Geophysical Research Abstracts
Vol. 20, EGU2018-8864, 2018
EGU General Assembly 2018

Coulomb Mechanics And Landscape Geometry Explain Landslide Size Distribution

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It is generally observed that the dimensions of large bedrock landslides follow power-law scaling relationships. In particular, the non-cumulative frequency distribution (PDF) of bedrock landslide area is well characterized by a negative power-law above a critical size, with an exponent $\sim$2.4. However, the respective role of bedrock mechanical properties, landscape shape and triggering mechanisms on the scaling properties of landslide dimensions are still poorly understood. Yet, unravelling the factors that control this distribution is required to better estimate the total volume of landslides triggered by large earthquakes or storms. To tackle this issue, we develop a simple probabilistic 1D approach to compute the PDF of rupture depths in a given landscape. The model is applied to randomly sampled points along hillslopes of studied digital elevation models. At each point location, the model determines the range of depth and angle leading to unstable rupture planes, by applying a simple Mohr-Coulomb rupture criterion only to the rupture planes that intersect downhill surface topography. This model therefore accounts for both rock mechanical properties, friction and cohesion, and landscape shape. We show that this model leads to realistic landslide depth distribution, with a power-law arising when the number of samples is high enough. The modeled PDF of landslide size obtained for several landscapes match the ones from earthquakes-driven landslides catalogues for the same landscape. In turn, this allows us to invert landslide effective mechanical parameters, friction and cohesion, associated to those specific events, including Chi-Chi, Wenchuan, Niigata and Gorkha earthquakes. The cohesion and friction ranges (25-35 degrees and 5-20 kPa) are in good agreement with previously inverted values. Our results demonstrate that reduced complexity mechanics is efficient to model the distribution of unstable depths. It also shows the importance of landscape variability in landslide size distribution and in the total volume of sediments produced by one triggering event.