Low-cost UAVs for long-term glacier monitoring: the evolution of the Belvedere Glacier during the period 2015-2020

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1 Introduction

Unmanned Aerial Veichles (UAVs) and Structure-from-Motion (SfM) are widely considered as valuable tools for geoscience and cryoshpere monitoring. By acquiring aerial images and measuring well-distributed Ground Control Points (GCPs), 3D models of glaciers can be derived and employed to compute glacier velocities, ice volume variation and, finally, mass balances. This remote-sensing approach might reduce potentially dangerous in-situ operations, and allows for recurrent and extensive glacier monitoring.

1 Goals of the study

The aims of this study are:

- Estimate annual ice volume variations of the Belvedere glacier between 2015 and 2020
- Prove the effectiveness of low-cost UAV-based photogrammetry for long-term alpine glacier monitoring

2 The Belvedere Glacier

The Belvedere Glacier is a debris-covered glacier (Fig. 2) located in Valle Anzasca (Italian Alps), at the feet of the Monte Rosa east face (Fig. 1).

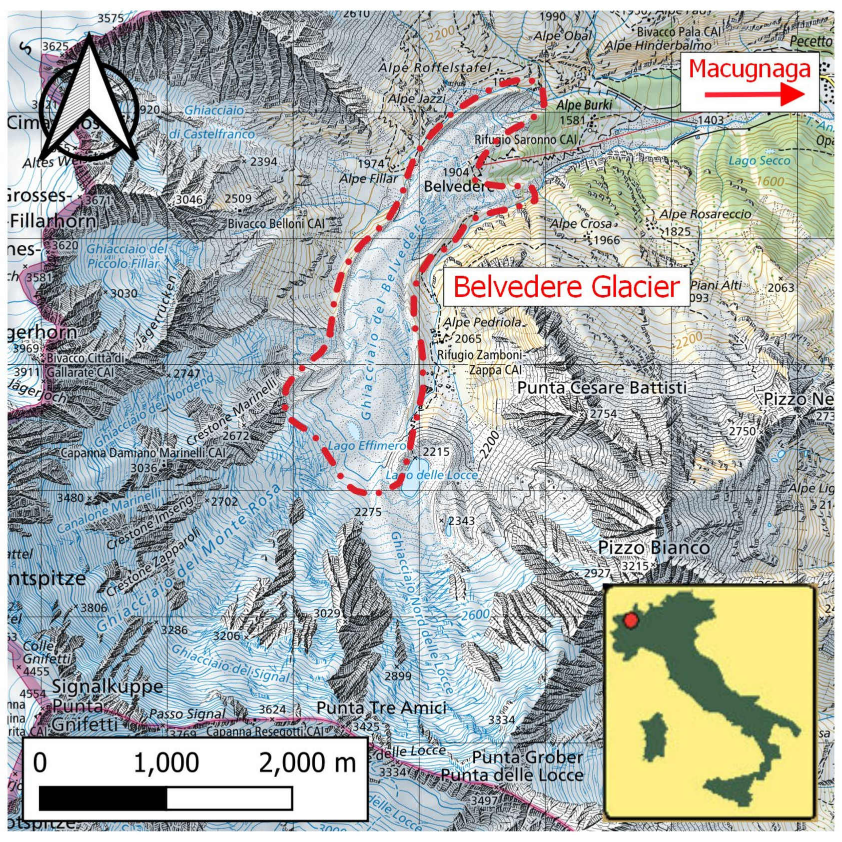

Fig. 1: Location of The Belvedere Glacier

Fig. 2: The Belvedere Glacier is a debris-covered glacier [ph. F. Ventura 2020, onthetrailsoftheglaciers.com]

Belvedere Glacier:

- Altitude range: 1800 – 2250 m a.s.l
- Glacier area 1.8 km^2
- Length: ~ 3 km
- Width: ~ 0.5 km

3 UAV-based photogrammetric surveys

- Between 2015 and 2020, yearly UAV surveys were carried out on the Belvedere Glacier.
- Low-cost cameras, mounted on-board fixed-wing UAVs and quadcopters (Fig. 3), were employed to acquire images with Ground Sample Distance (GSD) ranging between 5 and 9 cm. Overlaps between images were ~80% in along-flight direction and ~60% in transversal direction (Fig. 4).
- Main camera characteristics are listed in Tab. 1.
- At least, 24 photogrammetric targets spread over the glacier were used as Ground Control Points (GCPs), while at least 8 targets were used as Check Points (CPs).
- Every year, on average 1500 JPG images were acquired, for a total of 87.6 GB of storage memory occupied for raw data only. This value rose to ~750 GB after processing.

