Final Project Report
SCEC Project #18201

Updating GPS site positions and velocities and improving GPS coverage in southern California for the Community Geodetic Model

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We surveyed over 40 campaign GPS sites in the Inland Empire and Mojave Desert areas of southern California in the summer of 2018 and winter of 2019. These surveys will be incorporated into the SCEC Community Geodetic Model, and served as vital reconnaissance for the response to the July 2019 Ridgecrest earthquakes, which occurred in the northernmost part of our study area.

Introduction and motivation

In areas of limited continuous GPS station coverage, GPS survey campaign measurments (e.g. Figure 1) are a cost-effective way to increase the density of deformation velocities. GPS velocities are important inputs to the process of interseismic strain accumulation estimation, and therefore to seismic hazard assessments such as the Uniform California Earthquake Hazard Forecast (UCERF). Such data is also an important input to community data products such as the Community Geodetic Model (CGM), an effort to produce a comprehensive, integrated geodetic data set that can be used by modelers and other nonspecialists.

For this project, we targeted two areas in particular: (i) the Inland Empire, including sites along the northern San Jacinto fault, including the Cajon Pass ‘earthquake gate’ area; and (ii) the Mojave Desert, including sites bracketing the San Andreas and Garlock faults, and the western portion of the Eastern California Shear Zone. Measurement of the Inland Empire sites, part of a network that has been measured by multiple SURE interns in the past, was led by SURE Intern Eneas Torres-Andrade. In the Mojave region, in a survey campaign led by graduate student Rachel Terry, we prioritized sites that had not been occupied in over a decade, according to the UNAVCO campaign data archive, or that had only been measured once before, including a handful of sites measured by SURE intern Lisa Jose Knowles in 2014.

Such repeat surveys are valuable, as new measurements will either provide an update to the long-term geodetic deformation rates at those locations, reduce the uncertainties in such rates, or indeed enable a new velocity estimate. Beside the improved GPS velocity coverage, maintaining an up-to-date inventory of GPS benchmark locations can enable rapid response in the event of an earthquake – as we discovered when the July 2019 Ridgecrest earthquakes occurred in the northern part of the Mojave Desert field area we had surveyed five months before.

Figure 1: Examples of data collection. Left: SURE intern Eneas Torres-Andrade, leveling a GPS tripod at site G036 in the Cajon Pass area in June 2018. Right: Graduate student Rachel Terry, setting up a GPS receiver at site PASO, SE of Ridgecrest in February 2019.

Data collection

In total, we measured 45 sites in the duration of the project, distributed between the Inland Empire and Mojave Desert regions. (Figure 2).

Inland Empire campaign: Led by SURE intern Eneas Torres-Andrade, we measured 24 sites in the Inland Empire between May and July 2018. These included sites along the San Andreas fault in the Cajon Pass area and in Whitewater Canyon, as well as sites along and transecting across the San Jacinto fault zone.

Mojave Desert campaign: We made two four-day campaign trips to the Mojave Desert area in February and March, 2019, focusing on the northern and southwestern Mojave, respectively. 21 sites were occupied for durations of between 17 and 26 hours each (Figure 3), including a transect of the Garlock Fault southwest of Ridgecrest.

Documentation: On the basis of both our reconnaissance efforts and our field visits, we produced updated or new site descriptions, including local maps and photos of sites, to be shared with the community to facilitate future surveys.

