Sentinel-2 data fusion for remote sensing of snow cover

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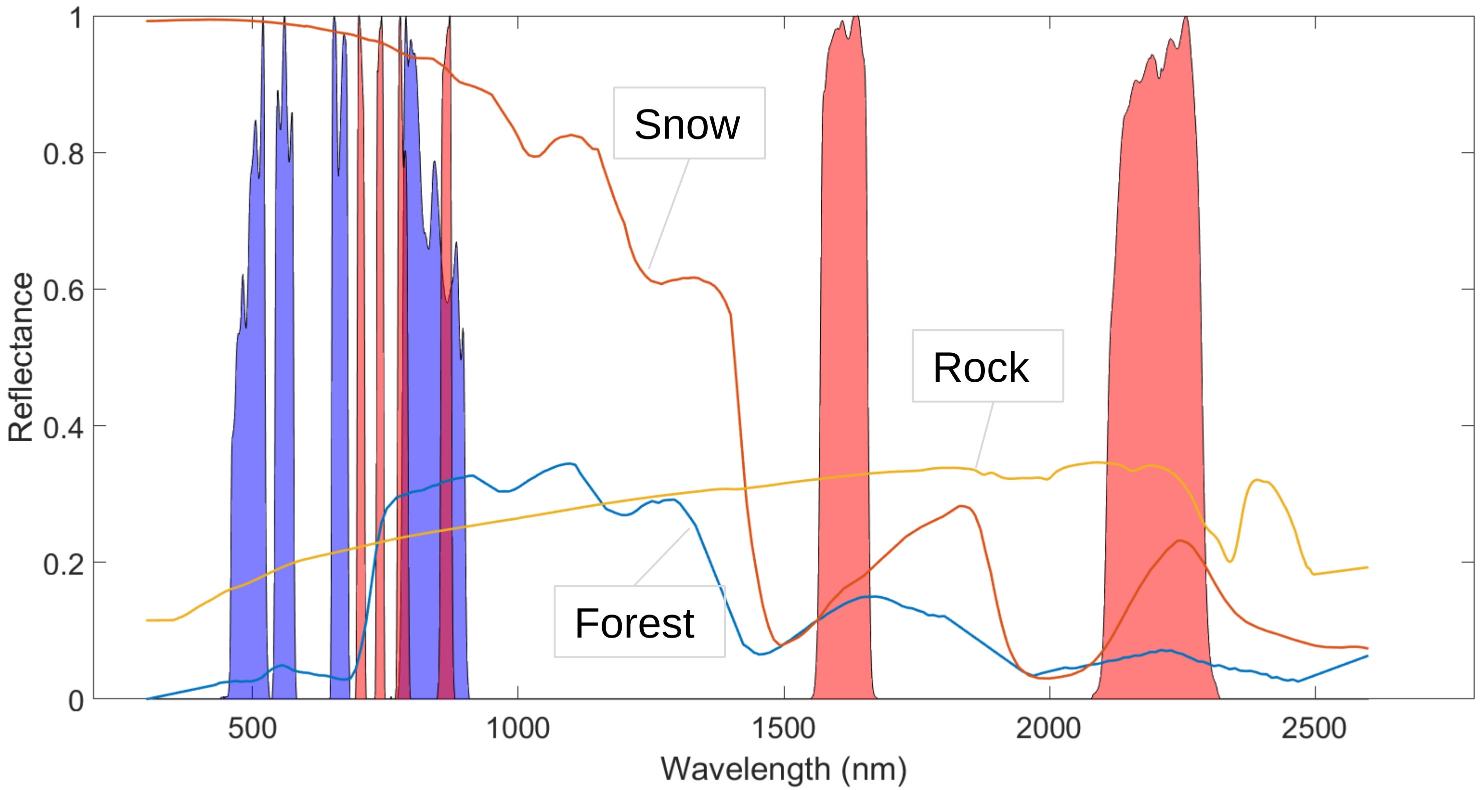
Sentinel-2 (S2)

- 5 days return time (with S2A and S2B)
- 10 bands in VIS and NIR/SWIR (4 at 10 m in blue, 6 at 20 m in red)
- Suitable to monitor snow
- CESBIO (Let-it-Snow) and ESA produce a snow cover product at 20 m



The Let-it-Snow product

Based on the Normalize Difference Snow Index (NDSI)

$$\mathrm{NDSI} = \frac{R_{SWIR} - R_{VIS}}{R_{SWIR} + R_{VIS}}$$

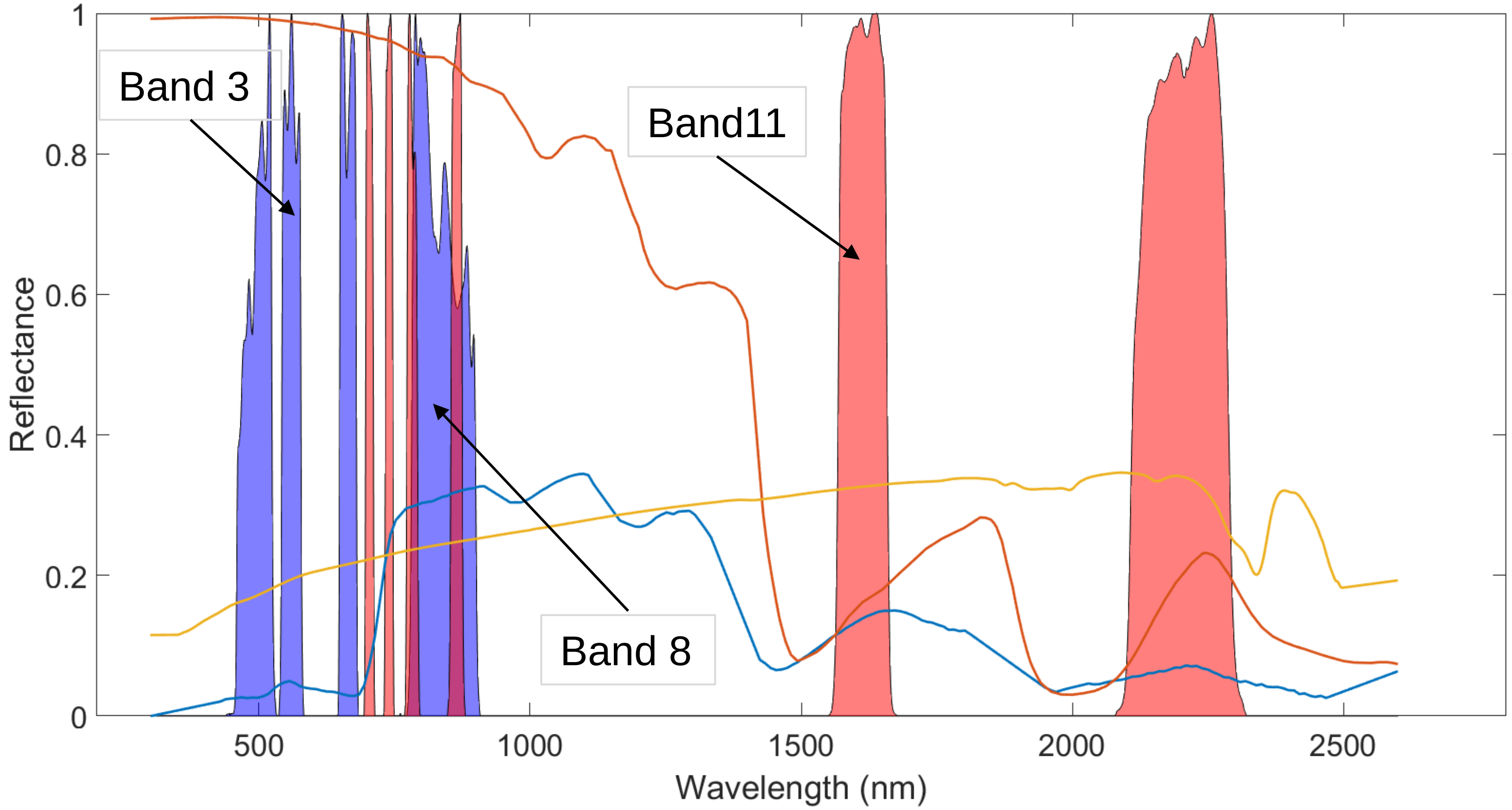
(Dozier et *al*, 1989)

In S2, VIS is band 3 and SWIR is band 11

Complete workflow :

- A first pass is made with NDSI thresholds at 0.40 and band 8 (centered at 865nm) threshold at 0.20 to avoid false detection of snow.
- This allows to determine the snow line elevation (with a MNT).
- A second pass is then made over all non-cloudy pixels above this line with NDSI threshold at 0.15 and band 8 threshold at 0.12 to extract all the snow covered pixels.
- The result is binary (i.e., snow or not snow)

Goal: spatial resolution



- Band 3 and 8 are at a spatial resolution of 10 m
- Band 11 is at a spatial resolution of 20 m

-> The LIS product is at a spatial resolution of 20 m

Is it possible to produce snow cover estimation at 10 m ?

