

Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

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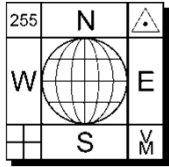
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<https://www.staff.tugraz.at/viktor.kaufmann/>

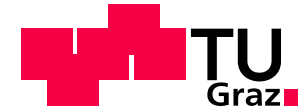


V. Kaufmann, 25.8.2016

Panorama: Tschadinhorn rock glacier, Grossglockner (3798 m) in the background

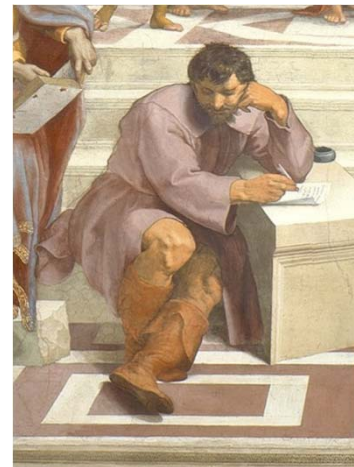


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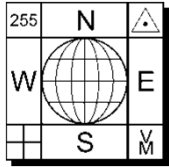


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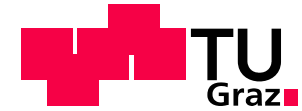
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2. Study area
3. Previous work
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5. Methods
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7. Discussion



Raphael's *School of Athens*, detail showing Raphael's portrait of Michelangelo as Heraclitus 1500s, permission PDART

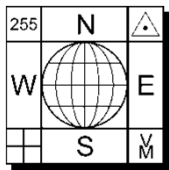


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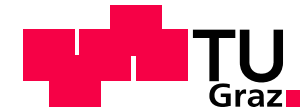


1. Introduction

- Rock glaciers are creep phenomena of mountain permafrost.
- Rock glaciers are responsible for extensive mass transport in alpine environments.
- The movement of rock glaciers is generally not constant over time but changes within different time scale.
- The main goal of this work is to reconstruct the surface movement (kinematics) of Tschadinhorn rock glacier for the time period 1954 to 2017 on a multi-annual to interannual time scale.
- The results obtained are intended to provide a basis for the investigation of climate change and more in-depth morphological studies.
- Different measurement techniques of surface movement exist.
- Repeat aerial surveys
 - Archive data from the Austrian Federal Office of Metrology and Surveying (BEV)
 - UAV-based data

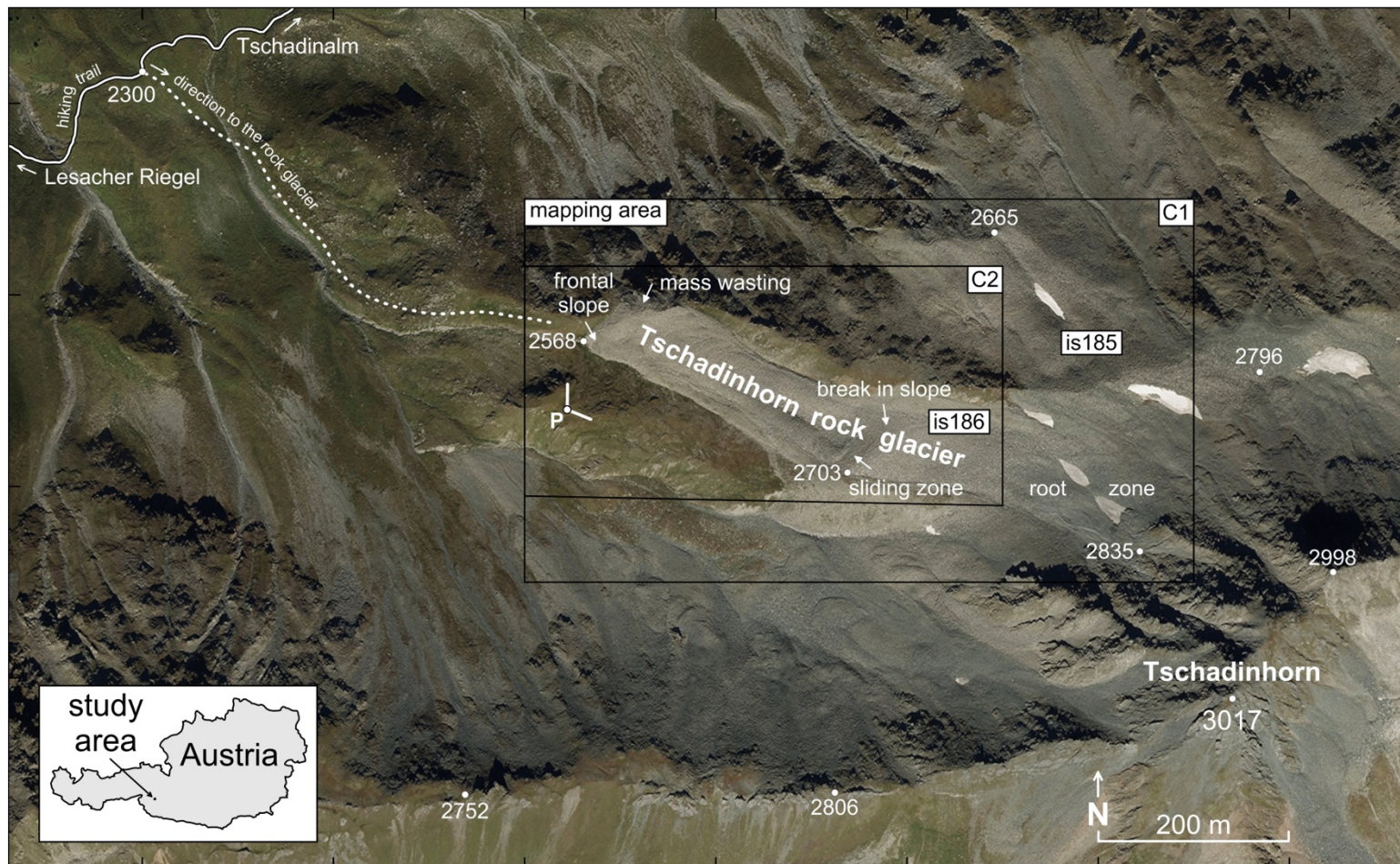


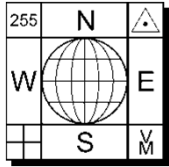
Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017 2. Study area



