Interseismic and post-South Napa earthquake deformation in the Northern San Francisco Bay Region from survey GPS observations

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1. Recent GNSS surveys

A major task for our project is to continue to survey geodetic marks. This contributes to two significant scientific objectives: (1) densify the relatively sparse continuous network in the region (e.g. NOTA*, USGS and BARD); and (2) maintain fundamental observations relative to which we may measure coseismic displacements and postseismic deformation in the event of a future earthquake on the coastal San Andreas Fault, Rodgers Creek and/or southern Maacama Faults, or Green Valley Fault.

* Network of the Americas, which now incorporates the Plate Boundary Observatory (PBO) and Geodesy Advancing Geoscience and EarthScope (GAGE) networks

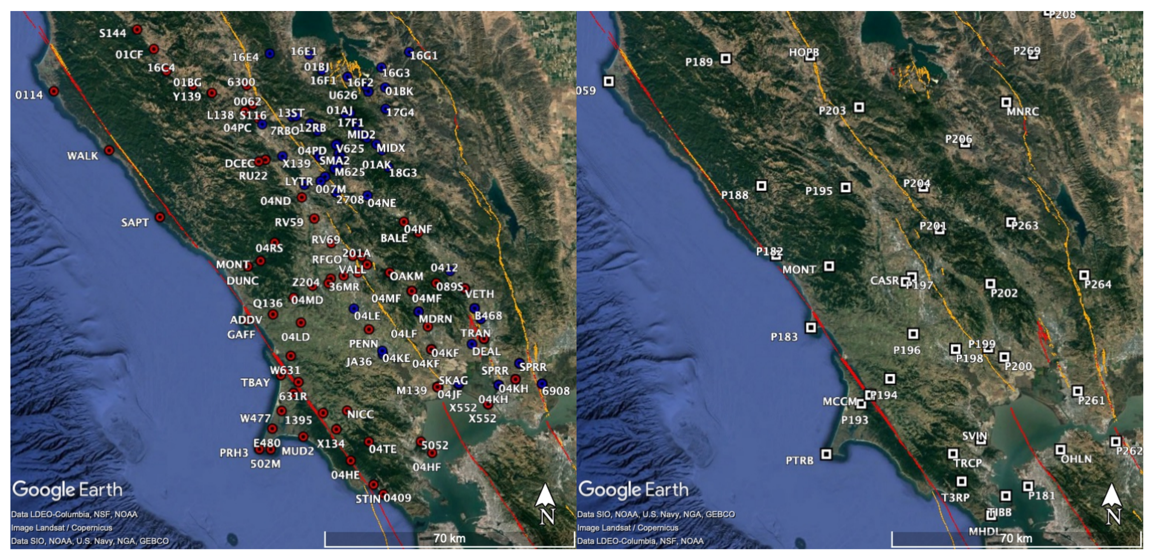
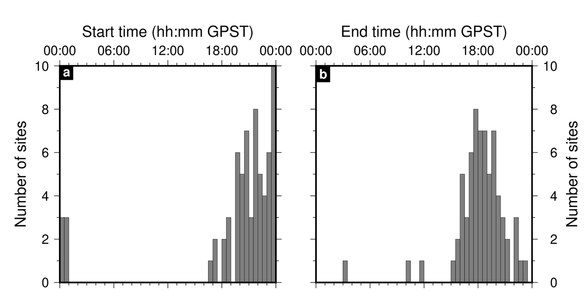


Figure 1 Left: Geodetic marks measured during the September 2017 (blue) and August 2018 (red) GNSS surveys; Right: The regional network of continuous GNSS sites upon which we are spatially densifying the geodetic observations.



