

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

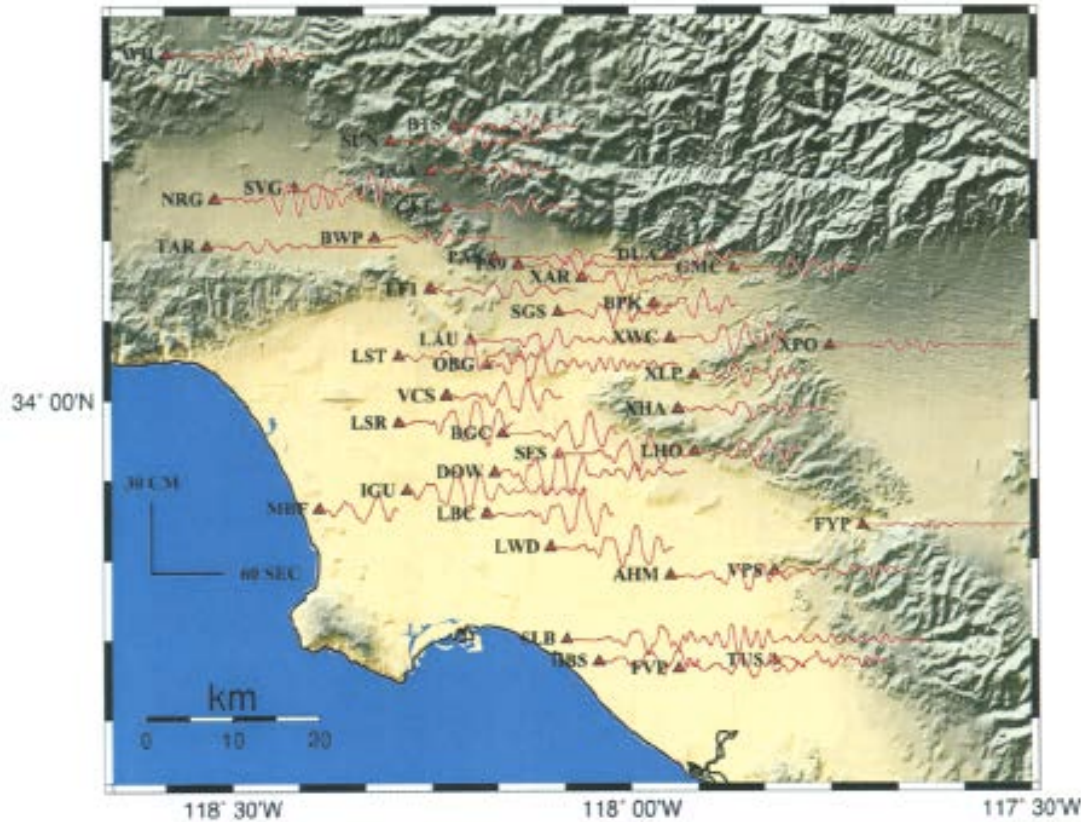
Morgan Moschetti  
U.S. Geological Survey

2018 National Seismic Hazard Model Workshop

Newark, CA

March 8, 2018

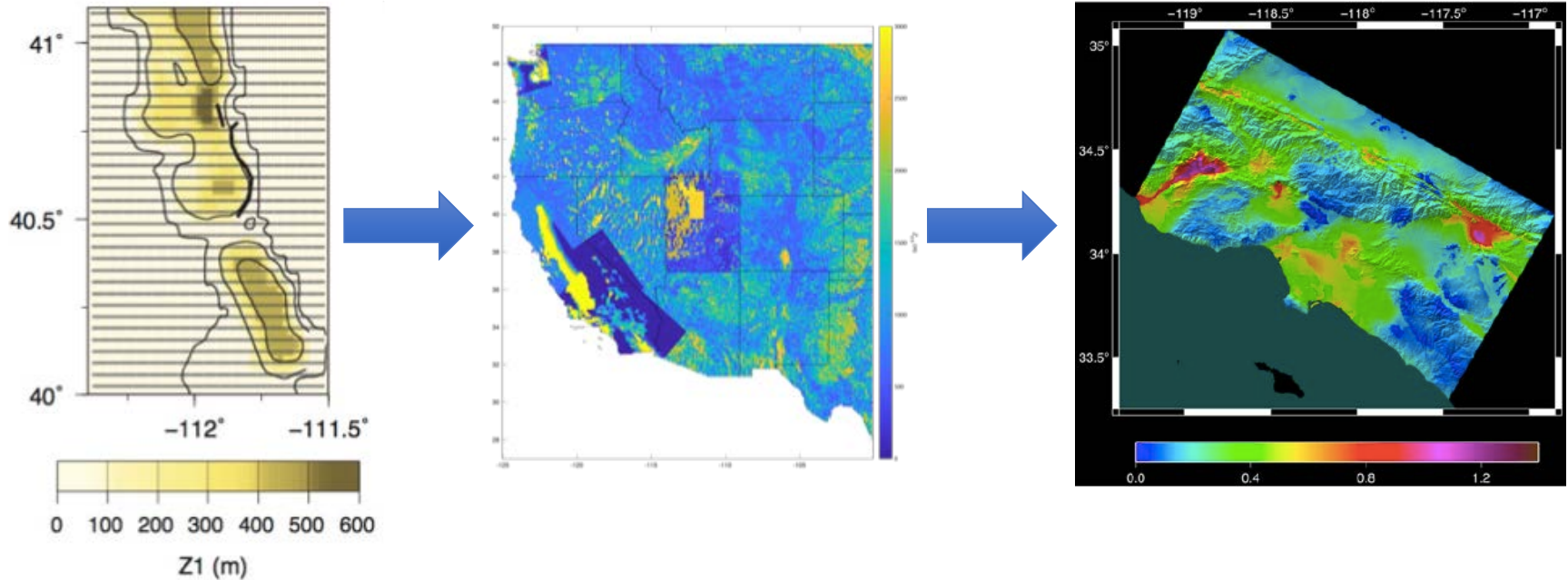
Wald and Graves (1998, BSSA)



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)

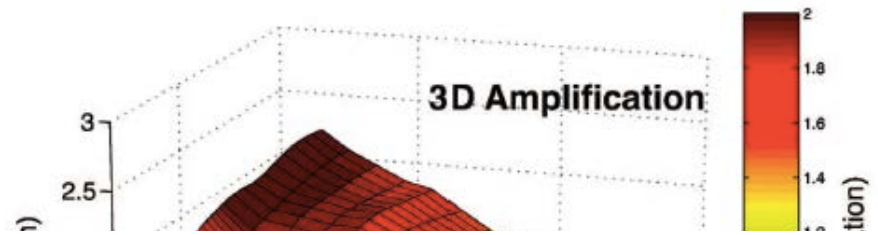
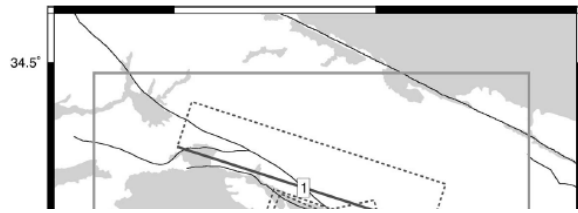
# *Plan for incorporating basin effects: 2018, 2020 NSHM and beyond*



- 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

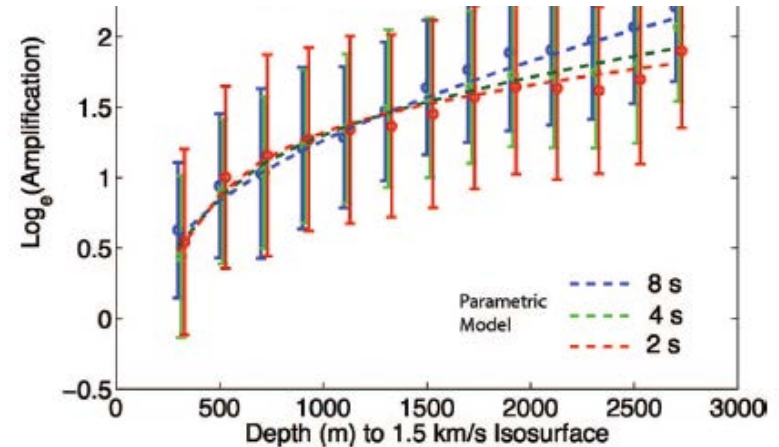
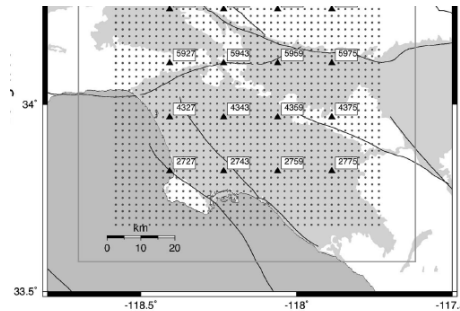
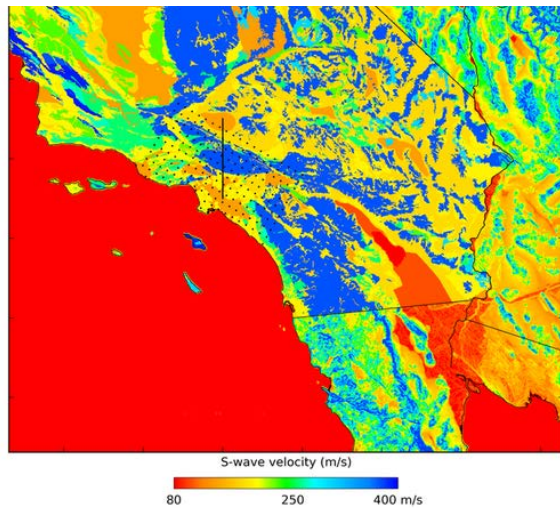
# Outline

