Rock glaciers identification and characterisation with remote sensing and machine learning

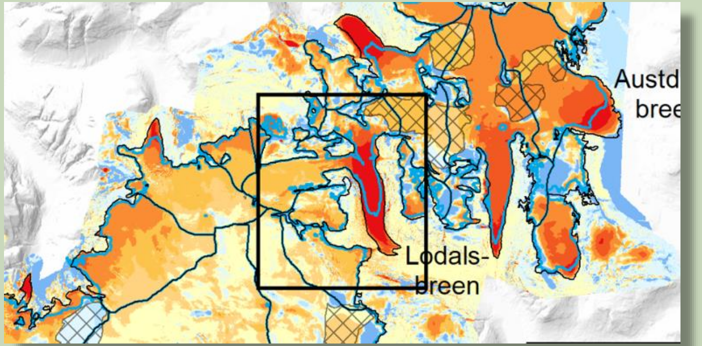
Benjamin Aubrey Robson
benjamin.robson@uib.no

University of Bergen, Norway

with contributions from Daniel Thomas and Emma Hauglin

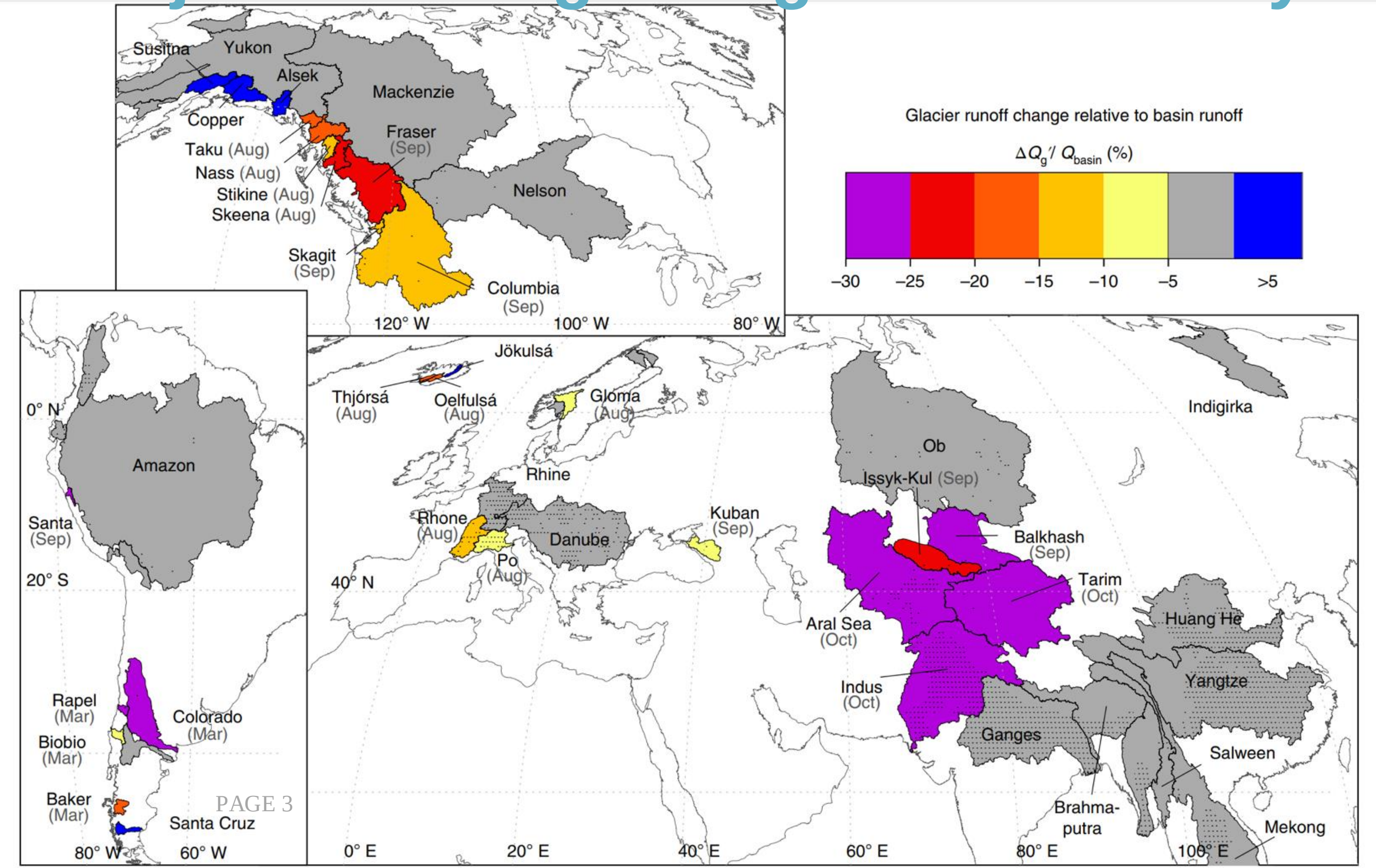
Overview of this talk

Machine learning based mapping of the cryosphere



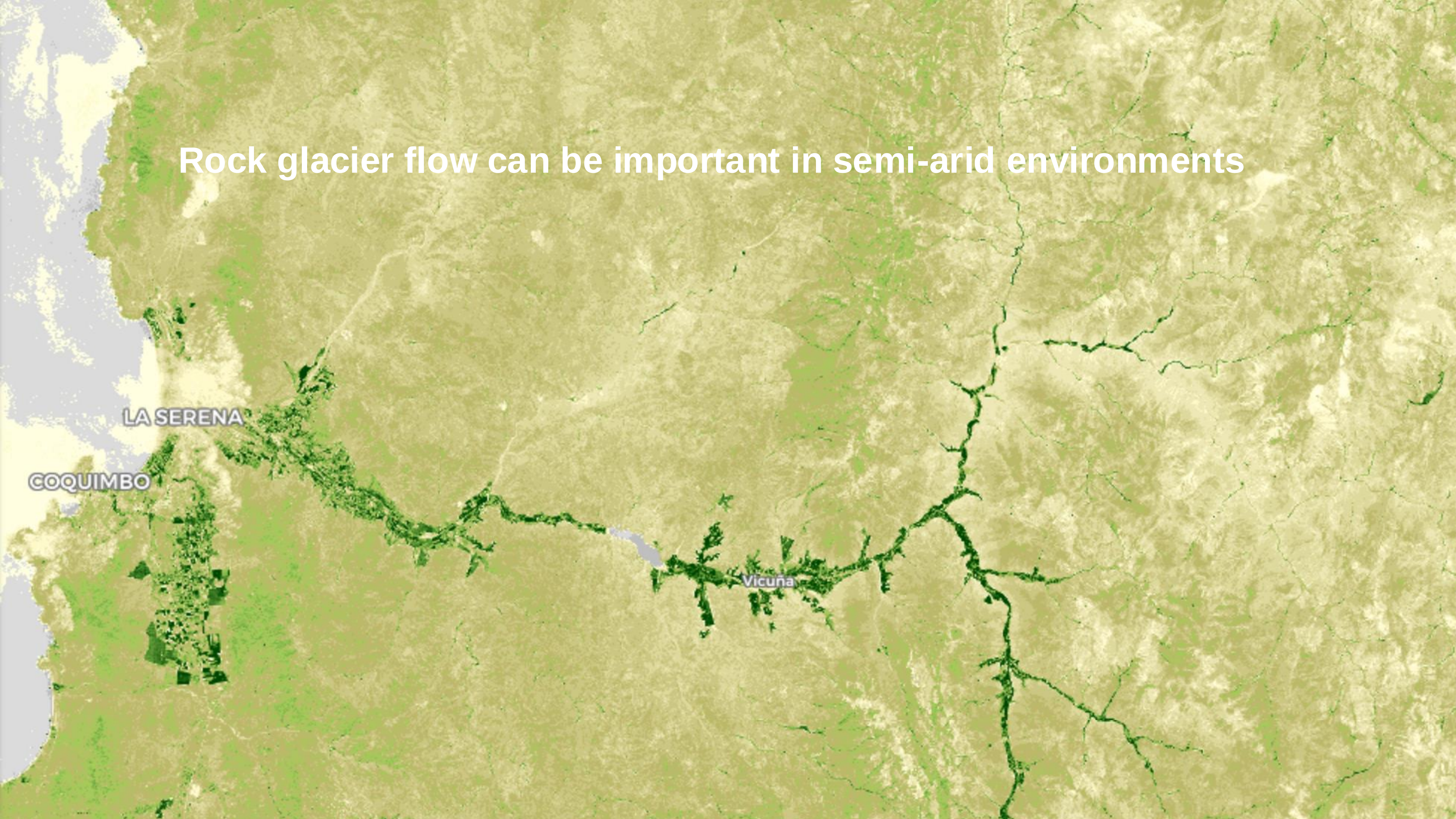
Quantifying rock glacier changes using remote sensing

Projected changes in glacial runoff by 2100

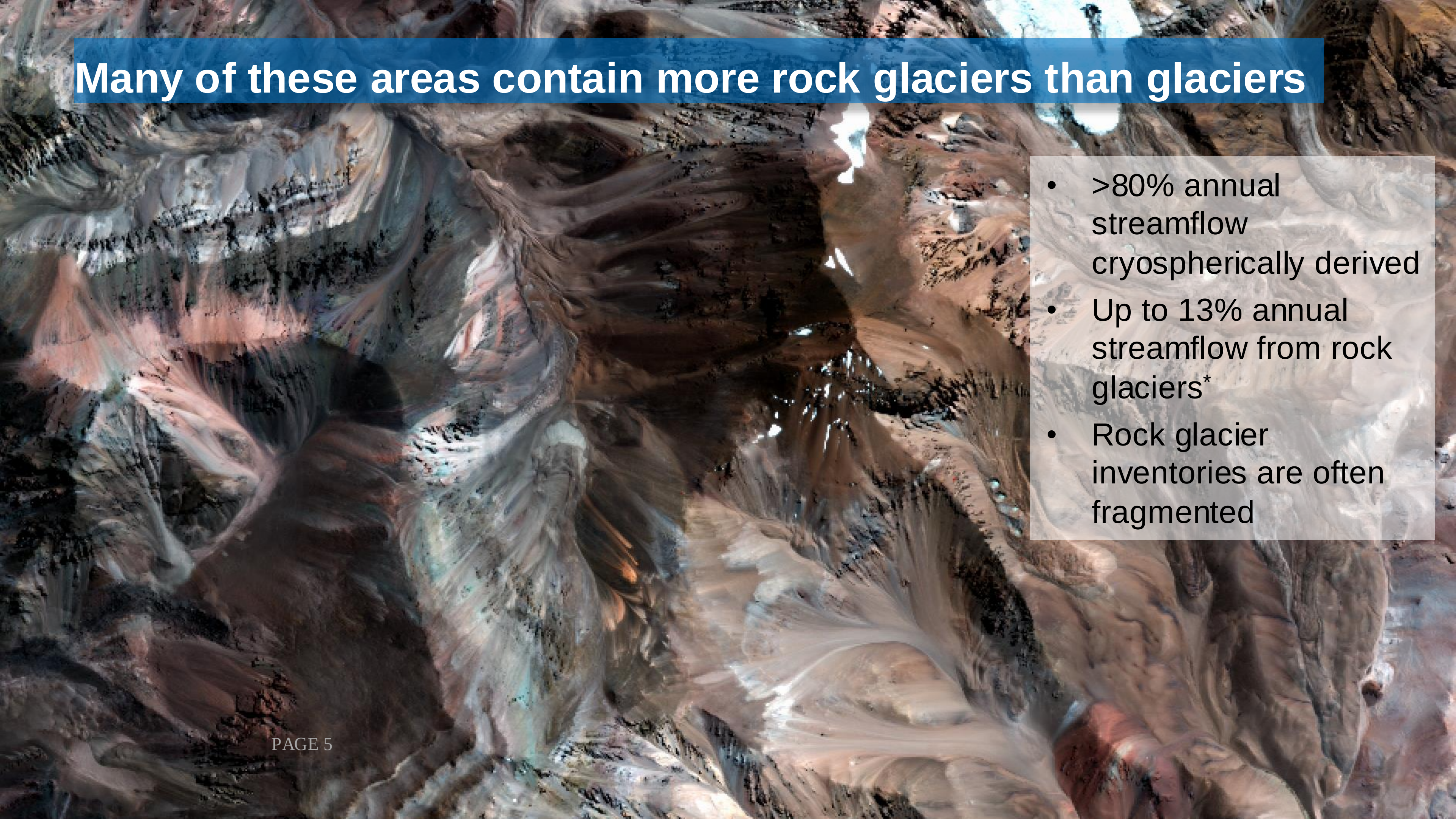


Huss and Hock, 2018

Rock glacier flow can be important in semi-arid environments



Many of these areas contain more rock glaciers than glaciers



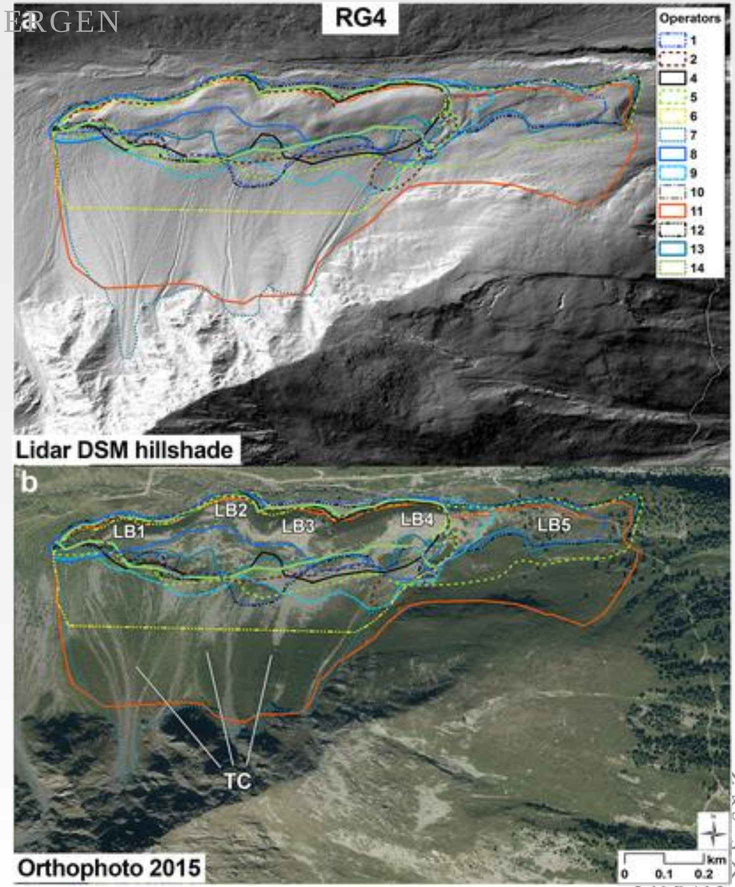
- >80% annual streamflow cryospherically derived
- Up to 13% annual streamflow from rock glaciers*
- Rock glacier inventories are often fragmented

Identifying rock glaciers

Rock glacier mapping uncertainty

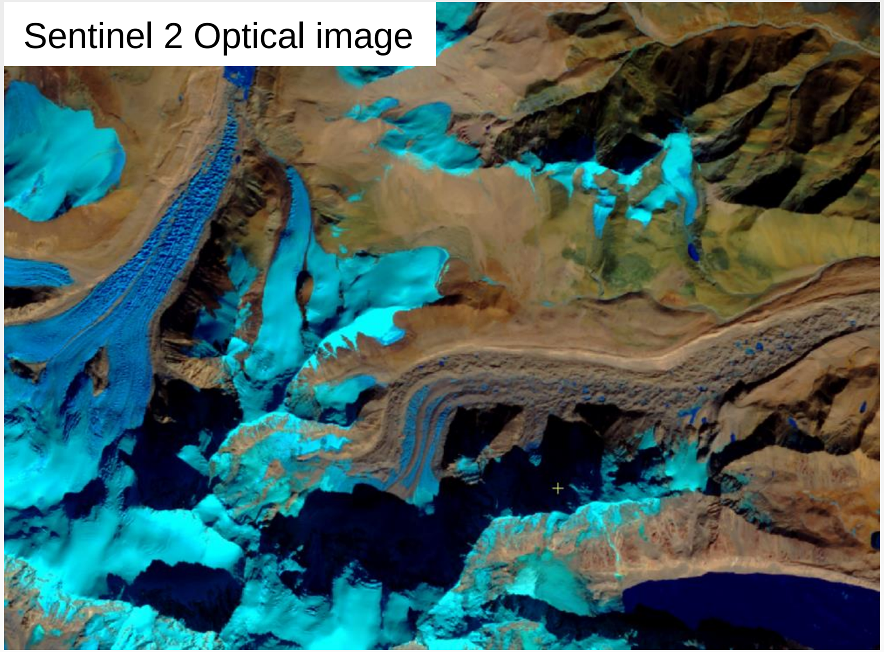
Large subjective biases

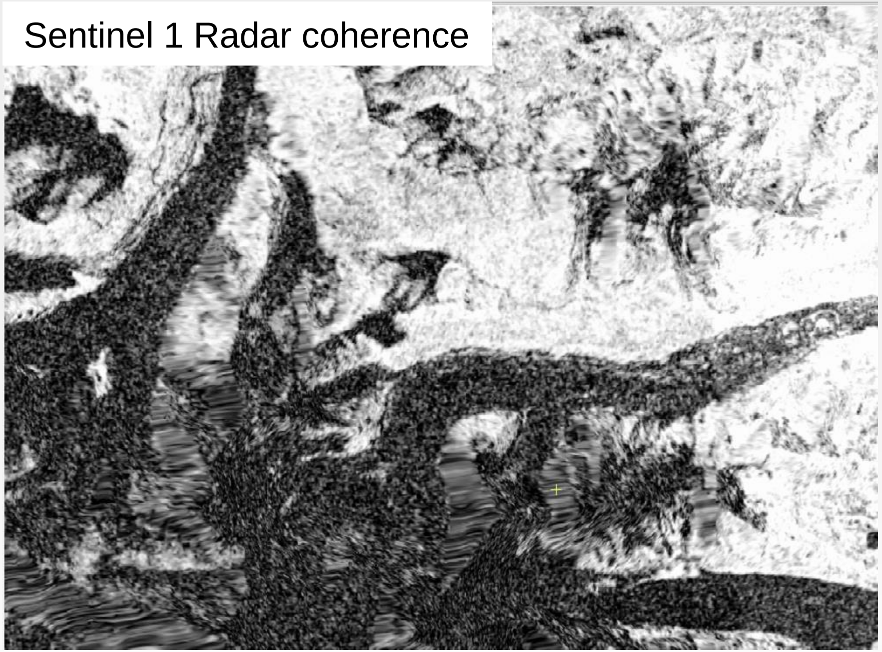
- Up to 70% variation in RG area
- Can machine learning can be used to create a more objective inventory?



