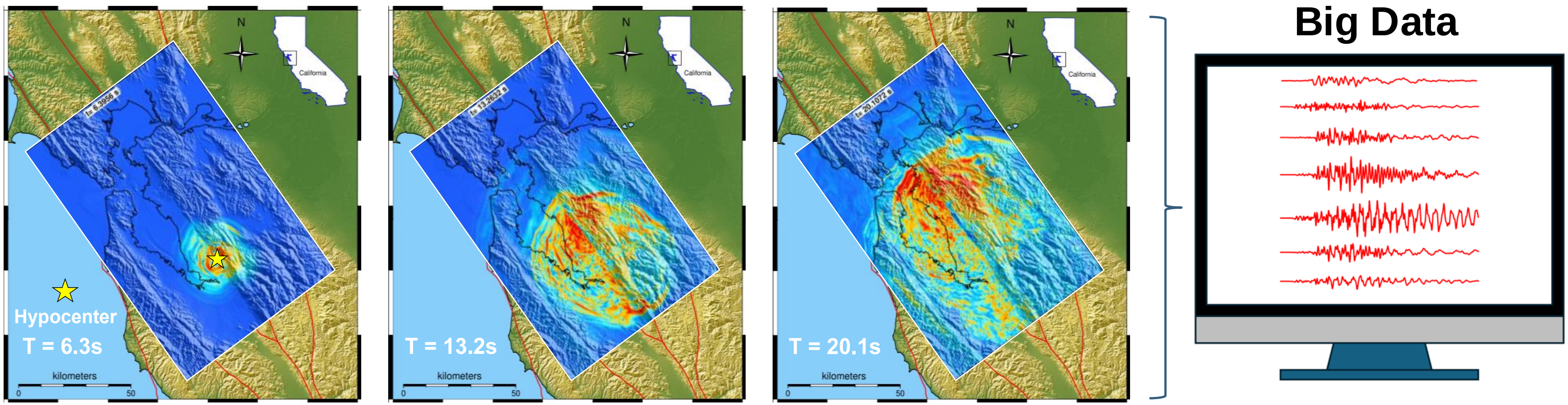


# The EQSIM Earthquake Simulation Framework and Plan for Open Access Data Sharing

*2025 PEER-LBNL Workshop on the Regional Scale Simulated Ground Motion Database (SGMD) for the San Francisco Bay Area*

**D. McCallen**
**Energy Geosciences Division**
**Lawrence Berkeley National Lab**

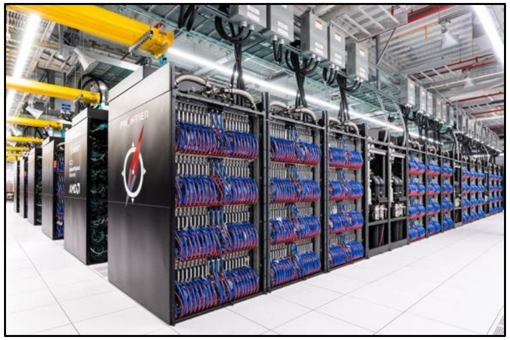
BERKELEY LAB PEER EQSIM U.S. DEPARTMENT OF ENERGY | Office of Cybersecurity, Energy Security, and Emergency Response

# Two major Department of Energy projects have supported computational advancements

## Computational R&D (2017-2023)

**Provided the simulation tools**

EXASCALE COMPUTING PROJECT



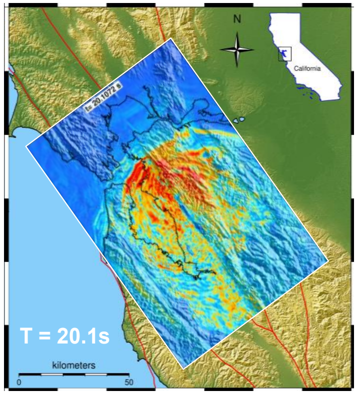
DOE developed the first *exascale* computational ecosystem based on GPU accelerator technologies

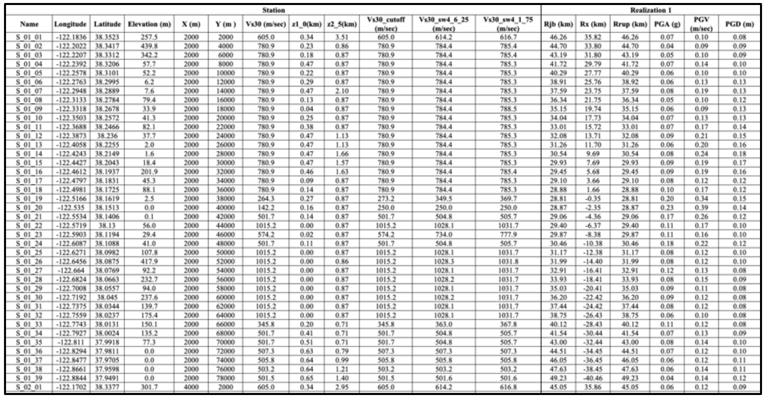
## Energy System Applications (2023-2025)

