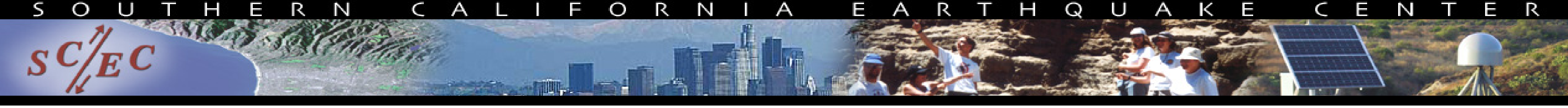


CyberShake

A Computational Platform for Physics-Based Seismic Hazard Analysis

SCEC CyberShake Collaboration:

Robert Graves (URS); Scott Callaghan, Thomas H. Jordan, Philip Maechling, Kevin Milner, Gideon Juve, David Okaya, Patrick Small (USC/SCEC); Ewa Deelman, Gaurang Mehta, Karan Vahi (USC/ISI); Edward Field (USGS)

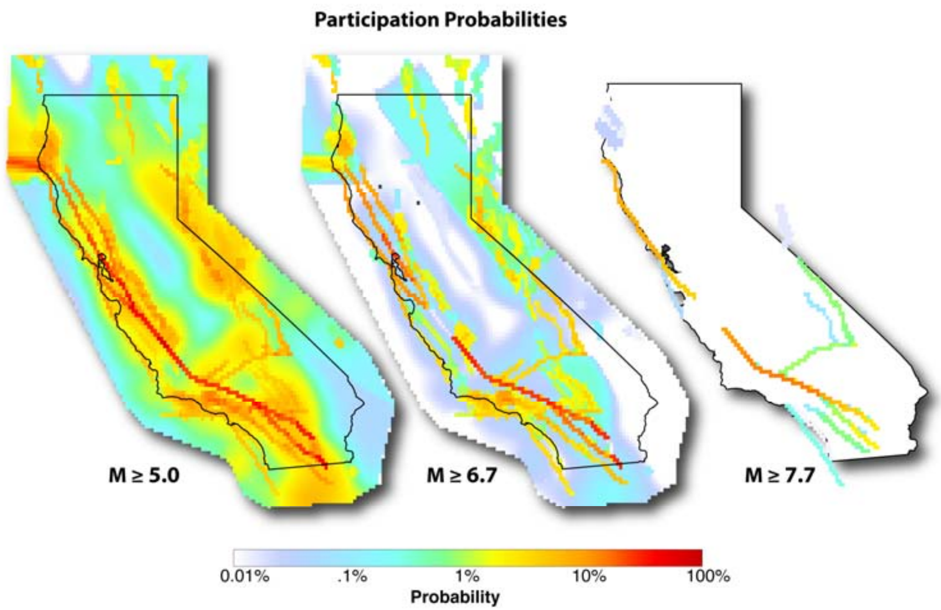
3rd SCEC-ERI Joint Workshop

March 15, 2010

CyberShake Goals

- **Improve long-term seismic hazard analysis by replacing empirical ground motion prediction equations (GMPEs) with physics-based simulations**
  - Account properly for rupture directivity and basin effects
  - Predict full time-histories of ground motion rather than simple intensity measures
- **Extend seismic hazard analysis to account for space-time variations in earthquake probability**
  - Provide a computational platform for “operational earthquake forecasting”

Long-Term Seismic Hazard Modeling



SCEC-USGS-CGS Working Group on California Earthquake Probabilities (2007)

Uniform California Earthquake Rupture Forecast (UCERF2)

Earthquake Rupture Forecast → **Attenuation Relationship** → **Intensity Measure**

$P(S_n)$ $P(IM_k \mid S_n)$ $P(IM_k)$

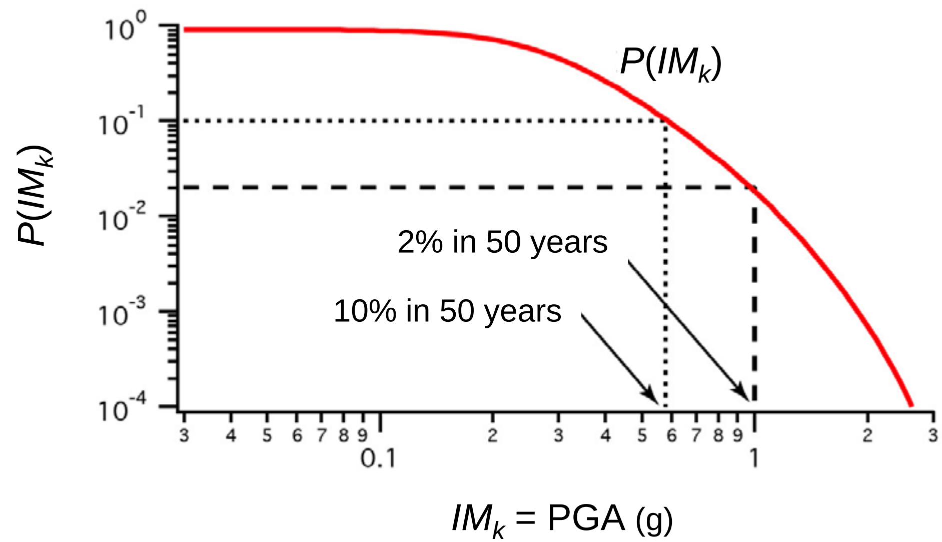
Probabilistic Seismic Hazard Analysis

Long-Term Seismic Hazard Modeling

Hazard Curve

$P(IM_k)$ = Probability of Exceedance in 50 years

IM_k = PGA (%g) in downtown LA



Earthquake Rupture Forecast → **Attenuation Relationship** → **Intensity Measure**

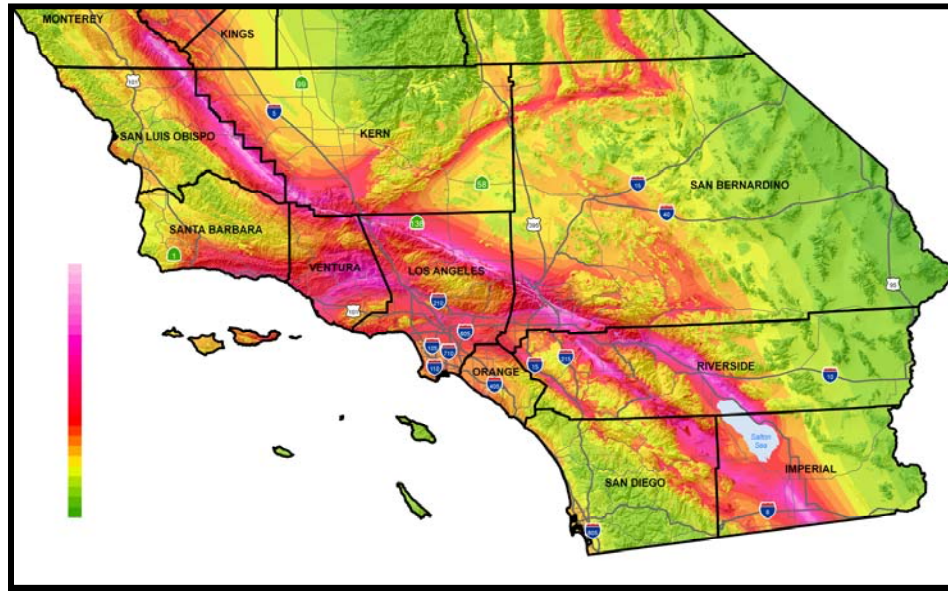
$P(S_n)$ $P(IM_k \mid S_n)$ $P(IM_k)$

Probabilistic Seismic Hazard Analysis

Long-Term Seismic Hazard Modeling

Hazard Map

PGA (%g) with 2% Probability of Exceedance in 50 years



Earthquake Rupture Forecast → **Attenuation Relationship** → **Intensity Measure**

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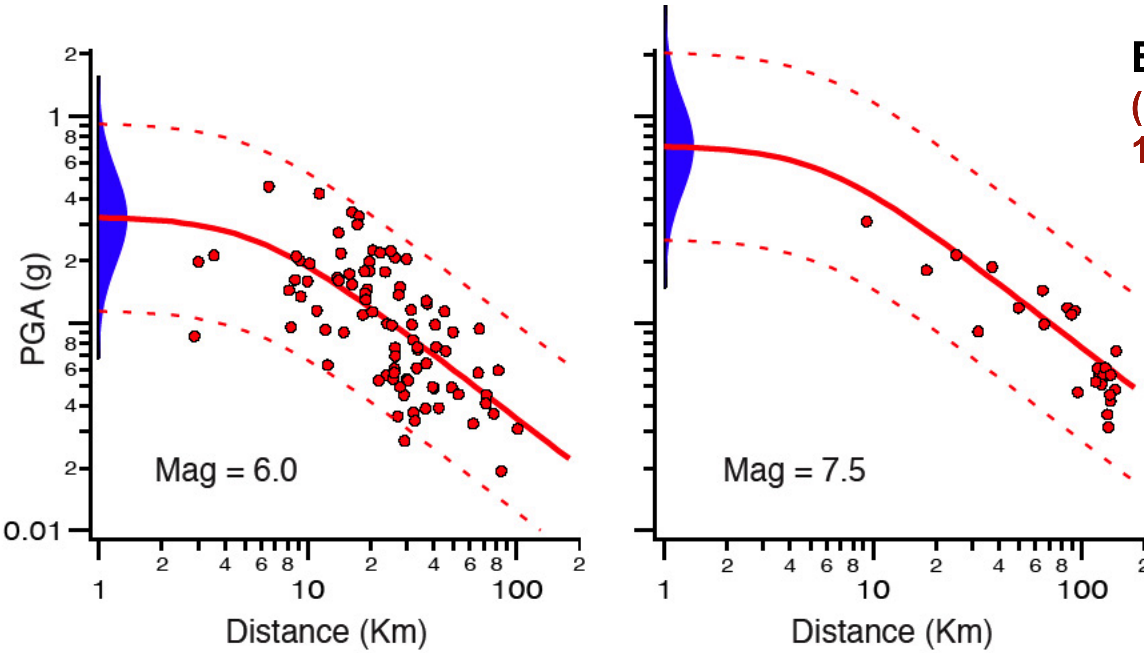
Long-Term Seismic Hazard Modeling



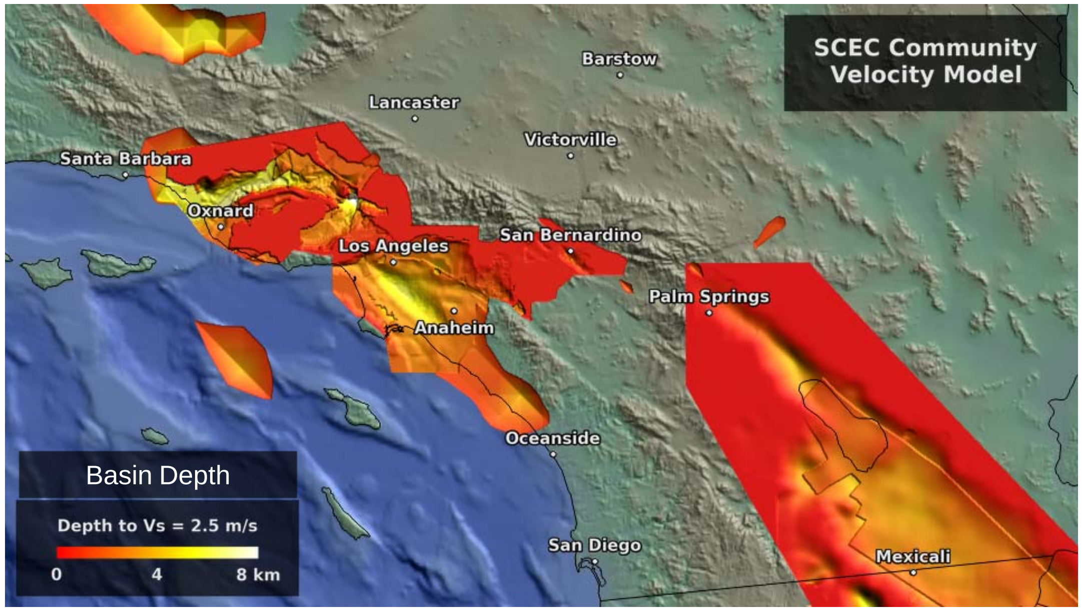
Empirical GMPEs
(Boore, Joyner & Fumal, 1997)

