Disentangling On-Fault and Off-Fault Contributions to Geodetic Strain Rates in California

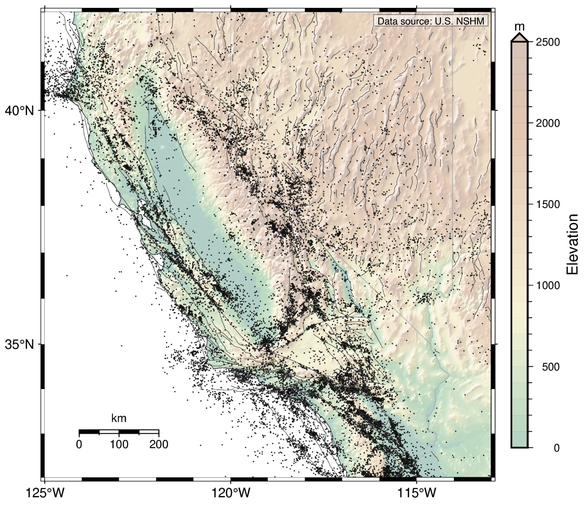
Nicolás Castro-Perdomo, Kaj M. Johnson

INDIANA UNIVERSITY

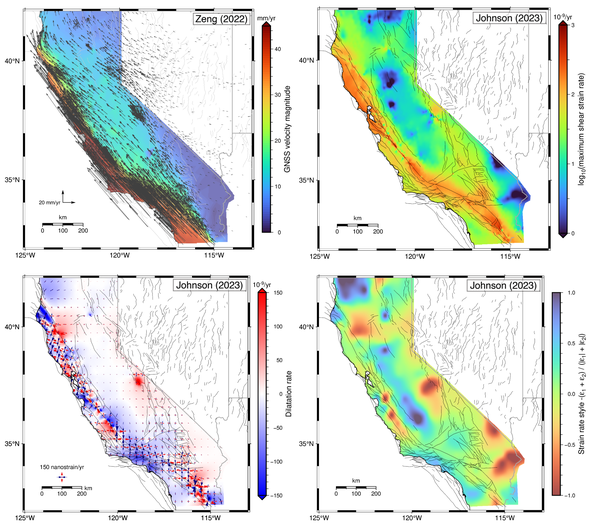
INTRODUCTION

Determining the distribution of on-fault and off-fault deformation is essential for understanding seismic hazards. **Here, we estimate the contributions and uncertainties of on-fault and off-fault deformation to GNSS-derived surface strain rates in California**. For this purpose, we used a model that assumes strain rates in the crust are due to a combination of elastic distortions due to slip deficit rates on 3D faults (fault coupling) and distributed depth-averaged moment rate tensor sources in an elastic plate.

