Text S1. GPS data processing

High-rate positions of GPS sites were computed using single station bias fixing [Bertiger et al., 2010] and point-positioning [Zumberge et al., 1997] with the GIPSY/OASIS II software package, developed at the Jet Propulsion Laboratory. We used JPL fiducial ITRF2008 orbits and high rate satellite clock products [Desai et al., 2011] and estimated the station position as a stochastic parameter. Water vapor in the troposphere can cause significant delays in the GPS signal, and is usually estimated as a temporally varying parameter simultaneously with estimate of a single station position for 24 hours’ worth of GPS data. For the high-rate (1Hz or greater) position estimates, we provided tropospheric parameters that were first calculated holding the station position fixed. For the 20 minute position estimates, we estimated the troposphere along with the station positions. In order to improve the estimates at the end of the 24 hour period for the 20 minute position estimates, we used 30 hour data arcs that matched the JPL high precision orbit products, which include satellite orbit and clock information for 3 hours before and 3 hours after the UTC day.

Figure S1. Velocity models and corresponding waveform fits. The left panel shows the best Vs and Vp profiles for the various stations with the name of stations indicated on the top of each profile. The right panels shows the waveform fitting between the data (black) and synthetics (red), the name of station is indicated at the beginning of each traces and the above numbers are the peak amplitude of data (front) and synthetics (back). All waveforms have been filtered to 0.02~3Hz.
Figure S2. Waveform comparisons of the high-rate GPS stations (upper panel) and strong motion stations (middle panel) for the M\textsubscript{w}5.4 event, here the synthetics (red) are generated by the preferred slip model for the M\textsubscript{w}5.4 event. Both data and synthetics are filtered to 0.1~3.0Hz with GPS waveform displayed in displacement and strong motion in velocity. The prediction for the strong motion station 05060 is shown in the lower panel. Since the data was obtained after we have derived the model, they did not include this station in the inversion.

Figure S3. Similar waveform comparison for the M\textsubscript{w}5.3 event (15199681), note that we only used strong motion data in the inversion. See caption of figS2 for detail descriptions.

Figure S4. Resolution test for the inversion set up as used for inverting the real data. A checker-board like slip model (a) was used to generate synthetics data, a constant rise time (0.6s) and rupture velocity (2.5km/s, indicated as iso-rupture time) is assumed in the input model (c). During the inversion we used the same inversion setup as used for the real data, in which the slip amplitude is searched in the range of 0~100cm, the rise time can change from 0.05 to 1.05s and the rupture velocity can vary from 2.0km/s to 3.0km/s. The inverted slip model and rise time are shown in (b) and (c) respectively, the rupture velocity is shown as iso-rupture time in (c). Note that the rise time is smoothed by averaging the values over the neighboring subfaults, similar as shown in Fig.3.

Figure S5. Vertical velocity waveforms of the M\textsubscript{w}3.9 (green), M\textsubscript{w}5.3 (red) and M\textsubscript{w}5.4 events recorded on the closest station Q0044. All the waveforms are not filtered and plotted in absolute
amplitude. Note that the M>5 events take 0.5 sec or more after initiation to get the largest motions, suggesting the hypocenter is at a region of weak radiation.

**Figure S6.** Shallow slip sensitivity test for the static and seismic data. The input model has 20cm of uniform slip distributed in a rectangular region as shown in (a). The iso-rupture time is indicated by the contours. The rise time for each subfault is chosen randomly between 0.1 and 1.0s. (b) Seismic signals (red) produced by the input model at the three strong motion stations. The data (black) are for the $M_{w}5.4$ event with peak amplitude shown at the end of each trace. Note that the synthetics are much higher in amplitude than the data and the waveform similarity is poor, implying little or no co-seismic rupture at shallow depths. (c) Static signals (red arrows) produced by the slip model in (a). The black triangles are the strong motion stations. (d) Three dimension static deformation produced by the slip model in (a), with vertical component indicated by the color bar and horizontal deformations indicated by the white arrows. Note the large signals are concentrated close to the fault, which means the GPS data set has lower resolution to very shallow aseismic creep.

**Figure S7.** InSAR data fitting by model predictions. (a) Line of Sight (LOS) displacement prediction for ascending TerraSAR-X interferogram (A015) by the combined slip models for the $M_{w}5.3$ and $M_{w}5.4$ events, the synthetics have been multiplied by a constant (1/0.7) to account for the difference between the moment of the largest two events and the entire swarm. The red star indicates the epicenter of the $M_{w}5.4$ event and the rectangle is the map projection of the fault plane. Red circles are the nearby GPS stations and the red dashed line indicates the approximate plate boundary between the Pacific and North America plate. Prediction from the hypothetical
slip model in Fig.S6 is shown in (c). The corresponding TerraSAR-X ascending track interferogram for 2012/08/09–08/31 is shown in (e) and the black line shows the location of the center of a swath (with width of 4km). The looking angle from vertical is 26.3° (at center) and the azimuth is 78°. The InSAR phase converted to range-change is shown in gray in the swath profile (g). The heavy black line is the average within the swath, the red line is the model prediction along the black line in (a) and the green line is prediction along the black line in (c). Panels (b), (d), (f) and (h) are similar plots for the descending interferogram (D068) of 2012/08/12–09/03. The looking angle from vertical is 28.9° (at center) and the azimuth is -78°. Original TerraSAR-X data is copyright 2012 DLR. Note the sharpness of the predictions in (g,h) from the hypothetical slip model.

Reference


