Assessing the Utility of Strong Motion Data to Determine Static Ground Displacements During Great Megathrust Earthquakes: Tohoku and Iquique

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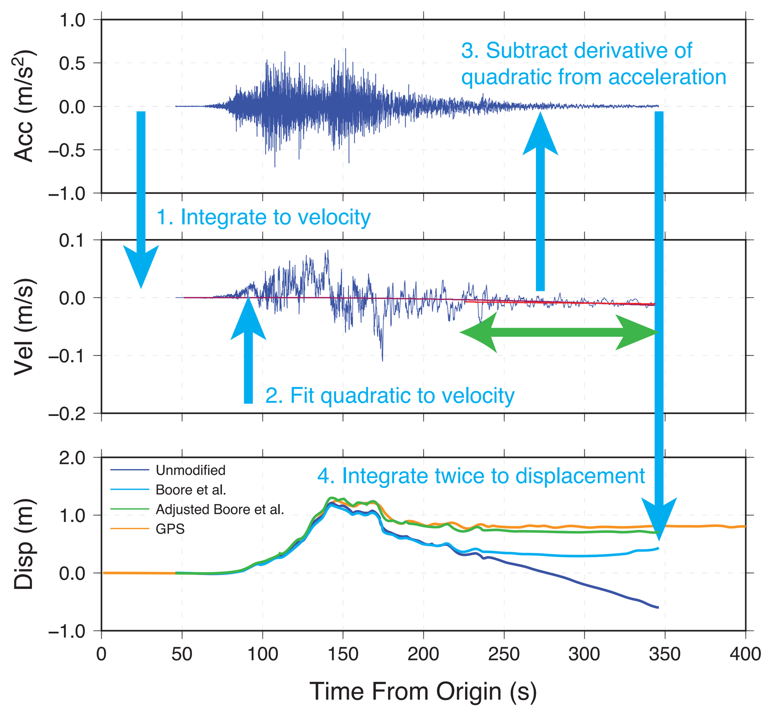
Static Displacements from Strong Motion

Strong motion accelerometers can record broadband, large amplitude shaking on-scale in the near-field of large earthquake ruptures; however, numerical integration of such records to determine static displacement is typically unstable due to baseline changes (i.e. distortions in the zero value) during strong shaking.