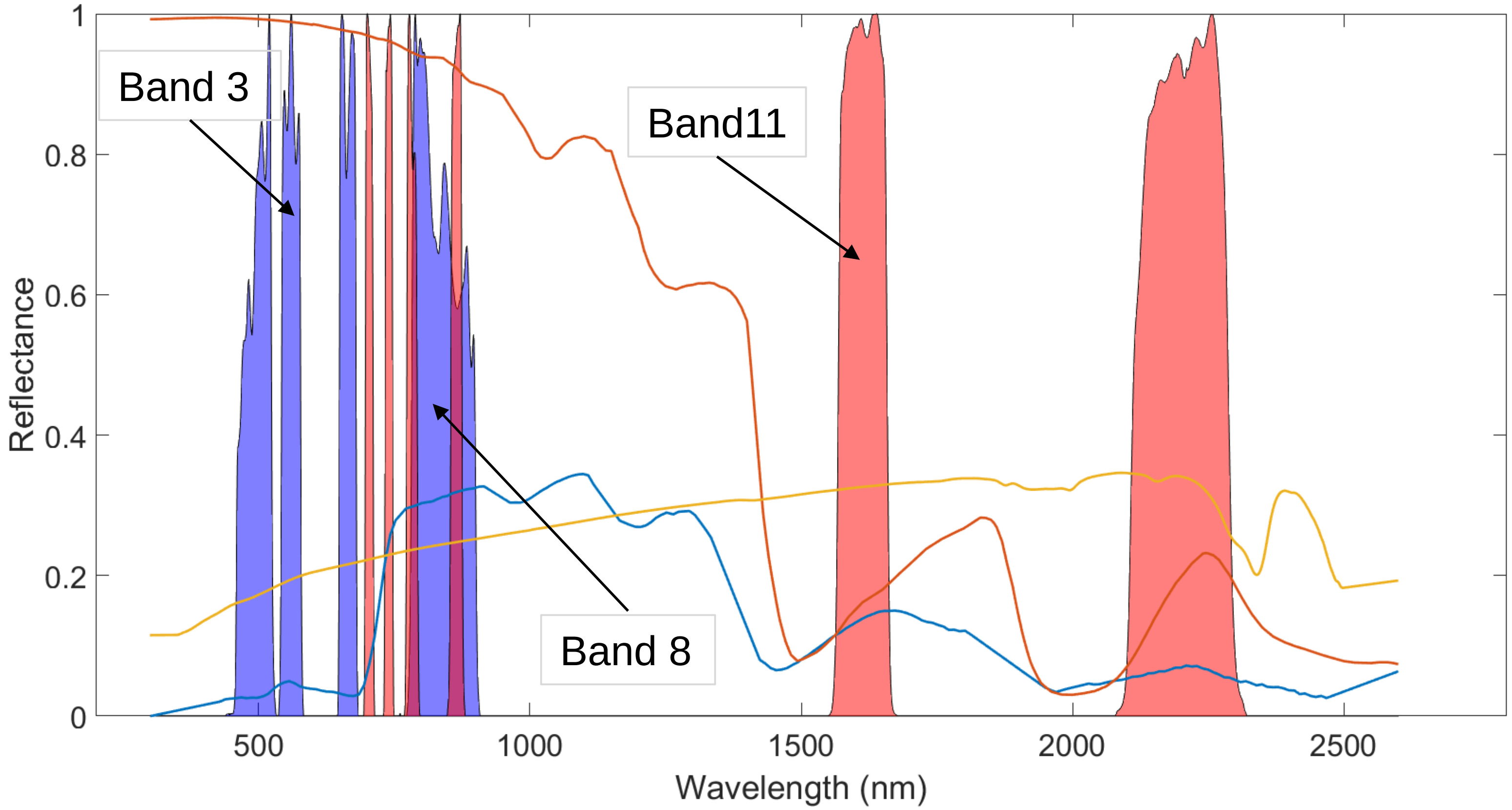
-> Data fusion

-> Interpolation

Data fusion: the ATPRK approach

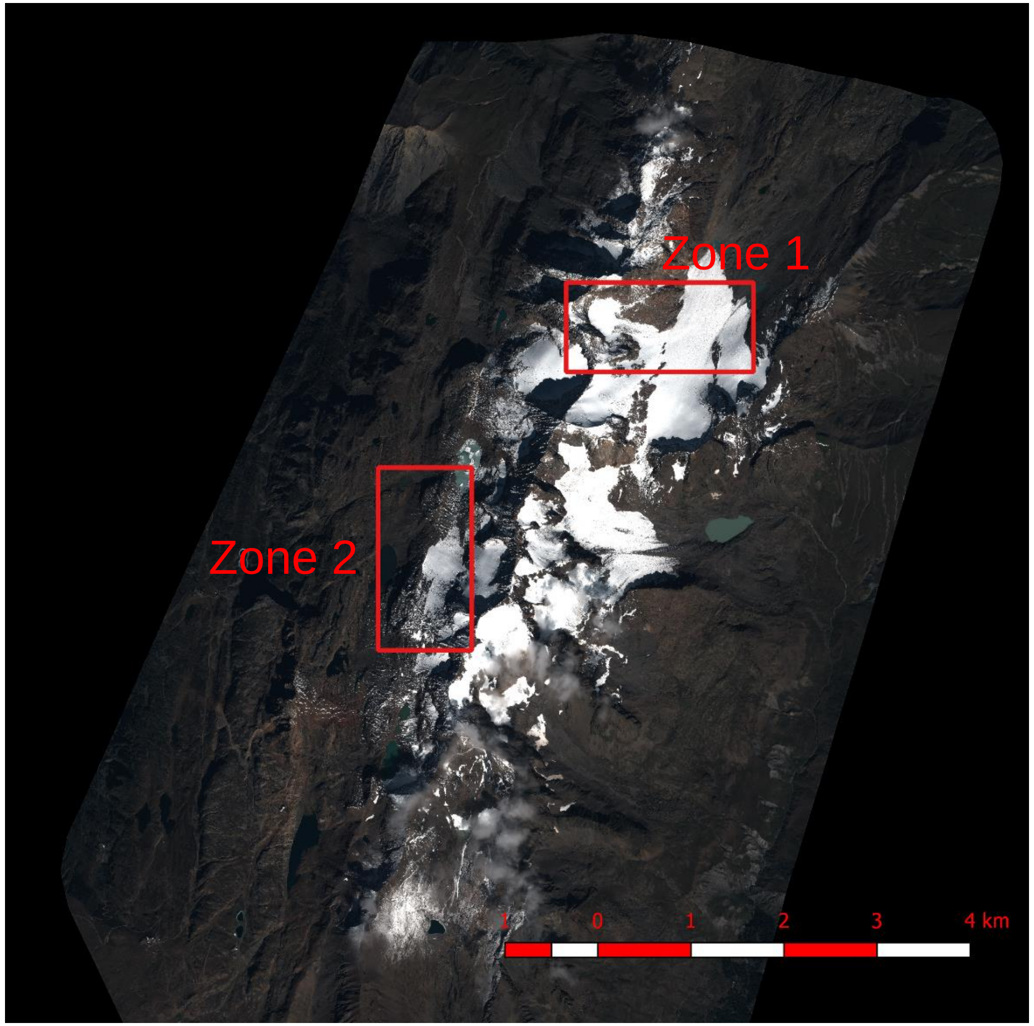
- The area-to-point regression kriging (ATPRK) fusion scheme allows to fuse the 6 bands at 20 m spatial resolution with the 4 bands at 10 m. (Wang et *al,* 2015,2016)
- The product is composed of 10 independent bands at 10 m spatial resolution.
- The approach consists of regression-based overall "trend" estimation and area-to-point based residual downscaling.
- It accounts explicitly for the size of pixels, band correlation and the point spread function of the sensor.

