The employment of MODIS time series and soil temperature to monitor snow cover in the Majella National Park (Italian Central Apennines)

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ABSTRACT: Italian Apennines are an unique mountain environment in the central Mediterranean basin as their peaks and massifs reach remarkable altitudes like Corno Grande, in the Gran Sasso d'Italia Massif (2912 m a.s.l.), the highest peak with Calderone glacier, the southernmost known glacier in Europe, and Mt. Amaro, in the Majella Massif (2793 m a.s.l.). These areas are characterized by abundant snow precipitation and relict permafrost features, increasing the interest on the area for the monitoring and investigation of cryosphere features and their influence on ecosystem functioning. Moreover the area is included in the Italian LTER network. Particularly, the current work is focused on snow cover dynamics in the Majella IT01-001-T research site, including the Majella National Park covering approximately a surface equal to 630 km².

Snow falls are abundant, especially along the eastern sides of the mountain range, due to the direct exposition to Balcanic - Danubian cold currents. Snow cover may last for approximately 100 to 200 days in accordance with elevation. Mean snow depth on the ground may reach remarkable values, up to 400 cm.

In order to reconstruct the snow cover dynamics a geomatic approach was adopted. MODIS satellite time series (2001-2011) of the study area were processed in an automated procedure developed by the authors, in R language. Each scene was reclassified in “Snow - No Snow - No Data” values, according to pixel values, and grouped in yearly summarizing tables. These results allowed to process yearly snow cover duration maps of the entire site. Moreover, by the employment of a Digital Terrain Model, snow cover duration was compared with morphological parameters evaluating snow cover behavior in the time series and highlighting different trends in the investigated years.

The outputs have also been compared with topsoil temperature data, whose daily amplitude could be used to detect the presence or absence of snow on the ground. These independent measurements were used as reference data to be compared with the MODIS processing results.

Future aim of the work is the replication of the methodology in other research sites belonging to this LTER site, as for example the Gran Sasso massif, and the relationships with the distribution of high elevation vegetation types and plant phenology.

KEYWORDS: Daily soil temperature amplitude, Phenology, Remote sensing, Snow cover duration.

1 INTRODUCTION

Snow cover is a key factor in mountain environments, influencing several ecological processes. In particular the monitoring of the snow cover duration could be used to investigate changes in vegetation life cycles, plant phenology and plant communities distribution (Bokhorst et al., 2009; Dirnböck et al., 2003; Edwards et al., 2007).

Several approaches are used for snow cover monitoring: satellite remote sensing (Hall et al., 1995; Tang et al., 2013), solar energy budget (Brun et al., 1989; Pielke et al., 2000) and combination of previous approaches and morphological analyses (Allen, 1998).

Soil temperature can also be employed as a proxy for determining the presence of snow cover. Several authors have pointed out that a reduction of daily temperature fluctuation means the presence of a snow layer. Sensor placed in the topsoil (0-10 cm) can detect the presence absence of snow cover and track it in time (Lundquist and Lott, 2008; Zhang, 2005). Moreover comparisons between soil temperature and air temperature have confirmed method’s feasibility and reliability (Schmid et al., 2012).

The importance of accomplish such analyses in Park or Reserves is highly crucial for the management and conservation of their resources. Moreover protected areas are often provided with monitoring network which allows a comparison between the previously listed modelling approaches and in situ data.

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In this paper an investigation of snow cover duration was carried out by means of MODIS satellite time series in the Majella National Park. The research area is part of the International Long Term Ecological Research (ILTER) network belonging to the IT01-001-T site and the GLObal Research Initiative in Alpine ecosystems (GLORIA) (Pauli et al., 2004), thus several monitoring actions are carried out including soil temperature measurements (Stanisci et al. 2010, 2012).

