2019 Caltech Report to SCEC

SCEC Award: 19069

SCEC Community Data Products of Earthquake Catalogs with Improved Focal Depth Estimation, for Resolving Fine-Scale Fault Structures and Crustal Rheology in Southern California

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Abstract

For more than a decade UCSD and Caltech have worked on improving earthquake locations and focal mechanisms, and systematically estimating stress drops from source spectra. Our results have produced large improvements in earthquake location accuracy for small earthquakes and dramatically sharpened seismicity features in southern California, while providing insight into fault zone processes. We have also produced large catalogs of focal mechanisms and Brune-type stress drop estimates, which have facilitated large-scale analyses of the stress state of the southern California crust. This work has led to a substantial body of published results, both by our group and by others who have used our data products in their own research.

The emphasis of this project has also been to produce and use the updated earthquake catalogs to address specific scientific research problems, such as fine-scale fault structures and rheological properties of the crust, and contribute to SCEC community models. In particular, we analyzed specific new earthquake sequences that are both of significant scientific and public interest.

We have maintained and updated our SCEC Community Products of refined earthquake locations and focal mechanisms for southern California, building on our previous SCEC work, which needed to be continued as more data accumulate and the methodology is improved.

During 2019, we further refined the earthquake locations and focal mechanisms. We updated our procedures by replacing the old location code with GrowClust developed by *Trugman and Shearer* (2017). The updated catalogs that extend from 1981 through 2019 include the first six months of the M6.4 and M7.1 Ridgecrest sequence. We have also used this catalog to analyze the seismotectonics of the Ridgecrest Coso region (*Hauksson and Jones*, 2020).

Results: Relocated earthquake (1981-2019)

The relocated (1981 – 2019) HS catalog (*Hauksson et al.* 2012) of almost 700,000 earthquakes is shown in **Figure 1**. It is produced via the following steps: (1) Initial locations are computed using existing phase picks and a 1D *P* and *S* velocity crustal model of *Hauksson* (2000); (2) refined locations are computed using existing phase picks and a 3D *P* and *S* velocity crustal model; (3) Waveform cross-correlation is performed for 500 nearest neighbors or all events on both *P* and *S* arrivals; (4) Similar event clusters are identified based on the waveform correlation coefficients and (5) Events are separately relocated within each similar event cluster using the waveform cross-correlation times and an L1-norm method as applied in the GrowClust program (*Trugman and Shearer*, 2017). The relocated catalog can be downloaded from here:

http://scedc.caltech.edu/research-tools/alt-2011-dd-hauksson-yang-shearer.html

Results: Focal catalog of mechanisms (1981-2019)

In 2012 *Yang et al*. (2012) published a large refined catalog of focal mechanisms for 1981 to 2010 using the HASH method of *Hardebeck and Shearer* (2002, 2003.). Both P-wave first motion polarities and S/P amplitude ratios are used to determine these focal mechanisms. We continue updating this catalog based on the latest relocated hypocenters. We have added the following recent improvements to our focal mechanism processing: 1) the capability to use the latest relocations from the refined catalog; 2) modified scripts to use already-downloaded sac waveforms; 3) corrected the code to better include known instrument reversals by referring to station by net code, station, code and location code. The focal mechanisms catalog can be downloaded from here:

