High Frequency Fault-to-Structure Simulations in the San Francisco Bay Area with the EQSIM Framework

A U.S. DOE Exascale Computing Application Development

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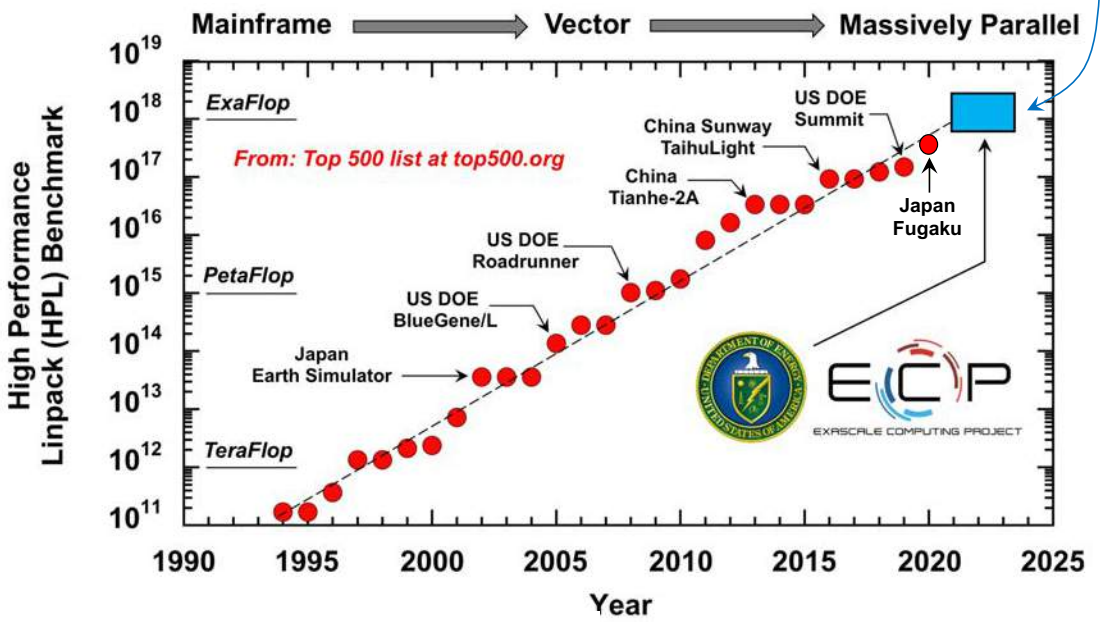
BERKELEY LAB

