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Award #14055: *Deformation and Fault Slip Rates in the Ventura Basin and Western Transverse Ranges*

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Abstract

The far-field, regional loading rate constrained by geodetic data is a critical component to Ventura Special Fault Study Area (SFSA) project. To this end, we have incorporated existing and newly acquired geodetic data from the western Transverse Ranges into a regional kinematic model of present-day deformation rates. We use a kinematic method in which a long-term horizontal and vertical velocity field is constructed assuming slip on faults in elastic plate over an inviscid fluid. The interseismic deformation field is modeled with backslip on the faults in an elastic halfspace. We also account for vertical surface motions due to San Joaquin Valley water withdrawal following Amos et al. (2014). In the forward model, slip is imposed on the faults. Using Monte Carlo Metropolis methods, we invert the geodetic data for slip rates and coupling, constrained by the upper and lower slip rate bounds in the UCERF3 geologic model. We adopt the UCERF3 fault geometry. The horizontal GPS velocity field is from UCERF3, and the vertical GPS and InSAR velocity field is from Bill Hammond (2014 SCEC grant). We find significant shortening across the Transverse Ranges of ~10 mm/yr. This is shortening attributed only to motion along faults in western Transverse Ranges, after removing contributions from the San Andreas and other large strike-slip faults as well as far-field loading. The summed reverse-slip rate across the Transverse Ranges along a profile through Ventura is >15 mm/yr with 8-10 mm/yr across the Ventura Basin (Oak Ridge and Ventura Faults).

Purpose and Design

The purpose of this study is to use geodetic measurements of horizontal and vertical present-day motions to infer the regional contraction rate across the western Transverse Ranges and the slip rates and coupling on active faults. As shown in Figure 1, a cursory inspection of horizontal GPS velocities in the region indicates 6-10 mm/yr of shortening across the off-shore region. Farther east the shortening is obscured by strain related to the San Andreas fault, but there is about 10-13 mm/yr of shortening on shore. The main questions we pose about this data include: How much of the observed deformation can be attributed to motion on faults in the Transverse Ranges? And, Is the observed uplift associated with contraction across western Transverse Range thrusts/reverse faults?

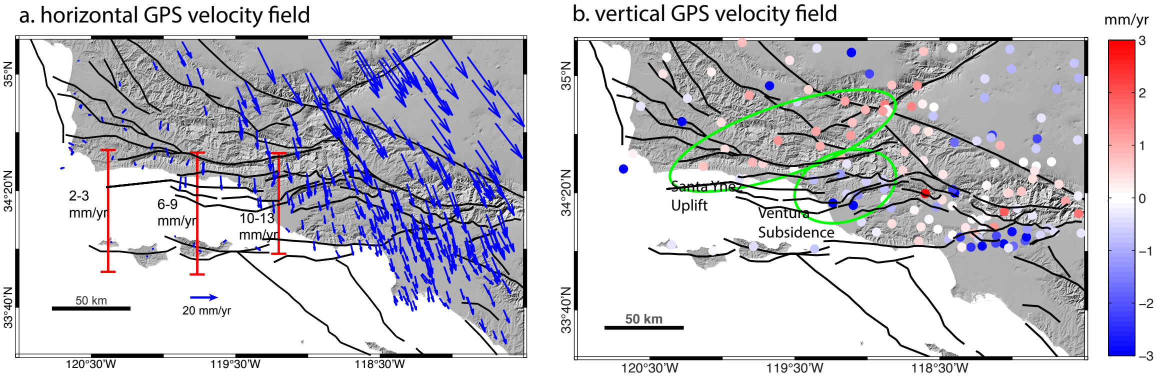

Figure 1. a. SCEC CMM4 velocity field relative to Santa Cruz Islands. 6-10 mm/yr of present-day shortening across the off-shore western Transverse Ranges. Vertical GPS velocity field from Amos et al. (2014). A vertical gradient of 2-4 mm/yr over 100 km is seen from Ventura Basin to the Santa Ynez mountains. Also gentle uplift (0-1 mm/yr) of the Santa Monica and San Gabriel mountains.

We construct a surface velocity field in two parts: 1. The long-term velocity field is generated by imposing slip on fault surfaces in an elastic plate overlying an inviscid substrate with gravitational restoring forces, 2. The interseismic velocity field is constructed by adding the contribution from fault coupling with backslip on fault surfaces in an elastic halfspace. The model fault geometry in the elastic plate is shown in Figure 2a. The Fault geometry is taken from UCER3 and CFM4.