Schober Mountains, Hohe Tauern NP

Orthophoto, 28.8.2015
 © BEV & Land Tirol



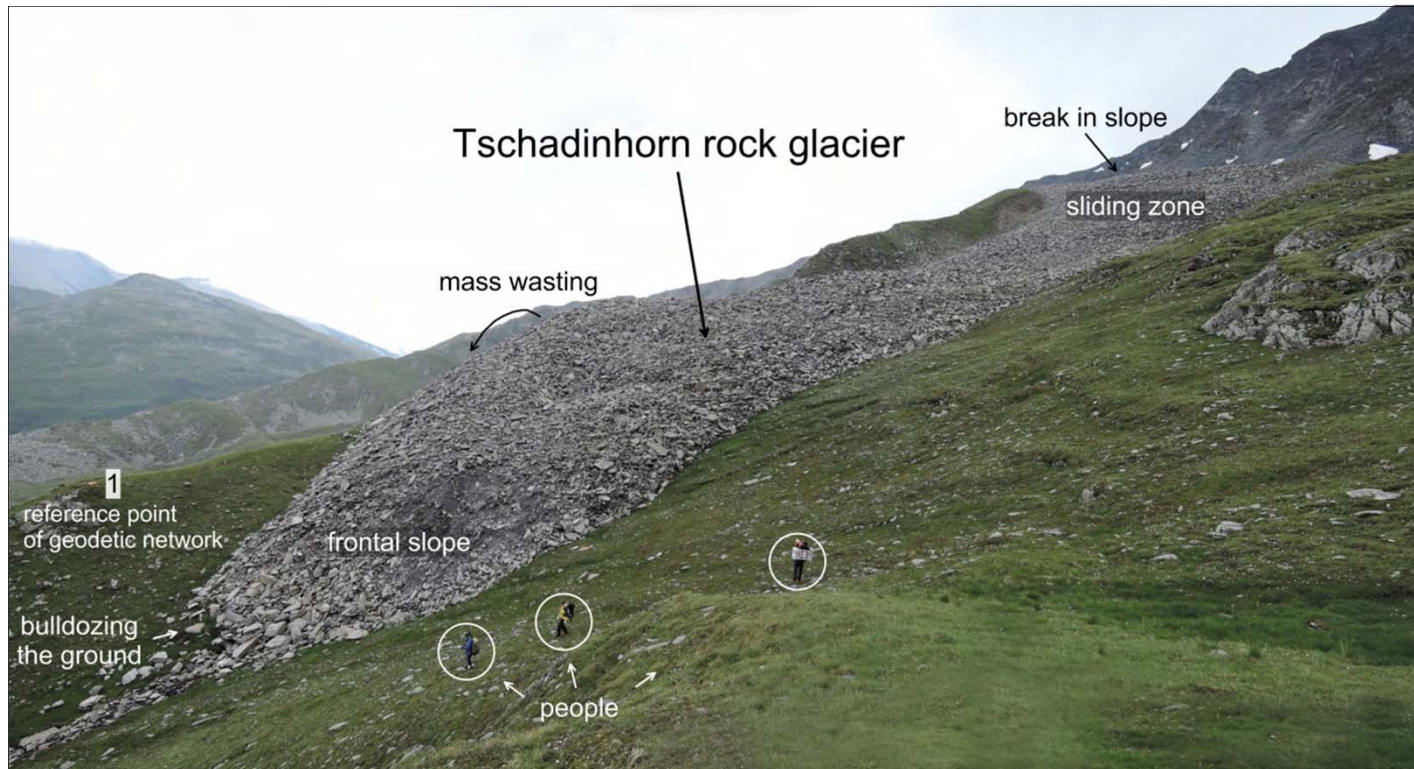


Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

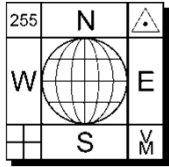
2. Study area



Tschadinhorn rock glacier



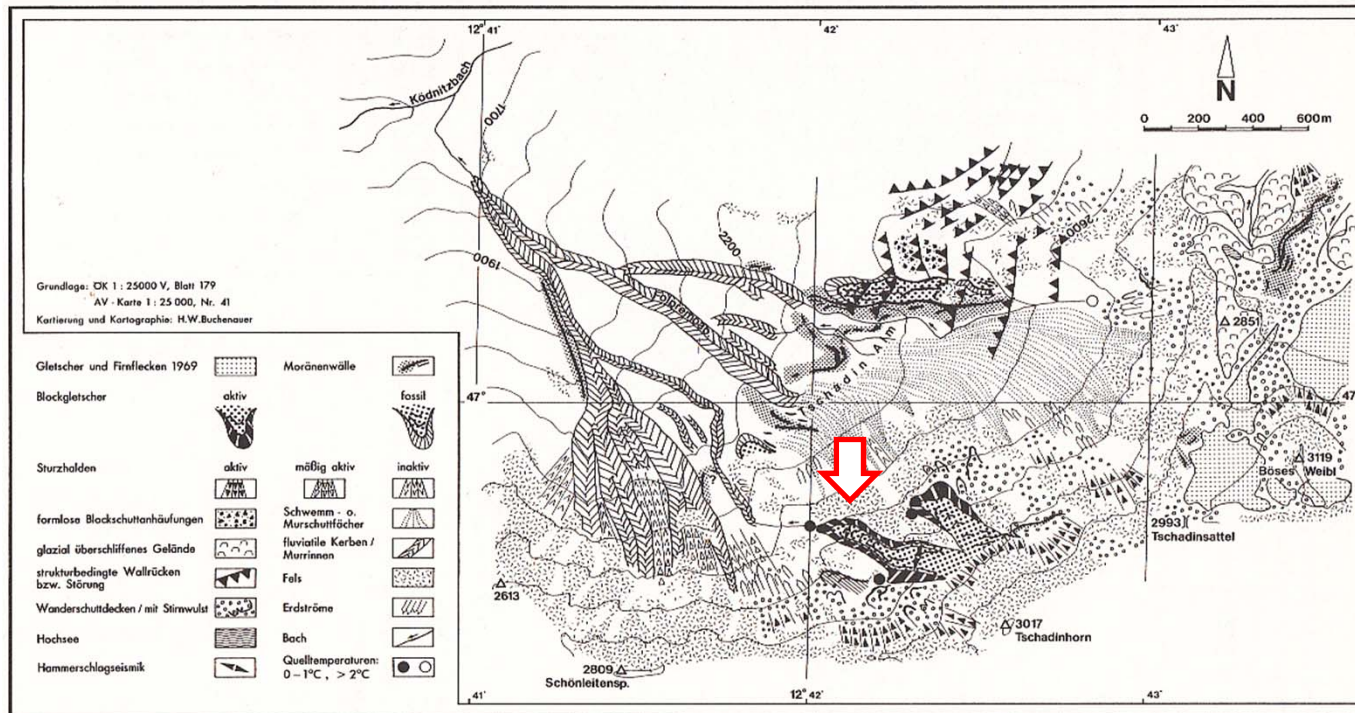
Panoramic photo taken on 31.8.2015 by V. Kaufmann.



Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017 3. Previous work

First permafrost studies

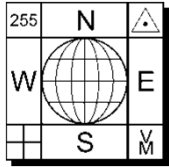
by Buchenauer (1990)



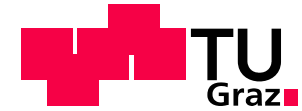
Source: Buchenauer (1990: p. 207)

Measurement of flow velocity

by Kaufmann (2010) using Google Maps and Microsoft Bing Maps,
by Kaufmann and Kellerer-Pirklbauer (2015) using governmental GIS data, and
by Filwarney and Wisiol (2012) and Mikl (2015) using original aerial photographs.



Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

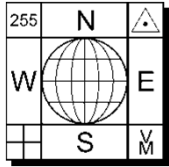


4. Data

Metric aerial photographs 1954-2015

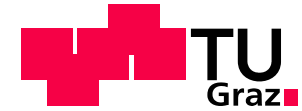
Date	Flying height above ground (m)	Camera type	Scale/ GSD* (cm)	Remark
24.9.1954	3250	analog	1:15,450/ 23	b&w, fresh snow cover
29.9.1969	4345	analog	1:28,460/ 43	b&w
6.9.1974	2080	analog	1:12,830/ 12	b&w
9.10.1981	4660	analog	1:30,400/ 46	b&w
18.9.1992	3000	analog	1:13,97/ 21	false color IR
18.9.2002	4050	analog	1:13,280/ 20	color
21.9.2006	4630	analog	1:15,250/ 23	color
8.9.2009	4880	analog	1:15.970/ 24	color
28.8.2012	2070	digital	(1:22,450)/ 13	R,G,B, NIR
28.8.2015	3060	digital	(1:30,560)/ 16	R,G,B, NIR

* ... ground sampling distance



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4. Data



Non-metric aerial photographs 2016 and 2017

Date	UAS/UAV	Type	Number of photographs ⁺	Digital camera	GSD* (cm)
26.7.2016	hexacopter twinHEX v.3.0	rotary-wing	13 (western part) 4 (eastern part)	Ricoh GXR A12	4.5 4.4
22.8.2017	QuestUAV	fixed-wing	68	Sony ILCE-6000	5.1

⁺ ... used in the photogrammetric mapping

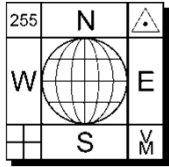
^{*} ... ground sampling distance



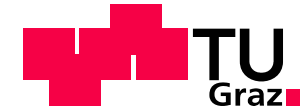
Aerial survey 2016



Aerial survey 2017



Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017 4. Data



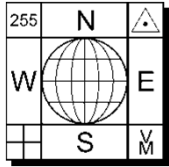
Geodetic measurements 2016 and 2017

Date	Number of points of the geodetic network		Number of additional points	
	on the rock glacier	outside the rock glacier	on the rock glacier	outside the rock glacier
27.7.2016	14	1	3	12
25.8.2016	14	4	-	-
22.8.2017	14	3	6	18

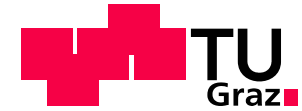
Additional geodetic measurements from 2014 and 2015.



