Finite Fault Modeling of the Major Earthquakes in the 2012 Brawley Earthquake Swarm

Shengji Wei[1], Don Helmberger[1], Rob Graves[2], Ken Hudnut[2] and Susan Owen[3]
1, Seismological Labatory, Caltech, Pasadena; 2, USGS, Pasadena; 3, JPL, Caltech, Pasadena

Earthquake swarms have been considered as a characteristic seismic phenomenon on the active transform plate boundary. Yet the detail source processes of major events in the swarm have not been studied before 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 these dataset, we derived slip model for the two events (Mw5.4 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 waveform inversion up to 2Hz. The results indicate that the Mw5.4 event ruptured unilaterally towards south-east and has most of the slip distributed about 3~6km in depth and about 6km along strike with maximum slip amplitude of about 40cm. Correspondingly, the earlier Mw5.3 event ruptured slightly deeper depth and complementary to the slip distribution of the Mw5.4 event. The rise time for the Mw5.4 event favors larger values (~1s) than that for the Mw5.3 event (~0.4s), we consider the Mw5.4 event generated stronger long period (>1s) energy but weaker higher frequency energy, indicating higher stress drop for the deeper event.

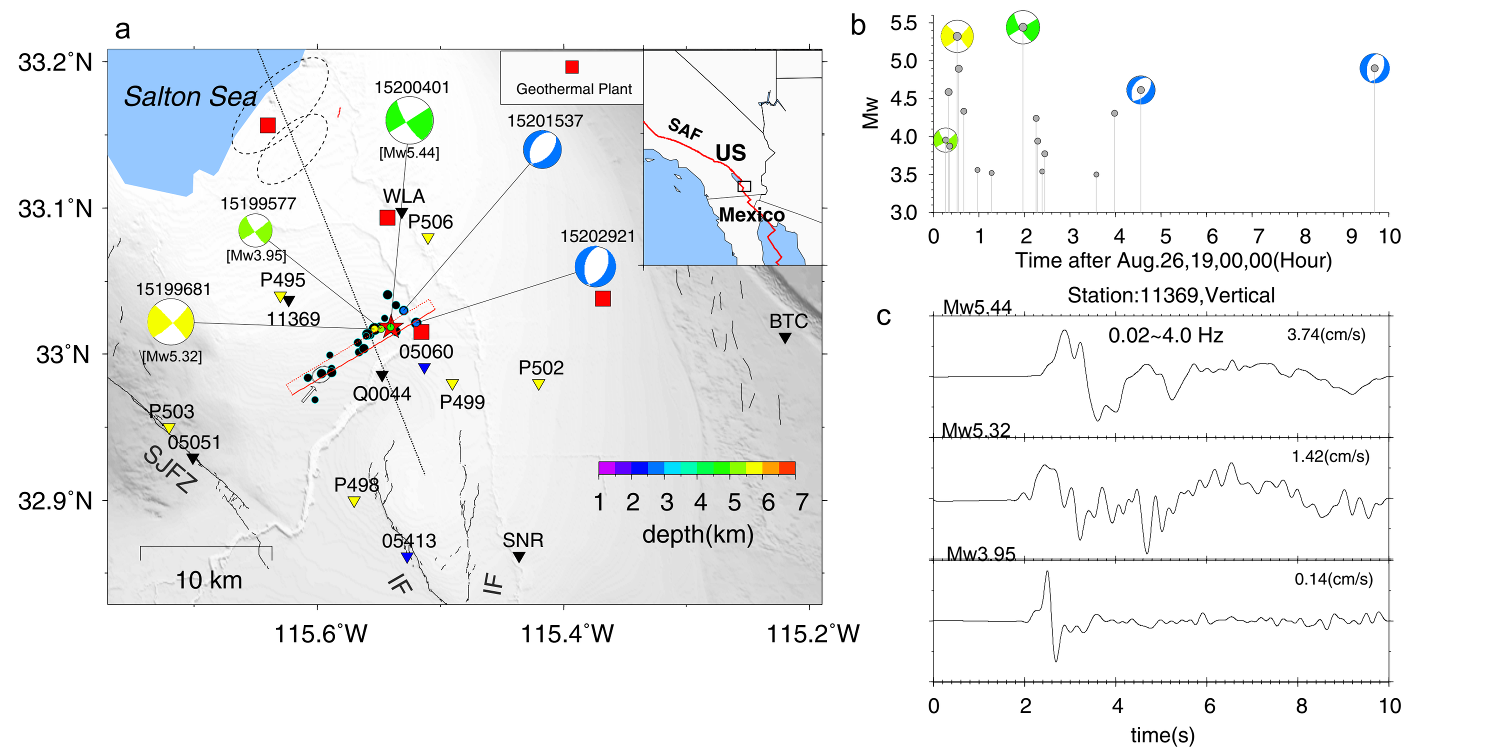


Figure 1. Overview of the 2012 Brawley swarm. (a) The inset shows the location of the swarm along the boundary between the Pacific plate and North America plate. Larger map shows the seismicity for the M>3.5 events in the 2012 Brawley swarm, indicated as black dots. The epicenter of largest event (Mw5.4, ID: 15200401) is shown as the red star and the fault plane used in the finite fault inversion is displayed as the red rectangle with the solid line indicating the upper boundary of the fault. Beach balls are the mechanism of five events used in this study with their depth indicated by the color bar. Geothermal power plants are shown as red squares and the triangles 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 (larger) and 1987 (smaller) swarms. The heavy dashed line indicates the Brawley Seismic Zone (BSZ). IF SJFZ and SAF are the short terms of Imperial Fault, San Jacinto Fault Zone and San Andreas Fault, respectively. (b) 10hr time serial of the swarm for the events with M>3.5 which the same five beach balls shown as in (a). (c) 0.02~4.0Hz velocity waveform records at the strong motion station 11369 for event 15199577, 15199681 and 15200401. The peak amplitude is indicated at the end of each record, note the source complexity of the two M>5 events.