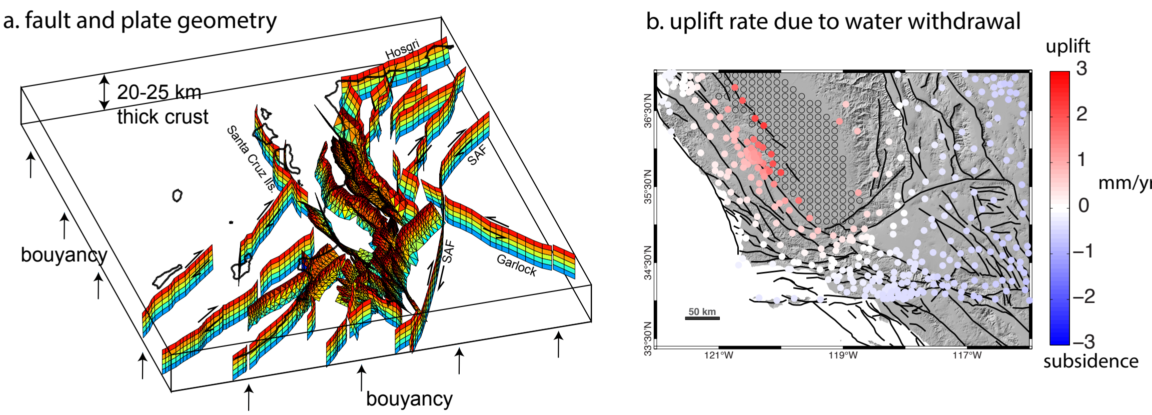

Figure 2. a. Fault geometry from UCERF3 and CFM4. b. Computed uplift rate due to San Joaquin Valley groundwater withdrawal following Amos et al. (2014). Black circles show locations of sources.

We also include the substantial contribution to the vertical velocity field from groundwater withdrawal in the San Joaquin Valley following Amos et al. (2014). We impose surface loads (Boussinesq solution) to an elastic halfspace at the black circular points shown in Figure 2b. The predicted vertical rates at GPS sites are shown in Figure 2b. This shows tilting of several mm/yr across the western Transverse Ranges due to groundwater withdrawal.

To estimate fault slip rates and coupling, we conduct Monte Carlo-Metropolis inversions of the geodetic data. Fault slip rates are bounded by the upper and lower bounds from the UCERF3 geologic model.

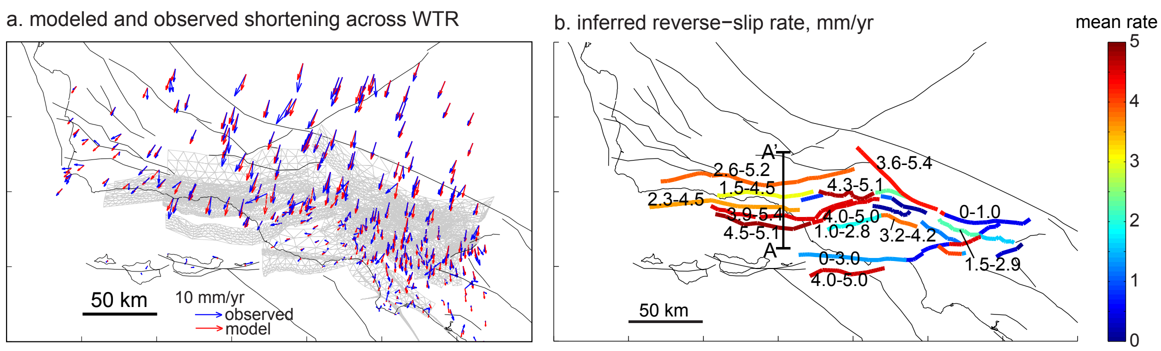

Figure 3. Inversion results. a. Modeled and observed shortening rates across the western Transverse Ranges. b. Inferred reverse-slip rates. Model mean and 99% confidence interval of reverse slip rate on dipping faults is shown. The maximum allowable rate is 6 mm/yr for all reverse faults.

Figure 3 shows the result of the inversion for fault slip rates. Figure 3a shows the velocity field attributed only to motion along faults in western Transverse Ranges (gray mesh faults). The contribution from the San Andreas and other large strike-slip faults as well as far-field loading is removed from model and observed velocities in order to isolate the influence of Transverse Range faults. Note that there is about 10 mm/yr of shortening across the entire western Transverse Range. The summed slip rate across A-A' in Figure 3b is >15 mm/yr. About 8-10 mm/yr of shortening occurs across the Ventura Basin (Oak Ridge and Ventura faults).

