Using digital camera images to analyse snowmelt and phenology of a subalpine grassland

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Using digital camera images to analyse snowmelt and phenology of an alpine grassland.

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Abstract

Plant phenology is a good indicator of the impact of climate change on vegetation. In mountain areas phenology is in general governed by environmental constraints such as air temperature, photoperiod and presence of snow. Several studies in literature showed the effectiveness of using automated repeat digital photograph for monitoring plant phenology. Most of these works analyse a small region of interest of the image do not considering the potential of using the entire image to exploit temporal and spatial evolution of phenology of a heterogeneous vegetated target. In the present study, digital images collected with a Campbell Scientific Camera (model CC640) over 3 years (2009, 2010 and 2011) in a subalpine grassland were used to analyse the spatial patterns of phenological events and their relationship with the timing of snowmelt.

Yearly time series of green chromatic coordinates (gcc) were computed from hourly images. In order to analyse the spatial pattern of phenological metrics, gcc time series were computed for each 10x10 pixel regions of the target ecosystem and the beginning of the season for the 10x10 regions was extracted. Based on the same grid dimension a snowmelt date map corresponding to the day of the year in which the snow disappears from the ground was obtained.

Despite the snowmelt occurs rapidly, as maximum in seven days, several distinct spatial patterns were identified. A negative correlation was found between the two snowmelt dates and the beginning of the season, meaning that the growing season begins later in areas characterized by an early snowmelt, and vice versa. Moreover the early snowmelt occurred in 2011 (about 40 days earlier than the previous two years) highlighted two main phenological patterns at the beginning of the season. A field vegetational analysis revealed that these patterns were related to communities with different plant composition. In particular differences in terms of species seem to be related to convex and concave areas, suggesting that different

patterns of snow and soil accumulation due to micromorphology affect the vegetation communities and so indirectly phenology. These results support the possibility of using digital repeat photography to analyze the spatial variability of phenological development of complex ecosystems such as alpine grasslands.

1 Introduction

Climate change, is expected to strongly influence high altitude ecosystems in Europe, by increasing temperature, changes in timing of winter and summer precipitation and duration of snow-pack (Alcamo et al., 2007; Auer et al., 2007; Beniston, 2005).

Plant phenology is highly sensitive to climate change (Menzel et al., 2006) and particularly in ecosystems with seasonality a clear correspondence exists between climate and phenological patterns (Richardson et al., 2013). Snow is among the most important environmental factors controlling high-altitude plant phenology (Galvagno et al., 2013; Wipf et al., 2009) moreover snow provides frost protection for plants in winter, and water supply and nutrient mobilisation at snowmelt (Keller and Körner, 2003). Any changes in the date of snowmelt or snow season establishment can induce strong ecosystem responses: 1) differences in seasonal patterns of carbon and water fluxes related to the time for plant photosynthesis and growth (i.e. snow-free season, (Galvagno et al., 2013)), 2) changes in interaction between species (Wipf et al., 2006), between plants and their pollinator, pests or pathogens (Roy et al., 2004), 3) the timing of soil nutrient availability and ecosystem functioning promoting conservative species (Saccone et al., 2013; Schimel et al., 2004). According to the literature the expected warming of the Alpine region lead to more frequent earlier snowmelt (Foppa and Seiz, 2012) that might cause changes in phenological patterns in alpine vegetation.

Efforts have been made to review in a comprehensive way the numerous studies conducted by means of direct snow manipulation (Wipf and Rixen, 2010). In fact several studies have investigated the effect of changing snow cover on alpine plant phenology and high variability in responses has been related both to species, growth forms and habitat (e.g. snowbed, fellfield). Previous studies (Keller and Körner, 2003; Wipf and Rixen, 2010; Wipf et al., 2006) proposed that species adapted to habitats characterised by different time of snow lying on the ground (such as snowbed or fell-field) can show distinct responses to snowmelt advancement or delay.

Because many vegetation-climate feedbacks (albedo, evapotranspiration and CO_2 fluxes) are mediated by phenology (Richardson et al., 2013) the monitoring and modelling of vegetation phenological cycle has become a major issue in global change research (Cleland et al., 2007). In this study we hypothesised that even within the same ecosystem it is possible to distinguish separate phenological behaviours related to site microheterogeneity and snow patches. Since mountain ecosystems are generally located in complex topography, the presence of microhabitats and the related different snow patches may induce, also within the same alpine plant community, several vegetation developmental strategies. The observed phenological patterns may reflect distinct adaptations to resource use efficiency, reproductive competition, site micromorphology, life cycle completion strategies (Keller and Körner, 2003). Monitoring of diverse phenological patterns in a plant community is useful to interpret the whole ecosystem response to climate variability. In heterogeneous plant communities, such as mountain grassland, disentangling the contribution of single species to community phenology is onerous. For the time being, to our awareness no methodology has been proposed for long-term monitoring community-level phenological responses to, first, the snowmelt variability, and, second, to the snow patches due to complex topography.

