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, Äußeres Hochebenkar cirque, Gurgler Ferner

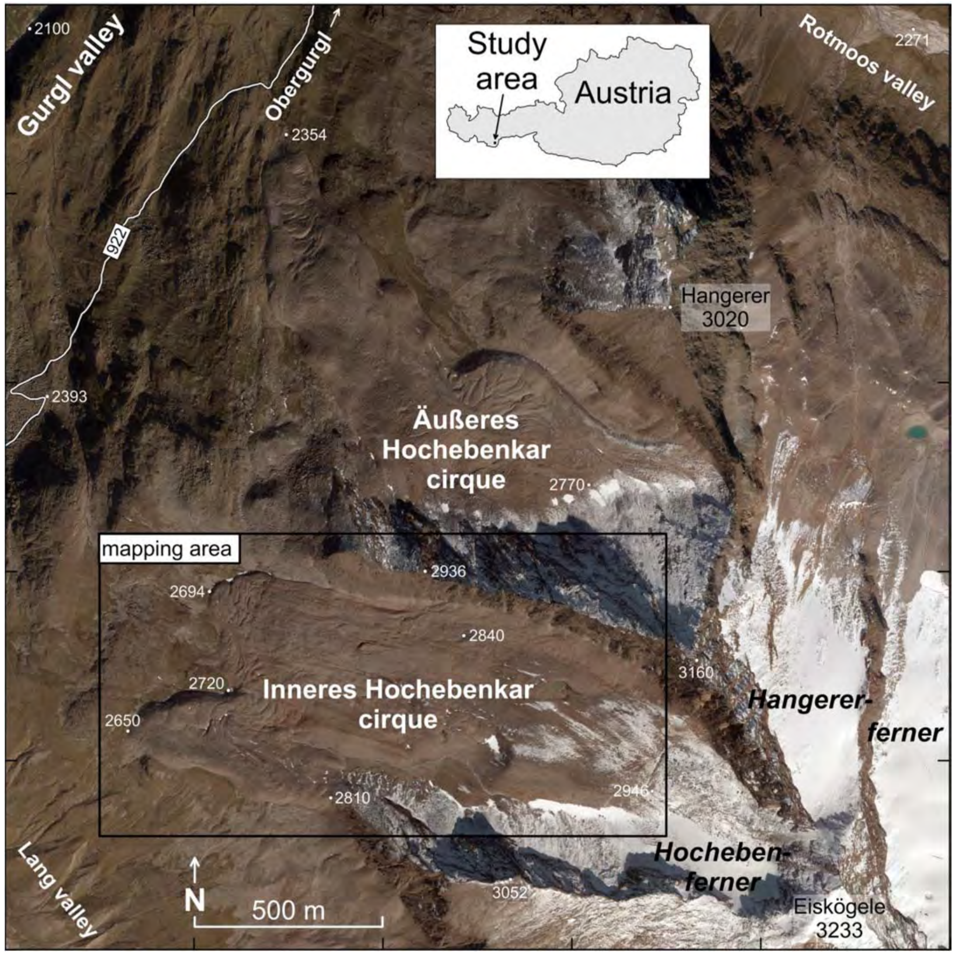
Contents

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.

2. Study area

Inneres Hochebenkar cirque



Orthophoto, 11.9.2010

2. Study area

Inneres Hochebenkar cirque | **Inneres Hochebenkar rock glacier**

Photo taken on 31.8.2015 by A. Kleb.

