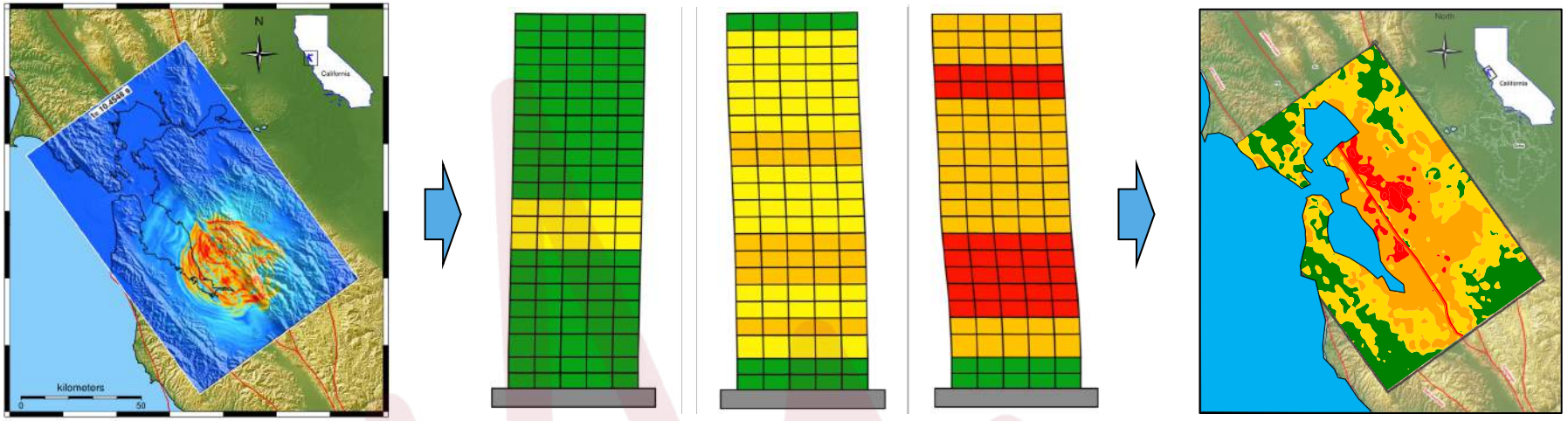



# EQSIM and the generation of San Francisco Bay Area large datasets

## PEER – LBNL workshop

## January 18-19, 2024

**David McCallen**
**Critical Infrastructure Program**
**Energy GeoSciences Division**
**Lawrence Berkeley National Laboratory**

