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Southern California Earthquake Center

An Overview of the SCEC CyberShake Project

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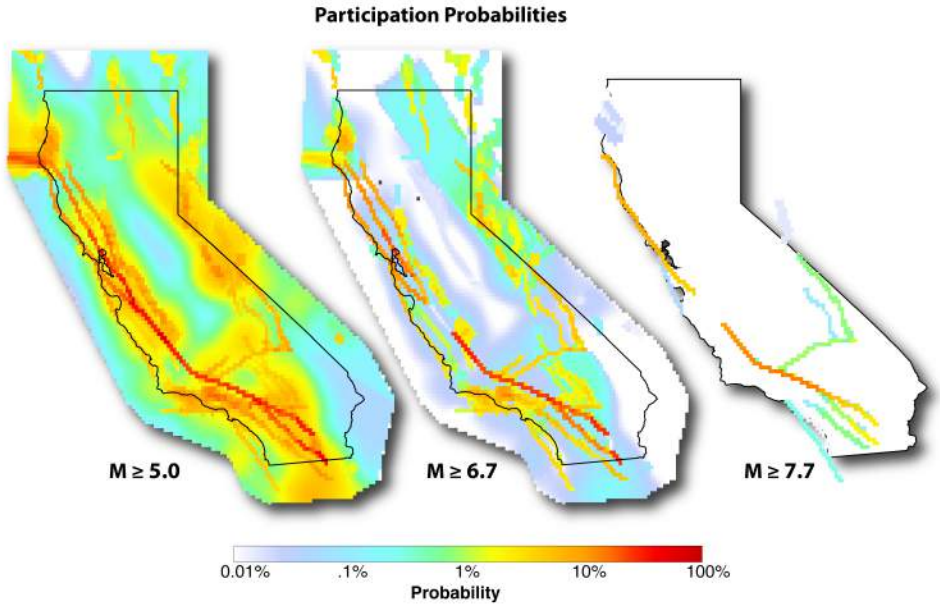
CyberShake co-developers: S. Callaghan, Y. Cui, R. Graves, F. Wang, K. Olsen, K. Milner, and P. Maechling, E.-J. Lee, P. Chen

Meeting of the SCEC Committee for the Utilization of Ground Motion Simulations

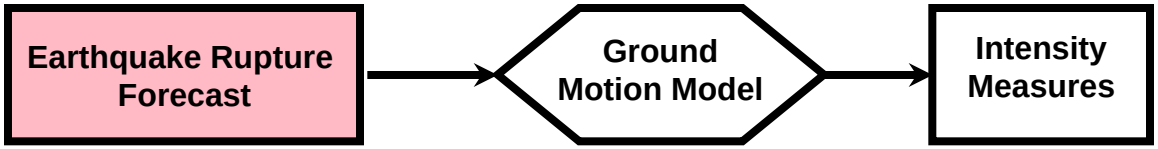
4 May 2015

Probabilistic Seismic Hazard Analysis



Working Group on California Earthquake Probabilities (2007)

Uniform California Earthquake Rupture Forecast (UCERF2)

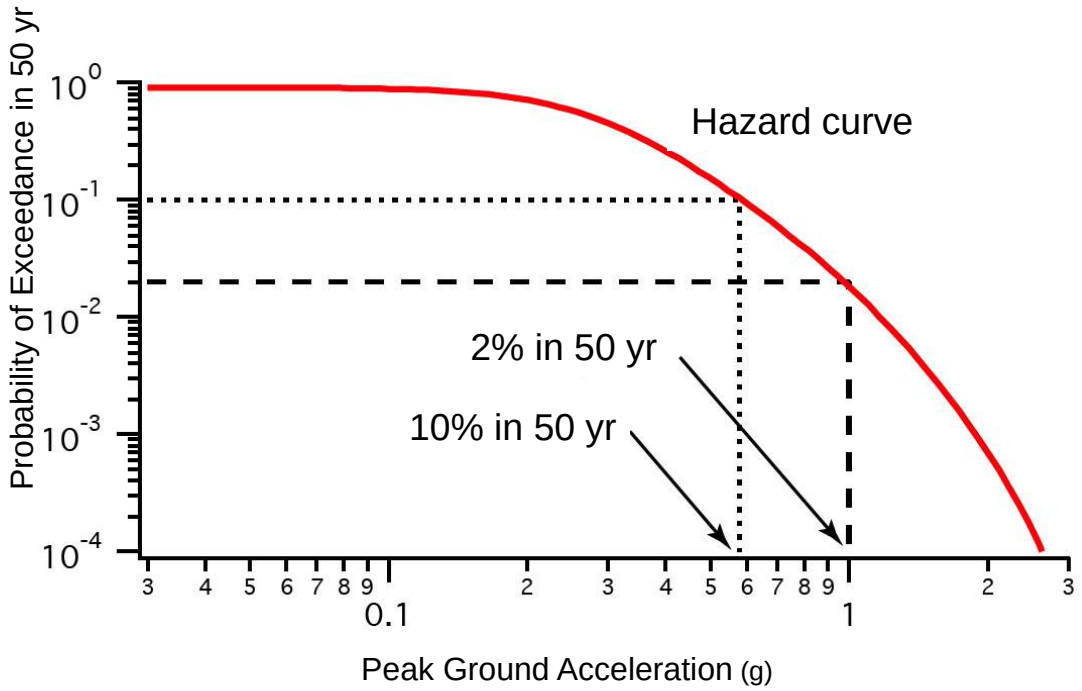


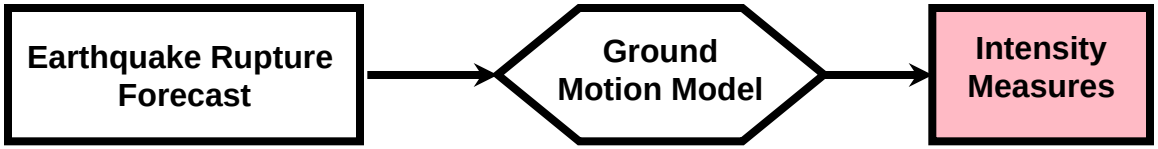
$P(S_k)$ $P(Y_n \mid S_k)$ $P(Y_n)$

Probabilistic Seismic Hazard Analysis

Hazard Curve

- **Shaking intensity:** **Peak Ground Acceleration (PGA)**
- **Interval:** **50 years**
- **Site:** **Downtown LA**



