IMPROVED SNOW PARAMETERS ESTIMATION THROUGH INTEGRATION OF SIMULATED AND REMOTELY SENSED SNOW COVER INFORMATION

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ABSTRACT: The main idea of this work is the development of an innovative data fusion approach through which state-of-the-art remotely sensed products and hydrological modelling simulations can be integrated in order to improve the retrieval and the reliability of the snow cover mapping in the Euregio area.

The fusion approach, based on a machine learning technique and, specifically, on Support Vector Machine (SVM), involves snow cover maps derived from remote sensing and from hydrological model simulation together with their uncertainty layers. The results obtained are promising and the agreement with ground data is in average of 96%.

KEYWORDS: Data fusion, snow cover mapping, machine learning, remote sensing, hydrological model.

1. INTRODUCTION

Understanding and studying snow processes and parameters plays a key role in mountainous areas due to the role of snow as water reservoir in hydrological cycle. Traditional methods for snow properties retrieval are based on point-scale observations at meteorological stations, which, however, cannot provide information in remote areas.

Consequently, remote sensing (RS) can make a valuable contribution, by providing information at higher spatial and temporal resolution than traditional methods.

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Nevertheless, snow parameters retrieval with optical sensors have some limitations (snow detection in cloudy or shaded areas and under the canopy).

Moreover, for some snow parameter, only RS products based on coarse spatial resolution imagery are available (e.g.
snow water equivalent, SWE, De Lannoy et al. (2010)).

An alternative approach for gaining information about snow are physically-based models. Although extensively tested and validated in gauged areas, these models are still subject to uncertainties in spatially distributed applications, due to their connection with meteorological data which are punctual observations and need to be extended to regional scale.

The joint use of RS and physically-based models has thus received an increased attention (Bøgh et al. (2004)).

The aim of this work is to develop a method for integrating physically-based model and RS products, to improve snow mapping in mountain areas. The innovative aspect is that the fusion, provided by means of a Support Vector Machine (SVM) classifier, involves the final products of both RS and model outcomes and their uncertainties, differing from all approaches where RS is only used for model tuning (model calibration or data assimilation, Duethmann et al. (2014), Khan et al. (2011) and Sini et al. (2008)).

2. STUDY AREA AND DATASET

The fusion method has been applied to EUREGIO area, which includes Tyrol (Austria), South Tyrol (Italy) and Trentino (Italy) and has a total area of about 26000 km² (Figure 1).

Figure 1 Study area: Euregio region and test sites

The preliminary analyses have been performed on two test sites located in the study area: Rofental (98 km², Ötztal Alps, Austria) and Mazia valley (101 km², Eastern Alps, Italy).

In the second phase of the study, the method has been extended to the overall EUREGIO area to generalize the procedure and provide a time series of fused products.

The study involves the hydroloclimatological model AMUNDSEN (Strasser, (2008)) developed by University of Innsbruck and MODIS snow cover maps (Notarnicola et al. (2013a)), both at 250m ground resolution. Higher resolution images (Sentinel-2 and Landsat-8) have been used as reference dataset.

3. METHOD

The idea of this study is to develop a new fusion method to improve snow cover mapping, especially in the areas where the two sources of information disagree, by taking advantage of specific properties of remote sensing data, such as detailed spatial representation of the estimated parameters, and from the characteristics typical of physical model such as solid physical basis and good generalization capabilities. Together with the snow maps derived from remote sensing and model simulation, the uncertainty layers are provided. In the case of remotely sensed product the uncertainty is based on NDSI, which is not used for snow cover estimation, unlike the standard MODIS product. Regarding the model snow product, the uncertainty has been calculated in two different ways and is based on snow water equivalent values for snow covered pixels and on the number of days without snow for snow free pixels. The binary ("snow" or "no snow") snow maps together with their uncertainty layers are used as input for the classifier.

Training and test dataset have been selected by randomly extracting dates in the test period (October 2012 – July 2016), in order to have a representative sample set.

Once selected the dates, disagreement points are extracted from snow maps and randomly divided in training and test dataset. In correspondence of selected points, through a visual interpretation, reference points are manually extracted from RGB of Sentinel-2 and Landsat-8 images. The fusion strategy is summarized in figure 2.

4. RESULTS AND DISCUSSION

The performance evaluation was carried out by validating the new product at two levels: by exploiting the high resolution RGB images from Sentinel-2 and Landsat-8 and by using the ground data derived from manual measurements sites during the whole winter season (from October to May).

By considering all data deriving from measurement sites, about 4600, the average agreement of fused product with ground data is 96% with respect to that of MODIS, 90%, and model, 92%.

In particular, by considering the sites in Trentino, the cases where model and MODIS disagree (about 25%) are all correctly classified by the fusion method.

