SC/EC

A CyberShake Probabilistic Seismic Hazard Model for Northern California

CyberShake Study 18.8 Working Group Including: Scott Callaghan, Philip J. Maechling, Christine A. Goulet, Kevin R. Milner, Mei-Hui Su, Karan Vahi, Ewa Deelman, Robert W. Graves, Kim B. Olsen, Yifeng Cui, Xiaofeng Meng, Thomas H. Jordan, Brad Aagaard, Kathryn E. Wooddell, Albert R. Kottke

Presenter: Philip Maechling

2019 Blue Water Symposium Annual Meeting
June 5, 2019
Sunriver, Oregon

Earthquake System Science on Blue Waters

SCEC Researchers use Blue Waters to:

Calculate accurate ground motions up to 1Hz for any site in California for most possible future earthquakes.

Earthquake System Science on Blue Waters

Research Challenge (or, success criteria for earthquake system science research):

Calculate accurate ground motions at any site on earth for any possible earthquake.

Why do we want to do this? What value does this have?

Earthquake Reports In the News


The New York Times

Buildings Can Be Designed to Withstand Earthquakes.

Why Doesn't the U.S. Build More of Them?

By Thomas Fuller, Anjali Singhvi, Mika Gröndahl and Derek Watkins

June 4, 2019

Buildings Can Be Designed to Withstand Earthquakes. Why Doesn't the U.S. Build More of Them?

Thomas Fuller et al.
The New York Times
June 4th, 2019

Resilience By Design
City of Los Angeles Earthquake Preparedness Plan (2015)


L.A. Now

California: This just in

Los Angeles Times

LOCAL / L.A. Now

This article is related to: Hurricane Sandy (2012)

L.A. becomes first U.S. city to enact quake safety standards for new cellphone towers

"The Los Angeles plan requires new freestanding cellphone towers to be built to the same seismic standards as public safety facilities. Cellphone towers are currently built only strong enough to not collapse and kill people during a major earthquake. They're not required to be strong enough to continue working.."

- Los Angeles Times 8 May 2015

Civil Engineering Groups to Want Use Specific-Types of Seismic Hazard Information to Define Building Codes

Earthquake System Science Researchers

Civil engineers and federal, state, and local governmental seismic hazard and risk organizations

Site-specific Probabilistic Seismic Hazard Curves

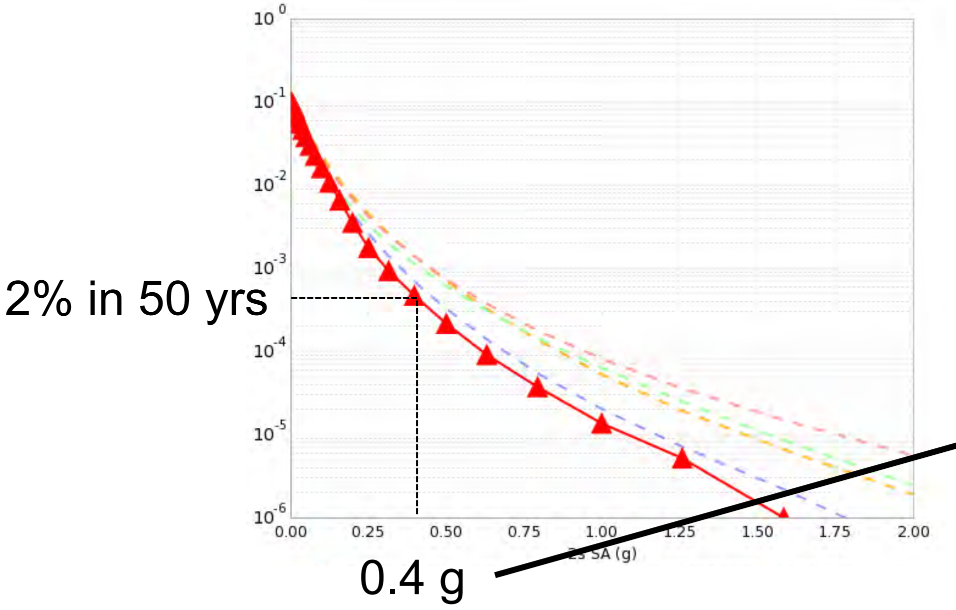
Site-specific, risk-targeted Maximum Considered Earthquake (MCER) response spectra

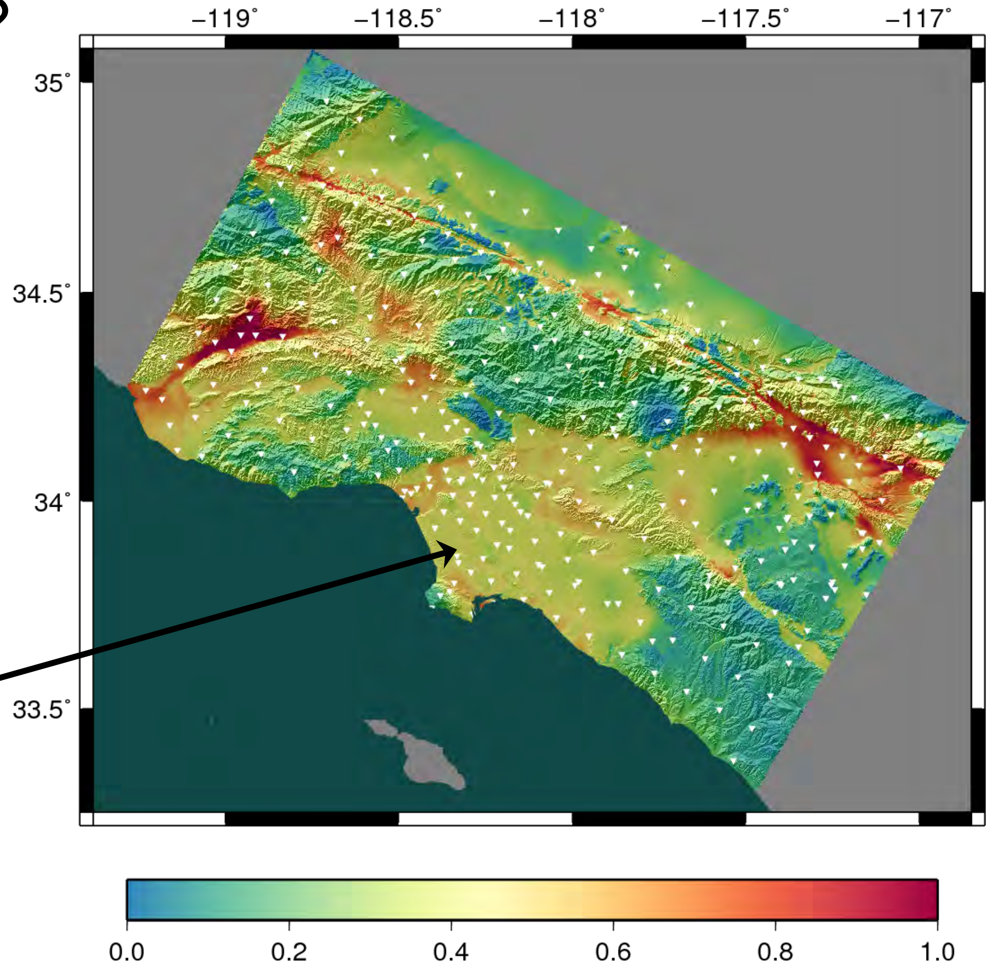
Like software interfaces, seismic hazard and risk governmental and engineering regulatory interfaces define data products and formats so seismic research results must be presented in these formats for consideration.

SCEC's CyberShake Method Calculates Site-specific Probabilistic Seismic Hazard Analysis (PSHA) Hazard Curves and Maps

What will the peak earthquake shaking be over the next 50 years?

- Useful information for:
  - Building engineers
  - Disaster planners
  - Insurance agencies

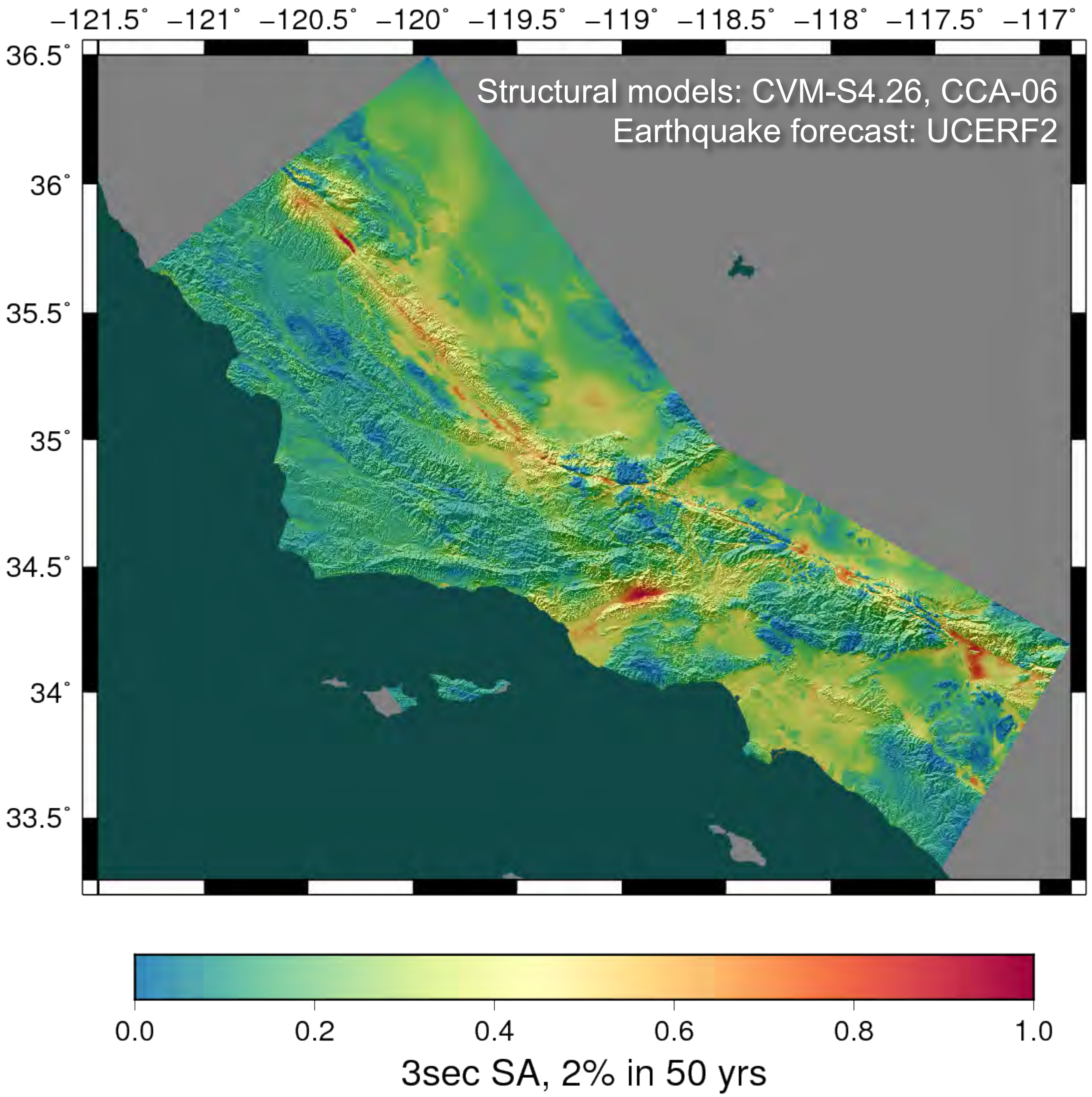




US Geological Survey responsible updates California and National seismic hazard maps using best available science approximately every 5 years. Physics-based PSHA methods use regional and local earth structure information to provide more accurate site-specified ground motion estimates.

