Winter precipitation in Western Italian Alps (1926-2010): trends and connections with the North Atlantic/Arctic Oscillation

Terzago S.; Fratianni S.; Cremonini R.. Winter precipitation in Western Italian Alps (1926-2010): trends and connections with the North Atlantic/Arctic Oscillation. METEOROLOGY AND ATMOSPHERIC PHYSICS. 704 pp: 125-136.

Meteorology and Atmospheric Physics manuscript No.
(will be inserted by the editor)

Winter precipitation in Western Italian Alps (1926-2010):

Trends and connections with the North Atlantic/Arctic Oscillation

S. Terzago · S. Fratianni · R. Cremonini

Received: date / Accepted: date

Abstract Six snow depth and total precipitation time series recorded in Western Italian Alps between 960 and 2177 m a.s.l. have been analyzed to investigate variability and trends over the 1926-2010 period. The results outline a significant decrease of snow depth in the period 1951-2010 ranging from -0.2 cm/y in the lowest station up to -1.4 cm/y in the highest one. The contribution to this negative trend comes mainly from spring. These results have been related to the changes in the amount/frequency of total precipitation and to the temperatures analyzed in former studies.
The connections between winter precipitation and large scale atmospheric forcings have been investigated by looking for regular oscillations embedded in the time series. Two different techniques have been used, the MultiTaperMethod and the Monte Carlo Singular Spectral Analysis. Both highlight oscillations corresponding to 2.4-2.7 year periods which are found to be driven by the North Atlantic Oscillation.

Keywords snow · winter precipitation · Alps · NAO · spectral analysis · climate change

1 Introduction

Major rivers in Europe such as the Po, Rhine, Rhone and Danube are fed by a network of tributaries that originates in the Alps, making this mountain chain

---

S. Terzago, S. Fratianni
Department of Earth Sciences, University of Torino, Via Valperga Caluso, 35 - 10125 Torino (Italy)
Tel.: +39 011 670 5172
E-mail: silvia.terzago@unito.it

R. Cremonini
Regional Agency for Environmental Protection (ARPA) of Piemonte, Via Pio VII, 9 - 10135 Torino (Italy)

a key element of the hydrological cycle. A shift in Alpine climatic regimes, particularly winter precipitation and snow cover duration, would impact heavily on the river systems originating in that area, affecting life and socio-economic structures of populations living within the mountains and downstream (Beniston et al, 1997). The strongest impacts would be on water availability for agriculture, industries and hydroelectrical power production, but also on winter tourism that sensitively depends on a reliable snow cover throughout the skiing season (Fazzini et al, 2004).

In current general circulation climate models (GCMs) the complexity of mountain topography is difficult to represent and these areas remain poorly resolved, implying too coarse resolution and big uncertainties in climate predictions. In order to draw reliable conclusions on climate characteristics, climate change and its possible impacts on mountain areas, it is fundamental to relie on observational data representative of local scale. During the IPCC Second Assessment report (Watson et al, 1995) it was highlighted the need of understand and predict effects of climate change on mountain regions with monitoring, experimental studies and modelling. Since then a lot of works have been carried out on winter precipitation. A relevant number of studies were addressed to Swiss Alps: Laternser and Schneebeli (2003) evaluated long term snow depth and duration trends in about one hundred stations over the 1931-1999, Beniston et al (1997) linked the abundance or dearth of snow cover over 1945-1995 period with the pressure fields over the Alpine region highlighting the dominant role of large scale forcings in controling the timing and amount of snow in the Alps. Scherrer et al (2004) evaluated trends in snowy days in Swiss Alps and used a regression model to quantify the importance of mean temperatures, precipitations as well as large scale climate variability to explain the observed trends. Marty (2008) evidenced a significant decrease in the number of snowy days induced by temperature increase since the end of the 80's.

Concerning Austrian Alps Schöner et al (2009) used the snow measurement network of the Sonnblick region to describe temporal trends of snow-depth as well as its relation to climate change for a high-elevated site (2400-3100 m.a.s.l.) of the European Alps. Hantel et al (2000) and Hantel and Hirtl-Wielke (2007) studied the sensitivity of Alpine snow cover duration as a function of the height and the mean temperature over Europe.

Regarding the French slope Martin et al (1994) used a numerical snow model to study the sensitivity of snow cover to changes in meteorological variables and Durand et al (2009) draw the main climatic features of the French Alps through modeled snowfields at different spatial and temporal scales in the period 1958-2005.

Concerning Italian Alps the information on winter precipitation variability is still scarce compared to the Swiss, French and Austrian sides. A general study considering the entire Alpine region over the 1971-1992 winters has been conducted by Quadrelli et al (2001), who investigated also the links between snow precipitation and the North Atlantic Oscillation and the North Hemisphere blocking frequency. Valt et al (2005) analyzed the Standardized Anomaly Index (SAI, Giuffrida and Conte (1989)) of snow precipitation over the Southern

Alps over the period 1920-2005 and highlighted a decrease of snow precipitation in the recent period (1985-2004). In particular it has been carried out an in-depth analysis of snow climatology of two representative areas of Western and Eastern Italian Alps (Valt et al, 2008). Even though some regional studies have already been produced (Biancotti et al 1998, Fratianni and Motta 2002, Fazzini and Gaddo 2003, Mercalli et al 2008), this field can be still considered as underexplored due to the difficulty of finding long term, continuous and homogeneous time series.

