Automatic glacier outlines extraction from Sentinel-1 and Sentinel-2 time series

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Glacier changes

Glaciers can store large volumes of water and their changes can affect human activities in different sectors, such as:

Water Consumption

Agriculture

Hydropower production

Tourism

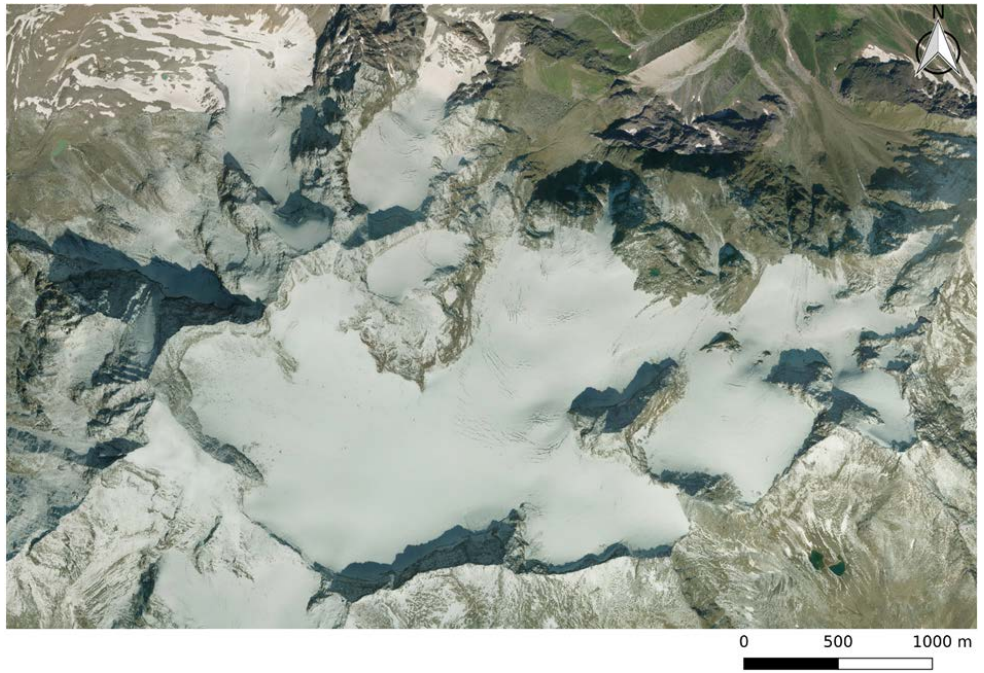
Glacier changes during the last century

For more examples see photo exibition **GOODBYE GLACIERS**

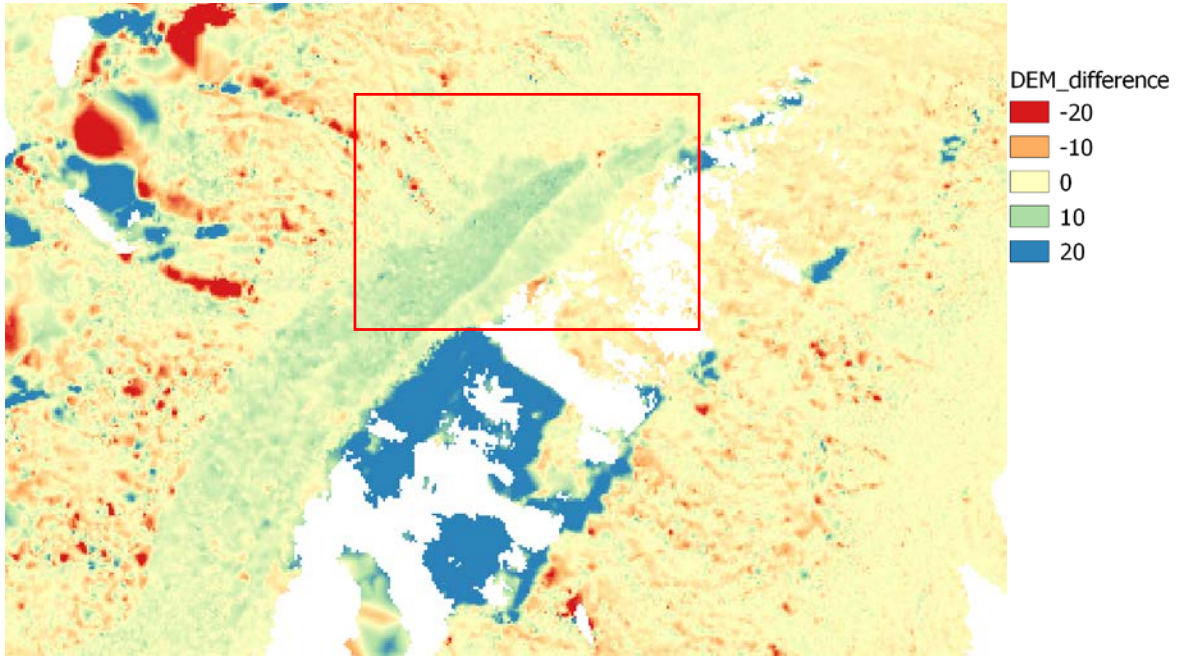
Traditional method for glacier mapping

One important activity to quantitatively monitor glacier changes is done through glacier inventories. These are usually realized through:

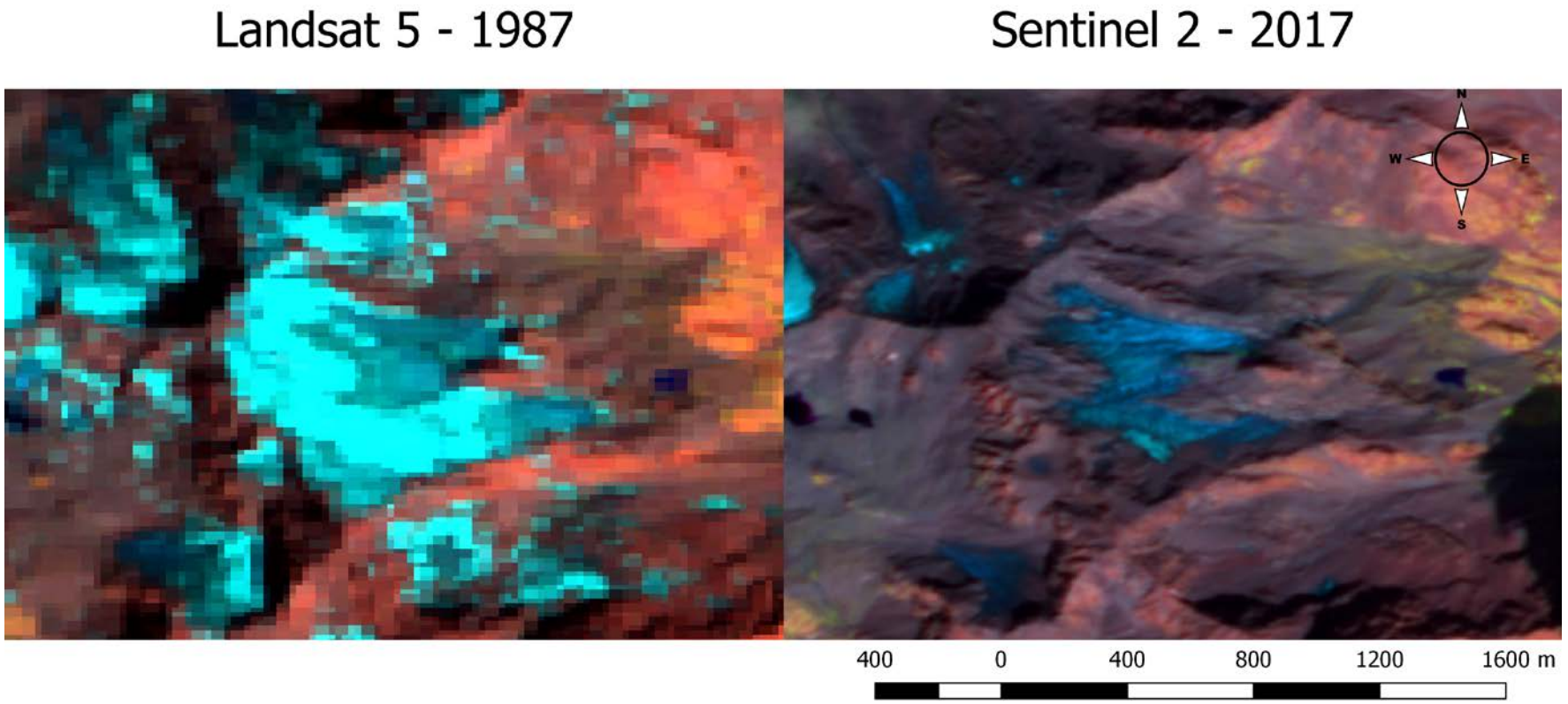
Analysis of aerial orthophotos



Analysis on DEM differencing for debris covered glaciers



Glacier changes observed from space



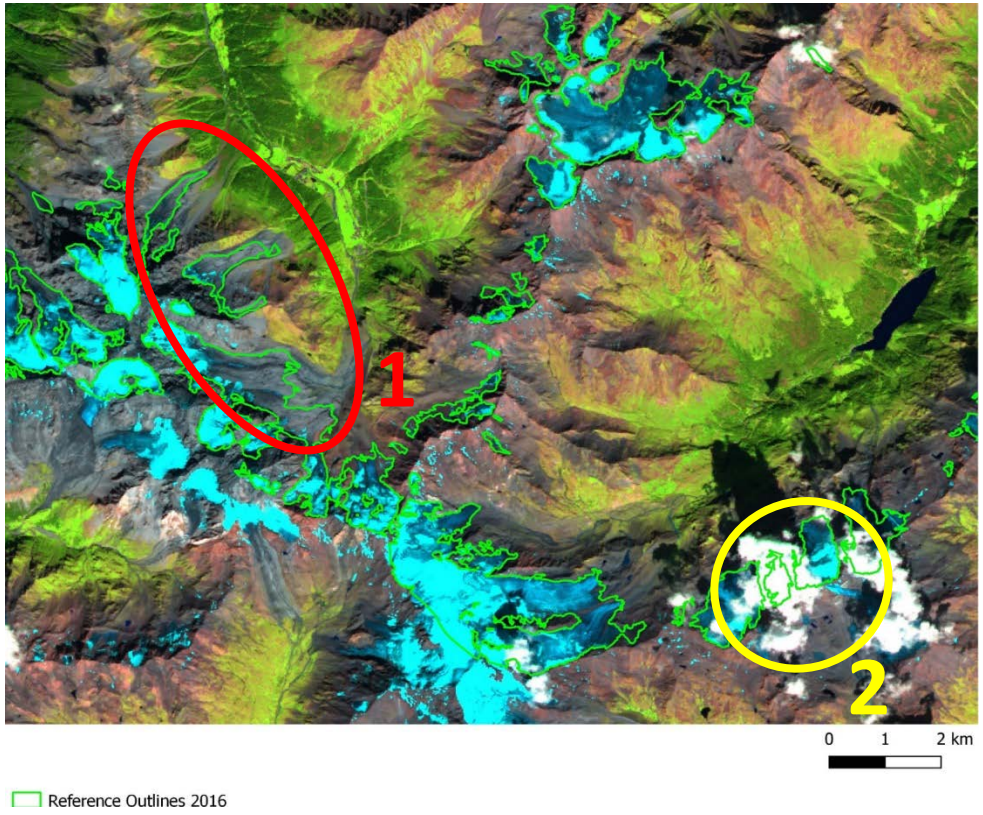
Advantages

- Global coverage
- High temporal frequency
- Free data

Disadvantages

- Lower resolution than orthophotos

Main issues in glacier mapping from satellite



1- Debris covered glaciers are difficult to be detected with optical data

Solution: SAR data can detect surface deformation allowing debris cover glacier detection

