Southern California Earthquake Center

Collaboratory for the Study of Earthquake Predictability (CSEP)

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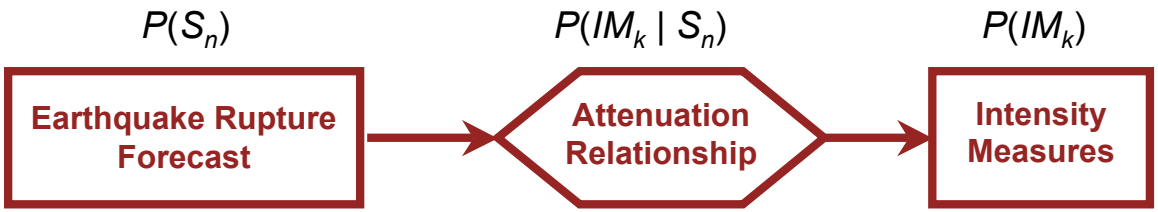
SCEC

an NSF+USGS center

Starting Points

- **PSHA provides the conceptual framework for physics-based predictions of earthquake effects**



- **Long-term earthquake forecasting is adequate for many PSHA applications (e.g., building codes)**
- **However, we still cannot predict large earthquakes with the short-term reliability to needed to prepare communities for impending disasters**
- **Dialog on earthquake prediction has become corrupted by the controversies surrounding this type of "operational" earthquake prediction**

Three Definitions

- ***Earthquake predictability***
  - **degree to which the future occurrence of earthquakes is encoded in the behavior of an active fault system**
- ***Scientific earthquake prediction***
  - **a testable hypothesis, usually stated in probabilistic terms, of the location, time, and size of fault ruptures**
- ***Useful earthquake prediction***
  - **advance warning of potentially destructive fault rupture precise and reliable enough to warrant actions to prepare communities**

Three Questions

Q1. **How should scientific earthquake predictions be stated and tested?**

- **How should prediction experiments be conducted and evaluated?**

Q2. **What is the intrinsic predictability of the earthquake rupture process?**

- **Are there coherent space-time structures in the chaotic evolution of active fault systems?**

Q3. **Can knowledge of large-earthquake predictability be deployed as useful predictions?**

- **Is operational earthquake prediction feasible?**

"Silver Bullet" Approach

- **Seeks useful, short-term earthquake predictions; i.e., focuses on direct answer to *Q3***
  - **motivated by laboratory studies of rupture nucleation**
  - **dominated research in the 1970's and 1980's**
- **Searches for signals diagnostic of approach to rupture, including:**
  - **foreshocks**
  - **strain precursors**
  - **electromagnetic precursors**
  - **hydrologic changes**
  - **geochemical signals**
  - **animal behavior**
- **Has not thus far led to useful prediction methodologies**

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Anticipating Earthquakes

High above Earth where seismic waves never reach, satellites may be able to detect earthquakes--before they strike.

"Although earthquakes seem to strike out of the blue, the furious energy that a quake releases builds up for months and years beforehand in the form of stresses within Earth's crust. At the moment, forecasters have no direct way of seeing these stresses or detecting when they reach critically high levels.

"That may be changing, however. **Satellite technologies being developed at NASA and elsewhere might be able to spot the signs of an impending quake days or weeks before it strikes, giving the public and emergency planners time to prepare.**"

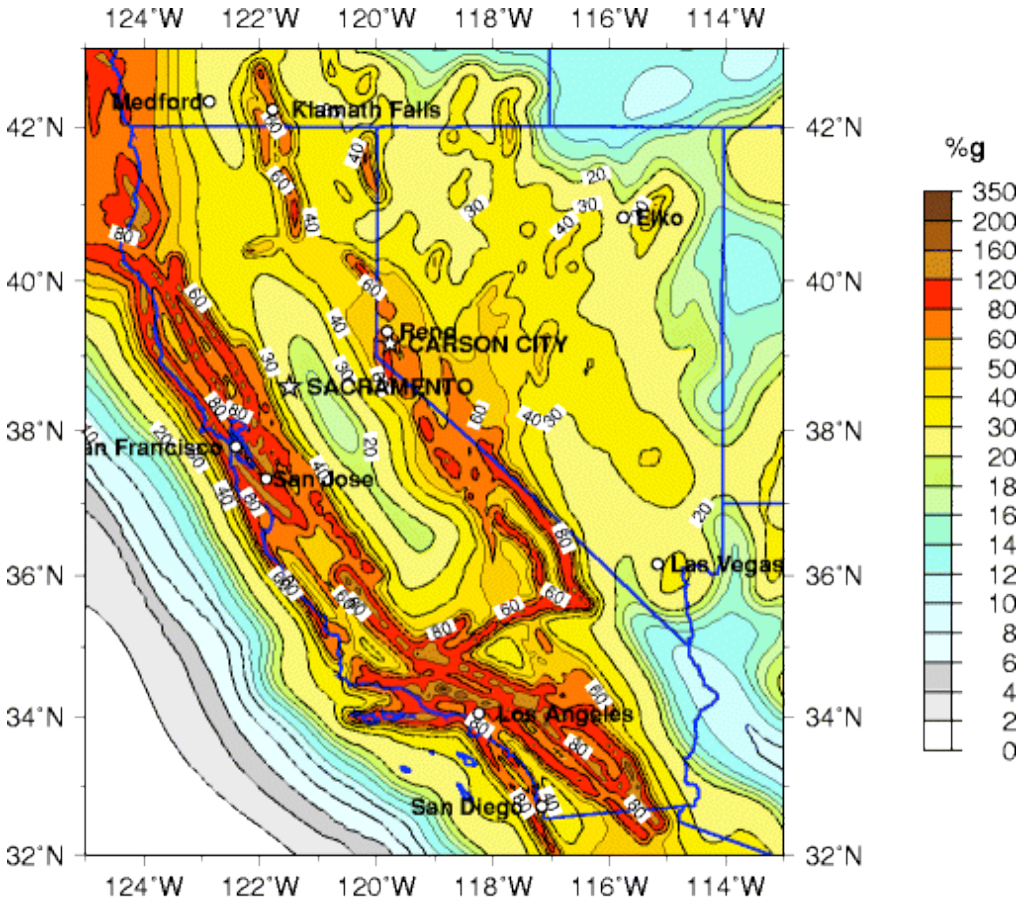
[i.e., might answer Q3]

