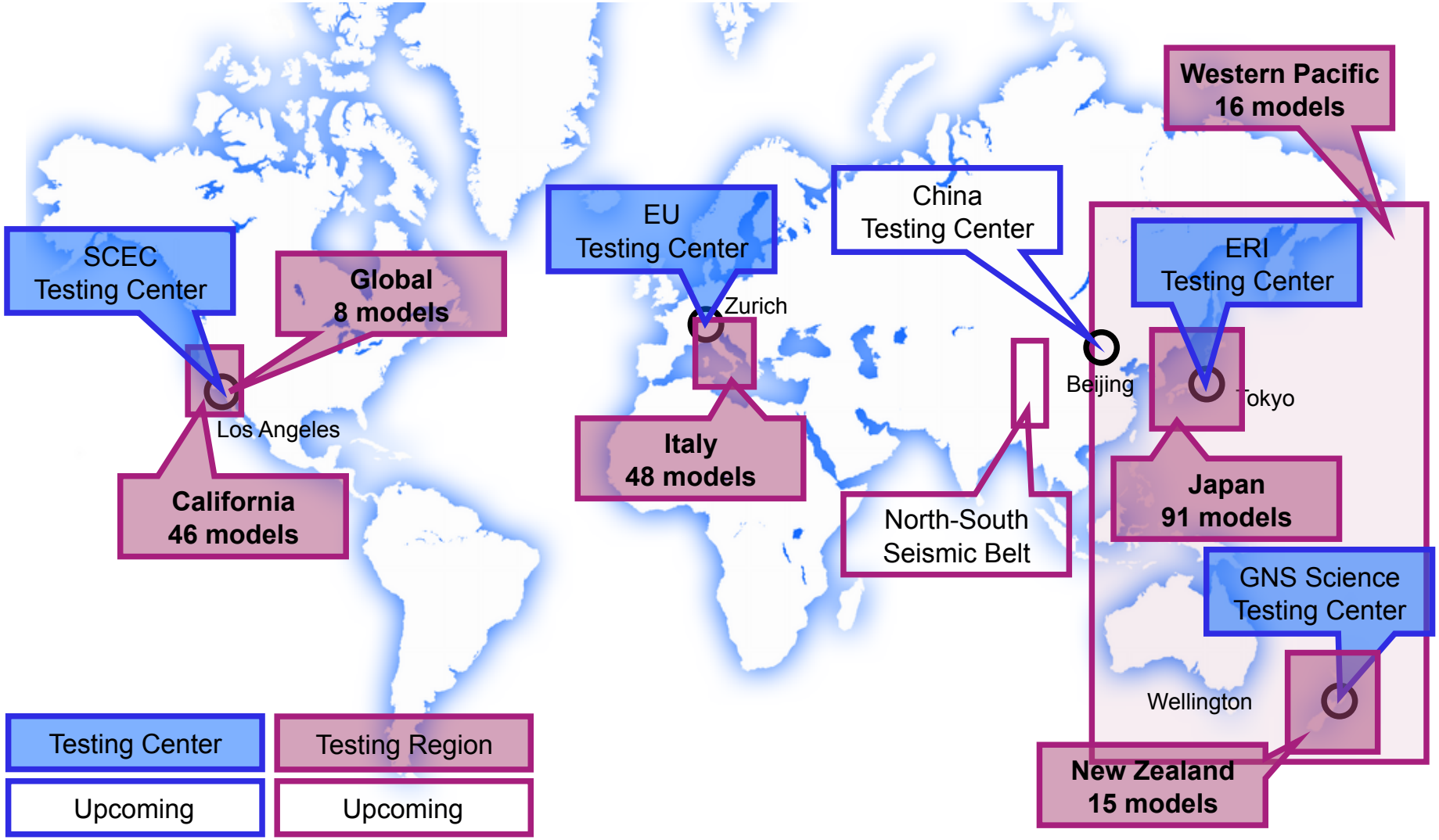
- **CSEP goal is rigorous testing of predictability hypotheses and forecasting models**
  - **Automate blind, prospective testing in a standardized, controlled environment**

    N.B. current testing is only "quasi-prospective" owing to catalog latencies
  - **Establish experiments in a variety of tectonic environments and on a global scale**

