# *Collaboratory for Interseismic Simulation and Modeling (CISM) Meeting*

**Palm Springs, California**

**11 Sept 2016**

an **NSF+USGS** center

SCEC

Southern California Earthquake Center

# *Collaboratory for Interseismic Simulation and Modeling (CISM)*

## Project Goal

**Develop a collaboratory where interdisciplinary teams can create system-specific models for time-dependent earthquake forecasting that are comprehensive, physics-based, data-calibrated, and prospectively testable**

**CISM has been funded for a three-year period by a $2M grant from W.M. Keck Foundation**

## Meeting Objectives

1. Review first-year progress of the CISM program
2. Solicit community input to the second-year research plan
3. Identify other earthquake models needed to achieve CISM goals
4. Encourage SCEC scientists to participate in CISM development

W.M. KECK FOUNDATION

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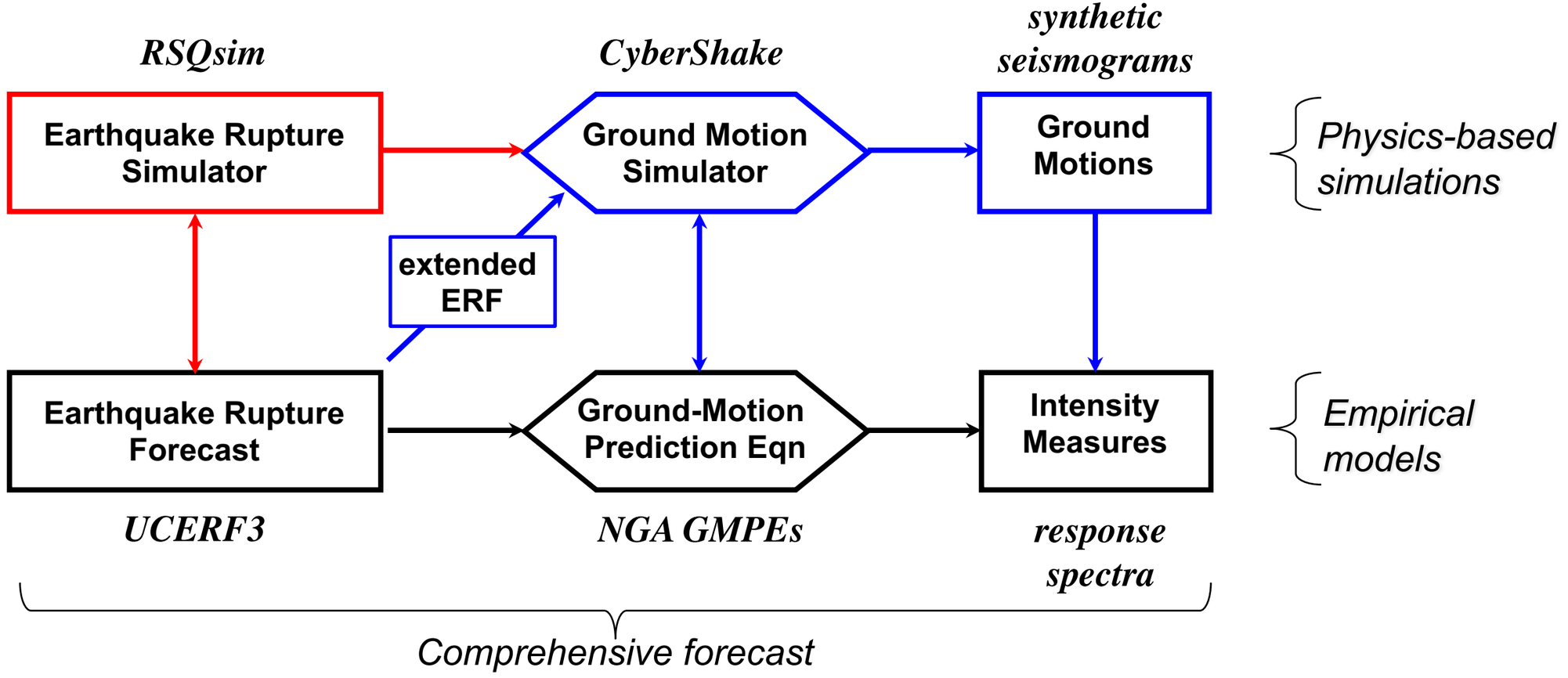
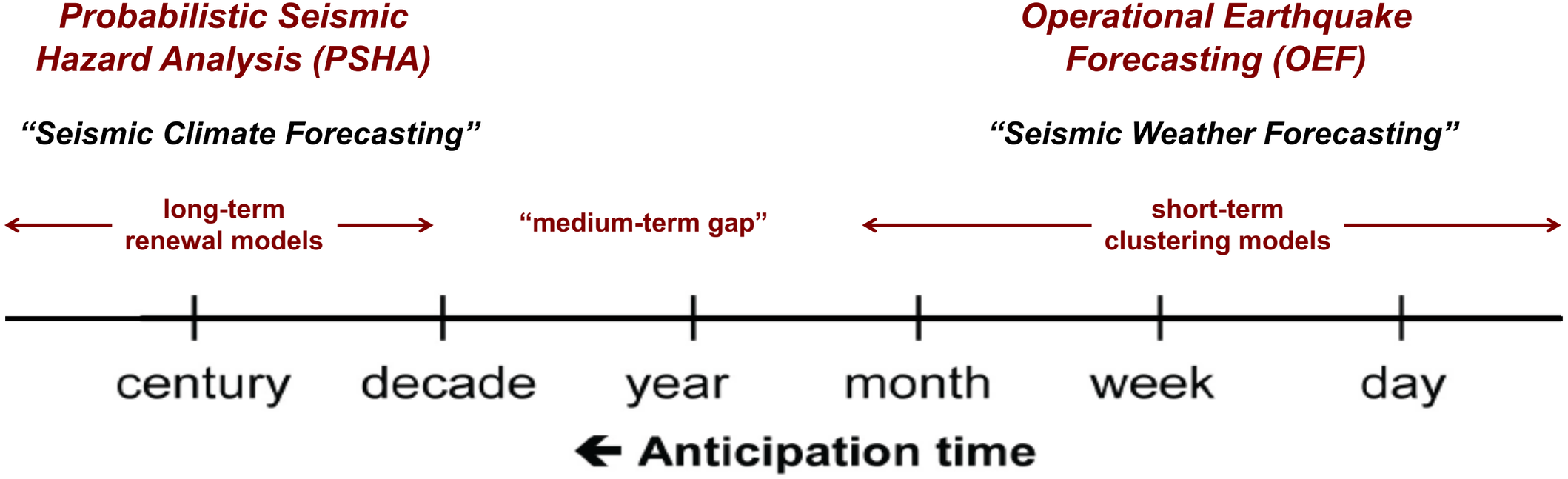


# *Scales of Seismic Hazard Change*

- **Faults accumulate stress over centuries during quasi-static tectonic loading**
  - **stress cycle represented by Reid *renewal* models**
- **Faults redistribute stress in seconds during dynamic ruptures**
  - **earthquake sequences represented by Omori-Utsu *clustering* models**



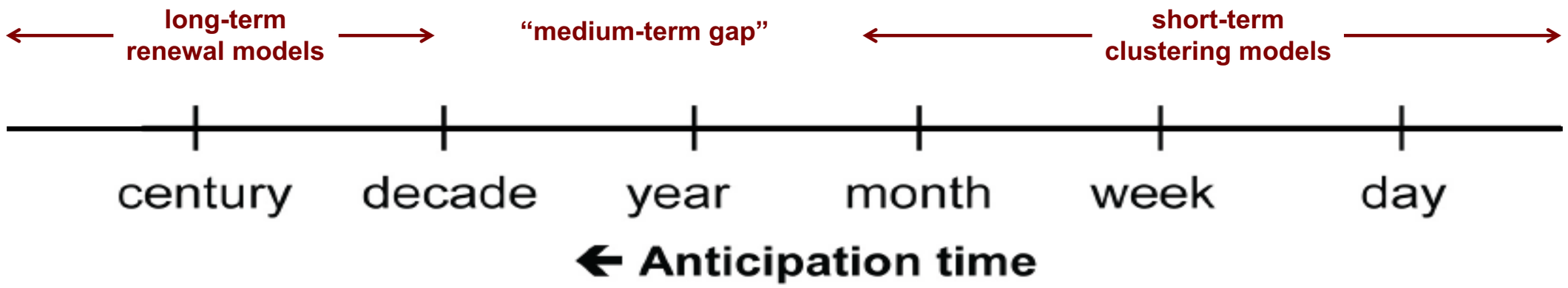
# California Earthquake Forecasting Models

