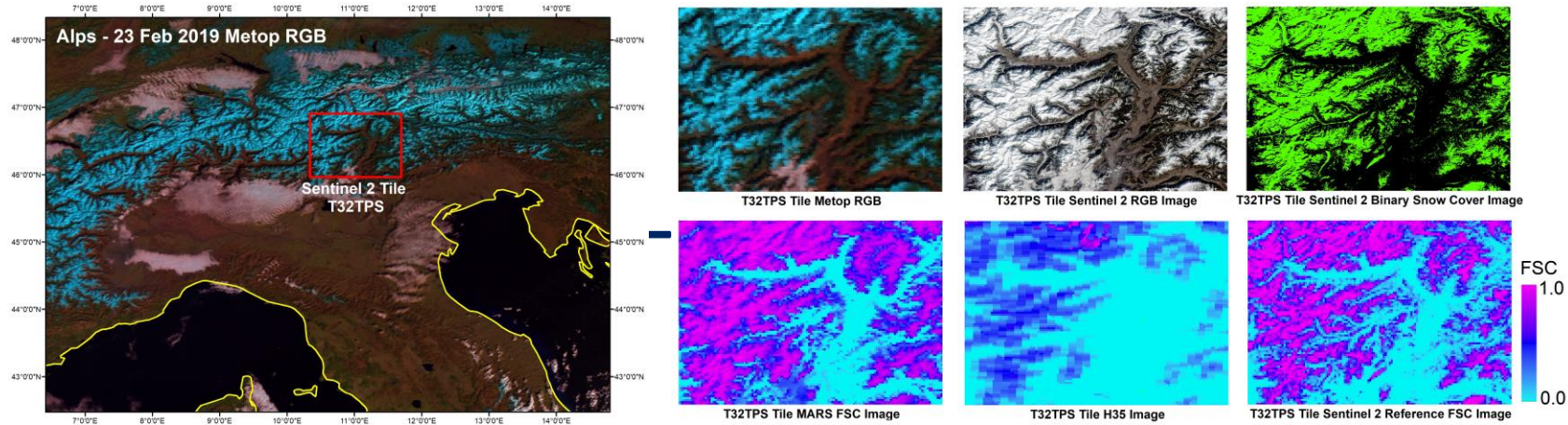


An Alternative Machine Learning-Based Methodology for H-SAF H35 Fractional Snow Cover Product



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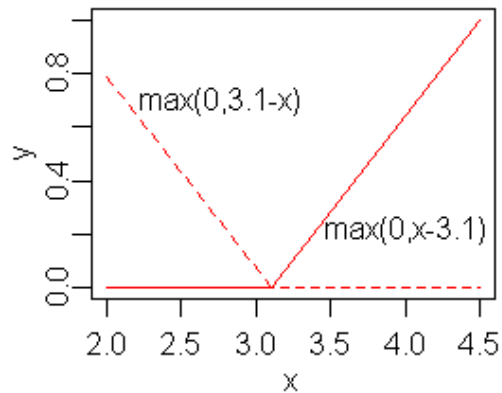
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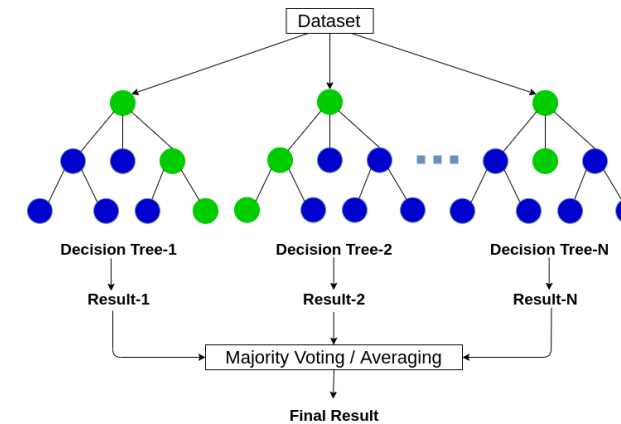
- Machine Learning Algorithms:

Multivariate Adaptive Regression Splines MARS



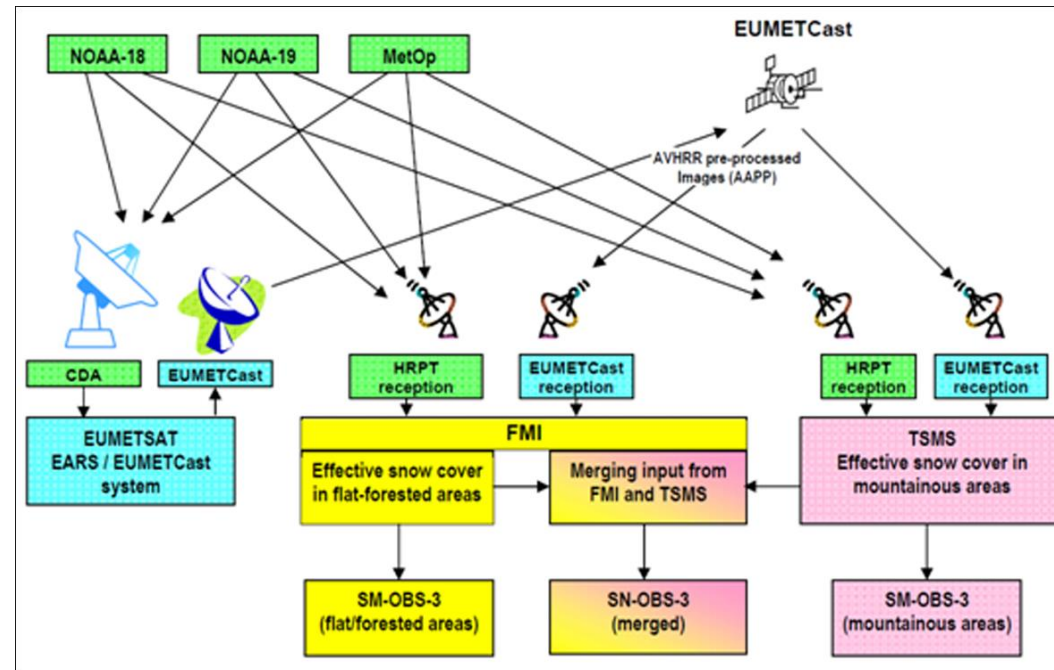
In MARS, one-dimensional piecewise linear basis functions (BFs) are used to define relationships between a response variable and a set of predictors (Friedman, 1991). It is a powerful nonparametric adaptive regression procedure, suitable for solving high-dimensional and complex problems.