2- Cloud coverage

Solution: High satellite revisit time can be exploited to mitigate the cloud problem

Sentinels

Satellite	Operativity	Spatial resolution	Revisit time	Sensor type	Characteristics
Sentinel-2	2015 → 2017	20 m	5 days	Optical	Similar characteristic of Landsat data but with improved spatial and temporal resolution. The multi-spectral information allows to detect snow and bare ice
Sentinel-1	2014 → 2015	20 m	6 days	SAR	First free SAR data with almost global coverage and predefined acquisition plan. Can detect surface deformation allowing debris cover glacier detection

A

A+B

Objective

Given the new opportunities offered by Sentinel-1 and Sentinel-2 the objective of this work is to develop a new method for glacier inventory updating. This method:

- exploits the new rich multi-temporal information provided by Sentinel-2 to detect snow and bare ice mitigating the cloud problem
- exploits the availability of Sentinel-1 SAR data to detect debris cover glacier
- is fully automatic to allow an efficient global and yearly glacier outline extraction

Test area and data

From 1st of July to 30th of September 2017 over South Tyrol - Tyrol:

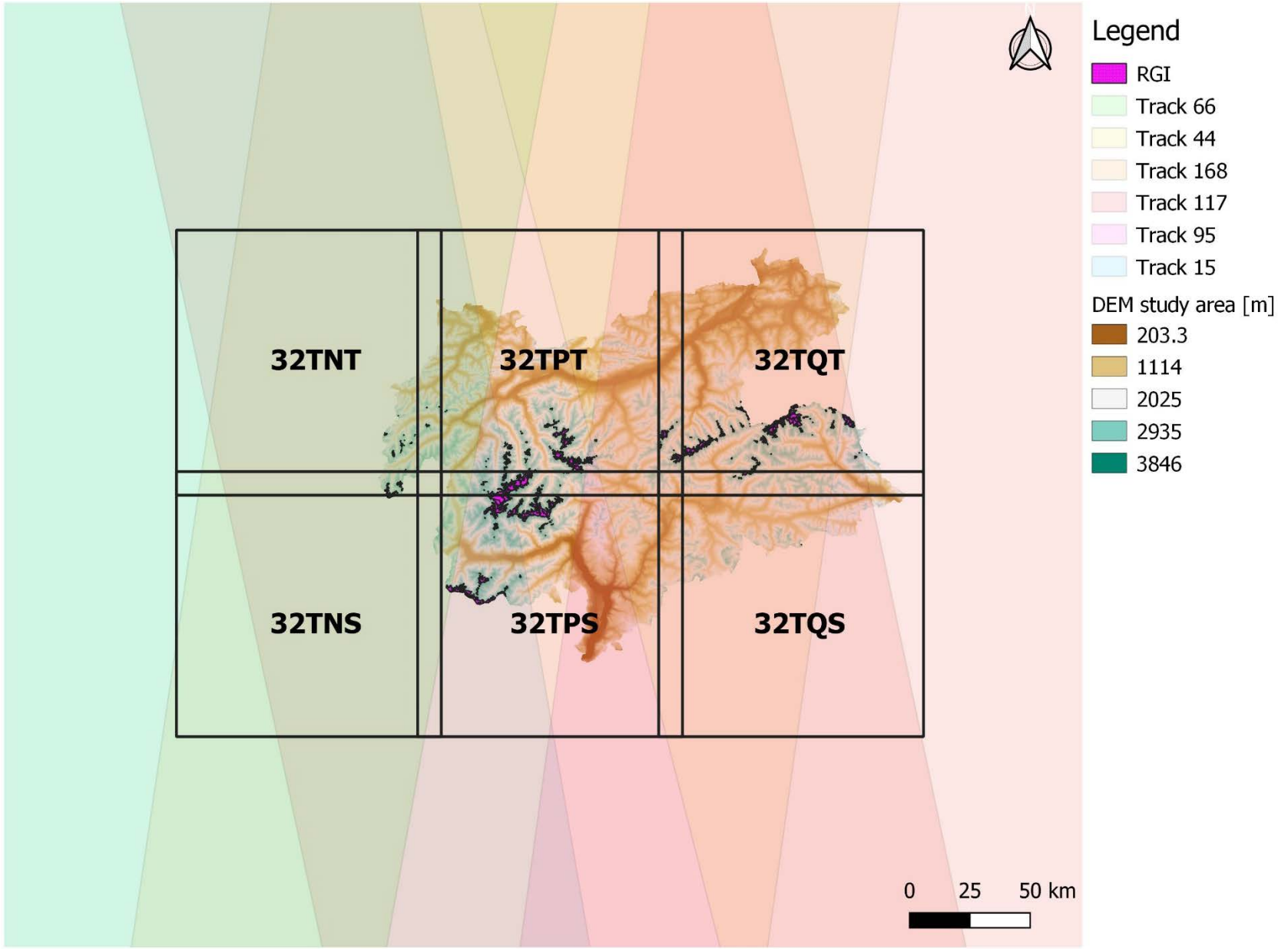
- Sentinel-2: **6** tiles acquired each 5 days (or less):

  ~220 images = ~220 GB data to be analyzed for each season

- Sentinel-1: **6** tracks acquired each 6 days:

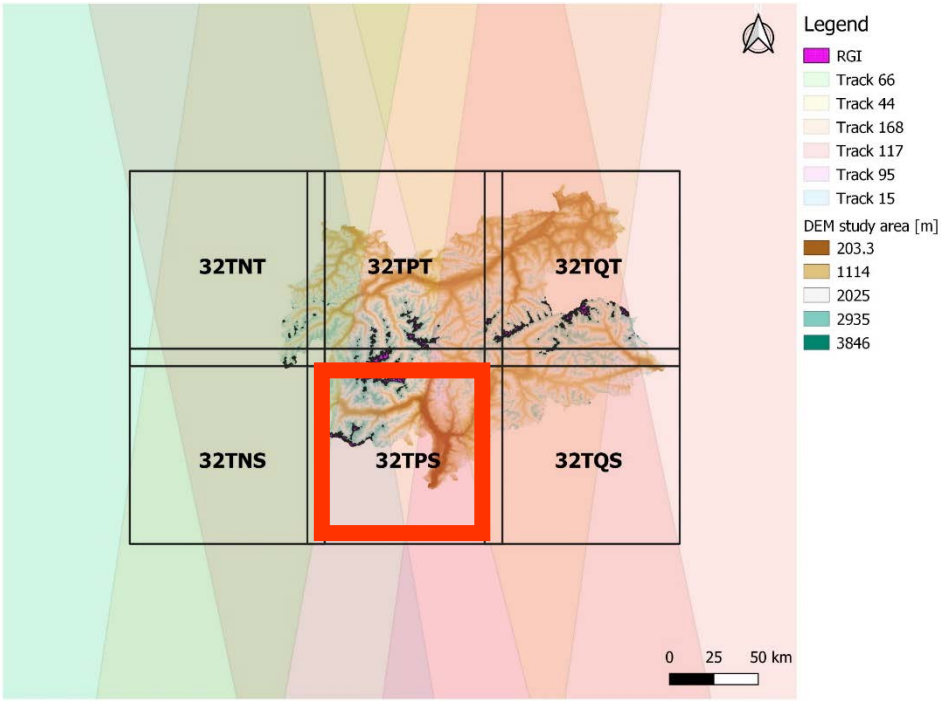
  ~140 images = ~1.1 TB data to be analyzed for each season

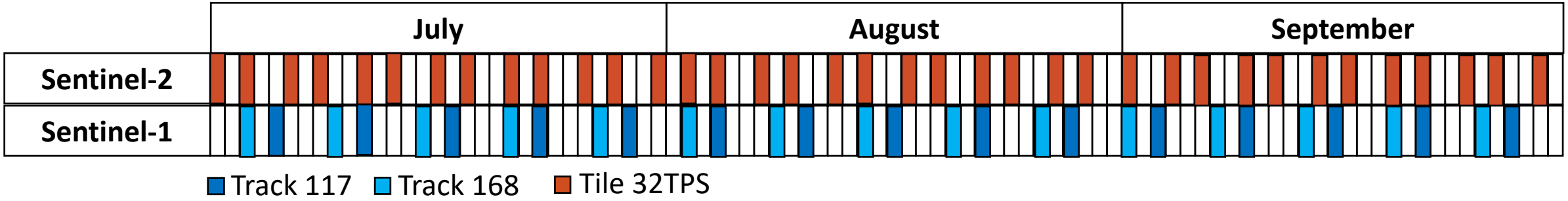
Automated methods needed for a fast and effective analysis of all this big amount of data



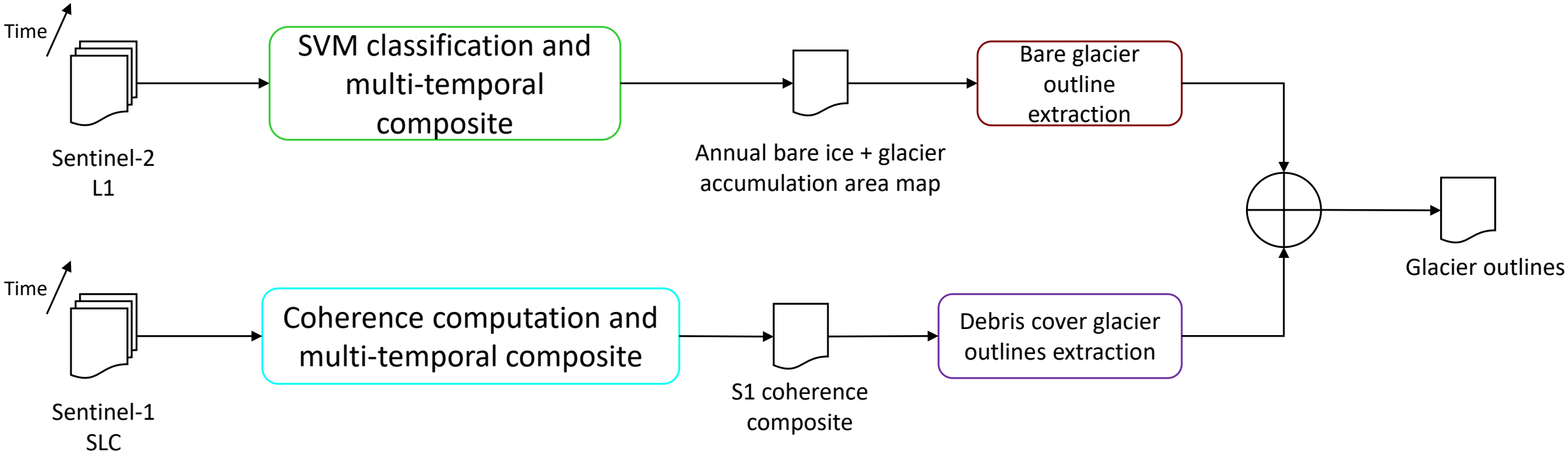
Test area and data

Sentinel-1 and Sentinel-2 acquisition calendar on the area corresponding to the Sentinel -2 tile 32TPS for the ablation season 2017



