An Active Approach to Predicting Earthquake Shaking with Passive Seismology

Greg Beroza

Co-Director, Southern California Earthquake Center
Professor, Stanford University, USA

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SCEC Mission Statement

***Gather data* on earthquakes in southern California, and elsewhere**

***Integrate information* into a comprehensive physics-based understanding of earthquake phenomena**

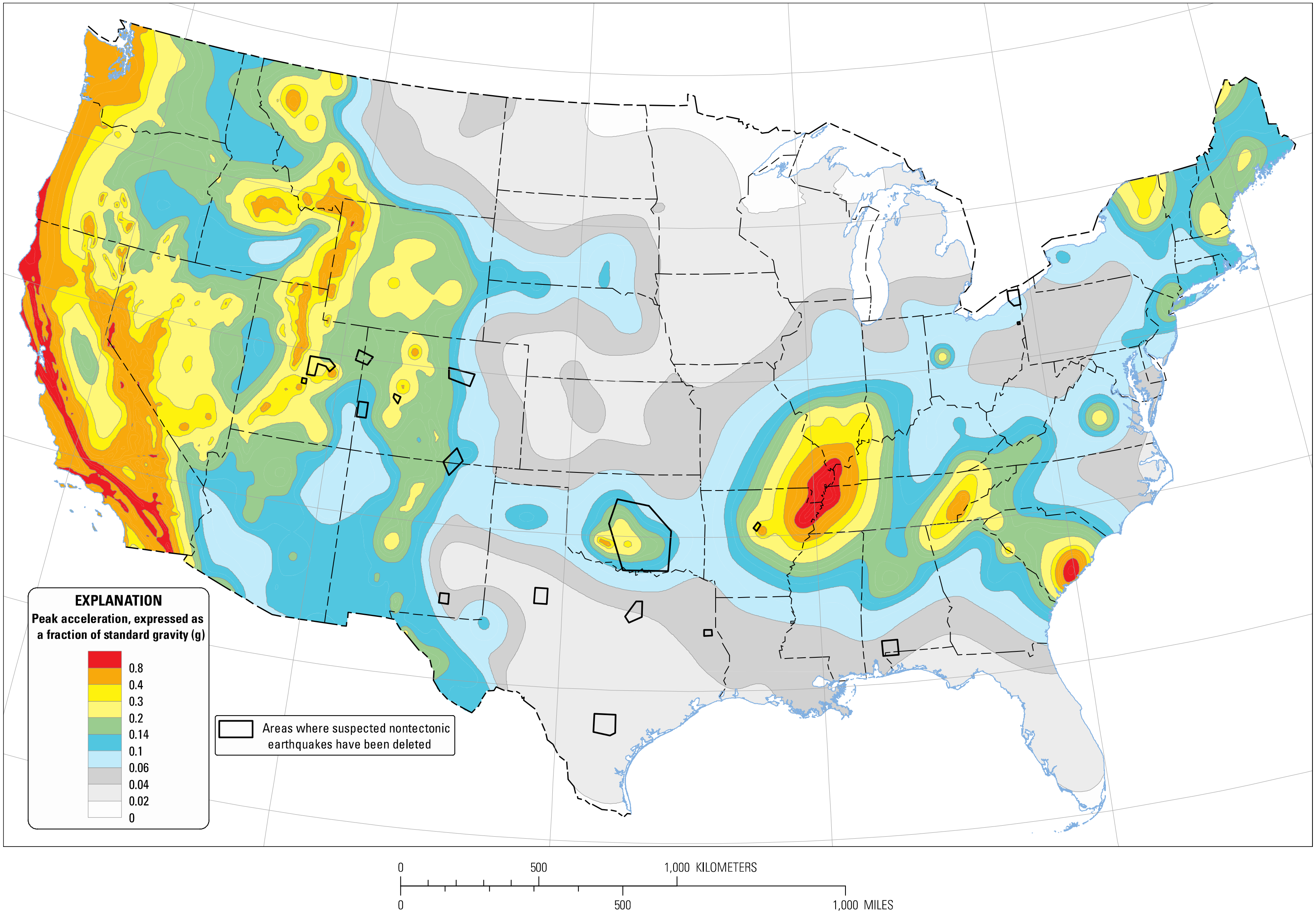
***Communicate understanding* to the world at large as useful knowledge for reducing earthquake risk and improving community resilience**

Predicting Earthquake Shaking (Strong Motion)

"The correct modeling of strong motion is really the bottom line in earthquake prediction..."

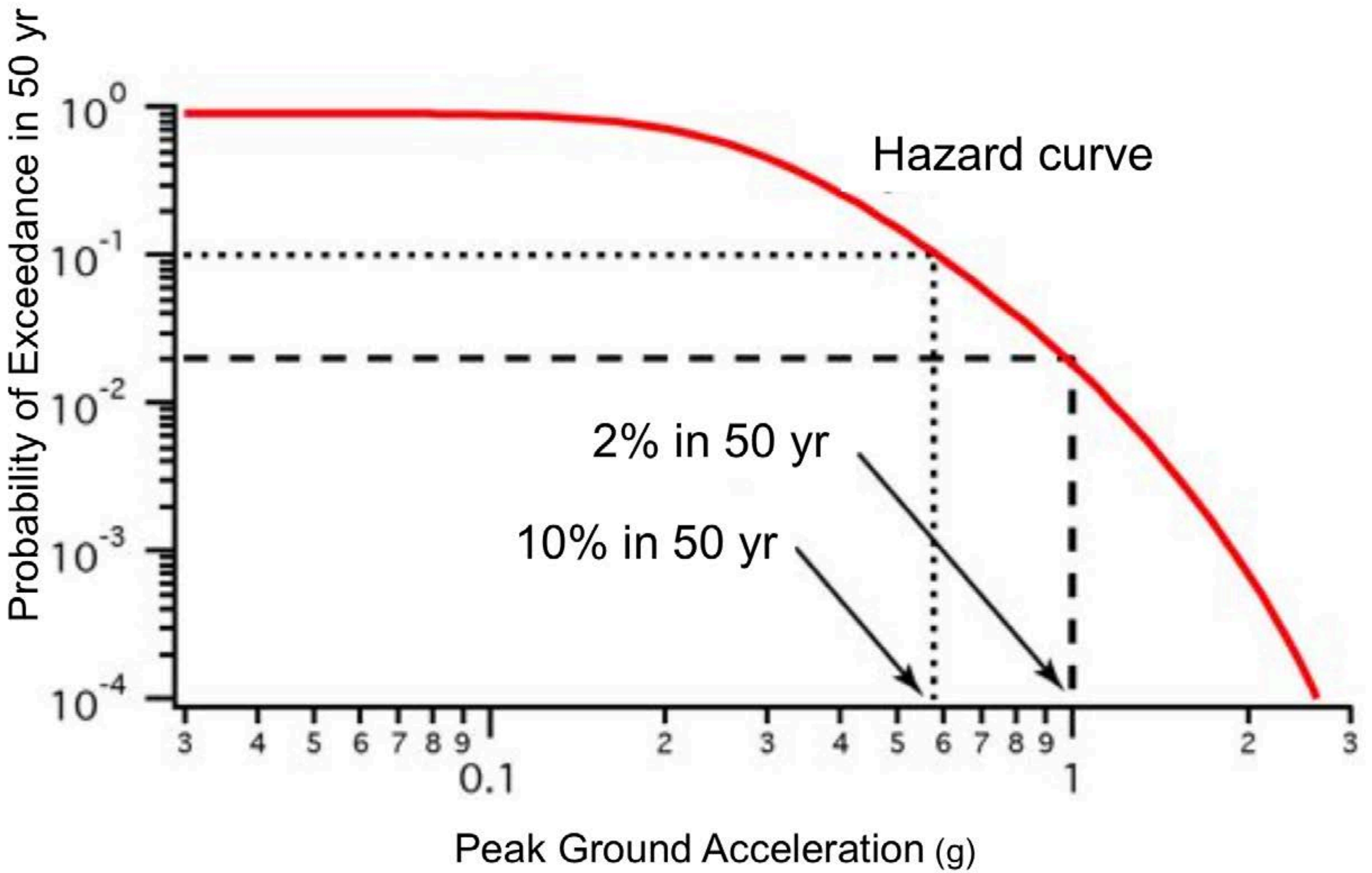
***Alan Ryall** (1982 SSA Presidential Address)*

