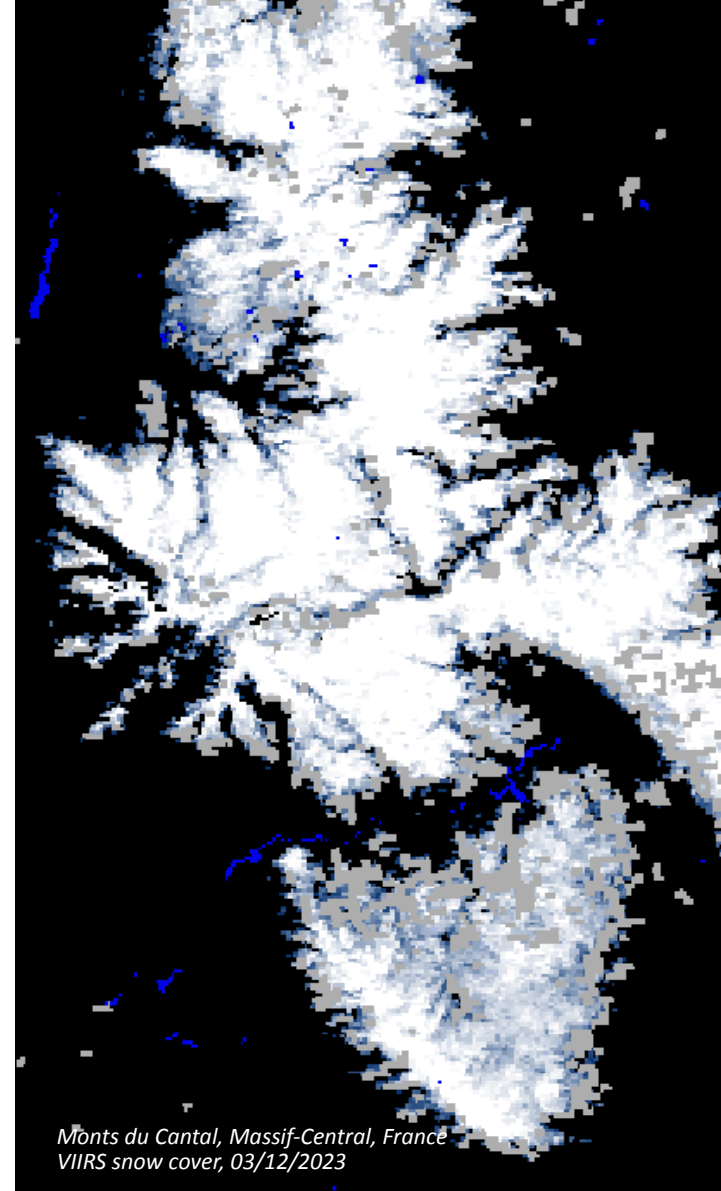


Towards the assimilation of VIIRS snow cover into a distributed ensemble snow simulation system

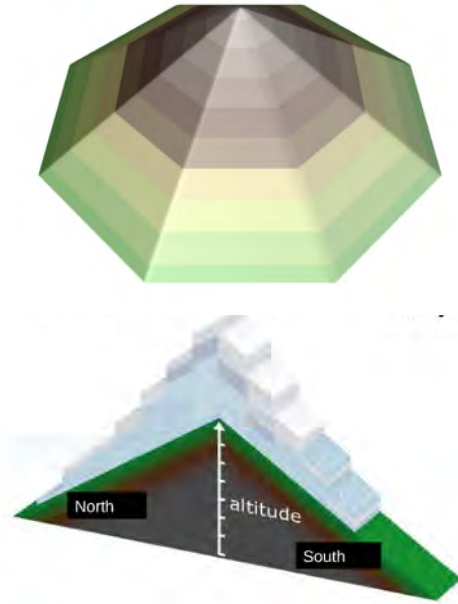
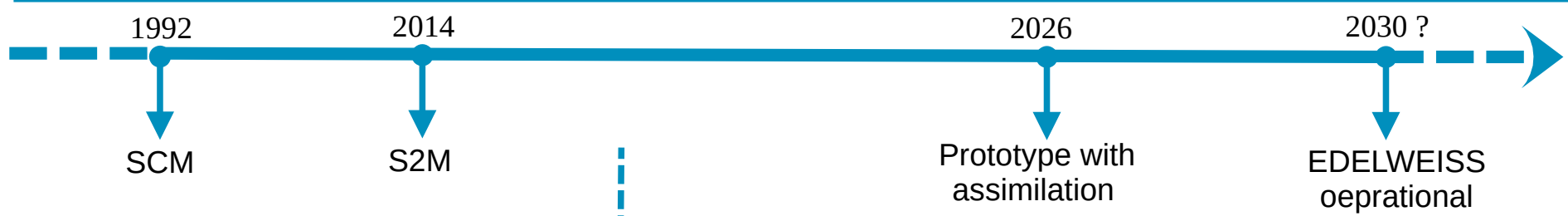
Speaker : N. Imperatore¹, PhD student

PhD supervisors : S. Gascoin², M. Lafaysse¹

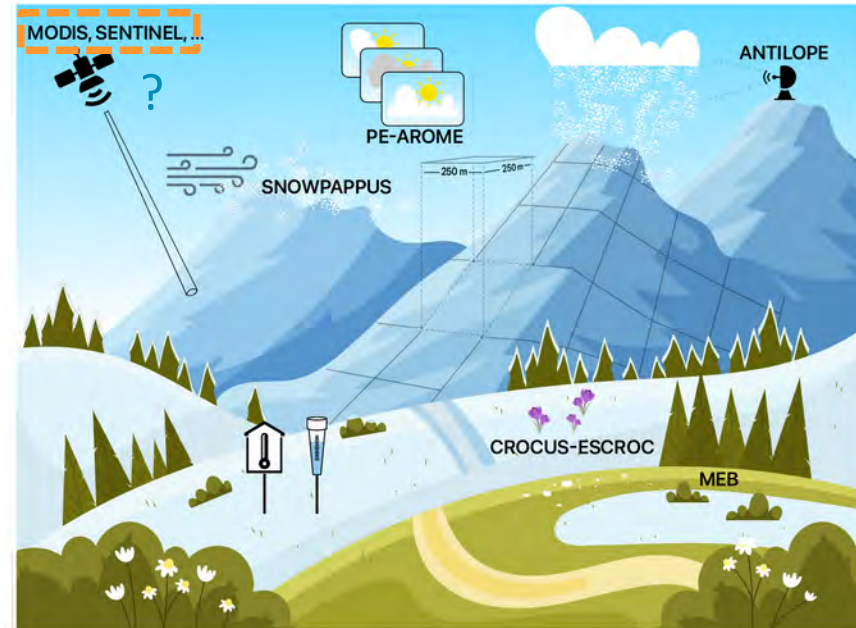
Co-authors : M. Dumont¹, S. Guével³, A. Mauss³, J.-B. Hernandez³,
M. Vernay¹, M. Fructus¹



