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Simulating landslides using a long-term landscape evolution model in the Southern Alps of New Zealand

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Landscape evolution models (LEMs) are a virtual representation of geomorphic processes as observed in the field or in experimental settings. LEMs offer the flexibility to evaluate a range of interactions between surface processes at timescales which cannot be observed. Notwithstanding the added value of LEMs in unravelling the tectonic-climate-erosion enigma at geological timescales, the use of LEMs to explain real-world earth surface processes remains challenging. For a LEM to be representative for a specific area, field data should be used to calibrate and validate the simulated processes. Notwithstanding the continuously growing database on erosion rates at different spatial and temporal scales, the number of datasets and the area they cover is inversely correlated with the timescale considered. Although more data is thus available at shorter timescales, including them into LEMs is not straightforward as short-term observations are known to reflect the stochasticity of earth surface processes.

In this contribution, we focus on the role landslides, a stochastic hillslope processes in steep mountainous mostly not included in long term LEMs, but strongly reflected in short term field data. We first integrate the formation of landslides and the transport of the thereby generated sediments in a previously developed LEM (TTLEM). Landslide initiation is implemented as a stochastic process depending on a landslide failure index whereas landslide size depends on the slope stability calculated using the Cullman index. The updated model (TTLEM_Sed) is thereafter applied to the New Zealand-Alps where long term erosion measurements and landslide inventories allow to calibrate model parameters. Landslide inventories are traditionally analyzed using statistical relationships between slope stability and conditioning factors such as distance to rivers and distance to active faults. However, the use of conditioning factors in landslide hazard maps is based on empirical observations and lacks physical grounding. Indeed, hillslopes closer to rivers should automatically become more prone to landslides as rivers incise and undercut hillslope foots. The integration of landslides in a LEM now allows to simulate this dynamic interplay over different timescales. By varying the simulated timescale over which the model is run, we identify critical timescales at which a-priori imposed statistical relations between landscape characteristics and landslide occurrence are no longer required and represented by the internal dynamics of the evolving landscape.

With TTLEM_Sed, we present an open-source model tool that allows to simulate landslides and sediment propagation. A modelling approach to study landslides is different from classical landslide hazard mapping approaches as it allows to simulate landscapes over longer timescales therefore allowing to identify physical drivers of landslide formation and landslide initiation. Moreover, the explicit integration of landslides in TTLEM_Sed potentially allows for the integration of widely available short-term field data in future model applications.