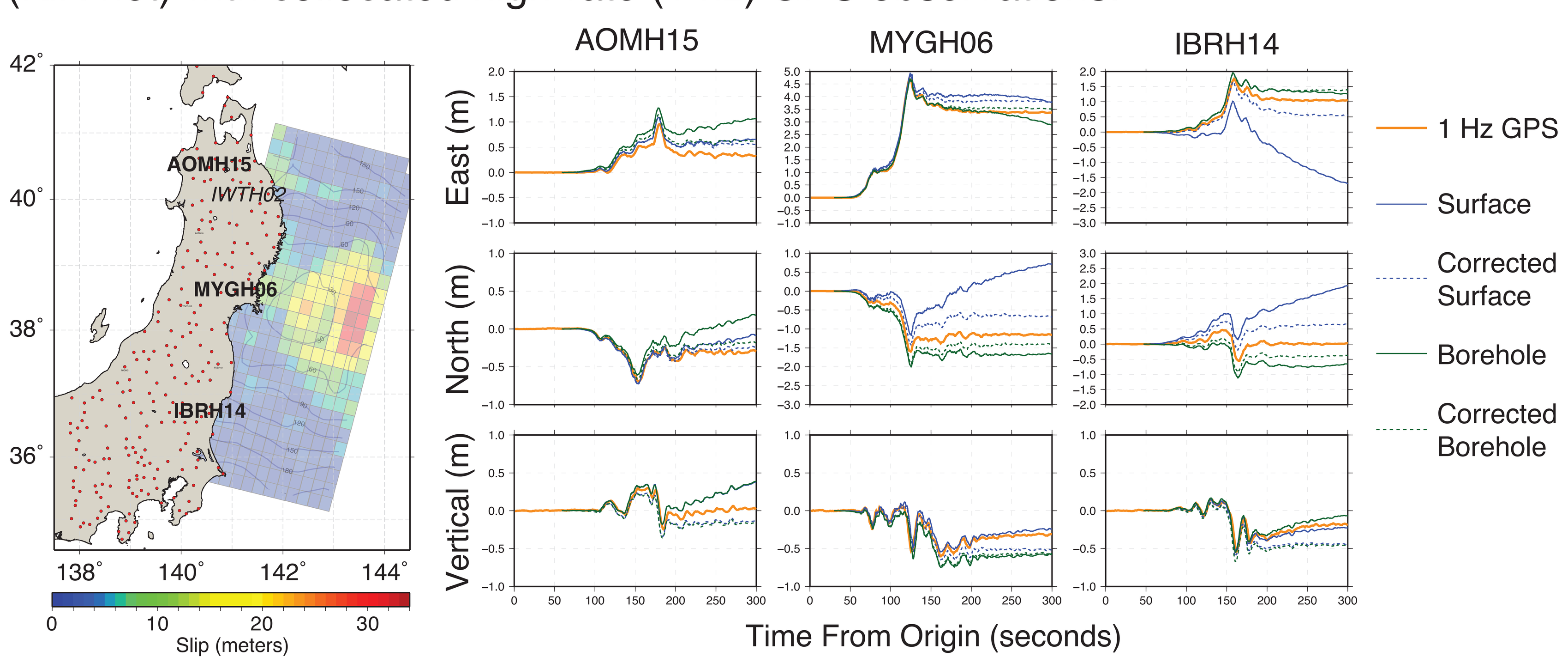
We follow Boore et al. (2002) to correct for random, unknown baseline changes in acceleration records in an effort to recover static displacements:

0. Convert to m/s². Perform zeroth-order correction, i.e. remove mean.
1. Integrate to velocity.
2. Fit a quadratic to velocity, constrained to zero at first motion.
3. Subtract derivative of quadratic from acceleration.
4. Integrate twice to obtain displacement time series.

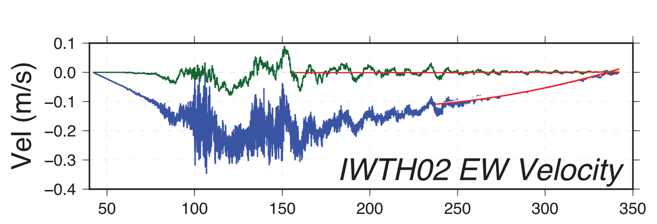
We modify the technique by fitting a quadratic to the end of the velocity time series, because the drift at the end of the time series is a direct consequence of baseline shifts only. In contrast, the significant non-zero velocity during the accumulation of static displacement biases the quadratic fit.