2014 US National Strong Motion Hazard Map

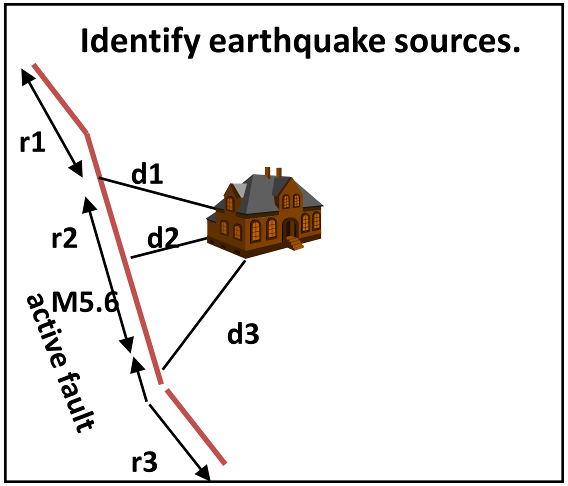


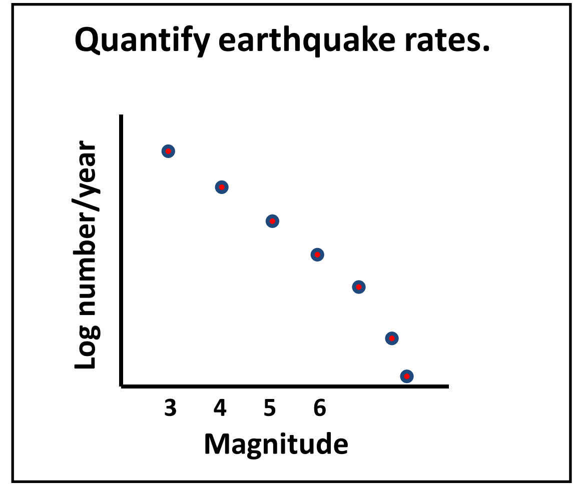
Two-percent probability of exceedance in 50 years map of peak ground acceleration

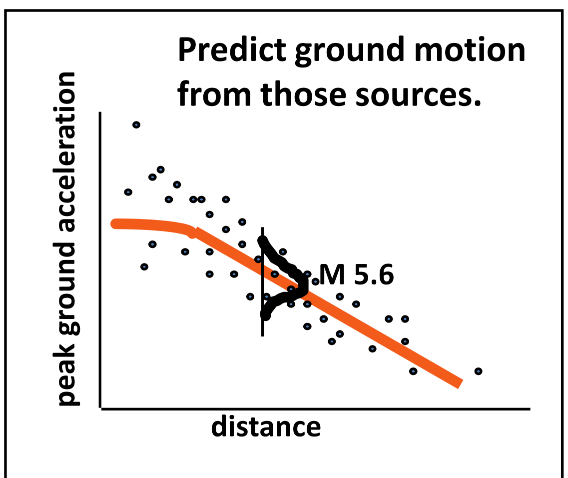
Hazard Curve for Downtown Los Angeles

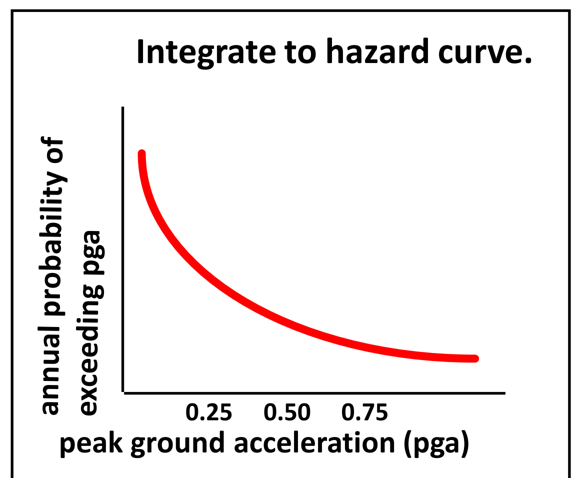


Probabilistic Seismic Hazard Analysis



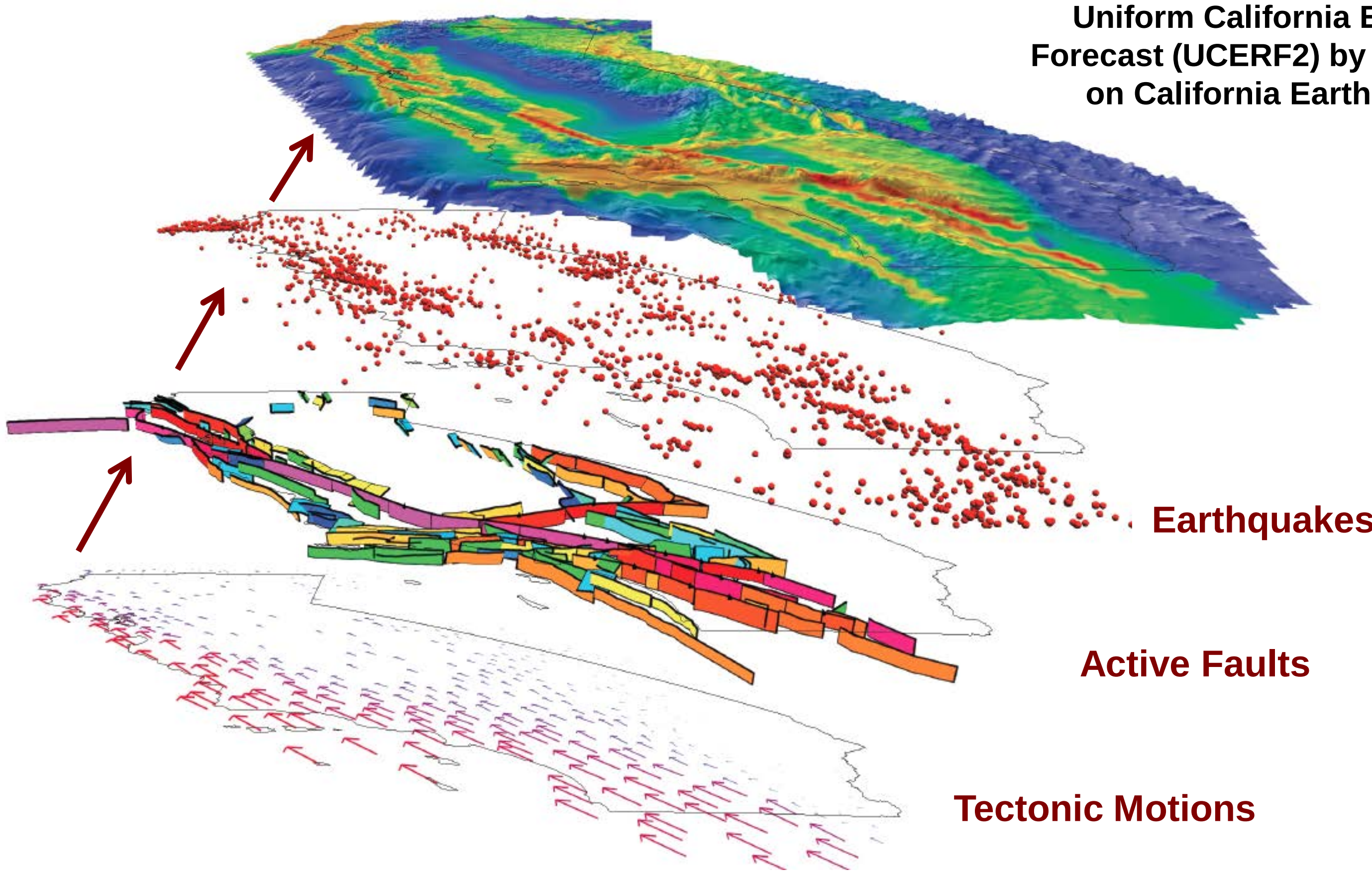






Long-Term Forecasting Models

Uniform California Earthquake Rupture Forecast (UCERF2) by the Working Group on California Earthquake Probabilities (Field et al., 2008)



Fault Models

Specifies the spatial geometry of larger, more active faults.

Deformation Models

Provides fault slip rates used to calculate seismic moment release.

Eathquake-Rate Models

Gives the long-term rate of all possible damaging earthquakes throughout a region.

Probability Models

Gives the probability that each earthquake in the given Earthquake Rate Model will occur during a specified time span.

Ground Motion Prediction Equations (GMPEs)

