Earthquake simulation and building response evaluation using HPC platforms

Mamun Miah

Postdoctoral Fellow

Lawrence Berkeley National Laboratory

EXASCALE COMPUTING PROJECT

A multidisciplinary team is essential – a National Lab scale problem

CS/Algorithms/Applied Math

Anders Petersson

Hans Johansen

Structural Engineering

David McCallen

Mamun Miah

Seismology

Artie Rodgers

Geophysics/ Soil mechanics/ Ground motion expert

Boris Jeremic

Kurt Nihei

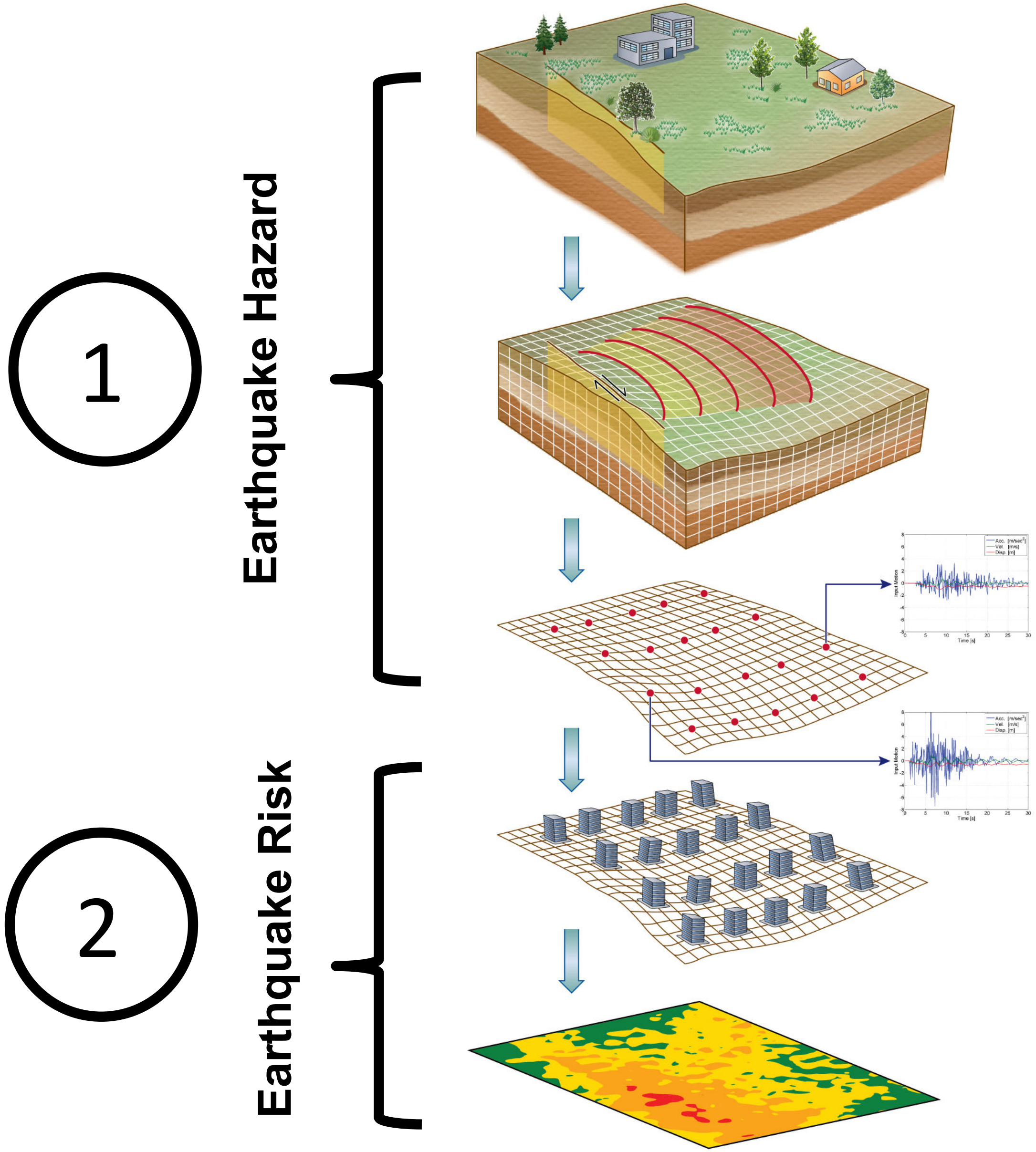
Norm Abrahamson

Computational framework

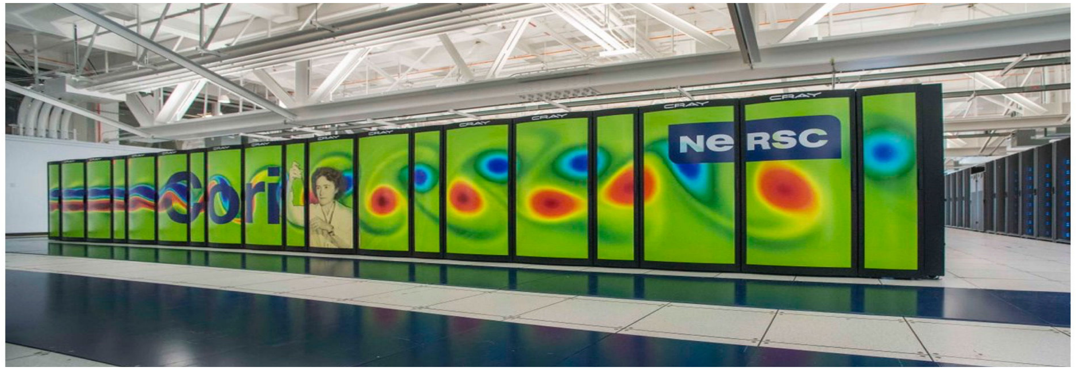
Two steps:

(1) Earthquake hazard simulation

(2) Building response simulation



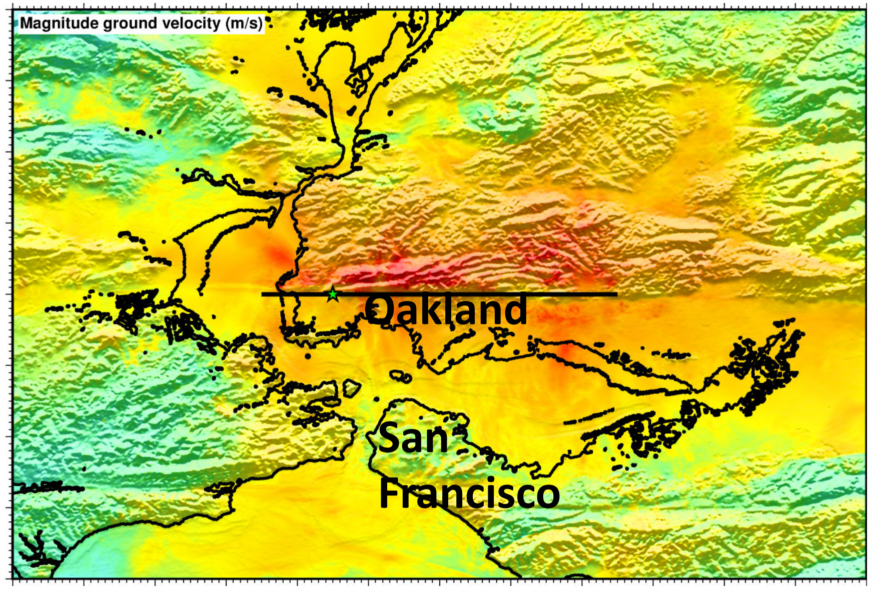
High-performance computing is essential



524,288 cores for hazard simulation (5 Hz)

