

The influence of aspect on physical and chemical properties of the snow cover in a basin on the Monte Rosa Massif (North-western Italian Alps).

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ABSTRACT: In Alpine ecosystems, snowpacks are characterized by both spatial and temporal variability, as a function of topographical and meteorological factors.

This study aims to evaluate the spatial variability of the seasonal snowpack at a small scale to quantify the influence of aspect and slope angle on the snow cover evolution. Three sites were chosen in the Monte Rosa Massif (North-western Italy) at an altitude of 2600 m asl with different slope angles and different aspects: North and 25°, South and 25°, fl at. In winter 2006-2007, physical snow parameters, and chemical (pH and Electrical Conductivity) were periodically recorded.

The structure and composition of snow displayed significant differences among sites, with consequences on the snow stability. The snowpack at the flat site was comparable to the North-facing site in the lower part of the profile, while it was similar to the South-facing site in the upper part of the profile. Concerning chemistry, the nutrient release started at the end of February at the South-facing and flat sites, occurring through different ionic pulses during the winter. On the contrary, at the North-facing site the release occurred with a unique relevant ionic pulse at the end of April.

This study shows that the physical properties of a snowpack can vary broadly as a function of plot-scale topography, determining different stability conditions that are not always considered while forecasting the avalanche risk. The same topographic conditions play a role in the process of solute release, with different consequences in the nutrient input from snowmelt to subnivalian mountain soils.

KEYWORDS: snowpack variability, topography, snow chemistry, stability.

1 INTRODUCTION

Together with other nivometeorological parameters, such as wind and temperature, the solar radiation plays an important role in the snowpack evolution. Such parameters are very variable and therefore they determine a great spatial variability of the snow cover, which must be taken into account in evaluating, for example, the snow avalanche hazard level or the snow water equivalent.

The influence of aspect on the spatial variability of snow has been already studied by many scientists in the past. For example, Pielmeier (2003) studied the snowpack structure at a regional scale, while Birkeland et al. (1995) and Kronholm et al. (2004) at a smaller scale, on a single slope level. All stressed the fact that

the physical characteristics of the snow are not uniform at the considered scale and tried to develop a method for the localization of the most dangerous slopes.

Other studies analyzed the spatial variability of the snow cover in order to correctly model the snow melting process to evaluate the snow water equivalent in the arctic regions or on the Alps (Anderton et al., 2003; Barber et al., 2002; Bocchiola and Rosso, 2007).

Concerning the snow chemistry, past research limited to the analysis of the temporal and spatial distribution of the nutrients and of the pollutants on the Alps, e.g. with the project SNOSP from 1991 to 1993 (Puxbaum e Wagenbach, 1994). More recently, the snow chemistry has been studied in the Eastern Alps (Nickus et al., 1998), in the Southern Alps (Kuhn et al., 1998) and in the Western Alps (Pecci et al., 2006; Pecci et al., 2009; Filippa et al., this issue). Yet, there is only scarce literature about the influence of aspect on the snowpack structure and chemical properties at a small scale.

The present study aims to evaluate the influence of aspect on the physical and chemical properties of the snowpack and to analyze the spatial variability of the snowpack stability.

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2 MATERIAL AND METHODS

The study area is placed at the head of the Lys Valley in Aosta Valley (Italy) at an elevation of 2600 m asl in the Monte Rosa Massif (Fig 1). We choose three sites, 50 m apart from each other, with different slope angles and different aspects: North and 25°, South and 25°, flat.



Figure 1. Location of the study area.

The evolution of the physical properties of the snow cover was monitored through periodical snow profiles (twice a week, 39 in total), while the chemical properties (i.e pH and electrical conductivity along the profiles) were monitored during the season through 24 sampling campaigns.

The snowpack stability was evaluated for each profile with the compression test used by the Canadian Avalanche Warning Service in the '70s and well described by Jamieson e Jonhston (1997).

3 RESULTS AND DISCUSSION

In this paper we only focus on some of the results about the physical and chemical properties of the snowpack.

3.1 Snowpack physical structure

3.1.1 Temperature

Our data showed that aspect directly influenced the snow temperature, modifying the surface temperature and therefore influencing the temperature gradient within the snow cover.

Concerning superficial layers (we consider the first 30 cm) we generally observed, as expected, warmer layers at the South-facing and flat sites and cooler layers at the North-facing site (Fig 2).