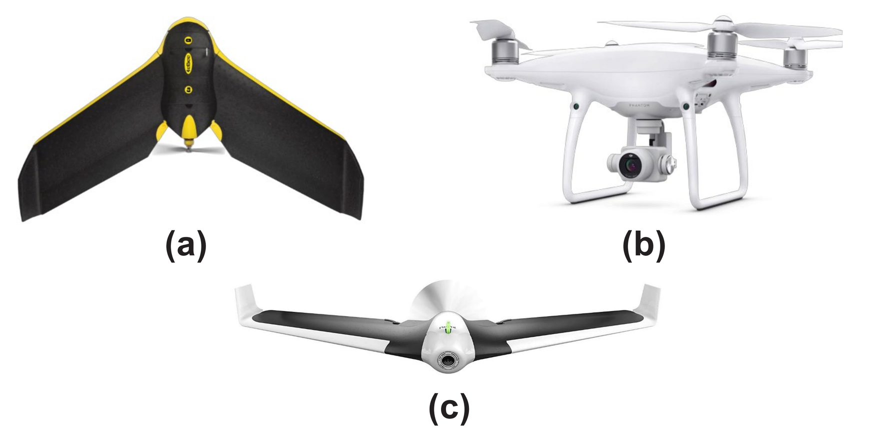

Fig. 3: UAVs and cameras employed: (a) SenseFly eBee + Canon PowerShot S110 (labelled as ***S110***) and SenseFly S.O.D.A; (***SODA***) (b) DJI Phantom 4 Pro + DJI FC6310 (***DJI***); (c) Parrot Disco + Hawkeye Firefly 8S.(***FireFly***).

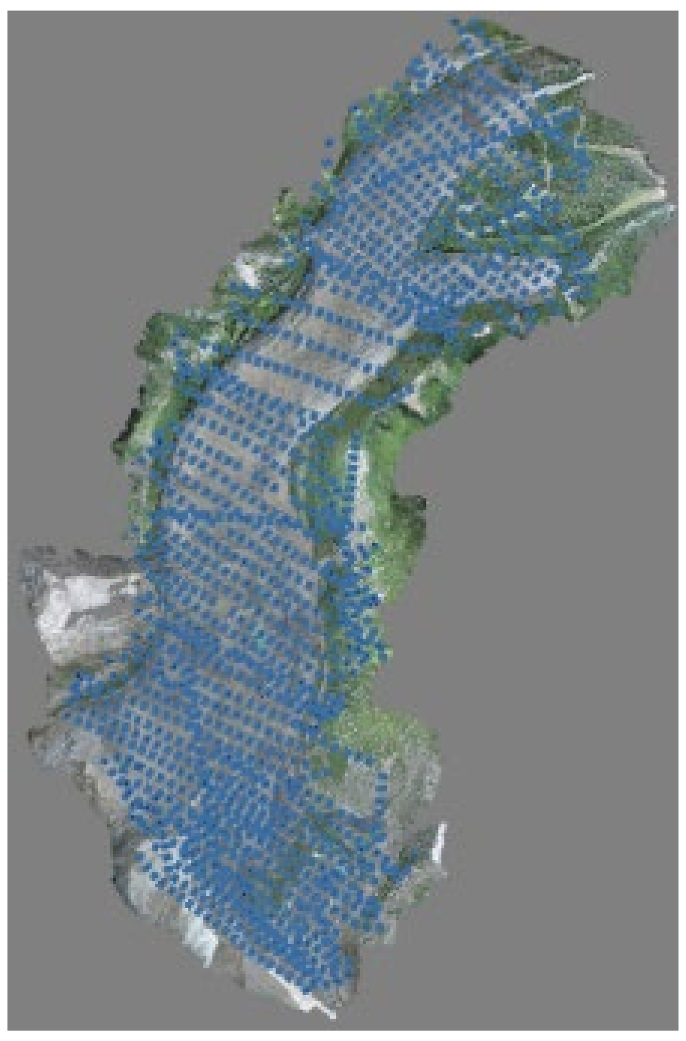

Fig. 4: Acquisition geometry for the 2019 survey. Blue rectangles represent images.

