ShakeOut Scenario 2.0: Dynamic Rupture Modeling of the M7.8 Earthquake on Southern San Andreas Fault and the Resulting Long-Period Ground Motion

Laura Grenot Jones[1]; Clare Ip[2]; Tomoka Ohmori[3]; Ashley Seeman[4]; Kristen Chiama[5], Chunhui Zhao[5]; Ahmed Elbanna[5]

[1]University of California, Los Angeles, [2]Dartmouth College, [3]Princeton University, [4]San Diego State University, [5]Statewide California Earthquake Center

1. Abstract

Southern California sits atop the southern San Andreas Fault, which has not produced a major rupture in over 300 years and is widely regarded as capable of a magnitude ~7.8 earthquake. Anticipating how such an event would nucleate, propagate, and shake the Los Angeles region is central to hazard assessment for millions of people. The 2008 ShakeOut scenario established a landmark M7.8 simulation using a kinematic source with pre-assigned slip. Dynamic rupture modeling relaxes this assumption, letting slip emerge spontaneously from fault stress and friction. We present dynamic rupture simulations run with SeisSol on the Quakeworx/Expanse HPC platform, integrating SCEC Community Earth Models for fault geometry (CFM 7.0), velocity structure (CVM), stress (CSM), and thermal structure (CTM). We set the hypocenter at 33°28'32.1"N, 115°52'33.1"W at 10 km depth and employ rate-and-state friction with enhanced dynamic weakening, testing two fault geometries and a range of stress conditions. Rupture directivity focuses stronger shaking toward the Los Angeles Basin, establishing a baseline for physics-based hazard assessment in southern California.

