SCEC

Updates on CyberShake Ground Motion Simulations for Southern California

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NGA-W3 meeting
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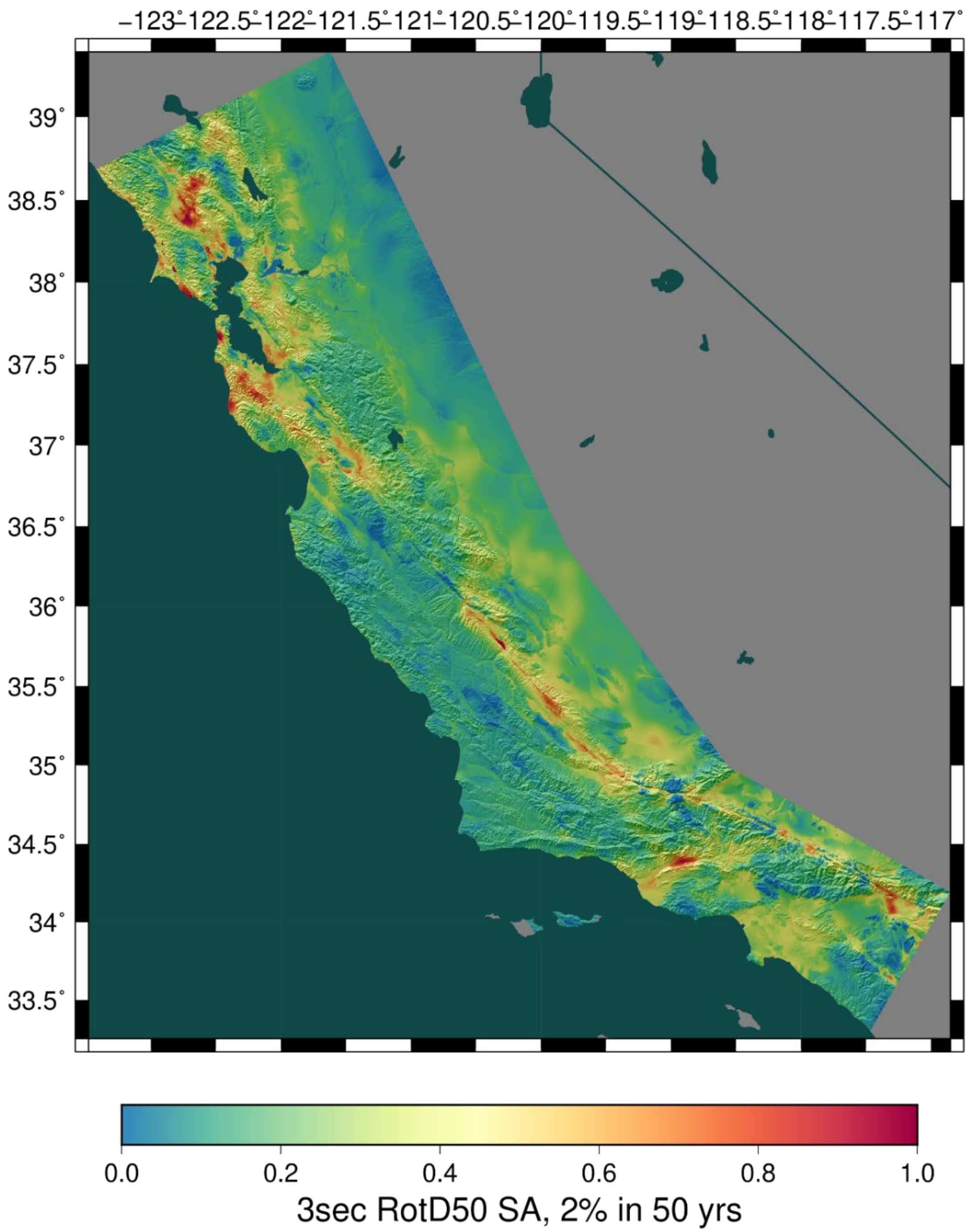
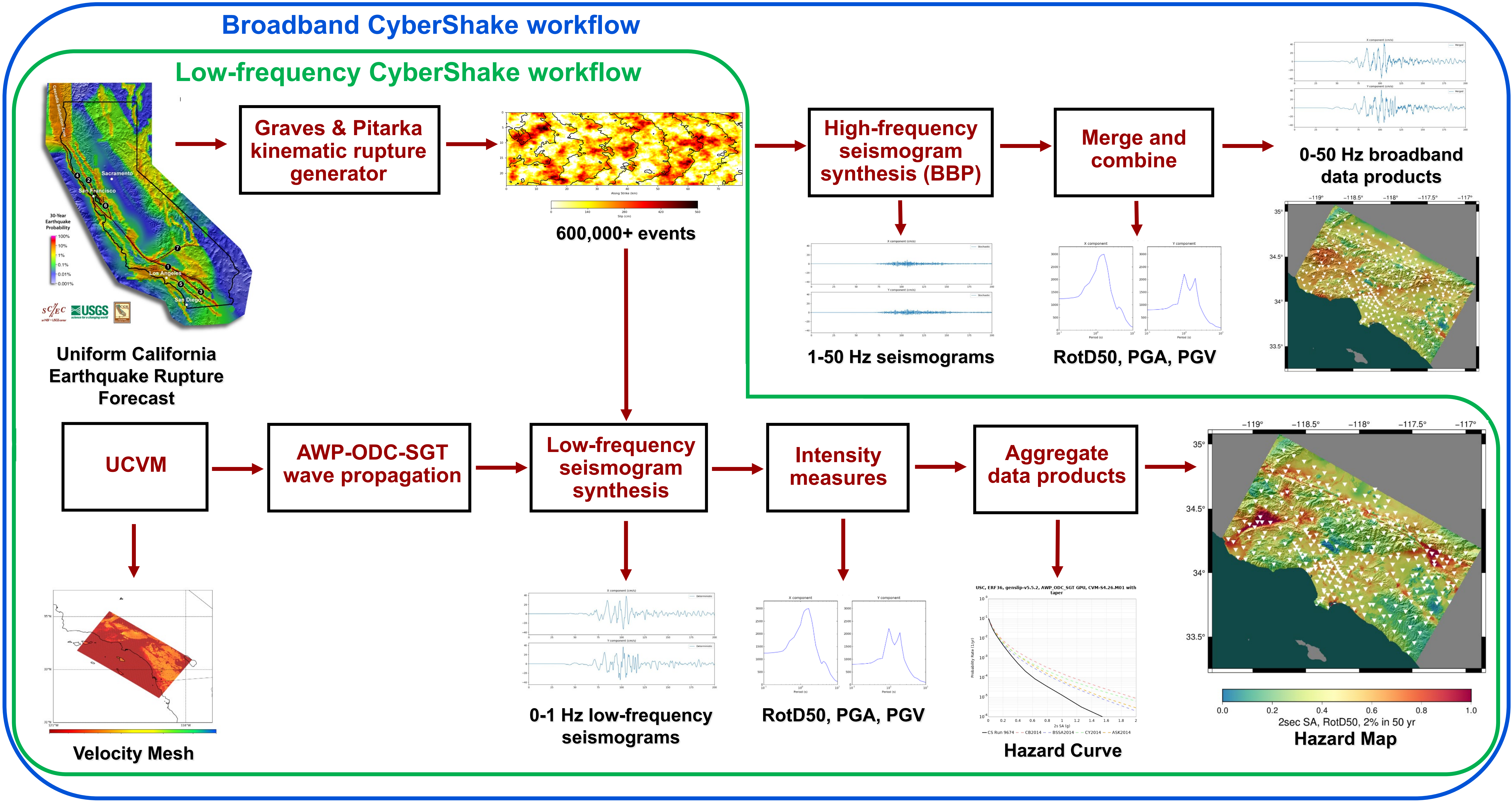
CyberShake Overview

- SCEC's 3D physics-based probabilistic seismic hazard analysis (PSHA) platform
- Earthquake Rupture Forecast (ERF) provides list of relevant events with probabilities
  - 625,000 events per site
- Reciprocity-based approach to simulate low-frequency seismograms
- Intensity measures derived from seismograms
- Hazard results from individual sites interpolated with GMM basemap



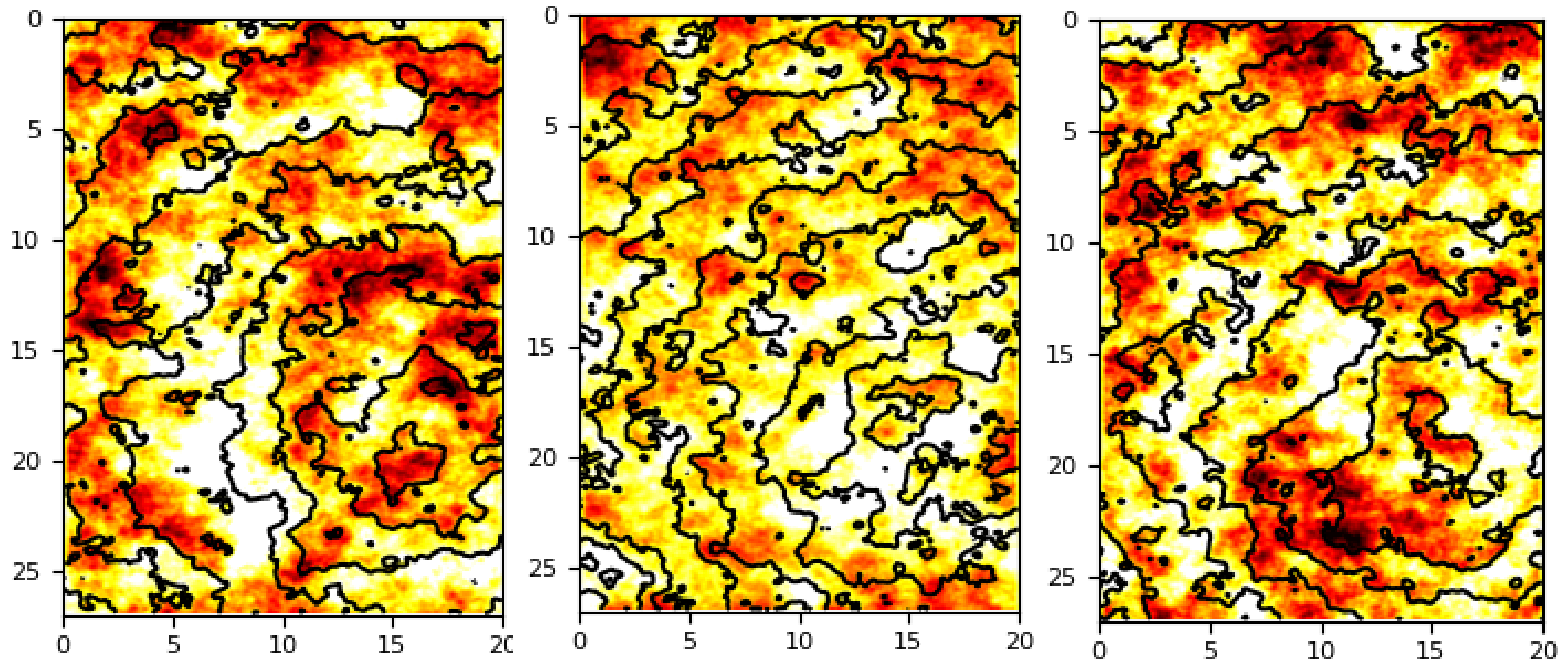

Broadband CyberShake workflow
Low-frequency CyberShake workflow
Sacramento
San Francisco
Los Angeles
San Diego
30-Year Earthquake Probability
Uniform California Earthquake Rupture Forecast
Graves & Pitarka kinematic rupture generator
600,000+ events
High-frequency seismogram synthesis (BBP)
Merge and combine
0-50 Hz broadband data products
1-50 Hz seismograms
RotD50, PGA, PGV
UCVM
AWP-ODC-SGT wave propagation
Low-frequency seismogram synthesis
Intensity measures
Aggregate data products
Velocity Mesh
0-1 Hz low-frequency seismograms
RotD50, PGA, PGV
Hazard Curve
2sec SA, RotD50, 2% in 50 yr
Hazard Map

New Features in CyberShake Study 22.12

- Update to Study 15.4 and 15.12
- Broadband simulations
  - Validated against historic events
- Modifications to 3D velocity model
  - Goal is to resolve issues with high velocities at the surface
- Updates to rupture generation for individual events
  - Migration to more recent kinematic rupture code
  - Sampling of additional variability

Broadband Validation

- Selected validation events from the SCEC Broadband Platform
  - Northridge, Whittier, Chino Hills, Landers
- 64 realizations created for each event
  - Hypocenter and magnitude preserved
  - Different slip realizations
  - GP rupture generator used
- CyberShake pipeline run for sites with recordings in BBP
  - Usually ~40 stations per event
- Calculate metrics



3 slip realizations for 1994 Northridge

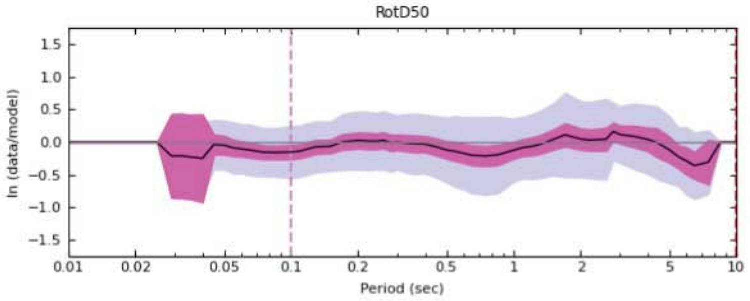
Validation Metrics

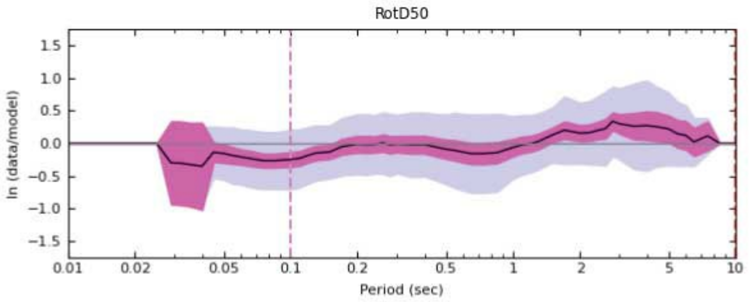
- Looking at BBP goodness-of-fit metric
  - Both overall GoF (all sites, all realizations) and best realization
  - Compare 3D CyberShake, 1D BBP, and GMMs to observations
- Show that CyberShake works
  - Reasonable ground motions for both historic and hypothetical events
- Wiggle-to-wiggle agreement not the goal
  - Can get very good low-frequency agreement with tuning
  - Here, want to validate entire method on known and unknown events
  - Goal is to get reasonable results on realization sweeps

