Improvement on EUMETSAT H-SAF H35 Effective Snow-Covered Area Product by Multivariate Adaptive Regression Splines

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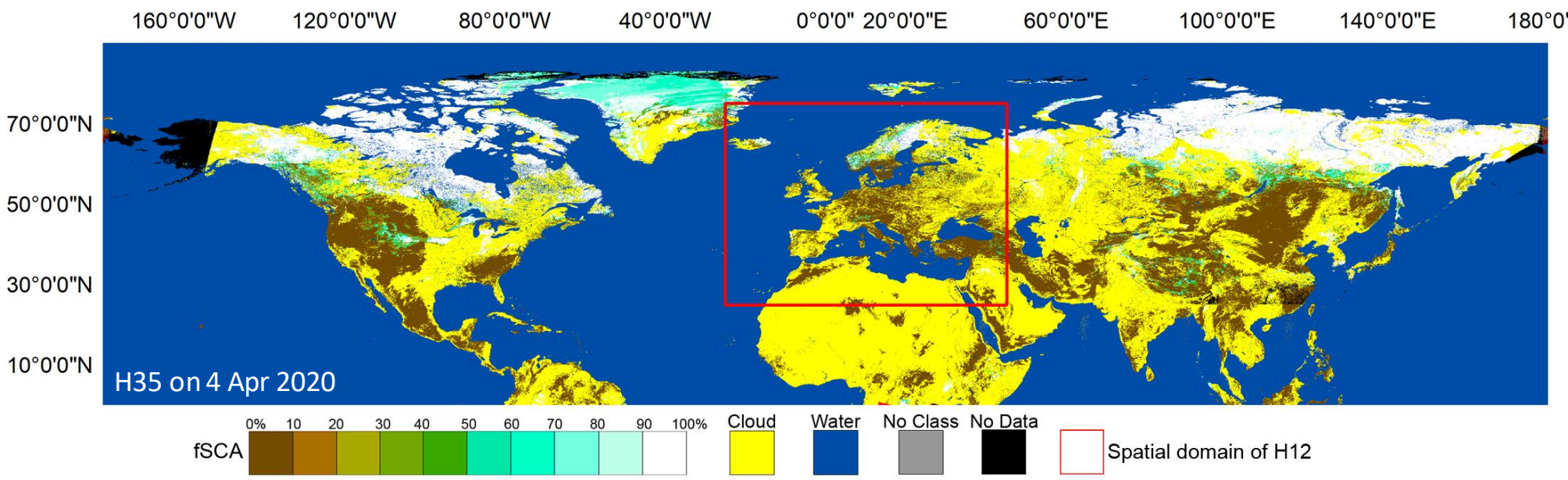
Improvement on EUMETSAT H-SAF H35 by MARS

- Pre-operational **H35 (SN-OBS-1P)** daily fractional snow-covered area (fSCA) product is developed within the frame of H-SAF. It is based on **traditional VIS/IR radiometry**.

- **Cycle:** Daily
- **Coverage:** Northern Hemisphere
- **Grid/Projection:** EPSG 4326 (Lat/Lon Grid)
- **Resolution:** 0.01 ° x 0.01 ° (~1 km)
- **Formats:** gzip compressed GRIB2

Product digital pixel coding:
- [0, 100]: Ground - fSCA
- 101: Cloud
- 102: Sea/Water
- 104: Dark
- 105: No Data



A full disk H35 product: An image of **8,999** rows by **35,999** columns (i.e., **324M** pixels approximately)

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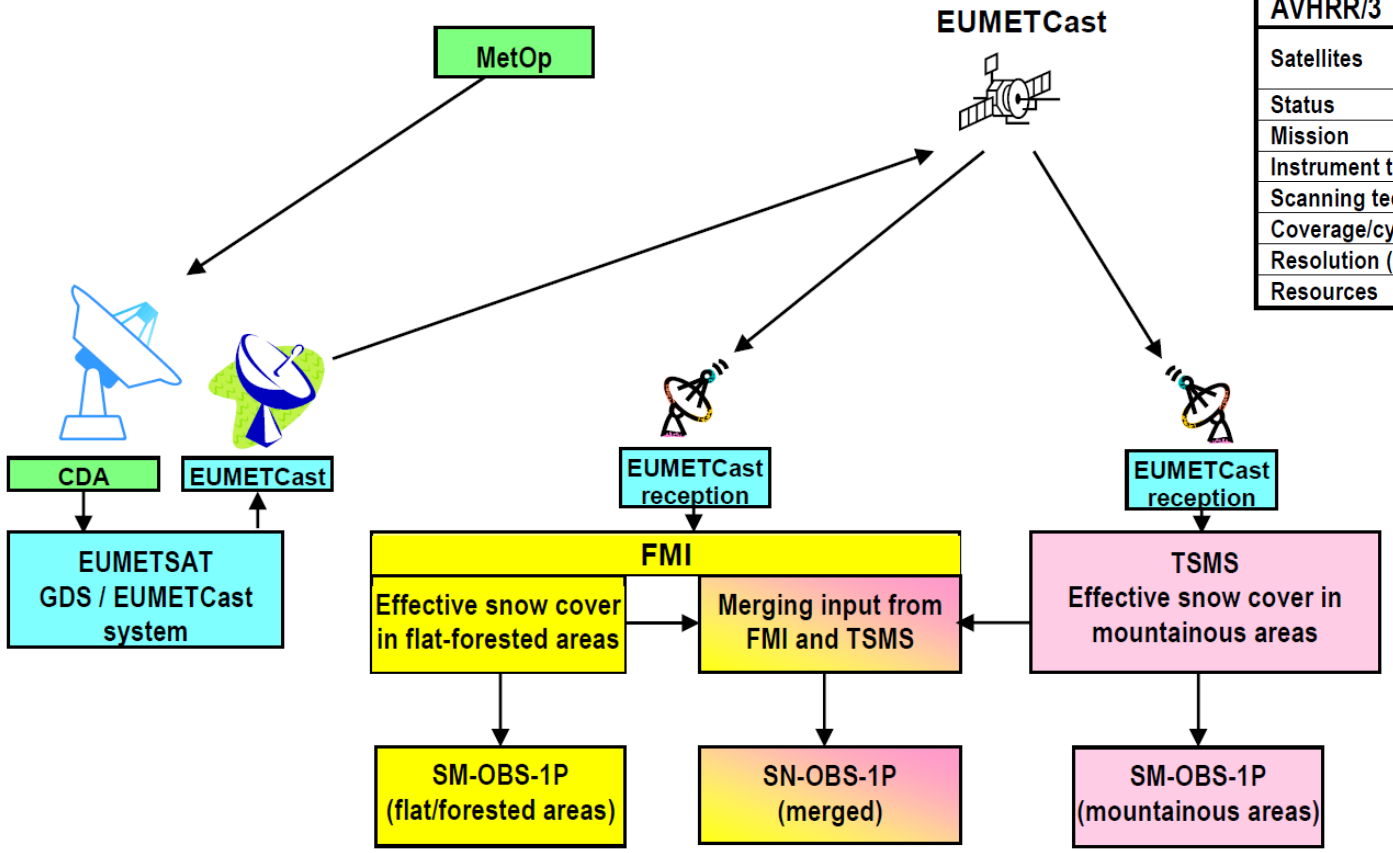
- Architecture of the H35 product generation chain



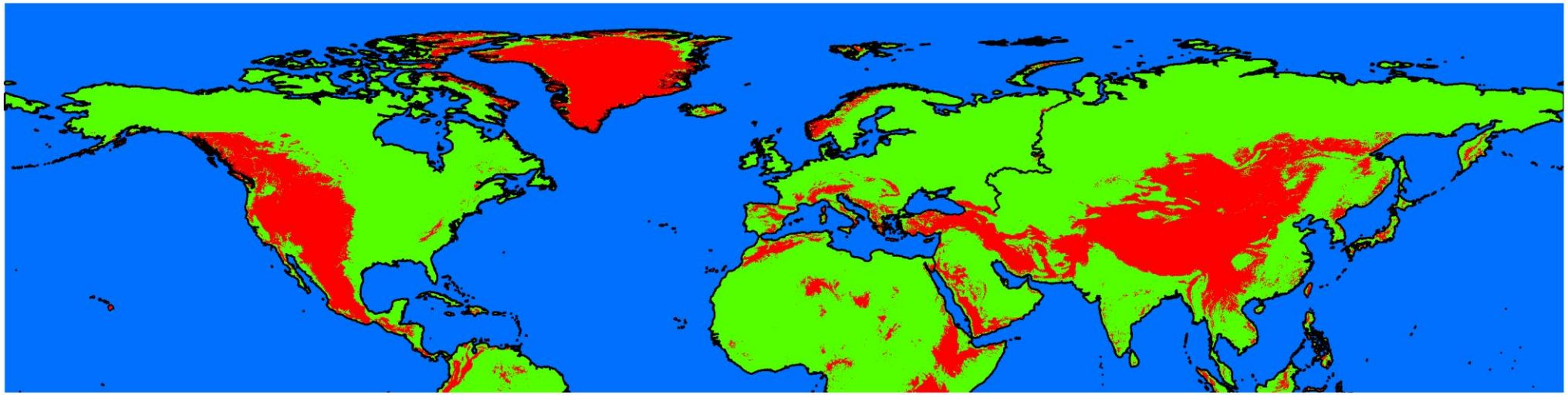
AVHRR/3	Advanced Very High Resolution Radiometer / 3
Satellites	TIROS-N, NOAA 6 to 14, NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-19, MetOp-A, MetOp-B, MetOp-C
Status	**Operational** - Utilisation period: 1978 to ~ 2014 on NOAA, 2006 to ~ 2024 on MetOp
Mission	Multi-purpose imagery
Instrument type	Multi-purpose imaging VIS/IR radiometer - 6 channels (channel 1.6 and 3.7 alternative)
Scanning technique	Cross-track: 2048 pixel of 800 m s.s.p., swath 2900 km - Along-track: six 1.1-km lines/s
Coverage/cycle	Global coverage twice/day (IR) or once/day (VIS)
Resolution (s.s.p.)	1.1 km IFOV
Resources	Mass: 33 kg - Power: 27 W - Data rate: 621.3 kbps