Brardinoni et al. 2019

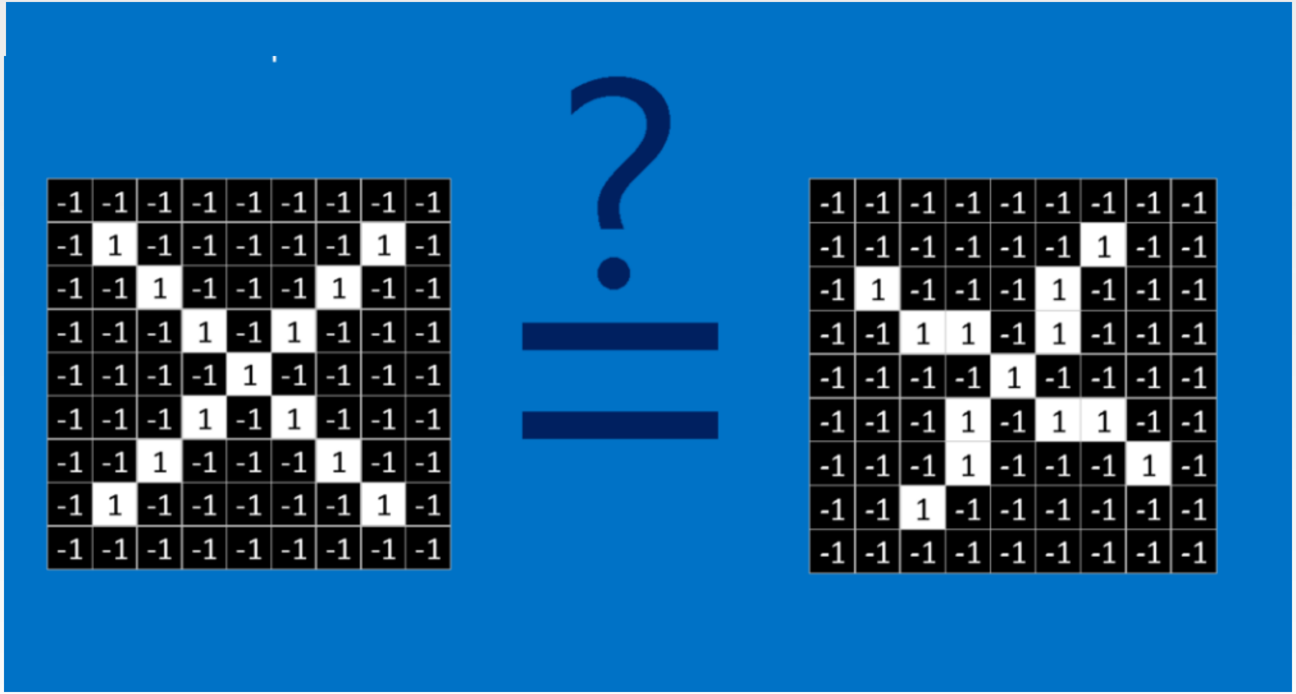
Are methods transferable from other landforms?



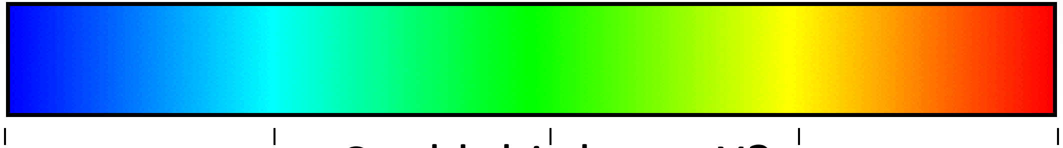


Robson *et al., 2020*

Deep-learning: recognising rock glaciers by their image texture



0% sure this is an X



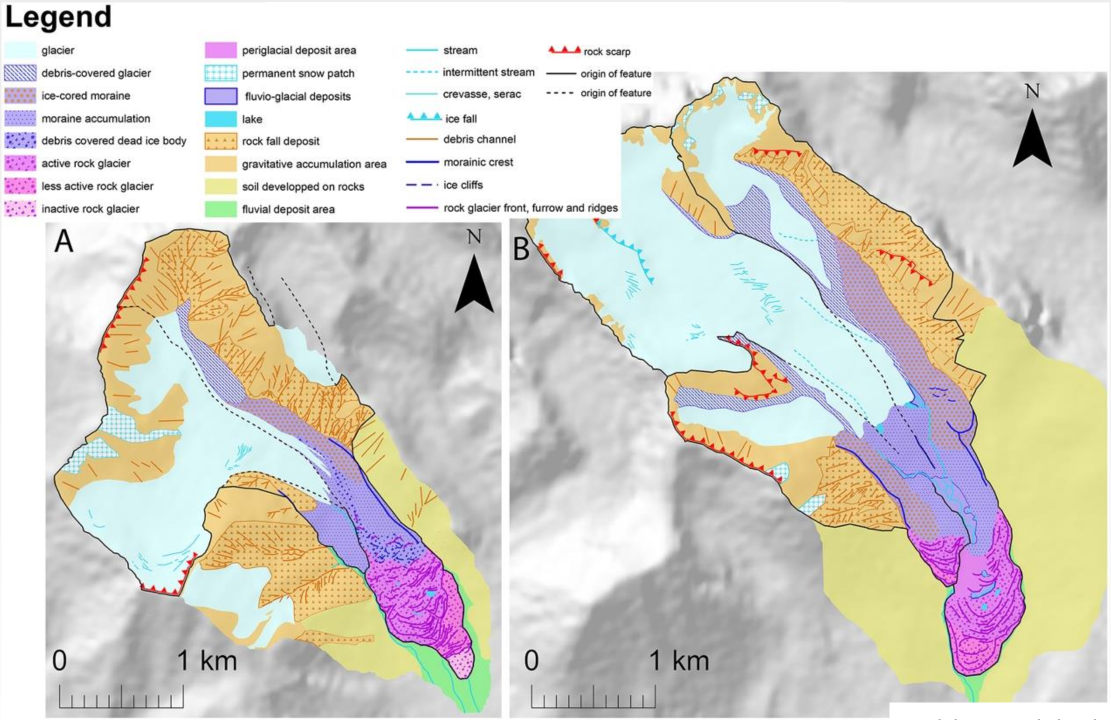
100% sure this is an X

Could this be an X?

Deep-learning: recognising rock glaciers by their image texture

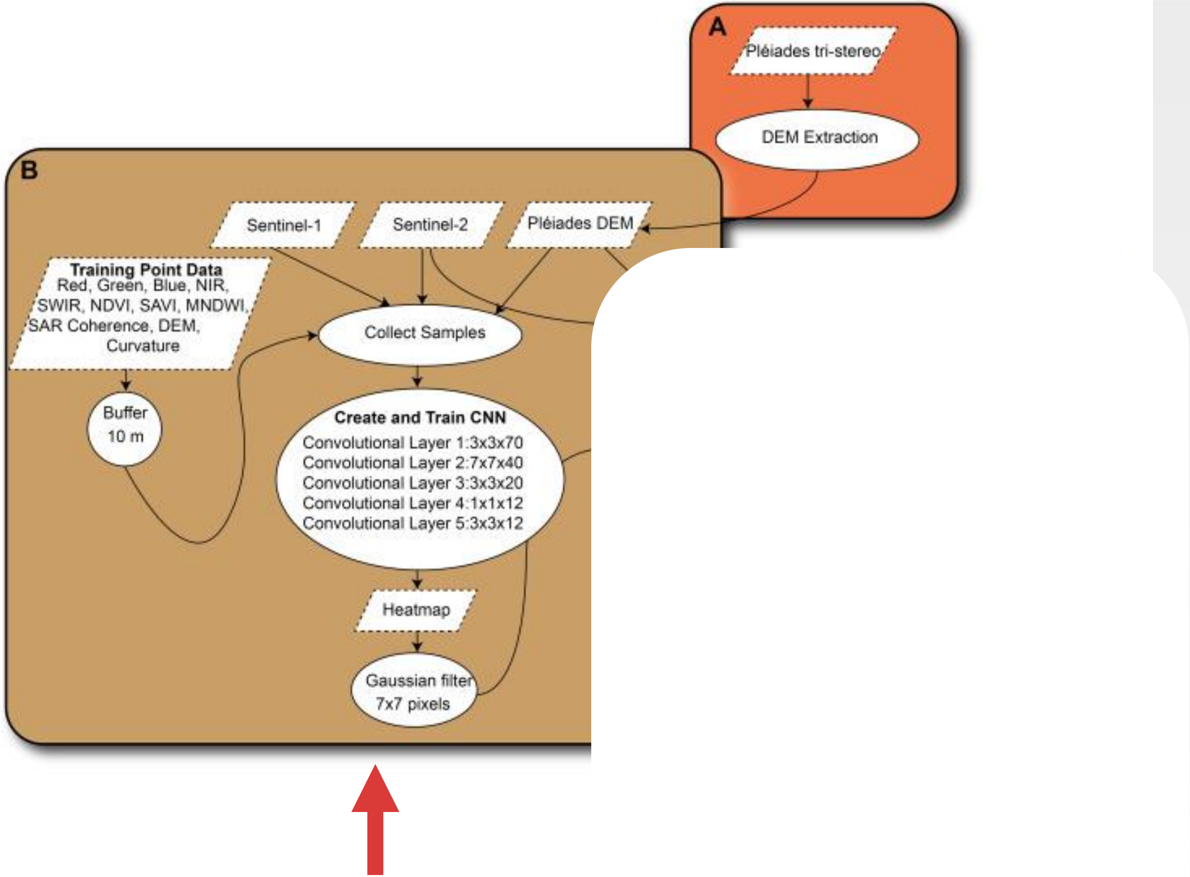
We can create sample patches and train a model to recognise these patterns

Artificial intelligence needs a lot of data to be trained



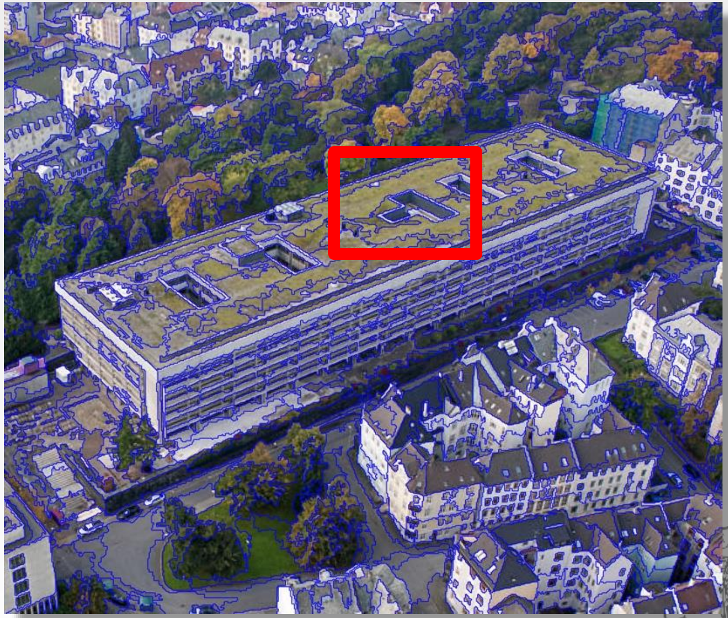
Bolch, T., Rohrbach, N., Kutuzov, S., **Robson**, **B.A.** and Osmonov, A., 2019. Occurrence, evolution and ice content of ice-debris complexes in the Ak-Shiirak, Central Tien Shan revealed by geophysical and remotely-sensed investigations. *Earth Surface Processes and Landforms*, *44*(1), pp.129-143.

