Broadband Ground Motion Simulations for a Mw 7.8 Southern San Andreas Earthquake: ShakeOut

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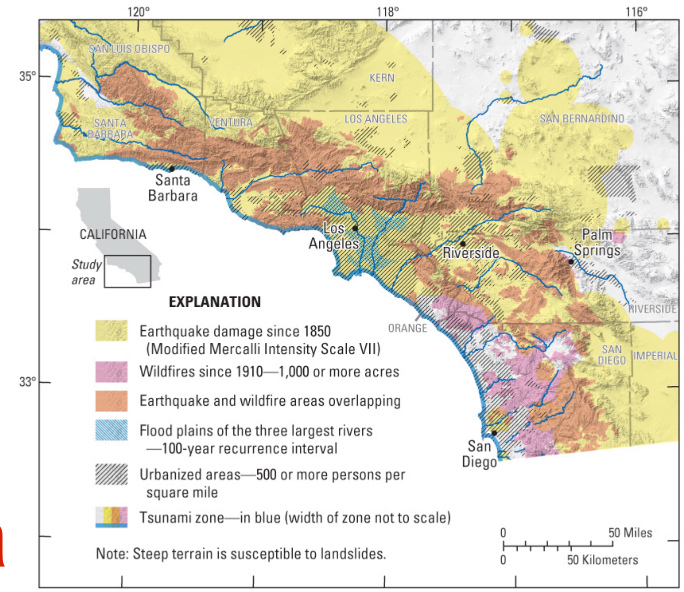
Support:

- **SCEC (USGS, NSF)**
- **USGS**
- **High Performance Computing & Communications (USC)**

ShakeOut Earthquake Scenario:

NEHRP Coordinated Multi-Hazards Demonstration Project in Southern California



PARTNERS:

Office of Emergency Services, City of Los Angeles, SCEC, EERI, PEER, FEMA, California Geological Survey, California Seismic Safety Commission, Counties of Los Angeles, San Bernardino, Riverside, Imperial, Ventura and Orange, Office of Homeland Security, Los Angeles Chamber of Commerce, Los Angeles County and City Fire Departments, Caltech, Art Center College of Design, UCLA School of Public Health, ABS Consulting, NBC Universal, Los Angeles Unified School District, Southern California Association of Governments, Metropolitan Transportation Authority, California Department of Transportation, Metropolitan Water District, Southern California Edison, California Utilities Emergency Association, Homeland Security Advisory Council, American Red Cross, URS Corporation

“Earthquakes are among the most complex terrestrial phenomena, and modeling of earthquake dynamics is one of the most difficult computational problems in science.”

Tom Jordan
Director, Southern California Earthquake Center

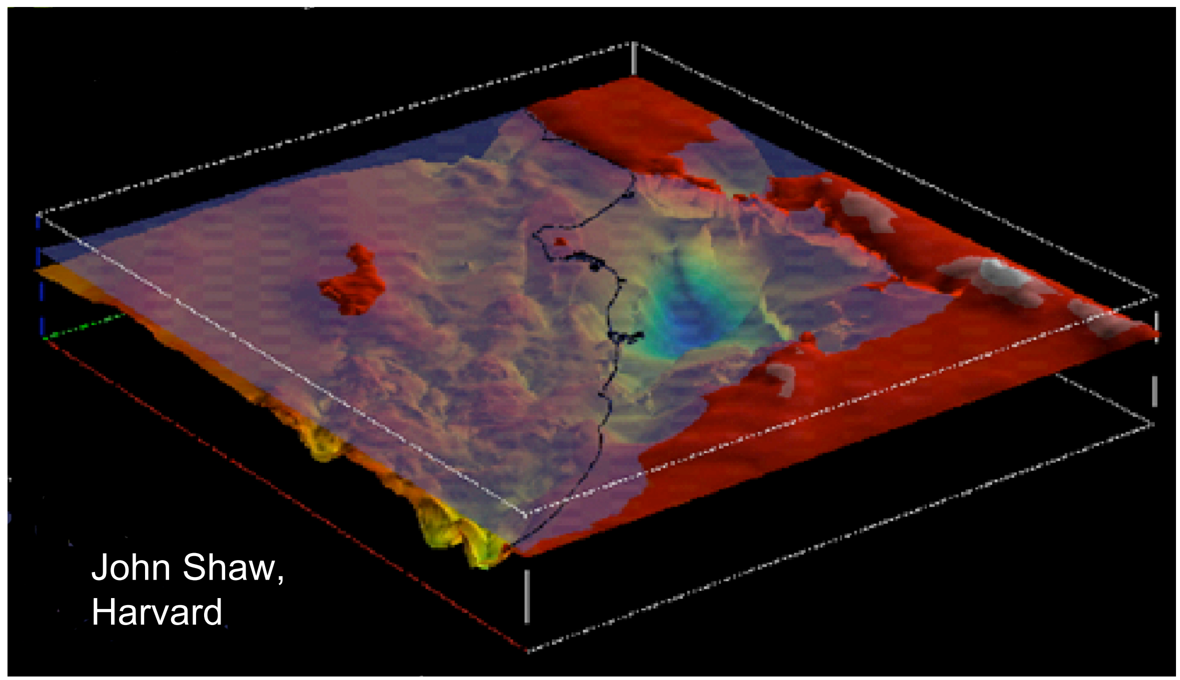
Highly Complex Geologic Structure

Large Computational Demands

HPCC Linux Cluster @ USC

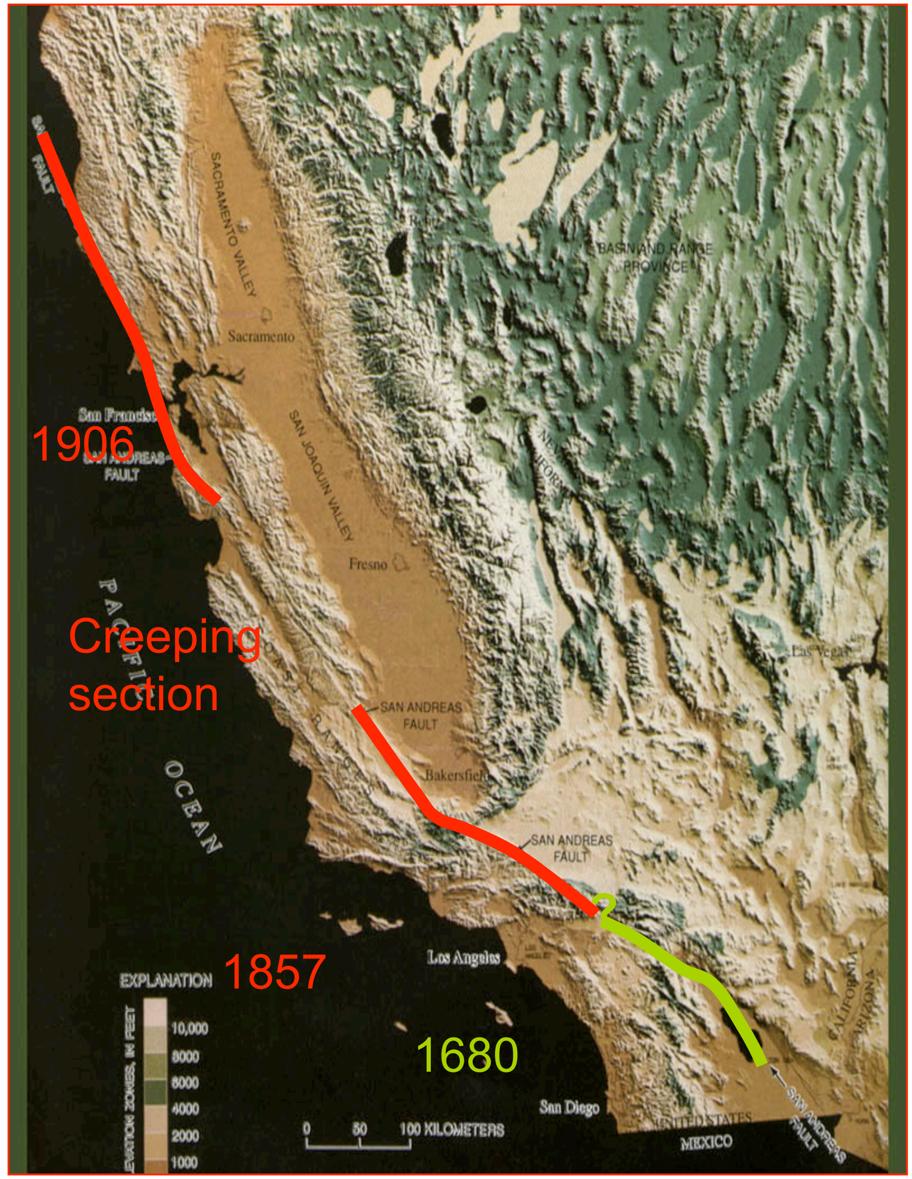
FAULTS

VELOCITY STRUCTURE

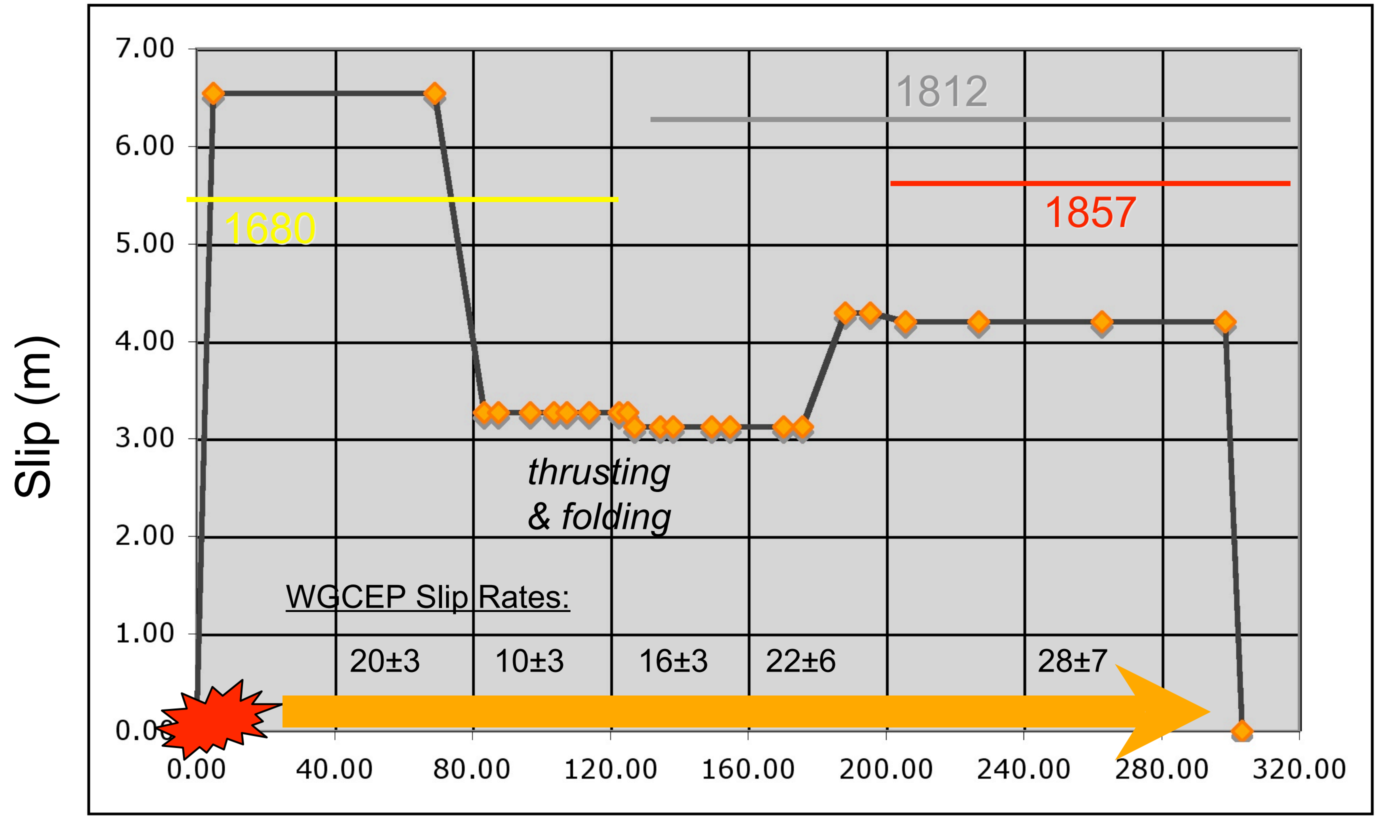


Scenario Earthquake on the Southern San Andreas Fault

- Not a prediction - a plausible event
- Average time between previous events: 150 years
- First step: define rupture characteristics
  - Rupture Length
  - Magnitude
  - Slip distribution
  - Slip function
  - Rupture velocity
  - Hypocenter