**Providing the mission "pull"**

U.S. DEPARTMENT OF ENERGY

Office of Cybersecurity, Energy Security, and Emergency Response





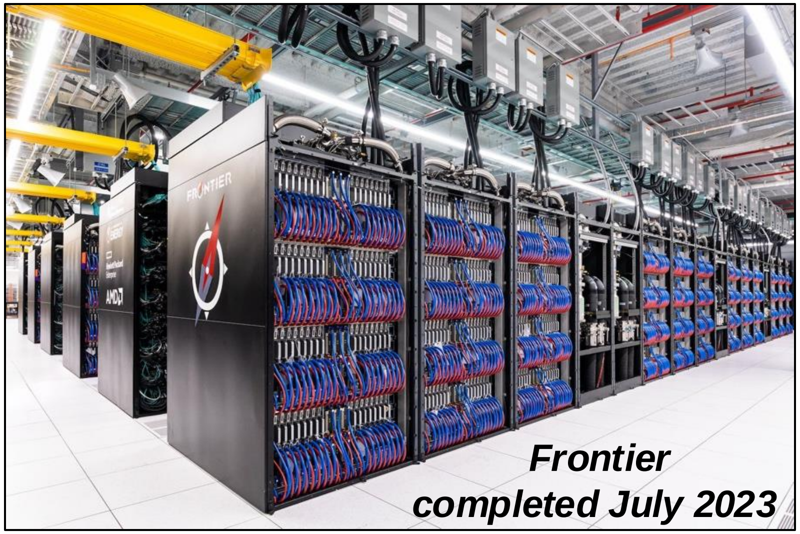
| Station | | | | | | | | | | | | Realization 1 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Longitude | Latitude | Elevation (m) | X (m) | Y (m ) | Vs30 (m/sec) | z1_0(km) | z2_5(km) | Vs30_cutoff (m/sec) | Vs30_sw4_6_25 (m/sec) | Vs30_sw4_1_75 (m/sec) | Rjb (km) | Rx (km) | Rrup (km) | PGA (g) | PGV (m/sec) | PGD (m) |
| S_01_01 | -122.1836 | 38.3523 | 257.5 | 2000 | 2000 | 605.0 | 0.34 | 3.51 | 605.0 | 614.2 | 616.7 | 46.26 | 35.82 | 46.26 | 0.07 | 0.10 | 0.08 |
| S_01_02 | -122.2022 | 38.3417 | 439.8 | 2000 | 4000 | 780.9 | 0.23 | 0.86 | 780.9 | 784.4 | 785.4 | 44.70 | 33.80 | 44.70 | 0.04 | 0.09 | 0.09 |
| S_01_03 | -122.2207 | 38.3312 | 342.2 | 2000 | 6000 | 780.9 | 0.18 | 0.87 | 780.9 | 784.4 | 785.4 | 43.19 | 31.80 | 43.19 | 0.05 | 0.10 | 0.09 |
| S_01_04 | -122.2392 | 38.3206 | 57.7 | 2000 | 8000 | 780.9 | 0.47 | 0.87 | 780.9 | 784.4 | 785.3 | 41.72 | 29.79 | 41.72 | 0.07 | 0.14 | 0.10 |
| S_01_05 | -122.2578 | 38.3101 | 52.2 | 2000 | 10000 | 780.9 | 0.22 | 0.87 | 780.9 | 784.4 | 785.3 | 40.29 | 27.77 | 40.29 | 0.06 | 0.10 | 0.10 |
| S_01_06 | -122.2763 | 38.2995 | 6.2 | 2000 | 12000 | 780.9 | 0.29 | 0.87 | 780.9 | 784.4 | 785.3 | 38.91 | 25.76 | 38.92 | 0.06 | 0.13 | 0.13 |
| S_01_07 | -122.2948 | 38.2889 | 7.6 | 2000 | 14000 | 780.9 | 0.47 | 2.10 | 780.9 | 784.4 | 785.3 | 37.59 | 23.75 | 37.59 | 0.08 | 0.19 | 0.13 |
| S_01_08 | -122.3133 | 38.2784 | 79.4 | 2000 | 16000 | 780.9 | 0.13 | 0.87 | 780.9 | 784.4 | 785.3 | 36.34 | 21.75 | 36.34 | 0.05 | 0.10 | 0.12 |
| S_01_09 | -122.3318 | 38.2678 | 33.9 | 2000 | 18000 | 780.9 | 0.04 | 0.87 | 780.9 | 784.4 | 788.5 | 35.15 | 19.74 | 35.15 | 0.06 | 0.09 | 0.13 |
| S_01_10 | -122.3503 | 38.2572 | 41.3 | 2000 | 20000 | 780.9 | 0.25 | 0.87 | 780.9 | 784.4 | 785.3 | 34.04 | 17.73 | 34.04 | 0.07 | 0.13 | 0.13 |
| S_01_11 | -122.3688 | 38.2466 | 82.1 | 2000 | 22000 | 780.9 | 0.38 | 0.87 | 780.9 | 784.4 | 785.3 | 33.01 | 15.72 | 33.01 | 0.07 | 0.17 | 0.14 |
| S_01_12 | -122.3873 | 38.236 | 37.7 | 2000 | 24000 | 780.9 | 0.47 | 1.13 | 780.9 | 784.4 | 785.3 | 32.08 | 13.71 | 32.08 | 0.09 | 0.21 | 0.15 |
| S_01_13 | -122.4058 | 38.2255 | 2.0 | 2000 | 26000 | 780.9 | 0.47 | 1.13 | 780.9 | 784.4 | 785.3 | 31.26 | 11.70 | 31.26 | 0.06 | 0.20 | 0.16 |
| S_01_14 | -122.4243 | 38.2149 | 1.6 | 2000 | 28000 | 780.9 | 0.47 | 1.66 | 780.9 | 784.4 | 785.3 | 30.54 | 9.69 | 30.54 | 0.08 | 0.24 | 0.18 |
| S_01_15 | -122.4427 | 38.2043 | 18.4 | 2000 | 30000 | 780.9 | 0.47 | 1.57 | 780.9 | 784.4 | 785.3 | 29.93 | 7.69 | 29.93 | 0.09 | 0.19 | 0.17 |
| S_01_16 | -122.4612 | 38.1937 | 201.9 | 2000 | 32000 | 780.9 | 0.46 | 1.63 | 780.9 | 784.4 | 785.4 | 29.45 | 5.68 | 29.45 | 0.09 | 0.19 | 0.16 |
| S_01_17 | -122.4797 | 38.1831 | 45.3 | 2000 | 34000 | 780.9 | 0.09 | 0.87 | 780.9 | 784.4 | 785.3 | 29.10 | 3.66 | 29.10 | 0.08 | 0.12 | 0.12 |
| S_01_18 | -122.4981 | 38.1725 | 88.1 | 2000 | 36000 | 780.9 | 0.14 | 0.87 | 780.9 | 784.4 | 785.3 | 28.88 | 1.66 | 28.88 | 0.10 | 0.17 | 0.12 |
| S_01_19 | -122.5166 | 38.1619 | 2.5 | 2000 | 38000 | 264.3 | 0.27 | 0.87 | 273.2 | 349.5 | 369.7 | 28.81 | -0.35 | 28.81 | 0.20 | 0.34 | 0.15 |
| S_01_20 | -122.535 | 38.1513 | 0.0 | 2000 | 40000 | 142.2 | 0.16 | 0.87 | 250.0 | 250.0 | 250.0 | 28.87 | -2.35 | 28.87 | 0.23 | 0.39 | 0.14 |
| S_01_21 | -122.5534 | 38.1406 | 0.1 | 2000 | 42000 | 501.7 | 0.14 | 0.87 | 501.7 | 504.8 | 505.7 | 29.06 | -4.36 | 29.06 | 0.17 | 0.26 | 0.12 |
| S_01_22 | -122.5719 | 38.13 | 56.0 | 2000 | 44000 | 1015.2 | 0.00 | 0.87 | 1015.2 | 1028.1 | 1031.7 | 29.40 | -6.37 | 29.40 | 0.11 | 0.17 | 0.10 |
| S_01_23 | -122.5903 | 38.1194 | 29.4 | 2000 | 46000 | 574.2 | 0.02 | 0.87 | 574.2 | 734.0 | 777.9 | 29.87 | -8.38 | 29.87 | 0.11 | 0.16 | 0.10 |
| S_01_24 | -122.6087 | 38.1088 | 41.0 | 2000 | 48000 | 501.7 | 0.11 | 0.87 | 501.7 | 504.8 | 505.7 | 30.46 | -10.38 | 30.46 | 0.18 | 0.22 | 0.12 |
| S_01_25 | -122.6271 | 38.0982 | 107.8 | 2000 | 50000 | 1015.2 | 0.00 | 0.87 | 1015.2 | 1028.1 | 1031.7 | 31.17 | -12.38 | 31.17 | 0.08 | 0.12 | 0.10 |
| S_01_26 | -122.6456 | 38.0875 | 417.9 | 2000 | 52000 | 1015.2 | 0.00 | 0.86 | 1015.2 | 1028.3 | 1031.8 | 31.99 | -14.40 | 31.99 | 0.08 | 0.12 | 0.10 |
| S_01_27 | -122.664 | 38.0769 | 92.2 | 2000 | 54000 | 1015.2 | 0.00 | 0.87 | 1015.2 | 1028.1 | 1031.7 | 32.91 | -16.41 | 32.91 | 0.12 | 0.13 | 0.08 |
| S_01_28 | -122.6824 | 38.0663 | 232.7 | 2000 | 56000 | 1015.2 | 0.00 | 0.87 | 1015.2 | 1028.2 | 1031.7 | 33.93 | -18.41 | 33.93 | 0.08 | 0.15 | 0.09 |
| S_01_29 | -122.7008 | 38.0557 | 94.0 | 2000 | 58000 | 1015.2 | 0.00 | 0.87 | 1015.2 | 1028.1 | 1031.7 | 35.03 | -20.41 | 35.03 | 0.09 | 0.11 | 0.08 |
| S_01_30 | -122.7192 | 38.045 | 237.6 | 2000 | 60000 | 1015.2 | 0.00 | 0.87 | 1015.2 | 1028.2 | 1031.7 | 36.20 | -22.42 | 36.20 | 0.09 | 0.12 | 0.08 |
| S_01_31 | -122.7375 | 38.0344 | 139.7 | 2000 | 62000 | 1015.2 | 0.00 | 0.87 | 1015.2 | 1028.1 | 1031.7 | 37.44 | -24.42 | 37.44 | 0.08 | 0.12 | 0.08 |
| S_01_32 | -122.7559 | 38.0237 | 175.4 | 2000 | 64000 | 1015.2 | 0.00 | 0.87 | 1015.2 | 1028.1 | 1031.7 | 38.75 | -26.43 | 38.75 | 0.06 | 0.10 | 0.08 |
| S_01_33 | -122.7743 | 38.0131 | 150.1 | 2000 | 66000 | 345.8 | 0.20 | 0.71 | 345.8 | 363.0 | 367.8 | 40.12 | -28.43 | 40.12 | 0.11 | 0.12 | 0.08 |
| S_01_34 | -122.7927 | 38.0024 | 135.2 | 2000 | 68000 | 501.7 | 0.41 | 0.71 | 501.7 | 504.8 | 505.7 | 41.54 | -30.44 | 41.54 | 0.07 | 0.13 | 0.09 |
| S_01_35 | -122.811 | 37.9918 | 77.3 | 2000 | 70000 | 501.7 | 0.51 | 0.71 | 501.7 | 504.8 | 505.7 | 43.00 | -32.44 | 43.00 | 0.08 | 0.14 | 0.10 |
| S_01_36 | -122.8294 | 37.9811 | 0.0 | 2000 | 72000 | 507.3 | 0.63 | 0.79 | 507.3 | 507.3 | 507.3 | 44.51 | -34.45 | 44.51 | 0.07 | 0.12 | 0.10 |
| S_01_37 | -122.8477 | 37.9705 | 0.0 | 2000 | 74000 | 505.8 | 0.64 | 0.99 | 505.8 | 505.8 | 505.8 | 46.05 | -36.45 | 46.05 | 0.06 | 0.12 | 0.11 |
| S_01_38 | -122.8661 | 37.9598 | 0.0 | 2000 | 76000 | 503.2 | 0.64 | 1.21 | 503.2 | 503.2 | 503.2 | 47.63 | -38.45 | 47.63 | 0.06 | 0.14 | 0.11 |
| S_01_39 | -122.8844 | 37.9491 | 0.0 | 2000 | 78000 | 501.5 | 0.65 | 1.40 | 501.5 | 501.6 | 501.6 | 49.23 | -40.46 | 49.23 | 0.04 | 0.14 | 0.12 |
| S_02_01 | -122.1702 | 38.3377 | 301.7 | 4000 | 2000 | 605.0 | 0.34 | 2.95 | 605.0 | 614.2 | 616.8 | 45.05 | 35.86 | 45.05 | 0.06 | 0.12 | 0.09 |

Simulated high-fidelity earthquake ground motions across key regions for engineering risk applications

# The DOE Exascale Computing Project created the opportunity to advance earthquake simulations

## The DOE Exascale Computing Project (ECP) developments (2017-2023)

**Advanced computer platforms** – Frontier was the world's first exaflop ($1X10^{18}$ Flops) GPU-accelerated supercomputer


*Frontier completed July 2023*

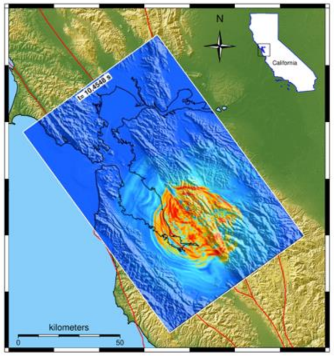
**9,400 nodes, 1.194 exaflops**

ECP
EXASCALE COMPUTING PROJECT

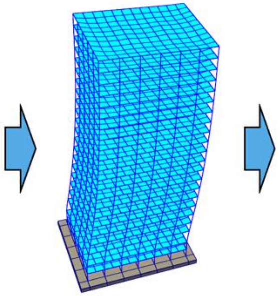
**1,000,000,000,000,000,000 Flops**

**24 competitively selected software apps**

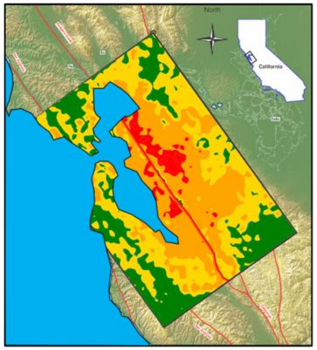
**Advanced software** – the *EQSIM* framework for regional-scale fault-to-structure simulations purpose built for GPU-accelerated platforms



