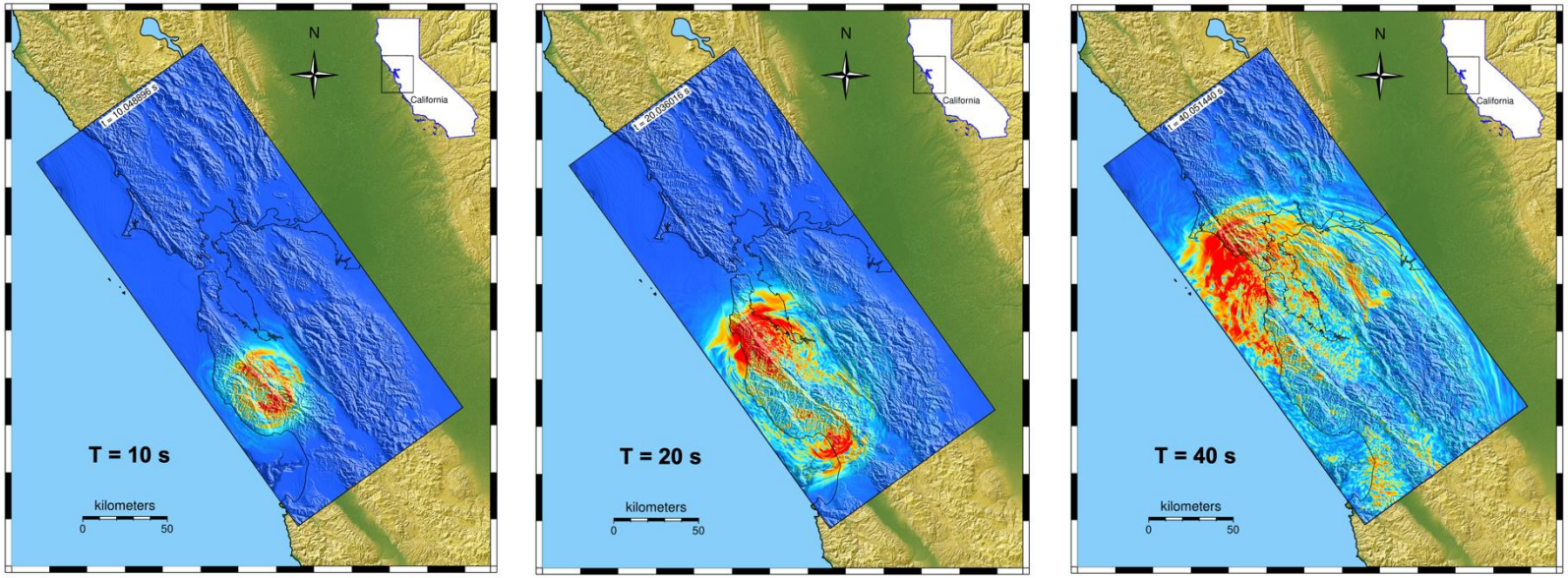


M7.5 San Andreas Fault Earthquake Simulation

The PEER – LBNL Simulated Ground Motion Database (SGMD)

2025 PEER annual meeting

David McCallen
Energy Geosciences Division
Lawrence Berkeley National Laboratory

BERKELEY LAB

PEER

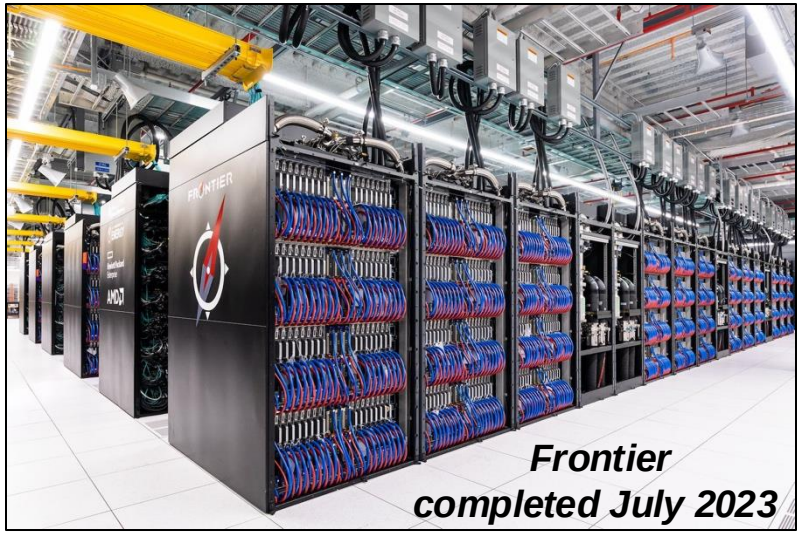
U.S. DEPARTMENT OF ENERGY

Office of Cybersecurity, Energy Security, and Emergency Response

Our computational capabilities dictate what we can include in a simulated motion database

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

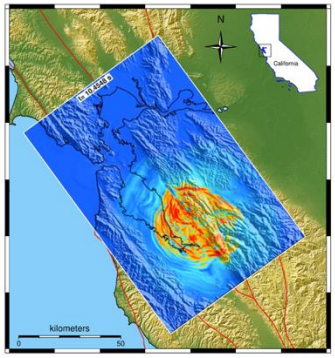
Advanced computer platforms – Frontier was the world's first exaflop ($1X10^{18}$ Flops) GPU-accelerated supercomputer



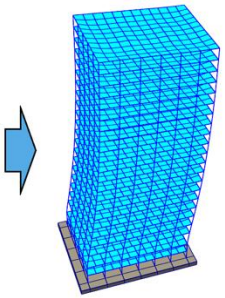
9,400 nodes, 1.194 exaflops (1,000,000,000,000,000,000 Flops)

ECP
EXASCALE COMPUTING PROJECT

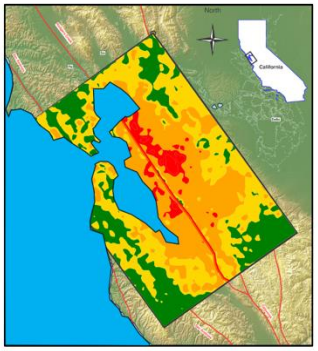
Advanced software – the *EQSIM* framework for regional-scale fault-to-structure simulations purpose built for GPU-accelerated platforms



