Evaluation of a terrestrial photogrammetry method to assess rock glacier dynamics

A study case in the Argentinean Andes of Mendoza

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Abstract—**This paper investigates the potential and limits of terrestrial photogrammetry for studying rock glacier dynamics, and more especifically its interannual surface changes. Using a rather simple digital photogrammetric workflow, the restitution of two 3D-models was done thanks to multi-correlation of more than 100 images acquired in summers 2013 and 2014 on an active rock glacier in the Argentinian Andes. The quality of the output datasets is evaluated by comparing to GPS data, collected on artificial targets (XYZ) and along tracks (Z). Based on this results, we can consider ± 0.24 m as the margin of error that has to be taken into account to assess the surface changes between the two DEMs. Vertical differences affecting the rock glacier front over the one-year time lapse can then be quantified and interpreted in terms of geomorphological processes.**

I. Introduction

When compared to other available remote-sensing and ground-based technics, terrestrial photogrammetry can appear as an interesting option to measure relatively homogeneous surface displacements, such as those generally affecting rock glaciers [1]. With a reasonable cost in time and money, this approach allows to survey several ha and up to a few km² with an accuracy and a precision potentially high enough to get valuable insights into the spatial and temporal variations of surface characteristics (e.g. [2]). We evaluated this method on an active rock glacier in the semi-arid Andes of Argentina and we present in this paper the main results after comparison between the 3D models generated from 2 photography datasets (processed within a commercial software) and GPS measurements.

II. Study site and methodology

The Quebrada del Medio rock glacier is located on the Cordón del Plata, in the Argentinian Andes of the Mendoza Province. The landform is almost 3 km long, oriented N-S, has a glacigenic origin [3] and is characterized by steep lateral and frontal taluses and arcuate ridges and furrows evidencing the present activity of the deformation mechanisms [4]. The study area is limited to the lowest 600 m of the tongue, with a mean width of 200 m and elevations ranging between 3600 and 3400 m asl (Fig. 1). It benefits from a relatively easy access and is also surveyed with thermal and kinematic monitoring since April 2014.

The photogrammetric method uses several images of the same object taken with a sufficient overlapping between each ones to measure their relative orientations and to restitute 3-dimensional properties of the object. The apparition of digital photography and better hardware and software computational capacities have recently made the terrestrial, or ground-based, photogrammetry a powerful and affordable tool to generate high resolution models, extremely valuable for Geosciences applications, like 3D point clouds, Digital Elevation Model (DEM) and orthophotography (e.g. [5]).

In this work, two acquisition campaigns were carried out in May 2013 and August 2014 (Fig. 1), with two photographic devices sligthly different (Table 1), based on Nikon digital single lens reflex models (D7000 and D7100) equiped with fixed focal length lenses (respectively 27 and 36mm eq. 35mm, and with sensor size of 4928 x 3264 pixels and 6000 x 4000 pixels, respectively).

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TABLE I. CHARACTERISTICS OF THE PHOTOGRAPHIC DATASETS FOR THE TWO FIELD CAMPAIGNS

Date	Acquisition system	Number of images	Characteristics of the images			
			Size (pixel)		Time of shot	
			heigth	width	start	end
01/05/13	D7000 + 27mm	151	4928	3264	12h10	12h50
15/08/14	D7100 + 36mm	145	6000	4000	11h29	14h57

Date	Acquisition system	Characteristics of the terrain		
		Elevation (m asl)		Others
		min	max	
01/05/13	D7000 + 27mm	3307	3432	Only lower part
15/08/14	D7100 + 36mm	3478	3694	Snow remnants

A survey of 15 artificial targets (B&W cross printed on laminated canvas sheet, 10 targets of size 40 x 40 cm, and 5 targets of size 80 x 80 cm) was performed during the campaign of 15-Aug.-2014 with differential bi-frequency GPS (Trimble R5 used in PPK mode, with a computed precision of 0.01 m horizontally and 0.02 m vertically), in order to obtain accurate ground control points (GCP). A kinematic differential GPS survey (with the same device and a 5-second interval of acquisition) was also conducted the same day along two transversal tracks crossing the rock glacier, with an accuracy of ± 0.05 m (Trimble R5 factsheet).

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After grouping the images according to the terrain they cover and eliminating those with wrong exposure, blurred or unnecessary coverage, the following steps were followed within the software Photoscan (© Agisoft): 1) aligning each groups of images (an additional optimization procedure was also performed to achieve better alignment results); 2) manual identification of the GCPs on each images; 3) dense cloud correlation; and 4) export of DEM and orthophotography at the best resolution (between 6 and 15 cm depending on the model).

For the GPS and photo campaign of 15-Aug.-2014, the mean positioning error based on 384 projections of 11 GCP is 0.154 m for X, 0.094 m for Y and 0.110 m for Z, corresponding to a mean overall error of 1.23 pixel after alignment optimization. Once generated, the 3D model of 15-Aug.-2014 was then used to georeference 1-May-2013 model by retrieving 7 new GCPs on fixed areas on both sets of images, achieving a mean error of 0.248 m.

