Rock glacier monitoring using aerial photographs: conventional vs. UAV-based mapping – a comparative study

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1. INTRODUCTION
1.1 What is a rock glacier?

Rock glaciers are creep phenomena of mountain permafrost and can be found in all high mountain areas of the Earth (Barsch, 1996). Rock glaciers are composed of rock debris and ice and are common geomorphological landforms of the periglacial environment. They must not be confused with glaciers or debris-covered glaciers. Rock glaciers move downslope by force of gravity as a result of the plastic deformation of their interstitial ice and other internal processes, such as sliding along distinct shear horizons. They thus become deformed over time, acting as prominent mass transport systems in alpine environments. From a bird's eye view rock glaciers resemble tongue or lobate shaped lava flows. Flow/creep velocities of rock glaciers are in the order of a few centimeters to several meters per year.

1.2 Motivation

In this research work we use aerial photographs taken from both manned aircraft (conventional aerial surveys) and unmanned aerial vehicles (UAVs) in order to retrieve multi-annual to intra-annual kinematic data of the fast moving Tschadinhorn rock glacier. Both historical and more recent aerial photographs (10 epochs between 1954 and 2015) were acquired from the Austrian Federal Office of Metrology and Surveying (BEV). BEV intends to repeatedly take aerial photographs of the whole territory of Austria every 3 years from 2010 onwards. In 2016 and 2017 in-house UAV overflights were carried out to fill the time gap until the next scheduled BEV survey. All of these data were processed to provide the basis of the intended monitoring of Tschadinhorn rock glacier using both multi-temporal high resolution digital orthophotos (DOPs) and digital terrain models (DTMs). Change in surface movement and surface height is determined by comparing these base data.

2. STUDY AREA

Tschadinhorn rock glacier (46°59′38″ N, 12°51′47″ E) is a fast-moving rock glacier located in the Schober Mountains, Hohe Tauern Range, East Tyrol, Austria. The study area is part of the core zone of the Hohe Tauern National Park (Figure 1). The tongue-shaped rock glacier is approx. 640 m long and 80 to 100 m wide and covers an area of approx. 5.35 hectares. It stretches between 2835 m a.s.l. (upper limit of the root zone) and 2568 m (lower end of the tongue). Its surface topography is characterized by typical flow structures, such as furrows and ridges, levees and tension cracks (Figures 2, 3). The study actually comprises two rock glaciers, i.e., Tschadinhorn rock glacier (no. is186) and another rock glacier (no. is185) which is located to the northeast. Furthermore, talus slopes exist to the south of the rock glacier (elevation range between 2675 and 2800 m), which show signs of surface deformation indicating active downward movement.

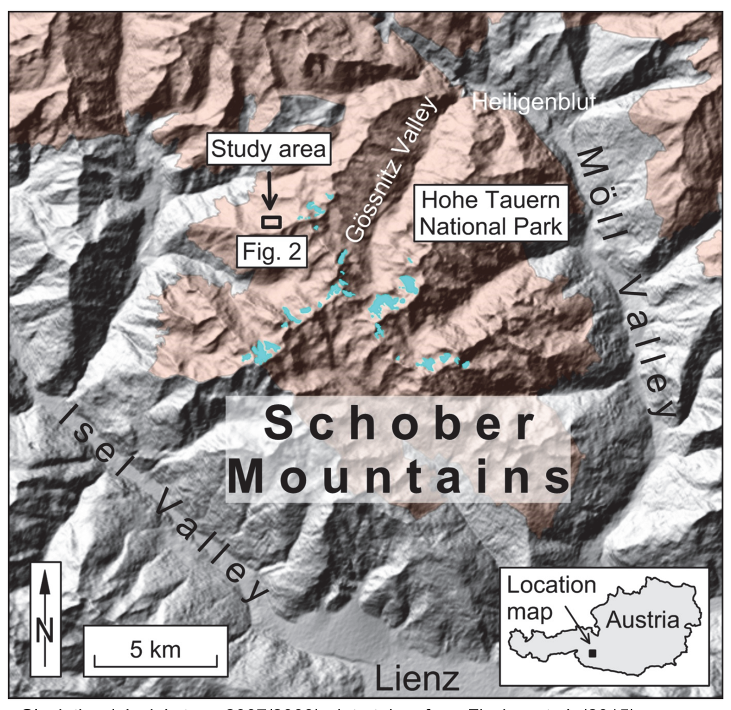


Fig. 1 Location map

Glaciation (glacial stage 2007/2009): data taken from Fischer et al. (2015)
Data source of digital terrain model: Land Tirol – data.tirol.gv.at