PAGE 11

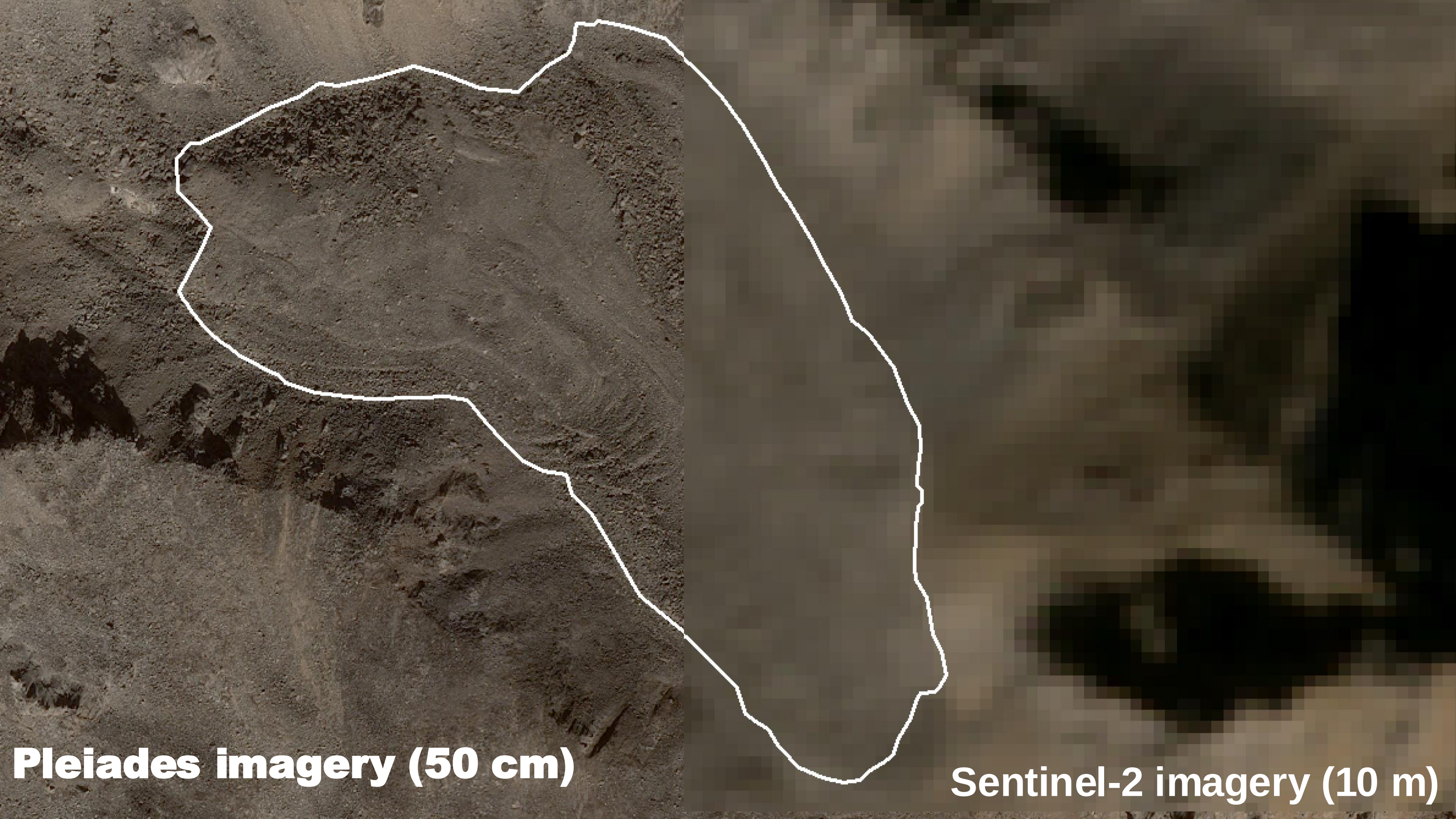


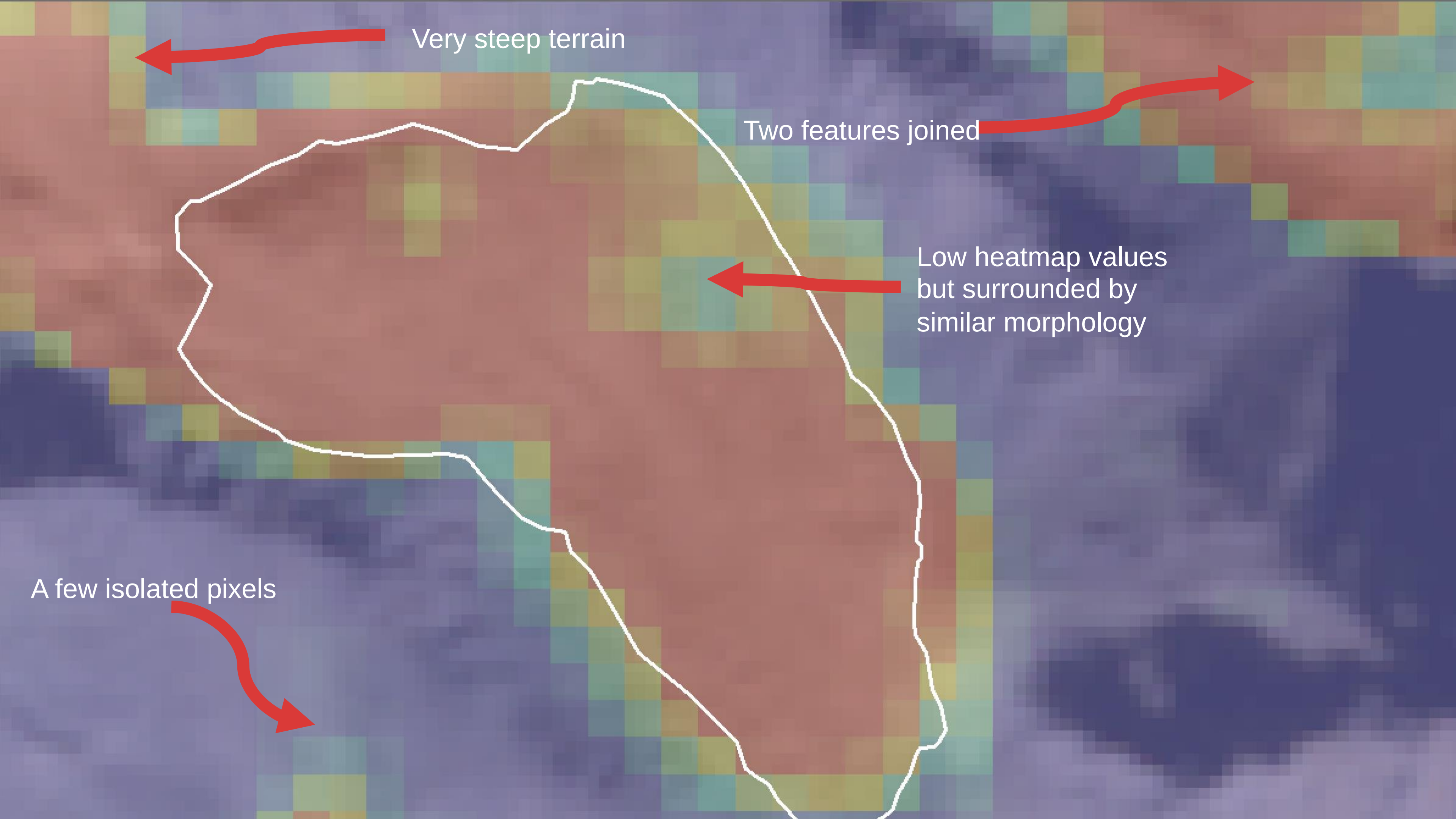
Most deep learning studies stop here

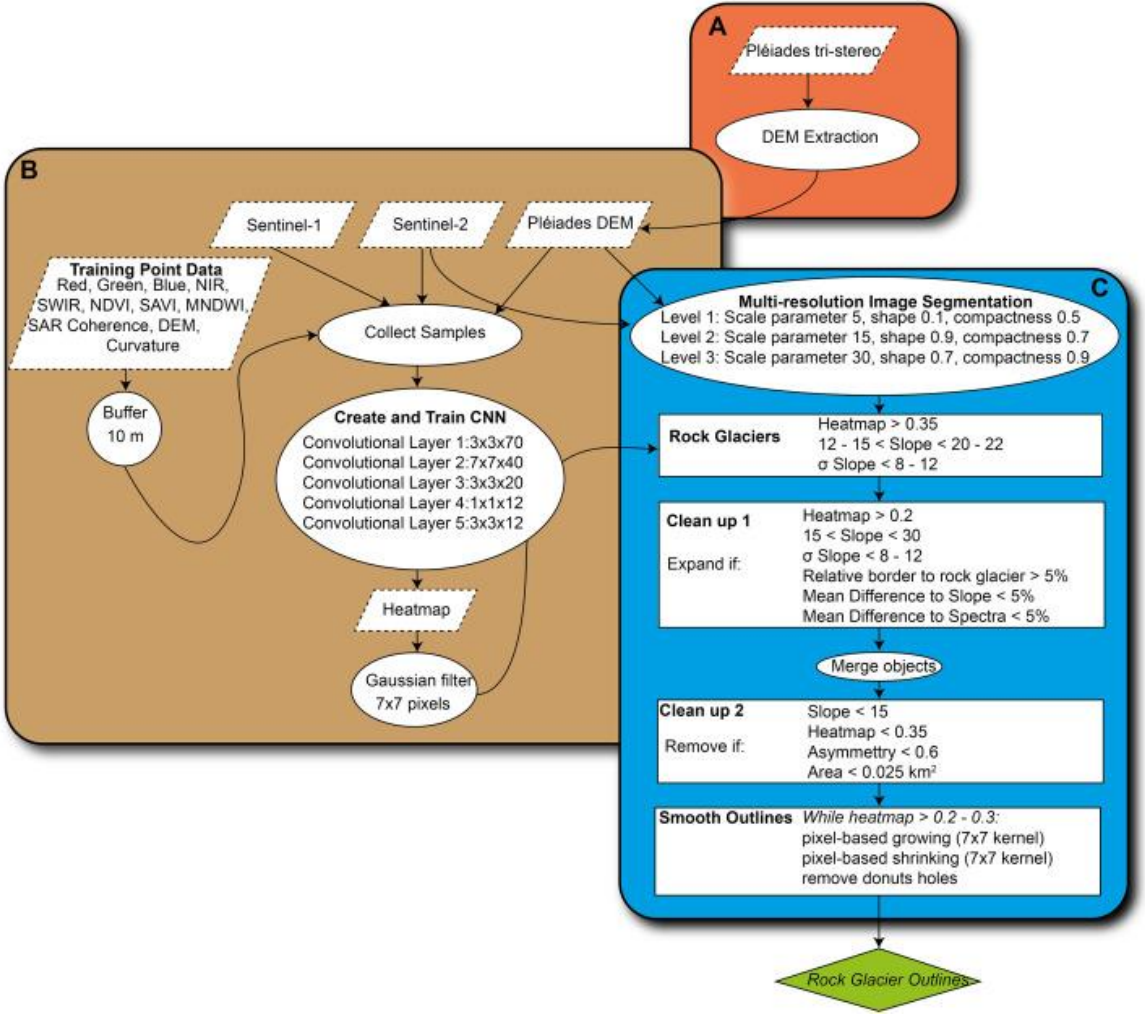
Image segmentation adds more information to a classifications



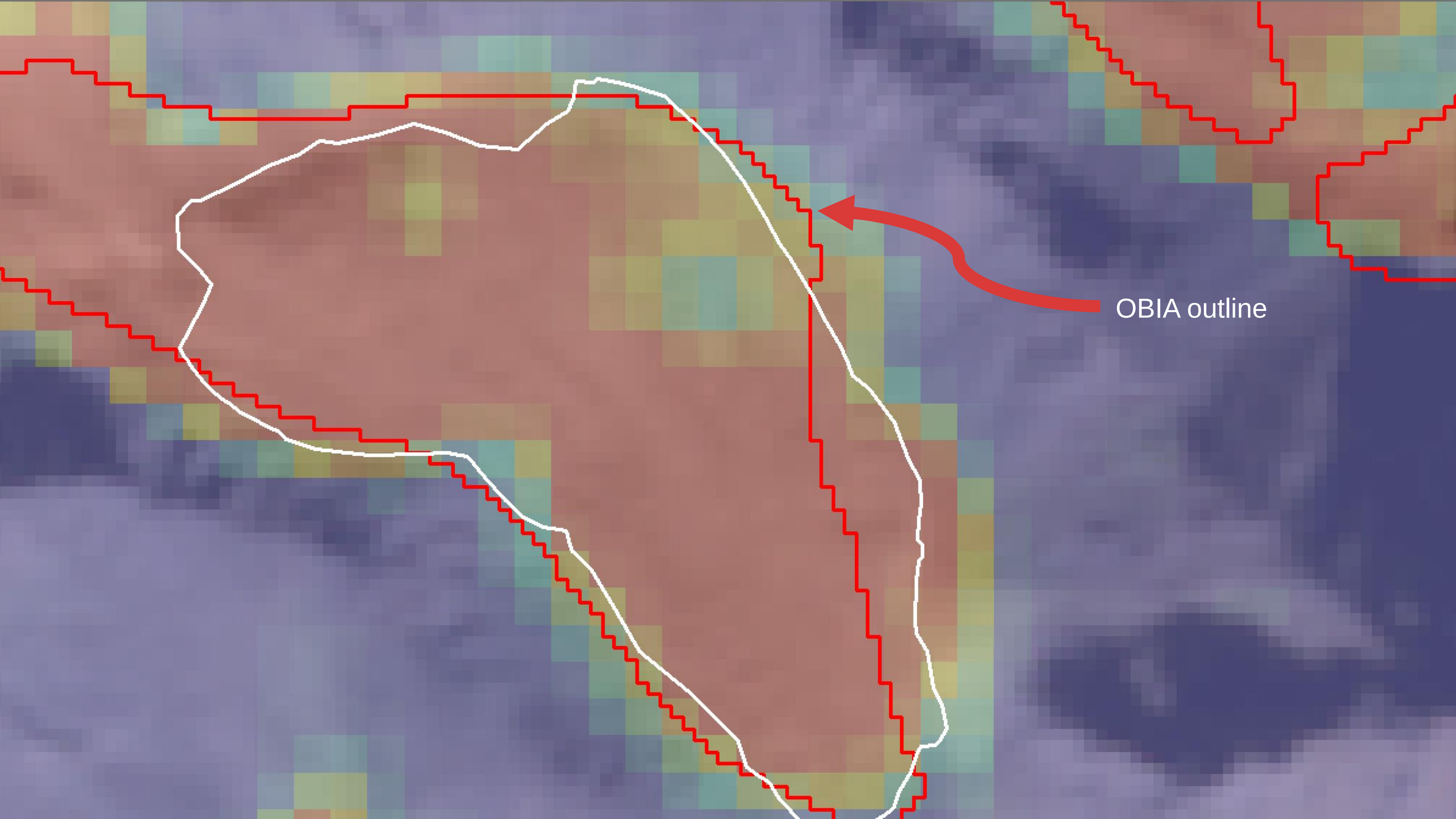
Object Based Image Analysis (OBIA)

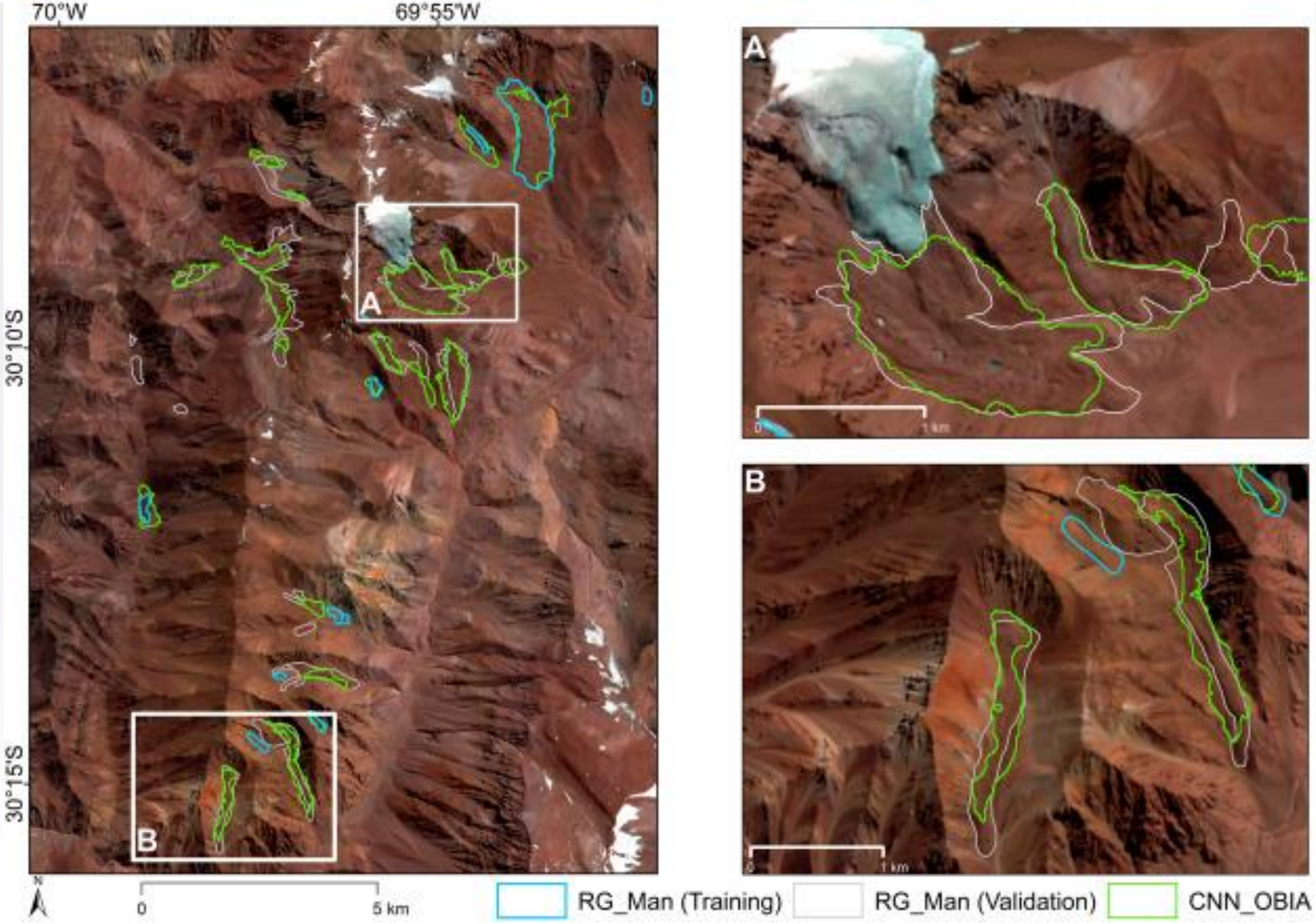

Pleiades imagery (50 cm)
Sentinel-2 imagery (10 m)


Very steep terrain
Two features joined
Low heatmap values
but surrounded by
similar morphology
A few isolated pixels