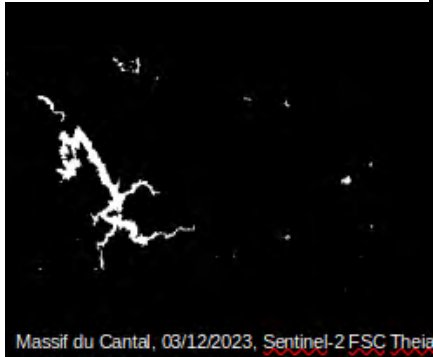
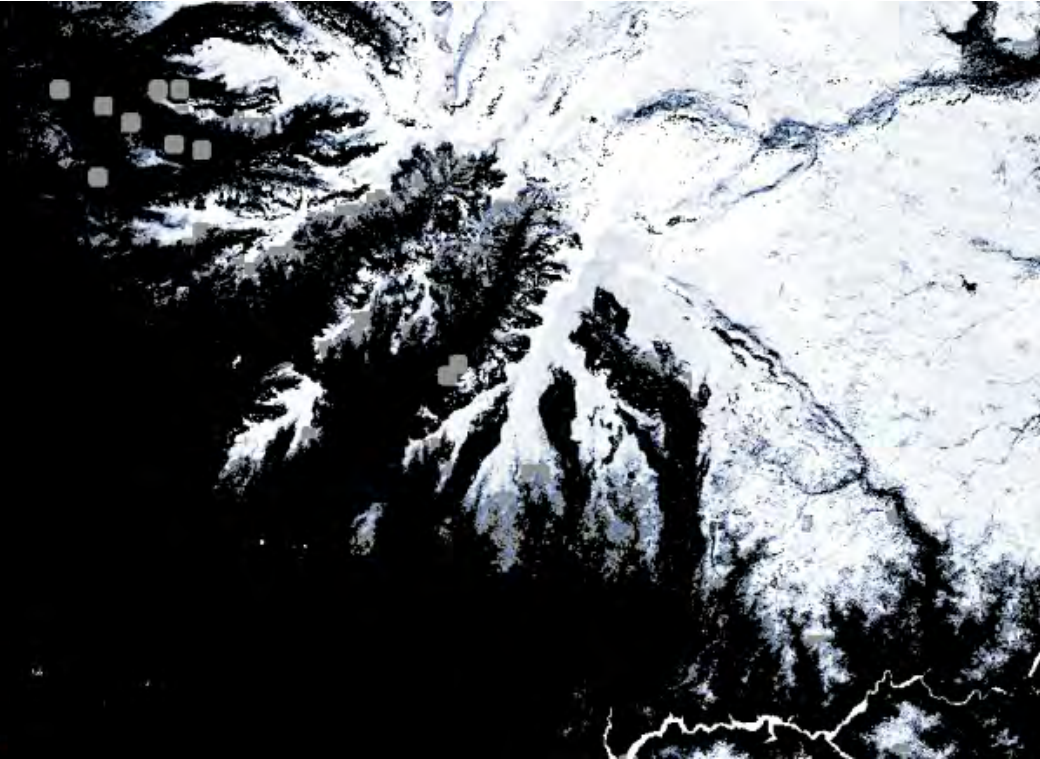
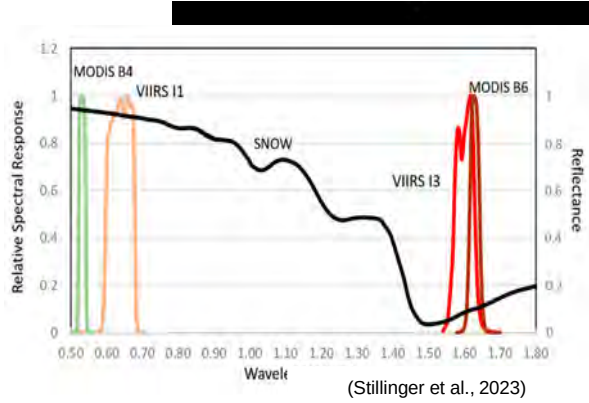
1. Context
 1. EDELWEISS
 2. MODIS to VIIRS transition
 3. Snow cover products
2. Large scale assessemnt of VIIRS snow cover
 1. Data and methods
 2. General performance
 3. Topographic characterization
 4. Mixed pixels
3. Daily multi-platform composite
4. Towards assimilation
5. Conclusions



(Durand et al., 1999) (Vernay et al., 2022)



(Lafaysse, 2023)



$$\text{NDSI} = \frac{I_2 - I_3}{I_1 + I_3} \quad (\text{Stillinger et al., 2023})$$

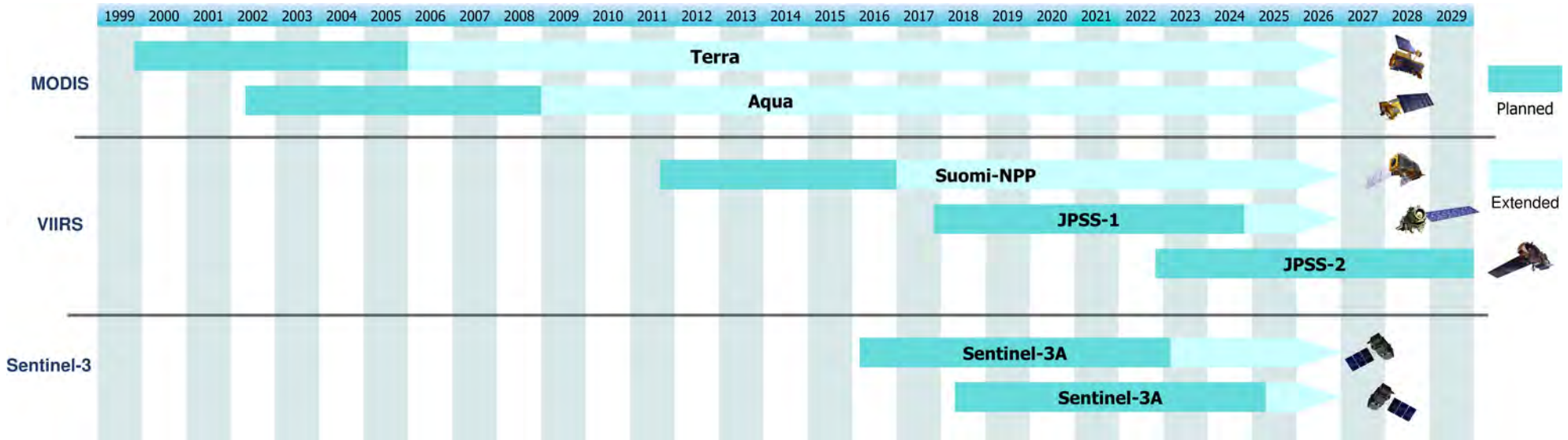
$$\text{SCA} = \begin{cases} 1 & \text{if NDSI} > \epsilon \\ 0 & \text{otherwise} \end{cases}$$

$$\text{FSC} = -0.01 + 1.45 \text{NDSI} \quad (\text{Salomonson and Appel, 2006})$$

MODIS ?

End of MODIS Operations in 2026-27

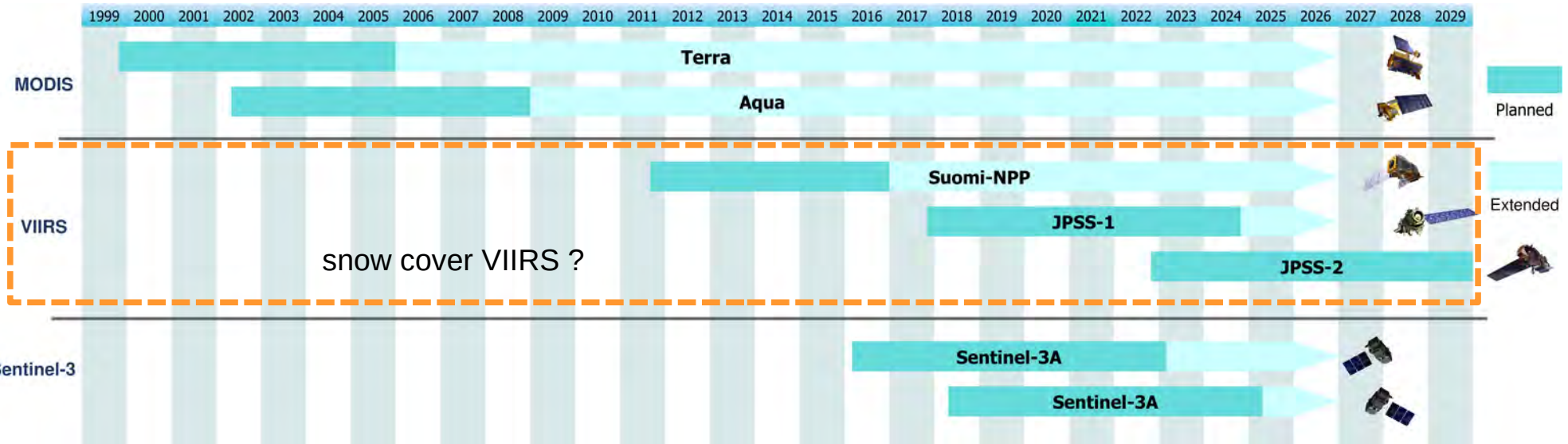
The NASA Earth Observing System (EOS) platforms, Terra and Aqua, each carry a MODIS instrument that have been successfully in operation since 2000 and 2002, respectively. Due to power limitations, NASA plans to stop science data collection from the Aqua MODIS instrument around August 2026 and from the Terra MODIS instrument around January 2027. After ending satellite



MODIS ?

