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Geomorphological mapping of an alpine rock glacier with multi-temporal UAV-based high density point cloud comparison

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The acquisition of high-resolution topographic data is a widely used tool for studies related to the processes and dynamics of the Earth's surface. In this work, we present the results of the repeated acquisition of photogrammetric data by Unmanned Aerial Vehicle (UAV) in order to detect the topographic evolution of an alpine rock glaciers located in Valtournenche (AO, Italy). Field monitoring conducted in recent years has shown significant variations in the behaviour of these landforms, with an increasing trend of their dynamism, raising questions about their stability in changing climatic conditions.

The photogrammetric shots were taken with a DJ Phantom 4 UAV equipped with a compact RGB digital camera. The acquisitions were performed yearly from 2012 up to 2019 with a ground sampling distance never exceeding 5 cm/px. Contemporary to the acquisitions, approximately 20 Ground Control Points were placed on the rock glacier and on the surrounding areas and their coordinates were measured with a differential GPS (dGPS) for georeferencing UAV images. Moreover, in 2014, 2015 and 2019 geophysical campaigns were carried out for the detection of ice lenses under the debris cover of the rock glacier.

Structure-from-motion techniques were applied on overlapping images to create high-density point clouds, than converted in orthophotos and digital surface models of the Earth's surface.

The point clouds were analysed using the M3C2 (Multiscale Model to Model Cloud Comparison) plug-in, freely available in the CloudCompare software. Maps of surface changes between acquisition pairs in the period from 2015-2019 have been created. The comparison allowed the identification of "material supply" and "material removal" zones, slightly variable from one year to the next. The major accumulation zones are concentrated along the frontal sector of the rock glacier, more focused on the western sector (black lobe) and secondly on the right side of the rock glacier (white lobe). The removal of material is mainly concentrated on the higher altitude of the

body but also in correspondence to the systems of crevasses and scarps and on the central part of the black lobe.

The surface displacement analysis of the rock glacier was also performed selecting manually several clearly identifiable features on the orthomosaics collected. Blocks and ridges-and-furrows complex were marked on the 2019 orthomosaic and found them on the 2015 orthomosaic. This approach allows improving and quantifying the dynamics of the different portions of the individual apparatus.

The velocity fields' patterns highlight non-homogeneous displacements between the West (black lobe) and East part (white lobe) of the whole rock glacier. Specifically, the black lobe showed an average horizontal displacement of around 1 m/y while the white lobe moved significantly slower than the previous one (approximately 0.5 m/y). Overall, the rock glacier moved downslope at an average horizontal velocity of 0.60 m/y in the frontal tongue, 0.48 m/y in the central portion and 0.30 m/y in the upper zone.