

Quantification and visualization of periglacial surface deformation in the Inneres Hochebenkar cirque, Ötztal Alps, Austria

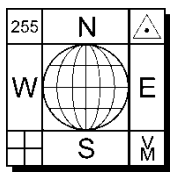
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V. Kaufmann, 10.8.2008

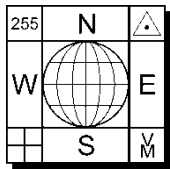
Panorama: Obergurgl, Rotmoos valley, Außerer Hochebenkar cirque, Gurgler Ferner



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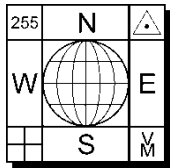
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Quantification and visualization of periglacial surface deformation in the Inneres Hochebenkar cirque, Ötztal Alps, Austria

1. Introduction

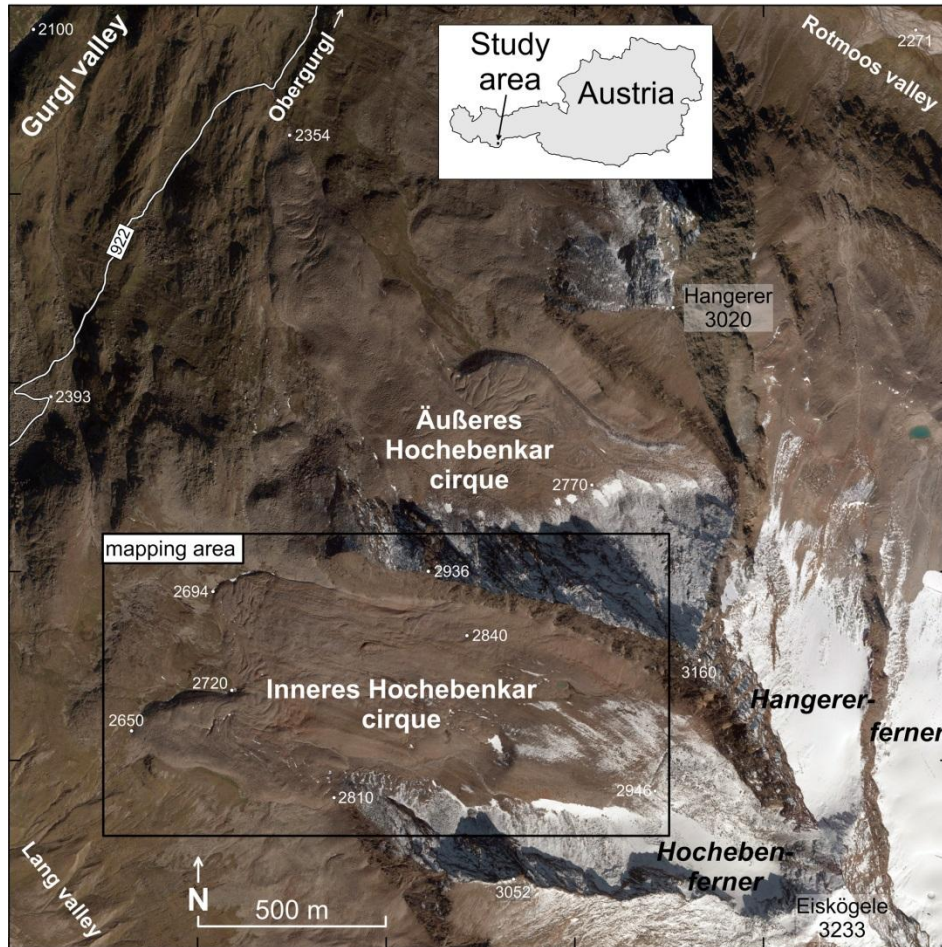
- Climate change has significant influence on the Earth's cryosphere.
- Atmospheric warming during the last 150 years has caused strong glacier recession and also permafrost degradation.
- Mountain/alpine permafrost
- Ötztal Alps, Austria
- **Äußeres Hochebenkar** cirque (rock glacier)
 - Austria's prime rock glacier
 - It is well-known for its long record of continuous photogrammetric and geodetic measurements.
- **Inneres Hochebenkar** cirque (rock glacier & glacier)
 - Haeberli and Patzelt (1982), Krainer et al. (2015)
- The main focus of the present paper is to document the past and the more recent surface change of the periglacial (= non-glaciated) environment of the Inneres Hochebenkar cirque.



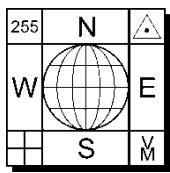
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2. Study area

Inneres Hochebenkar cirque



Orthophoto, 11.9.2010
© Land Tirol



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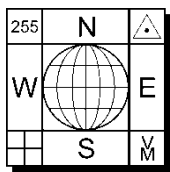
2. Study area

Inneres Hochebenkar cirque

Inneres Hochebenkar rock glacier



Photo taken on 31.8.2015 by A. Kleb.



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2. Study area

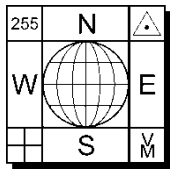
Virtual overflight



Source:
Kaufmann & Plösch (1999, 2001)
<http://www.geoimaging.tugraz.at/viktor.kaufmann/animations.html>

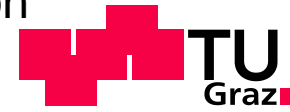
Aerial photograph
© BEV, Vienna

Inneres Hochebenkar
cirque/rock glacier



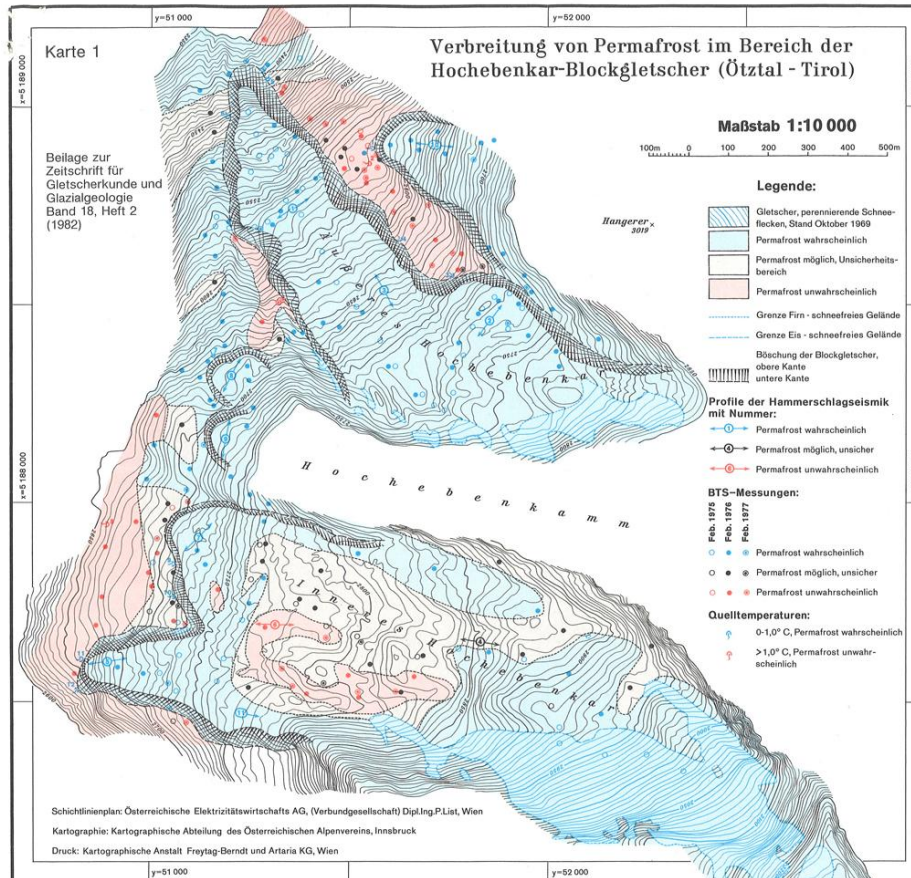
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3. Previous work

