$> Sentinel-2, Pléiades, Icesat-2, Trishna...|

Hijacking Earth observation satellites for snow science

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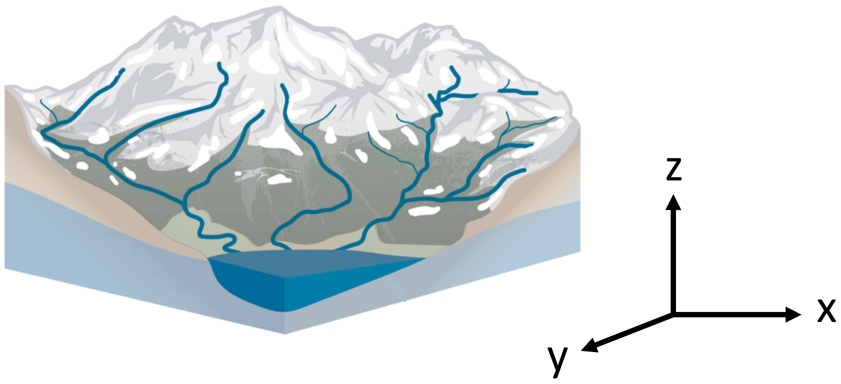
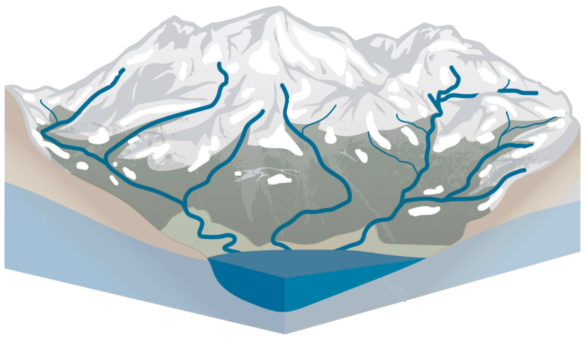
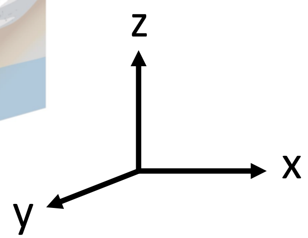
SWE in alpine catchments



$$M = \iint_{\mathrm{SCA}} \left(\int_{0}^{\mathrm{HS}(x,y)} \rho(x,y,z)\,\mathrm{d}z \right) \mathrm{d}x\,\mathrm{d}y$$

SWE in alpine catchments





Elevation differencing
Pléiades, ICESat-2

$$M = \iint_{SCA} \left(\int_0^{HS(x,y)} \rho(x,y,z)\, \mathrm{d}z \right) \mathrm{d}x\, \mathrm{d}y$$

Image classification
MODIS, Sentinel-2

Thermal inertia?
Trishna, LSTM

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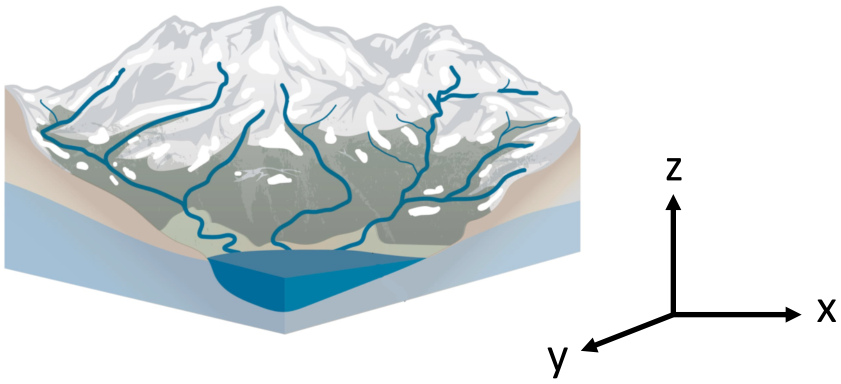

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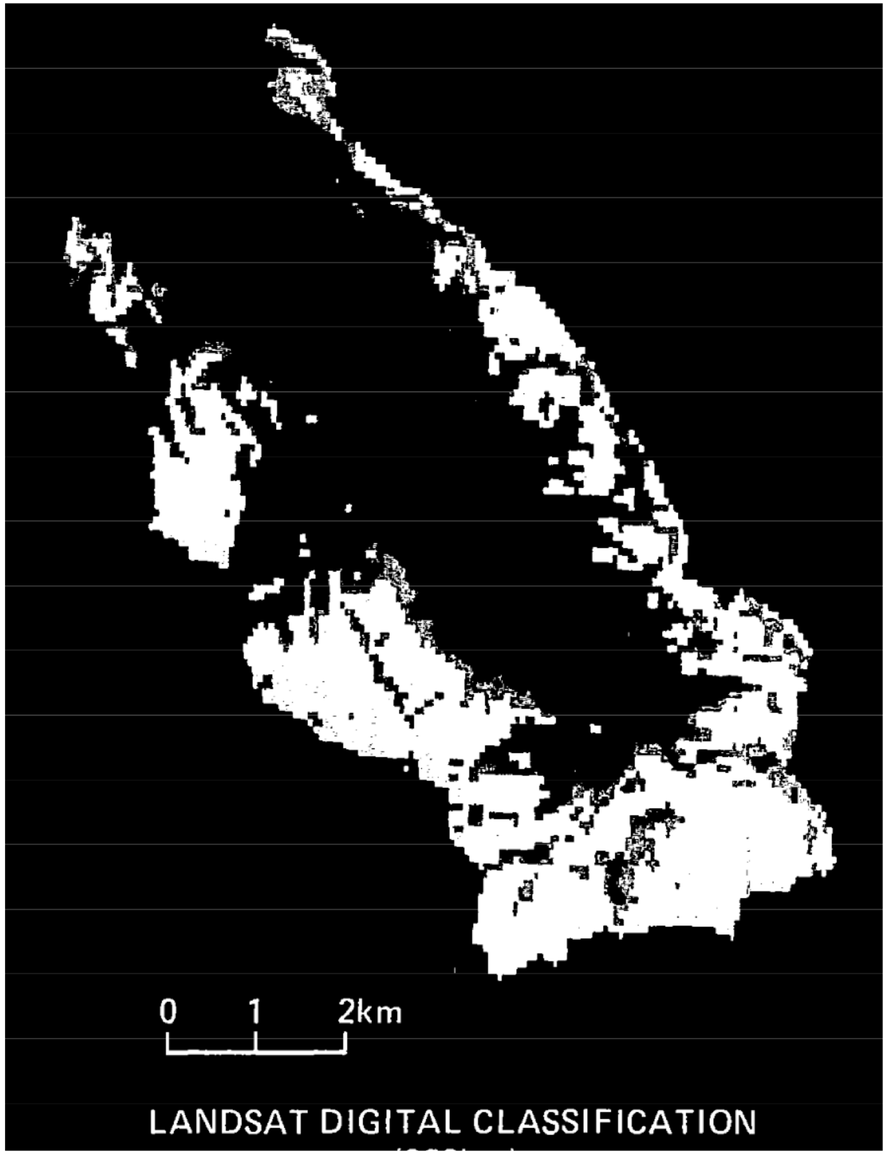
Image classification