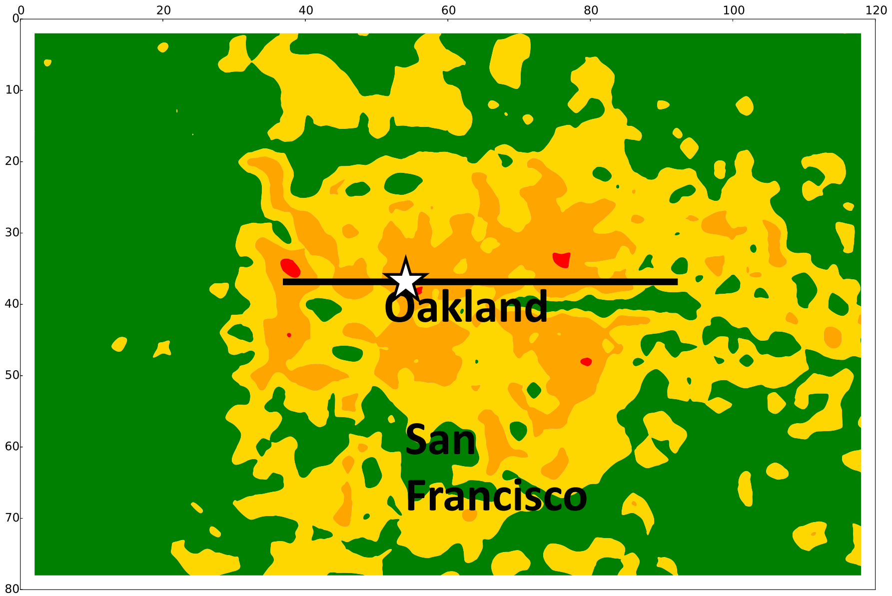
2,400 cores for structural response simulations