Random Forests RFs



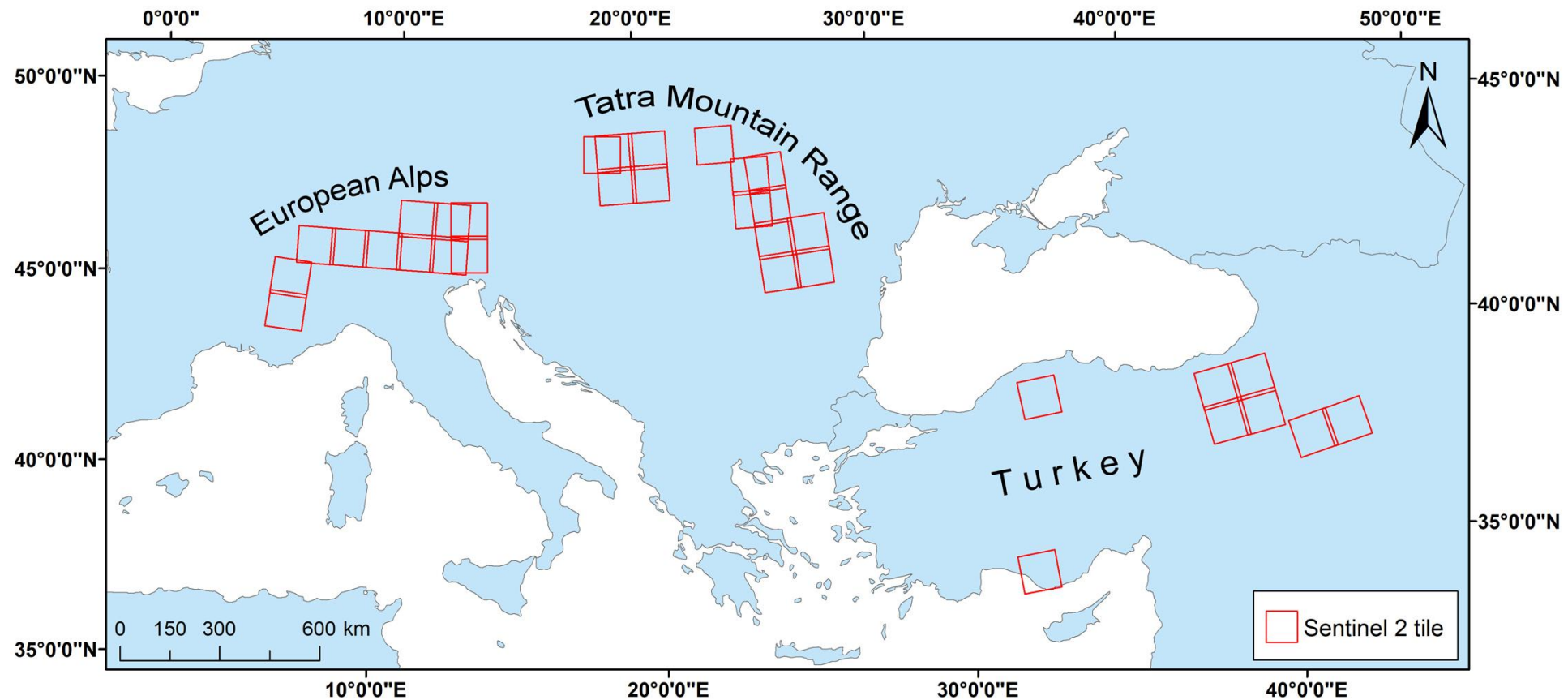
RFs introduced by Breiman (2001) is an ensemble of CARTs and fundamentally based on the Breiman's bagging idea, which is also known as bootstrap aggregation.

- H-SAF H35 effective snow cover product using MARS and RFs
 - EUMETSAT HSAF H35 SN-OBS-3 product, i.e., effective snow cover (*fractional snow cover - FSC*) by VIS/IR radiometry, is based on multi-channel analysis of the **AVHRR** instrument onboard to NOAA and MetOp satellites. The product for flat/forested regions is generated by **Finnish Meteorological Institute (FMI)**, and the product for mountainous areas is generated by **Turkish State Meteorological Service (TSMS)**. Both products, thereafter, are merged at FMI.

