H SAF CDOP-3
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Final report

Validate and use HSAF products (H11, H12/H35) in order to characterize / identify snowmelt-driven floods and droughts

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REPORT: Validate and use HSAF products (H11, H12/H35) in order to characterize / identify snowmelt-driven floods and droughts

1 Project tasks

The estimation of snow cover extent, snow water equivalent and wetness of snow mantle are important parameter in the context of hydrology as they give fundamental information on the water which will be available during the melting season in snow-influenced catchements. An accurate estimation of such parameters make it possible to properly forecast floods, droughts, and wet snow avalanches in such catchments.

In this context, H SAF, which provides products and data sets for operational hydrological applications, could be of great help. In particular, the project aims at assessing which are the benefits that H SAF snow products (H11, H12, and H35) can provide in snow-hydrology, also investigating applications at different spatial scale. The outlined project steps are:

1. comparison of H SAF products with Sentinel-1 observations in different snow-influenced regions over the Alps. The considered case study is the Mallero basin, in province of Sondrio;
2. comparison of H SAF products with snow parameters (snow cover extent, snow wetness, and snow cover) simulated by the Hys snow model;
3. use of HSAF products to identify catchments with different mechanisms of floods and droughts, within Po river basin.

2 Case study

2.1 Mallero basin

The Mallero basin (see Fig. 1.b) is a middle size catchment, 320 km^2 wide, with altitudes that range from 282 to 4018 m a.s.l.. We considered such a case study because it reflects the main features, in size and flow regime, of snow melted driven basins. In fact, Mallero basin has a hydrological regime mostly dominated by snow melting and glacier ablation during spring and summer seasons. A reliable assessment of the snow wetness and snow water equivalent, at each day of the melting season is hence essential in this basin for hydrological purposes. For the melting season of year 2017, we led a comparison of H11 and H13 products. We compared the H11 with (1) snow dynamic simulations from HyS model, and (2) Sentinel-1 data. H13 products were instead compared just with the simulations of HyS model. In the following we will provide a brief description of the different products (HSAF, HyS model, and Sentinel-1). We will then describe results on the maps comparisons, underlying advantages and drawbacks.

2.2 Po basin

The Po valley (see Fig. 1.a) is the biggest water catchment in Italy, with an area of 71 000 km^2. It includes a large portion of Alps, with altitudes up to 4500 m a.s.l. The mountain part (where altitudes are higher that 1000 m a.s.l.) covers about the 25% of the total catchment. The snow mantle, as well glaciers, are a huge water resource for the whole basin, and the flow regime is highly affected by the snow mechanisms. For this case study we considered the melting season of year 2021 and we compared H35 products (providing effective snow cover) with simulations from HyS model. The HyS model simulations were performed by using the spatial resolution of H35 products.

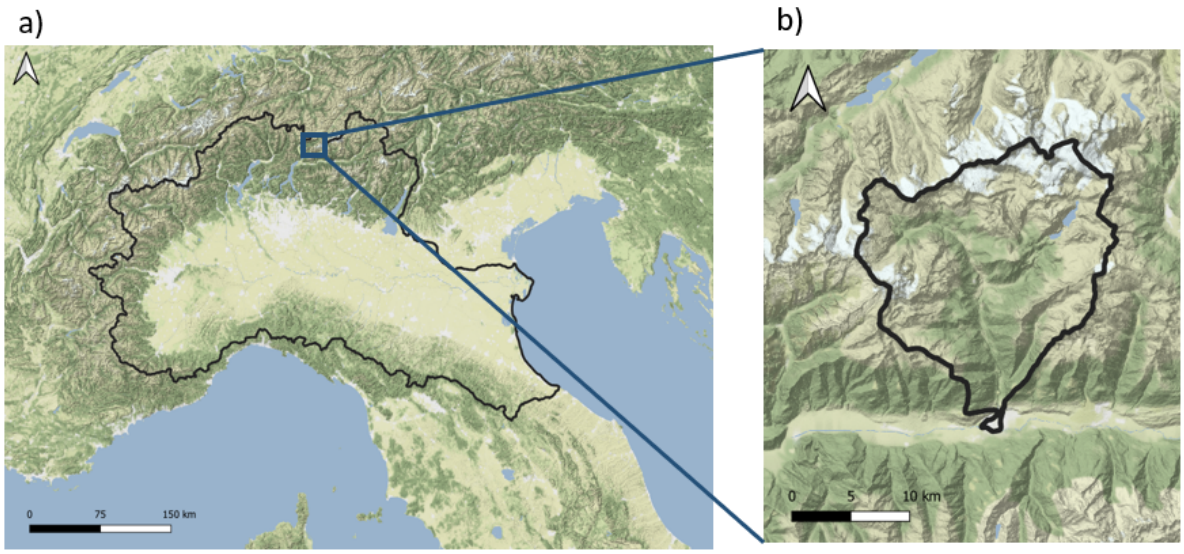

Figure 1: Contour of Po basin, in panel a), and Mallero basin, in panel b).

