SOUTHERN CALIFORNIA EARTHQUAKE CENTER

Forecasting, Prediction, and Testing

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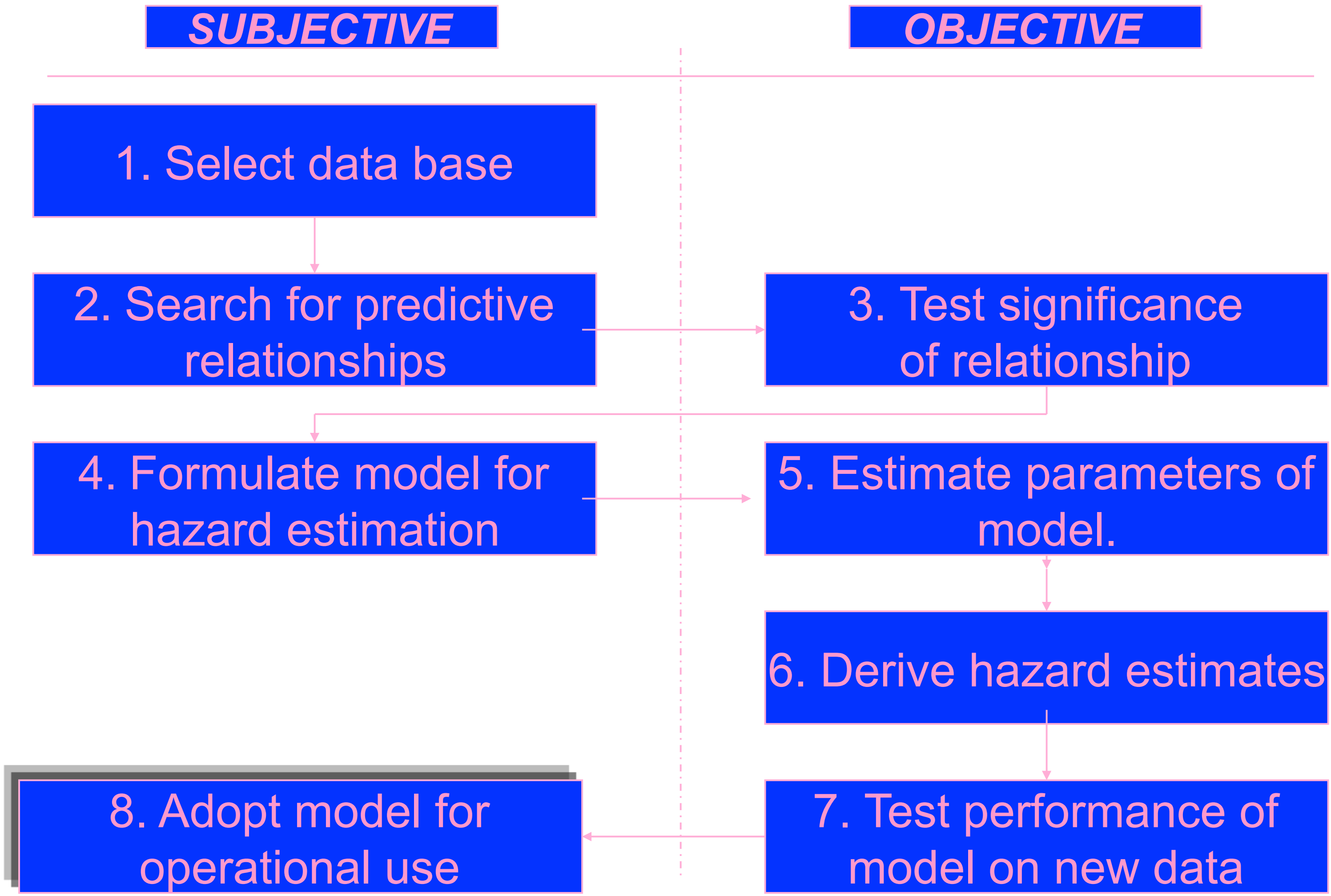
Scheme for earthquake prediction research
Rhoades and Evison 1986



Geophys. J. Int. (1997) 131, 425–450

SPECIAL SECTION—ASSESSMENT OF SCHEMES FOR EARTHQUAKE PREDICTION

Earthquake prediction: a critical review

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Accepted 1997 August 15. Received 1997 August 8; in original form 1997 April 24

SUMMARY

Earthquake prediction research has been conducted for over 100 years with no obvious successes. Claims of breakthroughs have failed to withstand scrutiny. Extensive searches have failed to find reliable precursors. Theoretical work suggests that faulting is a non-linear process which is highly sensitive to unmeasurably fine details of the state of the Earth in a large volume, not just in the immediate vicinity of the hypocentre. Any small earthquake thus has some probability of cascading into a large event. Reliable issuing of alarms of imminent large earthquakes appears to be effectively impossible.