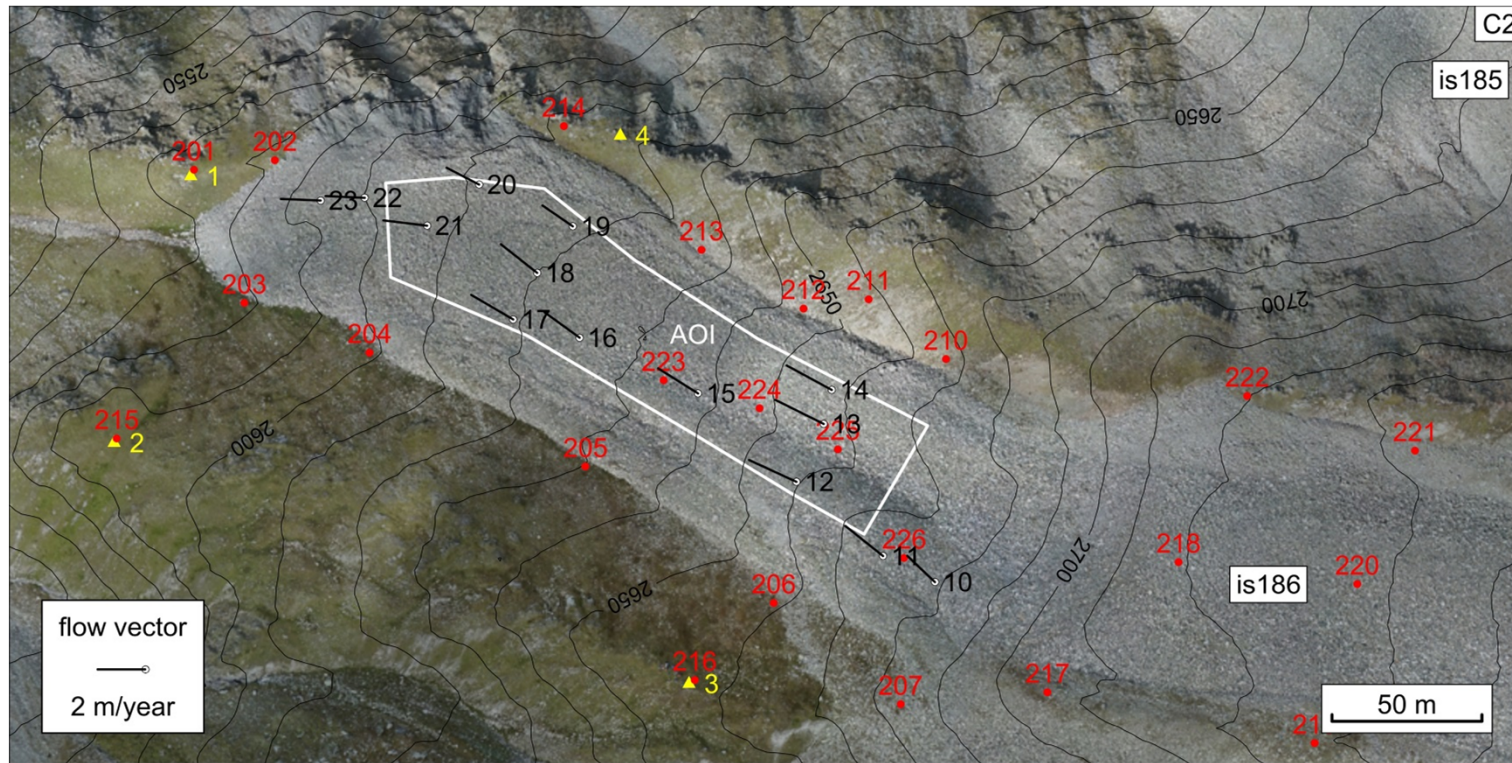
Measurement of a GCP using RTK-GNSS.
Photo taken on 27.7.2016 by G. Seier.



Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017 4. Data

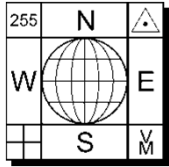


Flow vectors for 2016-2017



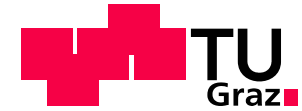
UAV-based orthophoto, 28.8.2017

yellow points:	geodetic network, stable points
white points:	geodetic network, moving points
red points:	temporarily marked ground control/check points of 28.8.2017

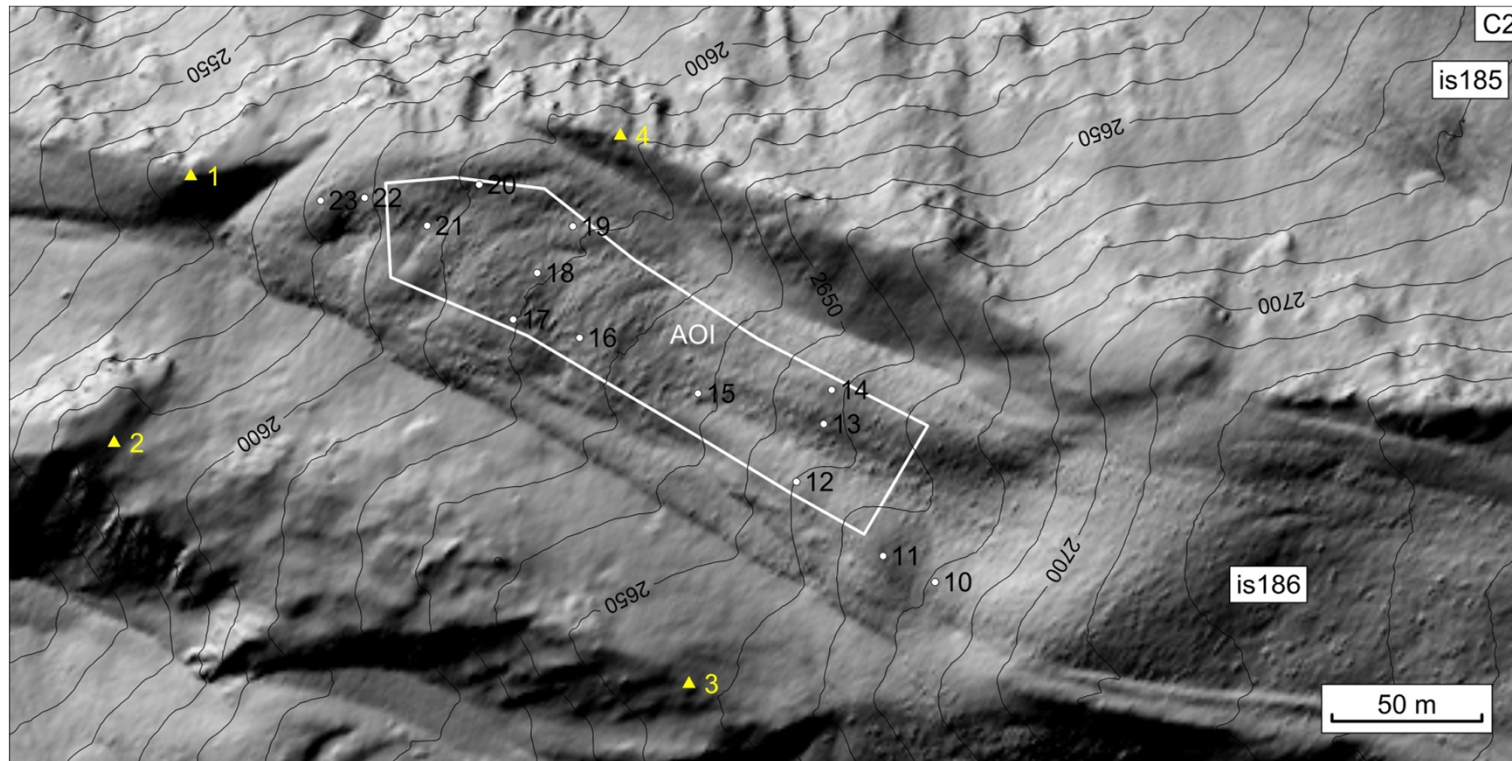


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4. Data



ALS data 2009



DSM, grid spacing: 1 m, 8.9.2009

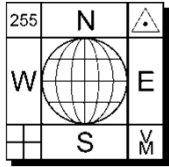
© TIRIS, Land Tirol

yellow points:

