Preliminary results: Northern California CyberShake Simulations Study 18.8

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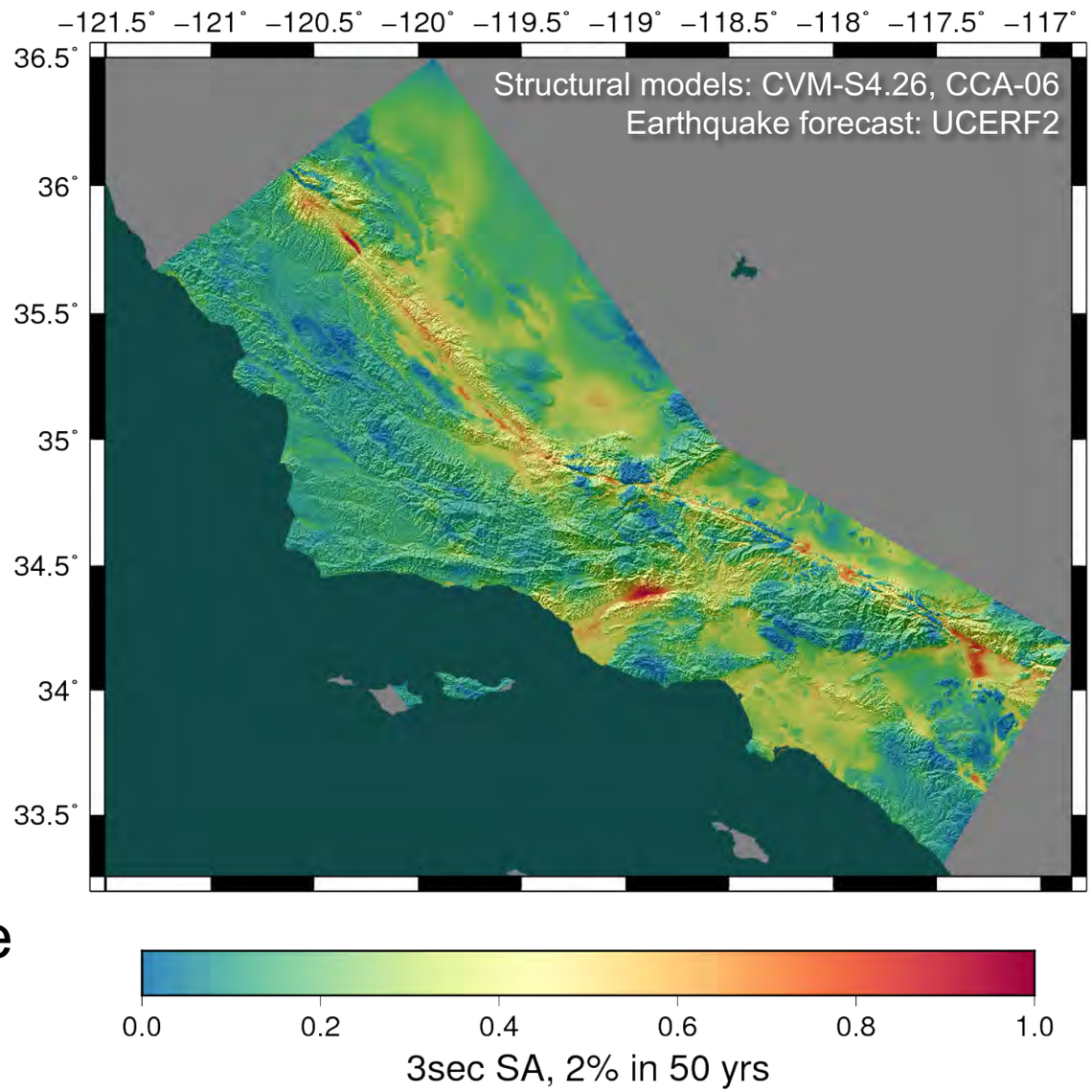
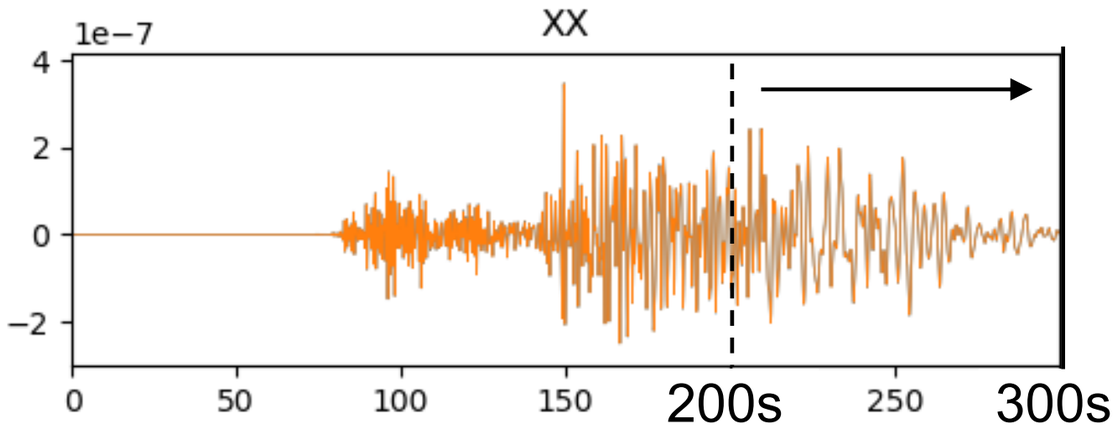
CyberShake Overview

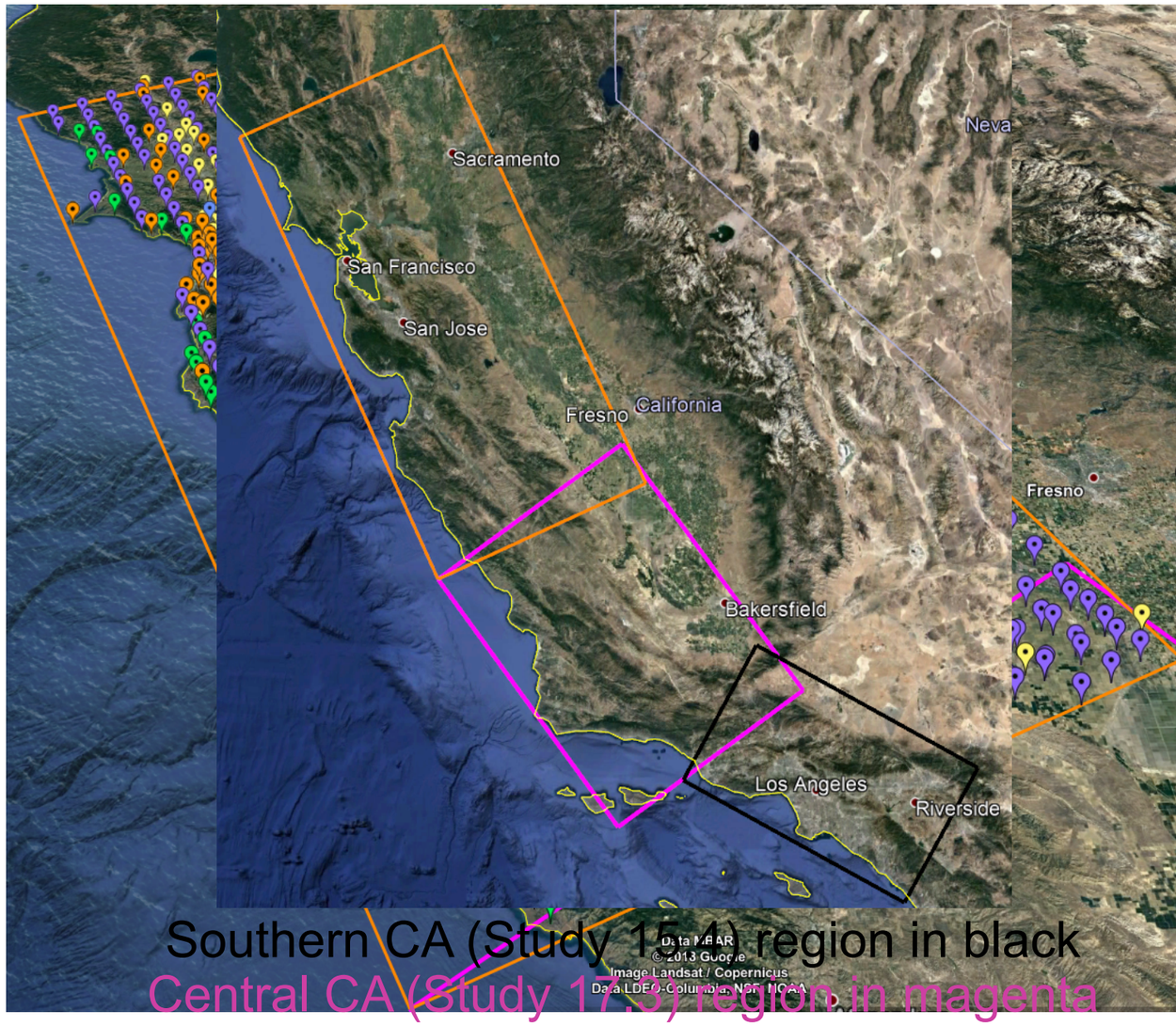
- Southern California Earthquake Center's 3D physics-based probabilistic seismic hazard analysis (PSHA) platform
- UCERF2 ERF (M≥6.5, ≤200 km) with Graves & Pitarka rupture generator (~500,000 events per site)
- Reciprocity-based approach to simulate seismograms (AWP-SGT code)
- Intensity measures (RotD50 PSA, PGA, CAV, IA duration…) derived from seismograms
- Hazard results from individual sites interpolated with NGA-West2 GMMs to create map



Northern California: Study 18.8

- After success of SoCal and Central California CyberShake, moved further north where CVMs are available
- 869 locations
- 1 Hz
- Vs min = 500 m/s
- Longer SGTs for some sites

