Snow Cover Classification over Mountainous Terrains at Optical Wavelengths by Machine Learning: Existing Challenges and New Opportunities

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10th EARSeL Workshop on Remote Sensing of Land Ice & Snow | 6-8 Feb 2023

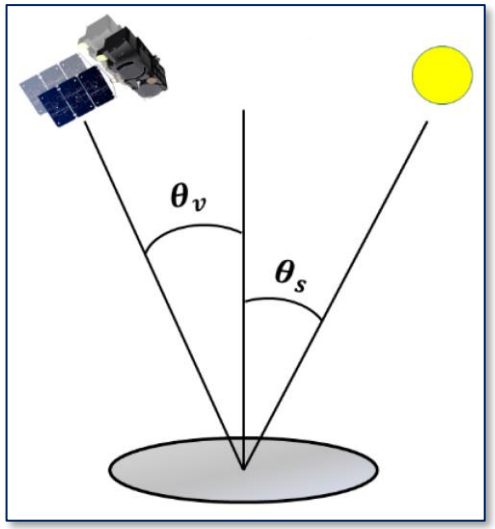
semihkuter@karatekin.edu.tr cansu.aksu@metu.edu.tr zakyurek@metu.edu.tr

Challenges in snow cover mapping at optical wavelengths

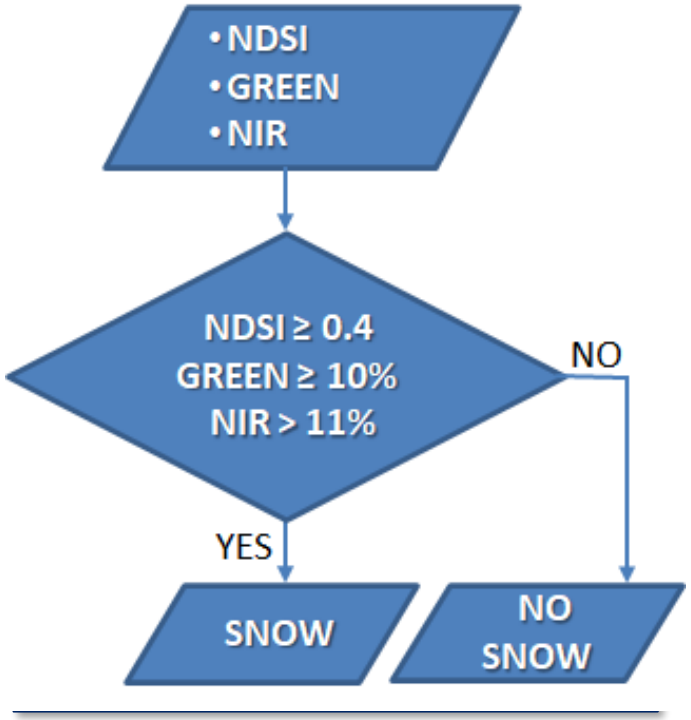
- **The most ideal scenario**
  - Clear sky and relatively flat surface without dense vegetation
  - Good illumination and sensor viewing conditions
  - Snow cover with depth of several centimeters



…works fine..!



Hall *et al.* (1995)



Challenges in snow cover mapping at optical wavelengths

- **Known issues in snow cover retrieval by optical remote sensing**
  - Mixed-pixel problem over the areas with complex and rough topography
  - Patchy snow cover





Challenges in snow cover mapping at optical wavelengths

- **Known issues in snow cover retrieval by optical remote sensing**
  - Variations in illumination conditions over rough mountainous terrains
  - Slope-casted shadows





Challenges in snow cover mapping at optical wavelengths

- **Known issues in snow cover retrieval by optical remote sensing**
  - Snow cover - forest interaction
  - Clouds

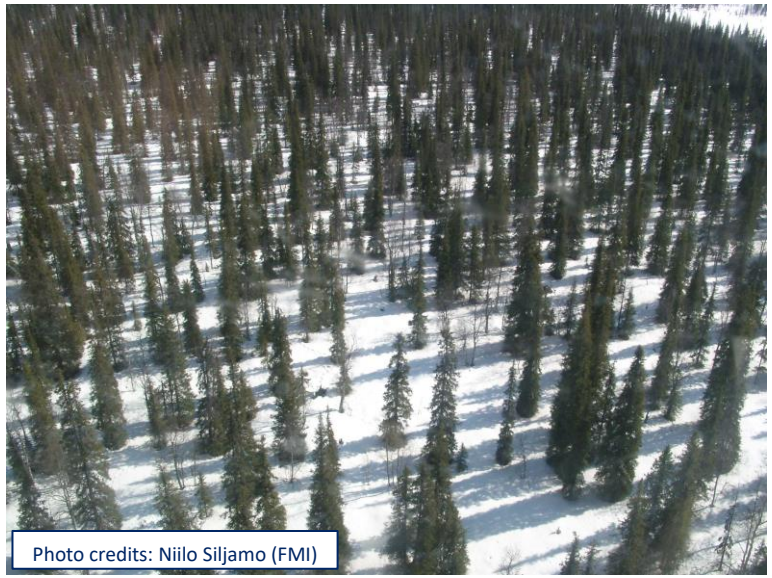
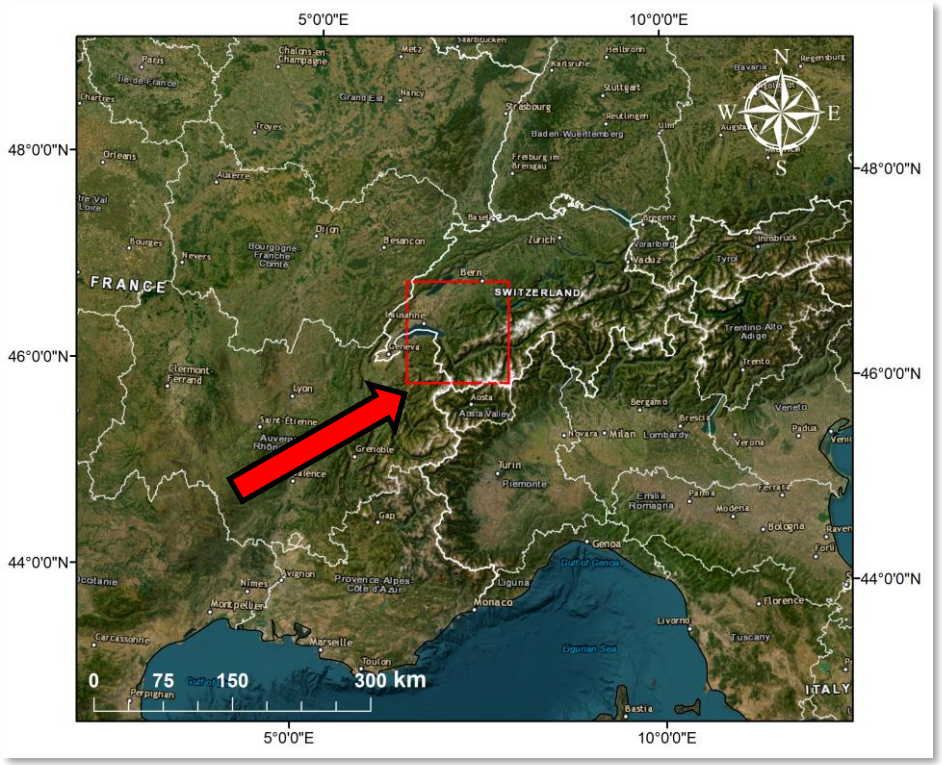

Photo credits: Niilo Siljamo (FMI)


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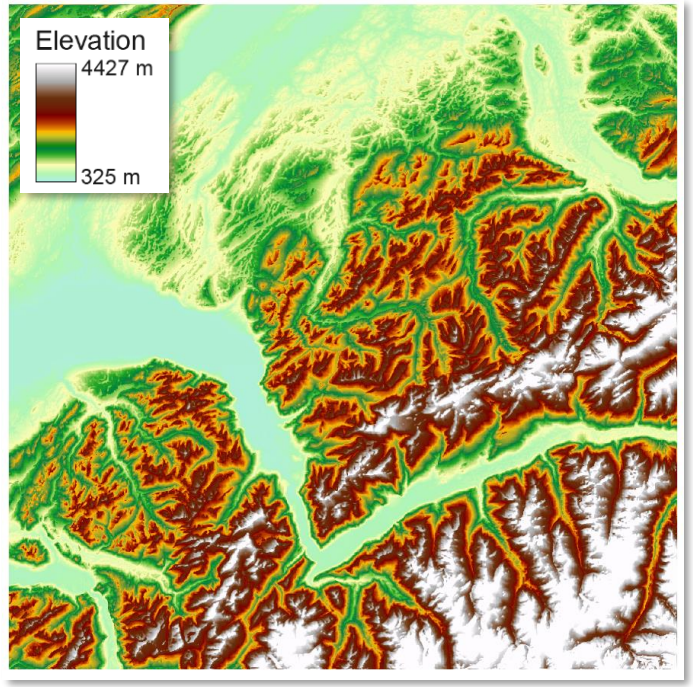