- 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



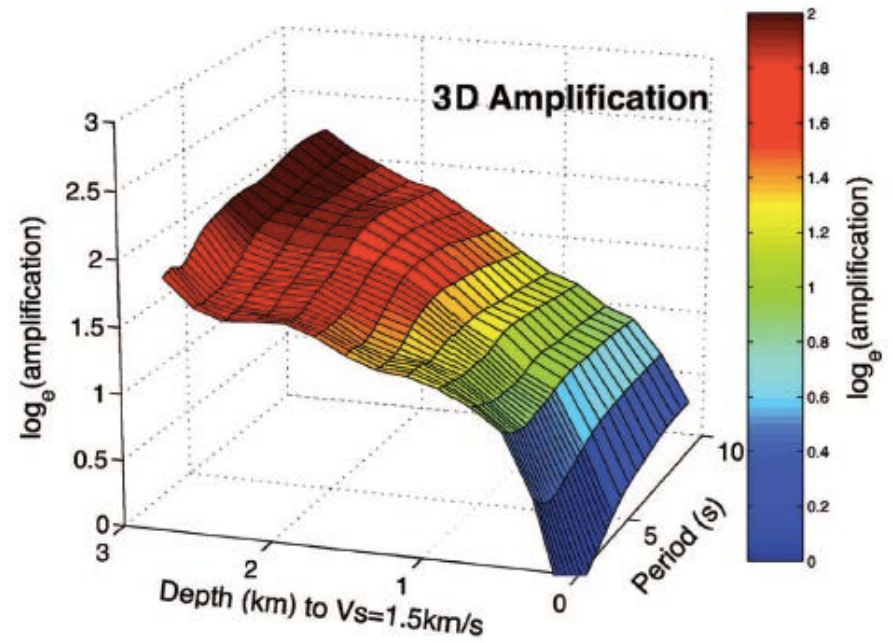
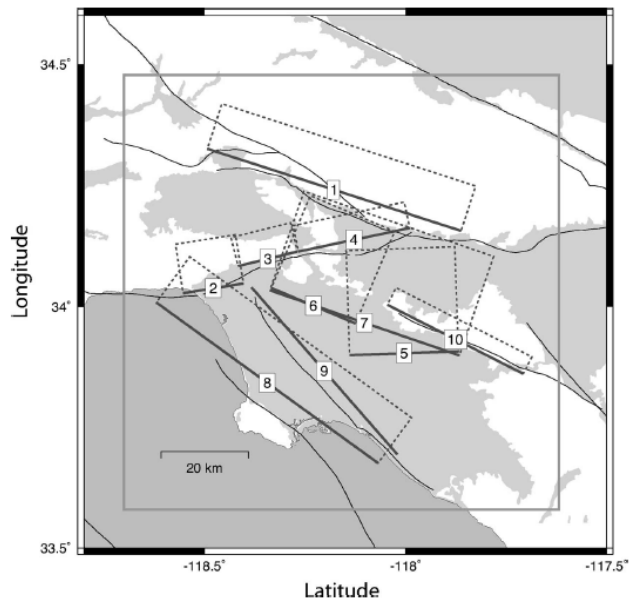
The trend for  $Z_{2.5} > 3$  km, which is due presumably to 3-D basin effects, was based on too few data to empirically determine how these effects could be extrapolated with sediment depth and spectral period. Instead, this trend was constrained using the sediment-depth model developed by Day (2005) 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)

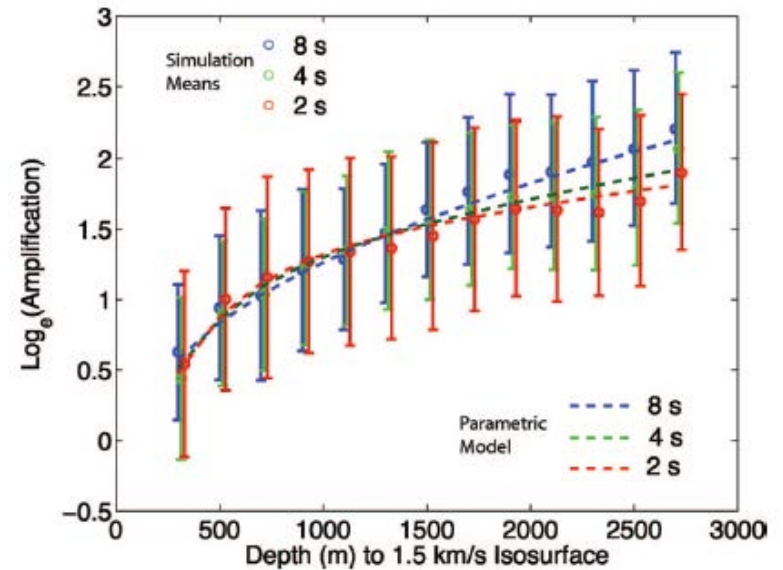
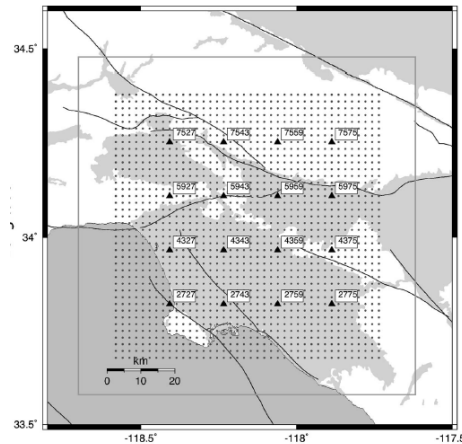
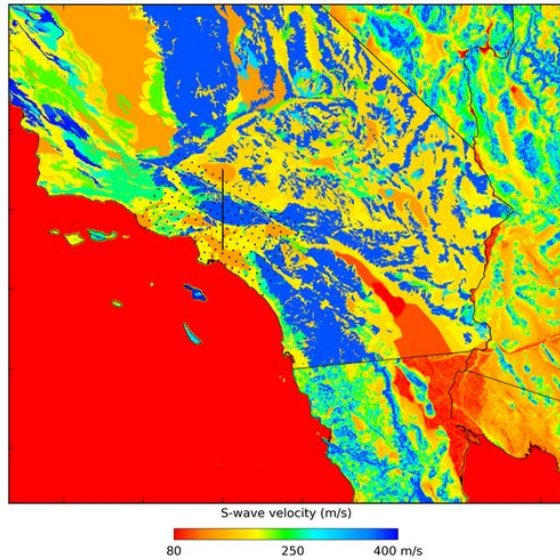


Day et al. (2005, PEER; 2008, EQS)

GTL surface S-wave velocity derived from Wills and Clahan (2006) geology based  $V_{330}$  map, supplemented outside of California with Wald et al. (2007) map.



**CVM-H v6.3 + GTL**



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

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.

