Recent snow cover variations and avalanche activities in the Southern Alps

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ABSTRACT: Snow and albedo play a significant role in the planet's radiation balance. Snow cover extension, of the Northern Hemisphere in the last forty years, generally decreased causing direct and indirect feedback both on climate and atmospheric circulation.

Up-to-date available data on seasonal snow cover trend are scarce and limited to few nations. Few European studies in the Northern Alps highlighted a decrease in snow cover duration and an increase of its elevation for tourism purposes.

Using the data of more than 60 sites located in the Southern Alps a first budget of the recent snow cover trend has been outlined. Compared to the 1961-90 mean value, the average snow cover duration decreased of about 14 days, with a major influence on elevations lower than 1600 metres. Seasonal snow precipitation accumulation has been decreasing, at all elevations, since 1990. Winter 2008-2009 was the 3rd or 4th more snowy season since 1930. During this winter spontaneous avalanche activity was frequent and extreme avalanches often detached. The 2008-2009 winter daily observation data of several sites located in the Southern Alps were used to find interconnections between recent snow cover variations, spontaneous avalanche activity and avalanche accidents.

KEYWORDS: snow cover variation, avalanche activity, risk.

1. INTRODUCTION

Snow and ice cover as well as their albedo play a crucial role in the Earth's radiative balance (Groisman et al., 1994) and their general reduction, during the last 40 years, coincides, indeed, with significant direct and indirect reverberations over climate and atmospheric circulation.

Available data about seasonal snow cover distribution are scarce and limited to few nations. European studies highlighted a reduction of snow cover period and a general snowline raise with direct consequence on winter tourism.

Winter season 2008-2009, in Italy, was one of the snowiest since 1930. During such winter spontaneous avalanche activity was frequent and extreme avalanches often detached. This study attempts to find possible links between recent snow cover variations, spontaneous avalanche activity and accidents using daily survey data from some snow stations of Italian Alps collected during the 2008-2009 winter season.

2. SNOW ROLE IN CLIMATE CHANGES

During winter, 49% of the Northern Hemisphere (NH) is covered by snow and an important property of snow and ice is their reflective power (albedo). Snow cover's albedo results from several factors including surrounding vegetation height, sun incidence angle, cloud cover (IPCC, 2007 – section 4.2), total thickness and age of snow cover. Snow cover's age is related to grains shape and to their metamorphism (O'Neill and Gray, 1973); albedo is approximately 90% for precipitation particles and can reach less than 50% for old and wet snow. Anyhow solar energy reflection by snow is higher than ocean or forest ones (10%).

Snow cover variation shows also an indirect influence on other climate components such as soil moisture and the atmospheric circulation variability both at the seasonal time scale (i.e. monsoon, Lo and Clark, 2001) and the interannual-to-interdecadel oscillations (Saito and Cohen, 2003).

Therefore snow and ice have a crucial role in the Earth's radiative balance (Groisman et al., 1994) and they are significant indicators of climate changes. A general reduction of snow covers coincides, indeed, with a higher accumulation of planet's energy due to failed albedo effect.

Data availability about snow cover is, however, restricted if compared to other parameters (e.g. temperature) and therefore also its interactions with climate are not easily quantifiable.

Measurements of snow cover thickness and of new snowfall accumulations are executed with different methods. There are few historic series starting in the XX century (Switzerland,

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USA, Russia, Finland). Data records about total thickness of snow cover and its water equivalent (SWE, Snow Water Equivalent) are available since 1950 in North America, Europe and in few Australian mountains (since 1960) – (IPCC, 2007). The first data used to compute the snow cover spatial distribution (Snow Covered Area – SCA), on a regional scale were remotely sensed images of the NOAA satellite in 1966 covering the NH.

