# Ground Deformation Data from GEER Investigations of Ridgecrest Earthquake Sequence

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## Abstract

**Following the Ridgecrest earthquake sequence, consisting of an M 6.4 foreshock and M 7.1 mainshock along with many other events, the Geotechnical Extreme Events Reconnaissance association deployed a team to gather perishable data. The team focused their efforts on documenting ground deformations including surface fault rupture south of the Naval Air Weapons Station China Lake, and liquefaction features in Trona and Argus. The team published a report within two weeks of the M 7.1 mainshock. This article presents data products gathered by the team, which are now published and publicly accessible. The data products presented herein include ground-based observations using Global Positioning System trackers, digital cameras, and hand-measuring devices, as well as unmanned aerial vehicle-based imaging products using Structure from Motion to create point clouds and digital surface models. The article describes the data products, as well as tools available for interacting with the products.**

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## Introduction

The 2019 Ridgecrest earthquake sequence began with an **M** 6.4 foreshock at 10:33 a.m. local time on 4 July, followed by an **M** 7.1 mainshock at 08:19 p.m. local time on 5 July. These events were the first earthquakes centered in southern California to rupture the ground surface since the 1999 Hector Mine earthquake. Considering the importance of quantifying surface rupture and gathering perishable data from the Ridgecrest earthquake sequence, the National Science Foundation-funded (NSF) Geotechnical Extreme Events Reconnaissance (GEER) association, with cofunding from the B. John Garrick Institute for the Risk Sciences at University of California, Los Angeles (UCLA) and support from the Southern California Earthquake Center (SCEC) and National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), deployed several teams of researchers to the Ridgecrest area. The first team arrived in Ridgecrest on 5 July to document perishable data on the **M** 6.4 event effects, and the team experienced the **M** 7.1 event at a hotel in Ridgecrest. Work then continued for several weeks after the earthquake sequence, during which investigators identified major effects, performed detailed mapping of ground failure features, and conducted unmanned aerial vehicle (UAV) imaging.

The GEER team is multidisciplinary, with expertise in geology, seismology, geomatics, geotechnical engineering, and structural engineering. GEER collaborated extensively with other reconnaissance teams operating in the region, including a fault mapping team comprised of the U.S. Geological Survey, California Geological Survey, and U.S. Navy personnel. The team released v.1 of their report on 19 July and v.2 on 3 August (Stewart *et al.* 2019). These reports are publicly available. Although the GEER reports have been published, the bulk of the data gathered during the reconnaissance missions were not published at the time of the release of the reports. In fact, reports are often the only products published after a GEER mission, whereas the majority of the data gathered during the missions is often not published.

This article presents data gathered during the GEER missions that has now been published and assigned a digital object identifier (DOI). Data that have been published to date

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TABLE 1
**Summary of Reconnaissance Missions**

| Mission | Dates in Field | Description of Activities | Team Members | DOI |
|---|---|---|---|---|
| GEER field reconnaissance | 5–7 July | Pictures of **M** 6.4 and 7.1 surface ruptures, liquefaction features, and ground measurements of lateral spreading in Trona and Argus | Ahdi, Brandenberg, Davis, Goulet, Hudson M., Hudson K., Nweke, Stewart, and Wang | http://dx.doi.org/10.17603/ds2-vpmv-5b34 |
| JPL UAV imaging | 9, 11, 15, and 22 July | UAV imaging of **M** 6.4 and 7.1 surface ruptures immediately south of highway 178 over repeated dates | Donnellan, Lyzenga, Wang, and Pierce | http://dx.doi.org/10.5967/5sq2-rs60 |
| UCLA UAV imaging | 10–11 July | UAV imaging of **M** 7.1 surface rupture, and liquefaction features in Trona and Argus | Brandenberg, Delisle, Kim, Lucey, and Winters | http://dx.doi.org/10.17603/ds2-wfgc-a575 |
| SCEC field reconnaissance | 11–12 July | Additional pictures of surface fault rupture and ground cracks near the Trona Pinnacles | Goulet and Meng | http://dx.doi.org/10.17603/ds2-c5z3-wy42 |
| UW RAPID UAV imaging | 16–18 July | UAV imaging of **M** 6.4 surface rupture south of highway 178 | Lyda, Yeung, Buckreis, Issa, and Yi | http://dx.doi.org/10.17603/ds2-tyca-se83 |

DOI, digital object identifier; GEER, Geotechnical Extreme Events Reconnaissance; JPL, Jet Propulsion Laboratory; RAPID, Natural Hazards Engineering Research Infrastructure (NHERI) Natural Hazards Reconnaissance Facility; SCEC, Southern California Earthquake Center; UAV, unmanned aerial vehicle; UCLA, University of California, Los Angeles; UW, University of Washington.

includes (1) ground-based observations gathered during field deployments several days after the earthquake sequence, with specific focus on mapping surface fault rupture south of the Naval Air Weapons Station China Lake (NAWSCL), (2) ground-based observations of liquefaction effects in Trona and Argus, (3) UAV imaging of the surface ruptures south of NAWSCL, and (4) UAV imaging of liquefaction effects in Trona and Argus. With the intent of facilitating application by other researchers, in this article we document details regarding the data types that are available, the location of the data files, and tools for interacting with the data.

Additional data products being published by researchers affiliated with GEER, and presented by Stewart *et al.* (2019), include measurements of the surface rupture that occurred on the NAWSCL (Ponti *et al.*, 2020), in which the largest fault offsets were measured. In addition, UAV images of the length of the **M** 6.4 and **M** 7.1 surface rupture south of NAWSCL were gathered by I. Pierce *et al.* (unpublished manuscript, 2020, Data and Resources) and are being published separately. The amount of data available through these efforts is simply too large to fit into a single paper. We therefore focus our attention in this article on specific missions conducted to study surface rupture south of NAWSCL, and liquefaction features in Trona and Argus.

## Field Reconnaissance Missions

The various field reconnaissance efforts are referred to as missions, whereas data products for each mission are organized into collections. Table 1 summarizes the missions, dates, activities, team members, and DOIs for these deployments. This article includes five separate missions conducted between 5 and 22 July 2019. Two of the missions, GEER field reconnaissance and SCEC field reconnaissance, involved ground-based measurements using digital cameras, Global Positioning System (GPS) trackers, tape measures, and rulers. Three of the missions, JPL UAV imaging, UCLA UAV imaging, and University of Washington (UW) Natural Hazards Engineering Research Infrastructure (NHERI) Natural Hazards Reconnaissance Facility (RAPID) UAV imaging, involved UAVs equipped with digital cameras to perform Structure from Motion (SfM) processing to obtain point clouds and digital surface models (DSMs). A map showing the locations studied during these missions is provided in Figure 1. Details of the data products from each mission are discussed in the sections that follow.

