Snowmelt lines over mountains from Sentinel-1 SAR images

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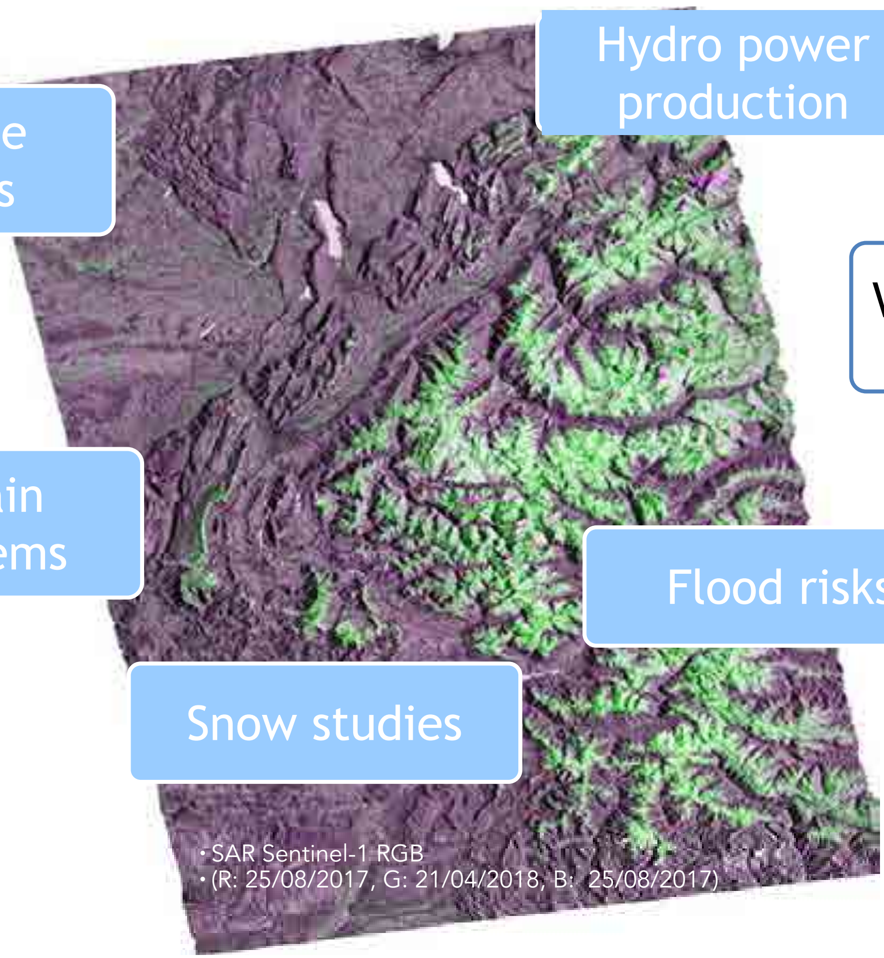
Funding from CNES via the APR SHARE Project

Introduction

Hydrology

Hydro power production

Avalanche forecasts



Wet snow variability in space and time

Mountain ecosystems

Flood risks

Snow studies

Introduction

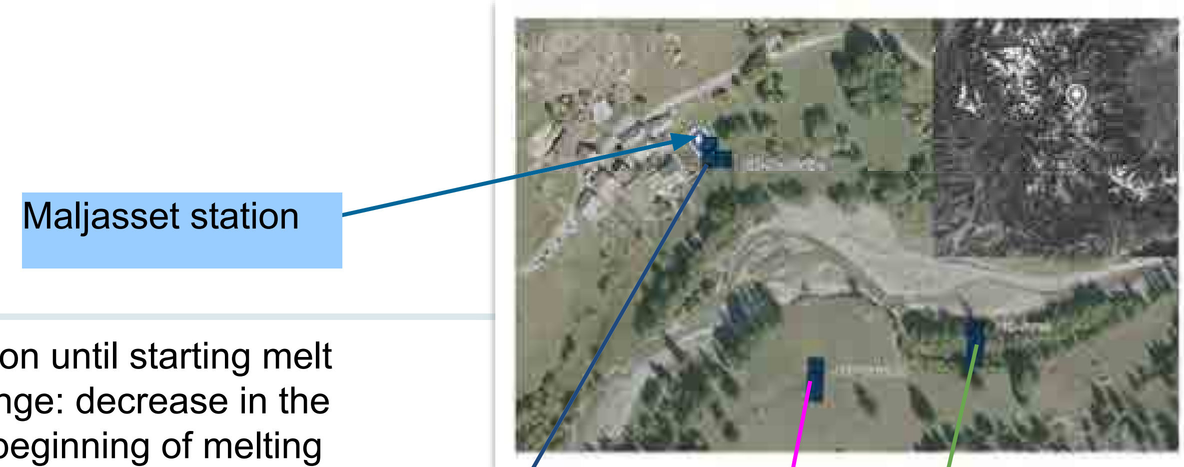
Sentinel-1

C-band, 2 satellites, data available since october 2014,
6 days revisit over France

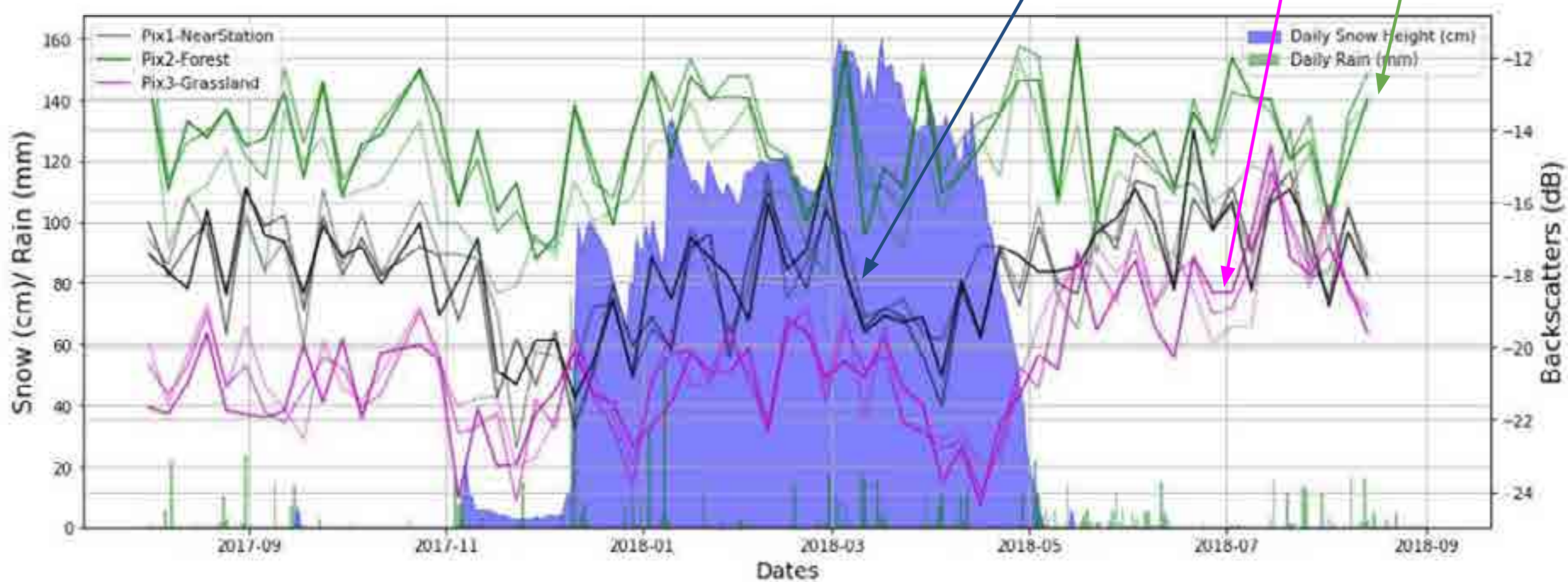
Sensitive to some snowpack properties (Snow liquid water content, wet snow lines, melt-out dates…)

All weather observations, Continuity of Sentinel-1 observations, free data policy, 20m resolution

Introduction



Gradual increase of backscatter with snow accumulation until starting melt
In agreement with Marin et al. 2020 indications of change: decrease in the afternoon backscatters of at least 2dB from winter ⇒ beginning of melting process, ripening phase if decrease in the morning ⇒ till local minima then runoff phase.

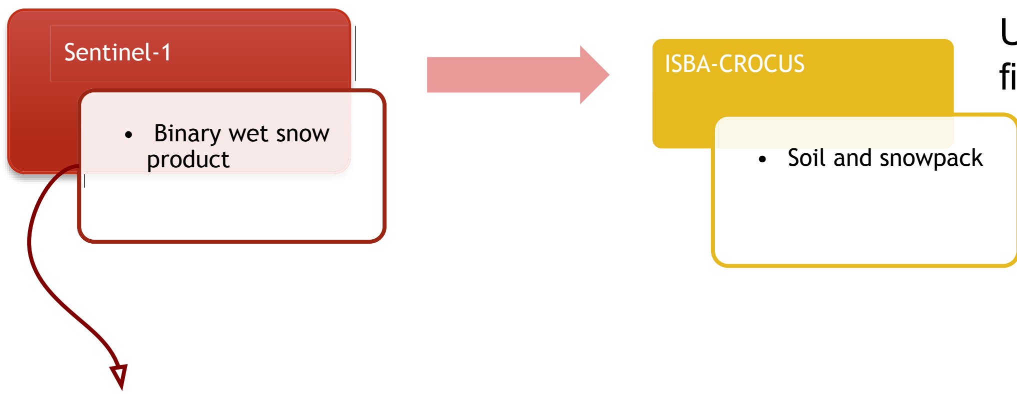


Sentinel-1 SAR signal (descending) near the in-situ station Maljasset (1908m)

Introduction

Studies along several directions at Météo-France : toward the assimilation of S1

(1) Qualification of an observation operator for Sentinel-1 (Veyssière et al. 2019)
(2) Assimilation of binary products



Using a particle filter approach
first results at ESA LP (Cap et al. 2022)

Binary wet snow extent from Sentinel-1:

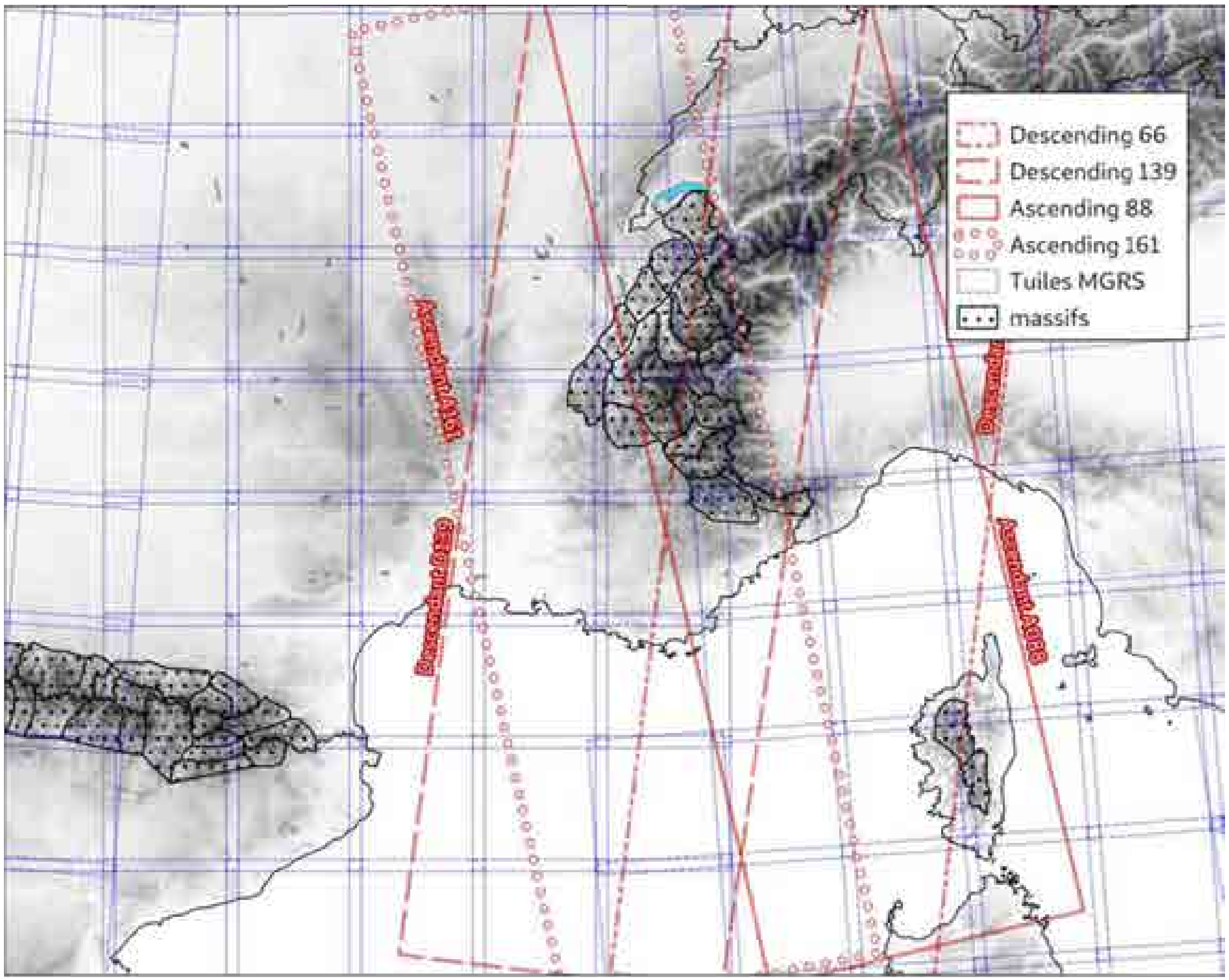
- Several algorithms/methods using C-band (Nagler et al. 2016, Baghdadi et al. 1997, Magagi and Bernier 2003, Nagler and Rott 2000, Marin et al. 2019, Tsai et al. 2019, Awasthi and Varade 2021, among many others)
- Most commonly used method of Nagler et al. 2016 (fixed threshold of 2-3 dB on image ratio)
- This method is the baseline for the new copernicus products (operational pan-European High-Resolution Snow & Ice Monitoring service)
- Issues: fixed thresholds (Baghdadi et al. 2000, Malnes and Guneriussen 2002, Longépé et al. 2009, Rondeau-Genesse et a. 2016), forest areas, reference image selection (Koskinen et al. 1997, Luojus et al. 2007), scores or metrics for evaluation of products

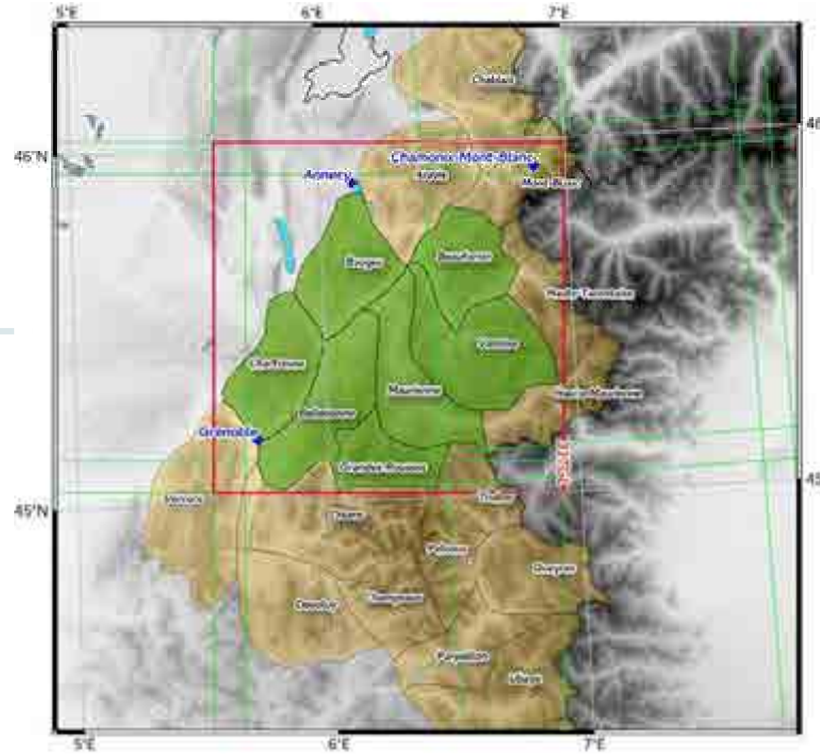
Outline

- ✓ Introduction
- ✓ Overview of Data, methods
- ✓ Meltlines from wet snow binary Sentinel-1 products
- ✓ Segmentation methods applied to Sentinel-1
- ✓ Conclusions & future work

Data, methods

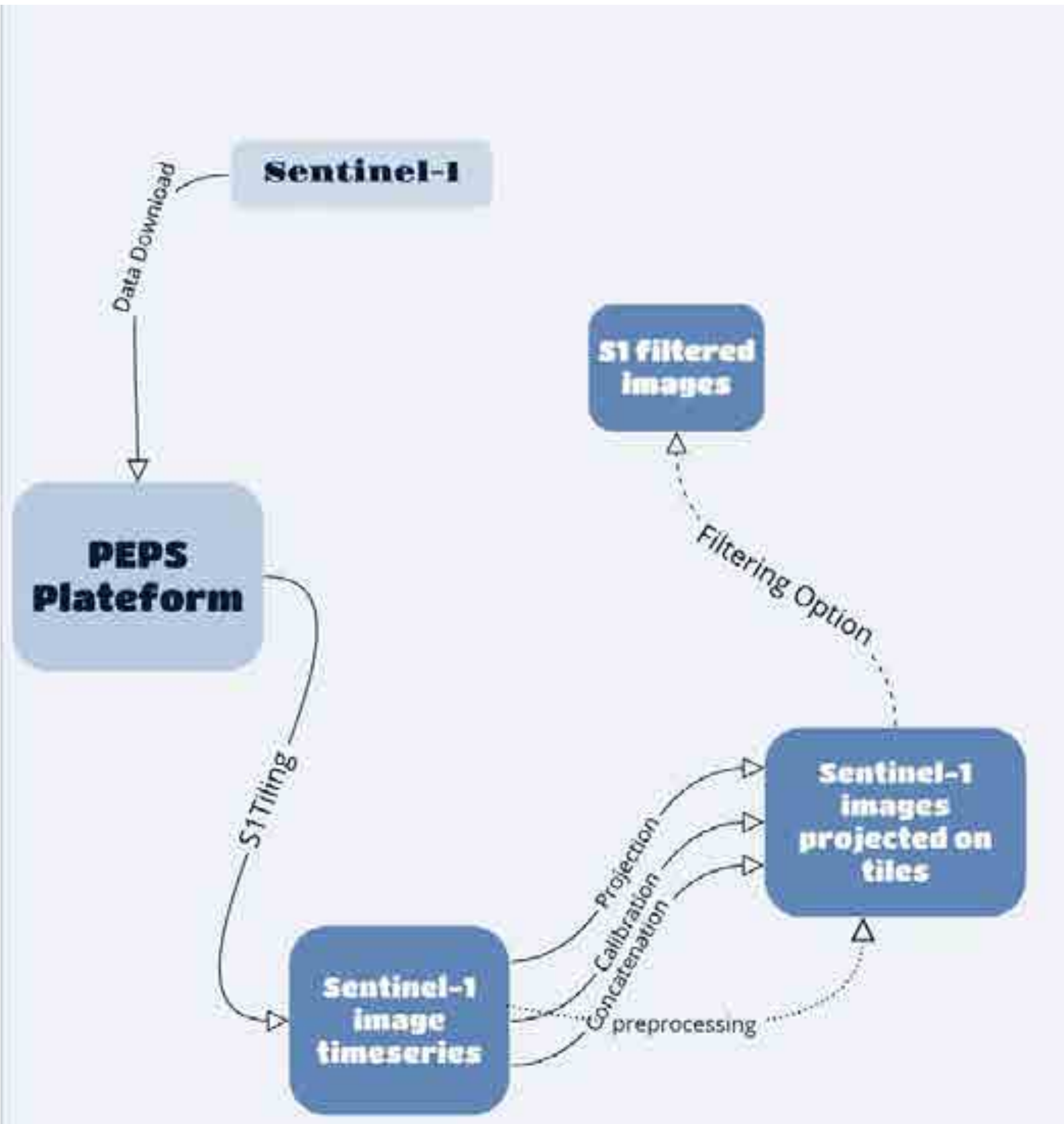
Our study area covers all French massifs, which are divided into massifs in our models.