http://scedc.caltech.edu/research-tools/alt-2011-yang-hauksson-shearer.html

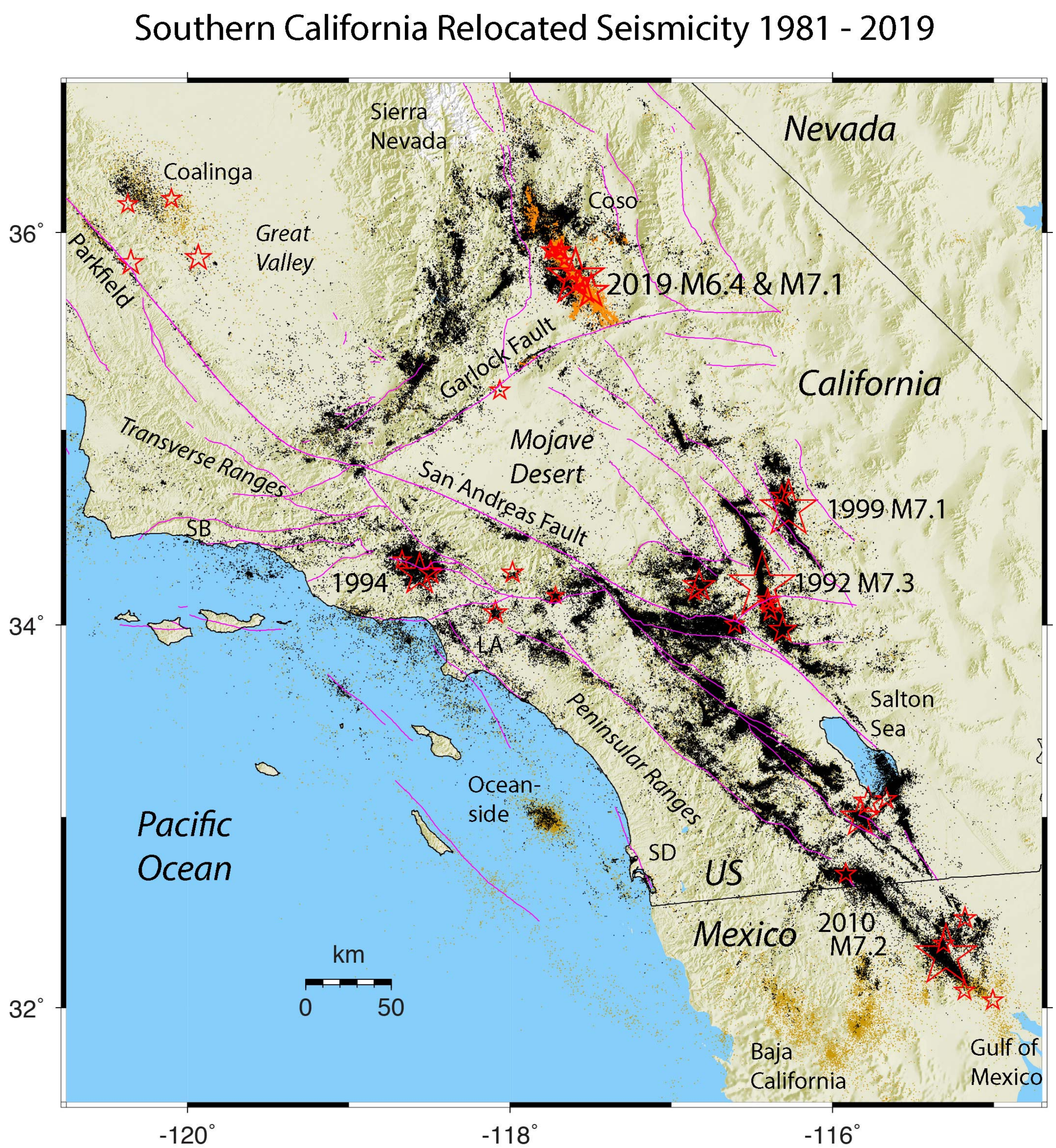

Figure 1. *The HS catalog (1981 – 2019). Similar-event clusters that have been relocated by using waveform cross-correlation are shown as black dots. Events in the SCSN catalog (and uncorrelated events in the other catalogs) are shown as brown dots. The 2019 Ridgecrest aftershocks are shown as orange dots. Events with M ≥ 5.5 are shown as red stars. Late Quaternary faults in magenta color are from Jennings and Bryant (2010). The relocated catalog is described here: Hauksson et al., (2012).*

The 2019 Mw6.4 and Mw7.1 Ridgecrest Earthquake Sequence

Decadal scale variations in the seismicity rate in the northern part of the Eastern California Shear Zone, called the Ridgecrest-Coso region, included seismic quiescence from the 1930s to the early 1980s, followed by increased seismicity through to the 2019 M_w6.4 and M_w7.1 Ridgecrest sequence. This sequence exhibited complex rupture patterns on almost orthogonal faults and triggered aftershocks over an area of ~90 km by ~5 to ~10 km wide, which is only a fraction of the previously seismically active area (Figure 2). During the last 40 years, the seismicity has been predominantly strike-slip faulting extending north from the Garlock fault, along the Little Lake and Airport Lake fault zones, and approaching the southernmost Owens Valley fault to the north. The Coso Range forms an extensional step over between these two strike-slip fault systems. This evolution of a plate boundary zone is driven by the northwestward motion of the Sierra Nevada, and crustal extension along the southwestern edge of the Basin and Range Province. Stress inversion of focal mechanisms showed that the new stress state rotates across the step over with the Coso Range and adjacent areas to the north have σ_1 trending ~N17°E while along the M_w7.1 mainshock rupture the trend is ~N6°E. The friction angles as measured between fault strikes and the σ_1 trends correspond to a frictional coefficient of 0.75, suggesting average fault strength. In comparison, the mature Garlock fault has a smaller frictional coefficient of 0.28, similar to weak faults like the San Andreas fault. Thus it appears that the heterogeneously spatially distributed but strong Ridgecrest Coso faults that accommodate seismicity at seemingly random places and times within the region, are in the process of self-organizing and forming a major through going plate boundary segment. For more information, also see *Hauksson and Jones* (2020).