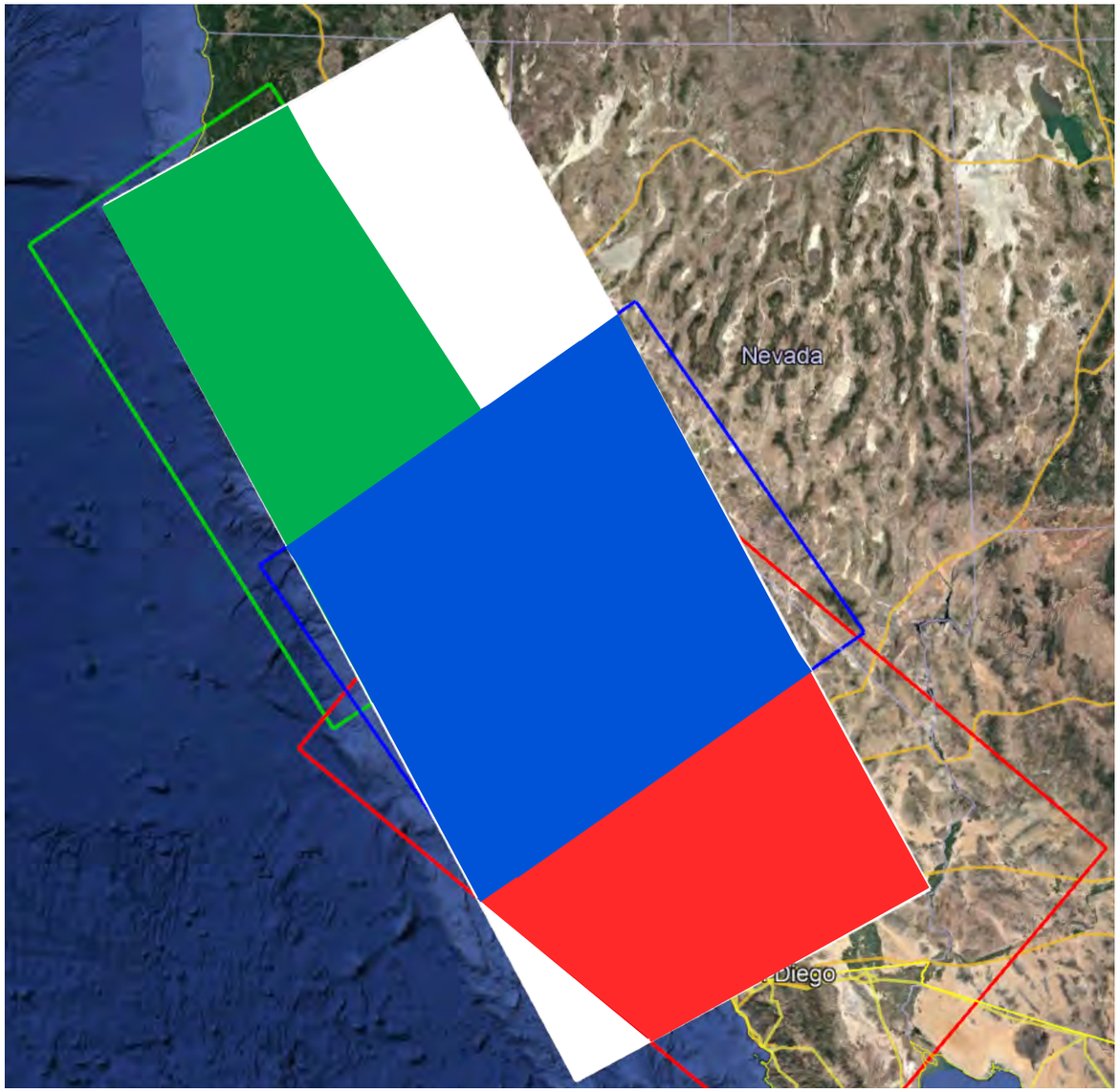




Southern CA (Study 15.4) region in black
Central CA (Study 17.3) region in magenta
Bay Area (Study 18.8) region in orange
869 sites, densest near San Francisco Bay

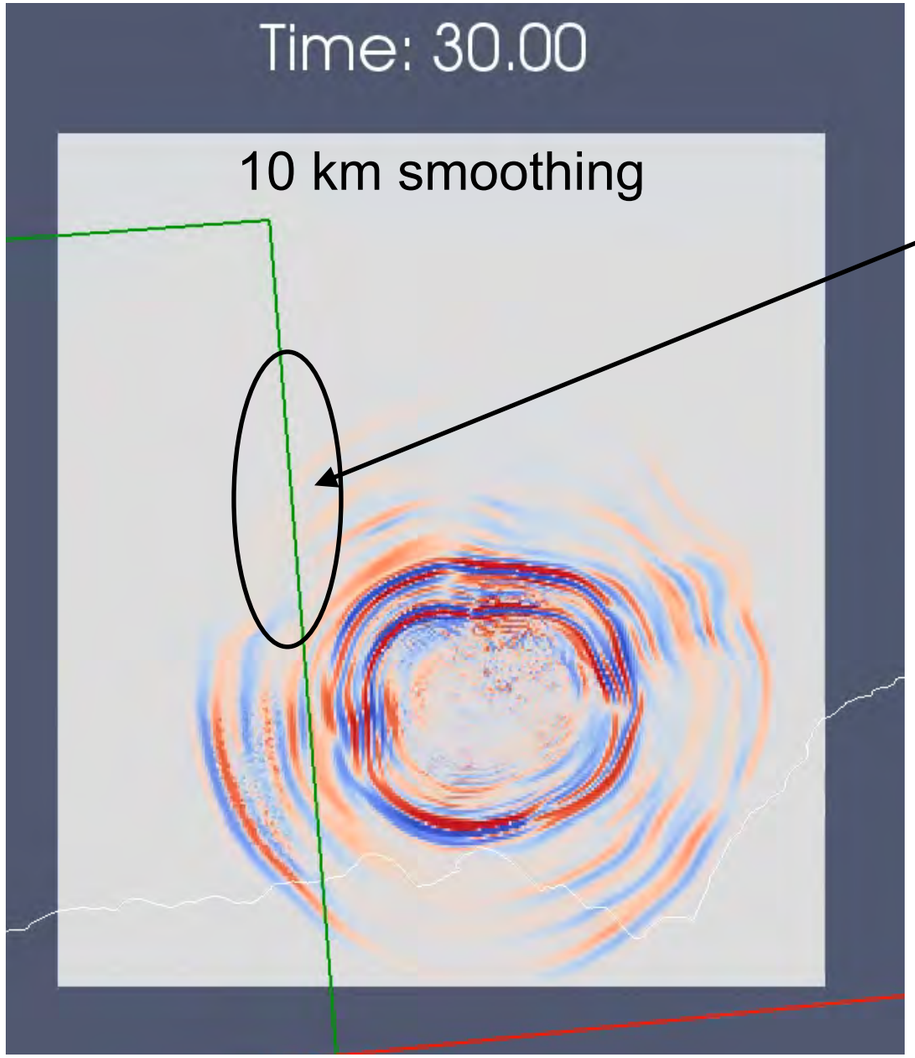
Combined Velocity Model

- No single model large enough for whole volume
- Stitch together models
  - CCA-06 + Ely GTL (blue)
  - USGS Bay Area (green)
  - CVM-S4.26.M01 (red)
  - 1D background model (white)
- Apply smoothing along model interfaces
  - Average of neighbor values



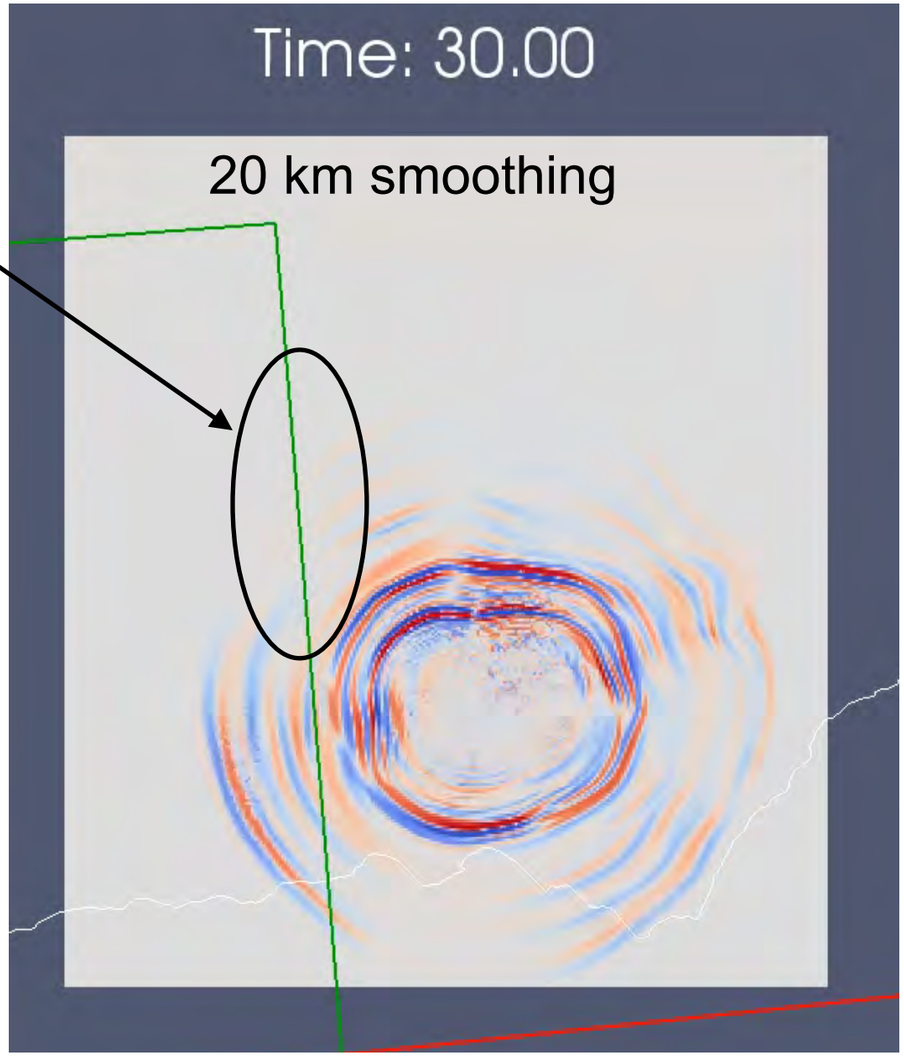
Smoothing Zone

- Performed forward simulations near model interface to test smoothing



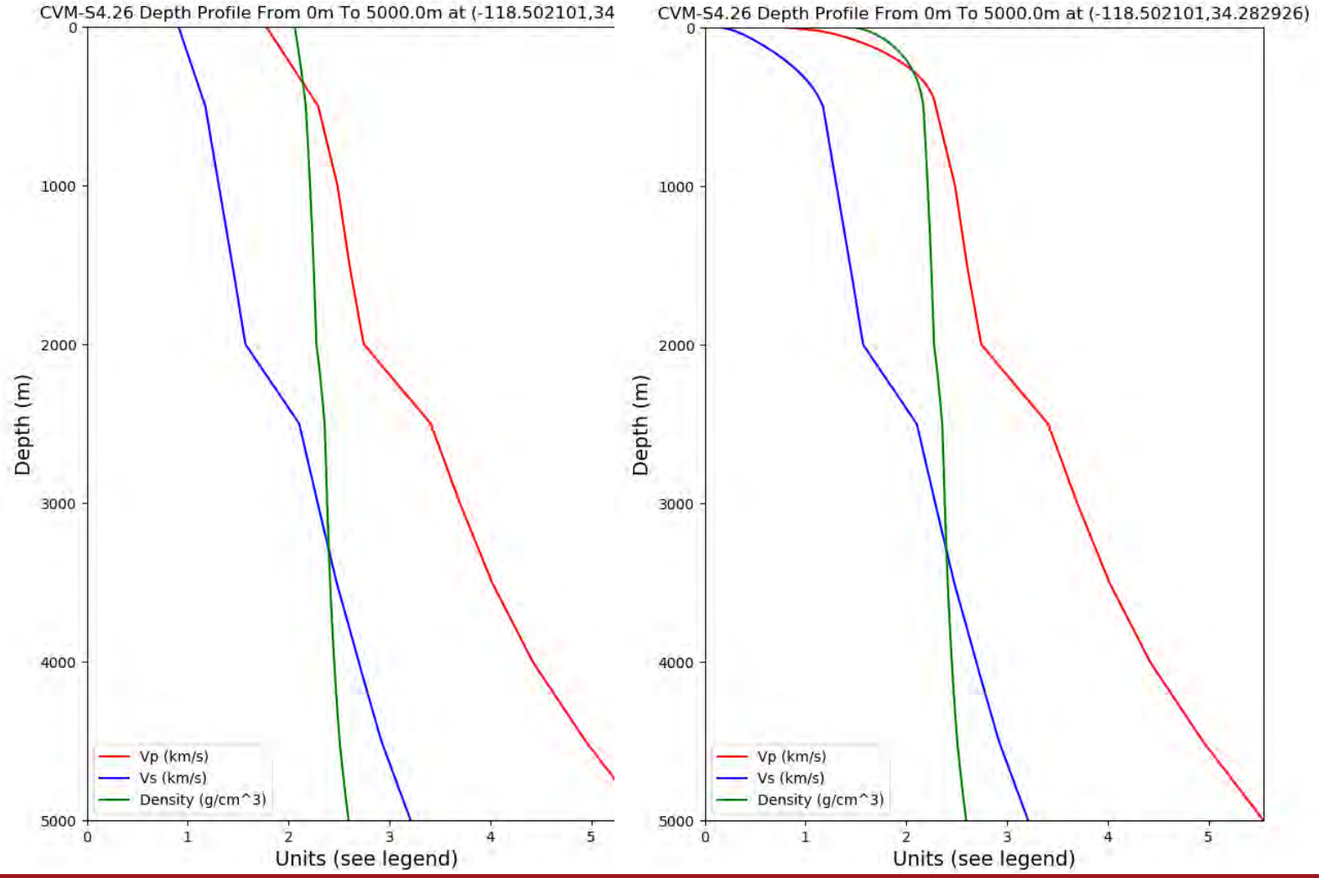
Wavefront encounters smoothed region

20 km smoothing shows reduced refraction effects



Shallow site model – Ely geotechnical layer (GTL)