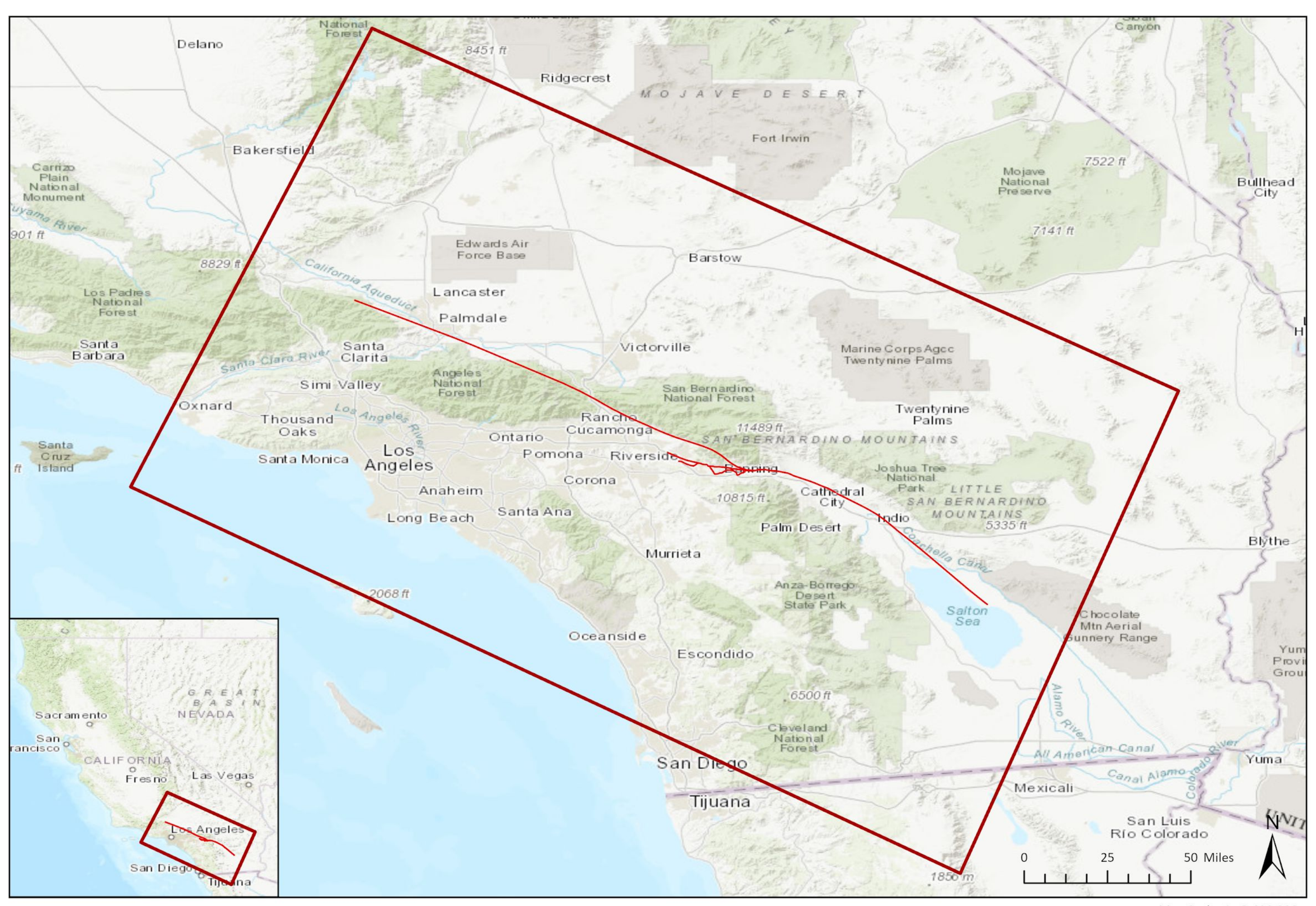


Figure 1: Map of the modeled M7.8 rupture trace (red) along the southern San Andreas Fault, extending from the Salton Trough region toward the Los Angeles region. The