### GEER field reconnaissance mission

The initial field reconnaissance mission team was formed after the **M** 6.4 event through the NSF-funded GEER association, with cofunding from the B. John Garrick Institute for the Risk Sciences at UCLA and support from the SCEC. The team experienced the **M** 7.1 event at a motel in Ridgecrest. Work then continued for two days, and involved initial reconnaissance to identify major effects, and detailed mapping of ground failures. Two members of the GEER initial reconnaissance team were able to access the NAWSCL, but most team members focused their attention on features south of the NAWSCL using GPS trackers, digital cameras with GPS geotagging capabilities, and hand-held measuring devices including tape measures and rulers.

Data from the GEER field reconnaissance mission (Brandenberg *et al.*, 2019) are published in DesignSafe (see Data and Resources, Rathje *et al.*, 2017), which is a cyberinfrastructure tool for the natural hazards community. The



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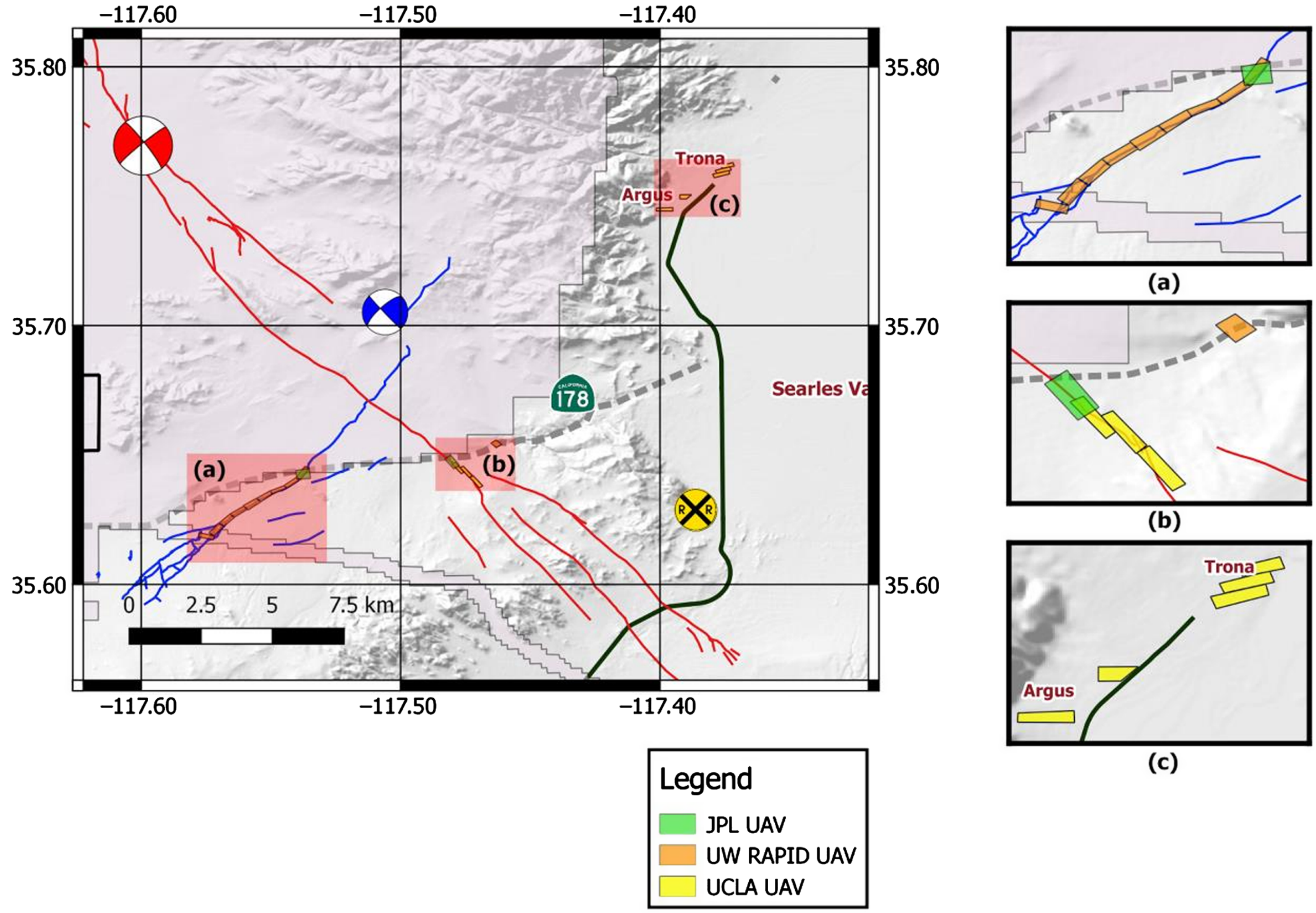


**Figure 1.** Map of the **M** 6.4 (in blue) and **M** 7.1 (in red) fault ruptures as given in Stewart *et al.* (2019) with shapefiles obtained from D. Ponti 17 July 2019, along with polygons flown during unmanned aerial vehicle (UAV) missions. Reconnaissance efforts in this article focused on the locations south of Naval Air Weapons Station China Lake (NAWSCL) where the fault ruptures cross highway 178, and liquefaction effects in Trona and Argus. JPL, Jet Propulsion Laboratory; UCLA, University of California, Los Angeles; UW, University of Washington. The color version of this figure is available only in the electronic edition.

field research project data model was utilized to organize the data within a mission into collections. The GEER field reconnaissance mission data are organized into nine separate collections. Eight of the collections are specific to the researcher who gathered the data, and are named "GEER team observations—NAME" in which NAME is an identifier for the researcher, and includes the following (Ahdi, Brandenberg, Goulet, Hudson K., Hudson M., Nweke, Stewart, Wang). The remaining collection is called "Quantum Geographic Information System (QGIS) products" and contains base maps and shape files from all of the researchers involved in the mission.

The individual collections contain Geographic Javascript Object Notation (GeoJSON) files that organize each researcher's track logs and photos into a file format that can be viewed using the HazMapper tool in DesignSafe. An example view of a GeoJSON file viewed using the HazMapper tool is shown in Figure 2 for the "GEER team observations—Brandenberg" collection, and shows a pipe that ruptured at the location where it crosses the **M** 6.4 surface rupture, and was subsequently repaired. Each photo appears as a thumbnail, and a reduced resolution version of the photo appears when a user clicks on the thumbnail. We recognize that users might want to view the full resolution versions of the images; therefore, we also included a zip file in each collection that contains the full resolution images. We suggest that users begin by viewing the GeoJSON files in the HazMapper tool to identify specific photos of interest and subsequently download the relevant zip file to locate the full resolution version of the photo.