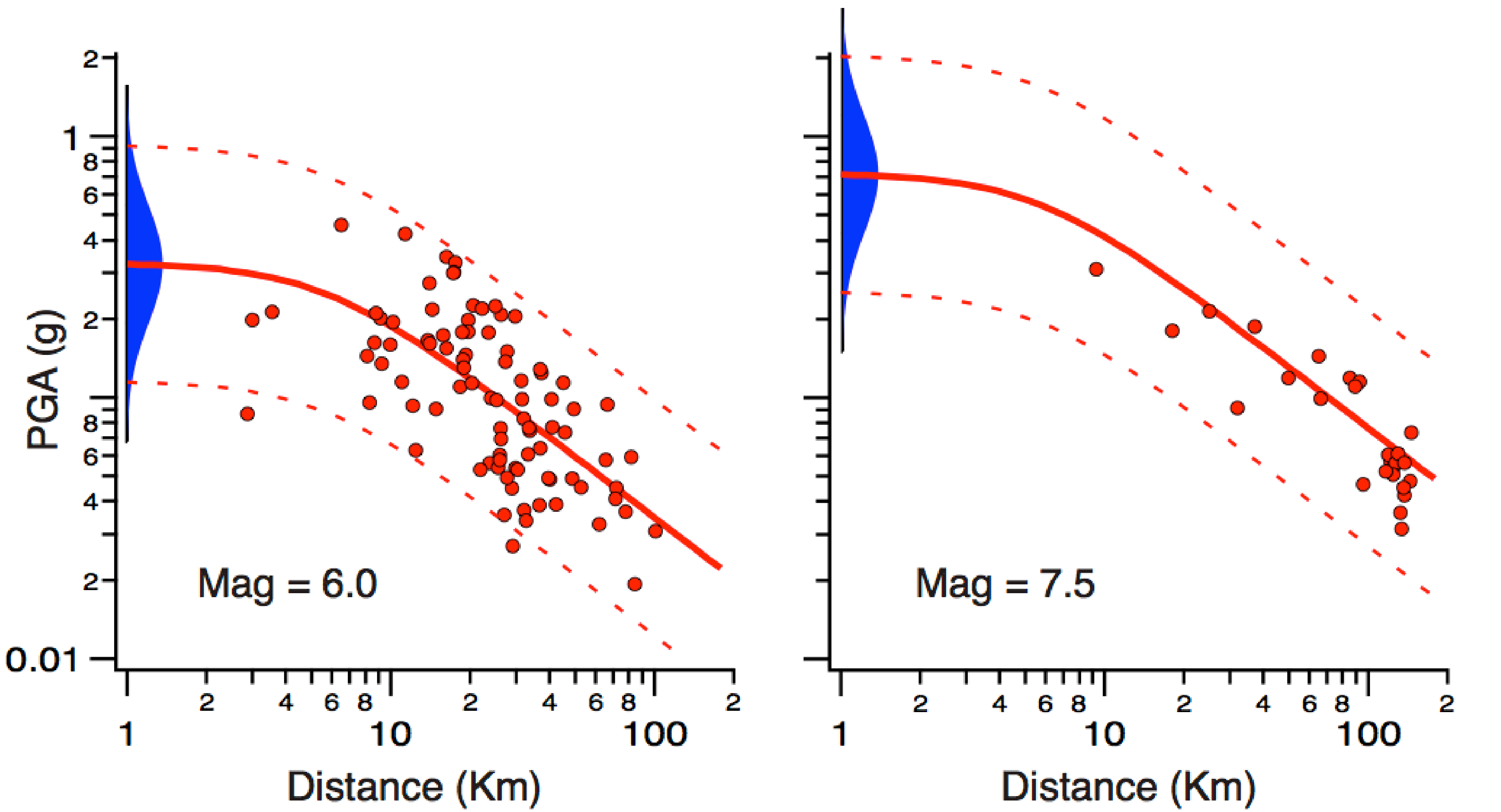
- ***Regression of variables for earthquake/geometry/site:***
  - *Magnitude*
  - *Distance to fault*
  - *Type of faulting*
  - *Hanging-wall effect*
  - *Site conditions*

Given an earthquake and site…

- ***Against measures of ground motion severity:***
  - *Peak acceleration*
  - *Peak velocity*
  - *Spectral acceleration*
  - *Spectral velocity*

…how strongly will it shake?

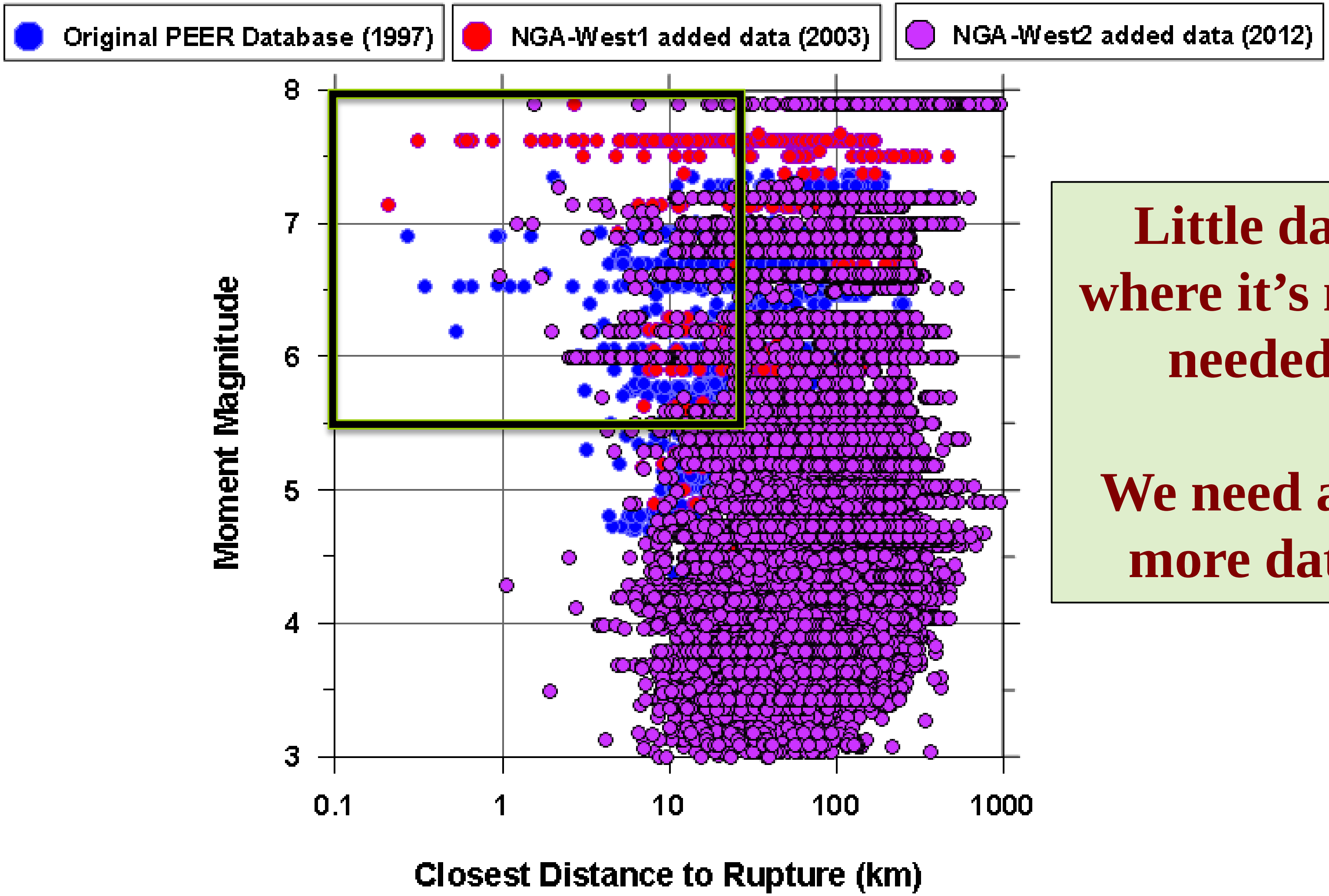
Ground Motion Prediction for California Earthquakes



Boore, Joyner & Fumal (1997)

From "PSHA: A Primer" (Field)

NGA-West2 Database



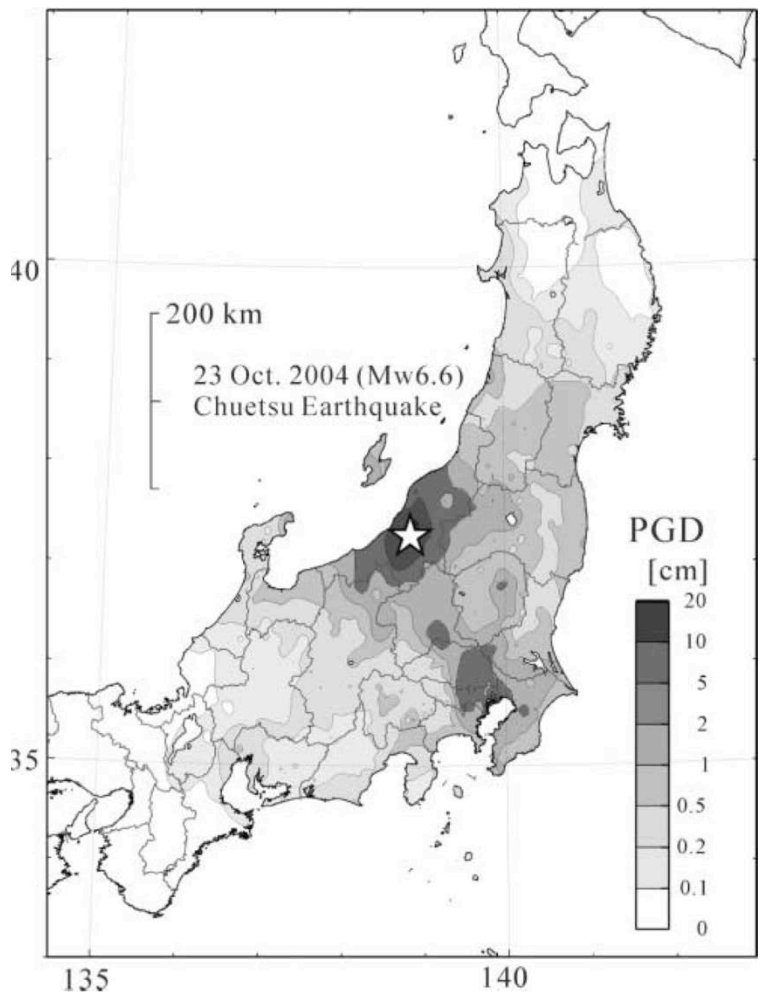
Little data where it's most needed.