Key word: Earthquake prediction.

Definitions

- **Forecast**: statement of probability per unit magnitude, location, time, etc. Used to manage normal risk.
- **Prediction**: special case for **temporarily**
  - **high probability and**
  - **high probability gain**
- **Format**
  - **Probability**
  - **Alarms**: on or off
- **Retrospective**: test uses data also used to formulate model
- **Pseudo-prospective**: Parameters determined from learning phase, test uses past earthquakes not included in parameter estimation.
- **Prospective**: all equations, rules, parameters, regions fixed before earthquakes used in test

Credibility Criteria

- **Co-seismic effect:** observed anomalies should be strongest at the time of the earthquake itself
  - stress changes and cracking are far more intense than in the preparation period,
- **Proximity:** anomalies should be strong nearer to the site of the future earthquake and weaker at greater distance,
- **Mechanism:** anomalies should be reasonably explained by stress dependence of crust. Should explain whether model is for nucleation (small earthquakes) or eventual size.
- **Noise**: non-seismic effects should be unlikely or modeled reliably.
- **Redundancy:** anomalies should be observed at more than
- one site.

Before testing: specify

- Bounded location
- Time interval, or termination rule
- Magnitude range, and scale; test small earthquakes?
- Probabilities or alarms
  - Formal criteria for alarm declaration
  - Rules for calculating conditional probability
- Hypocenters or fault rupture
  - Rupture end points, or area?
  - Minimum displacement?
- What to do with clustering (aftershocks +)
  - Keep or exclude
  - How to define them

Track Record

	Alarm On	Alarm Off
Earthquake	HITS	MISSES
No earthquake	FALSE ALARMS	CORRECT PASSES

How many quakes does it take to confirm forecast model?

Assume two zones, one with alarm and one without. In "normal" conditions (null hypothesis), events equally likely in either zone (p0=0.5). Under test hypothesis, probability in alarmed zone is twice that in unalarmed zone (p1=2/3) . Five straight hits would be enough to reject "normal", but unlikely even under the test hypothesis.

HITS	Background Probability	Conditional Probability	Reject Normal?	Rejection Probability
0	3%	0%	0	0%
1	16%	4%	0	0%
2	31%	16%	0	0%
3	31%	33%	0	0%
4	16%	33%	0	0%
5	3%	13%	1	13%
			Sum	13%

How many does it take? Even 30 events might not be enough to assure rejection of null hypothesis.

Quakes	Background probability	Conditional probability	Hits needed	Probability of rejecting H0
5	50%	67%	5	13%
10	50%	67%	9	11%
15	50%	67%	12	21%
20	50%	67%	15	30%
25	50%	67%	18	37%
30	50%	67%	20	58%

How many does it take if quakes are unlikely in “normal” conditions?

Quakes	Background probability	Conditional probability	Hits needed	Probability of rejecting H0
5	10%	50%	3	50%
10	10%	50%	4	83%
15	10%	50%	5	94%
20	10%	50%	5	99%

Collaboratory for Study of Earthquake Predictability

- Design and implementation of prospective tests
  - Hypocenters; working on fault rupture
  - Most models prescribe rate density: probability per uniit time and area for given magnitude.
  - Test periods run from hours to 5 years

- Models must cover enough time and area that several events are forecast by at least one hypothesis.

Features of CSEP Forecasts

- Expressed as probability per unit area, magnitude in specified time interval
- "Point source" representation; earthquakes specified by epicenter, magnitude, time.
- Two types: All earthquakes, and mainshocks only
- Tests use fixed time intervals:
  - 1 day at magnitude 4.0+
  - 1 year and 5 years at magnitude 4.5+

Global Forecasts

- Common properties
  - -90< latitude < 90
  - 0.1 by 0.1 deg resolution
  - Based on smoothed seismicity, +focal mechanisms
  - Separable number, magnitude, and spatial distributions
  - Updated daily
- Ready forecasts
  - Long-term, based on CMT catalog
  - Long-term, based on PDE catalog
  - Short-term, based on CMT catalog
  - Short-term, based on PDE catalog
- In preparation
  - Regionalized by tectonic style