BERKELEY LAB

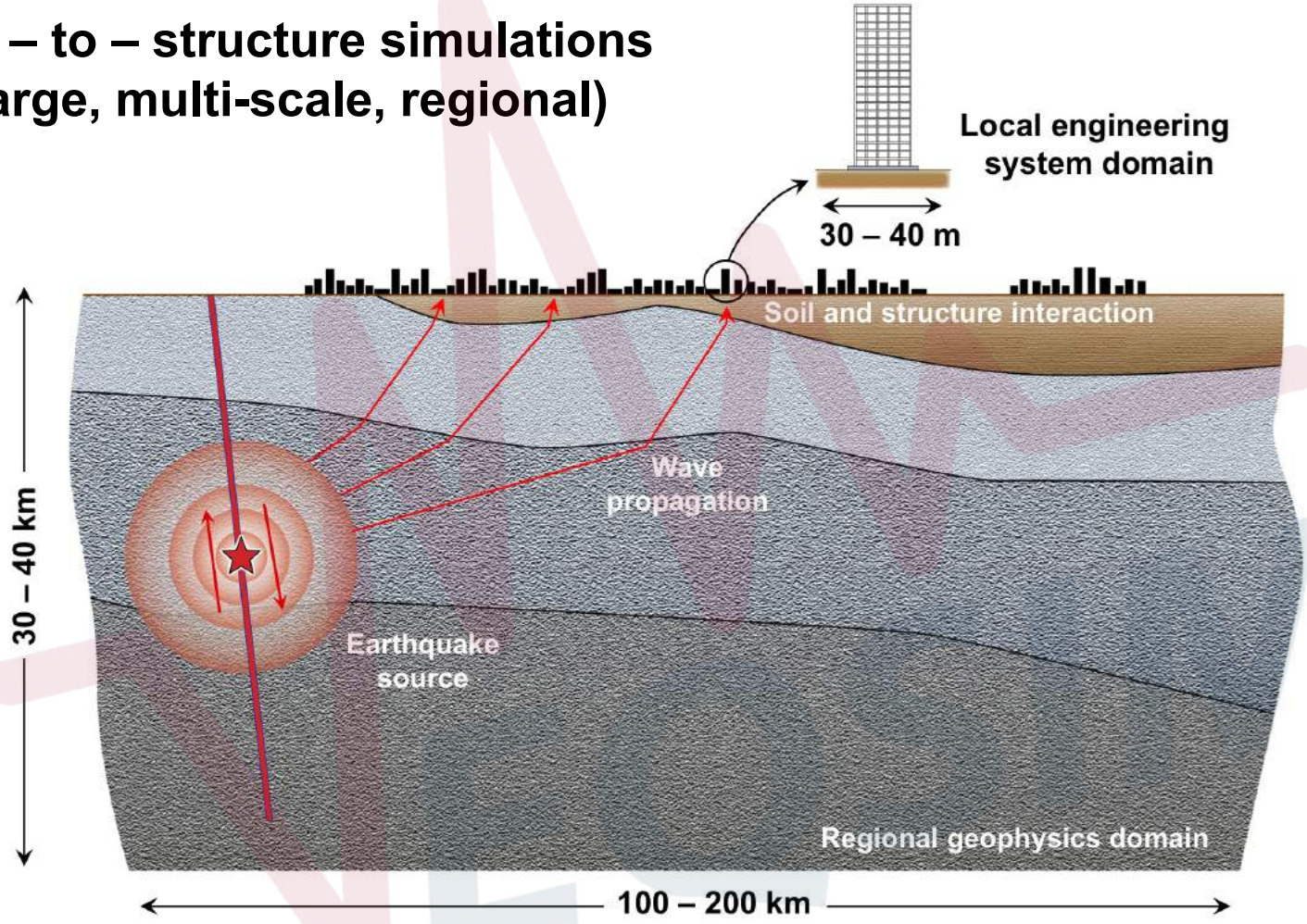
U.S. DEPARTMENT OF ENERGY

Office of Cybersecurity, Energy Security, and Emergency Response

EXASCALE COMPUTING PROJECT

# Fault-to-structure simulations present a multidisciplinary simulation challenge

**Fault – to – structure simulations (large, multi-scale, regional)**




**Seismology ⟶ Engineering ⟶ Applied Math ⟶ Computer Science**

# The EQSIM development team

## Engineering Mechanics

David McCallen

Floriana Petrone

Mamun Miah

## Seismology / Geophysics

Arben Pitarka

Rie Nakata

Arthur Rodgers

## Computer Science

Houjun Tang

Ramesh Pankajakshan

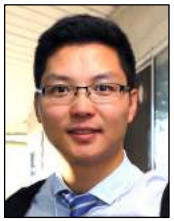
## Applied Math Numerical Methods

Anders Petersson

Bjorn Sjogreen

## Postdocs / early career

Kenawy



Wu

Panilla Ramos

## Graduate students

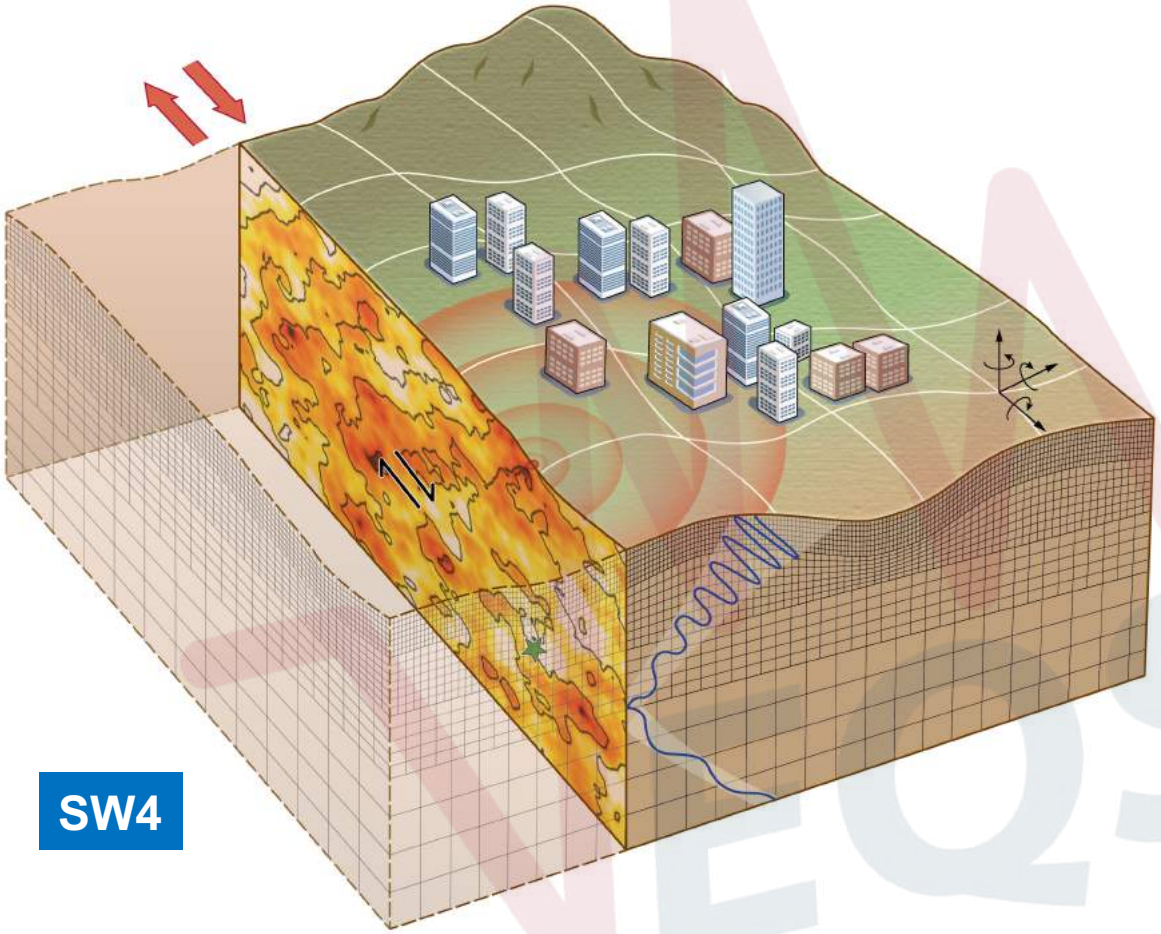
Huang

Rahmani

Aryal

# We have completed many advancements to the SW4 geophysics wave propagation code

**SW4 – Fourth order in space and time**




**ST dependencies RAJA, ExaIO (HDF5), ALPINE (ZFP)**

**Algorithms**

- Mesh refinement in Cartesian and curvilinear grids

**IO and workflow**

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

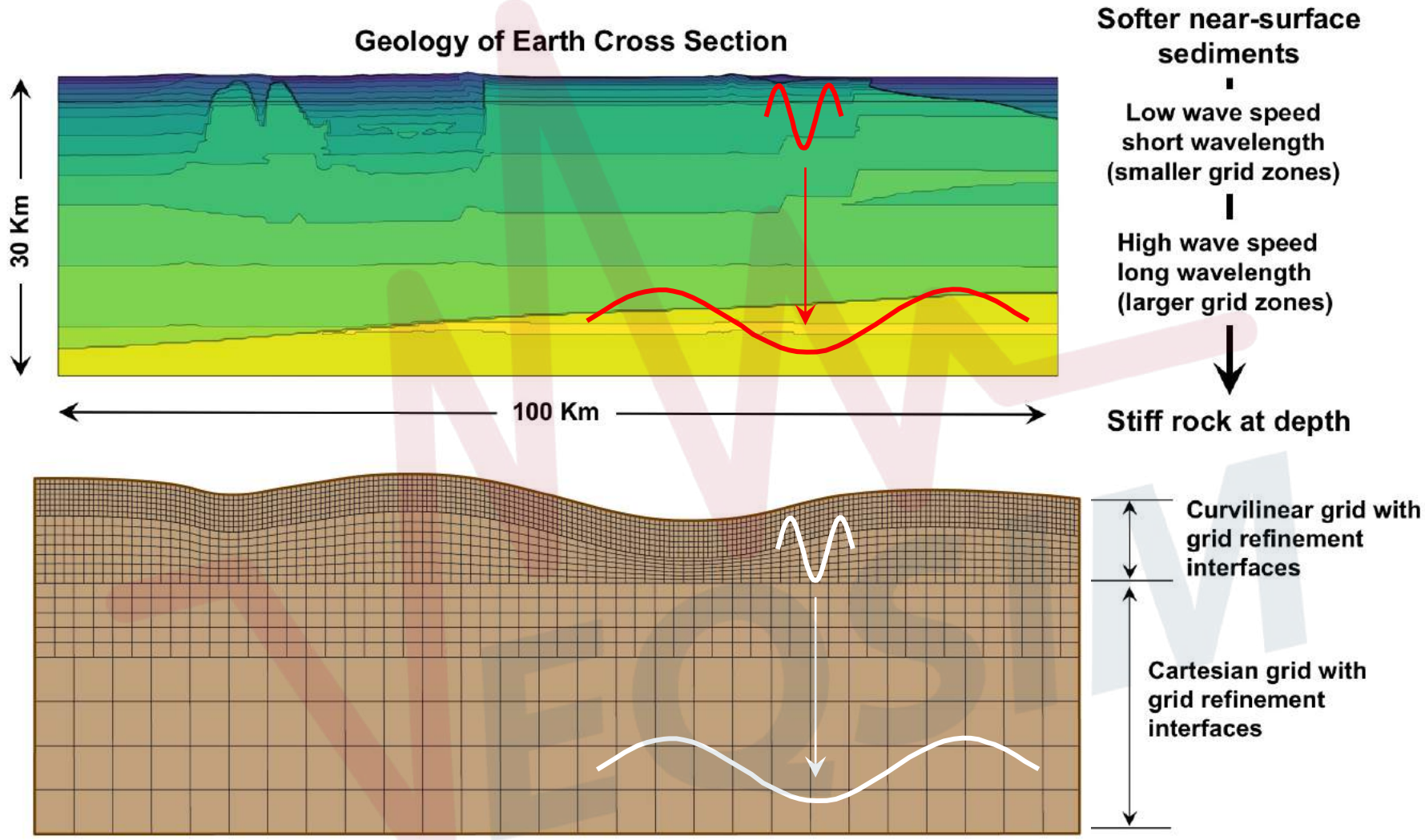
**Readiness for GPU-based platforms**

- Implementation of RAJA libraries

**Enhanced physics models**

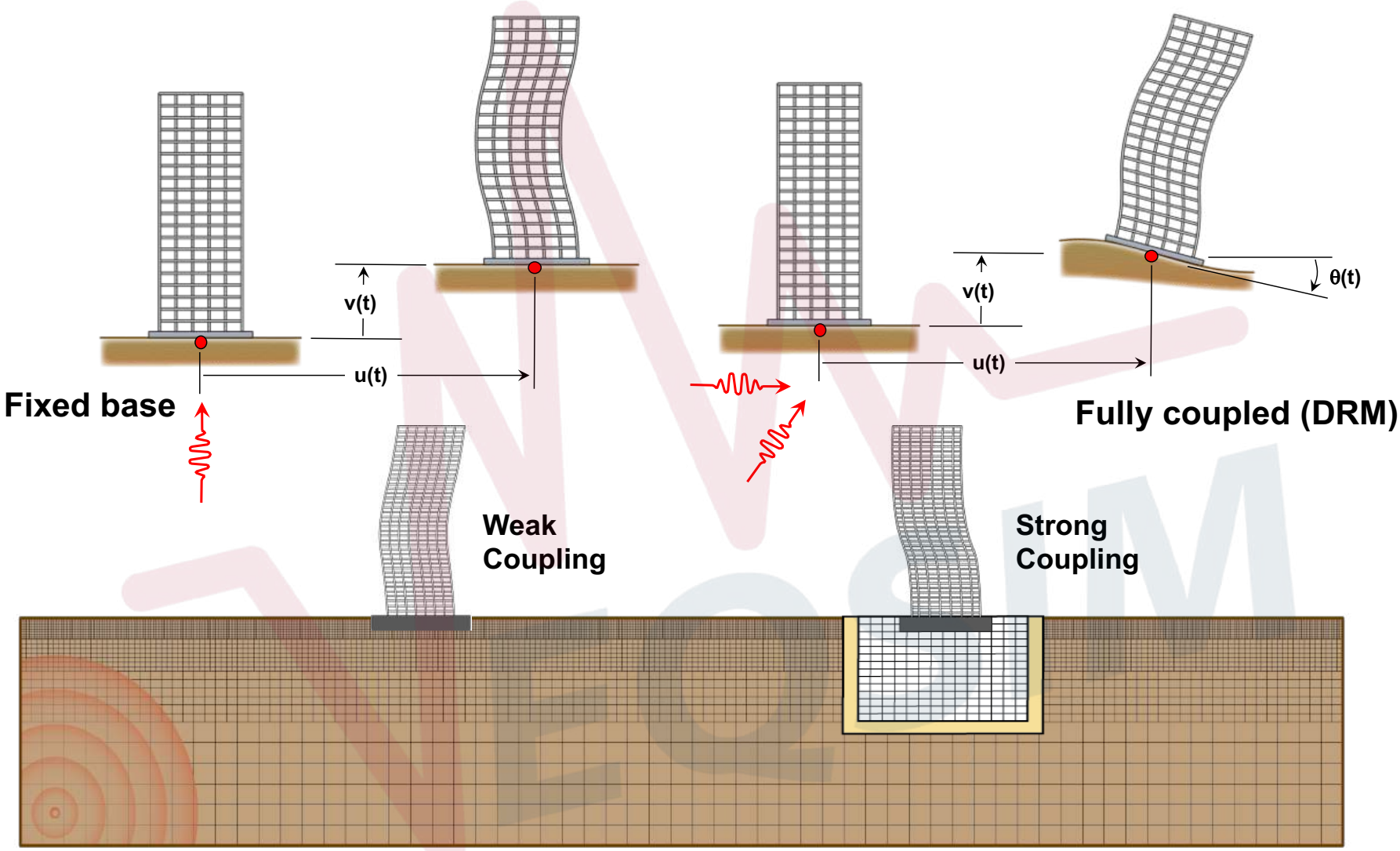
- Enhancements to the Graves - Pitarka rupture model

