2018 Caltech Report to SCEC

SCEC Award: 18037

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 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 a large improvement in earthquake location accuracy for small earthquakes and dramatically sharpened seismicity features in southern California, while providing insight into fault zone processes (see **Figure 1**). 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.

During 2018, we further refined earthquake locations and focal mechanisms. We also developed a new method for seismic imaging of the Moho beneath thick sedimentary basins, which is challenging as low-velocity materials often cause strong reverberations that mask desired signals from the Moho. Instead, we take advantage of the sedimentary effect and develop a new method to image the Moho. The new method utilizes the first *Pn* crustal multiple from regional earthquakes, *PnPn*, and its differential travel time with respect to *Pn* to constrain the depth of the Moho. *PnPn* is usually weak in amplitude and thus is difficult to identify for a normal crust without sediments.

Results: Relocated earthquake (1981-2018)

The relocated (1981 – 2018) HS catalog (*Hauksson et al.* 2012)) of more than 650,000 earthquakes is shown in **Figure 1**. It is produced via the following steps: (1) Initial locations are computed using existing phase picks and the 3D *P* and *S* velocity crustal model of *Hauksson* (2000), (2) Waveform cross-correlation is performed for 500 nearest neighbors or all events on both *P* and *S* arrivals, (3) Similar event clusters are identified based on the waveform correlation coefficients, (4) Events are separately relocated within each similar event cluster using the waveform cross-correlation times and an L1-norm method. 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 (1981-2018)

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.). 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