AVHRR/3 Spectral Bands (µm)	
	Band 1 : 0.580-0.680
	Band 2 : 0.725-1.000
	Band 3a : 1.580-1.640
	Band 3b : 3.550-3.930
	Band 4 : 10.300-11.300
	Band 5 : 11.500-12.500

AVHRR Handbook

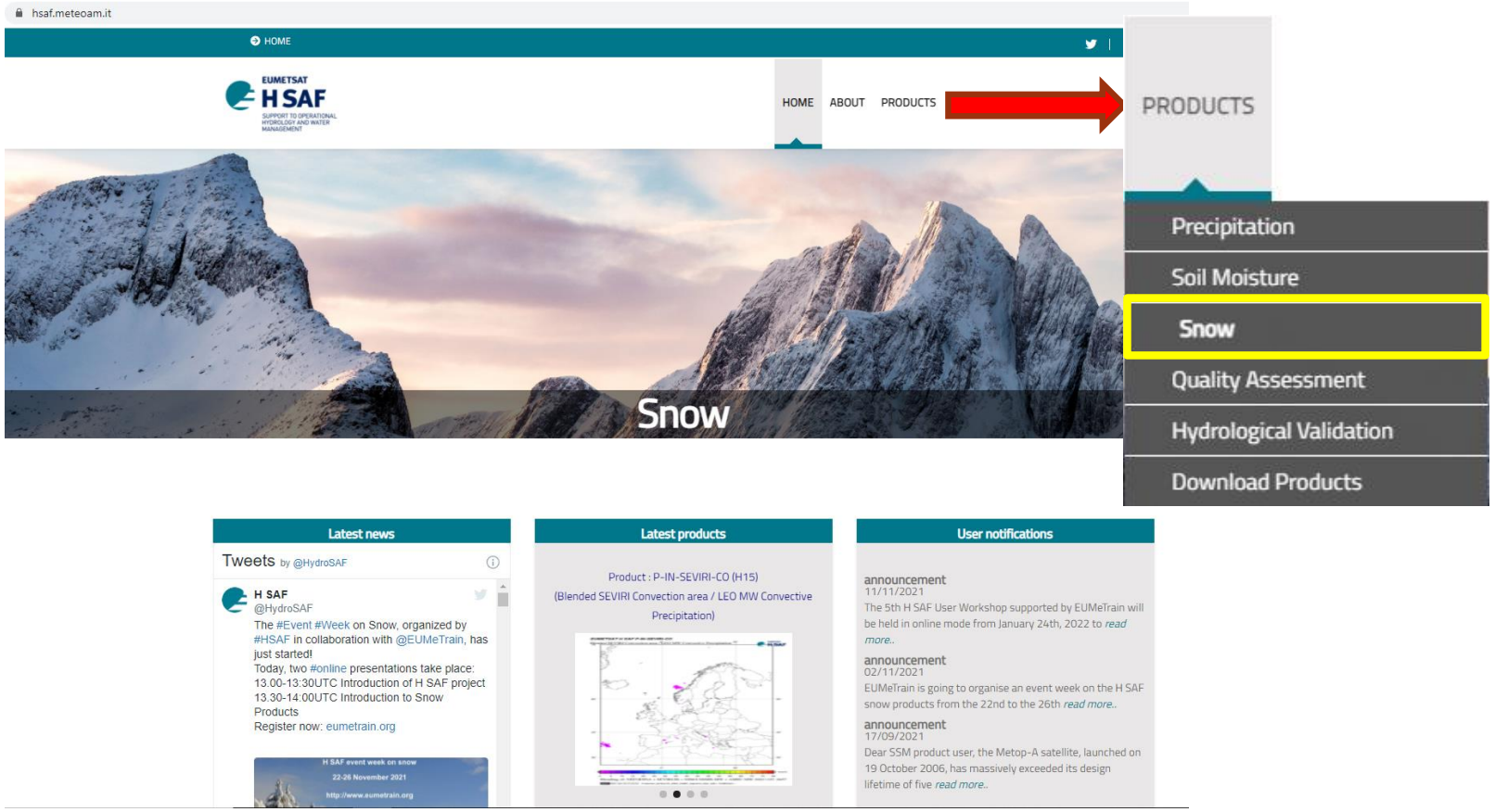
Improvement on EUMETSAT H-SAF H35 by MARS

- **Flat/Forested vs Mountainous Areas**



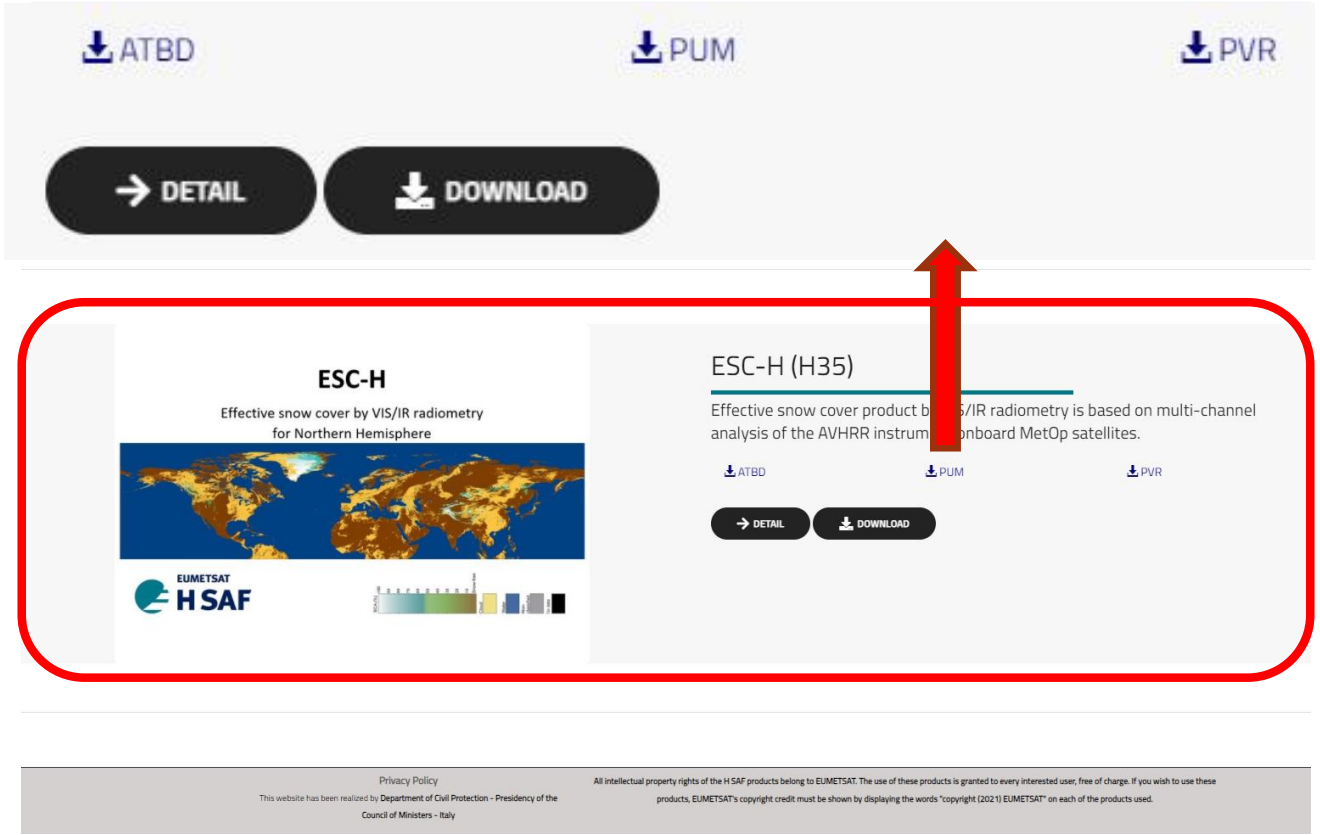
Improvement on EUMETSAT H-SAF H35 by MARS