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A large scale evaluation of VIIRS snow cover - data & methods



High resolution reference:
Sentinel-2

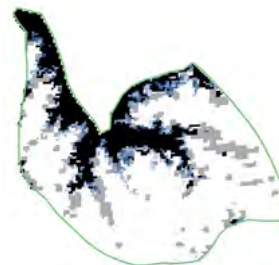


Produits NASA couverture globale

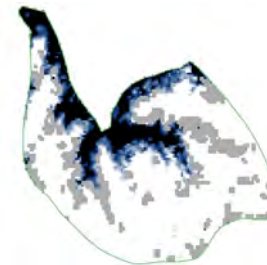
NASA L3 SNPP
(VNP10A1)



NASA L3 JPSS1
(VJ110A1)

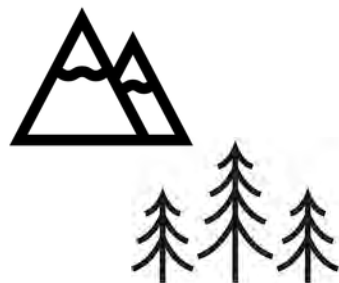


NASA L3 JPSS2
(VJ120A1)

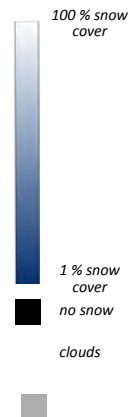


Produits Météo-France couverture France temps réel

Météo-France SNPP
(MF-FSC-VNP-L3)



Météo-France multi-platform
composite (MF-FSC-VNP-L3)



General performance

Product	N pixels	% Snow Cover	Accuracy	F1-score	Commission Error	Omission Error	Bias [%]	RMSE [%]
VNP10A1	4.33e+06	17.10	0.98	0.93	0.02	0.06	0.53	9.83
VJ110A1	4.45e+06	17.94	0.97	0.92	0.02	0.06	0.80	10.88
VJ210A1	4.68e+06	17.96	0.97	0.93	0.02	0.07	-0.03	10.57
MF-FSC-VNP-L3	3.09e+06	34.15	0.94	0.92	0.05	0.08	0.41	14.73

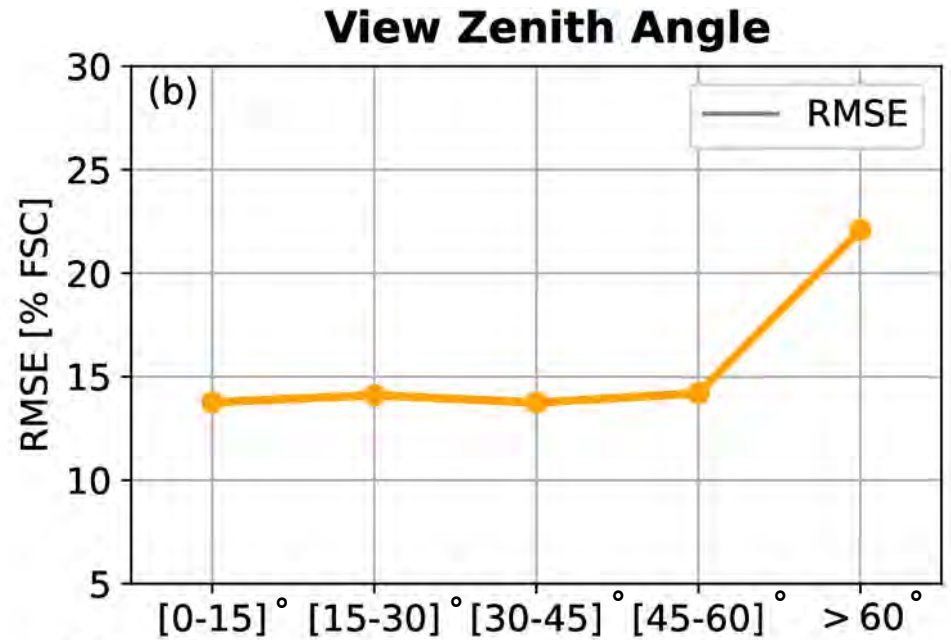
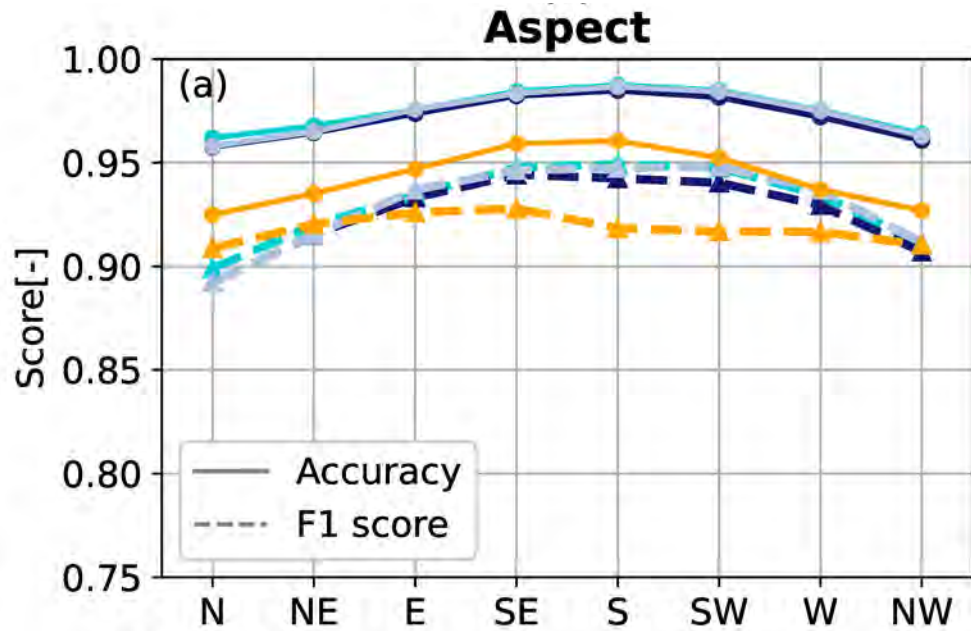
Metric	Equation
Precision	$TP / (TP + FP)$
Recall	$TP / (TP + FN)$
F-Score	$2 * TP / (2 * TP + FP + FN)$
Omission Error	$FN / (TP + FN)$
Commission Error, False Alarm Rate	$FP / (FP + TN)$
Overall Accuracy	$(TP + TN) / (TP + FP + TN + FN)$