1

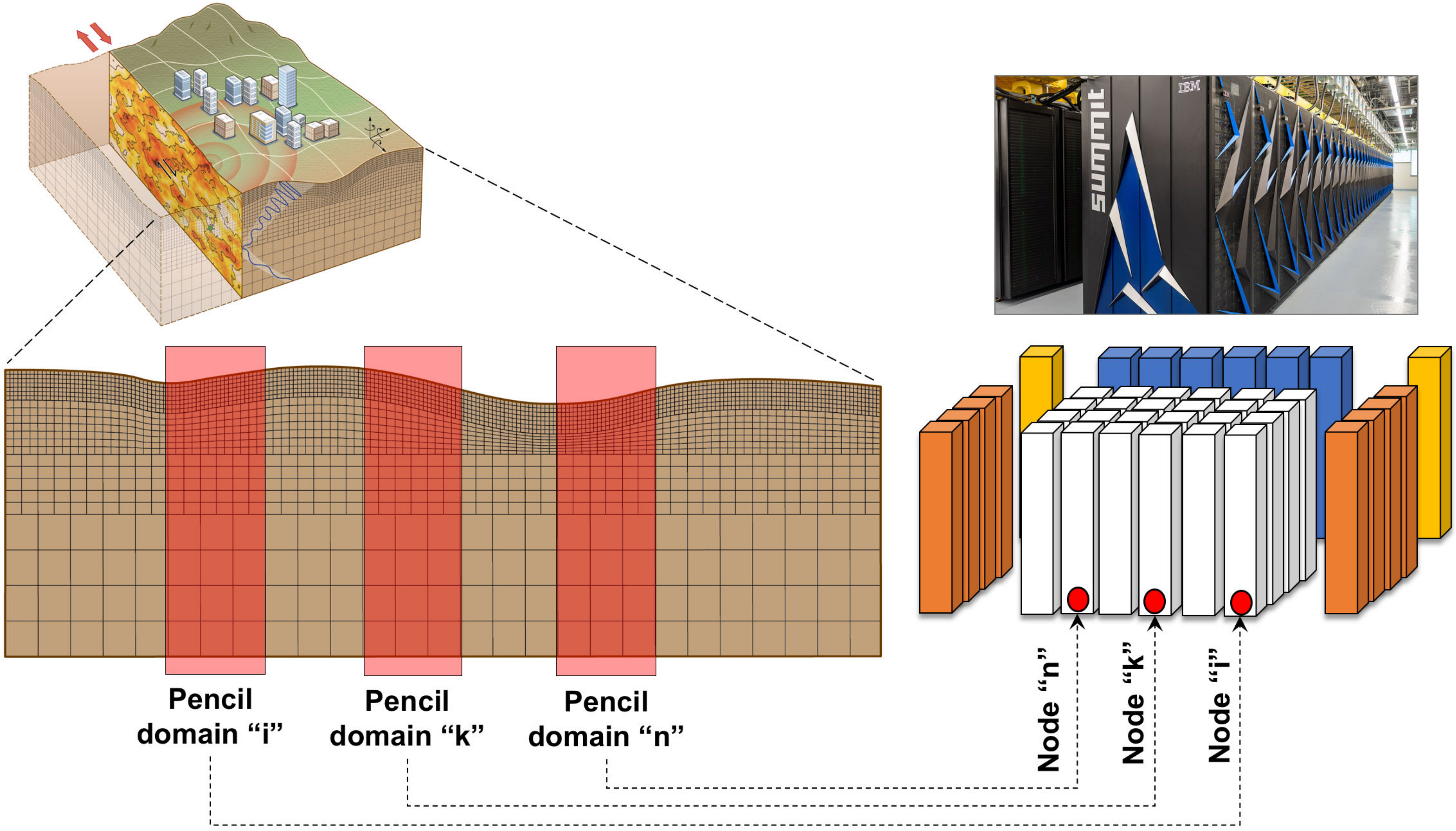


Hazard to Risk

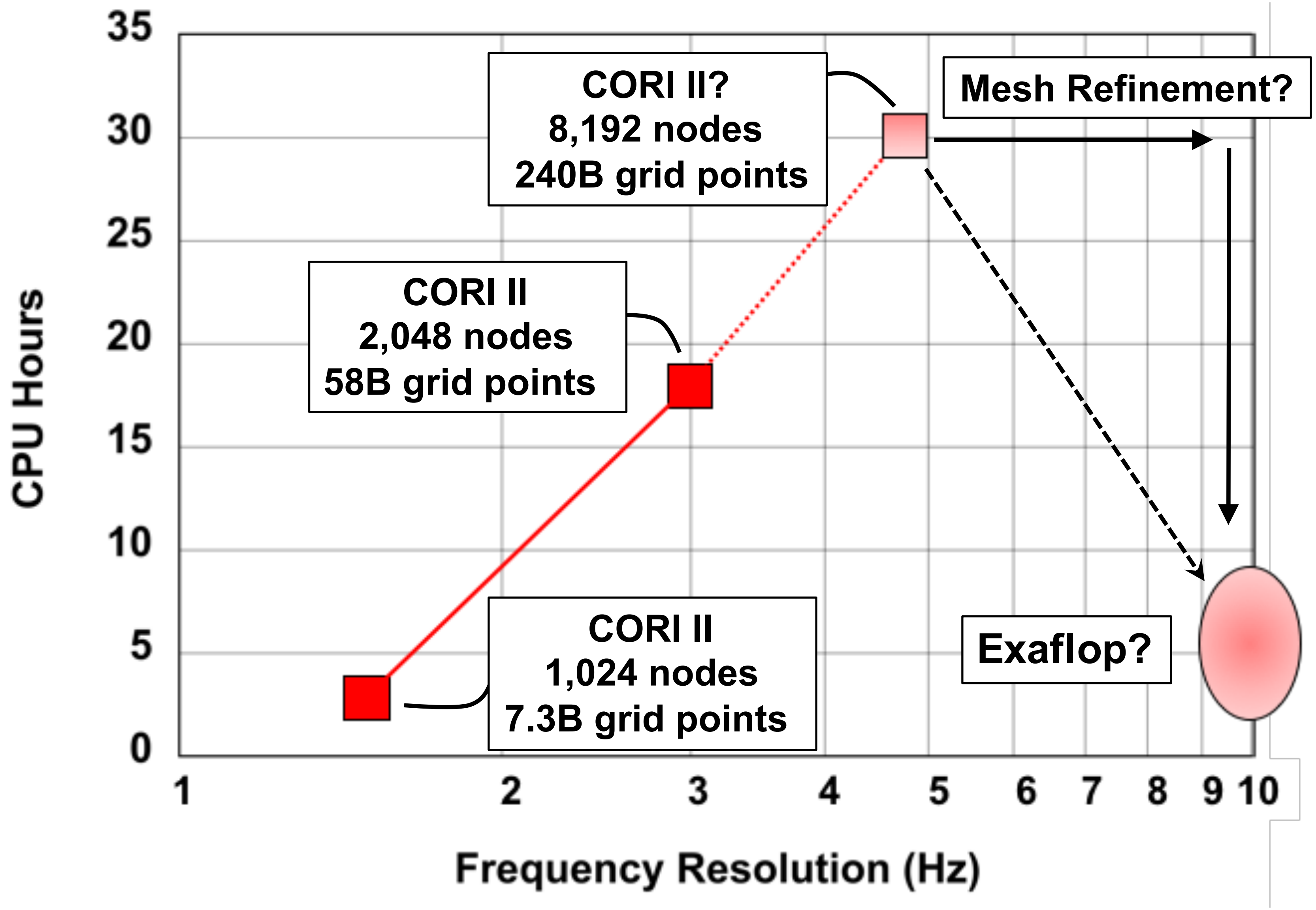
2



Distributing computations in different nodes using MPI framework

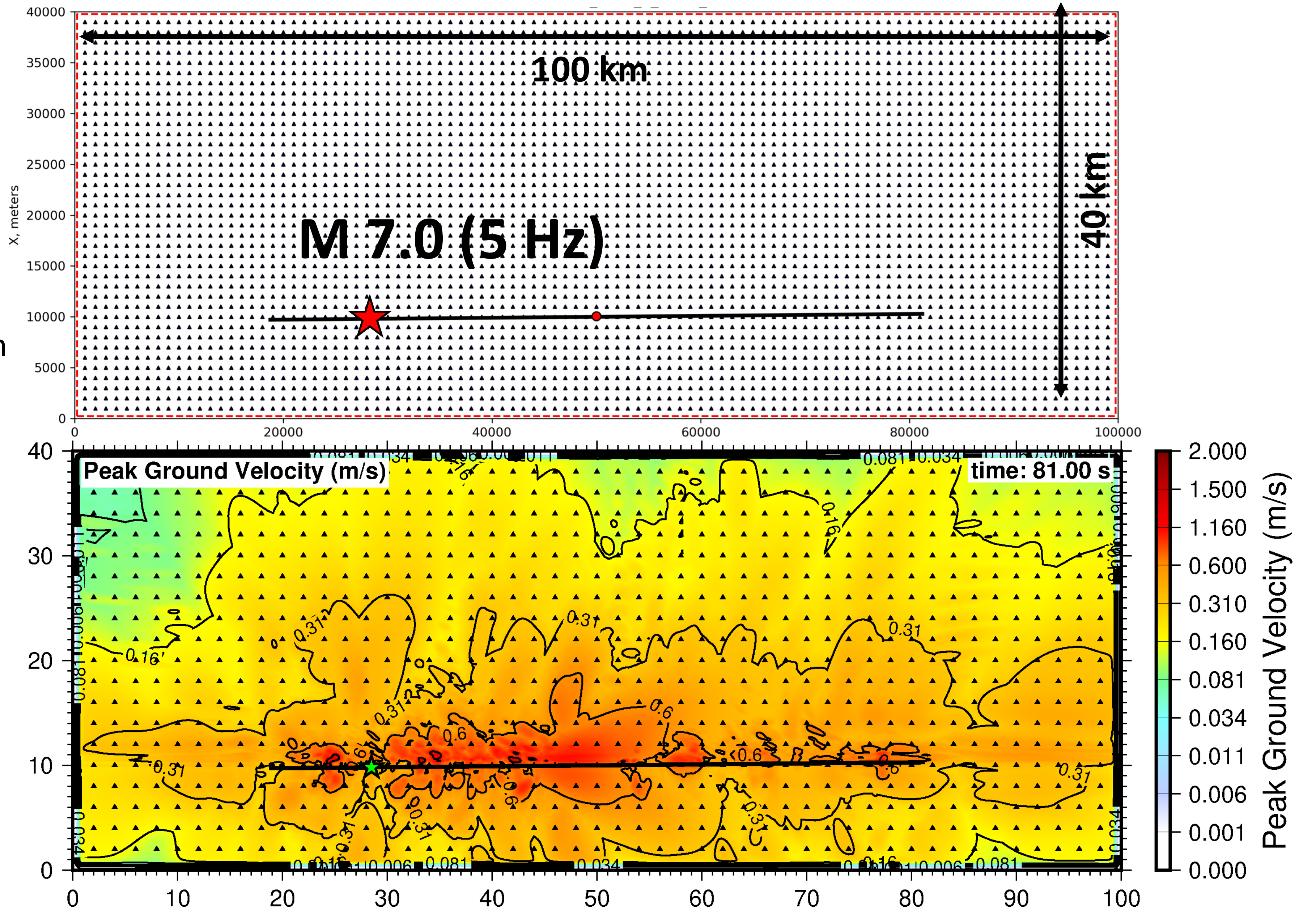


Scalability to higher frequency resolution

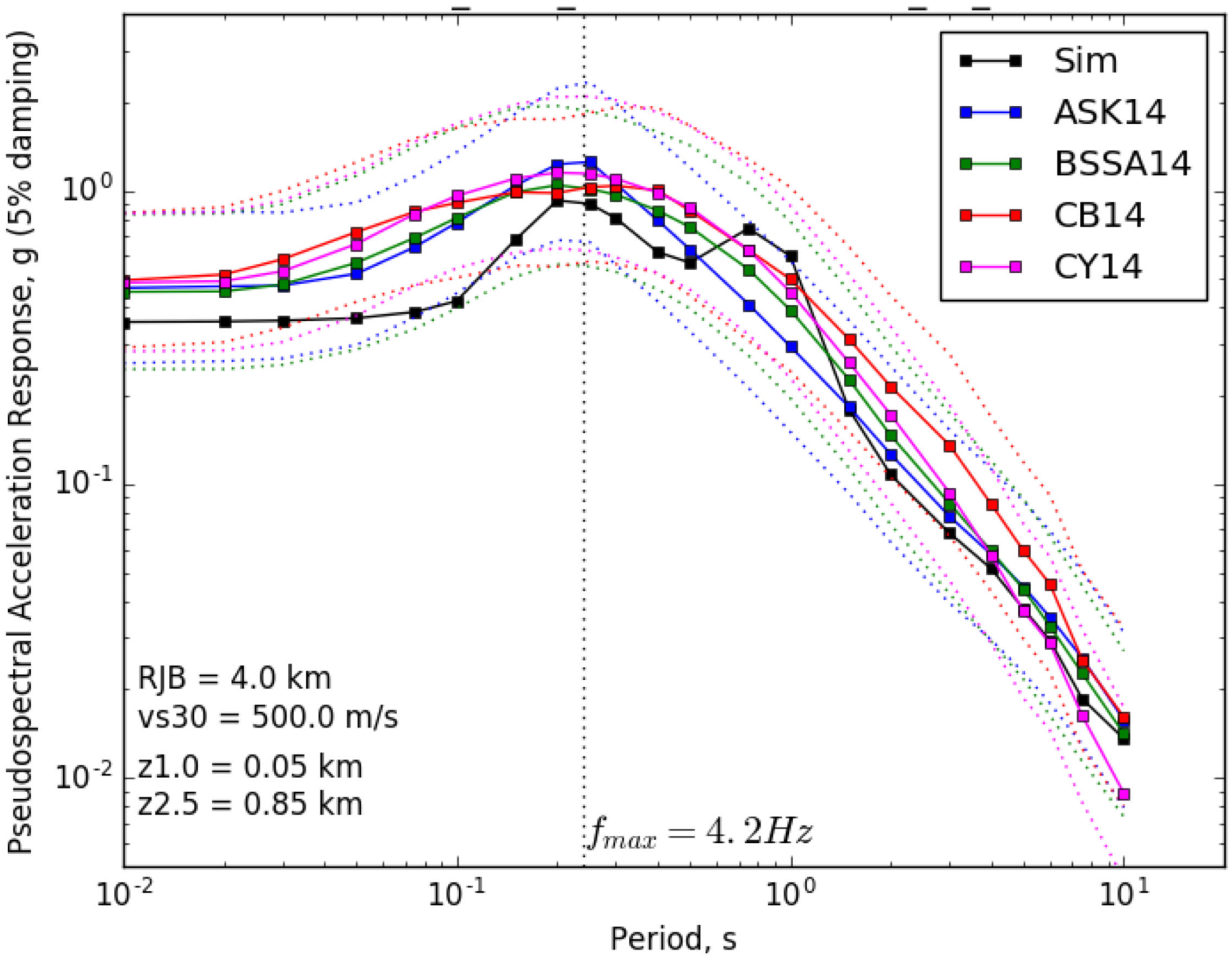


Ground motion model and computational domain

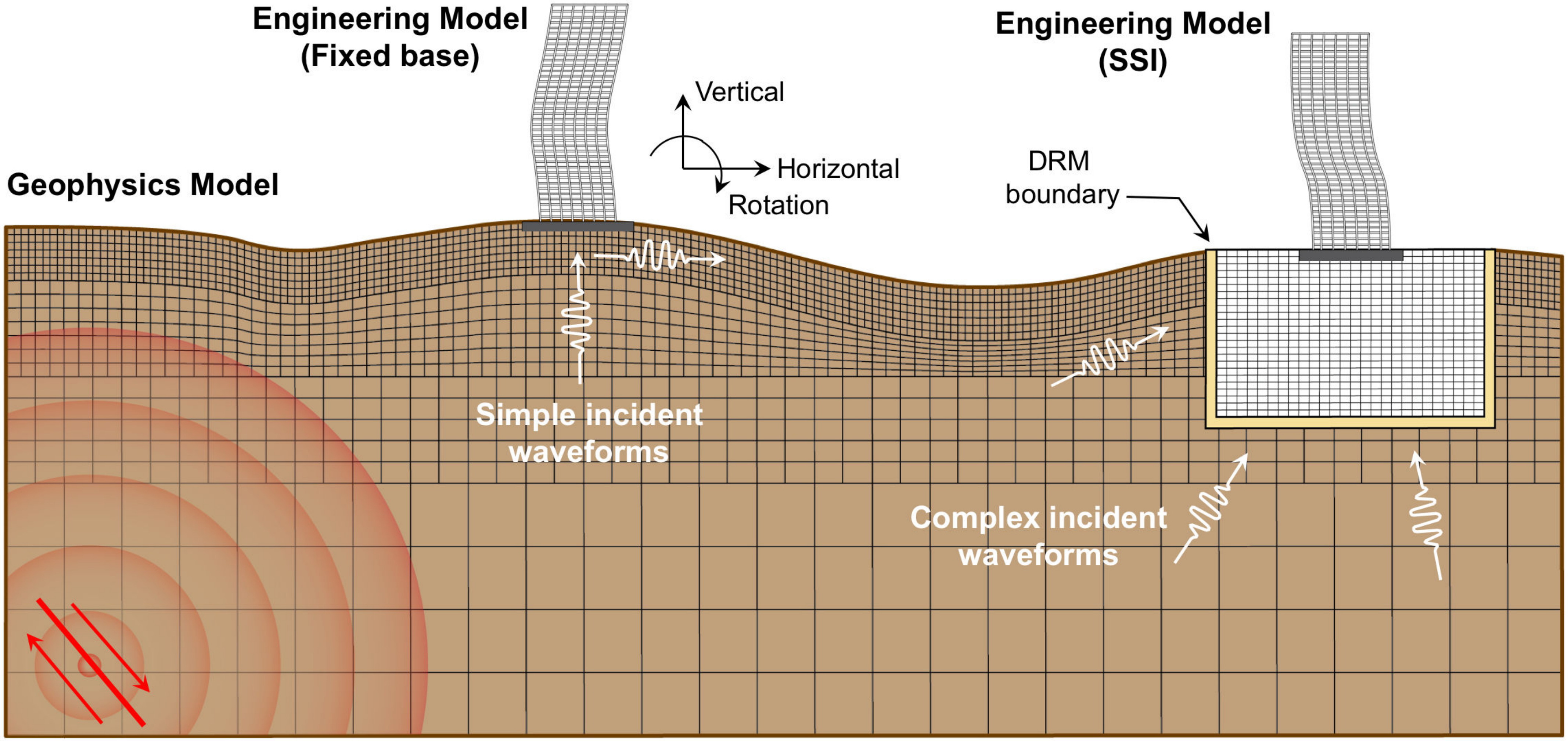
- Domain
  - 100 km x 40 km x 30 km (Depth)
  - Minimum shear wavespeed, vsmin = 320 m/s
  - Minimum grid spacing, hmin = 8 (two mesh refinements)
  - Maximum frequency, fmax = 320/(8*8) = 5.0 Hz at 8 PPW
- Earth model – Generic Open Basin
  - Sloping edge dx/dz = 200/600, dip ~ 81°
- Source Model
  - M_W 7.0 rupture, fault dimensions: 62.5 km x 16 km
  - Vertical strike slip, dip = 90 °
  - Z_{TOR} = 0. (depth to top-of-rupture)
  - Three slip distributions, same hypocenters
- Stations every 1 km (99 x 39 = 3861 stations)

