Alpine Algorithms-Time Series of Innovative Remote Sensing Products for Alpine Areas: Snow Cover, Leaf Area Index, and Soil Moisture

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Motivation and Outline

Mountains are home to a significant fraction of the world population and to half of global **biodiversity hotspots**.

Mountains make essential **ecosystem services** available:

- acting as water towers of the world,
- provide freshwater to many lowland regions for domestic use, irrigation, hydropower, or industry.
- ecosystem services such as unique flora and fauna,
- critical habitat for rare and endangered species,
- snow-based recreation, and others.

Mountains are very fragile environments and are among the regions that are most sensitive to climate change and to the impacts of human activities.

Developing EO-based methods and products able to take into account the peculiarities of mountain areas are necessary to assure a long term monitoring.

We present products specifically developed for mountain areas:

- Snow cover
- Leaf area index
- Soil moisture
- Derived products such as snow cover duration, phenology

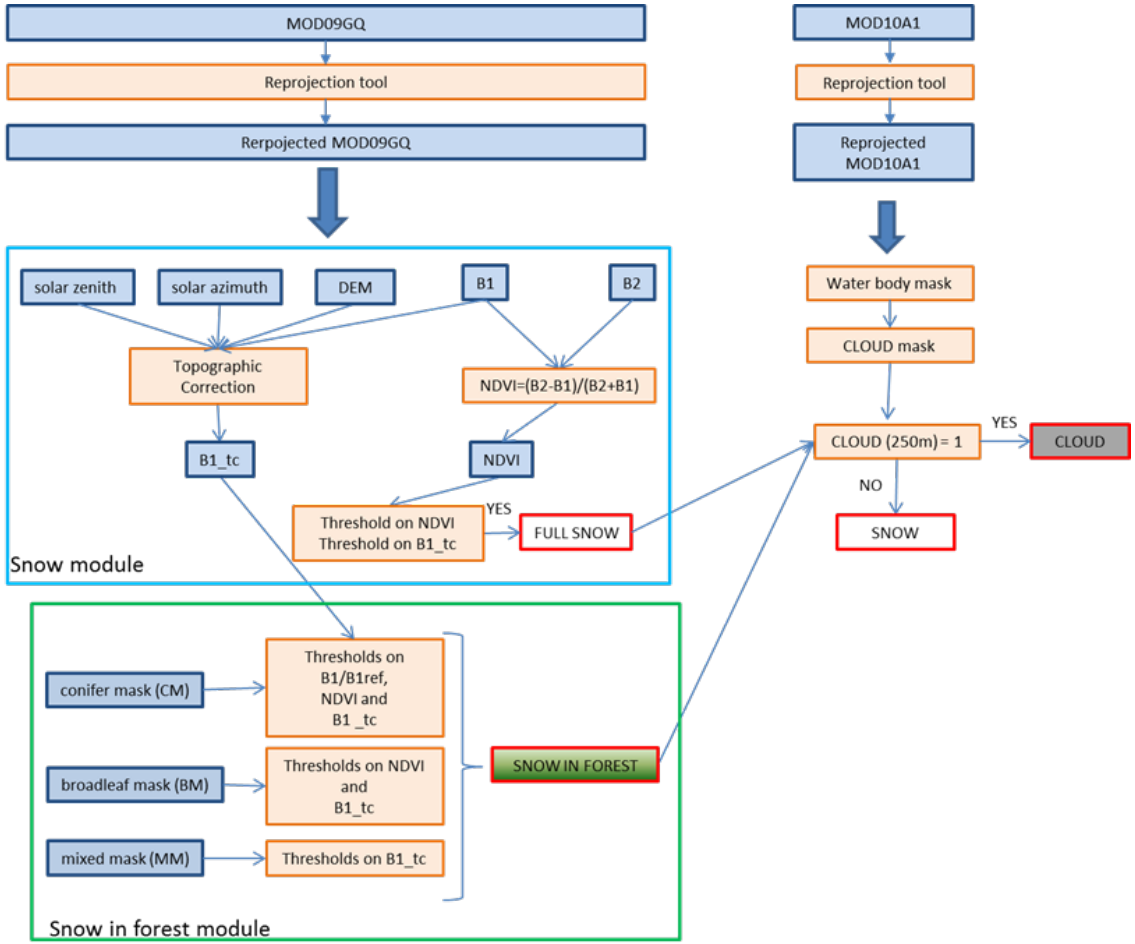
Overview of User requirements

Variables	Data Requirements			Data Specifications				
	Context	Problems	Users	Spatial Resolution	Time Resolution	Accuracy	Lead Time	Scale
Soil moisture	Agriculture	Irrigation	Consortium	Variable	Weekly			Macro
		Hydrographic services	Hydrographic office	250 m	daily			
				20 m				
Evapotraspiration	Agriculture	Irrigation		Variable				
		Vertical profiling		1km				
Snow cover	Civil Protection (e.g. avalanche forecast)	Resolution	Civil Protection	250 m	weekly			
	Tourism	Aspect	Consortium		daily			
					monthly			
Snow water equivalent	Civil Protection	Hydrographic services	SKITOUR	250 m	weekly			
	Idroelectric productivity	Wind						
Infiltration	Agriculture	Irrigation		Variable				
		Humidity						
Run-off	Civil Protection	Outlier detection			Daily			Basin
					Weekly			
River discharge	Civil Protection	variability of monthly discharge with altitude	Water resources					Basin
		48h forecasting	Idroelectric Company					
		Outlier detection						
Precipitation	Tourism	irrigation	management	250 m				
	Agriculture	measuring errors	Idroelectric Company					
	Civil Protection	Gridded data						

Overview of the products

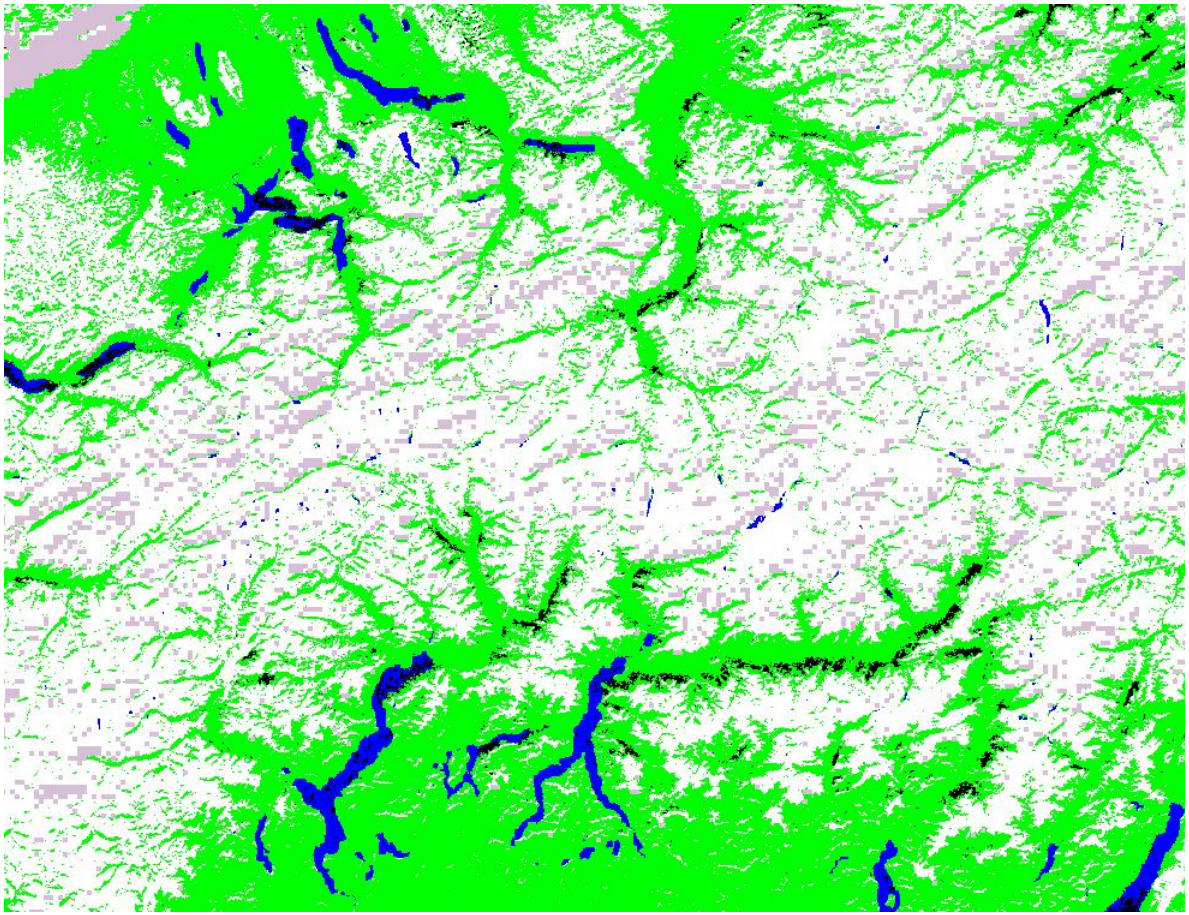
Product	Remote sensing data	Bands	Spatial resolution	Temporal resolution	Main specifications
Snow	MOD09GQ – MYD09GQ surface reflectance	1, 2	250 m	Daily	Use of B1 and B2 to maintain the highest reslution Topography correction
	MOD10A1-MYD10A1 cloud cover	-	500 m – 1km	Daily	
LAI	MOD/MYD 09GQ/GA-LG2 surface reflectance, quality, and geometry information	1, 2, 3	250 m / 500 m / 1 km	4-day composite	Topography is taken into account in the retrieval
	SRTM DEM	-	250 m	-	
Soil moisture	ASAR WS (C-band SAR)	-	150 m	weekly	Topography: correction for local incidence angle
	MOD13Q1 NDVI	-	250 m	16-day composite	
	SRTM DEM		90 m	-	

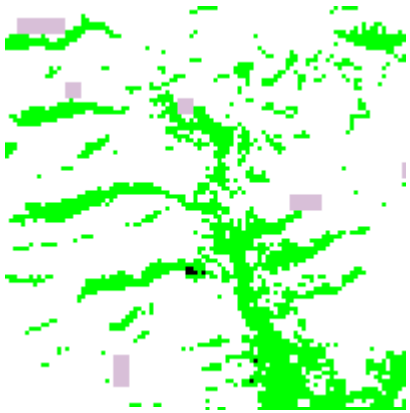
Snow cover retrieval algorithm



Notarnicola, C.; Duguay, M.; Moelg, N.; Schellenberger, T.; Tetzlaff, A.; Monsorno, R.; Costa, A.; Steurer, C.; Zebisch, M. Snow Cover Maps from MODIS Images at 250 m Resolution, Part 1: Algorithm Description. *Remote Sens*. 2013, 5, 110-126.