3 Snow products

HyS model

HyS is a local model developed in [4, 3] to predict the dynamics of bulk volumetric liquid water content during a snow season. For this work, we implemented it in a distributed way in order to make it capable of investigating the spatial distribution of the snow dynamic all over the basin. We applied the distributed version of HyS model with a spatial resolution of 100 m x 100 m, which is a trade-off between an acceptable computational time and a resolution sufficient to detect the snow cover spatial variation in a middle-size catchment as the Mallero basin is. The model's outputs are various snow parameters in each cell of the 100 m x 100 m grid among which we can mention the snow depth, the bulk volumetric liquid water content, the bulk snow density, and the snow water equivalent. Maps of wet-dry snow can be created assuming a threshold on bulk volumetric liquid water content above which the snow is considered to be wet and viceversa. We selected a threshold equal to 3% according to the International Classification of Seasonal Snow on the Ground [5].

Sentinel-1 products

For pre-processing of Sentinel-1 data (Level-1 GRD products in IW mode) and wet-dry snow maps retrieval we referred to two different approaches:

1. the first methodology is the most common used and is based on thresholding. A reference image is acquired in a period when it is most likely that there is no no snow on the ground. Then backscatter ratios of the melting period images versus the reference one are computed. Wet areas are those where such a ratio is below a defined threshold (here is set equal to -3), viceversa when the ratio is above the threshold the area is defined as dry. This approach just gives a binary information. The whole methodology is well explained in [6];

2. this methodology provides a stochastic approach to map wet snow probability occurrences. It was proposed in [1] and applied in [2]. The method relies on a soft threshold providing a probability that the difference between the backscattering coefficient and the reference image is due to wet snow in the pixel:

$$F(x) = 50 - 50\tanh\left[a(x = 3)\right] \tag{1}$$

   where x is the difference in backscattering coefficient and a is a steepness factor (here set equal to 0.75).

Please note that the resolution of sentinel-based images is very high, about 25 m x 25 m. We resampled the wet-dry snow maps at a resolution of 100 m x 100 m to make them comparable with the HyS model-based maps.

H11 products

The H11 (WS-E) products reveal the status of the snow mantle wetness, in time series all over Europe. The wet-dry snow retrieval algorithm is based on thresholding. Maps resolution is 0.25 degree x 0.25 degree (from 10 to 27 km), which is quite a coarse resolution, in particular if exploited for hydrological applications at middle-scale catchments.

H13 products

The H13 (SWE-E) products give information on the snow water equivalent derived from MW measurements sensitive to snow thickness and density. Resolution of maps is 0.25 degree x 0.25 degree, the same of H11 products.

H35 products

H35 (ESC-H) products (that are pre-operational) contain maps of effective snow cover obtained from VIS/IR radiometry, which is based on multi-channel analysis of the AVHRR instrument onboard MetOp satellites. Effective snow cover in HSAF products is generated at pixel resolution, by exploiting the brightness intensity that is the convolution of the snow signal (highest) and the fraction of snow within the pixel. The spatial resolution of the maps is high, equal to 0.01 x 0.01 degrees.