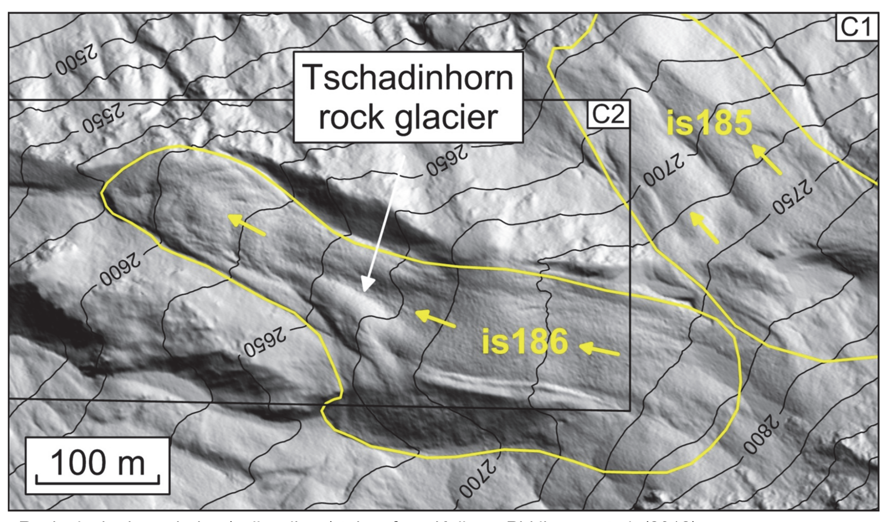


Fig. 2 Shaded relief of the study area

Rock glacier boundaries (yellow lines) taken from Kellerer-Pirklbauer et al. (2012)
Data source of ALS-based digital terrain model: Land Tirol – data.tirol.gv.at

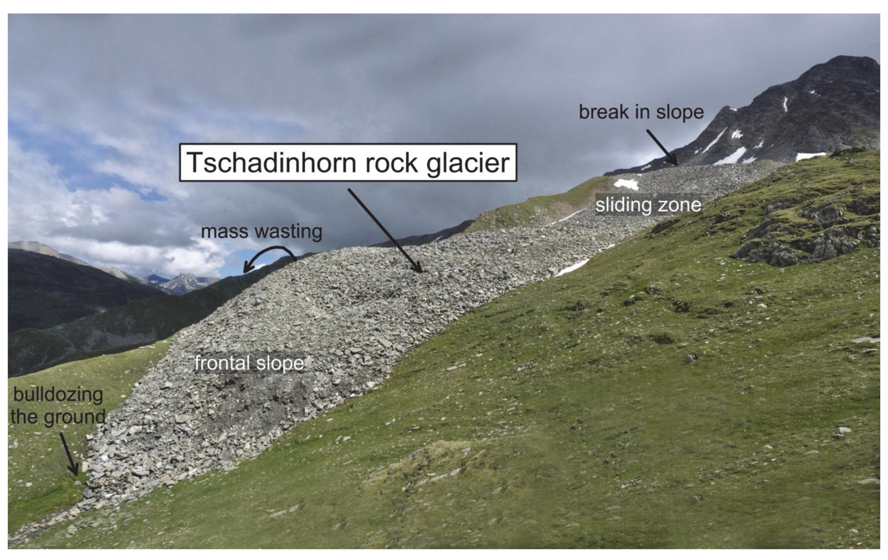


Fig. 3 Panoramic photo taken on 1.8.2014

Northeasterly viewing direction

3. DATA
3.1 Metric aerial photographs 1954-2015

Date	ΔH_g[1] (m)	Camera	Scale/GSD[4] (cm)
24.9.1954	3250	A[2] (b&w)	1:15,450/ 23
29.9.1969	4345	A (b&w)	1:28,460/ 43
6.9.1974	2080	A (b&w)	1:12,830/ 12
9.10.1981	4660	A (b&w)	1:30,400/ 46
18.9.1992	3000	A (color)	1:13,970/ 21
18.9.2002	4050	A (color)	1:13,280/ 20
21.9.2006	4630	A (color)	1:15,250/ 23
8.9.2009	4880	A (color)	1:15,970/ 24
28.8.2012	2070	D[3] (RGB,NIR)	(1:22,450)/ 13
28.8.2015	3060	D (RGB,NIR)	(1:30,560)/ 16