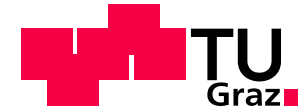
geodetic network, stable points

white points:

geodetic network, moving points

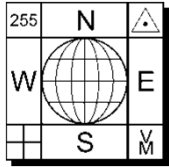


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- ## 5. Methods

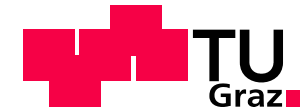


Measurement of flow velocity

- Orthophoto-based measurement
 - Metric data: ImageStation of Intergraph (orthophotos, DTMs)
 - UAV-based data: Agisoft PhotoScan applying SfM (orthophotos, DTMs)
 - Image matching (normalized cross-correlation coefficient)
 - Matlab-based toolbox
- DTM-based measurement
 - Height field matching (normalized cross-correlation coefficient)
- Velocity graph
 - Absolute/relative flow velocity



Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017



6. Results

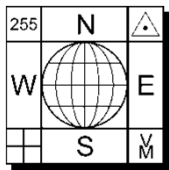
Horizontal movement

Time interval	Number of years	Precision ⁺ of velocity data (cm/year)	Maximum flow velocity (cm/year)	Mapping area (coverage)
1954 - 1969	15.014	±1.9	59.5	C1 (few points)
1969 - 1974	4.936	±4.5	38.0	C1
1974 - 1981	7.091	±3.0	27.9	C1
1981 - 1992	10.943	±2.2	35.6	C1
1992 - 2002	9.999	±2.2	101.7	C1
2002 - 2006	4.008	±2.3	119.6	C1
2006 - 2009	2.965	±2.9	106.4	C1
2009 - 2012	2.971	±3.1	199.0	C1
2012 - 2015	2.998	±3.2	353.3	C1
2015 - 2016	0.912	±6.2 (west), ±12.0 (east [#])	355.6 (west), 282.9 (east [#])	C2 (2 parts)
2016 - 2017	1.073	±5.0 (west)	230.0 (west)	C2 (western part)
2016 - 2017*	1.073	±10.9	227.5	C2 (both parts)
2009 - 2016*	6.932	±3.3	-	C2 (few points)
2009 - 2017*	8.005	±2.6	-	C2 (few points)

⁺ ... standard deviation (SD, 1 σ)

^{*} ... DTM-based solution

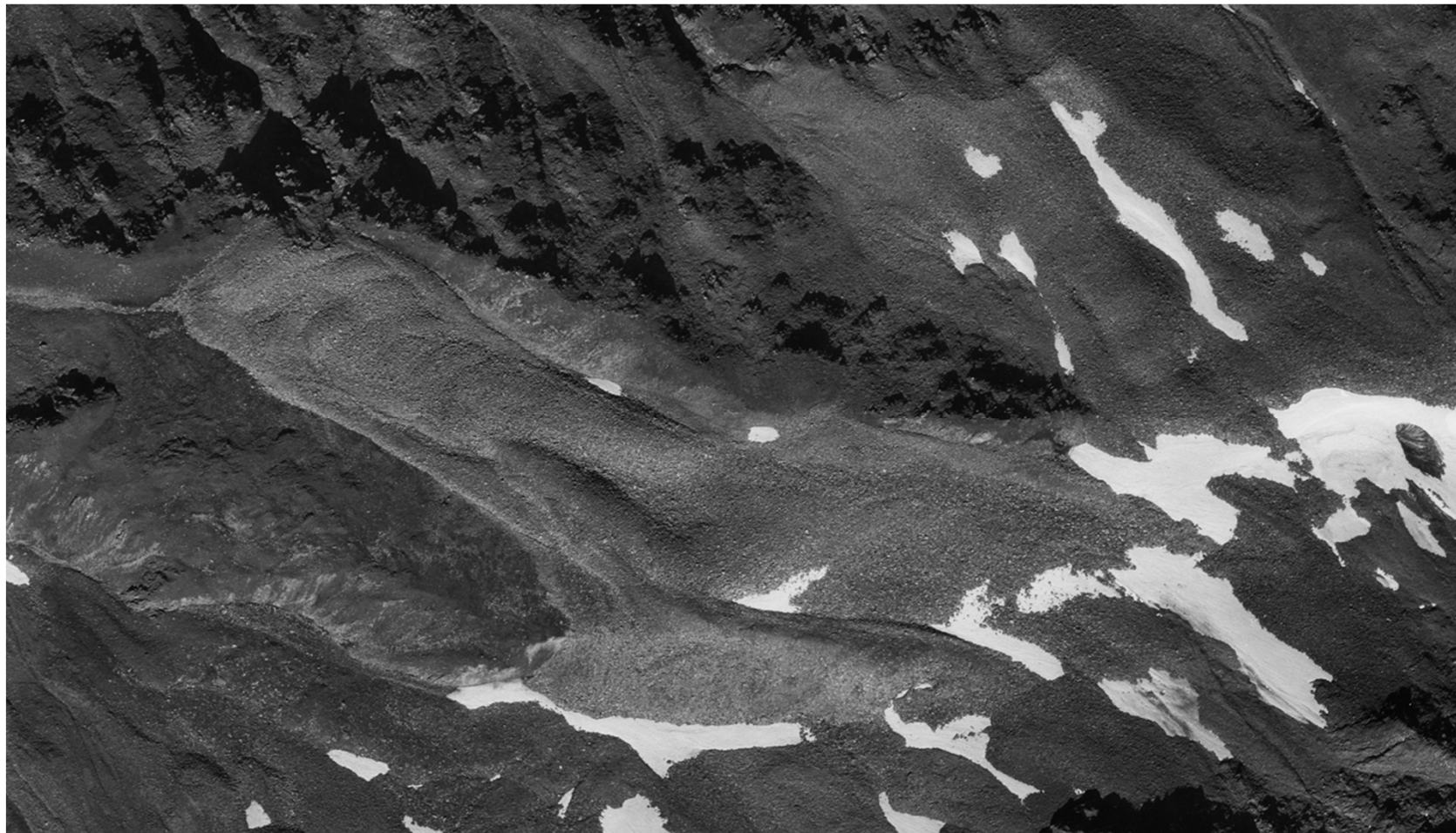
[#] ... The eastern part was georeferenced using landmarks measured in the stereomodels of 2015.



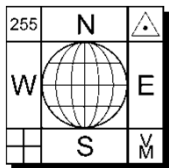
- Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017
- ## 6. Results