	S110	*SODA*	*DJI*	*FireFly*
Sensor	1/1.7" CMOS	1" CCD	1" CMOS	1/2.3" CMOS
Focal length [mm]	5.2	10.6	8.8	3.8
Image size [px]	4000 x 3000	5472 x 3648	5472 x 3648	5472 x 3648
Pixel size [µm]	1.9	2.4	2.4	1.34

Tab. 1: Summary of the characteristics of the cameras employed.

4 SfM data processing

Photogrammetric blocks were processed with the SfM software Agisoft Metashape, running on a parallelized cluster of servers (Fig. 6). For each year, images and GCPs coordinates were processed through aerial triangulation: dense clouds, triangulated meshes, Digital Surface Models (DSMs), orthophotos were computed. Model accuracy was assessed by CPs (Fig. 5).

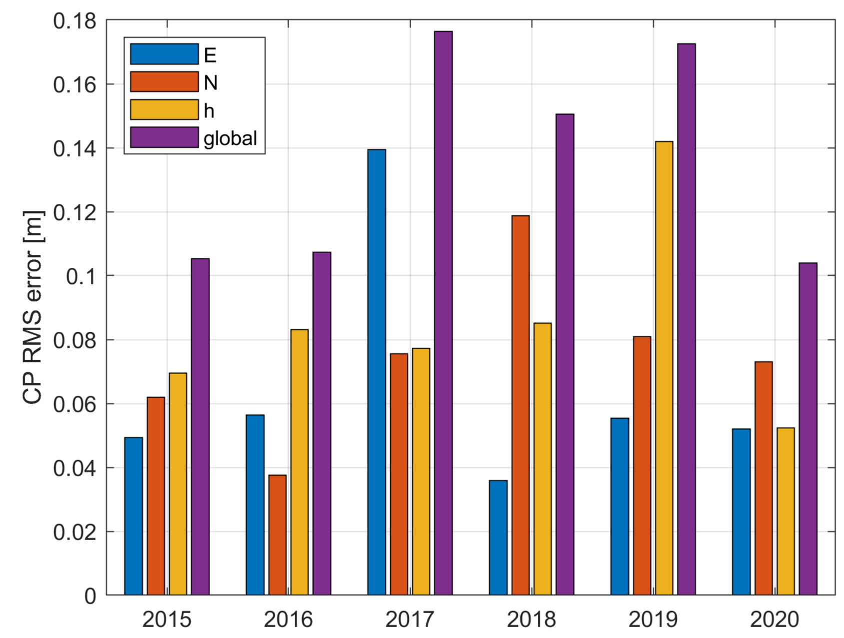

Fig. 5: Geometrical accuracy of the photogrammetric blocks computed on CPs.

Fig. 6: Metashape processing cluster was composed of 9 parallel HP ProLiant SE1102 servers, with the following characteristics:

- CPU: 2 x Intel Xeon L5420 (4 cores @ 2.5 GHz)
- RAM: 24 GB DDR2
- OS: Windows Server 2019
- Storage: network attached storage WD Black 2 TB

4 Glacier annual volume variations

Annual glacier volume variation were computed by difference of consective DSMs. Each DSM was rasterized from the photogrammetric point cloud with a resolution of 0.5 m/px (e.g., Fig. 7). Every year, a reduction of volume ranging between 2.2 and 3.2 million of m^3 was found.

