# SCEC Project 25325: Updating GNSS measurements of postseismic deformation after the 2019 Ridgecrest earthquake sequence and site positions in the central Mojave Desert

Final Report

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## Abstract

The goal of this project was to conduct field GNSS surveys in the Mojave desert to improve coverage and precision of existing GNSS time series and velocities. One target was to add additional positions to the time series of postseismic deformation in the area affected by the Ridgecrest earthquakes in 2019. Another was to improve our estimates of secular deformation velocities in areas not affected by the Ridgecrest earthquakes – by making additional measurements in areas where the existing GNSS survey data is sparse, imprecise or contains a critical data gap. The data will ultimately be incorporated into the Community Geodetic Model (CGM), and used to improve estimation of geodetic fault slip rates. Postseismic deformation time series from the Ridgecrest area can additionally be used to constrain the constitutive relationships governing the faults and lithosphere in the area, and to validate the Community Rheology Model (CRM). An additional benefit of occasional revisits to GNSS survey benchmarks is building or refreshing institutional knowledge of benchmark locations, which could potentially expedite earthquake response fieldwork in the event of an earthquake occurring in our study area. In total, we occupied 32 survey benchmarks during the project, 16 of which were sites in the Ridgecrest area. The fieldwork was led by a SCEC SURE undergraduate intern, Katie Baraggiotta, who also did some basic GNSS data processing as a quality assurance check, under the supervision of UCR graduate student Karlee Rivera and the PI.

## Introduction and background

GNSS velocities and time series are critical inputs into seismic hazard models, such as the National Seismic Hazard Model. By providing constraints on the deformation caused by the moment rate deficits along active faults in the interseismic phase of the earthquake cycle, they can be used to estimate the rate of strain accumulation on those faults. In the event of an earthquake in that area, such interseismic deformation rates can be used to estimate pre-event positions so that displacements of the earthquake, and of any postseismic deformation that may follow, can be accurately determined with subsequent remeasurements.

Survey-mode GNSS is an inexpensive way to add density to the coverage of GNSS velocities across areas of geophysical interest. A single survey project, such as this one, can produce updated velocities for less than the installation costs of a single continuous GNSS station. Thus, while the continuous GNSS station network in the US is large (over 1200 stations), it still has significant gaps, particularly in less populated areas. While good precision can be obtained from infrequent (~5 year repeat) visits to survey sites, in the event of a major earthquake, survey sites can be occupied for longer periods, to greatly increase the density of measurements of the transient deformation following the earthquake. So it proved after the 2019 Ridgecrest earthquakes (e.g. Floyd et al., 2020), in which we mobilized rapidly on the day of the first, M6.4 event, and eventually, in partnership with colleagues at UNR, Scripps and the USGS, added time series from over 30 sites, many of which were continuously occupied for 2-3 years, to the records of the postseismic deformation from the earthquakes.

Indeed, part of the explanation for the speed of our response in 2019 was the fresh memory of the locations of multiple benchmarks in the Ridgecrest area, following a survey campaign, targeting the Garlock fault and based in Ridgecrest that we had conducted five months before. In our opinion, a significant additional benefit of maintaining a regular rotation of survey campaigns across the SCEC region is the expediting of post-earthquake response.

## GNSS field data collection

In total, we occupied and measured 32 GNSS benchmarks in the course of the project – 16 sites in the Ridgecrest area, and 16 sites elsewhere in the Mojave area (Figure 1, Table 1). The majority of the latter sites were accessible on day trips from our base at UC Riverside, and constituted the bulk of the project work, whereas the sites in the Ridgecrest area were surveyed on a four-day trip in early August.

Each site occupation followed the same procedure. At installation, we would center and level a tripod above the benchmark, install the antenna on the tripod and orient it to true north, measure the slant height of the antenna above the benchmark using a precise measuring stick, and connect and power on the receiver (e.g. Figure 2). At take-down we would remeasure the slant heights and recheck the centering and leveling of the antenna. All of these actions are documented on a log sheet, which includes additional information on the site, such as the benchmark details, summary maps and an estimate of the elevation mask. Occupations were typically for 14-18 hours, overnight – equipment was set up in the afternoon, and then taken down the following morning. All sites were measured using the PI's Trimble 5700 and R7 receivers, with Trimble Zephyr Geodetic antennas.