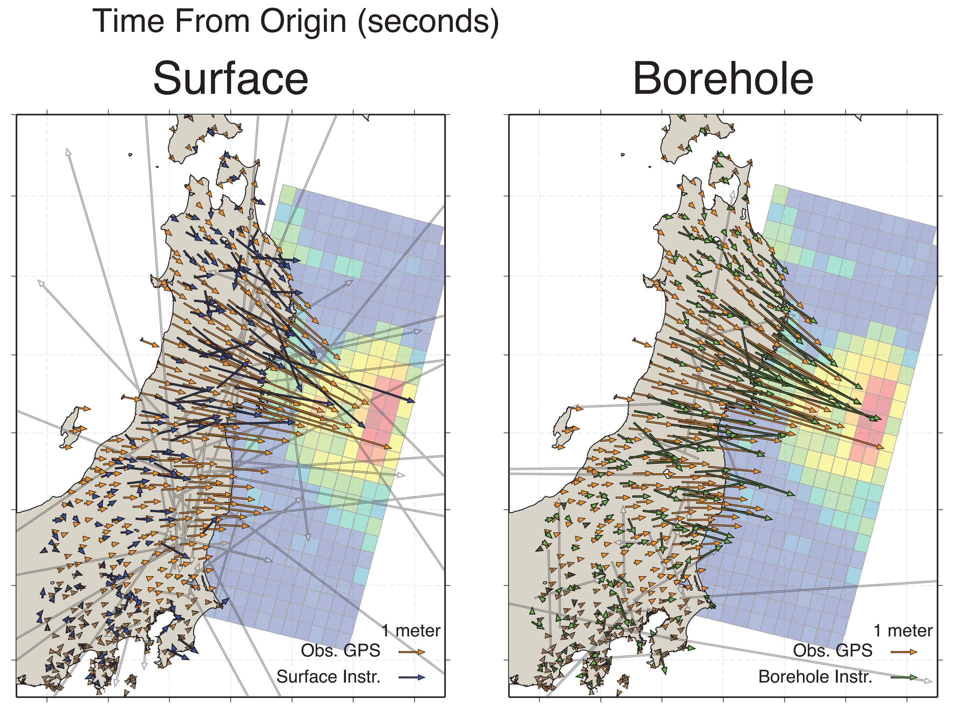
Strong Motion Records From Tohoku

To validate this correction scheme, we compare corrected and integrated surface and borehole acceleration records from the 2011 Mw 9.0 Tohoku earthquake (KiK-net) with collocated high-rate (1 hz) GPS observations.



When baseline changes are severe, this simple correction scheme fails. These records are easily identifiable from the velocity time series. Borehole instruments are less susceptible to severe baseline changes, but near Tokyo, a major source of noise, both surface and borehole instruments were discarded.