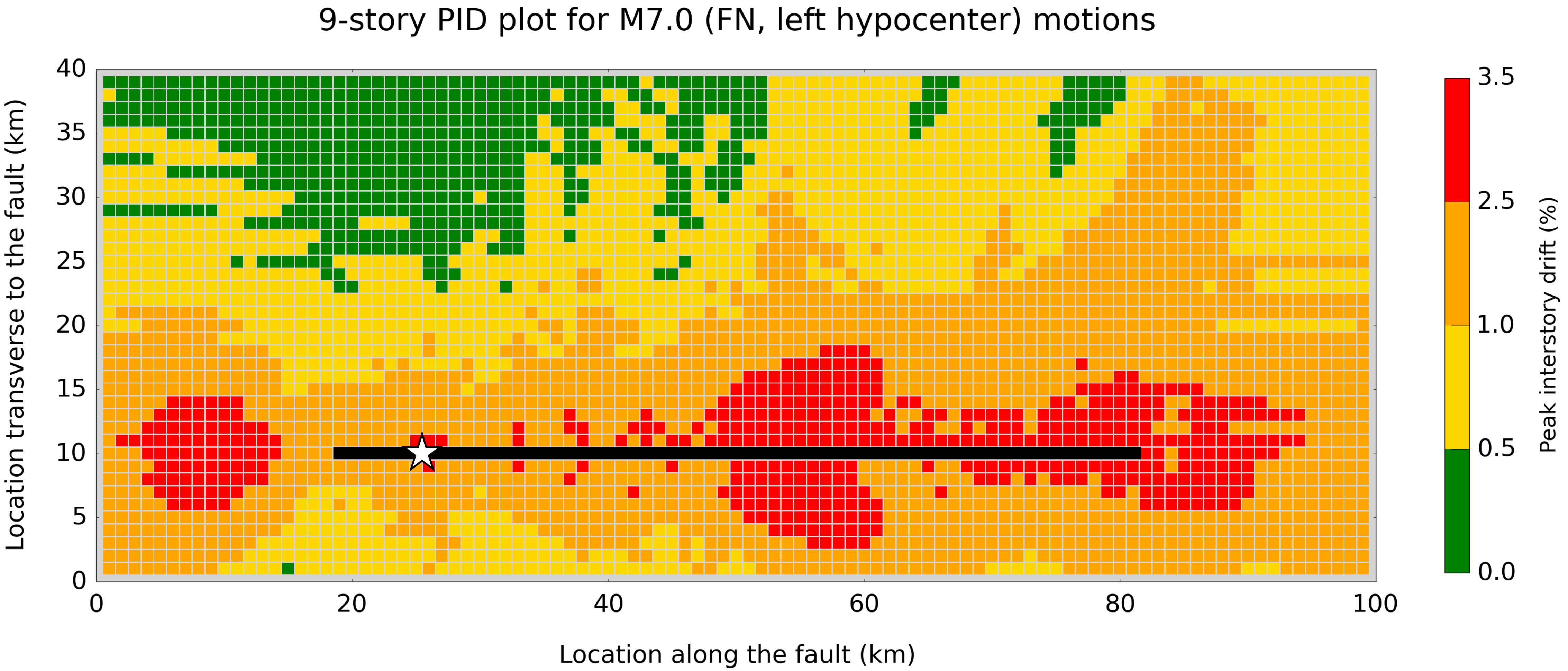


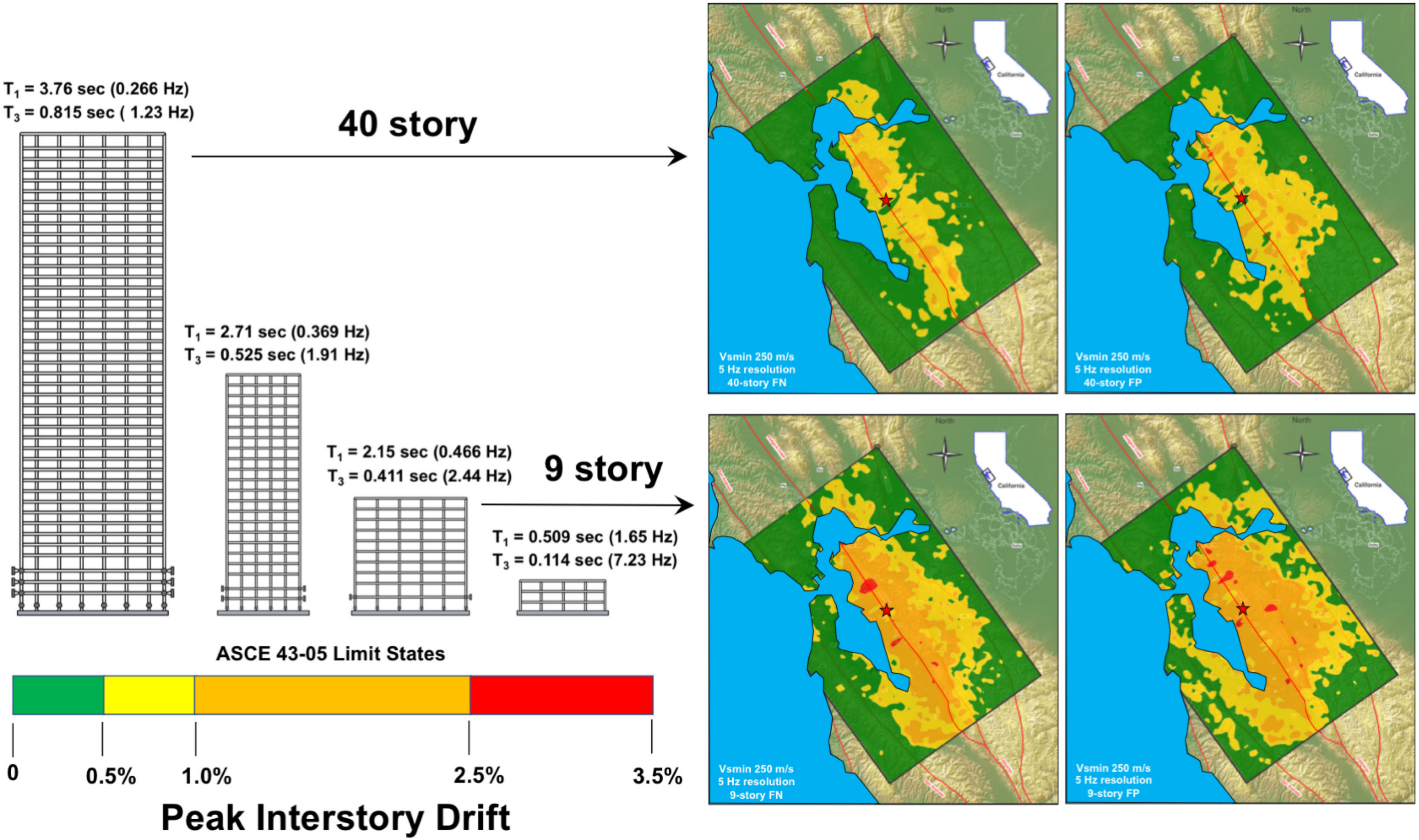
Simulated data are validated by comparing with empirical models



Dynamic response of buildings are simulated using a nonlinear Finite Element Code




9-story PID plot for M7.0 (FN, left hypocenter) motions
Location transverse to the fault (km)
Location along the fault (km)
Peak interstory drift (%)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
0.0
0.5
1.0
2.5
3.5


T1 = 3.76 sec (0.266 Hz)
T3 = 0.815 sec (1.23 Hz)
40 story
T1 = 2.71 sec (0.369 Hz)
T3 = 0.525 sec (1.91 Hz)
T1 = 2.15 sec (0.466 Hz)
T3 = 0.411 sec (2.44 Hz)
9 story
T1 = 0.509 sec (1.65 Hz)
T3 = 0.114 sec (7.23 Hz)
ASCE 43-05 Limit States
0
0.5%
1.0%
2.5%
3.5%
Peak Interstory Drift
North
California
Vsmin 250 m/s
5 Hz resolution
40-story FN
Vsmin 250 m/s
5 Hz resolution
40-story FP
Vsmin 250 m/s
5 Hz resolution
9-story FN
Vsmin 250 m/s
5 Hz resolution
9-story FP

Challenge to constraining a target earthquake event through multiple realizations

- A single event realization takes 8-10 hours of Cori (13^{th} on the top500) platform.
- We need in the order of 10’s-100’s realizations in order to constrain the uncertainty resulting from the earthquake source and geology.
- This is a huge computational challenge in terms compute cost and time. So A machine learning framework will prove beneficial provided there is enough realistic training data.
- Unfortunately there is not enough ground truth data for a particular region so that an ML model could be trained.
- This is where our simulation framework is giving us an upper hand by providing us synthetic data to train an AI model.

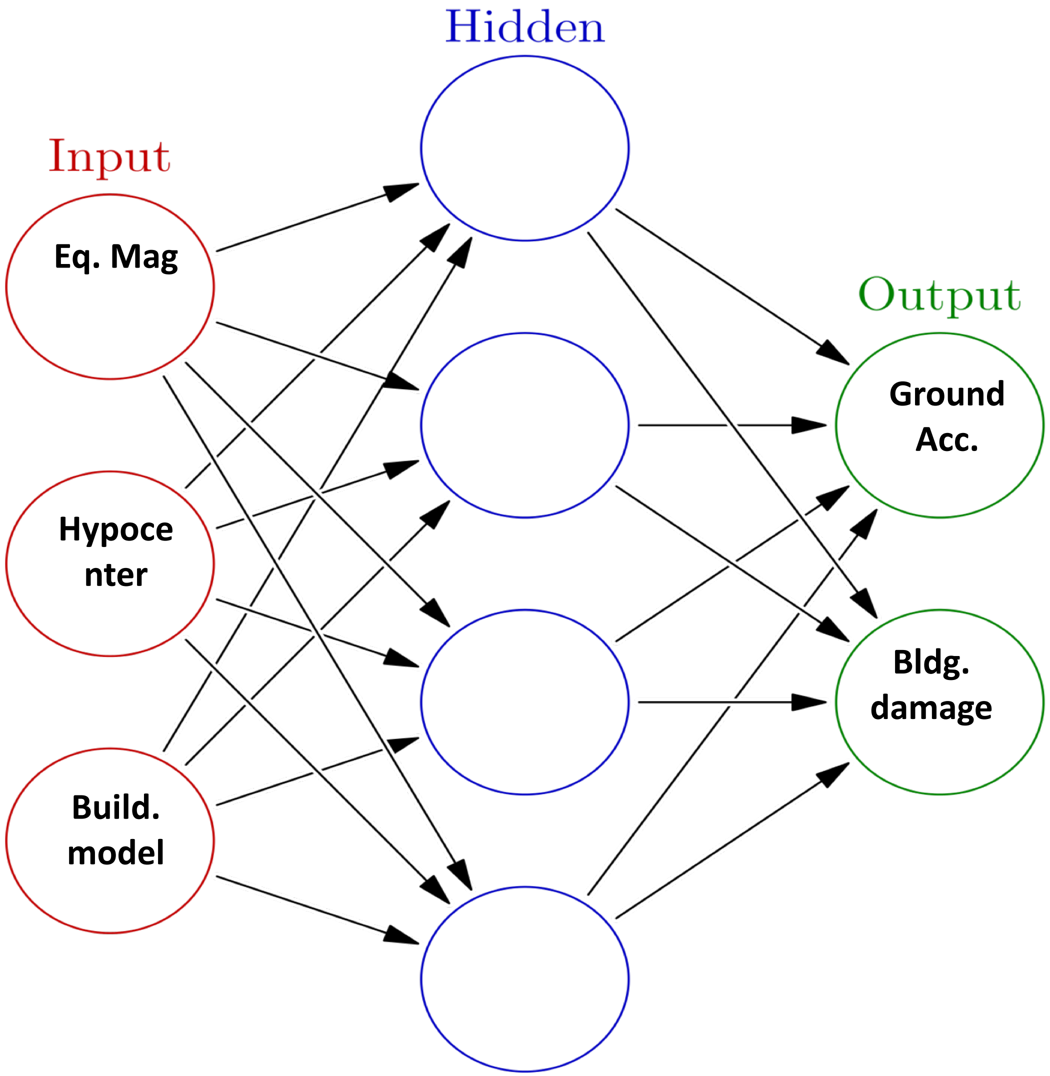
A conceptual AI model for earthquake hazard and risk evaluation