To illustrate some of the results, I will use the 31TGL tile which includes 7 massifs

Data, methods



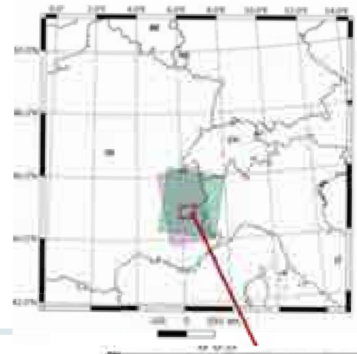
Sentinel-1 pre-processing using the CNES facilities and S1Tiling developed by Th. Koleck

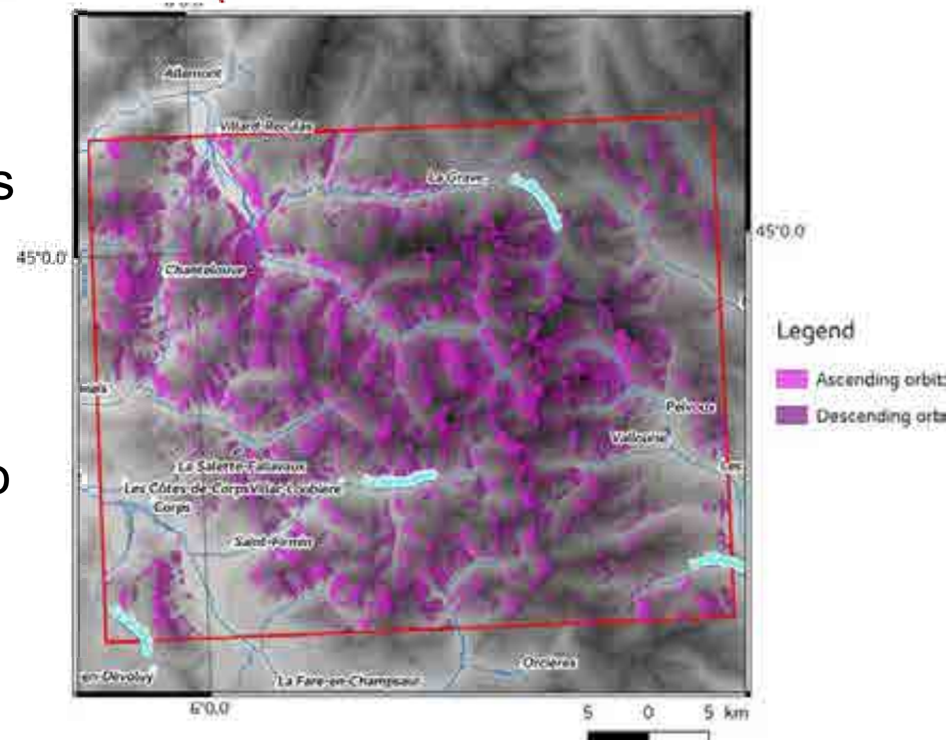
Orbit correction, calibration, speckle filtering, geometric correction, co-registration, selection of reference images, geometric distortion zones

Sentinel-1 binary wet snow

Pre-processing

Data, methods

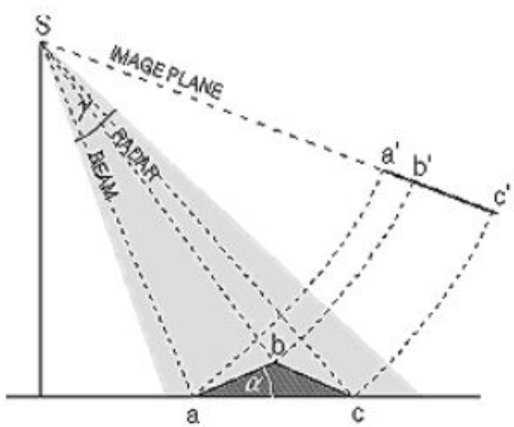




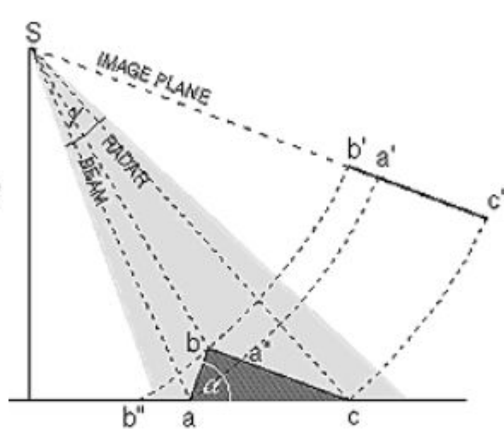
Exemple: from two relative orbits (D139, A161)

→ No corrections are applied ⇒ screen out areas with geometric distortion …)
→ methods can attenuate these effects (see for instance Small (2012))
→ normalizing effects of terrain slope (e.g., using 'terrain flattening' approach) will make it easier to combine ascending/descending orbits

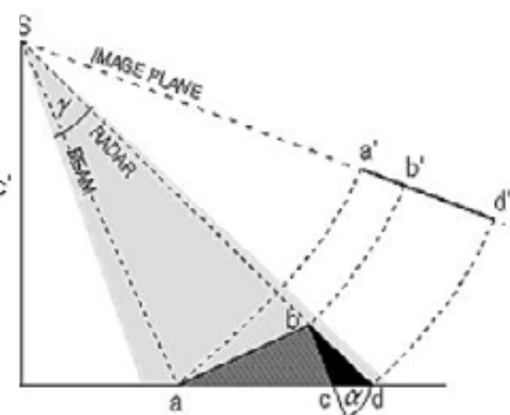
Layover



Foreshortening



Shadow

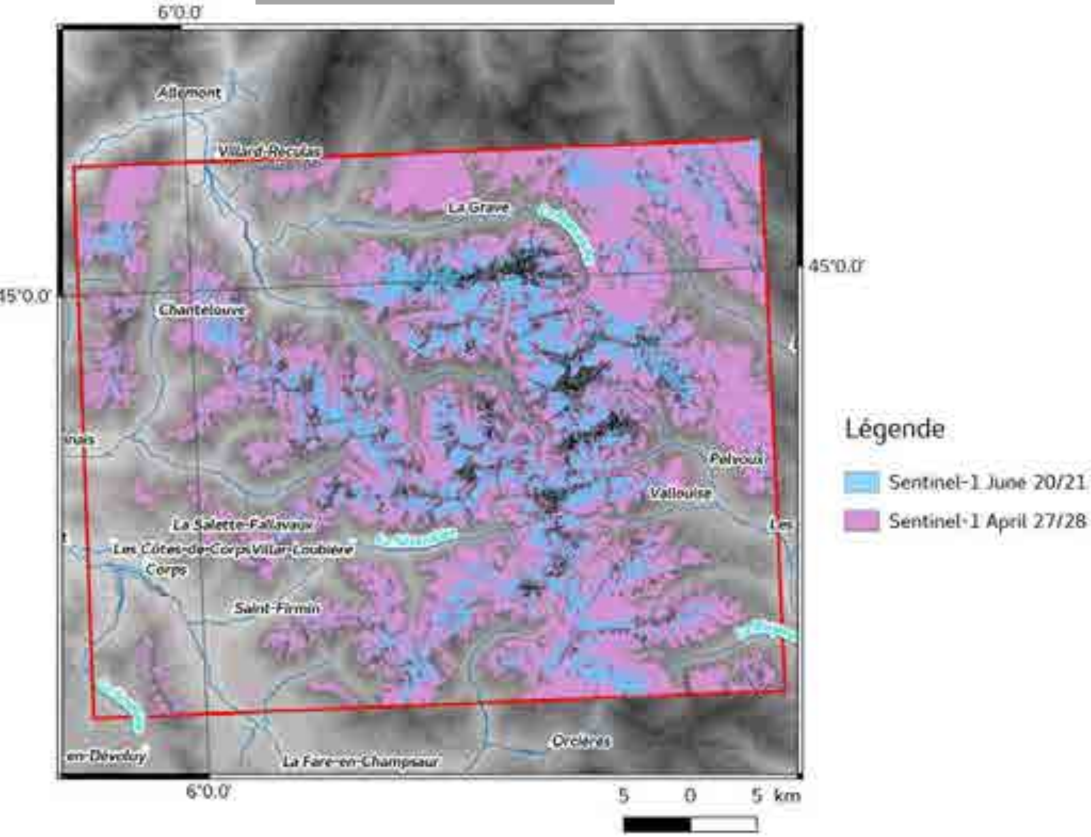


Data, methods

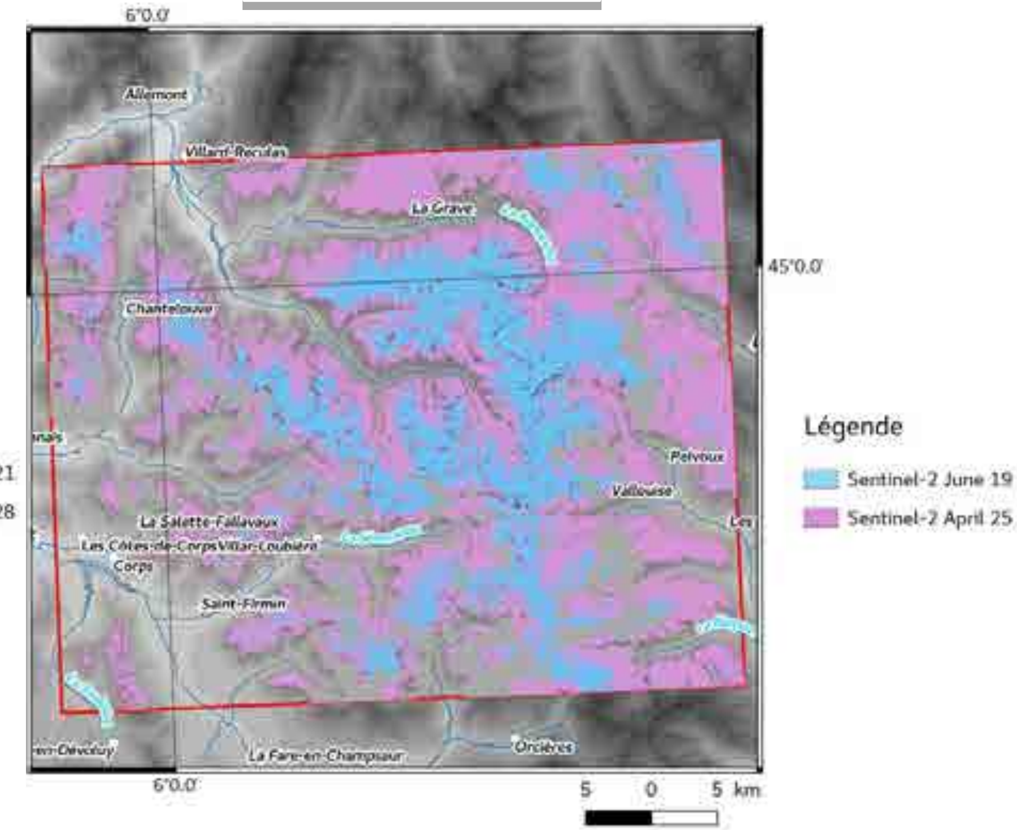
Example

using the Nagler et al. 2016 method

Sentinel-1



Sentinel-2



The spatial variability consistent between the two satellite products, smaller extension of wet snow is observed compared to S2. Situations of disagreement: very high elevation areas (dry snow at very high elevations and to glaciers signature), some northern slopes at low elevations (thin snow totally refrozen and transparent to Sentinel-1), forest