- CCA-06 limited to Vs min=900 m/s used in tomography
- Wanted to include lower-velocity information with Study 18.8
- Added Vs30-derived GTL to top 500m using Ely (2010)
  - Wills (2015) as source for Vs30



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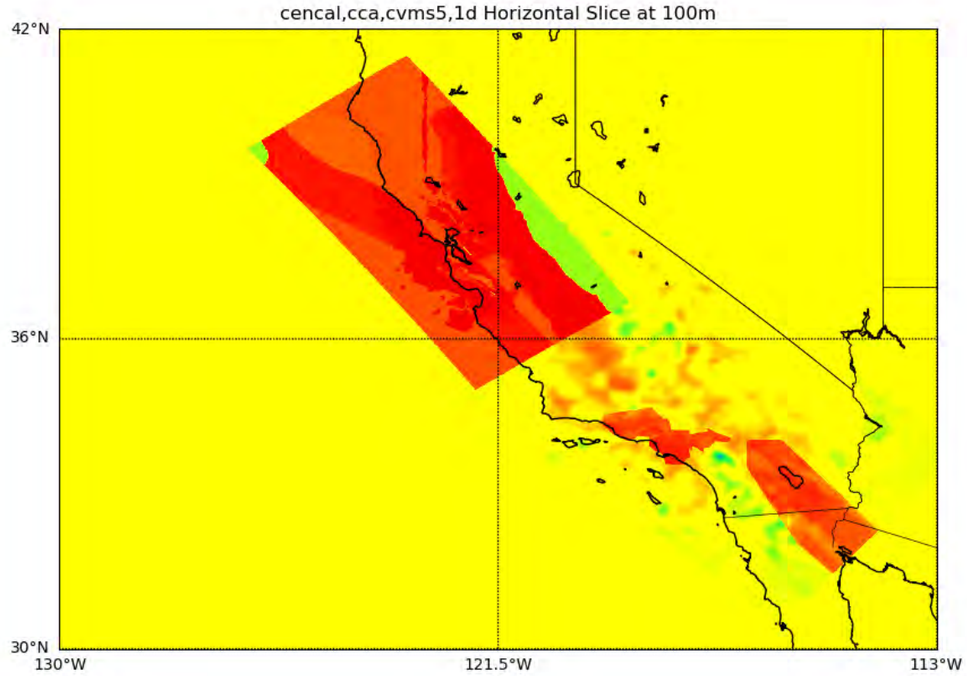
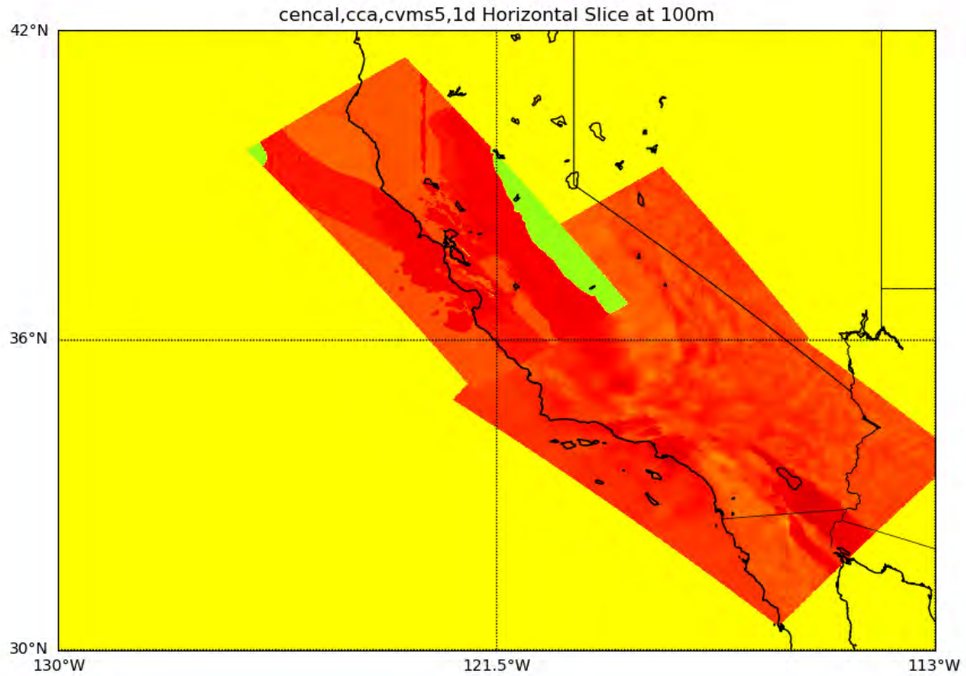
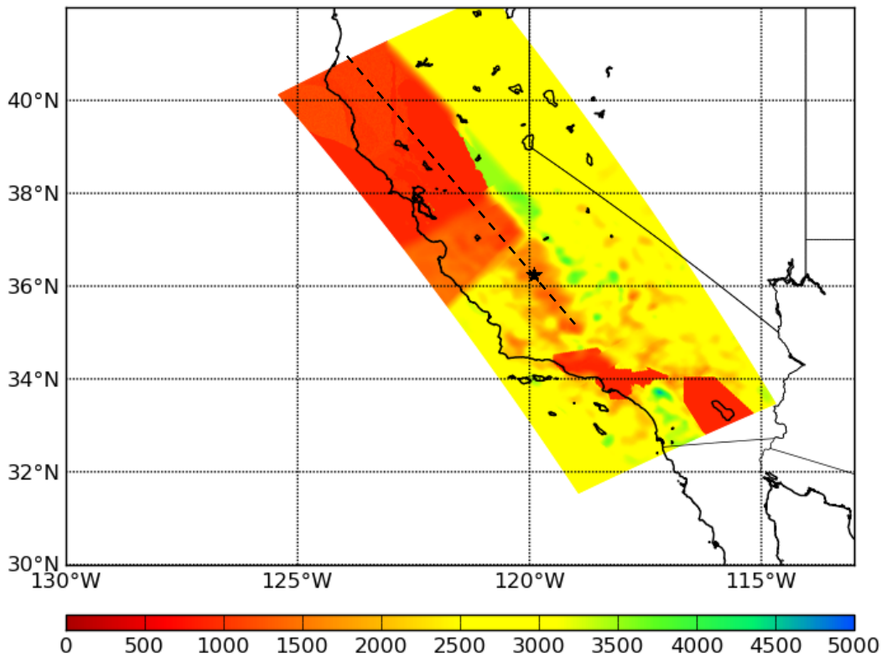


