Active Faulting, Soil and Rock Type, and Groundwater Elevations Beneath Salt Lake City

Vp, Vs, and Reflection Images from a Seismic Land Streamer System

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Project objectives
via USGS award G15AP00054

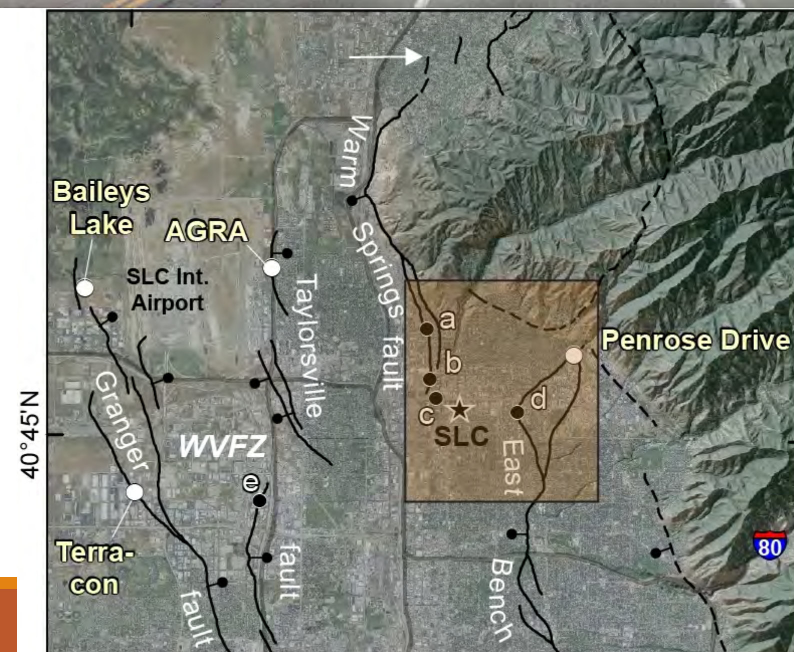
Identify and characterize active faults beneath the Salt Lake City urban corridor through p-wave reflection profiling to ~200 m depth - processing with Seismic Unix & ProMAX.

Shear wave velocity profiles beneath Salt Lake City through Rayleigh wave (MASW) inversions to estimate NEHRP-class soil/rock type to >30 m depth (Vs30) processing with Surfseis.

Depth to water table to assess liquefaction potential – p-wave refraction profiling to >20 m depth processing with Rayfract

Identify shallow bedrock locations that may produce localized earthquake site amplification – p-wave reflection/refraction profiling

Vp/Vs or Poisson's ratio to identify lithology or fluid pathways – p-wave/s-wave tomography to 20 depth



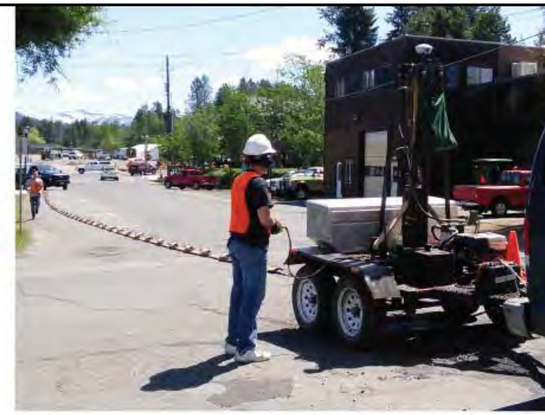
Approach
Multi-component Land Streamer

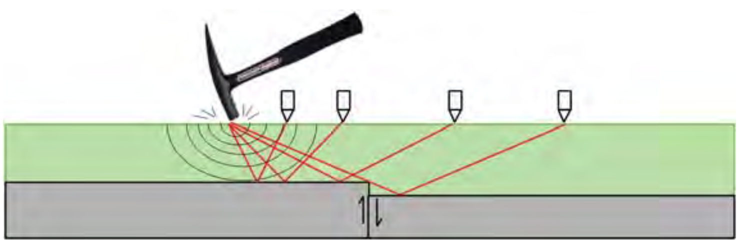
Land streamer first developed by van der Veen and Green (1998)

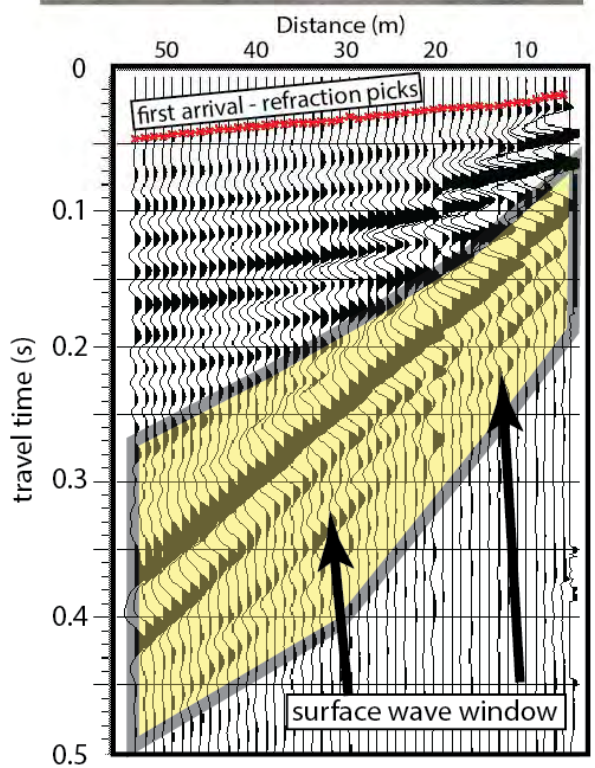
Contact-coupled geophones with seismic source
- P-wave and S-wave refraction
- Surface wave analysis (MASW - Vs estimates)
- P-wave and S-wave reflection (boundary information)

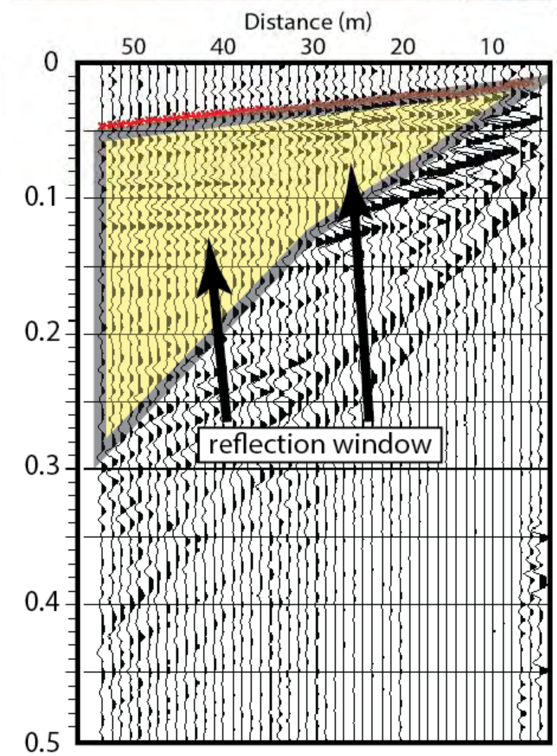
- On road and off-road applications

- Our focus is surface and body wave urban seismic characterization.

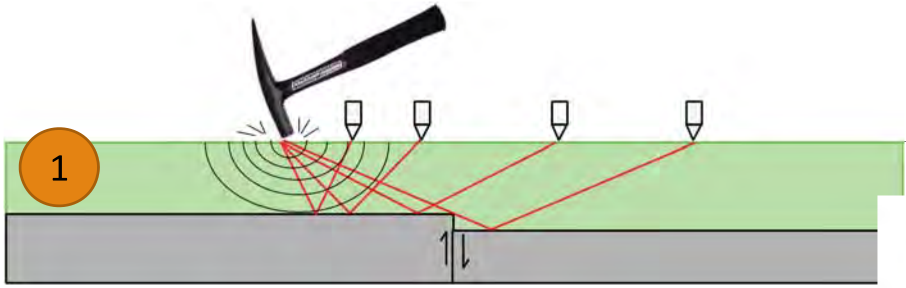


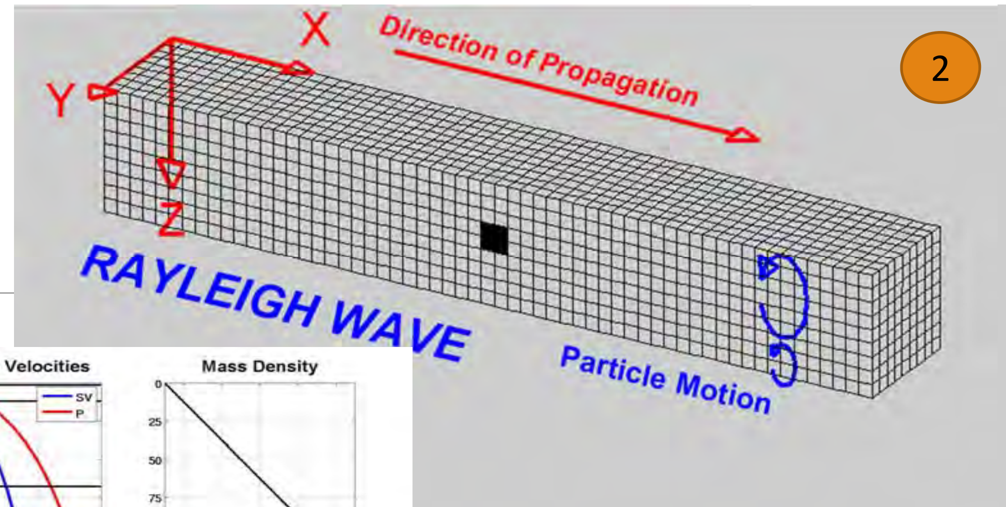


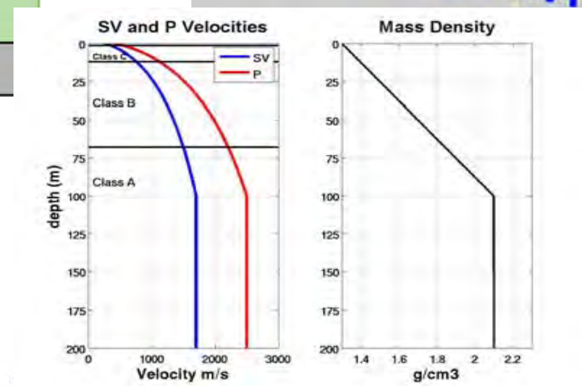


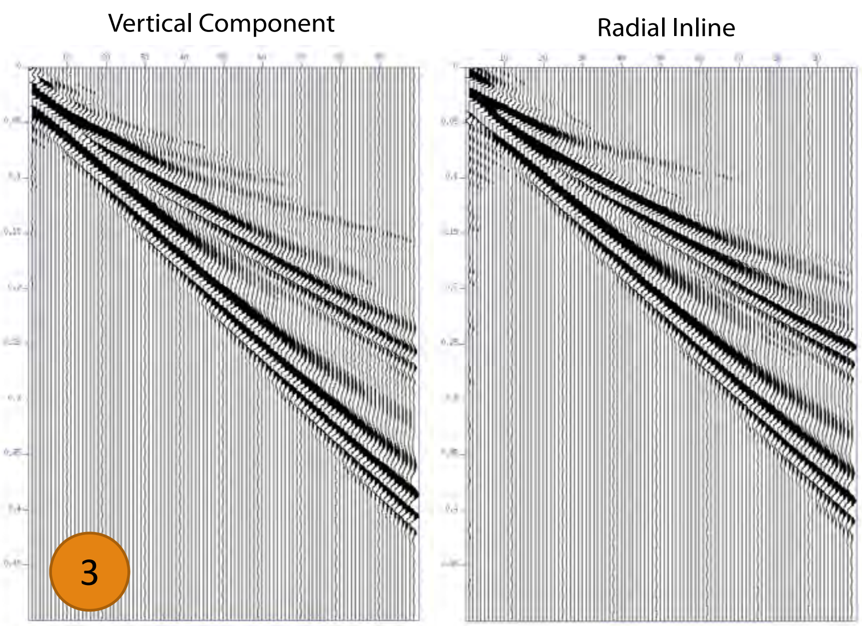


Surface waves to Vs

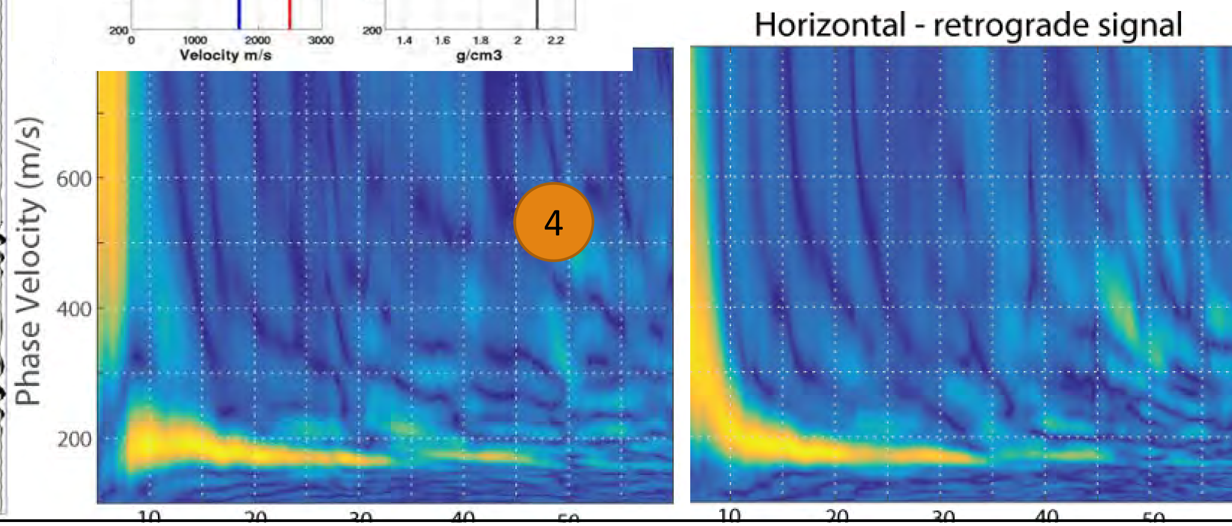








Multicomponent approach
Gribler et al (in review)



Boise State land streamers

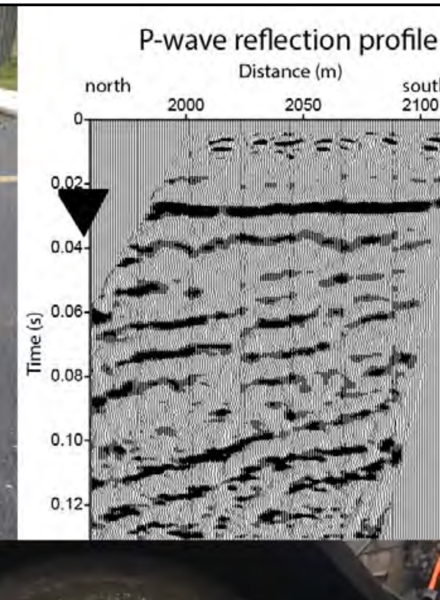
1-, 2- and 3-component streamers with 4.5/10/40 Hz geophones

Comparable data quality to planted geophones
- Uniform plate coupling and consistent road surface/grade/base

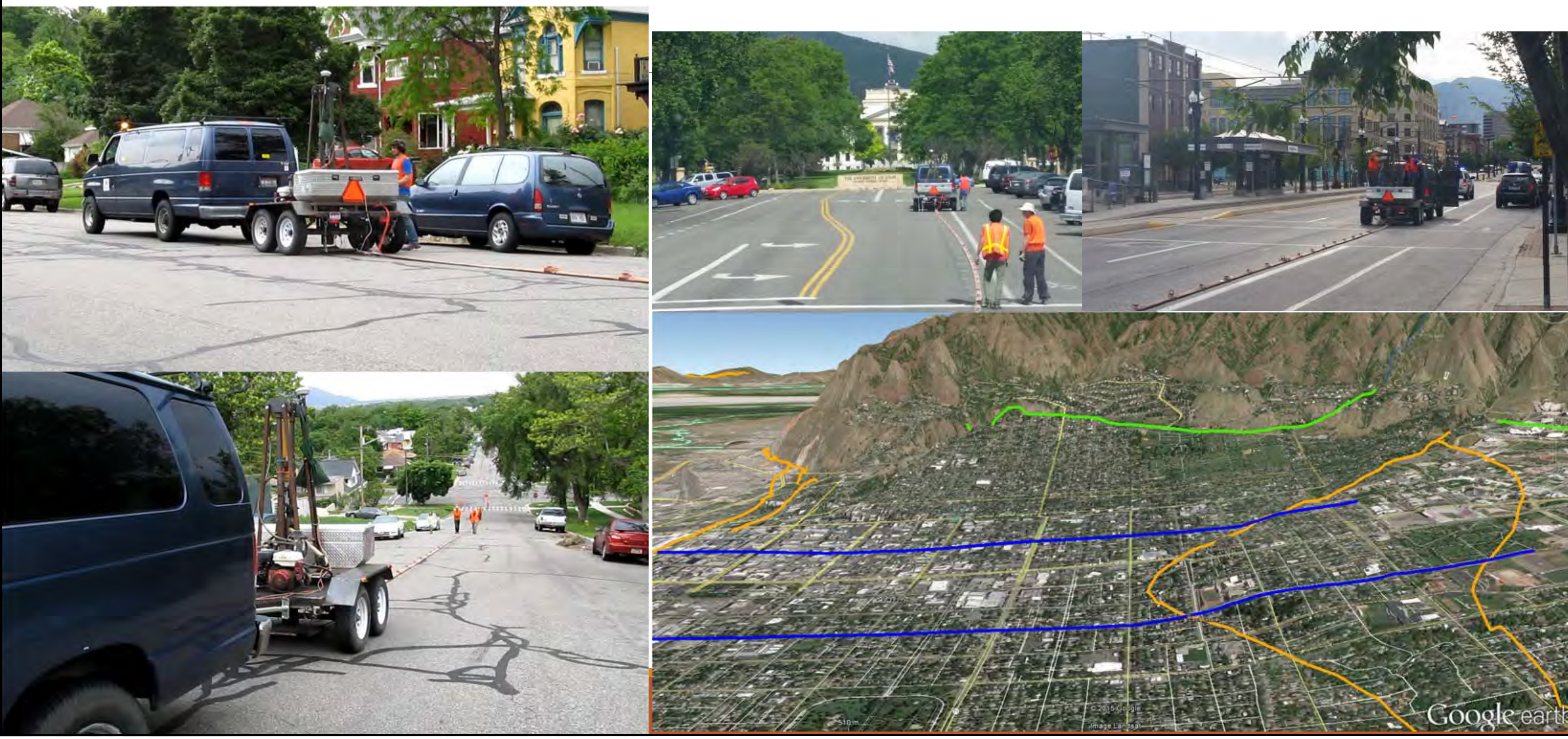
Operations along straight (paved or gravel) roads

Coupled with accelerated 200 kg (vertical) weight dr
- (8 seconds per 2 m shot spacing)

For Salt Lake City experiment
48 2-component shoes (vertical and in-line)
4.5 Hz geophones
1.25 m spacing (60 m aperture) with a 5 m near offset
2 m nominal shot spacing



Salt Lake City land streamer acquisition



Salt Lake City 2015
Land Streamer Survey

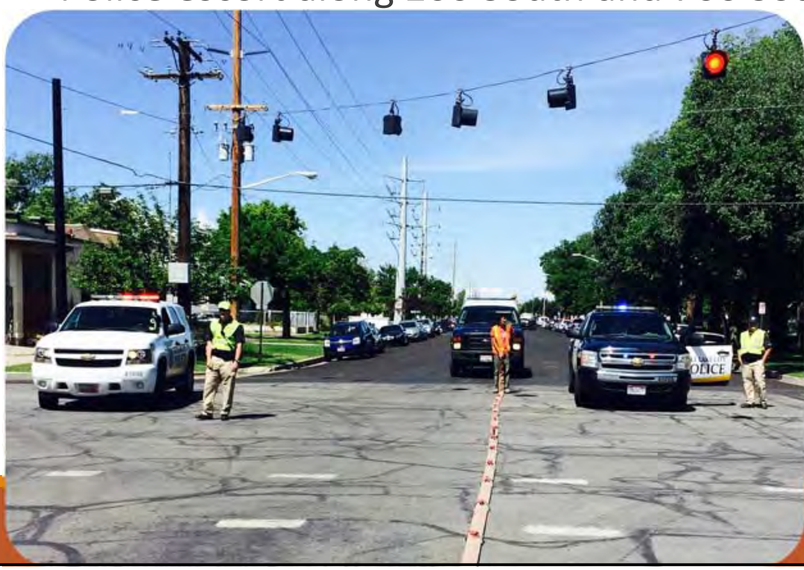
5,576 shot gathers – 2 m spaced shots (gaps at major roads)

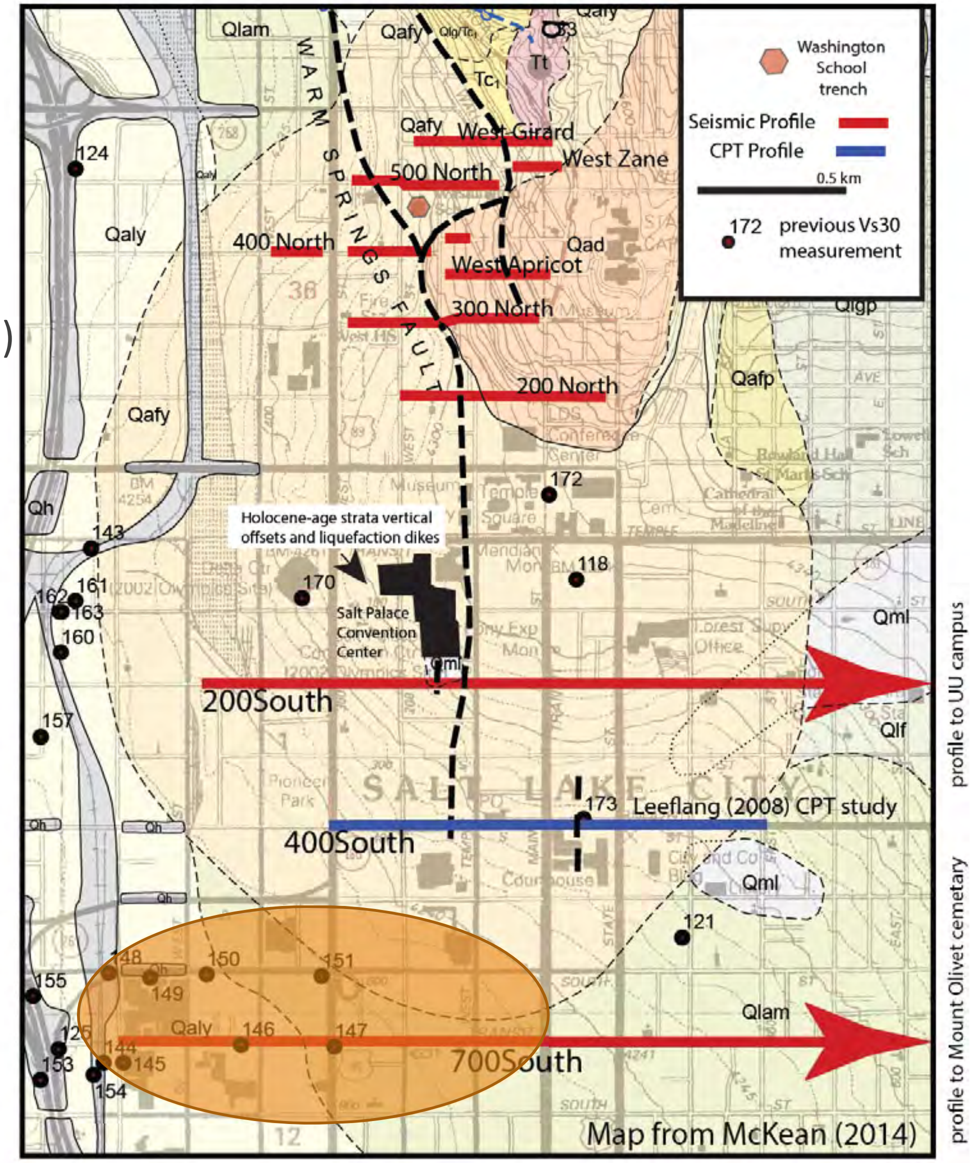
About 15 km length along 9 west-east profiles

3 field days

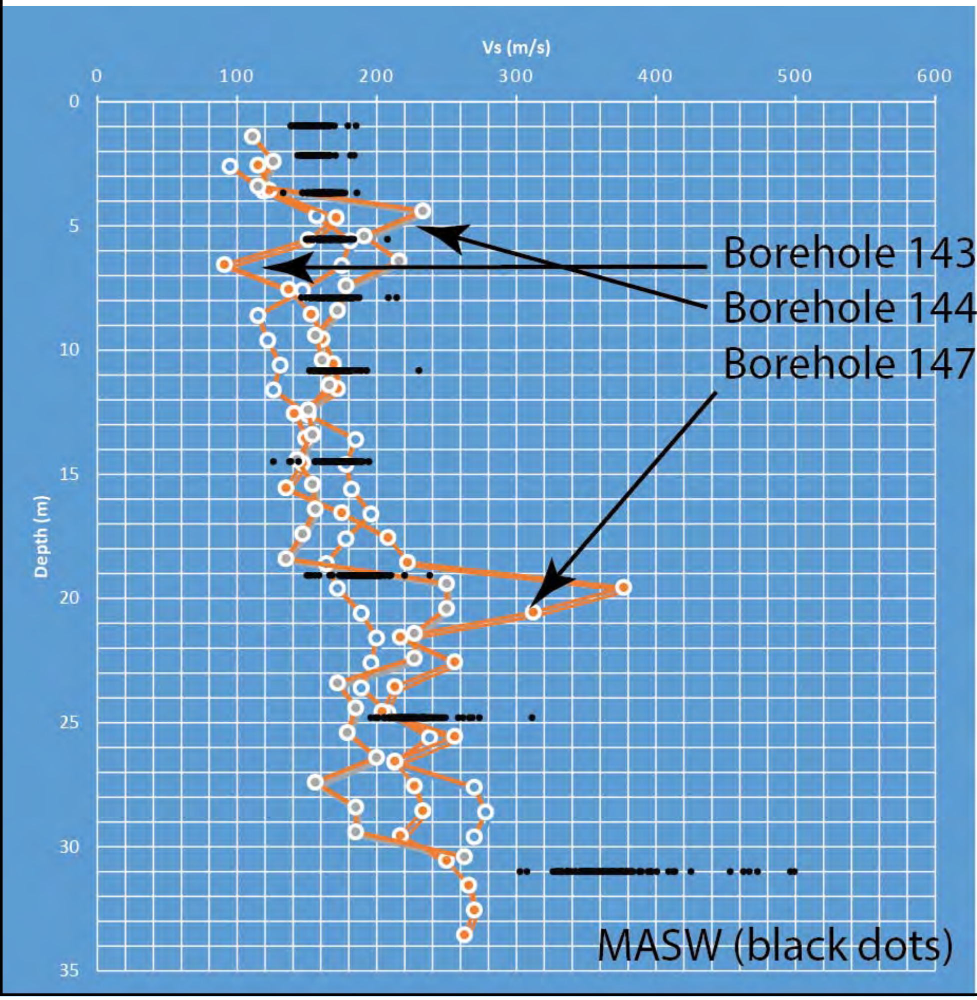
Flagger crew in North Salt Lake City

Police escort along 200 South and 700 South

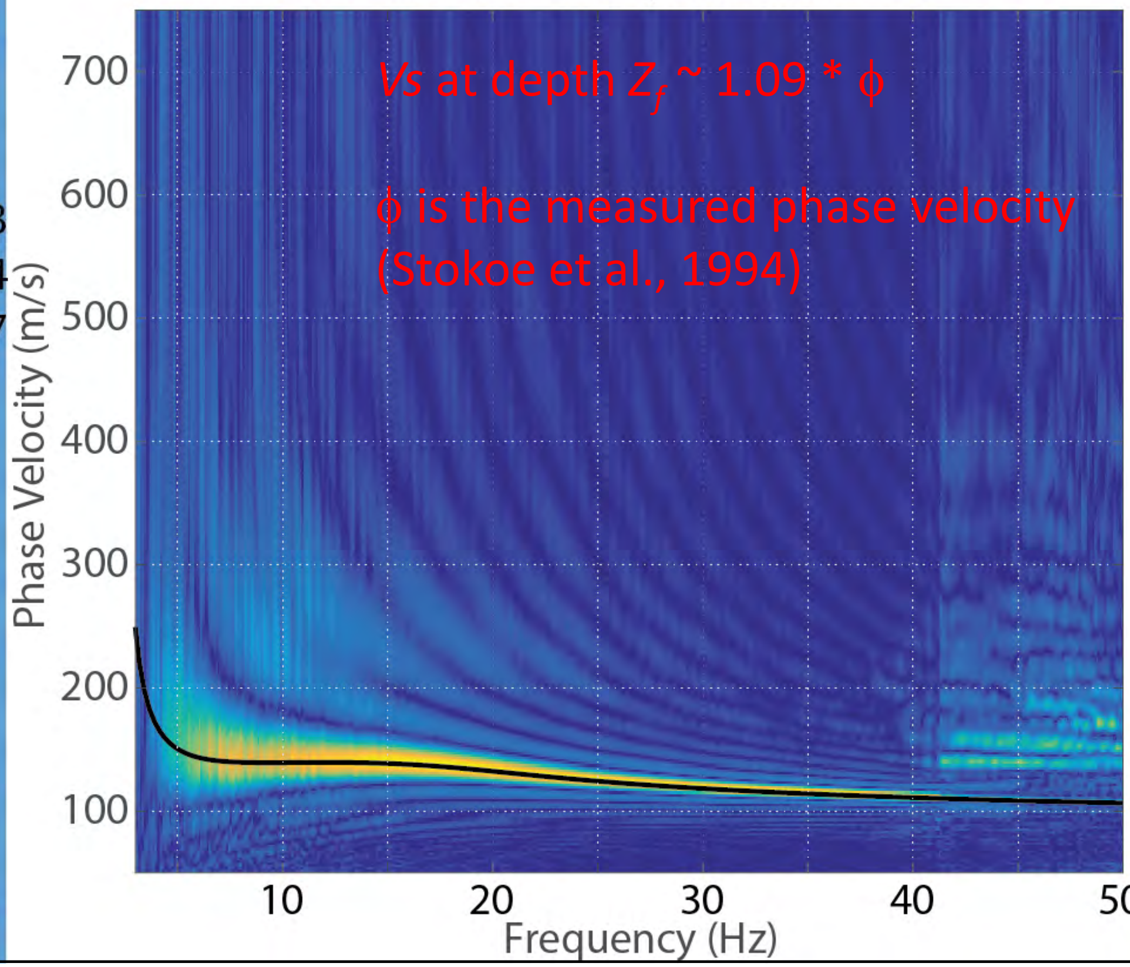




Vs/phase velocity via dispersion plots

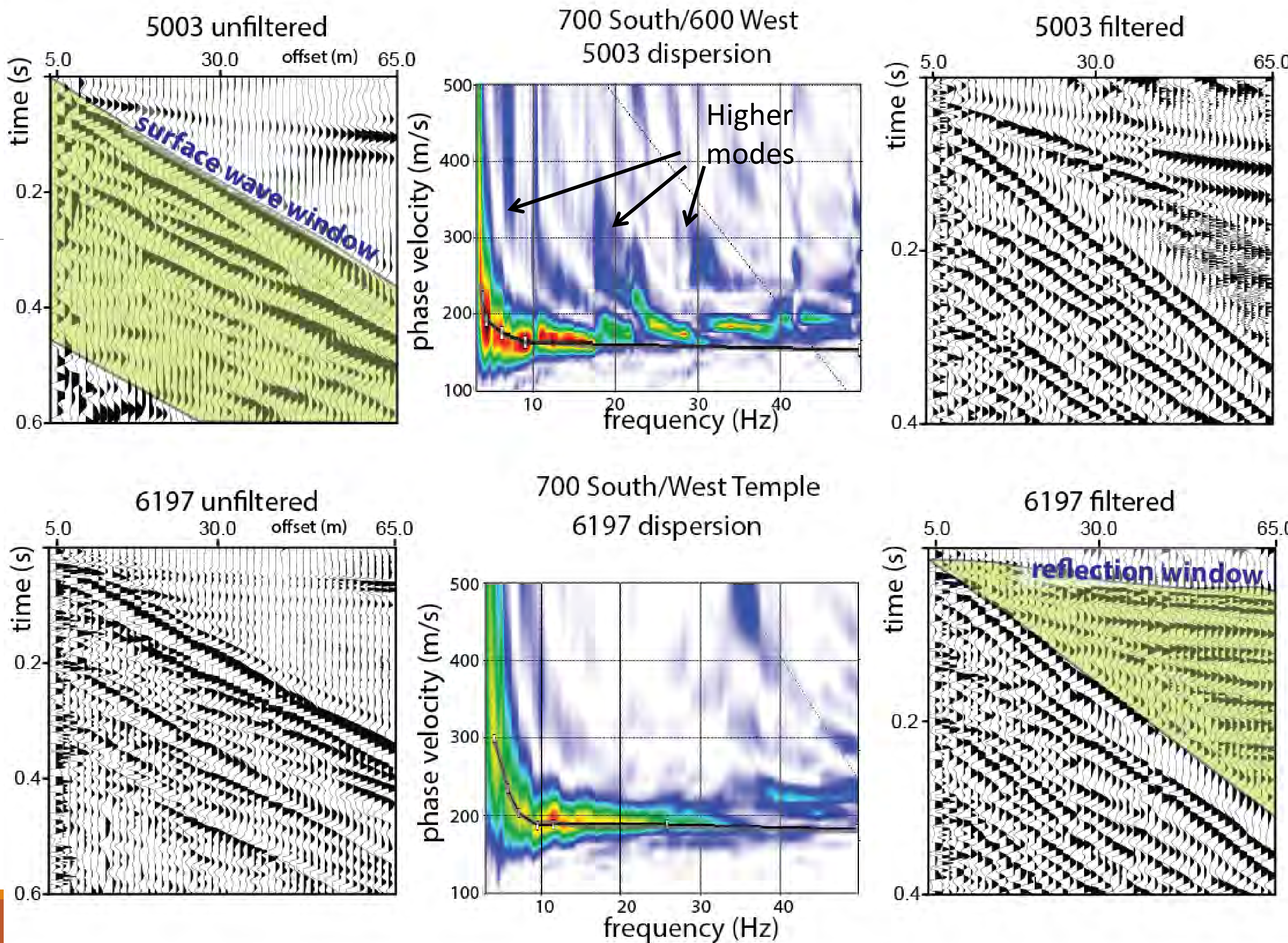


Borehole 143 dispersion curve



Vs (MASW) profiling

700 South shots and dispersion curves



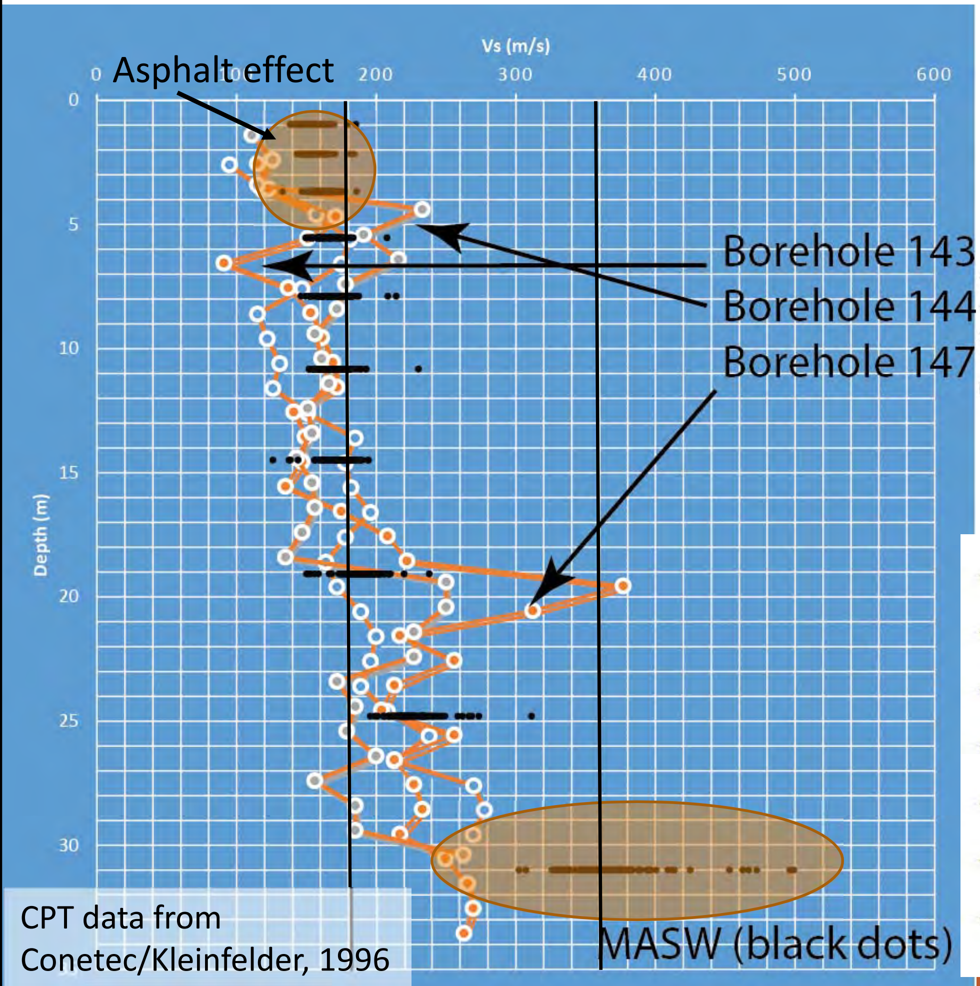
NEHRP site classification

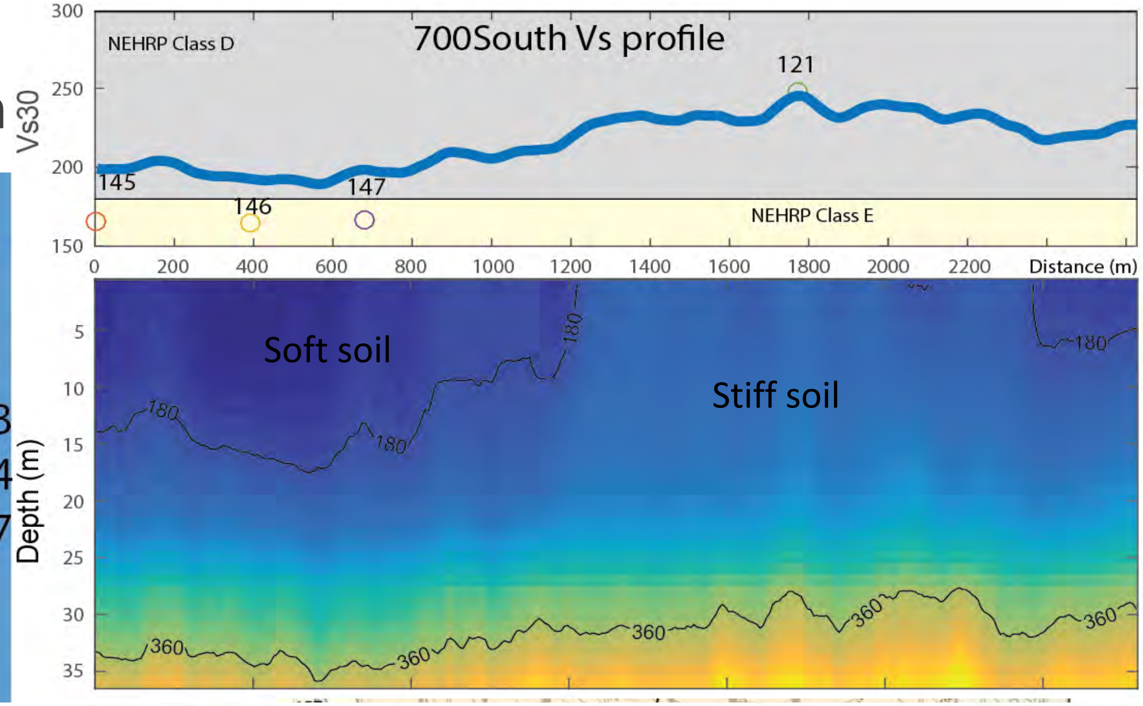
$Vs_{30} = 30 / \Sigma (d/Vs)$

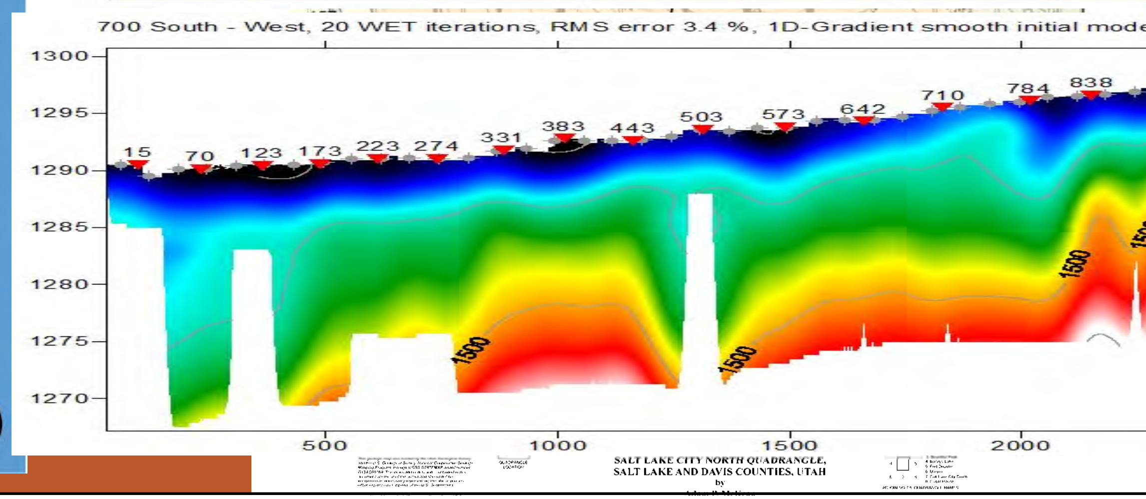
Table 1. NEHRP Modified Site Classification criteria based on shear wave velocity (FEMA, 1994; International Code Council, (2009). Equivalent p-wave velocities (Vp) are estimated using a Vp/Vs ratio or 2.5.

NEHRP Class		Vs Range (m/sec)	Vp unsaturated (est @2.5x Vs) (m/sec)	Vp saturated (est) (m/sec)	Sediment Type
E		< 180	<450	1500	Soft soil
	D1	180 - 240	600	1600	Stiff soil
D	D2	240 - 300	750		
	D3	300 - 360	900		
	C1	360 - 490	1225	2000	Very dense soil/soft rock
C	C2	490 - 620	1550		
	C3	620 - 760	1900		
B		> 760	>1900	>3000	Rock
A		>1500	>3750	>3000	Hard Rock

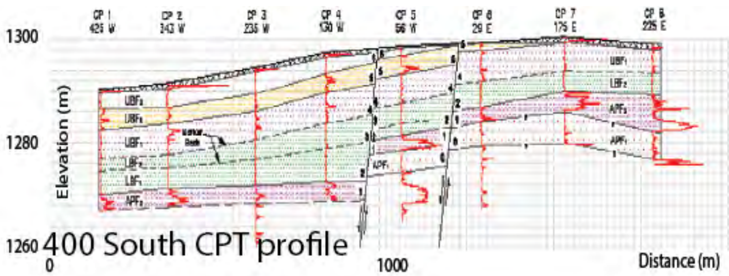
700 South CPT /MASW Vs comparison

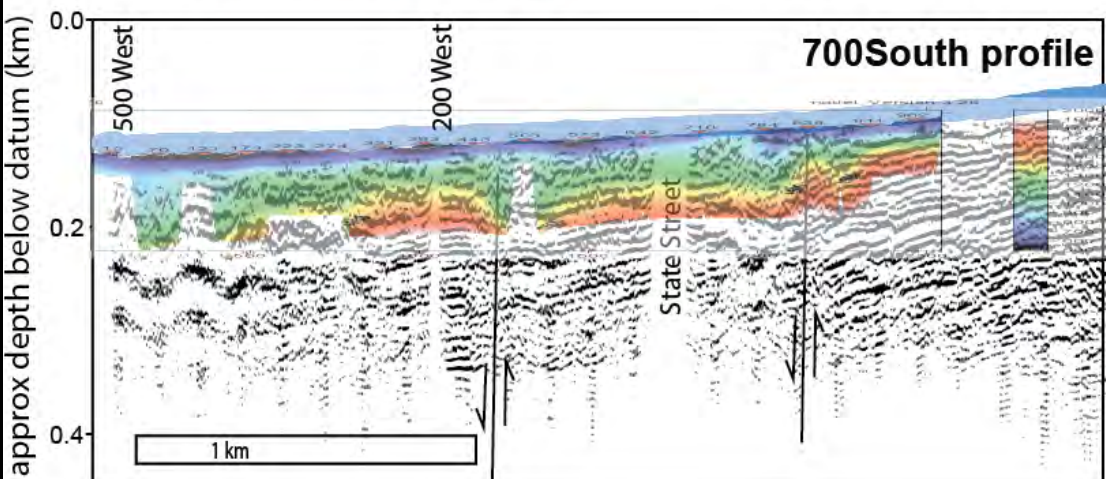




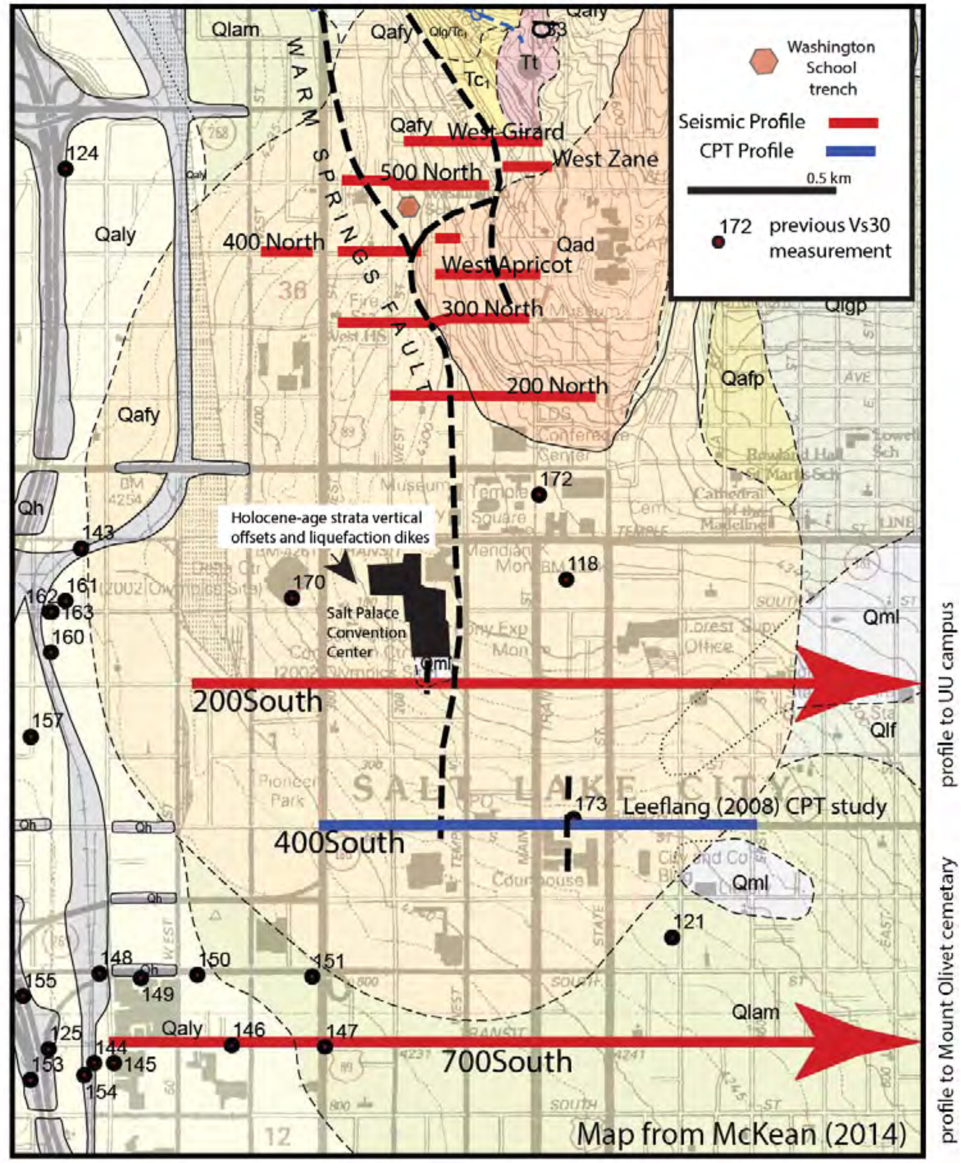


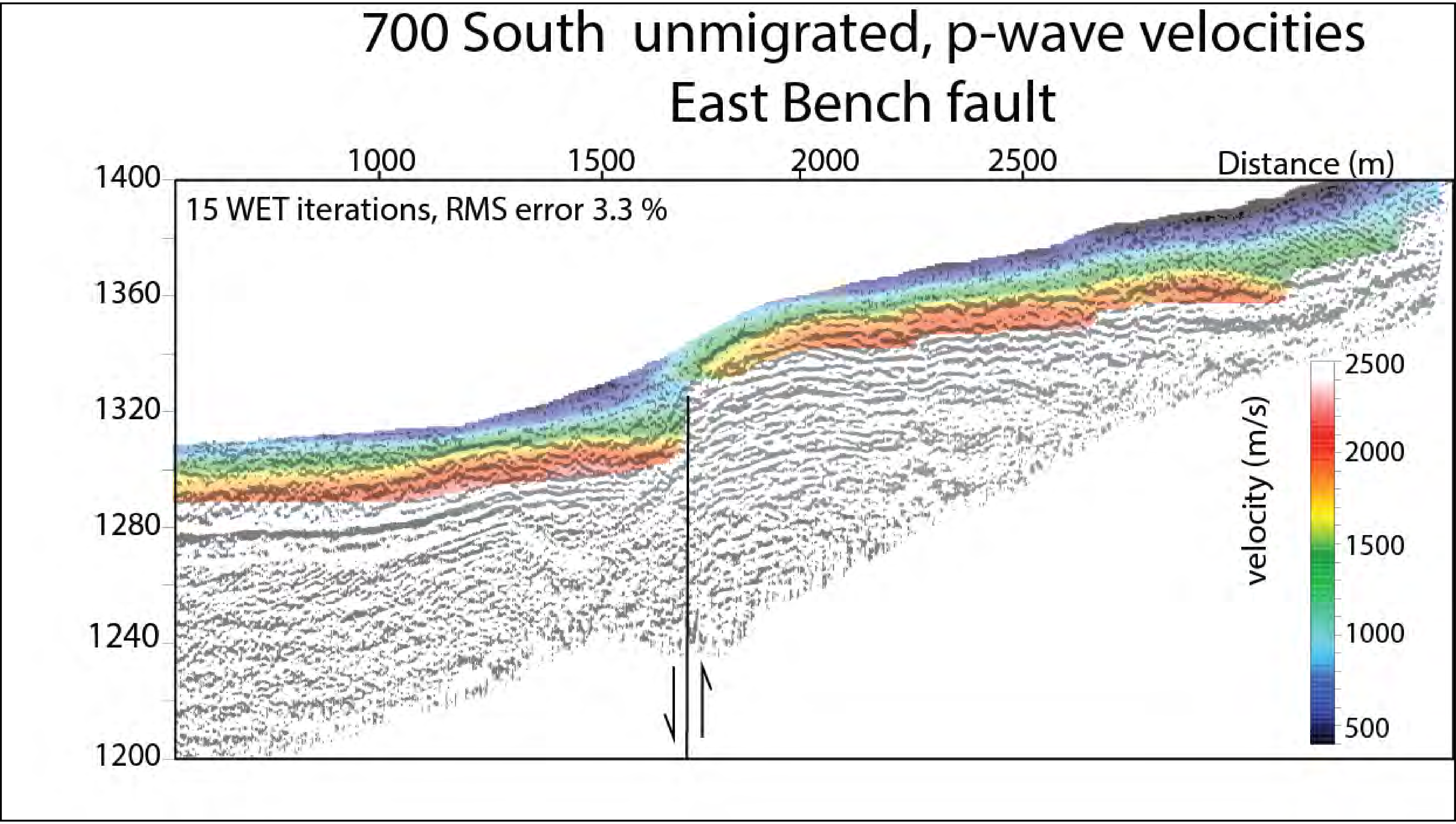
Salt Lake City 2015 Land Streamer Survey



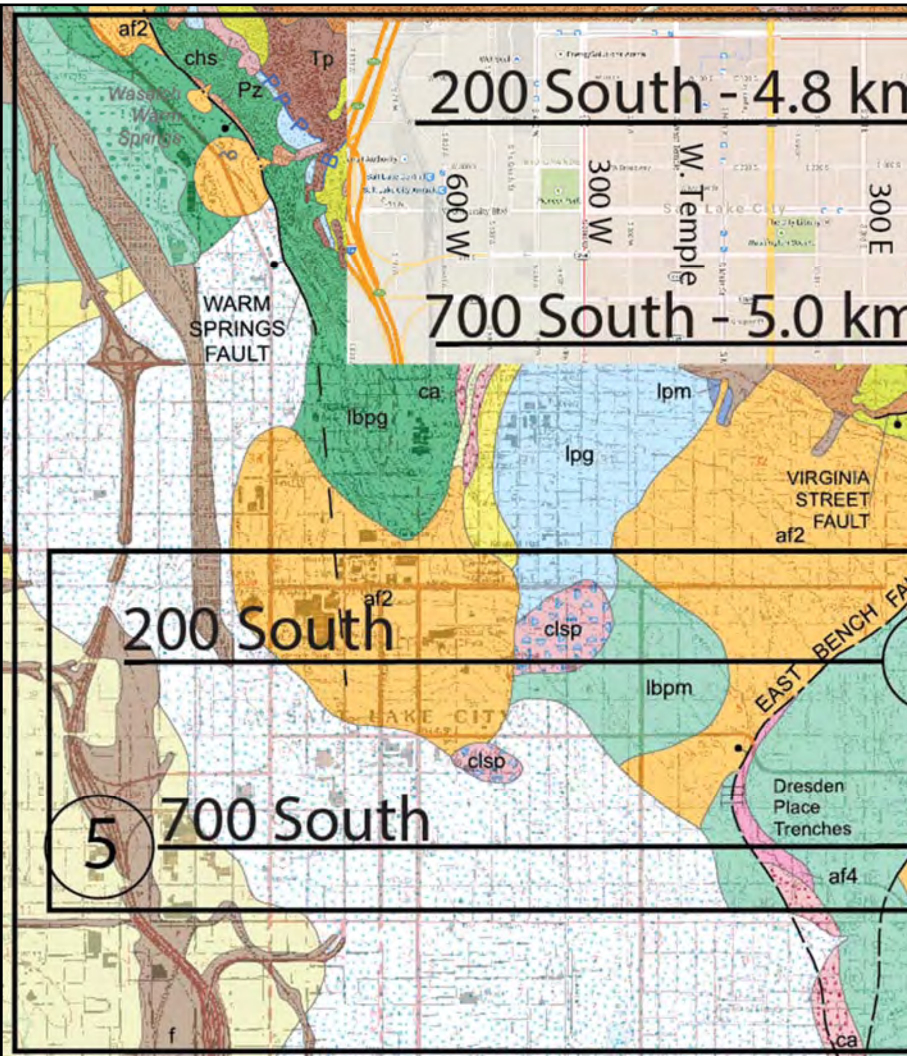


400 South CPT interpretation (Leeflang, 2008)

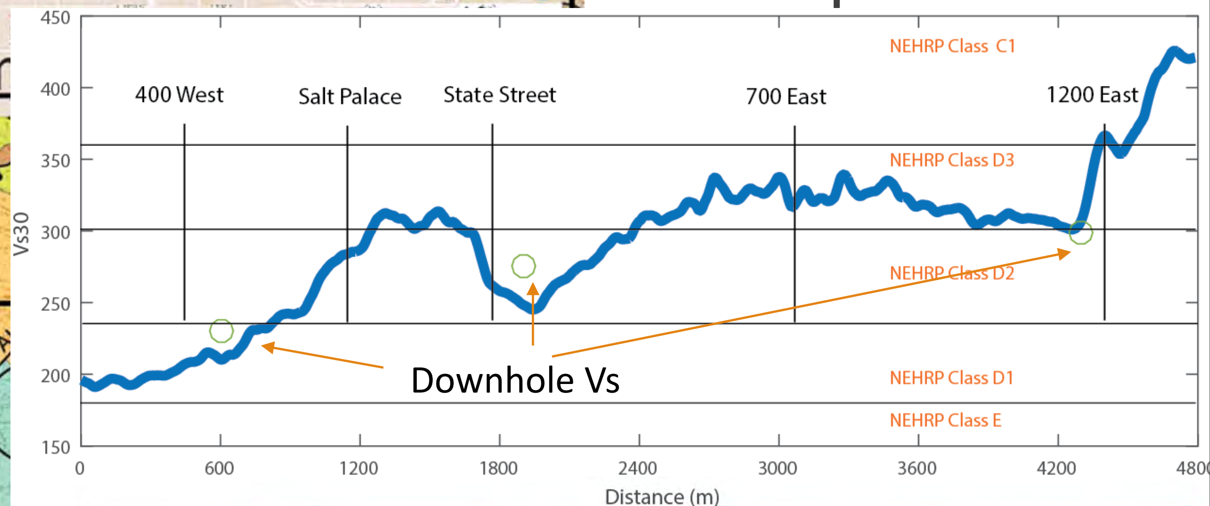


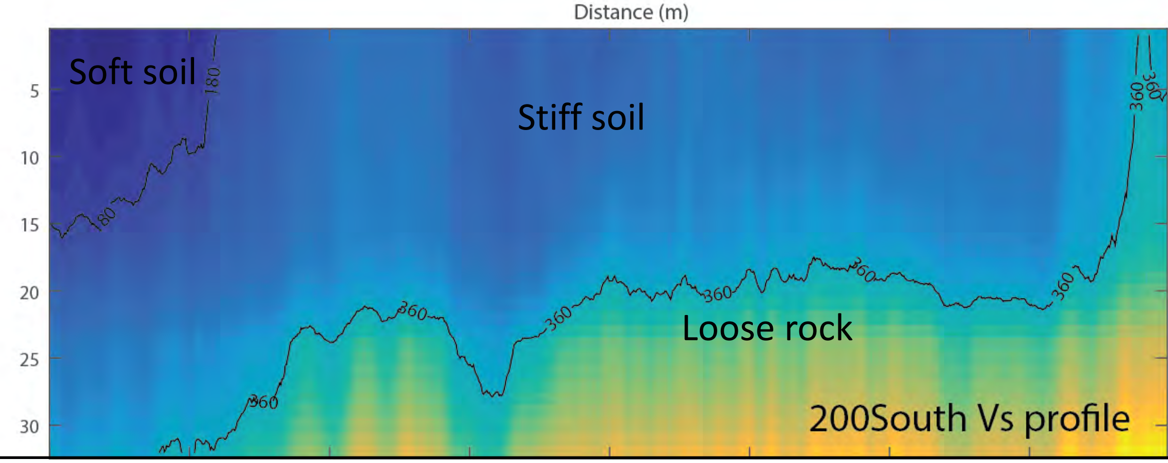

700 South unmigrated, p-wave velocities
East Bench fault
15 WET iterations, RMS error 3.3 %
Distance (m)
1000
1500
2000
2500
1400
1360
1320
1280
1240
1200
velocity (m/s)
2500
2000
1500
1000
500