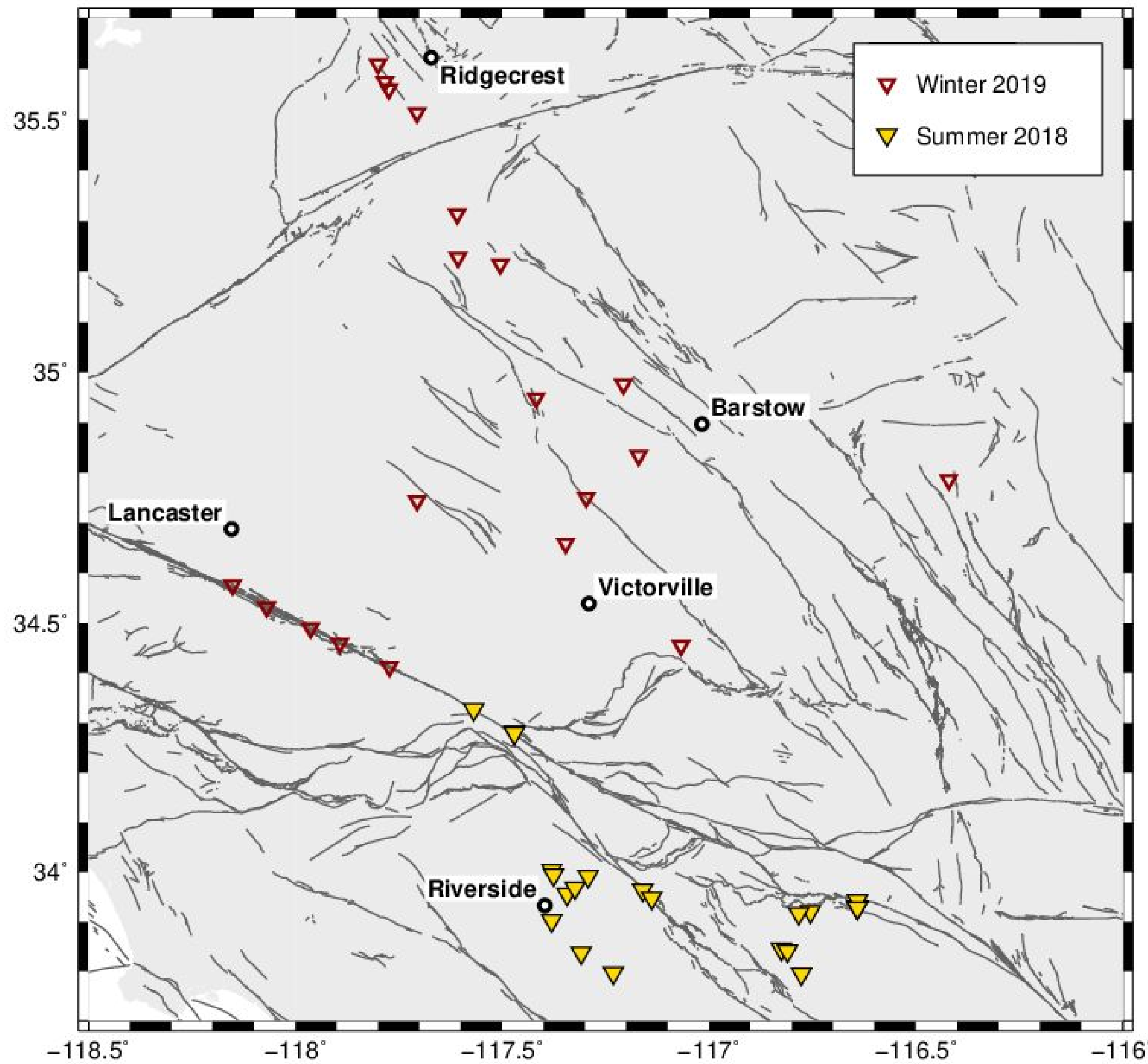

Figure 2: GPS sites measured during this project. Gold, filled triangles: data collected by intern Eneas Torres-Andrade, targeting the San Andreas and San Jacinto faults, in the summer of 2018. Red hollow triangles: data collected by graduate student Rachel Terry, targeting the Mojave San Andreas, Garlock and Blackwater faults, in the winter of 2019. The latter stations include multiple sites in the vicinity of the city of Ridgecrest, which were reoccupied in the aftermath of the nearby earthquakes in July 2019.