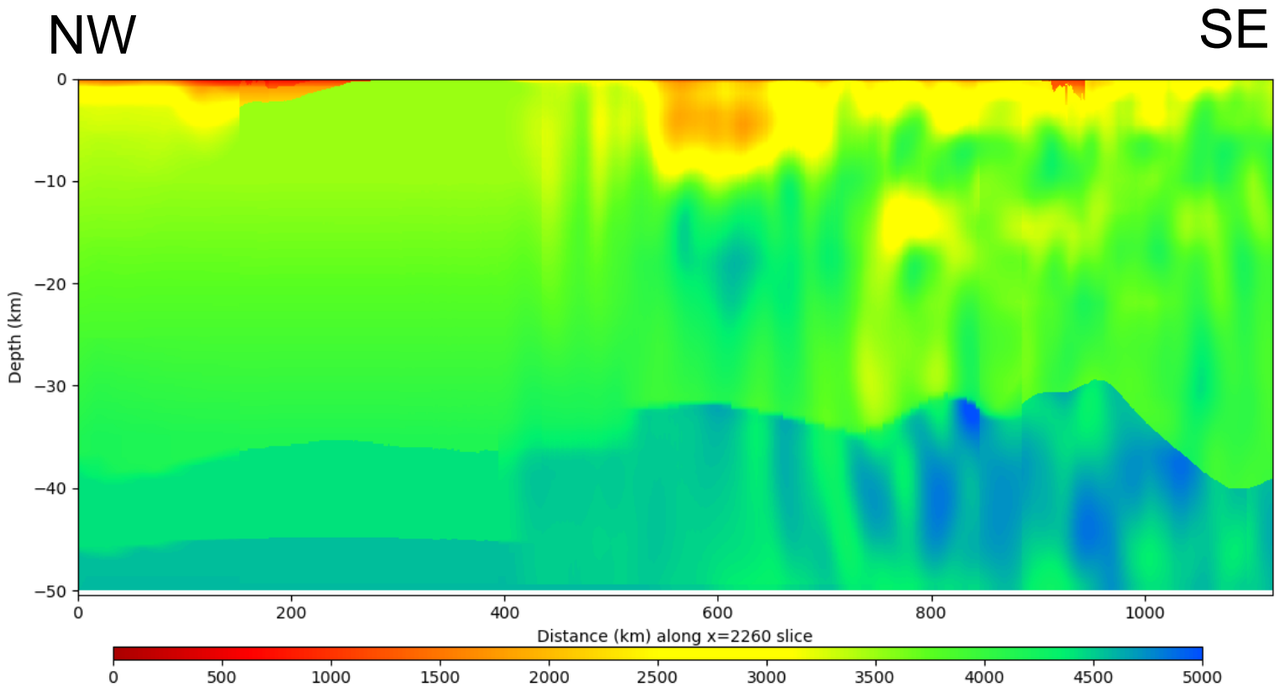
No GTL applied



Ely GTL applied

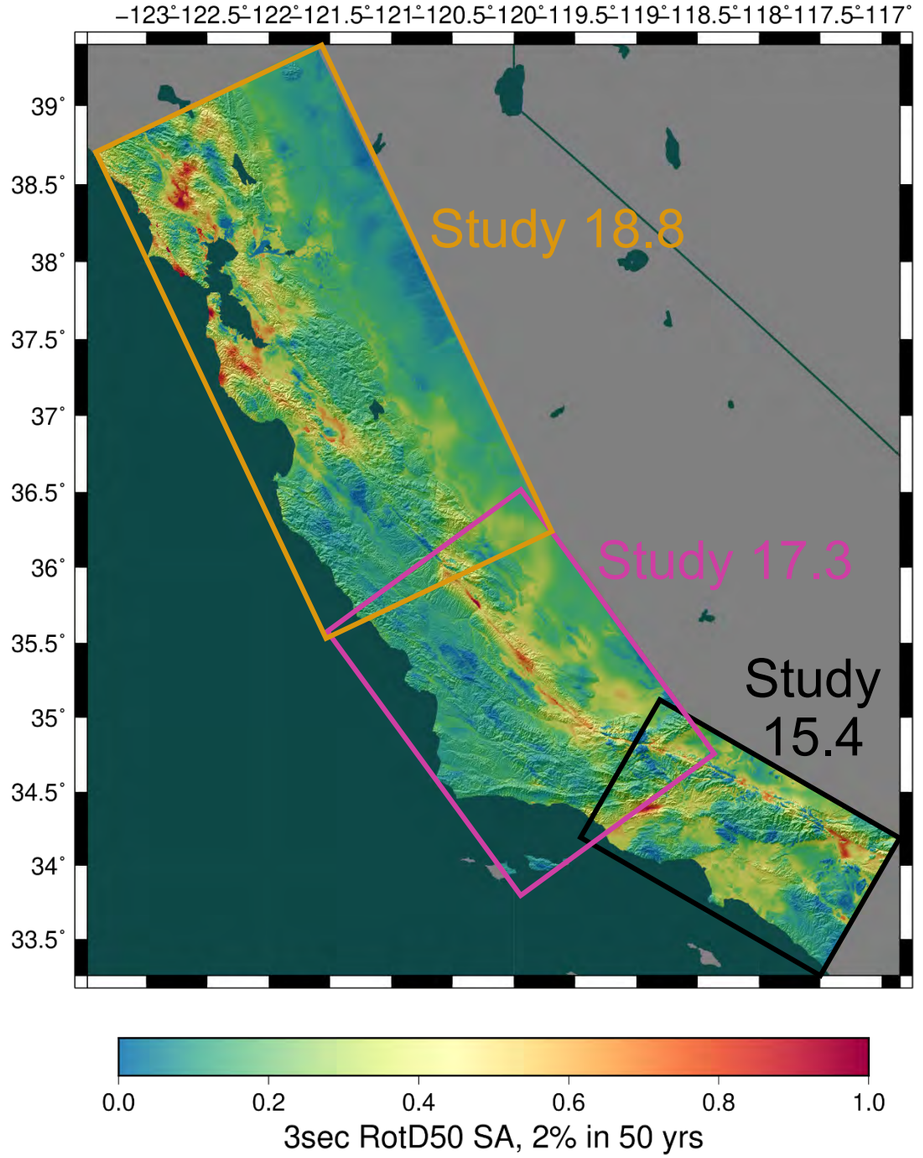
Smoothing Zone with Ely GTL in CCA



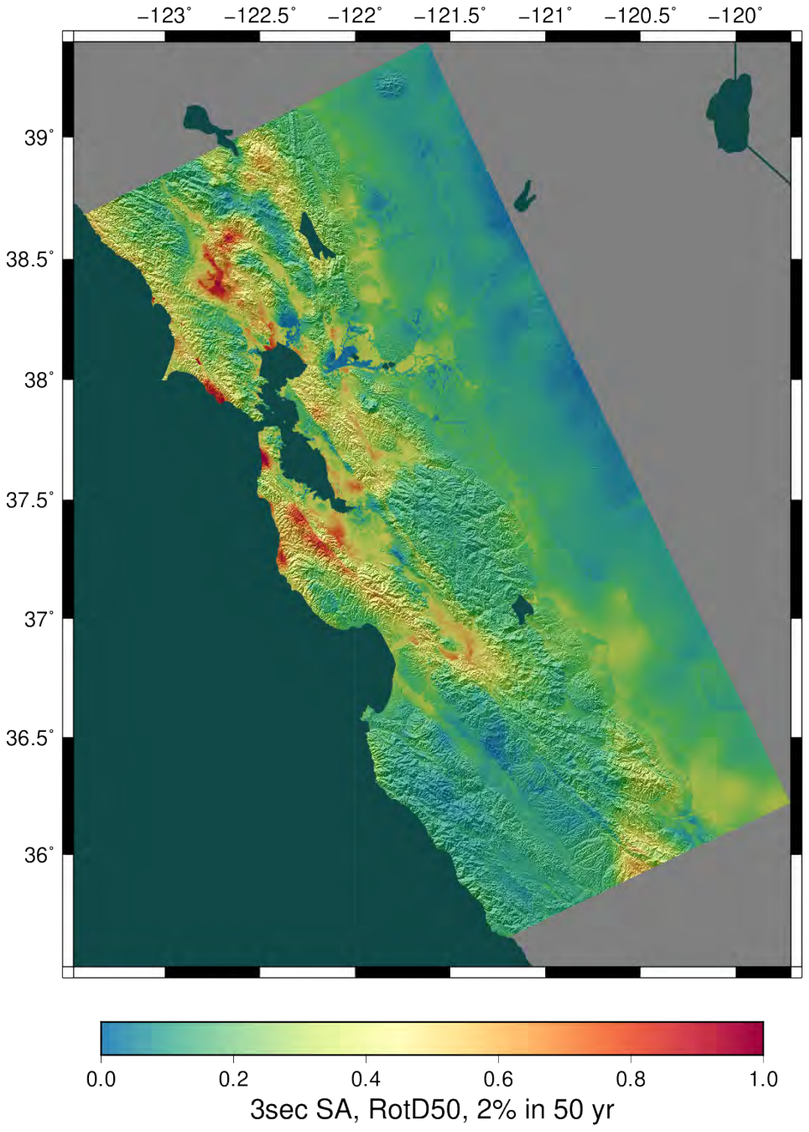


Study 18.8 Metrics

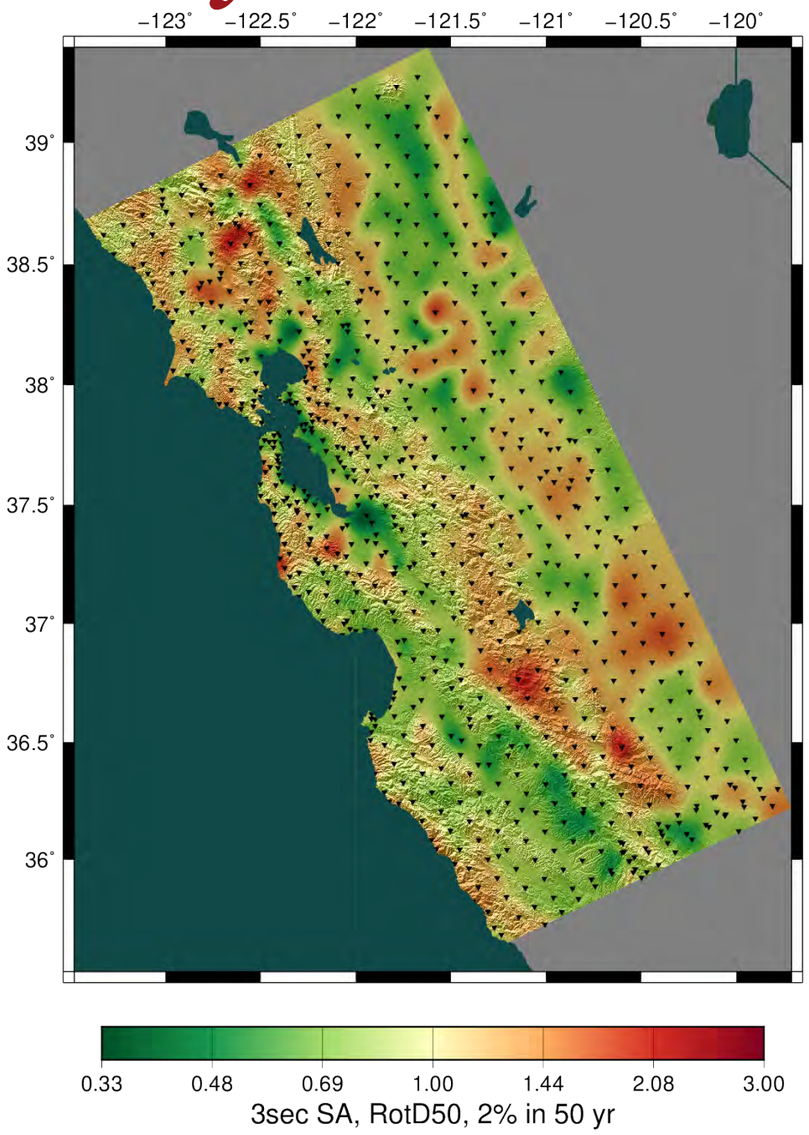
- Study conducted over 128 days
  - NCSA *Blue Waters*, OLCF *Titan*
- Consumed 6.2 million node-hours (120 million core-hours/13,650 core-years)
  - Averaged 2,018 nodes / 38,850 cores
- 1.2 PB of data generated
  - 14.4 TB of final data products
- Synthesized 203 million two-component seismograms
  - 30.4 billion intensity measures



