Snow cover monitoring and modelling in the Alps using multi temporal MODIS data

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This study presents an intercomparison of three snow cover products derived from satellite data: the MODIS MOD10 standard product, a new MODIS snow cover product developed specifically for Alpine regions, and a snow cover mapping algorithm based on Landsat images, which was mainly used for validation.
The snow cover maps were compared with snow data modelled by the hydrological model GEOtop, to show the potential of an assimilation of satellite data into the hydrological model. Such an assimilation could support a better characteristics of temporal evolution of snow water equivalent.

KEYWORDS: South Tyrol, MODIS, snow cover, time series, climate change, modelling.

1 INTRODUCTION

Snow is an important physical parameter in hydrology, weather forecast and in climatological models. Traditional methods used for snow cover assessment are limited by sparse in situ point measurements. Due its temporal and spatial synoptic view, the satellite sensors offer a unique advantage in monitoring snow cover even though with some main limitations such as cloud cover, the difficulty to detect snow under forest and shadows (especially during winter season due to lower solar elevation).

In this context, the Moderate Resolution Imaging Spectrometer (MODIS) from NASA is useful for many global cryospheric applications due to its high temporal frequency. However, for regional issues, the MODIS standard product, e.g. the snow cover (MOD10) do not always satisfy local needs, especially in mountain regions because of its coarse resolution (500 m).

This paper presents a comparison of three different algorithms for snow cover monitoring over alpine areas. The standard NASA MOD10 snow cover product is compared with a new snow cover algorithm (Tampellini et al, 2005) with improved resolution 250 m, and secondly with EURAC snow cover algorithm for Landsat images. In addition, the results are compared to the hydrological GEOtop model for the river basin of Matschertal in the Vinschgau valley.

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2 STUDY AREA AND DATA

The study was carried out in the western part of South Tyrol region, Northern Italy, with a total area of 4115km².

The intercomparison was carried out on 10th December 2002, 16th March 2003 and 1st April 2003 so that to cover the beginning of the winter season as well as the snow melting period. To minimize the gap between the acquisitions of MODIS and Landsat images, only MODIS TERRA images were chosen. This choice reduces differences due to rapid changes in cloud cover. The MODIS data and standard products were downloaded from WIST (Warehouse Inventory Search Tool), a NASA web interface for ordering earth science data (https://wist.echo.nasa.gov/). The Landsat images have been downloaded from the GLOVIS (Global visualization viewer: http://glovis.usgs.gov/) website.

3 METHODOLOGY

The following section contains a short description of the three snow cover. The results from different algorithms are then compared based on a statistical approach.

3.1 Customized (CGS) and standard (NASA) algorithms for snow covers over alpine areas with MODIS images

The algorithm was developed by Carlo Gavazzi Space in the framework of ESA funded project EO-Hydro (Tampellini et al. 2005). The input data for this algorithm are the atmospherically corrected reflectance from MODIS MOD09GQ, MOD09GA and the MODIS level 1 product MOD021KM, which is used mainly for the cloud cover detection. The processing steps include the georeferencing in UTM WGS 84 and a topographic correction based on a digital elevation model (DEM). Then snow and clouds are classified by using a decision tree algorithm. Finally, snow under forest is detected by comparing the Normalized Difference Vegetation Index (NDVI) of a winter image and a reference image from summer season. The main advantage of this algorithm with respect to the standard MODIS MOD10 snow product is the 250 m resolution.

The MOD10 data from NASA with it's 500m resolution had to be reprojected from the sinusoidal in UTM 32 N – WGS 84 projection with the MODIS conversion toolkit (Visual Information Solutions, 2009). As final step a subset of the relevant area was taken and interpreted.

3.2 Customized EURAC algorithms for snow cover over alpine areas with LANDSAT (5 and 7) images

After calculating radiance and reflectance for Landsat bands 2,3,4,5 the Normalized Difference Snow Index (NDSI), the Normalized Difference Vegetation Index (NDVI) were calculated. Temperature was retrieved based on band 6 (Landsat 7, 2009) and a threshold of 283K defined. A cloud mask was produced based on a modified ACCA (Automated Cloud Cover Assessment) algorithm (Irish 2000). An initial snow mask is obtained by the threshold NDSI >0.40 and NIR threshold >0.11 (Hall et al., 1987, Kaushal et al, 2004). For shadowed areas, which were identified by a solar radiation calculation, slightly adapted thresholds (Temperature<270, 0.85<NDSI<1.0 and Green>0.1) were applied. All those resulted images were put in a final step in a decision tree classifier (fig. 1) to classify snow, no snow and clouds.