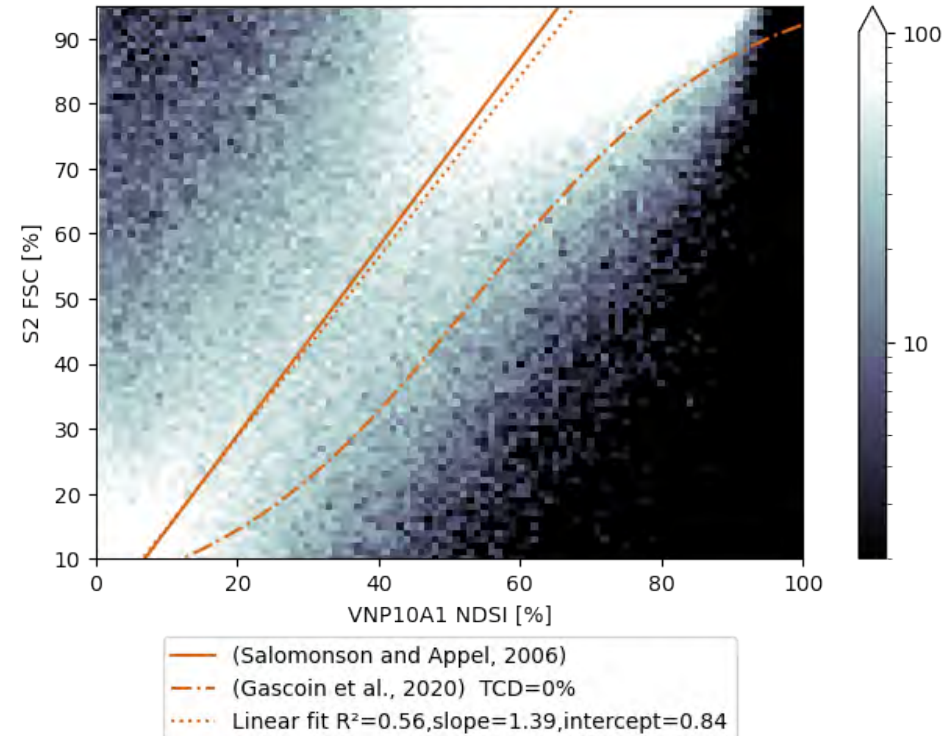
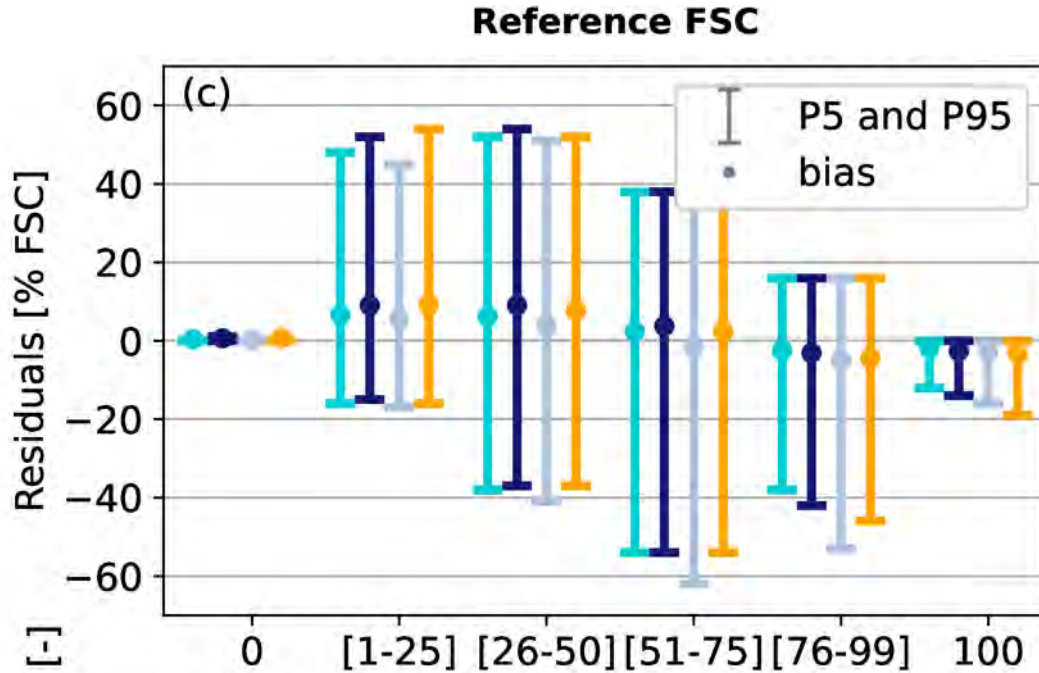
(Schweizer et al., 2023)

Stratified error analysis VNP10A1

Reference FSC	Landcover	Aspect	N pixels	% Snow Cover	Accuracy	F1-score	Commission Error	Omission Error	Bias [%]	RMSE [%]
1-99 %	Forest	N	4.57e+04	37.09	0.77	0.69	0.19	0.29	-0.95	29.57
1-99 %	Forest	S	1.13e+04	39.90	0.83	0.80	0.15	0.19	-0.01	22.05
1-99 %	open	N	6.27e+04	67.06	0.86	0.90	0.17	0.12	-1.80	23.09
1-99 %	open	S	5.45e+04	64.32	0.91	0.93	0.17	0.04	3.94	17.89
0-100 %	Forest	N	3.07e+05	6.72	0.96	0.72	0.02	0.27	0.55	13.08
0-100 %	Forest	S	1.95e+05	2.82	0.99	0.82	0.01	0.16	0.06	5.82
0-100 %	open	N	2.36e+05	34.90	0.96	0.94	0.02	0.07	-0.65	12.88
0-100 %	open	S	3.59e+05	17.24	0.99	0.96	0.01	0.02	0.65	7.26