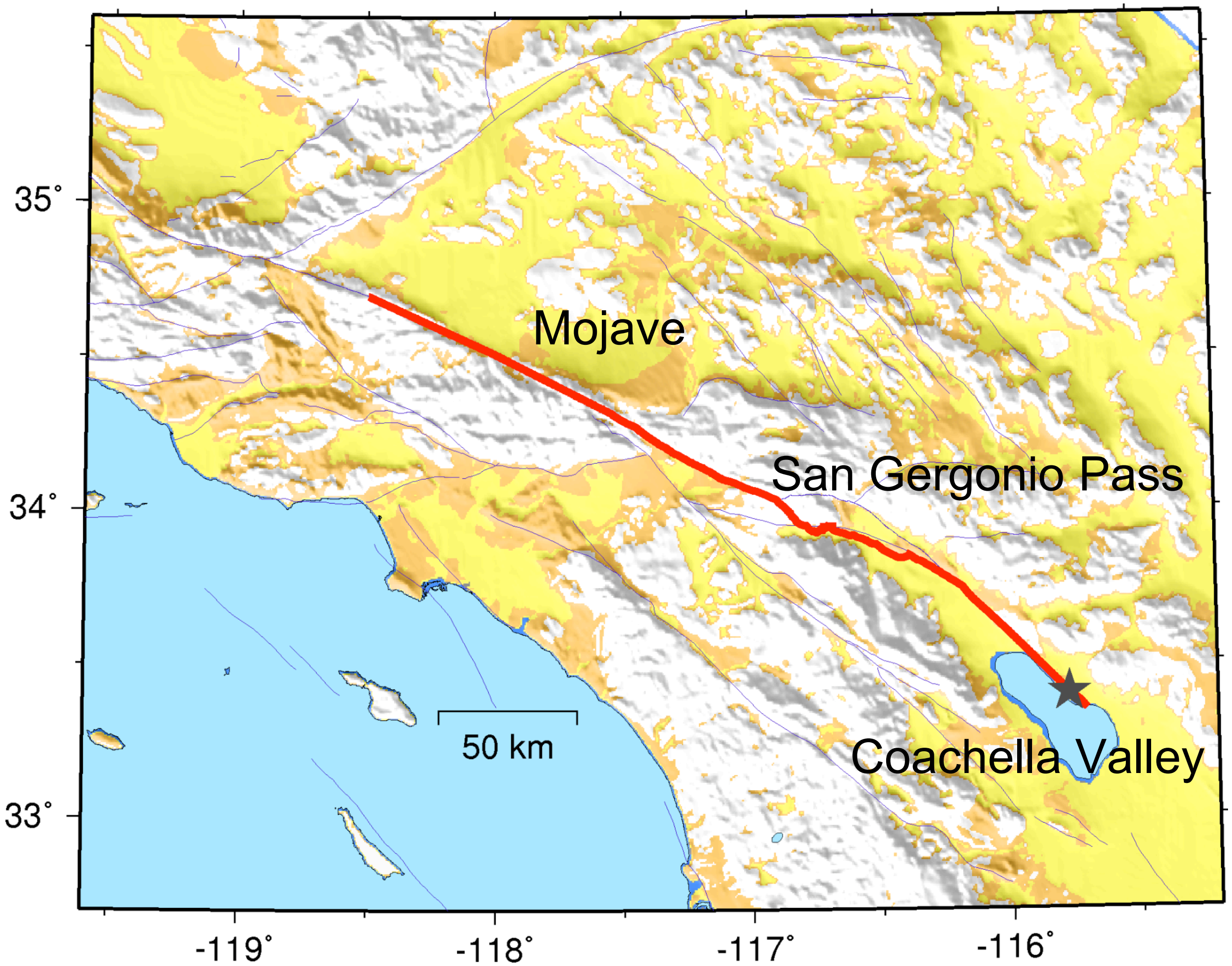
Static Displacement Characterization



SOUTH Coachella Valley Mojave NORTH

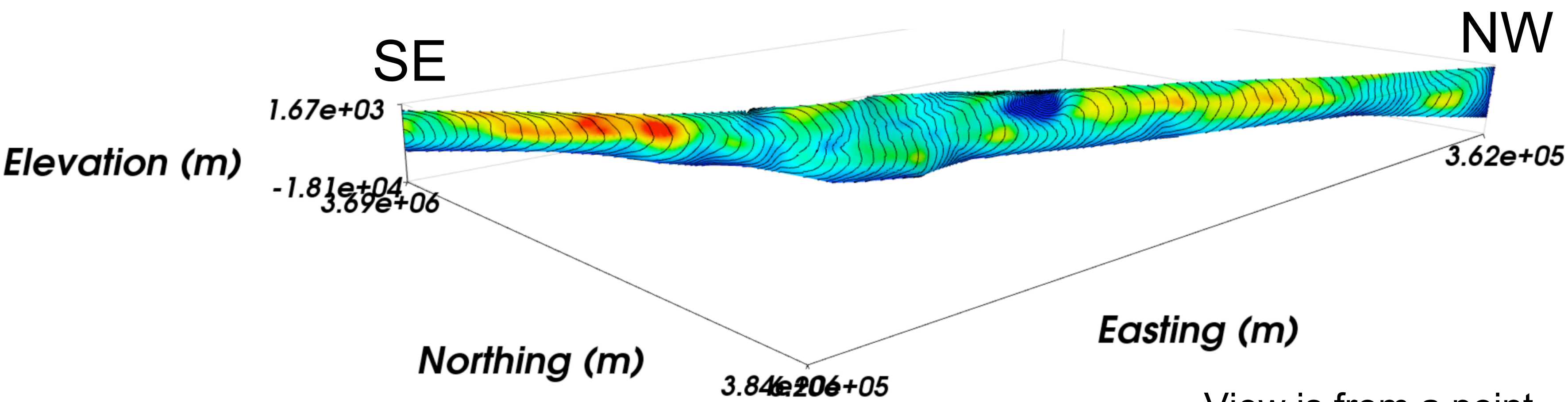
San Gergonio Pass

Fault / Rupture Characterization



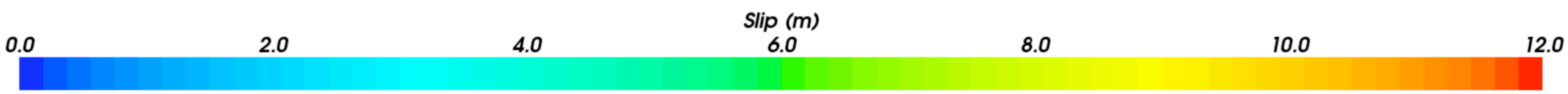
- Length = 300 km
- Mw 7.8
- 2D fault surface (SCEC CFM)
- Southern hypocenter

Kinematic Rupture Model (v1.2.0)



View is from a point to the NE and above the San Andreas fault

Slip (meters)



- **Slip has K^{-2} falloff at shorter length scales**
- **Rupture velocity scales with local shear velocity and slip**
- **Slip function is Brune pulse, rise time scales with square-root of slip**

Low Frequency Simulation Methodology (f < 1 Hz)

- Kinematic representation of heterogeneous rupture on a finite fault
  - Slip amplitude and rake
  - Rupture initiation time
  - Slip function
- Visco-elastic wave propagation using 3D FDM approach
  - MPI code
  - SCEC CVM version 4.0
- Site-specific non-linear amplification factors based on Vs30 (Campbell and Bozorgnia, 2006)

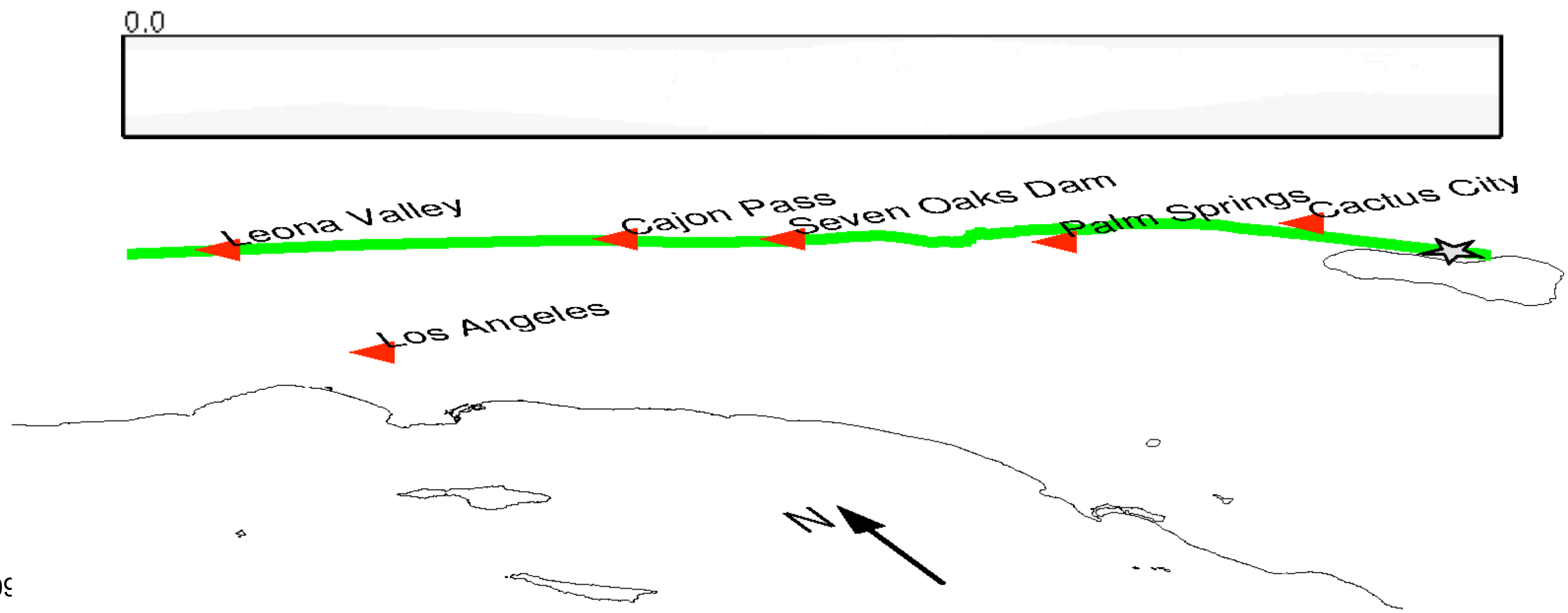
High Frequency Simulation Methodology (f > 1 Hz)

- Limited kinematic representation of heterogeneous rupture on a finite fault (extension of Boore, 1983)
  - Slip amplitude
  - Rupture initiation time
  - Conic averaged radiation pattern
  - Stochastic phase
- Simplified Green's functions for 1D velocity structure
  - Separate GFs for direct and downgoing rays
  - Amplitude decays as inverse of ray path length
  - Gross impedance effects based on quarter wavelength theory (Boore and Joyner, 1997)
- Site-specific non-linear amplification factors based on Vs30 (Campbell and Bozorgnia, 2006)

Simulation Parameters

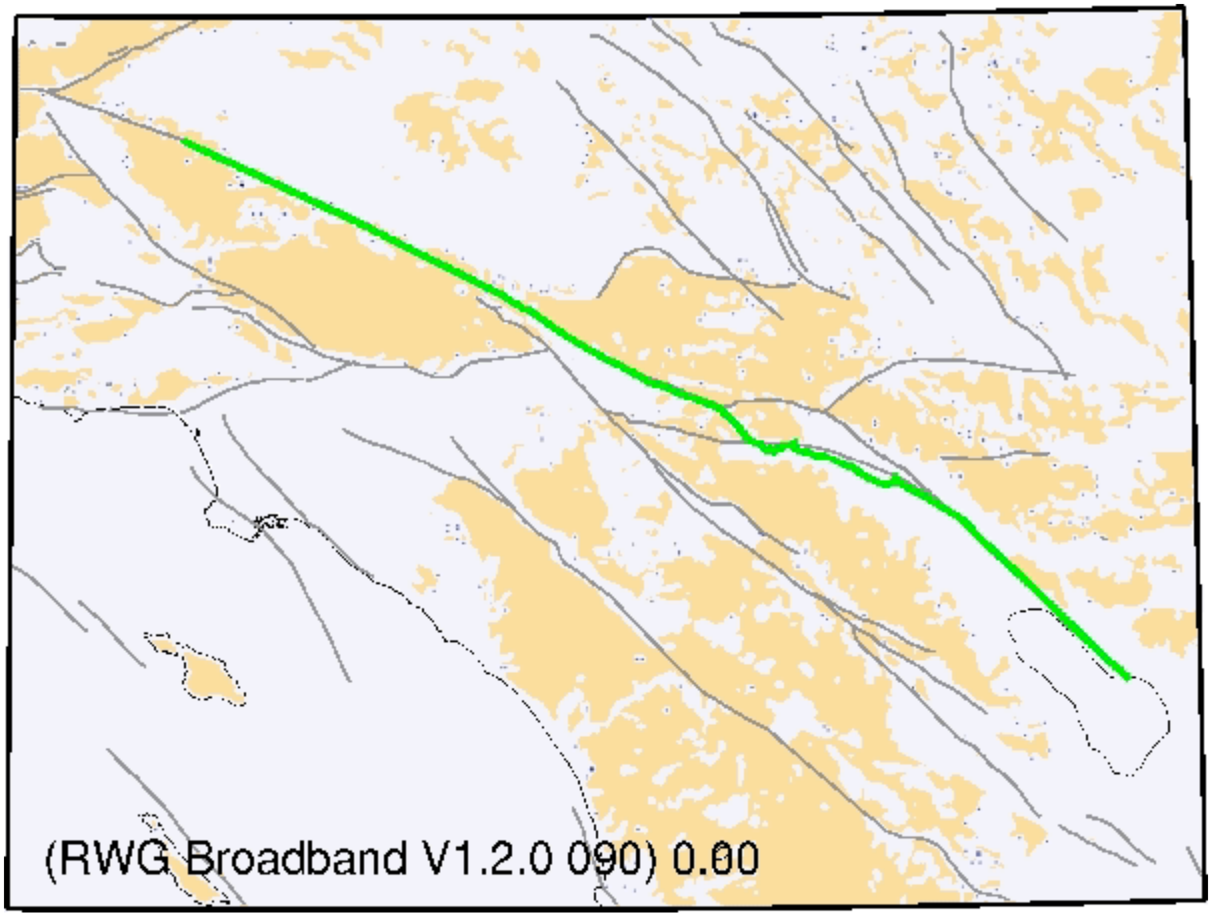
- Low Frequency
  - 3D FD model using 2.33 x 10^9 grid nodes (450 km x 225 km x 45 km @ h=0.125 km)
  - 24 hours run-time on 520 CPUs of HPCC Linux cluster at USC (260 GB RAM)
  - 3 component time histories saved at 25,500 locations (2 km x 2 km grid)
- High Frequency
  - 24 hours run-time using single Linux PC
  - 3 component time histories saved at 25,500 locations
- Post-Processing
  - 24 hours to process and sum HF and LF into Broadband response
  - Broadband (0 – 10 Hz) 3 component time histories at 25,500 locations