- H-SAF Snow Products Web Page: https://hsaf.meteoam.it/



Improvement on EUMETSAT H-SAF H35 by MARS

- H-SAF Snow Products Web Page: https://hsaf.meteoam.it/

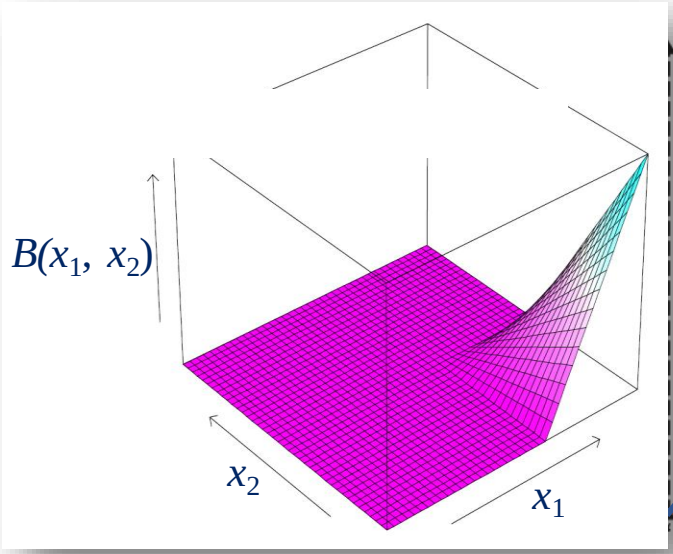


Improvement on EUMETSAT H-SAF H35 by MARS

- **H_AVS18_03: Implementation of Machine Learning on H35**

  – ***Multivariate Adaptive Regression Splines*** (**MARS**) (Friedman, 1991)

In **MARS**, one-dimensional piecewise linear ***basis functions*** (**BFs**) are used to define relationships between a response variable and a set of predictors. It is a powerful nonparametric adaptive regression procedure, suitable for solving high-dimensional and complex problems.

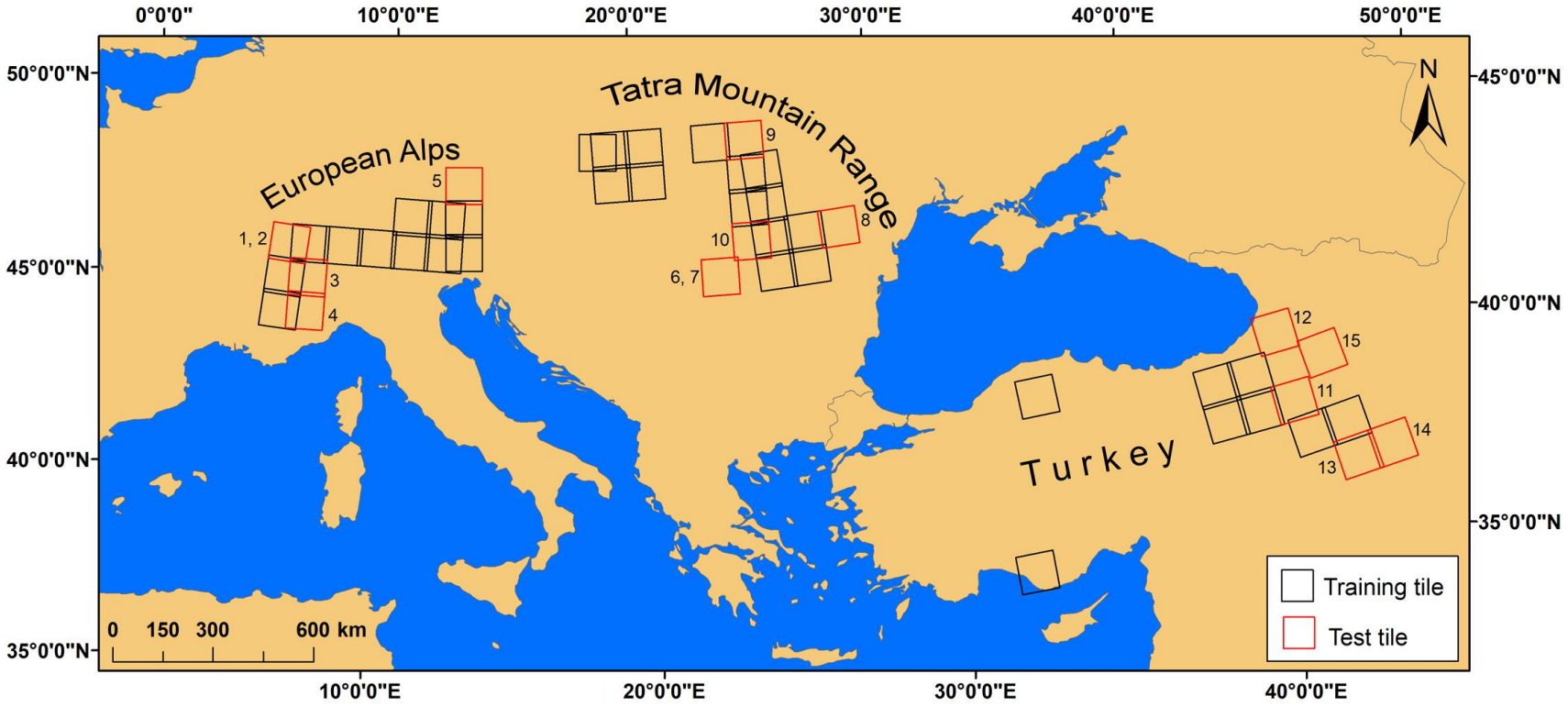


$B(x_1, x_2) = [x_1\text{-}t_1]_+ \cdot [t_2\text{-}x_2]_+$ generated by the **multiplication of two piecewise linear BFs** of MARS (Hastie et al., 2009).

- **Kuter, S.**, **Akyurek, Z. and 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.

Improvement on EUMETSAT H-SAF H35 by MARS

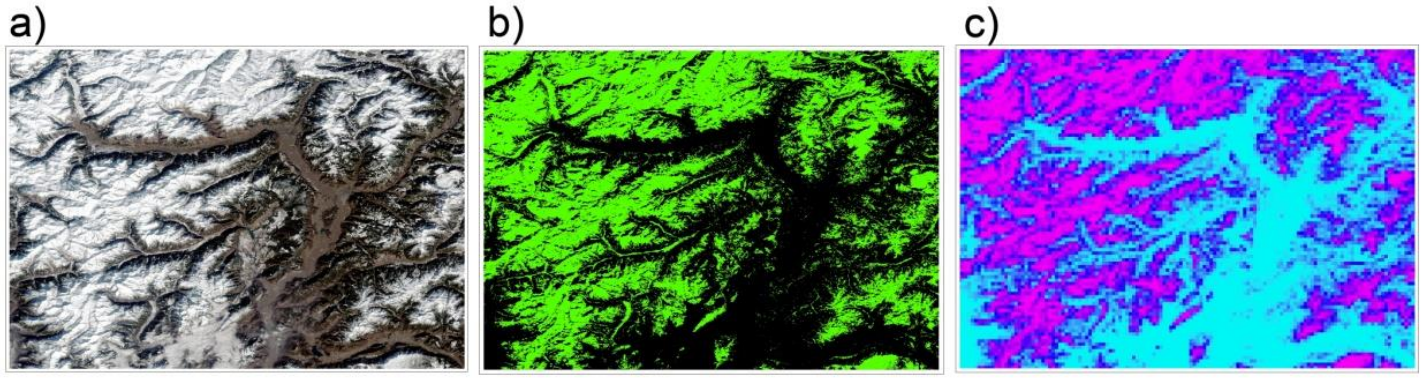
- **Reference data from higher resolution Sentinel 2 imagery**
  - Over **European Alps**, **Tatra Mountains** and **Turkey**



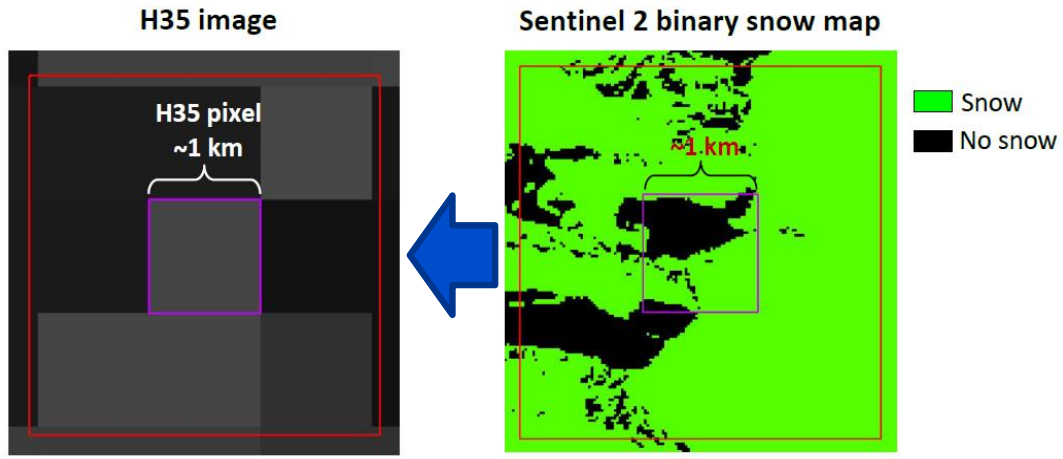
- Sentinel 2 imagery
- 332 images for Model Training
- 15 images for Initial Test
- 5 images over each region: 15 in total

Improvement on EUMETSAT H-SAF H35 by MARS

- **Reference data from higher resolution Sentinel 2 imagery**



Binary classified Sentinel 2 snow maps at 20 m.