Interpolation



- Nearest neighbor
- Bilinear
- Bicubic

Reference: Pleiades data

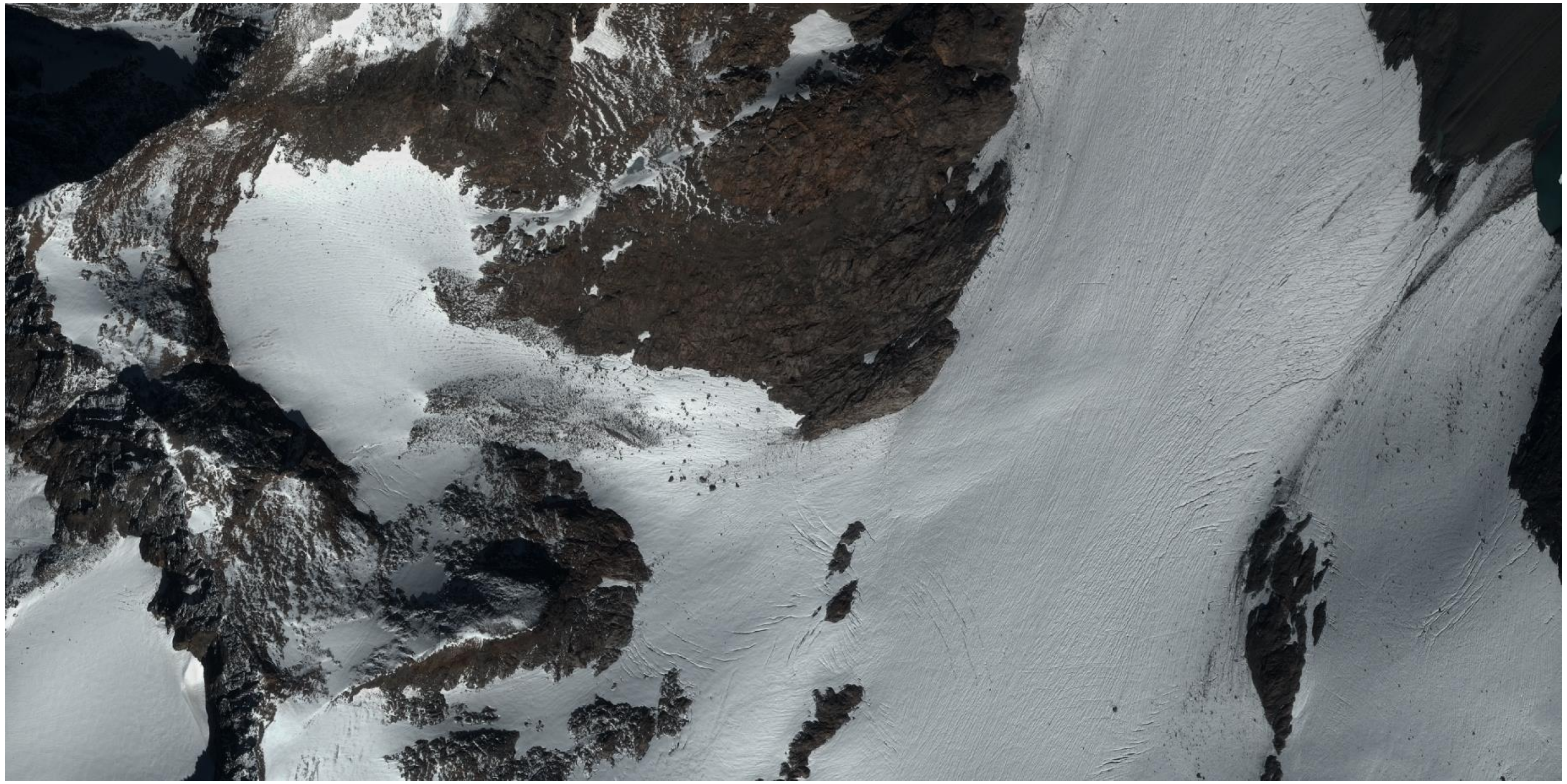


- Pleiades product « ORTHO-SAT »
- 4 Bands at a spatial resolution of 50 cm

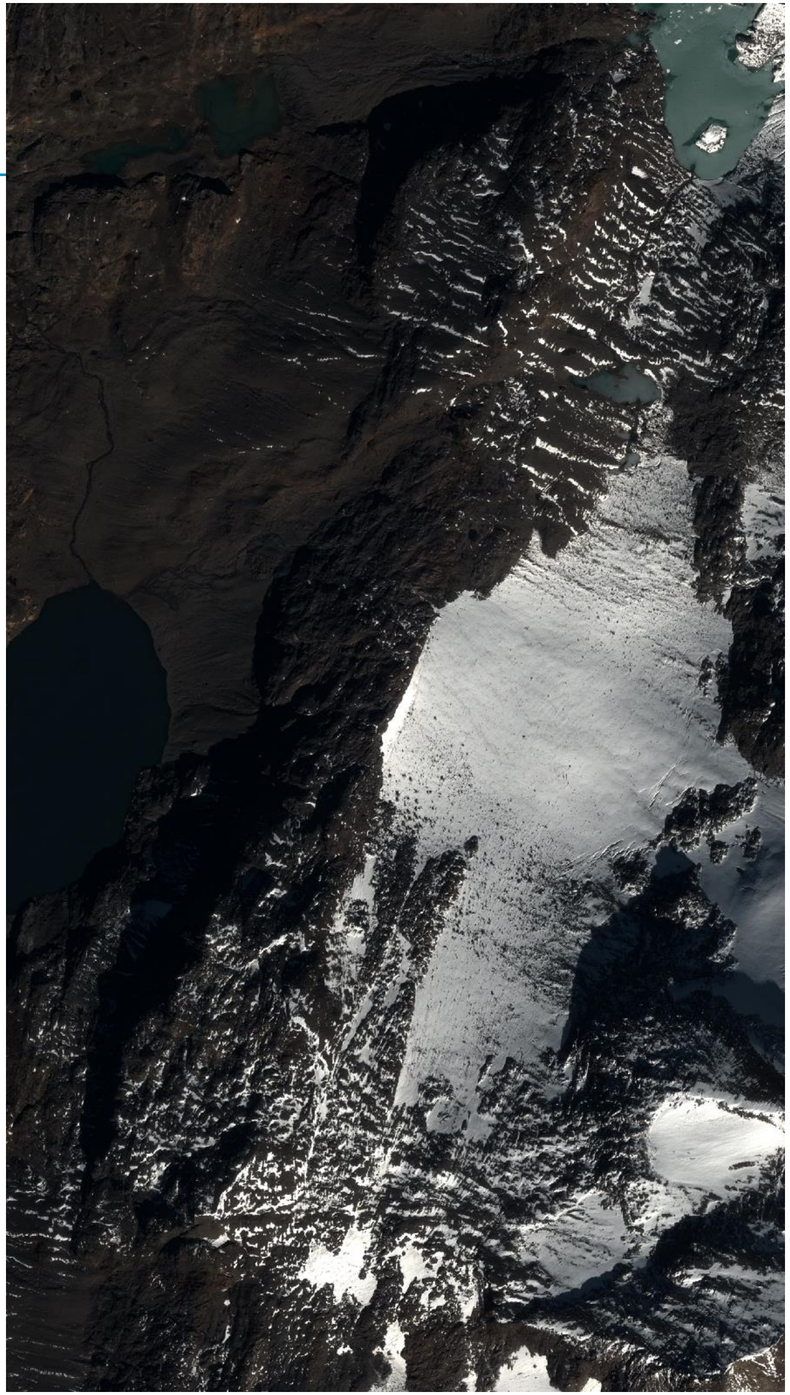
- First area acquired over the "Grandes Rousses" near the ski resort "Alpe d'Huez" in September 22, 2016
- 2 zones of 2 km²

Reference: Pleiades data

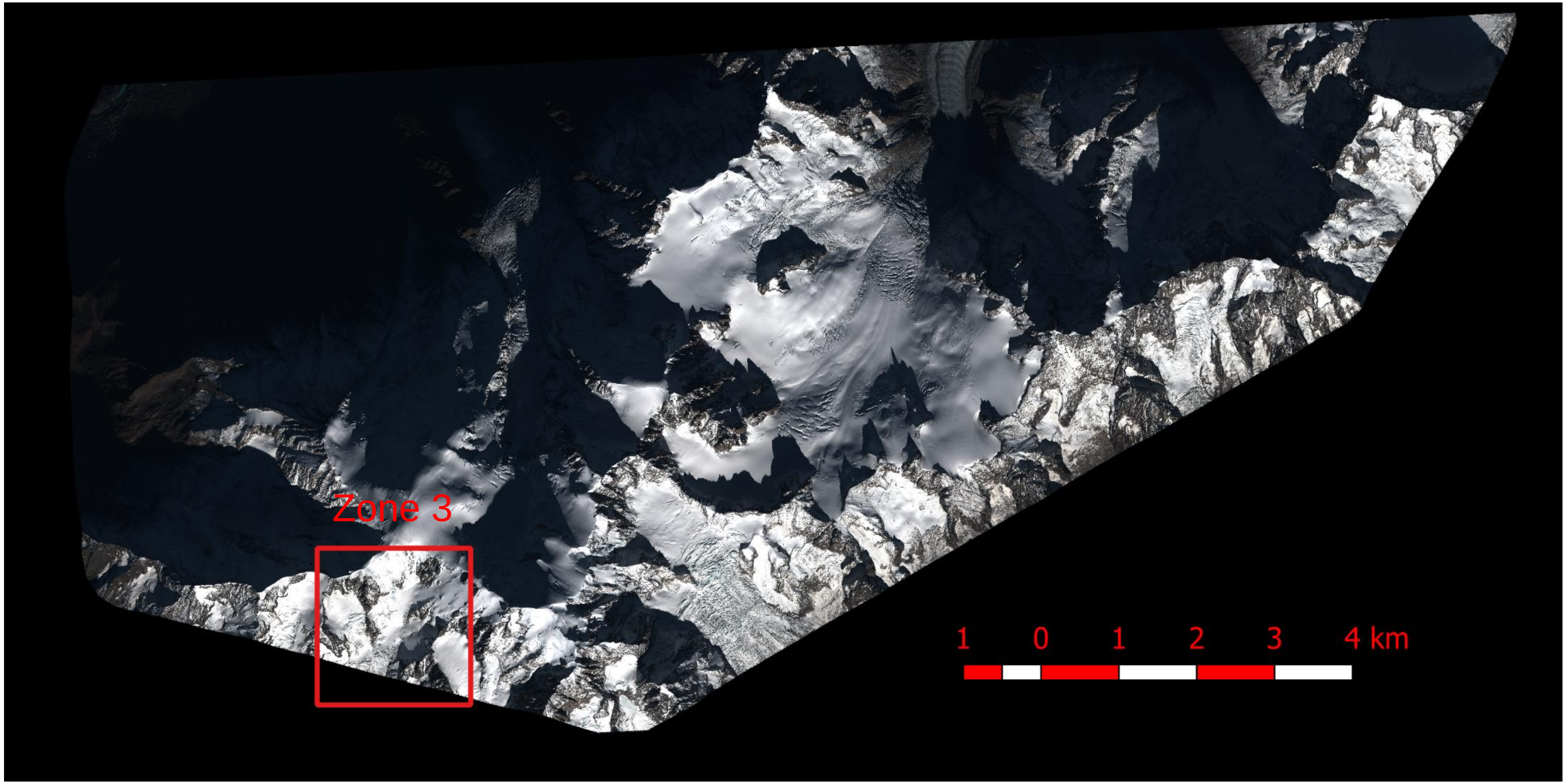
Zone 1



Zone 2



Reference: Pleiades data



- Second area acquired over the Mt Blanc in November 1, 2016
- 1 zone of 4 km²

Methodology

- Acquisition at same date for the same area.
- S2 data from the THEIA web site at a level 2A of processing, with atmospheric and topographic correction.
- Pleiades data were reprojected using nearest neighbor
- The different results are then upscaled again using nearest neighbor to the Pleiades spatial resolution to calculate the different evaluation metrics and avoid the use of fractional snow cover