This work has been conducted in the frame of the MEditerranean climate DAta REscue (MEDARE) initiative, born under the auspice of the World Meteorological Organization, with the main goal of developing, consolidating and progressing climate data and metadata rescue activities across the Greater Mediterranean Region (GMR). In Western Italian Alps (Piedmont) the effort is addressed to recover historical climatic time series and enhance a unique and under-explored climatic dataset realized by the *Ufficio Idrografico del Bacino del Po* (Po basin Hydrographic Office), the ex-*Servizio Idrografico e Maregrafico Nazionale* (National Hydrographic and Mareographic Service, SIMN), operational since the 1920's up to the 1990's and then merged to Arpa Piemonte.

The data originally reported over bulletins were digitized, quality controlled, checked for homogeneity and then analyzed to investigate trends and interannual and decadal variability of snow and total precipitation over Western Italian Alps. Further analysis has been addressed to explore the connections between winter snow precipitation variability and the North Atlantic Oscillation, the dominant mode of the atmospheric variability over the North Atlantic (Hurrell, 1995). Several previous studies were addressed to this subject but they obtained contrasting results: for example Beniston and Jungo (2002) detected clear links between strongly positive (negative) modes of the NAO and extremes of moisture, temperature and pressure in Switzerland, especially for high elevation sites; Schmidli et al (2002) detected only weak and highly intermittent correlations between winter Alpine precipitation during the period 1901-1990 and the North Atlantic Oscillation Index; similar results were found by Bartolini et al (2009) using a 20 km resolution precipitation dataset which covers all Europe. The availability of a historical high-quality dataset constitute a unique opportunity to clarify the effects of large scale forcings on local climate. In this work the newly recovered instrumental long term snow time series are used to obtain accurate and reliable information on the connections between high-frequency modes of climate variability and local winter precipitation in the area of study.

In summary this paper aims to (i) investigate the temporal variability and trends of snow and total precipitation and compare the results to the existing bibliography, (ii) determinate the regularities i.e. the periodic components embedded in the snow precipitation time series using two different methods, the Monte Carlo Singular Spectral Analysis (MCSSA) and MultiTaper Method (MTM) (Ghil et al, 2002) and finally (iii) explore connections between oscillatory modes found for winter precipitation and the North Atlantic Oscillation

(Hurrell, 1995) and the Arctic Oscillation (Li and Wang, 2003) for a better understanding of the influence of large scale atmospheric forcings on the local climate. Finally the outcomes of this study are drawn.

2 The Data

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 at the *Agenzia Regionale per la Protezione Ambientale* (Regional Agency for Environmental Protection) of Piemonte and Lombardia. All the measurements are performed manually by the observers with rain gauges, graduated snow stakes and snow tablets.

The main parameters used in this study are the total snow depth and the total precipitation. As defined in Cagnati (2003) total snow depth HS is the distance between the soil surface and the snow surface, measured along the direction normal to the ground. The total precipitation P is sum of liquid precipitation and melted snow. In some measurement sites fresh snow precipitation (HN) is not sistematically registered, so, in order to have continuous and comparable data, HN is calculated by subtraction of two consecutive HS values. With this procedure the possible snow melting between two consecutive snowfalls in a 24 hours period is neglected, appearently causing an underestimation of fresh snow precipitation. Nevertheless the comparison between the available HN data directly measured with snow tablets and the corresponding HN derived by subtraction of consecutive HS values shows that these time series are almost identical except for few cases in which the differences are on the order of 2-3 cm, so the derived HN gives a good approximation of the real amount of fresh snow precipitation.

In order to have information on the amount of snow precipitation in term of *water equivalent*, it has been considered the solid precipitation fraction S/T defined as the ratio between the sum of daily precipitation when $HN > 0cm$ and the total P over a given time period. The advantage of using this parameter is that, being proportional to the amount of melted snow, it does not dipendent on snow density. On the other hand, a possible overestimation of solid precipitation can arise in case of mixed (rain + snow) precipitation.

Other derived quantities are the number of snowy days SD, defined as the number of days when solid precipitation $HN > 0\ cm$, the number of rainy days PD, defined as the number of days when precipitation $P > 0\ mm$.

For the purpose of this study only stations located in the Alps were considered. The other criteria used for the selection of the stations have been the length, continuity and homogeneity of the series, the representativeness of different altitude ranges and the representativeness of different alpine sectors. The data finally analyzed refer to 6 stations covering the whole Piedmontese Alps and ranging between 960 and 2177 m a.s.l. (Table 1 and Fig. 1).

The two longest time series supply 85 year records (1926-2010) and the shortest ones 60 year records (1951-2010) and they are all continuous except

Fig. 1 Geographical position of the six stations selected for this study, located in the Piedmont, NW Italy.

Table 1 Denomination, elevation, position and operational periods of the six measurement sites considered in this study.

Station	Elevation [m a.s.l.]	UTM X [m]	UTM Y [m]	Period
Lago Vannino	2177	451230	5137189	1951-2010
Alpi Devero	1634	443114	5129624	1951-2010
Lago Castello	1589	345381	4942026	1943-2010
Ceresole Reale	1573	362763	5032442	1926-2010
Alpe Cavalli	1500	431707	5104302	1933-2010
Lago Piastra	960	371372	4898574	1926-2010

for minor gaps. Other time series used for the analysis are the Winter North Atlantic Oscillation index (DJF NAO), representing the normalized sea level pressure difference between Ponta Delgada (Azores) and Stykkisholmur/Reykjavik (Iceland) and the Winter Arctic Oscillation index (DJF AO), representing the normalized difference in zonal-averaged sea level pressure anomalies between 35°N and 65°N. The two indexes are provided by the Climate Analysis Section (Hurrell, 1995) and Li and Wang (2003).