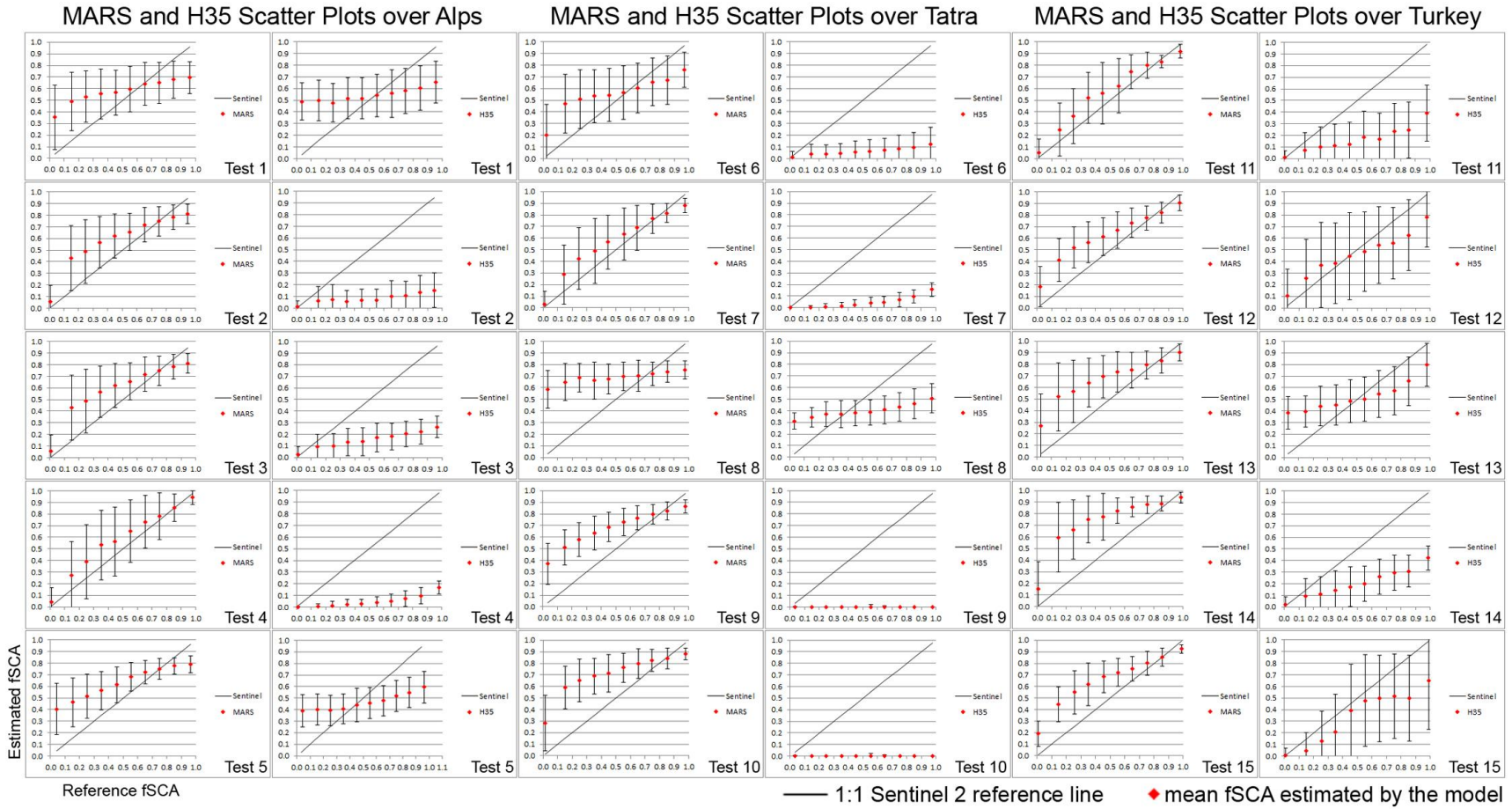
Sentinel 2 tile T32TPS (Alps) on 23 Feb 2019:

a) Sentinel 2 real color RGB image,
b) Sentinel 2 binary snow map (Snow: No snow:), and
c) Sentinel 2-derived reference FSC map.

For each H35 pixel:
Predictors: AVHRR Bands 1, 2, 3a, 4, 5, NDSI, NDVI
Response: Reference FSC value

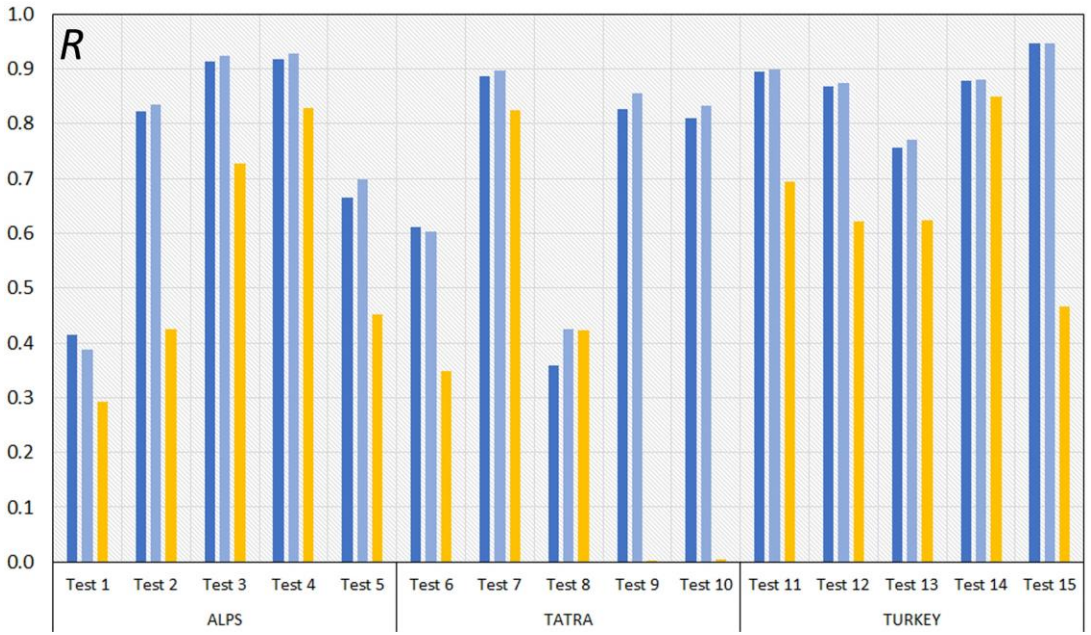
Improvement on EUMETSAT H-SAF H35 by MARS

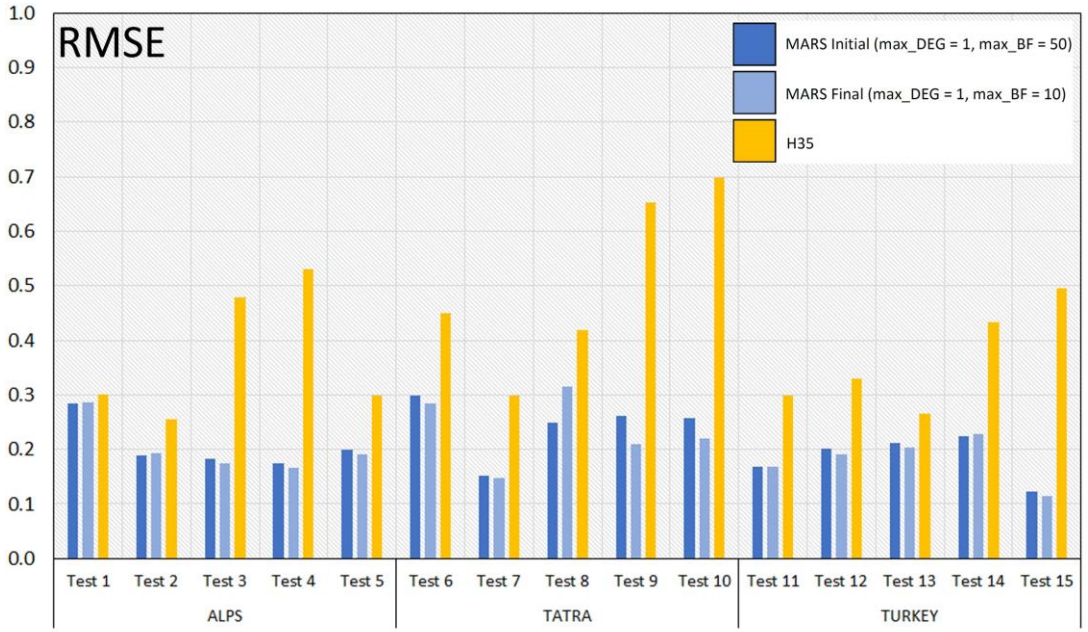
- **MARS-H35 on the initial test dataset**