2 MATERIAL AND METHODS

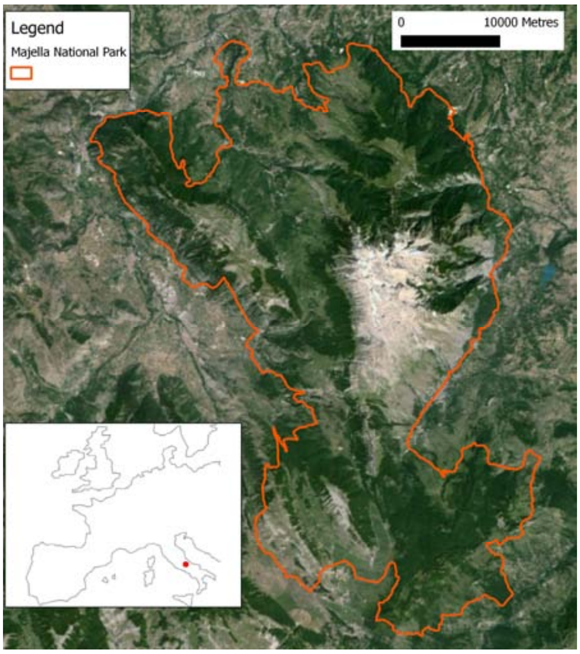

Figure 1. Location of Majella National Park

2.1 Study area

The widest alpine belt in the Apennines is located in the Majella National Park, 13.84-14.25 E ,41.85 - 42.25 N (Figure 1). This park represents a key site for studying the effects of climatic change in high altitude ecosystems.

The Majella massif, that reaches 2794 m a.s.l. with Mt. Amaro, is located in Abruzzo (central Italy) and it is articulated along a ridge north-southward aligned (42°00'14" N (Guado di Coccia) - 42°9'33" N (Majelletta)). The area is located 32,5 km far from the Adriatic Sea and 112,5 km from the Tyrrhenian Sea. The geology is characterized by large layers of limestone, where all the geological eras from the Triassic are represented. The Majella massif is characterised by a wide summit surface weakly sloped, of structural origin, bordered by steep inclinations, incised by deep valleys. The northern and eastern portions are modelled by large, deep glacial valleys, that show wide and evident circles at their heads and extensive buckling rocks (Giraudi, 1998). The western portion appears as a rather steep, extensive and homogeneous slope, furrowed only in correspondence of Fondo Majella, a large frontal moraines amphitheatre. The southern section, instead, slowly degrades southward to Guado di Coccia (1674 m a.s.l.). During the last glacial maximum (22000 years ago), the upper part of the massif was covered by a thick ice layer 30 square kilometres wide and more than 200 m thick. From here, glacial tongues spread over all the adjacent valleys up to 1330/1400 m a.s.l. of altitude.

While the Wurm glaciation gave origin to macroscopic forms of erosion, circles and moraines deposits, the current periglacial landscape is exposed to frost wedging and long-time snow persistence (seven-eight months a year). Thermo-cryoclastic phenomena chop the rock into characteristic tabular elements with sharp edges, of centimetric dimensions, which cover the white, large summit plateaux (Dramis and Kotarba, 1992) and the tectonic-karst depressions of Fondo Femmina Morta and Femmina Morta Valley.


Figure 2. Cannella valley

The Cannella valley (Figure 2) spans from 1900 and 2750 m a.s.l. of altitude and is about 5 km long and from 1 to 1.5 km wide.

In these environments, soils mostly derived from morainic materials. Along the flanks of the valleys soils are very stony (more than 90% skeleton) and because of xeric conditions, these soils (Entisols) generally have scarce vegetation coverage (from 5 to 20%). Along the depressions dotted by *kettle holes*, soils maybe skeletal or rich of organic matter; because of their position, the fine earth content and the richness of organic matter (Cioci et al., 2008), these soils (Mollisols) may retain water and consequently are completely covered by a grass vegetation,(Corti et al., 2012). The rather severe pedoclimatic conditions selected flora species like *Trifolium thalii* Vill., *Taraxacum apenninum*

(Ten.) Ten., *Crepis aurea* (L.) Cass. ssp. *glabrescens* (Caruel) Arcang., *Phleum alpinum* L. ssp. *raeticum* Humpries, and *Plantago atrata* Hoppe.

From a bioclimatic point of view, the study area corresponds to the subalpine-alpine humid type (Blasi et al., 2005). The highest weather station in central Apennines is Campo Imperatore (2125 m a.s.l.), where the mean annual temperature is 3.6 °C and the mean annual precipitation is 1613 mm (1960-1990).

In terms of altitudinal vegetation zones, the study area currently lies between the upper altitude limit of the Pinus mugo thickets, referring to the alliance Epipactido atropurpureae-Pinion mugo (Stanisci, 1997), and high altitude grasslands belonging to the alliances Leontopodio–Elynenion (Seslerion apenninae), Ranunculo pollinensis–Nardion strictae, Arabidion coerulae, Thlaspenion stylosi (Linario–Festucion dimorphae) (Biondi et al., 2000; Blasi et al., 2003)

The alpine belt of Majella massif was subjected to the traditional summer pasturing until fifties and since high altitude pasture abandonment, upward moving of Pinus mugo dwarf-shrubland is ongoing. (Di Giustino et al. 2002; Stanisci et al., 2005).

