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GPS and InSAR constraints on vertical tectonic motion improve the estimate of slip rate of the San Andreas Fault in southern California

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The San Andreas fault (SAF) is the fastest slipping member of a complex plate boundary system that poses a looming earthquake hazard to millions of people in southern California. Seismic hazard analysis products rely on accurate estimates of fault slip rate in order to best forecast the shaking from future damaging earthquakes. Data from geodetic GPS networks such as the EarthScope Plate Boundary Observatory, SCIGN, and other municipal networks place strong constraints on faults slip rates. However, models based geodetic measurements in the eastern Transverse Ranges suffer from uncertainties in fault dip, slip history, and viscoelastic Earth structure. Part of the problem is that data are commonly limited to horizontal interseismic rates of motion at GPS stations.

Here we present results of integrated analysis of GPS and space-based InSAR data that together provide a high-resolution three-component estimation of the interseismic velocity field around the SAF. Aligning the InSAR to GPS mitigates long wavelength errors in InSAR while increasing the density of measurements between geographically sparse GPS stations. We use solutions from our GPS mega-network analysis of over 12,000 globally distributed stations processed using the GIPSY-OASIS software. Solutions are aligned to our new North America fixed reference frame (NA12), which provides strong vertical reference to compare rates across the plate boundary. Vertical data are considered if the station has at least 4 years of data, have time series that are fit well by a linear plus seasonal terms plus steps from known equipment changes and earthquakes. We use over 750 ERS and ENVISAT radar scenes from between 1992 and 2009 obtained from the WinSAR archive, including 4 frames from 5 tracks to form over 10,000 interferograms, providing line-of-sight (LOS) velocities for overlapping domains. To separate the contributions from vertical and horizontal signals, we align the InSAR LOS rates to the GPS LOS rates and subtract the LOS signal of horizontal deformation estimated from a GPS strain rate map. The result is an InSAR LOS rate map aligned to NA12, which we unproject into the vertical direction. InSAR and GPS motions track one another well, with RMS difference in vertical rate of 1.0 mm/yr, where the signal of vertical rate varies between -5.0 and 2.6 mm/yr.

The vertical rates show both basin-scale pockets of subsidence and regional wavelength variations in uplift rate. An uplift feature of near 2 mm/yr is centered on the SAF near its junction with the San Jacinto fault and eastern Transverse Ranges. We find that this feature can be explained using a viscoelastic earthquake cycle model, and suggests a slip rate on the San Bernardino section of the SAF of 15 mm/yr, in better agreement with geologic rates compared to earlier models.