Ground motion simulations



Infrastructure response simulations

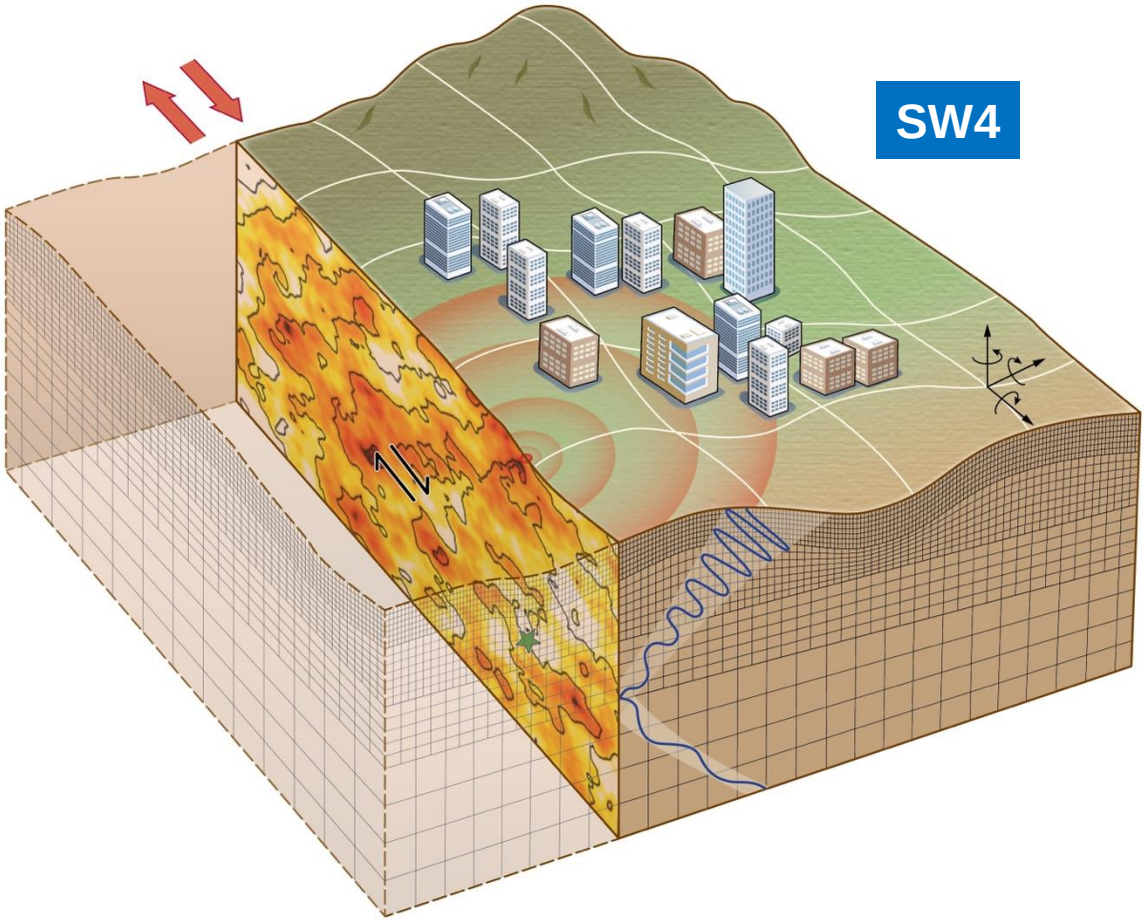


Deeper insight into regional infrastructure risk

EQSIM

ECP provided the opportunity to complete many key advancements to the SW4 geophysics code

SW4 – Fourth order in space and time
(Petersson et al.)



Advanced algorithms

- Mesh refinement in curvilinear and Cartesian grids

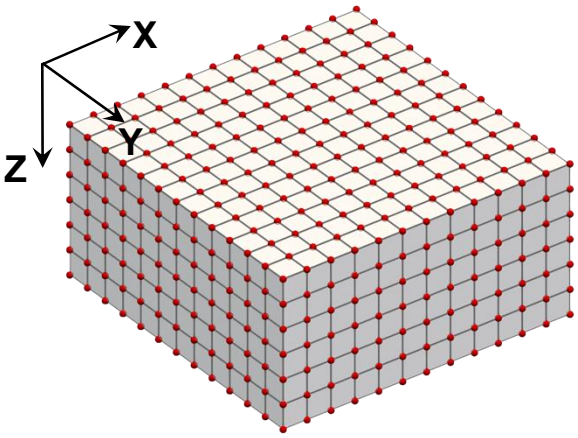
Readiness for GPU-based platforms

- Decompose computation loops into subtasks and tuning code for GPUs

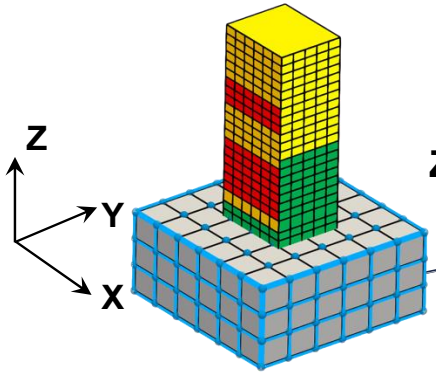
IO and data management

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

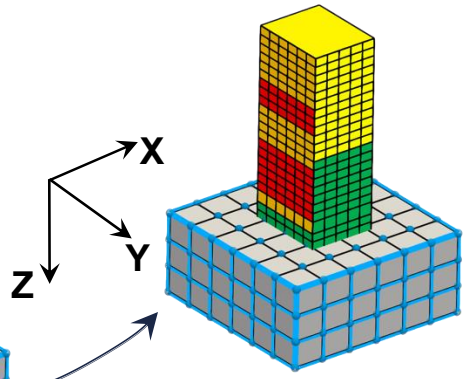
Implementation of DRM allows representation of SSI, inclined waves and local nonlinear soils



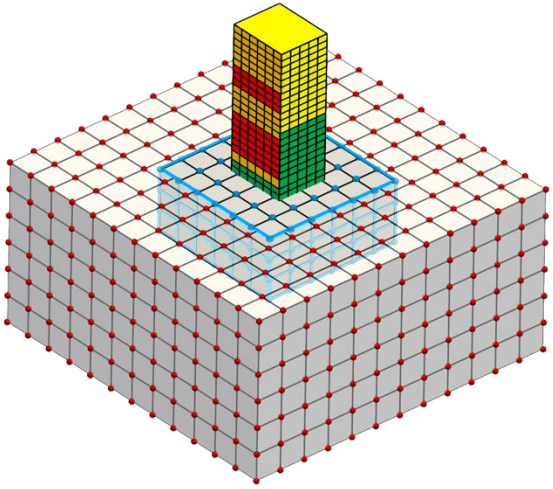
Global geophysics code coordinate system



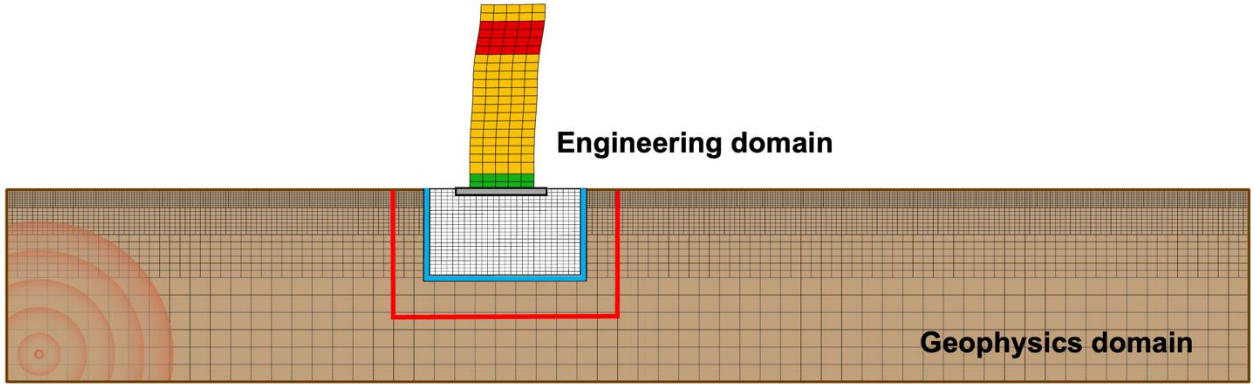
Local engineering code coordinate system (arbitrary orientation)