2.2 Snow Cover Assessment

Snow cover duration was quantified by the analysis of a MODIS time series (Hall et al., 2002). The dataset was downloaded by an automatic procedure and processed in R language environment (R Development Core Team, 2011; Godone et al., 2011). Firstly MODIS files were projected from the Sinusoidal reference system into the local system (UTM WGS84 Zone 33N), then each grid was reclassified in order to point out snow covered pixels, in contrast with ground (no snow), cloud or no data ones.

With the aim of comparing/correlated snow cover measurement with morphometric parameters - slope, elevation and aspect – an additional download was performed, thus obtaining SRTM tiles of the investigated area (Farr et al., 2007; Wolfe et al., 2002). Data were mosaicked and subsampled to MODIS resolution (i.e. 500 m) and clipped to the desired extension.

MODIS data were merged in summary table containing reclassified values, grouped in water years (October 1- September 30) and morphometric parameters. These tables were employed to compute the snow cover duration and statistics, by grouping the morphometric parameters into classes and mean snow cover duration was calculated in each one.

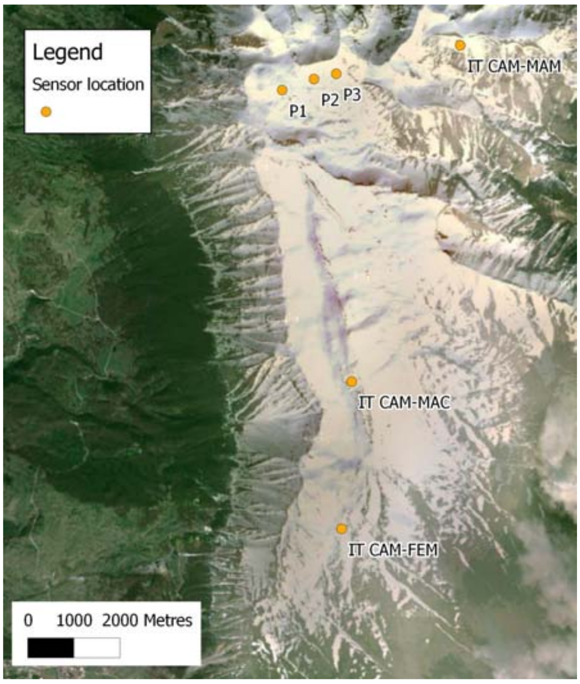

Figure 3. Location of soil temperature sensors (Background image: Google Earth©)

Moreover, to test/compare satellite data with ground ones, records from soil temperature monitoring sites (n=6; 10 cm depth) (Figure 3) were analyzed and snow cover duration was computed as a function of the daily temperature amplitude in the topsoil (Zhang, 2005). A threshold equal to 2°C was assessed in order to distinguish between a snow covered soil (t < 2°C) and a snow -free soil (t> 2°C), which is also considered as temperature limit for the vegetative period for alpine plants (Korner, 2003) . These data were compared with MODIS pixel values in each location. Sensors were located in three peaks (Femmina Morta, Monte Macellaro and Monte Mammoccio) and in the Cannella Valley (P1, P2, P3) at elevation ranging from 2405 to 2737 m a.s.l..

3 RESULTS AND DISCUSSIONS

The snow cover duration (Figure 4) showed an uneven behavior during the investigated time span. In particular year 2006/07 shows a severe reduction of the snow cover duration (Figure 5), if compared with neighboring years, while water years 2002/03 and 2004/05 (Figure 6) are characterized by positive peaks.

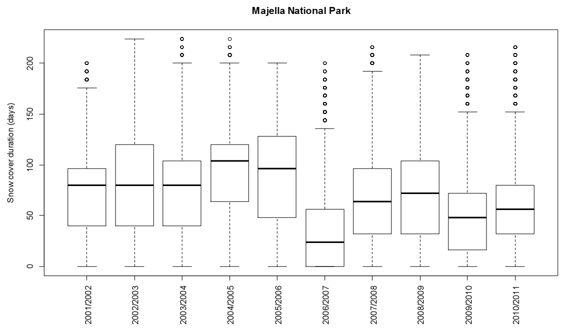

Figure 4. MODIS snow cover duration in the 2001 – 2011 time span.

In the last years a rising trend is detectable, following the 2009/10 dip.