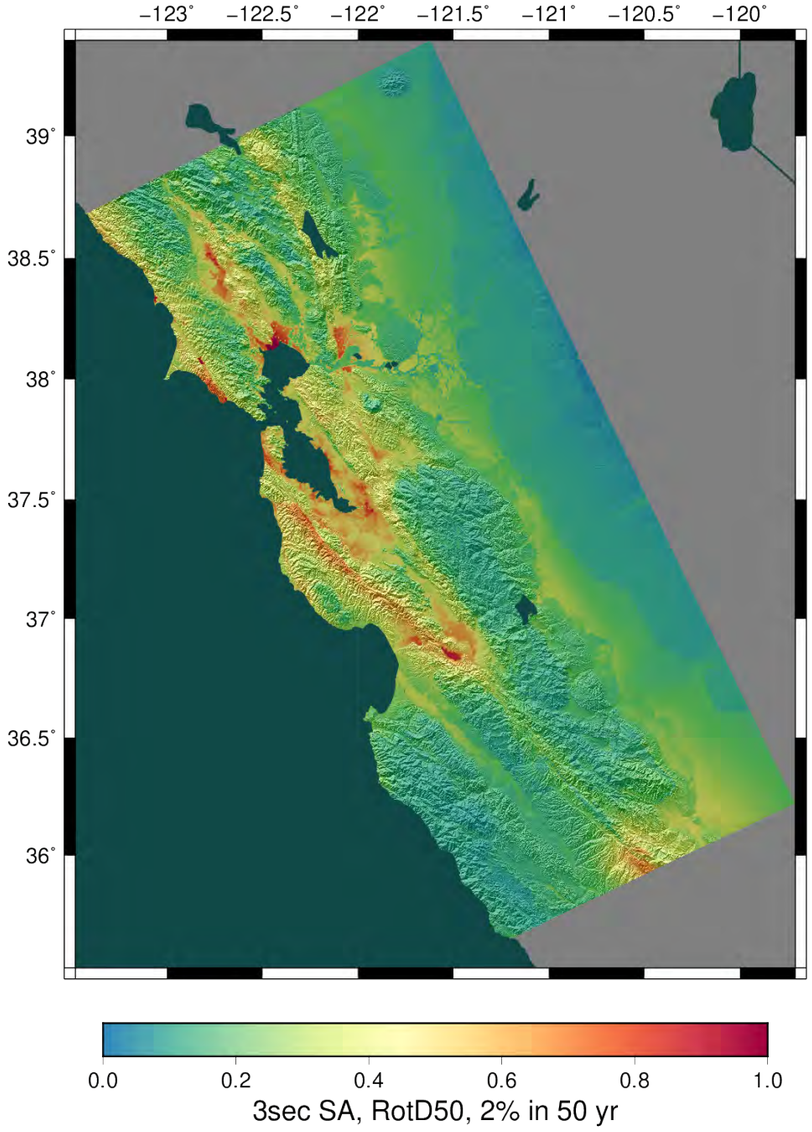
Study 18.8 Results



CyberShake

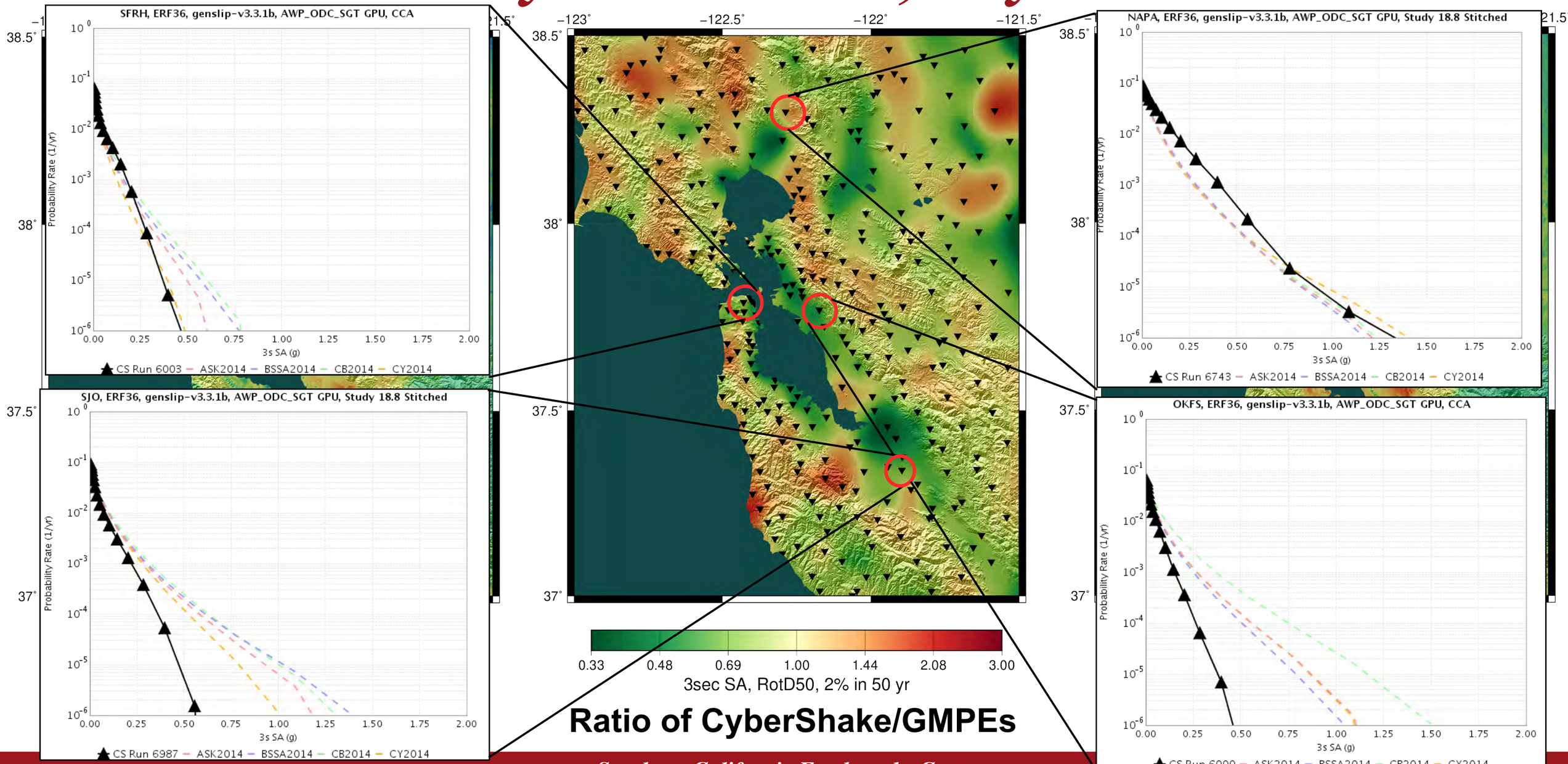


Ratio of CyberShake/NGA-West2 GMMs



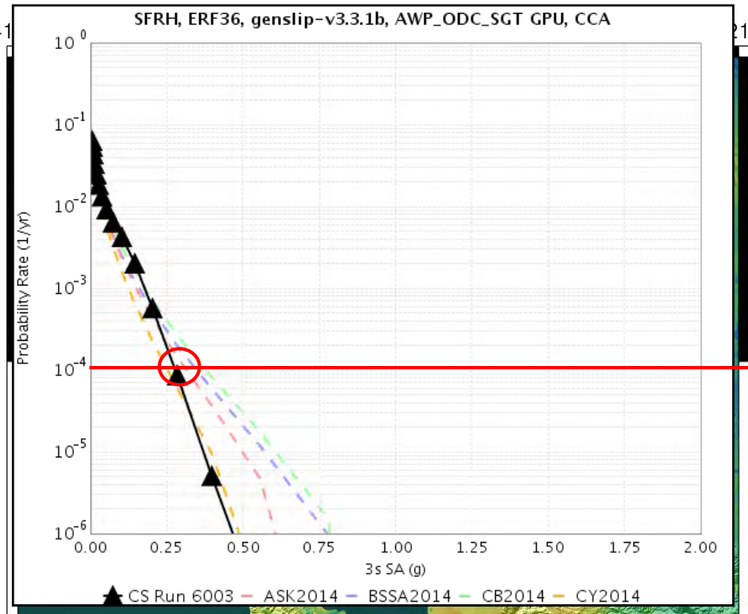
Avg of 4 NGA-West2 GMMs

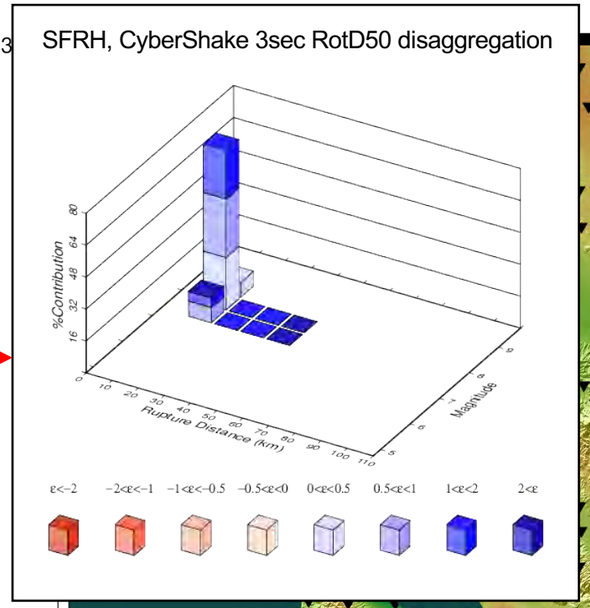
Study 18.8 Results, Bay Area

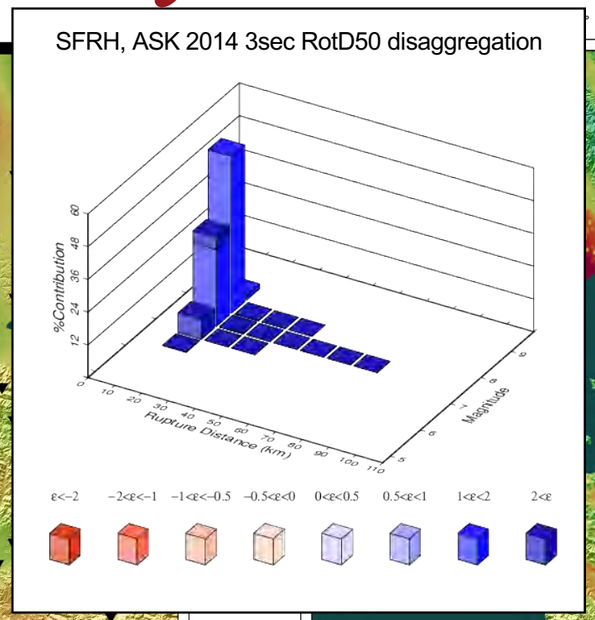


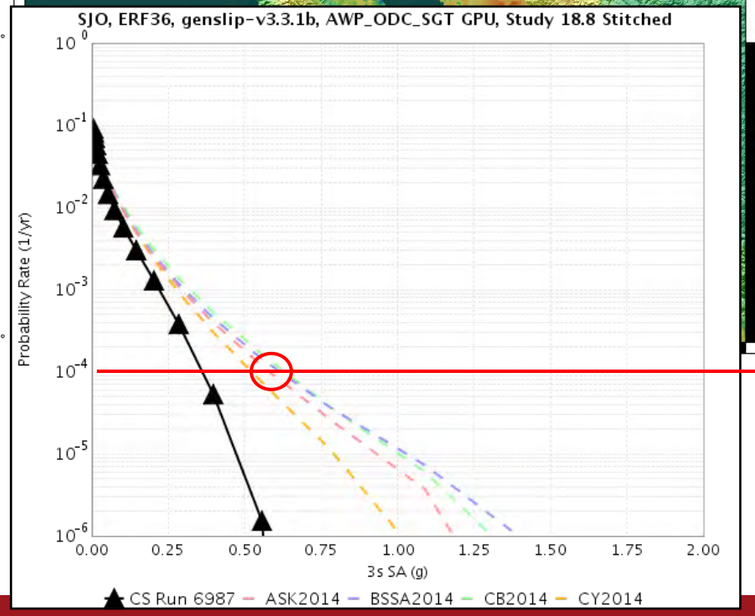
Ratio of CyberShake/GMPEs