SCEC's CyberShake Research Overview

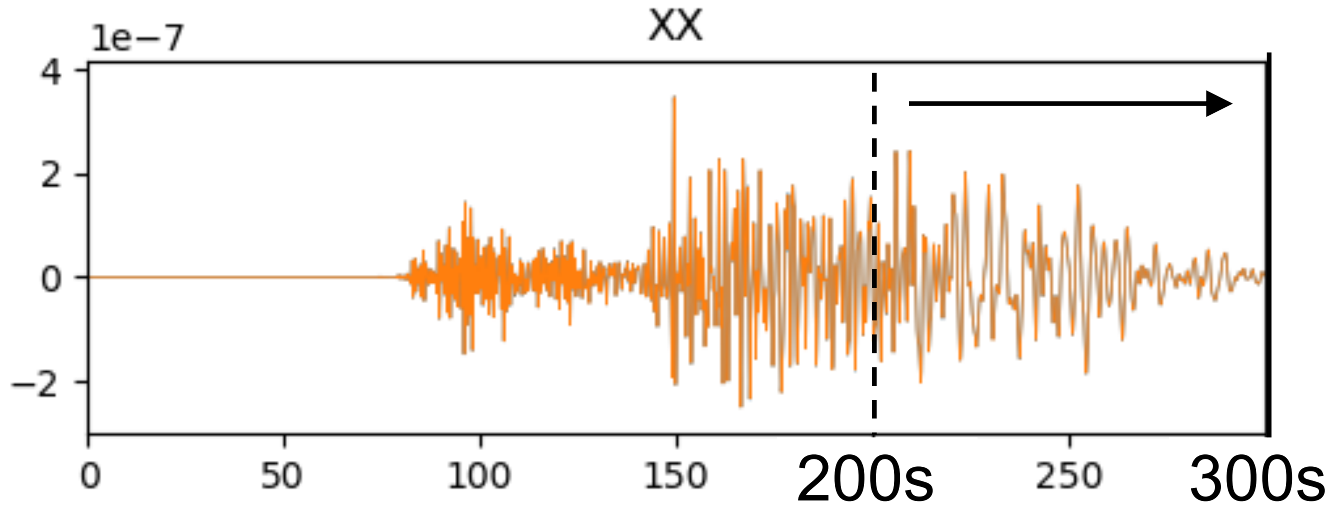
- CyberShake is the Southern California Earthquake Center's (SCEC) 3D physics-based probabilistic seismic hazard analysis (PSHA) method and software
- CyberShake is a computationally-intensive method that improves ground motion estimates by using accurate 3D velocity models of areas of interest
- By 2018, SCEC had calculated CyberShake hazard models for southern California (Study 15.4) and central California (Study 17.3)

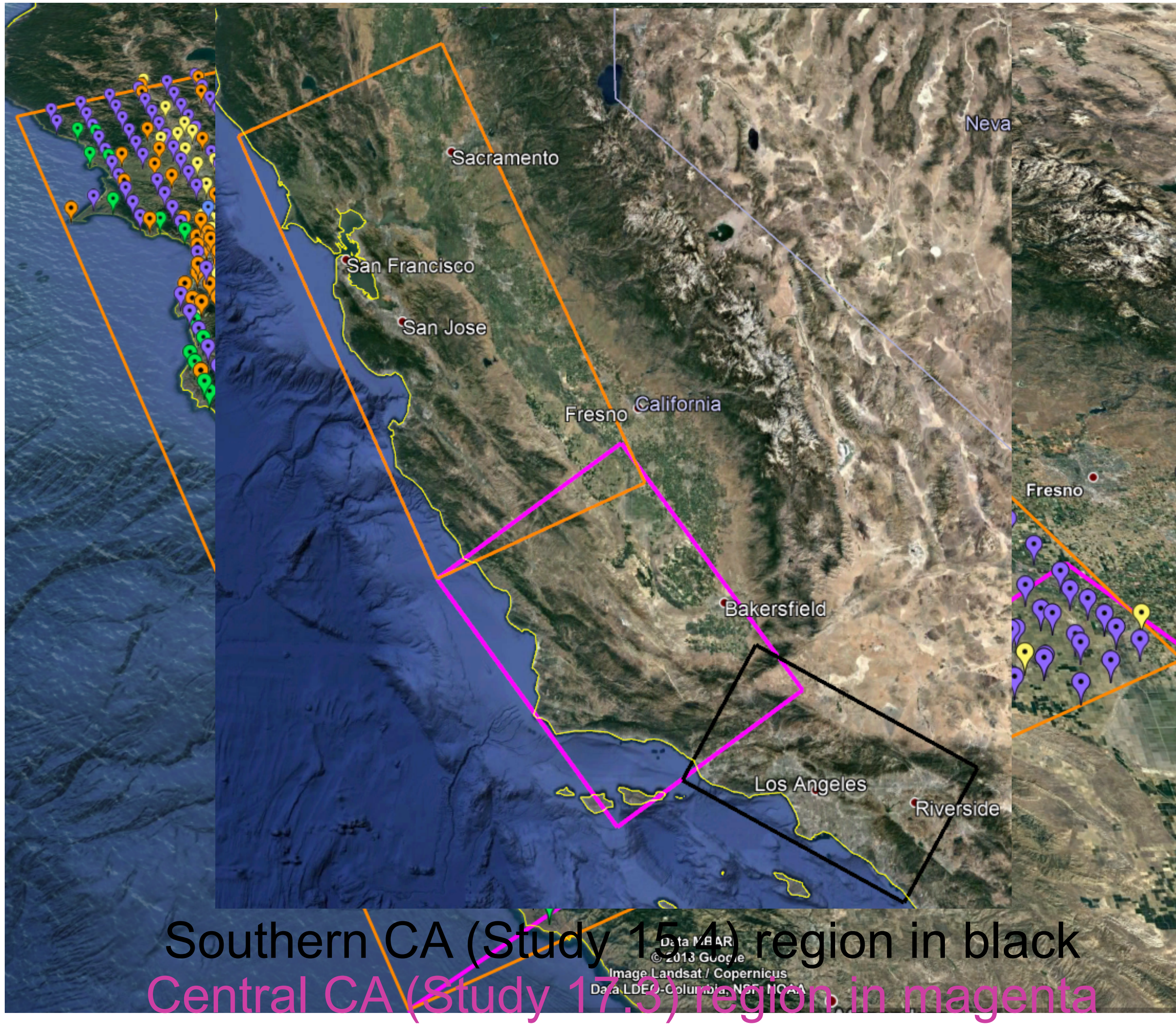


Northern California: Study 18.8

At start of 2018, SCEC was ready to apply the CyberShake method to areas of Northern California where 3D CVMs are available:

- 869 locations
- 1 Hz
- Large simulation volumes (1100 x 450 km)
- Vs min = 500 m/s
- Longer seismogram needed for some sites





Southern CA (Study 15.4) region in black

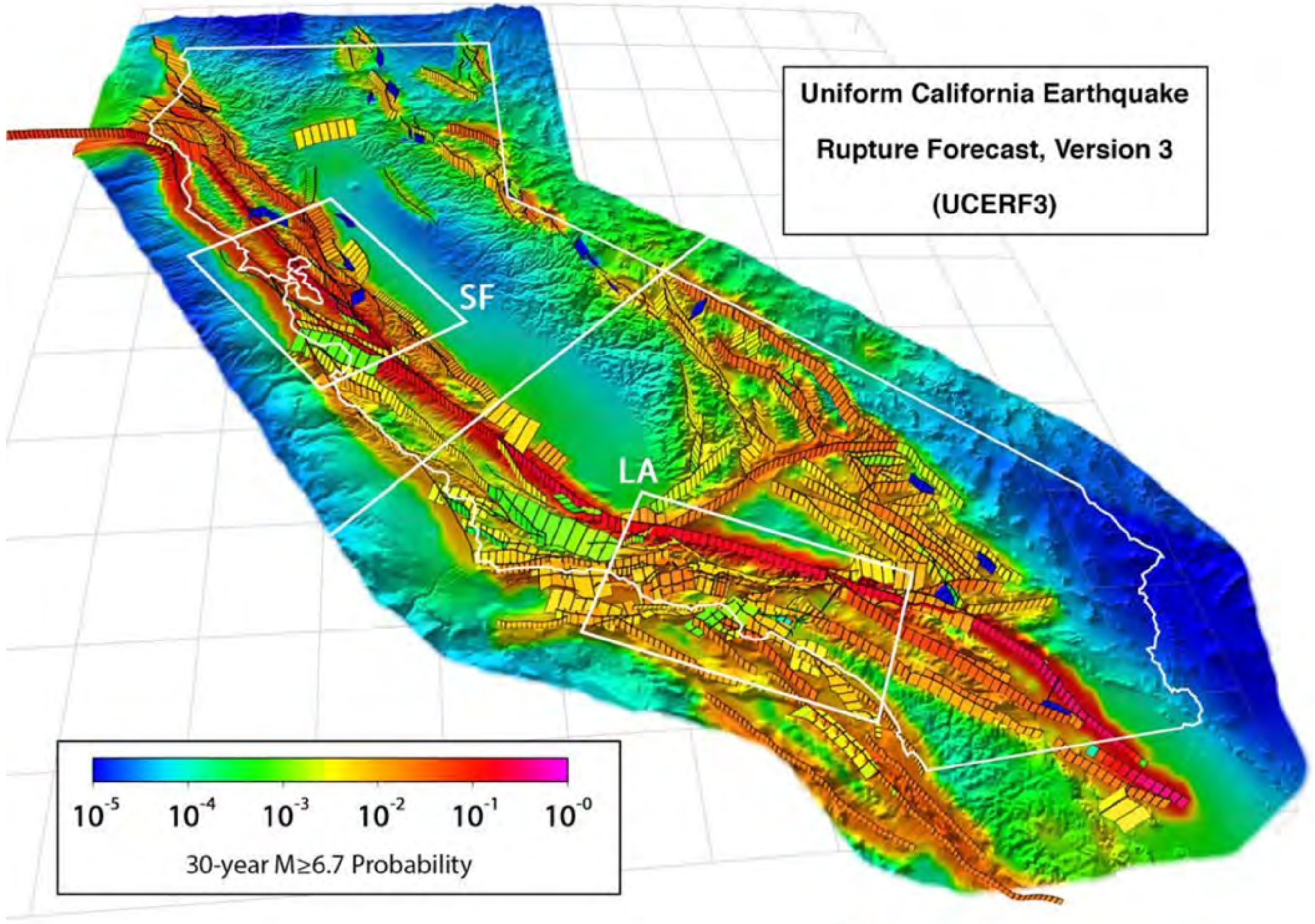
Central CA (Study 17.3) region in magenta