Earthquake Rupture Forecast → **Attenuation Relationship** → **Intensity Measure**

$P(S_n)$ $P(IM_k \mid S_n)$ $P(IM_k)$

Probabilistic Seismic Hazard Analysis

Long-Term Seismic Hazard Modeling

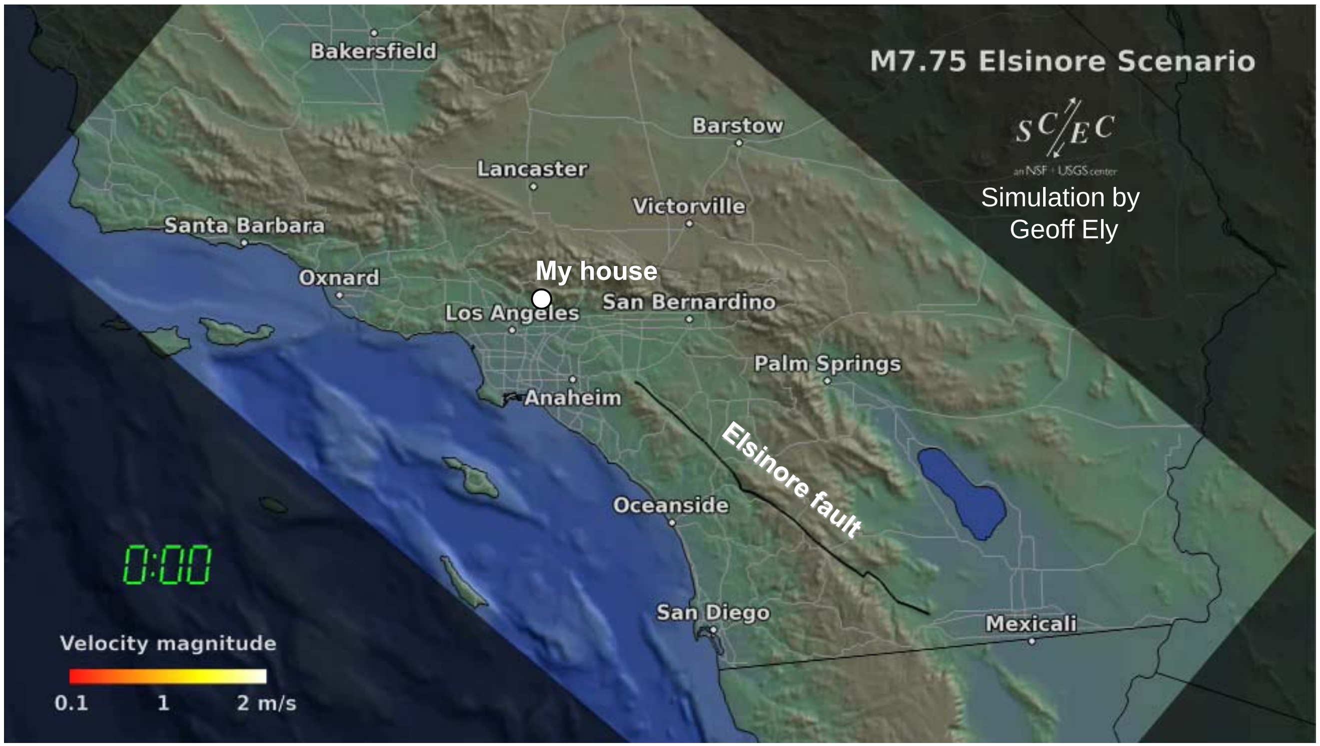


Earthquake Rupture Forecast → Attenuation Relationship → Intensity Measure

Phenomena poorly represented by empirical GMPEs:

- Source directivity
- Amplification of ground motions in sedimentary basins
- Small-scale variations caused by rupture-process complexity and 3D geologic structure

Long-Term Seismic Hazard Modeling



Earthquake Rupture Forecast → Attenuation Relationship → Intensity Measure

Phenomena poorly represented by empirical GMPEs:

- Source directivity
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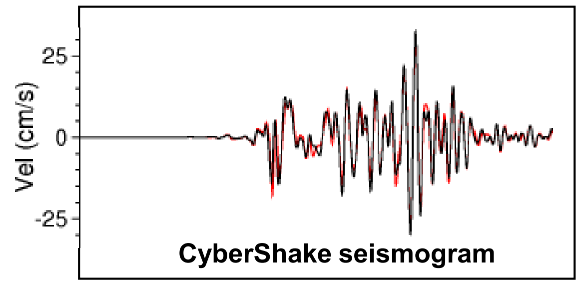
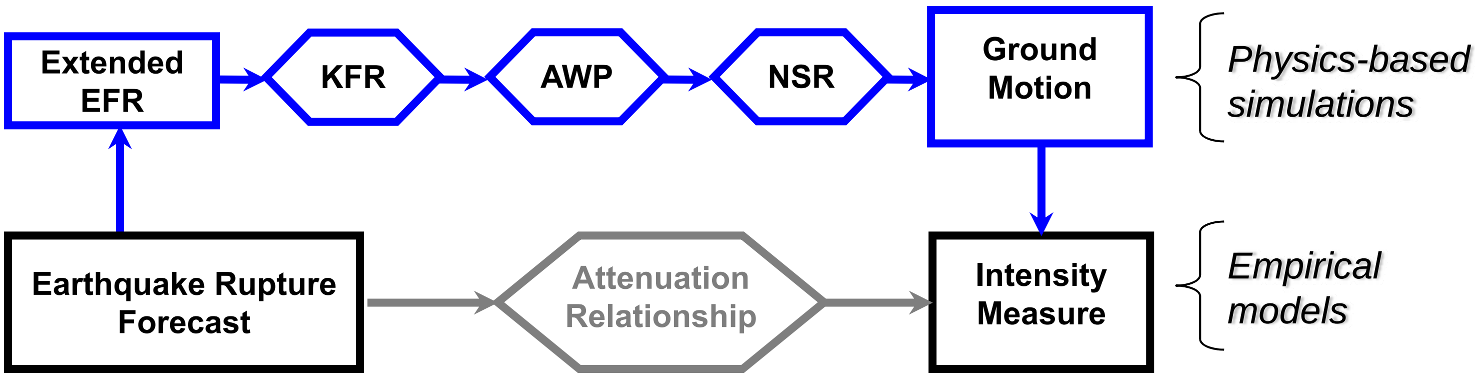
- Small-scale variations caused by rupture-process complexity and 3D geologic structure

Physics-Based PSHA: CyberShake Platform

- **Uses an *extended* earthquake rupture forecast**
  - Source area probabilities
  - Hypocenter distributions (conditional)
  - Slip variations (conditional)
- **Calculates *seismograms***
  - Psuedo-dynamic fault rupture
  - 3D anelastic model of wave propagation
  - Nonlinear site response (not yet implemented)

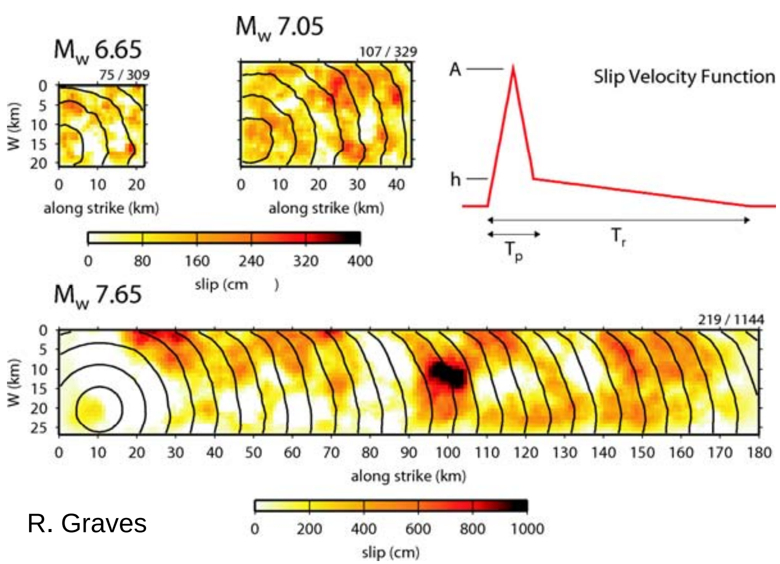




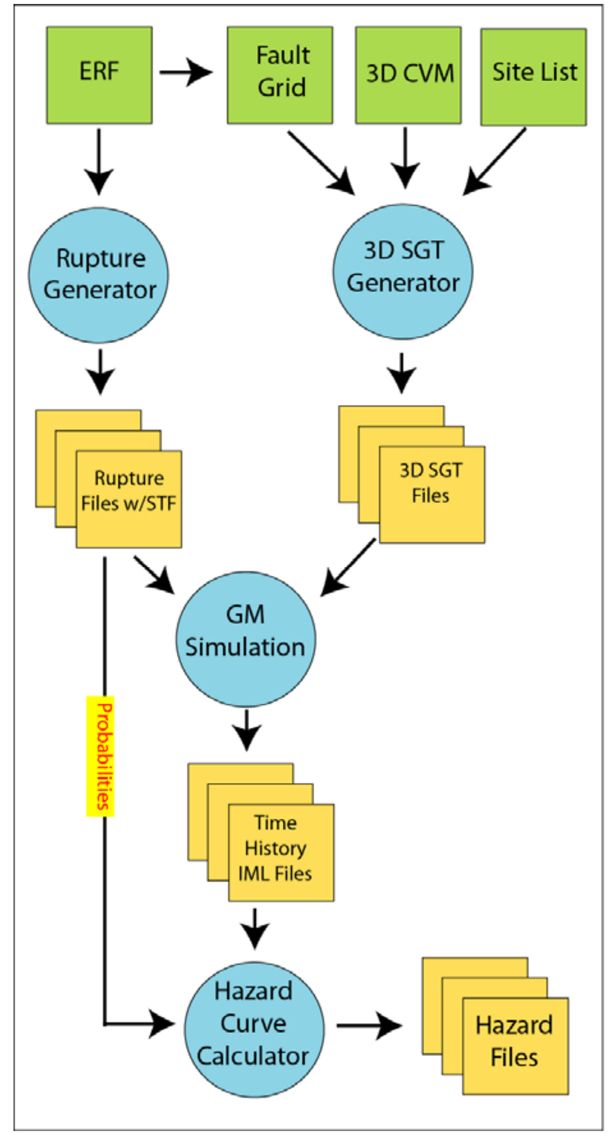
KFR = kinematic fault rupture model
AWP = anelastic wave propagation model
NSR = nonlinear site response

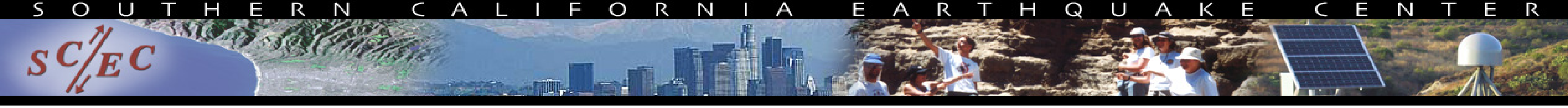
Physics-Based PSHA: CyberShake Platform

- **CyberShake 1.0 workflow**
  - **Extended earthquake rupture forecast (ERF)**
    - **uniform hypocenter distribution**
  - **Rupture generator**
    - **stochastic slip distribution**
  - **Strain Green tensor (STG) generator**
    - **site-based, using reciprocity**
  - **Ground motion simulation**
  - **Hazard curve calculator**



