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The effect of a compliant accretionary wedge on earthquake rupture and tsunamigenesis

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The 11 March 2011 Tohoku megathrust earthquake ruptured through the shallowest part of the subduction zone boundary, resulting in tens of meters of displacement at the seafloor. This extreme shallow slip generated a devastating tsunami. The elastic properties of off-fault materials have an important role in determining slip along a fault. Laboratory ultrasonic velocity measurements performed on samples of rock obtained from the area surrounding the Tohoku earthquake principal fault zone during the Japan Trench Fast Drilling Project (JFAST) have shown that shallow off-fault materials are extremely compliant – P-wave velocities of 2.0-2.4 km/s, S-wave velocities of 0.7-1.0 km/s, and shear moduli ranging from 1.0-2.2 GPa. Seismic imaging around the JFAST drill site corroborates the presence of a compliant, low-velocity frontal prism at the toe of the hanging wall. This compliant wedge is likely a fairly robust feature across the horizontal extent of the Japan Trench and may have contributed to the large amount of displacement recorded. In order to investigate the impact of compliant off fault materials on earthquake rupture and tsunamigenesis, we employ a 2-D finite difference method that models the full seismic and tsunami wavefield associated with dynamic rupture on a dipping fault in a heterogeneous medium. Our numerical method rigorously couples the elastodynamic response of the solid Earth to that of a compressible ocean in the presence of gravity. Idealized models of subduction zone earthquakes show that the presence of a compliant wedge leads to increased slip, greater seafloor displacement, and a larger tsunami. However, preliminary results for a representative Tohoku geometry were not so simple; the compliant wedge enhanced slip and seafloor deformation but only in a localized zone, and tsunami height was not significantly affected. This surprising result indicates that the details of geometry and material structure we observe in real subduction zones are very important to tsunami models.