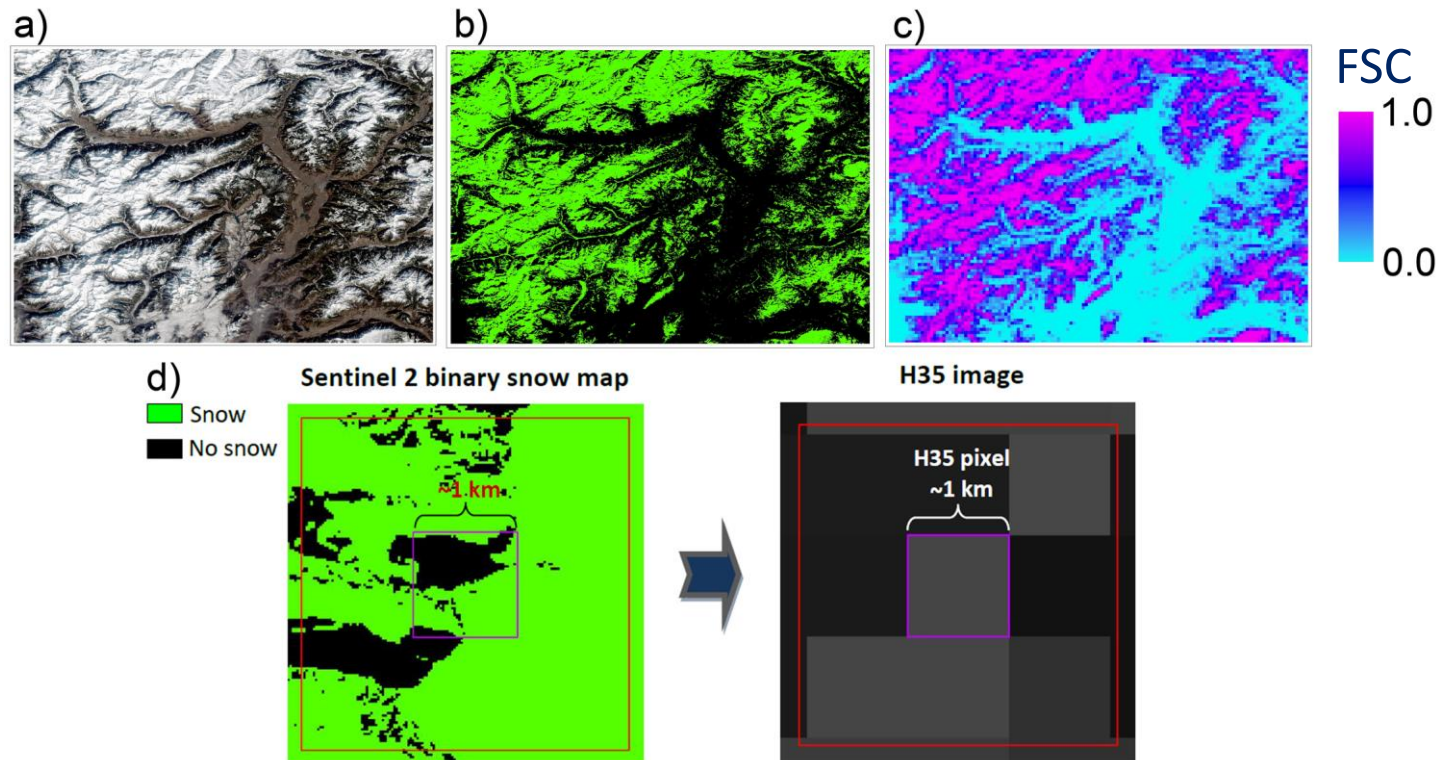


- **MARS and RFs for H-SAF H35**

- Training Dataset: European Alps, Tatra Mountain Range, and Turkey.
- 332 H35 – Sentinel 2 image pairs acquired between Nov 2018 and Apr 2019.



- **MARS and RFs for the mountainous areas of H-SAF H35**
 - Reference FSC maps are generated from binary classified Sentinel-2 images at 20 m by **Sen2Cor v2.08**:



T32TPS Alps - Test image 4 - 23 Feb 2019:

- a) Sentinel 2 real color RGB image,
- b) Sentinel 2 binary snow map (Snow: ■ No snow: ■),
- c) Sentinel 2-derived reference FSC map, and
- d) calculation of reference FSC for an H35 pixel.

Predictor Variables:

AVHRR Bands 1, 2, 3a, 4, 5, NDSI and NDVI

Response Variable:

FSC value

MARS- and RF-based H35 FSC Scatter Plots over Alps, Tatra, and Turkey

Alps

Tatra

Turkey

MARS-H35

RF-H35

H35

MARS-H35

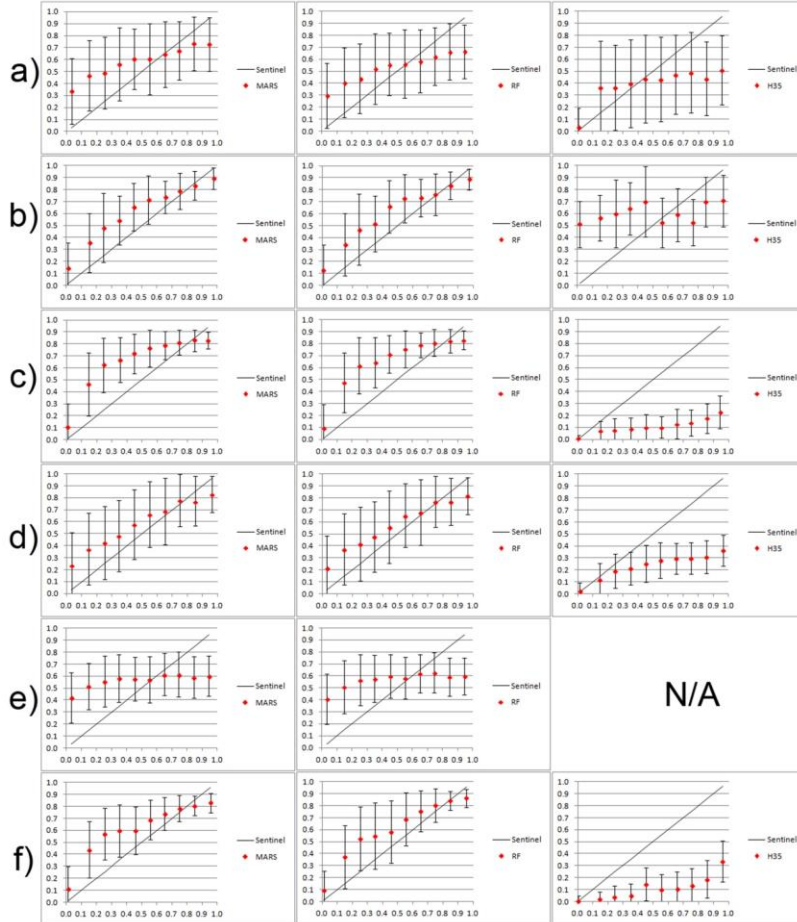
RF-H35

H35

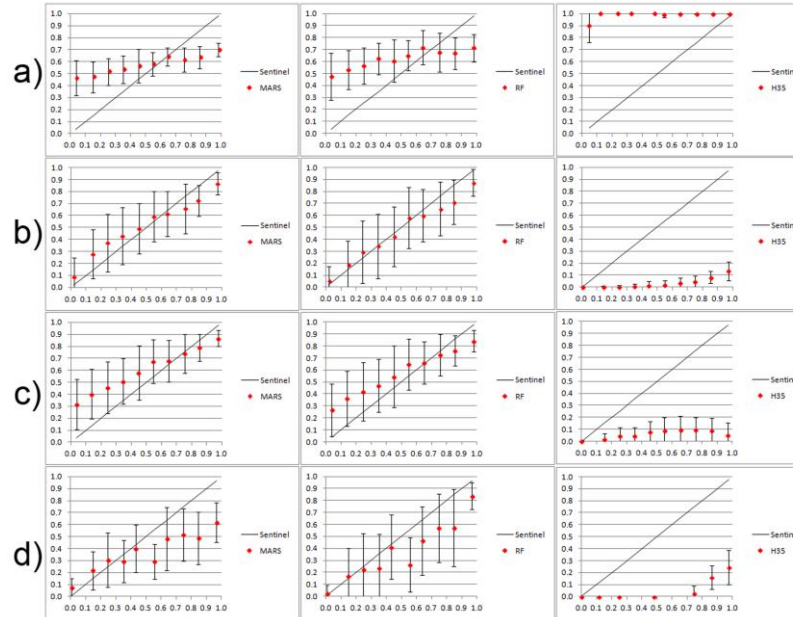
MARS-H35

RF-H35

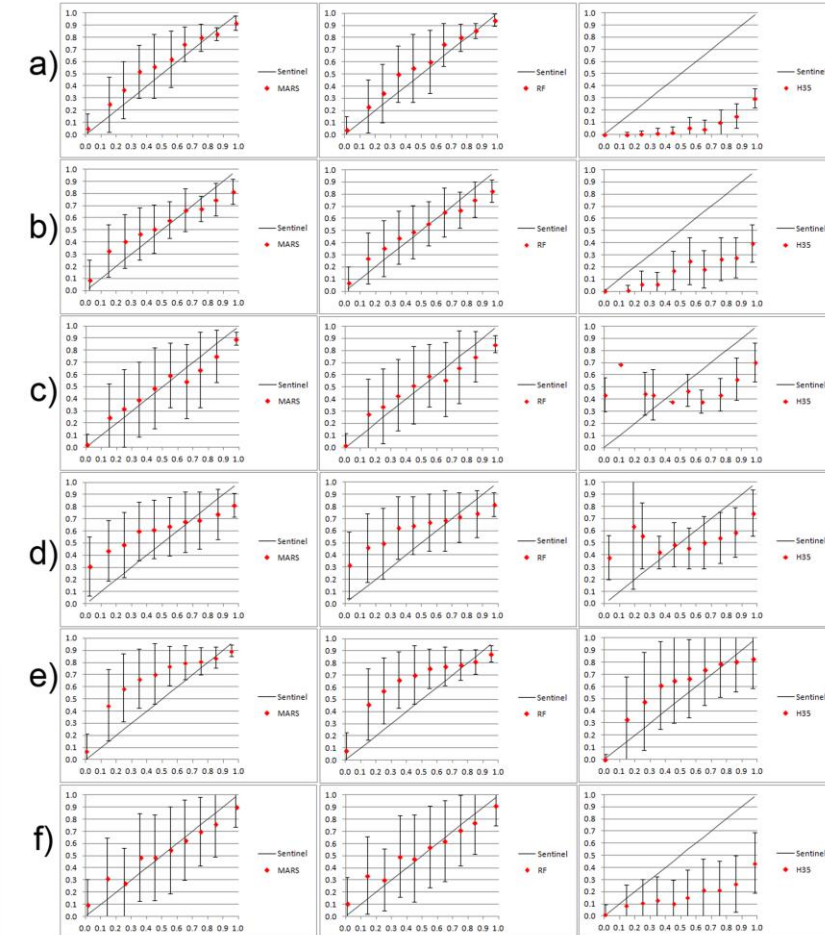
H35



N/A



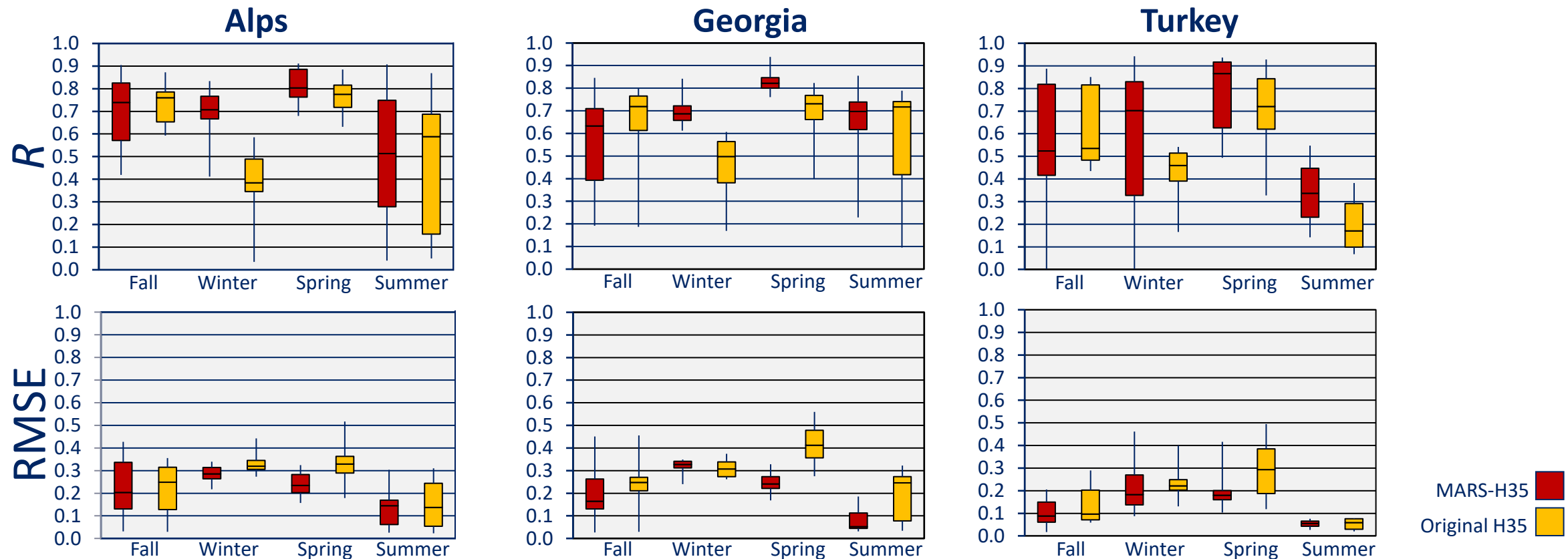
The scatter plots illustrate the performance of the generated FSC models versus reference Sentinel 2-derived FSC values on the initial test images over Alps, Tatra, and Turkey, respectively. These plots are obtained by drawing the mean value of the estimated FSC for each 10% range together with the corresponding standard deviation bars over the 1:1 Sentinel 2 reference FSC line.