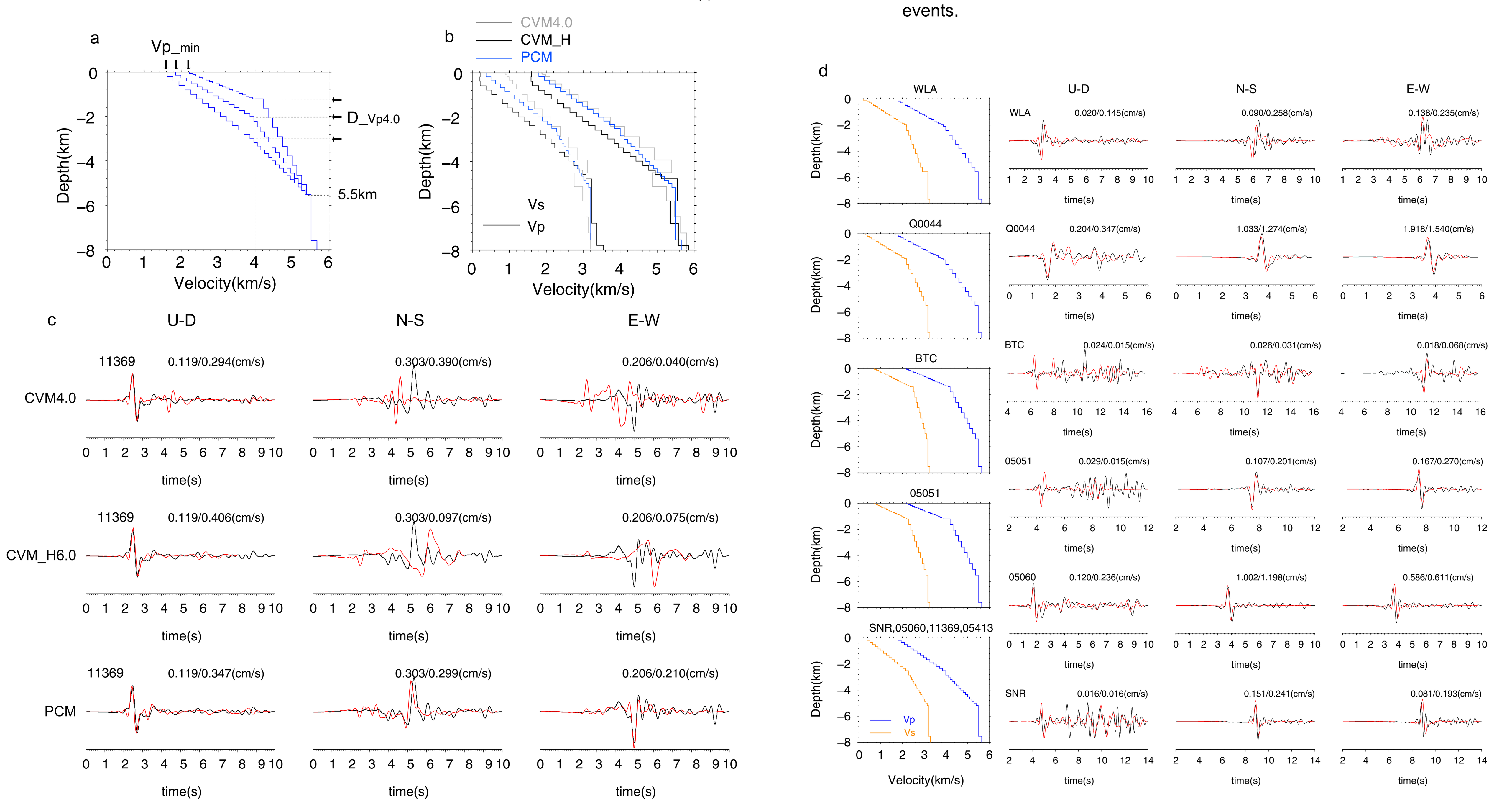