# Utilization of a hybrid grid with problem - tailored mesh refinement

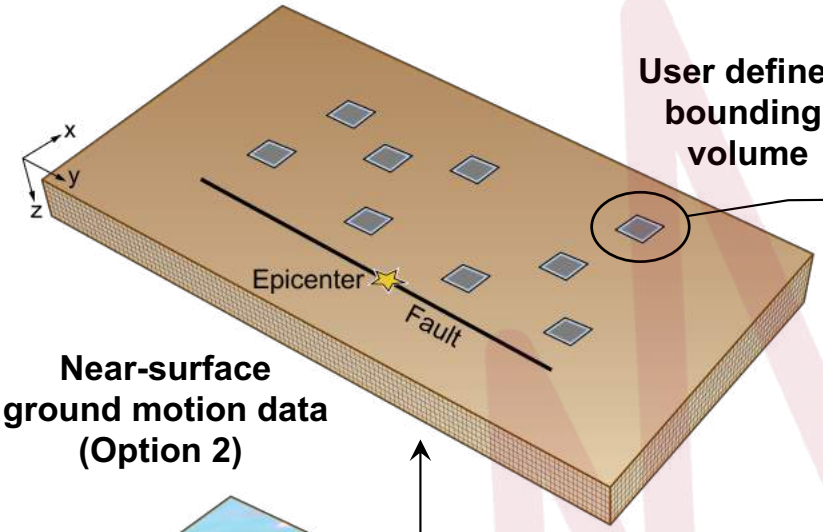



***Must*** **- Maintain fourth order accuracy** ***Must*** **- Traverse fault rupture zone**

# EQSIM has implemented two options for coupling geophysics and engineering models

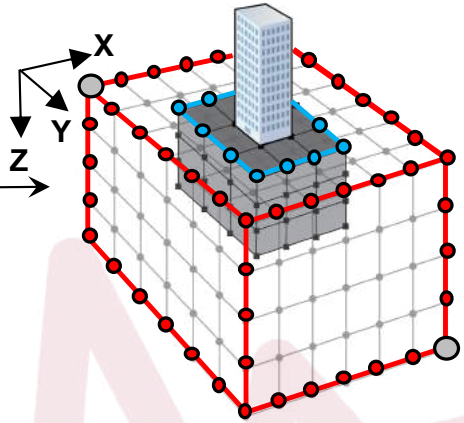


# EQSIM's efficient implementation of DRM coupling for geophysics and engineering models



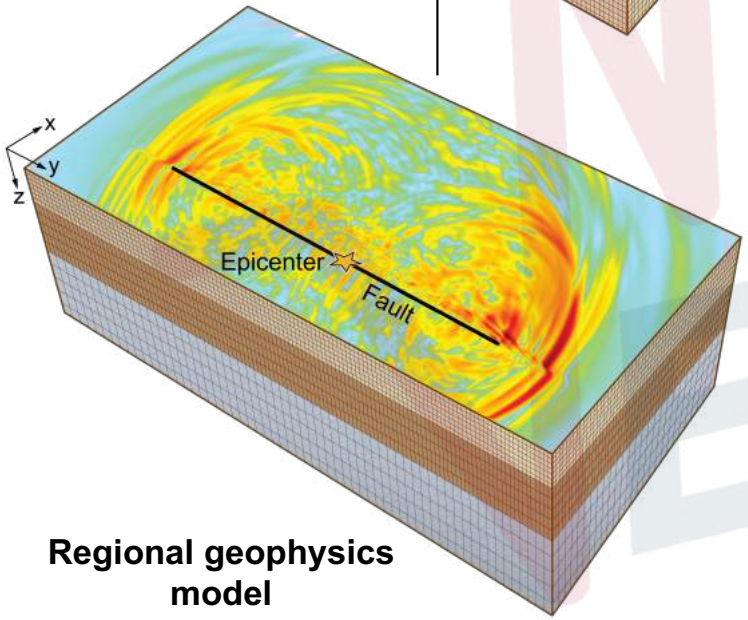

Near-surface ground motion data (Option 2)