Tab. 1 Metric aerial surveys 1954-2015

[1] … mean flying height above ground
[2] … analog [3] … digital [4] … ground sampling distance

3.2 Non-metric aerial photographs 2016-2017

Date	UAV/ type	Camera	Number of photos	GSD (cm)
26.7.2016	hexacopter twinHEX[1] v.3.0/ r-w⁺	Ricoh GXR A12	13 (west) 4 (east) waypoint♦	4.5 4.4
22.8.2017 (survey 1)	QuestUAV[2]/ f-w	Sony ILCE-6000	68 waypoint♦	5.9
(survey 2)	DJI[3] Phantom 4/ r-w*	DJI FC330	167 waypoint♦	3.9
(survey 3)	DJI[3] Mavic Pro/ r-w	DJI FC220	890 manual♦	1.6
(survey 4)	Falcon[4] 8/ r-w	Sony NEX-5N	495 manual♦	1.6

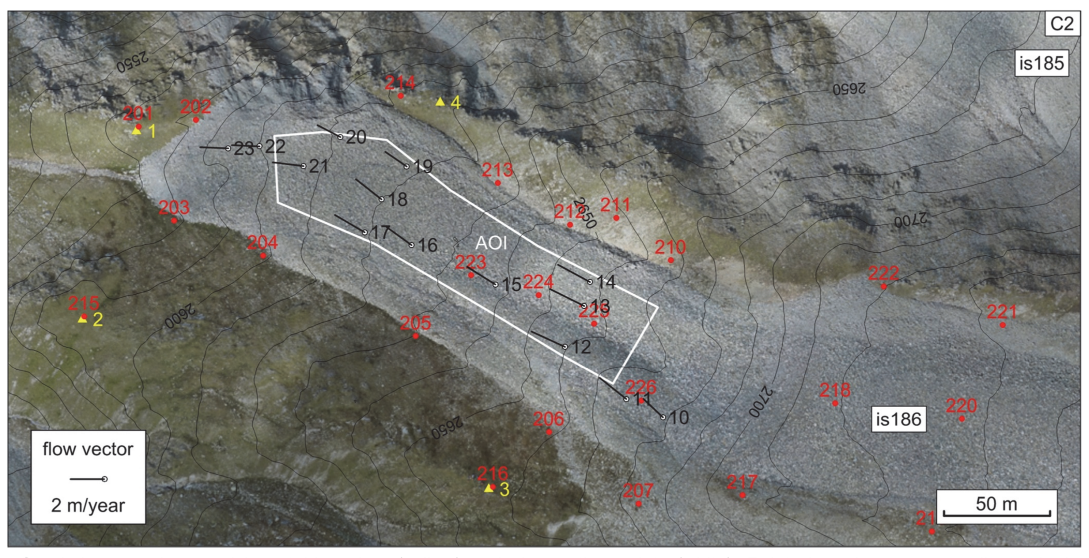
Tab. 2 UAV-based aerial surveys 2016-2017

[1] … (twinHEX, 2018) [2] … (QuestUAV, 2018) [3] … (DJI, 2018)
[4] … (ASCTEC, 2018) ⁺ … rotary-wing * … fixed-wing ♦ … flight mode

3.3 ALS data 2009

3.4 Geodetic measurements 2014-2017

In 2014 a geodetic monitoring network was set up. It consisted of 4 stable reference points located next to the rock glacier and 14 (moving) observation points on the rock glacier. Measurements have been repeated annually since then using Real-Time Kinematic (RTK) Global Navigation Satellite System (GNSS) technology.