Earthquake Rupture Animation



Ground Motion Animation:

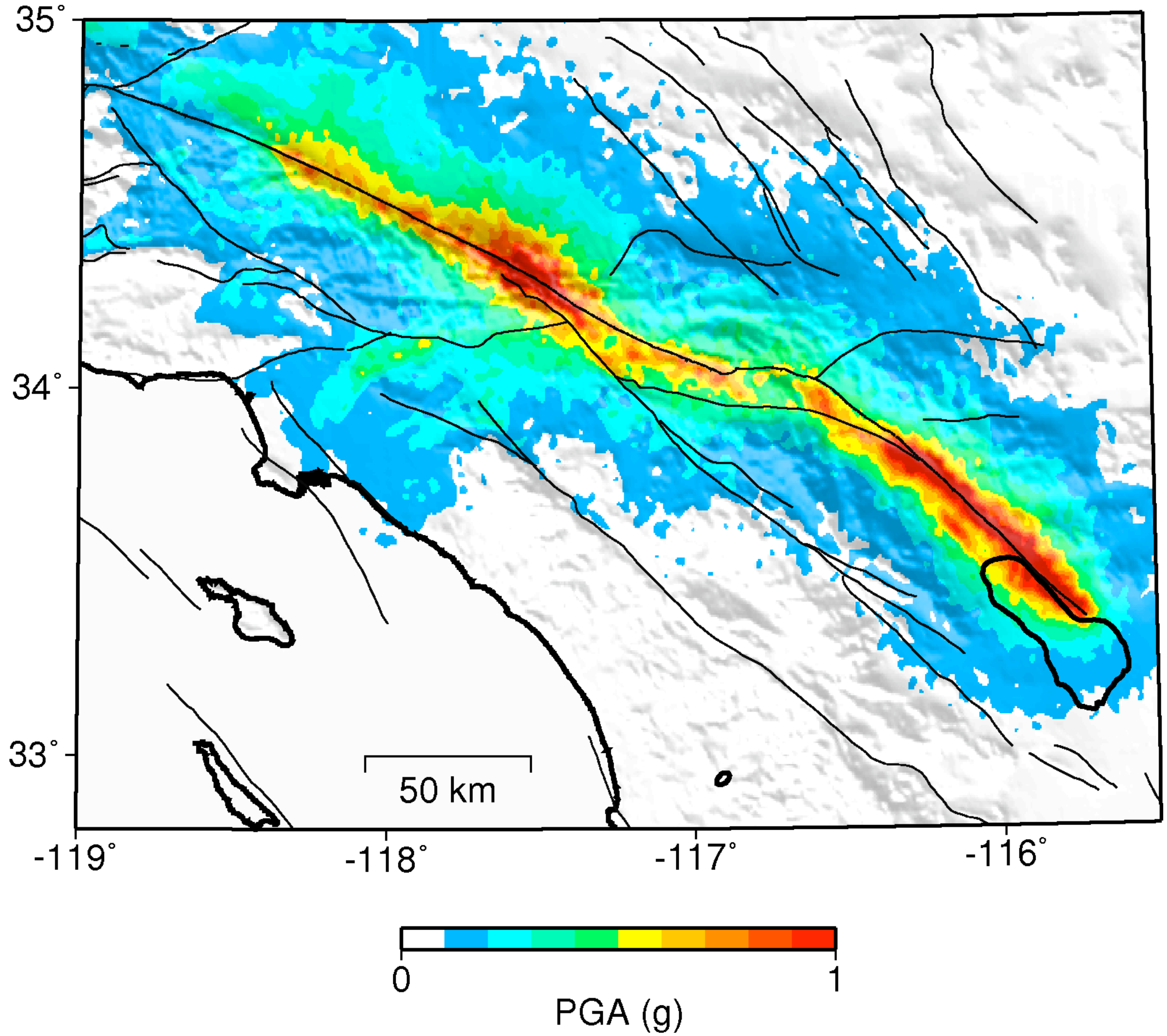
- Broadband time histories on 2 km X 2 km grid (25,500 sites)
- South Hypocenter



RWG ShakeOut (v1.2.0): PGA

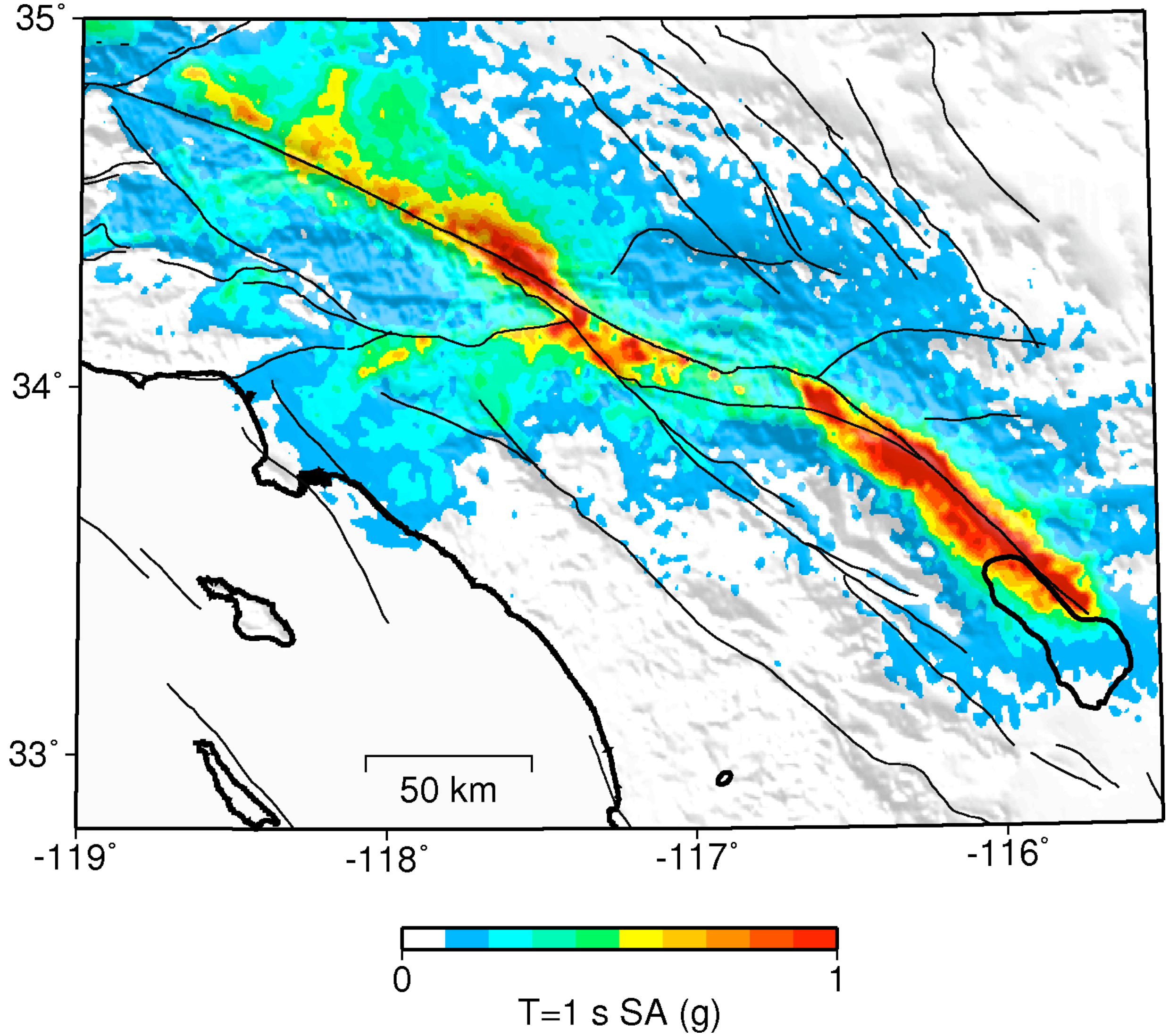
Broadband (0-10 Hz)

South Hypocenter



RWG ShakeOut (v1.2.0): T=1 s SA

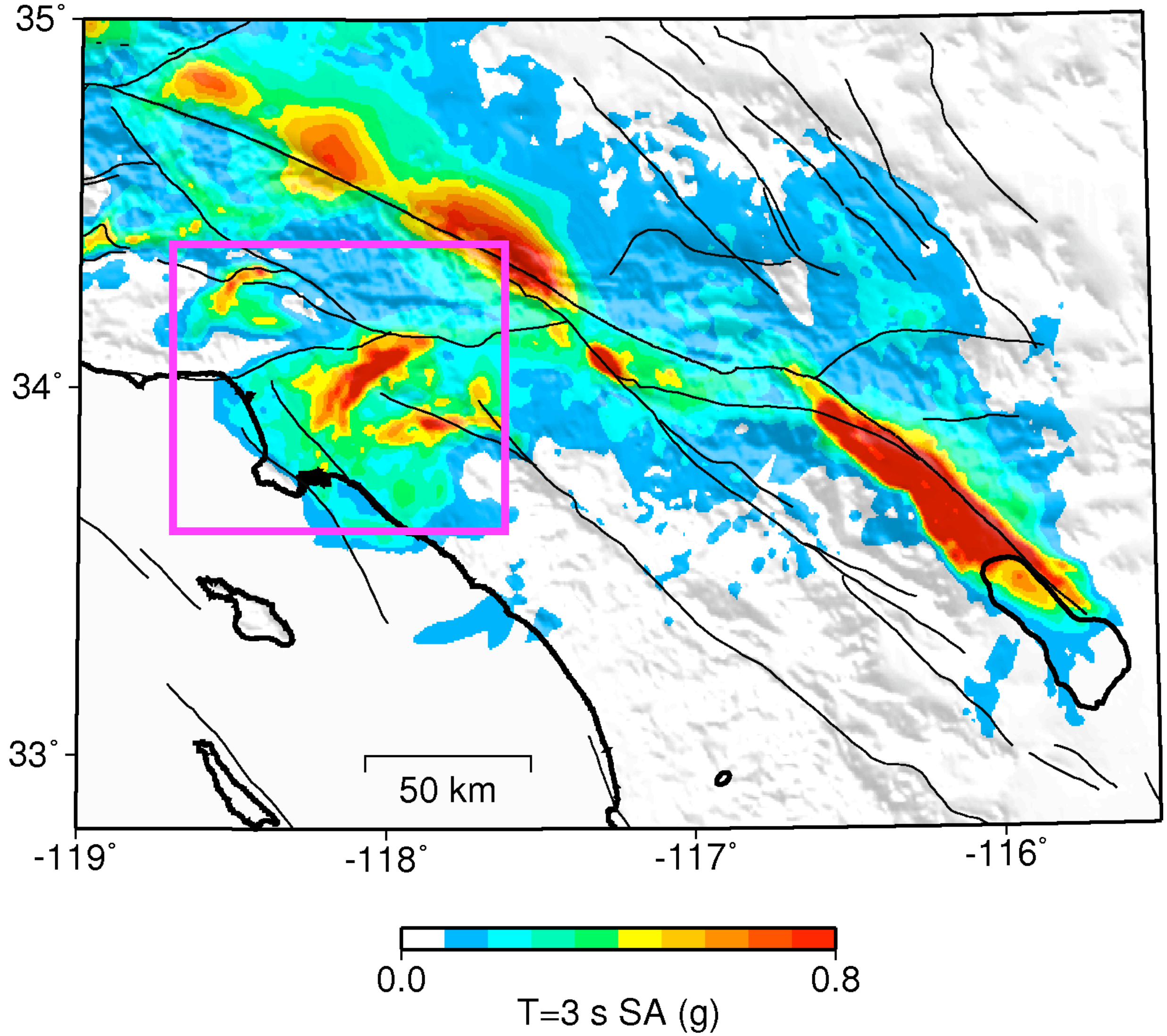
Broadband (0-10 Hz)
South Hypocenter



RWG ShakeOut (v1.2.0): T=3 s SA

Broadband (0-10 Hz)