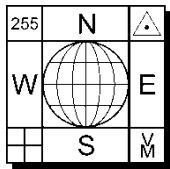


Permafrost studies

■ Haeberli and Patzelt (1982)



Source: Haeberli & Patzelt (1982)

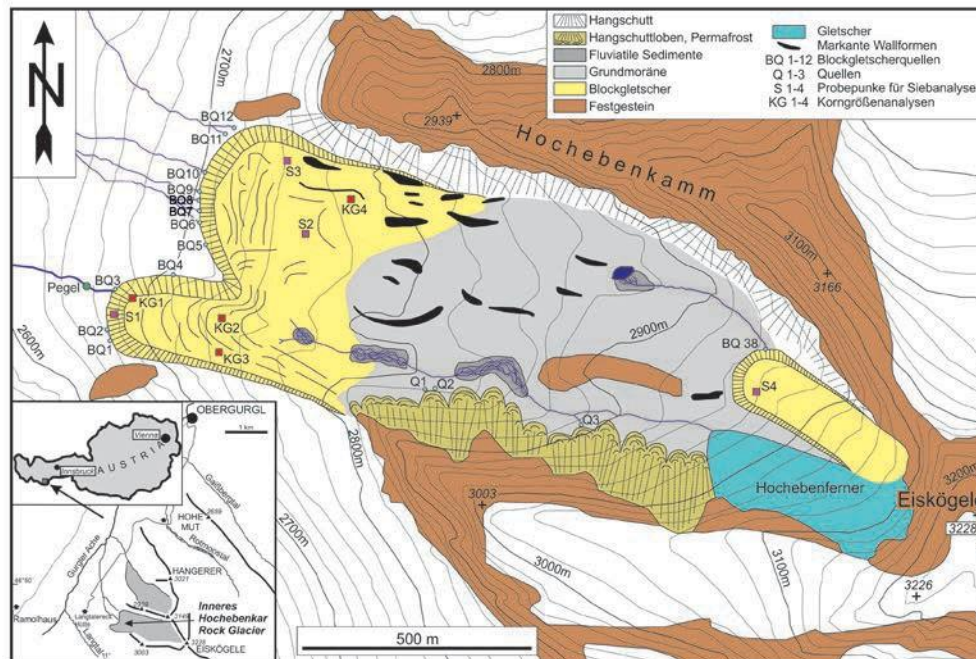


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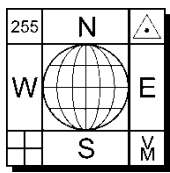
Permafrost studies

- Krainer et al. (2015)
 - Geomorphology
 - Hydrology



Geological/Geomorphological map

Source: Krainer et al. (2015)

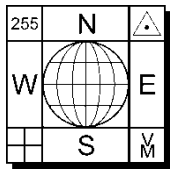


3. Previous work

Supporting maps



'Dritte Landesaufnahme' 1864-1887 (survey 1870-1873)



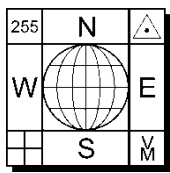
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3. Previous work

Supporting maps



Map 'Ötztaler Alpen, Blatt Gurgl' 1:25,000 (photogrammetric survey 1936), published in 1949 by the Austrian Alpine Club.

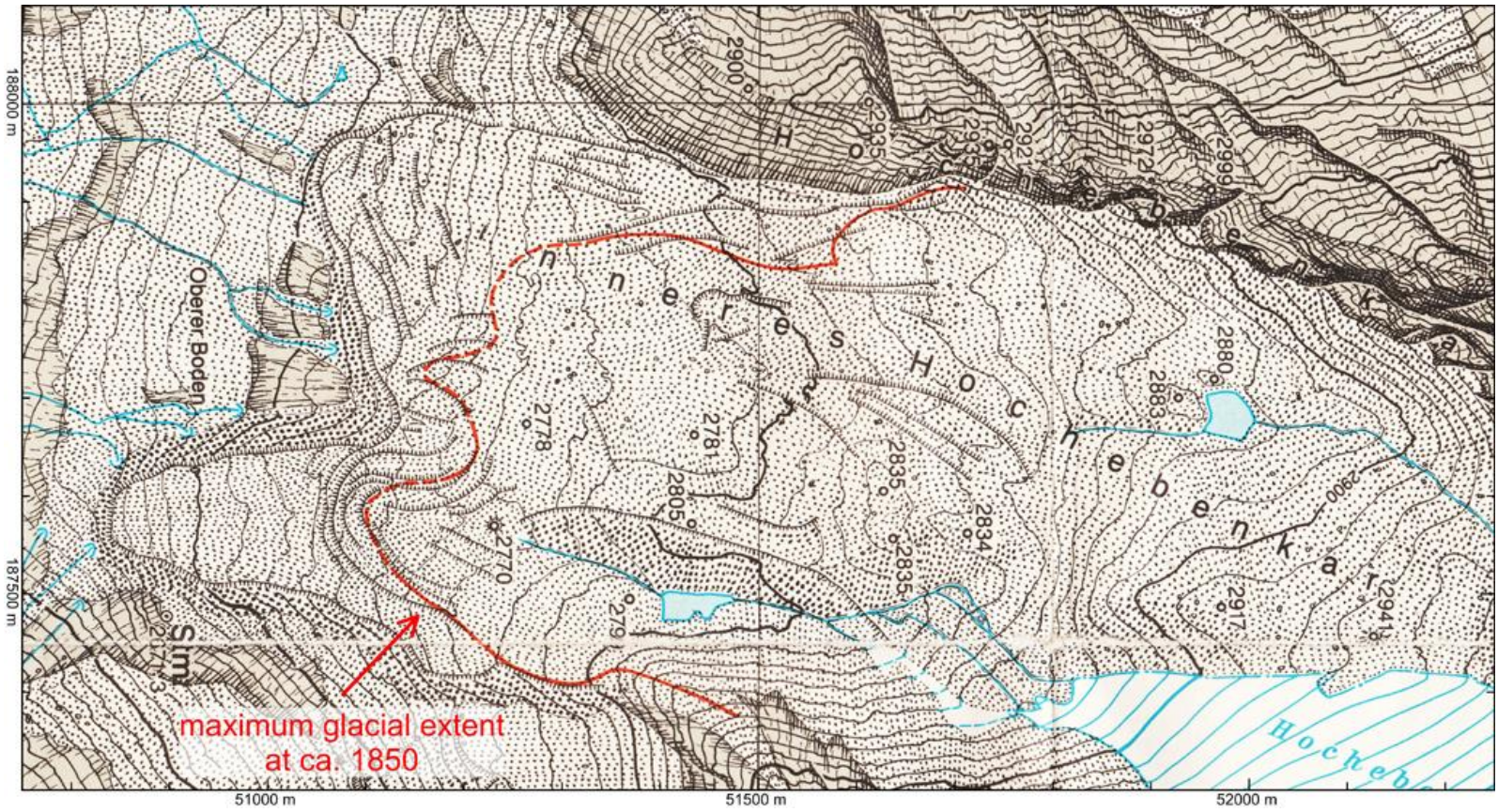


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3. Previous work

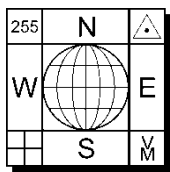


Supporting maps



Map 'Gurgler Ferner 1981' 1:10,000 (published in 1986)