"Brick-by-Brick" Approach

- **Focused on experimentation (*Q1*) and predictability (*Q2*), not operational prediction (*Q3*)**
- **Built on *system-specific* models of stress transfer and earthquake triggering**
  - **Probabilistic prediction of earthquakes on multiple time scales, incorporating geologic and geodetic information, as well as seismicity data**
  - **Steady efforts to understand and improve predictability, even if probability gains are small**
- **Demonstrates predictability by rigorous testing based on *intercomparison* of algorithms**
  - **RELM program and its extension to a Collaboratory for the Study of Earthquake Predictability (CSEP)**

Official U. S. Earthquake Forecast

USGS National Seismic Hazard Mapping Project (2002)



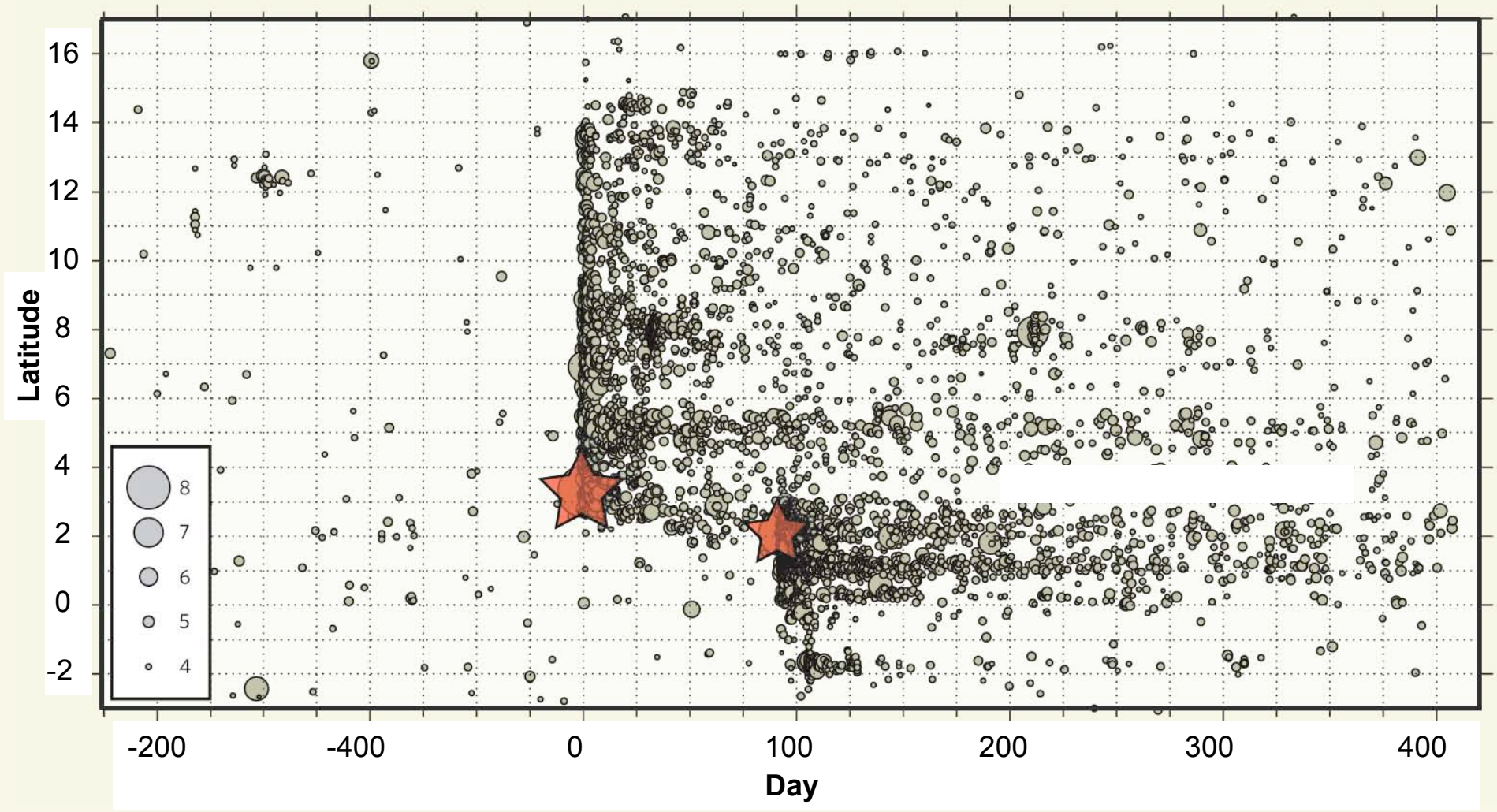
Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary
National Seismic Hazard Mapping Project