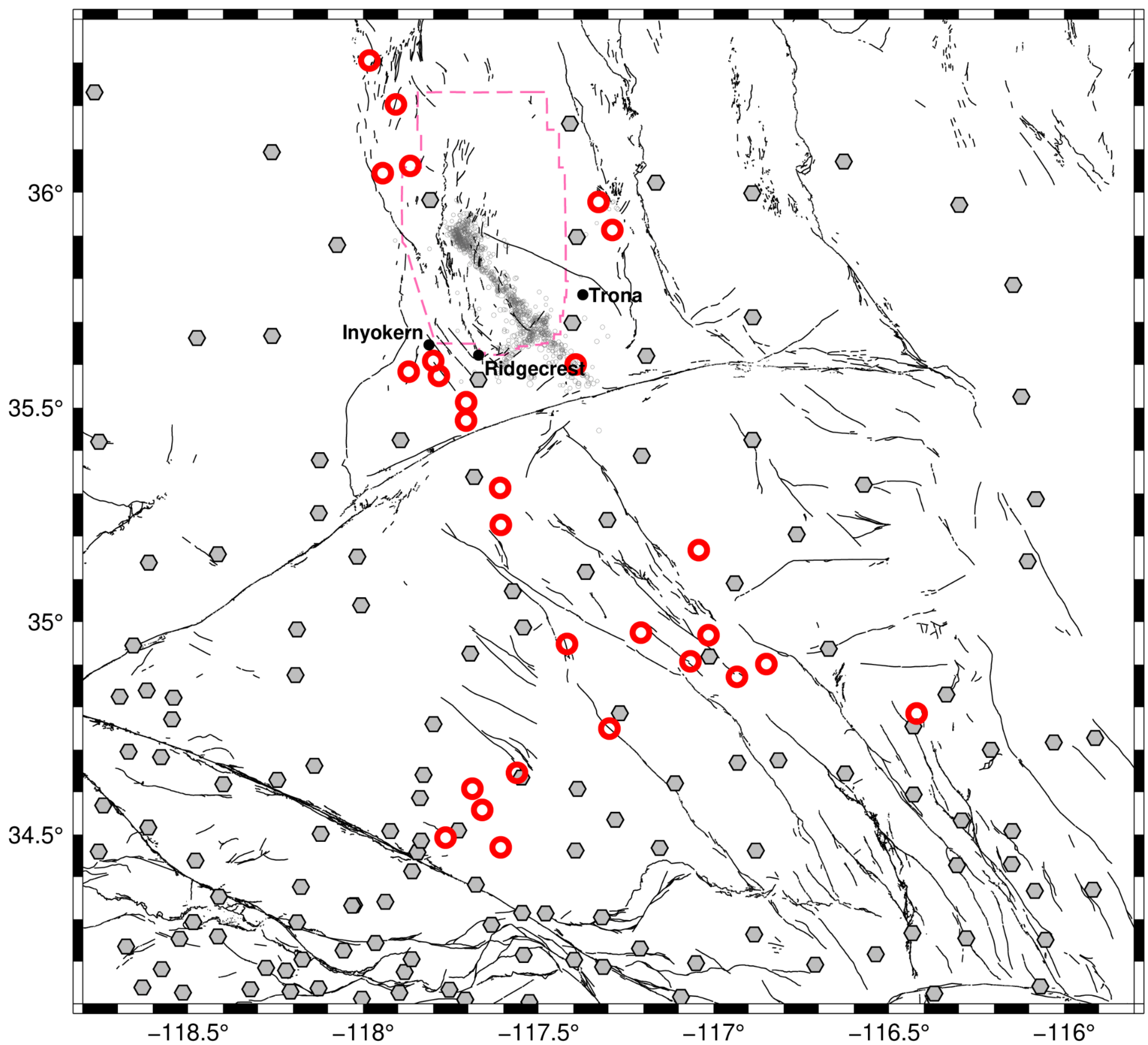


**Figure 1:** Map of the project area, covering the central Mojave desert and Ridgecrest areas. Red circles indicate sites that we measured in the summer of 2025; gray hexagons are the locations of continuous GNSS stations. Solid lines are Quaternary faults from the USGS and CGS; pink dashed line indicates the boundaries of the Naval Air Weapons Station at Ridgecrest.

