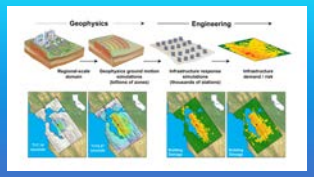


PEER International Pacific Rim Forum
June 16-17, 2021

The U.S. DOE EQSIM Exascale Application Development for Fault-to-Structure Regional-Scale Simulations

David McCallen
Lawrence Berkeley National Laboratory
& University of Nevada, Reno

June 16, 2021

BERKELEY LAB

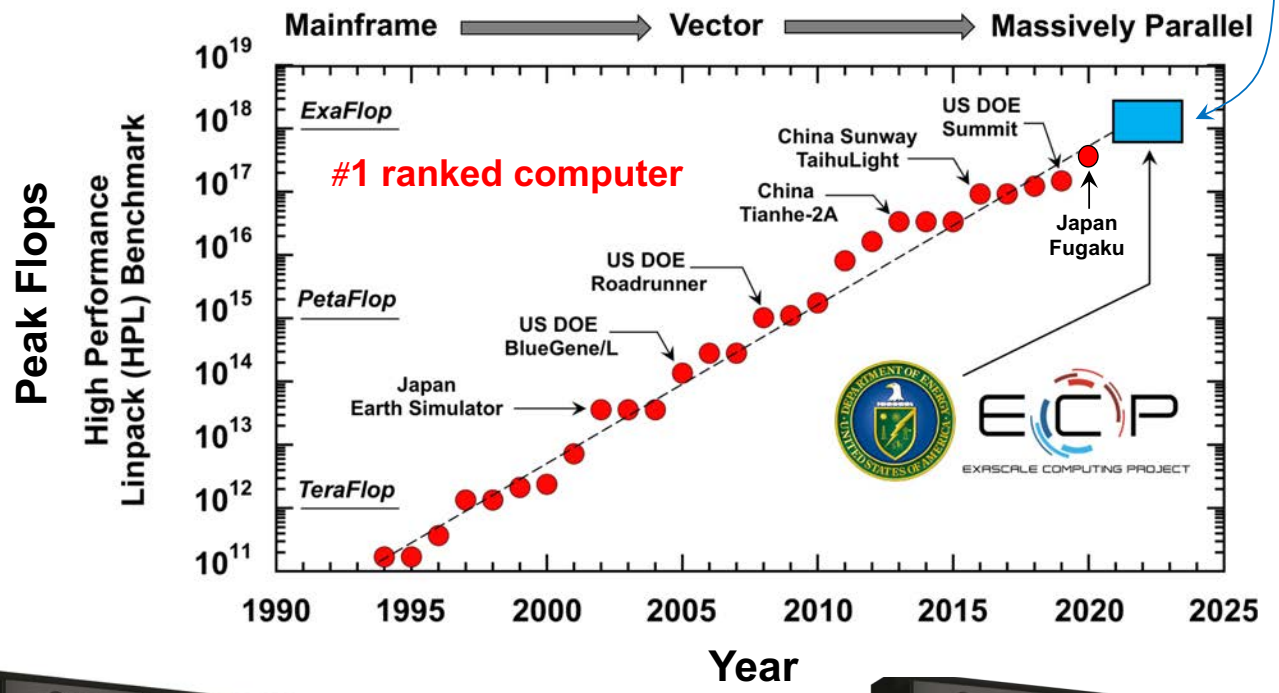
EXASCALE COMPUTING PROJECT

PEER

HPC advancements are enabling unprecedented scientific simulations

Source: Top500.org

1,000,000,000,000,000,000 (10^{18}) Flops (ECP)



AURORA
Argonne National Lab

FRONTIER
Oak Ridge National Lab

The DOE Exascale Computing Project (ECP) is preparing to exploit a billion-billion FLOPS

Three parallel components of the Exascale program…

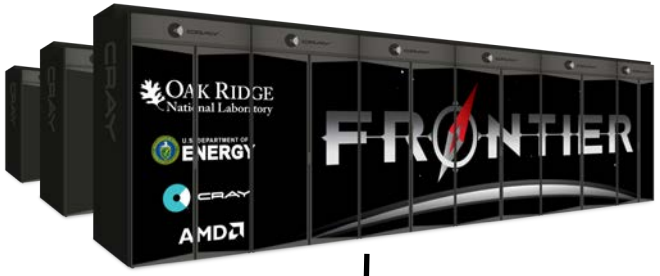
Software Technology → **Applications Development** → **Exaflop Computers**

Supporting software stack for the Exascale computational ecosystems

Selected science applications (24) for Exascale platforms

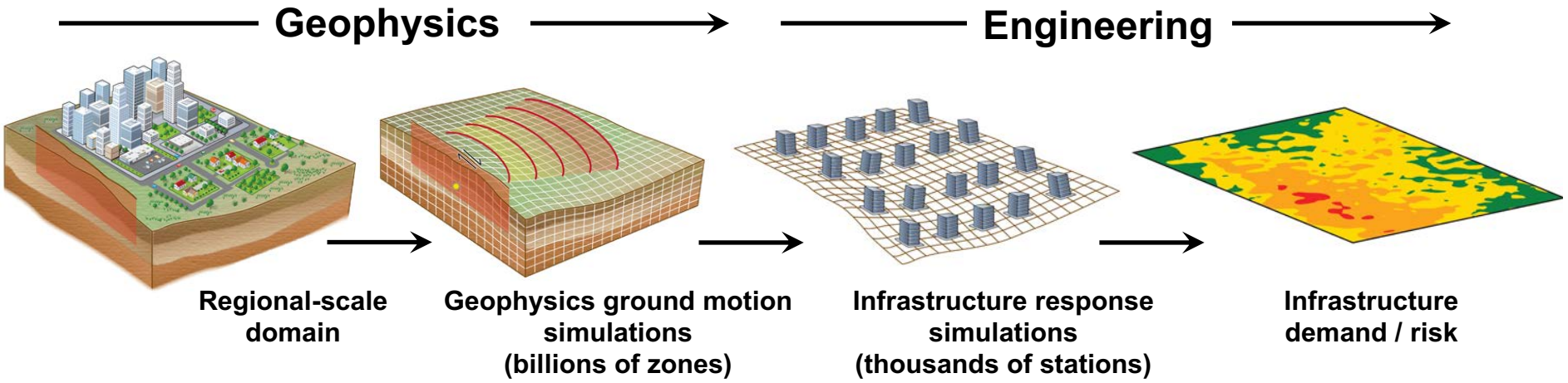
Advanced computer hardware at the Exascale

ECP EXASCALE COMPUTING PROJECT **is preparing for** →



2017 2018 2019 2020 2021 2022

EarthQuake SIMulation (EQSIM) framework - integrated fault-to-structure simulations

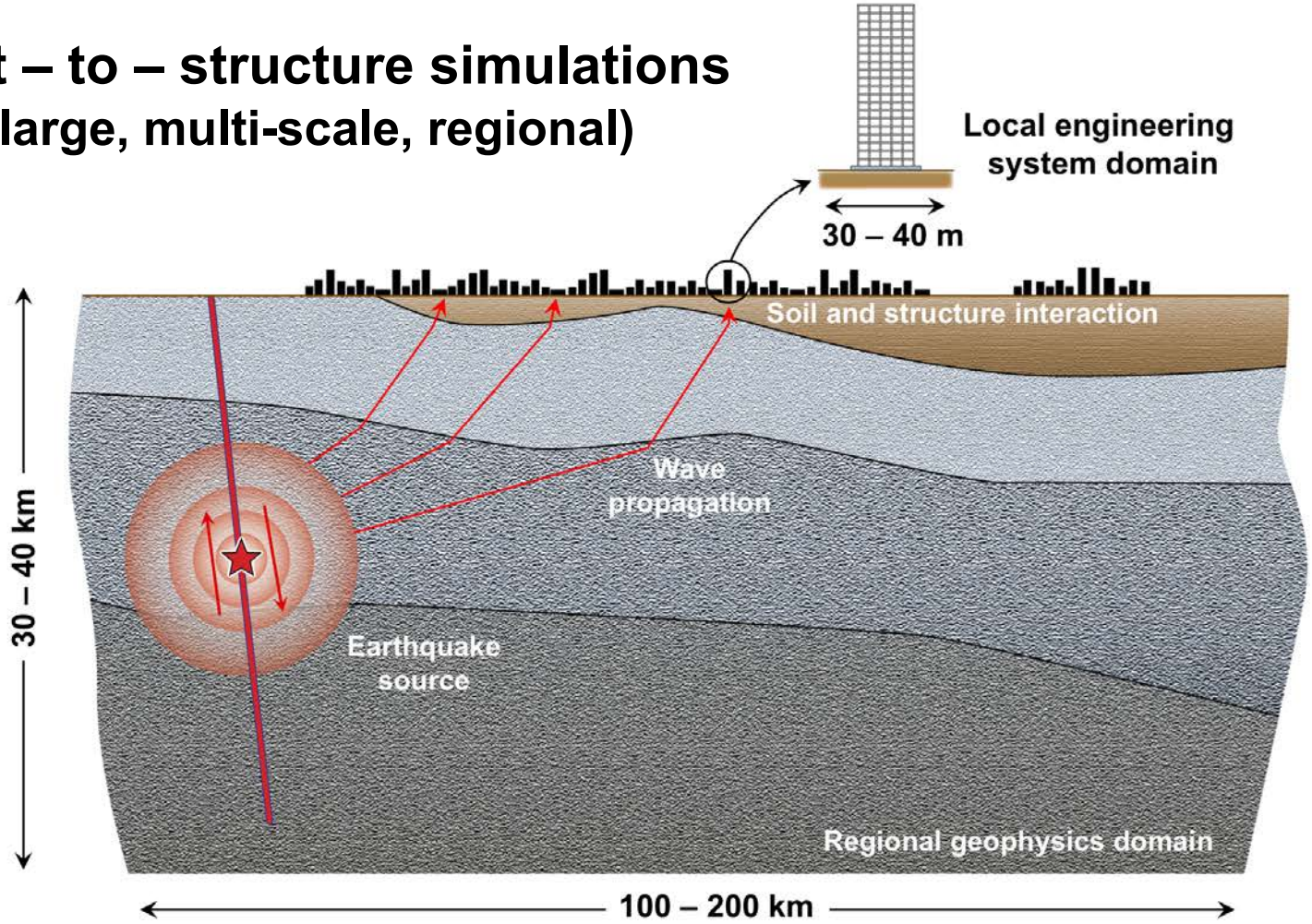


Key issues that will be explored through simulations…

- **How do earthquake ground motions actually vary across a region and how does this impact risk to infrastructure?**
- **How do complex (realistic) incident ground motion waveforms actually interact with a particular facility?**