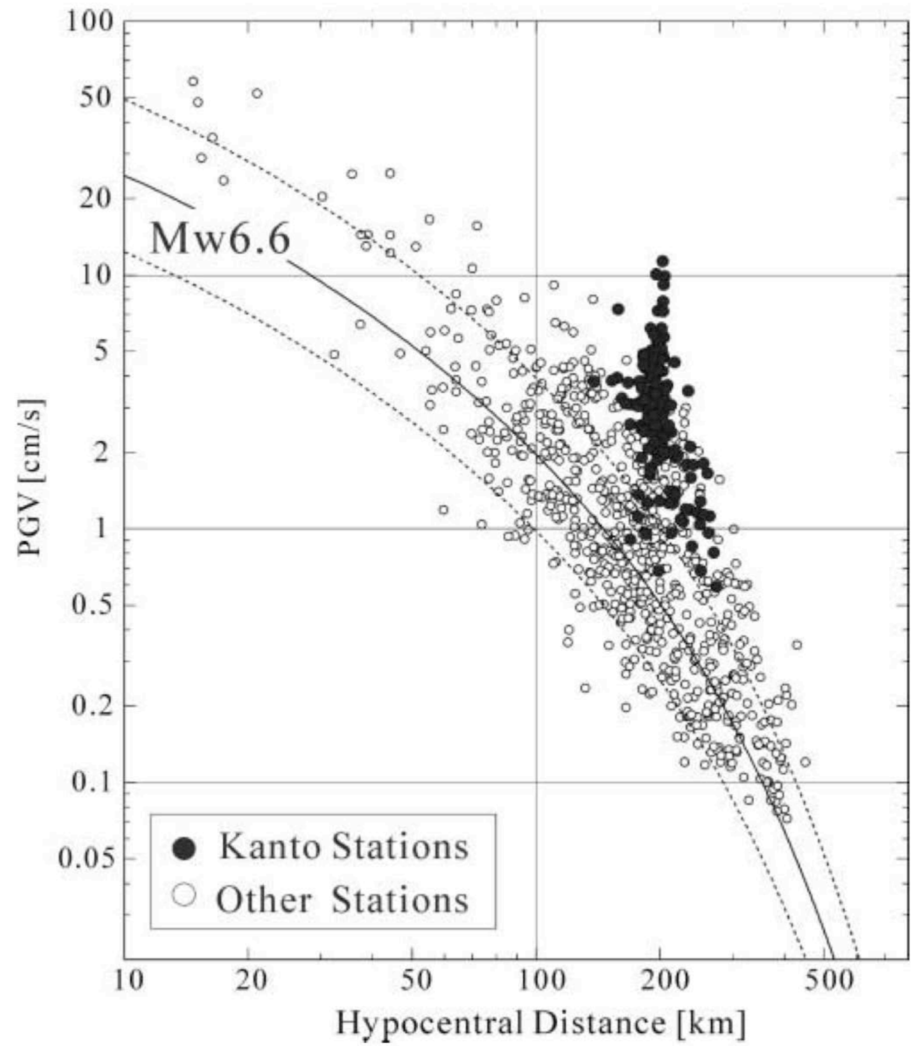
We need a *lot* more data!

[*Courtesy of Yousef Bozorgnia*]

PEER

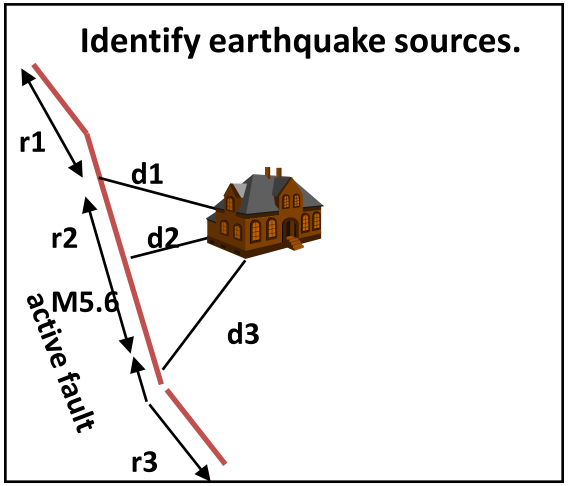
2004 Chuetsu Earthquake:
Stronger Shaking than Expected in Tokyo

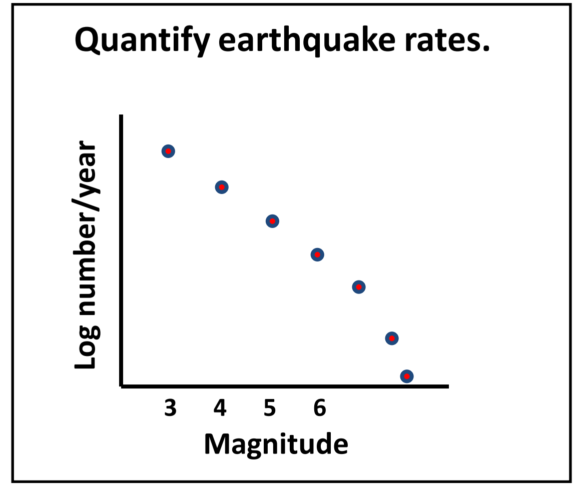




Furumura and Hayakawa **(2007)**

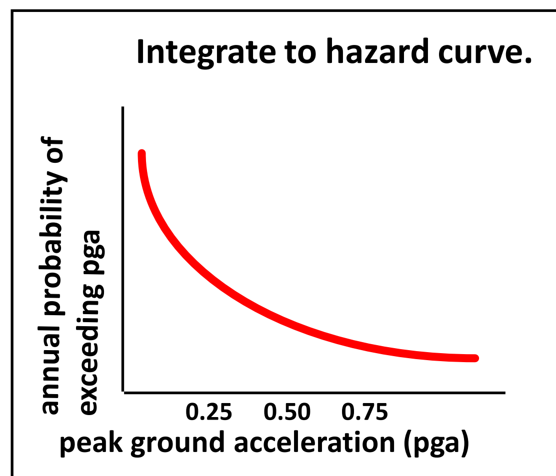
Probabilistic Seismic Hazard Analysis



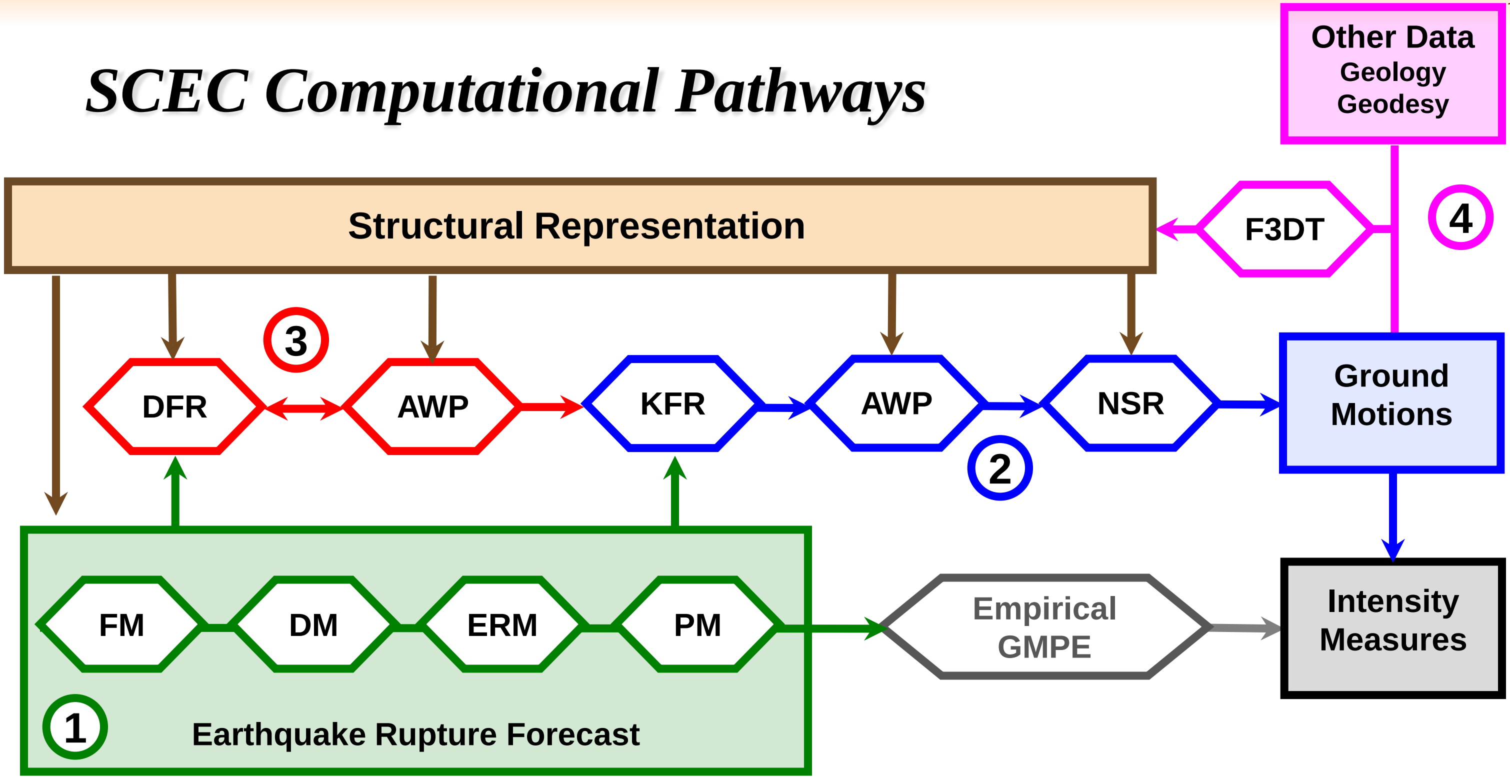


Predict ground motion

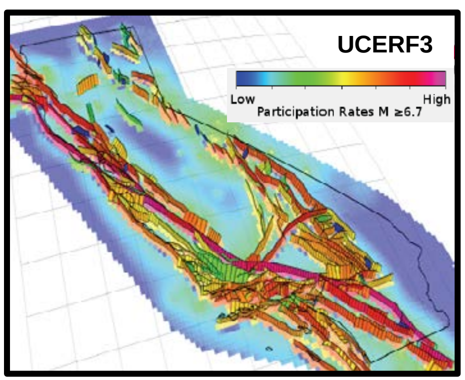
Substitute simulation for empirical GMPE approach.