Virtual overflight

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

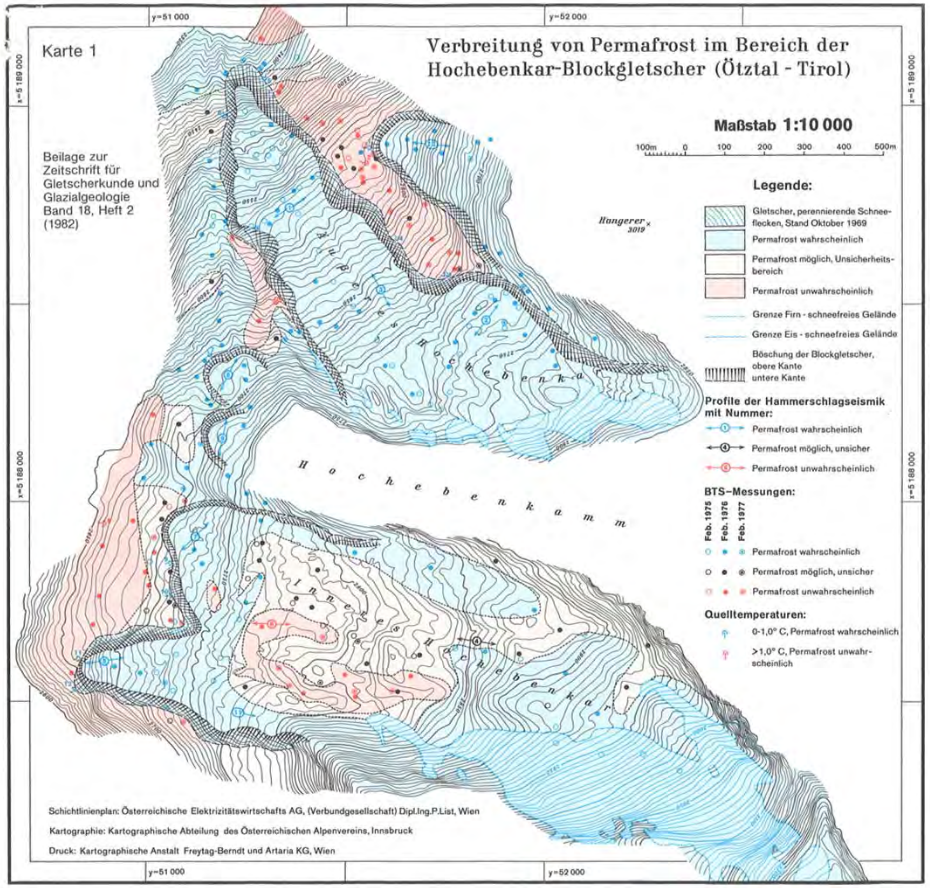
Aerial photograph
© BEV, Vienna

Inneres Hochebenkar
cirque/rock glacier

3. Previous work

Permafrost studies

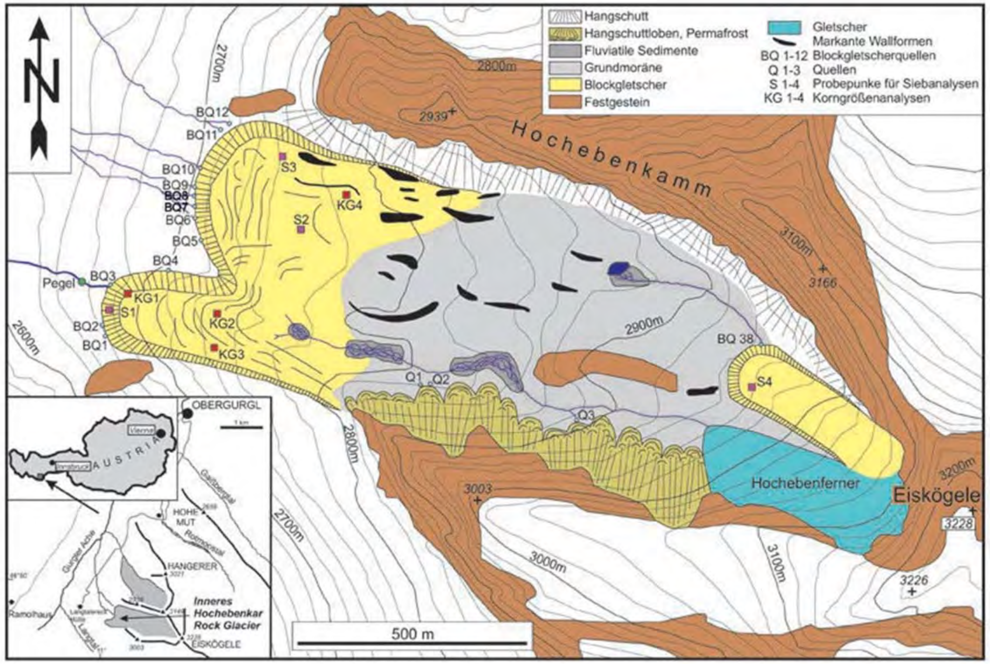
- Haeberli and Patzelt (1982)



Source: Haeberli & Patzelt (1982)

Permafrost studies

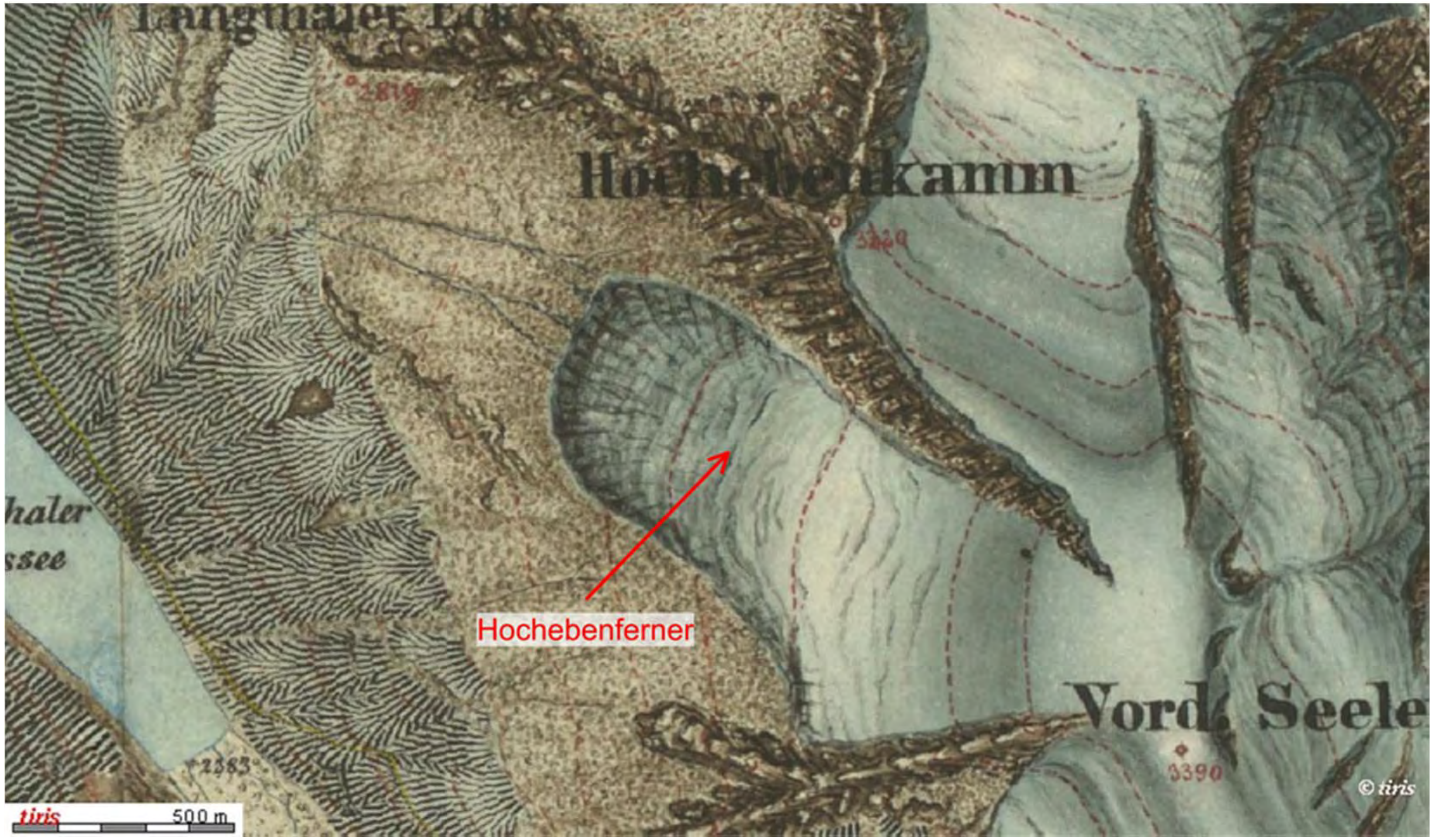
- Krainer et al. (2015)
  - Geomorphology
  - Hydrology



Geological/Geomorphological map Source: Krainer et al. (2015)