3 Methodology

The daily rainfall, snow depth and fresh snow data collected by the observers and registered on the bulletins have been digitized together with all the eventual notes regarding the measurements or the instruments anomalies.

A parallel in-depth historical research has been carried out in order to acquire stations metadata. Particular attention has been addressed to eventual relocations or changes undergone during the stations lifetime, which could reflect in inhomogeneities in the time series and relevant changes in the data not related to climatic factors (i.e. Aguilar et al (2003), Venema et al (2012)).

This inspection did not indicate relevant variations. The only exception is Alpe Devero station, where the manned observations stopped in 1991, about one year after the installation of an automatic station in the surroundings. In this case a careful control performed on the time series in the overlapping period 1991-1992 showed that the correlation coefficient exceeds 0.9 and the mean ratio between the automatic and the manual measurements exceeds 0.8: it was decided to join the two time series and to adjust them using the simple ratio method proposed by Thom (1958). The first stations daily values are multiplied by the ratio of total snow precipitation (average snow depth) at the two stations during the overlapping period. The ratios are computed separately for each month in order to avoid possible seasonal effects (Mekis and Hogg, 1999). Concerning the station of Ceresole Reale the manned observations of total precipitation end in 2002 and the joining with neighboring time series would have introduced large uncertainties so it has been preferred to exclude the total precipitation time series from this analysis. All the other stations are still manned then no artificial bias due to change in the method of measurement has been introduced in the time series. Moreover the need of meteorological records in very peculiar areas in the surroundings of the barrages for hydroelectric power production let us believe, in absence of other information, that the measurements were performed always in the same place. For these reasons the precipitation and snow depth data have been considered homogeneous.

All the time series have been quality controlled in order to identify and eventually correct anomalous values and errors due to the observers or to the process of digitization. Precipitation time series used in this study have been quality checked using the RClimdex package (Zhang and Yang, 2004) which highlights unresonable values (i.e. negative data, outliers exceeding n standard deviations, ...). All the "suspect" data have been compared with those of the other stations and eventually discarded. For daily snow depth data a tecnique has been developed for the purpose of this study. After a first visual check by plotting HS data against time to identify non reasonable values, a procedure for the identification of the data outlying pre-fixed thresholds is applied to two derived time series, the *snow accumulation* $HN(t)$ and the *snow depletion* $d(t)$, derived from $HS(t)$ as follows:

$$d(t) = \begin{cases} HS(t-1) - HS(t) & if \quad HS(t-1) - HS(t) > 0 \\ 0 & if \quad HS(t-1) - HS(t) \leq 0 \end{cases} \tag{1}$$

where t is the time. Values of $HN(t)$ and $d(t)$ exceeding a given threshold (the 99th percentile calculated on non-zero values) are highlighted and the corresponding HS is first checked with the original value reported on paper bulletins, then evaluated in relation to temperatures and precipitation and finally compared with the corresponding values recorded in the neighboring stations, in order to check the reliability of abrupt changes in snow thickness. After the quality control, daily values have been aggregated over monthly and seasonal time scales. These data have been retained only if at least 80% of the daily values were available (Klein Tank et al, 2002) and then a trend analysis has been performed. The significance of the trends has been evaluated with the non parametric Mann-Kendall test at 95% confidence level.

Searching the dynamical mechanisms underlying winter snow precipitation two different spectral methods have been used to separate oscillatory modes and regular behavior of the signal from the noise background: the Multi-Taper method (MTM) and the Monte Carlo Singular Spectrum Analysis (MCSSA). The Multi-Taper method (Thomson (1982); Percival and Walden (1993)) separates harmonic (pure sinusoids) and anharmonic signals (phase and amplitude modulated sinusoids) from continuous components (noise) of the spectrum, testing their significance against the null-hypothesis of white/red noise.
The Singular Spectrum Analysis technique (Vautard et al, 1992) uses the lag-covariance matrix of the data to derive a basis of Empirical Orthogonal Functions (EOFs) onto which the original time series can be projected, making thus individual data components (*modes*) linearly independent. The EOFs in phase quadrature associated to paired eigenvalues of the lag-covariance matrix identify an oscillatory mode of the time series (Vautard and Ghil, 1989). The Singular Spectrum Analysis has been firstly used to pre-filter the noisy part of the time series and to reconstruct the signal using the set of Principal Components that explain most of the signal variance. Then an ensemble of *surrogate time series* from an AR(1) model has been generated with the Monte Carlo method. The red noise coefficients have been determinated from the original time series using a maximum-likelihood criterion. Based on these coefficients, an ensemble of surrogate red-noise data has been generated (Allen and Smith, 1996). The SSA has been finally applied to both data and surrogates and it has been tested whether the regular oscillations found in the signal are significantly different from the noise background (Ghil et al, 2002).
The oscillatory modes found through spectral techniques in winter snow precipitation have been related to large scale forcings, represented by the North Atlantic Oscillation index (DJF NAO) and Arctic Oscillation index (DJF AO), using the coherence analysis. The coherence analysis, or cross-spectral analysis, is used to identify similar spectral properties in the time series (high power in the same spectral frequency bands), thus allowing to determinate if the variability of two distinct time series is inter-related in the spectral domain.