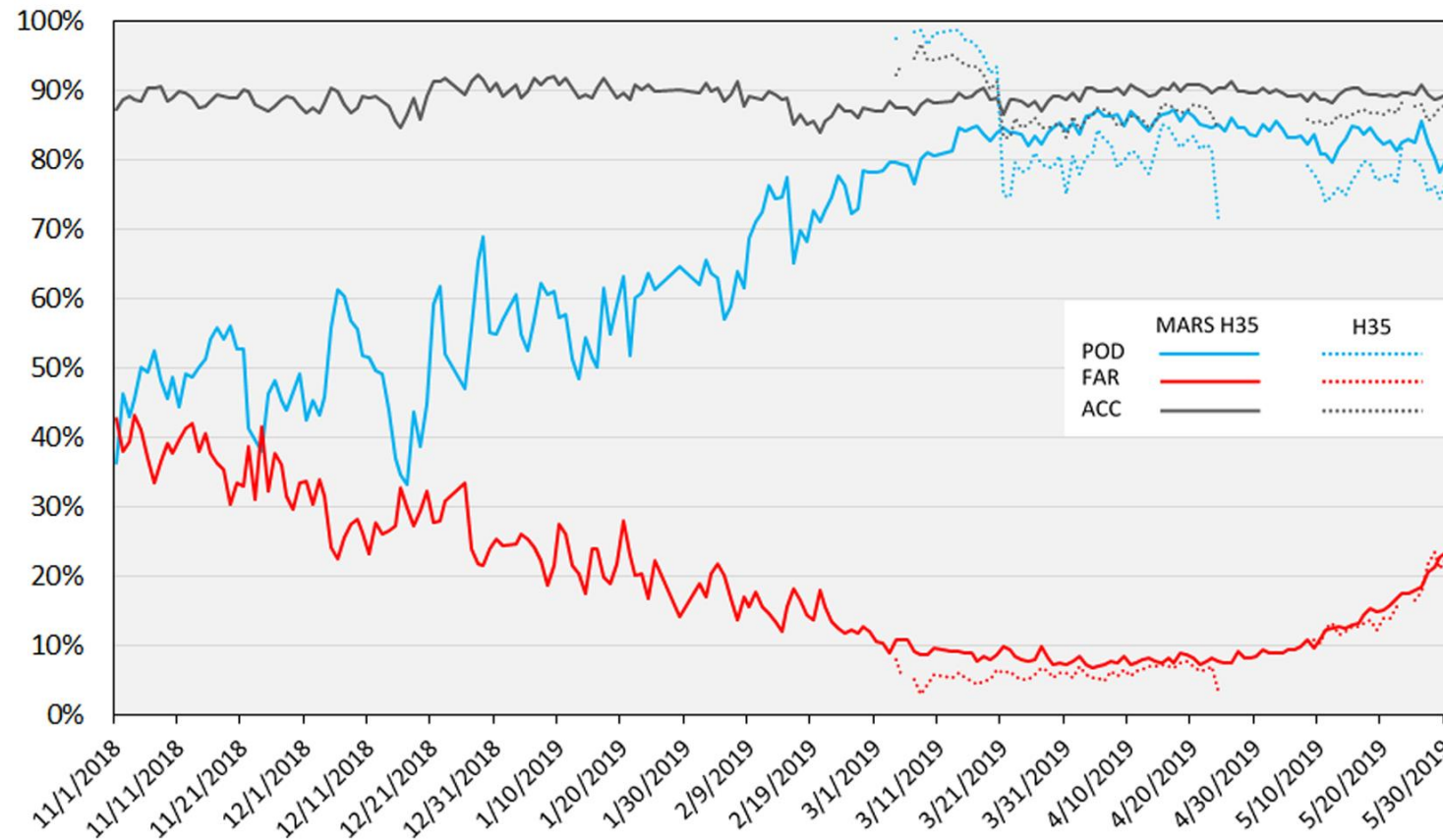
- **Preliminary Results**

- MARS and RF give the **importance of predictor variables** employed in the model training.
- Both MARS and RFs FSC models are successful in catching the spatial distribution of snow according to the corresponding RMSE and R values, as well as the visual analysis.
- It is decided to continue with **MARS FSC modelling** approach in producing H35 in CDOP4 since:
 - RF models are generated under MATLAB and the final RF FSC model has a closed form.
 - The process time takes too long in RF for a potential operational H35 product.
 - MARS model is a simple regression equation which is easy to implement in any programming environment.

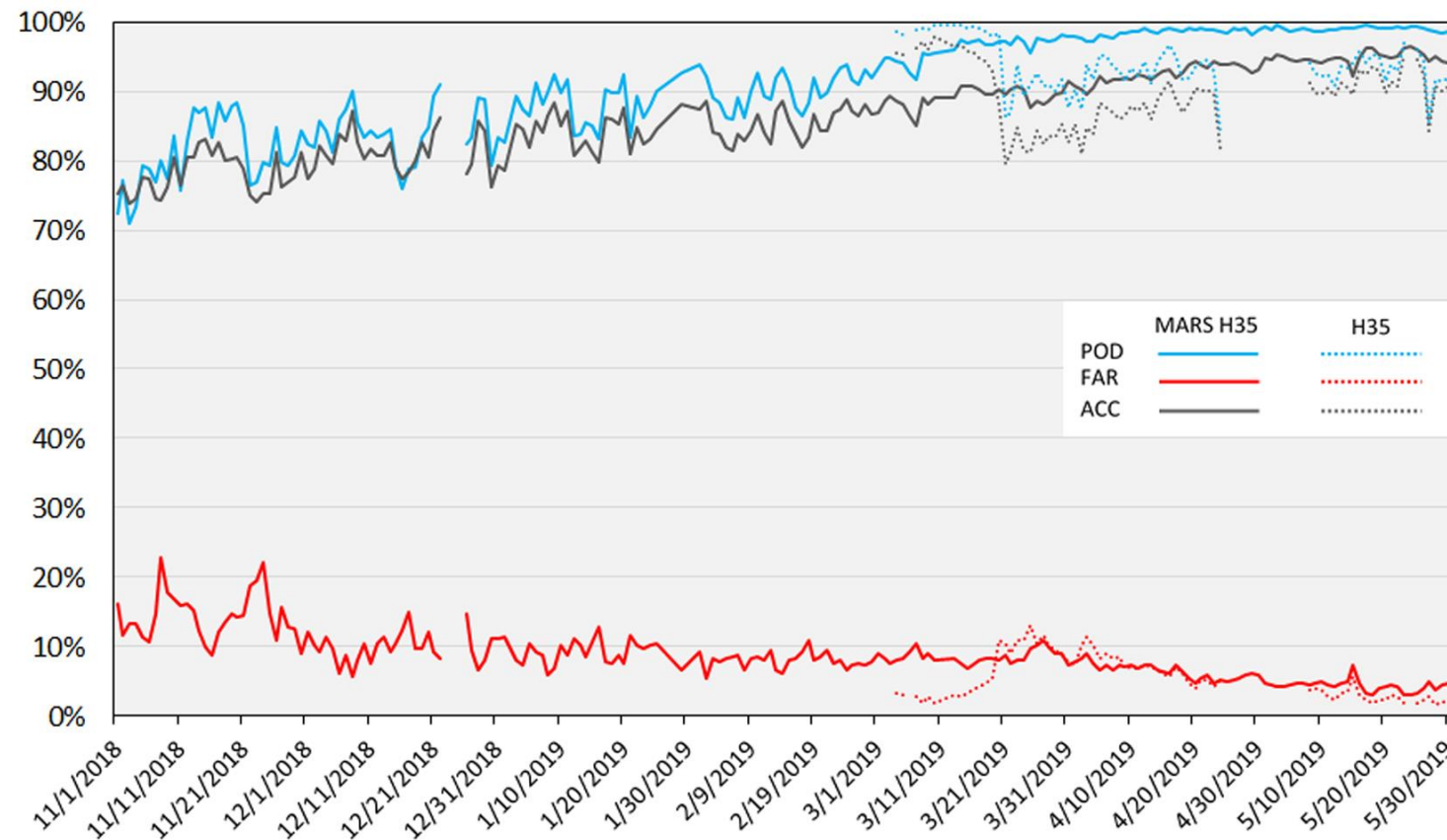
- Validation of MARS-H35 FSC Model for 2018-2019 Snow Season
 - Sentinel 2-derived Reference FSC Maps over European Alps, Georgia in the Caucasus, and Turkey in terms of RMSE and R