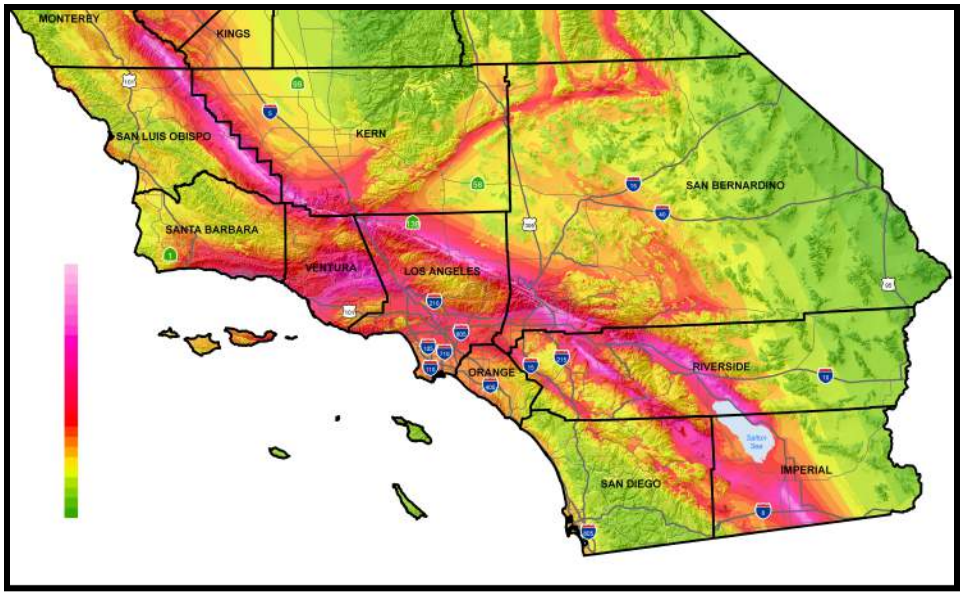


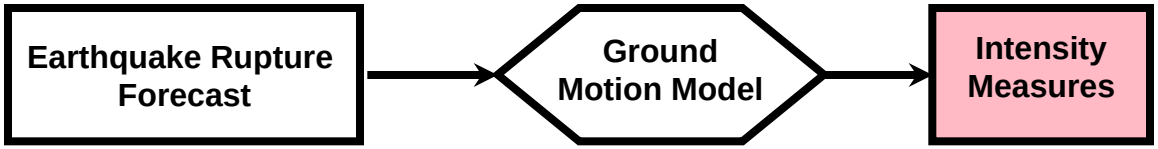
$P(S_k)$ $P(Y_n \mid S_k)$ $P(Y_n)$

Probabilistic Seismic Hazard Analysis

Seismic Hazard Map

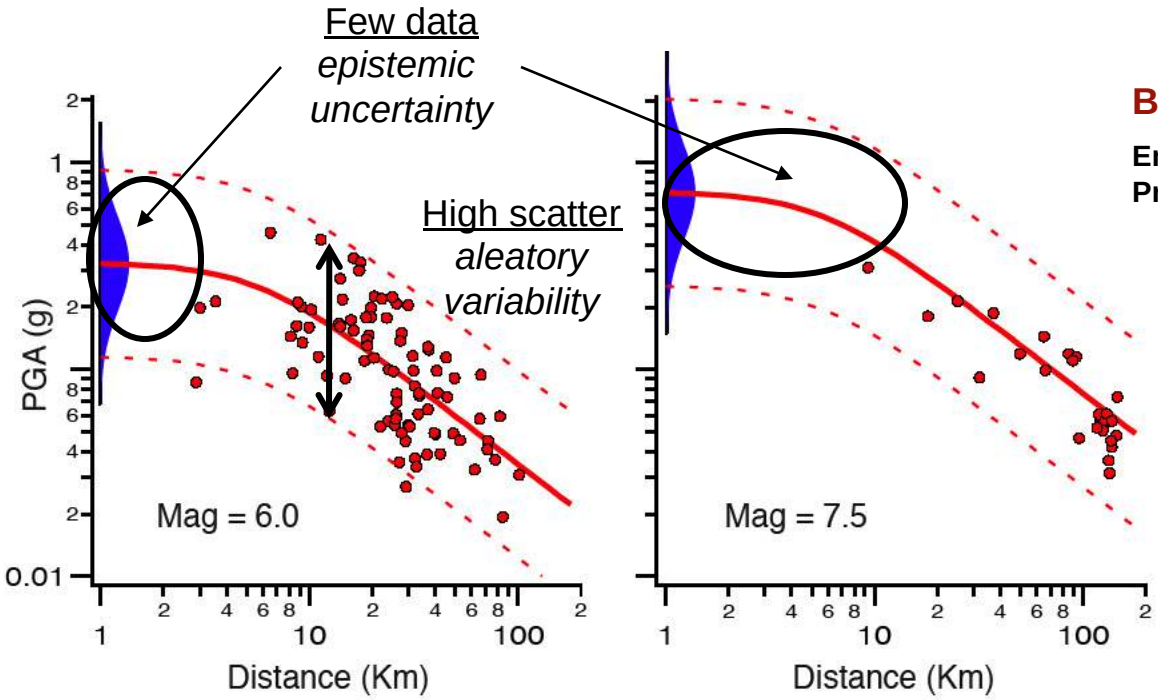
- **PGA (%g) with 2% Probability of Exceedance in 50 years**





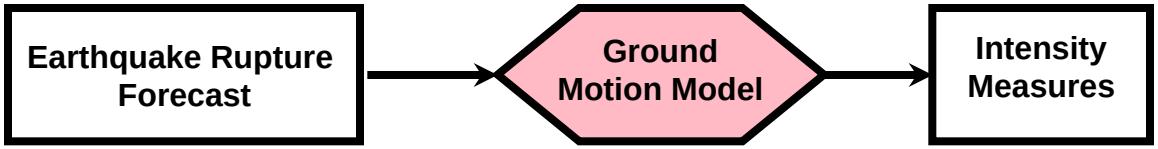
$P(S_k)$ $P(Y_n \mid S_k)$ $P(Y_n)$

Probabilistic Seismic Hazard Analysis



Boore et al. (1997)

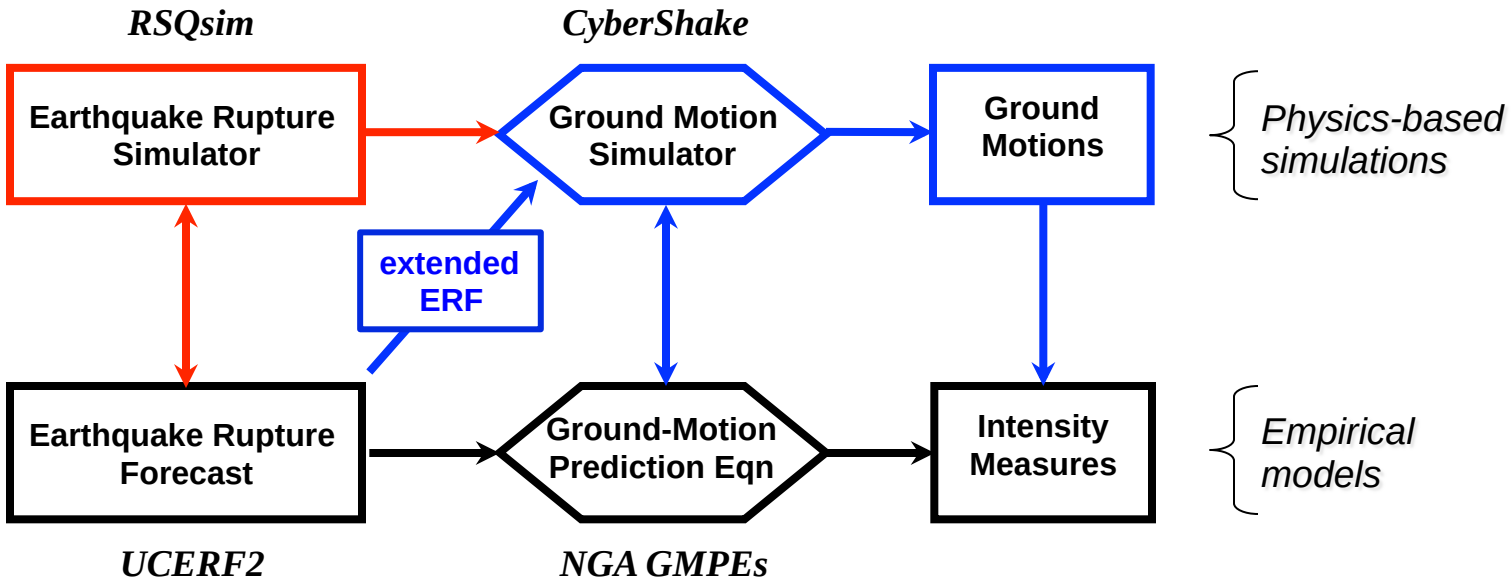
Empirical Ground Motion Prediction Equations (GMPEs)