EXASCALE COMPUTING PROJECT

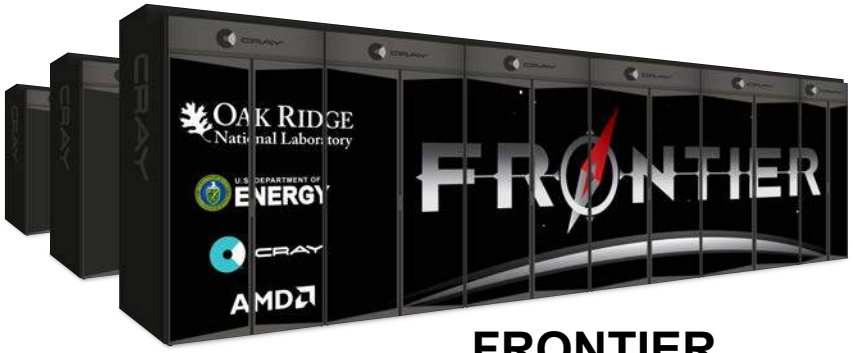
DOE's Exaflop computers are on the way

Source: Top500.org

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



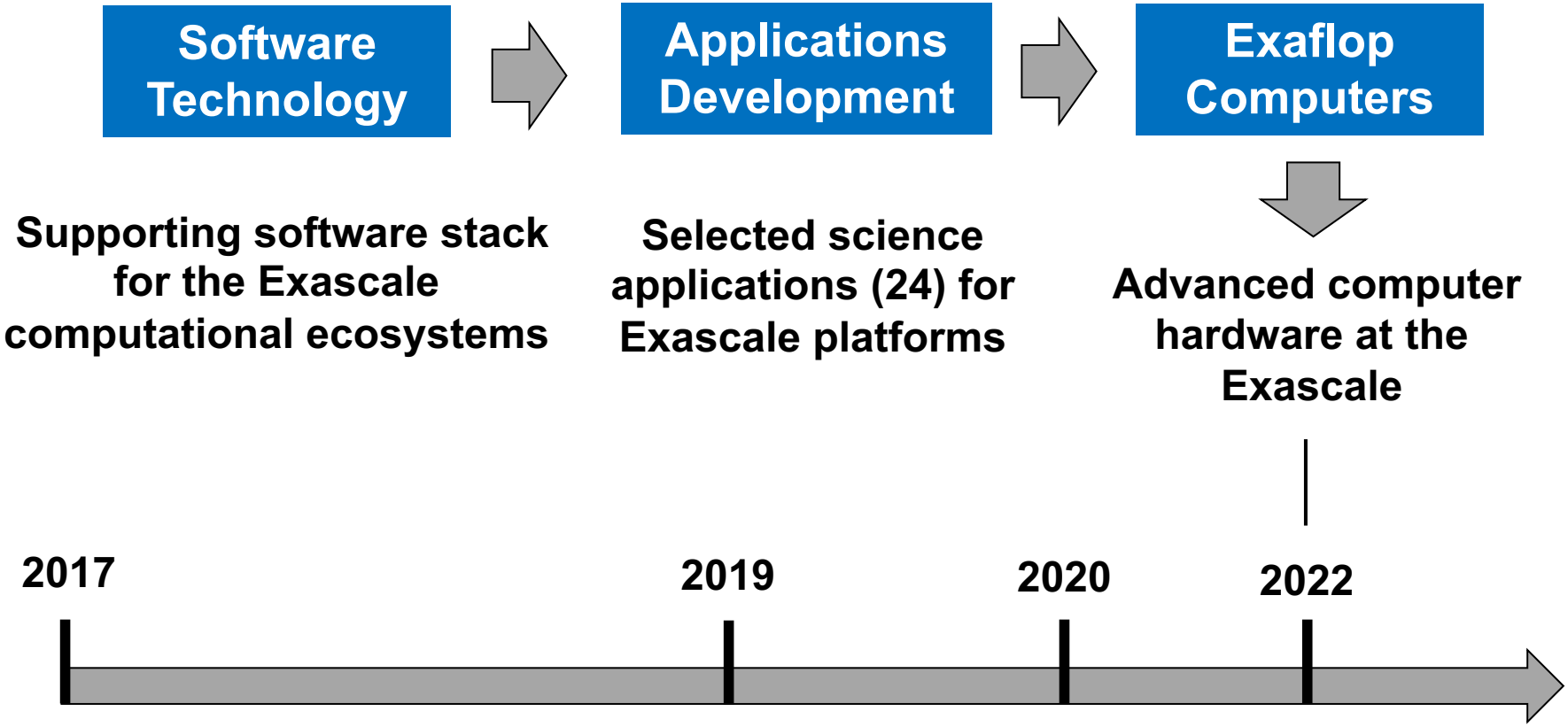
AURORA
Argonne National Lab



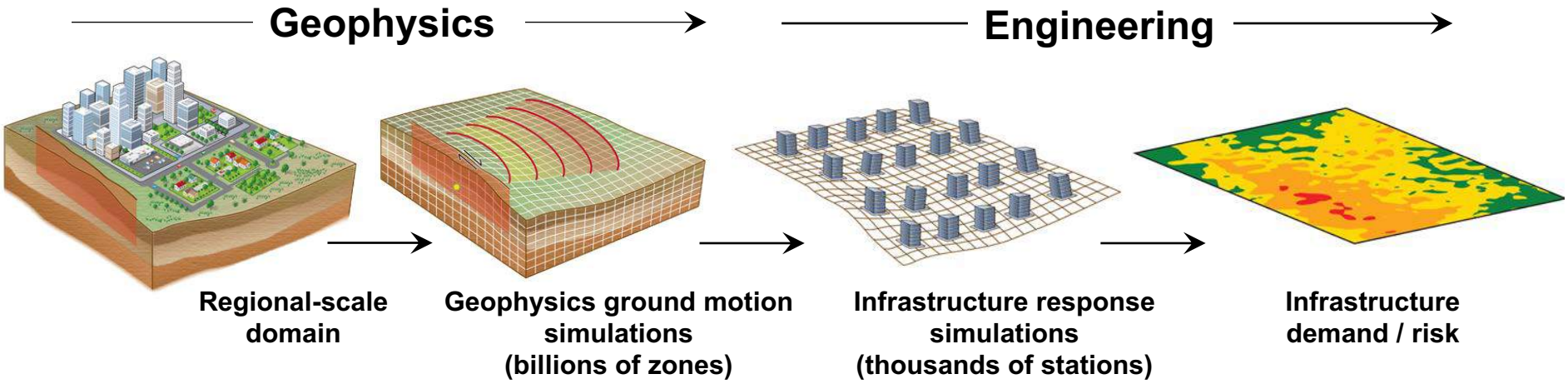
FRONTIER
Oak Ridge National Lab

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

Three components…



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

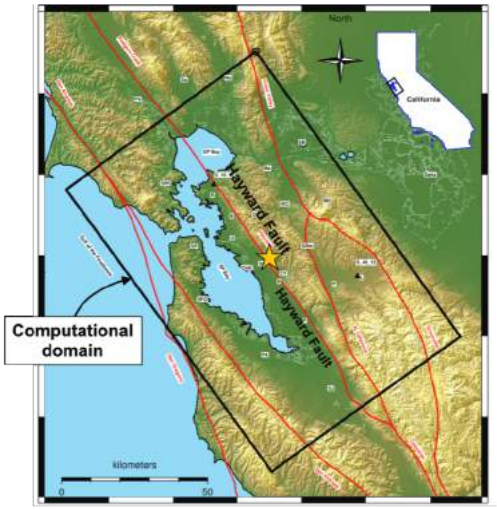


Key issues that will be explored through simulations…

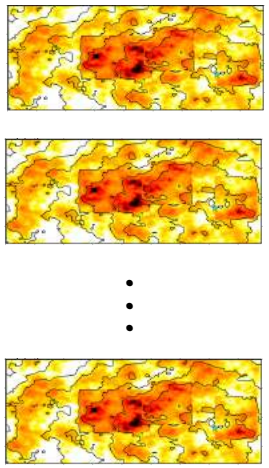
- **How do earthquake ground motions actually vary across a region and how does this impact risk to infrastructure?**
- **How do complex (realistic) incident ground motion waveforms actually interact with a particular facility?**

EQSIM - a compute engine for ground motion and structural response simulations

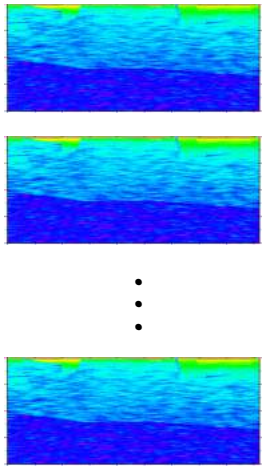
Earthquake rupture scenario e.g. M=7 Hayward Fault



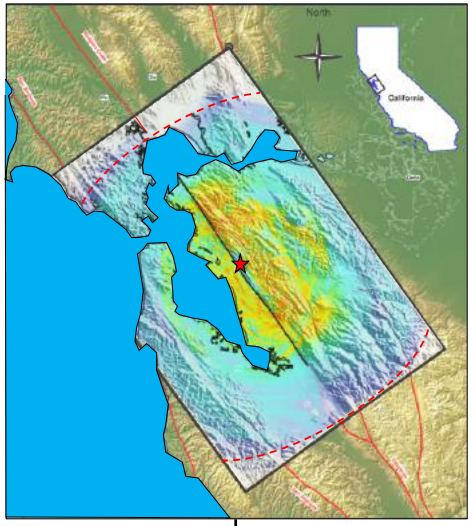
Multiple fault rupture realizations



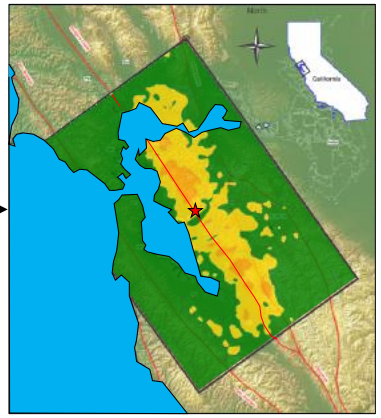
Multiple geologic characterizations



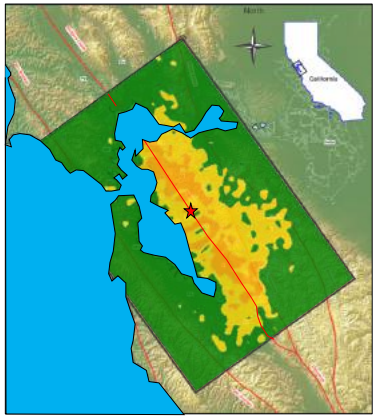
"N" fast, high frequency simulations



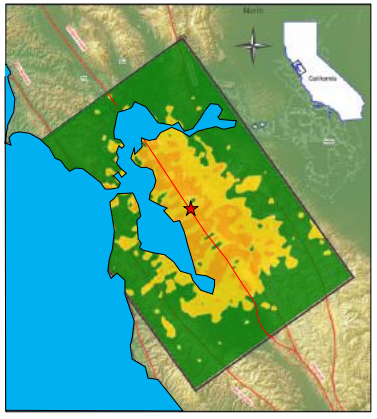
Realization 1



Realization 2

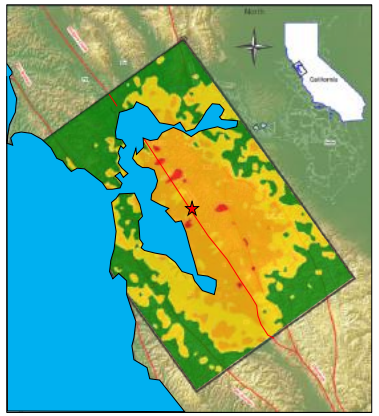


Realization 3



. . .