Fault-to-structure simulations are a very challenging multi-scale problem

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



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

The EQSIM core team spans engineering, seismology, math and computer science

Engineering Mechanics

David McCallen

Mamun Miah

Maryam Tabbakhha

Applied Math / Numerical Methods

Anders Petersson

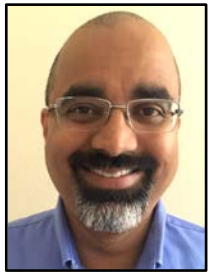
Bjorn Sjogreen

Wei Liu

Computer Science

Houjun Tang

Ramesh Pankajakshan



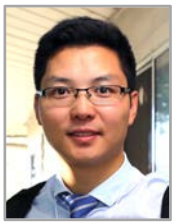
Seismology / Geophysics

Arben Pitarka

Arthur Rodgers

Rie Nakata

Postdoctoral scholars

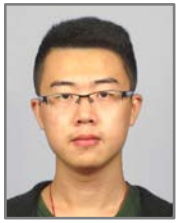


Wu

Kenawy

Graduate students

Eckert

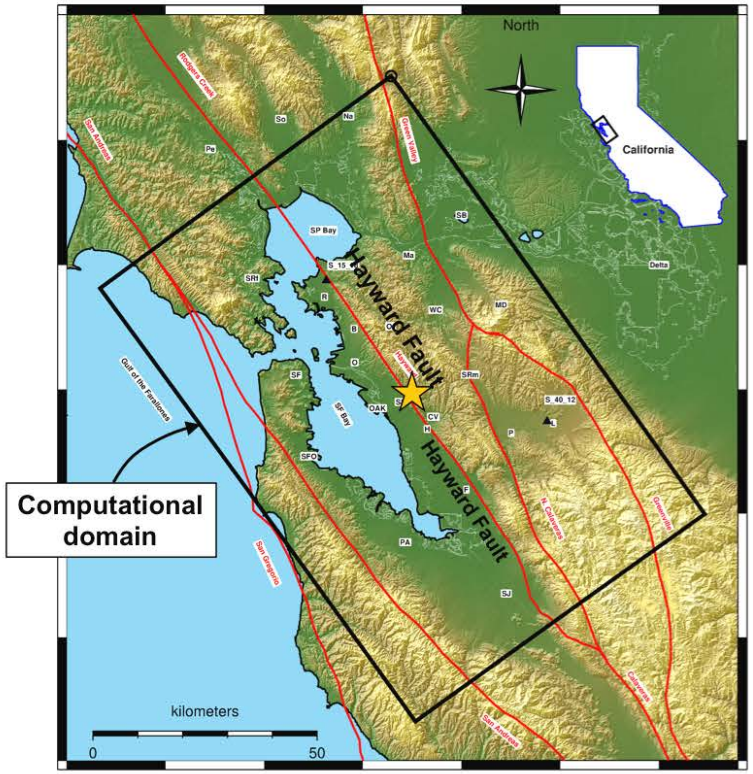


Huang

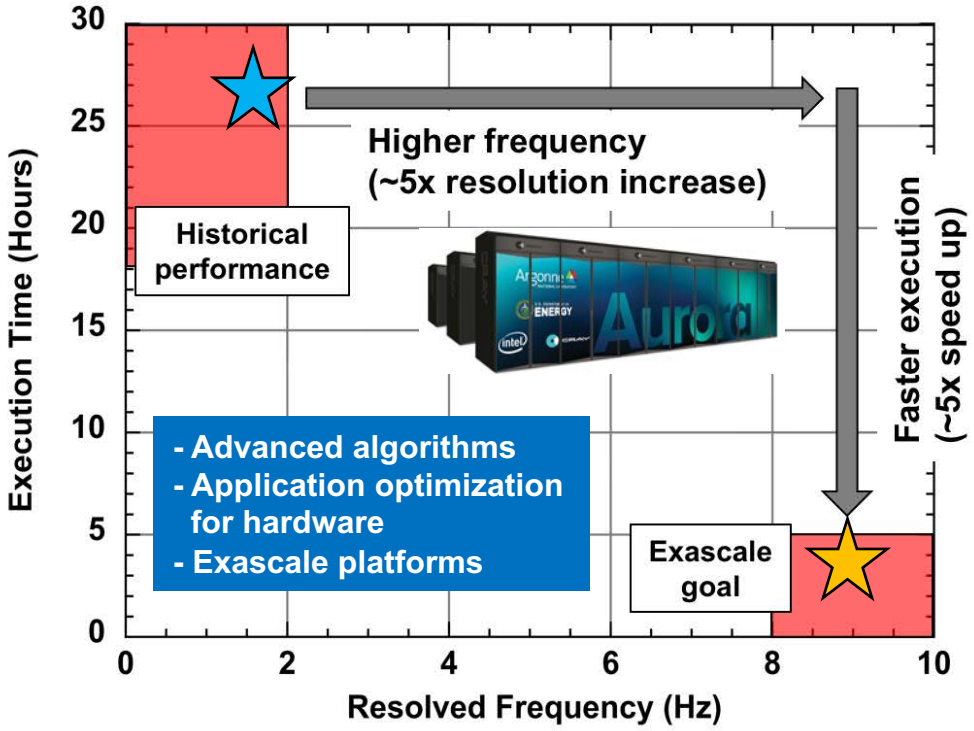
Statement of the EQSIM exascale goal – high frequency, fast regional simulations

Deterministic, *fast* forward ground motion simulations at frequencies of engineering interest are the core focus of our developments

Regional-scale model (SFBA)