Improvement on EUMETSAT H-SAF H35 by MARS

- **MARS-H35 on the initial test dataset**

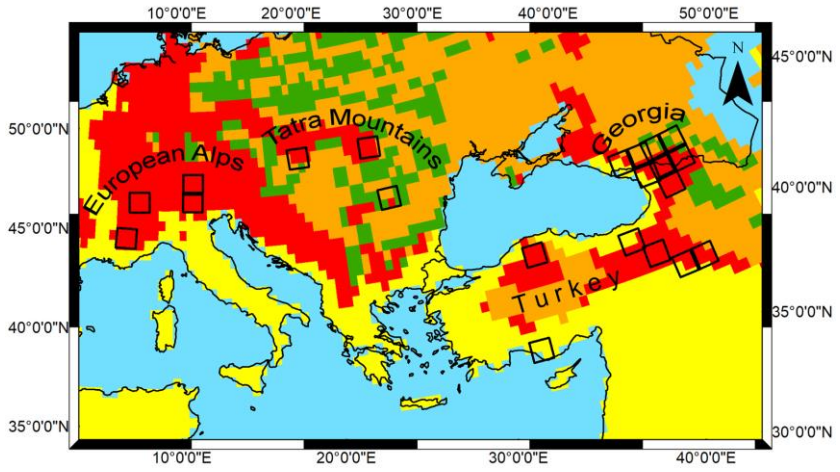


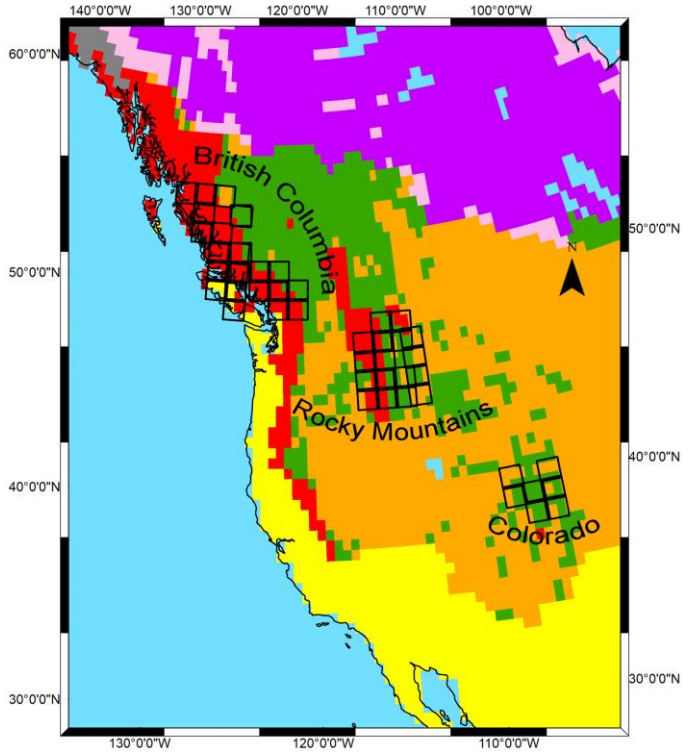


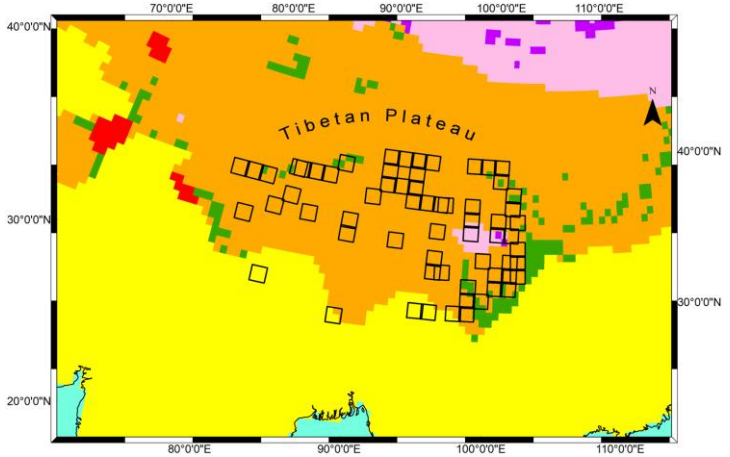
Improvement on EUMETSAT H-SAF H35 by MARS

- **Final validation dataset with four main components:**

  – 1) **Sentinel 2 reference FSC maps** with respect to **Sturm's (1995)** snow cover types:





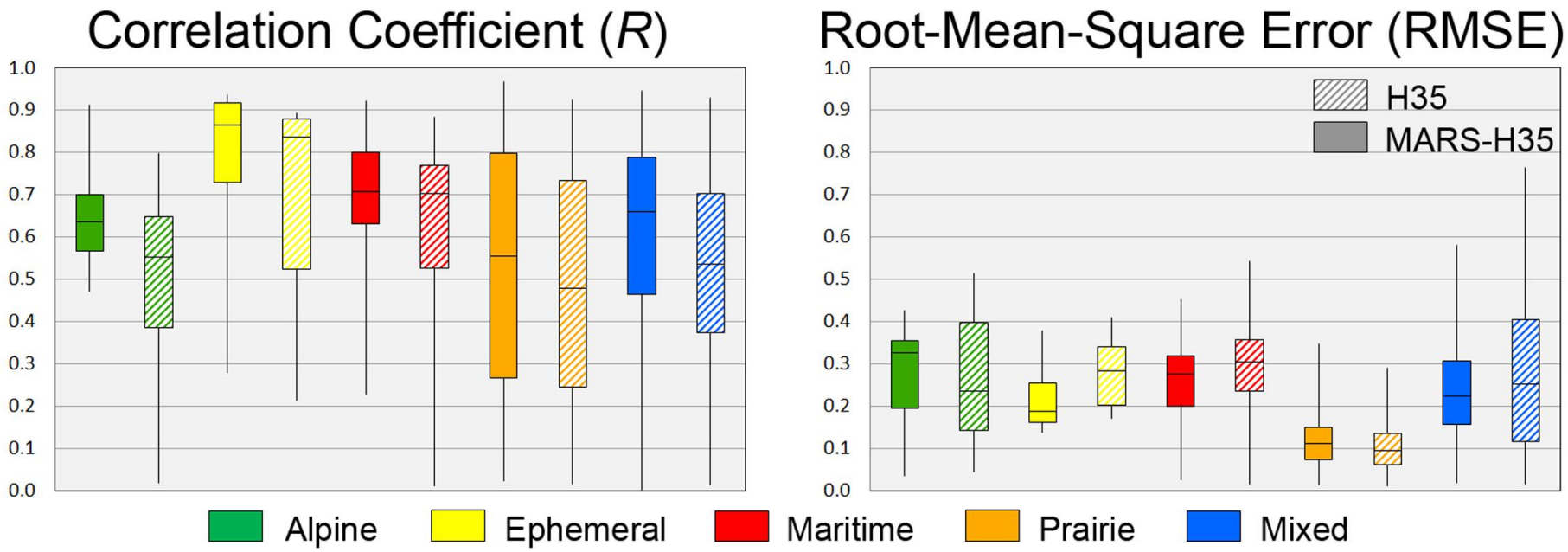


~450 Sentinel 2 images

Improvement on EUMETSAT H-SAF H35 by MARS

- **Final validation dataset with four main components:**

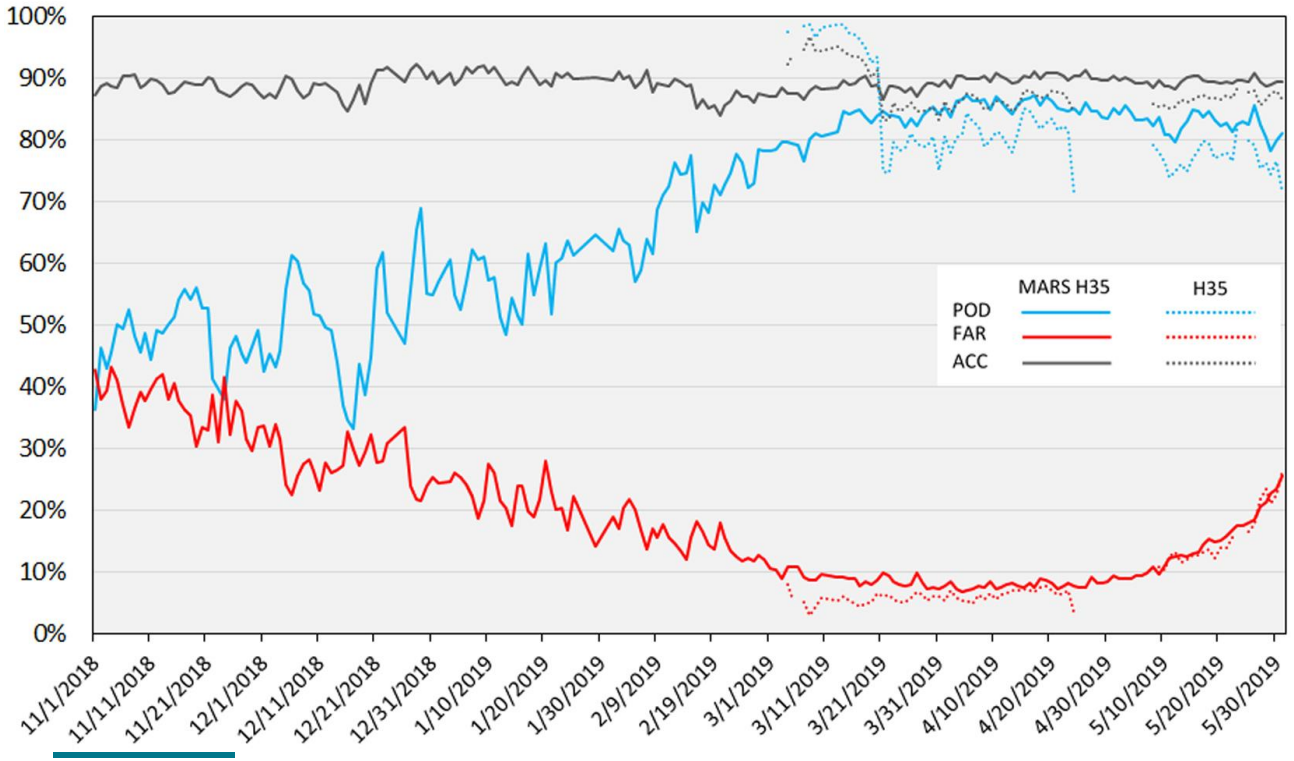
  – 1) **Sentinel 2 reference FSC maps** with respect to **Sturm's (1995)** snow cover types:



Improvement on EUMETSAT H-SAF H35 by MARS

- **Final validation dataset with four main components:**

  – 2) **ERA5-Land Snow Depth Data** (Northern Hemisphere):



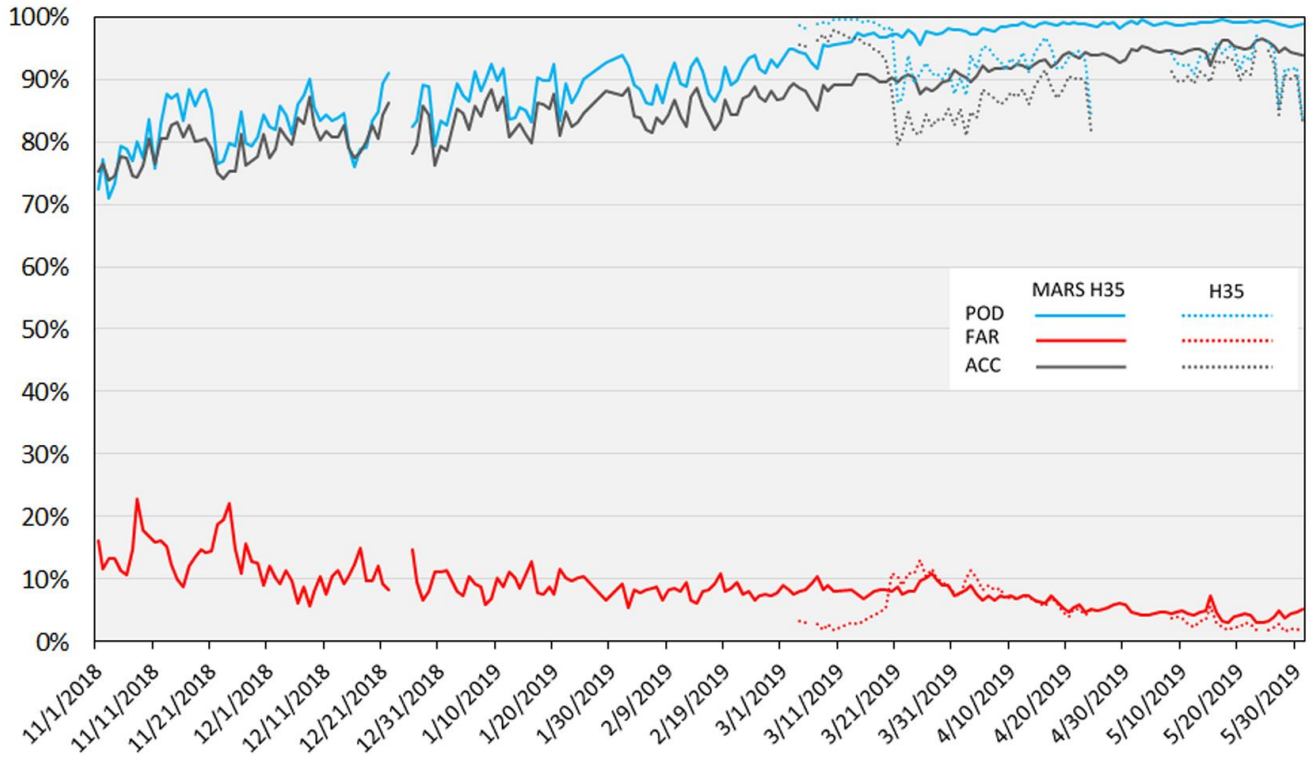
		Reference Data		
		Snow	**No Snow**	
Satellite Product	**Snow**	**HITS (A)**	**FALSE ALARMS (B)**	HITS + FALSE ALARMS
	No Snow	**MISSES (C)**	**CORRECT NEGATIVES (D)**	MISSES+ CORRECT NEGATIVES
		HITS + MISSES	FALSE ALARMS + CORRECT NEGATIVES	

Probability of detection (POD): A/(A+C)
False alarm ratio (FAR): B/(A+B)
Overall Accuracy (ACC): (A+D)/(A+B+C+D)

Improvement on EUMETSAT H-SAF H35 by MARS

- **Final validation dataset with four main components:**

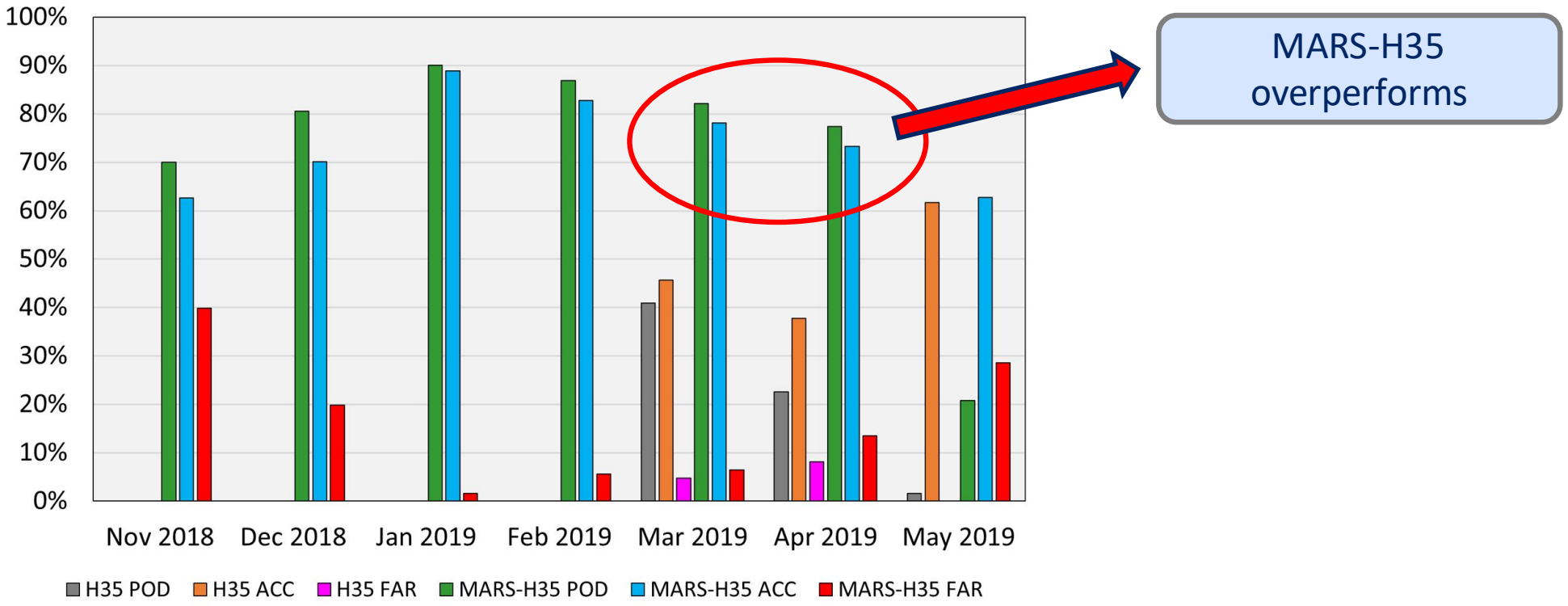
  – 3) **MODIS MOD10A1 V6 NDSI Snow Cover Data** (Northern Hemisphere):



