BIMODAL SEISMICITY IN THE HIMALAYA CONTROLLED BY FAULT FRICTION AND GEOMETRY

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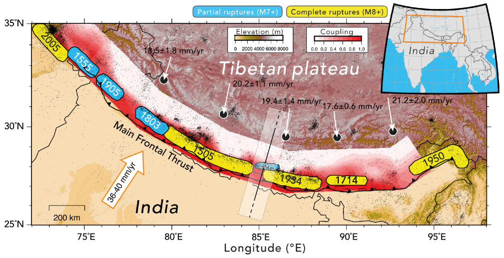
The Himalayan seismicity



Assessing the magnitude and return period of large earthquakes along the Himalayan arc is both a major societal concern and a scientific challenge. **Ample observations document the bimodal behavior of large Himalayan earthquakes: partial ruptures (Mw 7+) tend to cluster in the downdip part of the Main Himalayan Thrust (MHT) fault, whereas infrequent mega-earthquakes (Mw 8+) propagate up to the surface.**

The 2015 Gorkha earthquake was well recorded by geodetic and seismic instruments, enhancing our understanding of earthquake physics and induced ground shaking. Two of the main remaining questions, very relevant for the hundreds of millions of people living in the Ganges Plain, are:

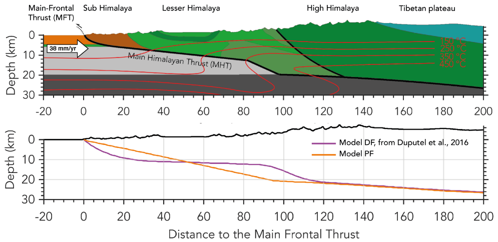
1) Why did the Gorkha earthquake not rupture the frontal part of the Main Himalayan Thrust?

2) How likely is it to rupture in future earthquakes?

Model setup

To explore the conditions that could explain this bimodal seismicity, we developed a 2D, seismo-thermo-mechanical (STM) model of the Nepal Himalaya.

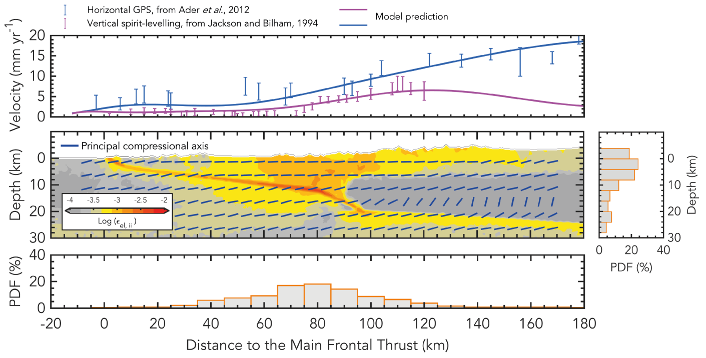
The reference geometry of the MHT, inferred from Elliott *et al.* (2016)[a] and denoted as Model EF, is comprised of three segments to reflect the ramp-flat-ramp geometry[b], whereas the temperature distribution is based on a thermokinematic model[c].



We also perform numerical experiments considering an alternative, smoother fault model (Model DF), from Duputel *et al.* (2016)[d]. To test the sensitivity of the model to the fault geometry, we consider a simple planar fault as well (Model PF).

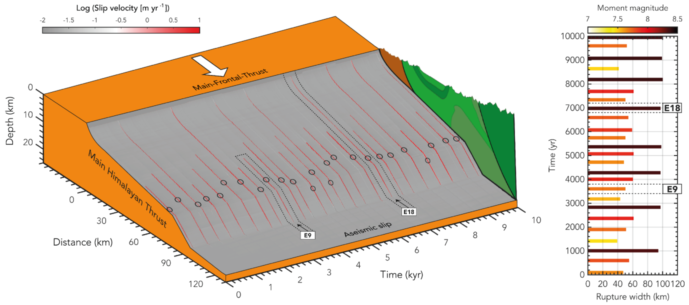
Consistency with interseismic deformation

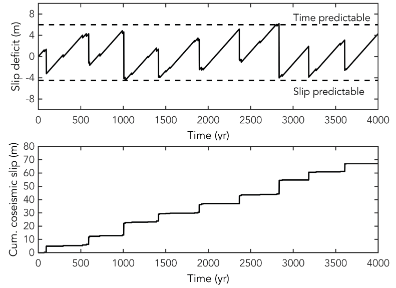
The reference model EF produces about 19–20 mm/yr of convergence across the Himalaya, a value consistent with the long term geological rate. Most importantly, the model fits the geodetic measurements of interseismic strain remarkably well. **The mid-crustal ramp operates as a geometric asperity** during interseismic periods where elastic strain build up and accounts for as much as two thirds of the convergence rate.