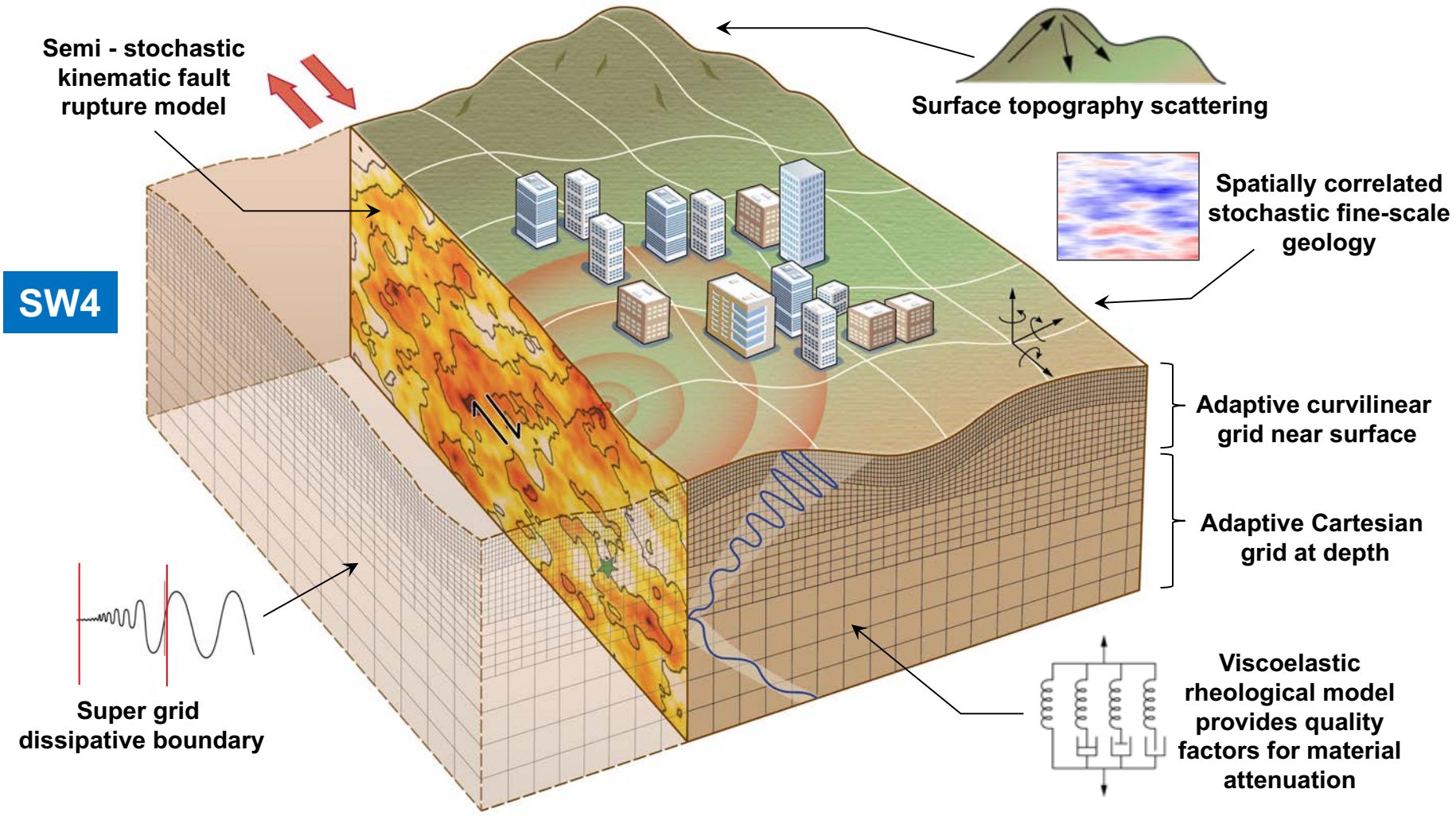


Simulation of one earthquake realization



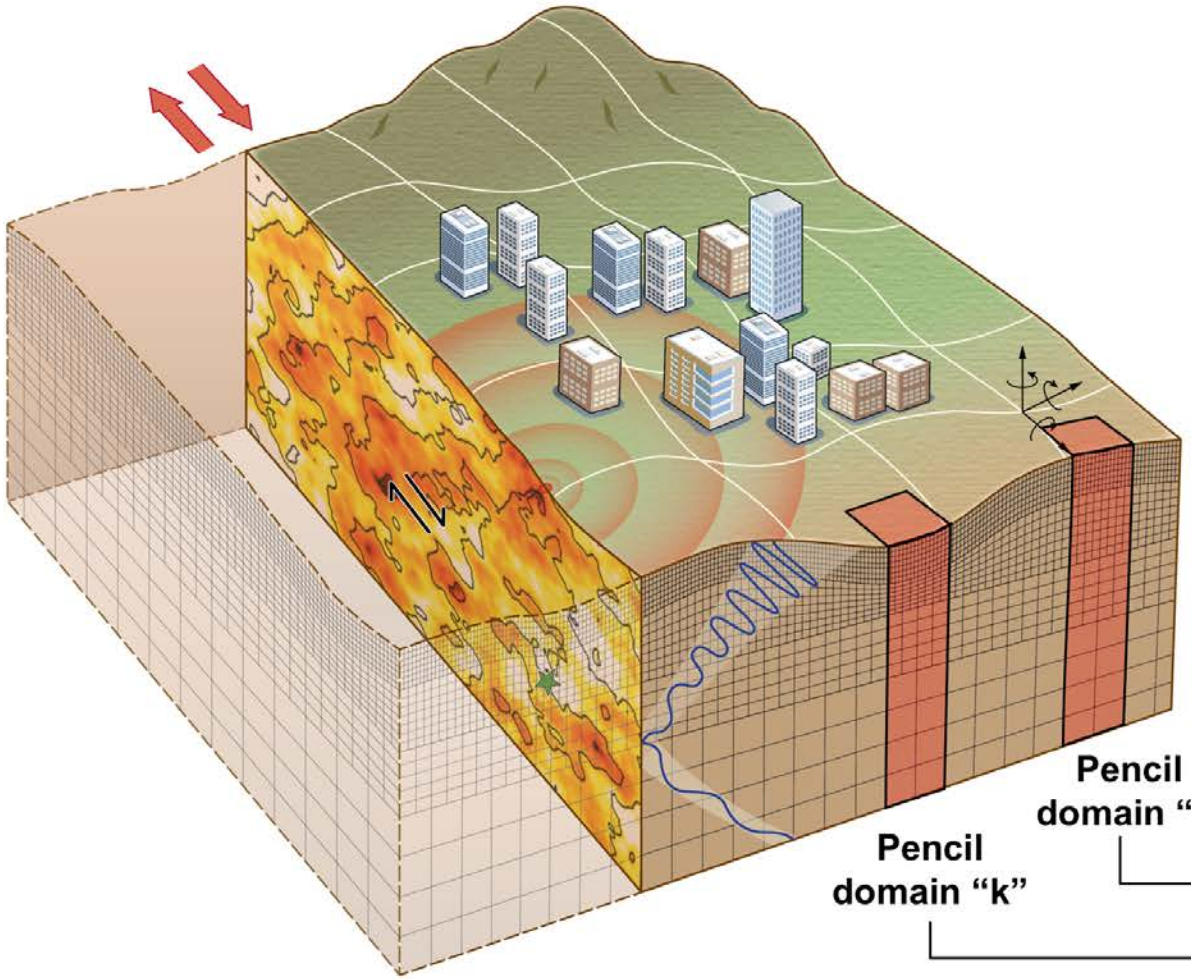
Advancing the SW4 geophysics code for simulating earthquake ground motions

Improved physics, computational efficiency at 300 billion grid points



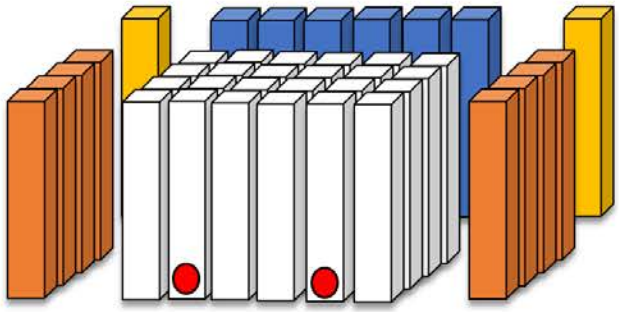
Optimizing the code for execution on massively parallel GPU-based computers

Effective parallelism, I/O and workflow



OAK RIDGE National Laboratory

4,608 nodes, 27,648 NVIDIA GPUs

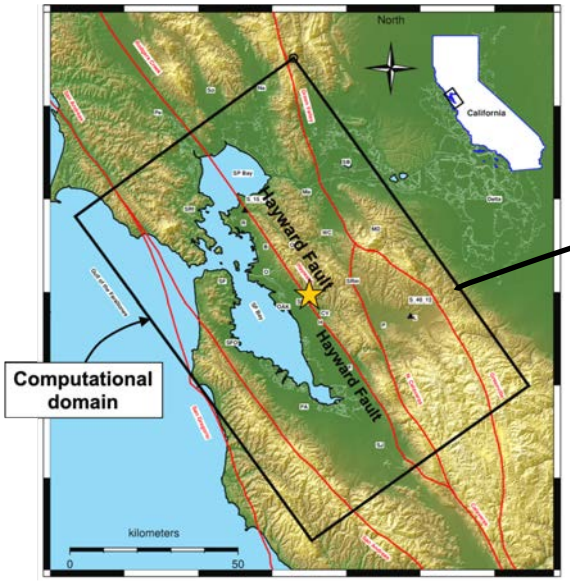


Pencil domain "i"

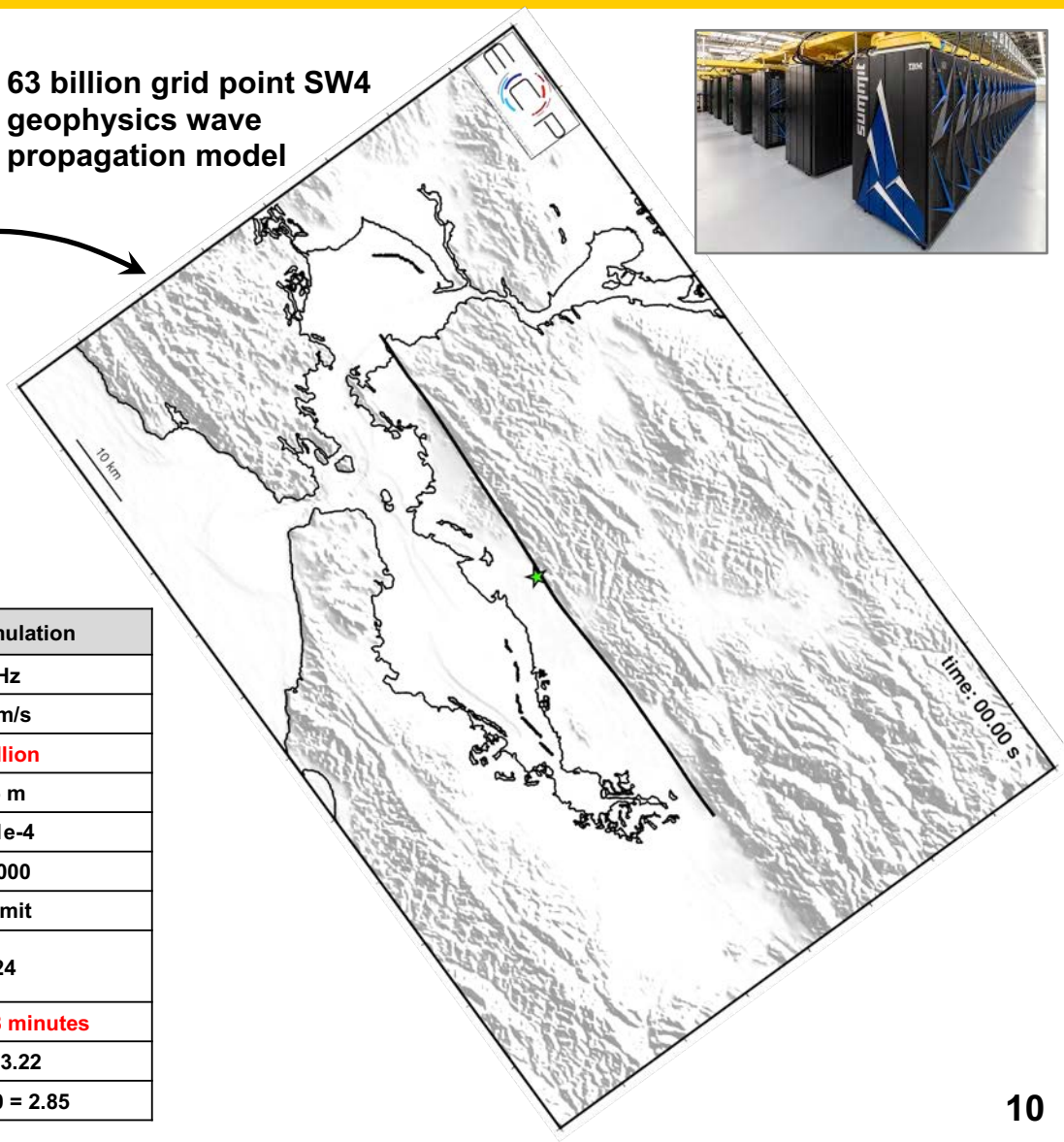
Pencil domain "k"