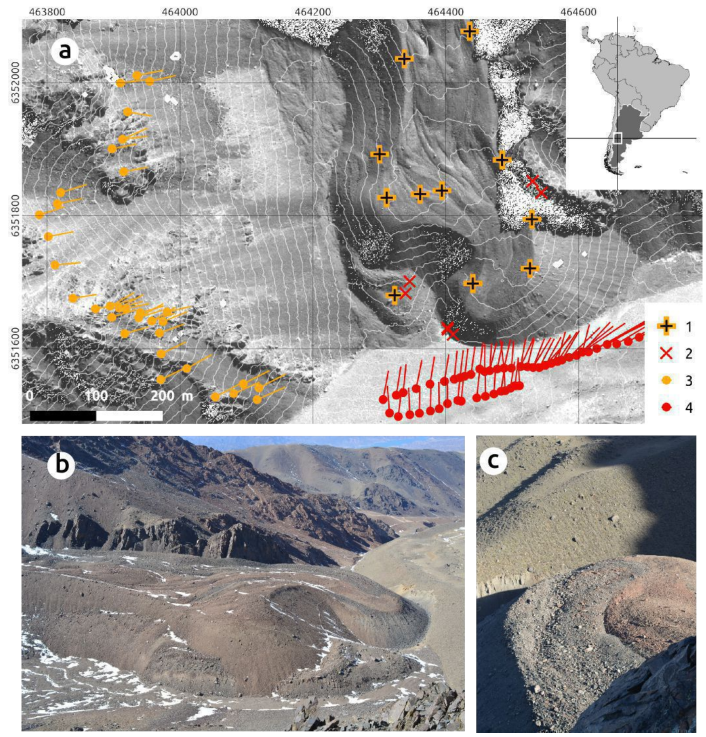

Figure 1. a) Map of the study area and location of the different photogrammetric elements. Legend: 1) target used for the GPS and photo campaign of 15-Aug.-2014; 2) GCP extracted from 2014's model to georeference 2013's models; 3) position of cameras and view angle of the photos for 2014's campaign; 4) position of camera and view angle of the photo for 2013's campaign. 10-m contour lines and background orthoimagery are from Pléiades images [6]; b) View from the West of the tongue of the rock glacier; c) View from the North of the terminus.

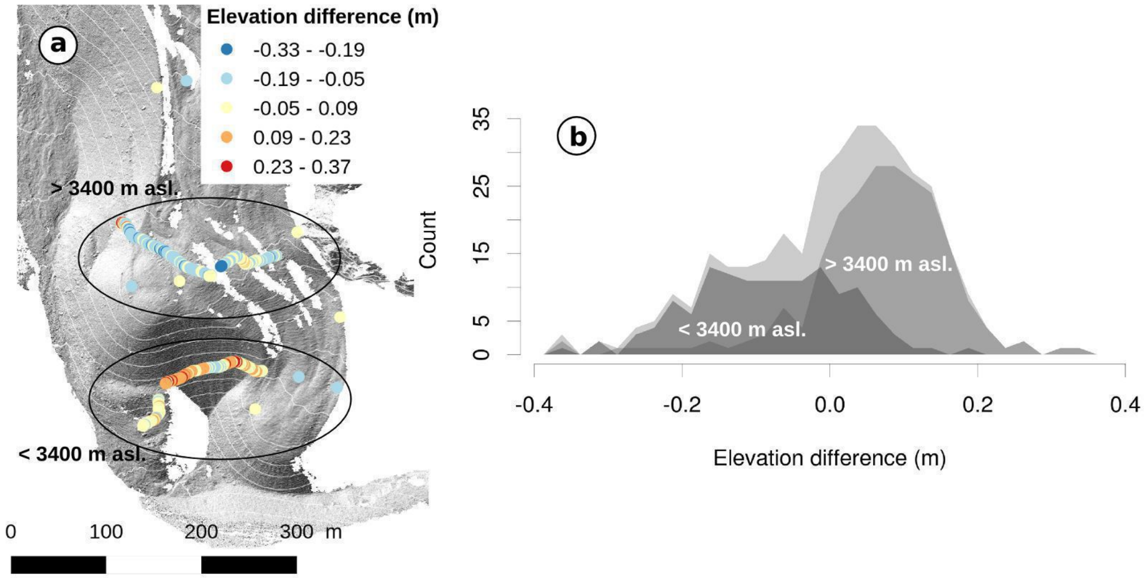

Figure 2. Comparison of the elevation values between 2014 DEM and 361 GPS measurements along two tracks on the rock glacier: a) Overall view of the DEM and location of the GPS points (areas above and below 3400 m asl. are distinguished); b) distribution of the error (difference in elevation between GPS value and corresponding DEM cell) for each area (above and below 3400 m asl.) and for the total.