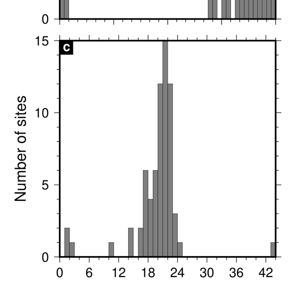
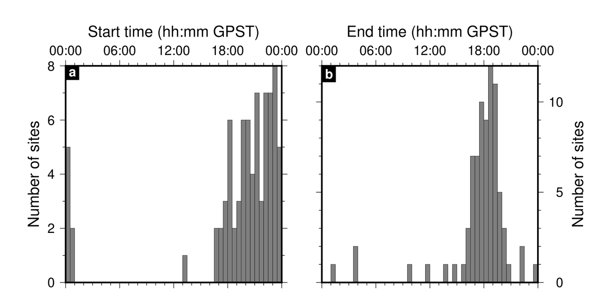


***Figure 2** Summary of data collected during the September 2017 survey (blue dots in Figure 1).*



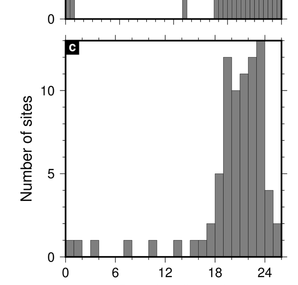


***Figure 3** Summary of data collected during the August 2018 survey (red dots in Figure 1).*

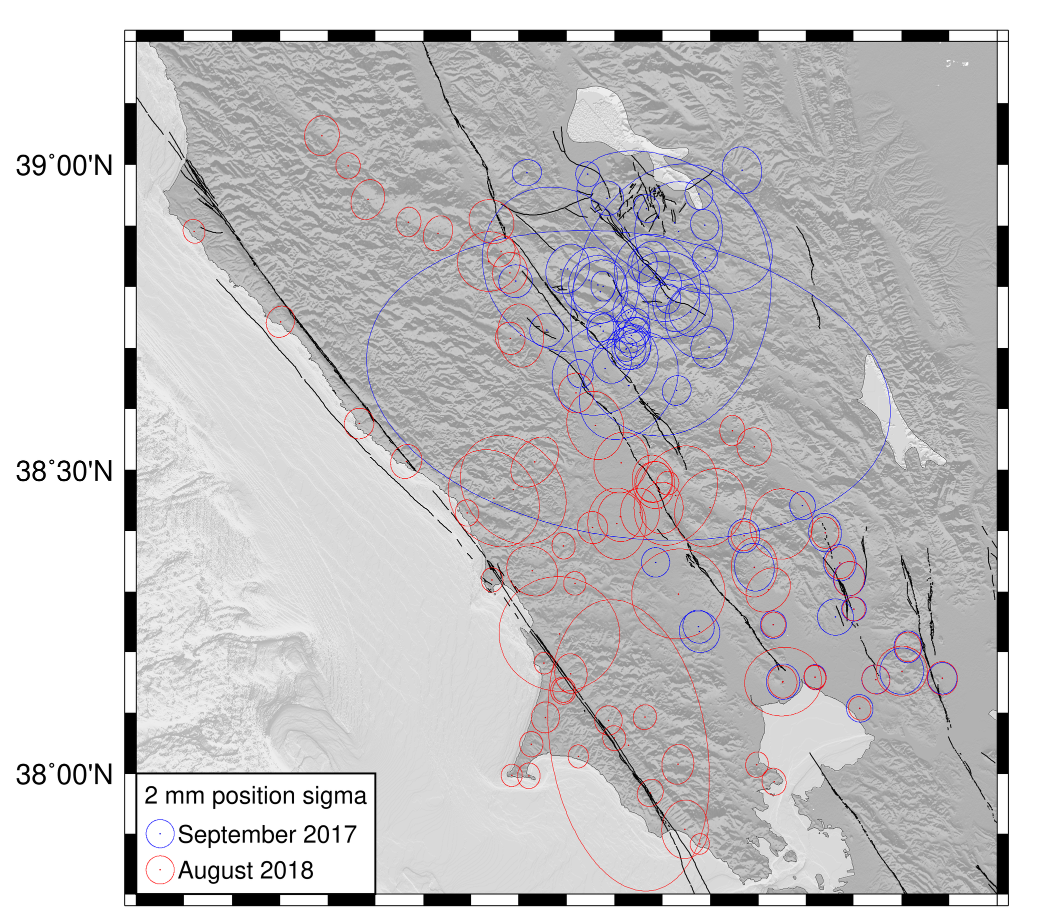


***Figure 4** Position uncertainties from the two recent surveys described here. Sites are generally measured to a (1-sigma) precision of approximately 2 mm, although a few suffer from problematic occupations, such as short observation time due to field schedule or power failure (e.g. Figures 2 and 3), and some have a systematically poor observation environment.*

