European Geosciences Union
EGU General Assembly 2020
4 – 8 May 2020

Geomorphological mapping of an alpine rock glacier

with multi-temporal UAV-based high density point cloud comparison

Acknowledgment
The research is founded by the Italian MIUR project Dipartimenti di Eccellenza 2018-2022

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1. Introduction and objectives

Rock glaciers and their dynamics have received much attention in recent years in the study of the impact of global warming on permafrost in high mountain environments. They are commonly present in many poorly-glacierized mountain regions around the world, and represent key features to understand the high-altitude cryosphere in conditions of climate change (Muller et al., 2016). Active rock glaciers are characterized by movement due to deformations and creep of the buried ice inside the body and they represent one of the most visible expressions of creeping mountain permafrost.

In this study, the geomorphological changes related to the deformation of an active rock glacier were investigated with UAV (Unmanned Aerial Vehicle) surveys between 2016 and 2019.

The aims of this work consist of (i) monitoring the activity status of the whole rock glacier, (ii) detecting in very high detail its 3D surface changes over the study period and (iii) relating these changes to its internal structure, described by geophysical surveys.

2. Study area and dataset

The study area is located in the south-western Alps at the head of the Valtournenche Valley (Valle d'Aosta, Italy) on the Matterhorn basin.

The rock glacier develops from 2600 to 2750 m a.s.l, and its apparent thickness is 20-30 m, estimated at the front and confirmed by geophysical surveys. The body of the rock glacier is characterized by longitudinal ridges in the central part and a complex of transverse ridges and furrows in the compressive part of the tongue.

Four surveys were organized on the rock glacier body on 24th August 2016, 26th August 2017, 23rd August 2018 and 21st August 2019. The UAVs (DJI Phantom 4 and SenseFly ebee RTK) was equipped with a high resolution digital camera (20 Mpx), and flew at a constant altitude from the rock glacier surface (height variable from 80 to 110 m). Acquisitions were made with ground sampling distance never exceeding 5 cm/px. 21 ground control points were placed and their coordinates were determined in GNSS RTK mode, for georeferencing each photogrammetric block. The accuracy was assessed based on the residuals of the ground control points (GCPs) and the check points (CPs); the Root Mean Square Error (RMSE) was lower than 5.25cm (for both GCPs and CPs) for all models except the year 2018 where the RMSE of CPs is 9.30 cm.