Realization N



Our project team spans engineering, seismology, math / computer science

Structural / Geotechnical Mechanics

David McCallen

Mamun Miah

Postdoc

Maryam Tabbakhha

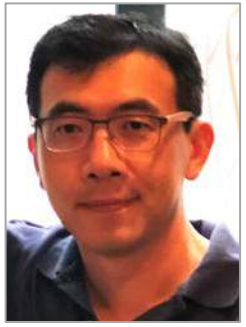
Postdoc

Applied Math / Numerical Methods

Anders Petersson

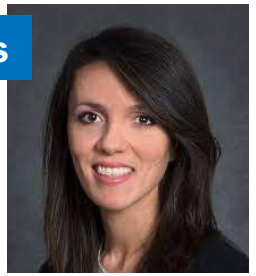
Bjorn Sjogreen

Wei Liu



Collaborators

Floriana Petrone



Norm Abrahamson

Computer Science

Houjun Tang

Ramesh Pankajakshan

Seismology / Geophysics

Arben Pitarka

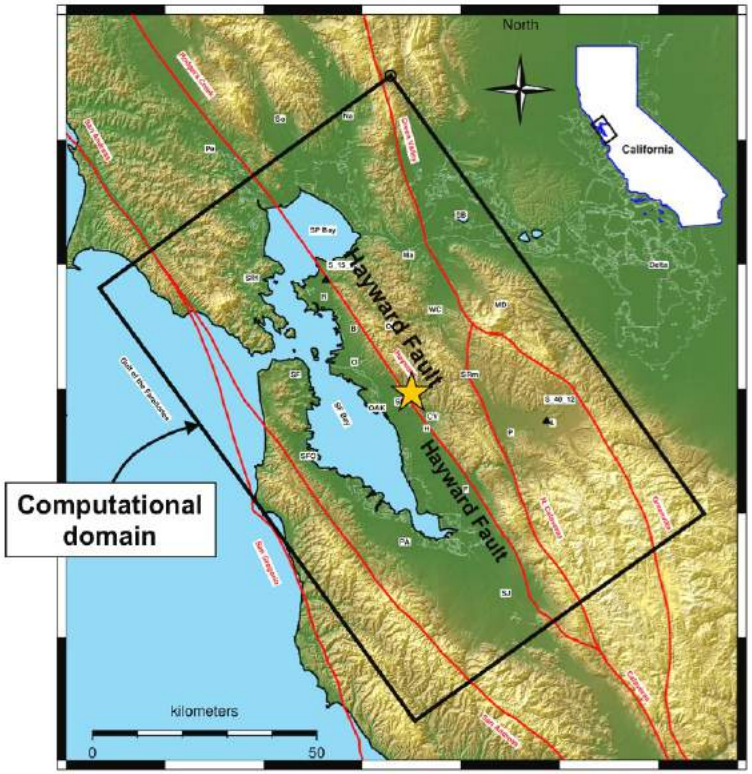
Arthur Rodgers

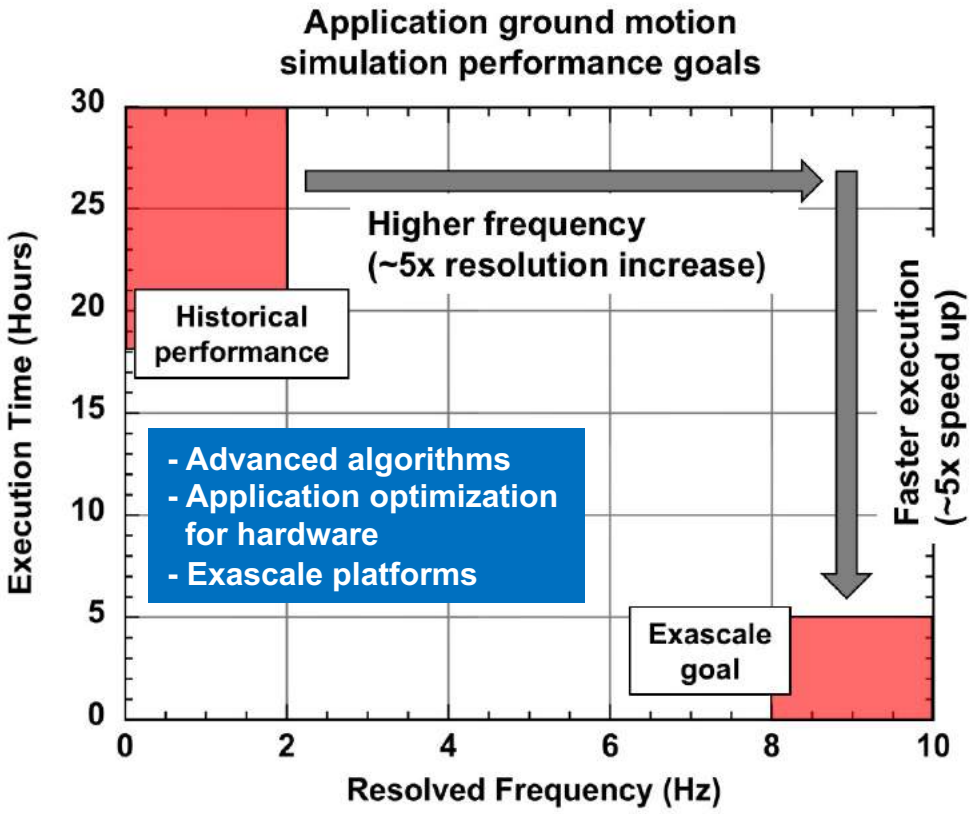
Rie Nakata

Our statement of the exascale goal with the SFBA "numerical laboratory"

Fast, high-resolution forward ground motion simulations are at the core of our developments

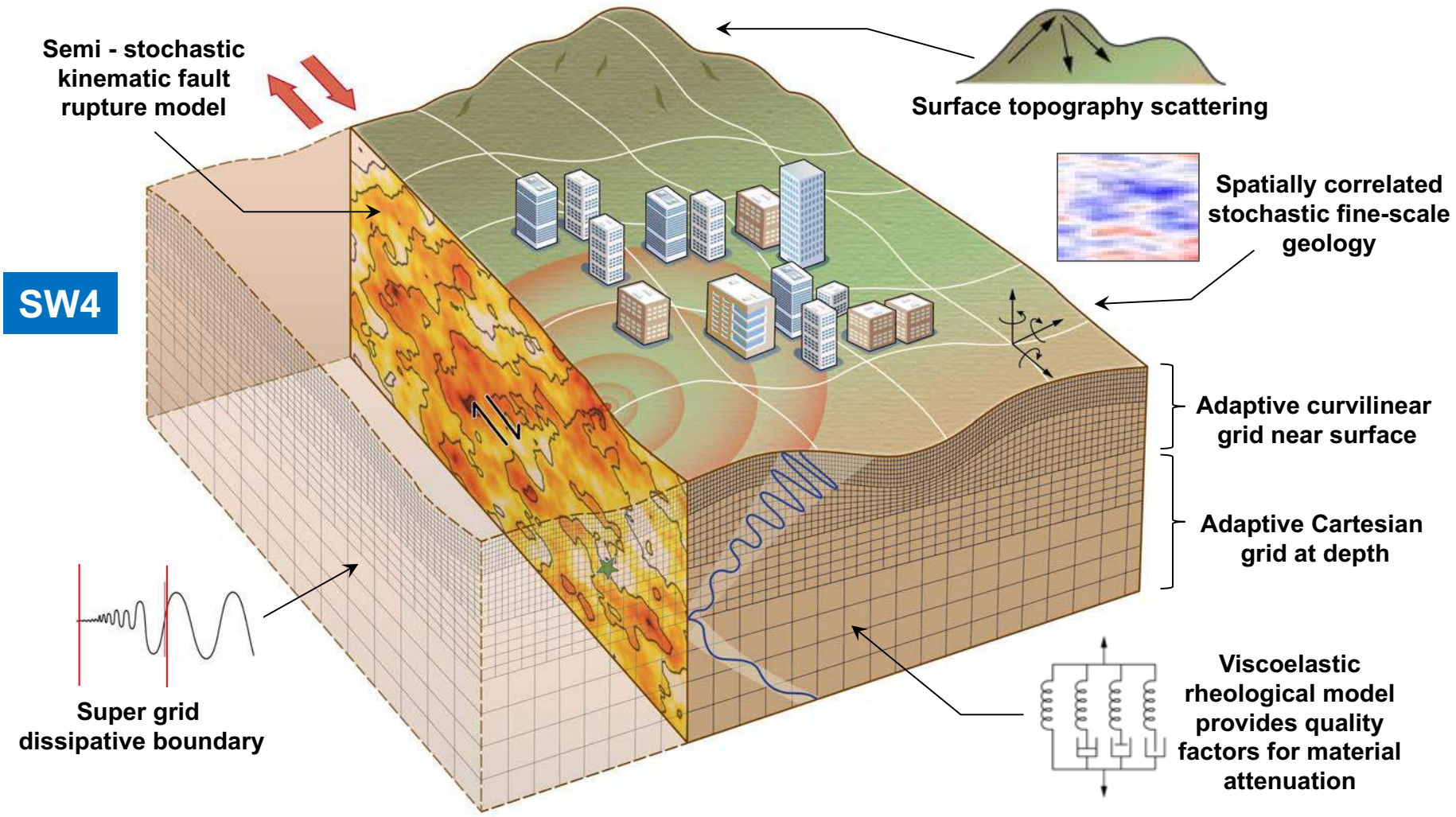
Regional-scale model (SFBA)