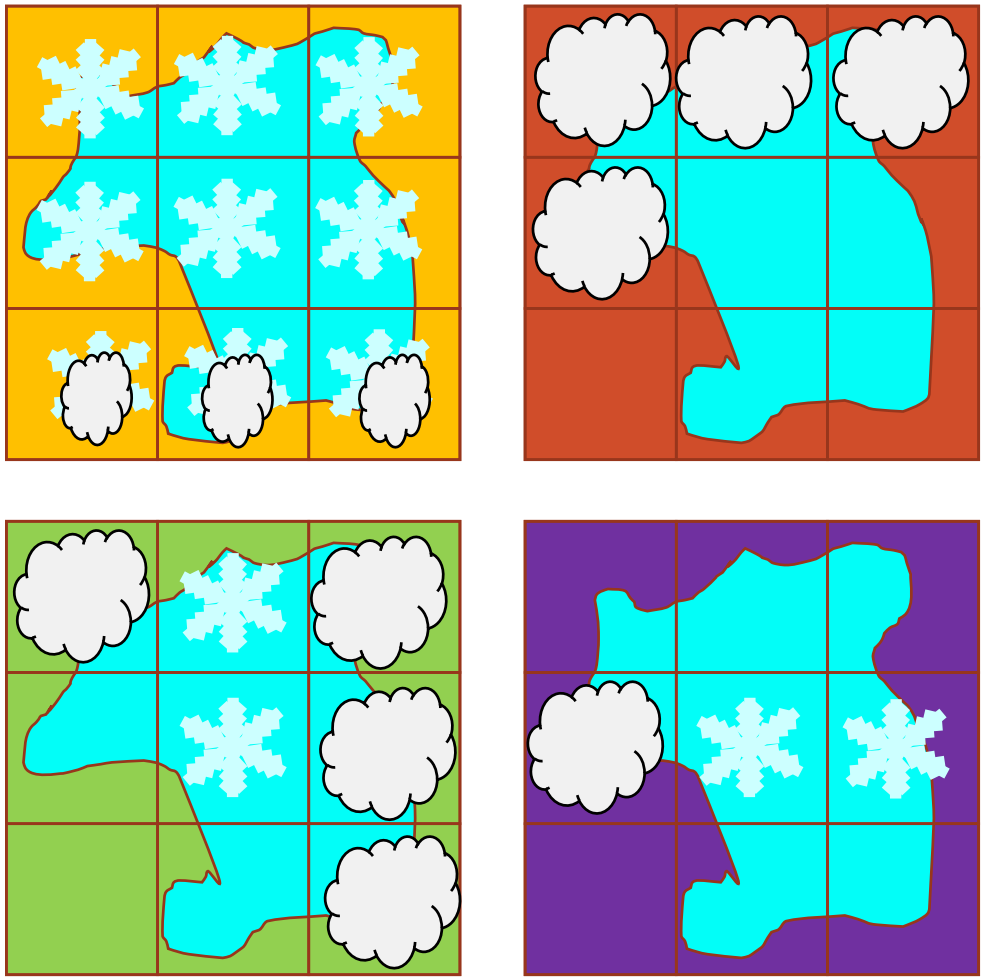


Method overview



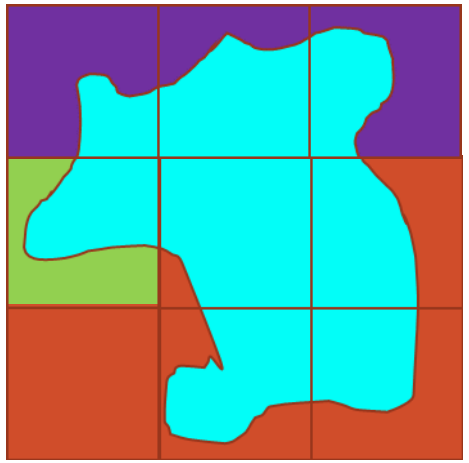
SVM classification and multi-temporal composite

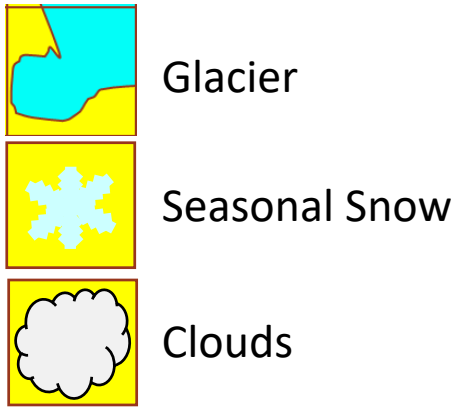
Sentinel-2 Time series



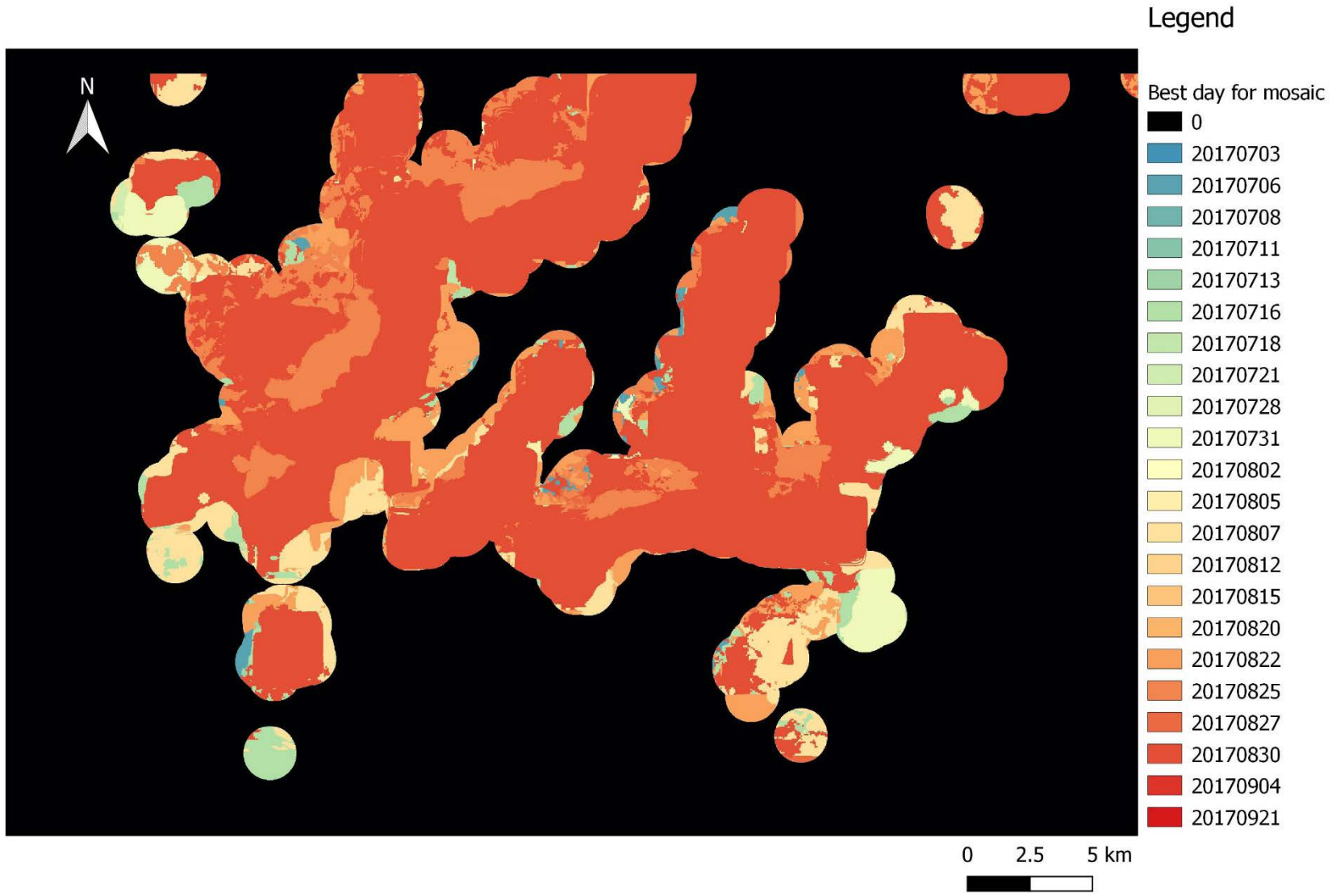
Aim of this step: to produce an annual cloud free image with the minimum snow cover over the glaciers

