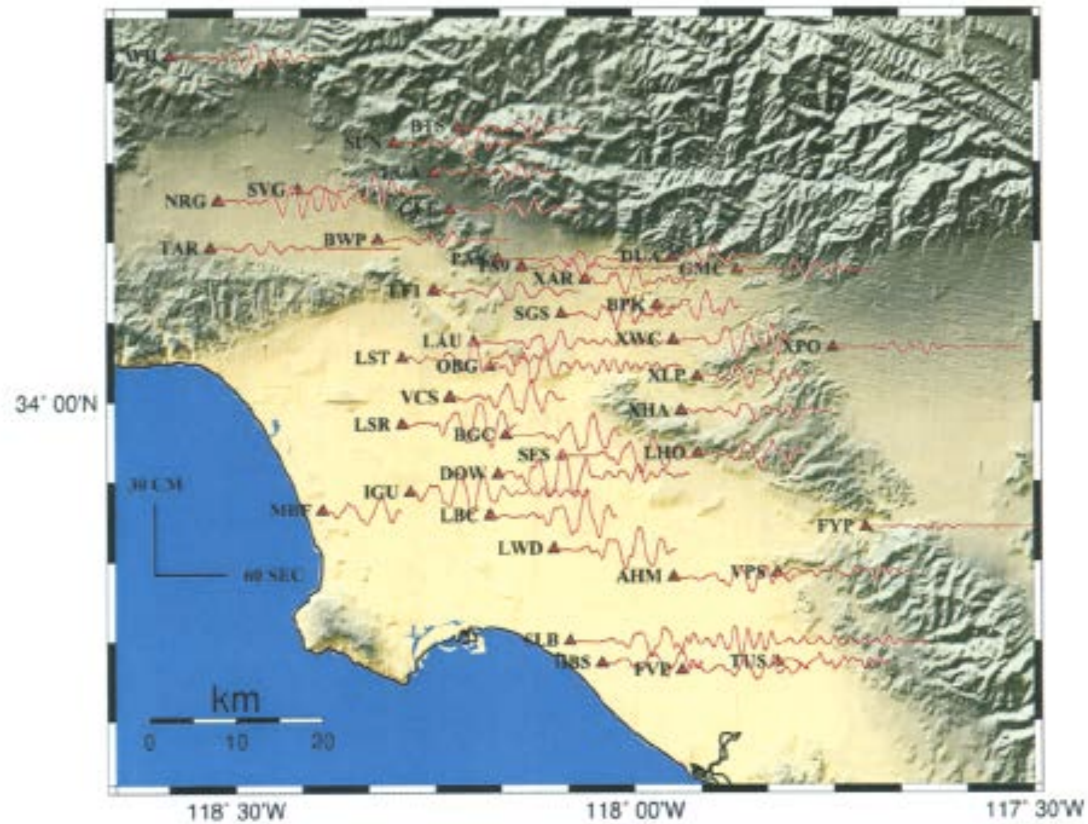
Use of 3D earthquake ground motion simulations in future updates of the NSHM

Morgan Moschetti
U.S. Geological Survey

2018 National Seismic Hazard Model Workshop
Newark, CA
March 8, 2018

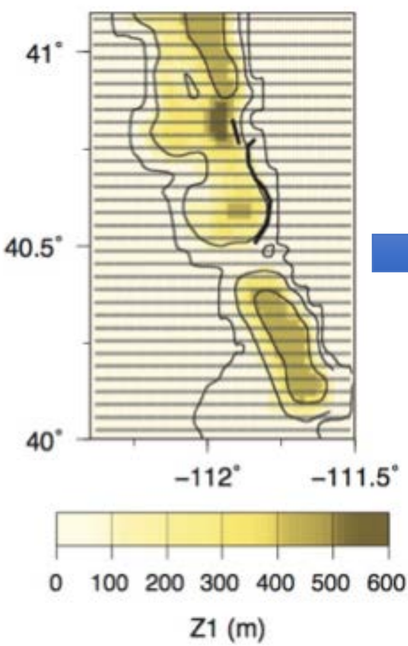
Wald and Graves (1998, BSSA)

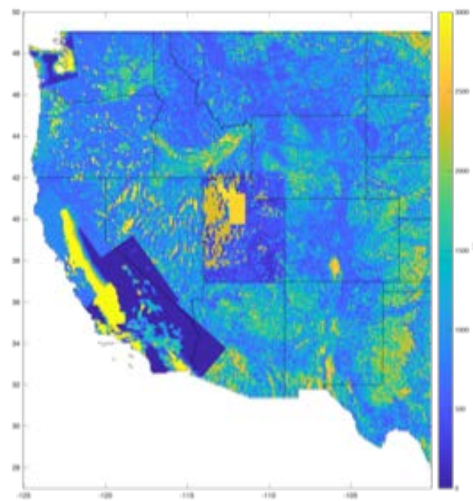


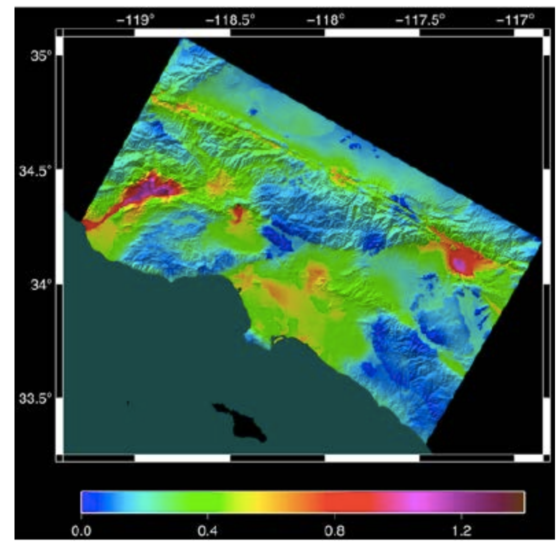
Displacements from M7.3 Landers EQ (2–17-s band-pass)

- Wave-structure interactions (amplification—structure deeper than 30 m, incidence at basin geometry, surface waves, trapping, scattering)
- Wave-wave interactions (basin-edge)

Plan for incorporating basin effects: 2018, 2020 NSHM and beyond



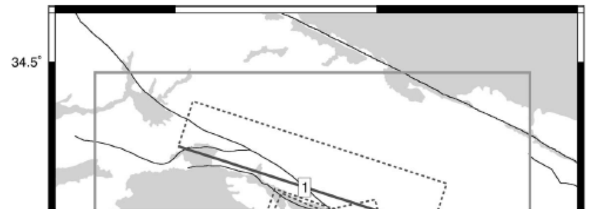


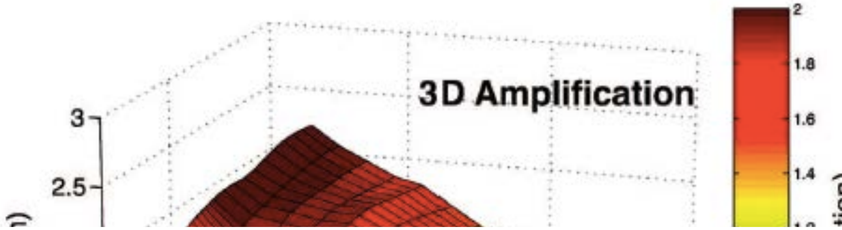


1) **Empirical GMPEs, varying Vs30 values, default basin depths**
2) **Empirical GMPEs, varying Vs30 values, basin depths (Z1/Z2.5)**
3) **Use of GMPEs with basin amplifications from 3-D simulations**

Outline

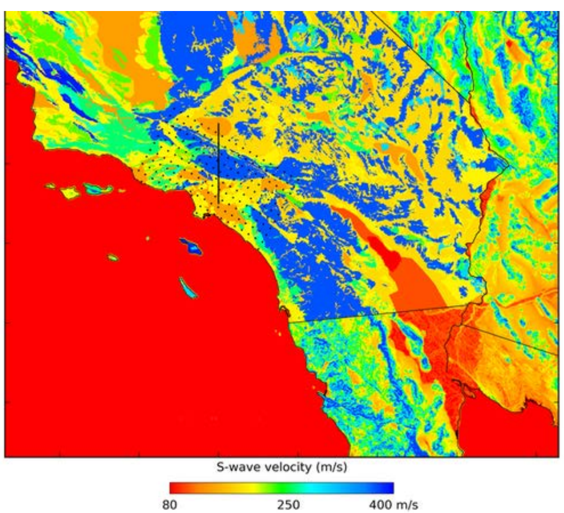
- Influence of 3D simulations in empirical GMMs (NGA-West-2)
- Motivation for use of regional 3D simulations
- Availability of 3D-simulations in western U.S.
- Requirements for using ground motions from 3D simulations
- Plan for incorporating ground motions from 3D simulations into NSHM
- Example hazard sensitivity from use of basin terms from the SCEC CyberShake simulations



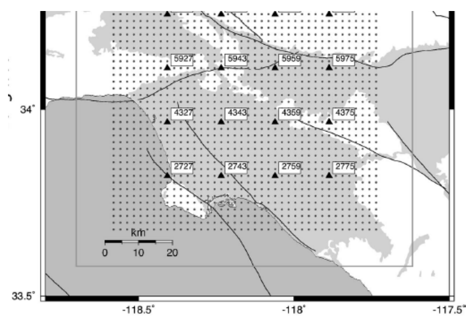


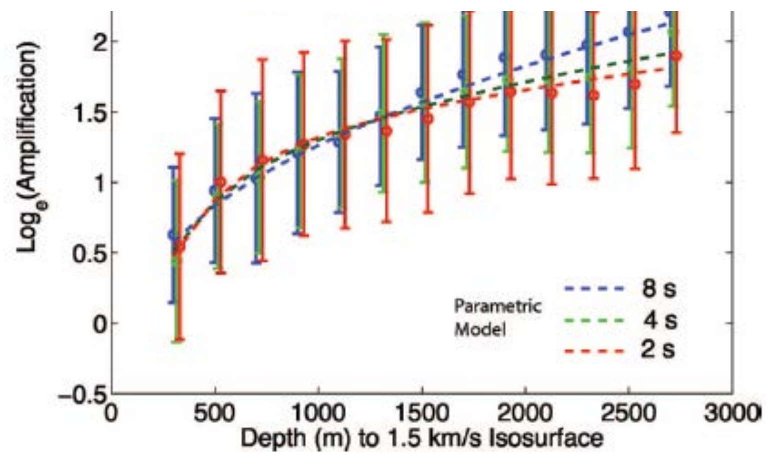
The trend for $Z_{2.5} > 3$ km, which is due presumably to 3-D basin effects, was based on too few data to empirically determine how these effects could be extrapolated with sediment depth and spectral period. Instead, this trend was constrained using the sediment-depth model developed by Day (2005) and Day et al. (2005) from theoretical ground motion simulations of the 3-D response of the Los Angeles, San Gabriel, and San Fernando basins in southern California.

