Climate change in Italian Alps: analysis of snow precipitation, snow durations and avalanche activity

Mauro Valt [1*] and Cianfarra Paola [2]

, [1] ARPAV DRST SNV Centro Valanghe di Arabba, BL, Italy
[2] Università degli Studi Roma Tre, Dipartimento di Scienze Geologiche, Roma, Italy
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ABSTRACT: The historical record (1961-2010), of snowfall, snow duration and of temperatures collected in the Italian Alps are presented and analysed. A reduction of the snow cover duration and of the snowfall stronger in springtime was detected during the last 40 years with the greatest decreasing rate during the 1990s. The last decade is characterised by a recovery from the documented decreasing trend mainly evident between 800 m and 1500 m. Principal component trend analysis of the snow duration and of the snowfall showed a long term decreasing trend. The change point test showed the existence of breakpoints between 1984 and 1994 that characterise the snow duration and snowfall time series analysed by elevation range and by seasons. These breakpoints mark a drastic trend variability in the time series: a positive trend characterises the time series before the breakpoint and a decreasing trend characterises the historical record after the breakpoint. The described negative trends result from the documented decrease in winter and spring precipitation. This in turn may either relate to a change in fraction of liquid to solid precipitation, and/or be associated to an increase of the temperatures.
Northern Hemisphere and Italian Alps snow cover trends strongly correlate in the frequency domain. Among the dominant frequencies the 11.2 period was detected that may relate to the 11-year solar activity cycle. Analysis of the temperature record showed similar trend. Comparison of snow duration and temperatures during springtime (March-April) showed a strong linear correlation (significance level 0.001). This study will contribute to better understand the avalanche activity in the investigated region.

Activity data avalanche have a very limited range time compared to time series of temperature and snow. Good coverage of data is available since 1980 for a limited number of stations the Italian Alps. The data processed in the number of days with avalanches show an increase of days with avalanches from 1980 to 2013. The trend of days with avalanches seems to follow the same trends in the accumulation of snow (SAI Index) processed for the same time interval (1980 - 2013).

KEYWORDS: snow cover, avalanche activity, climate change

1 INTRODUCTION

The snowpack and its albedo play an important role in the radiative balance of the planet (Groisman et al. 1994, 2001) and is very sensitive to climate changes.

Variation of the duration of the snowpack and of the amount of snowfall, may have consequences both from environmental and economic point of view.

For example, from the environmental point of view, the effects impact the river flows during the spring thaw, the protection of soil and nutrients for vegetative growth (Freppaz et al., 2007).

From the economic point of view the changes in snow cover impact the production of hydropower and the winter tourism (Uhlmann et al. 2009). It has been estimated that 1℃ increase of the average air temperature causes 150 m upward shift of the limit for reliable skiing and so a direct impact on winter tourism (Haubner-Köll, 2002).

In the present paper we present the preliminary results on the analysis of the winter and spring temperatures variations and their interactions with the snowfalls and avalanche activity in the Italian Alps.

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

2 DATA AND METHOS

Air temperature data belong from online databases (www.nimbus.it, www.meteotrentino.it, www.arpa.veneto.it, www.provincia.bz.it) and from are Annual Reports (Ministero dei lavori pubblici, 1973, Mercalli et al, 2003).

We used the maximum and minimum values of air temperature from 10 meteorological stations distributed between 300 m and 2200 m altitude in the Italian Alps. Missing data were derived following WMO guidelines.

We used the departure of the mean monthly values from mean 1961-1990 reference value.

Temperature data of the Northern Hemisphere (NH) were freely available at http://www.cru.uea.ac.uk/cru/data/temperature/ website.

Snowpack dataset derive from several databases including the Italian Avalanche Services, the AINEVA, the Annual Reports (Ministry of Public Works, 1927-1996) and the Italian Meteorological Society.

Data from more than 70 stations around the Italian Alps were used in the present work.

Avalanche activity data derive from the databases of the Avalanche Services AINEVA based on the daily observation of avalanche events (Cagnati, 2003).