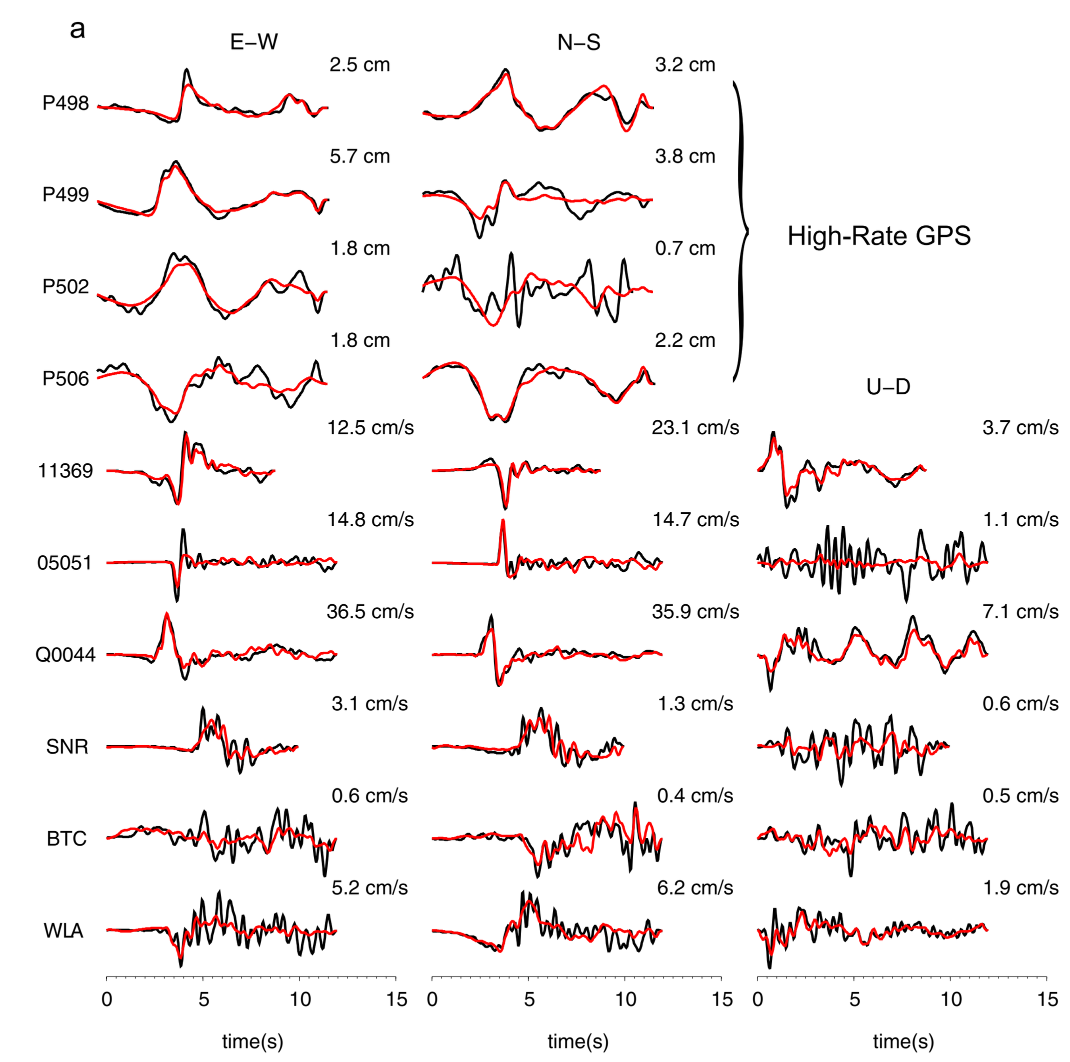