Node "i" Node "k"

San Francisco Bay Area – progress on simulations at 10Hz on Summit



63 billion grid point SW4 geophysics wave propagation model

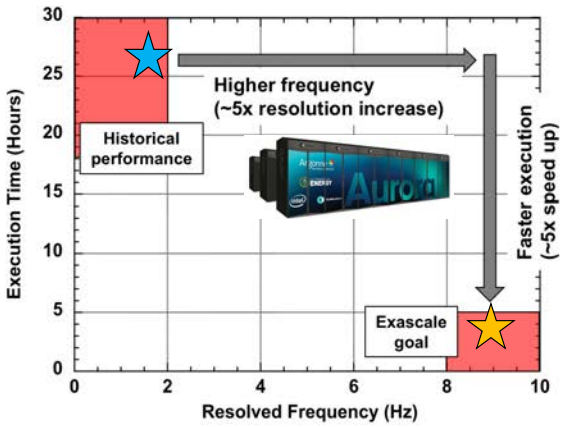


	FY19 Simulation	FY20 Simulation
Frequency Resolved	10 Hz	10 Hz
Vs_{min}	500 m/s	500 m/s
Number of grid points	203 Billion	63 Billion
Smallest cell size	6.25 m	6.25 m
Time step size	7.119e-4	8.491e-4
Total time steps	126,430	106,000
Platform	Summit	Summit
Number of compute nodes	1200 (1/4 of Summit)	1024
Wall clock time	19 hours 52 minutes	6 hours 58 minutes
	Grid points 2019 / grid points 2020 = 3.22	
	Compute time 2019 / compute time 2020 = 2.85	

Advancements in EQSIM performance for a M7 Hayward fault 10 Hz SFBA simulation

Goal

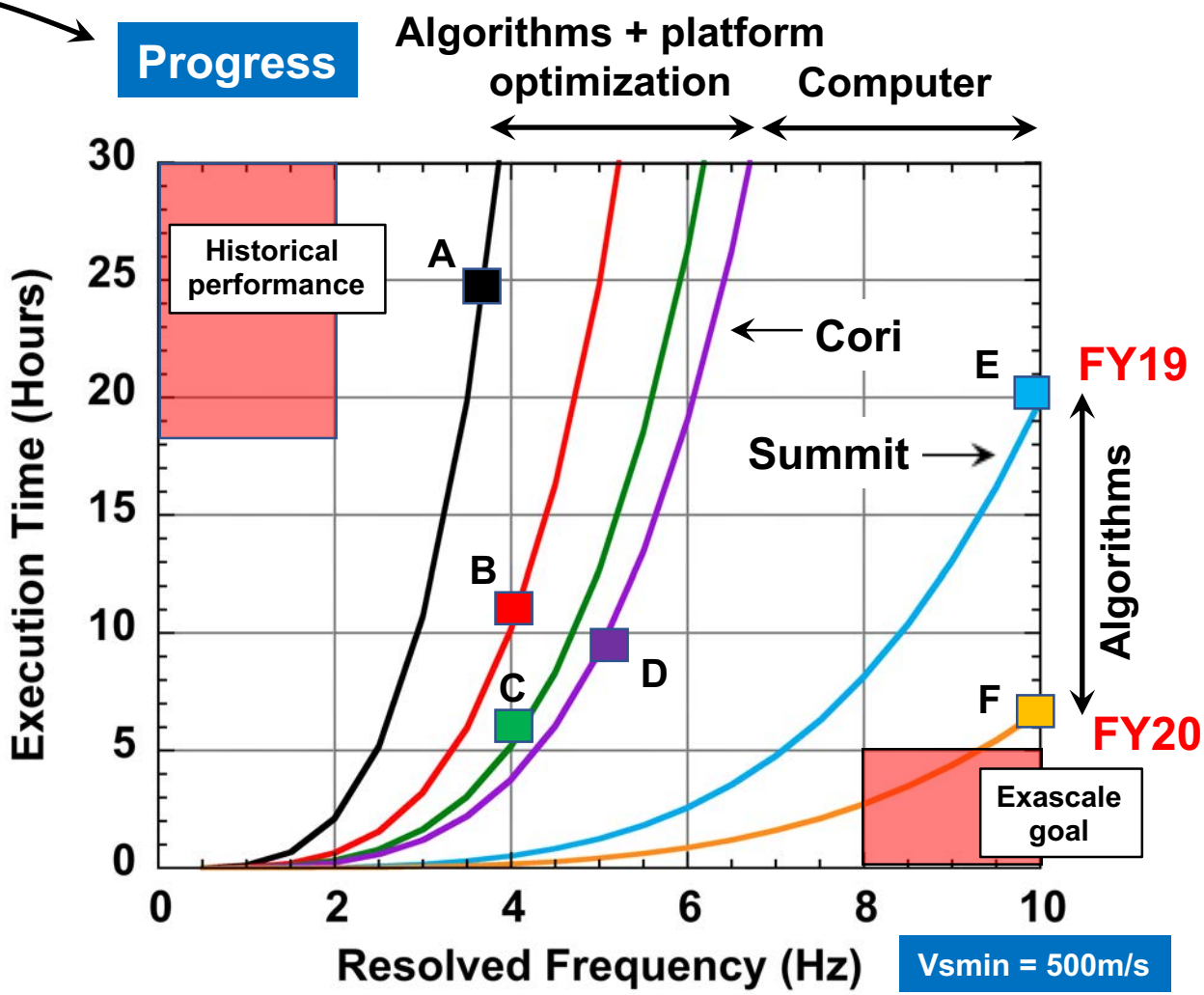
Simulation of one earthquake realization



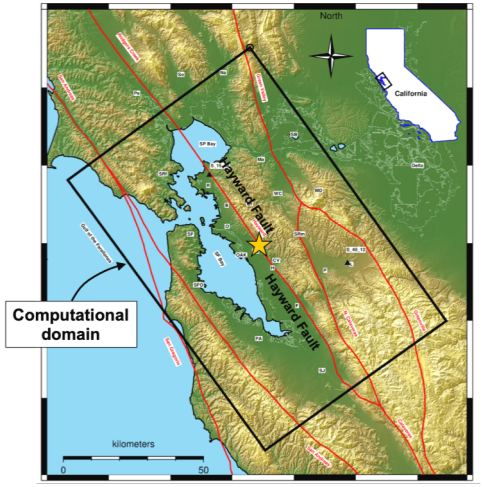
Cori ~30 PF

Summit ~200 PF

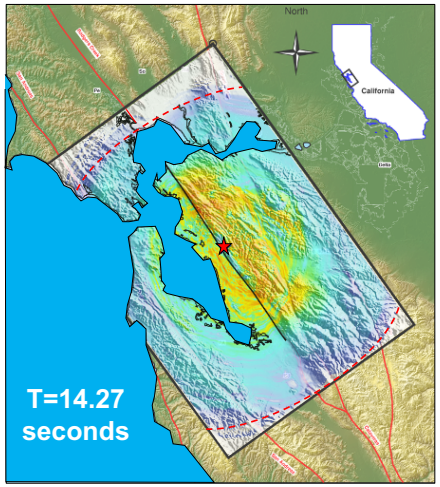
Progress

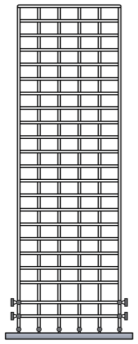


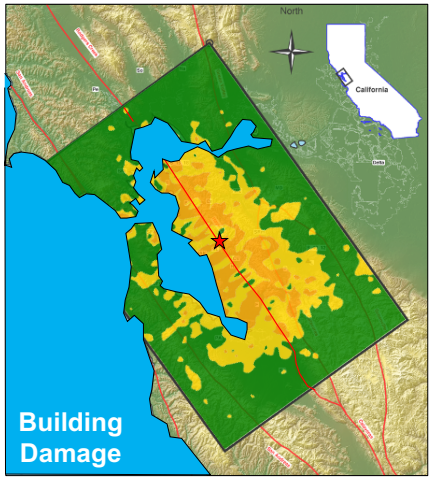
History of San Francisco Bay Area simulations (2000 – 2021)