**Table 1**: Details of GNSS survey benchmarks sites occupied in the project

| Site code | Lat | Lon | Date |
|---|---|---|---|
| *Mojave desert interseismic (16 sites)* | | | |
| 0705 | 34.4927 | -117.7651 | 2025-06-30 |
| DANE | 34.9073 | -117.0660 | 2025-07-14 |
| 6024 | 34.4698 | -117.6076 | 2025-06-30 |
| 6025 | 34.5065 | 117.5385 | 2025-06-30 |
| 6034 | 34.6455 | -117.5611 | 2025-07-01 |
| 6046 | 34.9011 | -116.8495 | 2025-07-15 |
| ANGL | 34.5579 | -117.6604 | 2025-06-30 |
| B129 | 34.9688 | -117.0147 | 2025-07-15 |
| GS36 | 35.1678 | -117.0425 | 2025-07-15 |
| HAWE | 34.9481 | -117.4185 | 2025-07-14 |
| HECT | 34.7850 | -116.4207 | 2025-07-15 |
| MOOD | 34.6082 | -117.6884 | 2025-07-01 |
| NEBO | 34.8709 | -116.9335 | 2025-07-15 |
| NORM | 35.2268 | -117.6072 | 2025-07-14 |
| RAIN | 34.9748 | -117.2075 | 2025-07-14 |
| SUNH | 34.7495 | -117.2974 | 2025-07-14 |
| *Ridgecrest area postseismic (16 sites)* | | | |
| 0913 | 36.3046 | -117.9822 | 2025-08-05 |
| 0914 | 35.9780 | -117.3285 | 2025-08-07 |
| ABER | 36.9790 | -118.2884 | 2025-08-06 |
| ATOL | 35.3132 | -117.6093 | 2025-08-06 |
| BAMA | 36.6023 | -118.1195 | 2025-08-05 |
| BM25 | 36.0446 | -117.9440 | 2025-08-06 |
| G016 | 35.4702 | -117.7065 | 2025-08-07 |
| G018 | 35.5839 | -117.8703 | 2025-08-07 |
| GS04 | 36.2036 | -117.9066 | 2025-08-06 |
| GS25 | 35.9132 | -117.2890 | 2025-08-07 |
| H701 | 35.6090 | -117.8002 | 2025-08-07 |
| J701 | 35.5745 | -117.7839 | 2025-08-07 |

| | | | |
|---|---|---|---|
| PASO | 35.5129 | -117.7061 | 2025-08-07 |
| PNCL | 35.6009 | -117.3937 | 2025-08-07 |
| RITA | 36.9142 | -118.1010 | 2025-08-05 |
| V511 | 36.0613 | -117.8658 | 2025-08-06 |

**Figure 2:** SCEC SURE intern Katie Baraggiota, standing by a completed GNSS antenna set-up.

## Data curation and quality assurance

Following data collection, throughout the project, an important next step is quality assurance and preparation of the data for processing. We have built a Jupyter notebook-based workflow for estimating the antenna height parameters, and converting and adding metadata to the data files. In this workflow, we use the 'runpkr00' and 'teqc' codes to convert the data from Trimble's proprietary raw binary data format to RINEX format, and to populate the RINEX headers with appropriate metadata (e.g. the names of the data collectors, the antenna details, the vertical height of the antenna above the benchmark). These files will be archived through the EarthScope Consortium's GNSS Campaign Data Archive for all to use in future.

Finally, we assess the quality of the data files though a trial data processing, using the NOAA Online Positioning User Service (OPUS; https://geodesy.noaa.gov/OPUS/). This online tool uses simple double-difference processing approaches to estimate static positions for provided RINEX files. If we are able to complete data processing successfully for a given RINEX file, it is a sign that the data are of sufficient quality to be used in future processing efforts, and to be contributed to the archive.

## References

Floyd, M, 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., 91, 2047-2054, https://doi.org/10.1785/0220190324