Campbell and Bozorgnia (2007, PEER)

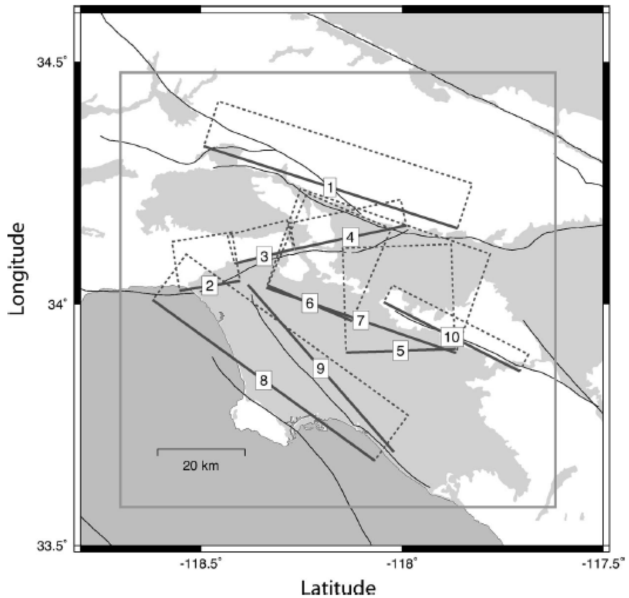


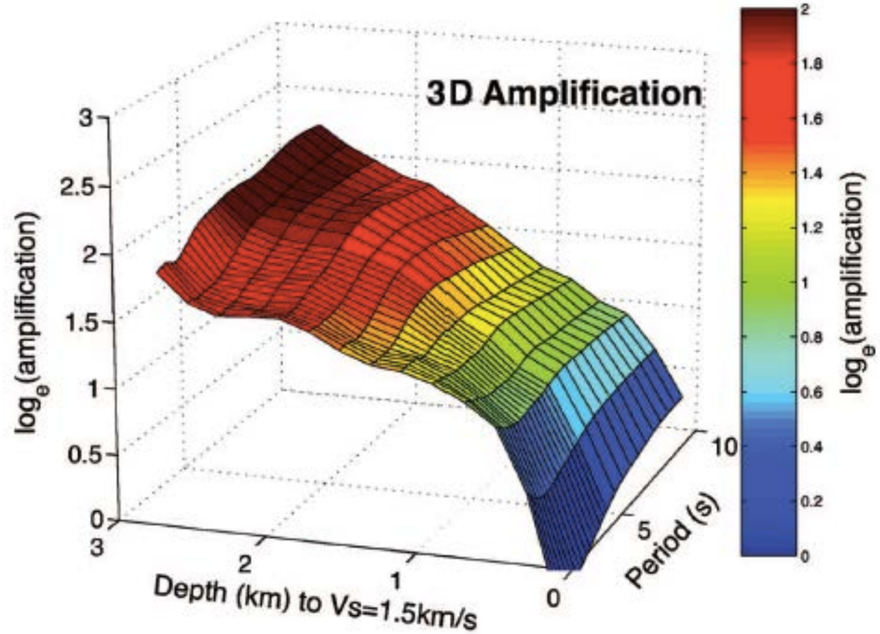
GTL surface S-wave velocity derived from Wills and Clahan (2006) geology based V_{S30} map, supplemented outside of California with Wald et al. (2007) map.



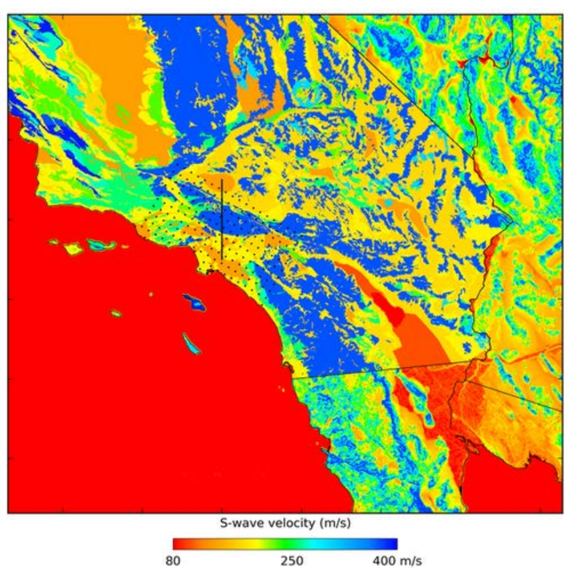


Day et al. (2005, PEER; 2008, EQS)

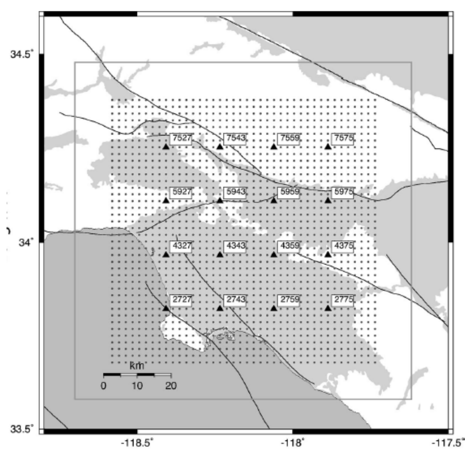


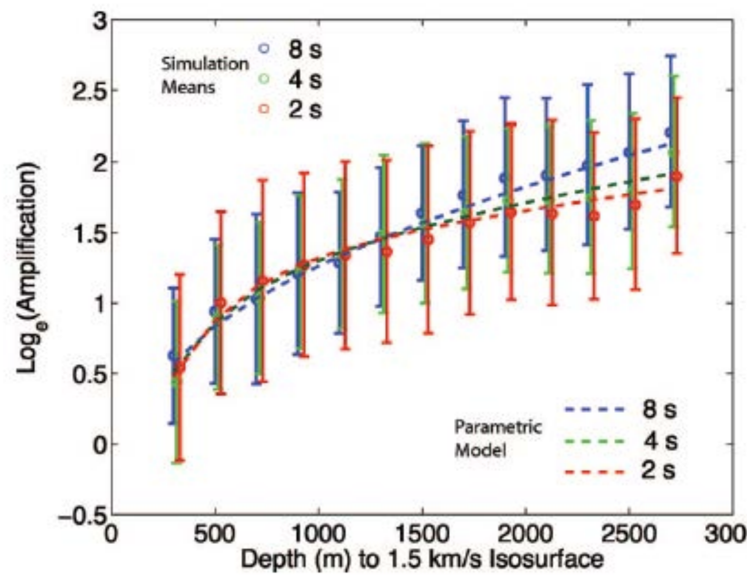


CVM-H v6.3 + GTL



GTL surface S-wave velocity derived from Wills and Clahan (2006) geology based V_{S30} map, supplemented outside of California with Wald et al. (2007) map.





Day et al. (2005, PEER; 2008, EQS)

Key questions for implementation of basin amplifications (and potential for 3D simulations)

- How well are basin depths constrained?
- How well do the GMPEs behave in the regions for which they were developed?
- How similar is the geologic structure/geometry of sedimentary basins in different regions (e.g., Los Angeles, San Francisco Bay Area, Seattle, Salt Lake City)?

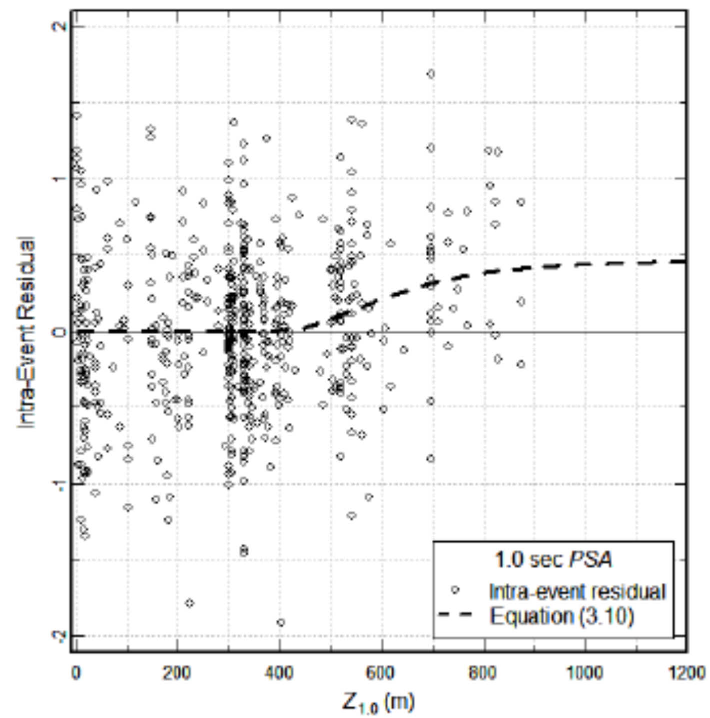
Chiou and Youngs (2008; PEER)

Key questions for implementation of basin amplifications (and potential for 3D simulations)

- ~~How well are basin depths constrained?~~
- How well do the GMPEs behave in the regions for which they were developed?
- How similar is the geologic structure/geometry of sedimentary basins in different regions (e.g., Los Angeles, San Francisco Bay Area, Seattle, Salt Lake City)?