**Ground motion simulations**



**Infrastructure response simulations**

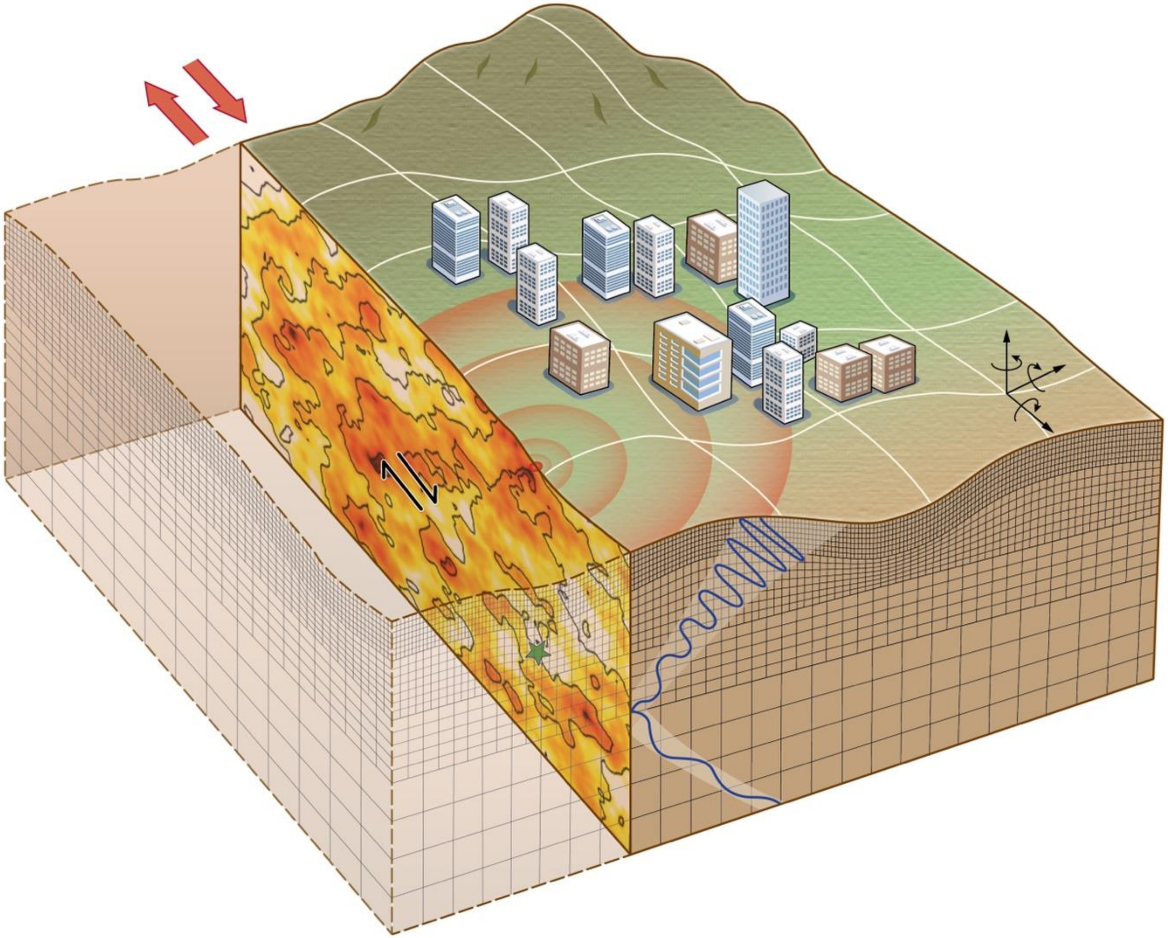


**Deeper insight into regional infrastructure risk**

EQSIM

# ECP provided the support to complete many key advancements to the SW4 geophysics code

**SW4 – Fourth order in space and time**
(Petersson, Sjogreen, Pankajakshan)



**Advanced algorithms**

- Mesh refinement in curvilinear and Cartesian grids

**Readiness for GPU-based platforms**

- Decompose computation loops into subtasks / tuning code for GPUs

**Massive data management**

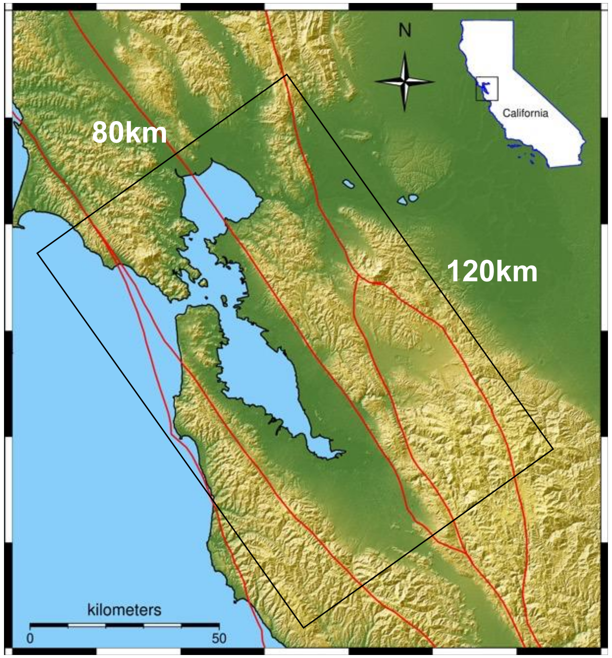
- Transition to HDF5-based IO (from SW4 homebrew)
- Utilization of ZFP for data compression

**Enhanced physics models**

- Enhancements to the Graves - Pitarka model

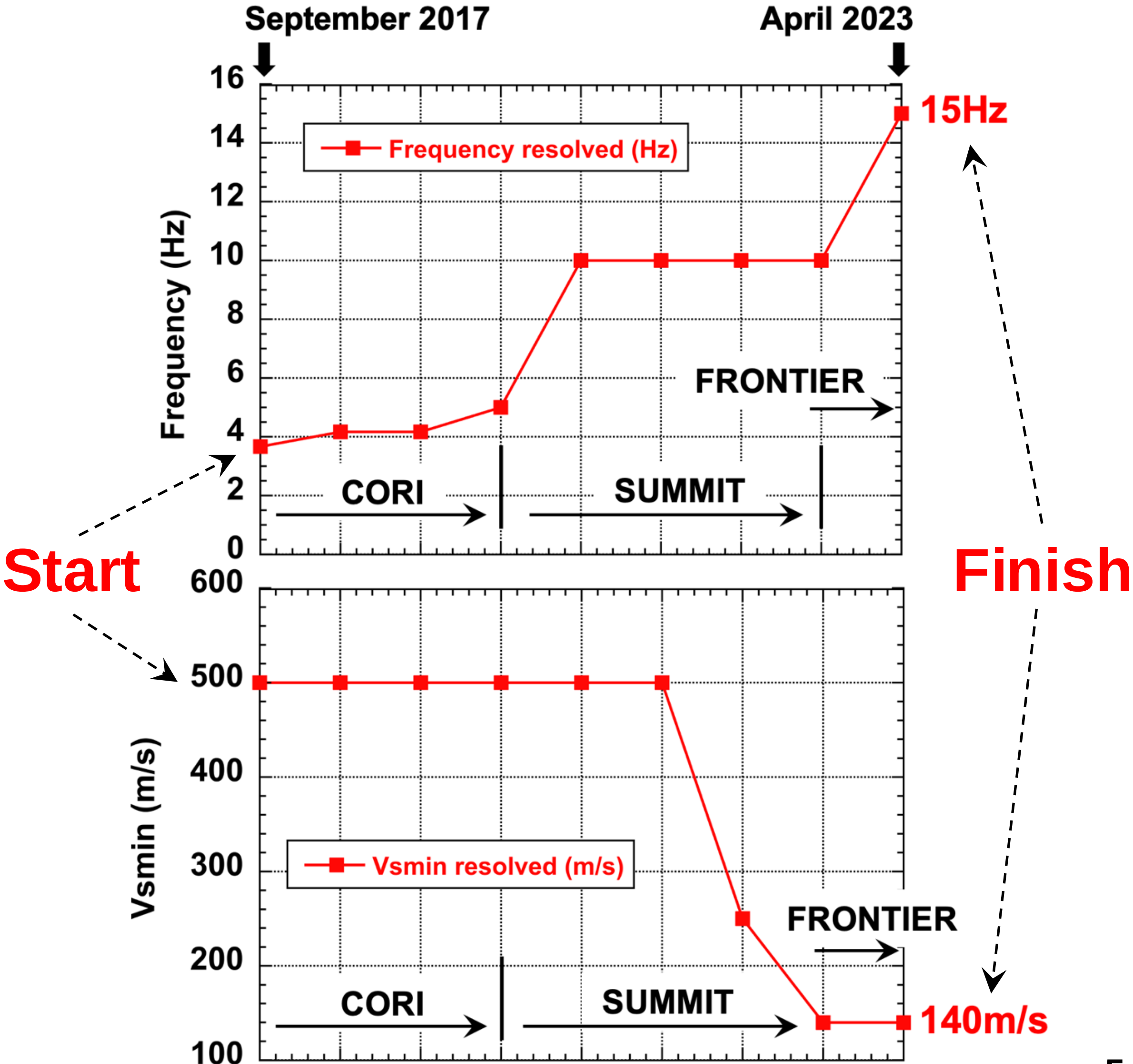
# On GPU systems EQSIM has pushed the computational edge of simulation *resolution*

**San Francisco**
**Bay regional model**

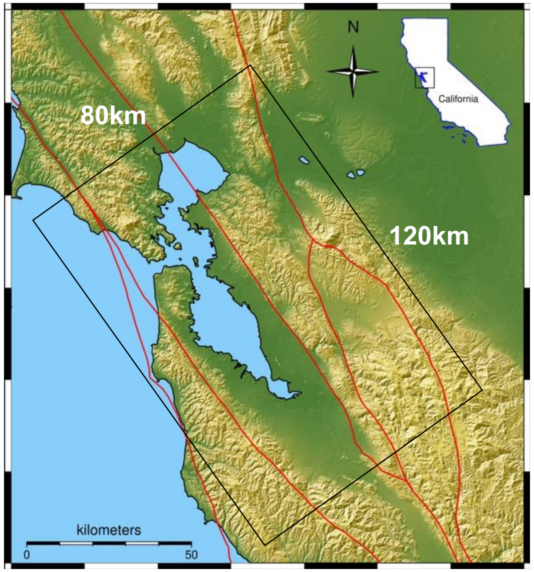


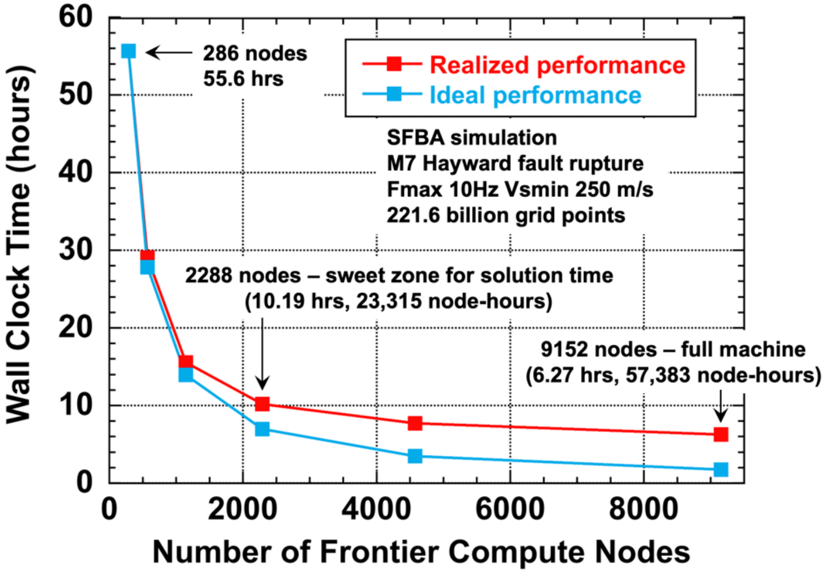
**Computational effort…**

f (domain size)
f (max frequency resolved)
f (min Vs resolved)



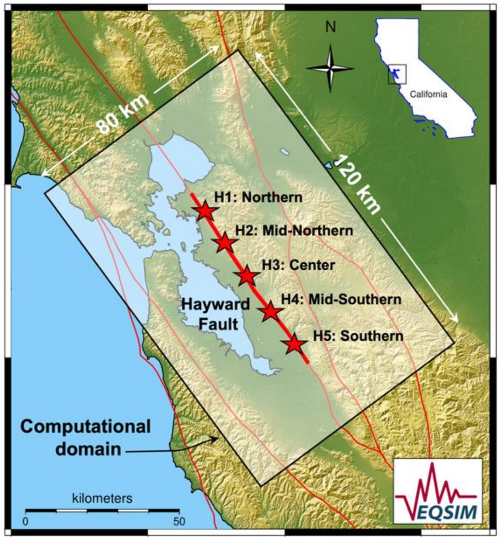
# On GPU systems EQSIM has pushed the computational edge of simulation *speed*