Improvement on EUMETSAT H-SAF H35 by MARS

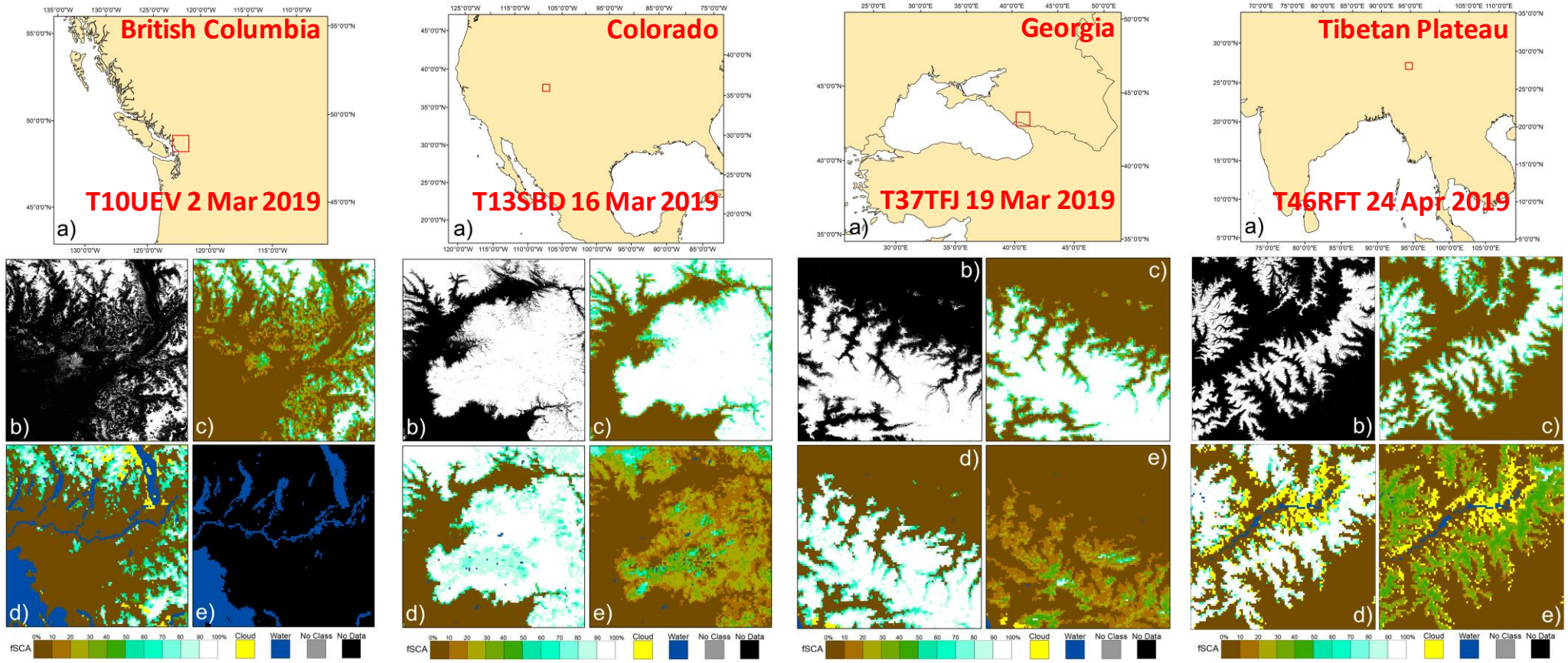
- **Final validation dataset with four main components:**

  – 4) **In-situ Snow Depth Data** (Turkey):