MODIS, Sentinel-2

SCA is easy

- **1972 : Landsat (30 m, 16 day)**
- 2000 : MODIS (500 m, 1 day)
- 2015 : Sentinel-2 (20 m, 5 day)



Dischma, Switzerland, 8 Jun 1976
Rango & Martinec (1979)

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- 1972 : Landsat (30 m, 16 day)
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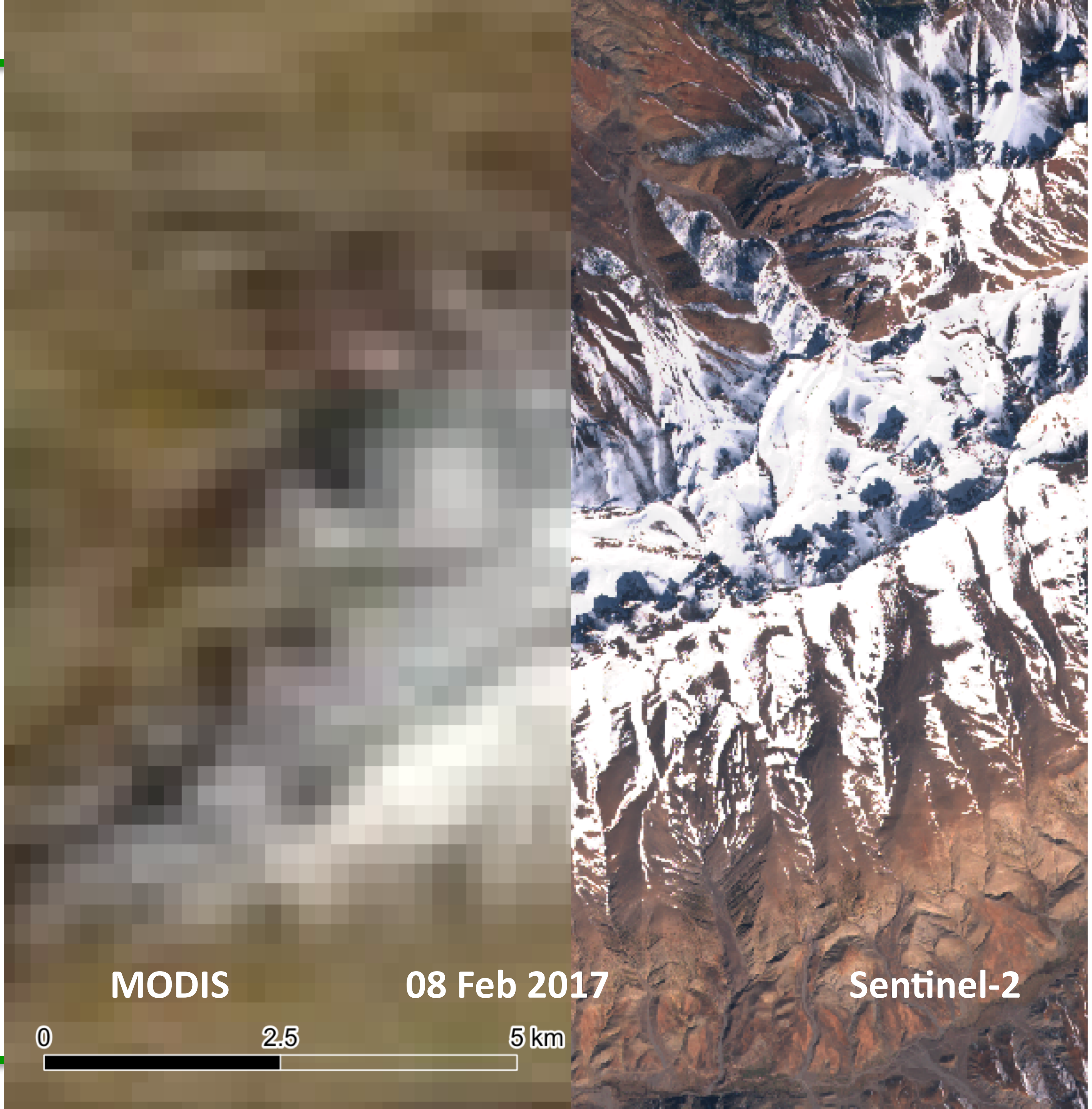