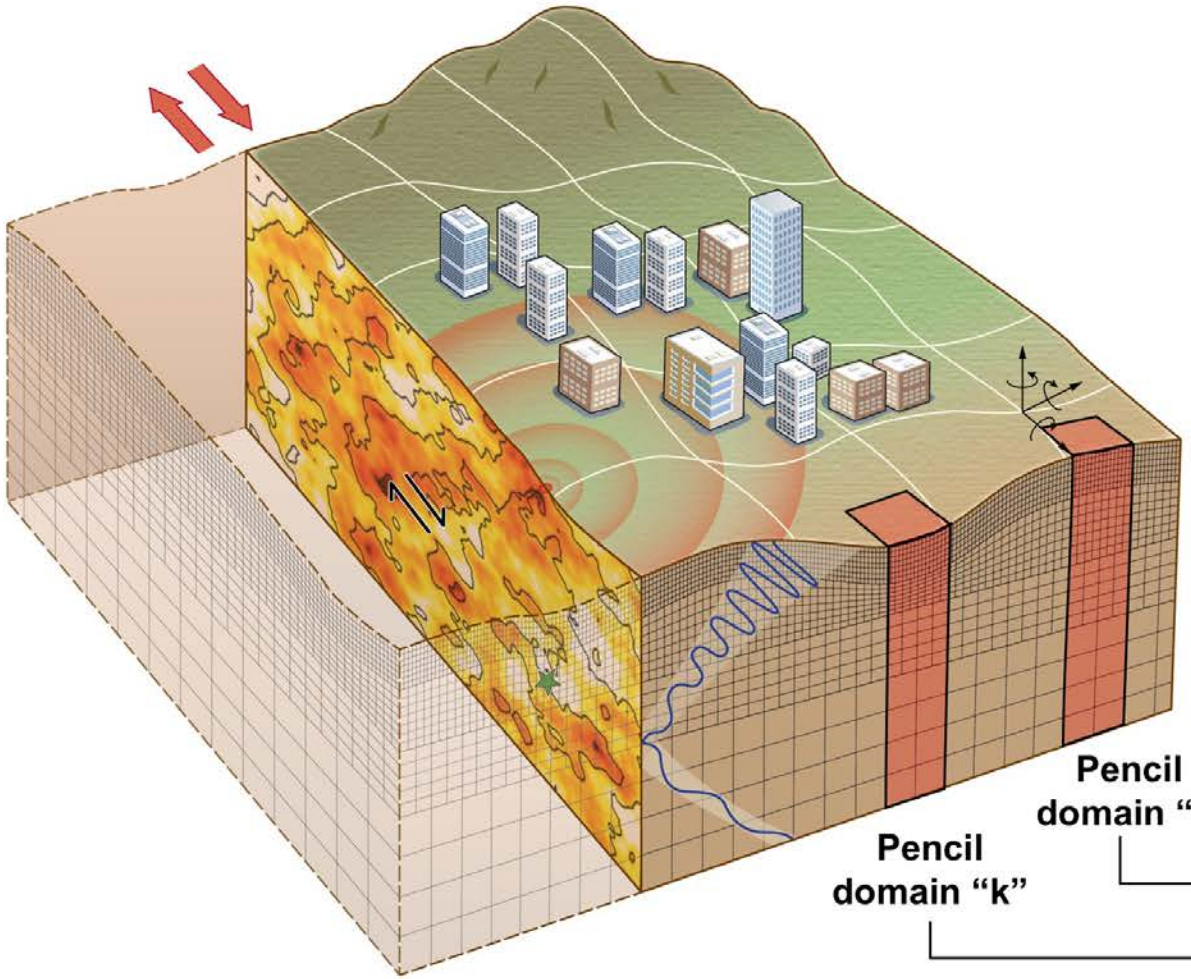
Advancing the SW4 geophysics code for simulating earthquake ground motions

Improved physics, computational efficiency at 300 billion grid points



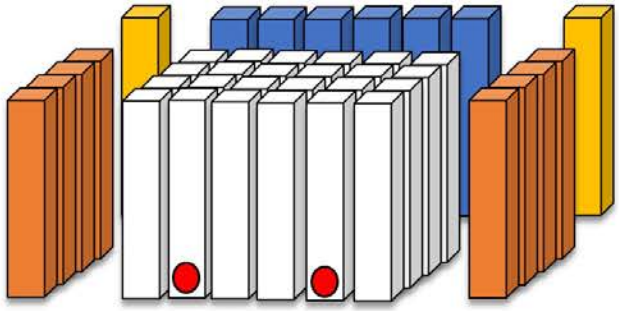
Optimizing for execution on massively parallel GPU-based computers

Getting prepared to exploit the world's fastest scientific platforms



OAK RIDGE National Laboratory

4,608 nodes, 27,648 NVIDIA GPUs

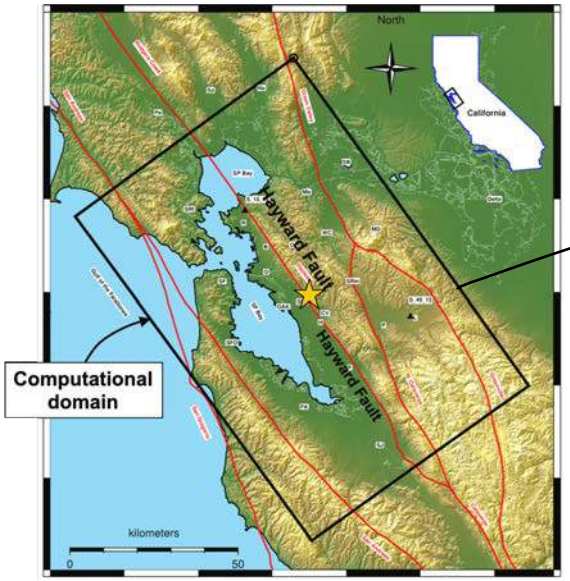


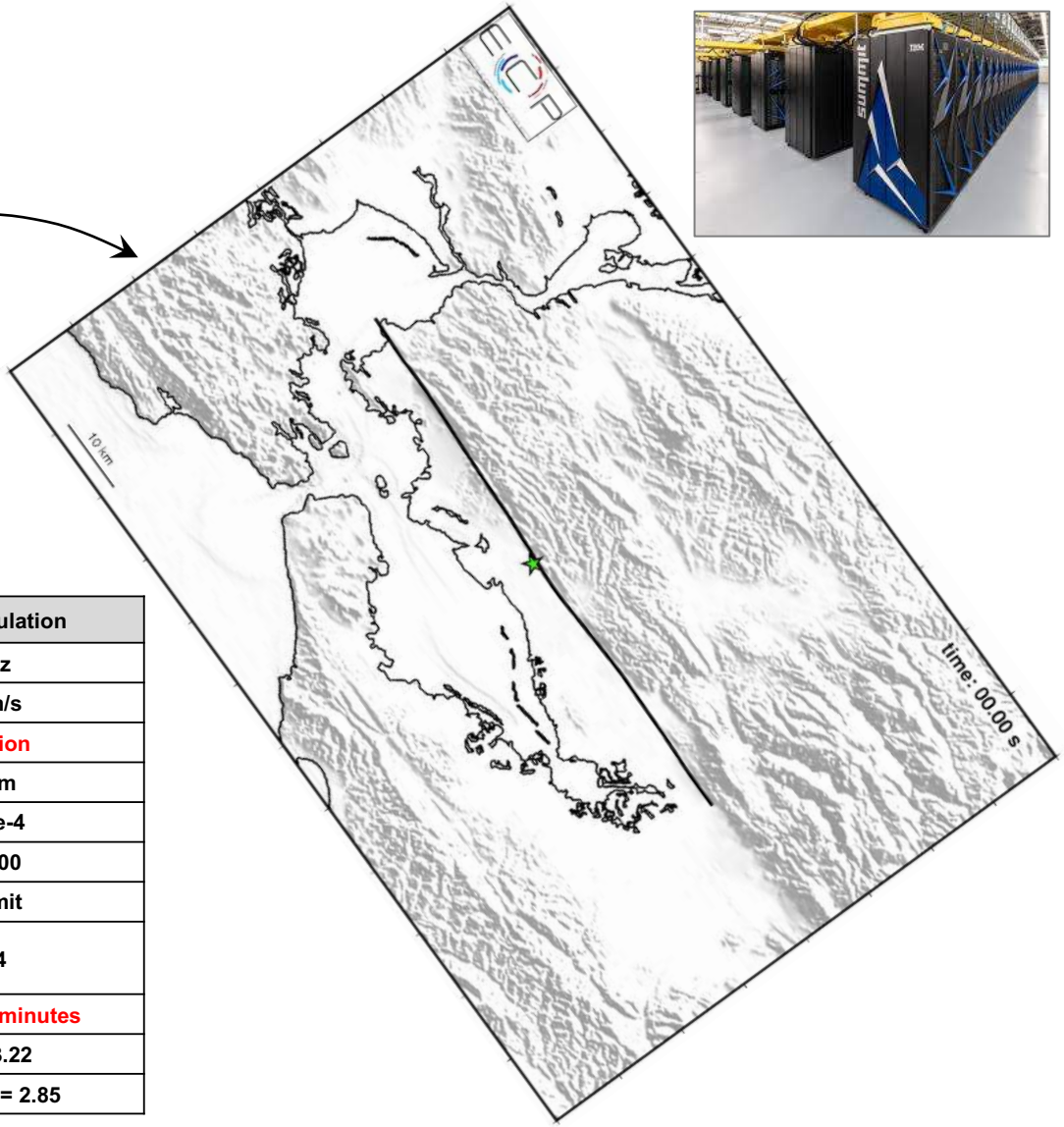
Pencil domain "i"

