RECENT VARIABILITY OF AVALANCHE ACTIVITY AND SNOWFALL IN THE ITALIAN ALPS

Valt M.[1*] and Cianfarra P.[2]
ARPAV Centro Valanghe di Arabba – BL (Italy)
[2] Università degli Studi Roma Tre, Dipartimento di Scienze Geologiche, Roma (Italy)

ABSTRACT : The study of the snow cover variability is fundamental for alpine countries for many reasons, specifically winter tourism, hydro-electricity production, avalanche activity/forecasting, and for its potential in shaping the mountain ecosystem. There is also an open debate in the scientific community on the relationship between snow cover variability and climate change both as direct feedback and as indirect ones. The aim of this work is to publish an up-to-date record of avalanche observations of the last 25 years (1985-2009) together with the record of avalanche fatalities from 1966 to 2009 in the Italian Alps.

1. INTRODUCTION

Relationship between local to global climate changes and snow cover variations in the mountainous areas have been widely documented (IPCC, 2007). On the other hand the impact of climate trends on the variation of avalanche activity is difficult to assess for many reason including the biases related to the difficulties of human observation of avalanche; change in the observation regulations over the time and the different countries; lack or limited availability of avalanche observations.

Debate is open in the scientific community on the complex feedback existing between climate change, variation of the snow pack physical properties and avalanche activity and typology.

2. DATA AND METHODS

Data used in present study were compiled from regional and provincial AINEVA Avalanche services, from the Ministry of Public Work's hydrological annals (1927-1996); from the Italian Meteorological Association's on-line dataset, monthly updated, which is sponsored by Vodafone Italia Foundation (http://www.nimbus.it/clima/Canavese/CartaStaz.asp) and, mostly, from the automatic stations of hydropower companies around the Alps. Location of the used stations and further details (e.g. altitudes) are reported in Figure 1 and Table 1, respectively.

Avalanche activity (namely avalanche size and typology parameters) and surface snow features (wet- or dry-snow) 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 in-homogeneity with older data.

All graphics and tables of this study refer to the hydrological year (e.g. 2009 year starts the 1st October 2008 and ends the 30th September 2009).

Big efforts have been done in order to eliminate in-homogeneities within the time series resulting from several factors that changed during the historical investigated period. These factors include i) the uneven geographic distribution of the stations (see Figure. 1) ; ii) change in location of the stations; iii) change in the observer or change in the observation regulations for the avalanche activity.

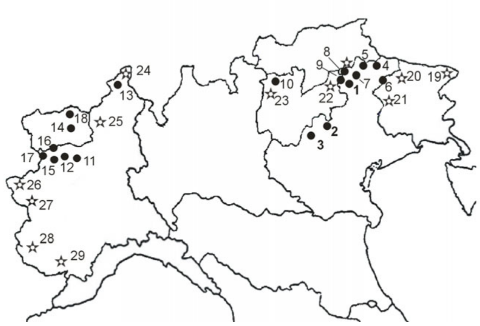

Figure 1: Location of the station used in the present work.

To highlight regional trends with only one series we have used the adimensional Standardized Anomaly Index (SAI index, Giuffrida and Conte, 1989) which expresses anomalies of studied parameter through the contribution of each station mean annual or seasonal values. For each station

* *Corresponding author address:* Valt Mauro, ARPAV- Centro Valanghe Arabba, Via Pradat 5, 32020 Arabba (BL) Italy;
email: mvalt@arpa.veneto.it

the SAI is computed as the departure of the annual or seasonal value from the mean of the studied time series divided by the standard deviation of the time series (standardization). The derived values are then averaged for all the stations in the investigated region. An annual anomaly index SAI=0 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).

Number in Fig.1	Stations	Snowfall (HN)	Avalanches activity	Days with wet-snow and avalanches
1	Ghirlo, 750 m	●		
2	Asiago, 1000 m	●		
3	Tonezza, 990 m	●		
4	Auronzo, 835 m	●		
5	Cortina d'Ampezzo, 1265 m	●		
6	Passo Mauria, 1270 m	●		
7	Andraz, 1440 m	●		
8	Arabba, 1630 m	●	☆	☆
9	Lago di Cavia, 2100 m	●		
10	Careser, 2500 m	●		
11	Rosone, 714 m	●		
12	Noasca, 1062 m	●		
13	Formazza Ponte, 1280 m	●		
14	Ussin, 1321 m	●		
15	Ceresole Reale, 1579 m	●		
16	Lago Telessio, 1917 m	●		
17	Lago Serrù, 2275 m	●		
18	Lago Golliet, 2529 m	●		
19	Passo del Tonale, 1880 m		☆	
20	Paneveggio, 1535 m		☆	
21	Piancavallo, 1400 m		☆	
22	Forni di Sopra, 900 m		☆	☆
23	Cave del Predil, 935 m		☆	
24	Entracque- Chiotas, 2010 m		☆	☆
25	Formazza Lago Vannino, 2117 m		☆	☆
26	Macugnaga, 1270 m		☆	☆
27	Pragelato, 1540 m		☆	☆
28	Lago Rochemolles, 1975 m		☆	
29	Vinadio- Bagni, 1305 m		☆	

Table 1: List of the stations used in the present study. Symbols indicate the station used for the different analysis.