4 Results

4.1 Temporal variability of DJF snow precipitation (1933-2010)

The three longest snow records, Alpe Cavalli, Ceresole Reale and Entracque Lago Piastra representative of North, Central and South Piedmont, have been used to compare DJF snowfall HN, number of days with snow precipitation SD and average snow depth HS over a common period 1933-2010 (Fig. 2). It has been applied a 5 years filter to avoid interannual fluctuations.

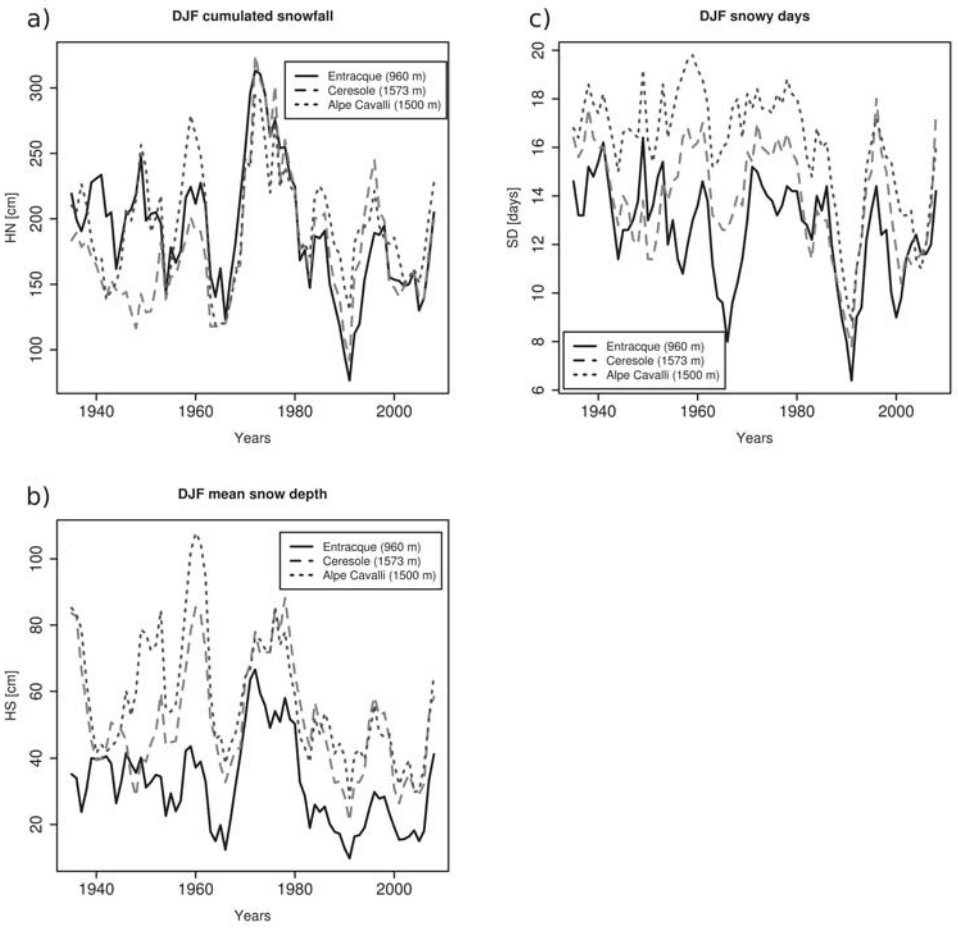

Fig. 2 Temporal variability of 5-years averaged DJF cumulated snowfall (**a**), average snow depth (**b**) and number of snowy days (**c**) for the three longest records representative of North, Central and South Piedmontese Alps: Alpe Cavalli (1500 m, dotted line), Ceresole Reale (1573 m, dashed line) and Lago Piastra (960 m, solid line).

Snow precipitation shows fluctuations of irregular period of about one decade, with relative maxima around 1940, 1950, 1960. The most prominent peak is registered in the '70s, when average DJF cumulated snowfall was around 300 cm in all the tree stations. The maximum has been followed by an absolute minimum around 1990, with snowfall amount reduced by 1/3. Then an other complete fluctuation is registered and in the last snow seasons we are in a phase of increasing winter snow precipitation amount. Winter days with precipitation and average snow depth (SD and HS) have a similar pattern as the snowfall amount but they show more spread between stations, because of both elevation and local factors. In fact, the Northern and Central stations located at about 1500 m a.s.l. register higher SD and HS than the low elevation station at 960 m a.s.l.. Nevertheless the difference between values registered at about 1500 m is quite large, as the station located North Piedmont has more frequent and abundant snowfalls and higher snow depth than the one located in Central Piedmont due to its exposition also to North and North-Western perturbations (Biancotti et al, 1998).

Looking at the temporal evolution of snow parameters, snow depth at about 1500 m a.s.l. presents large fluctuations that result stronger compared to the low level station up to the 1970's. After the 1970's the spread between high and low elevation stations decreased reducing the range of SD and HS variability at 1500 m. In order to check significant variations in snow precipitation characteristics the analysis of the trends has been performed.

4.2 Trends in annual, seasonal (November-May), DJF and MAM total and solid precipitation (1951-2010)

This section presents the analysis of the total and solid precipitation trends comparing the results of all the 6 the stations (5 for total precipitation) over the common period 1951-2010.

The analysis of annual records (Table 2) shows a general decrease of total precipitation (P) ranging between -0.6 and -4.7 mm/y althought the trend is not statistically significant at 0.05 level. A negative trend in annual precipitation is registered also in the stations located in the Piedmontese plain (Torino, Asti, Vercelli) where the decrease ranges between -1 and -3 mm/y (Acquaotta et al, 2009).