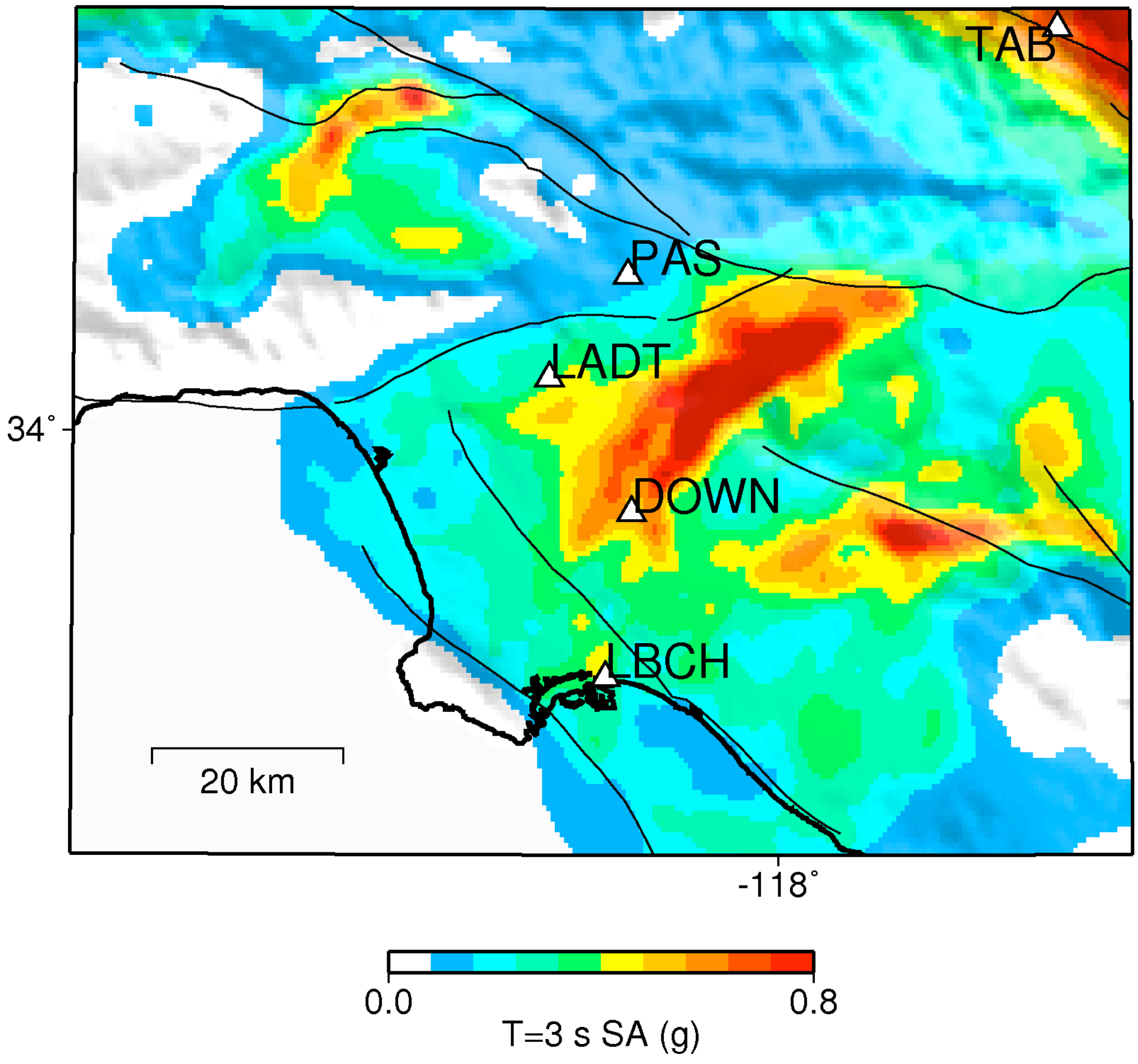
South Hypocenter

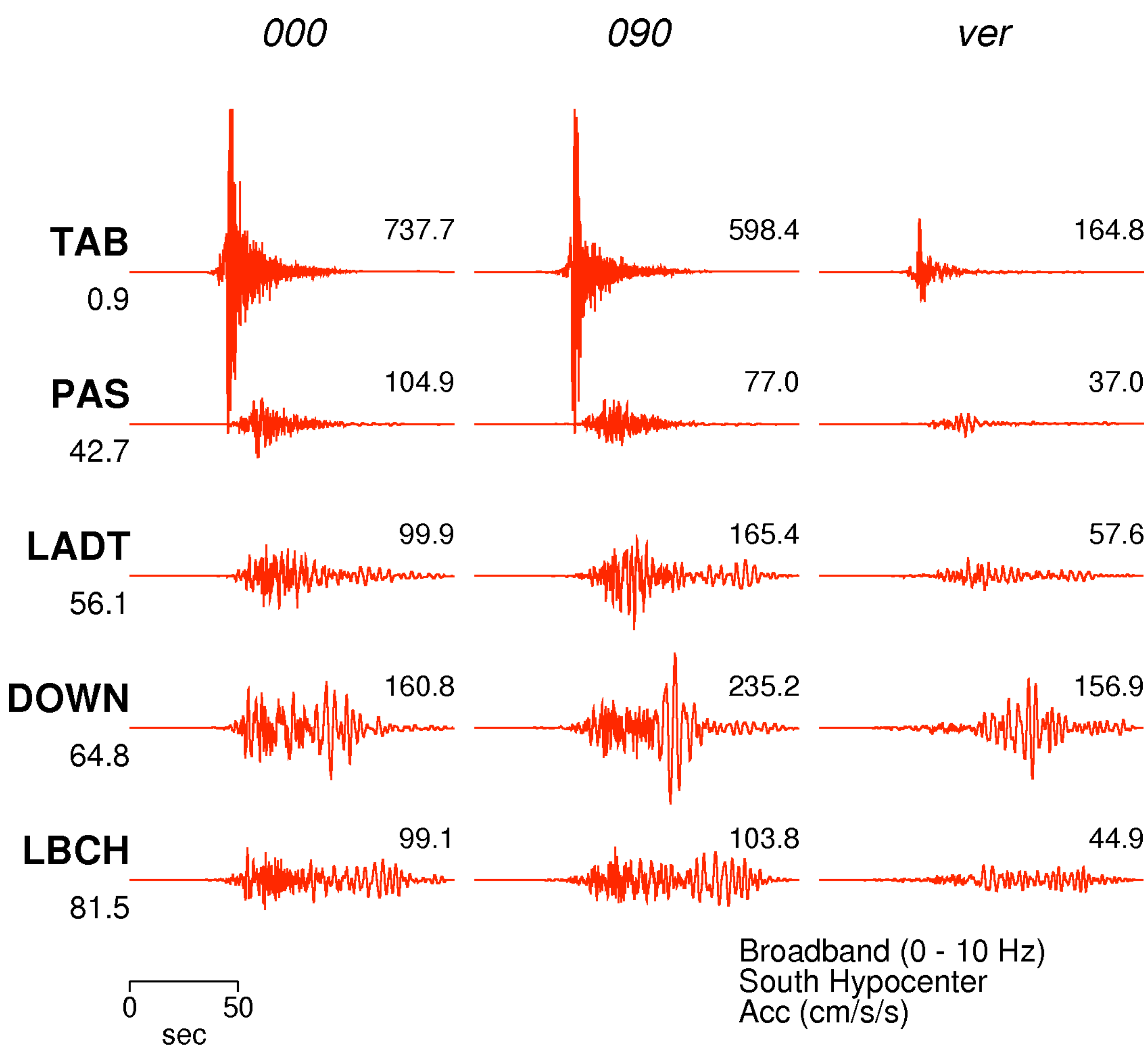


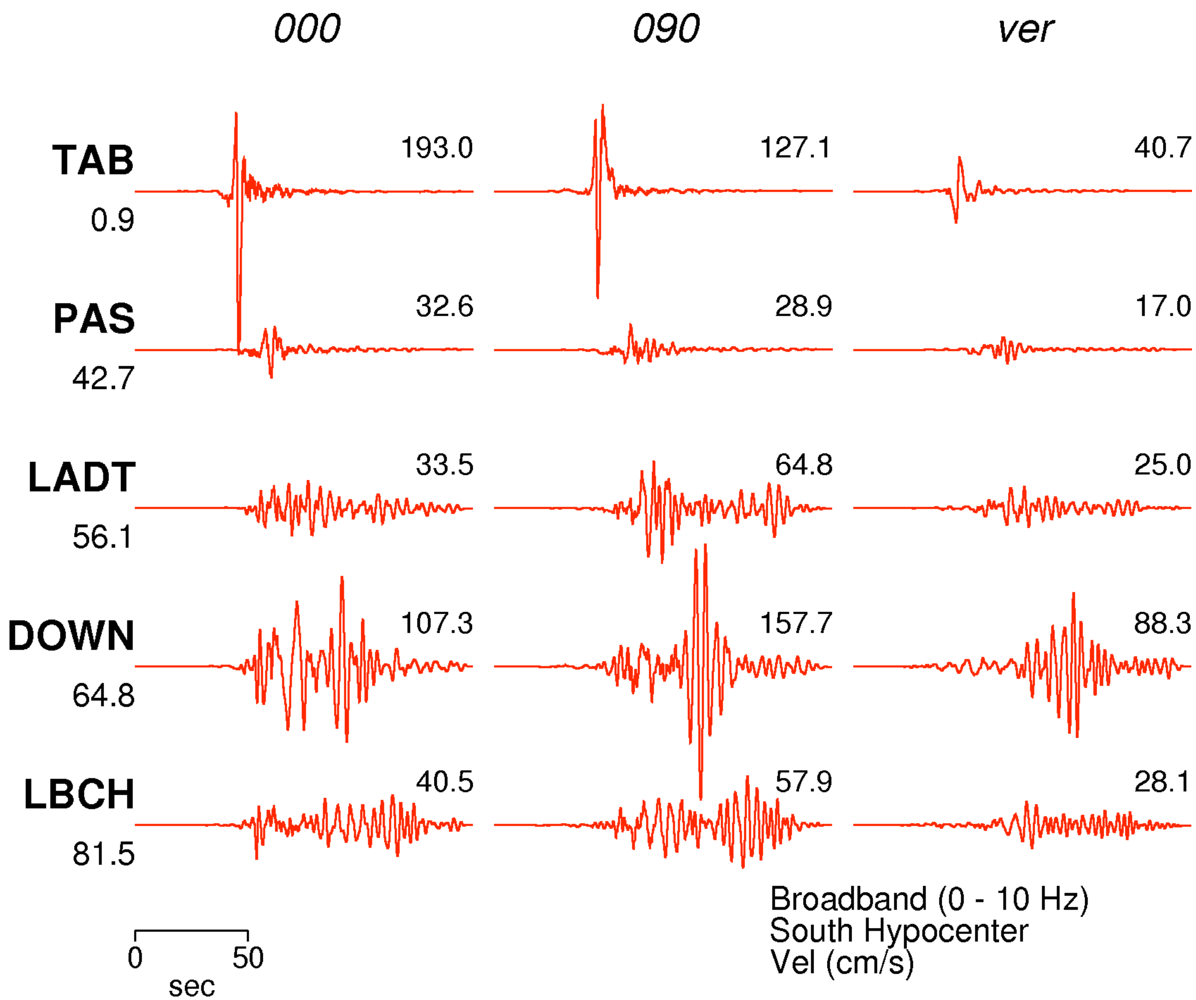
RWG ShakeOut (v1.2.0): T=3 s SA

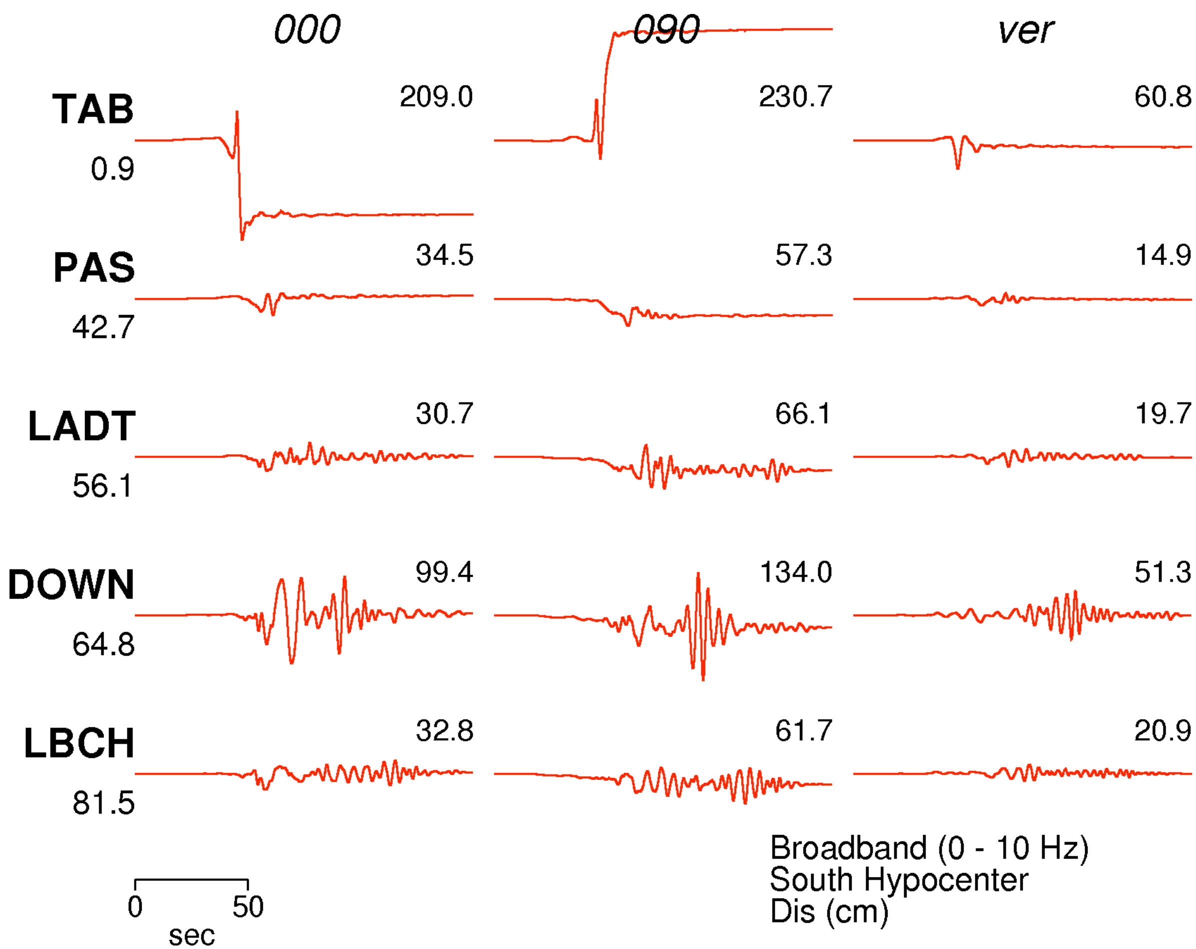
Broadband (0-10 Hz)