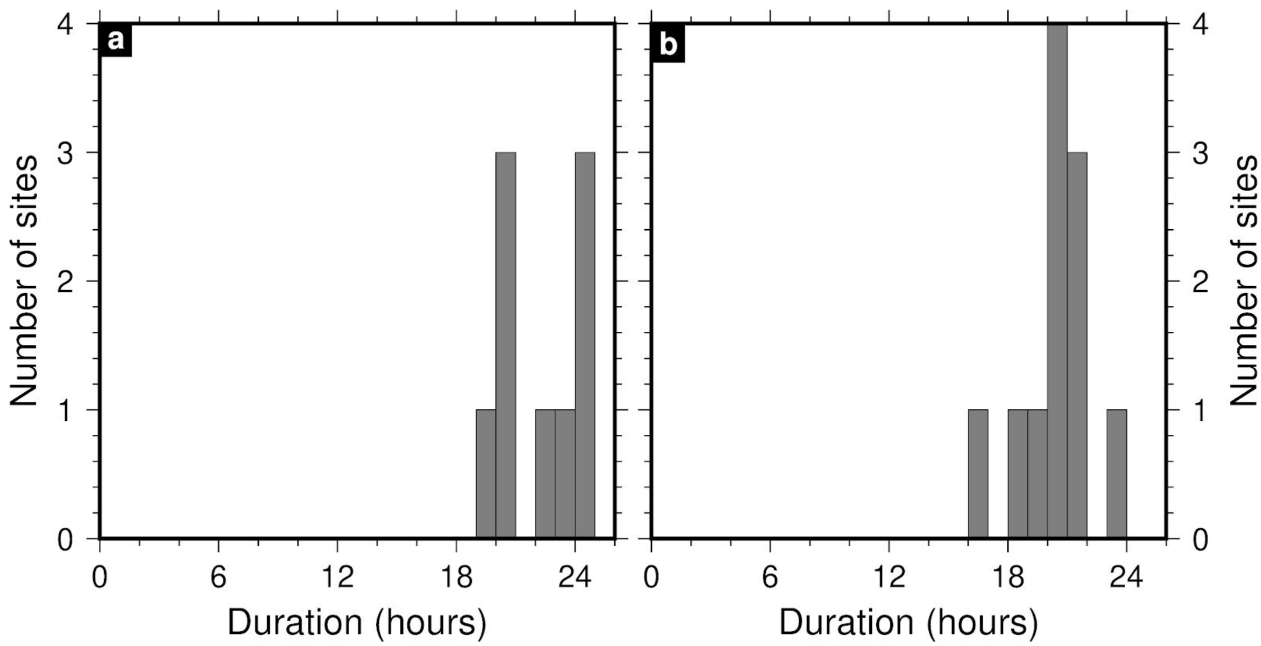

Figure 3: Summary of the occupation times for survey sites during the (a) February and (b) March 2019 surveys conducted in the region of the July 2019 earthquakes. The resulting positions are approximately 1.5–2.1 mm in the horizontal components. (From Floyd et al., 2020).

Data preprocessing and quality assurance

Preprocessing: Data were converted to RINEX format, and QC'd using the teqc program developed by UNAVCO. Antenna heights for each occupation were calculated from the survey log sheets and incorporated into the RINEX headers.

Site positions: We used the GAMIT package (Herring et al., 2018) to solve for precise site positions in the ITRF 2008 reference frame, using precise satellite orbits and ephemerides. Both our newly-collected data, and previously-collected data from the same sites were processed. We included 30 regional and global continuous GPS stations in our solution to assist with stabilization and reference frame realization.

Site velocities: We used the GLOBK software (Herring et al., 2018) to combine our processed positions from long observation epochs into time series and solve for deformation velocities in the ITRF 2008 reference frame (Figure 2). Then, we estimated and rotated our velocities into a fixed North America reference frame using the GLORG software. The updated velocities are presented in Floyd et al. (2020) and have been used to estimate pre-Ridgecrest earthquake positions for our campaign sites (see below).

The 2019 Ridgecrest earthquakes

On July 4th and 5th, 2019, a pair of large earthquakes (M6.4 and M7.1, respectively) occurred on conjugate strike-slip faults near Ridgecrest, California. As we had surveyed sites near Ridgecrest as part of our winter campaign, we were well placed to respond promptly to the first earthquake, arriving in the field in the afternoon of July 4th. That afternoon, and on the morning of July 5th, we occupied four sites to the west and southwest of the M6.4 epicenter (H701, J701, F048 and ATOL) that had previously been measured in February, as well as one site to the south (PNCL) that had been measured in 2001. The first of these measurements were started within seven hours of the M6.4 event, with all five sites operating within 30 km of the rupture within 26 hours (see Figure 4). All five remained standing and running during and after the second, M7.1 earthquake that occurred 34 hours after the M6.4, providing a unique, near-field constraint on the deformation from each event separately. Site PNCL, as it turned out, was fortuitously located only 600 m from the surface rupture of the M7.1 event, and so detected the highest displacements – over 70 cm of horizontal displacement in the M7.1 earthquake. Our response, and the data set collected as a result, is documented by Floyd et al. (2020).