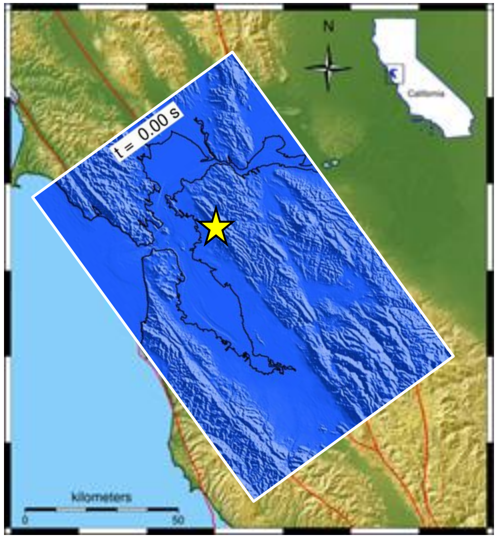


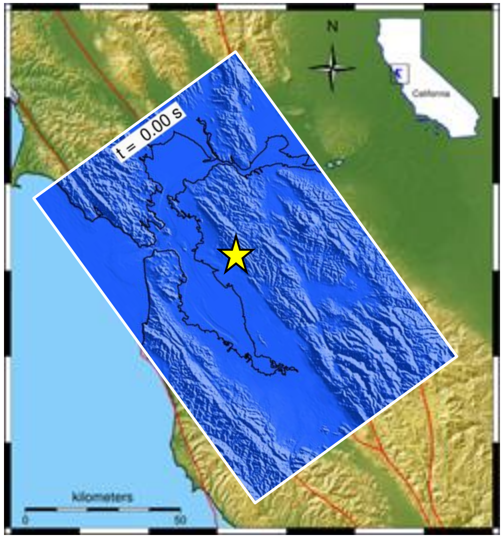


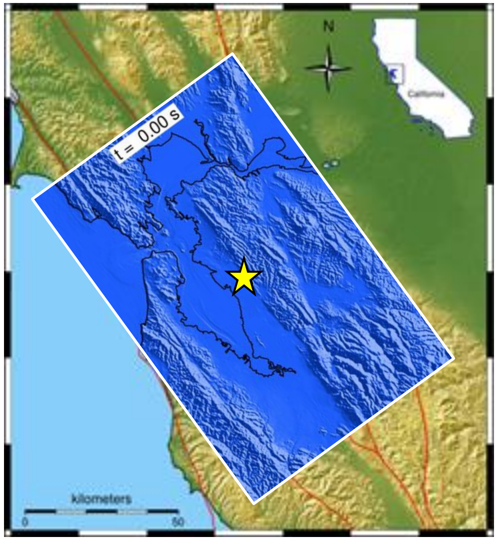
| Model | # Frontier nodes | Wall clock time (hrs) |
|---|---|---|
| Fmax 5 Hz Vsmin 250 m/s | 3072 | 1.8 |
| Fmax 10 Hz Vsmin 250 m/s | 9152 | 6.3 |
| Fmax 15 Hz Vsmin 140 m/s | 9152 | 29.2 |

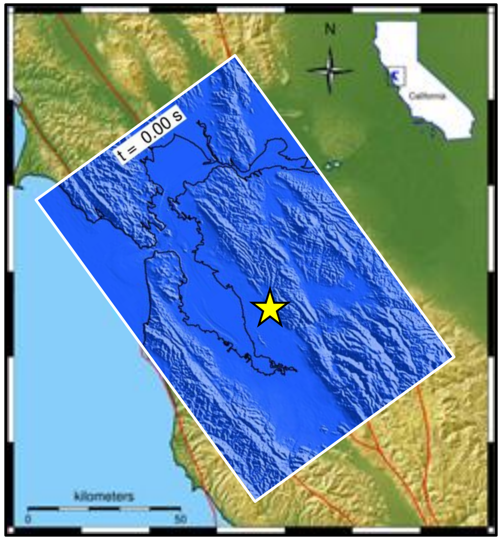
# Take away – virtual exploration of the parameter space impacting ground motions is within grasp

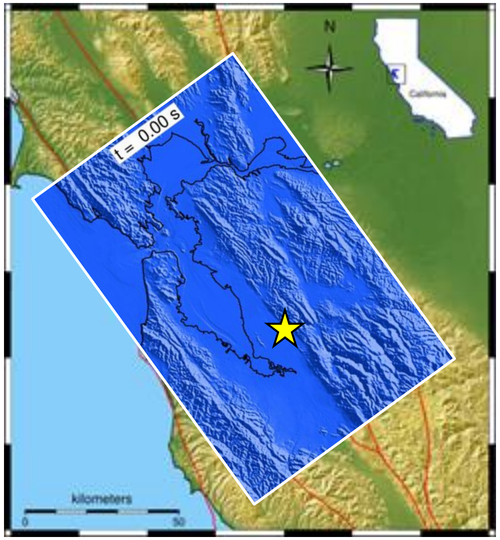






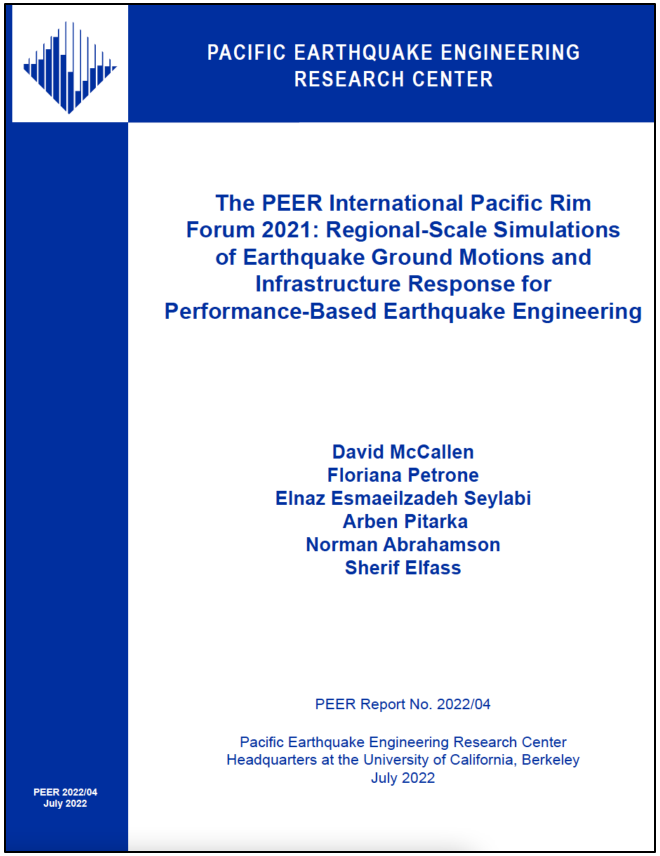






# With the transition toward applications, we have teamed with PEER to frame the path forward

**PEER Pacific Rim Forum**
**June 2021**



PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

**The PEER International Pacific Rim Forum 2021: Regional-Scale Simulations of Earthquake Ground Motions and Infrastructure Response for Performance-Based Earthquake Engineering**

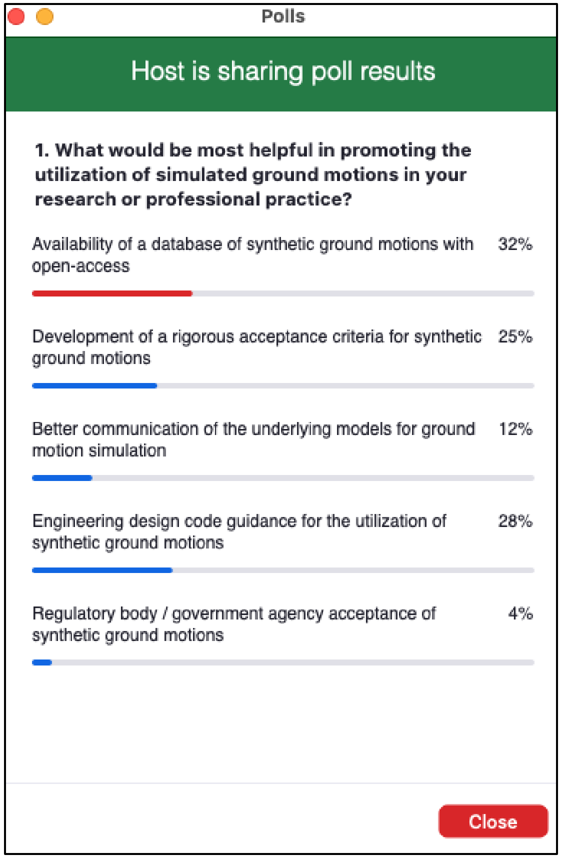
**David McCallen**
**Floriana Petrone**
**Elnaz Esmaeilzadeh Seylabi**
**Arben Pitarka**
**Norman Abrahamson**
**Sherif Elfass**

PEER Report No. 2022/04

Pacific Earthquake Engineering Research Center
Headquarters at the University of California, Berkeley
July 2022

PEER 2022/04
July 2022

**261 International Participants**
**41 International Speakers**



Host is sharing poll results

**1. What would be most helpful in promoting the utilization of simulated ground motions in your research or professional practice?**

| | |
|---|---|
| Availability of a database of synthetic ground motions with open-access | 32% |
| Development of a rigorous acceptance criteria for synthetic ground motions | 25% |
| Better communication of the underlying models for ground motion simulation | 12% |
| Engineering design code guidance for the utilization of synthetic ground motions | 28% |
| Regulatory body / government agency acceptance of synthetic ground motions | 4% |