3. Previous work

Supporting maps



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

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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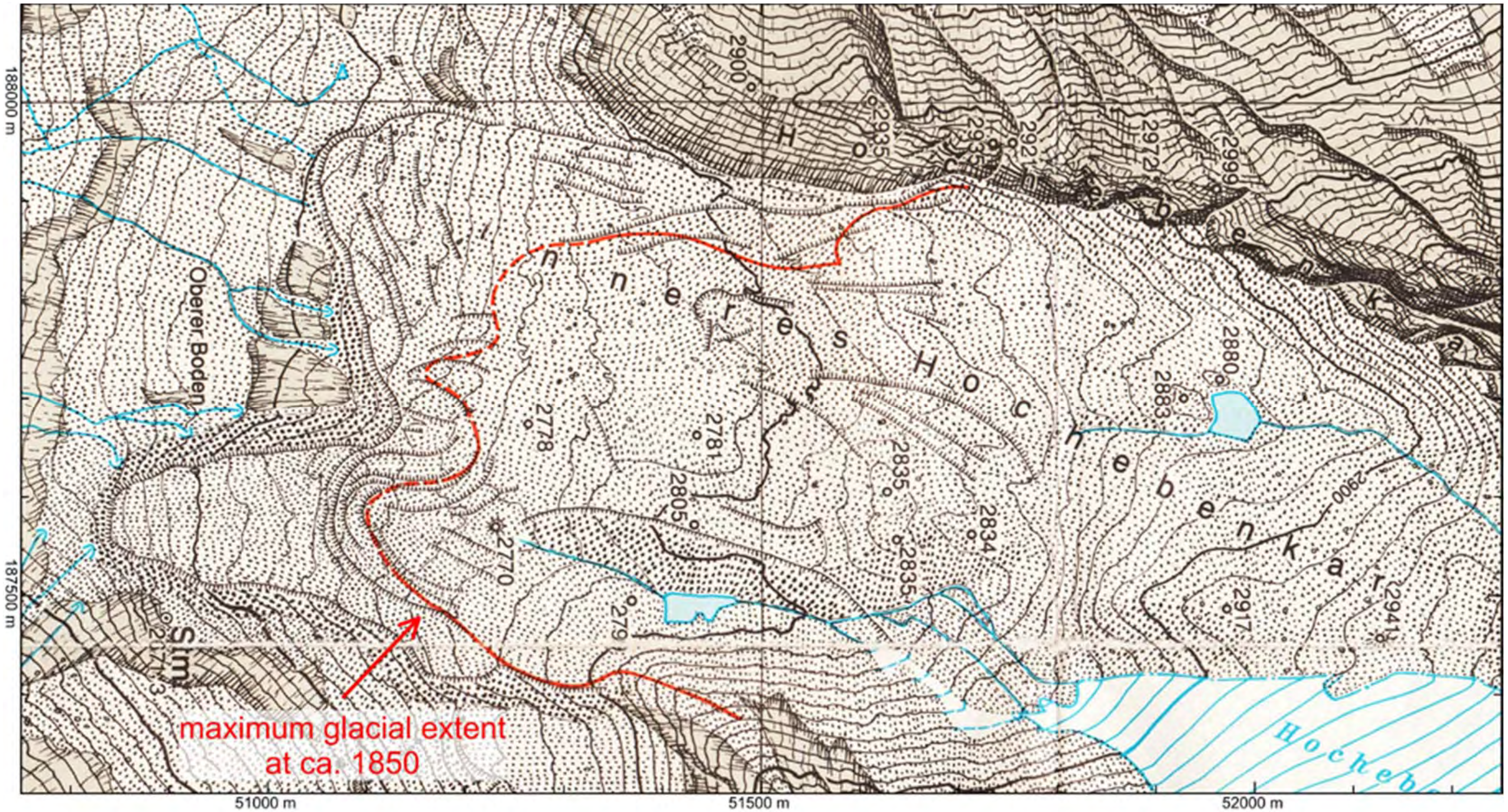
Supporting maps



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

Source: Patzelt (1986)

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 cm a^{-1})