User defined bounding volume

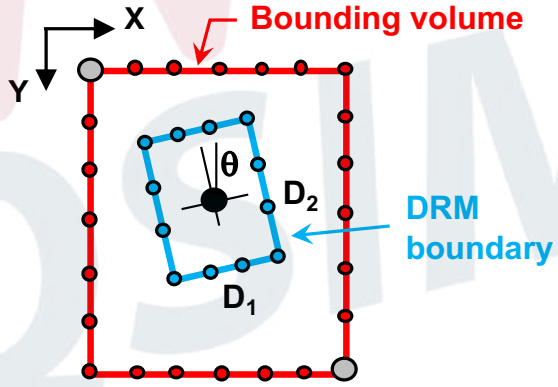



**DRM coupling has been achieved with OpenSees and LS-DYNA**

- Geophysics domain grid points
- Engineering domain grid points

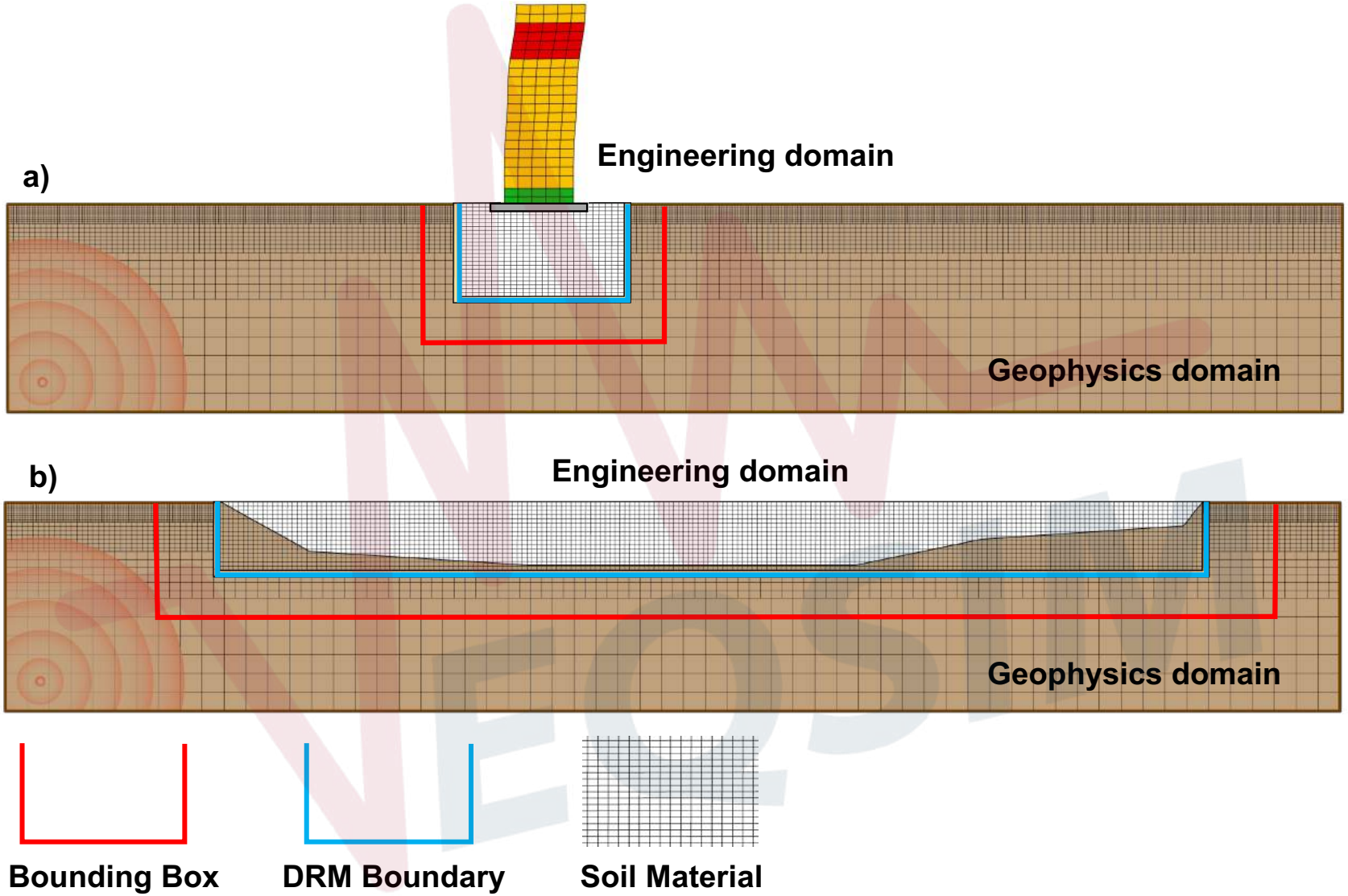



Regional geophysics model

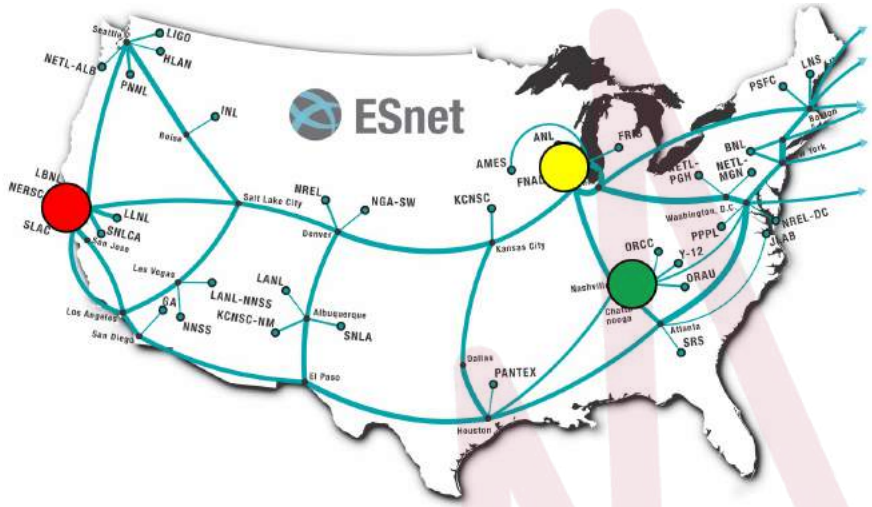



- User specified center and angular orientation of engineering domain
- Computed bounding geophysics domain

# DRM allows representation of SSI, inclined waves and nonlinear soft near-surface soils



# The EQSIM workflow is optimized for the DOE Exascale ecosystem




ESnet 24/7 operations

**Data transfer**

**9.42 Billion time histories = 267TB of ground motion data**

↓

**ZFP compression**

↓

**2.67TB HDF5 file**

↓

**Chunk into 1332 2GB files**

↓

**ESNET parallel transfer 8 minutes 38 seconds**


**Perlmutter (completed 2022)**
**Lawrence Berkeley National Lab**
**National Energy Research Scientific Computing Center (NERSC)**
**1536 GPU accelerated nodes**
**4 NVIDIA A100 GPUs / node**
**71 PetaFlops**
**Top500.org #8**

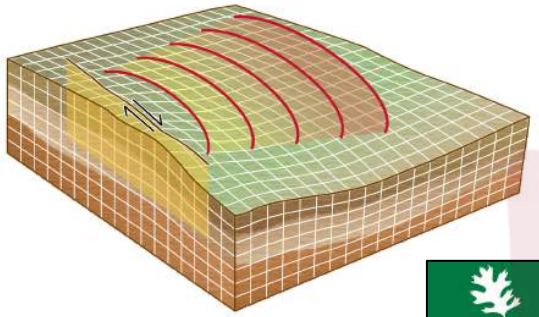

**Frontier (completed 2023)**
**Oak Ridge National Lab**
**Oak Ridge Leadership Computing Facility (OLCF)**
**9402 GPU accelerated nodes**
**4 AMD MI250X GPUs / node**
**1.194 ExaFlops**
**Top500.org #1**

**Aurora (scheduled 2024)**
**Argonne National Lab**
**Argonne Leadership Computing Facility (ALCF)**
**10,624 GPU accelerated nodes**
**6 Intel Max GPUs / node**
**Projected ~ 2 ExaFlops**
**Undergoing final assembly**

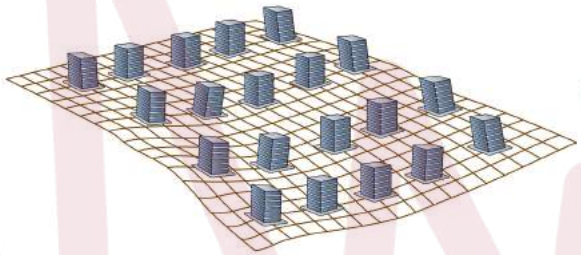
ESnet
ENERGY SCIENCES NETWORK

# EQSIM workflow is designed around exploitation of multiple platforms and efficient data transfer

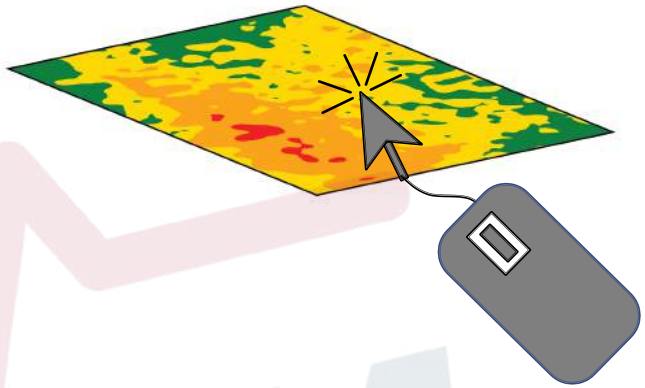
**Component 1**
**Regional simulation of ground motion**