- **Specifies the maximum shaking expected over a long period of time (typically 50 years)**
  - **at all U.S. sites**
  - **from all potential earthquake sources**
- **Rupture forecast is based on time-independent (Poisson) probabilities**
- **Ignores information about current state of the fault system**

Long-Term Forecasting

- **SCEC goals:**
  - **Time-dependent earthquake rupture forecasts with better skill than the National Seismic Hazard Maps**
  - **Extension of earthquake rupture forecasts to include parameters needed for physics-based PSHA**
- **Methodology guided by fault-system models**
  - **Paleoseismic models of fault rupture histories**
  - **Stress evolution models**
- **Synthesis by new Working Group on California Earthquake Probabilities (WGCEP)**
  - **USGS-CGS-SCEC project will develop a Uniform California Earthquake Rupture Forecast (UCERF) by 2007**

Short-Term Prediction



Sumatra Earthquake Sequence (Ammon, 2006)

Short-Term Prediction

- **SCEC goal:**
  - **Establish short-term reference predictions using earthquake triggering models**
- **Epidemic Type Aftershock Sequence (ETAS) models**
  - **Observation: Statistics of aftershock sequences are well behaved**
  - **Hypothesis: clustering of foreshocks, mainshocks, and aftershocks is described by the same triggering mechanism**
  - **Builds on many previous studies**
    - **Y. Kagan & L. Knopoff (1981, etc.)**
    - **Y. Ogata (1988, etc.)**
    - **P. Reasenberg & L. Jones (1989, etc.)**
    - **A. Helmstetter & D. Sornette (2002, etc.)**