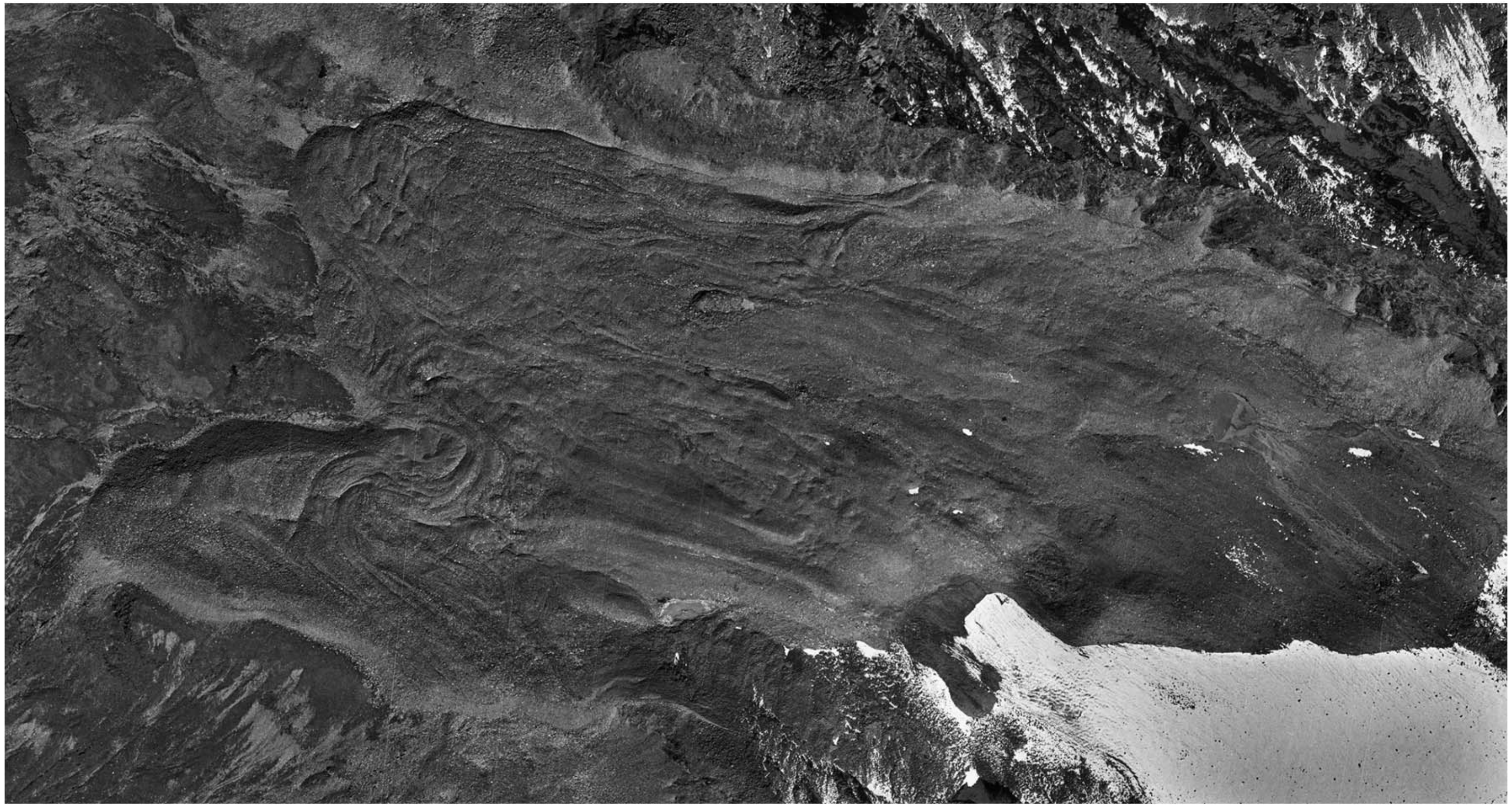
Aerial surveys 1953-2010

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



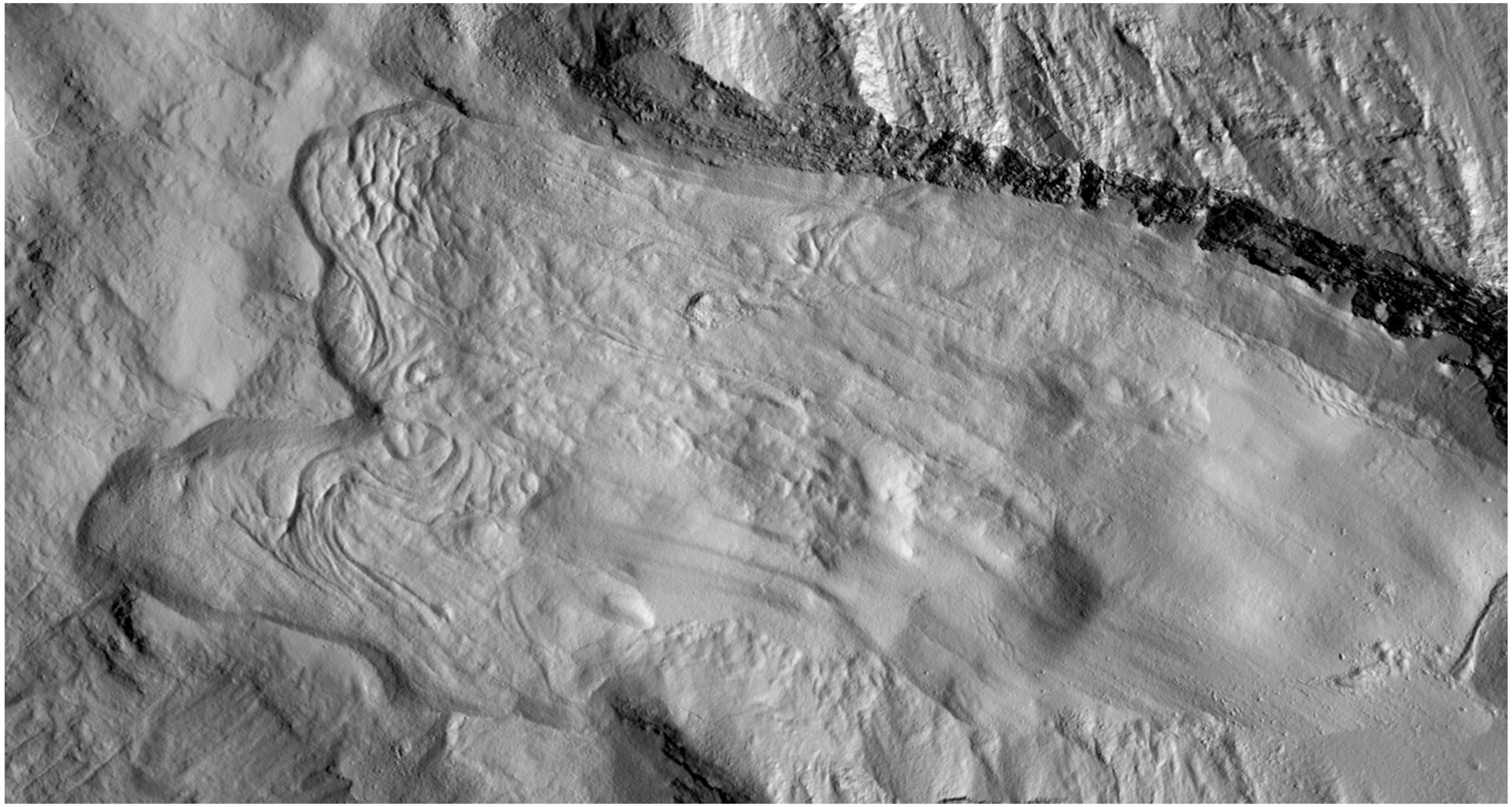
Computer animation: Orthophotos 1953/2003

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

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

4. Data acquisition



Computer animation: DSM 2006/2010

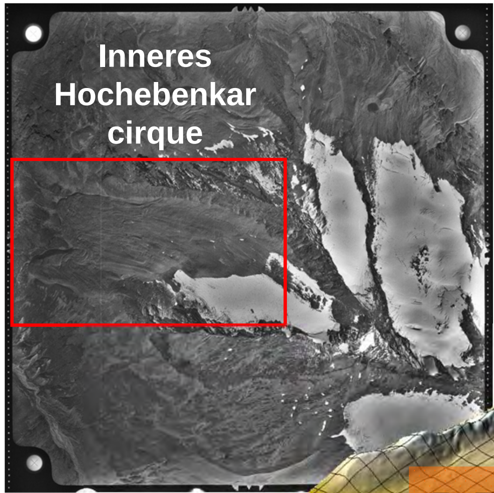
Measurement of flow velocity

- 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)