Traditional methods used to monitor plant phenology mainly consist of field observations and remote sensing data (Busetto et al., 2010; Linderholm, 2006). However, both strategies present some limits in term of spatial and temporal resolution. Direct phenological surveys hardly provide continuous information on plant phenology and do not allow covering vast areas (Schwartz et al., 2002). Moreover observations do not refer to a land surface phenology but to single plant and are frequently affected by the observer subjectivity. As regard the satellite products, while they can provide invaluable synoptic phenological information, are often challenging in mountainous areas due to complex topography, and do not allow a detailed evaluation of the variability in species responses (Ide and Oguma, 2013).

Several studies demonstrated the capability of RGB digital imagery to provide accurate phenological data (Ahrends et al., 2009; Ahrends et al., 2008; Bater et al., 2011; Migliavacca et al., 2011; Mizunuma et al., 2013; Richardson et al., 2007; Richardson et al., 2009). The digital cameras are usually fixed above a vegetated target (e.g. forests, croplands, grasslands and peatlands) and the images are continuously acquired during the season. The colour information contained in the images (chromatics coordinates) is then used as index of the canopy development. The time series of the indices extracted can be used to identify the timing of key phenological events. Most of the studies that use digital repeated photography for phenological applications compute the analysis on a single region of the image, considering it as representative of the entire monitored ecosystem. An interesting improvement in this technique is to analyse the spatial information in the considered frame in order to identify spatial differences of phenology within the image (Ide and Oguma, 2013).

The RGB images can also be used to retrieve important information of the snowmelt processes, as reported in literature (Hinkler et al., 2002; Parajka et al., 2012). Therefore the combination of the spatial information of phenology and the spatial characterization of the snowmelt process can improve the knowledge of the dependencies of plant development on the snowmelt timing.

In this study we investigate temporal and spatial patterns of phenology and their relationship with snowmelt using digital images. Therefore the objectives of the study are: *(i)* can we use digital camera photograph to identify spatial patterns of phenology within the image? *(ii)* Does phenology change according to the snowmelt? What is the effect on phenology during early snowmelt year?

To this aim snowmelt and spring phenology maps were computed using digital images collected at a subalpine grassland during three years and spatial patterns of phenology and their relationship with spatial patterns of snowmelt and species compositions was evaluated and discussed.

2 Materials and Methods

2.1 Site description

The study site is located in the northwestern Italian Alps (Aosta Valley, IT) at 2160 m a.s.l. (45° 50’40’’ N, 7° 34’41’’ E). The region is classified as intra-alpine with semi-continental climate. The mean annual temperature is 3.1 °C while the mean annual precipitation is 880 mm. The site is generally covered by snow from the end of October to late May. The site is a subalpine unmanaged pasture with two different plant compositions related to micromorphological conditions: the first one with dominant *Nardus stricta* the second with dominant forbs (*Crocus vernus, Geum urbanum verde, Ranunculus pyrenaeus, Poa alpine*).

2.2 Data collection

Digital images were collected using a Campbell digital camera (model CC640 Campbell Scientific, Logan, UT, USA) installed in 2009 at the experimental site. Following Richardson et al. (2007) the camera was pointed north, and set at an angle of about 20° below horizontal. Camera focal length was 3.5 mm and the field of view was approximately 79.8°. The camera was fixed at 2.5 m above ground and the same view scene has been captured (Fig 1). The JPEG images collected have a resolution of 0.3 megapixels, with three colours channels, red, green and blue, of 8-bit. The images were collected hourly from 10 am to 5 pm and exposure mode and white balance were set to automatic. The 5644 JPEG images analysed during the study were collected between 21st May 2009 and the 22nd November 2011.

2.3 Image analysis

Usually digital images are used to track the phenological plant development by considering a single Region of Interest (ROI) in the image as reference of the mean behaviour of the entire ecosystem analysed (Migliavacca et al., 2011; Richardson et al., 2006; Sonnentag et al., 2012). Few published works use more than one ROI to analyse phenological differences between plants contained in the same image (Ahrends et al., 2008; Jacobs et al., 2009; Mizunuma et al., 2013) while Ide and Oguma (2013) are the first that perform a pixel per pixel analysis. In our study we evaluated the spatial evolution of snowmelt in the time considering the effect of the snowmelt patterns on the spring vegetation phenology. The same ROI of the image was used to analyse snowmelt and vegetation phenology (Fig 1). ROI position was defined to select only the foreground part of the grassland in the image, less affected by clouds sometimes present in the background (Migliavacca et al., 2011). Pixel size in the ROI ranges from 1 to 4 cm and the extension of the analysed area corresponds approximately to 150 m^2. Then to investigate the spatial variability of the processes, the analysis was conducted resampling the original ROI on a 10x10 pixels grid (Fig 1) providing a number of cells grid equal to 931 (19 rows and 49 columns).