Bay Area (Study 18.8) region in orange

869 sites, densest near San Francisco Bay

CyberShake Study 18.8 Earthquake Rupture Forecast

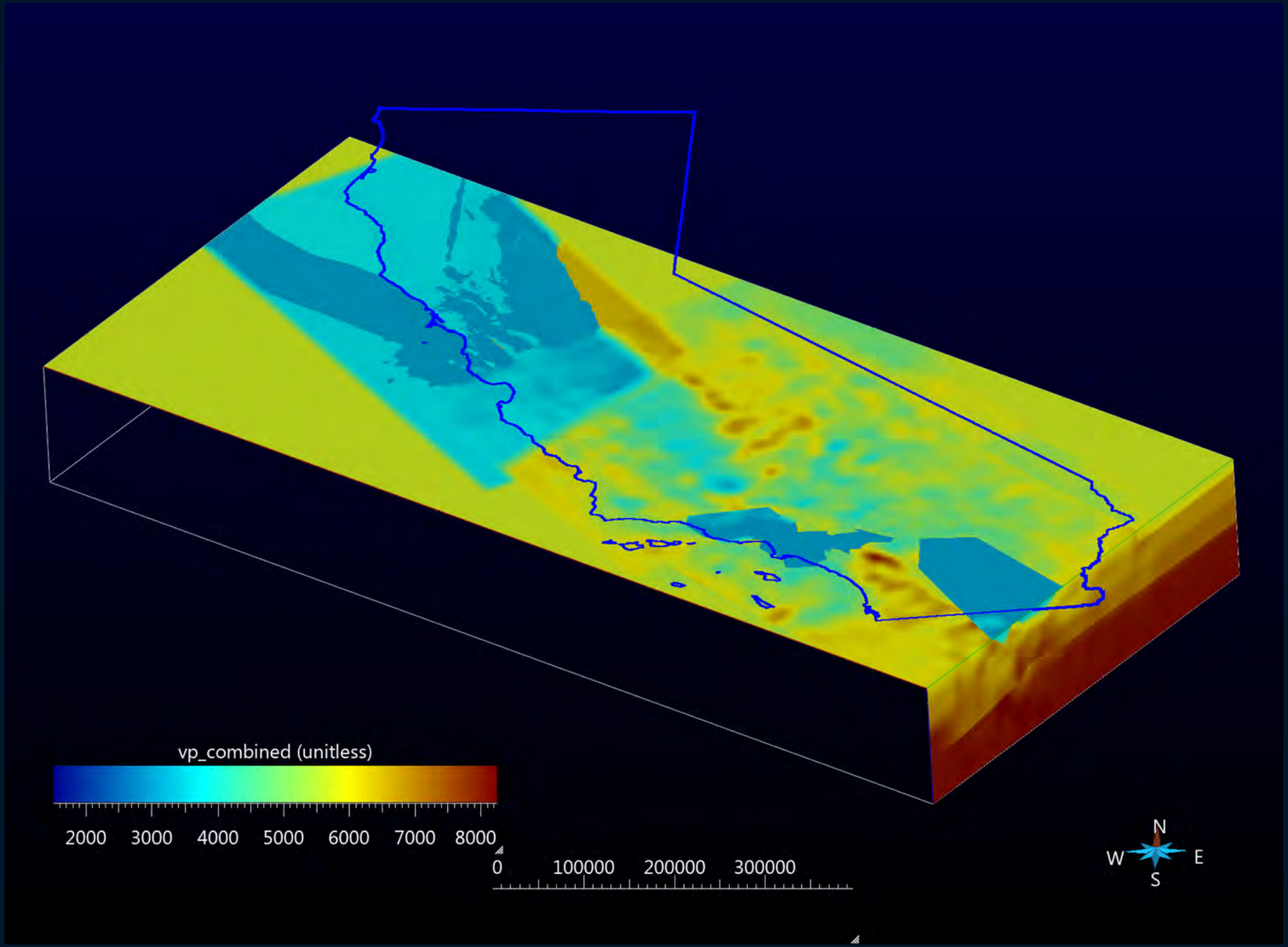
- The earthquake rupture forecast (ERF) provides a lists of future potential earthquakes plus more information:
  - How big are the potential earthquakes?
  - What faults do they occur on?
  - How often should we expect them?



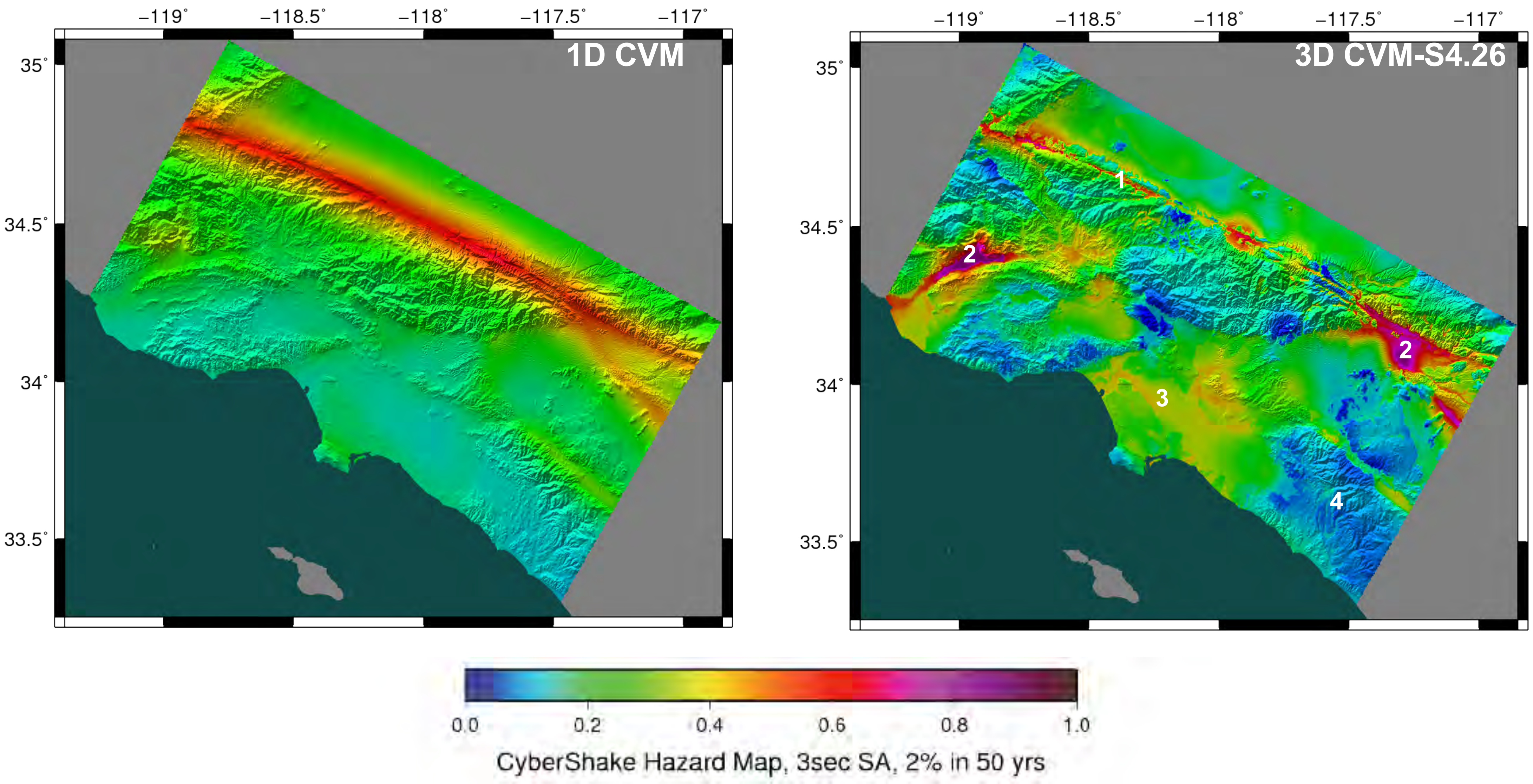
- CyberShake Study 18.8 used the USGS created Unified California Earthquake Rupture Forecast 2 (UCERF2) ERF (M≥6.5, ≤200 km) with Graves & Pitarka rupture generator (~500,000 events per site)

Example California Seismic Velocity Simulation Mesh

- 6960 x 3200 x 288 cells (6.4 billion cells)
- 175m x 175m x 175m resolution
- origin at S corner at 548969, 3459243, 0 (UTM Z11, WGS84)
- Regular grid in UTM space



Why 3D Velocity Models are Important



Comparison of two seismic hazard models for the Los Angeles region from CyberShake Study 14.2. The left panel is based on an average 1D velocity model, and the right panel is based on the F3DT-refined structure CVM-S4.26. The 3D model shows important amplitude differences from the 1D model, several of which are annotated on the right panel: (1) lower near-fault intensities due to 3D scattering; (2) much higher intensities in near-fault basins due to directivity-basin coupling; (3) higher intensities in the Los Angeles basins; and (4) lower intensities in hard-rock areas. The maps are computed for 3-s response spectra at an exceedance probability of 2% in 50 years. Both models include all fault ruptures in the Uniform California Earthquake Rupture Forecast, version 2 (UCERF2), and each comprises about 240 million seismograms.

Available California Velocity Models

SCEC researchers use multiple seismic velocity models including:

(1) CVM-S4 (SCEC original S. California model developed at Caltech)

(2) CVM-H v15.1 (Harvard-developed S. California model)

(3) CVM-S4.26 (Tomography improved Southern California velocity models)

(4) CCA06 (Tomography improved Central California velocity model)