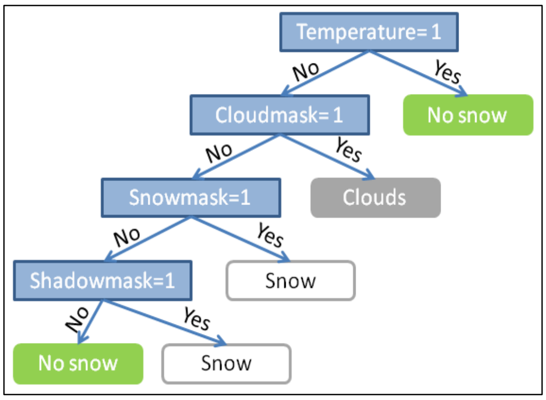

Figure 1. Classification steps in the decision tree.

3.3 The GEOtop model and simulation settings

In this paper the snow cover map is compared with the outputs of the spatially distributed process-based hydrologic model GEOtop (Rigon et al., 2006) in the river basin Matschertal. Its capabilities include simulation of: (i) water and energy budgets, (ii) radiation budget in complex topography, (iii) surface temperature, (iv) sensible and latent heat transfer, (v) surface and subsurface soil water processes, and (vi) multi-layer snow cover. An overall description of the snow module can be found in Endrizzi (2009). The GEOtop model showed a good performance in reproducing the point-wise and catchment scale snow cover evolution in mountain catchments (Zanotti et al., 2004). The model was run for the whole 2002 – 2003 snow season, with an hourly time step and a grid resolution of 60 m, using the meteorological inputs collected in the stations of Matsch ca. 1500m a.s.l. and Glurns ca. 1000m a.s.l.. A temperature gradient of 0.6 C° each 100 m was assumed.

4 RESULTS

4.1. Remote sensing image comparisons

In order to compare the different snow maps, an approach based on zonal statistics was applied. This technique calculates the statistics on values of a raster within the zones of another dataset (ArcGIS 9.2 Desktop Help 2009). A grid of 500m cell size was created for each date and statistically compared with the NASA, CGS and EURAC snow map. To investigate the influence of forest on snow coverage also a forest map (retrieved from the official land-use map of South Tyrol 2001) was taken into account.

An example of the calculated snow products is presented in fig. 2. The top image shows the snow cover map of the 16-03-2003 processed by NASA. The central image the snow cover map processed with the Carlo Gavazzi Space algorithm and the latter one the result of the EURAC snow cover algorithm. The points indicate the position of the snow stations and the values indicate the snow height for each date.

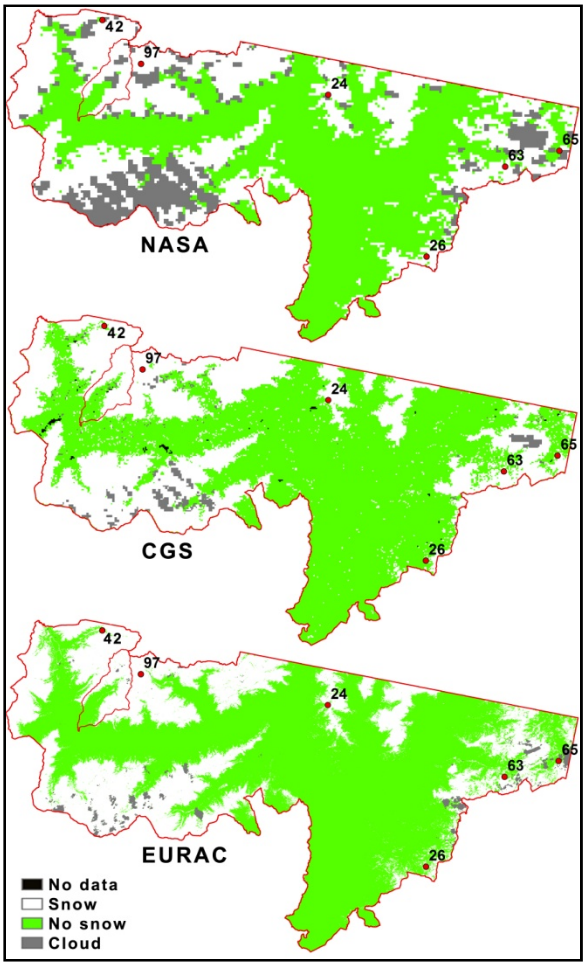

Figure 2. Example of snow cover map products of 16-03-2003 where the values indicate the snow heights (cm) of snow stations. The boundary of Matschertal is shown on the left hand side.

The results of the comparison is illustrated in fig.3 for the three dates considered in this analysis. The results indicates an overall good agreement among the methods. For the 10th December, the major disagreement is due to the presence of hard shadows which constrain a correct classification. These pixels were indicated as no data.