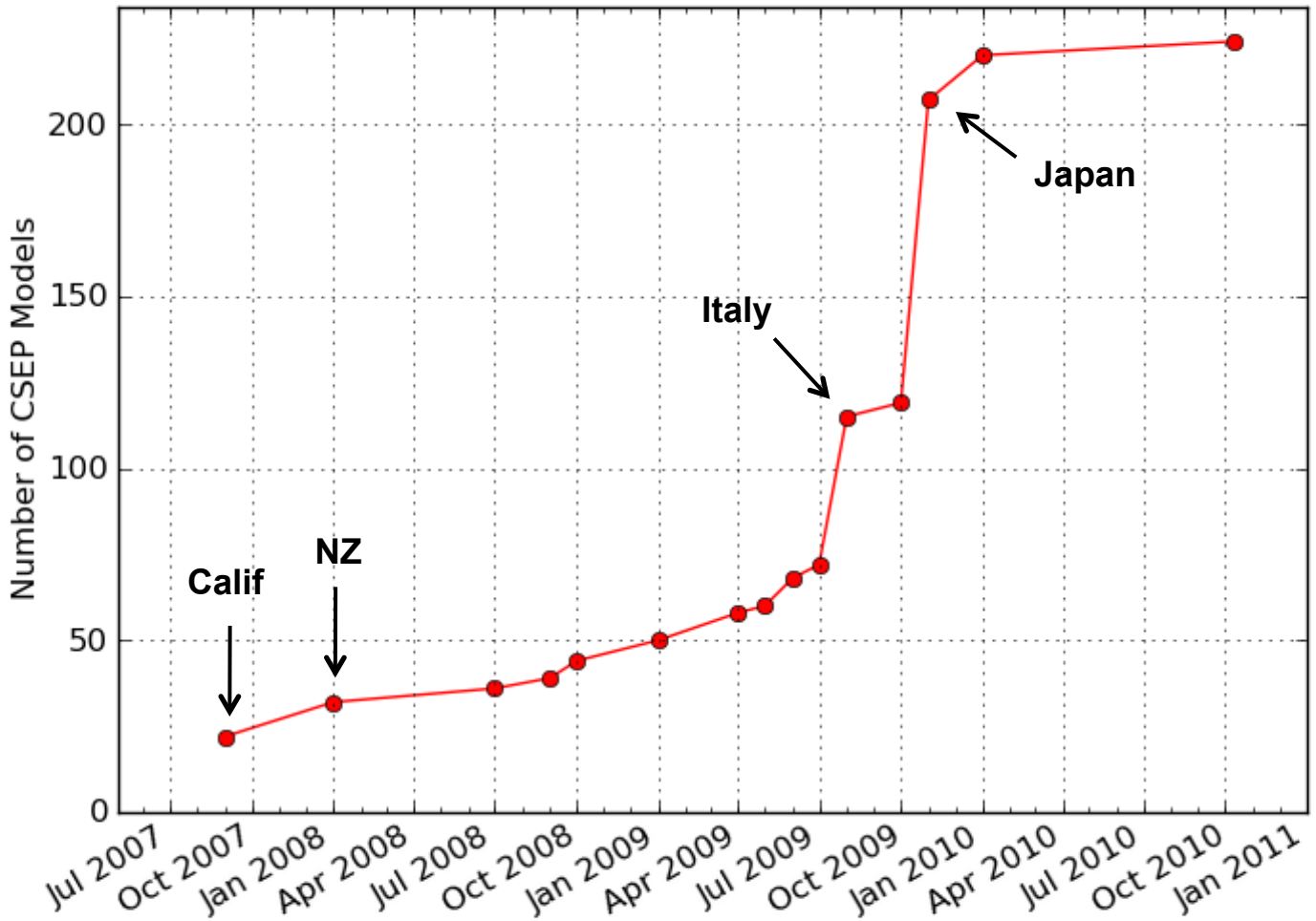
- **CSEP components:**
  - ***Natural laboratories*** **comprising active fault systems with adequate, authorized data sources for conducting forecasting experiments**
  - ***Testing centers*** **with validated procedures for registering and evaluating prediction experiments**
  - ***Model classes*** **with common target events, forecasting regions, and forecast updating intervals**