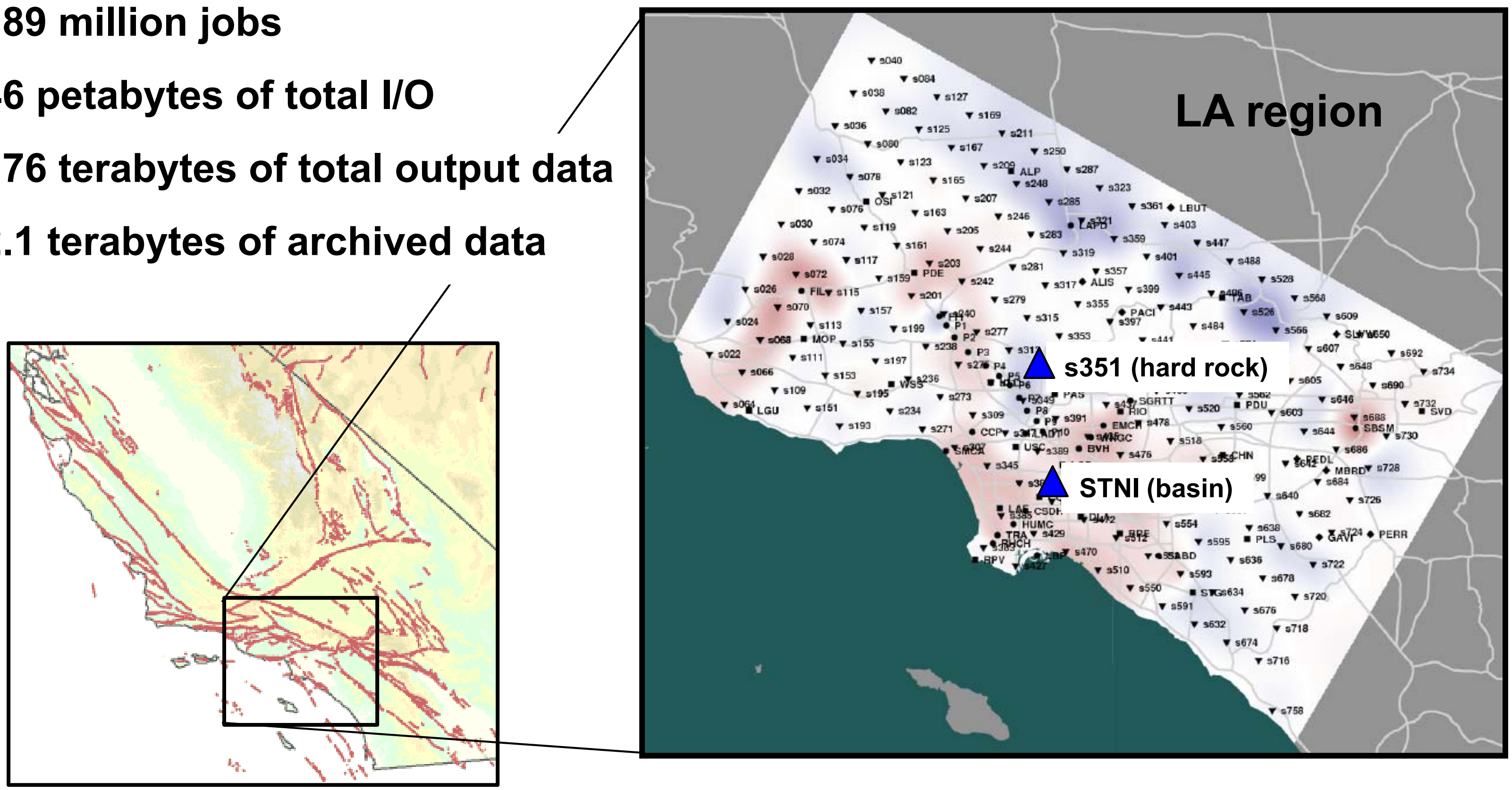
R. Graves





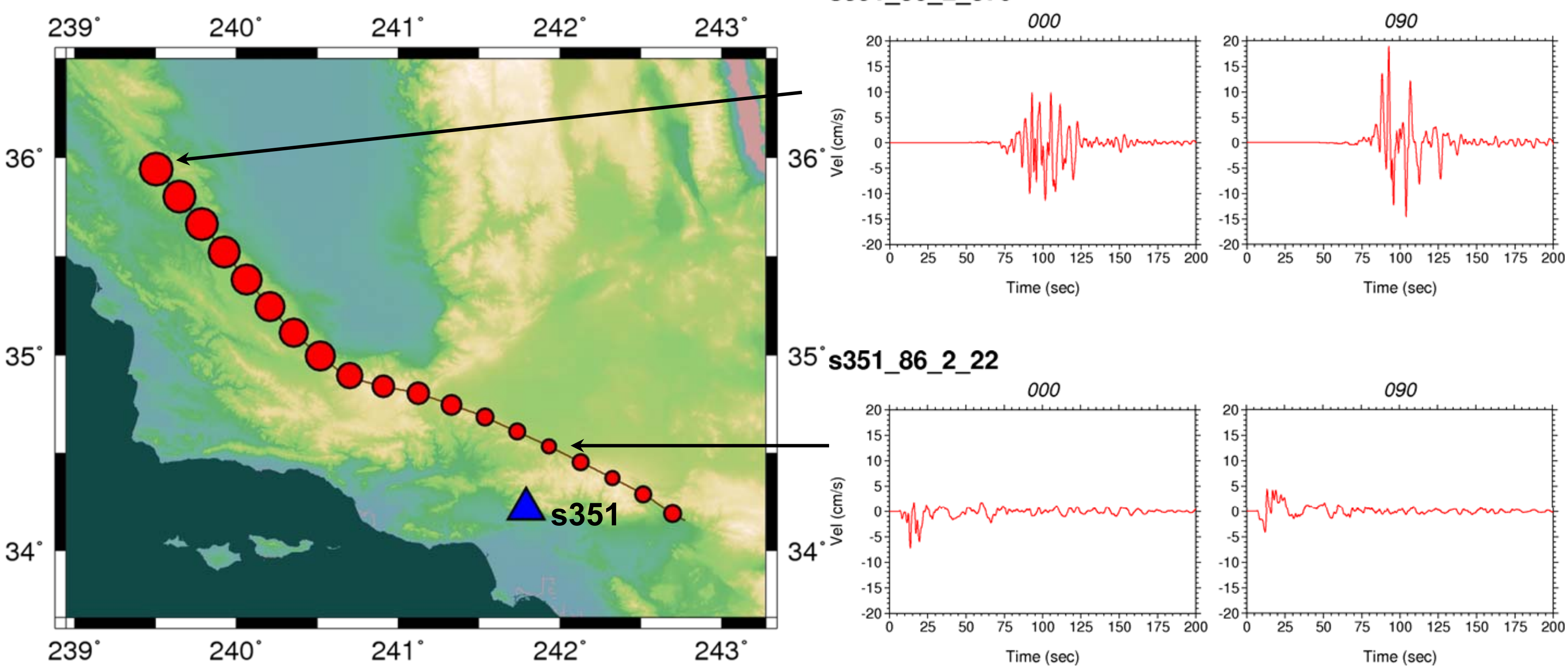
Physics-Based PSHA: CyberShake Platform

- **CyberShake 1.0 model: 225 sites in LA region, f < 0.5 Hz (low frequency)**
  - **440,000 simulations per site**
  - **50-day run on *Ranger* (5.3 million hrs, 4,400 cores)**
  - **189 million jobs**
  - **46 petabytes of total I/O**
  - **176 terabytes of total output data**
  - **2.1 terabytes of archived data**



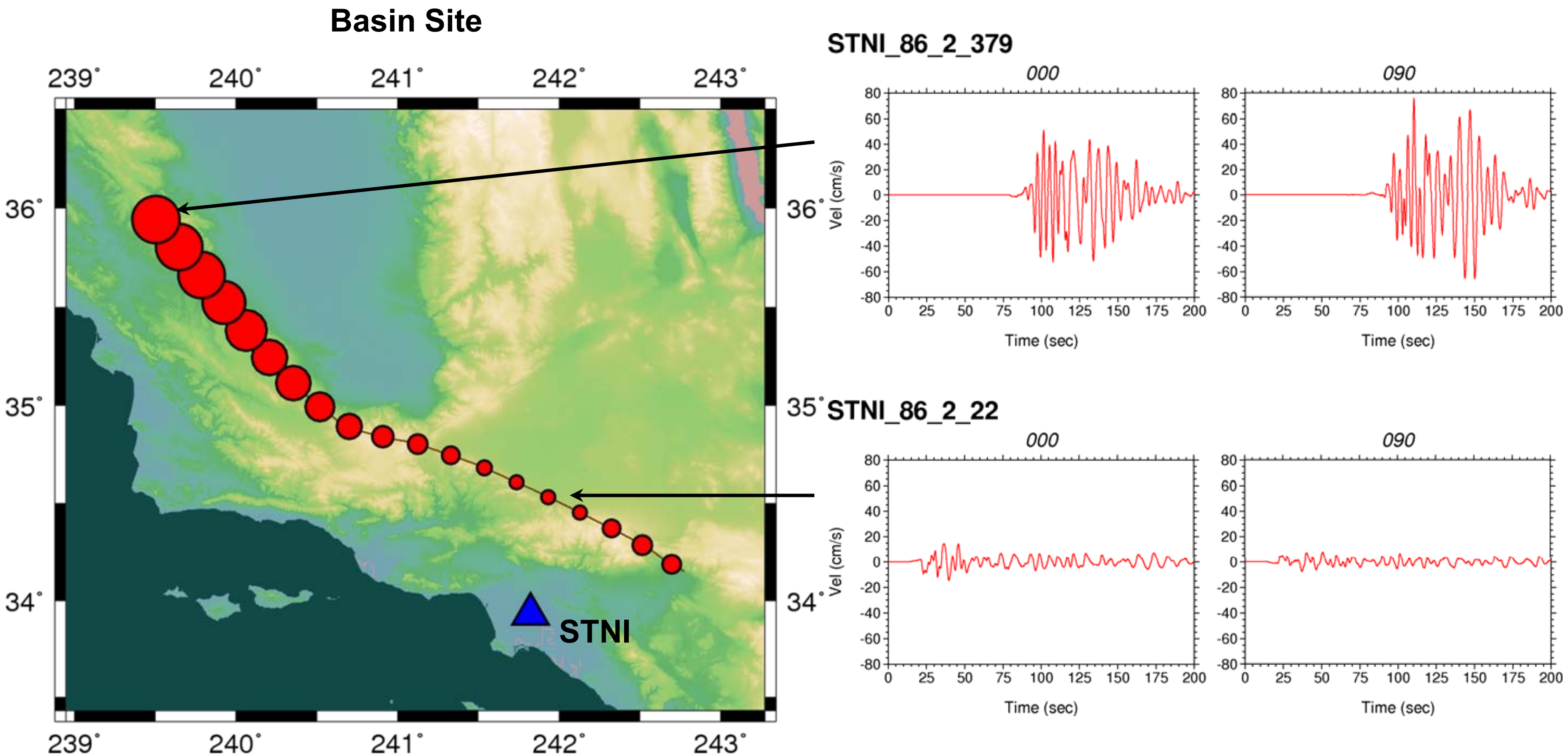
M_w7.85 rupture on San Andreas fault

Hard Rock Site



Red circles are epicenters of the rupture variations. Sizes represents the 3s SA at the station averaged over all 38 rupture variations for each epicenter.