Bimodal earthquake behaviour of the reference model

Spatiotemporal evolution of slip on the Main Himalayan Thrust fault for the reference model EF. Red lines show slip during the simulated earthquakes. Note that hypocenters (black circles) are typically located in the lower edge of the flat segment, just before the mid-crustal ramp.

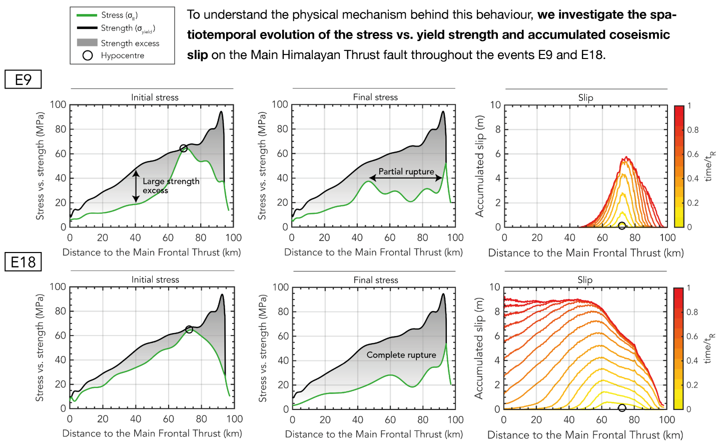




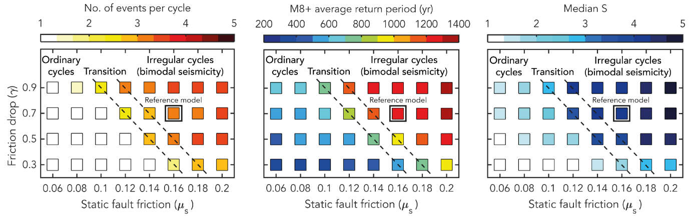
Although the whole seismogenic zone is interseismically nearly fully locked, **most of the simulated earthquakes nucleate and propagate only in the lower edge of the locked Main Himalayan Thrust.**

It appears that the static stress change due to partial ruptures is the major factor introducing irregularity in the seismic cycle. This is the main reason that could explain why **the model obeys neither the slip- nor time-predictable behaviour.**

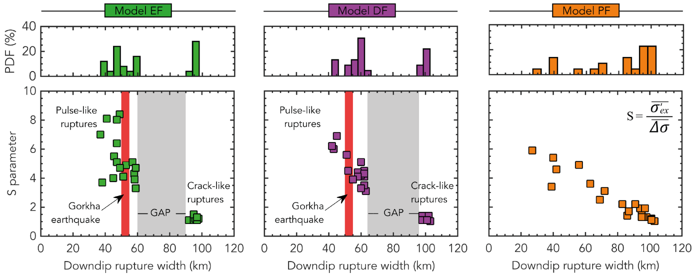
To understand the physical mechanism behind this behaviour, **we investigate the spatiotemporal evolution of the stress vs. yield strength and accumulated coseismic slip** on the Main Himalayan Thrust fault throughout the events E9 and E18.



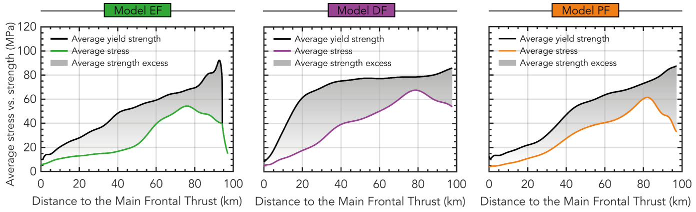
The role of fault friction and geometry



The model produces distinctly different rupture patterns within a narrow range of frictional parameters. **An increase of both the static fault friction and friction drop leads to an increase of (1) the number of events per cycle, (2) the average recurrence interval between the largest events, and (3) the median S values.**



Model EF and model DF show that the strength excess in the shallower region of the fault is notably high. This behaviour arises because the steeper the fault dips in the updip region of the megathrust, the higher would be the pressure-dependent fault strength: $\sigma_{yield} = C + \mu_{eff}\, P$



Conclusions

Frictional properties and non-planar geometry of the Main Himalayan Thrust fault control a variety of observations of the MHT behaviour, such as the along-dip stress conditions, the relative persistence of along-dip variations of seismic ruptures and the variable recurrence time of large (M7+) and great (M8+) earthquakes.

Based on our numerical experiments, we postulate that large crack-like earthquakes on the MHT may incorporate and release a heterogeneous historical reservoir of mid-decollement stress inherited from former pulse-like partial ruptures.

Because a heterogeneous along-dip stress condition is likely to prevail throughout the Himalayan arc, our results may provide an answer to the long-standing difficulties in explaining the source of the stored stresses needed to drive large (>8–10 m) paleoseismic surface ruptures recorded on the Main Frontal Thrust.

References

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