Improvement on EUMETSAT H-SAF H35 by MARS

- **Visual qualitative assessment: MARS-H35 vs Sentinel 2-derived FSC maps**

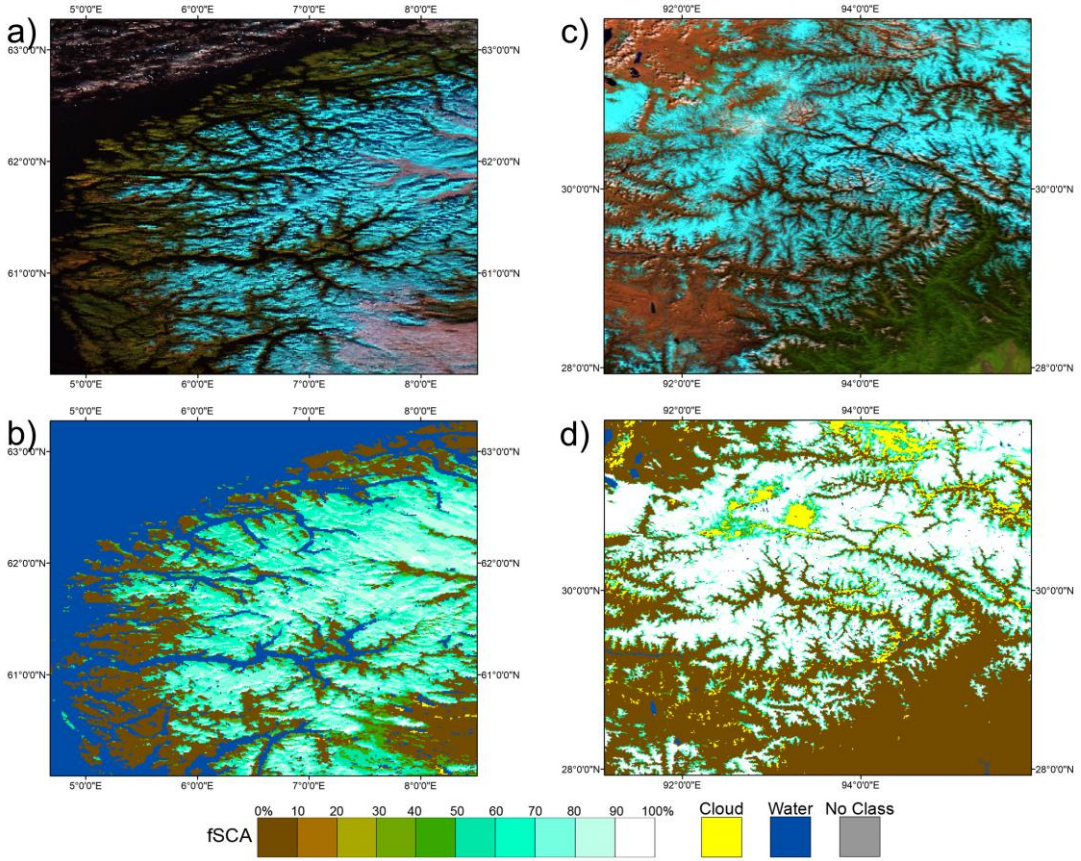


a) Sentinel 2 tile
b) Binary snow
c) Reference FSC
d) MARS-H35
e) H35

Improvement on EUMETSAT H-SAF H35 by MARS

- **Visual qualitative assessment: MARS-H35 vs MODIS False-Color RGB**

2 Nov 2019 2 Nov 2019



MODIS False-Color Composite:
R: Band 6
G: Band 2
B: Band 4

a) **Norway: MODIS**

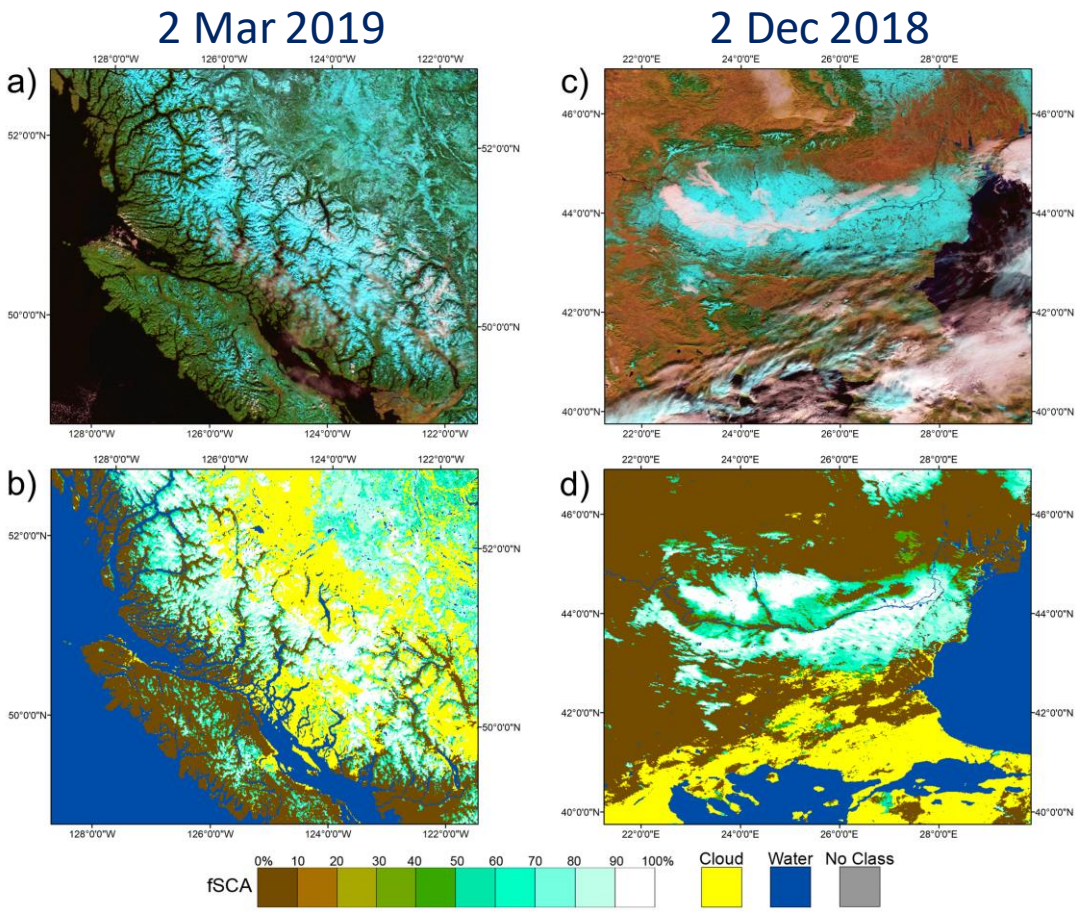
b) **Norway: MARS-H35**

c) **Tibet: MODIS**

d) **Tibet: MARS-H35**

Improvement on EUMETSAT H-SAF H35 by MARS

- **Visual qualitative assessment: MARS-H35 vs MODIS False-Color RGB**



MODIS False-Color Composite:
R: Band 6
G: Band 2
B: Band 4

a) British Columbia: MODIS

b) British Columbia: MARS-H35

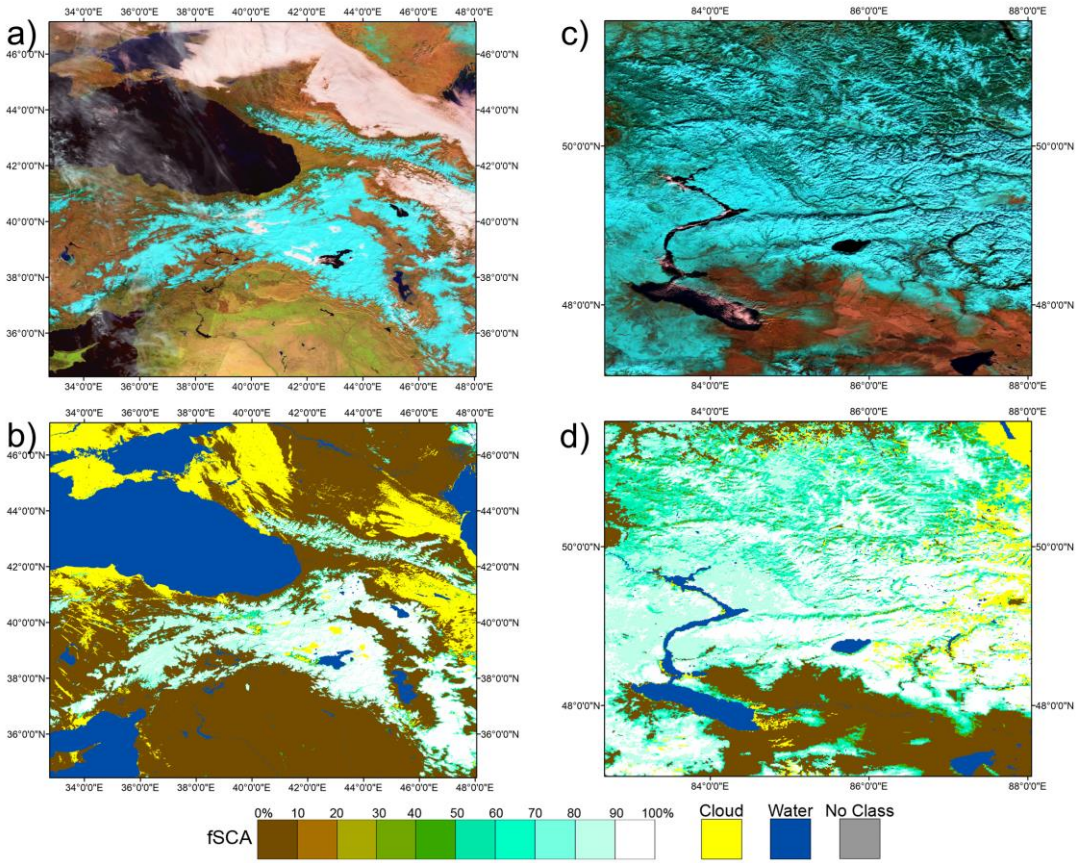
c) Bulgaria/Romania: MODIS

d) Bulgaria/Romania: MARS-H35

Improvement on EUMETSAT H-SAF H35 by MARS

- **Visual qualitative assessment: MARS-H35 vs MODIS False-Color RGB**

4 Feb 2019 | 2 Nov 2018



MODIS False-Color Composite:
R: Band 6
G: Band 2
B: Band 4

a) Turkey: MODIS

b) Turkey: MARS-H35

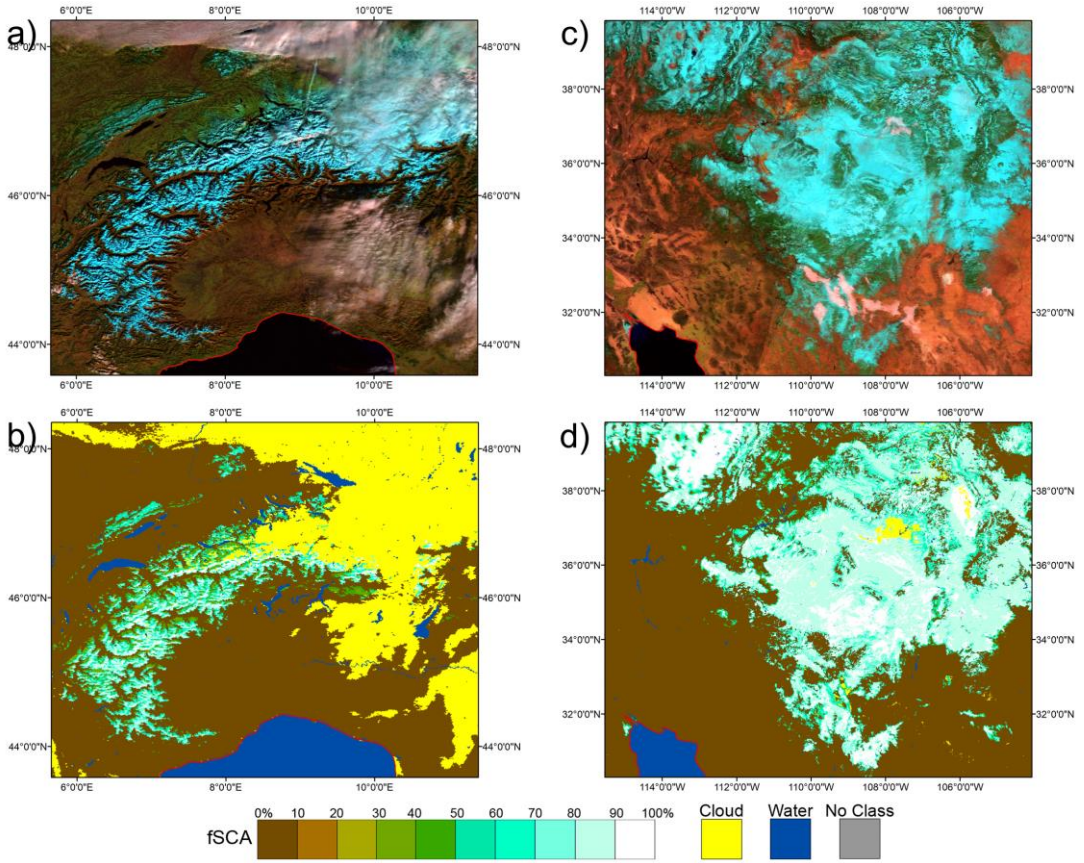
c) Kazakhstan: MODIS

d) Kazakhstan: MARS-H35

Improvement on EUMETSAT H-SAF H35 by MARS

- **Visual qualitative assessment: MARS-H35 vs MODIS False-Color RGB**

3 Jan 2019 | 3 Jan 2019



MODIS False-Color Composite:
R: Band 6
G: Band 2
B: Band 4

a) **Alps: MODIS**

b) **Alps: MARS-H35**

c) **Phoenix, AZ: MODIS**

d) **Phoenix, AZ: MARS-H35**

Improvement on EUMETSAT H-SAF H35 by MARS

- **H86: Effective Snow Cover by EPS-SG METimage in CDOP4 (2022 Mar - 2027 Feb)**

Cycle: Daily
Coverage: Northern Hemisphere
Grid/Projection: Equidistant cylindrical
Resolution: 0.01° x 0.01°
Formats: HDF5, PNG quicklook
Operational status: In development

- Successor of H35: Improved version by implementing **Machine Learning** (**MARS**).
- Further validation efforts continue.
- Algorithm development and refinement is still in progress.

Improvement on EUMETSAT H-SAF H35 by MARS

- **References**

  - **Friedman, J. H. (1991)**. Multivariate adaptive regression splines. *The Annals of Statistics*, 19, 1-67.
  - **Hastie, T., Tibshirani, R. and Friedman, J. (2009)**. *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*. (2nd ed.). NY, USA: Springer.
  - **Kuter, S., Akyurek, Z. and 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.
  - **Metsämäki, S. J., Anttila, S. T., Markus, H. J. and Vepsäläinen, J. M. (2005)**. A feasible method for fractional snow cover mapping in boreal zone based on a reflectance model. *Remote Sensing of Environment*, 95, 77-95.
  - **Sturm, M., Holmgren, J. and Liston, G. E. (1995)**. A Seasonal Snow Cover Classification System for Local to Global Applications. *Journal of Climate*, 8, 1261-1283.

Thank You...

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