SCEC Computational Pathways

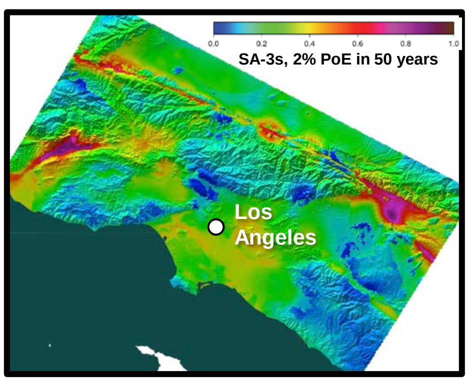


TACC *Stampede*



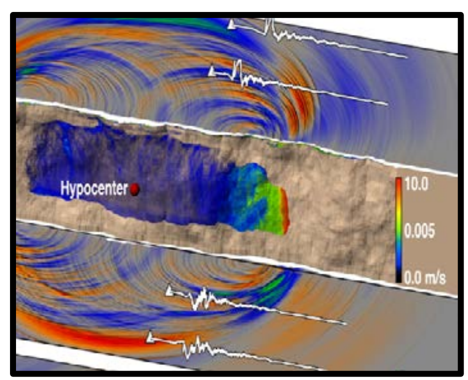
1 Uniform California Earthquake Rupture Forecast (UCERF3)

NCSA *Blue Waters*



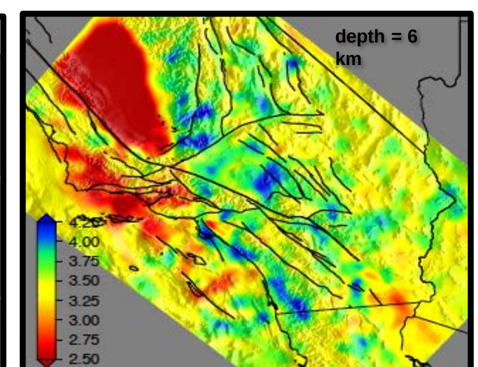
2 CyberShake 14.2 seismic hazard model for LA region

OLCF *Titan*



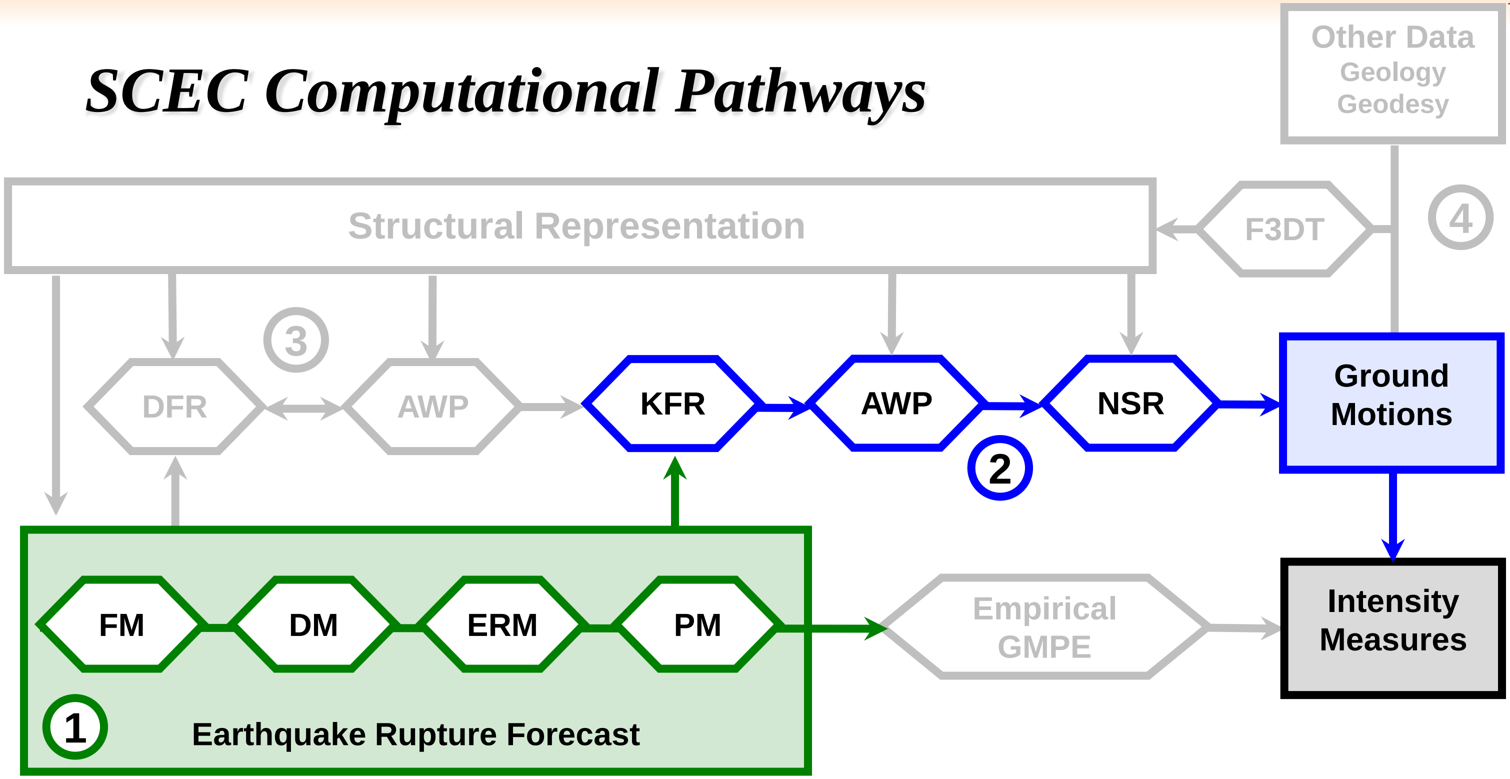
3 Dynamic rupture model of fractal roughness on SAF

ALCF *Mira*

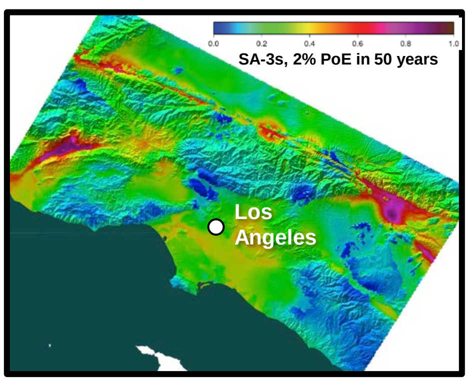


4 Full-3D tomographic model CVM-S4.26 of S. California

SCEC Computational Pathways



NCSA *Blue Waters*



2 CyberShake 14.2 seismic hazard model for LA region

KFR = Kinematic Fault Rupture

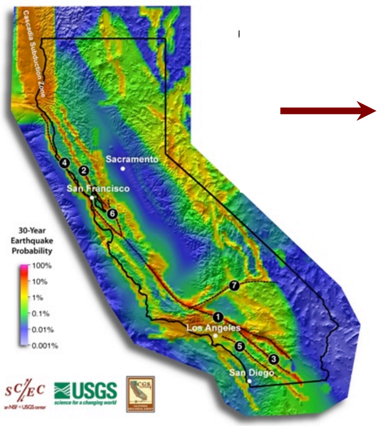
AWP = Anelastic Wave Propagation

NSR = Nonlinear Site Response

DFR = Dynamic Fault Rupture

F3DT = Full-3D Tomography

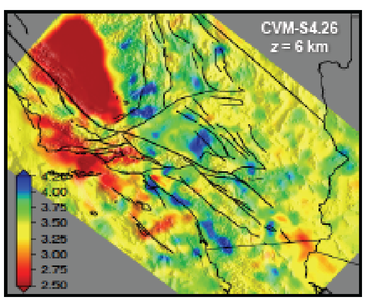
Coupling of Computational Pathways in the CyberShake Workflow