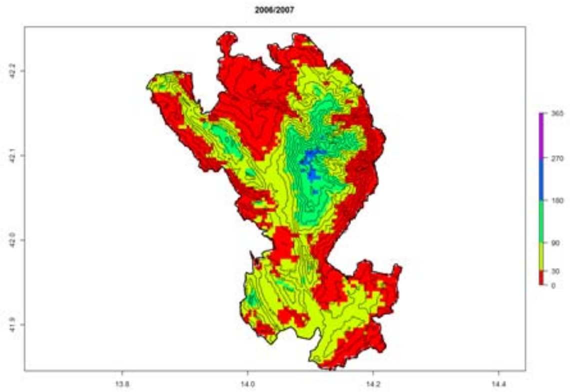

Figure 5. Cartographic representation of snow cover duration in water year 2006/07, characterized by the minimum mean snow cover duration in the study area

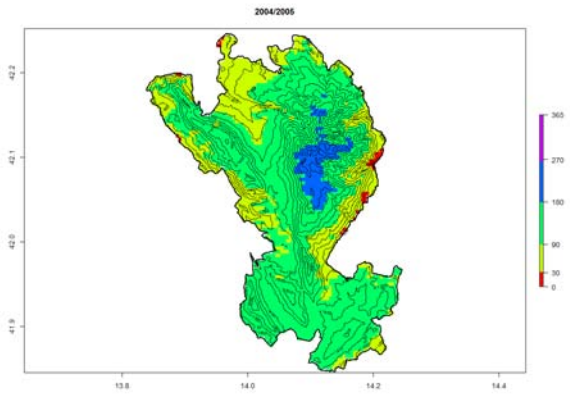

Figure 6. Cartographic representation of snow cover duration in water year 2004/05, characterized by the maximum mean snow cover duration in the study area

Soil temperature daily amplitude allowed the comparison between the two independent datasets used for the assessment of the snow cover duration. The analyses provided encouraging correspondences (> 85%) between the two data sources as shown in figure 7, where snow cover detected by MODIS is plotted as a blue line and orange asterisk represent the snow cover inferred by soil temperature analyses.

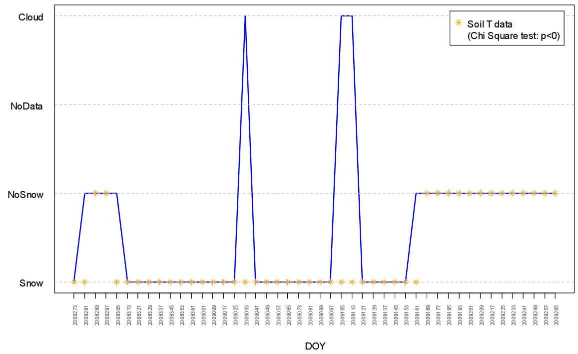

Figure 7. Comparison graph between MODIS (blue line) and soil temperature sensor (orange asterisks) data (water year 2008/09, sensor P3).

MODIS data processing have to cope with sensor malfunctioning, giving missing values, and satellite sensor masking due to cloud cover (Tong et al., 2009a) which prevent a correct snow cover detection by optical sensors (Figure 8).

There are several approaches to face this issue, e.g. by statistical processing or spatial filtering. In the continuation of the work a cloud removal process, based on a moving window method (Tong et al., 2009b), will be implemented in the previously described procedures.

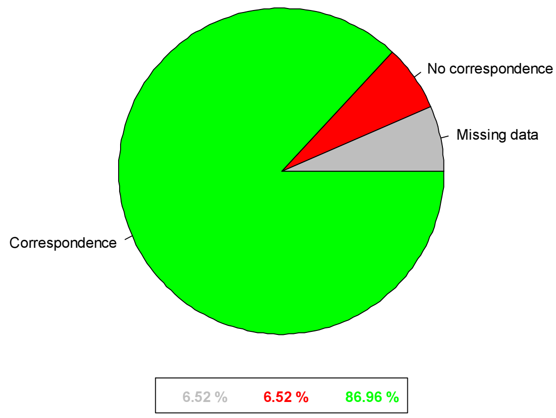

Figure 8. Pie chart showing correspondence between MODIS and soil temperature sensors (water year 2008/09, sensor P3).

4 CONCLUSIONS

MODIS data contributed to the comprehension of snow cover duration dynamic during the studied period but the limited time-span of available data (10 water years) do not allow a deep climatic analysis.

Soil temperature analysis has confirmed its effectiveness in the assessment of snow cover duration and the comparison with MODIS data revealed good correspondences between the 2 approaches. The issue of missing data in temperature sensor records is still pending and it should be adequately faced, e.g. by a correct sensor setting, by periodical monitoring of their status (when feasible) or gap filling by interpolation techniques (Brunetti et al., 2006), in order to provide trustworthy dataset for the analyses.

The monitoring of snow cover duration by soil temperature sensors appeared of great importance in areas currently difficult to examine by satellite data due to their spatial resolution, contributing to the improvement of snow cover duration assessment, a key parameter in ecological and phenological researches.

5 ACKNOWLEDGMENTS

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