The collection "QGIS products" synthesizes information from multiple researchers into a single data object that is also viewable using the QGIS app in DesignSafe. The individual products available in the QGIS products collection are also available in the individual researcher collections, but we believe that synthesizing these products together into a single collection is beneficial for data reuse because users can obtain a more immediate understanding of the activities performed by the entire team.

Figure 3 shows measurements of ground cracks at the location where the surface rupture from the **M** 6.4 event crosses



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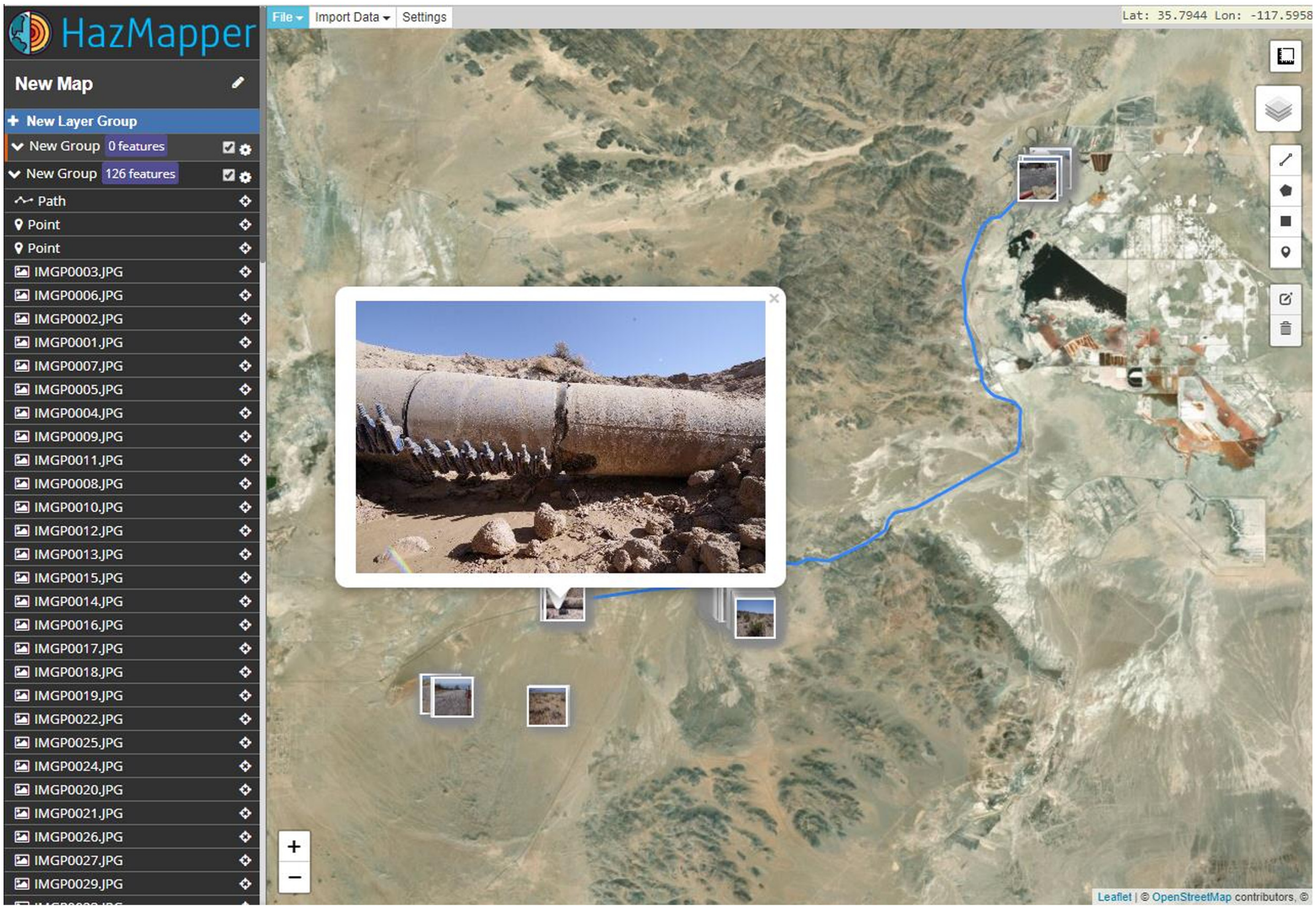


**Figure 2.** Visualization of "Brandenberg_July_6_2019.geojson" file using the HazMapper tool in DesignSafe. The color version of this figure is available only in the electronic edition.

highway 178. The purple lines were obtained by walking along each visible ground crack while recording a GPS track log and subsequently importing the track logs to QGIS. These lines were gathered at this location because we observed that the surface rupture was spread over a broad region, with the slip accommodated by many splays. The green lines are transects along which detailed measurements of ground crack position and width were made. Measuring these ground cracks soon after the earthquakes proved to be important because they degraded quickly from foot traffic, roadway repair efforts, wind-blown sand and dust, and collapse of the soil along the vertical crack walls. These ground measurements also provide an important benchmark against which the resolution and accuracy of SfM and light detection and ranging point clouds and DSMs can be evaluated. The ground crack measurements for the **M** 6.4 surface rupture have not yet been processed and are not included as part of the published dataset. However, we share all the field pictures documenting those features. Highlighted in red in Figure 3 is the region where a water pipe was broken at the locations where it crossed the surface rupture, disrupting water supply to Trona. Repair activities were ongoing during the reconnaissance mission.

Figure 4 shows reconnaissance measurements at the location where the surface rupture from the **M** 7.1 event crosses highway 178. The **M** 7.1 surface rupture at this location was concentrated in two main strands, and our efforts focused on characterizing these strands. The purple line is a GPS track log obtained by walking along the surface rupture from highway 178 toward the southeast. The green lines are transects along which ground cracks were measured. The ground crack measurements for the **M** 7.1 surface rupture have not yet been processed and are not included as part of the published dataset. However, we share all the field pictures documenting those features. At location B5, the ground in the extension zone is about 40 cm lower relative to the ground outside the fault strands. The yellow lines are survey lines along which the fault crack widths were measured at regular intervals. Lateral offsets along these survey lines were as large as 40 cm, and crack widths were as large as 50 cm.