Evaluation metrics: Binary

TP : True Positive

TN : True Negative

FP : False Positive

FN : False Negative

$$Precision = \frac{TP}{TP + FP}$$

Probability that a pixel where snow is detected (SCF>0) indeed contain snow.

$$Recall = \frac{TP}{TP + FN}$$

Probability of a detection of a snow-covered pixel

$$F\ score = \frac{2TP}{2TP+FP+FN}$$

F score penalizes both missing snow and falsely positive detection of snow without dependency of the total snow-free area.

Evaluation metrics: Average Symmetric Surface Distance (ASSD)

- Let $S(R)$ denotes the snow line of the reference map from Pleiades and $S(M)$ the snow line from one of the Sentinel-2 maps.
- The shortest distance between a pixel $s_M \in S(M)$ to $S(R)$ is defined as

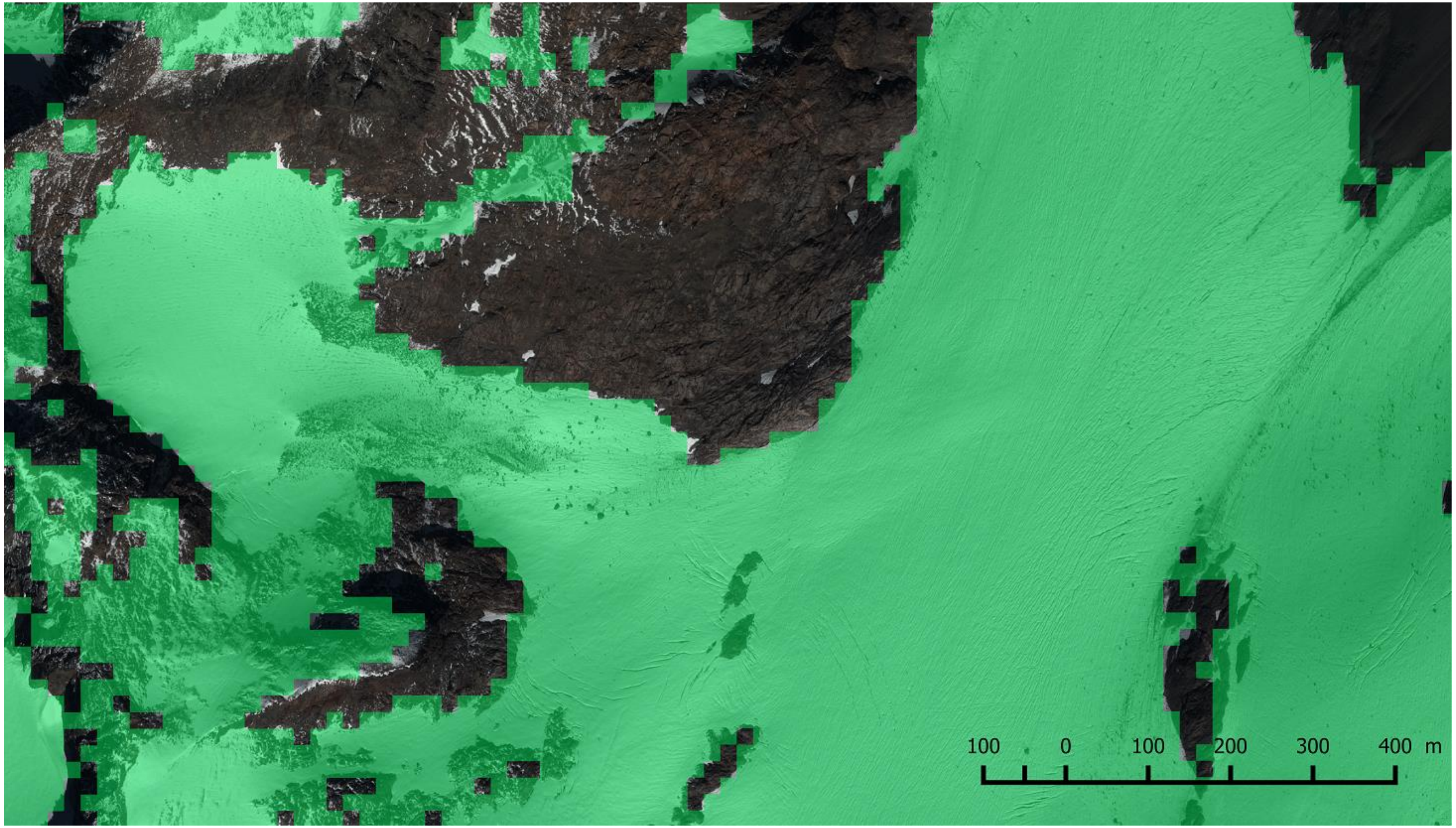
$$d(s_M, S(R)) = \min_{s_R \in S(R)} \| s_M - s_R \|$$

where ‖ . ‖ denotes the 2D Euclidean distance. The ASSD is then given by:

$$ASSD(R, M) = \frac{1}{|S(R)| + |S(M)|} \left(\sum_{s_R \in S(R)} d(s_R, S(M)) + \sum_{s_M \in S(M)} d(s_M, S(R)) \right).$$