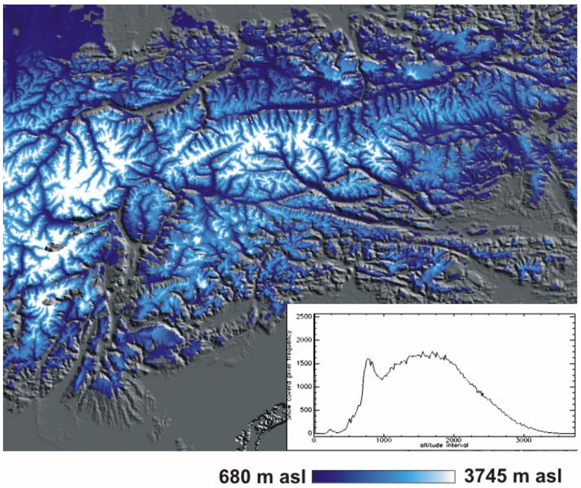

Figure 1. Snow cover spatial distribution by colour coded altitude interval in the Dolomites from MODIS data .

Detailed SCA mapping is very recent and several works are in progress to develop an automatic methodology to identify SCAs using satellite images available for free on the web in order to produce a near real-time and low-cost product (Cianfarra et al., 2009) – (Fig. 1).

3. NH SNOW COVER TRENDS AND VARIABILITY

Since 1972 and up to 2005, NH snow cover spatial extension decreased of 5,6% following NOAA's data elaborated by Global Snow Lab and minimum extension, was observed during 1990 solar year (Fig. 2).

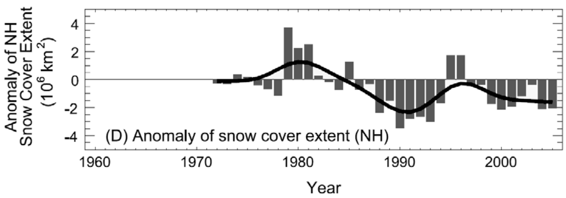

Figure 2. Northern Hemisphere snow cover extension variation expressed as anomaly [FAQ 4.1 Figure 1 (IPCC, 2007), p. 376].

SCA variability, in Europe's mountainous regions, is characterized mainly by regional changes in elevation. Recent SCA variations are proved in Switzerland (Scherrer et al., 2004) and in central Europe (Falarz, 2002) - e.g. in Slovakia (Vojtek et al., 2003) - whereas no changes have been documented in Bulgaria (Petkova et al., 2004). SCA reduction in Switzerland has been observed mainly at low elevations with a strong correlation with the increase of mean winter temperatures (Alp Media, 2002); besides, estimation shows that a 1°C increase determines a snowline raise of 150 m, with direct consequence on winter tourism (Alp Media, 2002).

Snow cover extension is anyway decreasing in several regions, especially during spring time, and it will impact melt water availability.

3.1. Italian Alps Snow Cover Trends and Variability

Data about Italy's snow cover spatial extension, in km^2, for each month and for long time series are scarce or not available. Up today only few regional-based studies on snow cover trends have been published (Aosta Valley – AA.VV., 2006; Piedmont Region – ARPA Piemonte, 2007; Emilia Romagna Region – Covoni and Merletto, 2005) and two papers (Valt et al., 2005; 2008) describe snow precipitation trends and annual snowdrift for all the southern Alps.

4. DATA SOURCE AND METHODS

To compare NH and southern Alps trends we used snow cover duration value, that is to say the number of days with snow cover during winter time (October – May); such approach has been used also in the northern Alps by other authors (Wielke et al., 2004).

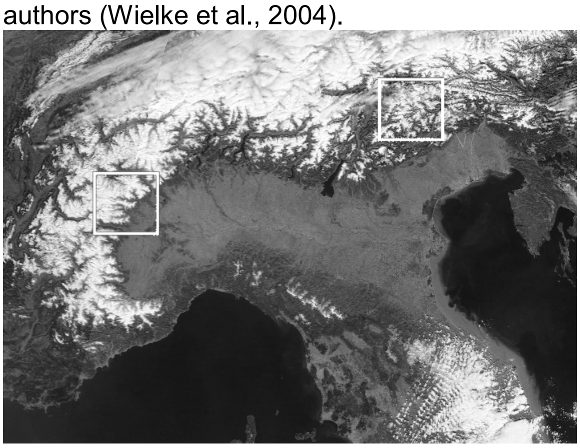

Figure 3. Two significant study areas for the southern Alps. To the right Belluno's Dolomites (Eastern Alps), to the left Valle Orco - Canavese (Western Alps).