Pencil domain "k"

Node "i" Node "k"

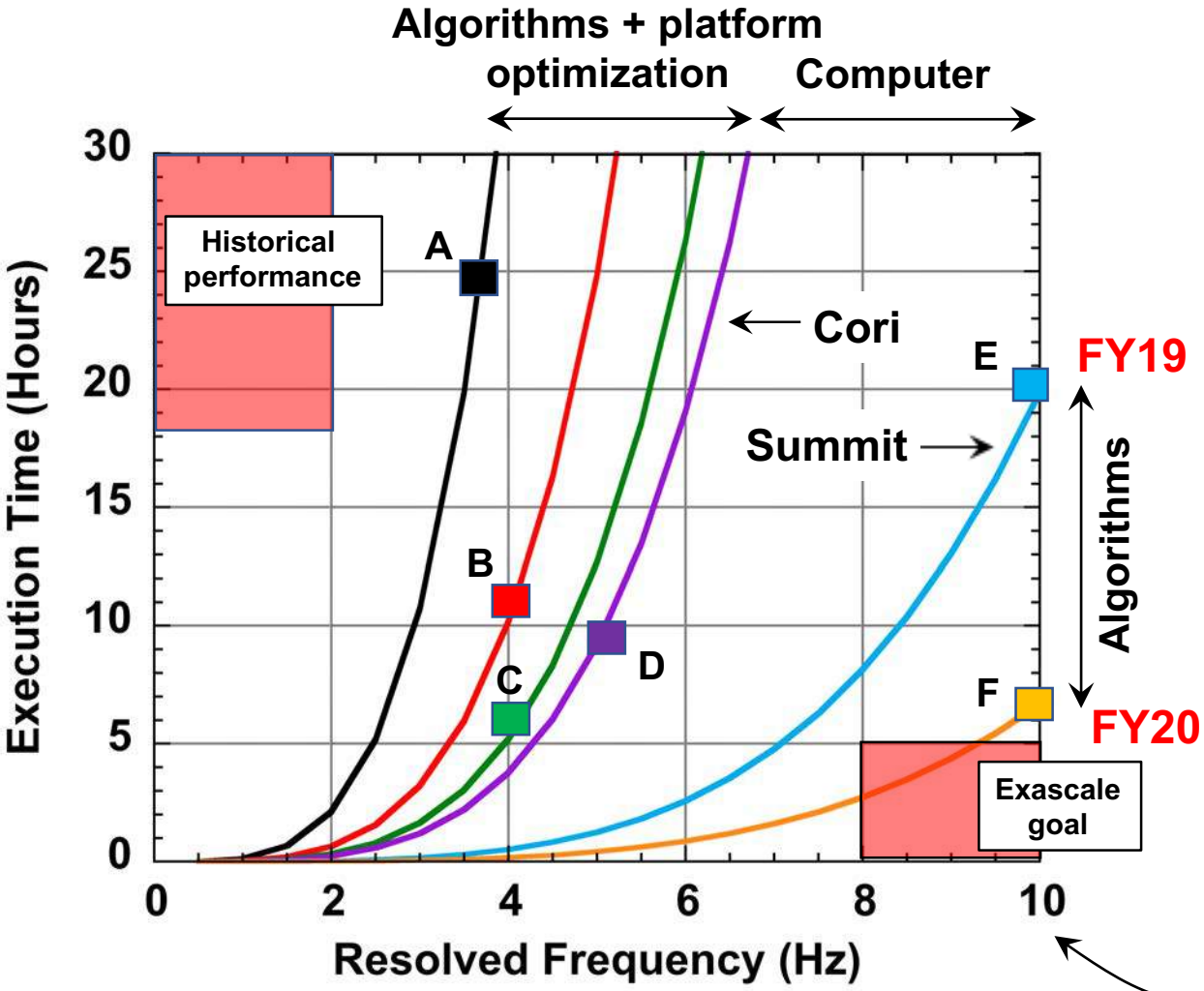
San Francisco Bay Area simulations to 10Hz on Summit





	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	

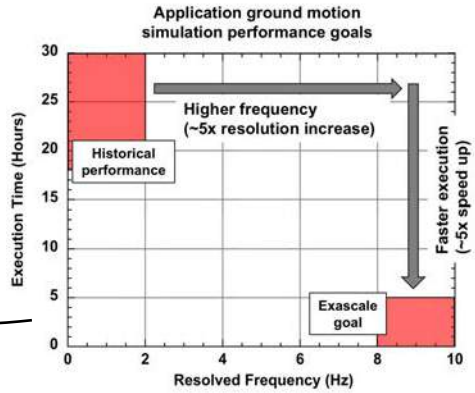
FY20 EQSIM performance evaluation for a M7 Hayward fault 10 Hz SFBA simulation



