Living Planet Symposium - Milan 13-17 May 2019

Validation of snow-estimation model with the help of Sentinel-2 images:

a case study for the HERASE project in Val Camonica

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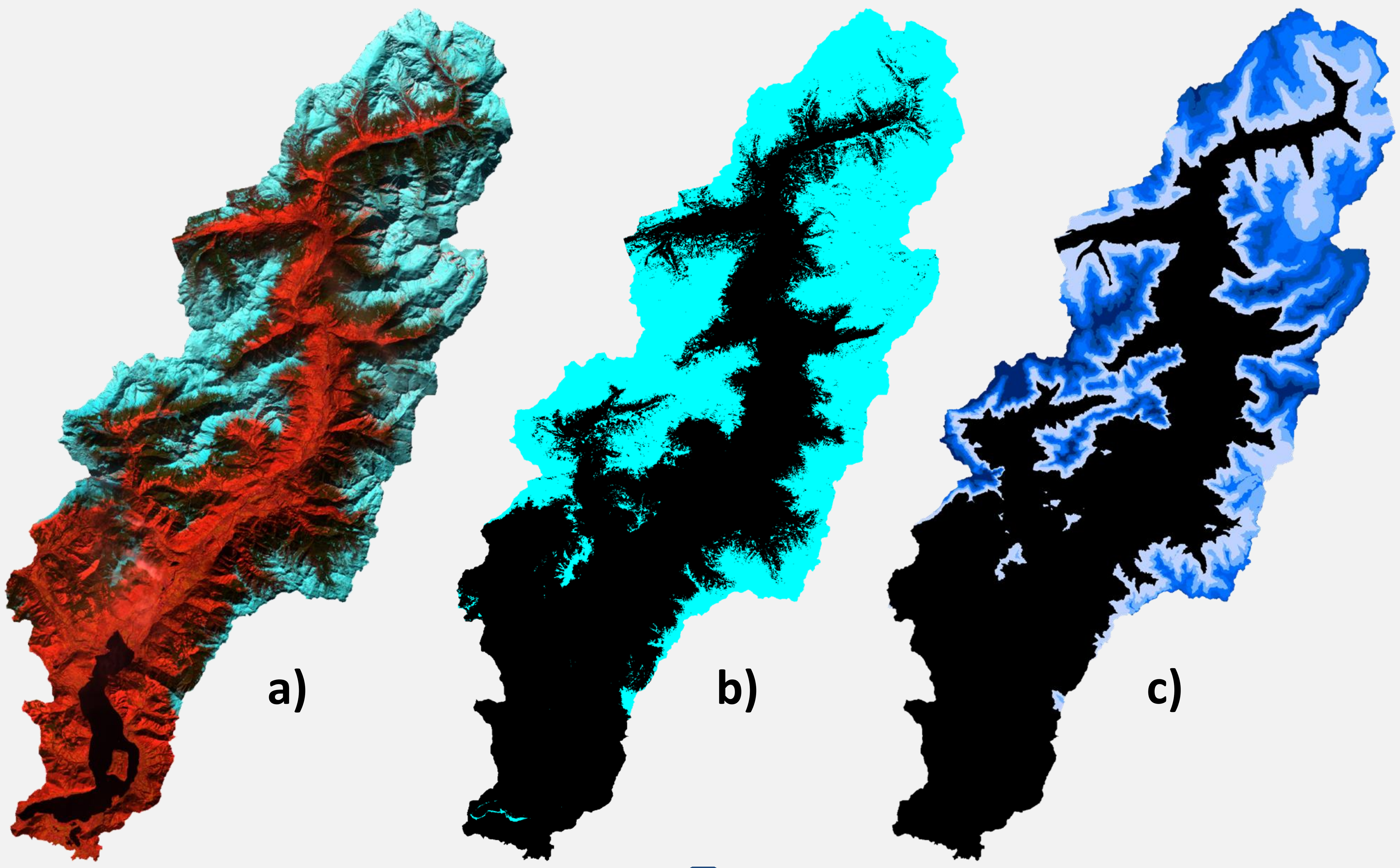
1 INTRODUCTION

- As a part of the HERASE project (a soil-erosion study in the Val Camonica area) a snow-water-equivalent (SWE) model is included.
- In this work we took advantage of the high revisiting time of the Sentinel-2 satellites, to compare the outputs of the model with the remote sensed images, with the goal of validating the model.
- 41 almost-clean images between September-2015 and the end of 2017, with snow covering more then the 2% of the entire sudy area, were selected and processed.