Transformation to global coordinates



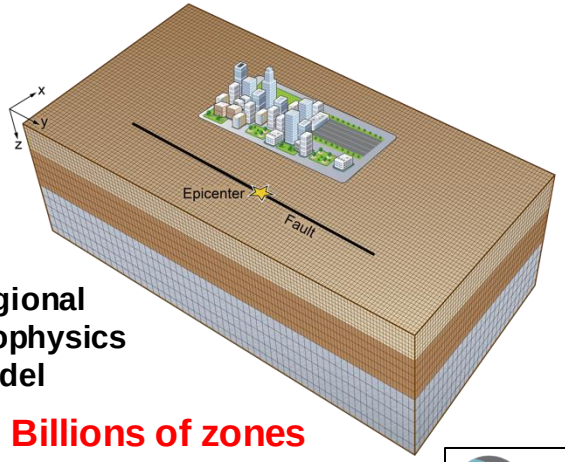
Common global coordinates



The resulting EQSIM workflow for regional-scale, fault-to-structure simulations

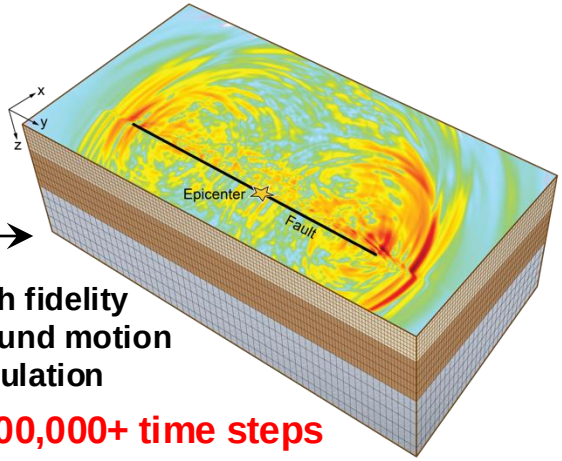
Geophysics

Engineering



Regional geophysics model

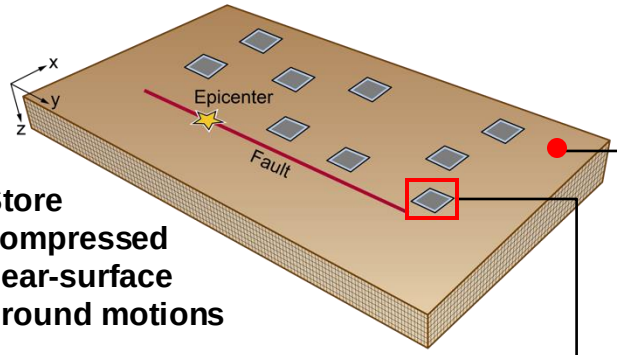
Billions of zones



High fidelity ground motion simulation

200,000+ time steps

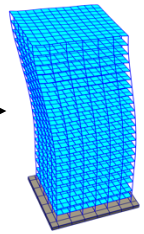
ESnet

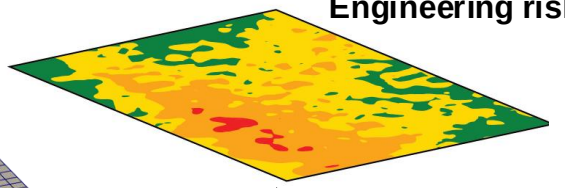


Store compressed near-surface ground motions

Billions of stations

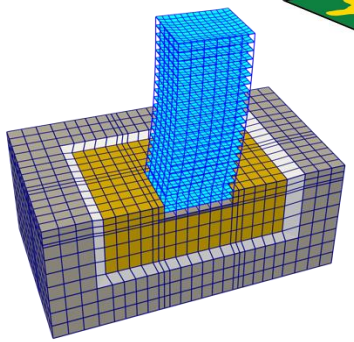
Surface motions





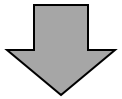
Engineering risk

Volume motions



In the EQSIM workflow development three principal objectives were front of mind

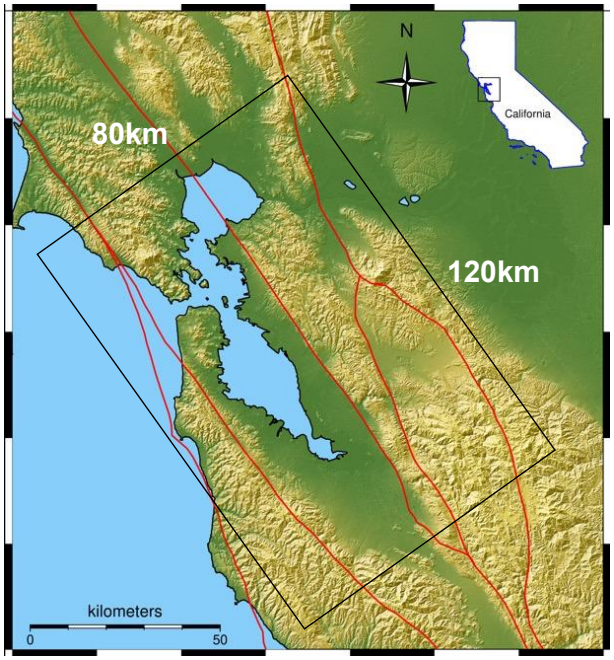
1. **Resolution** – the ability to simulate higher frequencies (Fmax) of engineering relevance and to resolve soft near-surface sediments (Vsmin)
2. **Speed** – achieve regional simulation wall clock times that allow the practical execution of many realizations
3. **Usability** – efficient and effective operational interfaces for large problems with extreme data