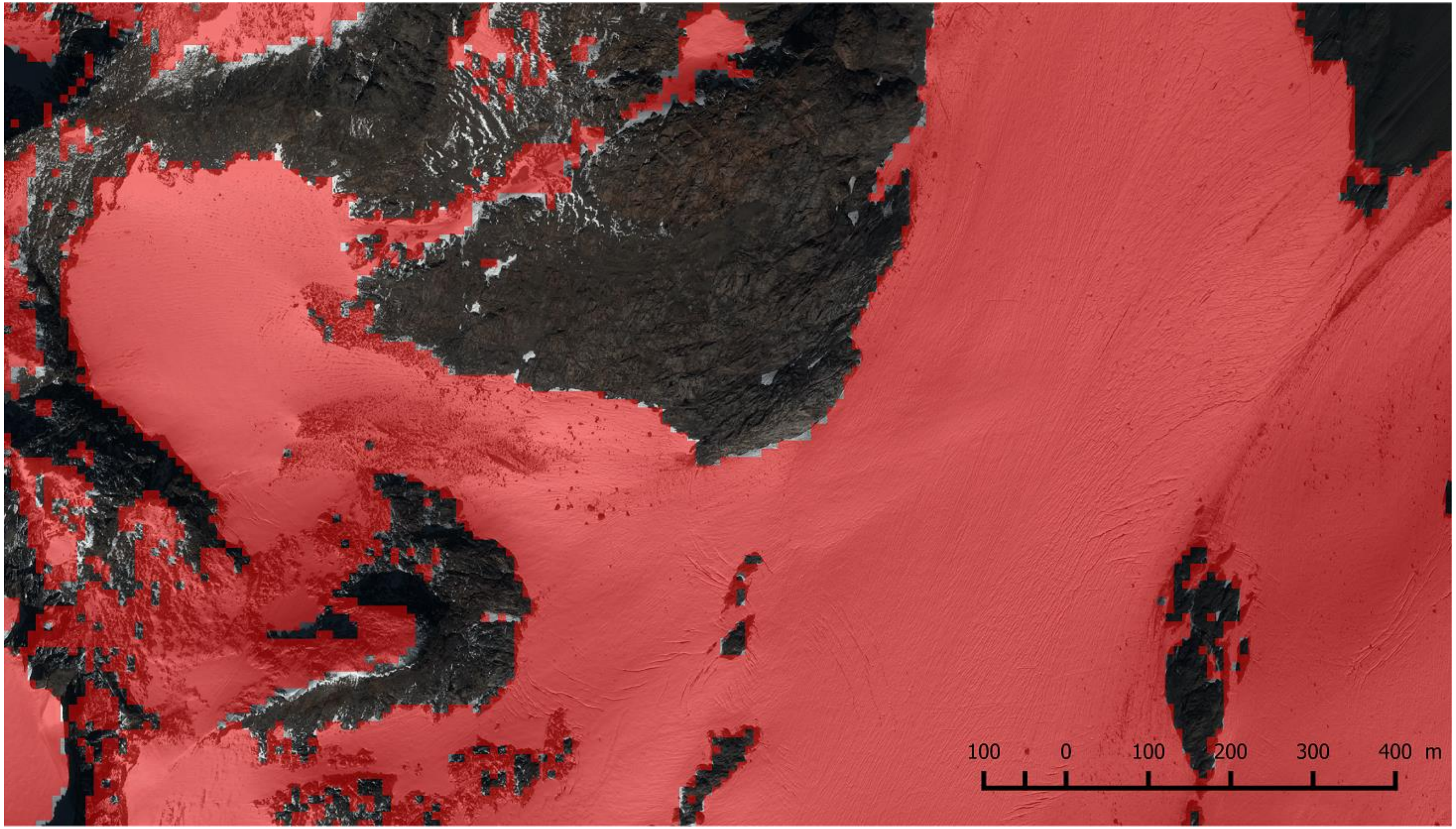
Visual results

20 m



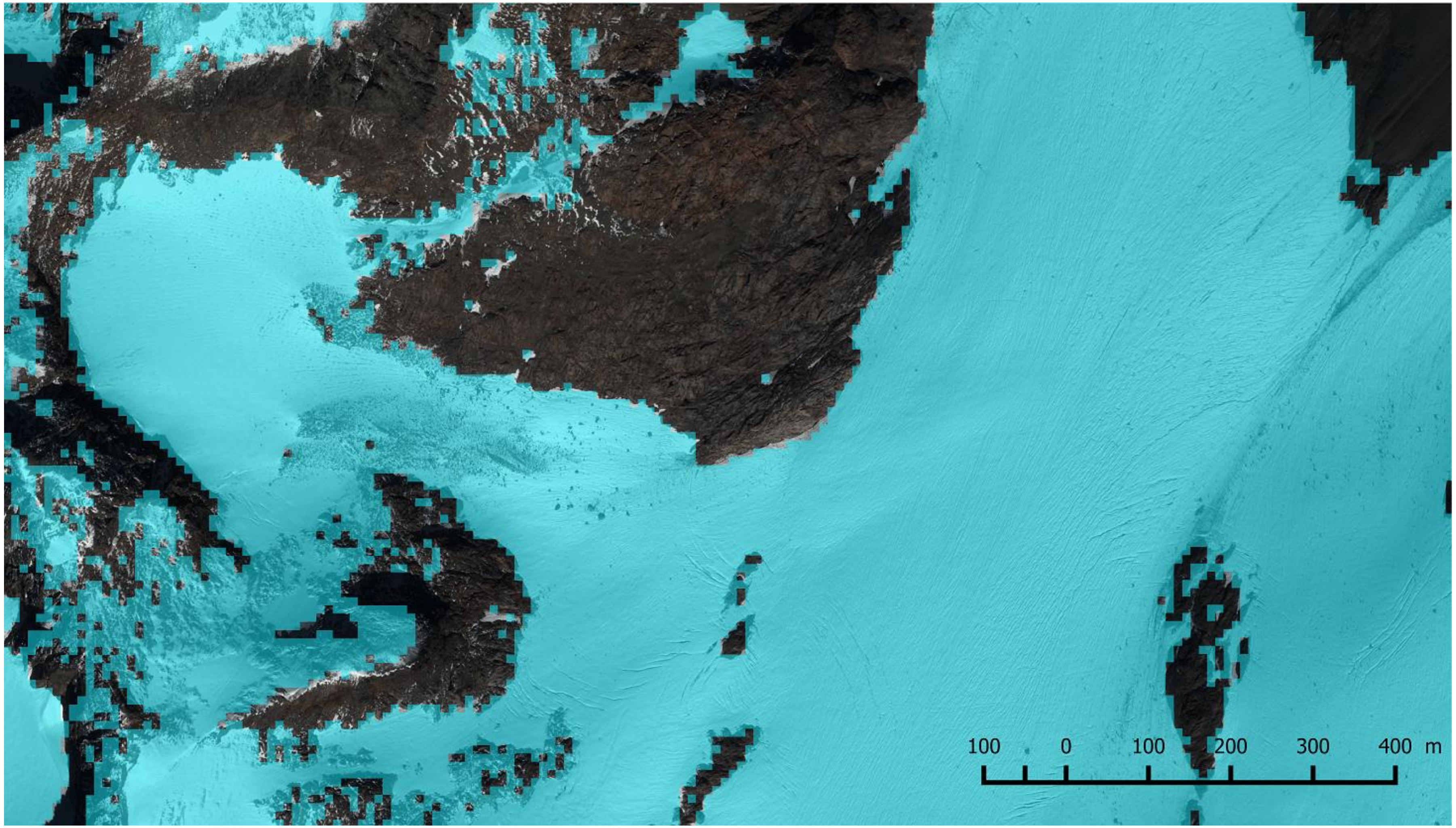
Visual results

10 m
resampled

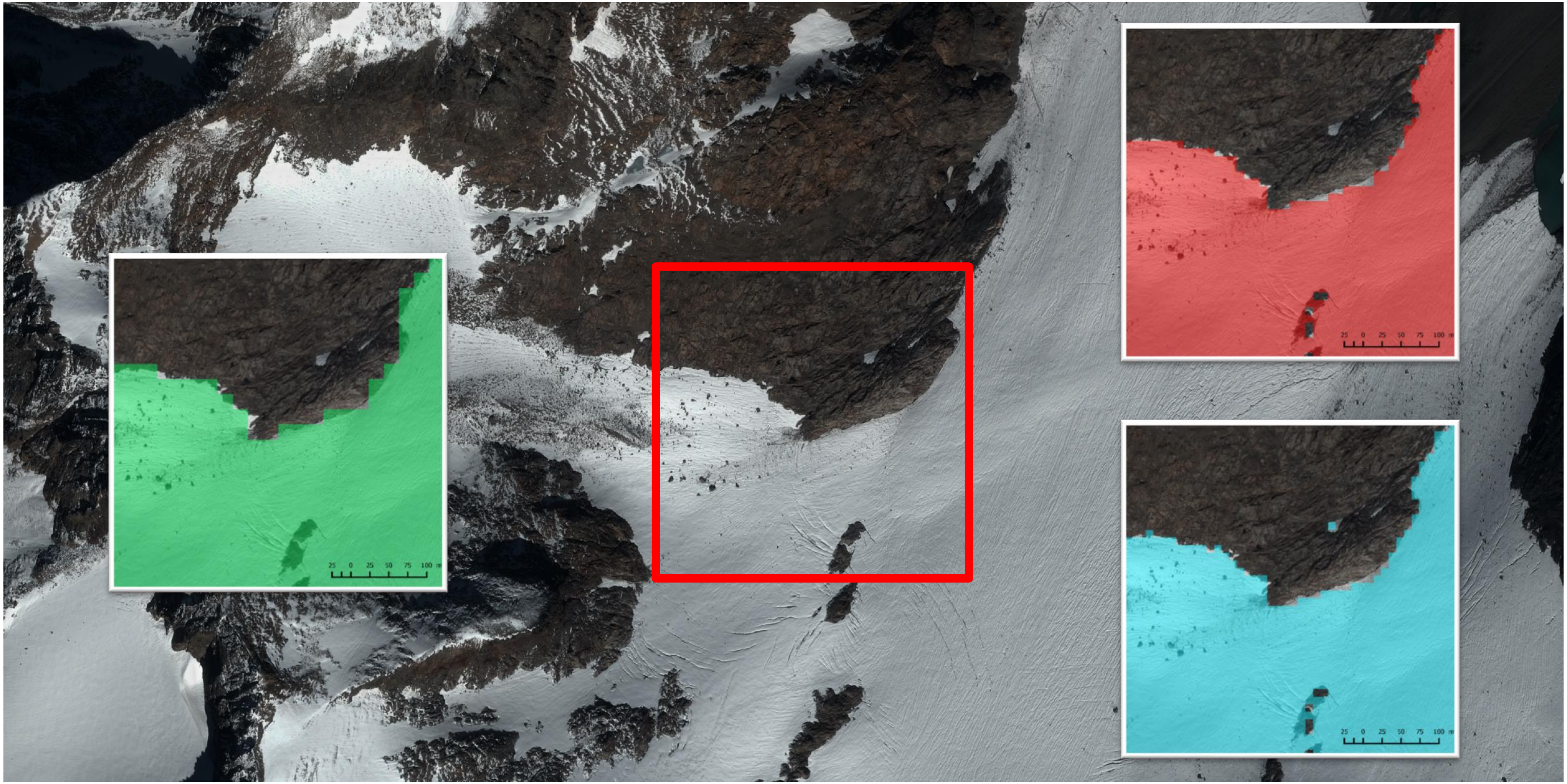


Visual results

10 m
Fused

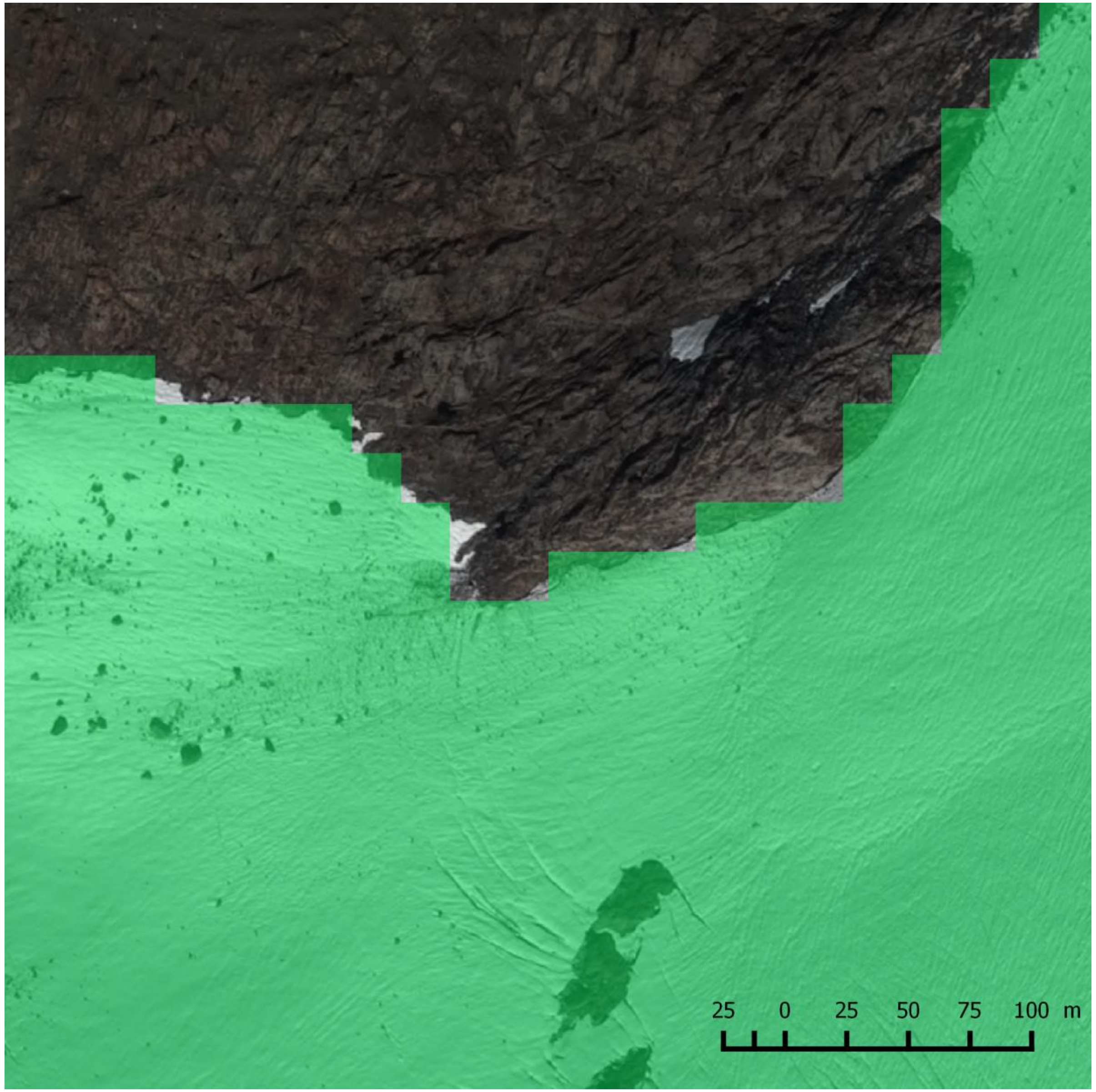


Visual results



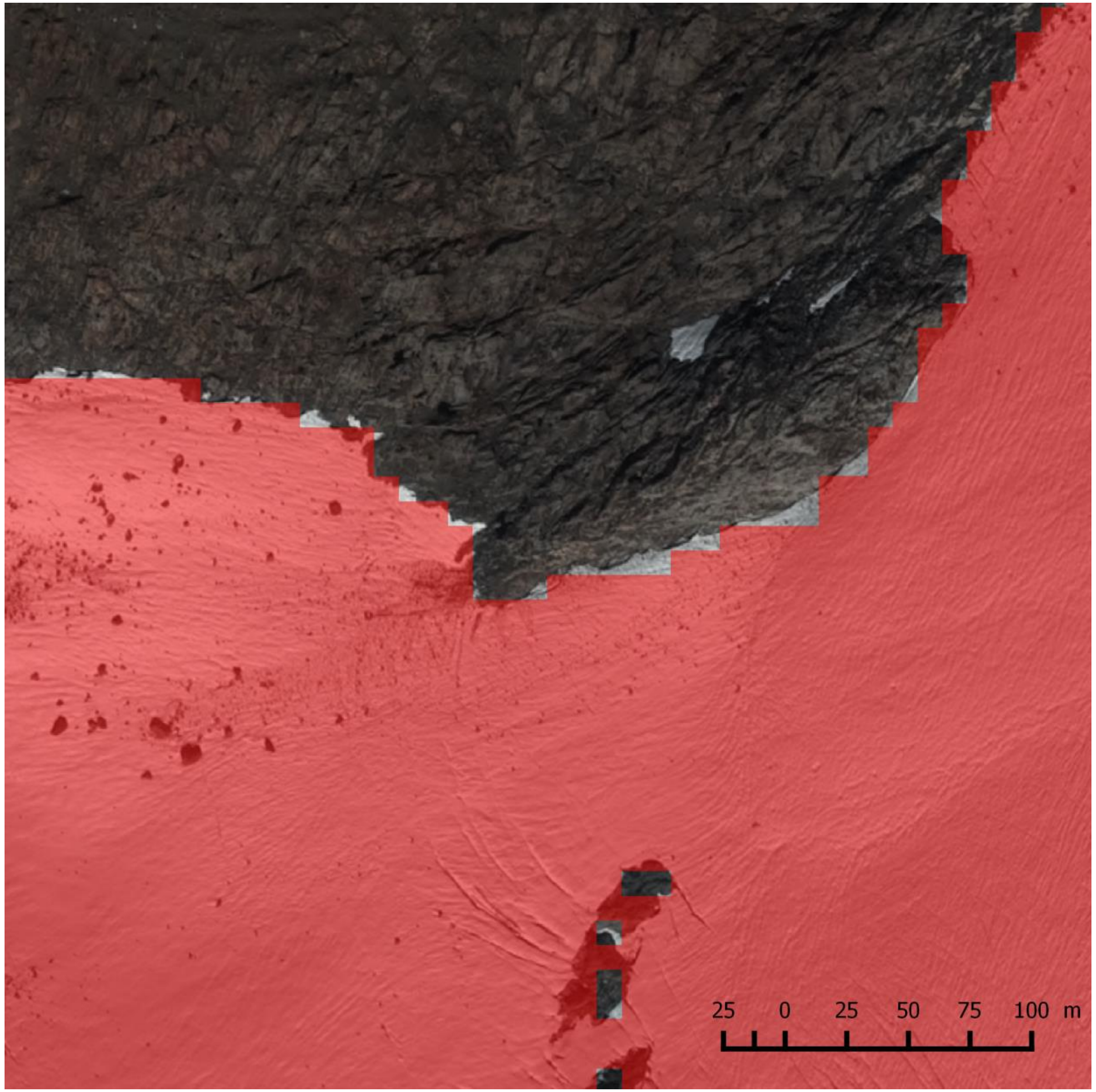
Visual results

20 m



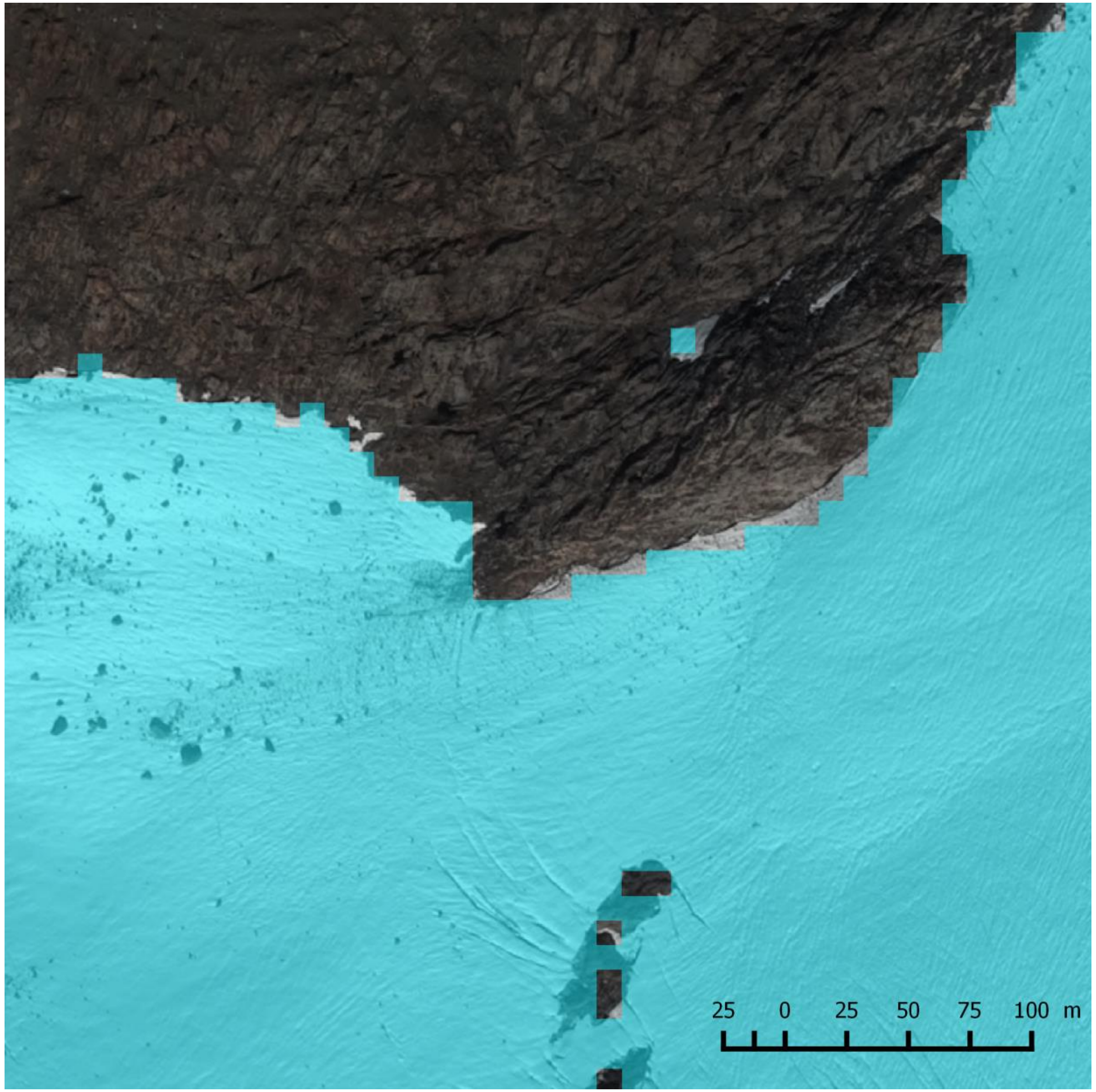
Visual results

10 m
resampled

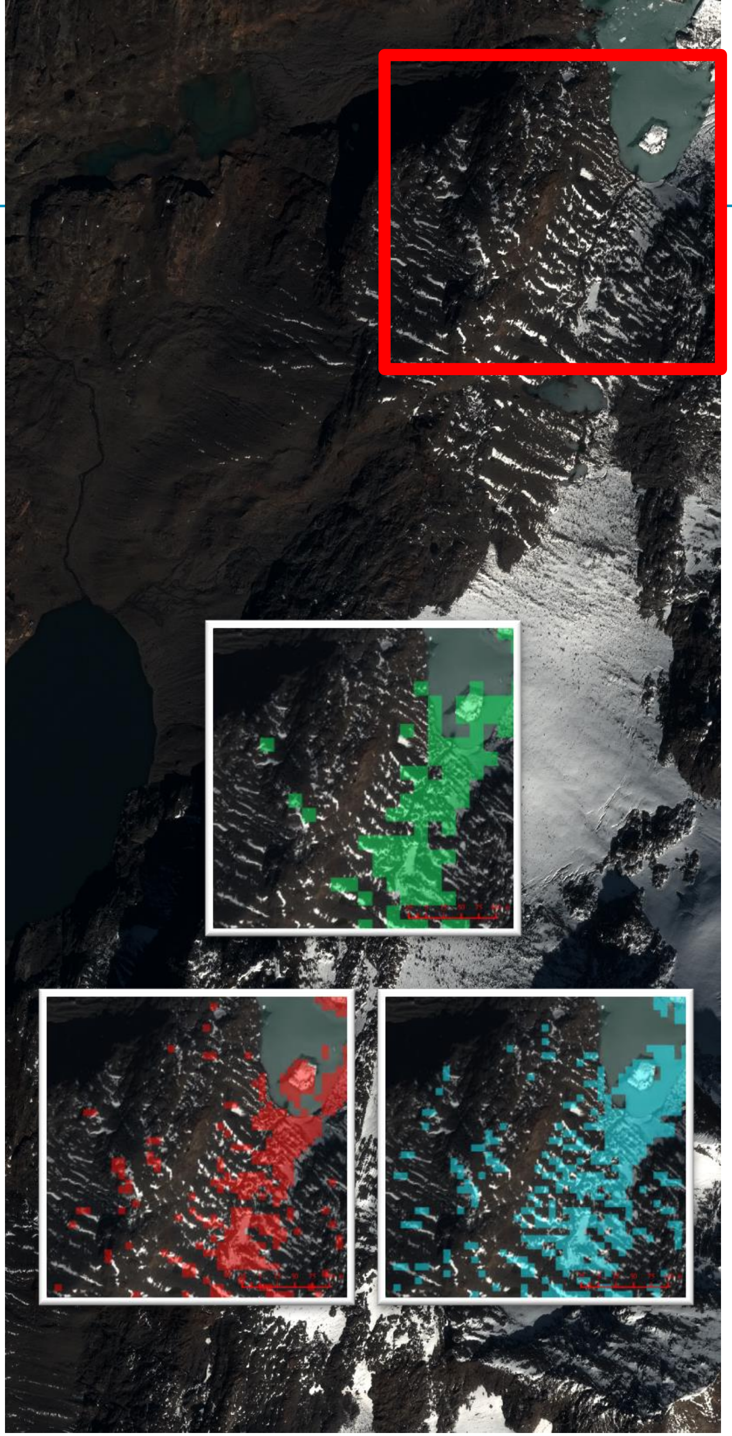


Visual results

10 m fused

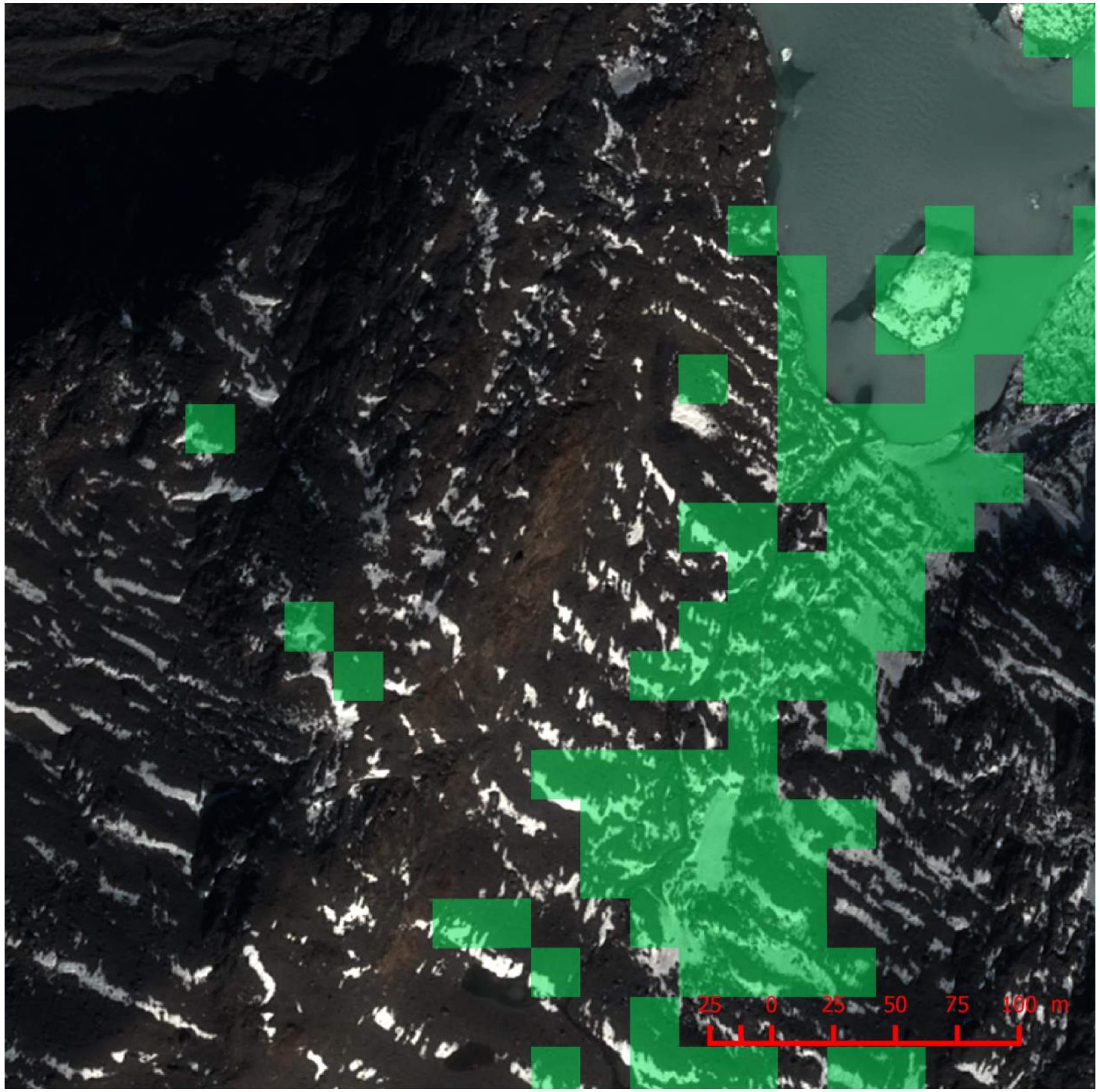


Visual results



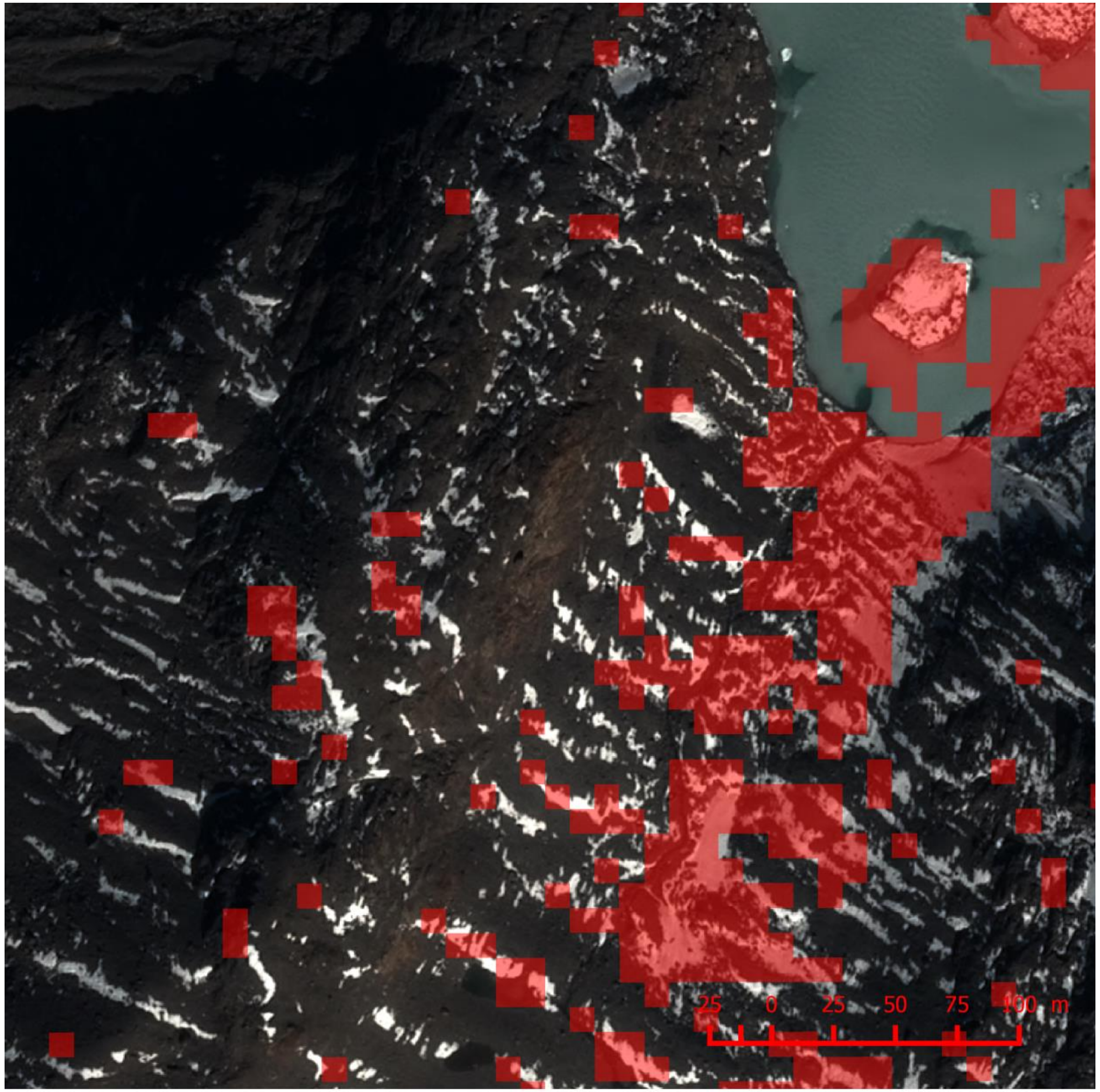
Visual results

20 m



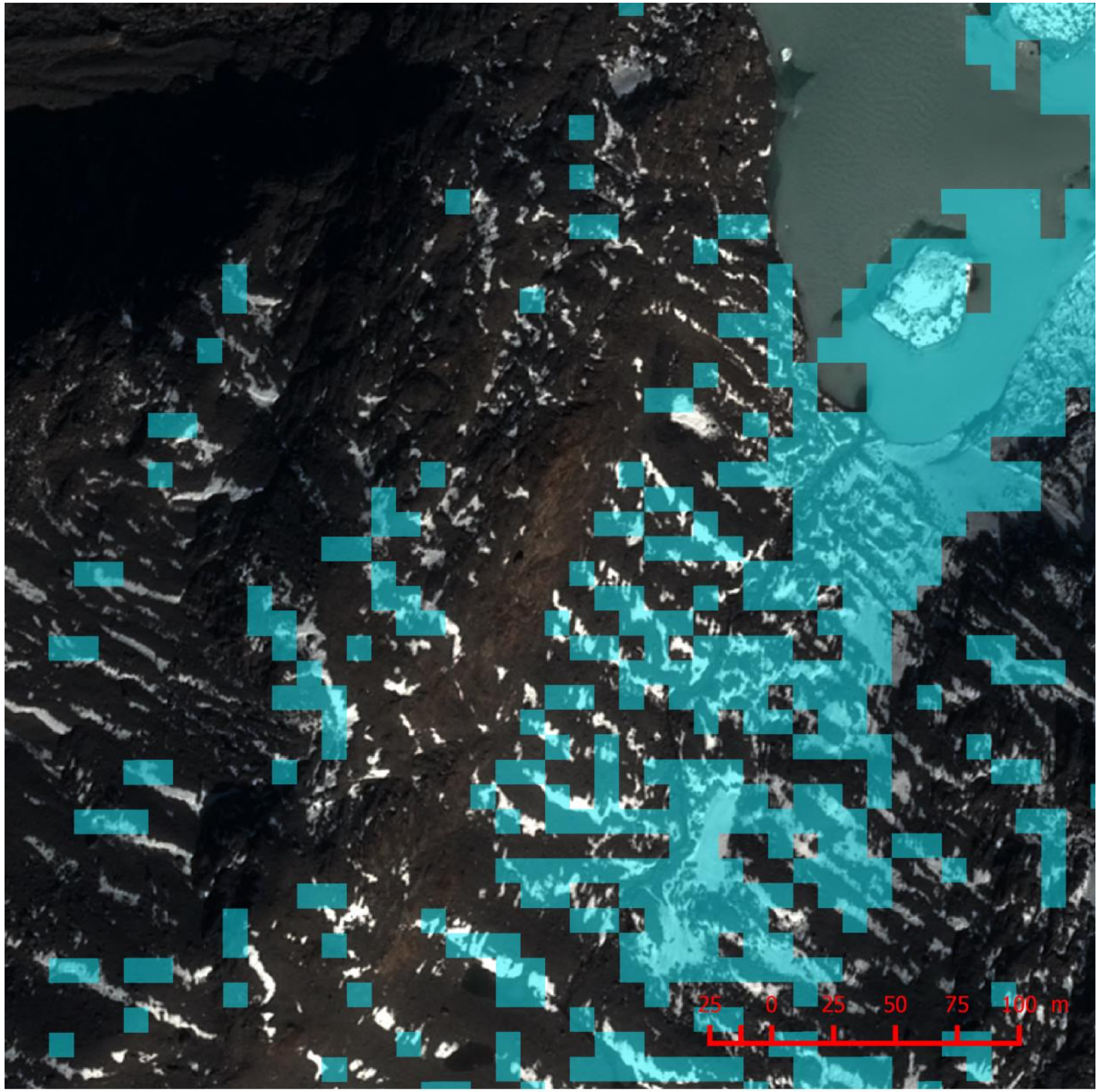