2 DATA

Satellite images	41 Sentinel-2 (A and B) images (2015-2017)	ESA
Digital Elevation Model (DEM)	Shuttle Radar Topography Mission product at full resolution of 1 arc-second (~30m)	NASA
Meteorological data	Rain and Temperature data from 2015 to 2017	Regione Lombardia
Land Cover Map	DUSAF 2015	Regione Lombardia

3 SATELLITE PROCESSING

Atmospheric correction

Mosaicking

Snow classification

$$\begin{cases} NDSI > 0.4 \\ NDSI > 0.3 \text{ and } NDVI > 0.1 \\ Green\ reflectance > 2.5\%^{*} \end{cases}$$

**Rigg & Hall method: Green reflectance > 10%, but due to the topography of the study area, with strong shadows, a lower threshold was required*

Cloud Masking

$$\begin{cases} Blu\ reflectance > 30\% \\ SWIR\ (b11)\ reflectance > 30\% \\ SWIR\ (b12)\ reflectance > 30\% \\ NDSI < 0.3 \end{cases}$$

4 SWE MODELING

- At each time step the SWE model is updated, pixel by pixel, as a function of the local temperature and the measured precipitation.
- At the same day and time of the 41 Sentinel-2 images the state of the model is saved as an image output (**fig-1 c**).

$$SWE_t = SWE_{t-1} + \begin{cases} +\min\left\{\max\left\{0; \frac{T_{sup} - T_t}{T_{sup} - T_{inf}}\right\}; 1\right\} \times i_t \text{ IF } i_t > 0, \\ -\min\{\max\{0; C_m \times (T_t - T_m)\}; SWE_{t-1}\} \text{ IF } i_t = 0 \end{cases}$$

SWE_t [mm] is the snow water equivalent;
T_t [°C] is the air temperature;
T_{inf} [°C] is the temperature below all the precipitation is snow (T_{inf} = -3 [°C]);
T_{sup} [°C] is the temperature above all the precipitation is rain (T_{sup} = 0 [°C]);
T_m [°C] is the temperature above snow melting starts (T_m = 0 [°C]);
i_t [mm h^{-1}] is the measured precipitation by the rain gauge (=rain+snow);
C_m [mm h^{-1} °C^{-1}] is the snow melting rate (C_m = 0.18 [mm h^{-1} °C^{-1}]).

5 METHODOLOGY

- Comparison, at the same date, between satellite-derived snow masks (**fig-1 b**) (assumed as the true values) and the results of the model (**fig-1 c**). The area is considered covered by the snow, according to the model, if **SWE > 0.5 mm**.
- Confusion matrix between satellite-derived snow masks and model outputs (Snow-covered areas = 1, Not Snow-covered areas = 0)

		Model Output	
		0	1
Satellite Mask	0	A	B
	1	C	D

Accuracy indices:

$$\begin{cases} F_{Score} = \frac{2D}{B + 2D + C} \\ Over - estimation = \frac{B}{C + D} \\ Under - estimation = \frac{C}{C + D} \end{cases}$$

6 RESULTS

Analysis results for the entire dataset (41 images)