$P(S_k)$ $P(Y_n \mid S_k)$ $P(Y_n)$

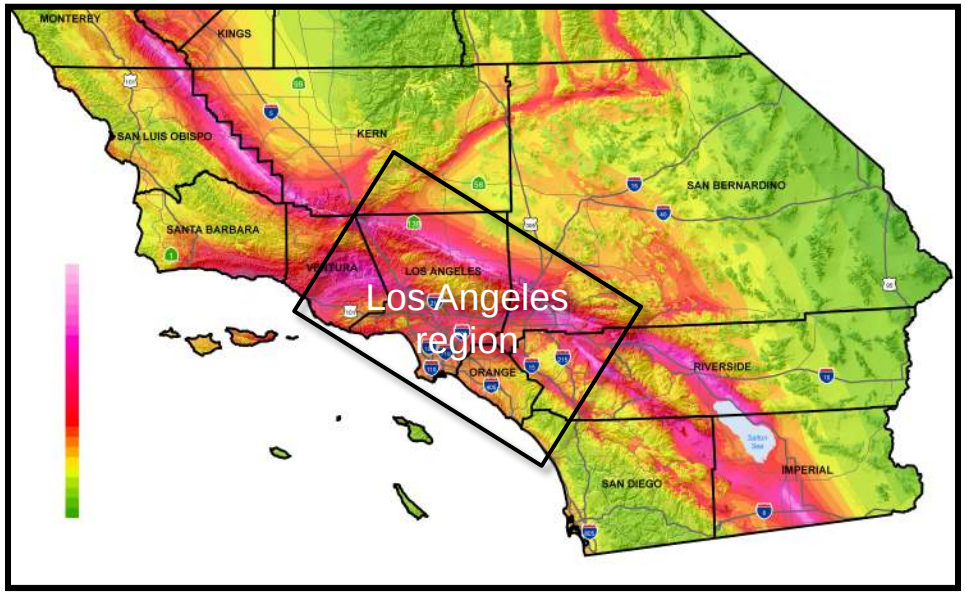
Probabilistic Seismic Hazard Analysis

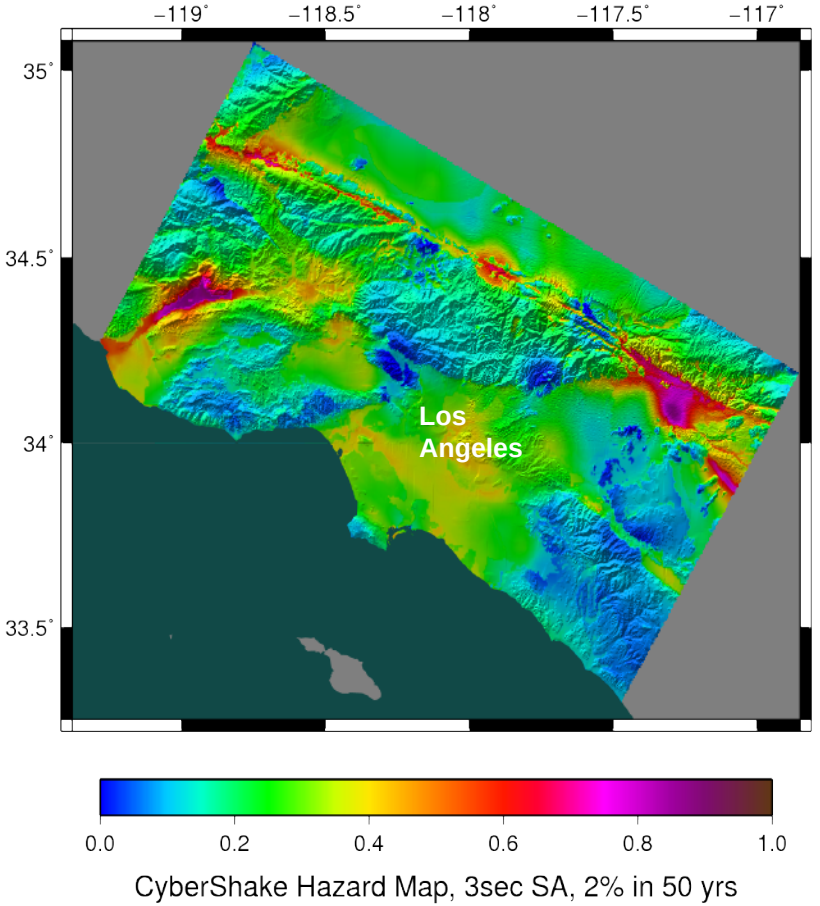
- **PSHA, as currently practiced, is based on empirical statistical models**
- **We seek to improve earthquake forecasting by incorporating more physics through numerical simulations**



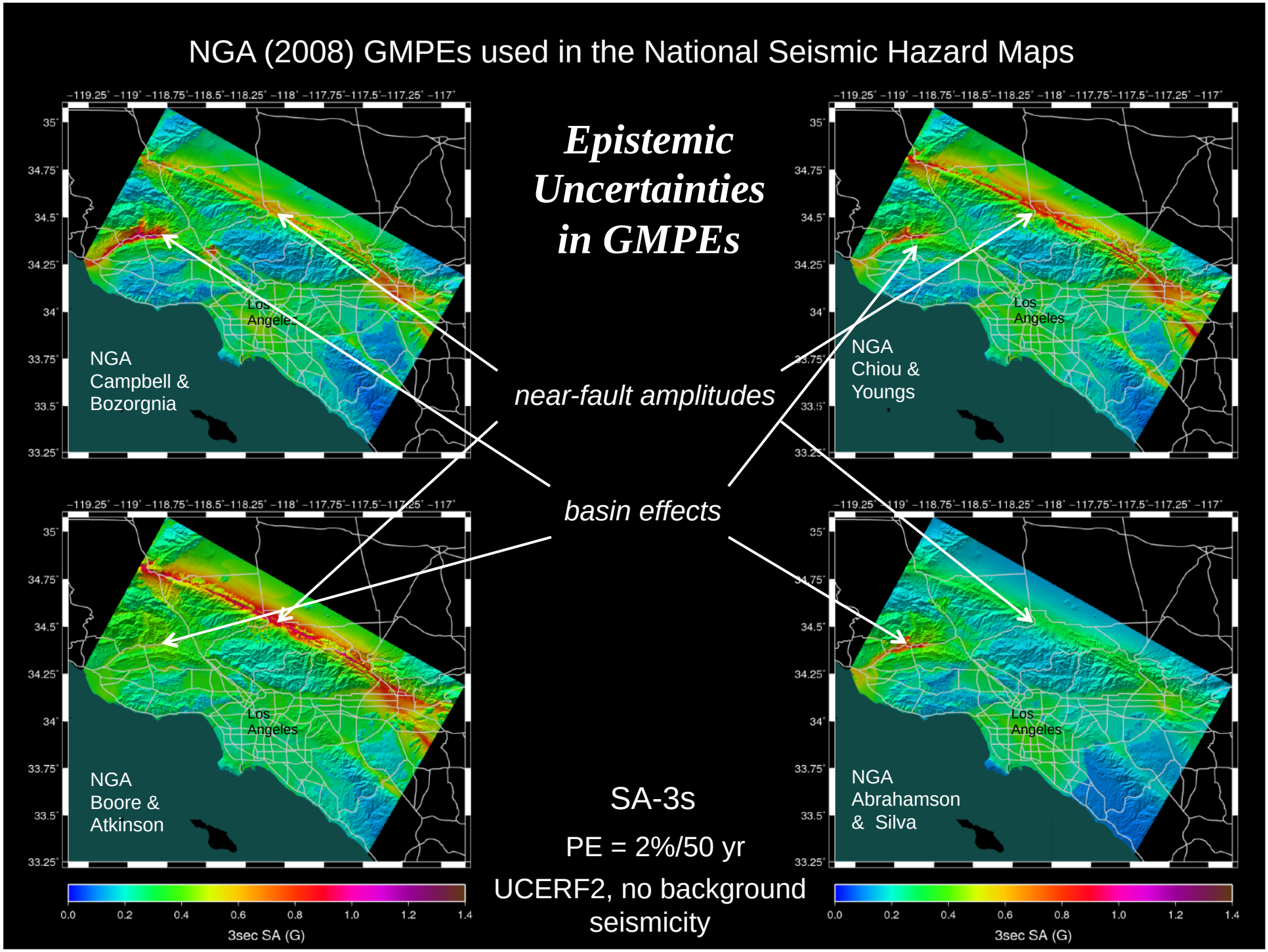
CyberShake Hazard Model 14.2

- **Sites:**
  - 289 sites in the greater Los Angeles region
- **Ruptures:**
  - All UCERF2 ruptures within 200 km of site (~14,900)
- **Rupture variations:**
  - 415,000 per site using Graves-Pitarka pseudo-dynamic rupture model
- **Seismograms:**
  - 240 million per model