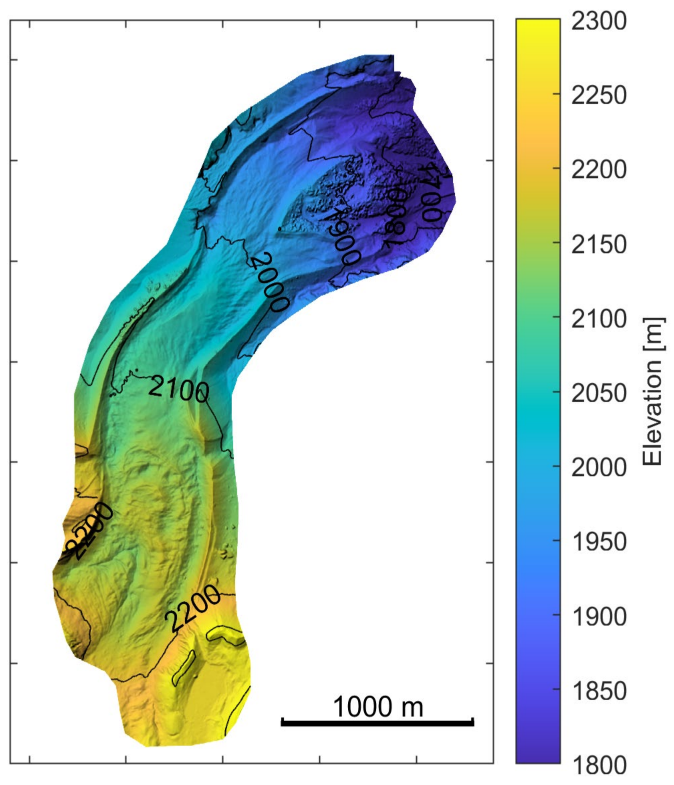

Fig. 7: DSM computed from the 2019 photogrammetric model.

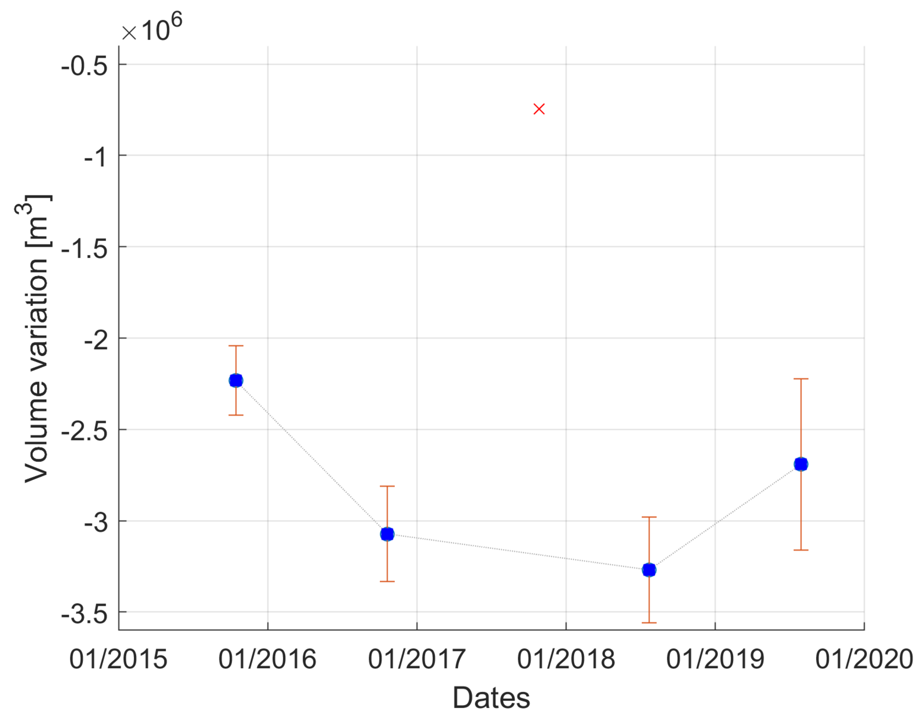

Fig. 8: Annual volume variations (note that the y-axis is expressed in million of m^3). The volume variation estimated for the year 2017-2018 was an outlier (marked with a red cross in the graph) and should not be considered.

From DSMs, elevation profiles were extracted along 4 cross-sections (Fig. 9). In the lower part of the glacier (profiles AA', BB' CC'), on average, a lessening of ~2 m/yr occurred. In the upper part (profile DD'), the less regular evolution of the glacier surface is caused by the presence of many crevasses.