# 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)?

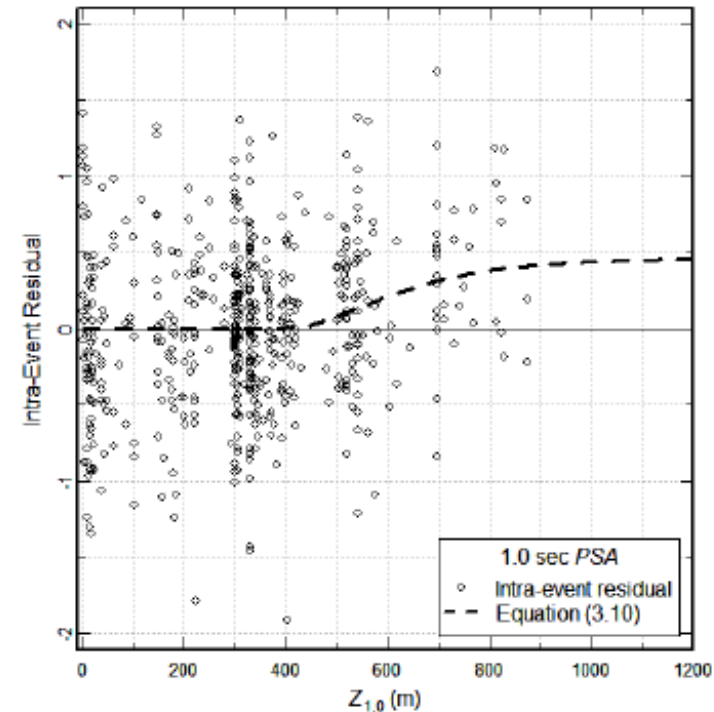
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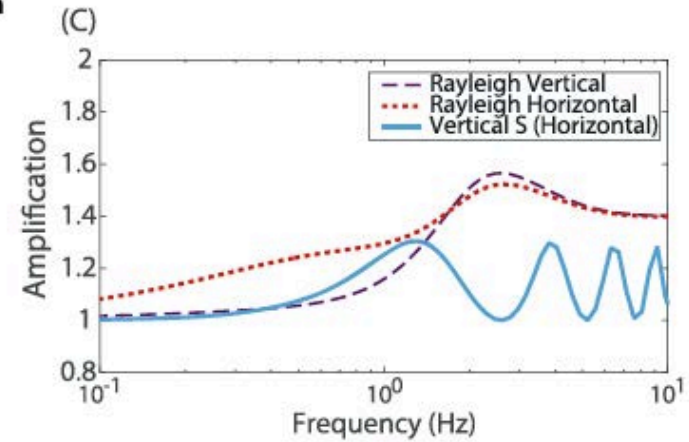
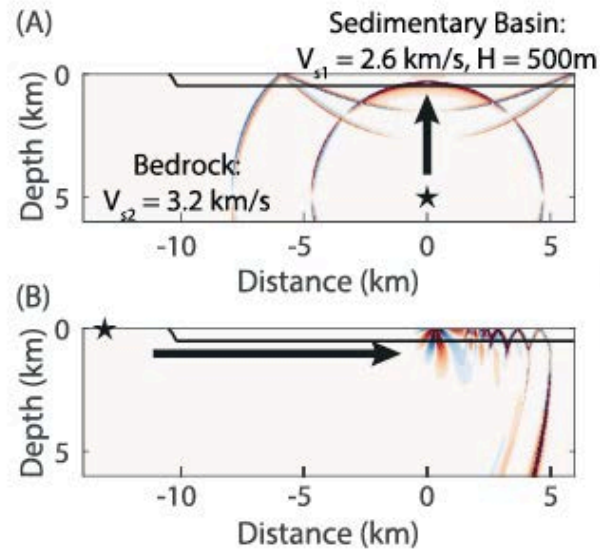
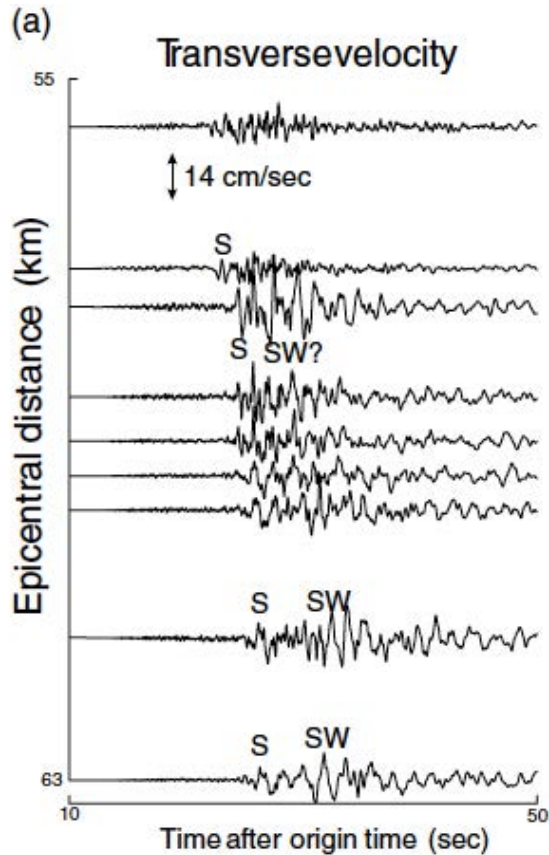


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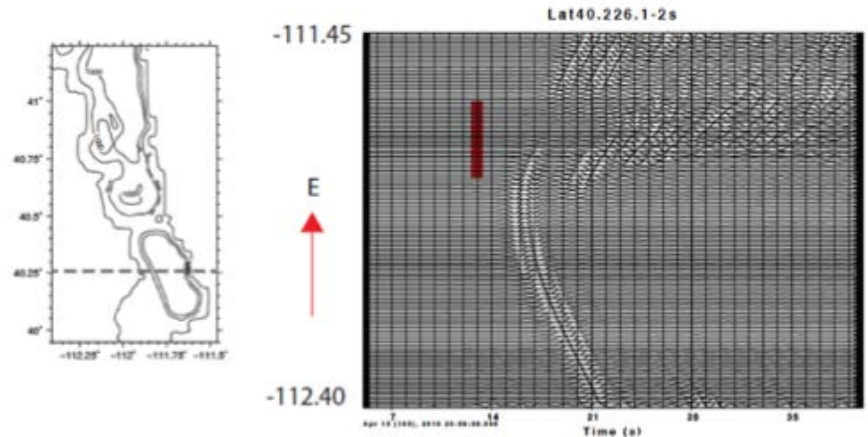
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# Differences in body- and surface-wave amplification



Bowden and Tsai (2017; GRL)



Frankel et al. (2002; BSSA)

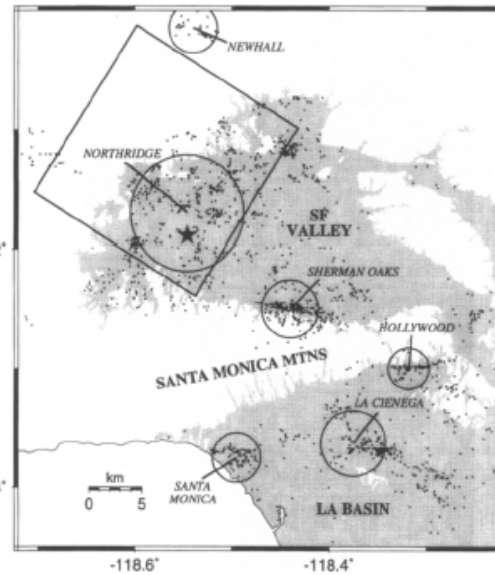
# Higher-order effects of sedimentary basins

Northridge 1994, Los Angeles

Hyogo-ken Nambu 1995, Kobe

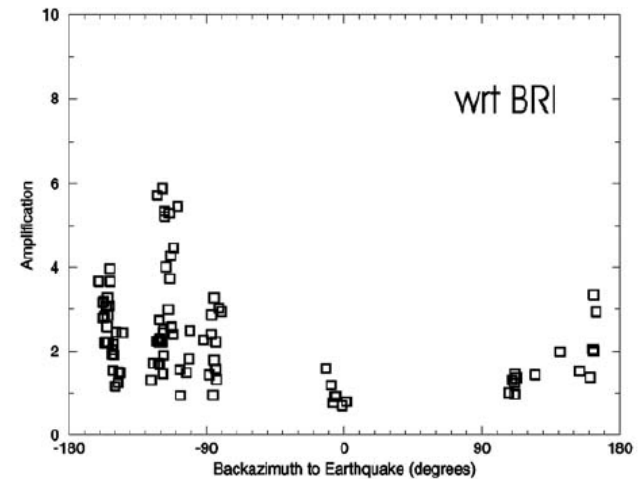


Kawase (1996)



Graves et al. (1998)