During cold periods, the air temperature penetrated up to 1 m below the surface of the snow cover, which however maintained its insulating effect on the substratum. This influence in depth, more active at the South-facing and the flat sites, probably because of the presence of crystals of type 3 with higher density and thermal conductivity, caused high local temperature gradients with the formation of small layers of faceted crystals.

In general, the mean basal temperature, at the snow/soil interface, during the entire season was different in the three sites: -0.4°C at the South-facing site, -0.8°C at the flat one and -1.5°C at North-facing one. Such temperature caused different temperature gradients and subsequently different snow metamorphisms.

At the South-facing site, the anomalous meteorological conditions of February, which was exceptionally warm, produced an early isothermal snowpack, which might have had consequences on the snow melting process and on nutrient release to the soil.

3.1.2 Snow crystal types

Concerning the deeper layers of the snow cover, 20-50 cm of depth hoar were found at the North-facing and flat sites throughout the whole season. Its thickness was always greater at the flat site, probably due to the higher kinetic gradient, as the snow/soil temperature was closer to

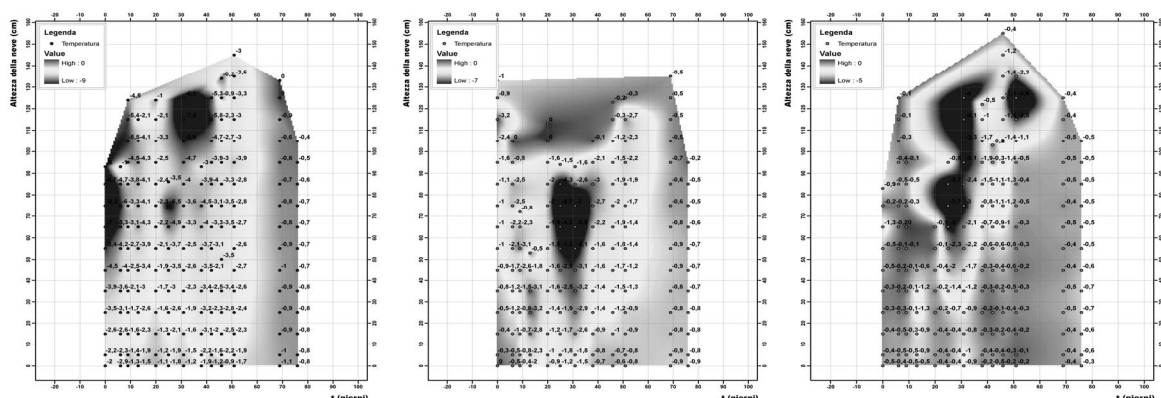


Figure 2 : Evolution of snowpack temperatures during the season (from the left: North, Flat, South). X axis represent the time, Y axis the snow depth and the grey scale the temperature values.

0 °C than on the North-facing site.

At the South-facing site, the basal layer was characterized by the presence of round grains at the beginning of the season, which then rapidly transformed into melt-freeze grains due to the percolating water coming from the surface.

Some ice crusts were found in the deeper layers, closed to the ground, at the South-facing site, while none were found at the other two sites.

On the surface, the snow cover was very variable at the three sites, with the presence of wind crusts, melt-freeze crusts, fresh snow, etc. without any obvious relation between snow type and site. During many surveys, however, we found, on the same day, firn-spiegel on the South-facing site and surface hoar on the North-facing one. Moreover, in the South-facing site ice columns were found inside the snowpack (26/02; 09/05) revealing the presence of preferential flow paths in melting snowpacks (Williams et al., 2000). Figure 3 summarizes the mean composition of the snow cover at the three study sites.

3.1.3 Snow hardness

The snow hardness was measured with the empirical "hand test". The main differences were found at the base of the snow cover: at the North-facing and flat sites the depth hoar had a low hardness (level 1 and 2), while at the South-facing site the hardness of the basal layer was equal to level 5 or 6 on a thickness up to 1 m.

3.2 Snowpack stability

We did not observe significant differences in the snowpack stability, except in late Spring when the stability was lower at the South-facing site. We think the reason could be the low cohesion of the superficial layers, due to high water content.

No large difference was found in the stability indexes of the three sites, but it is interesting to highlight the large difference in the thickness of the released layer: at the North-facing site the mean thickness was 56 cm (with a max of 120 cm), while only 18 cm at the South-facing site.