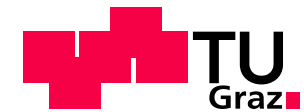
Time-lapse aerial photography 1974-2015



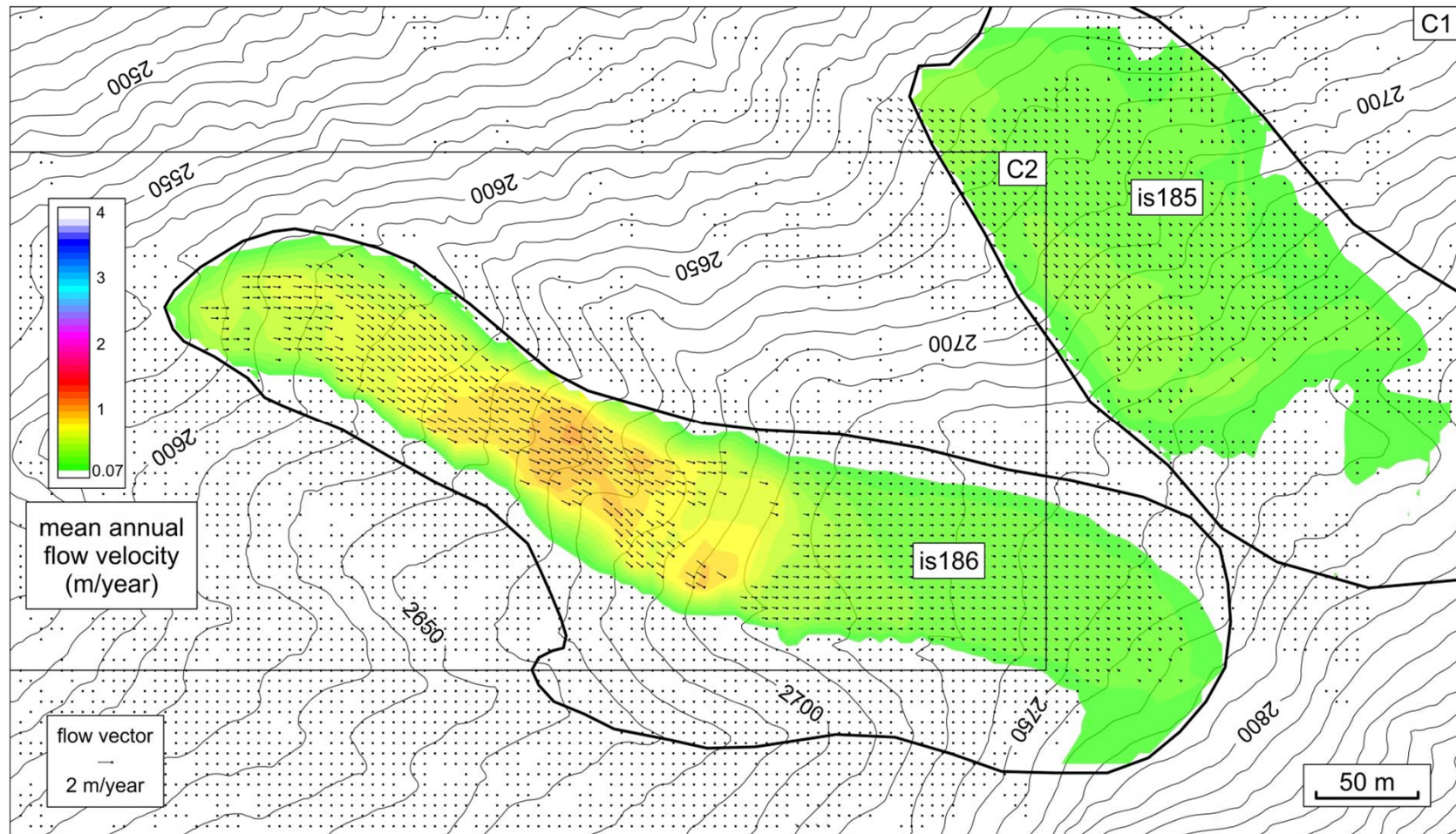
Epochs: 1974-1992-2002-2009-2012-2015
GSD: 25 cm



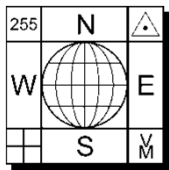
Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017 6. Results



Mean annual horizontal flow velocity 1992-2002

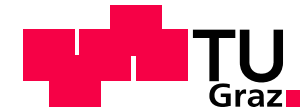


Significance level at 3σ

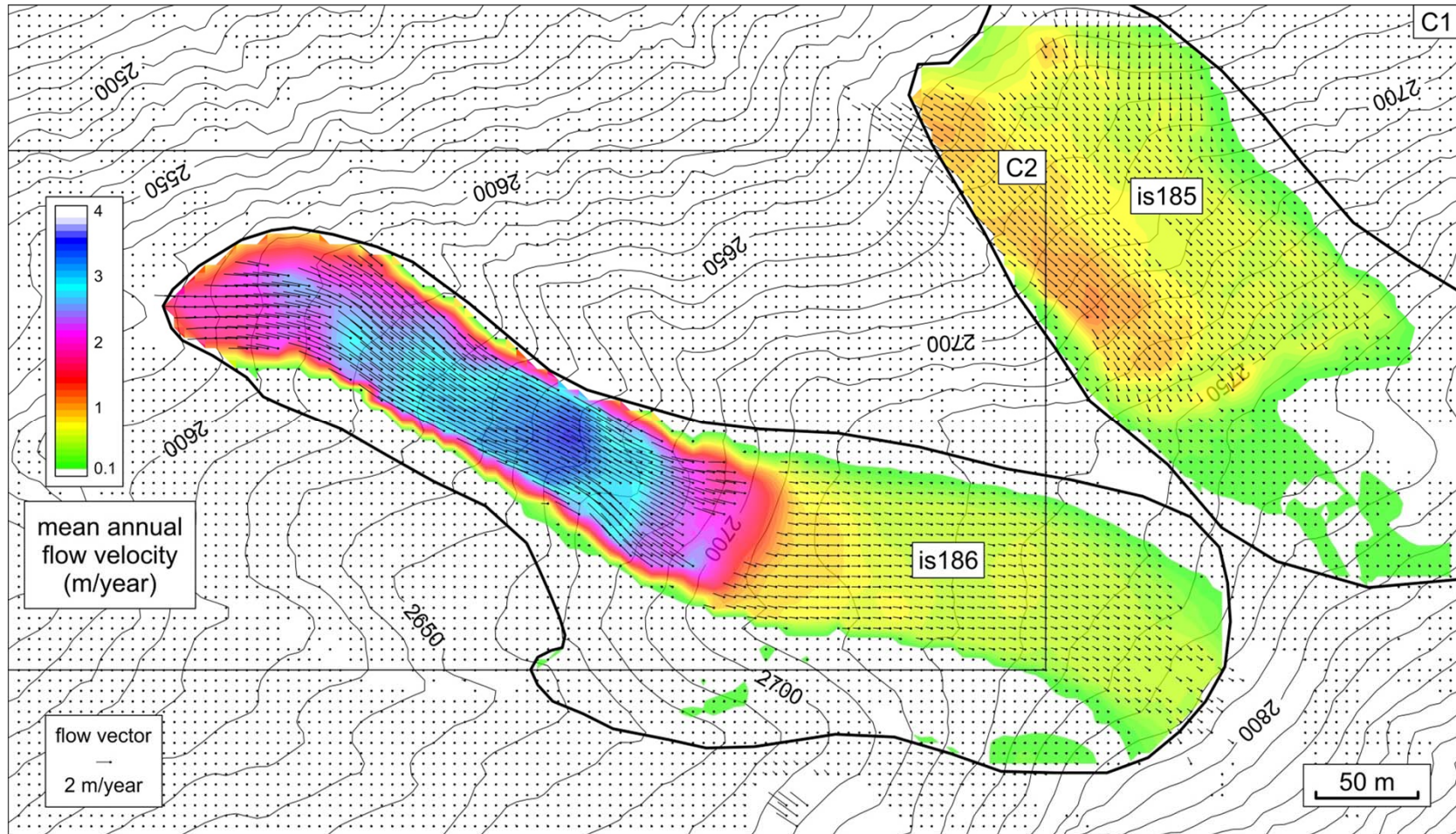


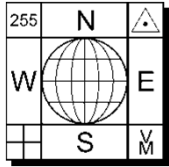
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6. Results