## UCLA UAV imaging mission

A Dà-Jiāng Innovations (DJI) (SZ DJI Technology Company, Shenzen, China) Phantom 4 Pro UAV with a 20 million pixel



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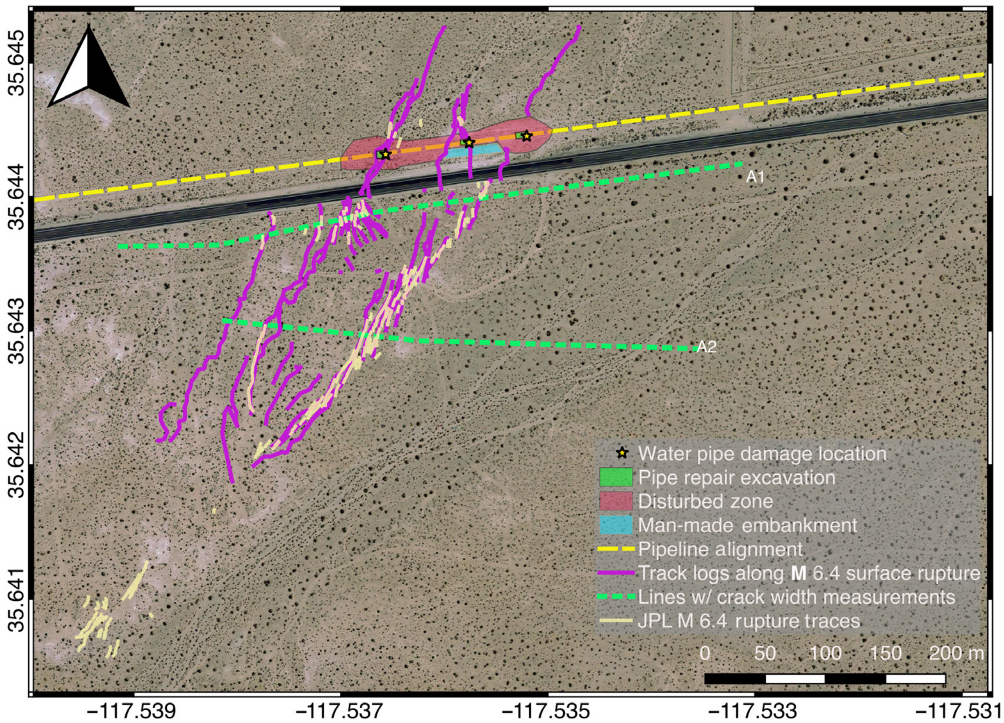


**Figure 3.** Map showing locations of measured ground cracks at location where **M** 6.4 fault rupture crosses highway 178 (Stewart *et al.* 2019). The color version of this figure is available only in the electronic edition.

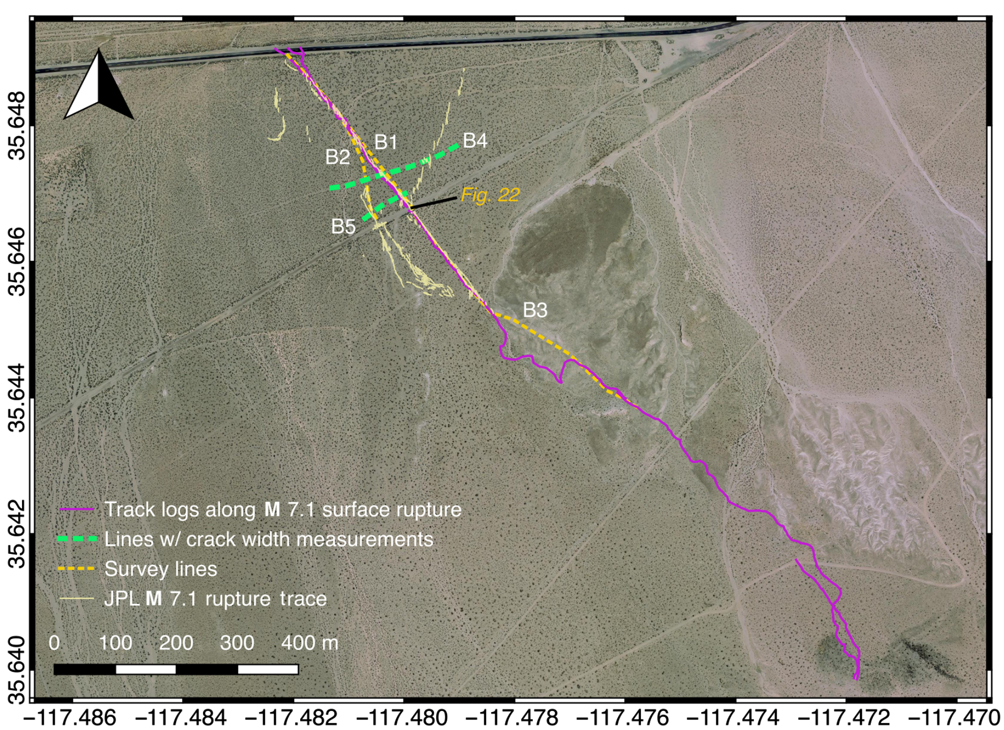


**Figure 4.** Map showing locations of measured ground cracks at location where **M** 7.1 fault rupture crosses highway 178 (Stewart *et al.* 2019). The color version of this figure is available only in the electronic edition.

camera was used to capture aerial photos of the surface rupture zone east of Ridgecrest, as well as liquefaction features in Trona and Argus areas on 10 and 11 July 2019. Flight parameters were managed using the DJI GS Pro iOS application wherein the autonomous flight path was based upon user-defined survey extents and a specified image overlap of 80% (Haala *et al.*, 2013). A Stonex S900A Global Navigation Satellite Systems (GNSS) receiver was used to geolocate ground control points (GCPs) spanning the survey region. GCPs were constructed of $0.3\ \text{m} \times 0.3\ \text{m} \times 1.3\ \text{cm}$ (½″) plywood with a high-contrast (monochrome) pattern. GCP locations were recorded in World Geodetic System 1984 (WGS84), UTM zone 11N using network real-time Kinematic (RTK) position corrections from Scripps Orbit and Permanent Array Center base station P618, approximately 100 km away. GCP density ranged from 0.6 to 1.9 GCP/ha above the 0.5 GCP/ha recommendation for highly accurate digital elevation model and orthomosaics (Coveney and Roberts, 2017).

