<u>Title:</u> How do rock glaciers deactivate? Geomorphic and activity states of French Alpine rock glaciers in transition

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Rock glaciers are the visible expression of mountain permafrost. The deformation of internal ice and basal horizon make them creeping downward, which allows their detection. Their geomorphological characteristics tend to evolve as a response to degrading permafrost conditions. If the internal ice is melting, the surface creeping gradually decreases until the landform stabilizes. This gradual deactivation has led to the definition of "rock glaciers in transition". Recent studies highlighted a general trend of active rock glaciers' increasing surface velocity in the last decades. In this context, we are asking if remaining ice in rock glaciers in transition could allow an increase of surface velocity trend similar to active rock glaciers? This study aims to describe rock glaciers in transition geomorphic settings and their present-day kinematics, and explore how their intrinsic and extrinsic characteristics can explain their activity.

To answer this question, we applied remote sensing techniques from a French inventory of rock glaciers such as i) High resolution differential radar interferometry images to describe present days surface velocities for all "inactive" inventoried rock glaciers and reveal global trends at a large scale. ii) Geomorphic mapping of the rock glaciers characteristics such as their geometry, geomorphological and geological settings (rock glacier system, slope, latitude/longitude, altitude, concavities, exposition, and lithology of the blocks…). iii) By combining a dataset with i) and ii), we analyze correlations and dominant parameters using an MCA factorial analysis and a multimodal linear regression.

Over more than 500 rock glaciers, 250 present displacements detectable from 30 InSAR images during 2017 and 2018 summer periods. Most of them have velocities rates lower than 10 cm. yr^{-1} (N=175), however surface velocities higher than 10 cm are visible for 23% of them (N = 119. Higher rates (> 100 cm / year)) also concern 28 rock glaciers. For 80% of them (N=247), the mean surface area of displacements is lower than a half of the rock glacier surface area. The most represented geomorphic criteria are related to sagging landforms. Indeed, the application of NCI to transversal profiles described more than 50% of rock glaciers as concave with many of them displaying a high asymmetric topography. The surface slope and the concavity/convexity index of transversal profiles should be the best parameters to describe the state of a transitional rock glacier in accordance with its activity. Small and local subsidence could not be detected with our method which must be improved.

The factorial analysis results show that our rock glaciers population is clearly divided into 2 sub-population : those where higher surface velocities are met (> 10 cm / year), and the others with lower surface velocities (< 10 cm / year). This is explained by the combinations of parameters owed by these rock glaciers which is clearly different. Parameters which are shared in both populations are related to favorable and not favorable permafrost conditions that can explain this activity pattern : slope, altitudinal range, exposition and PFI. Rock glacier system is either associated to this differential activity pattern. Multi-units systems are composed with other active units for rock glaciers where higher speeds are met, and the lowers mostly with other transitional and relict units. Small moving areas (< 20% of the total RG surface) are associated to lower surface velocities, which suggest remaining active units or local subsidence. Lithological classes of rock wall suppliers were not associated with any of these sub-populations. Further rugosity and morphological analysis is required to explain this RG allocation.

In another hand, morphodynamical approaches are essential to better understand the link between external parameters and morphological settings of rock glaciers in transition, in responses to their activity. Nonetheless, the ice content and amount of water input can be essential drivers of rock glaciers activity. It is therefore important to complement such morphodynamical studies with an analysis of the subsurface in order to correlate these characteristics with the actual internal properties of rock glaciers.