Mean annual horizontal flow velocity 2012-2015



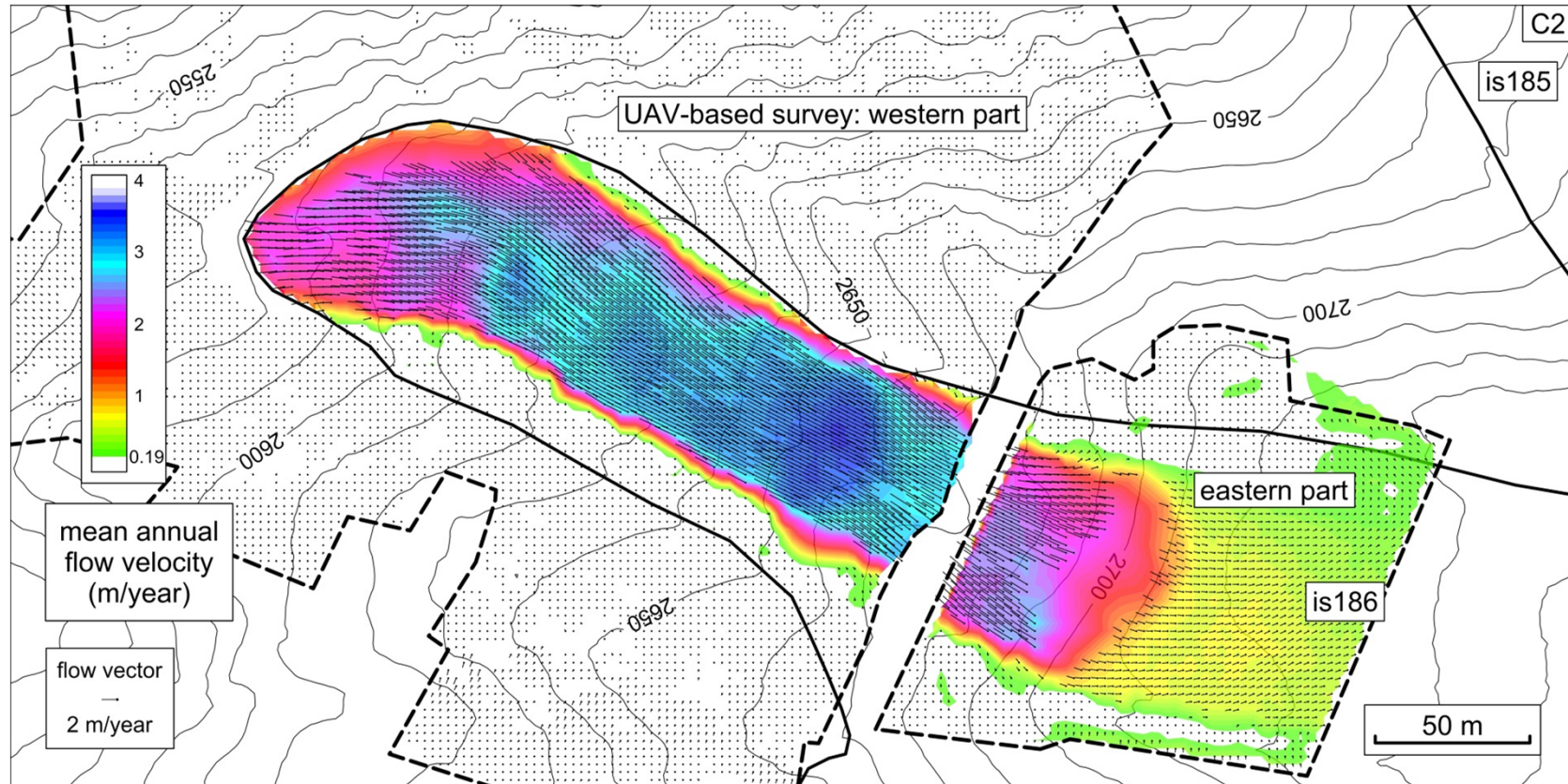


Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

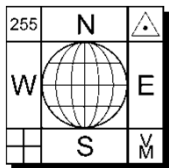
6. Results



Mean annual horizontal flow velocity 2015-2016



Significance level at 3σ (valid for the western part)

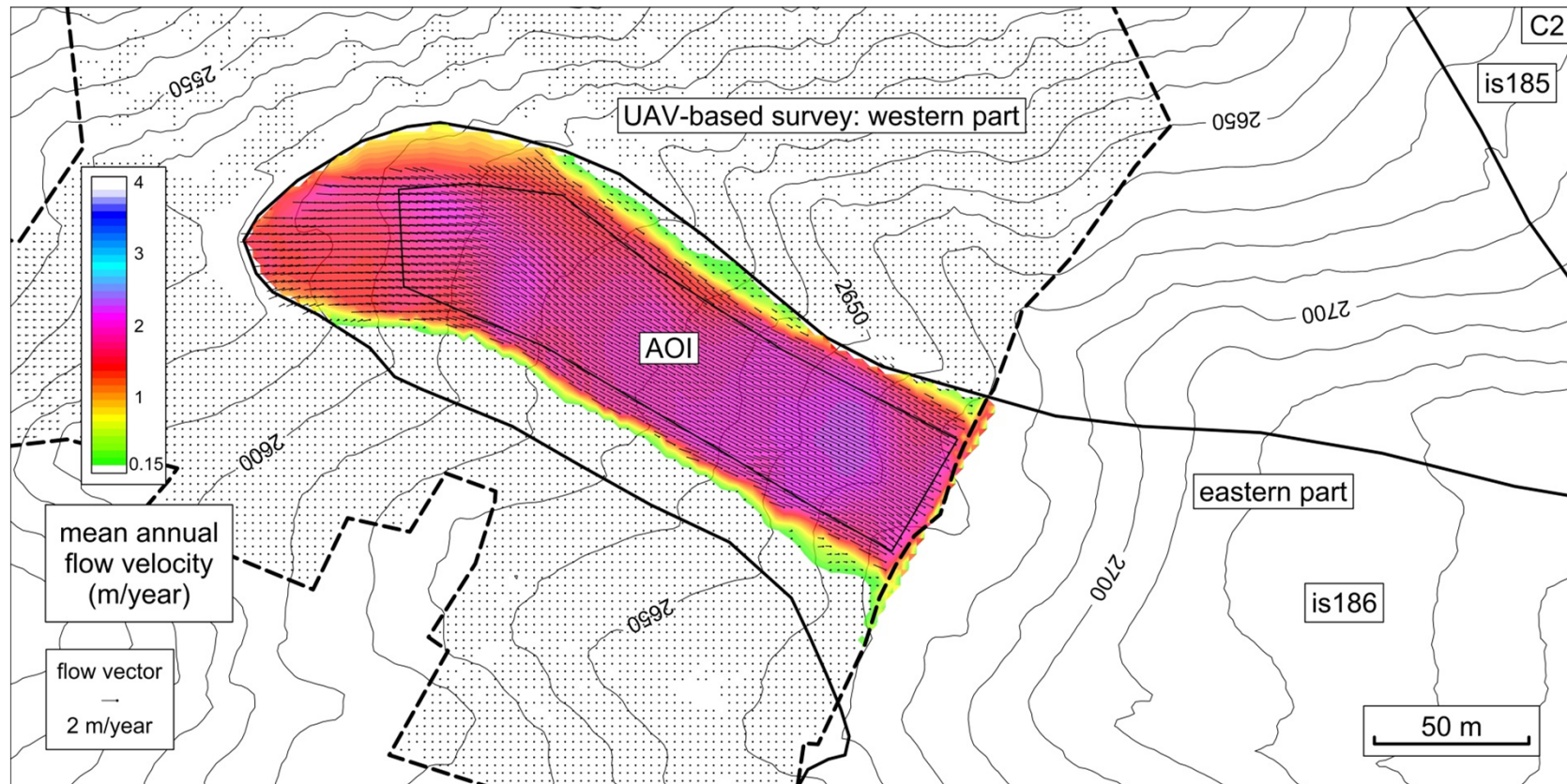


• Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

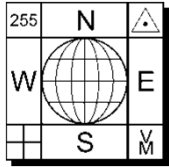
6. Results



Mean annual horizontal flow velocity 2016-2017



Significance level at 3σ (valid for the western part)
(UAV-based aerial surveys only)



- Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

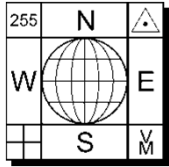
6. Results

Accuracy of the UAV-based velocity data

Time interval	Accuracy ⁺ (m/year) of DOP-based flow velocity	Number of geodetic points used for accuracy analysis
28.8.2015 - 26.7.2016	± 0.047	12
28.8.2015 - 22.8.2017	± 0.032	14
26.7.2016 - 22.8.2017	$\pm 0.051 / \pm 0.028^*$	12/ 13

⁺ ... root mean square error (RMSE)