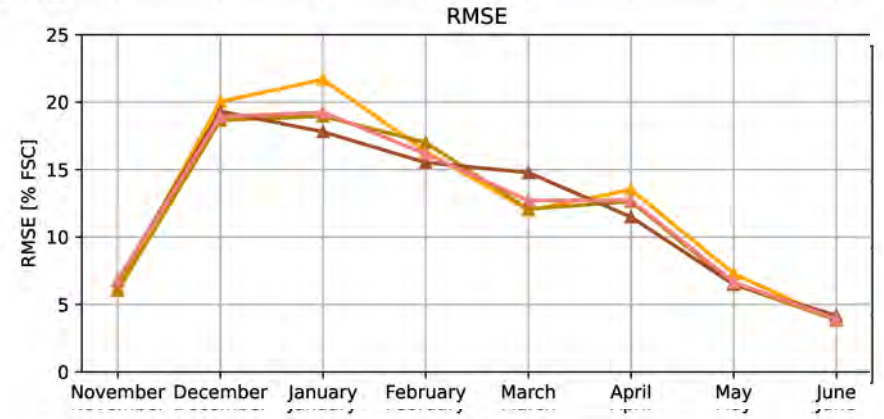
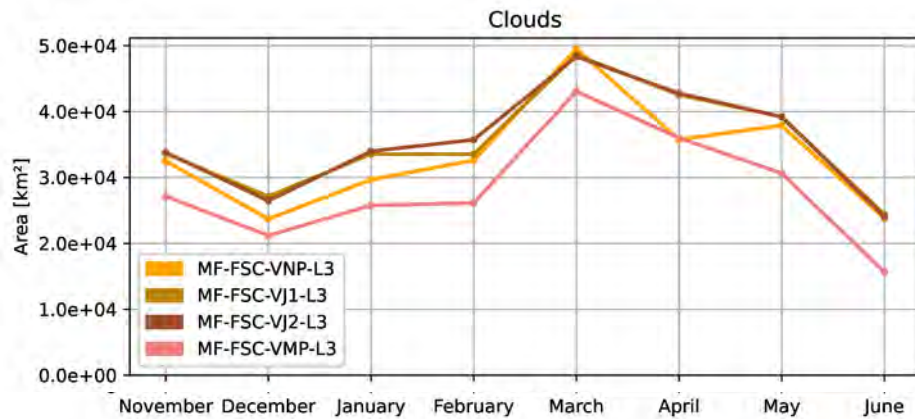
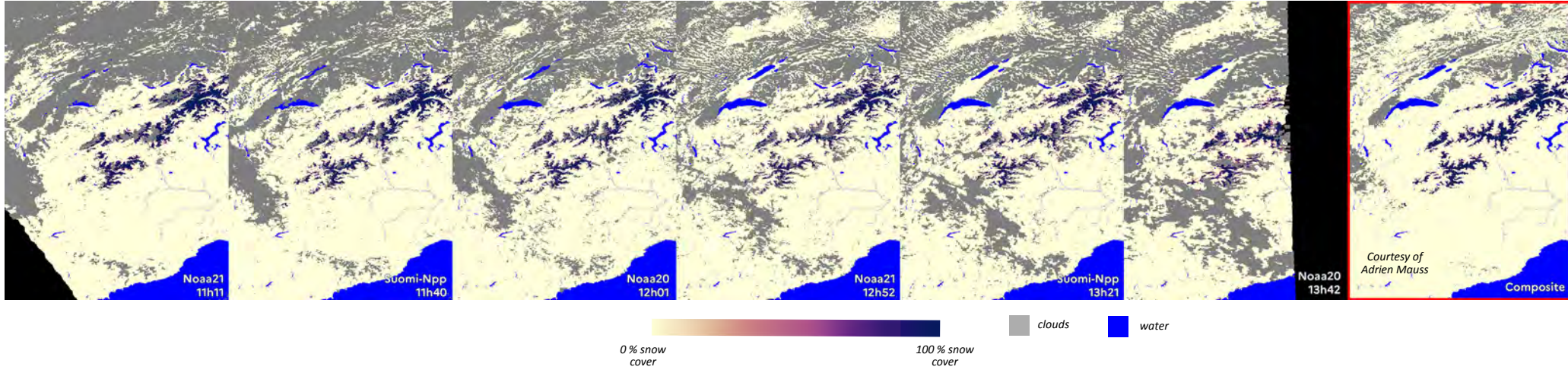




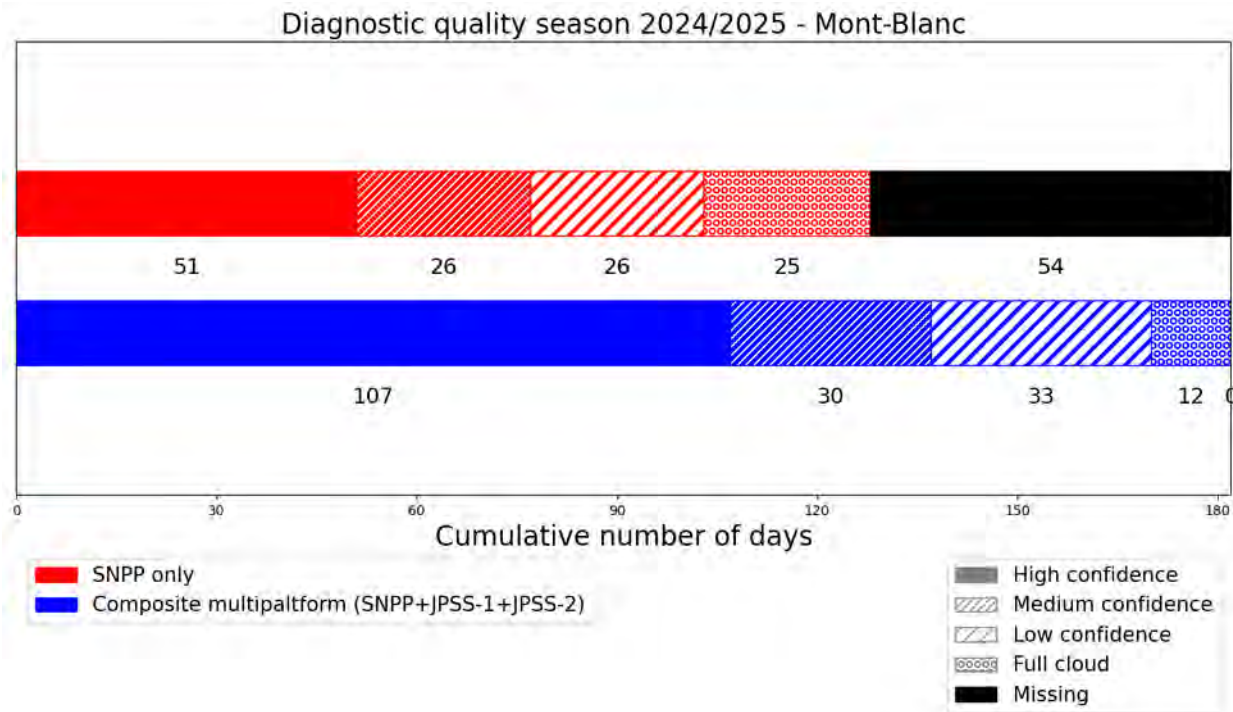
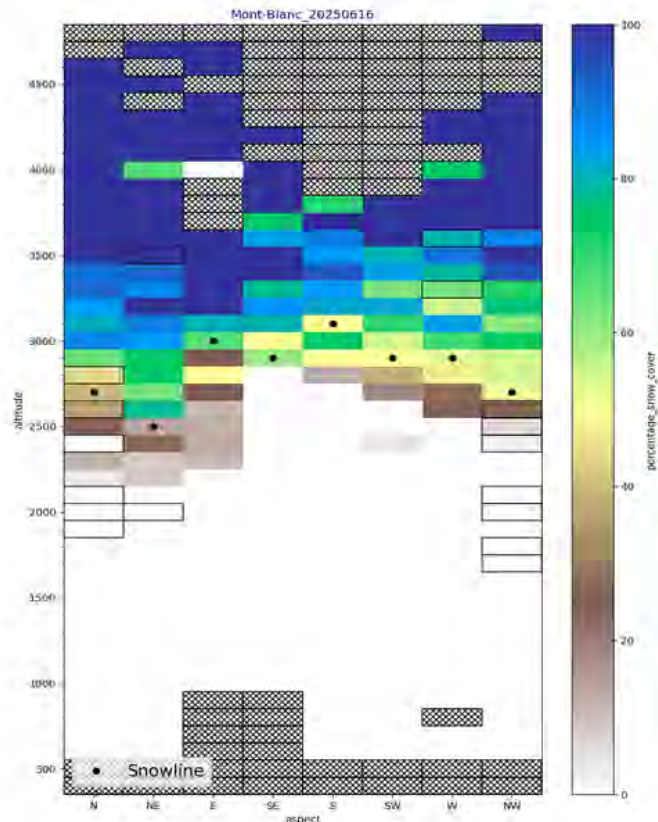