**Component 2**
**Regional simulation of infrastructure response**

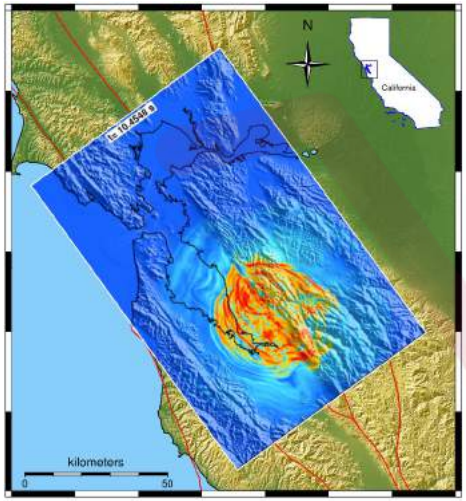


**Component 3**
**Interactive display and interrogation of large datasets**

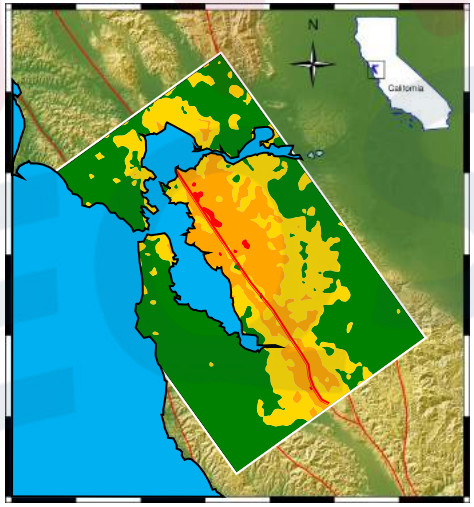


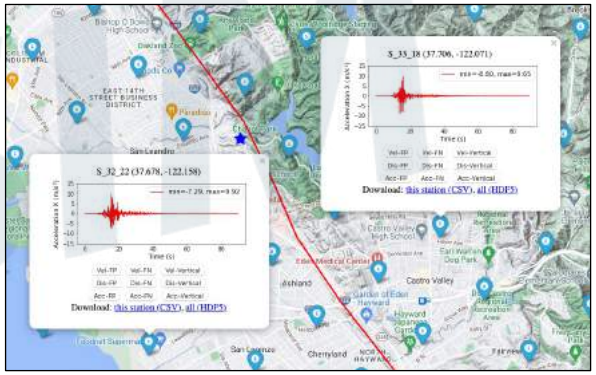
OLCF

NERSC




ESnet

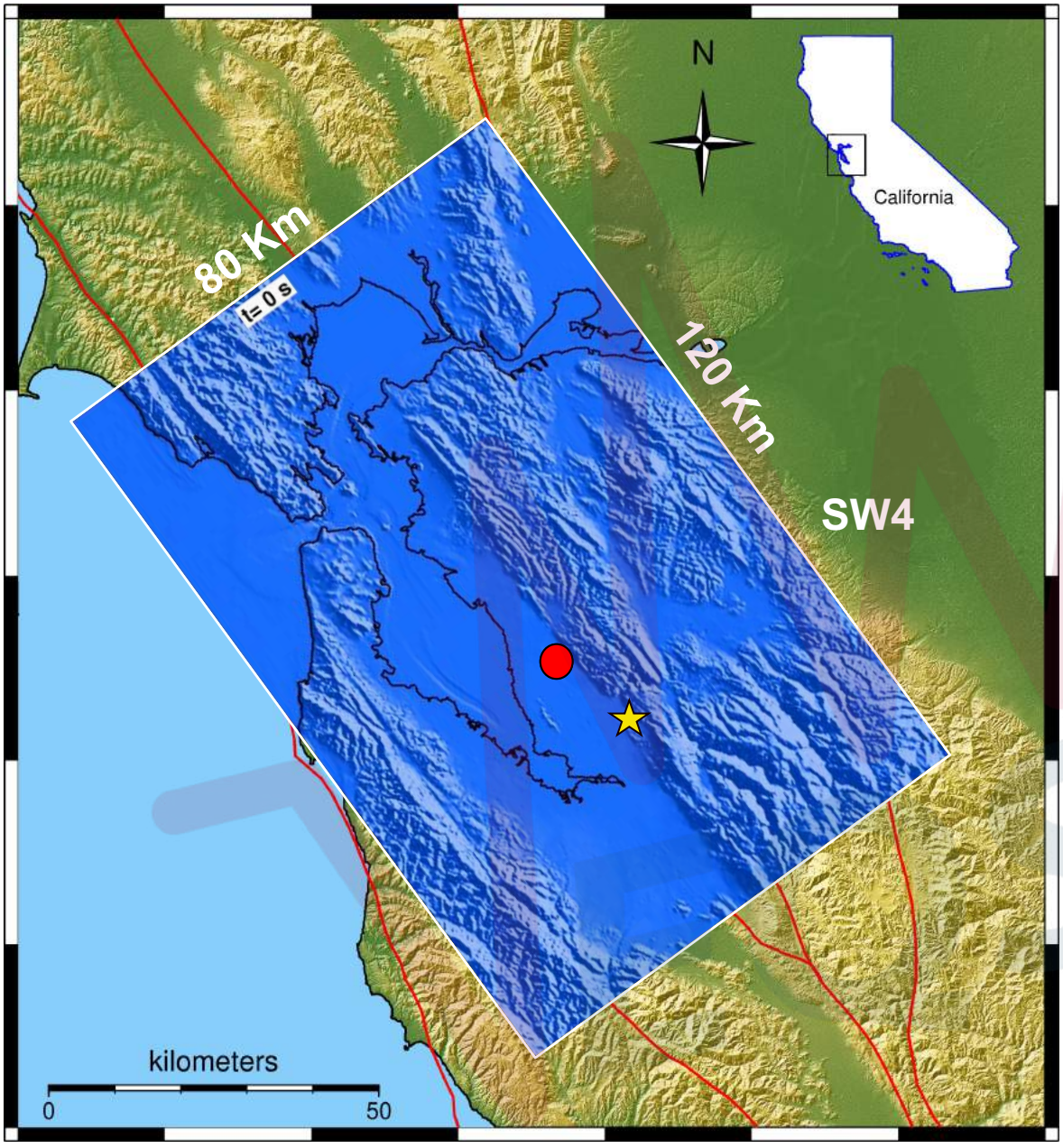


**NERSC Spin server**

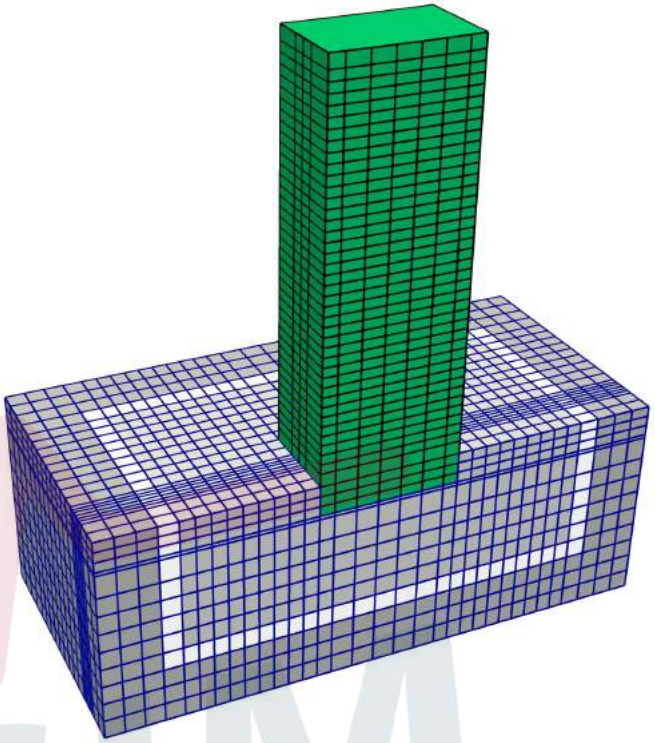
**Regional Geophysics Model**
**(M7 Hayward fault earthquake)**

**Fmax 10 Hz Vsmin 140 m/s**
**391 Billion grid points**

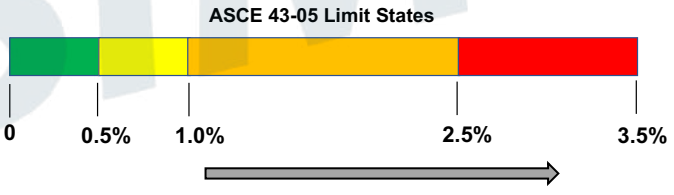



**Local Soil / Building Model**

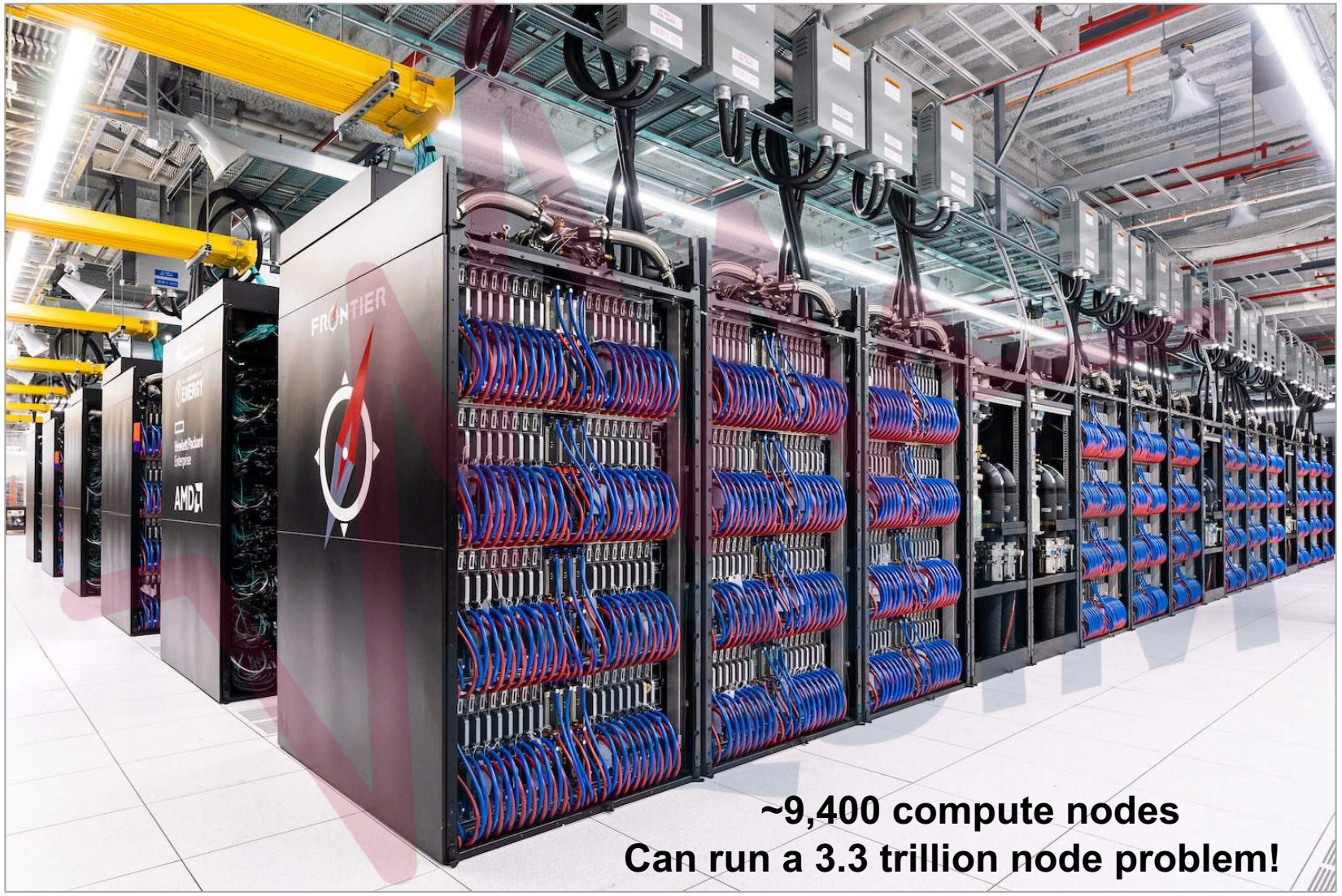
- **Soil-structure interaction**
- **Complex 3D waves**