200 South Vs profile

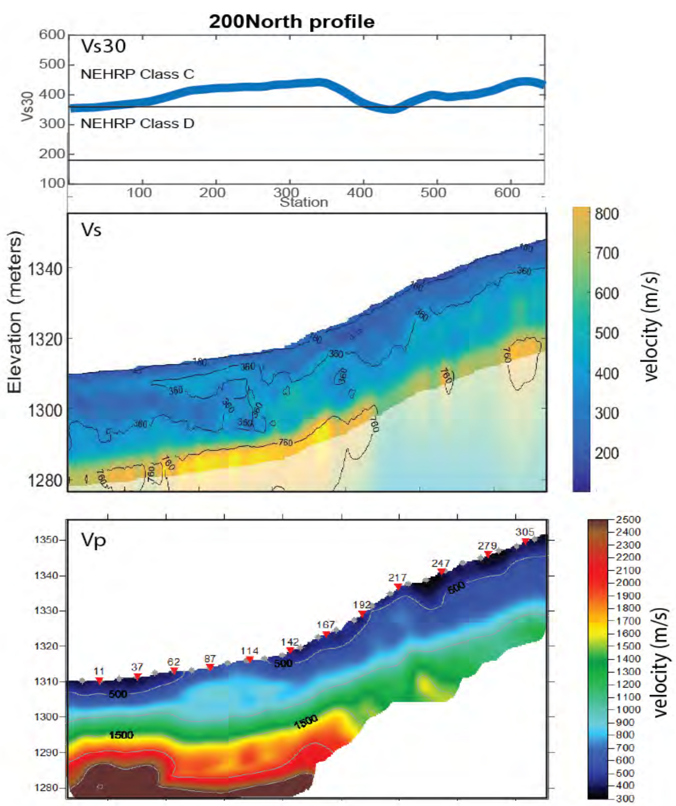


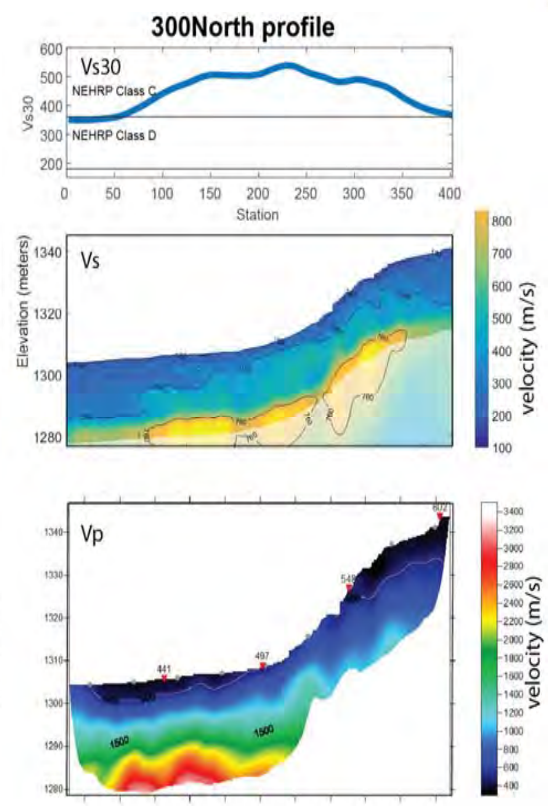
Surficial geologic map from Personius and Scott (2009)

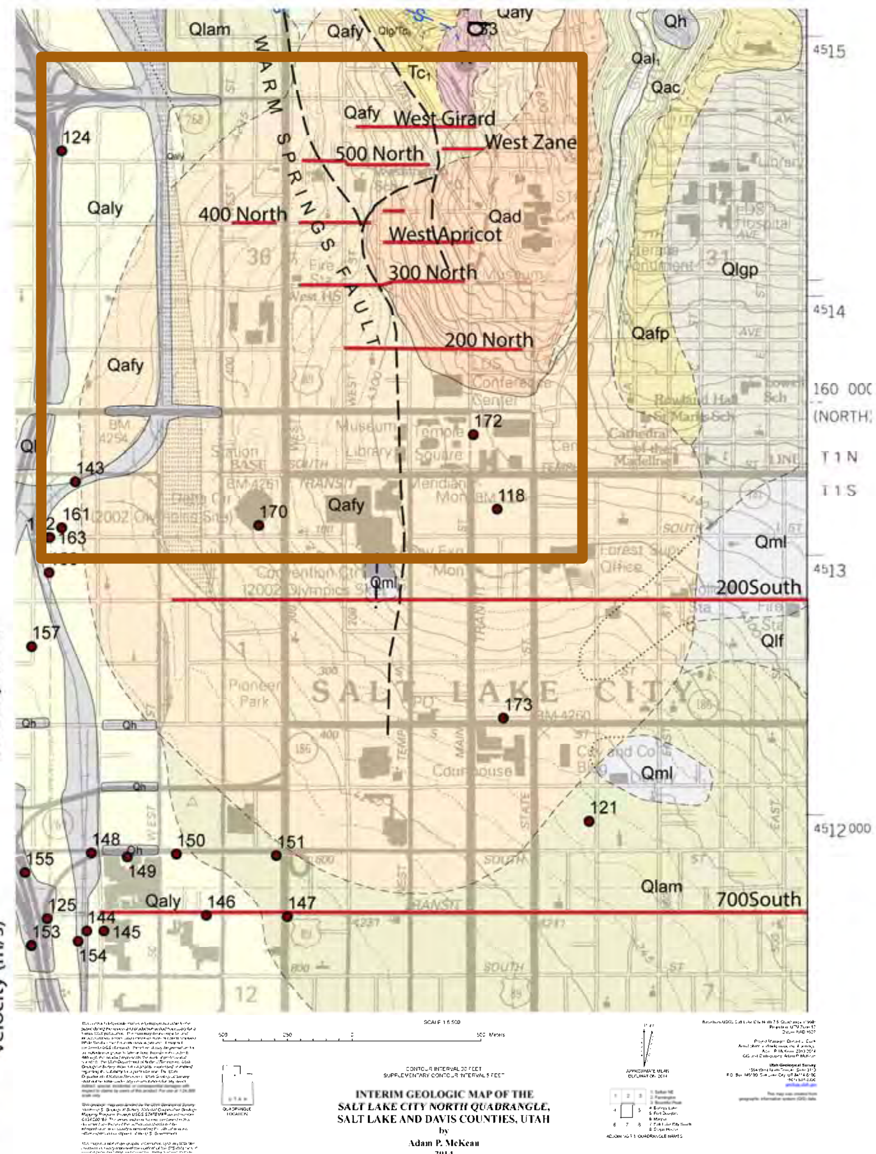




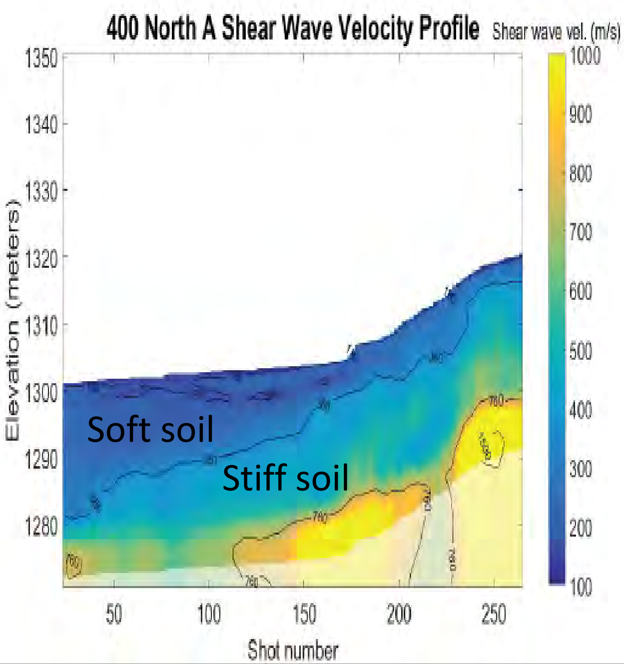
North Salt Lake City Vp and Vs

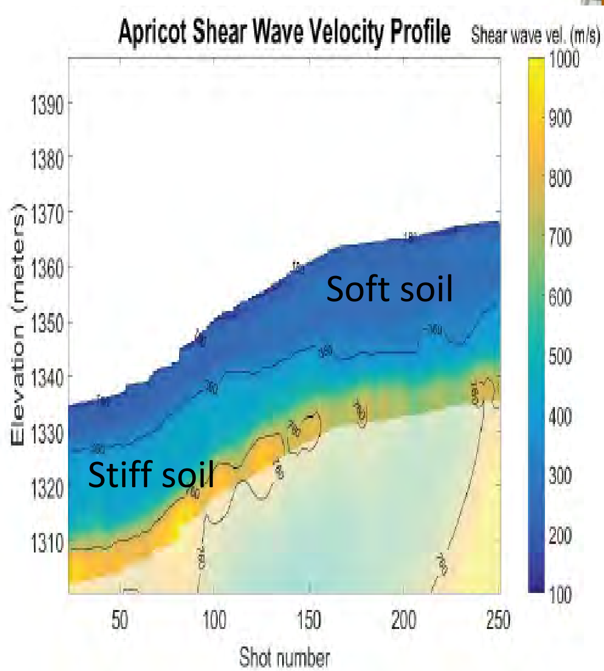


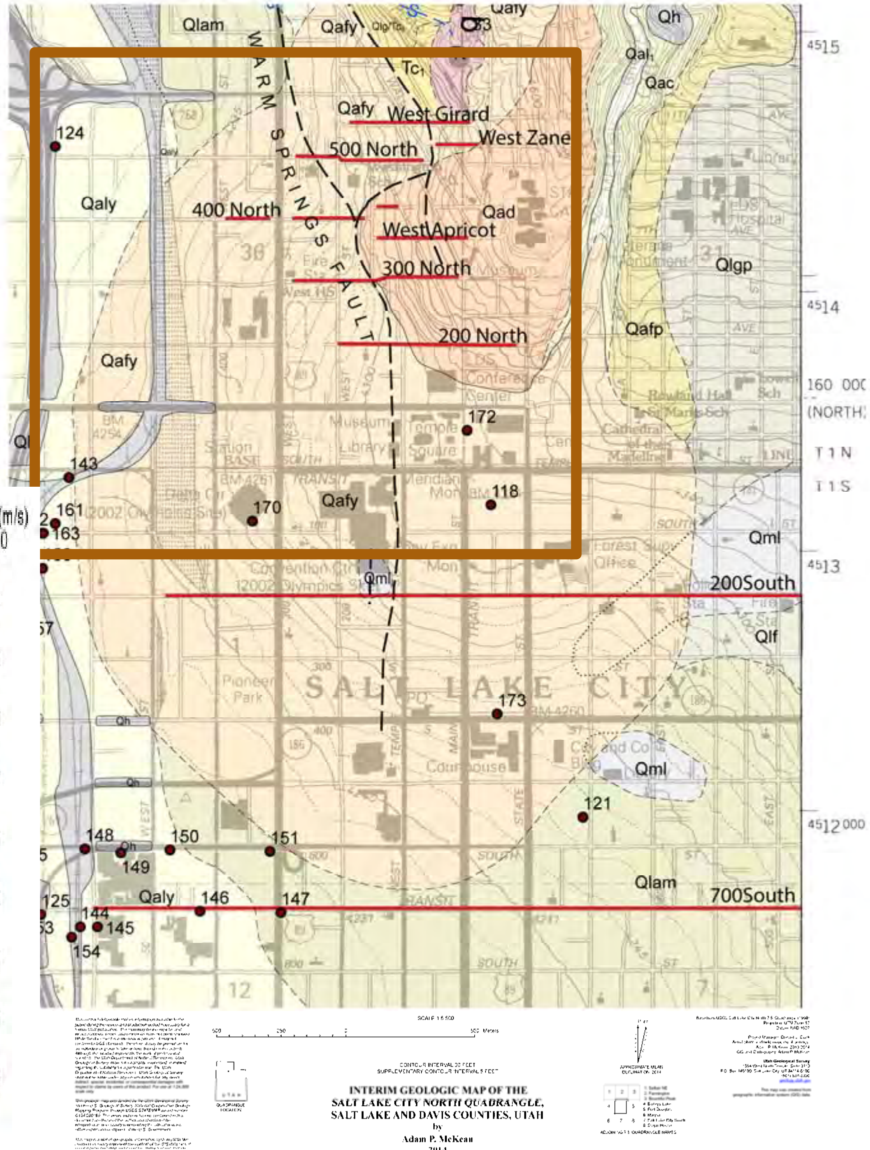




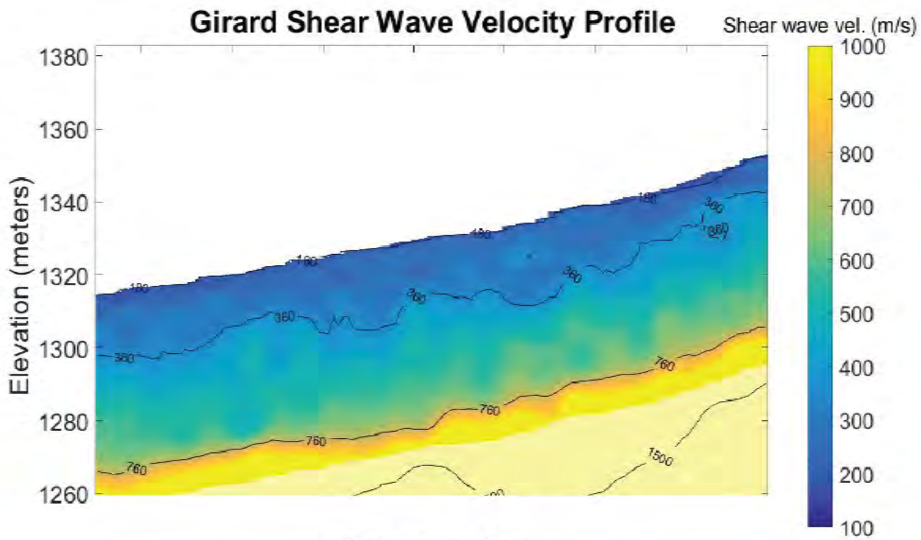
400 North and Apricot Street Vs profiles

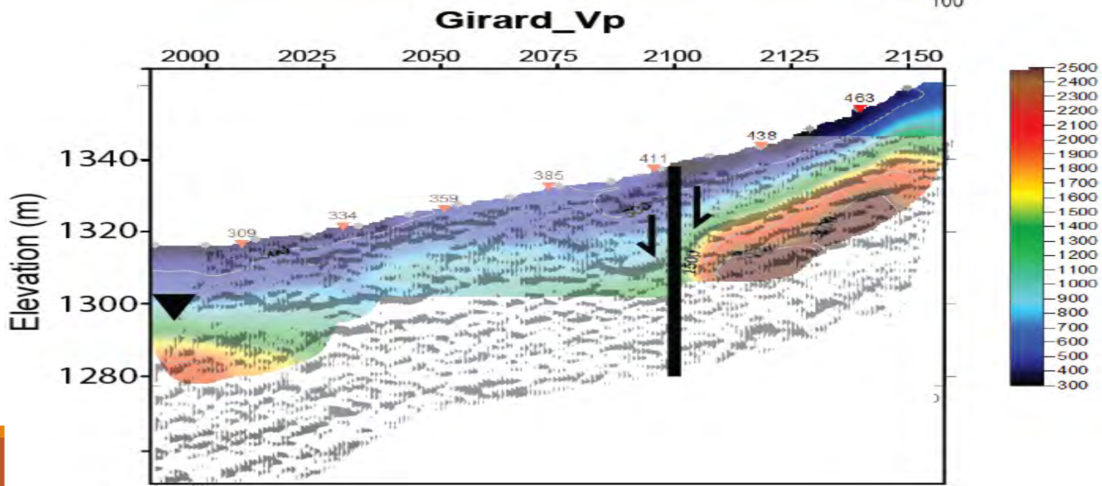


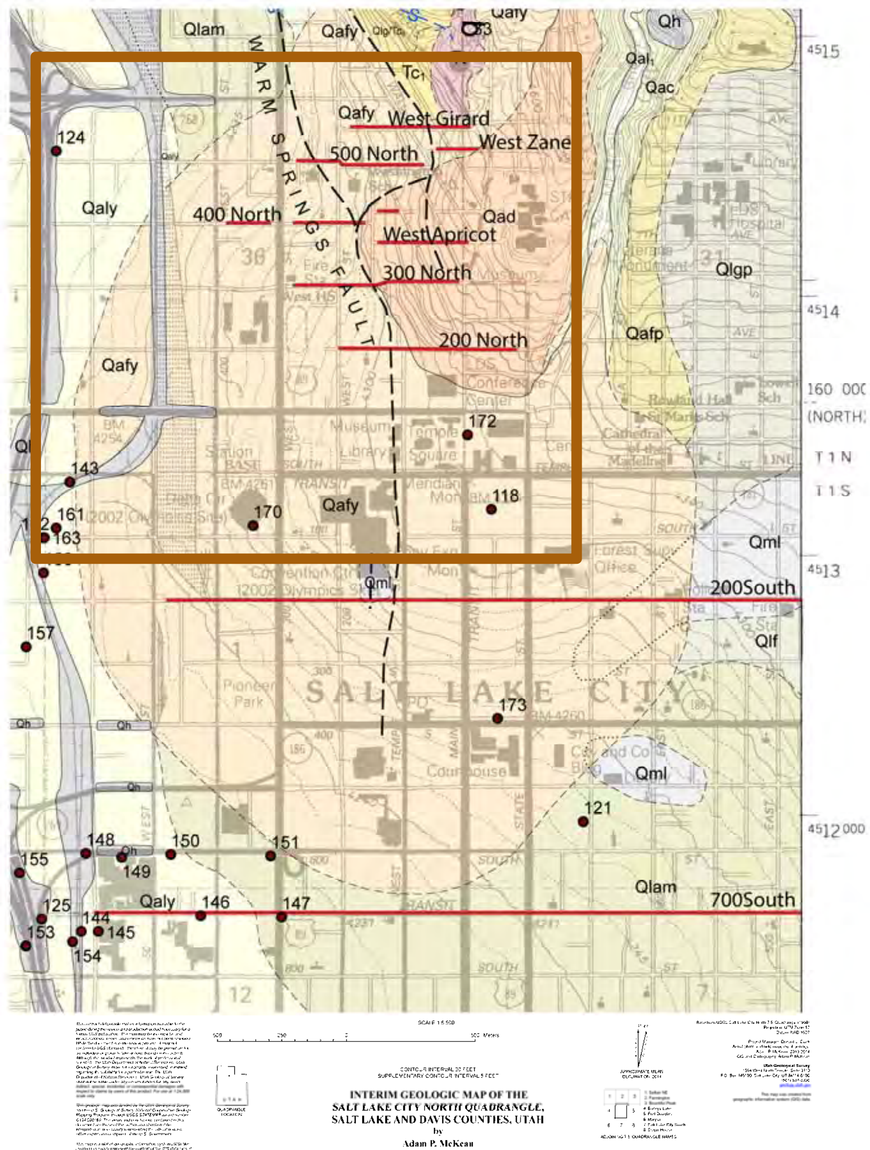




West Girard (shallow bedrock)

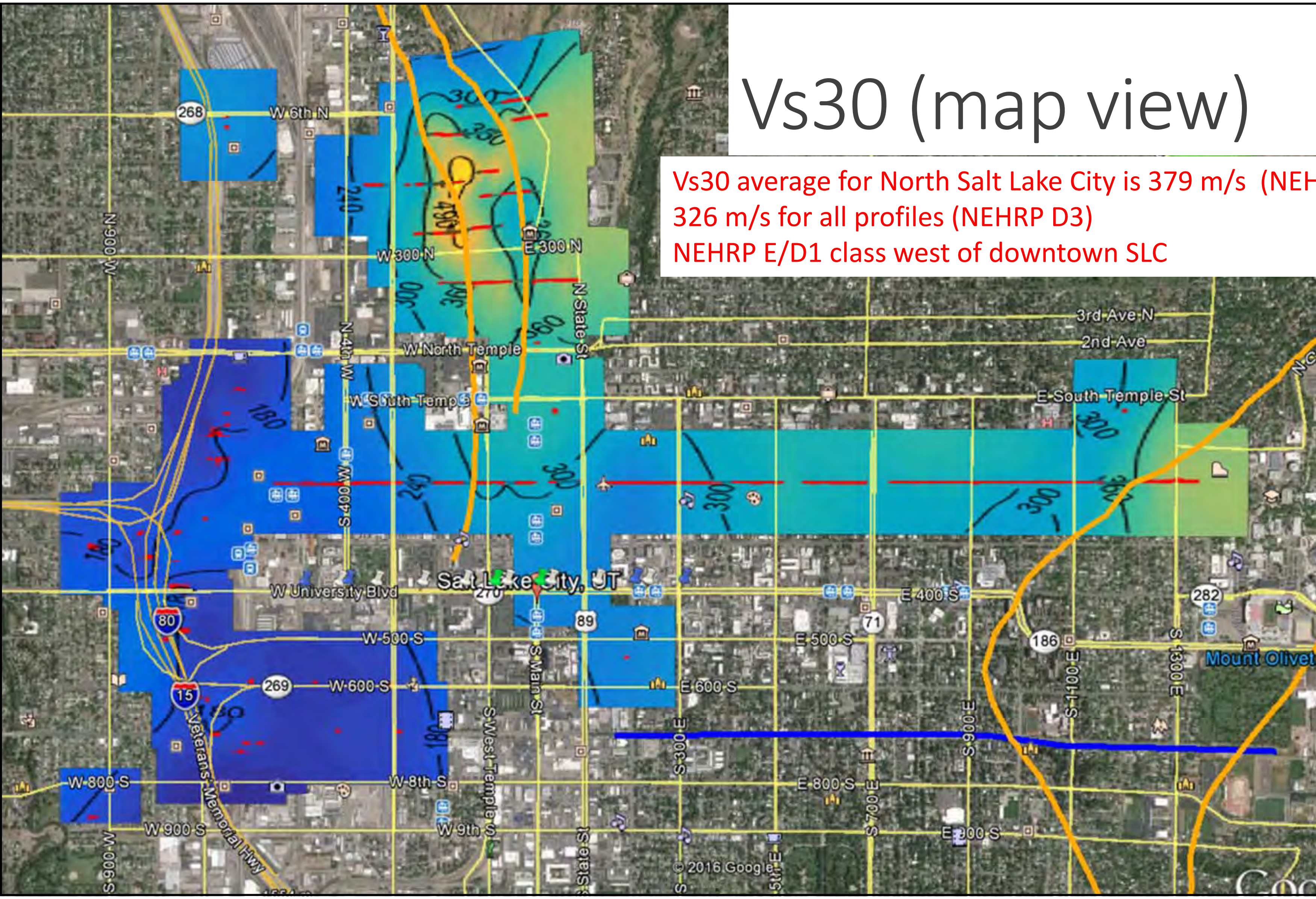






Vs30 (map view)

Vs30 average for North Salt Lake City is 379 m/s (NEHRP C1)
326 m/s for all profiles (NEHRP D3)
NEHRP E/D1 class west of downtown SLC



Summary

A seismic land streamer approach to urban seismic hazards provides a rapid tool to identify and characterize active faults, and to assess earthquake site response.

North Salt Lake City/Warm Springs fault

Vs30 average for North Salt Lake City is 379 m/s (NEHRP C1) and 326 m/s for all profiles (NEHRP D3)

Vs30 values increase from west to east with increasing surface elevation.

Shallow bedrock (Vp > 2,500 m/s) is mapped to the north of the Capitol building

Step in water table at the Warm Springs fault

Downtown Salt Lake City/Warm Springs fault extension

Vs30 values increase from west to east with increasing surface elevation.

We identify offset reflectors/Vs/Vp lateral variations consistent with active faults along 200 South and 700 South

Warm Springs fault extends to at least 700 South with decreasing offsets to the south

East Bench fault identified on both 200 S and 700 S with colluvial wedge material within fault zone

Numerical Simulation of Wasatch Fault Earthquakes

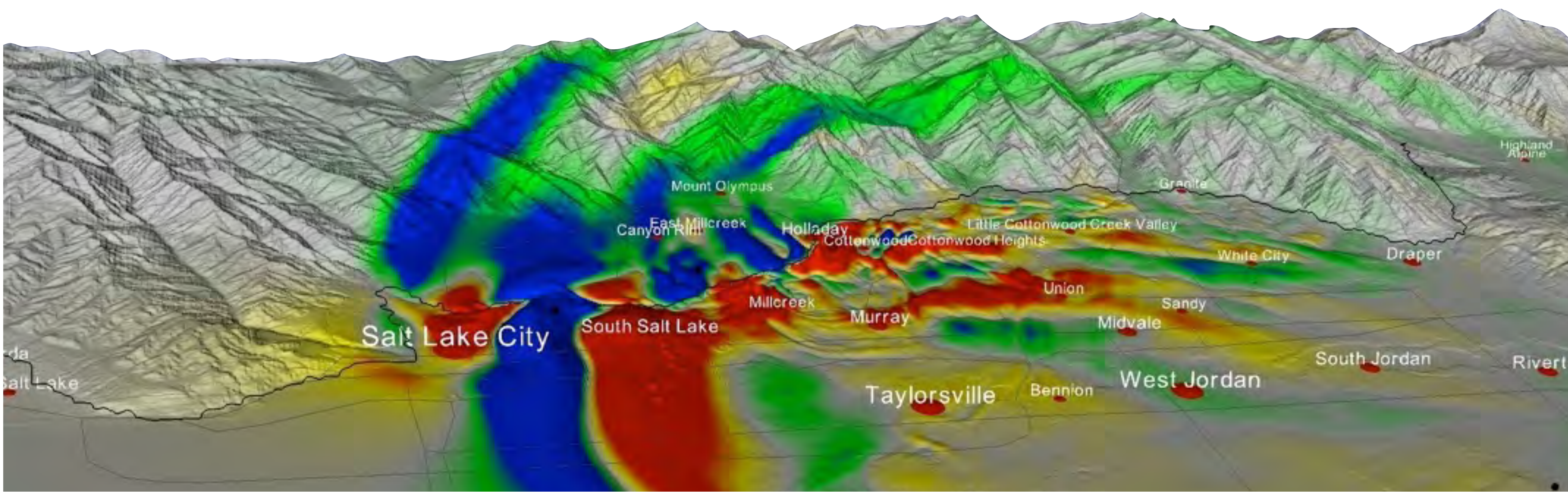
Roten, D.[1], Olsen, K.B.[1], and Pechmann, J.C.[3]

1 San Diego State University
2 University of Utah

San Diego State University

The University of Utah

2016 Utah Earthquake Working Group Meetings
Utah Ground Shaking Working Group
February 9, 2016



Outline

Summary of previous study

3D Simulations of M 7 Earthquakes on the Wasatch Fault, Utah

- Part I: Long-Period (0–1 Hz) Ground Motion

  D. Roten, K. B. Olsen, H. Magistrale, J. C. Pechmann, and V. M. Cruz-Atienza

  2011, BSSA, **101** (5)
- Part II: Broadband (0–10 Hz) Ground Motions and Nonlinear Soil Behavior

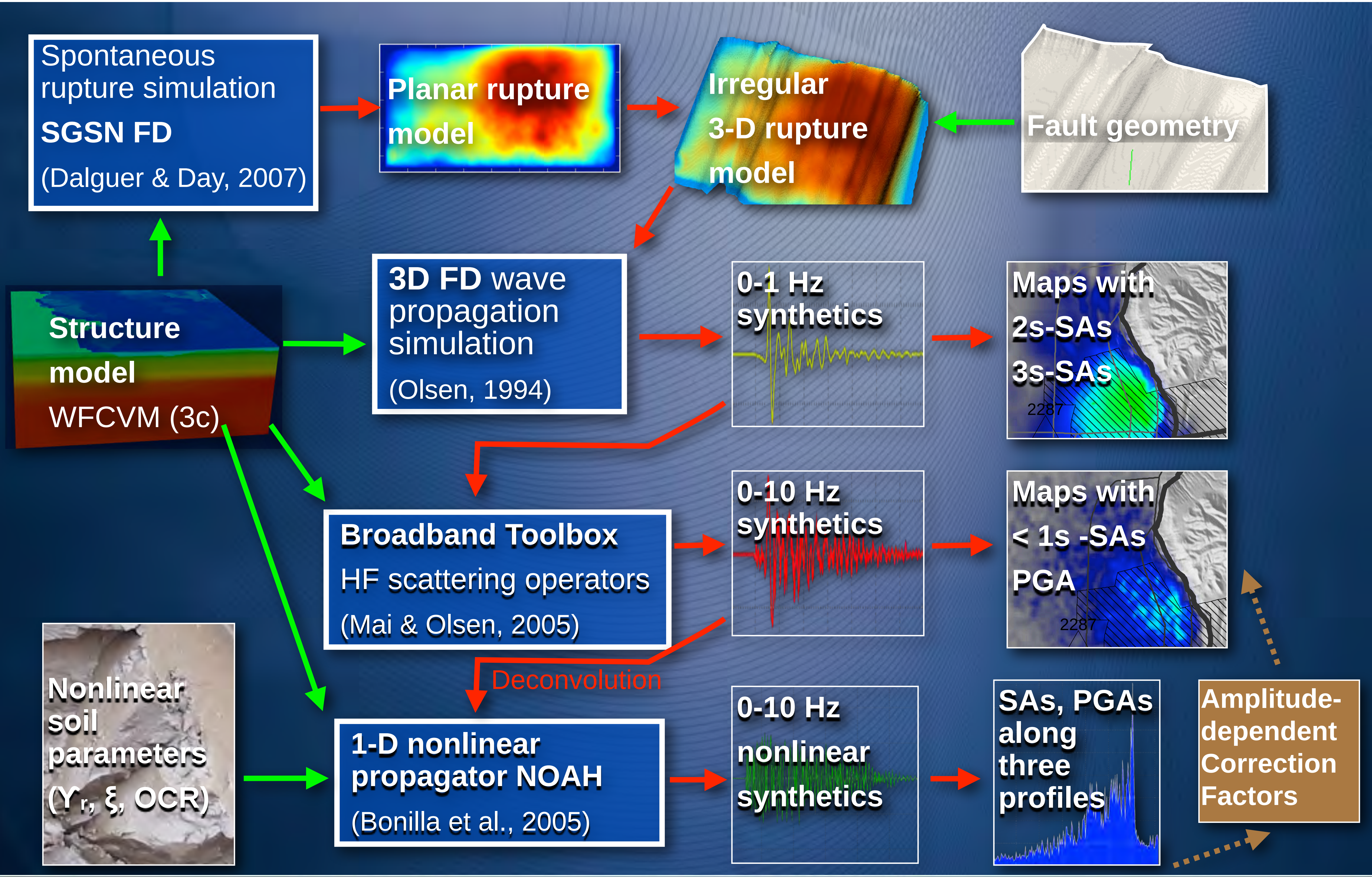
  D. Roten, K. B. Olsen and J. C. Pechmann

  2012, BSSA, **102** (5)

Follow-up research

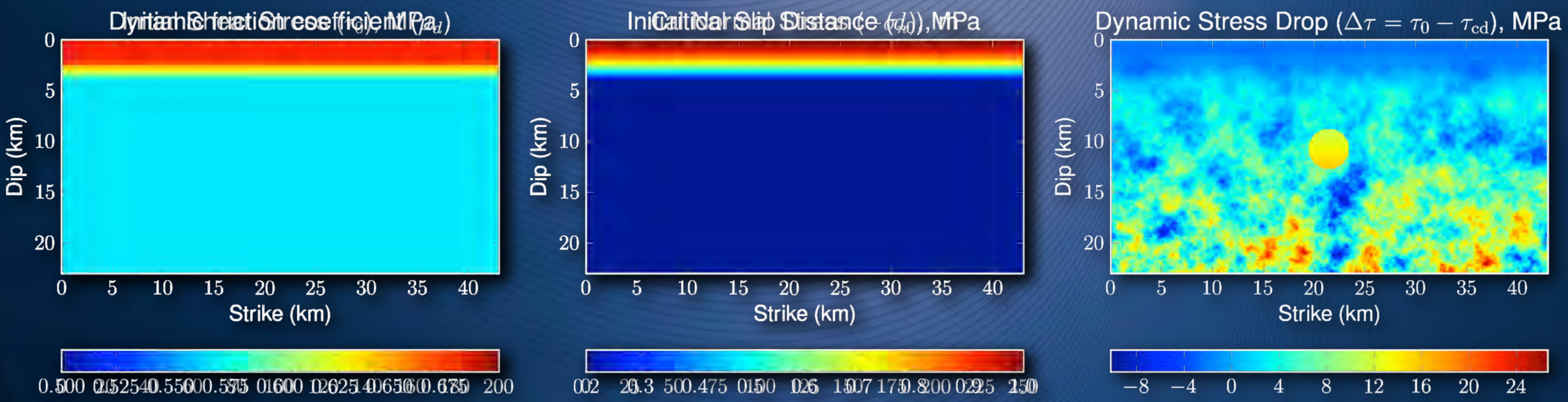
- Valley-wide 1D nonlinear simulations
- Analysis of source and rupture direction effects

Four-Step Method



Spontaneous rupture models

- Simulation of dynamic rupture process on a planar vertical fault
- Staggered-grid split node finite difference method (Dalguer & Day, 2007)
- Slip-weakening friction model using depth-dependent normal stress (Dalguer & Mai, 2008)
- Simulated velocity strengthening near the free surface (reduce τ_0, increase d_0, $\mu_d > \mu_s$)
- Four rupture models with different hypocenter locations

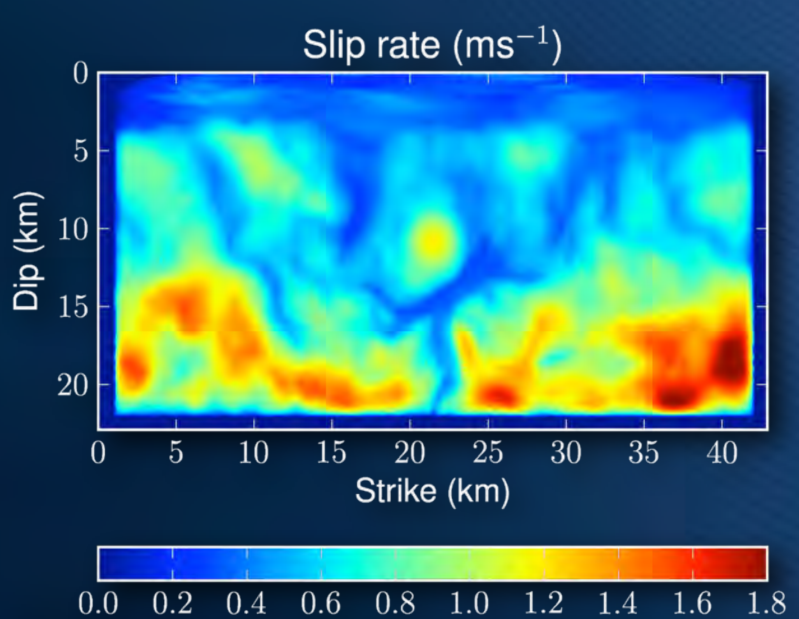


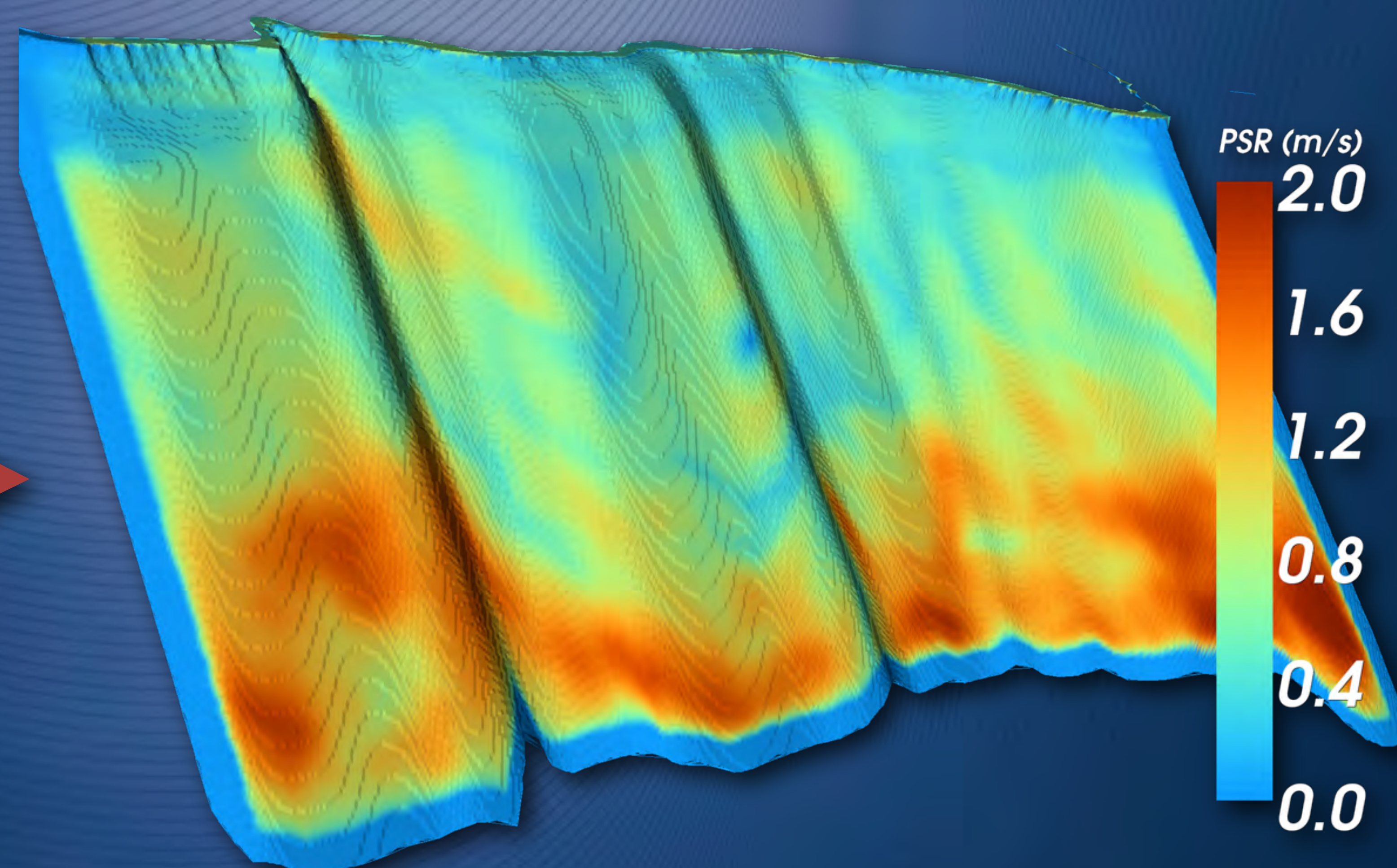
3-D FD Simulation of Wave Propagation

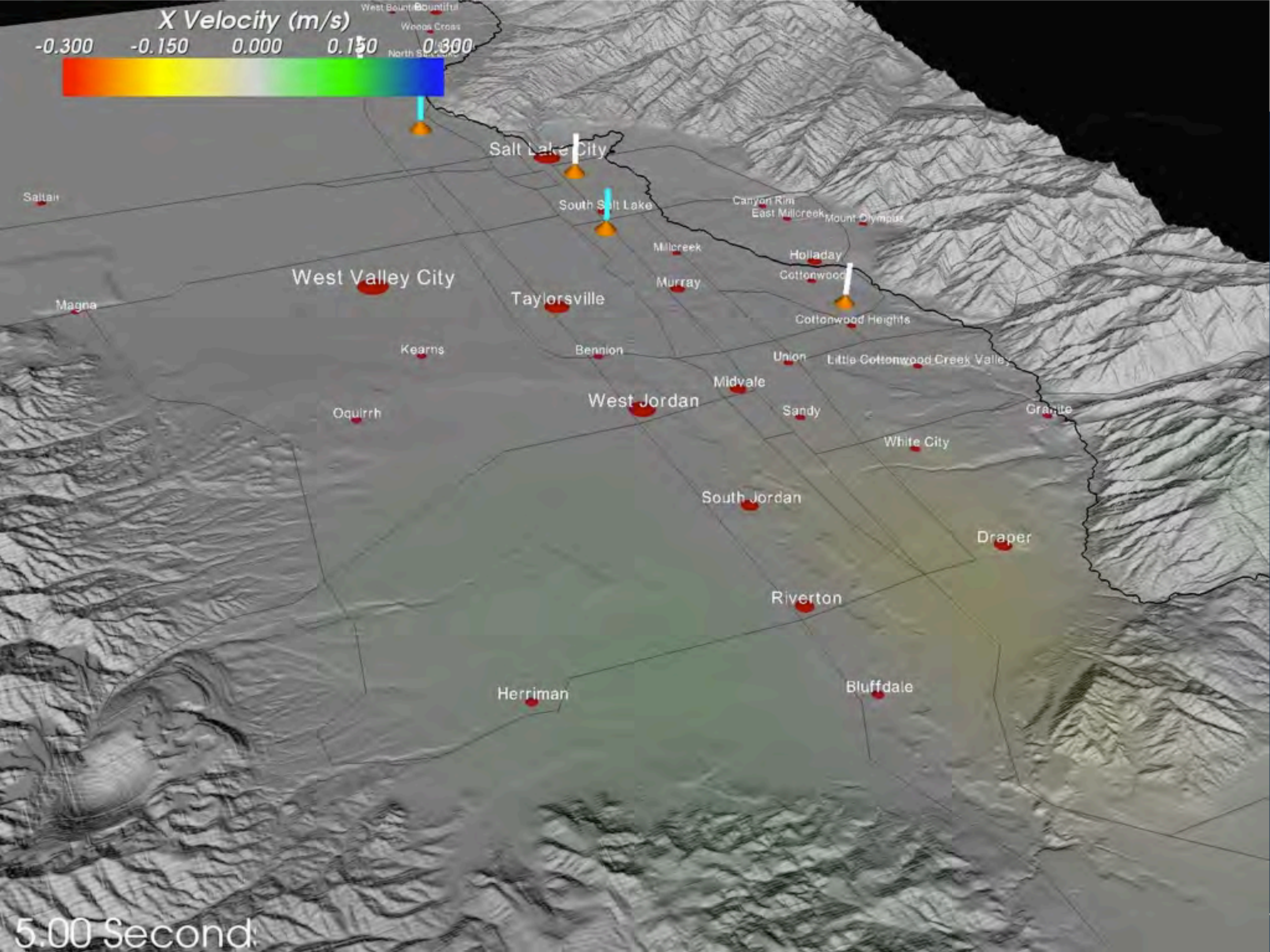
- Planar rupture model is projected onto irregular 3-D model of the WF and the moment rate time histories are inserted into grid nodes

- Wave propagation of this source model is simulated with velocity-stress staggered-grid finite difference AWP-ODC (Olsen, Day and Cui) code:

FD3D parameters	
Model dimensions	1500 x 1125 x 500
Simulation length	60s (24,000 iter.)
Discretization	40m / 0.0025 s
Minimum V_S	200 ms^{-1}
Highest frequency	1 Hz
# of CPU cores	1875
Wall-clock runtime	2.5 hrs (ORNL Kraken)

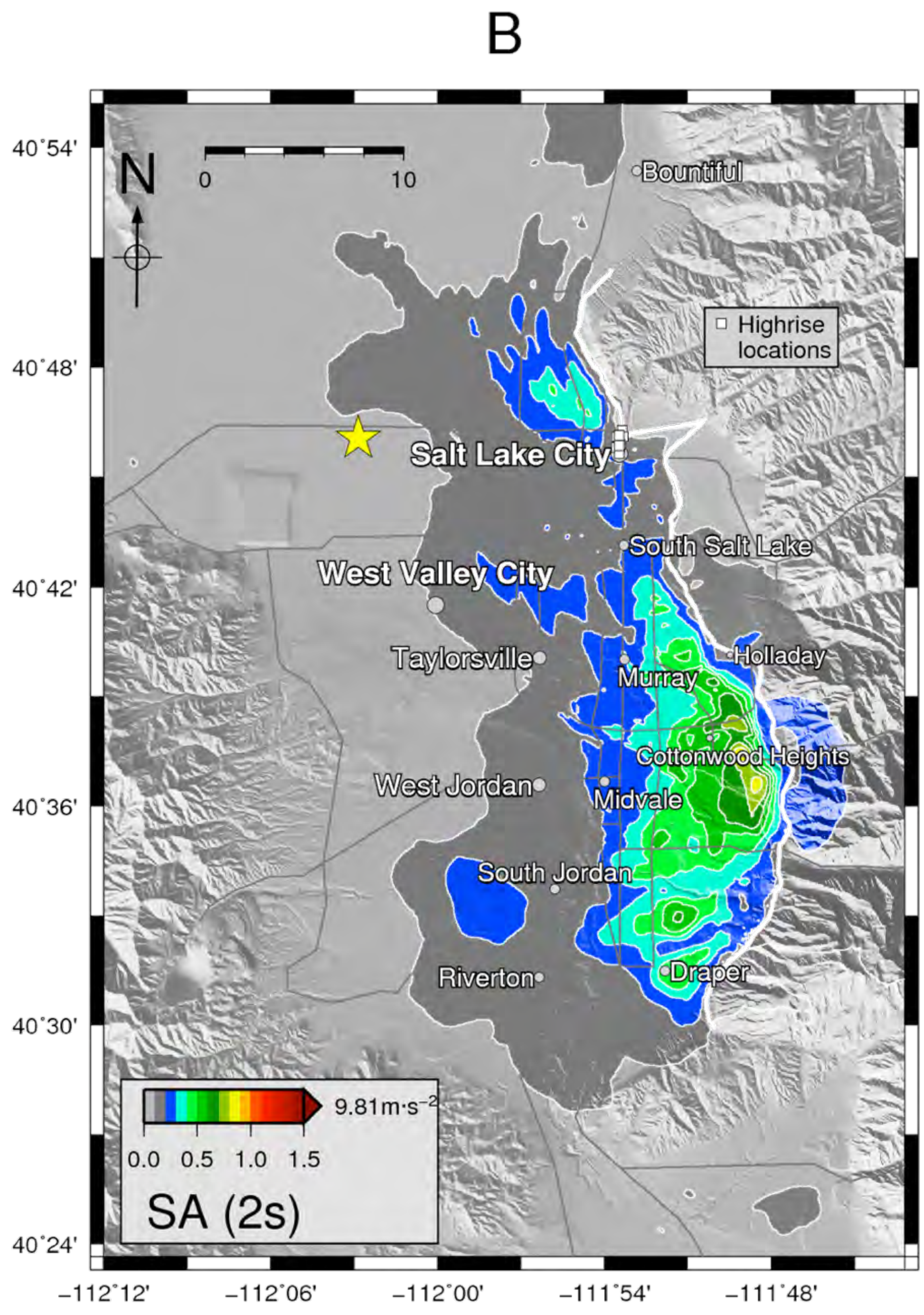


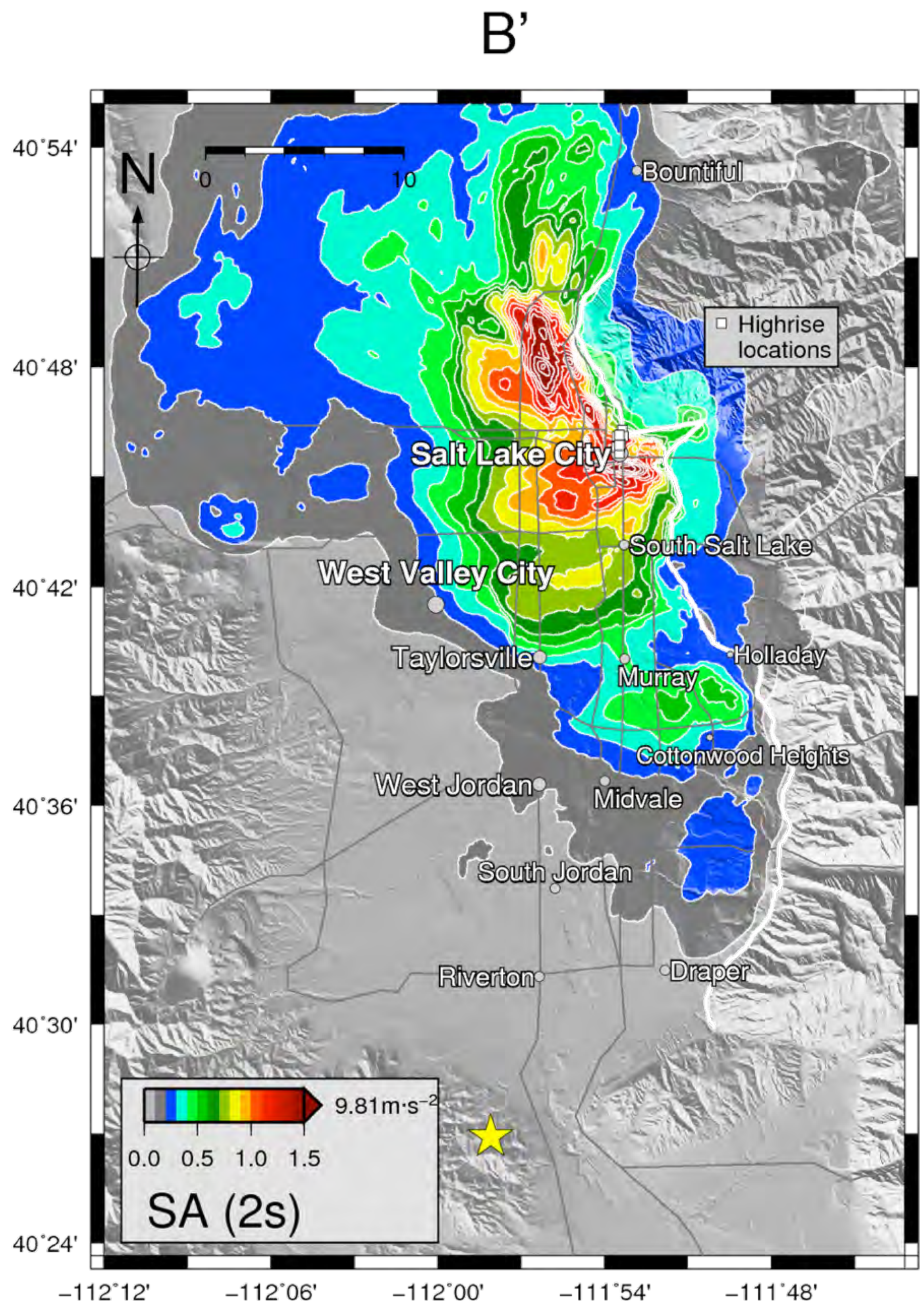




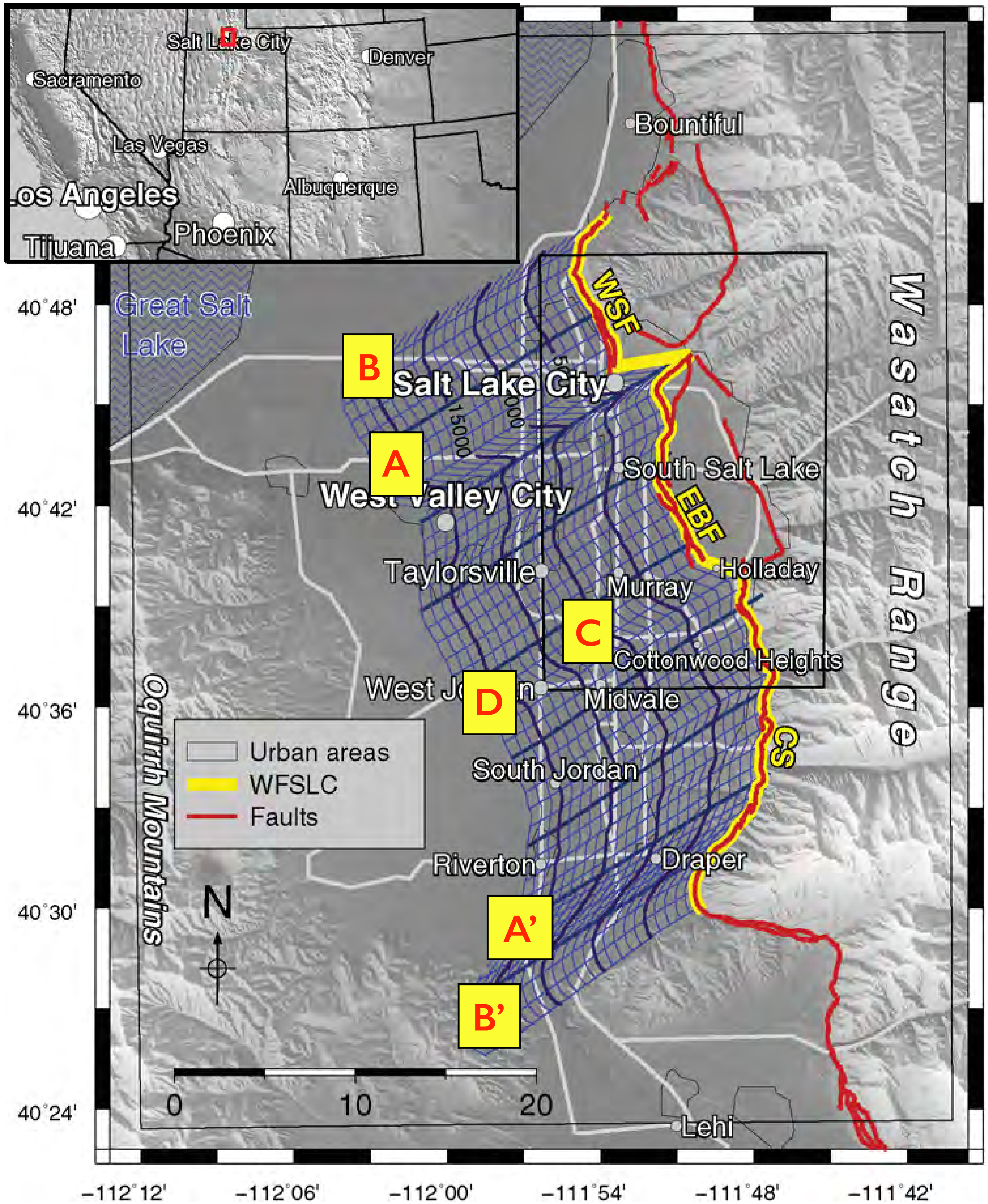
X Velocity (m/s)
-0.300
-0.150
0.000
0.150
0.300
Bountiful
Woods Cross
Salt Lake City
Saltair
South Salt Lake
Canyon Rim
East Millcreek
Mount Olympus
Millcreek
Holladay
West Valley City
Magna
Taylorsville
Murray
Cottonwood Heights
Kearns
Bennion
Union
Midvale
West Jordan
Oquirrh
Sandy
Granite
White City
South Jordan
Draper
Riverton
Herriman
Bluffdale

Spectral Accelerations at 2s (2s-SAs)