South Hypocenter



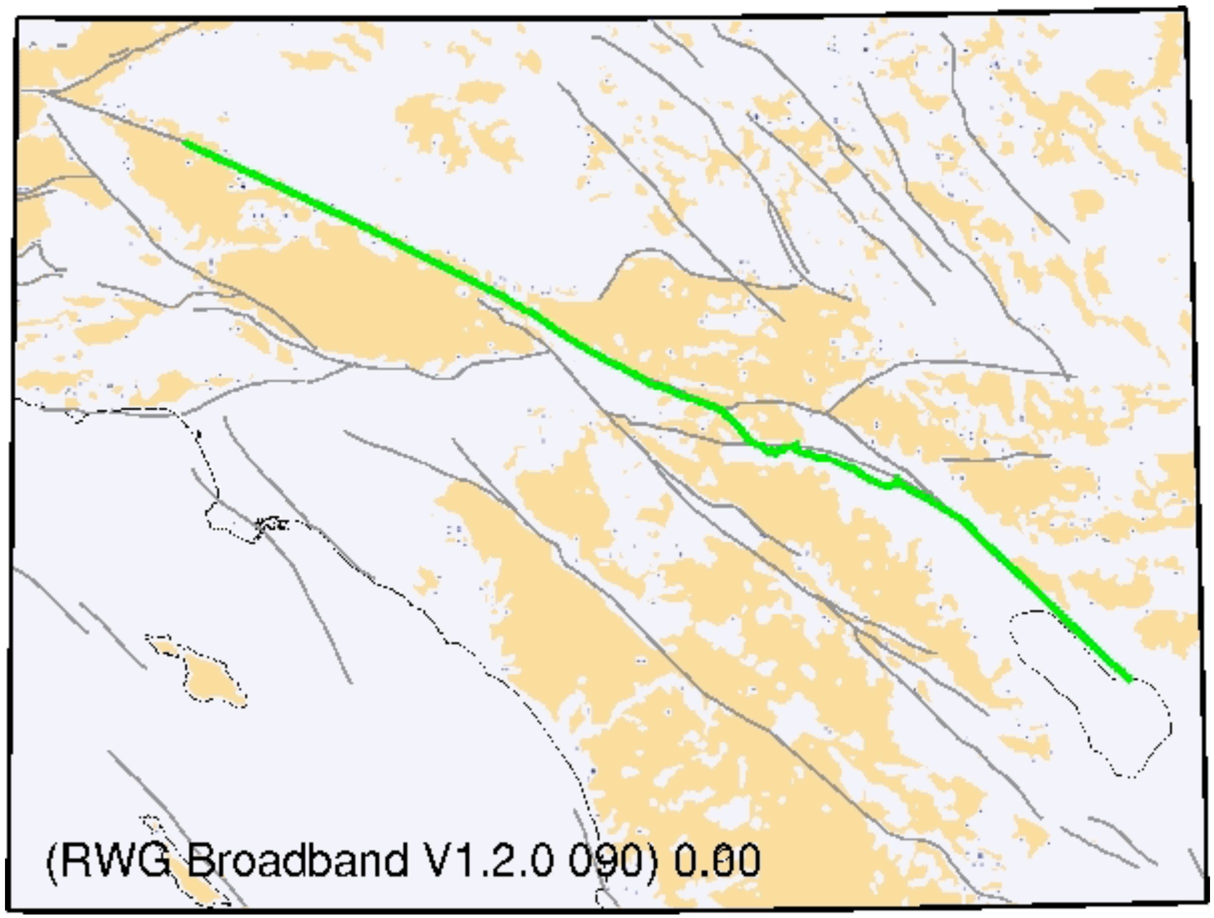

000
090
ver
TAB
0.9
737.7
598.4
164.8
PAS
42.7
104.9
77.0
37.0
LADT
56.1
99.9
165.4
57.6
DOWN
64.8
160.8
235.2
156.9
LBCH
81.5
99.1
103.8
44.9
0
50
sec
Broadband (0 - 10 Hz)
South Hypocenter
Acc (cm/s/s)


000
090
ver
TAB
0.9
193.0
127.1
40.7
PAS
42.7
32.6
28.9
17.0
LADT
56.1
33.5
64.8
25.0
DOWN
64.8
107.3
157.7
88.3
LBCH
81.5
40.5
57.9
28.1
0
50
sec
Broadband (0 - 10 Hz)
South Hypocenter
Vel (cm/s)


000
090
ver
TAB
0.9
209.0
230.7
60.8
PAS
42.7
34.5
57.3
14.9
LADT
56.1
30.7
66.1
19.7
DOWN
64.8
99.4
134.0
51.3
LBCH
81.5
32.8
61.7
20.9
0
50
sec
Broadband (0 - 10 Hz)
South Hypocenter
Dis (cm)

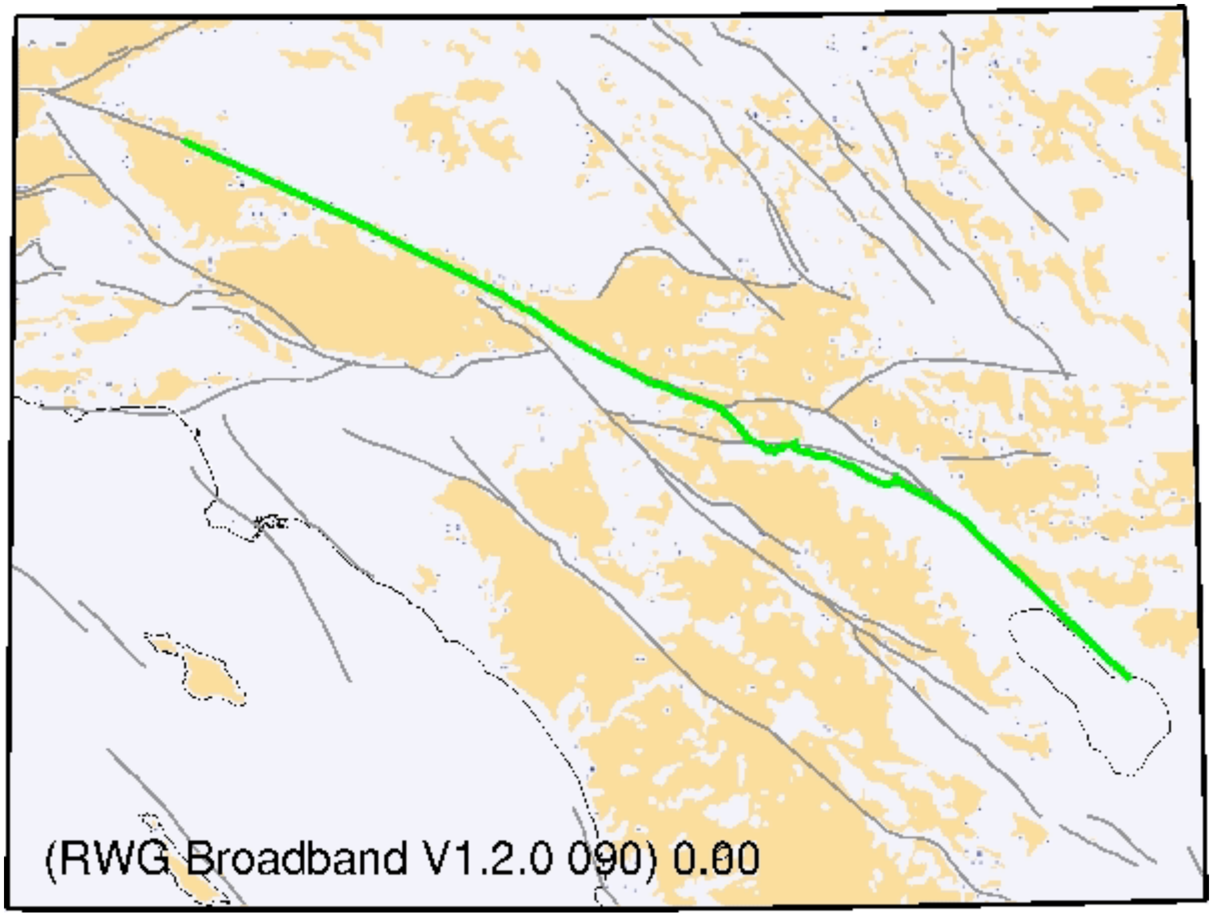
Ground Motion Animation:

- **Central Hypocenter**

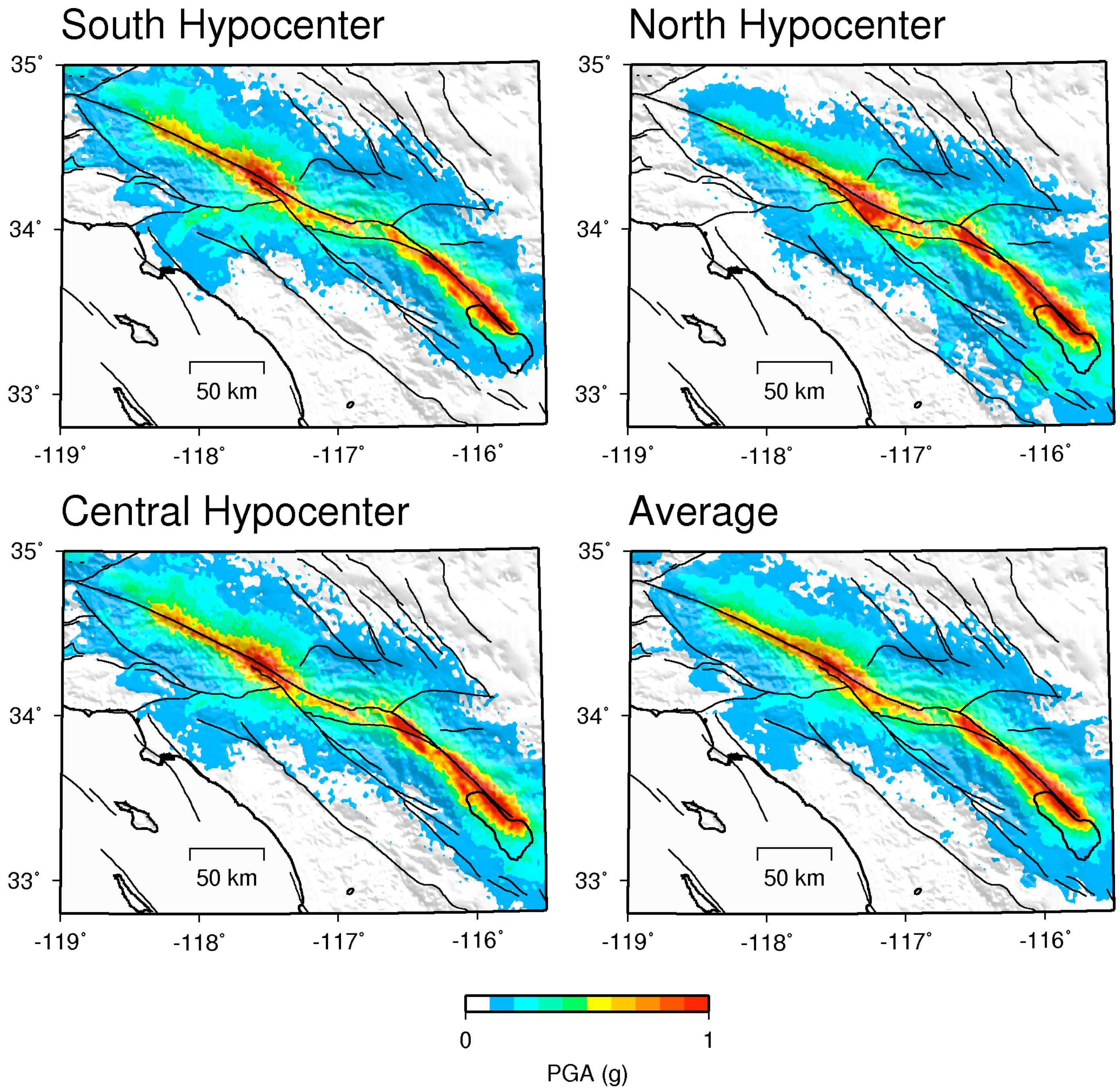


Ground Motion Animation:

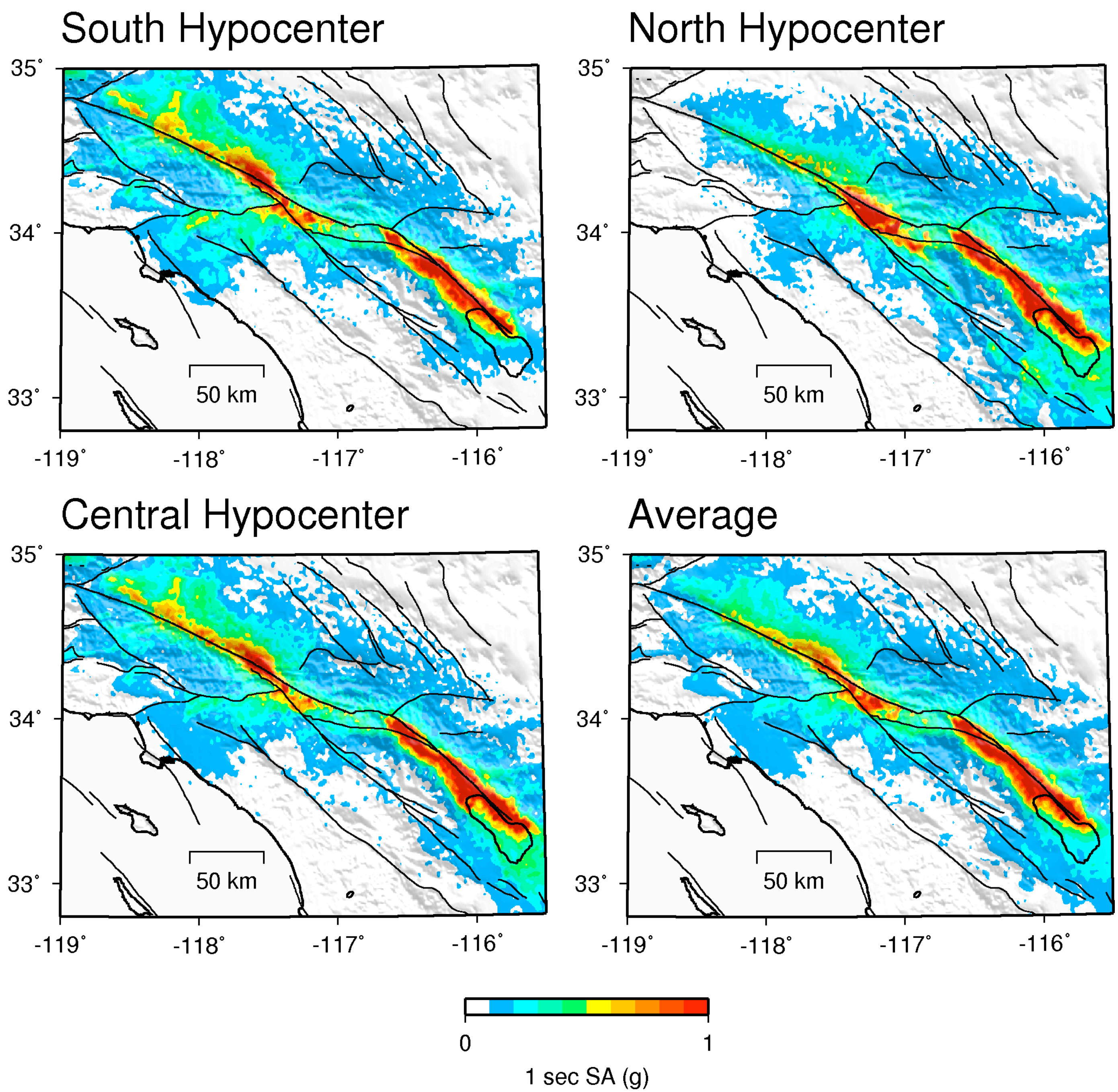
- **North Hypocenter**



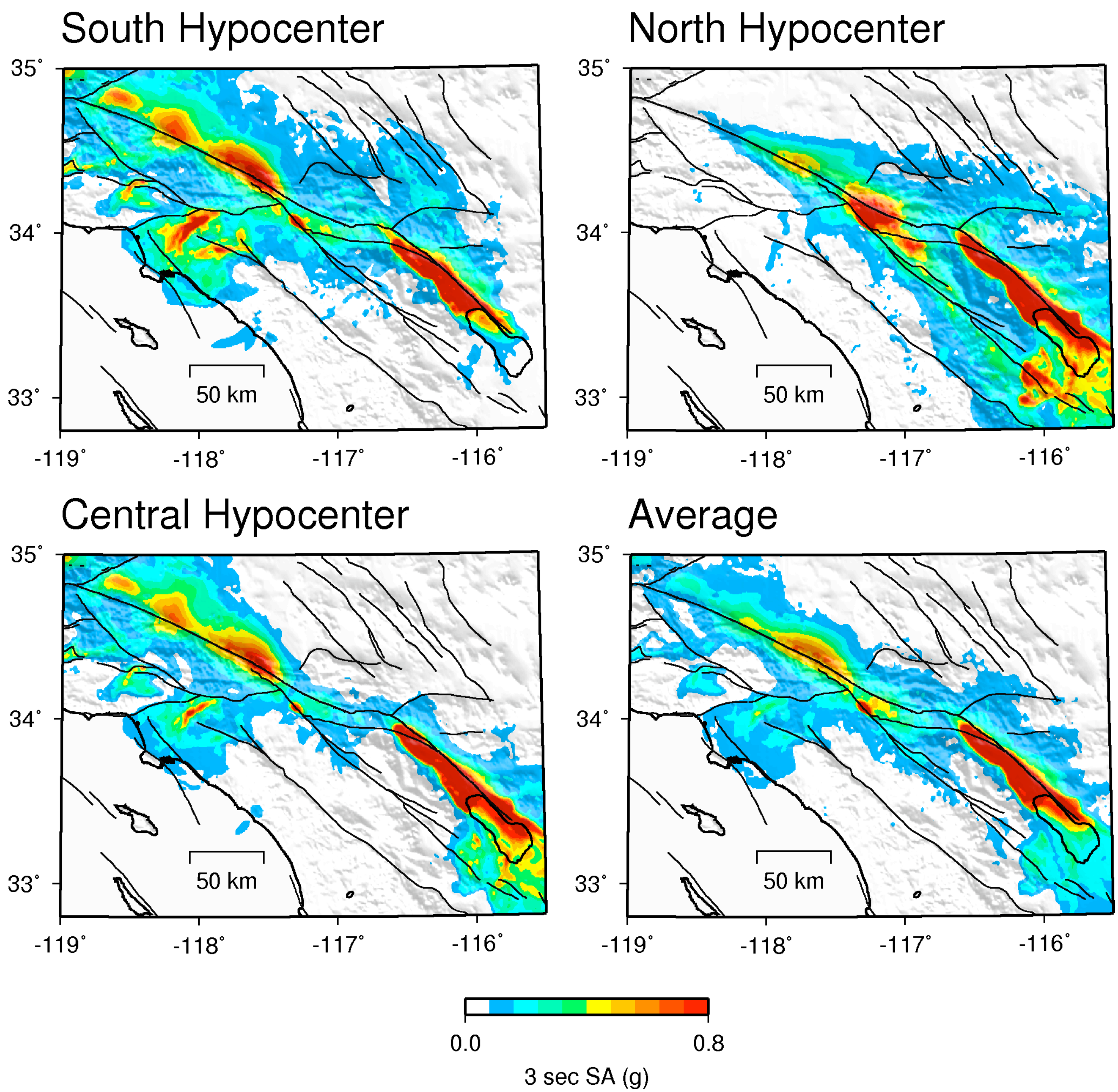
PGA

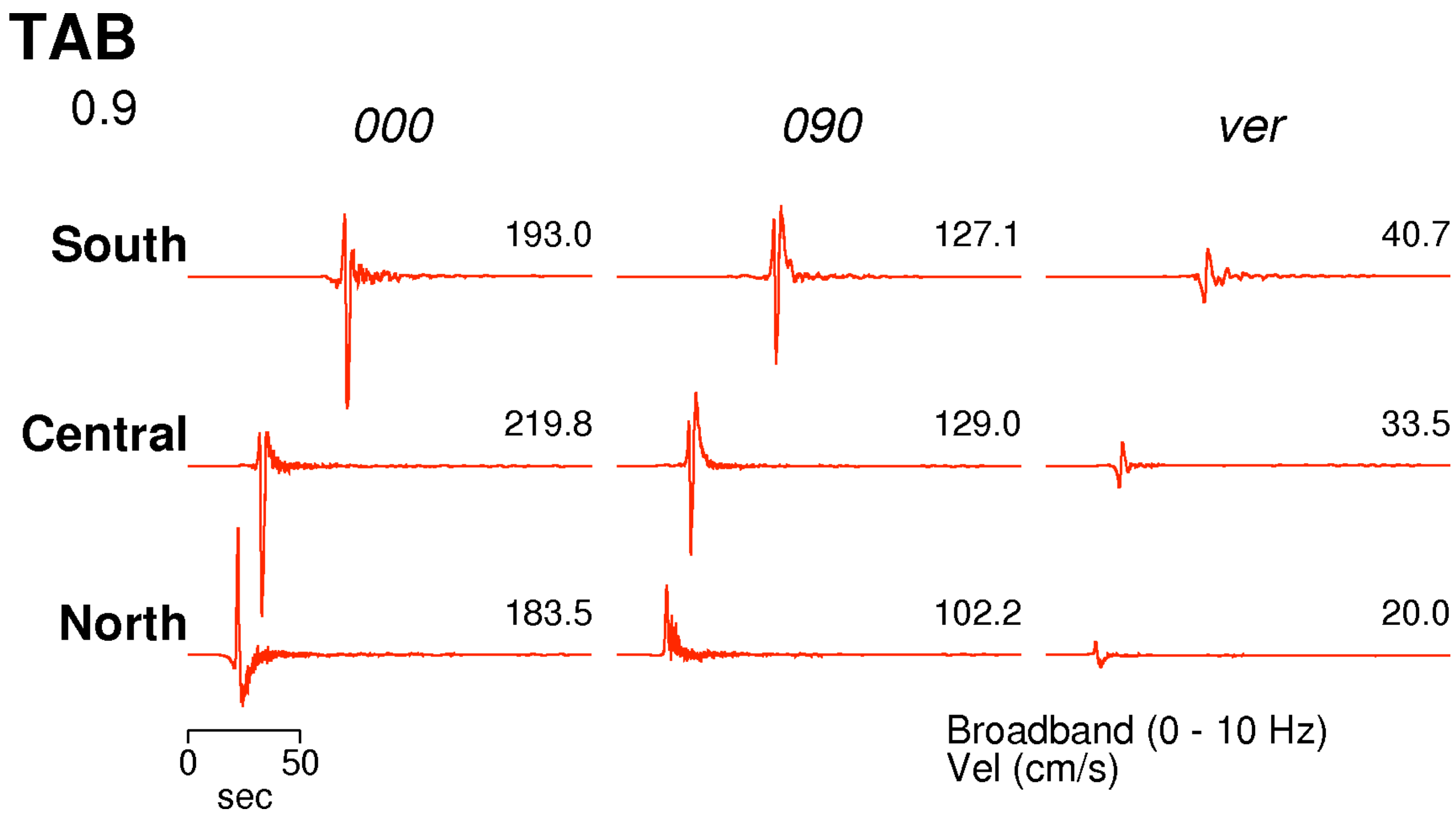

South Hypocenter
North Hypocenter
Central Hypocenter
Average
35˚
34˚
33˚
-119˚
-118˚
-117˚
-116˚
50 km
0
1
PGA (g)

1 sec SA

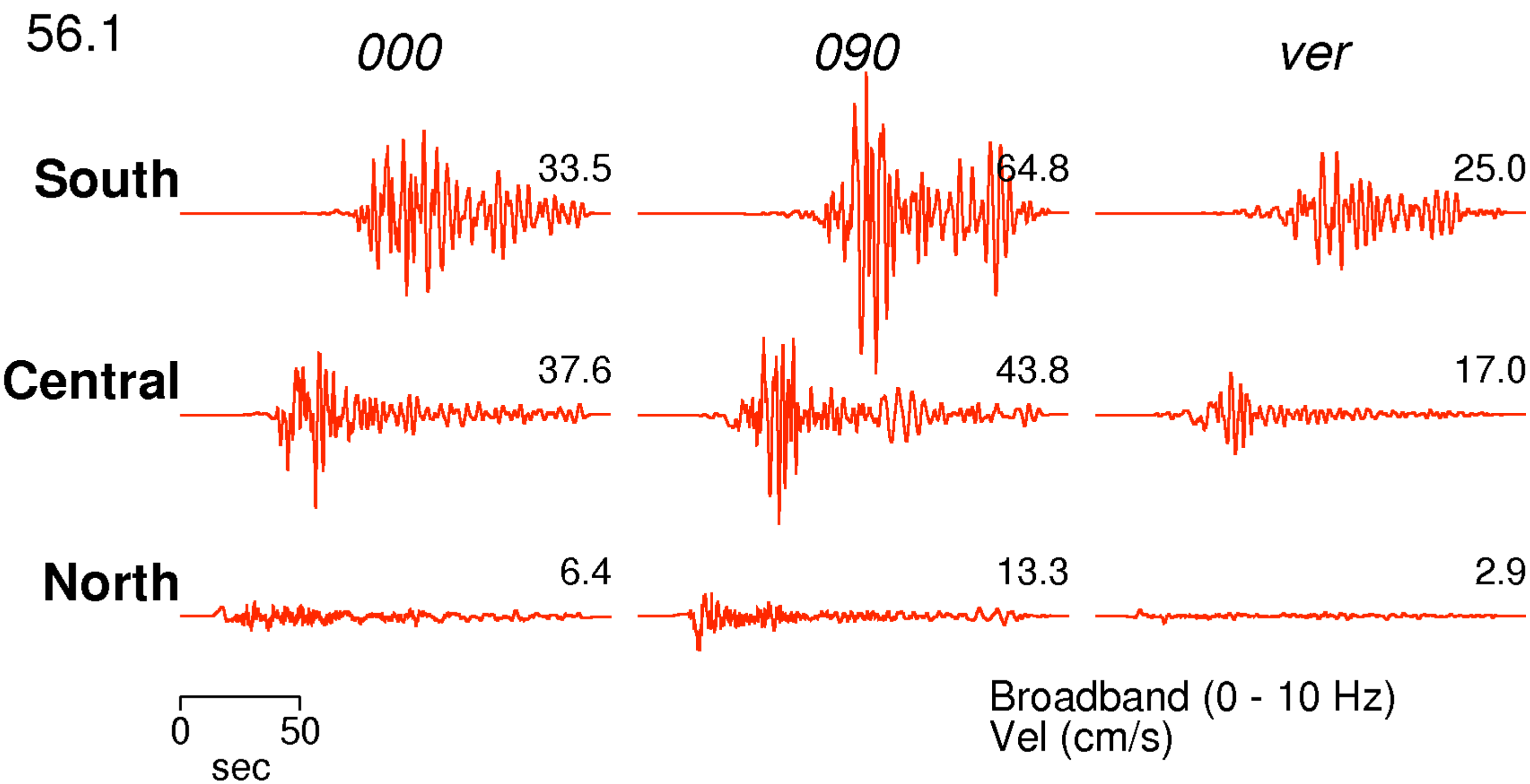

South Hypocenter
North Hypocenter
Central Hypocenter
Average
35˚
34˚
33˚
-119˚
-118˚
-117˚
-116˚
50 km
0
1
1 sec SA (g)