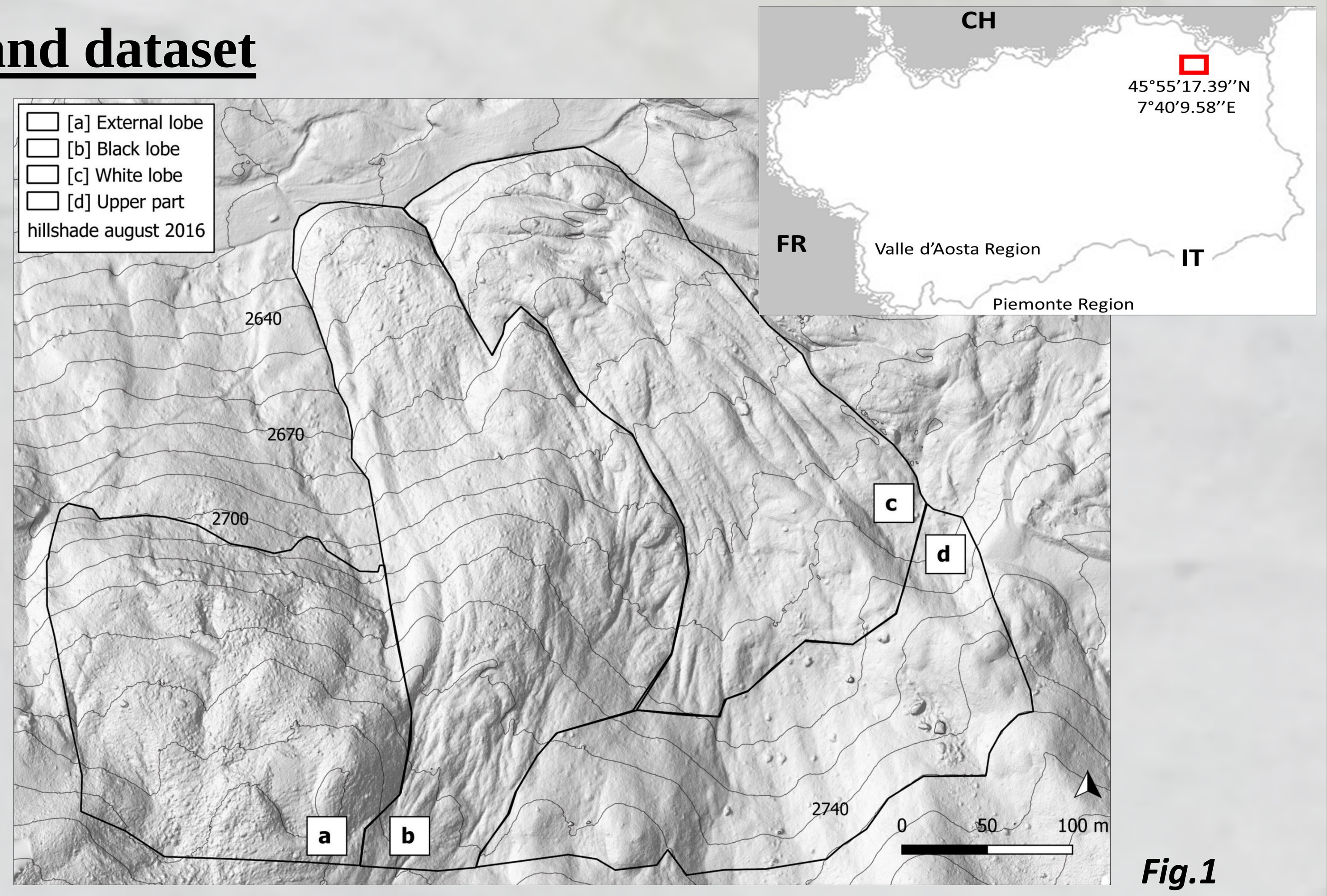


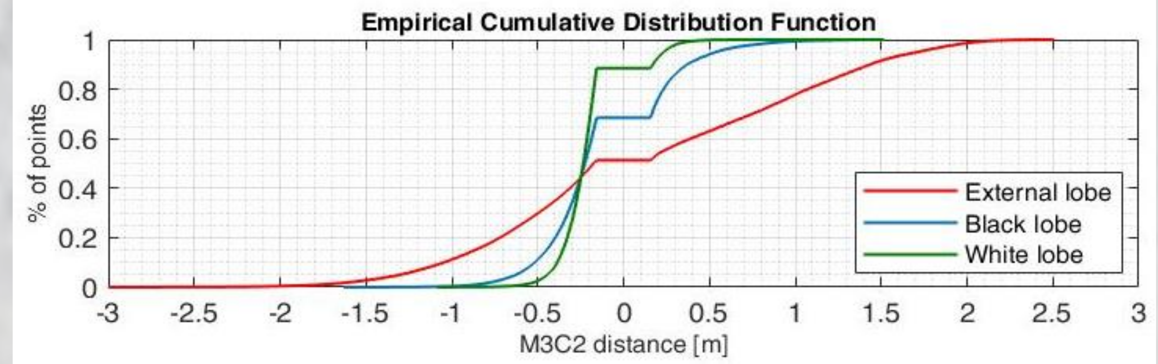
Fig.1

3. Methods

- The Structure from Motion (SfM) technique was used to generate dense point clouds (approximately 55M points for each dataset) and high-resolution orthomosaics and DSMs (Digital Surface Models);
- The estimation of a three-dimensional changes (3D-changes) was carried out by using Multiscale Model to Model Cloud Comparison (M3C2) plug-in (Lague et al., 2013) applied to pairs of points clouds;
- Three models (2019-2018, 2019-2017 and 2019-2016) was computed to simulate 3D-changes over time and to quantify them in each period (Zahs et al., 2019);
- The M3C2 *distance map* (**Fig.2a**) was created and compared with the DoD map (**Fig.2b**) to evaluate the consistency of the results (**Tab.1**);
- The Level Of Detection (LOD) was determined for each 3D-changes model and subsequently the 95% quantile of its distribution was calculated; changes smaller than the $LOD_{95\%}$ value have been disregarded;
- Considering the significant differences, the surface areas were distinct into positive/negative (**Fig.3**) to describe the rock glacier behaviour;
- The planimetric displacements have also been calculated (**Fig.4**, **Fig.5a-5b**);
- The analysis was considered for all three time intervals (**Tab.2**).

Only the results referring to the period 2016-2019 are reported below.

4. Results



External lobe [a] shows a greater dynamism than the black and white lobes. The first of these, lobe [b], shows major changes than the adjacent lobe [c]. This difference in 3D behaviour was then verified by analysing the planimetric displacements (2D displacements section). The lobe [d] was not taken into account given its low percentage of significant areas, less than 2%.
See **Fig.1** for lobe division.