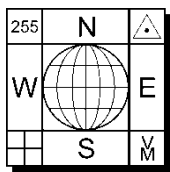
Source: Patzelt (1986)



3. Previous work

Measurement of flow velocity

- Terrestrial photogrammetry (Pillewizer, 1957; Vietories, 1972)
 - Surveys 1953/1955 by W. Pillewizer
 - frontal slope of the southern unit
 - mean annual flow velocity of 1.10 m a^{-1}
 - Surveys 1959/1966 by E. Dorrer
 - stable rock outcrop at 2800 m
 - no movements were detected
- Satellite radar interferometry (Rott & Siegl, 1999)
 - ERS-1/2 SAR images (two interferometric pairs in July/August 1995)
 - two separate moving units were detected; calculated displacements rates were several centimeters within the 35 days repeat cycle
- Aerial photogrammetry (Kaufmann & Ladstädter, 2002)
 - stringent photogrammetric approach
 - time period 1953-1997 (max. flow velocity of $55/49 \text{ cm a}^{-1}$)

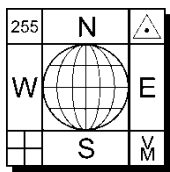


4. Data acquisition

Aerial surveys 1953-2010

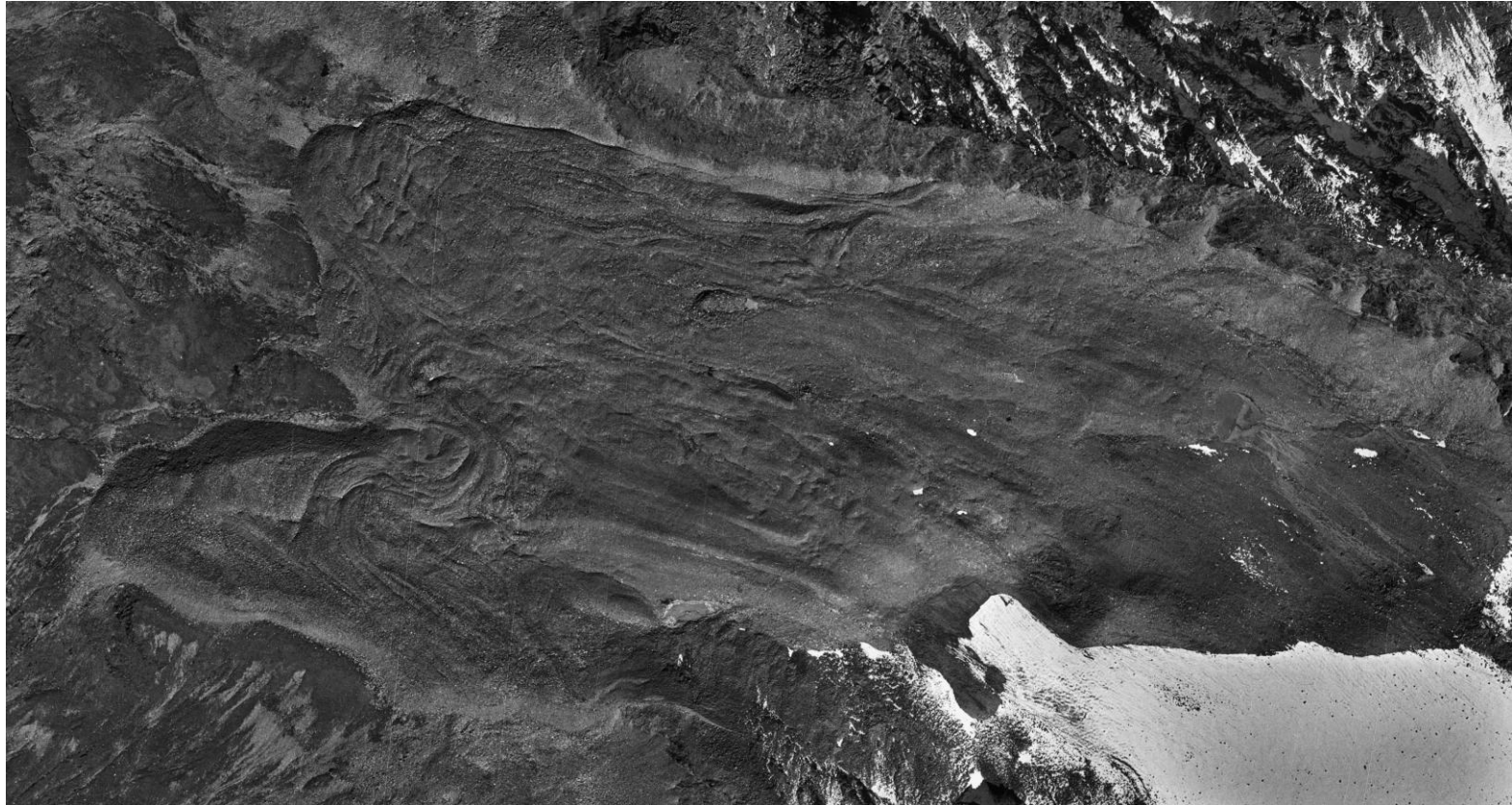
Date	Flying height above ground (m)	Camera type	Scale/ GSD*	Remark
31.8.1953	3250	analog	1 : 15,450	B&W
7.10.1969	4430	analog	1 : 29,150	B&W
7.9.1981	2930	analog	1 : 19,150	B&W
10.10.1990	5240	analog	1 : 34,300	B&W, snow cover
11.9.1997	5580	analog	1 : 36,550	B&W
5.9.2003	5360	analog	1 : 17,650	color- positive
11.9.2010	2810	digital	17* cm	R,G,B, NIR