4 Results and discussion

4.1 H11

From the description of the H11 and Sentinel-1 snow products it is evident the huge difference in spatial resolution. In particular Sentinel-1 offers very high resolution products whereas the H SAF have a resolution of 3 orders of magnitude lower. This specifically may have consequences on the capability of giving accurate information on the snow mantle parameters at the spatial scale of a middle-size basin. In Fig. 2 we report the comparison among the three dry-wet maps resulted from the products described above, for a single day (April 05, 2017) of the melting season. Please note that the Sentinel-derived map (Fig. 2.c) is binary as it is produced through the first approach. It is immediately evident the good comparison between HyS and Sentinel-1 derived maps on the area which is classified as covered by wet snow, despite the second one seems to detect a higher portion of wet snow covered area. On the other side, the coarse resolution of H SAF derived map does not allow to give any information, neither quantitatively nor qualitatively. In fact, the two H SAF pixels covering the Mallero basin area are classified as bare soil probably because the largest portion of that is without snow. However, the actual snow covered area, which is proved to exist from the other two maps (HyS and Sentinel-1), is not negligible for hydrological forecasting during the melting season, as the melted snow is the biggest contribute to the flow at the outlet section of Mallero basin. A spatio-temporal comparison is then provided in Fig. 3. Considering the time series from March, 2017 to June, 2017 we reported the percentage of the Mallero area covered by wet snow, with the three products. For H SAF we can observe that just two conditions occur. The first occurs when the two pixels covering the area are identified as bare soil or dry snow, so that the estimated percentage is 0. The second occurs when one of the two pixels is detected as wet snow. In this case the percentage is 50%. It does not happen that wet snow is detected simultaneously in the both the pixels. Moreover for 22 days, the H SAF do not provide information due to cloud covering. Regarding Sentinel-1, we provided a shaded area, rather than a single line, using methodology 2. This area lies between two curves. For the lower curve we assumed as wet snow covered those pixels in which the estimated probability of having wet snow was higher than 5%. For the upper curve we instead considered a probability higher than 50%. We selected these thresholds as they are the most commonly used in literature [2]. The HyS-based curve matches, most of the time, the shaded area, with just the exception of some days in April, where the model does not identify wet snow areas. Here again the comparison with H SAF estimates shows that they are not particularly informative from a quantitative point of view.

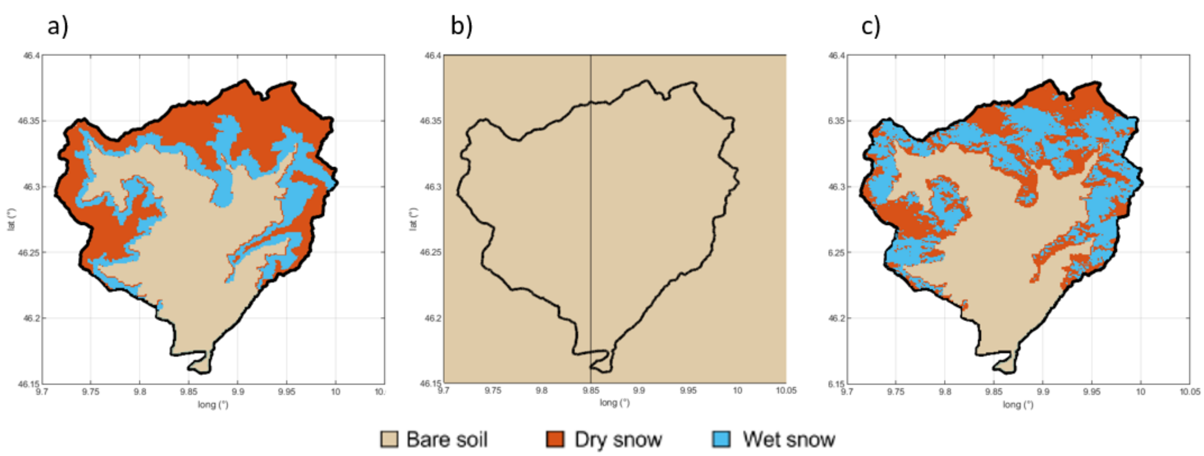

Figure 2: Comparison among wet-dry snow maps from April 05, 2017. From panel a) to c) maps from HyS model, H SAF products, and Sentinel-1 (methodology 1) are respectively reported.