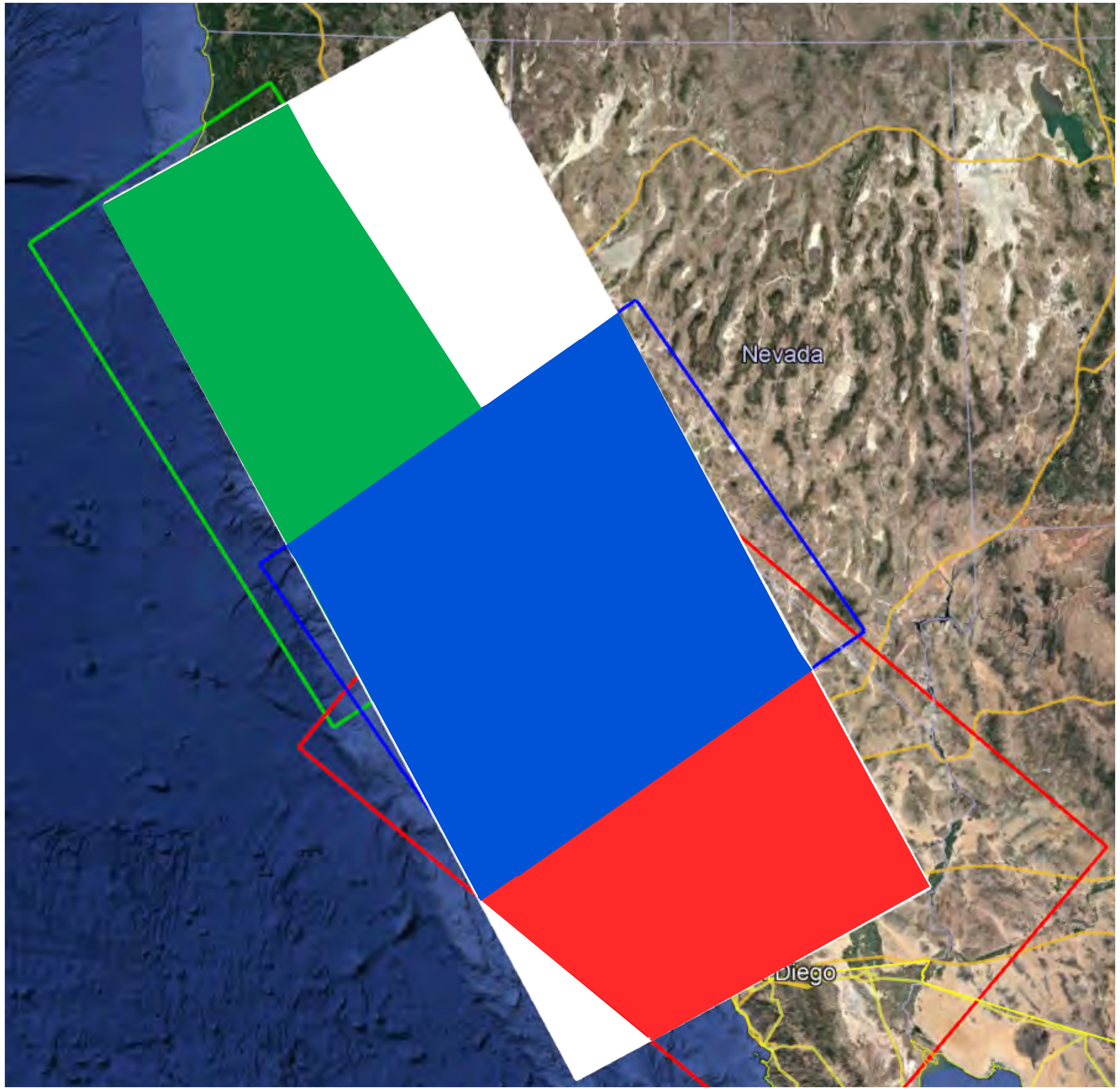
(5) USGS Bay Area CVM (cencal)

(6) And others…

Coverage regions may overlap, but material properties differ for each model

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



CyberShake Study 18.8 Computational and Data Scale

CyberShake stage	Node-hours	Output data
Velocity mesh creation using UCVM	232 CPU	177 GB
Strain Green Tensor (SGT) simulations	2,500 GPU	345 GB
Seismogram Synthesis (post-processing)	3812 CPU	17 GB
Total, 1 site	4,044 CPU 2,500 GPU	539 GB
Total, entire study (869 Sites)	**1.3 million CPU XE NodeHrs** **5.0 million GPU XK NodeHrs**	**457 TB**

CyberShake Study 18.8 Computational Measures

- CyberShake Study 18.8 required 6.3 million node hours on Blue Waters and Titan Combined
  - 3.8M CPU and GPU node hours on Blue Waters
  - 2.5M GPU node hours OLCF Titan
- Study of 869 Sites run (start to finish - the makespan) required:
  - 5719 Hours (238 days) (3.7 Sites/Day for 238 Days) : Aug 18 2018 – April 13, 2019
    - 3079 hours (128 days) submitting jobs (6.7 Sites/Day for 128 Days)
    - 2640 hours (110 days) recess

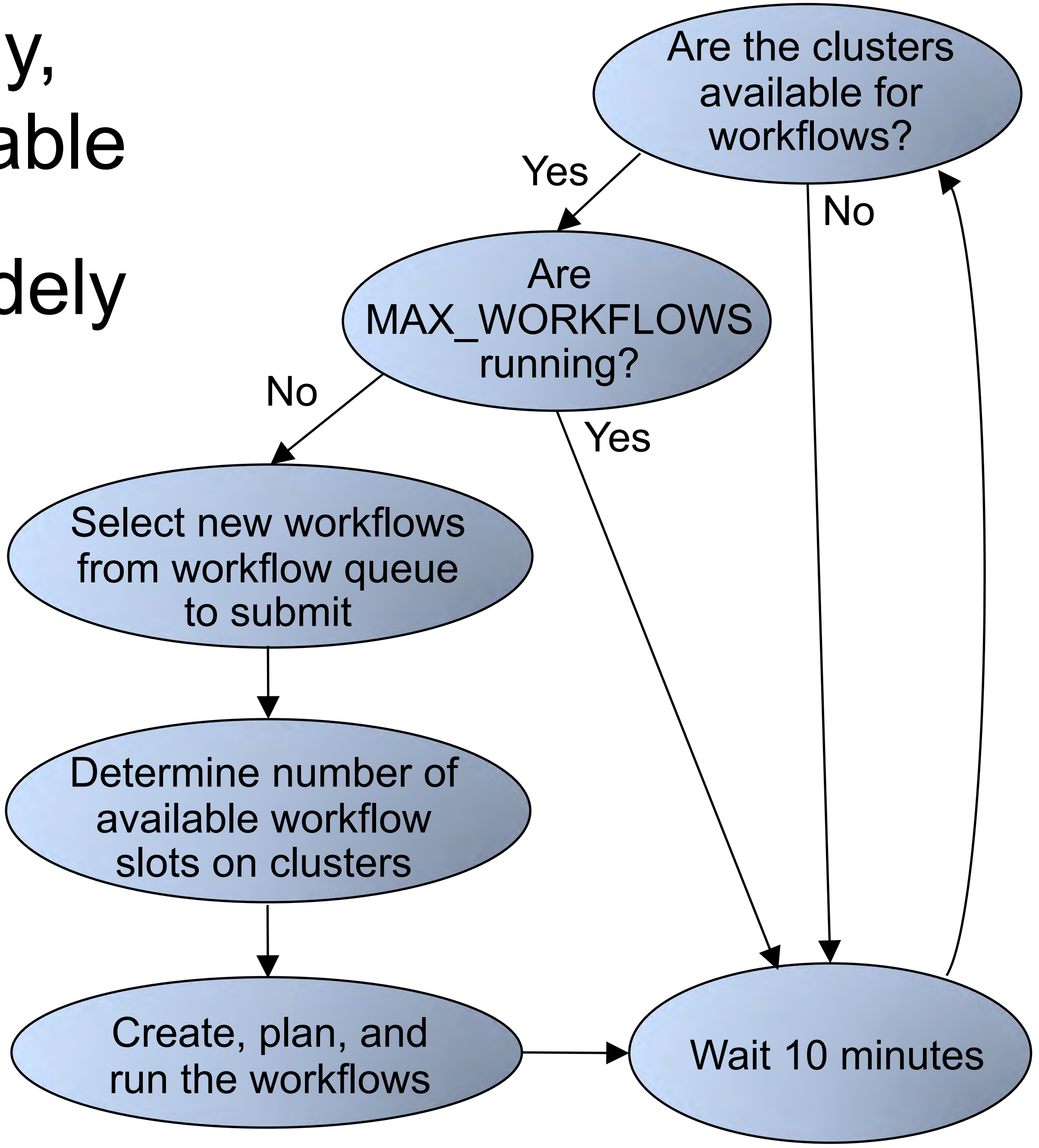
SCEC uses scientific workflow technology to orchestrate these simulations because they required a high degree of computing automation for around-the-clock execution over long production run time period.

Dynamic Workflow Assignment

- To accomplish CyberShake study efficiently, must be able to use resources when available
- Job throughput on large clusters varies widely
- Designed workflow metascheduler to submit workflows
  - Split workflows into SGT and post-processing
  - Ability to run each part on separate systems

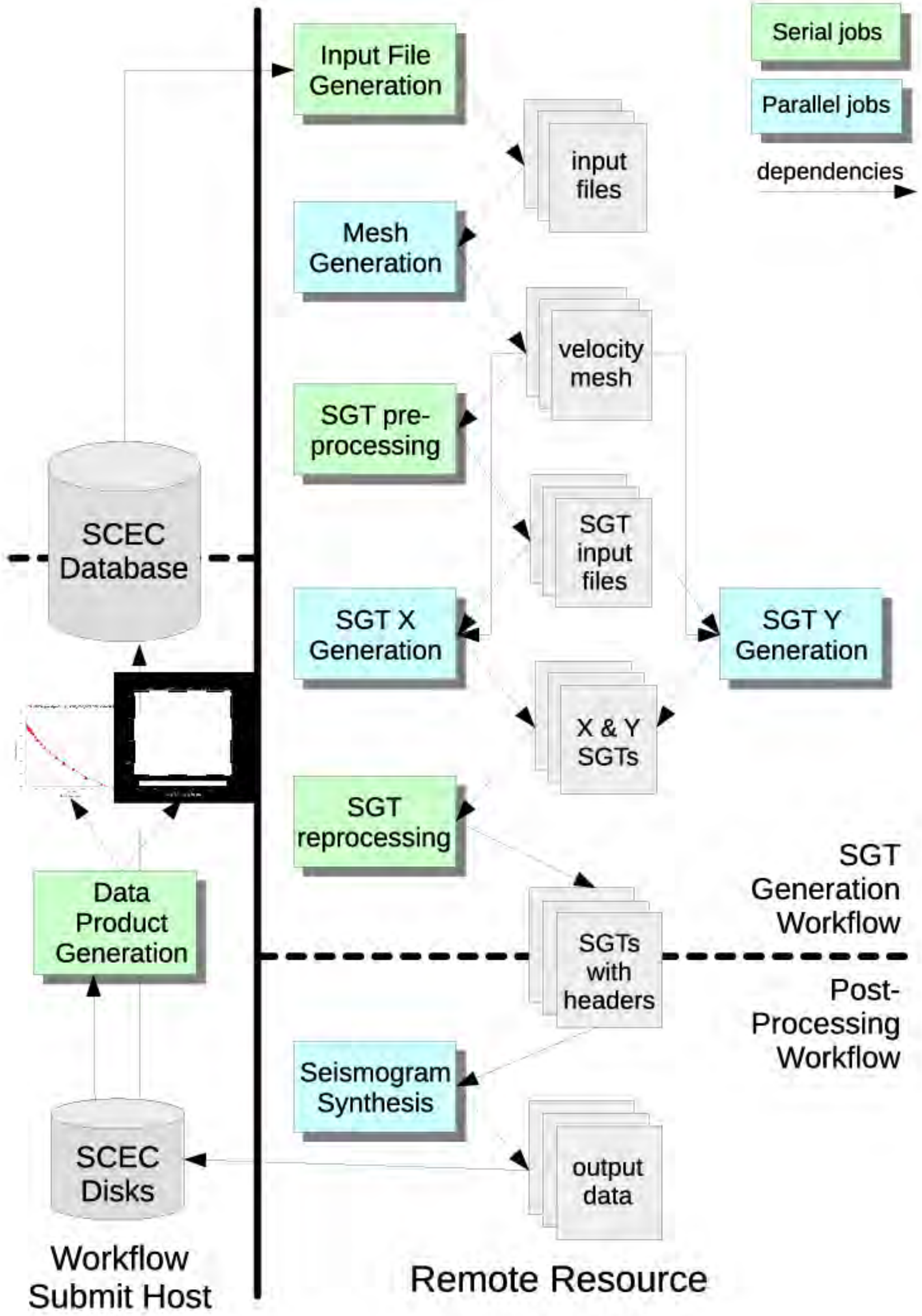
	BW SGTs	Titan SGTs	Total
BW PP	444	290	734
Titan PP	0	135	135
Total	444	425	869