Table 2 Annual trends in total (liquid+solid) precipitation P and precipitation days PD over the period 1951-2010. Statistically significant trends at 0.05 level are highlighted in bold.

Station	Elev	P [mm/y]	PD [days/y]
Vannino	2177	-4.51	-0.13
Alpi Devero	1634	-4.72	**-0.27**
Lago Castello	1589	-0.11	+**0.42**
Alpe Cavalli	1500	-0.61	-0.01
Lago Piastra	960	-2.33	+**0.79**

The number of days with precipitation has a dipole pattern, with a statistically significant increase in Southern Piedmont [+0.4;+0.8 days/y] and a reduction in Northern Piedmont, in particular in Alpe Devero (1634 m a.s.l.), where rain is significantly less frequent by 0.3 days/y. So it seems that over the period 1951-2010 the rainfall amount and frequency in Northern Piedmont has non-significantly decreased while in Southern Piedmont more frequent but weaker precipitation events occur.

The analysis of total and solid precipitation trends over Piedmontese Alps has been conducted also over the snow season November-March (NM) and over winter (DJF) and spring (MAM) three-month period (Table 3).
Similarly to what found for the annual time scale, the winter total precipitation has decreased in all the stations although in general the trend is not statistically significant, in agreement with Fratianni and Acquaotta (2011) who evaluated precipitation trends for Piedmontese stations located in the Po Valley. In spring the sign of the total precipitation trend depend on the location of the station, while the days with precipitation are significantly more frequent in Southern Piedmont.

Table 3 Winter (DJF), spring (MAM) and seasonal (NM) trends in total precipitation P [mm/y], number of days with precipitation PD [y^{-1}], solid precipitation fraction S/T [mm/y], snow precipitation HN [cm/y], number of snowy days SD [y^{-1}], and average snow depth HS [cm/y]. The statistically significant trends at 95% confidence level are highlighted in bold.

		Vannino	Devero	Castello	Ceresole	Cavalli	Piastra
NM	P [mm/y]	-1.37	-3.42	0.44	-	-0.51	-2.18
	PD [y^{-1}]	-0.08	-0.12	**0.24**	-	-0.05	**0.39**
	S/T [mm/y]	-0.0011	**-0.0046**	-0.0012	-	**-0.0037**	**-0.0021**
	HN [cm/y]	-1.54	-1.27	-0.85	-0.94	-1.41	**-1.92**
	SD [y^{-1}]	-0.10	0.04	0.03	-0.08	**-0.16**	-0.05
	HS [cm/y]	**-1.39**	**-0.42**	**-0.27**	**-0.32**	**-0.58**	**-0.19**
DJF	P [mm/y]	-1.57	**-2.24**	-0.17	-	-0.72	-1.31
	PD [y^{-1}]	-0.09	**-0.21**	0.06	-	-0.11	0.05
	S/T [mm/y]	**-0.0003**	-0.0036	-0.0005	-	**-0.003**	-0.0010
	HN [cm/y]	-0.90	-0.72	-0.34	-0.01	-0.53	-1.06
	SD [y^{-1}]	**-0.09**	-0.02	0.03	-0.02	**-0.09**	-0.03
	HS [cm/y]	**-1.82**	**-0.43**	-0.33	-0.34	-0.62	-0.23
MAM	P [mm/y]	0.58	-0.57	0.63	-	0.99	-0.69
	PD [y^{-1}]	0.04	-0.03	**0.14**	-	0.08	**0.27**
	S/T [mm/y]	-0.0003	-0.0017	-0.0009	-	-0.0021	-0.0017
	HN [cm/y]	0.14	0.37	-0.48	-0.43	-0.35	**-0.87**
	SD [y^{-1}]	-0.007	0.07	0.02	-0.02	-0.02	-0.03
	HS [cm/y]	**-1.39**	**-0.70**	**-0.28**	**-0.33**	**-0.63**	**-0.18**

The most relevant result is found for the snow depth: over the November-May snow season it has been registered a significant decrease ranging between -0.2 cm/y in the lowest and most Southern station and -1.4 cm/y in the highest and most Northern station. A significant contribution to the snow depth reduction is given by spring months in all the stations. Considering only stations located at comparable elevations, around 1500 m a.s.l., the strength of the decrease grows moving Northward, so the Northern Piedmont is the most subject to the spring snow thickness reduction. Contrarily to the expectations, the lowest station, situated in Southern Piedmont, suffers a smaller snow depth reduction than the one located in Northern Piedmont above 2000 m a.s.l.. In winter there is a similar pattern with a general snow depth decrease that becomes larger and statistically significant moving toward Northern Piedmont. Globally the complete NM snow season presents negative snow depth trends associated with a decrease in the solid precipitation fraction and in the number of snowy days, expecially in winter and in the Northern Piedmont. In spring the solid precipitation fraction decreased as well but the trend is not statistically significant, suggesting that the snow depth reduction is more related to the changes in the temperatures than in the total precipitation.

Further information on the temporal variability of snow precipitation can be inferred analyzing the time series in the frequency domain in order to find possible regular oscillations embedded in the signal. In the following paragraphs the results of the spectral analysis are presented and discussed in relation to the variability of the large scale atmospheric forcings.