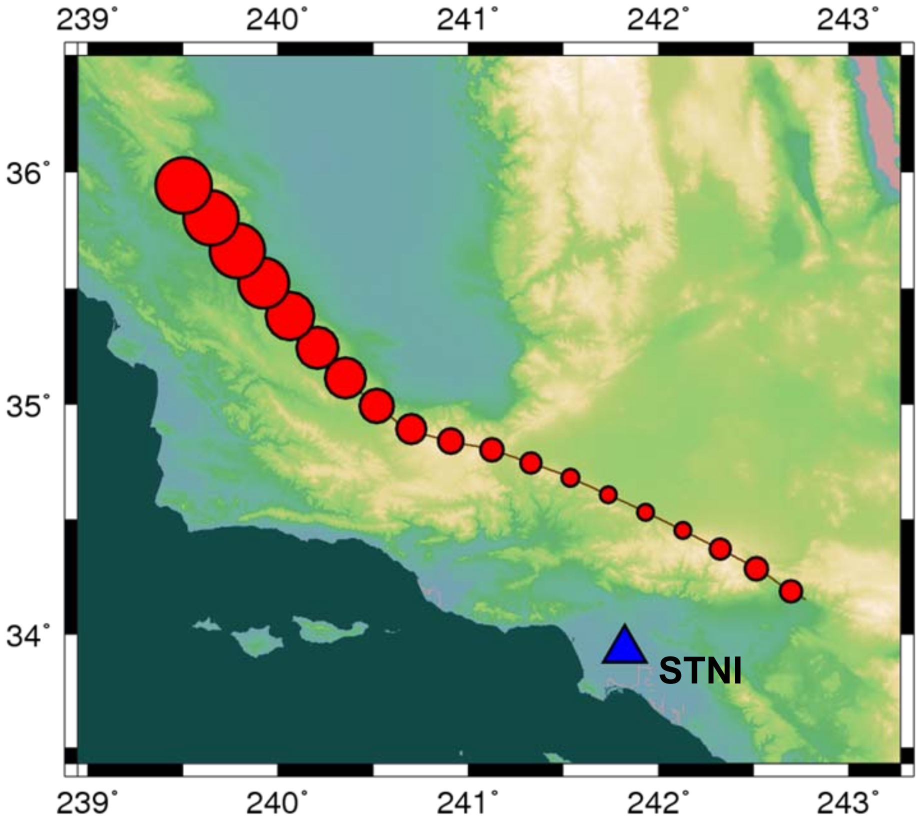
M_w7.85 rupture on San Andreas fault



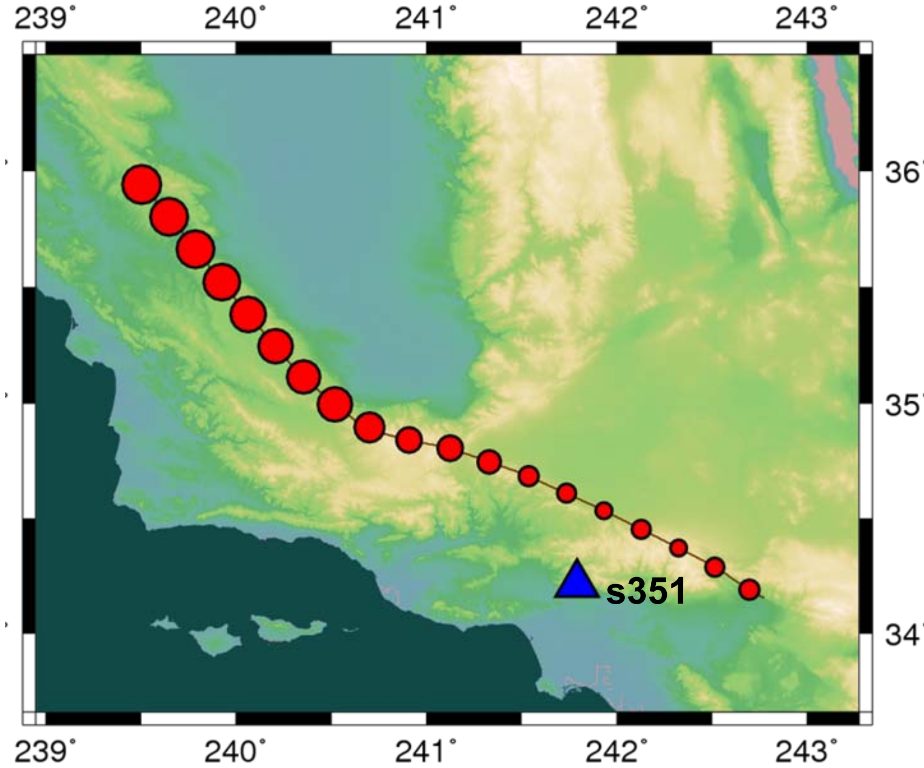
Red circles are epicenters of the rupture variations. Sizes represents the 3s SA at the station averaged over all 38 rupture variations for each epicenter.

M_w7.85 rupture on San Andreas fault

Basin Site



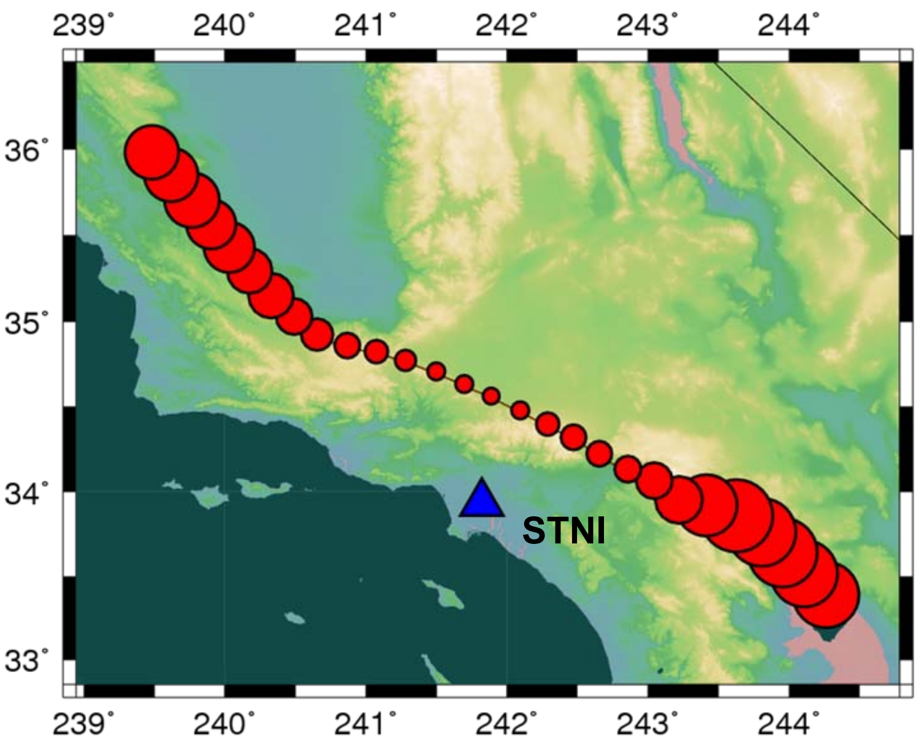
Hard Rock Site



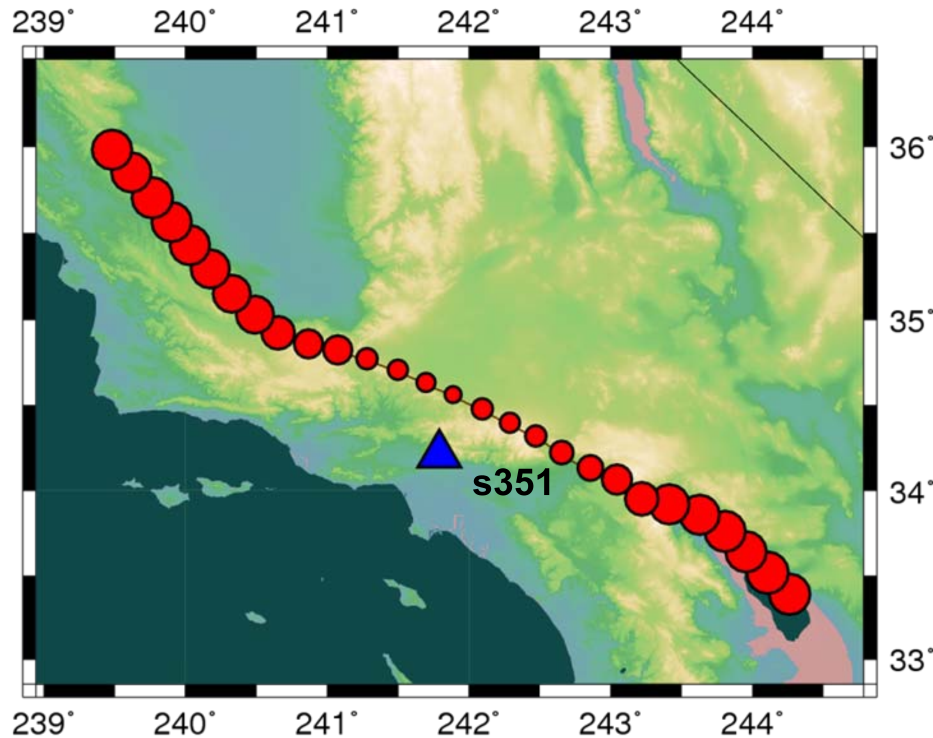
Conclusion: Rupture directivity couples into basin excitation.

M_w8.15 “wall-to-wall” rupture on San Andreas fault

Basin Site



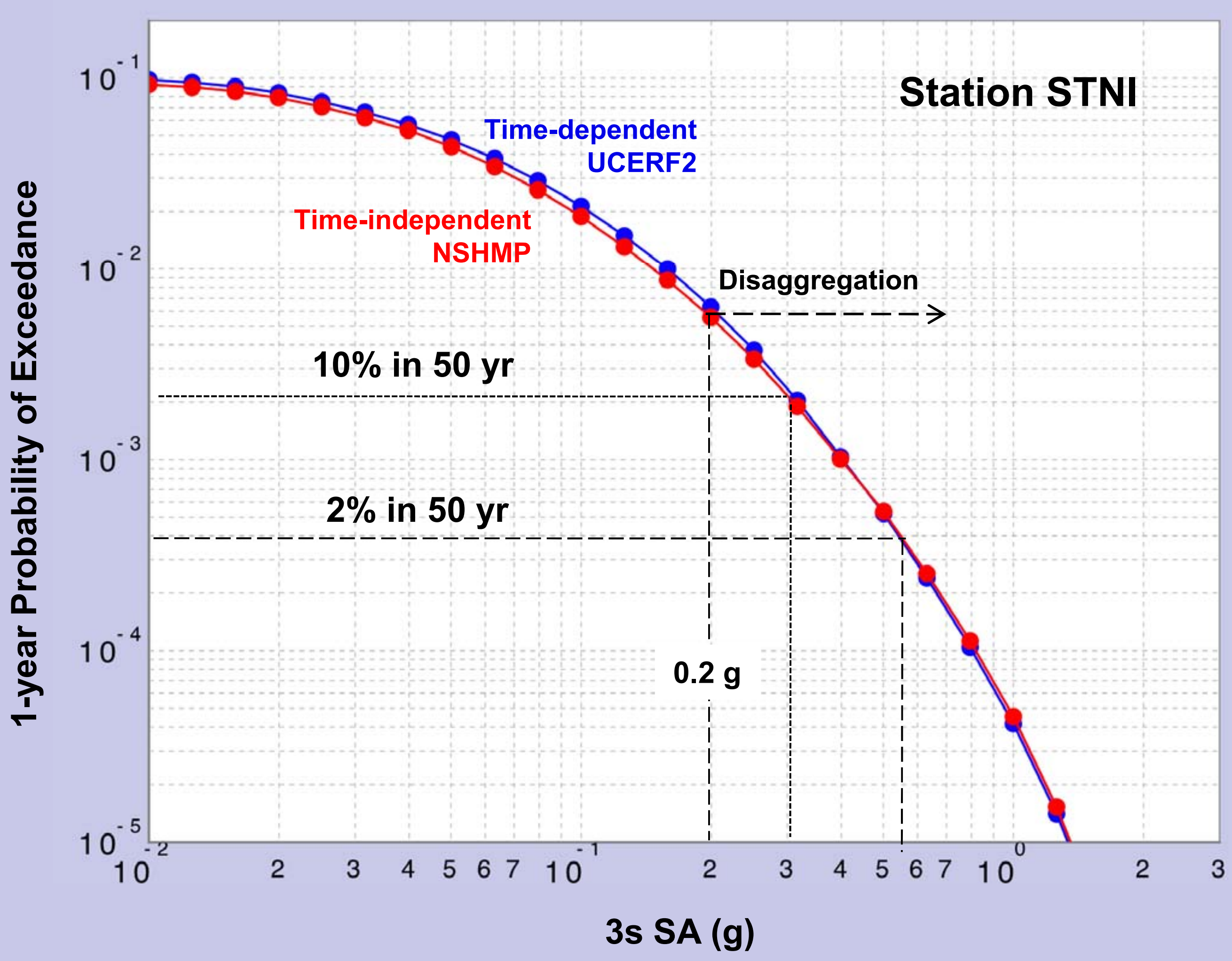
Hard Rock Site



Conclusion: Rupture directivity couples into basin excitation.