KEY PROPOSED FY20 TASKS:

- **More earthquake event simulation and structural risk simulation by changing parameters.**
- **The parameters change should envelope the extreme motions and building response so that an ML model could train on.**
- **The proposed model could be trained with the existing simulated data and more datasets be added afterwards as they are generated.**

LDRD SUCCESS COULD LEAD TO:

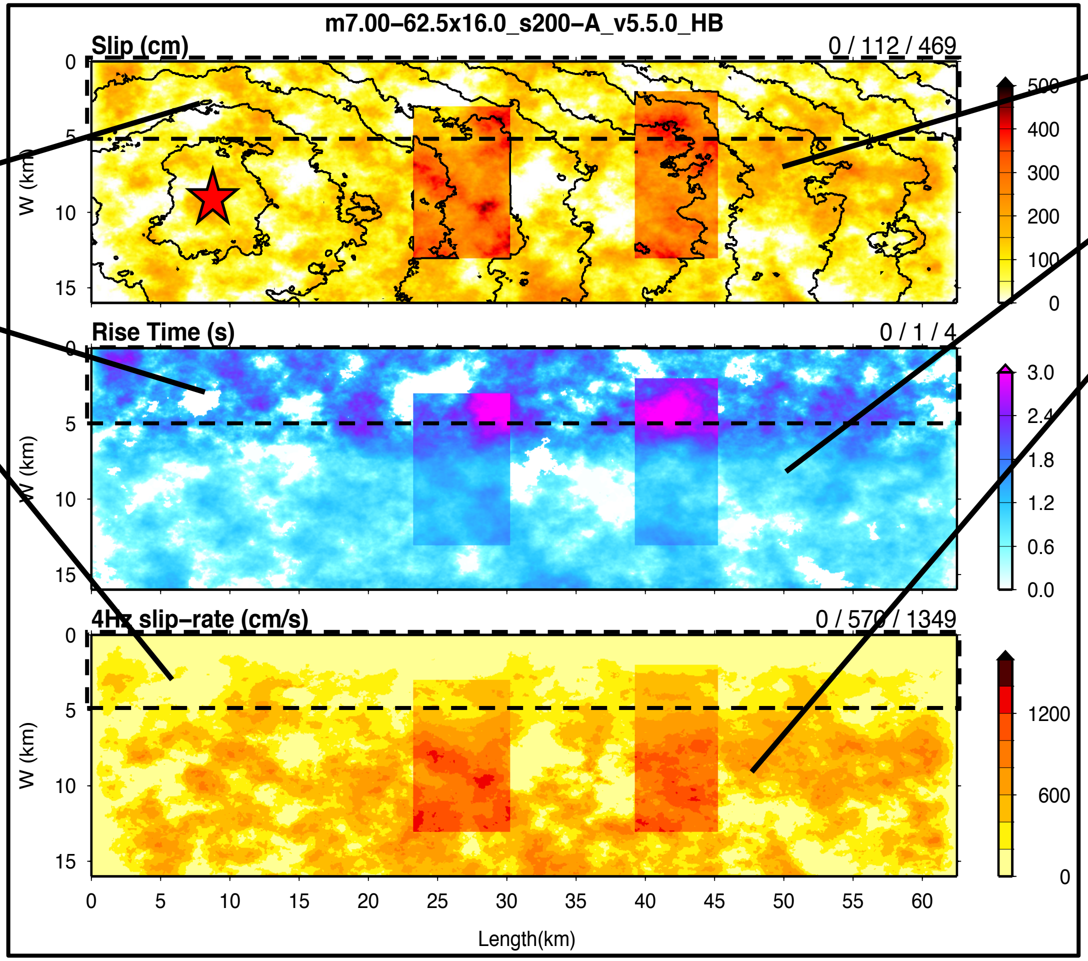
Development of a machine learning algorithm would enable us to predict earthquake hazard and risk with a scalable solution (**from supercomputers to laptops**) and an accelerated pace (**from years to hours**).



Earthquake source model

Weak Zone (top 5 km)

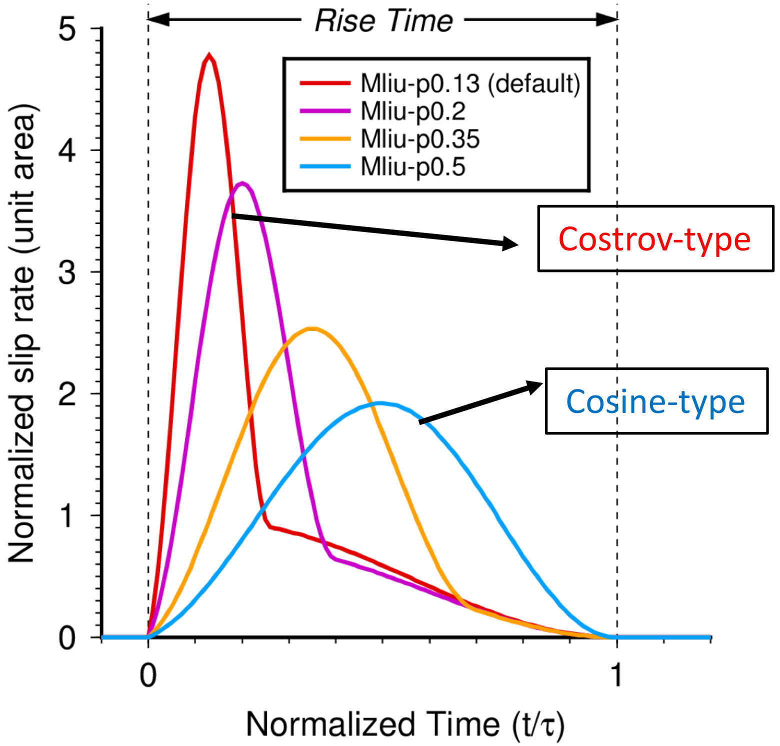
1. Longer Slip Rise Time
2. Lower Peak Slip Rate
3. Cosine-type Slip Rate Function