Project presentations and publication

Cheng, Y., Z. E. Ross, E. Hauksson and Y. Ben-Zion (2020). A focal mechanism catalog for Southern California derived with deep learning algorithms; (Abstract S53A-02) presented at the *AGU Fall Meeting 2019 in Washington, DC, 9-13 Dec 2019*

Hauksson, E., C. Yoon, E. Yu, J. R. Andrews, M. Alvarez, R. Bhadha, and V. Thomas (2020). Caltech/USGS Southern California Seismic Network (SCSN) and Southern California Earthquake Data Center (SCEDC): Data Availability for the 2019 Ridgecrest Sequence, *Seismol. Res. Lett.* XX, 1–10, doi: 10.1785/0220190290.

Hauksson, E., Z. E. Ross, and E. Cochran (2019). Natural Slow-Growing and Extended-Duration Seismicity Swarms: Reactivating Joints or Foliations in the Cahuilla Valley Pluton, Central Peninsular Ranges, Southern California; submitted to *J. Geophys. Res. Solid Earth; February 2019.*

Hauksson, E. and L. M. Jones (2020). Seismicity, Stress State, and Style of Faulting of the Ridgecrest-Coso Region from the 1930s through 2019: Seismotectonics of an Evolving Plate boundary Segment, *Bull. Seismol. Soc. Am.* Submitted Jan. 2020

Hauksson, E., Z. E. Ross, J. M. Stock, M.-A. Meier and E. S. Cochran (2020). The 2019 M6.4 and M7.1 Ridgecrest Earthquake Sequence in the eastern California Shear Zone: Overview of Tectonic and Seismological Lessons; (Abstract S34C-01) presented at the *AGU Fall Meeting 2019 in Washington, DC, 9-13 Dec 2019*

Hauksson, E., Z. E. Ross, and E. Cochran (2019). Slow-Growing and Extended-Duration Seismicity Swarms: Reactivating Joints or Foliations in the Cahuilla Valley Pluton, Central Peninsular Ranges, Southern California; *Journal of Geophysical Research: Solid Earth*, 124, 3933–3949. https://doi.org/10.1029/2019JB017494

Hauksson, E., Thermo-mechanical Properties of the Seismogenic Crust in Southern California (Abstract) presented at the *Crustal Dynamics (ISCD-2); UJI, Kyoto, Japan*, 1-3 March 2019

Hauksson, E. and M.-A. Meier (2018). Applying Depth Distribution of Seismicity to Determine Thermo-mechanical Properties of the Seismogenic Crust in Southern California: Comparing Lithotectonic Blocks; *Pure and Applied Geophysics*, https://doi.org/10.1007/s00024-018-1981-z

Idini, B., M. Simons, M. Zhong, O. Stephenson, Z. E. Ross, E. J. Fielding, S.-Ho Yun, E. Hauksson, C. W. D. Milliner, A. W. Moore, and Z. Liu (2020). The first three days of the 2019 Ridgecrest earthquake sequence, (Abstract S34C-08) presented at the *AGU Fall Meeting 2019 in Washington, DC, 9-13 Dec 2019*

Terakawa, T., and E. Hauksson (2020). Modeling and Estimating the 3D Absolute Stress Field Using Earthquake Focal Mechanism Solutions, (Abstract) presented at the *Crustal Dynamics (ISCD-2); UJI, Kyoto, Japan*, 1-3 March 2019

Terakawa, T., and E. Hauksson, (2018). Absolute Stress Fields in the Source Region of the 1992 Landers Earthquake; *J. Geophys. Res. Solid Earth,* doi:10.1029/2018JB015765

Unruh, Jeffery R., F. Monastero and C. Francis (2019). Anatomy of a Releasing Stepover Between the Airport Lake Fault and the Owens Valley Fault Through the Coso Range, California, (Abstract) Presented at the *GSA 2019 Annual meeting in Phoenix, AZ*.

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Trugman, D. T., and P. M. Shearer (2017). GrowClust: A Hierarchical Clustering Algorithm for Relative Earthquake Relocation, with Application to the Spanish Springs and Sheldon, Nevada, Earthquake Sequences, *Seismol. Res. Lett.* , 88 (2A), 379–391, doi:10.1785/0220160188 .

Yang, W., E. Hauksson, and P. Shearer, Computing a large refined catalog of focal mechanisms for southern California (1981 – 2010): Temporal Stability of the Style of Faulting; *Bull. Seismol. Soc. Am.*, 102, 1179–1194, doi: 10.1785/0120110311, 2012.