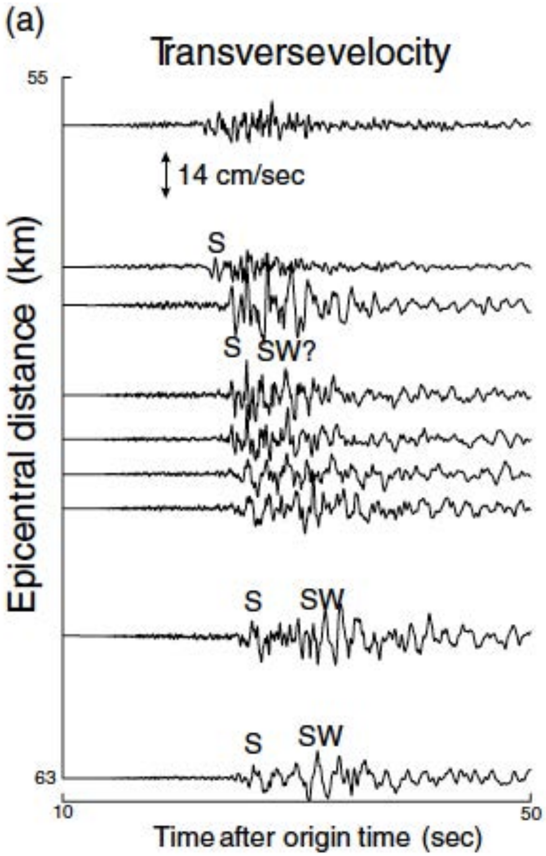
Key questions for implementation of basin amplifications (and potential for 3D simulations)

- ~~How well are basin depths constrained?~~
- How well do the GMPEs behave in the regions for which they were developed?
- How similar is the geologic structure/geometry of sedimentary basins in different regions (e.g., Los Angeles, San Francisco Bay Area, Seattle, Salt Lake City)?

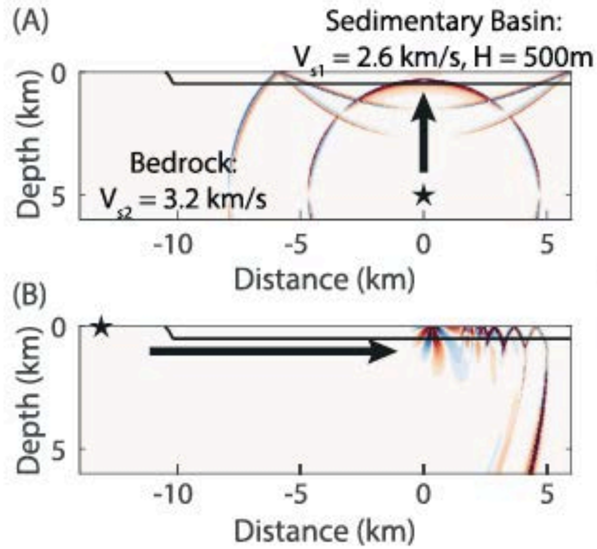


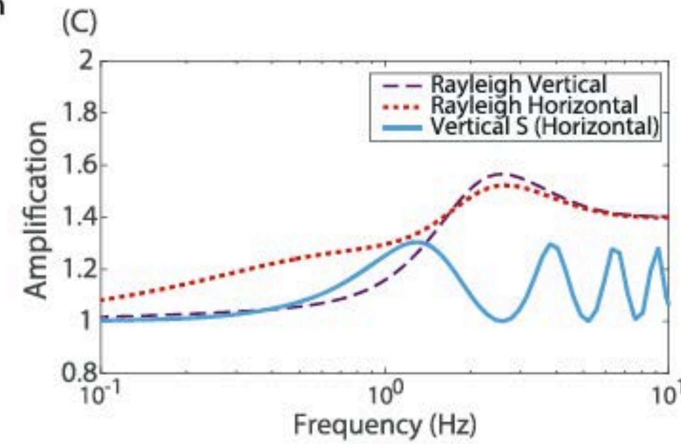
Chiou and Youngs (2008; PEER)

Differences in body- and surface-wave amplification

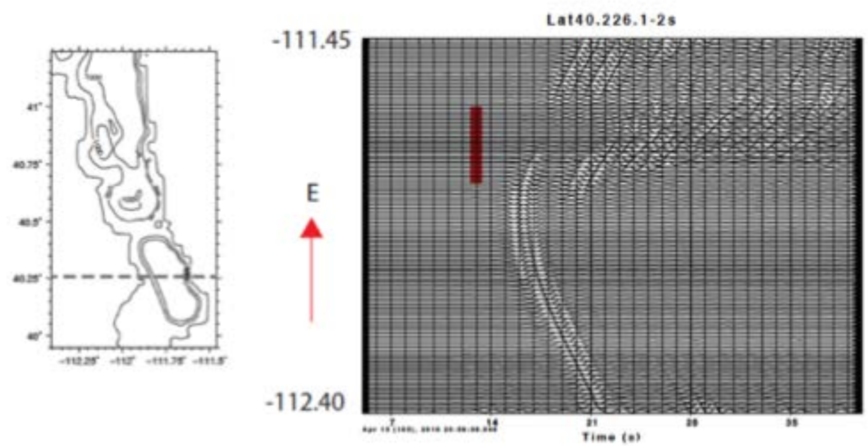


Frankel et al. (2002; BSSA)





Bowden and Tsai (2017; GRL)

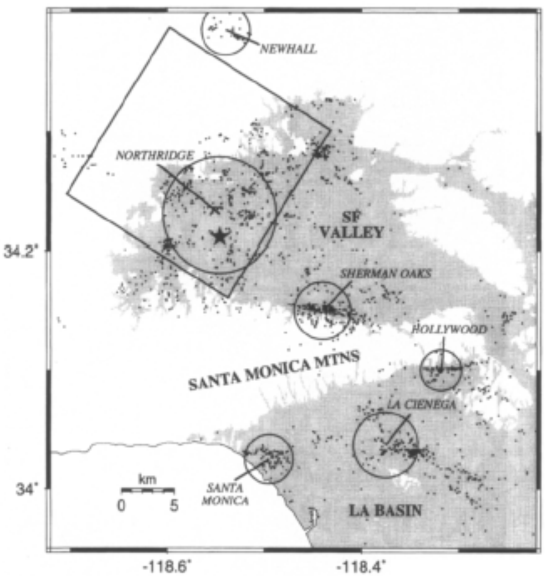


Higher-order effects of sedimentary basins

Hyogo-ken Nambu 1995, Kobe

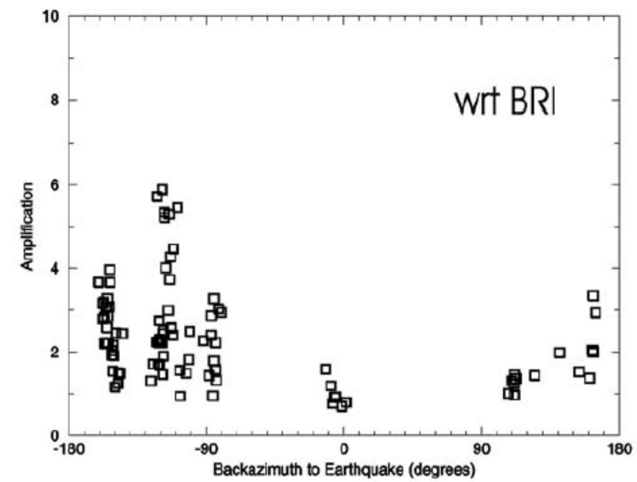
Kawase (1996)

Northridge 1994, Los Angeles



Graves et al. (1998)