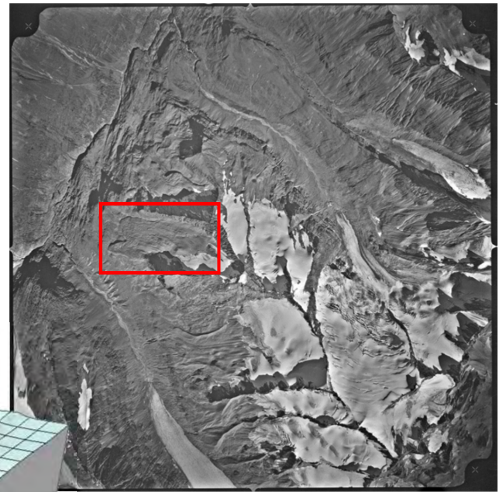
5. Methods

mapping area

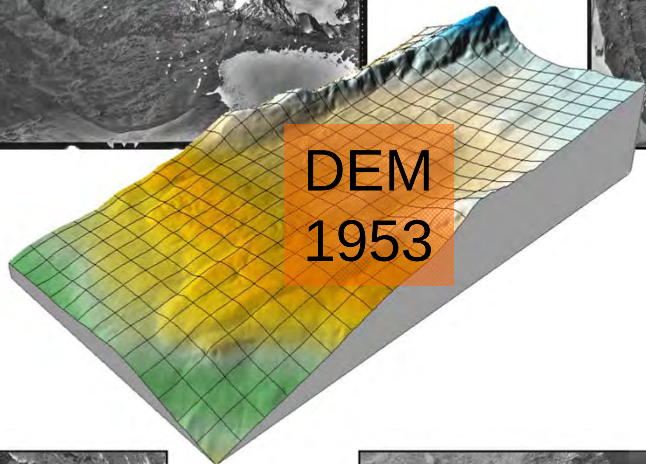
Image data
© BEV, Vienna



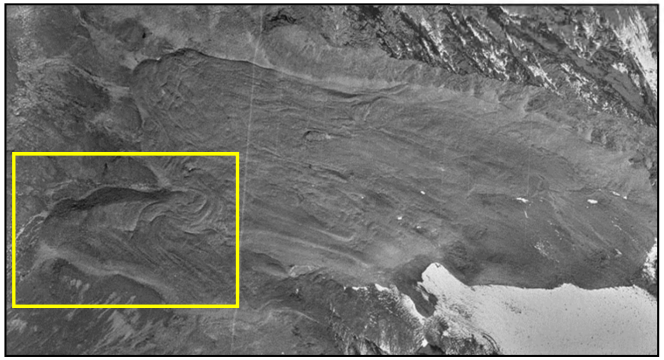
1953



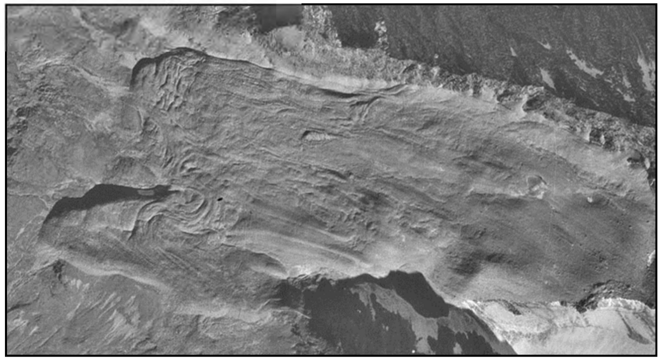
1969



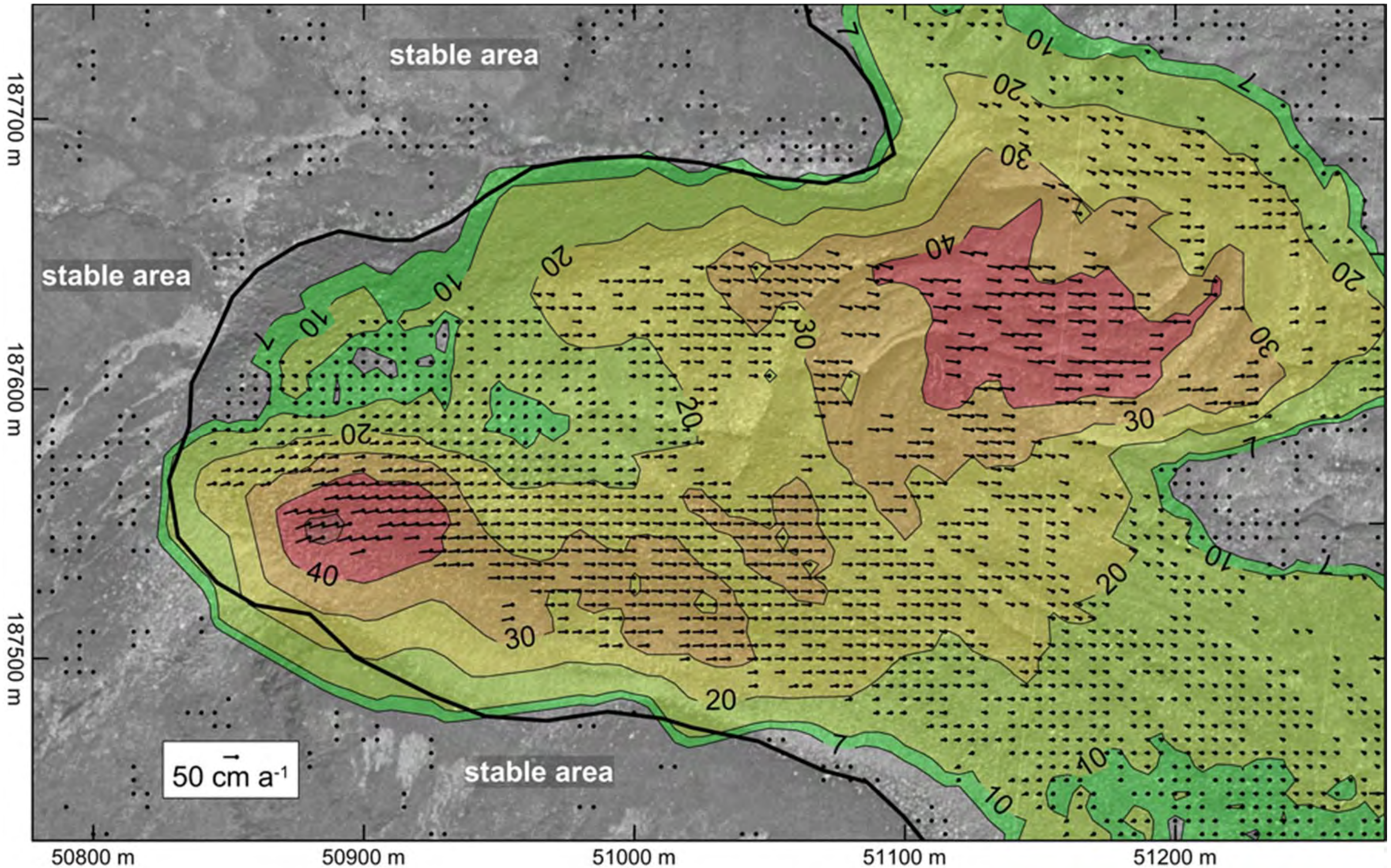
Orthophoto, 1953



Orthophoto, 1969