Average from 6 Scenarios Earthquakes



Representative distribution of

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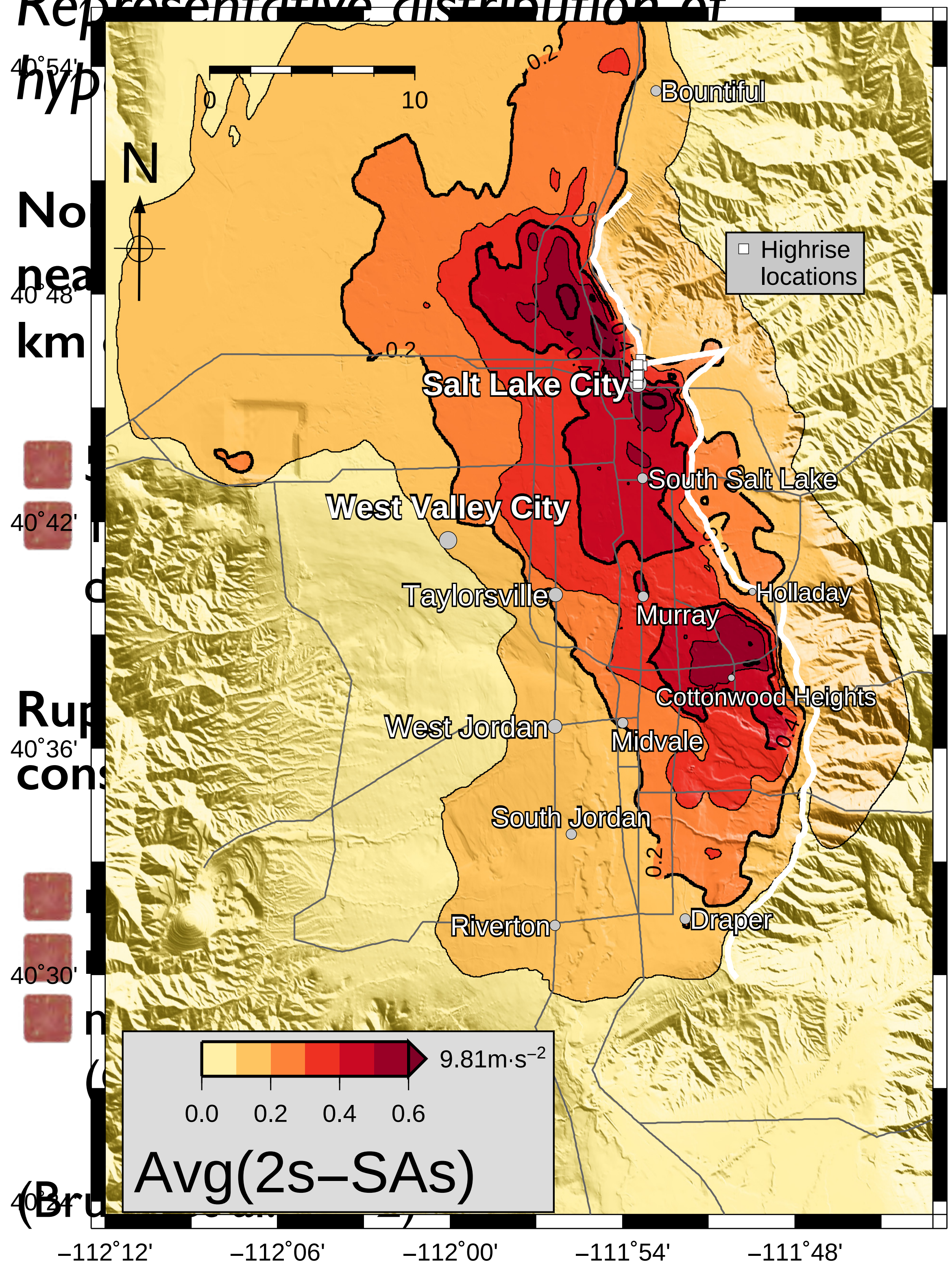
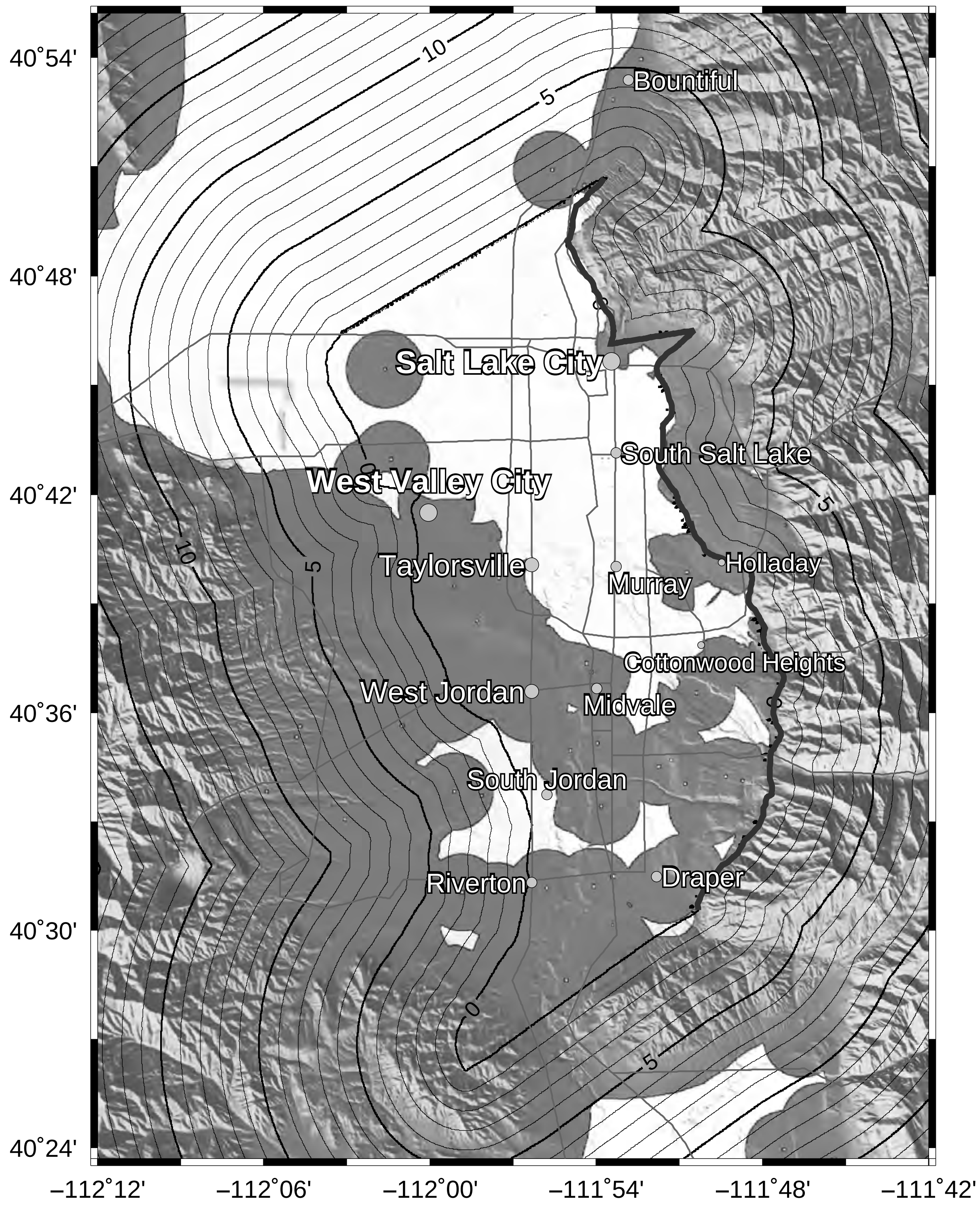
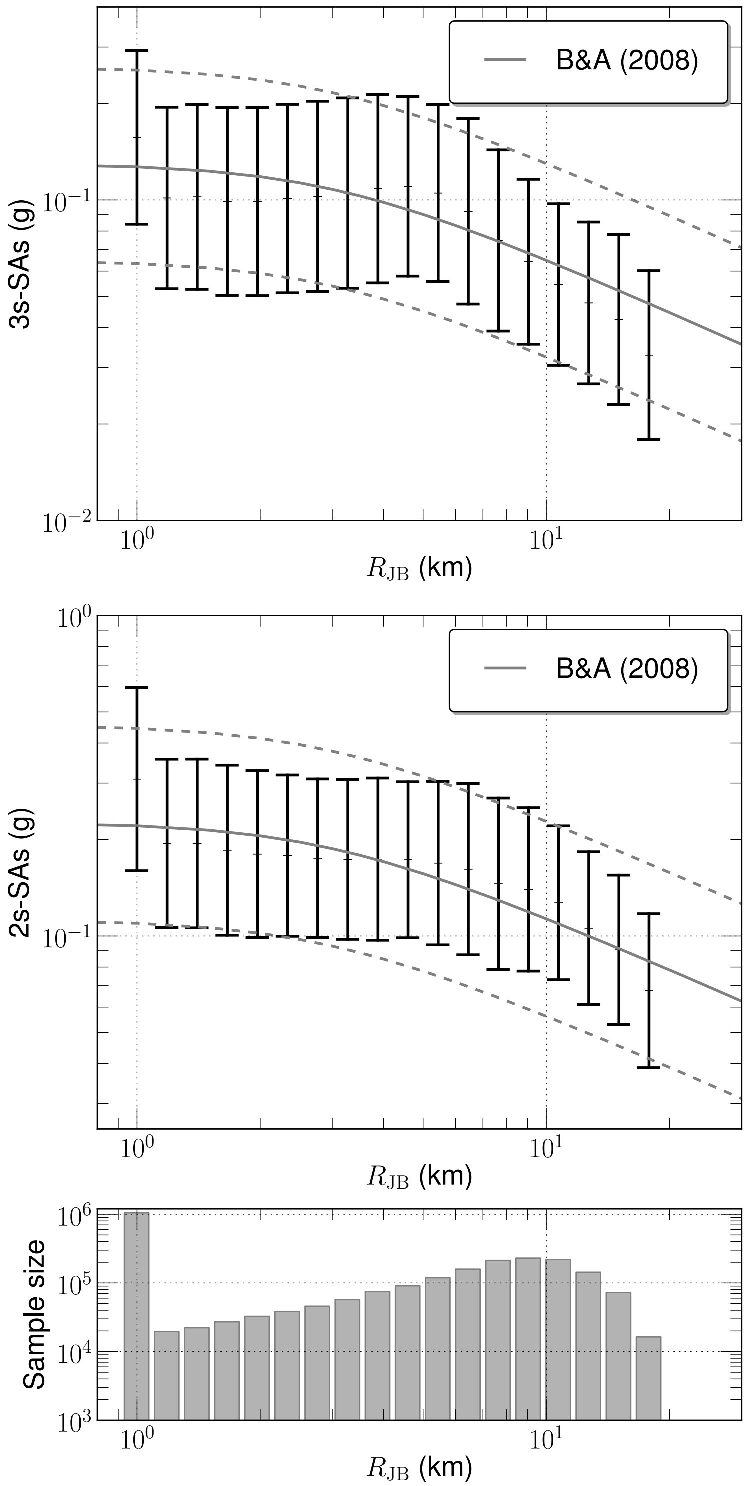


Comparison to recent GMPEs

Sites in the basin with 200 < V_{s30} < 300 m·s^{-1}



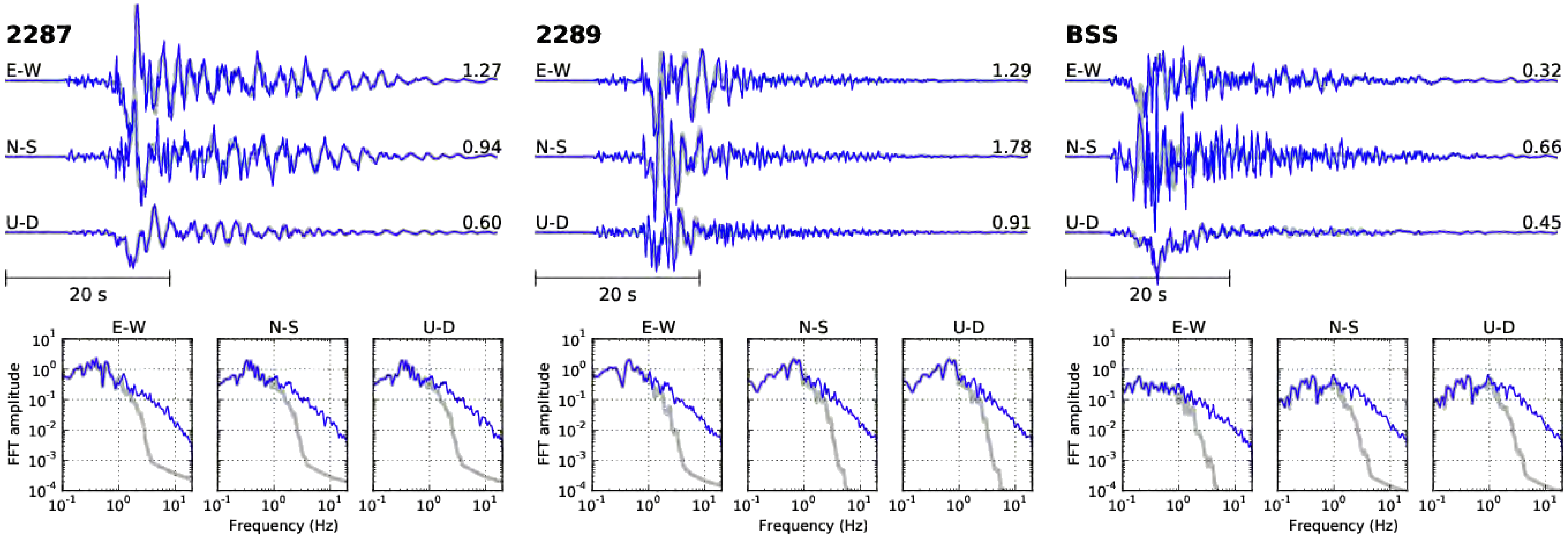


Boore & Atkinson (2008)

Synthetic Broadband Seismograms

Combining low-frequency FD synthetics with high-frequency scattering operators:

- Scatterograms are computed using multiple scattering theory with scattering parameters based on site-specific velocity structure
- Scatterograms are convolved with dynamically consistent source time function
- LF and HF synthetics are combined into broadband seismograms in the frequency domain using a simultaneous amplitude and phase matching algorithm (Mai & Olsen, 2009)



Simulation of Nonlinear Soil Response

- Nonlinear 1-D propagator *NOAH* (Bonilla et al., 2005) to model **SH** propagation in top 240m
- Not modeling pore water pressure or soil dilatancy (parameters are not available)
- Shear modulus reduction is controlled by **reference strain** γ_r:

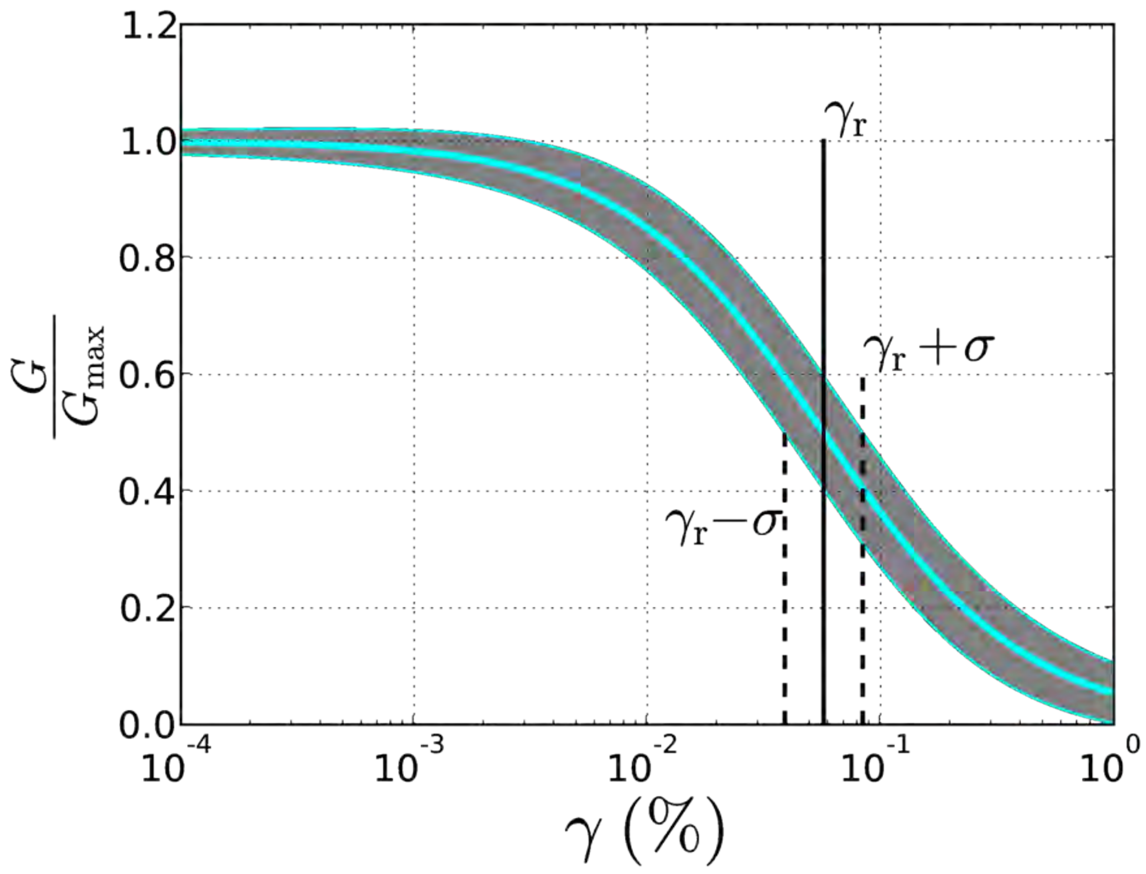
$$\frac{G}{G_{\mathrm{max}}} = \frac{1}{1 + \frac{\gamma}{\gamma_r}}$$

- *Reference strain* γ_r is derived from an **empirical relationship** (Darendelli, 2001), modified to take results of recent laboratory test of Bonneville clays into account (Bay & Sasanakul, 2005):

$$\gamma_r(\mathrm{PI}, \mathrm{OCR}, \sigma_v)$$

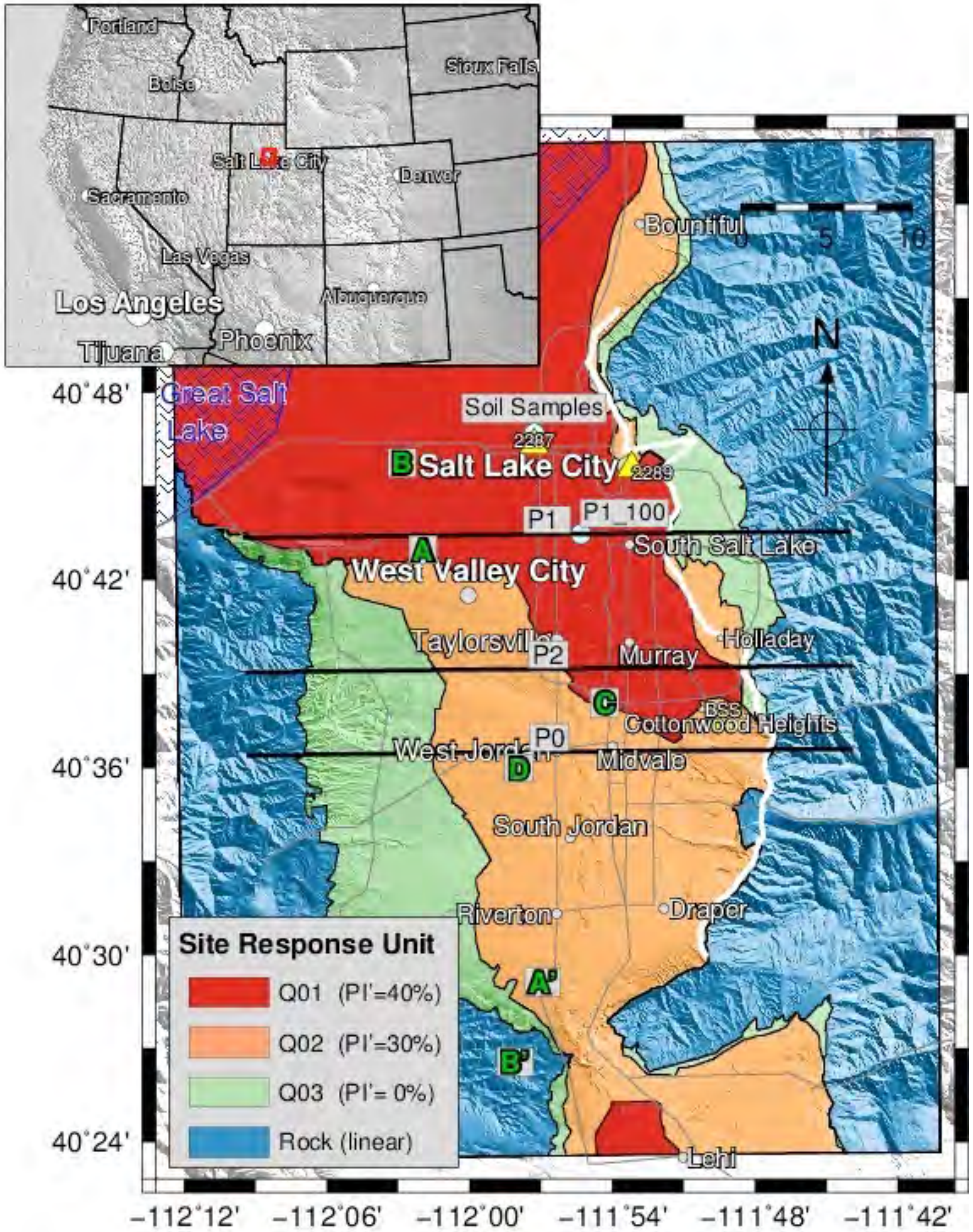
- Hysteresis dissipation is controlled by maximum damping ratio at large strains ξ_{max}, which we also estimate from Darandelli (2001):

$$\xi_{\mathrm{max}} = (\mathrm{PI}, \mathrm{OCR}, \sigma_v, N, f)$$



	Parameter	Value
PI	Plasticity Index	0 - 40%
OCR	Overconsolidation ratio	1
σ_v	Confining pressure	f(z)
N	Number of cycles	10
f	Frequency	1 Hz

Nonlinear Soil Parameters

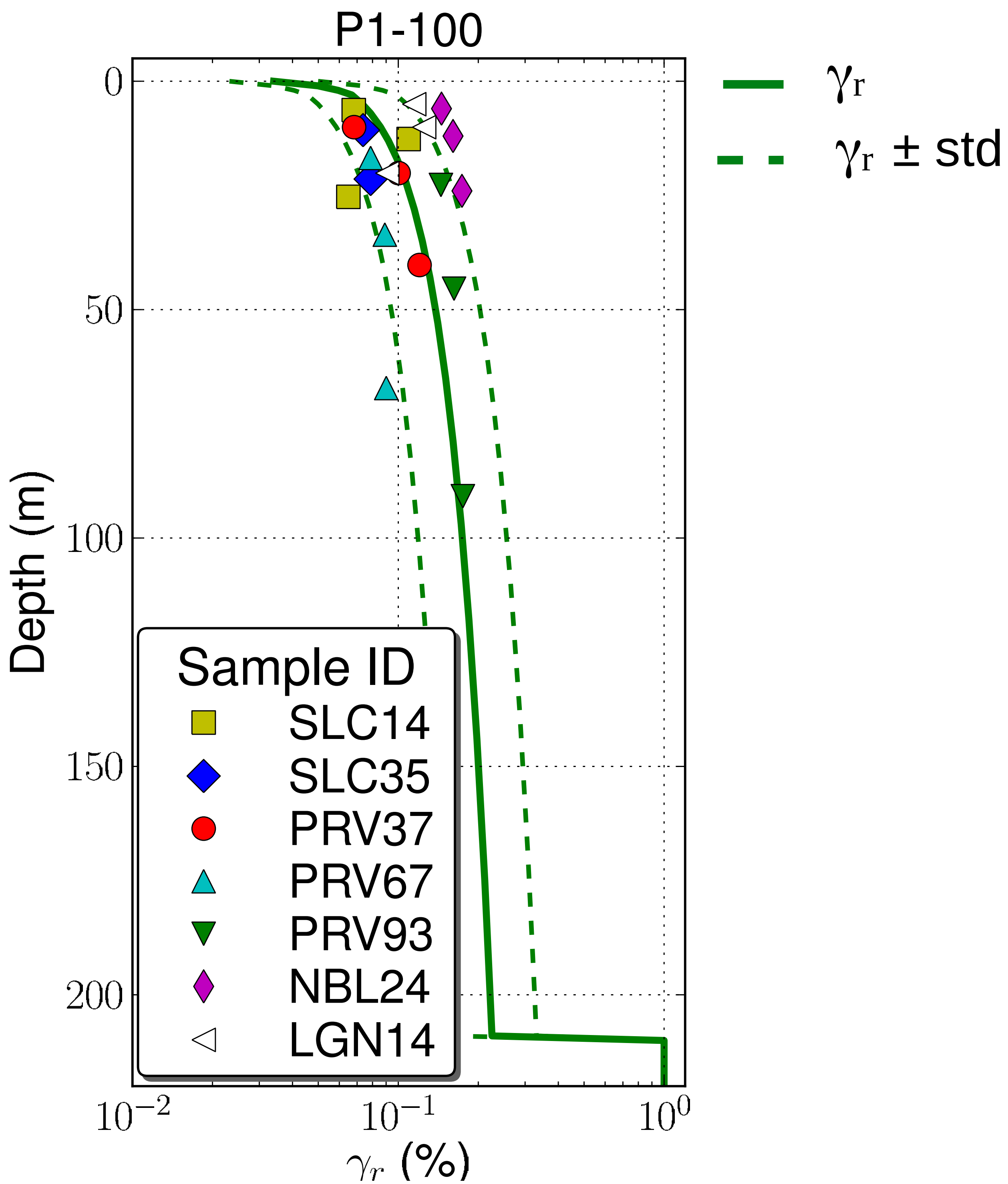


SRU	Description	PI
Q01	lacustrine and alluvial silt, clay and fine sand	40%
Q02	lacustrine sand and gravel, interbedded clay and silt	30%
Q03	lacustrine and alluvial gravel and sand	0%
R	Tertiary, Mesozoic, Paleozoic or Precambrian rock; treated as linear	N/A

McDonald and Ashland (2008)

Nonlinear Soil Parameters

Example site on P1 (5 km south of airport):

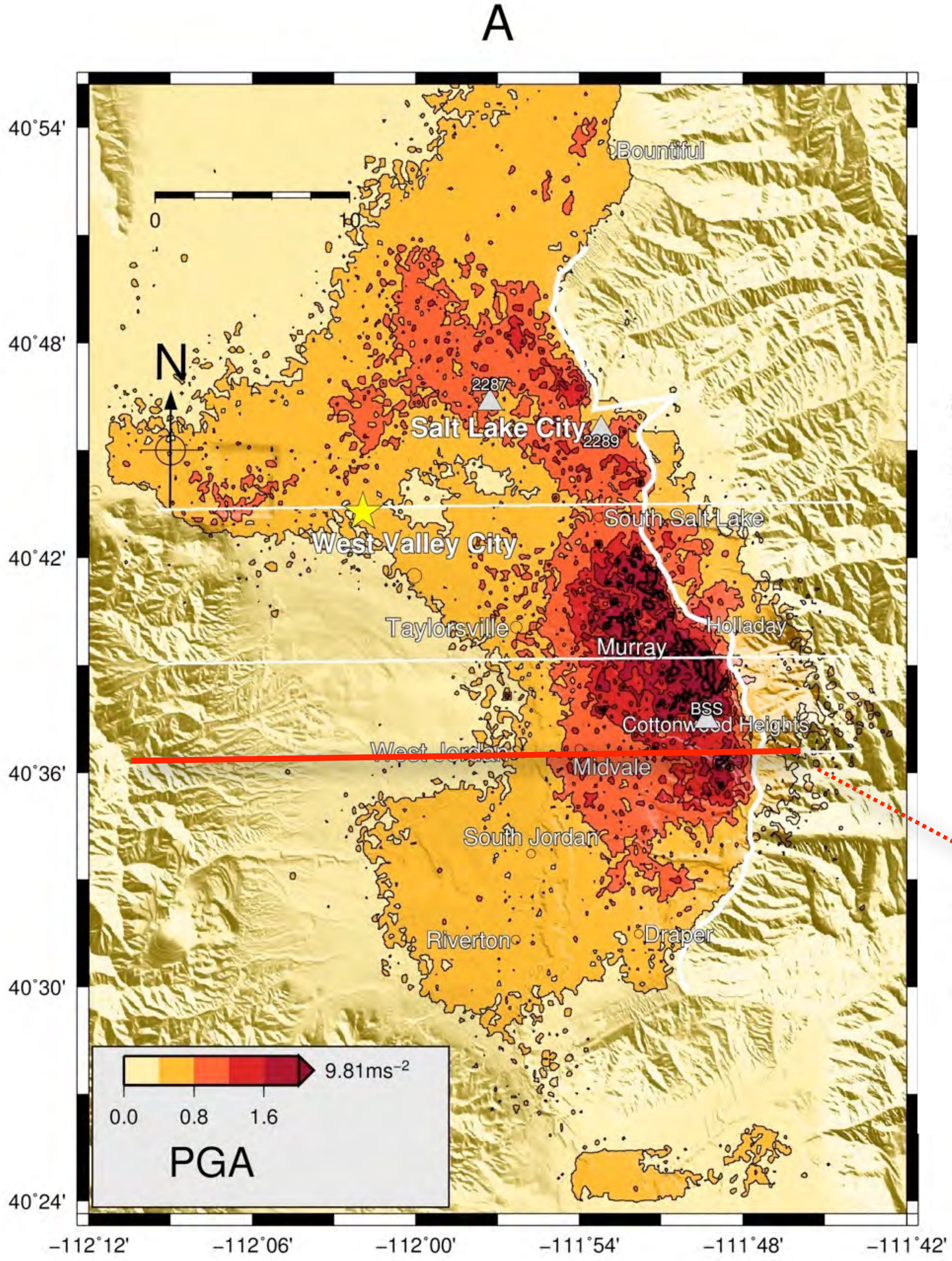


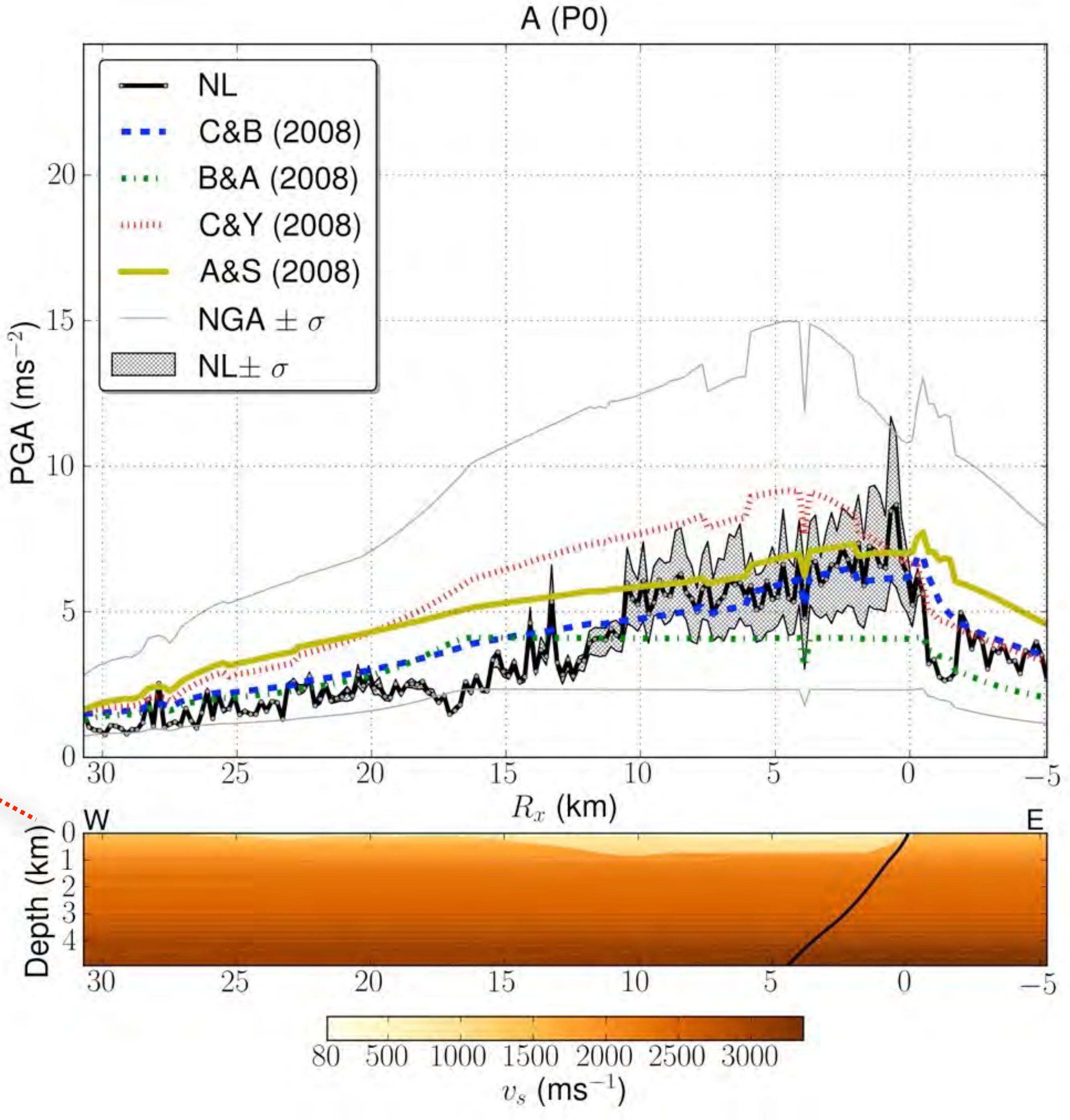
Three 1D models for each site:

Model	Reference strain	Damping ratio
Mean nonlinear	γ_r	ξ
upper bound	γ_r - std	ξ + std
lower bound	γ_r + std	ξ - std

- Broadband synthetics at free surface are deconvolved to remove response of upper 240m
- Resulting signal represents incoming wavefield at depth and serves as input for nonlinear simulation
- Nonlinear 1-D simulation yields ground motion on the surface of the nonlinear layer

Linear (Broadband) vs. Nonlinear

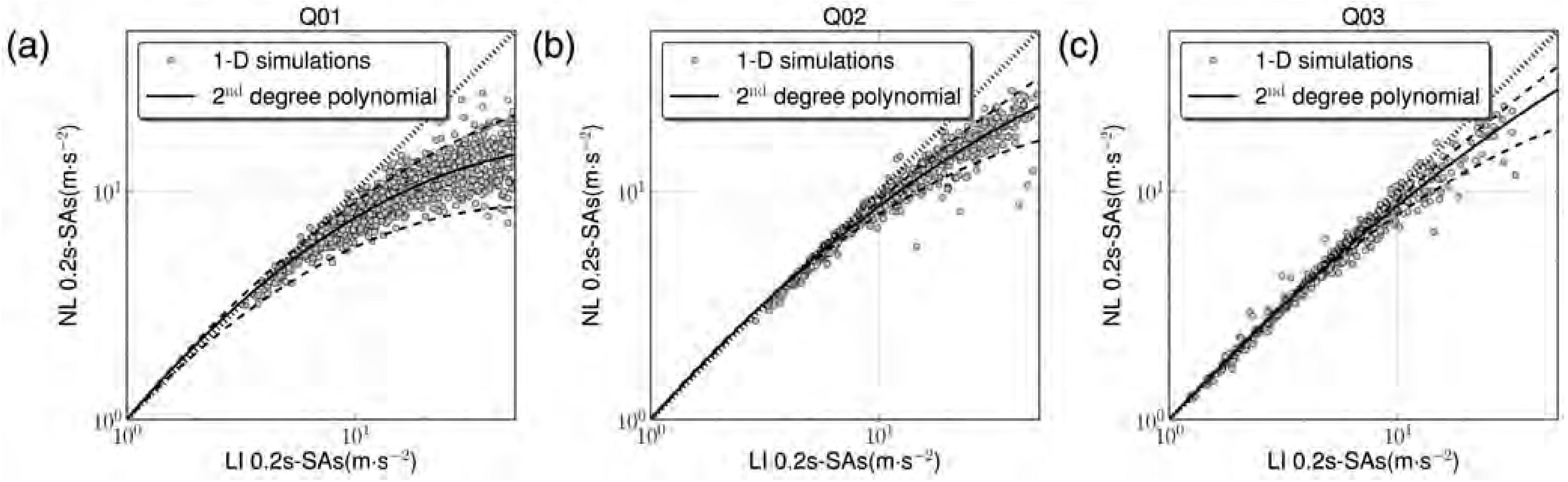




Correction Factors for Nonlinearity

- 1-D nonlinear simulations are used to define amplitude-dependent correction factors for BB spectral accelerations

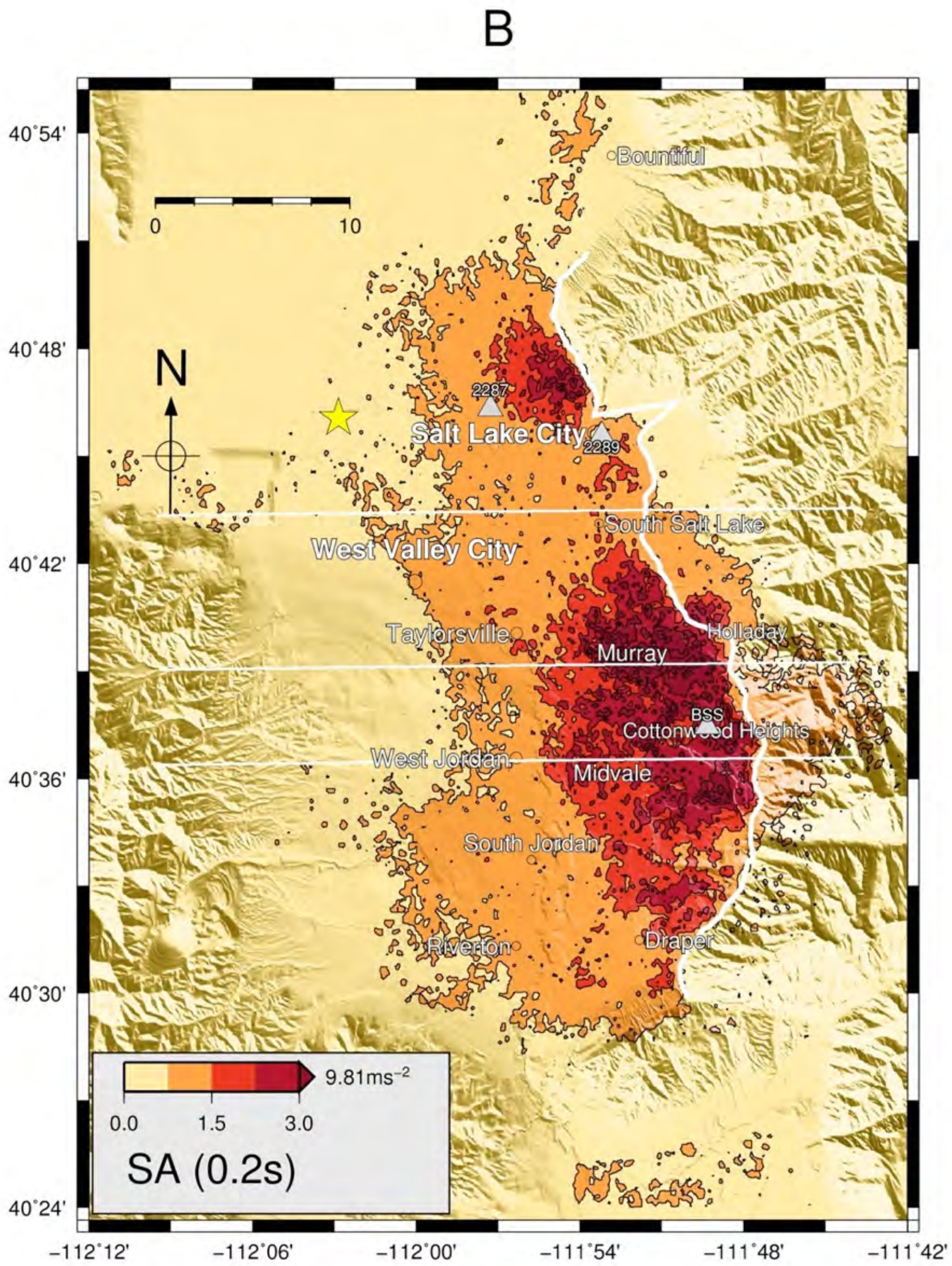
- Correction factors are defined for each SRU (site response unit) and PGA, PGV and SAs at 0.1-1s



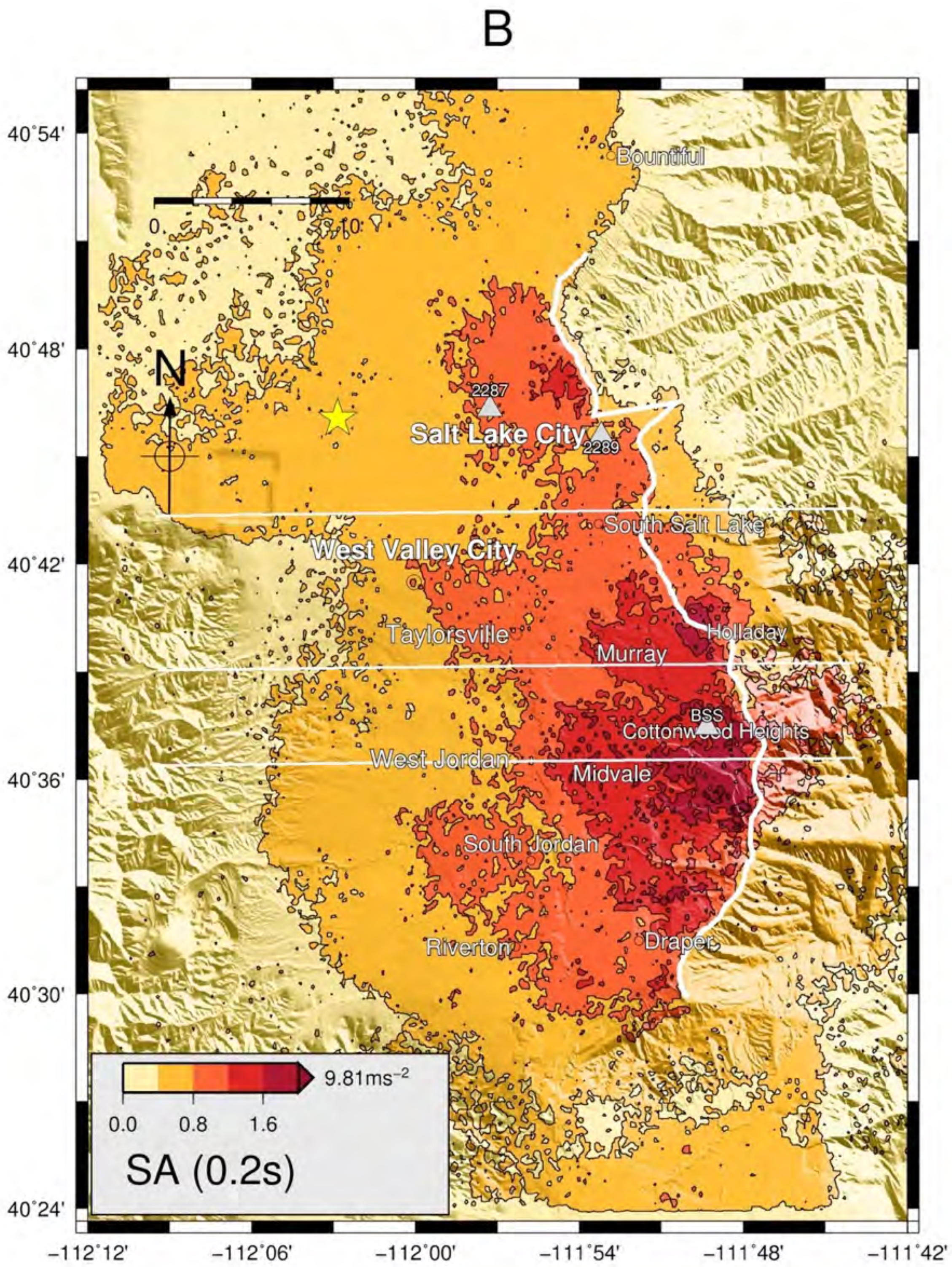
- Highest nonlinearity is encountered in Q01, and Q03 behaves most linear

Correction Factors for Nonlinearity

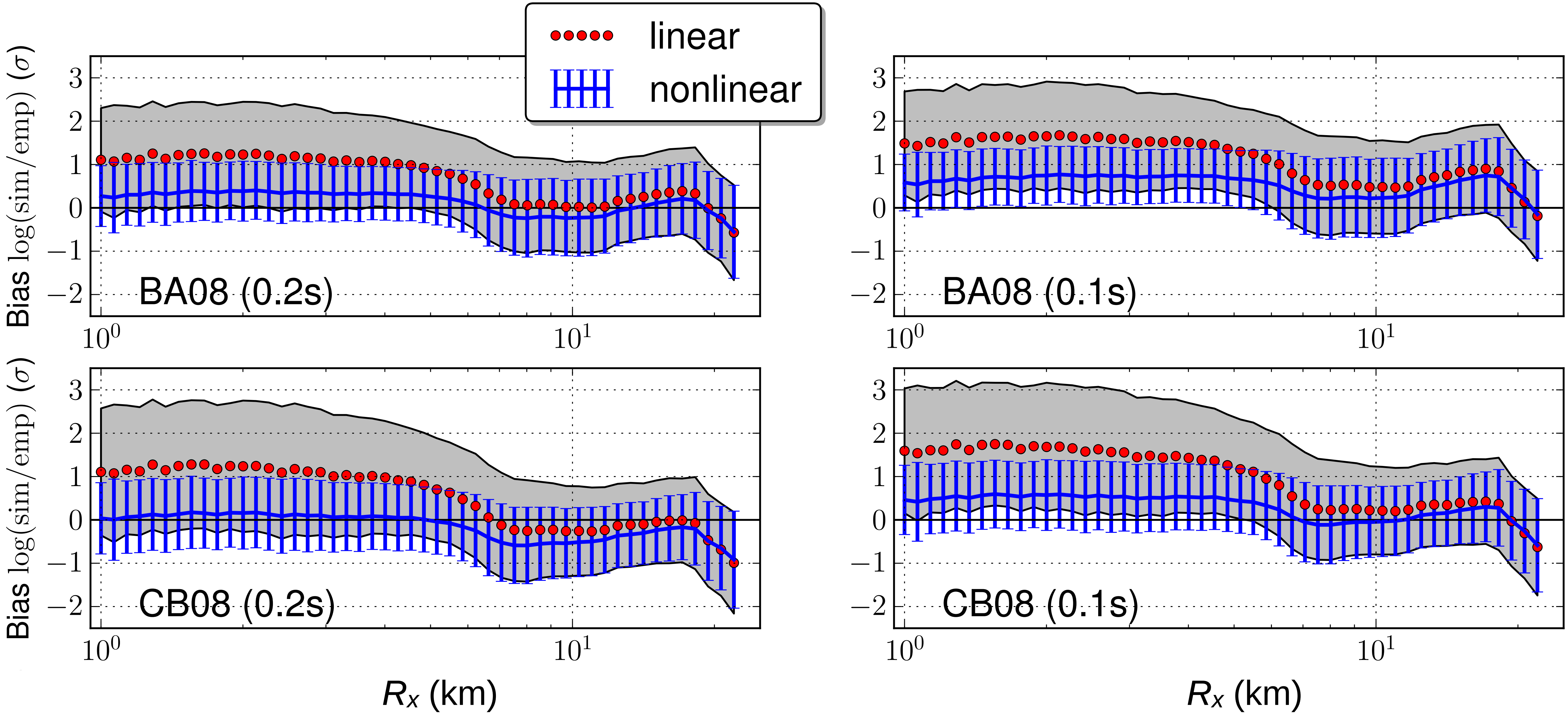
Linear (Broadband)



Corrected for nonlinearity



Comparison to GMPEs



Residuals between simulated and GMPE-predicted SAs, normalized by standard deviation of GMPE:

$$r_j = \frac{\ln\left(\mathrm{SA}_{\mathrm{sim},j}\right) - \ln\left(\mathrm{SA}_{\mathrm{emp},j}\right)}{\sigma_{\mathrm{emp},j}}.$$

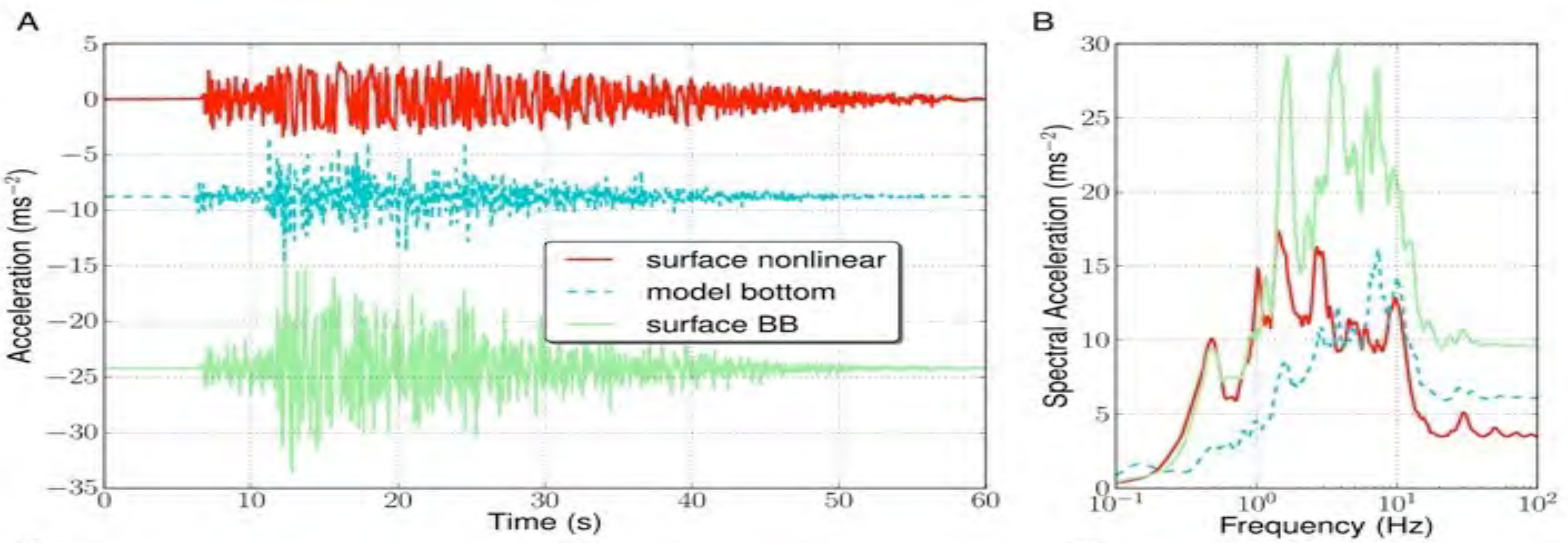
Follow-up research

- Perform fully nonlinear 1D simulations individually for each grid point on Salt Lake valley (200 m resolution) and create updated high-frequency ground motion maps
- Repeat all simulations for updated WFCVM (3d)
- Compare simulated ground motions to latest generation of GMPEs (2014)
- Simulate ground motions from six source realizations for 1D velocity structure (representative of Wasatch front rocks)
- Quantify contribution of 3D structure to direction-dependent amplification effects
- Estimate ground motion **rupture direction factors** in the Salt Lake Valley (SLV) for M~7 earthquakes on the WFSLC, compare with NGA predictions, and develop recommendations for new or modified prediction equations if necessary.
- Estimate ground motion **hanging-wall factors** in the SLV for M~7 earthquakes on the WFSLC, compare to NGA predictions, and modify one or more sets of the NGA hanging-wall factors if needed.
- Estimate ground motion **amplification factors** in the SLV for M~7 earthquakes on the WFSLC, compare to NGA predictions, and evaluate the applicability of the NGA soil depth factors to the SLV. Develop recommendations, if needed.
- Estimate **dependence of distance** from the fault rupture on the ground motions in the SLV for M~7 earthquakes on the WFSLC.