CSEP Testing Regions & Testing Centers

224 models under test in June, 2011



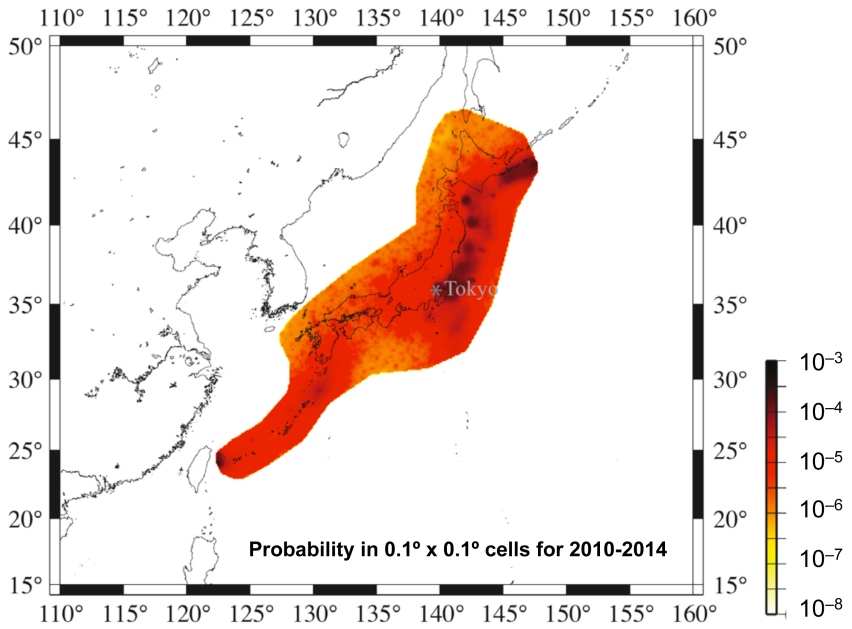
CSEP Models Under Test



CSEP Components

Example models

RELM	**Regional Earthquake Likelihood Models**
PPE	**Proximity to Past Earthquakes**
TripleS	**Simple Smoothed Seismicity**
EEPAS	**Every Earthquake a Precursor According to Scale**
STEP	**Short Term Earthquake Probability**
ETAS	**Epidemic Type Aftershock Sequence**
ETES	**Epidemic Type Earthquake Sequence**
DBM	**Double Branching Model**
Coulomb	**Coulomb stress + rate/state friction**



DBM model of Lombardi & Marzocchi (2011) for M ≥ 8 earthquakes in All-Japan testing region

CSEP Components

Example models

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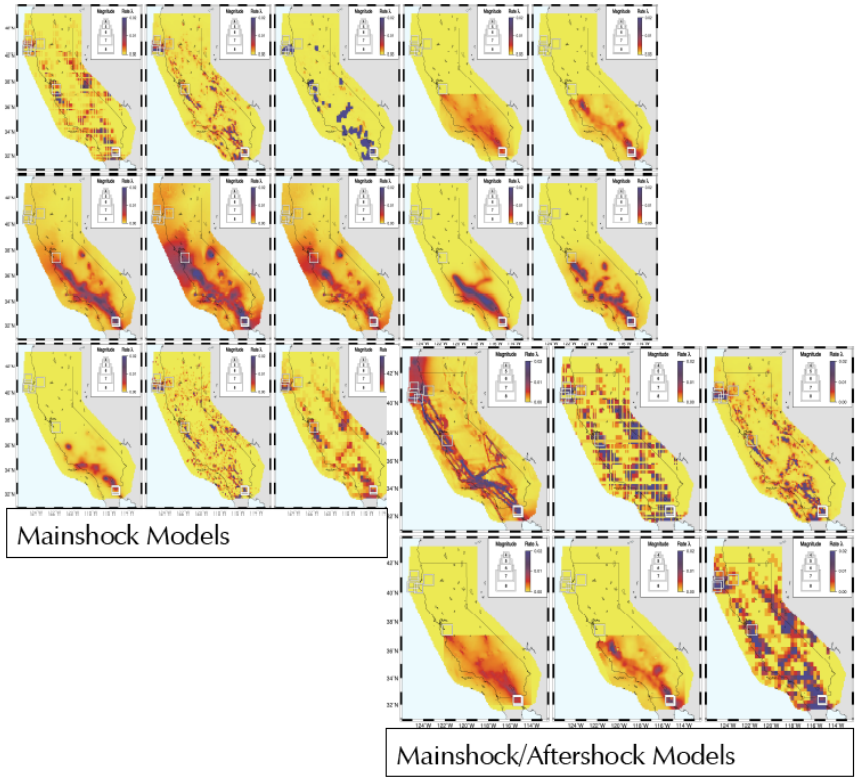
Example tests

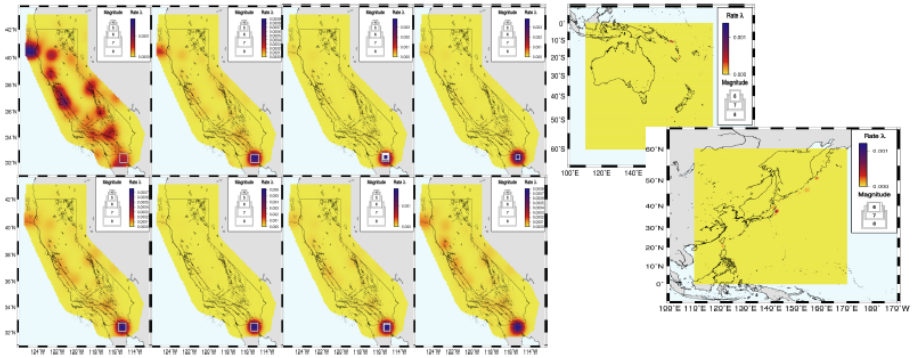
L-test	likelihood
N-test	number
M-test	magnitude
S-test	space
R-test	likelihood ratio
T-test	paired student *t*
W-test	Wilcoxon signed rank