Raw data and field logs are archived at UNAVCO and may be accessed by searching for "North San Francisco Bay Area 2018", e.g. via https://www.unavco.org/data/gps-gnss/data-access-methods/dai2/app/dai2.html

2. Latest GNSS velocity solution and geodetic fault slip rate estimates

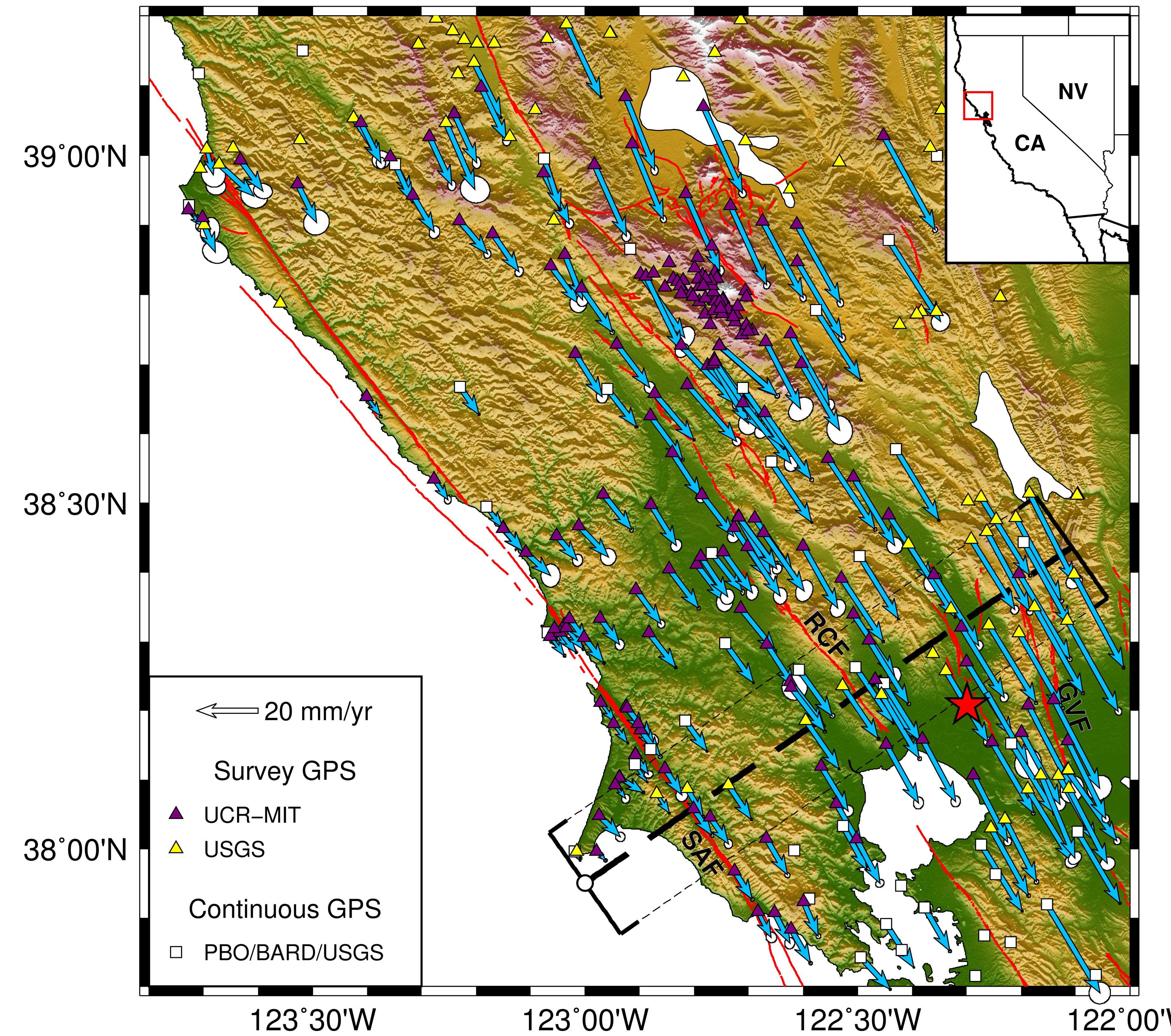


***Figure 5** Current GNSS velocity solution for the North San Francisco Bay Area, combining previous surveys conducted throughout the 1990s with those conducted by UCR/MIT since 2008 as well as the continuous sites in the region with data that are publicly available. Velocities are expressed relative to the Pacific. Red star marks the epicentre of the 2014-08-24 South Napa earthquakes (more detail in Figure 8, right).*

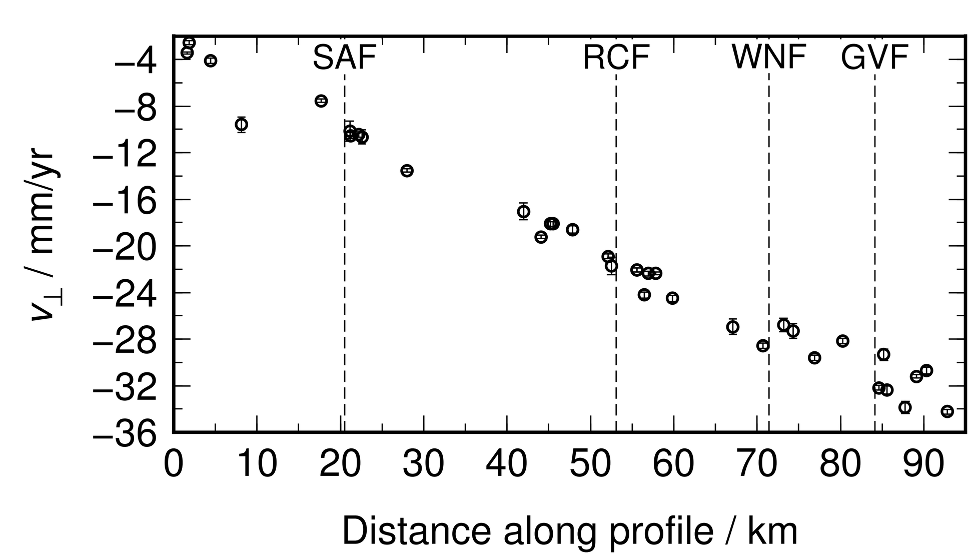


***Figure 6** Profile-perpendicular (i.e. approximately strike-parallel) GNSS velocities along the Point Reyes profile, as shown in Figure 5.*

The Point Reyes profile shows a velocity gradient of about 35 mm/yr over 100 km, with only a small residual motion relative to the Pacific at the tip of Point Reyes (< 2 mm/yr), indicating that there is nearly statistically insignificant remaining motion accommodated offshore.

Our analyses using one million Monte Carlo Markov Chain models approximately agrees with the current UCERF 3 slip rate for the San Andreas Fault, but we predict higher slip rates for the Rodgers Creek and Green Valley Faults, summing to approximately the total velocity gradient along the profile.

The West Napa Fault is not included in the analyses. Its location between and close to the Rodgers Creek and Green Valley Fault will likely result in highly correlated slip rates, even more so than shown in Figure 7b.