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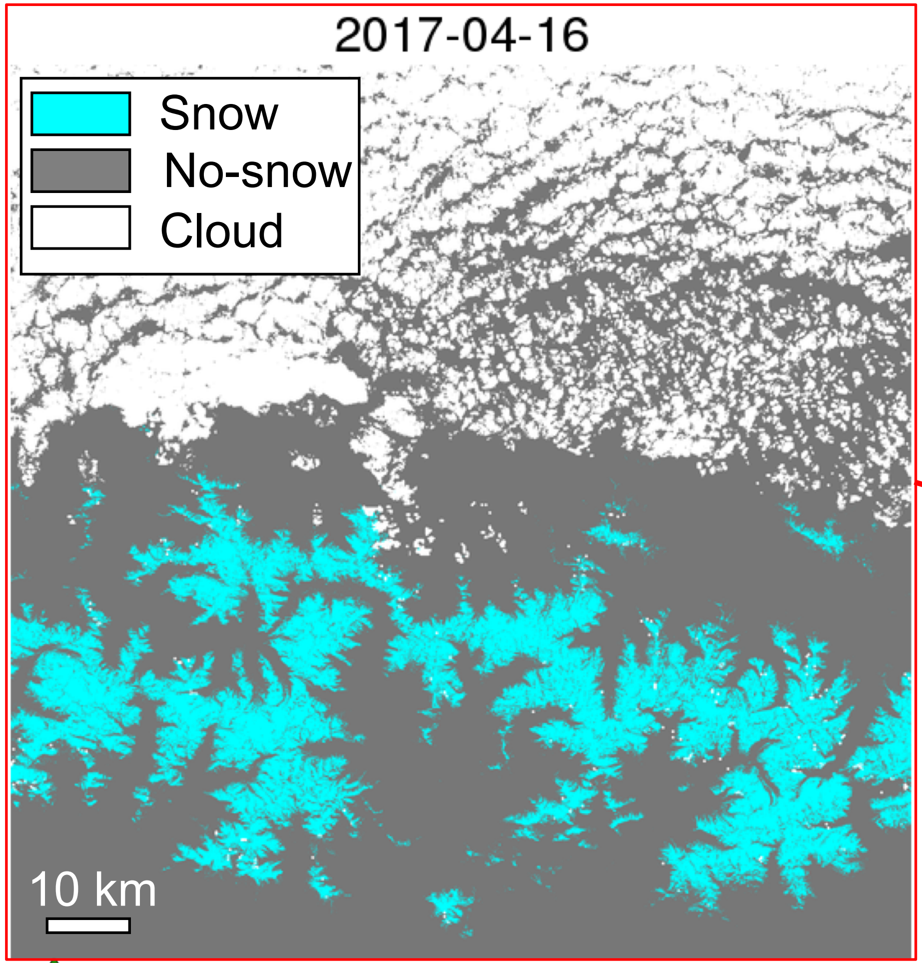
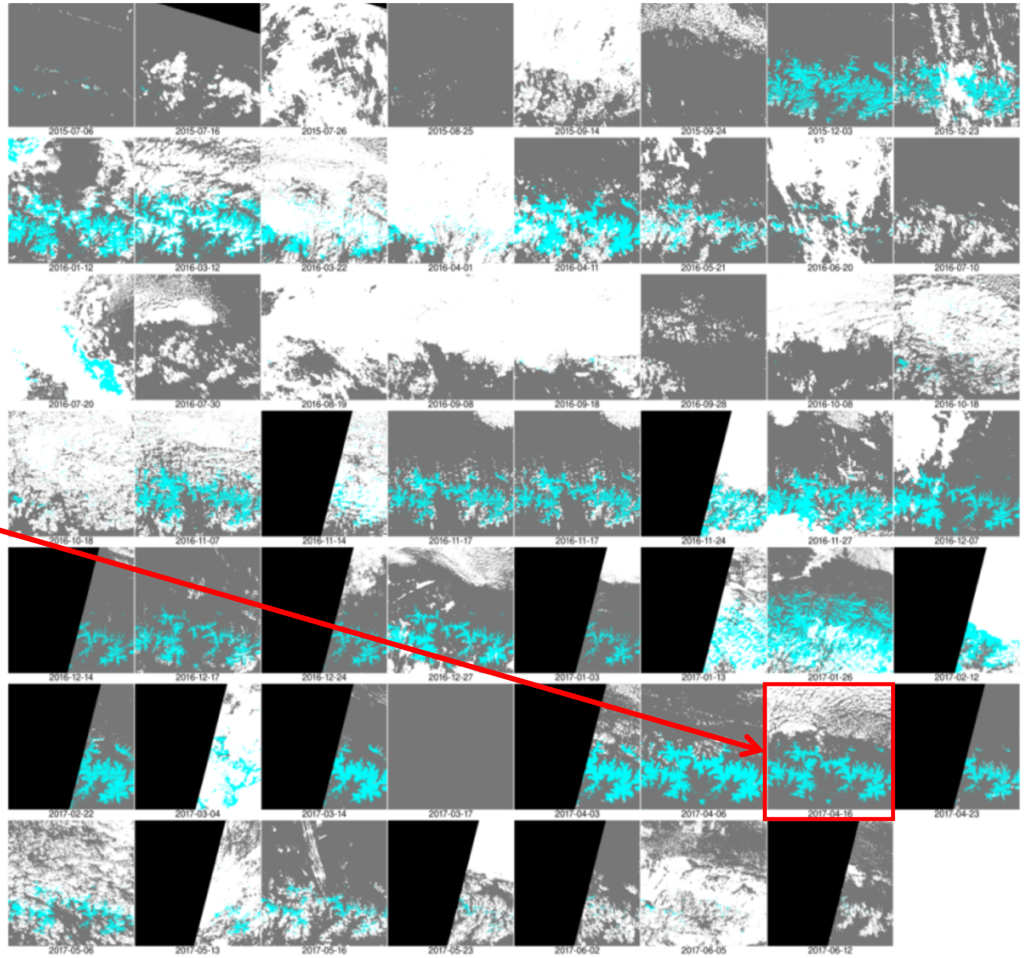
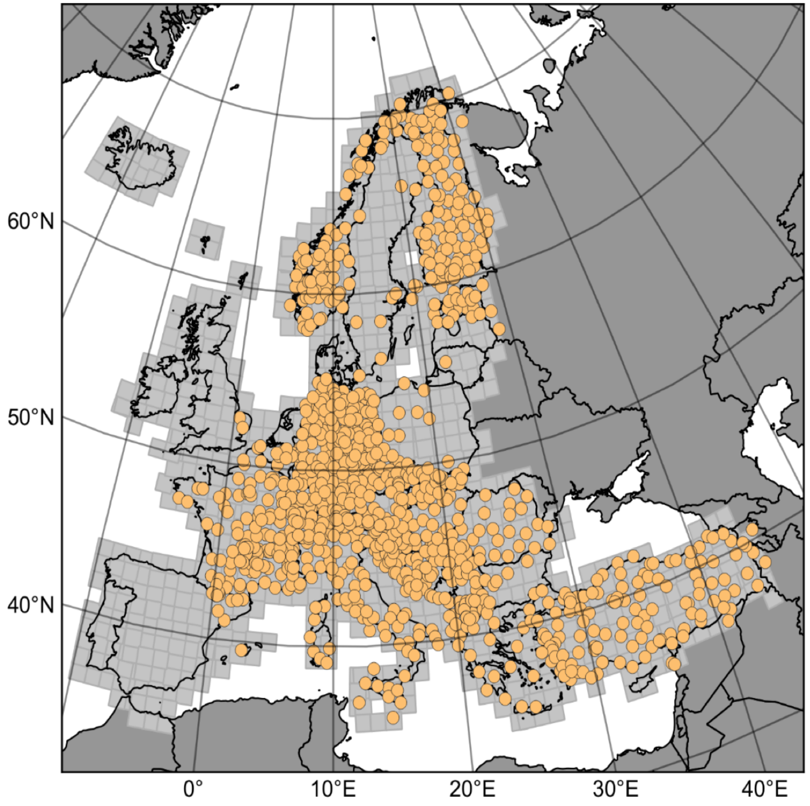
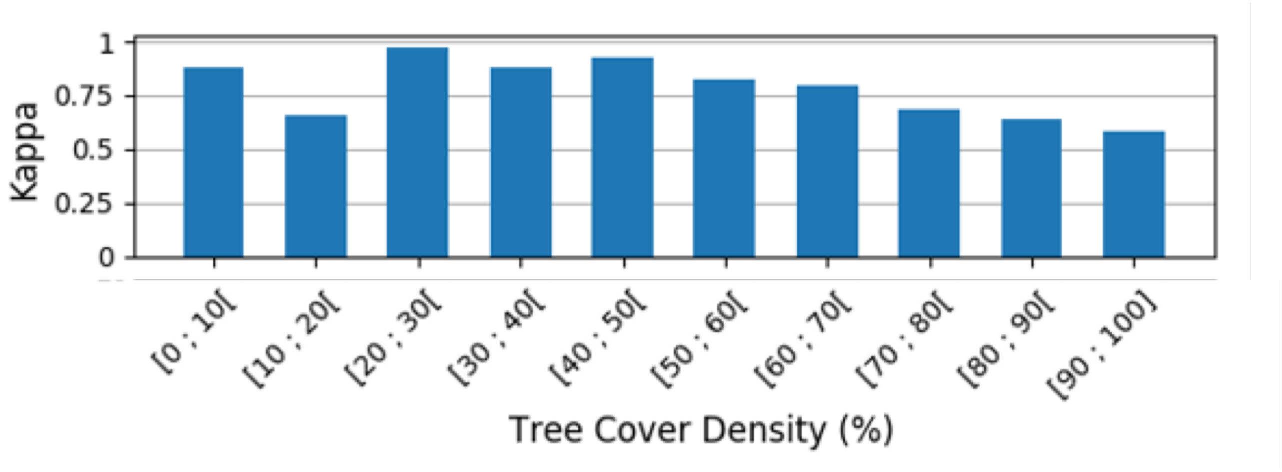
Sentinel-2 SCA time series