Figure 2. 1D velocity models from calibration event. (a) Schematic velocity profiles indicating how to obtain a calibrated velocity model. The depth of sediment base is fixed at 5.5km, the Vp_min and D_vp4.0, which are Vp at the top of the model and the depth of Vp equals 4.0km/s, repectively, are the two parameters allowed to change during a grid search. For Vp<4.0km/s, an empirical relation is used to link Vs with Vp. [ref] (b). The Vs and Vp depth profiles for the Path Calibration Model (PCM) and the two 1D models extracted from the CVM4.0 [ref] and CVM_H6.0 [ref] 3D velocity models at the location of epicenter of the Mw5.4 event. (c) Three component waveform comparison between the data (black) and the synthetics (red). Here the synthetics are computed using the three velocity models shown in (b). Both data and synthetics are filtered to 0.02~3.0Hz. The peak amplitudes of data (front) and synthetic (back) are shown on the top of each waveform pair. More waveform comparisons for other stations are shown in (d).



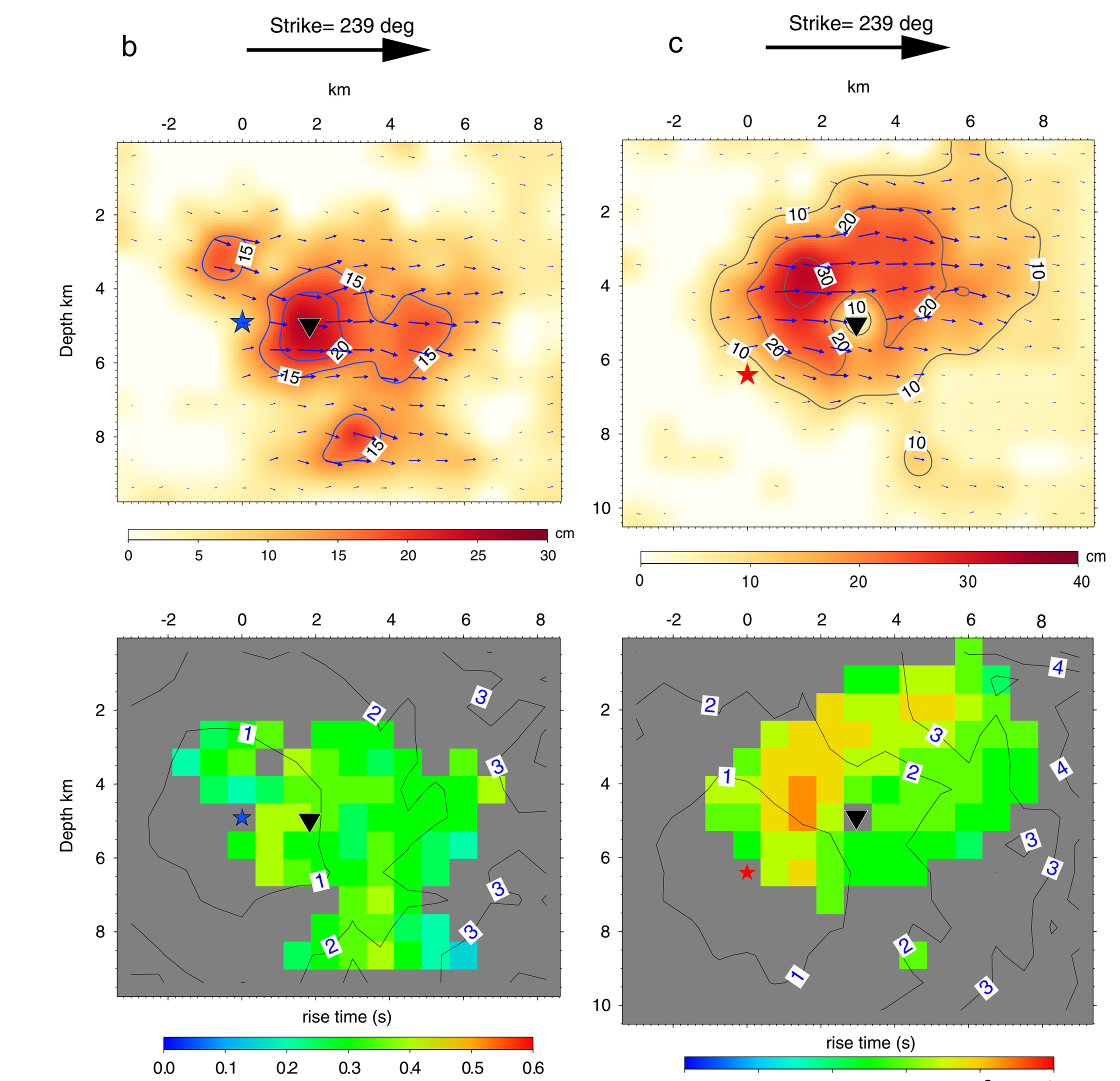
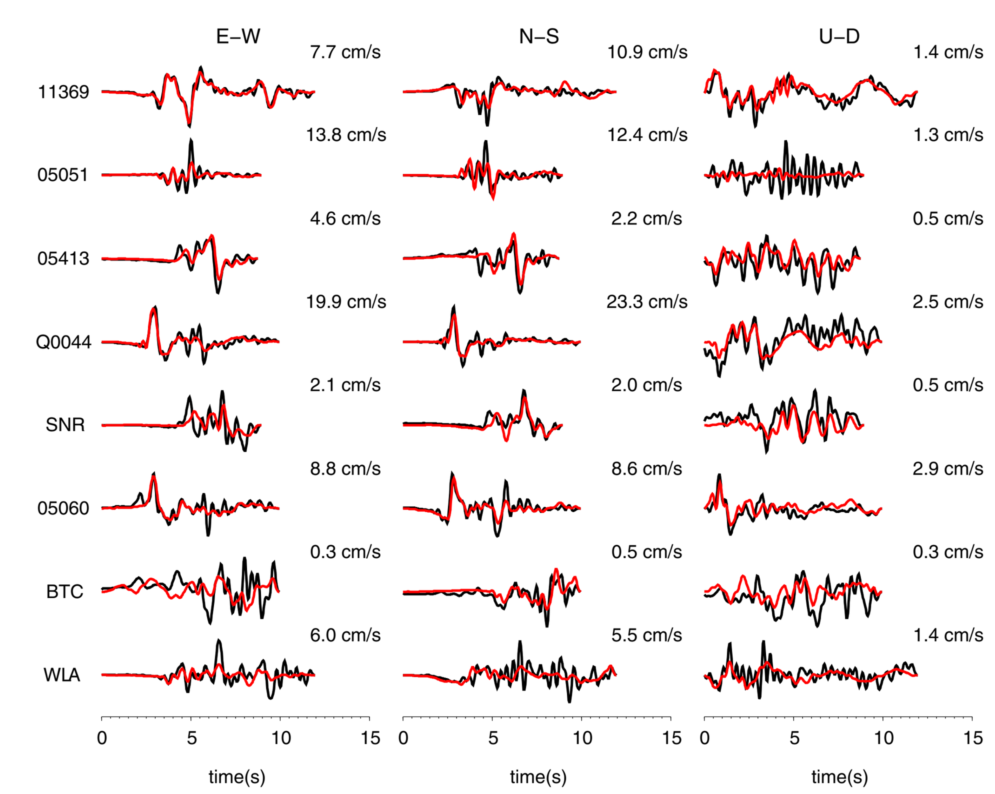
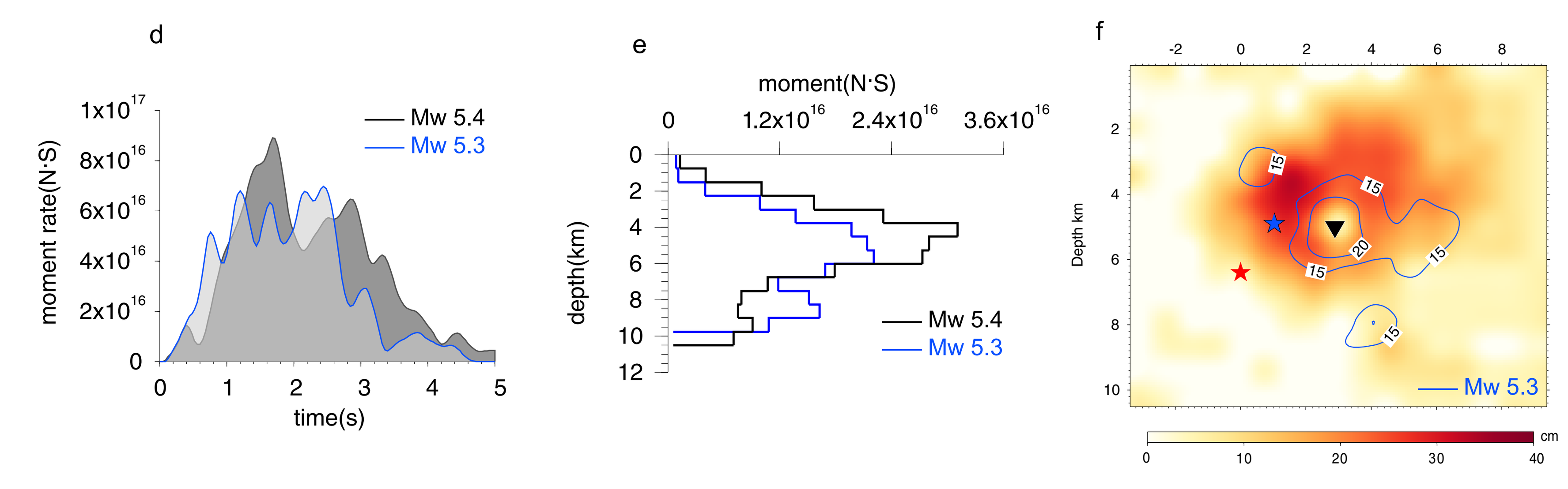
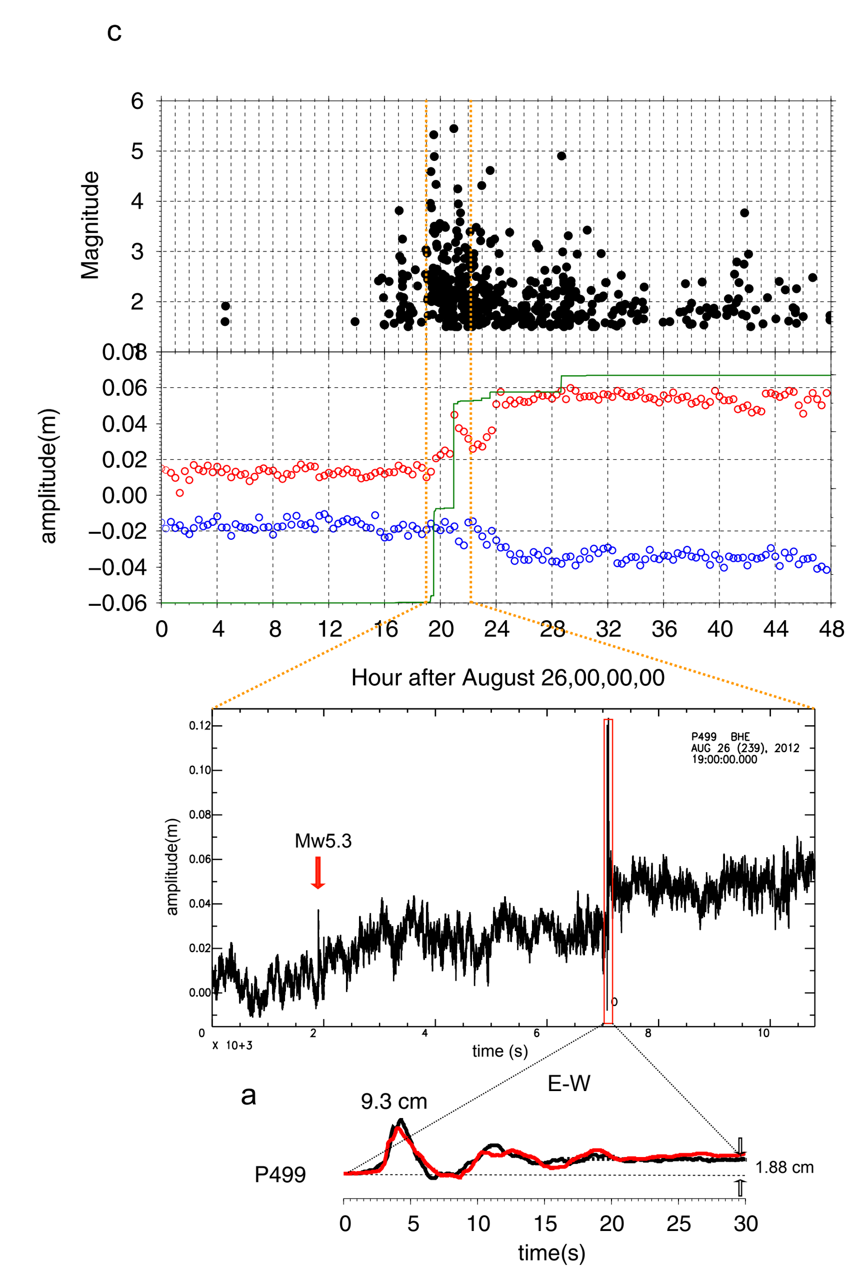


