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On the role of thermal pressurization in megathrust rupture: the case study of the 2011 Tohoku-Oki earthquake.

Nadaya Cubas (1), Jean-Philippe Avouac (1), Nadia Lapusta (1,2)
(1) GPS, CalTech, Pasadena, USA, (2) EAS, CalTech, Pasadena, USA

A number of unusual features were observed during the Tohoku-Oki earthquake: the maximum slip occurred along the shallower portion of the megathrust where aseismic creep is thought to be the dominant mode of slip; most of the ground shaking came from the deeper portion of the rupture which released a small fraction of the moment; the shallow portion of the megathrust also produced large afterslip suggesting rate-strengthenting friction which should have inhibited seismic slip. We test quantitatively that thermal pressurization can explain these seemingly contradictory observations, as suggested by Noda and Lapusta (Nature, 2013). The shallow portion of the megathrust could be rate-strengthening and creep aseismically but, on rare occasions, slip seismically due to the weakening effect of thermal pressurization. We show that, although the normal stress decreases toward the trench, efficient thermal pressurization and thus co-seismic weakening of the up-dip part of the megathrust can occur if permeability decreases upward along the megathrust or intrinsic friction increases. The conditions for thermal pressurization are assessed in view of the mechanical properties of the megathrust retrieved from morphology and tectonic structure of the forearc. Based on the critical taper theory and the limit analysis approach, we find an upward increase of intrinsic friction consistent with the conditions required for the shallow larger slip. The analysis also provides evidence for a dynamic increase of the pore pressure toward the trench consistent with thermal pressurization along the up-dip part of the megathrust. We show that many aspects of the seismic cycle on the Miyagi megathrust are reproduced by dynamic simulations of fault slip calibrated based on these constraints. The reproduced features include: shallow interseismic creep, frequent magnitude 7.5 earthquakes at depth, infrequent much larger earthquakes producing large shallow slip, and aseismic afterslip in the shallow portion. The simulations also reproduce some unusual particularities of the Tohoku-Oki earthquake such as the backward re-rupturing of the slipped areas.