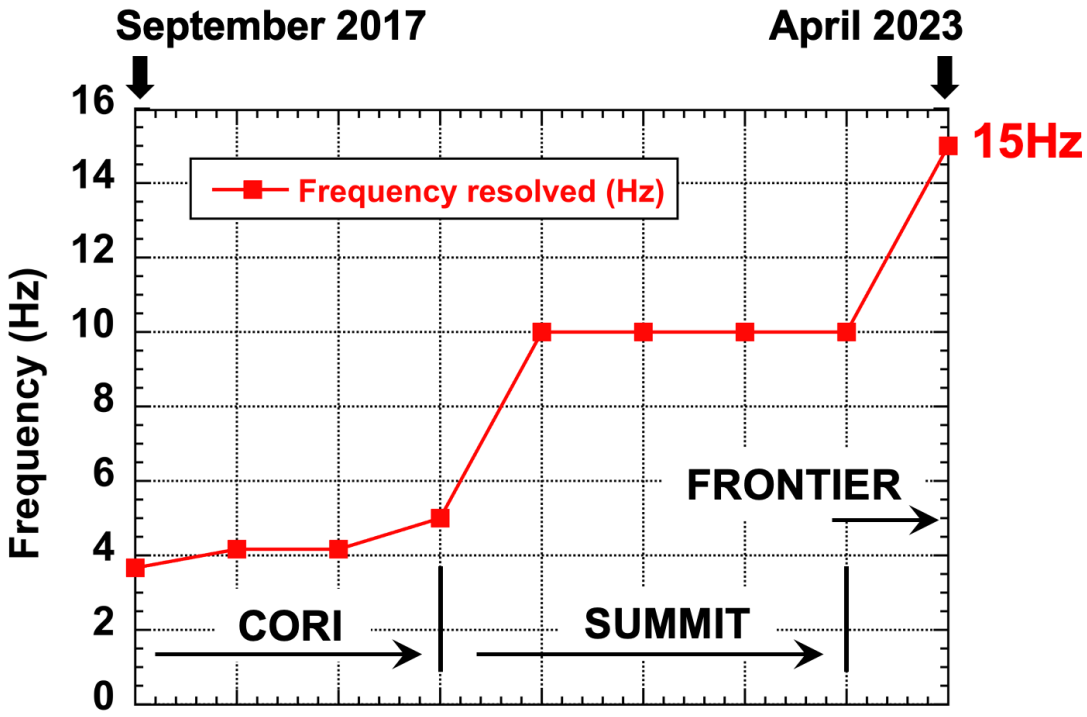


Transition from "heroic" to "routine" regional simulations

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

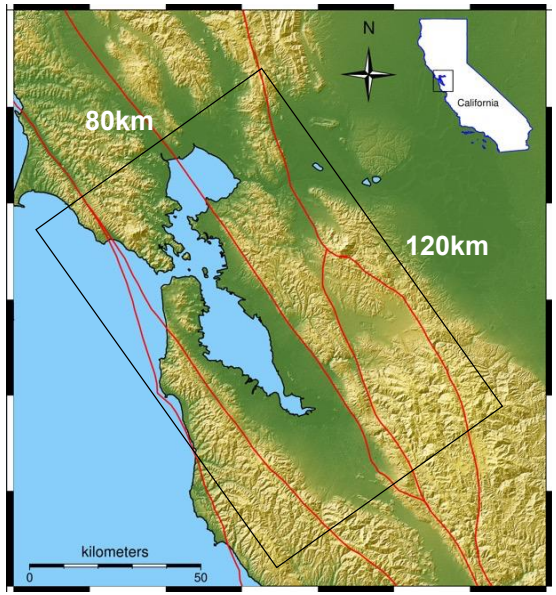
San Francisco Bay regional model

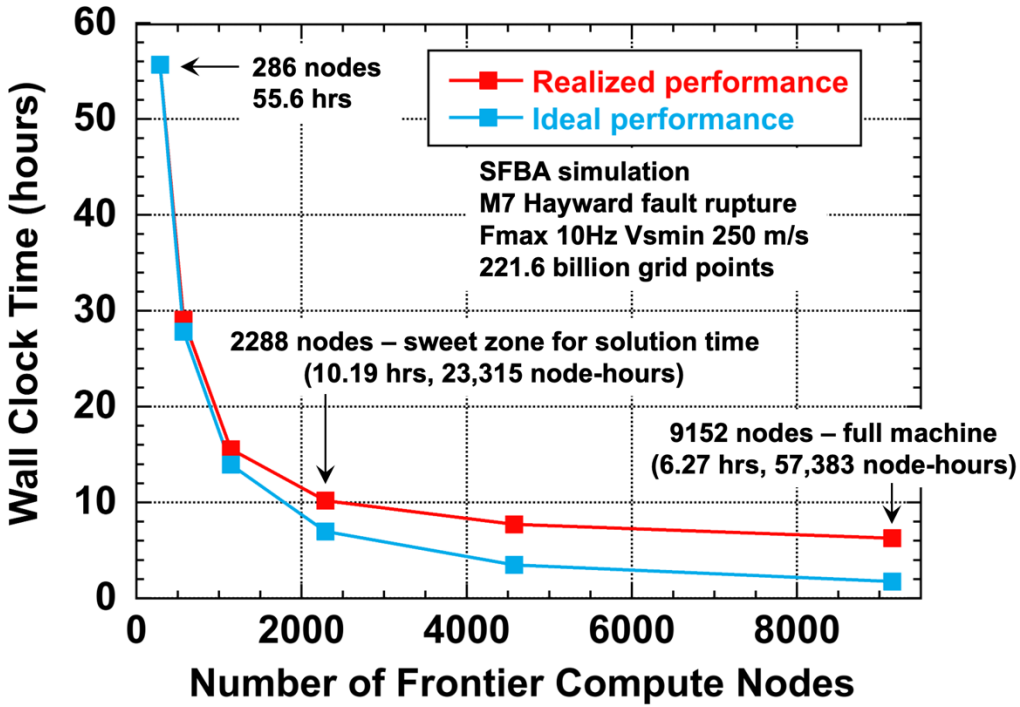




- Advanced algorithms
- Well designed workflow and IO
- Transition to GPU platforms

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

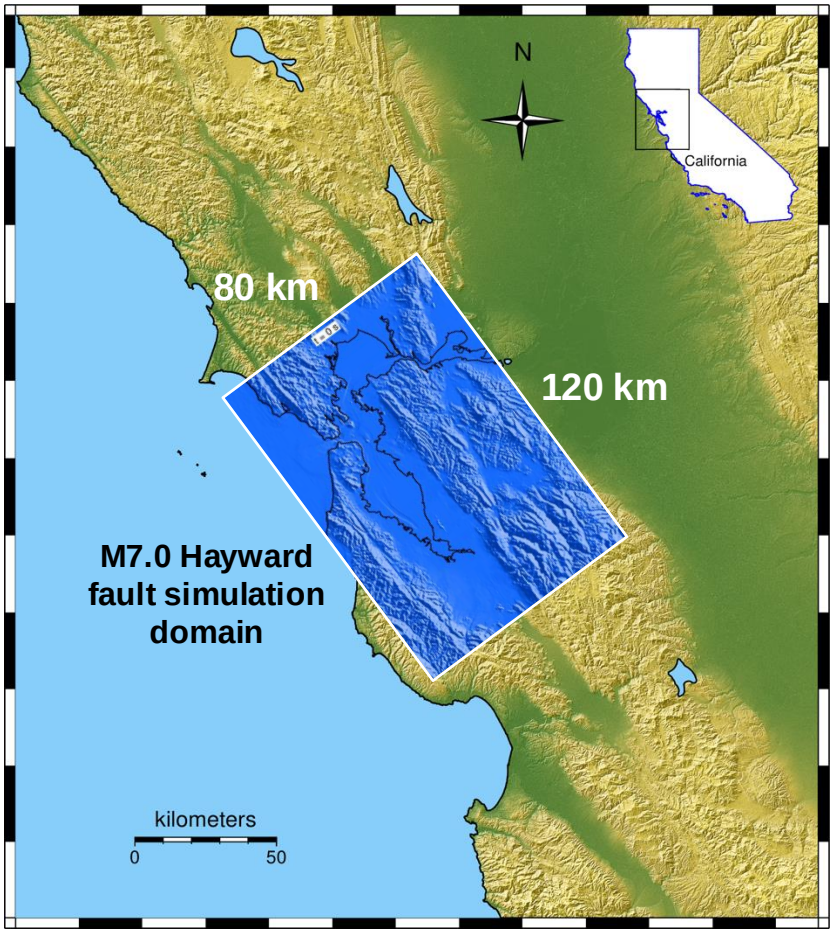




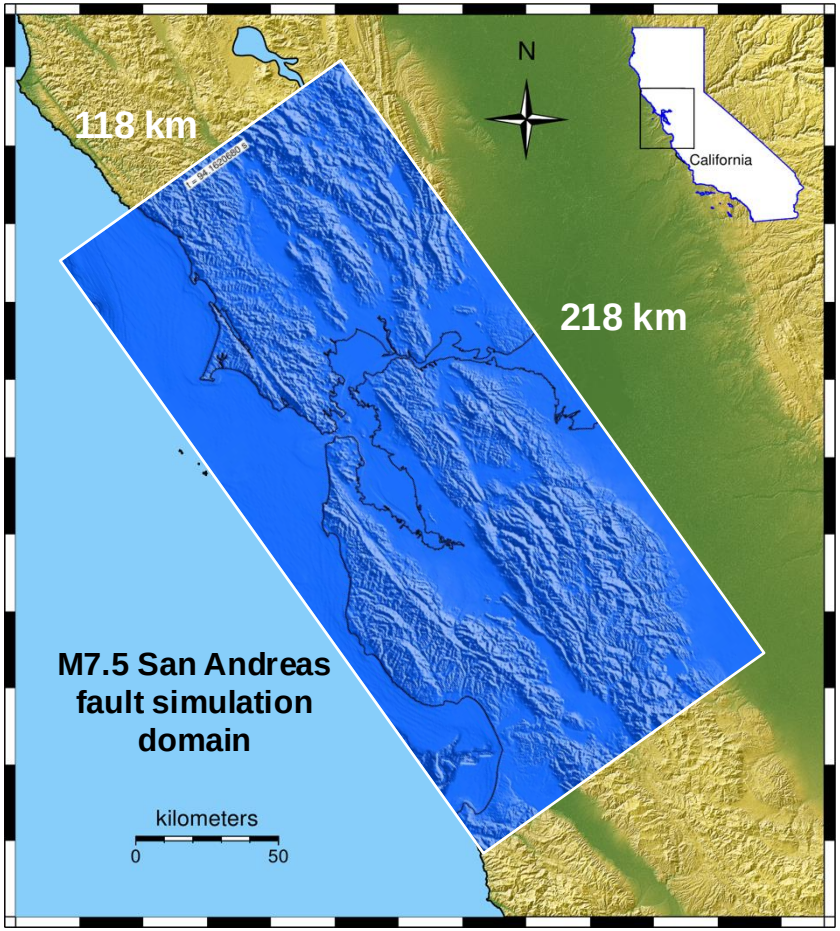
Model	# Frontier nodes	Wall clock time (hrs)
Fmax 5 Hz Vsmin 250 m/s	3072	1.8
Fmax 10 Hz Vsmin 250 m/s	9152	6.3
Fmax 15 Hz Vsmin 140 m/s	9152	29.2

Take away - much bigger problems are now within our computational grasp

M7.0 Hayward rupture
10Hz resolution, 221 billion grid points
9152 Frontier nodes
~6 hours for 90 second earthquake



M7.5 San Andreas rupture
10Hz resolution, 583 billion grid points
9152 Frontier nodes
~29 hours for 200 second earthquake