M_w8.15 “wall-to-wall” rupture on San Andreas fault

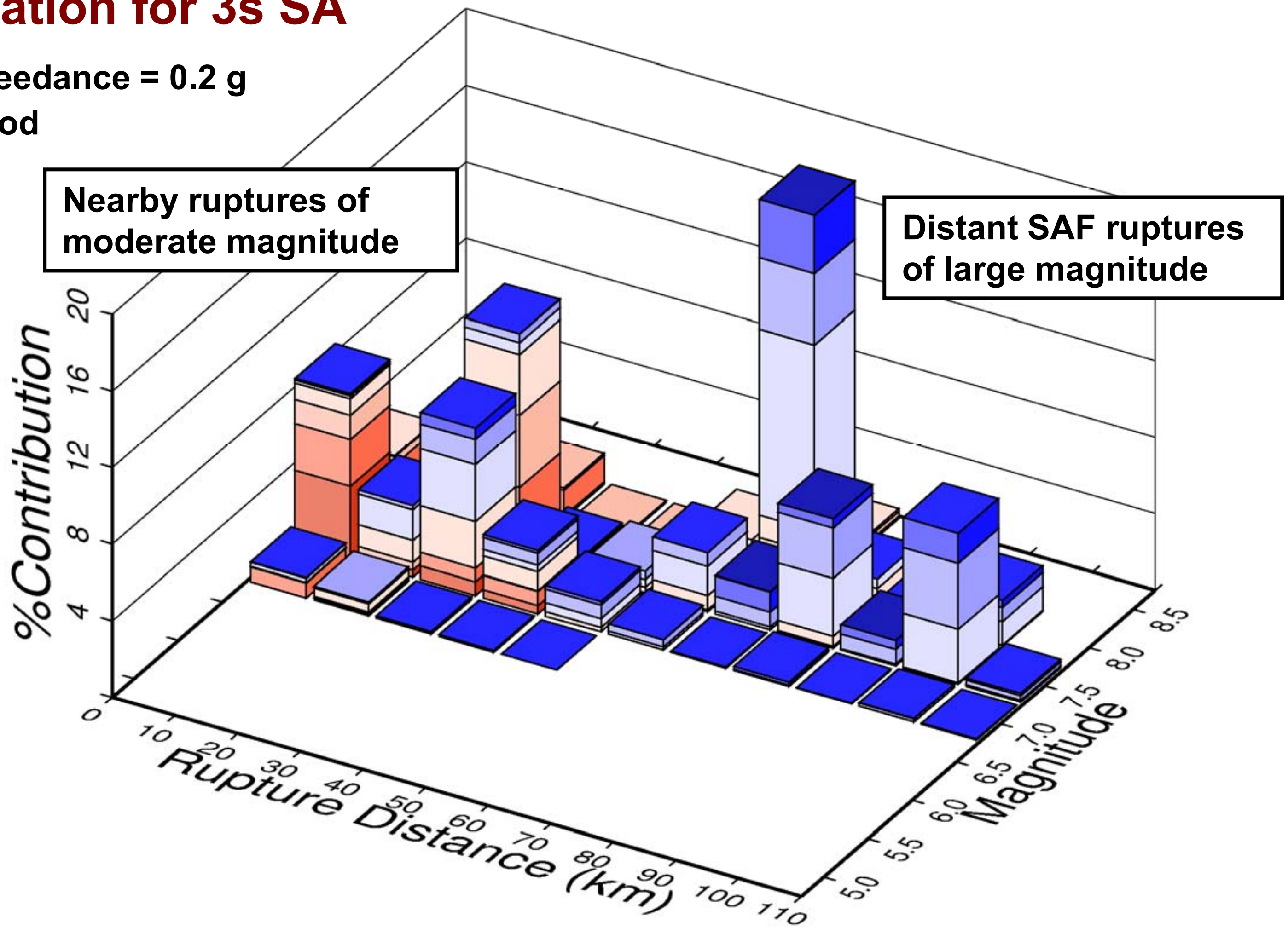
CyberShake Hazard Curves



CyberShake Hazard Dissaggregation

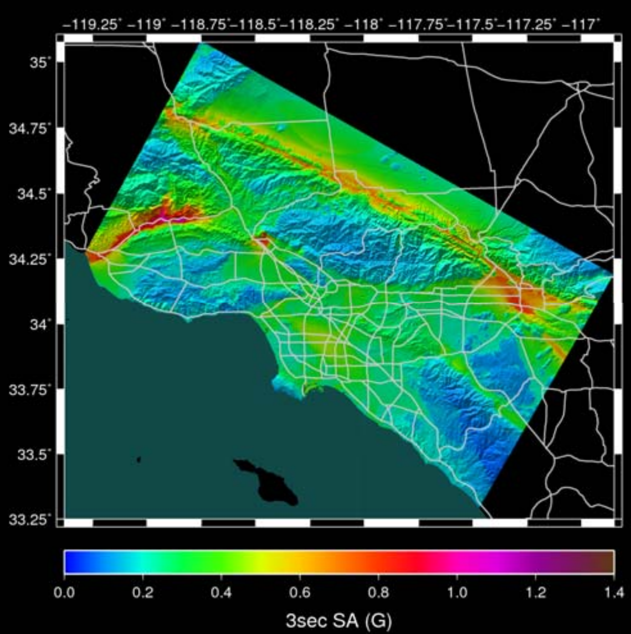
STNI Disaggregation for 3s SA

- Ground motion exceedance = 0.2 g
- 180 year return period



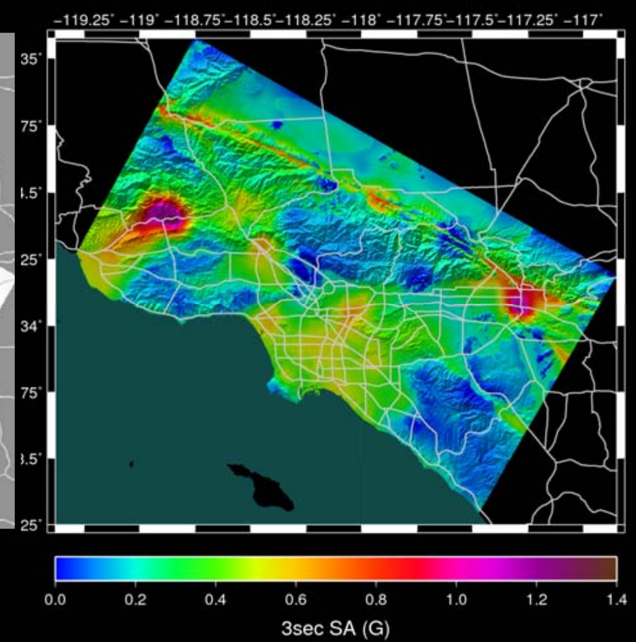
CyberShake Hazard Map Interpolation

Campbell & Borzognia (2008) GMPE with CGS soil map



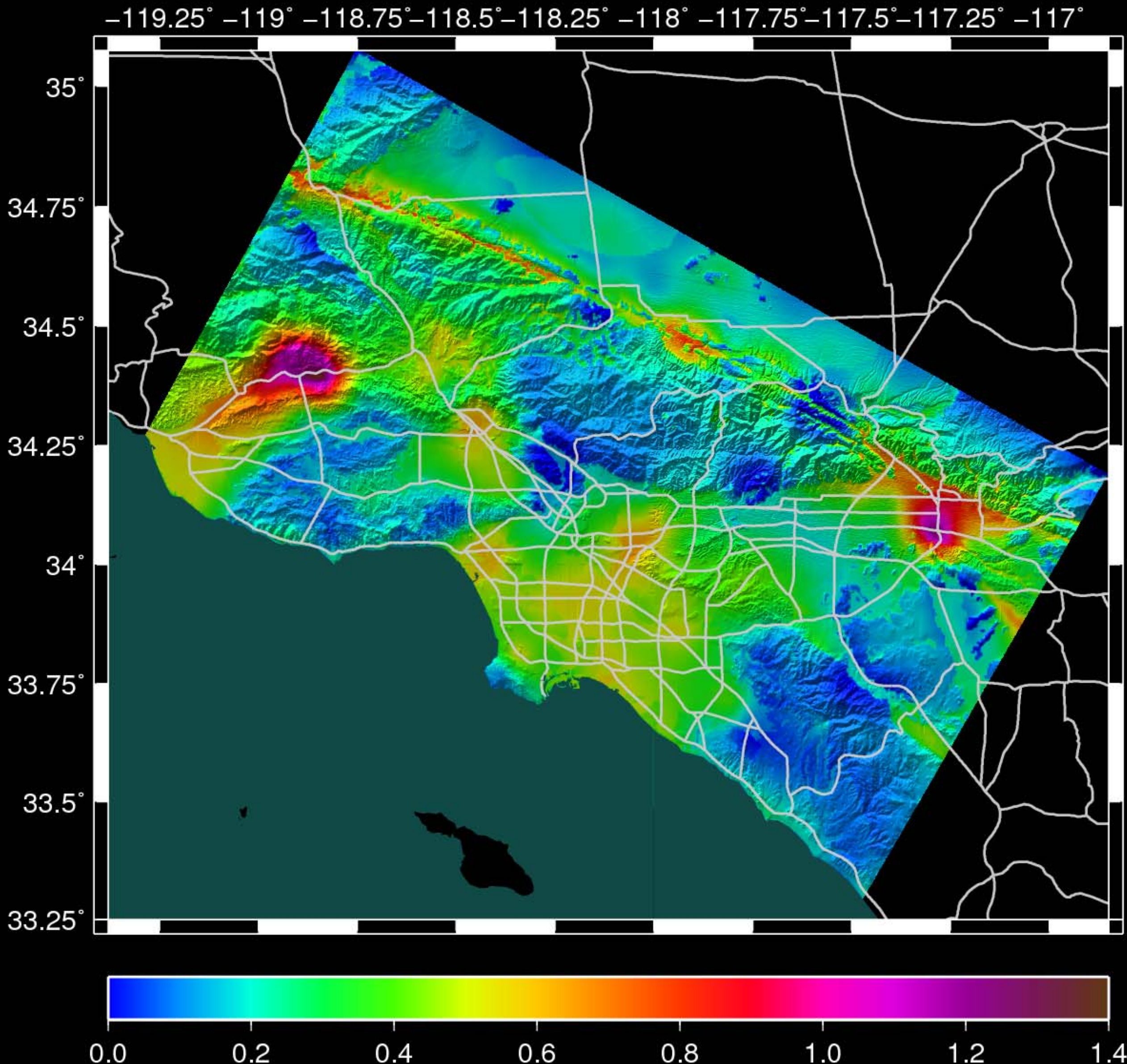
CyberShake (2009) differences

CyberShake (2009) map



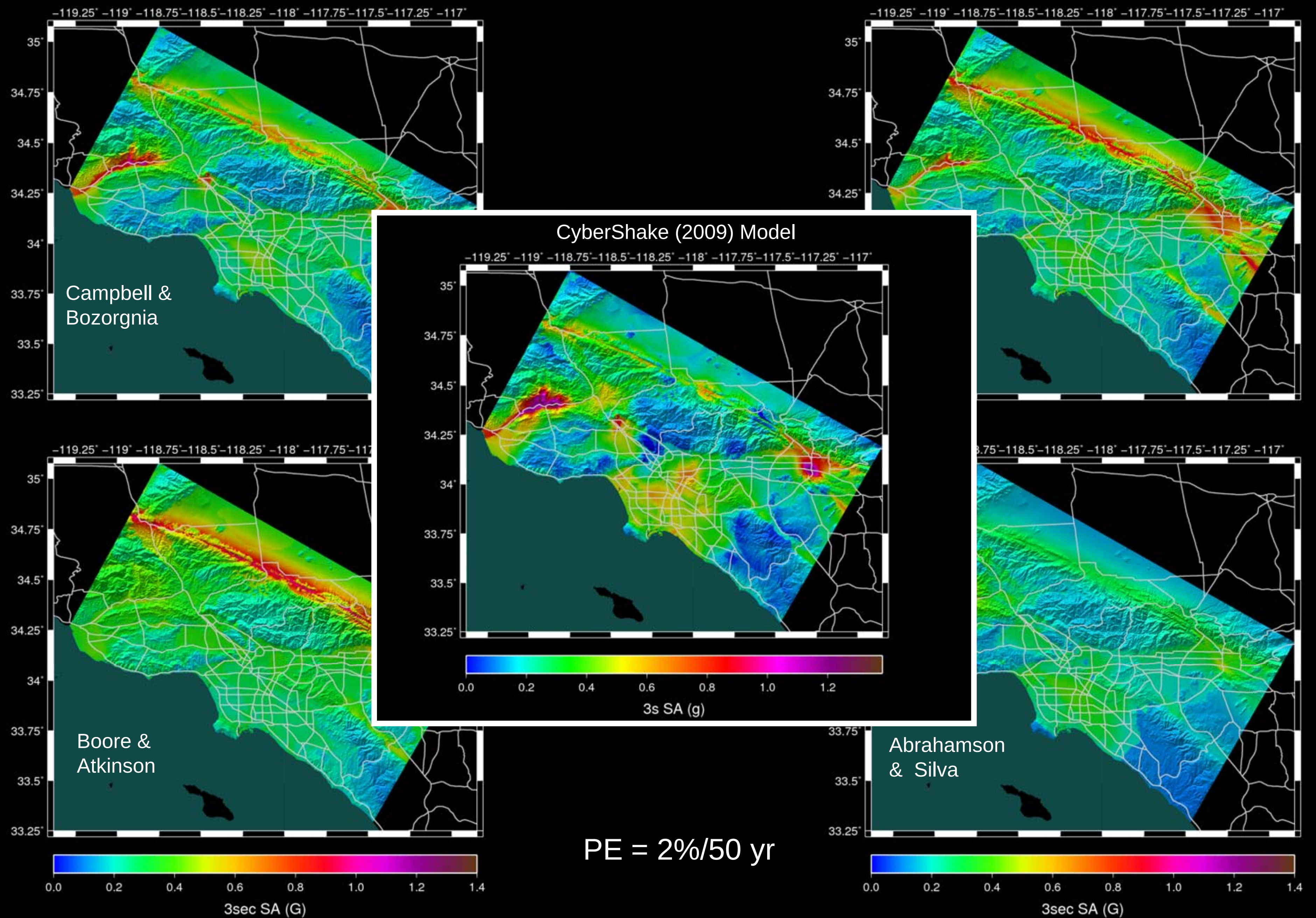
