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Convergence rate controls seismicity styles in collision orogens

Luca Dal Zilio, Ylona van Dinther, and Taras Gerya
ETH Zurich, Institute of geophysics, Department of Earth Science, Zurich, Switzerland (luca.dalzilio@erdw.ethz.ch)

The 25 April 2015 Mw 7.8 Gorkha earthquake in Nepal resulted from the unzipping of the previously locked Main Himalayan Thrust (MHT) fault, along which the Himalayan wedge is thrust over India. Strong ground shaking caused the collapse of more than half a million homes, killing more than 8500 people. Can such a large magnitude event also occur within the populated European Alps? Or is there a distinctly different seismicity pattern in different orogens? We show that their long-term seismicity patterns are indeed different and that their differences can be explained by a single parameter: their convergence rate. To do so we present the first self-consistent seismic cycle model for continental collisional margins. We use the viscoelastoplastic continuum Seismo-Thermo-Mechanical model (STM) validated for seismic cycle applications against a laboratory model (van Dinther et al., 2013a) and natural observations (van Dinther et al., 2013b), which includes Drucker-Prager plasticity and spontaneous rupture events governed by strongly rate-dependent friction. The 2-D model setup consists of two continental plates separated by an oceanic plate, in which the incipient subduction phase is followed by collisional orogeny.

Results show the physically consistent spontaneous emergence of complex rupture paths, both on and off the main frontal thrust. These off-main frontal thrust events within the upper and lower plate complement the main frontal thrust seismicity leading to a Gutenberg-Richter frequency-magnitude distribution. This is a key observational feature of seismicity, which is typically not reproduced in seismic cycle models. The range of simulated b-values agrees with natural ranges, as we observe values from 0.97 up to 1.25 for convergence rates decreasing from 5 to 1 cm/yr. Decreasing convergence rates thus lead to relatively larger amounts of smaller earthquakes (increasing b-value) and lower maximum magnitudes. This change in b-value also observed to corresponds to an inverse change in average shear stresses within the orogen. Furthermore, seismicity is observed to migrate from the main thrust into the orogenic wedge as convergence rate decreases. This more distributed form of brittle deformation is also accompanied by a larger contribution of ductile deformation, thereby also reducing seismic hazard for slower convergent margins. These results agree with general observations of seismicity patterns within the Alps and Himalaya. Himalayan-type orogens namely experience more localized seismicity along the Main Frontal Thrust, while seismicity is more distributed in the Alps.