Sentinel-2 SCA evaluation





Barrou Dumont, Z., Gascoin, S., Hagolle, O., Ablain, M., Jugier, R., Salgues, G., Marti, F., Dupuis, A., Dumont, M., and Morin, S.: Brief communication: Evaluation of the snow cover detection in the Copernicus High Resolution Snow & Ice Monitoring Service, The Cryosphere, 2021.

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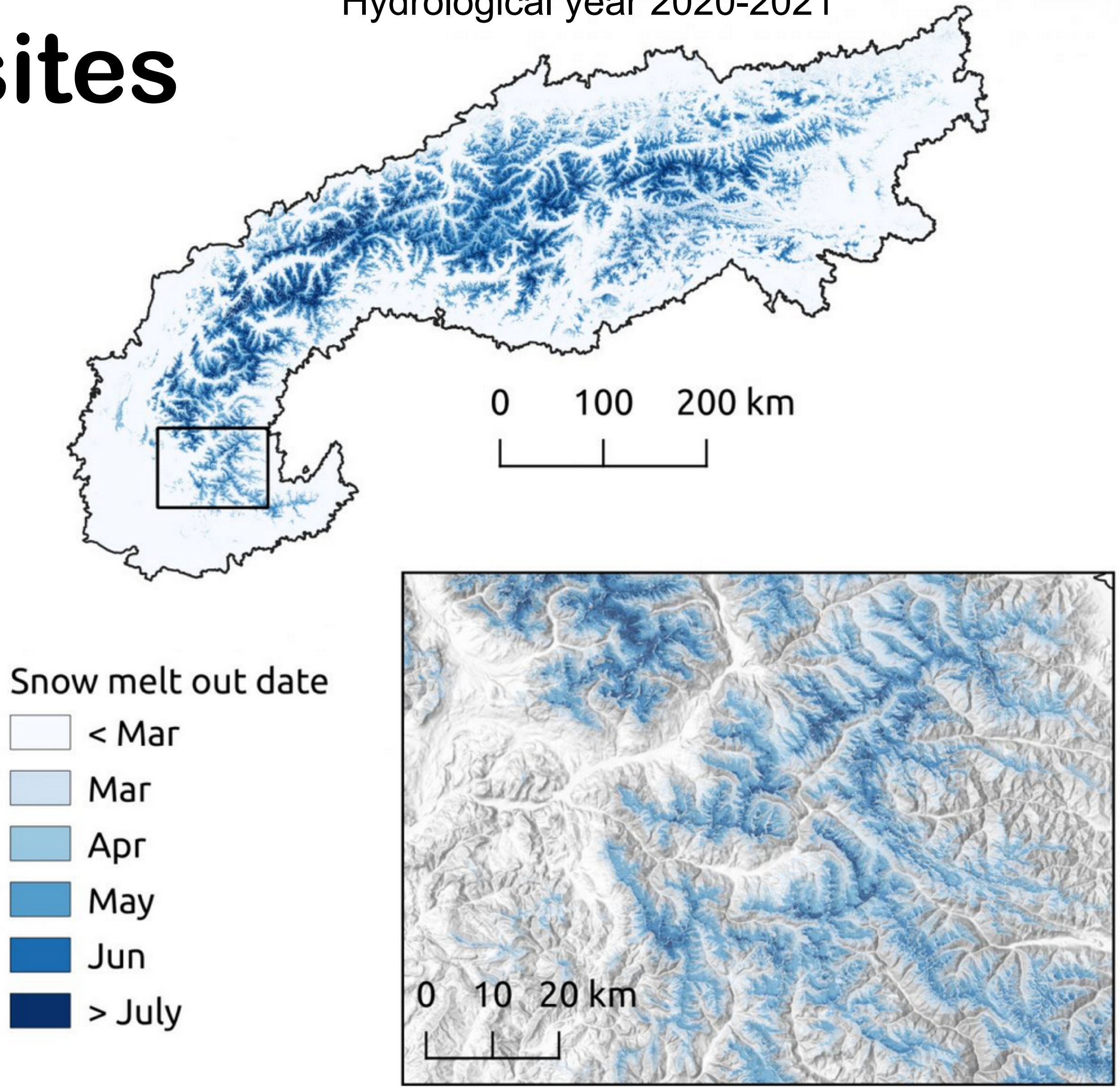
Sentinel-2 composites