During the compression tests (Jamieson and Johnston, 1997), we identified 4 types of snowpack (Fig. 3) among the 10 types described by McClung e Schaerer (1996).

At the North-facing site the profile C of Figure 3 represents more than 50% of the profiles: it had dry fresh snow on the surface with low cohesion. The profile A describes the profiles characterized by depth hoar at the base of a relatively cohesive snowpack (38% of the profiles).

At the South-facing site the most frequent type was the profile D with a wet superficial layer, generated by a high solar radiation (64% of the profiles); the profile C represents the 36% of the profiles and is characterized by several melt-freeze crusts which were good sliding planes.

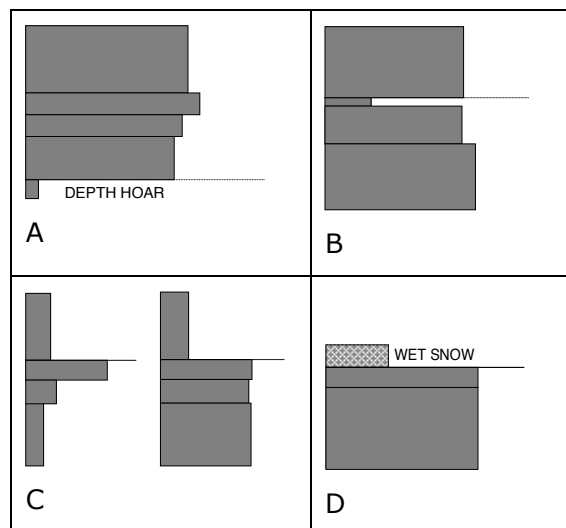


Figure 3 : Different types of snowpack structures found in this study. X axis represents the snow hardness and Y axis represents the snow depth; the black line indicates where the fracture occurred during the compression test.

3.3 Chemical properties of the snowpack

3.3.1 pH profiles

The profile-averaged pH observed during the whole study ranged from 3 to 7 (Table 1).

Table 1. Minimum and maximum values of pH at the three sites during the whole season (the dates are in month/day).

NORTH		FLAT		SOUTH	
min	max	min	max	min	max
4.9	6.8	3	7	5.1	7
03/08, 04/24	02/28	03/01	04/15	04/15	04/11

pH exhibited a significant decrease at the North-facing site in early March (i.e. a 0.5 decrease in 10 days), while it increased at the South-facing site. Such increase may be related to the melting process, that determined the preferential elution (Kuhn et al., 1998) of acidifying compounds (e.g. sulphate) with a consequent increase in pH. At the North-facing and flat sites we can hypothesize the decrease in pH to be due to the low temperatures recorded on March 3rd, 4th and 5th and the resultant higher solubility of CO₂ that may in turn acidify the snow. Afterwards, the pH increased at all sites (with a more

pronounced increase at North-facing and flat sites), although a late snowfall contributed some 20 cm of more acidic snow at the surface. The pH increase at the base of the snowpack was related to solute exchange between snow and substratum.

In April, the pH generally decreased, consistent to previous studies (Kuhn et al., 1998), as an effect of the so-called *Spring deposition* (Maupetit et al., 1995; Kuhn et al., 1998). This process is determined by the transition from stable air mass stratification in Winter and convective mixing in Spring that determines the transport of solute-enriched air masses from the lowlands to the remote sites over the Alps and the subsequent deposition of solutes on the snowpacks. Consistent with such hypothesis, the air masses generating the precipitation in this time period were from South-East (i.e. the Po Plane), where air quality is strongly influenced by acidifying anthropogenic emissions.

At the end of winter pH exhibited an increase first at the South-facing site (April, 15th), then at the flat (April, 24th) and finally at the North-facing site (May, 2nd), coinciding with the start of the melting period. This may be explained again by the preferential elution process that determines the early loss of acidifying compounds such as nitrate and sulfate compared to other compounds and resulting in an increase in the pH (Kuhn et al., 1998).

3.3.2 Electrical conductivity profiles

The profile-averaged electrical conductivity (EC) ranged from 76 to 127 $\mu\text{S}/\text{cm}$ during the whole season (Table 2).

Table 2. Minimum and maximum values of CE ($\mu\text{S}/\text{cm}$) at the three sites during the whole season (the dates are in month/day).