NGA (2008) GMPEs used in the National Seismic Hazard Maps



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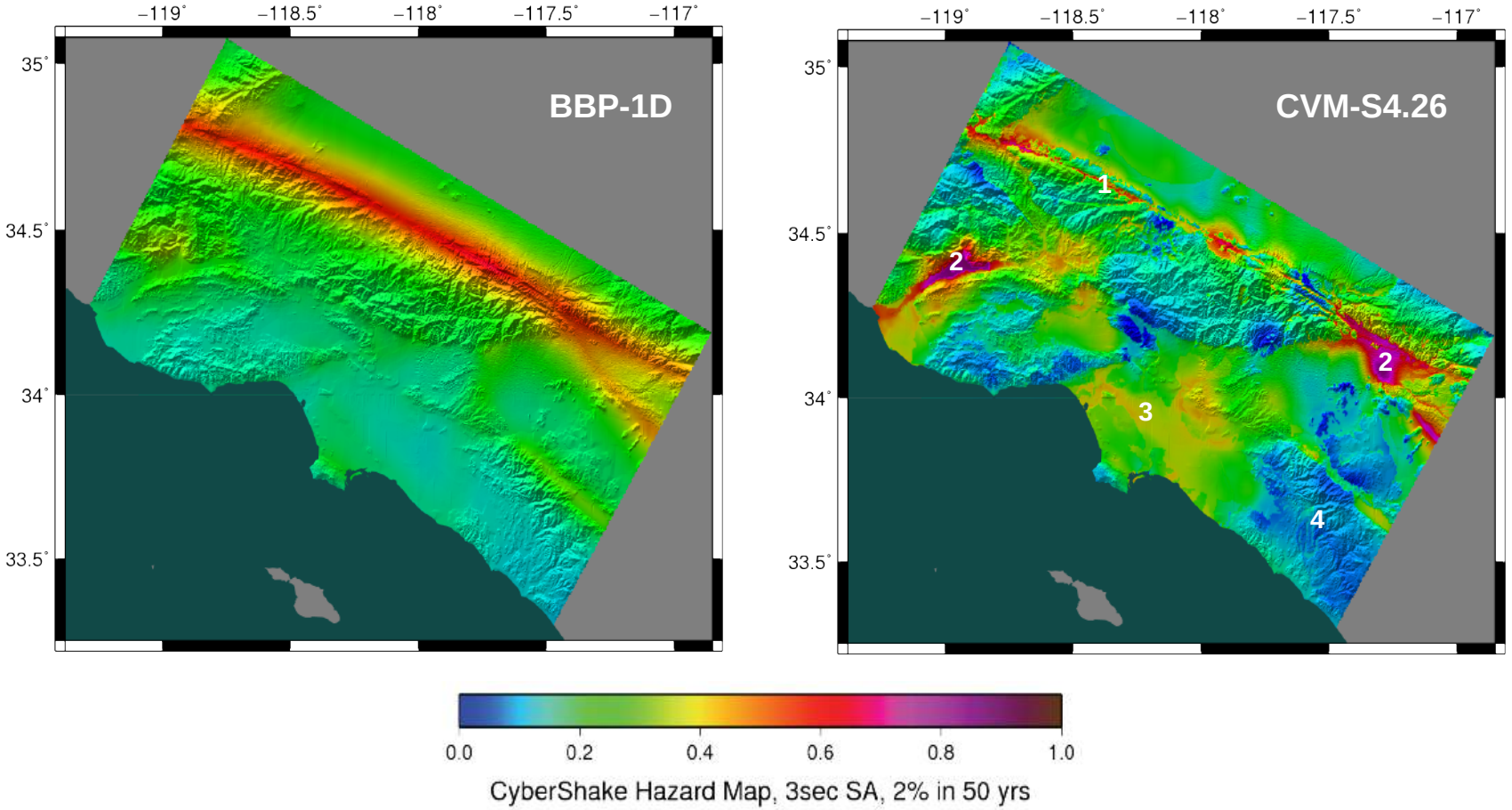
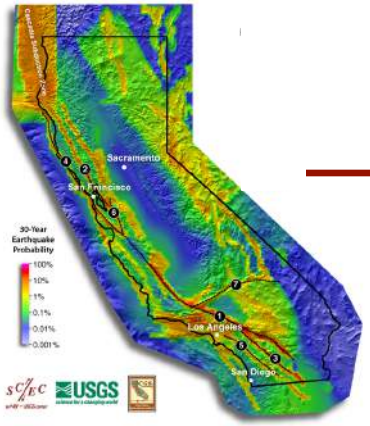
Comparison of 1D and 3D CyberShake Models for the Los Angeles Region



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

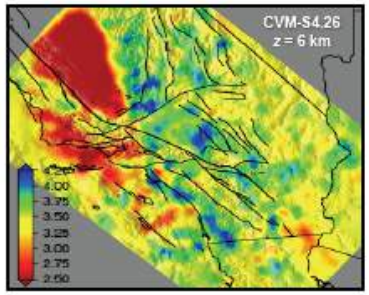
CyberShake Workflow



Uniform California Earthquake Rupture Forecast

UCVM

Mesh generation
1 job per site
MPI, 320 cores

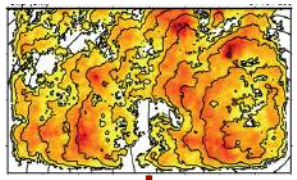


Full-3D tomographic model of S. California

AWP-ODC

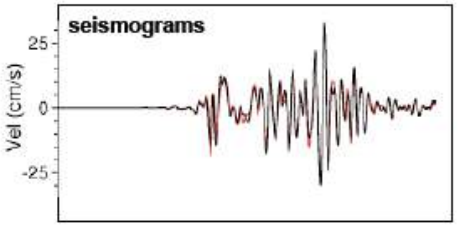
SGT computation
2 jobs per site
MPI, 10k CPUs or 100 GPUs

Kinematic rupture model



SeisSynth

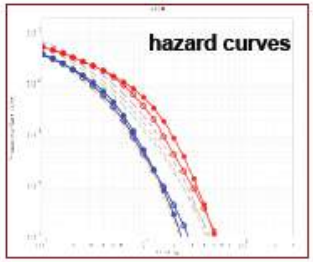
Post-processing
415,000 jobs per site
serial