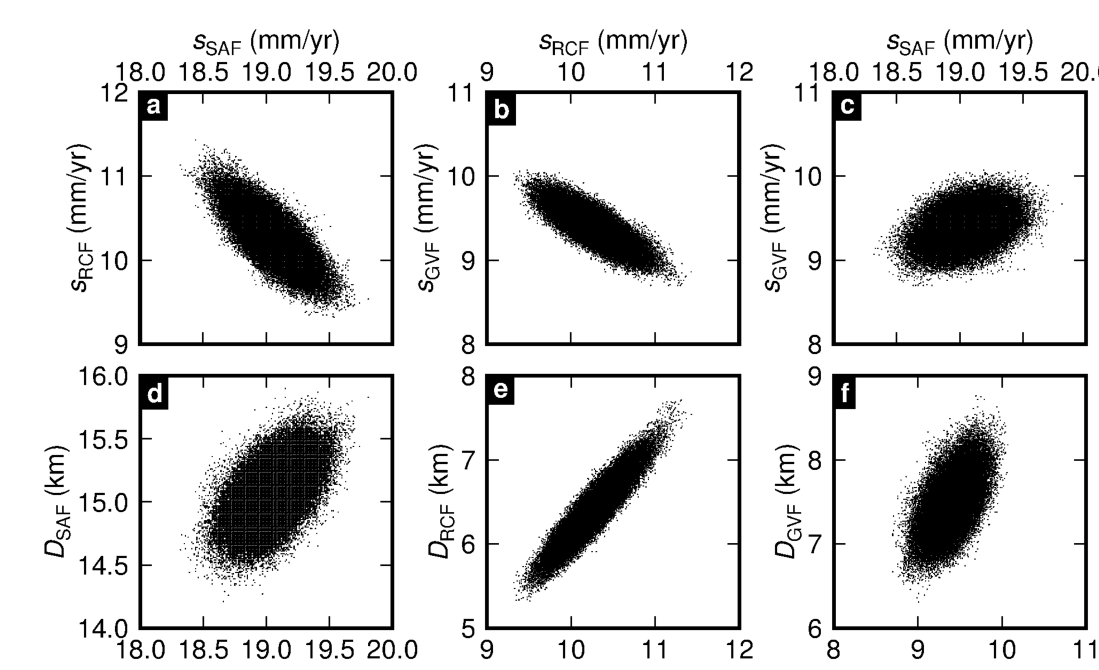


***Figure 7** Results of Monte Carlo Markov Chain analysis to estimate slip rate and locking depth of the three faults along the Point Reyes profile (A-A') shown in Figures 5 and 6. The gradient of the point clouds show the inherent trade-offs between geophysical parameters.*

Fault segment	UCERF 3.1	Our MCMC
	Mean (min-max) mm	
San Andreas (North Coast)	18.0 (13.2-22.8)	18.5-19.5
Rodgers Creek	5.7 (3.1-7.5)	9.5-11
Green Valley	3.8 (1.8-5.5)	9-10

***Table 1** Comparison to UCERF 3.1 fault slip rates*

3. Continuation of post-South Napa earthquake observations

A second task for our project is to continue to measure post-earthquake deformation following the 2014-08-24 South Napa event, to build on the work of Floyd et al. (2016), and many others. Several studies at the time detected significant afterslip on the fault plane and, given the fact that many faults in the region creep, we wish to know if the earthquake induced any change in characteristics of the West Napa Fault, including generating creep.

All data has been reprocessed using the latest IGS orbits (repro2) and expressed in the latest reference frame (ITRF2014/IGS14). Here we present these latest time series for sites around the epicentral region. They reveal that rapid afterslip mostly dissipated by the beginning of 2015, six months after the earthquake, with very little further motion after 2015. Even the closest PBO site, P261, show no residual motion relative to pre-earthquake velocities from the beginning of 2017 onwards, 2.5 years after the earthquake.