Evaluation of ETAS Models

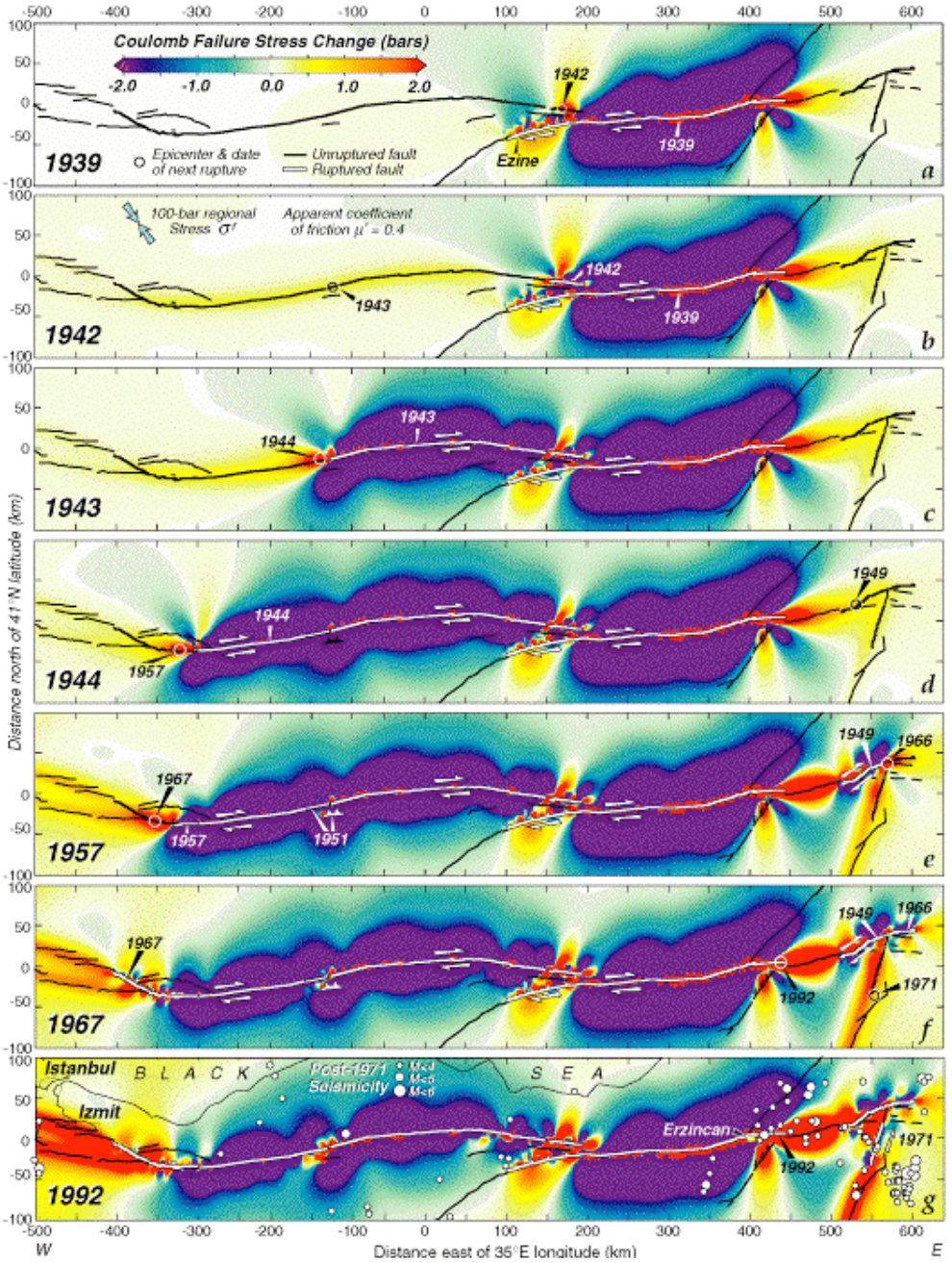
- **ETAS models provide a good first-order description of earthquake triggering**
  - **Suitable as a reference model for short-term predictions**
- **In Southern California, short-term predictions of seismicity rate based on ETAS achieve probability gain factors >10 relative to long-term Poisson models (Helmstetter et al., 2005)**
  - **Gain decreases with magnitude threshold; i.e., little gain for large earthquakes**
  - **Use of fault-based models may allow improvements**
- **Some regions, such as ridge transform faults, show anomalous statistics – and more predictability – relative to ETAS**
  - **J. McGuire, M. Boettcher & T. H. Jordan, Foreshock sequences and short-term earthquake predictability on East-Pacific Rise transform faults, *Nature*, 434, 457-461, 2005**

Unification Across Scales

- **Earthquake systems have significant predictability across a range of scales**
  - **Large-scale, long-term: fault-based models**
  - **Small-scale, short-term: at least as good as ETAS**
- **Unification across scales requires a focus on *intermediate-term predictability***
  - **Physical basis in stress evolution and transfer**
  - **Statistical basis in seismicity patterns**
  - **Integration into fault-system models**

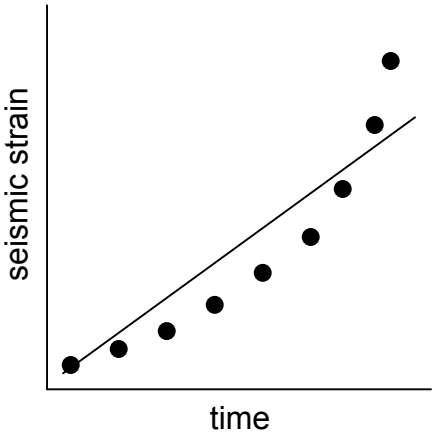
Stress Transfer in the North Anatolian Fault System

M7.6 Earthquake
Izmit, Turkey
Aug 17, 1999

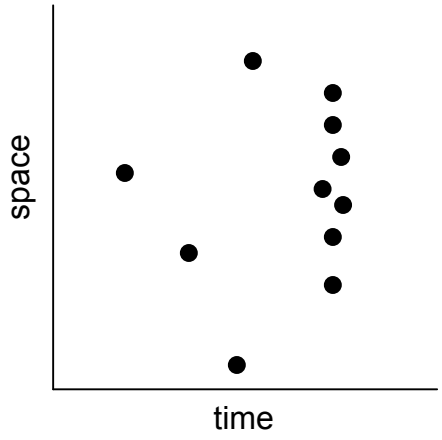


Stein et al., *J. Geophys. Res.*, 1997

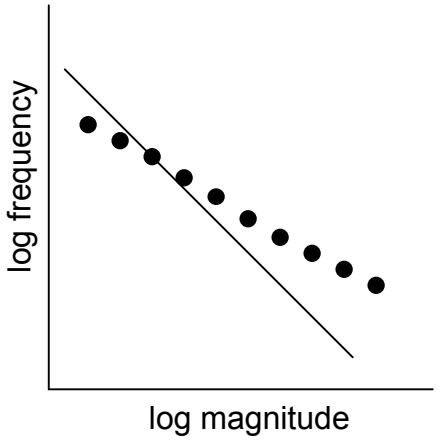
Seismicity Patterns Used in Intermediate-Term Prediction