Effect of topographic correction

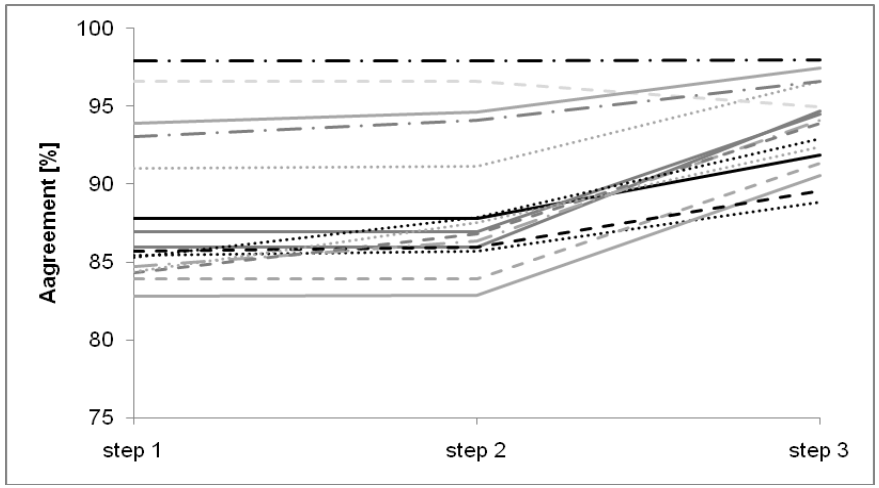




Validation activities

Comparison with Landsat snow maps

- Accuracy ranging from 88% to 98%, where most of the drawbacks come from the forested areas

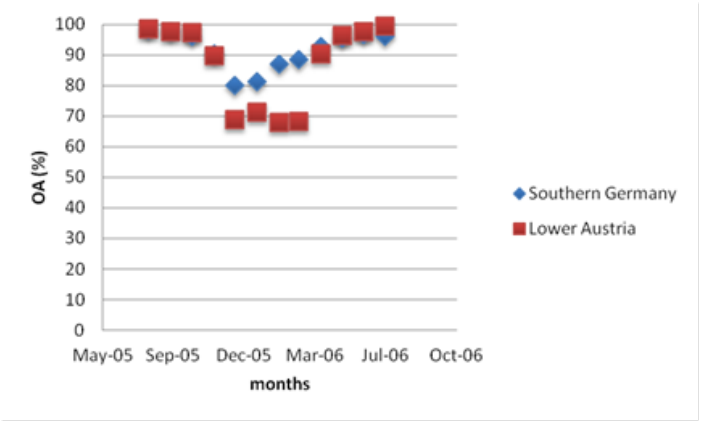


Comparison with ground data:

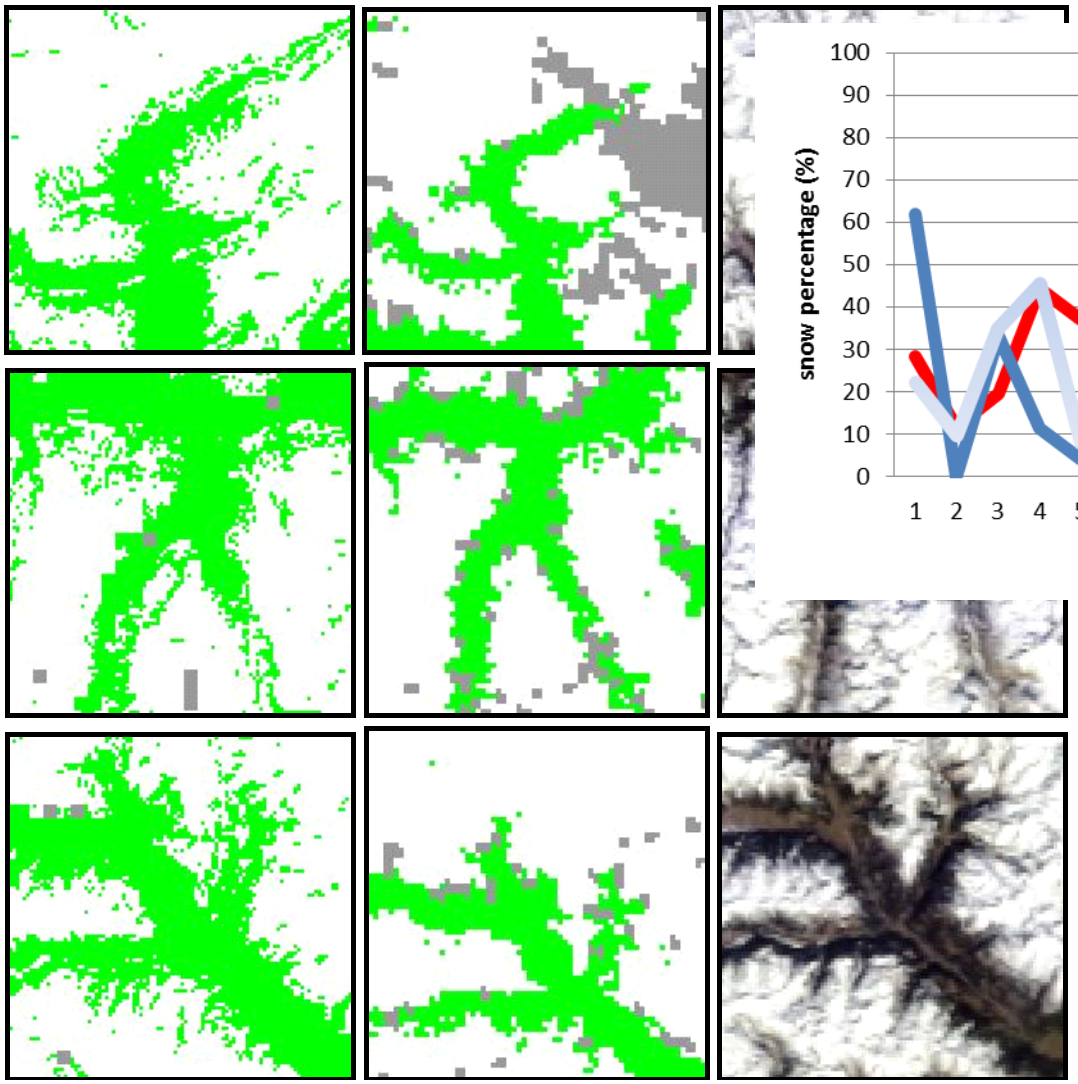
- Overall agreements between the EURAC snow product and *in-situ* snow measurements range between 82% and 94%.

Comparison with MOD/MYD10:

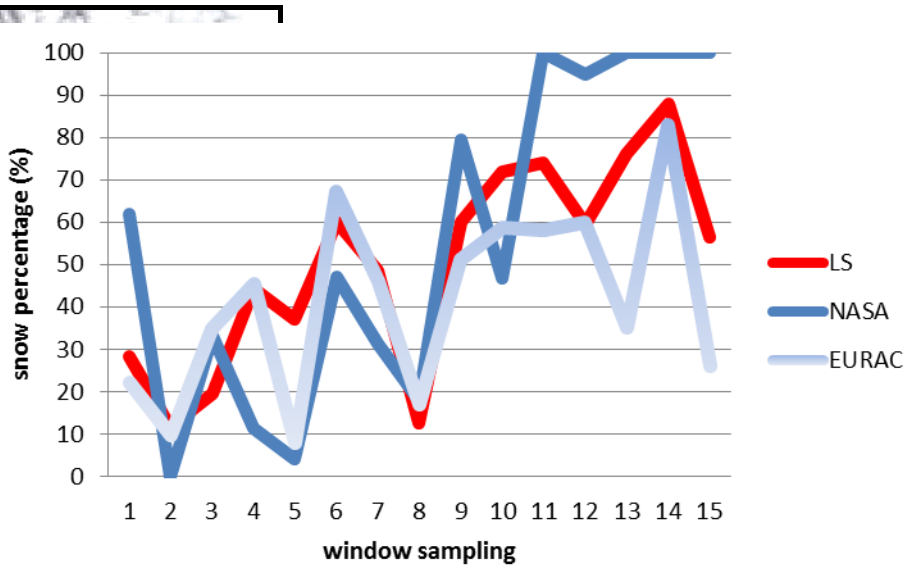
- Overall average agreement of 91%, where the commission is 5.5% and the omission error 16.2%. Outside forest, the overall accuracy is increased to 96%.