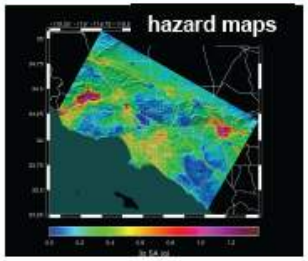


data transfer

Data Product Generation

Populate DB, construct queries
4 jobs per site



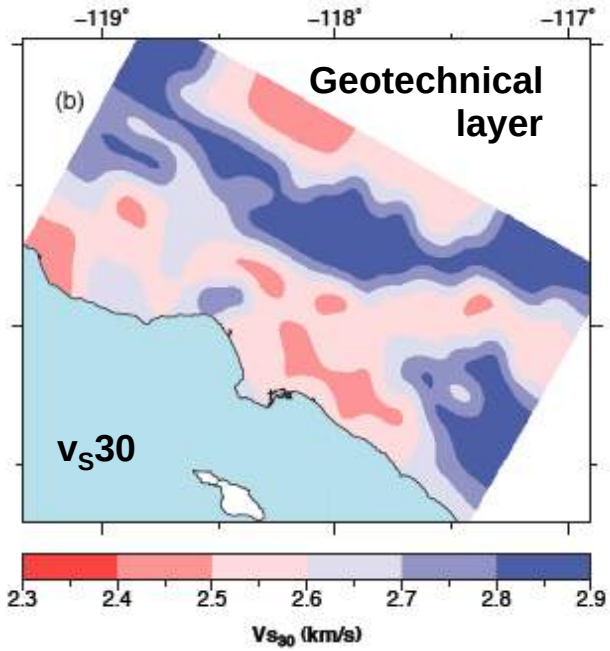


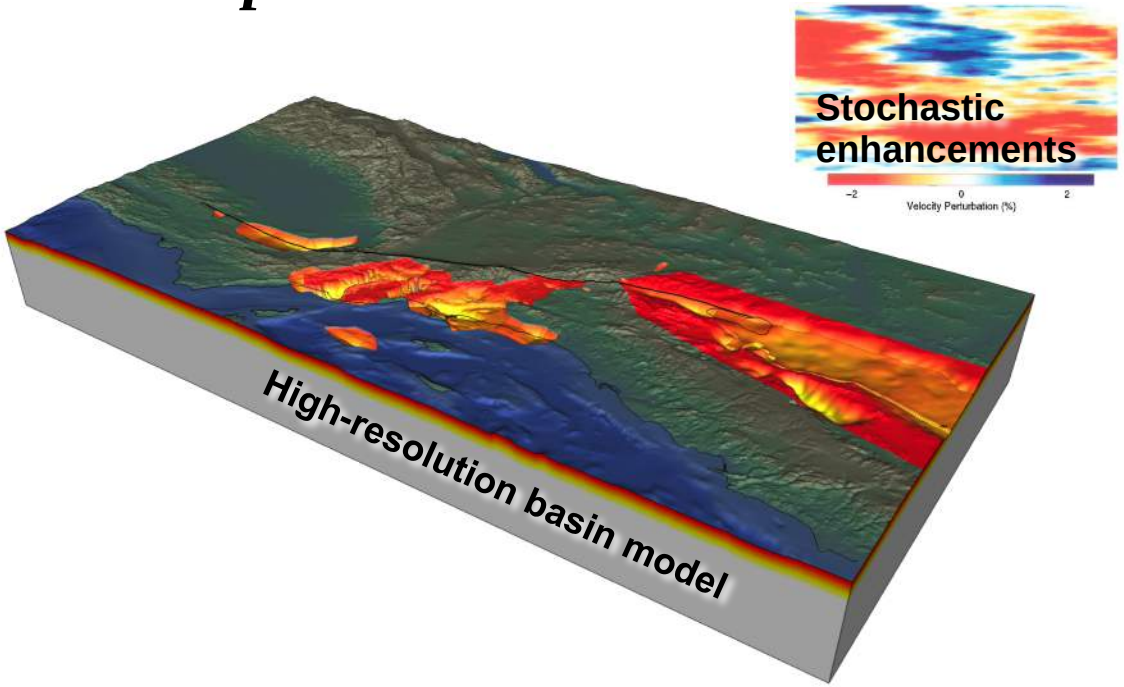
CyberShake: Essential ingredients

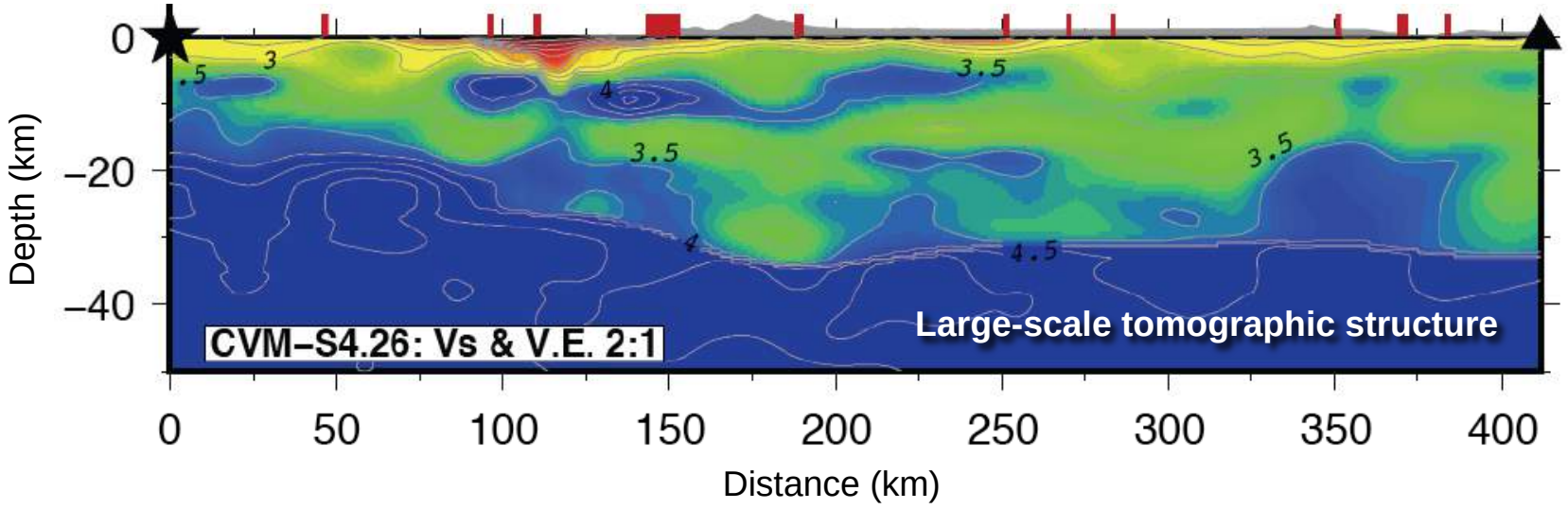
1. **Extended earthquake rupture forecast**
   - **probabilities of all fault ruptures (e.g., UCERF2)**
   - **conditional hypocenter distributions for rupture sets**
   - **conditional slip distributions from pseudo-dynamic models**
2. **Three-dimensional models of geologic structure**
   - **large-scale crustal heterogeneity**
   - **sedimentary basin structure**
   - **near-surface properties ("geotechnical layer")**

   } from SCEC CVMs
3. **Ability to compute large suites (> 10^8) of seismograms**
   - **efficient anelastic wave propagation (AWP) codes**
   - **reciprocity-based calculation of ground motions**