Northridge

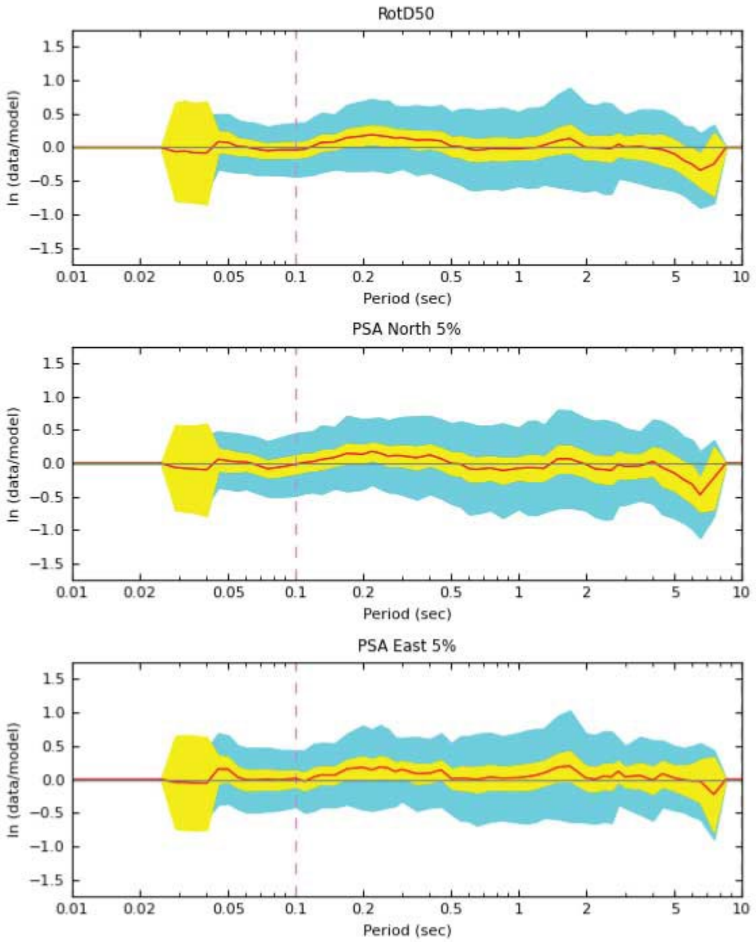
3D CyberShake | 1D BBP | GMMs

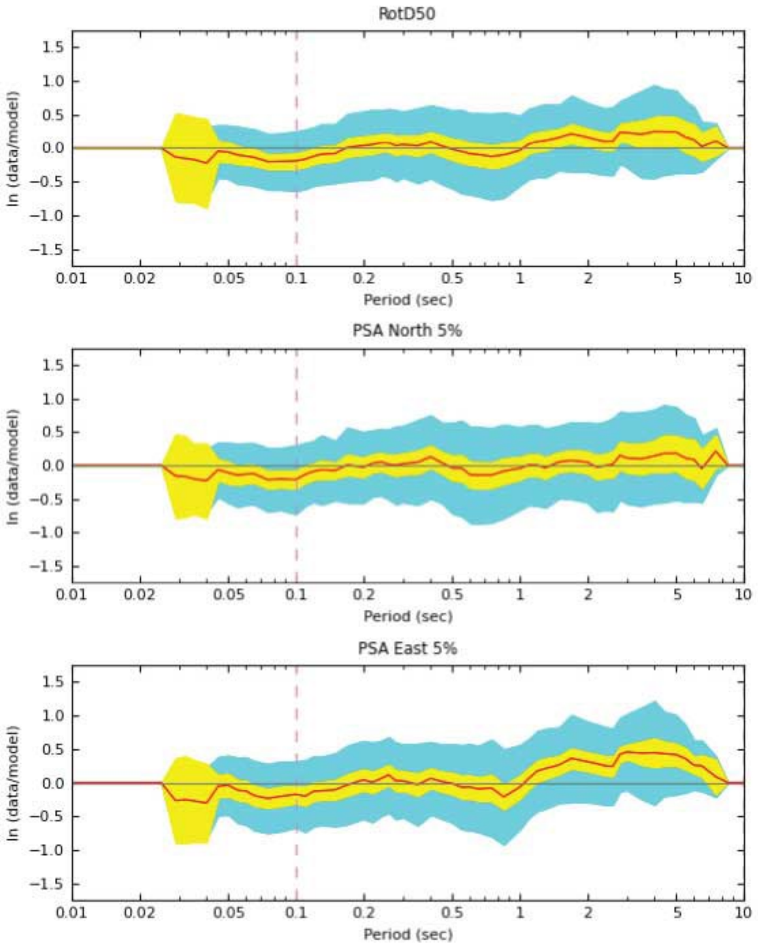
Overall GoF

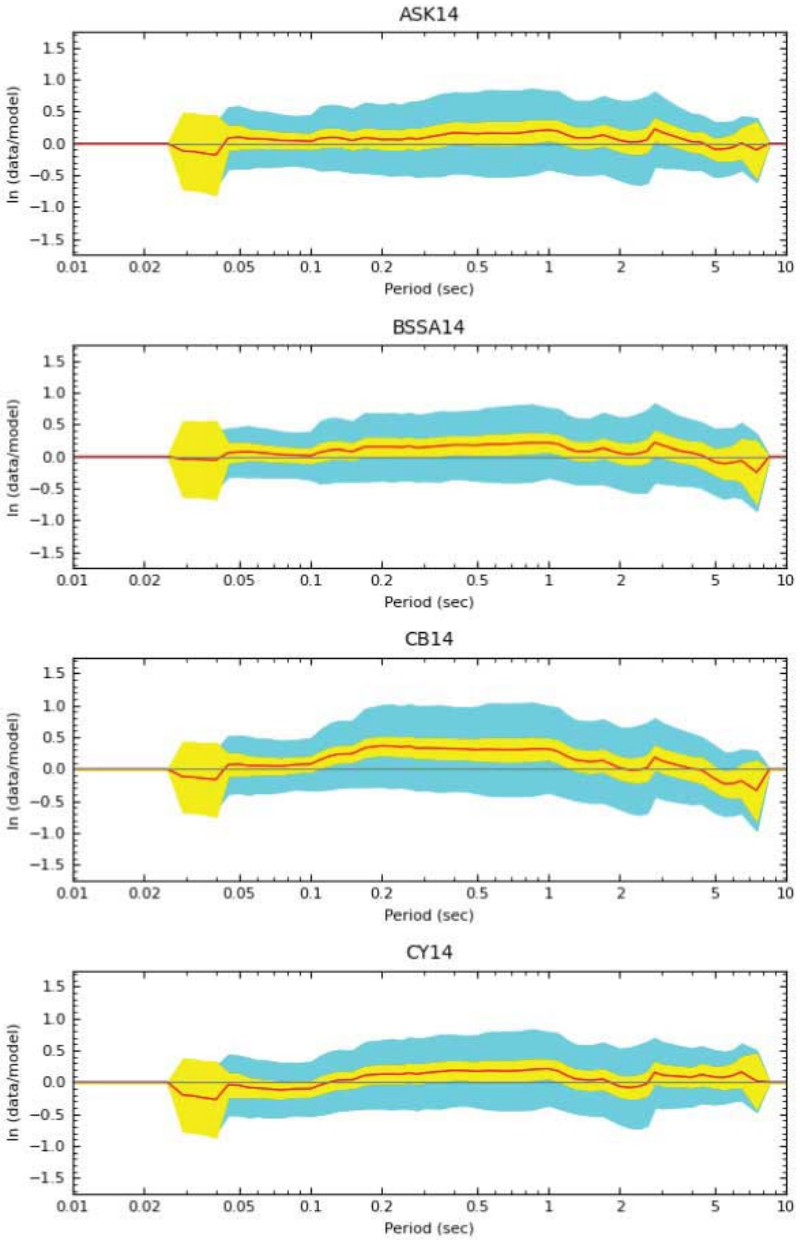




Best Realization







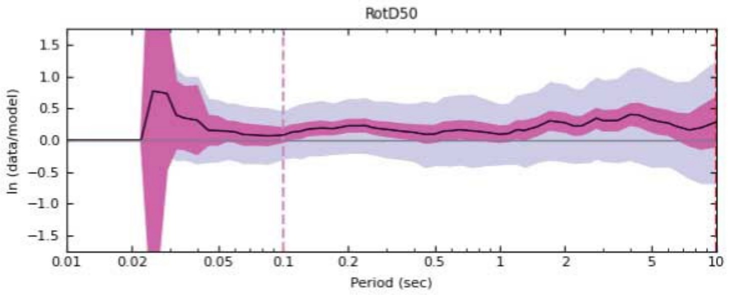
Landers (multi-segment)