Outlook

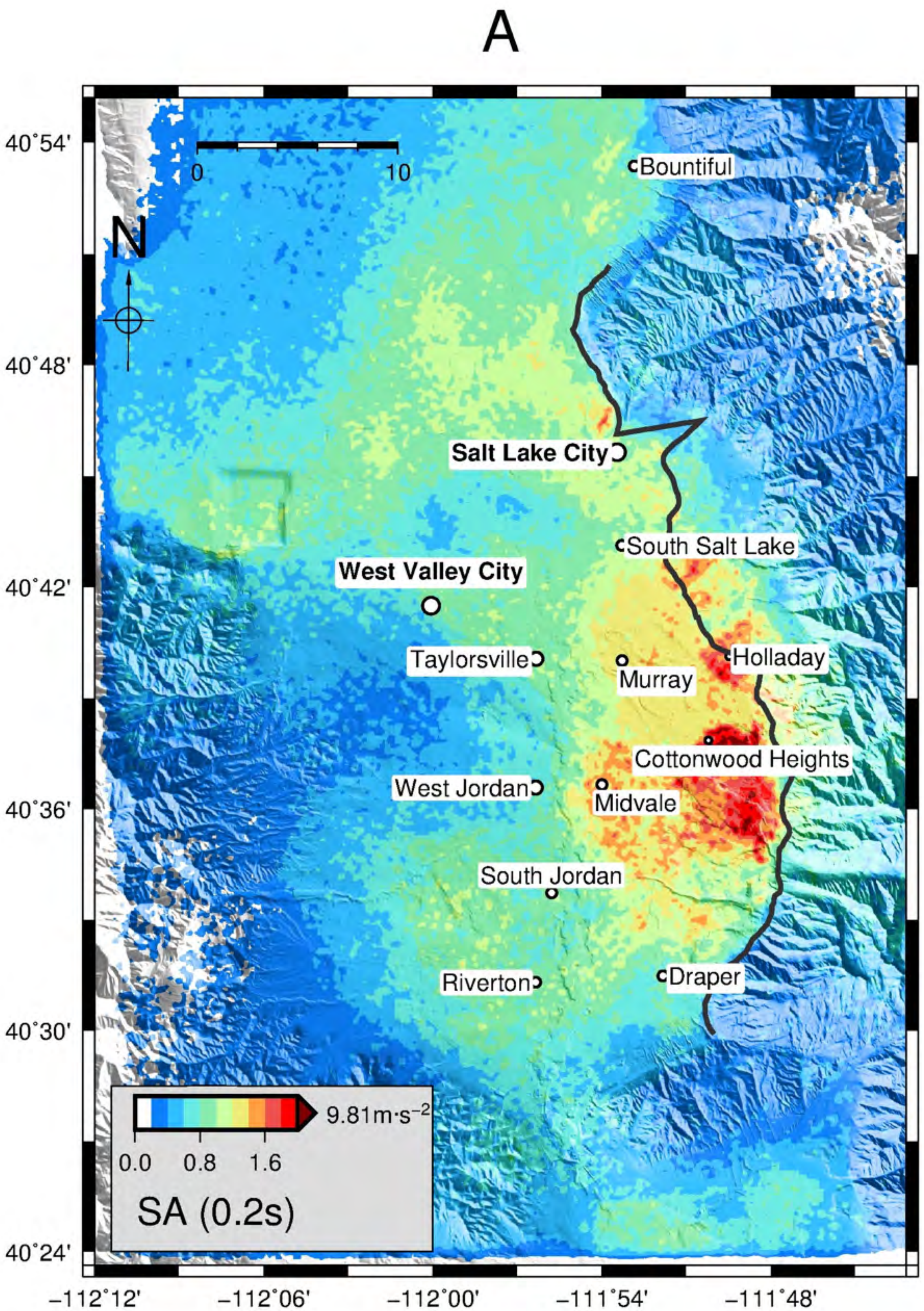
Valley-wide nonlinear 1D simulations

- Accounting for nonlinearity with amplitude-dependent correction factors represented a source of uncertainty (high variability)
- New ground motion maps should be based on 1D nonlinear response simulated individually for every point in the SLB
- Realized by implementing NOAH1D code into an *embarrassingly parallel* MPI program and running ~1000 CPU cores on parallel computer
- Response computed individually for 37,422 sites for each scenario

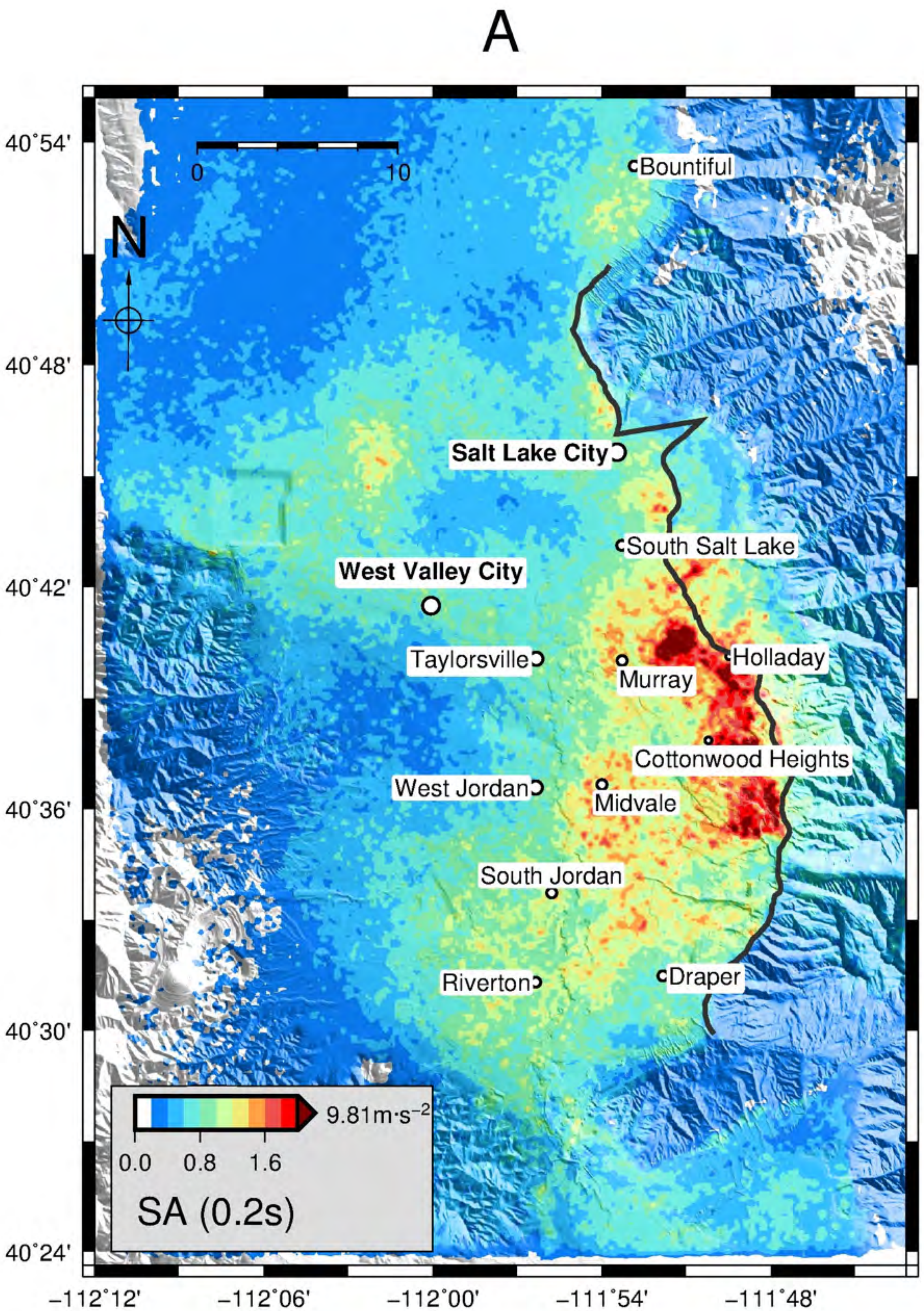


Nonlinear 1D simulations

Amplitude-dependent correction factors

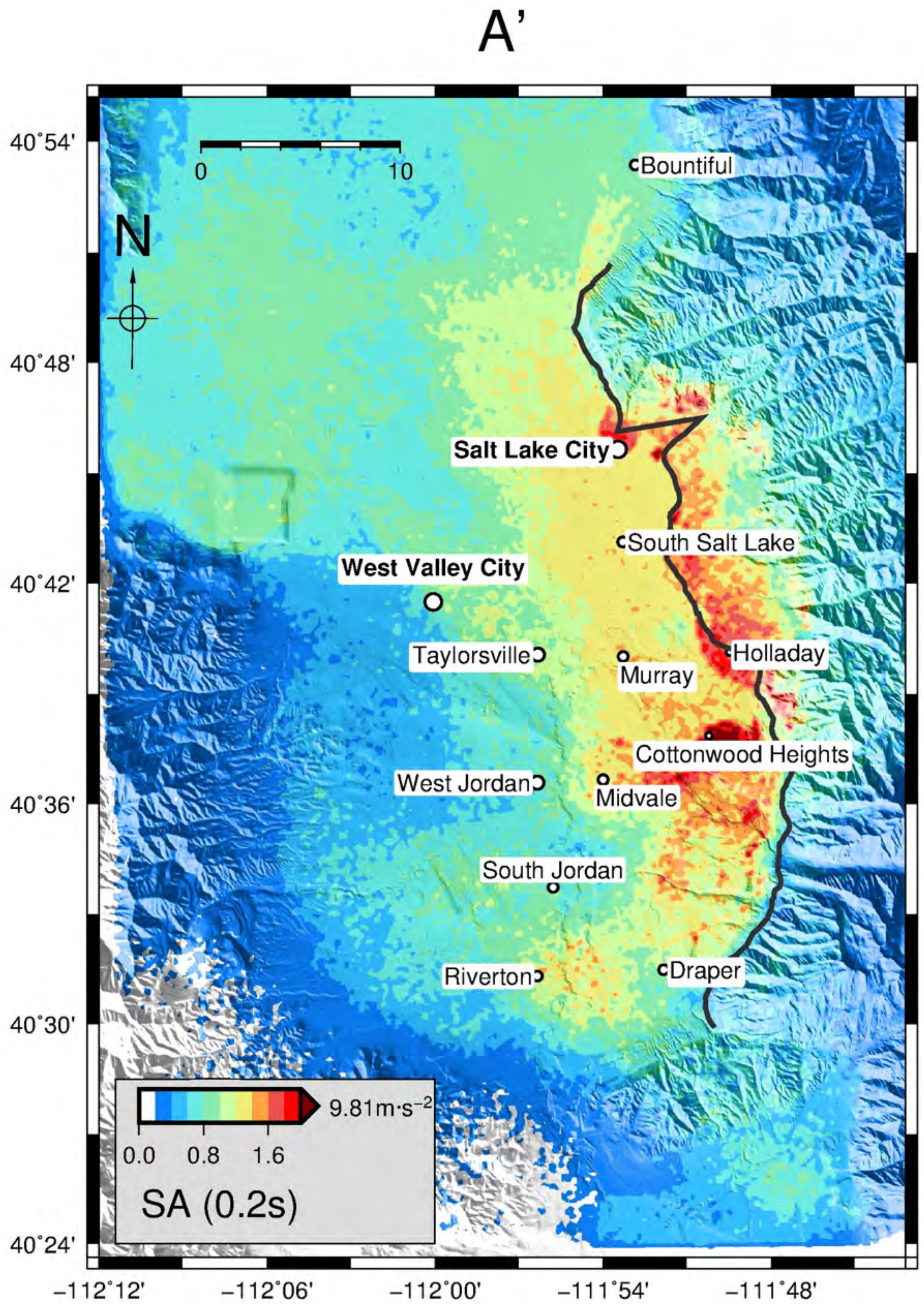


Valley-wide 1D nonlinear simulations

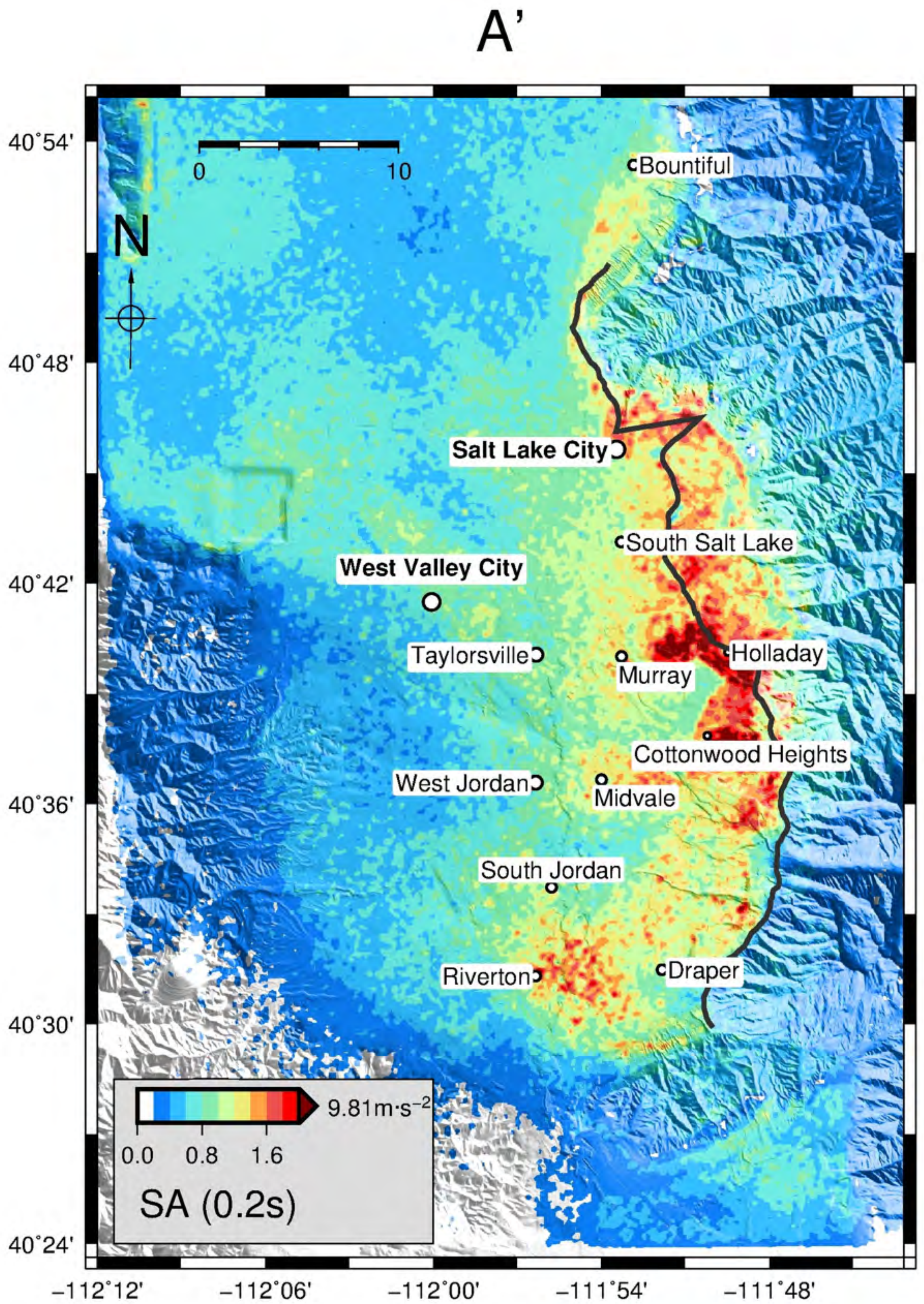


Nonlinear 1D simulations

Amplitude-dependent correction factors



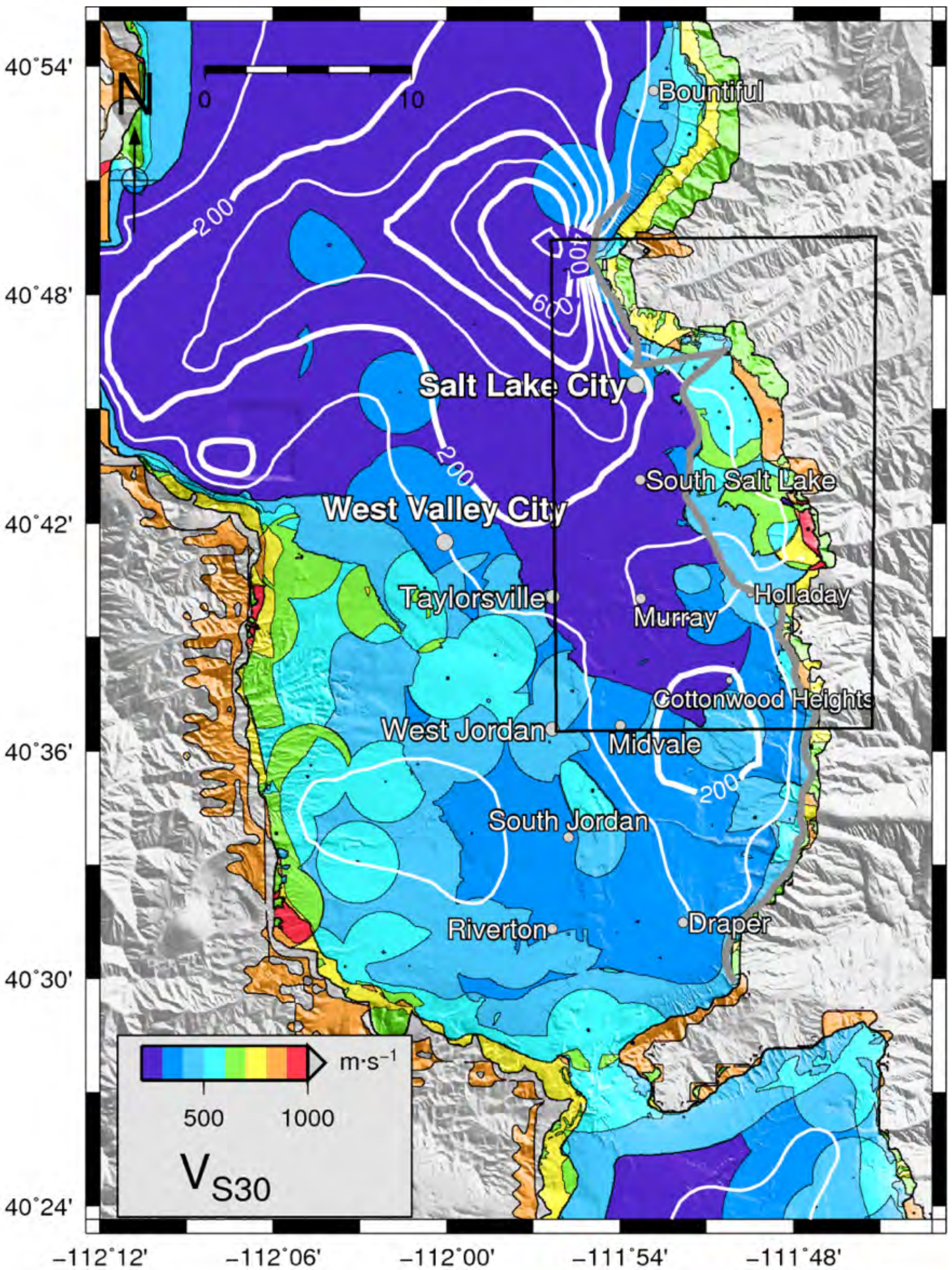
Valley-wide 1D nonlinear simulations

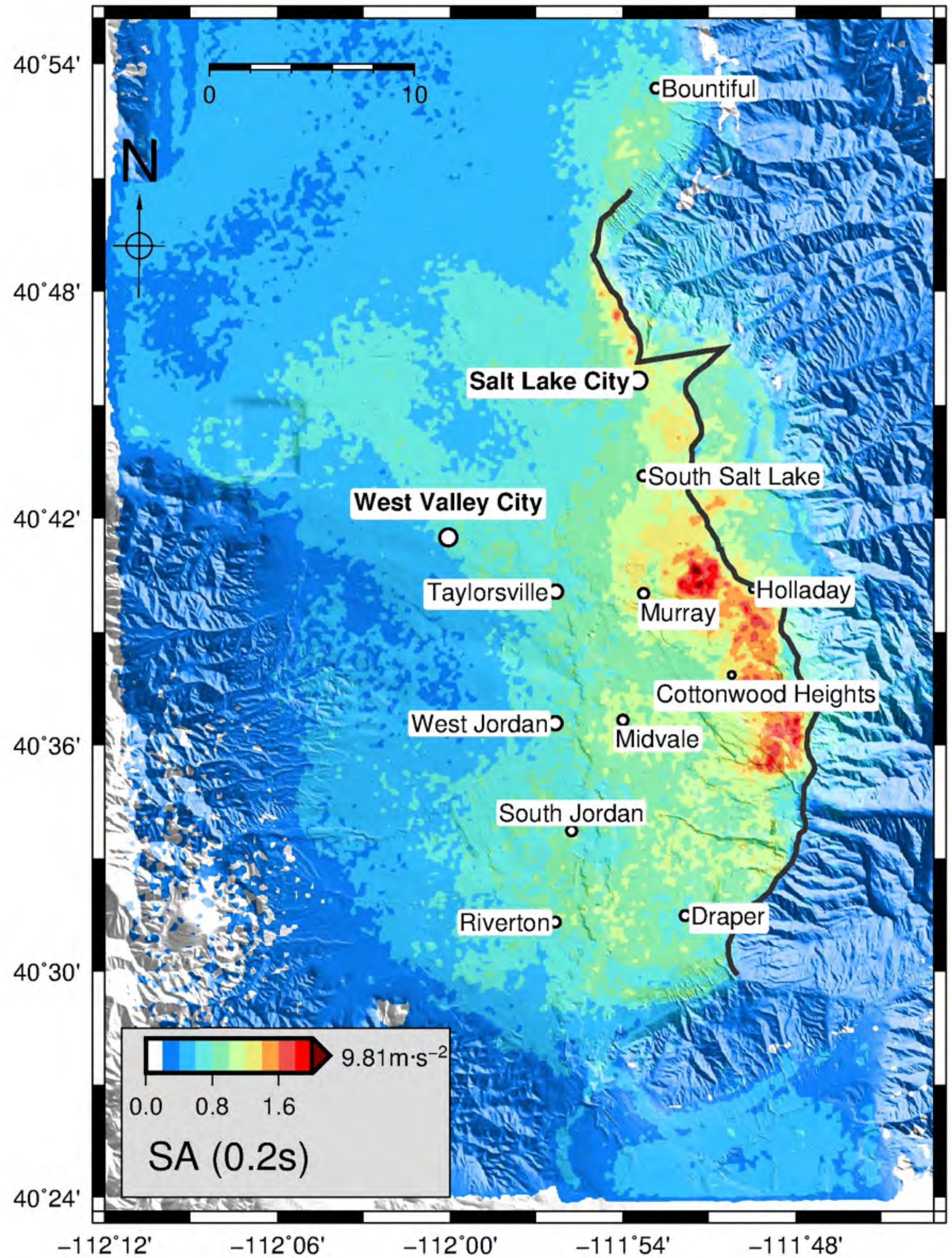


Nonlinear 1D simulations

Amplitude-dependent correction factors

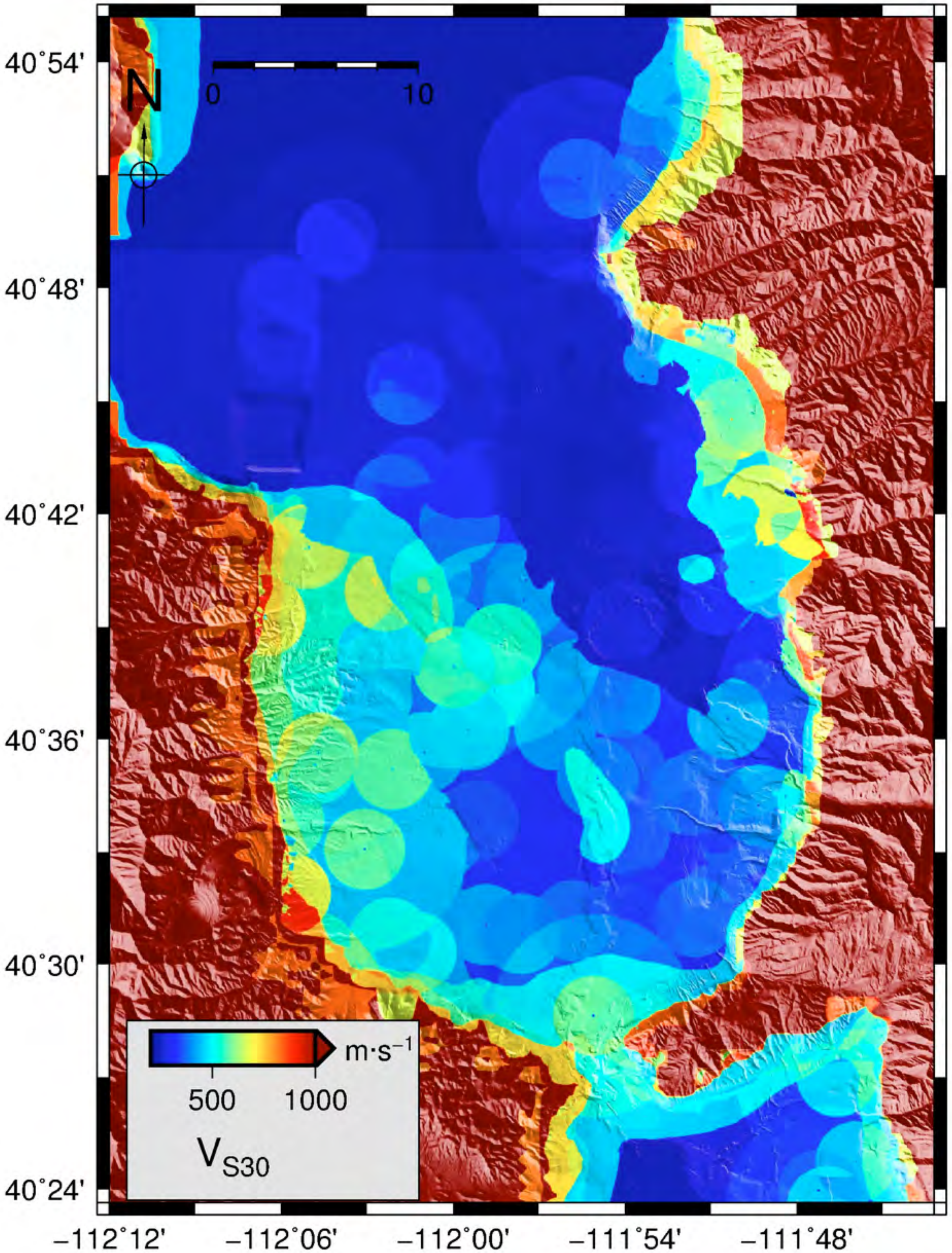
Valley-wide 1D nonlinear simulations



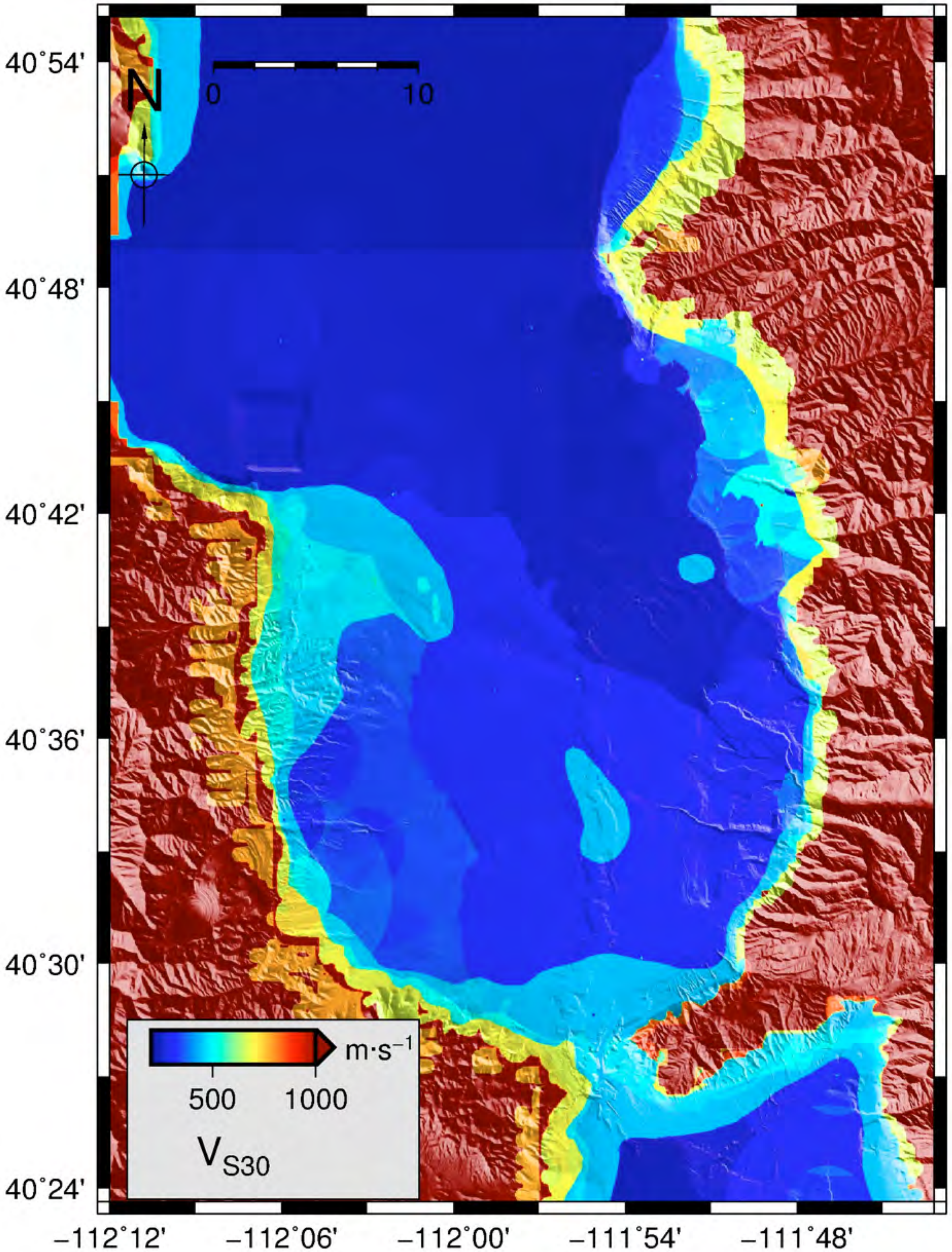


Updated WFCVM

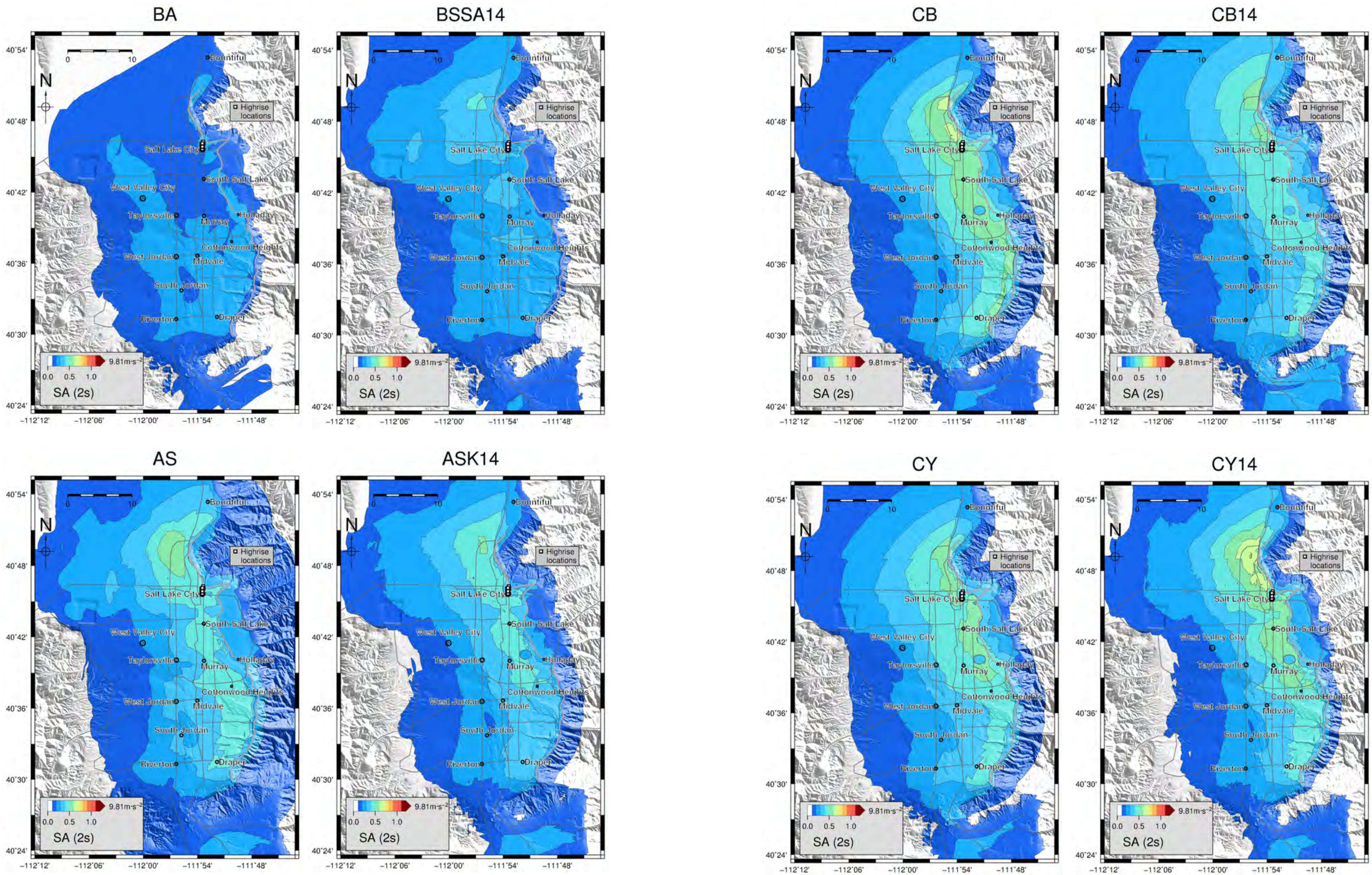
Version 3c



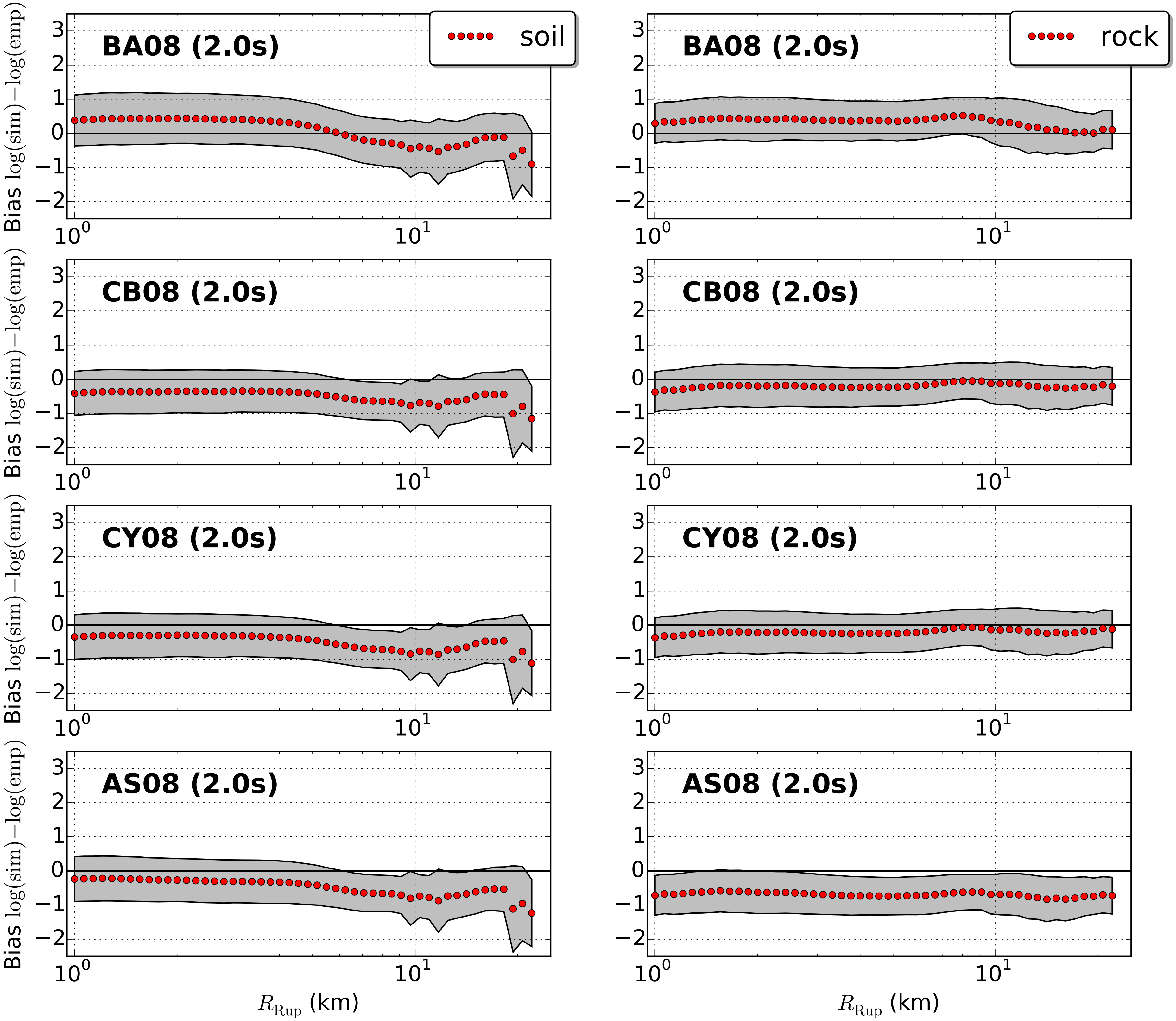
Version 3d



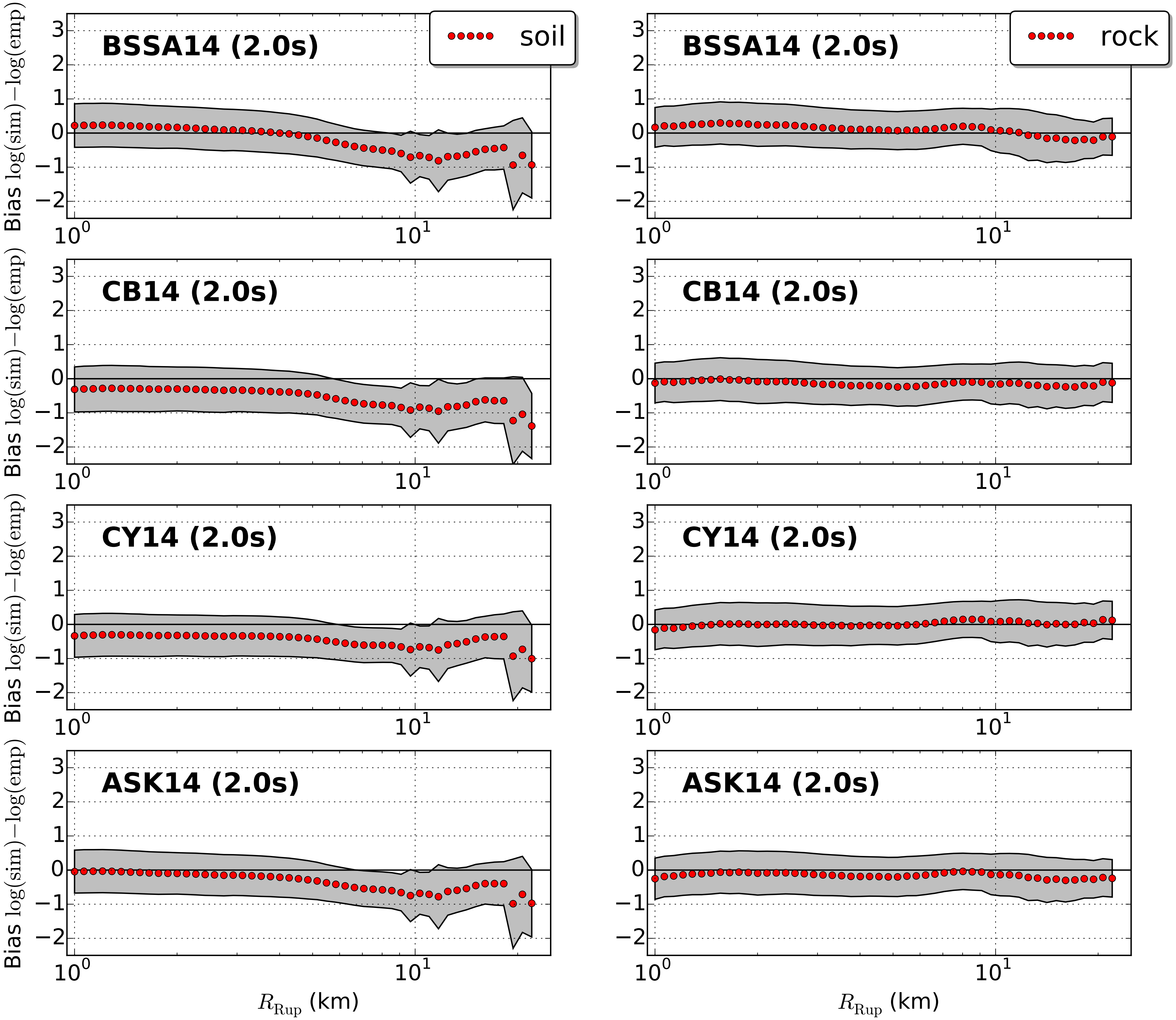
Updated GMPEs (2014)



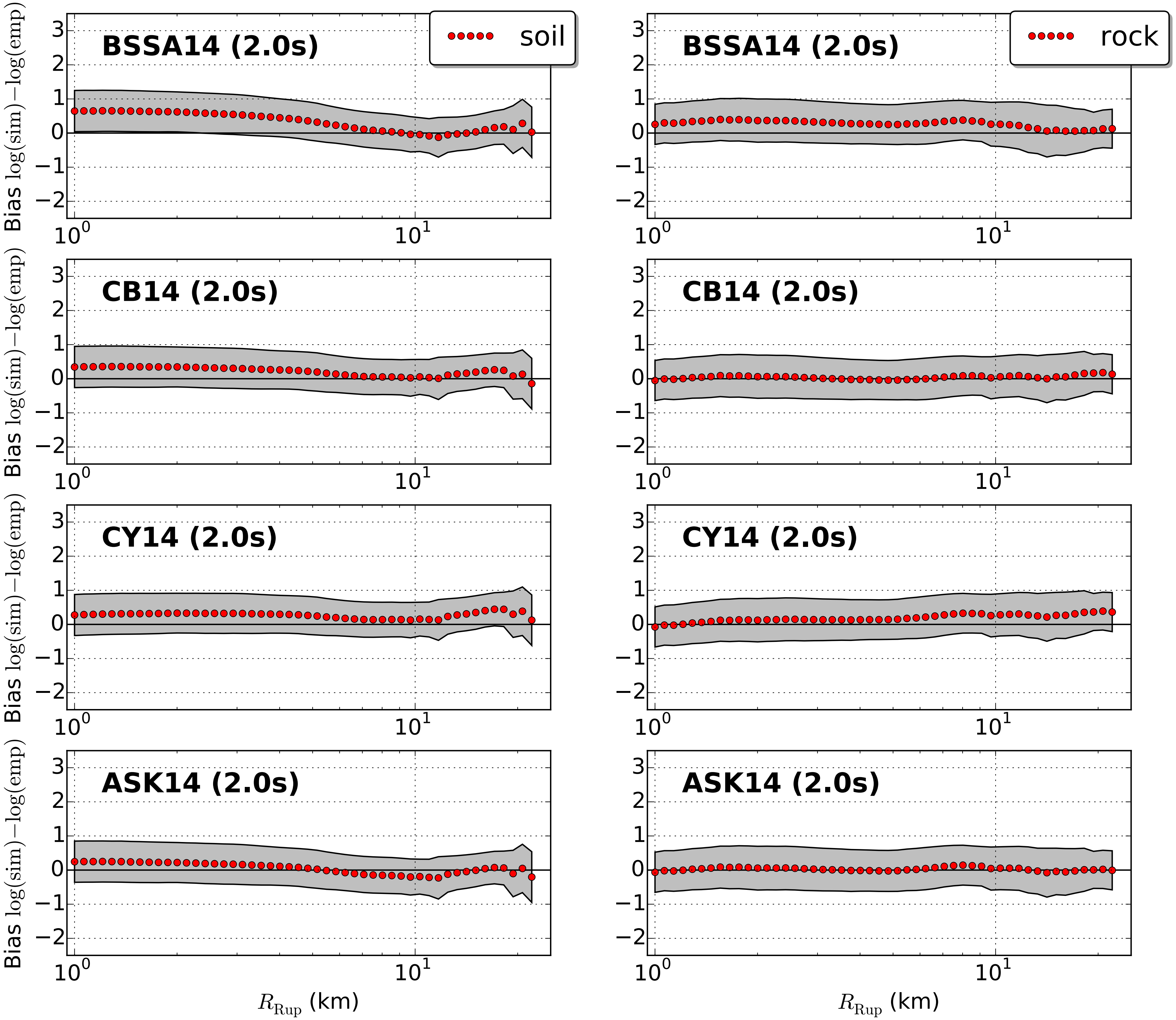
Comparison to 2008 GMPEs (WFCVM 3d)



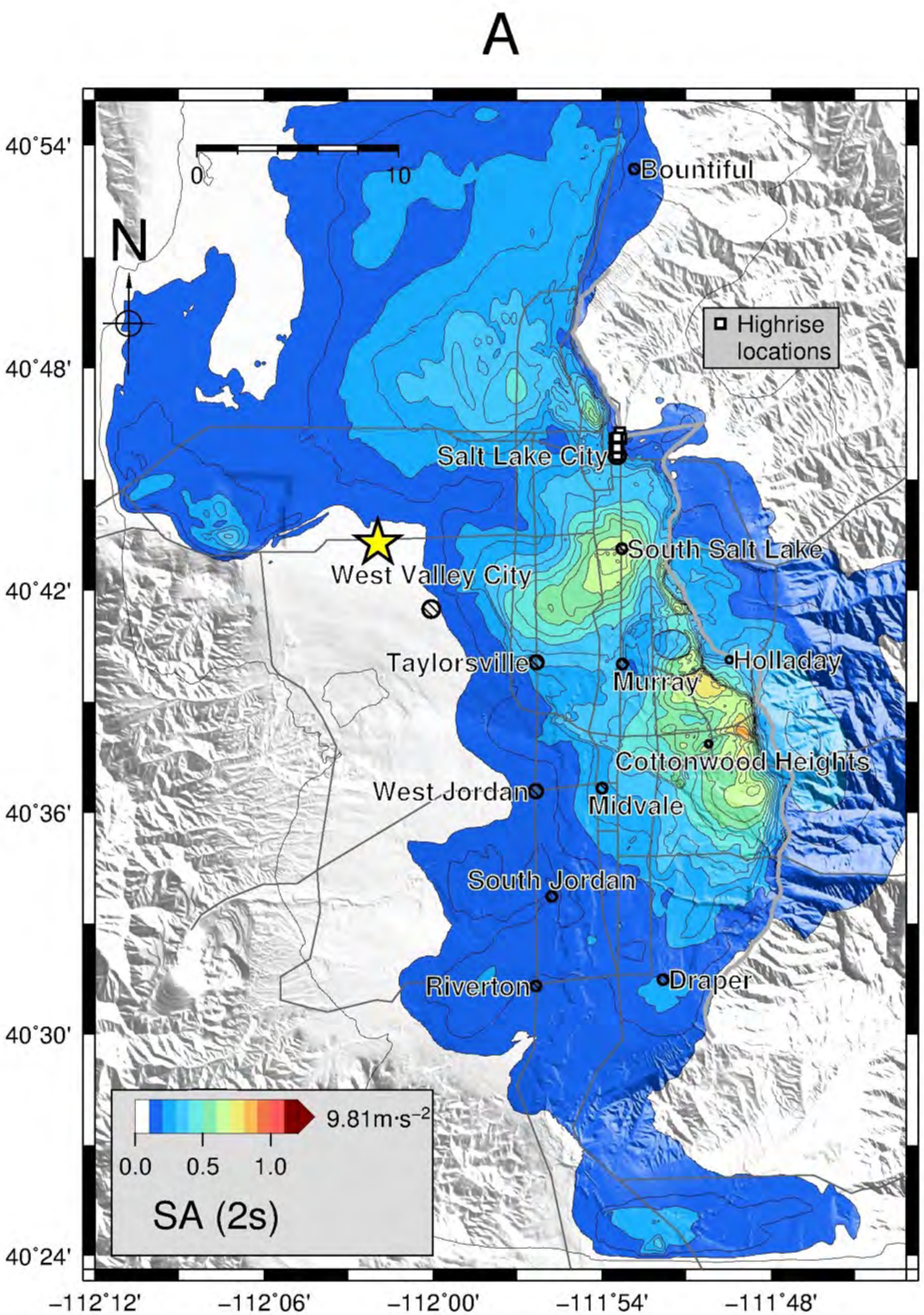
Comparison to 2014 GMPEs (WFCVM 3d)

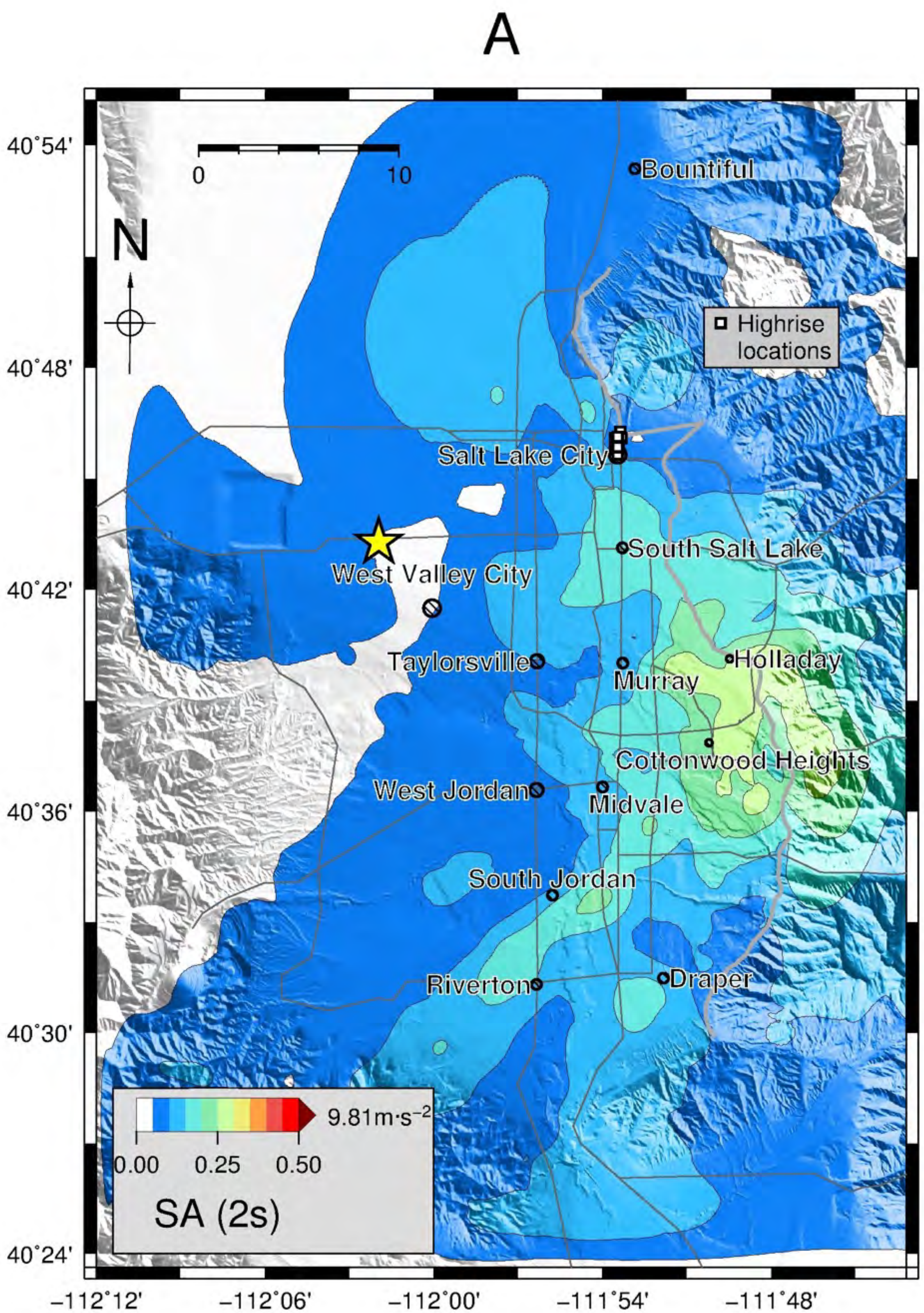


Comparison to 2014 GMPEs (rock model)

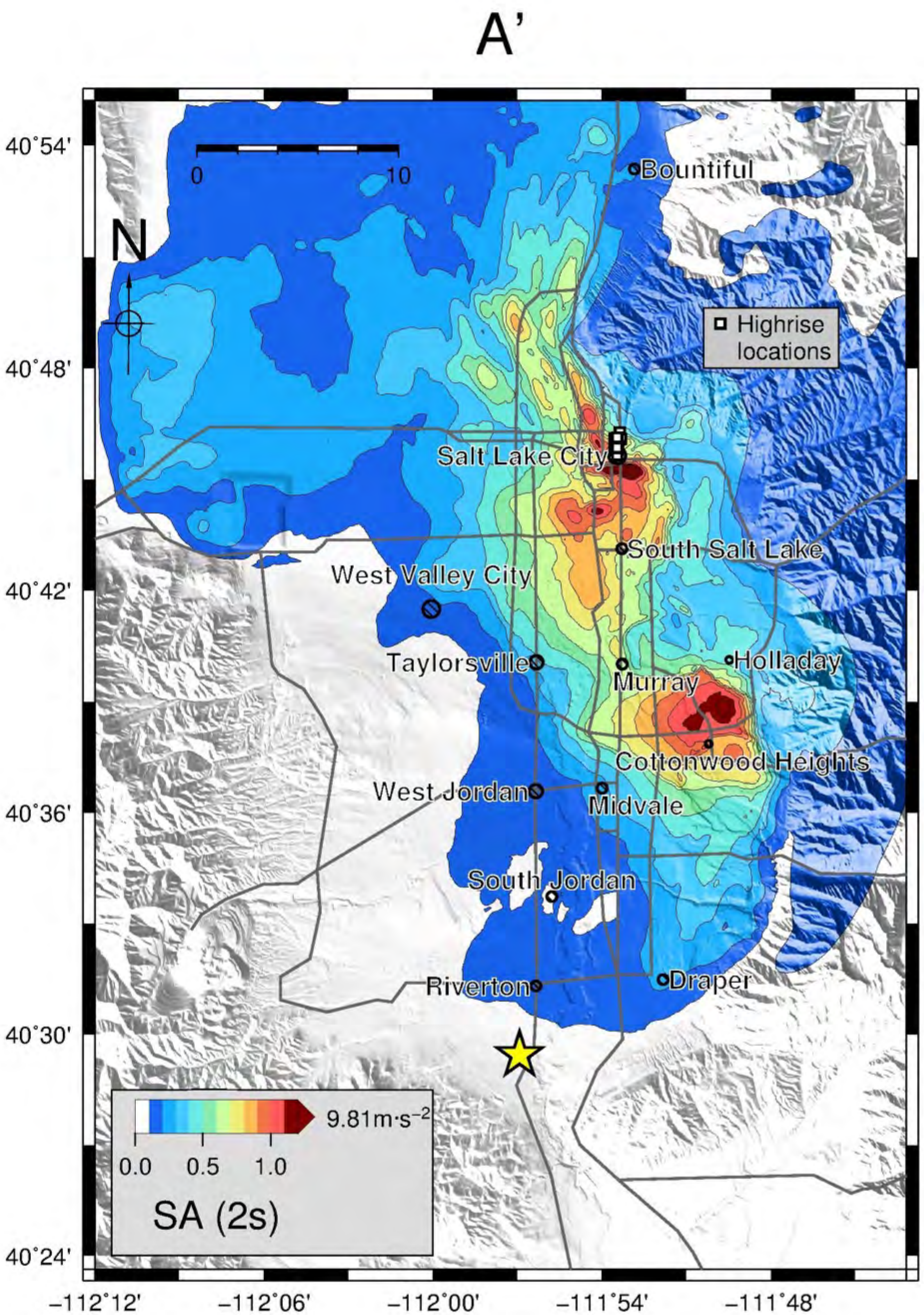


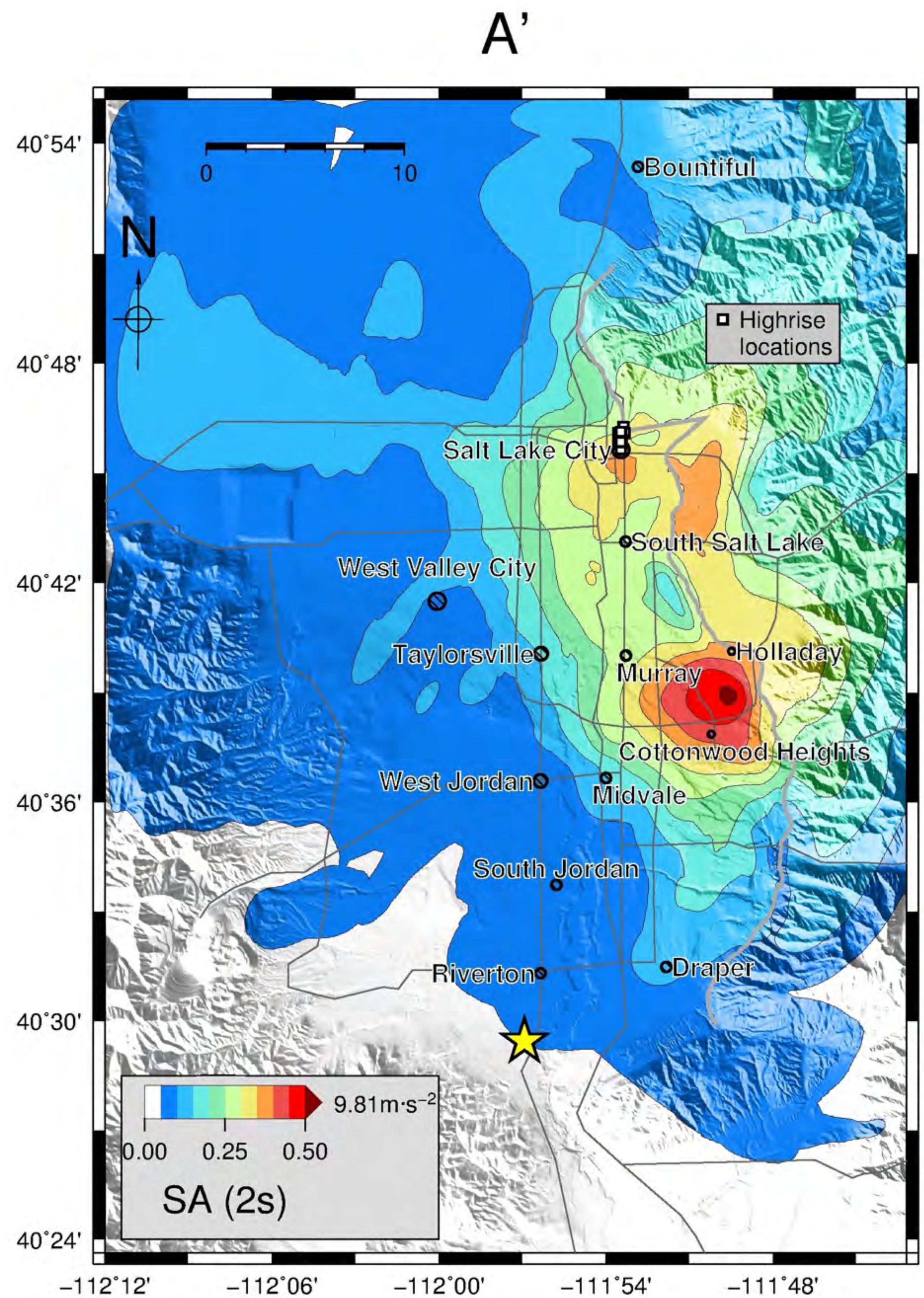
Direction-dependent amplification effects



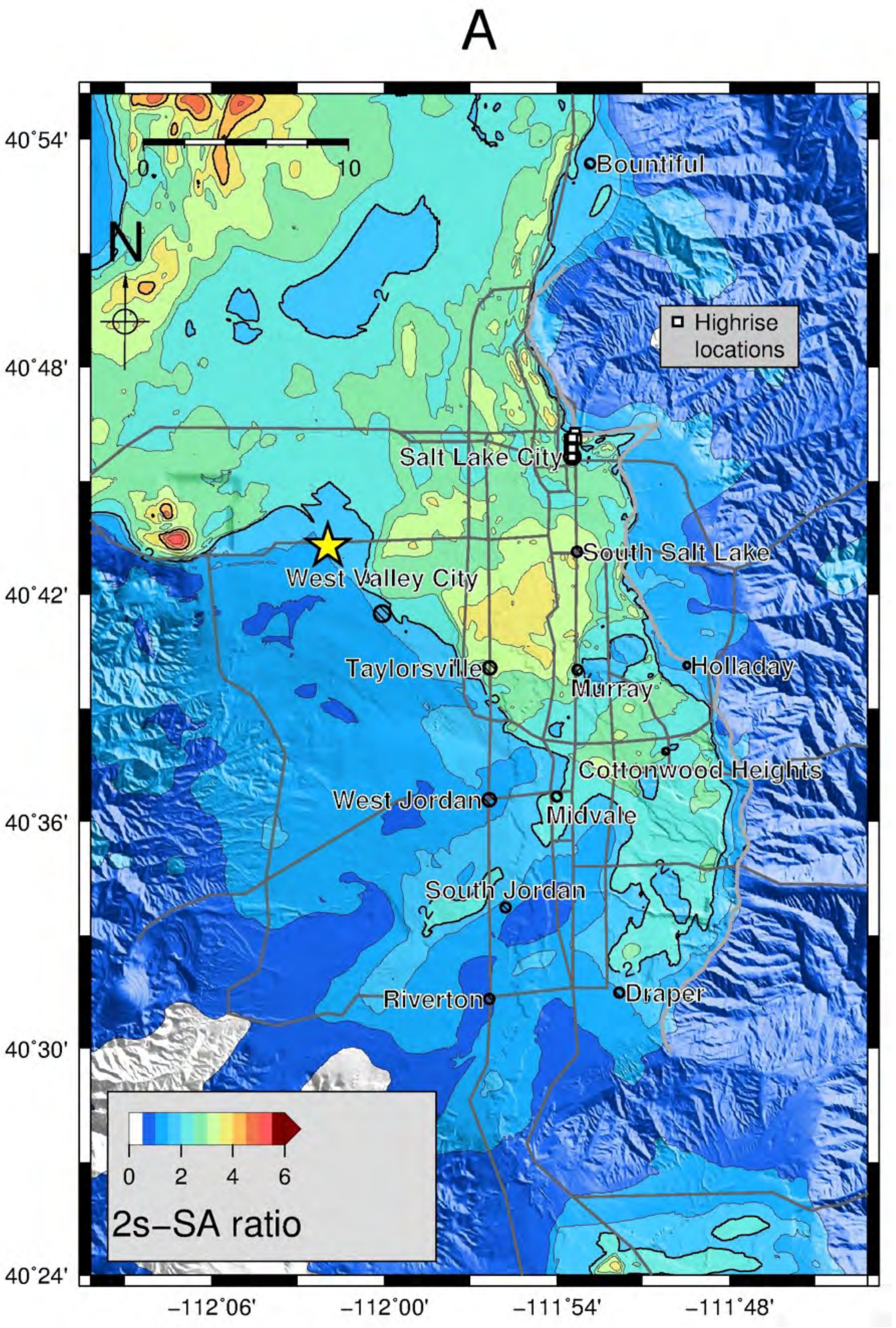


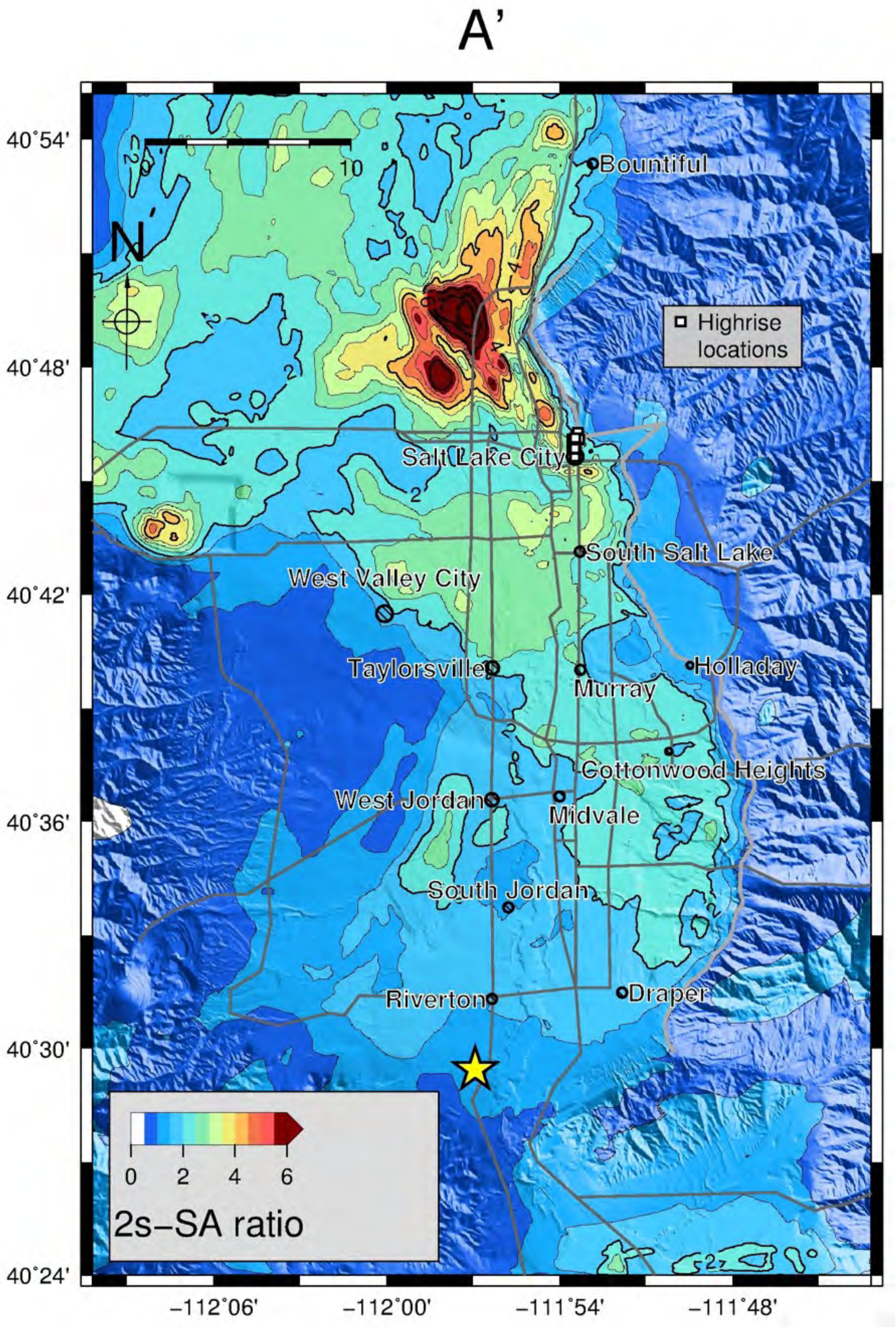
Direction-dependent amplification effects