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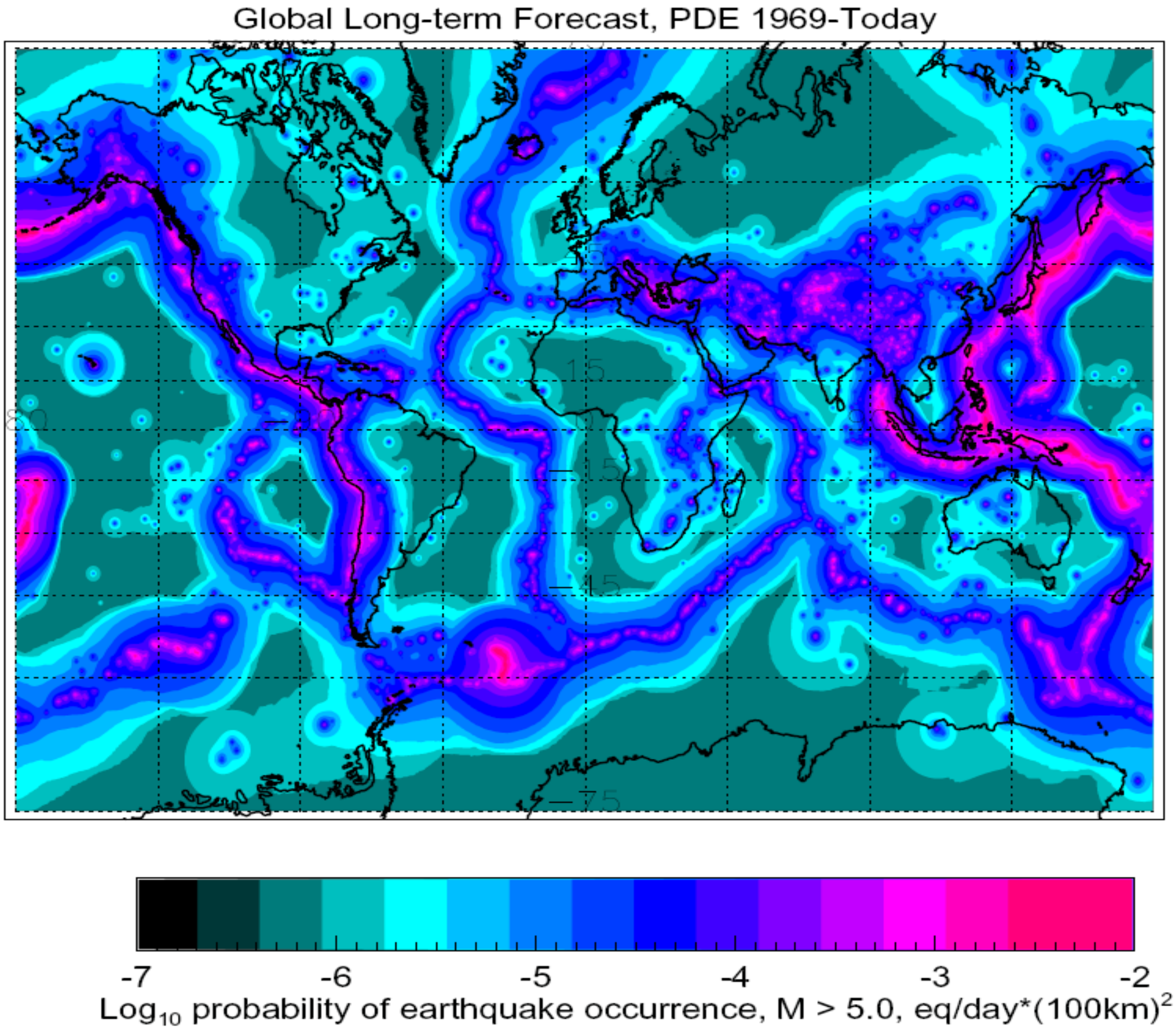
Fri Mar 27 03:41:02 2009



Long-term potential based on smoothed seismicity from the PDE catalog since 1969. Earthquake occurrence is modeled by a time-independent (Poisson) process.