inset (right) shows the location within California for regional context.

Model Inputs: Fault Geometry and Velocity Structure

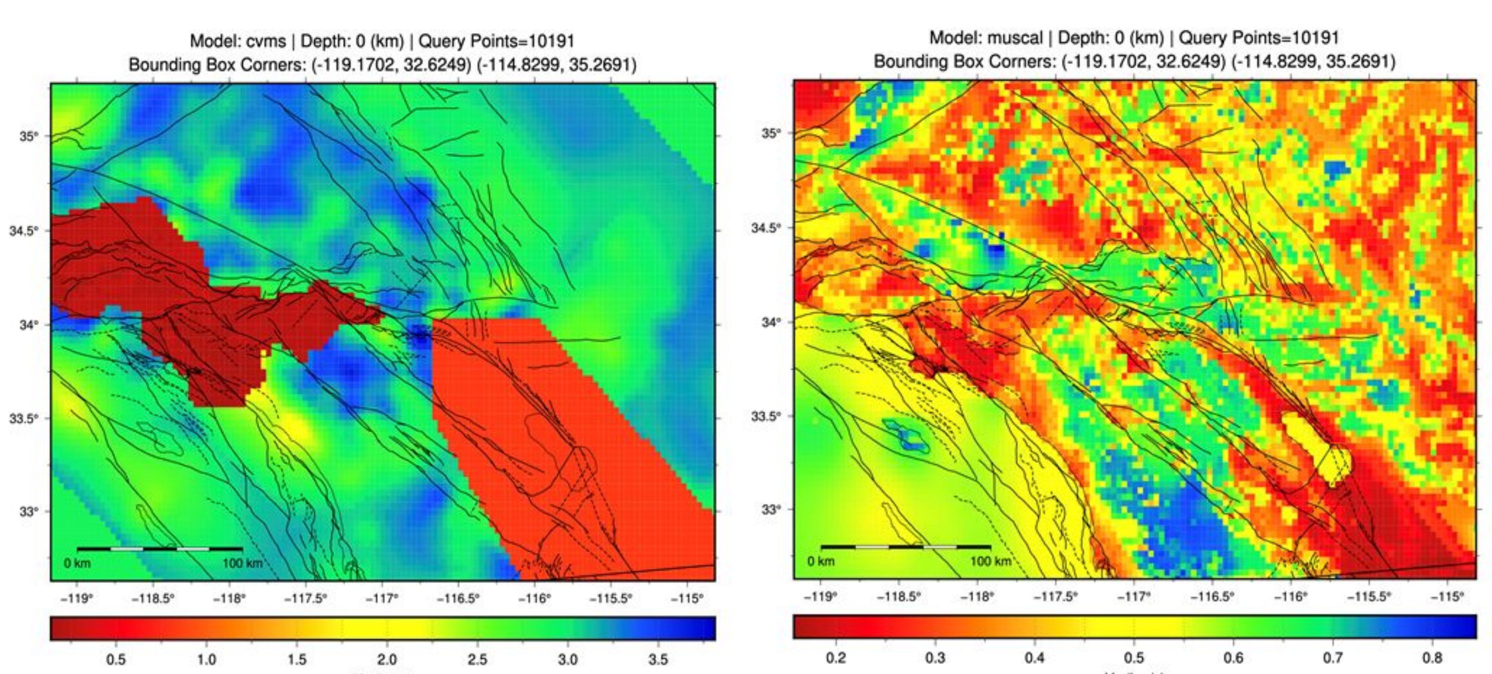
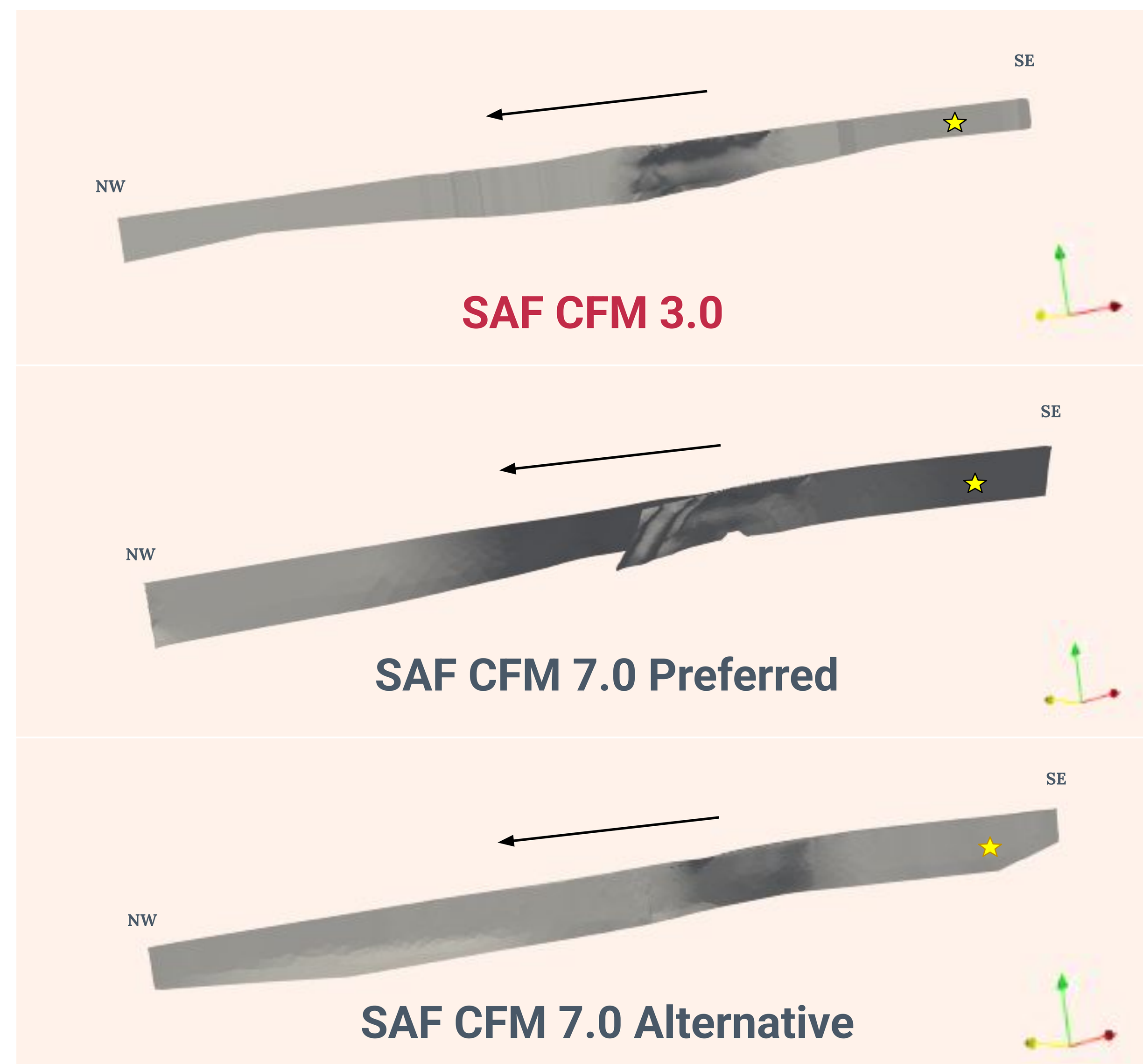