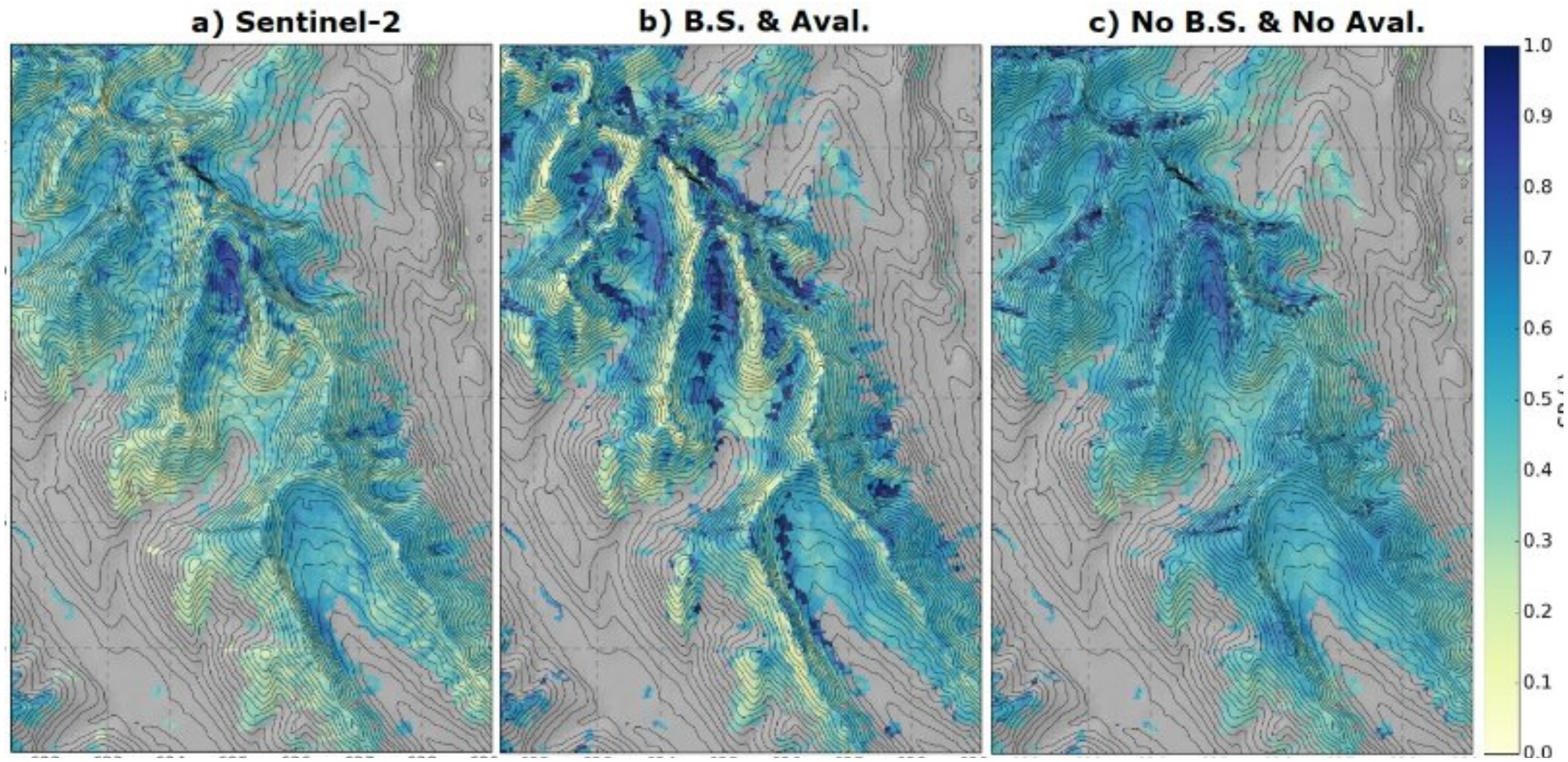
- Snow probability
- Snow duration
- Snow onset date
- Snow melt out date

Hydrological year 2020-2021



Evaluation of the Canadian Hydrological Model

Snow probability



Vionnet, V., Marsh, C. B., Menounos, B., Gascoin, S., Wayand, N. E., Shea, J., Mukherjee, K., and Pomeroy, J. W.: Multi-scale snowdrift-permitting modelling of mountain snowpack, The Cryosphere, 2020

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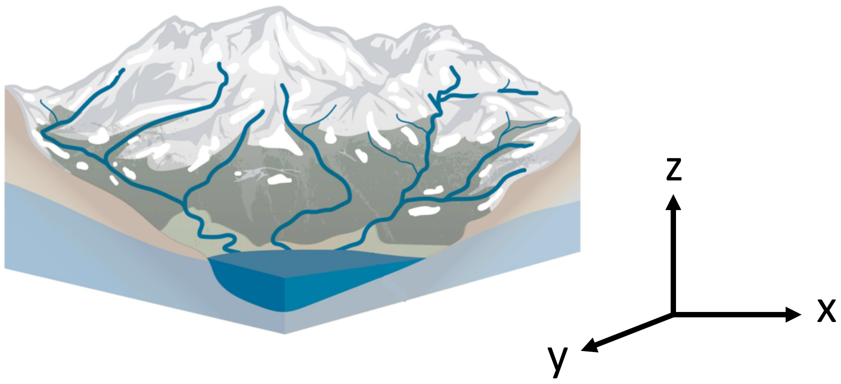

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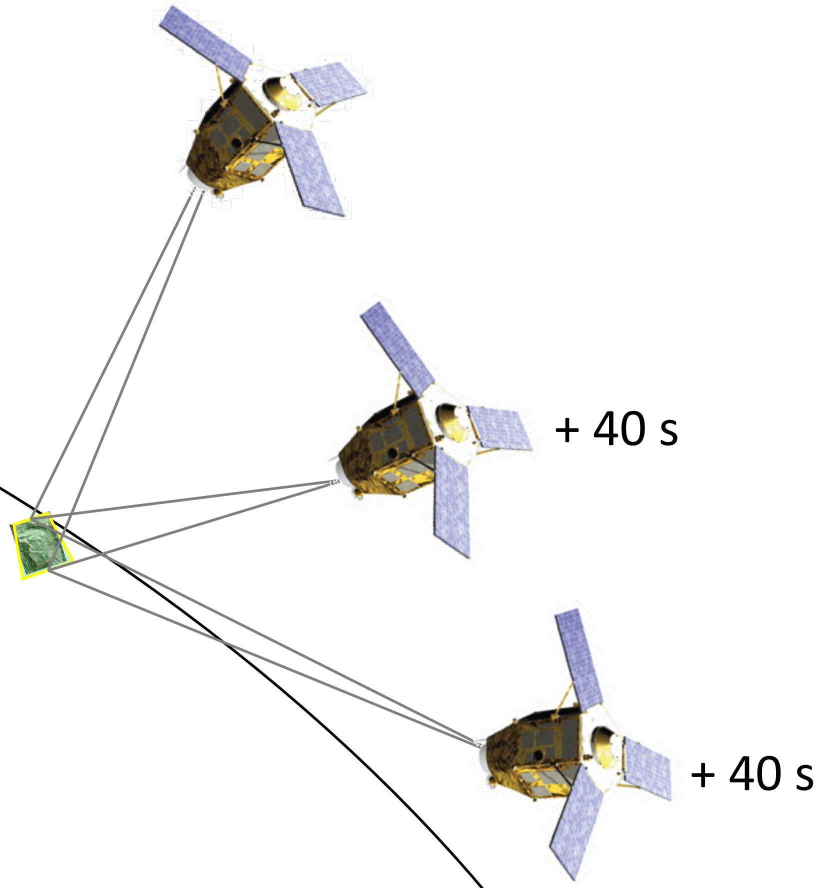
Pléiades snow depth