Geodetic network comprising stable points (yellow) and observation points (white). Points in red are temporarily marked GCPs/CPs of the UAV campaign of 22.8.2017. The orthophoto shown dates from this campaign. The white polygon delineates the area of interest (AOI) considered for computing the mean annual flow velocity as needed in the velocity graph.

Fig. 4 Mean annual horizontal flow vectors for 2016-2017

4. DATA PROCESSING
4.1 Georeferencing and mapping
4.1.1 Metric aerial photographs (archive data):

Date	Grid spacing (m) of DTM	GSD (cm) of DOP	Mapping area
24.9.1954	2	10⁺, 20⁺	C1, C2
29.9.1969	3 (2⁺)	10⁺, 20⁺	C1, C2
6.9.1974	2	10⁺, 20	C1, C2
9.10.1981	3 (2⁺)	10⁺, 20⁺	C1, C2
18.9.1992	2	10⁺, 20	C1, C2
18.9.2002	2.5 (2⁺)	10⁺, 20⁺, 25	C1, C2
21.9.2006	2.5 (2⁺)	10⁺, 20⁺, 25	C1, C2
8.9.2009	1 [ALS data], 2	10⁺, 20⁺, 25	C1, C2
28.8.2012	2.5 (2⁺)	10⁺, 20	C1, C2
28.8.2015	2 (1⁺)	10⁺, 20	C1, C2
26.7.2016	0.10, 1, 2	5, 10, 20	C2 (partial)
22.8.2017 (1)	0.10, 1, 2	5, 10, 20	C2
22.8.2017 (2)	0.10, 1, 2	5, 10, 20	C2 (partial)
22.8.2017 (3)	0.10, 1, 2	5, 10, 20	C2 (partial)
22.8.2017 (4)	0.10, 1, 2	5, 10, 20	C2 (partial)

Tab. 3 DTMs and DOPs 1954-2017

⁺ … interpolated value for easier comparison of multi-temporal data

4.1.2 Non-metric aerial aerial photographs (UAV data):

Date	RMS_X (cm)	RMS_Y (cm)	RMS_Z (cm)	Reprojection error (pix)
26.7.2016 west	11 GCPs			±0.31 (tie pts.) ±0.36 (11 pts.)
	±2.2	±1.6	±7.1	
26.7.2016 east	29 (natural) GCPs			±0.26 (tie pts.) ±0.51 (29 pts.)
	±9.3	±7.7	±14.0	
22.8.2017 (1)	18 GCPs			±0.35 (tie pts.) ±0.41 (18 pts.)
	±1.8	±1.2	±2.6	
(2)	18 GCPs			±0.47 (tie pts.) ±0.40 (18 pts.)
	±3.5	±2.6	±3.2	
(3)	12 GCPs			±1.22 (tie pts.) ±0.85 (12 pts.)
	±5.9	±6.2	±6.4	
(4)	10 GCPs			±0.68 (tie pts.) ±0.45 (10 pts.)
	±1.8	±1.8	±1.3	

Tab. 4 Statistics of the aerial triangulation

4.2 Change detection
4.2.1 Horizontal movement:

Horizontal displacement can be retrieved either by tracking (1) surface texture elements of DOPs or (2) surface relief elements of DTMs.

4.2.2 Surface height (volume change):

Surface height change was computed by DTM subtracting/differencing. We selected the ALS-based DTM as a height reference to account for systematic height offsets and to validate single DTM quality.

5. RESULTS
5.1 Horizontal movement

Velocity data were computed for various time intervals using combinations of BEV-BEV, BEV-UAV, and UAV-UAV image data.