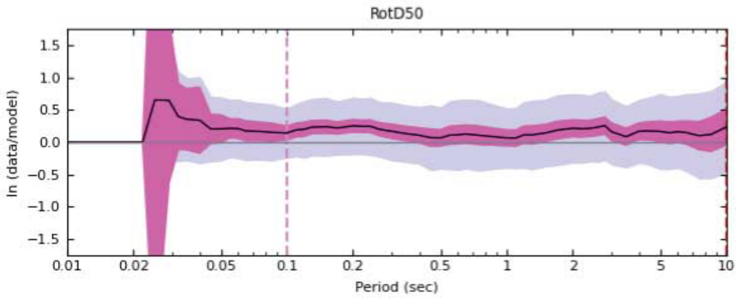
3D CyberShake

1D BBP

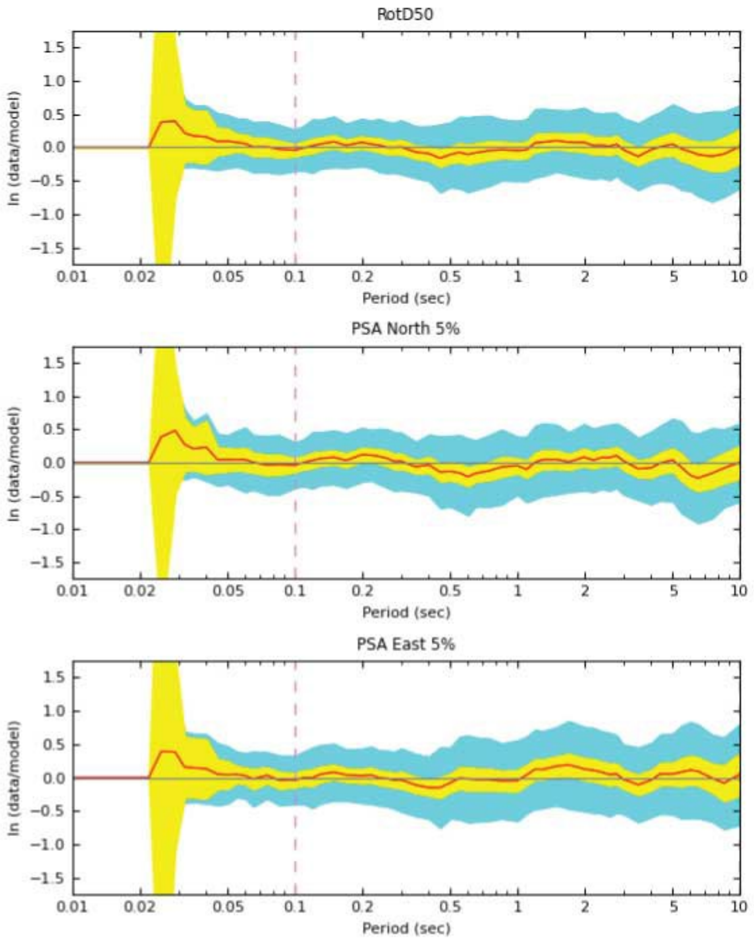
GMMs

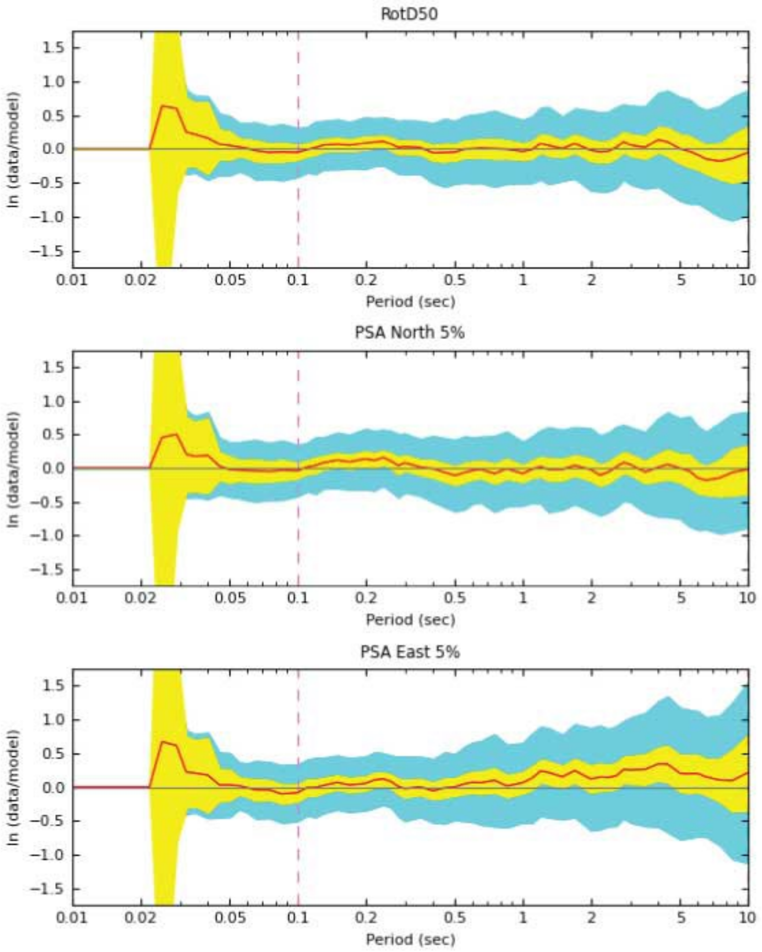
Overall GoF

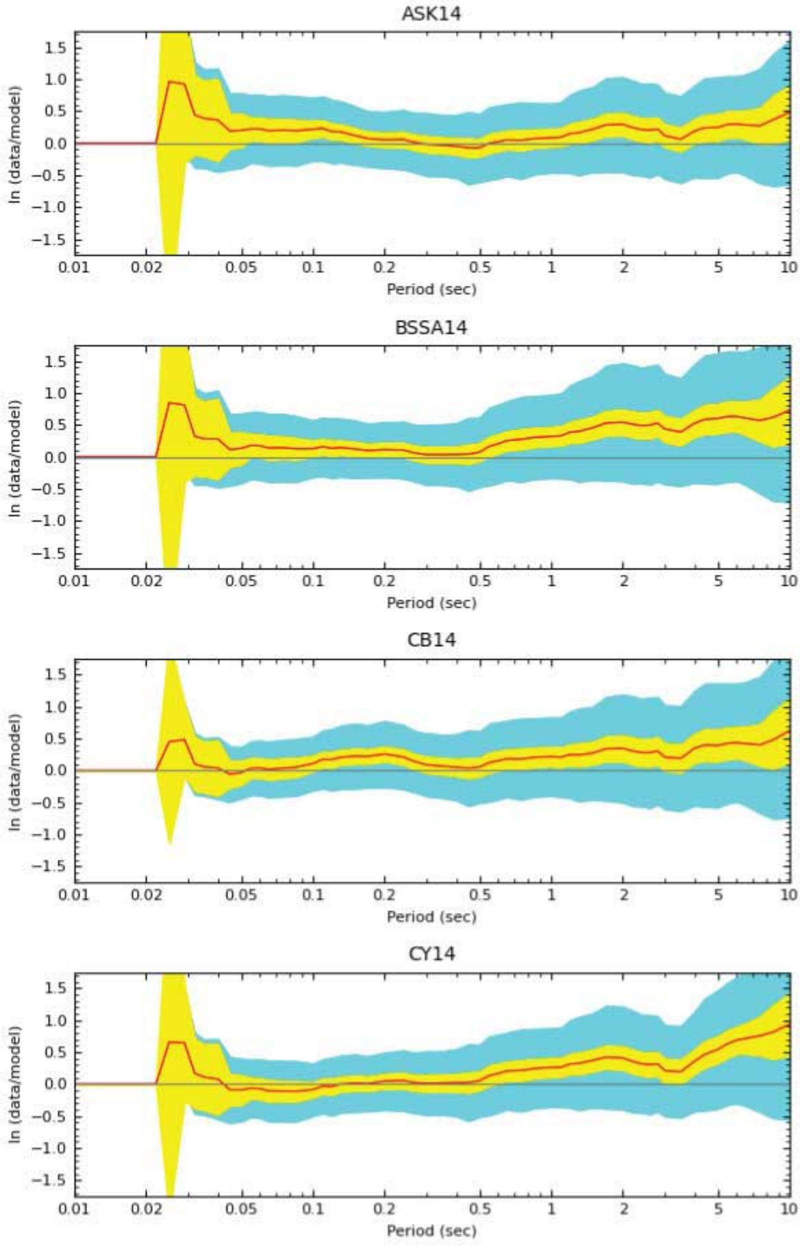




Best Realization



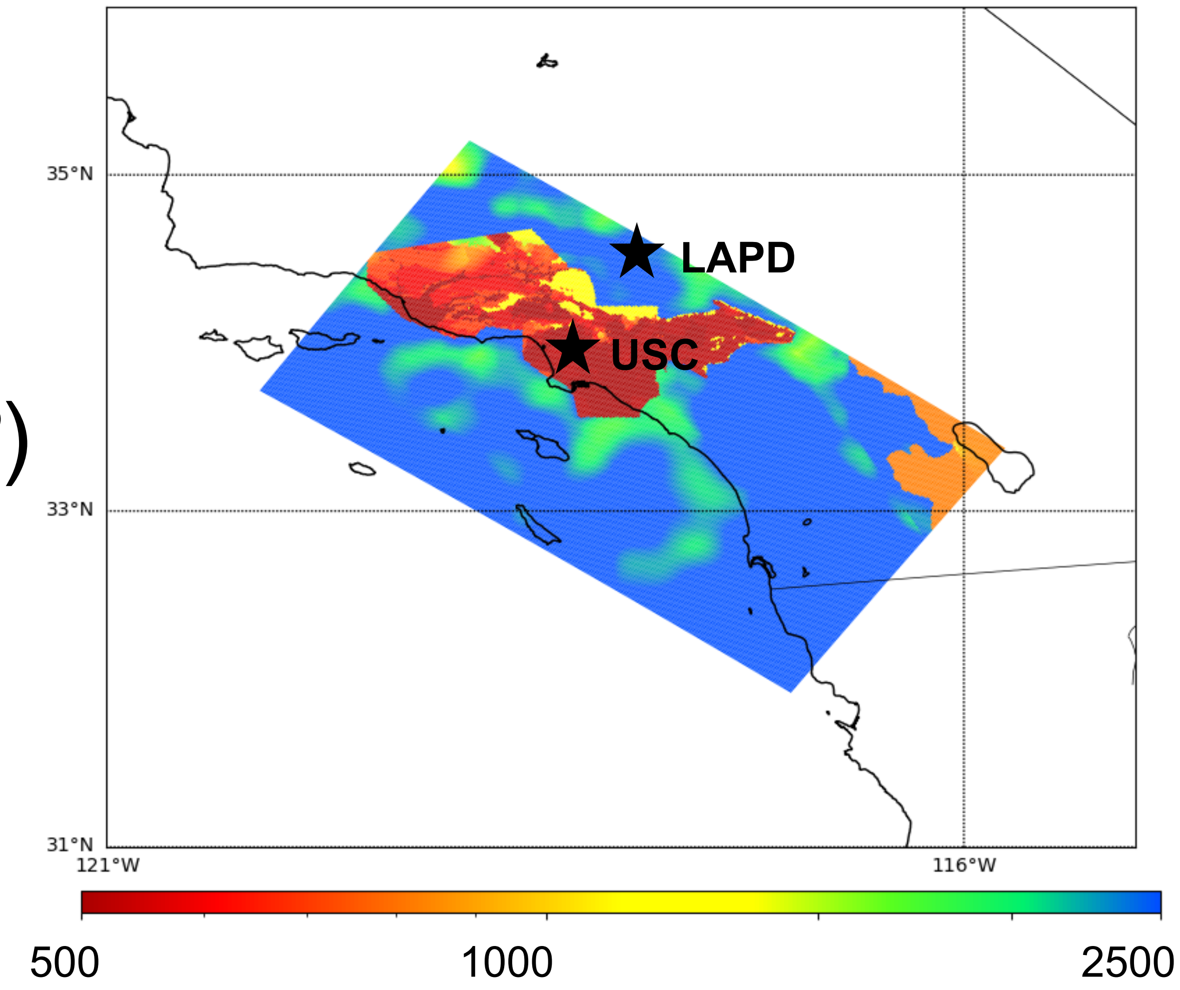




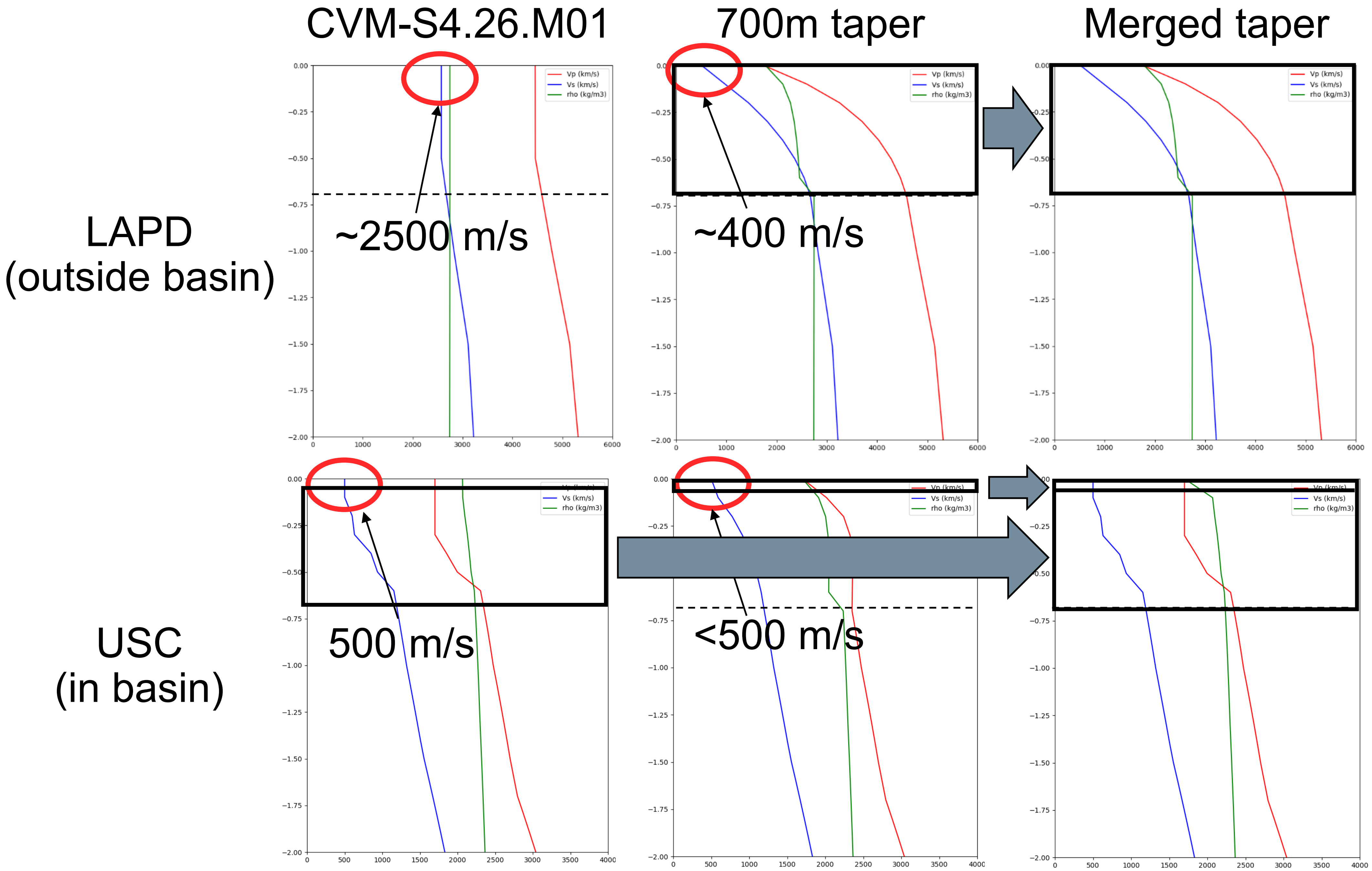
Velocity Model Merged Taper

- Previous studies used CVM-S4.26.M01
  - Tomography model + near-surface layer
  - High Vs values outside of basins
- Used Ely-Jordan approach to apply Vs30-based taper down to 700m (*Hu et al. 2022*)
  1. Using taper, determine Vp, Vs, rho values at each grid point in the mesh
  2. Compare taper and non-taper Vs value
  3. Select smaller Vs value (and corresponding Vp and rho) to preserve basins

CVM-S4.26.M01, surface Vs



Site Velocity Profiles



Taper is selected at all depths to 700m

Vs30: 2573 m/s -> 400 m/s
Z1.0: 0m -> 110m

Taper is only selected at surface point

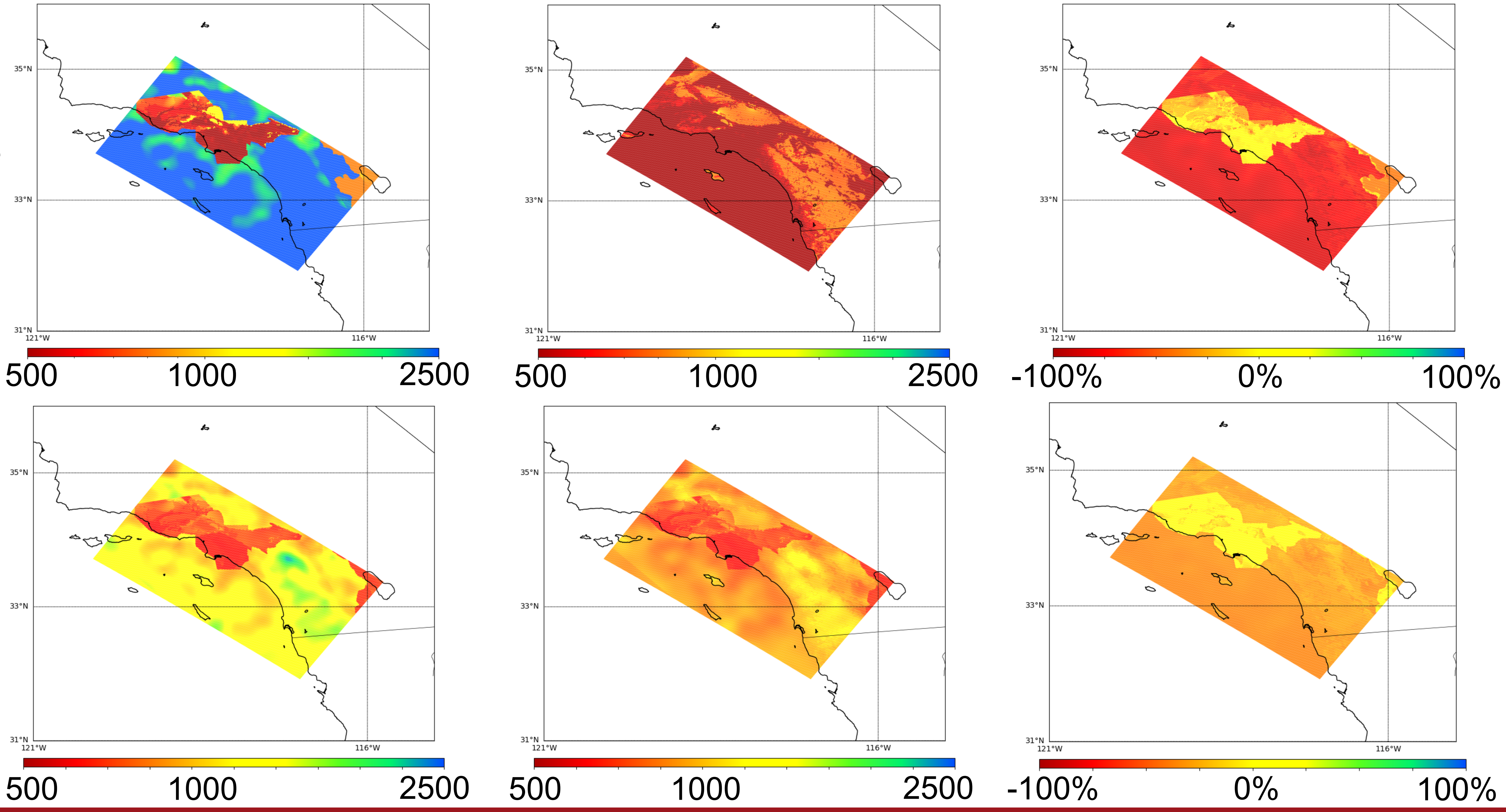
Vs30: 500 m/s -> 500 m/s
Z1.0: 580m -> 580m