Challenges in snow cover mapping at optical wavelengths

- **Slope-casted shadows**



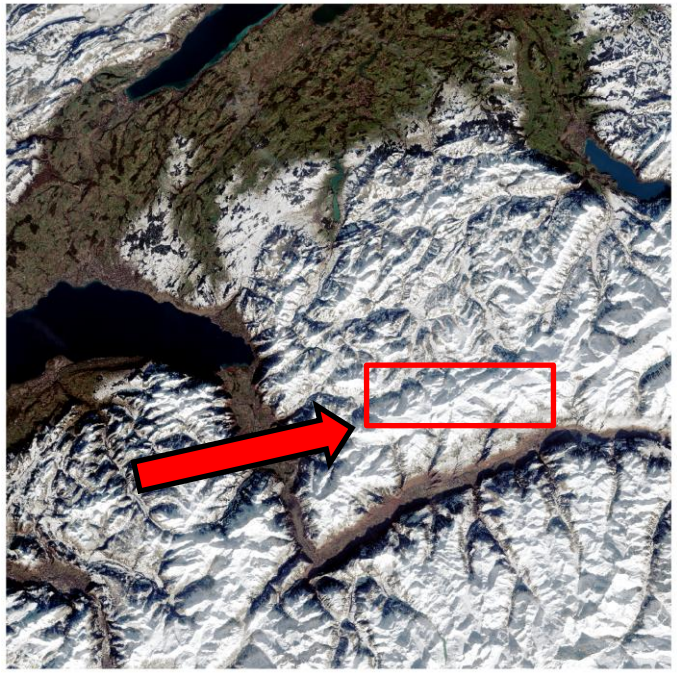




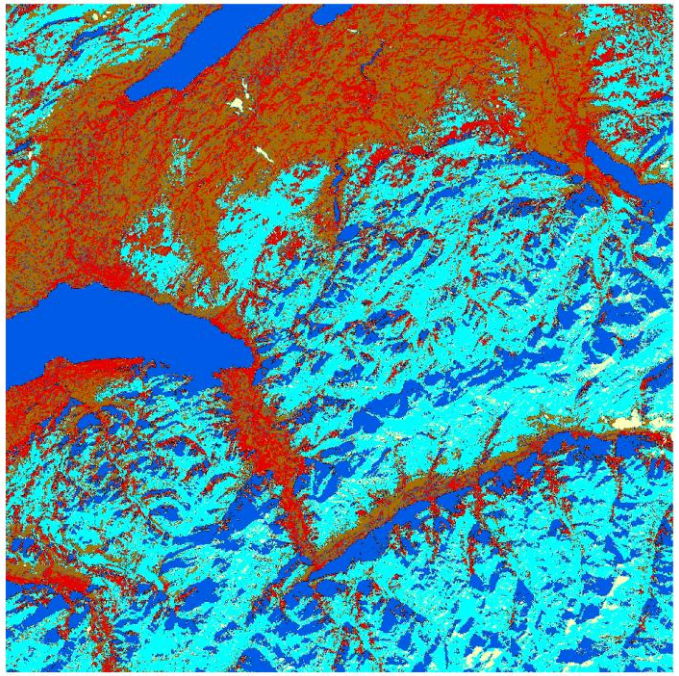
Sentinel 2 - T32TLS (15 Jan 2019)

Challenges in snow cover mapping at optical wavelengths

- **Slope-casted shadows**

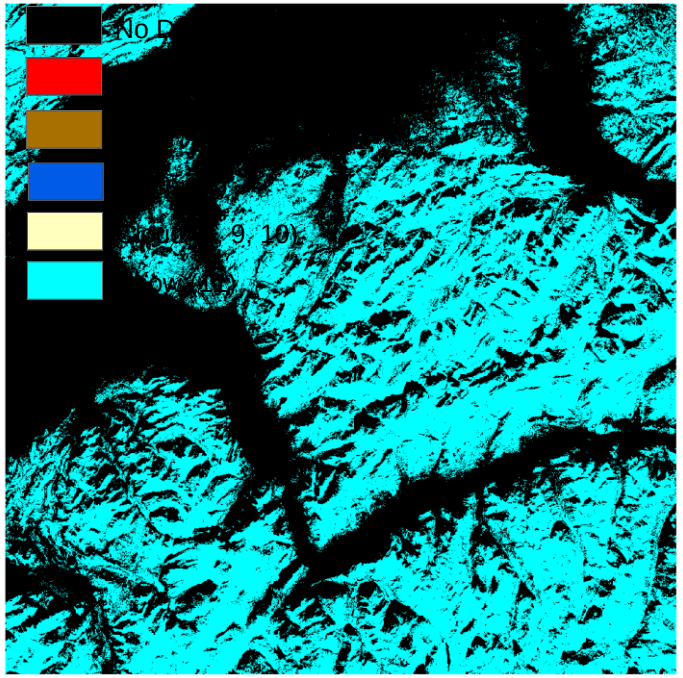


Sentinel 2 - T32TLS (15 Jan 2019)



Sen2Cor SCL (v2.11)





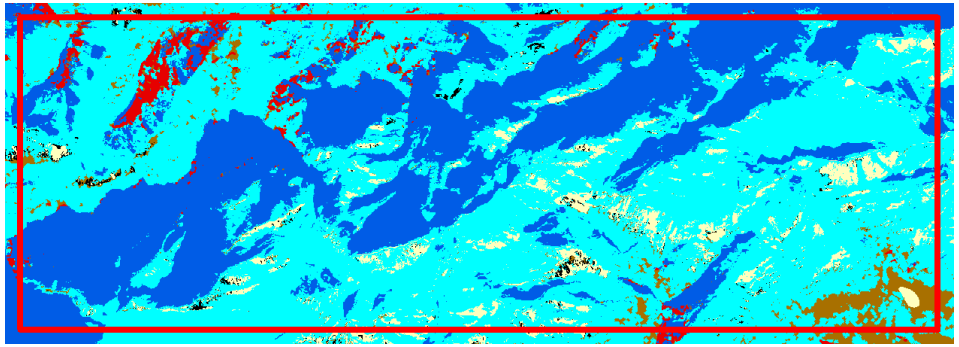
NDSI-based Binary Snow

Challenges in snow cover mapping at optical wavelengths

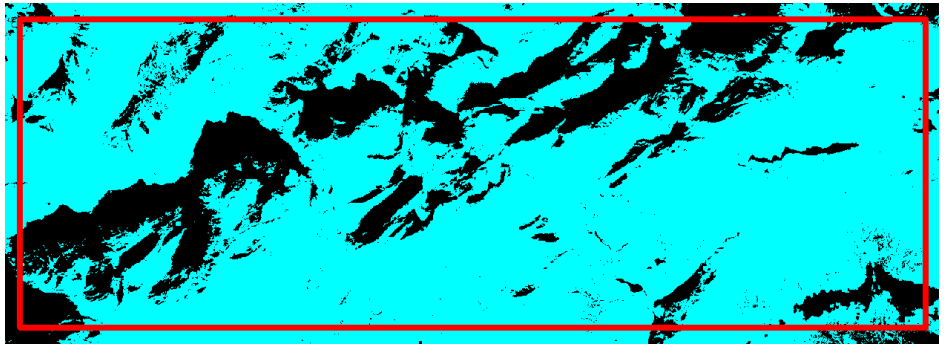
- **Slope-casted shadows**







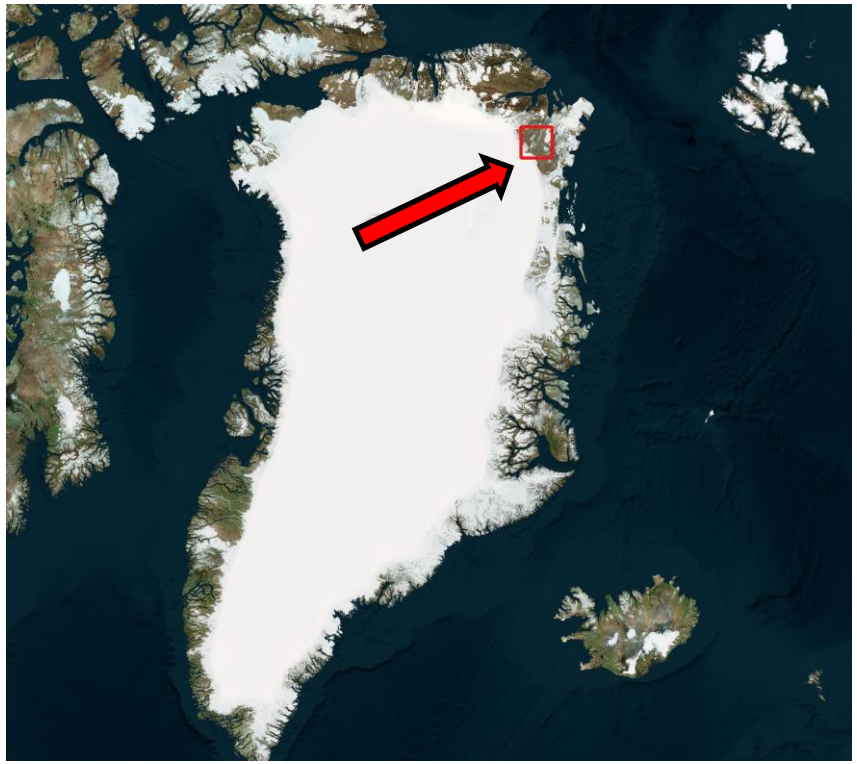
Sen2Cor SCL (v2.11)