Eight flights were conducted (Table 2) on 10 and 11 July. Three flights were flown at the **M** 7.1 rupture location (Fig. 1b), three flights at the Trona liquefaction site (Fig. 1c), and two at the Argus location (Fig. 1c). Ambient temperatures were approximately 40°C and winds calm. Flights were constrained to 55 m above ground level (AGL) and covered approximately 6 ha each. The UAV camera was angled 90° from the flight direction (i.e., perpendicular to the flight path) with the lens facing directly



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TABLE 2
**Summary of UAV Flights for UCLA UAV Imaging Mission**

| Flight Number | Date (yyyy/mm/dd) | Location | Time (UTC) | Flight Area (ha) | Flight Altitude (m, AGL) | Duration (min) | NTRIP Base | Number of GCPs | GCP/ Hectare | Rmse (cm) | GSD (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2019/07/10 | **M** 7.1 rupture | 19:30 | 6.65 | 54.86 | 15.5 | P618 | 4 | 0.60 | 10.8 | 1.3 |
| 2 | 2019/07/10 | **M** 7.1 rupture | 21:10 | 6.77 | 54.89 | 16.0 | P618 | 6 | 0.89 | 10.8 | 1.3 |
| 3 | 2019/07/10 | **M** 7.1 rupture | 23:15 | 5.56 | 59.47 | 10.5 | P618 | 6 | 1.08 | 10.8 | 1.3 |
| 13 | 2019/07/11 | Trona | 15:35 | 5.55 | 54.89 | 13.0 | P618 | 8 | 1.44 | 7.3 | 1.4 |
| 14 | 2019/07/11 | Trona | 16:45 | 6.49 | 54.89 | 15.0 | P618 | 9 | 1.39 | 7.3 | 1.4 |
| 15 | 2019/07/11 | Trona | 18:00 | 3.11 | 54.89 | 8.0 | P618 | 6 | 1.93 | 7.3 | 1.4 |
| 16 | 2019/07/11 | East Argus | 19:00 | 5.15 | 54.89 | 12.5 | P618 | 7 | 1.36 | 7.7 | 1.4 |
| 17 | 2019/07/11 | West Argus | 20:05 | 5.37 | 54.89 | 12.5 | P618 | 8 | 1.49 | 13.2 | 1.7 |

AGL, above ground level; GCP, ground control point; GSD, ground sampling distance; NTRIP, Networked Transport of RTCM via Internet Protocol; rmse, root mean square error; RTCM, Radio Technical Commission for Maritime.

downward for all flights. In flights covering the surface rupture, the UAV was flown in lines parallel to the fault strike.

Automatic photogrammetric image processing Pix4Dmapper (v.4.4.12, Pix4D S.A., Prilly, Switzerland) software and RTK surveyed GCPs were used to generate georectified point clouds, orthomosaics, and DSMs from UAV data. GCPs were imported into Pix4D, in which target centers were manually identified. Pix4D utilizes binary descriptors to photo-match points (Küng *et al.*, 2011). The matched points are then used, along with the image positions and orientations, to obtain georectified 3D coordinates. The point clouds were interpolated to a triangulated irregular network, and the DSMs and orthomosaics were generated. The DSMs were not filtered for vegetation, vehicles, people, or other surface objects. Average ground sampling distance (GSD) range from 1.3 to 1.7 cm. Root mean square error (rmse) estimates range from 7 to 13 cm depending on the individual flight (Table 2). The coordinate system is WGS1984 UTM zone 11N.

Data from this mission (Winters *et al.*, 2019) are organized into three collections titled “M7.1 Fault Rupture—UAV Survey,” “Argus Liquefaction—UAV Survey,” and “Trona LiquefactionUAV Survey.” Data included in each collection include the following: (1) a DSM in .tif format, (2) an orthomosaic image in .tif format, (3) a point cloud in .las format obtained from SfM processing, and (4) a folder containing data files to enable viewing the point cloud data using the Potree viewer in DesignSafe. The DSM and orthomosaic can be viewed using QGIS in DesignSafe, and Figure 5 shows an example of the DSM viewed in QGIS using the Hillshade rendering option.

The Potree point cloud converter in the DesignSafe discovery workspace was utilized to convert all of the .las files into an object that can be viewed using the Potree viewer, also available in the discovery workspace. Figure 6 shows the point cloud from the UAV survey over Trona. Liquefied sand ejected from the subsurface flowed over the parting lot at the Family Dollar store (near left center of Fig. 6), and sand boils are visible in the point cloud to the south of highway 178 in the foreground of the image. Ground cracks and compressional features indicative of liquefaction-induced lateral spreading are also visible throughout the imaged area.

## JPL UAV imaging mission

Five days after the mainshock, the 11th and 12th authors performed targeted surveys of the **M** 6.4 and 7.1 ruptures based on guidance from the 6th author and other members of the GEER team (Donnellan *et al.*, 2019; A. Donnellan *et al.*, unpublished manuscript, 2020, see Data and Resources). The two locations included a 480 × 410 m area just south of and including highway 178 over the **M** 6.4 rupture and a 460 × 640 m area over the **M** 7.1 rupture, also just south of and including highway 178 (Fig. 1). Double grids were flown at 45 m above ground on 9, 11, and 15 July at the **M** 6.4 and 7.1 locations, and on 22 July at the **M** 6.4 location using a Parrot Anafi vehicle with an integrated 21 megapixel camera and GPS for low-accuracy geotagging. The camera pointed forward 75° from horizontal. The side overlap of the images was 70 and the front overlap 80%. Iron cross ground control targets were placed and left at each site and surveyed each visit with a Septentrio RTK GPS system. A base station broadcast corrections, so that the GCPs are



