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Interlocking rupture at the weakly coupled plate boundary for the 2011 Tohoku-Oki megathrust earthquake

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Over the last few decades an asperity model has been developed to characterize the ruptures of large shallow subduction zone earthquakes in context of the strength of plate coupling [e.g., Ruff and Kanamori, 1980; Lay et al., 1982]. The 2011 Tohoku-Oki earthquake (Mw9) ruptured a large portion of the boundary between the subducting Pacific and the overriding Okhotsk plates where the coupling was considered weak and represented by sparsely distributed small asperities [e.g., Tajima and Kanamori, 1985a,b]. Thus, such a great earthquake had not been anticipated for this region in the previous scenario, in which a typical asperity break could produce an event of Mw~7.5 to lower 8, but the driving force of rupture propagation may not be large enough to break through a broad region, as was in the case of the interlocked Mw9 megathrust event in 2011. A typical large event is accompanied by a significant expansion of aftershock activity reflecting stress adjustment into the weakly coupled fault zones outside the ruptured areas.

The 2011 Tohoku-Oki earthquake sequence started with an Mw7.3 foreshock on March 9th. The 2-day aftershock area of this event mainly expanded trenchward until the March 11th main event took place at the western edge of the zone. After the March 11th earthquake ruptured the broad region in t~150 s, however, it is notable that the aftershock area did not show much expansion over time as compared with the 1-day area in spite of the numerous aftershocks (note that we consider the aftershock area to be linked to the main rupture zone, and the large events (M$>$6) in Niigata or Shizuoka, which were apparently induced after March 11 as a separate feature). Unlike the previous large earthquakes in this subduction zone, this expansion pattern is similar to that of the 1964 Mw9.2 Alaskan earthquake which occurred at the boundary between the Pacific and North American plates.

A recent joint seismic tomography model using both P and S wave arrivals provides an indication of the complex variations in physical properties of the fault zone [Gorbatov and Kennett, 2003; Kennett et al., 2011]. In the old subducting Pacific plate in the source region, shear wavespeed variations (dV_S/V_S) dominate variations in bulk-sound speed (dV_{ph}/V_{ph}) (the wavespeed associated with bulk-modulus alone). The variations in the wavespeed structure can be enhanced by examining a measure (R) of the relative variations in dV_{ph}/V_{ph} and dV_S/V_S with respect to the *ak135* reference model [Kennett et al., 1995]. The tomographic images taken on a plane approximately coincident with the March 11 main event fault surface show an anomalous zone of distinct reduction to zero in R, and slightly negative values just up-dip of the mainshock hypocenter. The zone of reduced R is largely associated with a reduction in dV_S/V_S with the effects enhanced by the increase in dV_{ph}/V_{ph}, and appears to have a strong influence on plate coupling over the rupture area. A consistent feature determined for the 2011 March 11 source rupture is the separation of areas associated with dominant high-frequency radiation down-dip and low-frequency up-dip from the hypocenter although the models show notable differences depending on the specific source of information employed. The down-dip edge of the anomalous zone in R corresponds to the separation between the areas of dominant high-frequency radiation and dominant low-frequency radiation. The edges of the anomalous zone we have delineated act as the initiation points for rupture process of the March 2011 sequence starting on March 9 as well as for the 1978 (Mw7.5) and 1981 (Mw7.0) events, and these locations will be where the strongest contrasts exist in physical properties.

In summary we suggest not to preclude a possibility that a weakly coupled plate boundary could produce an interlocked megathrust event as in the case of March 11th main event, given an effective plate coupling.

Keywords: 2011 Tohoku-Oki megathrust earthquake, Weakly coupled plate boundary, Interlocking rupture