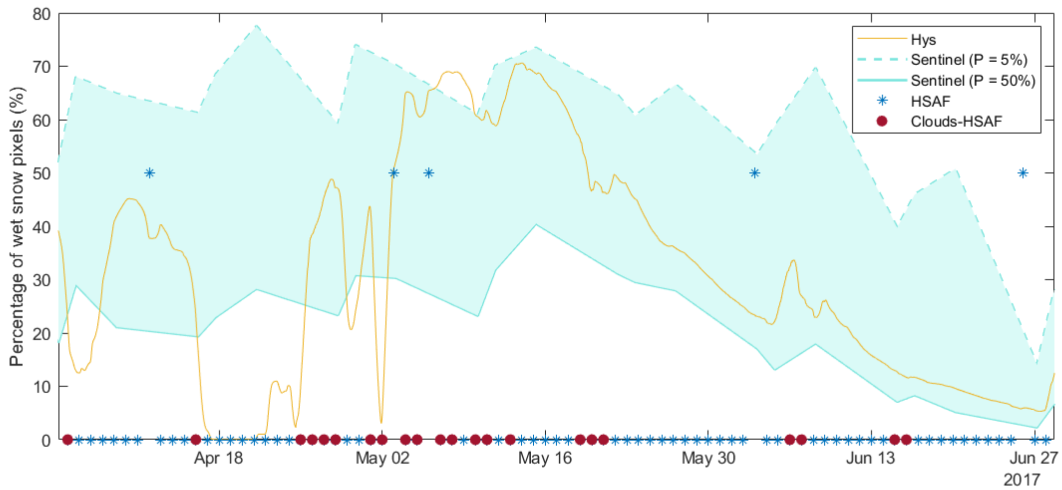

Figure 3: Time series of percentages of Mallero area covered by wet snow. The percentages are calculated from HyS model, H SAF products, and Sentinel-1 (methodology 2).

4.2 H13

The second comparison was lead on SWE products. In this case we just compared HyS model simulations with H SAF products, for the Mallero basin. In Fig. 4 are reported the two SWE maps referring to March 1, 2017. Again, it is evident the great difference in resolution, even if the order of magnitude of SWE estimates seems comparable. This means that qualitative information on SWE can be derived from the H SAF products, at small catchment scale. The time series of average SWE calculated all over the Mallero basin area are reported in Fig. 5. For the first 3 months of the time series (March, April, and May, 2017) we can observe a similar behaviour of the SWE values even if there is a downward shifiting of H SAF-based estimates with respect to the HyS-based ones. During June and July the two time series completely mismatch.

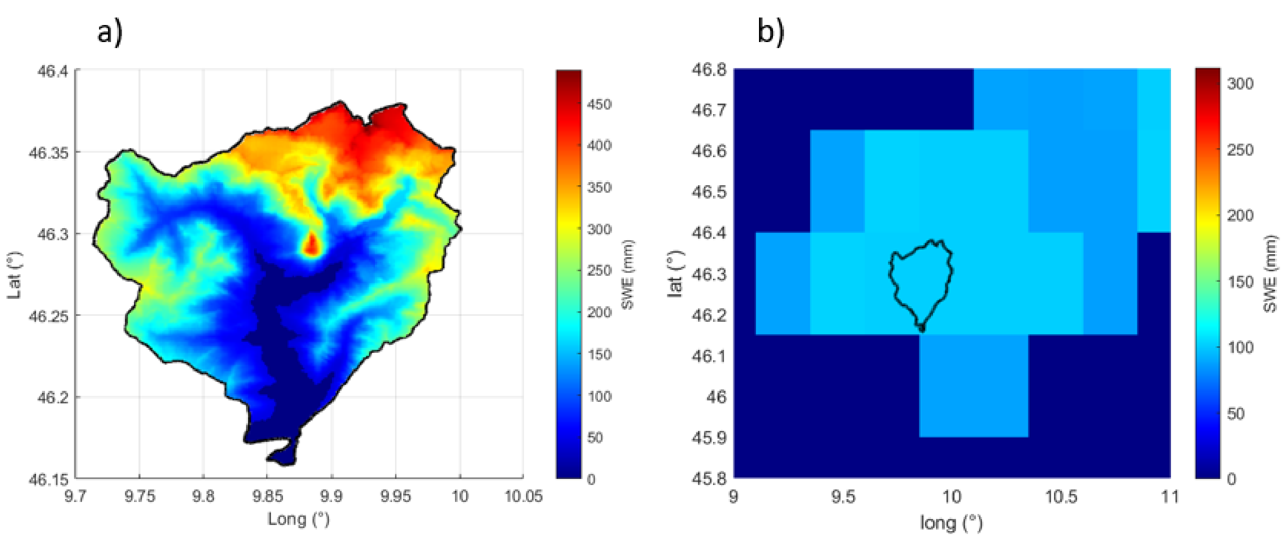

Figure 4: Comparison among SWE maps from March 01, 2017. Panel a) refers to HyS model simulations and panel b) to H SAF products.