Tectonic setting

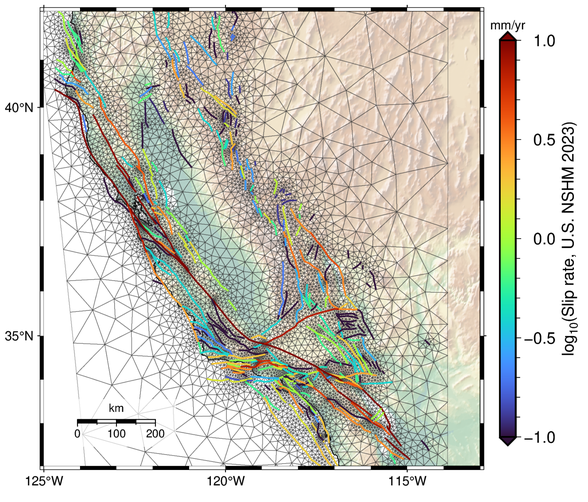


Input data: GNSS-derived strain rates



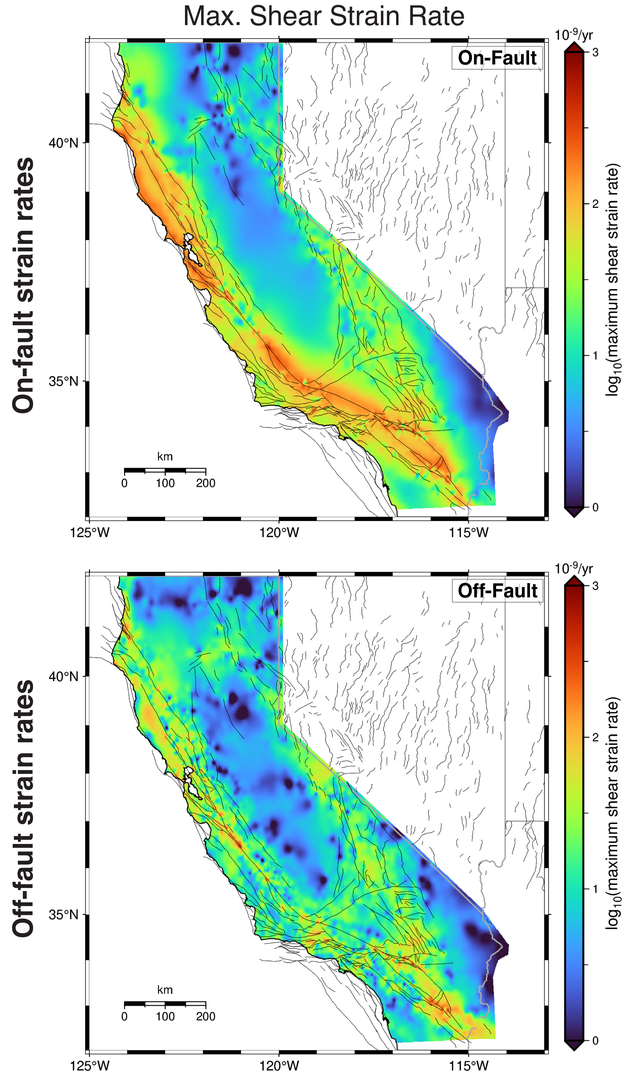
METHOD: INVERSION SCHEME

We inverted surface strain rates for both on-fault and off-fault sources. **The inversion employed least squares estimation and a Monte Carlo approach, generating a posterior distribution of slip deficit rates on 3D fault patches and moment rate sources on the centroids of a triangular mesh,** implementing lower and upper bounds on slip deficit rates based on the U.S. National Seismic Hazard Model (U.S. NSHM).