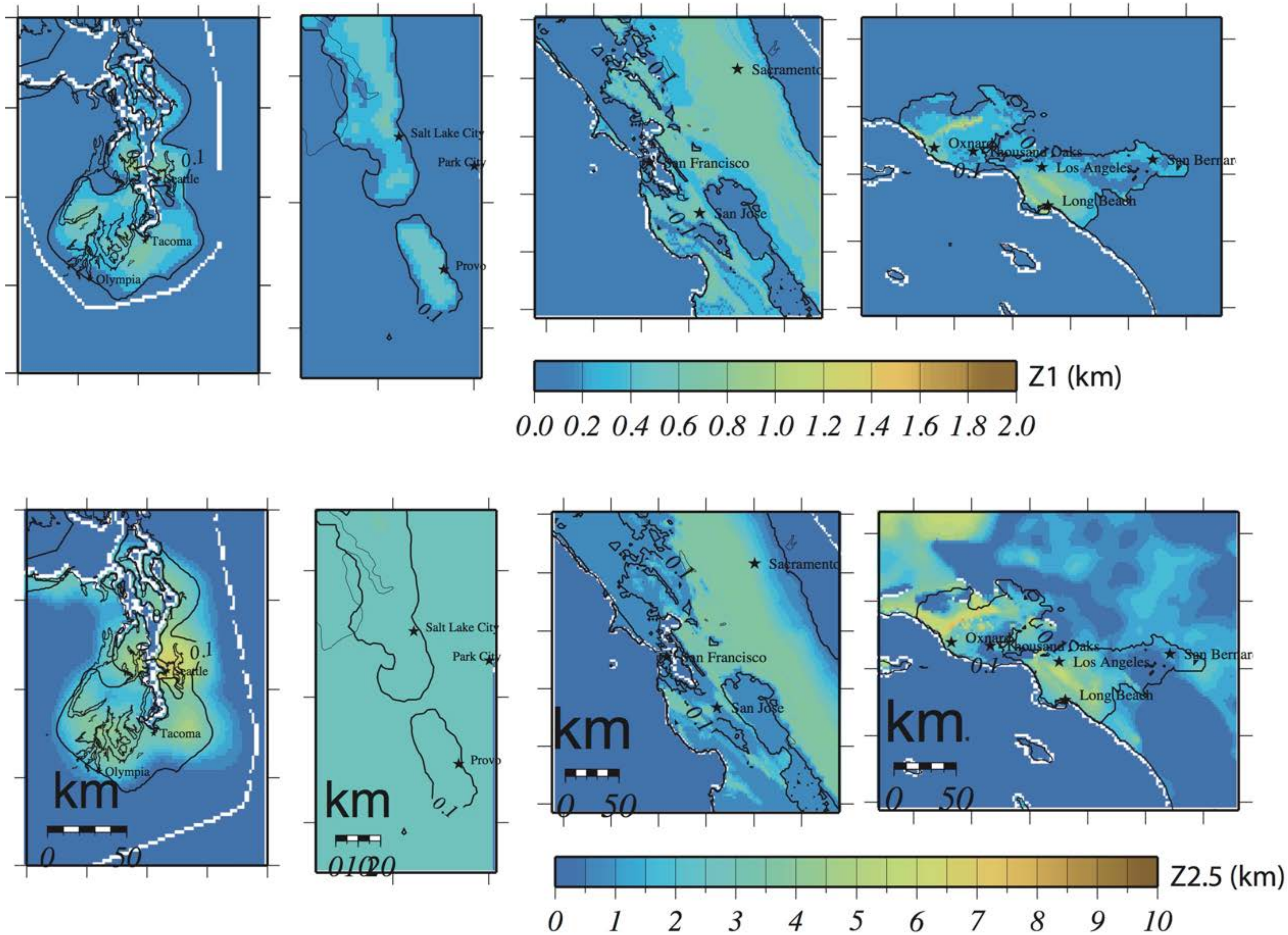
1-Hz amplifications, Seattle



Frankel et al. (2009)

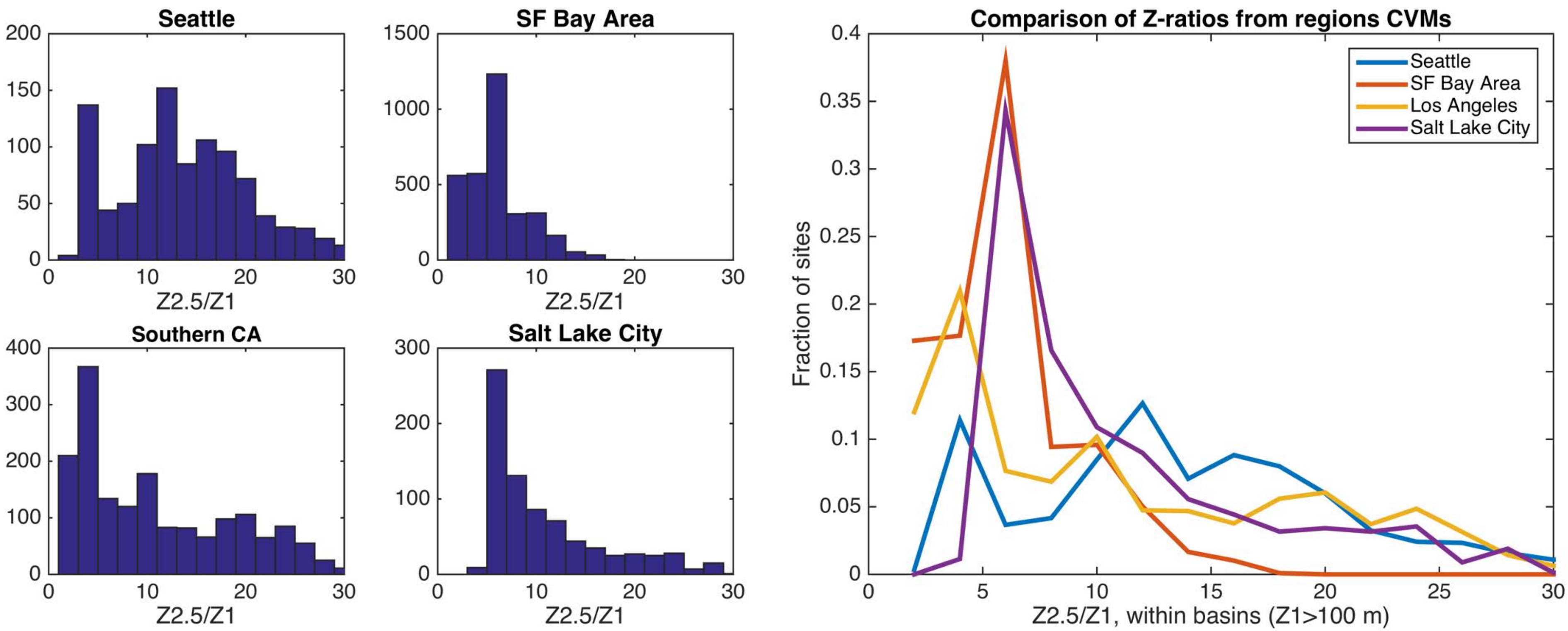
Key questions for implementation of basin amplifications (and potential for 3D simulations)

- ~~How well are basin depths constrained?~~
- How well do the GMPEs behave in the regions for which they were developed?
- How similar is the geologic structure/geometry of sedimentary basins in different regions (e.g., Los Angeles, San Francisco Bay Area, Seattle, Salt Lake City)?



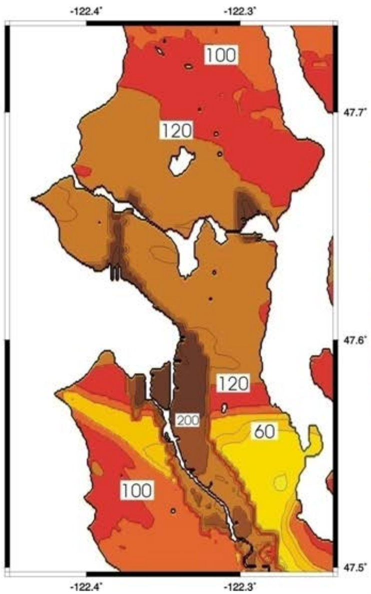
Los Angeles	Z1<1.9 km	Z2.5<8.7 km
Seattle	Z1<0.9 km	Z2.5<6.7 km
SF Bay Area	Z1<0.6km	Z2.5<3.6 km
Salt Lake City	Z1<0.7 km	Z2.5<3.1 km

Variations in basin structure

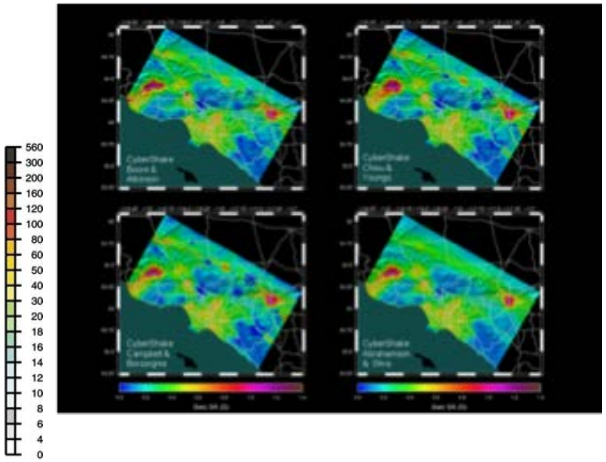


Urban seismic hazard maps

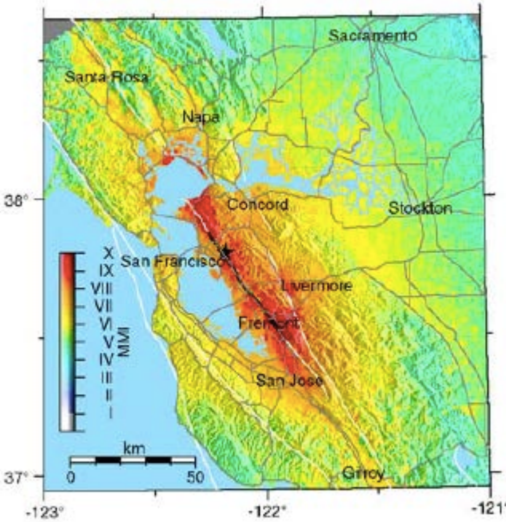
Seattle



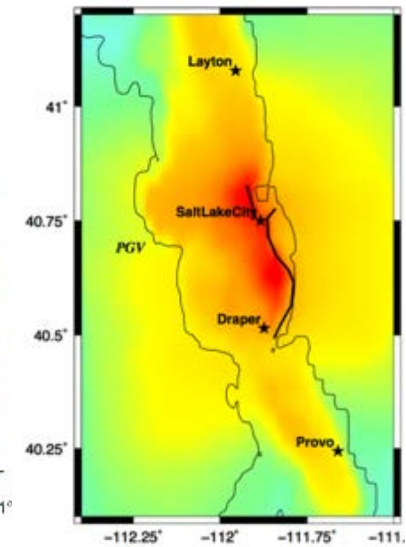
Los Angeles (SCEC CyberShake)