**Building location**

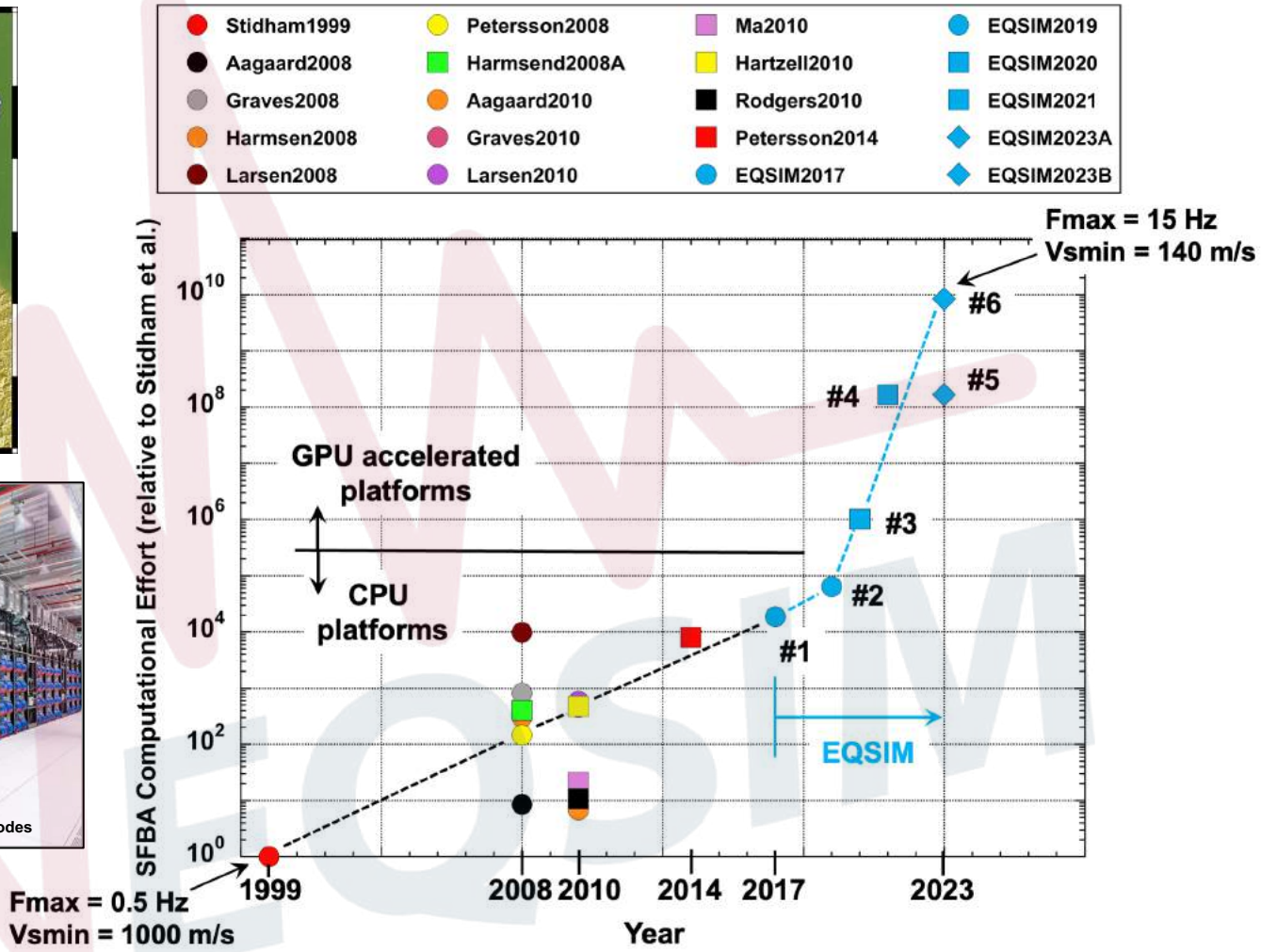


# Starting in June 2023 we have obtained access to the exaflop Frontier GPU-accelerated system



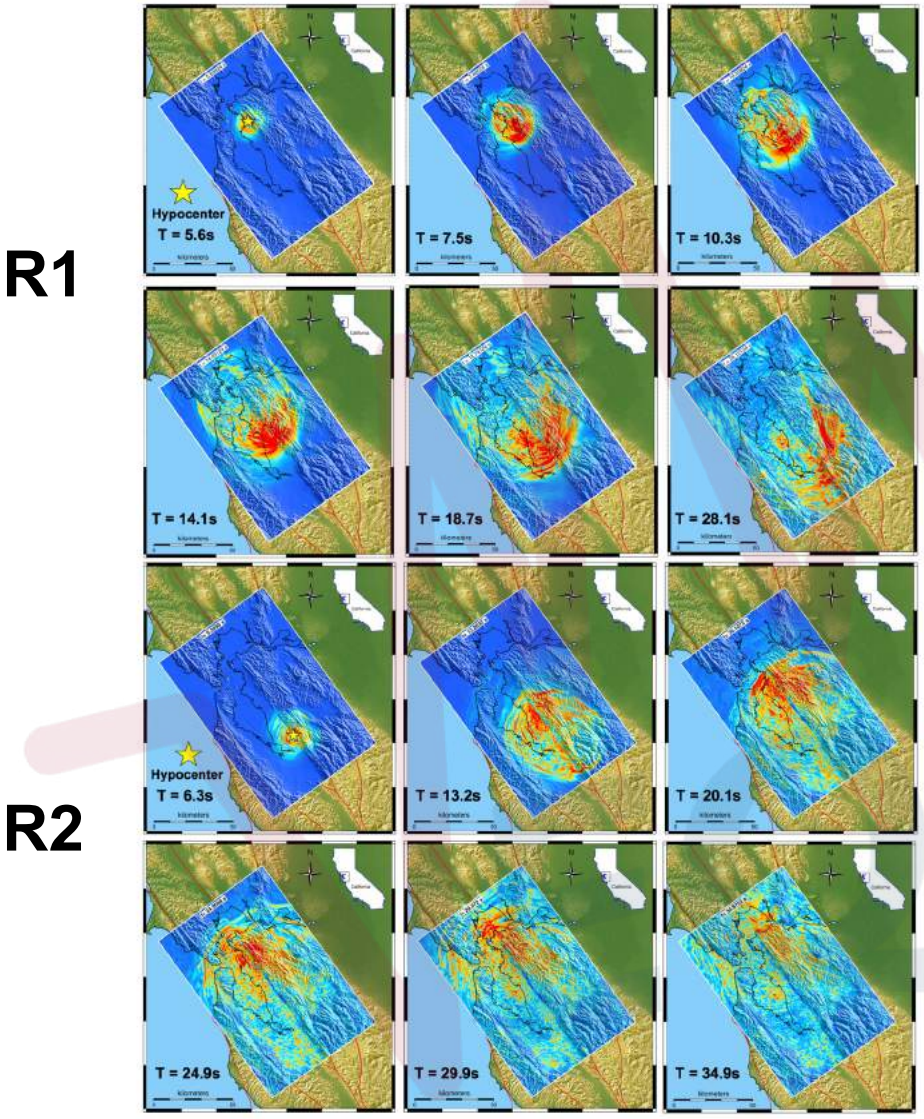
# Comparison of all San Francisco Bay Area simulations performed to-date