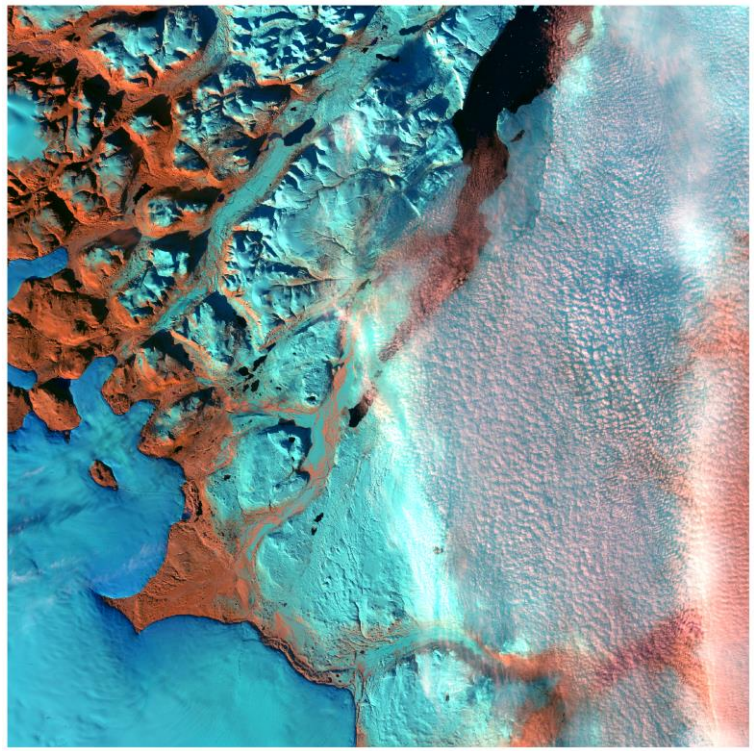
NDSI-based Binary Snow

Challenges in snow cover mapping at optical wavelengths

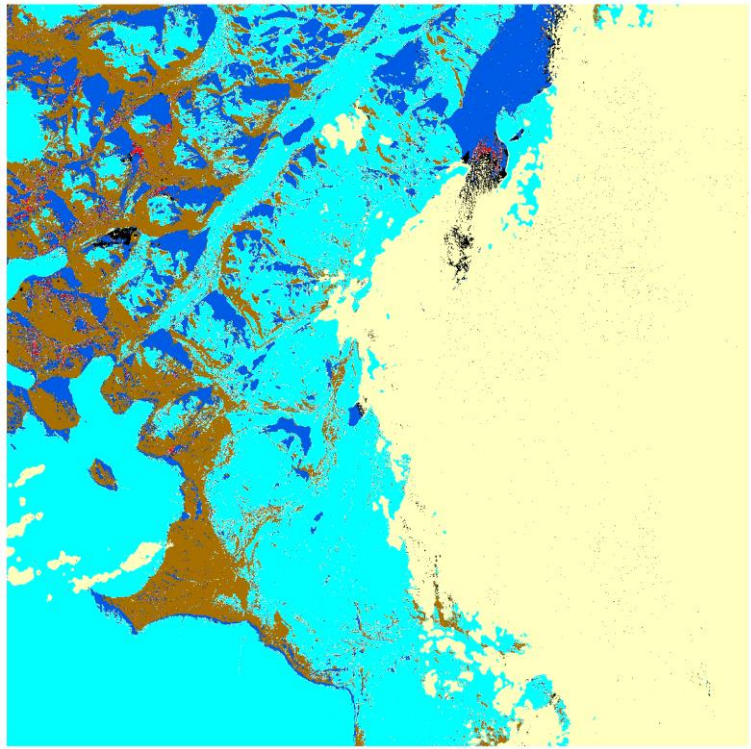
- **Cloud/snow confusion**



Sentinel 2 – T26XNQ



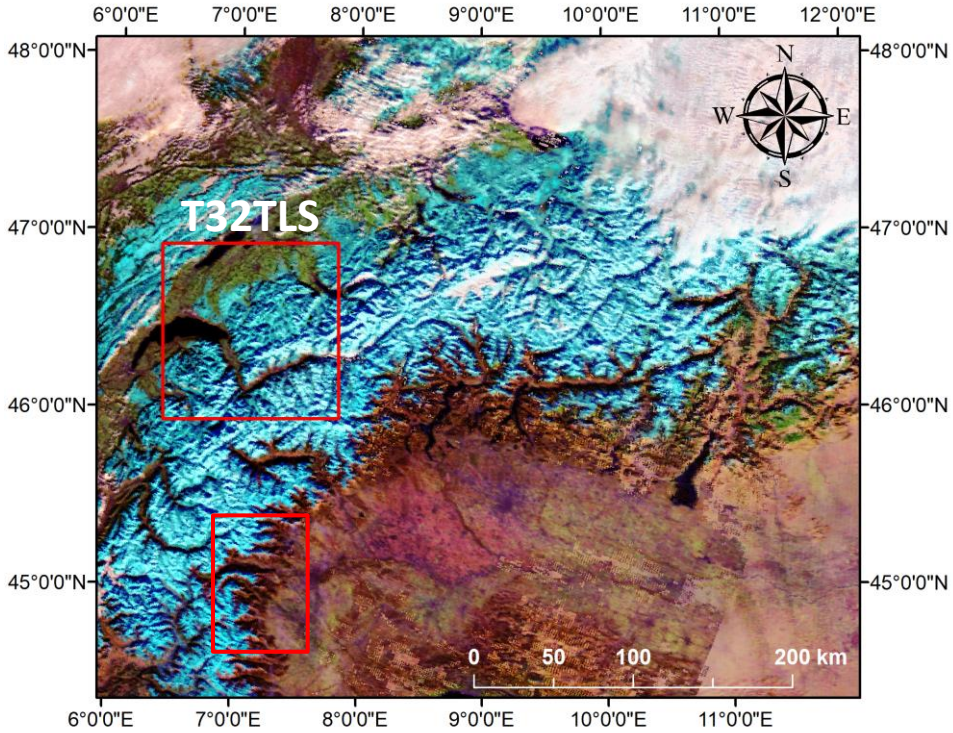
Sentinel 2 – T26XNQ (15 Sep 2020)



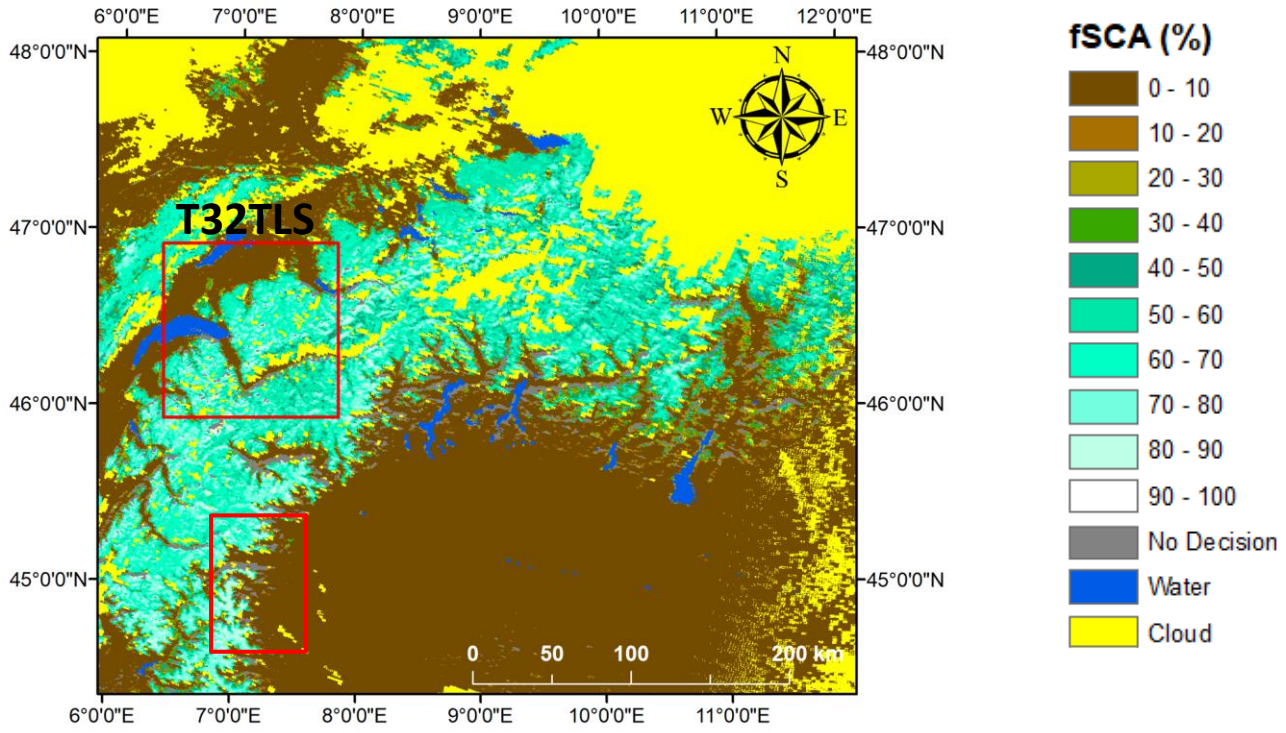
Sen2Cor v2.11

Challenges in snow cover mapping at optical wavelengths

- **Misclassification as cloud at the land/snow boundary**



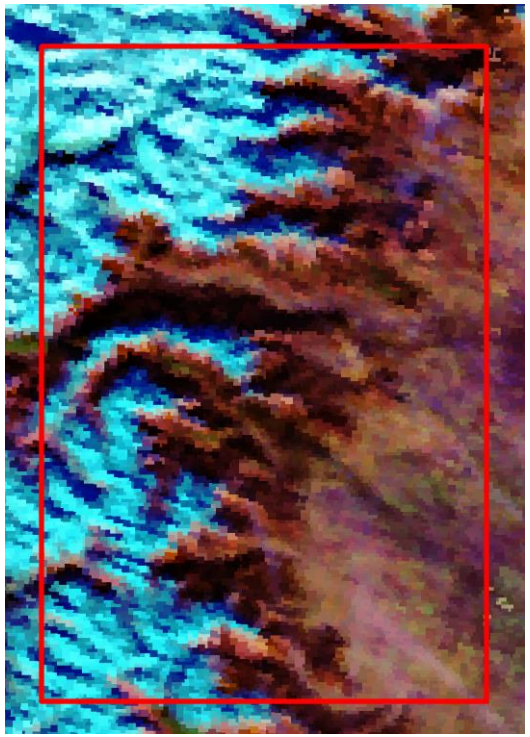
MOD09GA False RGB (15 Jan 2019)



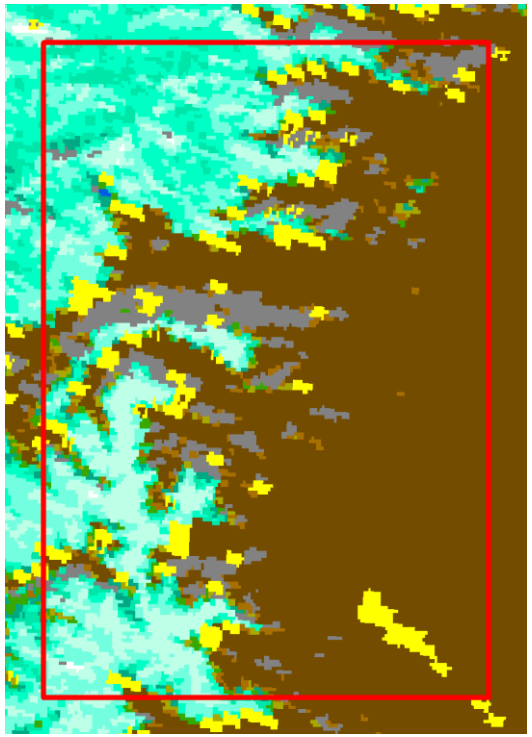
MOD10A1_061 fSCA (15 Jan 2019)

Challenges in snow cover mapping at optical wavelengths

- **Misclassification as cloud at the land/snow boundary**



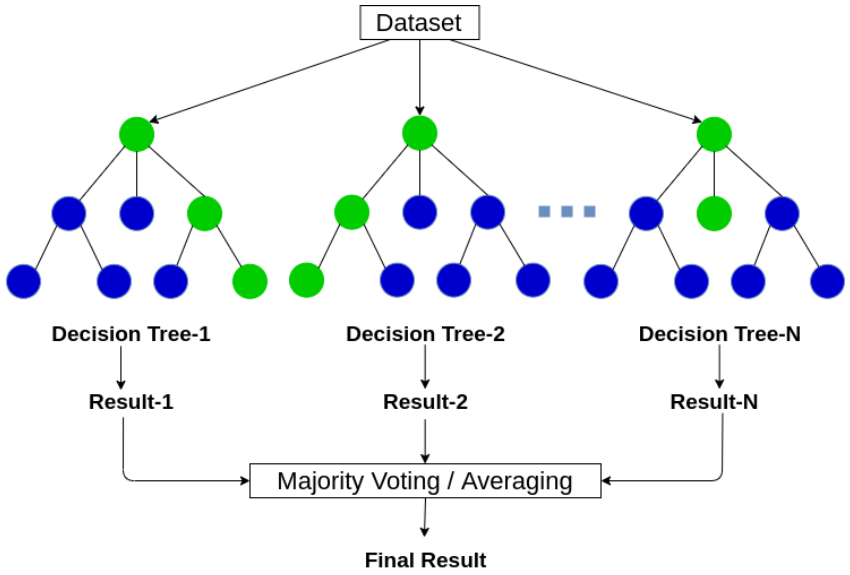
MOD09GA False RGB



MOD10A1_061 fSCA

Methods & Experimental Design

- **Machine Learning: Random Forests**



- by **Breiman (2001)**
- ensemble of CARTs

TOA vs. Atmo. & Topo. Corr. Reflectances

Input variable combination (i.e, Predictors)