Accelerating Seismicity



Long-Range Correlation



Large-Magnitude Enrichment

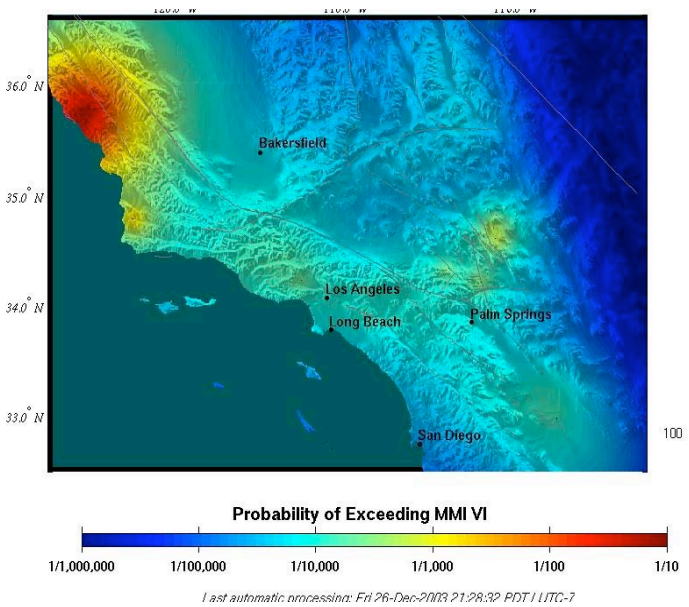
Problems in Assessing Earthquake Rupture Forecasts and Prediction Experiments

- **Scientific publications provide insufficient information for independent evaluation**
- **Active researchers are constantly tweaking their procedures, which become moving targets**
- **Difficult to find resources to conduct and evaluate long-term prediction experiments**
- **Data to evaluate prediction experiments are often improperly specified**
- **Standards are lacking for testing predictions against reference forecasts**

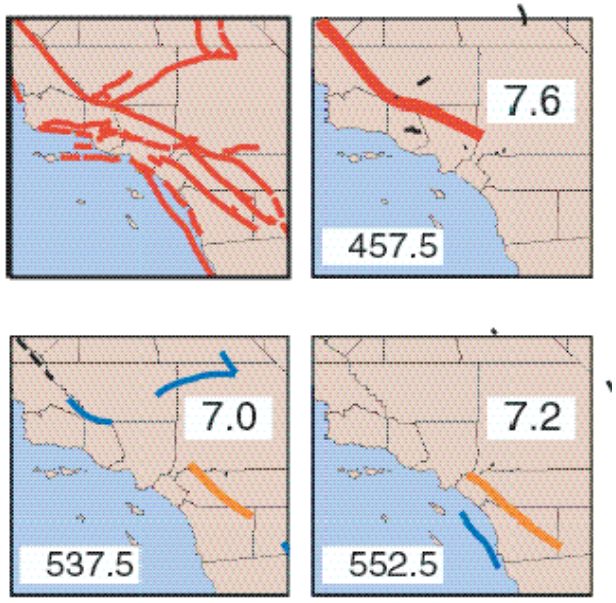
Bottom Line: Our experimental infrastructure is inadequate

SCEC/USGS Working Group for the Development of

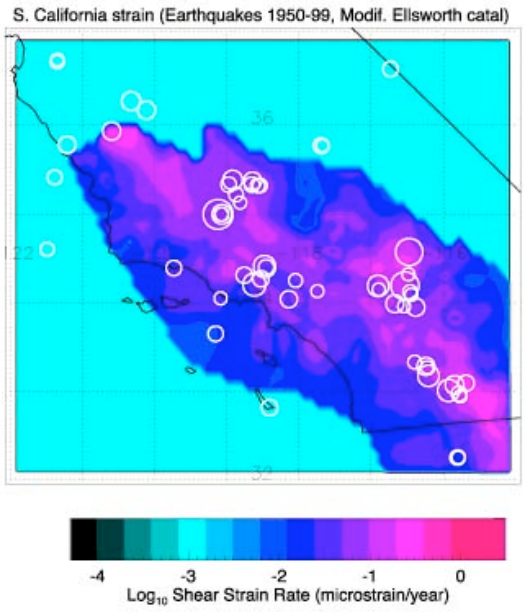
Regional Earthquake Likelihood Models



Seismicity-based model
(Gerstenberger & others)



Simulation-based model
(Ward)



Geodetic-based model
(Jackson & others)

Collaboratory for the Study of Earthquake Predictability (CSEP)