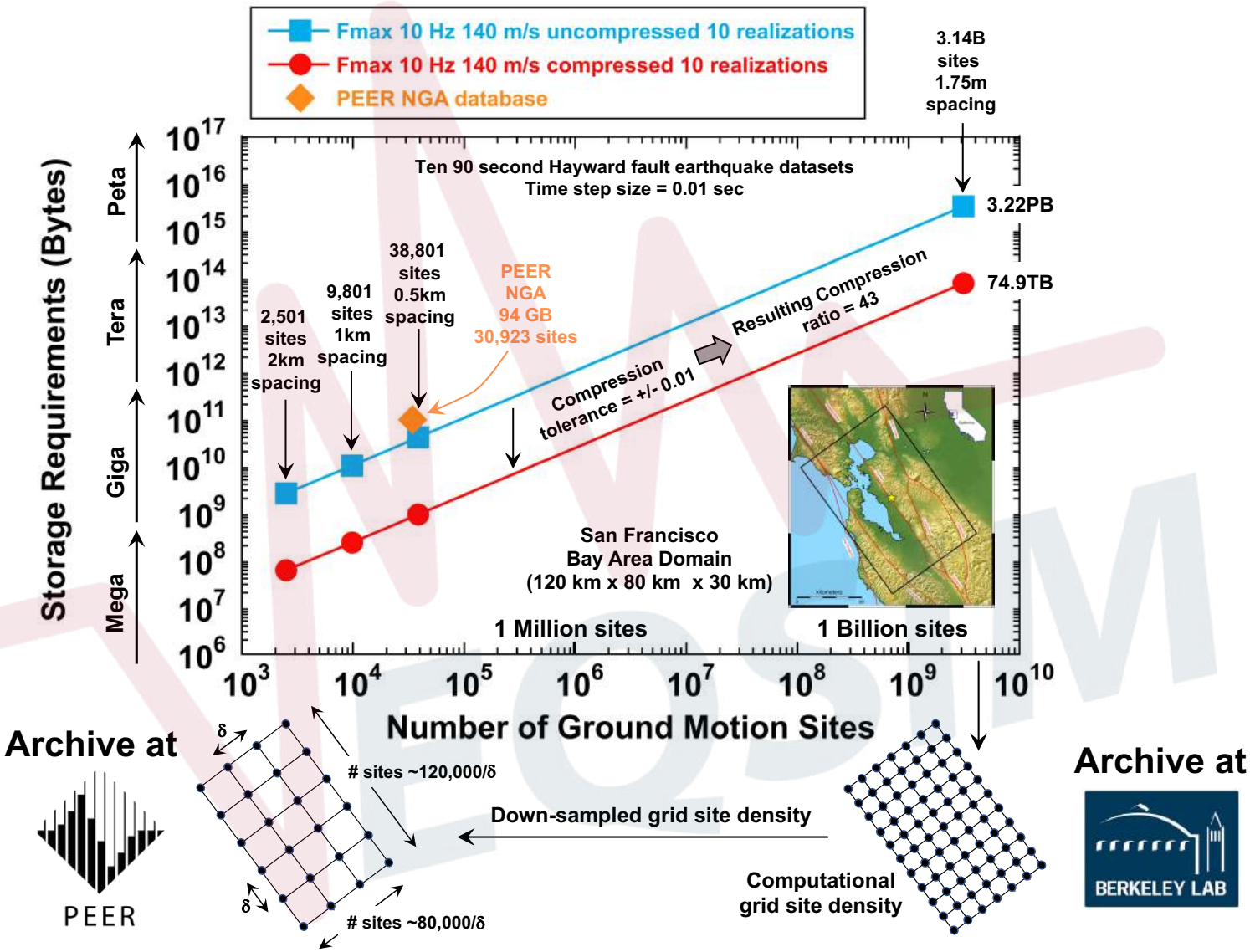



**Computational Effort** $\propto$ (Model Volume) x (Earthquake Duration) x $(\text{Freqmax} / \text{Vsmin})^4$

# For the initial database realization, we will create 25 Hayward fault rupture scenarios (at 5 Hz)




# A robust and scalable data management schema is essential



# The EQSIM-vis web-based tool for interrogating datasets can potentially be added to the mix

## Current features

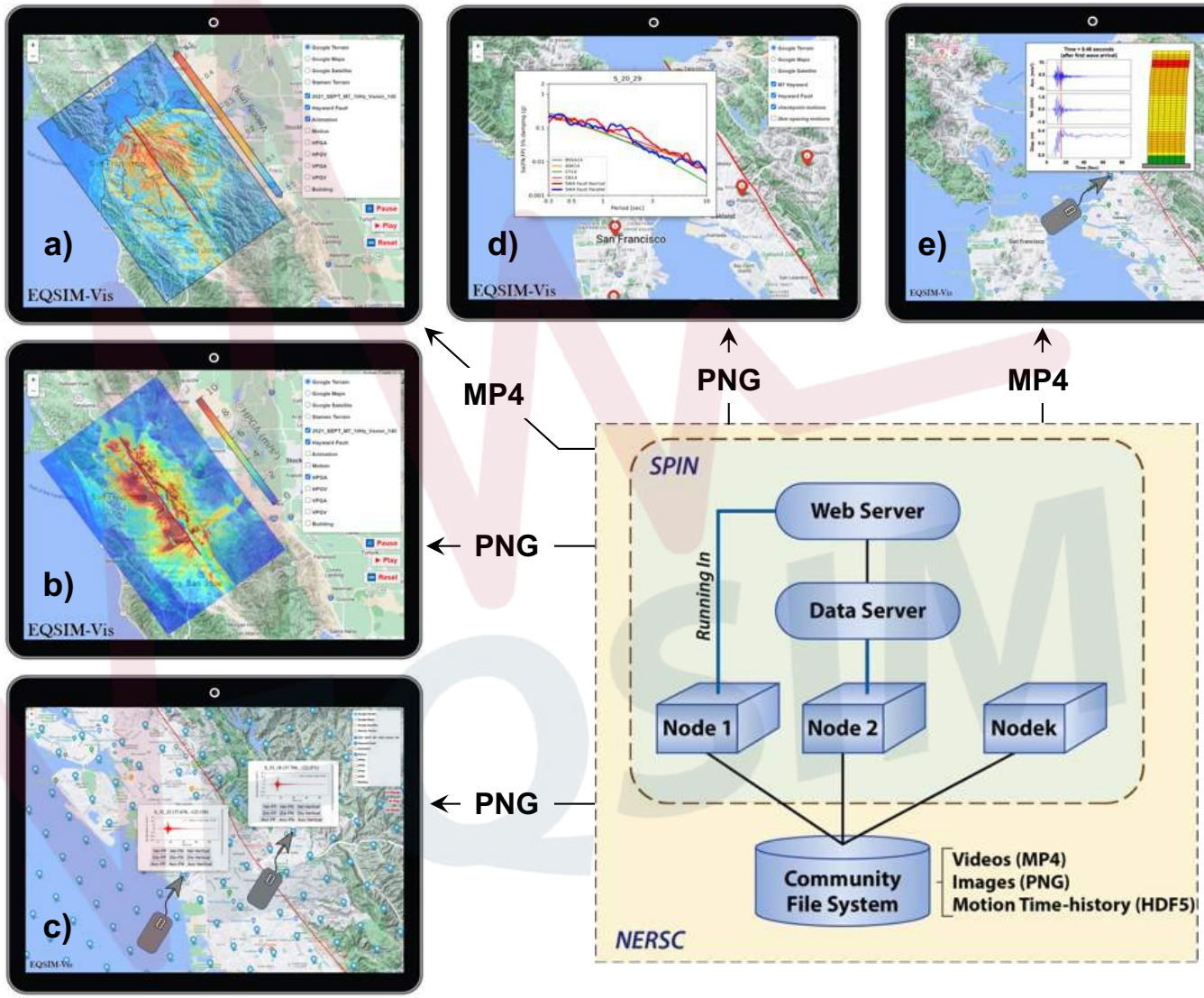
a) Rupture animation

b) Ground motion contour plots

c) Ground motion time history display and data download

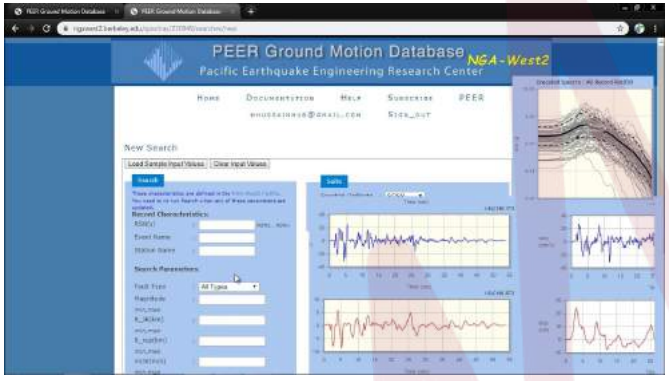
d) GMPE – simulation comparisons

e) Building response animations



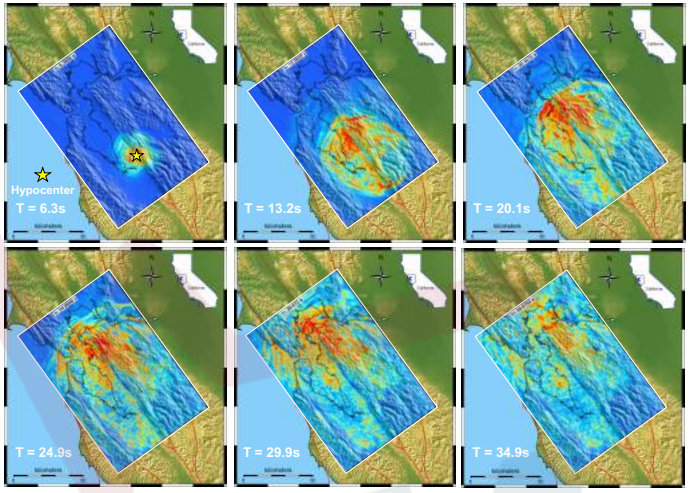
# PEER will strive to make the simulated ground motion database "familiar" to PEER users

