Comparing different MODIS snow products with distributed simulation of the snowpack in the French Alps

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ABSTRACT: Satellite images of the Earth surface are increasingly used to assist in the spatio-temporal assessment of ground conditions, including the presence of snow on the ground and its physical properties. Towards this end, MODIS multispectral imagers onboard both TERRA and AQUA platforms provides frequent images since 2000, that are relevant for snow monitoring as these sensors allow measurements of ground reflectance to be obtained in visible and near-infrared wavelengths. These data are closely linked to the physical properties of the snowpack, and thus allow properties of the snowpack to be retrieved, such as snow cover fraction, albedo, and grain size (optically equivalent grain radius). Over the French Alps, one image for each satellite is available per day at 500 m resolution for five reflective bands, as well as 250 m resolution in the red and near-infrared. The National Snow and Ice Data Center freely distributes the MOD10 snow products at 500 m resolution that include sub-pixel snow cover fraction and snow albedo. No correction is applied in these products to account for the complex topography of mountainous areas. Recently, we developed new post-processing algorithms for MODIS data generated at 250 m resolution specifically aimed at retrieval of snow information using a linear unmixing technique and addressing the effect of complex topography on the measured reflectance. This study reports on a comparison of the two products, namely MOD10 and MODImLab, over one domain in the French Alps centered on Chamonix-Mont-Blanc. The higher resolution products from MODImLab are also compared to distributed simulations of the snow cover performed at 250 m resolution using the detailed snowpack model SURFEX/ISBA-Crocus forced by the SAFRAN meteorological reanalysis. These comparisons demonstrate the performance of MODIS data and more generally remotely-sensed data to improve snowpack simulations and monitoring in mountainous regions through data assimilation.
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KEYWORDS: remote sensing, seasonal snow cover, modelling

1 INTRODUCTION

Snowcover is very important for many human activities, both locally and regionally for issues such as water resources or avalanches. It is also fundamental in the climate system at global scale. Due to its very unique radiative and thermodynamic properties, the snowcover induces profound changes in the surface energy budget.

Snowcover is highly variable both spatially and temporally. This variability is thus not easily depicted by point measurements. Remotely sensing data are therefore a crucial source of information for the study of the snow cover. Multispectral optical satellite imagers such as MODIS onboard the TERRA and AQUA platforms are able to retrieve the physical properties of the snowcover, such as its fraction and its albedo [Dozier et al., 2009].

In this study, we first compare two algorithms to process MODIS data for snow monitoring. The first is the MOD10 snow product developed by the National Snow and Ice Data Center (NSIDC) referred to as MOD10 [Hall and Riggs, 2007]. The second, one, hereafter referred to as MODImLab, includes corrections for complex topographic effects in mountainous terrain [Sirguey et al., 2009 ; Dumont et al., 2012a]. MODIS data are finally compared to the output of the detailed snow model SURFEX/ISBA-Crocus [Vionnet et al., 2012] driven by the meteorological reanalysis SAFRAN [Durand et al., 2009].

2 DATA AND METHODS

2.1 MODIS data

MODIS is a multispectral imager onboard TERRA and AQUA platforms. MODIS has 36 spectral bands among which seven are placed in atmospheric windows of the solar spectrum and allow the snowcover to be studied using its specific optical properties. Five bands are provided at a spatial resolution of 500m, while the red and near-infrared bands have an enhanced resolution of 250 m. Above the Alps, at least one image is acquired per day since 2000.

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2.2 MOD10 products

The National Snow and Ice Data Center (NSIDC) distributes freely the MOD10 MODIS products which provide information relevant for the snow cover. MOD10 products are initially generated with a 500 m spatial resolution and contain a binary mask of the snow cover, the snow cover fraction (percentage of snow with one 500 m pixel) and the snow albedo.

The snow cover detection and snow cover fraction are based on the Normalized Difference Snow Index (NDSI) algorithm [Salomonson and Appel, 2004; Hall and Riggs, 2007], taking advantage of the contrasting reflectance of snow in the visible and one short wave infrared bands. The snow albedo is estimated using a radiative transfer model [Klein and Barnett, 2003].

Several previous studies have evaluated the performance of these snow products with respect to field measurements showing less than 10% error for the snow presence [Hall and Riggs, 2007] and a 10% positive bias on the albedo values [Tekeli et al., 2006].