3-s Spectral Acceleration (in g) at 2%/50 yr Probability of Exceedance

CyberShake (2009) Model



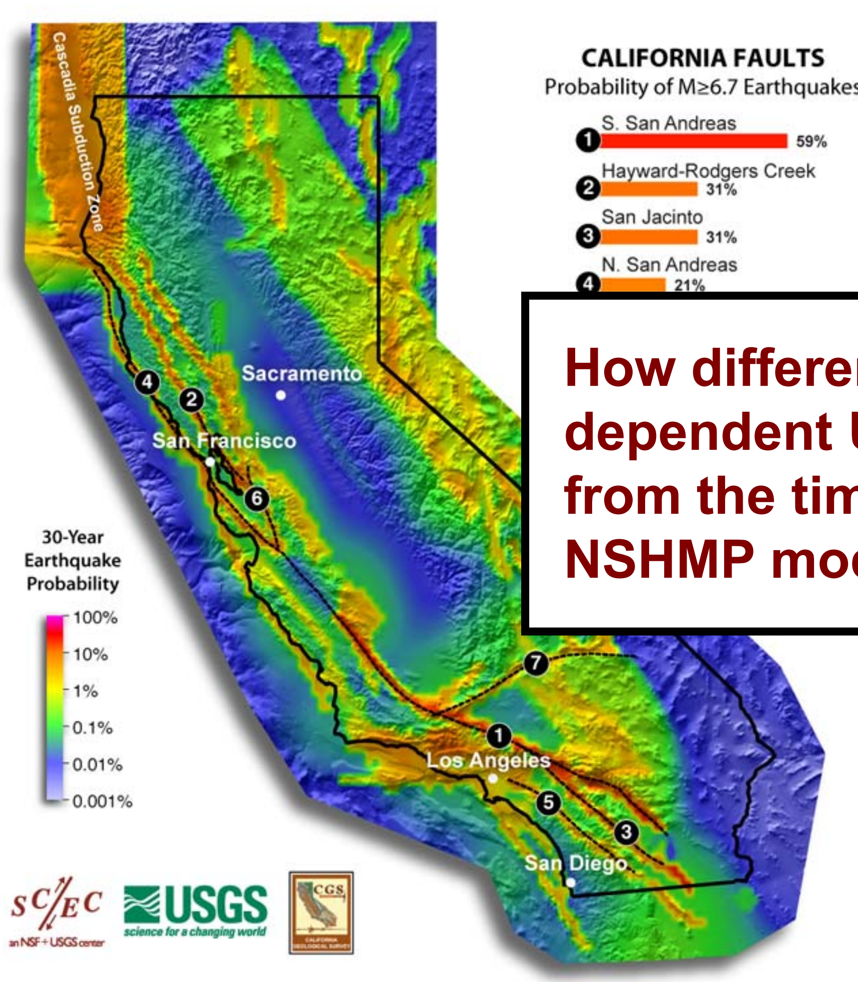
3-s Spectral Acceleration (in g) at 2%/50 yr Probability of Exceedance

NGA (2008) GMPEs

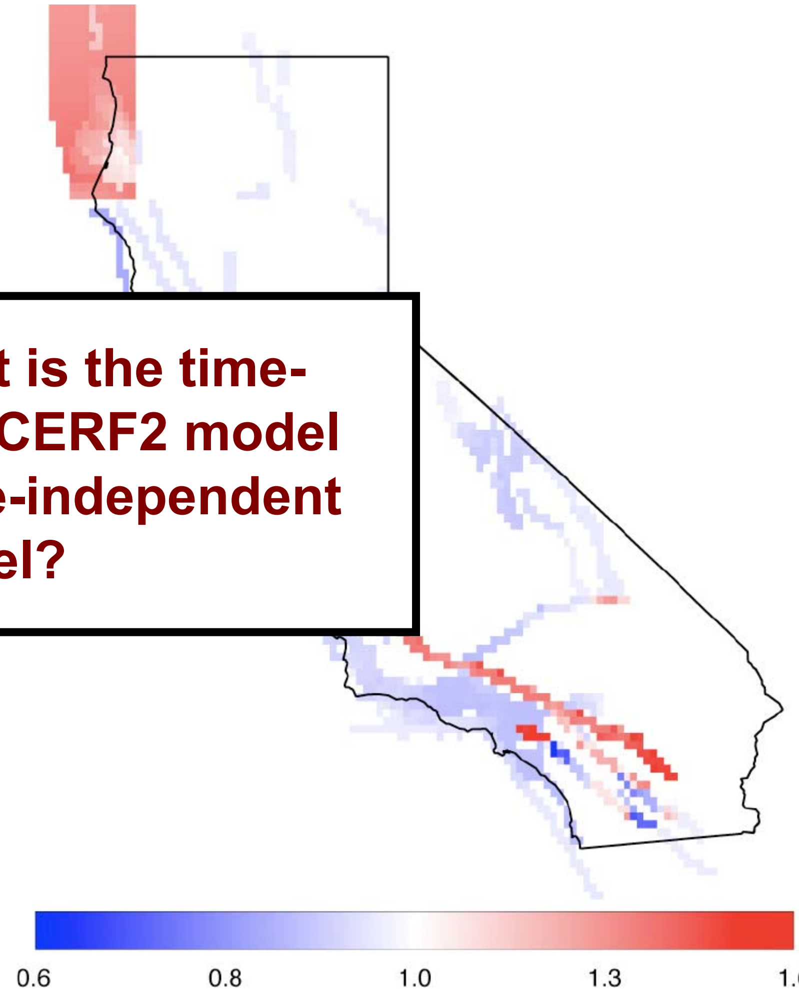


Working Group on California Earthquake Probabilities (2007)

Uniform California Earthquake Rupture Forecast (UCERF2)

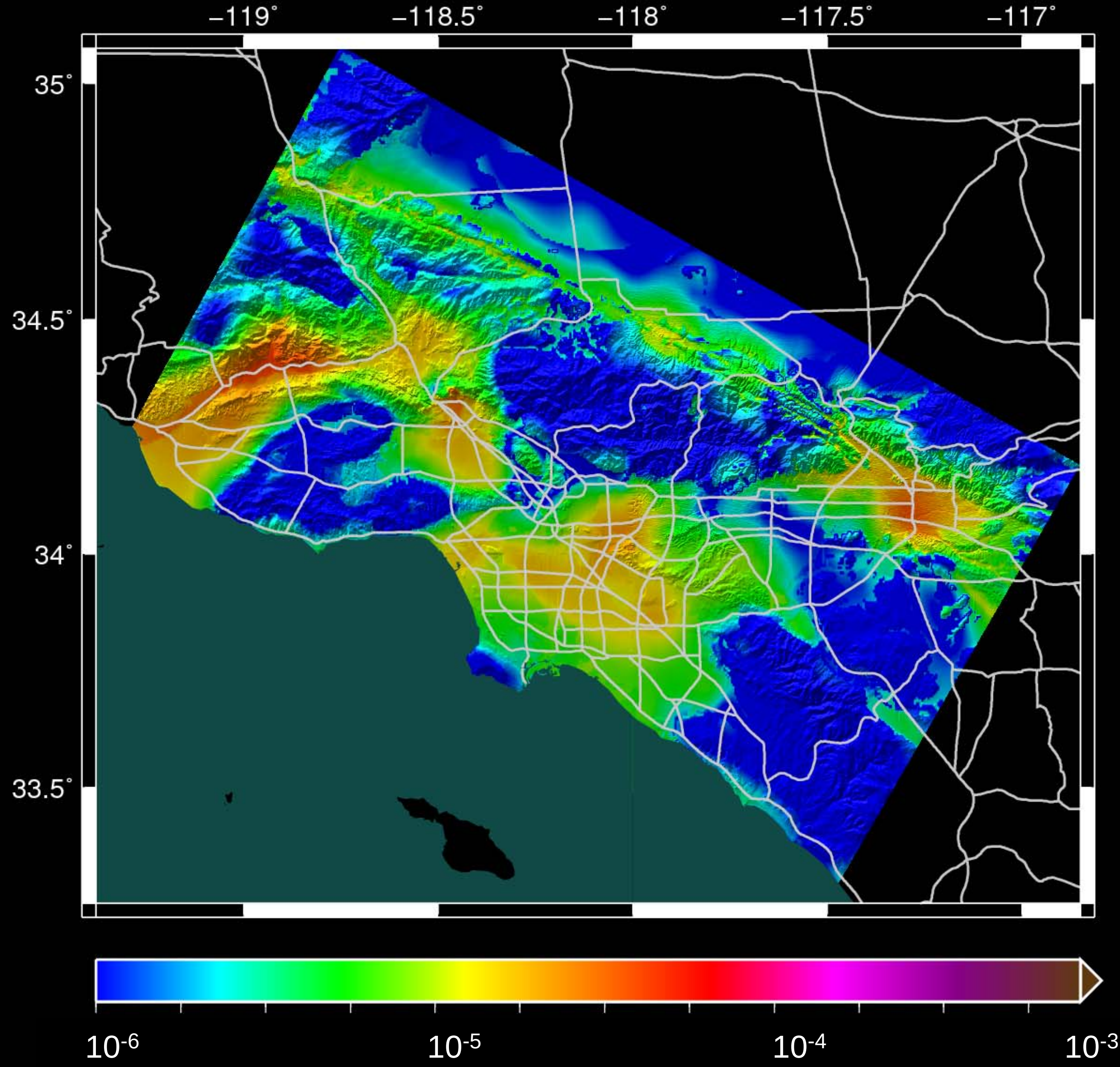


How different is the time-dependent UCERF2 model from the time-independent NSHMP model?