**Attendees recommended priorities** ✓

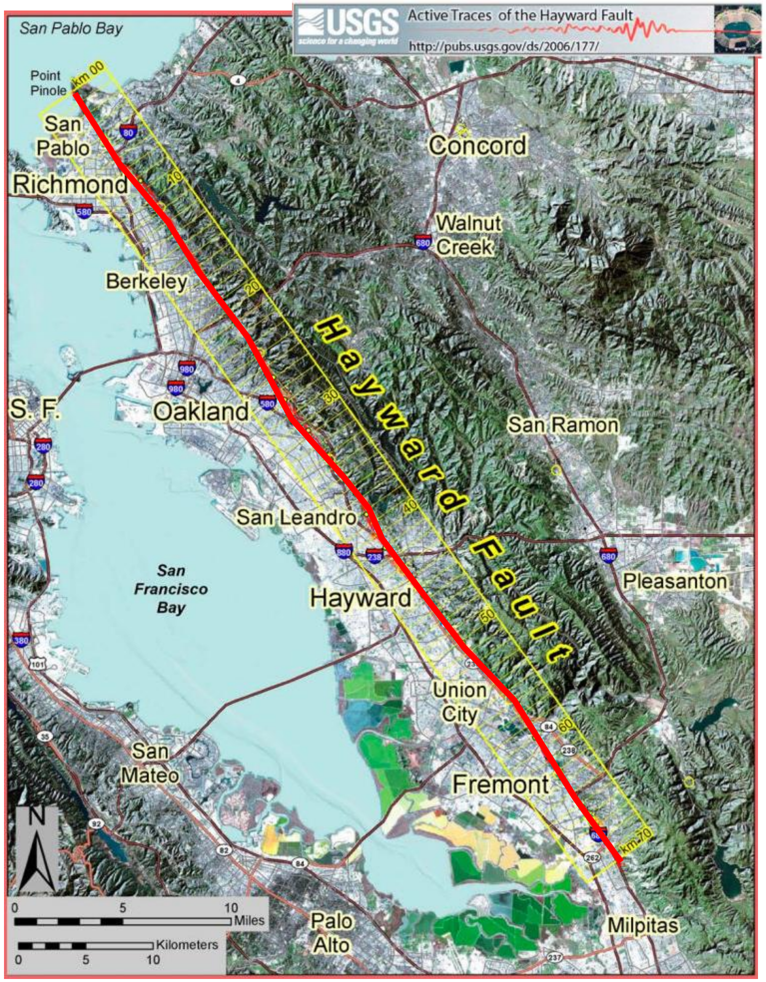
**Availability of a database of synthetic motions with *open-access*** ✓

**Assessment and acceptance criteria for synthetic motions** ✓

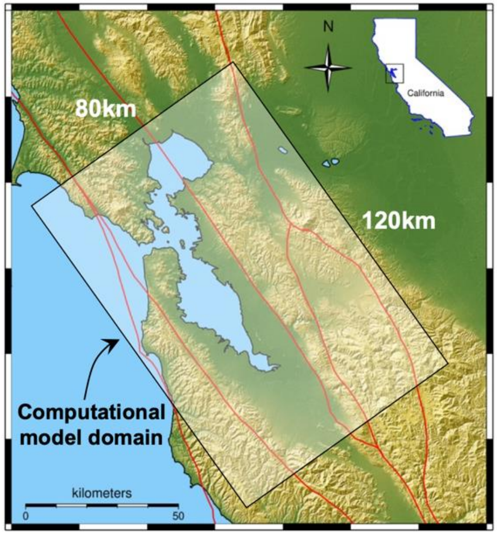
**An effective and operationally efficient user interface**

# Our initial baseline simulated ground motion database has focused on the SFBA

## The inaugural Simulated Ground Motion Database (SGMD)



### San Francisco Bay Area simulation model



Model domain 120 x 80 x 30km

29 billion grid points

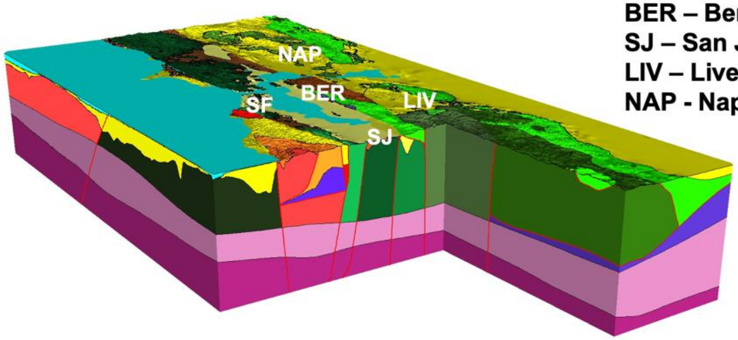
Fmax 5Hz

Vsmin 250m/s

Linear viscoelastic material model

Frequency independent attenuation factors Qp and Qs for P and S waves

USGS SFBR 3D geologic and seismic velocity model V21.1



SF – San Francisco
BER – Berkeley
SJ – San Jose
LIV – Livermore
NAP - Napa

# Activity 1 - completion of many SFBA regional-scale simulated earthquake ground motions

## Engineering

**D. McCallen**

Berkeley Lab

**F. Petrone**

Univ. Nevada

**M. Miah**

Berkeley Lab

## Seismology

**A. Pitarka**

Livermore Lab

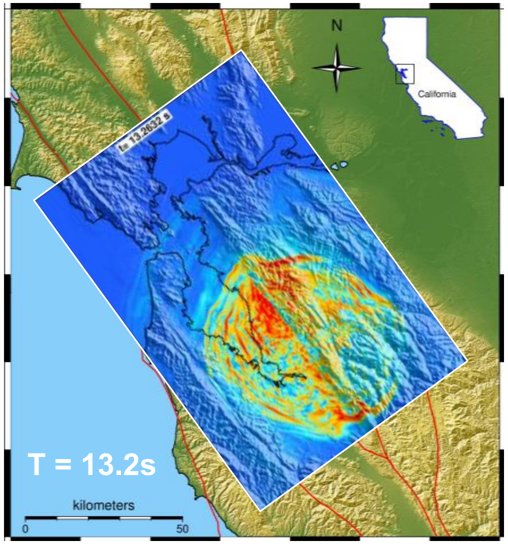
**R. Nikata**

Berkeley Lab

## Computer Science

**H. Tang**

Berkeley Lab



**E. Taciroglu**

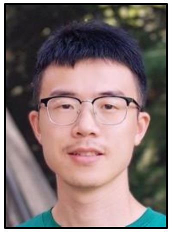
UCLA Civil Engineering

### Current postdoctoral scholars and PhD students

**Kostantinos Tsalouchidis**

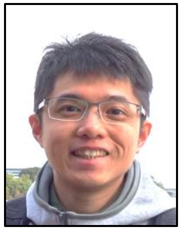
LBNL

**Junfei Huang**



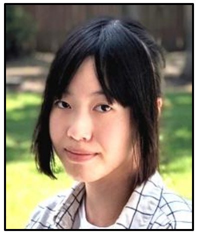
LBNL

**Clifford Yen**



UCLA

**Flora Xia**



CALTECH

BERKELEY LAB

UCLA Samueli School of Engineering

# Activity 2 - development of the interactive open access simulated ground motion database

**PEER Director &**
**UC Berkeley**

**K. Mosalam**

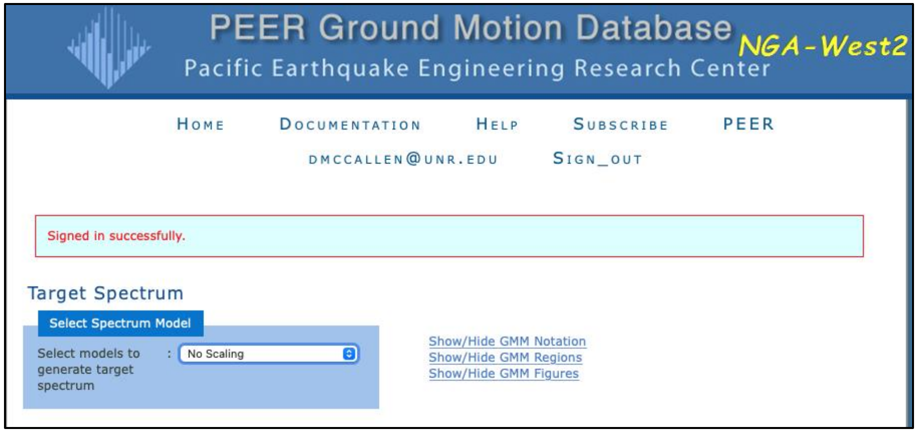
**S. Gunay**

**G. Vargas**

**A. Kasalanati**

**C. Perez**
**PhD student**

## Existing – Measured ground motion database



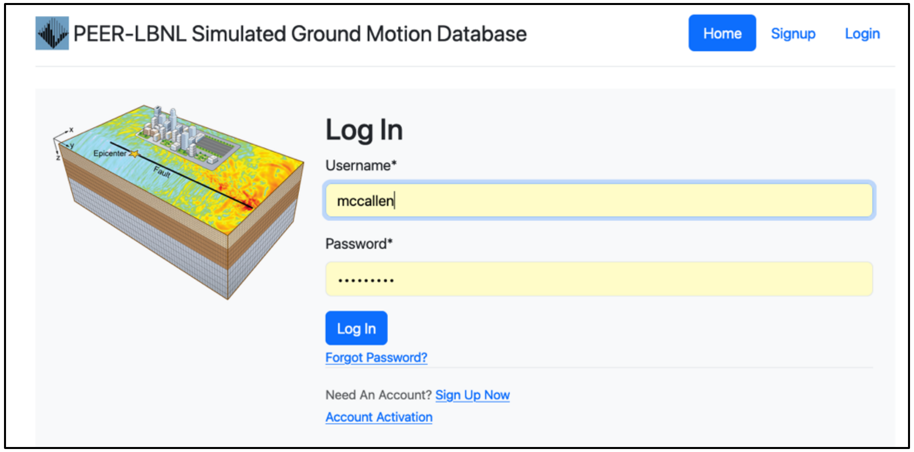
PEER Ground Motion Database NGA-West2
Pacific Earthquake Engineering Research Center

Signed in successfully.