* GSD ... ground sampling distance



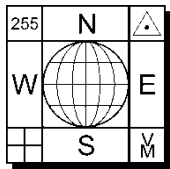
4. Data acquisition

Aerial surveys 1953/2003



Computer animation: Orthophotos 1953/2003

Data 1953: © BEV, Vienna
Data 2003: © Land Tirol

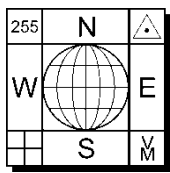


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4. Data acquisition

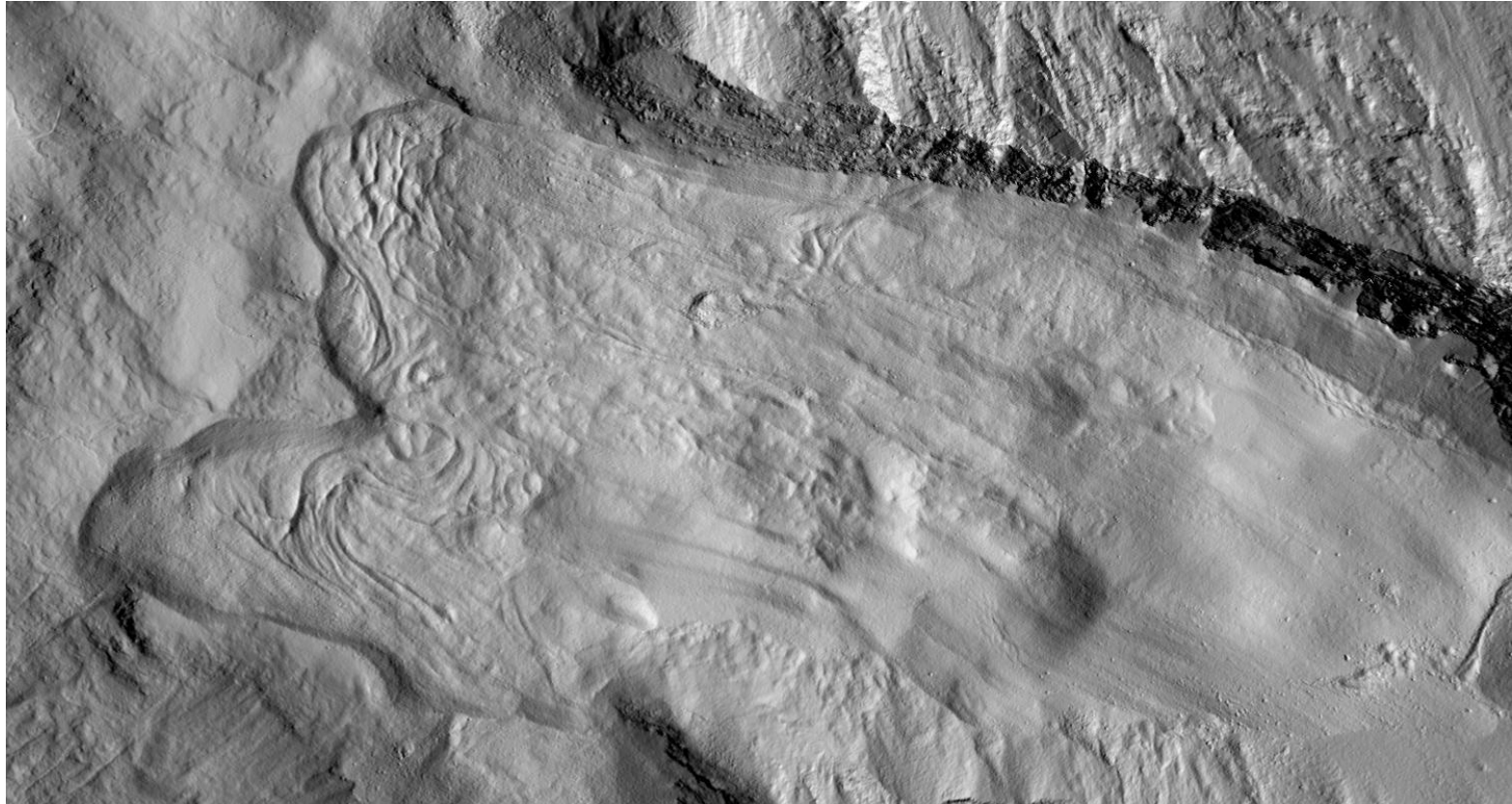
Digital elevation/surface models 1953-2010

Date	Grid spacing	Origin	Remark
31.8.1953	2.5 m x 2.5 m	photogrammetric mapping	DEM
11.9.1997	2.5 m x 2.5 m	photogrammetric mapping	DEM
23.8.2006	1 m x 1 m	ALS	DEM and DSM
9.10.2010	1 m x 1 m	ALS	DEM and DSM



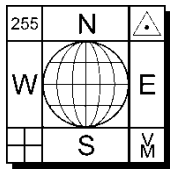
Quantification and visualization of periglacial surface deformation in the Inneres Hochebenkar cirque, Ötztal Alps, Austria

4. Data acquisition



Computer animation: DSM 2006/2010

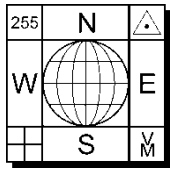
DSMs © Land Tirol



5. Methods

Measurement of flow velocity

- Image-based change detection
 - ImageStation of Intergraph (Orthophotos, DEMs)
 - Image matching (normalized cross-correlation coefficient)
 - Matlab-based toolbox
- DEM/DSM-based change detection
 - Height field matching (normalized cross-correlation coefficient)