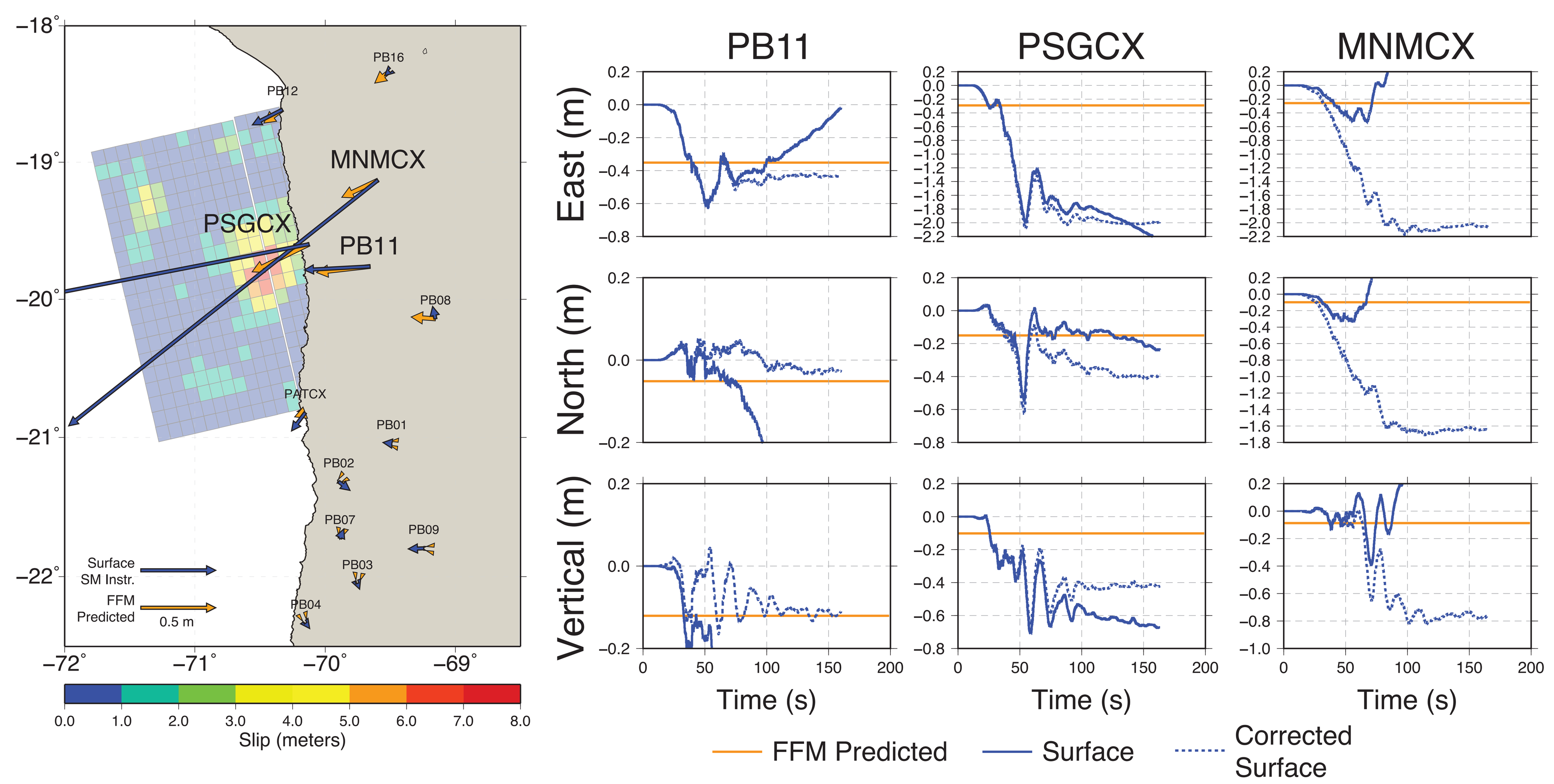




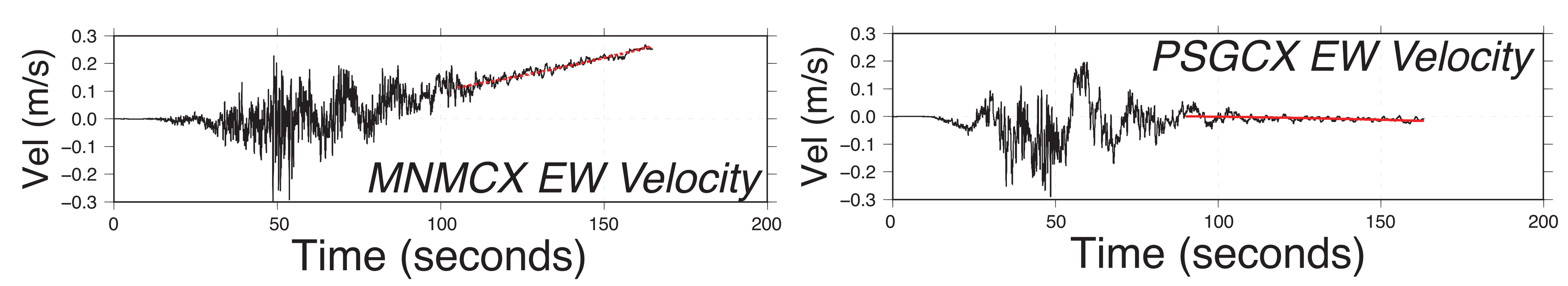
Static displacements from 1 Hz GPS (orange) and strong motion (blue, green). Channels identified as having severe baseline changes (left) are grayed out.

Strong Motion Records From Iquique

Several strong motion instruments along the western coast of Chile recorded the near-field shaking from the 1 April 2014 Mw 8.2 Iquique earthquake. We used the same correction technique to generate static displacements (shown in blue) from these acceleration time series, and compare them to displacements predicted from a seismological finite fault model in an elastic half-space (orange).