Results

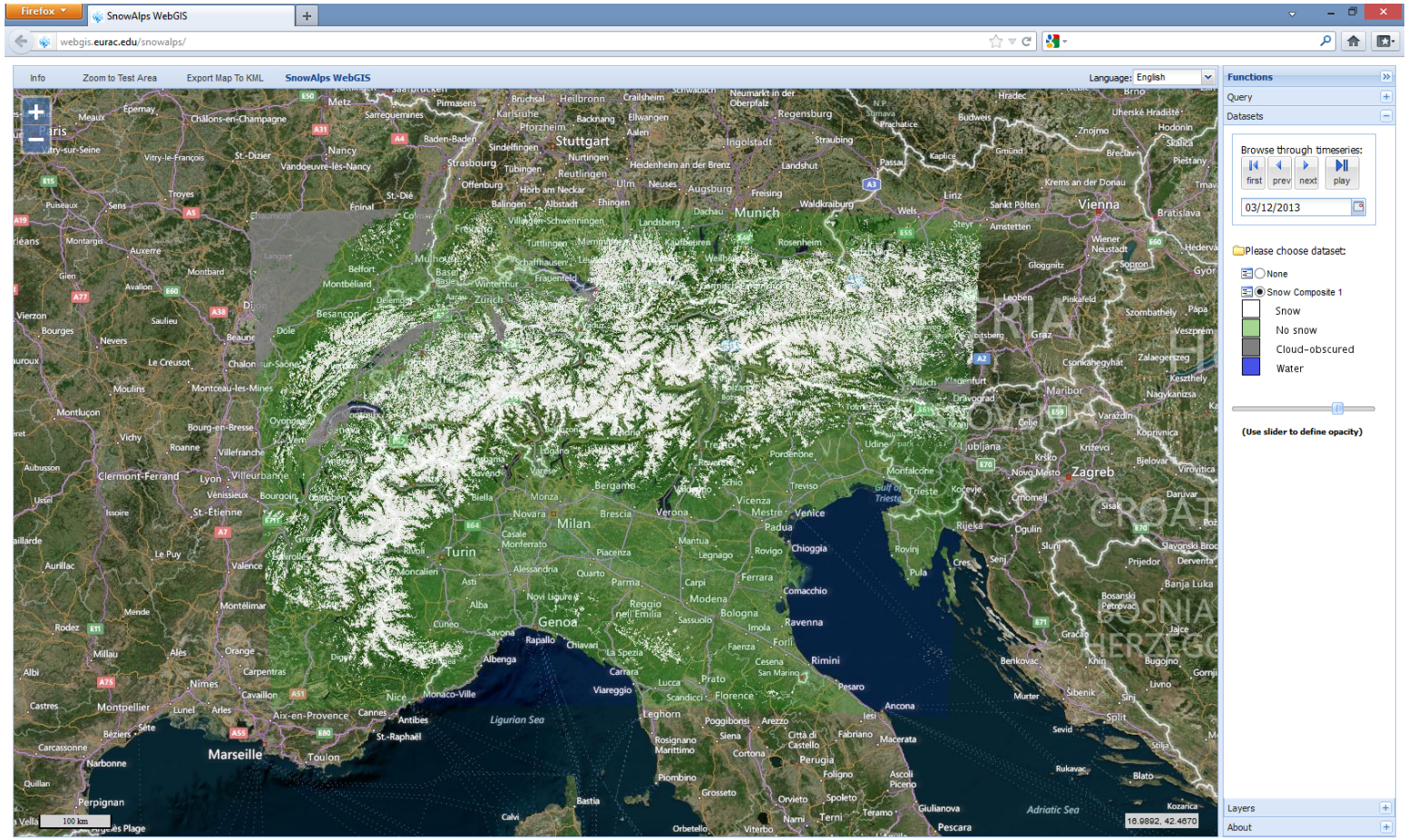


EURAC 250 m NASA 500 m RGB 500 m



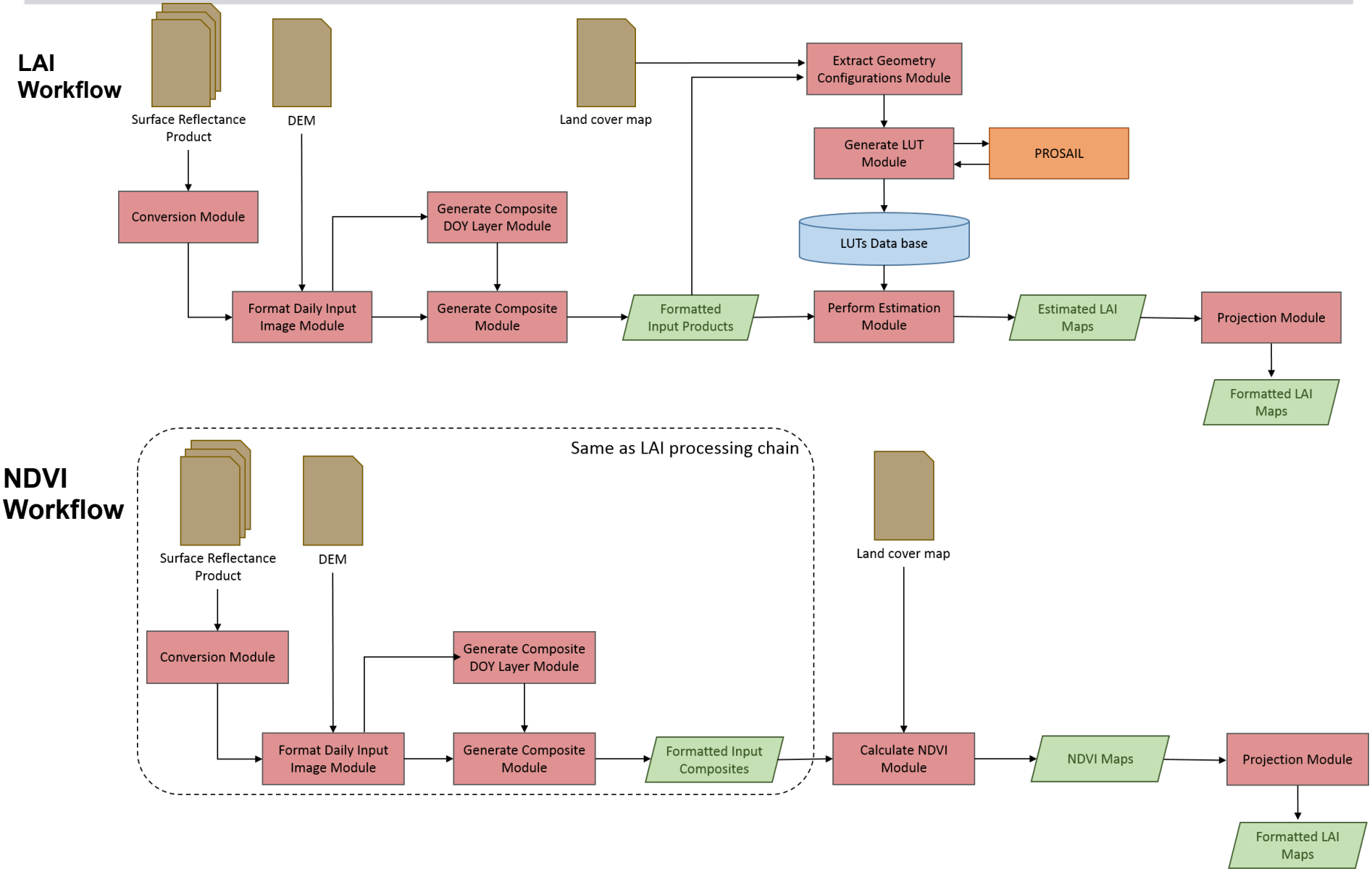
RMSE Landsat-NASA: 25%
RMSE Landsat-EURAC: 16%