^{*} ... DTM-based flow velocity



- Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

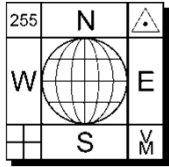
6. Results

Height accuracies of selected multi-temporal DTMs

Date	Height accuracy ⁺ (m) of DTM
24.9.1954	±0.42
6.9.1974	±0.17
18.9.1992	±0.16
8.9.2009	height reference (ALS data)
28.8.2015	±0.12
26.7.2016	±0.09/ ±0.09* (30 points)
22.8.2017	±0.07/ ±0.06* (42 points)

⁺ ... standard deviation (SD, 1 σ)

^{*} ... value derived from known geodetic points

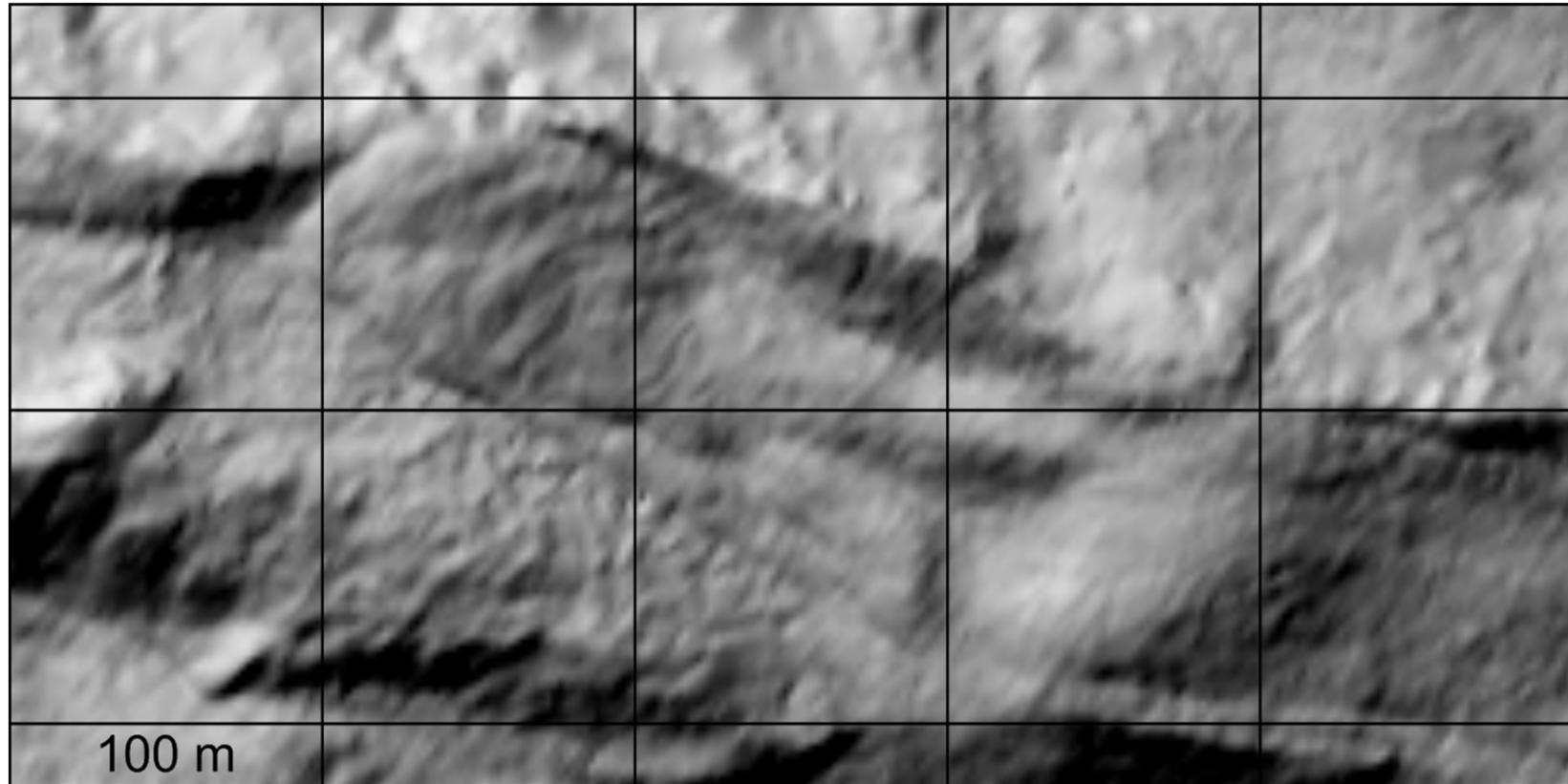


- Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017



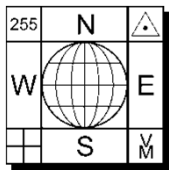
6. Results

Time-lapse relief change 1954-2017

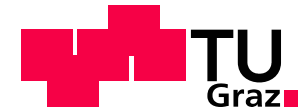


Epochs: 1954-1974-1992-2002-2006-2009-2012-2015-2017

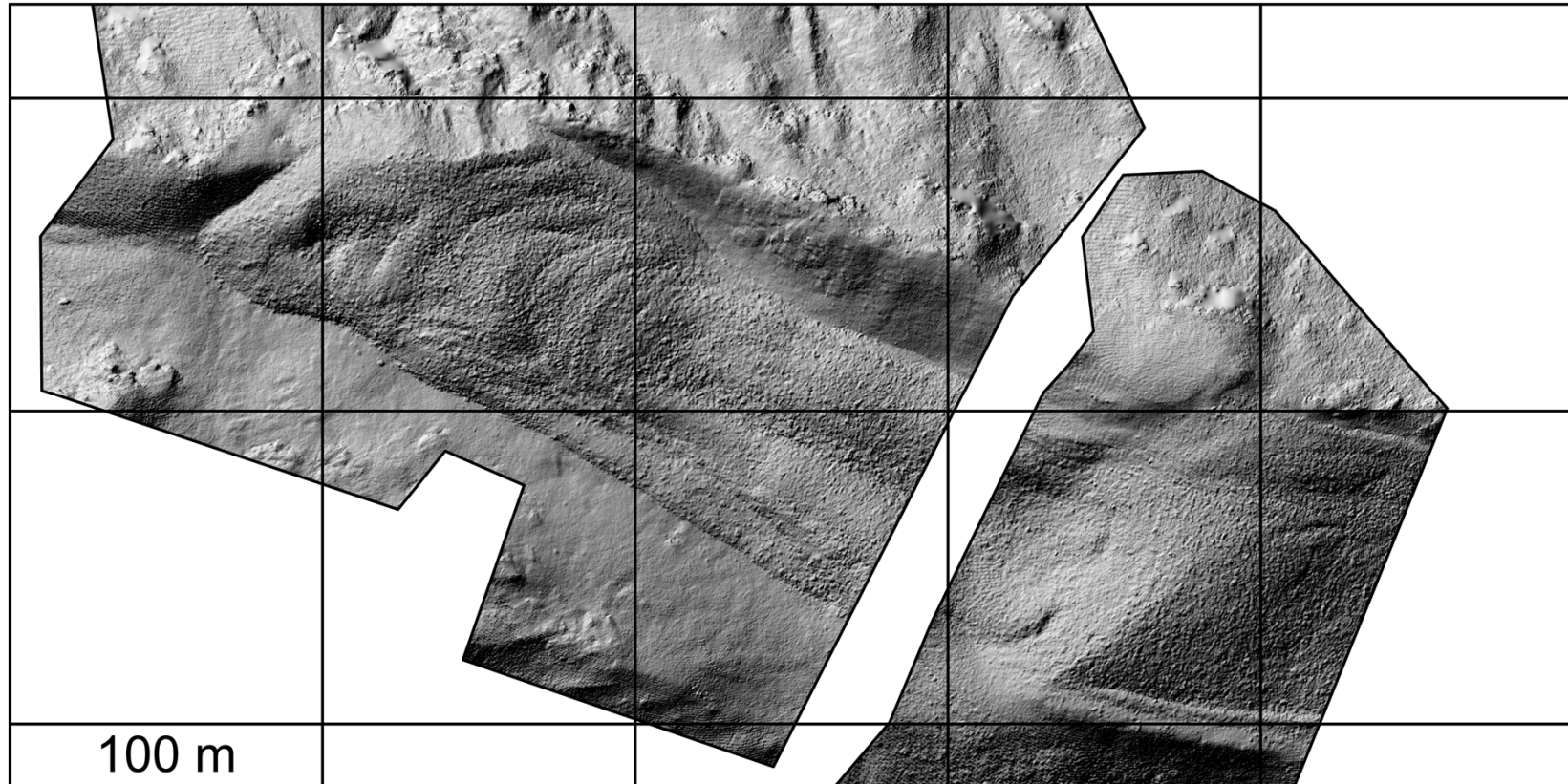
Grid spacing of DTM : 2 m



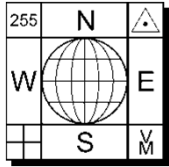
- Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017
- ## 6. Results