Two significant study areas for the southern Alps with several climate stations evenly distributed by elevation and with enough long data records (30-50 years) were selected (Fig. 3).

Data used in present study were retrieved from regional's or province's AINEVA Avalanche Services data sets, from Ministry of Public Work's hydrological annals (1927-1996) and, mainly, from automatic stations of hydropower companies along the Alps. For Canavese area we used the Italian Meteorological Association's on-line dataset, monthly updated, which is sponsored by Vodafone Italia Foundation [1].

Avalanche activity data have been surveyed around some traditional daily survey snow stations (Cagnati, 2003) and have been specifically coded following AINEVA's Mod. 1 standard; however, such code was updated in 1995, creating therefore some inhomogeneity with older data. This study considers avalanche size and typology parameters.

All graphics and tables of this study refer to hydrological year (e.g. 2003 year starts 1st October 2002 and ends 30th September 2003).

To highlight regional trends with only one series we have used the adimensional SAI index (Standardized Anomaly Index – Giuffrida and Conte, 1989) which expresses anomalies of studied magnitude through the contribution of each station mean annual or seasonal values. A 0 annual anomaly index suggests a season within the reference mean value, a positive or negative anomaly value indicates respectively an excess or deficit more or less important compared to normal value (Mercalli et al., 2003; 2006).

The availability of long enough record series for almost all stations allowed processing using a thirty-year period (1961-1990) as suggested by WMO (WMO, Climate Normals, CLINO, Tec. Note 847).

5. RESULTS

5.1. Snow Cover Duration

Snow cover shows a general decrease trend, in NH, mainly during autumn and spring-time months (Fig. 4).

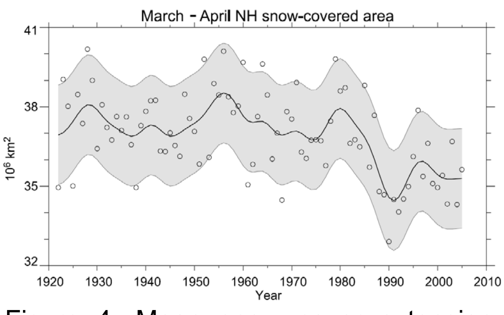

Figure 4. Mean snow cover extension for March and April months in northern hemisphere (Brown, 2000) – [from fig. 4.2, IPCC, 2007, p. 344].

Southern Alps's data on snow cover duration, for the two studied areas, are displayed in fig. 5 and compared with SCA's data for NH.

Moving average processed for Dolomites and Canavese clearly highlights a first period, during '30 years, characterized by a good snow cover duration, a drop between 1945 and 1960, and then a significant recover first in the Dolomites and later on, during '80 years, in Western Alps. Nevertheless in both areas, since 1985, a regression of snow cover duration has been started, reporting a sharply negative index. Index shows a turnaround after 2000 but, this time, moving average value is influenced by snowy and dry winters alternations.

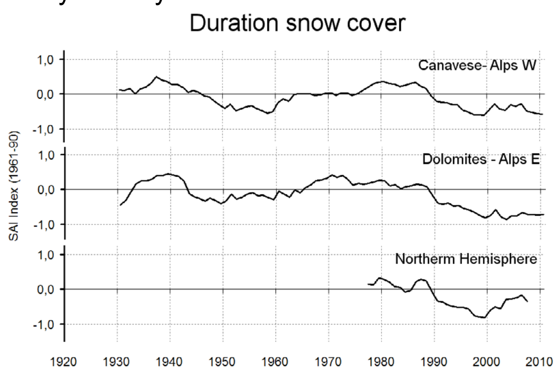

Figure 5. Comparison of snow cover duration anomaly of SAI index between the two studied areas and NH.

Comparison of moving average curve - using SCA values, since 1966, between NH and Southern Alps (Fig. 5) - illustrates, in good approximation, a similar reduction trend.

Recent period analysis (1991-2007), compared to mean value in 1961-1990 time span, depicts a reduction of snow cover duration, on average, of 14 days (12%).