Figure 2: Comparison of Community Velocity Model (CVM) at free surface of ShakeOut 1 (left) vs ShakeOut 2.0 (right)

Figure 3: Three representations of the southern San Andreas Fault geometry used as model inputs, with the hypocenter marked (yellow star) near the SE end. Top: SCEC Community Fault Model (CFM) 3.0, the geometry used in ShakeOut 1. Middle: CFM 7.0 Preferred used in ShakeOut 2.0. Bottom: CFM 7.0 Alternative used in ShakeOut 2.0. The Arrows indicate rupture propagation direction.



2. Methodology

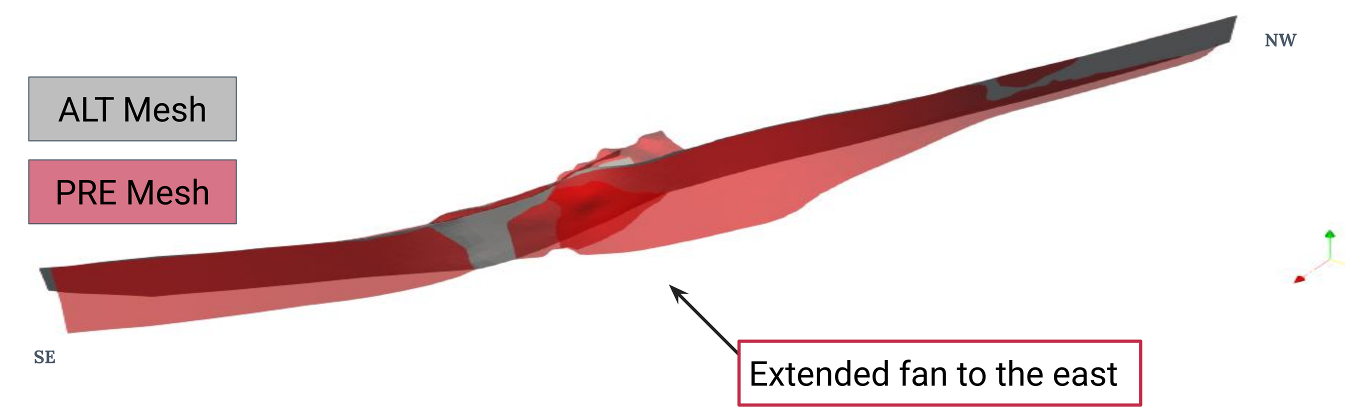


Figure 5: Combined fault geometry for the CFM 7.0 Preferred and Alternate model, both used in ShakeOut 2.0

- ★ **Fault geometry**
  - All ruptures nuclear on the southeastern end of the SAF at 10 km depth and propagate northwestward, consistent with ShakeOut 1
- ★ **Stress**
  - Principal stress orientations taken from CSM Hauksson model [4]
  - Vertical stress as σ_2 according to Anderson model
  - Test various k-values to achieve ~Mw 7.8 earthquake
  - Projecting stress tensors onto fault surface using strike and dip angles
- ★ **Friction**
  - Shear traction always equals frictional strength
  - Depth-dependent friction parameters are derived from the Community Thermal Model (CTM), with temperature increasing with depth [2] [3]
  - Case 1 sees velocity-strengthening near the surface and at depth, while case 2 sees velocity-strengthening only at depth

0. SCEC Model

Community Fault Model
Alternate/Preferred fault geometry

Community Velocity Model (MuSCAL)
Density ρ(z), velocity (Vs, Vp)

Community Thermal Model
Rate-and-state friction
Strong rate-weakening friction parameters

Community Stress Model
Orientations for tectonic stresses

Simulation Target
Mw 7.8 Earthquake

1. Set Scenarios

Nucleation: Southern part of San Andreas Fault
Depth: 10 km

A. Alternative mesh
Less dynamic weakening at shallow fault zone

B. Alternative mesh
Enhanced dynamic weakening at shallow fault zone

C. Preferred mesh
Less dynamic weakening at shallow fault zone

D. Preferred mesh
Enhanced dynamic weakening at shallow fault zone

2. Run SeisSol [5]

Simulation results
- Moment Magnitude
- Max/Avg Slip

3. Calibrate Stress

1. Principal stress orientations

$R = \frac{\sigma_1 - \sigma_2}{\sigma_1 - \sigma_3}$, S_{Hmax} azimuth angles

2. Vertical stress as the intermediate principal stress

$$\sigma_2 = S_v^{eff}(z) = \int_0^z \rho g dz' - P_p$$

3. Constrain k-values

$k = \frac{\sigma_1}{\sigma_3}$

4. Project stress tensor onto fault surface

4. Rupture and Peak Ground Velocity Analysis

Peak Ground Velocity (PGV)
Compute, visualize, and animate PGV

Data Visualization
- Slip distribution
- Surface slip distribution
- Shear traction in strike and dip directions
- Initial normal stress
- Apparent friction over time

Figure 5: Workflow for developing M7.8 simulations and ground-motion maps

Acknowledgements

This research was supported by the Statewide California Earthquake Center. SCEC is funded by NSF Cooperative Agreement EAR-2225216 and USGS Cooperative Agreement G24AC00072-00. We acknowledge Mark Benthien for his mentorship throughout the internship and Gabriela Noriega for application review and onboarding process. We are grateful to Scott Callaghan, Fabio Silva, Akash bhattal, Kevin Milner, and Rob Graves for their enlightening instructions on topics related to seismic hazard, high performance computing, ground motion modeling, and science gateways. C.Z. And A.E. are grateful for the support from the Seisol team, Fabian kutchera, Gabrielle Hobson, and Alice Agnes Gabriel. The team is also grateful for the guidance from Andreas Plesch on the fault geometry meshing and the feedback and on-going discussions with Kate Scharer, Rob Graves, Ruth Harris, and Michael Barrel