*Reid renewal* *Omori-Utsu clustering*

**UCERF3 long-ter** **UCERF3 short-term**

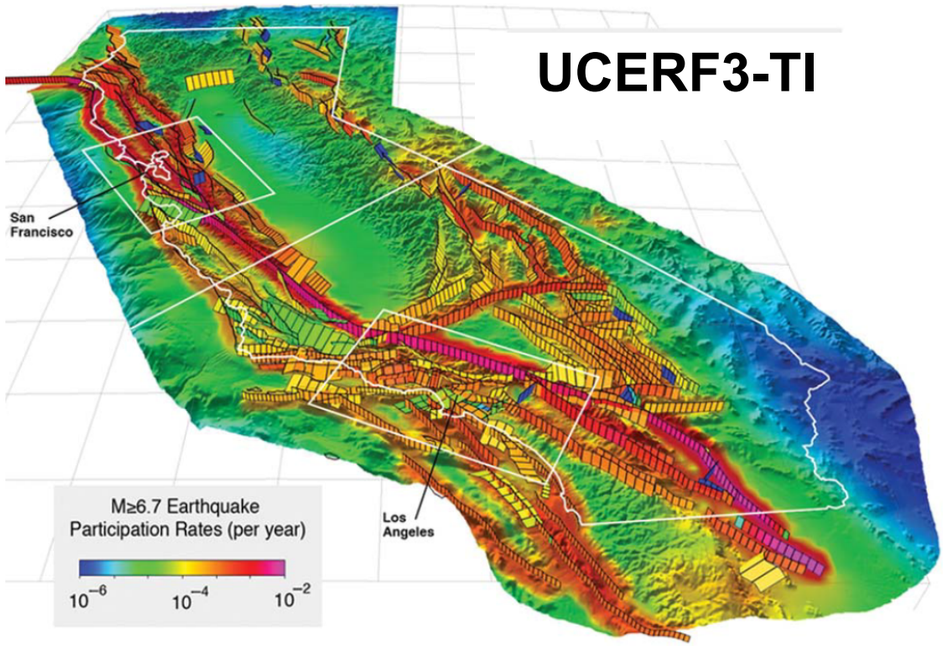
**UCERF2** **STEP/ETAS**

**NSHM**

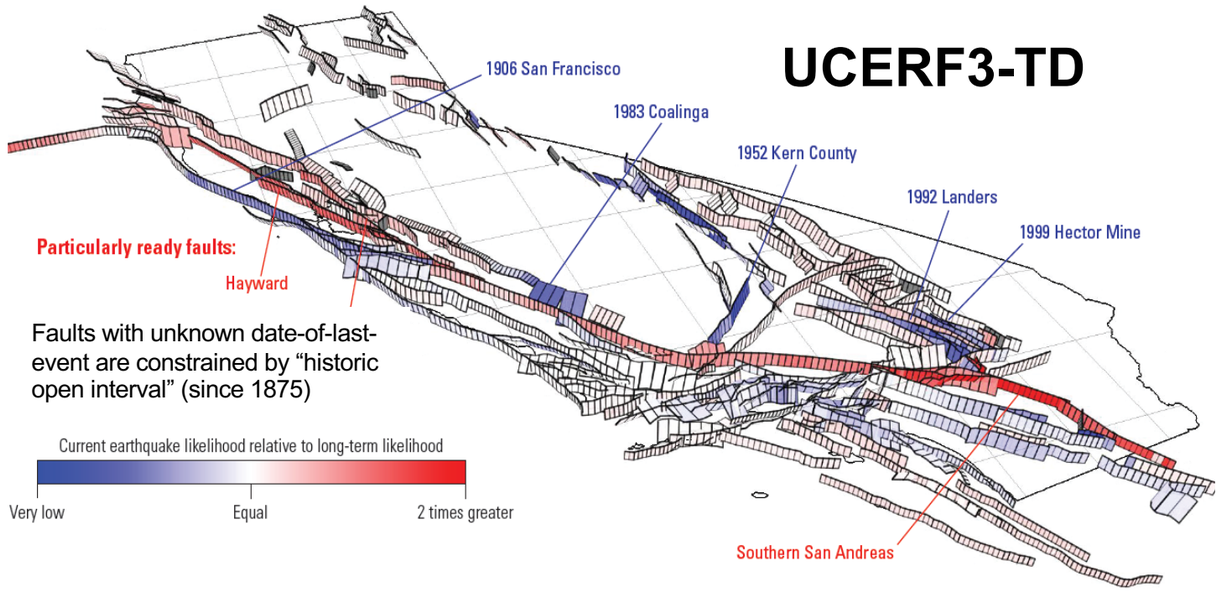


# Uniform California Earthquake Rupture Forecast (UCERF3)

## UCERF3-TI

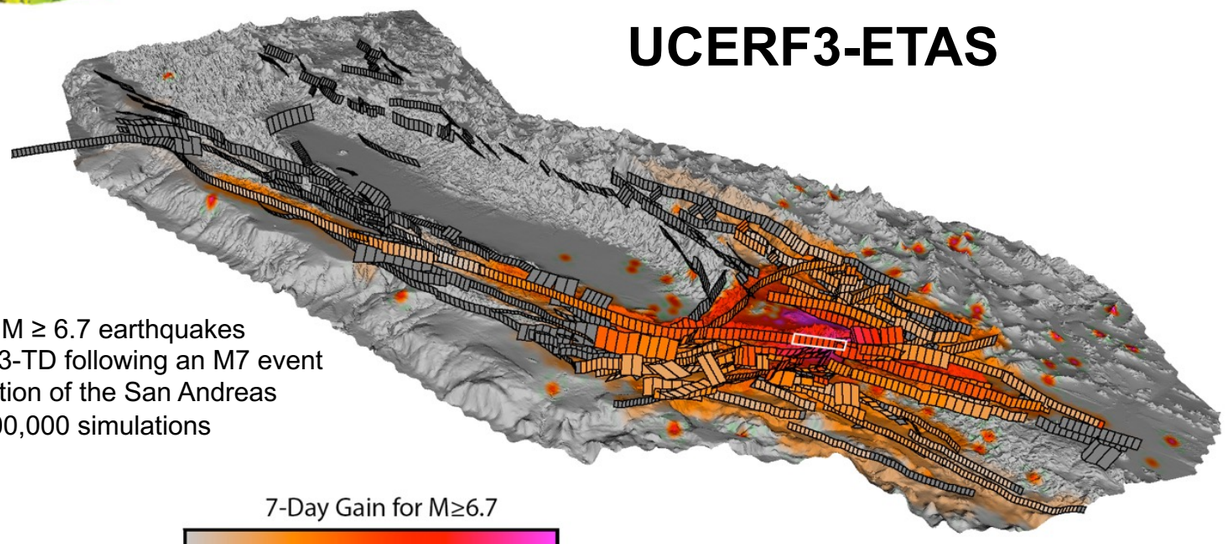



## UCERF3-TD




Faults with unknown date-of-last-event are constrained by "historic open interval" (since 1875)

## UCERF3-ETAS



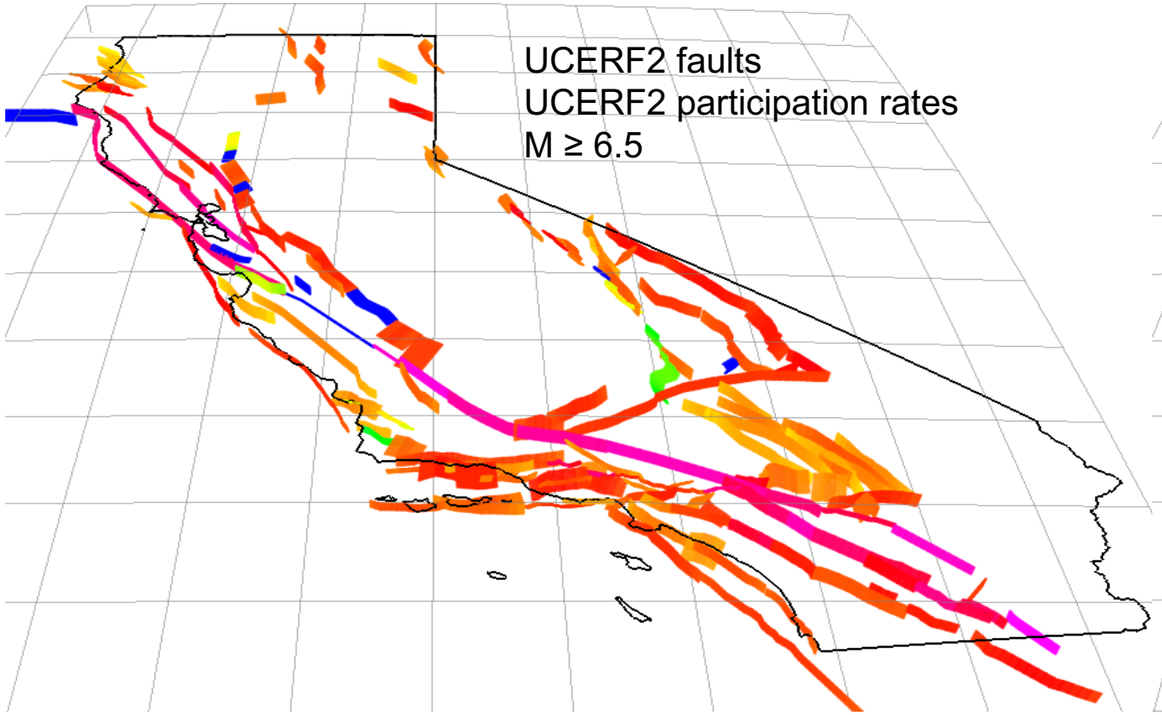

Probability gain of M ≥ 6.7 earthquakes relative to UCERF3-TD following an M7 event on the Mojave section of the San Andreas Fault, based on 100,000 simulations

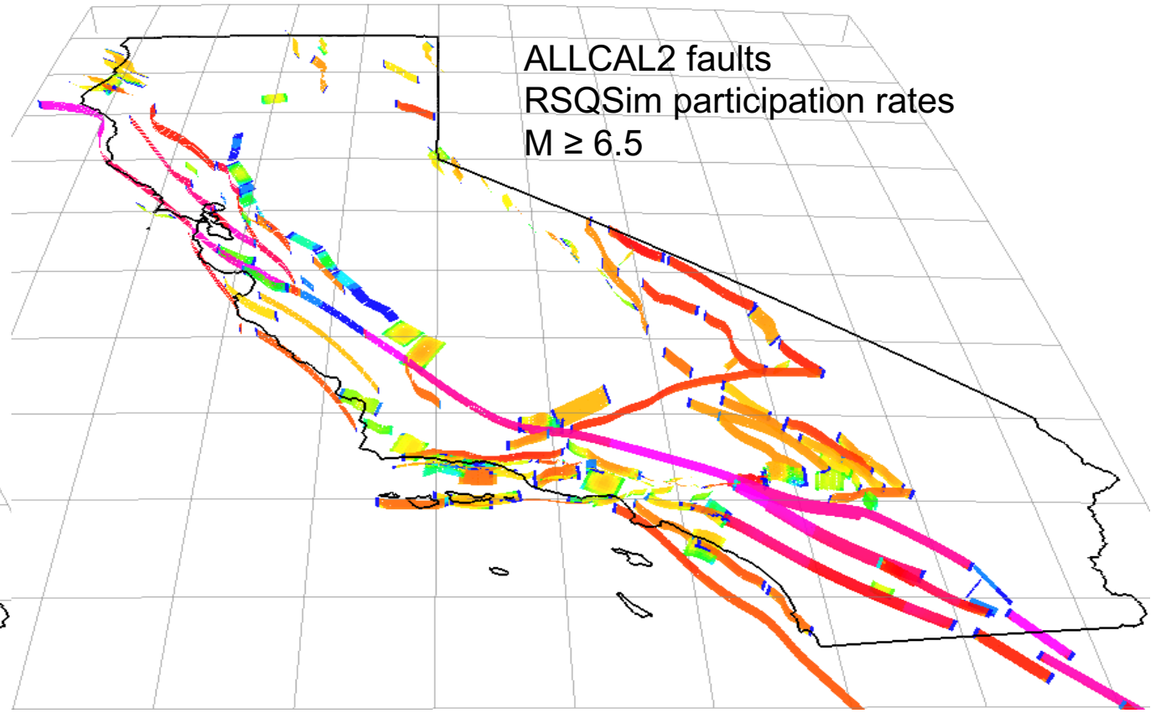
Field et al. (2014, 2015, 2016)