Systems used for SGT and post-processing workflows



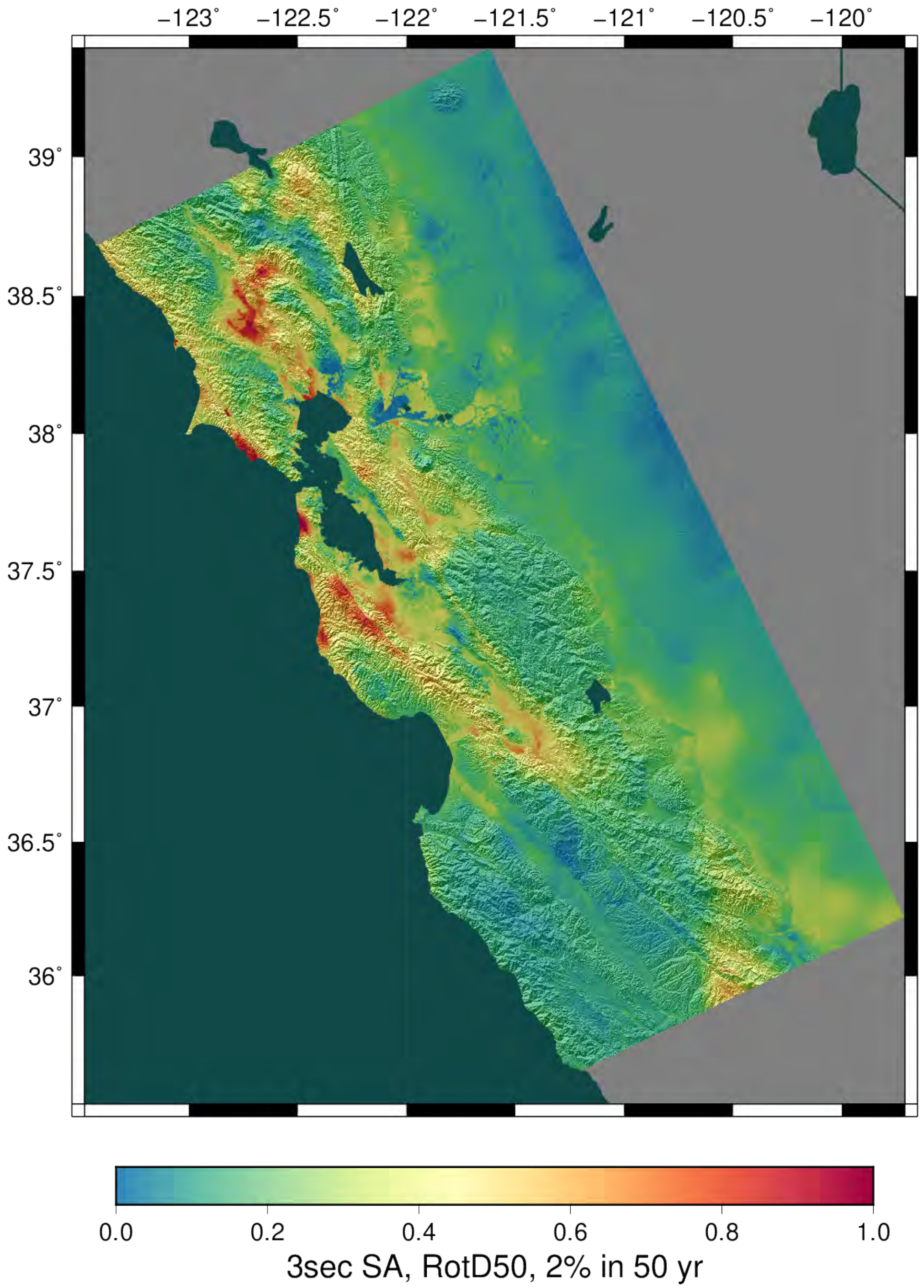
Scientific Workflow Tools

- Pegasus-WMS
  - Use API to create description of workflow
    - Tasks with dependencies
    - Input/output files
  - Plans workflow for execution on specified systems
  - Adds jobs to manage data
  - Wraps executables to track metadata
- HTCondor
  - Manages real-time execution of jobs
  - Submits jobs to remote systems, checks on success
  - Monitors dependencies
  - Checkpoints workflow
- GridFTP used to transfer data