CVM Components



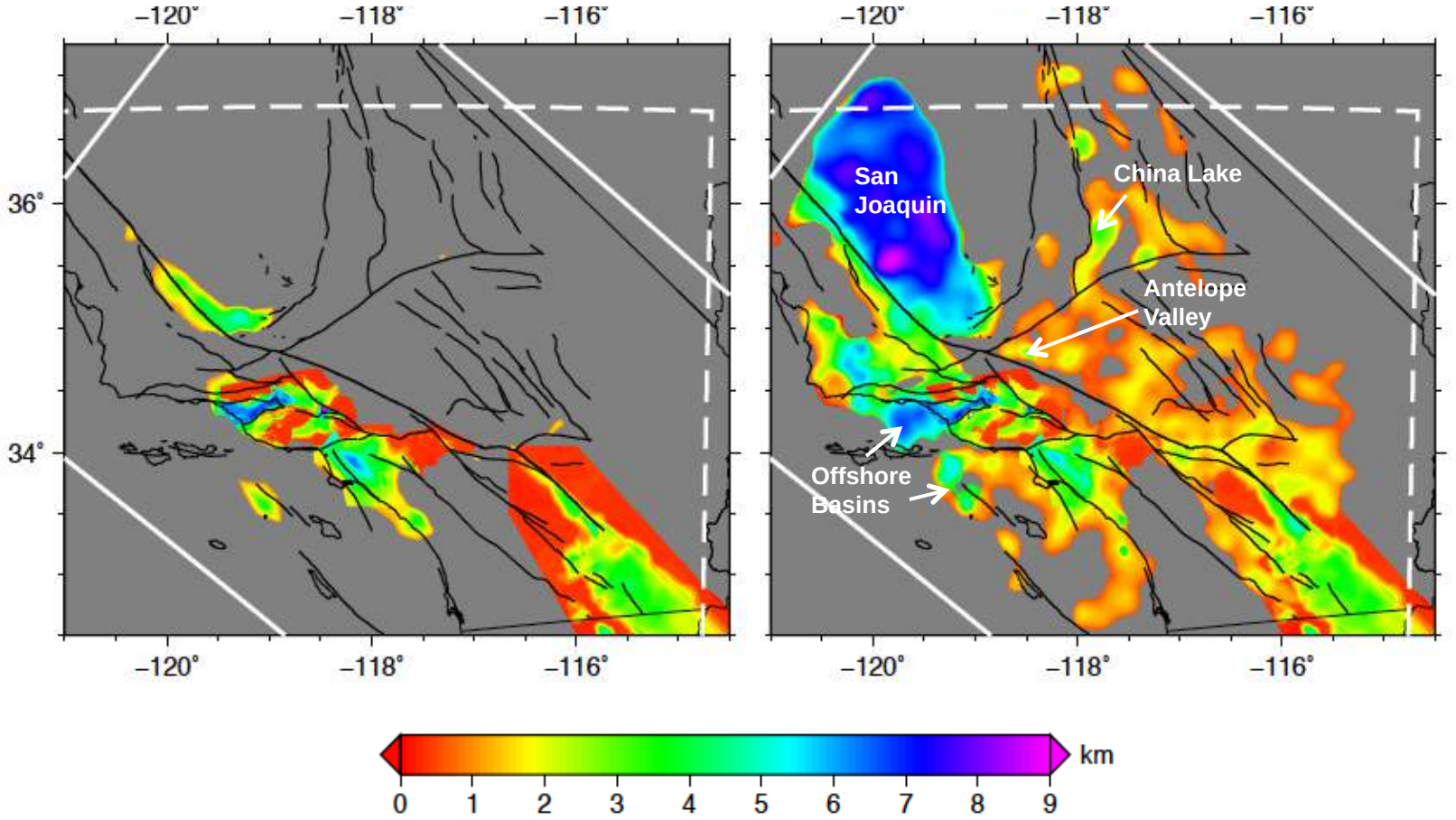




F3DT Improvements to Basin Structures

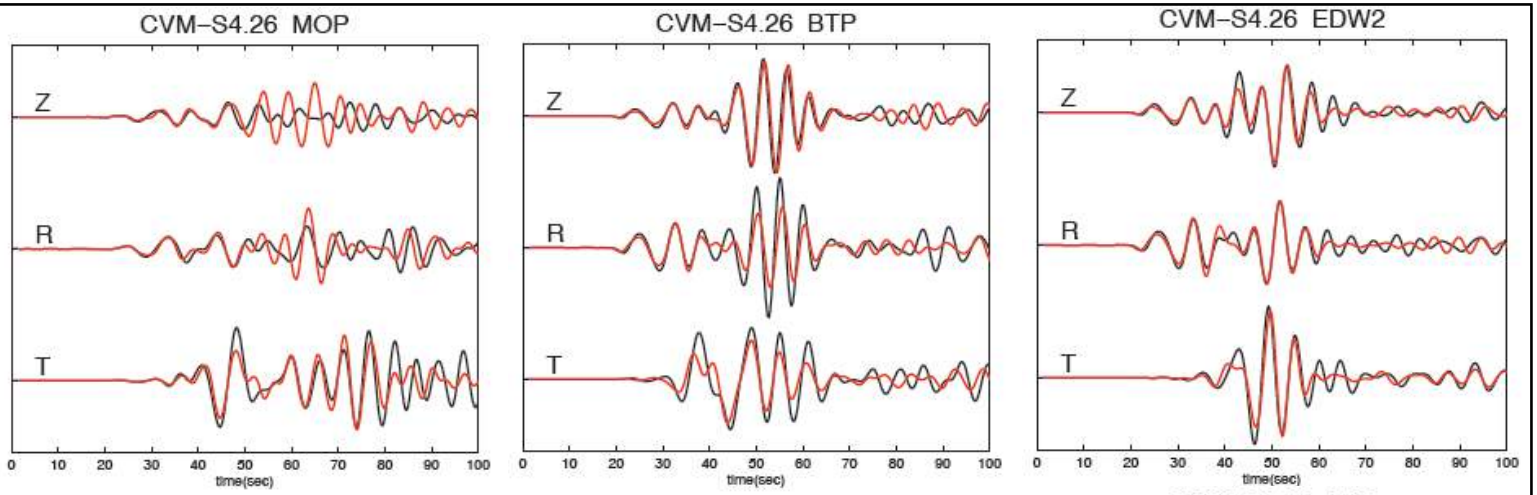
Starting model: CVM-S4

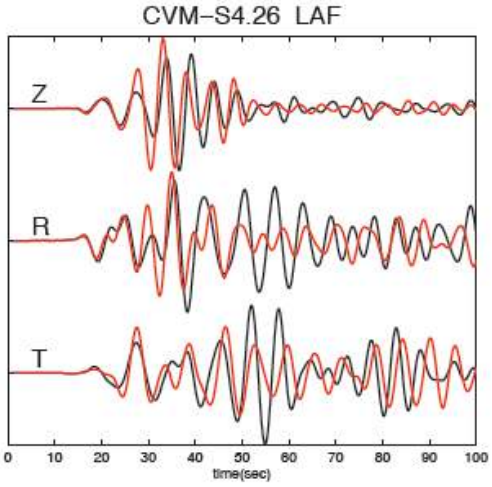
26th Iterate: CVM-S4.26

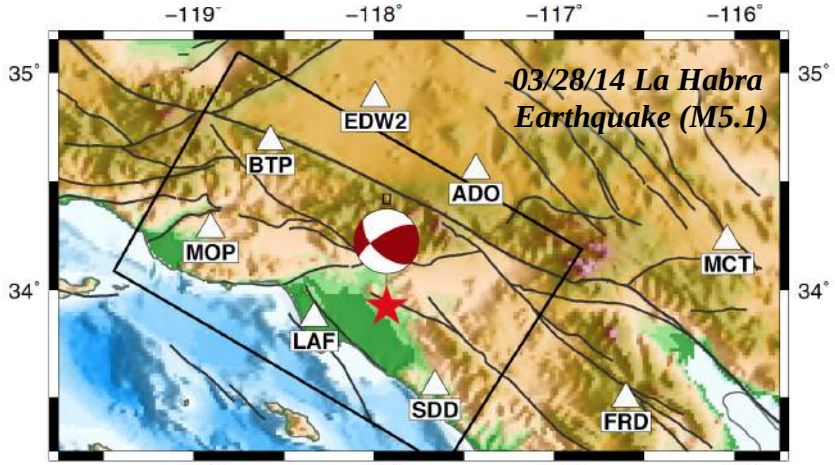


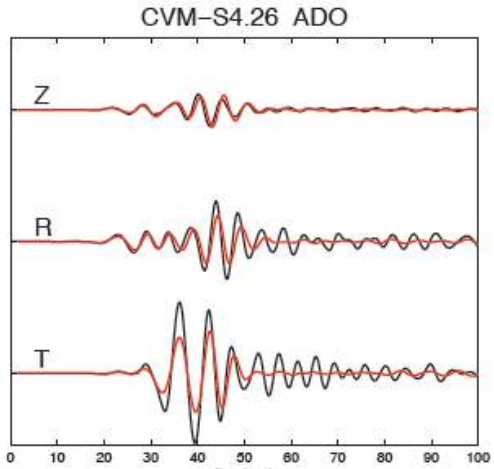
Z_{2500} : iso-velocity surfaces at V_S = 2.5 km/s

Test of CVM-S4.26 synthetics against data from the 03/28/14 La Habra Earthquake (M5.1)