# *Rate-State Quake Simulator (RSQSim )*

(Dieterich & Richards-Dinger, 2010; Richards-Dinger & Dieterich, 2012)

- **Tectonic loading of faults by backslip approximation**
- **Rupture nucleation by rate- and state-dependent friction**
- **Radiation damping and dynamic overshoot**
- **Slip-mediated stress transfer in homogeneous elastic halfspace**
- **Very efficient 3-state computational algorithm**



RSQSim simulation using
1-km triangulated
UCERF3 fault model

Simulator Output Animation: slip (m) per event

0.00 1.67 3.33 5.00 6.67 8.33 10.0

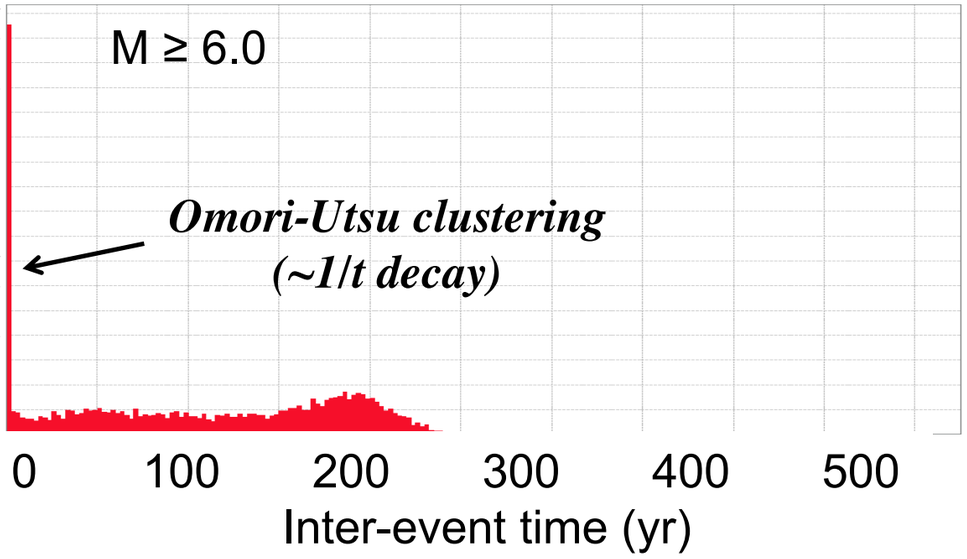
3423.33 years

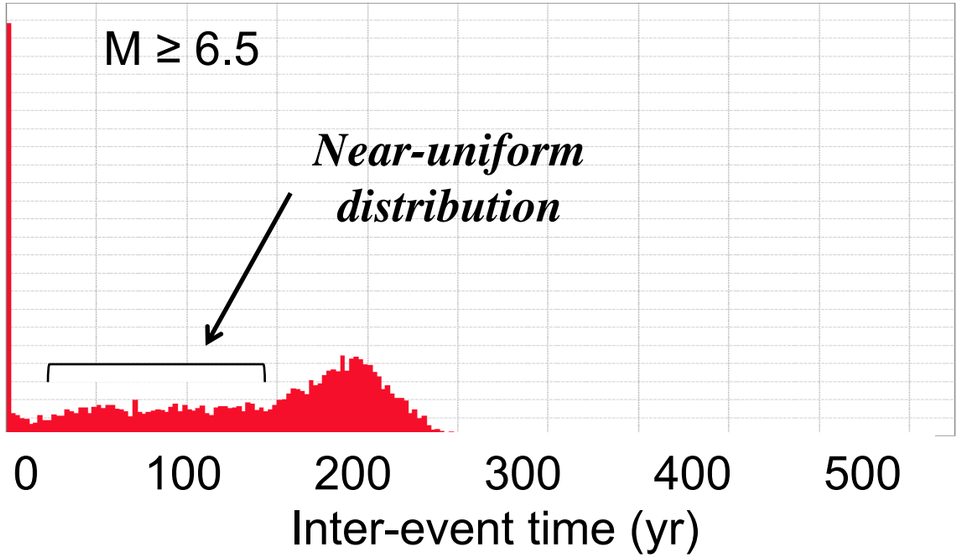
00:34

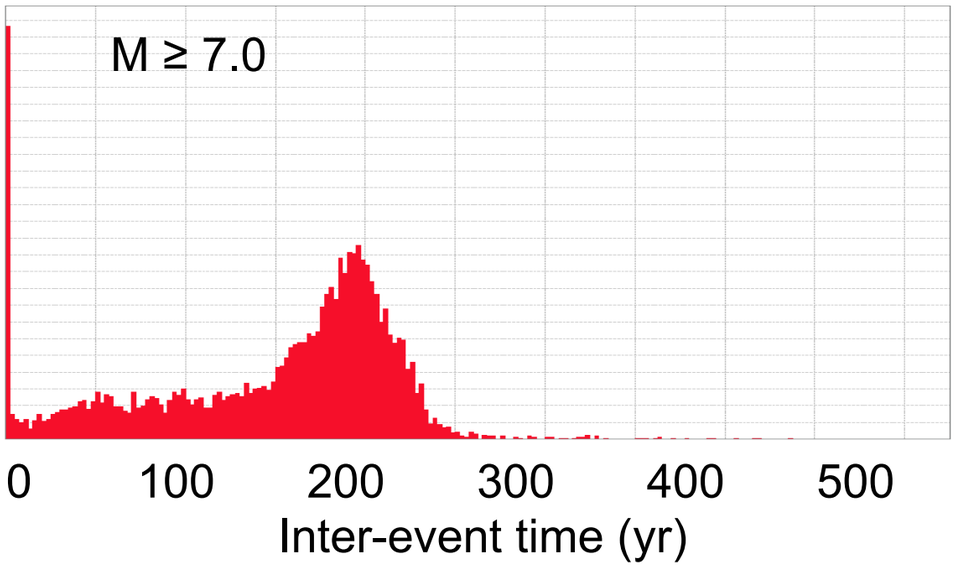
# *RSQSim Earthquake Simulator*

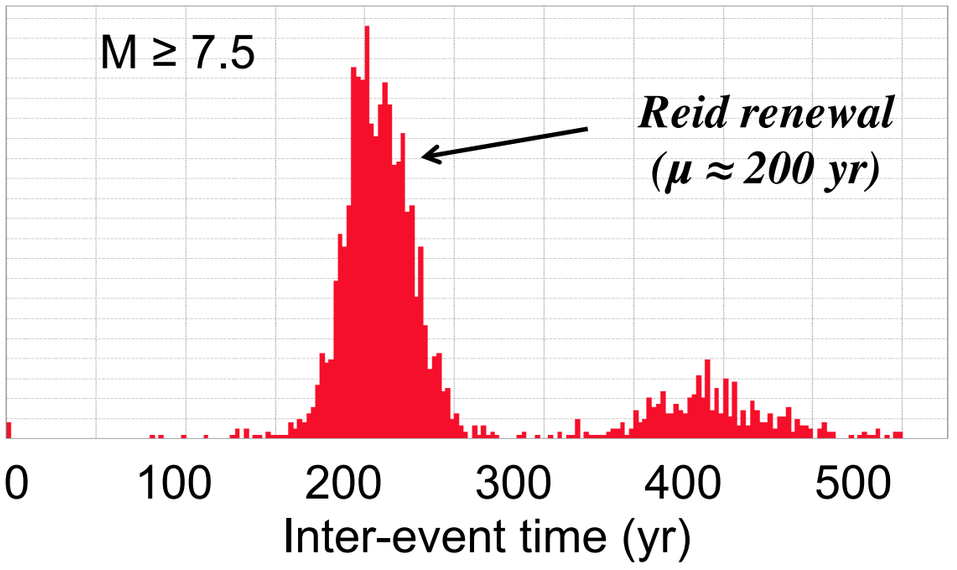
(Dieterich, 1995; Dieterich & Richards-Dinger, 2010; Richards-Dinger & Dieterich, 2012)

**Magnitude dependence of inter-event times on the Carrizo-Cholame sections of the San Andreas fault from a million-year catalog**



