Snow climatological analysis and assessments of the extreme events in western Italian Alps

S. Fratianni[1], S. Terzago[1], M. Faletto[2] Corresponding author, F. Acquaotta[1], MC. Prola[2], S. Barbero[2]

[1] Università di Torino – Dipartimento di Scienze della Terra, Torino, Italia - Department of Earth Sciences, University of Torino,Via Valperga Caluso, 35-10125 Torino, Italy
[2] Arpa Piemonte, Dipartimento Sistemi Previsionali, Torino, Italia - Regional Agency for Environmental Protection (ARPA) of Piemonte, Via Pio VII, 9-10135 Torino, Italy

ABSTRACT: In this study we will present the results of an activity of the strategic project STRADA (STRategies of ADAptation to climate change) in the frame of the interreg Italy-Switzerland 2007-2013. This is the analysis of snow depth variations in the western Italian Alps during the period 1930-2010. These series were available until now, only on paper: we performed the recovery and digitization of daily data. We carried out the historical research and data quality control which allowed a complete climate analysis, with the identification of trends and their statistical significance. The availability of daily series also allowed the application of advanced statistical techniques based on the Generalized Distribution of Extreme Events to assess the return period. Moreover, in the last period (2001-2010) the study has been enhanced by data provided by 46 automatic nivo-meterological stations of ARPA Piemonte in order to obtain more detailed informations on climatic features in the western Italian Alps. In fact, automatic stations provide data from a larger altitude range (under 700 m asl and over 2500 m asl) and allow to obtain data in unreachable areas during the winter season.

KEYWORDS: Climatological analysis, snow measurement, extreme events.

1 INTRODUCTION

This study analyzes the theme of snow in Piedmont with particular reference to the fifty years 1961-2010 with a focus for the years since 1933. The work is the result of a scientific collaboration between Arpa Piemonte and the Department of Earth Sciences, University of Turin. The main aim is to promote and continue the recovery activities of long term snow data, to develop complete sets, consistent, reliable and high quality making it possible to have a great deal of information about climate change in progress. The datasets recovered not only have scientific value, but have an impact in the economic development of the territory.

The knowledge of the distribution and variability of snowfall and duration of snow cover is fundamental that given their strong impact on the hydrological balance with direct consequences on the availability of water in agriculture, industry and energy production, and also on winter tourism during the ski season. This investigation also reveals essential also to provide reference values for spatial planning and the construction of works for the management of avalanche danger and in general for risk management in the environments of high altitude.

Corresponding author address: Faletto M., Dipartimento Sistemi Previsionali, Turin, Italy;
tel: +39 011 1968 0312; fax: +39 011 1968 1341;
email: mattia.faletto@arpa.piemonte.it

2 STUDY AREA

The area of the Piedmont region is characterized by a very large mountainous zone (42% of the total) that surrounds it to the south, west and north. The topographic location, sea distance and close interactions with near French Alpine region, define and regulate the climatic peculiarities of the Piedmont. This is an area where continental air masses in coming from the plains collide with warm wet air masses from the Mediterranean and the Atlantic north-western fresher that interact with riliefs triggering frequent local circulations.

The synoptic large-scale configurations most influence the events of significant and widespread snowfall in the Alps north western (Esteban, 2005). It should be considered that, given the location of orographic Piedmont Alps, snowfall are triggered by cold and wet. These flows are of very diverse nature and origin, having a provision the Alps south-west-north spanning more than two quadrants of the compass rose (Ronchi et Nicolella, 2011).

3 STATIONS MEASUREMENT

The data analyzed in this study are derived from the regional measurements network which includes manual and automatic stations. Currently there are 109 snow measuring points of which 32 traditional snow stations - TSS - and 77 are automatic snow station - ASS-.

The method of collecting data from the TSS are carried out according to the technical specifications applied in the AINEVA (Modello 1) (AINEVA, 2009).

The automatic snow measurements are usually located in sites not easily accessible by an operator, especially during the winter, are therefore essential to expand the spatial detail of the monitoring network and are important for the evaluation of snow average and distribution of snowfall (Frigo et al., 2012).

16 TSS were chosen for the study. These are distributed uniformly throughout the Piedmont Alps, at altitudes between 700 meters asl and 2412 meters asl, are representative of all alpine zones, with the exception of the Ligurian Alps.

The ASS are 46 out of which 39 are located above 1000 m a.s.l. and distributed almost uniformly in all alpine areas. The 7 ASS located below 1000 meters a.s.l. are representative of the hills (Appennino) and the plains as low as Vercelli station at 155 m a.s.l.. 3 stations are located above 2500 m a.s.l., the highest one is Passo Moro – Macugnaga at 2820 m a.s.l.