Merged Taper Cross-sections

CVM-S4.26.M01 | Merged Taper | % difference

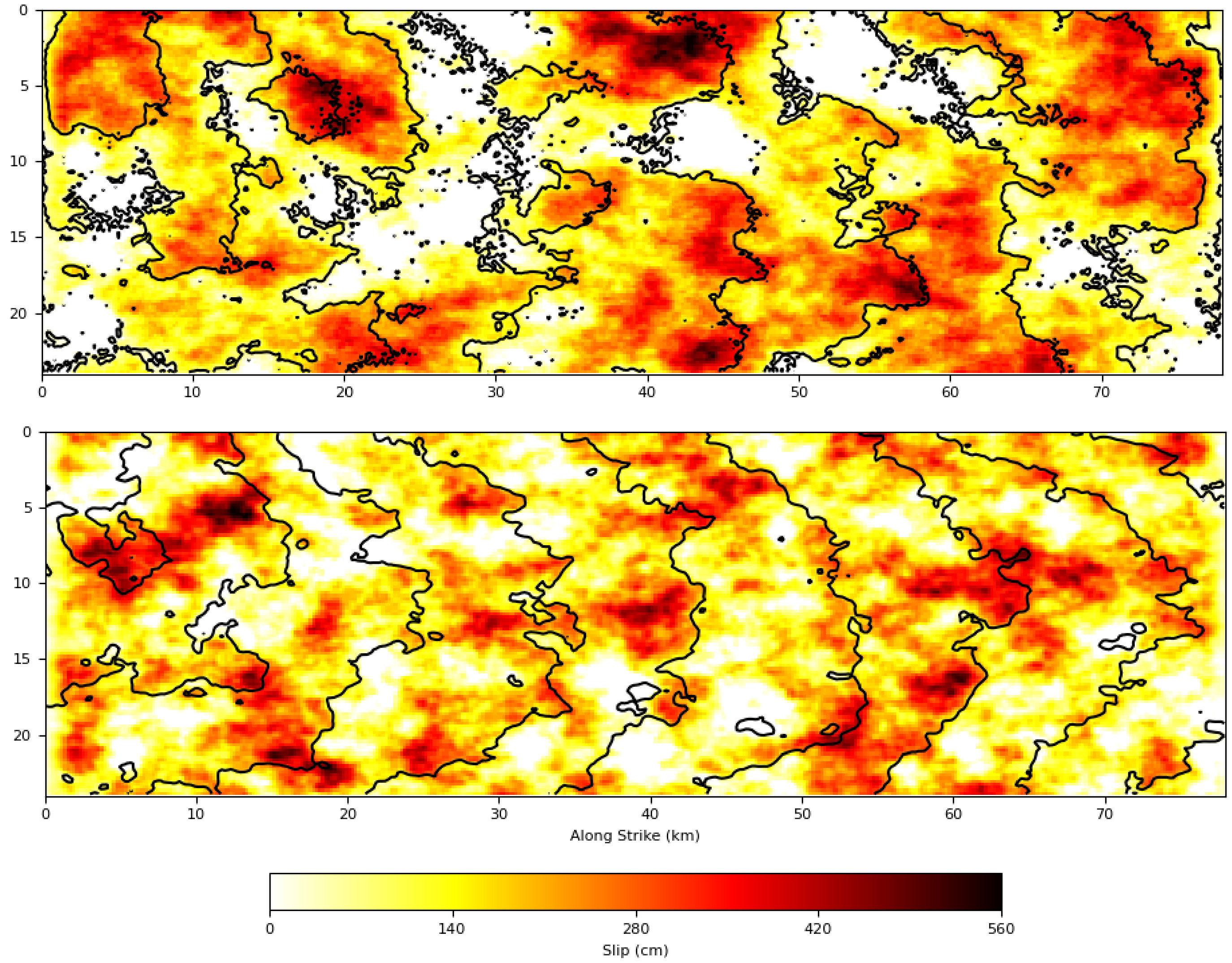
Surface

300m depth



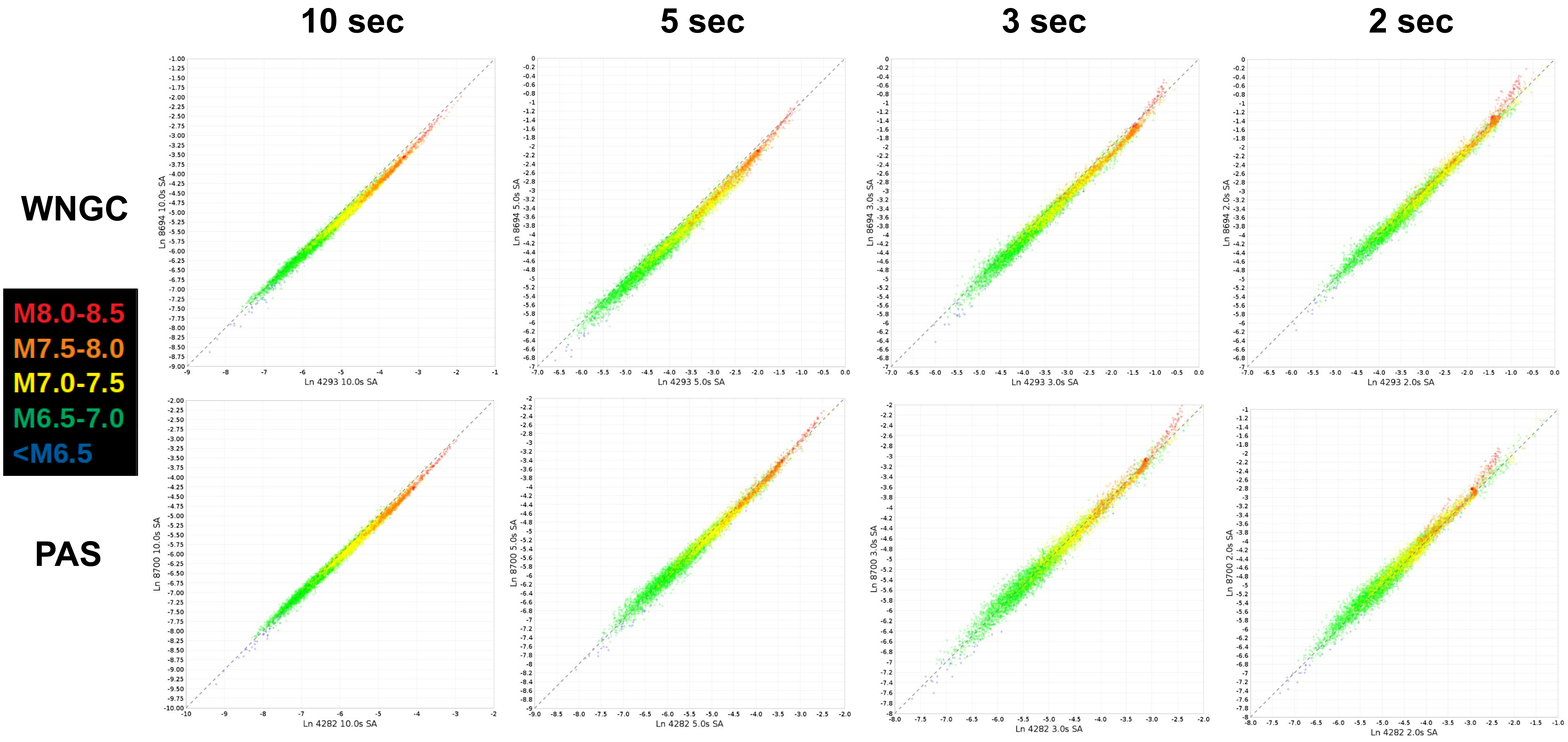
Updates to Rupture Generation

- New version of GP generator (v5.5.2, same as in latest BBP release)
  - Reduced correlation between slip and risetime
  - Reduced shallow fault rupture speed
  - Slightly weaker directivity
  - Variable strike & dip
  - Increased energy at 2-3 sec
- Rupture velocity is no longer fixed
  - 67.5%-87.5% of shear wave velocity
- Denser hypocentral spacing
  - 4.5 km -> 4 km
  - ~31% increase in rupture variations

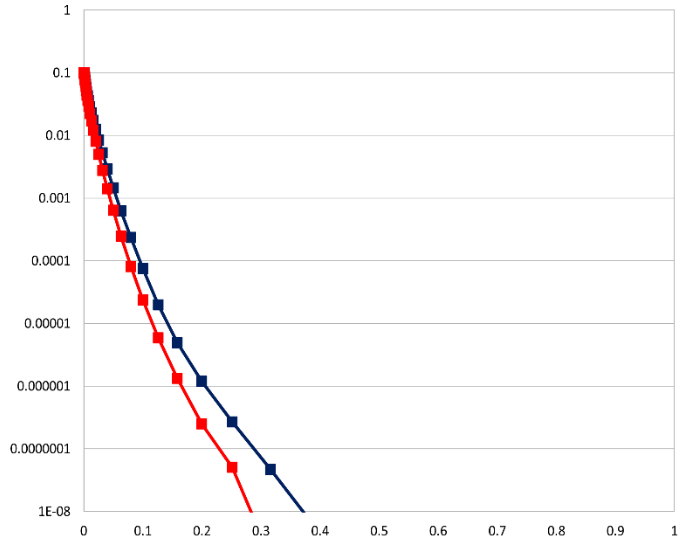
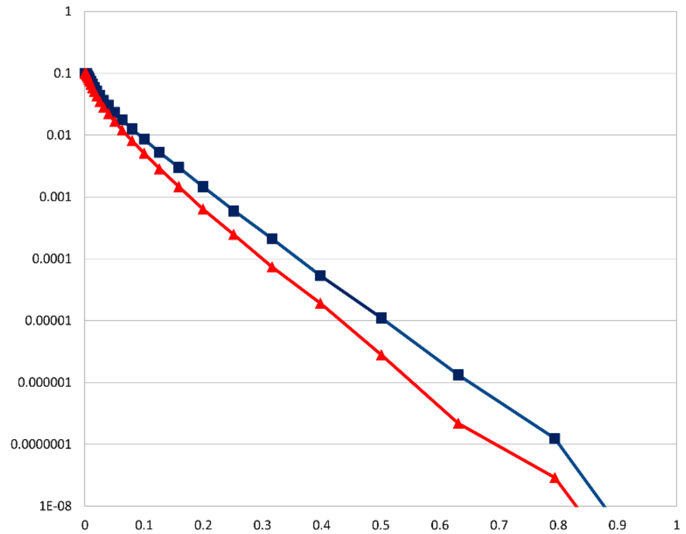
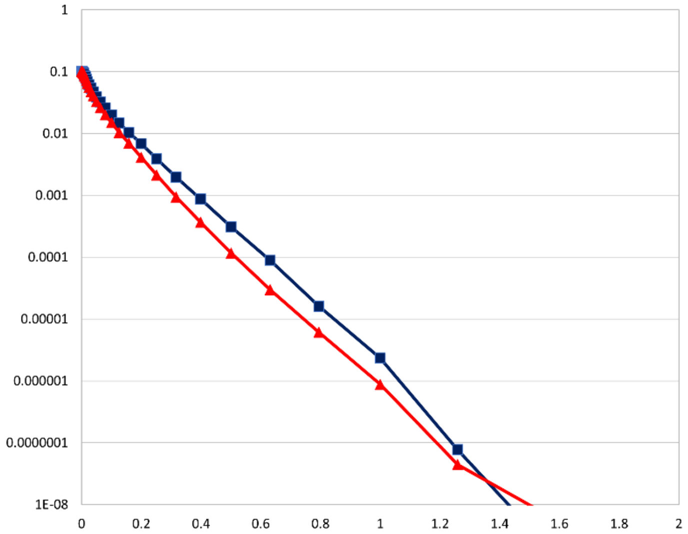
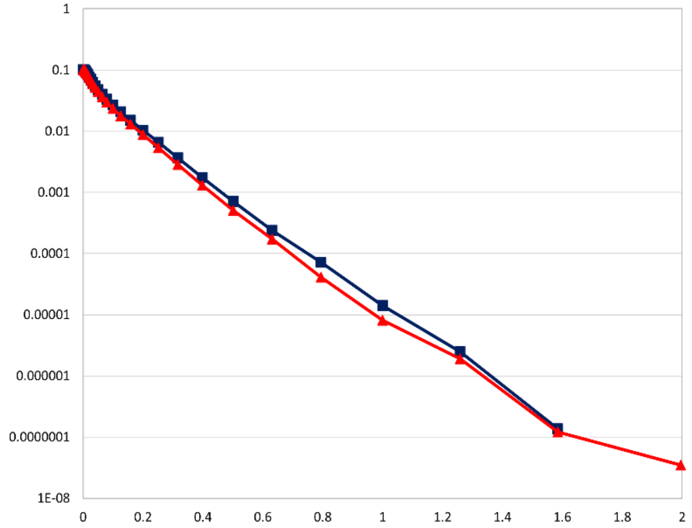
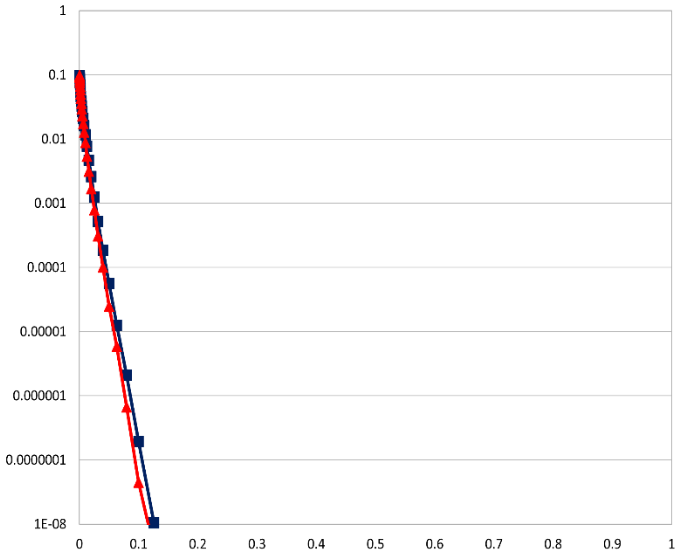
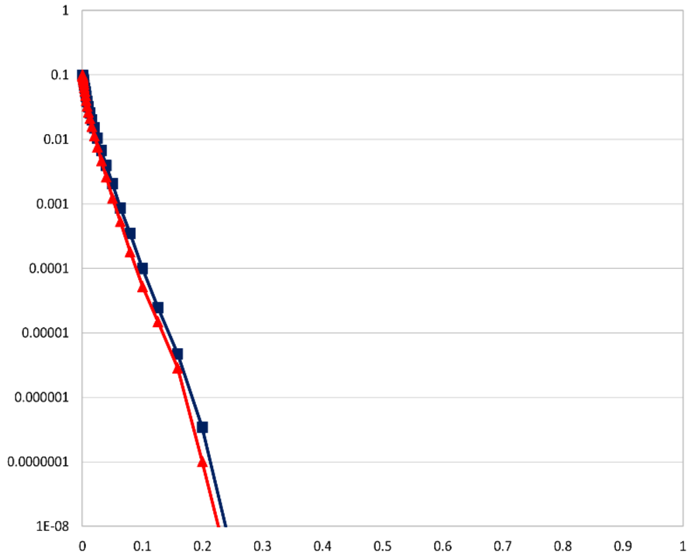
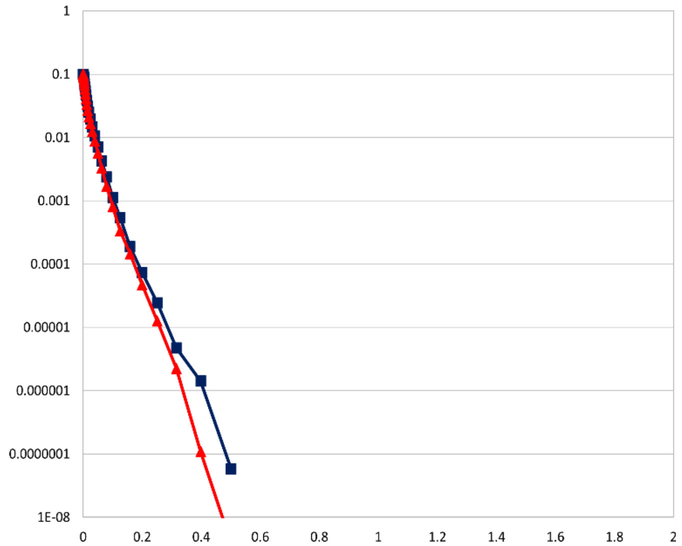
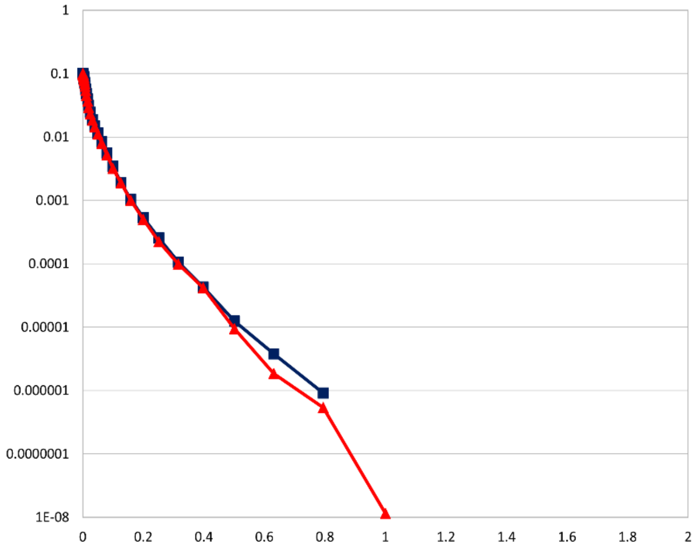