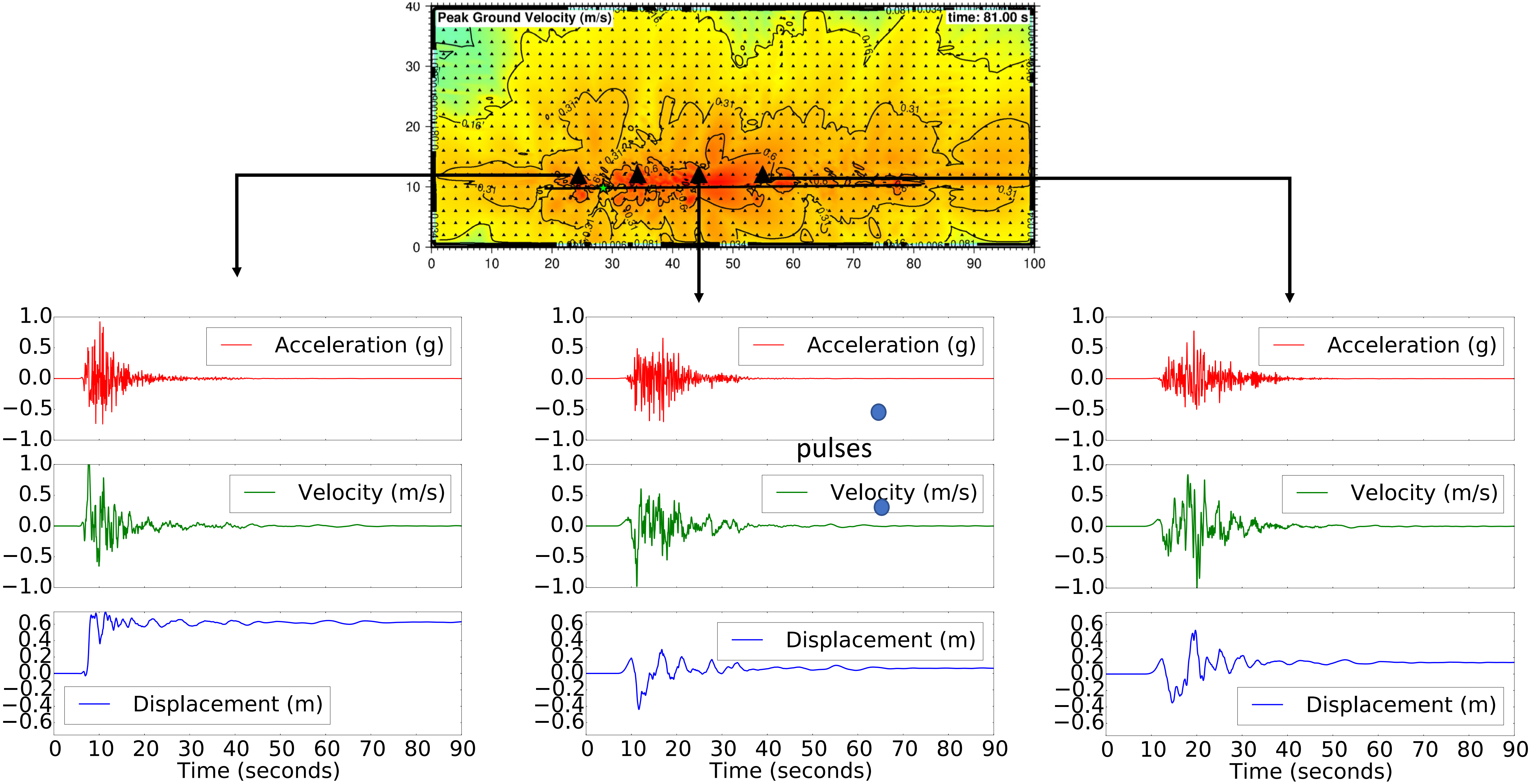


Concentrated Large-Slip Areas

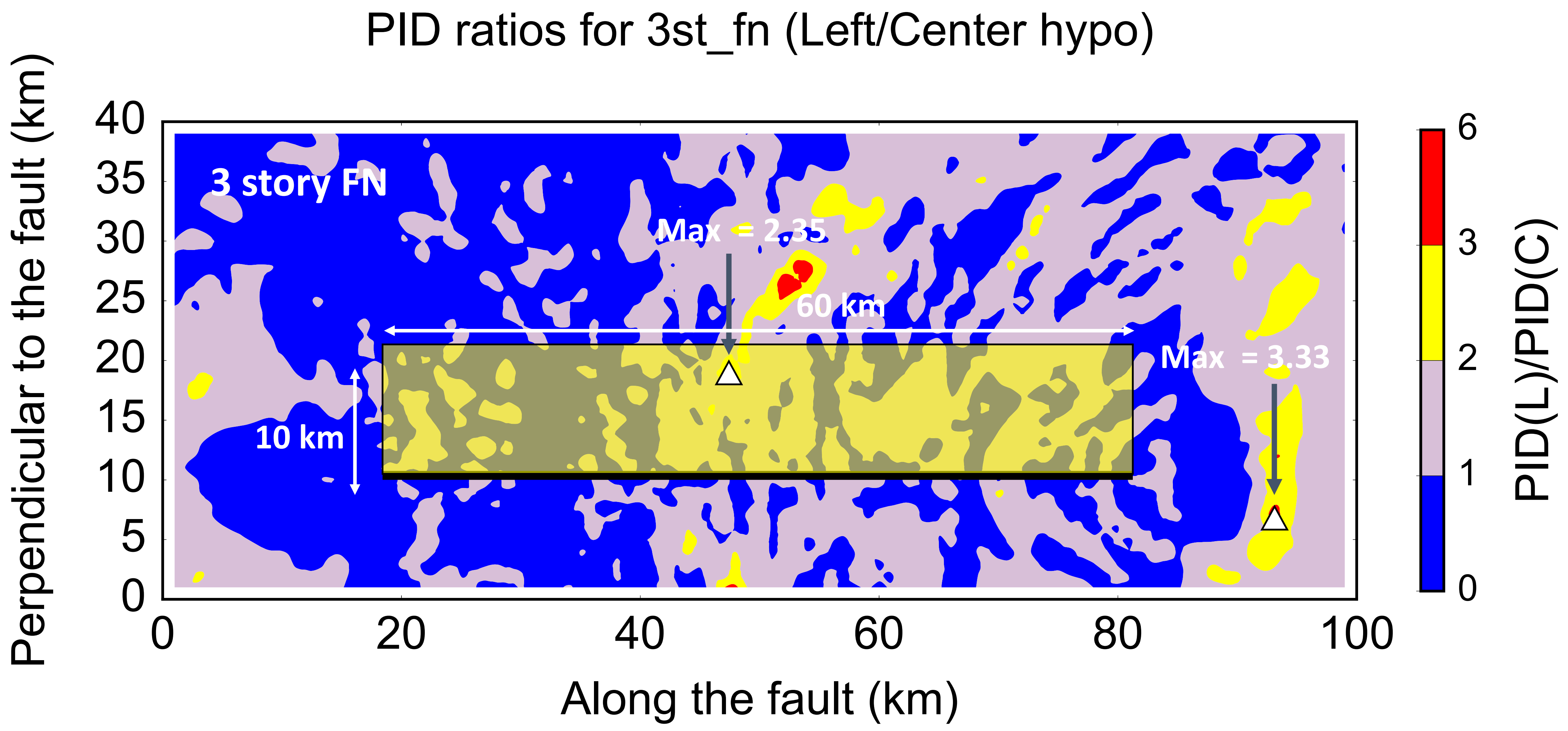
1. Shorter Slip Rise Time (below 5km)
2. High Peak Slip Rate (below 5km)
3. Kostrov-type Slip Rate Function (below 5km)