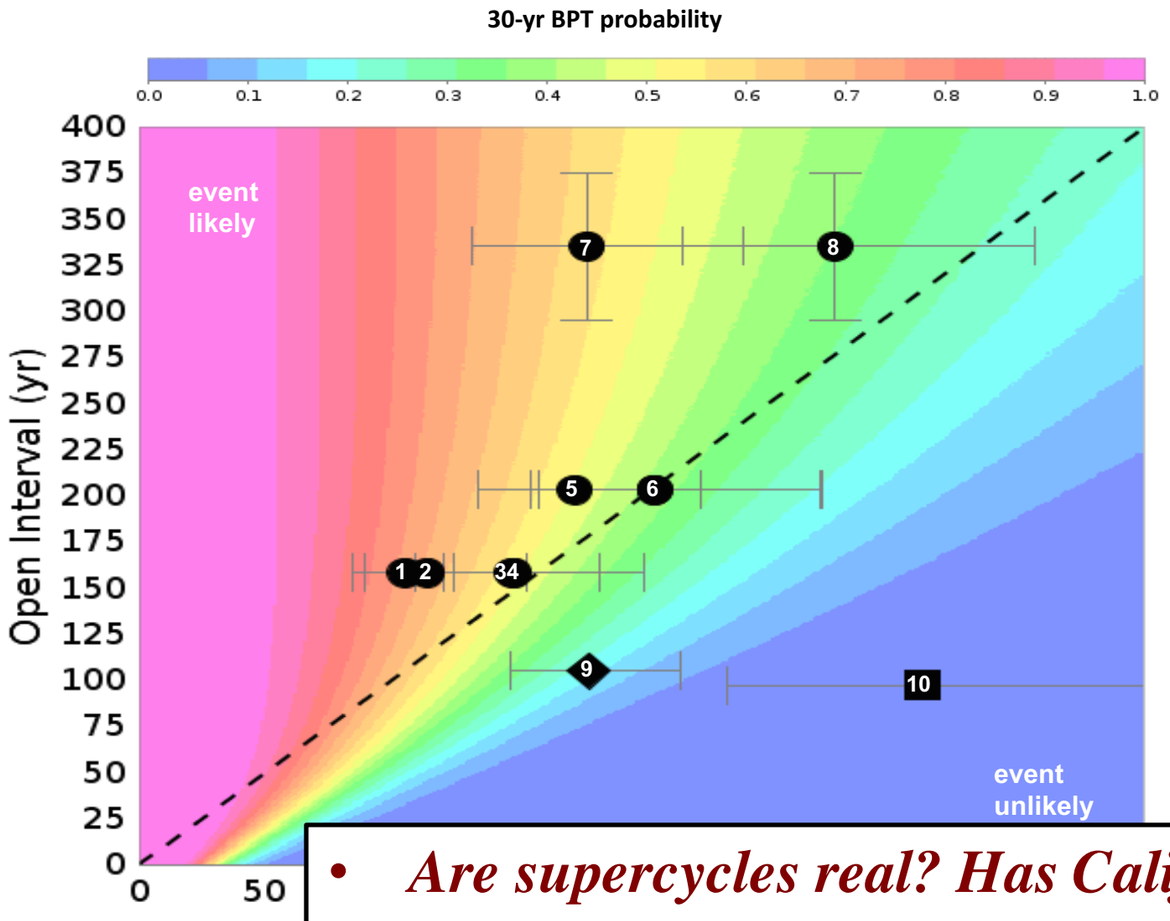



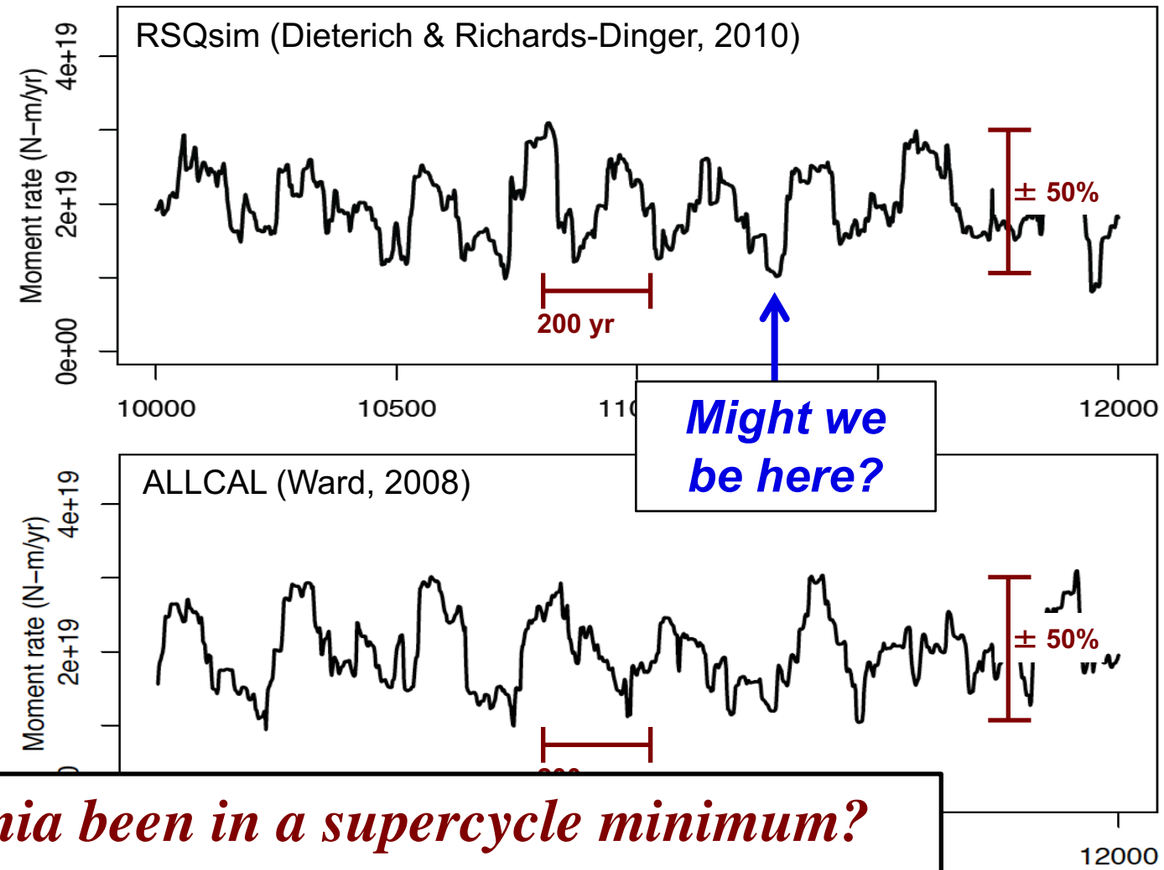



# *Seismic Supercycles?*

## UCERF3 Paleoseismic Data for Selected Sites




## 100-yr Moving Average of Seismic Moment Release from Simulators

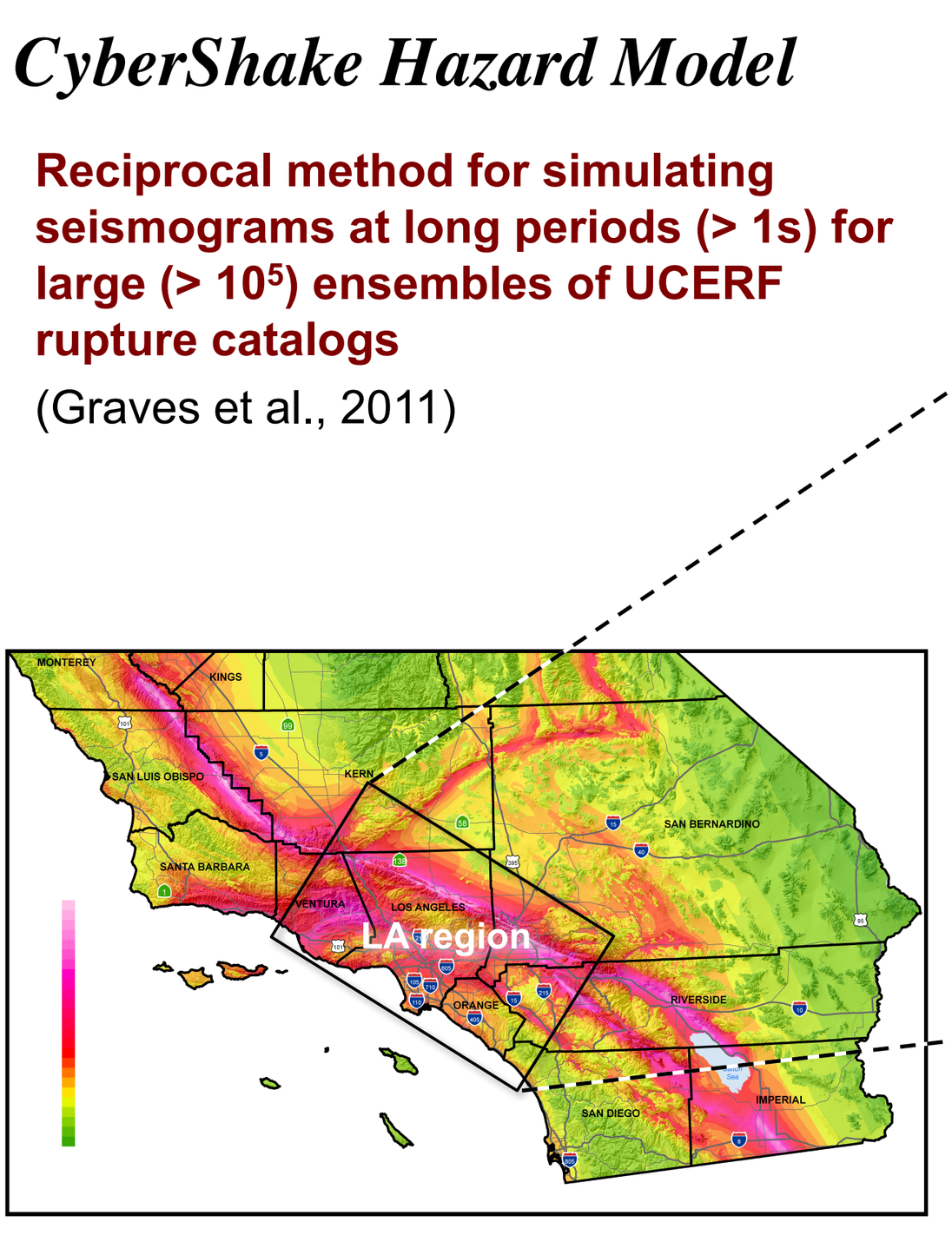


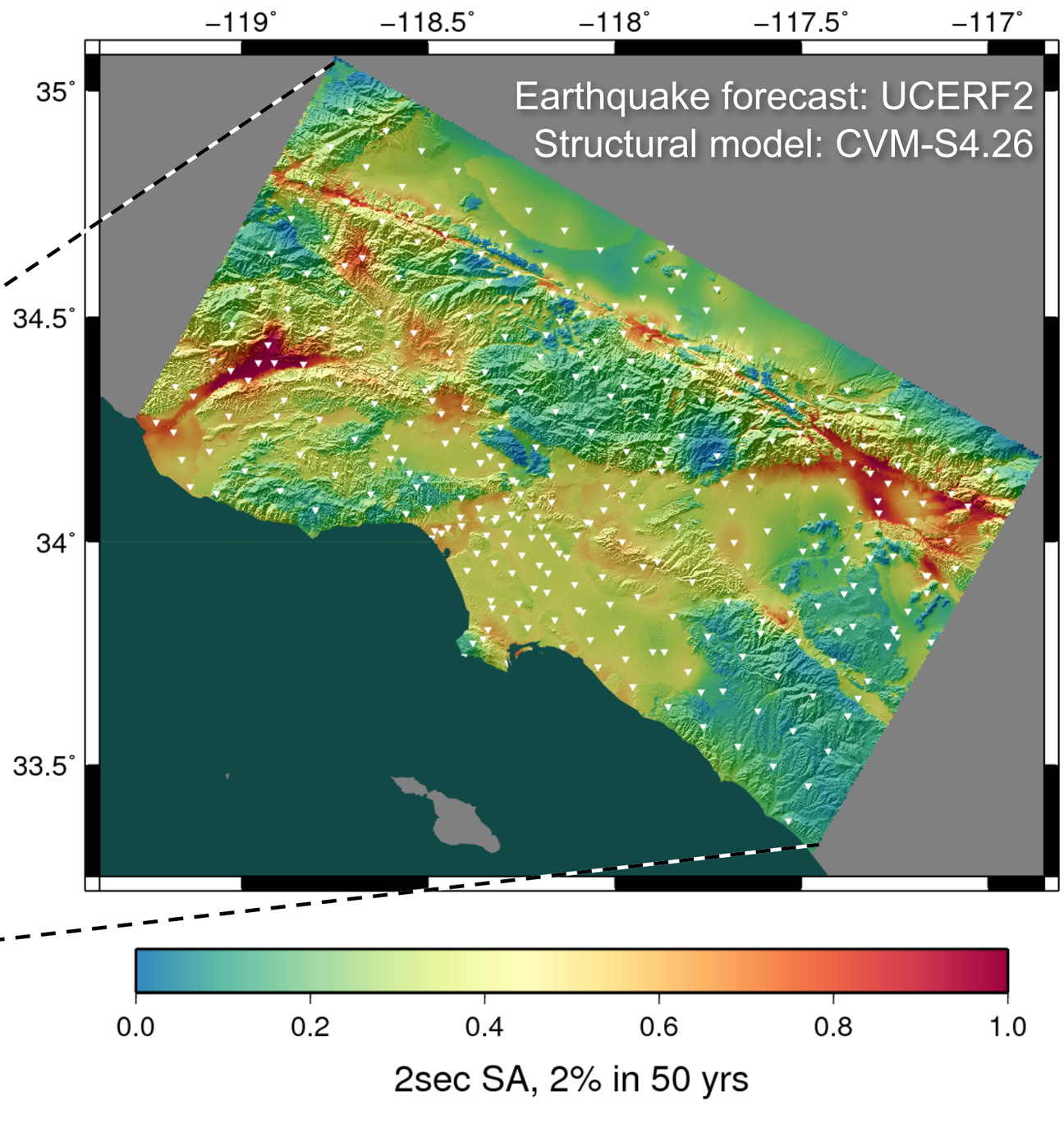

- ***Are supercycles real? Has California been in a supercycle minimum?***
- ***What are the transition times to periods of enhanced seismic activity?***