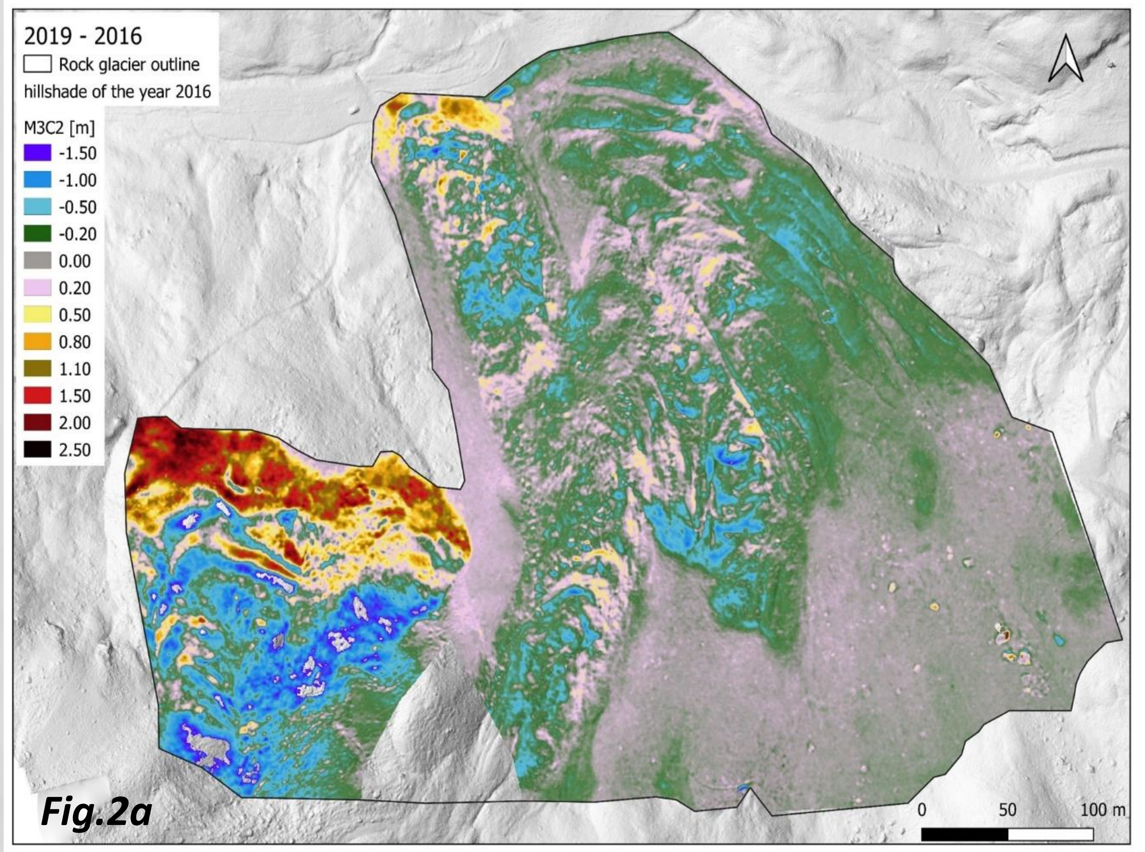


Fig.2a

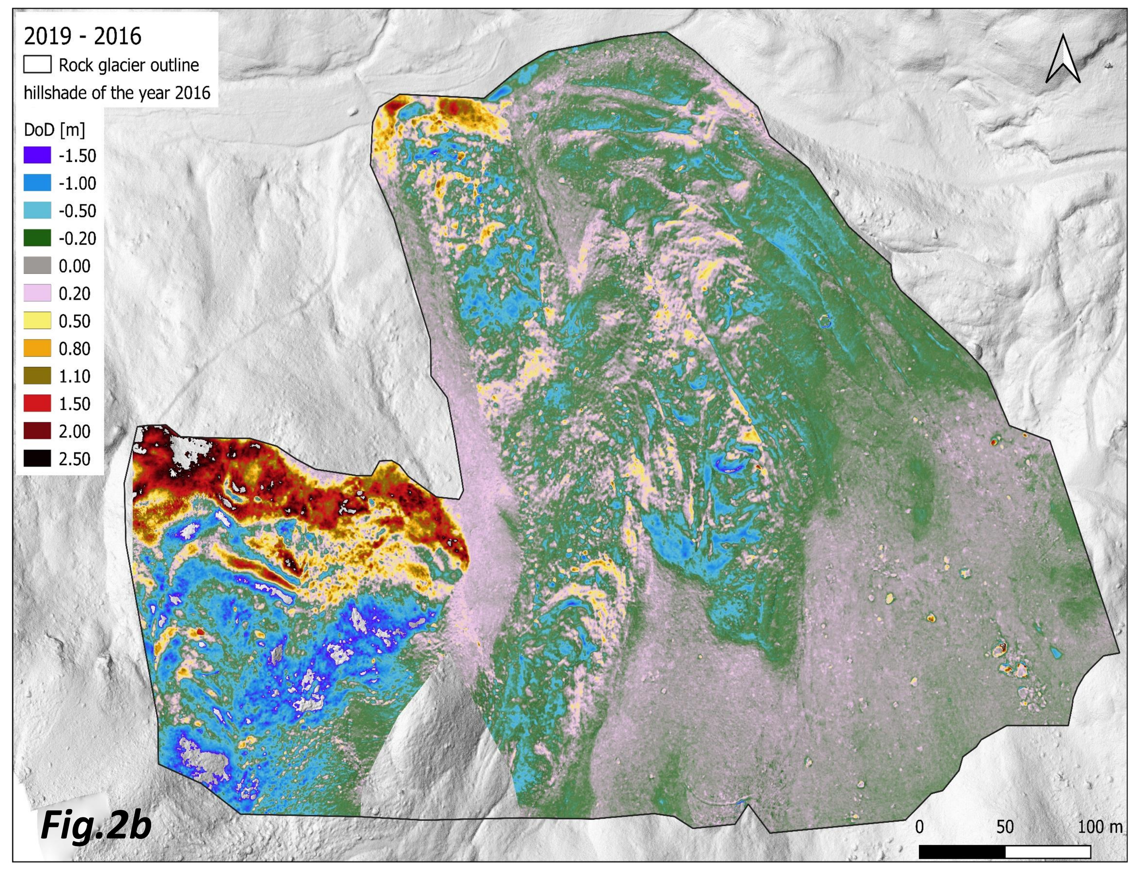


Fig.2b

Surface changes are reported in **Fig.2a** (M3C2) and **Fig.2b** (DoD). The two maps are in good agreement, confirming the consistency of the results obtained with the two methods. Small exception for the front of the lobe [b] where max values of 1.5m are recorded with DoD method, compared to the max values of 1.1m, via M3C2.