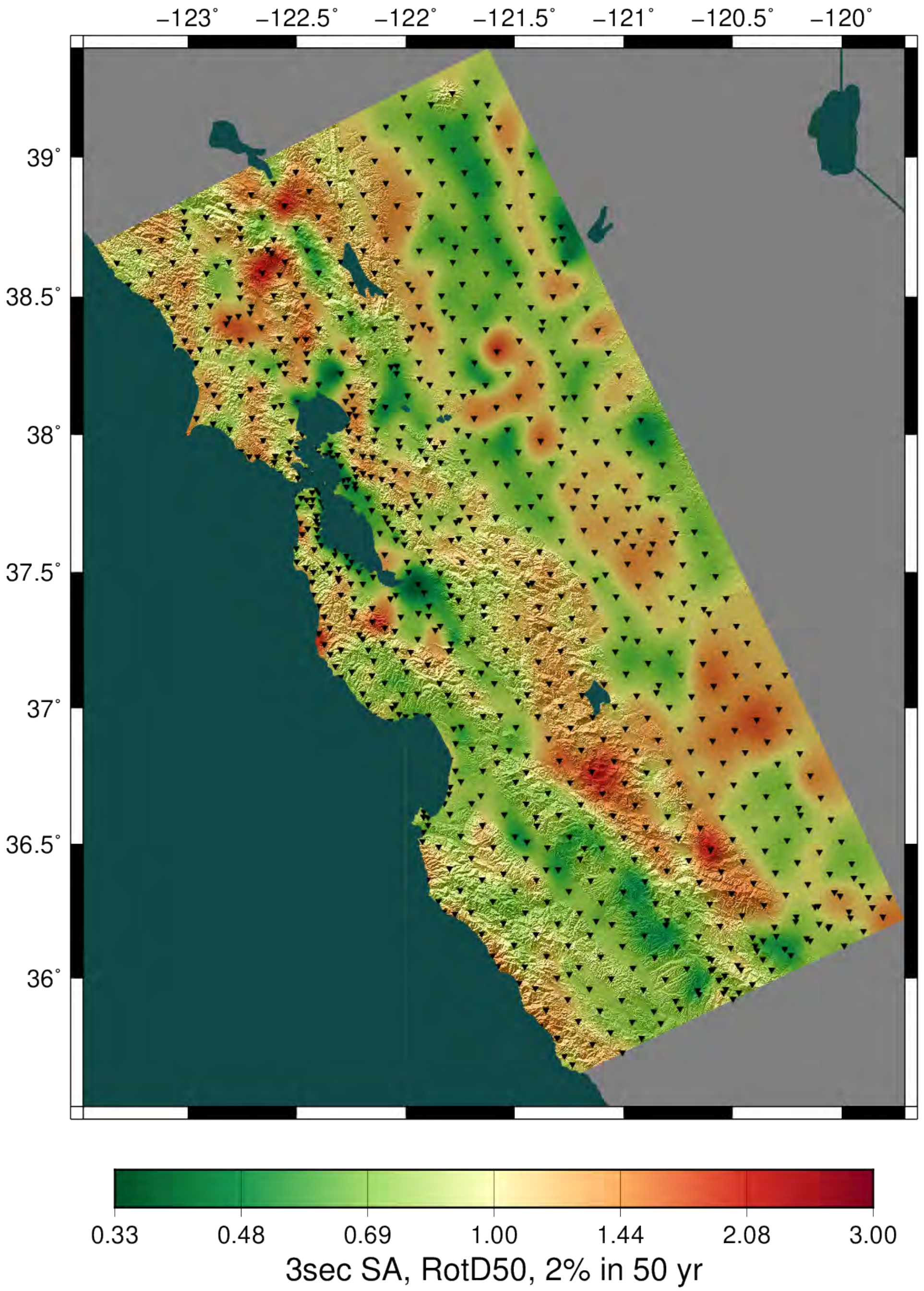


Schematic of CyberShake workflow

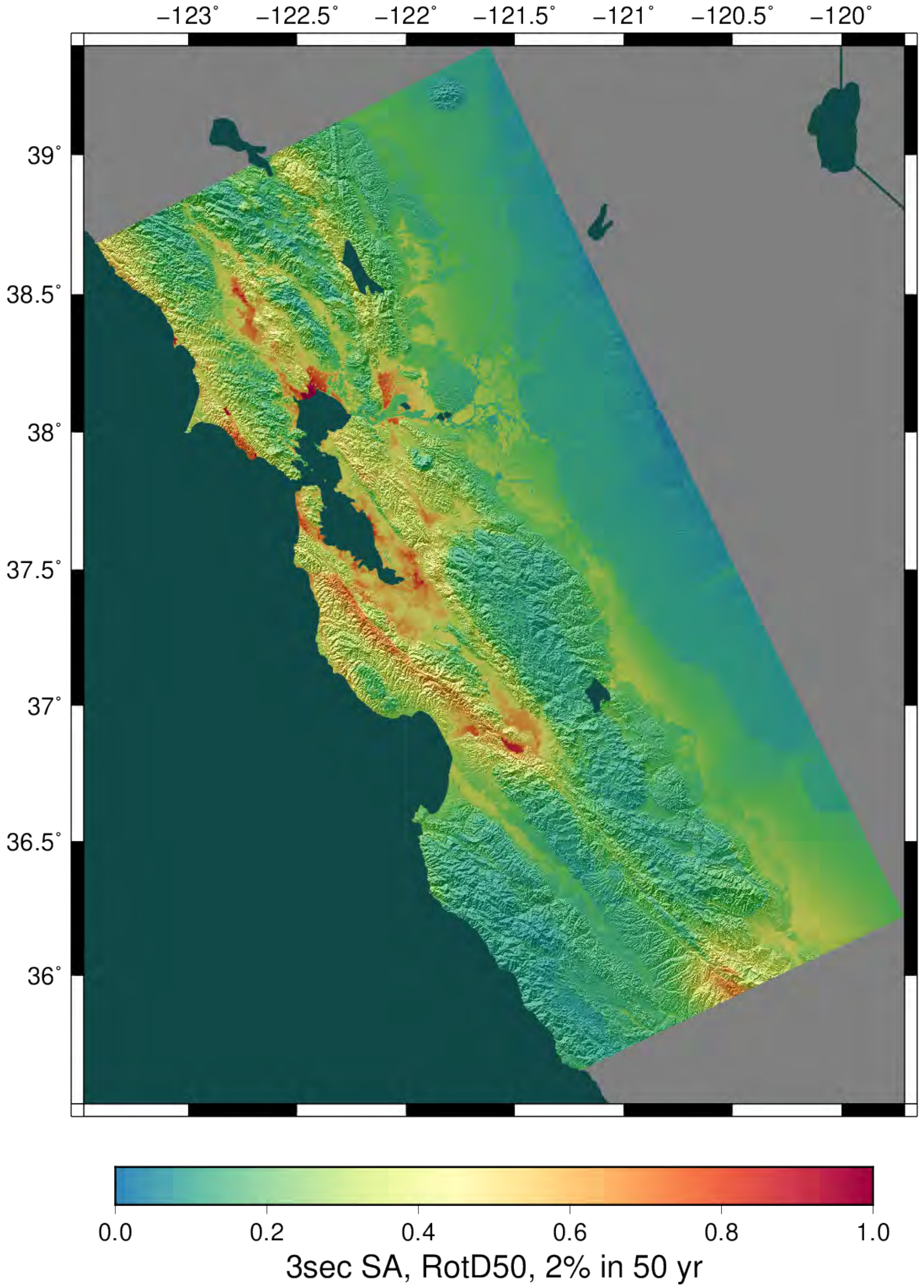
Study 18.8 Results



CyberShake

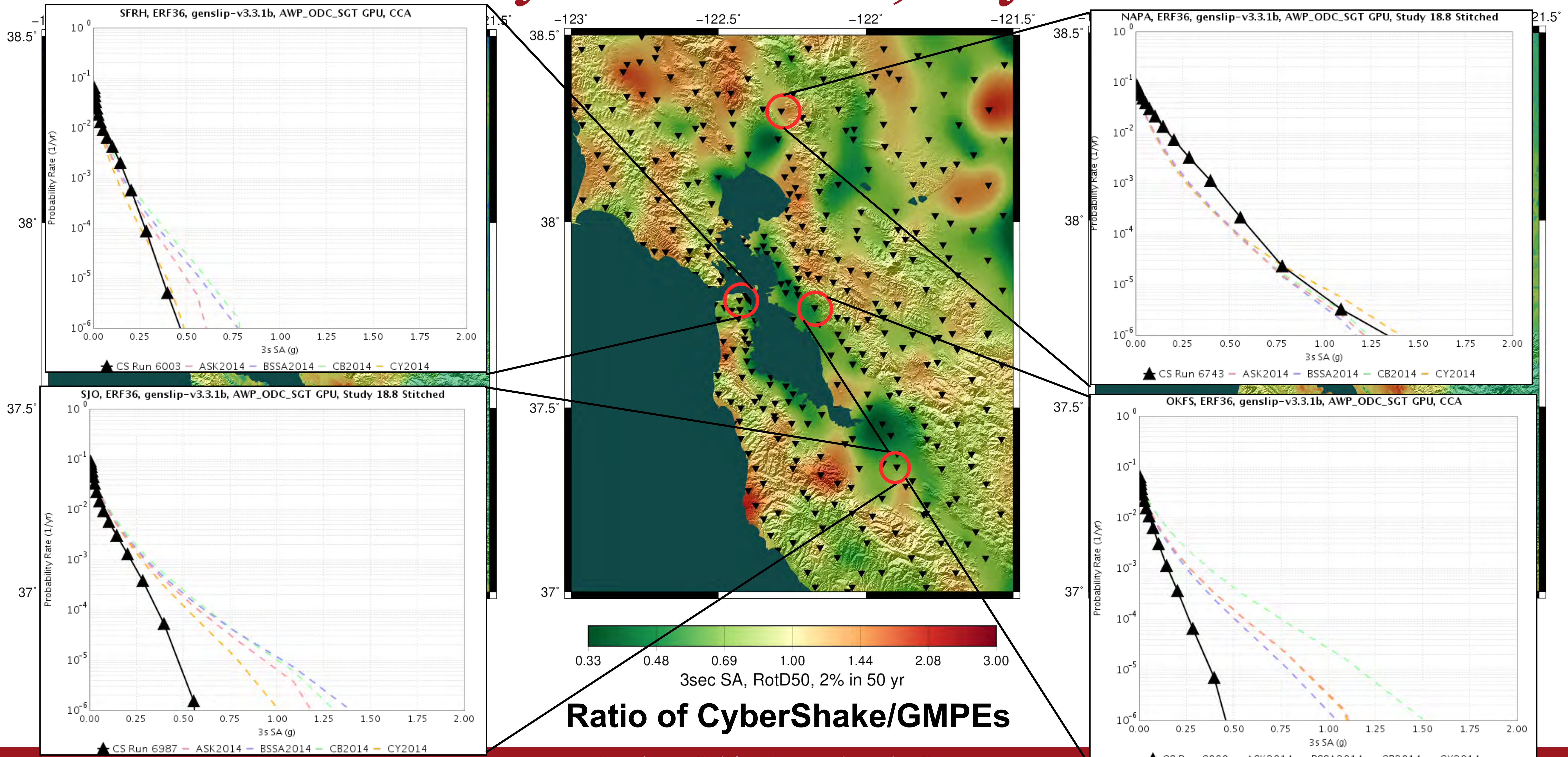


Ratio of CyberShake/GMPEs



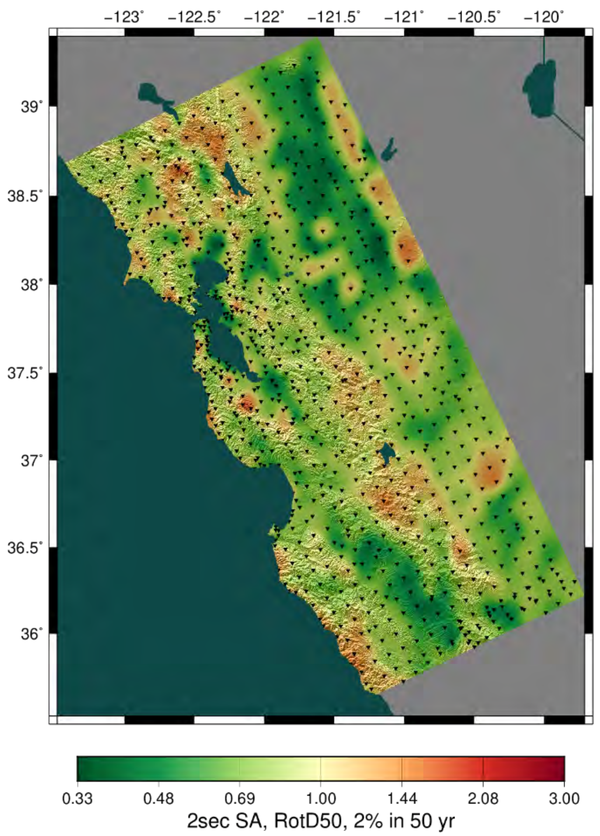
Avg of 4 NGAWest2 GMPEs

Study 18.8 Results, Bay Area

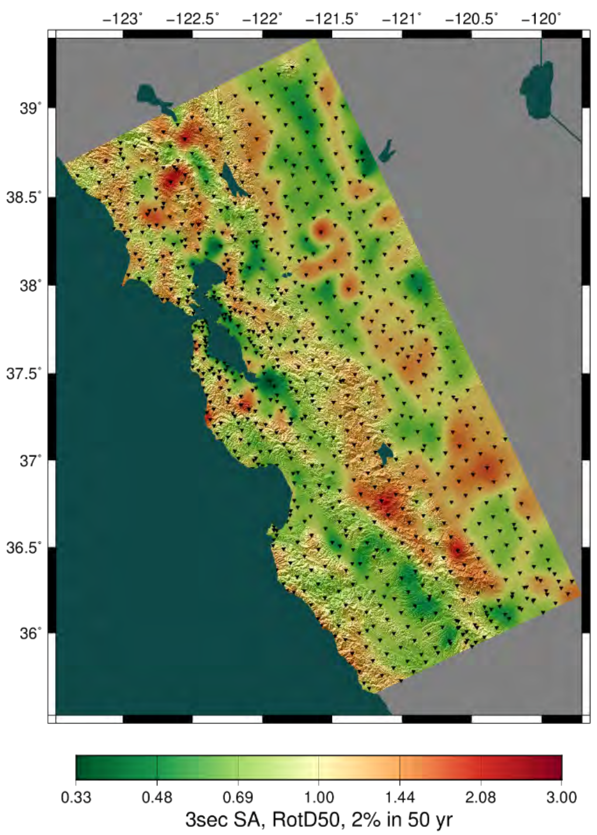


San Joaquin Valley

- CyberShake shows increased hazard in San Joaquin Valley, especially at longer periods
- Likely due to basins in tomographic CCA-06 model