Exemplary Figure

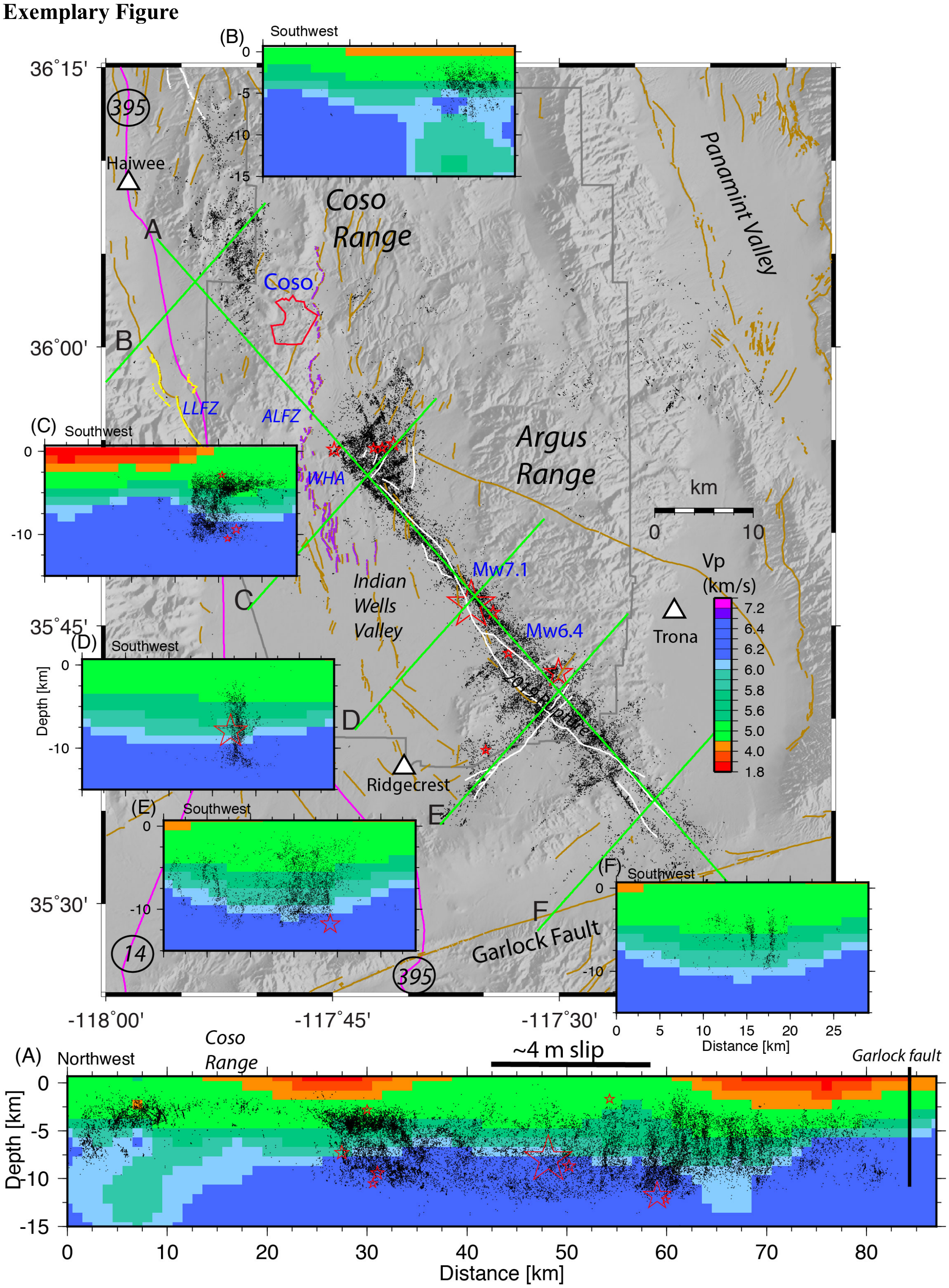

Figure 2. Map and depth cross sections showing the depth distribution of seismicity, which is plotted on top of the three-dimensional Vp velocity model by Hauksson and Unruh (2007). Each aftershock is plotted as a black dot except the M≥5 events which are shown as stars. The A-cross section is parallel to the M_w7.1 mainshock rupture. The B through F cross sections are taken parallel to the M_w6.4 rupture. The 2019 surface ruptures are shown in white. ALFZ – Airport Lake fault zone; LLFZ – Little Lake fault zone; WHA – White Hills anticline; From *Hauksson and Jones* (2020).