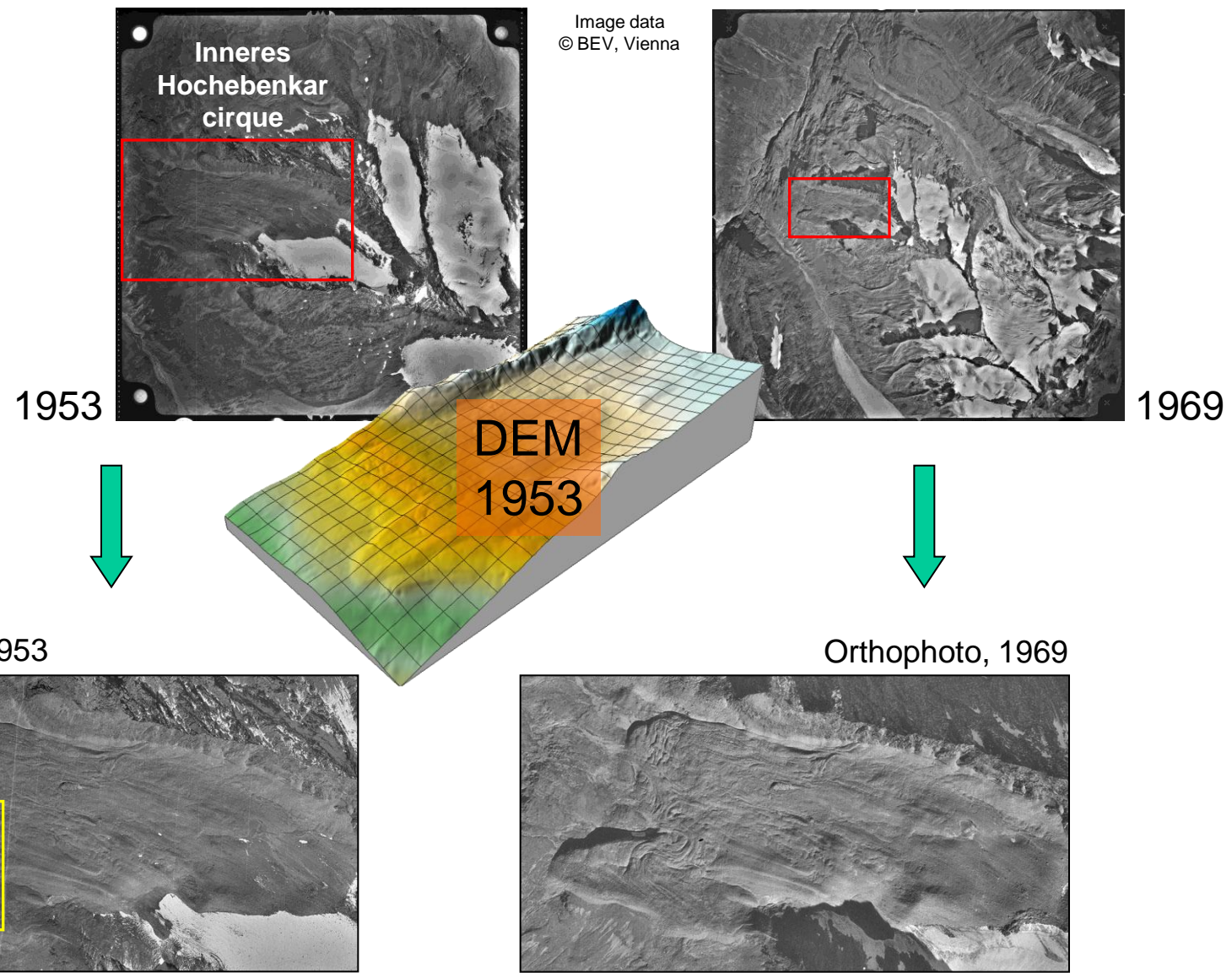


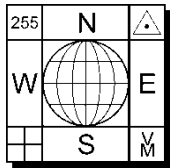
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5. Methods

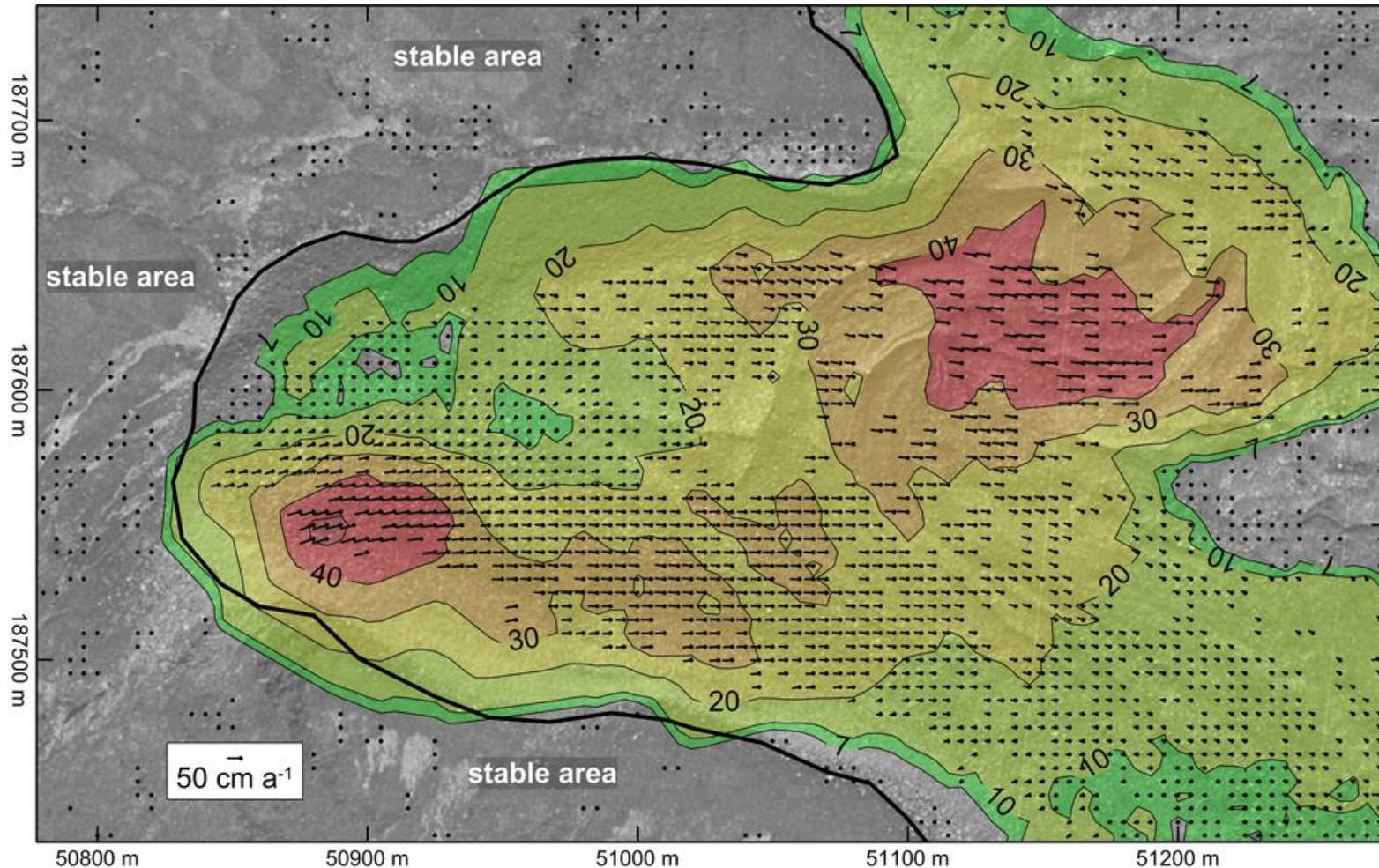
mapping area





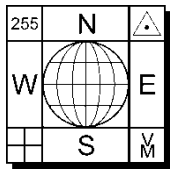
Quantification and visualization of periglacial surface deformation in the Inneres Hochebenkar cirque, Ötztal Alps, Austria

5. Methods



Mean annual horizontal flow velocity of the southern unit of Inneres Hochebenkar rock glacier for the time period 1953-1969.

© BEV, Vienna



5. Results

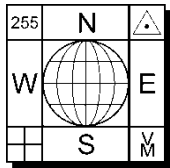
Horizontal flow velocity

Time interval	No. of valid measurements	Significance level ⁺ of flow velocity (cm a ⁻¹)	Max. flow velocity (cm a ⁻¹) – northern unit	Max. flow velocity (cm a ⁻¹) – southern unit
1953-2010	12009	±2.5	36.4	36.7
1953-1969	10625	±7.0	56.5	52.7
1969-1981	10390	±10.0	34.0	37.8
1981-1997	19456	±6.5	31.8	39.8
1981-1990	9921	±8.5	26.2	39.5
1990 [♦] -1997	too few points	---	---	---
1997-2010	24293	±7.0	33.1	40.1
2003-2010	29279	±10.0	32.9	46.7
2006-2010 [*]	10556	±8.5	24.6	57.2