- **Motivation**
  - Earthquake prediction research is hampered by inadequate infrastructure for conducting scientific prediction experiments
- **Primary objective**
  - Rigorous *comparative* testing of scientific prediction experiments spanning a variety of fault systems to study the physical basis for earthquake predictability
- **CSEP will build on the RELM program and similar efforts elsewhere**
  - International partnerships will establish natural laboratories for scientific earthquake prediction experiments

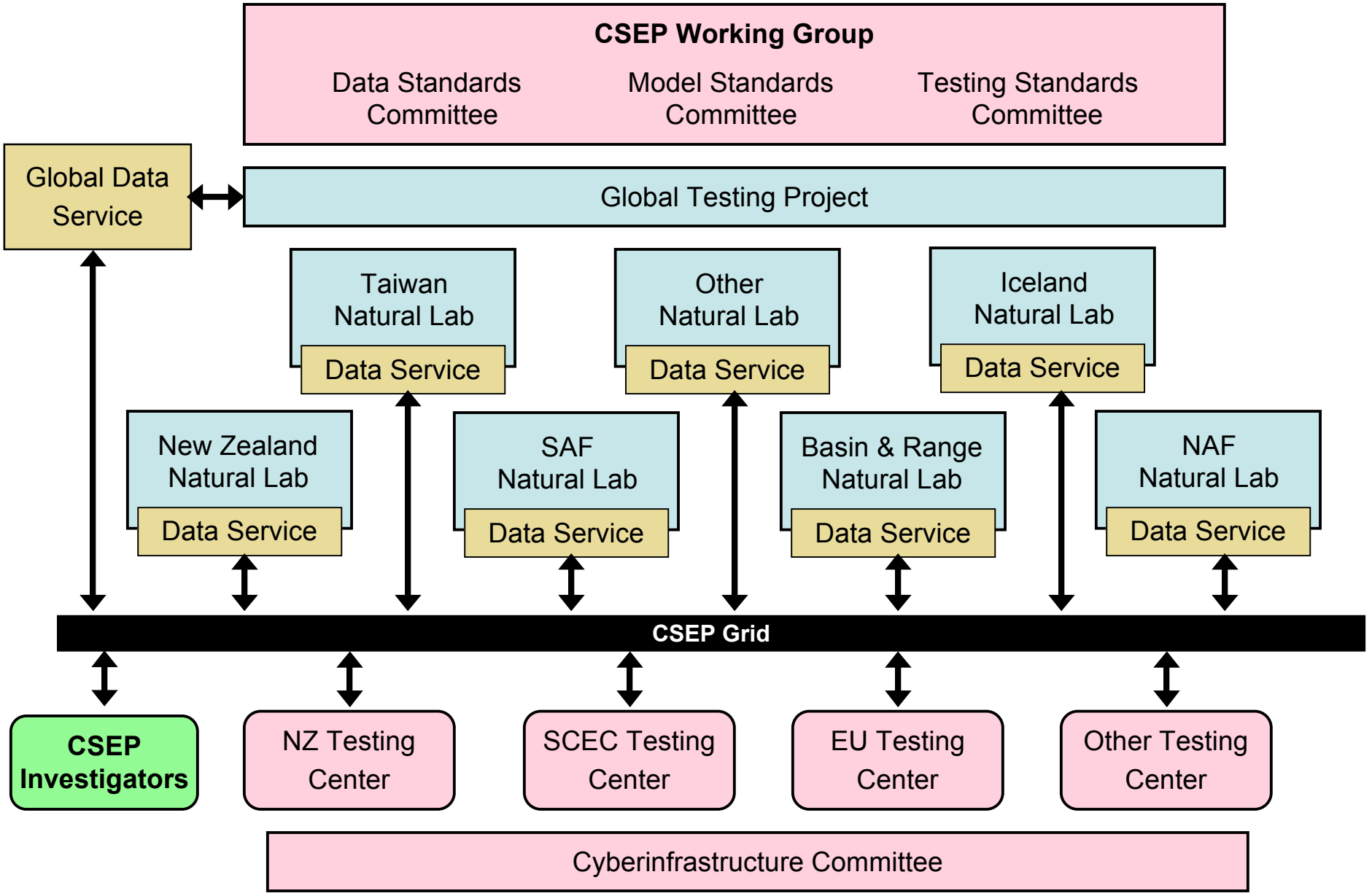
CSEP Goals

1. **Reduce the controversies through a collaboratory infrastructure that can support a wide range of scientific prediction experiments**
2. **Promote rigorous research on earthquake predictability through the SCEC program and its global partnerships**
3. **Help government agencies assess the feasibility of earthquake prediction and the performance of proposed prediction algorithms**