Meltlines from Sentinel-1

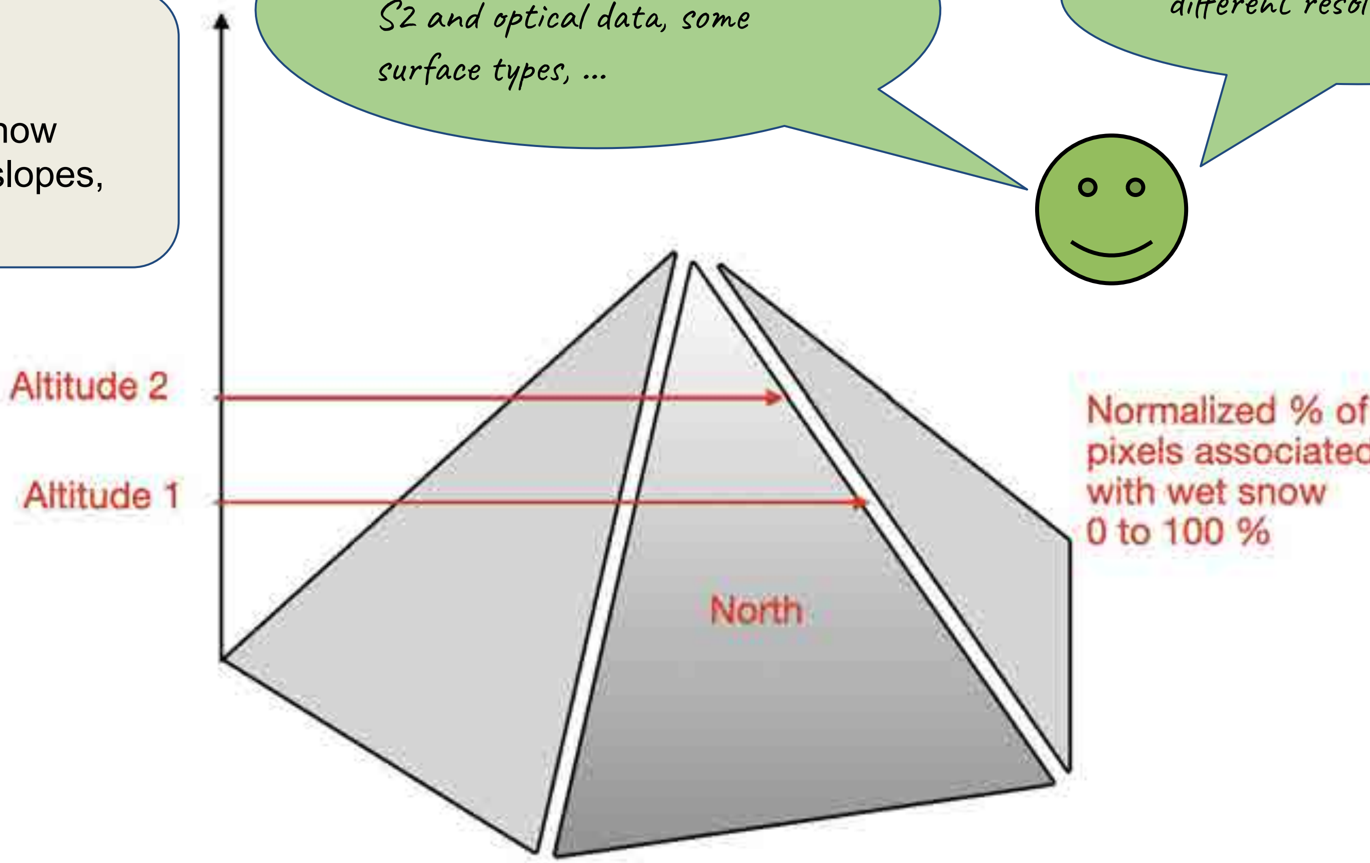
In addition to cartographic representations, how can relevant information be easily read from binary maps ?

Input data:

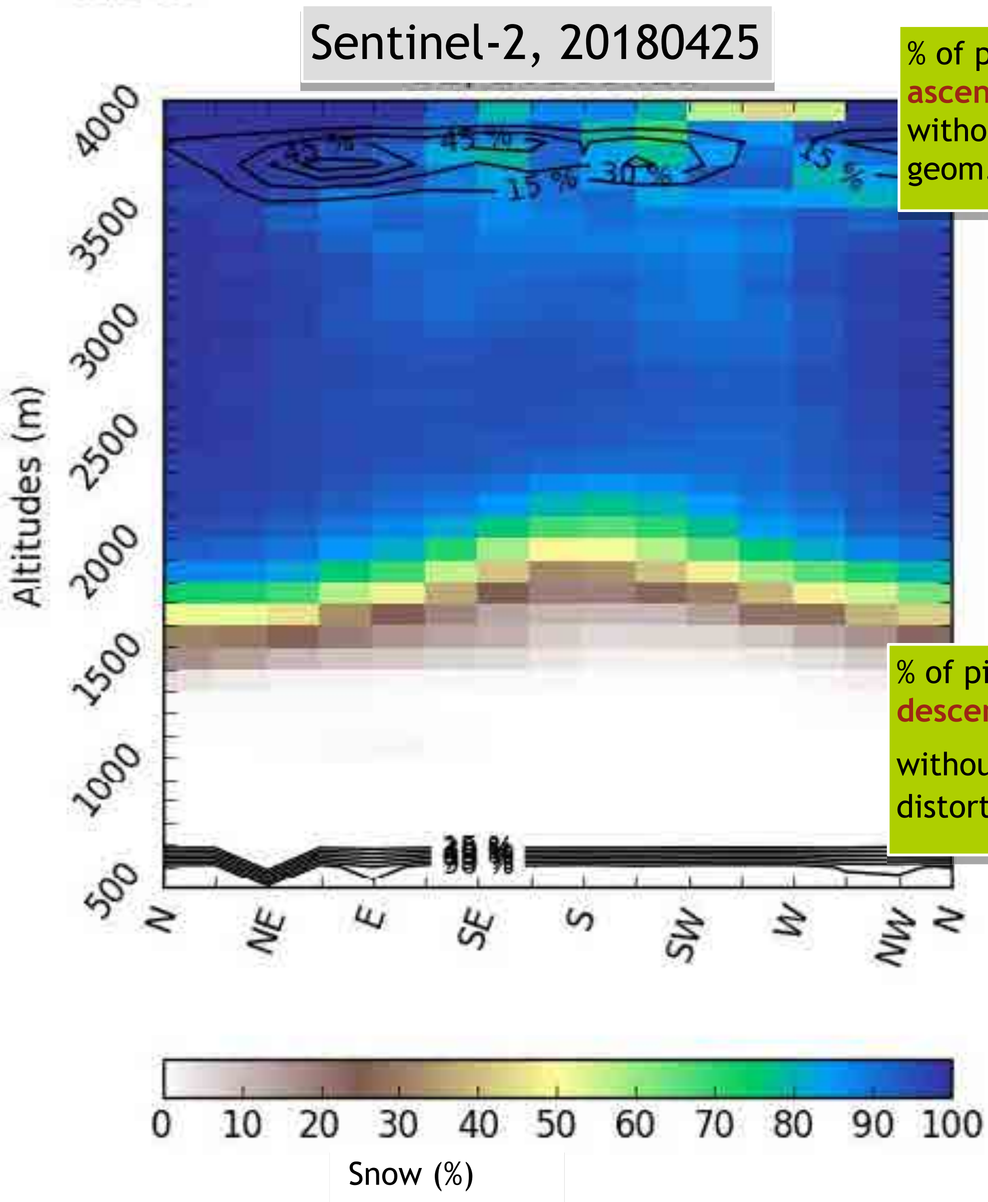
- Binary wet snow
- Terrain (Alt, slopes, aspect)

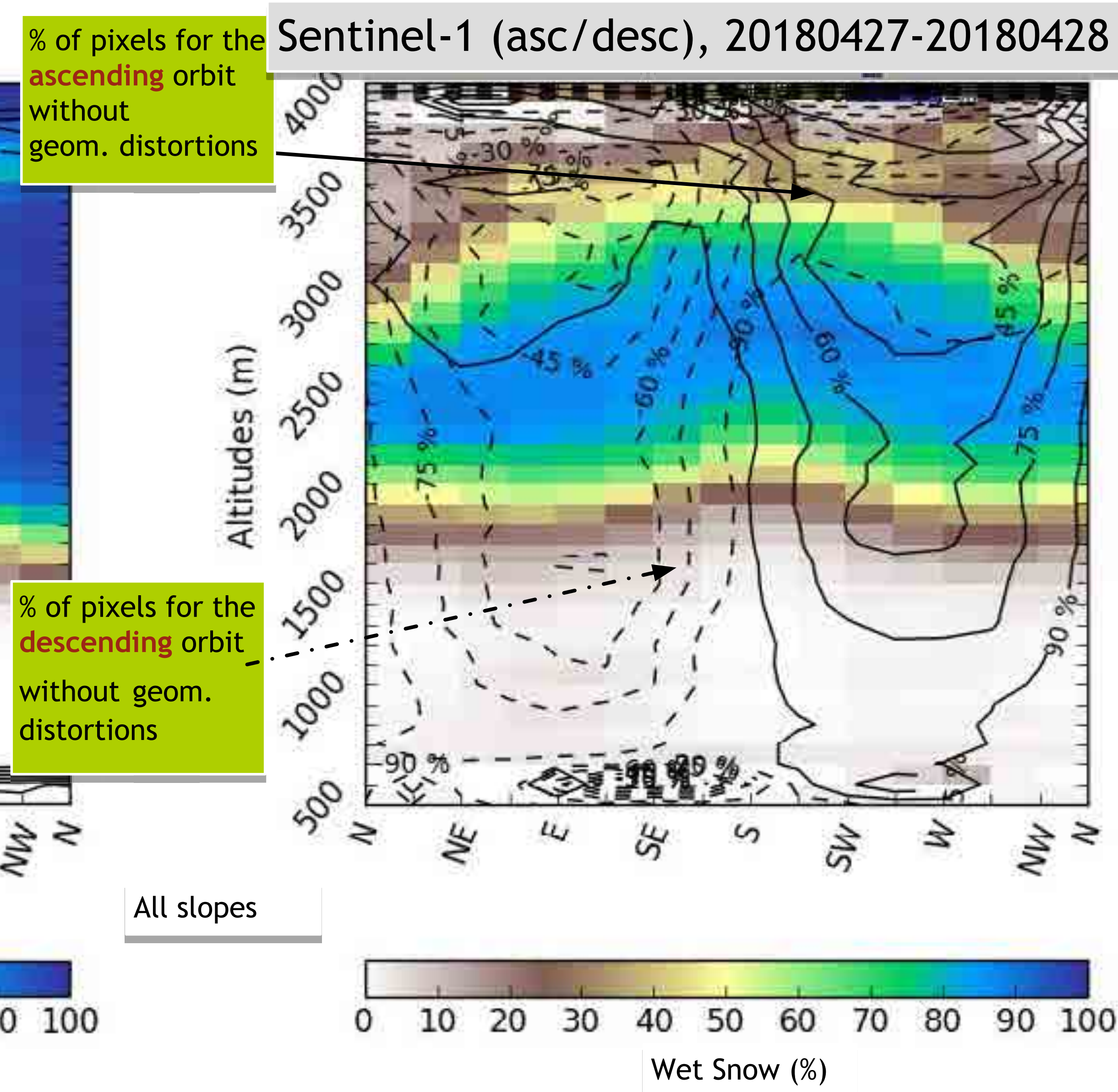
Exclude pixels with geom. distortions for S1, clouds for S2 and optical data, some surface types, ...