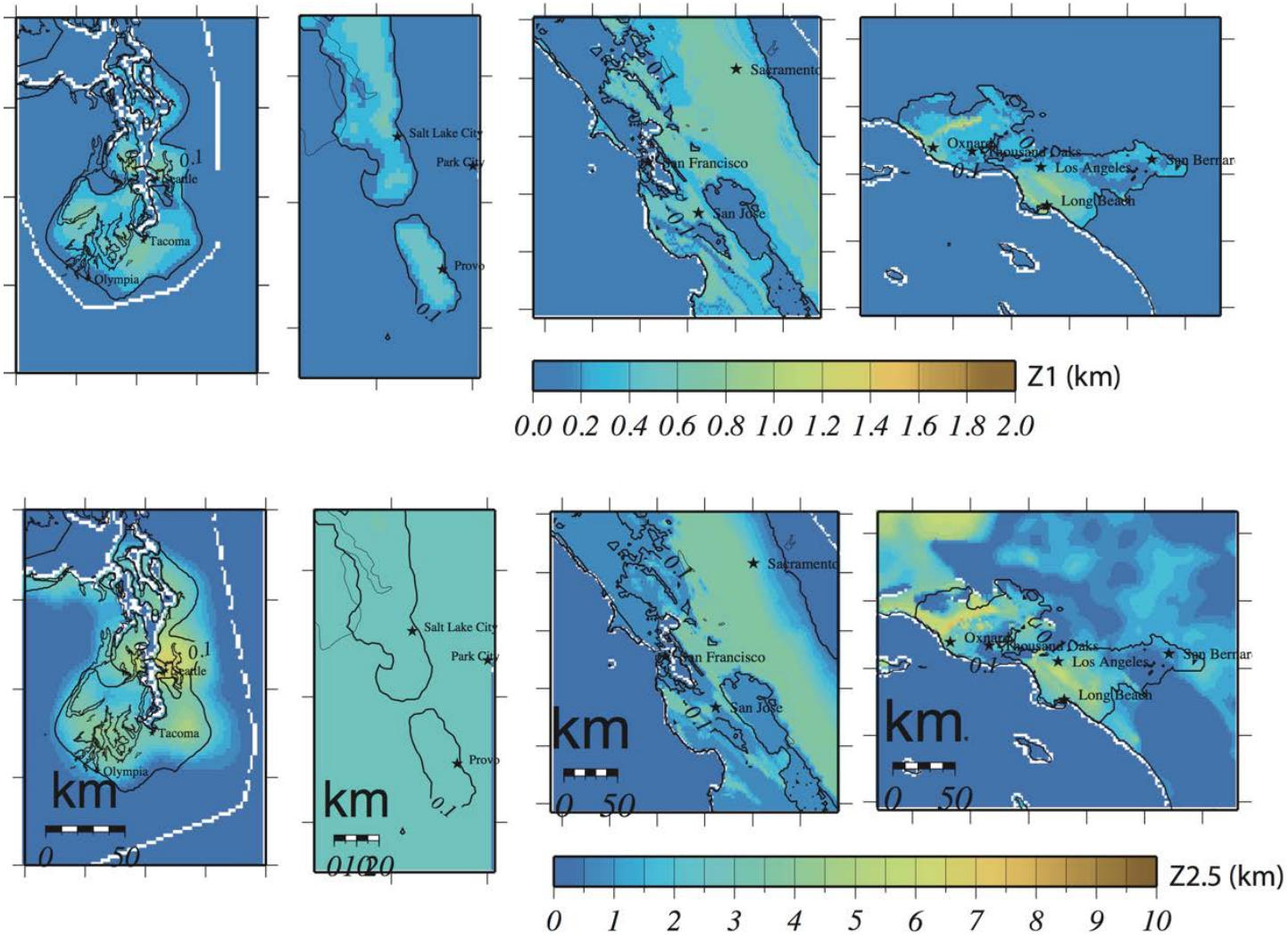
1-Hz amplifications, Seattle



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 < 0.6 km

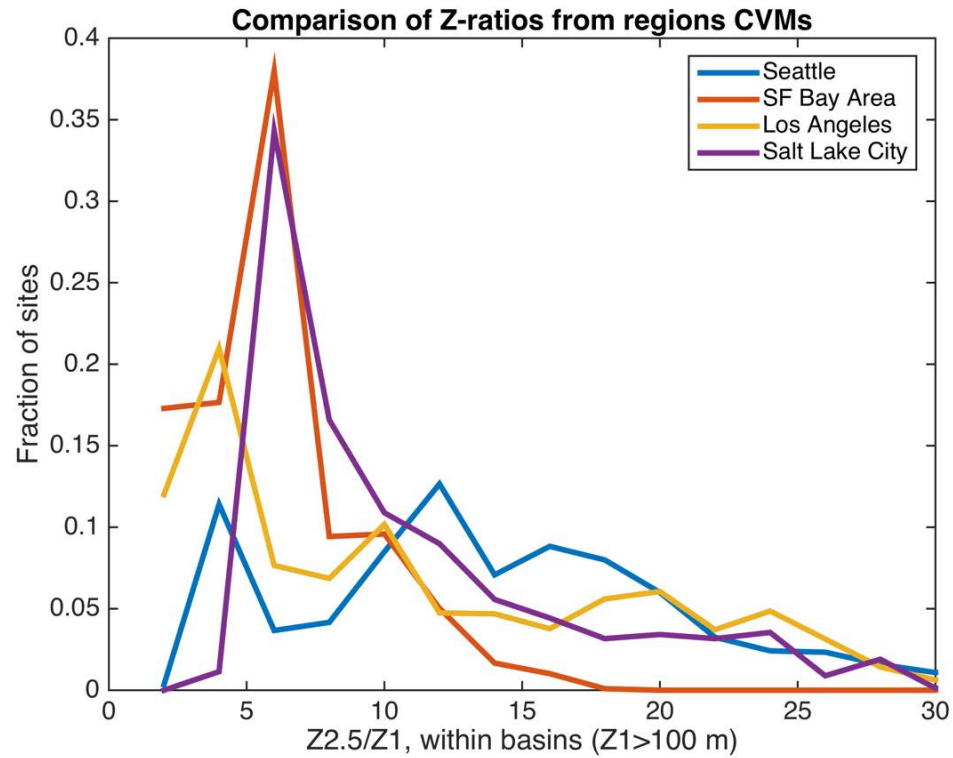
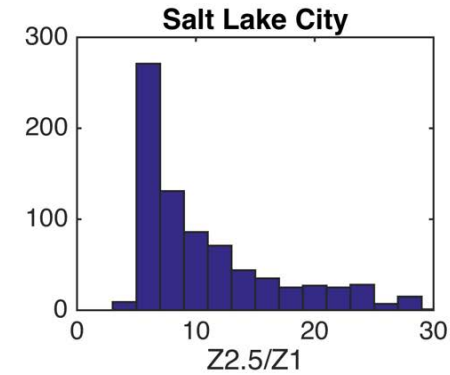
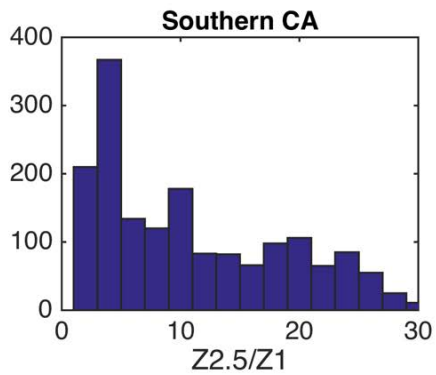
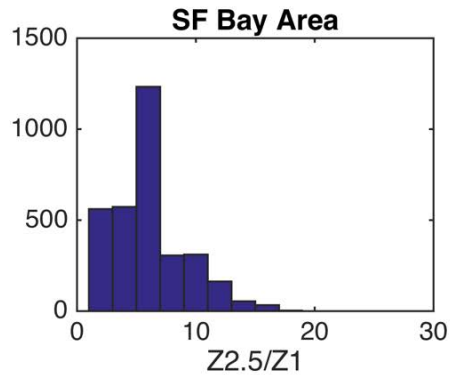
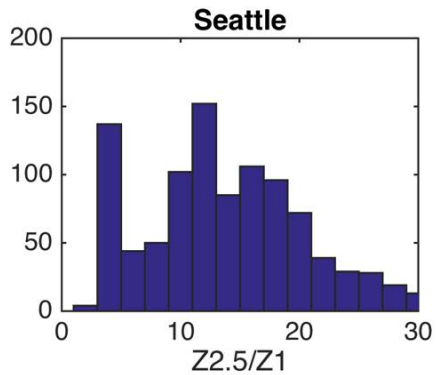
Z2.5 < 3.6 km

Salt Lake City

Z1 < 0.7 km

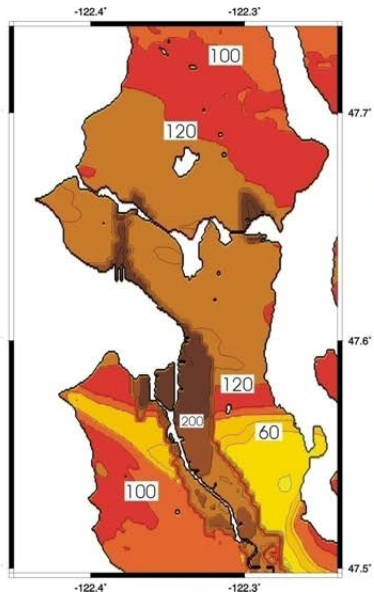
Z2.5 < 3.1 km

# Variations in basin structure

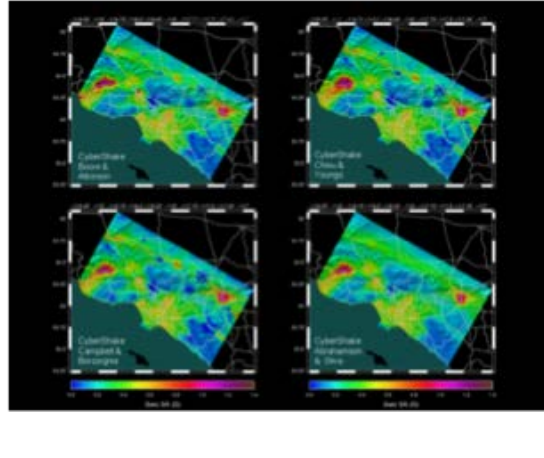


# Urban seismic hazard maps

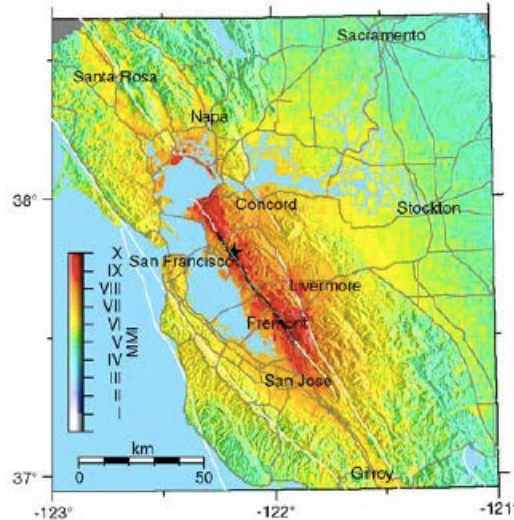
Seattle



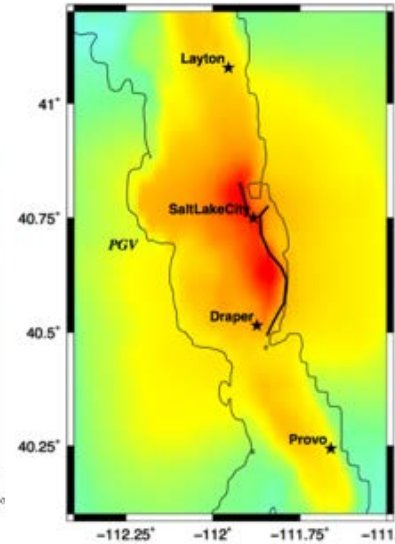
Los Angeles (SCEC CyberShake)



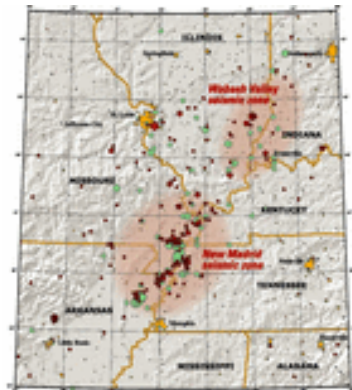
San Francisco Bay Area



Salt Lake City



Evansville, IN



St. Louis

**St. Louis Area Earthquake Hazards Mapping Project**

St. Louis has experienced minor earthquake damage at least 12 times in the past 200 years. Because of this history and its proximity to known active earthquake zones, the St. Louis Area Earthquake Hazards Mapping Project will produce digital maps that show variability of earthquake hazards in the St. Louis area. The maps will be available for public use. They can be customized by the user to show specific areas of interest, such as neighborhoods or transportation routes. Photographic images and/or geographic information system (GIS) data, as they become available.