2.3.1 Snowmelt date maps

Snowmelt maps were computed performing an unsupervised classification (K-means) on the grid for identifying two classes, corresponding to ''snow'' / ''no snow''. In a second step the date of snowmelt per each cell of the grid was defined as the DOY when more than 50% of pixels of the cell are classified as ''no snow''. Finally spatial anomalies of snowmelt were computed for each year as the difference between cell values and mean snowmelt date of the entire grid.

2.3.2 Spring phenology maps

The chromatic information contained in the collected images can be extracted using indices that synthesize the primary colours content of the images: red (R), green (G), and blue (B). The time series of single channels (R,G,B) digital number (DN) values are known to be sensitive to illumination condition and camera acquisition setup. These influences can be minimized transforming the RGB DN to RGB chromatic coordinates (Gillespie et al., 1987; Woebbecke et al., 1995) as follow:

$$gcc = G_{DN}/(R_{DN} + G_{DN} + B_{DN}) \quad (1)$$

$$bcc = B_{DN}/(R_{DN} + G_{DN} + B_{DN}) \quad (2)$$

where R_{DN}, G_{DN}, B_{DN} are the red, green and blue DN values of each color channel respectively. In literature gcc is widely used to track the greenness of the canopy and could be considered as a good descriptor of the plant phenology (Migliavacca et al., 2011; Richardson et al., 2007; Richardson et al., 2009; Sonnentag et al., 2012).

The green chromatic coordinates (g_{cc}) were computed for each pixel of the ROI and then averaged for each cell for all the images recorded during the three years, resulting in a cell based g_{cc} time series. The illumination changes in the field of view, especially due to cloudy sky conditions, affected the diurnal and seasonal trend of the index producing spikes in the time series. The time series was consequently filtered to reduce data noise. The filtering strategy could be divided into two steps.

I) The diffuse light conditions affects the blue channel more than the others, thus the presence of the clouds could be detected considering the behaviour of the blue channel (Ide and Oguma, 2010). When the weather conditions are not stable the blue channel value shows a higher daily variability. Here a threshold on the b_{cc} trend has been chosen. The images were discarded if the b_{cc} value is outside the range:

$$bcc_{dm} - 5^{th} \text{ percentile } (bcc_{sd}) < bcc < bcc_{dm} + 5^{th} \text{ percentile } (bcc_{sd}) \quad (3)$$

where b_{cc} is blue chromatic coordinate defined in formula 2, $b_{cc\ dm}$ is the daily mean value of b_{cc} and $b_{cc\ sd}$ is the seasonal standard deviation of $b_{cc.}$

Form a visual inspection the filter based on the use of the b_{cc} time series pointed out that this strategy removed all the cloudy images but also images collecting during clear sky condition. This conservative approach could be applied considering a time series with 7 daily images.

II) The approach suggested by (Sonnentag et al., 2012) that consists in a 3 days moving-window assigning the 90th percentile to the center day (calculated using all the gcc values referred to the images acquired in 3 days of measurements) was used to process the data. The effect of this filters is to reduce the temporal resolution of gcc time series from daily to three daily.

A curve fitting (cubic smoothing spline following Migliavacca et al. (2011) was computed to the gcc time series. The beginning of the season (BOS) was defined as the time where the greenness curve reaches the half maximum of the spring growth (Bradley et al., 2007; Fisher et al., 2006; White et al., 1997). According to the literature we used a fixed threshold on the curve (50% of the growth) to obtain the BOS. The defined methodology was automatically applied first to the averaged ROI value and subsequently to all the cells of the grid leading to a BOS map. A no value flag was assigned to grid cells occupied by the grey panel visible in the images and to grid cells having BOS values outside the range snowmelt date - end of July. Yearly BOS anomaly maps were obtained subtracting to each cell the mean BOS value of the entire grid.

2.4 Comparison of the beginning of the season and the snowmelt dates

In order to evaluate the influence of snowmelt temporal and spatial patterns on spring phenology, BOS and snowmelt maps of the three years were compared performing the non-parametric Kendall correlation test using all the values of the maps. Correlation analysis was also performed on data aggregated with the following approach: grid cells were grouped in 15 classes according to snowmelt quantiles, for each cell falling in a given class snowmelt and BOS median was computed. Lastly generalized linear models (glm, (McCullagh and Nelder, 1989) were computed to analyse the sensitivity of the BOS to the snowmelt.

3 Results

3.1 Spring phenology and snowmelt maps

Air temperature trend was comparable during the 3 years. While a warm spring spell in April 2011 caused an extremely early snowmelt (~40 days) if compared to both 2009 and 2010 or to long term (1928-2010) data (Galvagno et al., 2013). The spatial distribution of snowmelt dates is highly heterogeneous (Fig 2). Mean snow melt date occurred at DOY at 145, 143 and 103 in 2009, 2010, 2011 respectively even if the time needed for a complete snowmelt on all the area analysed ranged between 3 days in 2009 and 2010 and 6 days in 2011 (Fig 3). Considering the BOS map a similar heterogeneous behaviour has been found. Mean BOS occurred at DOY 172, 173, 162 in 2009, 2010, 2011 respectively while considering the variability of the BOS dates in the analysed area of each year ranged between 66 days in 2009 and 111 days in 2011 (Fig 3). A consistent spatial dynamic can be seen in the 3 years both in the snowmelt and in the BOS maps. The correlation analysis results performed between the snowmelt maps and the spring phenology maps are reported in table 1 (expressed in terms of tau, Kendall rank correlation coefficient). The results showed a significant inverse correlation between the two maps, meaning that later snowmelt areas correspond to areas with earlier BOS.