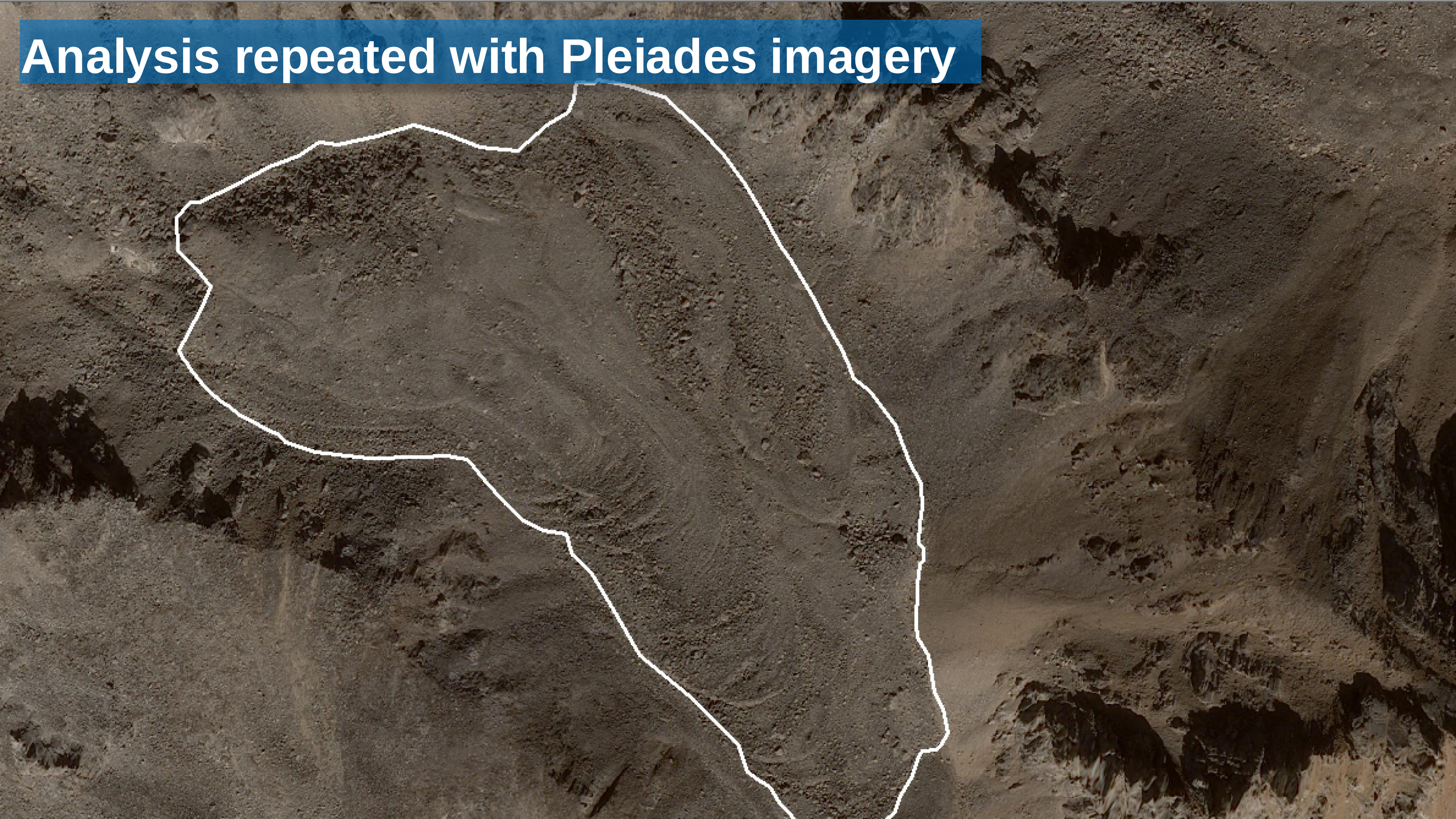
Refinement due to image segmentation

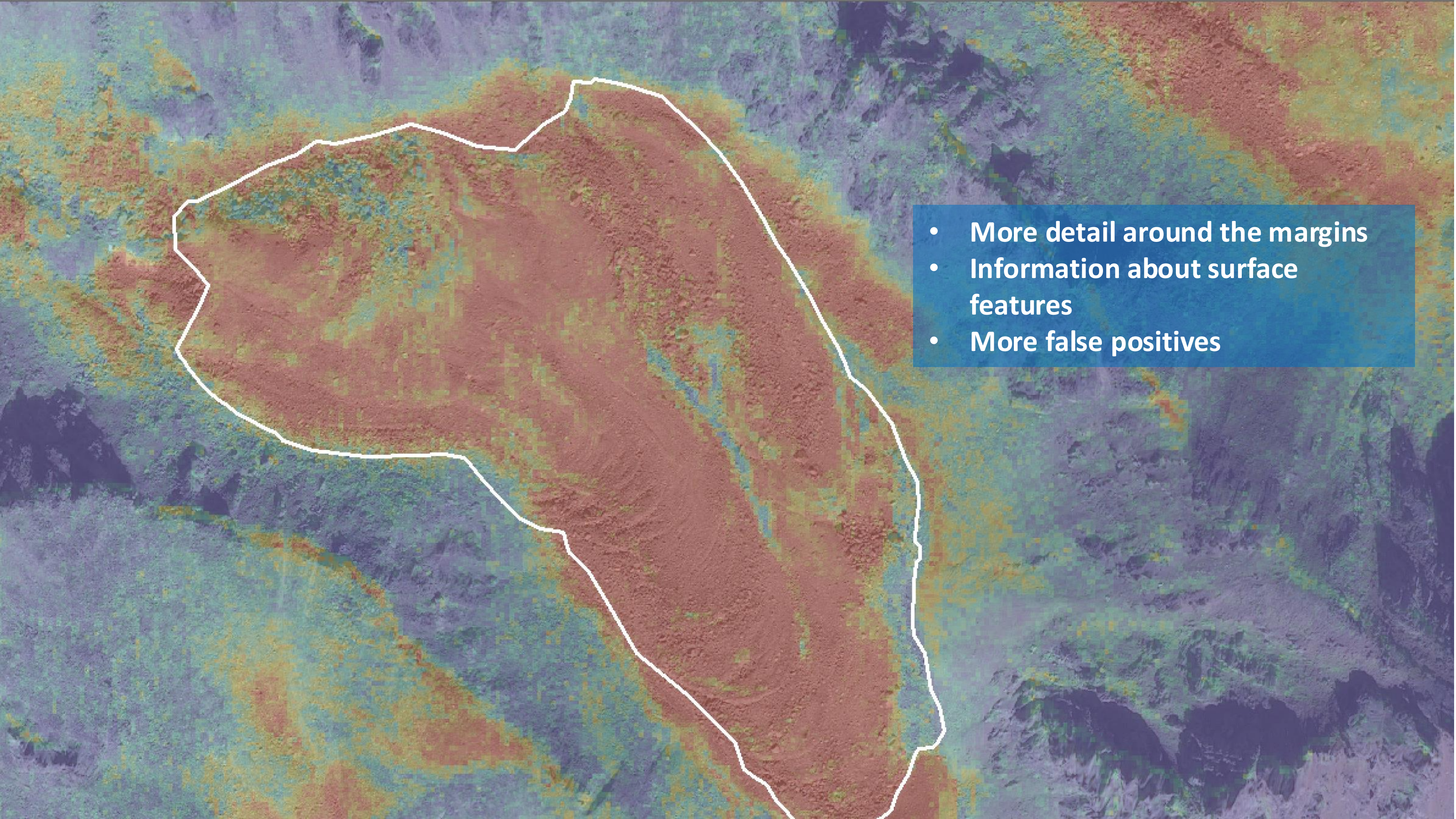

OBIA outline



Robson, B.A., Bolch, T., MacDonell, S., Hölbling, D., Rastner, P. and Schaffer, N., 2020. Automated detection of rock glaciers using deep learning and object-based image analysis. *Remote sensing of environment*, *250*, p.112033.

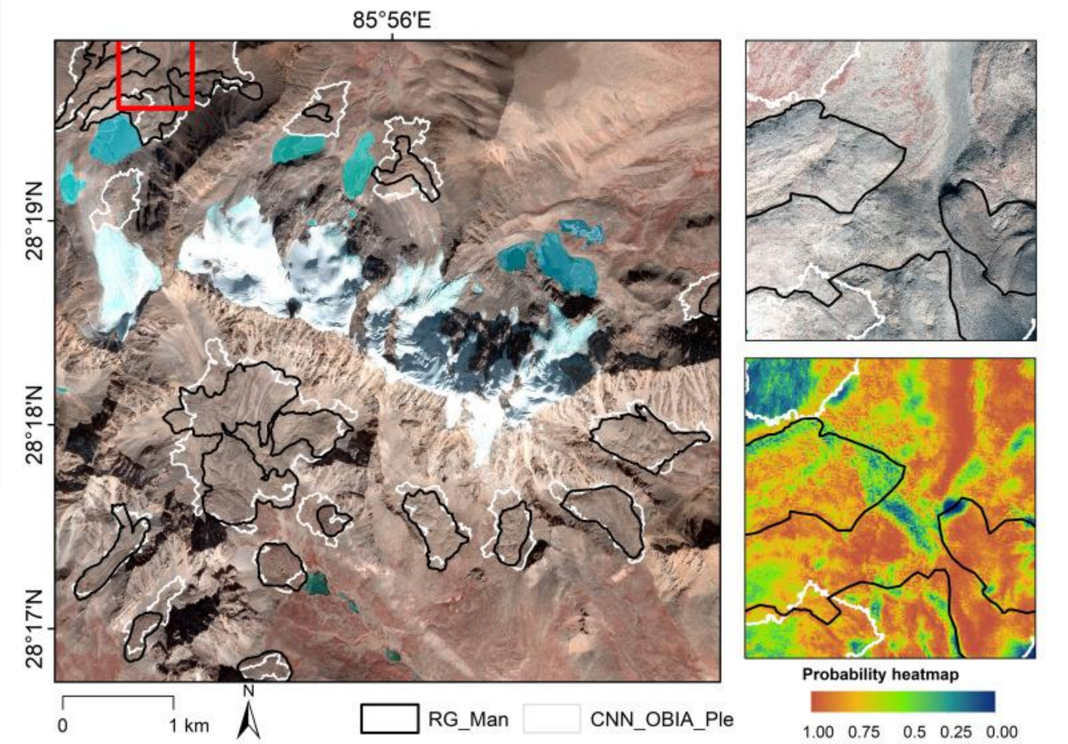
Analysis repeated with Pleiades imagery





- More detail around the margins
- Information about surface features
- More false positives

Using higher-resolution imagery increases the user accuracy



Classification	User accuracy (%)	Producer accuracy (%)
Poiqu subset (Sentinel-2)	62.9	87.4
Poiqu subset (Pléiades)	72.0	88.4

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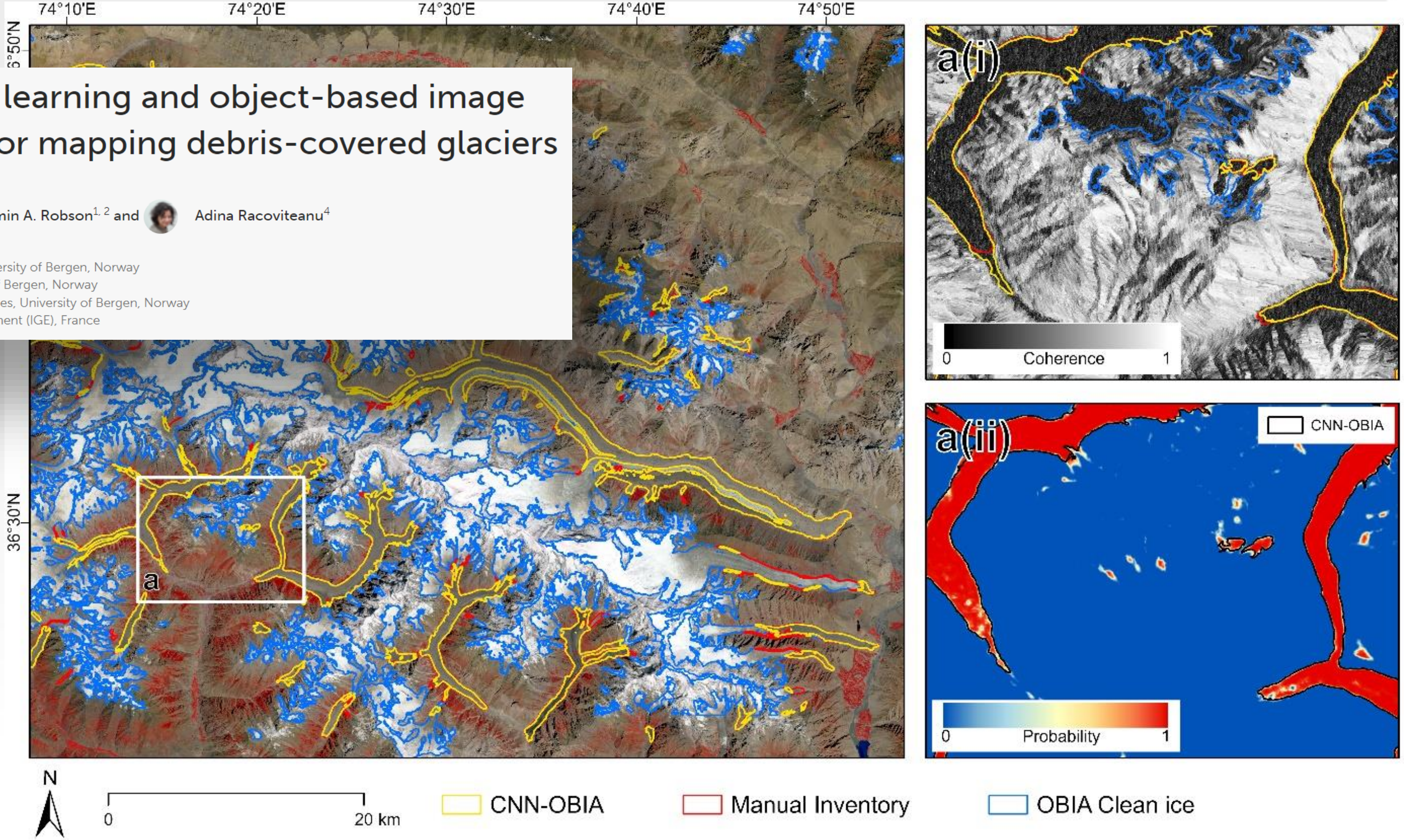
Automated debris-covered glacier mapping

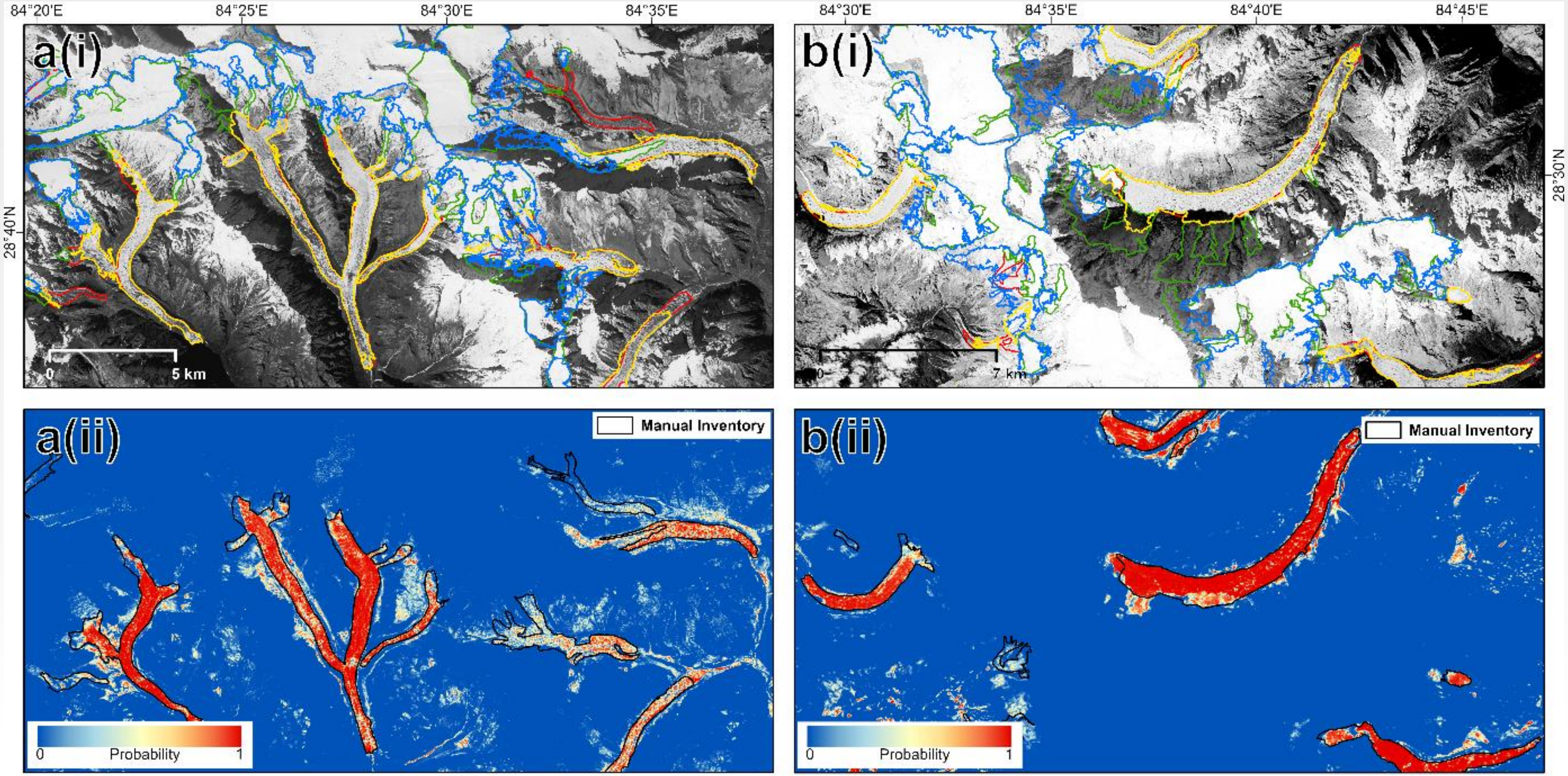
An integrated deep learning and object-based image analysis approach for mapping debris-covered glaciers

Daniel J. Thomas[1, 2, 3*], Benjamin A. Robson[1, 2] and Adina Racoviteanu[4]

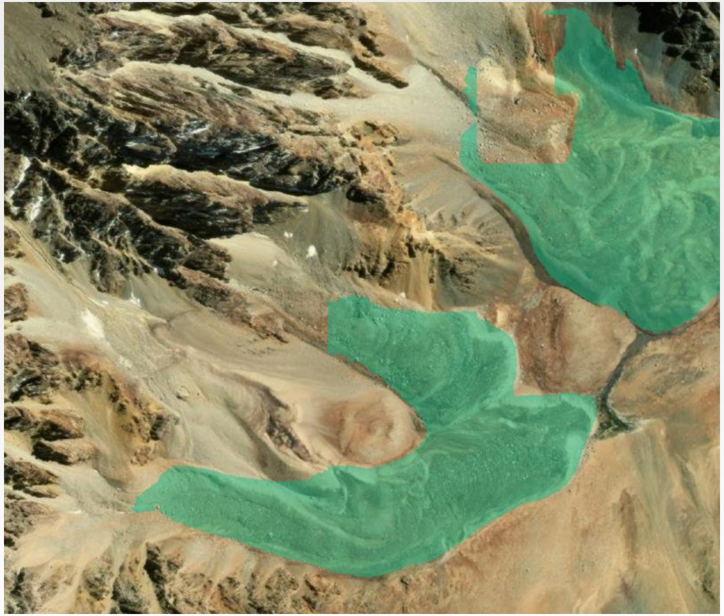
[1] Faculty of Mathematics and Natural Sciences, University of Bergen, Norway
[2] Bjerknes Centre for Climate Research, University of Bergen, Norway
[3] Department of Geography, Faculty of Social Sciences, University of Bergen, Norway
[4] UMR5001 Institut des Géosciences de l'Environnement (IGE), France



Deep learning for multi-temporal analysis



Scaling up to a regional scale

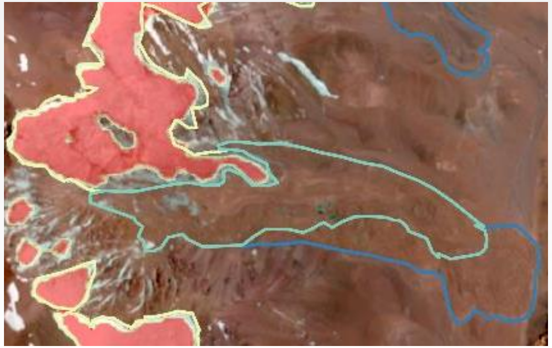


- DeepLabV3 improves image segmentation accuracy through atrous convolution and multi-scale context.
- Used to produce Tibetan Plateau RG inventory (TroGI) (Sun et al, 2024)
- Retrained and being applied to the Andes (PhD thesis Daniel Thomas)