Direction-dependent amplification effects





Preliminary Conclusions

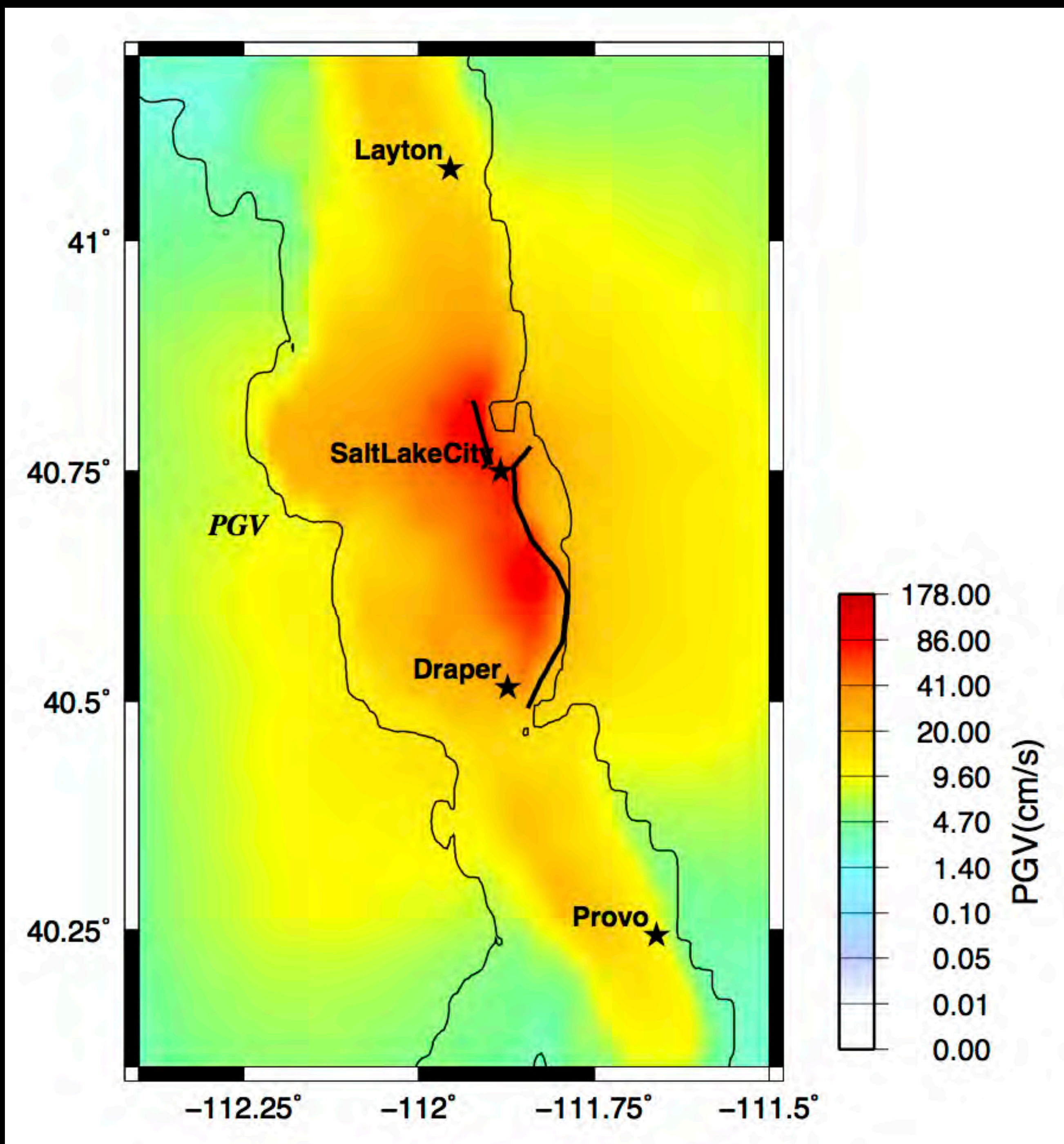
Valley-wide nonlinear simulations:

- Compared to the use of amplitude- and site-dependent correction functions, individual 1D nonlinear simulations predict lower 0.2s-SAs for hanging wall sites in the northern half of the basin, and higher values in the southern half
- A possible reason could be the large variability in the depth to the R1 interface encountered on site response unit Q01

3D simulations with horizontally layered rock model:

- Simulations performed with 1D rock model predict ground motion extremes near fault bends, in particular near downtown SLC and Holladay.
- This suggests that the large ground motions predicted at these locations from simulations with the WFCVM can partly be attributed to effects of the fault geometry.
- Dynamic simulations for a non-planar fault would be needed to predict such effects more accurately.
- At other sites (e.g. west of the Warm Springs fault), amplifications are clearly caused by the 3D velocity structure, with a strong sensitivity to the direction of rupture propagation

Ground motions from kinematic rupture models of M7 earthquakes on the SLC-segment, Wasatch fault zone: Comparison with GMPEs and sensitivity to rupture parameters



Morgan Moschetti, Stephen Hartzell, Leonardo Ramirez-Guzman, Steve Angster, Arthur Frankel, Peter Powers

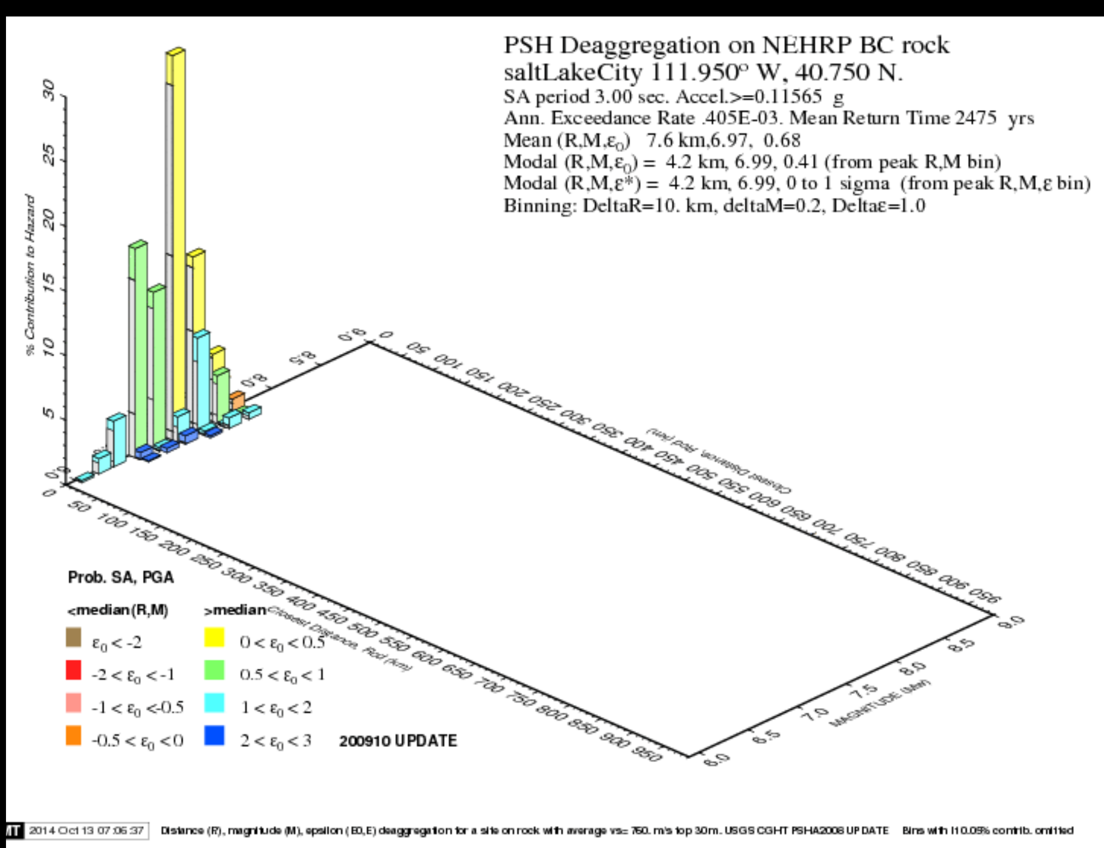
Utah Ground Shaking Working Group
Salt Lake City, February 9, 2016

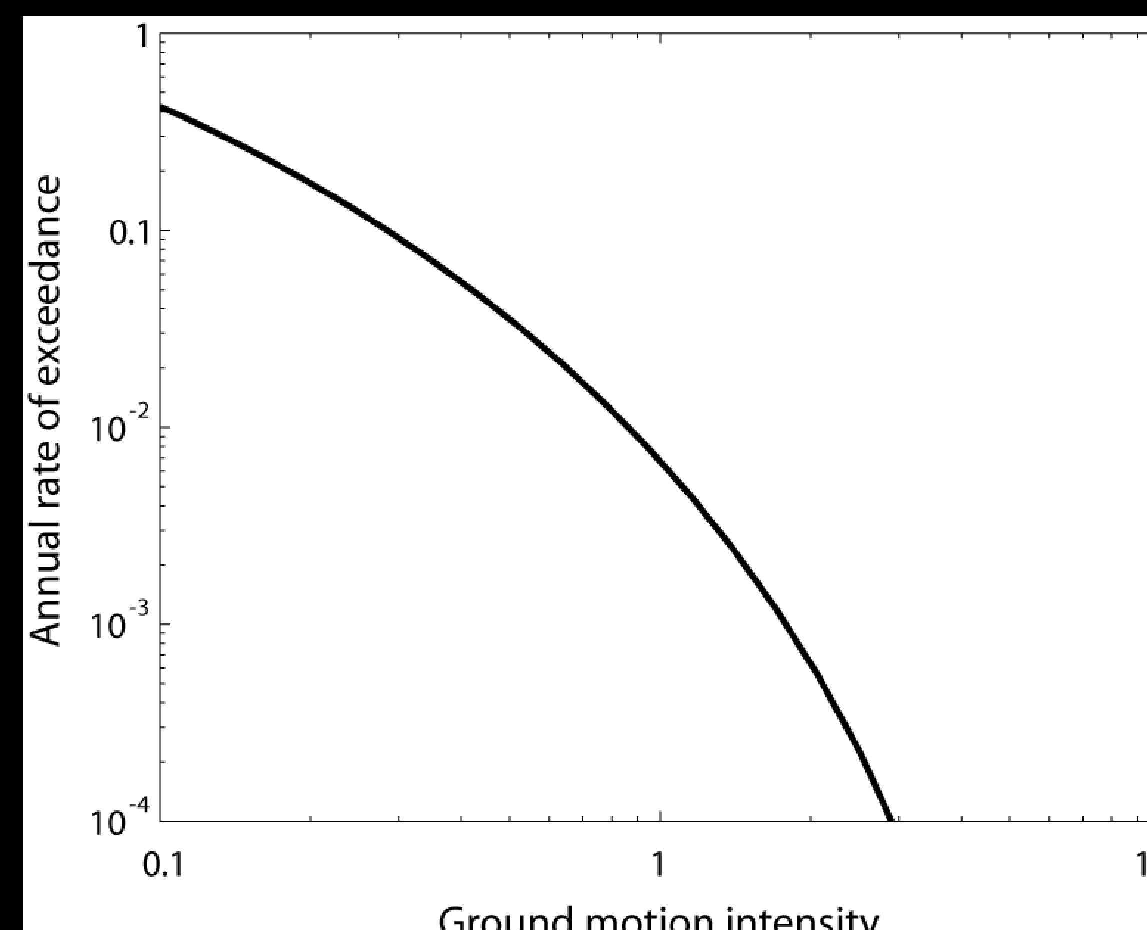
Probabilistic seismic hazard analysis (PSHA)

$$P(PGA > x \mid m,r) = 1 - \Phi\left(\frac{\ln x - \overline{\ln PGA}}{\sigma_{\ln PGA}}\right)$$

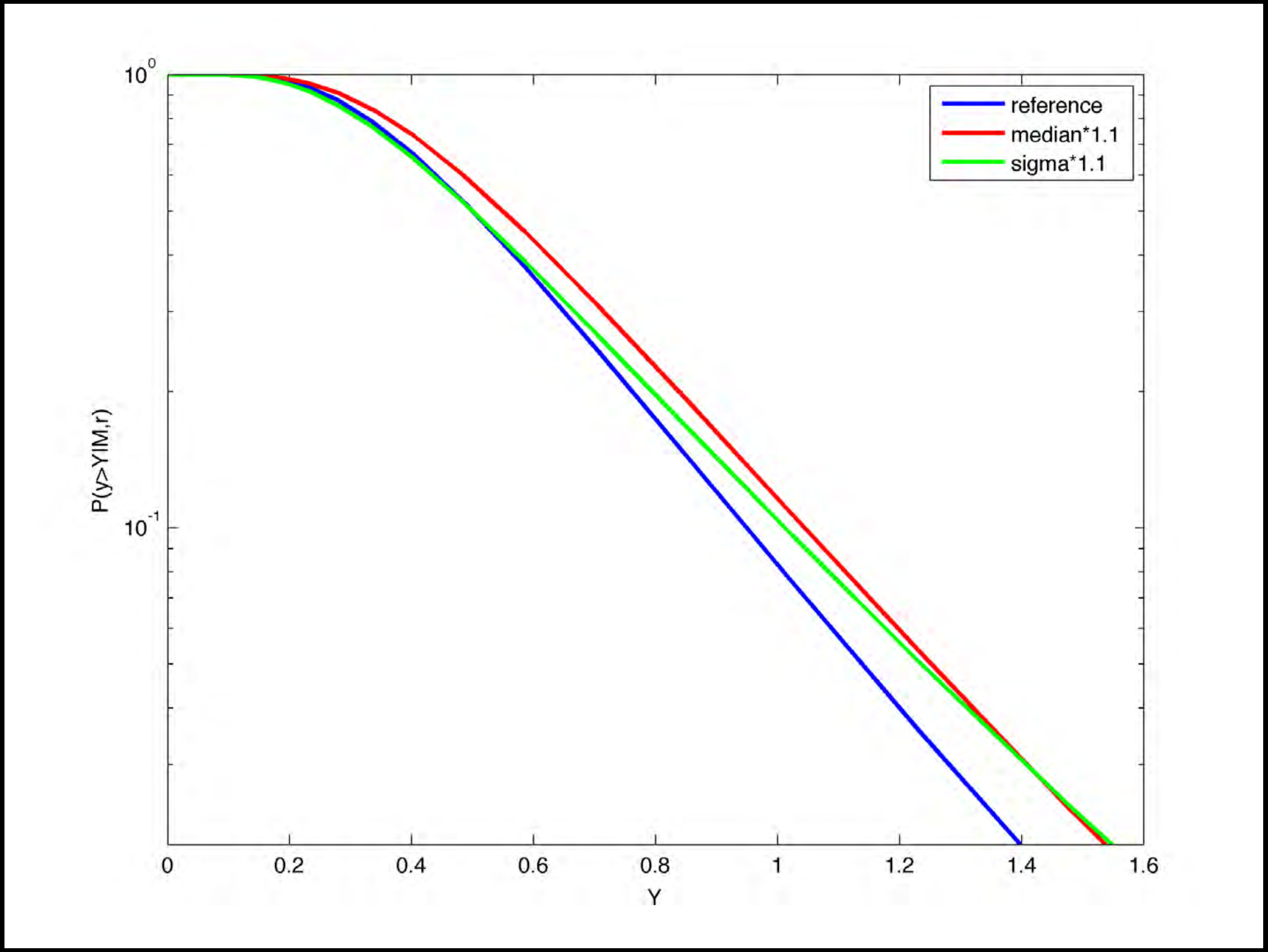
$$\lambda(IM > x) = \sum_{i=1}^{n_{sources}} \lambda(M_i > m_{\min}) \int_{m_{\min}}^{m_{\max}} \int_{0}^{r_{\max}} P(IM > x \mid m,r) f_{M_i}(m) f_{R_i}(r)\, dr\, dm$$

Baker (2008), An Introduction to PSHA





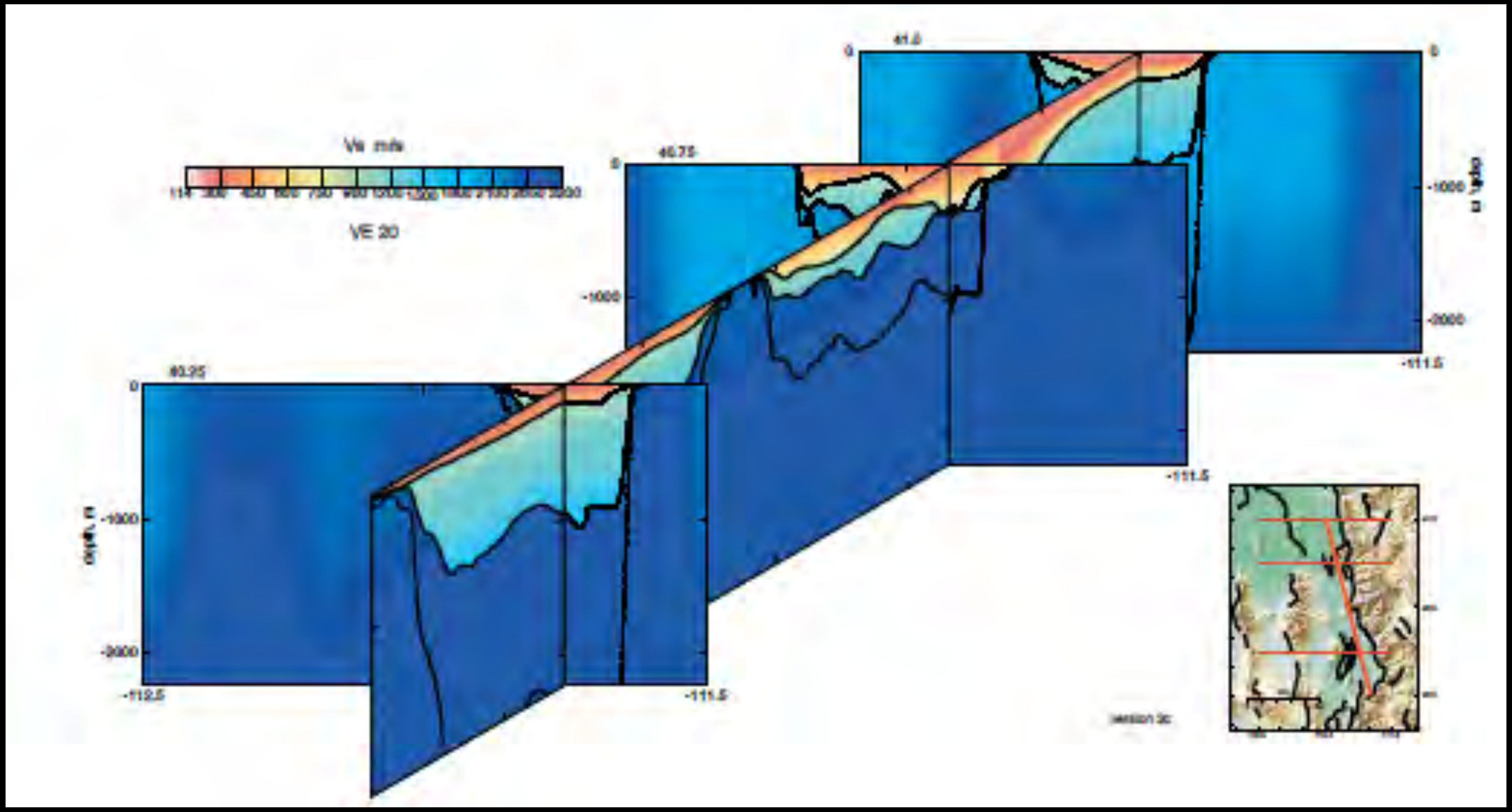
Importance of mean and variance of ground motion distributions



Outline

- Ground motion modeling for SLC-segment, WFZ
    - Kinematic rupture model
    - Selection of kinematic rupture parameters
    - 3-D representation of fault
- Examination of ground motions
    - comparison with GMPEs
    - spatial variability
    - effect of kinematic rupture parameters on hazard parameters (response SA) and ground motions (FAS)

WCVM



Wasatch community velocity model with minor modification: Kriging of near-surface (above R1) seismic velocities to reduce “borehole effects”

Rupture modeling considerations

- M7 normal-faulting earthquakes
- Fault dimensions: ~40 km x 20 km (Wells and Coppersmith, 1994)
- Rupture generator methodology (Frankel, 2009, 2010)
- Kinematic rupture parameters supported by seismological studies, literature search, ground-motion modeling

Kinematic rupture generator, Frankel (2009, 2010)

- Kinematic earthquake rupture
    - Fault rupture discretized by sub-events, 81x41
    - Sub-events parameterized by moment, rise time, rupture initiation time, strike, dip, rake, slip-rate function

variable parameters		
Hypocenter (3 models)	north, center, south	
Average rupture speed (2 models)	60%, 80% Vs	
Random slip field (4 models)	seed values (103, 103-r, 56, 83)	
Correlation length (2 models)	mean (13/6 km), 3-sigma (3/1.5 km)	Mai and Beroza (2002)
Slip velocity (rise time) (2 models)	2.7, 1.0 m/s	Frankel (2009)

96 scenarios:
- 4 slip realizations
- 2 correlation lengths
- 2 slip velocities
- 2 average rupture velocities
- 3 hypocenter locations

Kinematic rupture generator, Frankel (2009, 2010)

- Kinematic earthquake rupture
    - Fault rupture discretized by sub-events,
    - Sub-events parameterized by moment, ion

variable parameters	
Hypocenter (3 models)	
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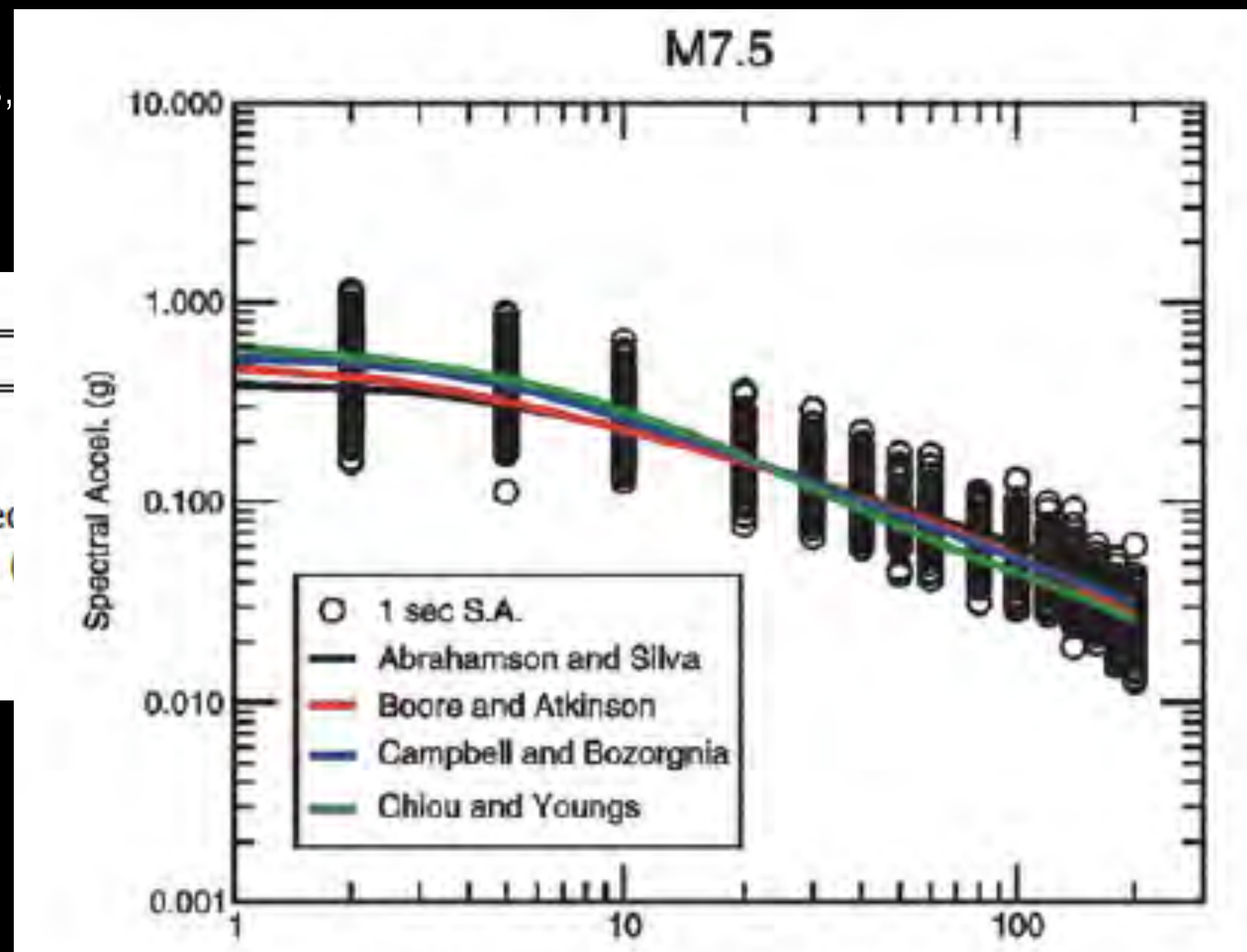
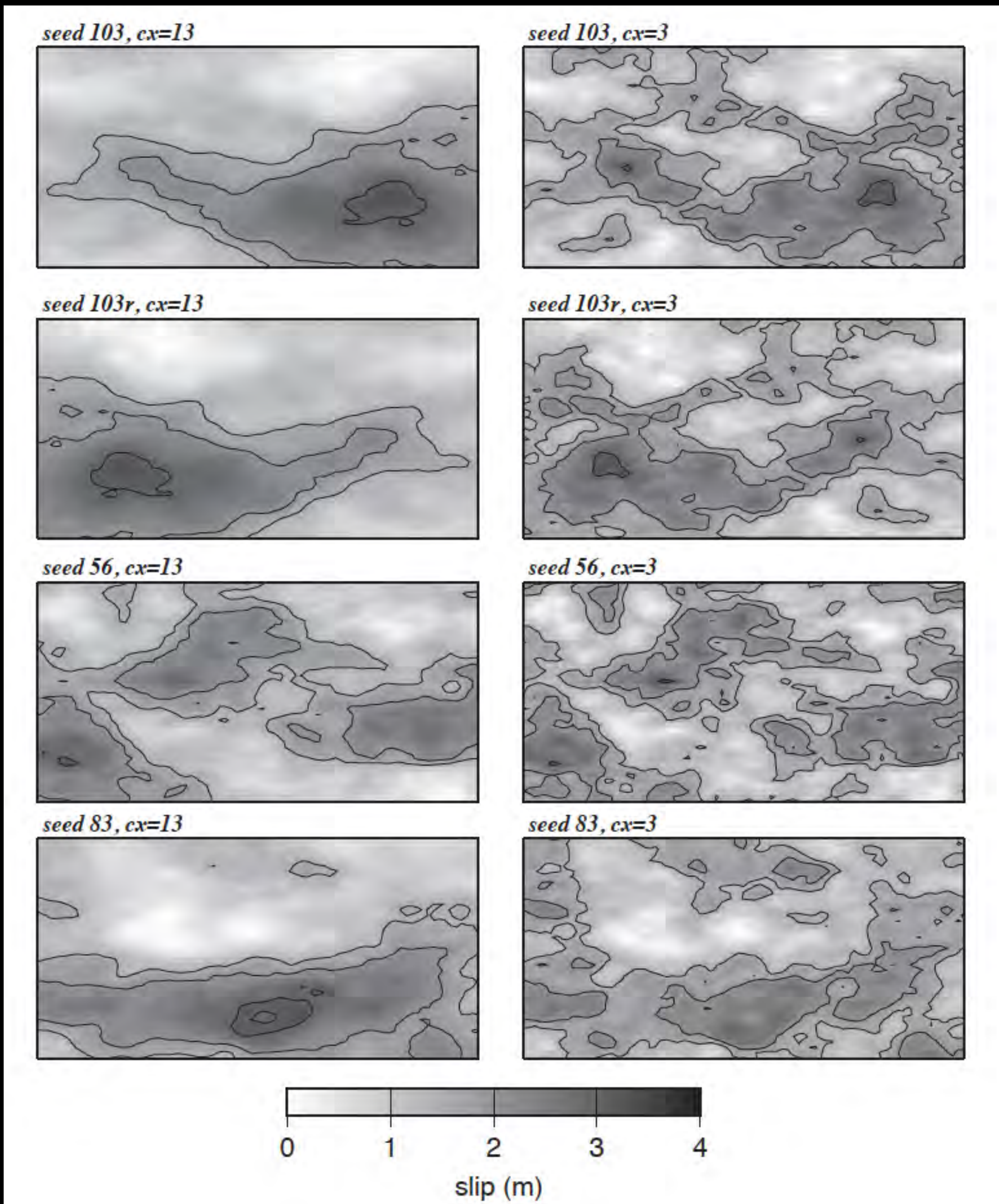
Random slip field (4 models)	seec
Correlation length (2 models)	mean (
Slip velocity (rise time) (2 models)	



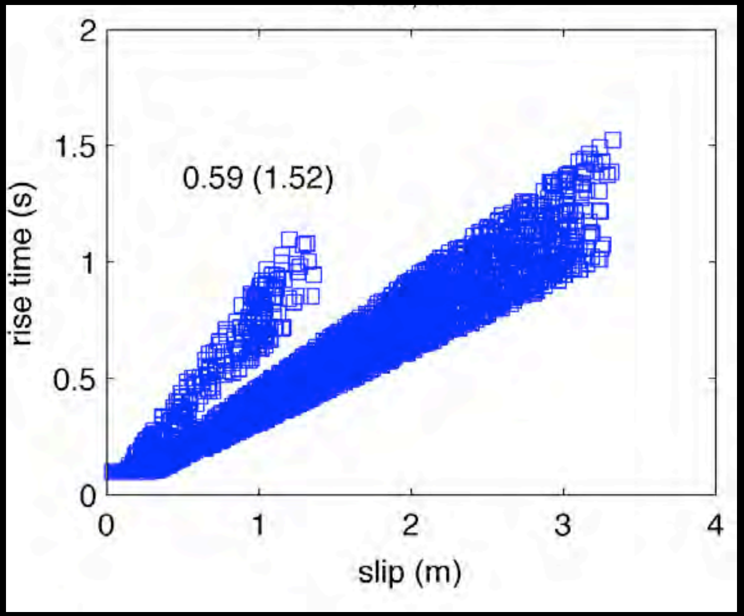
96 scenarios:
- 4 slip realizations
- 2 correlation lengths
- 2 slip velocities
- 2 average rupture velocities
- 3 hypocenter locations

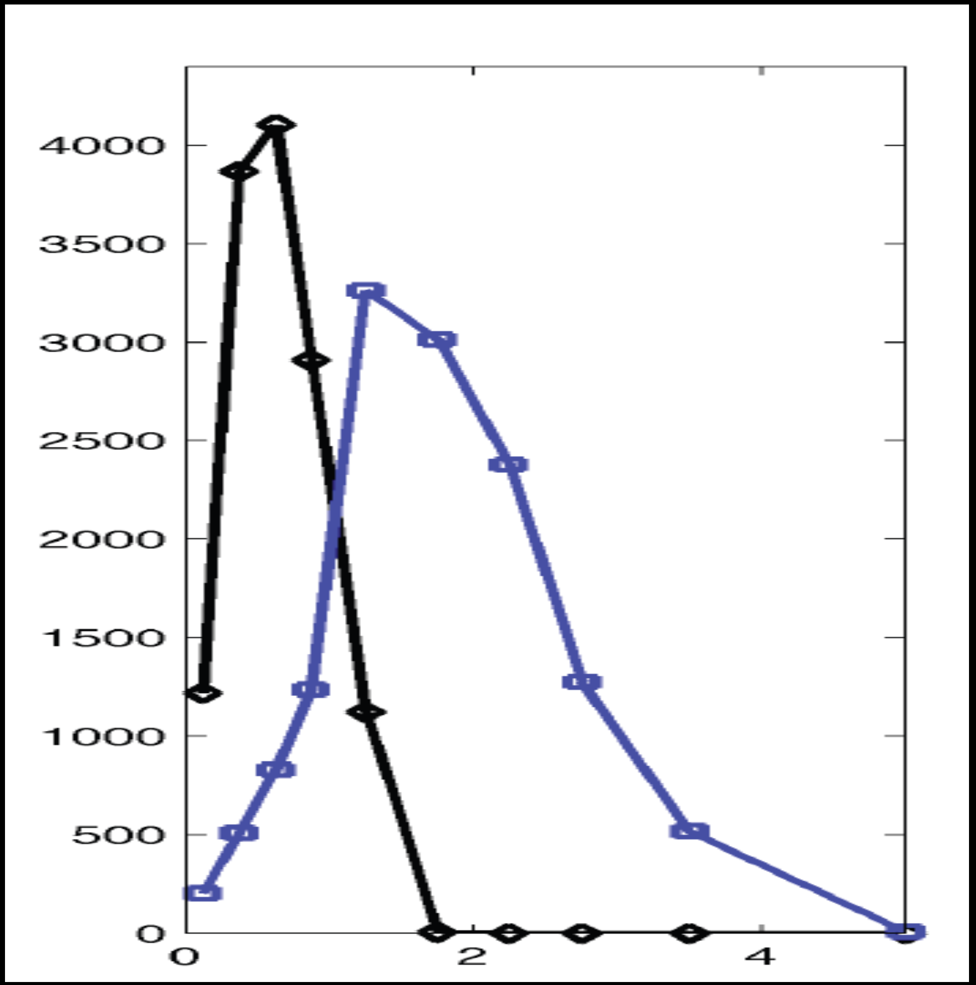
Slip fields



- Fractal distributions of slip, flat below corner wavenumber. Above the corner wavenumber, slip amplitudes decay as k-square (von Karman autocorrelation function)
- Random field realizations that localize moment release: north, south, bottom, distributed (Somerville et al., 2001)
  - Maximum and average slip consistent with WC94
- Correlation lengths from Mai and Beroza (2004): mean correlation length and ~ -3-sigma

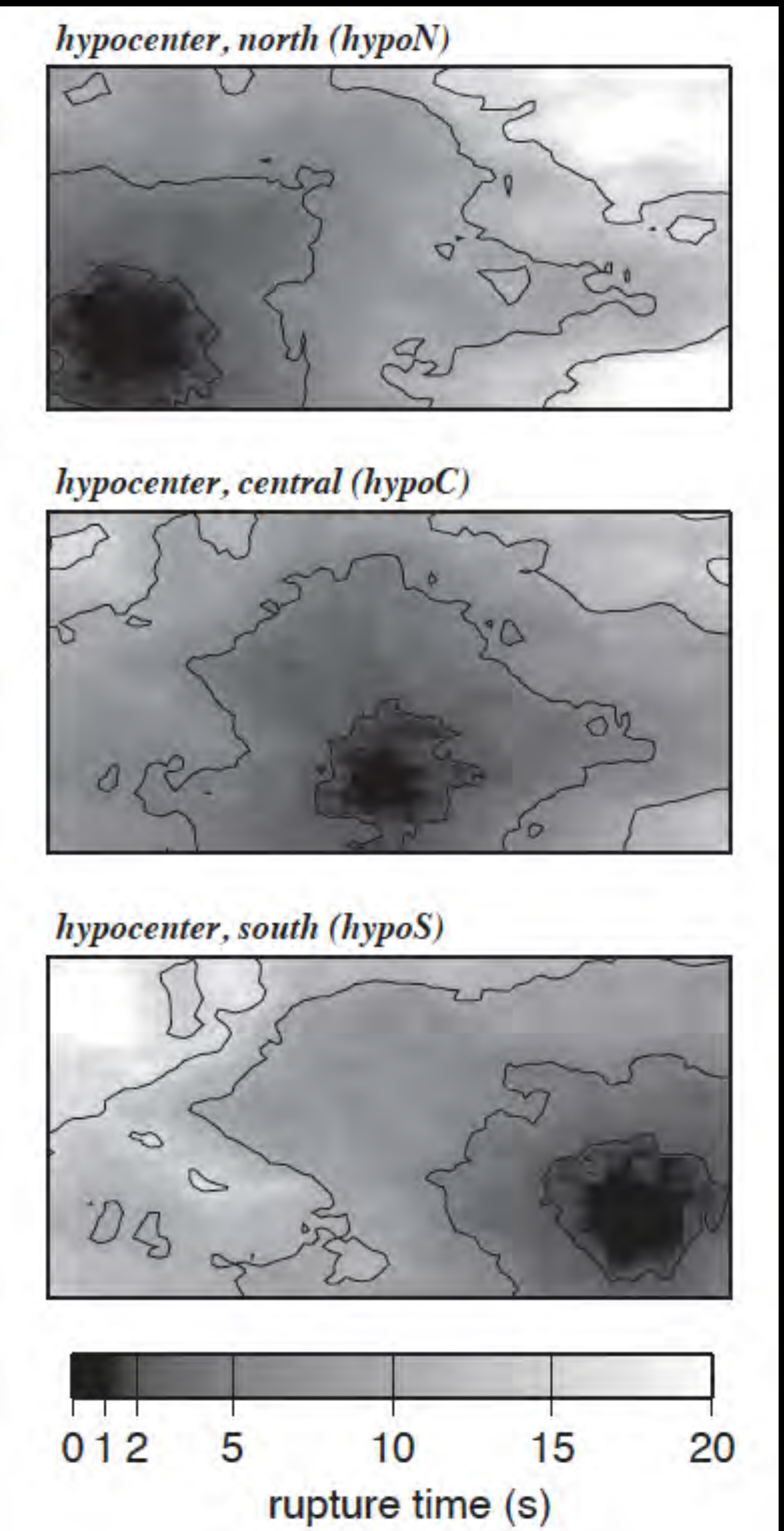
Sub-event rise times





- Rise times related to final slip (moment) by specified slip velocity.
- Formulation ensures constant dynamic stress drop scaling with magnitude
- Scaling with local S-wave velocity: effect of slowing rupture as it propagates into near-surface
- Two slip velocities:
    - 2.7 km/s (Frankel, 2009); shorter rise times, consistent with interpretation that S01 from longest rise time
    - 1.0 km/s; longer rise times, consistent with interpretation that S01 from mean rise times
- Pseudo-dynamic slip rate function of Liu, Archuleta and Hartzell (2006): Flat acceration spectral amplitudes above corner frequency with pulse shape consistent with simple dynamic rupture modeling.

Hypocenter and initiation times



- Rupture initiation times

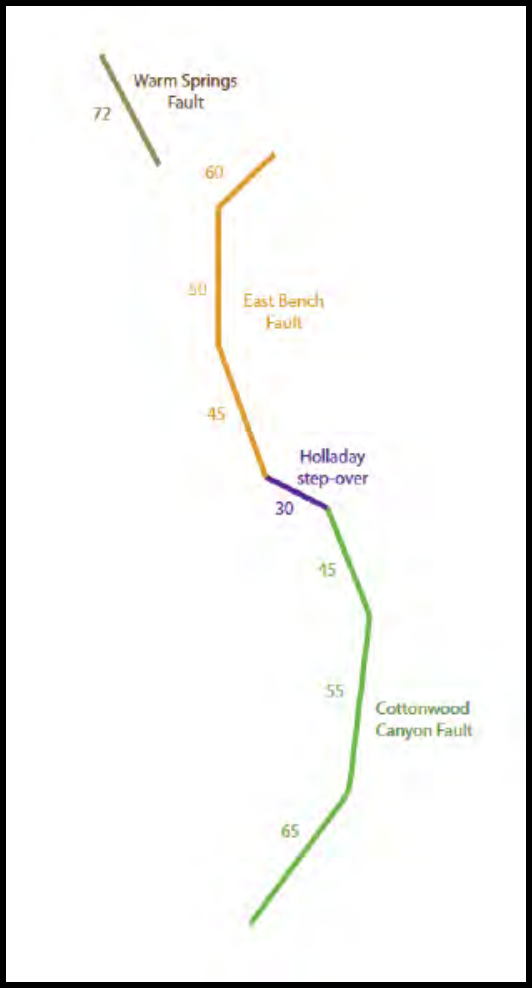
  - Rupture times defined by average rupture speed with initiation-time perturbations

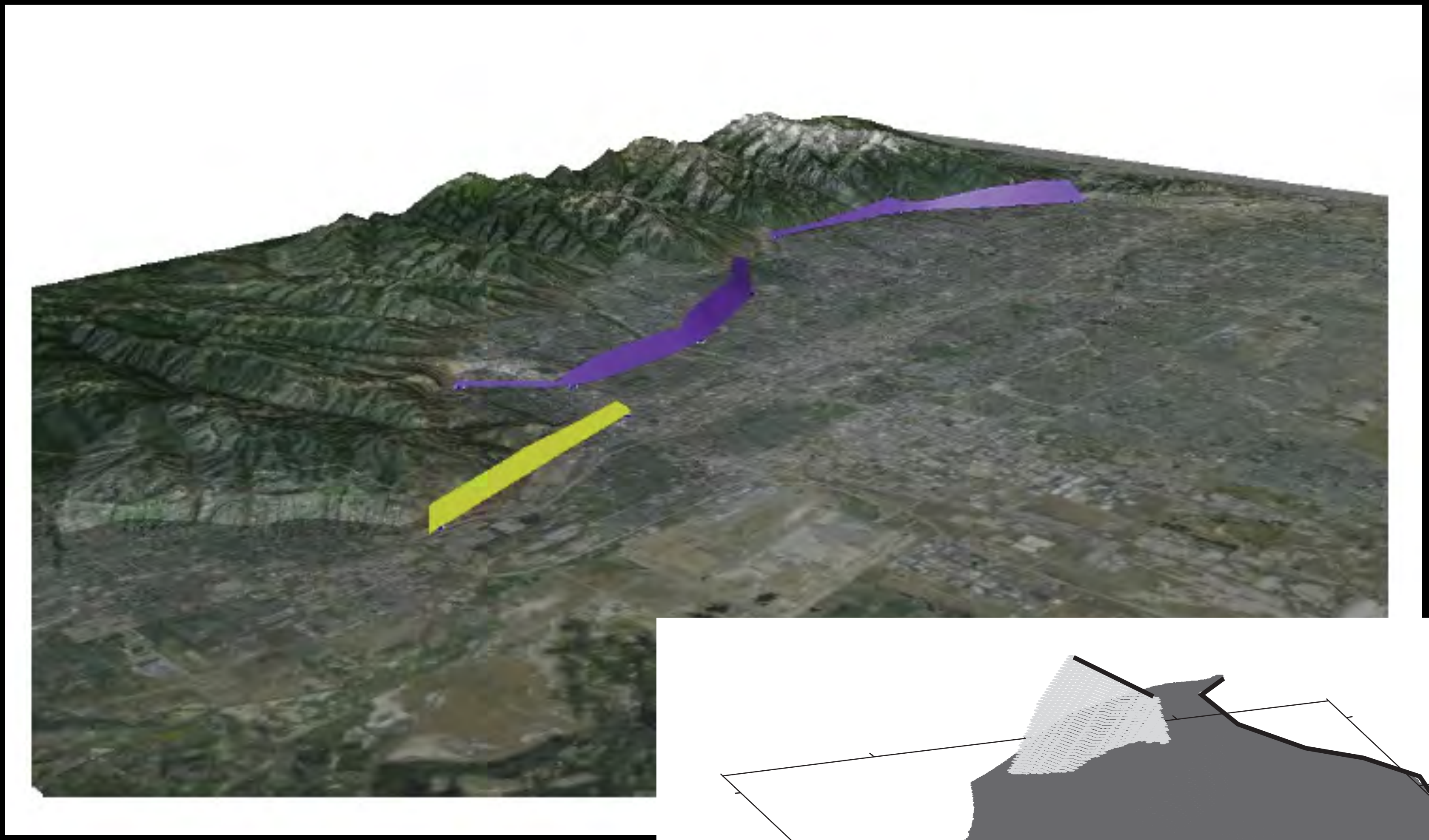
  - Average rupture speed implemented with 2-D finite-difference travel time calculation

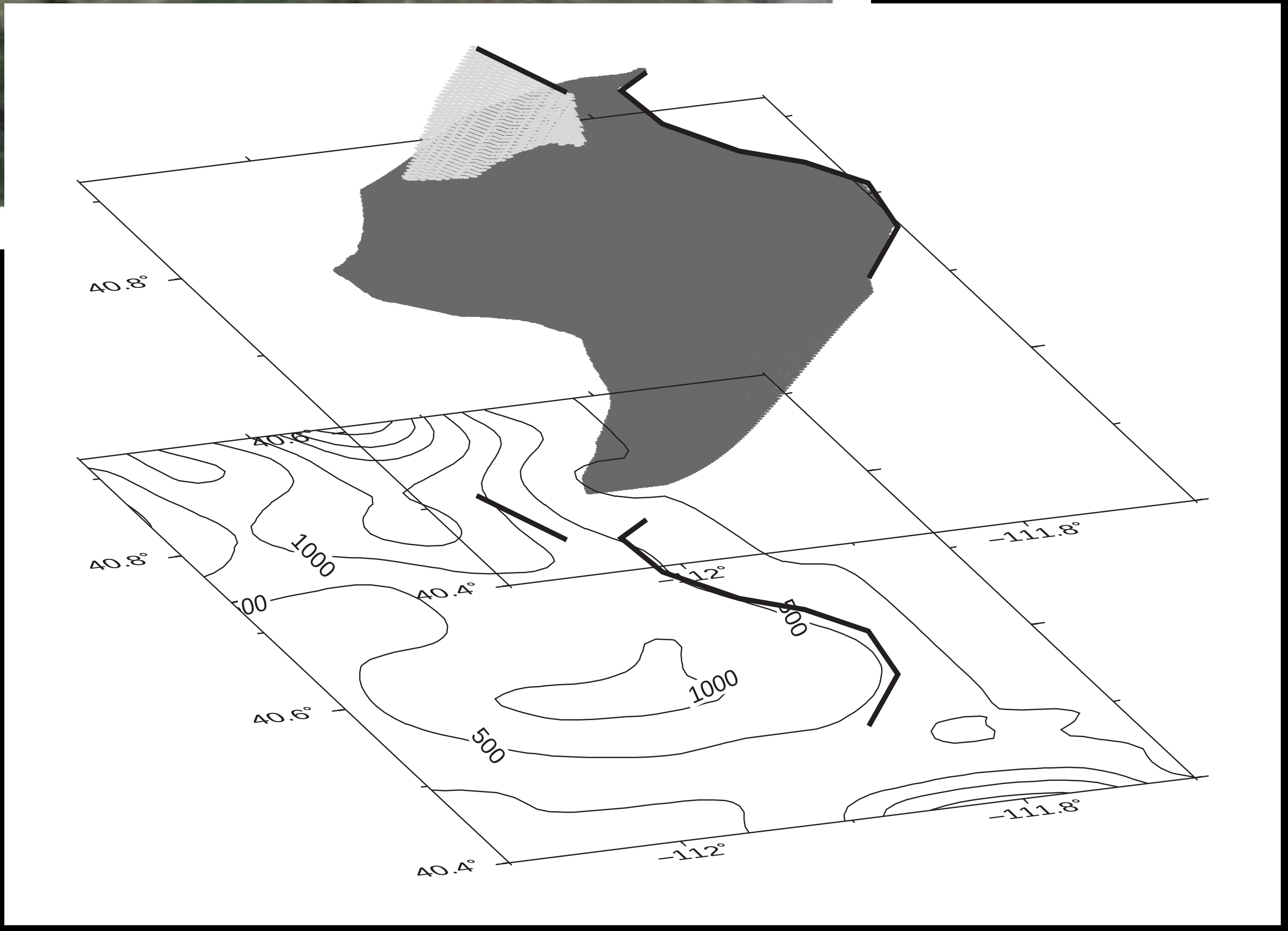
  - Perturbations: (1) Secant rupture velocity: local rupture velocity pertubation relative to mean proportional to local moment perturbation relative to mean sub-event moment; (2) Additional, random initiation-time perturbations

- Hypocenters located at north, central, south positions

Fault representation: SLC-segment, WFZ

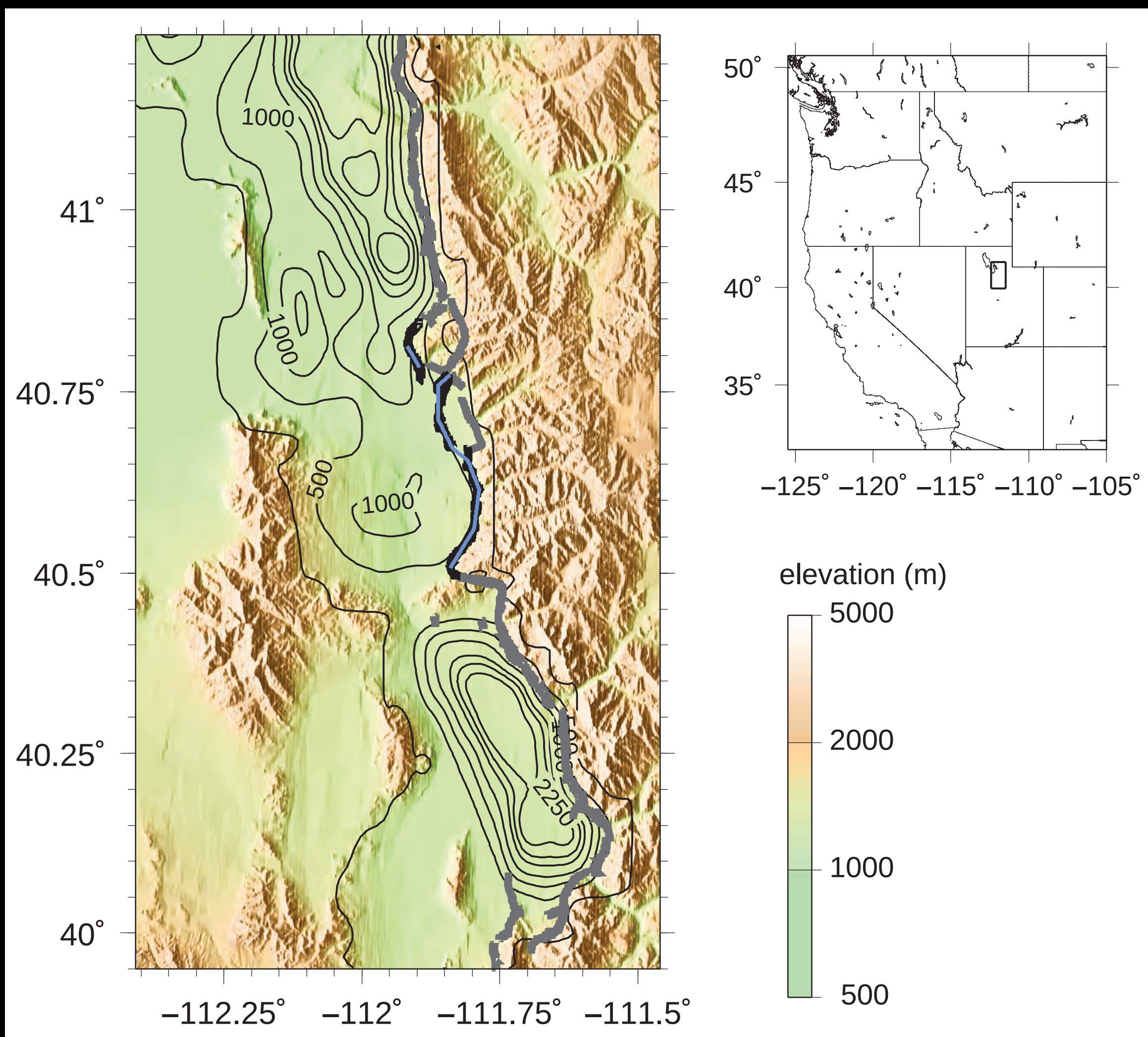






- Adhere to mapped fault surface trace, basement contacts and average dip (50 deg) below basins

3-D wave propagation: Hercules finite-element tool



- Hercules finite-element tool: meshing, partitioning, solving
- Simulations:

  - fmax=1 Hz

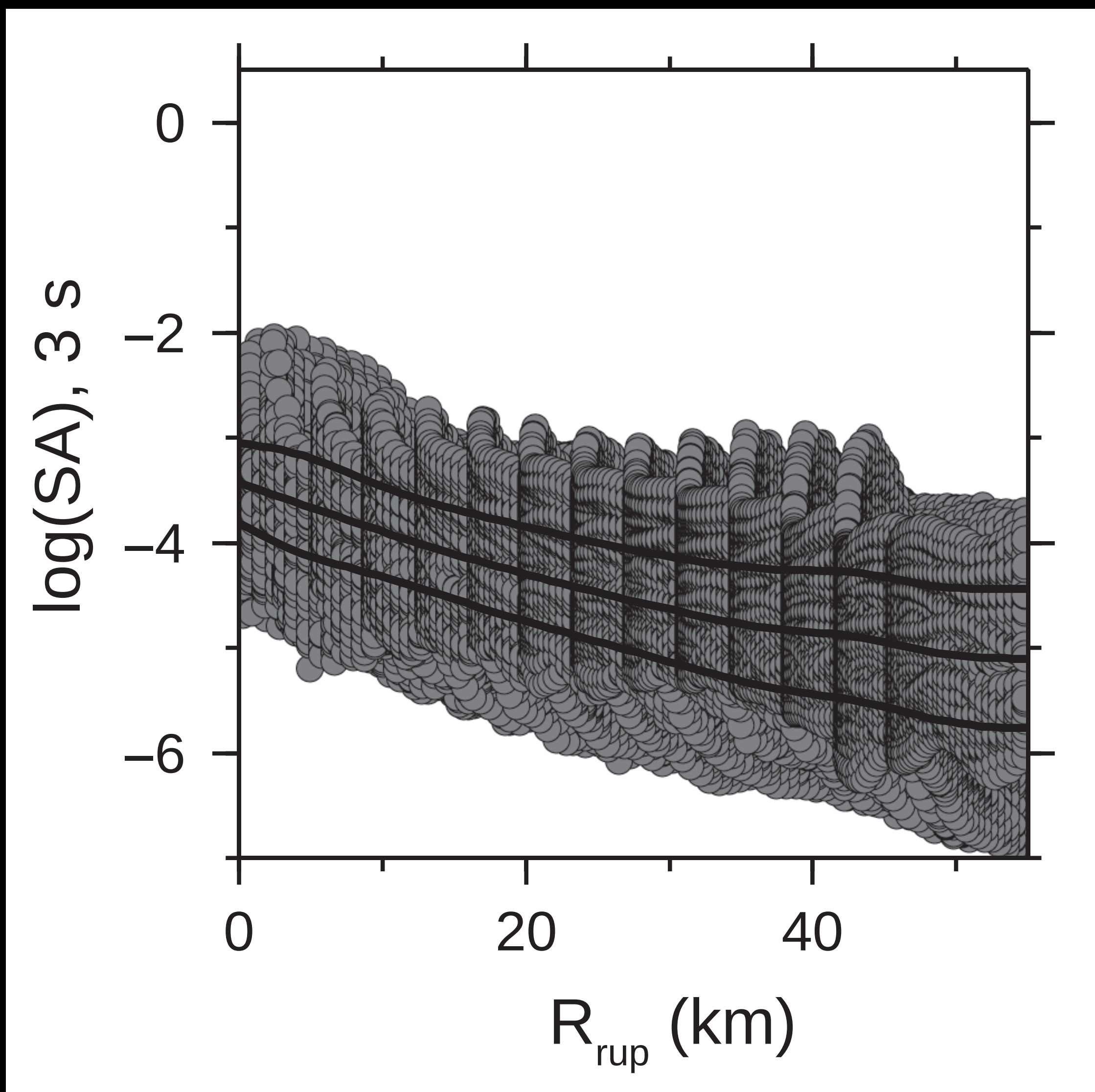
  - 200 m/s, min Vs

  - 10 pts/wavelength

  - 4096 cores, ~4000 SUs/simulation (Xsede-Kraken)

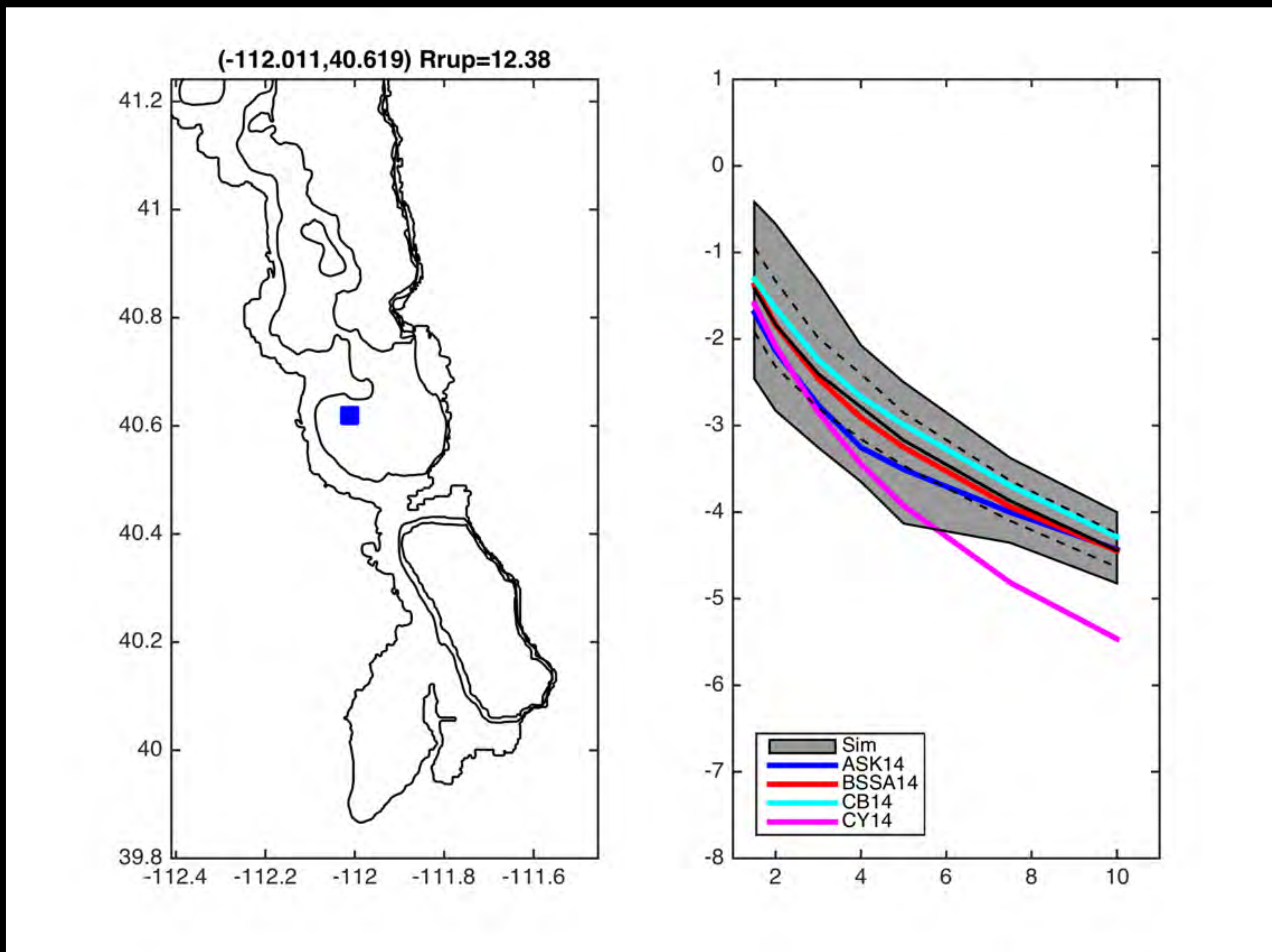
  - Recorded surface displacements at 3600 locations across the region