Statistic variable	M3C2 distance [m]	DoD [m]
Max	2.26	3.30
Min	-2.31	-3.30
Mean	-0.06	-0.05
Std	0.42	0.50

Tab.1

The areas with positive variation indicate a material supply, while the negative ones are the areas where a material loss occurs (i.e. erosion, creep..).

Time interval	LOD threshold	% significant surface change	% positive surface areas	% negative surface areas
2019-2016	0.16 m	44 %	35 %	65 %
2019-2017	0.14 m	36 %	32 %	68 %
2019-2018	0.22 m	14 %	52 %	48 %

Tab.2

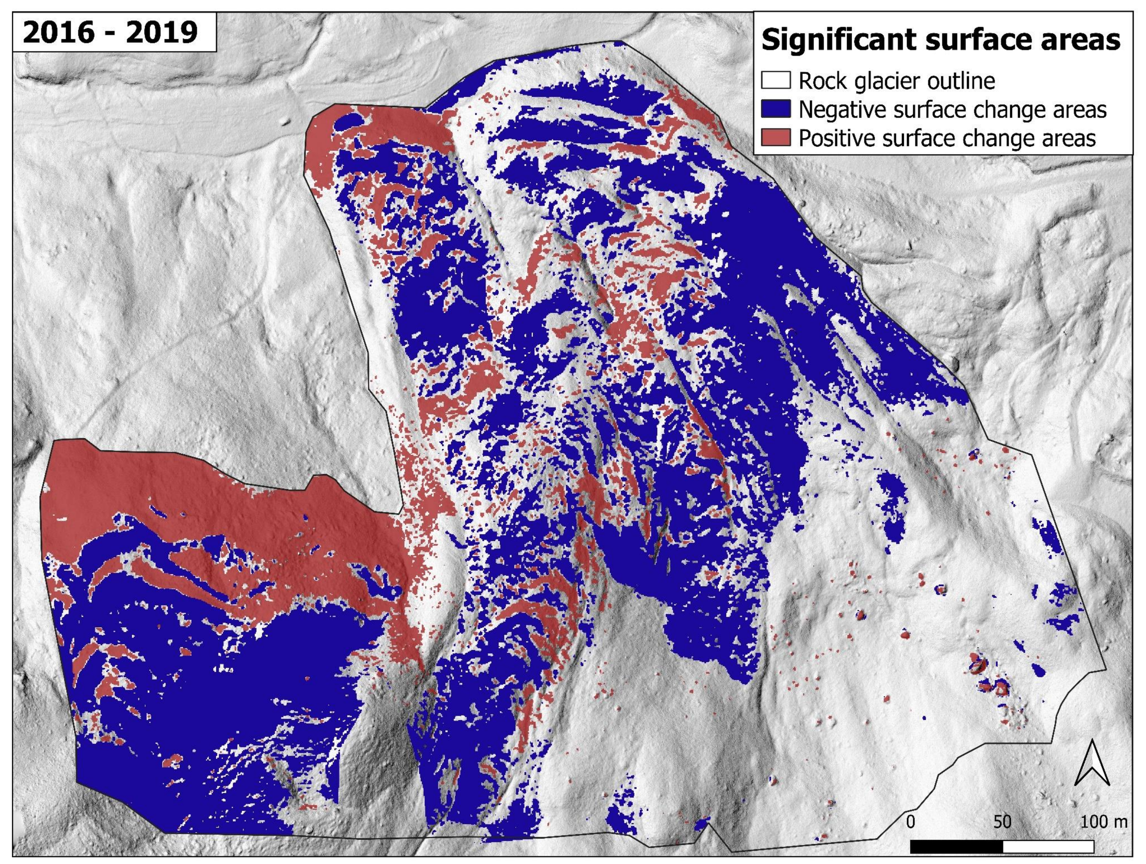


Fig.3

The total volume of negative areas is 20367 m^3 while the volume of positive areas is 11932 m^3.
The percentage of significant surface change areas is 45.39% for the lobe [a], 30.90% for [b], 22.55% for [c] and 1.17% for the upper part.