Examples of Forecasting Models Currently Under CSEP Testing in California

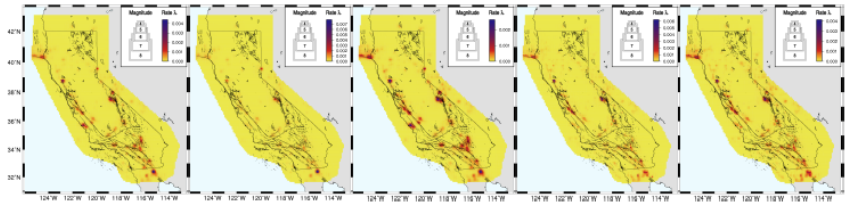
RELM 5-Year Models



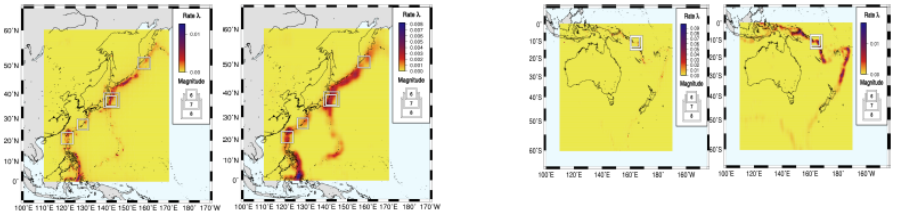
1-Day Models



3-Month Models



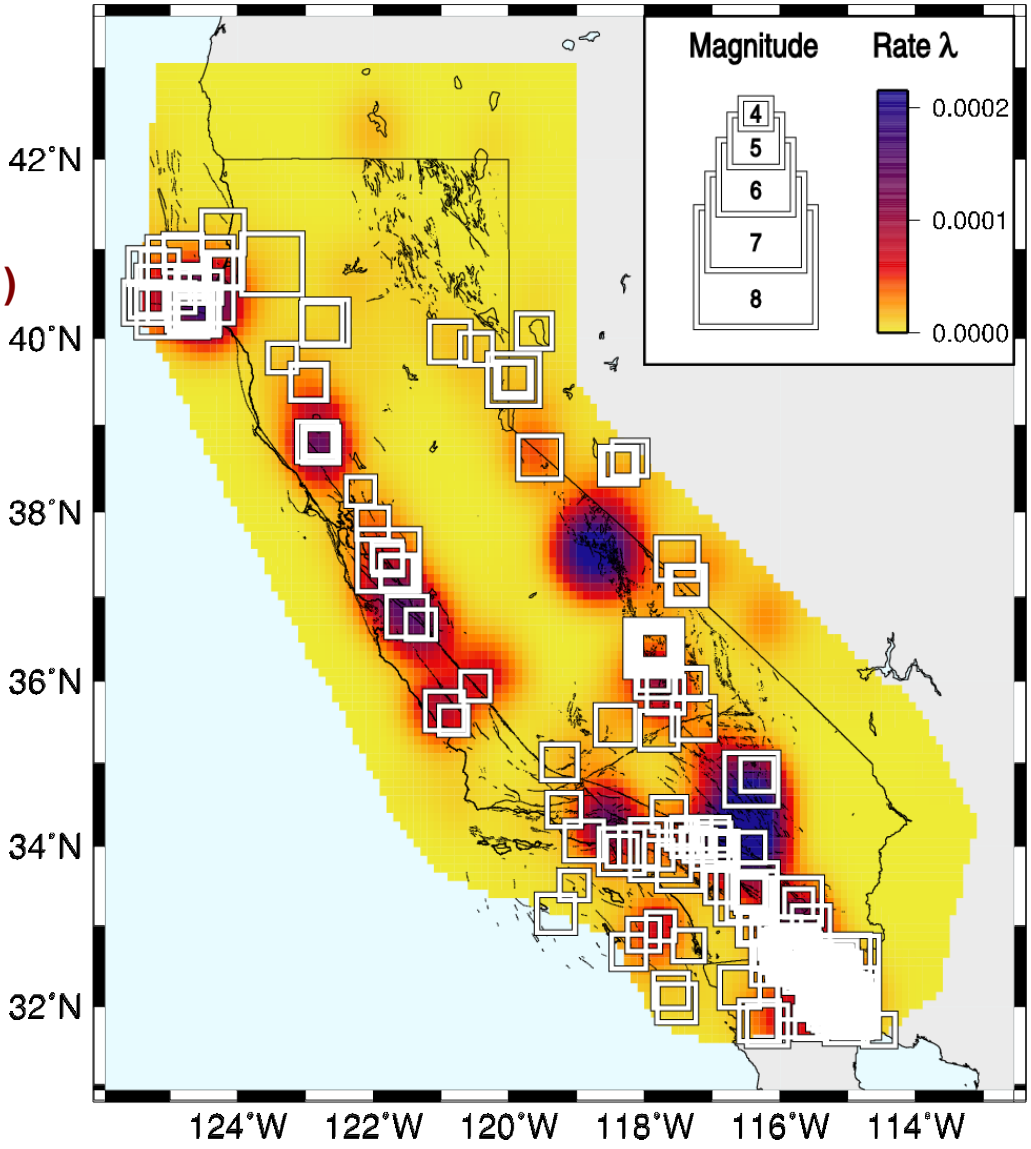
1-Year Models



Examples of Forecasting Models Currently Under CSEP Testing in California

Testing region: California
Forecast model: TripleS

Testing period: 2008-2010