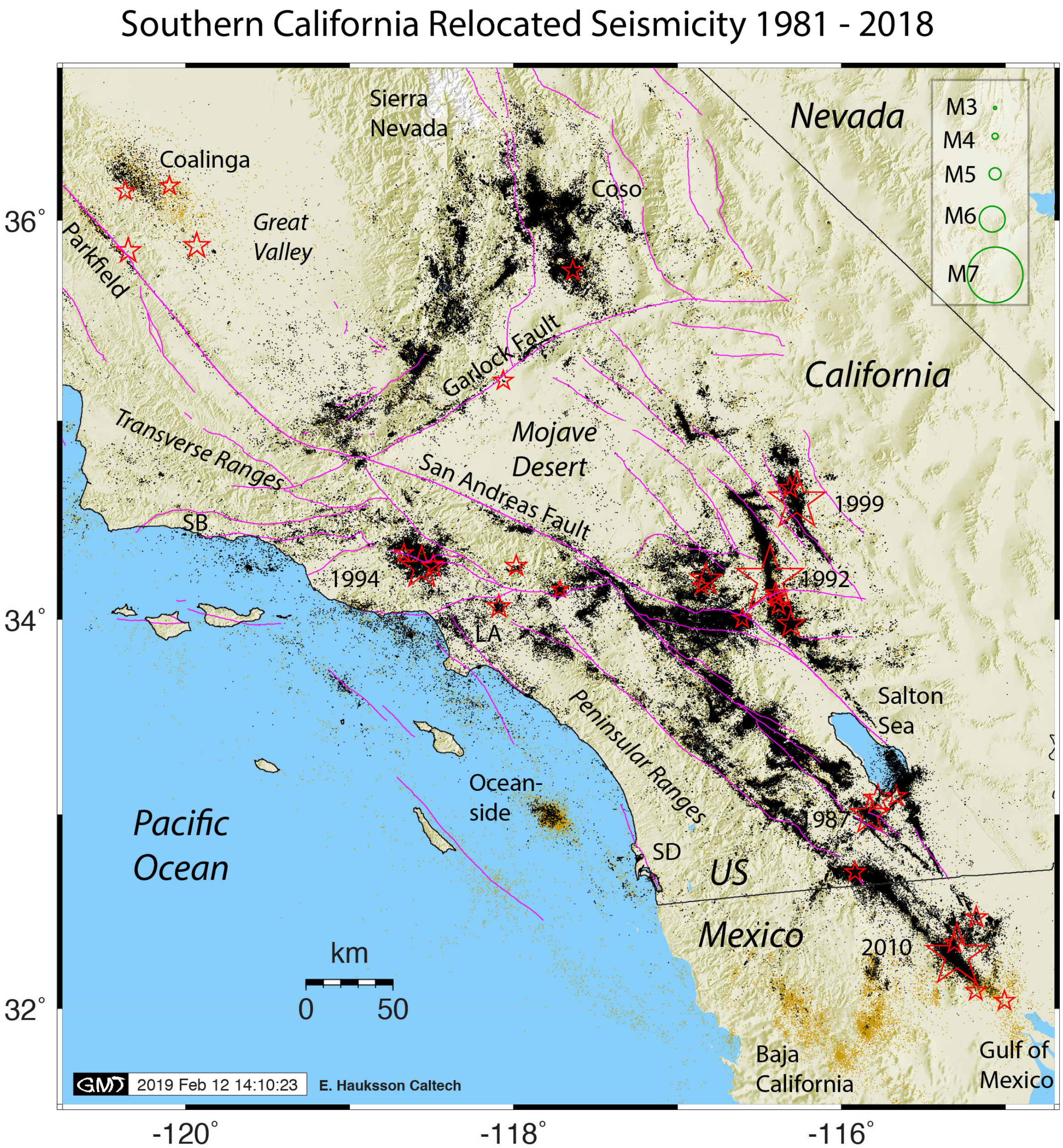

Figure 1. *The HS catalog (1981 – 2018). Similar-event clusters that have been relocated by using waveform cross-correlation are shown in black. Events in the SCSN catalog (and uncorrelated events in the other catalogs) are shown in brown. Events with M ≥ 5.5 are shown as red stars. Faults are from Jennings and Bryant (2010) with late Quaternary faults in shades of red. The relocated catalog is described here: Hauksson et al., (2012).*

Imaging the Moho beneath sedimentary basins using regional *Pn* multiples

Seismic imaging of the Moho beneath thick sedimentary basins is challenging as low-velocity materials often cause strong reverberations that mask desired signals from the Moho. Here, instead, we take advantage of the sedimentary effect and develop a new method to image the Moho. The new method utilizes the first *Pn* crustal multiple from regional earthquakes, *PnPn*, and its differential travel time with respect to *Pn* to constrain the depth of the Moho. *PnPn* is usually weak in amplitude and thus is difficult to identify for a normal crust without sediments. However, it is significantly amplified in the presence of low-velocity sediments as a result of increase in near-surface *P*-to-*P* reflection coefficient. The arrival time, amplitude and wave shape of *PnPn*, if normalized by the reference *Pn*, are insensitive to earthquake source parameters, including focal mechanism and focal depth. We demonstrate the usefulness of this method using both 1D and 2D waveform simulations. Synthetic waveforms suggest that *PnPmp* and *PmpPn* mostly contribute to the *PnPn* amplitudes, which depend on the near-surface structure at their free-surface *P*-to-*P* reflection points. We further validate the method with two field examples in the Imperial Valley (Figure 2) and in the central US. Both examples suggest that the new method can be used to image the Moho either near the source or near the receiver. For further details see Yu et al. (2019b).

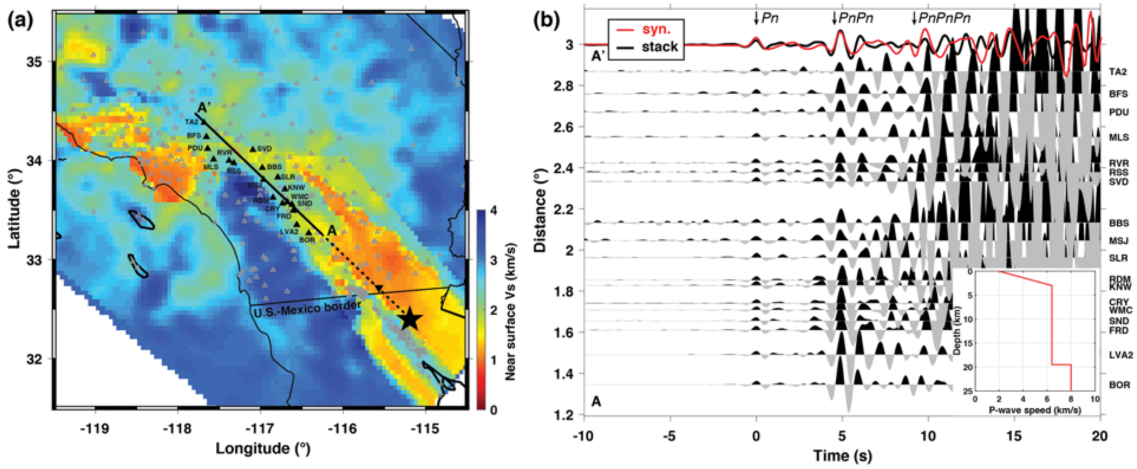

Figure 2. *Observations and modeling of PnPn from a M_w 4.3 event in the Imperial Valley. (a) Map showing mean shear wave speed in the top 2 km from the SCEC community velocity model CVM-S4.26 (Lee et al., 2014). The event used in the study (black star) is an aftershock in the 2010 El Mayor-Cucapah earthquake sequence (gray pluses). Triangles show the distribution of the Southern California Seismic Network. Stations selected along a NW-SE profile (AA') as indicated by the black solid triangles. (b) Seismic waveforms along profile AA', normalized and aligned by Pn. A zero-phase, Butterworth filter between 0.5 and 1.5 Hz is applied. The stacked waveform and its synthetic fitting is shown at the top. The inset in the lower right is the P-wave velocity model derived by the modeling.*

Project presentations and publication

Yu, C., E. Hauksson, Z. Zhan, E. S. Cochran, and D. V. Helmberger (2018), Absolute and relative focal depth determination of moderate-sized earthquakes: An example from the 2010 El Mayor Cucapah earthquake sequence, (Poster Presentation 056; SCEC Annual Meeting Palm Springs, 9-13 Sept. 2018).