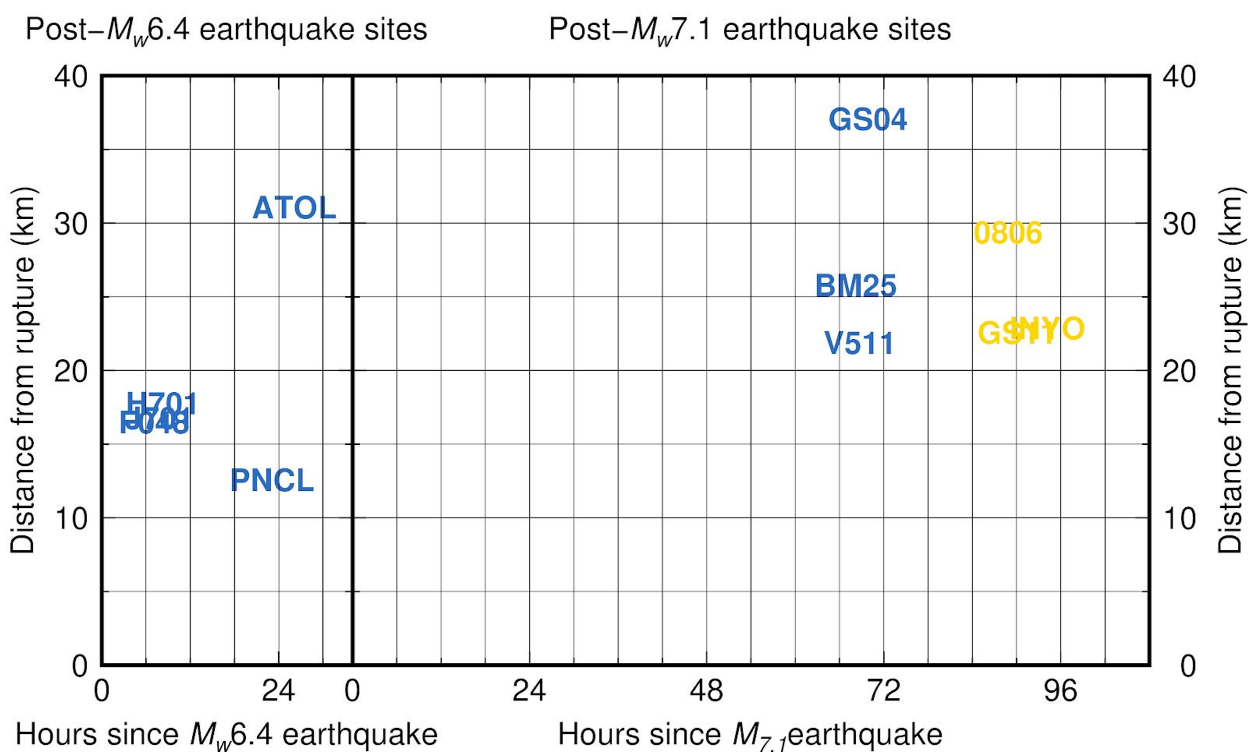

Figure 4: Summary of first survey observations during the post-earthquake response. Blue are survey sites occupied by the UCR field team and gold are survey sites occupied by the SIO/UCSD field team.

Summary

Intellectual merit: We collected GPS data in two areas of high current seismic hazard – the Inland Empire (home of the northern San Jacinto fault and the Cajon and San Gorgonio Pass segments of the San Andreas fault), and the Mojave desert (containing the Eastern California Shear Zone and Garlock fault). The data collected will be used to estimate updated campaign GPS velocities for future updates of the SCEC Community Geodetic Model. They were also used to provide a strong constraint on site positions before the 2019 Ridgecrest earthquakes, and facilitated a rapid response to those events (and measurements of coseismic offsets for each).

Broader impacts: The field work elements of the project were led by members of two underrepresented minorities – a Latino undergraduate intern and a female graduate student. The data collected will be used to update secular deformation rates across the region, which are inputs for seismic hazard models that are widely used by local governments and agencies for hazard remediation planning.

References

M Floyd, G Funning, Y Fialko, R Terry and T Herring, 2020, Survey and Continuous GNSS in the vicinity of the July 2019 Ridgecrest earthquakes, Seismol. Res. Lett., accepted. https://doi.org/10.1785/0220190324

T A Herring, M Floyd, R W King, S C McClusky, 2018, Introduction to GAMIT-GLOBK, Massachusetts Institute of Technology (http://geoweb.mit.edu/gg/)