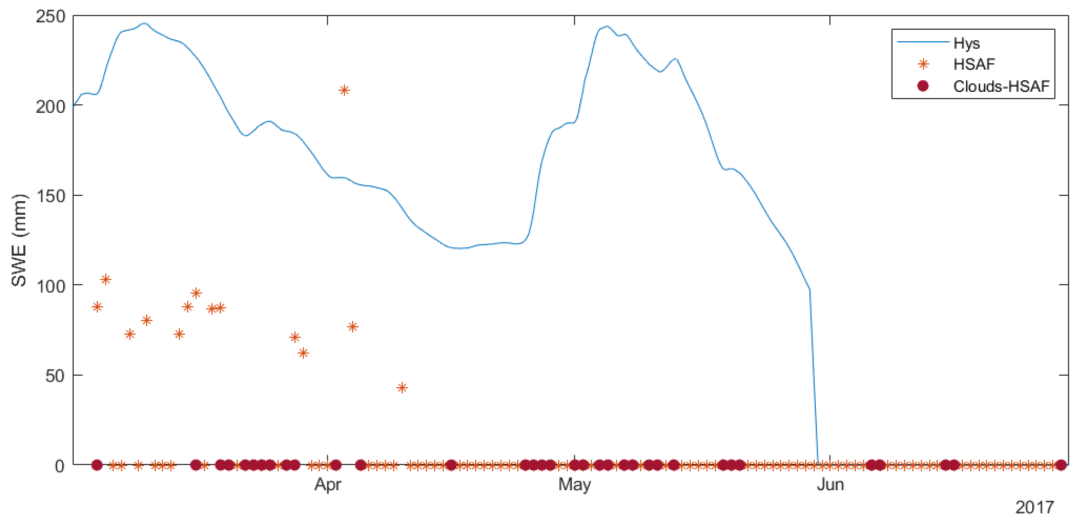

Figure 5: Time series of average SWE (in mm) over the Mallero area. They are calculated from HyS model and H SAF products.

4.3 H35

H35 products were tested with respect the Po basin area for a time period different from that used in the previous analyses, which ranges from March 01, 2021 to July 31, 2021. In fact, these pre operational products are recent and were not available in 2017. In Fig. 6 it is showed the comparison between two maps obtained from HyS model and from H SAF, for March 28, 2017. The simulations of HyS model return, for each cell, quantitative information on the snow cover (SWE, snow depth,...). However, such information is assumed uniform all over the cell. For this, in Fig. 6.a the values related for the snow cover can be only 0% or 100%, and it cannot be derived the effective snow cover. The comparison shows that HyS simulations are comparable with H35 products as the snow covered area are similar. However, H35 seems to be able to provide a more detailed estimate of the real snow coverage. The estimated percentages of Po basin area covered by snow are 37% (HyS model) and 17% (H35). For this event, the clouds (white cells), do not strongly affect results since they are mainly located along the most flat region (central and east part), where snow is not present.

A final quantitative comparison on the time series is implemented by using Jaccard similarity coefficient. The Jaccard similarity between two finite sample sets A and B is defined as:

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|}. \tag{2}$$

In our case A is the set of ESC estimates from HyS model (which in this case reduces to snow cover estimates) in each cell of the basin and B is the set of ESC estimates from H SAF products. The higher is J the most similar are the two maps. While A just assumes discrete values (0 or 100), the set B can assume continuous values from 0 to 100. We undertook two approaches to deal with this problem. Firstly we assumed a threshold, equal to 10, for the set B to distinguish between snow covered (ESC > 10) from bare soil (ESC < 10). The second one is to slightly modify the Jaccard similarity, as follows:

$$J_{\text{mod}}(A,B) = \frac{\sum_i (A_i \cdot B_i) + (1 - A_i) \cdot (1 - B_i)}{|A \cup B|}. \tag{3}$$

where i is the i-th element of each sample. Results are reported in Fig. 7. here are present