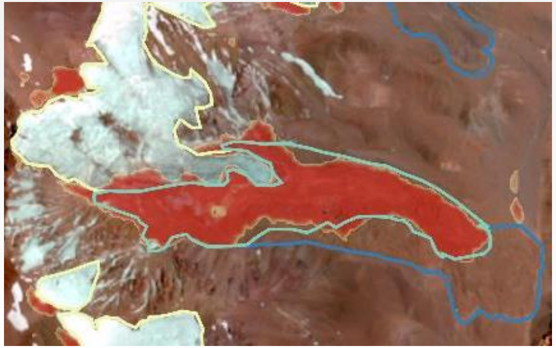
Future directions of AI-based mapping

- Multi-class deep learning for cryospheric mapping in the Andes
  Daniel Thomas – PhD student at UiB
- Trustworthyness and ground truthing of AI-based mapping
  Sunil Tamang – PhD student at UC/GRI

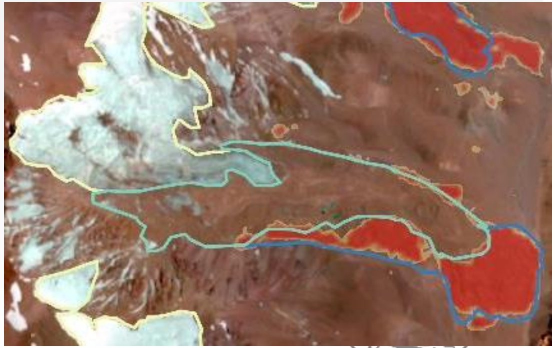
Heatmap – clean ice



Heatmap – debris-covered ice

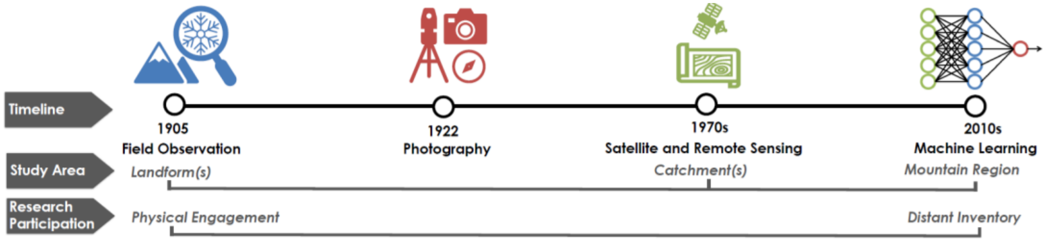


Heatmap – rock glaciers



Clean Ice Manual Inventory
Debris-covered Ice Manual Inventory
Rock Glacier Manual Inventory

Trustworthiness and Ground-Truthing of Machine Learning Approach for Regional Scale Rock Glacier Inventories



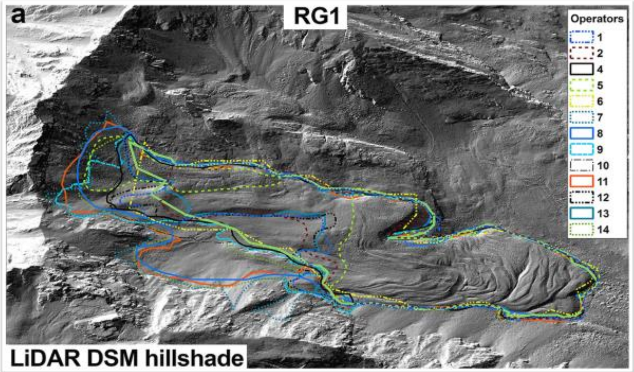


Figure adapted with permission from Brardinoni et al. (2019).

Practices of Rock Glacier Inventory

Subjectivity in Rock Glacier Inventory

Sunil TAMANG
PhD Candidate
University of Canterbury, New Zealand
sunil.tamang@pg.canterbury.ac.nz

Quantifying changes using remote sensing data

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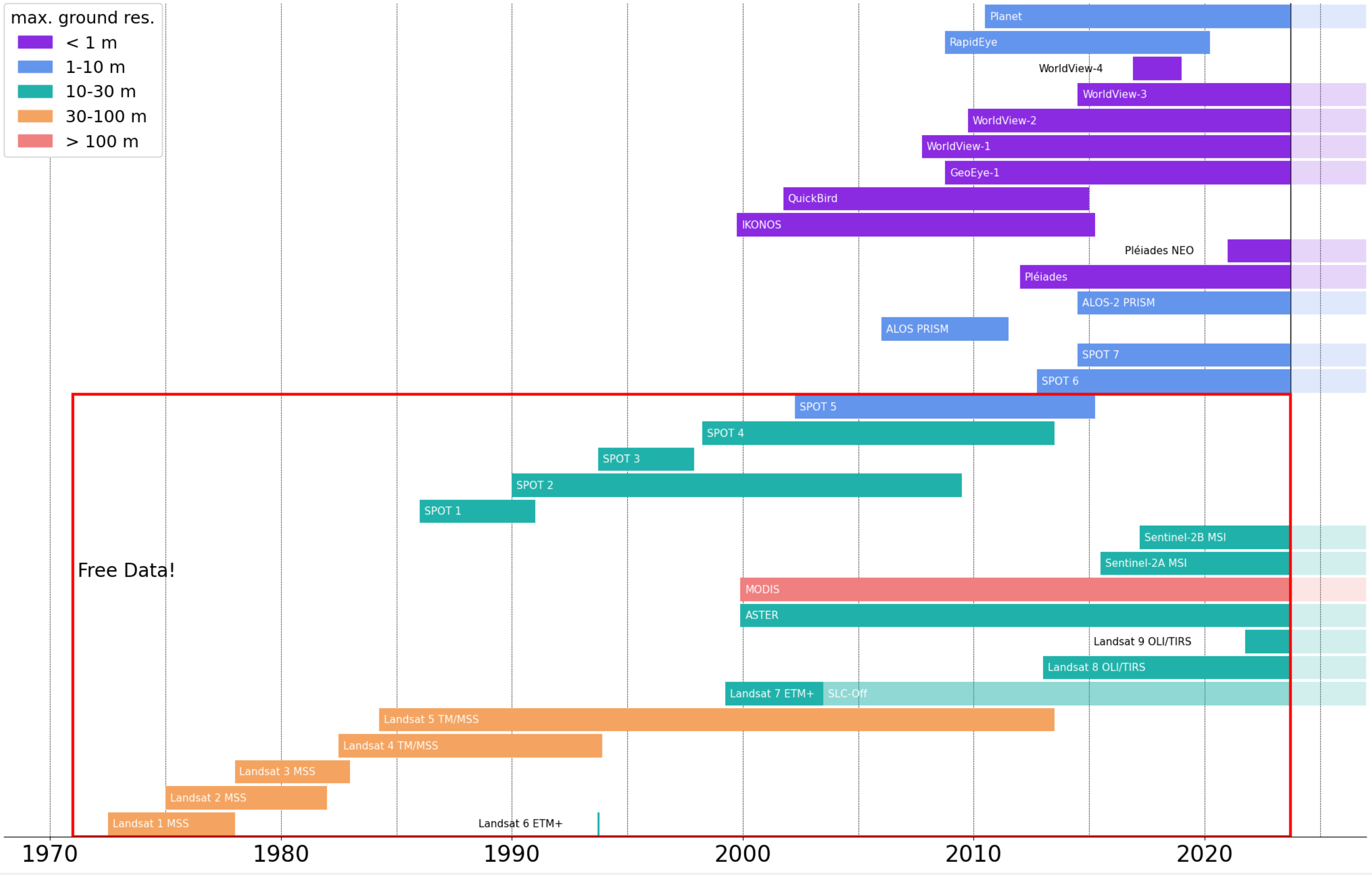
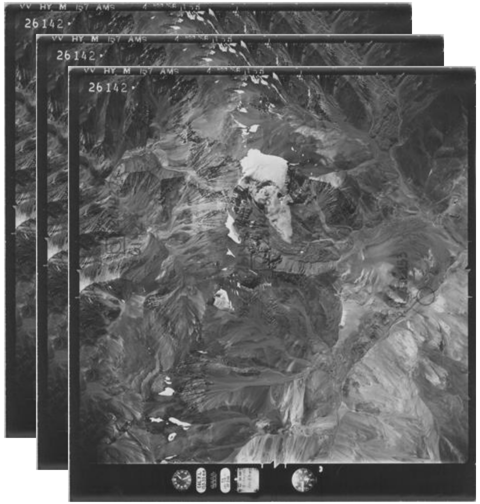


Data available for studying rock glacier change

Terrestrial Laser scanning

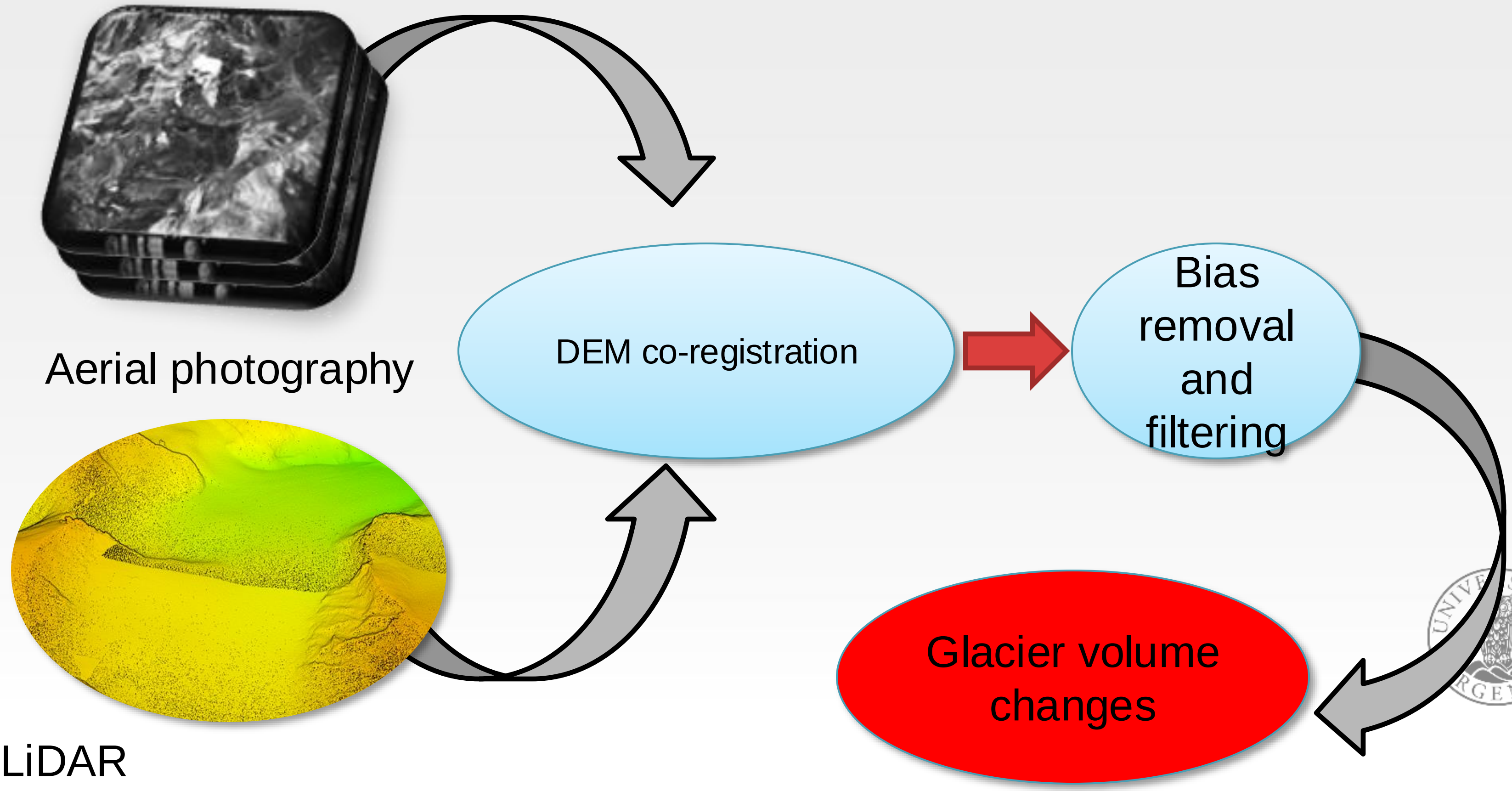


Historical Aerial Photography

Stereo Satellite Imagery

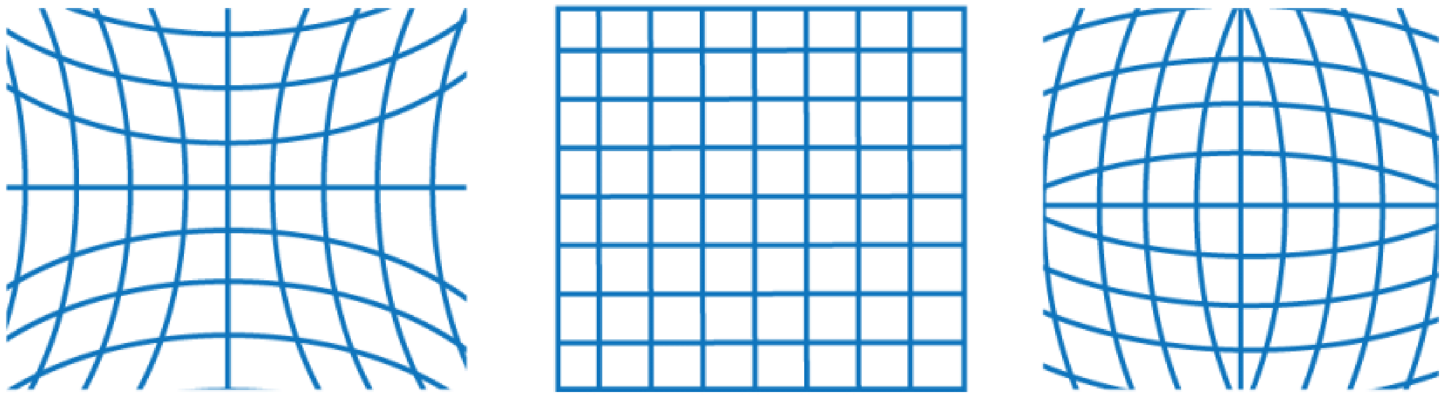
UAVs

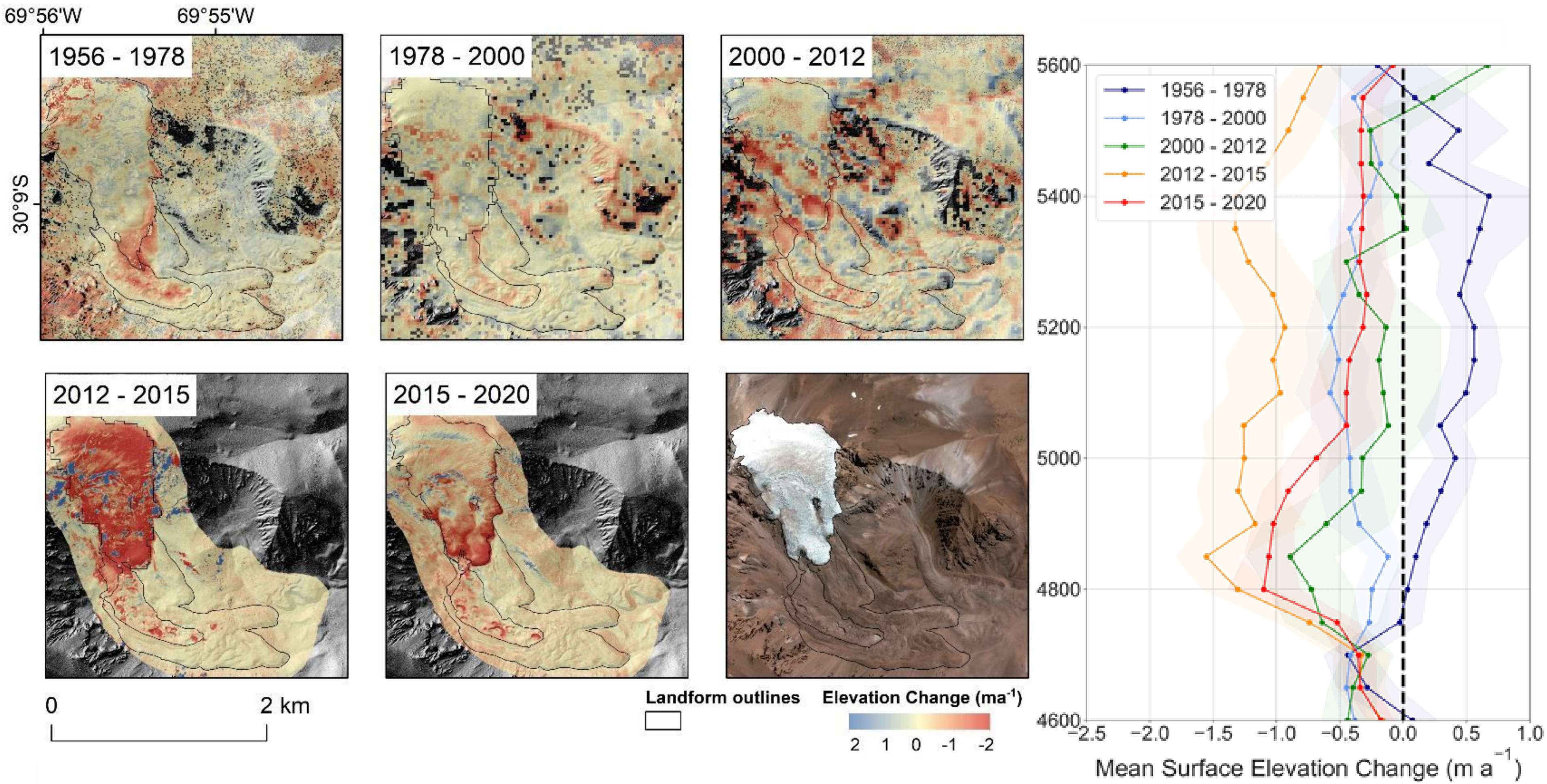
Methods


Aerial photography
LiDAR
DEM co-registration
Bias removal and filtering
Glacier volume changes

Problems with the data

- Aerial photographs had no camera calibration report
  - Focal length written on the photographs
  - Fiducial marks can be estimated (ish)
  - …radial lens distortion?