Uniform California Earthquake Rupture Forecast

→ **UCVM** → **AWP-ODC** → **SeisSynth** → *data transfer* → **Data Product Generation**

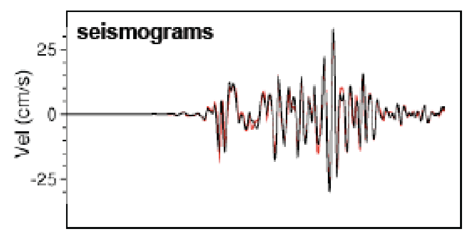
UCVM
Mesh generation
1 job per site
MPI, 320 cores



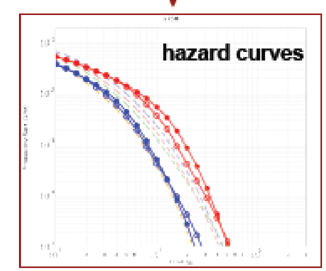
Full-3D tomographic model of S. California

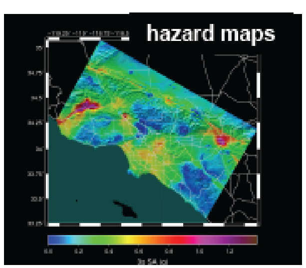
AWP-ODC
SGT computation
2 jobs per site
MPI, 10k CPUs or 100 GPUs