Slip plot, v3.3.1 from Study 15.4 (top); v5.5.2 from Study 22.12 (bottom)

Rupture Generator Impact on Ground Motions



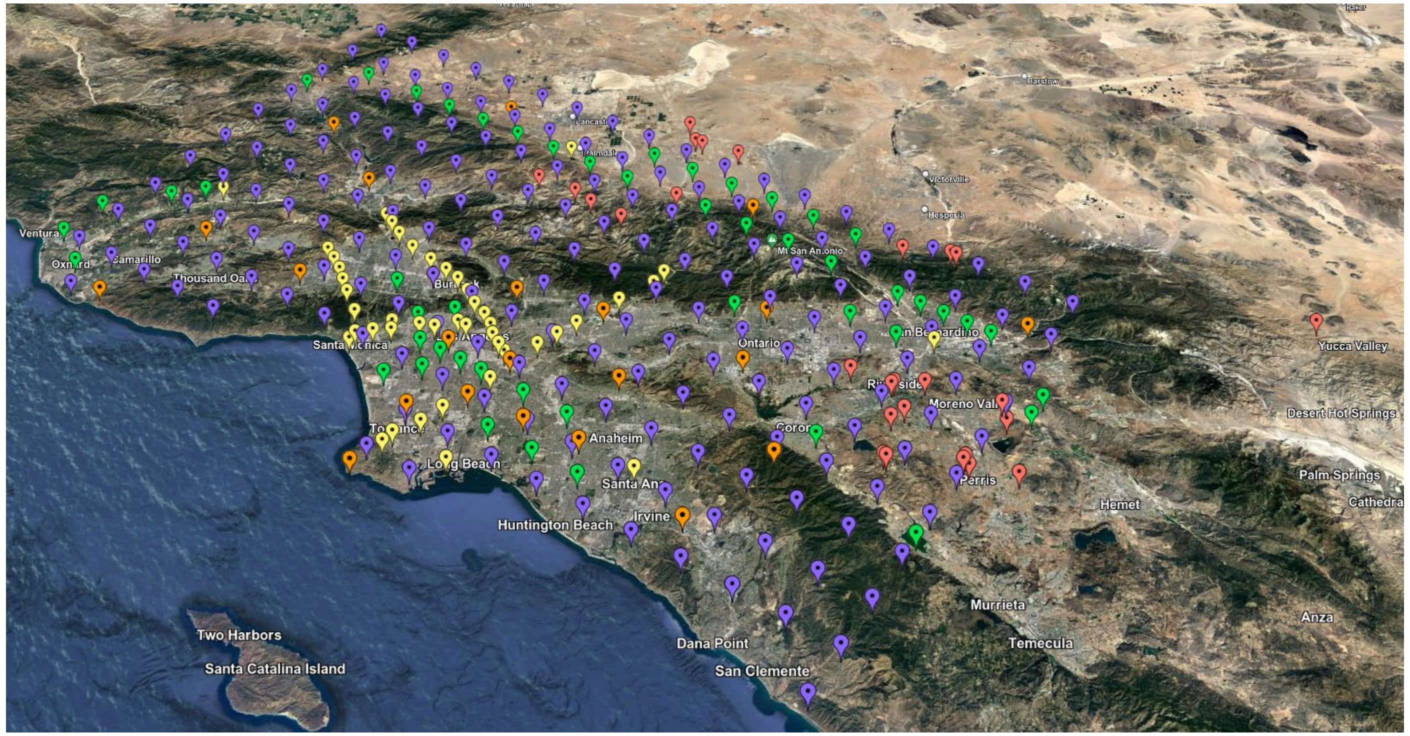
Rupture Generator Impact on Hazard

	10 sec	5 sec	3 sec	2 sec
WNGC				
PAS				

Study 15.4 rupture generator (v3.3.1)
Study 22.12 rupture generator (v5.5.2)

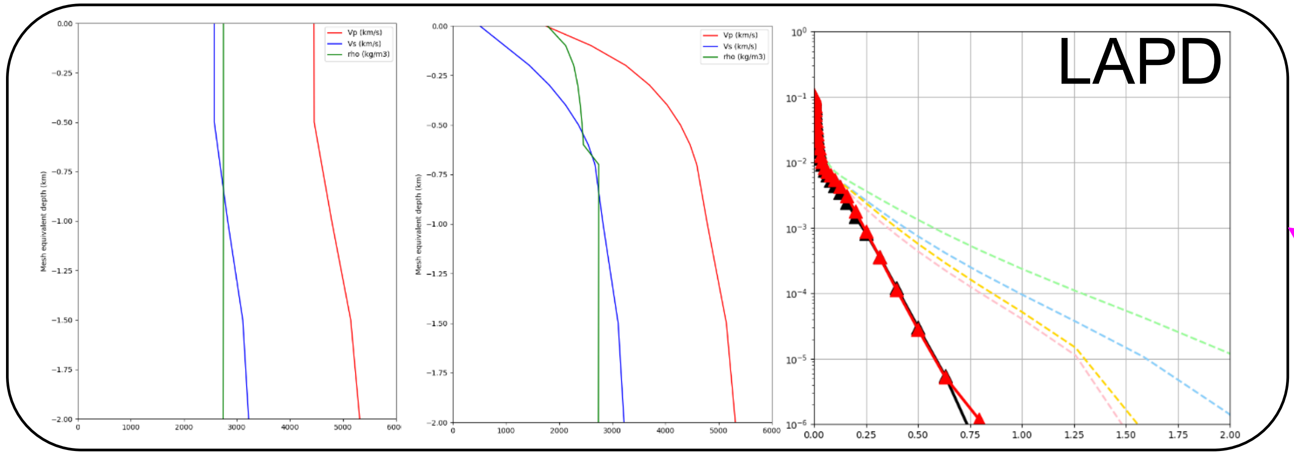
Study 22.12 Statistics

- 335 sites around SoCal
- Study performed over 76 days
- 772,000 node-hrs on OLCF *Summit*
  - Averaged 422 nodes
  - Max of 3382 (73% of *Summit*)
- Managed ~2.5 PB of data
- 74 TB of data staged back to archival storage
  - 420 million two-component low-frequency and broadband seismograms
  - 83 billion intensity measures and durations