San Francisco Bay Area

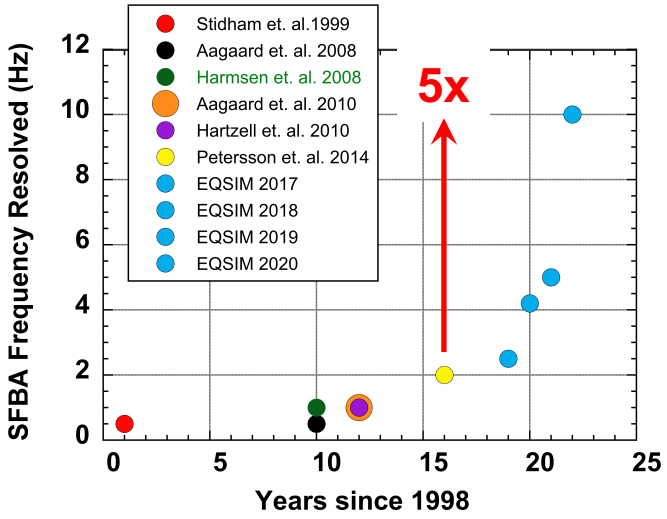




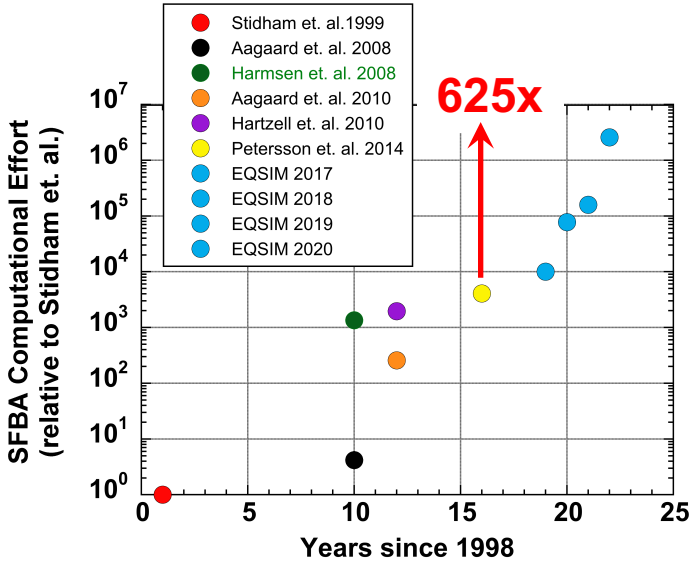


Computational progress

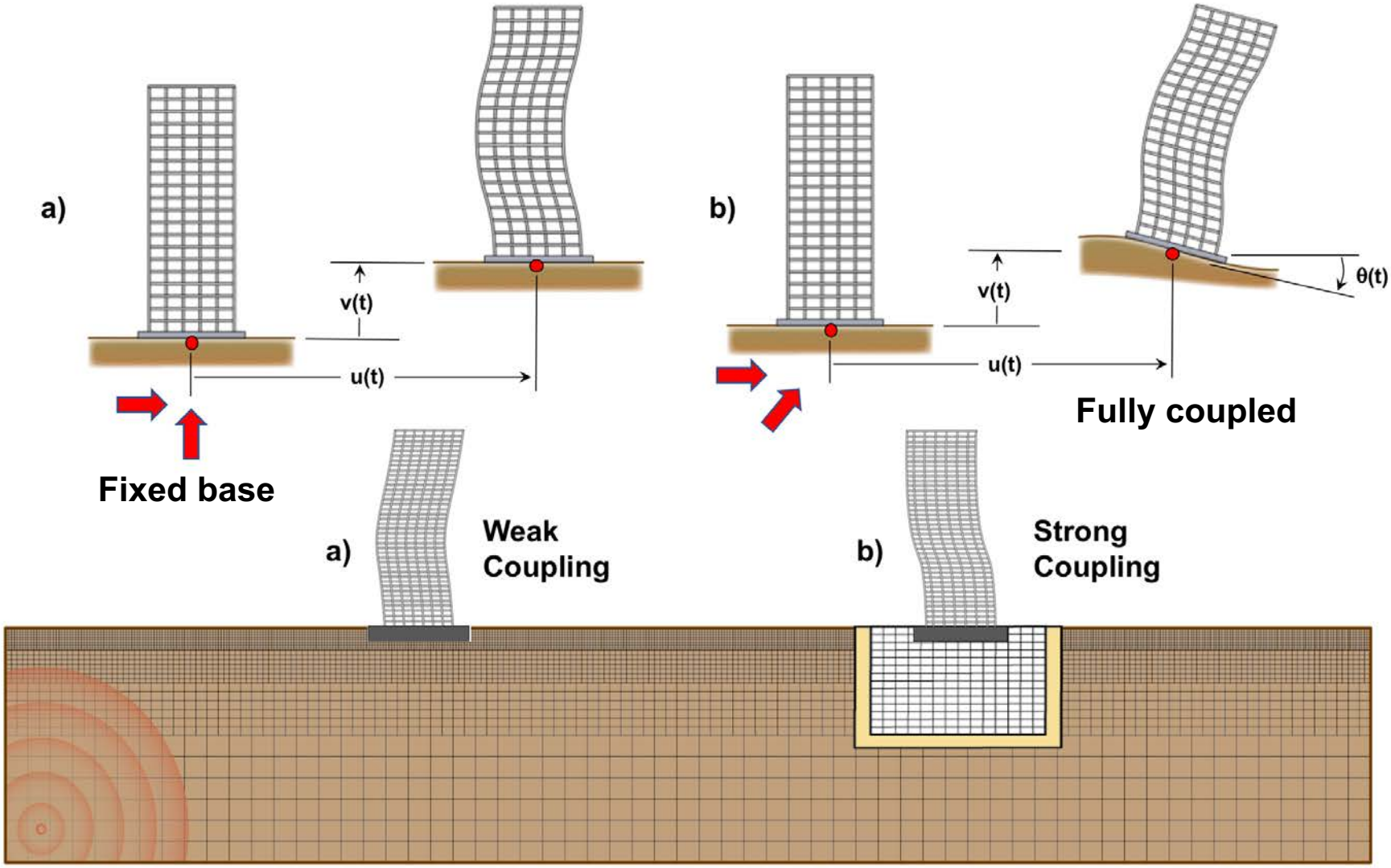
Frequency resolution



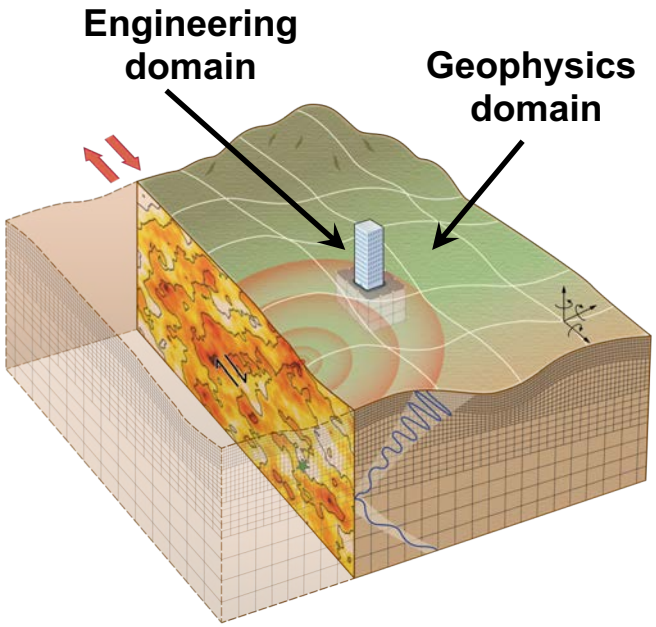
Computational effort

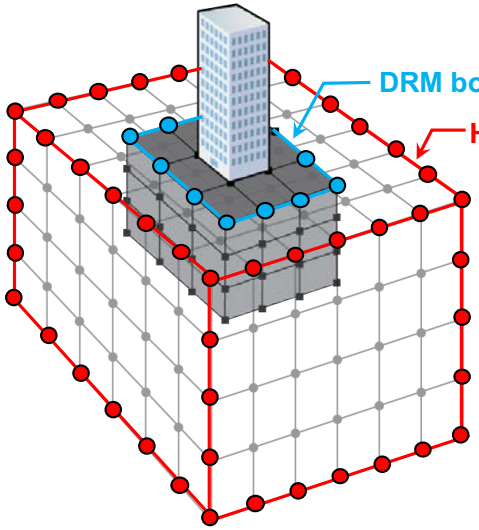


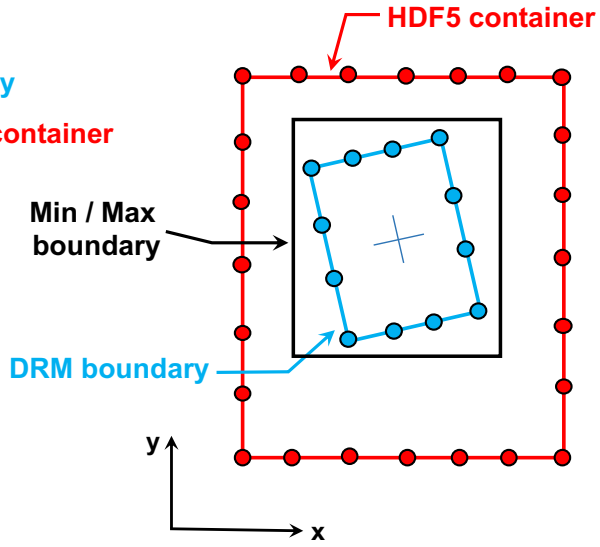
EQSIM has alternate workflows for coupling geophysics and engineering models