5. Methods



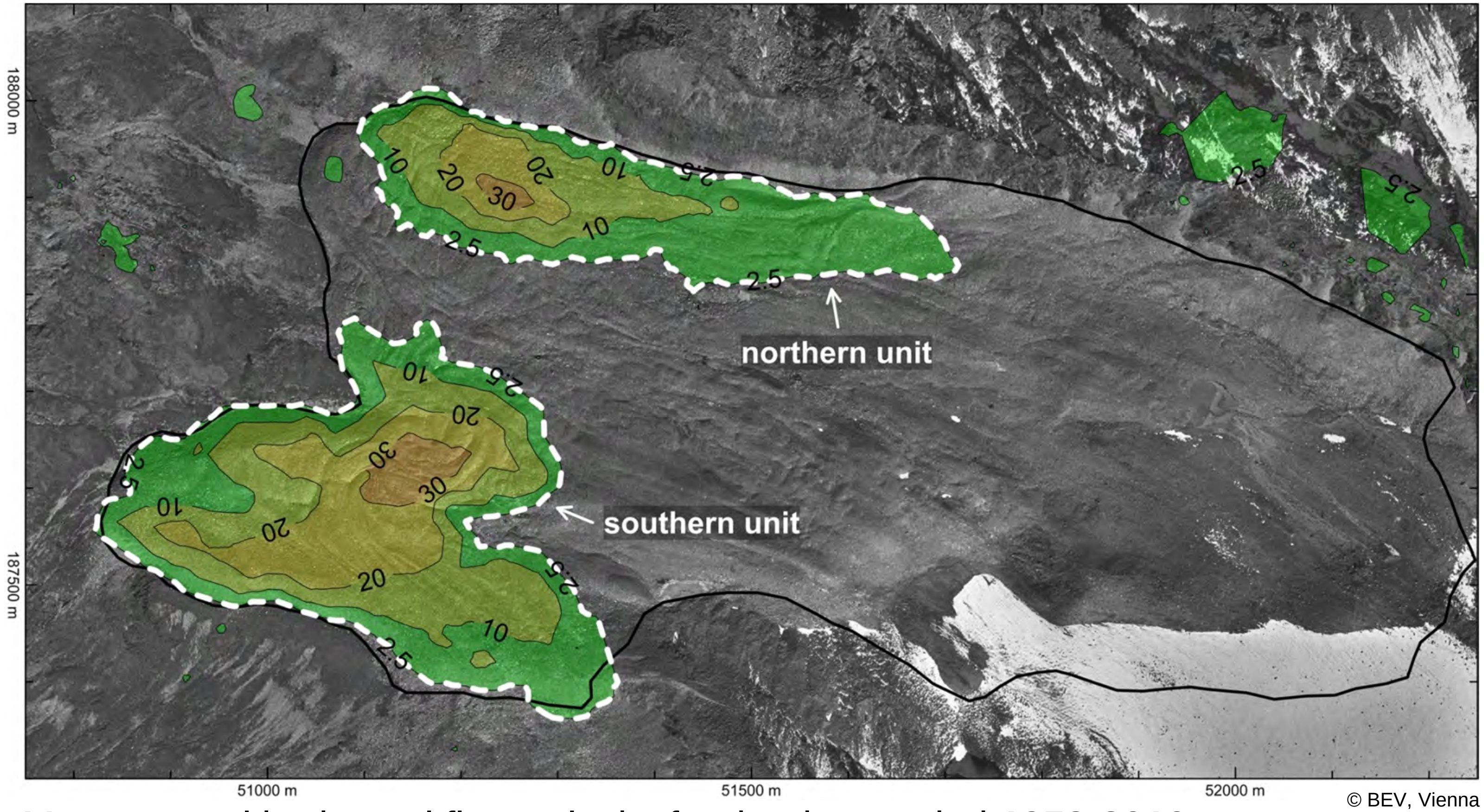
Mean annual horizontal flow velocity of the southern unit of Inneres Hochebenkar rock glacier for the time period 1953-1969.

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

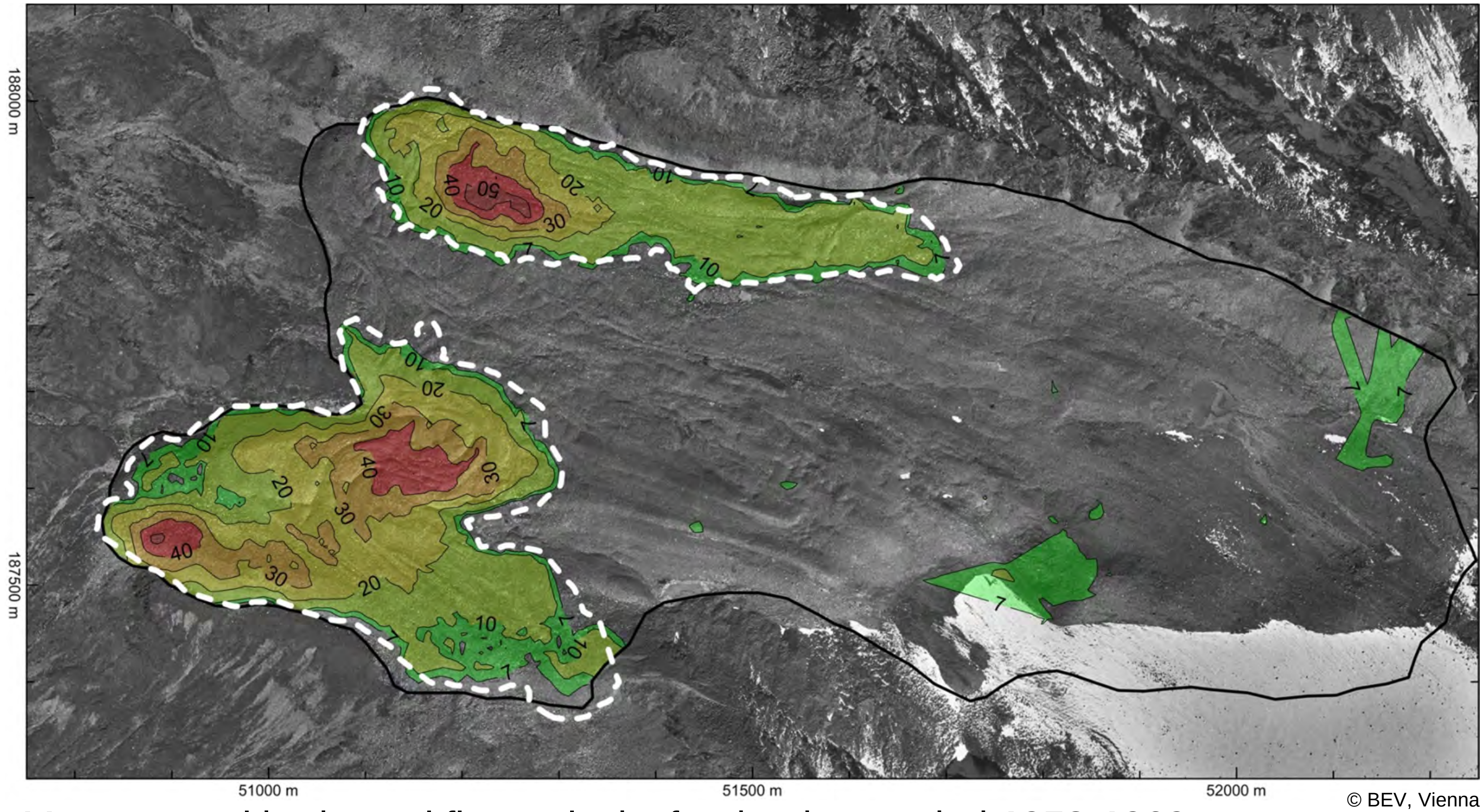
⁺ … 3σ
♦ … snow cover
* … evaluation of DSMs