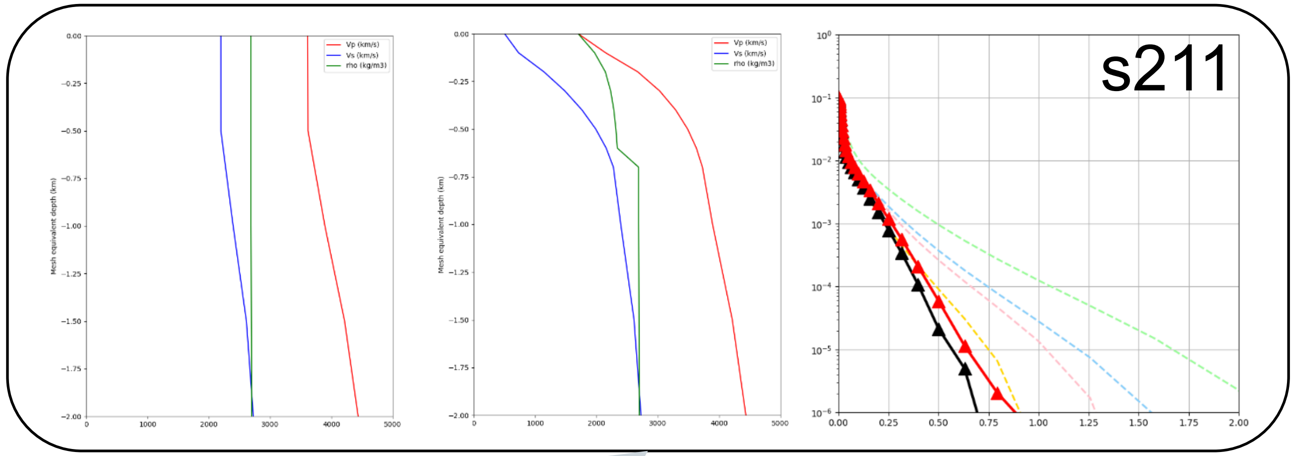


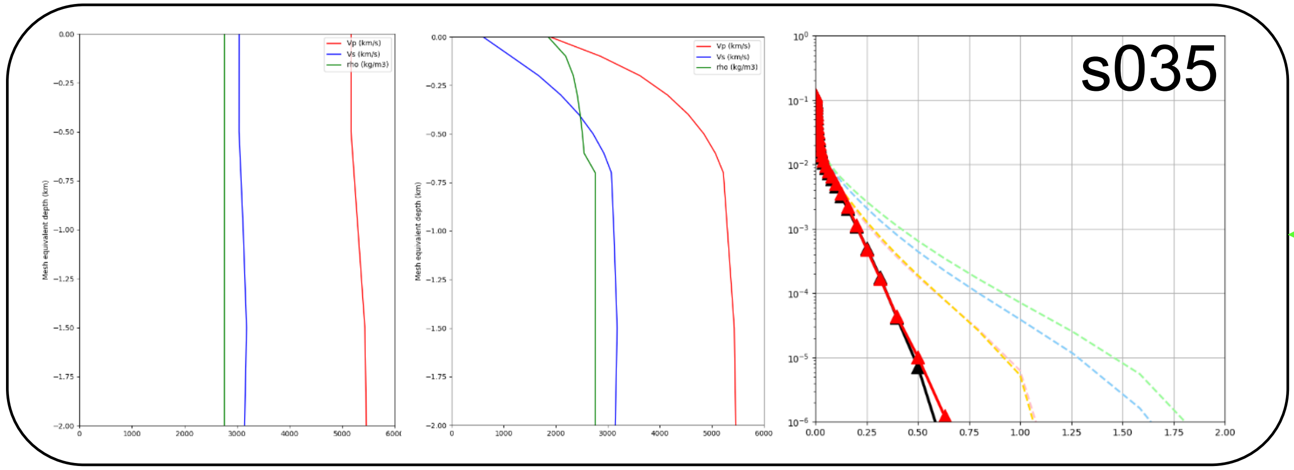
Study 22.12 site map

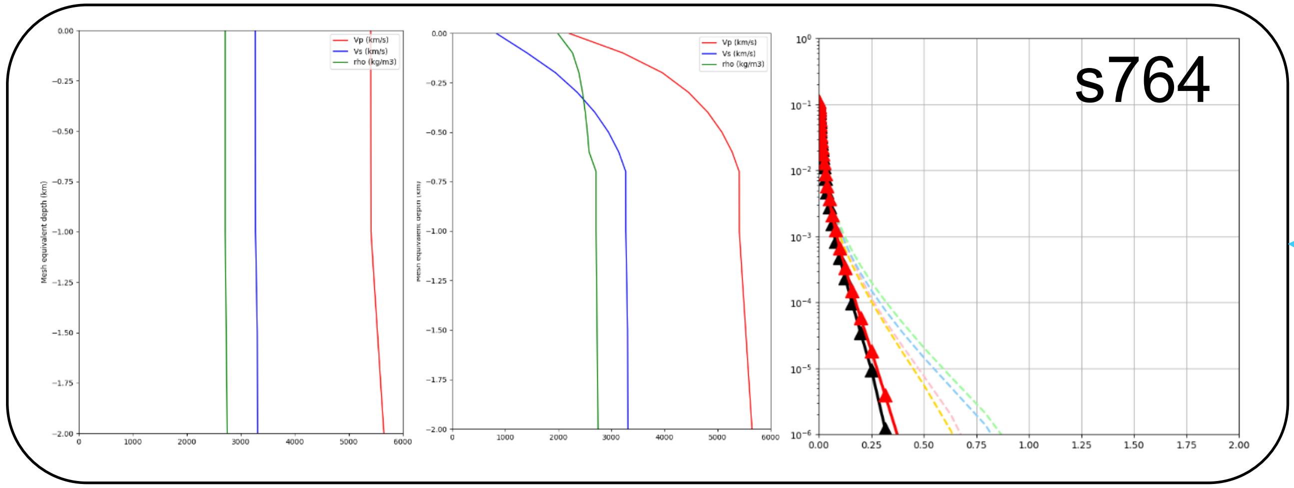
Change in Hazard, non-basin sites

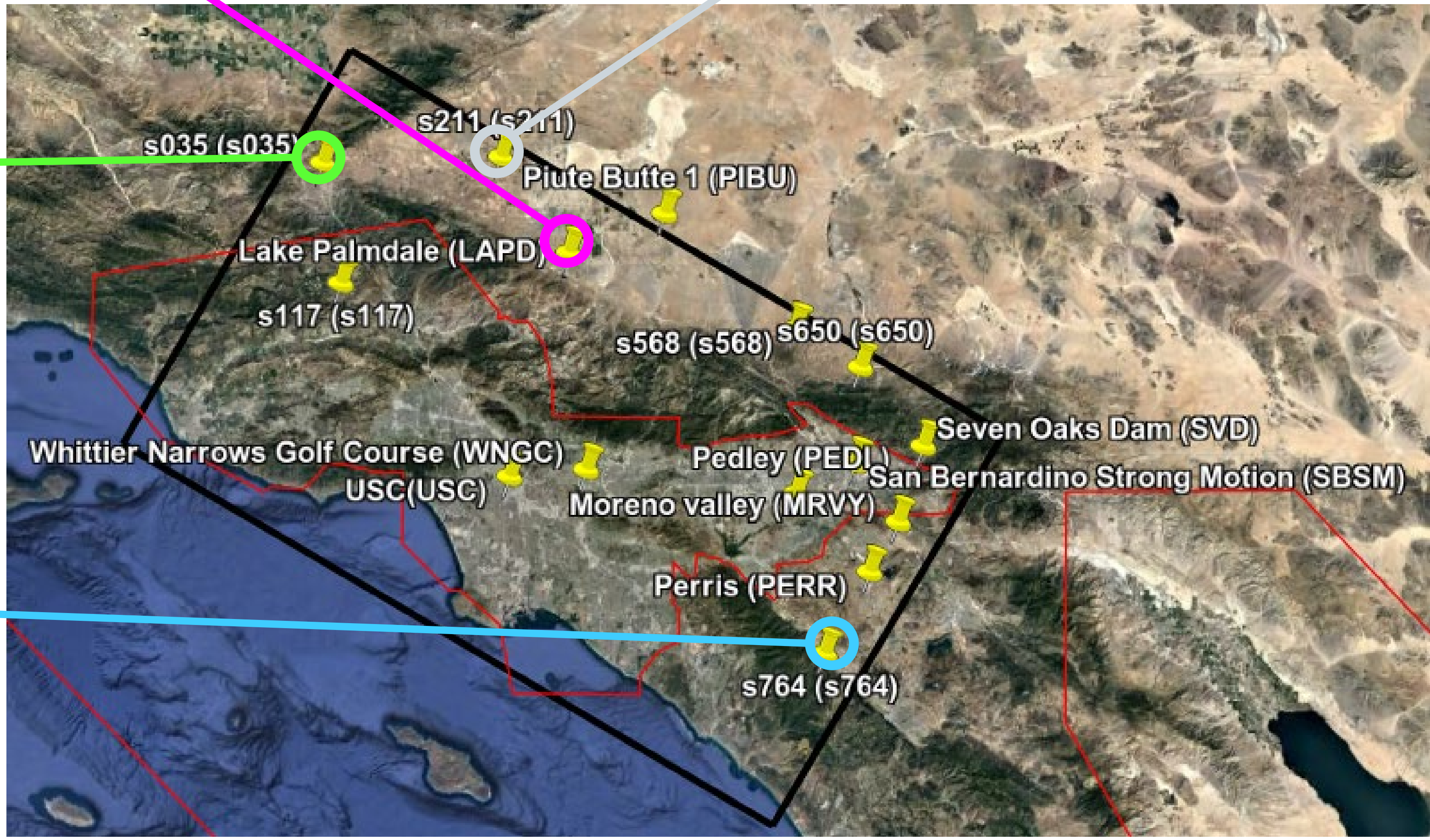


3 sec curves
Study 15.4
Study 22.12

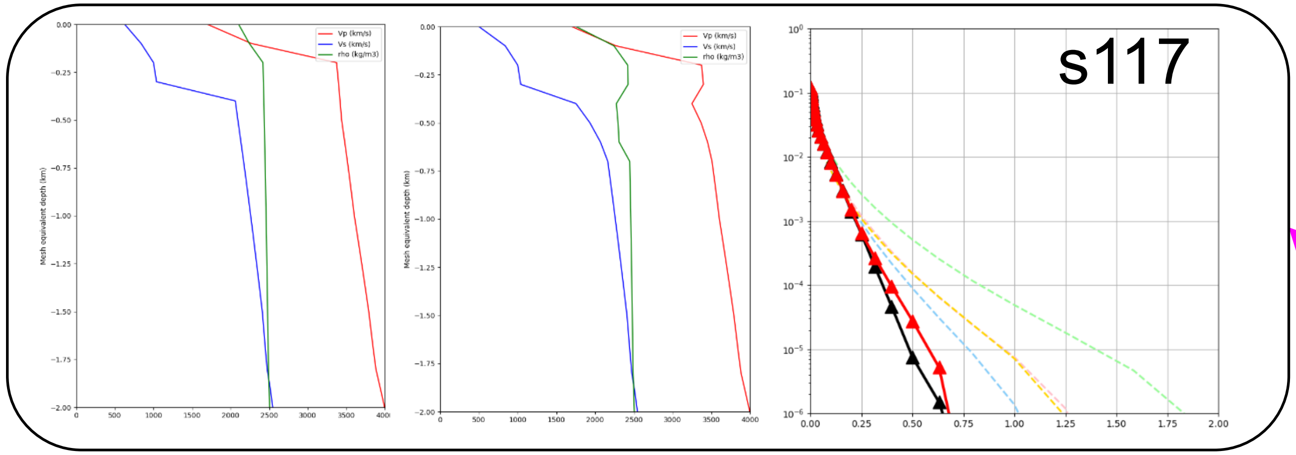




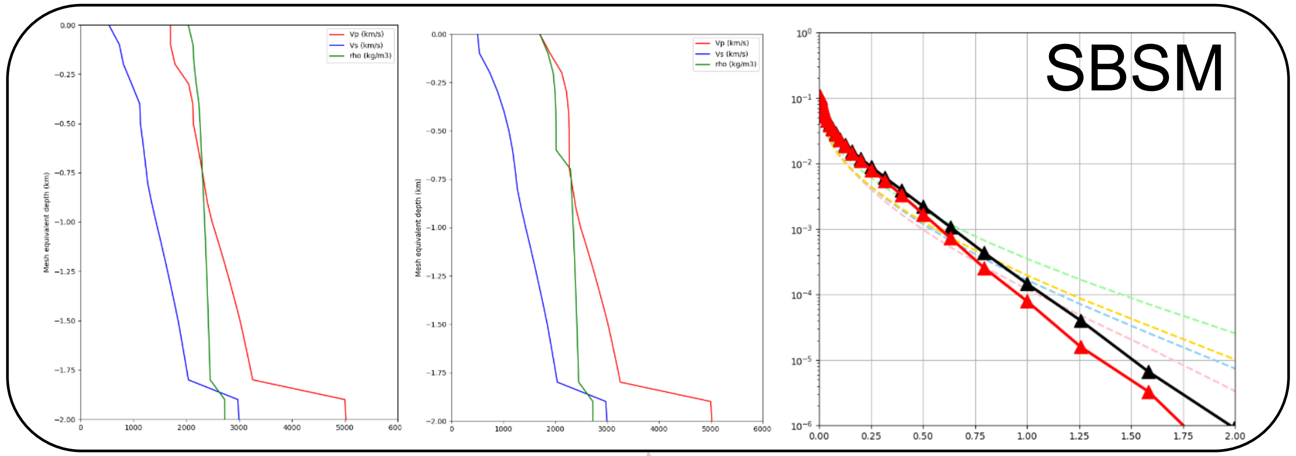


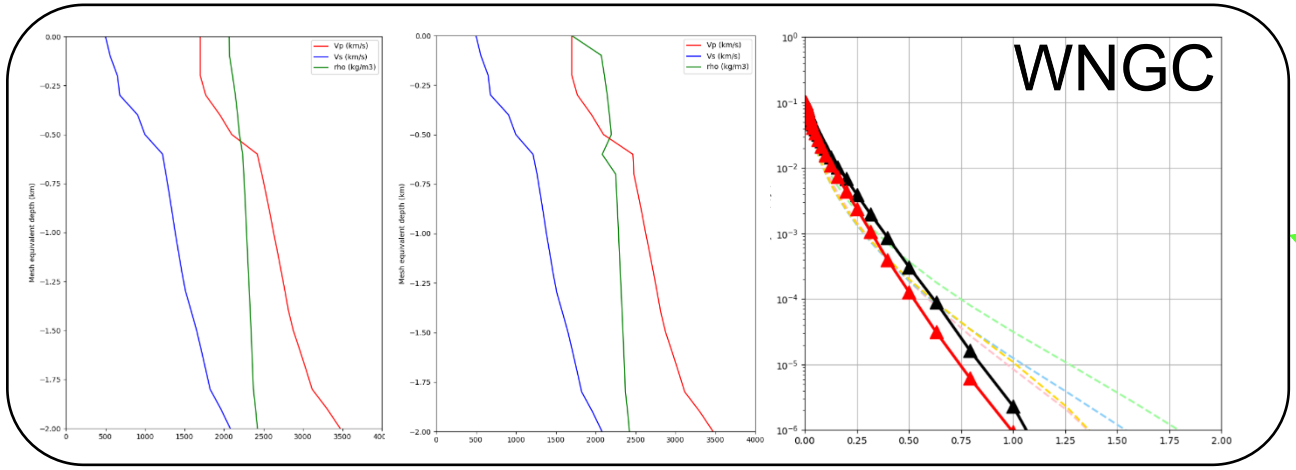


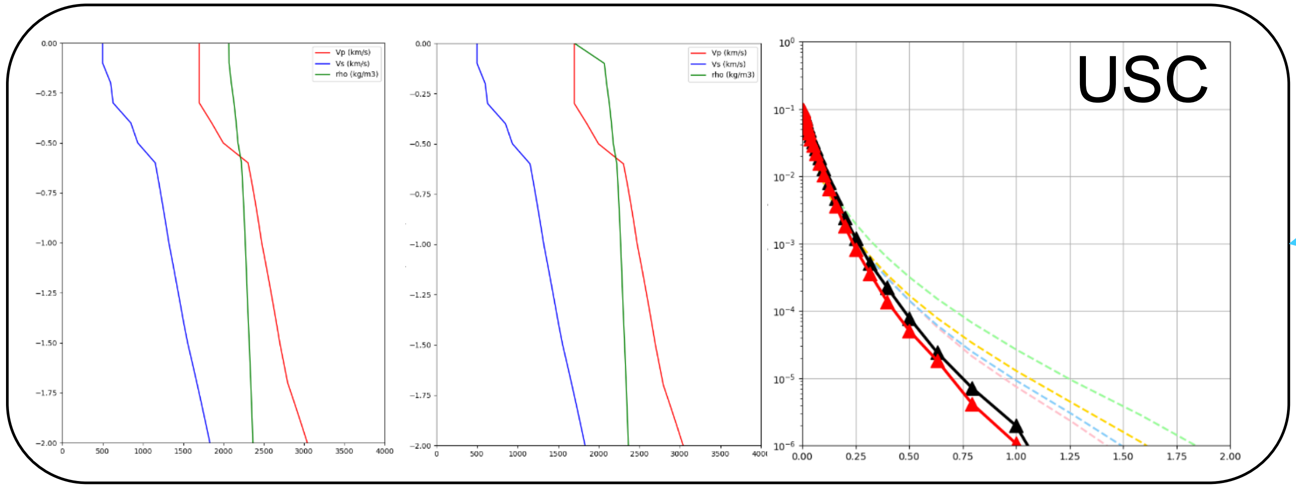
Change in Hazard, basin sites