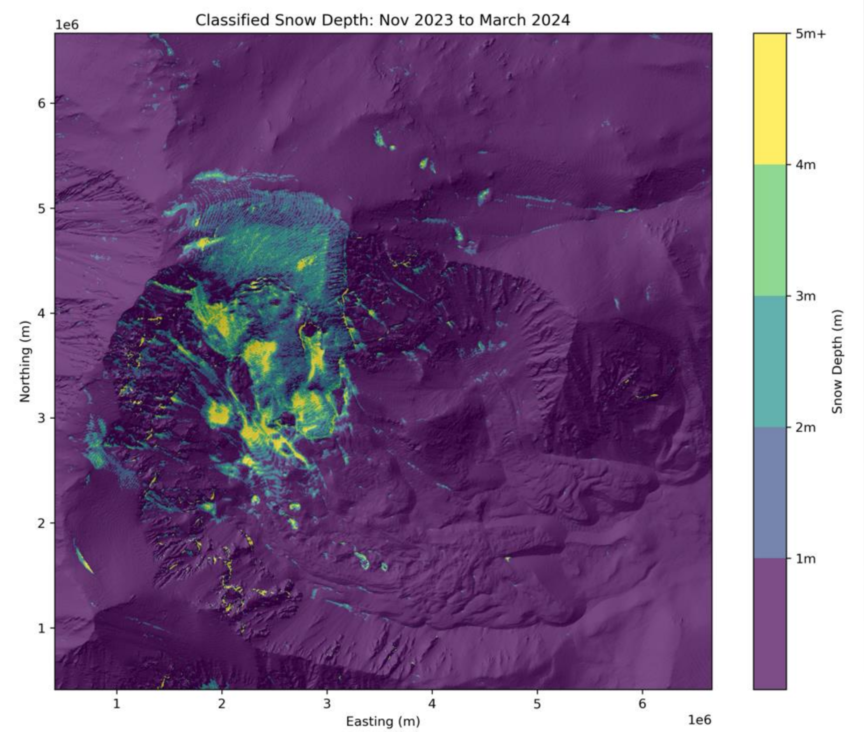


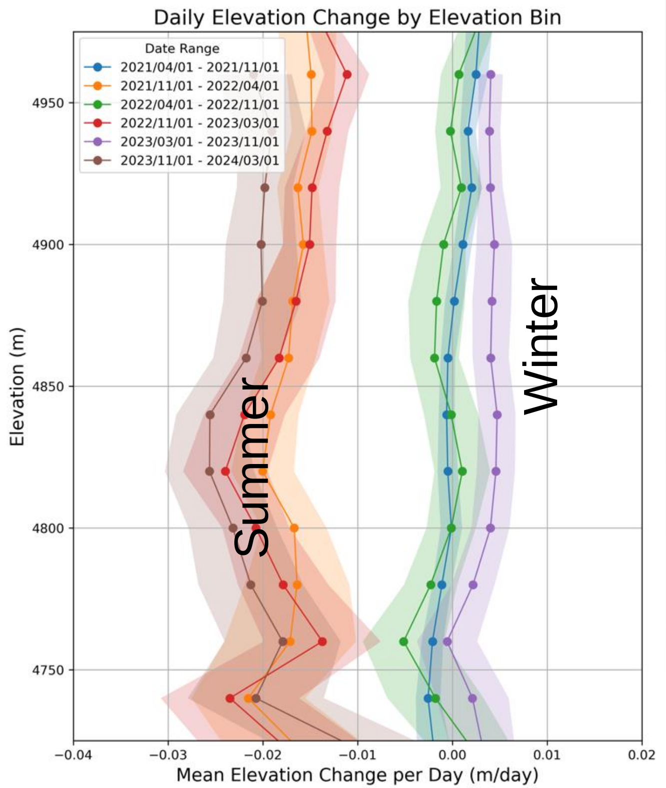
Robson, B.A., MacDonell, S., Ayala, Á., Bolch, T., Nielsen, P.R. and Vivero, S., 2022. Glacier and rock glacier changes since the 1950s in the La Laguna catchment, Chile. *The Cryosphere*, *16*(2), pp.647-665.