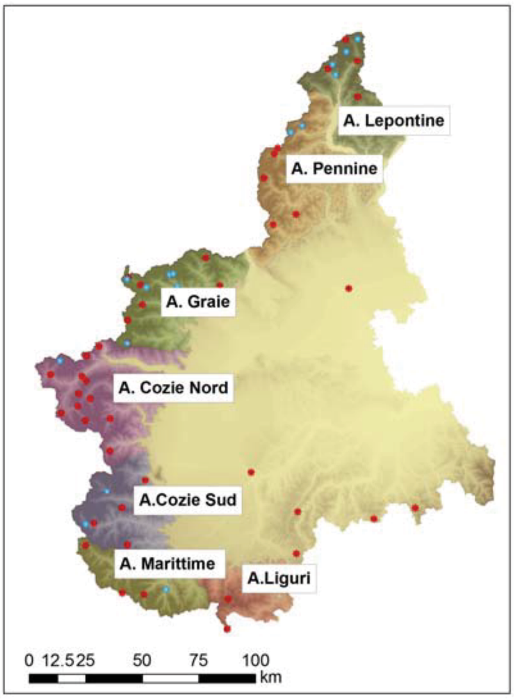

Figure 1. Snow stations network and sector names of Piedmont Alps. TSS (ASS) stations are represented in red (blue)

TSS stations data are available since 1930, thus allow to analyze the snow depth variations over long period. ASS stations data are available since 2001 and allow to analyze in more detail the altitudinal variation of snow parameters, from 155 m to 2820 m a.s.l..

4 DATA PROCESSING

4.1 Data digitalization and quality control of T.S.S.

The historical time series used in this study have been recovered from the paper archives of the Ufficio Idrografico del Bacino del Po (Po basin Hydrographic Office) now hosted by the Agenzia Regionale per la Protezione Ambientale (Regional Agency for Environmental Protection) of Piemonte and Lombardia.

The original bulletins report daily maximum and minimum temperatures, rainfall, snow depth and occasionally fresh snow data acquired by observers. A parallel in-depth historical research has been carried out in order to acquire stations metadata, i.e. information on the geographical position, elevation, exposure and any other characteristics of the measurement site, as its instrumentation and operational period.

Particular attention has been addressed to possible relocations or changes occurred during the stations lifetime, which could reflect in relevant changes in the data not related to climatic factors (Aguilar et al., 2003). All the historical time series have been quality controlled in order to identify and eventually correct errors due to the observers and to the process of digitization.

A procedure for the identification of the data outlying pre-fixed thresholds is applied to the snow accumulation a(t) and snow depletion d(t) time series, Values of a(t) and d(t) exceeding a given threshold (typically 99th or 95th percentile calculated on non-zero values) are highlighted and the corresponding HS is (i) checked with original value reported on the paper bulletins, (ii) evaluated in relation to temperatures and precipitation and finally (iii) compared with corresponding values registered in the neighboring stations, in order to test the reliability of abrupt changes in snow thickness.

4.2 Data validation and storage of A.S.S.

The snow data is acquired by ultrasonic snow gauge every 30 minutes and transmitted to the Functional Centre to ARPA Piedmont, where it is stored in a relational database RBDMS. These data are then daily subjected to a quality semi-automatic control to detect any anomalies, also through the use of a algorithm (Terzago et al., 2012) that identifies and correct anomalous data.

5 RESULTS

5.2 Climatological feautures

Several snow parameters were considered in order to describe the average climatological features of snow precipitation at seasonal (November-May) scale. The statistics over the 1961-2010 period have been calculated. In summary:

- snow precipitation (HN) median is about 62 cm at 700 m a.s.l., 300-400 cm at about 1500 m a.sl. and 600 cm at about 2000 m a.s.l.;
- snow depth (HS) median is about few centimeters at 700 m a.s.l., about 50 cm at about 1500 m a.s.l. and 100-150 cm at 2000 m a.s.l.;
- days with snow precipitation (SD) median is about 9 days/season at 700 m a.s.l., 30 days at about 1500 m a.s.l. and 46 days at about 2200 m a.s.l.;
- days with snow cover (HS0) median is <100 days per season until 1000 m a.s.l., between 130 and 180 days at 1500-2000 m a.s.l. and > 200 days at > 2000 m a.s.l.