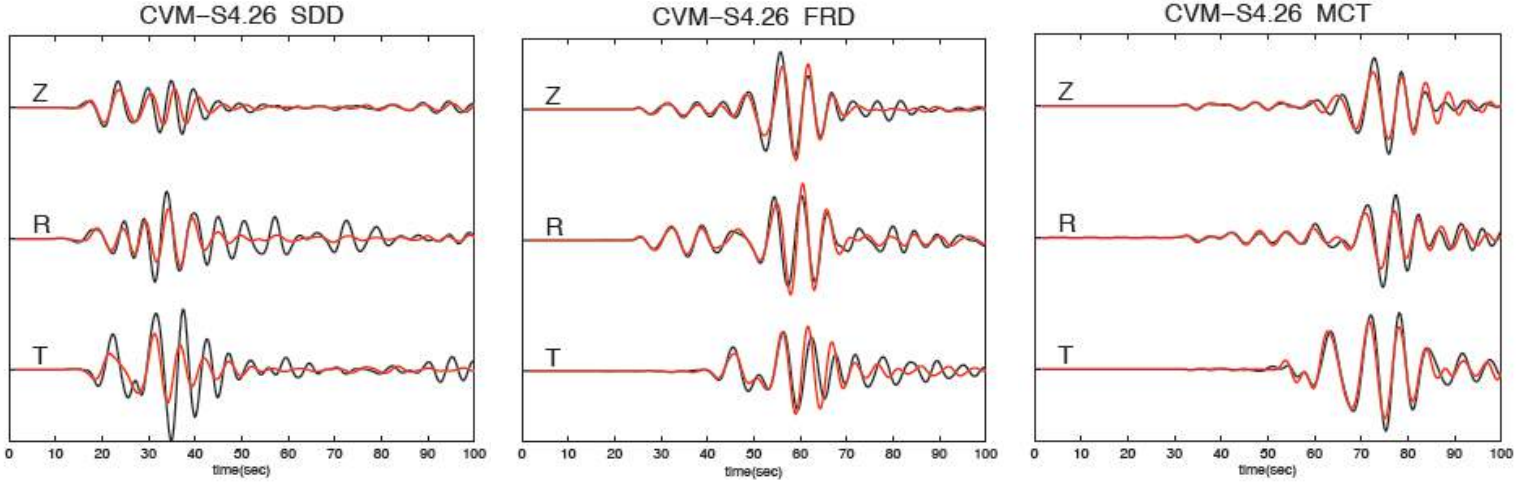






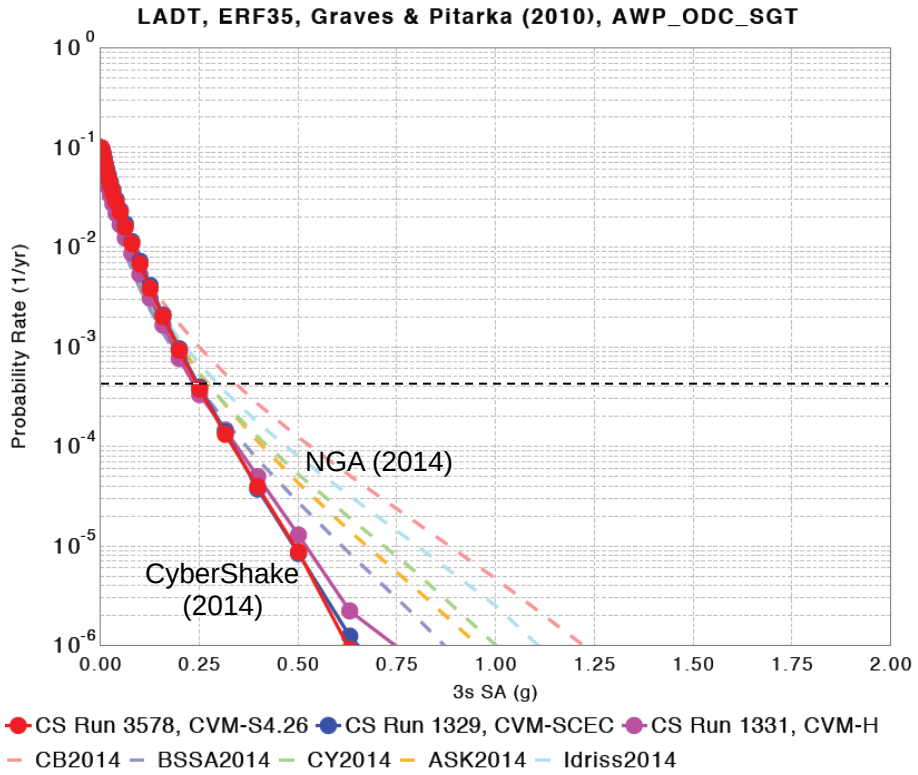


data in black,
synthetics in red,
low-passed at 0.2 Hz

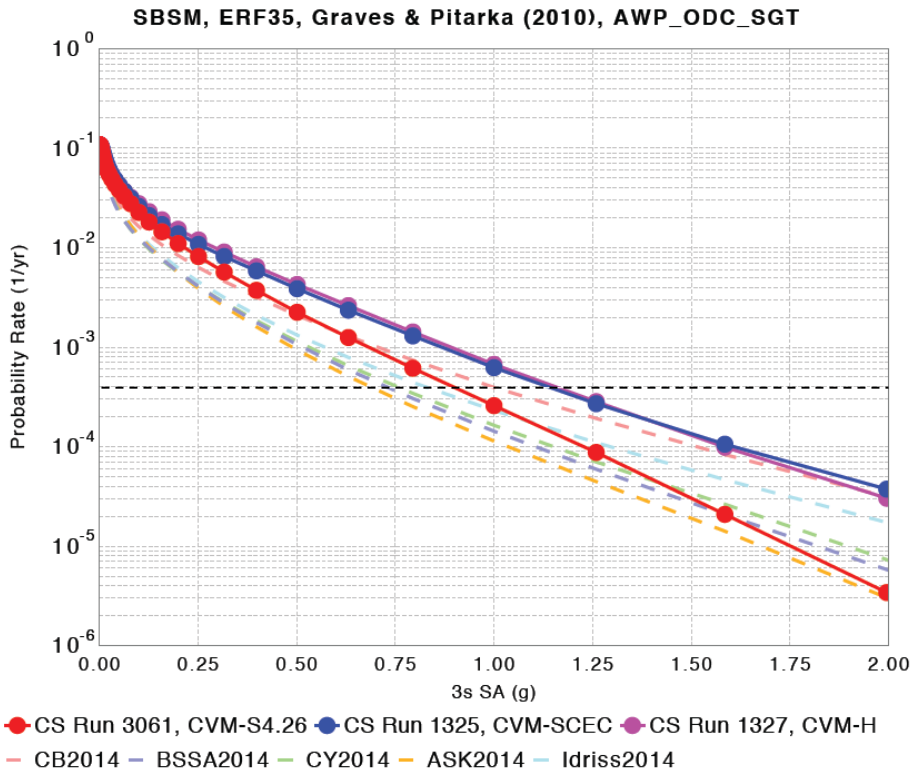


NGA(2014)-CyberShake Hazard Curve Comparisons

Intensity measure: RotD50 SA-3s



Site LADT
(Los Angeles)



Site SBSM
(San Bernardino)

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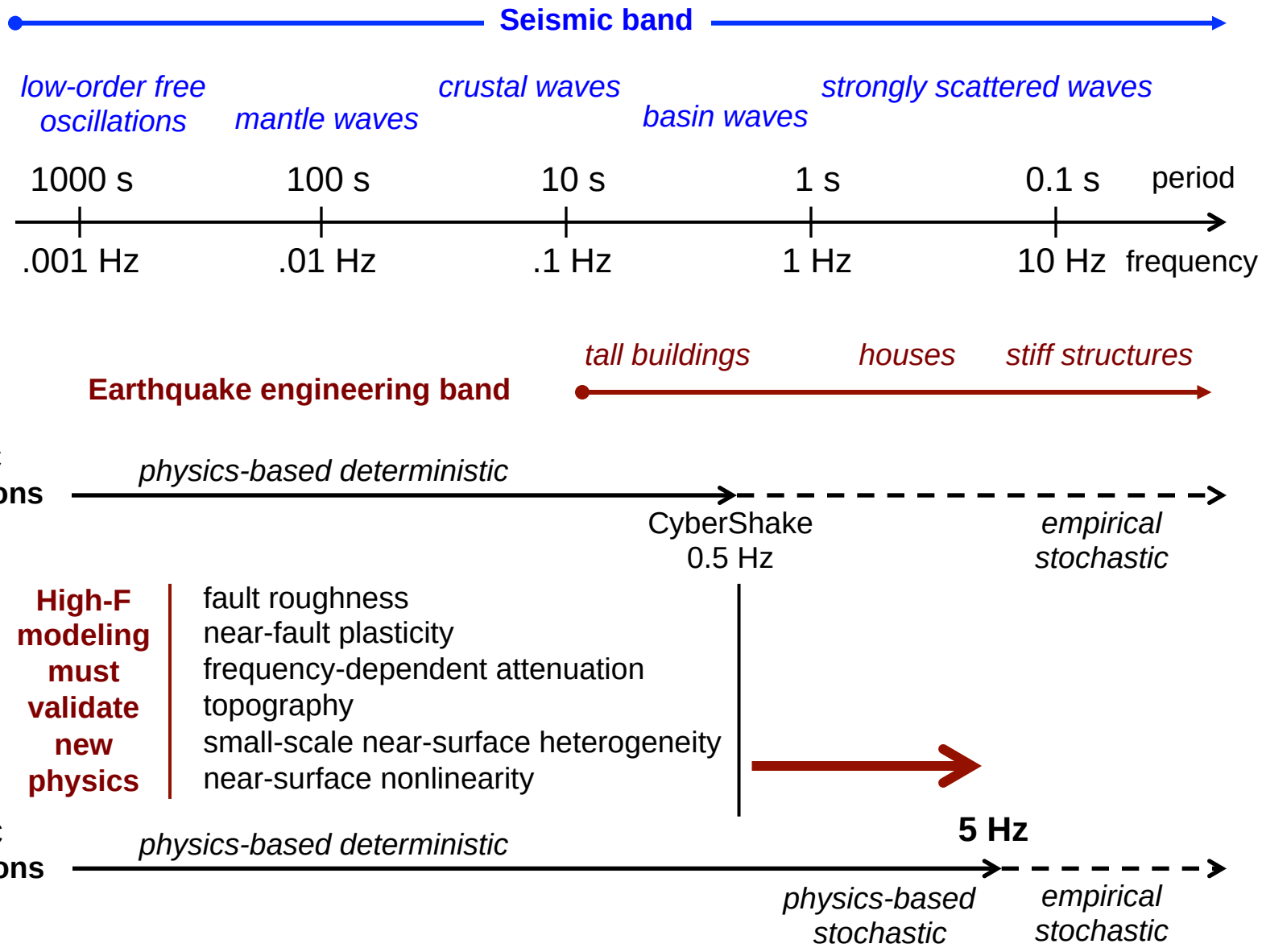
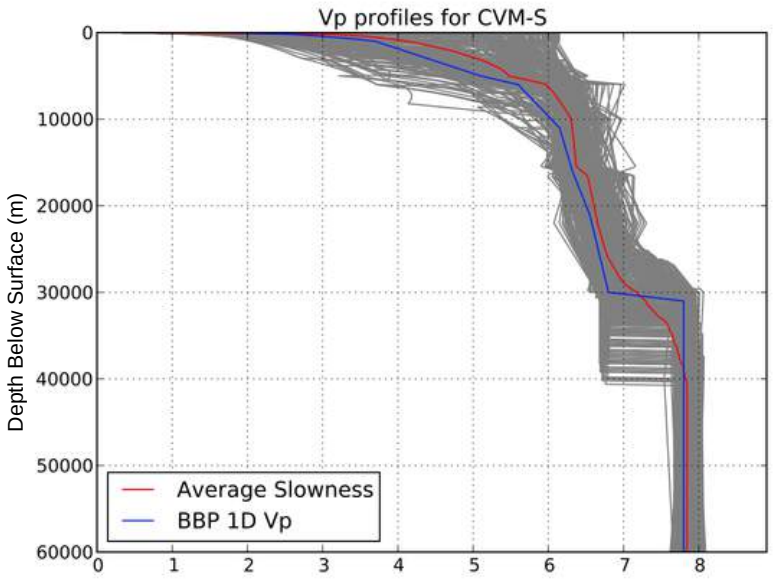
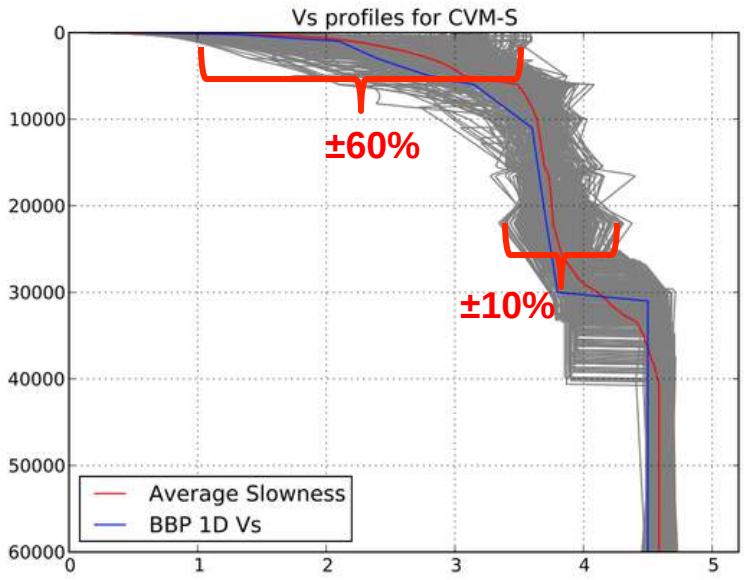
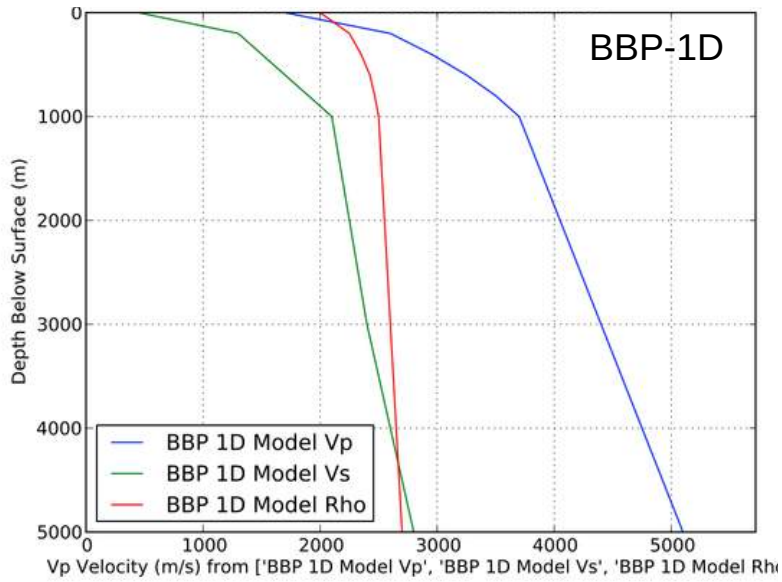
SCEC High-F Project: Push to Higher Seismic Frequencies