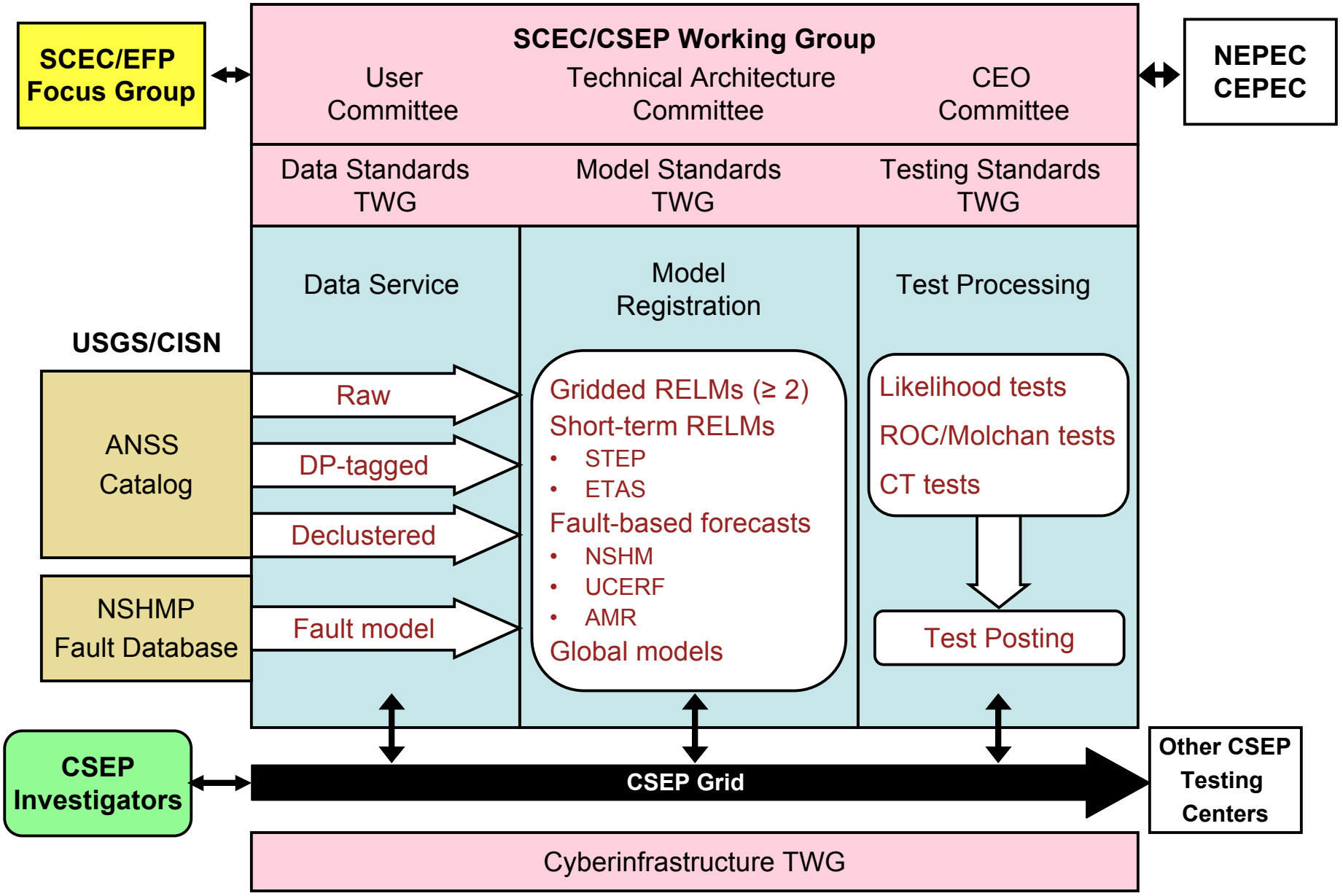
CSEP Objectives

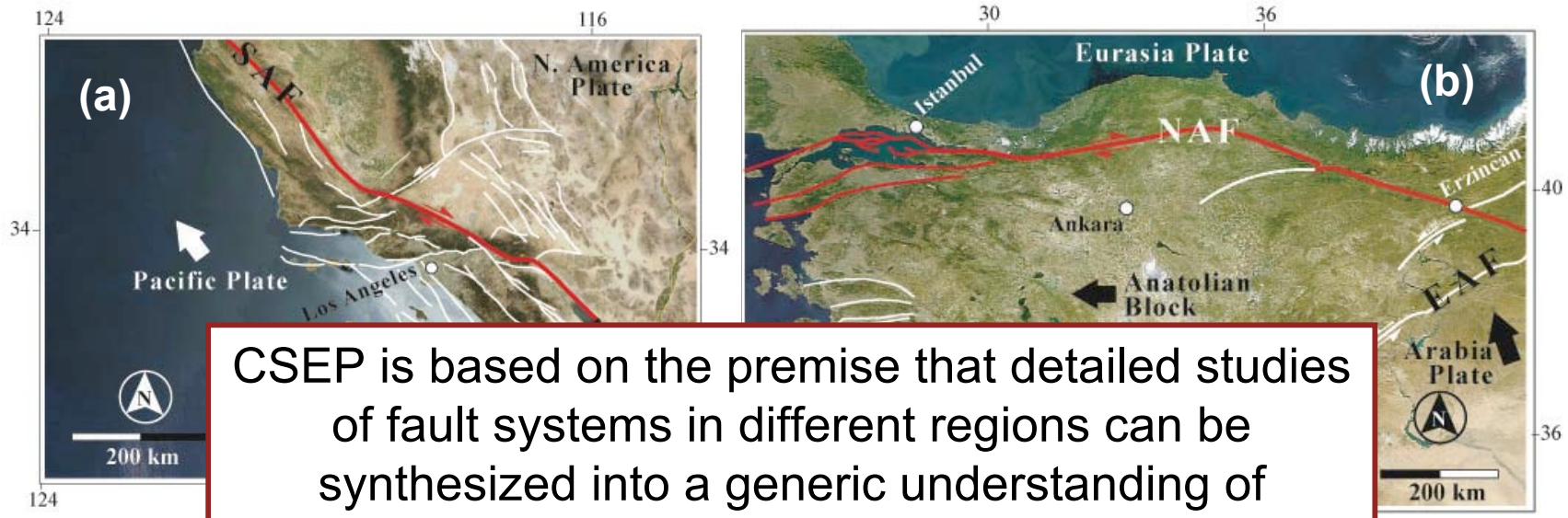
1. Establish rigorous procedures for registering and evaluating prediction experiments
2. Construct community standards and protocols for comparative testing of predictions
3. Develop an infrastructure that allows groups of researchers to participate in prediction experiments
4. Provide access to authorized data sets and monitoring products for calibrating and testing prediction algorithms