Figure 3. Slip models of the two M>5 events. (a) Upper: The waveform comparisons of the high-rate GPS stations and strong motion stations for the Mw5.4 event. Here the synthetics (red) are generated by the preferred slip model for the Mw5.4 event. Both data and synthetics are filtered to 0.1~2.0Hz with GPS waveform displayed in displacement and strong motion in velocity. Lower: Strong motion waveform fits for the M5.3 event. (b) Kinematic slip model for the Mw5.3 earthquake, slip distribution is displayed in upper panel , smoothed rise time and rupture time (contours) are shown in the lower panel. The black triangle is an indicator of the same place on the fault for better comparison. (c) Similar as (b) for the Mw5.4 event. (d) Moment rate function for both M>5 event. (e) Moment distribution in depth. (f) Overlapping of two slip models with color indicated slip distribution for the Mw5.4 event and the blue contour for the Mw5.3 earthquake.







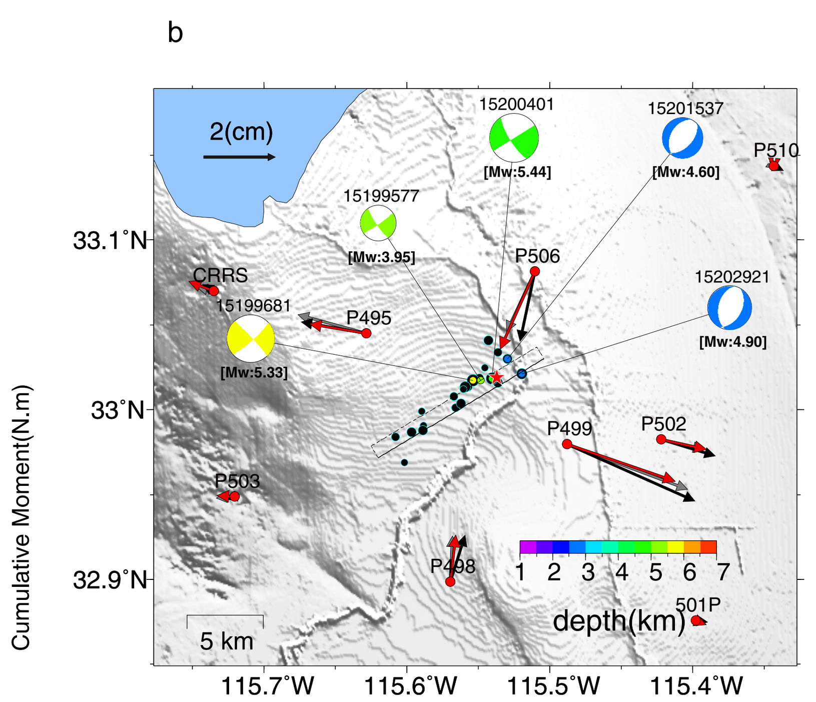


Figure 4. GPS data fitting. (a) E-W component of 5Hz GPS record at station P499 with the signal of Mw5.3 event indicated as the arrow. 30s record for the Mw5.4 event is enlarged and plotted with the synthetic generated from the preferred model. (b) The horizontal static offsets (black, USGS; gray, MIT) on nearby GPS stations are plotted along with the synthetics (red) produced by the total slip models of Mw5.3 and Mw5.4 events. Note that the data has been scale by a factor of 70% to account for the moment difference. (c) Upper panel shows 48hr seismicity, the E-W (red) and N-S (blue) components at station P499 are plotted along with the cumulative moment (heavy green).

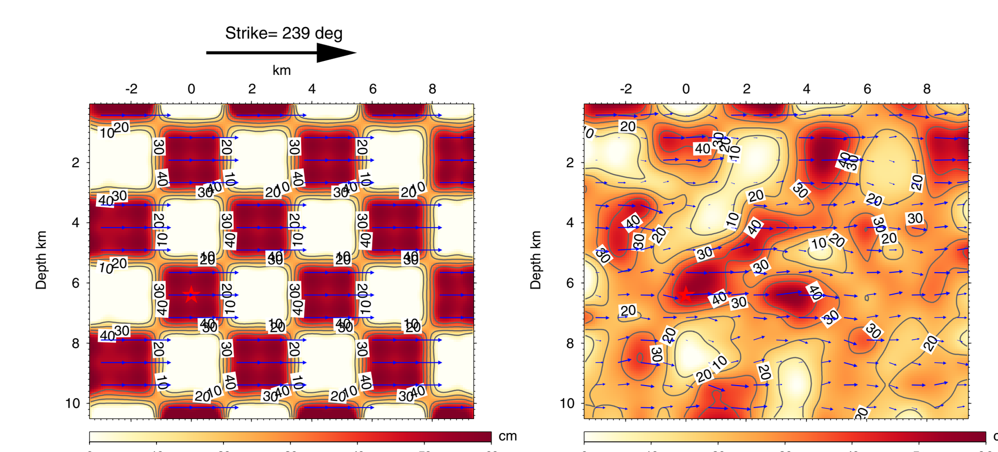


Figure 5. Checker-board test for the inversion set up as used for inerting the real data. The left panel shows the input slip model, and right panel shows the test result.

Conclusion

1, The slip distributions of the M5.4 and M5.3 event are complementary to each other.

2, The slip distribution depth for M5.3 event is slighter deeper than the M5.4 event and rise time is shorter (0.4s) than that of the M5.4 event (0.8s), thus it has more high-frequency content in its radiated seismic waves.

3, The earlier (1.5hrs) M5.3 event has likely triggered the M5.4 event indicating some type of rate-and-state friction process.