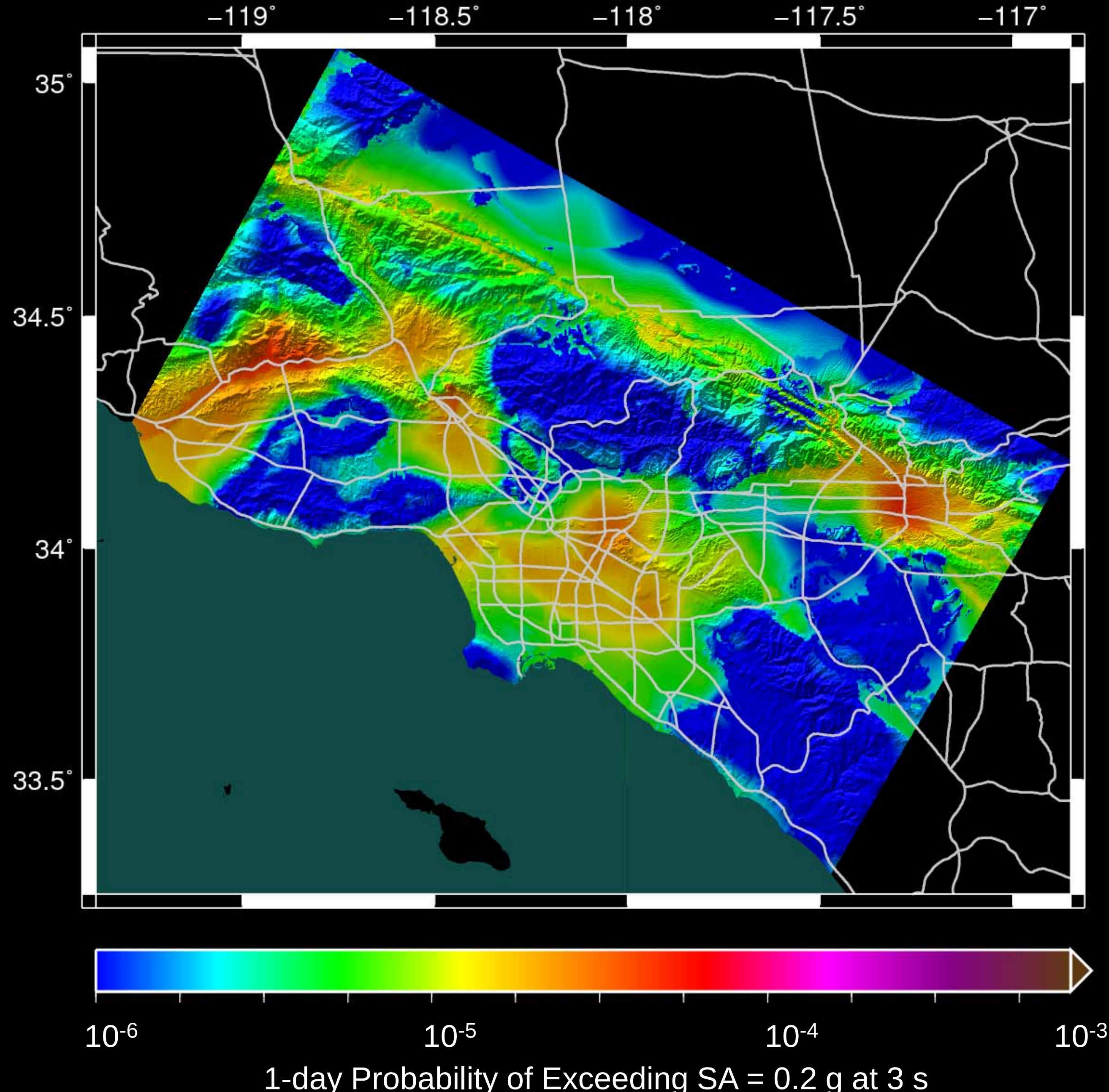
Ratio of time-dependent to time-independent participation probabilities for M ≥ 6.7

CyberShake (2009) NSHMP Time-Independent Model

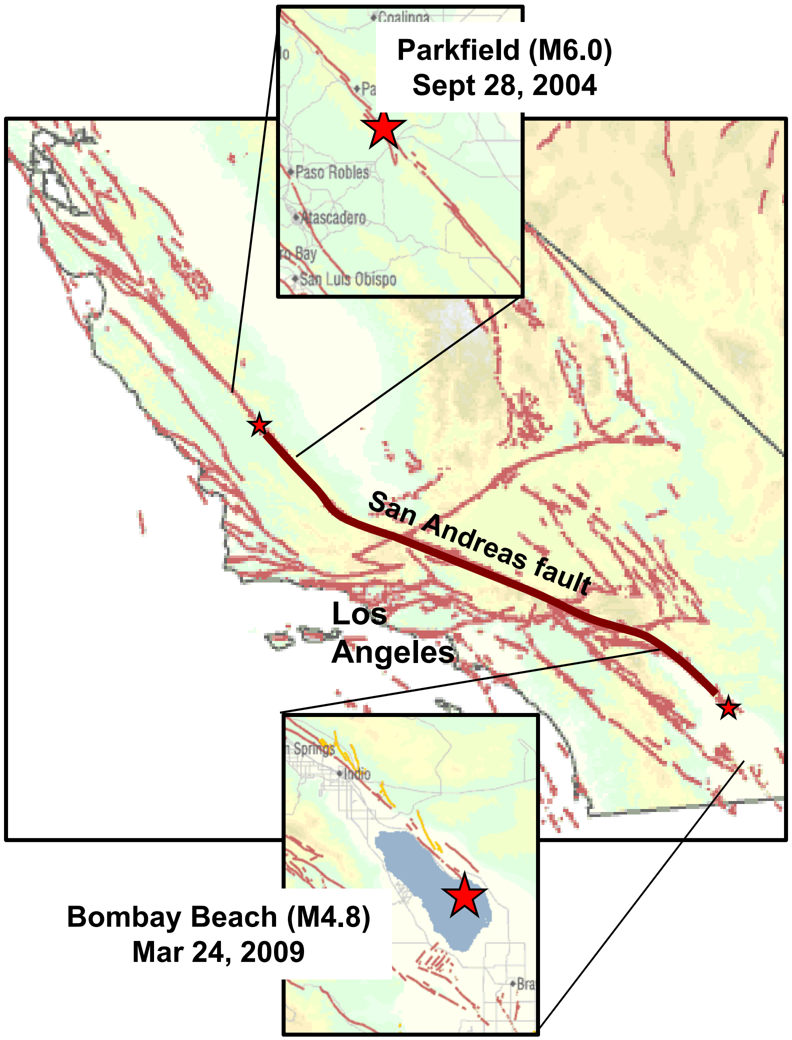


1-day Probability of Exceeding SA = 0.2 g at 3 s

CyberShake (2009) UCERF2 Time-Dependent Model



CyberShake as a Platform for Short-Term Earthquake Forecasting



- **Compute probability gain associated with recent seismic activity**

  Example: Agnew-Jones model

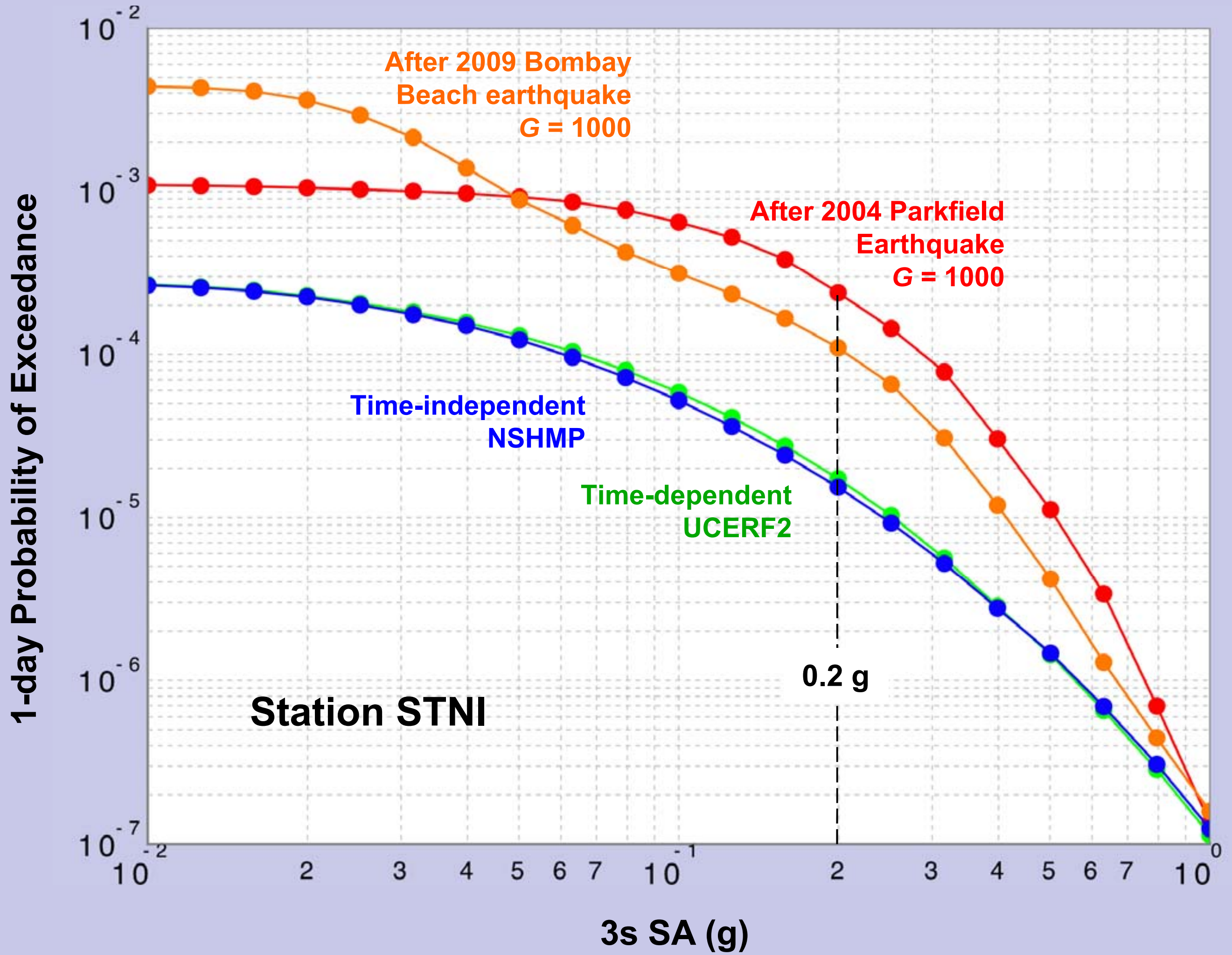
- **Apply probability gains to CyberShake ruptures with hypocenters near recent events**