3.2 Phenology at community level

The early spring spell occurred in 2011 gave us a unique opportunity to analyse the BOS distribution within the image. The two modes highlighted in the 2011 BOS frequency distribution (Fig 3) have been used to create two masks on the BOS map distinguishing the areas where the BOS occurred early or later. Therefore the two masks have been considered to define plots at ground level for a phyitosociological surveys with the aim of characterizing plant species composition. The survey was conducted in May 2012. A total of 8 early and 8 late phenology plots were selected for the observations. Species composition, grouped into early or late BOS, are reported in table 2. Generally the areas characterized by an earlier BOS correspond to areas with abundance of forbs while in areas with late BOS the main coverage is attributable to grasses species. In figure 4 the yearly averaged BOS is shown grouped into forbs and grasses species (according to the bimodal distribution of 2011 BOS) and considering the averaged BOS referring to the overall ROI value as well. The variation in the grasses BOS within the 3 years varies of 7 days as maximum in 2011. On the contrary the averaged forbs BOS is similar in 2009 and 2010 while occurs 26 days before in 2011. Considering the ROI averaged value of BOS during the three year (2009: DOY mean 171 ± 13, 2010: DOY mean 173 ± 14, 2011: DOY mean 165 ± 23) no significant advance can be noticed.

3.3 Phenology and snowmelt relationship

Due to the relationship detected between snowmelt and phenology and considering the differences between the two main functional groups (grasses and forbs) we carried out the sensitivity analysis between snowmelt and phenology using glm both on the entire community and on the two functional groups (Fig 5). A strong negative correlation was found between BOS and snowmelt as reported in table 3. The table reports separately the results obtained by *(i)* applying the model on all the grid cells or *(ii)* distinguishing between the grid cells referred to each of the two plant functional group (forbs and grasses). The results suggested that a constant inverse relation between snowmelt date and BOS existed, meaning that areas characterized by early snowmelt corresponded to area where the BOS took place later (and vice versa). In particular the results referred to the all community show a strong relationship in the 3 years considered (high value of r^2) with a similar slope in the three years considered. On the contrary analysing separately the two functional groups we obtained different results. The forbs BOS in 2011 took place before and the slope of the relationship, constant in 2009 and 2010, decreased, meaning a less sensitivity to snowmelt on the BOS when the snowmelt occurs before even if the r^2 values of these relationships are still high. For grasses in 2011 the BOS took place few days later (as shown in Fig 4). While the BOS increased during the 3 years, the slopes of the relationship between snowmelt and BOS decreased suggesting a reduction of the influence of snowmelt on grasses BOS depending on when the snowmelt takes place.

4 Discussions

4.1 Snowmelt and spatial phenology

We showed the suitability of using digital repeated images for analysing the phenological heterogeneity of an ecosystem such as grasslands. The results show the potential of using a standard digital camera collecting automatically repeated images to monitor patterns of phenology in relation to snowmelt variability in subalpine grassland. The combination of temporal and spatial information gave important insights on the grassland vegetation development dynamics, improving the characterization of the study site. In turn, the spatial analysis of the snowmelt can provide useful information for interpreting the complex relationships existing between this process and the phenological behaviour of a heterogeneous ecosystem. The obtained outcomes of the analysis point out the importance of using spatial disaggregated data. In figure 6 the gcc curves are separately plotted distinguishing between the ROI value, the forbs and the grasses. Without disentangling the contribution of forbs and grasses in the phenological development of the ROI we obtain a similar time series during the three considered years, while analysing separately the information related to forbs and grasses a different behaviour can be noticed. In particular in 2011 the differences between the two functional groups are more evident as expected.

The snowmelt occurred in latest May in 2009 and 2010 while in the middle of April in 2011, due to a strong spring warm. The differences in terms of date also caused a different overall duration of the snowmelt process that varies between 3 and 6 days, depending on the year (Fig 3). Even if the snowmelt took place differently according to the year considered similar snowmelt spatial patterns have been found in all the years considered, meaning that areas where the snow disappears earlier or later are constant among years. These spatial patterns are related to the surface microtopography, in fact in concave areas the snow lasts longer, while in the convex ones the snow disappears before.

Similar patterns exist in the spring phenology maps as well. We showed an interesting negative correlation between snowmelt and BOS patterns (tab 1) indicating that the way in which snow melt takes place also affects phenology as previously indicated by (Evans et al., 1989) and (Walker et al., 1995). The phenological differences are strictly related to the presence of two functional groups. The presence of different species is shown in Fig 3 where the bimodal distribution of BOS observed in 2011 underlines two different phenological behaviours. In particular these phenological behaviours are related to the presence of grasses and forbs (tab 2). This observation confirms the hypothesis that the spatial pattern of snowmelt, through the influence exerted on species distribution, is indirectly responsible for the observed heterogeneity in phenology (BOS).