Pléiades : 70 cm, swath 20 km

- Difference of snow-off and snow-on DEMs

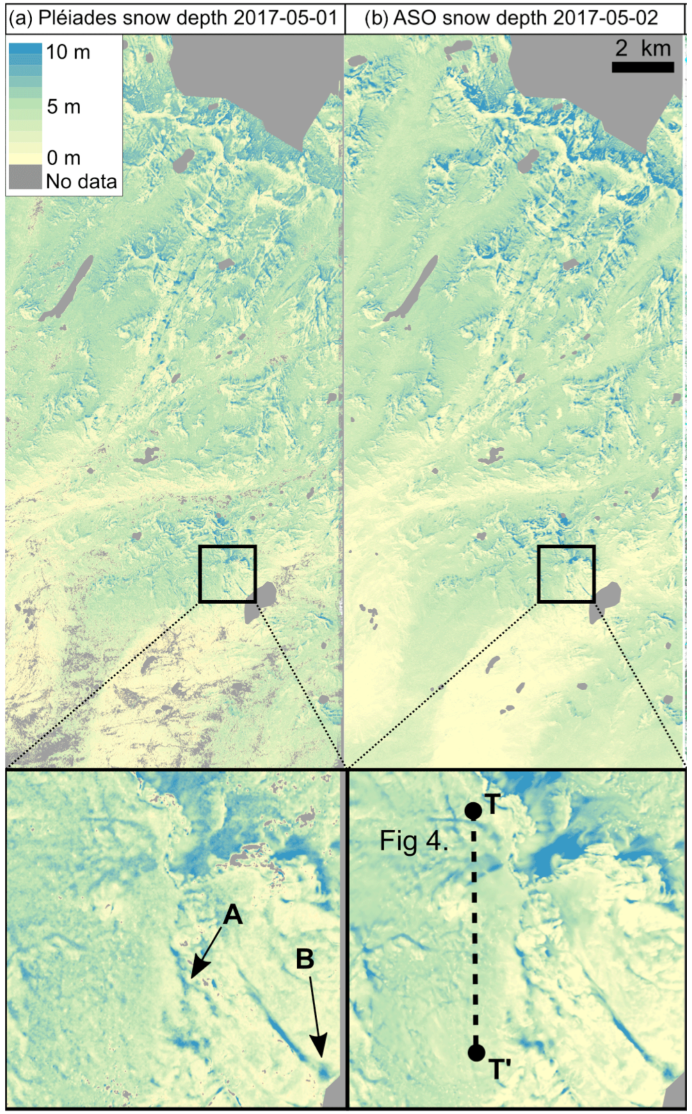


Pléiades snow depth

- Difference of snow-off and snow-on DEMs
- Accuracy ~ 50 to 70 cm at 2 m resolution

Marti, R., Gascoin, S., Berthier, E., de Pinel, M., Houet, T., and Laffly, D.: Mapping snow depth in open alpine terrain from stereo satellite imagery, The Cryosphere, 2016

Deschamps-Berger, C., Gascoin, S., Berthier, E., Deems, J., Gutmann, E., Dehecq, A., Shean, D., and Dumont, M.: Snow depth mapping from stereo satellite imagery in mountainous terrain: evaluation using airborne laser-scanning data, The Cryosphere, 2020

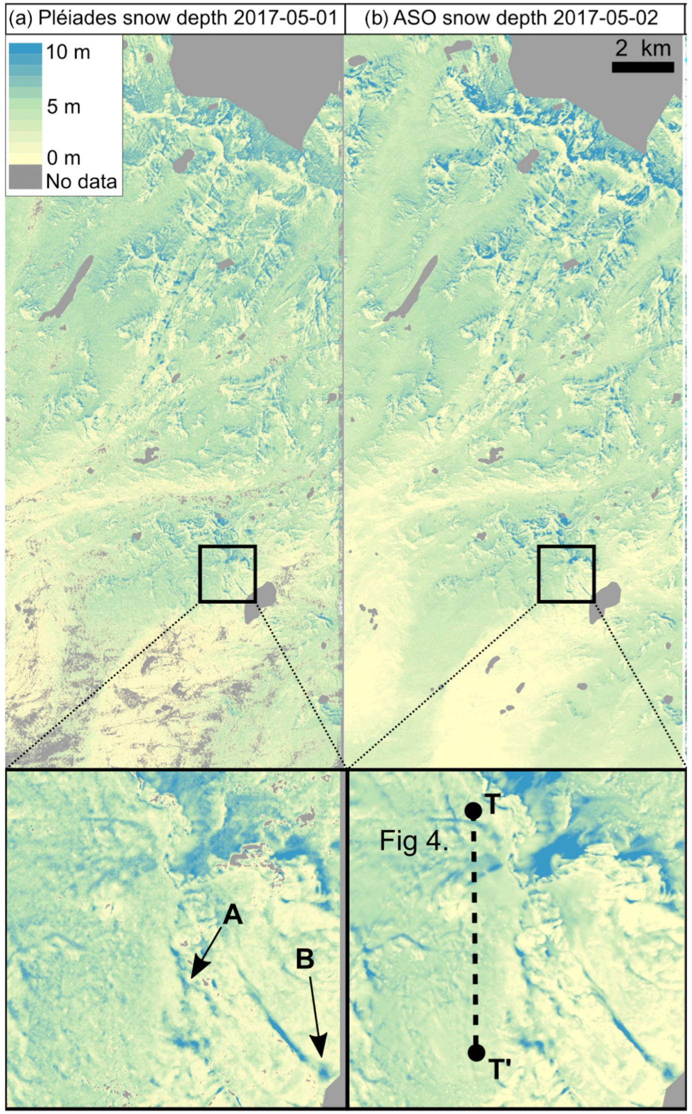


Pléiades snow depth

- Difference of snow-off and snow-on DEMs
- Accuracy ~ 50 to 70 cm at 2 m resolution
- Accuracy ~ 30 cm at 30 m resolution