The analysis of the results of the last 10 years ASS agrees with the values of TSS. The ASS allow to extend the altitude range analyzed. Over 2500m asl wind activity can significantly alters snow depth measurements. Under 500m asl the average value are considerably reduced until values close to 0 (HN, HS, SD, HSD) at lower altitude.

The seasonal distribution of snow precipitation is mainly dependent on the elevation:

- below 2000 m a.s.l. it is unimodal, with an absolute maximum in winter (January). Some stations above 1500 m present comparable snowfall amount in January, February and March;
- between 2000 and 2200 m January is still the month with maximum snow precipitation but a sensible amount of snow fall in March/April;
- above 2200 m the distribution is unimodal with a maximum in spring (April).

5.3 Snow data vs altitude

To correlate snow data with altitude of all stations it was necessary to make a weigthed regression respect the periods on which are carried out the avereges: weight 5 for manual station (1961 to 2010), weight 1 for automatic stations (2001 to 2010).

In the table value are

- seasonal snowfall average (∑HN) increases of 30 cm / 100m;
- days number average with snowcover (HSD) increases of 9 days / 100m;
- days number average with snowfalls (SD) increases of 2 days / 100m;
- the logarithm of snow cover thickness average (Log10(HS)) increases of 0,09cm/100m.

	Coeff.	Int.	R2
ΣHN [cm]	0.301	-101.573	**0.86**
HSD [gg]	0.084	10.154	**0.9**
log10(HS) [cm]	0.001	0.265	**0.82**
SD [gg]	0.023	-3.662	**0.84**

Table1 Summary of the correlation coefficient

5.3.1 Regional distribution of snowfalls

For each station we calculated the accumulated snowfall according to the empirical altitudinal gradient (30cm/100m) and we compared it with the real value. Figure 2 shows the difference between the observed values of seasonal snowfall and the corresponding value derived from the altitudinal gradient. This spatial representation allows to evaluate the local effects of the different exposure of the valleys to the low pressure disturbances (Biancotti et al.,1997).

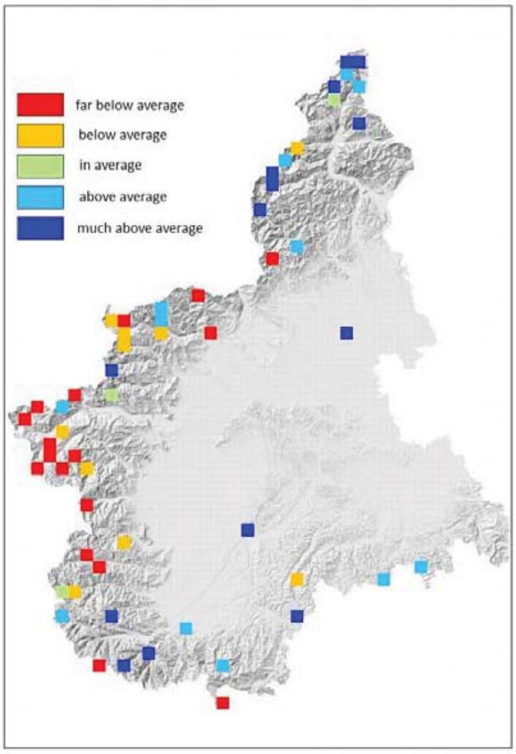

Figure 2. The difference from real values of seasonal snowfalls and mean value calculating with the correlation gradient.

The northern and southern slopes are generally characterized by higher values respect to those derived from the theoretical regression line, on the contrary western slopes shows lower values.

6 TEMPORAL EVOLUTION

6.1 SAI

For each station, the seasonal snow depth standardized anomalies have also been considered. All the stations time series have been averaged to get the regional Standardized Anomaly Index, which express the anomaly of the studied parameter respect to the mean value over a reference 30-year period, in this case 1971-2000. During the last 25 years almost all seasons were characterized by negative anomalies. The SAI calculated on snow precipitation shows the same phases of positive snow depth anomalies. The snow precipitation has been below average along the 1940 till the mid 50's, during the 1960's and from the mid 80's up to 2008. In the last 25 years only 6 seasons present positive anomalies, all the others had below average snow precipitation (Fig. 3).

