A017 - Near Field Dynamic, Co-seismic and Post-seismic Deformations Associated with the 2013, M7.8, and 2003, M7.6, South Scotia Ridge Earthquakes Observed with GPS


Abstract: The South Scotia Ridge (SSR) left-lateral transform/slip-strike (S-S) fault defines the Scotia plate’s (SP) southern boundary separating it from S. America and opening of Drake Passage. Two significant microseismic events occurred on the AP, with max displacements of ~70 cm, over an ~80 second time interval during 2003 and 2013. Moment tensor solutions show they occurred on faults dip- ping ~30° and 45° to the south. The 2013 event was almost pure, left-lateral strike-slip, while the 2003 event was oblique but predominantly strike-slip. This is an unusual combination of fault dip and slip direction for a strike-slip plate boundary. The half duration of both events is also relatively long.

A continuous GPS (CGPS) station on Laurie Island is located immediately west of the rupture zone of the 2003 event and at the approximate center, and close to the surface projection, of the finite fault models for the 2013 earthquake. We present co-seismic and post-seismic transients for both earthquakes from GPS daily position estimates. In addition, the CGPS station now records at 1 Hz and we present the GPS displacement seismogram for the 2013 event. This record contains a complex signal that includes the passage of the Love and Rayleigh surface waves, with max displacements of ~70 cm, over an ~80 second time interval during which a ~30 cm static offset developed.

Fig. 1. SP tectonic history. Left from Dalziel et al., 2013, right from Civile et al., 2013.

Fig. 2. Scotia plate seismotectonics. Plate boundaries: green - transform, blue - subduction, brown - onland, purple - active, filled - inactive, open - extinct boundaries in darker colors, dashed lines indicate inferred. Focal mechanisms for larger earthquakes along SSR, SGVR, and BORC, are shown.

Fig. 3. Argentine base on Laurie Island, South Orkney Islands. It is the oldest, continuously operating Antarctic base. It was founded in 1903 (giving the 2003 earthquake its name). The ‘centennial earthquake’ by the Scotia-Antarctica plate boundary constrained from seismic and seismological data, Tectonophysics, 2012, 590-594, doi:10.1016/j.tecto.2012.05.002.

Fig. 4. Seismotectonics. Co-seismic static displacements (red vectors) for 2003 and 2013 events at CGPS station BORC. BORC seismosismic velocity vectors with respect to SP (orange) and AP (green). BORC is located on the AP and in the plate boundary deformation zone (BORC). Two significant events are apparent: S-S tectonics. BORC co-seismic displacements are approximately 100 times larger, consistent with a seismic cycle of hundreds of years. Note different scales for co-seismic and post-seismic displacements. Main shocks (beachballs at GCMT locations with time to PDE location, colors as in Fig. 5) seem to occur between two large events on the same segment of plate boundary 10 years apart which was challenging to explain in elastic rebound/seismic gap models, but the aftershock distributions are complementary. Ye et al. (2014), using global seismic data and the GPS seismograms and static offsets presented here, show the two events did not rupture the same fault plane.

The mainshocks also occurred on shallow dipping (30°-45°) – S oriented faults with almost pure strike (2013), or large strike-slip motion (2003). While BORC is ~100 km from the epicenter, as rupture progressed eastward for >200 km the rupture’s downdip edge passed approximately beneath BORC due to the southward shallow dip of the fault plane.

Fig. 5. GPS displacement time series for BORC, located ~40 km south of bathymetric morphological expression of the plate boundary. Left, time series showing co-seismic displacements for 2003 event (NEU in meters: -0.102, 0.268, 0.012), with an unexpectedly large post-seismic response. Right, time series showing coseismic and initial post-seismic response of 2013 event. There was no observable vertical offset associated with the 2013 event. Red vertical line on right marks the day of the 2013 mainshock (NEU in meters: -0.232, 0.557, 0 within errors, total 0.613 m), thin red lines indicate foreshocks. There is no discernable coseismic offset for the first and a hint of EW coseismic offset for the second. The constant 2003 vertical coseismic offset associated with the 2013 event seems to separate a period of no vertical movement from one with a slow decrease in height for which we have no clear explanation (isostatic adjustment, dynamic topography?). Note: co-seismic displacements are estimated from an average of pre-event daily positions, and the average position the day after the event. We used the last 15 hours of the day of the earthquake to estimate post event position for the 2013 event, so there are no “missing” days. Using “daily” positions, coseismic displacement estimates will always be too large as they include the initial, most rapid part, of the postseismic displacements.

Fig. 6. High-rate (1 Hz) GPS displacement seismograms at BORC for Mw 7.8, Nov 17, 2013, SSR earthquake estimated using TRACK (Herring, 2009). Raw (green) and sidereally filtered (blue) seismograms, and difference (red). TRACK calculates differential per-event baselines that are transformed to local NEU at one end (BORC end selected). We used all 1 Hz continuous GPS stations within 1600 km of BORC (see Fig 2) processing individual station data. The postseismic response (AVGE) of the 2013 event identified by comparing NEU data with respect to SP shown by orange vectors.

Fig. 8. Particle motion (PM) analysis of GPS displacement seismograms. The left set of panels shows unrotated NS time series in green, EW in blue, and UD in red. In the two sets of rotated panels, blue is the static displacement (SD, center) or radial (right), and green is the cross static displacement (SSD, center) or transverse (right), the top right plot of each set, with the horizontal components, simply rotates from one set to the other. Red asterisks show start time for the particle motion plots. Horizontal PM is relative to the vertical component of the particle motion. The vertical panel is a rotation (23°) into the co-seismic static displacement direction (SD). The right set of panels shows the rotation (68°) producing the cleanest separation into Rayleigh (radial) that arrive first, which is unusual, and Love (transverse), wave motions. The particle motion plots show the oftentimes observed “overshoot” of the displacement in the near field, that is, post-slip rebound and is not a dynamic overshoot and subsequent slip on the displacement at the fault. The modeling of Ye et al., 2014, show this more rigorously.

Fig. 9. BORC location.