3 sec SA

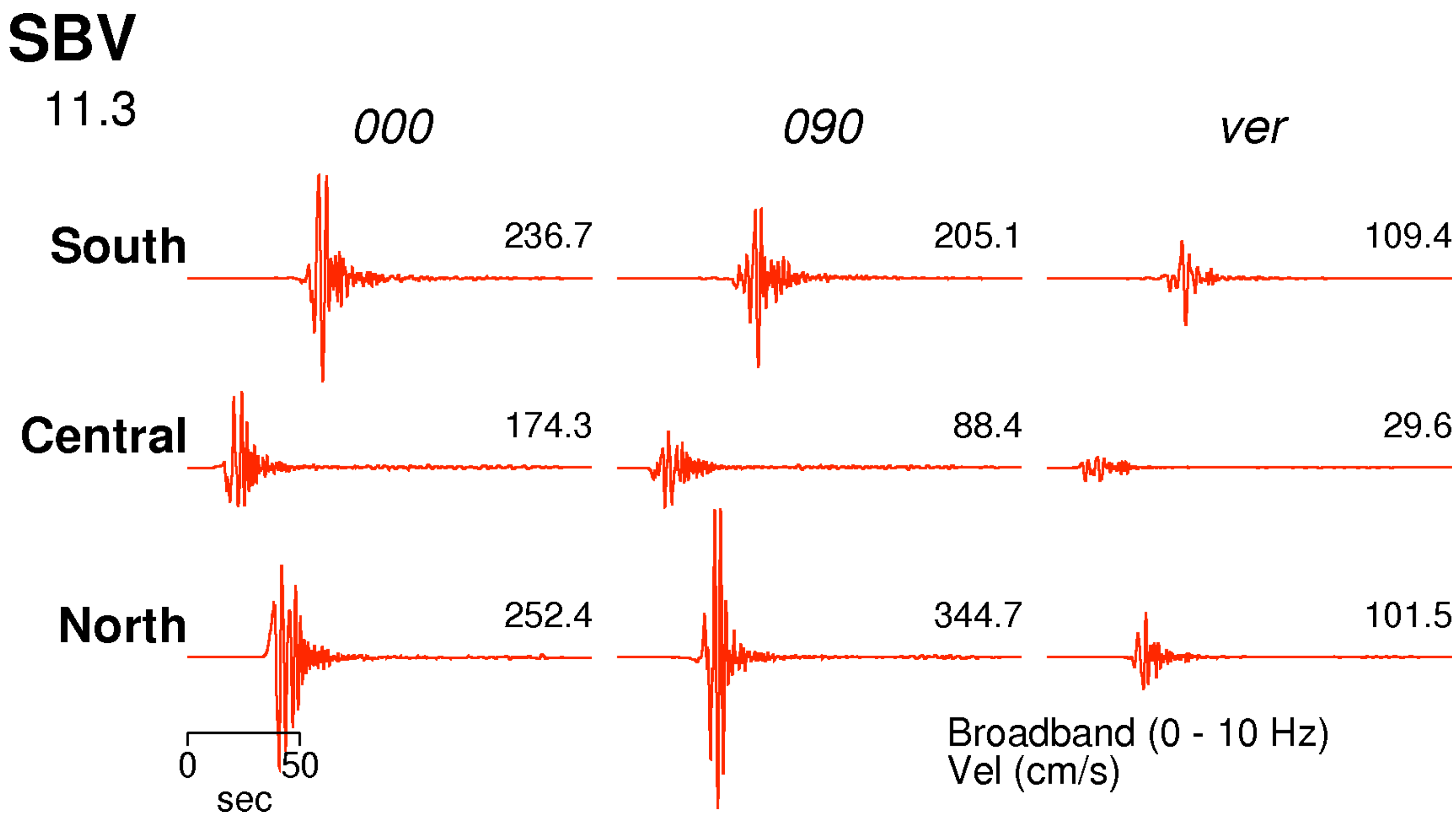

South Hypocenter
North Hypocenter
Central Hypocenter
Average
35˚
34˚
33˚
-119˚
-118˚
-117˚
-116˚
50 km
0.0
0.8
3 sec SA (g)


TAB
0.9
000
090
ver
South
193.0
127.1
40.7
Central
219.8
129.0
33.5
North
183.5
102.2
20.0
0
50
sec
Broadband (0 - 10 Hz)
Vel (cm/s)

LADT

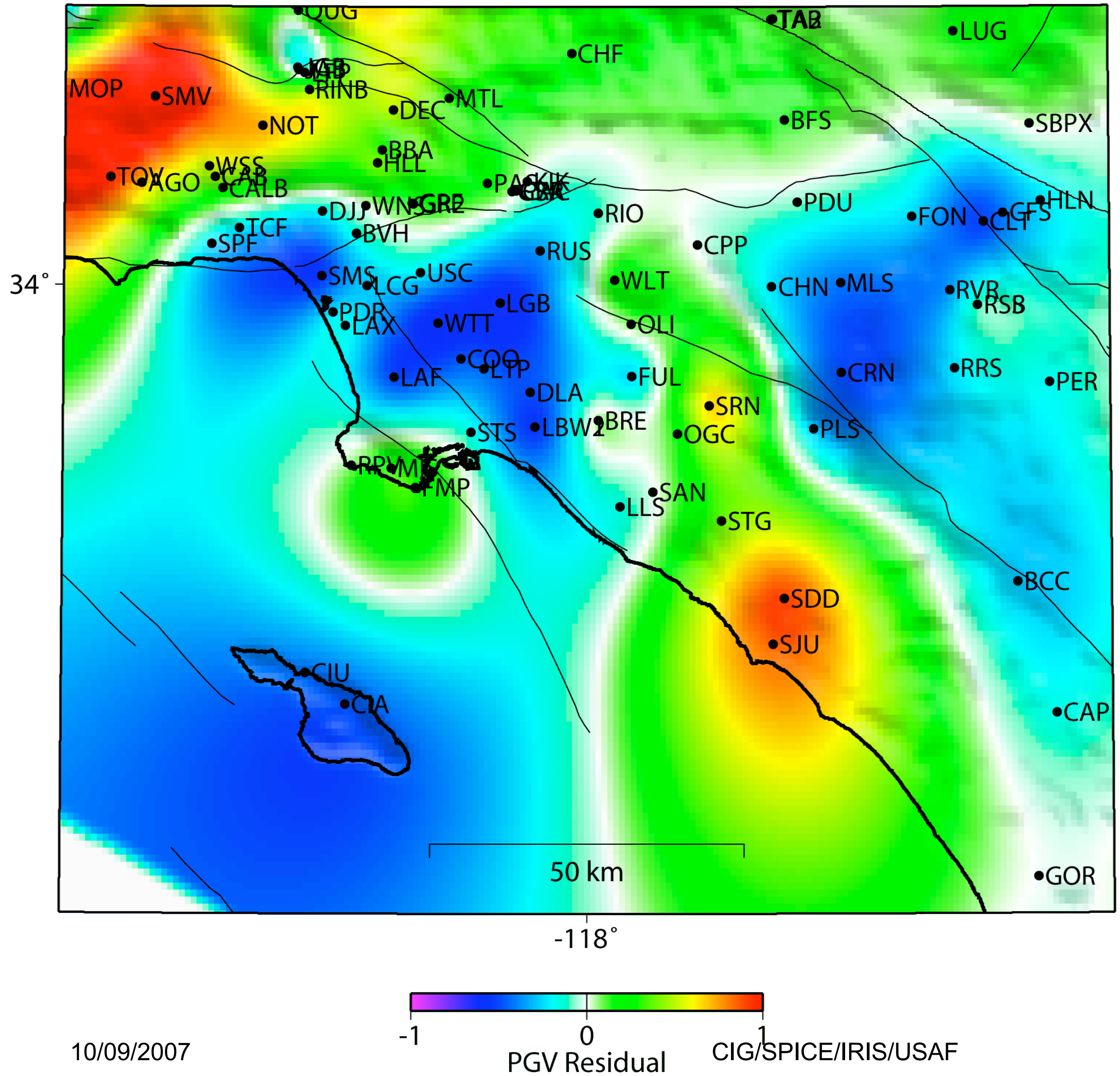


56.1
000
090
ver
South
33.5
64.8
25.0
Central
37.6
43.8
17.0
North
6.4
13.3
2.9
0
50
sec
Broadband (0 - 10 Hz)
Vel (cm/s)


SBV
11.3
000
090
ver
South
236.7
205.1
109.4
Central
174.3
88.4
29.6
North
252.4
344.7
101.5
0
50
sec
Broadband (0 - 10 Hz)
Vel (cm/s)

3D Velocity Structure Uncertainty

(Mw 4 Devore EQ)



- **SCEC CVM v4:**

  30 – 50% higher simulated PGV in LA/Chino basins (BLUE)

- **Harvard CVM v2:**

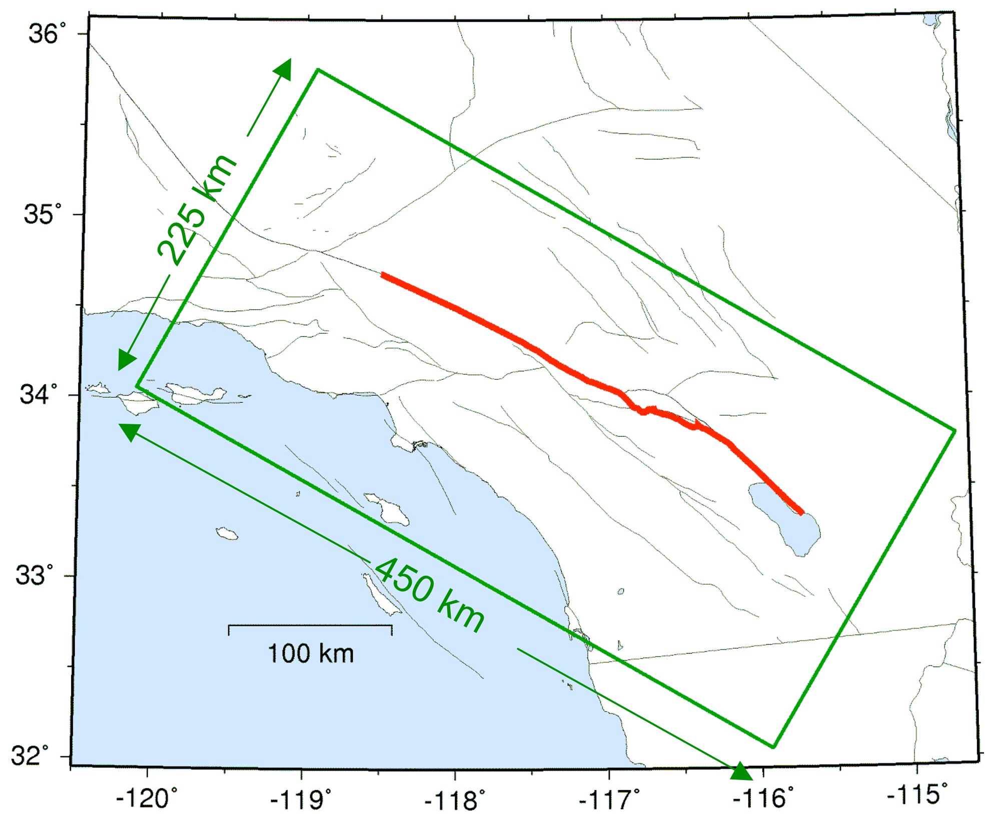
  30 – 50% higher simulated PGV in SF/Ventura basins (RED)

Broadband ShakeOut Simulation Summary

- Strong shaking over large area of southern California
- Strong rupture directivity effects (near fault)
- Significant basin amplification at longer periods ($T > 1$ sec), strongly coupled with directivity (even > 50 km from fault)
- Multiple realizations (hypocenters) allow for quantification of average response and variability about mean
- Median response similar to empirical models at shorter periods ($T < 1$ sec), larger than empirical models at longer periods
- Research in progress …
  - Damage and loss estimates using HAZUS
  - Landslide/liquefaction hazards
  - Lifeline (pipelines/highways/railroads) impacts
  - Structural analysis of tall buildings

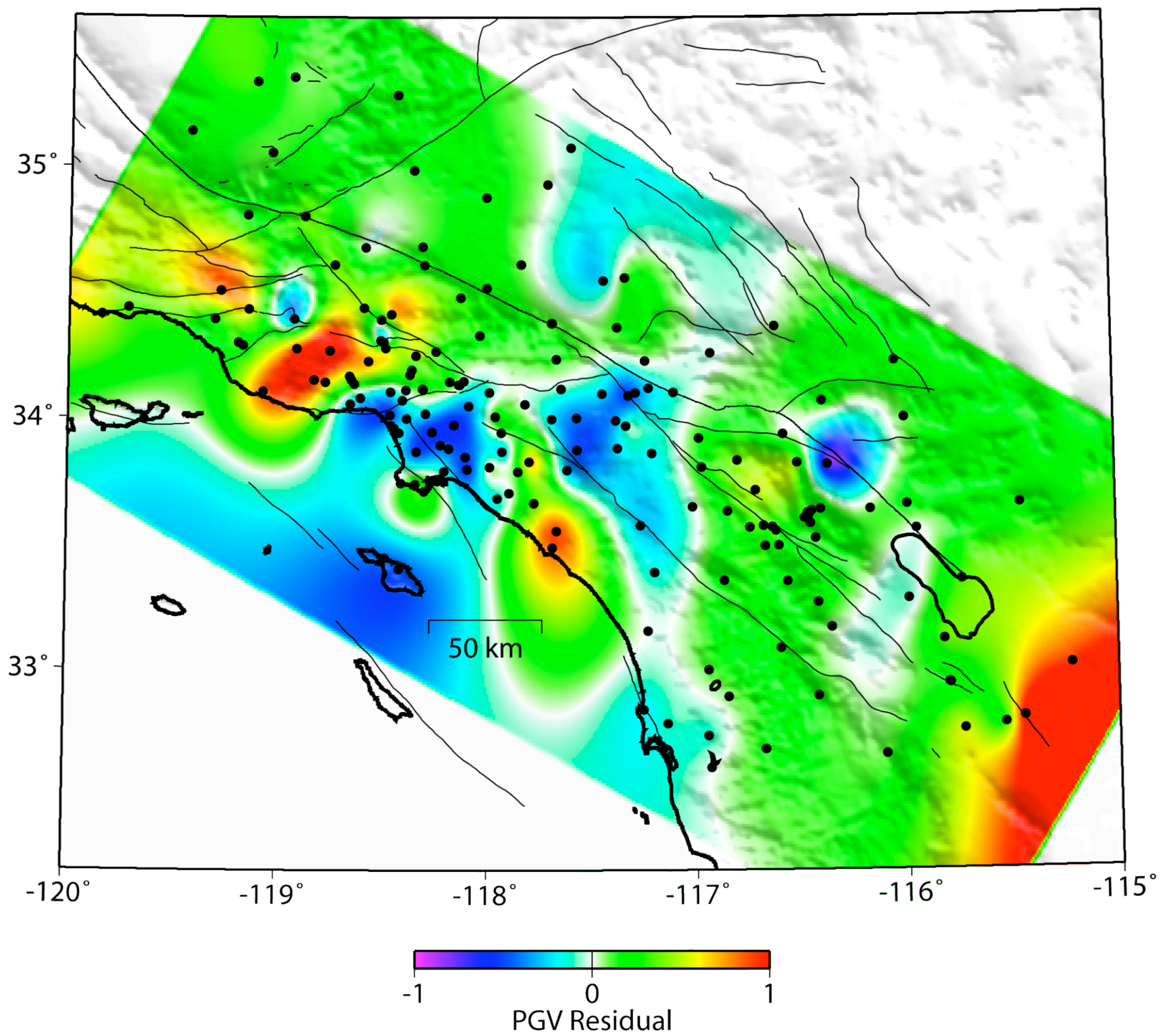
3D Computational Model

- 450 km x 225 km x 45 km
- 2.33 x 10^9 grid points
- h = 125 m
- Vsmin = 620 m/s
- SCEC CVM version 4.0
- Computational Requirements
  - MPI coding
  - HPCC Linux cluster (USC)
  - 520 CPUs
  - 260 Gb RAM
  - 24 hour runtime