Training sample size

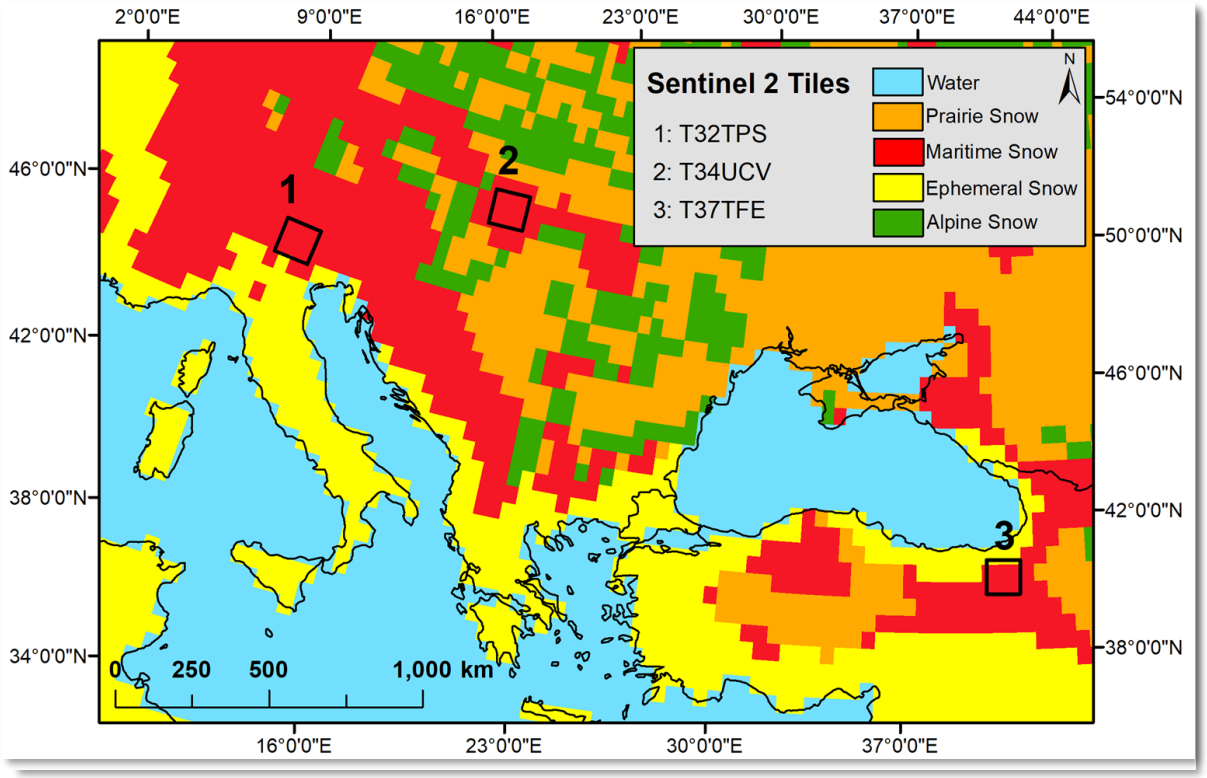
Pixel-based Classification by RF

- **Clear Sky - Land**
- **Cloud**
- **Snow**
- **Water**

- Kuter, S., Akyurek, Z., & Weber, G. W. (2018). Retrieval of fractional snow covered area from MODIS data by multivariate adaptive regression splines. *Remote Sensing of Environment*, 205, 236-252.
- Kuter, S. (2021). Completing the machine learning saga in fractional snow cover estimation from MODIS Terra reflectance data: Random forests versus support vector regression. *Remote Sensing of Environment*, 255, 112294

Methods & Experimental Design

- **Dataset**



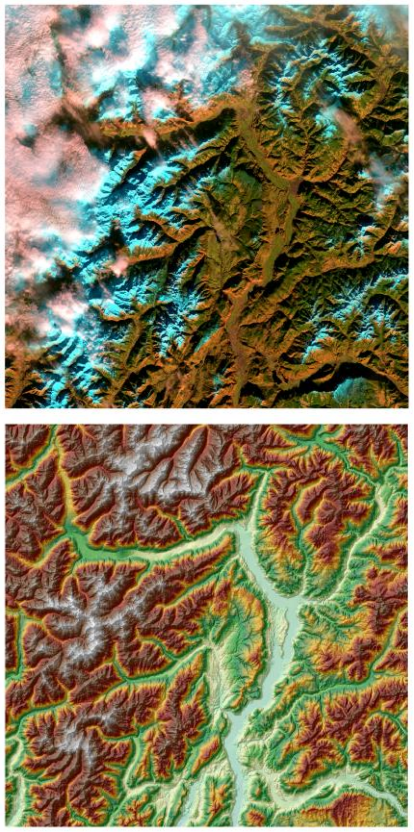
Snow cover types (Sturm *et al.*, 1995)

Location	Tile Number	Date of Acquisition
1- Alpine Region	T32TPS	5 December 2018
		24 January 2019
		13 June 2019
2- Tatra Mountains	T34UCV	29 November 2018
		23 January 2020
		8 April 2019
3- Kaçkar Mountains	T37TFE	19 December 2019
		19 March 2018
		8 April 2018

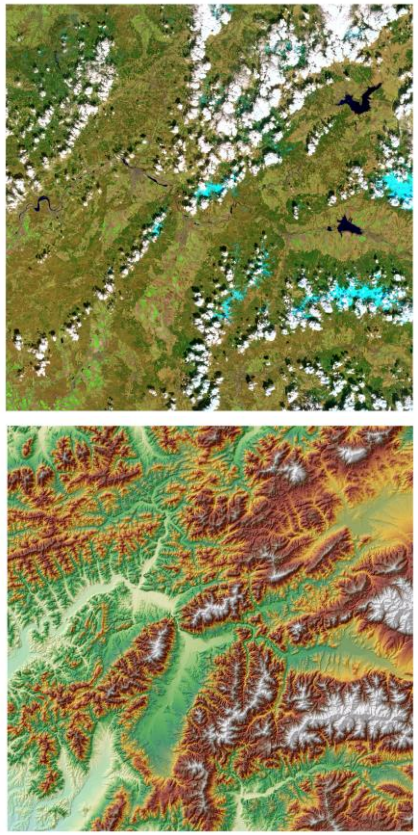
Methods & Experimental Design

- **Preprocessing**

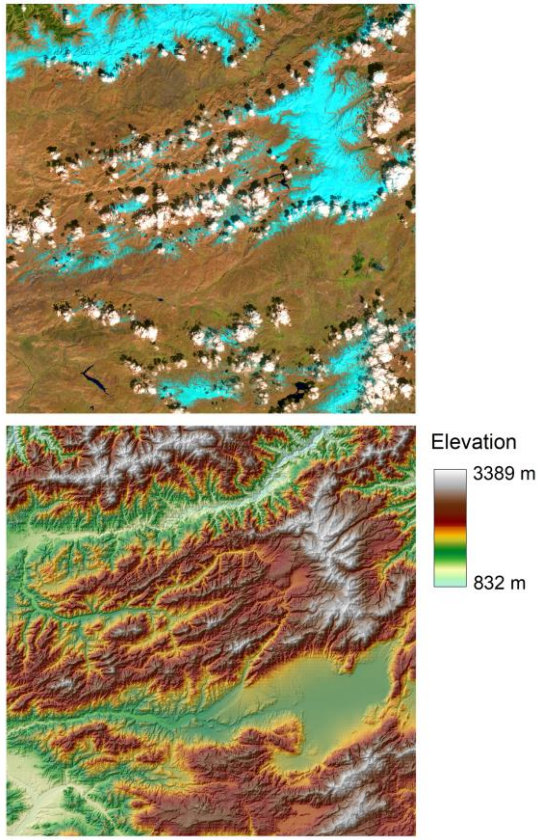
5 Dec 2018 - Alps



8 Apr 2019 - Tatra



8 Apr 2018 - Kaçkar



Sentinel-2A		
Band 1	0.430 – 0.458 µm	60 m
Band 2	0.447 – 0.545	10
Band 3	0.538 – 0.582	10
Band 4	0.645 – 0.683	10
Band 5	0.694 – 0.714	20
Band 6	0.731 – 0.749	20
Band 7	0.768 – 0.796	20
Band 8a	0.848 – 0.882	20
Band 8	0.763 – 0.907	10
Band 9	0.932 – 0.958	60
Band 10	1.336 – 1.412	60
Band 11	1.542 – 1.686	20
Band 12	2.081 – 2.323	20

10 m resampled to 20 m by Sen2Cor

Methods & Experimental Design

- **Preprocessing**

Reflectance values (20 m):
- TOA
- Atmo. & Topo. Corr. by Sen2Cor

Input Combinations:

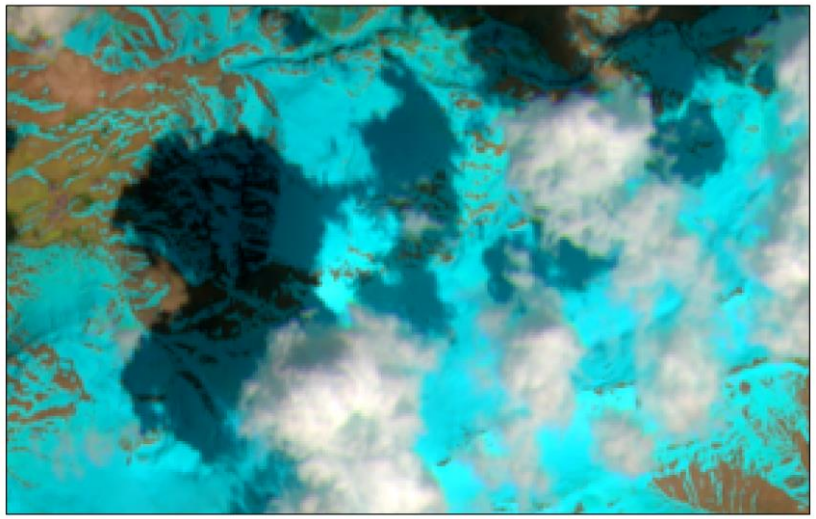
- **TOA:** Bands 2-7, 8a, 11, 12 + NDSI, NDVI, NDWI
- **Atmo. & Topo. Corr.:** Bands 2-7, 8a, 11, 12 + NDSI, NDVI, NDWI
- **DEM:** Bands 2-7, 8a, 11, 12 + NDSI, NDVI, NDWI, Elevation
- **PCA:** The first 3 PC bands of 9-band Sentinel 2 stack + NDSI, NDVI, NDWI