Target Spectrum

Select models to generate target spectrum : No Scaling

## New – Simulated ground motion database



PEER-LBNL Simulated Ground Motion Database

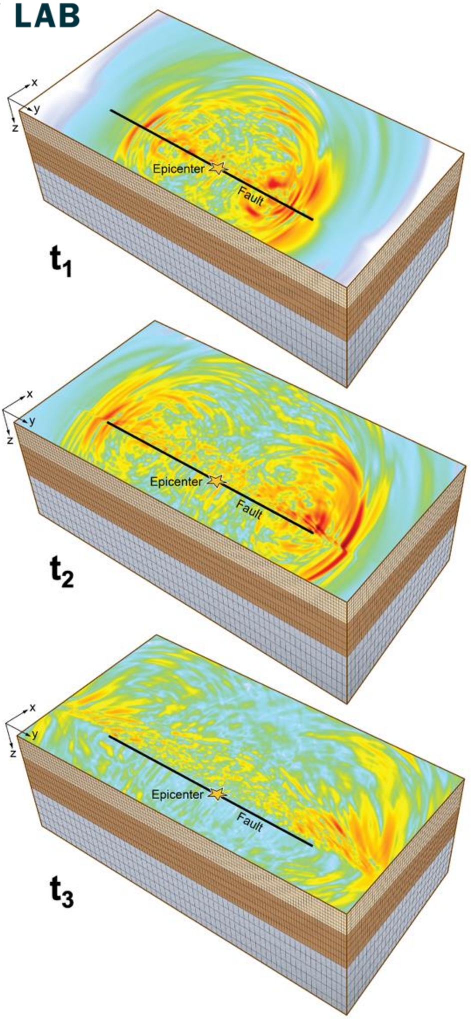
Log In

Username*: mccallen

Password*: •••••••••

Need An Account? Sign Up Now

# Workflow from simulation to SGMD server - developing a flexible data schema that can scale



**Regional simulation** → **Down sampling** → **Processing** → **Storage for open access**

EQSIM
HDF5
Ground velocities
data options
- Compressed
- Uncompressed

Spatial and temporal down sampling options

Numerical differentiation with 2nd order central difference

Ground velocities
- Fault normal
- Fault parallel
- Vertical

Numerical integration with trapezoidal rule

Ground accelerations

Ground velocities

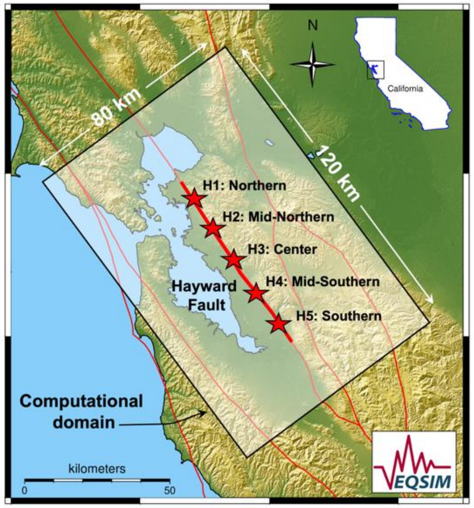
Ground displacements

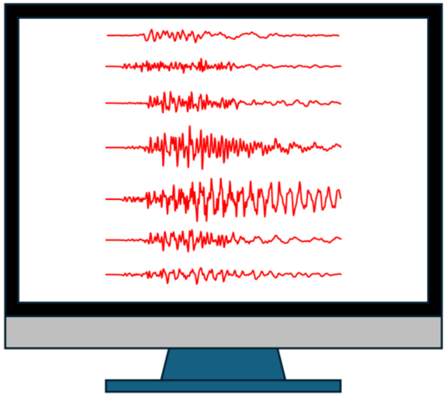
SGMD server

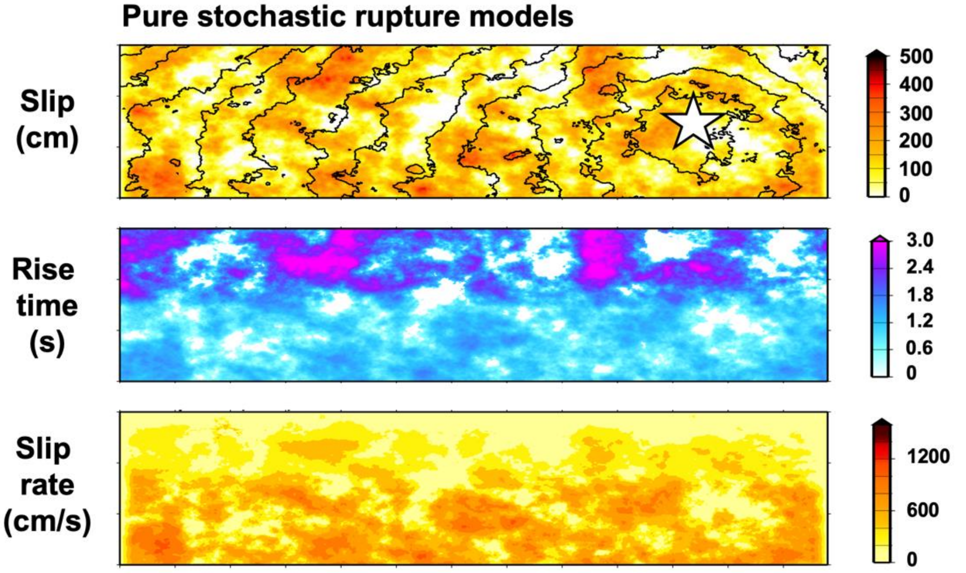
Linux server
64 core AMD processor
128 GB RAM
68TB of SSD storage
RAID 6 storage configuration

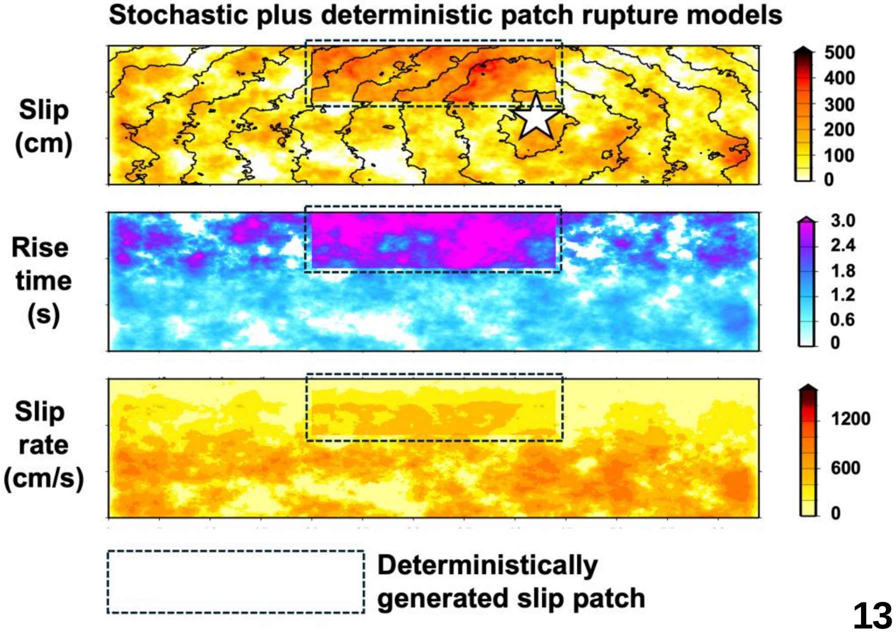
# Focus on representing source rupture variability with the Graves - Pitarka rupture model

**50 Hayward fault rupture realizations**





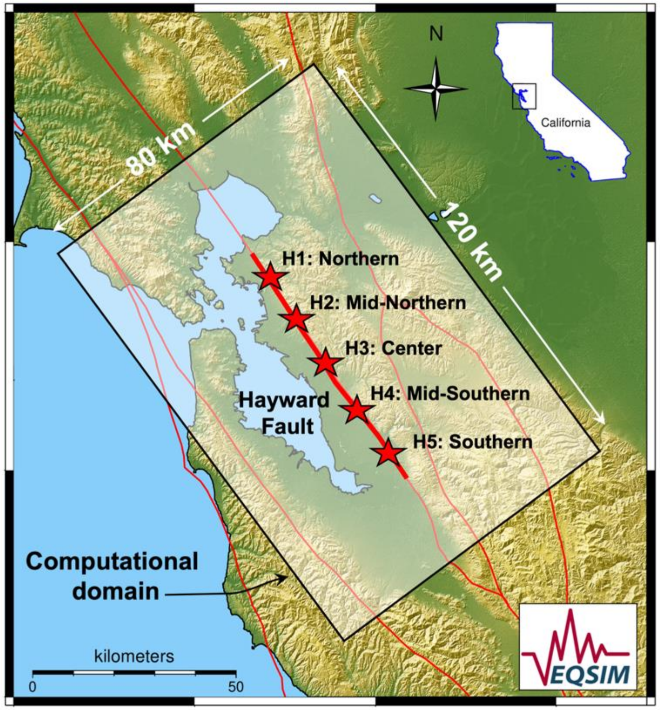

Pure stochastic rupture models

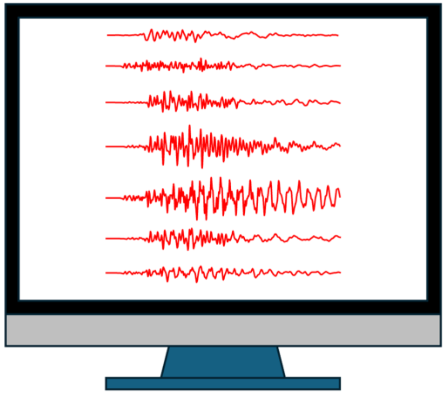

Stochastic plus deterministic patch rupture models

Deterministically generated slip patch

# Simulated ground motions for 50 M7 Hayward ruptures are complete and on the SGMD server

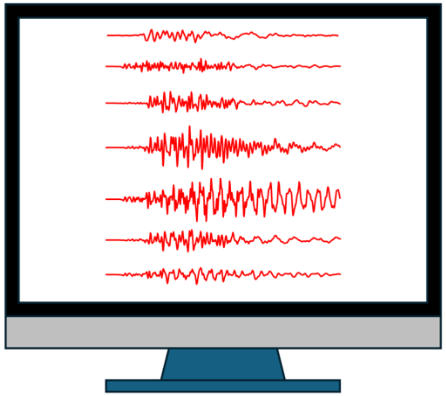
**50 Hayward fault rupture realizations**





PEER

**1,021,500 time series @ 2 km spacing (uncompressed HDF5 files - 330GB uncompressed ASCII files - 700GB)**



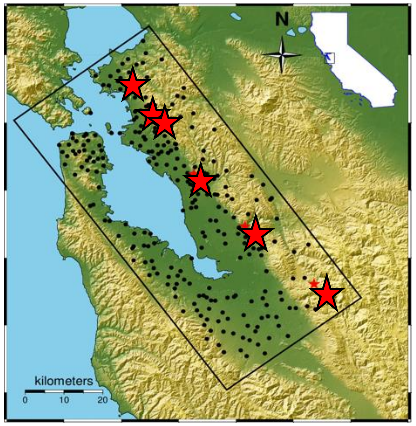
BERKELEY LAB

**110,606,400,000 time series @ 6.25 m spacing (compressed and time down sampled HDF5 files - 42TB)**

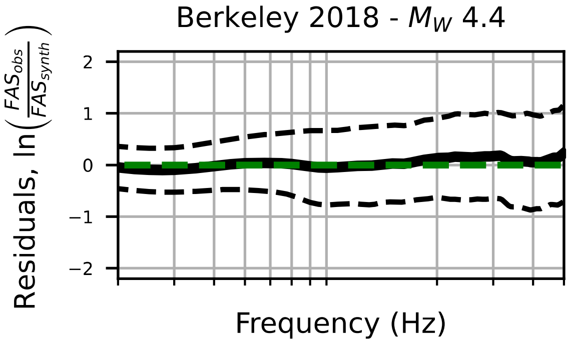
# We have tested our simulations in multiple ways