3. Results

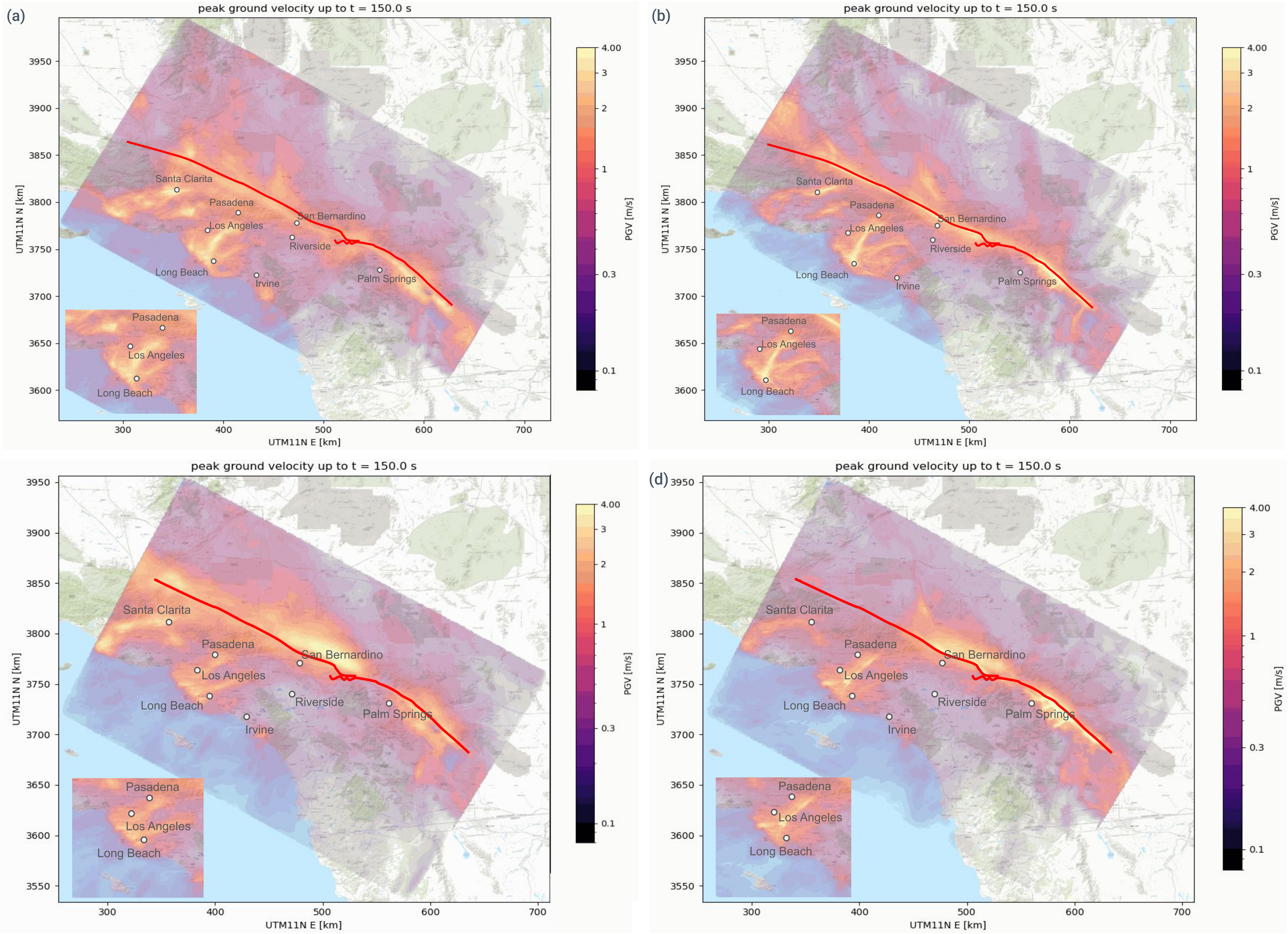


Figure 7: Annotated peak ground velocity (PGV) distribution comparison in Southern California with the LA Basin area. PGV distribution reflects fault geometries, subsurface velocity structure and directivity. (a) ALT case 1 (supershear rupture). (b) ALT case 2 (sub-Rayleigh rupture). (c) PRE case 1. (sub-Rayleigh) (d) PRE case 2 (sub-Rayleigh).

