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Reduction of frictional stability illuminated by rapid afterslip following the 2011 Tohoku-oki earthquake

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Spatial and temporal variations of seismic and aseismic slip on plate boundary faults have been interpreted to result from spatially heterogeneous distribution of frictionally unstable, rate-weakening, regions and frictionally stable, rate-strengthening, regions. Spatial distribution of frictional stability is usually assumed to remain stationary with time and this assumption has been supported by a number of observations. However, experimental and modeling studies show that frictional stability is not a stationary feature but is variable depending on slip rate and that this nonstationary behavior is an important factor in controlling extent of earthquake ruptures and evolution of slip rate. Here we invert Global Positioning System (GPS) data following the 2011 moment magnitude (MW) 9.0 Tohoku-oki earthquake to derive spatial and temporal evolution of afterslip and postseismic shear stress changes on the plate interface. We find that rapid afterslip for the first 15 days and subsequent slower slip cannot be reproduced by slip on a rate-strengthening patch with stationary frictional stability but can be reconciled with reduced frictional stability at high slip rate during the early period and progressive increase in frictional stability with decrease in slip rate. The slip rate dependence of frictional stability is qualitatively similar to laboratory measurements for serpentinite. The reduced frictional stability at high slip rate could potentially control rupture extent of early interplate aftershocks by promoting significant rupture propagation into the rapid afterslip area.