All graphs and tables of this study refer to the hydrological year (eg. 2012 year starts the 1st October 2011 and ends the 30th September 2012).

To highlight the regional trend with a single time series we have used the adimensional Standardized Anomaly Index (SAI, Giuffrida and Conte, 1989; Mercalli et al., 2003, 2006).

Snow data sets are long enough for almost all the considered stations therefore the analysis were done on the basis of the 1961-1990 reference period, as suggested by the WMO (WMO Climate Normals, CLINO, Technical Note 847).

3 AIR TEMPERATURE ANALYSIS: PRELIMINARY RESULTS

Air temperature data of the NH and of the Italian Alps showed a positive trend during the period December-April (DJFMA) (Figure1).

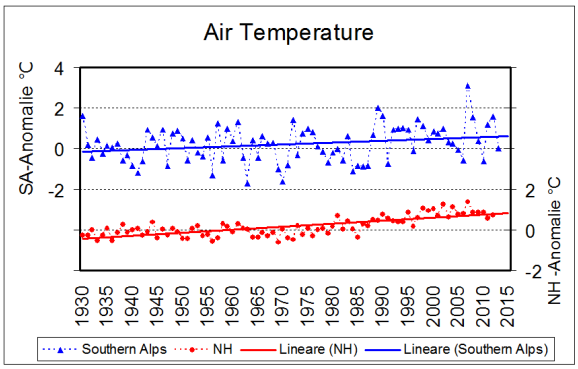

Figure 1. Anomalie of the air temperature (1961-1990) in the Northern Hemisphere and the Italian alps.

From the 1987 onwards, the average air temperature was almost always higher than the average 1961-1990 value (with the exception of 1991, 2005, 2006, 2010, and 2013).

From 2000 onwards, the DJFMA periods with an average temperature higher than the 0.9th percentile were three: 2007, 2008 and 2012 (Figure 2).

	℃	DJFMA	℃
perc 0.1	-0.86		
1 quartile	-0.56	**2007**	**+3.09**
3 quantile	0.91	**2008**	**+1.56**
perc 0.9	**+1.26**	**2012**	**+1.44**

Figure 2. Statistical data (1961-1990) of the Italian Alps and recent winters with positive anomaly over 0.90 percentile.

The preliminary results of the analysis of the air temperature in the Italian Alps show a 0.6-0.7 ℃ increase during the DJFMA period between 1991 and 2010 compared to the mean value of the 1961-1990 decade. No significant differences between the mean temperature values of the 1991 – 2000 and 2001-2010 decades were detected.

Nevertheless, the mean air temperatures of the DJF and MA periods during the above mentioned two decades are characterised by different trends.

Between 2001 and 2010 the average DJF air temperature was 0.3 ℃ higher than the mean value of the reference period 1961-1990 (and 0.4 ℃ higher during the 2004-2013 decade). Between 1991 and 2000 it was 0.7 ℃ higher during the same DJF. MA mean air temperature was 0.9 ℃ higher during the 2001-2010 decade than the mean value of the reference period 1961-1990 (and 1.1 ℃ higher during the 2004-2013 decade). Between 1991 and 2000 it was 0.8 ℃ during the same MA season.

4 CUMULATED SNOW FALL

The cumulated snow fall in the Italian Alps has an overall negative trend (Valt and Cianfarra, 2010). Between 1984 and 1994 a change in the snow fall regime as well as a change in the snow duration was identified.

Snowfall decreased about 16-31% below 1500 m between 1991 and 2010 and decreased about 8-14% above 1500 m altitude in the same period.

The found decrease is greater in MA season below 1500 m with the highest deficit between 1991 and 2000 (Figure 3).

	Elevation range 800- 1500 m		Elevation range above 1500 m	
	DJF	MA	DJF	MA
1961-1990	**140**	**68**	**233**	**174**
1991-2000	108	47	205	148
2001-2010	128	48	211	149
2004-2013	140	48	231	164

Figure 3. Statistical values of snow (cm) for various periods calculated for the Italian alps.

The SAI trend shows that since 1987 the snowfall is characterised by a decreasing trend (Figure 4). However, the 2004, 2006, 2009 and 2013 winters were very snowy.