3. AVALANCHE ACTIVITY VARIABILITY

Studies on observed avalanche parameters (e.g. Laternsen at al. 1998) showed that the variation in snow precipitation did not significantly affect the avalanche activity. On the other hand recent studies by Martin (2001) and Ecket (2009) showed small variations in the avalanche activity but significant variations in avalanche typology, with a relative increase of wet-snow avalanches replacing dry snow avalanche.

In the Italian Alps available data on the avalanche typology (wet- or dry-snow avalanche) are missing. Few data are available regarding the number, the dimension and typology (slab, loose, full depth) of the observed avalanches (Cagnati, 2003).

Preliminary results from observations belonging from 6 stations showed a moderate increase of the avalanche activity in springtime (MA) during the 1985-2009 period (Figure 2a).

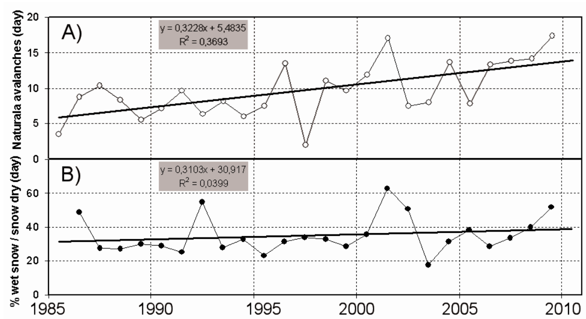

Figure 2: a) Plot of the number of day with spring natural avalanches in the period 1985-2009 (upper part) and b) plot of the number of day with wet snow in the morning during the spring season of the period 1985-2009 (lower part).

Winter season 1996, 2001 and 2009 were characterised by the highest frequency of snow-avalanches days.

In the same period (1985-2009) it was observed a relative increase of days with wet snow in the morning with respect to day with dry snow.

This type of observation was done using the surface characteristics of the snow pack measured at 8:00 am at 6 significant stations (Figure 2b).

These preliminary results, that need to be confirmed by further observations possibly increasing the number of the used stations, are in agreement with Martin (2001) and Ecket (2009) studies. They proposed that recent variation of snow precipitations may have feedback on the avalanche activity.

As regard as the avalanche activity in the entire season (Nov-April), we computed the SAI of i) the number of days with avalanches (hereafter indicated as avalanche activity SAI), ii) number of day with loose avalanche, with slab avalanches, with full depth and surface avalanches using the mean value of the 1985-2009 period according to the length of the available time record.(see Fig. 3b, c, d, e, f). These values derived from observation done from 12 stations (Table 1).

Average values of the avalanche activity SAI was compared with the SAI of seasonal snow accumulation, calculated on the period 1927-2009. (Figure 3a).

The graphs a and b in Figure 3 show very similar trend. A fase concordance exists between snow precipitation and avalanche activity, and a strong variability exists in the last decade although no significant trend was evidenced. This is true also for the comparison of SAI trend of seasonal snow precipitation with surface avalanche and loose snow avalanche (Figure 3a, c, e).

Slab and full depth avalanches seem to show a slightly different trend, which is not directly connected to snowfall events but, more easily, to wind activity These results are summarised quantitatively in Table 2 that shows the computed linear correlation parameter between seasonal snowfall and avalanche activity, for the three reference time interval (1920-2009; 1961-1990; 1979-2009).

4. SNOW COVER VARIABILITY AND RECENT AVALANCHE ACCIDENTES IN ITALY

To explore the relationship between avalanche fatalities and winter snowfall we examined the snowfall SAI and number of avalanche victims during the winter season (Figure 4).

Italian database of avalanche accident is edited by AINEVA (Valt et al. 2009). Record of the avalanche, described according to their typology, and avalanche fatalities starts from 1985. On the other hand record of number of victims of each winter season starts from 1966.

At first glance it seems that the number of avalanche victims does not correlate with heavy snowy seasons. During the two snowy winter seasons 1977 and 1978 several avalanche victims were recorded but similar snowy winters, such as 1986 and 2009, were associated to a smaller number of victims.

