Earthquake swarms have been considered as a characteristic seismic phenomenon on the active transform plate boundary. Yet the detailed processes of major events in the swarm have not been studied due to the lack of station coverage and the medium size of earthquakes. The two M>5 earthquakes in the recent 2012 Brawley swarm have been well recorded by the dense strong motion and GPS stations nearby. Using this dataset, we derived slip models for two events (Mw4.4 and Mw5.3) by joint inversion of strong motion and GPS data. Both static and high-rate components of the GPS data have been used. Different shallow 1D velocity models are applied for various strong motion stations. These essential path calibrations are obtained by waveform modeling of a smaller event (Mw3.95) in the swarm and allow us to push the waveforms through the present time. The major event in the swarm has not been studied before due to the lack of station coverage and the medium size of earthquakes.

Figure 1. Overview of the 2012 Brawley swarm. (a) The inset shows the locations of the events along the boundary between the Pacific plate and North America plate. Larger map shows the location of the Mw5.3 events in the 2012 Brawley swarm on the section of black data. The epicenter of the larger event (Mw5.4, ID: 15200401) is shown as the red star and the fault plane used in the finite fault inversion is displayed as a red rectangle with the solid line indicating the upper boundary of the fault. Beach balls are the strong motion stations (black and blue) and GPS stations (yellow). The two blue triangles only record the Mw5.3 event. The two dashed ellipses are the regions of 2005 (green) and 1987 (purple) swarms. The heavy dashed line indicates the Brawley Seismic Zone (BSZ). If 3.5< and 3.5> are the coarse faults of Imperial Fault, San Jacinto Fault Zone and San Andreas Fault System, respectively, then the upper boundary of the fault plane is between the fault plane of the Mw5.3 event and the BSZ and the lower boundary is between the fault plane of the Mw5.4 event and the fault plane of the Mw5.3 event. 

Figure 2. 1D velocity models from calibration event. (a) Schematic velocity profiles indicating how to obtain a calibrated velocity model. The depth of sediment base is fixed at 5.5 km, the Vp, min and Vo, max of which are the top of the model and the depth of f=4.3 km, respectively, are the two parameters to be inverted in a grid search. For UPW4, an empirical relation is used to link Vp with Vp, min [16]. The Vp and Vp depth profiles for the Path Calibration Model (PCM) and the ten 1D models extracted from the CVM4.0 [17] and CVM5.0 [18] 1D velocity models at the top of the model are shown in (b). The three-component waveform comparison between the data (black) and the synthetic (red) in the synthetic are computed using the three velocity models shown in (d). Both data and synthetics are filtered to 0.2-3.5 Hz. The peak amplitudes of data (brown) and synthetic (black) are shown on the top of each waveform pair. More waveform comparisons for other stations are shown in (d).

Figure 3. Slip models of the two M5+ events. (a) Upper The waveform comparison of the high-rate GPS stations and strong motion stations for the Mw5.4 event. Here, the synthetic (red) are generated by the preferred slip model for the Mw5.4 event. Both data and synthetics are filtered to 0.2-3.5 Hz. With GPS waveform displayed in displacement and strong motion in velocity. Lower: Strong motion waveform for the Mw5.3 event. (b) Moment tensor slip model for the Mw5.3 1D event. The distribution is smoothed with rise time and rupture time (moment) are shown in the lower panel. The black triangle is an indication of the rocky slope of the fault for better comparison. (c) Similar as (b) for the Mw4.4 event. (d) Moment rate function for both M5+ events. (e) Moment distribution in depth. (f) Overlapping of two slip models with color: red indicates slip distribution for the Mw5.4 event and the blue contour for the Mw5.3 earthquake.

Figure 4. GPS data fitting. (a) E-W component of 3Hz GPS record at station P499 with the signal of Mw5.3 event indicated as the arrow. 3Hz record for the Mw4.4 event is plotted in (b). (c) The synthetic waveforms recorded at station P499 are plotted along with the synthetic (red) produced by the slip model of Mw5.4 and Mw4.4 events. Notice that the data has been scaled by a factor of 70% to account for the moment differences. (c) Upper panel shows 5Hz seismogram, the E-W (red) and N-S (blue) components at station P499 are plotted along with the cumulative moment (heavy green).