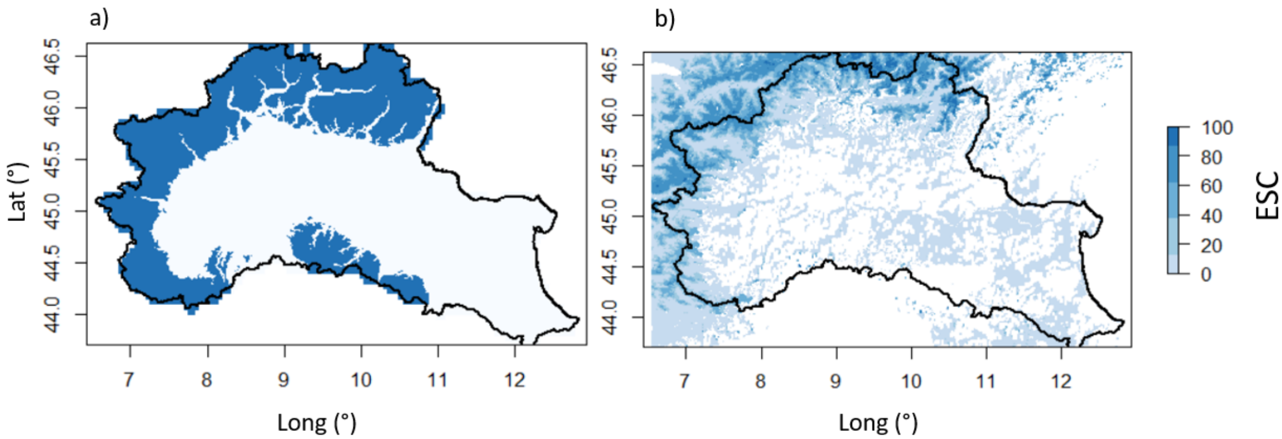

Figure 6: Effective snow cover maps related for March 28, 2017. Panel a) and b) respectively refers to HyS model simulations and H35 products. The white cells inside the Po basin area refer to invalid data due to cloud covering.

the estimated coefficients (in both the two versions) for the whole time period investigated. It is worth to point out that such coefficients are estimated by neglecting the pixels covered by clouds in H SAF products. From the figure it can be noted a positive trend, with lower values of J (and J_{mod}) in March and higher values from May to July as the snow covered area decreases. In general, the percentage of days where $J > 0.5$ is 68% and 52%, respectively for J and J_{mod}. As expected, in the second case the percentage is lower. Nevertheless, this results proves that the overall correspondence between the two maps is acceptable. From

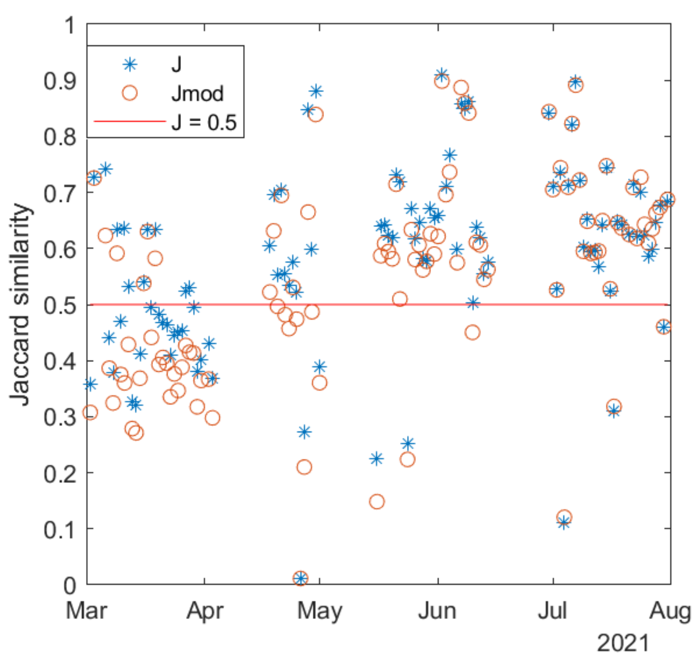

Figure 7: Time series of Jaccard similarity coefficients: original and modified versions.

an hydrological point of view, we can state that H35 products, with high spatial resolution, provide highly accurate information on the area covered by snow, at a large-catchment scale.

References

[1] Retrieval of wet snow by means of multitemporal sar data. *IEEE Transactions on Geoscience and Remote Sensing*, 38(2):754–765, 2000.

[2] Monitoring snow wetness in an alpine basin using combined c-band sar and modis data. *Remote Sensing of Environment*, 183:304–317, 2016.

[3] F. Avanzi, S. Yamaguchi, H. Hirashima, and C. De Michele. Bulk volumetric liquid water content in a seasonal snowpack: modeling its dynamics in different climatic conditions. *Advances in water resources*, 86:1–13, 2015.

[4] C. De Michele, F. Avanzi, A. Ghezzi, and C. Jommi. Investigating the dynamics of bulk snow density in dry and wet conditions using a one-dimensional model. *The Cryosphere*, 7(2):433–444, 2013.

[5] C. Fierz, R. L. Armstrong, Y. Durand, P. Etchevers, E. Greene, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. The international classification for seasonal snow on the ground. 2009.

[6] T. Nagler, H. Rott, E. Ripper, G. Bippus, and M. Hetzenecker. Advancements for snowmelt monitoring by means of sentinel-1 sar. *Remote Sensing*, 8(4):348, 2016.