+ ... 3σ

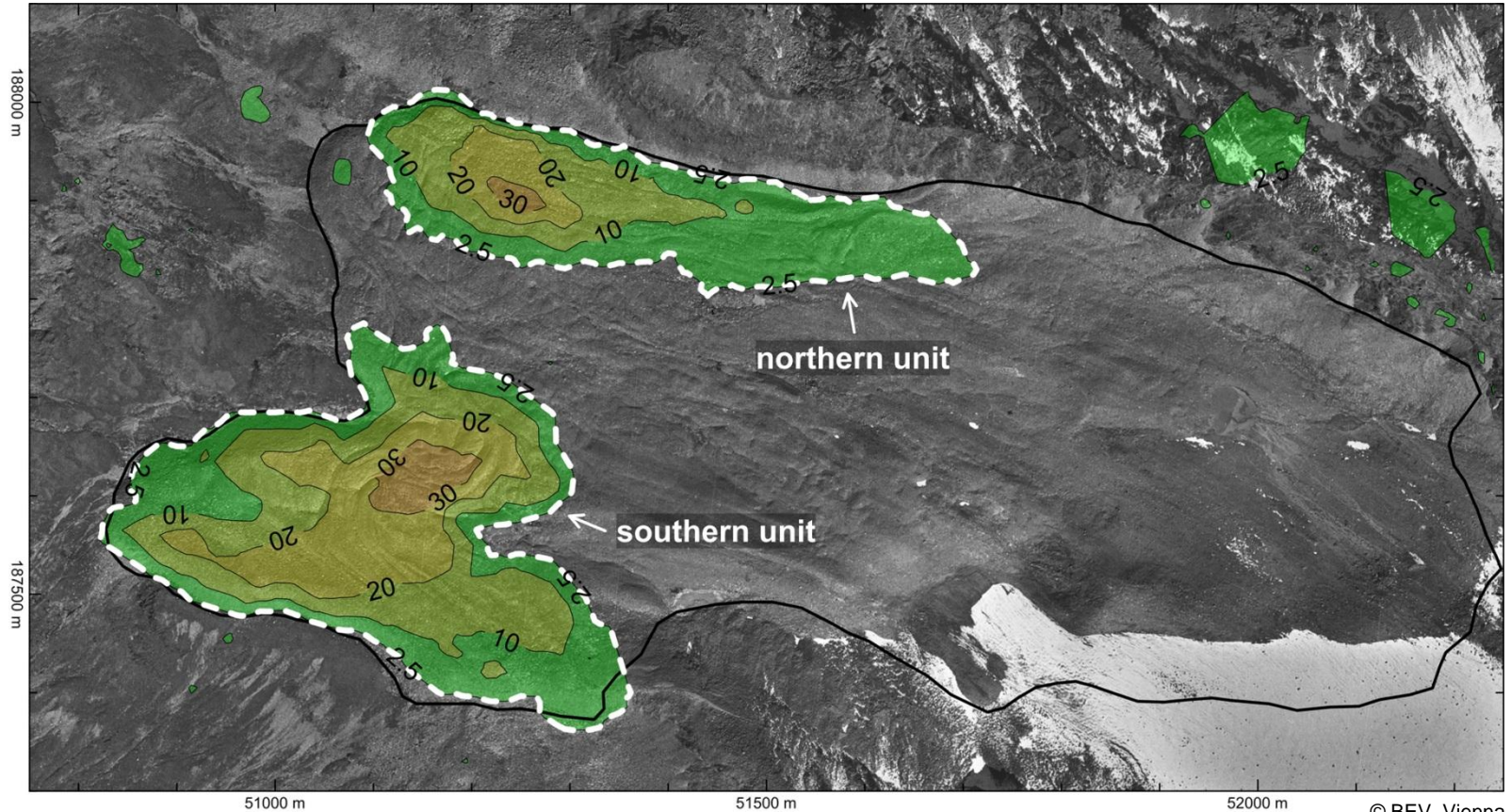
♦ ... snow cover

* ... evaluation of DSMs

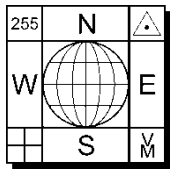


5. Results

Horizontal flow velocity

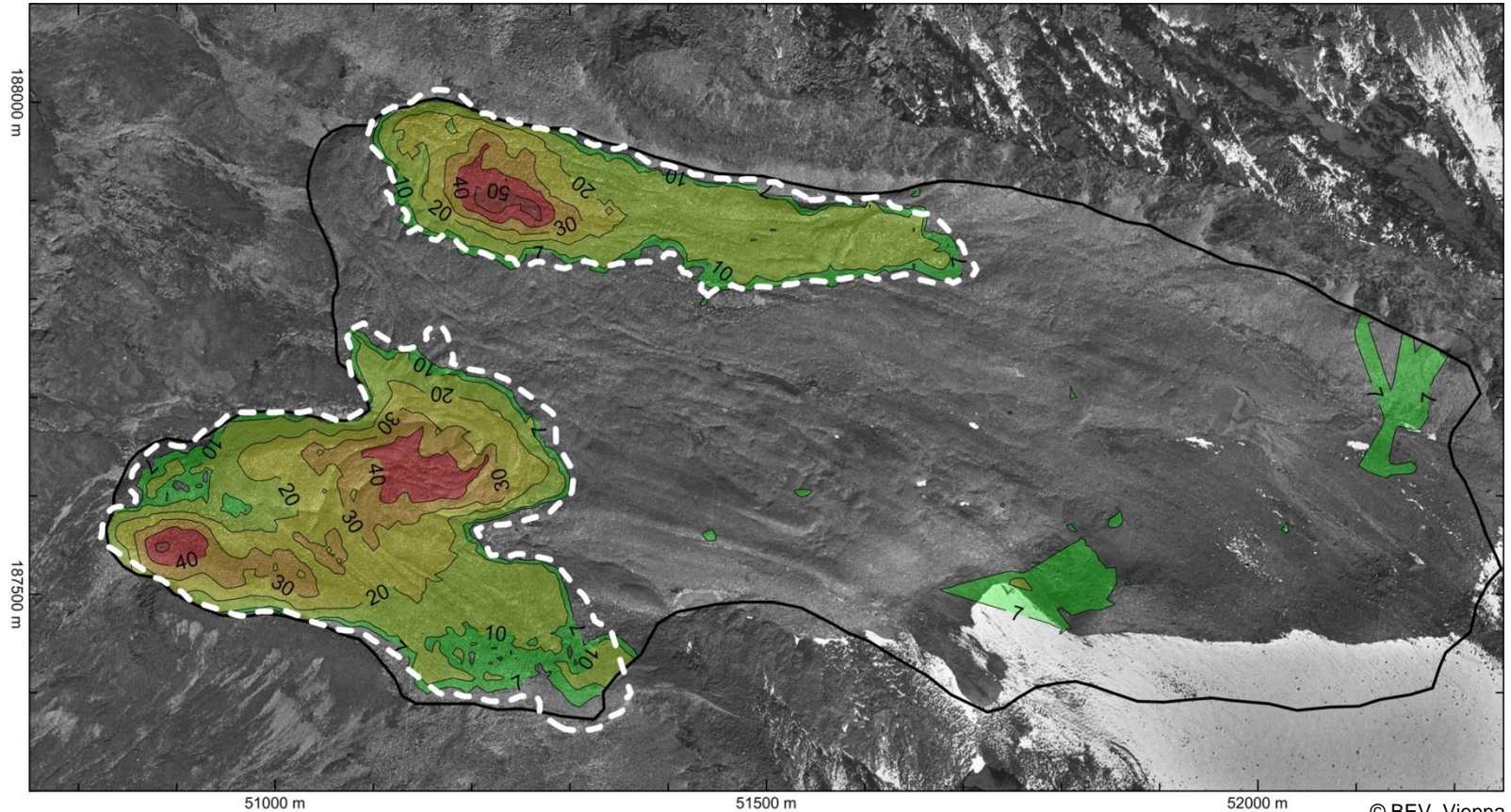


Mean annual horizontal flow velocity for the time period **1953-2010**, isotachs (cm a^{-1}), significance level at 2.5 cm a^{-1} (3σ).