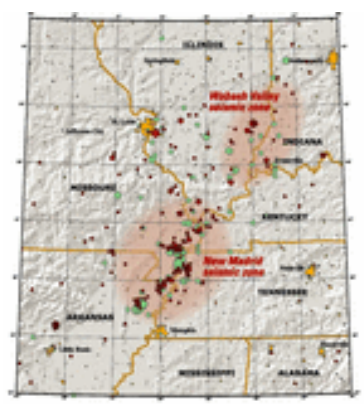
San Francisco Bay Area



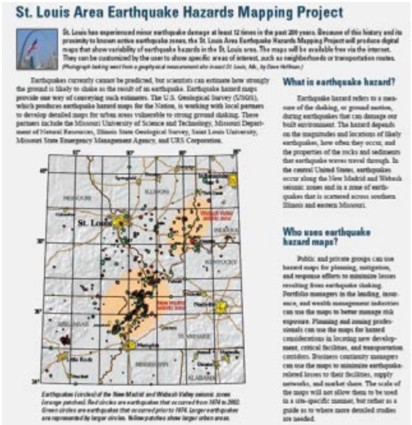
Salt Lake City



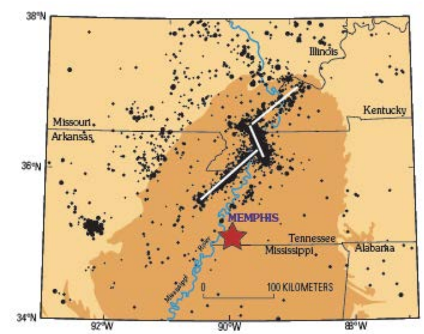
Evansville, IN



St. Louis



Memphis

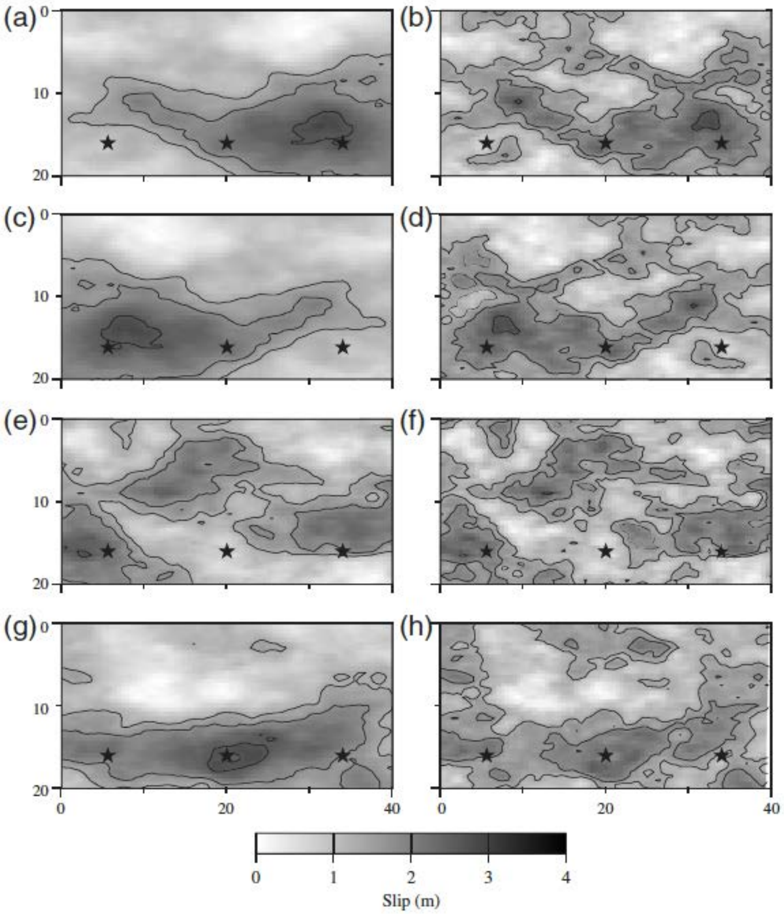


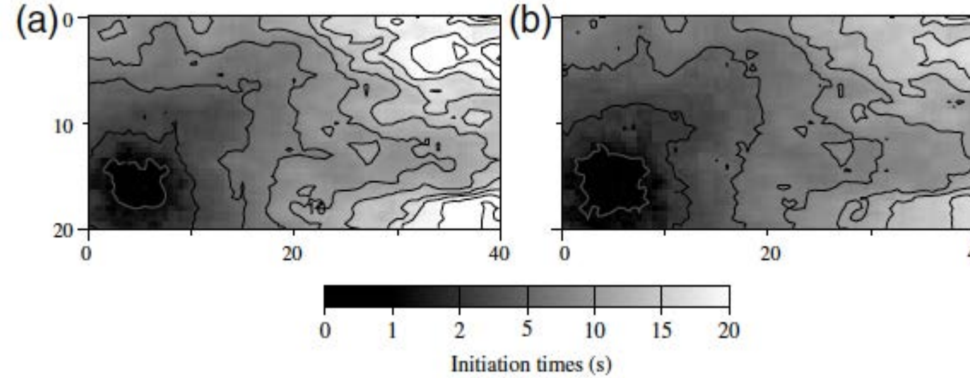
Multiple classes of urban seismic hazard maps

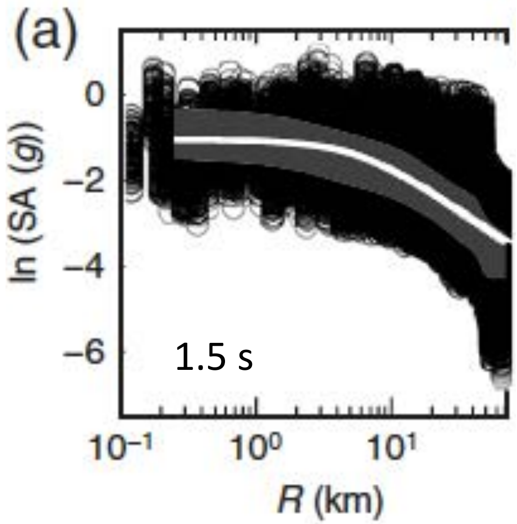
- Including, 3-D simulation-based ground-motions* (Seattle and southern California)

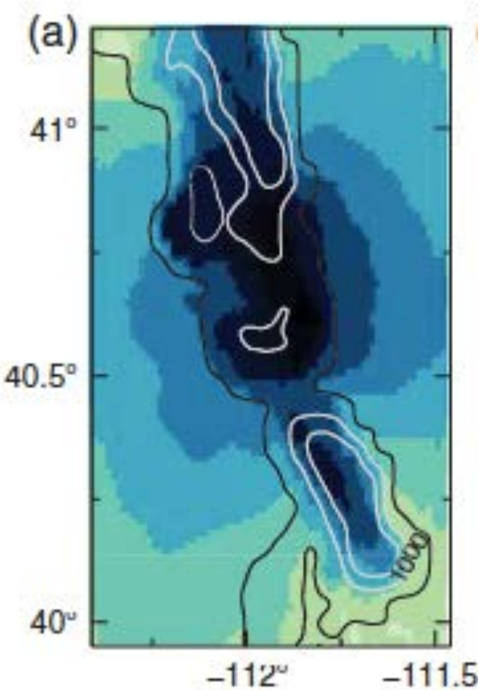
More urban seismic hazard maps in-progress (Reno, Las Vegas, …)