4.3 Oscillation modes in DJF snow precipitation

Two different approaches have been used to separate the oscillatory modes of snow precipitation HN and snow depth HS from the continuous noise background. The MultiTaper Method extimates the power spectrum $S(f)$ of the signal and the levels of confidence for a peak to be statistically significant from red/white noise. It distinguishes the harmonic peaks (corresponding to pure sinusoidal signals) from anharmonic peaks (phase and amplitude modulated sinusoids).

This method, applied to DJF accumulated snowfall in Entracque Lago Pias-

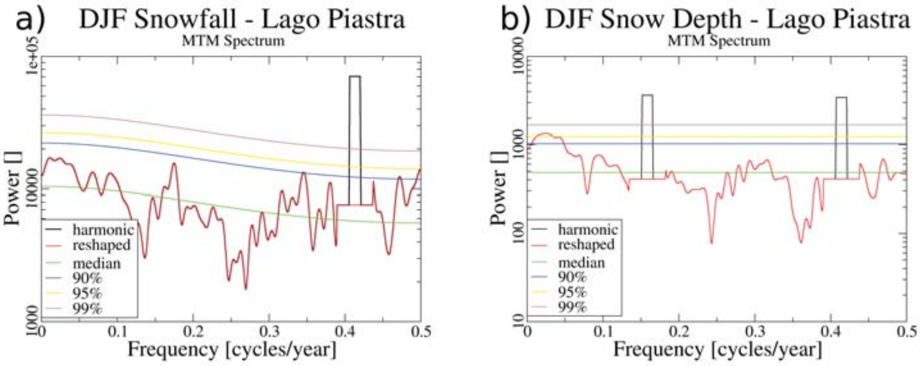

Fig. 3 MTM power spectrum (red line) of DJF cumulated snowfall (**a**) and average snow depth (**b**) in Entracque Lago Piastra station, Southern Piedmont. The estimated noise background and associated 90%, 95%, and 99% significance levels are shown by the four smooth curves, in this order, from the lowest to the highest curve in the figure. The harmonic peaks at frequency f=0.41 y^{-1} (graphically highlighted by squared shapes) correspond to a periodicity of 2.4 years.

tra data, allows to recognize one highly significant interannual harmonic peak centered at about $f = 0.41 \pm 0.02$ $cycles/y$, corresponding to a period of about 2.4 years, significant above the 99% confidence level. The power spectrum is shown in Fig. 3a, where the harmonic peak has been graphically highlighted by a squared shape. The same 2.4 year periodicity is found for DJF average snow depth, together with another one at about $f \sim 0.18$ $cycles/y$ corresponding to a periodicity of about 5.6 years (Fig. 3b).
The Monte Carlo Singular Spectrum Analysis allows to identify the oscillatory modes of a signal detecting the couples of paired eigenvalues of the data lag-covariance matrix exceeding the level of confidence given by an ensamble of simulations of red noise (Allen and Smith, 1996). The MCSSA applied to the same data of Fig. 3 allows to detect a couple of nearly equal eigenvalues significantly different from red noise at the same frequency found with MTM (Fig. 4).

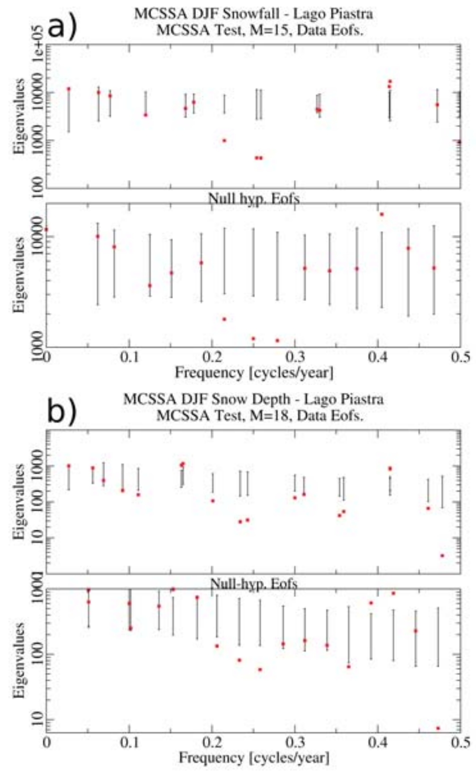

Fig. 4 Monte Carlo Singular Spectrum Analysis (MCSSA) of DJF cumulated snowfall (**a**) and average snow depth (**b**) in Entracque Lago Piastra station, Southern Piedmont. The red diamonds represent the eigenvalues of the two signals plotted against the frequency, the vertical bars are the confidence limits within which lies the 95% of the surrogate realisations of red noise. The paired eigenvalues at f=0.41 y^{-1} burst the 95% confidence level error bars and thus represent the 2.4 year period oscillatory mode.

This analysis has been performed on all the snow time series, taking into account that the longer is the record the longer is the periodicity that can be captured by spectral methods. A summary of the results is reported in Table 4. All the records present an oscillation whose period ranges from 2.4 to 2.7 years and it is confirmed by both MTM and MCSSA methods. In Lago Piastra, one of the longest records available since 1926, another oscillations is found at 5.9 years. This periodicity is probably too long to be identified using short (60 years) time series. As a consequence, the 2.3 and 2.7 year oscillations, which are common to all the time series, have been further analyzed, while the longer period oscillations have been neglected.
As the 2.3 and 2.7 years modes are typical high frequency modes of the North Atlantic/Arctic Oscillation Index, it has been explored if any relation can be established between this large scale pattern and the local meteo/climatic conditions.

Table 4 Oscillatory modes of DJF cumulated snowfall and average snow depth obtained using MTM method and MC Singular Spectrum Analysis (MCSSA).