$$\text{FSC} = -0.01 + 1.45 \text{ NDSI}$$

Daily multi-platform composite



Daily multiplatform composite – snowline diagnostics



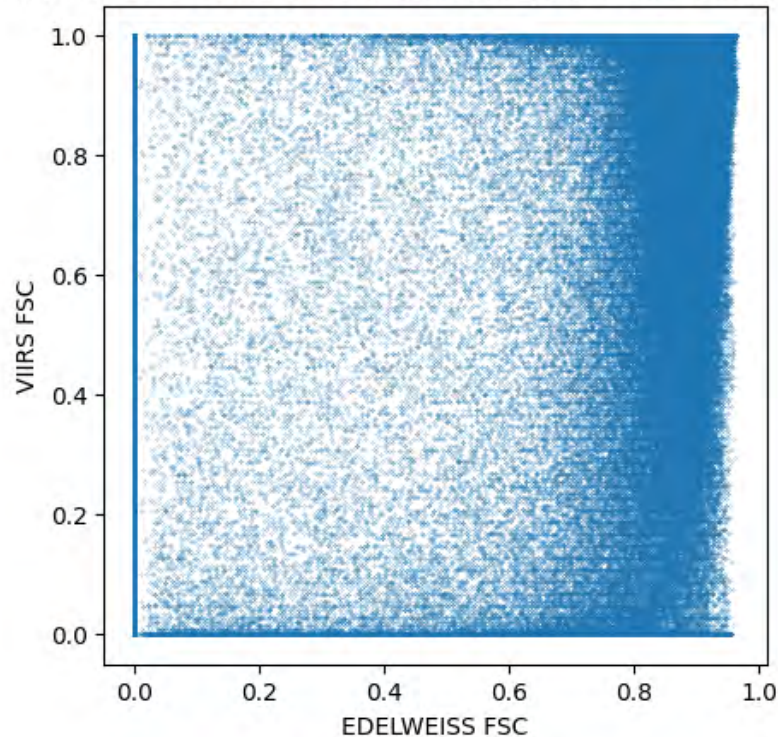
Towards assimilation - observation operator

(WIP!) Link model snow depth (SD) to fractional snow cover (FSC)

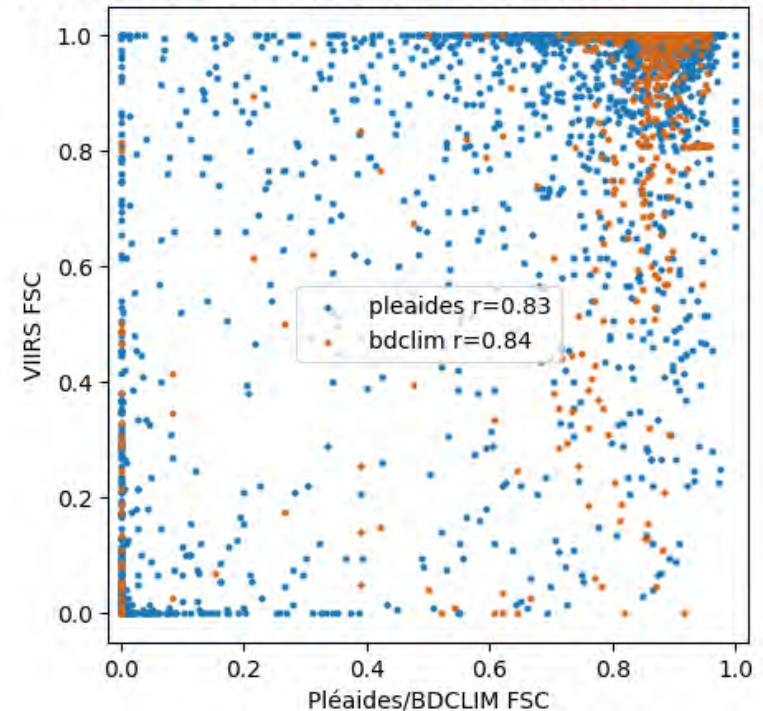
$$FSC = \frac{a \text{ SD}}{\text{SD} + b}$$

(Dickinson et al., 1993), (Sourp et al., in prep.)

VIIRS FSC vs EDELWEISS median FSC (dick93 a=1.00, b=0.1):



VIIRS FSC vs Pléiades/ BDCLIM FSC (dick93 a=1.00, b=0.11)



PhD research questions : which observation to assimilate ? Associated uncertainty ?

Large scale evaluation of VIIRS snow cover products for all three platforms

VIIRS observations are mature and consistent across platforms

Average error ~15 % but the analysis showed a complex error dynamics in mountained

Mixed pixels first error source, then forest and topography

« Side » results

Operational Météo-France VIIRS daily composite

Fusion of the three platforms' data allows cloud cover reduction without degrading data accuracy

Comparison with model and reference

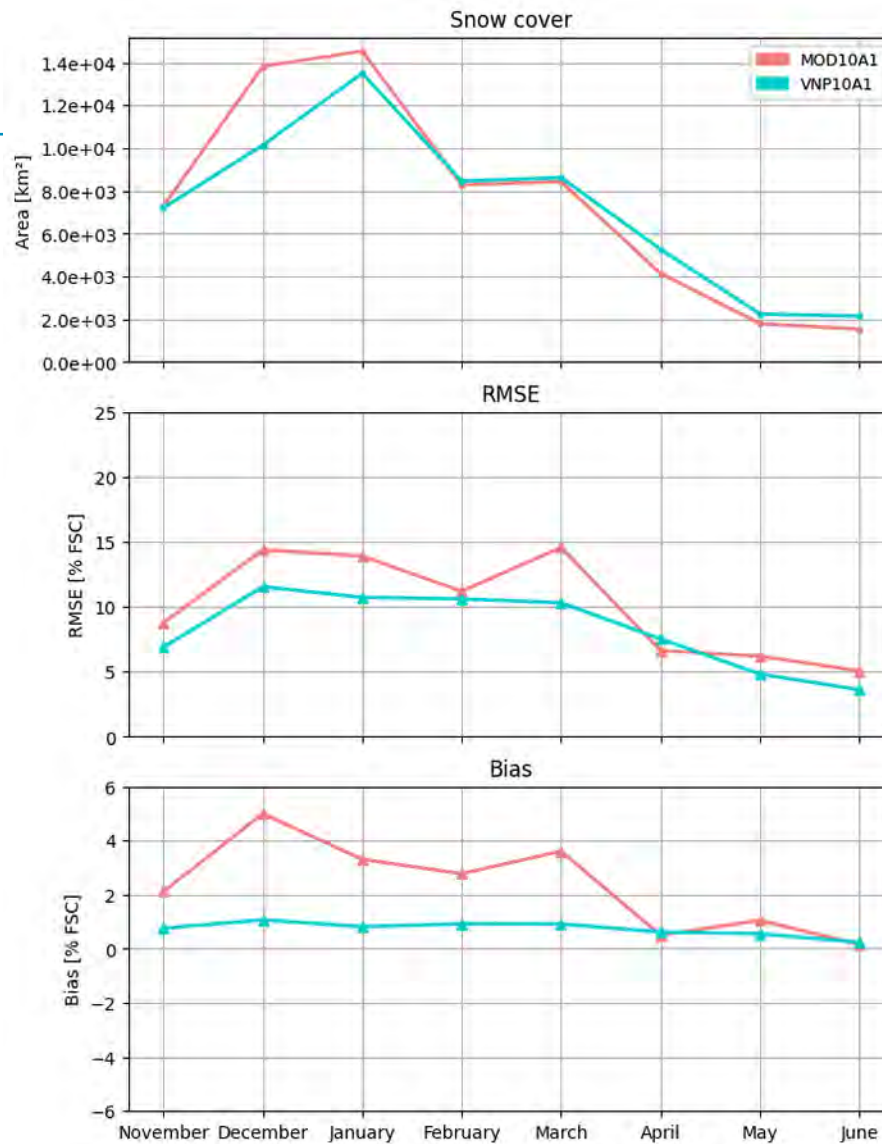
An aerial photograph of a mountain range, likely the Massif-Central in France, showing significant snow cover. A grid of small, semi-transparent squares is overlaid on the image, covering the central and right portions of the frame. The terrain is rugged, with deep valleys and high peaks. The snow is bright white, contrasting with the darker, forested or rocky areas.