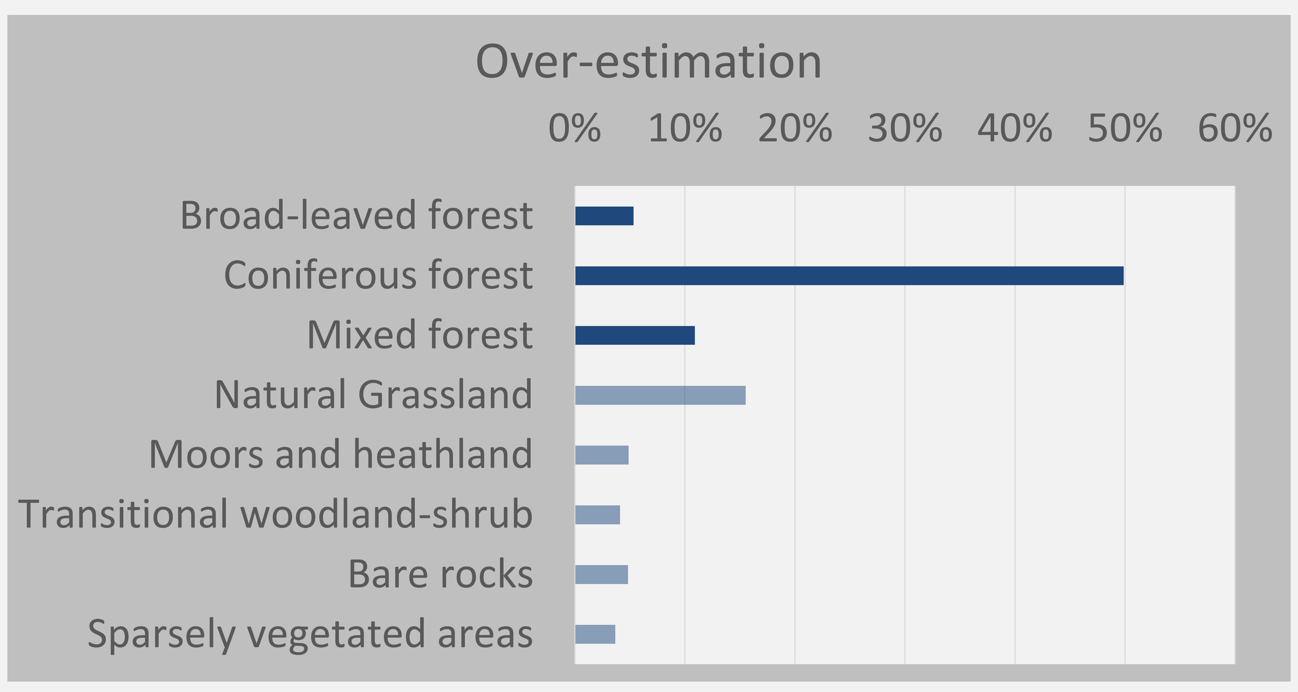
- **Average F-Score = 0.565751**
- Average Under-estimation = 0.4212**
- Average Over-estimation = 0.265625**
- 23/41 images Under-estimation > Over-estimation
- 18/41 images Under-estimation < Over-estimation

Only with images acquired in 7 days after a snowing event registered by snow-gauges (21 images)

- **Average F-Score = 0.754774**
- Average Under-estimation = 0.180744
- Average Over-estimation = 0.34435
- 8/21 images Under-estimation > Over-estimation
- 13/21 images Under-estimation < Over-estimation

**Parameter strongly affected by a set of 7 images where, due to extremely high temperature in winter, the model melted all the snow.

Over-estimation



7 CONCLUSIONS

The results show that the model is well capable of predicting the areas where snow has fallen, while its accuracy decrease when the melting process starts to be relevant. On this purpose the follow-up of the study is to find the best set of parameters of the model, to better describe the melting process, while keeping the model as simple as it is. The fact that the over-estimation is prevalent on forested areas may be explained with the fact that tree branches prevent the satellite from sensing the snow covering the ground. In this sense the error may be in the satellite-derived mask, assumed as the true value.

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ACKNOWLEDGEMENTS This work is part of the project *Hydrogeological modeling for Erosion Risk Assessment from SpacE* (HERASE), funded from Fondazione Cariplo for the years 2017-2019 (Grant Nr.2016-0768). Authors thank also: i) Parco dell'Adamello and Comunità Montana della Val Camonica for their support and interest in the project and for supplying useful data; ii) Regione Lombardia Territorial Office (Brescia) for information and data on the study area. iii) ENEL Production for data on sediment deposition rates within their dams. iv) Servizio Glaciologico Lombardo for its help.