Ratio, 2 sec



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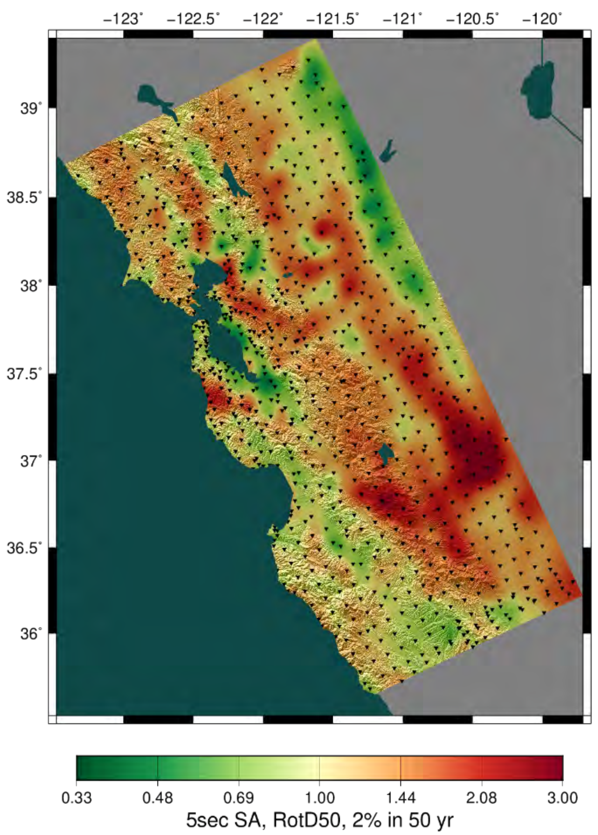
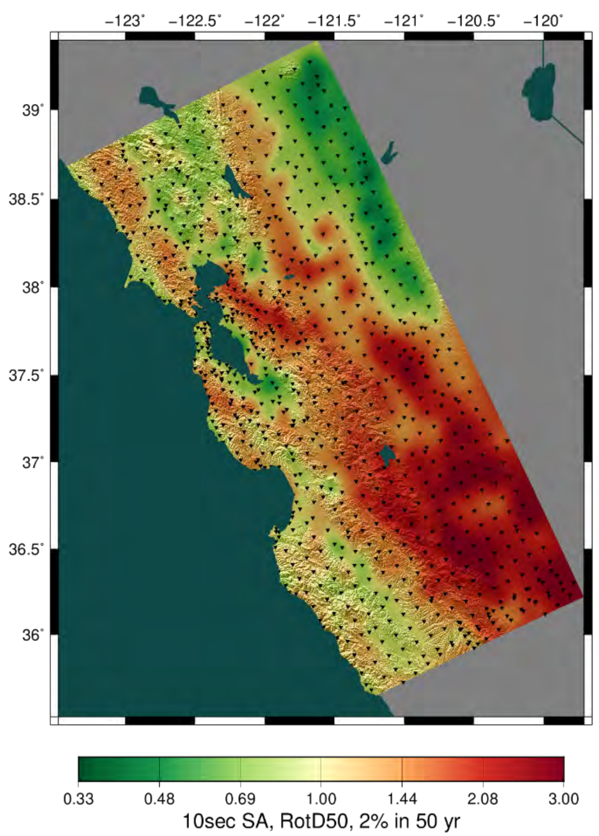
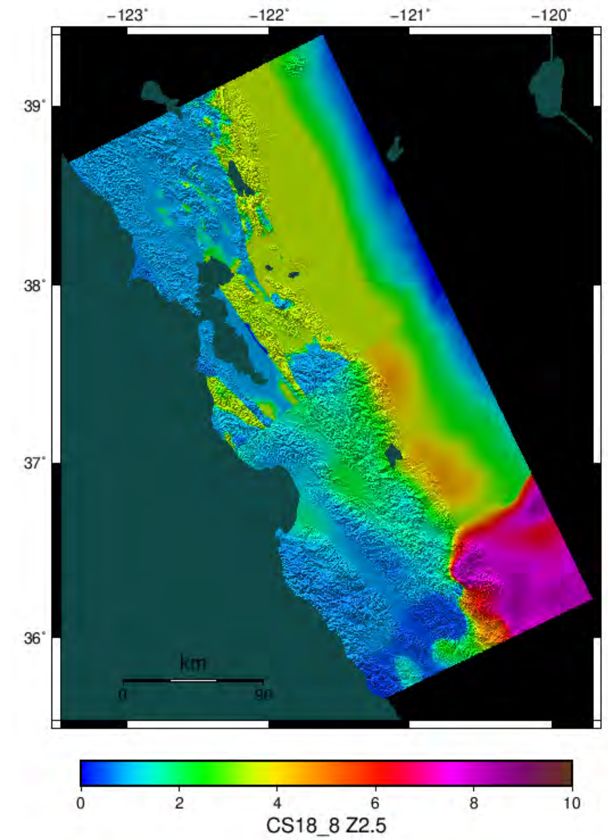


Ratio, 5 sec



Ratio, 10 sec

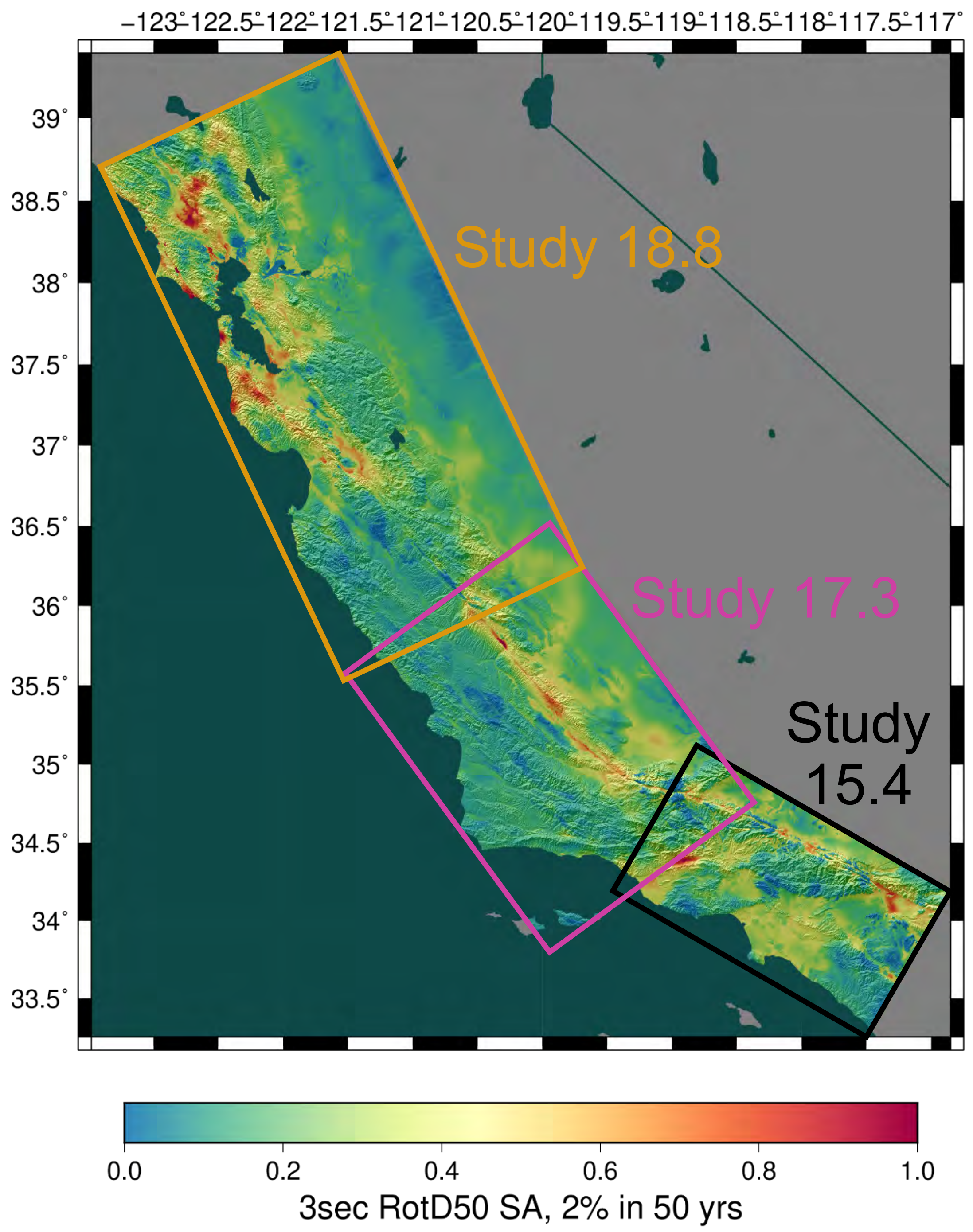


Z2.5 map

CyberShake California Hazard Model

Map combining three SCEC California probabilistic seismic hazard models (CyberShake 15.3, CyberShake 17.3, and Cybershake 18.8) where colors show estimated maximum ground motions (based on RotD50 Peak Spectral Acceleration at 3 seconds period) during the next 50 years calculated using 3D velocity Models including the CVM-S, CCA06, and USGS Bay Area models.

Use of 3D models in PSHA studies suggest that seismic hazards are increased in basin areas, and decreased in rock areas as compared to commonly used Ground Motion Prediction Models (GMPEs).