One main difference is also found in cloud coverage. This aspect can be due to different acquisition time. In fact, Landsat images are acquired over this area from 09.53.02am till 09.53.29am, while the MODIS images from 10.20am till 12.05pm (WIST 2009). On the other side, NASA and CGS algorithms work on the same images, but produces different results. This is due to the fact that NASA algorithm works globally, while the CGS algorithm is adapted to the conditions of the Alps (Cappellutti et al., 2006). Because of different cloud coverage and cloud classification the area of the no snow class is considerably lower for the NASA standard product on all three dates and for CGS on the 1st of April 2003 compared to the Landsat snow cover map.

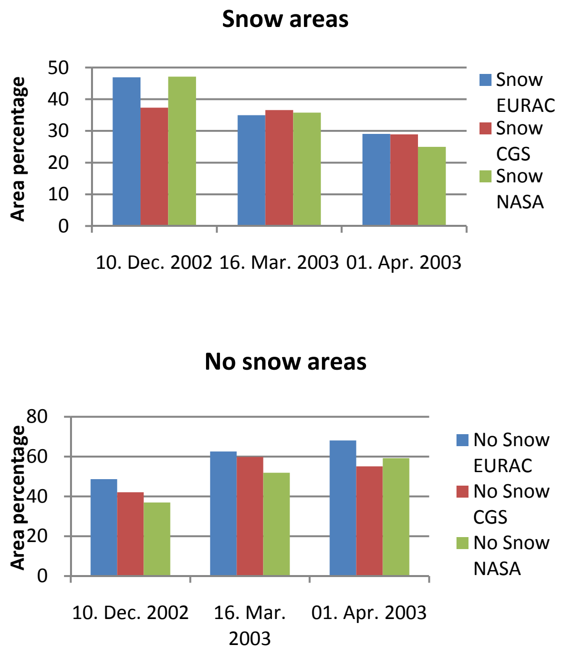

Figure 3. Comparison of the three algorithms for snow areas and no snow areas.

A further analysis was the comparison with some fixed snow measurement stations. The results are indicated in fig.4. The best agreement is found for the Landsat images where it was also easier to locate the position of the station due to the high resolution. For the NASA and CGS algorithm, the disagreement in some stations is mainly due to the pixel dimension which sometimes prevent from a correct location of the stations.

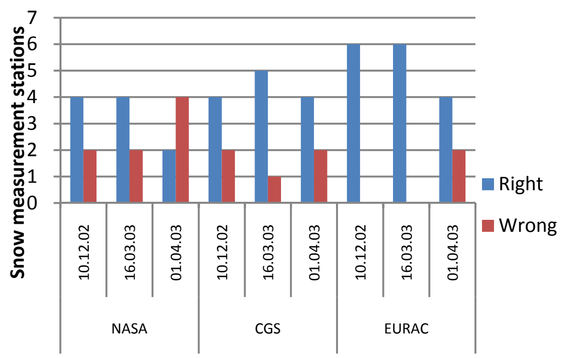

Figure 4. Comparison of snow stations with snow pixels of each algorithm for the three considered dates.

In order to understand where the disagreement among the images appear, maps which represent the comparison among the different snow cover images were produced (fig.5). These maps represent a comparison between the CGS and EURAC snow cover with respect to NASA standard products. White pixels show no agreement and black pixels illustrate high agreement. The line layer represents the actual forest cover.

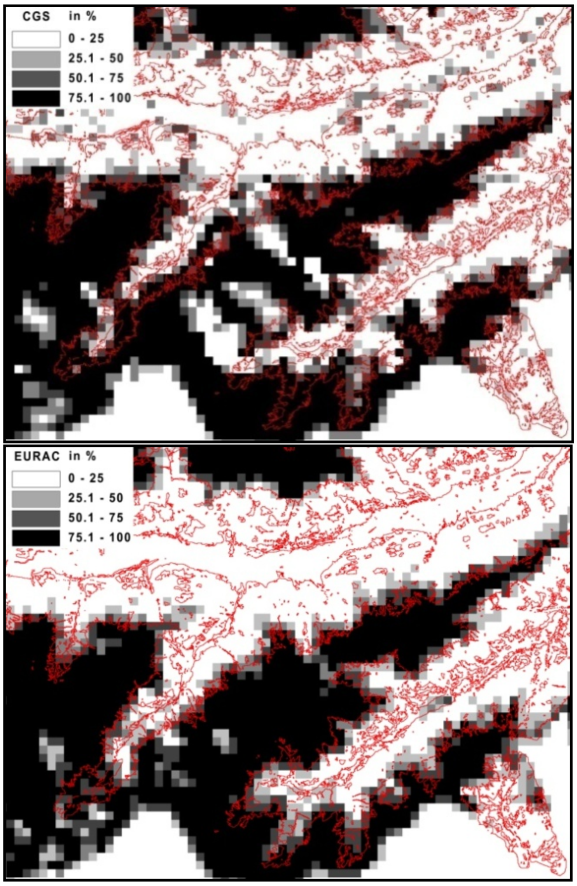

Figure 5. Percentage of snow classified pixels in CGS and EURAC maps within each snow pixel according to NASA algorithm. Red line: Forest layer. Top image: CGS-NASA; Bottom image: EURAC-NASA. White = low agreement, Black = high agreement.