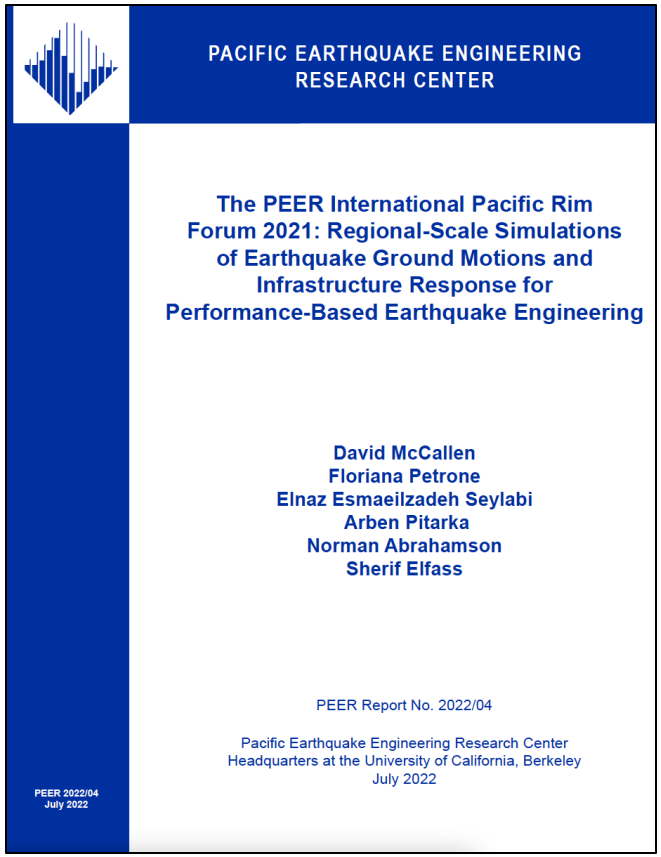


The notion of a Simulated Ground Motion Database grew from the PEER-LBNL workshops

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

PEER Pacific Rim Forum
June 2021

261 International Participants
41 International Speakers



PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

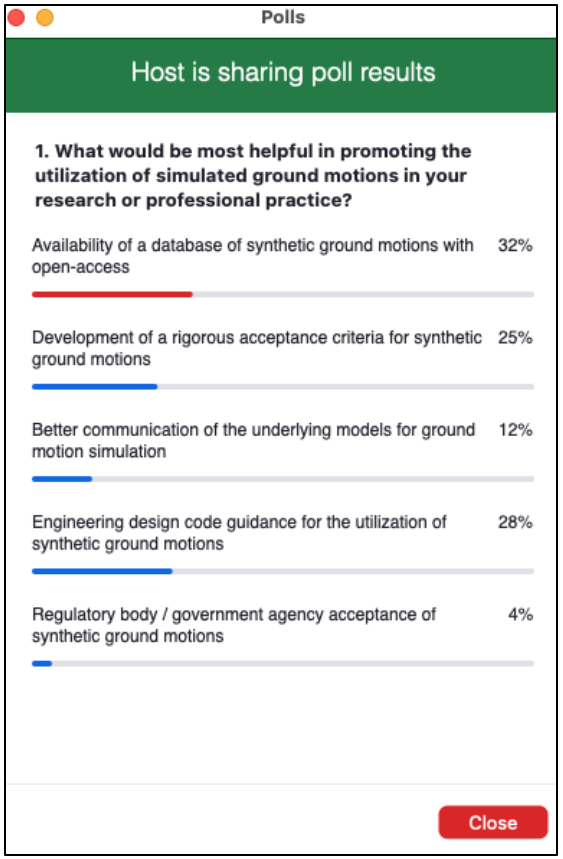
The PEER International Pacific Rim Forum 2021: Regional-Scale Simulations of Earthquake Ground Motions and Infrastructure Response for Performance-Based Earthquake Engineering

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



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

Activity 1 - development of regional-scale simulated earthquake ground motions

Engineering

D. McCallen

Berkeley Lab

F. Petrone

Univ. Nevada

M. Miah

Berkeley Lab

Seismology

A. Pitarka

Livermore Lab

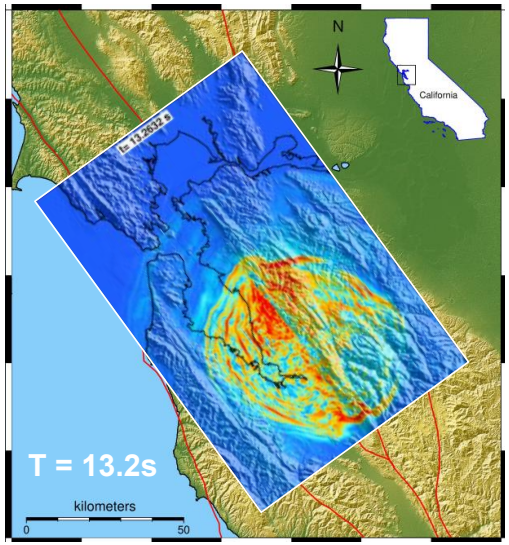
R. Nikata

Berkeley Lab

Computer Science

H. Tang

Berkeley Lab



E. Taciroglu

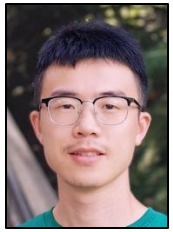
UCLA Civil Engineering

Current postdoctoral scholars and PhD students

Kostantinos Tsalouchidis

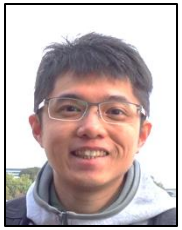
LBNL

Junfei Huang



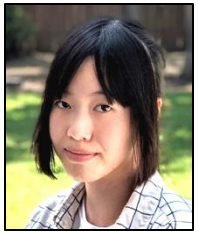
LBNL

Clifford Yen



UCLA

Flora Xia



CALTECH

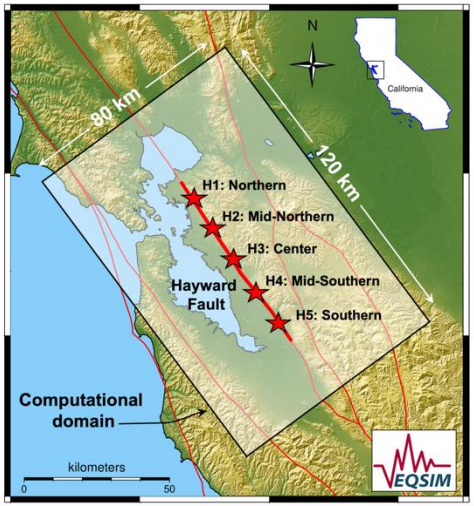
BERKELEY LAB

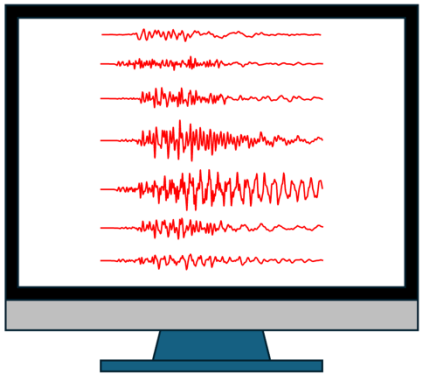
UCLA Samueli School of Engineering

For the inaugural database we have generated 50 realizations of a M7 Hayward fault rupture

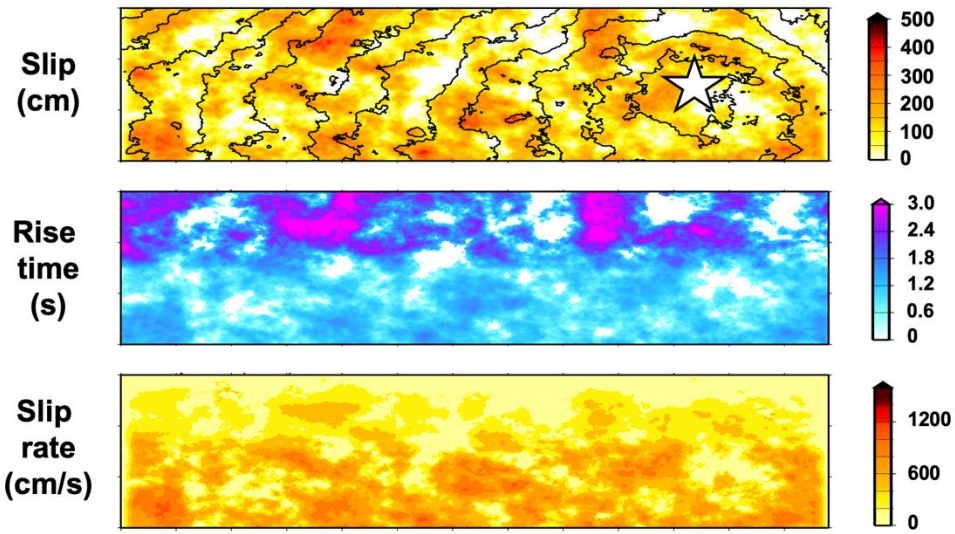
50 M7 Hayward fault rupture realizations
0 - 5 Hz