SeisSynth
Post-processing
415,000 jobs per site
serial

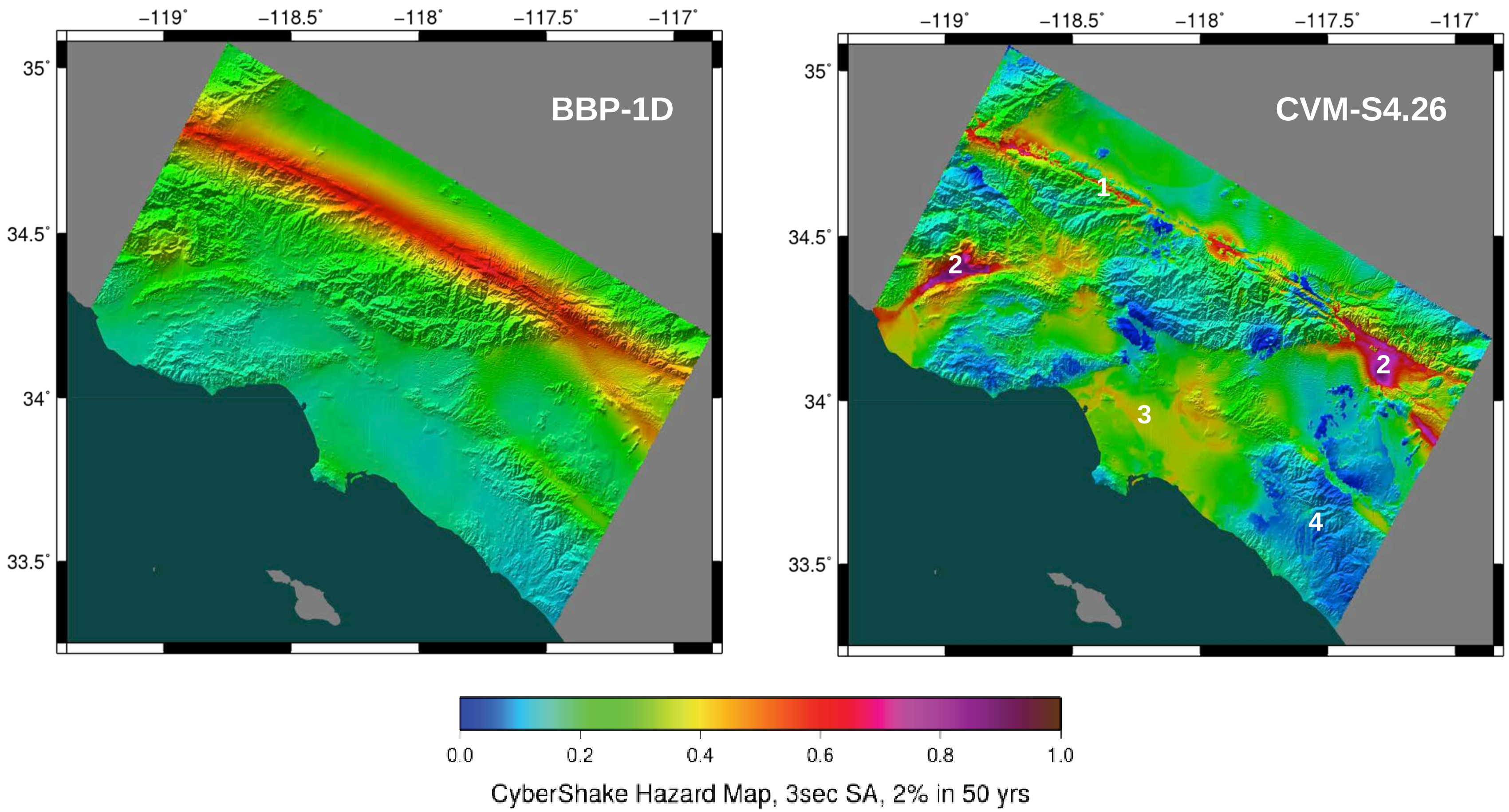


Data Product Generation
Populate DB, construct queries
4 jobs per site



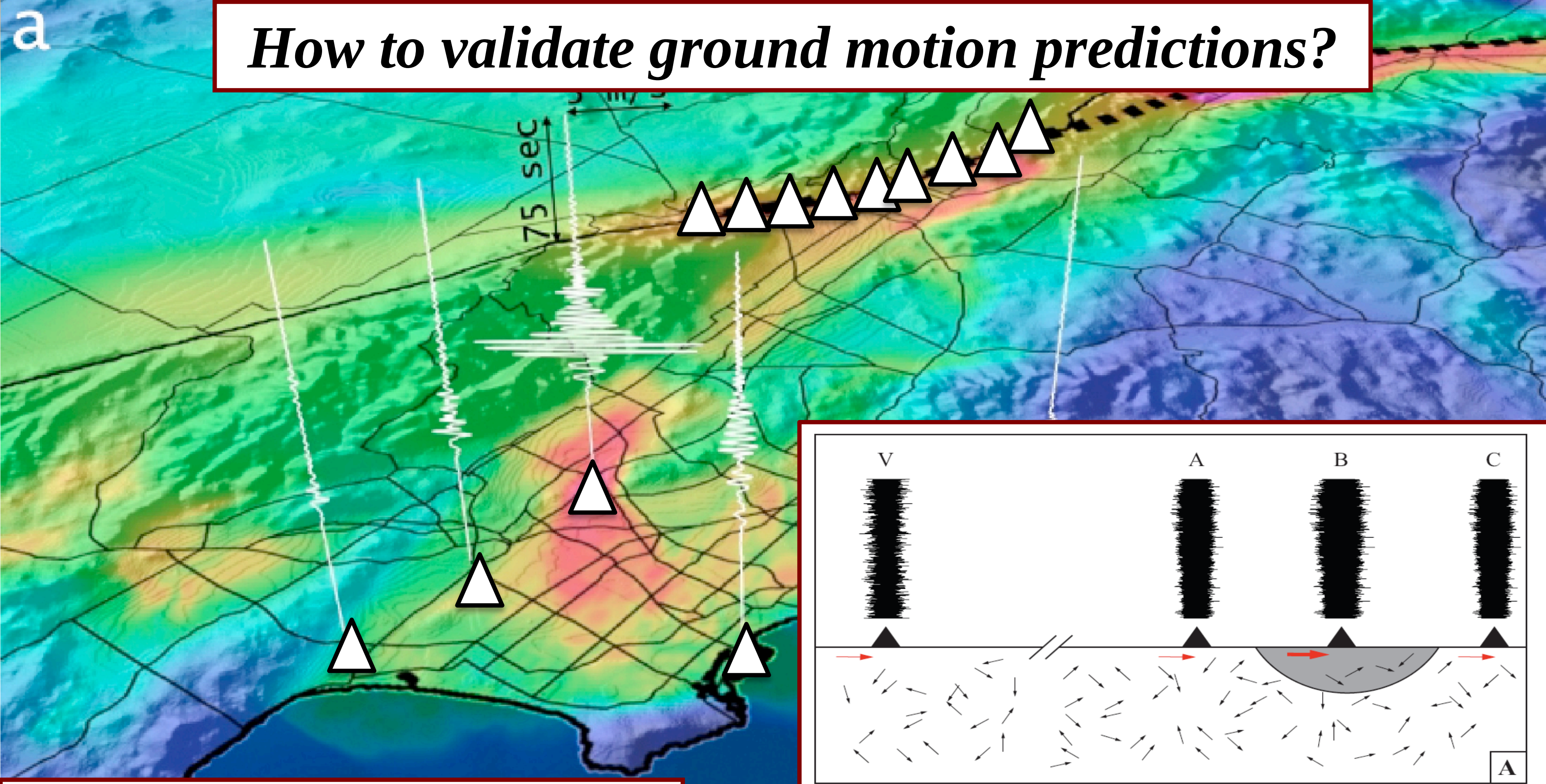


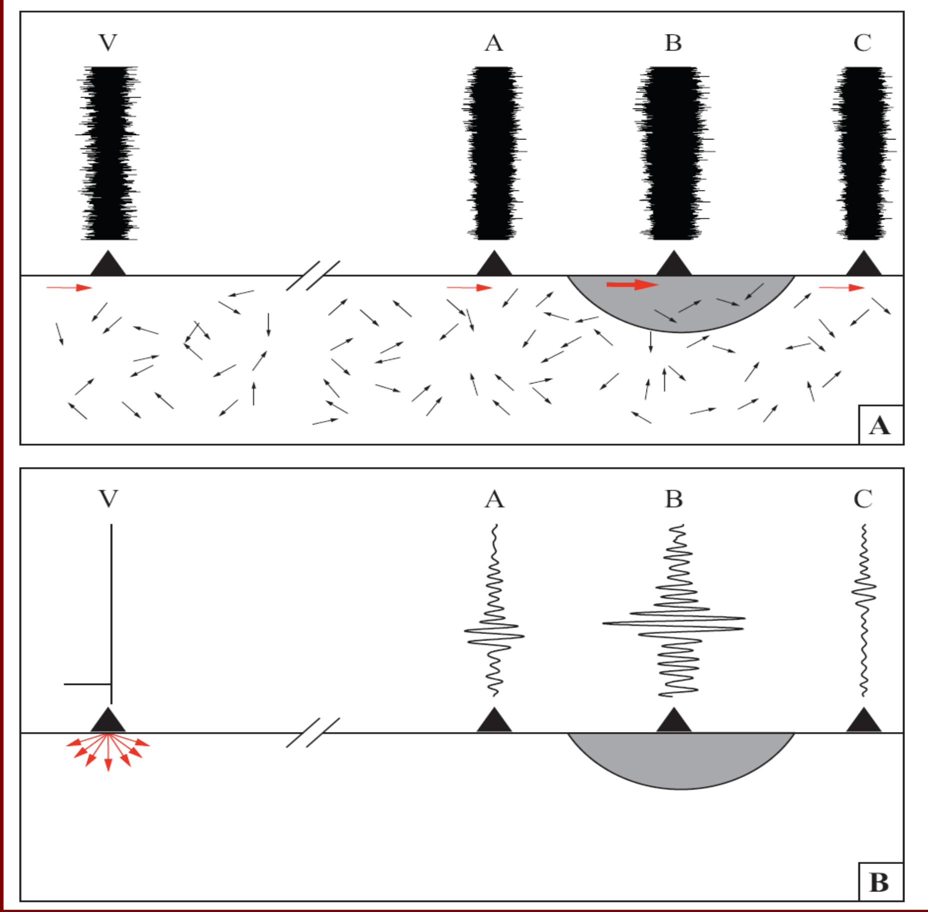
Comparison of 1D and 3D CyberShake Models for the Los Angeles Region



1. **lower near-fault intensities due to 3D scattering**
2. **much higher intensities in near-fault basins**
3. **higher intensities in the Los Angeles basin**
4. **lower intensities in hard-rock areas**

How to validate ground motion predictions?

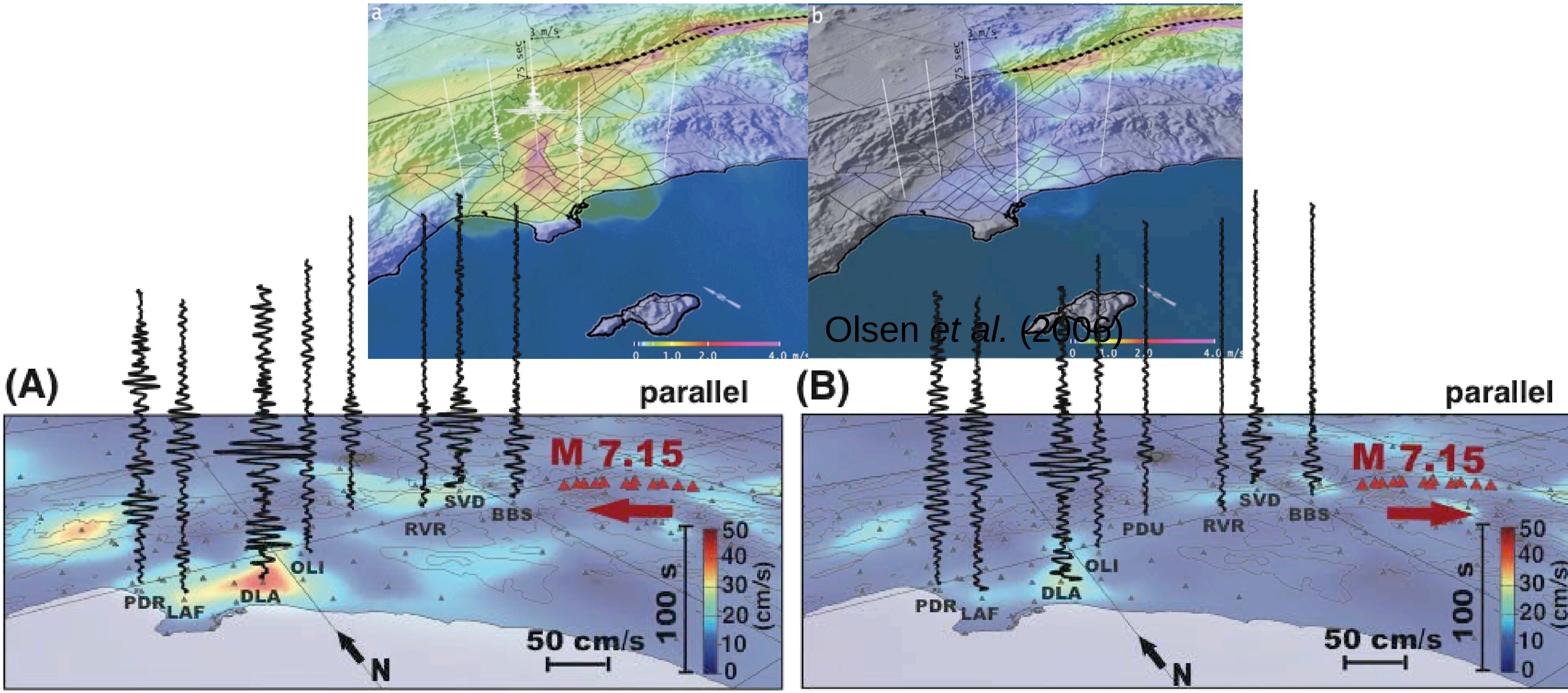




Active Approach: Deploy instruments and construct virtual earthquake from ambient-field Green's functions.

Passi
statio
test p

Virtual Earthquake Method Validates Simulations



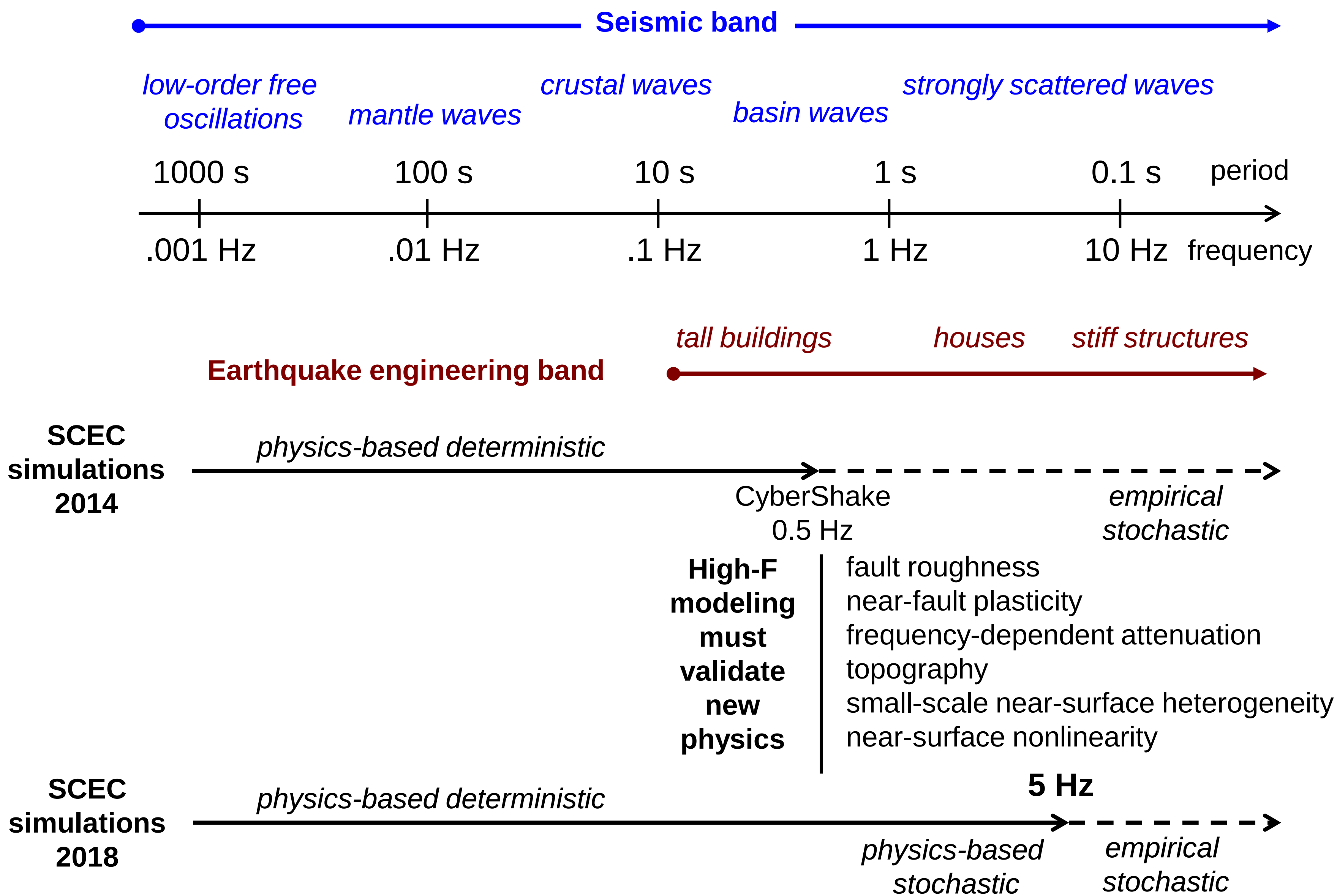
Details of amplification differ (need more data)