Visual results

10 m
resampled



Visual results

10 m fused



Metric results

	Metric	ASSD	Surface overestimation	Precision	Recall	Accuracy	F_{score}
Huez Zone 1	Source	40.96	13.25%	0.847	**0.960**	0.866	0.900
	$S2_{nearest}$	32.06	**10.53%**	0.858	0.949	0.870	0.901
	$S2_{bilinear}$	32.18	10.80%	0.857	0.949	0.869	0.901
	$S2_{bicubic}$	32.13	10.72%	0.857	0.949	0.869	0.901
	ATPRK	**29.02**	10.56%	**0.869**	**0.960**	**0.884**	**0.912**
Huez Zone 2	Source	31.88	6.46%	**0.773**	**0.823**	**0.881**	**0.797**
	$S2_{nearest}$	18.83	**1.52%**	0.754	0.765	0.863	0.759
	$S2_{bilinear}$	18.85	1.74%	0.752	0.765	0.862	0.759
	$S2_{bicubic}$	18.90	1.69%	0.753	0.766	0.862	0.759
	ATPRK	**15.04**	8.93%	0.755	0.822	0.874	0.787
MtBlanc	Source	50.53	20.40%	0.783	**0.943**	**0.791**	**0.855**
	$S2_{nearest}$	28.36	**16.85%**	**0.790**	0.923	0.788	0.851
	$S2_{bilinear}$	**28.27**	16.97%	0.789	0.923	0.788	0.851
	$S2_{bicubic}$	28.33	16.91%	0.753	0.923	0.788	0.851
	ATPRK	29.00	16.99%	**0.790**	0.924	0.790	0.852

Discussion and concluding remarks

- Both visual and quantitative evaluations show that the snow line at 10 m is more accurate and that smaller features are extracted.
- From the observation the lower size of an object that can be detected in a binary map is around 1.5 times the spatial resolution of the products.
- Diagonal ribbons of snow are identified by the 10 m product (improve the ASSD) but do not have the same orientation than the S2 acquisition, leading to an increase of the false positive detection. In these cases the use of the 10 m product can degrade the global estimation of the snow cover.

-> This could be partially resolved by Spectral Unmixing. The final product will be fractional and will take into account of these mixed areas for the total amount of visible snow.

- Slight advantage of the fusion in front of the resampling (only done over one band)
- Important limitation come from the shadowed areas.

Shadows