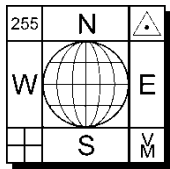


5. Results

Horizontal flow velocity

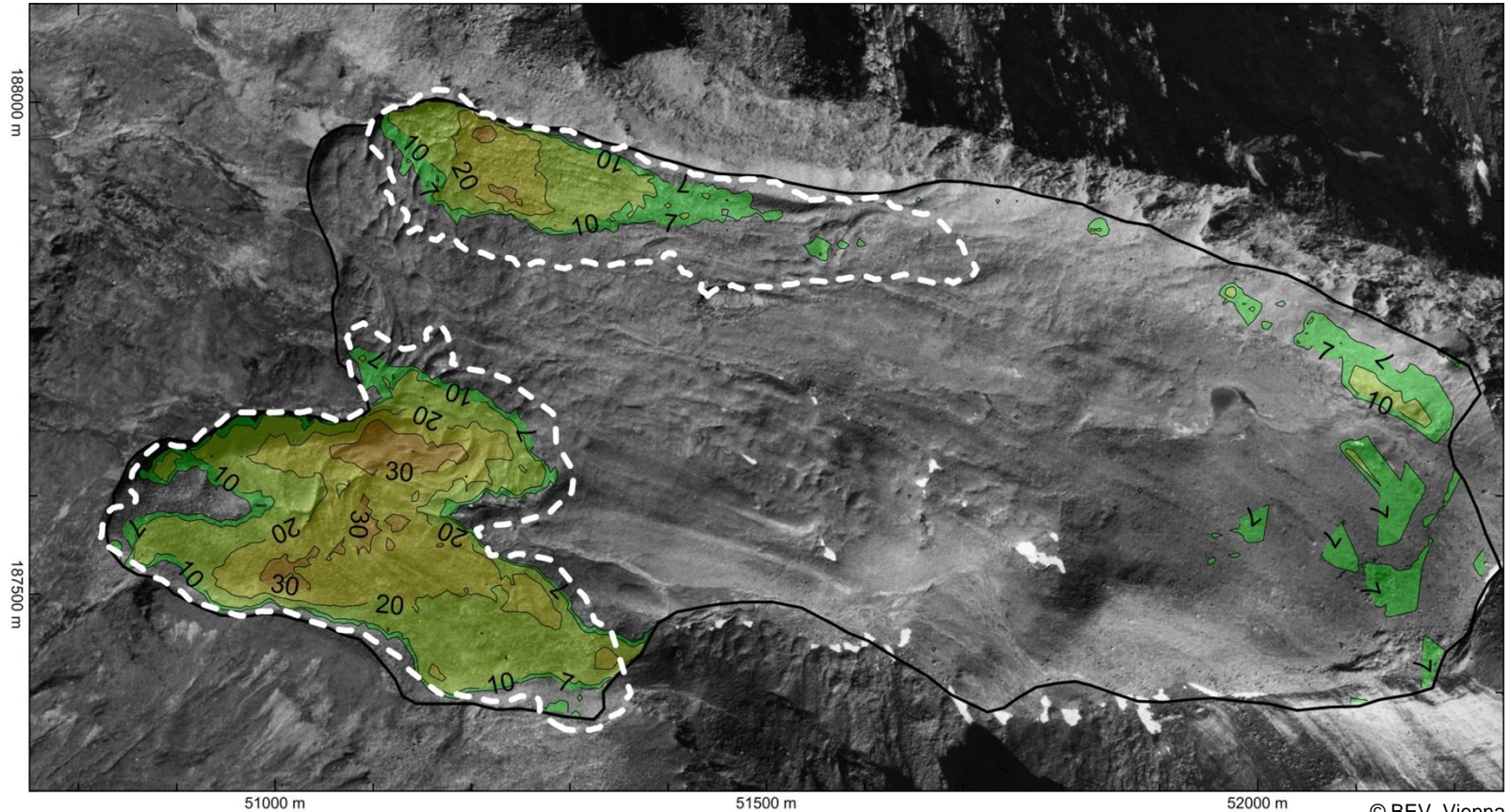


Mean annual horizontal flow velocity for the time period **1953-1969**, isotachs (cm a^{-1}), significance level at 7 cm a^{-1} (3σ).

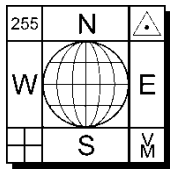


5. Results

Horizontal flow velocity



Mean annual horizontal flow velocity for the time period **1997-2010**, isotachs (cm a^{-1}), significance level at 7 cm a^{-1} (3σ).