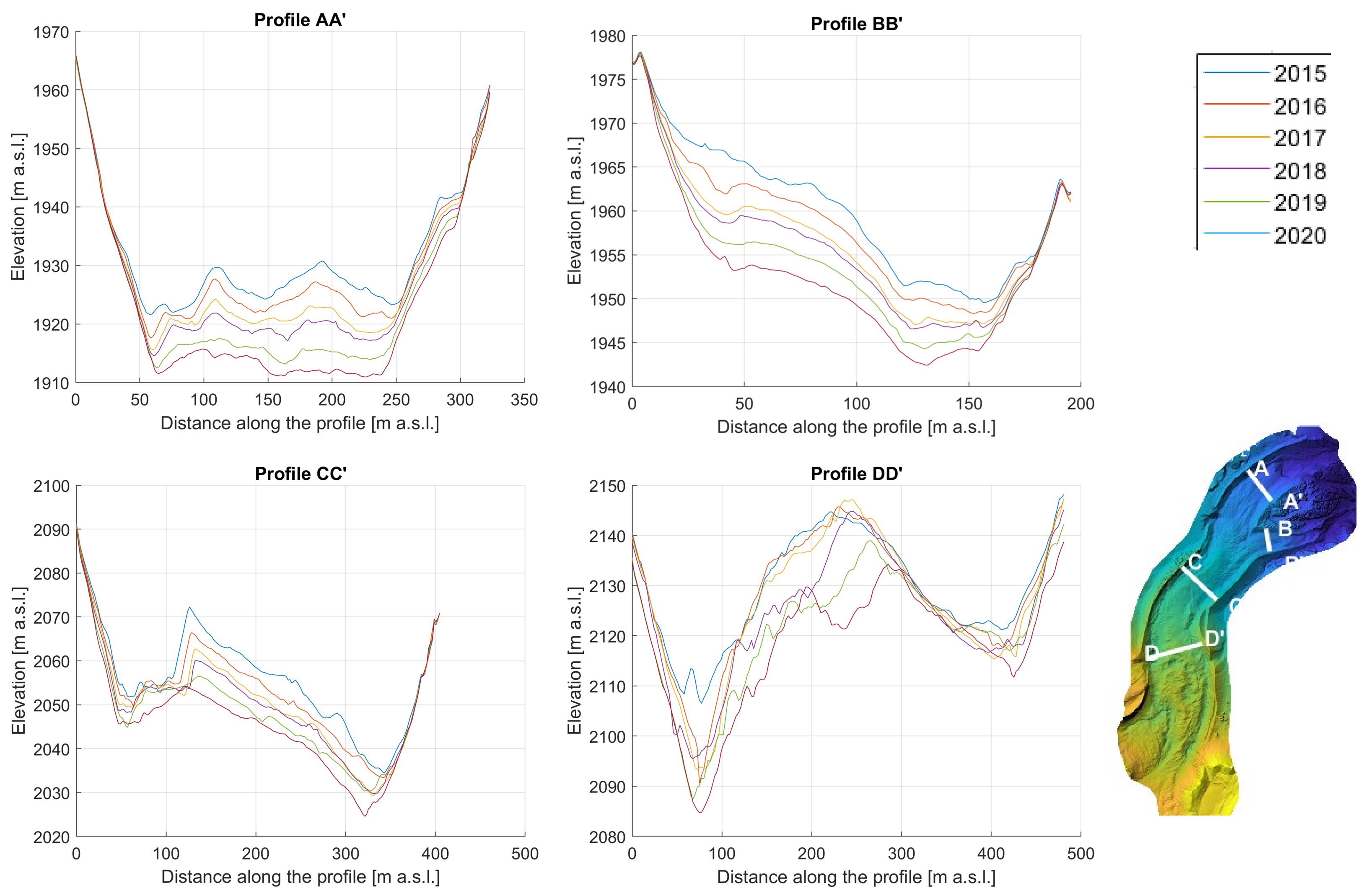

Fig. 9: Time-series of elevation profiles extracted from DSMs along 4 different cross-sections.

4 Conclusive remarks

- With this study, the evolution and the volume variation of the Belvedere Glacier during the period 2015-2020 was estimated by UAV-based photogrammetry. On average, the Belvedere Glacier experienced an annual reduction of 2.8 million of cubic meter.
- UAV-based close-range sensing allows for high geometrical resolution and accuracy, as well as for limiting potentially dangerous in-situ operations.

References

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