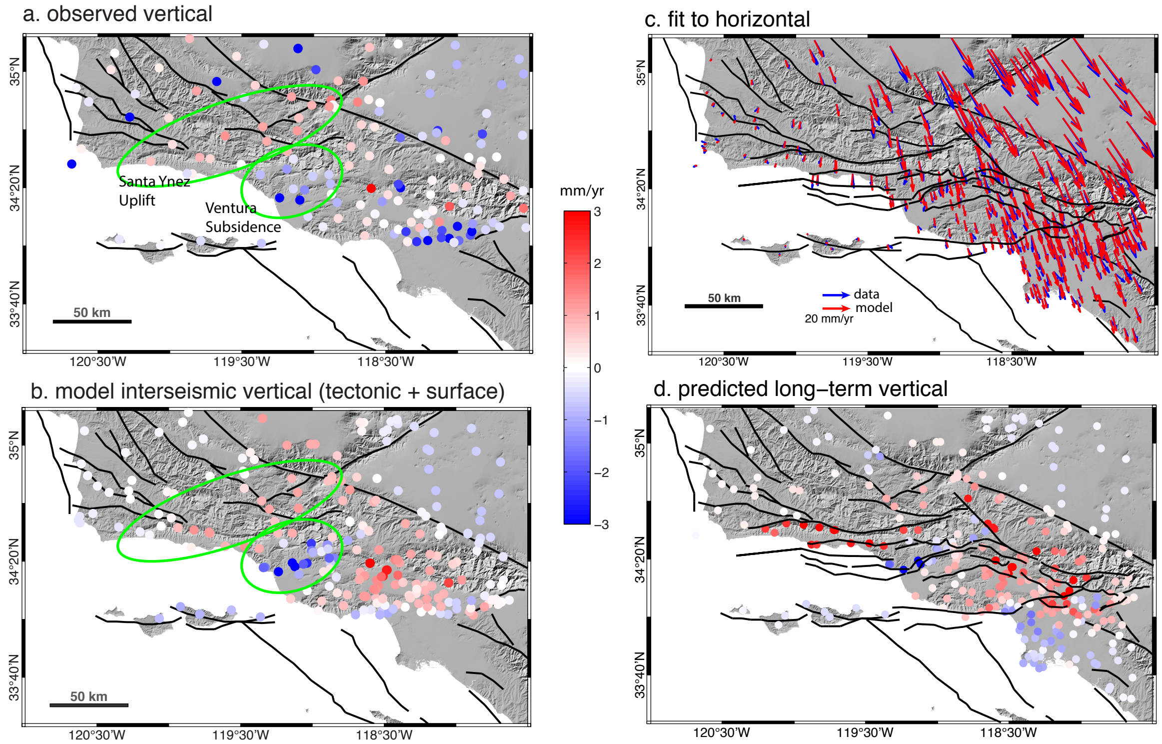

Figure 4. a. observed interseismic vertical velocities. b. Modeled interseismic vertical velocities. c. Fit to horizontal velocities. d. Predicted-long-term surface uplift rates.

Figure 4 a-c shows the observed and modeled interseismic horizontal velocities. The majority of the data are fit within 2σ uncertainties which are not shown for clarity. Although the model does not explain the details of the vertical velocity field, whish is relatively noisy,tThe observed trend of 1-2 mm/yr of subsidence in the Ventura Basin and 1-2 mm/yr of uplift in the Santa Ynez mountains is predicted by the model. The observed gentle uplift (0-1 mm/yr) of the Santa Monica and San Gabriel mountains is also predicted by the model. The predicted “long-term” vertical rates (long-term is roughly Holocene) is shown in Figure 4d. Uplift of 1-3 mm/yr is predicted in Santa Ynez, Santa Monica, and San Gabriel mountains. These predicted rates should be compared with any available geologic surface uplift rate constraints as they become available.

Intellectual Merit

The far-field, regional loading rate constrained by geodetic data is a critical component to Ventura Special Fault Study Area (SFSA) project. We have incorporated existing and newly acquired geodetic data from the western Transverse Ranges into a regional kinematic model of present-day deformation rates. We also account for vertical surface motions due to San Joaquin Valley water withdrawal following Amos et al. (2014). We invert the geodetic data for slip rates and coupling, constrained by the upper and lower slip rate bounds in the UCERF3 geologic model. We find significant shortening across the Transverse Ranges of ~10 mm/yr. This is shortening attributed only to motion along faults in western Transverse Ranges, after removing contributions from the San Andreas and other large strike-slip faults as well as far-field loading. The summed reverse-slip rate across the Transverse Ranges along a profile through Ventura is >15 mm/yr with 8-10 mm/yr across the Ventura Basin (Oak Ridge and Ventura Faults).

<u>Broader Impacts</u>

This project contributes directly to improved understanding of the seismic hazard in the western Transverse Ranges and, in particular, the Ventura and Santa Barbara regions.

<u>Publications and Presentations</u>

1. Kaj M. Johnson, William C. Hammond, and Reed Burgette, "Geodetic constraints on shortening, uplift, and fault slip across the Ventura Basin" (*2014 SCEC Annual Meeting poster*)

2. A paper with Bill Hammond and Reid Burgette is in preparation.