Target events: M ≥ 3.95 (301)



Short-Term Earthquake Probability (STEP) Model

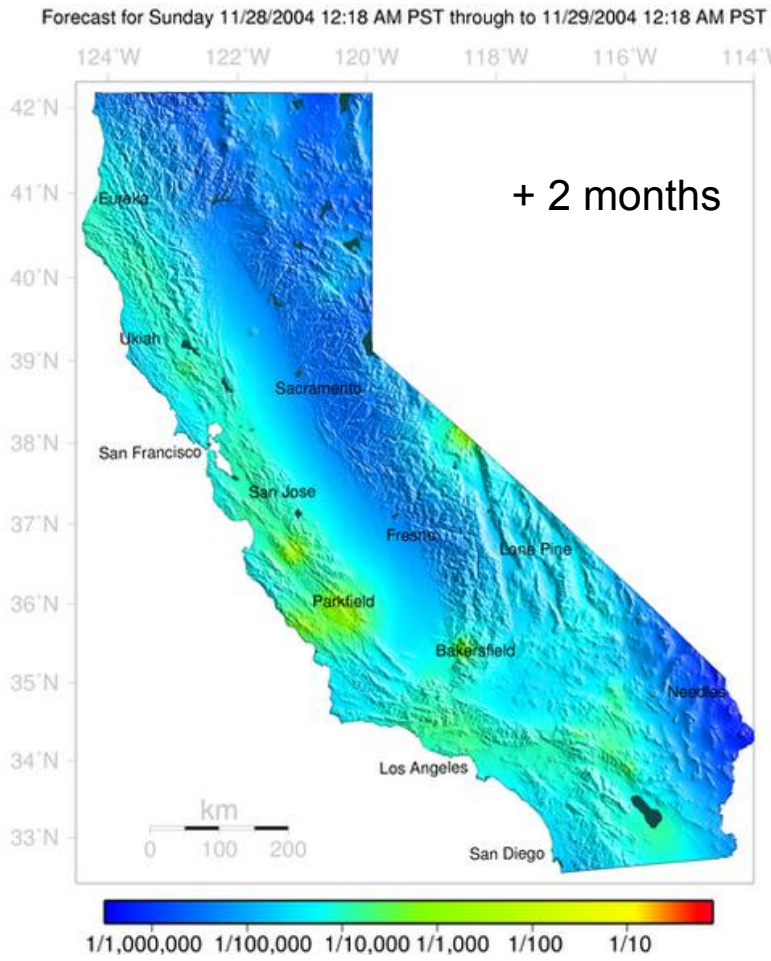
Map Archive
What Is This Map?
How Do We Make This Map?
How Can I Use This Map?
What Are Aftershocks, Foreshocks and Earthquake Clusters?

These maps are made with contributions from ETH-Zurich, Switzerland, and the Southern California Earthquake Center.

ETH

SCEC
an NSF+USGS center

Gerstenberger et al. (2005)