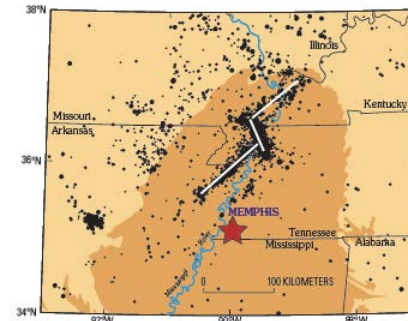
**What is earthquake hazard?**

Earthquake hazard refers to a measure of the shaking, or ground motion, direct earthquakes that can damage our built environment. The hazard depends on the magnitude and frequency of likely earthquakes, how often they occur, and the properties of the rocks and sediments that earthquake waves travel through. In the central United States, earthquakes occur along the New Madrid and Wabash seismic zones and in a zone of earthquake that is scattered across western Illinois and eastern Missouri.

**Who uses earthquake hazard maps?**

Public and private groups can use hazard maps for planning, mitigation, and response efforts to minimize losses resulting from earthquake shaking. Hazard maps can be used to help manage risk, assess, and evaluate management objectives can use the maps to better manage their response. Planning and zoning professionals can use the maps for hazard considerations in building new developments, critical facilities, and transportation corridors. Business continuity managers can use the maps to minimize earthquake-related losses to their facilities, supply networks, and market share. The scale of the maps will not allow them to be used in a site-specific manner, but rather as a guide as to where more detailed studies are needed.

Memphis

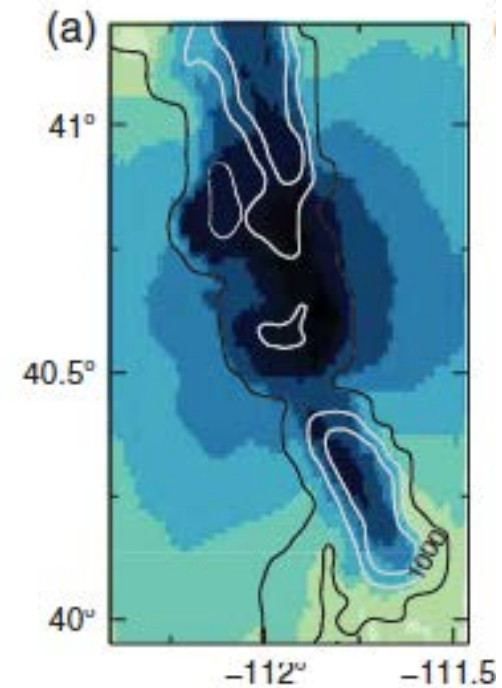
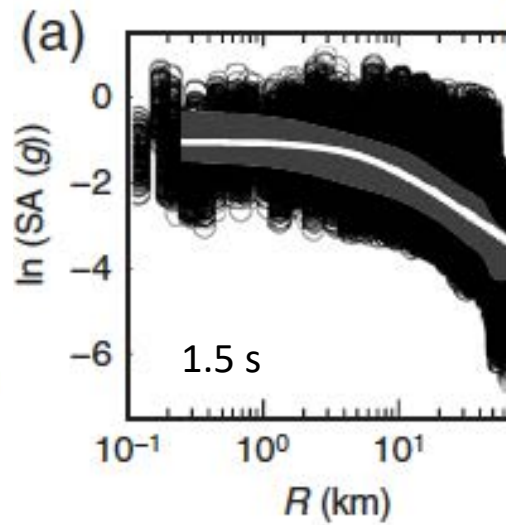
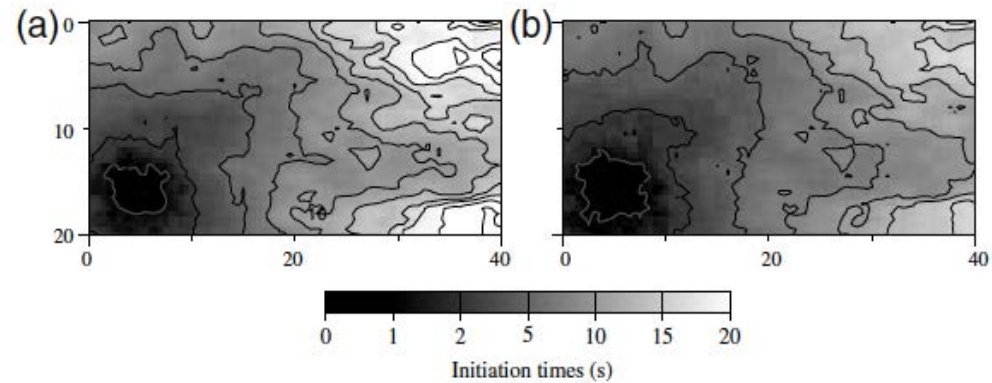
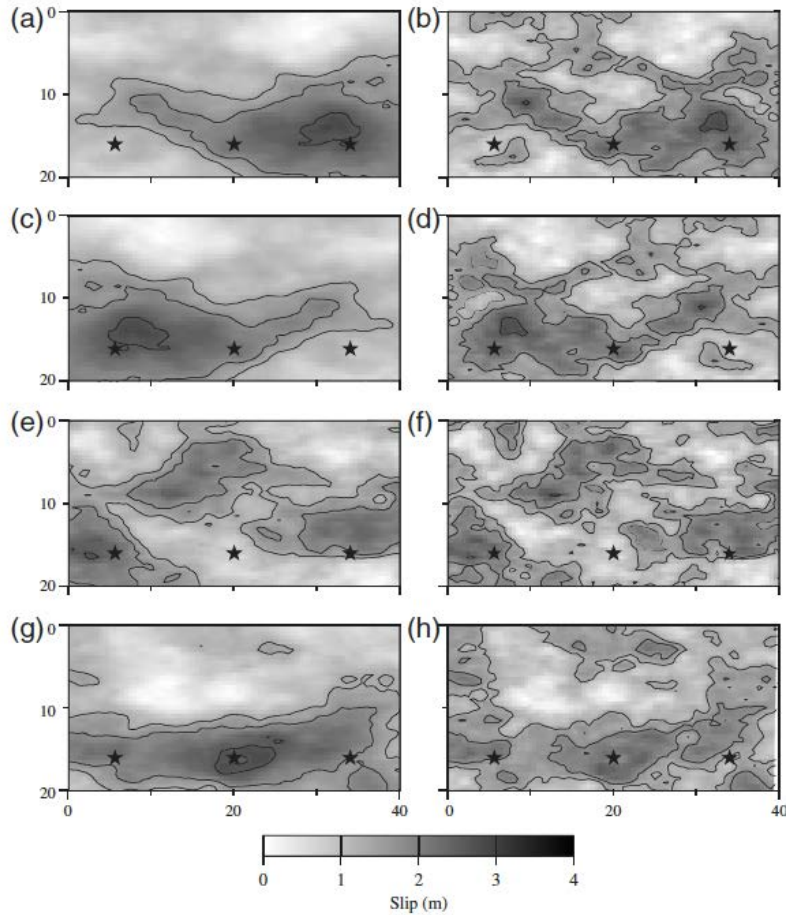