Snow maps webgis EURAC

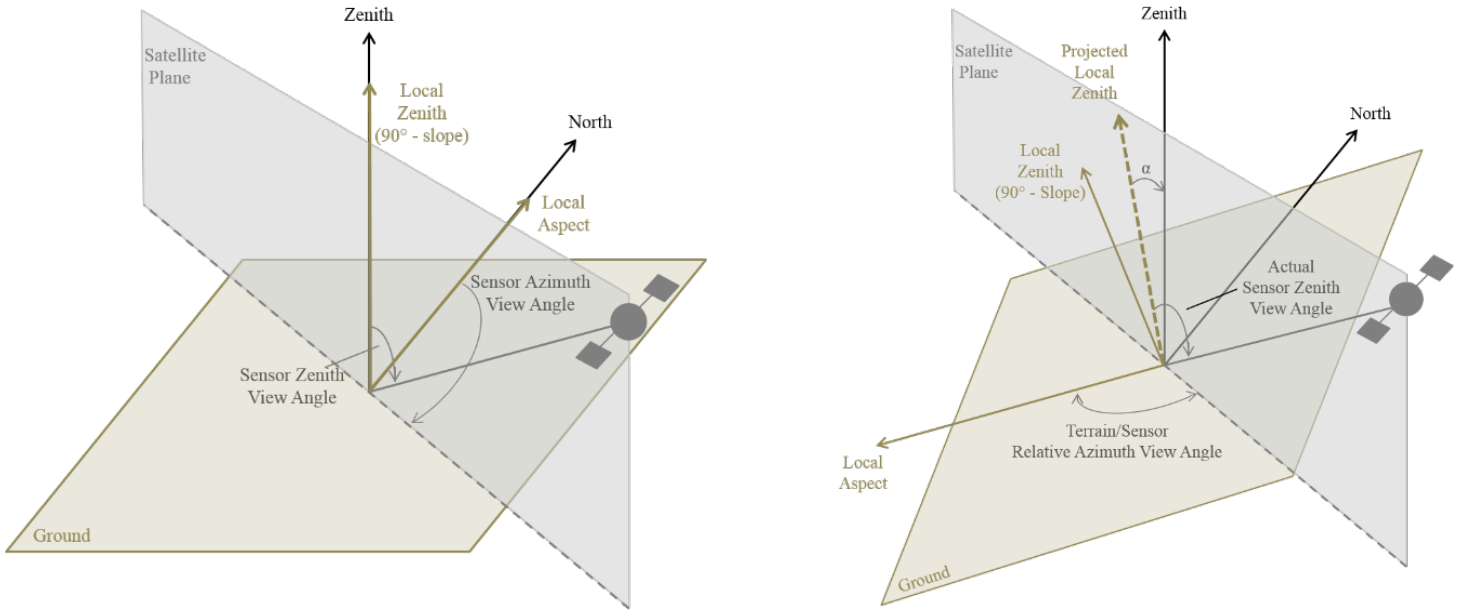


http://webgis.eurac.edu/snowalps/

Leaf Area Index (LAI) retrieval algorithm

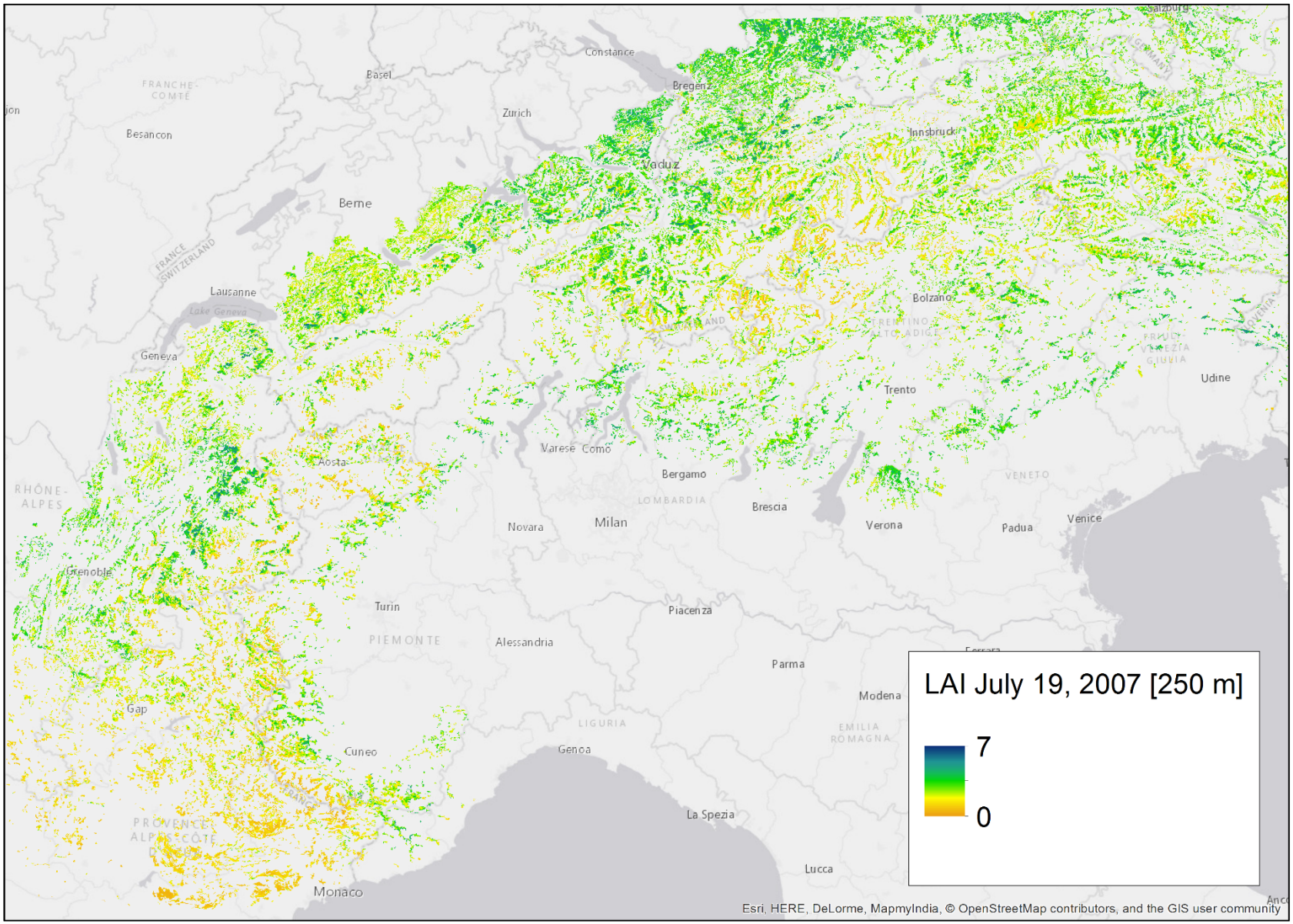


Correcting for terrain effect

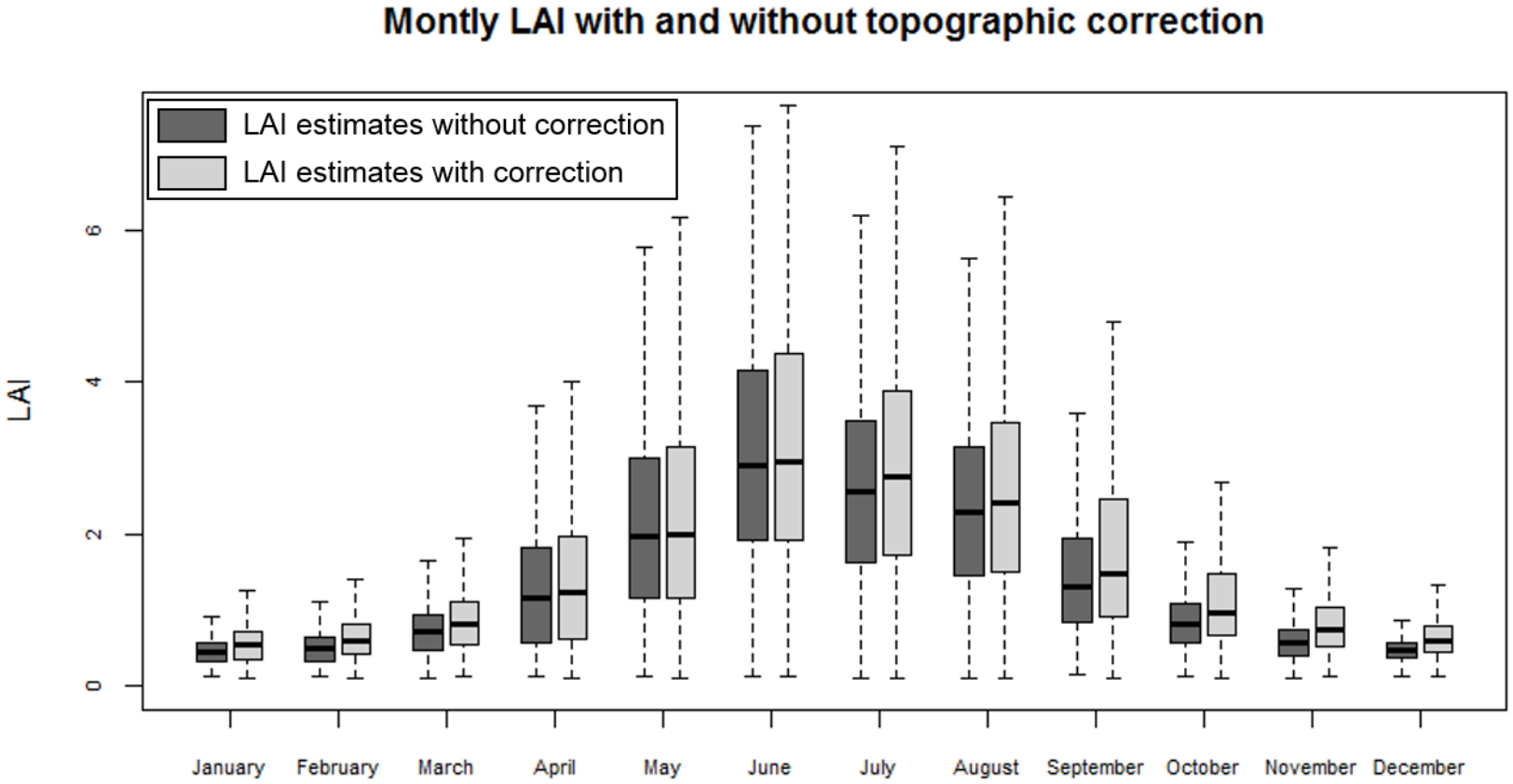


Representation of the sensor acquisition geometry in case of (a) horizontal surface and (b) inclined surface. Note that the same conditions hold for the sun illumination geometry.

LAI retrieval algorithm



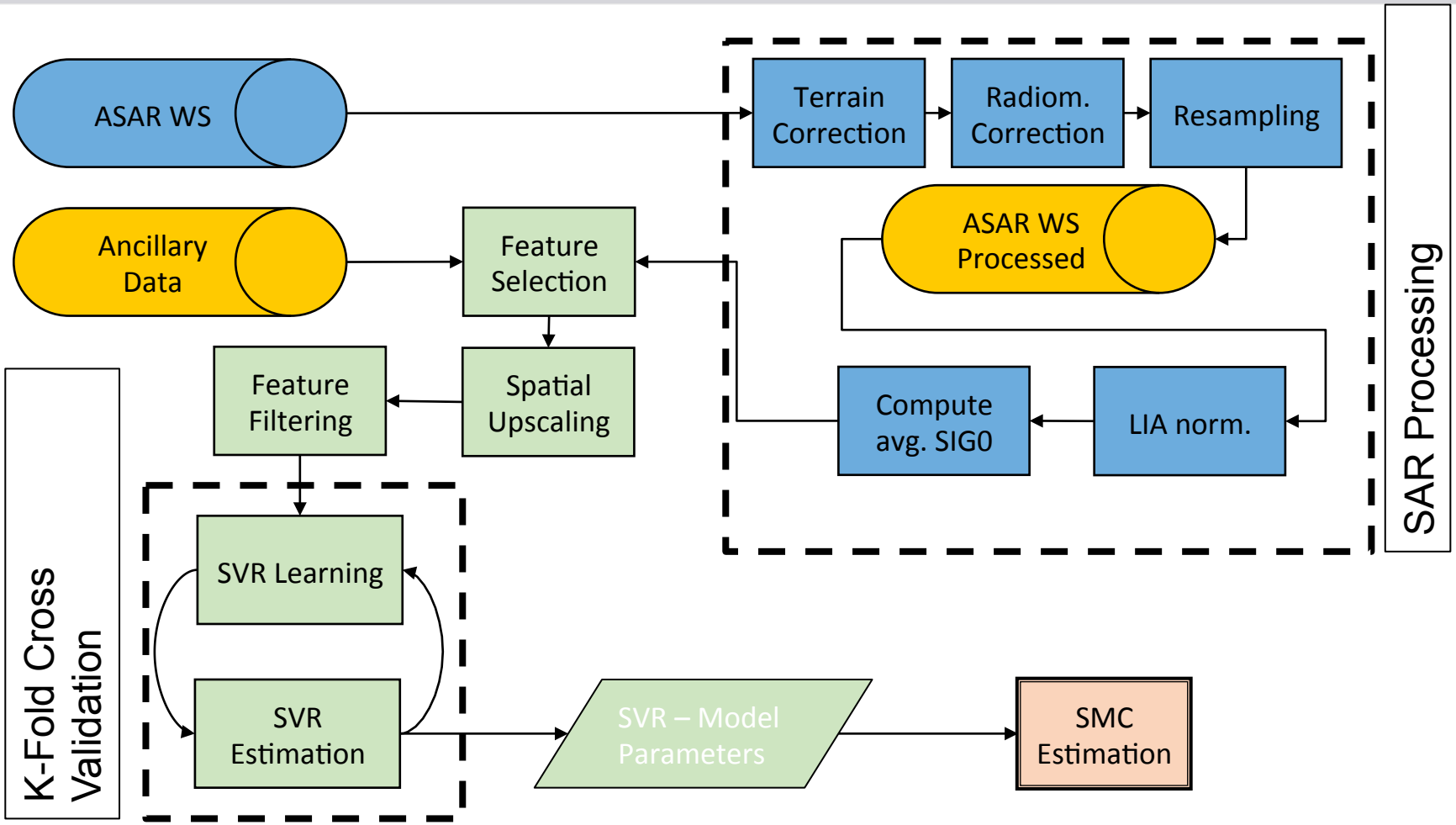
Main characteristics LAI product



Comparison with ground truth over different test sites for grassland and pasture ranges from 1.35 to 1.85 [m^2/m^2]. Considering all the years and the sites together, the metric equals 1.68 [m^2/m^2]. For MODIS standard products the metric ranges up to 2.5 [m^2/m^2].

Pasolli, L.; Notarnicola, C.; Bruzzone, L.; Zebisch, M.; Wohlfahrt, G.: Retrieval of Green Area Index in Mountain pasture and meadows from satellite MODIS imagery, *Remote Sensing of Environment,* 165 (2015) 159–174

Soil moisture retrieval algorithm



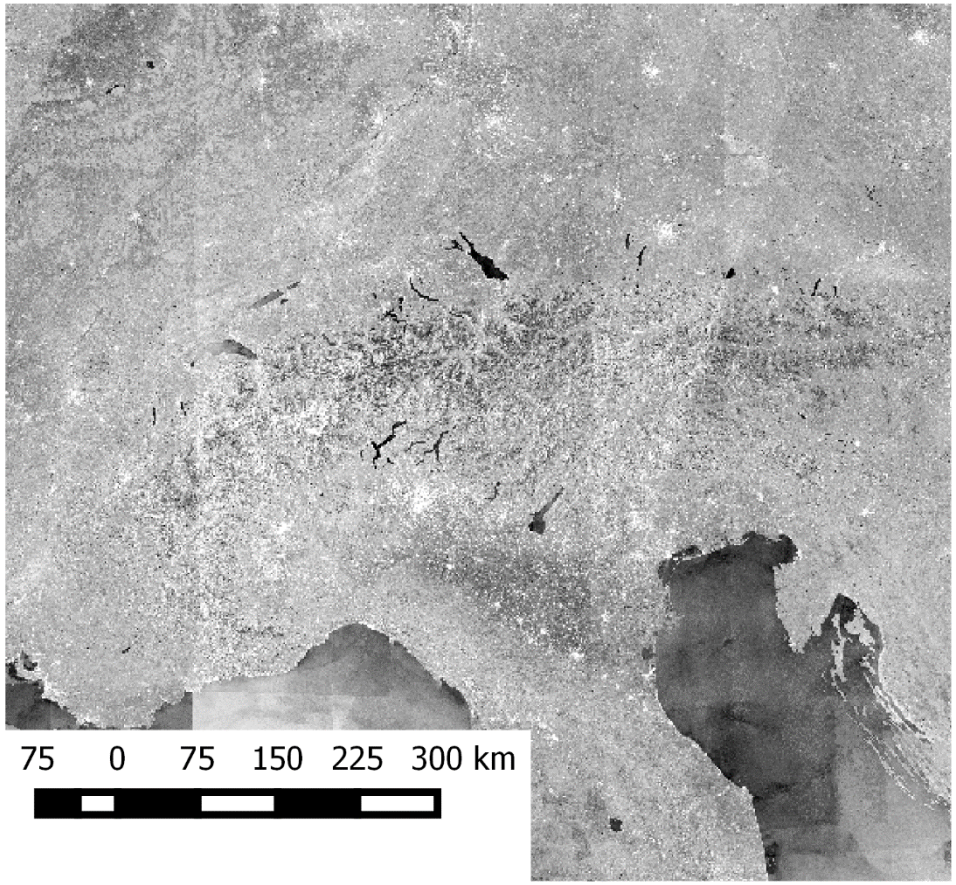
L. Pasolli, C. Notarnicola, G. Bertoldi, L. Bruzzone, R. Remelgado, F. Greifeneder, G. Niedrist, S. Della Chiesa, U. Tappeiner and M. Zebisch, Estimation of soil moisture in mountain areas using SVR technique applied to multiscale active radar images at C band, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 01/2015; 8(1):262-283.