3 sec curves
Study 15.4
Study 22.12





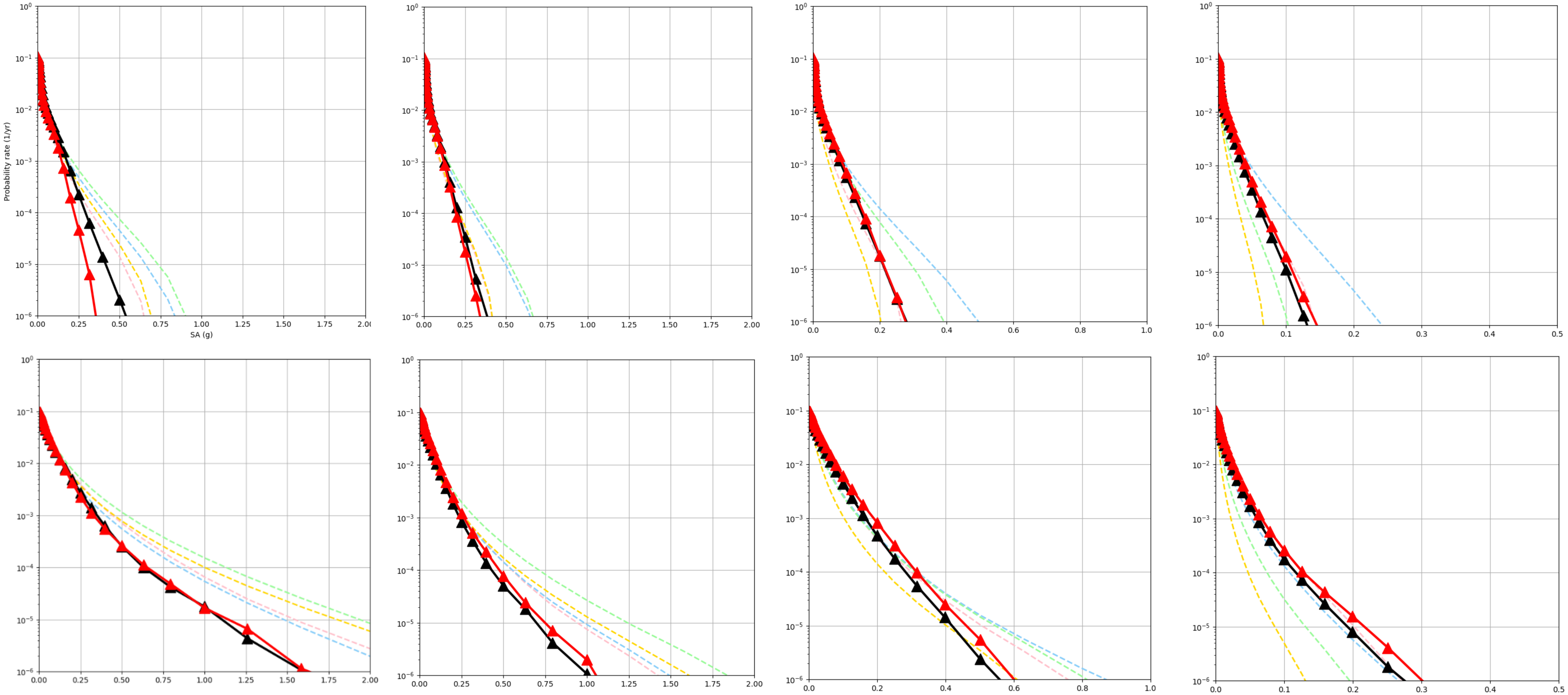


Study 22.12: Low-Frequency Curves

	2 sec RotD50	3 sec RotD50	5 sec RotD50	10 sec RotD50

LBUT (outside basin)

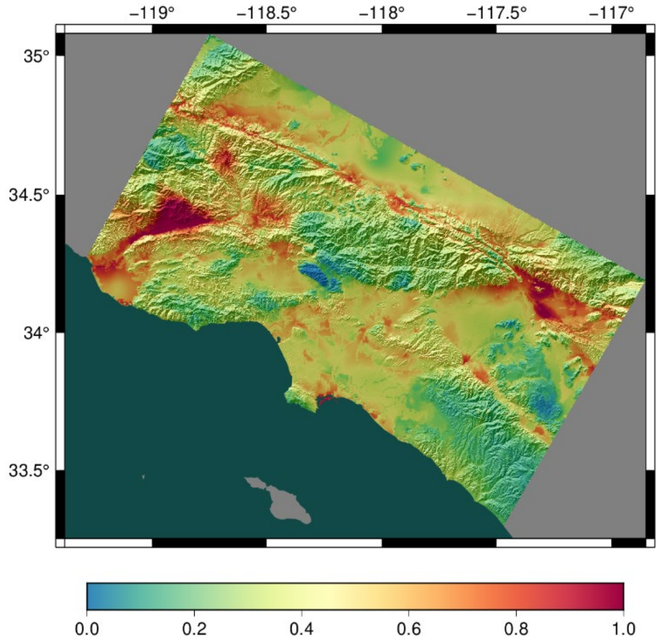
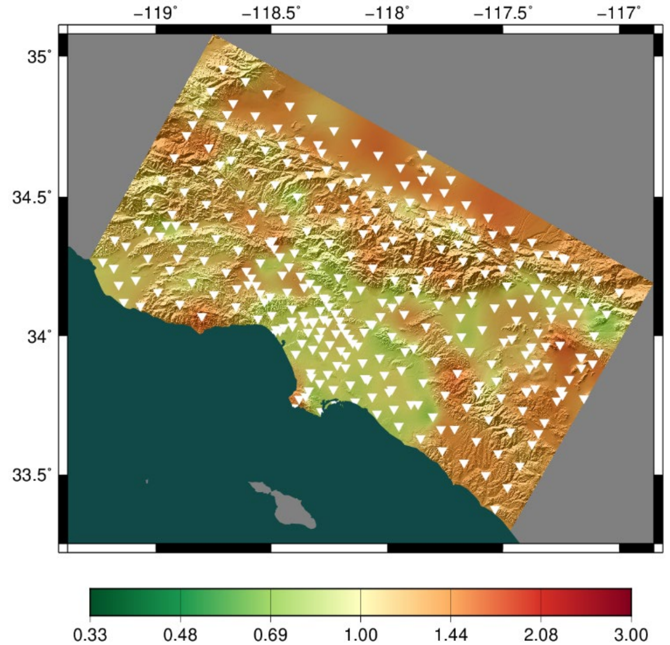
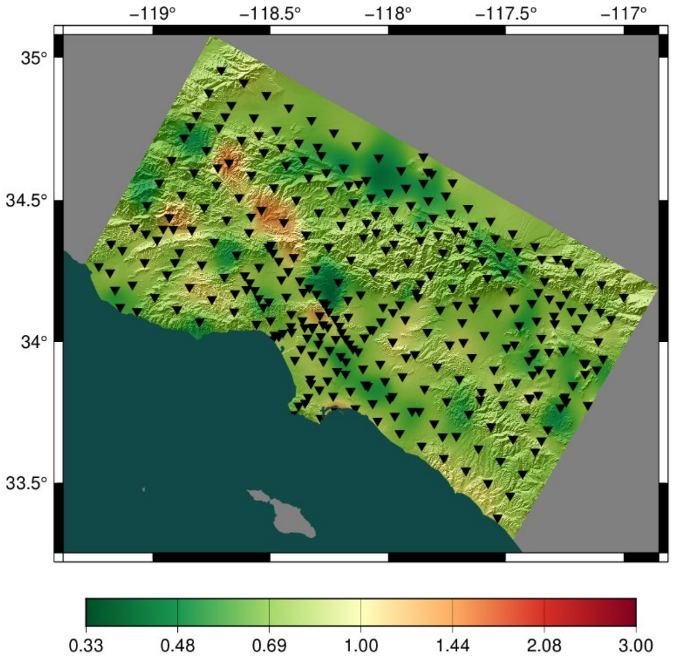
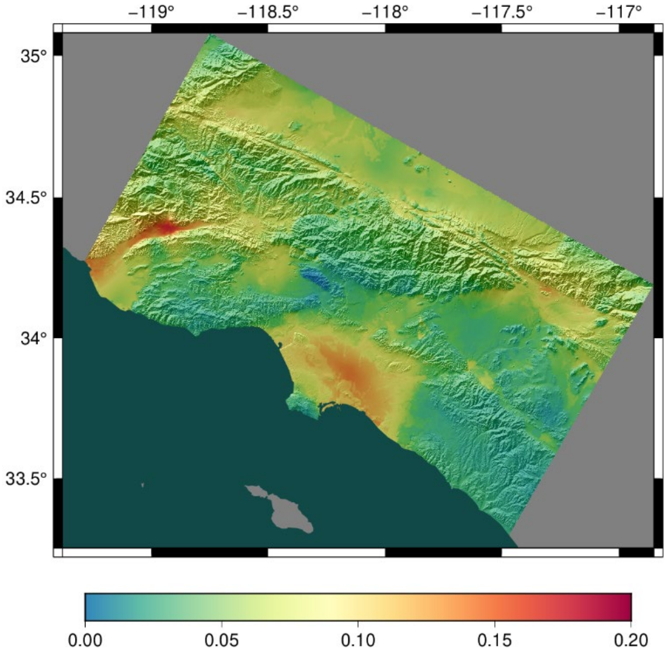
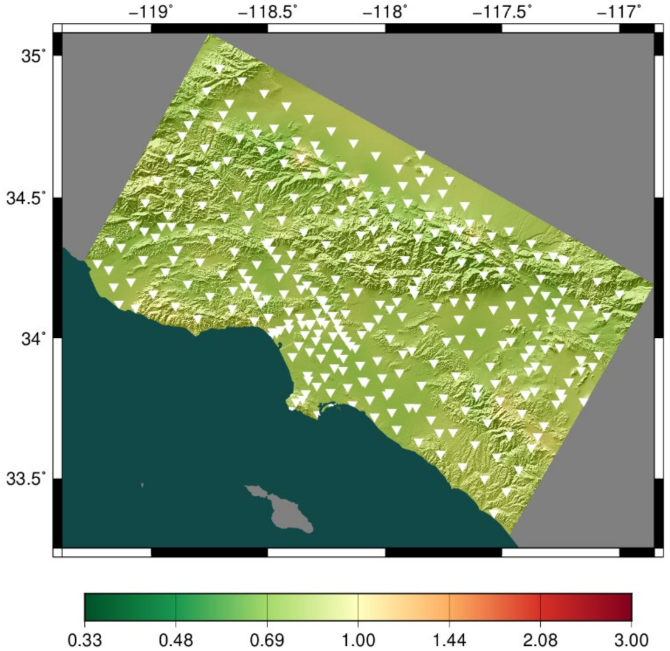
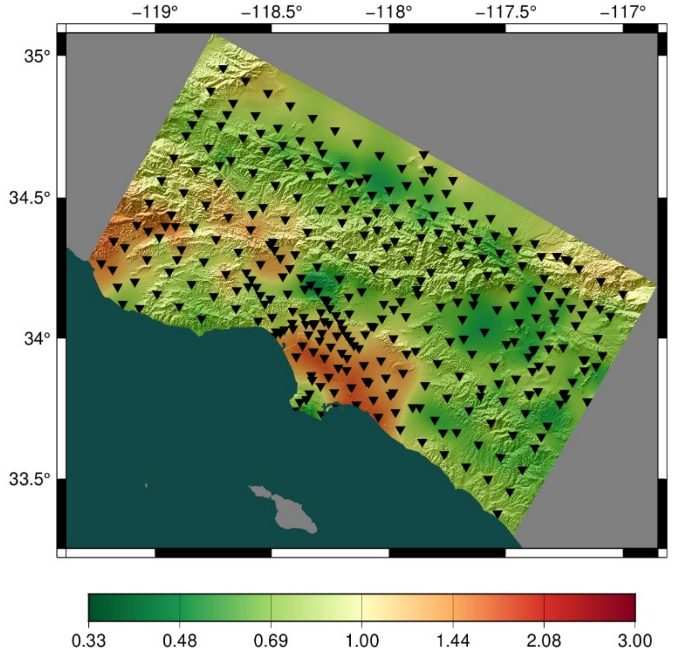
USC (inside basin)