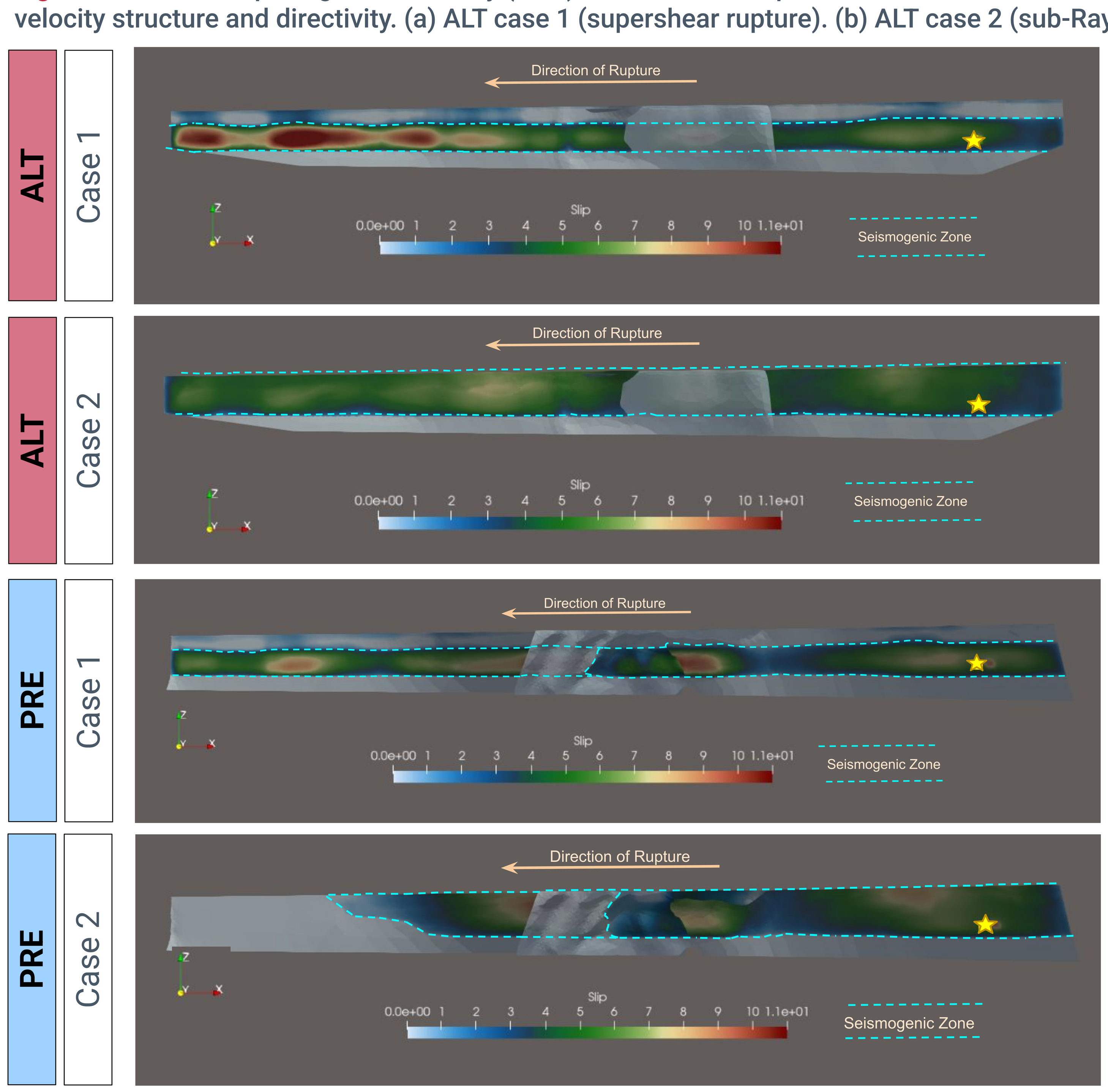


Figure 9: Final slip distribution comparison along the faults. (a) ALT case 1. (b) ALT case 2. (c) PRE case 1. (d) PRE case 2.