Graves-Pitarka rupture model

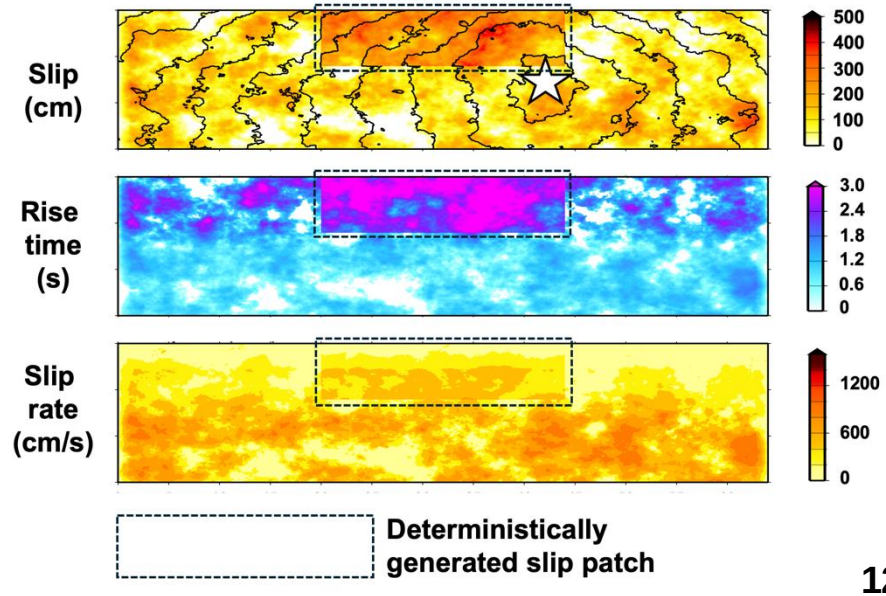




Pure stochastic rupture models



Stochastic plus deterministic patch rupture models



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

PEER Director & UC Berkeley

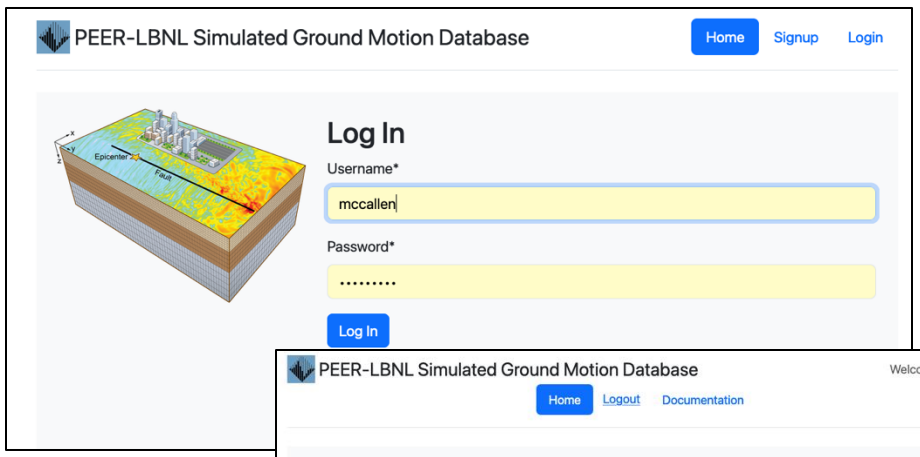

K. Mosalam

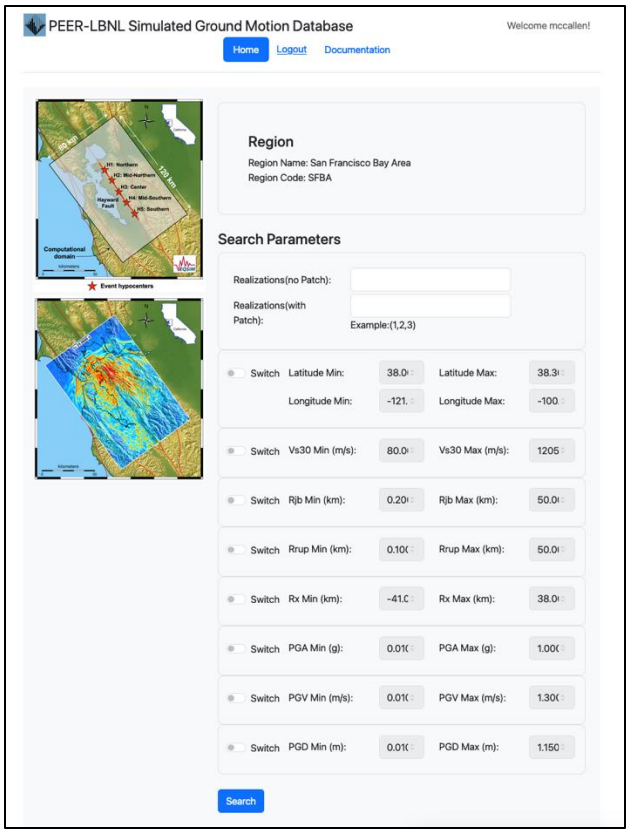

S. Gunay


G. Vargas


A. Kasalanati

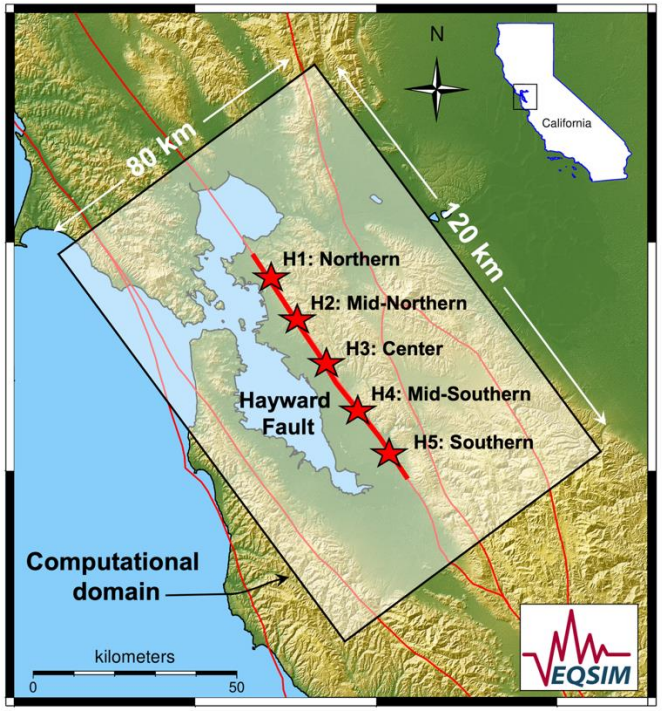
C. Perez
PhD student

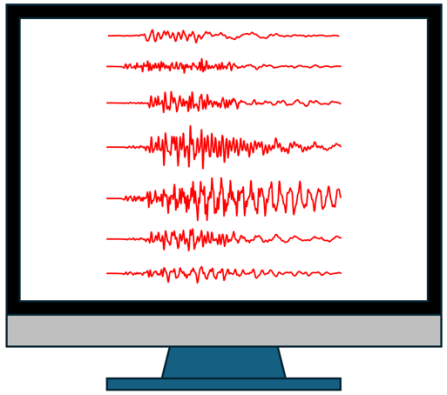




The SGMD is ready for access (15 Beta Users have had access since January)