Multitemporal Composite

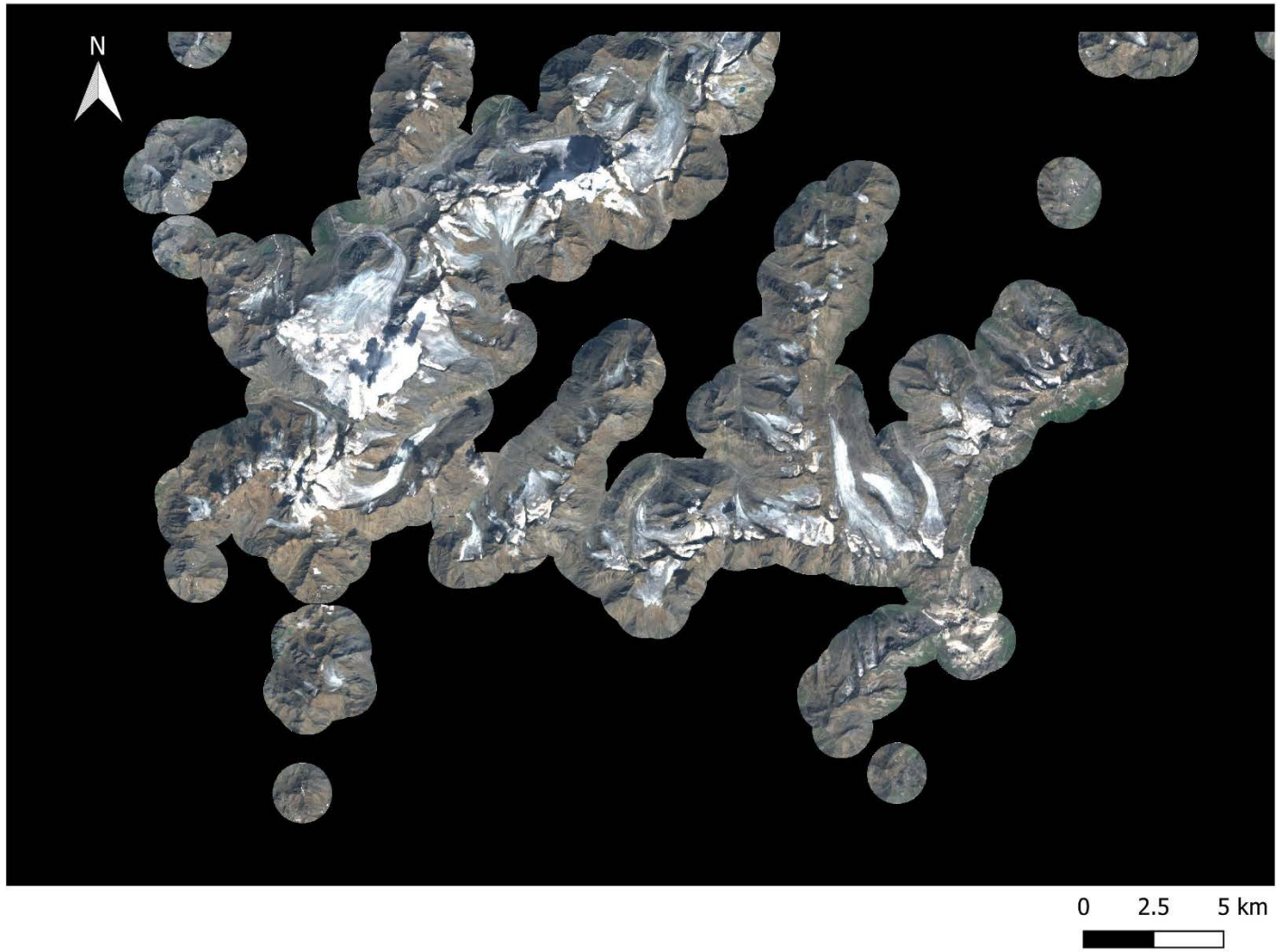




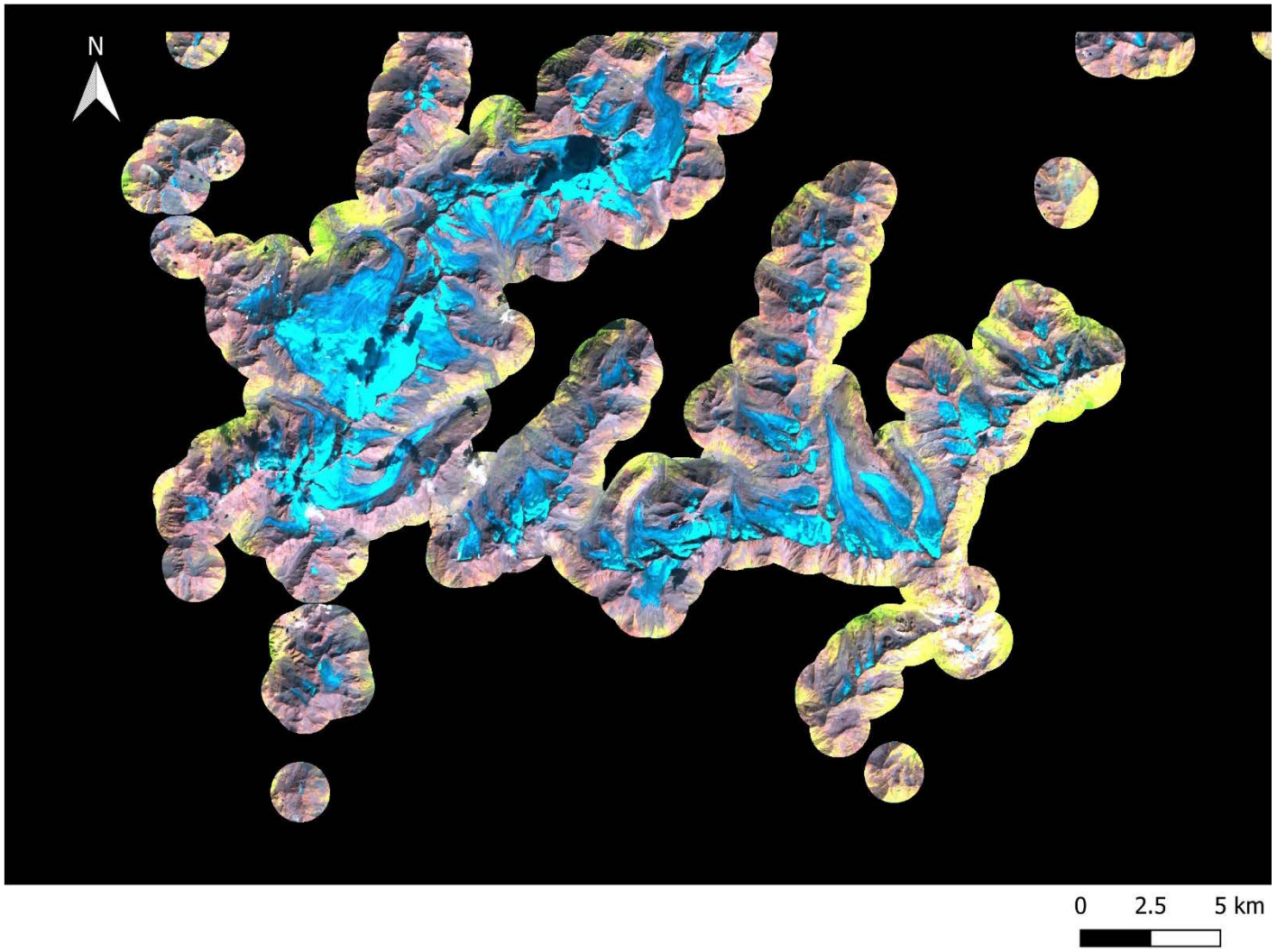
Used Date Map



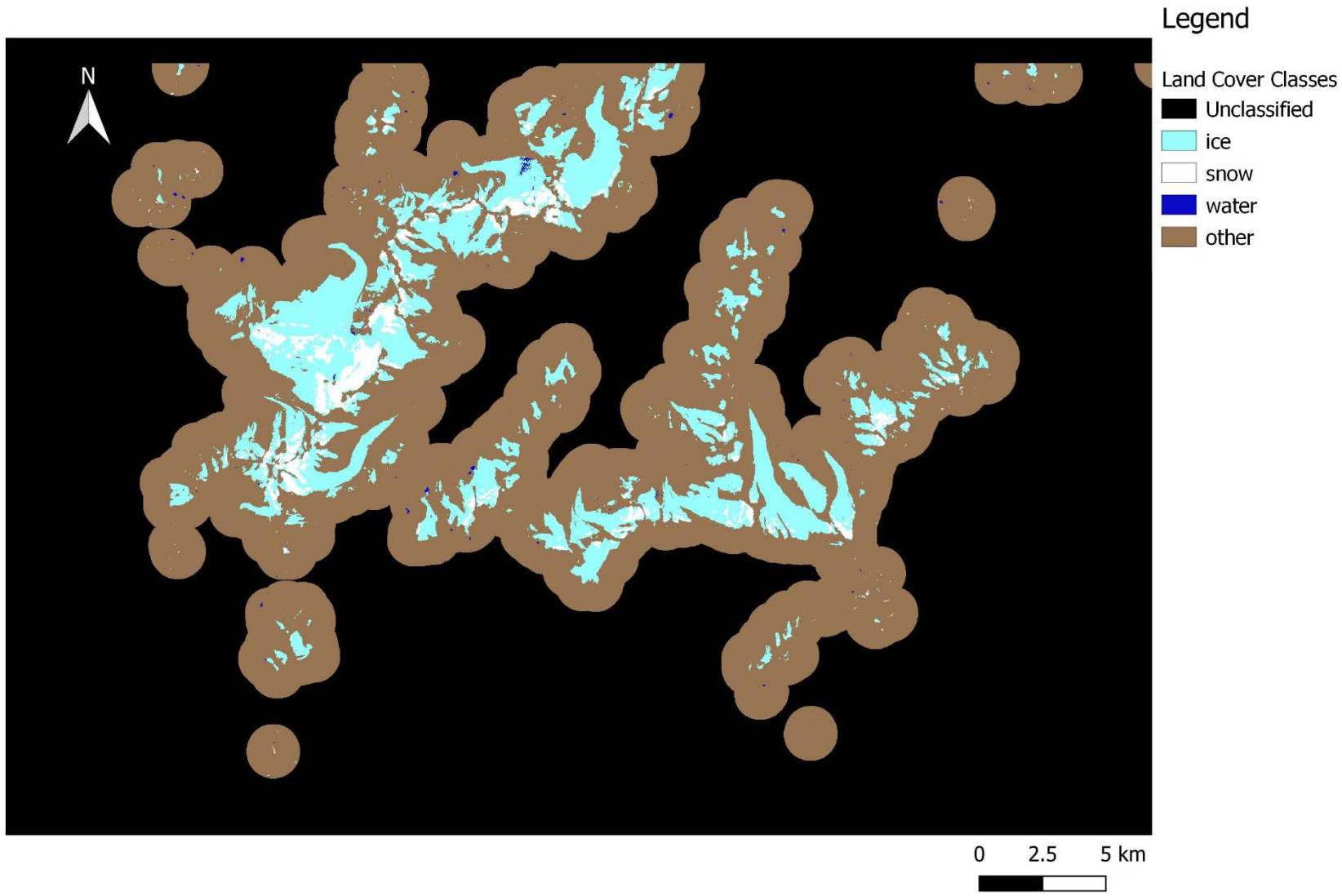
Natural Color Mosaic



False Color Mosaic

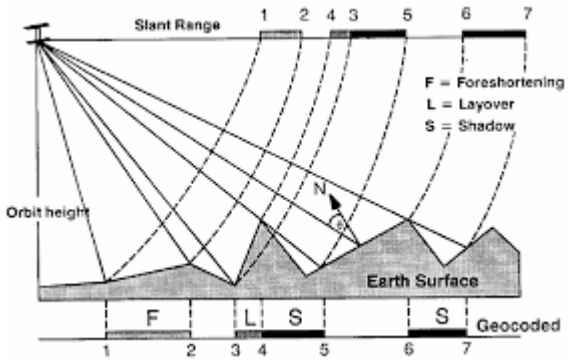


Classified Mosaic

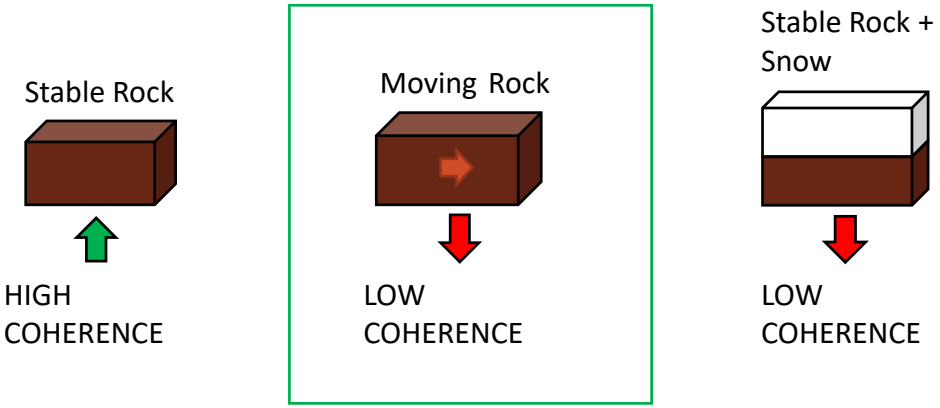


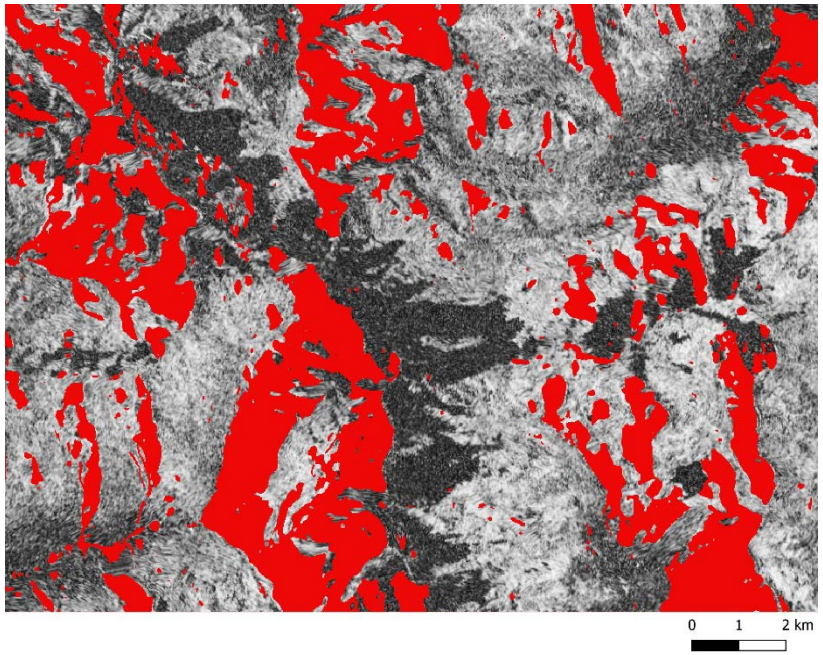
Problems affecting coherence

Layover and Shadow



Presence of seasonal snow