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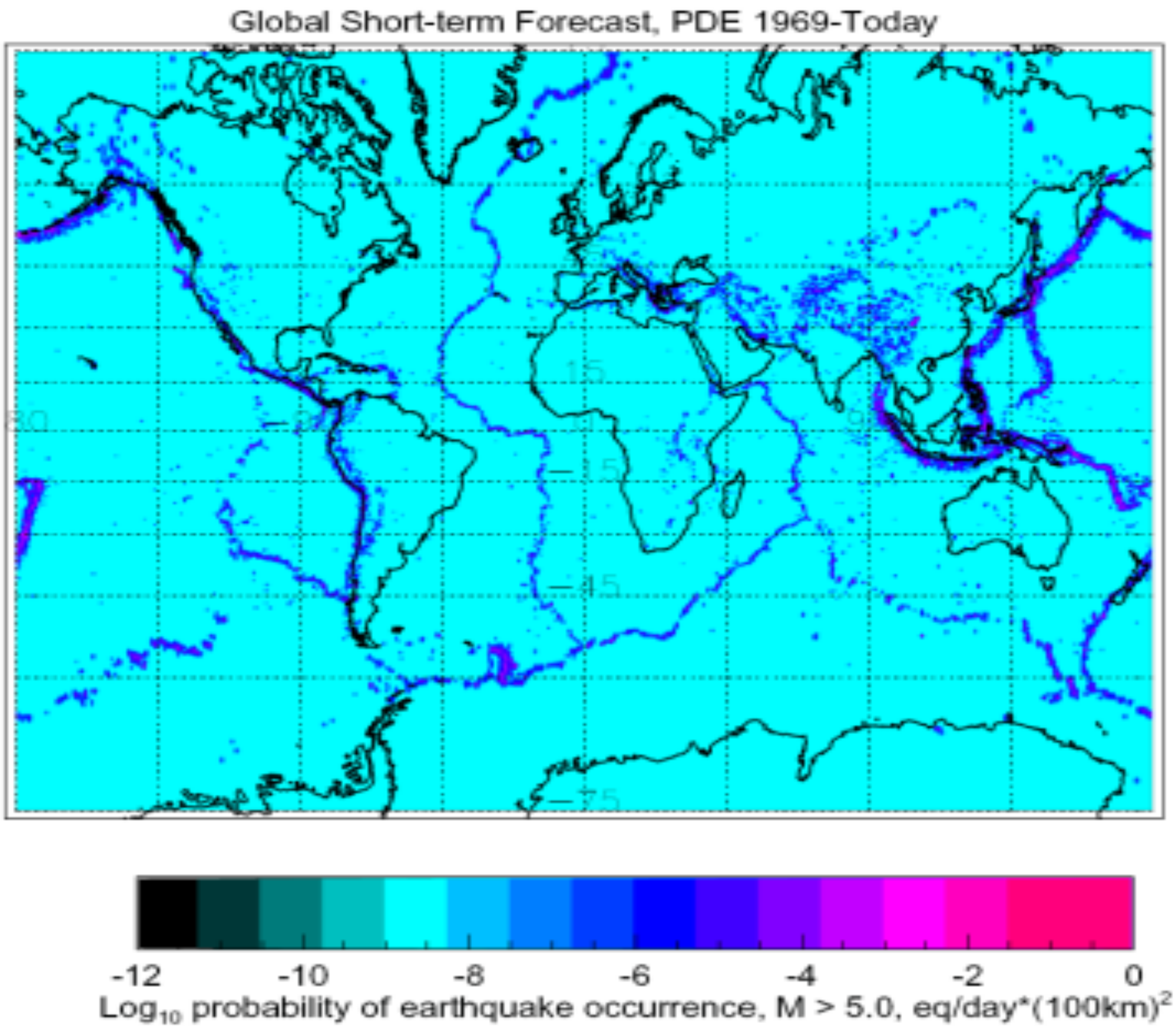

Earthquake short-term potential based on smoothed seismicity. Earthquakes from the PDE catalog since 1969 are used. Earthquake occurrence is modeled by a temporal process controlled by Omori's law type dependence.

CSEP Testing

- Simulate catalogs using Λ(lat,lon)
- Compute log likelihood function for observed and simulated catalogs

$$L = \sum_{\text{quakes}} \log(\Lambda) - \langle N \rangle$$

Λ is probability per unit area and magnitude in specified time interval; <N> is expected number of earthquakes according to forecast.

- Compare L for actual catalog with that for simulated catalogs.

Conclusions

- Forecasting can be made more rigorous. It might eventually approach prediction, but don’t hold your breath!
- Implementation must await convincing prospective testing
- Testing requires
  - Clear definitions: magnitude scale, source for locations, conditions for alarm, conditions for counting success and failure.
  - Plan for aftershocks; include in model, exclude from data, or other.
  - Earthquakes
- Null hypothesis is crucial; should be based on tested seismicity model.