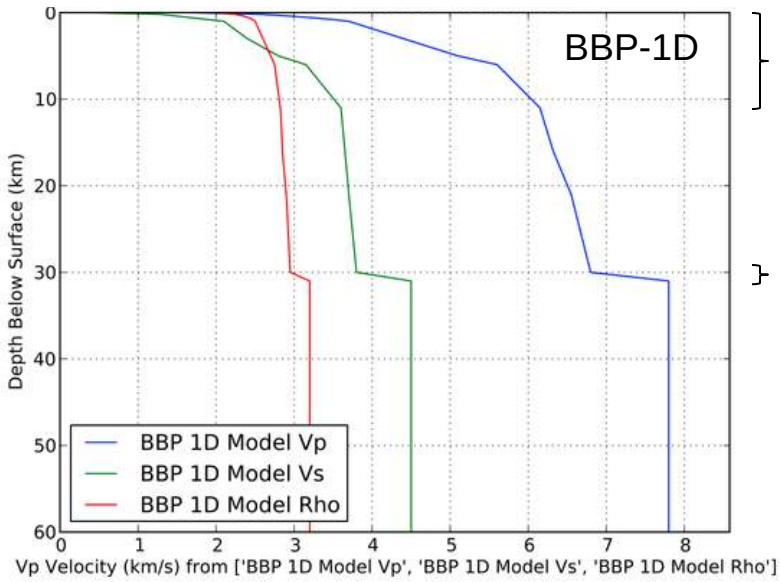


BBP-1D Regional Model



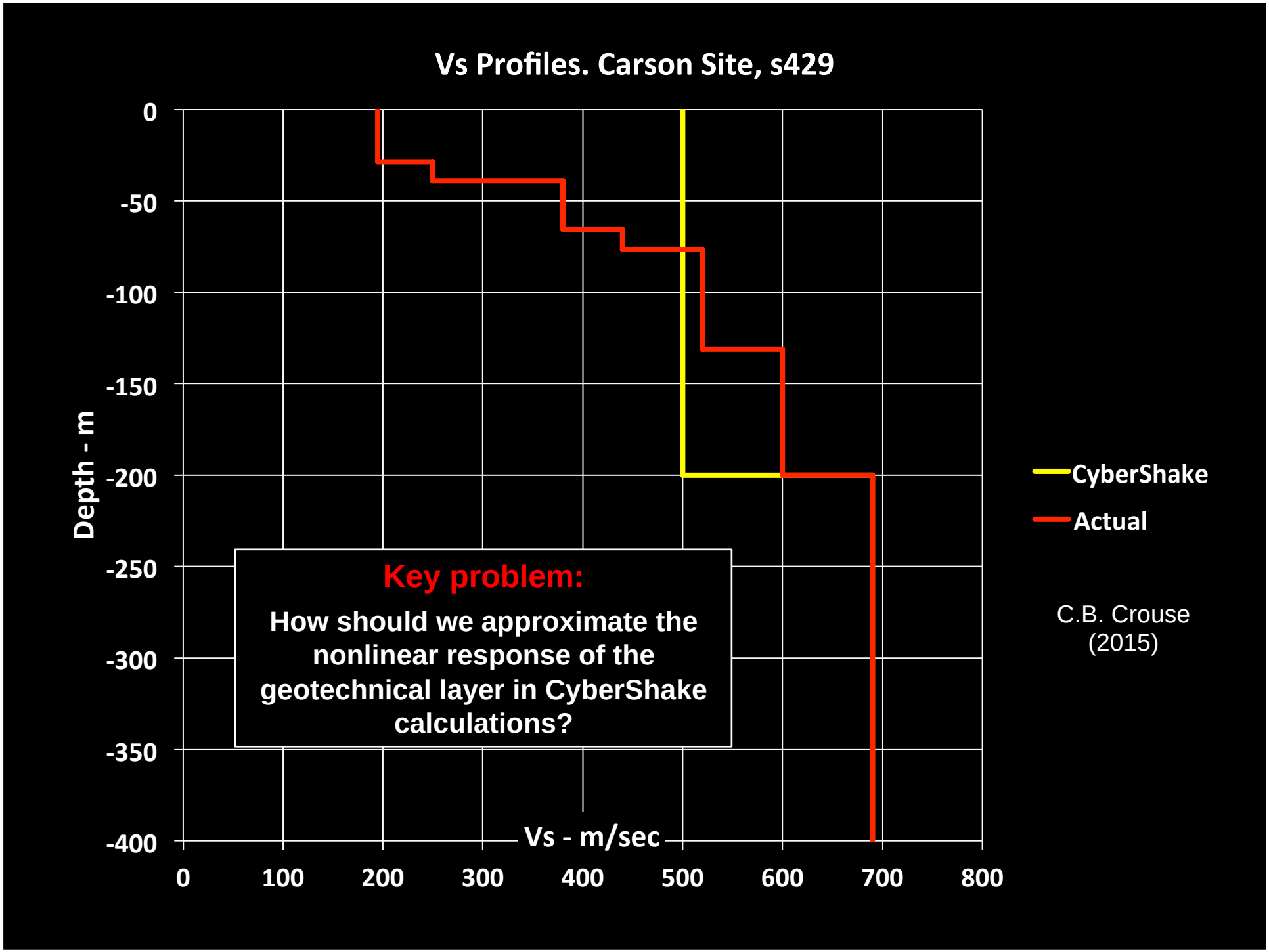






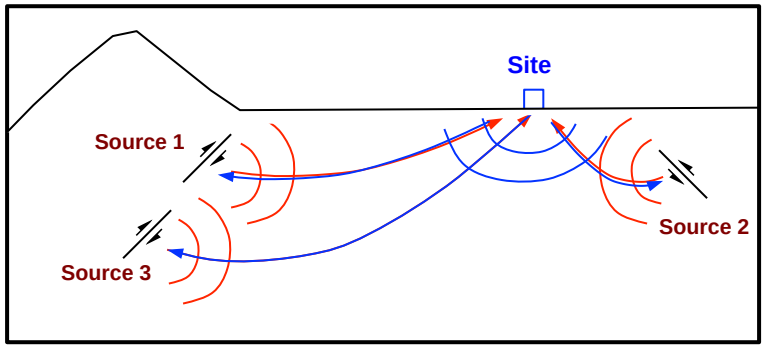
Near-surface waveguide

Moho


Vs Profiles. Carson Site, s429
Depth - m
0
-50
-100
-150
-200
-250
-300
-350
-400
Vs - m/sec
0
100
200
300
400
500
600
700
800
CyberShake
Actual
Key problem:
How should we approximate the nonlinear response of the geotechnical layer in CyberShake calculations?
C.B. Crouse (2015)

Rapid Simulation of Large Rupture Ensembles

- **To account for source variability requires very large sets of simulations**
  - **14,900 ruptures from UCERF2; 415,000 rupture variations**
- **Ground motions need only be calculated at much smaller number of surface sites to produce hazard map**
  - **289 in LA region, interpolated using empirical GMPEs to obtain hazard maps**
- **Use of seismic reciprocity reduces CPU time by a factor of ~1,000**
  - **Depends on linearity of the wave equation**



Key problem:

Can we approximately account for near-source and near-surface nonlinearities while retaining the computational advantages of reciprocity?

***M* sources to *N* sites requires *M* simulations**

***M* sources to *N* sites requires 2*N* or 3*N* simulations**

End