## 1) Testing the EQSIM Bay Area model – 7 small Hayward event simulations

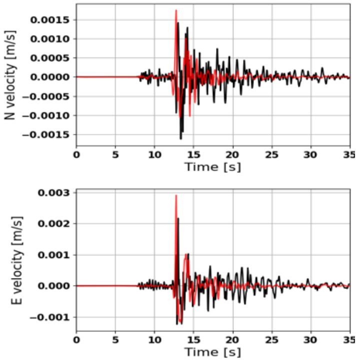
**C. Pinilla Ramos**



Spectral comparisons



Comparison to measured ground motion waveforms

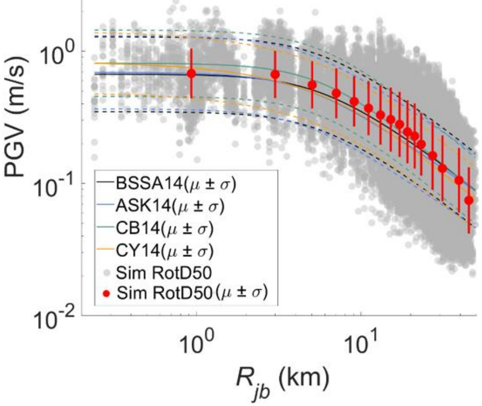


## 2) Evaluating the simulated large events - 50 M7 Hayward fault realizations

**F. Petrone**

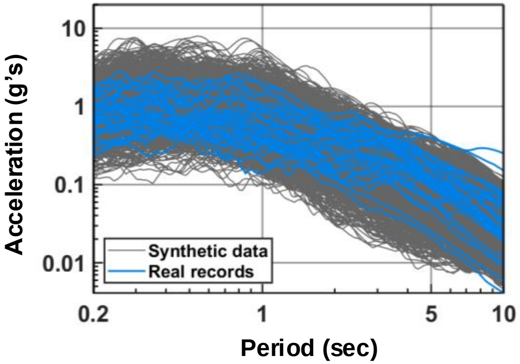
**R. Nikata**

Comparison to existing empirical GMP equations

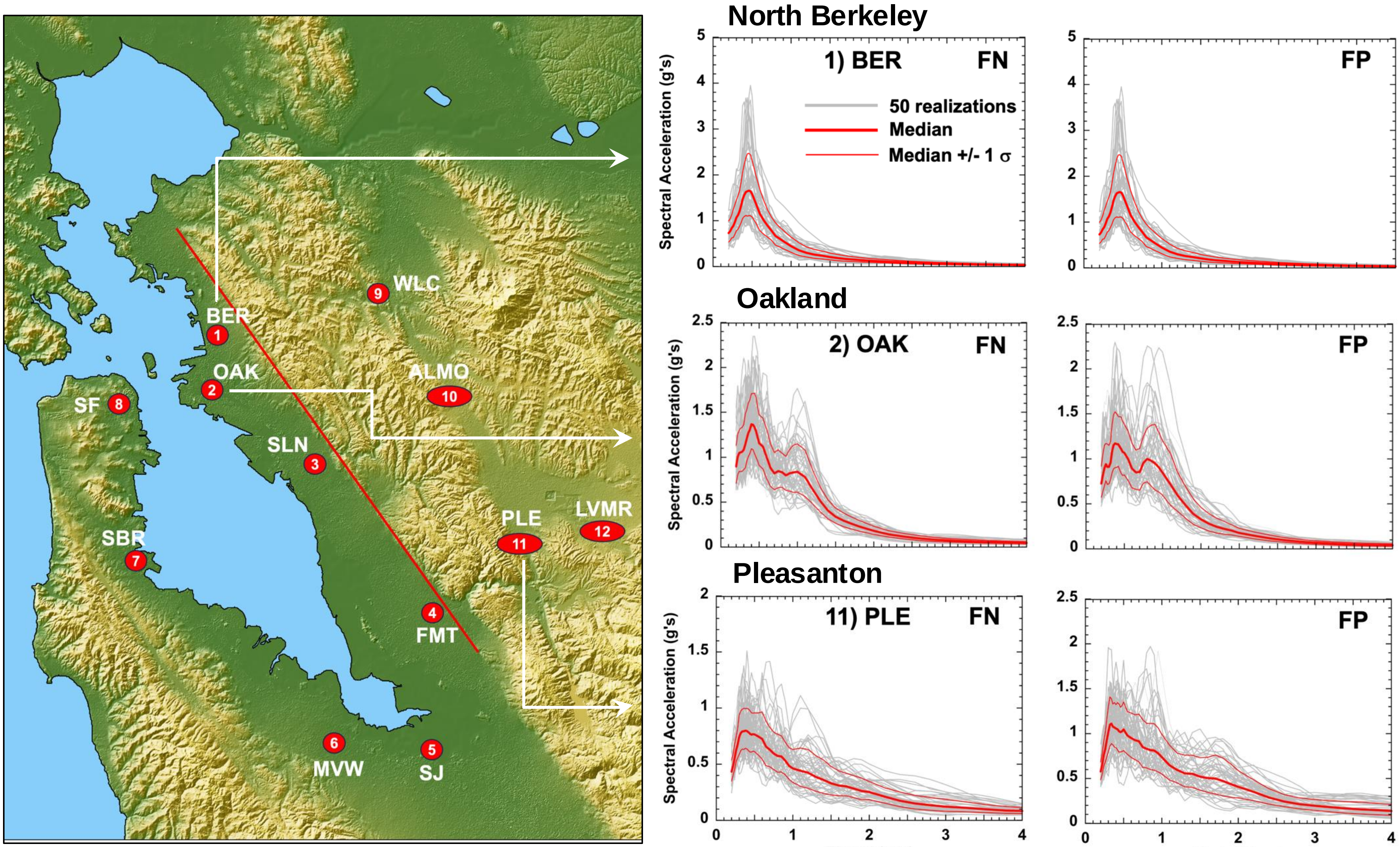


Comparison to existing commensurate ground motion data (near-fault sites < 10 km)

Spectral scatter - FaultNormal



# There is a *LOT* to analyze, e.g. complex within- and between-event distributions of motions



# Since January 2025, 15 SGMD *Beta Users* have downloaded 5,633,712 time series

**P. Arduino**

UW/SimCenter

**F. McKenna**

UCB/SimCenter

**S. Muin**

USC

**T. Opabola**

UC Berkeley

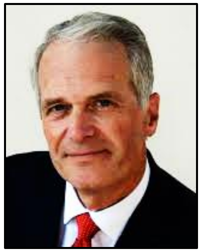
**M. Esteghamati**

Utah State

**J. Dai**

SoCal Edison

**K. Hudnut**



SoCal Edison

**B. Low**

PG&E

**A. Kottke**

PG&E

**A. Shepard**

FEMA

**I. Kim**

Degenkolb

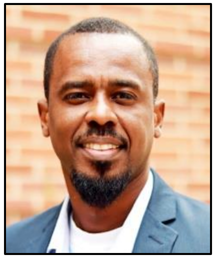
**M. Kenawy**

OK State

**B. Rowshandel**

CA EQ Authority

**H. Burton**

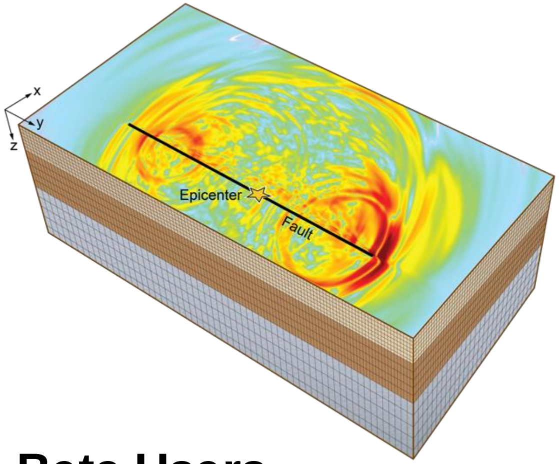


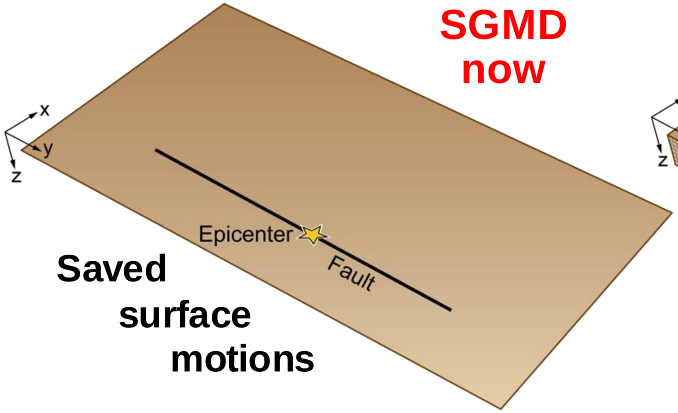
UCLA

**E. Miranda**

Stanford

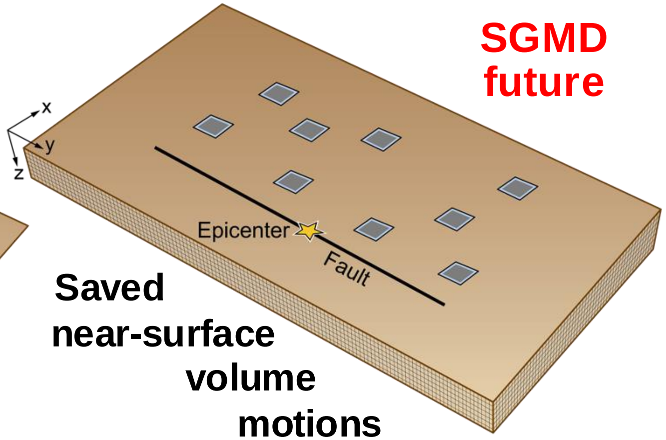
# The SGMD can continue to evolve to support advanced engineering risk applications