http://earthquake.usgs.gov/earthquakes/step/

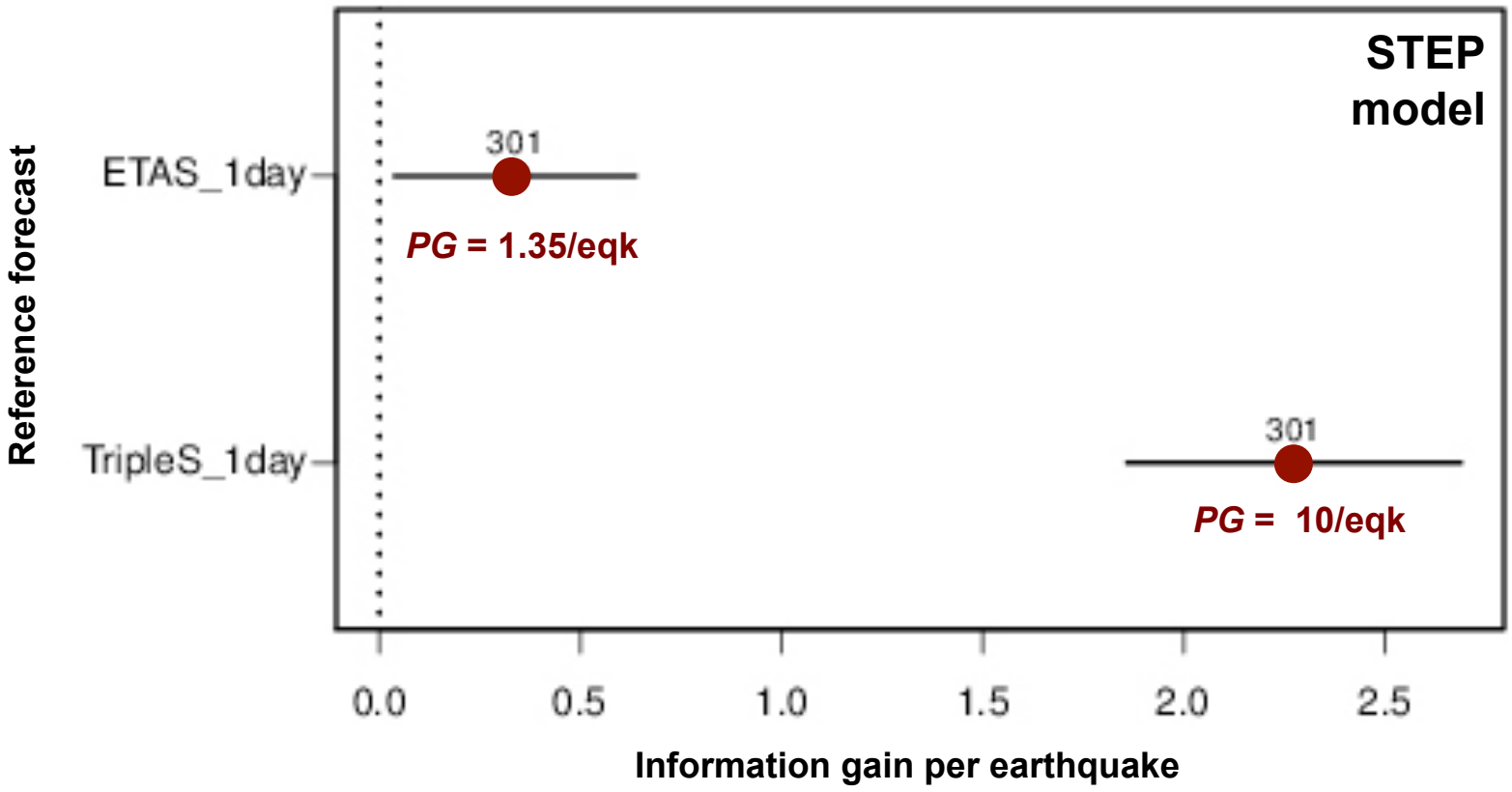
2004 Parkfield Earthquake

Triggering Models vs. Smoothed Seismicity

Testing region: California
Target events: M ≥ 3.95
Testing period: 2008-2010
Testing method: T-test

PG = probability gain
= P / P_0

IG = information gain
= $\log_e(PG)$



Japan and NZ Testing Regions

Testing region	Model class				
	1 day	3 month	1 year	3 year	Total
All Japan	5	9	12	9	35
Mainland	2	9	11	7	29
Kanto	4	7	8	8	27
Total	11	25	31	24	91