**Existing - Spatially sparse measured motions**

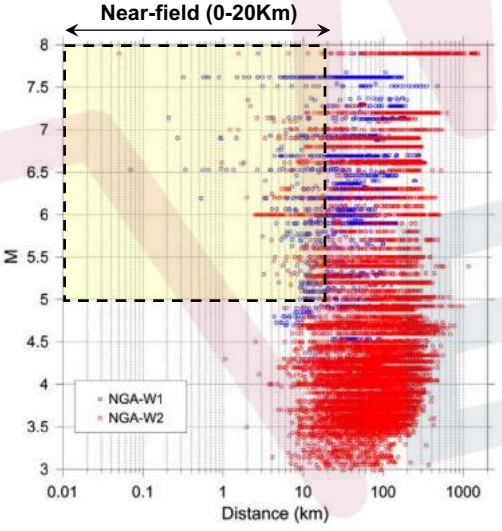



+

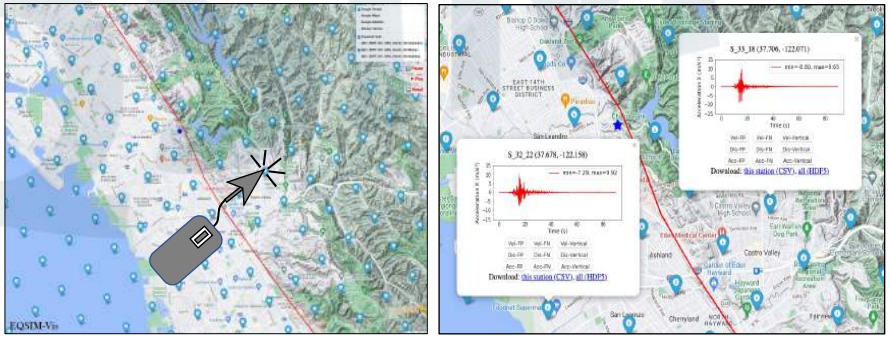
**New - Spatially dense simulated motions for the San Francisco Bay Area**



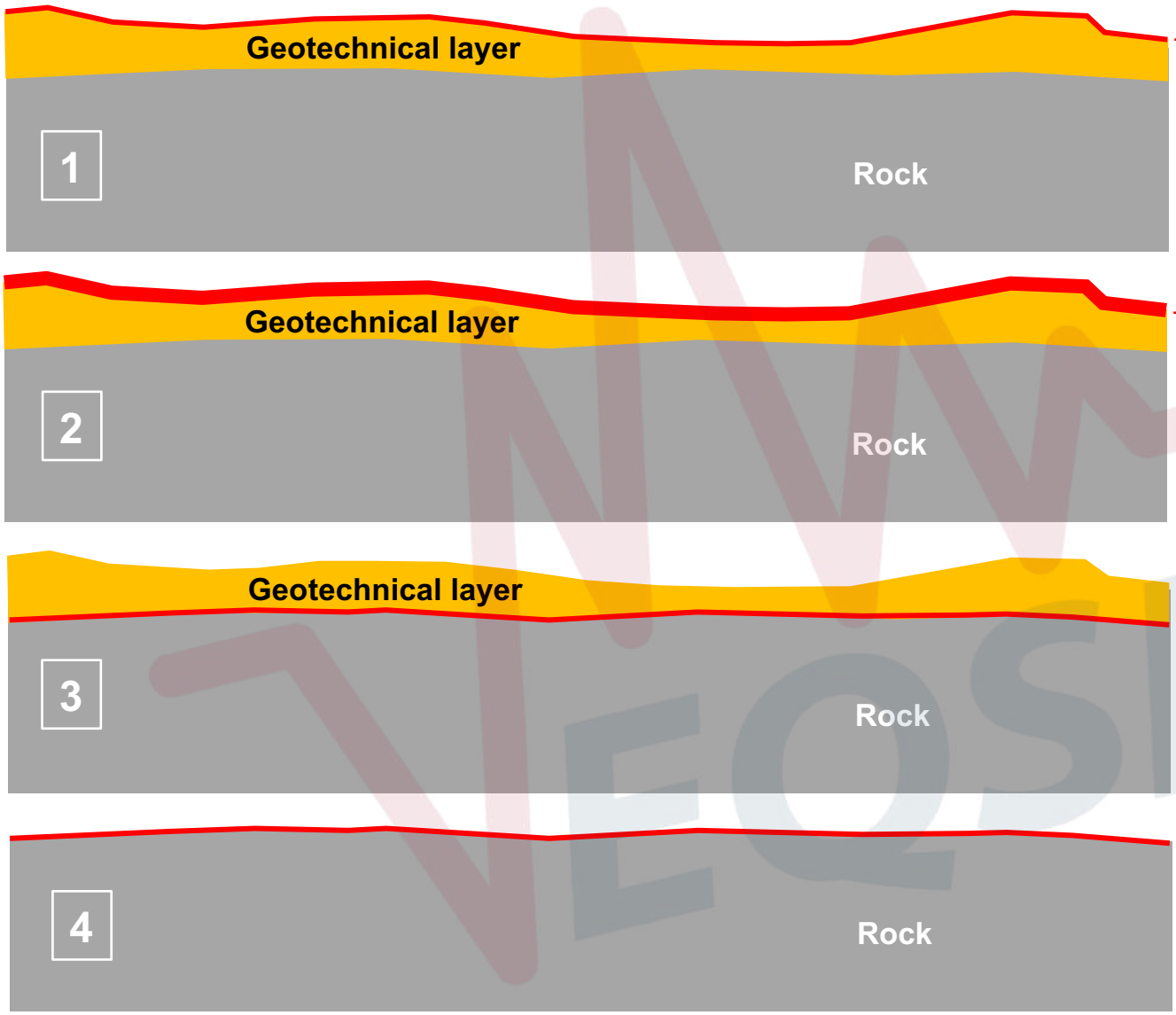

**Sparse ground motions from everywhere**




**High-fidelity, spatially dense regional ground motions**



# Ultimately the PEER - LBNL database could support multiple use cases




→ Ground surface motions
- fixed base structural response

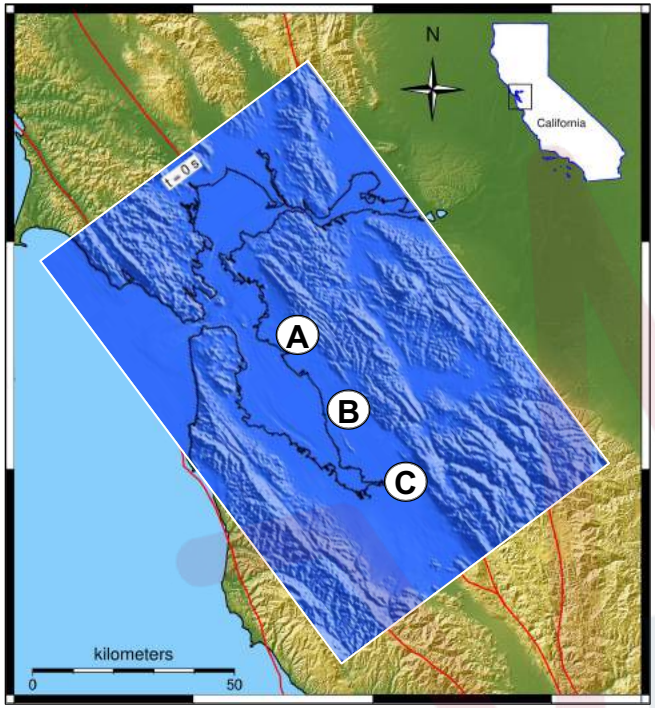
→ Near surface volume motions
- DRM utilization for SSI and/or nonlinear soil response

→ In-column motions
- 1D site response

→ Outcrop motions
- 1D site response

# There will be *a lot* to explore! e.g. within-event variability showing site-specific response

**Magnitude 7**
**Hayward fault**
**northern hypocenter**




Elastic | Limited permanent distortion | Moderate permanent distortion | Large permanent distortion

**20 story streel frame Nevada fiber model**
**(fault-normal motions)**