- ***How frequent are large earthquakes during the peak episodes?***

# CyberShake Hazard Model

**Reciprocal method for simulating seismograms at long periods (> 1s) for large (> $10^5$) ensembles of UCERF rupture catalogs**

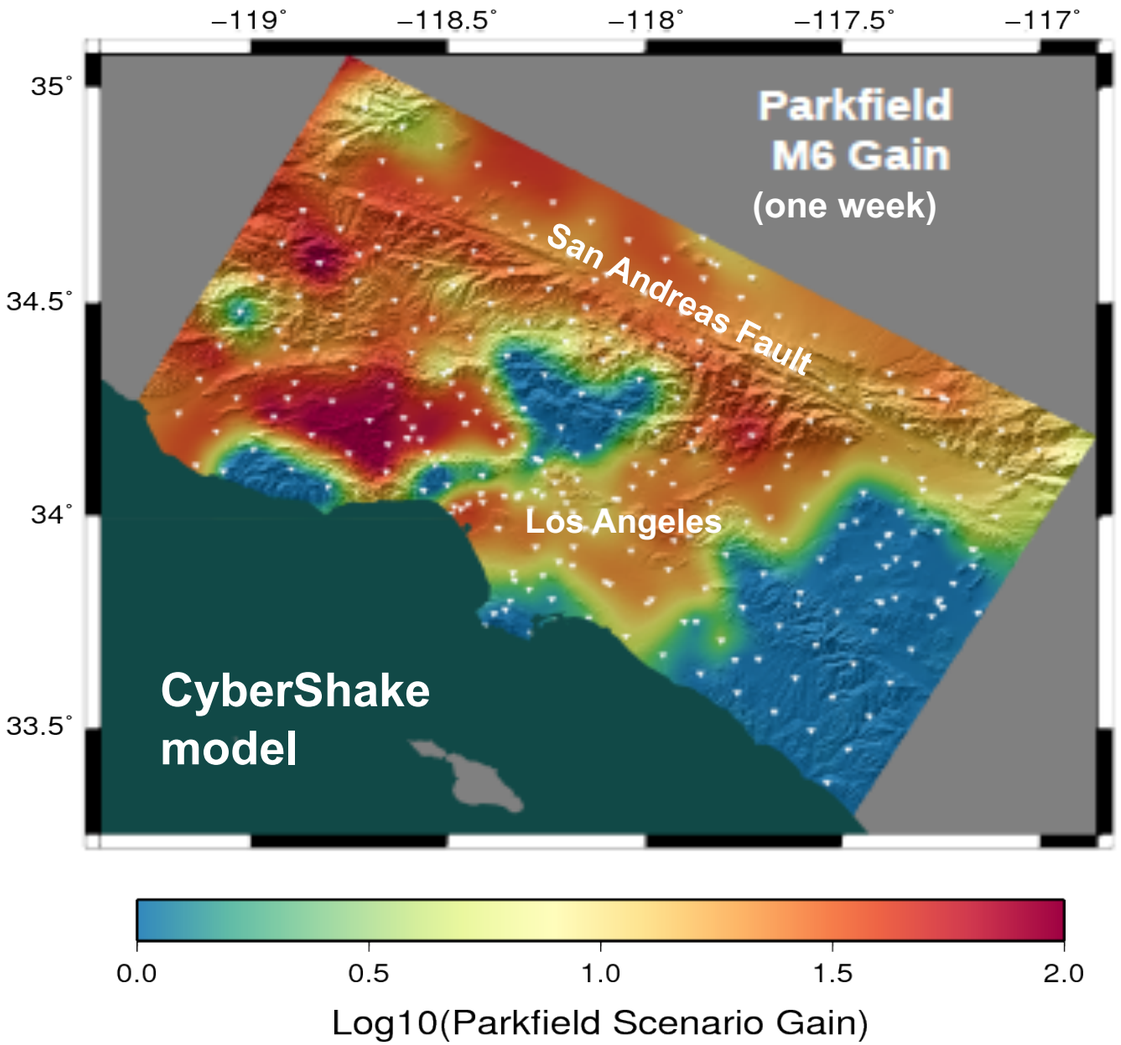
(Graves et al., 2011)

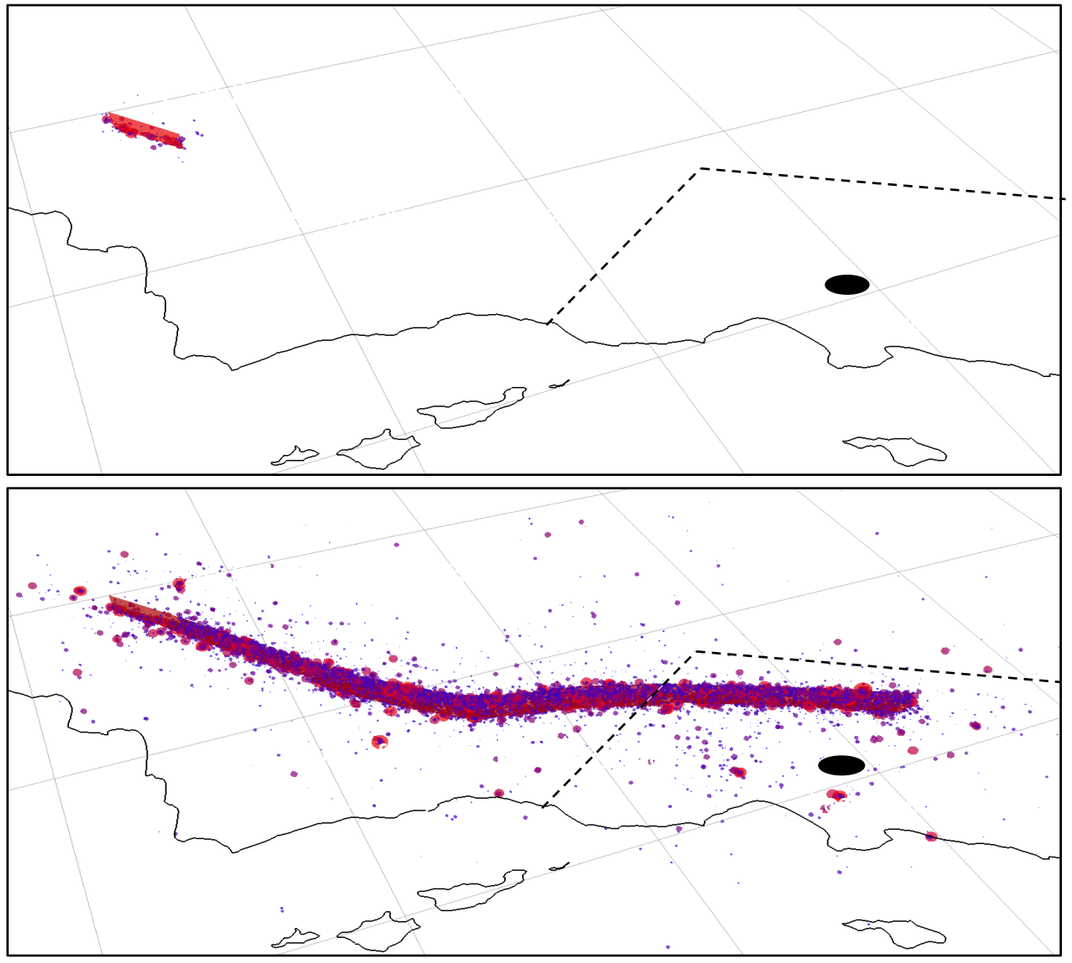


# *Coupling CyberShake with UCERF3-ETAS*

**Because it may be a foreshock of a large San Andreas rupture, a Parkfield earthquake significantly amplifies the shaking hazard in Los Angeles**