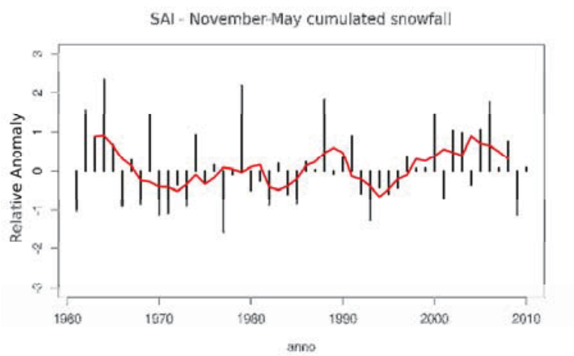

Figure 3. SAI of Snowfall, reference period 1971-2000. Red line is the 5 years moving average.

6.2 Trend

The analysis of trends has been conducted over the complete snow season November-May (Tab. 2).

To assess the significance of trends was used the nonparametric Mann-Kendall test.

In the period 1961-2010 the seasonal snowfall has negative trends in 14 stations out of 16 and in 3 cases are statistically significant: Rochemolles, Malciaussia and Agaro.

This decrease was higher at medium – low altitude, in fact, especially below 2000 meters, they receive less snow today than in the past. In the station of Rochemolles are witnessing a strong decrease of snowfall: in this station the seasonal average of snowfall during the period 1990-2010 decreased by 26% compared to the period 1961-1990.

In most of the stations considered (10 of 16) the seasonal trend in the number of snowy days show significant changes in the values of ≤ 0.10 days/year.

Trend analysis shows a general decrease of the average thickness of the seasonal snowpack.

Stations	Trend [cm/sea] 1961-2010	Error [cm/sea]	P_{MK}
Valsoera	-1,83	1,92	0,157
Camposecco	-1,46	1,65	0,198
Lago Serru	-1,22	2,10	0,248
Lago Vannino	-1,29	1,31	0,146
Toggia	0,11	1,46	0,789
Rochemolles	**-3,72**	1,11	**0,003**
Telessio	-2,70	2,48	0,083
Malciaussia	**-2,68**	1,63	**0,028**
Alpi Devero	-1,44	1,36	0,297
Agaro	**-2,89**	1,21	**0,017**
Lago Castello	-0,50	1,00	0,408
Ceresole Reale	-1,72	1,35	0,116
Acceglio Saretto	-1,71	1,09	0,225
Alpe Cavalli	-1,48	1,32	0,389
Lago Piastra	-1,88	1,19	0,093
Rosone	0,10	0,52	0,552

Table 2. Trend, error, statistical significance (P_{MK}) of seasonal snowfall period 1961-2010. In red bold values statistically significant (sea=season).

The trends are negative in all the stations considered, with the exception of the station situated at an altitude lower (Rosone, 701 m).

6.3 Extreme events

	Snowfall				
	R1 [cm]	R10 [cm]	R30 [cm]	R50 [cm]	R100 [cm]
Piastra 1	23	78	94	100	110
Piastra 3	31	110	127	134	142
Cavalli 1	25	80	91	96	101
Cavalli 3	34	130	153	163	175
Saretto 1	27	75	91	99	109
Saretto 3	36	113	140	151	167
Ceresole R. 1	21	79	97	104	115
Ceresole R. 3	30	124	169	193	228
Toggia 1	42	97	110	116	122
Toggia 3	63	150	171	180	190

Table 3. Snowfall of 1 or 3 days related to return times (1,10,30,50,100 years), time series for the period 1933-2010.

In order to evaluate the frequency of extreme snowfall events return periods were calculated using the Generalized Extreme Values (GEV) distribution. For this type of analysis we have considered the 5 stations with the longest series, since 1933. On average, we obtain maximum of snow precipitation of 20-30 cm per day each year. 70-80 cm of snow accumulated over 24 h occur once every 10 years, while quantities of 100 cm / day occurring every 50 years. Rarer are the daily snowfall in excess of 100 cm that occur on average once in 100 years (Tab. 3).

7 CONCLUSIONS

The present study gives a contribution to the assessment of the temporal and spatial variability of the climatic conditions at high elevation sites in Western Italian Alps in the last 50 years.

The investigation on temporal evolution of snow precipitation shows snow precipitation fluctuations with an irregular period of about one decade, with relative maxima around 1940, 1950, 1960, and the absolute maximum in the '70s. Snow was abundant till the early 80's, then a sequence of poor snow winters leads to the absolute minimum of the record in the 1990's.

This study outlines a significant decrease of snow depth in all the stations over seasonal (November to May) time scale in the period 1961-2010. The northern stations suffer an higher significant decrease, so North Piedmontese Alps result the most sensitive to climate change. The availability of daily series also allowed the application of advanced statistical techniques based on the Generalized Distribution of Extreme Events to assess the return period. The results will provide useful information to the prediction and adaptation of climate risks.

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