Multiple classes of urban seismic hazard maps

- 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

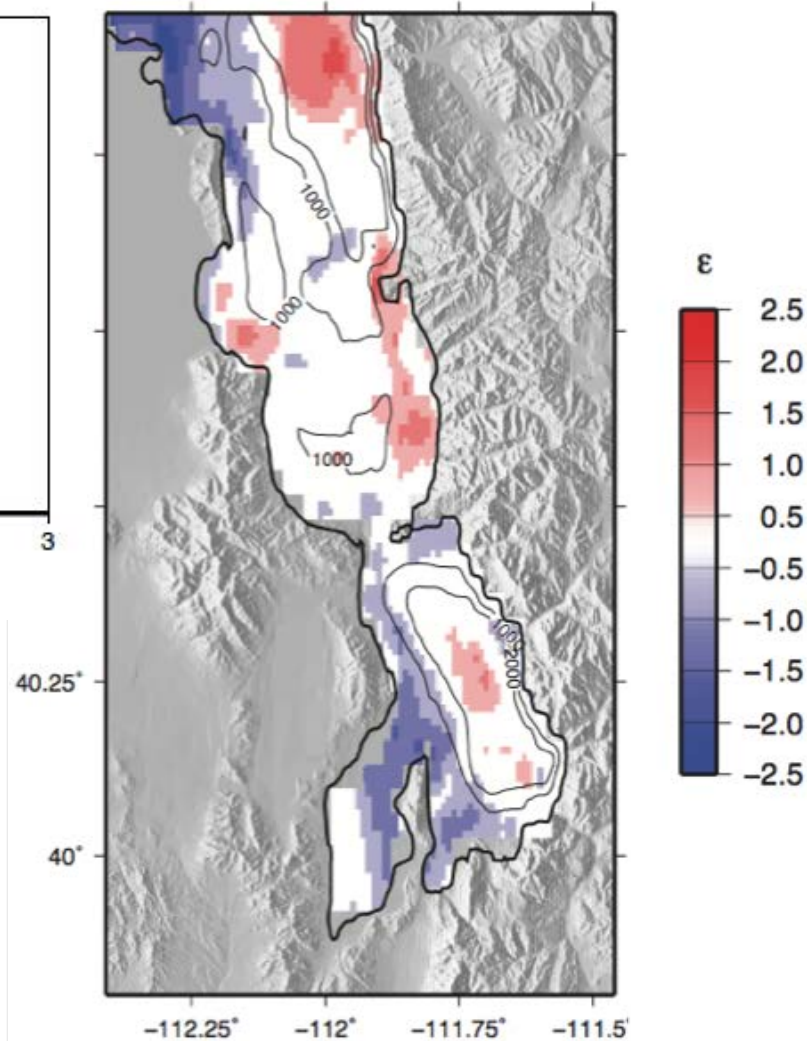
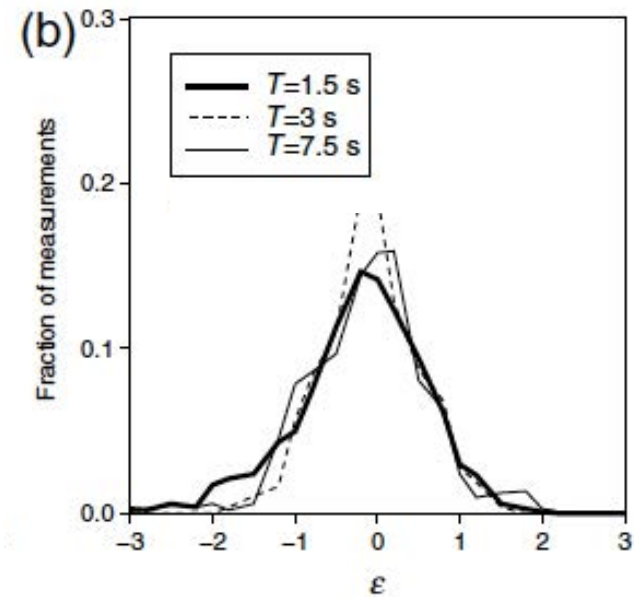


Moschetti et al. (2017; BSSA)

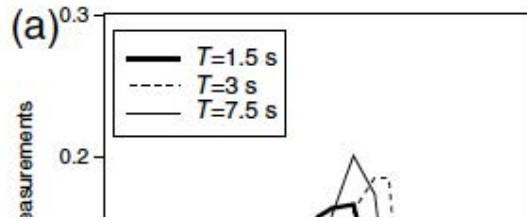


# Example from Wasatch Front, Utah

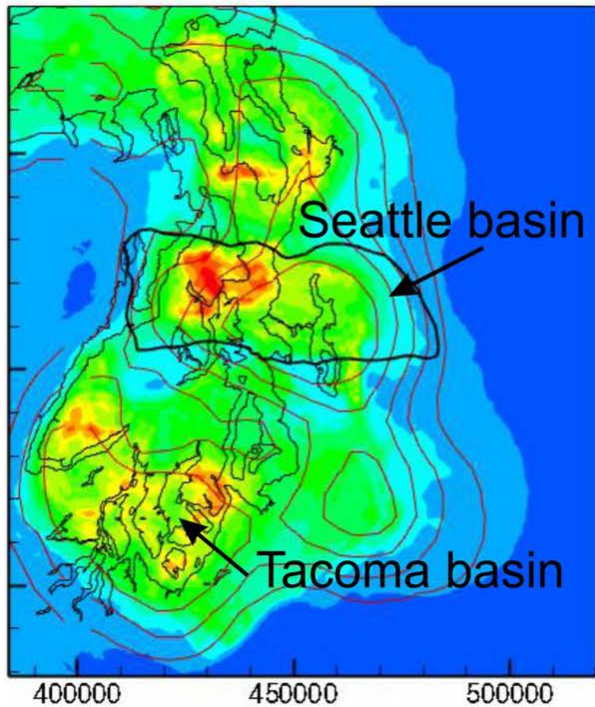
$T=1.5\text{ s}$



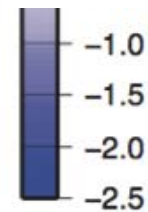
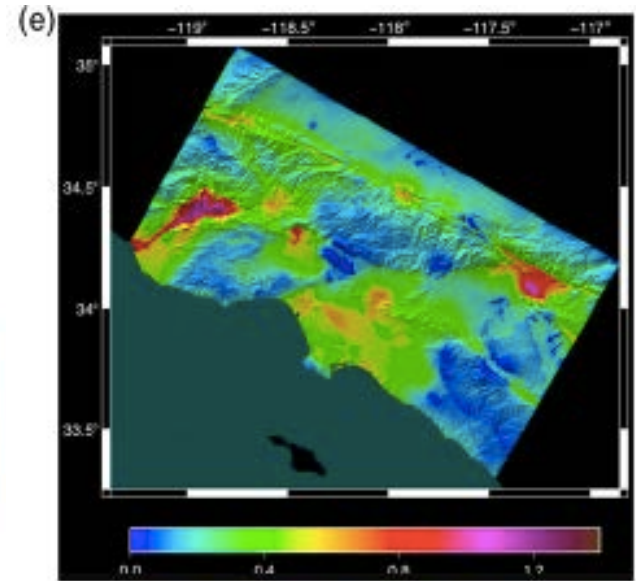
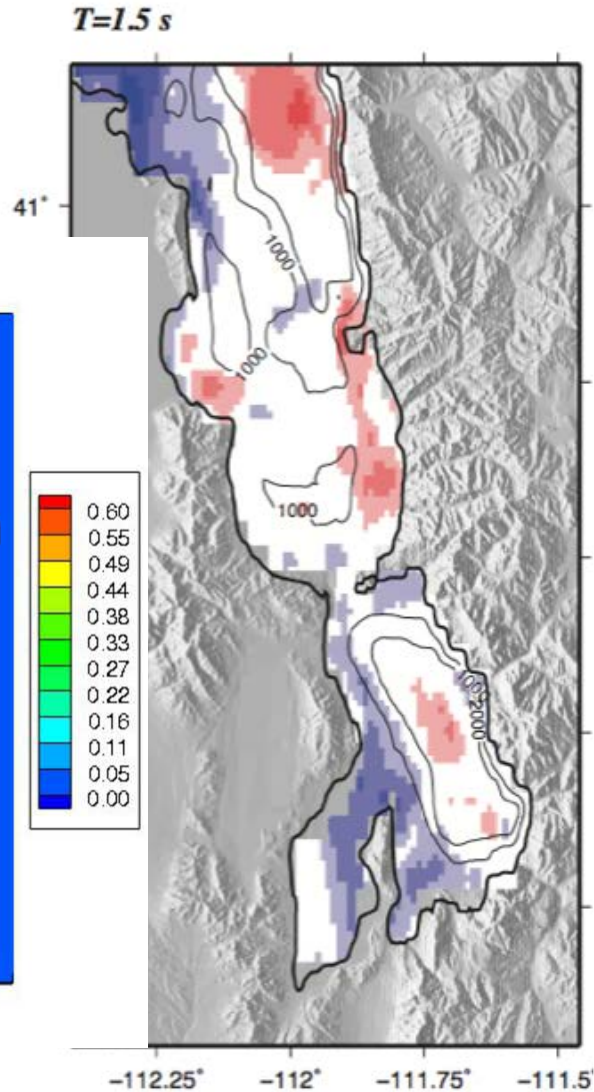
# Example from Wasatch Front, Utah



2 s SA (g)