Merge satellite products of different resolution



Meltlines from Sentinel-1

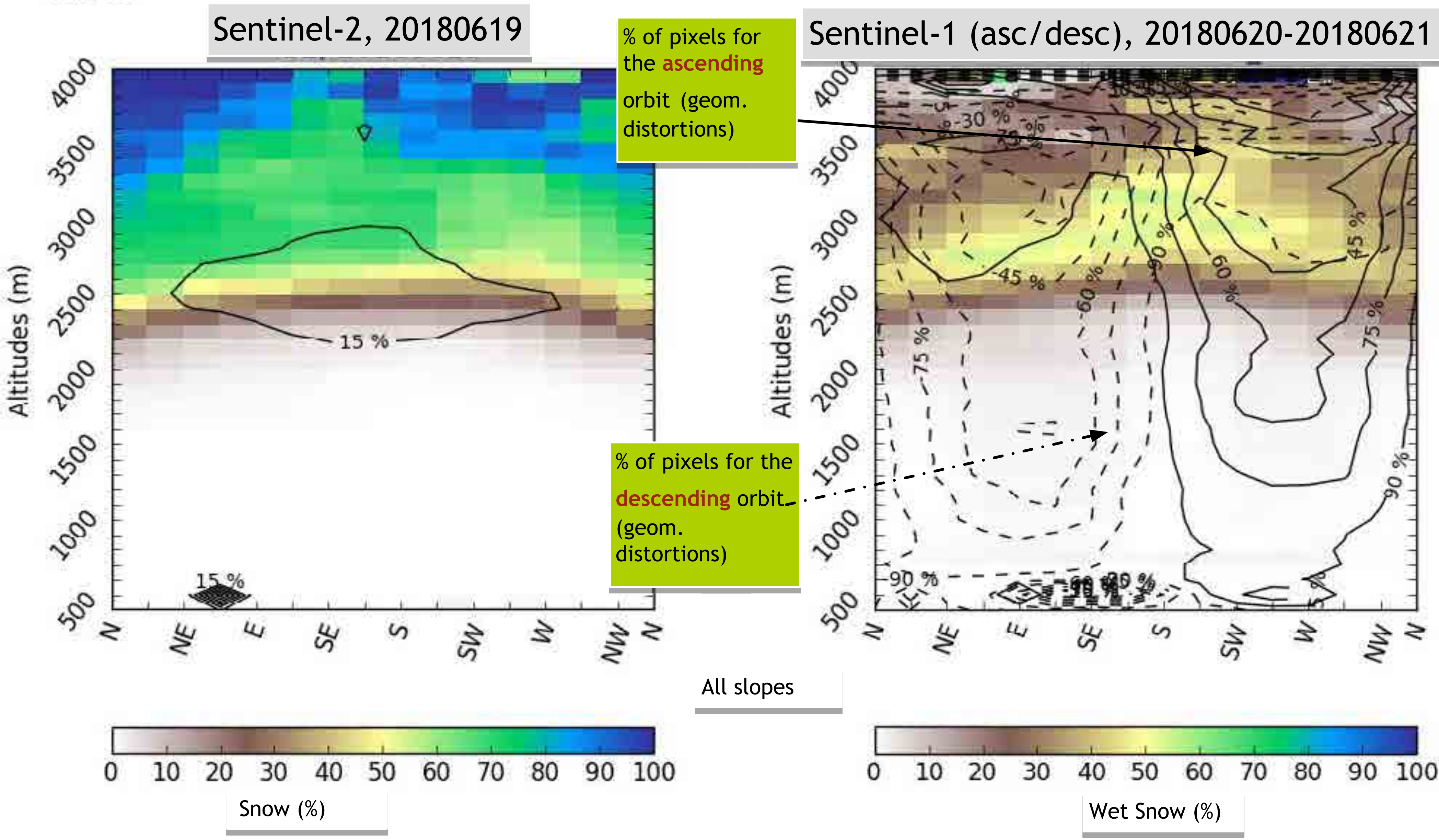




All slopes

The normalized percentage of snow-covered pixels by classes of elevation and orientation (0 to 100%) for the massif “Oisans”
Way to mix the two representations to delimit dry snow and wet snow.

Meltlines from Sentinel-1



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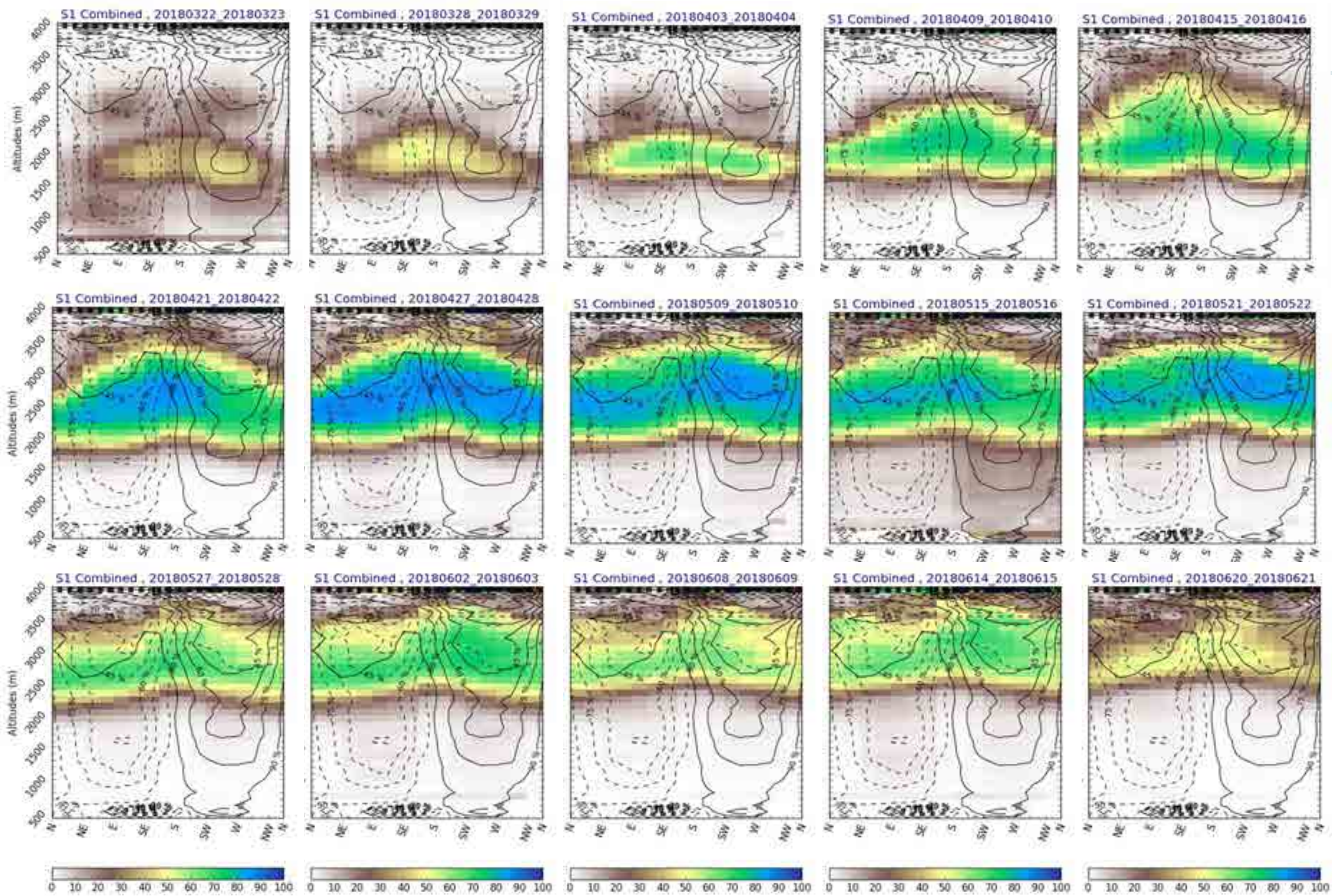
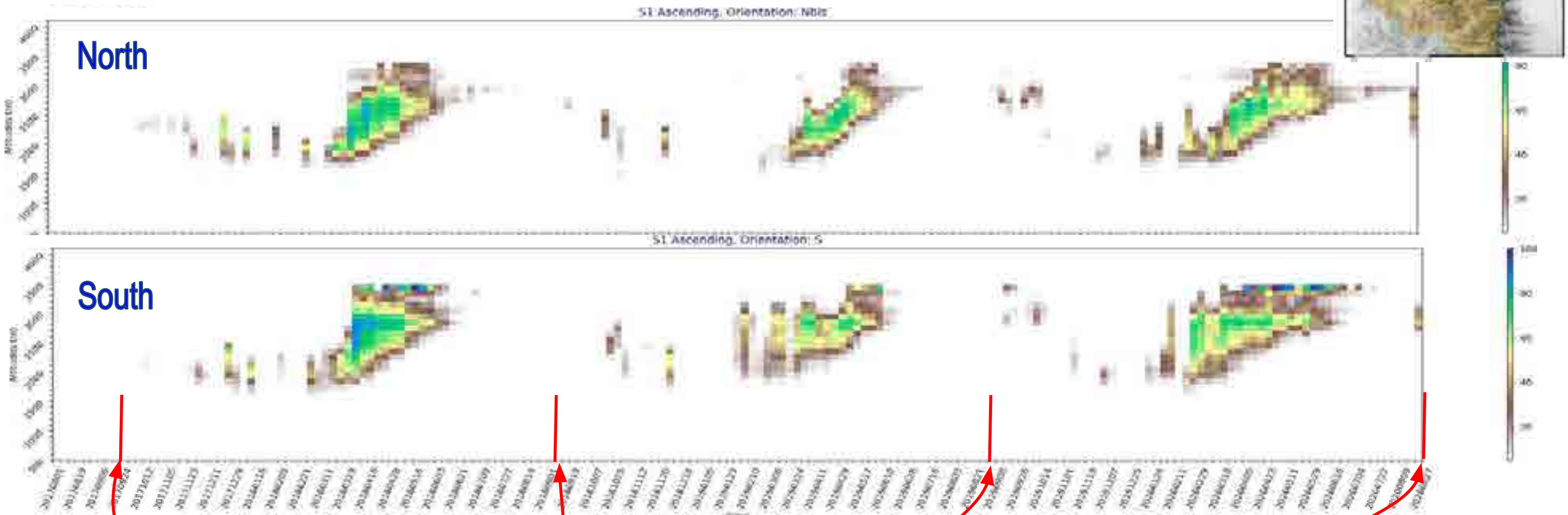
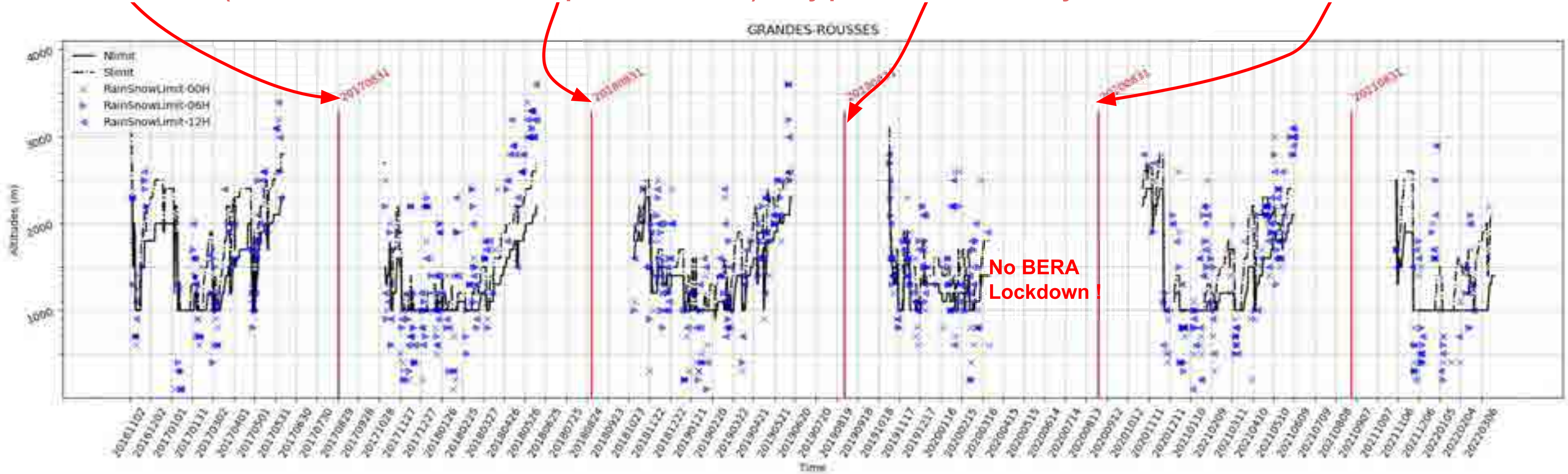