2.3 MODImLab processing

Sirguey et al. [2009] and Dumont et al. [2012a] have developed a new algorithm to process MODIS data for the study of the snow cover that is specifically aimed to address complexities encountered in moutaineous areas.

MODImLab products are processed at 250 m spatial resolution using a multispectral fusion technique. Among others variables, MODImLab provides an estimation of subpixel snow cover fraction and snow albedo.

The snow cover fraction within 250-m pixels is computed using a linear unmixing technique, i.e. taking into account the effect of rock, snow and vegetation within a pixel. The radiometric corrections of ground reflectance is adapted to mountainous terrain and addresses the effect of local illumination and multiple reflections over surrounding slopes. As for the MOD10 products, the albedo is estimated using a radiative transfer model although it is based on corrected ground spectral reflectance and a different account of the anisotropic reflectance of snow targets.

MODImLab products have been evaluated in terms of snow cover fraction and albedo. The snow cover fraction in 250-m pixels have an error smaller than 10% with respect to high resolution imagery [Sirguey et al., 2009]. The broaband albedo exhibited a Root Mean Square Deviation (RMSD) of 0.05 with respect to field measurements obtained over two summers on a French Alps glacier [Dumont et al., 2012a].

2.4 Crocus simulations

Crocus is a one-dimensional detailed snow model which computes a full expression of the snow energy budget [Brun et al., 1992]. It has been widely used in France to support the forecast of the avalanche risk. Crocus is now embedded into the more comprehensive surface scheme SURFEX [Vionnet et al., 2012].

Simulations of the snowpack evolution in Crocus require numerous meteorological variables, i.e. temperature, wind speed, humidity, precipitation amount and phase, shortwave and longwave incoming radiations. In this study, the meteorological analysis system SAFRAN [Durand et al., 1993] was used to generate input data for Crocus. Snow simulations were generated at 250 m resolution to be compared to MODIS data.

3 STUDY SITE AND DATES

The comparisons were conducted over the Mont Blanc area located around Chamonix Mont Blanc in the French Alps (45.92°N, 6.86°E). The domain covers an area of 550 km² with elevation ranging from 900 m to 4810 m.

The comparisons have been performed over five winter seasons (from November to June) selected for their contrasted meteorological conditions as shown in Figure 1.

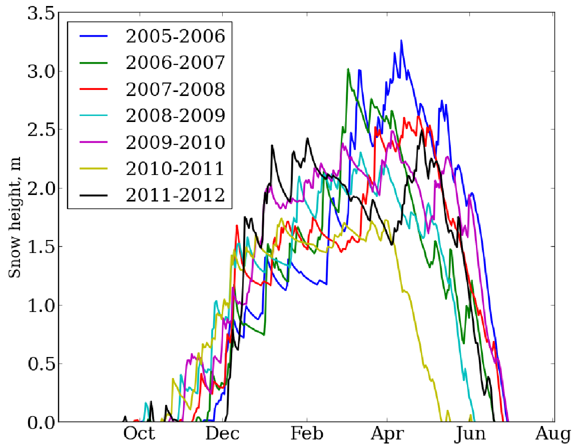

Figure 1 – Snow water height in m simulated by SAFRAN-Crocus at 2400 m elevation in the Mont Blanc massif, illustrating the wide range of snow conditions during the snow seasons.

4 RESULTS AND DISCUSSIONS

First, both MOD10 and MODImLab sub-pixel snow fraction were compared. Then MODImLab products were compared to simulated data from Crocus. A systematic comparison of all the variables was performed although only one variable in each case is presented here for clarity.

4.1 MOD10 vs MODImLab

Due to the difference in spatial resolution of the two MODIS products, MODImLab products were first aggregated to 500 m resolution. To allow a rigorous comparison, the comparison was performed only on pixels identified as cloud-free by both in MOD10 and MODImLab.

We present here the results in terms of snow cover fraction. Figure 2 presents an example of MOD10 and MODimLab snow cover products over the Mont Blanc massif.