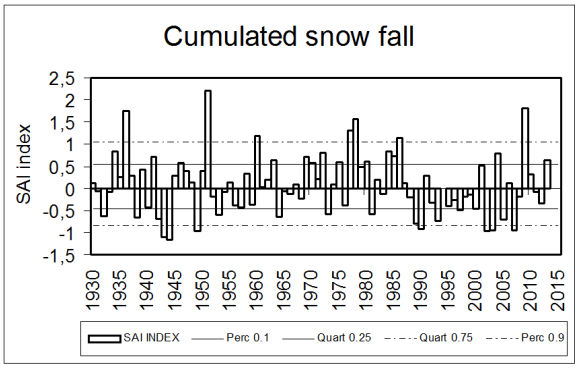

Figure 4. SAI index (1961-1990) of cumulated snow fall calculated for the Italian Alps.

5 SNOW COVER DURATION

Snow cover duration is characterised by decreasing trends particularly below 1500 m altitude. During the period 1991 - 2000 there were 19 days decrease in DJFMA and 11 days decrease between 2001 and 2010 (Valt and Cianfarra, 2010). A smaller decreas of 5/6 days in the snow cover duration was detected above 1500 m. During MA season 13 and 8 days decrease were detected between 800 and 1500 m and above 1500 m, respectively (Figure 5).

	Elevation range 800- 1500 m		Elevation range above 1500 m	
	DJF	MA	DJF	MA
1961-1990	**74**	**36**	**87**	**58**
1990-1999	68 *(-6)*	23 *(-13)*	86 *(-1)*	53 *(-5)*
2000-2009	71 *(-3)*	28 (-8)	86 *(-1)*	54 *(-4)*
2004-2013	77 *(+3)*	31 *(-5)*	88 *(+1)*	55 *(-3)*

Figure 5. Statistical values (days) of duration of snow cover.

Analysis of the time series relative to duration of the snow depth (HS) for reliable skiing (HS> 30 cm) (Uhlmann et al. 2009) shows a reduction of days with a snow depth higher than 30 cm during all the investigated periods and seasons (Figure 6).

Snow day HS > 30 cm				
	DJF	+/-	MA	+/-
1961-1990	**51**		**31**	
1990-1999	43	*-8*	22	*-9*
2000-2009	46	*-5*	25	*-6*
2004-2013	50	*-1*	26	*-5*

Figure 6. Statistical values (days) of duration of snow cover (HS> 30 cm).

6 AVALANCHE ACTIVITY

Avalanche activity dataset span over a shorter period than the temperature and snow time series.

The analysed dataset includes the daily observation of avalanche events between 1985 and 2013. An increasing trend of the avalanche activity during this period was detected (Figure 7). This increasing trend relates to the documented trends of the cumulated snow fall (expressed as SAI) during the same time interval (1980-2013): the higher the detected cumulated snow fall, the higher the avalanches activity is. Please note that the two trends are not similar, in fact the snowfall are characterised by an overall decreasing trend. This is true also for the MA season.

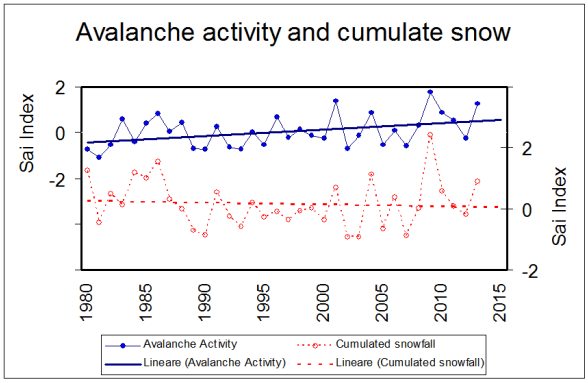

Figure 7. SAI Index calculated for days with avalanches and for cumulated snow fall.

7 CONCLUSION

Italian Alps the air temperature time series are characterised by increasing trends. Snowfall trends are negative and an increasing trend of the avalanche activity was detected.

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