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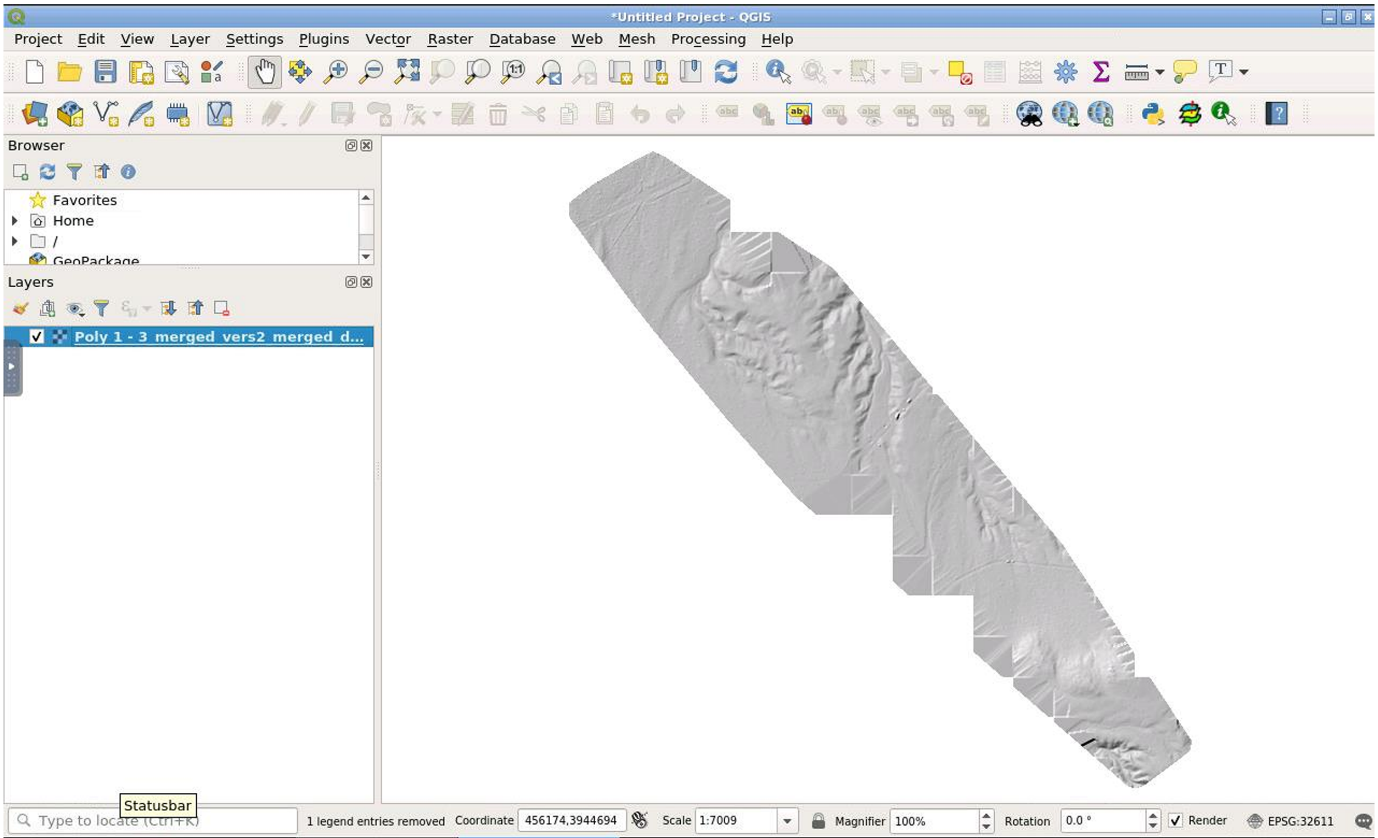


**Figure 5.** Digital surface model (DSM) "Poly 1-3_merged_-vers2_merged_dsm.tif" viewed in Quantum Geographic Information System (QGIS) in DesignSafe. The color version of this figure is available only in the electronic edition.

precise relative to each other. Data are recorded at the base station and later downloaded and processed using the National Geodetic Survey Opus system. Absolute accuracy of the GCPs is ±2 cm. We used check points to validate the accuracy. Absolute accuracy may be biased, particularly in the vertical for each solution, and we have no external local continuous GNSS reference for validation. Point clouds, orthomosaics, 2 cm DSMs, and quality reports for each survey are posted at GeoGateway under the 3D imaging tab (see Data and Resources). We are working to share our products to OpenTopography, DesignSafe, and GeoCollaborate. Figure 7 shows the point cloud for the **M** 7.1 rupture.

## SCEC field reconnaissance mission

On 11 July 2019, the 6th and 7th authors conducted the SCEC field reconnaissance mission to gather additional ground measurements at the location of the **M** 6.4 and 7.1 surface ruptures, observe ground cracks near the Trona Pinnacles, and visit Argus and Trona (Goulet and Meng 2019). Observations from this mission are organized into a collection titled "SCEC Recon Observations—Goulet." Goulet was a member of the GEER team, and observations from this mission are included in the GEER report. However, this mission and collection use the SCEC title to reflect the primary affiliation of Goulet and Meng. Within the collection is a GeoJSON file titled "SCEC.geojson" that contains all of the geotagged images from the mission, and a zip file containing the full-resolution images from the mission. A screenshot of the GeoJSON file viewed in DesignSafe is shown in Figure 8, along with a photo of a ground crack near the Trona Pinnacles.

## UW RAPID UAV imaging mission

The RAPID facility is sponsored by the NSF through the NHERI program, and provides investigators with equipment, software, and support services needed to collect, process, and analyze perishable data from natural hazards events. The RAPID facility is headquartered at the UW and is a collaboration between UW, Oregon State University, Virginia Tech, and the University of Florida. Members of the RAPID team, Andrew Lyda and Sean Yeung, conducted the UW RAPID UAV imaging mission on 16–18 July with help from the 22nd to 24th authors. Aerial imagery was gathered using a DJI Matrice 210 UAV with ground control provided by a Leica GS18 in base rover setup. A total of 10 separate polygons were flown over the **M** 6.4 surface rupture, and aerial imagery was processed in five batches titled "Ridgecrest1" to "Ridgecrest4" for the area south of highway 178, and titled "Highway178" for the polygon near the highway. Data from this mission (Lyda *et al.*, 2019) are organized in DesignSafe