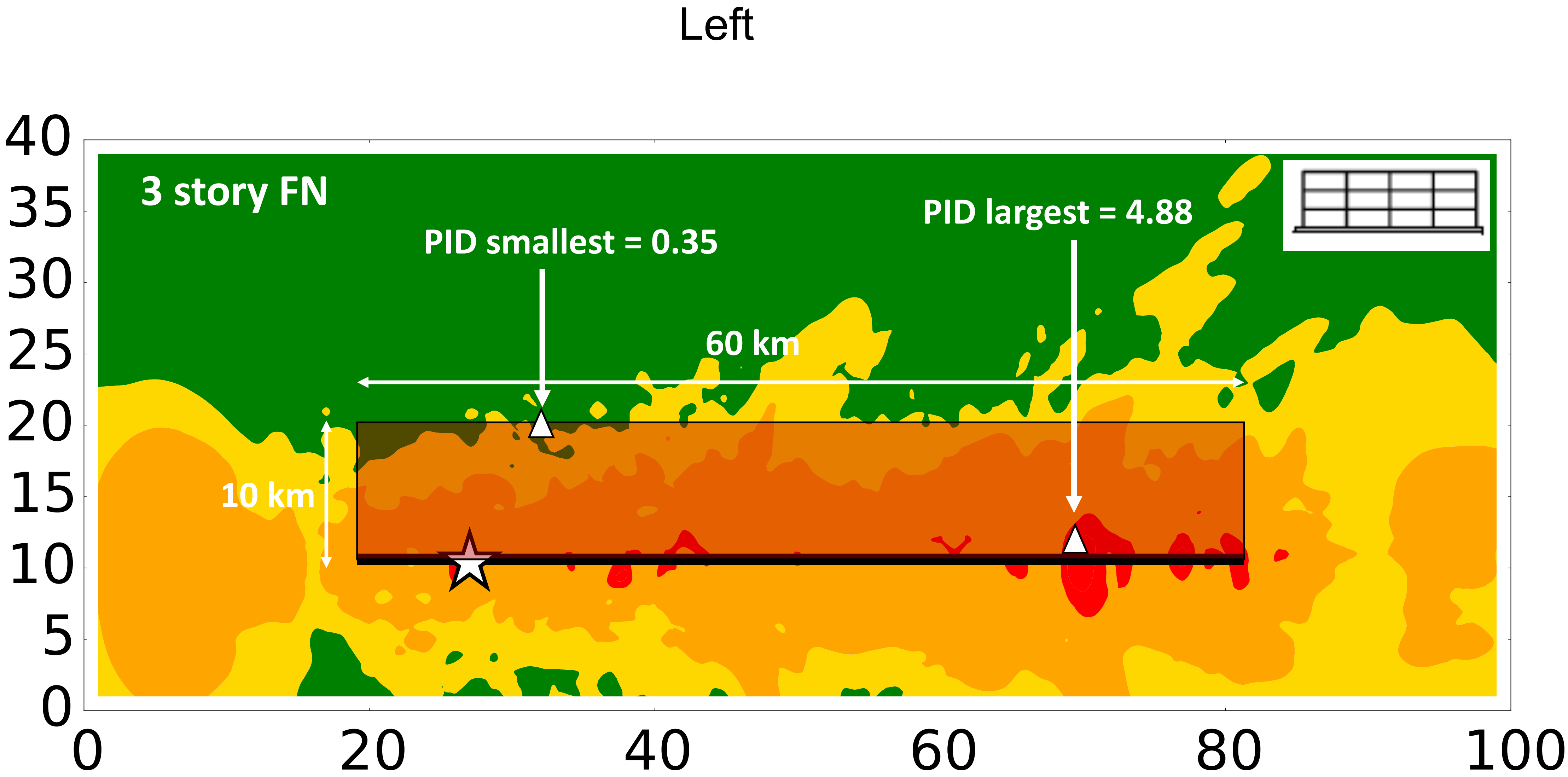
Slip Rate Functions

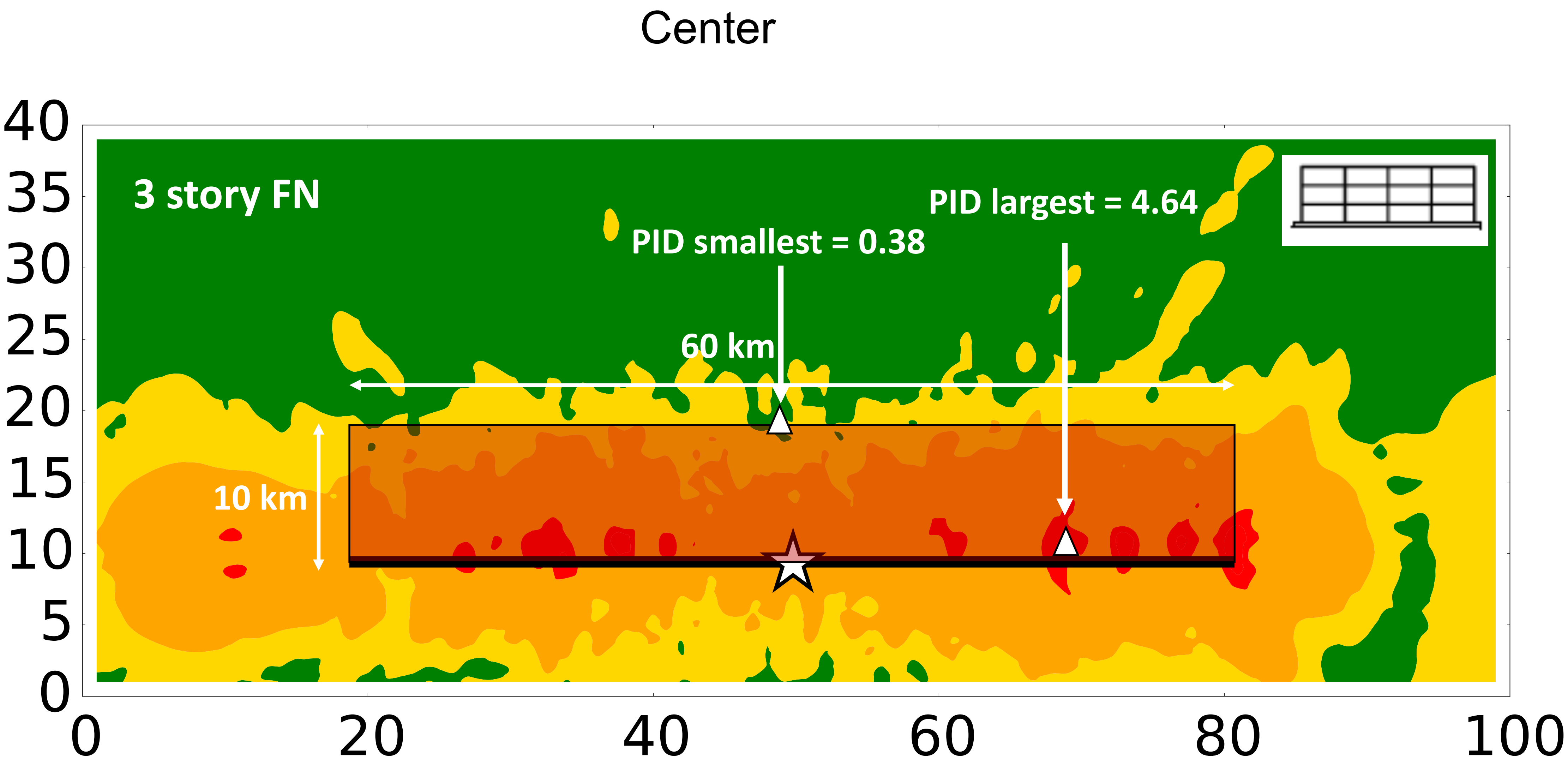




Peak Ground Velocity (m/s)
time: 81.00 s
Acceleration (g)
Velocity (m/s)
Displacement (m)
pulses
Time (seconds)


PID ratios for 3st_fn (Left/Center hypo)
3 story FN
Max = 2.35
60 km
Max = 3.33
10 km
Perpendicular to the fault (km)
Along the fault (km)
PID(L)/PID(C)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
0
1
2
3
6


Left
3 story FN
PID smallest = 0.35
PID largest = 4.88
60 km
10 km
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100



Center
3 story FN
PID smallest = 0.38
PID largest = 4.64
60 km
10 km
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100

Spectral acceleration shows better correlation with drift

- Synthetic ground motions are within 10 km off the fault
- Real records are all from the near-fault locations
- Spectral acceleration at the building's first mode period shows a good correlation with the building's seismic demand