Example from Wasatch Front, Utah



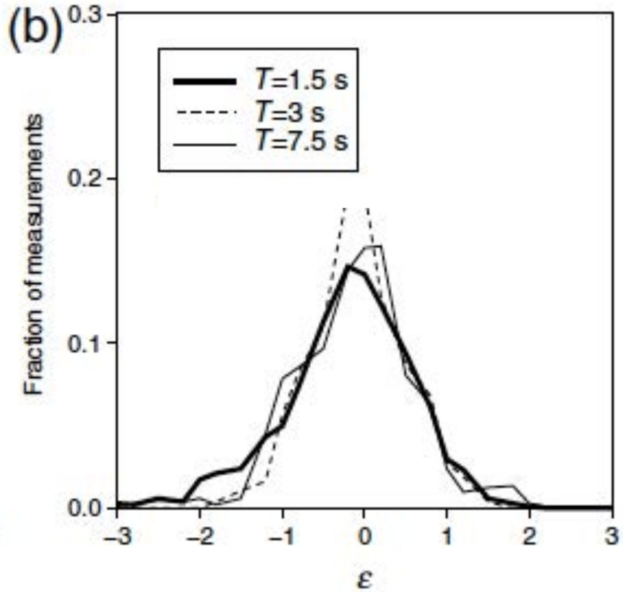


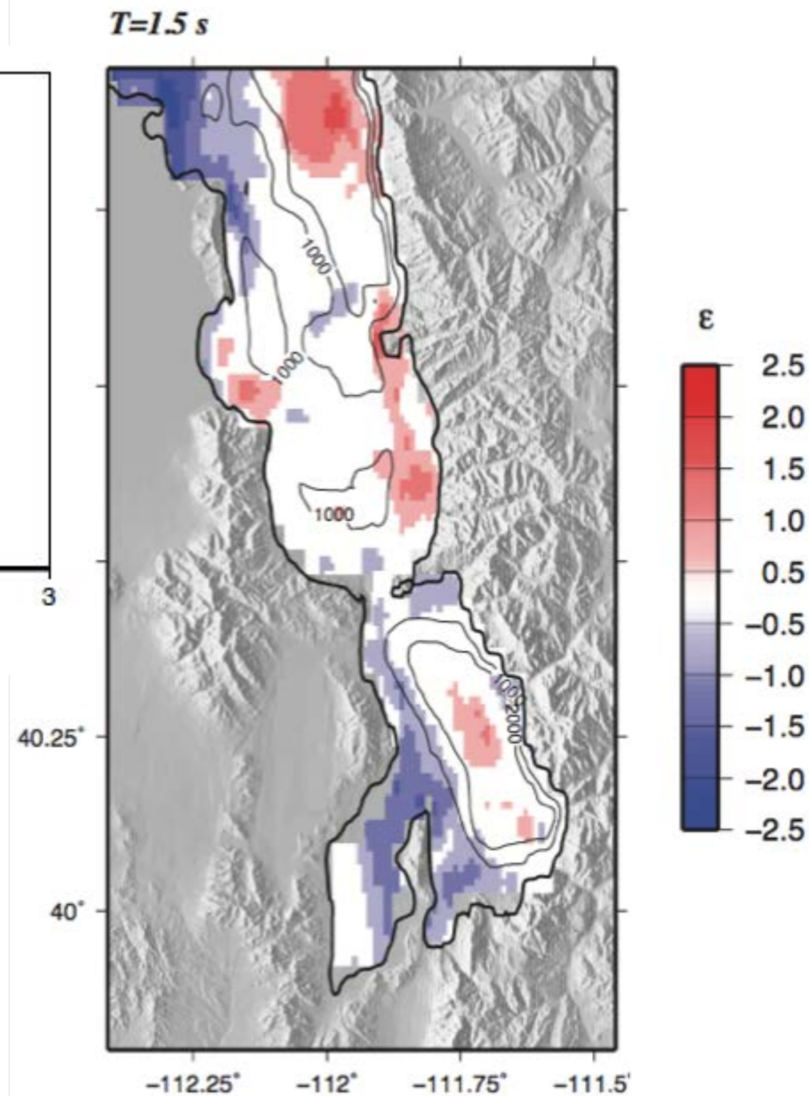




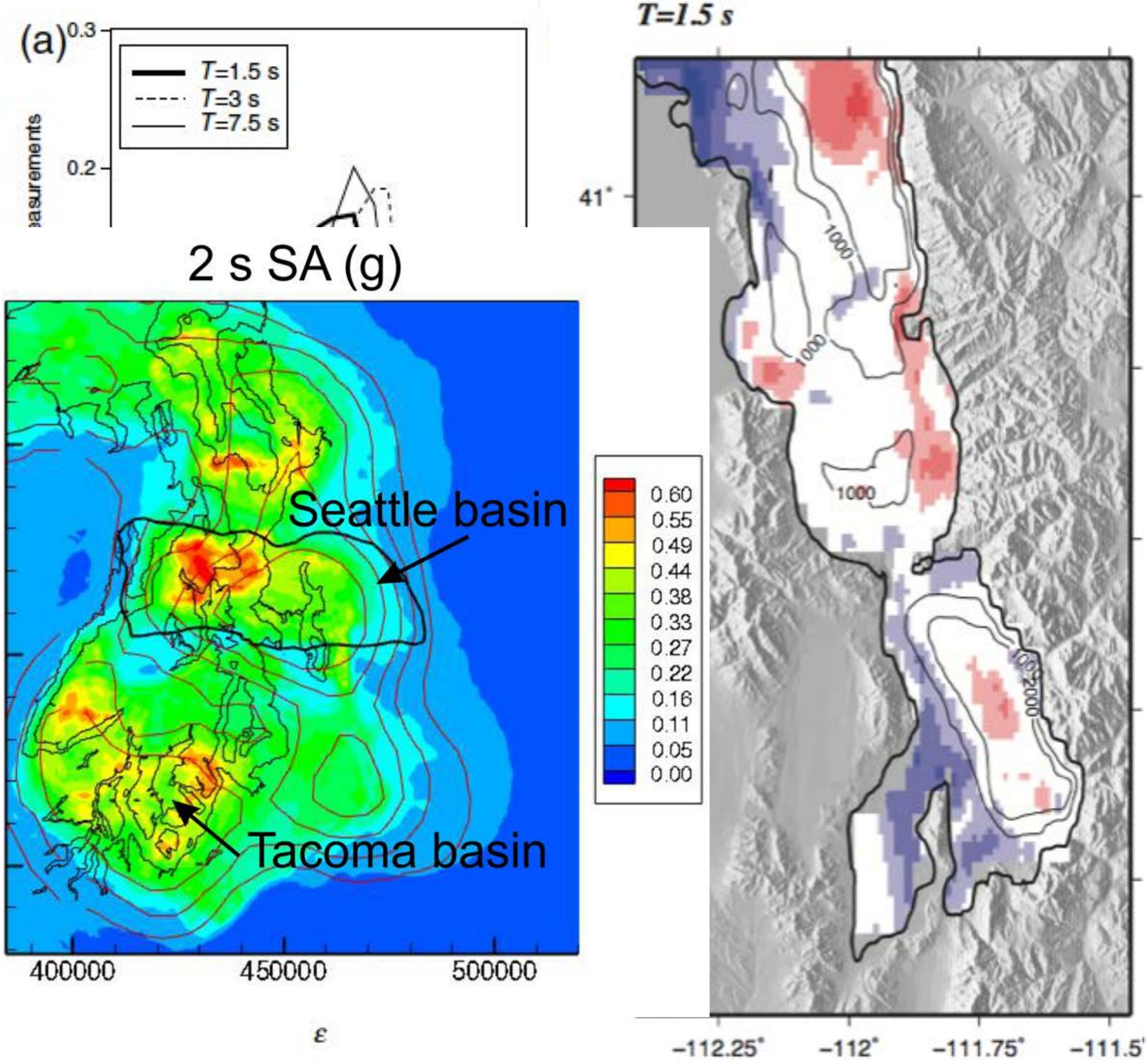
Moschetti et al. (2017; BSSA)

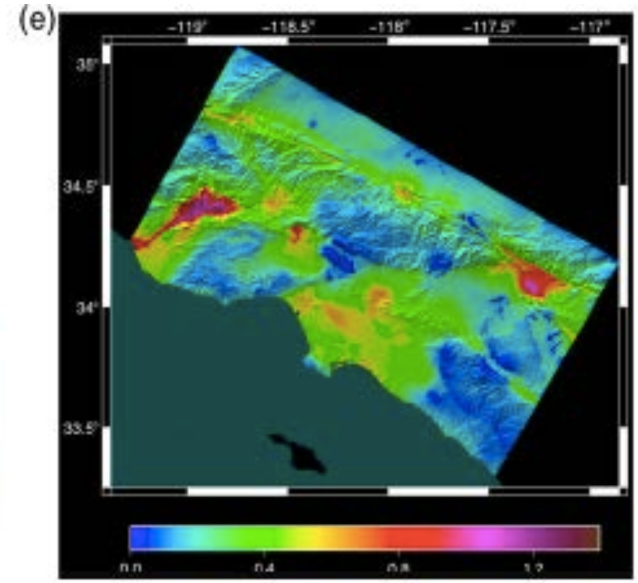
Example from Wasatch Front, Utah

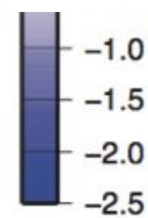




Example from Wasatch Front, Utah







Wang and Jordan (2014)

Requirements for using ground motions from 3D simulations

- Based on feedback from WG-USHM, Earthquake Hazards Program, NSHMP Steering Committee
- Only incorporate well-vetted components from earthquake simulations
  - Initial focus on basin amplifications
  - At this point, not considering effects from path, directivity, source complexity
- Validate the simulated ground motions (or components); are simulations providing improvements relative to empirical GMMs

Plan for incorporating ground motions from 3D simulations into NSHM

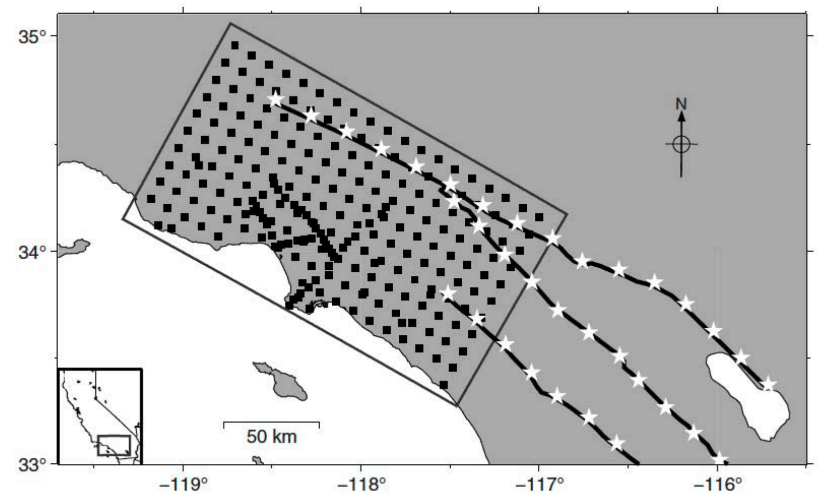
- Empirical GMMs, with basin amplifications from 3-D simulations
  - Implementation of basin amplification terms from CyberShake in nshm-haz code and sensitivity testing (Los Angeles)
  - Validation of 3-D-simulation-derived amplification factors—comparison with small-M earthquake data
  - Sensitivity testing for other regions and incorporation, 2020 NSHM
    - NSHM GMMs would presumably use weightings between simulated and empirically based GMPEs (period-dependent, similar to SCEC-UGMS recommendations?)
    - On-going simulation efforts in Seattle and Salt Lake City

Averaging-based factorization (ABF)
(Wang and Jordan, 2014)

$$G(r,k,x,s) \equiv \ln Y(r,k,x,s).$$

$$A \underset{R}{\leftarrow} B \underset{K}{\leftarrow} C \underset{X}{\leftarrow} D \underset{S}{\leftarrow} E.$$