Auxiliary data

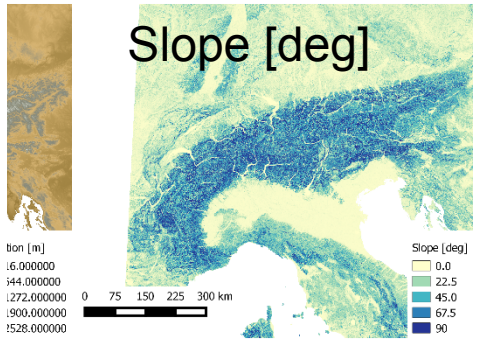
Reference Da
- Daily SMC

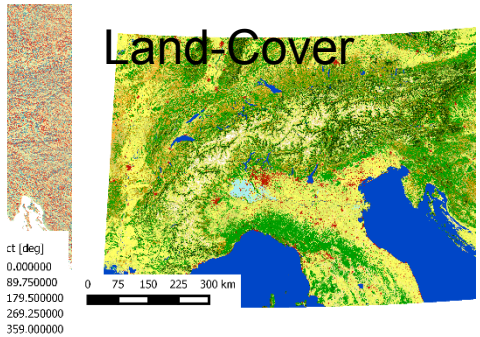
SRTM Digital
- Spatial resol
  - Elevati
  - Slope [
  - Aspect

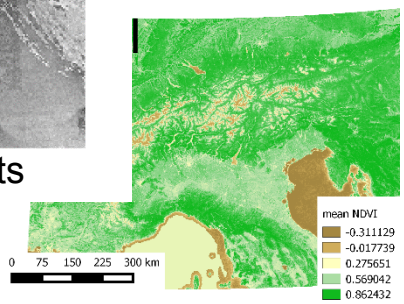
Further Ancill
- GLOBcove
- Normalized maps extra



Composite maps of backscattering coefficients



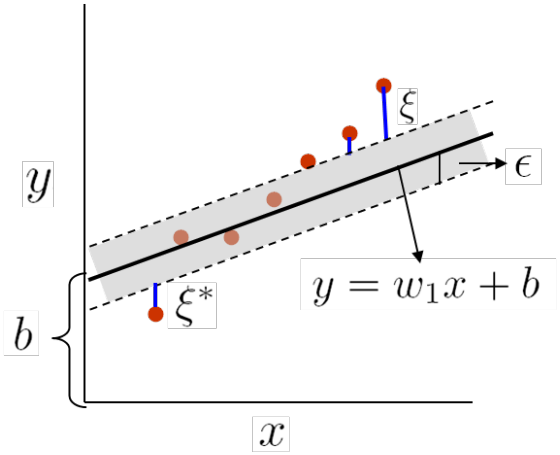




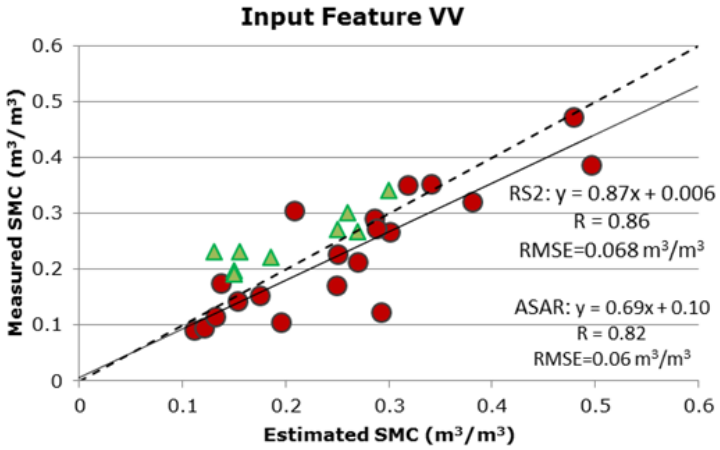
Method and Accuracy

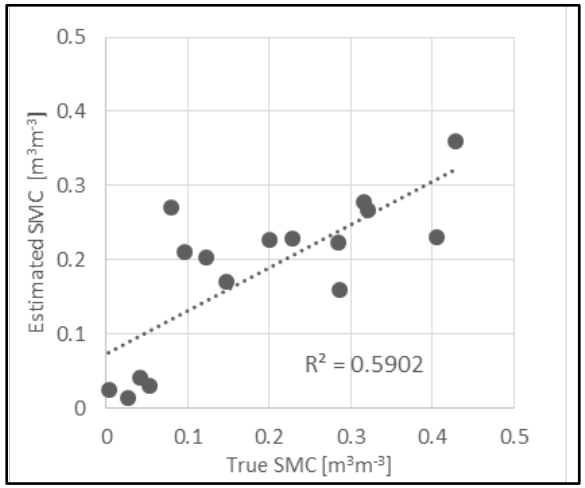
Machine Learning - Support Vector Regression (SVR)

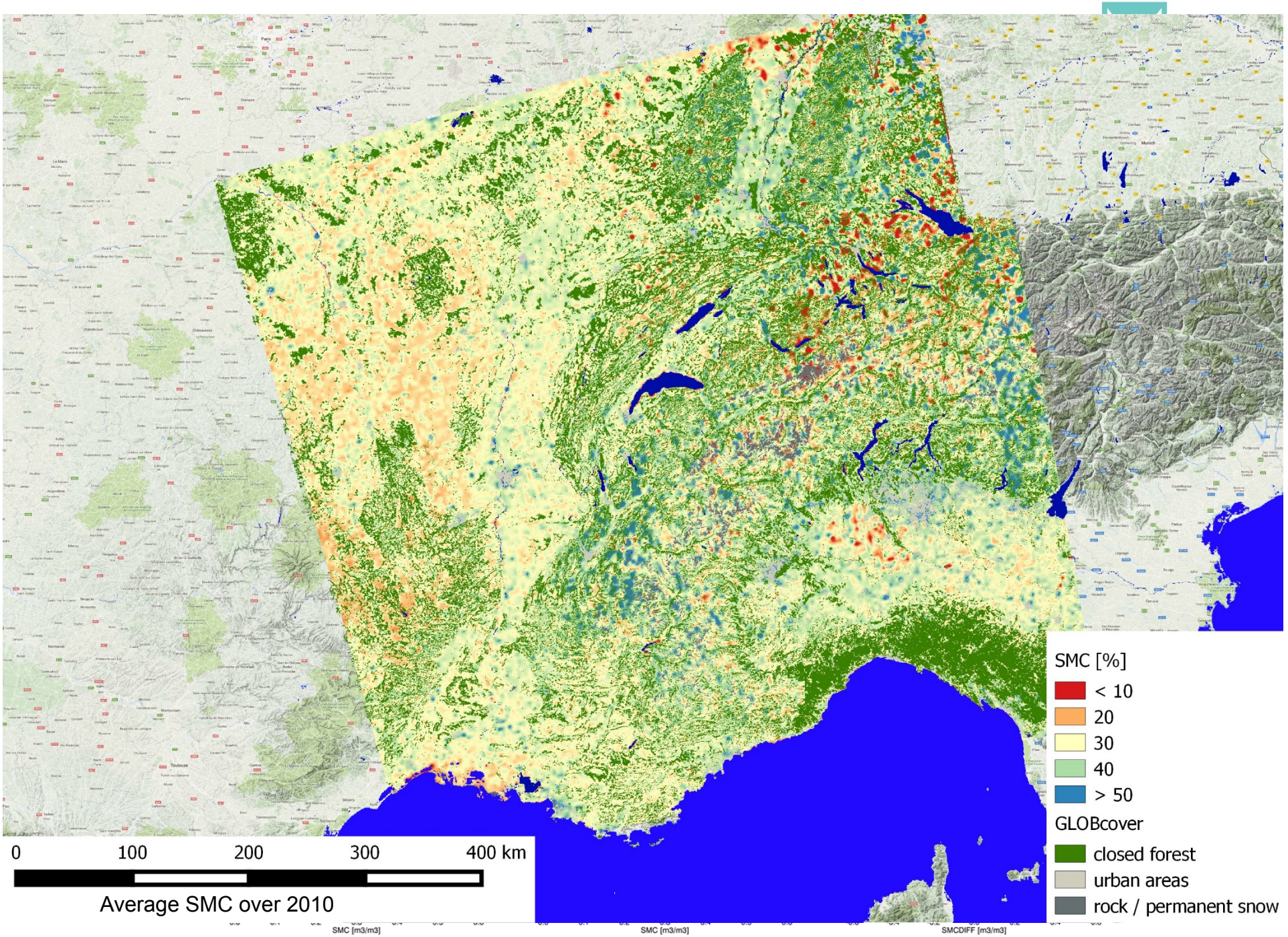
- Model relationship between measures SMC and input features
- Linear case:
- Minimize:
- „Kernel-trick" is used to map non-linear input to a higher dimensional feature space



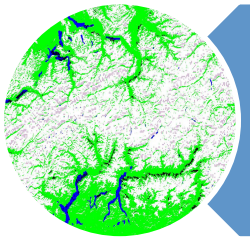
True vs. estimated soil moisture (Mazia Valley, IT)






SMC [%]
< 10
20
30
40
> 50
GLOBcover
closed forest
urban areas
rock / permanent snow
0
100
200
300
400 km
Average SMC over 2010
SMC [m3/m3]
SMC [m3/m3]
SMCDIFF [m3/m3]

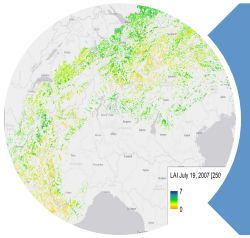
Derived parameters



Snow cover duration (SCD)

First snow fall (FSF)

Last snow day (LSD)



Phenology

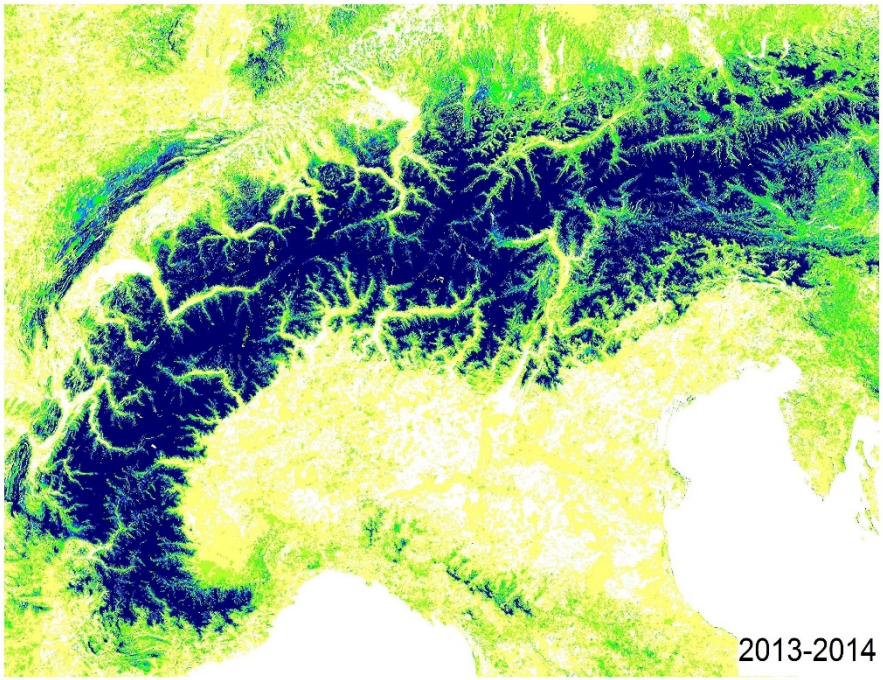
Start of the season (SOS)