Marti, R., Gascoin, S., Berthier, E., de Pinel, M., Houet, T., and Laffly, D.: Mapping snow depth in open alpine terrain from stereo satellite imagery, The Cryosphere, 2016

Deschamps-Berger, C., Gascoin, S., Berthier, E., Deems, J., Gutmann, E., Dehecq, A., Shean, D., and Dumont, M.: Snow depth mapping from stereo satellite imagery in mountainous terrain: evaluation using airborne laser-scanning data, The Cryosphere, 2020



Pléiades snow depth

Successful case studies

- 🇫🇷 Bassiès, France (Marti et al. 2016)
- 🇺🇸 Tuolumne, USA (Deschamps-Berger et al. 2020)
- 🇨🇱 Yeso, Chile (Shaw et al. 2020abc)
- 🇩🇪 Zugspitze, Germany (Koch et al., WIP)

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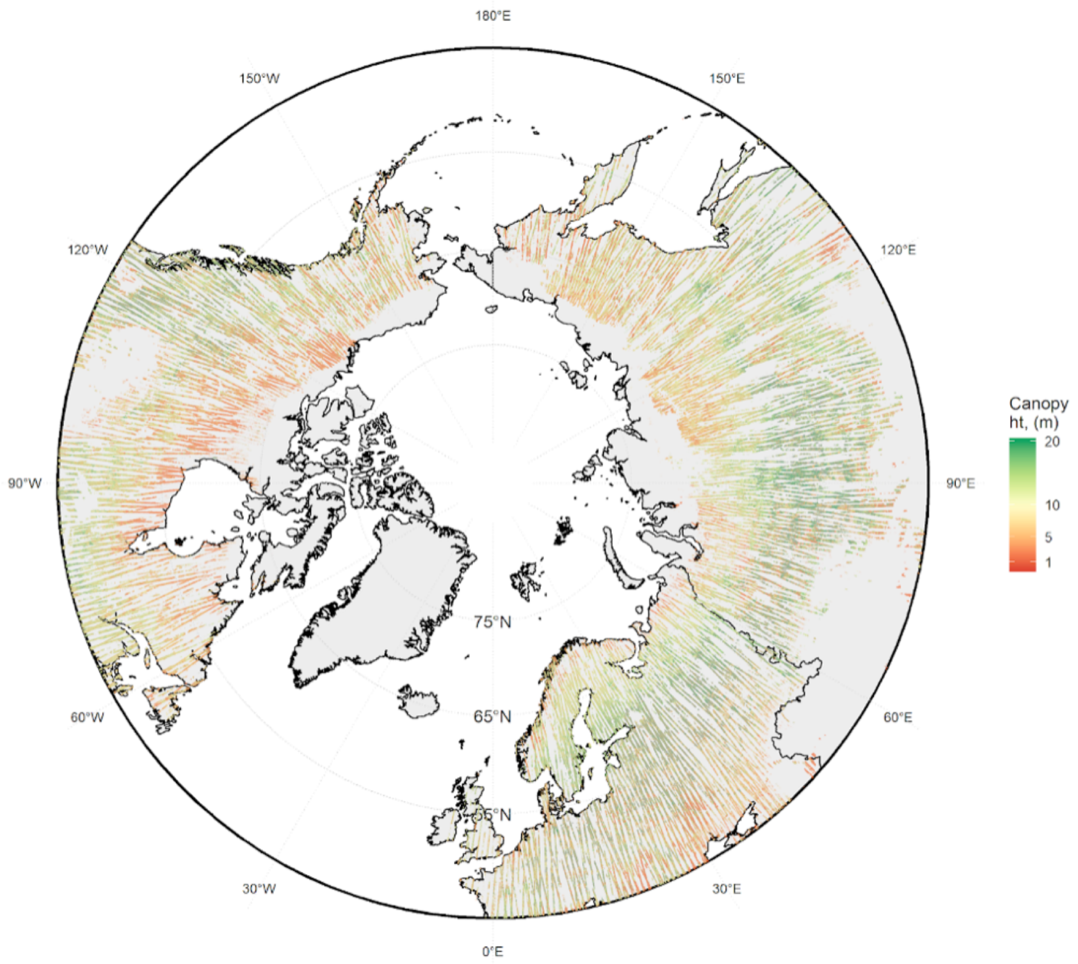
ICESat-2 snow depth?

Accurate altimeter with
91-day repeat orbit

ICESat-2 snow depth?