Meltlines from Sentinel-1

Grandes-Rousses massif
ascending (late afternoon)



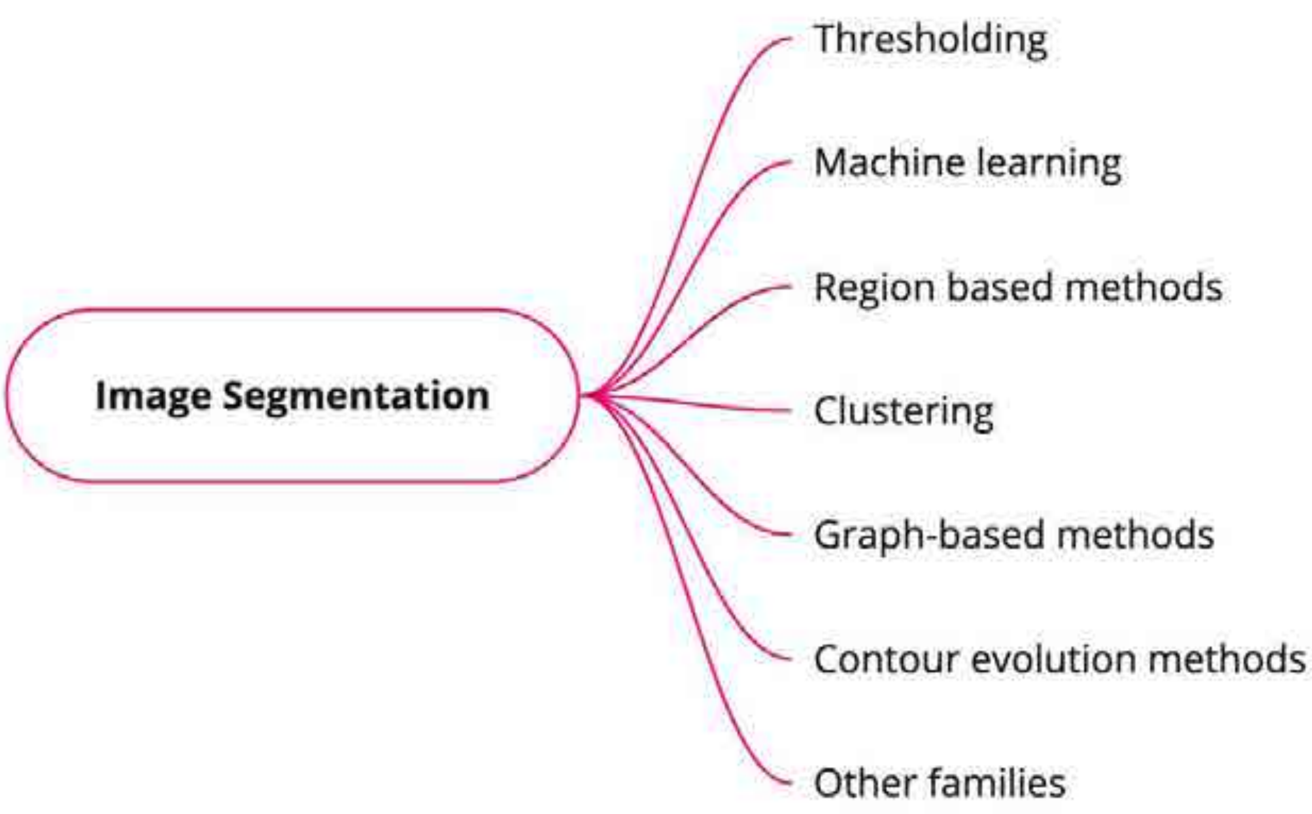
BERA bulletins (Bulletin d’Estimation du Risque d’Avalanche) daily provided in winter by the snow forecasters of Météo-France



Segmentation methods applied to Sentinel-1

Image segmentation

⇒ to divide the image into meaningful and/or perceptually uniform regions , locate objects/boundaries
⇒ all or part of the image information (texture, graylevel, colour, pixel position, …).
⇒ more than 1000 algorithmes in the litterature

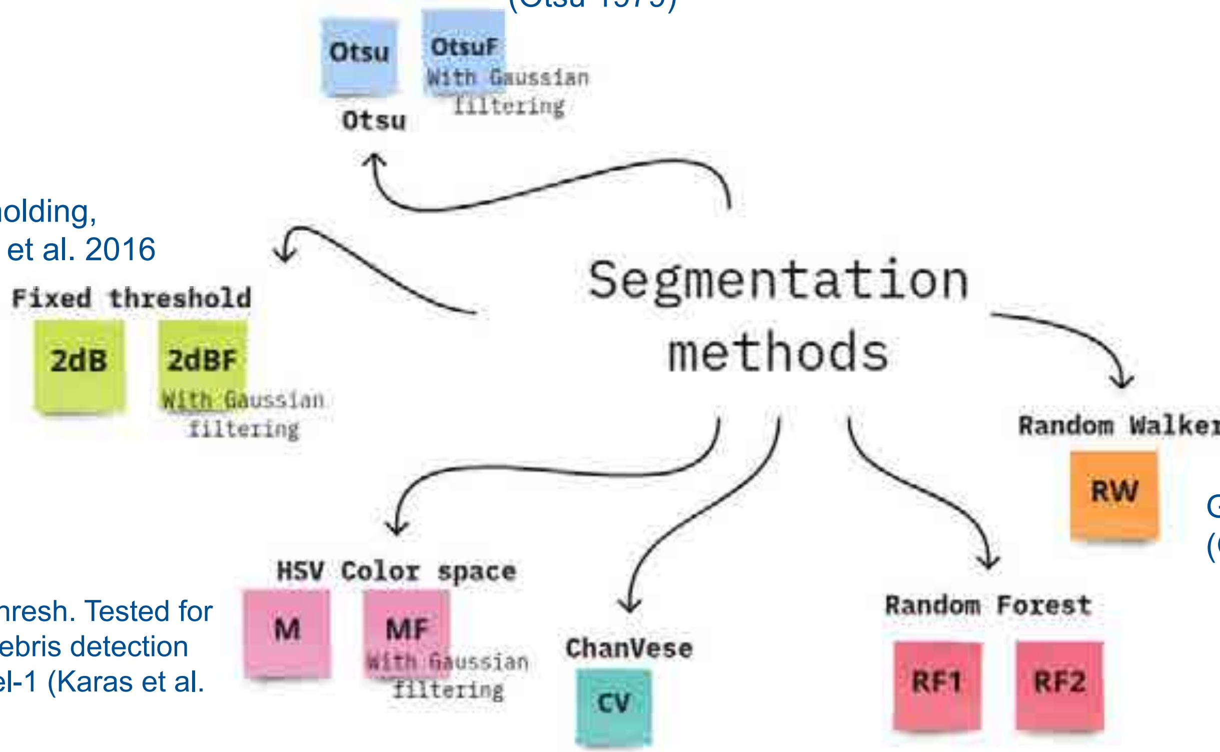


Segmentation methods applied to Sentinel-1

Image segmentation tested:

Thresholding, adapted for the image (Otsu 1979)

Thresholding, Nagler et al. 2016



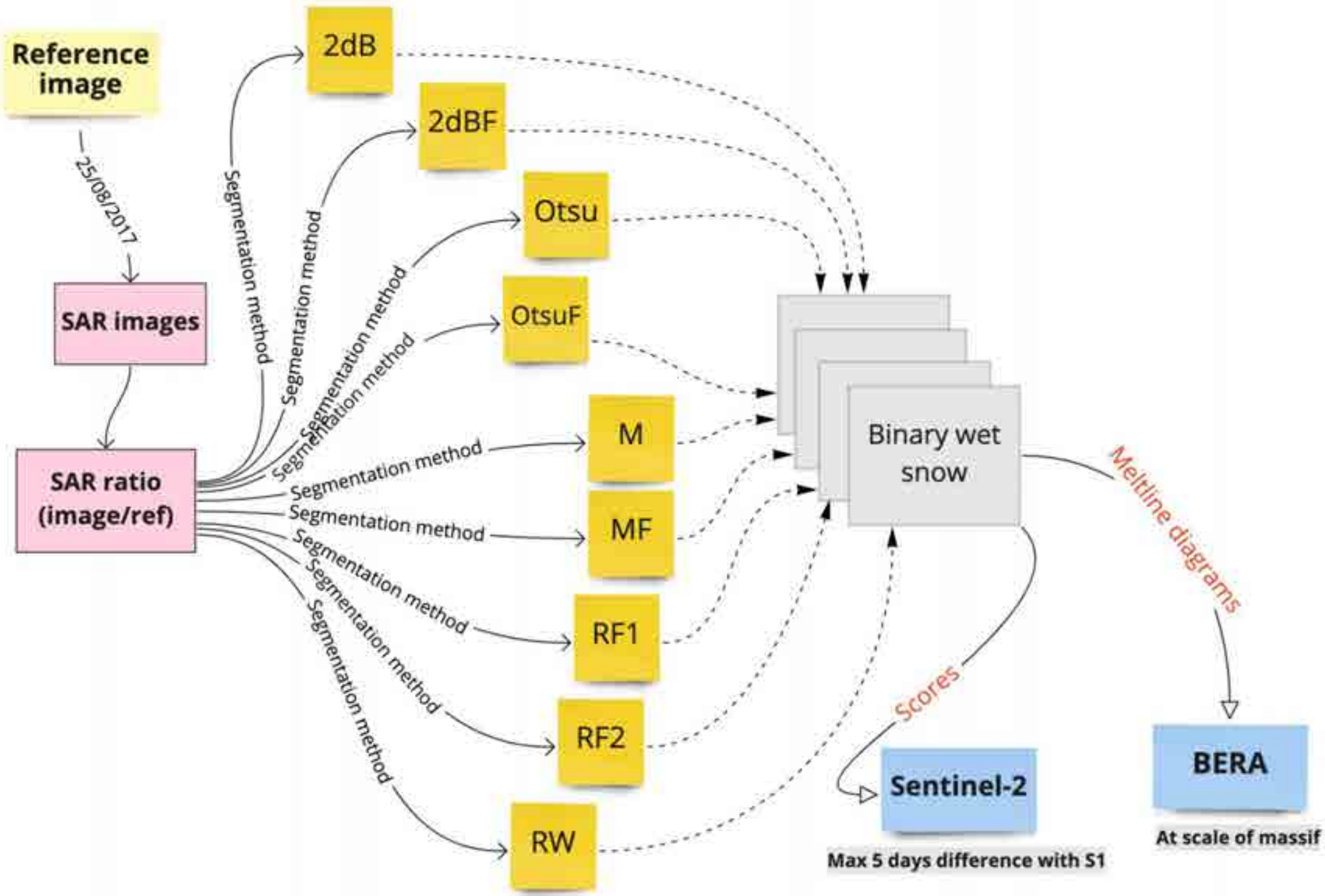
Graph Partitionning (Grady 2006)

Adaptative thresh. Tested for avalanche debris detection from Sentinel-1 (Karas et al. 2021)

Contour evolution (Chan and Vese, 2011)

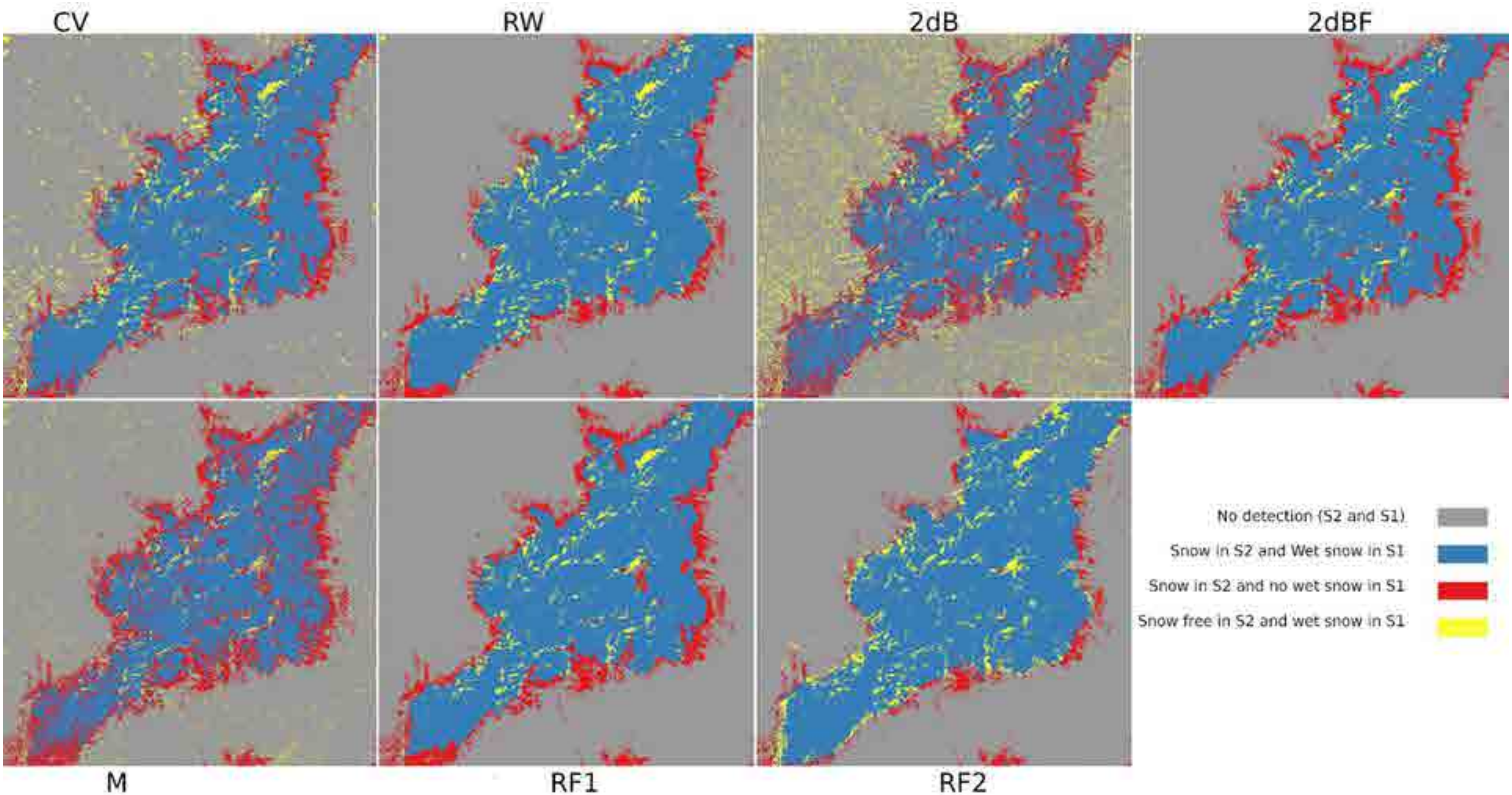
Machine learning (Breiman 2001)

Segmentation methods applied to Sentinel-1



Segmentation methods applied to Sentinel-1

Example of segmentation outputs over the massif of Belledonne using SAR data from April 22nd 2018.
Results are superposed with Sentinel-2 snow mask (20/04/2018).



Some apparent false detections: shaded northern slopes with snow, results vary degree filtering, smooth or variable contours

Segmentation methods applied to Sentinel-1

Scores (target product is snow product from Sentinel-2)

Correlation

Contingency table:

Snow by SAR	Snow by optical image		
	Yes	No	Total
Yes	a	b	$a+b$
No	c	d	$c+d$
Total	$a+c$	$b+d$	$a+b+c+d=n$

Hamming distance: proportion of pixels out of agreement (b+c/n)

False Alarm Rate (FAR) : false snow detection with respect to the number of detected pixels (b/(a+b))

True Detection Rate: true snow detection with respect to the number of detected pixels (a/(a+c))

Structural Similarity Index: difference of structure

Segmentation methods applied to Sentinel-1

Segmentation scores of the April 22, 2018 SAR image, over the entire 31TGL tile. The target image is the Sentinel-2 snow product image from 04/20/2018