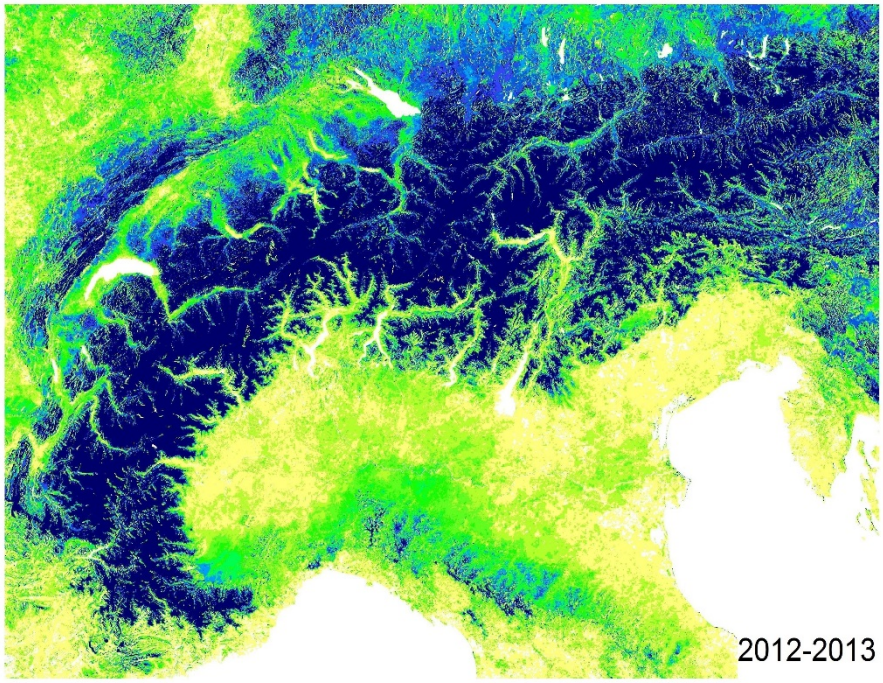
End of the season (EOS)

Anomalies over the 12 years available

Snow cover duration (SCD)

The Snow Cover Duration (SCD) have been calculated as number of snow days during the hydrological year for each pixel.



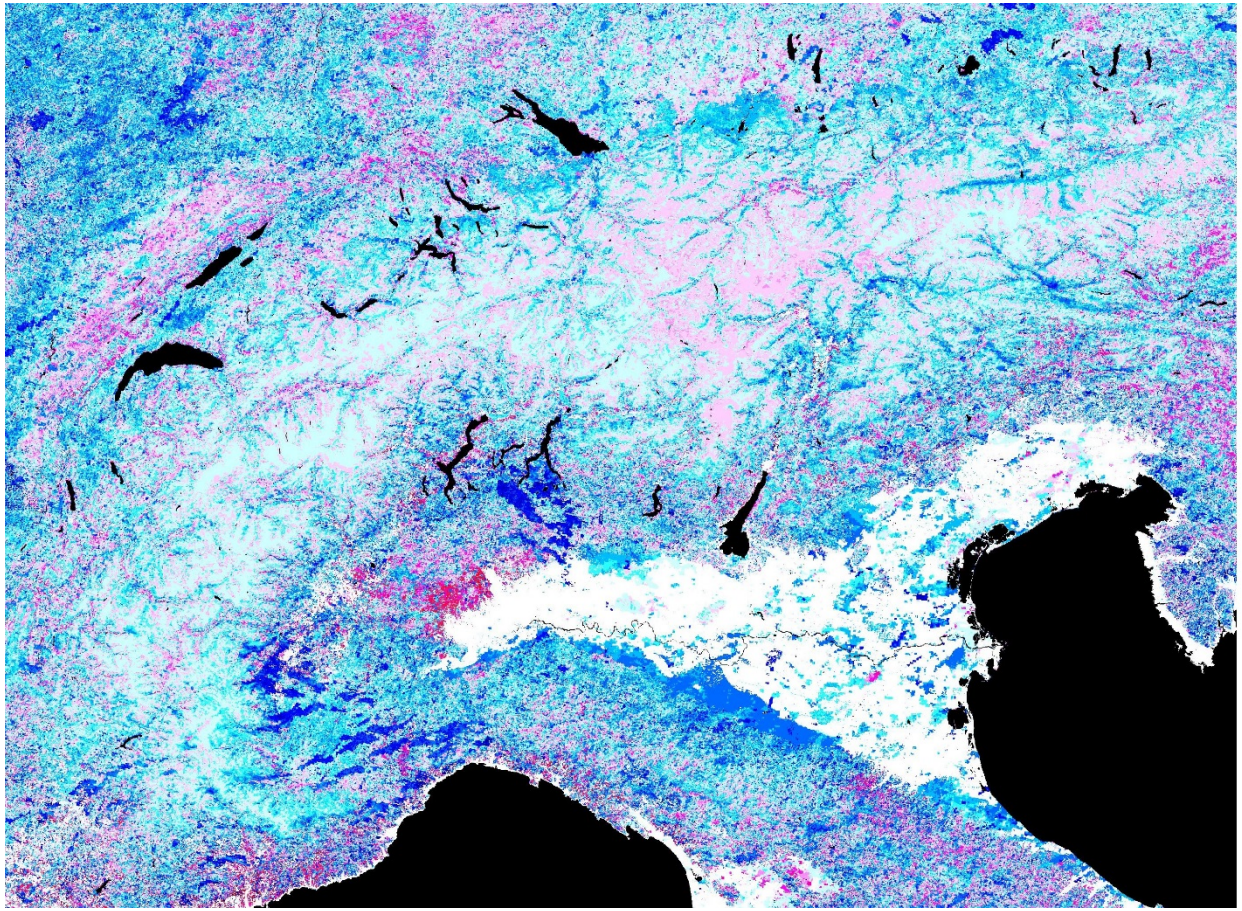


Snow Cover Duration (days)

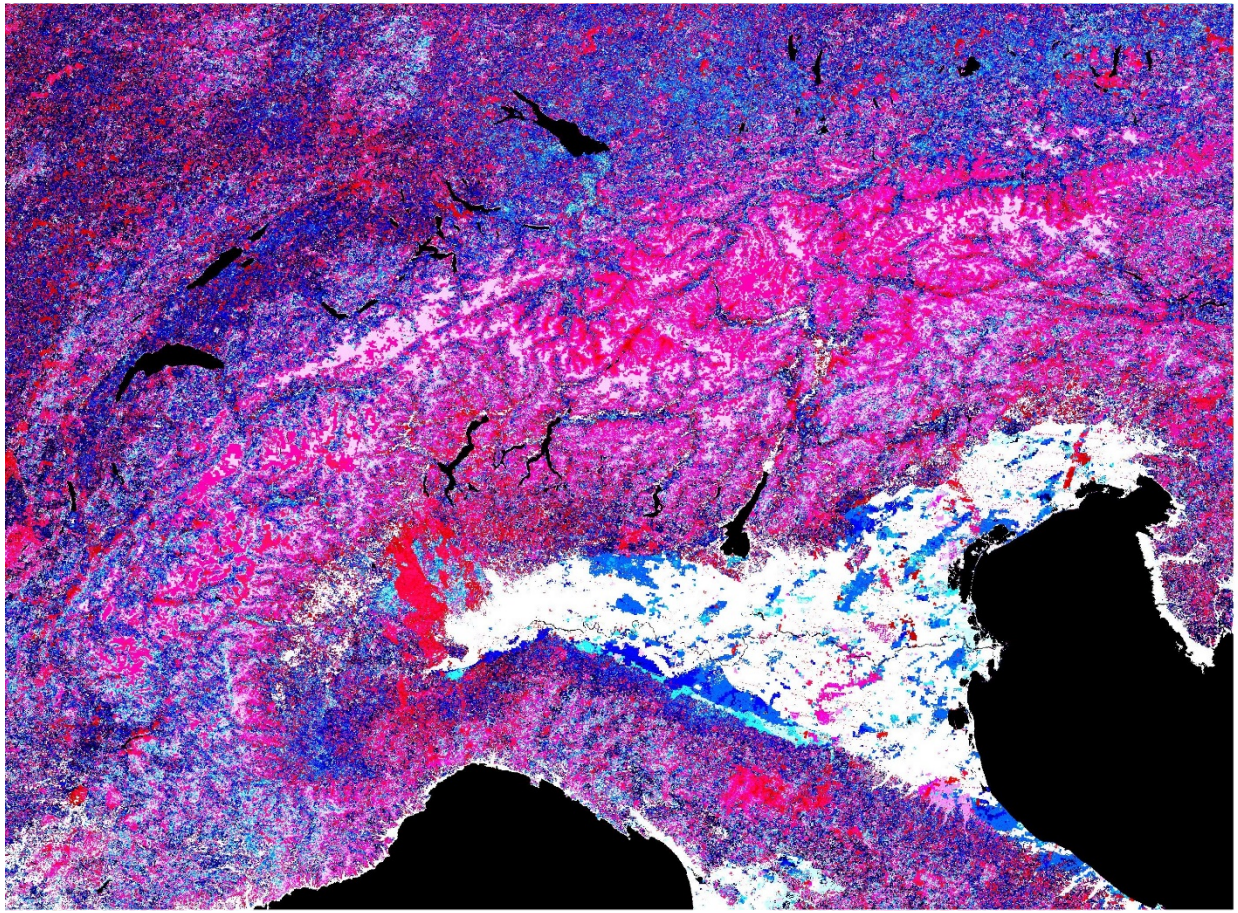
0-10 10-20 20-30 30-40 40-50 50-60 60-70 70-80 80-90 >90

Snow anomalies

The anomalies of first snow fall (FSF) day and last snow day (LSD) have been calculated for all hydrological years (1st October - 31st September of the following year) from 2002 to 2014 as difference between the average value over all years and the yearly value of FSF/LSD of each pixel.