4.3 Ecological feedback

The results point out that the forbs species, whose opportunistic behaviour is well known in literature (Keller and Körner, 2003), are capable to immediately tune its growth even in very early years (Fig 4), regardless of air temperature and photoperiod. Indeed in 2011, the year characterized by an extreme early snowmelt, a strong anticipation of BOS is observed in areas of the grassland dominated by forbs. Conversely the grasses (mainly *Nardus stricta*) showed a "safer" behaviour and started to develop in similar periods among years and did not show any advancement in BOS neither in the extreme year 2011. The BOS grasses seems to be more stable trough years (fig 4) and thus more affected by photoperiod (and temperature) rather than the date of snowmelt. These results agree with (Wipf and Rixen, 2010), where grasses did not show any consistent response to snow manipulations. Forbs are sensitive precursors of snowmelt (Keller and Körner, 2003). Hence the fast BOS of forbs species in 2011 could be the response of a species adapted to grow in late lying snow areas. While in habitats with early snowmelt (e.g. convex areas), any advancement of snowmelt may lead to frost-damage, hence a photoperiod-dependent BOS may be a safer strategy for this species. Differences in phenological development may also have an important role on the whole ecosystem processes, especially during years characterised by extreme snowmelt. For example a reduction in net CO_2 ecosystem uptake was observed in spring/summer 2011 (Galvagno et al., 2013): this may in part be due to the later development of grasses compared to forbs (less abundant at ecosystem level).

5 Conclusions

During this study we demonstrate that digital repeat photographs can provide reliable information on the analysis of the effect of snowmelt on plant phenology in a heterogeneous ecosystem such as grassland without any manipulation experiment. The repeated images can be used to describe the spatial evolution of snow patches during the snowmelt phase. At the same time we show that by combining temporal and spatial information of the images we're able to appreciate a phenological spatial heterogeneity within the same ecosystem. We underline the importance of considering the spatial information of the images usually not taken into account in most of the published studies that analyse digital repeated images for phenological purposes. This analysis approach can provide a more detailed description of heterogeneous ecosystems, helpful for a better knowledge of the phenological process.

The analysis show that plant phenology reflects the evolution of snowmelt (mainly driven by microtopography), through the influence exerted on species distribution, confirming a dependency of the plant development on the snowmelt.

We can conclude that digital repeat photographs can be a tool for long-term monitoring of the community-level phenological responses to the snowmelt variability.

Acknowledgments

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TABLES

	2009	2010	2011
Raw	-0.34	-0.25	-0.3
Aggregated	**-0.89**	**-0.63**	**-0.73**

Table 1 Kendall correlation coefficient (tau) computed between the snowmelt date and the BOS. The two lines refer to the correlation analysis conducted considering all the grid cell values (Raw line) and using only the aggregated data (Aggregated).

	Early beginning of season	Late beginning of season
Grasses	52.8±14	93.4±5
Forbs	47.2±14	6.6±5
Nardus stricta	51 ±17	93.4±5
Poa alpine	1.8±2	-
Crocus vernus	12.2±10	2.4±3
Potentilla alpine	3±4	2.2±2
Trifolium alpinum	3±4	-
Arnica Montana	5±8	-
Polygonum bistorta	2±4	-
Hieracium pilosella	1±2	-
Geum urbanum verde	16±9	2±2
Ranunculus pyrenaeus	3±4	-
Leontodon	1±2	-
Ranunculus acris	1±0.4	-

Table 2 Field phenological analysis results, May 2012. The table represent the averaged species composition distribution expressed in terms of percentage of cover. The plots considered in the field were defined according to areas identified in the 2011 BOS anomaly map. 16 plots were analysed in the field distinguishing 8 areas characterized by an early beginning of the season and 8 areas were the season took place later.

	All				Forbs				Grasses			
	r2	**m**	**St er**	**P**	**r2**	**M**	**St er**	**p**	**r2**	**M**	**St er**	**p**
2009	0.9	-17.21	1.93	< 0.01	0.70	-14.48	3.56	< 0.01	0.74	-11.48	2,46	< 0.01
2010	0.75	-13.50	3.107	< 0.01	0.75	-14.4	3.22	< 0.01	0.56	-4.11	1.29	0.02
2011	0.8	-20.84	3.29	< 0.01	0.6	-3.93	0.82	< 0.01	0.63	-2.79	0.68	< 0.01

Table 3 Results of the analysis conducted using Generalized Linear Model. The relationship between the BOS and the snowmelt dates is here reported in terms of r^2, slope, standard error and p value. The table distinguish between analysis conducted on the all scene, or divided into the two main plant communities (forbs or grasses).