Training sample size:
- 300 per class (i.e., $n = 30p$)
- 1000 per class (i.e., $n = \sim 3 \times 30p$)

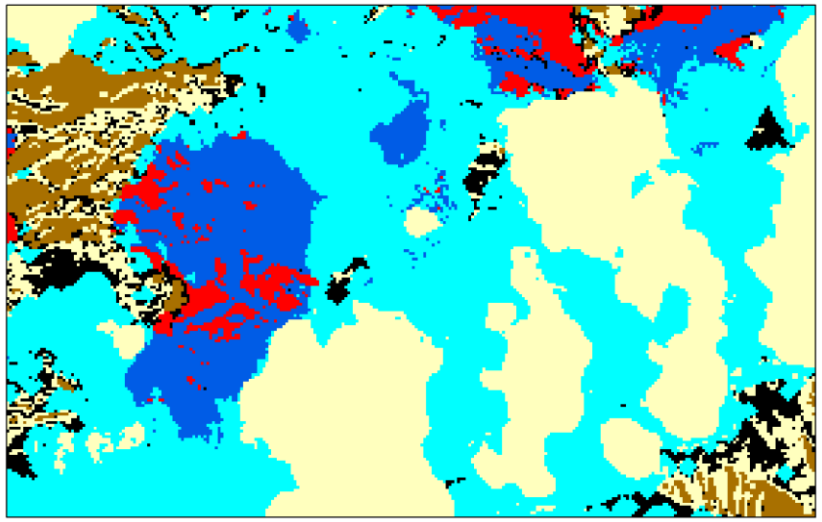
Close-up Visuals

- **8 Apr 2018 – Kaçkar T37TFE**

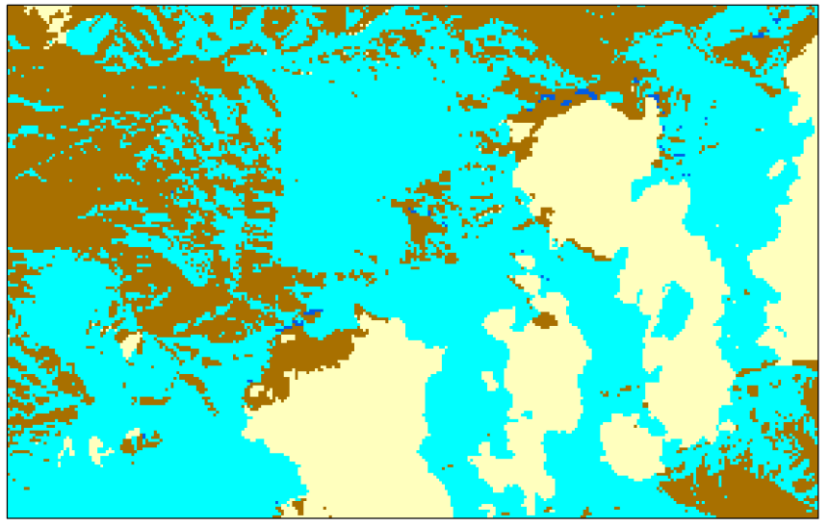
False RGB



Sen2Cor SCL



DEM 300

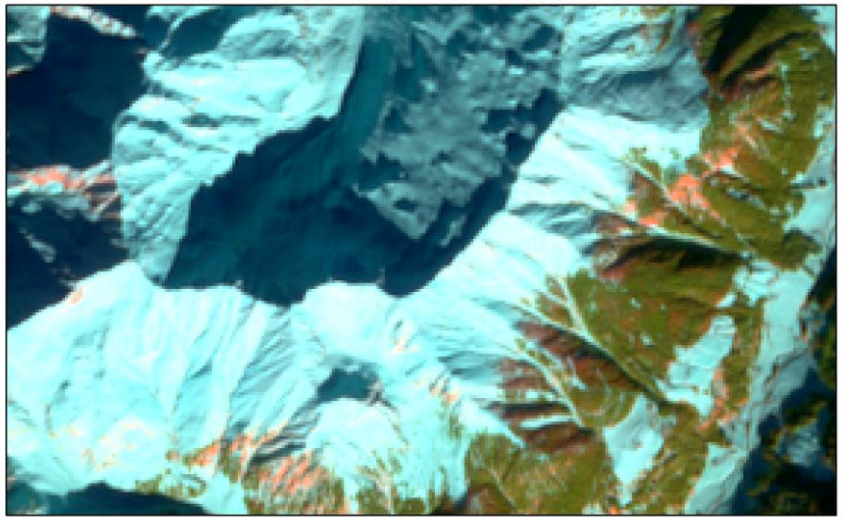




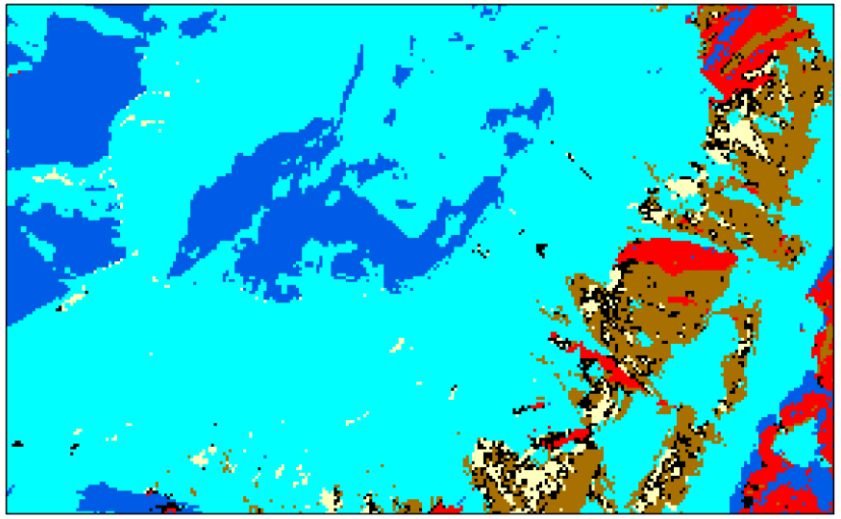
Close-up Visuals

- **24 Jan 2019 – Alps T32TPS**

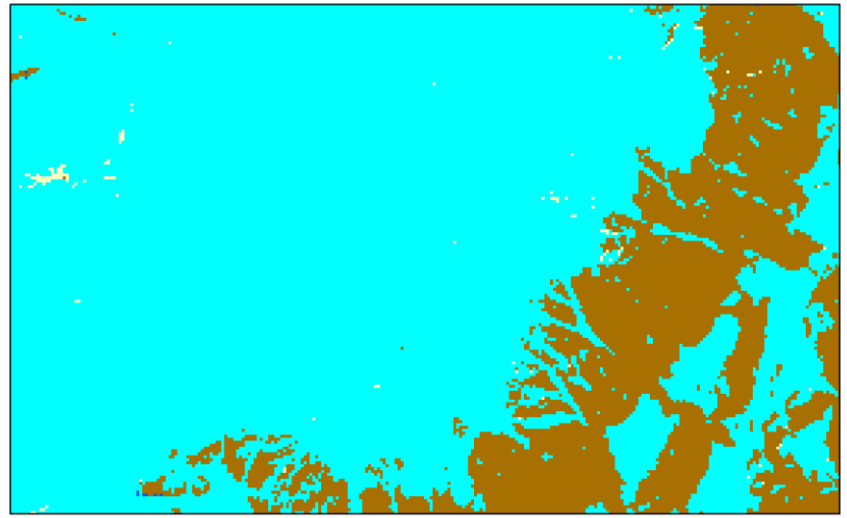
False RGB



Sen2Cor SCL



Atmospheric Correction

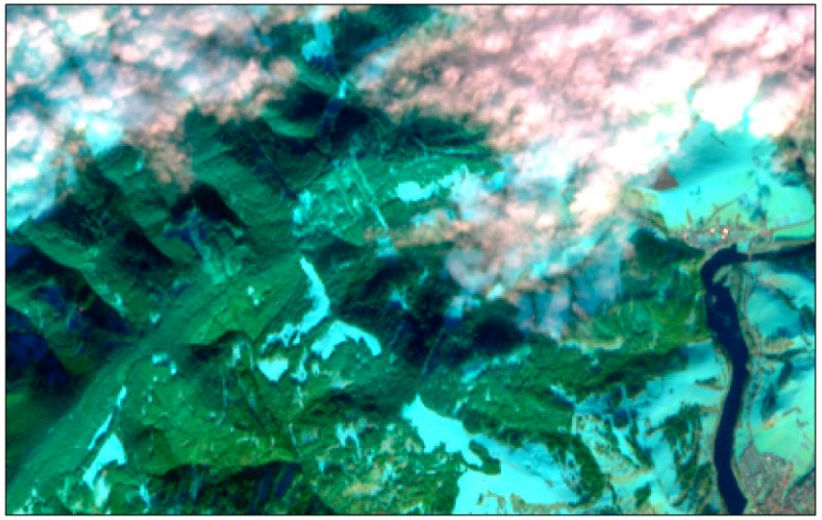


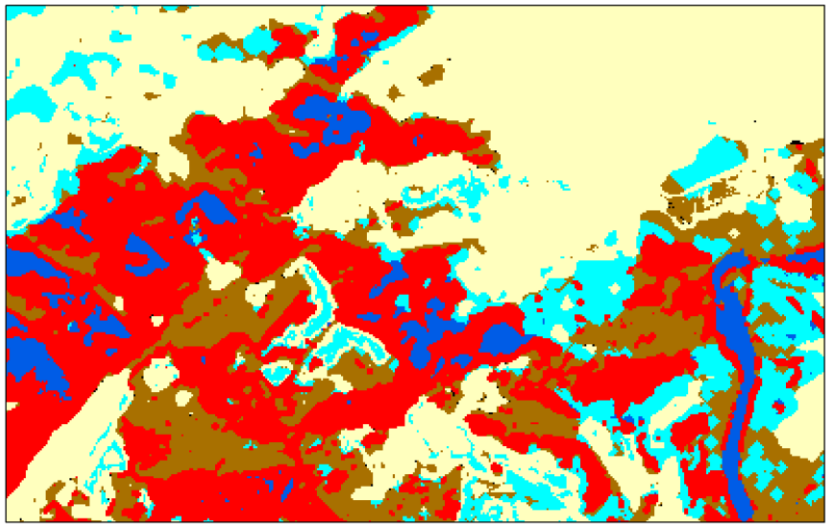