Only one station (MNMCX) had velocity time series with severe enough drift to be discarded (below, left). Static displacements from stations PATCX, PB02, and PB11 appear to match the FFM derived displacements well. Although station PSGCX had very little net drift in the velocity time series (below, right), the final static displacement in the east component (~2.0 m) was much larger than the predicted displacement (~0.4 m). This station was nearly coincident with the event centroid, which may account for the large accelerometer-derived static displacement.



Can Strong Motion Observations Yield Reliable Static Displacements?

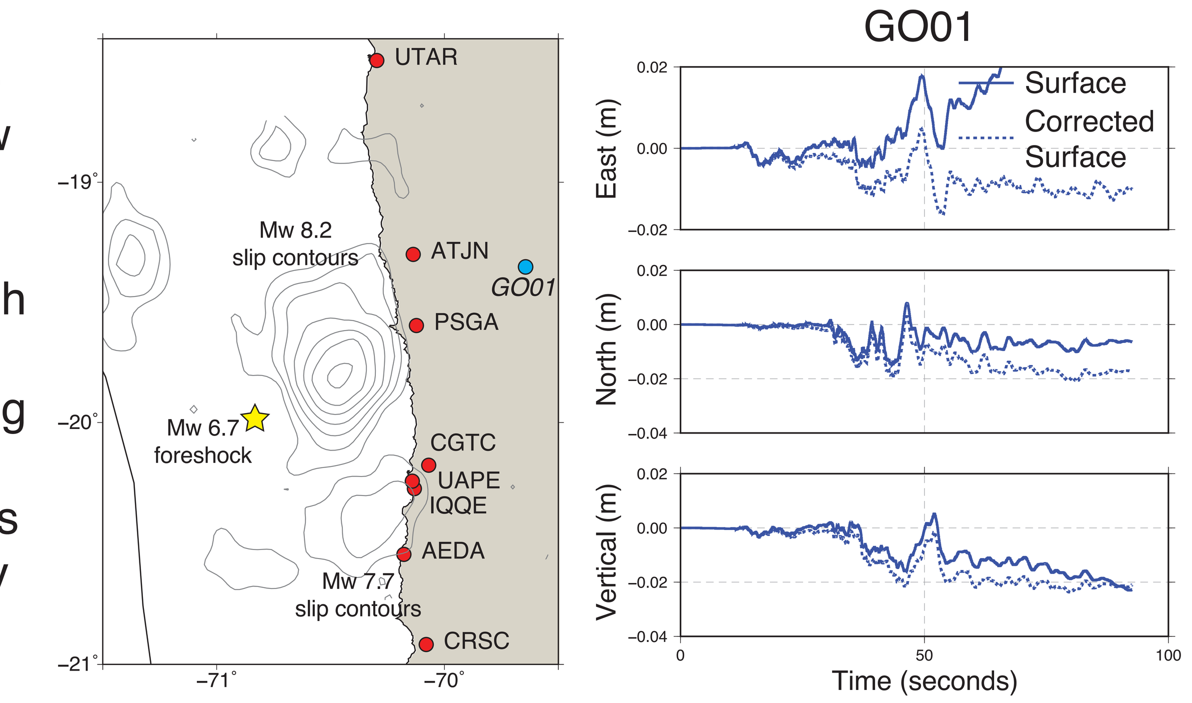
	KiK-Net Borehole	KiK-Net Surface	Chile Surface
Percent Correctable (Reliable Displacement)	~85%	~65%	~80%
Percent of Remaining Matching GPS/FFM Prediction	~90%	~75%	~80%

In the worst case from these three datasets (surface instruments from KiK-Net), nearly 50% of the strong motion stations produced accurate coseismic static displacements, suggesting that a network of strong motion instruments can yield an accurate displacement field for large megathrust earthquakes. In addition, these corrected records contain the displacement time series, which may be used for constraining the coseismic rupture evolution from the near-field.