		HN modes [y]		HS modes [y]	
Station	Elev	MTM	MCSSA	MTM	MCSSA
Station	Elev	MTM	MCSSA	MTM	MCSSA
Lago Vannino	2177	**2.6**	-	**2.7**	**2.7**
Alpi Devero	1634	-	-	**2.6**	**2.7**
Lago Castello	1589	**2.5**	**2.5**	**2.5**	**2.5**
Ceresole Reale	1573	**2.5**	**2.5**	**2.6**	**2.8**
Alpe Cavalli	1500	**2.4**	**2.4**	**2.4**	**2.4**
Lago Piastra	960	**2.5**	**2.4**	**2.4**	**2.4**
		-	-	5.9	5.9

4.4 Correlation between winter precipitation and NAO/AO

The correlation between the winter snow and total precipitation time series (DJF HN, HS and P) and DJF NAO and AO has been investigated using the Spearman Rank correlation test, a non-parametric test that measures the statistical dependence between two variables. Spearman's rank correlation coefficient ρ measures the extent to which, as one variable increases, the other variable tends to increase, without requiring that increase to be represented by a linear relationship. In this way the correlation coefficient is less sensitive to non-normality in distributions. A test to find out whether an observed value of ρ is significantly different from zero is performed using the 0.05 significance level threshold. The results of this analysis are reported in Table 5.

Looking at the correlation between the winter total precipitation and NAO/AO, it results that the influence of the large scale forcing on Piedmontese Alps is not uniform in space. In particular NAO significantly affects the total precipitation over Southern Piedmont, while in the North the relation depends on

Table 5 Spearman's rank correlation of DJF accumulated snow precipitation (HN), snow depth (HS) and total precipitation (P) with NAO and AO. The bold font indicates the significance at least at 0.05 significance level.

Station	Elev [m]	ρ_{nao-hn}	ρ_{nao-hs}	ρ_{nao-p}	ρ_{ao-hn}	ρ_{ao-hs}	ρ_{ao-p}
Lago Vannino	2177	-0.10	**-0.30**	-0.19	-0.23	**-0.29**	**-0.33**
Alpi Devero	1634	-0.06	**-0.33**	**-0.26**	-0.21	**-0.38**	**-0.34**
Lago Castello	1589	**-0.32**	**-0.41**	**-0.31**	**-0.31**	**-0.37**	-0.17
Ceresole Reale	1573	**-0.24**	**-0.26**	—	**-0.33**	**-0.27**	—
Alpe Cavalli	1500	**-0.25**	**-0.32**	-0.21	-0.2	**-0.26**	-0.14
Lago Piastra	960	**-0.23**	**-0.30**	**-0.31**	**-0.32**	**-0.38**	**-0.29**

local factors.

In the stations of Central and Southern Piedmont both snow precipitation and snow depth are significantly anticorrelated with the sea level pressure difference over Atlantic Ocean: this confirms that positive phases of NAO/AO correspond to dry air advection and mild temperatures over Mediterranean, which conditions are unfavourable to solid precipitation. On the contrary negative phases of NAO/AO correspond to the advection of cold and moist air that impinges on the mountains and determinates snowfall and longer persistence of winter snow cover at low-middle elevation.

In Northern Piedmont snow depth is as well significantly anticorrelated with large scale patterns, while snow precipitation abundance seems controlled by local factors. Furthermore a stronger snow precipitation-NAO dependence is registered at middle/low elevation probably due to the snow vulnerability in correspondence of the 0°C isotherm: here small changes in temperatures may force the precipitation to fall as rain instead of snow, while at higher elevation this forcing is less marked.

The significant anticorrelation between snow depth and sea level pressure difference over Atlantic Ocean remarks that the characteristics of the snow pack are linked to temperatures and precipitation not only in correspondence of the snowfall event but over longer period prior and after the precipitation. So it is clear that the mean winter conditions represented by NAO/AO index better describe the depth and the persistence of the snow mantle rather than the accumulated precipitation, that may be due to strong but isolated snowfalls.

Finally, the strong links between NAO and snow depth in all the measurement sites and the weaker relation with solid and total precipitation suggest that NAO mainly controls snow depth via temperature, which affects the snow melt and the occurrence of liquid versus solid precipitation, and only secondarily via the total precipitation.

4.5 Relations beween oscillatory modes of snow depth and NAO/AO

The winter NAO and AO time series have been tested for the presence of oscillatory modes using the MTM method. The considered NAO (AO) time series, extending since 1865 (1873), presents a common oscillation with period of 2.3 years, at 95% (99%) confidence level. The NAO time series has other significant oscillations with 2.7 and 8.3 year period (Fig. 5).

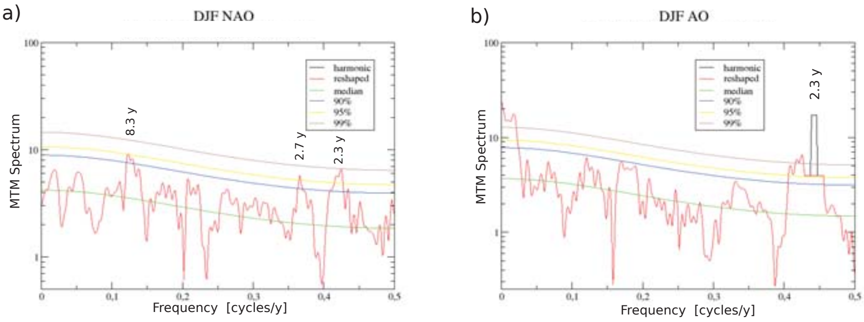

Fig. 5 MTM spectrum of DJF NAO (**a**) and AO (**b**). The estimated red noise background and associated 90%, 95%, and 99% significance levels are shown by the four smooth curves, in this order, from the lowest to the highest curve in the figure. Harmonic and anharmonic peaks are highlighted.