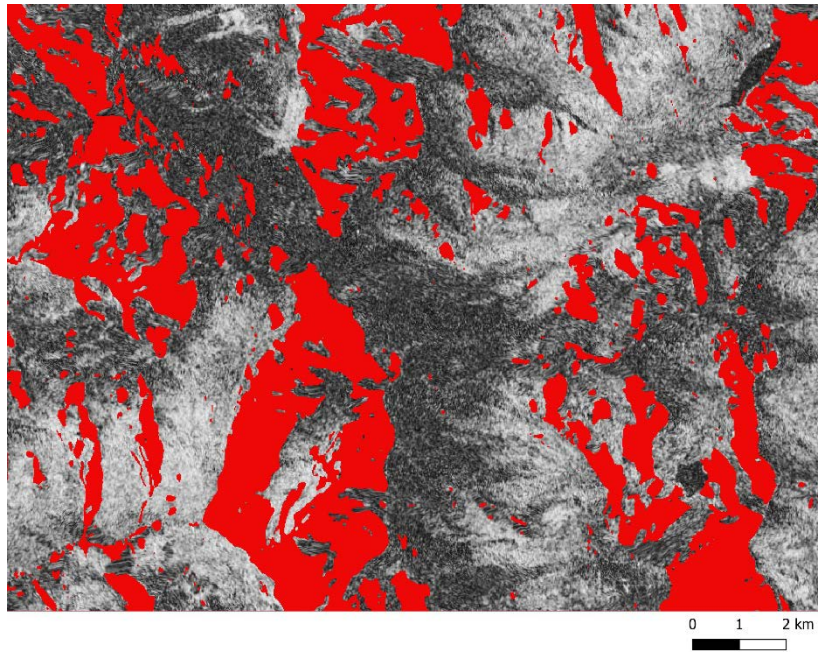




12 Days coherence images over Ortles-Cevedale group relative to Track 117

Pixels in layover or shadow

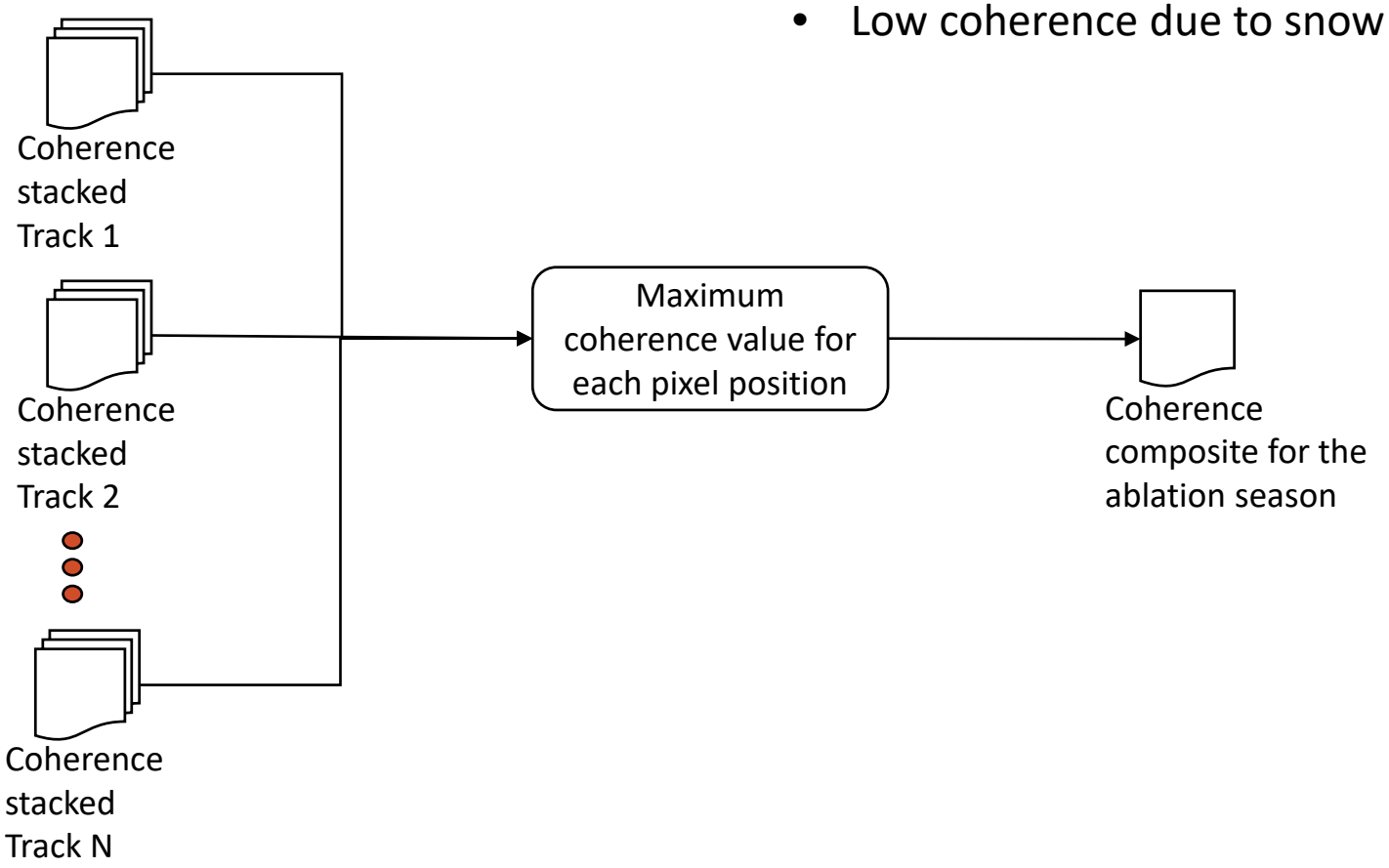
0 1



Multitemporal filtering and coherence composite

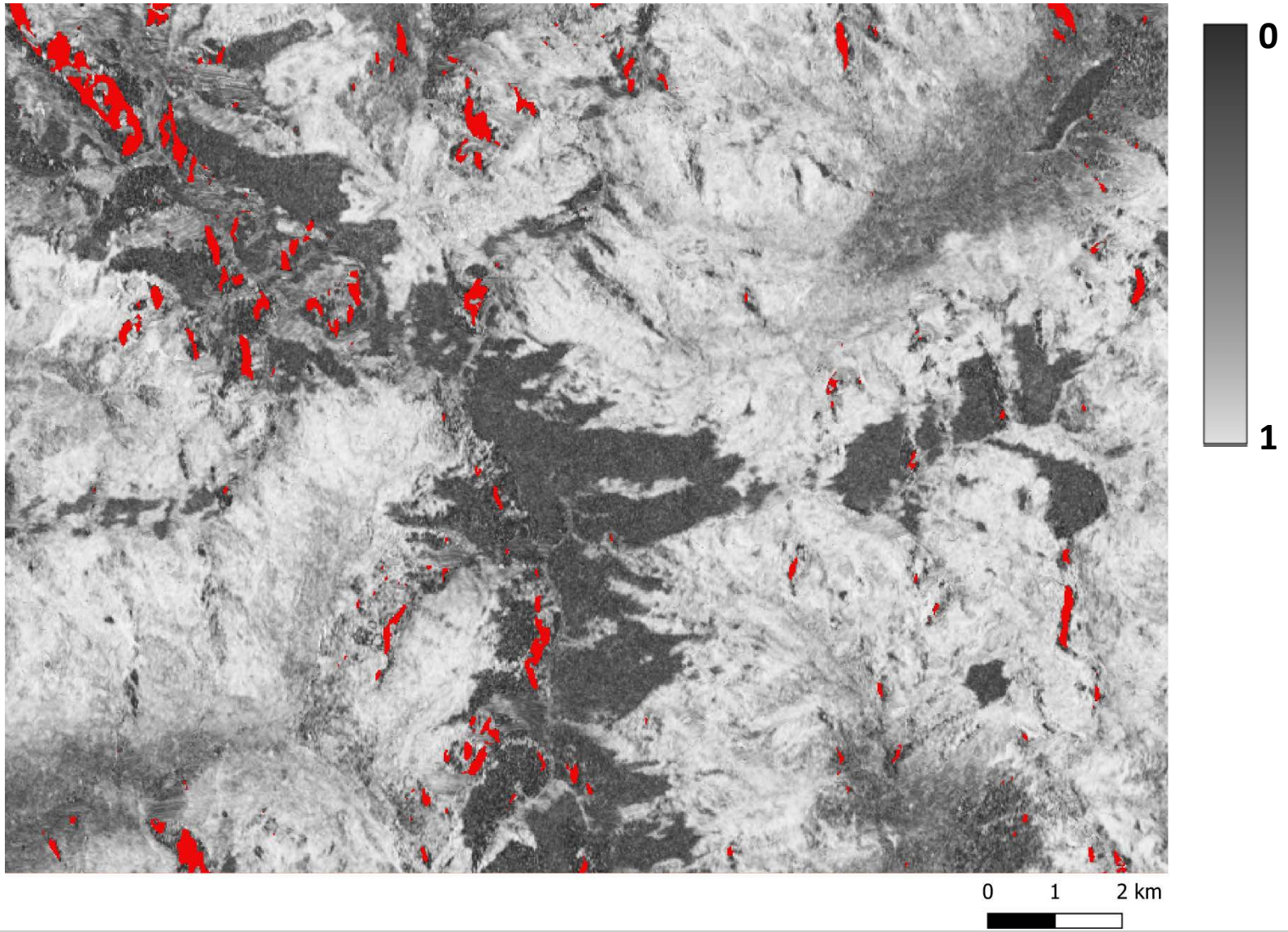
Aim of this step: to produce a single coherence map where:

- Shadow and cloud effects are removed
- Low coherence due to snow cover is filtered out