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., Ross, Z., E., and Cochran, E. S., 2018. Sudden Surges of Seismicity within Natural

Slow Growing and Long Duration Seismicity Swarms near Cahuilla Valley in the Central Peninsular Ranges, Southern California, (*Poster Presentation 069); SCEC Annual Meeting Palm Springs, 10-12 Sept. 2018*.

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; PAGEOPH, https://doi.org/10.1007/s00024-018-1981-z May 2018.

Hauksson, E., Z. E., Ross, M.-A. Meier, and L. M. Jones (2017), Evolution of seismicity near the southernmost terminus of the San Andreas Fault: Implications of recent earthquake clusters for earthquake risk in southern California, *Geophys. Res. Lett.,* 44, doi:10.1002/2016GL072026.

Ross, Z. E., E. Hauksson, Y. Ben-Zion (2017), Abundant off-fault seismicity and orthogonal structures in the San Jacinto fault zone, *Sci. Adv.* 3, doi: e1601946.

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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

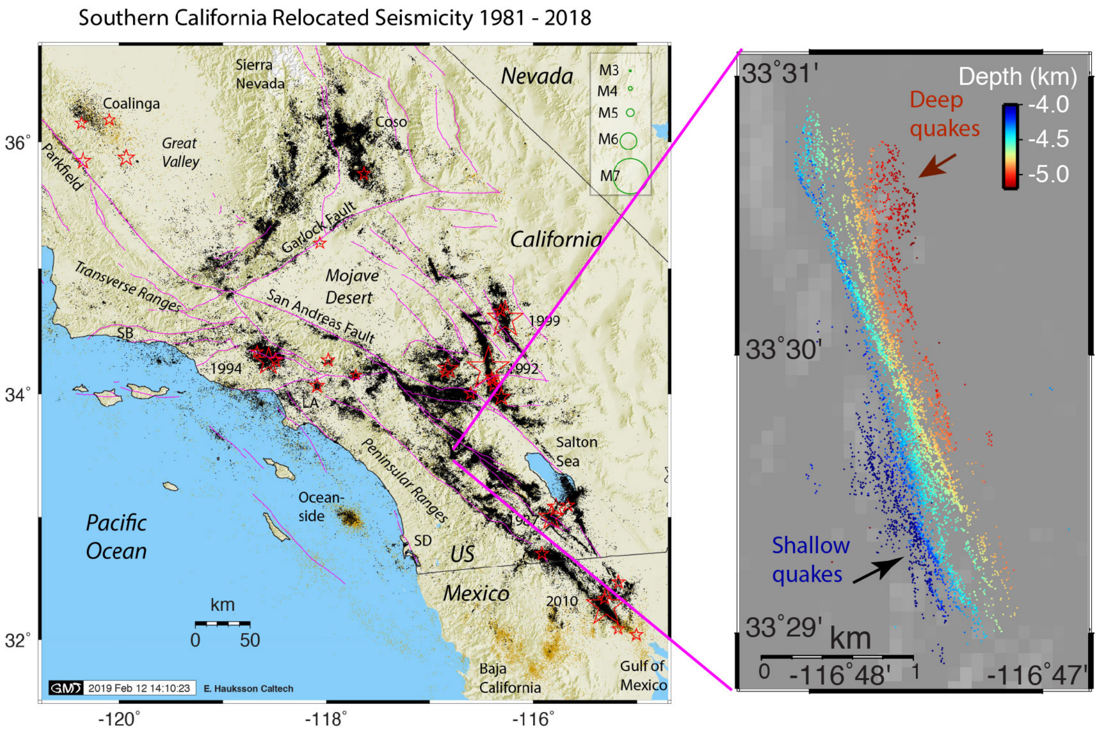

Figure 3. *Map showing relocated 1981 – 2019 seismicity for southern California and high-resolution relocations of the ongoing Cahuilla swarm, near Temecula, southern California. The Cahuilla swarm defines a ~6 km long fault dipping steeply to the east (Hauksson et al., 2019).*