In order to understand if the error is due to an

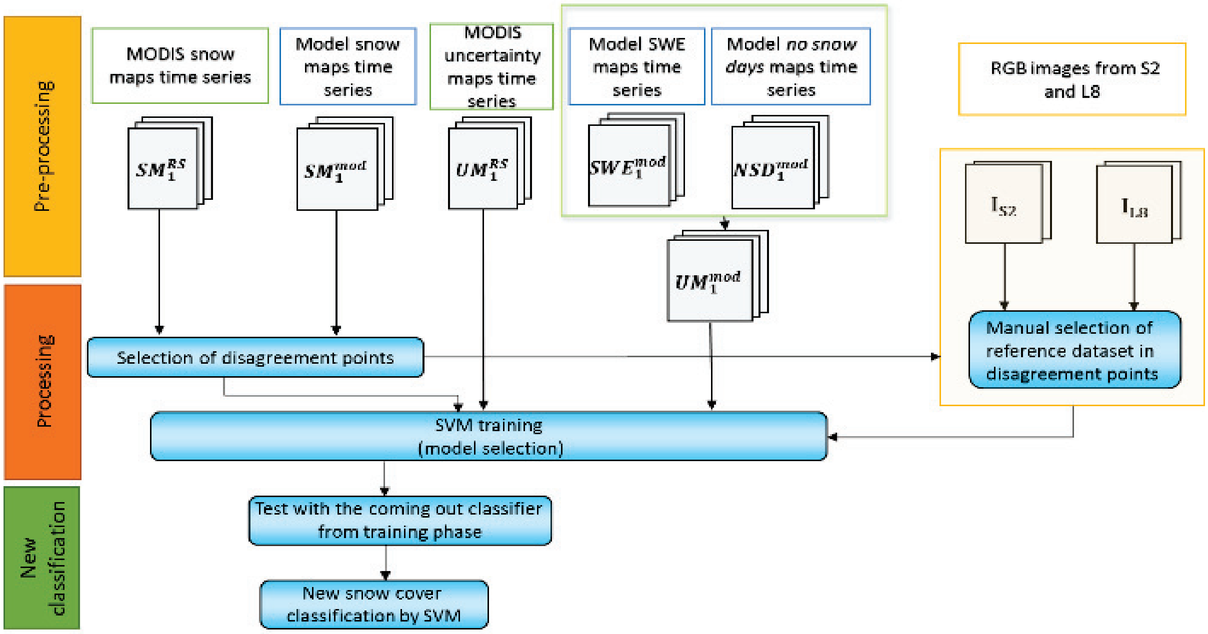

Figure 2 Fusion method flowchart

located throughout the Euregio area. Results of validation with high resolution remote sensing images show an improvement of overall accuracy of fused (89%) product with respect to model and MODIS products (66% and 44%, respectively).

The second level of validation involves ground data collected by observers in manual measuring sites located in Tyrol, in South Tyrol and in Trentino. In these sites, observers detect daily the snow height

underestimation or to an overestimation, the points where the three products disagree with ground data have been analyzed. From the analysis, it seems that MODIS underestimates in most cases by classifying as “no snow” the pixels where the snow is detected by ground measurements. Most of underestimations occur in winter months, when the illumination conditions are unfavorable for optical sensors due to scarcity of radiation and the presence of hard shadows that make difficult snow detection (Notarnicola et al. (2013b)).

The fused product commits minor errors in February and this could be related to the amount of snow that in this period is maximum and the error in snow detection is, thus, lower. Regarding the model, it seems that most errors are committed in spring season, i.e. in melting period. The difficulties in reproducing and modeling the snow melting processes could lead to a higher uncertainty in snow detection in this period (Essery et al. (2013)).

Once validated the new fused product, the fusion approach has been applied to the whole snow cover maps time series.

Snow cover area (SCA) over the Euregio region is analyzed for different land use, i.e. forest and open areas, and by elevation bands.

The most relevant result from the SCA trend analysis is that for all elevation bands the fused product in forested areas seems to follow the behavior of the model, by well reproducing the snow maximum values of winter season and by overcoming the well-known problem of MODIS product in snow detection in forest. This behavior is not so evident in open areas where model and MODIS products seem to have similar trends.

5. CONCLUSION

In this work a new method for fusing a hydrological model and remote sensing products has been developed. The fusion involves the products and their uncertainty layers and aims to improve the snow cover mapping in the Euregio region, in those areas where model and remote sensing disagree. Results obtained from validation with ground data are promising by showing an average agreement of fused product with ground data of 96% with respect to that of MODIS of 90% and model of 92%. Further validation analysis in forested areas could be useful in order to understand the behavior of fused product that seems, anyway, to improve the snow estimation in these areas with respect to the well-know underestimation of MODIS products.

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