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Accelerated subduction of the Pacific Plate

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In NE Japan, GPS stations move landward, and the velocity gets faster as the inter-plate coupling becomes stronger (interseismic crustal deformation). Once an interplate earthquake occurs, coseismic trench-ward movements occur and subsequent slow movements continue while the afterslip lasts. We divide the plate boundary in NE Japan into three segments, i.e. (1) Tokachi-oki, (2) Aomori-oki and Rikuchu-oki, and (3) Miyagi-oki and Fukushima-oki, from north to south. There relatively stable and uniform interseismic deformation continued in 1996-2003. Since 2003 autumn, however, these three segments have been in different situations. Here we study time evolution of plate coupling in these segments from a macroscopic viewpoint.

The figure shows the trench-ward (N110E) movements of the three GPS stations in Taiki (Hokkaido), Kuji (Iwate) and Soma (Fukushima), which reflect coupling in the segments (1), (2), and (3), respectively, from the F3 solution of GEONET. Long-term trends inferred from pre-2003 data are removed to isolate changes in trend after 2003. Large coseismic movements of the 2003 Tokachi-oki (Mw8.0) and the 2011 Tohoku-oki (Mw9.0) earthquakes are removed for visual simplicity.

In Taiki, afterslip of the 2003 earthquake is obvious, and the time series after that suggests that the coupling in (1) has not completely recovered till now (positive slope still remains). Similar decoupling is seen also in the segment (3). There, the coupling seems to be progressive weakening since 2003 (positive slope gradually increases). Microscopic inspection reveals that this comes from a series of M7 class earthquakes, i.e. the 2003, 2005, 2011 Miyagi-oki events (M6.8, 7.2 and 7.3), the 2008 Ibaraki-oki event (M6.9), and the 2008, 2010 Fukushima-oki (M6.7, 6.2) events, and their disproportionally large afterslips. From macroscopic point of view, however, these earthquakes could also be interpreted as ruptures of relatively small asperities occurred as parts of a huge slow earthquake that started in 2003 and continued until the 2011 Tohoku-oki earthquake.

In the segment (2), no large interplate events occurred during this period. The Kuji GPS station, in northern Iwate, showed a sudden increase of coupling (almost double) in 2003 September as seen by a clear break in slope. It is unlikely that interplate friction suddenly increased by nearby earthquakes. Here we hypothesize that this rather reflects the accelerated subduction and consequent apparent strengthening of the coupling in the segment (2).

When a large interplate earthquake decoupled the plate interface, subducting slab would be temporarily accelerated. This, however, will not enhance the slip deficit of the adjacent segment, i.e. decoupling in the segment (1) would not accelerate the landward movement of Kuji. If the entire slab spanning from (1) to (3) behaved like a coherent body, the segment (2) would follow the acceleration of the other segments.

The two opposite forces are exerted on the slab near a trench, i.e. slab-pull in the down-dip direction, and friction caused by interplate coupling in the up-dip direction (the latter is visible as the slip deficit with GPS). Their balance maintains stationary subduction. Once a certain segment is decoupled, the slab pull temporarily exceeds the friction and would let the slab accelerate until the increased coupling realizes a new equilibrium. The time series of the Kuji station suggests that such an adjustment occurs in a relatively short time, say a few days.

(Figure)

Trench-ward (N110E) movement of the three GPS stations in Taiki (Hokkaido), Kuji (Iwate) and Soma (Fukushima), detrended using data before 2003. Large coseismic movements are removed for visual clarity. In response to the decrease of the coupling (trend becomes upward) at Taiki and Soma, coupling increases (trend becomes downward) in Kuji.

Keywords: Northeast Japan, GPS, Interseismic crustal deformation, Pacific plate, acceleration, 2003 Tokachi-Oki earthquake

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