Devore EQ: Vel0.025-0.25

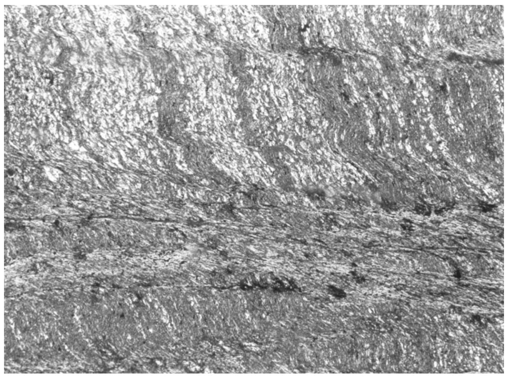
CVM-Hv2(CIT) / CVM-v4(RWG)

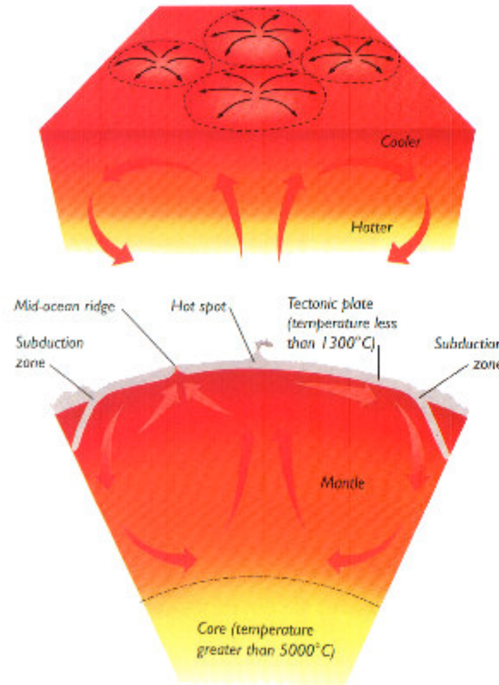


Mantle dynamics / Plate Tectonics

Rock micro-fracture

Earthquake rupture





10^{-3} meter
10^{-1} sec

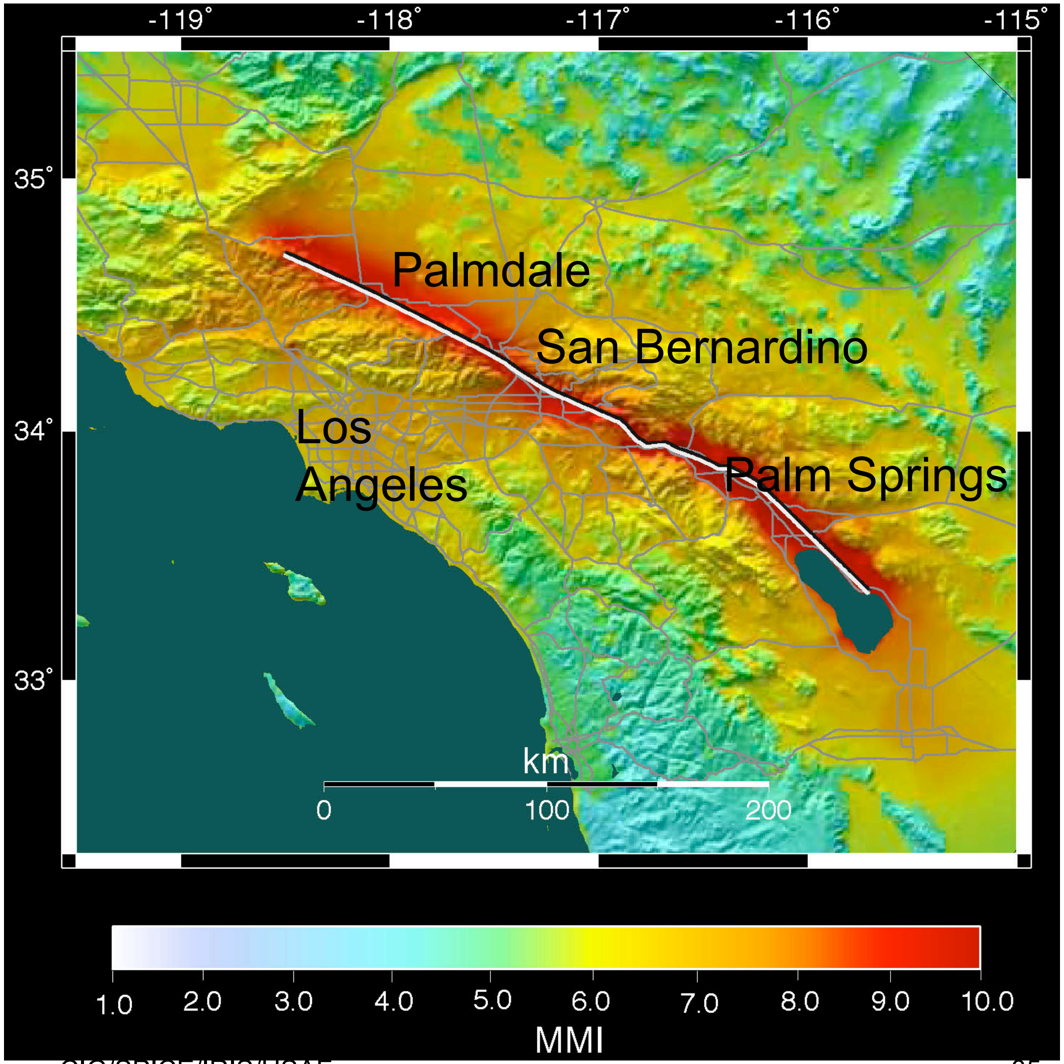
10^{4} meter
10^{2} sec

10^{6} meter
10^{10} sec

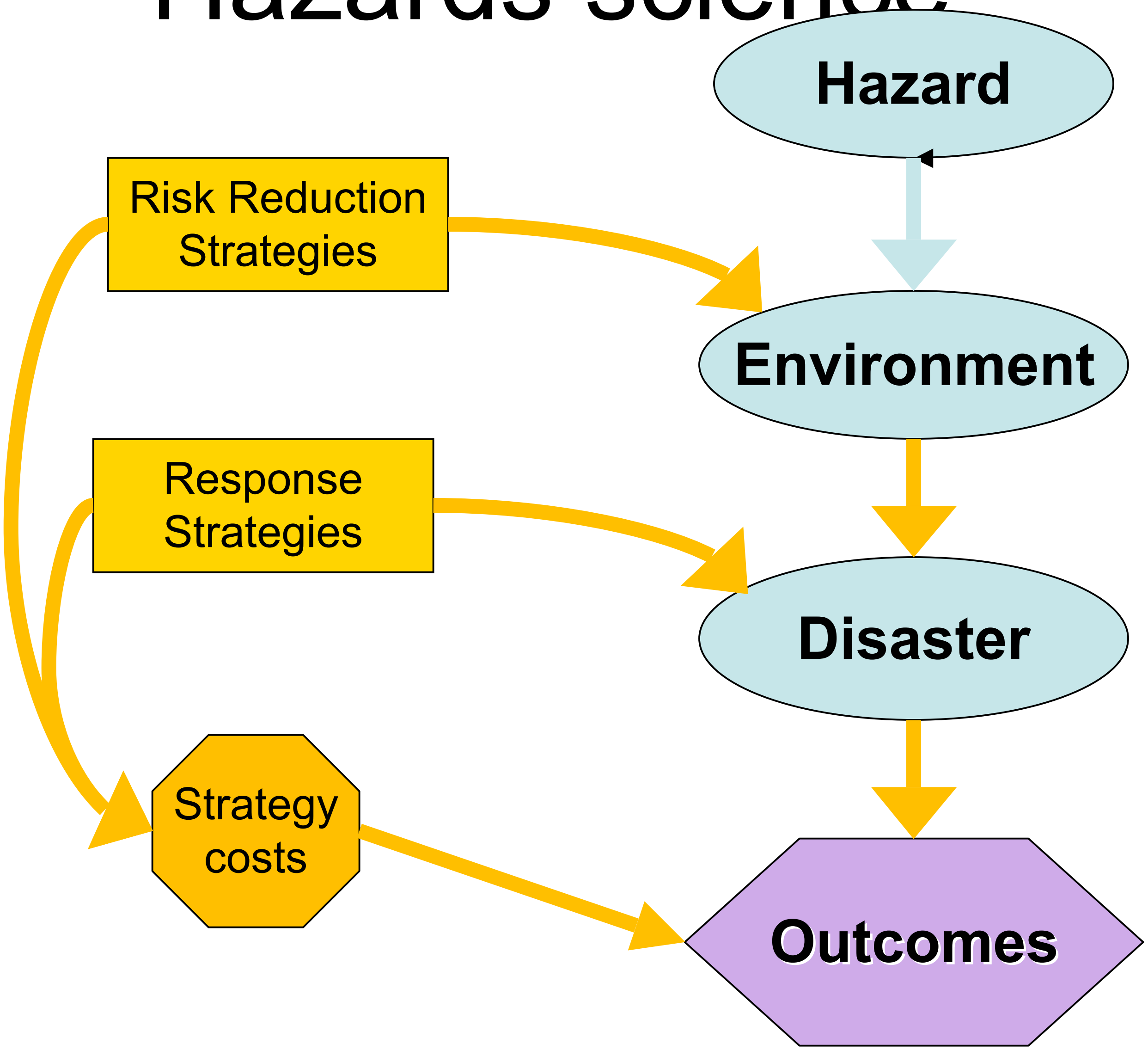
Spatial/temporal length scales vary over 10 orders of magnitude!

Scenario Earthquake

- 300 km long
- Mw 7.8
- 100 second duration

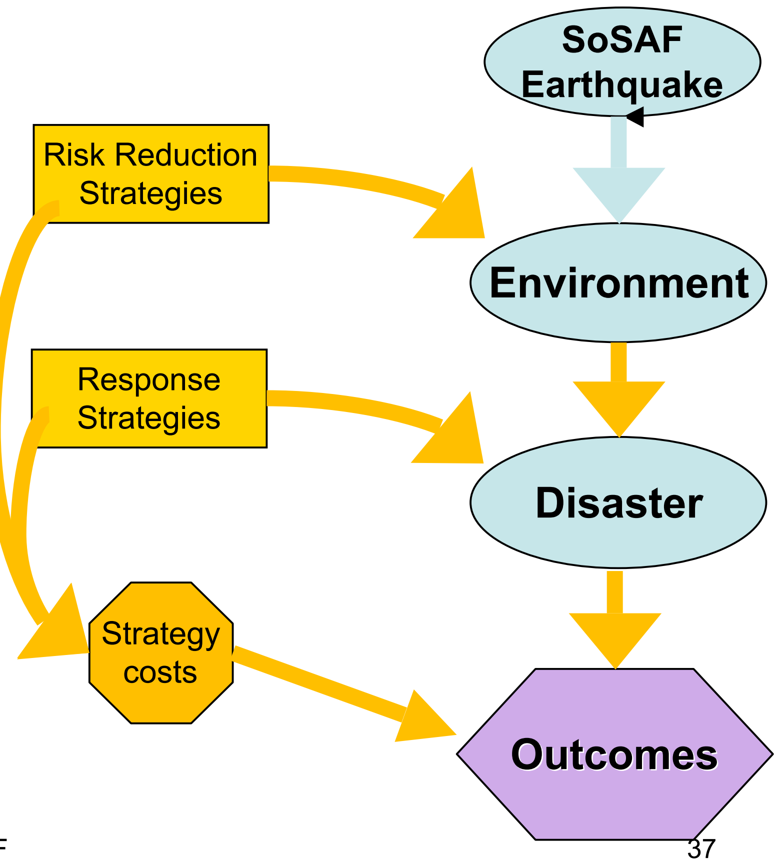


Hazards science



Earthquake scenario

- One realization of the hazard influence diagram where the probability of the hazards is assumed to be one.
- Total impact for all outcomes:
  - Economic
  - Life safety
  - Ecologic
  - Social
  - cultural



Planning for the *Big One*

1. Create a description of the earth movements
2. Estimate physical damages
3. Evaluate probable social & economic consequences
4. Plan for emergency response

5. Foster change?