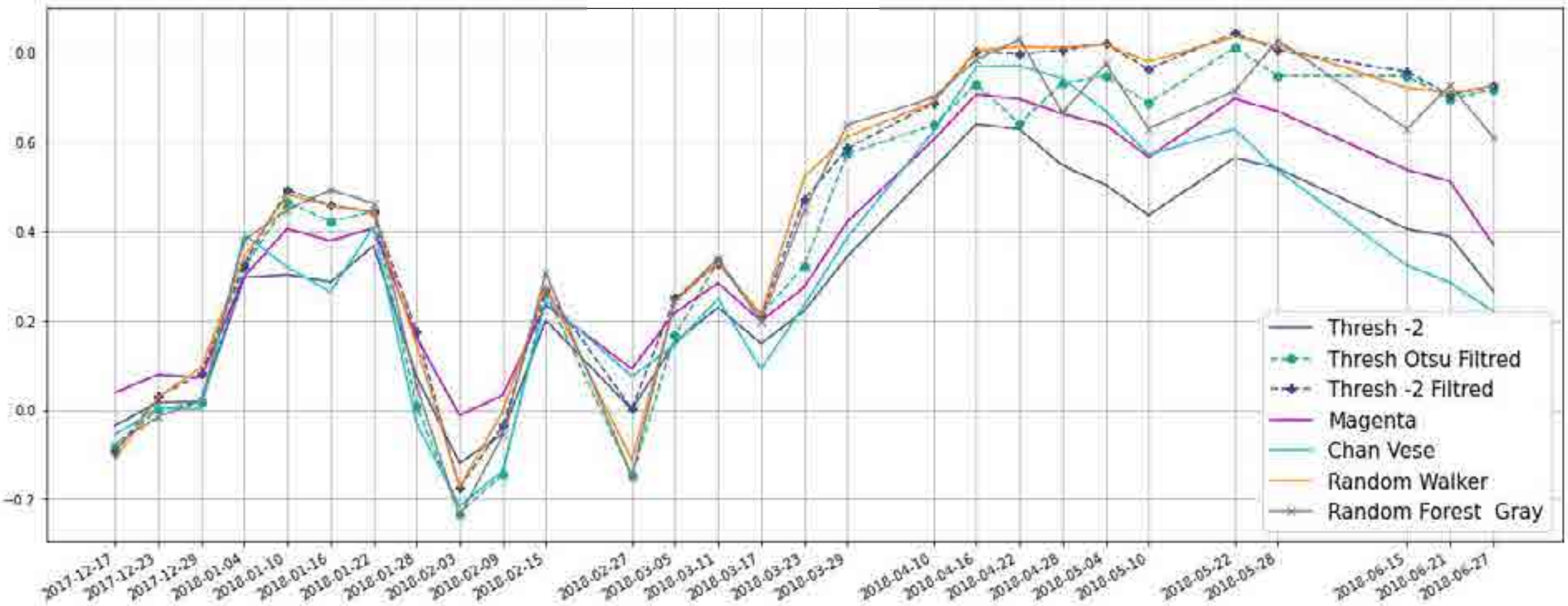
Scores	2dB	2dBF	M	MF	CV	RW	RF1	RF2	Otsu	OtsuF
Correlation	0.63	0.80	0.70	0.82	0.77	0.81	0.79	0.83	0.64	0.72
Hamming distance	0.18	0.10	0.15	0.09	0.11	0.09	0.10	0.08	0.18	0.14
Difference in area (%)	-7.88	-19.09	-21.38	-8.22	-11.62	-13.4	-20.37	-4.90	-31.24	-32.02
Struct. similarity (%)	50.19	84.76	62.47	85.46	78.26	85.83	84.47	85.57	59.44	81.60
True detections (%)	74.35	78.19	71.28	85.24	80.7	82.13	77.20	87.49	62.80	66.85
False alarms (%)	12.5	1.91	5.16	4.60	5.41	3.14	1.71	5.35	4.19	1.66
Heidke skill scores	0.63	0.79	0.68	0.82	0.77	0.81	0.78	0.83	0.61	0.69

using data from Sentinel-1 22/04/2018, Target: Sentinel-2 20/04/2018, 31TGL

Segmentation methods applied to Sentinel-1

Segmentation scores of the Melt season (from 10 April to 17 June 2018) over the entire 31TGL tile. The target images are Sentinel-2 snow products (up to 5 days of difference in observation date)

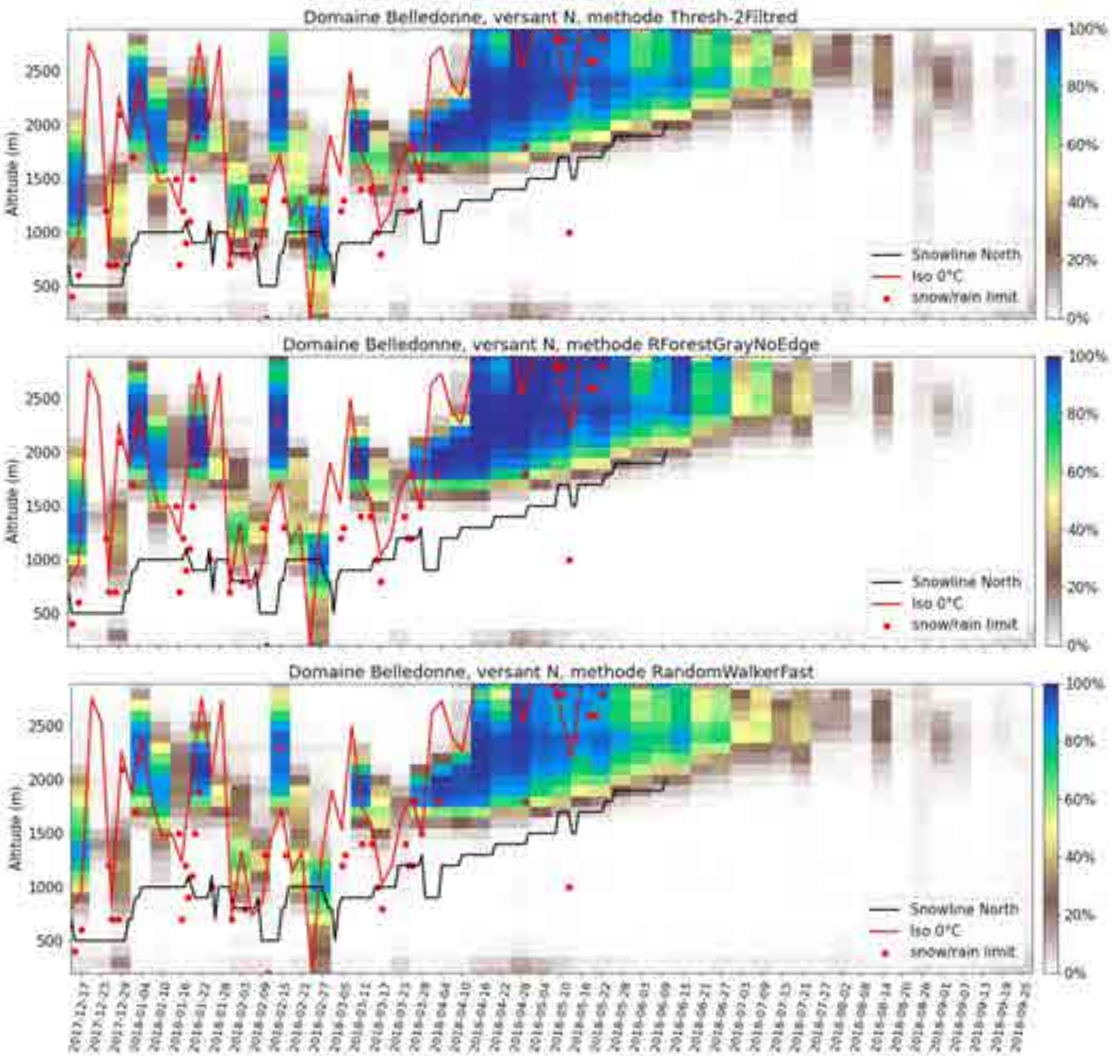
Correlation



Over the season: situations of over-segmentation, inversion of segmented classes

Segmentation methods applied to Sentinel-1

Meltlines, comparison with BERA bulletins



Meltline gradients in agreement with BERA estimates (North/South snow lines)

Differences between segmentation methods (more wet snow in RF for instance, methods with false detection in summer, …)

All methods show a slight S1A/S1B bias

Differences when the snow extent is limited

Some issues and conclusions

Scores (correlations, distances, …) gives only a partial view of method performances: favour methods that produce a smoothed wet snow mask as against other methods that save up some variability in the contours of the wet snow areas

Need for scores that discriminate between methods that would preserve the variability of wet snow contours.

Some methods used in this study (such as CV and RW) have a great potential for image segmentation but need further investigation in particular to optimise the computation time, to better calibrate the method regarding initial conditions, parameters, implementation and possible generalisations .

All methods have used image ratio using one reference image ⇒ possible improvement using the cross-correlations between images calculated over the entire time series allows for a better selection of reference images (with less similarity to the winter period) as described in Karbou et al. 2021, evaluated in Karas et al. 2021.

Some issues and conclusions

Wet snow monitoring is performed at Météo-France using data preprocessed using the PEPS facilities.

Meltlines diagrams are produced at the scale of massifs and make it easier to monitor wet snow altitude ranges, melt-out dates, altitudes, orientations and also to inter-compare products of different resolution

Ongoing studies to improve wet snow retrievals (Matthieu Gallet (PhD), Ludovic Breton (fellowship)), to improve snow simulations via assimilation trials in Crocus (Etienne Cap, CNES contract) and to better understand wet snow variability in space and time.

The CNES S1Tiling pre-processing chain is being installed on the Météo-France servers for operational use (support from CMS-Lannion and CNES).

Some issues and conclusions

More details in:

Cap, E., F. Karbou, M. Lafaysse, M. Fructus, M. Dumont (2022), Towards the assimilation of snow products derived from Sentinel-1/Sentinel-2 in the Crocus snow evolution model, ESA Living Planet Symposium, Bonn, 23-27 Mai 2022.

Guiot, A., F. Karbou, G. James, Ph. Durand (2022), Use of different segmentation methods and Sentinel-1 SAR images for wet snow monitoring, submitted.

Karas, A. , F. Karbou, S. Giffard-Roisin, P. Durand and N. Eckert (2021), Automatic Color Detection-Based Method Applied to Sentinel-1 SAR Images for Snow Avalanche Debris Monitoring, in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 60, pp. 1-17, 2022, Art no. 5219117, doi: 10.1109/TGRS.2021.3131853.

Karbou F, Veyssière G, Coleou C, Dufour A, Gouttevin I, Durand P, Gascoin S, Grizonnet M. (2021a), Monitoring Wet Snow Over an Alpine Region Using Sentinel-1 Observations. *Remote Sensing*. 2021; 13(3):381. https://doi.org/10.3390/rs13030381

Karbou F., Ph. Durand, I. Gouttevin (2021b) Spatial and temporal variability of wet snow in the French mountains using a color-space based segmentation technique on Sentinel-1 SAR images, Proceeding of International Geoscience and Remote Sensing Symposium, 2021 Brussel.

Karbou, F., G. James, Ph. Durand, A. M. Atto (2021c), Thresholds and distances to betterdetect wetsnow over mountains with Sentinel-1 SAR image time series,ISTE-WILEY Science - Change Detection and Image Time Series Analysis 1: Unsupervised Methods doi:https://doi.org/10.1002/9781119882268.ch5

Veyssière G., F. Karbou, S. Morin, M. Lafaysse, V. Vionnet, 2019, Evaluation of Sub-Kilometric Numerical Simulations of C-Band Radar Backscatter over the French Alps against Sentinel-1 Observations. Remote Sens. 2019, 11, 8.

Thank you for your attention