As illustrated in fig. 5, there is a big agreement between snow pixels in the three different snow cover maps for high altitudes above the treeline. Lower agreement appears in the transition zones between no snow and snow respectively clouds and snow.
Only few pixels are classified as snow within the forested area. This is particularly evident for the Landsat images because the algorithm does not consider a module to detect snow under forest. In the CGS algorithm however it is visible that more snow pixels fall in the forest area because CGS takes the snow under forest into account. The detection of snow under forest however is a challenging task. One possible approach could be coupling the satellite algorithms with a snow model like the one in GEOtop.

4.2. GEOtop model results

The Landsat 16.03.03 image was analyzed more in detail for a comparison with the GEOtop model, since it is representative of the melting season (fig. 6). GEOtop shows ca. -9% of snow cover underestimation with respect to Landsat. The model shows a much stronger aspect influence, with a higher snow line (about 200 m) in the South exposed slopes and lower in the North ones.

In the forested north facing part GEOtop simulates snow in the forest and Landsat may be not that reliable on those sites, therefore it is likely that the model is more exact.

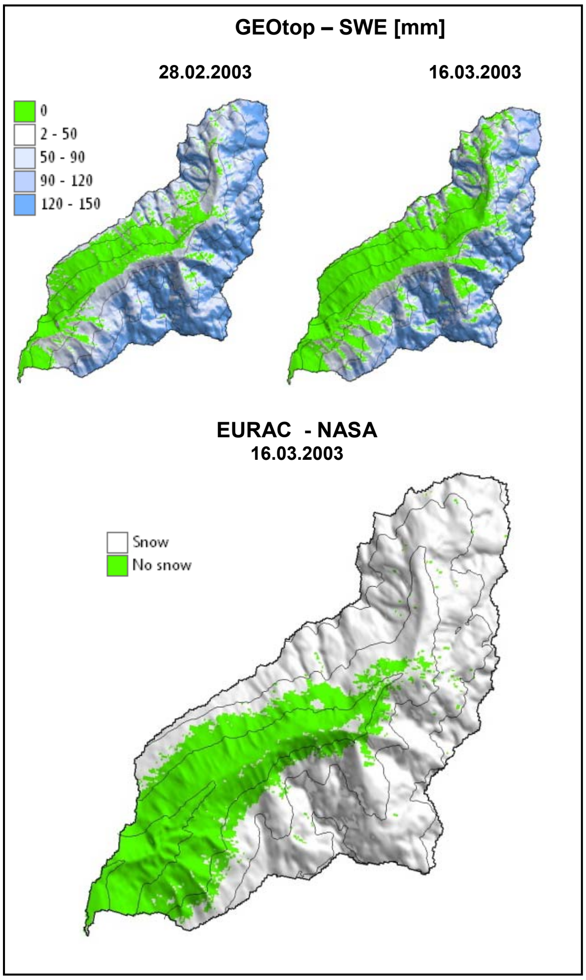

Figure 6. Top: GEOtop estimated snow water equivalent SWE [mm]. Bottom: EURAC NASA snow cover for the Matscher valley in South Tyrol.

If a two weeks earlier map (28.02.03) is considered, GEOtop shows ca. +8% snow cover overestimation with respect to Landsat, suggesting a too high spring snow melt rate on the south exposed areas. This is likely due to uncertainties in rainfall, temperature and solar radiation at the higher elevation.

Further work will be focused on installing micrometeorological stations in the valley to retrieve a better spatial variability of rain, temperature and solar radiation avoiding those uncertainties.

5 SUMMARY AND OUTLOOK

The aim of this work was to compare snow cover maps derived from algorithms developed for the alpine areas with the standard MODIS snow cover product MOD10. The comparison indicates a good agreement for the two products even though the high resolution of MODIS CGS (250 m) and LANDSAT (30 m) is an advantage in alpine areas, especially for monitoring the melting season. The main differences between those three algorithms occur in border areas where there is less snow and mixed with forest cover.

Furthermore, the results of the EURAC snow cover algorithm has been compared to the GEOtop model. The GEOtop model is able to simulate the snow cover evolution along the season. The long-term goal of this research is to establish data assimilation framework, where remote sensing images can improve model results. in particular areas such as in south facing and high elevation regions. On the other side, the model can estimate snow under forest and snow water equivalent.

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