UAV-based analysis for seasonal monitoring

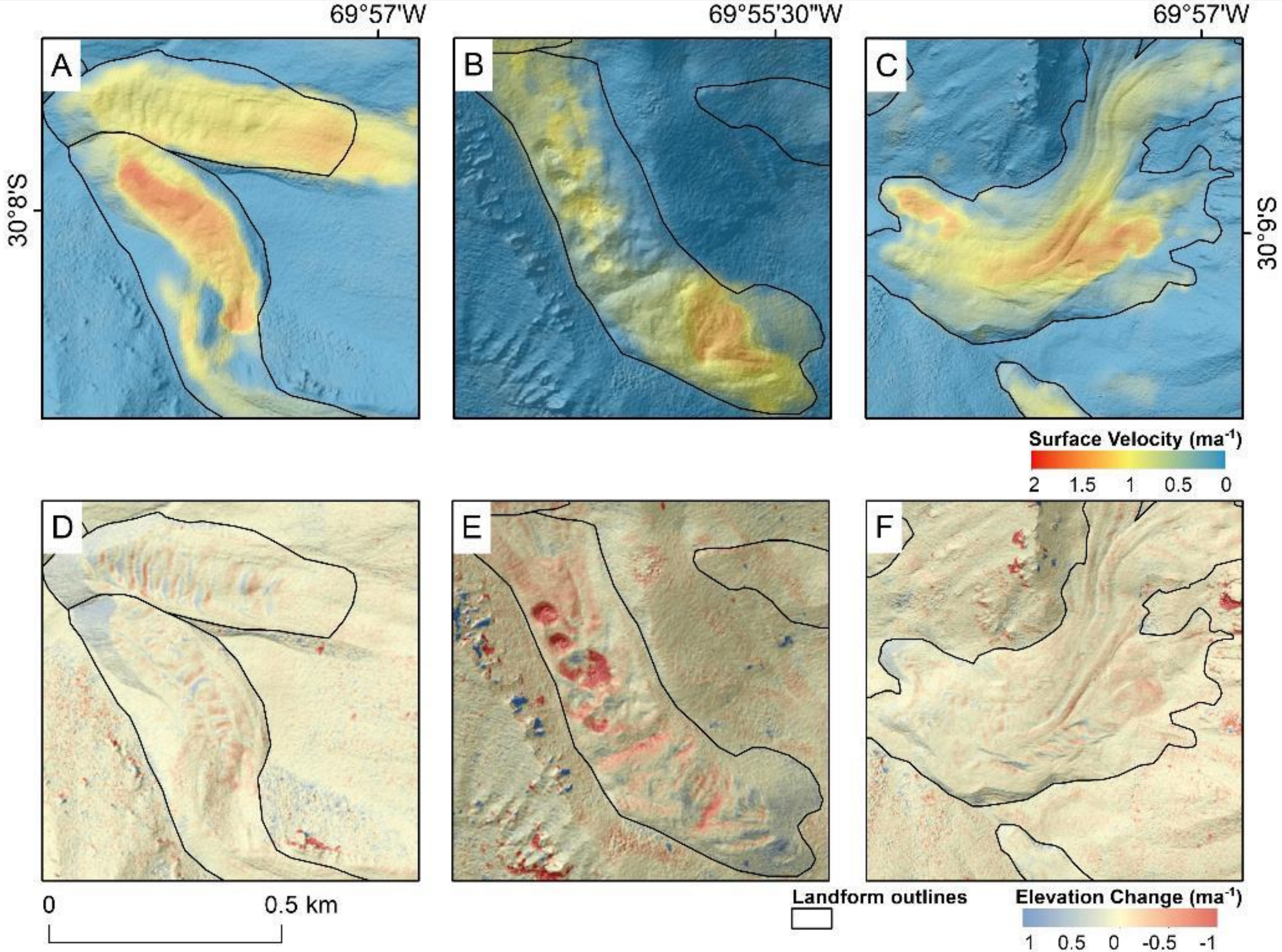
Data collected by Gonzalo Navarro

High-resolution seasonal changes

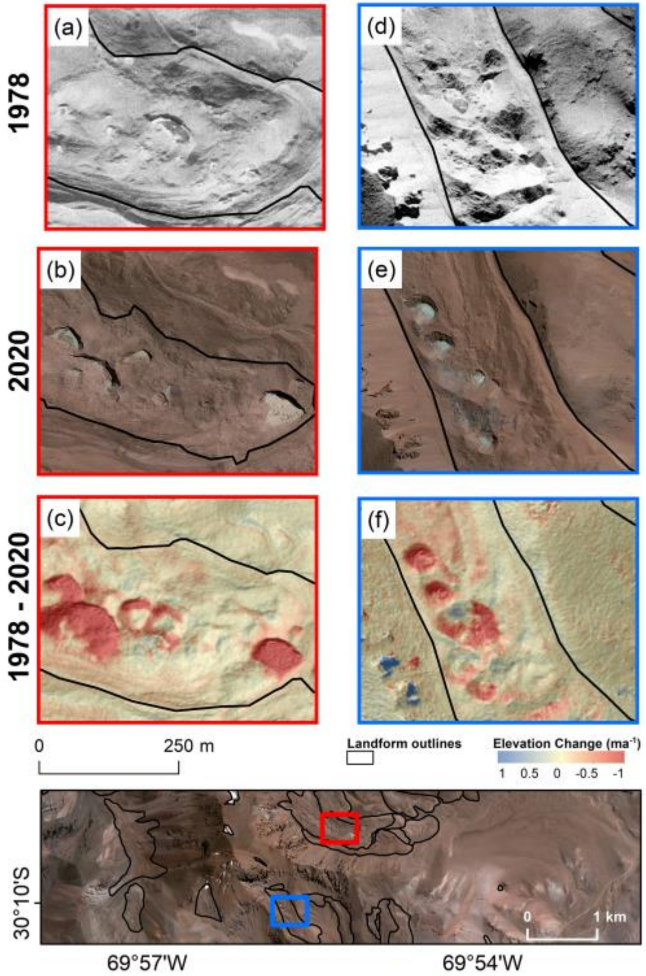


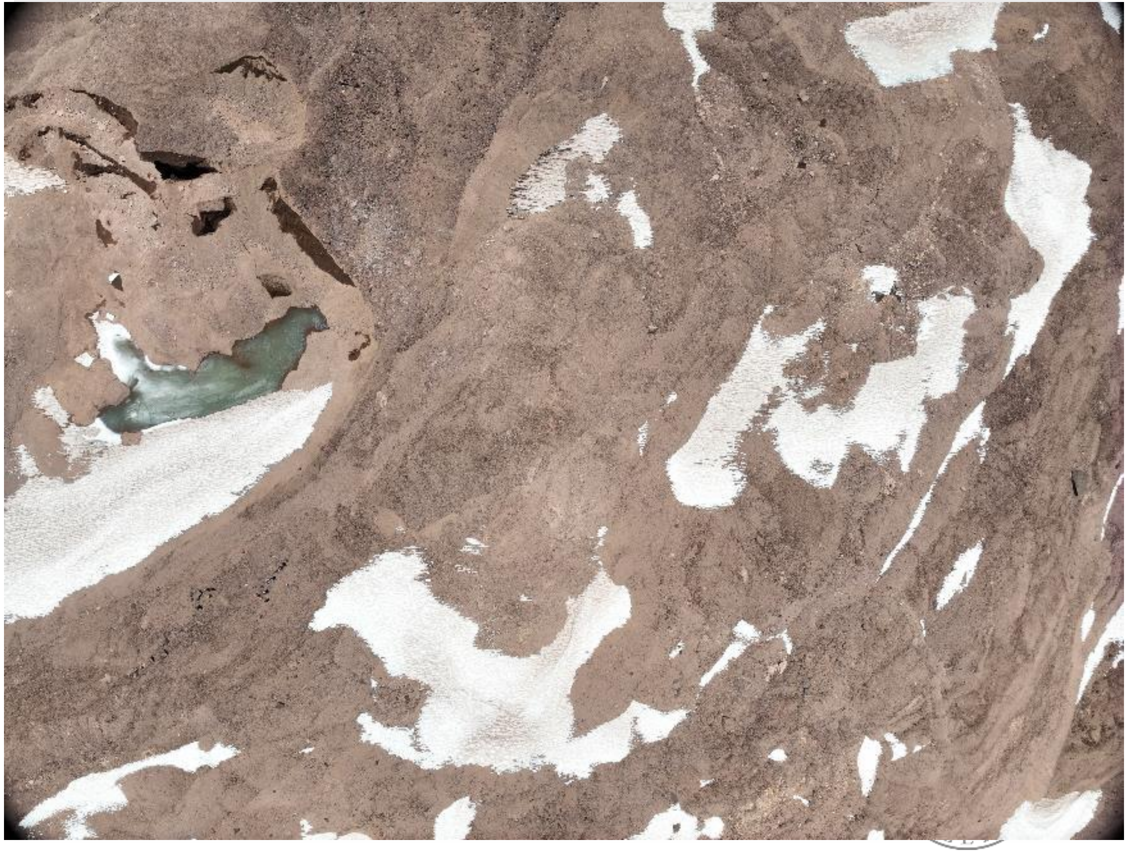


Rock glacier changes in the catchment

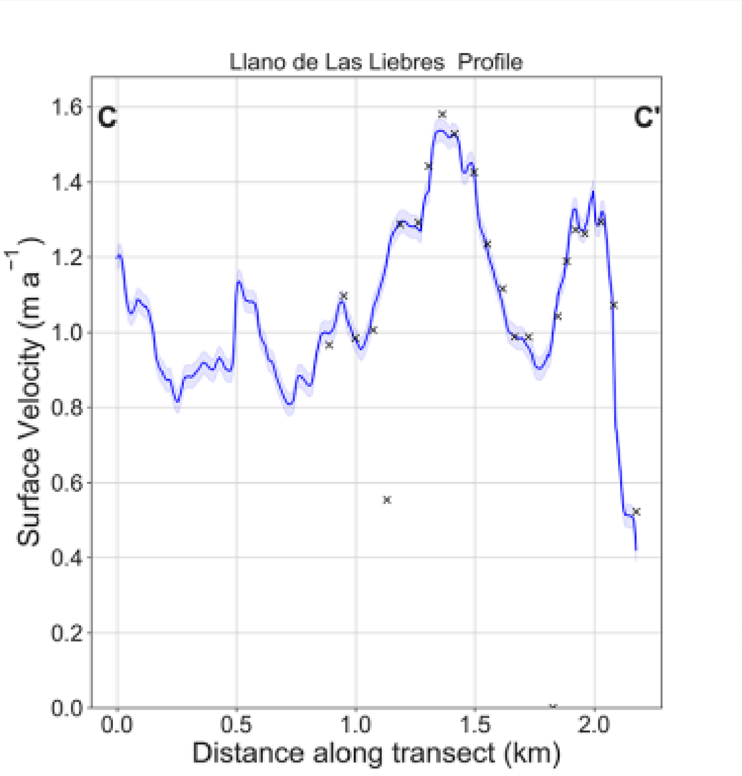


Evidence of glacier-rock glacier transition

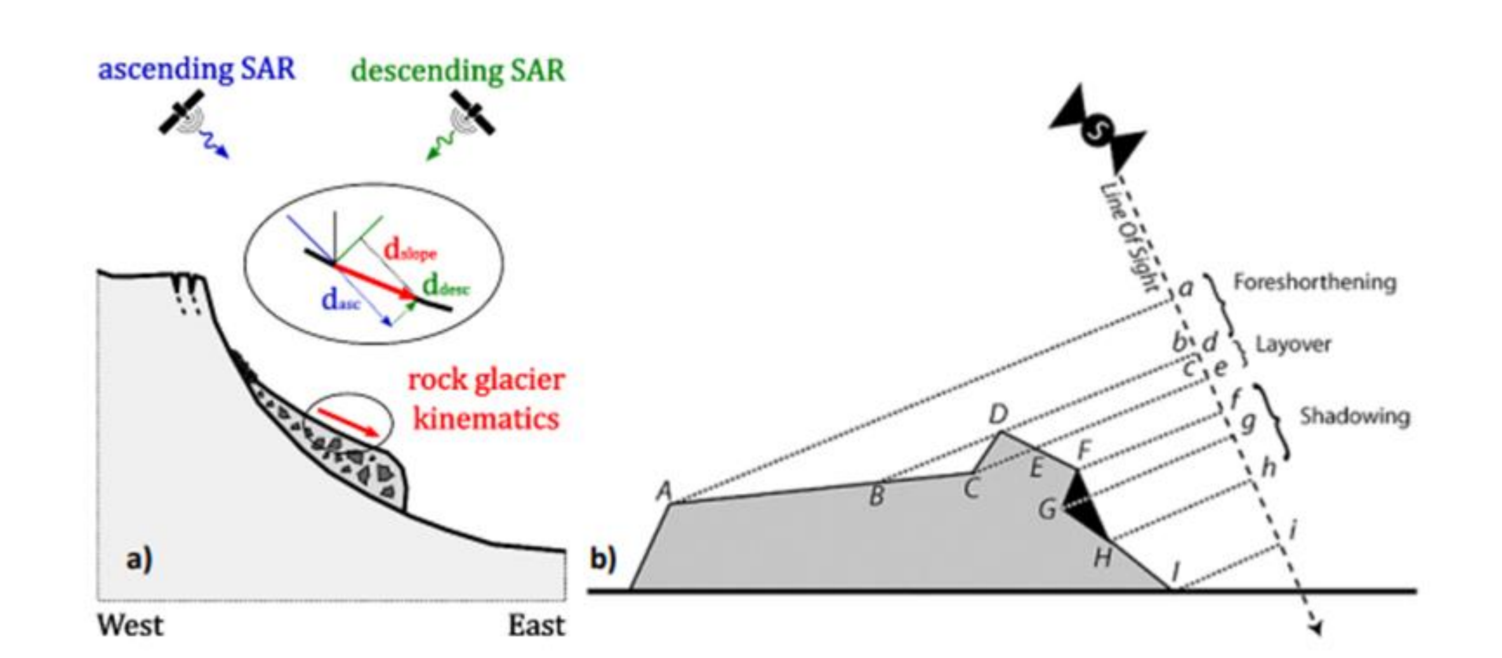




Validation of velocity data

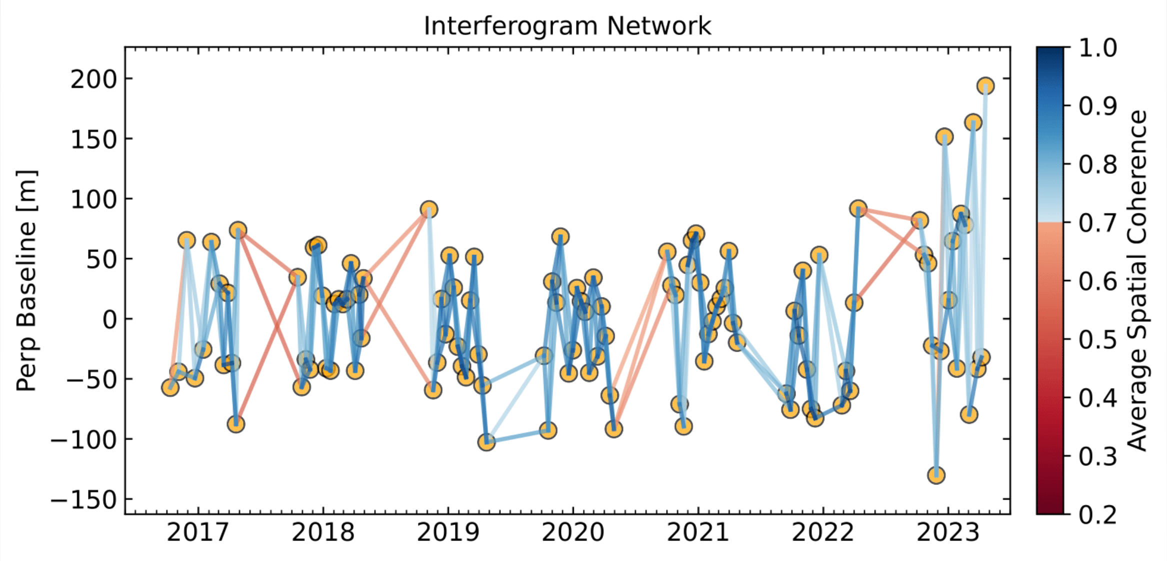


InSAR Analysis of rock glaciers



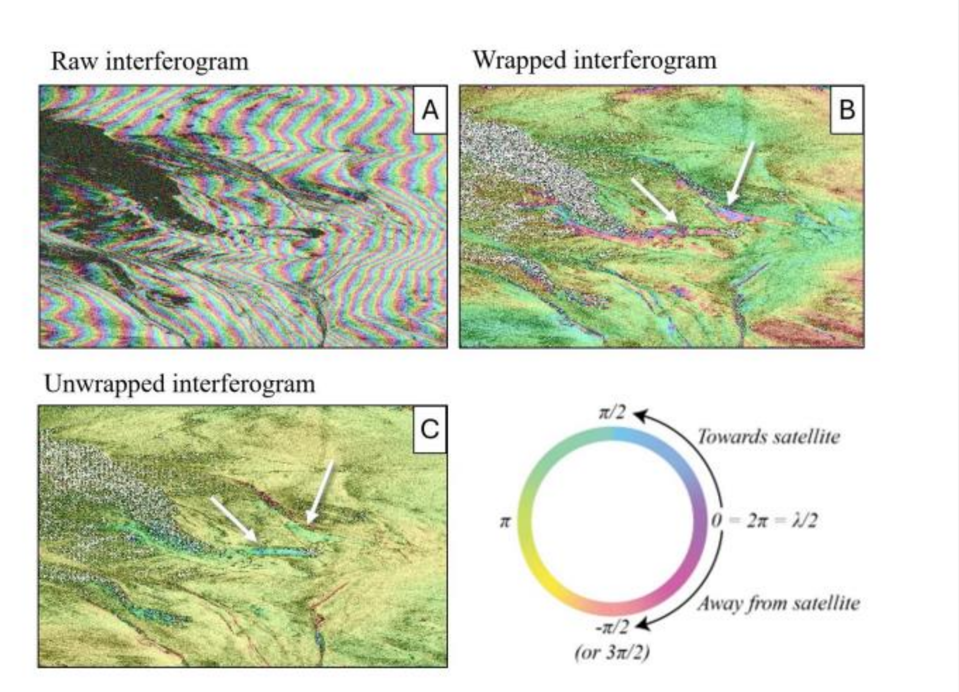
InSAR Analysis of rock glaciers

- Study areas: Manaslu (Himalaya) and Semi Arid Andes (Chile)
- Sentinel-1 InSAR processing in ISCE
- SBAS stacking in Mintpy



SAR Interferometry

- Produces a stack of co-registered and unwrapped interferograms



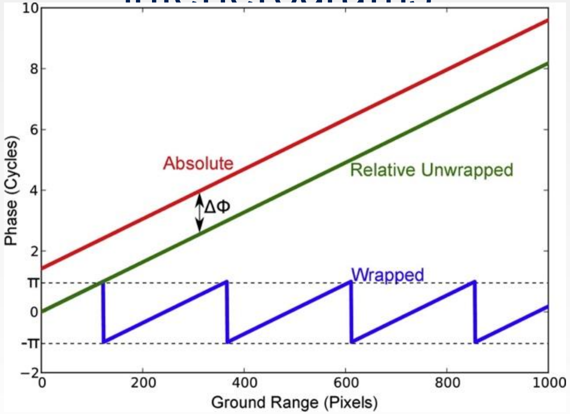
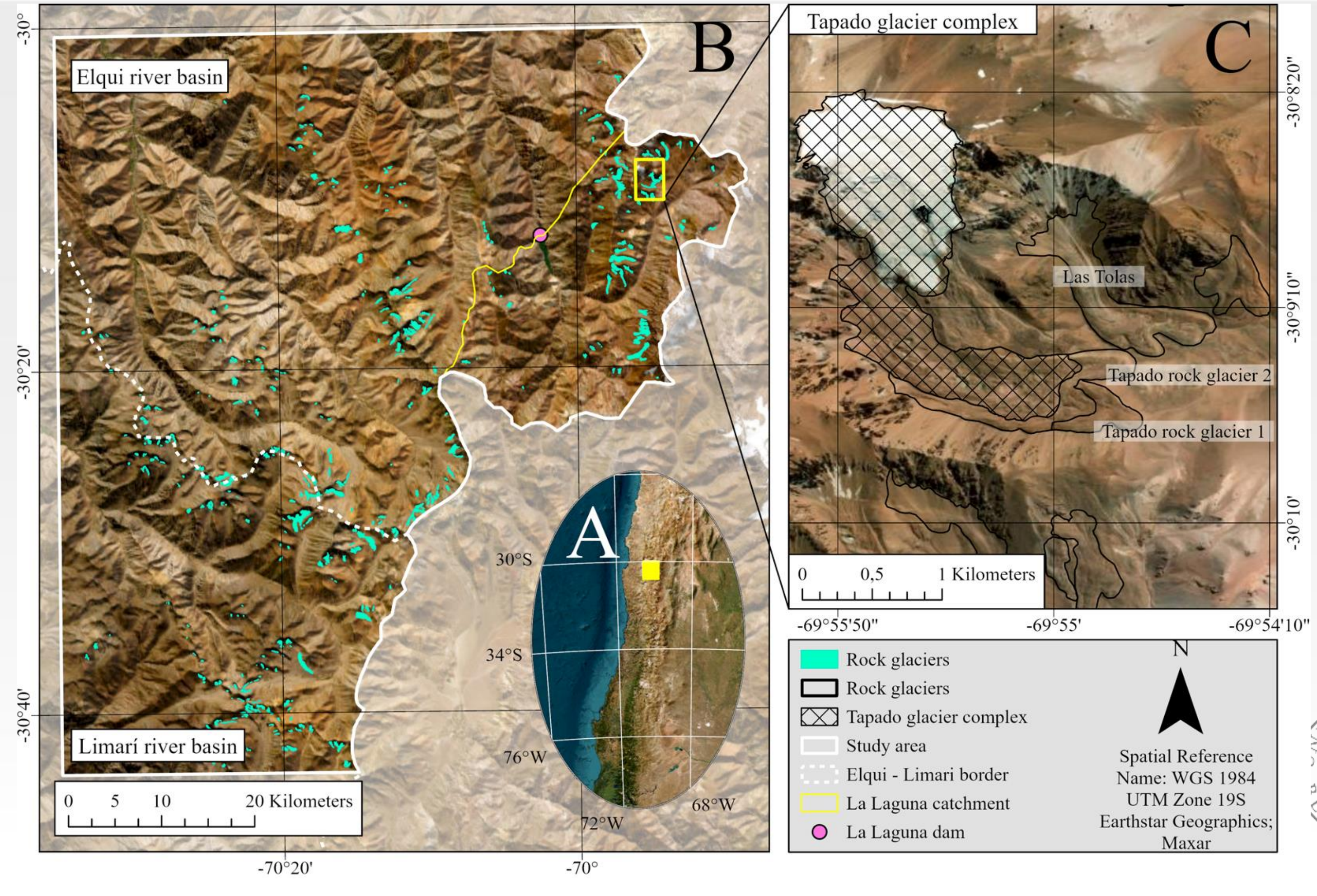
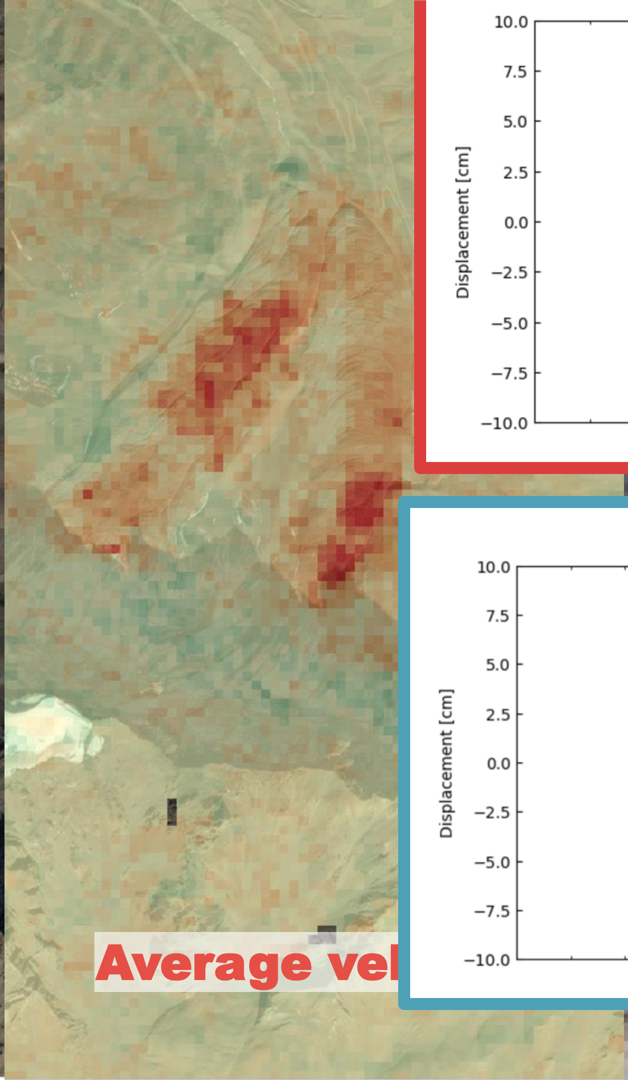
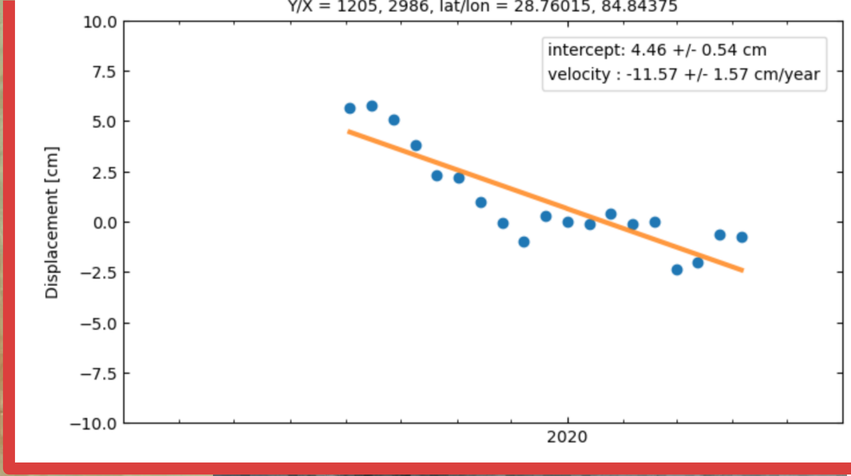


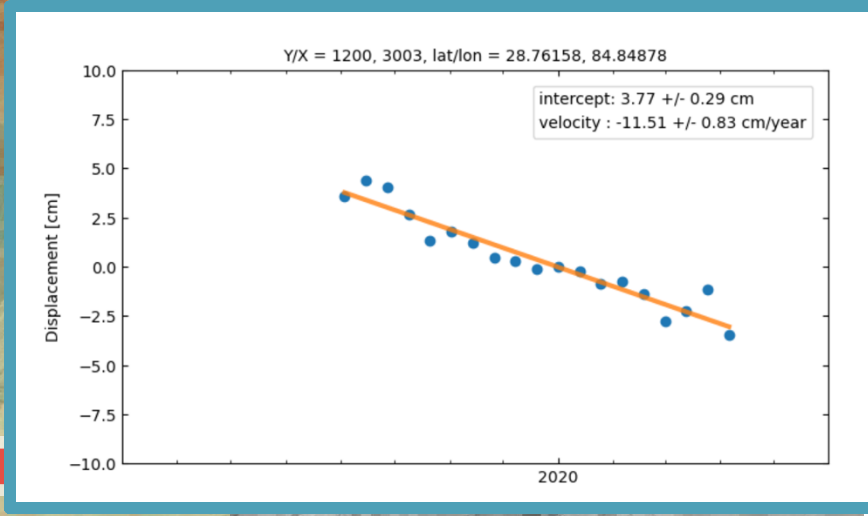
Figure 2-13: Wrapped phase in blue, relative unwrapped phase in green and absolute phase change in red. Figure from (Osmanoğlu et al., 2016).


B
C
A
Elqui river basin
Limarí river basin
Tapado glacier complex
Las Tolas
Tapado rock glacier 2
Tapado rock glacier 1
-30°
-30°20'
-30°40'
-70°20'
-70°
-30°8'20"
-30°9'10"
-30°10'
-69°55'50"
-69°55'
-69°54'10"
30°S
34°S
76°W
72°W
68°W
0 5 10 20 Kilometers
0 0,5 1 Kilometers
Rock glaciers
Rock glaciers
Tapado glacier complex
Study area
Elqui - Limari border
La Laguna catchment
La Laguna dam
N
Spatial Reference
Name: WGS 1984
UTM Zone 19S
Earthstar Geographics;
Maxar


Google Earth


Average vel


Y/X = 1205, 2986, lat/lon = 28.76015, 84.84375
intercept: 4.46 +/- 0.54 cm
velocity : -11.57 +/- 1.57 cm/year
Displacement [cm]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
2020


Y/X = 1200, 3003, lat/lon = 28.76158, 84.84878
intercept: 3.77 +/- 0.29 cm
velocity : -11.51 +/- 0.83 cm/year
Displacement [cm]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
2020