**This calculation couples UCERF3-ETAS with the CyberShake simulation-based ground motion prediction model**

Milner, Jordan & Field (2015)

# *Collaboratory for Interseismic Simulation and Modeling (CISM)*

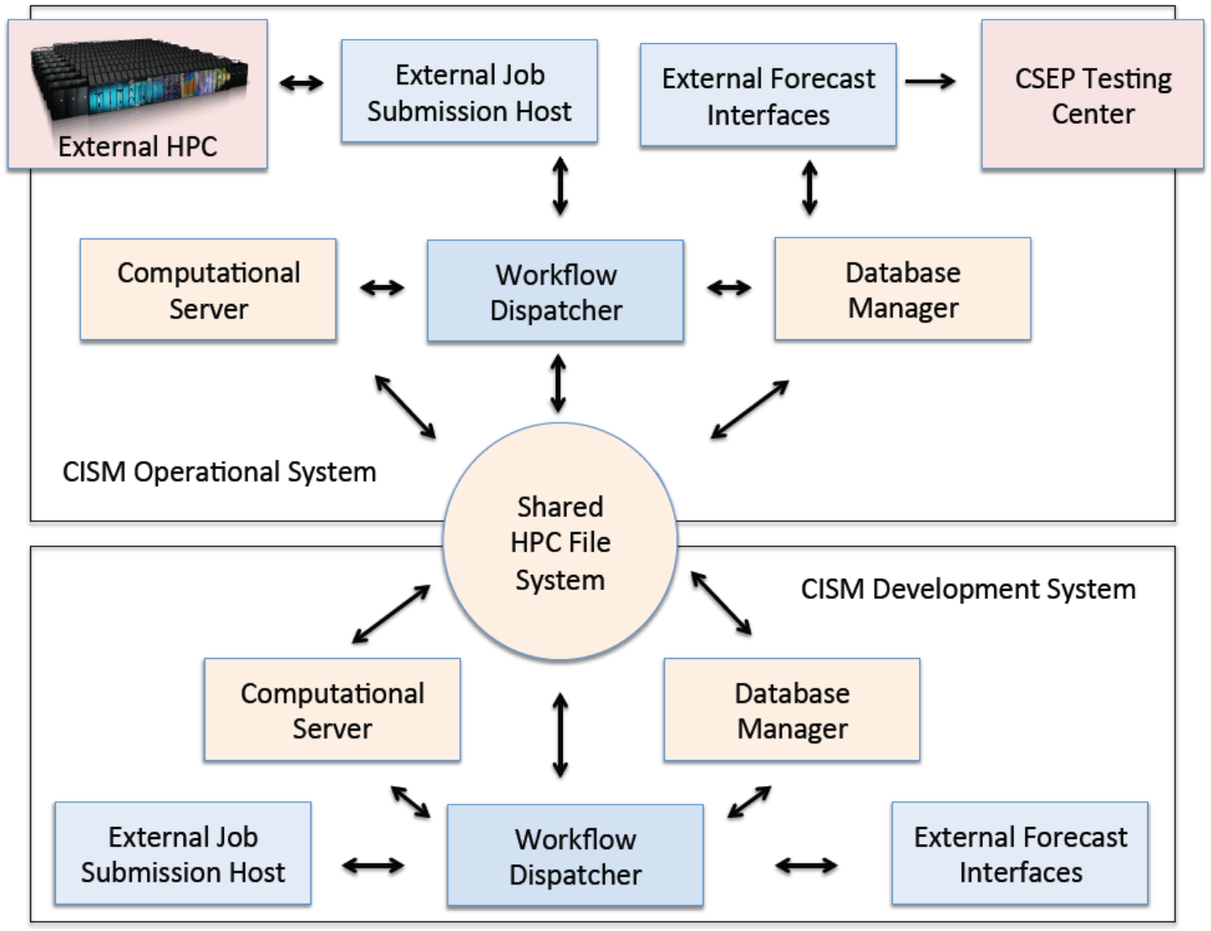
## Project Objectives

- **Develop a collaboratory where interdisciplinary teams can create system-specific models for time-dependent earthquake forecasting that are comprehensive, physics-based, data calibrated, and prospectively testable**
  - **Develop rupture simulators and ground-motion simulators using California as the primary test bed**
  - **Combine time-dependent earthquake rupture forecasting models with ground motion prediction models to forecast exceedance probabilities**
  - **Test models in CSEP and by other means (e.g., using virtual earthquakes)**
- **Develop a high-performance, workflow-oriented cyberinfrastructure that facilitates model verification, simulation, validation, and data assimilation**
  - **Provide researchers with advanced tools for integrating heterogeneous sets of scientific software modules into testable forecasting models**
  - **Maintain a high-performance computing environment in which system-level models can be rapidly executed and analyzed**
- **Initiate WMKF Fellowships in Earthquake Forecasting Research**
  - **Sponsor CISM participation of early-career scientists**

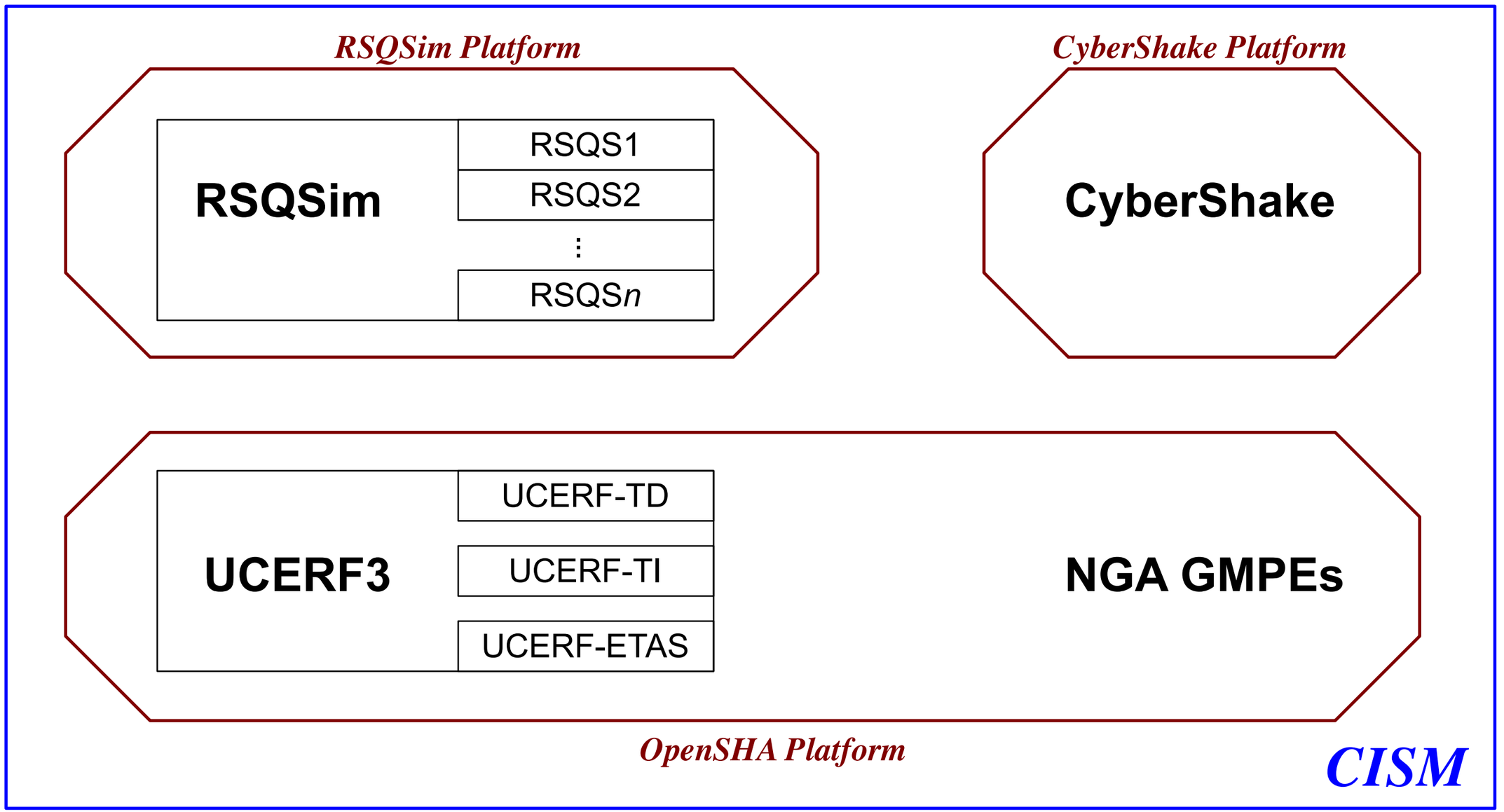
# Collaboratory for Interseismic Simulation and Modeling (CISM)

## Cyberinfrastructure Objective

- **Implement a high-performance, workflow-oriented cyberinfrastructure that supports research on comprehensive physics-based forecasting models by facilitating earthquake simulation and data assimilation**



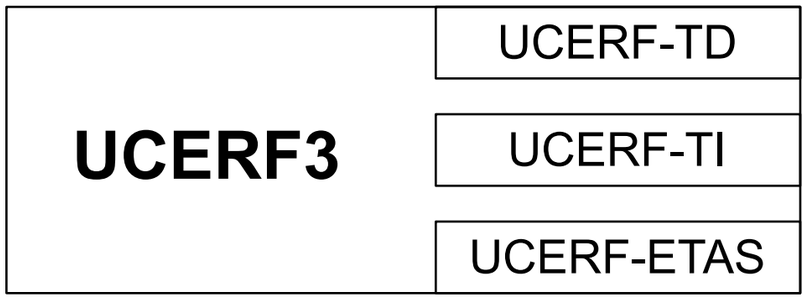
# CISM Structural Elements – Year 1



# CISM Validation Studies

## Earthquake Rupture Forecasting

Comparative testing with UCERF3
Retrospective testing:
- Historical seismic catalogs
- Paleoseismic model catalogs