2D displacements

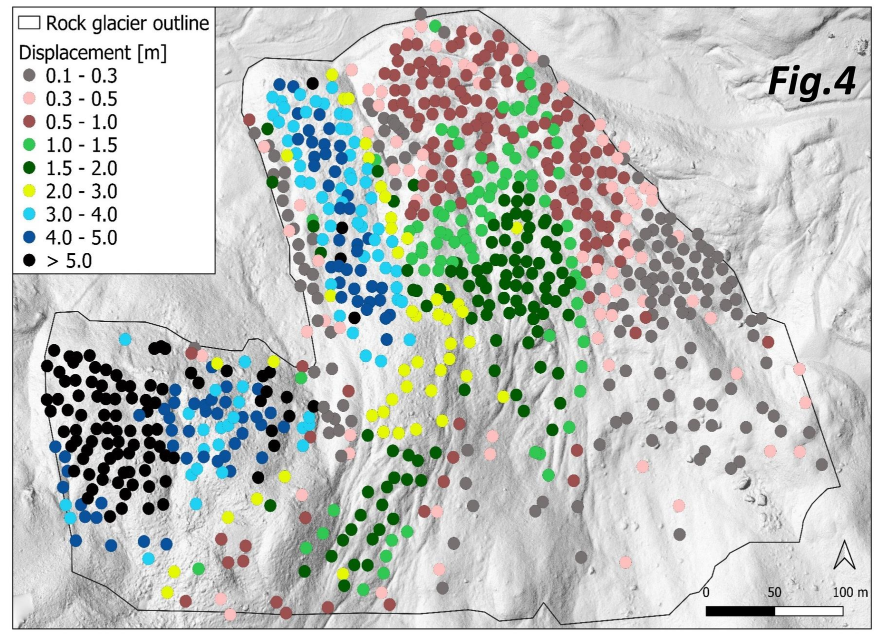


Fig.4

The lobe [a] is the most active lobe (probably due to greater steepness than the black and white lobes) and shows two displacement fields: the western part with displacements greater than 5m while the sector bordering the lobe [b] shows variations between 3-5m. The lobes [b] and [c], although morphologically comparable, show different behaviour; the first is more active with movements varying between 1.0-2m in the upstream sectors, while from approximately 2690 m a.s.l. to the front there are more intense movements (3-5m). In correspondence with the furrows-ridges complex, in the lobe [c], the majority of the displacements are in the range 0.5-1m with values of 1-2m, at the limit with the lobe [b]. The different behaviour between these two lobes could be dictated by the presence of buried ice under the debris cover: a continuous ice lens (20m thick) in the more active one while two ice lenses (20-30m thick) in the [c] lobe.