Merci

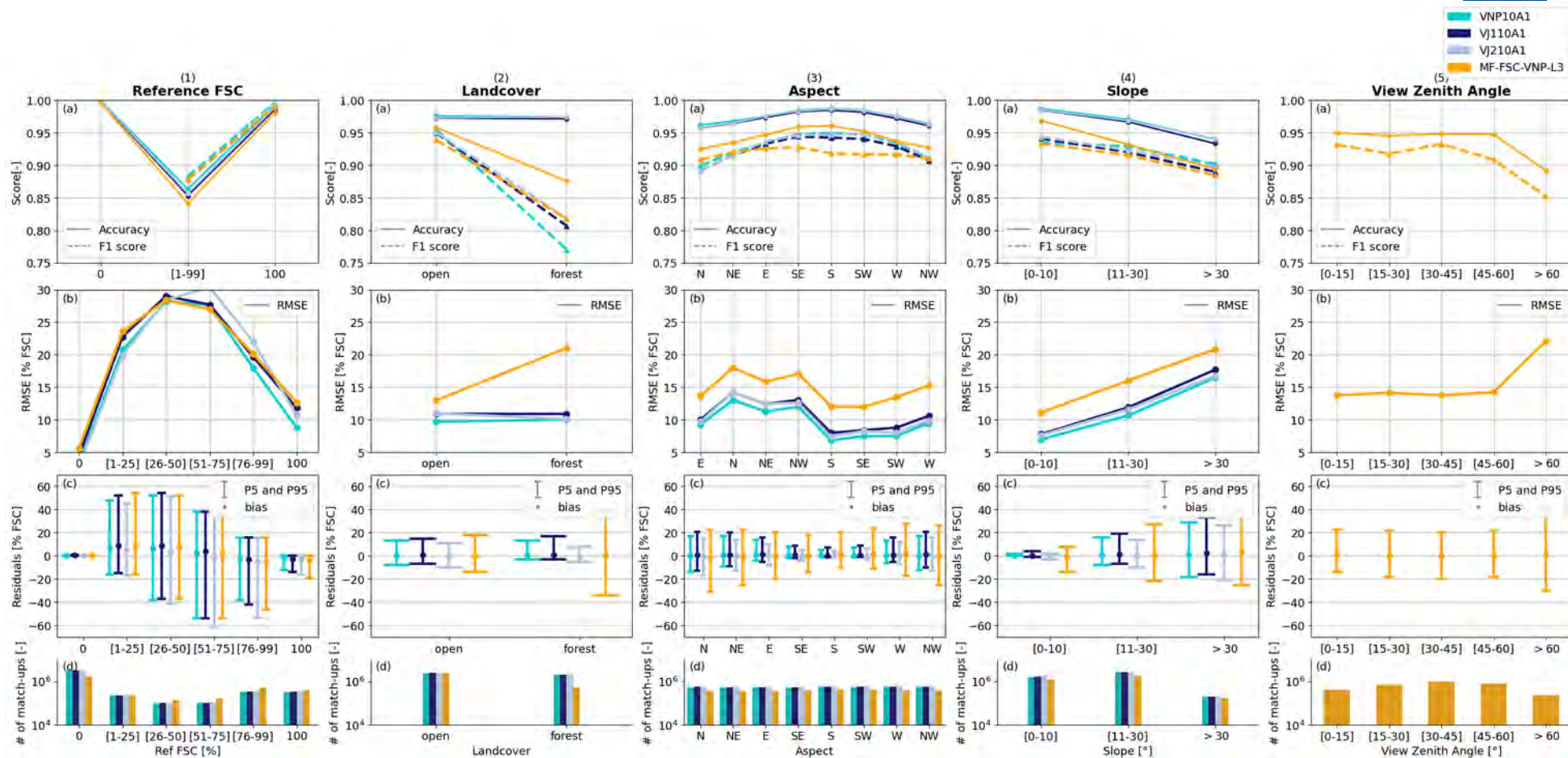
*Monts du Cantal, Massif-Central, France
Sentinel-2 snow cover, 03/12/2023*

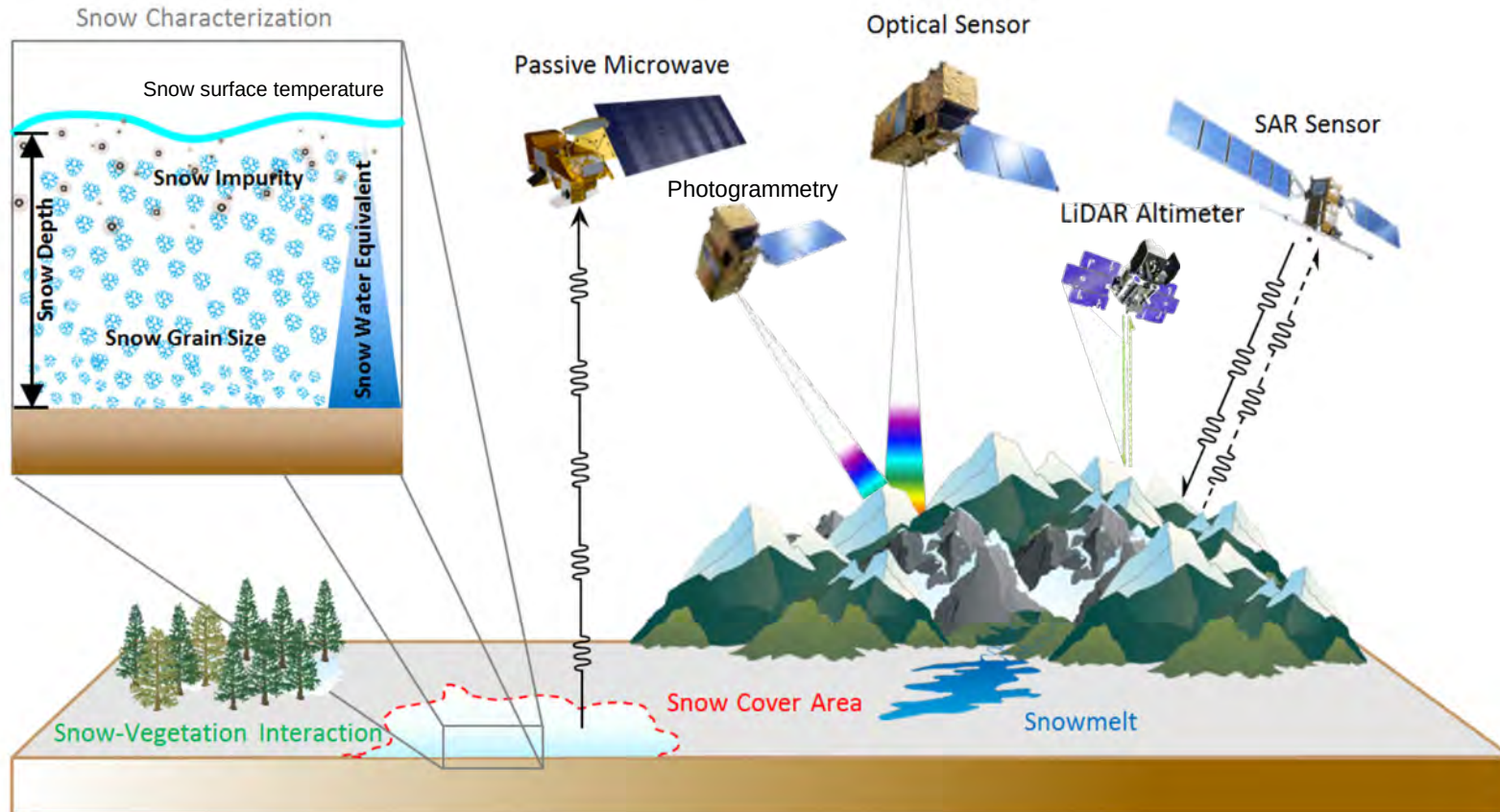
- [1] Deschamps-Berger, César. Apport de la photogrammétrie satellite pour la modélisation du manteau neigeux. Diss. Université Paul Sabatier-Toulouse III, 2021
- [2] Lafaysse, Matthieu. « Modélisation numérique de la neige : la fin du déterminisme ? » Thesis, Université Toulouse III - Paul Sabatier, 2023. <https://hal.science/tel-04130109>.
- [3] Stillinger, Timbo, Karl Rittger, Mark S. Raleigh, Alex Michell, Robert E. Davis, et Edward H. Bair. « Landsat, MODIS, and VIIRS Snow Cover Mapping Algorithm Performance as Validated by Airborne Lidar Datasets ». *The Cryosphere* 17, n° 2 (8 février 2023): 567-90. <https://doi.org/10.5194/tc-17-567-2023>.
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- [5] Vidot, Jérôme, Bernard Bellec, Marie Dumont, et Pascal Brunel. « A Daytime VIIRS RGB Pseudo Composite for Snow Detection ». *Remote Sensing of Environment* 196 (juillet 2017): 134-39. <https://doi.org/10.1016/j.rse.2017.04.028>.
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- [7] G. Schwaizer, S. Metsämäki, L. Keuris, et K. Luojus, « Snow Cover Extent Collection 1 km Quality Assessment Report v1.0 ». 16 avril 2020. [En ligne]. Disponible sur: <https://land.copernicus.eu/en/technical-library/quality-assessment-report-for-snow-cover-extent-northern-hemisphere-1-km-raster/@@download/file>
- [8] Rowan Jacques-Hamilton, Mihai Valcu, Eunbi Kwon, Tom S L Versluijs and Bart Kempnaers, Measurement error in remotely sensed fractional snow cover datasets: implications for ecological research, DOI 10.1088/2752-664X/ada8b3, january 2025
- [9] Keuris, Lars, et al. "An adaptive method for the estimation of snow-covered fraction with error propagation for applications from local to global scales." *Remote Sensing* 15.5 (2023): 1231.
- [10] G. A. Riggs et D. K. Hall, « NASA VIIRS Snow Cover Products User Guide v3 ». mars 2023. [En ligne]. Disponible sur: https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://viirsland.gsfc.nasa.gov/PDF/VIIRS%2520C2%2520Snow%2520Cover%2520Product%2520User%2520Guide%2520v3.pdf&ved=2ahUKEwjO4_zrks2JAxW6U6QEHe5cNF0QFnoECBEQAQ&usq=AOvVaw1SGbDnWBmZTXhZTzHpE th3
- [11] A. G. Klein, D. K. Hall, et G. A. Riggs, « Improving snow cover mapping in forests through the use of a canopy reflectance model », *Hydrol. Process.*, vol. 12, n° 10-11, p. 1723-1744, août 1998, doi: 10.1002/(SICI)1099-1085(199808/09)12:10/11<1723::AID-HYP691>3.0.CO;2-2.
- [12] M. von Kaenel et S. A. Margulis, « Improved modelling of mountain snowpacks with spatially distributed precipitation bias correction derived from historical reanalysis », *The Cryosphere*, vol. 19, n° 8, p. 3309-3327, août 2025, doi: 10.5194/tc-19-3309-2025.
- [13] M. Oberrauch, B. Cluzet, J. Magnusson, et T. Jonas, « Improving Fully Distributed Snowpack Simulations by Mapping Perturbations of Meteorological Forcings Inferred From Particle Filter Assimilation of Snow Monitoring Data », *Water Resources Research*, vol. 60, n° 12, p. e2023WR036994, 2024, doi: 10.1029/2023WR036994.
- [14] Vionnet, Vincent, et al. "The detailed snowpack scheme Crocus and its implementation in SURFEX v7. 2." *Geoscientific model development* 5.3 (2012): 773-791.