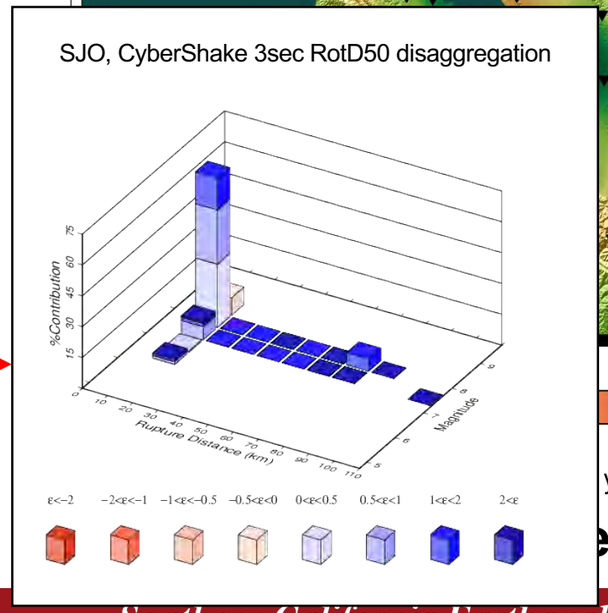
Study 18.8 Results, Bay Area

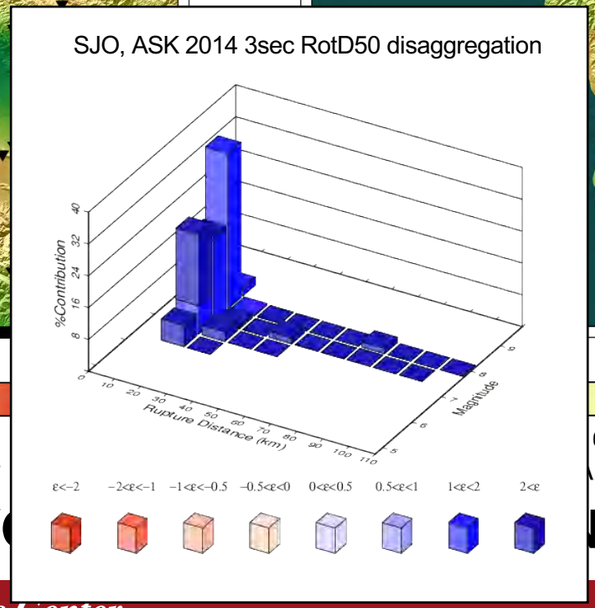


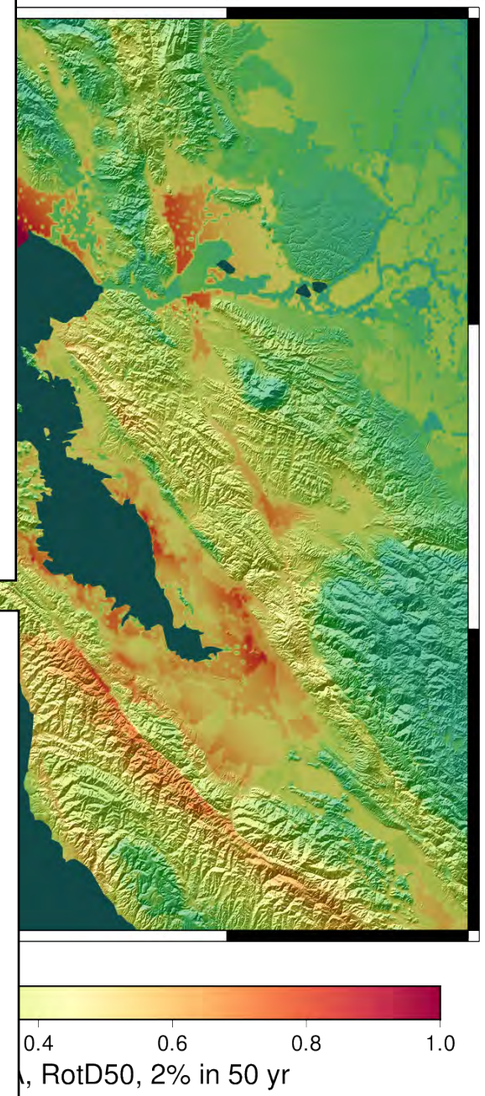






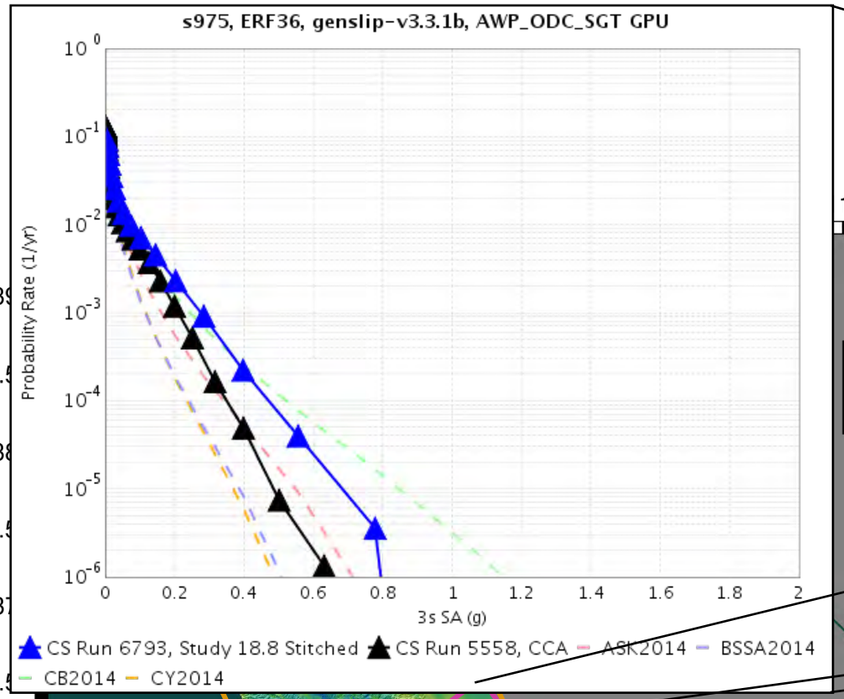


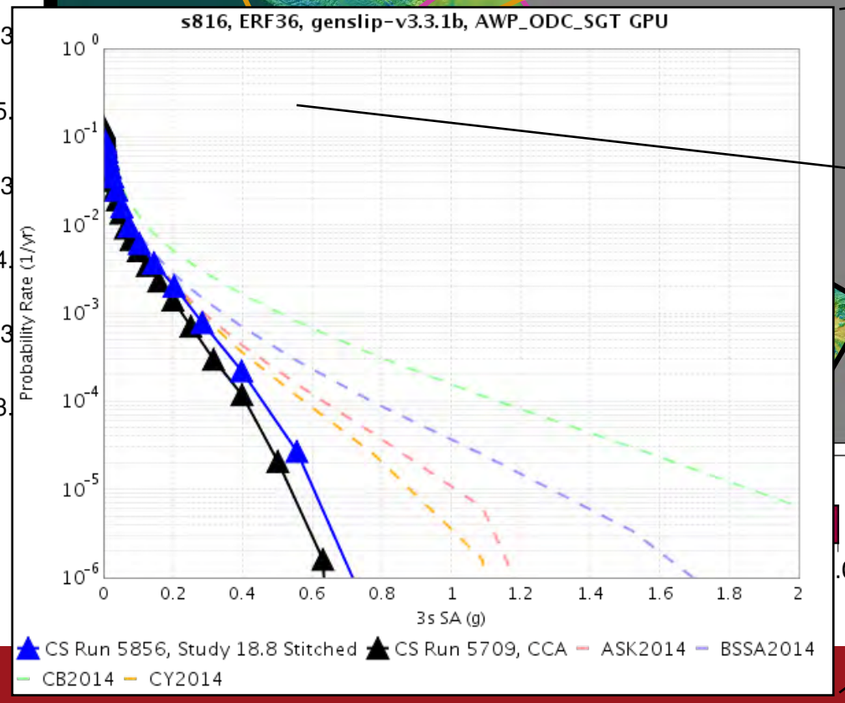


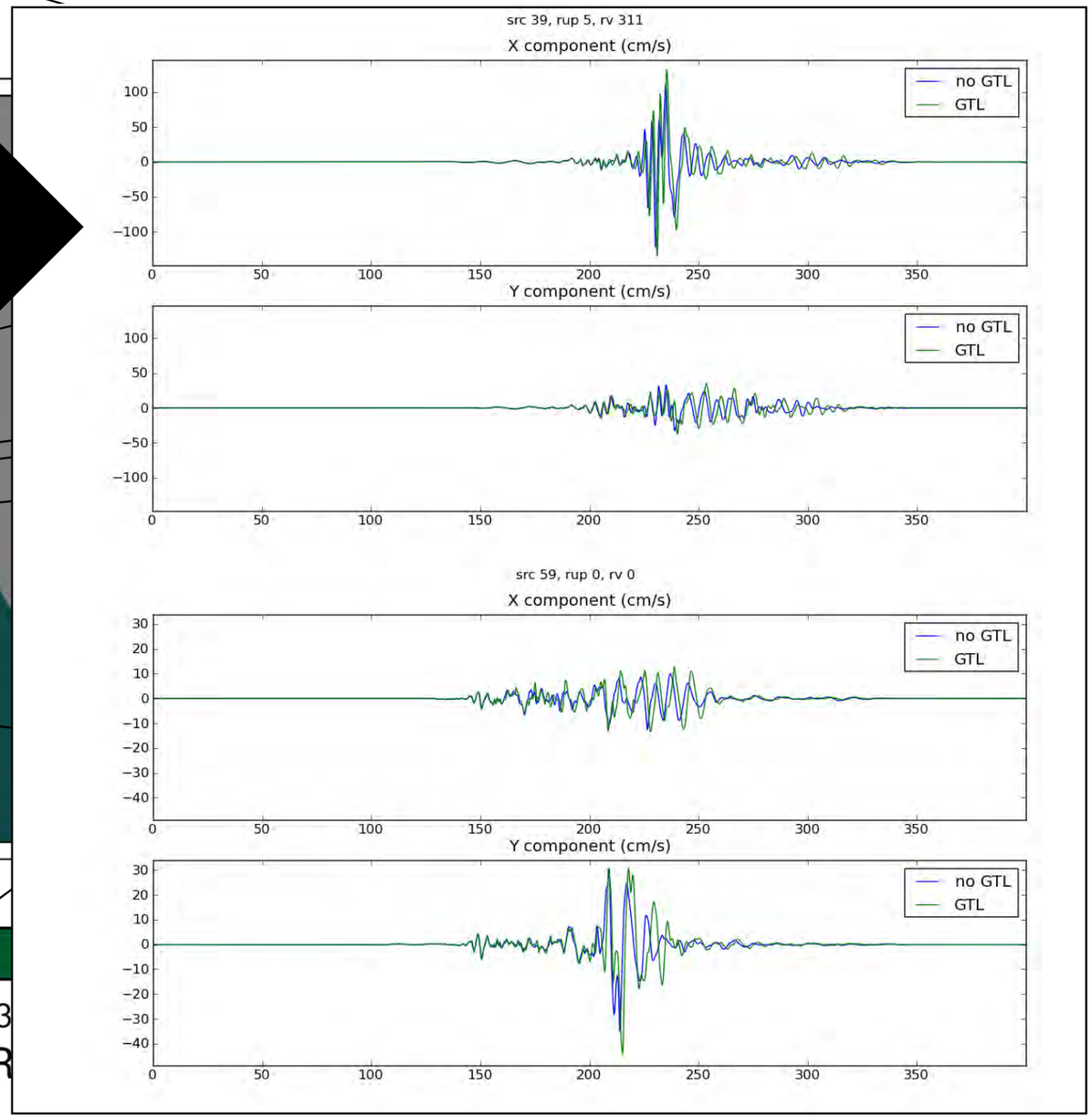


NGA-West2 GMMs

Study 18.8 vs 17.3







Residual analyses – initial results

GMPE modified from Boore et al. 2014 (NGA-West2 BSSA14)