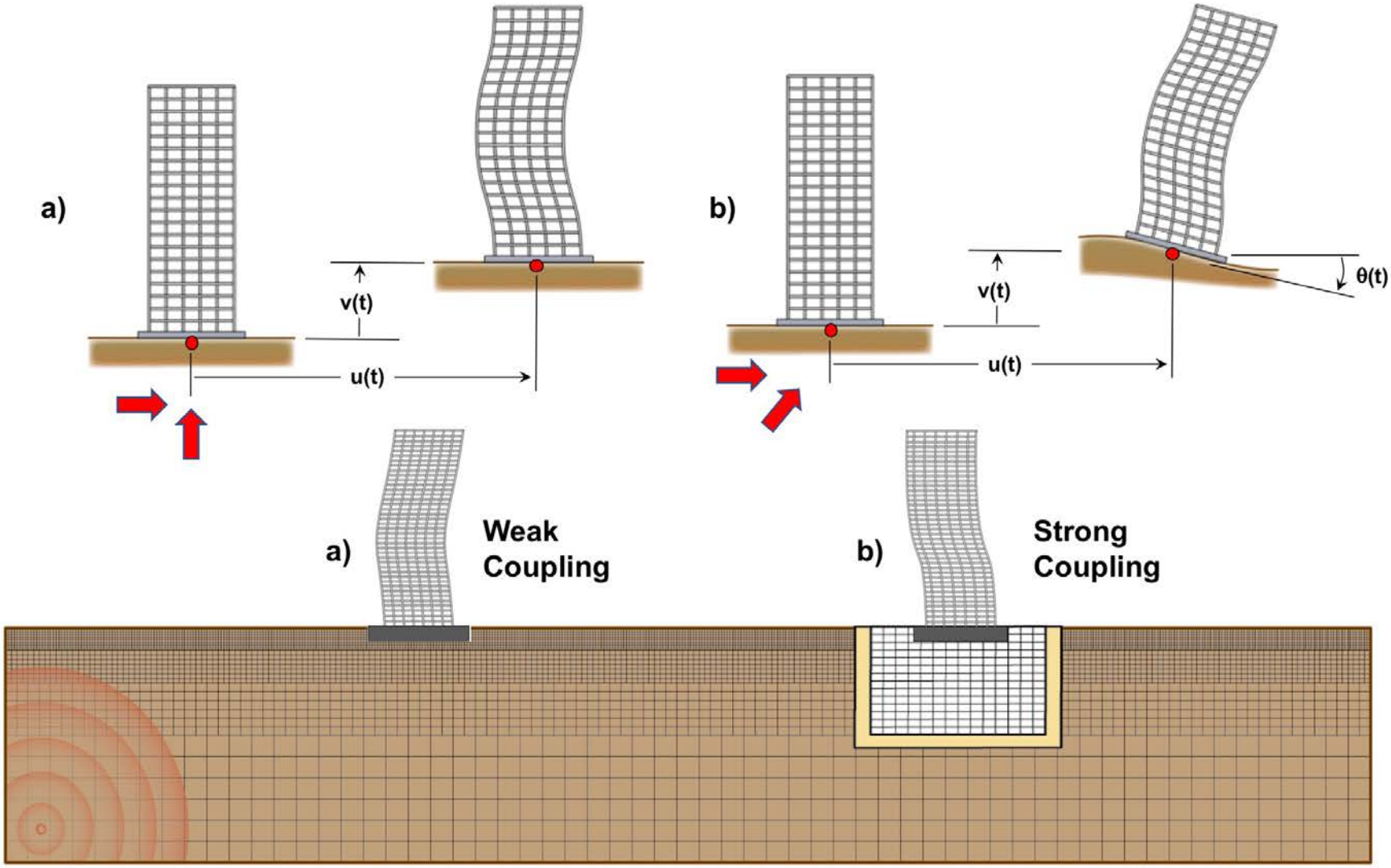
Vsmin = 500 m/s

Cori ~30 PF

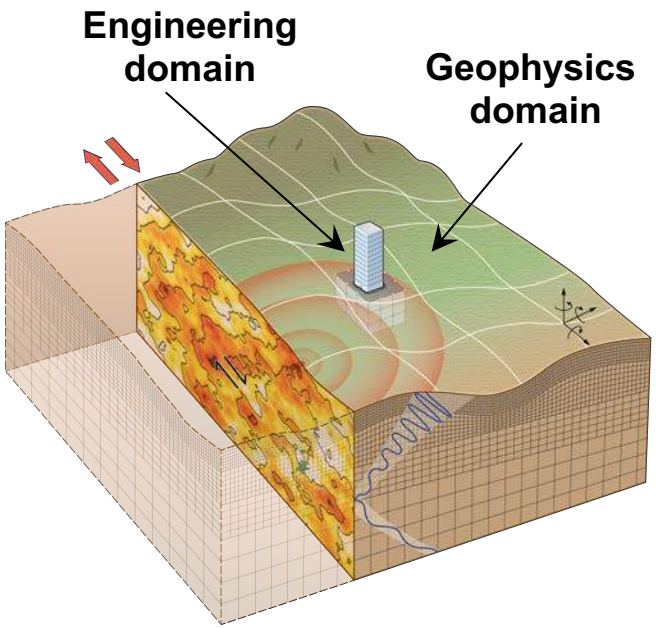
Summit ~150 PF

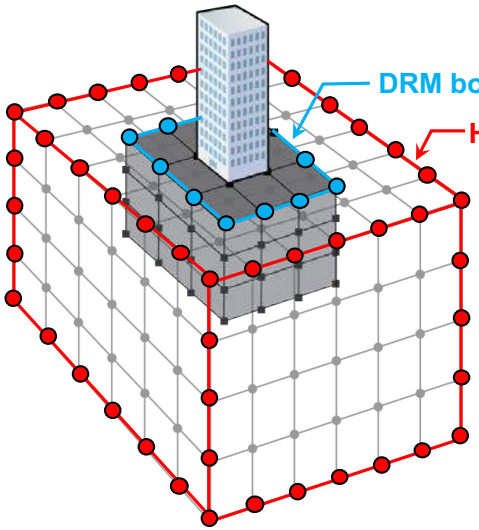


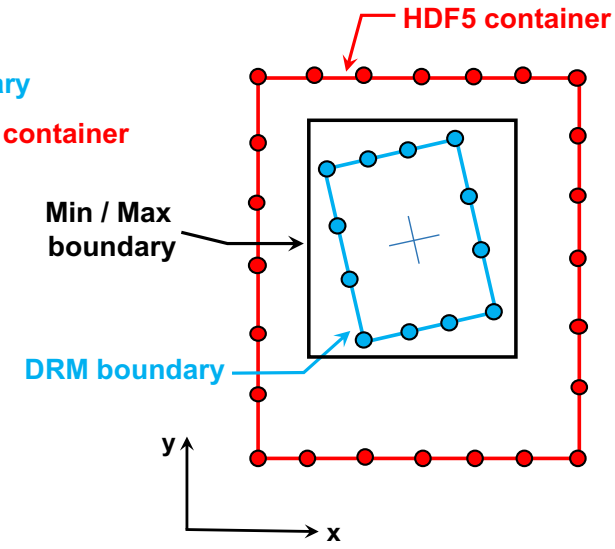
Advancing the coupling of geophysics and engineering models