Red: Study 15.4

Black: Study 22.12

Low-Frequency Results

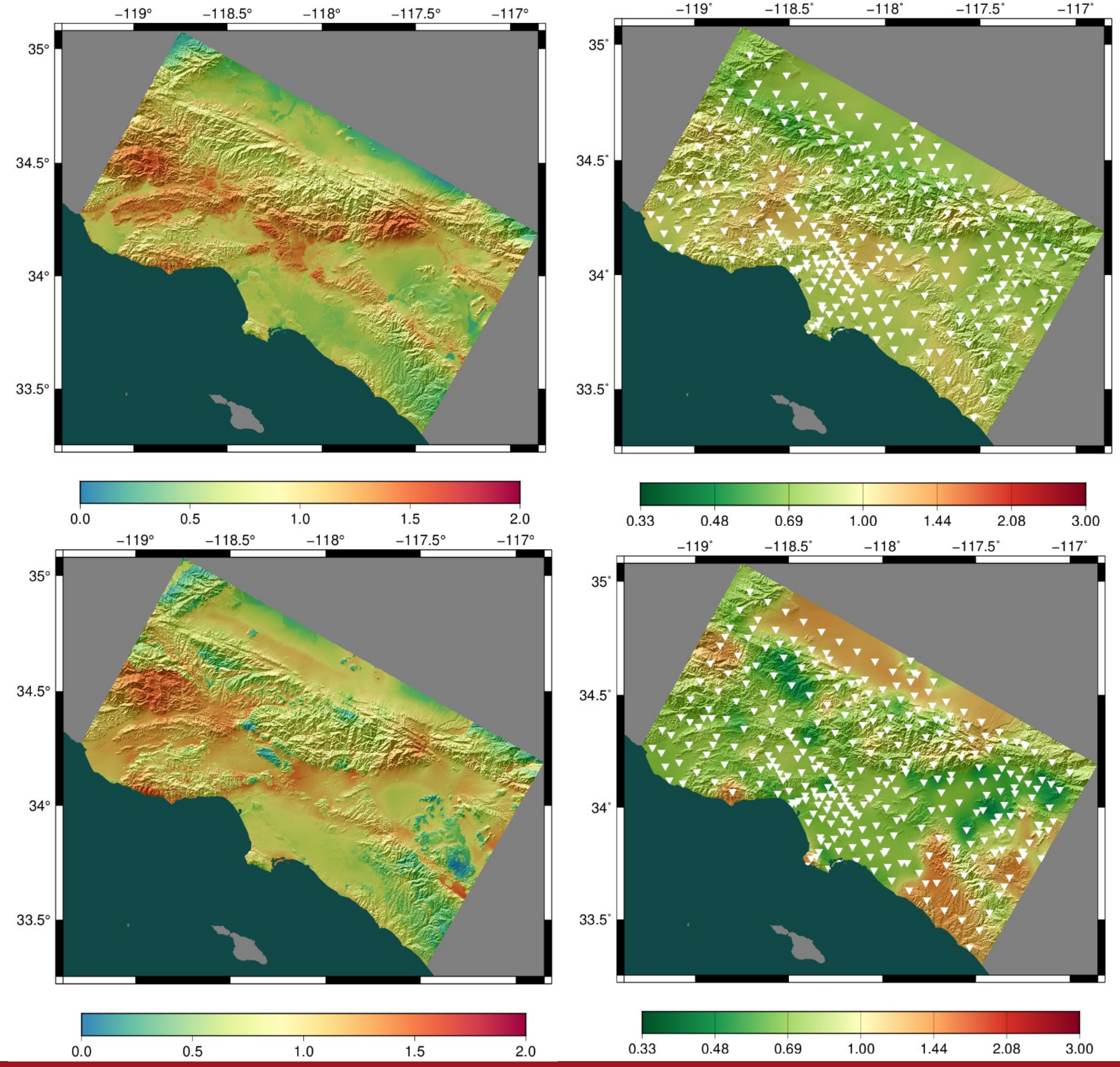
	Study 22.12	Ratio, 22.12/15.4	Ratio, 22.12/GMMs
2 sec, RotD50			
10 sec, RotD50			

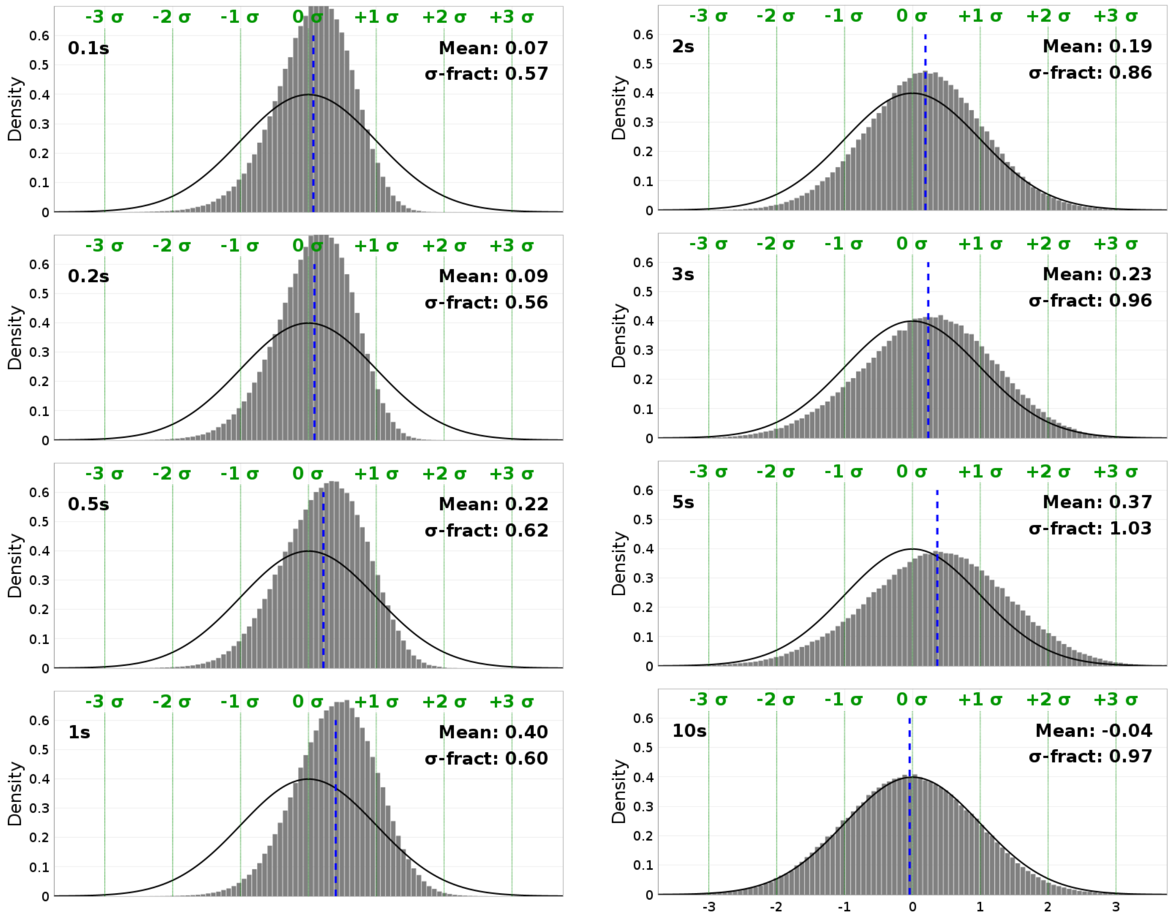
Study 22.12: Broadband Results

Study 22.12 | **Ratio, 22.12/15.12**

0.1 sec, RotD50

0.5 sec, RotD50

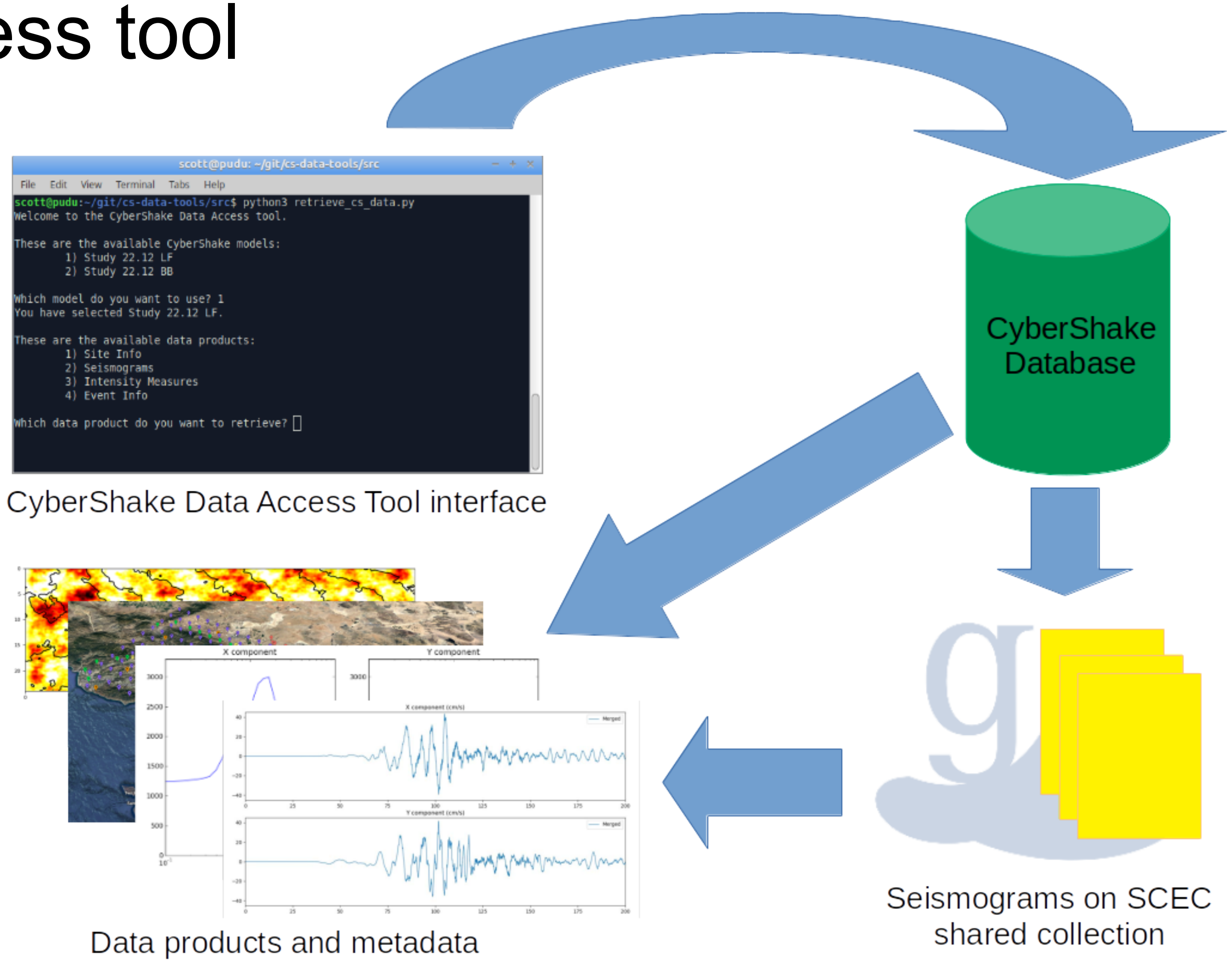




Distribution of z-scores between 22.12 BB and ASK2014

Study 22.12: Data Access

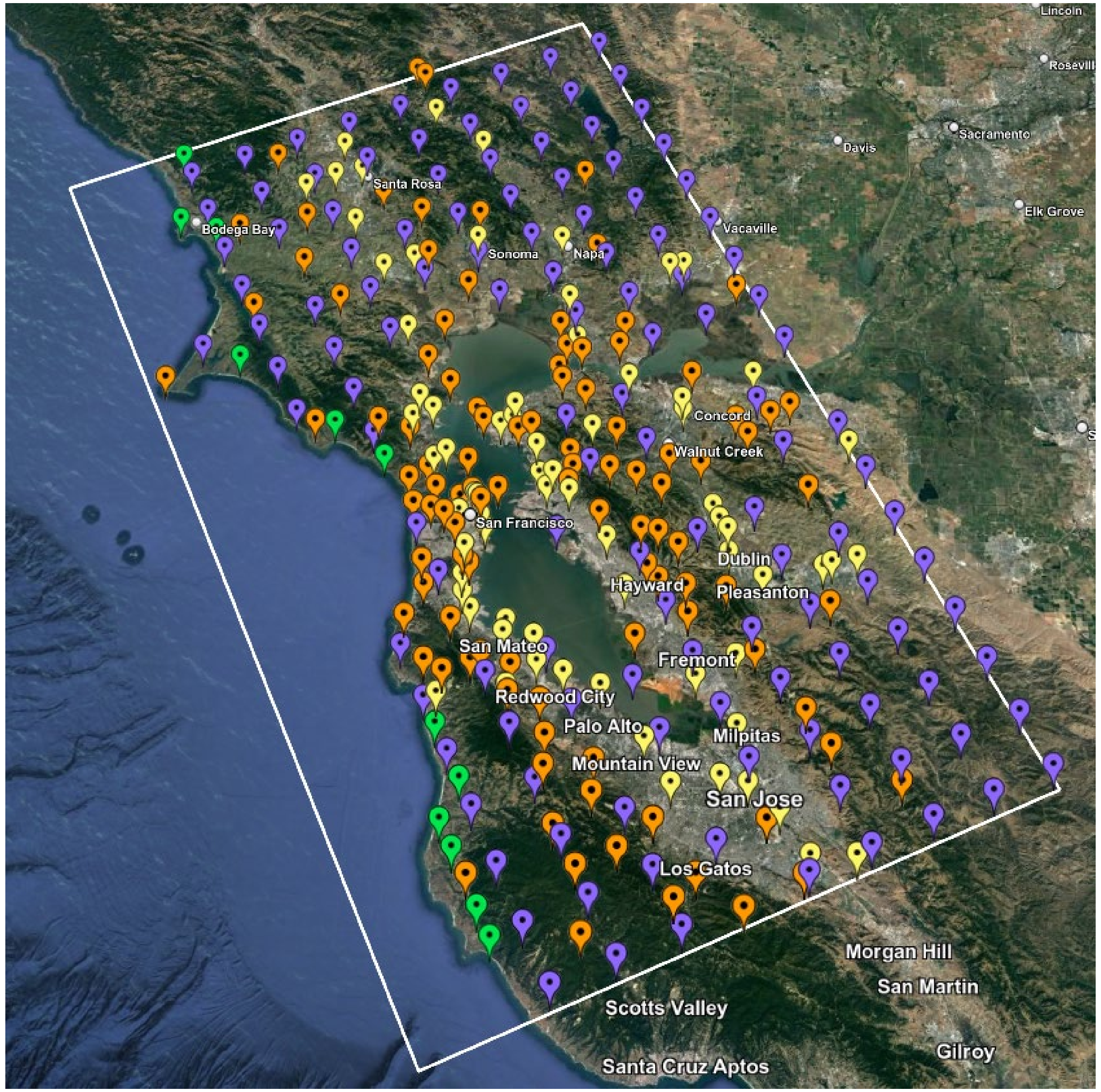
- Developed CyberShake data access tool
  - Python-based
  - Asks user series of questions
  - Applies filters to select subset
- Simplifies access to variety of CyberShake data products
  - Site metadata
  - Event metadata
  - Intensity measures
  - Seismograms



- Available on github: https://github.com/SCECcode/cs-data-tools/

Next Study

- Preparing for Study 24.1
  - Greater Bay Area
  - Similar to Study 22.12
  - Just got the compute time this week!
- Currently evaluating 3D velocity models
- Will validate with Central and Northern CA BBP validation events



Study 24.1 site map

Future Plans

- Increase deterministic frequency to 2 Hz
  - Frequency-dependent attenuation
  - Small-scale velocity heterogeneities
- Include nonlinear simulations
  - Reciprocity is by definition linear
  - Identify subset of events for full nonlinear simulations
  - Apply pseudo-nonlinearity to reciprocity results
- Streamline process of integrating new codes and models
  - Goal is to support multiple codes for each stage
  - Supports improved quantification of uncertainty

Thanks!

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