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The impact of groundwater dynamics on landsliding and hillslope morphology: insights from typhoon Morakot and landscape evolution modelling

Philippe Steer[1], Lucas Pelascini[1], Laurent Longuevergne[1], and Min-Hui Lo[2]
[1]Université de Rennes, Geosciences Rennes - UMR 6118, Rennes, France (philippe.steer@univ-rennes.fr)
[2]Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

Landslides represent a pervasive natural hazard, exerting a significant influence on hillslope morphology in steep regions. Intense rainfall events are well-established as primary triggers for landslides, particularly those characterized by high rainfall intensity, intermediate to long durations, and substantial cumulative precipitation during and before the event. While the evolving roles of soil saturation and mechanical properties are well-identified in shallow landslide occurrences, the influence of groundwater dynamics on the triggering of deep-seated or bedrock landslides remains less understood. Despite this knowledge gap, deep-seated landslides play a dominant role in the volume budget of landslide catalogs and serve as the primary geomorphological process shaping hillslope evolution in steep regions. In this study, we explore the impact of groundwater dynamics on landslide triggering. Our investigation focuses initially on landslides triggered during Typhoon Morakot, examining their relationship with water table fluctuations derived from the HydroModPy 3D hydrogeological model, forced by water recharge data obtained from the Community Land Model CLM 4.0. Analyzing several contrasting catchments, we demonstrate a strong correlation between the locations and depth of deep-seated landslides and the instability predicted by a simple landslide model that integrates pore pressure and water table depth. Notably, these predictions are valid within specific ranges of hydrogeological (i.e., aquifer thickness, porosity, and conductivity) and mechanical (i.e., cohesion and friction angle) parameters, providing valuable insights into the hydrogeological and mechanical properties of the studied catchments. In an exploratory study, we then shift our focus to the longer-term geomorphological impact of rainfall-triggered landslides on hillslope evolution and morphology. Using a coupled 2D model of water table evolution and landsliding, we investigate topographic changes at the hillslope scale, under different scenarios. Our investigation considers the influence of seasonal recharge, intense rainfall events, and hillslope hydrological convergence or divergence perpendicular to the hillslope orientation on resulting hillslope morphology and dynamics. Overall, our results particularly highlight the role of groundwater dynamics on hillslope finite shape.