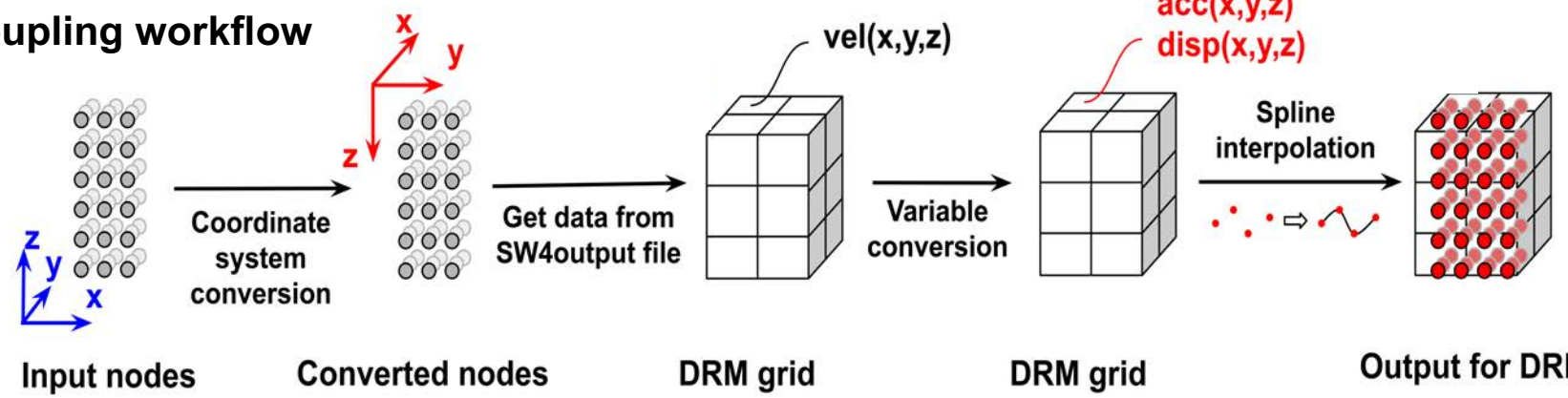
Generalizing coupling and software: linking geophysics and engineering codes



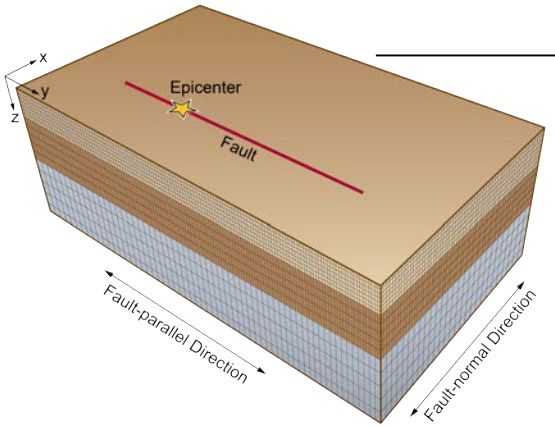




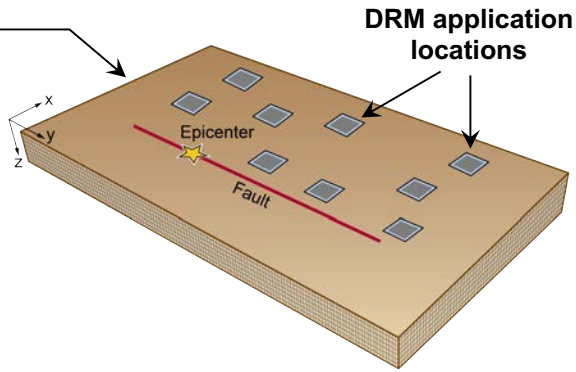
Coupling workflow



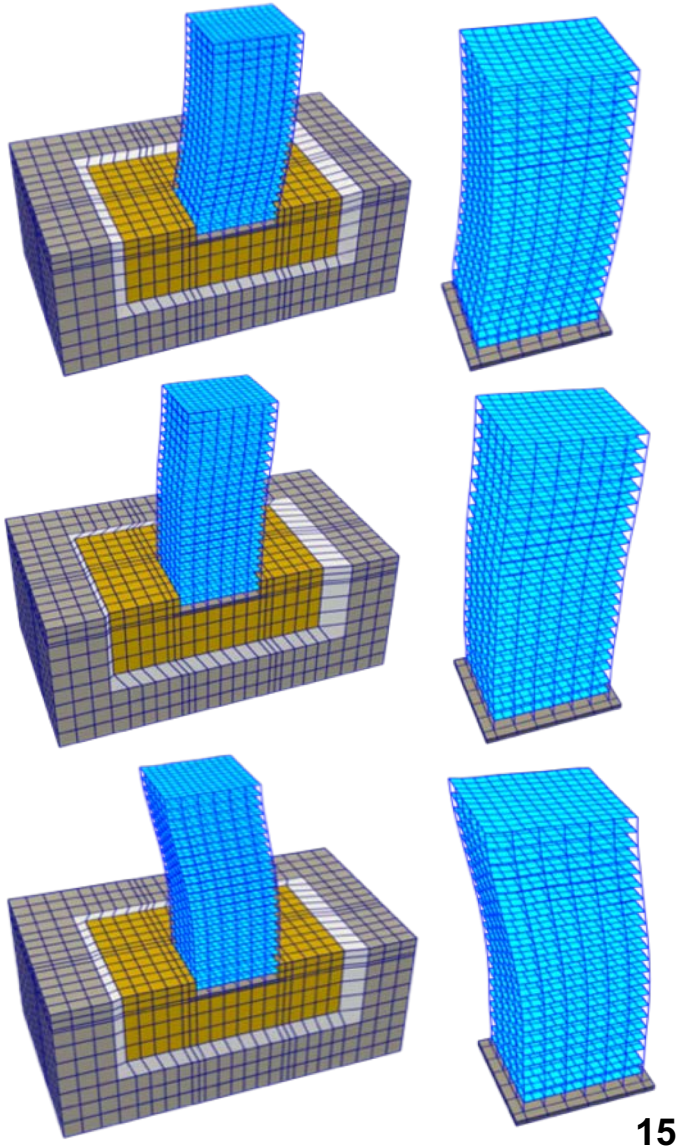
Strong coupling workflow – ground motion data compression for a near surface layer



Full regional-scale computational domain



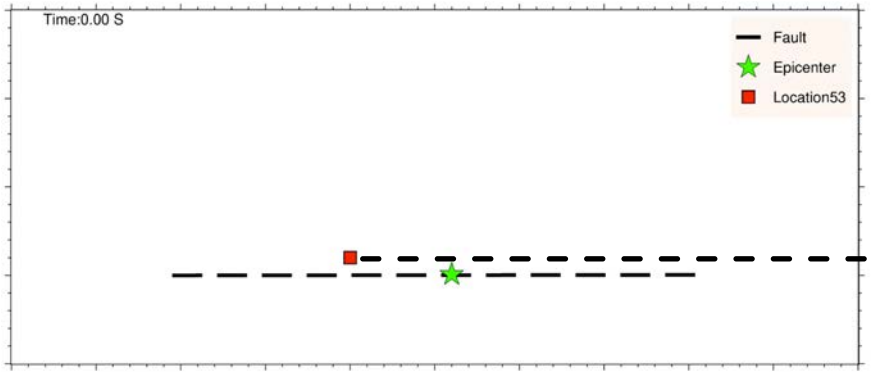
HDF5 data container of ZFP compressed grid point motions for the near-surface layer across the entire regional domain



I/O performance comparison with and without ZFP compression using 1024 nodes on the Cori supercomputer for an M7 Hayward fault earthquake simulation

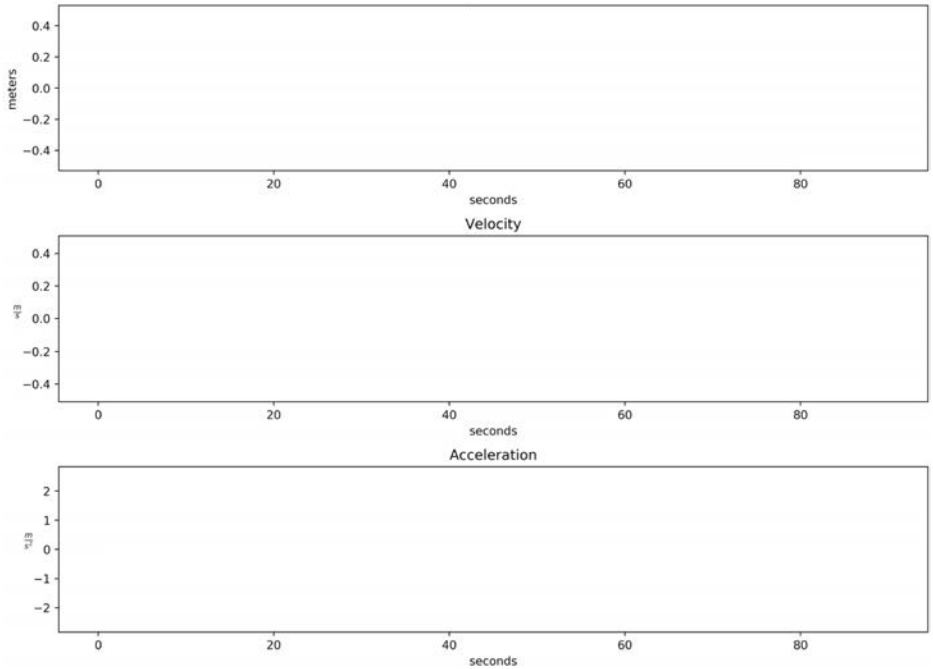
Case	HDF5 chunk size	I/O Time (s)	Total Time (s)	I/O percentage	Data size (GB)	Compression ratio
No compression	N/A	933	3986	23%	38912	N/A
ZFP	60x60x32	433	3568	12%	155	251
ZFP	32x60x32	284	3147	9%	164	237
ZFP	32x32x32	625	3708	17%	176	221