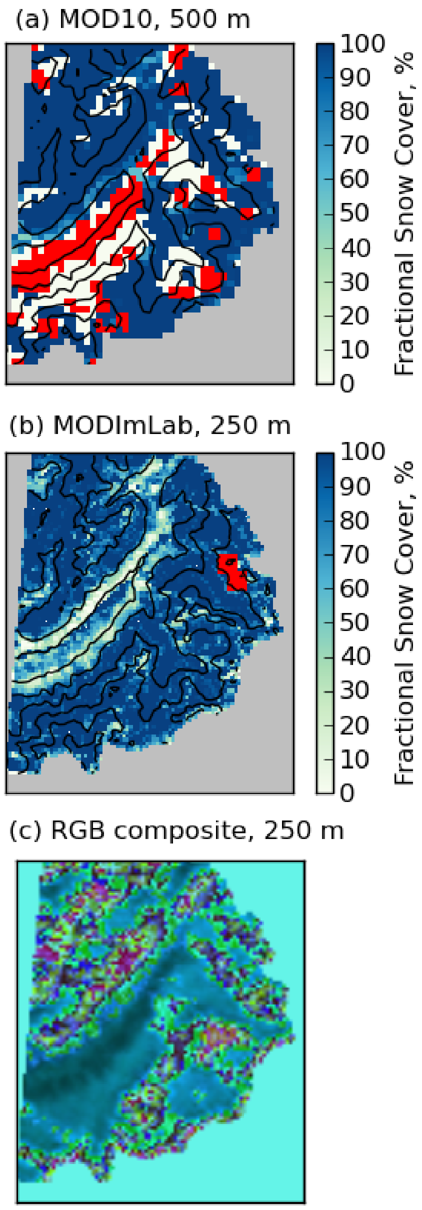

Figure 2 – Fractional snow cover retrieved using MOD10 products (a) and MODImLab (b) on 2006-01-24. Contour lines are indicated in black. Clouds are indicated in red. The last plot (c) shows the RGB composite of the MODIS reflectance bands 1, 3 and 4.

Over all seasons the bias between MOD10 and MODImLab subpixel snow fraction over the whole domain is less than 1% thus suggesting a good agreement between both algorithms overall. Nevertheless, the RMSD reaches 35% and indicates that, on a daily basis, the spatial representation of the snow cover fraction greatly contrasts between both algorithms as illustrated in Figure 2.

One difference is illustrated in Figure 3 that shows the bias between both products as a function of pixel aspect and reveals that the two variables are correlated.

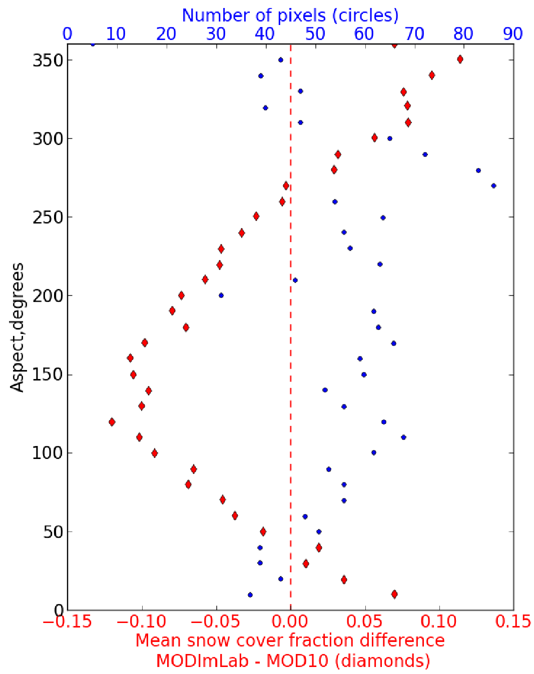

Figure 3 – Mean snow cover fraction difference between MODImLab and MOD10 as a function of the aspect for the winter season 2006/2007. North aspect is 0°.

The correlation between the deviation and the aspect may be explained by the fact that topographic corrections are applied in MODImLab but not in the MOD10 products. For example, for south aspect pixels, which are largely illuminated by the sun, the part of re-illumination by surrounding slopes is not negligible. Since this re-illumination is taken into account in MODimLab and not in MOD10, MOD10 tends to overestimates the snow cover fraction for these pixels. The use on an NDSI relationship to derive snow cover fraction in the MOD10 products might also be a explanation for this deviation.

Additional results obtained for snow albedo suggest that the topographic correction implemented in MODImLab is more appropriate for the study of snow cover in mountainous areas even if no field measurements were used in this study. In the following, only the outputs from MODImLab were compared with Crocus simulations.

4.2 MODImLab vs Crocus

In this section, we choose to present the results of the comparison only in terms of broadband albedo.