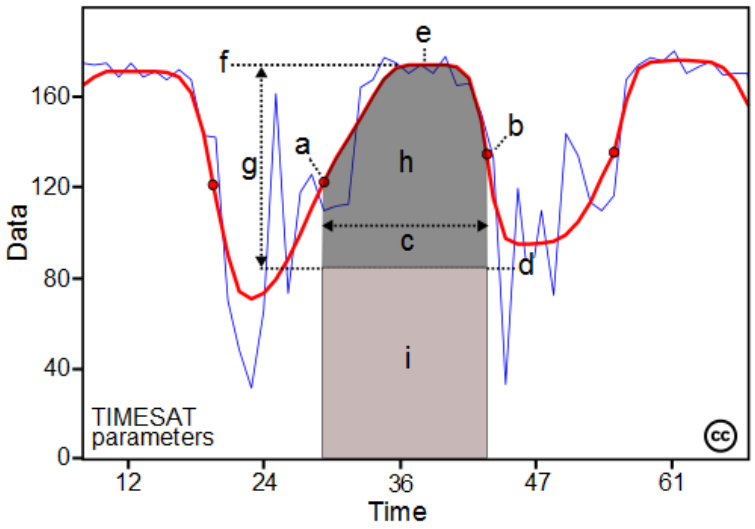
Snow anomalies

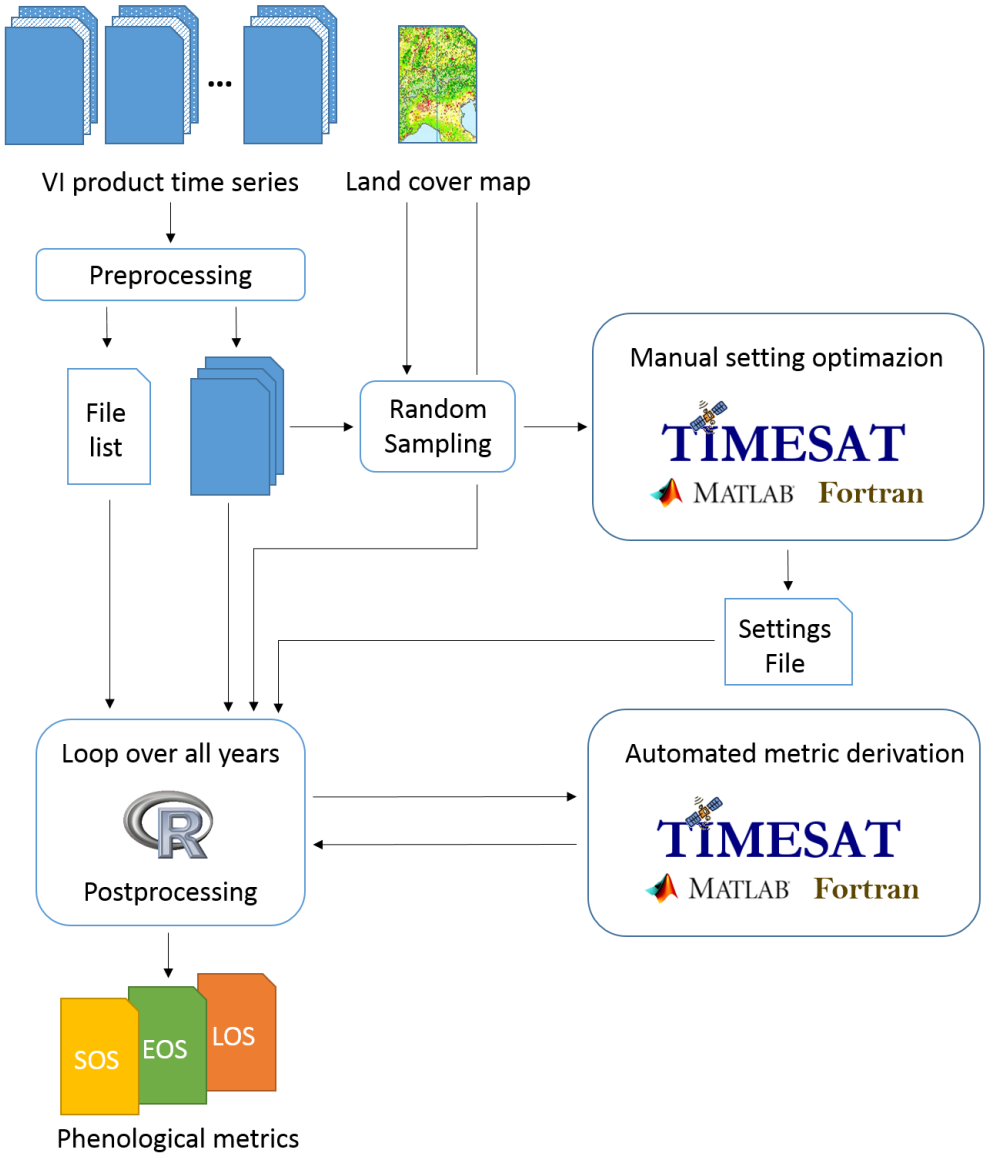


Last Snow Day anomalies 2010-2011

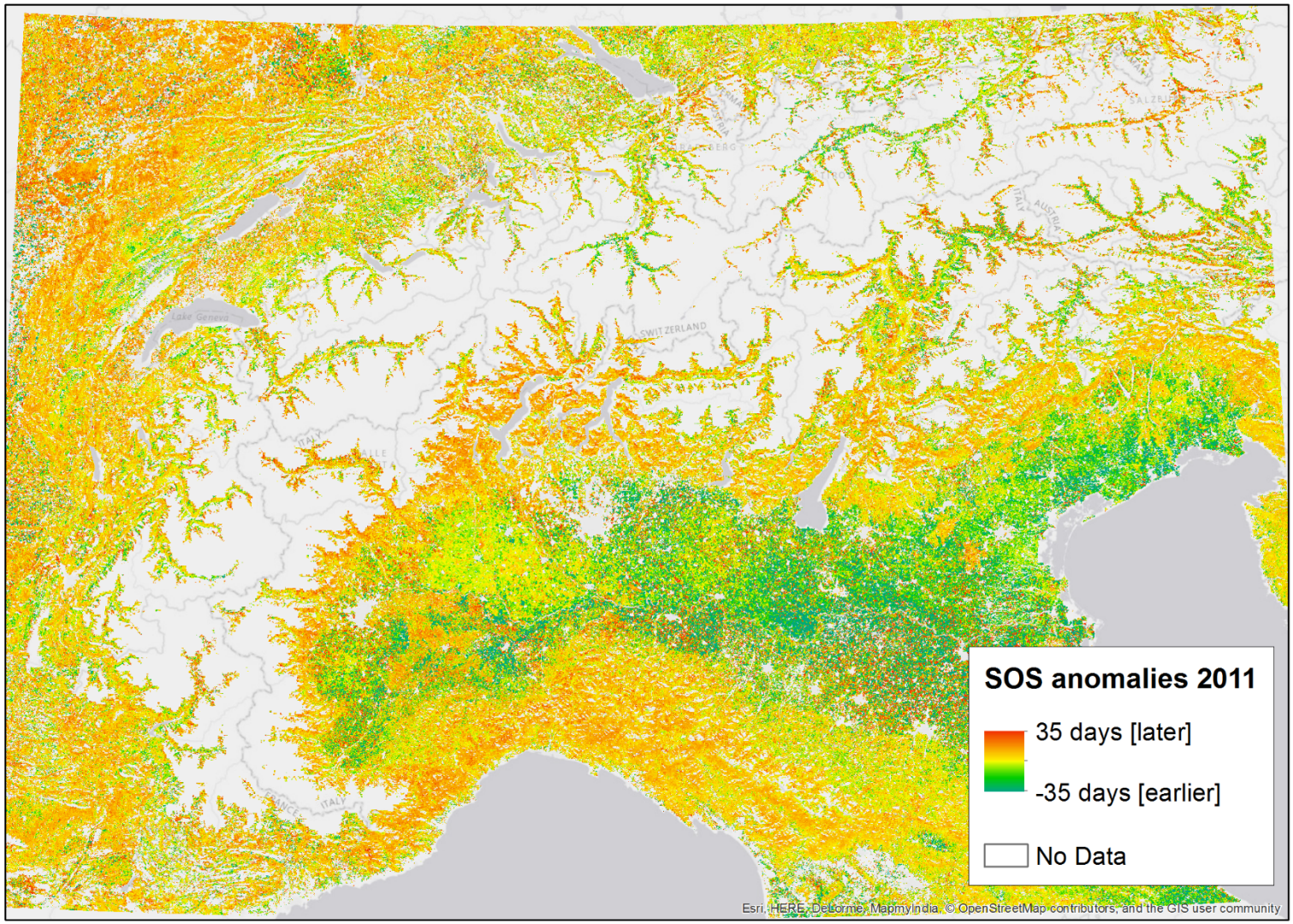
no data	water bodies
[-10;0]	[1;10]
[-20;-11]	[11;20]
[-30;-21]	[21;30]
[-50;-31]	[31;50]
[-70;-51]	[51;70]
[-90;-71]	[71;90]
[-110; -91]	[91;110]
< -111	> 111

Phenology workflow

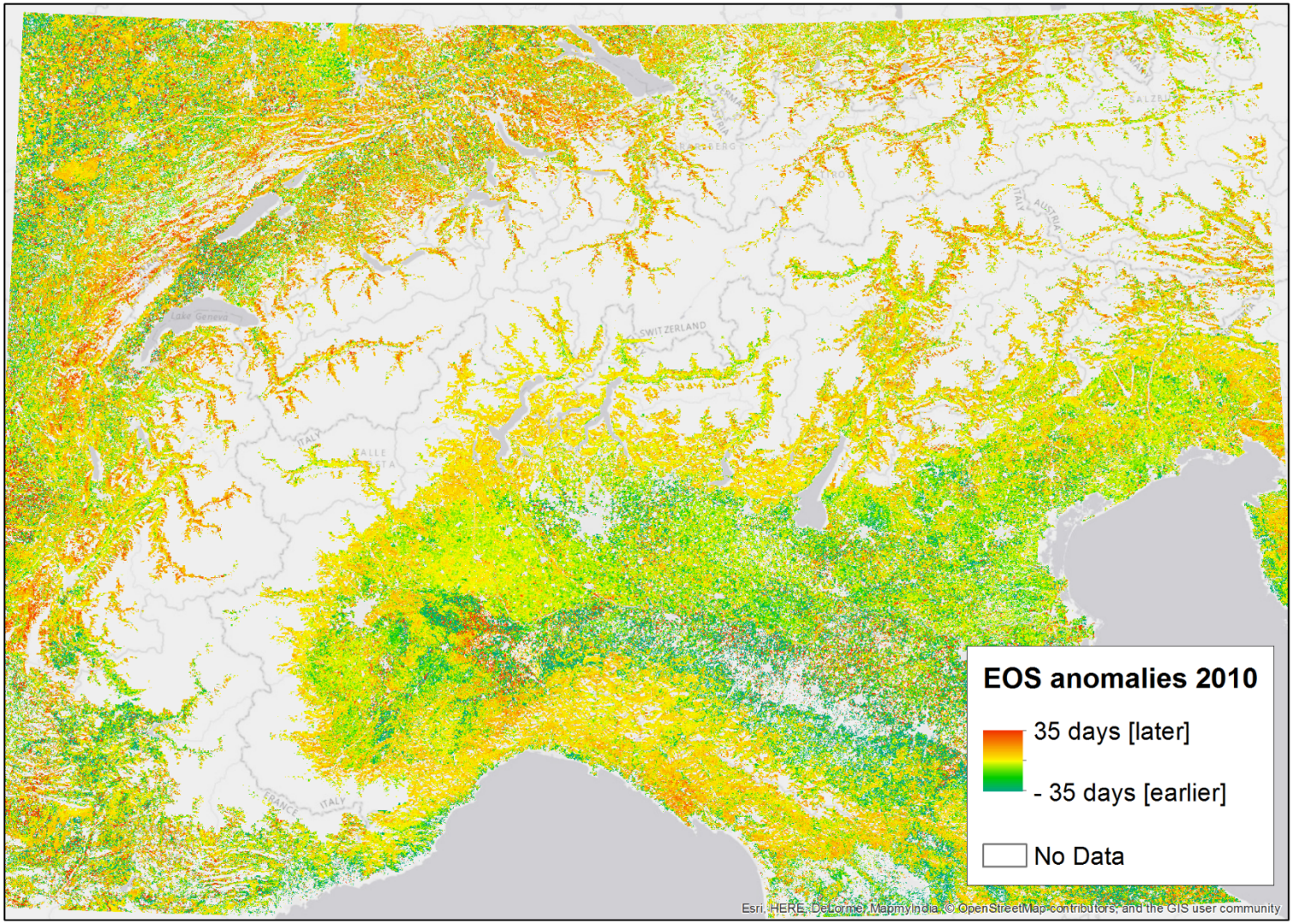




Phenology anomalies



Phenology anomalies



River discharge prediction

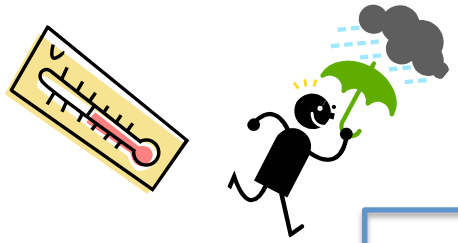
Objective:

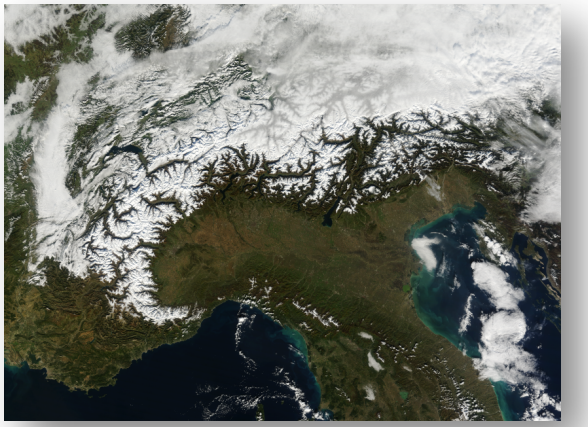
To estimate **monthly mean discharge** in **alpine catchments** with a prediction lag equal to 1, 3 and 6

Support Vector Regression used to predict the monthly discharge

In **alpine regions**, the **snow** accumulated in the basins plays the role of "water tower and it can provide relevant information for predicting the discharge

Snow cover area (SCA) is much easier to be estimated with respect to SWE
Test SCA time series as input feature in the SVR





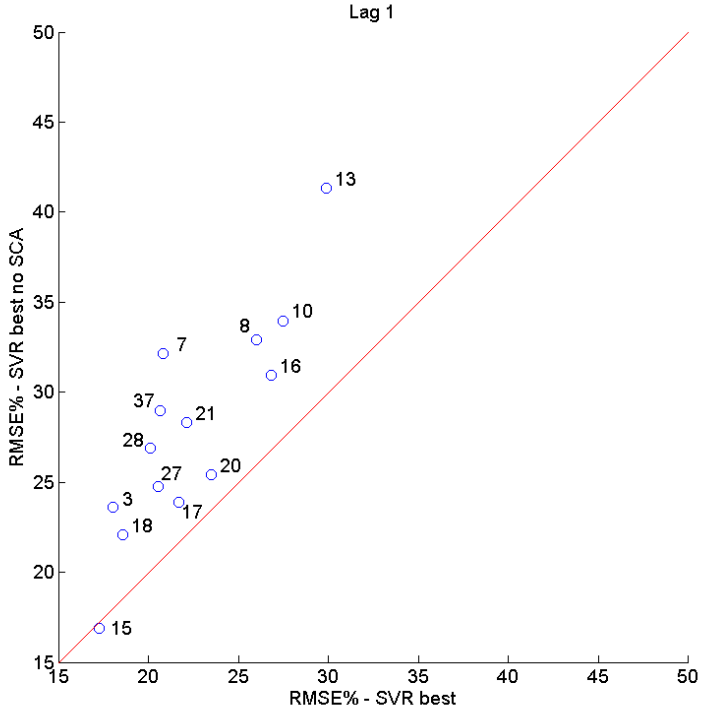
Estimated with SVR

$$Q(t+\Delta t)=f(Q(t),\ldots,Q(t-N),SCA(t),\ldots,SCA(t-M),meteoParams)$$

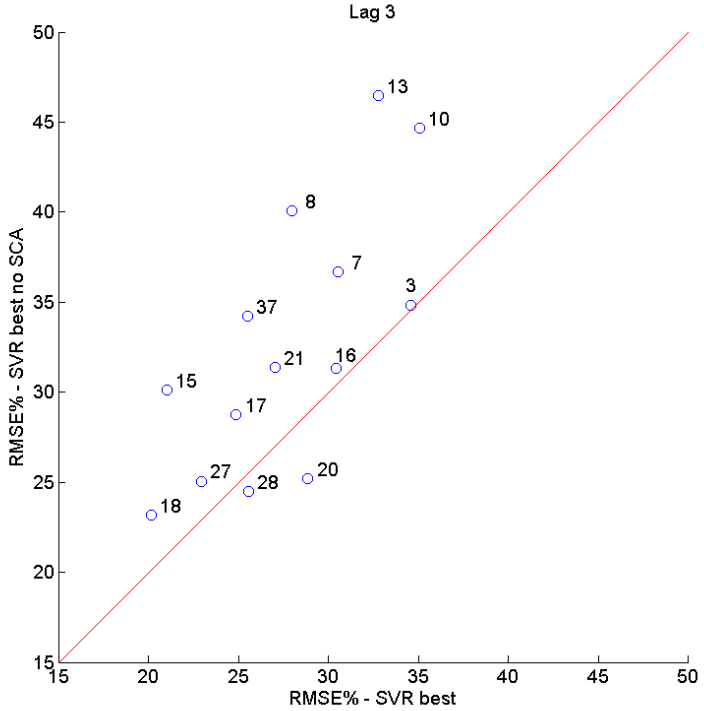
$$f(\boldsymbol{x})=Q(t+\Delta t)$$

Results: SCA importance

Prediction lag = 1 month



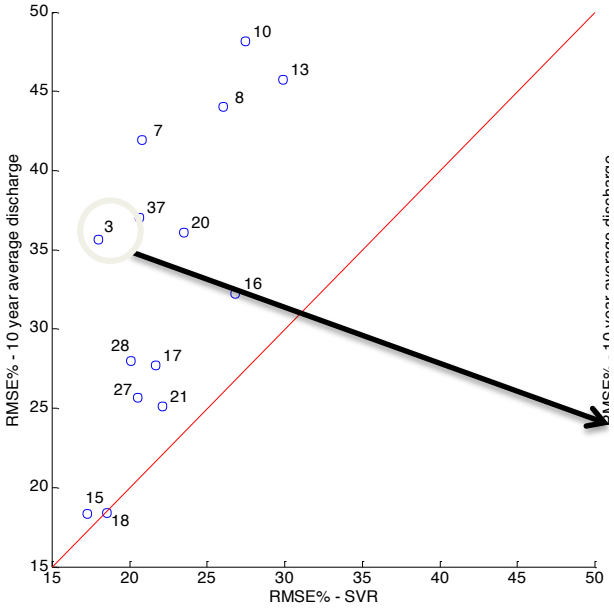
Prediction lag = 3 months



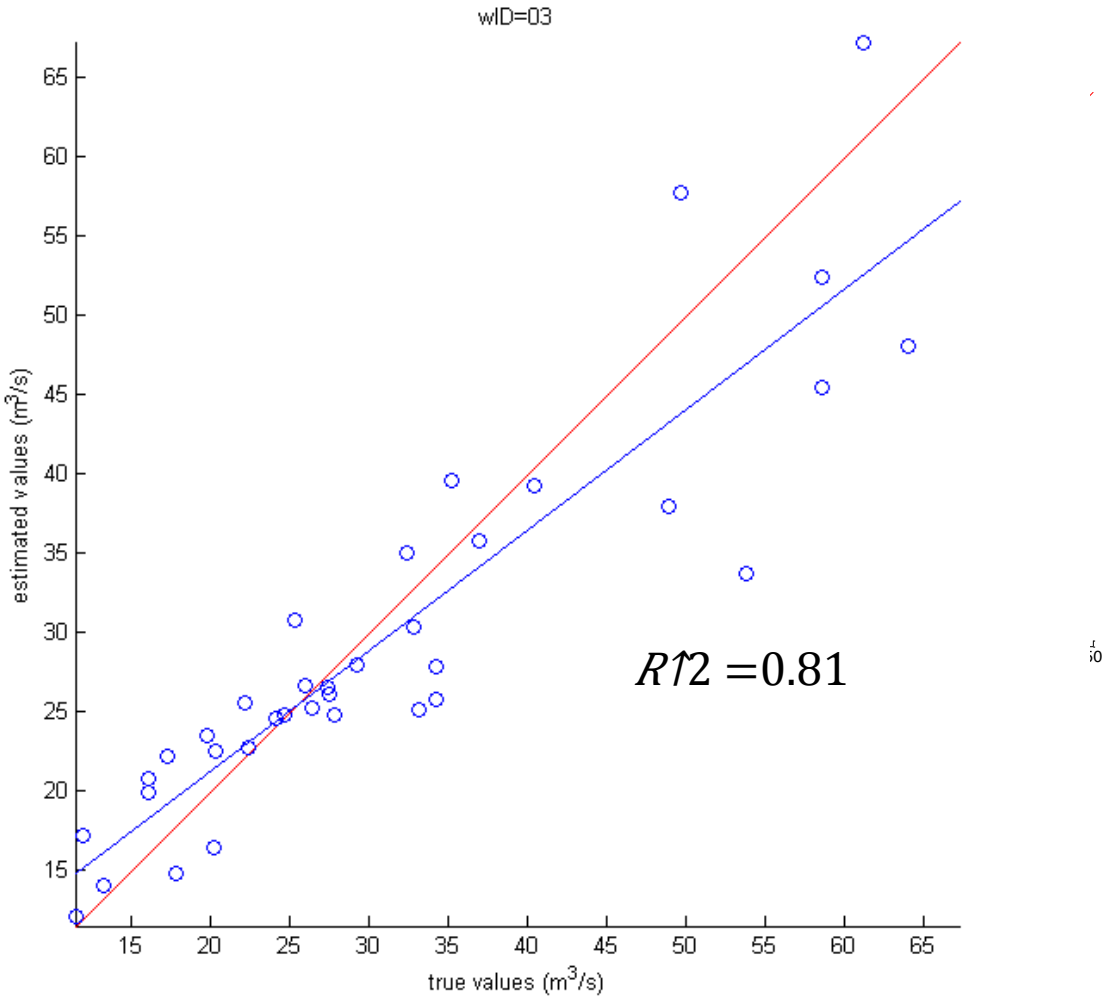
Prediction lag	Feature selected without SCA	Mean RMSE% without SCA	Feature selected with SCA	Mean RMSE% with SCA
1	disch-11:0, dischAvg10	28%	disch0, SCA-2:0, dischAvg10	22%
3	disch-10:0, dischAvg10	32%	disch0, SCA-1:0, dischAvg10	28%

Results: SVR / average comparison

Prediction lag = 1 month



PREDICTION LAG	FEATURE SE
1	disch0, SCA-2:0,
3	disch0, SCA-1:0,
6	disch-10:0, SCA0



Conclusions

- ✓ We have developed methods and generated products specifically tailored to mountain areas.
- ✓ The methods take into account the peculairities of mountain areas such as topography and landscape heterogeneity
- ✓ Snow cover and LAI maps have improved resolution (250 m) with respect to the standard MODIS products.
- ✓ Several derived parameters have been generated.
- ✓ These time series (snow, LAI) are made freely available to the scientific community. Soil moisture maps are still in preparation but will be available likely by end of the year.

Questions/comments?