Horizontal flow velocity



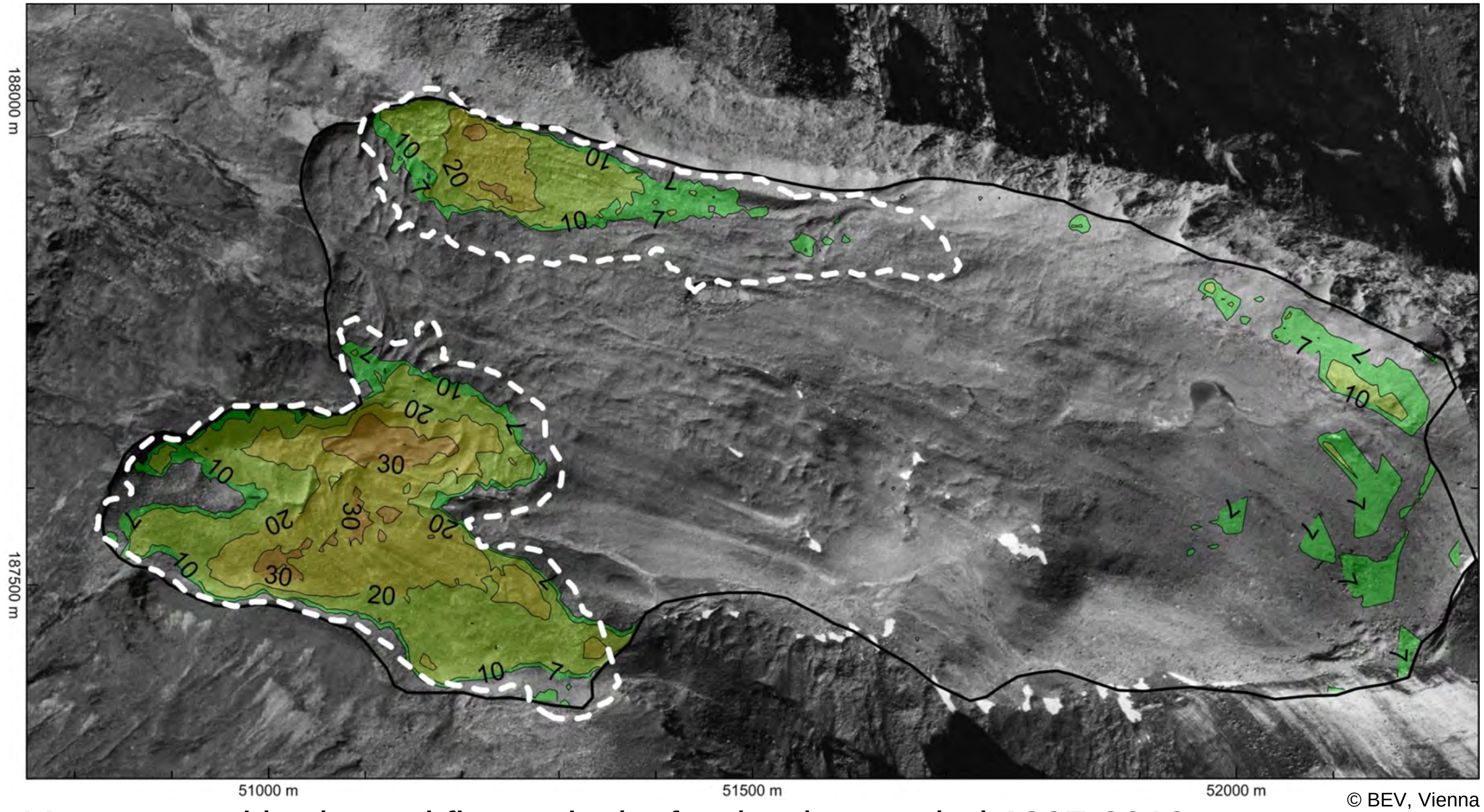
Mean annual horizontal flow velocity for the time period **1953-2010**, isotachs (cm a^{-1}), significance level at 2.5 cm a^{-1} (3σ).

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).