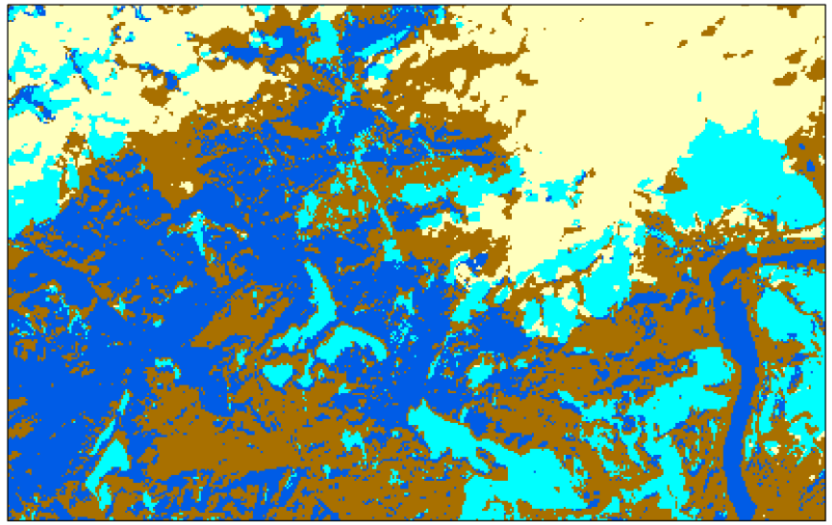
Close-up Visuals

- **29 Nov 2019 – Tatra T34UCV**

False RGB



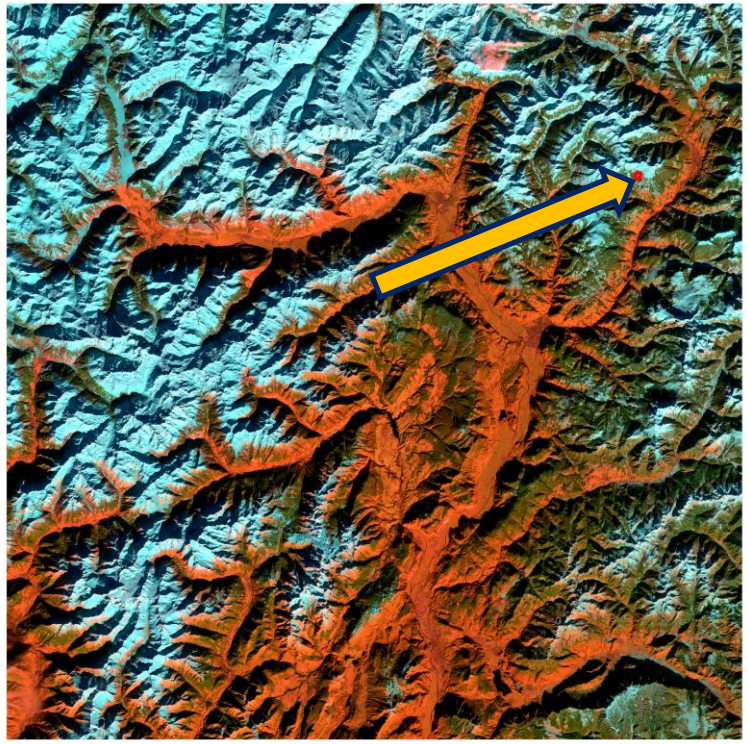




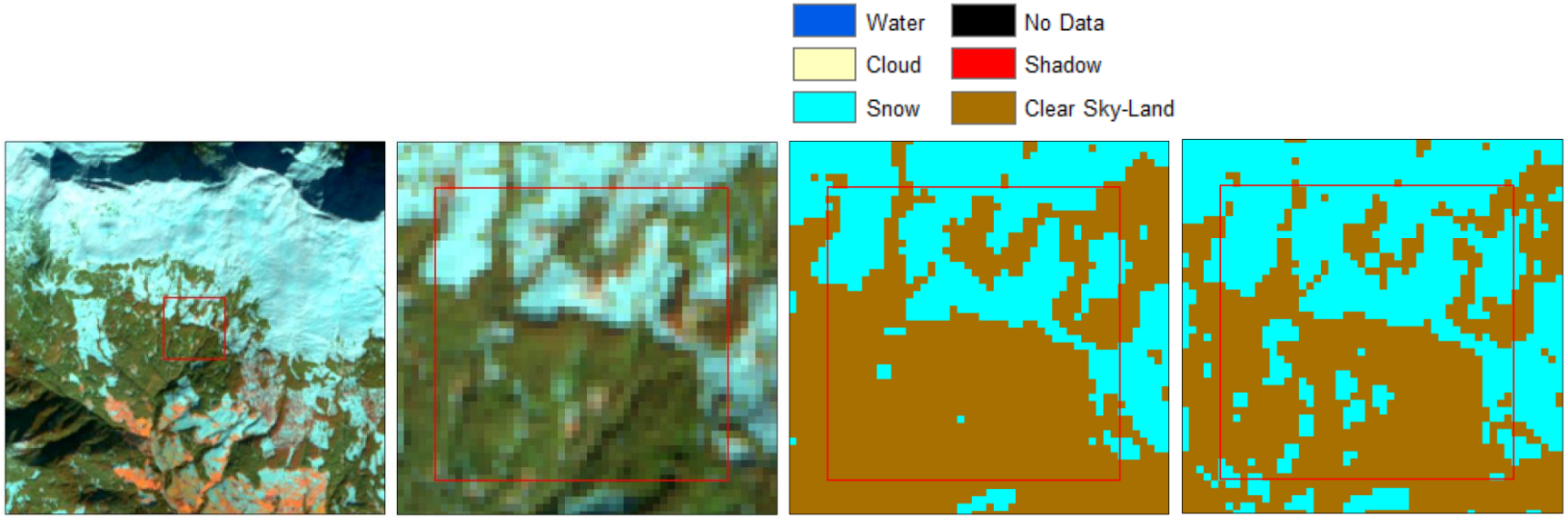


Close-up Visuals

- **Snow under the canopy: 24 Jan 2019 – Alps T32TPS**



False RGB



PCA_1000

HR-S&I FSCOG

Copernicus High Resolution Snow and Ice Monitoring

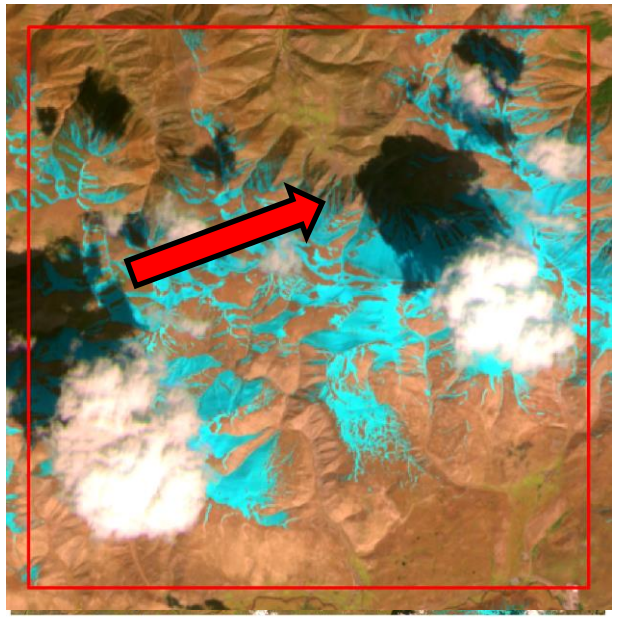
https://land.copernicus.eu/pan-european/biophysical-parameters/high-resolution-snow-and-ice-monitoring

Close-up Visuals

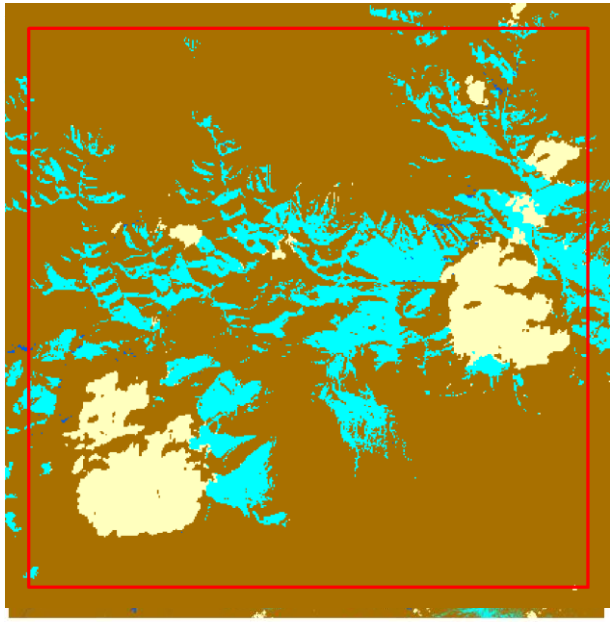
- **HR-S&I FSC: 8 Apr 2018 – Kaçkar T37TFE**