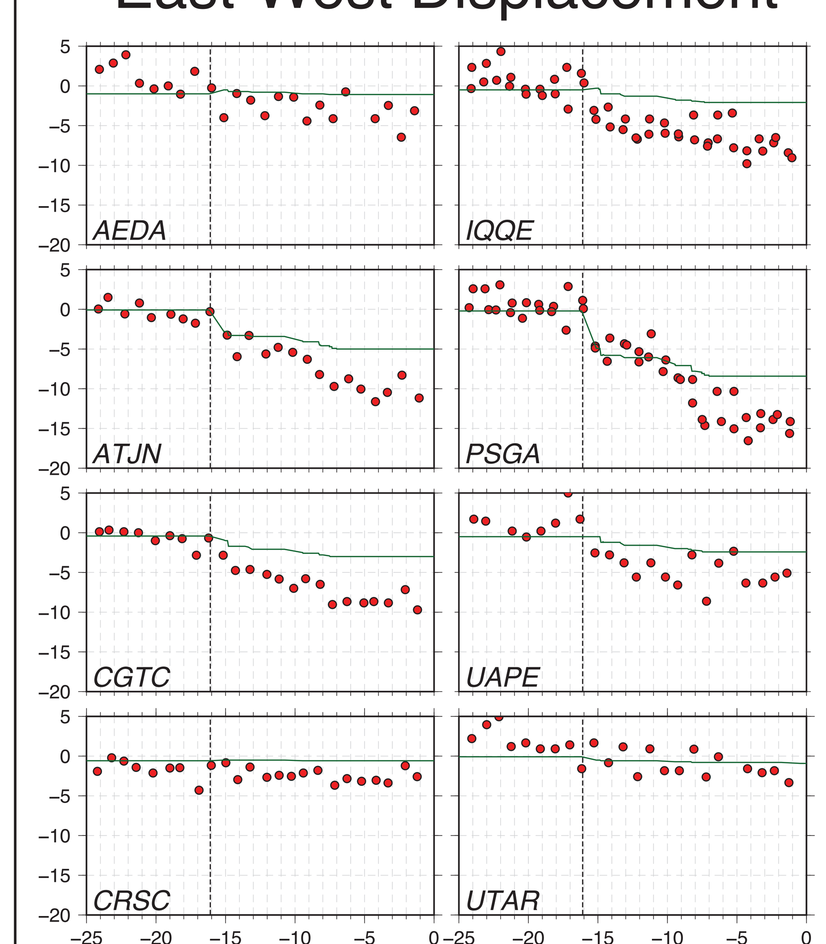
At The Limit - 2014 Iquique Foreshocks

This method is limited to instances of strong shaking that can be captured on an accelerometer. Low amplitude shaking from small events or at stations far from the source will not have reliable strong motion-derived static displacements. The minimum static displacements that we resolved from the Mw 8.2 Iquique dataset were ~20 cm.

The foreshock sequence preceding the Mw 8.2 Iquique earthquake began with an Mw 6.7 earthquake on 16 March 2014, west of the Mw 8.2 centroid (yellow star). Although this earthquake generated shaking detected on the strong motion instrument at station GO01, its static displacements are too small to be confidently resolved by strong motion integration.