Horizontal flow velocity

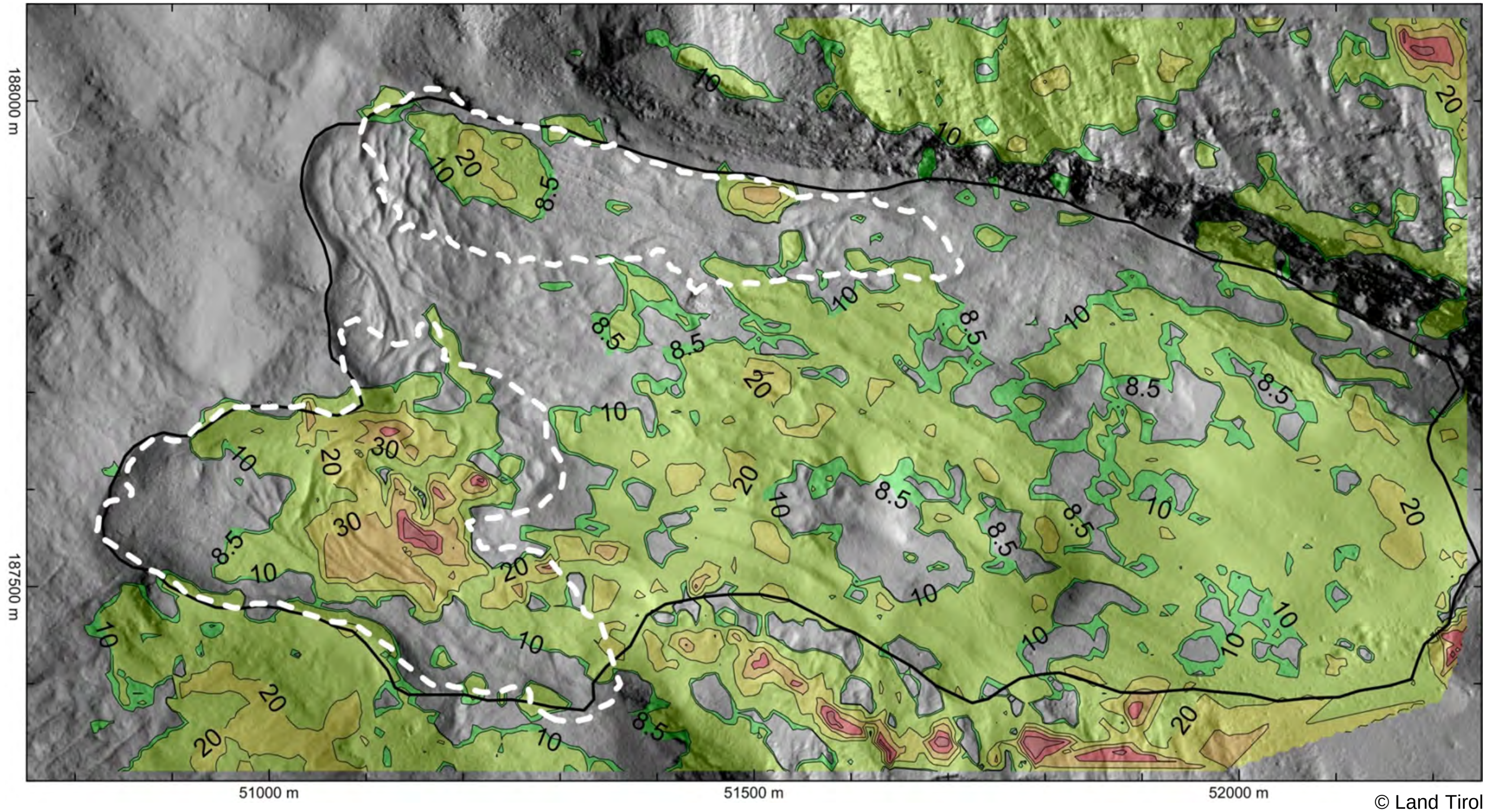


Mean annual horizontal flow velocity for the time period **1997-2010**, isotachs (cm a^{-1}), significance level at 7 cm a^{-1} (3σ).

Horizontal flow velocity

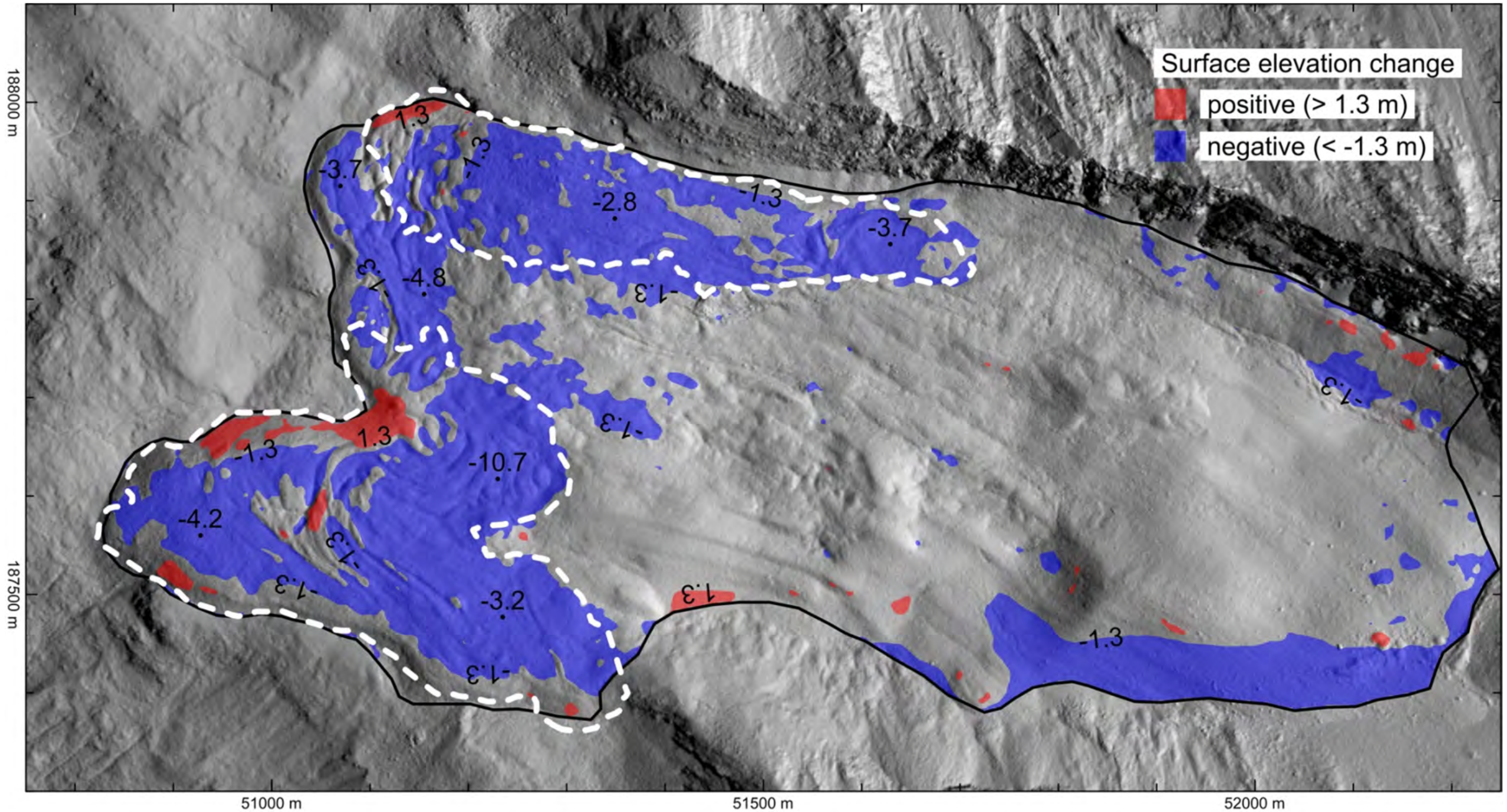
Mean annual horizontal flow velocity for the time period **2003-2010**, isotachs (cm a^{-1}), significance level at 10 cm a^{-1} (3σ).

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).

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.

Thank you for your attention!

V. Kaufmann, 10.8.2008