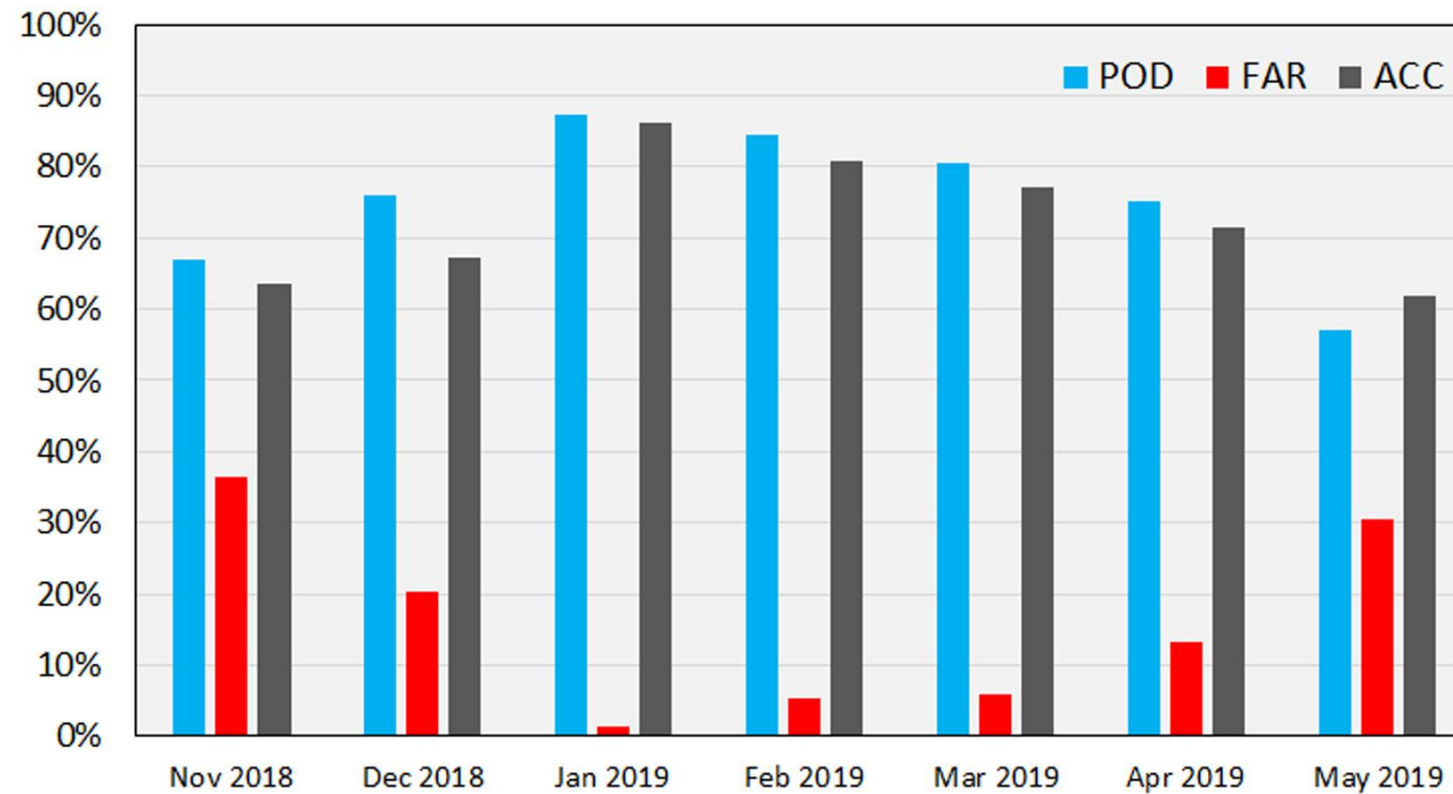
- Validation of MARS-H35 FSC Model for 2018-2019 Snow Season
 - MARS-H35 vs. ERA5 Snow Depth Data (Entire Northern Hemisphere)



- Validation of MARS-H35 FSC Model for 2018-2019 Snow Season
 - MARS-H35 vs. MODIS MOD10A1 NDSI Snow Cover Data (Entire Northern Hemisphere)