Comparison with NGA-W2



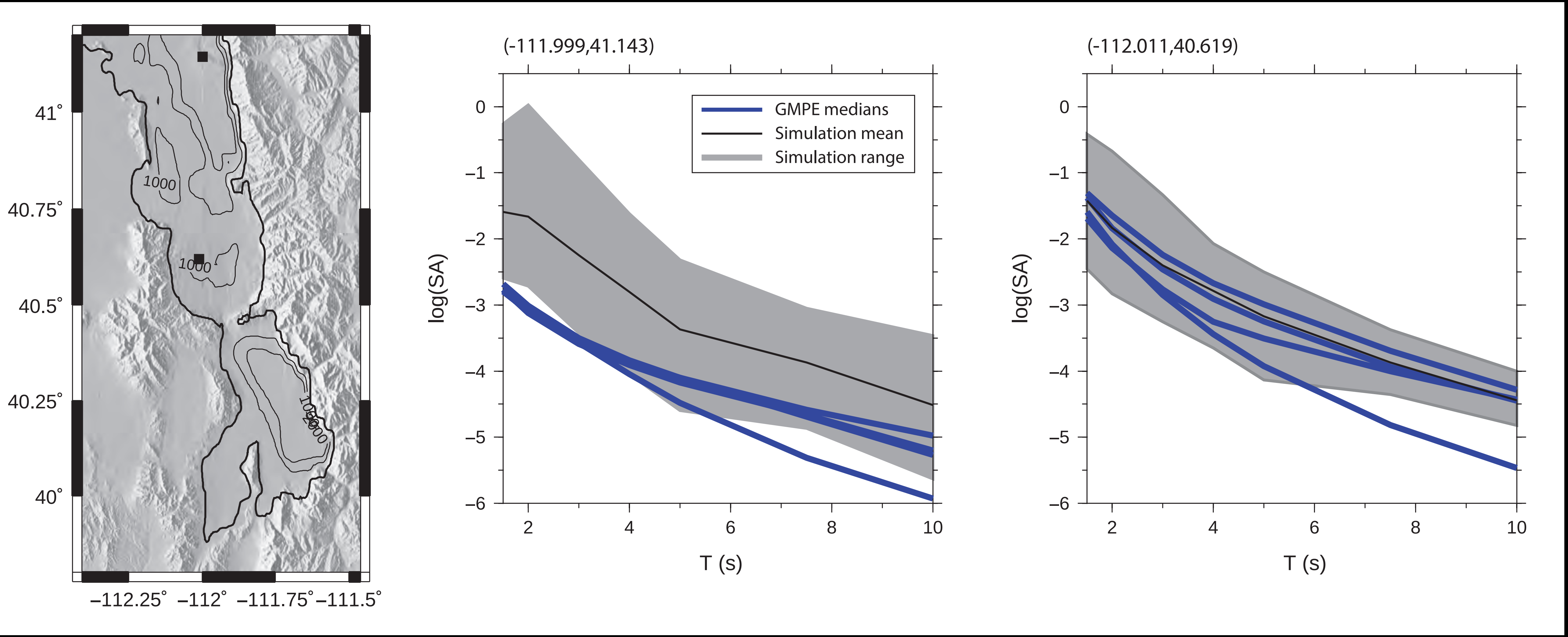
- 3-component time series from 96 events at 3600 locations: >1M seismograms
- Measured PGV, response spectral accelerations at long-period set of NGA-W2 GMPEs
- All comparisons with GMPEs used basin depths from the WCVM and Vs30 from Allen and Wald, topographic slope proxy

Comparison with NGA-W2



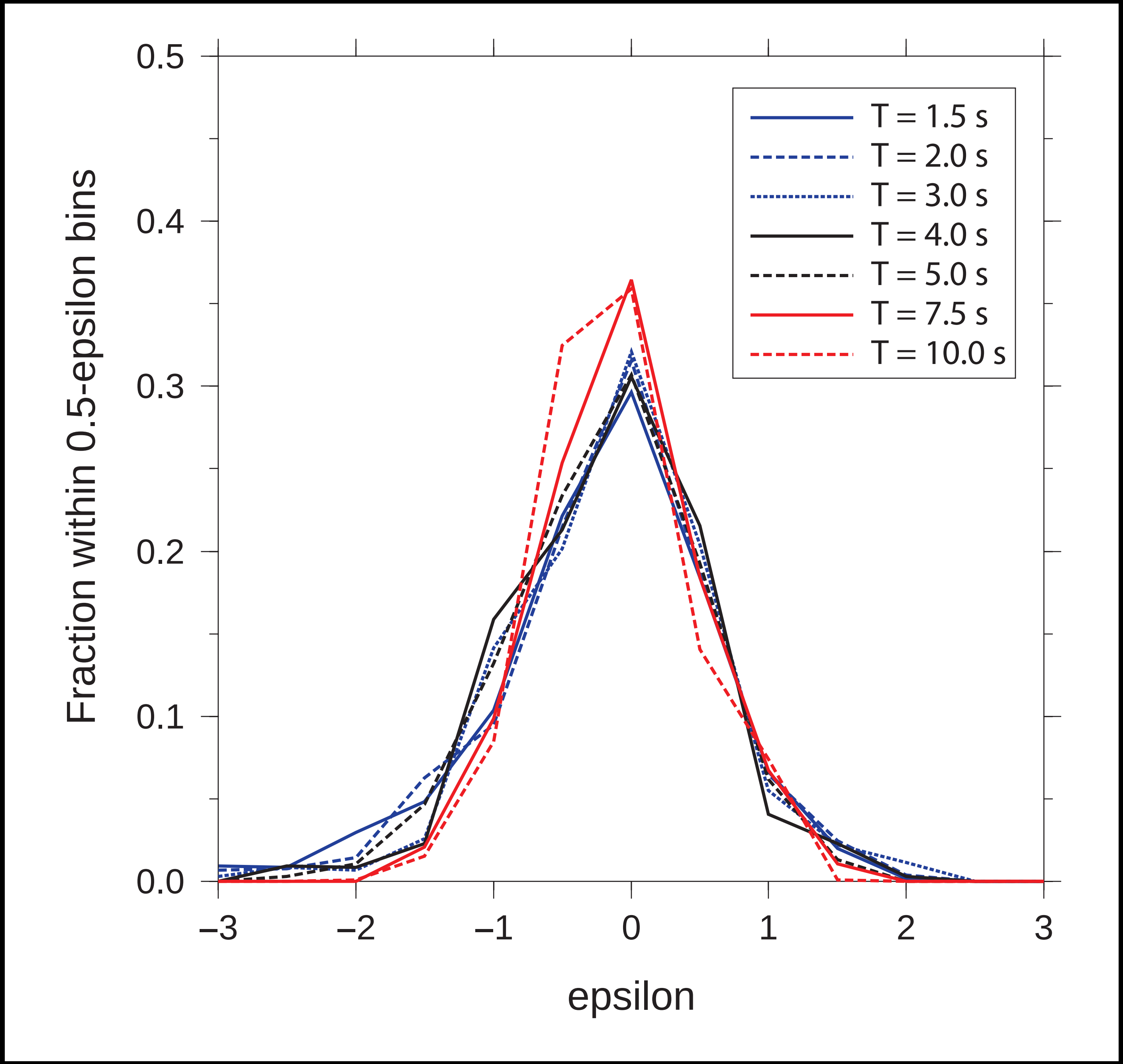
- Example comparison of simulated and GMPE-predicted ground motions (T=1.5, 2, 3, 5, 7.5, 10 s)
- Only compared simulated results with GMPEs allowing for low Vs30 values—no Idriss.
- Simulated ground motions: Full range, mean and standard deviations

Regional variation in comparison with GMPE-predicted ground motions

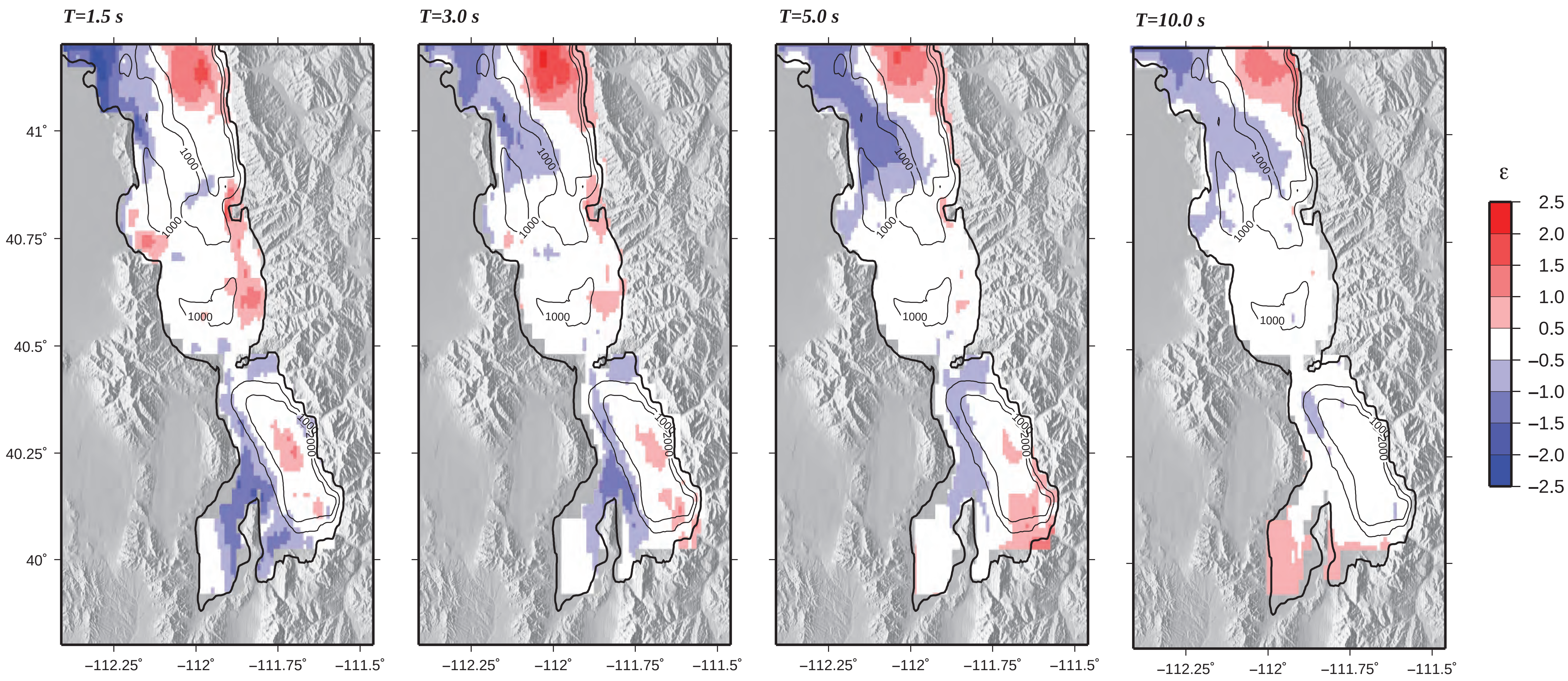


- Ground motions at many sites well modeled by GMPEs
- At some sites, large discrepancies between the simulated and GMPE-predicted ground motions

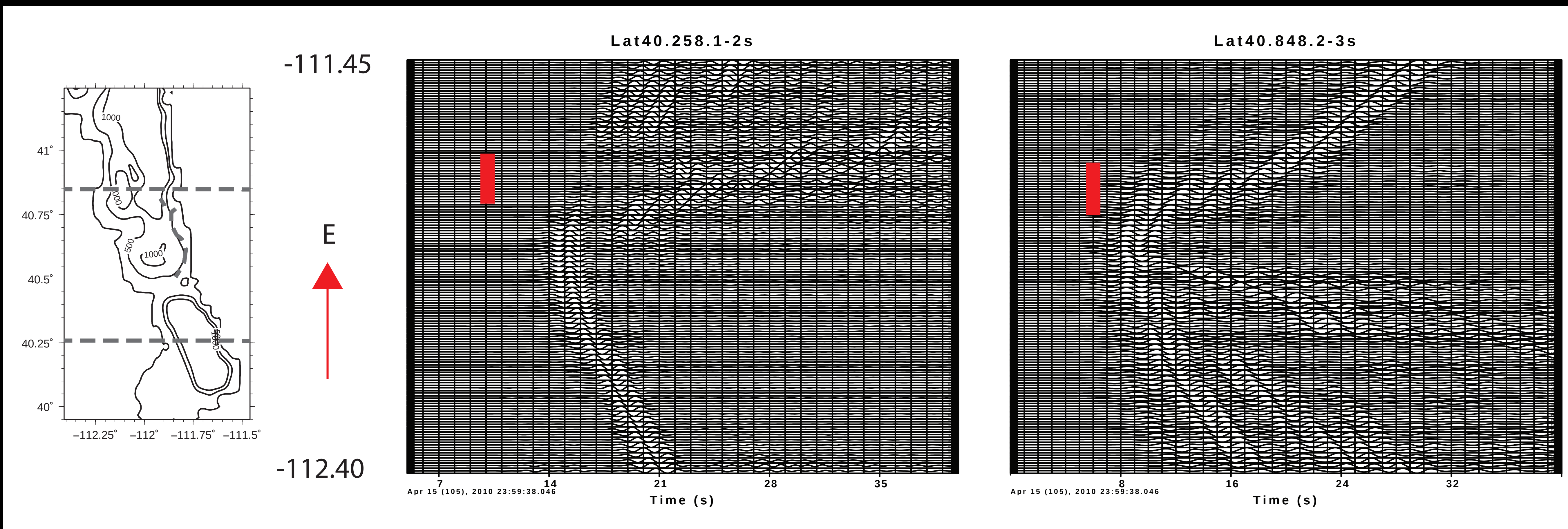
General agreement between simulated and GMPE-predicted ground motions



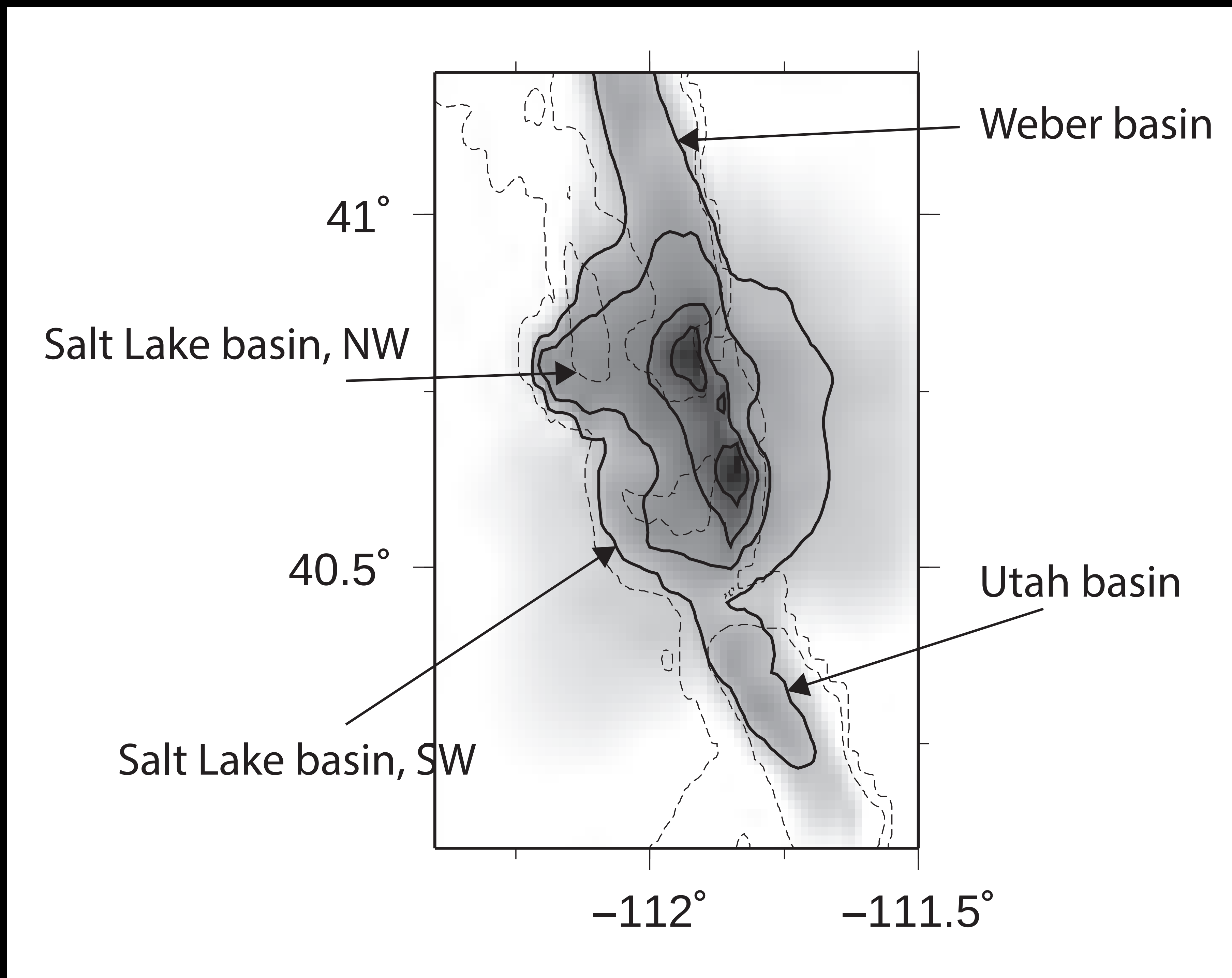
Ground motion residuals: epsilon



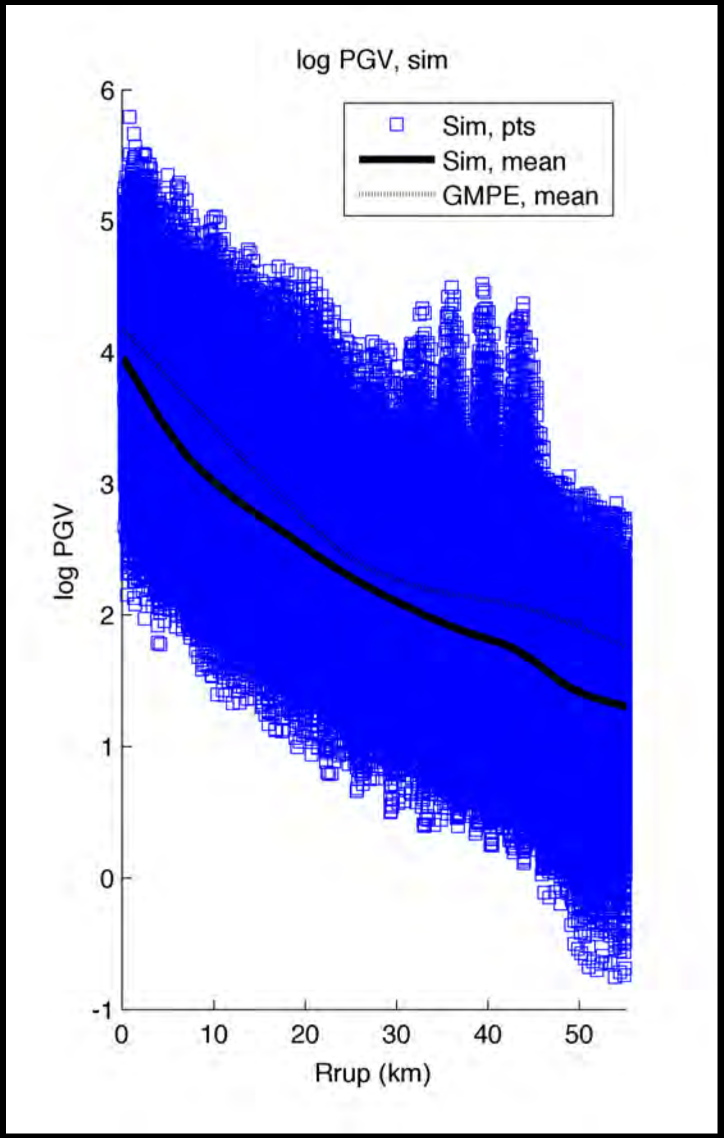
Surface wave excitation in deep basins

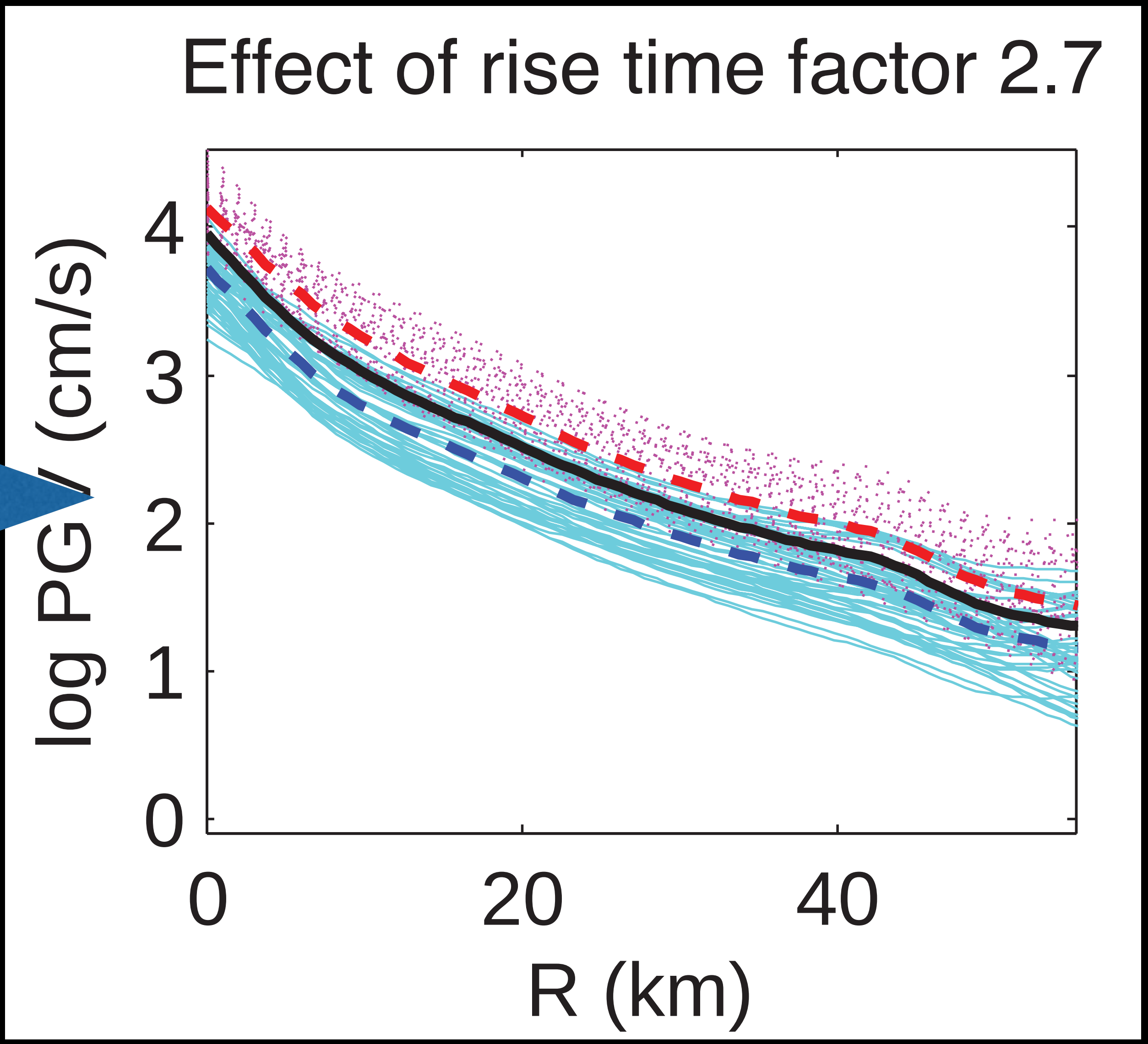


Four areas of anomalously high ground motions

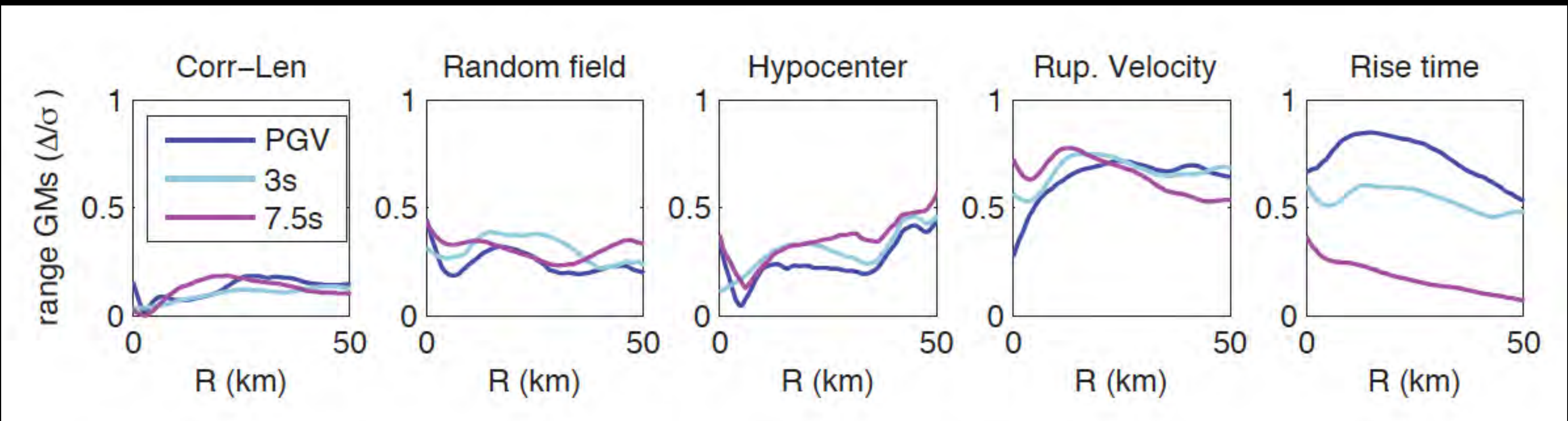


Effects of rupture parameters on ground motions

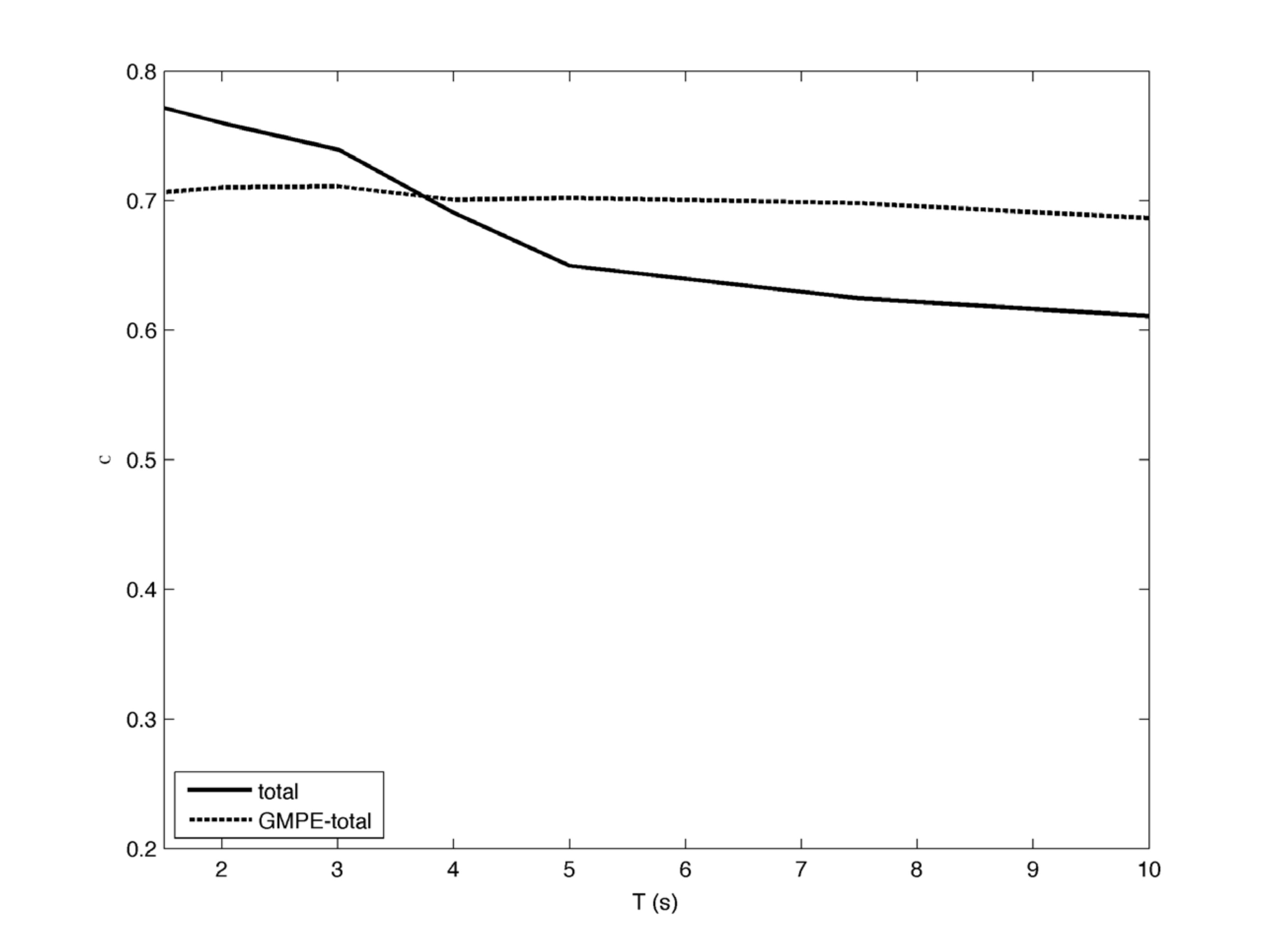




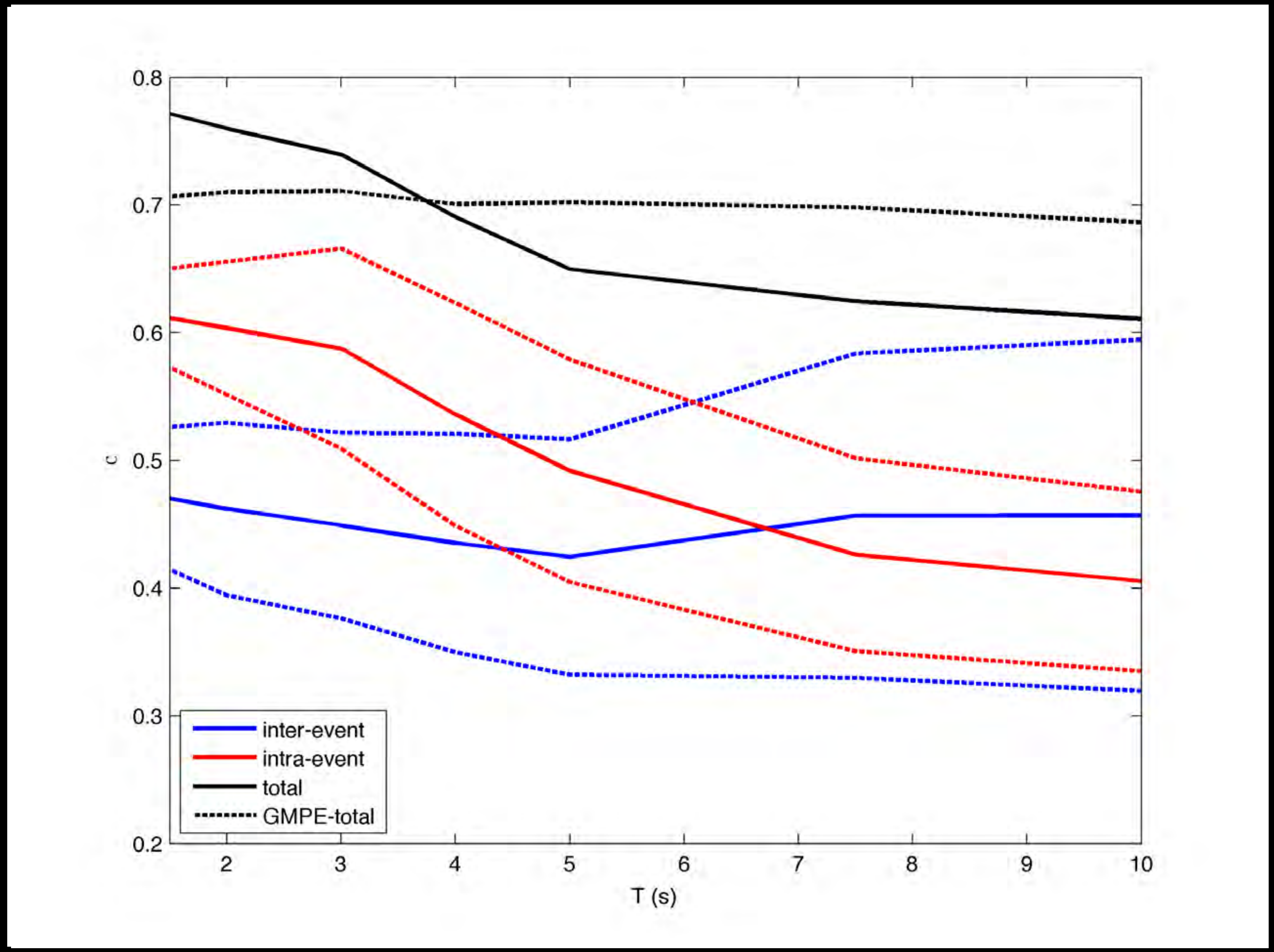
Effects rupture parameters on ground motions



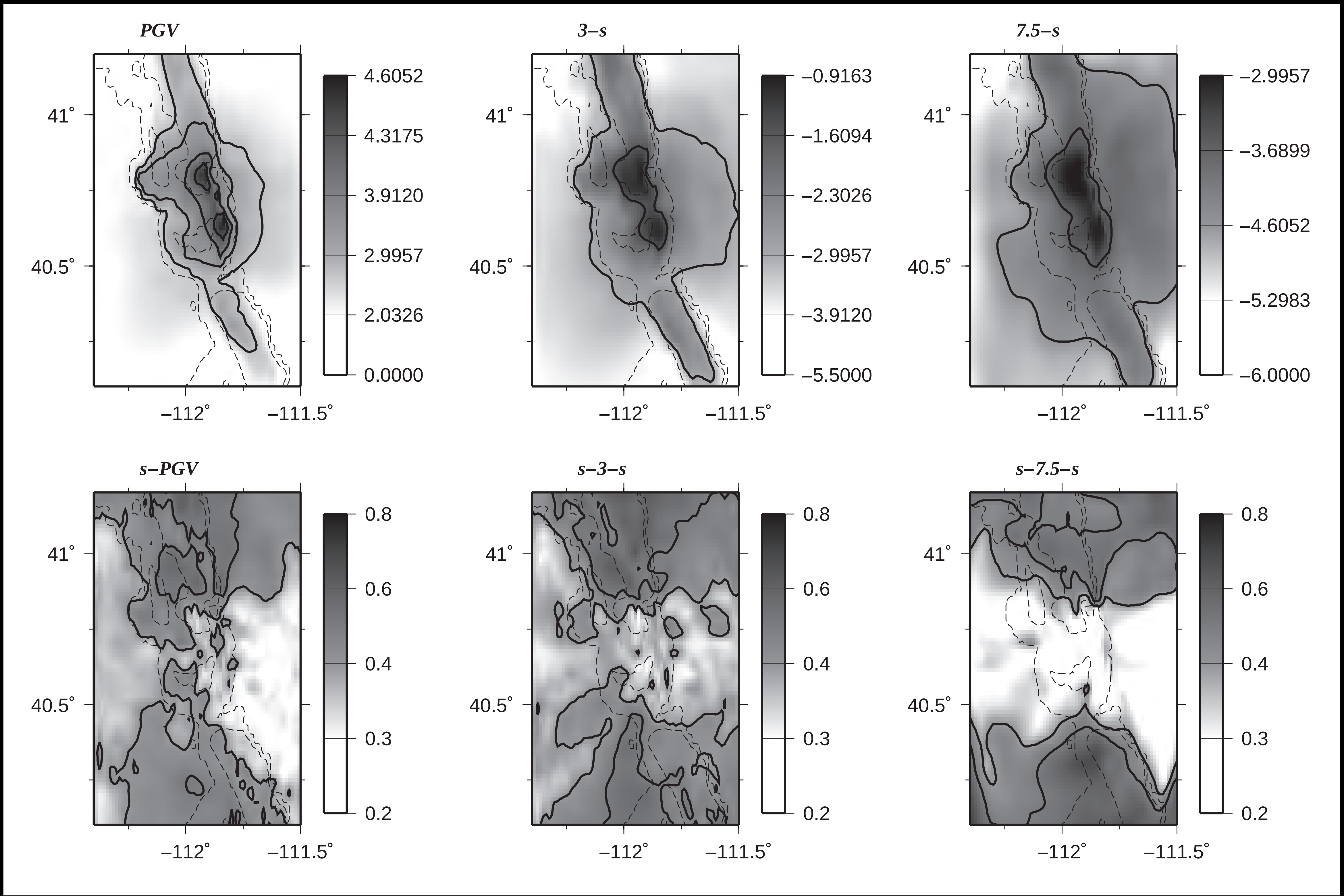
Ground motion variability



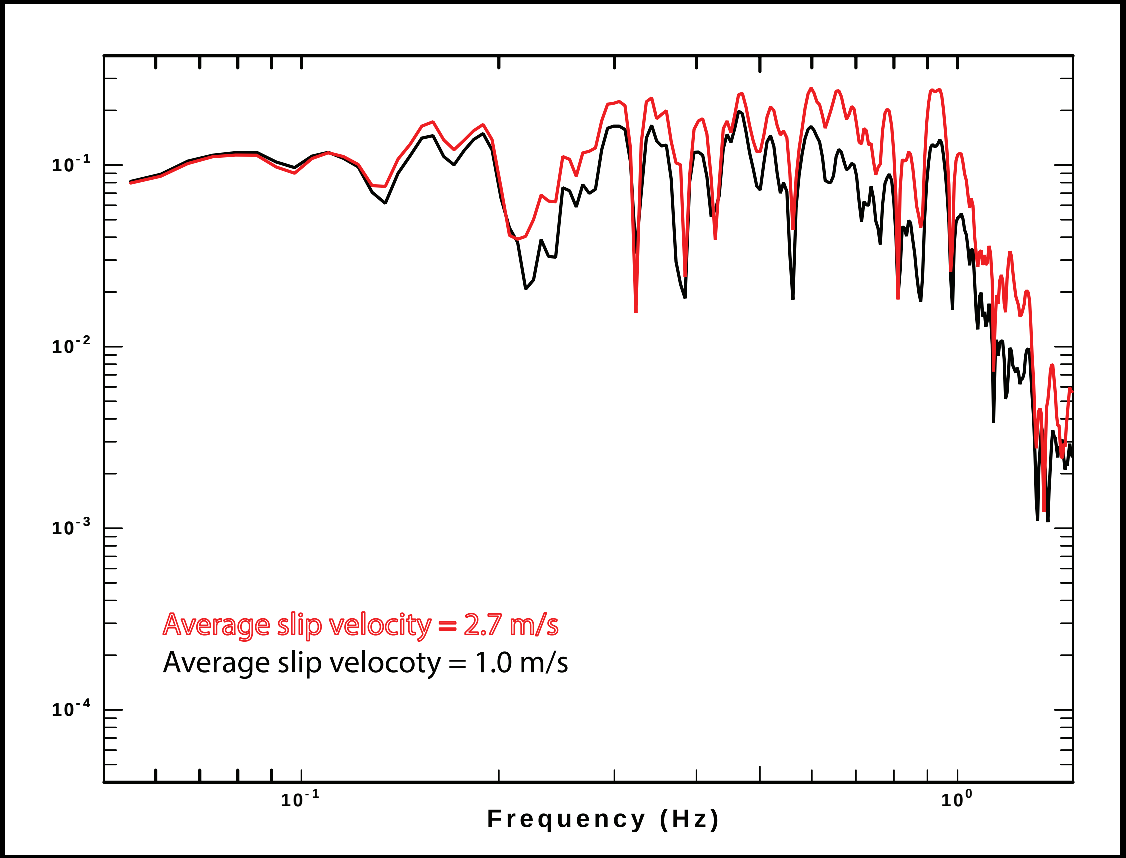
Ground motion variability

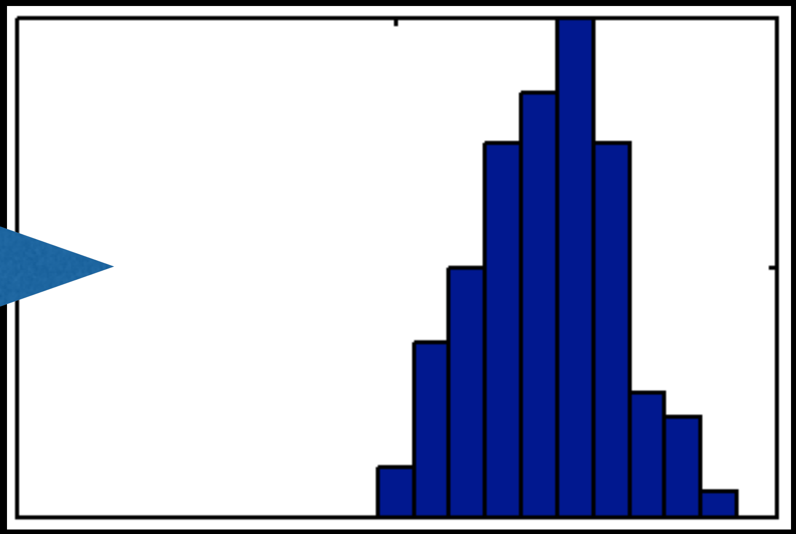


Spatial variation: means and standard deviations



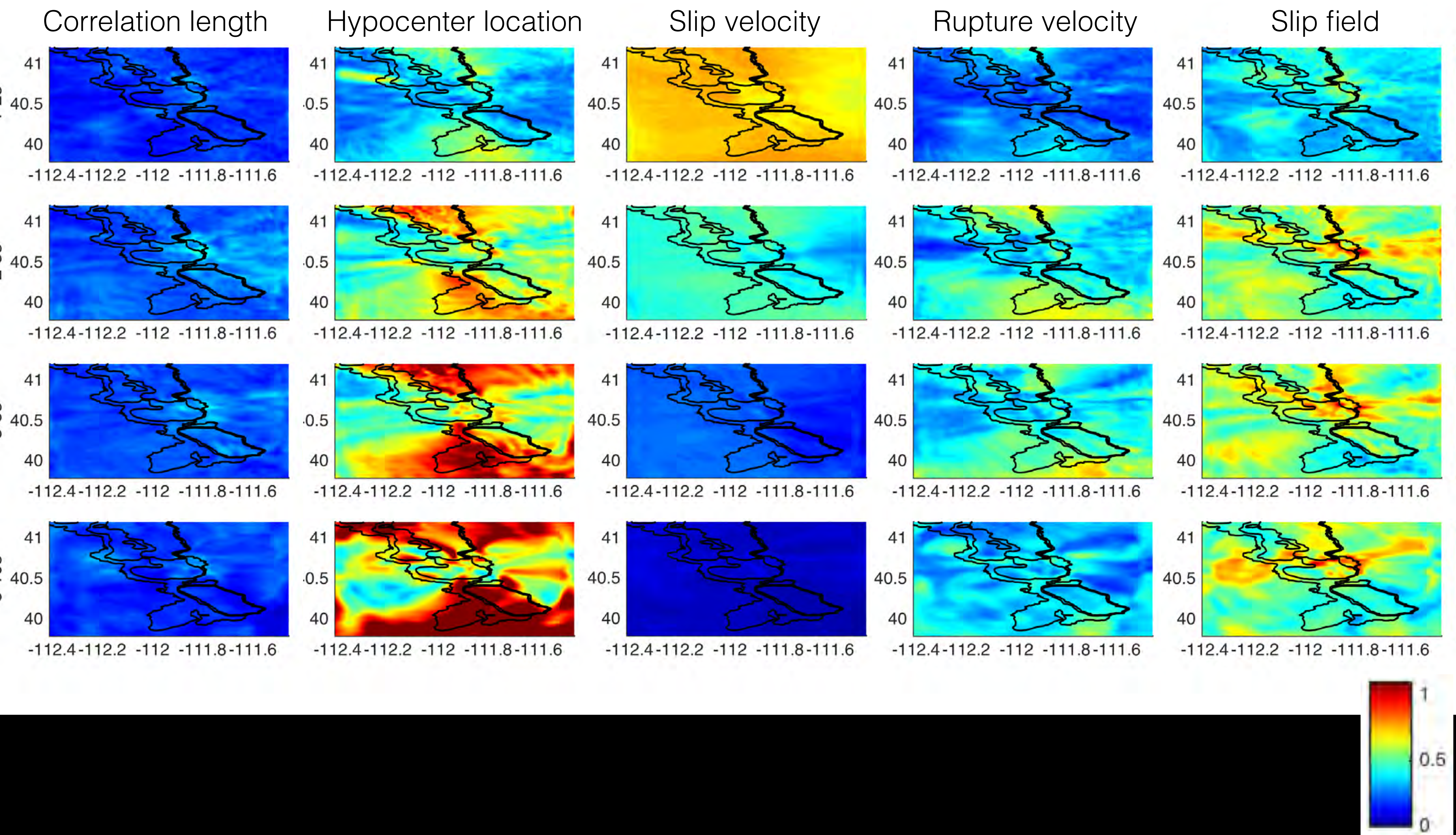
Ground motion amplification



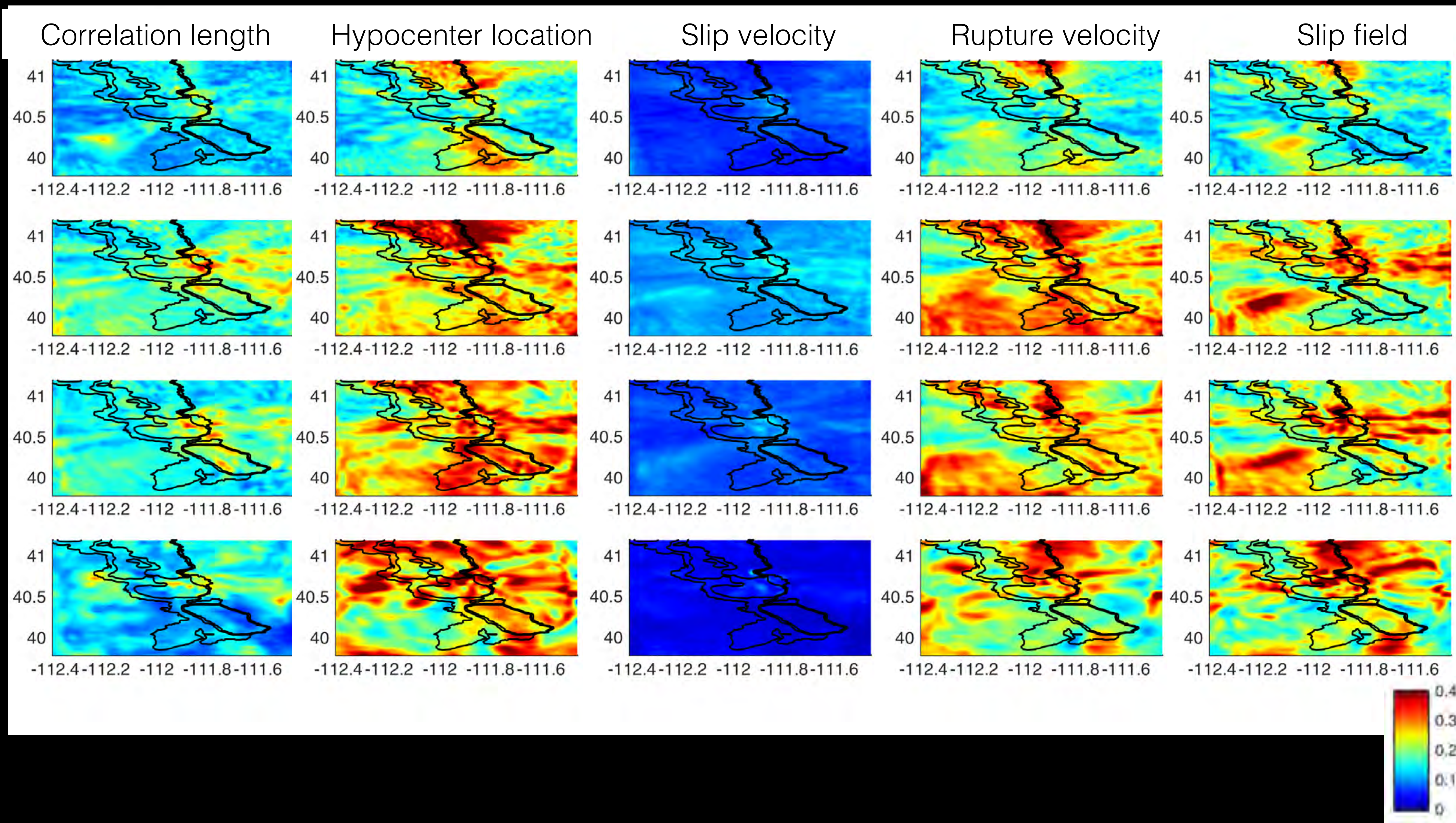


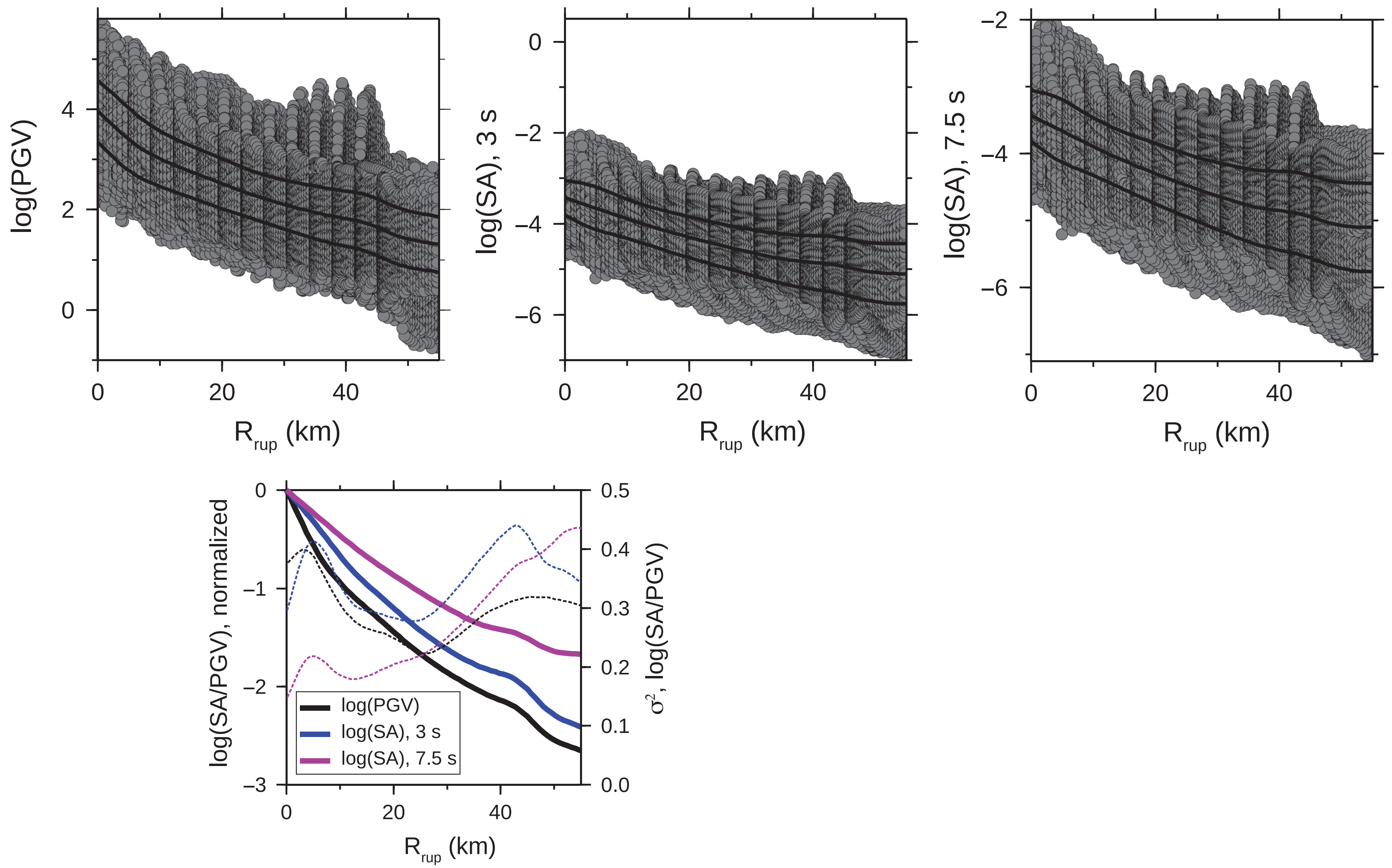
- Compute single-parameter amplifications (range) for period bands: 1–2 s, 2–3 s, 3–5 s, 5–10 s
- Compute mean and standard deviation of the amplifications
- Mean value corresponds to mean amplification caused by perturbing the parameter

Ground motion sensitivity to rupture parameters—means

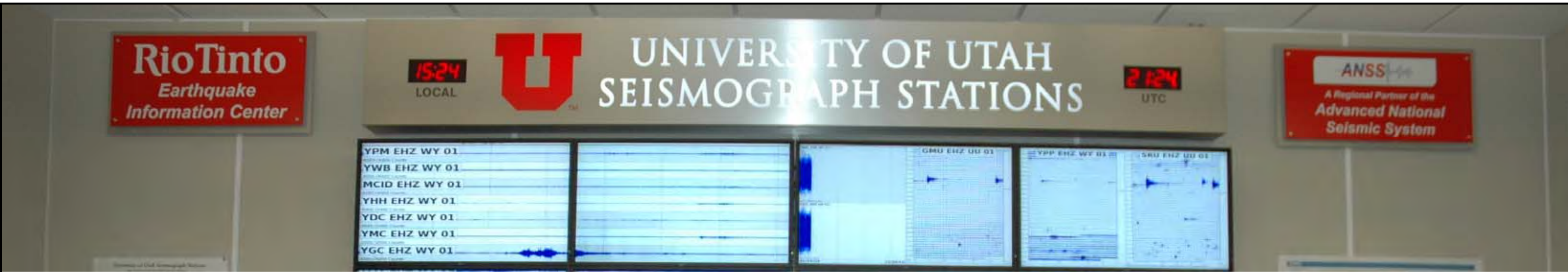


Ground motion sensitivity to rupture parameters—standard deviations





log(PGV)
log(SA), 3 s
log(SA), 7.5 s
R_rup (km)
log(SA/PGV), normalized
σ², log(SA/PGV)
log(PGV)
log(SA), 3 s
log(SA), 7.5 s



How ShakeMaps are Produced for Utah and the Wasatch Front

Kristine Pankow

Utah Earthquake Program
an integrated state agency partnership to reduce earthquake risk

University of Utah Seismograph Stations
THE UNIVERSITY OF UTAH

Seismology and Earthquake Data

Utah Seismic Safety Commission

Geology and Paleoseismology

Emergency Management and Preparedness

UNIVERSITY OF UTAH
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THE UNIVERSITY OF UTAH

Utah Ground Shaking Working Group
February 9, 2016

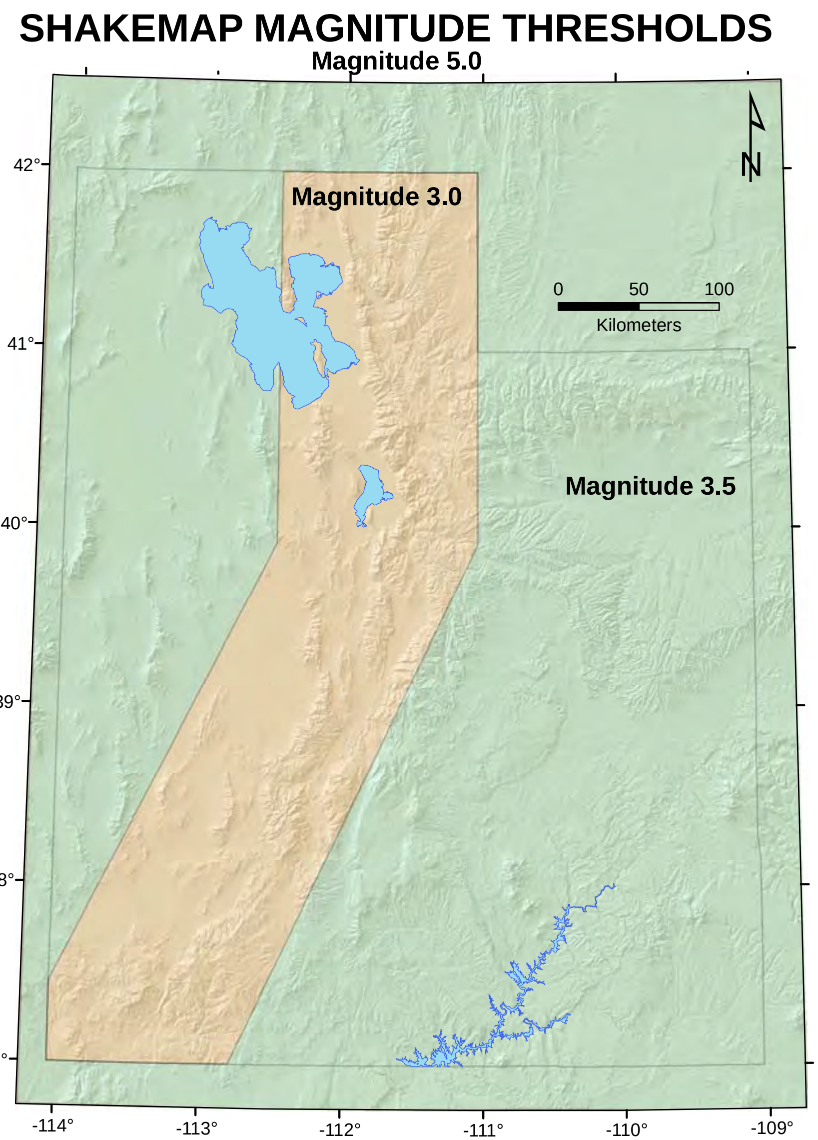
ShakeMap Summary

- Version 3.5 release 1449
- Data source: instrumentally recorded ground motions
- GMPE:

  Chiou et al 2010 (M < 5)

  Chiou and Youngs 2008 (M > 5)
- Site Amplification:

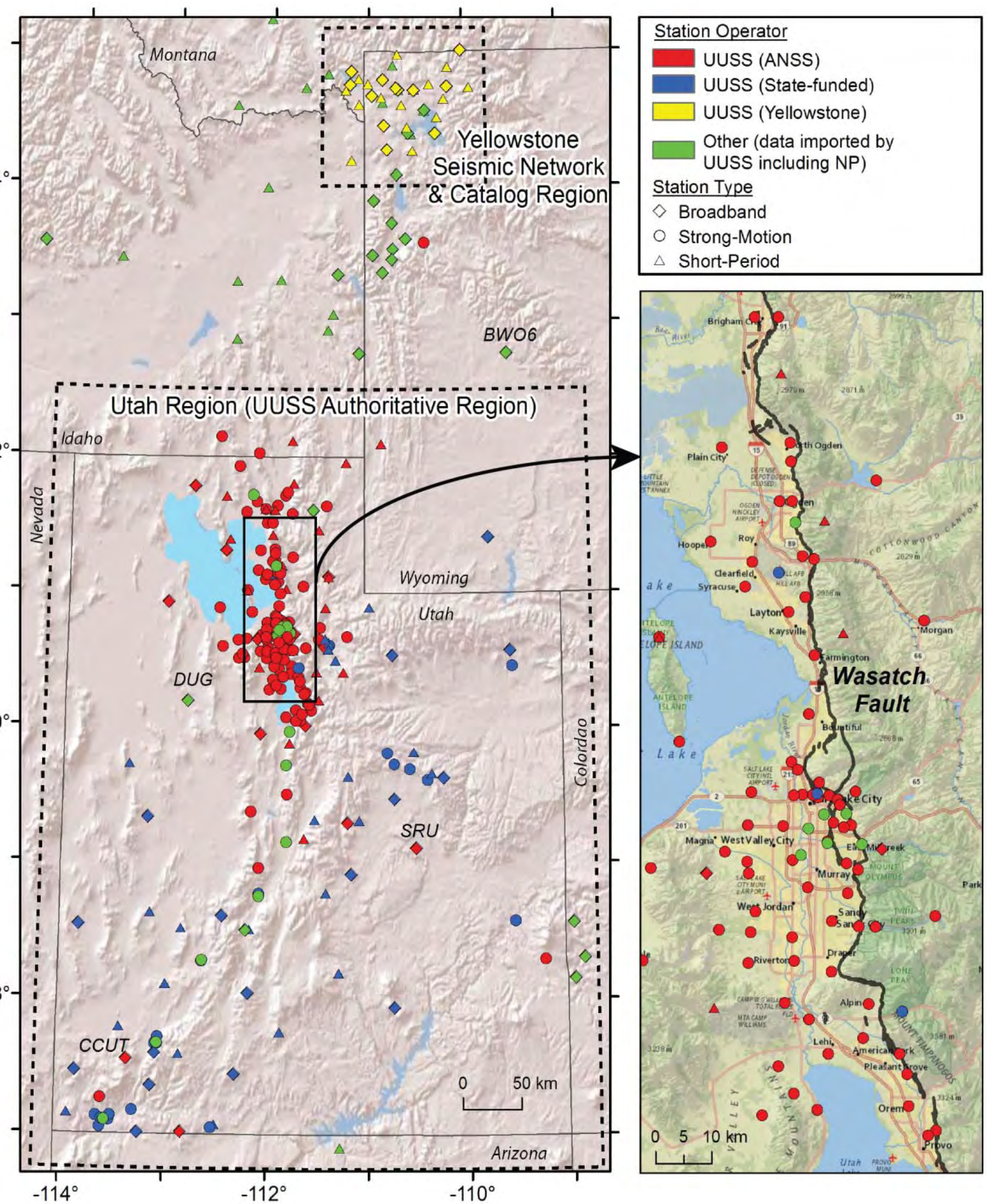
  GMPE
- Scenario vs. Earthquakes



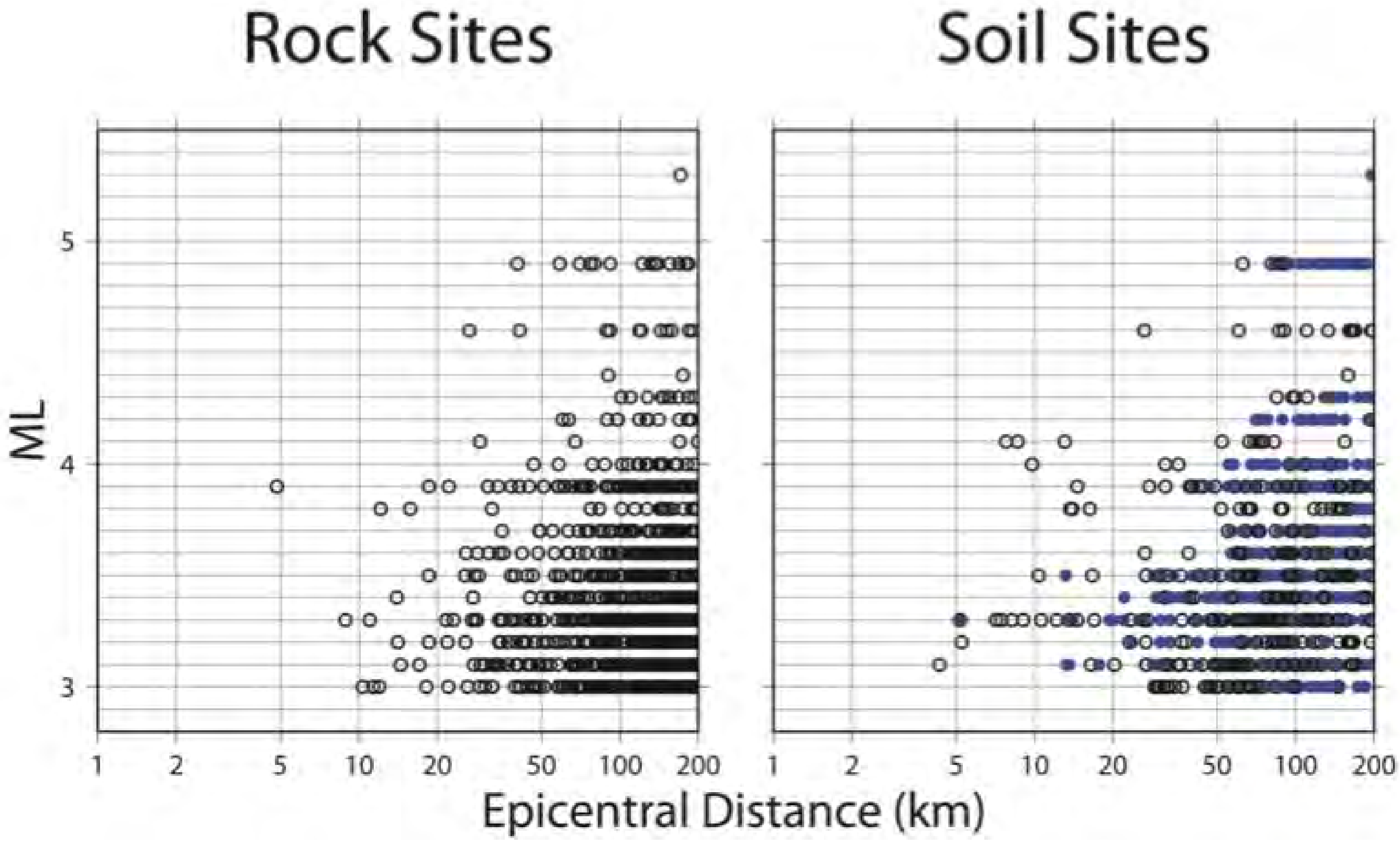
Seismic Network

Summary Statistics for Regional/Urban Seismic Network	#
No. of stations maintained & operated by network (UU and WY)	239 (44)
No. of ANSS stations (BB)	142 (12)
No. of State of Utah stations (BB)	69 (18)
No. of Yellowstone Stations (BB)	28 (14)

Other Seismic Instrumentation	#
6-channel portable systems for aftershocks	2
4-element infrasound arrays (NOQ, BRPU, PSUT)	3
3-Component Nodal seismometers	48



GMPE

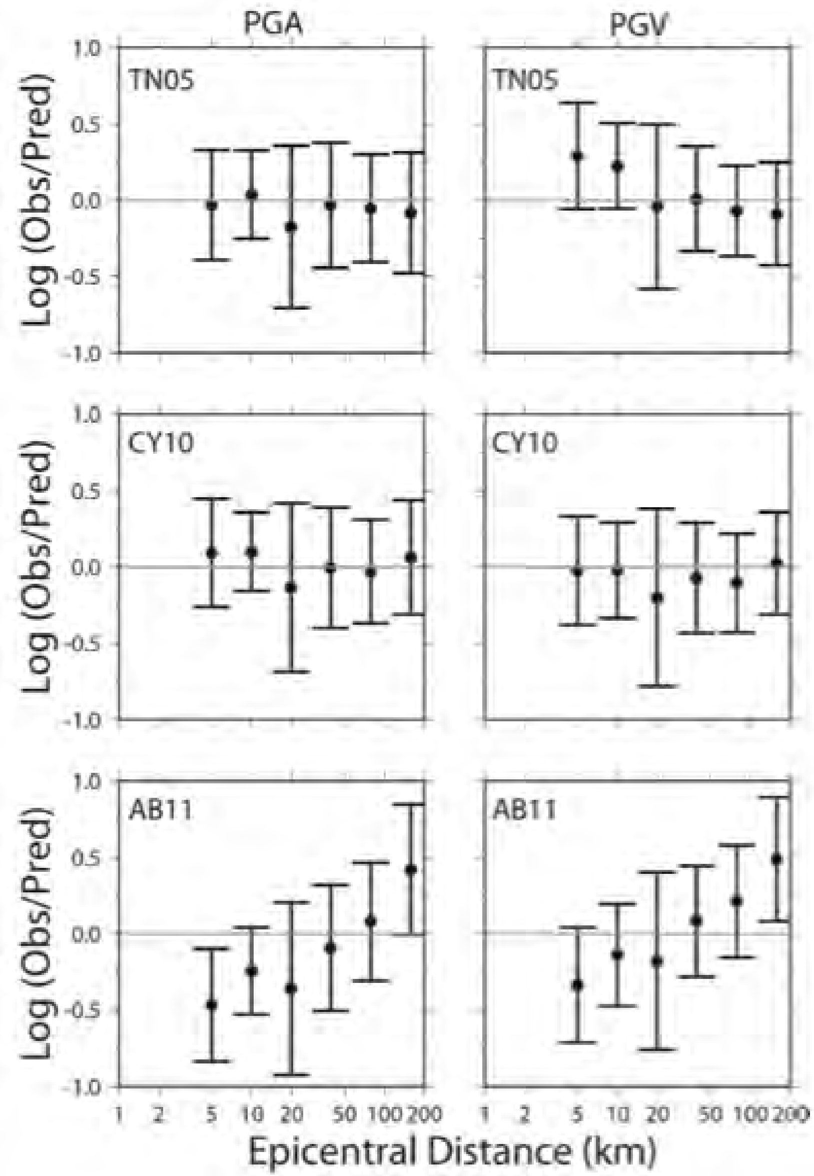


Pankow, 2012

M < 5.0

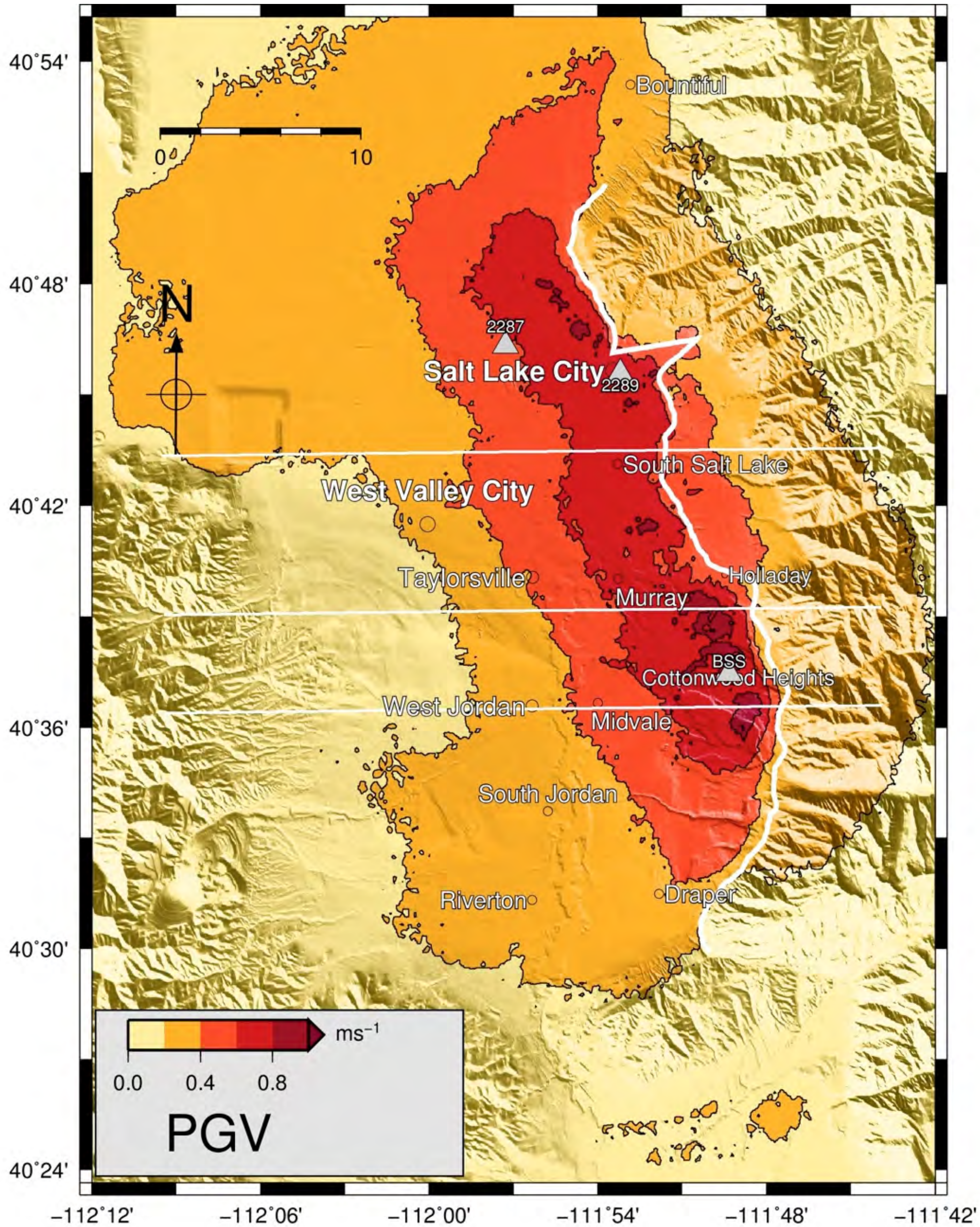
Results from Pankow (2012)

- Calculated a geometric mean PGA and PGV from horizontal components
- Compared to:
  - TN05; Wald et al. (2005)
  - CY10; Chiou et al. (2010)
  - AB11; Atkinson and Boore (2011)

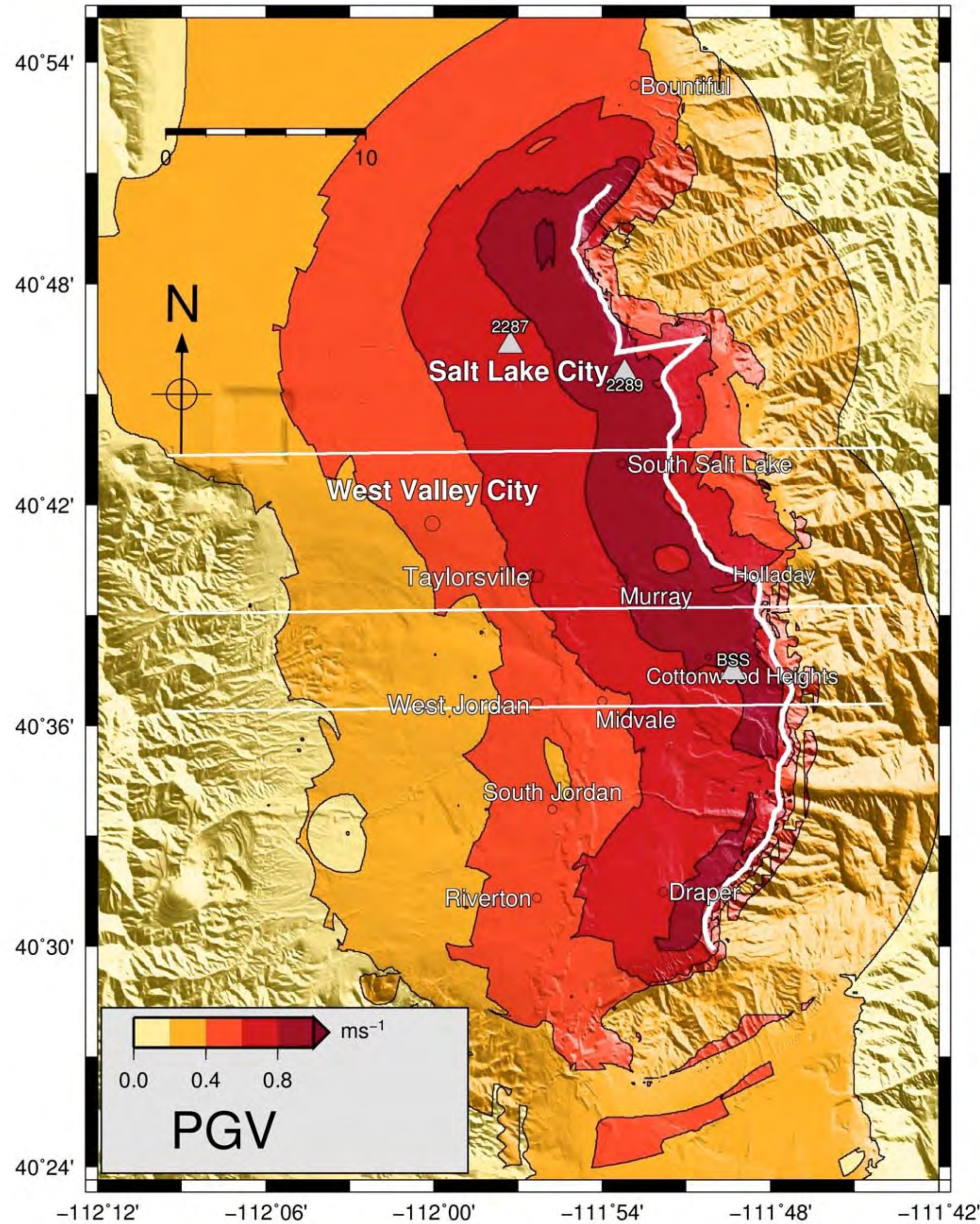


Peak Horizontal Ground Velocity Predictions: M 7.0, SLC Segment (Roten et al., 2012)

Geometric Mean of 6 Simulations

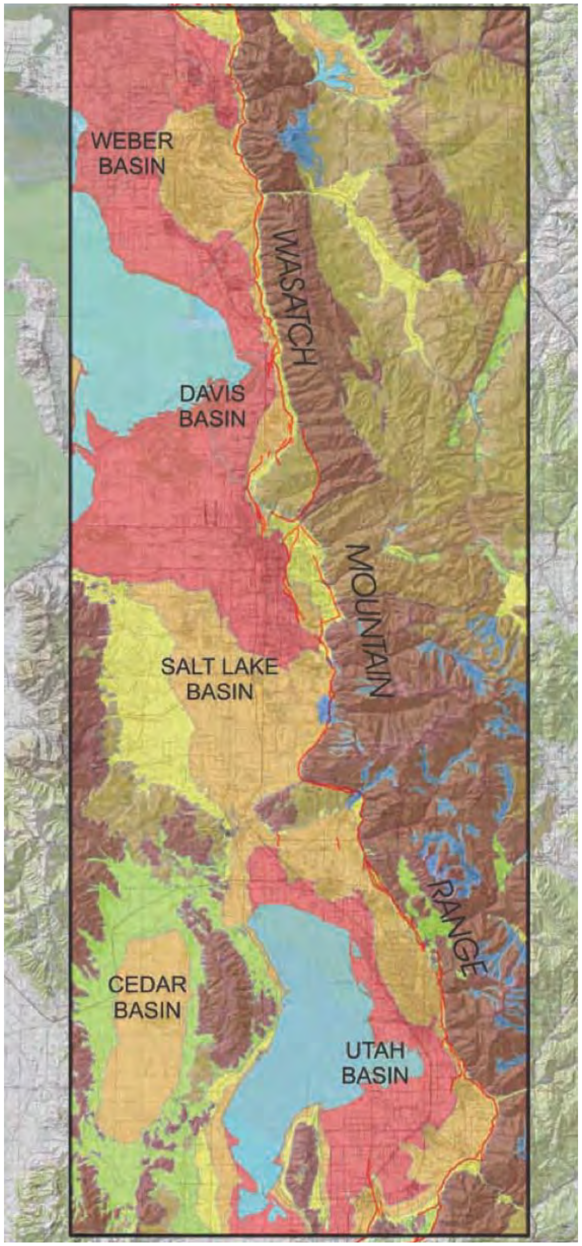


Chiou and Youngs (2008) GMPE



Site Amplification—Vs30

- McDonald and Ashland (2008)—Data from Wasatch Front
- Mapped to rest of the state by rock type
- Outside of Wasatch Front use an average Q Vs30 (198 m/s)



Scenario vs. Earthquake

- Reminder: ShakeMap was originally designed to map instrumentally recorded ground motions. GMPEs and site condition are *secondary* to fill in data gaps
- For Utah ShakeMaps just use recorded ground motion
- Could use DYFI reports. These would dominate intensity maps. Difficult because of large counties—delay for geocoding

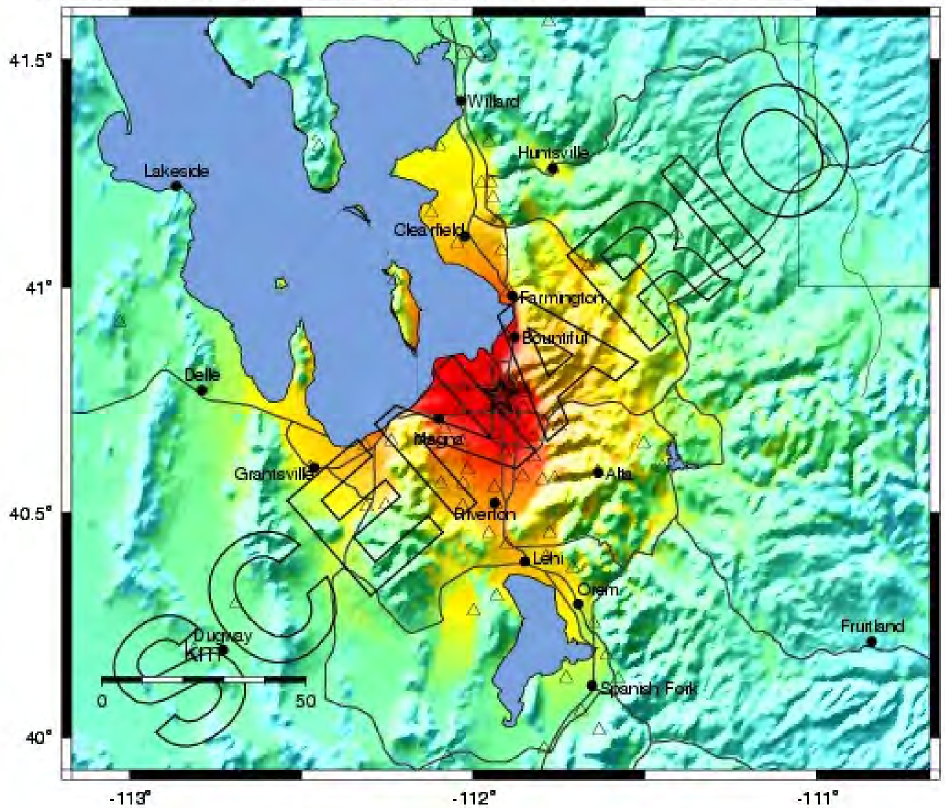
ShakeMaps are data driven products

M7.0 Scenario

Using Recorded Ground Motions

ShakeMap for Esfmainpt Scenario

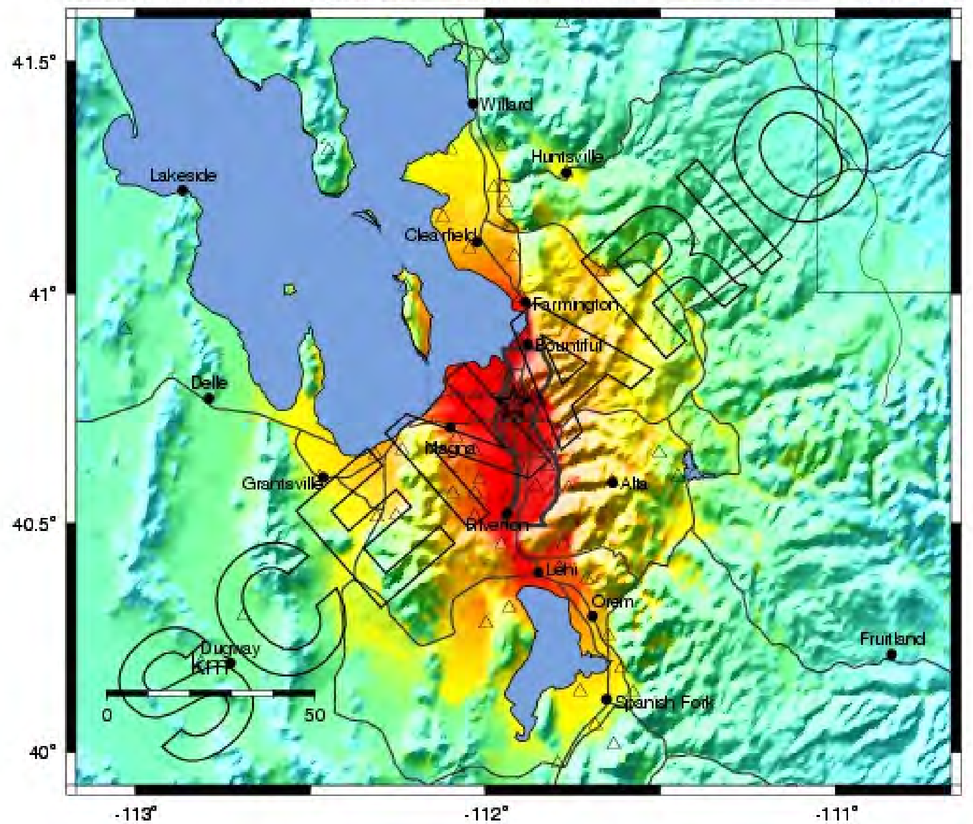
Scenario Date: Thu Apr 22, 2010 08:00:00 PM MDT M 7.0 N40.76 W111.92 Depth: 12.0km



Adding Fault to Ground Motion Data

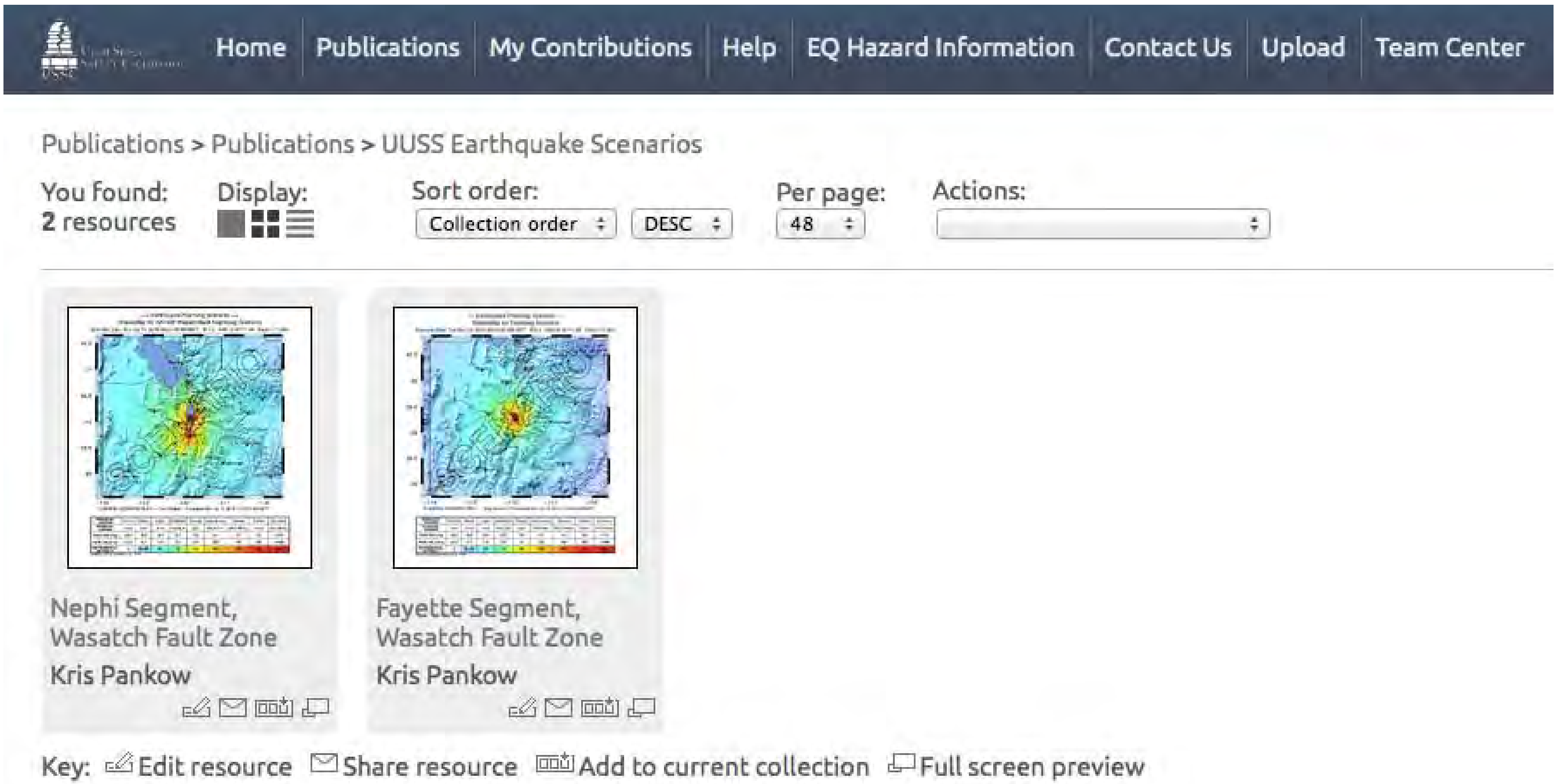
ShakeMap for Esfmainff Scenario

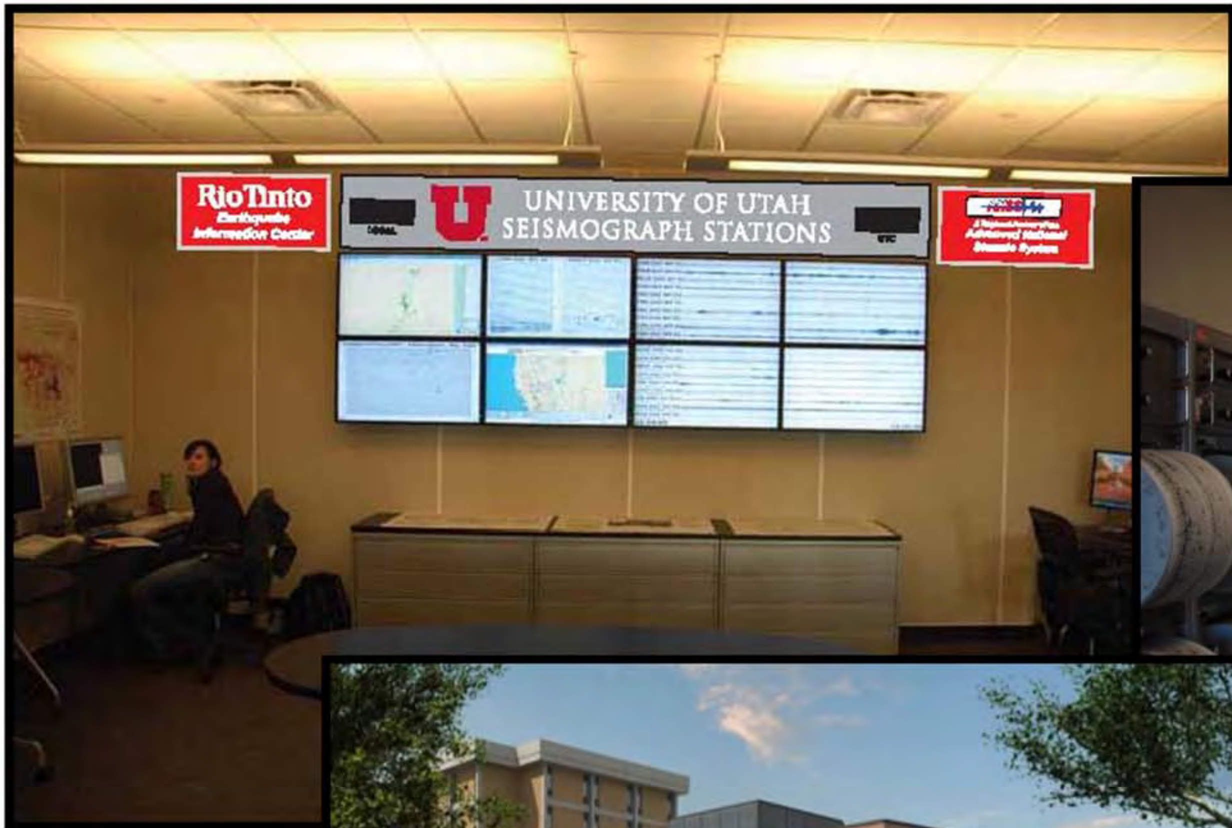
Scenario Date: Thu Apr 22, 2010 08:00:00 PM MDT M 7.0 N40.76 W111.92 Depth: 12.0km



Utah Scenario Catalog

(in progress)





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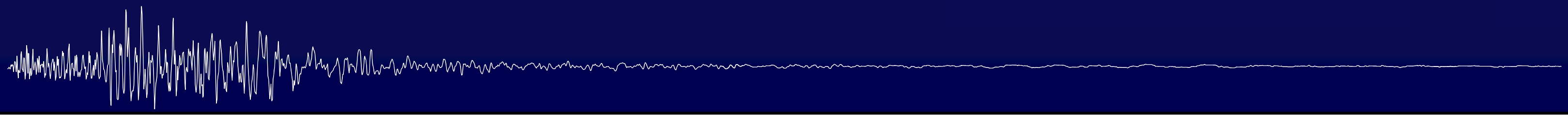
UUSS 50 Year
Anniversary April 11
Celebration April 8

Ground Motion Issues in Site-Specific Probabilistic Seismic Hazard Analyses for the Central Wasatch Front Region

Utah Ground-Shaking Working Group

Ivan G. Wong
Seismic Hazards Group
AECOM
Oakland, CA 94612

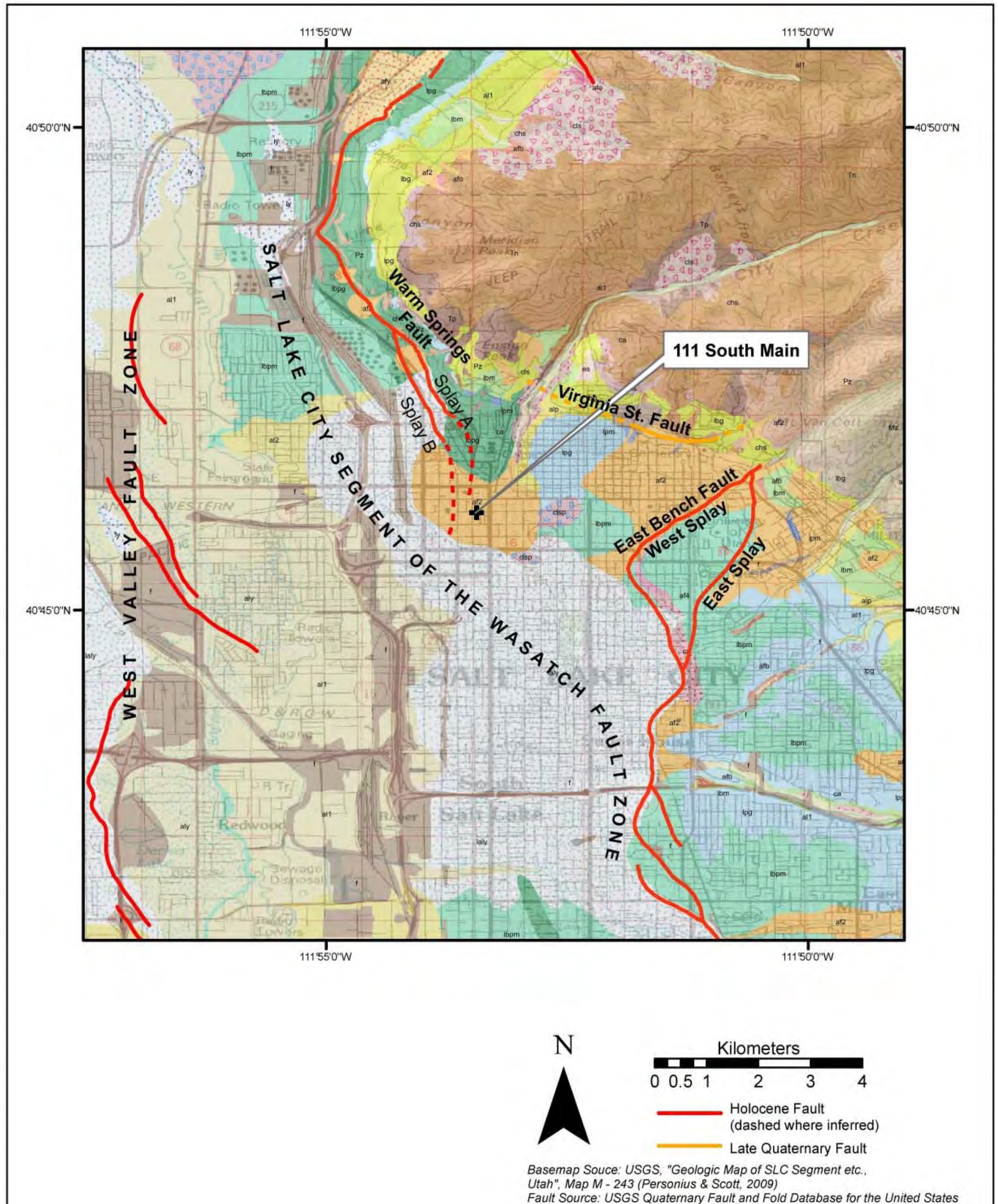
Annual Meeting 9 February 2016



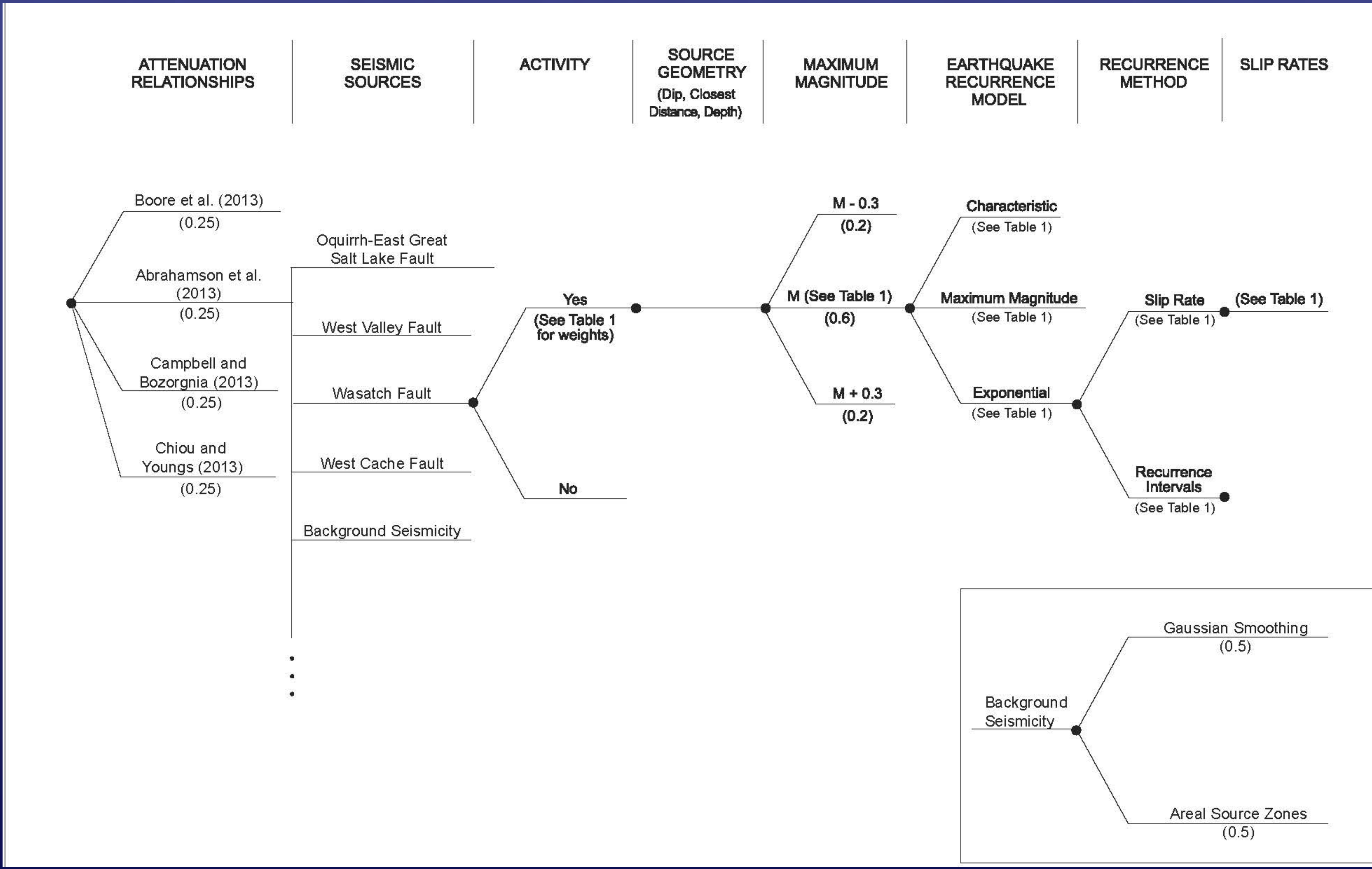
Introduction

- Although there are significant differences between site-specific PSHAs and PSHAs performed to develop urban, regional, and national seismic hazard maps, engineers will often look to the maps for guidance on design.
- In site-specific studies, at least those that follow the SSHAC (1997) process, there is a concerted effort to address capture the center, body, and range of the informed technical community.
- Hence epistemic uncertainties are more comprehensively captured in site-specific studies. The following is an example to illustrate issues in the central Wasatch Front region.

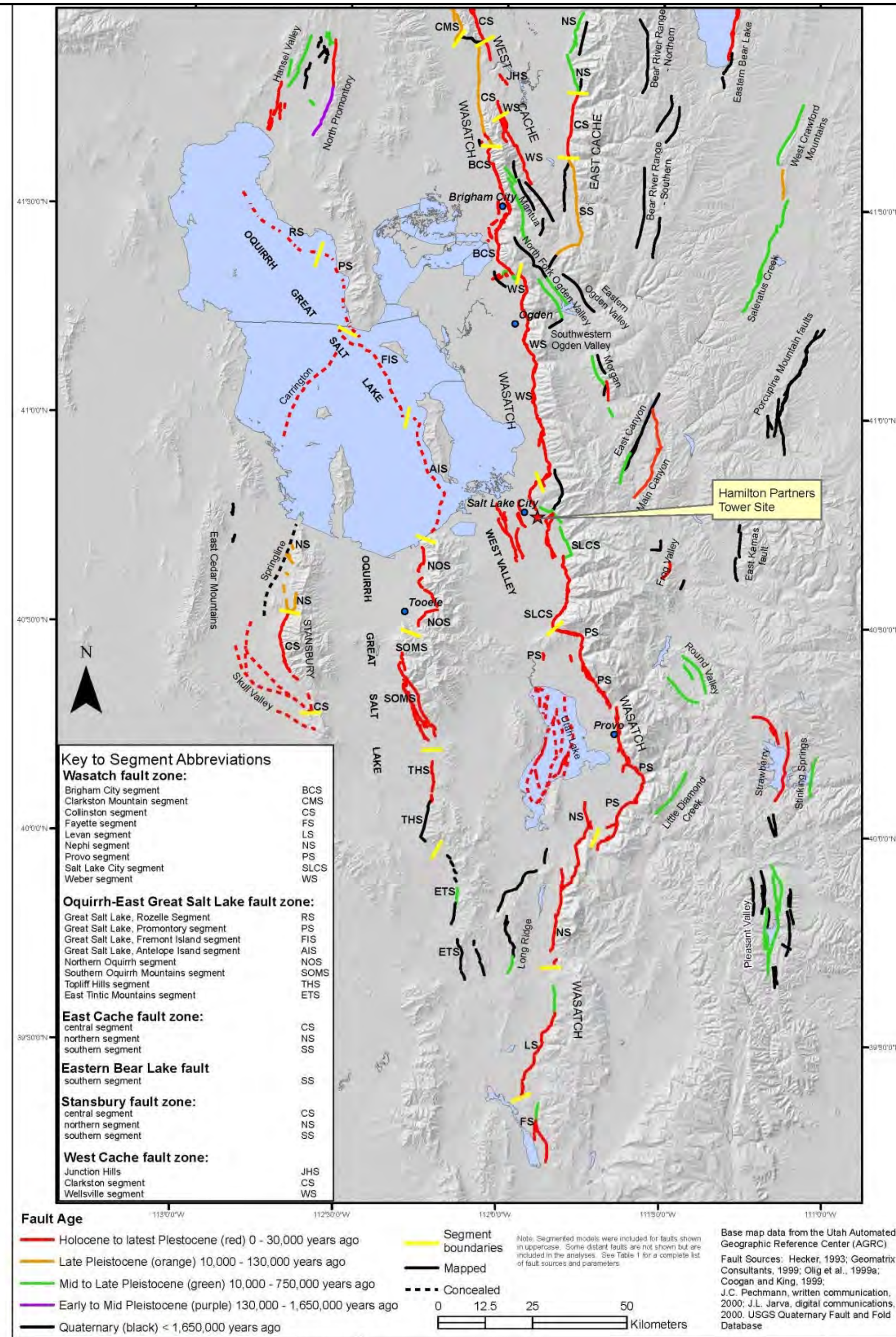
Geologic Map of the Site Vicinity



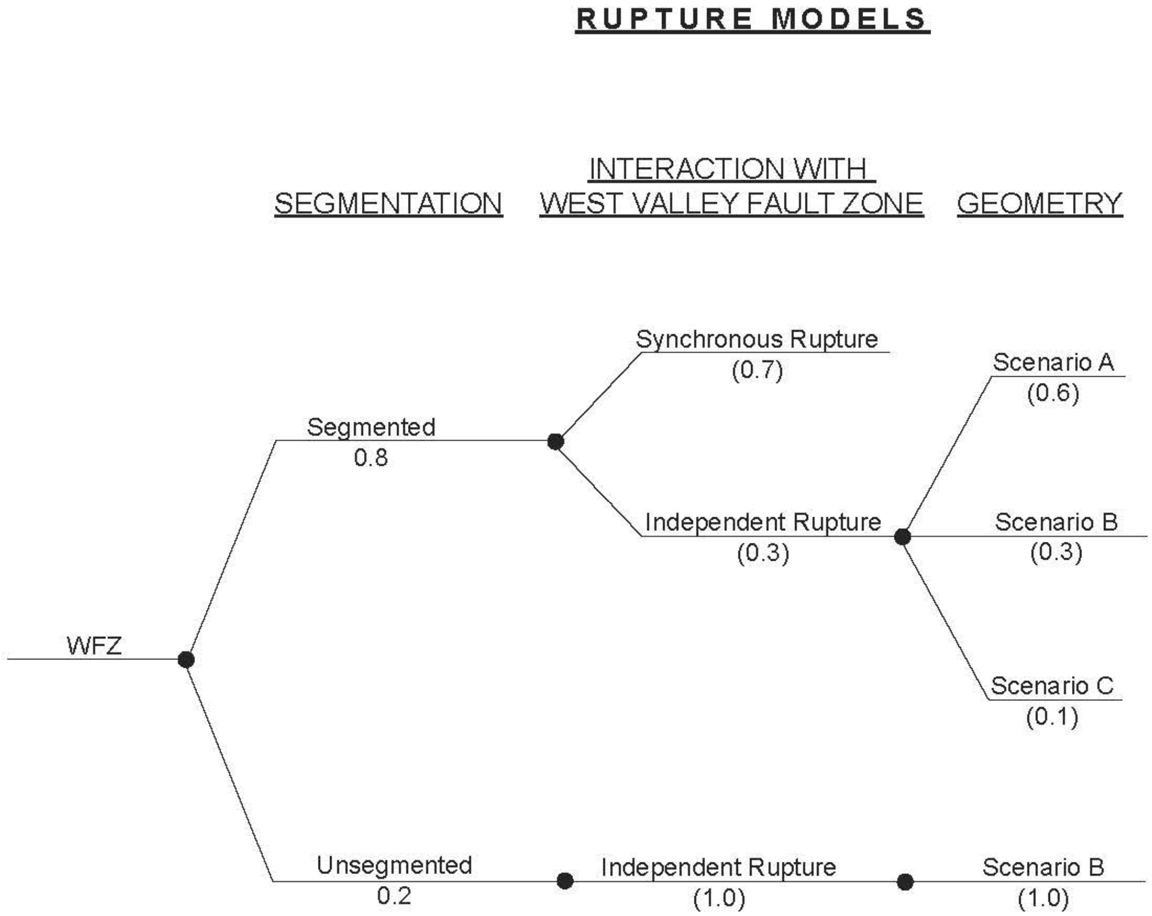
Seismic Hazard Model Logic Tree



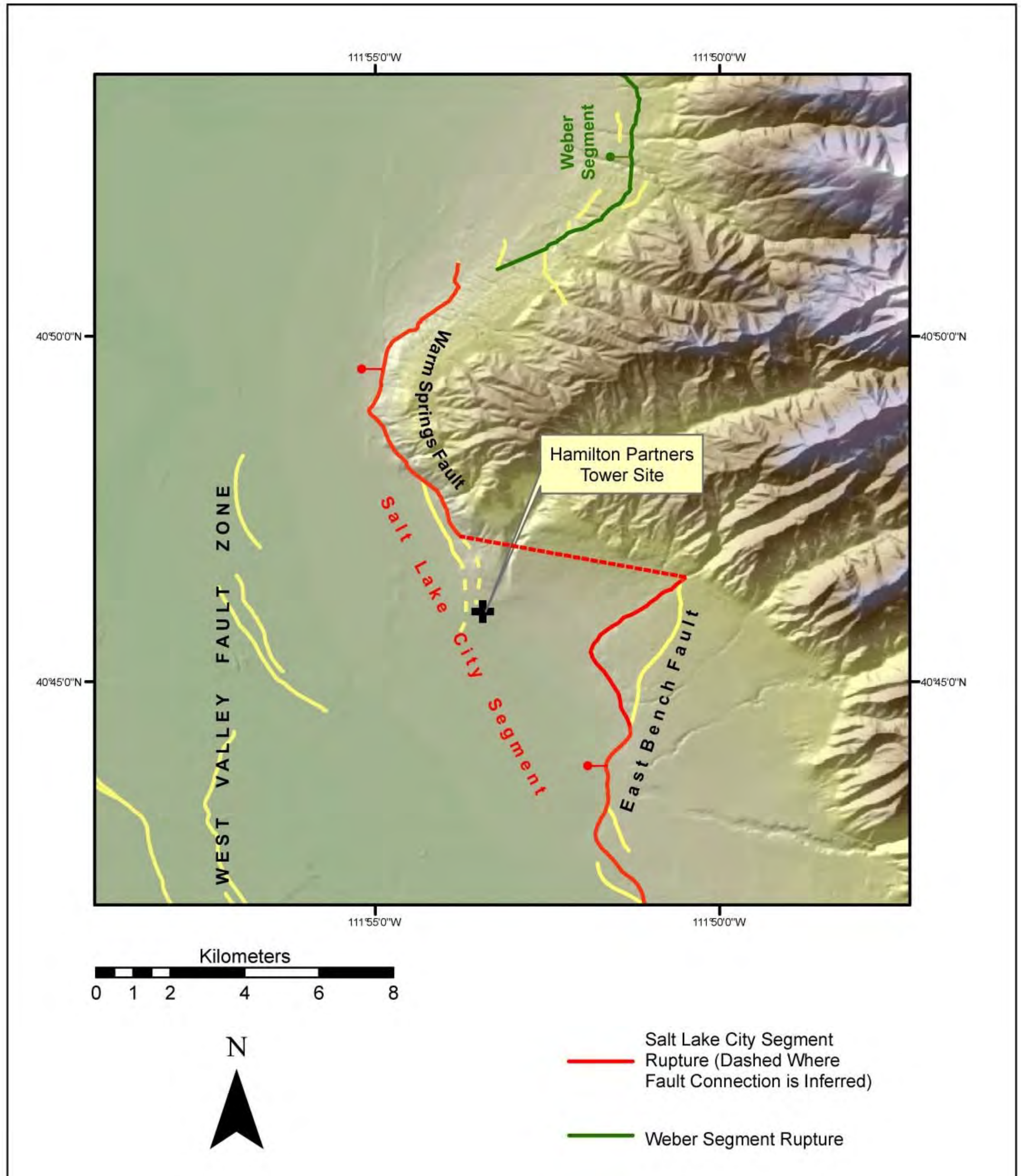
Selected Quaternary Fault Sources Included in the Hazard Analysis



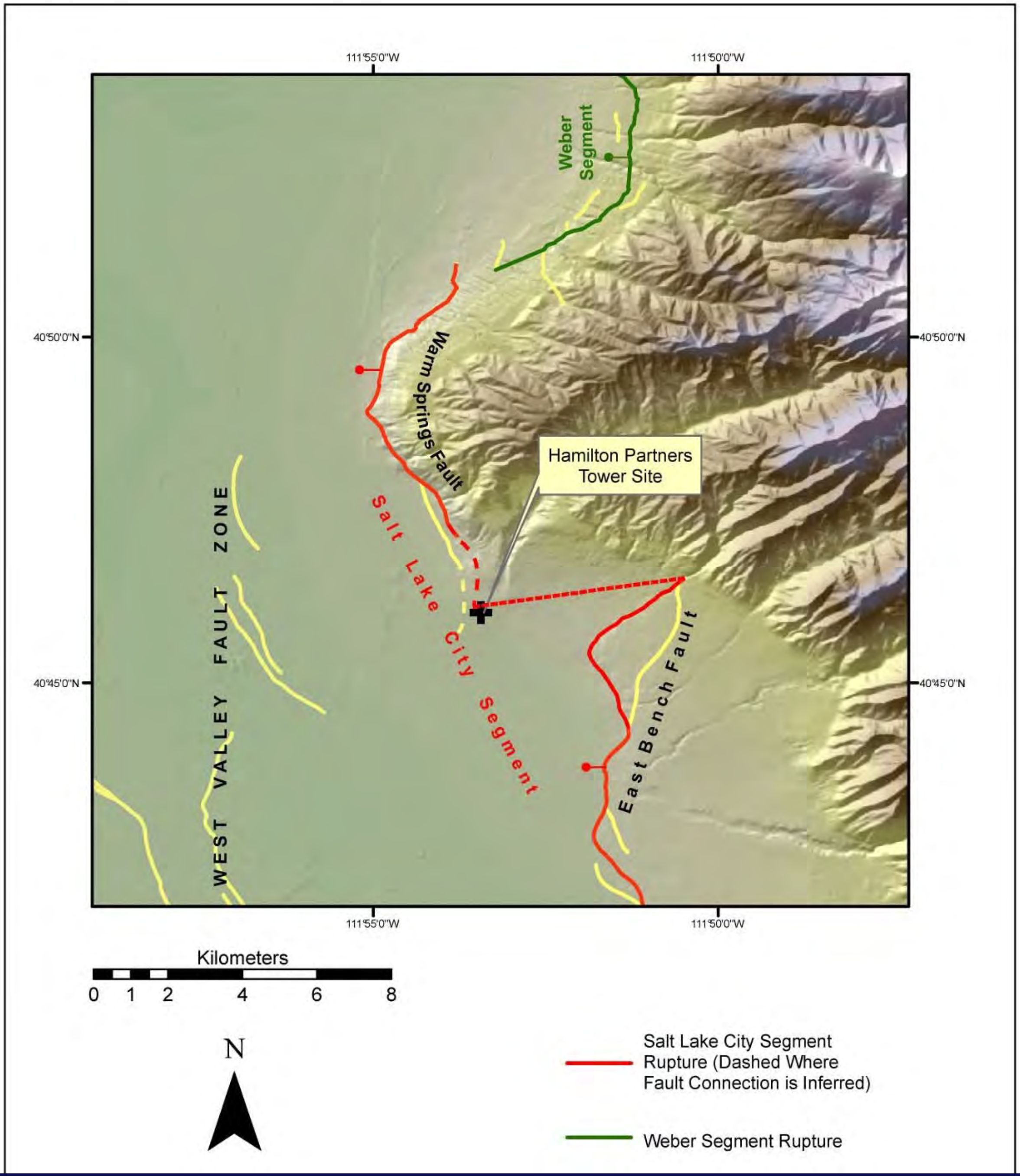
Logic Tree for Wasatch Fault Zone Rupture Models