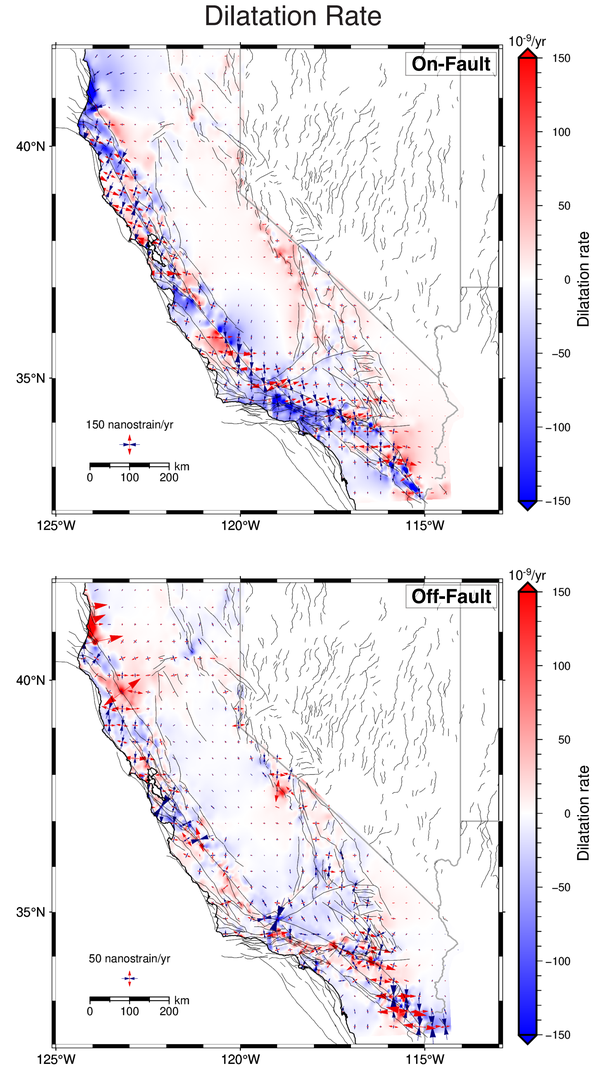


RESULTS

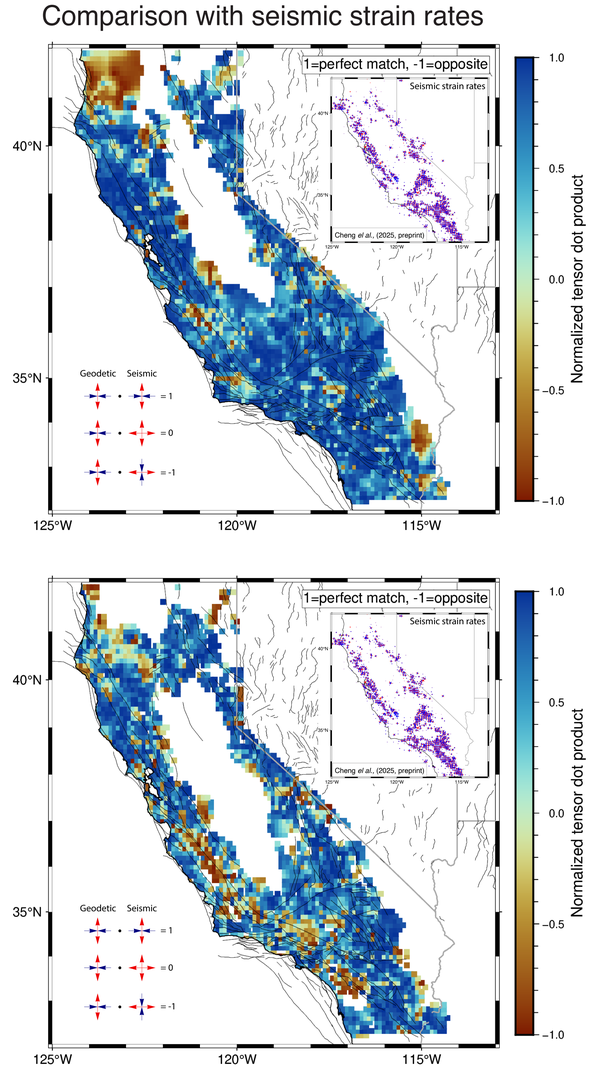
Max. Shear Strain Rate



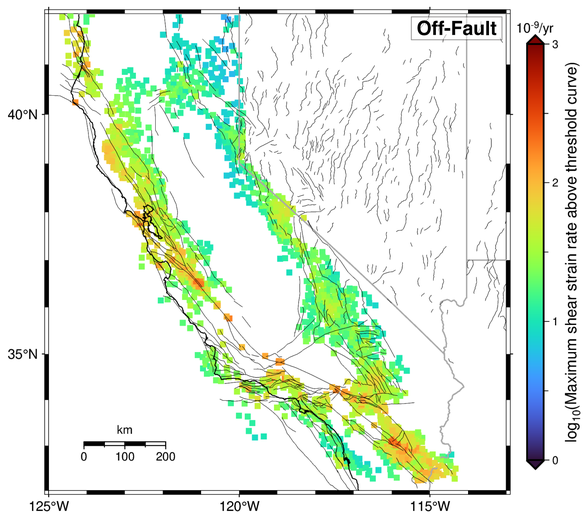
Dilatation Rate

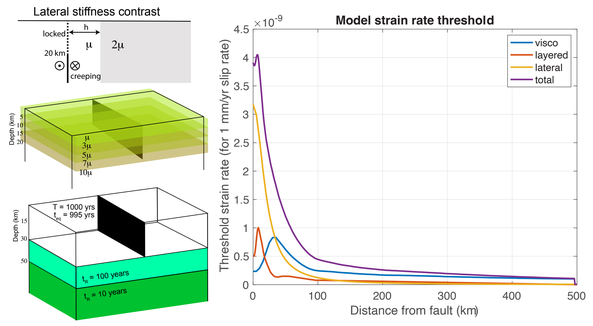


Comparison with seismic strain rates



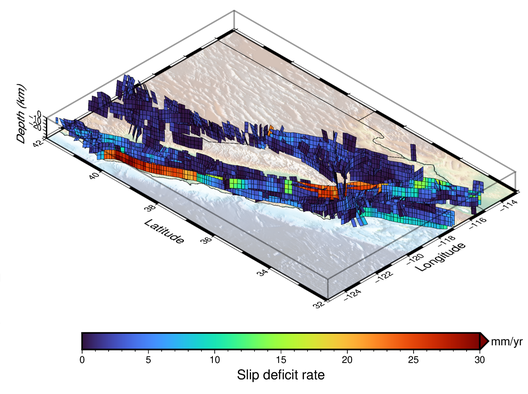
Accounting for elastic heterogeneity and viscoelastic mantle flow effects





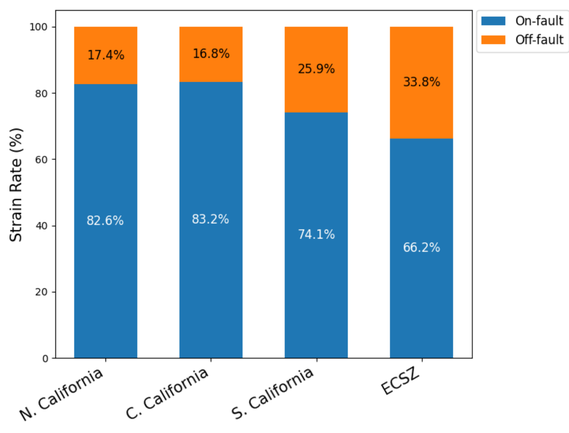
We derived a threshold curve for surface strain rates arising from:

- Viscoelastic earthquake-cycle transients from periodic earthquakes in a 3D 'layer-cake' Earth model.
- Elastic heterogeneity, including lateral (2D) and vertical (3D) variations in elastic properties.



CONCLUSIONS

- In localized fault systems such as the San Andreas, 75-85% of surface deformation is explained by fault coupling, whereas in the Eastern California Shear Zone, fault coupling accounts for only 60-70%, with the remainder off-fault.
- We account for elastic heterogeneity and viscoelastic mantle flow to isolate the off-fault contribution to geodetic strain rates not explained by these processes.
- On-fault and off-fault strain rate tensors agree regionally and align with seismically released strain rate tensors, with local discrepancies (e.g., along the creeping segment of the San Andreas fault).
- Our findings highlight the critical role of distributed deformation in shaping interseismic strain rates and the need to incorporate off-fault processes into earthquake hazard models.



REFERENCES

[1] Hatem, A. E., Collett, C. M., Briggs, R. W., Gold, R. D., Angster, S. J., Field, E. H., & Powers, P. M. (2022). Simplifying complex fault data for systems-level analysis: Earthquake geology inputs for US NSHM 2023. Scientific data, 9(1), 506.

[2] Zeng, Y. (2022). GPS velocity field of the western United States for the 2023 national seismic hazard model update. Seismological Society of America, 93(6), 3121-3134.

[3] Johnson, K. M. (2024). Disagreements in geodetically inferred strain rates in the western US with stress orientations and geologic moment rates. Journal of Geophysical Research: Solid Earth, 129(4).

[4] Yifang Cheng, Roland Bürgmann, Richard M. Allen, et al. Stress model of California: Interaction between faults and stress along the transform boundary inferred from focal mechanisms of small earthquakes. ESS Open Archive . June 27, 2025.

ACKNOWLEDGEMENTS

- This work is supported by the Statewide California Earthquake Center (SCEC) under award number 25350, "An Off-Fault Deformation Map for California."