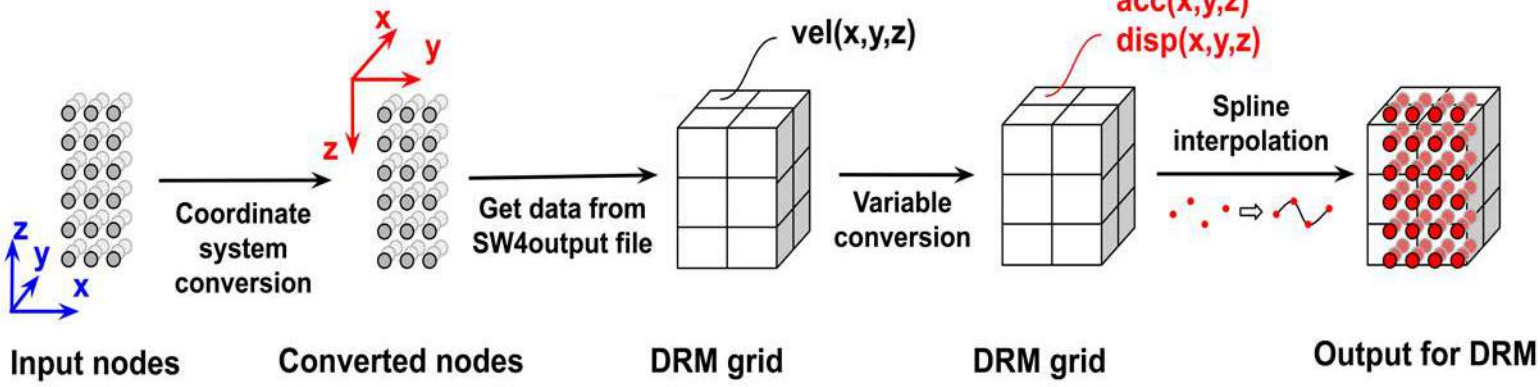


Strong coupling workflow

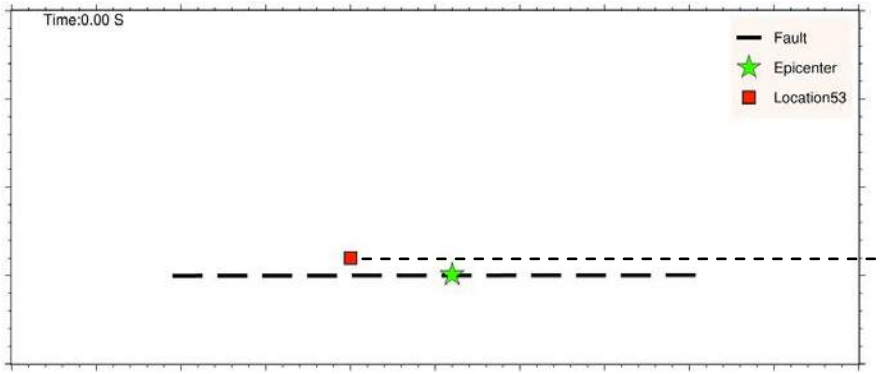






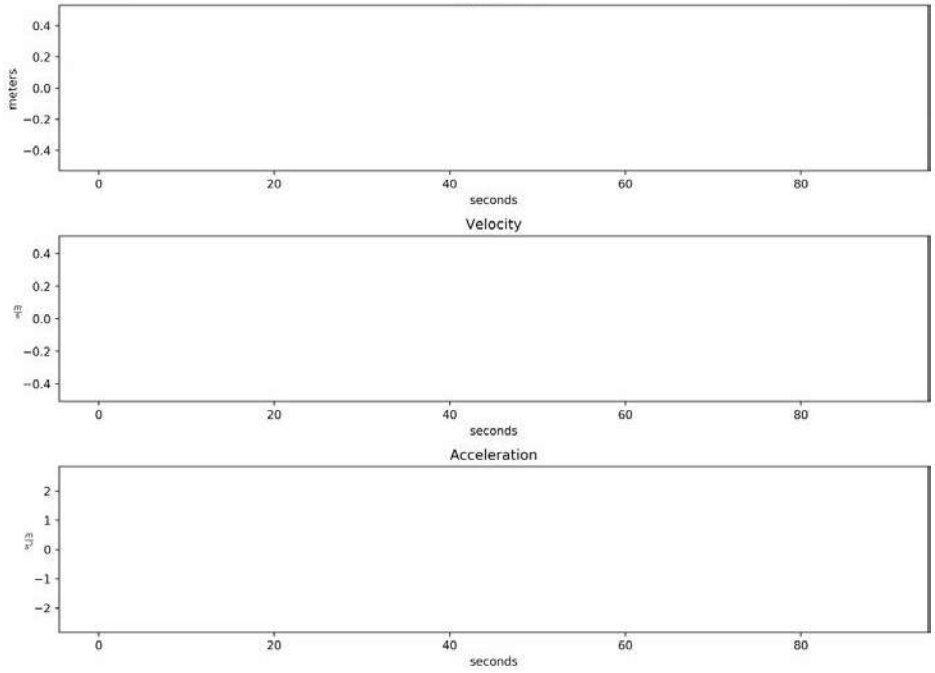


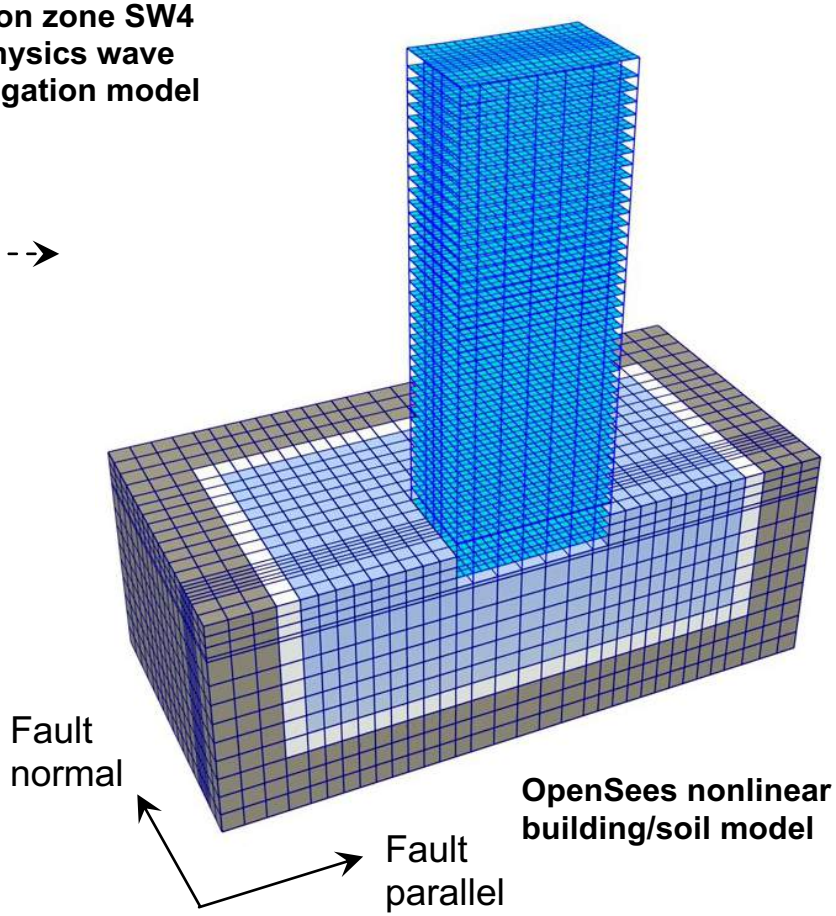
40 story building response at location 53 (2km off the fault)



9 billion zone SW4 geophysics wave propagation model

Fault parallel displacement, velocity and acceleration

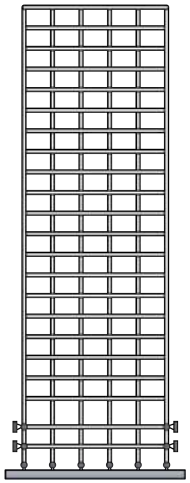


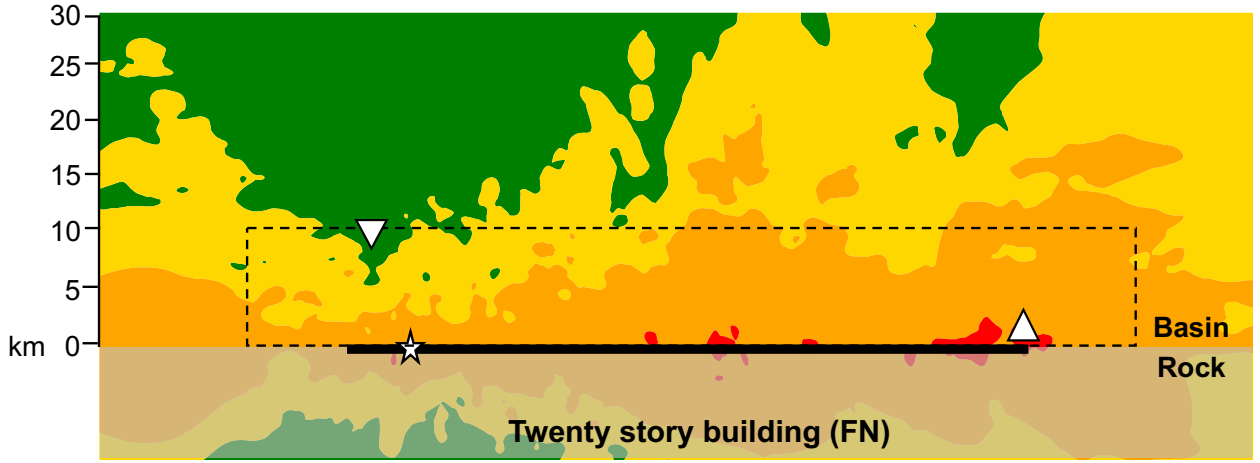


OpenSees nonlinear building/soil model

Building simulation
CEE PhD student Junfei Huang
Ground motion simulation
Geophysics MS student Eric Eckert