5. Accommodate experiments involving fault systems in different geographic and tectonic environments

Collaboratory for the Study of Earthquake Predictability



SCEC/CSEP Testing Center (Phase 1)

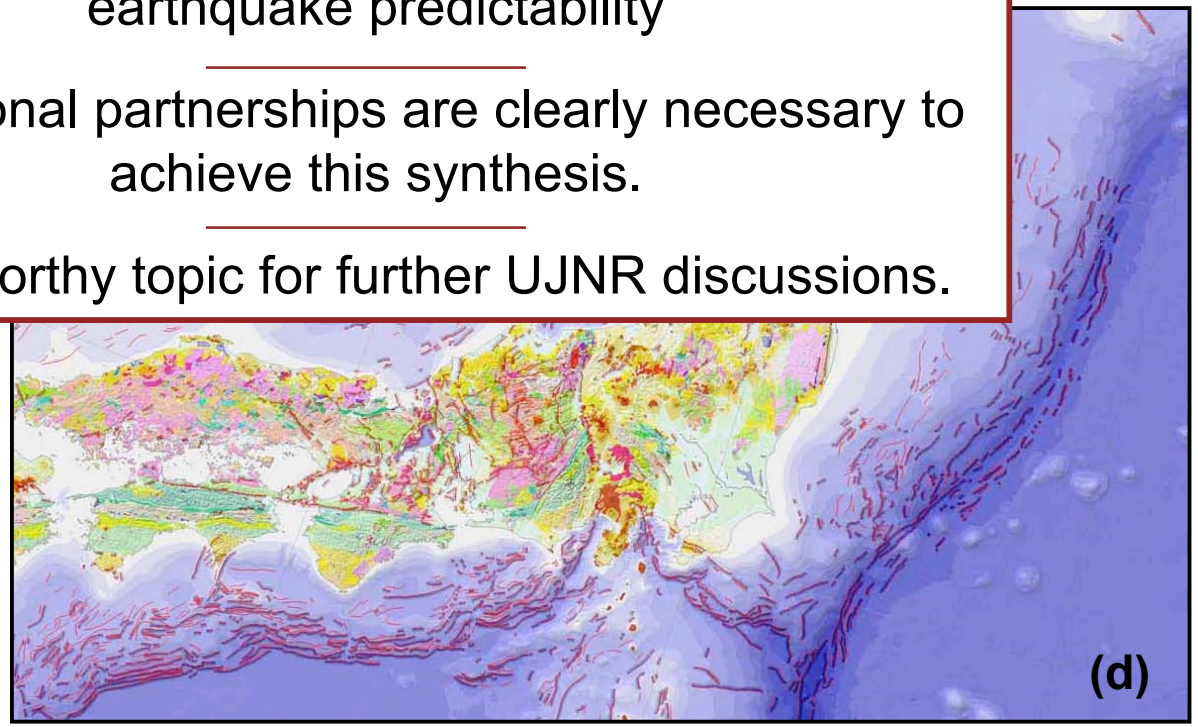




CSEP is based on the premise that detailed studies of fault systems in different regions can be synthesized into a generic understanding of earthquake predictability

International partnerships are clearly necessary to achieve this synthesis.

This a worthy topic for further UJNR discussions.



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