Prior to comparison, every pixel classified as cloudy by the MODImLab algorithm or as no snow by MODImLab or Crocus were removed from the dataset.

Figure 4 shows as an example the Snow Water Equivalent (SWE) simulated by Crocus on 2006-01-24 as in Figure 2.

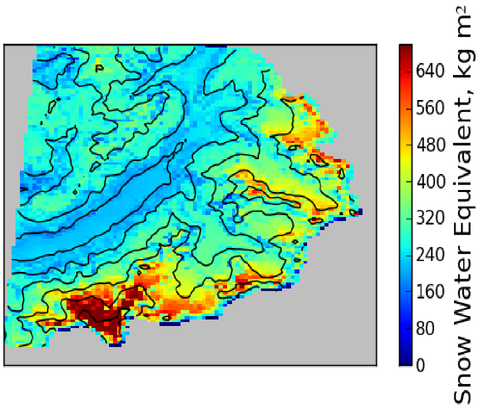

Figure 4 – Snow Water Equivalent simulated by SAFRAN-Crocus in kg m^{-2} on 2006-01-24. The gray areas are outside the studied zone. The iso-elevation lines are plotted in black.

Over all seasons and pixels, the bias (Crocus - MODImLab) in albedo is between 0.05 and 0.10 while the RMSD is 0.18. It shows that Crocus tends to overestimate the albedo with respect to MODIS.

To investigate the possible sources of discrepancies between the two datasets, Figure 5 shows the albedo bias for winter 2010/2011 as a function of the elevation.

Figure 5 shows that the bias is minimal for elevation higher than 1700 m which corresponds to forest free areas. Below 1700 m, trees are numerous. Their effect is taken into account in the MODImLab algorithm via the spectral unmixing. Nevertheless, snow-vegetation interactions are not taken into account in the Crocus simulations which might explained the high bias at lower elevations.

In the absence of trees, the albedo bias between MODIS and Crocus is positive. This positive bias has been confirmed by comparing Crocus simulated albedo with field measured values at Col de Porte. A possible explanation of this overestimation is the underestimation of the albedo decrease due to the increase of light absorbing impurity in the snowpack as snow ages [Warren, 1982].

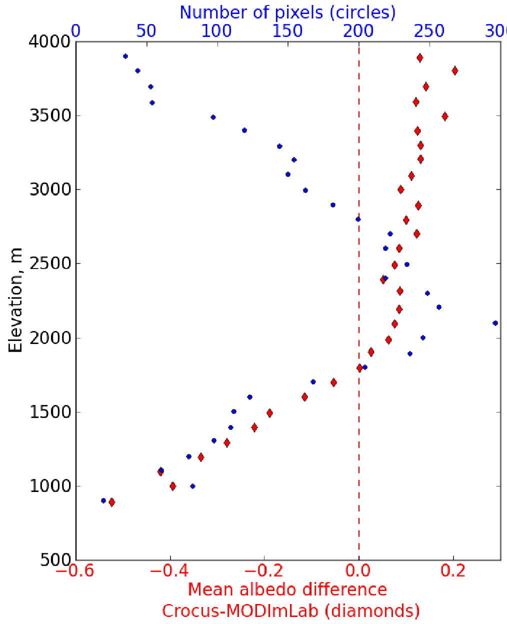

Figure 5 – Mean albedo difference between Crocus and MODImLab as a function of the elevation for winter season 2010/2011 for the Mont Blanc massif.

5 CONCLUSIONS

This study has first shown that despite an average good agreement between MOD10 products and MODImLab products overall, MODImLab products seems to provide a more accurate description of the snow cover distribution in mountainous areas. This improved accuracy may be attributed to the use of a more rigorous topographic correction in the processing of MODIS data.

Secondly, a systematic comparison framework has been built to allow the evaluation of Crocus simulated snow cover with respect to MODIS data. The comparisons between the two datasets shows an average good agreement but some discrepancies still exist. These discrepancies suggest that the implementation of snow-vegetation interactions and a better treatment of light absorbing impurities in the model would improve the snow cover simulations. This framework will allow evaluation of future versions of the Crocus model.

Furthermore, the discrepancies between the simulated and the remotely sensed data suggest that the assimilation of remotely sensed data in the modelling framework has the potential to improve model simulations [Dumont et al., 2012b].

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