Caveats: ***long-period only***

both assume linearity

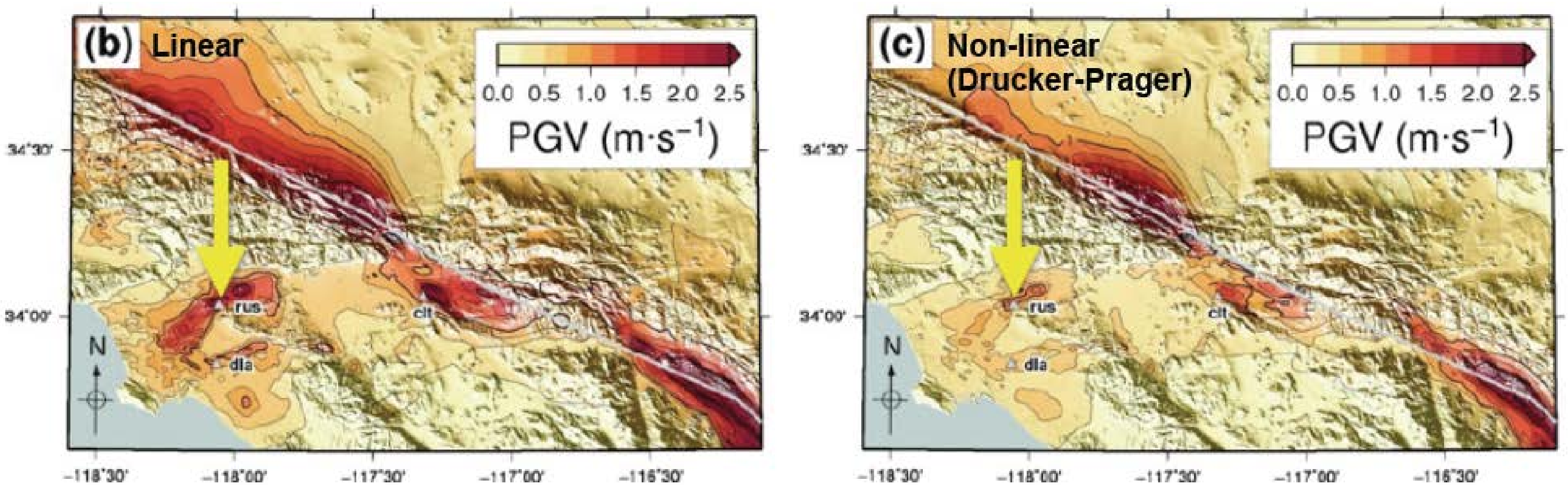
Denolle et al. (2014a)

Push to Higher Seismic Frequencies



Southern California Earthquake Center

Push to Higher Seismic Frequencies



SCEC simulations 2014

physics-based deterministic

CyberShake 0.5 Hz

empirical stochastic

High-F modeling must validate new physics

- fault roughness
- near-fault plasticity
- frequency-dependent attenuation
- topography
- small-scale near-surface heterogeneity
- near-surface nonlinearity

5 Hz

SCEC simulations 2018

physics-based deterministic

physics-based stochastic

empirical stochastic

2014 Update of ShakeOut Earthquake Drills

Participation History (worldwide)

2014: 26.5 million (+ NM, KS, FL, Quebec, Yukon, more)
2013: 25.0 million (+ Southeast, Northeast, MT, WY, CO)
2012: 19.5 million (+ Japan, New Zealand, UT, WA, AZ)
2011: 12.5 million (+ Central US, BC, OR)
2010: 8.0 million (+ Nevada and Guam)
2009: 6.9 million (+ Northern California)
2008 5.4 million (Southern California)

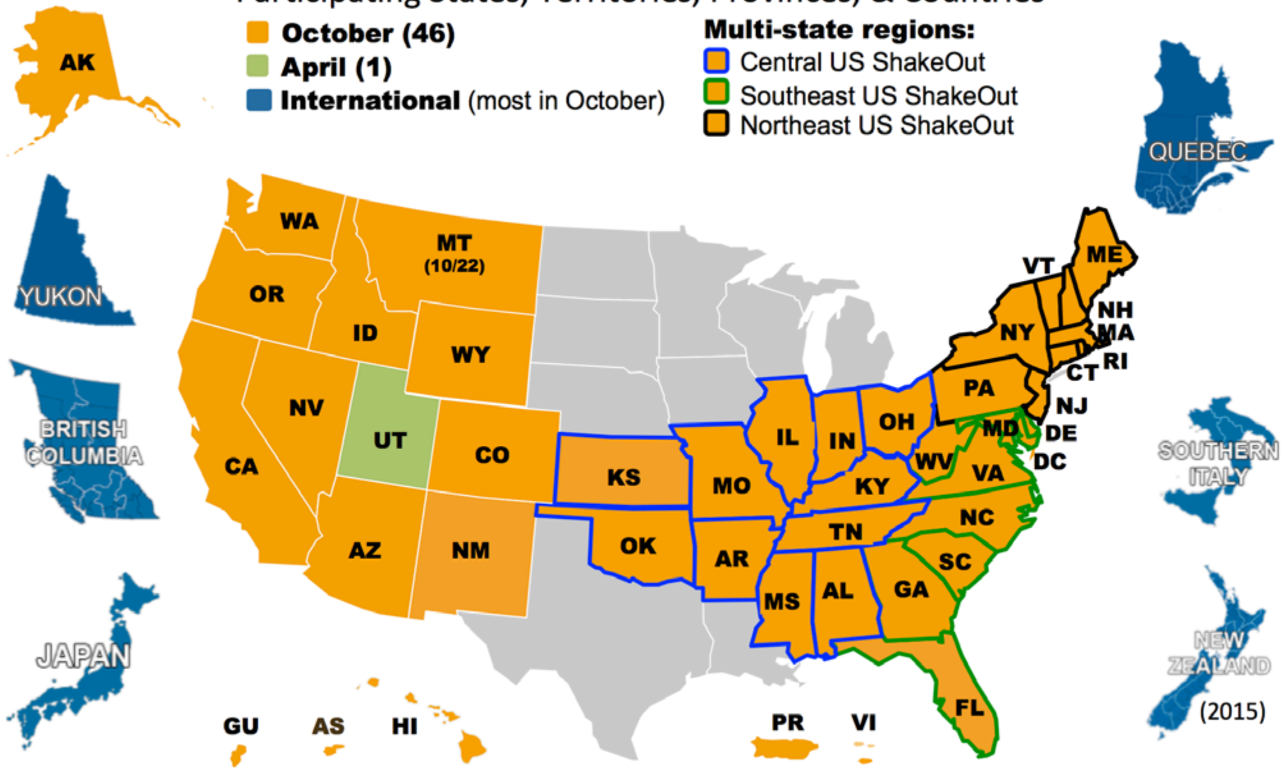
2014 Official ShakeOut Regions

27 Regions worldwide
21 Regions spanning 47 states & territories
55 additional countries with independent registrations (individuals, schools, etc.)

Key Facts

- Participants practice "Drop, Cover, and Hold On" and other aspects of their emergency plans.
- Register at www.ShakeOut.org.
- Largest component of FEMA's "America's PrepareAthon"

Participating States, Territories, Provinces, & Countries



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ShakeOut Scenario – 5 Major Areas of Loss for Los Angeles

1. Older buildings built to earlier standards

2. Nonstructural elements and building contents that are generally unregulated

3. Infrastructure crossing the San Andreas fault

4. Business interruption from damaged infrastructure, including telecommunications, and especially water systems

5. Fire following the earthquake

Jones (2015)

4 Areas to be Addressed by the City of Los Angeles

1. Pre-1980 non-ductile reinforced concrete buildings

2. Pre-1980 soft-first story buildings

3. Water system infrastructure, including impact on firefighting capability

4. Telecommunications infrastructure

(6 ordinances currently in process)

Jones (2015)