  Example: G = 1000 for $R \leq 10$ km

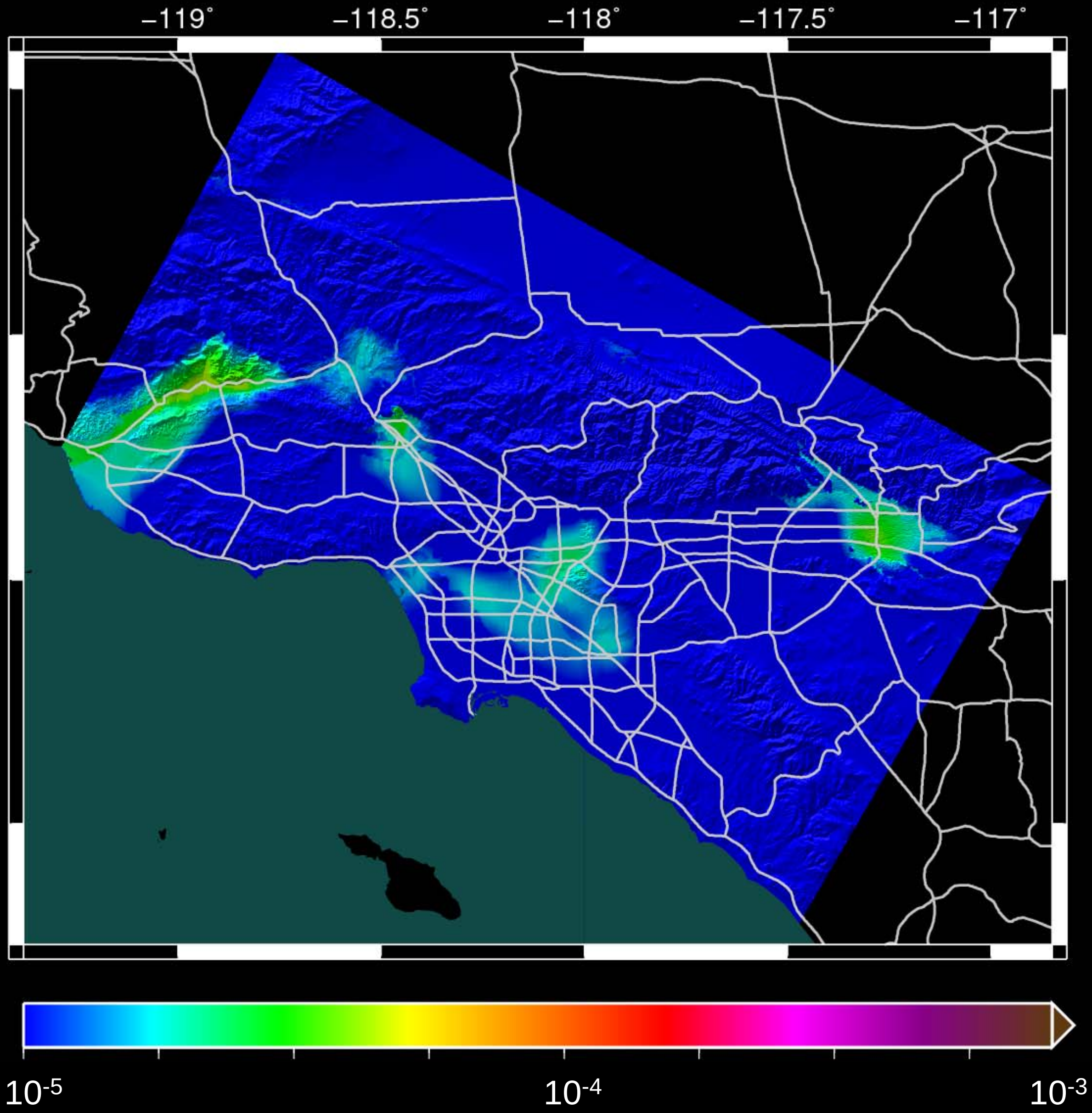
- **Re-compute CyberShake ground motion probabilities for short interval following events**

  Example: 1-day probabilities

CyberShake Time-Dependent Hazard Curves

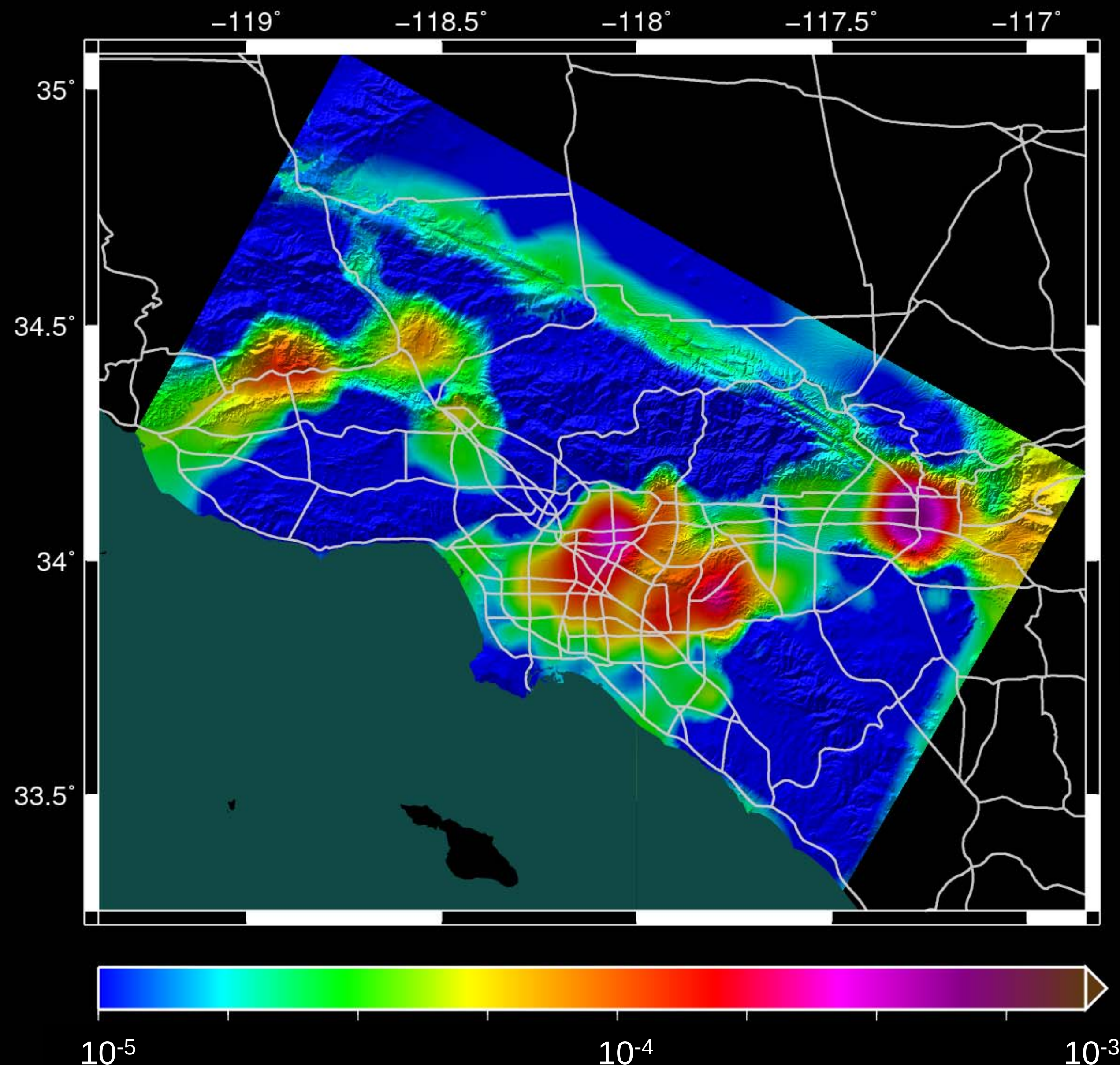


CyberShake (2009) Model – NSHMP Background



1-day Probability of Exceeding SA = 0.2 g at 3 s

CyberShake (2009) Model – After 2009 Bombay Beach

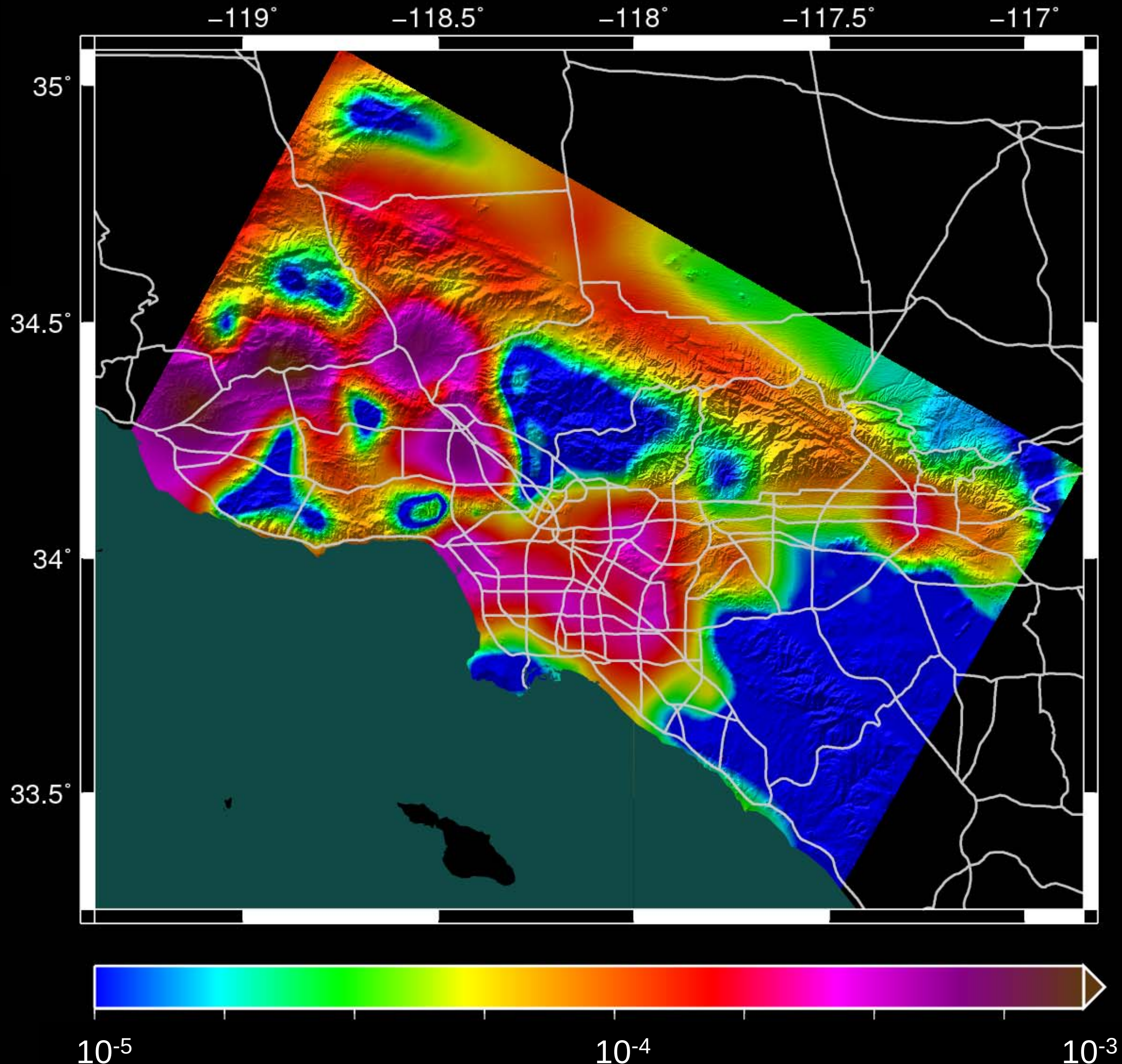


1-day Probability of Exceeding SA = 0.2 g at 3 s

Bombay Beach (M4.8)
Mar 24, 2009
***G* = 1000**

CyberShake (2009) Model – After 2004 Parkfield

Parkfield (M6.0)
Sept 28, 2004
***G* = 1000**



1-day Probability of Exceeding SA = 0.2 g at 3 s

Current Research Objectives

- **Reconcile magnitude-area relationships**
  - GMPEs are insensitive to changes in rupture area for same magnitude, but long-period simulations scale directly with average slip
- **Improve pseudo-dynamic rupture model**
  - Dynamic rupture simulations show less coherence than kinematic simulations
- **Improve velocity models**
  - Near-surface velocities are too high in hard-rock regions
- **Test CyberShake ground motion predictions with available data**
  - Ground motions recorded from small earthquakes
  - Constraints from precarious rocks
- **Extend CyberShake to higher frequencies and greater areas**
  - Two-year objective: 1-Hz model for all of California
- **Develop a CyberShake model that can assimilate information during earthquake cascades**
  - Operational earthquake forecasting
  - Earthquake early warning

End