Water
Cloud
Snow
No Data
Shadow
Clear Sky-Land

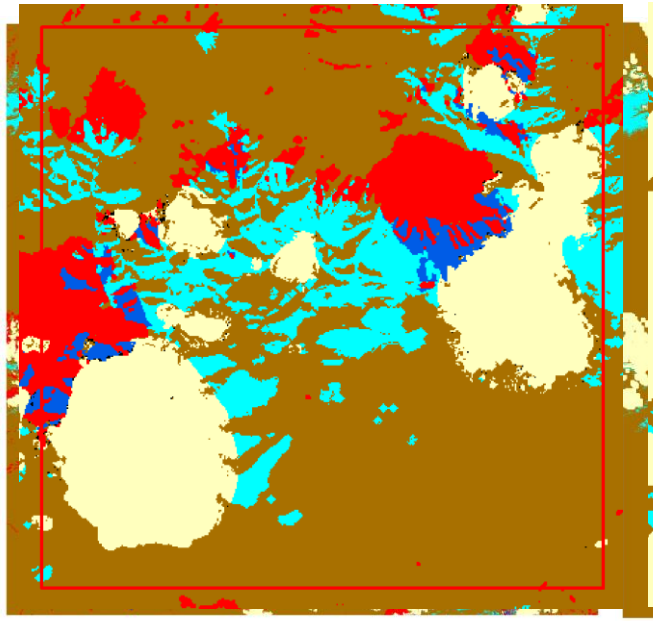
Cloud/Cloud Shadow by MAJA Processor



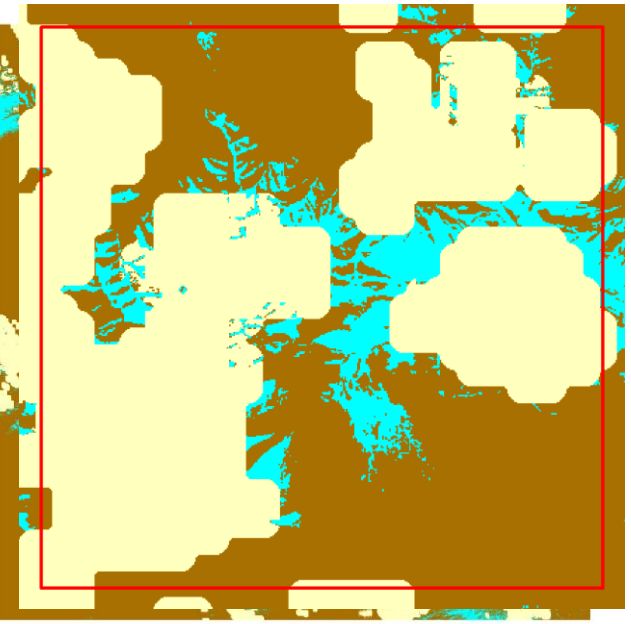
False RGB



PCA_1000



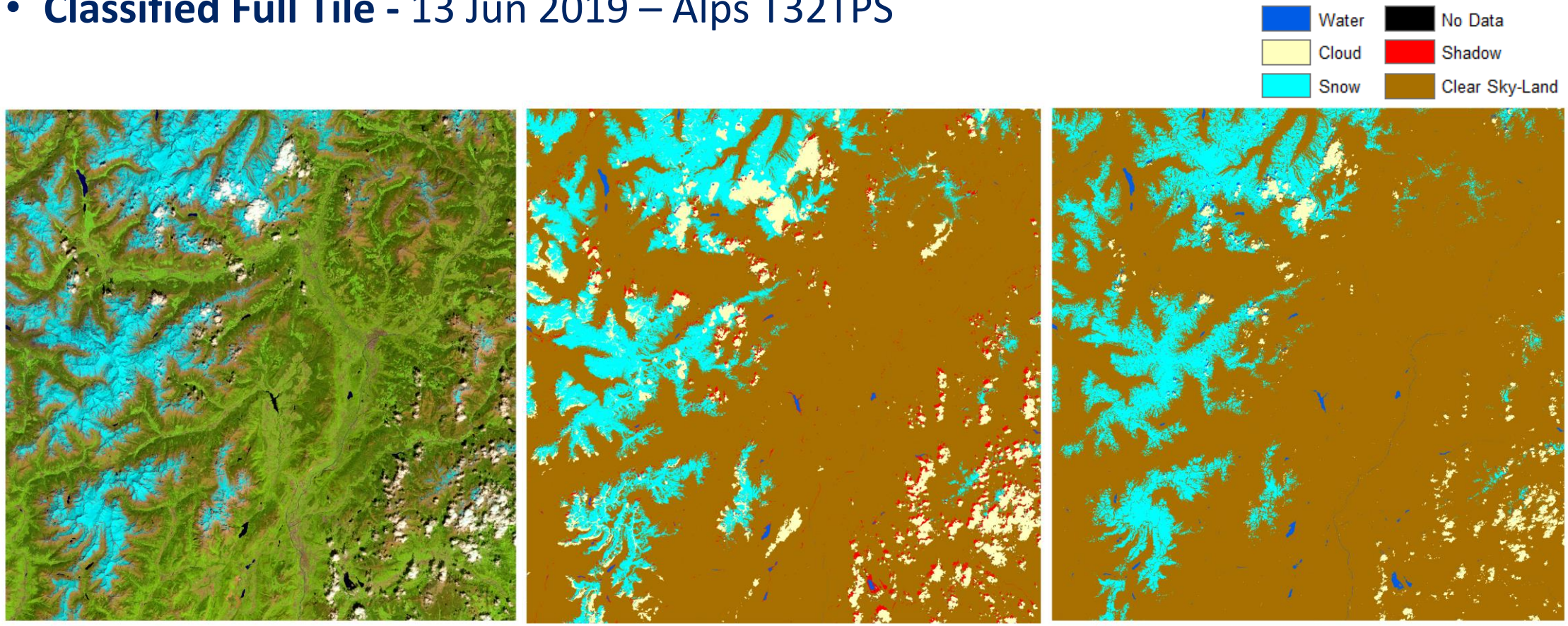
Sen2Cor v2.11



HR-S&I FSC0G

Close-up Visuals

- **Classified Full Tile -** 13 Jun 2019 – Alps T32TPS



False RGB

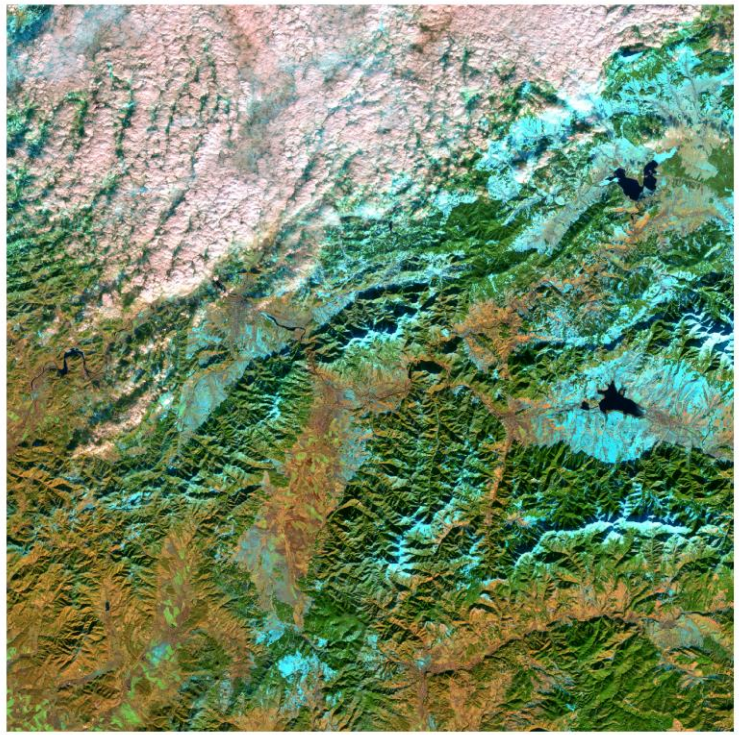
Sen2Cor v2.11

PCA_1000

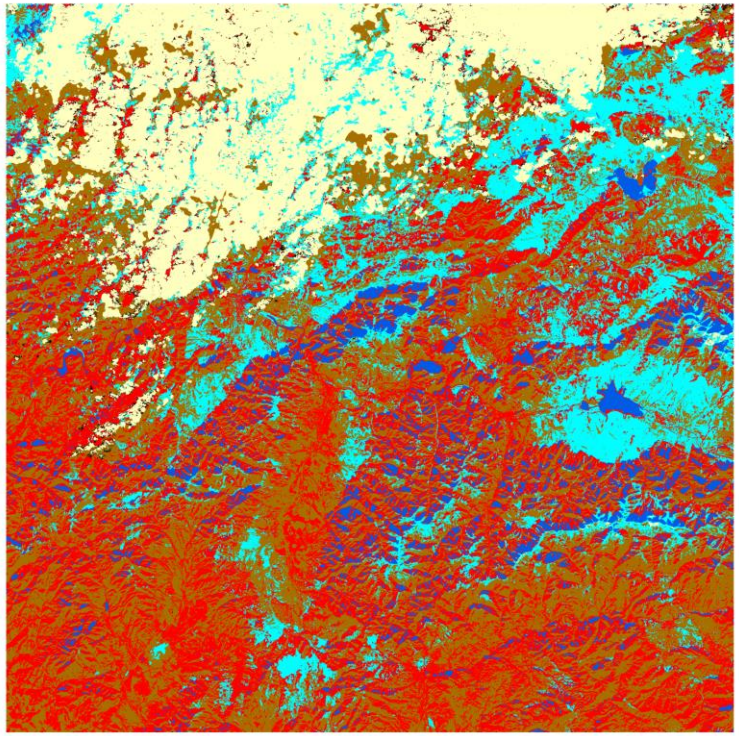
Close-up Visuals

- **Classified Full Tile -** 23 Jan 2020 – Tatra T34UCV

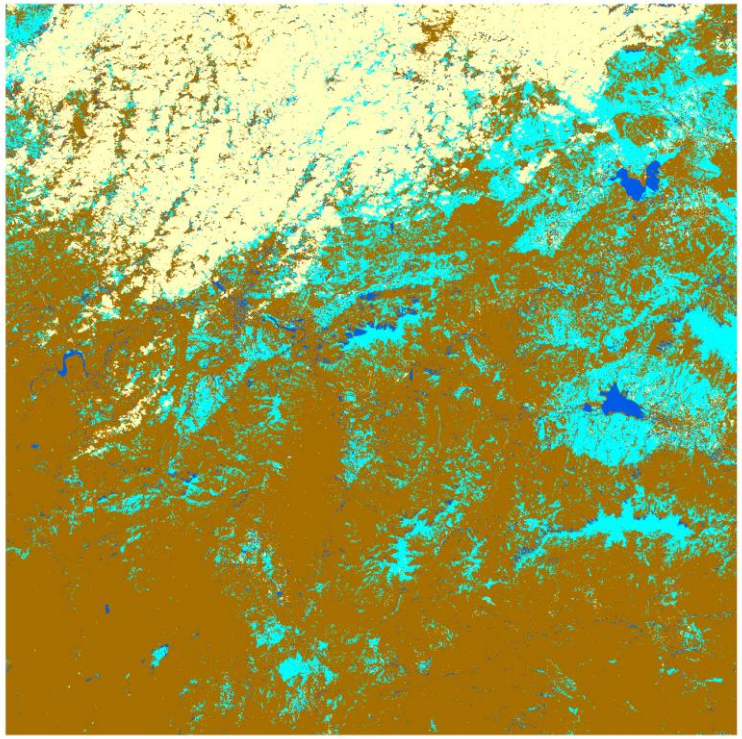




False RGB



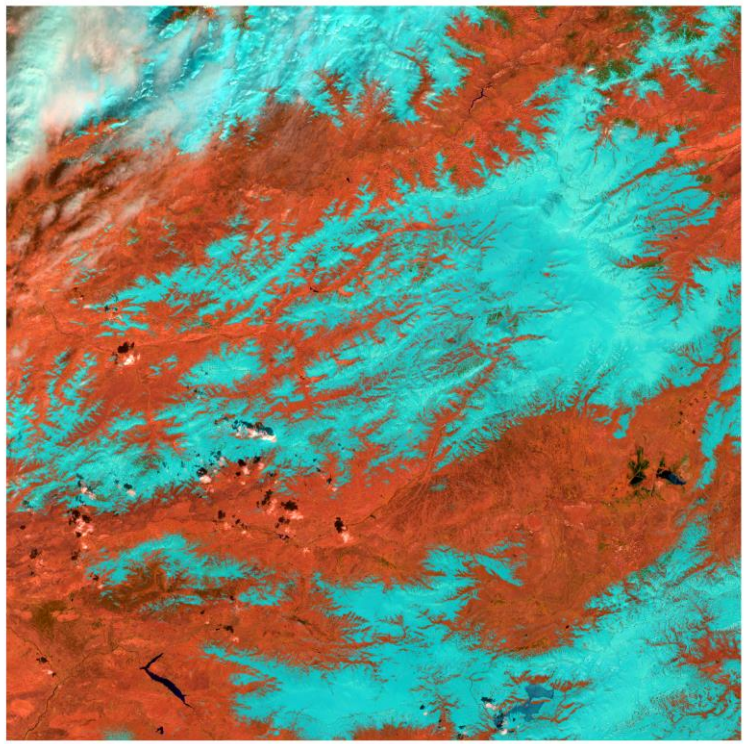
Sen2Cor v2.11



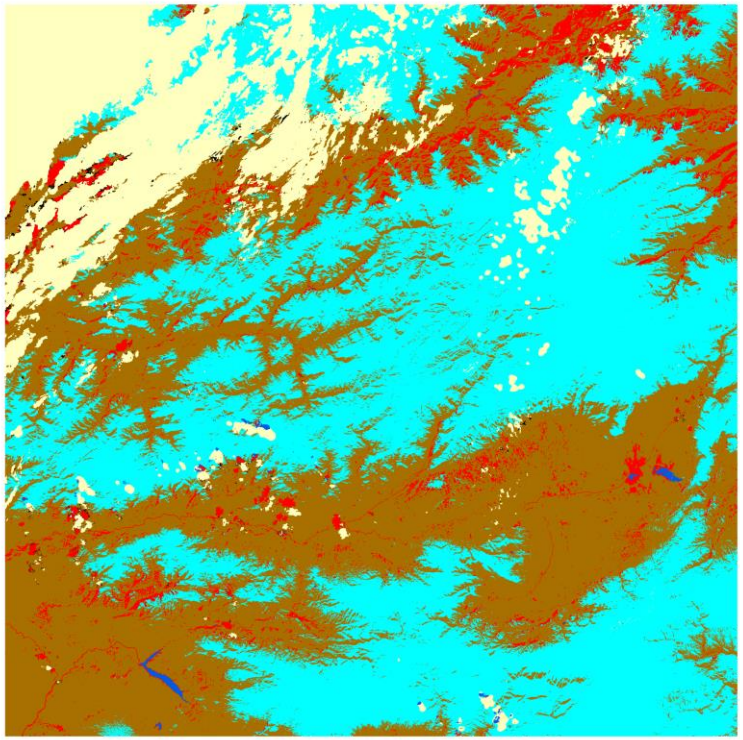
PCA_1000

Close-up Visuals

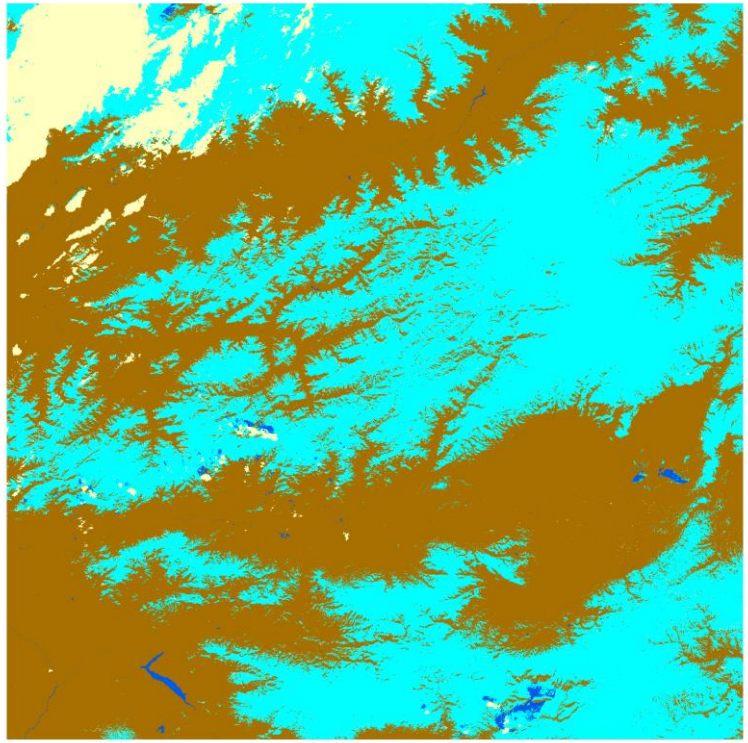
- **Classified Full Tile -** 19 Mar 2018 – Kaçkar T37TFE



False RGB



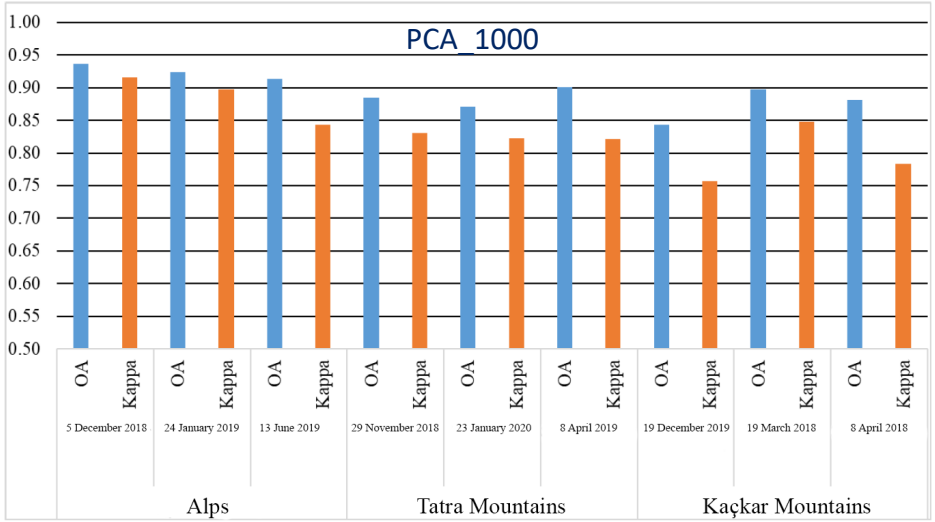
Sen2Cor v2.11



PCA_1000

Conclusions & Future Directions

- **Improvements with RF:**
  - Atmo./Topo. corrected spectral bands
  - PCA with increased number of training samples
  - Snow classification over cloud/slope-casted shadows