Accurate altimeter with 91-day repeat orbit

… but off-nadir pointing over land areas



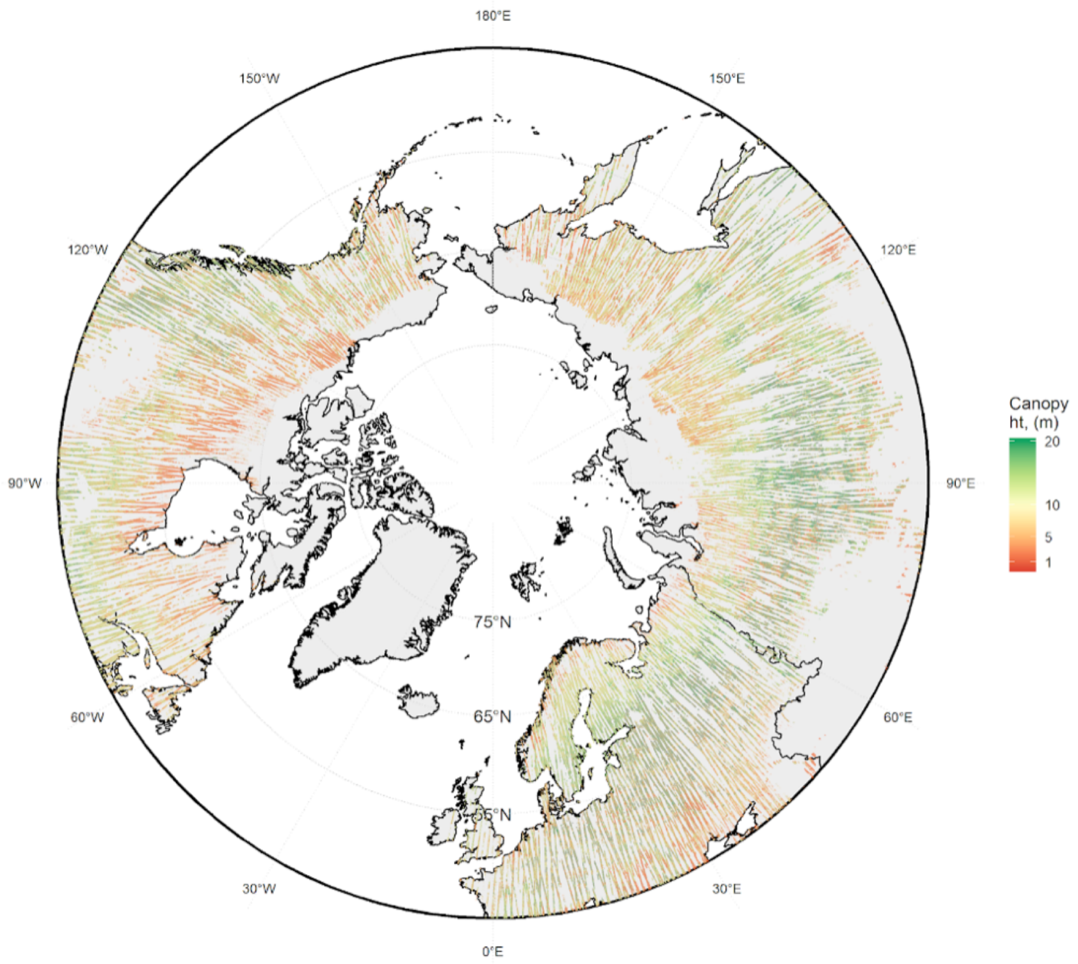
ICESat-2 snow depth?

Accurate altimeter with 91-day repeat orbit

… but off-nadir pointing over land areas

snow-on: ICESat-2

snow-off: airborne lidar, Pléiades

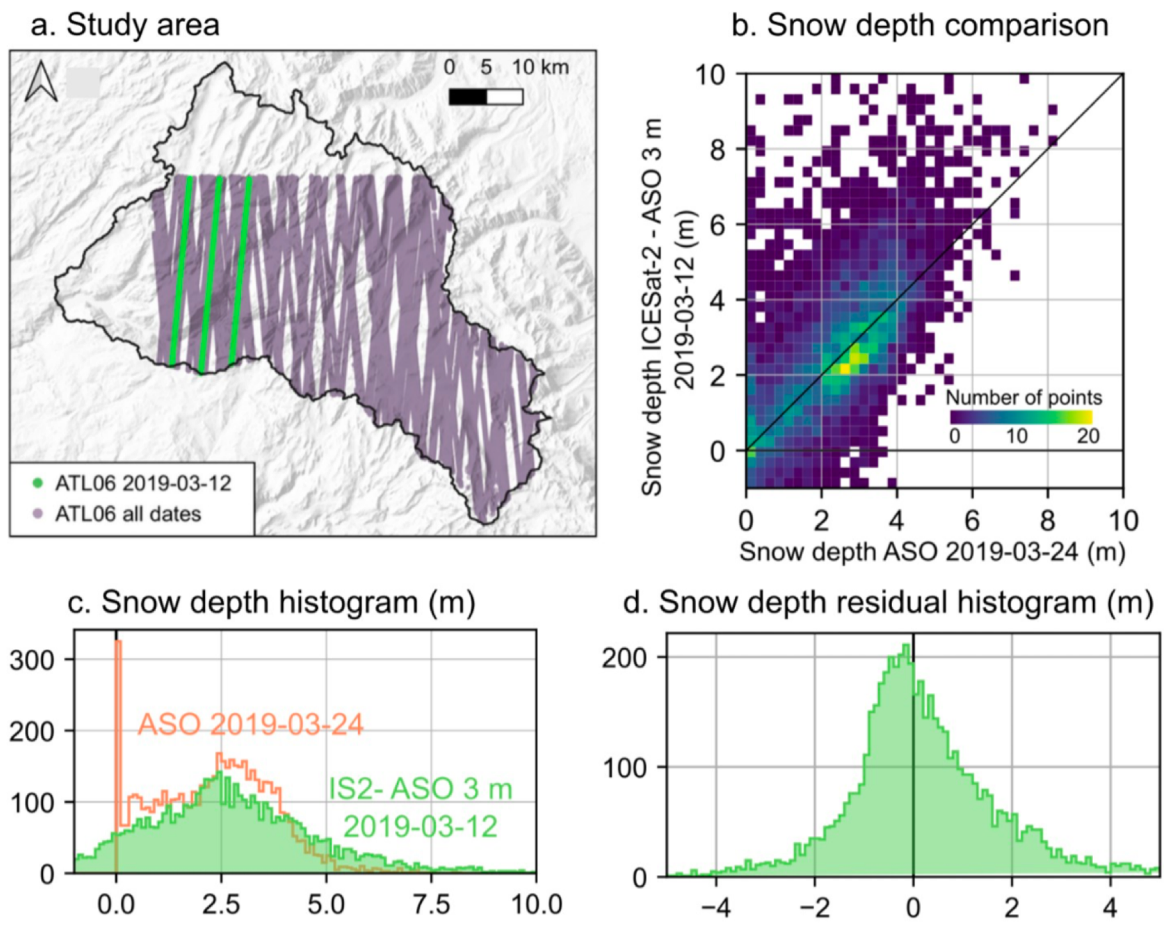


ICESat-2 snow depth?

Deschamps-Berger, C., Gascoin, S., Shean, D., Besso, H., Guiot, A., and López-Moreno, J. I.: Evaluation of snow depth retrievals from ICESat-2 using airborne laser-scanning data, The Cryosphere Discuss.

https://doi.org/10.5194/tc-2022-191

- ➔ Bias ~0.2 m, precision ~0.5 m (NMAD) for slopes < 10°
- ➔ Precision ~1.2 m > 30°



Combination of ICESat-2 ATL06 and ASO 3 m snow-off DEM

Conclusion

Remote sensing data for the Common observing period (COPE)?

Data	Cost	Technology readiness level	Workload
MODIS / SCA			
Sentinel-2 / SCA			
Pléiades / HS	20k$ or free		
ICESat-2 / HS			

*Considering 10 to 15 sites of ~ 100 km2

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