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Bimodal seismicity in the Himalaya controlled by fault friction and geometry

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The 2015 Mw 7.8 Gorkha earthquake ruptured the lower edge of the interseismically locked section of the Main Himalayan Thrust (MHT). There are indications that potentially much larger earthquakes have occurred in that area and could possibly occur anywhere in the Himalaya. Long-term observations document the spatial and temporal variability of large Himalayan earthquakes: partial ruptures (M7+) tend to cluster in the downdip part of the seismogenic zone, whereas infrequent large earthquakes (M8+) propagate up to the surface. Upon this a question arises: what controls the bimodal seismicity of large Himalayan earthquakes? To explore the conditions that could explain this bimodal seismicity, we developed a 2D, seismo-thermo-mechanical (STM) model of the Nepal Himalaya. This model allows to simulate how large earthquakes spontaneously nucleate, propagate and arrest in and off the MHT in relation to the interseismic period. Our results successfully reconcile a suite of independent observations from interseismic data of Himalayan crustal deformation. Most importantly, the model reproduces a realistic earthquake sequence of irregular moment magnitude main shocks, including events similar to the ones in 2015. We find that the bimodal behaviour emerges as a result of relatively higher friction and a non-planar geometry of the MHT due to along-dip variations in strength excess – that is, difference between stress and yield strength. An increase in fault friction leads to a transition from ordinary cycles of similar sized complete ruptures to irregular cycles. These irregular cycles are even more emphasised when the model accounts for a realistic ramp-flat-ramp geometry of the MHT, since a steep frontal ramp increases the depth-dependent strength. It takes longer and more partial events to reach a critical stress state in the frontal part of the MHT. Our simulations show how moderate earthquakes (M7+) can re-rupture regions that have already ruptured in recent smaller earthquakes and how large earthquakes (M8+) may propagate up to the surface, driven by residual stress following many centuries of smaller earthquakes. This model provides new ways to evaluate seismic rupture patterns that the MHT fault can produce based on its friction and geometry, and suggest that a major earthquake following partial ruptures is unavoidable. Thus, our simulations strongly support the emerging view that the next large earthquake in Nepal may rupture an area significantly greater than the section from the 2015 Gorkha earthquake.