  - Cloud labeled pixels at land/snow boundary



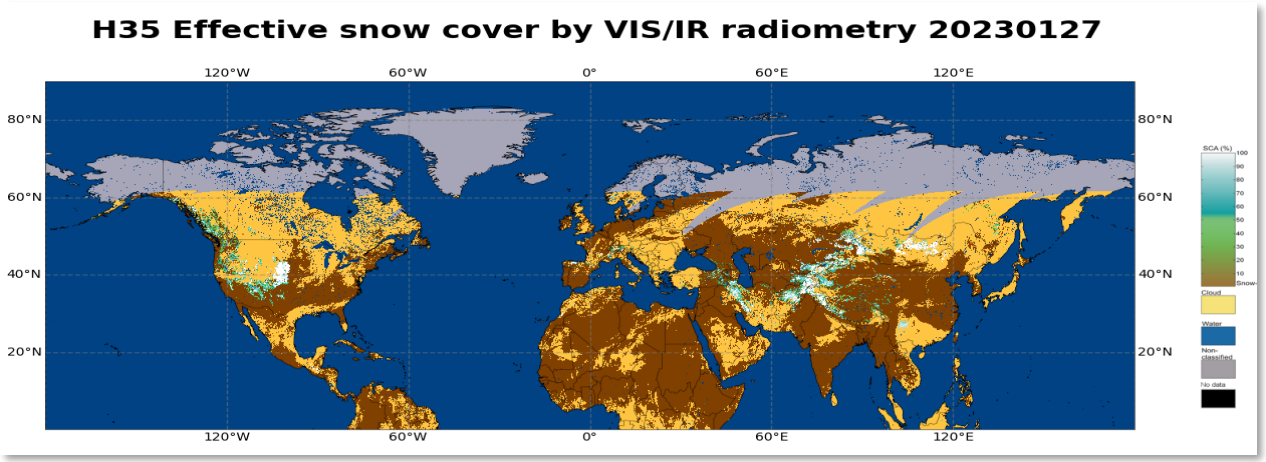
- **Points need clarification/improvement:**
  - Tatra case with PC bands
  - RF on other snow cover types
  - Underestimation of snow over forested areas





Conclusions & Future Directions

- **EUMETSAT H SAF H35 Effective Snow Cover Product**
  - **Improvement over Forested Mountainous Regions by AI/DL**
  - **H SAF AS/VS Activity**
    - **Status: Temporary**
    - **Anticipated Start Date: 1 Aug 2023**
    - **Anticipated End Date: 29 Feb 2024**
    - **Salary: The net amount will be set by EU**
    - **Contact: zakyurek@metu.edu.tr**



- Kuter, S., Bolat, K., & Akyurek, Z. (2022). A machine learning-based accuracy enhancement on EUMETSAT H-SAF H35 effective snow-covered area product. *Remote Sensing of Environment*, 272, 112947

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SUPPORT TO OPERATIONAL HYDROLOGY AND WATER MANAGEMENT

Thank You...



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Challenges in snow cover mapping at optical wavelengths

- **Overall Accuracies**