Parameterised analysis of snow cover duration, in a range altitudes between 1000-1600 m and higher values, points out, respectively, a 16% reduction (16 days - at low elevations) and a 6% reduction (11 days – at high elevations) – (Fig. 6).

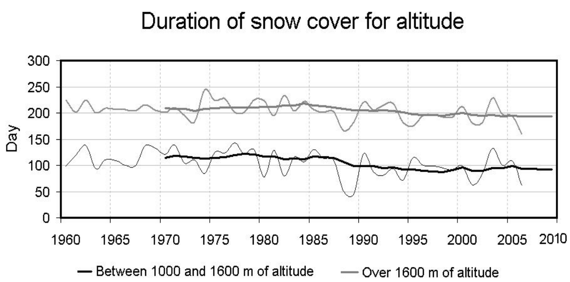

Figure 6. Duration of snow cover for altitude.

Besides, during spring time months, period between 1969 and 1987 points out to a long duration of snow cover, subsequently followed up by a marked decrease during the last decade.

5.2. Seasonal Snow Cover

Reduced snow cover duration can be related both to a general increase in temperatures and to a decrease of solid precipitations.

Seasonal snow fall processed for 10 stations highlights a constant decrease of solid precipitations between 1990 and 2000 and a certain amount of constancy after 2000 due to a series of snowy winters (2001, 2004, 2006) alternating to dry ones (2002, 2003, 2005, 2007).

SAI index for seasonal snow cover processed for stations located at altitude between 1000-1600 m and higher values does not highlight differences between precipitation trends, all decreasing, at high and medium elevations (Fig. 7).

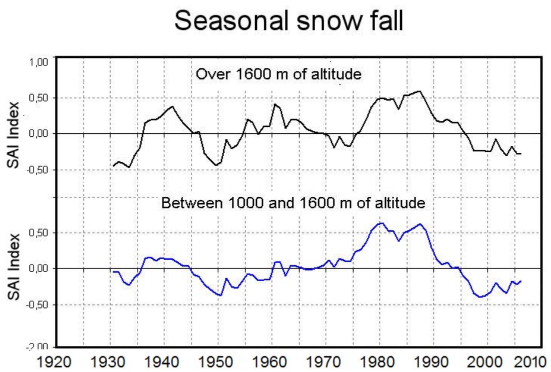

Figure 7. Seasonal snow fall trend (moving average 11) for 1930-2007 period.

6. RECENT – TIME SPONTANEOUS AVALANCHE ACTIVITY VARIATIONS

2008-2009 winter season data are not processed in this study, even if this winter season was one of the snowiest since 1930 all over the Southern Alps reporting a considerable and intense spontaneous avalanche activity. Since December and up to the end of April, 25 days of several large avalanches spontaneous detachment were recorded, in at least one of each 215 daily observation stations along the Southern Alps (excepted South Tyrol). The most crucial period was between 11 and 19 December 2008, during and immediately after heavy snowfalls: in this period, almost all days, several spontaneous large avalanche detachments were recorded.

Considering all stations, large avalanche reports for the last season are 4% of total events against 1% of three prior winters.

During 2006, 2007, 2008 winters, days with avalanche activity were, respectively, 11%, 7% and 11% of season period, whereas during the last exceptional snowy winter, such days were 22% of total.

Data processed for 6 daily observation stations in the Center-Eastern Alps (Passo Tonale, Paneveggio, Arabba, Piancavallo, Forni di Sopra, Cave del Predil) highlights that during the last 15-30 years avalanche activity was directly related to seasonal snowfall (Fig. 8).

Figure 8 shows SAI index and parameterised avalanche activity value observed in the 6 stations. Trend is in phase concordance with SAI index and is also tested using observed surface-layer or loose-snow avalanches and also, to a lesser degree, full depth avalanches.