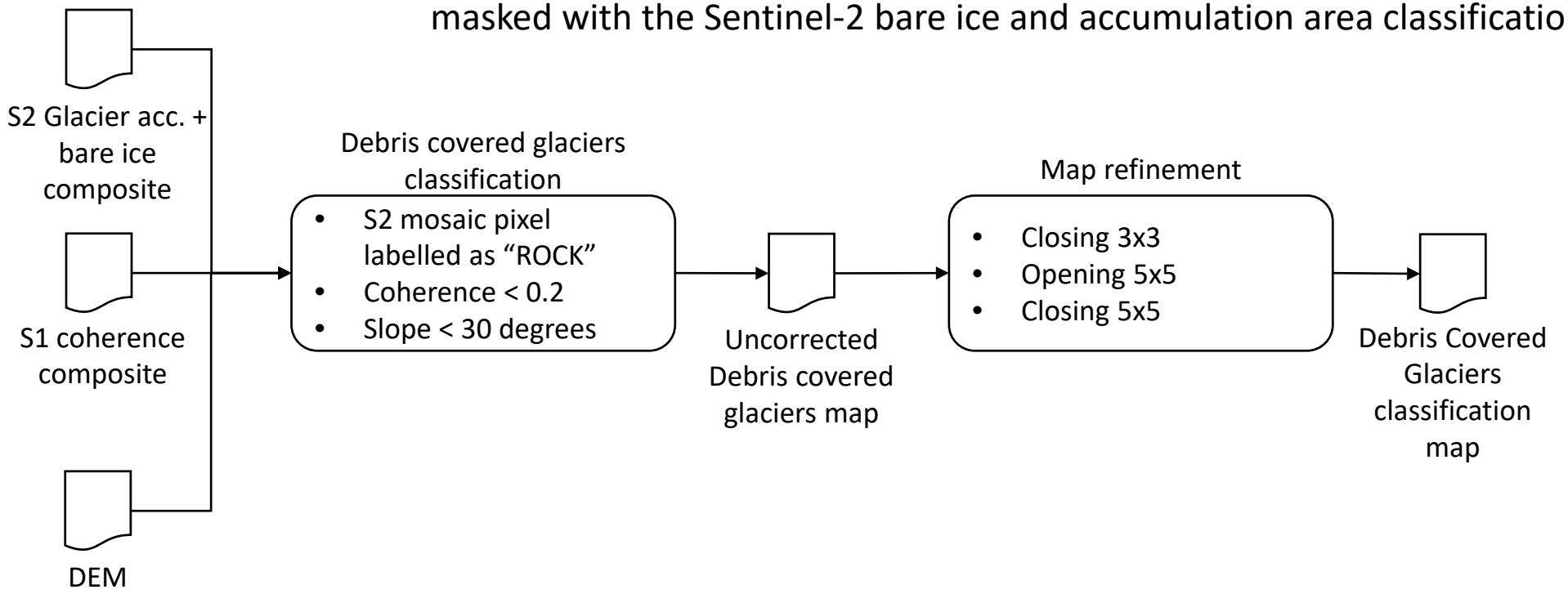
Coherence multi-temporal composite

12 Days coherence multitemporal composite image over Ortles-Cevedale group relatives to ablation year 2016



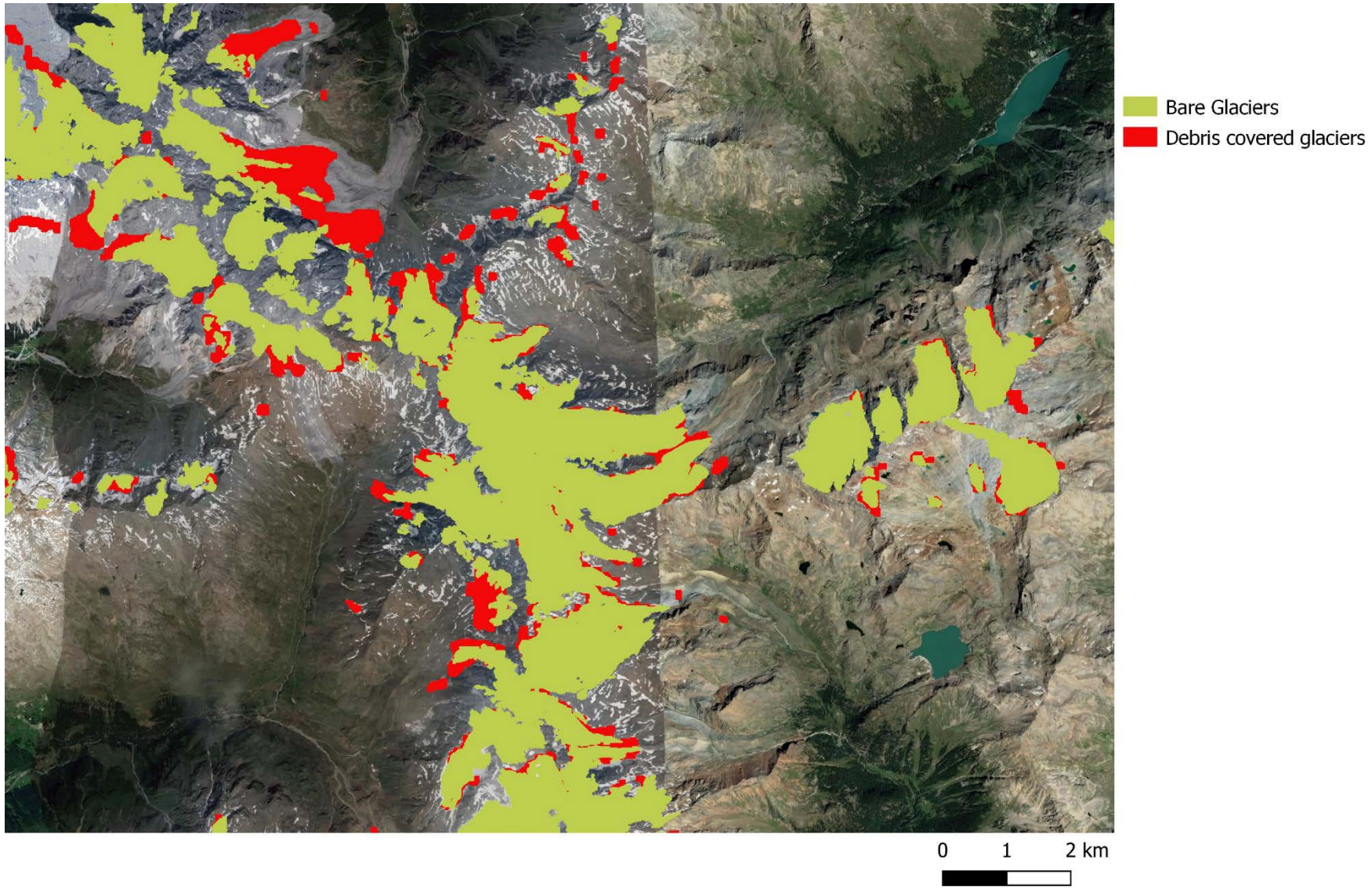
Debris covered glacier outlines extraction

Aim of this step: Classification of debris covered glaciers outlines using the coherence composite and applying tle method proposed by Lippl et al. 2018. Bare ice and snow are masked with the Sentinel-2 bare ice and accumulation area classification map



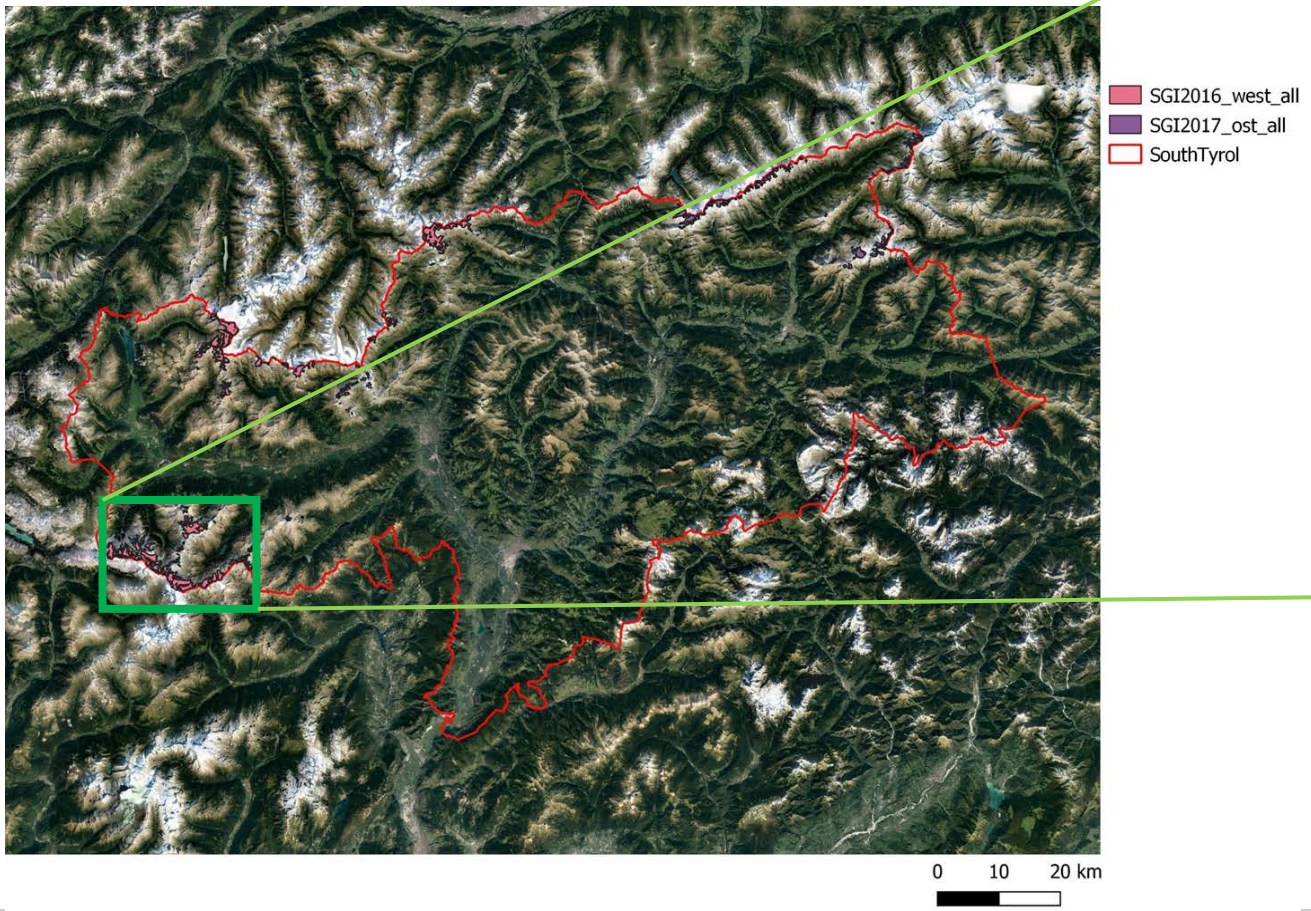
S. LIPPL, S. VIJAY, and M. BRAUN, "Automatic delineation of debris-covered glaciers using InSAR coherence derived from X-, C- and L-band radar data: a case study of Yazgyl Glacier," J. Glaciol., vol. 64, no. 247, pp. 811–821, 2018.