$\epsilon$



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

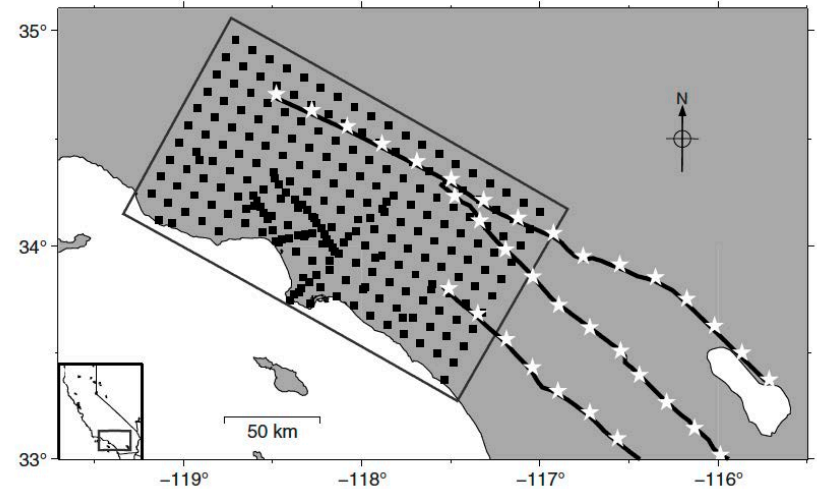
# *Averaging-based factorization (ABF)*

*(Wang and Jordan, 2014)*

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

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

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



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

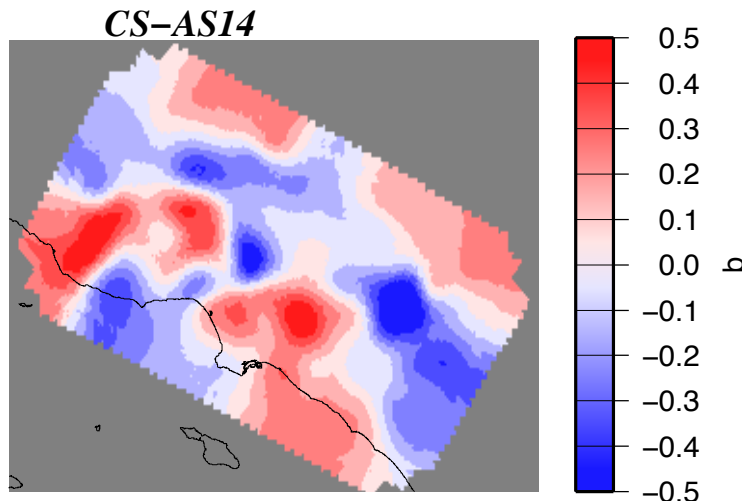
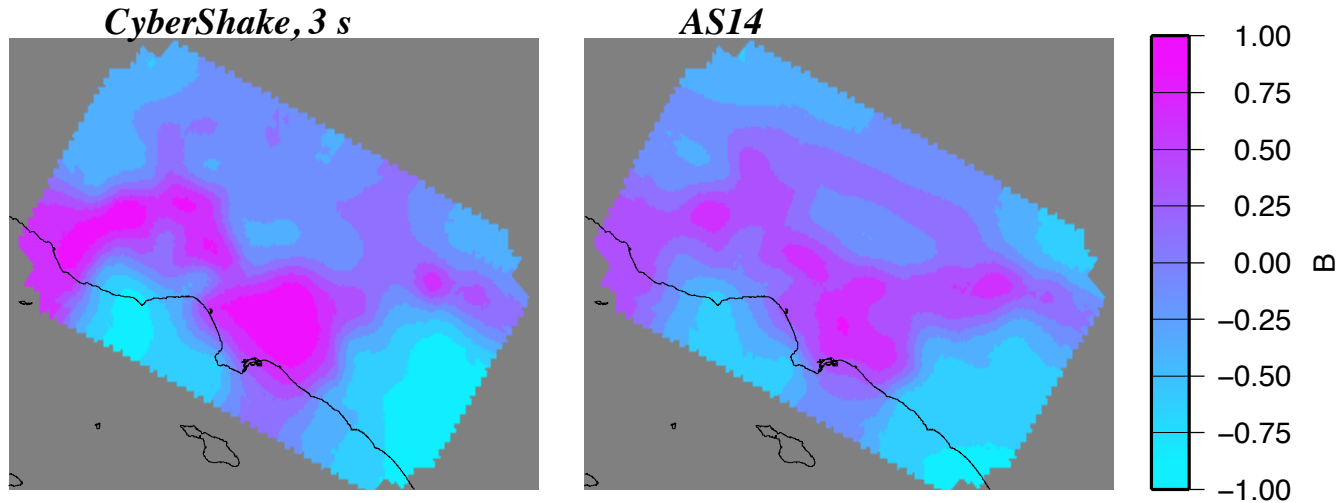
D: expectation over slip functions S; directivity effect

C: Expectation over hypocenters X; path effect

B: Expectation over seismic sources K; site effect

A: Expectation over all sites R; regional excitation level

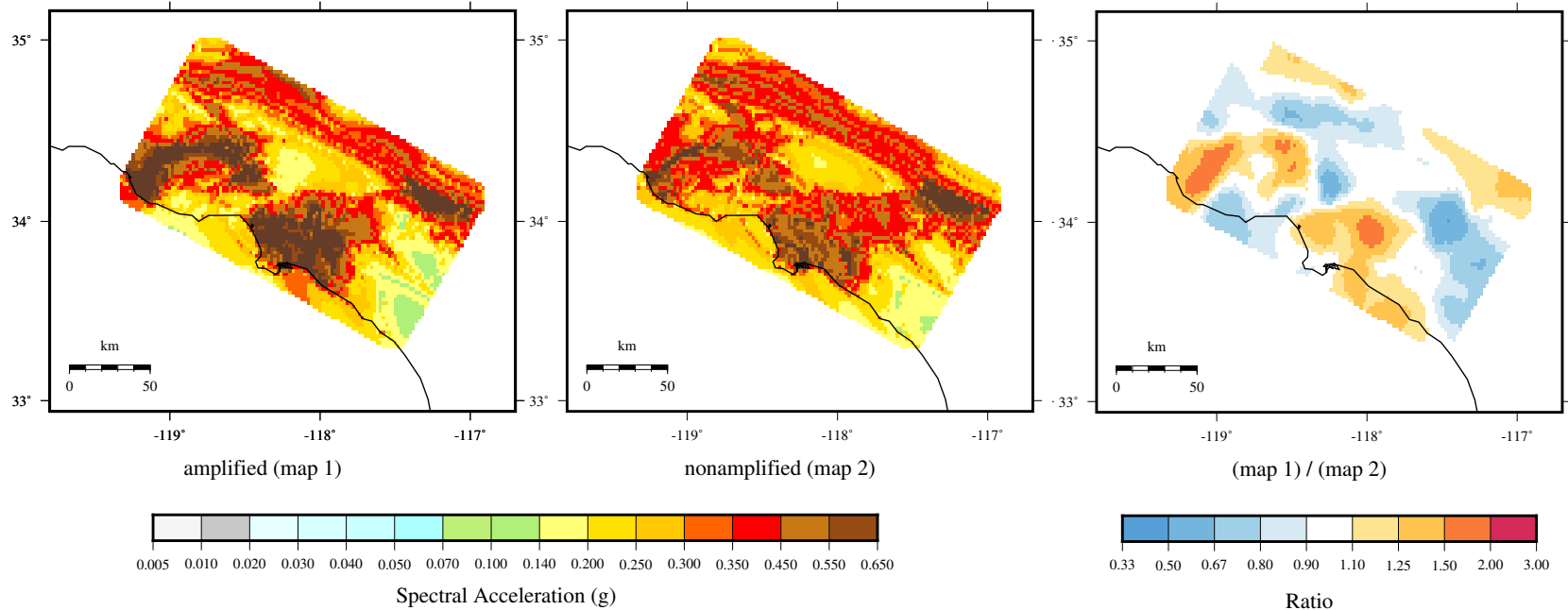
# Basin amplifications, CyberShake, ABF



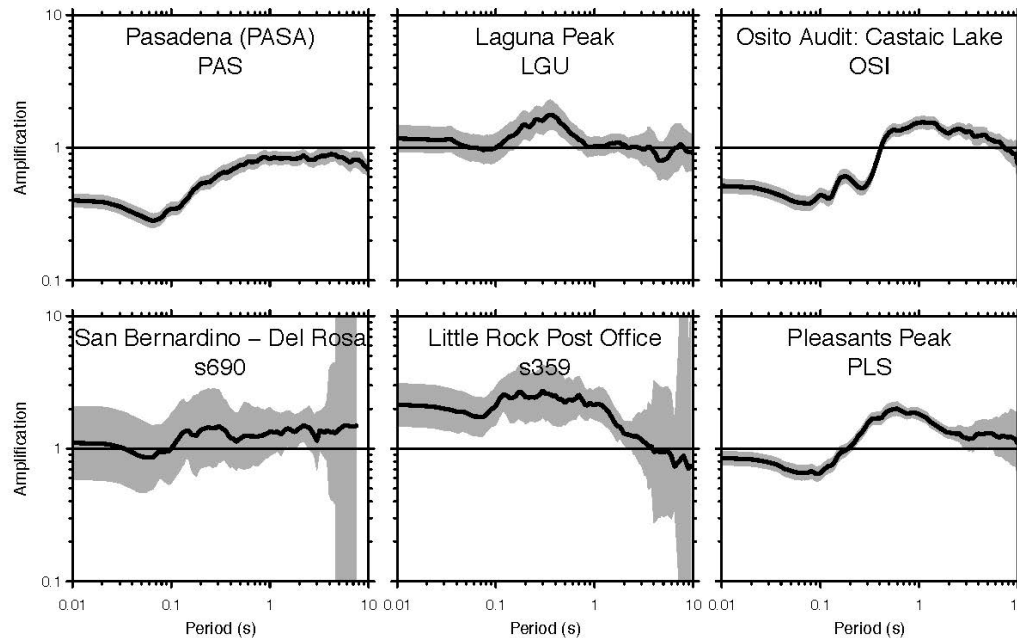
Example 3-s B- and b-values:  
Site effects (shallow site and  
basin amplifications, modeled  
by Vs30 and Z1/Z2.5)

# Hazard sensitivity, 3-s SA

Comparison of 3 Second ASK14 Mean Hazard for the LA Basin  
amplified vs. nonamplified  
2% in 50 Years Probability of Exceedance, Variable Vs30 (m/s)