FIGURES

Figure 1. The study site JPEG image. The Region of interest considered during the analysis is bordered in red. It has been chosen in the foreground avoiding problems related to distance, weather and excessive pixel size differences. The region selected has been then divided using a grid of 10x10 pixel. As depicted in the figure 19 row and 49 columns result from the division. In the right side the grey panel, considered as no value during the analysis

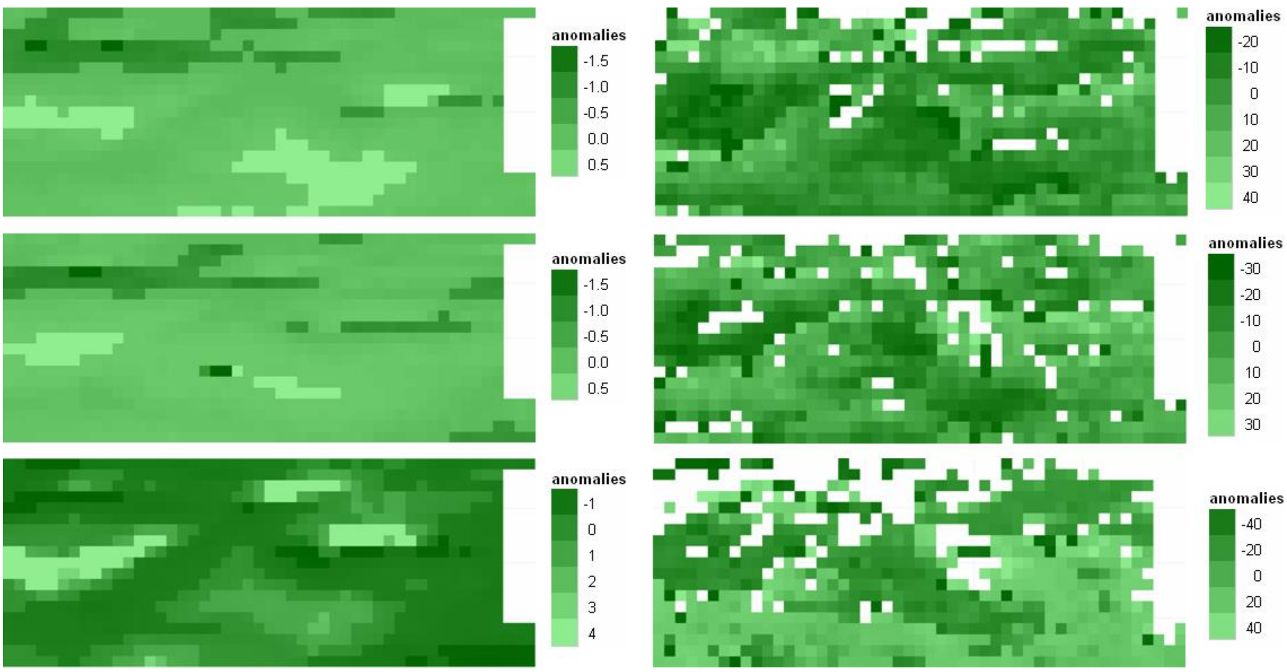

Figure 2. Left panel: snowmelt anomaly maps computed against the mean value of the entire grid; right panel: maps of the anomaly of BOS computed against the mean BOS of the entire grid. Each row identifies a different year. The color scales represent the range of variation of the snowmelt/BOS dates in the images. Dark green highlights areas where dates are anticipated, while the light green refers to areas where the snowmelt or the BOS are postponed.

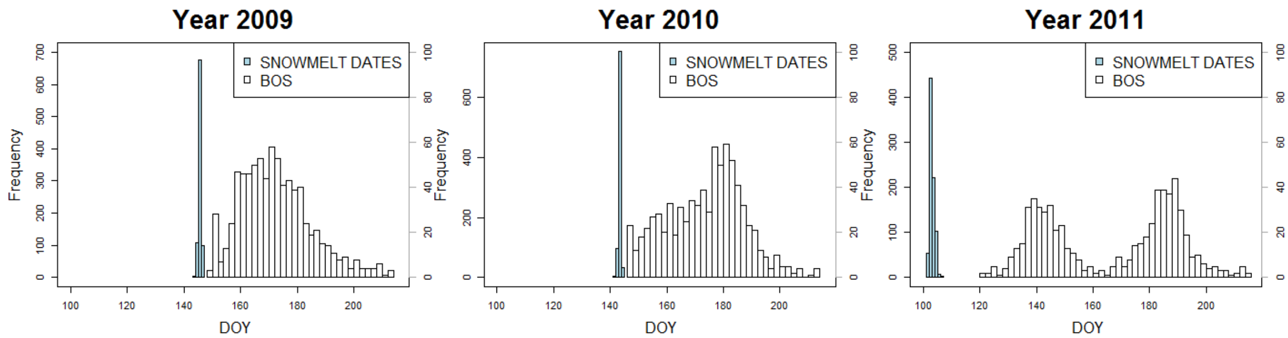

Figure 3. Frequency distribution of snowmelt dates (light blue) and BOS (white) in the 3 years considered. The unimodal distribution in the first two years becomes bimodal in the third one. In the year 2011 the snowmelt date is strongly anticipated compared to 2009 and 2010 (~40 days before).