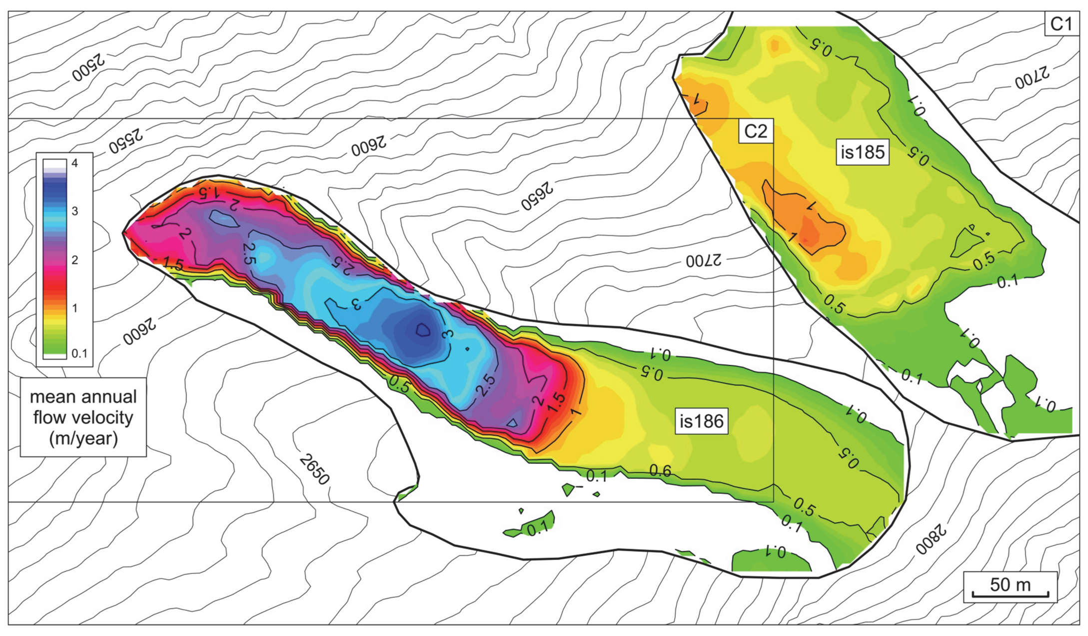


Fig. 5 Mean annual horizontal flow velocity 2012-2015
Example: BEV-BEV

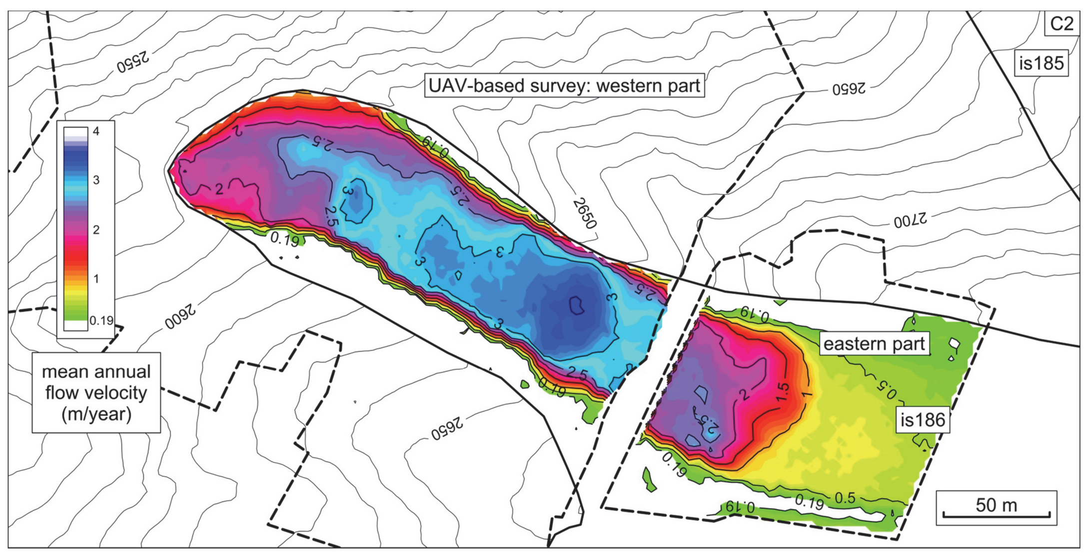


Fig. 6 Mean annual horizontal flow velocity 2015-2016
Example: BEV-UAV

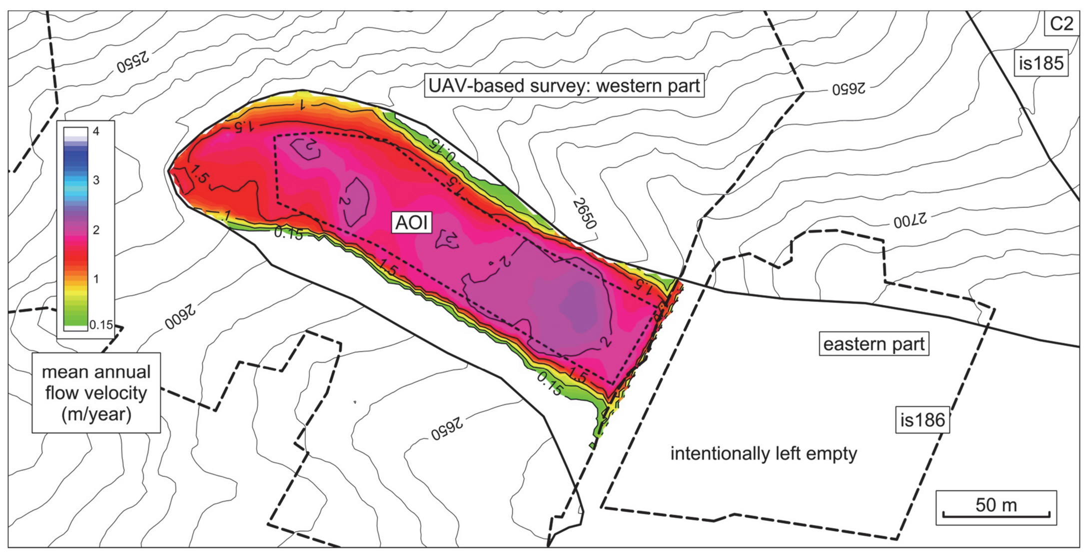


Fig. 7 Mean annual horizontal flow velocity 2016-2017
Example: UAV-UAV

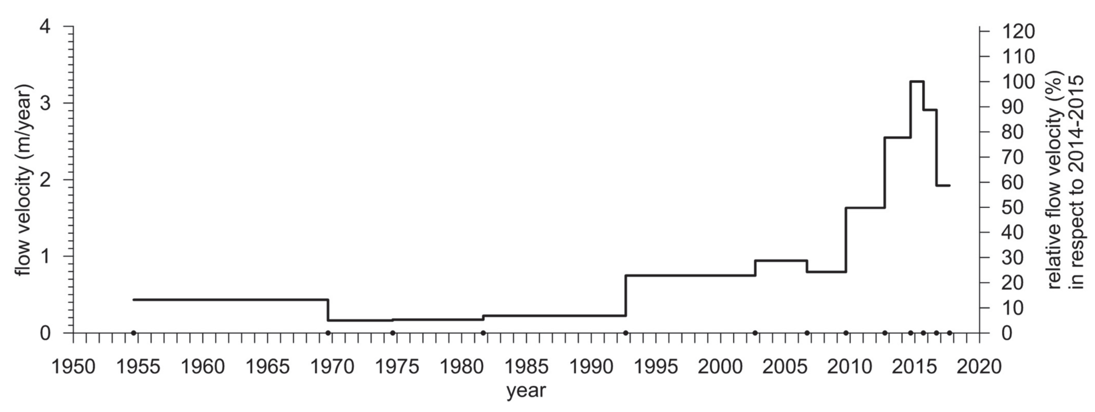


Fig. 8 Velocity graph 1954-2017 of Tschadinhorn rock glacier

5.1 Surface height (volume) change

Surface height change was analyzed for selected time intervals only .

5. DISCUSSION

The velocity graph obtained clearly shows changing movement rates over time: a maximum mean annual flow velocity of 3.282 m/year (geodetically measured) was reached in 2014-2015; a minimum value of 0.162 m/year (only 5 % of the maximum value) was calculated for the time period 1969-1974. The time period 1954-2009 was a period of generally little movement, whereas from 2009 onwards the flow velocities increased significantly.

The investigations presented in this poster have shown that UAV-based aerial surveys can fully replace manned aerial surveys (as carried out by BEV) for rock glacier monitoring given that (1) the UAV-based surveys are properly executed (high image overlap, good image quality, appropriate GSD, stable camera geometry, sufficient and accurate ground control) and also provided that (2) the monitoring/rock glacier area is limited in size and not too remote for convenient access. UAV-based fieldwork is intentionally restricted to one-day operations for reasons of cost efficiency.

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Weg ins Freie.

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