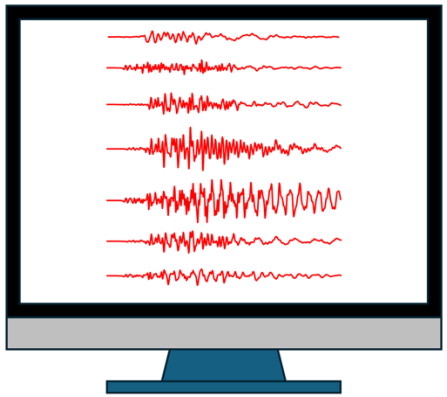
50 Hayward fault rupture realizations





PEER

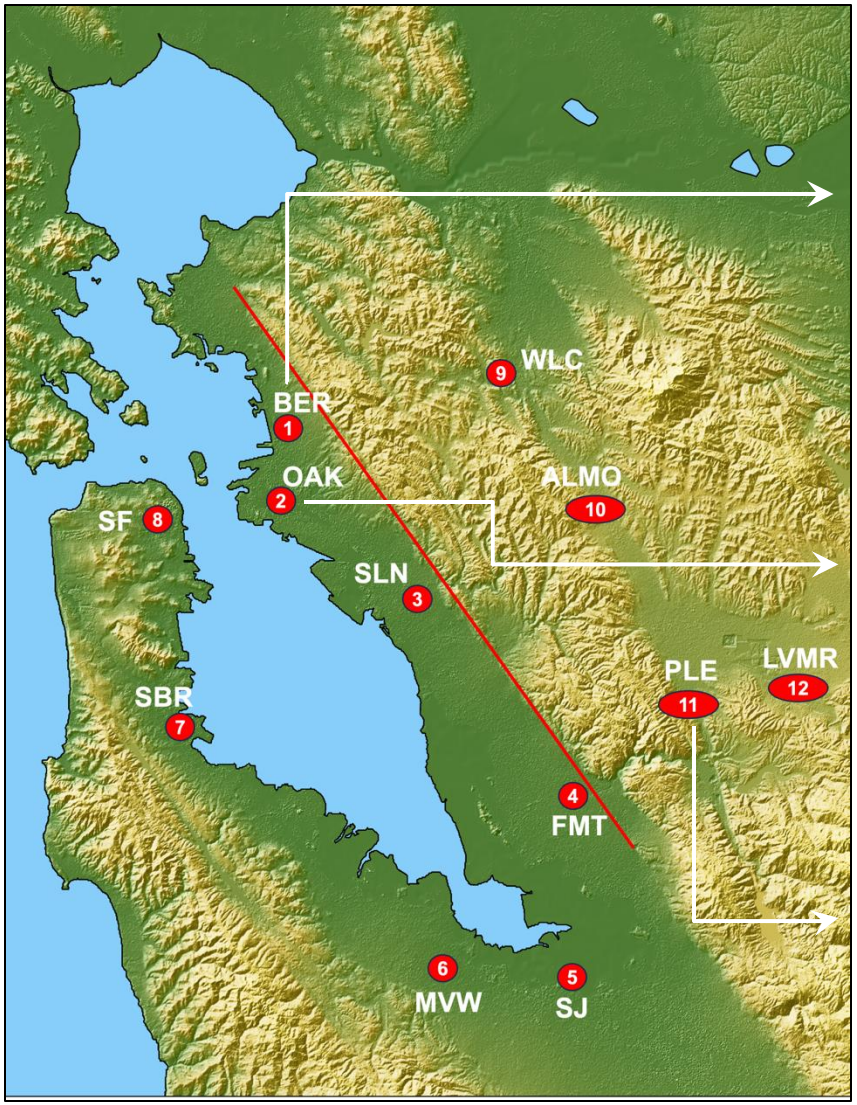
1,021,500 time series @ 2 Km spacing
(uncompressed HDF5 files - 330GB
uncompressed ASCII files - 700GB)