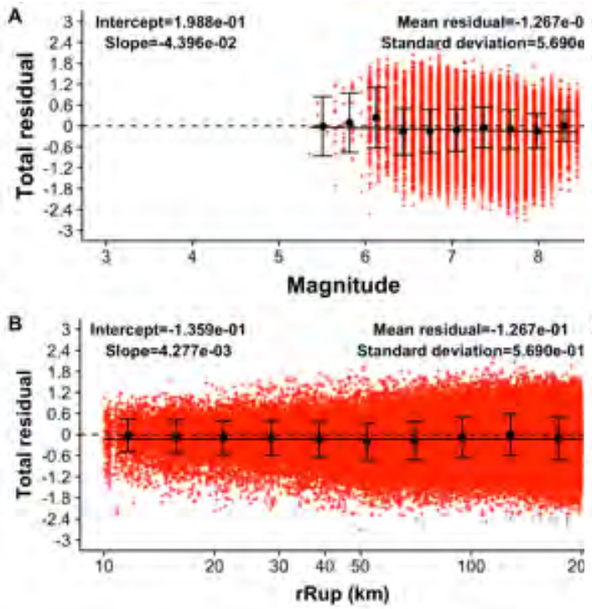
$$\ln y_{es} = b_1 + b_2 * (m - 7) + b_3 * (m - 7)^2 + (b_4 + b_5 * (m - 7)) * \left(\log\left(\sqrt{R^2 + 4.5^2}\right) - 4.73\right) - \ln\left(\frac{V_{S30}^*}{760}\right)$$

$$\text{if } V_{S30} > 760, V_{S30}^* = 760$$

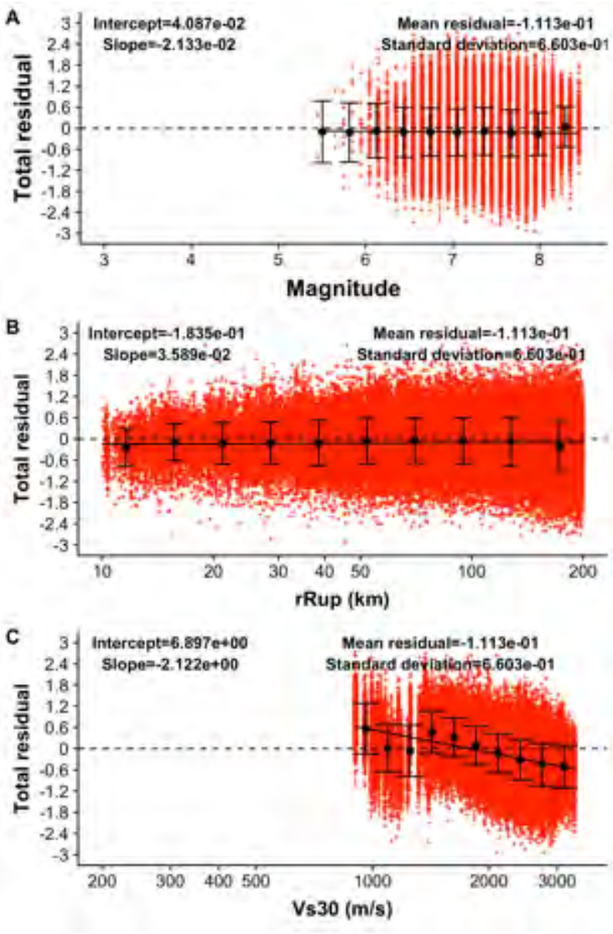
CS Study	Events	Sites	Total recordings
15.4	342,178	334	96,645,534
17.3 1D	566,237	438	141,573,206
17.3 3D	566,237	438	141,245,266
18.8	434,014	865	145,660,738