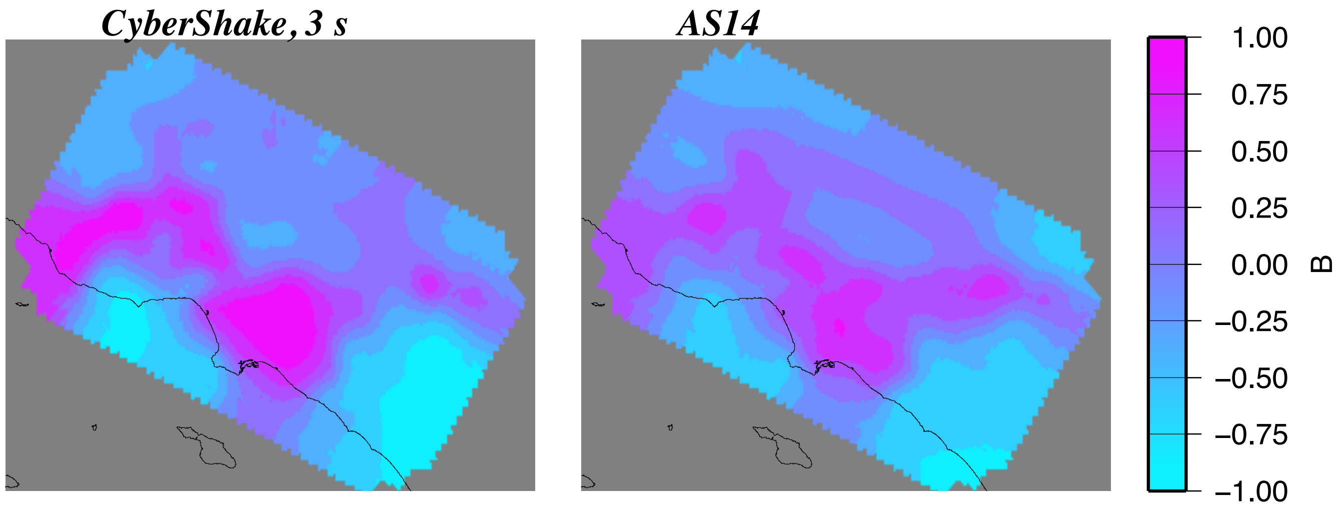
$$G(r,k,x,s) = A + B(r) + C(r,k) + D(r,k,x) + E(r,k,x,s).$$

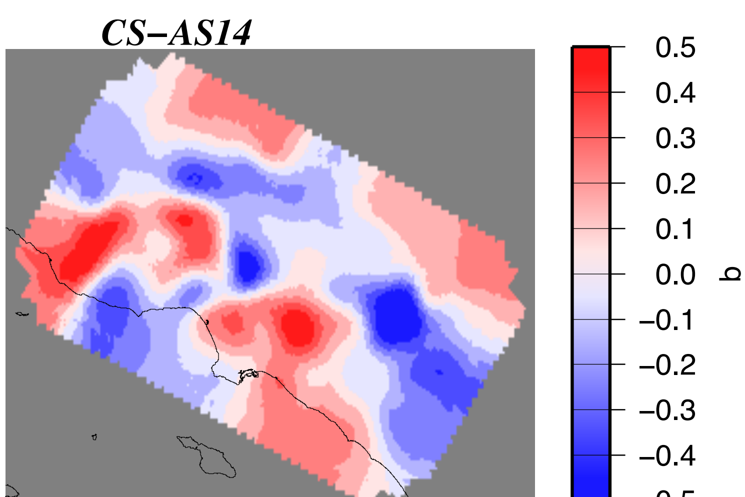


Successive averaging over sets of simulated ground motions permits parameterization of simulated ground motions into terms similar to GMPEs:

E: Total excitation level; source complexity
D: expectation over slip functions S; directivity effect
C: Expectation over hypocenters X; path effect
B: Expectation over seismic sources K; site effect
A: Expectation over all sites R; regional excitation level

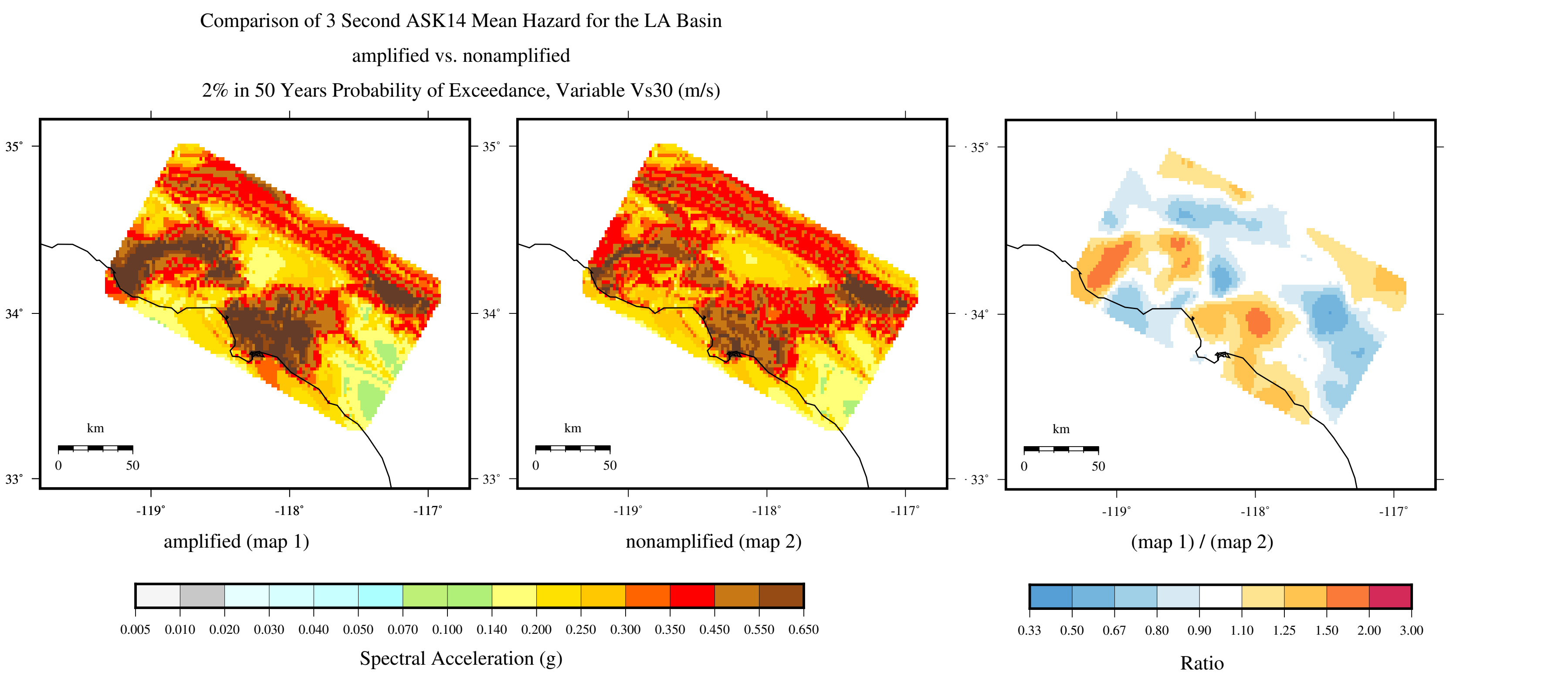
Basin amplifications, CyberShake, ABF



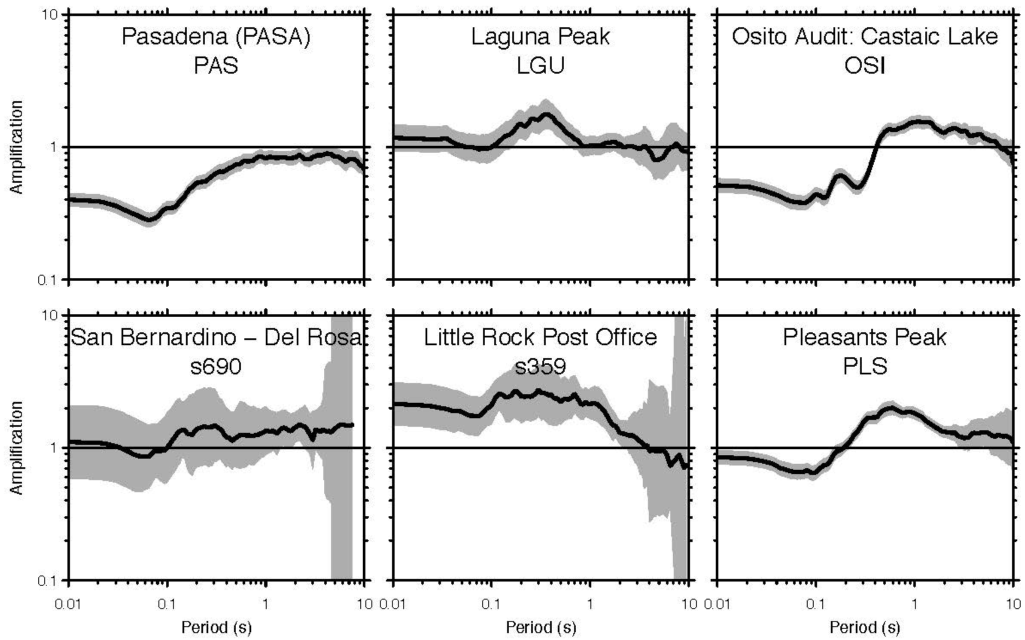


Example 3-s B- and b-values: Site effects (shallow site and basin amplifications, modeled by Vs30 and Z1/Z2.5)