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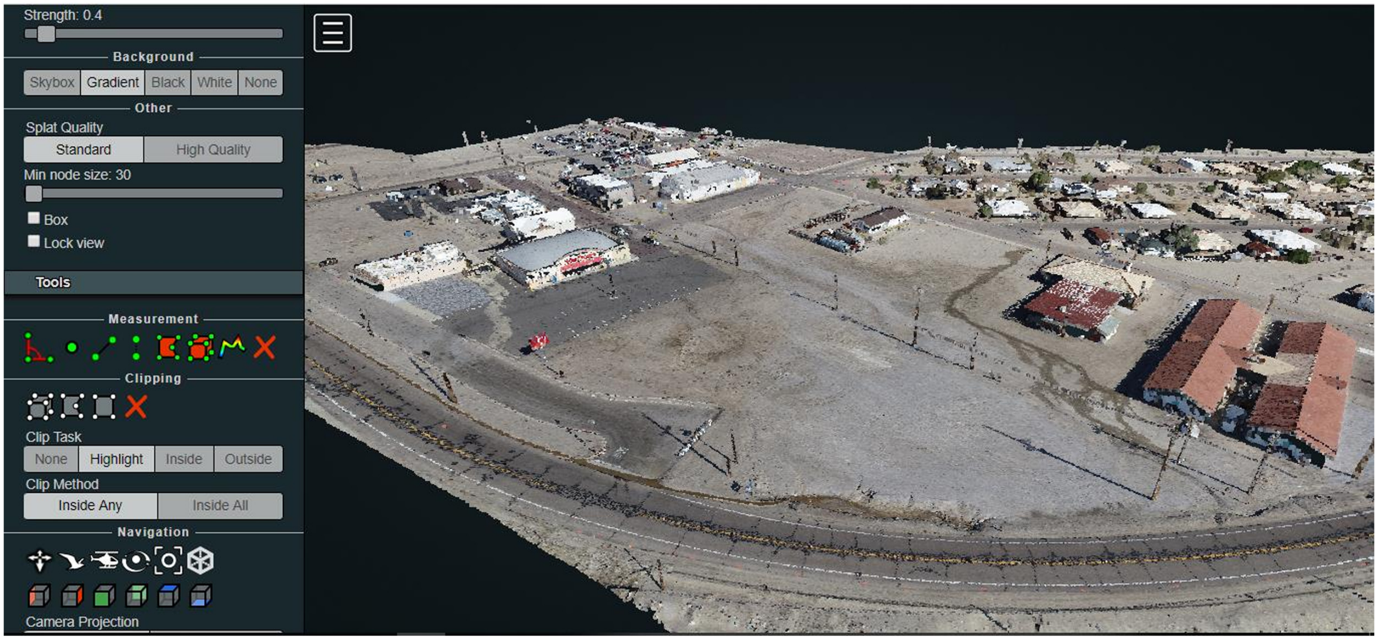


**F- i- gure 6.** Point cloud "TronaLiquefactionSurvey/point_cloud_potree" viewed using Potree viewer in DesignSafe. The color version of this figure is available only in the electronic edition.

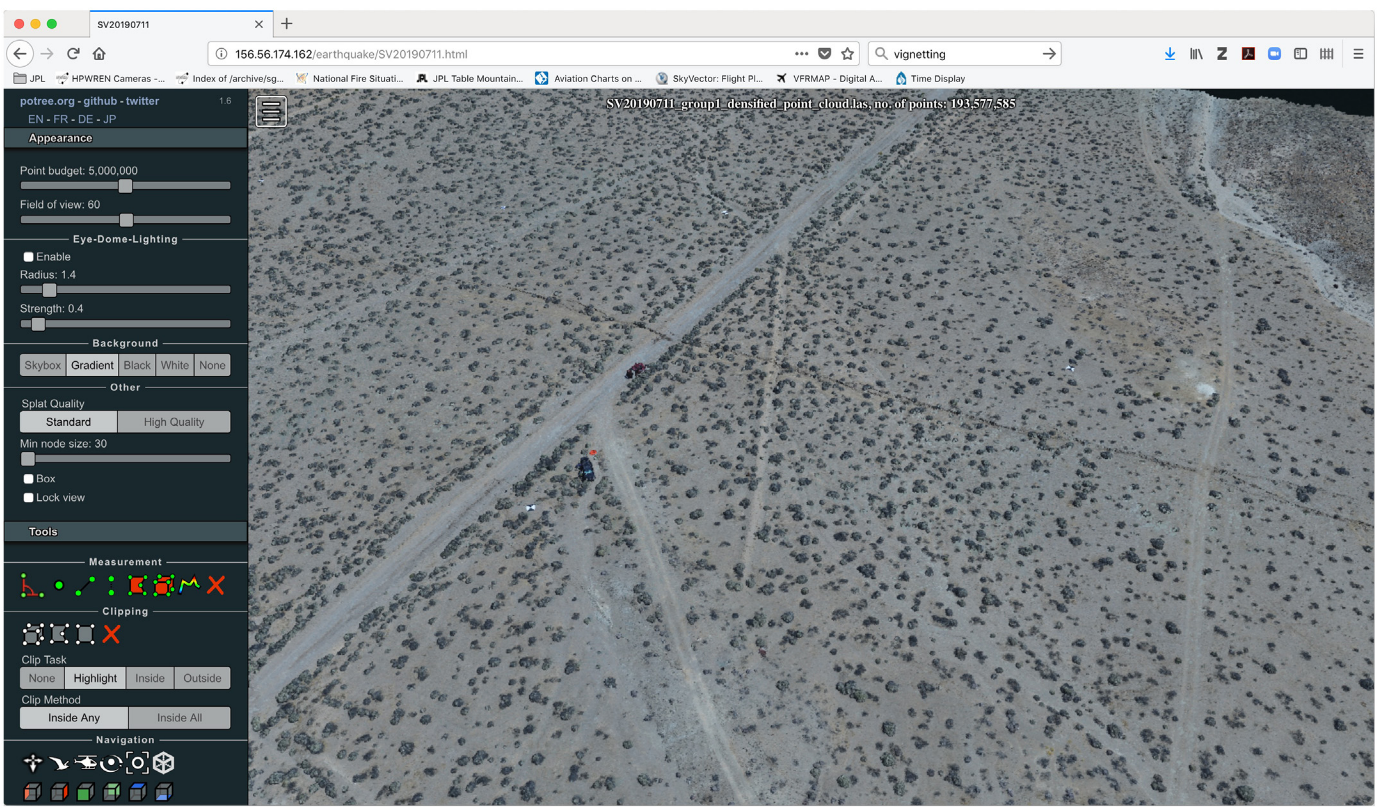


**Figure 7.** View of **M** 7.1 pointcloud in Potree from the GeoGateway (see Data and Resources) 3D imaging tab. This oblique view is to the northeast. The **M** 7.1 rupture can be seen in the image. The fault branches in the right of the image, at the south end of the point cloud. The color version of this figure is available only in the electronic edition.



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**Figure 8.** Screenshot from HazMapper showing "SCEC.geojson" file, with reduced-resolution image of a ground crack near the Trona Pinnacles. The color version of this figure is available only in the electronic edition.

into a collection titled "**M** 6.4 Fault Rupture—UAV Survey." Data products available for each processing batch from this mission include (1) a DSM in .tif format, (2) an orthomosaic in .tif format, (3) a point cloud in .las format, and (4) a folder for each point cloud created using the Potree converter in DesignSafe. Figure 9 shows a point cloud for the **M** 6.4 surface rupture at a location where the road is being repaired.