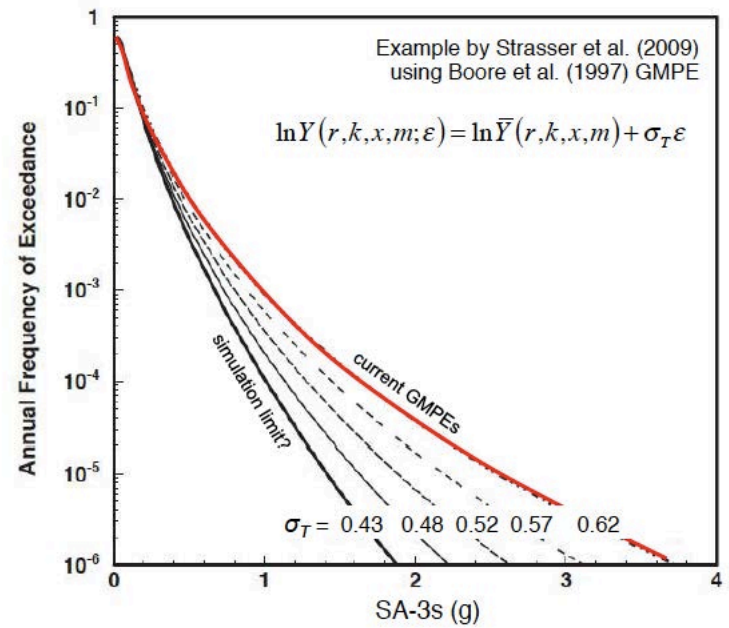
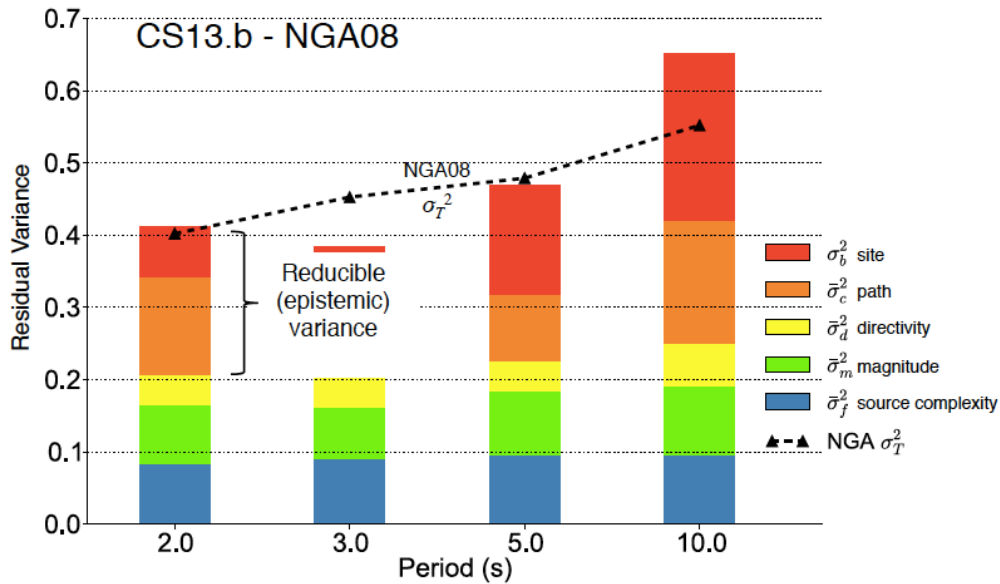
# *Testing amplification factors from 3D simulations using small-M earthquakes*



- 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

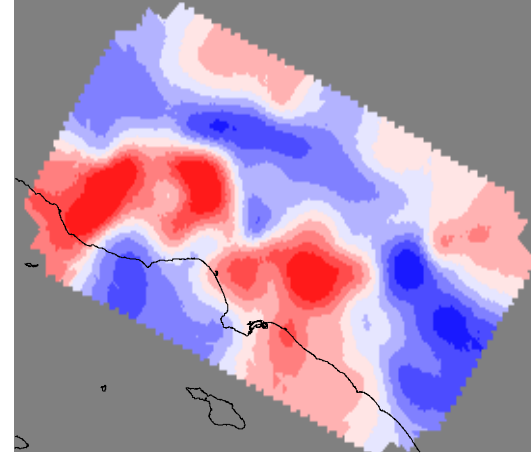
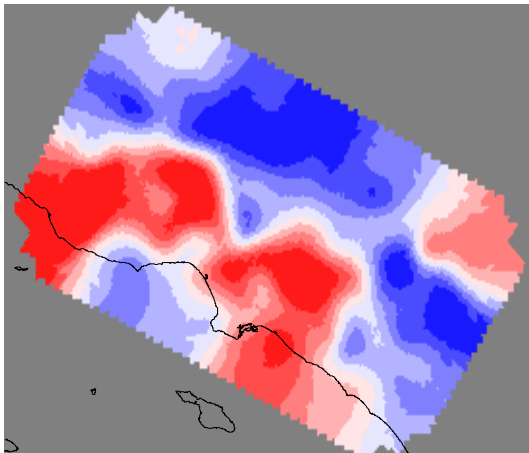
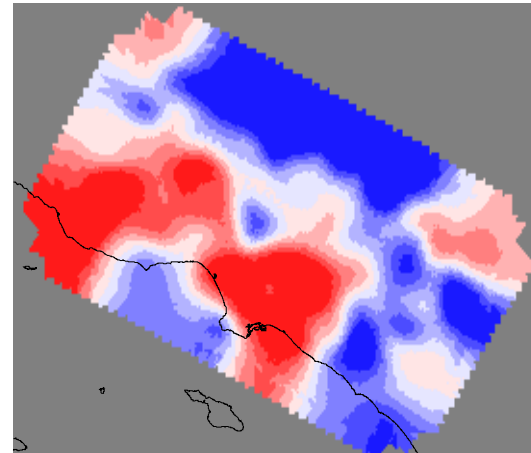
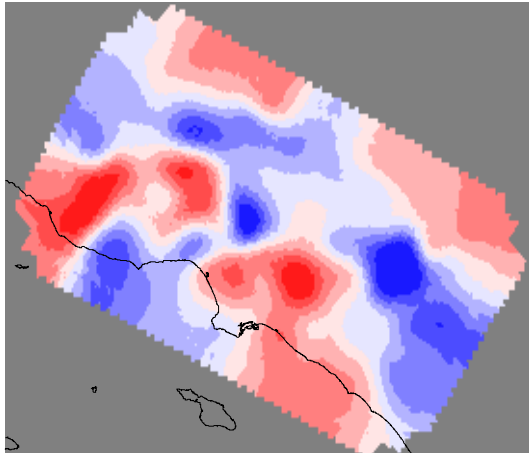


# Effects on ground motion variability

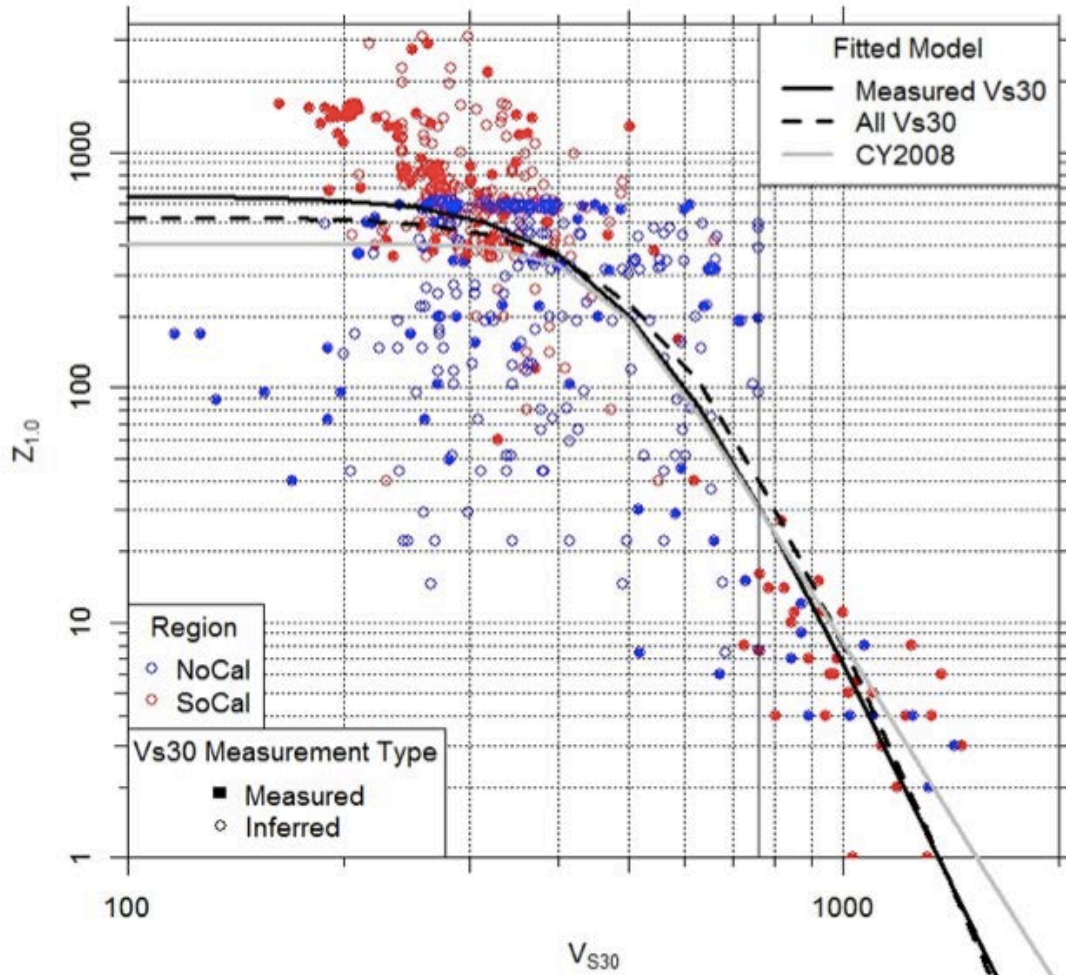


# *Basin amplifications, CyberShake, ABF*

3-s SA



# California



From Chiou and Youngs (2013)

# Example from Wasatch Front, Utah