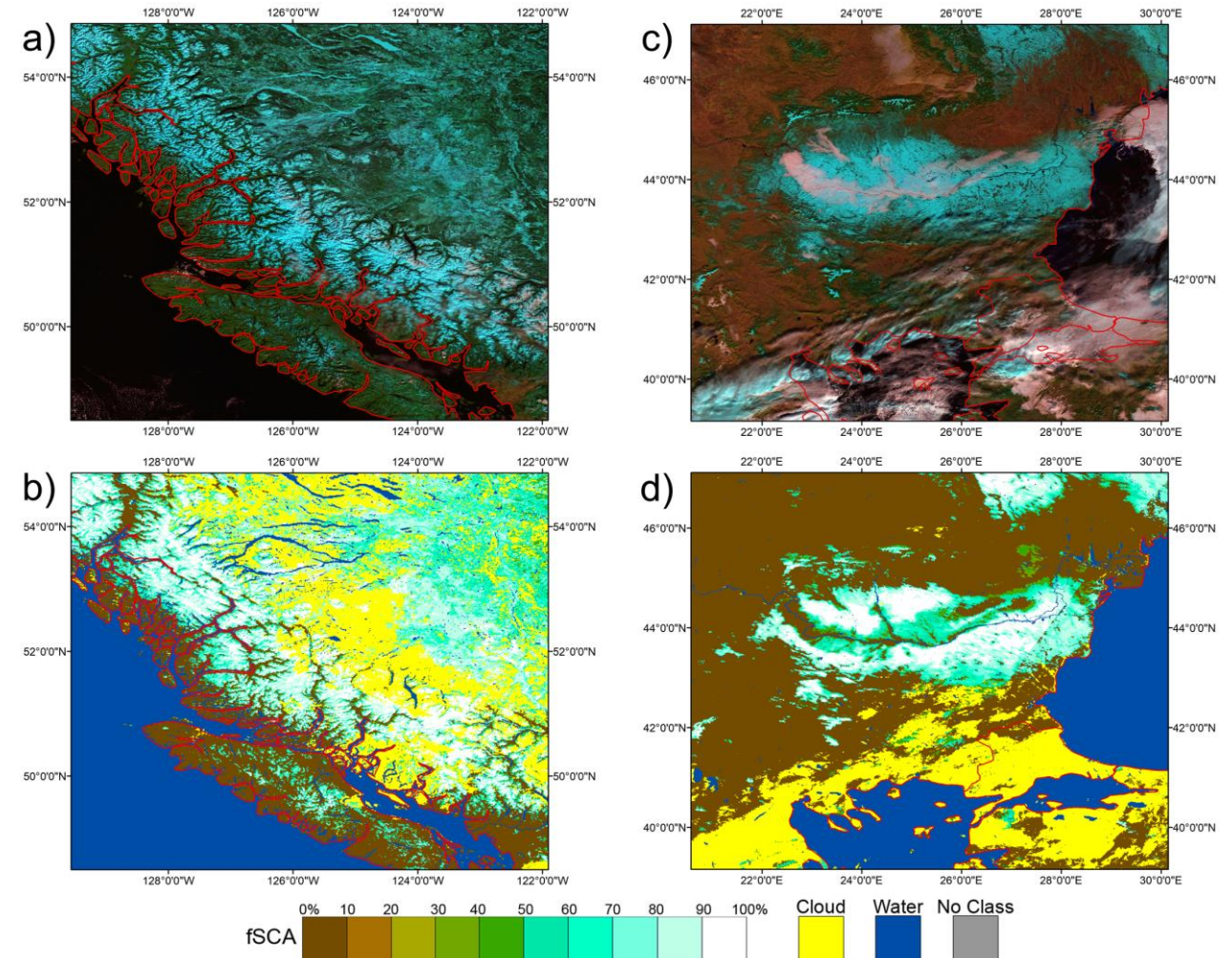


- Validation of MARS-H35 FSC Model for 2018-2019 Snow Season
 - MARS-H35 vs. In-situ Snow Depth Data from TSMS (Turkey)



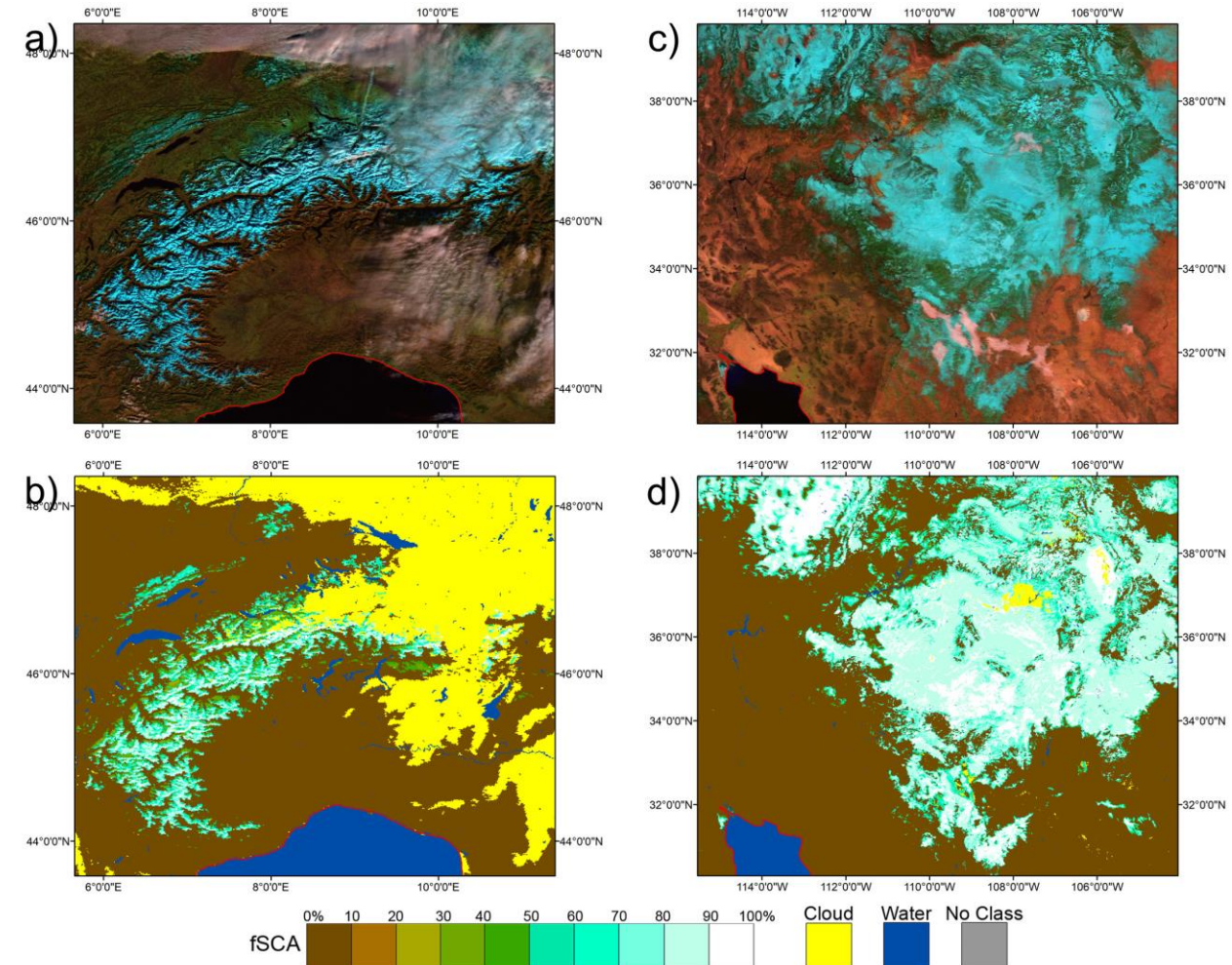
- Validation of MARS-H35 FSC Model for 2018-2019 Snow Season