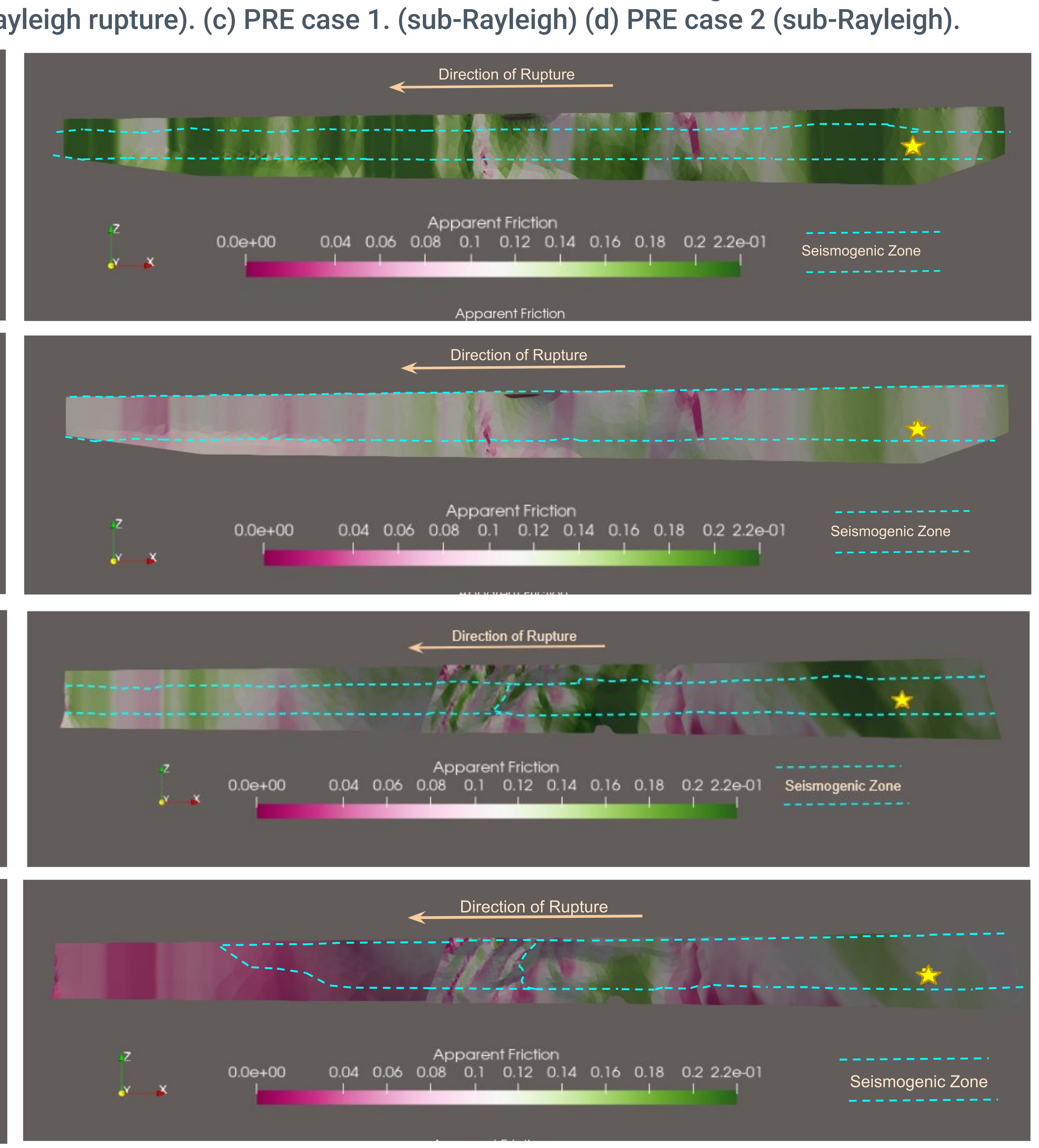


Figure 10: Initial apparent friction comparison along the fault. (a) ALT case 1. (b) ALT case 2. (c) PRE case 1. (d) PRE case 2.