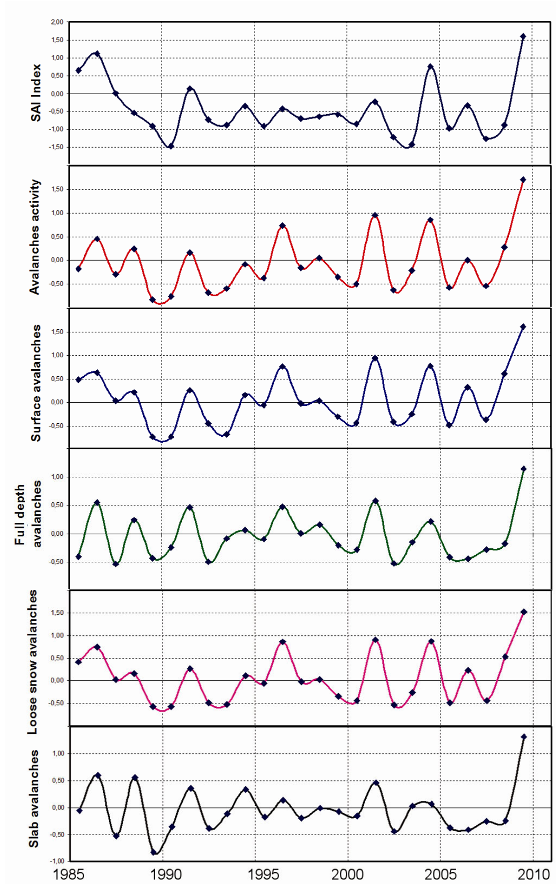

Figure 3: Comparison of the snow accumulation SAI index and Nov-Apr avalanche activity SAI index. a) SAI of seasonal snow accumulation, using the mean of the period 1927-2009; b) SAI of the number of days with avalanches; c) SAI of the number of day with surface avalanches; d) SAI of the number of days with full depth avalanches; e) SAI of the number of days with loose snow avalanches; f) SAI of the number of days with slab avalanches.

On the other hand, during poorly snow covered winter seasons - such as 1988, 1991 or, more recently, 2002 and 2003 - avalanche fatalities were higher than mean value. 5-year low pass filtering

	Seasonal snowfall					
	(1920-2009)		1961-1990		1979- 2009	
(1985-2009)	R	P	R	p	R	p
Avalanche activity	0,85	<0.001	0,881	<0.001	0,81	<0.001
Surface avalanches	0,82	<0.001	0,871	<0.001	0,83	<0.001
Full depth avalanches	0,78	<0.001	0,792	<0.001	0,74	<0.001
Loose avalanches	0,83	<0.001	0,861	<0.001	0,82	<0.001
Slab avalanches	0,79	<0.001	0,834	<0.001	0,75	<0.001

Table 2: Linear correlation coefficient and probability computed to investigate the correlation between seasonal (Nov-Apr) snowfall SAI and avalanche activity SAI.

of snow precipitation SAI and fatalities allows to study medium-to-long period variations. In the time interval 1968-1986 a significant linear correlation ($r=0.90$ and $p<0.001$) exists between the two smoothed dataset. Since 1987 the correlation is not significant anymore ($r=0.02$).

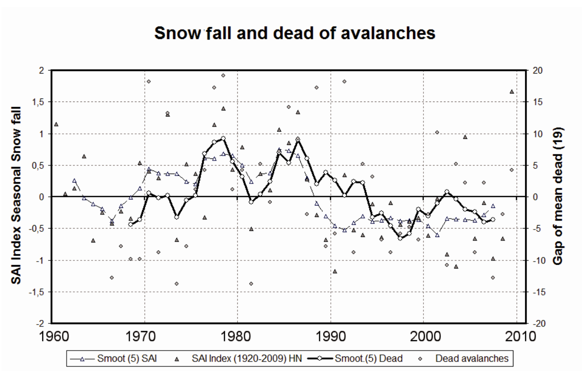

Figure 4: Comparison of the SAI of cumulated snowfall using the mean of the period 1927-2009 and avalanche fatalities between 1966 and 2009.

A possible explanation of the occurrence of heavy snow winters and a reduced number of victims may relate to a stronger wind regime responsible for the formation of many wind slab. It is well known that this type of avalanche produce many fatalities. Moreover winters with reduced snowfall are associated to reduced snow pack depth and therefore the formation of layer with faceted crystal and depth hoar is enhanced.

5. DISCUSSION AND CONCLUSIONS

Performed analysis and obtained results address a series of issue about the avalanche activity in the Italian Alps.

Preliminary results that need to be confirmed by further observations showed that in the period 1985-2009 there has been a moderate increase of the avalanche activity in spring time and an increase of days with wet snow in the morning. This may easily relate to the increase of the maximum spring temperatures (Chiaudani, 2008) in the same period that enhance modifications in the snow reology. In this way a relative increase of wet snow avalanche is expected with respect to dry snow avalanches. This is in agreement with Eckert (2009) and Martin et al. (2001) works.

As for the entire season (Nov-Apr) avalanche activity a significant linear correlation between avalanche occurrence and snow precipitations was detected in the last 25 years.

A significant linear correlation between avalanche fatalities and snow precipitations in the period 1968 - 1986 exists.

Monitoring of the snow cover variations is of keen interest for improving the understanding of the climate change in the alpine regions and its consequence on avalanche activity and hazard. Conversely, it will then also be possible to use snow avalanche as proxy indicators of climate change.

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