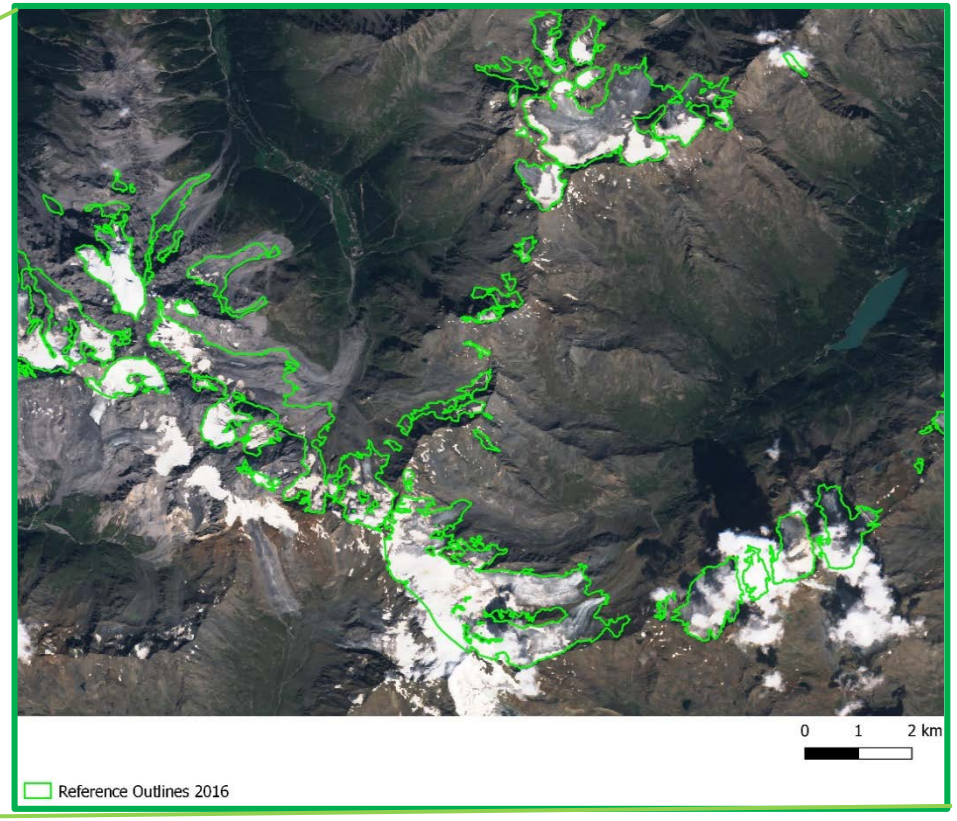
Final Result



Validation dataset

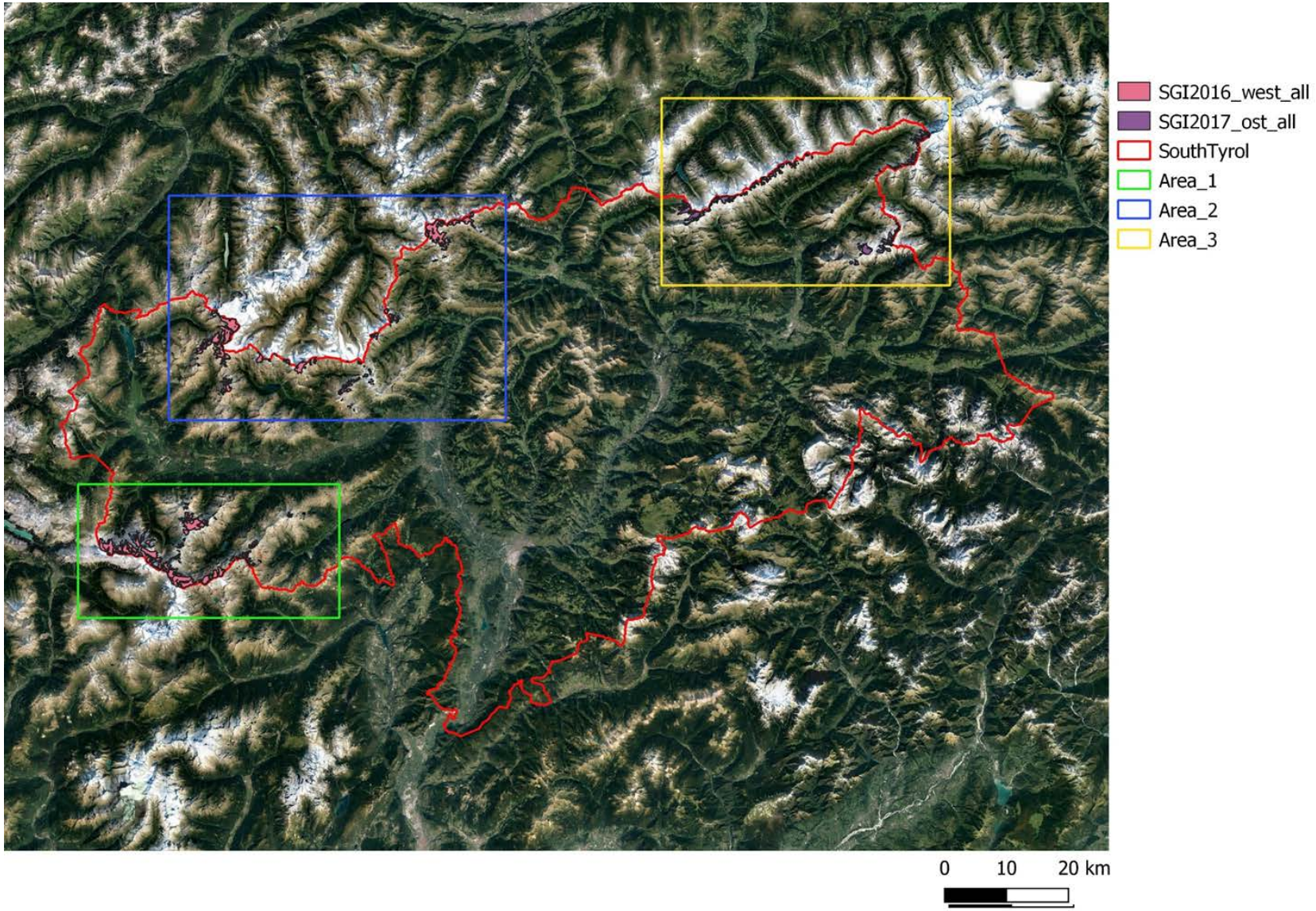
- As reference outlines we have available a manually produced inventory over South Tyrol of years 2016 and 2017.





Example of reference outine over Ortles-Cevedale group

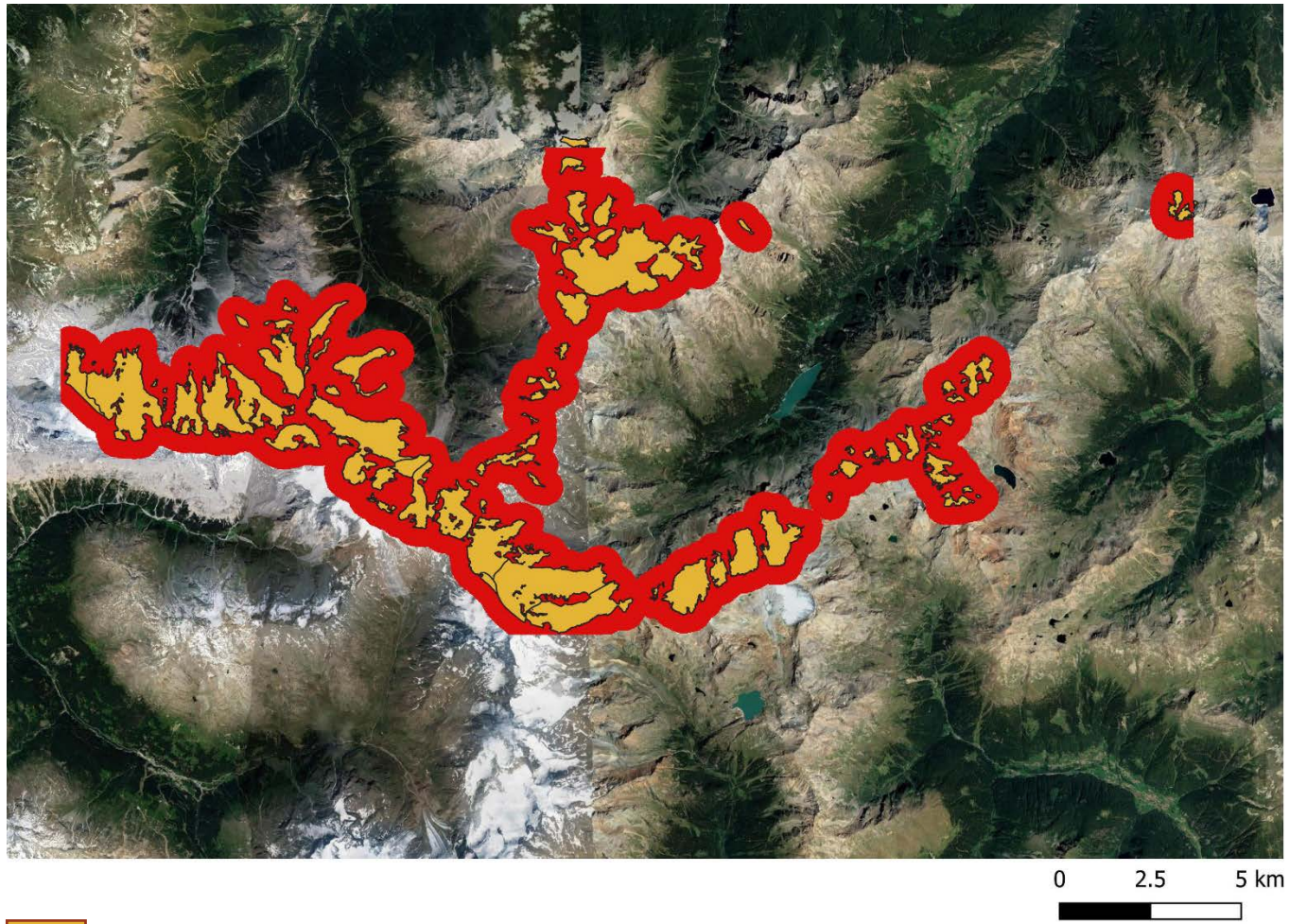
Validation dataset



The validation dataset has been split in three areas:

- Area 1) Ortles – Cevedale Group
- Area 2) Ötztal
- Area 3) Zillertaler Alps

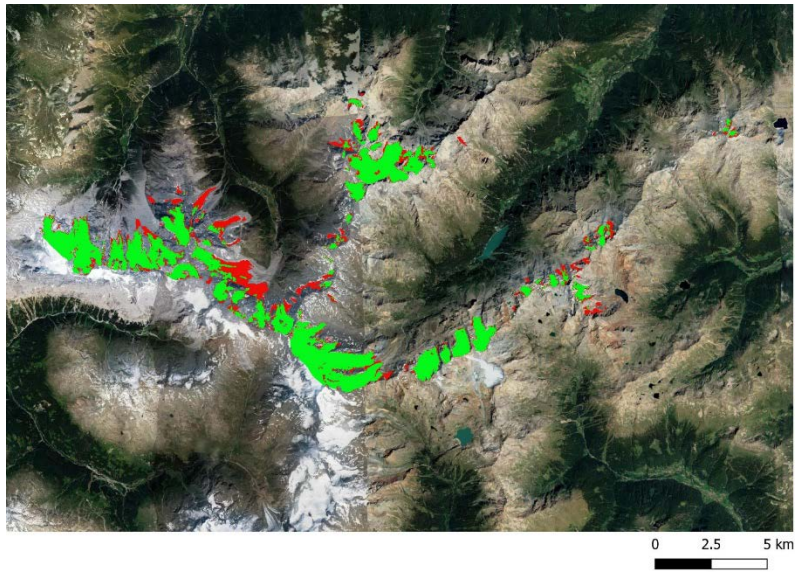
Validation Strategy



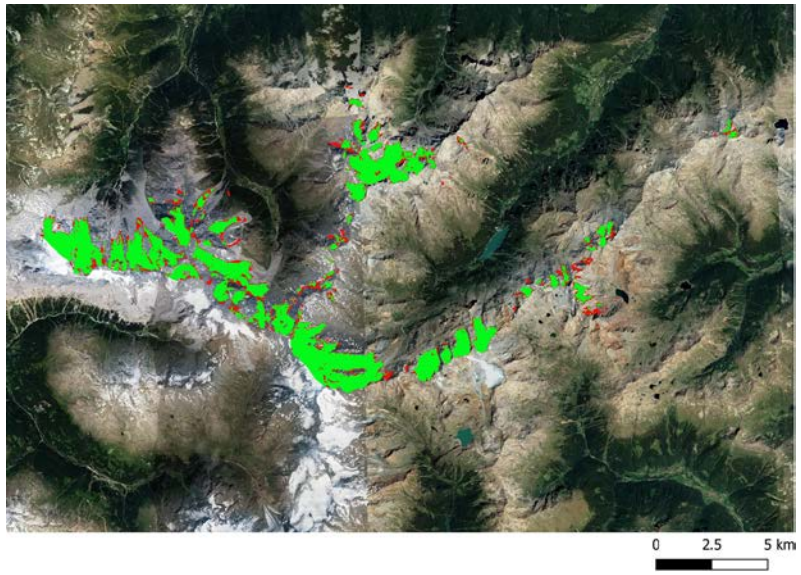
- For the validation we took into account the reference outline plus a 500 m buffer. The same used around the RGI 6.0 in the method.
- In this area are evaluated pixels in agreement and disagreement.
- Results are first assessed using only Sentinel-2 outlines. Then we evaluate the improvement brought by Sentinel-1.