a) MODIS false-color RGB image and b) MARS-H35 image over British Columbia, Canada on 2 Mar 2019; c) MODIS false-color RGB image and d) MARS-H35 image over south-eastern Bulgaria on 2 Dec 2018.



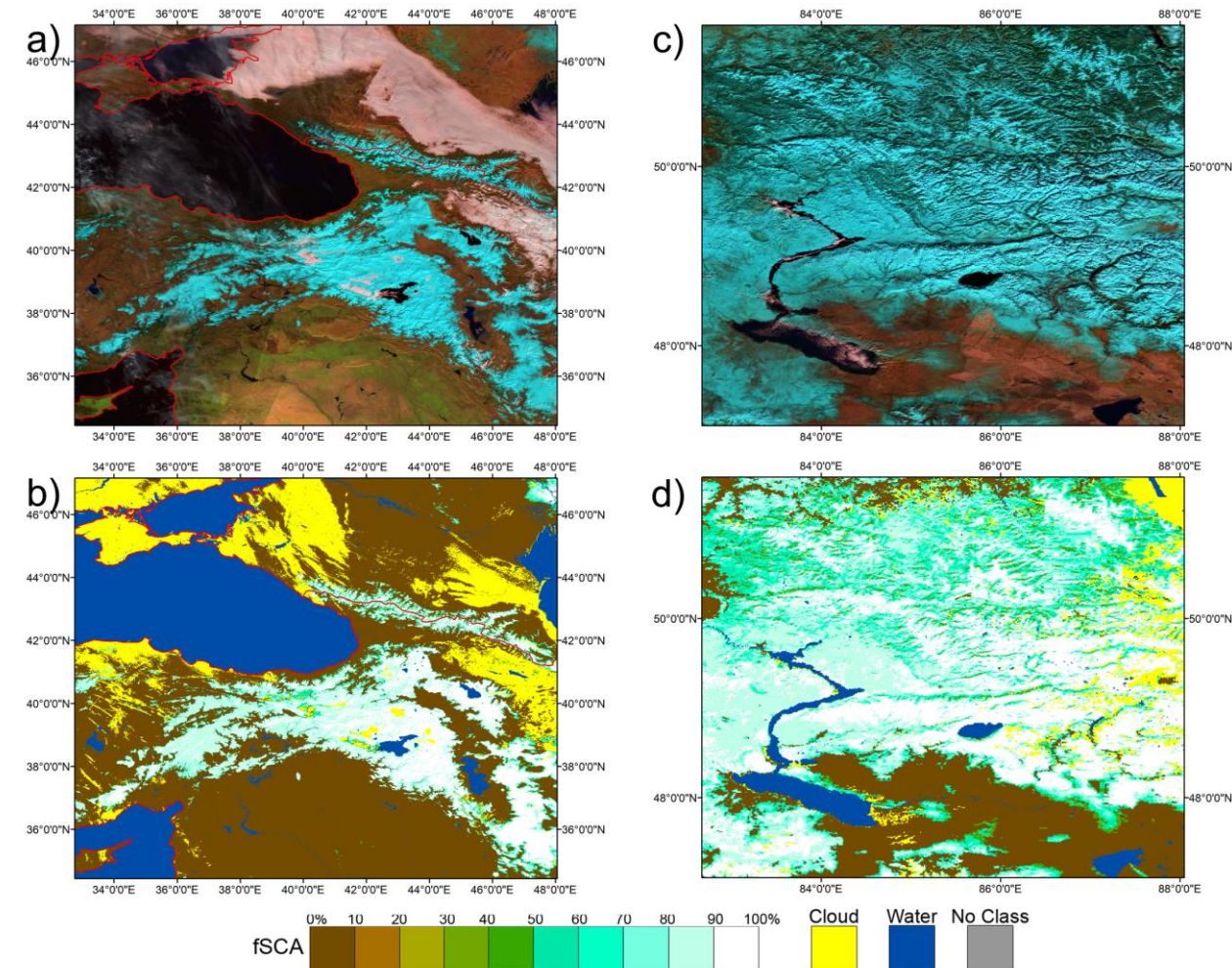
- Validation of MARS-H35 FSC Model for 2018-2019 Snow Season

3 Jan 2019: a) MODIS false-color RGB image and b) MARS-H35 image over European Alps; c) MODIS false-color RGB image and d) MARS-H35 image over Phoenix, Arizona.



- Validation of MARS-H35 FSC Model for 2018-2019 Snow Season

a) MODIS false-color RGB image and b) MARS-H35 image over eastern Turkey on 4 Feb 2019; c) MODIS false-color RGB image and d) MARS-H35 image over Lake Zaysan, East Kazakhstan on 2 Nov 2018.



- **Conclusions**

- Validation through ERA5 and MODIS NDSI data reveal that significant improvement in POD and ACC is achieved by MARS-H35.
- Visual analyses indicate that MARS-H35 is much more successful in catching fine spatial variations in the spatial extent of snow cover, especially in the fringes of the slopes in complex mountainous terrains.
- Further refinements on the MARS-H35 FSC algorithm are in progress:
 - Inclusion of viewing geometry parameters.
 - Validation for 2019-2020 and 2020-2021 snow seasons.

• References

- Breiman, L. (2001). Random forests. *Machine Learning*, 45(1), 5-32.
- Friedman, J. H. (1991). Multivariate adaptive regression splines. *The Annals of Statistics*, 19(1), 1-67.
- Hall, D. K., Riggs, G. A., & Salomonson, V. V. (1995). Development of Methods for Mapping Global Snow Cover Using Moderate Resolution Imaging Spectroradiometer Data. *Remote Sensing of Environment*, 54, 127-140.
- 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.



Thank You...