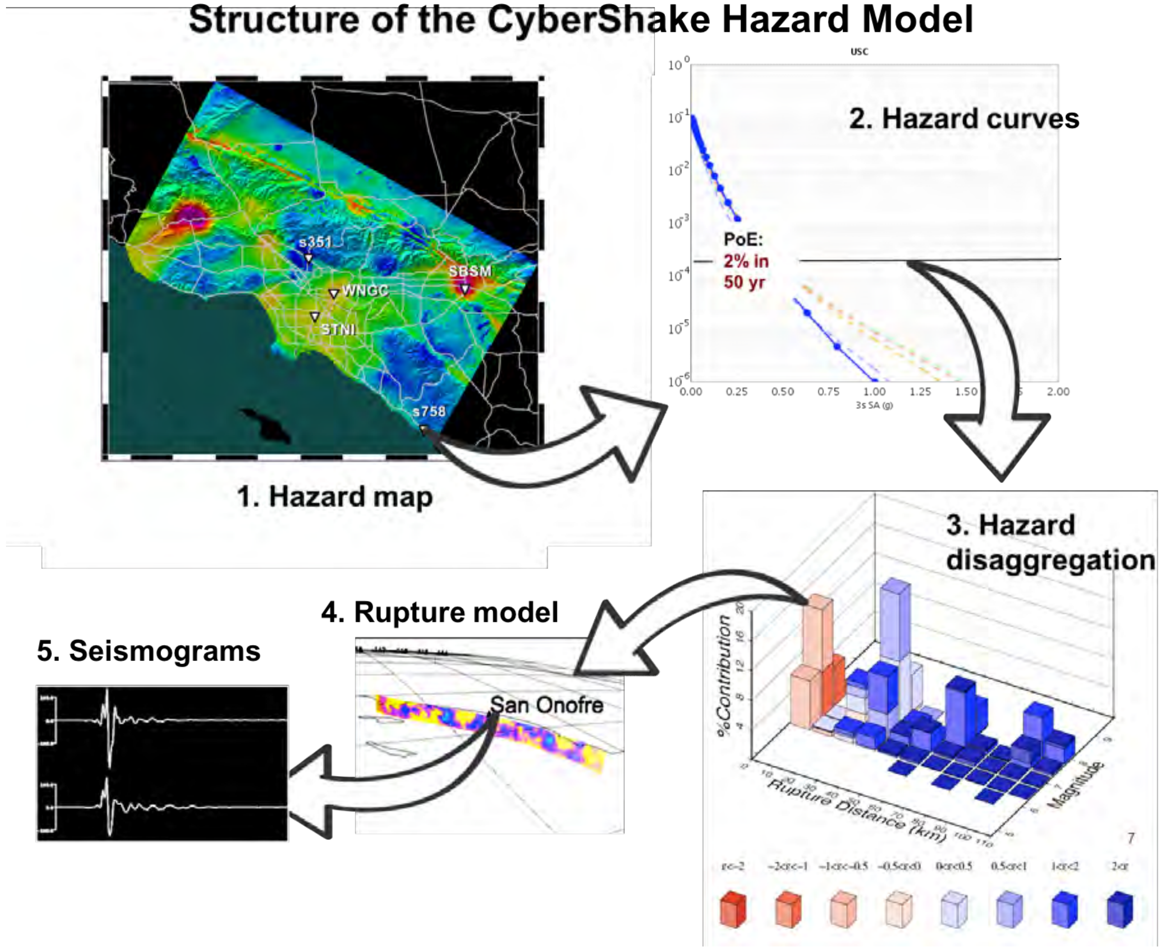


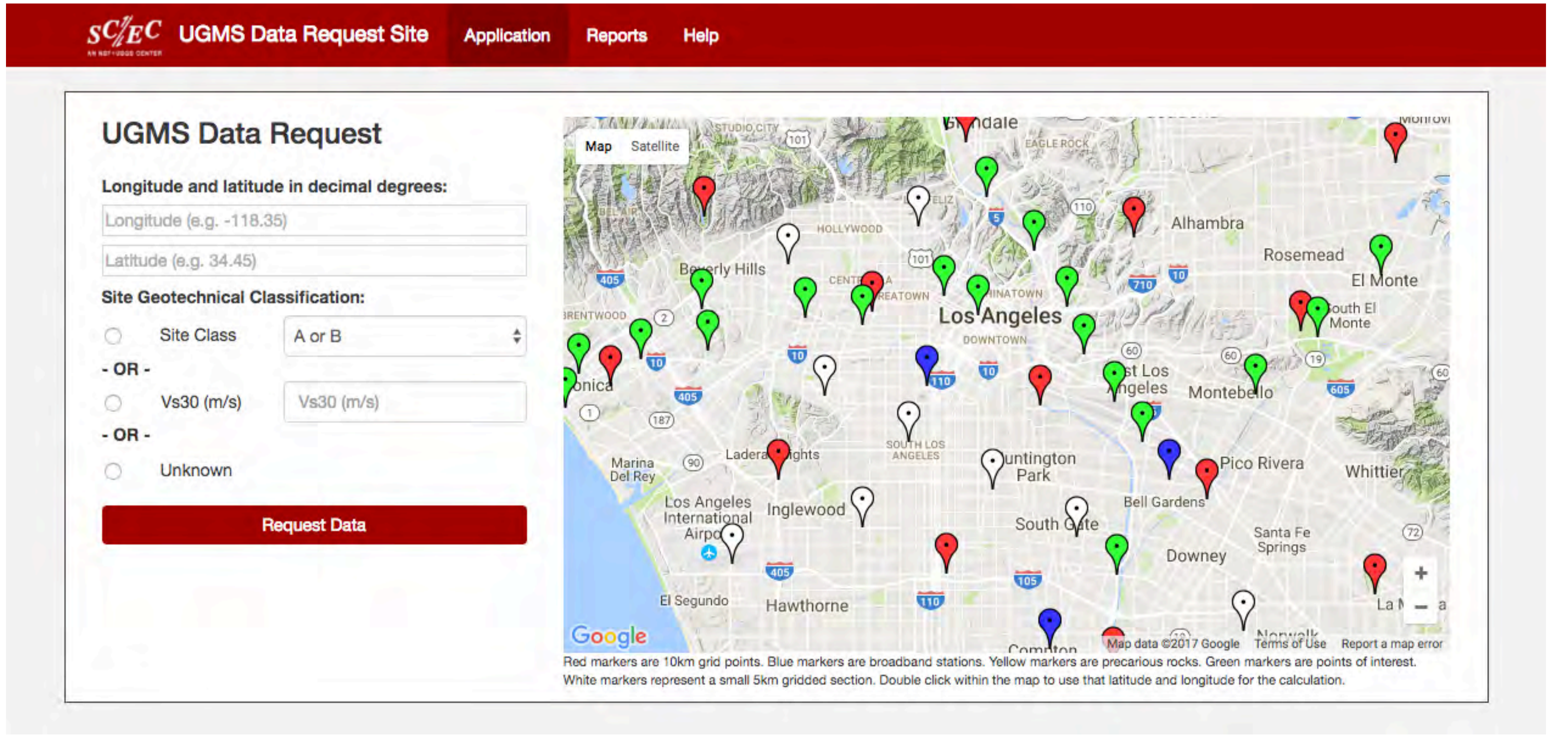
How Research Results Impact Civil Engineering Regulations

Building Engineers have expressed interest in using SCEC ground motion simulations:

1. SCEC uses Blue Waters to calculated improved peak ground motion estimates for southern California
2. Improved peak ground motions estimates are used to calculate maximum credible ground motions (at different frequencies) for all sites in a region of interest.
3. ASCE engineers include improved maximum credible ground motions and publish updated building code recommendations.
4. Public authorities (such as City of Los Angeles) reference ASCE codes in their laws, ordinances, regulations.
5. Civil engineers build new towers in Los Angeles using improved maximum credible ground motions during construction
6. Blue Waters results contribute to a safer environment

CyberShake Seismic Hazard Model Access Tools





SCEC developed data site delivers CyberShake results as Maximum Considered Earthquake Response (MCER) to Utilitization of Ground Motion Simulations (UGMS) engineering group: https://www.scec.org/research/ugms

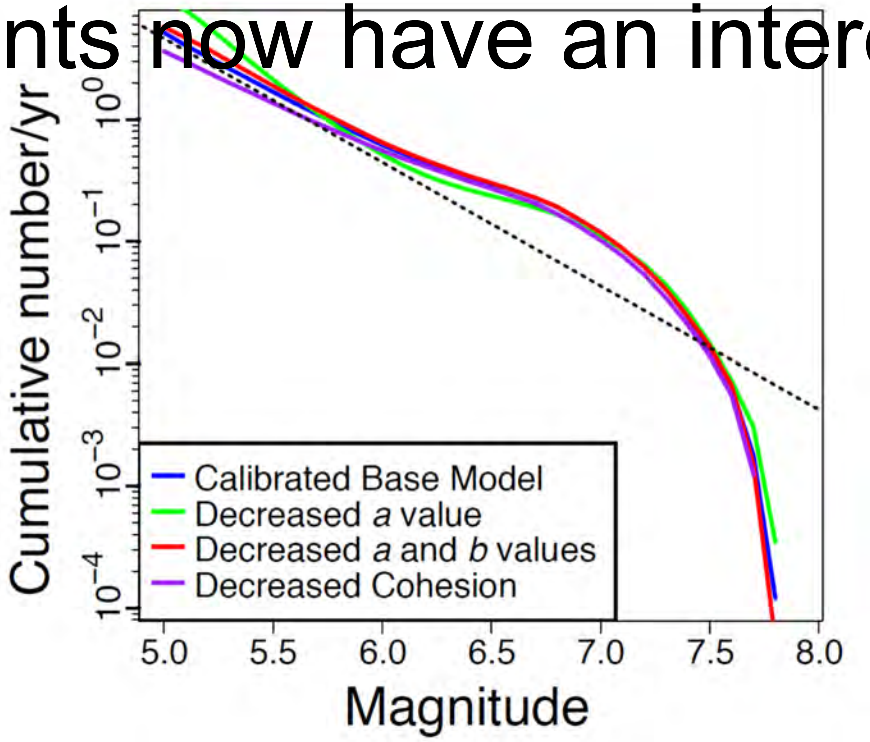
SCEC UseIT

- SCEC conducts an NSF-funded REU, Undergraduate Studies in Earthquake Information Technology (UseIT) since 2002
- 20-25 students from across the country for 8-week summer program
  - 44% female
  - 42% underrepresented minorities
  - 53% first-generation college students
- Students accomplish a ‘grand challenge’ which includes earth science and computer science elements
- Since 2016, has included an HPC component on Blue Waters
  - Goal is to make students aware of HPC as a field

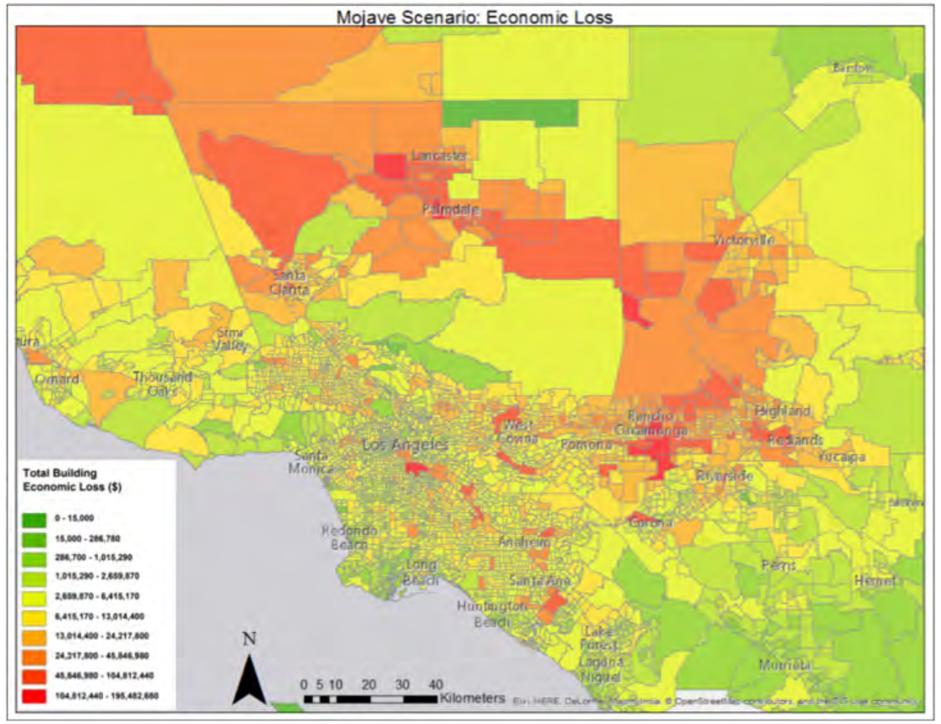
UseIT on Blue Waters

- In 2017 and 2018 SCEC UseIT interns used Blue Waters to generate RSQSim catalogs
  - 30,000 node-hours
  - Performed parameter sweeps
  - Catalogs used to predict likelihood of large aftershock sequences and losses
- Many students now have an interest in HPC

Magnitude frequency distribution of 4 RSQSim catalogs with varying frictional parameters



Projected economic loss due to a M7.7 on the Mojave fault



A Summing Up: Advancements in Seismic Hazard Research during BW Access

1. Increased computational scale :
    a. From selected sites (20 sites), to regional maps (286 sites) to large regional maps (869 sites)
2. Improved code performance:
    a. Through NEIS-P2 and PRAC-PAID program improved the efficiency of GPU codes for a speedup of 6.3
3. Improved physics:
    a. Integrated frequency dependent attenuation and non-linear response
4. Increased simulation frequency:
    a. Increased frequency from 1Hz to 4Hz (16 x 2) increase in computational time
5. Improved verification:
    a. Compared multiple California earthquakes against simulations
6. Cooperated and collaborated with Centers and Tool developers
    a. Provided admin policies in support of tools and tool developers (Pegasus-WMS, HT-Condor)
    b. Cooperated and Collaborated with external Centers (OLCF Titan, TACC Stampede2, USC HPC)
7. Increase student participation:
    a. Supported 3 Earth Science/HPC programs at SCEC
8. Extended method to new areas:
    a. Developed method for southern California (2013-2016)
    b. Applied method to Central California (2017)
    c. Applied method to Northern California (2018)
9. Created customized data access methods to support end users:
    a. MCER earthquake data website
10. Increased broad impact user communities:
    a. National Seismic Hazard mapping program
    b. ASCE building code regulations

Questions?

SC/EC
AN NSF+USGS CENTER

SDSC
SAN DIEGO SUPERCOMPUTER CENTER

U.S. DEPARTMENT OF ENERGY

USGS
science for a changing world

BLUE WATERS
SUSTAINED PETASCALE COMPUTING

NCSA

TACC

ISI
Information Sciences Institute

OAK RIDGE National Laboratory | OAK RIDGE LEADERSHIP COMPUTING FACILITY

U.S. DEPARTMENT OF ENERGY
INCITE
LEADERSHIP COMPUTING

NSF National Science Foundation

USCGRID

Pegasus