Comparative testing with RSQSim
Prospective testing:
- Collaboratory for the Study of Earthquake Predictability (CSEP)

## Ground Motion Prediction

### CyberShake

Retrospective testing:
- Historical seismograms
- Fragile geologic features

Comparative testing with GMPEs

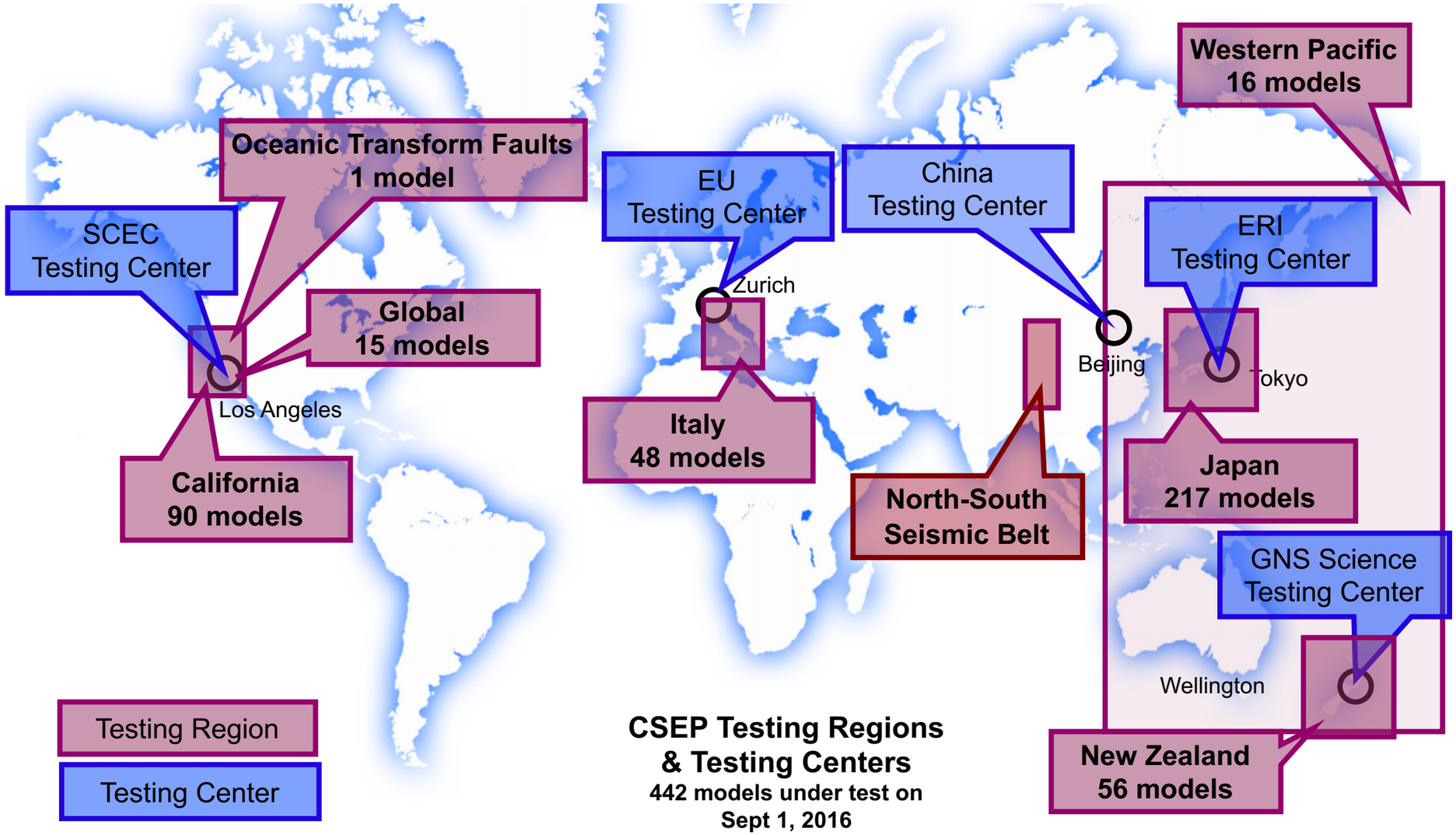
Prospective testing:
- Intensity measurements
- ShakeMap observations
- Virtual earthquakes

### NGA GMPEs

CISM

# *Collaboratory for the Study of Earthquake Predictability*

**Infrastructure for automated, blind, prospective testing of forecasting models in a variety of tectonic environments and on a global scale**




**CSEP Testing Regions & Testing Centers**

**442 models under test on Sept 1, 2016**

# CSEP Testing in New Zealand

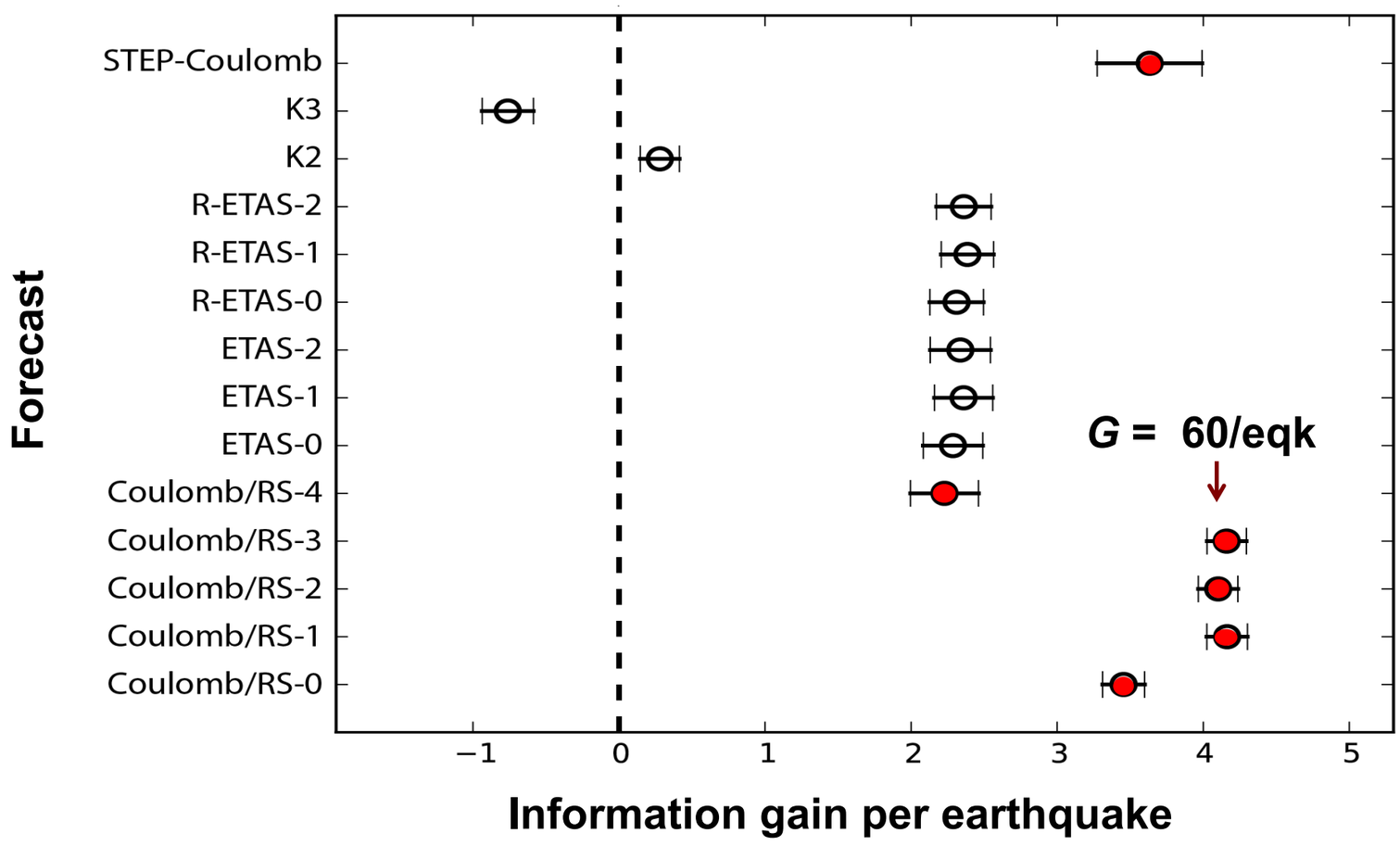
**Testing region:** New Zealand (Canterbury sequence, retrospective)

**Target events:** M ≥ 4 (394 events)

**Testing period:** 4 Sept 2010 - 4 Mar 2012

1 year

**Testing method:** T-test




**Physics-based models outperform statistical models in short-term forecasting**

(Werner et al., 2015)

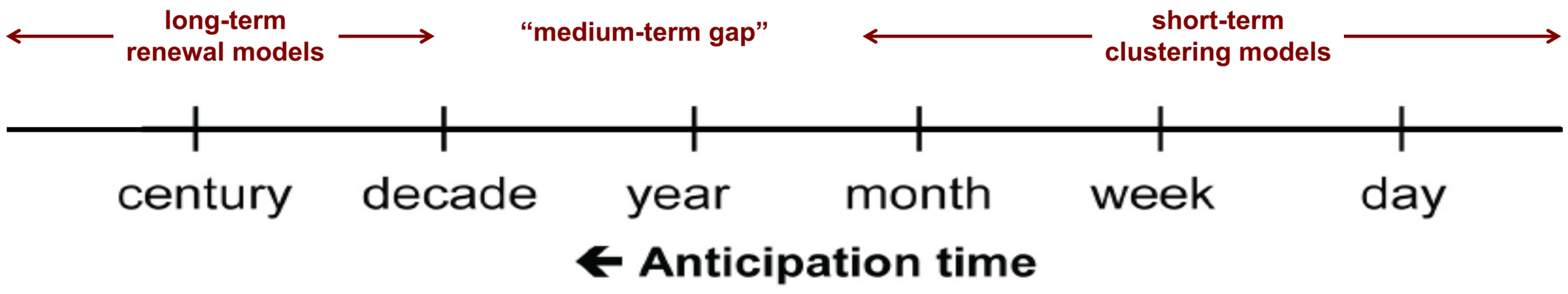
# California Earthquake Forecasting Models