NORTH		FLAT		SOUTH	
min	max	min	max	min	max
2	81	2	76	2	127
02/28	03/08	03/01, 04/15	03/08	03/01, 04/15	03/08

Until March, 8th, the profile-averaged electrical conductivity (EC) was low and subsequently decreased at all sites. Such pattern, also consistent with the pH pattern, allow us to identify the ionic pulse at the three sites, with a relatively less pronounced effect at the North-facing site.

The warm air temperatures recorded at the end of February determined a snowmelt event with subsequent ionic pulse earlier than usual for those elevations. When occurring on frozen soils, which could not efficiently retain snowmelt-derived nutrients, this process may lead to severe leaching and surface runoff with a net loss of nutrients within the soil, and potential acidifi-

cation in nearby waters (Williams and Tonnesen, 2000). Analysing last two winter seasons, there appears to be a tendency towards warmer periods intercalated with cold periods. These phenomena may have significant impact on the biogeochemistry of nutrients in subnivean alpine soils, but the magnitude of such effect remains unknown.

In early April, the already discussed snowfall determined a deposition of salts and an observed increase in EC. After that event, an interesting distribution of chemicals along the profiles was observed. At the South-facing site maximum EC was recorded at the base of the snowpack, as a consequence of the melting front that transports chemicals along the snowpack. In the flat site, maximum EC was observed at the surface, without any evidence of melting, while at the North-facing site, EC was about equally distributed along the profile.

On April 10th, and coinciding with a rise in air temperature, we observed another ionic pulse, which determined the nearly total loss of chemicals from the snowpack at the South-facing and flat sites, where EC decreased by more than 20 $\mu\text{S}/\text{cm}$ in few days, while the decrease was much more limited at the North-facing site (5 $\mu\text{S}/\text{cm}$).

At the end of the winter (April 24th) a strong ionic pulse was observed at the North, while at other sites the remaining chemicals were released to soil. Consistent with pH pattern, EC became comparable between the three sites for the rest of the winter.

4 CONCLUSIONS

This study highlights the strong influence of aspect on physical and chemical properties of the snowpack at the plot-scale. We documented a direct effect of aspect on fresh snow conservation and freeze-thaw processes together with an indirect effect on depth hoar and faceted crystals growth. Field observations, supported by statistical analyses, demonstrated that basal layers of snowpacks located in flat areas are comparable to those at North-facing sites, while surface layers are comparable to those observed at the South-facing site (Fig. 4).

Our preliminary results, whether supported by additional research under different geographic and climatic conditions, may be useful to spatially extend to adjacent slopes the traditional observations conducted in flat areas for avalanche risk forecasting.

Furthermore, our results confirm the robustness of the methodology used for the snowpack stability evaluation across the Alps, since the stability profiles on flat areas don't differ from those observed on the adjacent slopes.

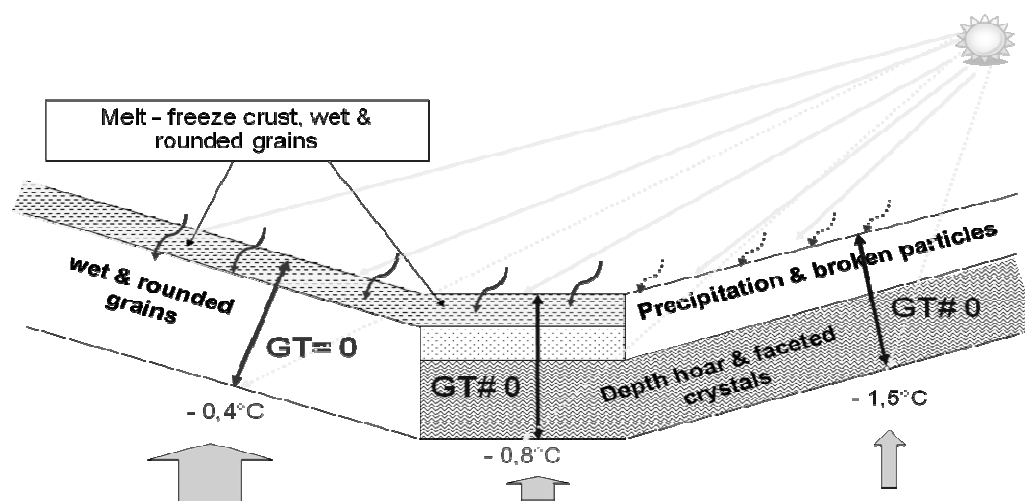


Figure 4: Different types of snowpack structures found in this study.

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