Area 1 Results

Sentinel-2

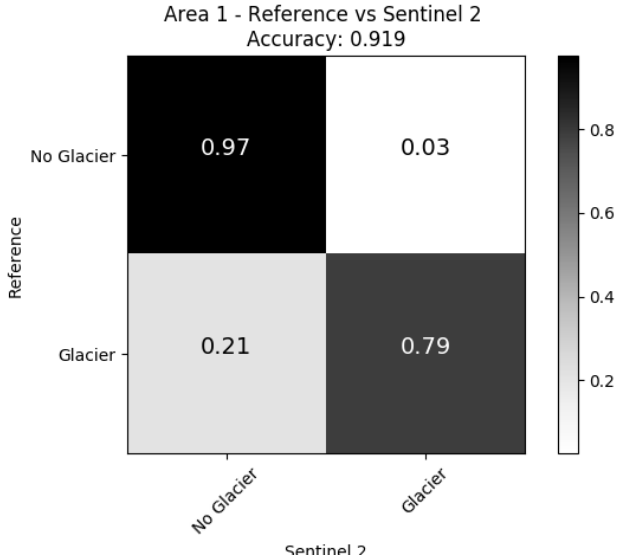


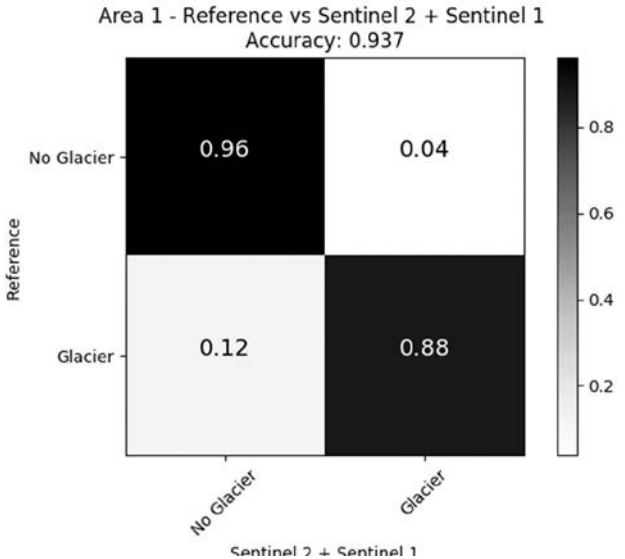
Sentinel-2 + Sentinel-1



Agreement area

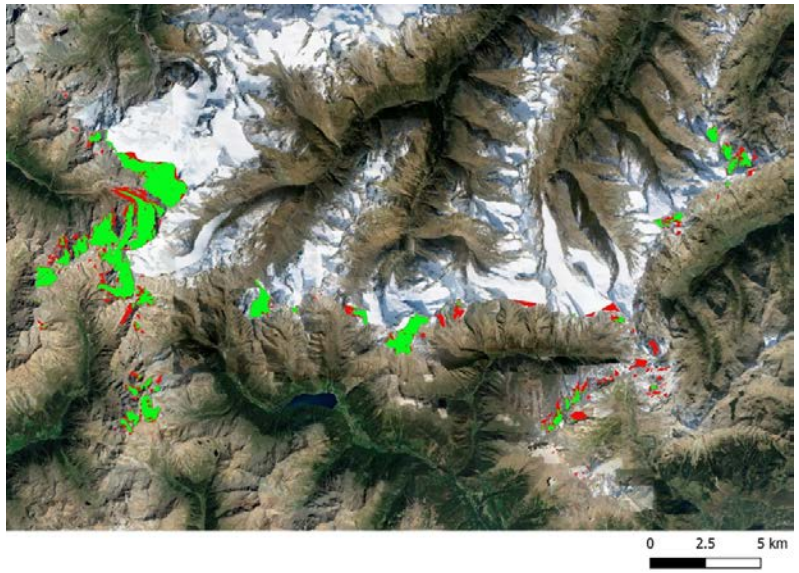
Disagreement area



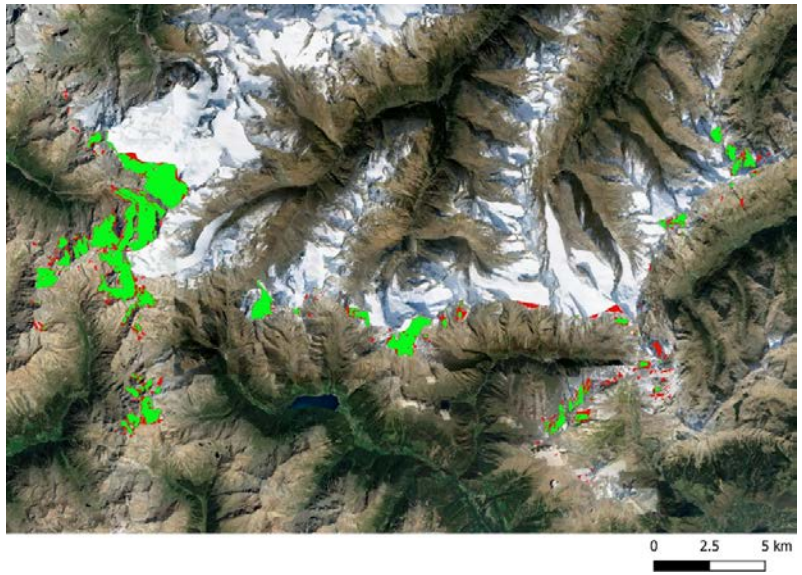


Area 2 Results

Sentinel-2

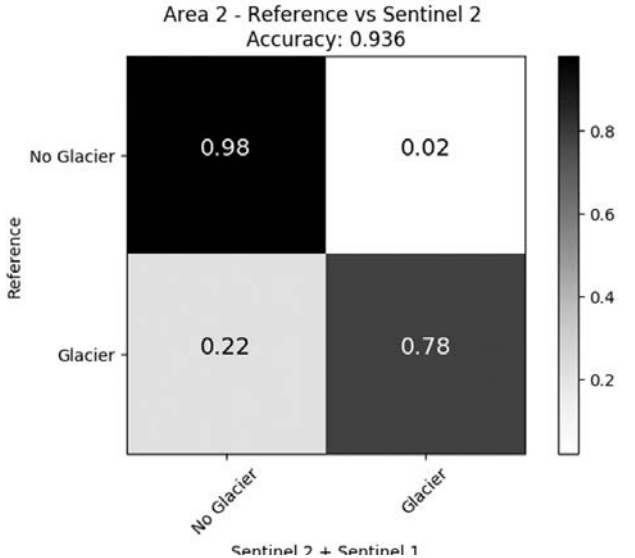


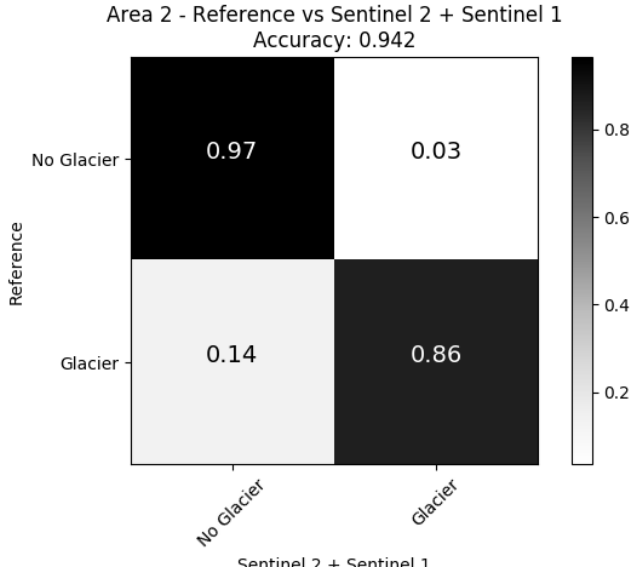
Sentinel-2 + Sentinel-1



Agreement area

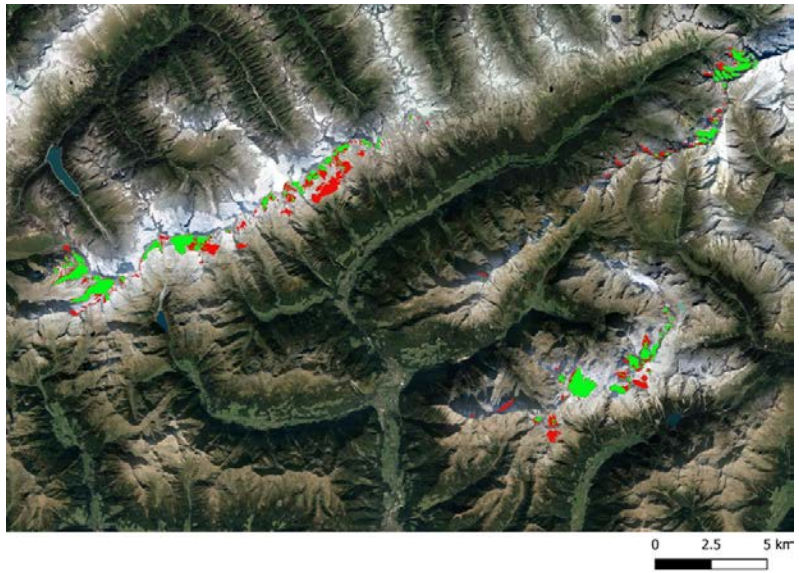
Disagreement area



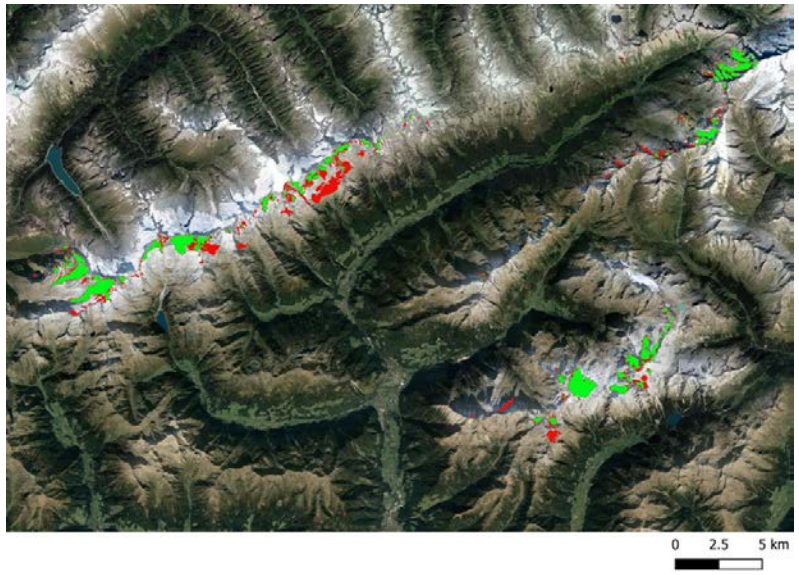


Area 3 Results

Sentinel-2

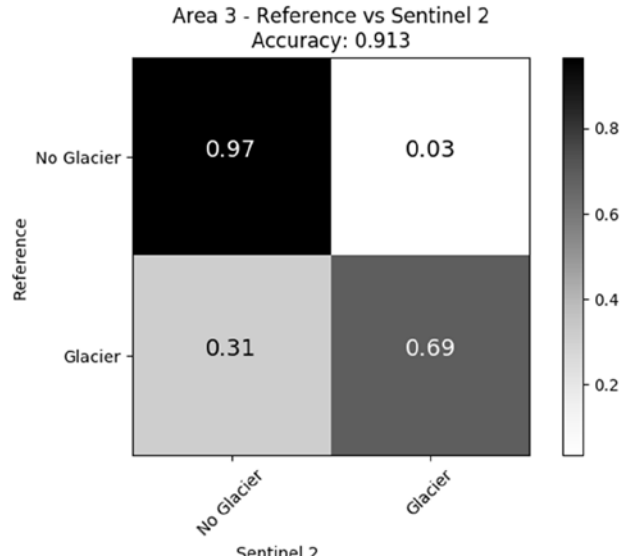


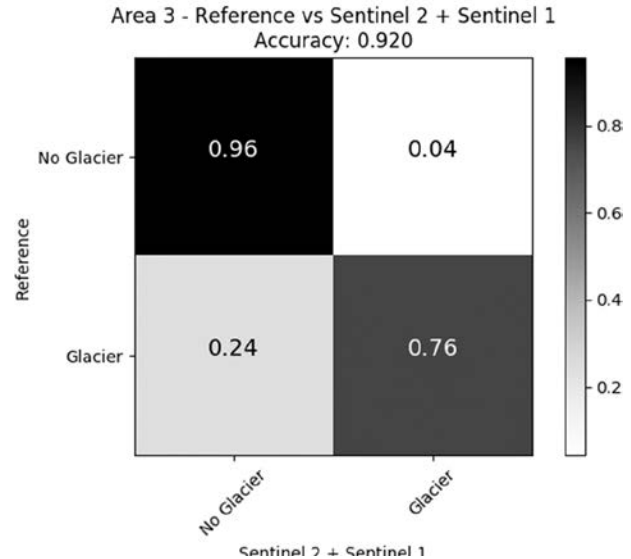
Sentinel-2 + Sentinel-1



Agreement area

Disagreement area





Conclusions:

- Sentinel-1 and Sentinel-2 missions provide a great amount of data that can be exploited for glacier mapping
- To exploit efficiently all that multitemporal information we produce multitemporal composites with data from the time series
- In the end we extract bare glaciers outlines from Sentinel-2 and debris covered glaciers outlines from Sentinel-1
- In the end we validated the method with manually extracted outlines, optaing an overall accuracy better than 90 %