Slope activity and processes in the Himalaya of Northern Bhutan

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Abstract

Bhutan is a small Himalayan country, located between India and Tibet. Its territory is characterised by active tectonics, erosion and extreme topographic gradients as well as highly varied climatic zones. Such geographical setting makes for a landscape prone to geological mass movements of different types. To investigate the spatial and temporal distribution of surface deformation in the Higher Himalaya of Bhutan, we combined the information from visual mapping of optical (GoogleEarth) imagery, high resolution DEM (5m GSD), as well as surface displacements retrieved from standard and advanced DInSAR methods with data acquired by different sensors (Envisat, ALOS-1/2 and Sentinel-1). Despite intrinsic limitations of the data used and of the analysis herein considered, we identified with DInSAR more than 1000 objects and classified them by landform including: 1) rockslides, 2) rock glaciers, 3) moraines, 4) talus or slope debris. We analysed the spatial distribution of the detected objects and generated an activity map for the investigated area. Almost 600 potential rockslides and more than 200 rock glaciers were detected with DInSAR analyses alone. The distribution of the mapped objects shows an irregular pattern across the area. Depending on the landforms, this could be in part related to permafrost and elevation but also to structural controls. However, we observe a lack of detected unstable slopes in the southeast of the study area, this most likely related to the unfavourable land cover within the forested regions. We also observe that only around 20% of the rockslides detected on optical images show signs of activity in the DInSAR analyses. This is in part related to the effects of detectability with DInSAR but it also to the state of activity of such rockslides during the observation period. Moreover, we attempted to identify spatially correlated atmospheric artefacts within the DInSAR time series and analysed the remaining seasonal cycles to discriminate between gravitational processes, reversible displacements related to permafrost freeze and thaw, and reversible displacements below the permafrost region, thus potentially related to groundwater recharge and depletion or thermomechanical effects. This analysis allowed to better define the underlying driving mechanisms of surface displacements. The results obtained through this analysis are expected to contribute to the understanding of processes conditioning large rock slope movements in the Higher Himalaya of Bhutan and to a future landslide hazard assessment of the region.

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