VIIRS vs MODIS



Caractérisation topographique et géométrique

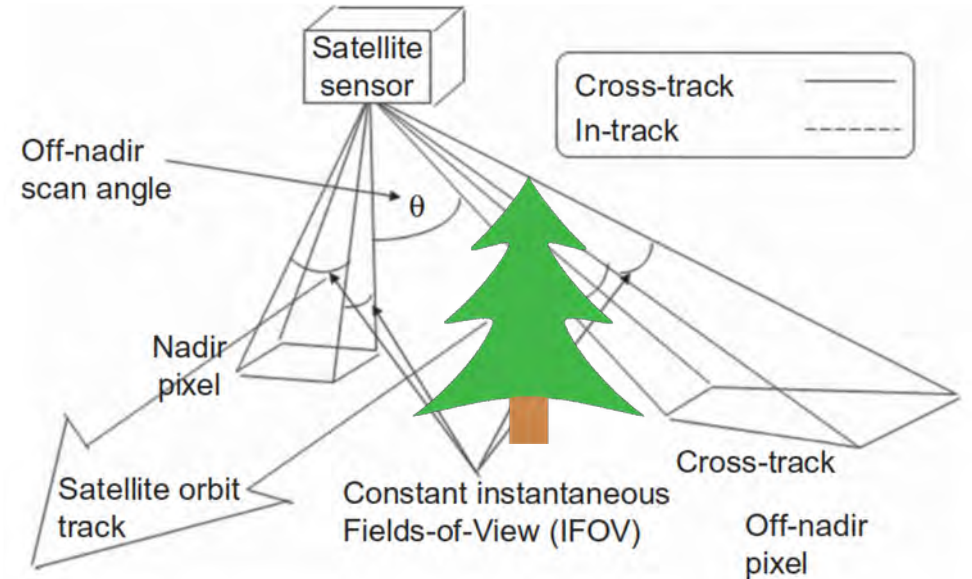
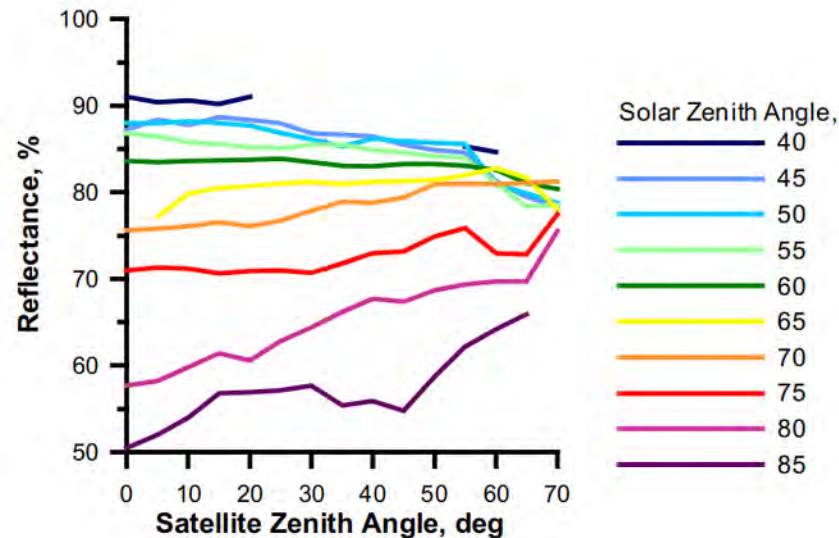




(Hu et al., 2017)

Facteurs qui peuvent affecter la détection de couverture neigeuse

- Végétation
- Nuages
- Angle de vue
- ...



- **Contrainte opérationnelle : produits matures, forte revisite, faible latence, résolution ~250 m**

Produit	Résolution spatiale	Fréquence temporelle	Fin mission	Latence	Maturité
S2 (Copernicus, Theia)	20 m	5 j	> 2032	Faible	Élevée
MODIS NASA	500 m	1/2 obs/j	2025	8h – 10j	Élevée
VIIRS NASA (L3)	375 m	2 obs/j	> 2030	8h – 10j	Moyenne
VIIRS Météo-France (L2)	375 m	3-6 obs/ j	> 2030	~3h	Faible