Studying seasonal changes

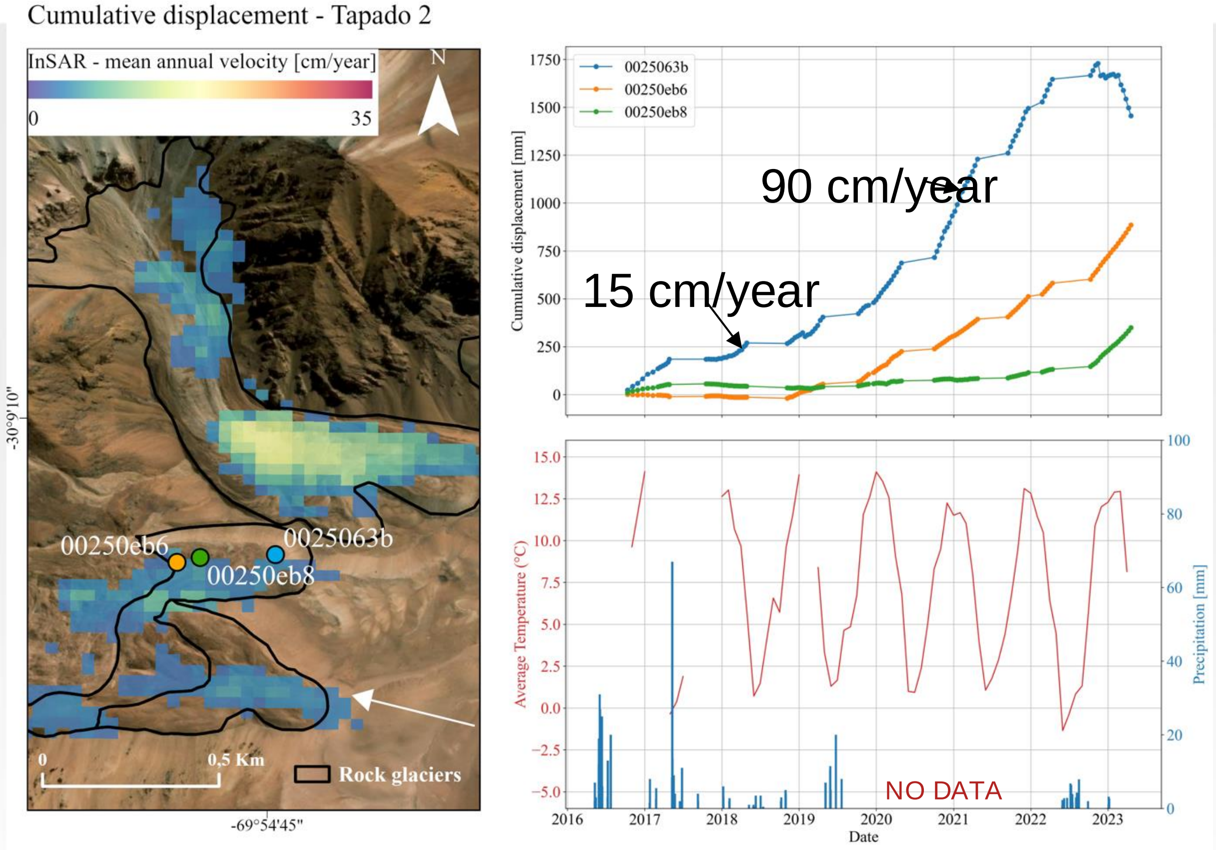


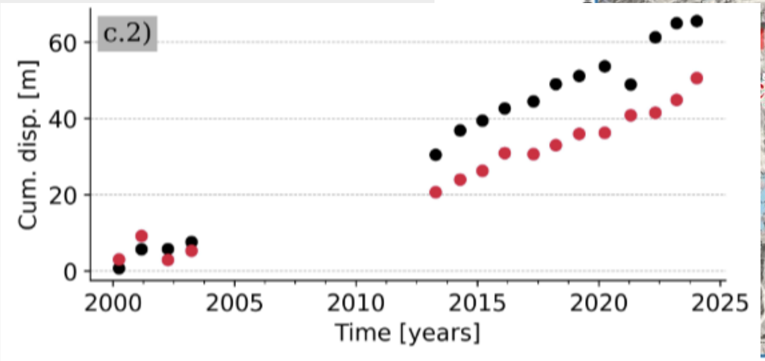
Figure 6-4: Overview map of the three selected rock glaciers in the A) La Laguna catchment. The three rock glaciers are: B) Tapado 2 rock glacier, C) Llano Des Las Liebres and D) Cl104300102. Location of the weather station is located at the La Laguna dam.

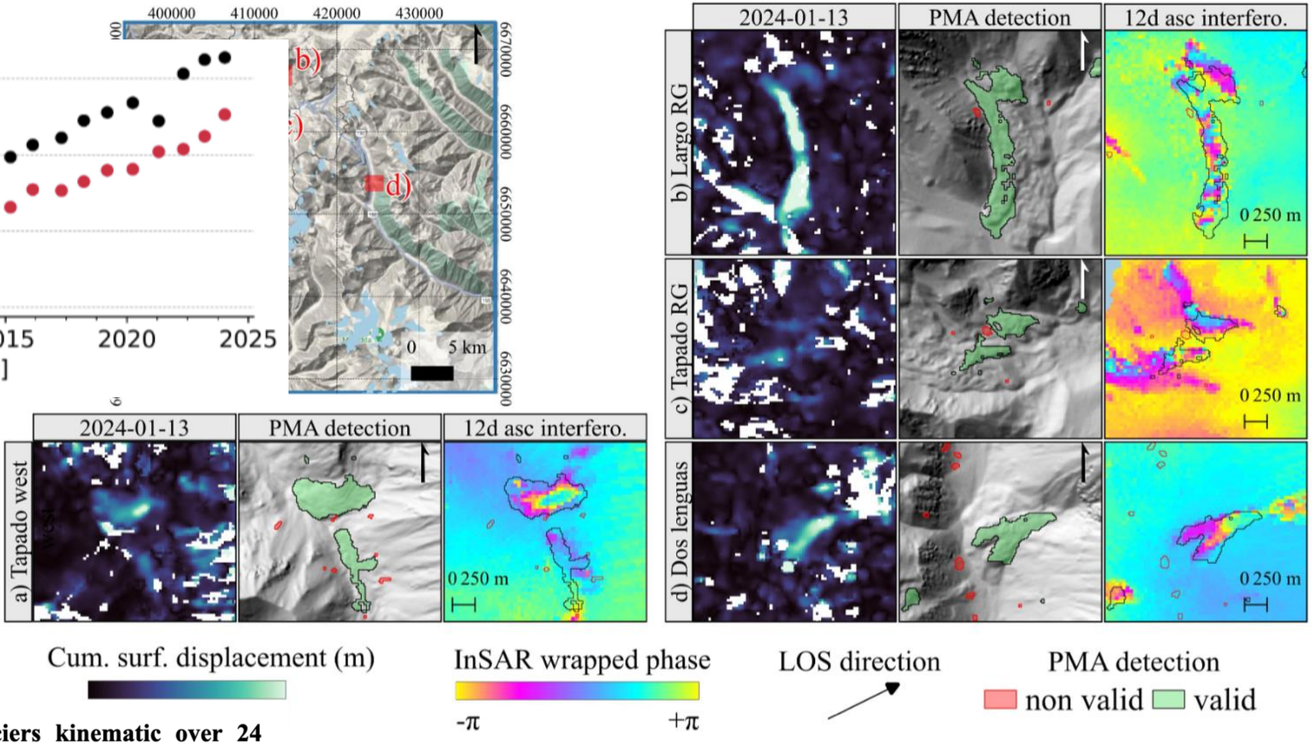
- Acceleration
  - 2017/2018 – 2020/2021

- Seems to be linked to changes in precipitation

Master thesis Emma Hauglin

Assessing RG velocity from Landsat imagery



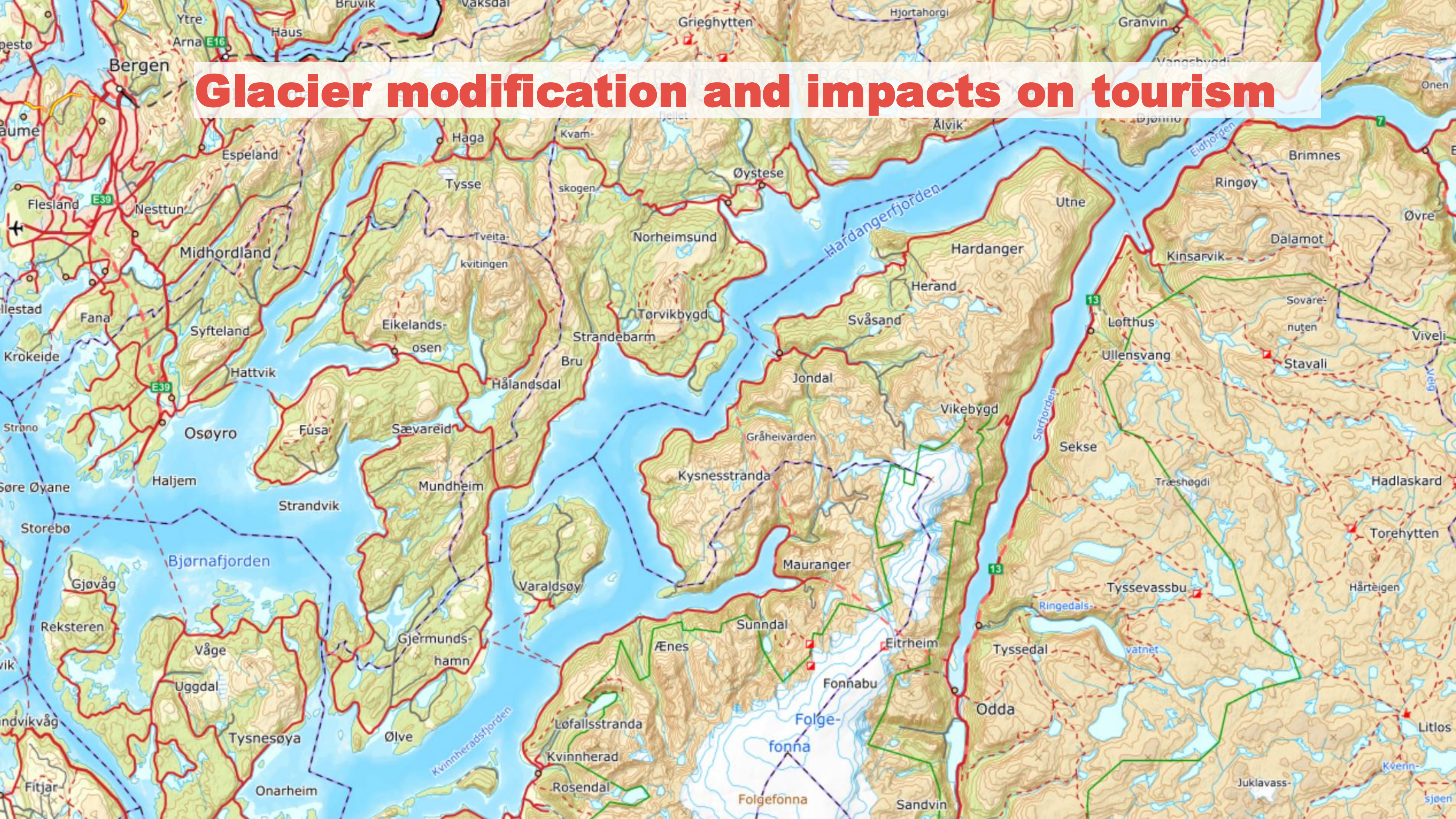


Detection and reconstruction of rock glaciers kinematic over 24 years (2000-2024) from Landsat imagery

Diego Cusicanqui[1], Pascal Lacroix[1], Xavier Bodin[2], Benjamin Aubrey Robson[3], Andreas Kääb[4] and Shelley MacDonell[5,6]

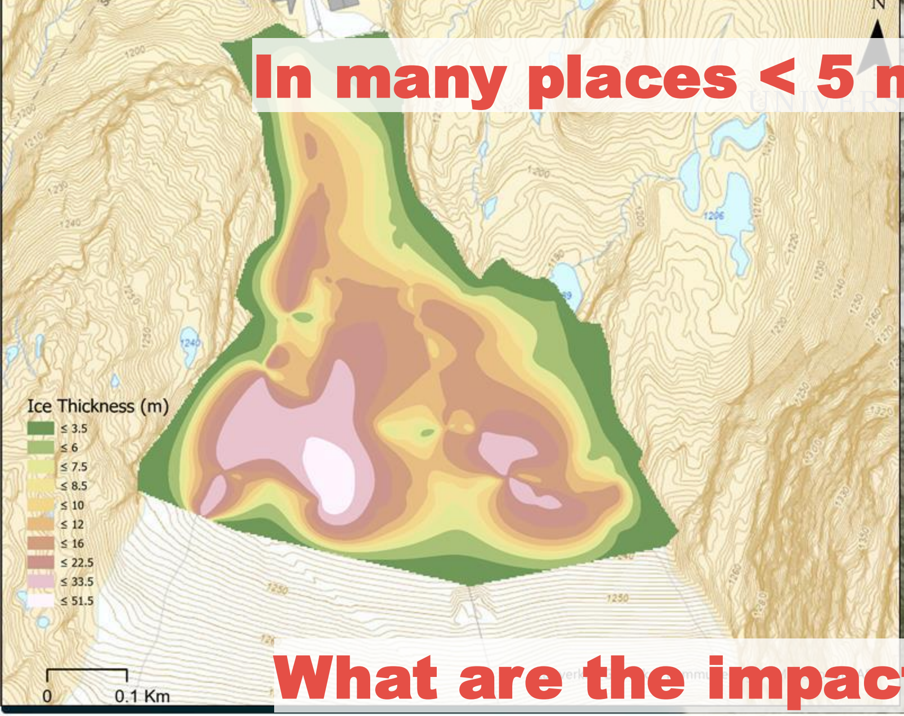
Glaciers a bit closer to home

Glacier modification and impacts on tourism

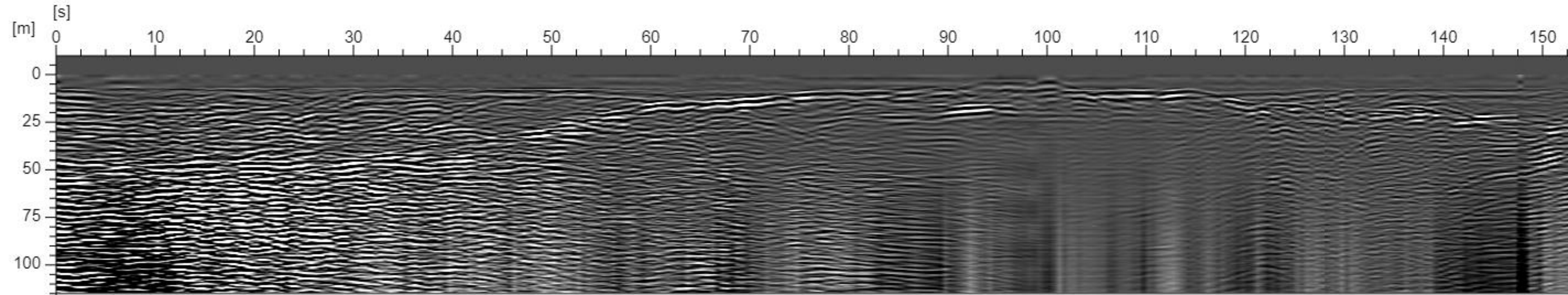



everest

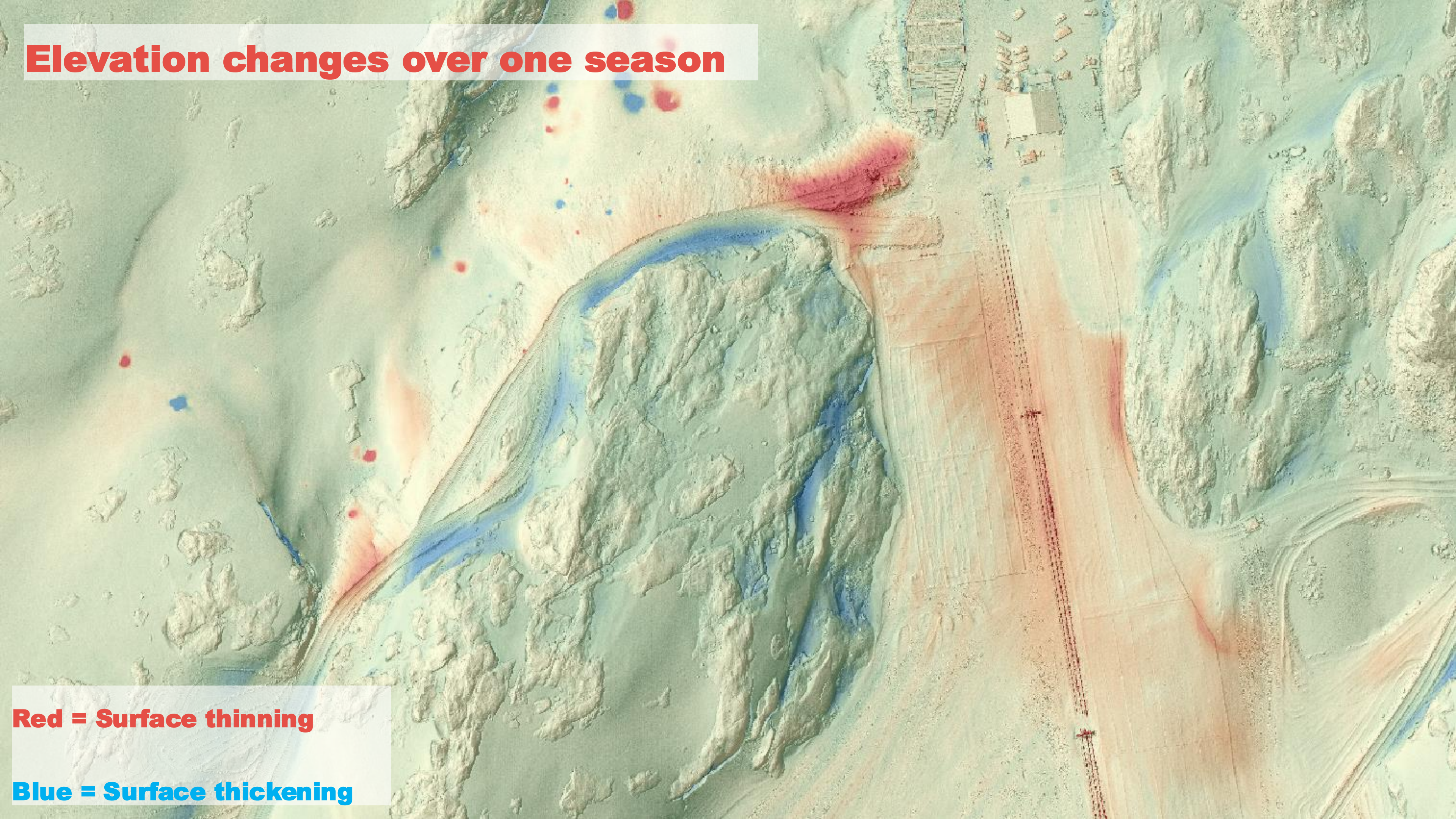
In many places < 5 m of ice on the ski area



What are the impacts of glacier modification?




Repeat seasonal measurements with Wingtra drone



Elevation changes over one season
Red = Surface thinning
Blue = Surface thickening


Thank you for your attention!