	1 day	3 month	6 month	5 year	Total
New Zealand	2	8	1	4	15

Darfield Aftershock Forecasting

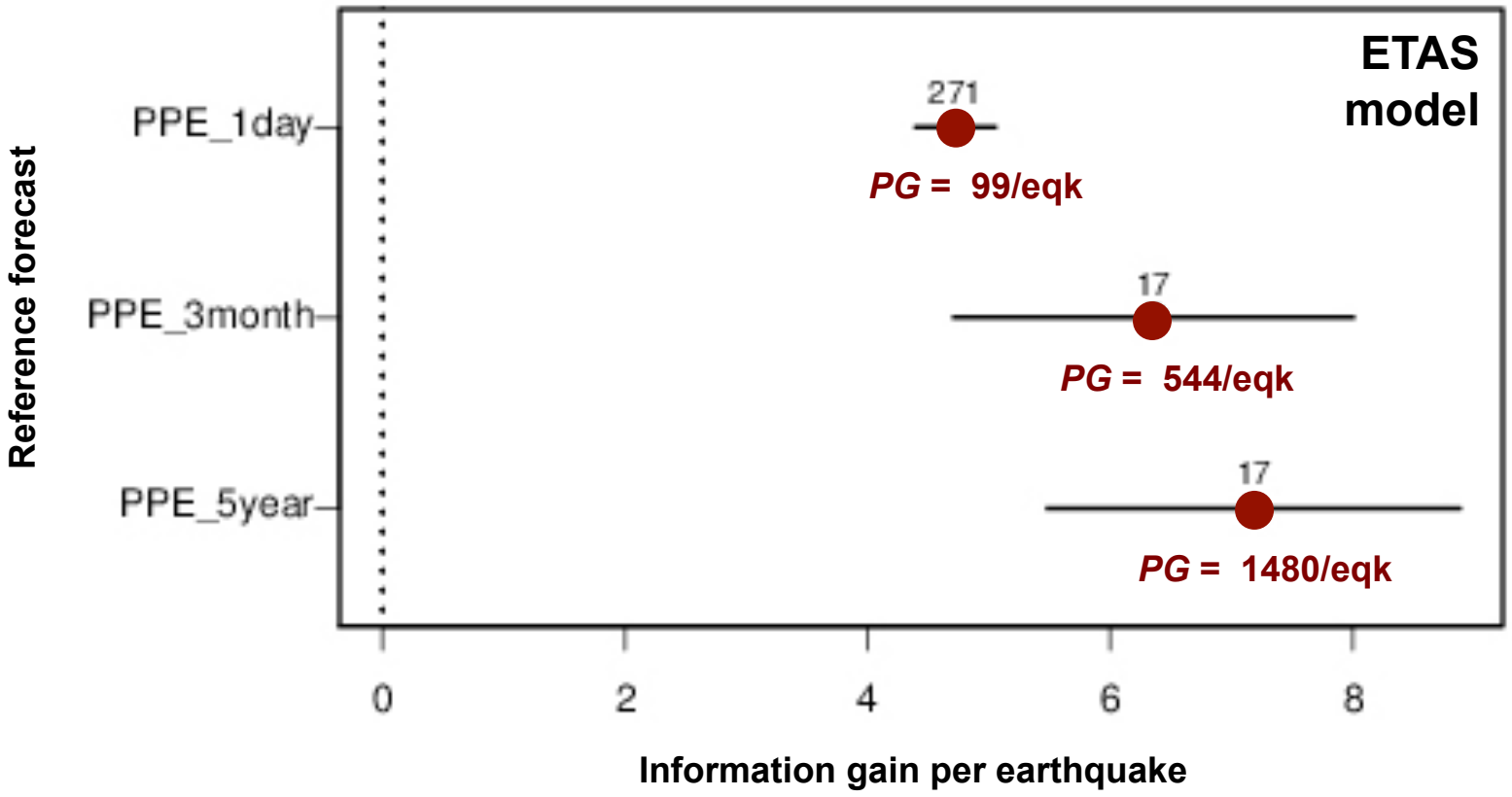
(Gerstenberger & Rhoades)

Testing region: New Zealand

Target events: M ≥ 4 (PPE-1d), M ≥ 5 (PPE-3m, PPE-5y)