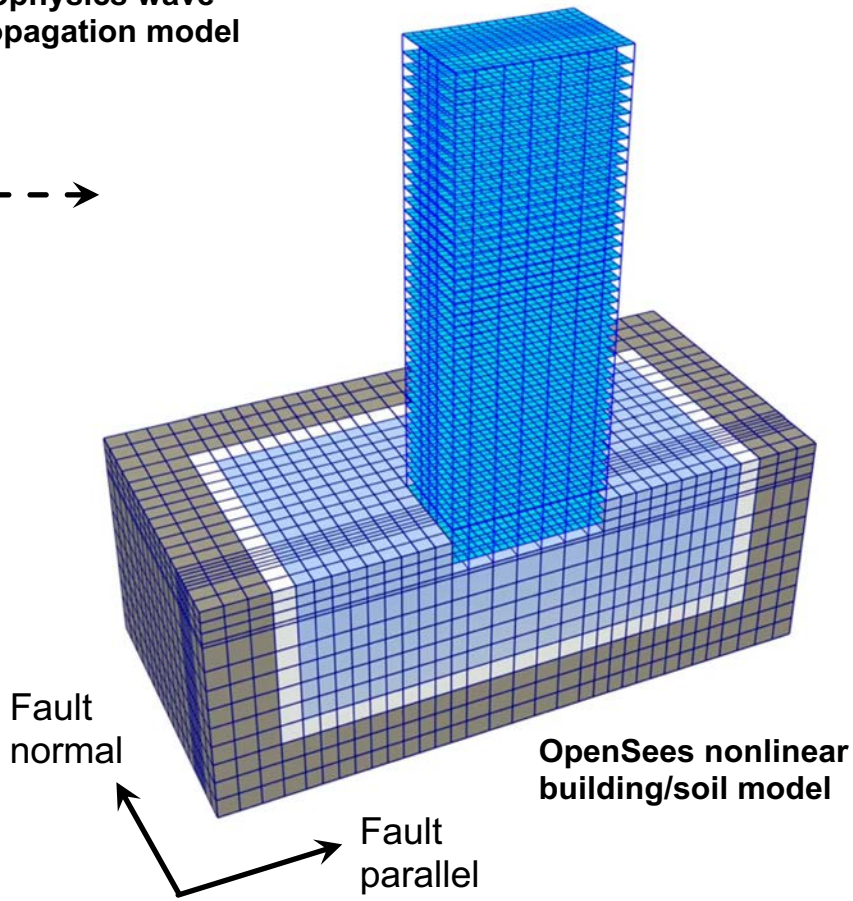
40 story steel moment frame building response at 2km off the fault



9 billion zone SW4 geophysics wave propagation model

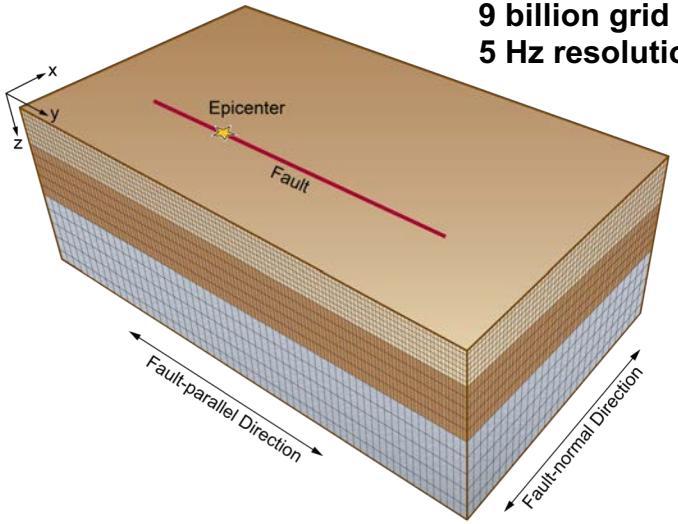
Fault parallel displacement, velocity and acceleration



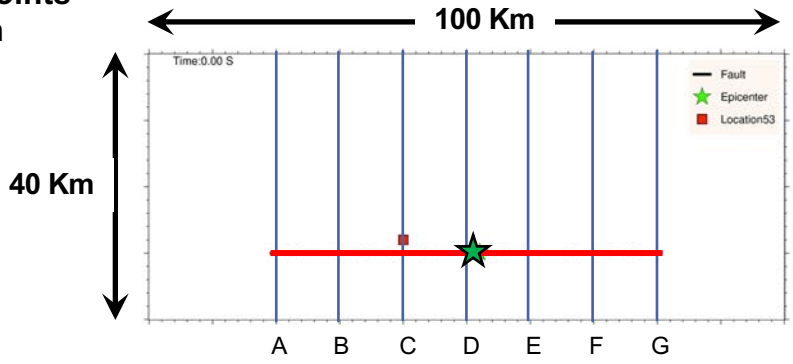


OpenSees nonlinear building/soil model

Simulations can provide new insight into wave propagation in the near-field domain

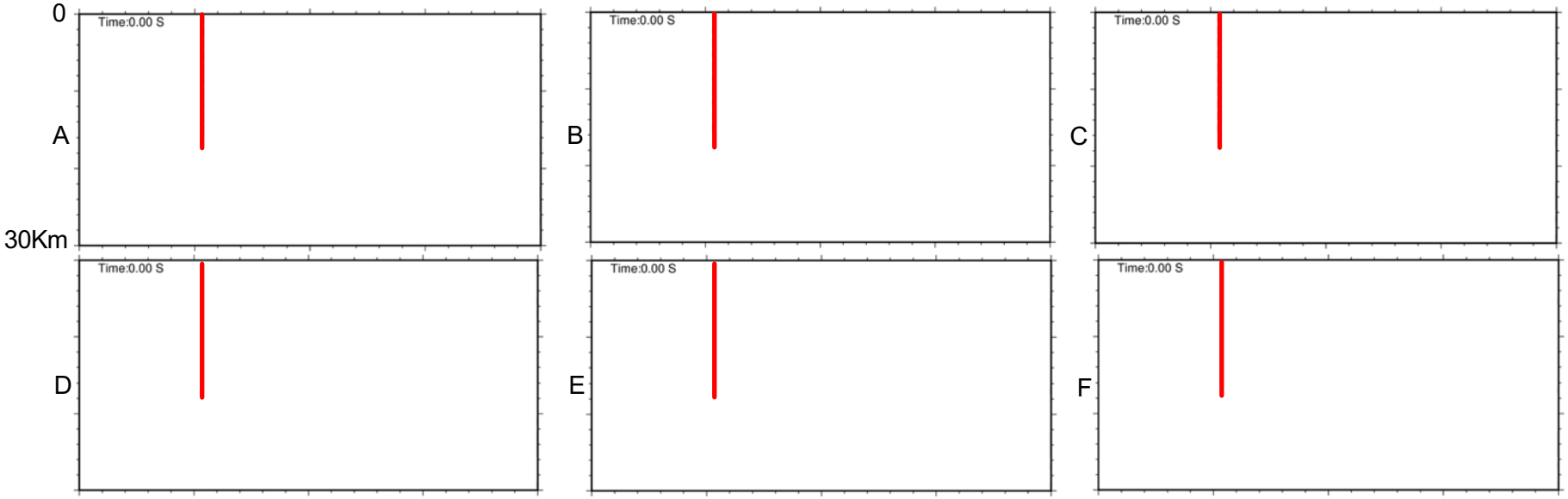


9 billion grid points
5 Hz resolution

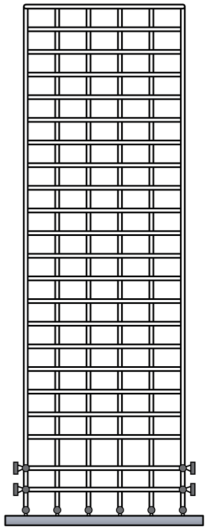


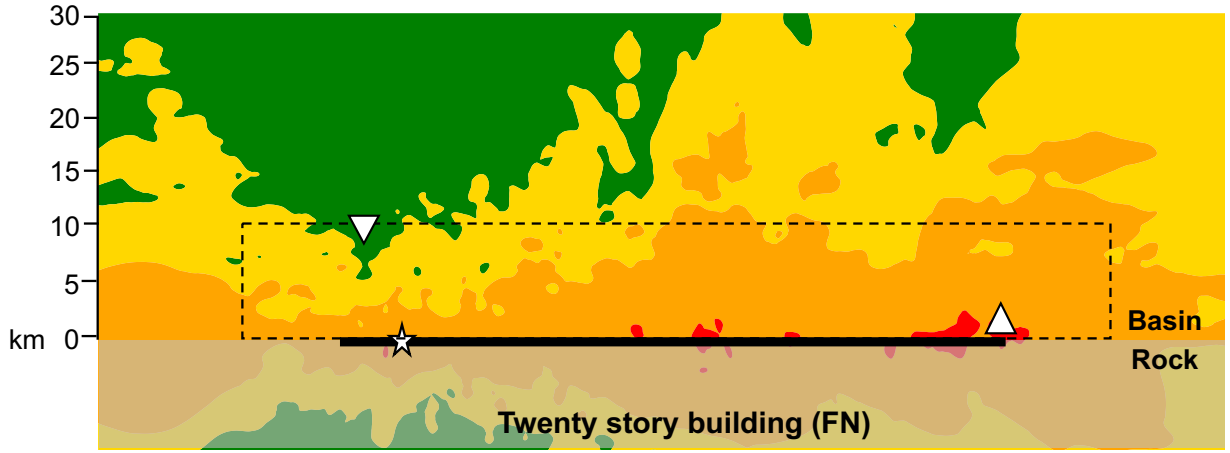
Map view
M=7 strike slip event

Elevation x-sections view
M=7 strike slip event



Simulations can provide new insight into building response in the near-field domain