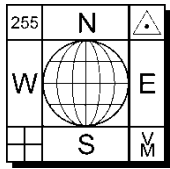


5. Results

Horizontal flow velocity

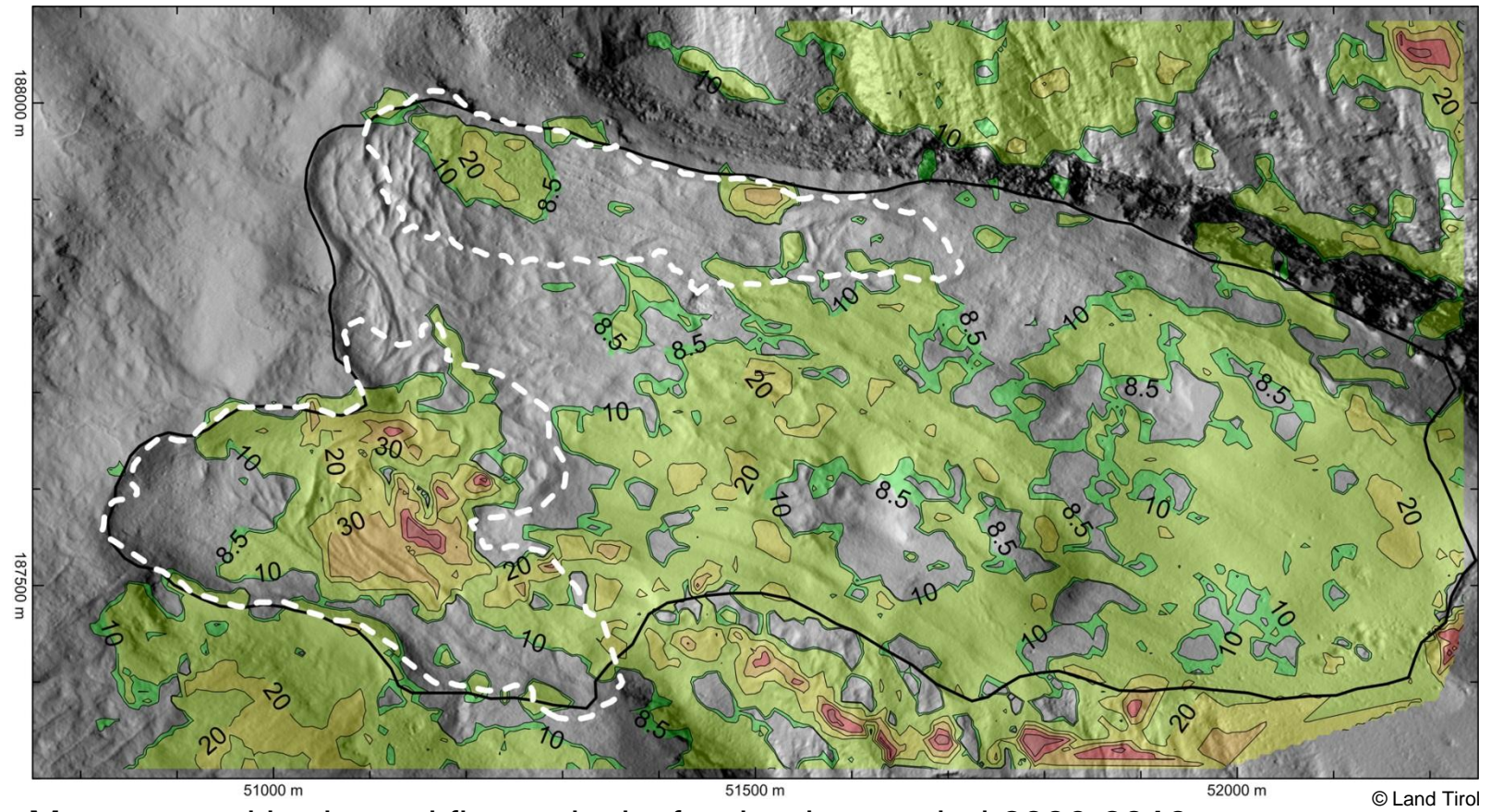


Mean annual horizontal flow velocity for the time period **2003-2010**, isotachs (cm a^{-1}), significance level at 10 cm a^{-1} (3σ).

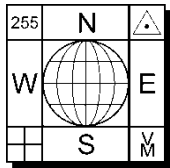


5. Results

Horizontal flow velocity (DSM-based change detection)

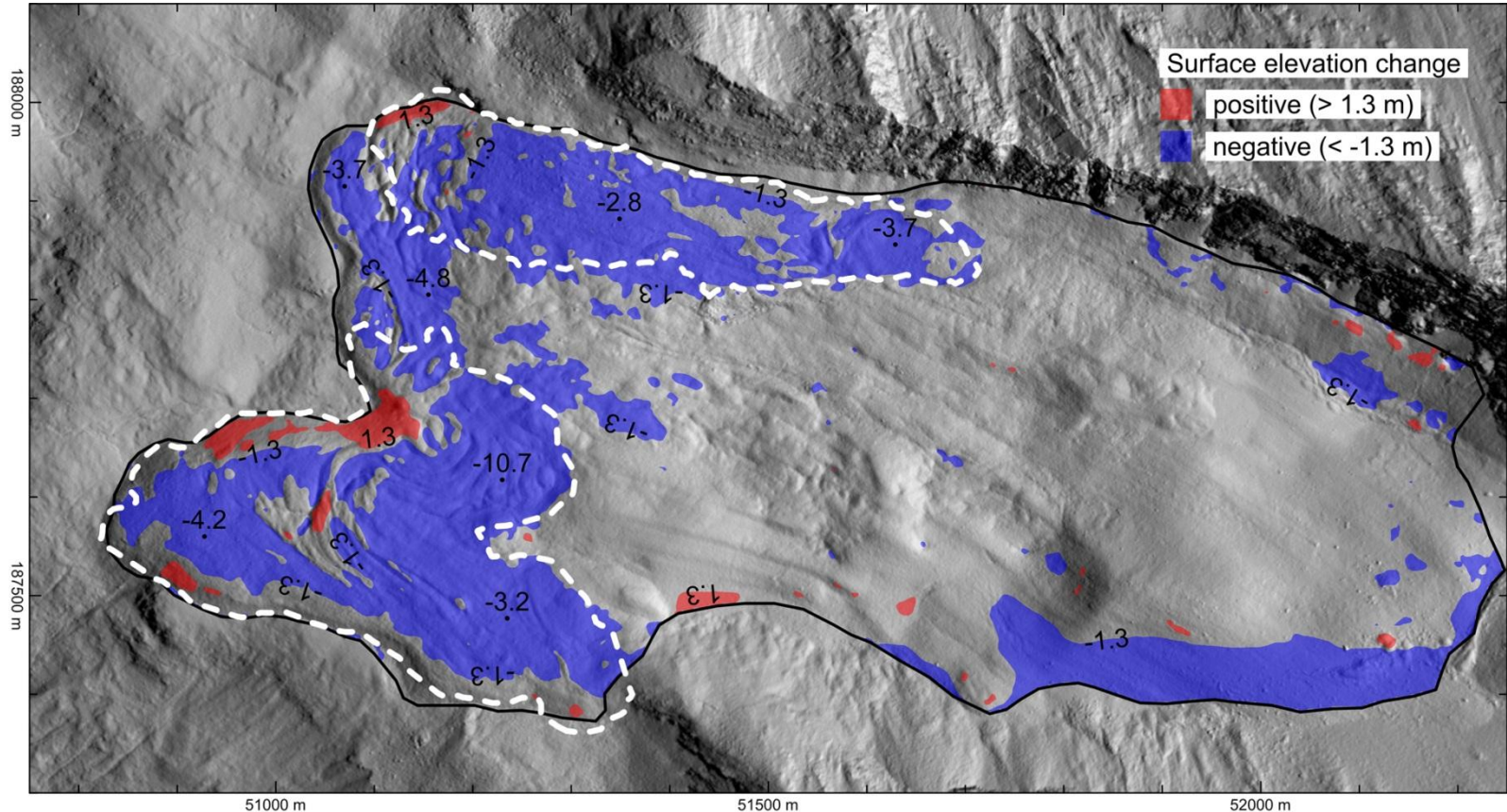


Mean annual horizontal flow velocity for the time period **2006-2010**, isotachs (cm a^{-1}), significance level at 8.5 cm a^{-1} (3σ).

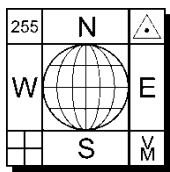


5. Results

Surface elevation change

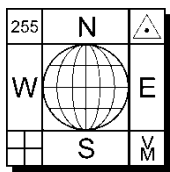


Surface elevation change for the time period **1953-2006**, significance level at ± 1.3 m (3σ).



6. Discussion

- The lower part of Inneres Hochebenkar cirque holds two independently moving parts, i.e., the northern and southern unit of Inneres Hochebenkar rock glacier.
- Highest flow velocities (1.10 m a^{-1}) of Inneres Hochebenkar rock glacier were measured by Pillewizer at the southern unit in the time period 1953-1955. In the overlapping observation period 1953-1969 the flow velocity has already decreased significantly. Maximum flow velocities hardly surpassed 50 cm a^{-1} . In the course of time the northern unit has reduced its speed more than the southern unit. A recent speed-up of the movement of the southern unit is speculative.
- Permafrost degradation/melt at Inneres Hochebenkar rock glacier is rather difficult to quantify.
- However, we found some strong indication that the lower (non-moving) end part connecting both moving units has undergone substantial surface lowering (2.0-4.7 m in 1953-1997).
- Dense image matching will allow the automatic generation of high-resolution DEMs. Thus, *true orthophotos* can be obtained more easily.
- The potential of the available multi-temporal ALS data could not be fully exploited because of obvious geometric problems in fusing both data sets.



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Thank you for your attention!



V. Kaufmann, 10.8.2008