**Simulator-based UCERF**

**UCERF3 long-ter** | **UCERF3 short-term**

**UCERF2** | **STEP/ETAS**

**NSHM**



# CISM Working Groups

- **Working Group on California Earthquake Probabilities**
  - Chair: Ned Field
  - IT liaison: Kevin Milner
- **RSQSim Working Group**
  - Co-Chairs: Jim Dieterich and Keith Richards-Dinger
  - IT liaison: Kevin Milner
- **A-Team**
  - Chair: Dave Jackson
  - IT liaison: Kevin Milner
- **CyberShake Working Group**
  - Chair: Christine Goulet
  - IT liaison: Scott Callaghan
- **CSEP**
  - Chair: Max Werner
  - IT liaison: Masha Liukis

# *CISM Objectives – Year 1*

1. **Develop formats for exchanging data across the ERF → GMP → EHM computational pathway**
   - **Develop RSQSim workflows**
2. **Generate RSQSim catalogs for UCERF3 fault system**
   - **Derive empirical probability distributions to condition UCERF forecasting variables**
   - **Prototype physics-based ERF using RSQSim**
3. **Couple UCERF3 to the CyberShake (LA region)**
   - **Demonstrate UCERF3-ETAS → CyberShake as OEF prototype**
4. **Submit a short-term ERF for CSEP testing**
   - **UCERF3-ETAS**

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Southern California Earthquake Center

# *Collaboratory for Interseismic Simulation and Modeling (CISM)*

## Palm Springs Meeting Agenda, Sunday, Sept 11

| | | |
|---|---|---|
| 07:30 - 08:00 | *Continental Breakfast & Check-In* | |
| 08:00 - 08:20 | Introduction to CISM | Tom Jordan |
| 08:20 - 09:00 | Multiscale forecasting using UCERF3 | Ned Field |
| 09:00 - 09:40 | Earthquake forecasting using the RSQSim earthquake simulator | Jim Dieterich |
| 09:40 - 09:50 | Contributions of the UseIT summer research program to CISM | Kevin Milner |
| 09:50 - 10:00 | Generating long RSQSim catalogs for CISM analysis | Jacqui Gilchrist |
| 10:00 - 10:15 | Discussion: Use of simulators in CISM forecasting research | All |
| 10:15 - 10:30 | *Break* | |
| 10:30 - 11:00 | Testing forecasting models in CSEP | Max Werner |
| 11:00 - 11:30 | Is there an earthquake drought in California? | Dave Jackson |
| 11:30 - 11:45 | CyberShake as a CISM ground motion prediction platform | Scott Callaghan |
| 11:45 - 12:00 | Discussion: CISM plans for 2017 | All |
| 12:00 - 13:00 | *Lunch* | |

# *End*

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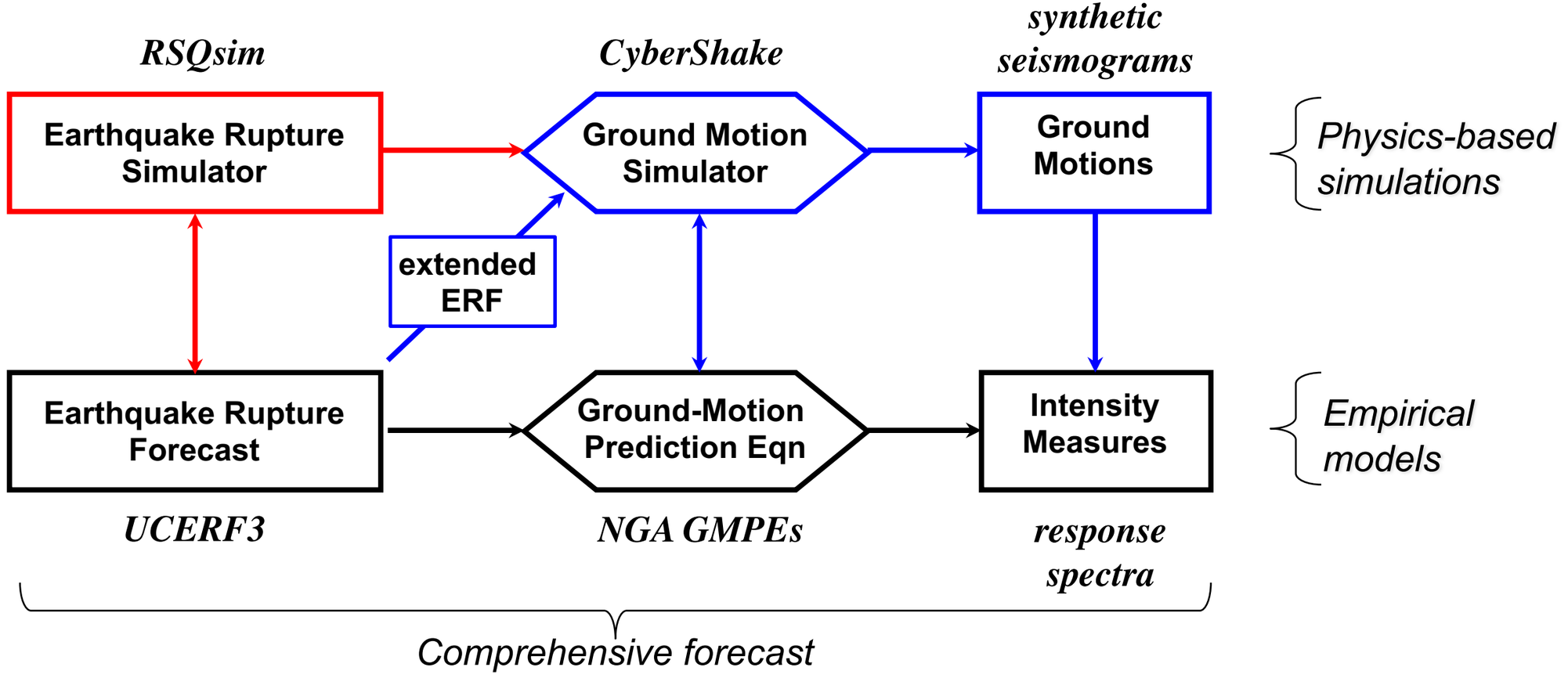
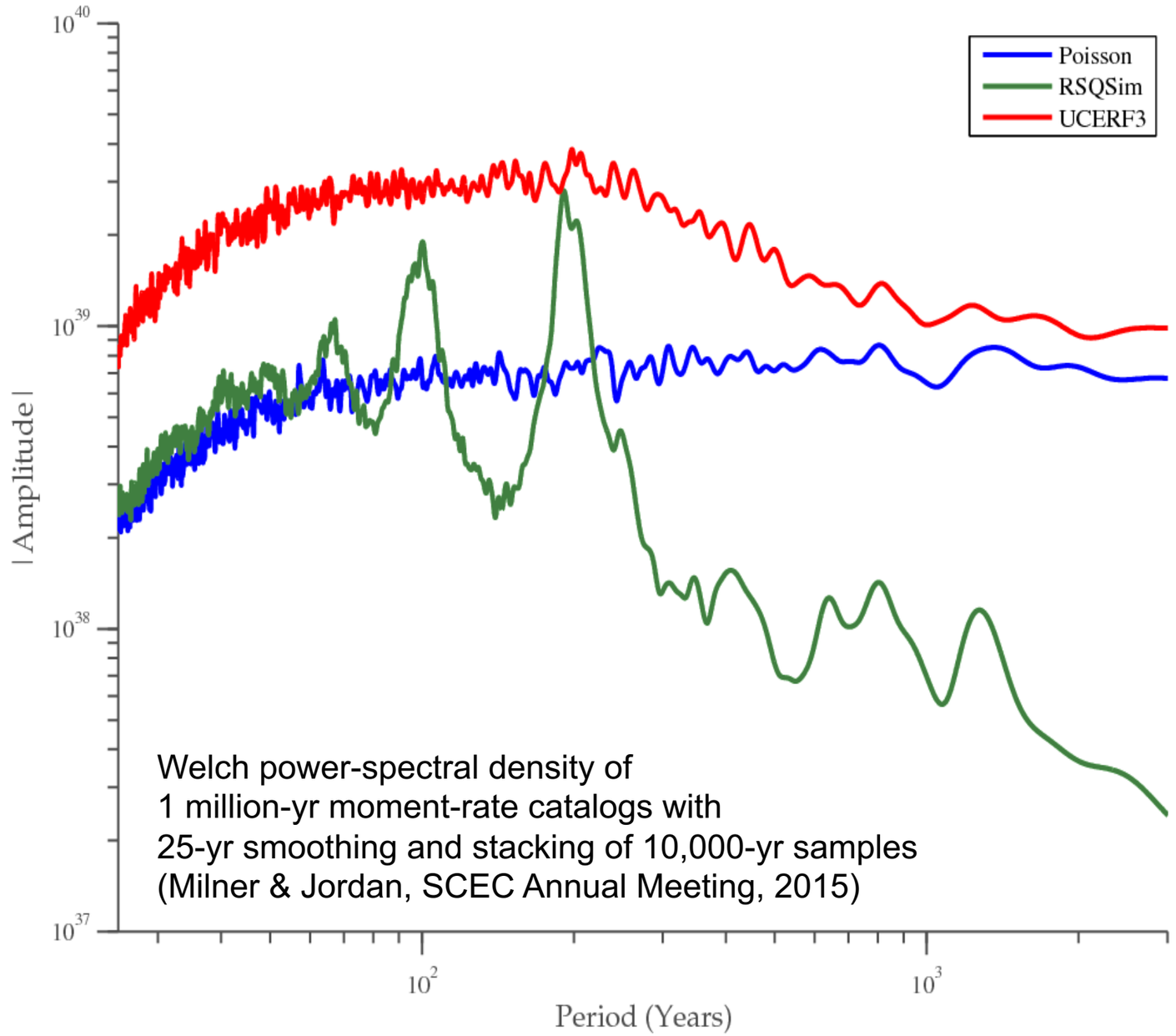
# *Synchronization Signature in RSQSim Sequences*