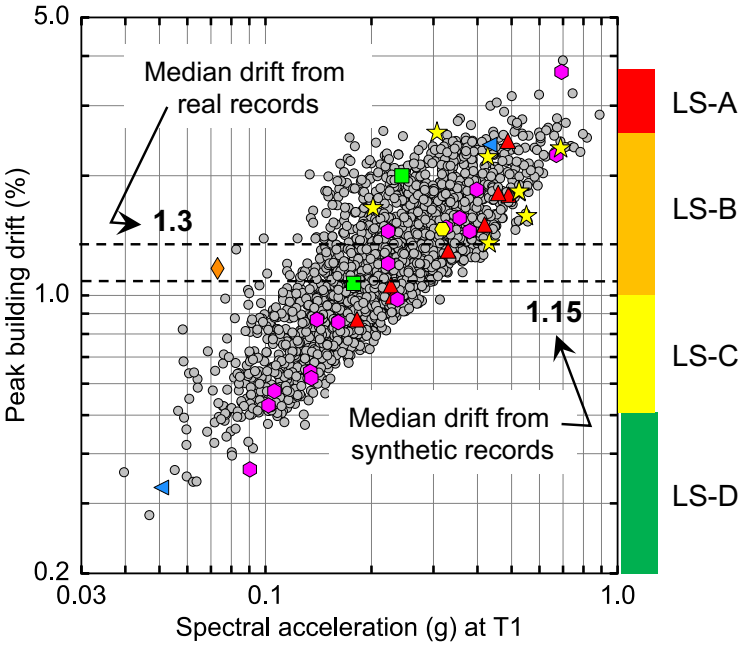


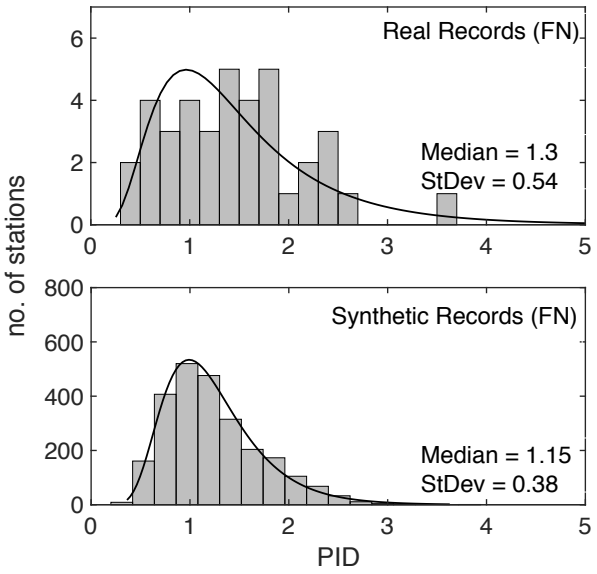
Min/Max PID

▽ 0.28%

△ 3.20%

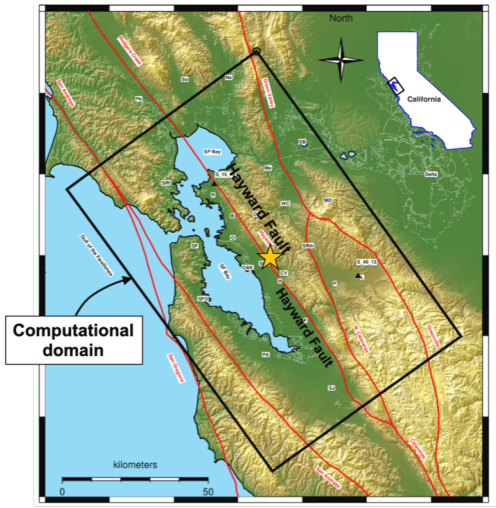
3.2 / 0.28 = 11.0 !!



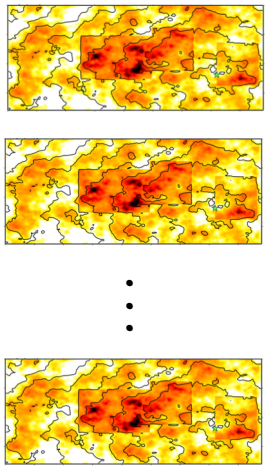


Our end-game – making regional scale fault-to-structure simulations "non-heroic"

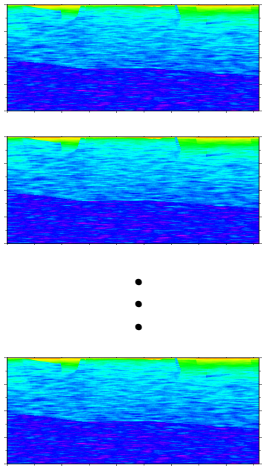
Earthquake rupture scenario
e.g. M=7 Hayward Fault



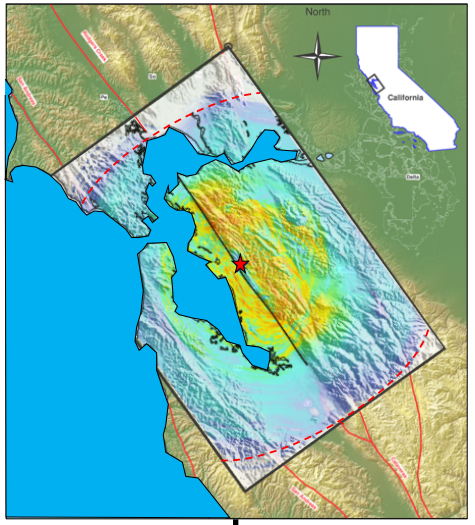
Multiple fault rupture realizations



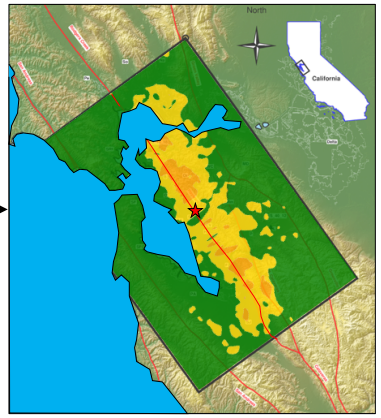
Multiple geologic characterizations



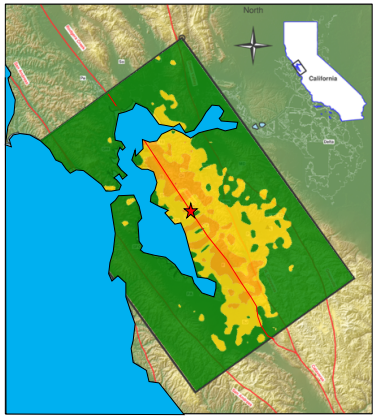
"N" fast, high frequency simulations



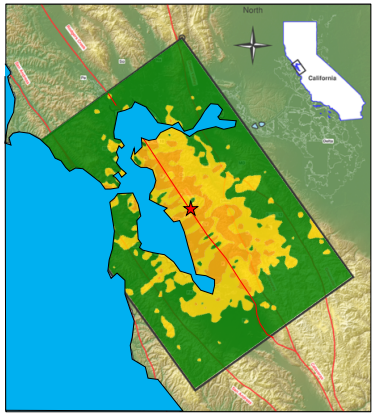
Realization 1



Realization 2

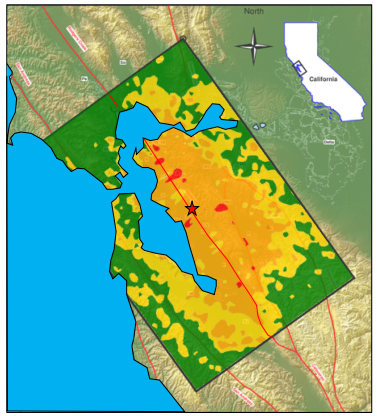


Realization 3



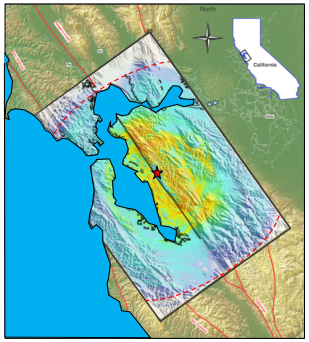
. . .

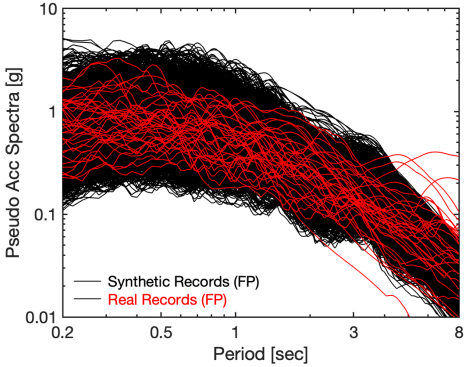
Realization N



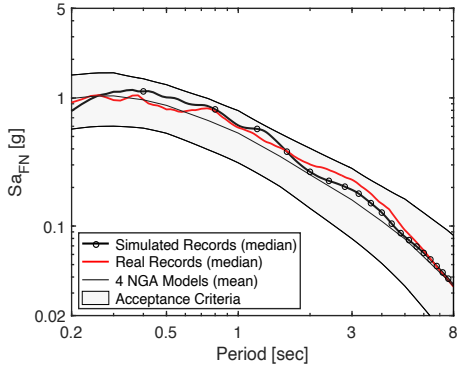
The EQSIM project is collaborating with PEER to frame an operational environment for use

1) Synthetic records from simulations, thousands of response histories (EQSIM)





2) Four part "acceptance" criteria under development (PEER)



Petrone

PEER

Abrahamson

3) Archive a compressed set of response histories for a near-surface 3D volume (PEER)

Community access

4) Fetch surface motions or 3D motions and utilize coupling code (EQSIM)