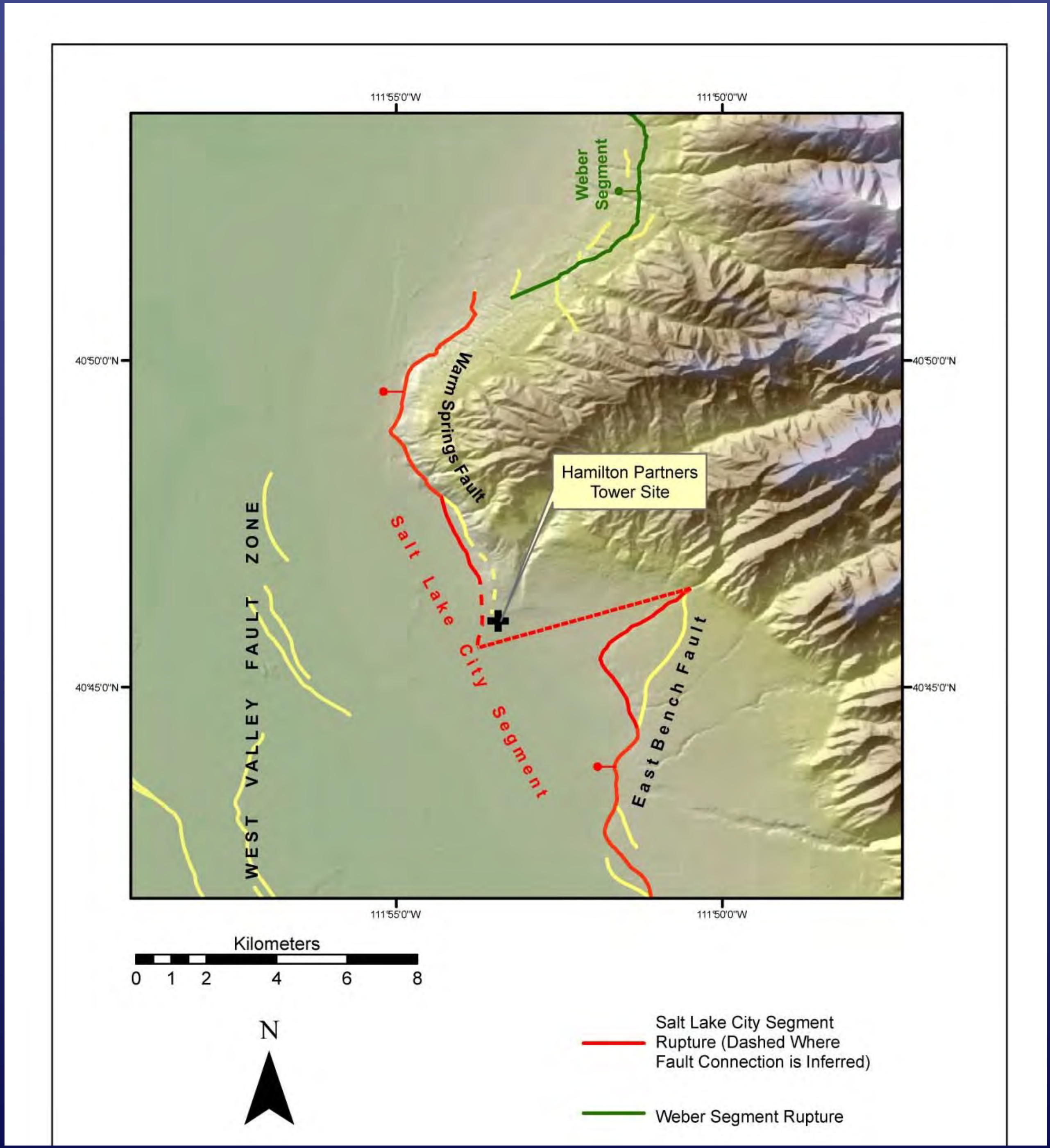
Rupture Scenario A for the East Bench – Warm Springs Faults Stepover Zone



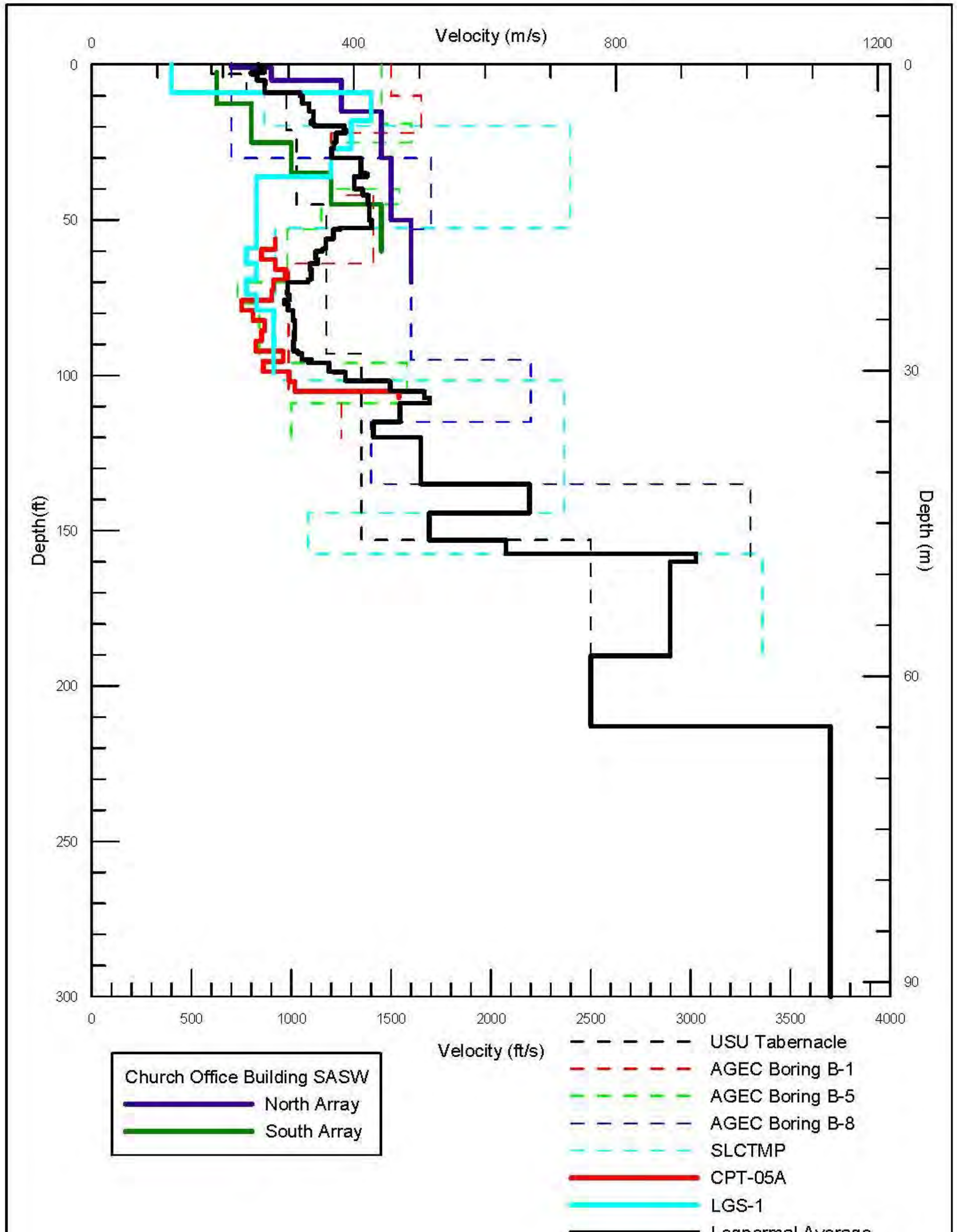
Rupture Scenario B for the East Bench – Warm Springs Faults Stepover Zone



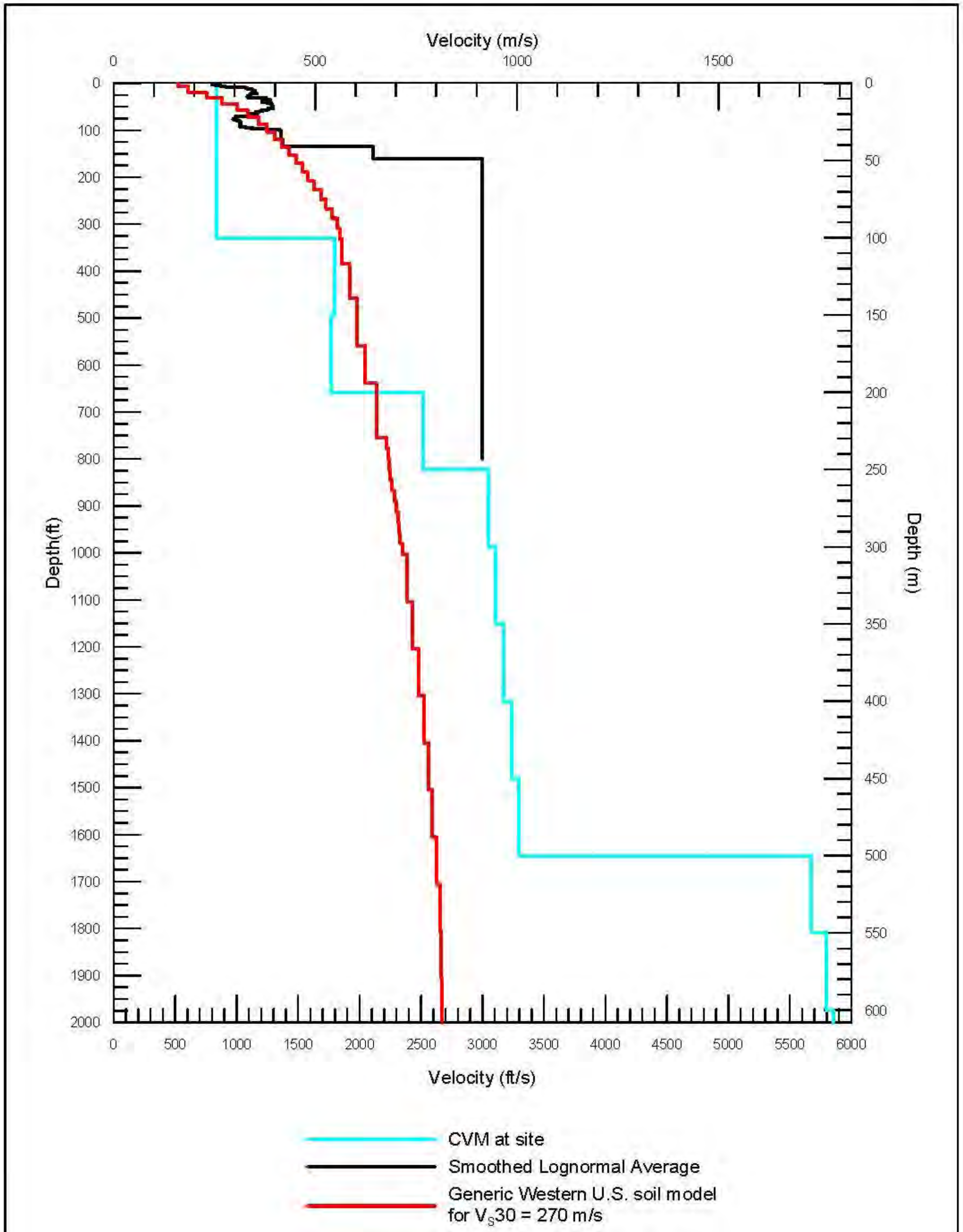
Rupture Scenario C for the East Bench – Warm Springs Faults Stepover Zone



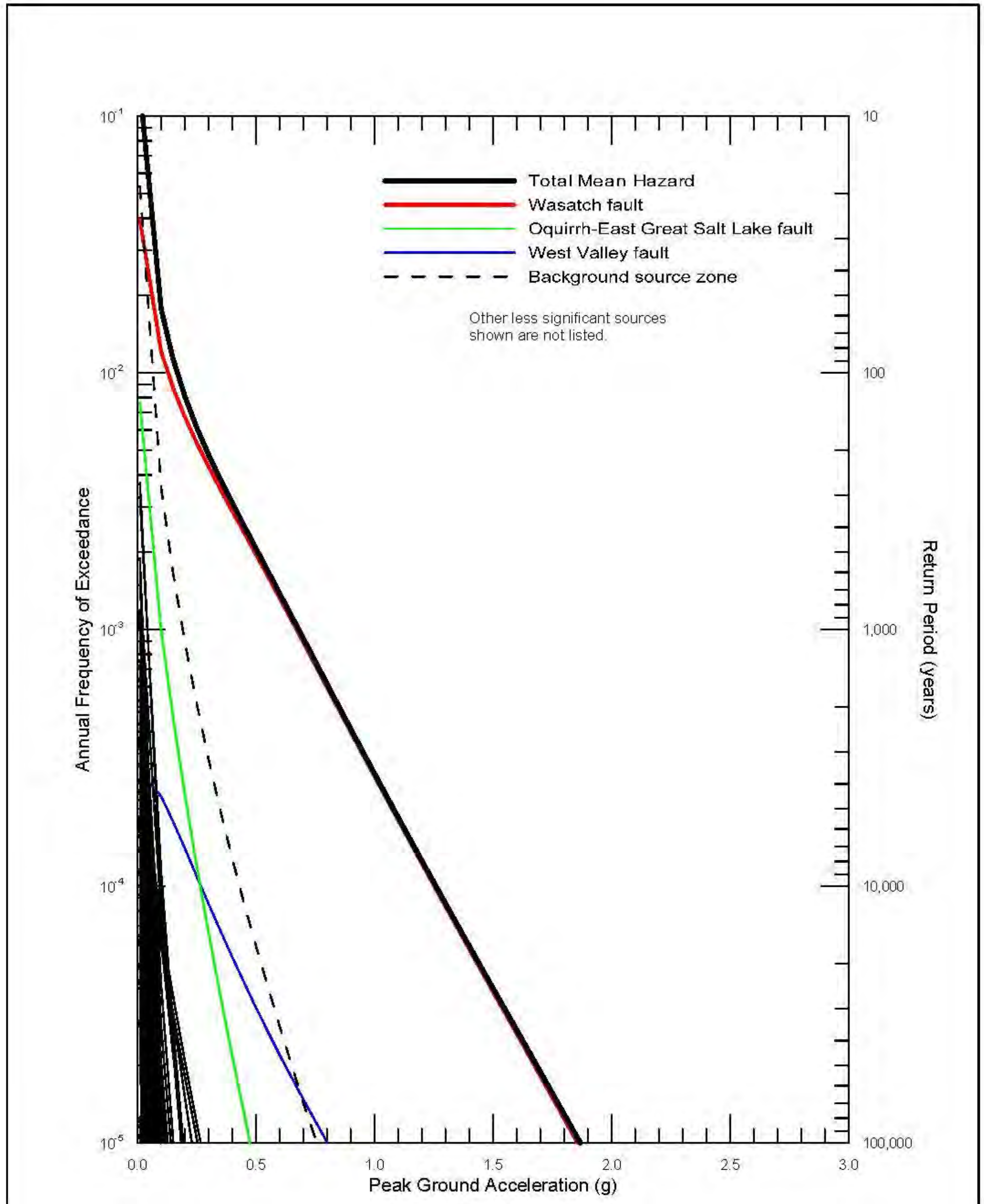
V_S Profiles for Downtown Salt Lake City



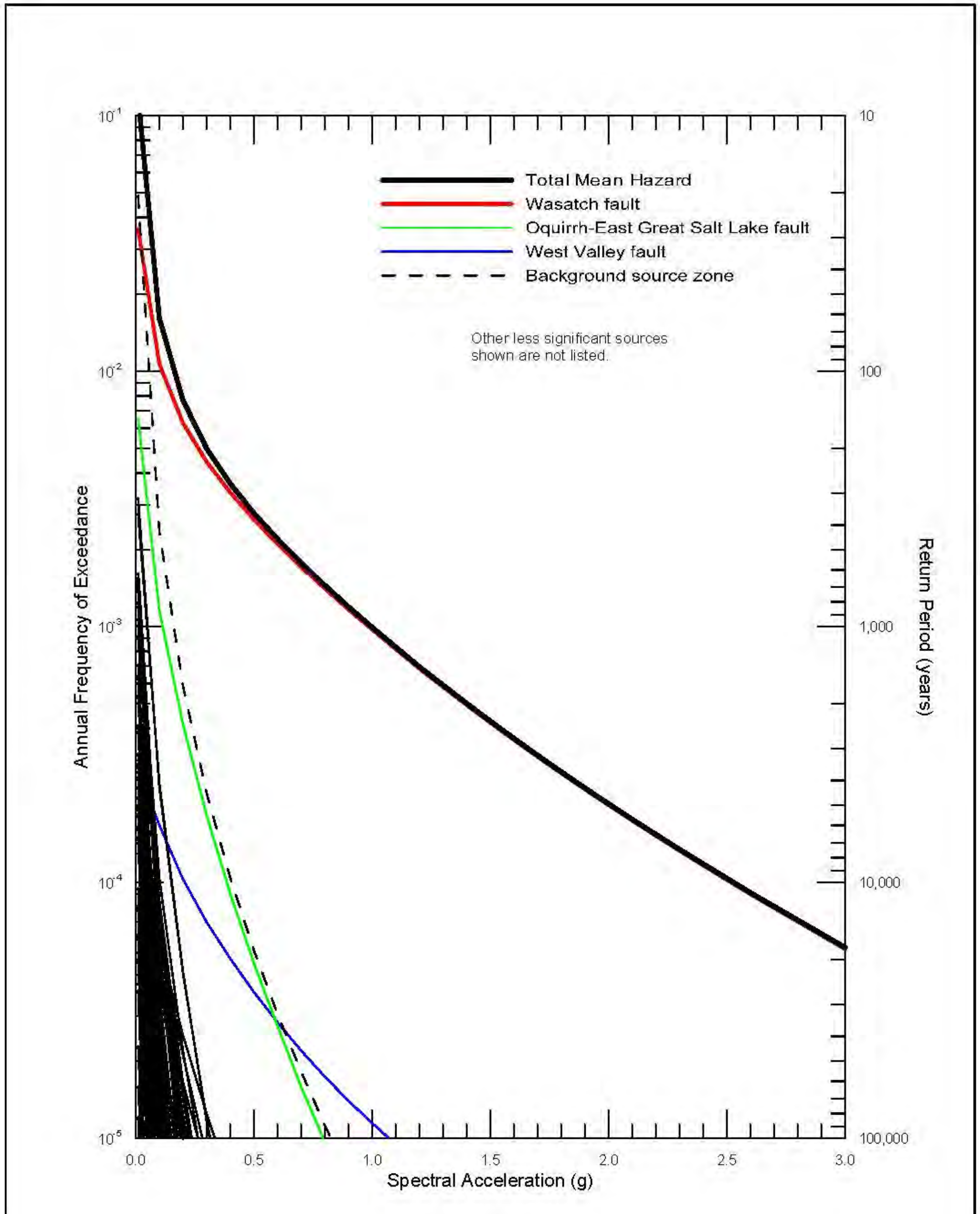
Basecase V_S Profile and Generic Soil Model Used in Site Response Analysis



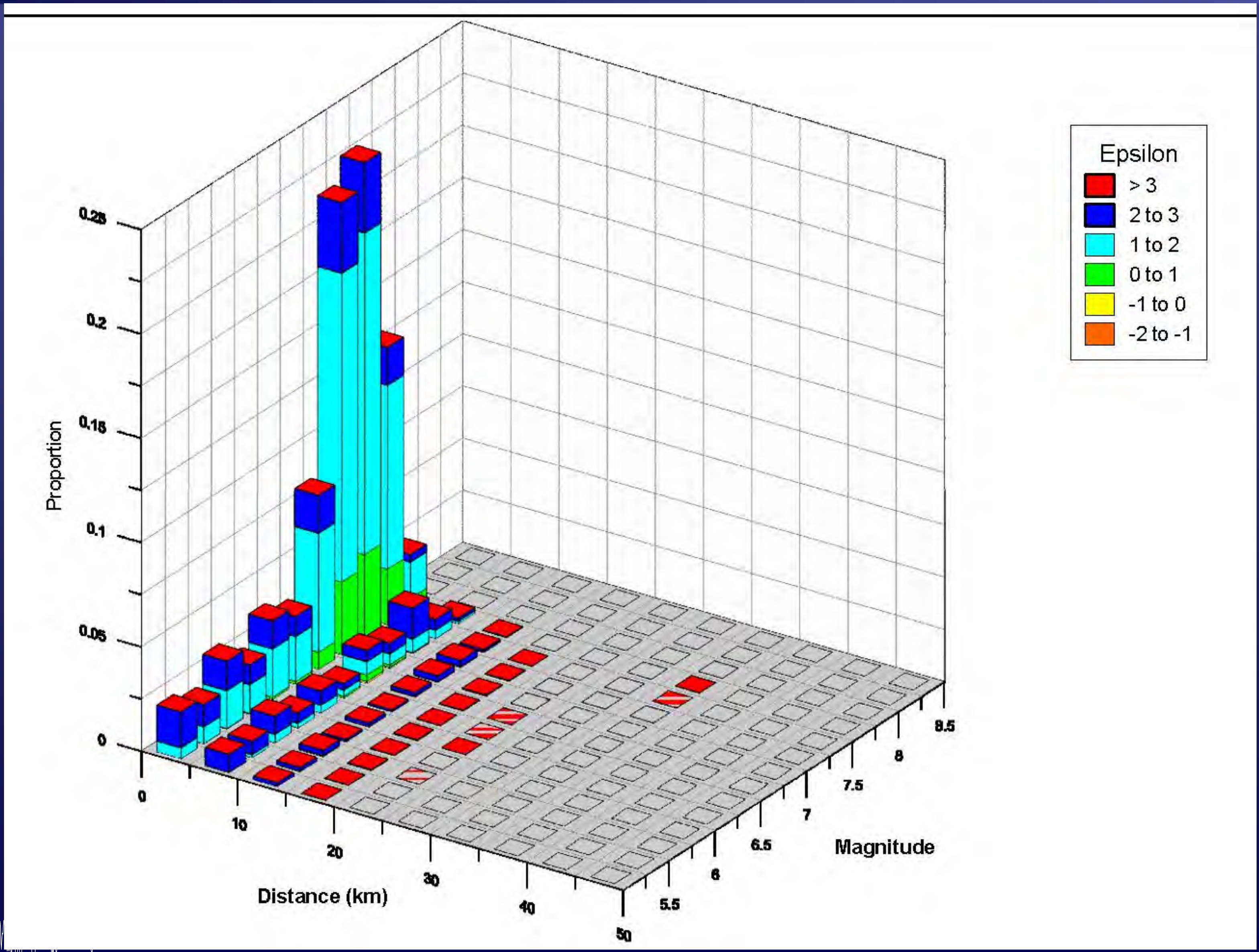
Seismic Source Contributions to Mean Peak Horizontal Acceleration Hazard



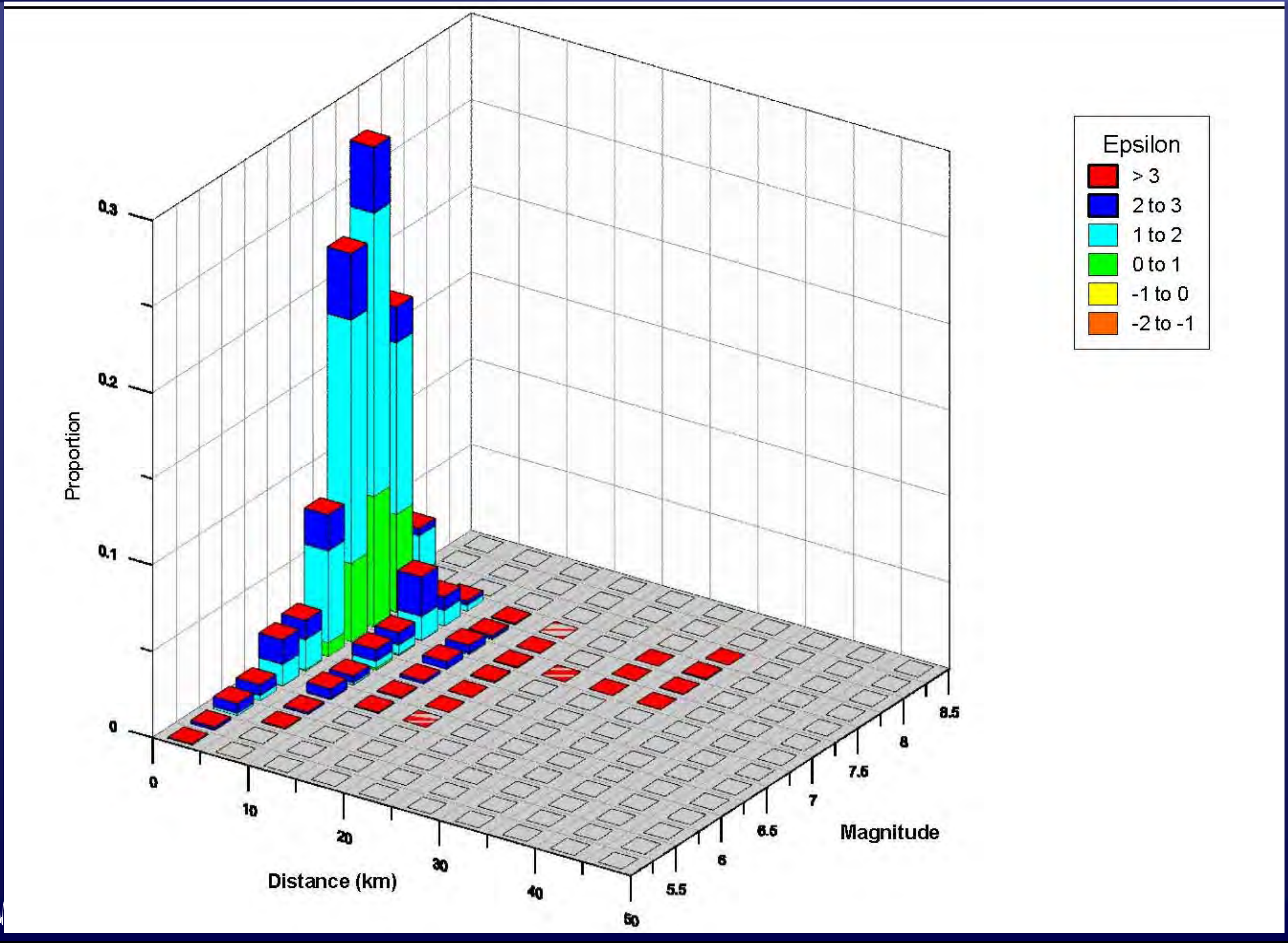
Seismic Source Contributions to Mean 1.0 Sec Horizontal Spectral Acceleration Hazard



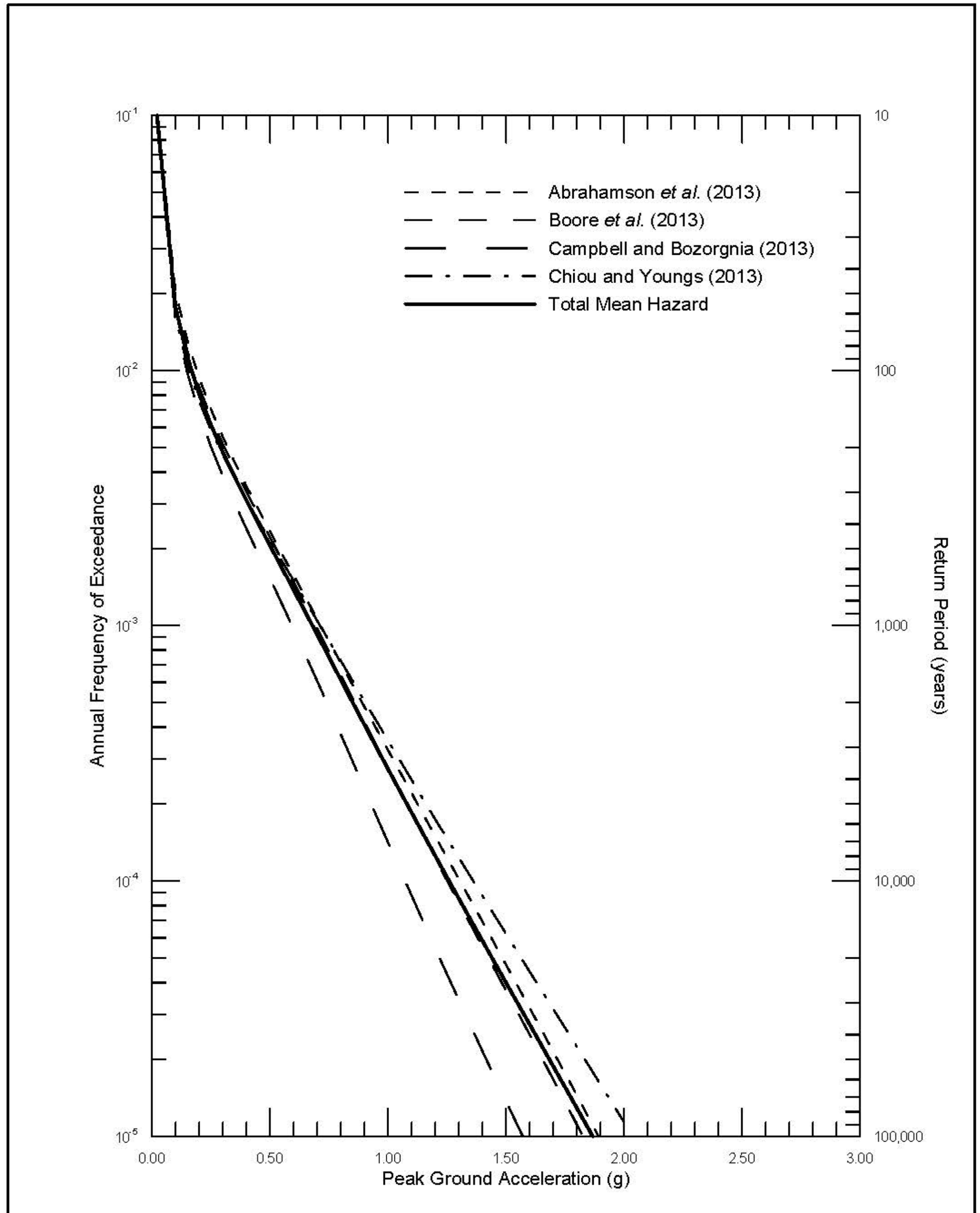
Magnitude and Distance Contributions to the Mean Peak Horizontal Acceleration Hazard at 2,475-Year Return Period



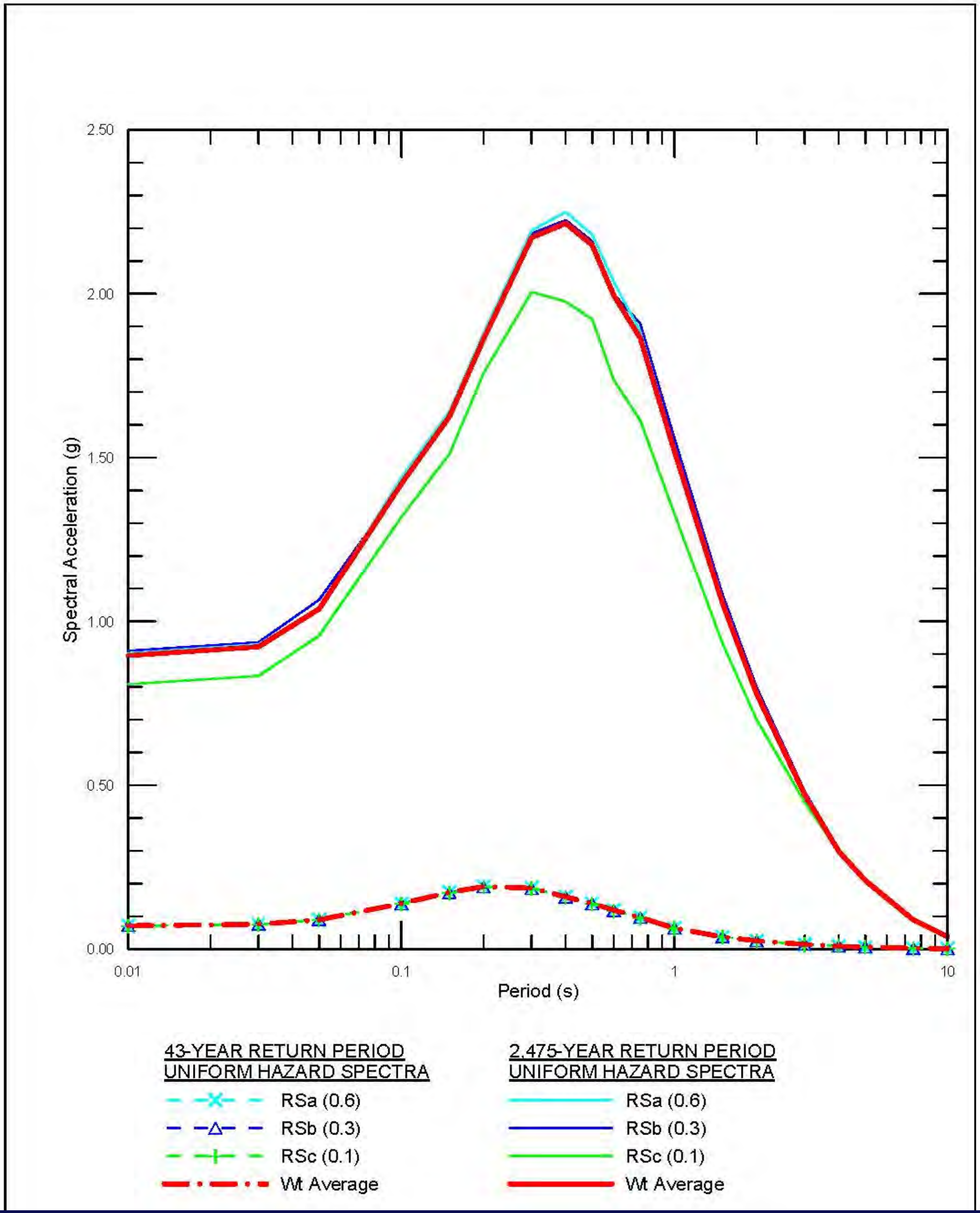
Magnitude and Distance Contributions to the Mean 1.0 Sec Horizontal Spectral Acceleration Hazard at 2,475-Year Return Period



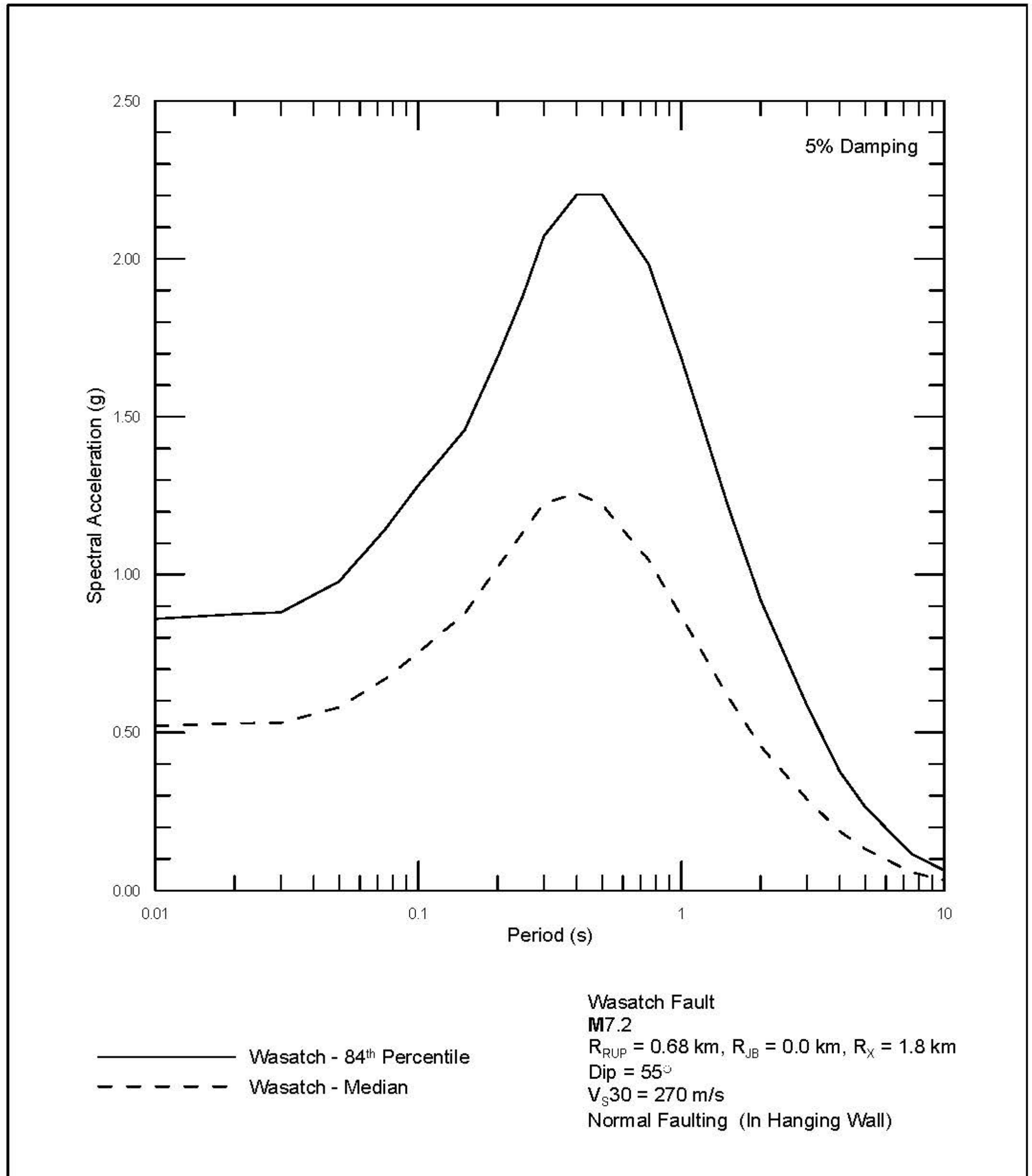
Sensitivity of the Peak Horizontal Acceleration Hazard to the Selection of Ground Motion Prediction Models



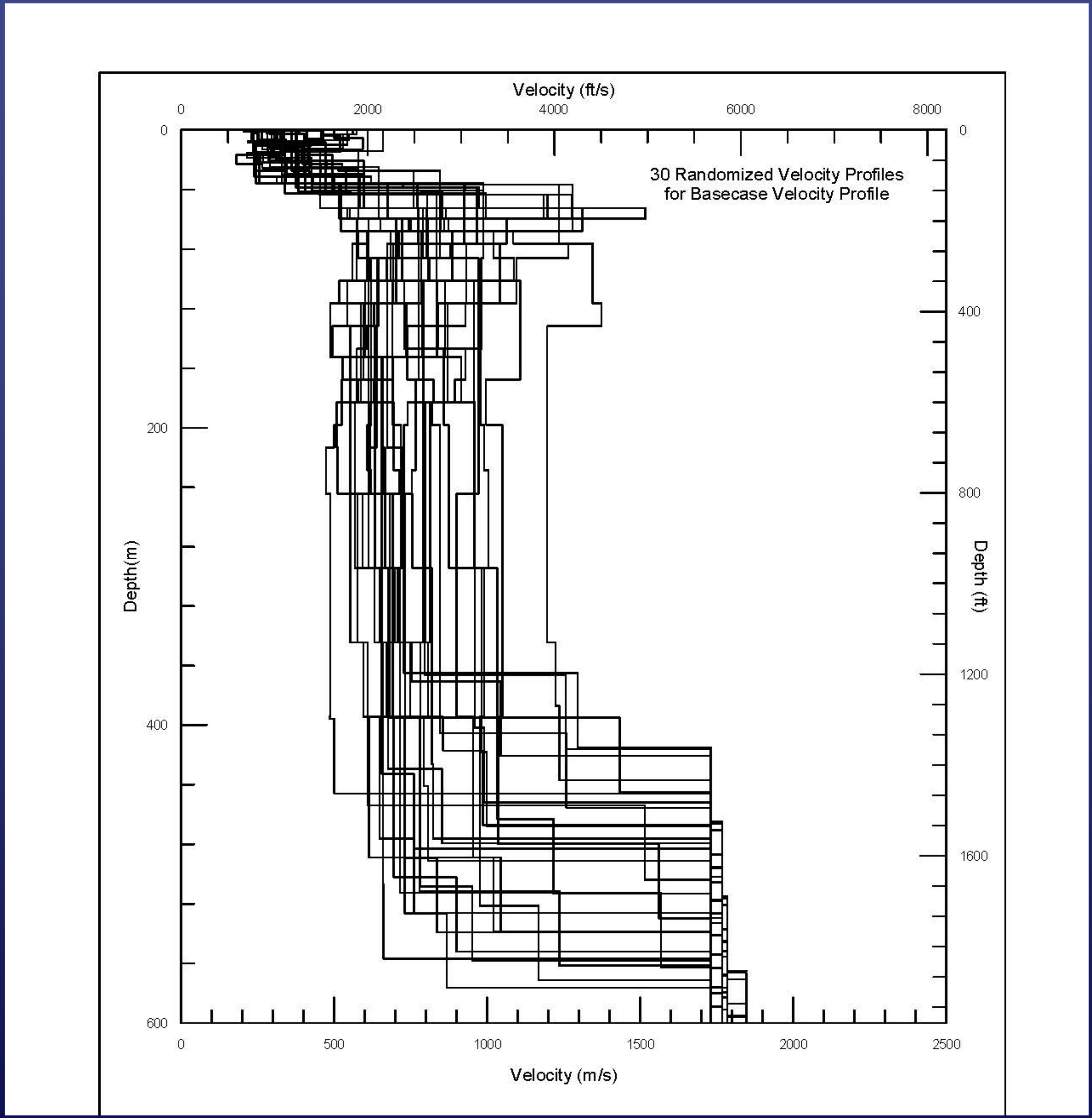
Sensitivity to East Bench-Warm Springs Faults Stepover – 5%-Damped Uniform Hazard Spectra at 43- and 2,475-Year Return Periods



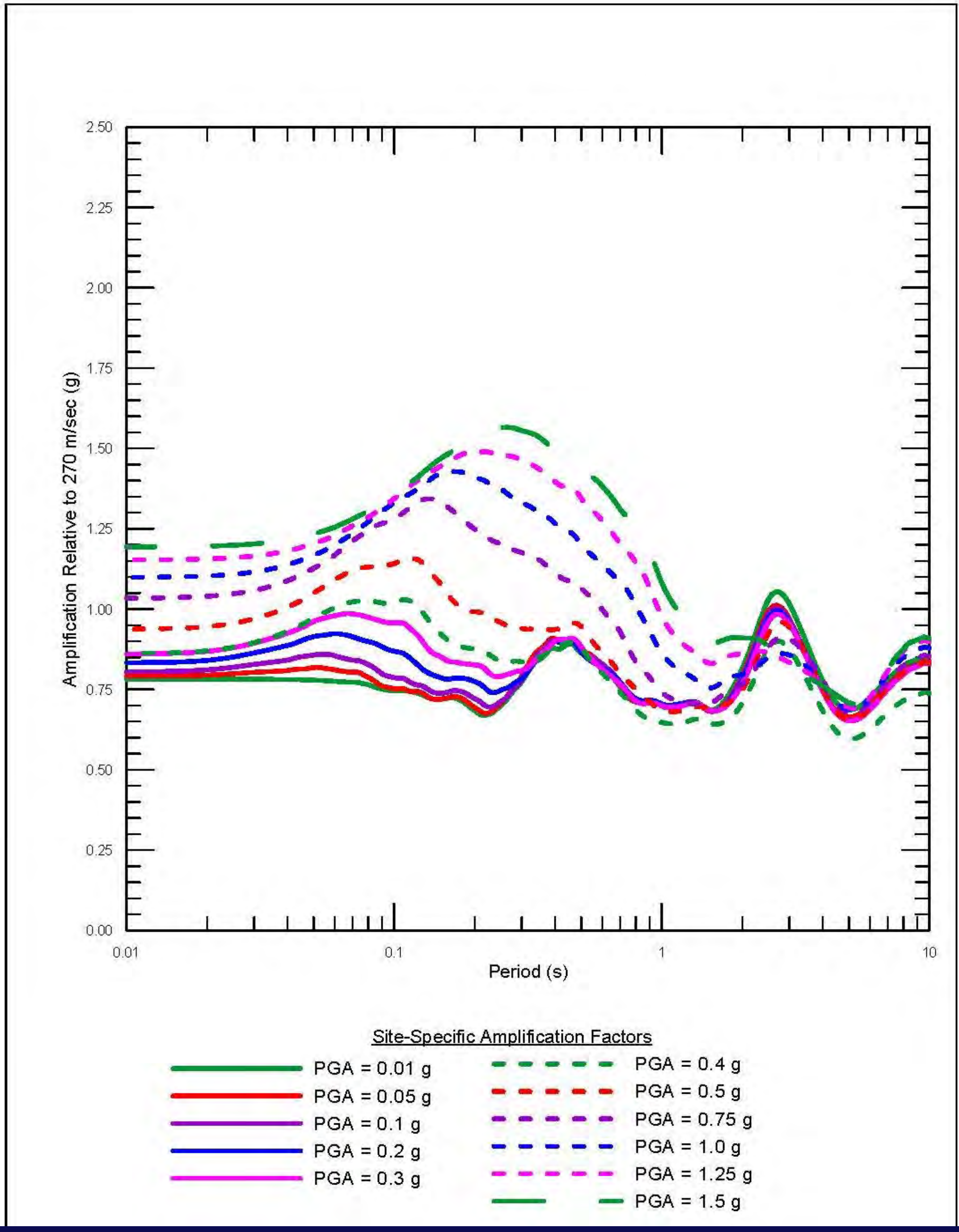
Median and 84th Percentile Deterministic Horizontal Spectra for M 7.2 Salt Lake City Segment Earthquake



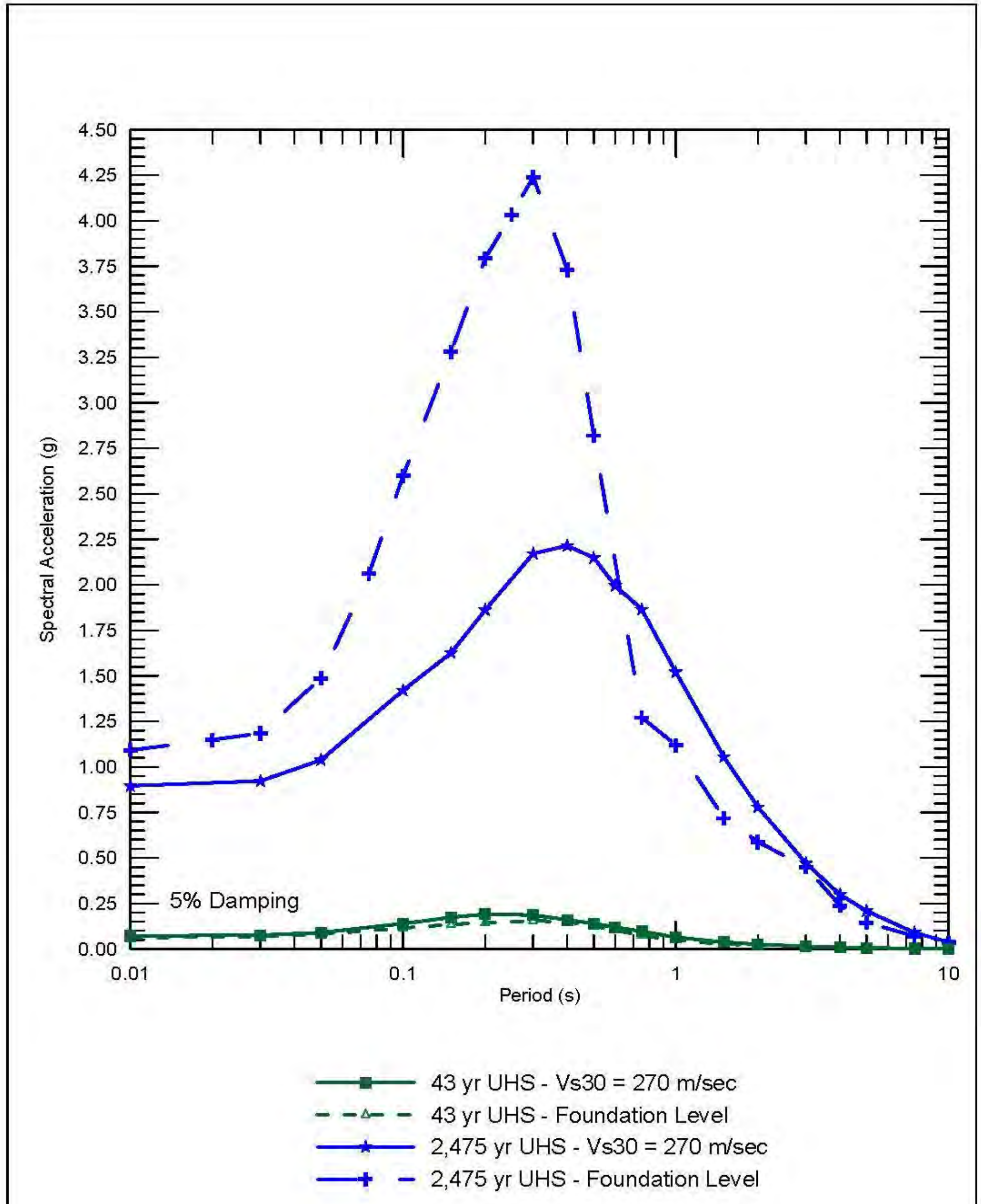
Sample of Randomized V_S Profiles



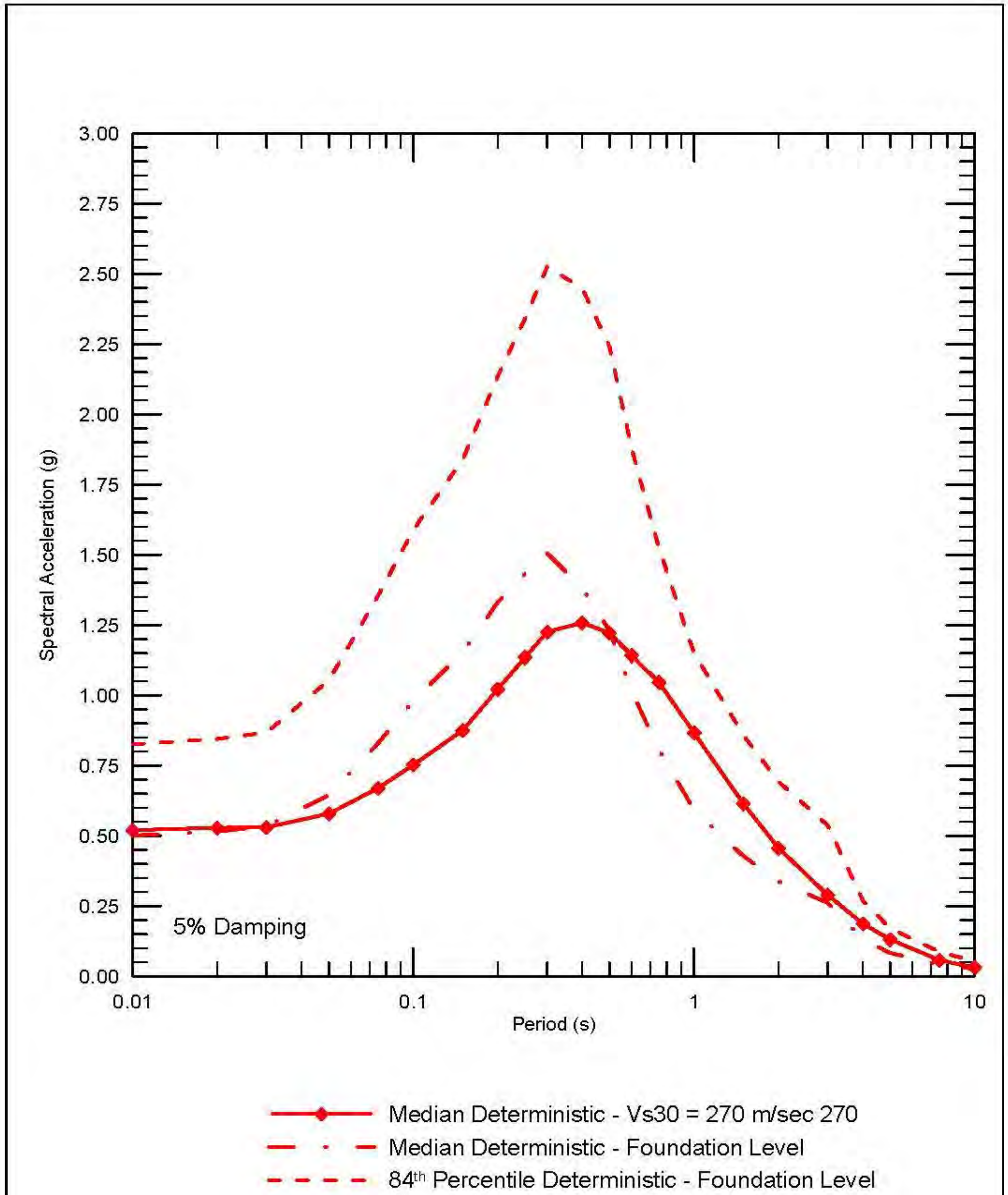
Site-Specific Amplification Factors



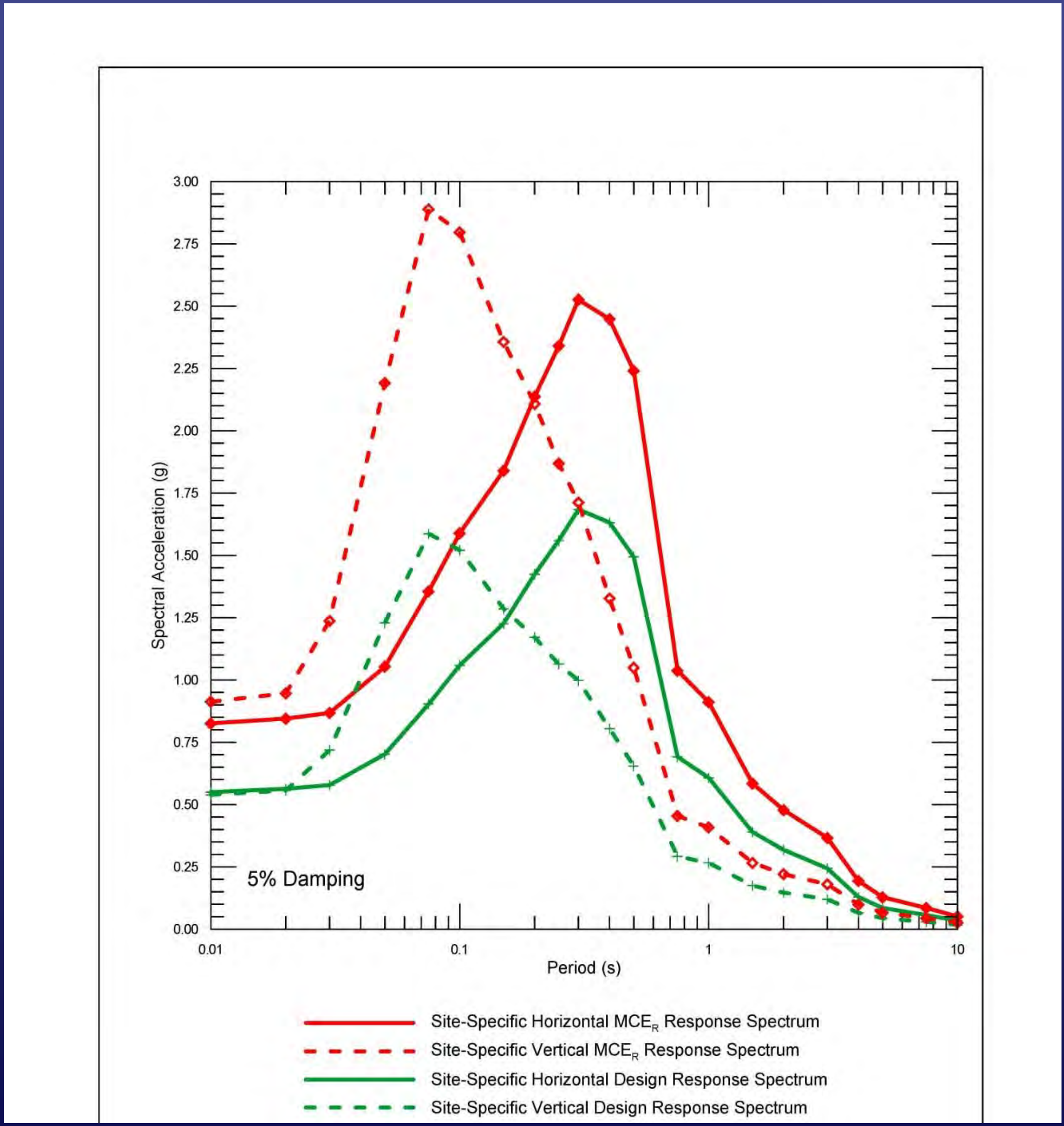
5%-Damped Uniform Hazard Spectra Before and After Site Response Analysis



5%-Damped Deterministic Spectra Before and After Site Response Analysis



Site-Specific Horizontal and Vertical MCE_R and Design Response



Summary

- There are several seismic source, path, and site effect issues that are typically addressed in site-specific PSHAs in the Wasatch Front region that should be addressed, to the extent possible, or at least acknowledged in the next urban hazard maps for the Salt Lake City metropolitan area.

- A few issues include (1) time-dependent behavior of the central Wasatch fault, (2) coseismic rupture of the West Valley fault, (3) Warm Springs-East Bench faults connection, (4) additional epistemic uncertainty in GMPMs, (5) kappa, (6) epistemic and aleatory uncertainites in Vs, (7) basin effects, (8) forward rupture directivity? , and (9) directionality?