Time-lapse relief change 2016-2017

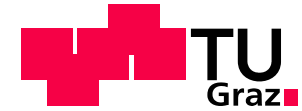


Epochs: 2016 and 2017 (UAV-based aerial surveys only)
Grid spacing of DTM: 20 cm



• Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

6. Results



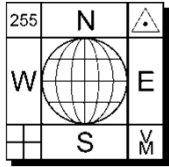
Numerical values of the velocity graph 1954-2017

Time interval	Mean annual horizontal flow velocity ⁺ (m/year)	Relative value (%) in respect to 2014-2015
24.9.1954 - 29.9.1969	0.433	13.18
29.9.1969 - 6.9.1974	0.162	4.95
6.9.1974 - 9.10.1981	0.175	5.32
9.10.1981 - 18.9.1992	0.224	6.83
18.9.1992 - 18.9.2002	0.749	22.82
18.9.2002 - 21.9.2006	0.941	28.68
21.9. 2006 - 8.9.2009	0.794	24.20
8.9.2009 - 28.8.2012	1.631	49.71
28.8.2012 - 2.8.2014	2.550 [#]	77.72
2.8.2014 - 28.8.2015	3.282 [*]	100.00
28.8.2015 - 26.7.2016	2.911	88.72
26.7.2016 - 22.8.2017	1.925	58.65

⁺ ... area average referring to AOI

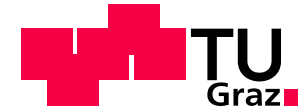
^{*} ... RTK-GNSS measurements scaled to AOI

[#] ... value derived from velocity data 2012-2015 and 2014-2015

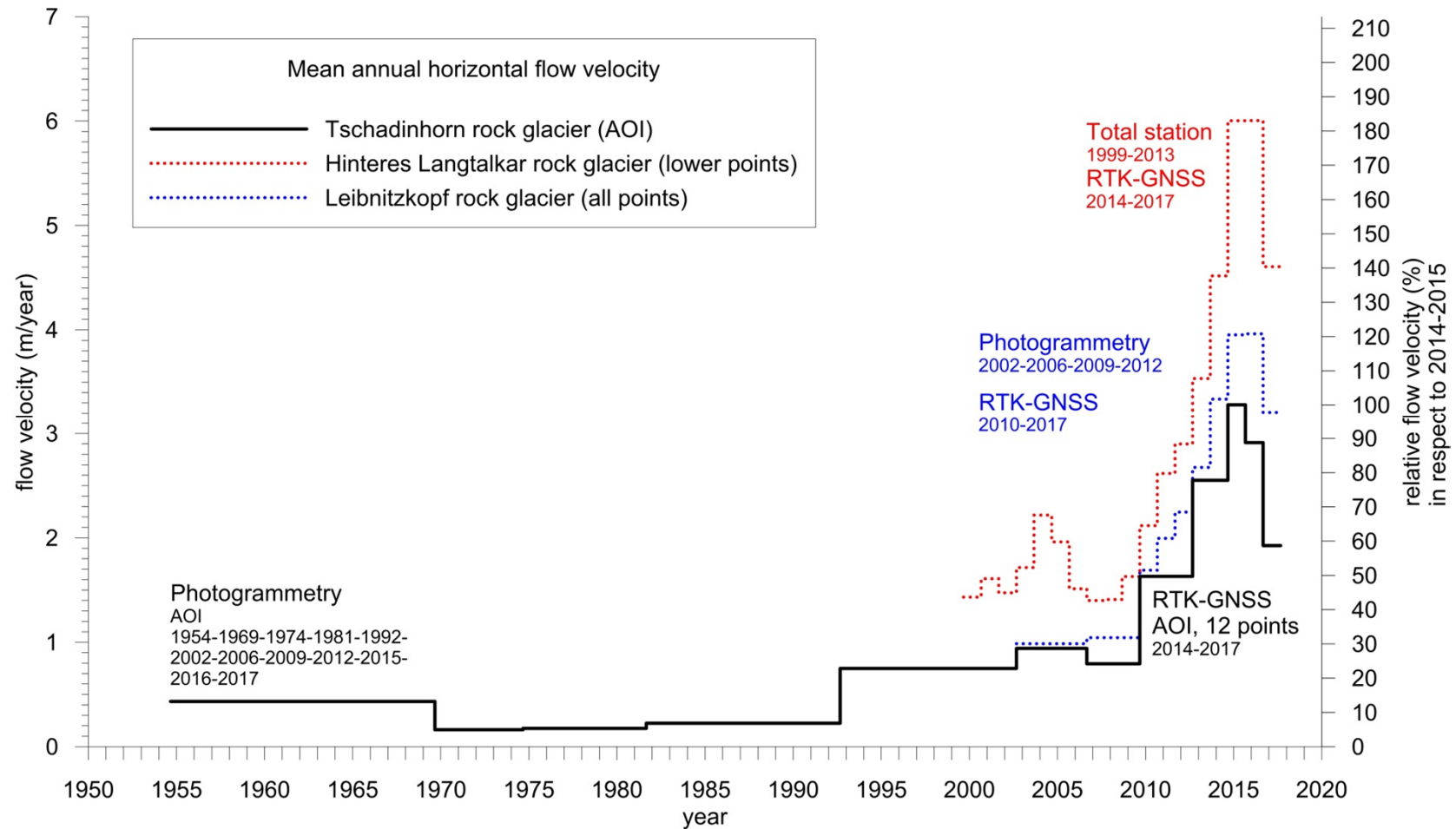


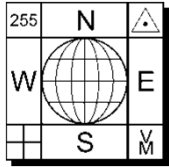
Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

6. Results



Velocity graph 1954-2017 of Tschadinhorn rock glacier

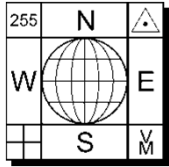




Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017

7. Discussion

- Tschadinhorn rock glacier was moving throughout the whole observation period of 63 years, albeit at different activity levels.
- A maximum flow velocity of 3.28 m/year was obtained for 2014-2015,
- whereas the lowest flow velocity of 0.16 m/year was observed for 1969-1974.
- The time span 1954-2009 is characterized by generally moderate activity (0.16 - 0.79 m/year)
- and much higher flow velocities prevail from 2009.
- The present value for 2016-2017 is 1.92 m/year.
- Since 1954 the front of the rock glacier has advanced 29.5 m, which amounts to an average velocity of approx. 0.47 m/year.
- Flow velocities derived from UAV data were verified by geodetic measurements and high accuracies in the order of $\pm 3\text{-}5$ cm/year (1σ) were reached.
- DTM-based flow velocities correlate well with DOP-based ones only in case of fine grid-spacing (≤ 10 cm).
- The standards of conventional photogrammetric mapping of governmental agencies, e.g., BEV, could be reached easily, provided that sufficient ground control points are available and GSD of the image data is better than 5 cm.
- UAV-based aerial surveys have also the potential to support intra-annual change detection analyses.
- The flow velocities obtained will be correlated with climatic parameters in a follow-on study.



- Panta rhei: Movement change of Tschadinhorn rock glacier (Hohe Tauern range, Austria) for the time period 1954-2017



Thank you for your attention!



V. Kaufmann, 26.7.2016