Testing period: 4 Sept 2010 - 8 Mar 2011

Testing method: T-test

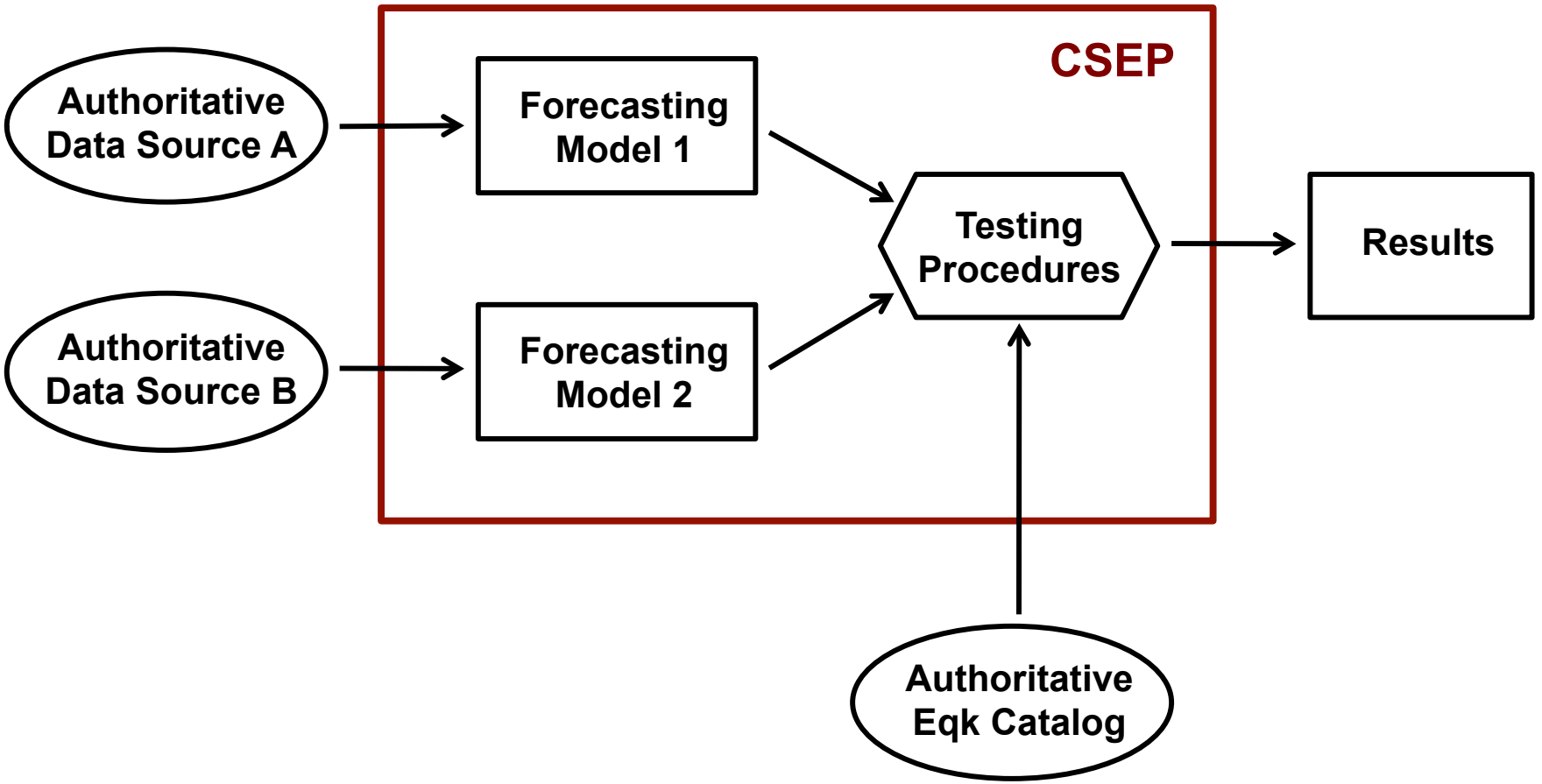


Summary of Probability Gains

Method	Gain Factor	P_{max}(3 day) SAF-Coachella	Prospectively validated?
Long-term renewal	1-2	1×10^{-4}	
Medium-term seismicity patterns	2-4	2×10^{-4}	✔
Short-term STEP/ETAS	10-100	3×10^{-3}	✔
Short-term empirical foreshock probability	100-1000	3×10^{-2}	

ICEF Finding: ***The probability gains of short-term, seismicity-based forecasts can be high (> 100 relative to long-term forecasts), but the absolute probabilities of large, potentially destructive earthquakes typically remain low (< 1% per day).***

CSEP Structure



End

Pathway Towards Practical Utility

- **Exploratory research on earthquake precursors**
  - Physics-based concepts regarding physical principles and statistical properties of earthquake predictability
- **Hypothesis formulation**
  - Casting of testable precursory hypotheses
- **Hypothesis testing**
  - Retrospective and prospective testing of forecasting methods to assess reliability, skill, and information gain
- **Implementation**
  - Incorporation of significant precursory information into operational earthquake forecasting

What Is Validation?

- **Criteria for asserting model is credible representation of the real system, usable for forecasting behaviors (not that "model is true")**
  - Consistent with knowledge of the system (includes verification)
  - Not too sensitive to initial conditions or unknown forcings
  - Aleatory and epistemic uncertainties are properly characterized
  - Consistent with relevant observations
- **Substantiation that a model is sufficiently accurate in predicting system behaviors**
  - within its domain of applicability
  - consistent with its intended purposes
- **Techniques**
  - Testing against observations (surviving ***invalidation***)
  - Competition among models
  - Validation of model components
  - Improvement by data assimilation (inversion)

Problems in Assessing the Quality of Earthquake Forecasts & Predictions

- Scientists are over-optimistic about their own results
- Scientific publications provide insufficient information for independent evaluation
- Active researchers are constantly tweaking their procedures, which become moving targets
- Standards are lacking for testing predictions against reference forecasts
- Data to evaluate prediction experiments are often improperly specified
- Infrastructure for conducting and evaluating long-term prediction experiments has not existed

Validation of Forecasting Methods

Criteria for operational fitness:

- Quality validated by retrospective and prospective testing
- Consistency across temporal and spatial scales
- Value to users

ICEF Recommendations:

- *To be qualified for operational use, forecasting methods should be scientifically tested against the available data for reliability and skill, both retrospectively and prospectively.*
- *All operational models should be under continuous prospective testing.*