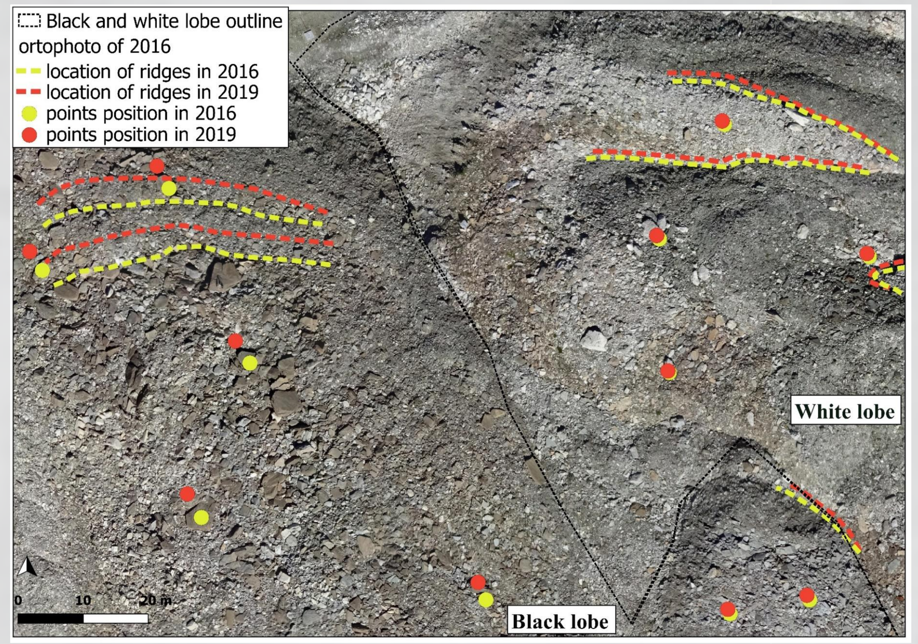


Fig.5a

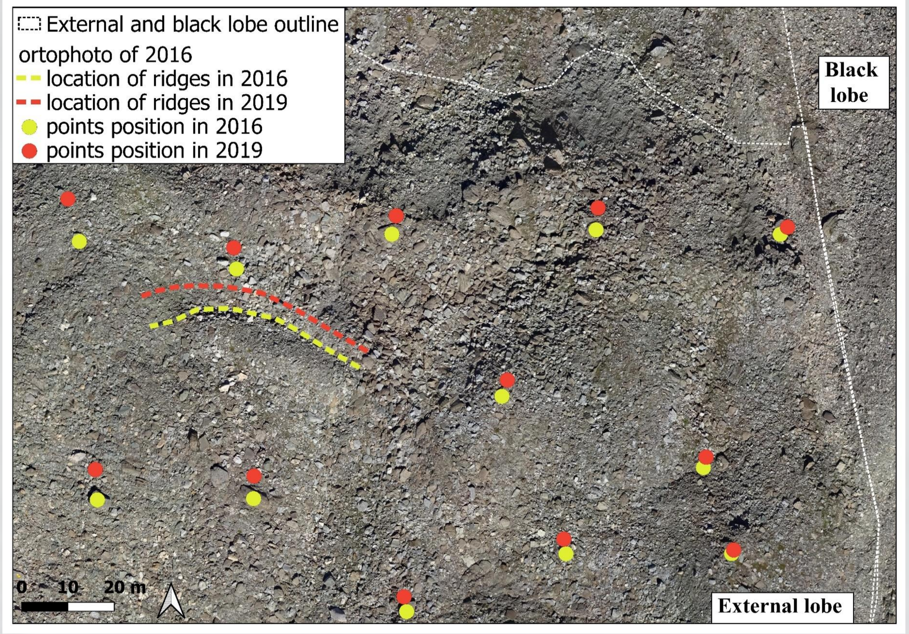


Fig.5b

Fig.5: Advancing of the ridges and moving rock blocks downstream forehead lobes. **Fig.5a**: Displacements of 3-5 meters for the lobe [b] and max values around 1.5m in the lobe [c]. **Fig.5b**: Max movements at the ridge (>4m) of lobe [a] and gradually decreasing towards the lobe [b] limit.

5. Conclusions

The results obtained highlight the potential of using high spatial resolution UAV data in combination with M3C2 algorithm in order to map three-dimensional the spatial distribution of significant surface change areas. This innovative approach to 3D analysis has enabled a better understanding of the dynamics of rock glaciers, drawing attention to areas subject to material gain from those with negative surface variations.

References

- Lague D., Brodu N., Leroux J. (2013). "Accurate 3D comparison of complex topography with terrestrial laser scanner: application to the Rangitikei canyon (N-Z)". *ISPRS Journal of Photogrammetry and Remote Sensing*, 82, 10-26. doi: 10.1016/j.isprs.2013.04.009
- Müller J., Vieli A., Gärtner-Roer I. (2016). "Rock glacier on the run – understanding rock glacier landform evolution and recent changes from numerical flow modelling". *The Cryosphere*, 10, 2865-2886. doi: 10.5194/tc-10-2865-2016
- Zahs V., Hämmerle M., Anders K., Hecht S., sailer R., Rutzinger M., G. Williams J., Höfle B. (2019). "Multi-temporal 3D point cloud-based quantification and analysis of geomorphological activity at an alpine rock glacier using airborne and terrestrial LiDAR". *Permafrost and Periglac. Process.*, 30, 222-238. https://doi.org/10.1002/ppp.2004