**SGMD now**

**Saved surface motions**



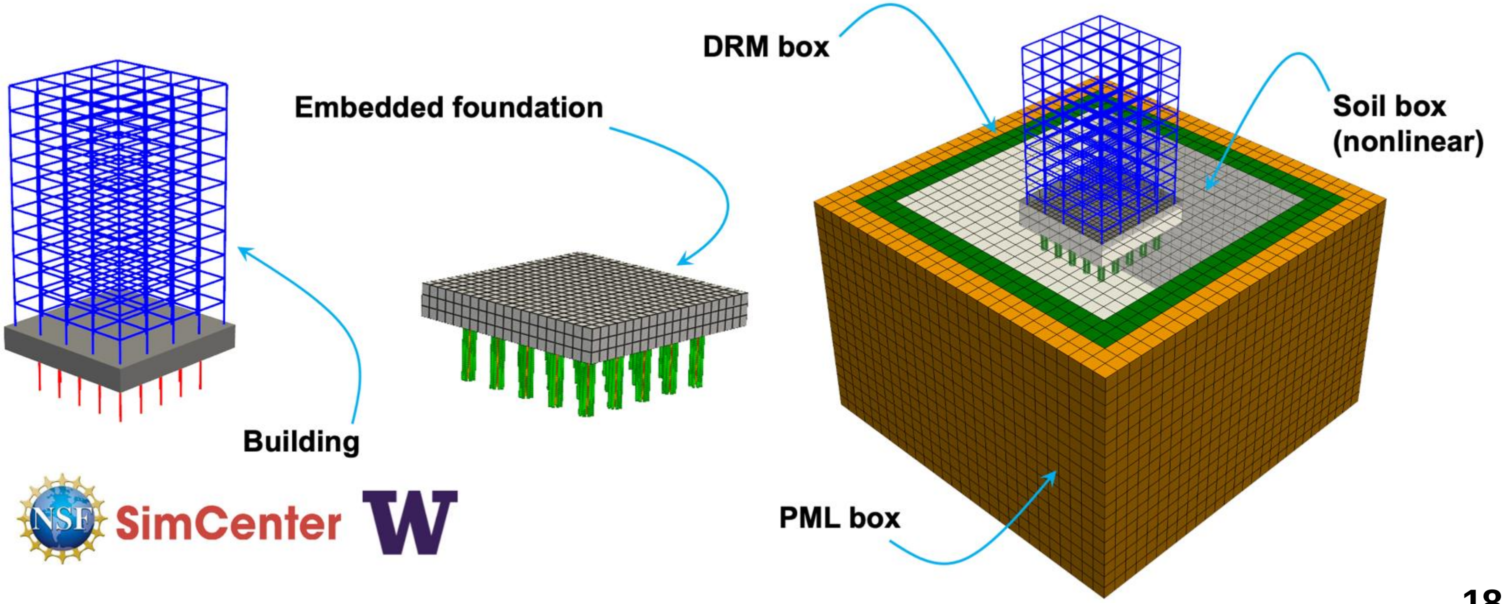
**SGMD future**

**Saved near-surface volume motions**

## Beta Users

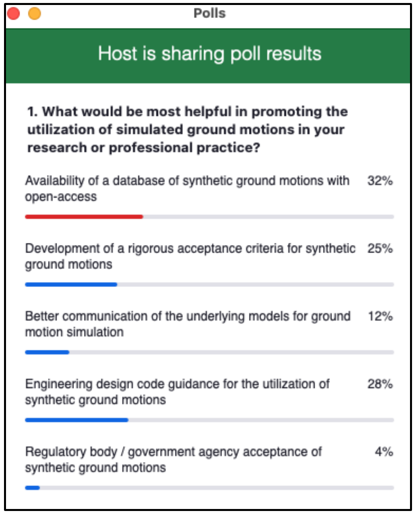
**P. Arduino**

**F. McKenna**



NSF SimCenter W

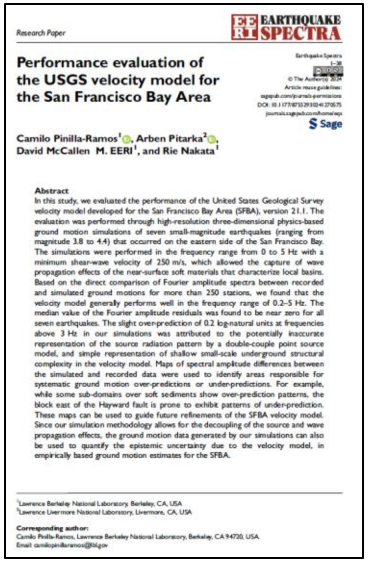
# Community input for defining additional capabilities and enhancements is crucial



**1. What would be most helpful in promoting the utilization of simulated ground motions in your research or professional practice?**

| | |
|---|---|
| Availability of a database of synthetic ground motions with open-access | 32% |
| Development of a rigorous acceptance criteria for synthetic ground motions | 25% |
| Better communication of the underlying models for ground motion simulation | 12% |
| Engineering design code guidance for the utilization of synthetic ground motions | 28% |
| Regulatory body / government agency acceptance of synthetic ground motions | 4% |

# Links to more detailed info are on the SGMD website



*Research Paper*

EARTHQUAKE SPECTRA
Earthquake Spectra
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## Performance evaluation of the USGS velocity model for the San Francisco Bay Area

**Camilo Pinilla-Ramos[1], Arben Pitarka[2], David McCallen M. EERI[1], and Rie Nakata[1]**

**Abstract**
In this study, we evaluated the performance of the United States Geological Survey velocity model developed for the San Francisco Bay Area (SFBA), version 21.1. The evaluation was performed through high-resolution three-dimensional physics-based ground motion simulations of seven small-magnitude earthquakes (ranging from magnitude 3.8 to 4.4) that occurred on the eastern side of the San Francisco Bay. The simulations were performed in the frequency range from 0 to 5 Hz with a minimum shear-wave velocity of 250 m/s, which allowed the capture of wave propagation effects of the near-surface soft materials that characterize local basins. Based on the direct comparison of Fourier amplitude spectra between recorded and simulated ground motions for more than 250 stations, we found that the velocity model generally performs well in the frequency range of 0.2–5 Hz. The median value of the Fourier amplitude residuals was found to be near zero for all seven earthquakes. The slight over-prediction of 0.2 log-natural units at frequencies above 3 Hz in our simulations was attributed to the potentially inaccurate representation of the source radiation pattern by a double-couple point source model, and simple representation of shallow small-scale underground structural complexity in the velocity model. Maps of spectral amplitude differences between the simulated and recorded data were used to identify areas responsible for systematic ground motion over-predictions or under-predictions. For example, while some sub-domains over soft sediments show over-prediction patterns, the block east of the Hayward fault is prone to exhibit patterns of under-prediction. These maps can be used to guide future refinements of the SFBA velocity model. Since our simulation methodology allows for the decoupling of the source and wave propagation effects, the ground motion data generated by our simulations can also be used to quantify the epistemic uncertainty due to the velocity model, in empirically based ground motion estimates for the SFBA.

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[2]Lawrence Livermore National Laboratory, Livermore, CA, USA

**Corresponding author:**
Camilo Pinilla-Ramos, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA.
Email: camilopinillaramos@lbl.gov

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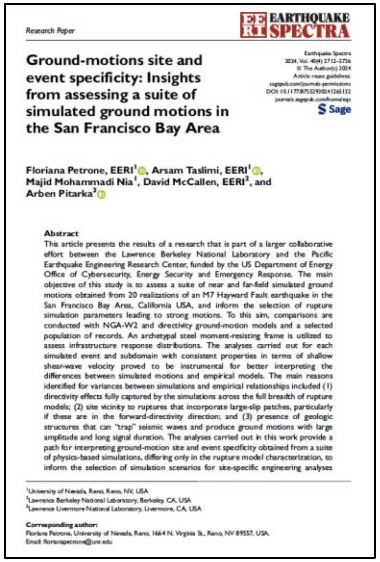

*Research Paper*

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Earthquake Spectra
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## Ground-motions site and event specificity: Insights from assessing a suite of simulated ground motions in the San Francisco Bay Area

**Floriana Petrone, EERI[1], Arsam Taslimi, EERI[1], Majid Mohammadi Nia[1], David McCallen, EERI[2], and Arben Pitarka[3]**

**Abstract**
This article presents the results of a research that is part of a larger collaborative effort between the Lawrence Berkeley National Laboratory and the Pacific Earthquake Engineering Research Center, funded by the US Department of Energy Office of Cybersecurity, Energy Security and Emergency Response. The main objective of this study is to assess a suite of near and far-field simulated ground motions obtained from 20 realizations of an M7 Hayward Fault earthquake in the San Francisco Bay Area, California USA, and inform the selection of rupture simulation parameters leading to strong motions. To this aim, comparisons are conducted with NGA-W2 and directivity ground-motion models and a selected population of records. An archetypal steel moment-resisting frame is utilized to assess infrastructure response distributions. The analyses carried out for each simulated event and subdomain with consistent properties in terms of shallow shear-wave velocity proved to be instrumental for better interpreting the differences between simulated motions and empirical models. The main reasons identified for variances between simulations and empirical relationships included (1) directivity effects fully captured by the simulations across the full breadth of rupture models; (2) site vicinity to ruptures that incorporate large-slip patches, particularly if these are in the forward-directivity direction; and (3) presence of geologic structures that can "trap" seismic waves and produce ground motions with large amplitude and long signal duration. The analyses carried out in this work provide a path for interpreting ground-motion site and event specificity obtained from a suite of physics-based simulations, differing only in the rupture model characterization, to inform the selection of simulation scenarios for site-specific engineering analyses

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[2]Lawrence Berkeley National Laboratory, Berkeley, CA, USA
[3]Lawrence Livermore National Laboratory, Livermore, CA, USA

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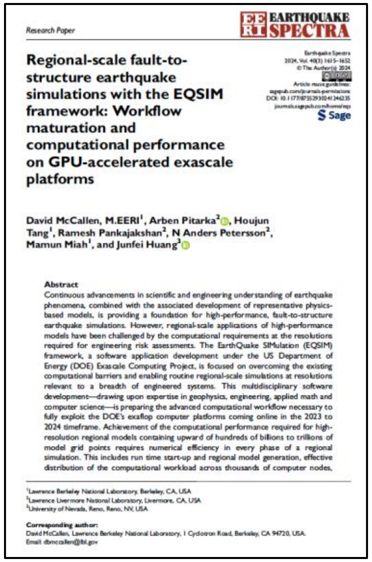

*Research Paper*

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Earthquake Spectra
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## Regional-scale fault-to-structure earthquake simulations with the EQSIM framework: Workflow maturation and computational performance on GPU-accelerated exascale platforms

**David McCallen, M.EERI[1], Arben Pitarka[2], Houjun Tang[1], Ramesh Pankajakshan[2], N Anders Petersson[2], Mamun Miah[1], and Junfei Huang[3]**

**Abstract**
Continuous advancements in scientific and engineering understanding of earthquake phenomena, combined with the associated development of representative physics-based models, is providing a foundation for high-performance, fault-to-structure earthquake simulations. However, regional-scale applications of high-performance models have been challenged by the computational requirements at the resolutions required for engineering risk assessments. The EarthQuake SIMulation (EQSIM) framework, a software application development under the US Department of Energy (DOE) Exascale Computing Project, is focused on overcoming the existing computational barriers and enabling routine regional-scale simulations at resolutions relevant to a breadth of engineered systems. This multidisciplinary software development—drawing upon expertise in geophysics, engineering, applied math and computer science—is preparing the advanced computational workflow necessary to fully exploit the DOE's exaflop computer platforms coming online in the 2023 to 2024 timeframe. Achievement of the computational performance required for high-resolution regional models containing upward of hundreds of billions to trillions of model grid points requires numerical efficiency in every phase of a regional simulation. This includes run time start-up and regional model generation, effective distribution of the computational workload across thousands of computer nodes,

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