III. Results and discussion

We compared the DEM produced with the 15-Aug.-2014 images with the kinematic GPS measurements performed the same day, by extracting in a GIS the DEM value corresponding to each of the 361 GPS points and then compute the difference in elevation (Fig. 2). Taking into account that an error of ± 0.08 m should be empirically added due to the movements of the antenna mounted on the top of the stick and hand-held along the tracks, the elevation differences between GPS and 2014's DEM are ranging from -0.371 to 0.326 m, with an RMSE of 0.123 m.

Two significantly different distributions of the errors are found on the two evaluation areas (roughly grouped according to the elevation, ie. above and below 3400 m asl), which is most probably related to unsolved alignment problems on the 3D models. A third campaign is planned in December 2014 with a greater number of large targets (80 x 80 cm) to try to better understand and hopefully solve this problem.

If we now consider 2σ (0.24 m) of the DEM-GPS elevation differences as a reasonnable error margin, then the differences between the 3D models of 15-Aug.-2014 and 1-May-2013 (Fig. 3) can be interpreted in terms of geomorphological dynamics that affect the Quebrada del Medio rock glacier. Due to the above mentionned alignment problem, the comparison has been only focused on the frontal part of rock glacier tongue, where numerous GCP better constrain the alignment between 2013 and 2014 3D models.

Over the 15-month time interval between the two campaigns, several phenomena are nicely imaged by this approach. First, a characteristic pattern of elevation difference observed here probably reflects the advance mechanism of the rock glacier: the advection of frozen debris to the front due to the creeping of the ice and debris mixture leads to higher horizontal displacements, which is reflected by a gain of elevation spread homogeneously on the upper part of the talus (see [7]). Most probably related to the same process, the fall of three pockets of debris is also evidenced by a loss of elevation on the upper part of the talus immediately followed below by a gain, where the fallen material accumulated.

IV. Conclusion

We evaluate the potential of a low-cost procedure to generate 3D models, from which high resolution DEMs and orthoimages can be easily derived, for studying rock glacier dynamics. The comparison between DEM and GPS measurements made in 2014 gives a margin of error of ± 0.24 m. Though unsolved problem of alignment between the 3D models limits the comparison between 2013 and 2014 DEMs, characteristic processes affecting the front of the rock glacier have been highlighted. This approach therefore appears as a very promising tools, as computational performance and optical quality of the digital cameras are still progressing.

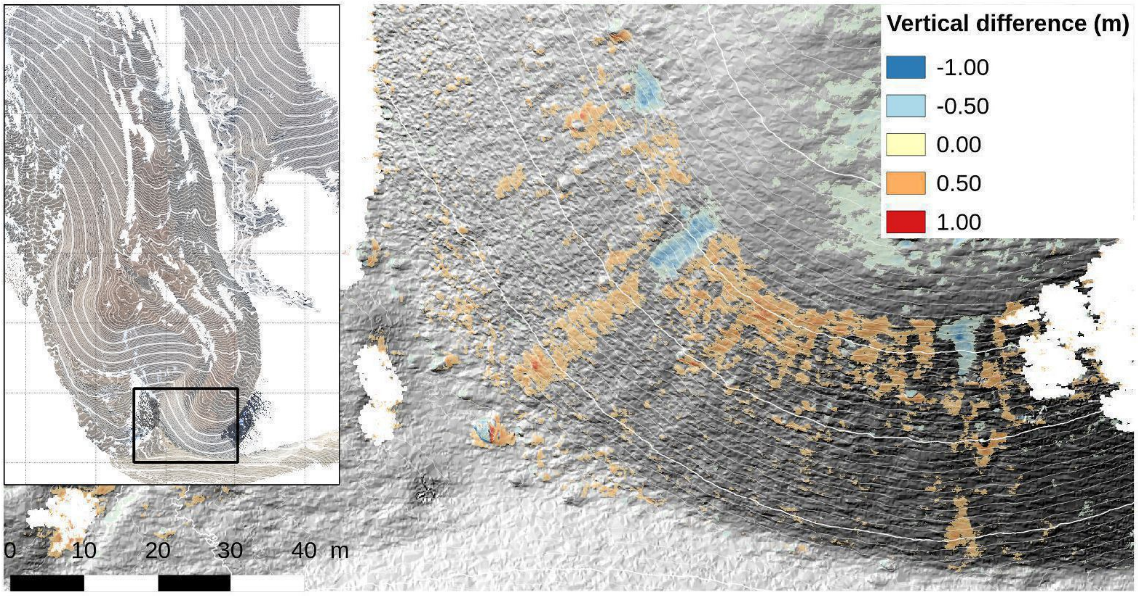

Figure 3. Vertical changes between 15-Aug.-2014 and 1-May-2013 DEMs on the frontal part of the Quebrada del Medio rock glacier (values between -0.24 and 0.24 m, corresponding to the error margin, have been set to transparent). Inset map shows the location of the zoomed area (background is the 2014 orthoimage overlaid with 1-m contour lines)

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