Hazard sensitivity, 3-s SA

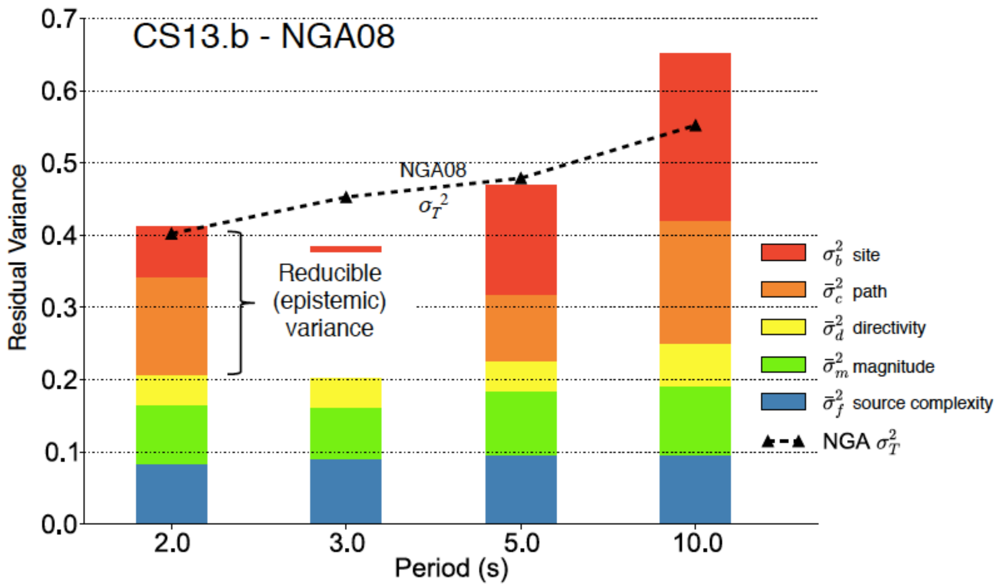


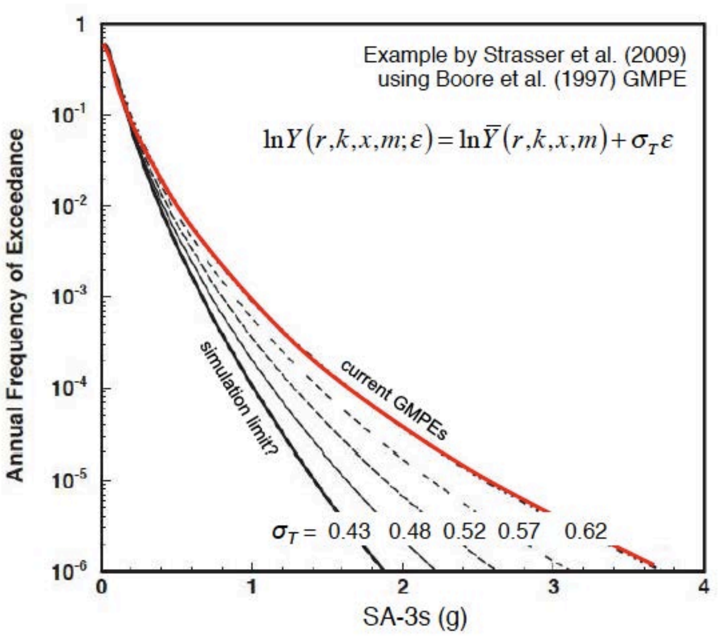
Testing amplification factors from 3D simulations using small-M earthquakes



- Empirical amplification factors, Thompson and Wald (2016)
- Comparison of small-M ground motions with GMPE-predictions
- Use simulation-derived site response terms to assess whether empirical amplification factors improve

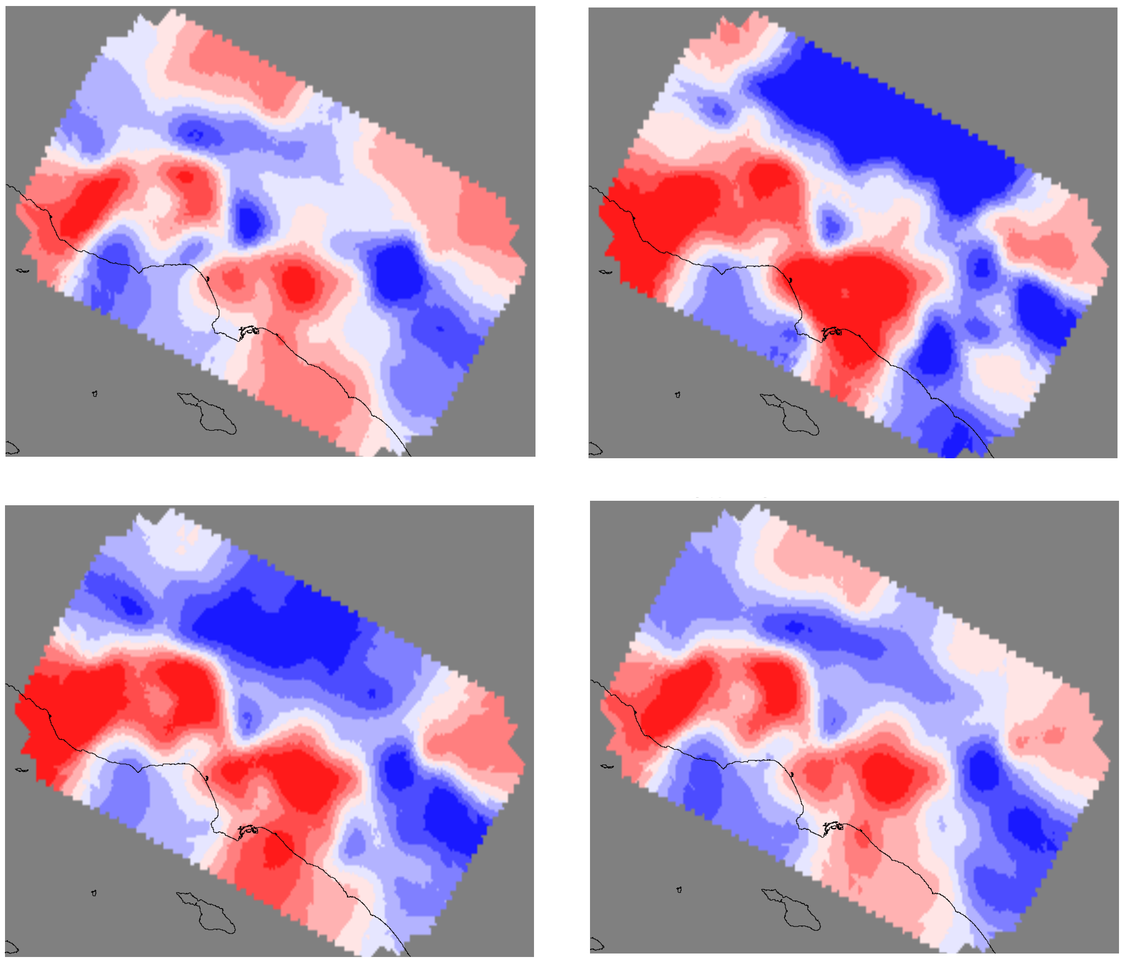
Effects on ground motion variability

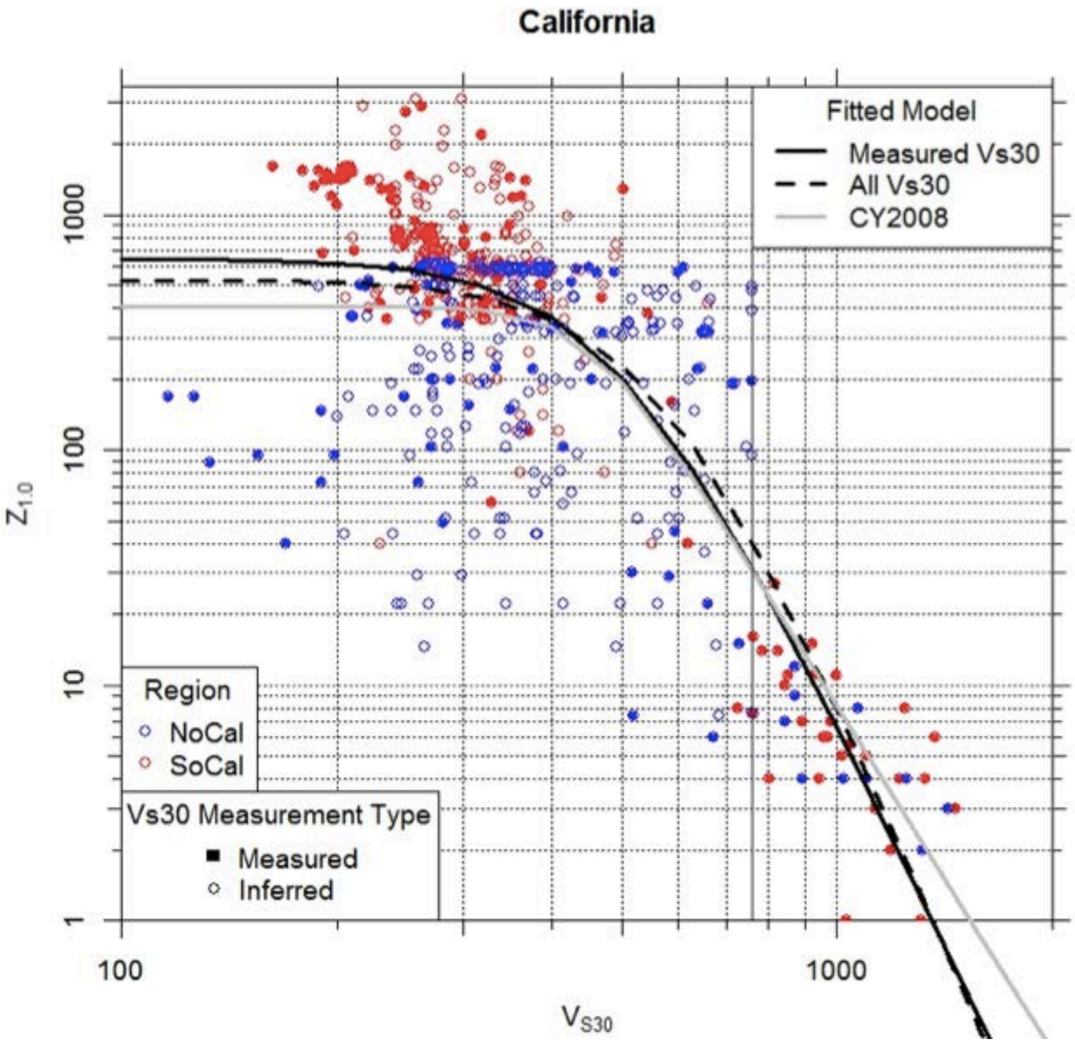




Basin amplifications, CyberShake, ABF

3-s SA





From Chiou and Youngs (2013)

Example from Wasatch Front, Utah