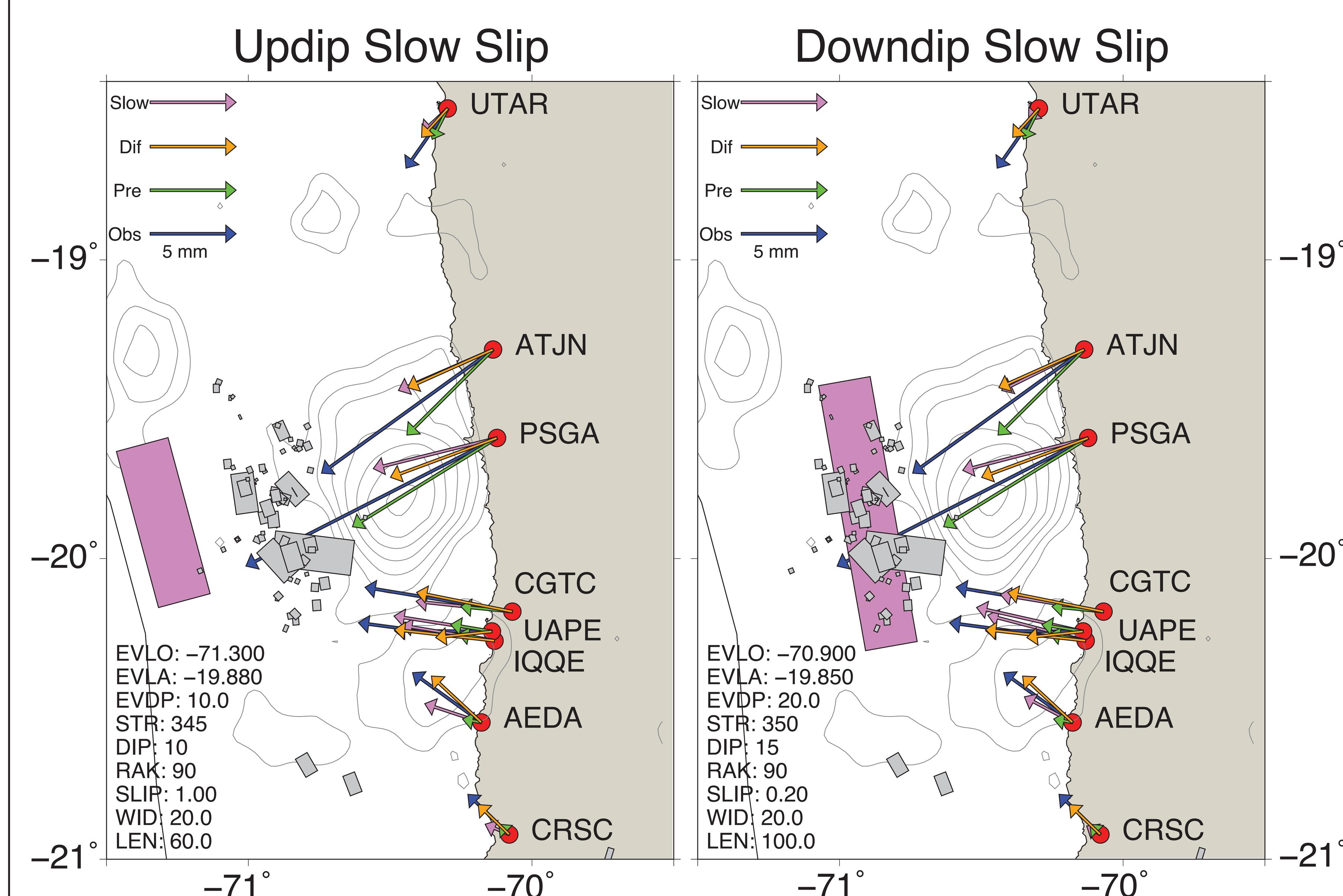


East-West Displacement



Slow or aseismic slip events also do not generate strong shaking, and are not recorded on strong motion instruments, despite potentially large displacements accumulating. These must be inferred from geodetic measurements, such as in the case of the foreshocks leading up to the 2014 Iquique earthquake.

The observed GPS displacements from 16 March 2014 through 1 April 2014 are not completely accounted for by displacements from foreshock seismicity. Following Ruiz et al. (2014), we infer that aseismic slip must have occurred on the megathrust plate boundary to account for the extra observed displacement.



These maps show the GPS displacements immediately before the 1 April 2014 Mw 8.2 Iquique main shock (blue), the cumulative displacements in an elastic half-space of the foreshocks (green), the difference vectors (obs-pre; orange), and the displacements predicted for the slow slip patch shown (pink). Note that it is difficult to account for the extra displacements at stations UTAR and CRSC unless the slow slip patch is updip of the foreshock sequence.