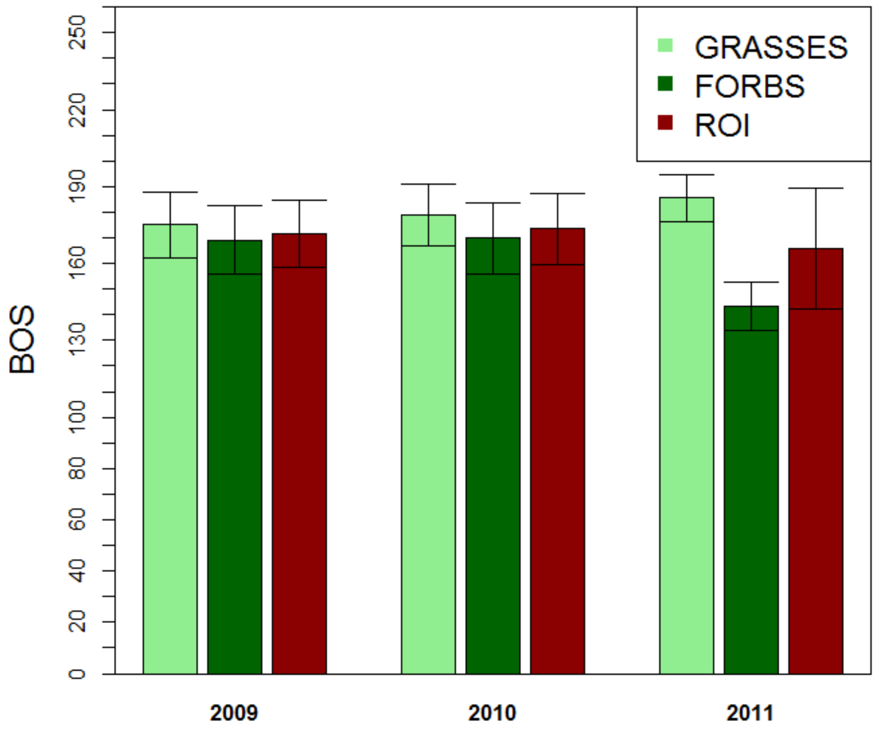

Figure 4. The graph shows the 3 years averaged BOS and related standard deviation obtained by distinguishing between the two main functional groups (grasses and forbs) and the overall ROI value. The BOS of the forbs species is strongly anticipated in 2011 (26 days before the two previously years) while the variation of grasses BOS is stable in the 3 years considered. Analysing the averaged BOS value of the ROI a small advance with the higher standard deviation is recorded in 2011.