## Conclusions

This article presents ground deformation data collected by the GEER team following the 2019 Ridgecrest earthquake sequence. Five separate missions were performed to collect data using GPS trackers, digital cameras, hand-held measuring devices, and UAVs equipped with digital cameras. The GEER team published their report within two weeks of the **M** 7.1 mainshock event. This article presents the data that have been published in the time since the GEER reports were released. All of the data presented in this article are publicly available through the five DOIs in Table 1. In addition to making the data available, resources are also available for users to interact with the datasets in the cloud. The following apps available in the DesignSafe discovery workspace can be used to interact with the data: HazMapper can be used to view the GeoJSON files, QGIS can be used to view the mapping products synthesized from numerous different researchers, and the Potree viewer can be used to visualize point clouds produced from UAV SfM surveys. The Potree viewer is also available in the GeoGateway site where the JPL UAV imaging data are located. Our intention is that other researchers will be able to access the data resources presented herein, and integrate the data into their own workflows to learn about ground deformations from the Ridgecrest earthquake sequence.

## Data and Resources

The data presented in this article are publicly available, and have been assigned digital object identifiers (DOIs), as summarized in Table 1. The DesignSafe research platform is available at www.designsafe-ci.org. GeoGateway project is available at http://geo-gateway.org. All websites were last accessed in December 2019. Data published through GeoGateway are described by the unpublished manuscripts A. Donnellan, G. Lyzenga, A. Ansar, C. Goulet, J. Wang, and M. Pierce (2020), "Targeted high-resolution structure from motion observations over the M6.4 and M7.1 ruptures of the Ridgecrest earthquake sequence" and I. Pierce, A. Williams, R. D. Koehler, and C. Chupik (2020). "High resolution structure-from-motion models and orthophotos of the southern sections of the 2019 Mw7.1 and Mw6.4 Ridgecrest earthquakes surface ruptures," were submitted to *Seismol. Res. Lett.*

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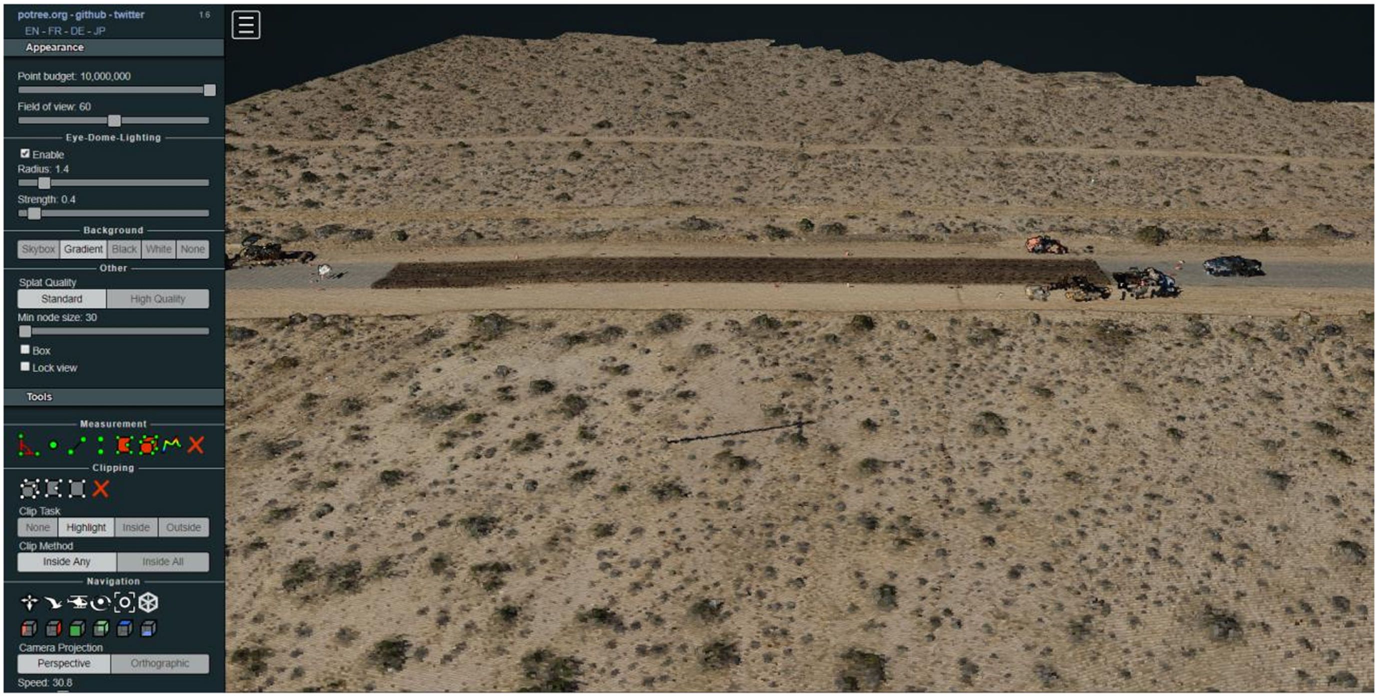


**Figure 9.** Screenshot of point cloud "M6.4_Ridgecrest1_point_cloud_for_potree" showing location where **M** 6.4 surface rupture crosses a rod that is being repaired. The color version of this figure is available only in the electronic edition.

field observations of the effects of extreme events. Sponsorship of this GEER deployment was also provided by the Natural Hazards Risk and Resilience Research Center (NHR3), the Southern California Earthquake Center (SCEC), and the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL). Portions of this work were carried out by the JPL, California Institute of Technology under contract with NASA. Data were collected in part using equipment provided by the NSF as part of the Natural Hazards Engineering Research Infrastructure (NHERI) Natural Hazards Reconnaissance Facility (RAPID) Facility, a component of the NHERI, under Award Number CMMI: 1611820. Any opinions, findings, conclusions, and recommendations presented in this paper (or presentation) are those of the authors and do not necessarily reflect the views of the NSF. The authors would like to thank the following individuals for their support during the various GEER missions: Shawn Barker (Shawn Barker Construction, Argus, California), Priscilla Benadom (Trona resident), Dale Fuller (Ridgecrest resident), Raymond Becker (Searles Valley Domestic Water), Ken Santini (Santini & Associates, Tucson, Arizona), Albert Kottke (PG&E), Jeff Keaton (Wood.), Wyatt Iwanaga (Wood.), Chris Madugo (PG&E), David Frost (Georgia Tech), Fangzhou (Albert) Liu (Georgia Tech), Niket Agrawal (Ridgecrest Super 8), Pinkal Panchal (Ridgecrest Super 8), and Gabriel Martinez (Ridgecrest Super 8).

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