Total residuals

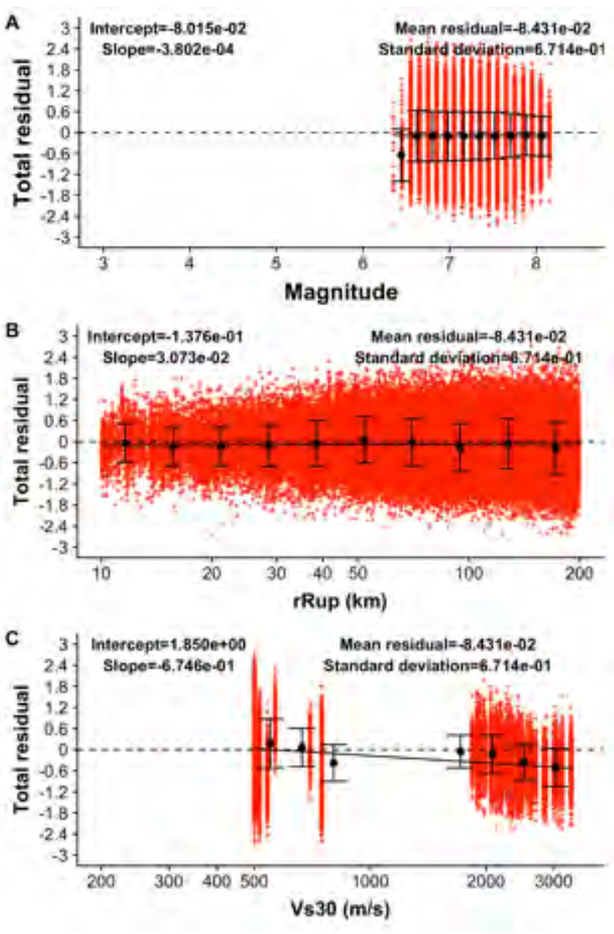
17.3 1D



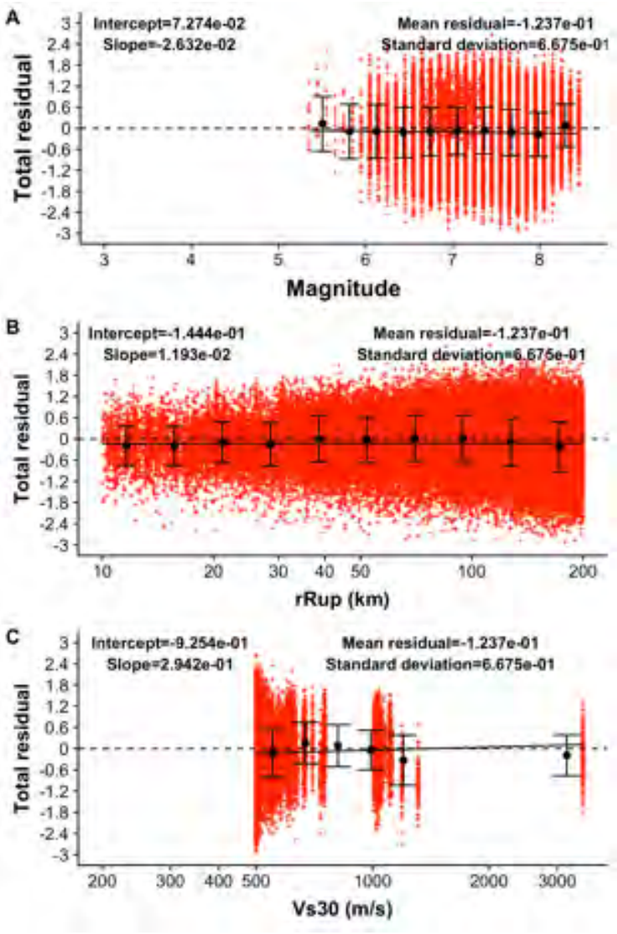
17.3 3D



15.4

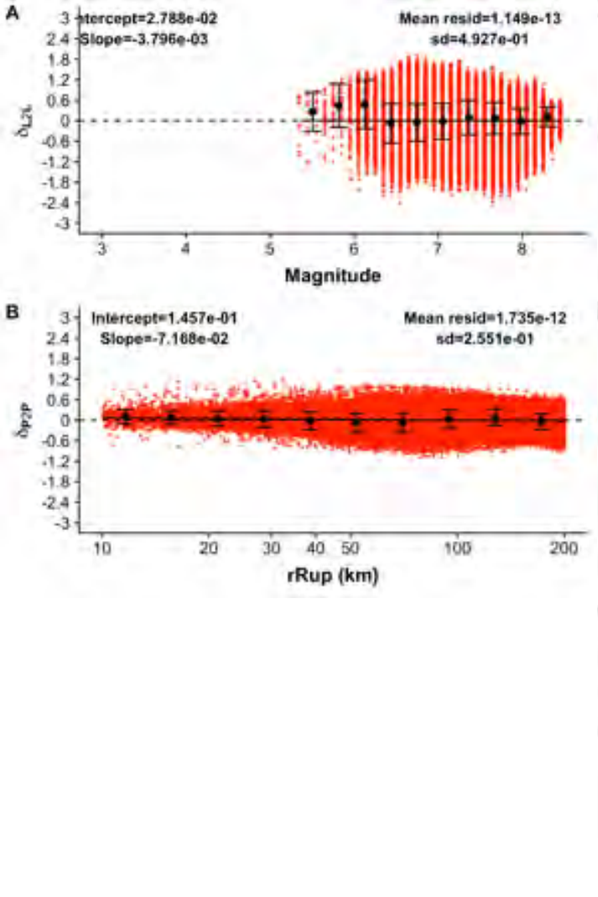


18.8

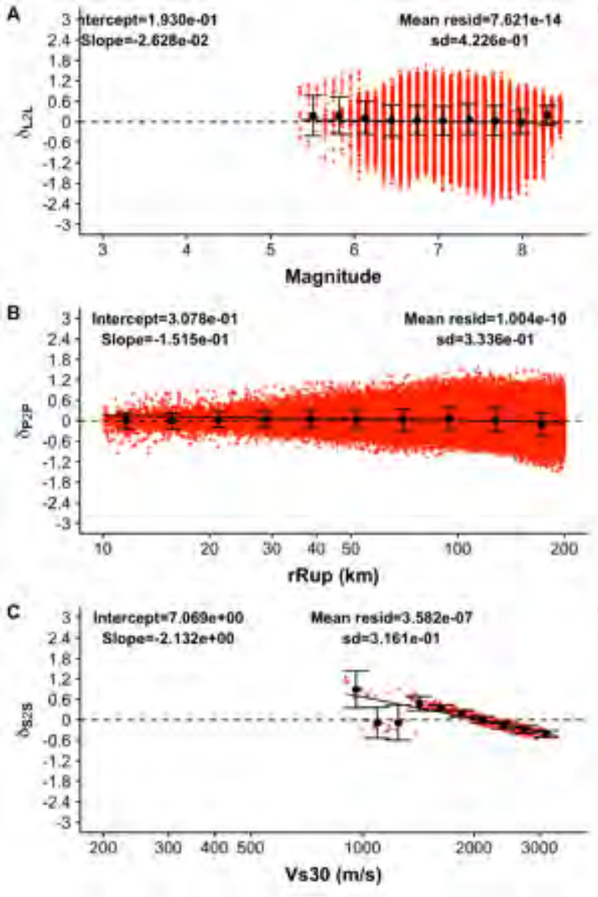


Partitioned residuals: location, path, site

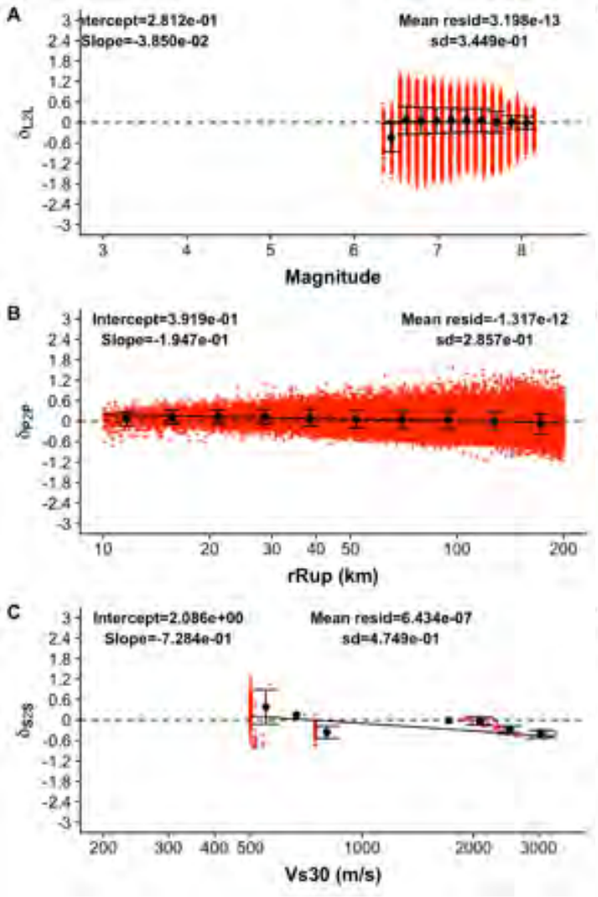
17.3 1D



17.3 3D



15.4



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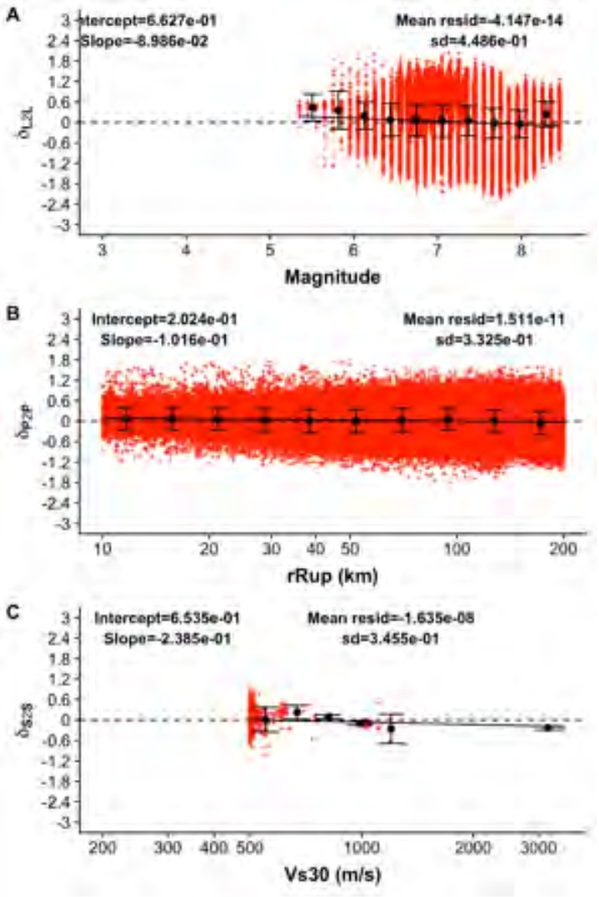
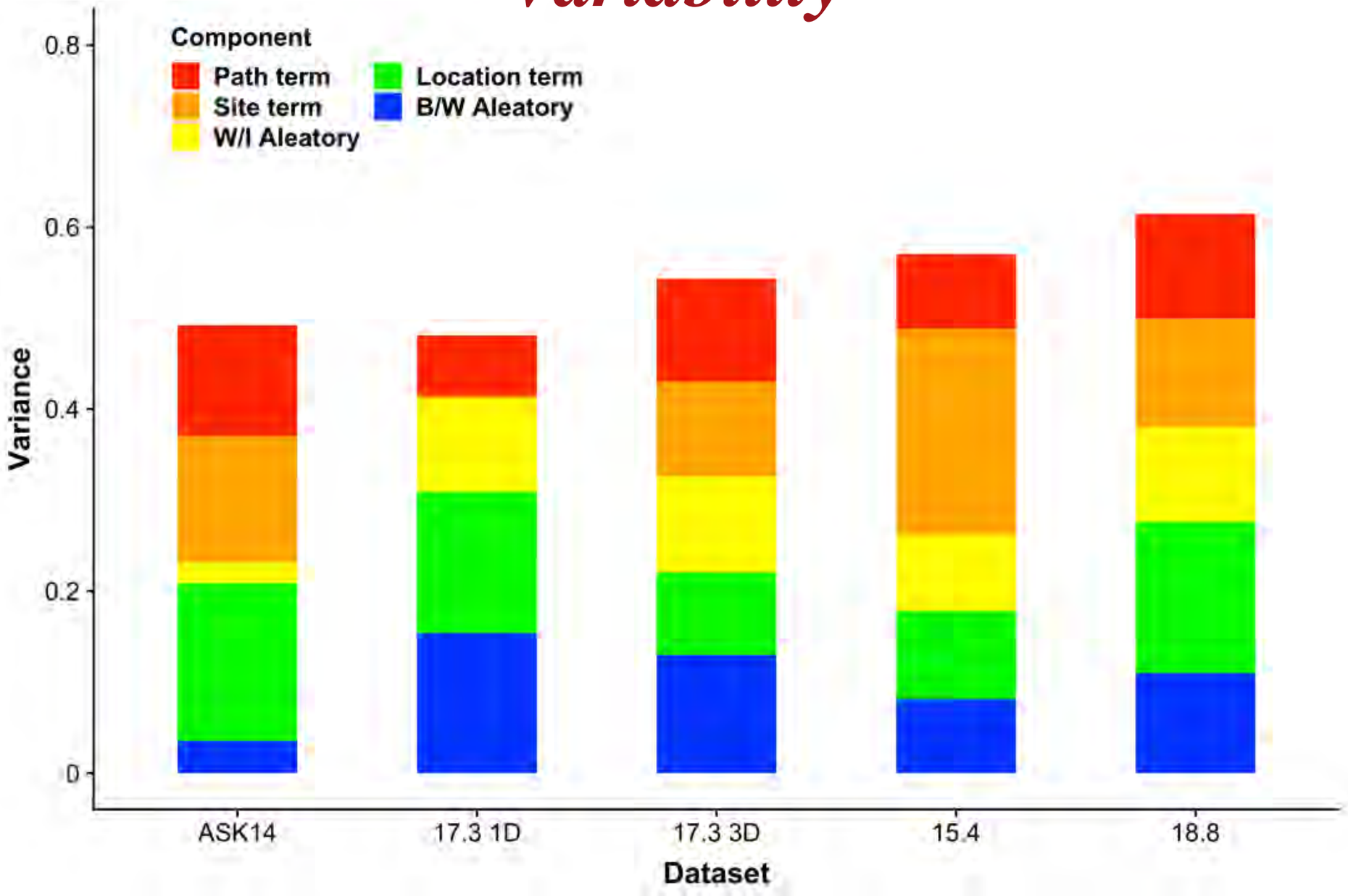


Variability



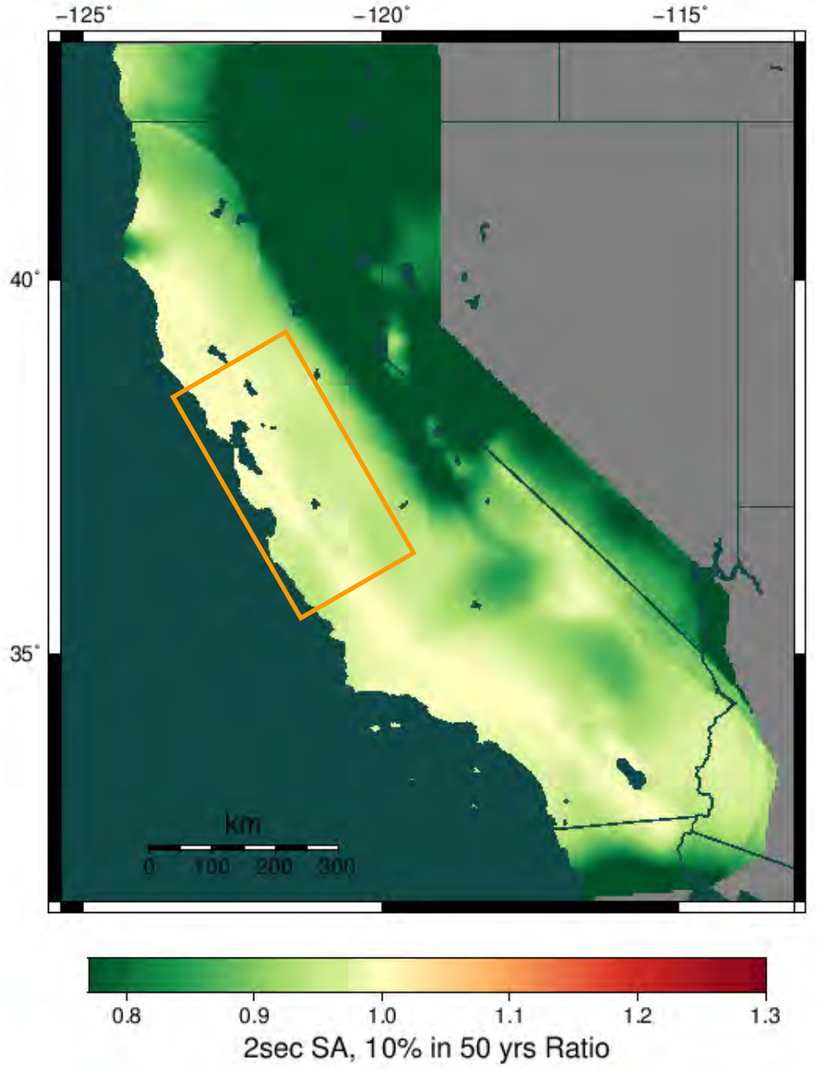
Outstanding Issues in CVMs

- Critical issue: refine CVMs beyond the F3DT models
- Current Unified Structural Representation (USR) interface problems
  - Imposing hard constraints on known basin edges and fault contacts (CFM)
  - F3DT perturbation of interfaces: contact uncertainty and oversmoothing
  - Integration of geology-based models with tomography (e.g. basins)
  - Integration of high-res studies
  - Bias introduced when assuming no topography
- Importance of anisotopy
  - Bias in isotropic inversions
  - Anisotropic F3DT
- Push to higher frequencies
  - Representation of source complexity
  - Frequency-dependent attenuation
  - Small-scale heterogeneities
  - Stochastic F3DT
  - Nonlinearity (near fault and near surface) and multi-resolution issues
- Quantification of uncertainty
  - Velocities
  - Boundaries
  - …

(Some) Future Work in CyberShake

- Background seismicity contributes 5-10% to hazard in region (GMM-based assessment)
  - Can add to Study 18.8 results
- Better understand results from CS studies, validate them, and investigate CVMs
- Update CS with latest Graves and Pitarka rupture generator
- Going to higher frequencies
  - Critical issue: refine CVMs beyond the F3DT models
  - Include nonlinearity and near-surface refinements in CS mesh
    - Reciprocity require linearity and gives CyberShake a 500x advantage over forward simulations
    - Mix of reciprocal and forward nonlinear simulations
    - Use discontinuous mesh (AWP-DM and AWP-SGT)

Ratio of hazard with background seismicity to hazard without, with GMMs



Questions?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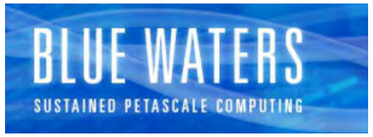
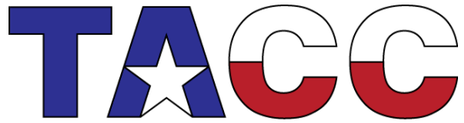

BLUE WATERS
SUSTAINED PETASCALE COMPUTING


NCSA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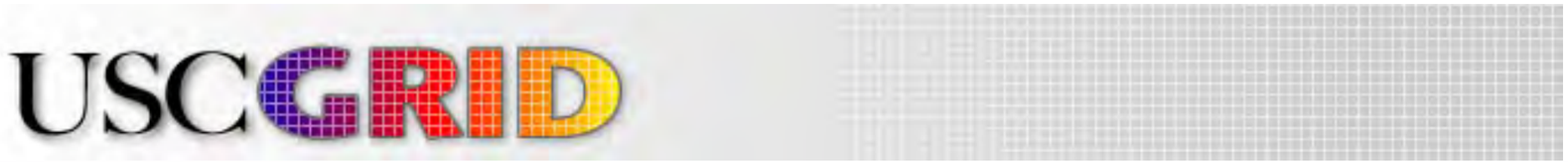
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