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Temporal acceleration of the Pacific Plate subduction by a deep earthquake

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Landward velocities of GPS points accelerated on segments adjacent to the segments ruptured in the 2003 Tokachi-Oki (Mw8.0) and the 2011 Tohoku-Oki (Mw9.0) earthquakes in NE Japan. Sea floor GPS measurements by Japan Coast Guard also revealed fast post-2011 landward movement of MYG1 reaching ˜30 cm per year. From these observations, we hypothesized that the movement of the Pacific Plate slab was accelerated after mega-thrust earthquakes (Heki and Mitsui, EPSL 2013). The accelerated velocities are considered to have reached ˜1.5 and ˜3 times as fast as the geological average.

During interseismic periods, the balance between the up-dip forces (viscous side resistance and interplate coupling) and down-dip forces (slab pull and ridge push) realizes constant subduction velocity (Seno, 2001). Megathrust earthquakes reduces inter-plate coupling, and let down-dip force temporarily exceed the other forces. Then the slab is accelerated downward, and increased side resistance will achieve new force balance. Accelerated regime would be temporary and time-averaged rate is expected to resume as interplate coupling recovers.

Past examples suggest that within-slab seismicity of down-dip compression mechanisms is activated in the deep part of subducting slabs (Lay et al., PEPI 1989). This would reflect the increase of the edge resistance caused by the slab acceleration. After the 2012 Tohoku-Oki earthquake, an Mw7.7 deep earthquake occurred close to the down-dip end of the Pacific Plate slab beneath Sakhalin, Russia, on August 14, 2012.

GPS stations in the eastern Hokkaido are known to have significantly accelerated landward after the 2011 Tohoku-Oki earthquake (Fig.5 of Heki and Mitsui (2013)). The attached figure shows the movements of the Shari, Bekkai, Nemuro, Hanamaka, and Kushiro-city GPS stations toward the trench (N150E) during 2008-2013 based on the F3 solution of GEONET. To isolate post-2011 trend changes, we removed the linear component estimated using the portion from 2008/1/1 to 2011/3/11. In addition to the coseismic steps of the Tohoku-Oki earthquake, negative changes in trends (i.e. landward acceleration) are clear. Afterslip shows large temporal decay characterized by the time constant of ˜0.4 years (Ozawa et al., 2012), but we see only small such decay in these stations. Hence, these landward movements would reflect the apparent enhancement of coupling due to the acceleration of the Pacific Plate slab subduction. We show the 2012 Aug. 14 earthquake with a vertical line, and we can see further landward acceleration synchronized with this earthquake.

A deep earthquake with a down-dip compression mechanism occurring near the lower end of the slab would relax the increased edge resistance to a certain extent. This would reduce the up-dip force just like an interplate earthquake does, and may accelerate the subduction causing an apparent increase of the slip deficit as seen in the figure. Here we propose the following scenario, (1) upper surface of the slab moved by a few tens of meters in the 2011 Tohoku-Oki earthquake, and the compressional stress generated within the down-sip side of the slab diffused down to the depth of 500 km against viscous resistance in the low viscosity channel on the slab surface, (2) increased down-dip compression near the slab edge slightly braked the accelerated subduction (as seen in the small decay of the landward velocity during the 1st half of 2012), and caused the 2012 deep earthquake, (3) relaxation of the down-dip compression diffused upward and recovered the fully accelerated state. In the presentation, we also present quantitative discussions of these processes.

(Figure caption)

Trenchward (N150E) movement of the five GPS stations in eastern Hokkaido after 2007.0. We de-trended the time series using the portion between 2008/1/1 and 2011/3/11. Enhanced coupling (negative trend) slightly decayed during the first 1.5 years, but the original accelerated rate resumed after the 2012 deep earthquake.

Keywords: Pacific Plate, acceleration, deep earthquake, GPS, crustal deformation, Hokkaido

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