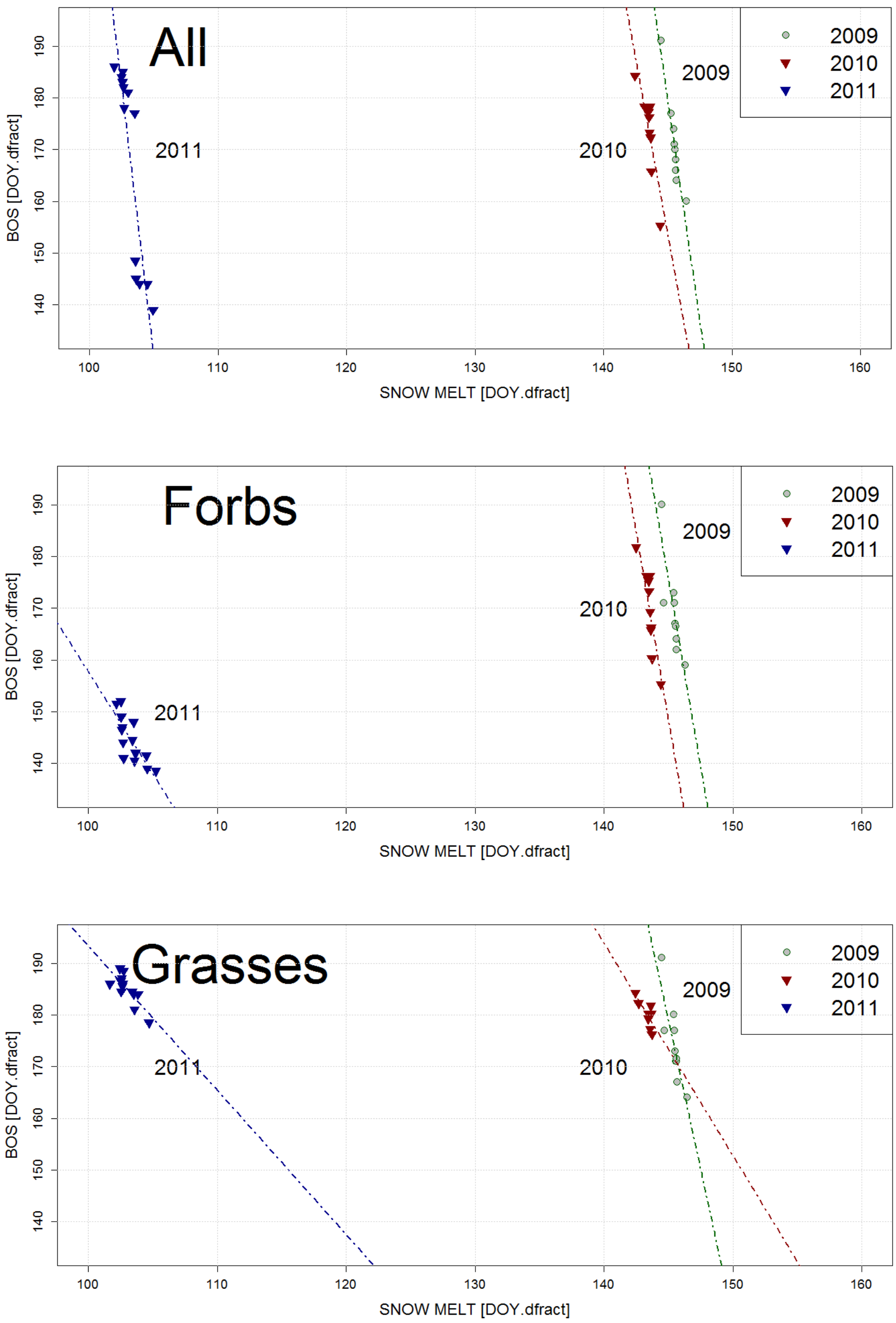

Figure 5. Relationship between snowmelt date and BOS analysed using the glm. The models have been applied considering the overall value of all the grid cells (A), and distinguishing the plant communities existing at the grassland site (B, C). In particular the second graph represents the analysis carried out considering only the grasses species, while the third one refer to the forbs community.

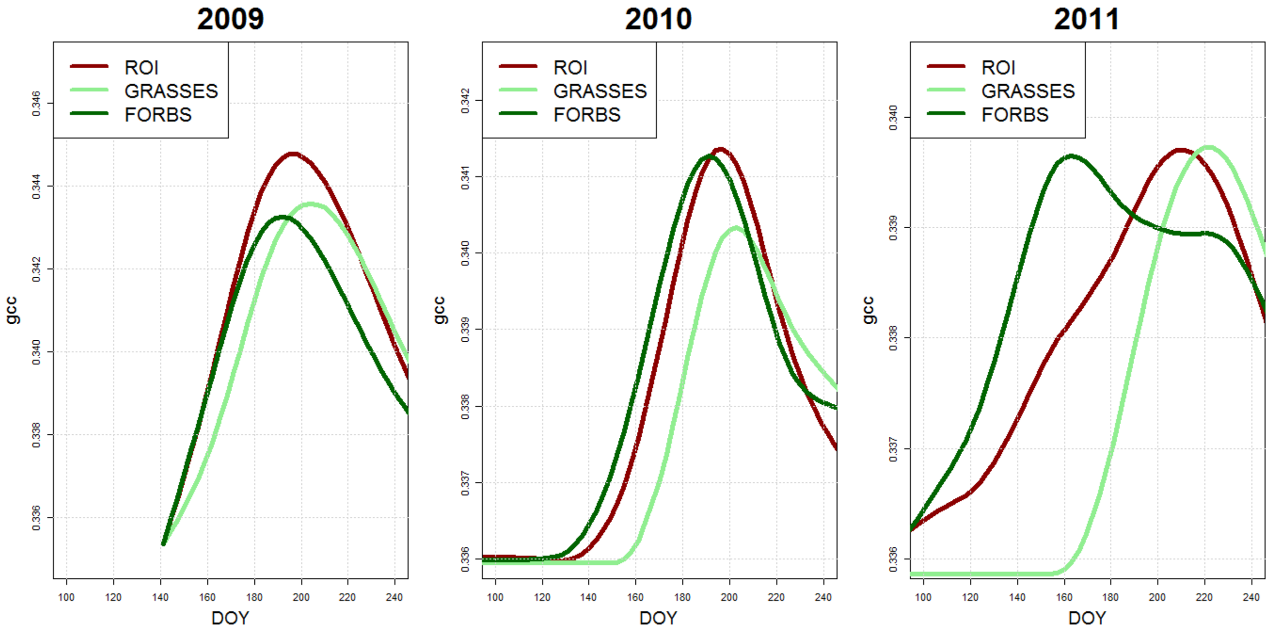

Figure 6. The 3 years GI time series are separately plotted considering averaged value of the overall ROI (red line), and the two functional groups (Forbs, dark green line and grasses, light green line). The 2011 is characterized by a strong advance in the growth of the forbs species while in 2009 and 2010 the difference of the two functional groups is not so emphasized.

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