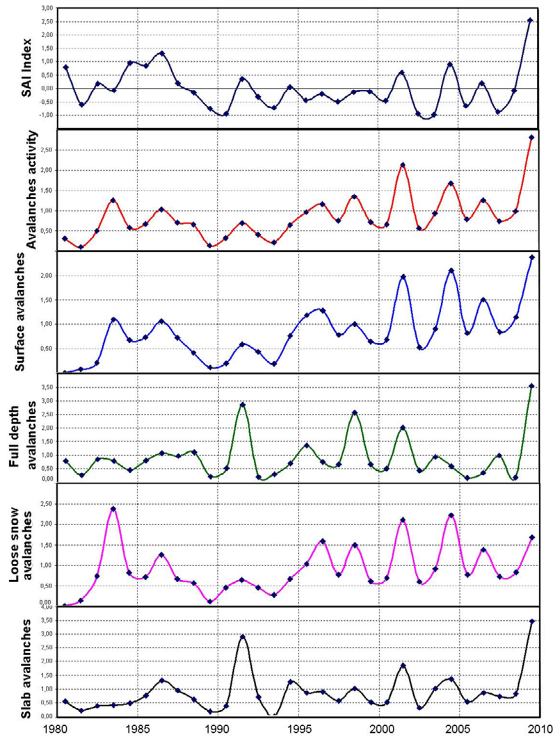

Figure 8. Analysis of Eastern Alps avalanche activity.

Slab avalanches seem to show a slightly different trend, which is not directly connected to snowfall events but, more probably, to wind activity.

7. SNOWCOVER VARIATIONS AND RECENT AVALANCHES ACCIDENTS IN ITALY

Data analysis, starting from the snowy winter season 2008-2009, points out that there is not any direct correspondence between snow cover and accidents.

Fig. 9 compares SAI index since 1960 and avalanche victims since 1966. During the two snowy winter seasons 1977 and 1978 several avalanche victims were recorded but equally snowy winters such as 1986 and 2009 showed a lesser account.

On the other hand, during poorly snow covered winter seasons - such as 1985, 1988, 1991 or, more recently, 2002 and 2003 - avalanche fatalities were higher than mean value.

Despite such trends, during snowy winters like 2008-2009, a direct correlation with avalanche accidents along roads does exist (both on open or closed roads due to avalanche danger – in the latter road technicians were involved). During last winter season avalanche accidents along roads were 10, concentrated during December and January months (five per month respectively). For out of bound recreational activities, during winters with long periods of bad weather, accidents are less common but tend to increase during weekends or following fair weather periods.

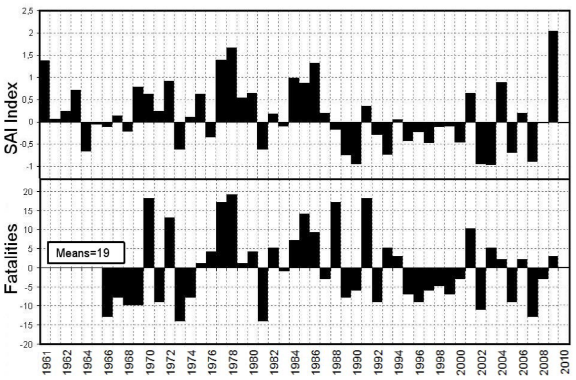

Figure 9. comparison of SAI index of seasonal total depth of daily new snowfall and avalanche fatalities.

8. CONCLUSION

Data analysis highlighted that also Southern Alps show similar trends as for NH.

Recent period analysis (1991-2007), compared to mean value in 1961-1990 time span, depicts a reduction of snow cover duration, on average, of 14 days (12%). Such reduction is stronger at lower elevations (between 1000 and 1600 m – 16 days) than at higher ones (between 1600 and 2100 m – 11 days). Indeed, snowfalls are decreasing at all elevations both on Western and Eastern Alps.

In this general context, the 2008 – 2009 snowy winter is enlisted in the climate variability and any other consideration is untimely.

Spontaneous avalanche activity and natural variability of snow cover during the last 30 years appears connected: snowy seasons correspond to winter with several days of avalanche activity. Instead, data analysis of avalanche accidents allows the reasonably statement that not all snowy winters show a high number of avalanche accidents, even because weak layers are often too deep and are not stressed by skiers overload.

Data on recent snow cover trends are mainly retrieved from:

Variazioni recenti del manto nevoso sul versante meridionale delle Alpi di Valt M., Cagnati, A., Crepaz, A., and Catberro, D., 2008, Neve e Valanghe, 63, 46– 57.

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