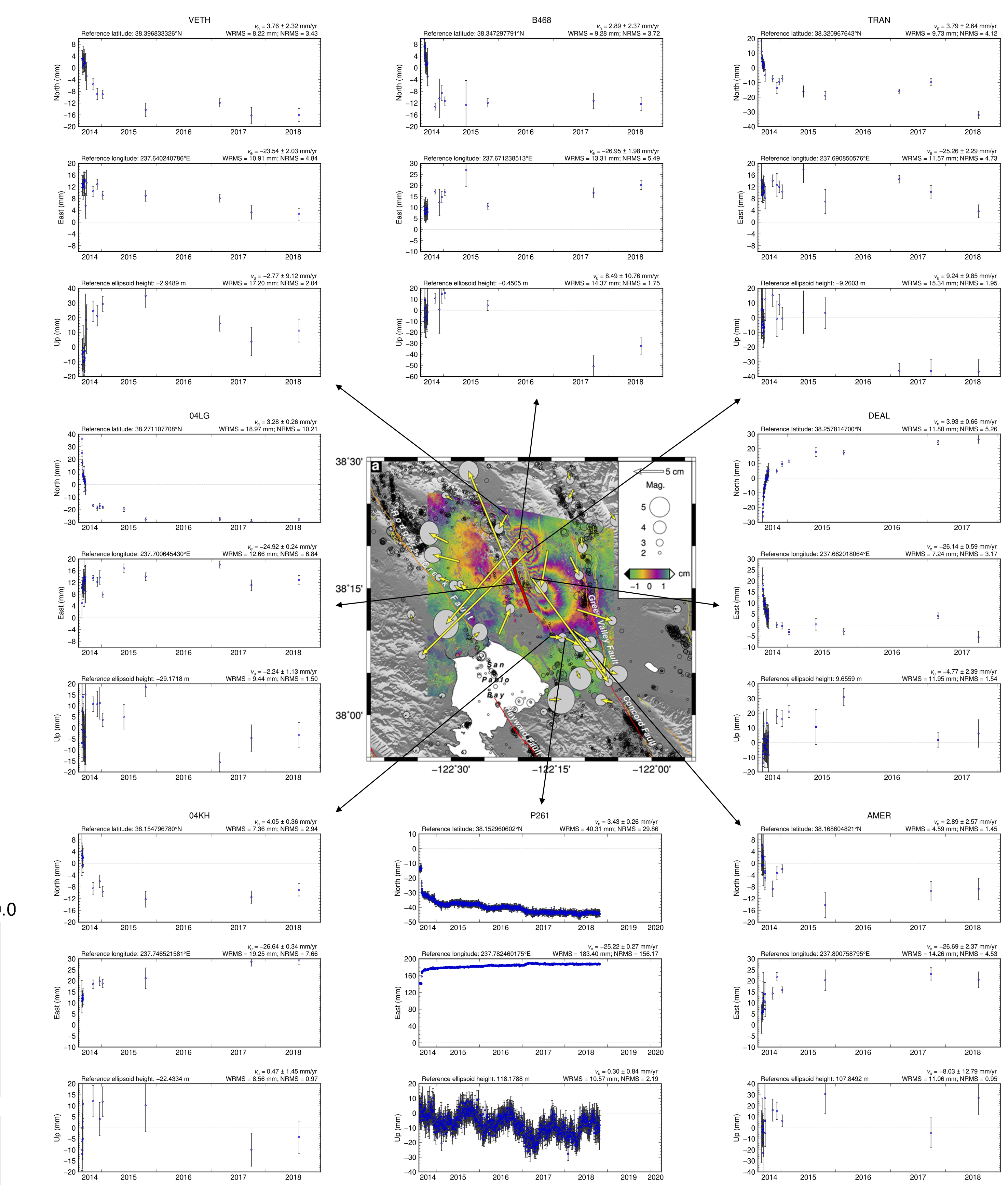


***Figure 8** Latest time series, including the September 2017 and August 2018 surveys, for GNSS sites surrounding the South Napa earthquake rupture, relative to their pre-earthquake velocities (numbers are velocities in the ITRF2014). Most if not all post-South Napa deformation appears to have ceased after 18 months. There is little to no gradient in the time series relative to pre-earthquake velocities from 2015 onwards. Central plot is modified from Floyd et al.'s (2016) Figure 1.*

Raw data and field logs, from both the USGS and UCR/MIT, for the post-earthquake surveys are archived at the Northern California Earthquake Data Center (NCEDC) and may be accessed via ftp://www.ncedc.org/pub/gps/survey/usgs/.

This work is supported currently by USGS EHP Award G18AP00051 (Floyd) and G18AP00052 (Funning).