Simulations can provide new insight into near-fault building response



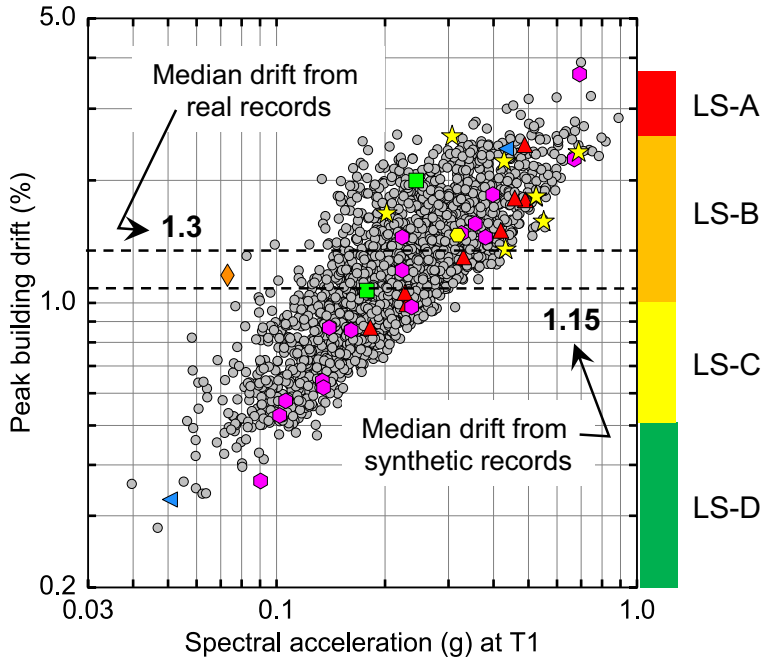


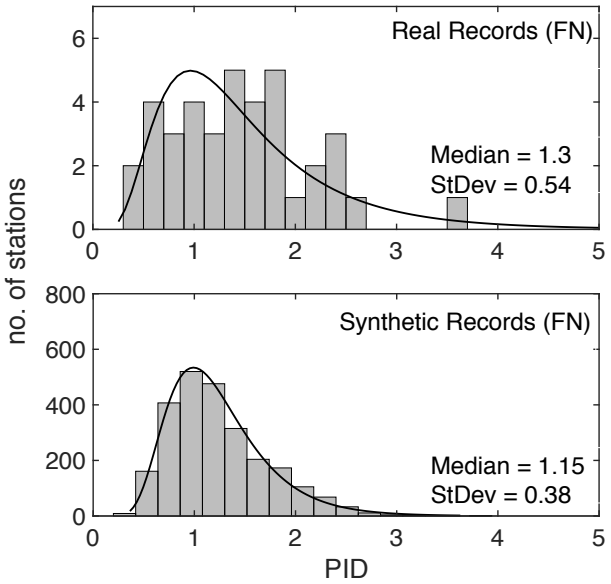
Min/Max PID

▽ 0.28%

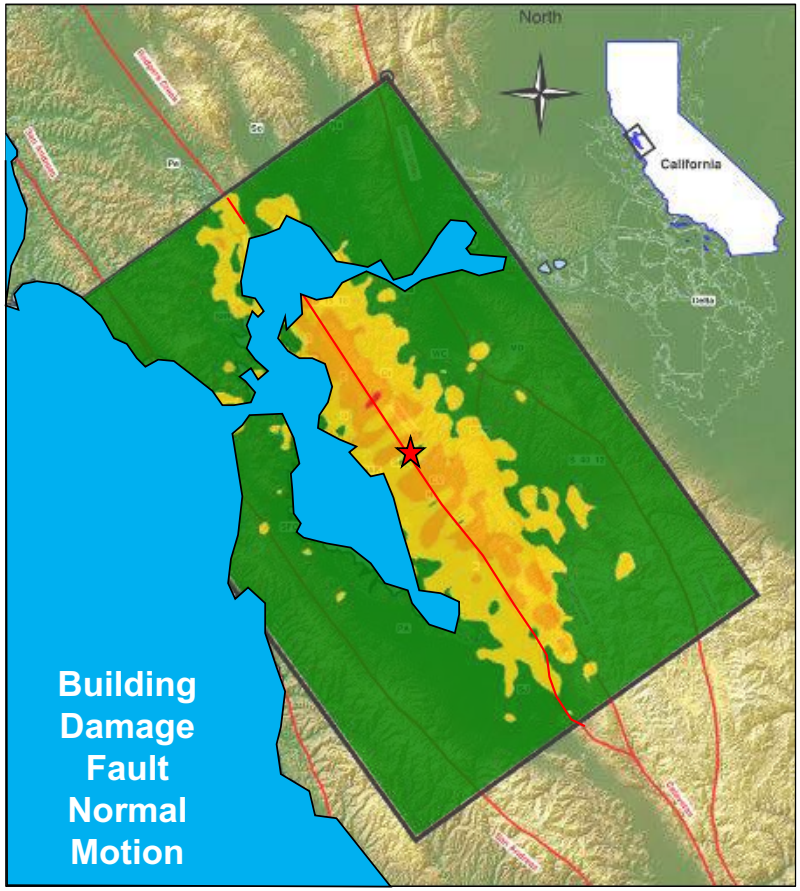
△ 3.20%

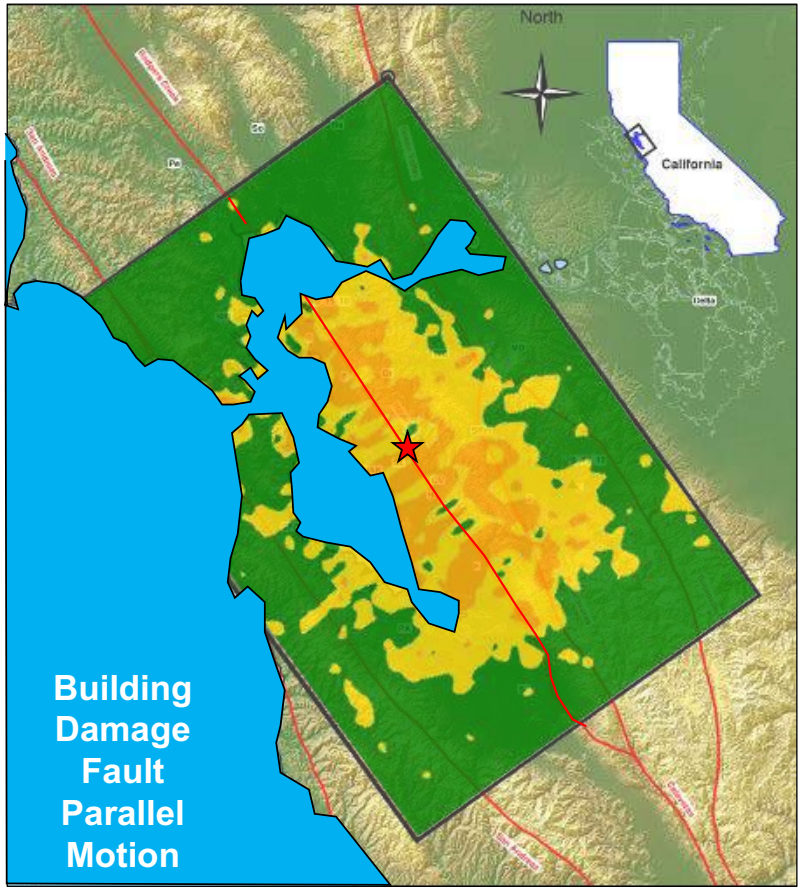
3.2 / 0.28 = 11.0 !!



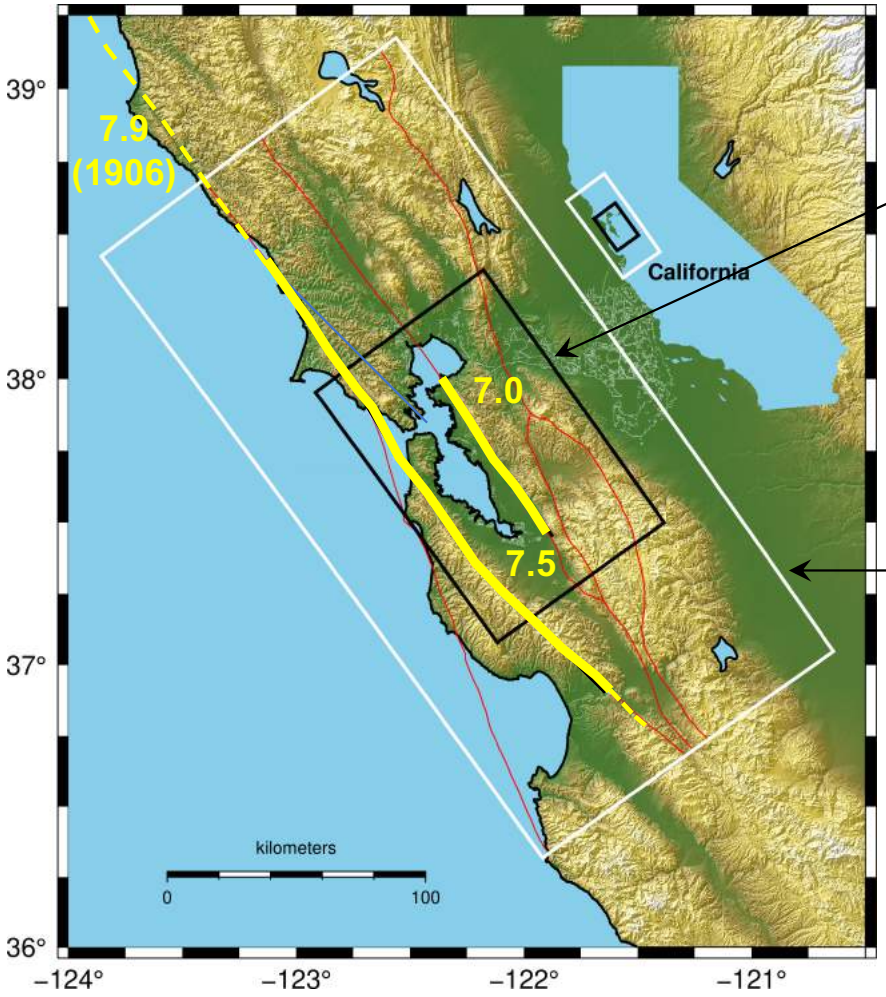


We are currently evaluating representative SFBA building response to 10Hz motions





The promise of exascale platforms is clear, question is how far can we go?



M =7.0 Hayward Fault Event

F=10Hz, Vsmin=500m/s, Run time ~5 hrs

Essentially done

F=10Hz, Vsmin=250m/s, Run time ~5 hrs

Probable

M =7.5 San Andreas Fault Event

F=10Hz, Vsmin=500m/s, Run time ~5 hrs

Possible

F=10Hz, Vsmin=250m/s, Run time ~5 hrs

Very challenging

We need higher resolution geologic models!

A workflow for Full Waveform Inversion is under development