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Seismic cycle in the Nepal Himalaya inferred from instantaneous modelling across time scales

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The Himalayan mountain range has been the locus of some of the largest continental earthquakes, including the 2015 magnitude 7.8 Gorkha earthquake. This event ruptured a previously locked portion of the Main Himalayan Thrust (MHT) fault that has not slipped in a large event since 1833 (Mw 7.6). The earthquake sequence was well recorded by geodetic and seismic instruments, enhancing our understanding of earthquake physics and induced ground shaking. One of the main remaining questions—very relevant for the hundreds of millions of people living in the Ganges plains—is why did the Gorkha earthquake not rupture the frontal part of the MHT-fault? How likely is it to rupture in future earthquakes? And what does this tell us about its frictional properties? To explore these challenging questions we analyze the relation between interseismic periods and the kinematic rupture process of the MHT-fault in the Nepal Himalaya using a new 2D Instantaneous Seismo-Thermo-Mechanical (I-STM). This approach utilizes a visco-elasto-plastic rheology with slip rate-dependent friction to simulate spontaneous rapid slip events throughout the orogen. By employing geodetic data, combined with a geological and geophysical analysis, we design a high-resolution model (200 m) of the present-day lithospheric structure and geometry of the MHT beneath the Kathmandu area. Results show how large earthquakes nucleate on the lower edge of the locked portion, grow and terminate on the MHT-fault in relation to the long-term interseismic period. In agreement with observed geodetic data, our numerical experiments suggest that interseismic convergence across the Himalaya is mostly accommodated by MHT—no relevant slip on smaller faults is required. Fault slip during coseismic MHT events causes up to 1–2 m of uplift in the Kathmandu basin and the surrounding Lesser Himalaya, whereas a large region of the higher Himalaya subside by about 1 m. After partial ruptures of the MHT we observe upward transfer of the stresses which build up around the downdip edge of the locked fault zone. This process is observed in several seismic cycles, and ultimately leads to rupture of the whole locked zone. Furthermore, our simulations establish the dependence of earthquake rupture patterns and interseismic coupling on variations of fault friction. We find that a low fault friction decreases the average strength and thus favours irregular over ordinary cycles of complete ruptures. The occurrence of large ruptures is therefore related to the fault friction properties and the reservoirs of residual strain inherited from former partial ruptures of the MHT. Our study opens the possibility of improving the physical understanding of seismic rupture patterns that the MHT can produce on the basis of its interseismic coupling and frictional properties. Particularly, our results suggest that low fault friction may not prevent large earthquakes to propagate up to the surface.