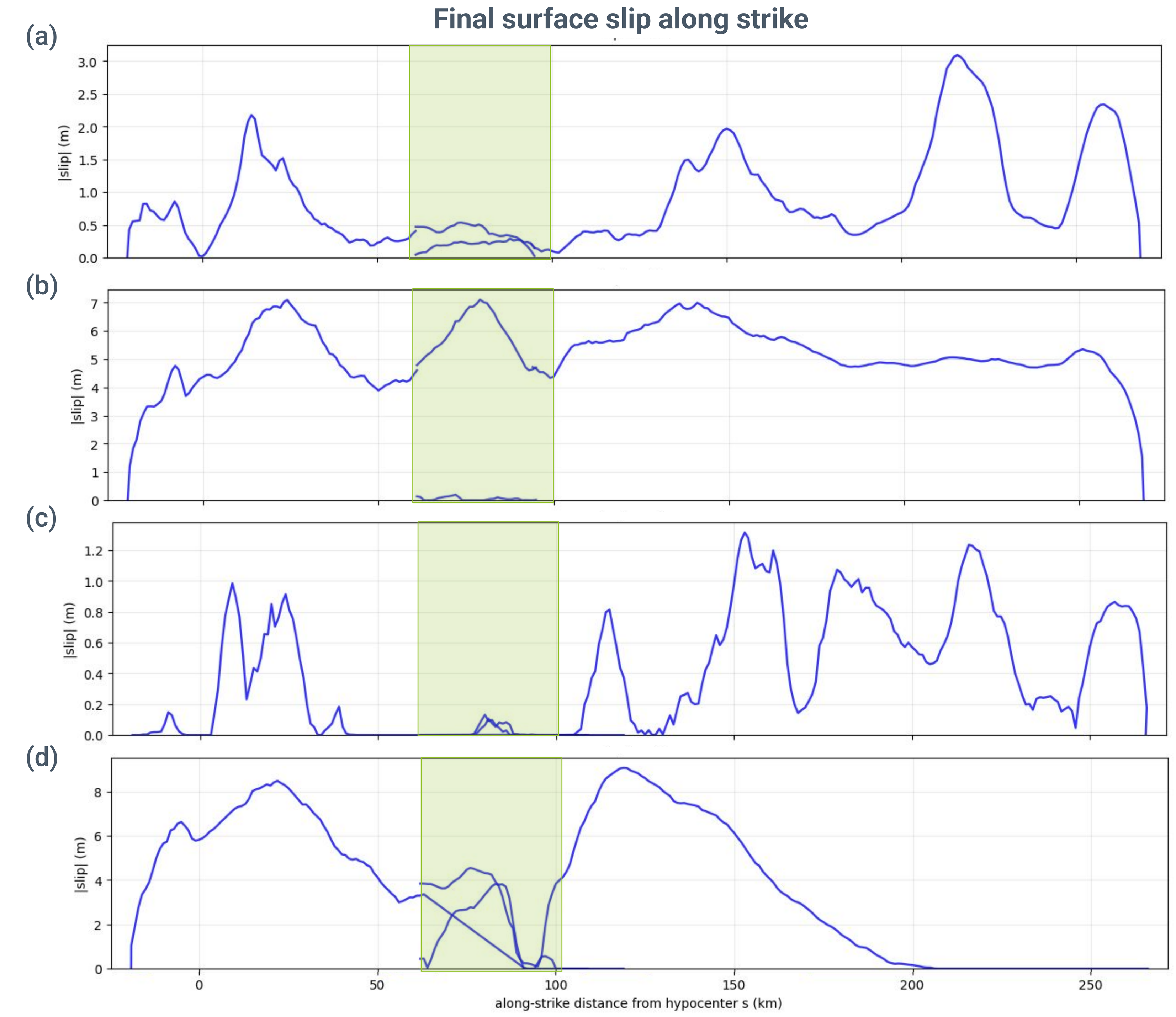


Figure 8: Surface slip distribution; positive x-axis represent the rupture to the north section of the fault, with San Gorgonio Path indicated with a green box. (a) ALT case 1. (b) ALT case 2. (c) PRE case 1. (d) PRE case 2.

Mesh	ALT elastic	ALT elastic	PRE elastic	PRE elastic
Case	1	2	1	2
k-value: Before the structural knot	1.65	1.4	1.7	1.45
k-value: After the structural knot		1.25	1.4	1.1
Moment magnitude	7.81	7.85	7.84	7.81
Peak slip [m]	12.77	8.91	10.12	10.00
Avg. slip [m]	4.64	4.74	4.42	4.72
Area avg. Stress Drop [MPa]	11.47	6.51	11.65	6.26
Static Energy Stress Drop [MPa]	25.22	8.29	22.08	8.71
Spectral Stress Drop [MPa]	4.38	5.02	4.91	4.42

Table 1: Constrained k-values for each mesh and case with resulting fault and rupture parameters. Slip distribution is governed by the width of seismogenic zone and k-value variations. Low apparent friction functions neat the structural knot as a 'gate' to suppress the slip.

4. Conclusion

- ★ PGV distribution governed by
  - Directivity, fault geometries, strong rate-weakening near the surface, subsurface velocity structure
- ★ Expected strong ground motion in the LA basin area as a result of M7.8 earthquake, but reliable up to 0.5 Hz.
- ★ Future work: **Broadband** analysis to capture effects from higher frequency waves & Investigation on **non-linear rheology** (plasticity models)
- ★ Application of this study
  - Improvement of building codes
  - Resilient infrastructure and community planning across Southern California.

Scan here for additional poster figures

SCEC
U.S. National Science Foundation
UCLA
SDSU San Diego State University
SeisSol
USGS science for a changing world
PRINCETON UNIVERSITY
DARTMOUTH
USC
QUAKEWORX

References

[1] Tse, S. T., & Rice, J. R. (1986). Crustal earthquake instability in relation to the depth variation of frictional slip properties. *Journal of Geophysical Research: Solid Earth*, 91(B9), 9452-9472.

[2] Lapusta, N., Rice, J. R., Ben-Zion, Y., & Zheng, G. (2000). Elastodynamic analysis for slow tectonic loading with spontaneous rupture episodes on faults with rate-and state-dependent friction. *Journal of Geophysical Research: Solid Earth*, 105(B10), 23765-23789.

[3] Yang, W., & Hauksson, E. (2013). The Tectonic Crustal Stress Field and Style of Faulting Along the Pacific North America Plate Boundary in Southern California. Geophysical Journal International, 194(2), 1000–1020.

[4] San Diego Supercomputer Center (2025): Expanse. University of California San Diego. Service. https://doi.org/10.1145/3437359.3465588

[5] Gabriel, A.-A., Kurapati, V., Niu, Z., Schliwa, N., Schneller, D., Ulrich, T., Dorozhinskii, R., Krenz, L., Uphoff, C., Wolf, S., Breuer, A., Heinecke, A., Pelties, C., Rettenberger, S., Wollherr, S., & Bader, M. (2025). SeisSol. Zenodo. https://doi.org/10.5281/zenodo.4672483