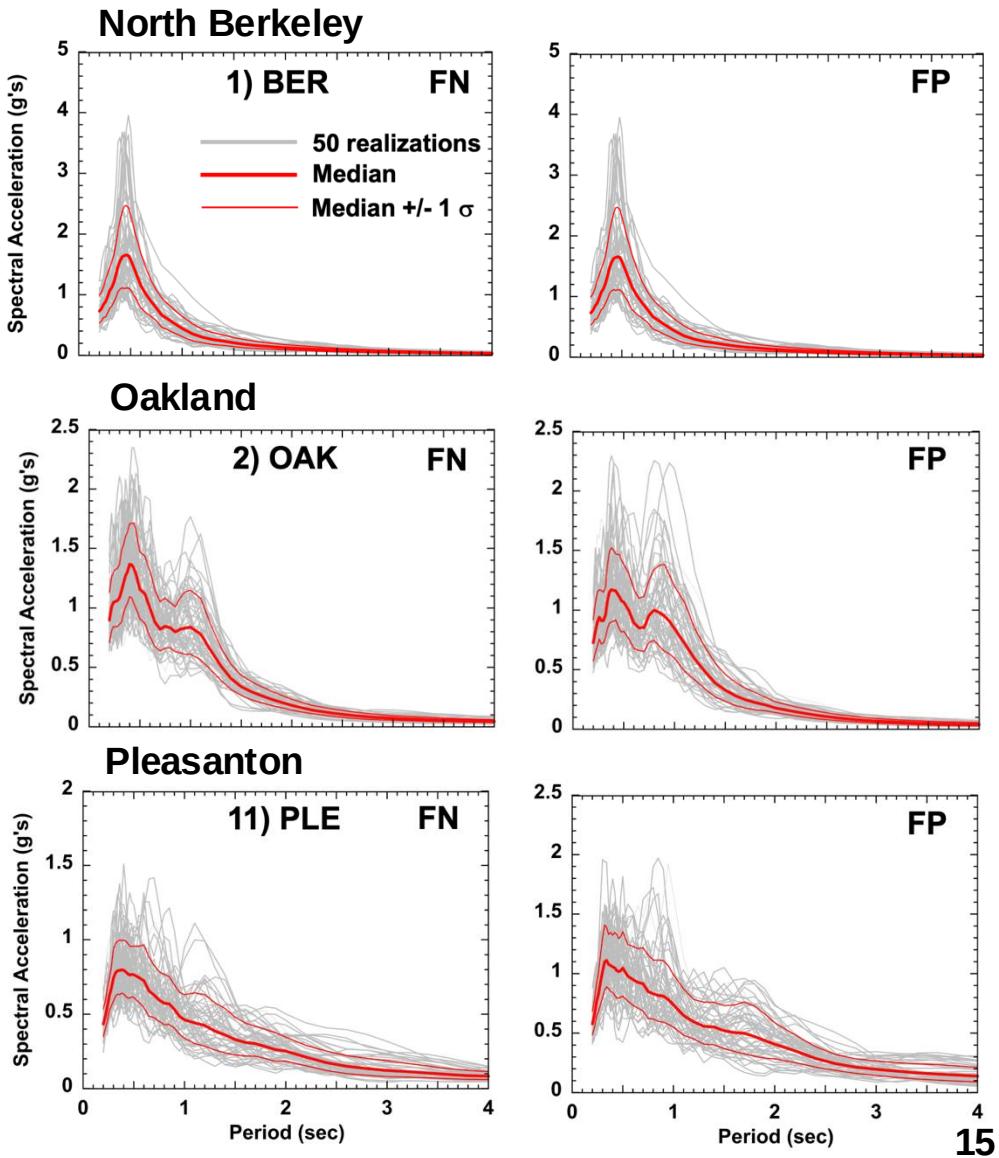


BERKELEY LAB

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

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

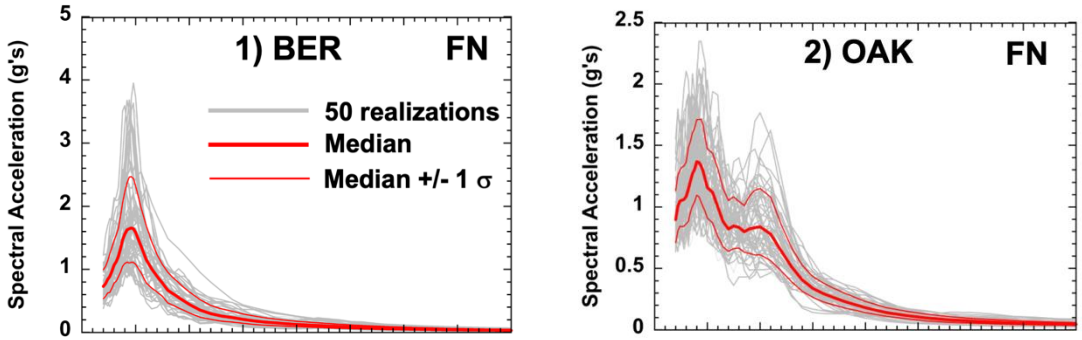




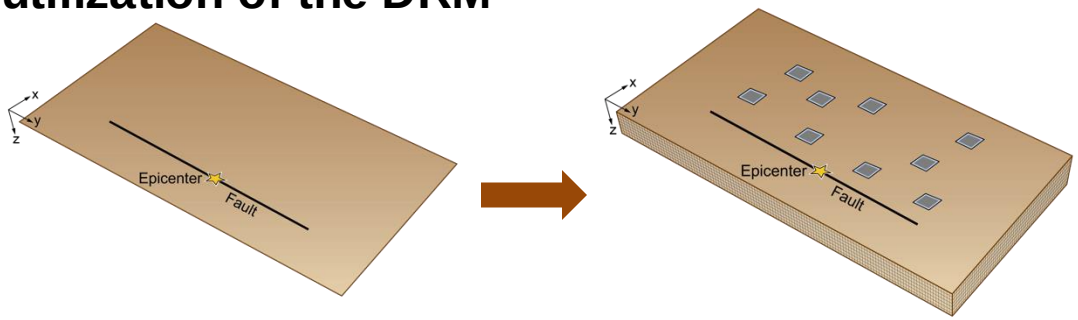
Poll results from yesterday's workshop

Voted "most popular" future features for the SGMD

- **Downloadable response spectra showing for all 50 realizations at every site**



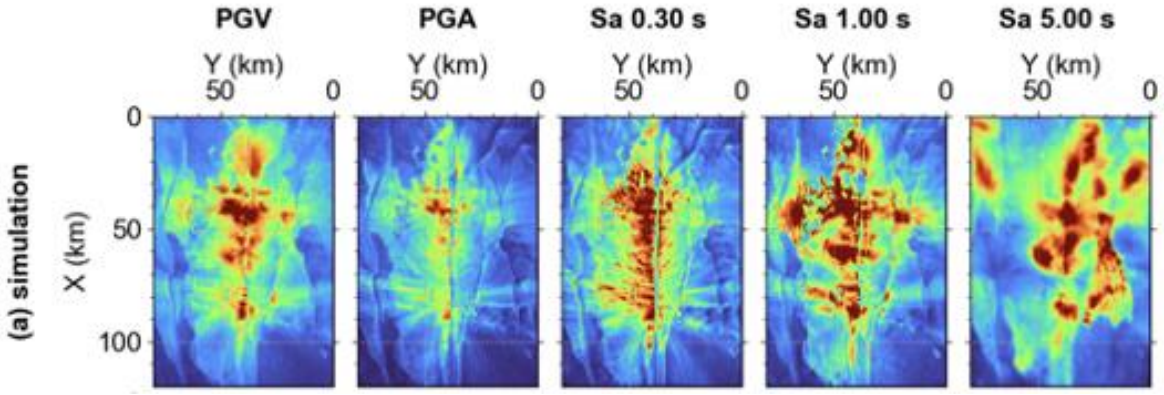
- **Implementation of a nonlinear soil representation for near-surface layers**
- **Provide motions in a near-surface volume (not just surface) to enable utilization of the DRM**



Poll results from yesterday's workshop

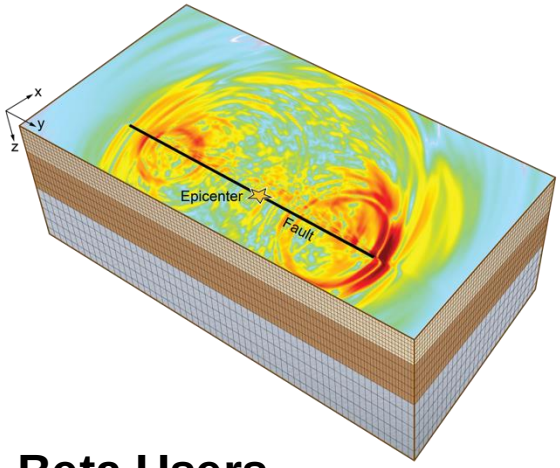
Voted "most popular" future features for the SGMD

- **Additional ground motion intensity measures in the database for each realization**

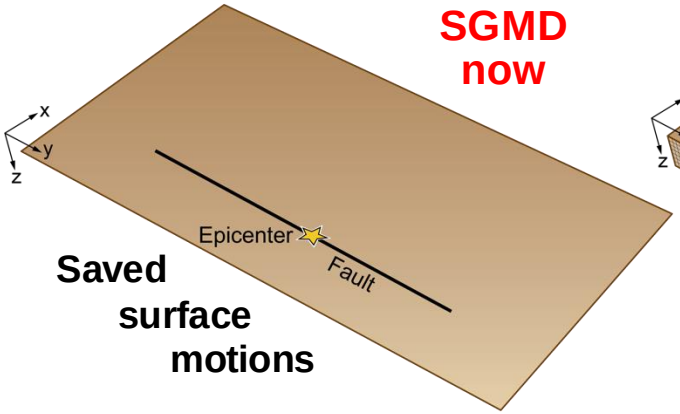


- **Creation of an on-line chat tool for application examples and discussion of best practices ad**

The SGMD will continue to evolve and add features in response to engineering objectives

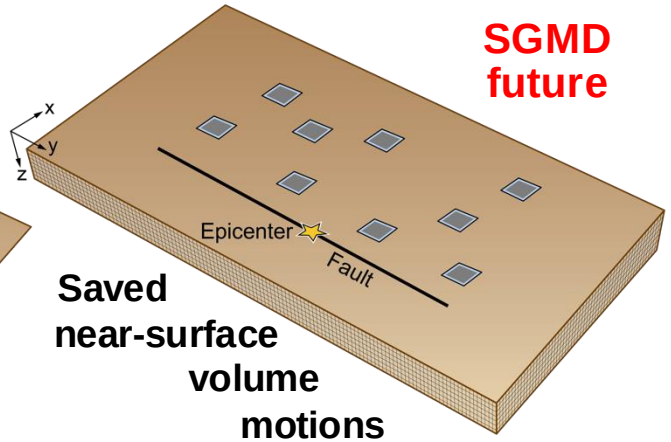


SGMD now



Saved surface motions

SGMD future

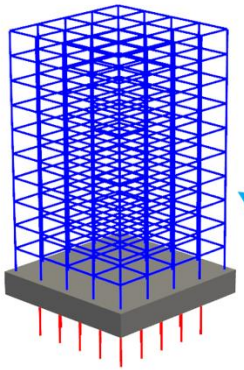


Saved near-surface volume motions

Beta Users

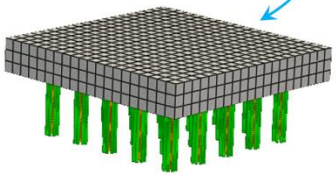
P. Arduino

F. McKenna



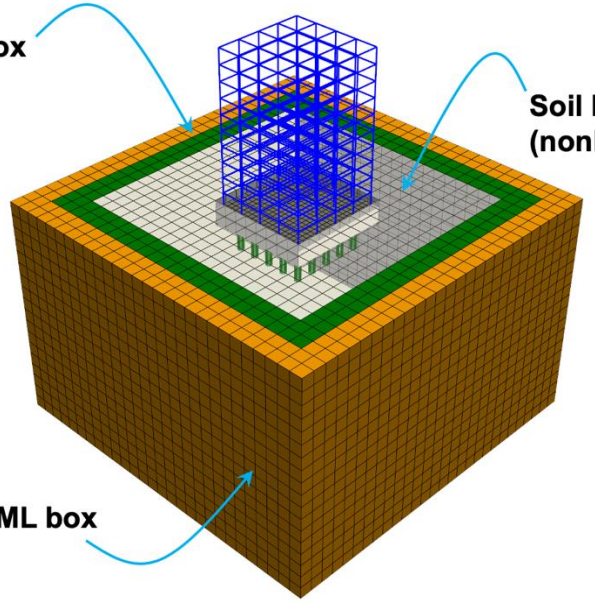
Building

Embedded foundation



DRM box

Soil box (nonlinear)



PML box

NSF SimCenter W