The common periods of snow precipitation and NAO suggest to investigate if it is possible to establish a cause-effect relation between the large scale circulation, represented by the index, and the local effects, i.e. the snow abundance and persistence. The coherence analysis is a common methods to reveal interactions between the components of the climate system (i.e. Benner (1999); Rodriguez-Puebla et al (2001)) and it has been used here to explain the snow depth variability in relation to the North Atlantic Oscillation.

The advantage of the coherency function over the correlation coefficient is that the former is a function of frequency, so it can show at which frequencies two time series are coherent and at which frequencies they are not. The coherency is expressed as a number ranging from 0 (no similarity) to 1 (perfect similarity).

For each couple of NAO and snow depth records the squared coherency between the two signals has been estimated. Table 6 reports the squared coherency peaks and the corresponding frequencies for all the stations. The squared coherency between NAO and snow depth reaches a maximum at the frequencies corresponding to about 2.3 and 2.7 year periods. The example of Alpe Devero is presented in Fig. 6.

The final step in the coherence analysis is the determination of the confidence limits for the squared coherency estimates. For all frequencies the limiting value of the squared-coherency (i.e. the level up to which squared coherency values can occur by chance) is given by:

$$C_k^2 = 1 - \alpha^{1/(n-1)}$$

Table 6 Squared Coherency between snow depth and NAO signal at frequecies of the snow depth harmonics. The statistically significant values are highlighted in bold.

Station	Elev	Period [y]	Frequency[y^{-1}]	C^2_{NAO-HS}
Lago Vannino	2177	2.7	0.37	**0.53**
Alpi Devero	1634	2.6	0.37	**0.66**
Lago Castello	1589	2.5	0.41	**0.8**
Ceresole Reale	1573	2.6	0.38	**0.86**
Alpe Cavalli	1500	2.4	0.42	**0.61**
Lago Piastra	960	2.4	0.42	**0.82**

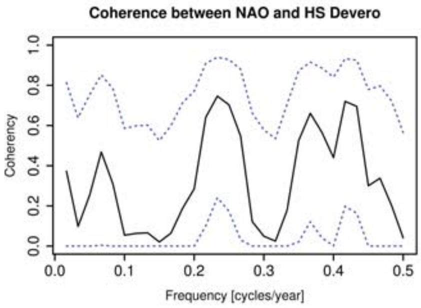

Fig. 6 Coherence analysis on Alpe Devero snow depth and NAO signals. The coherency peaks correspond to the 2.3 and 2.7 years oscillations.

where n=DOF/2 (called the *equivalent* degrees of freedom) is the number of indipendent cross-spectral realizations in each frequency band, and α the level of significance (Thompson, 1979).
In this case the coherence estimate is computed from an average of 6 adjacent cross-spectral Fourier components (n=6) and the 95% confidence level for the squared coherency is C^2_k=0.45. The squared coherency between NAO and snow depth time series in correspondence of the 2.3/2.7 y periods results $C^2 > C^2_k$ for all the stations, so the signals are coherent at that frequencies.
In conclusion, as the time series have significant spectral peaks at the same frequencies and the signals are coherent, the local and global information constitutes a true climate signal (Rodriguez-Puebla et al, 2001) and it is possible to establish a causality relation between the atmospheric large scale patterns and the local climate. In particular the NAO drives the 2.7 and 2.3 year period oscillations of snow precipitation.

5 Conclusion

This works gives a contribution to the understanding of winter precipitation characteristics over Western Italian Alps, through the recovery and analysis of long term high quality time series, spanning a 85 year period, from 1926 up to 2010. The investigation on temporal evolution of snow precipitation shows 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 1990s. Now we are in a phase of increasing winter snow precipitation amount. A similar investigation has been conducted over the Switzerland (Laternser and Schneebeli, 2003) considering individual winters and the results are comparable between the two sides of Alps.

This study outlines a significant decrease of snow depth in all the stations over seasonal (November-May) time scale in the period 1951-2010. The main contribution to this negative trend comes from spring when the snow depth decrease is comparable to the one registered over the complete season. In particular November-May trends range from -0.2 cm/y in the lowest (960 m a.s.l.) and most Southern station up to -1.4 cm/y in the highest (2177 m a.s.l.) and most Northern station. At comparable elevation, around 1500 m a.s.l. the strength of the snow depth decrease grows moving Northward. In addition to the strongest spring snow depth reduction, the Northern stations suffer also a significant decrease in winter months, so North Piedmontese Alps result the most sensitive to climate change.

The shallower seasonal snow depth cannot be explained only by a reduction in total precipitation, in general not statistically significant. This is true especially in spring, when different stations present different behavior with increased or decreased precipitation. The fraction of precipitation falling as snow has significanly decreased in several stations especially in winter, suggesting that the causes of the snow depth reduction are mainly related to the temperature variations. Ciccarelli et al (2008) analyzed a set of daily temperature time series in North-Western Italy in the period 1952-2002 and found that average temperatures significantly increased of about 1°C over the period of observation. The increase in daily temperature anomalies is particularly evident for winter months and it ranges from +0.018°C/year for minimum temperatures and +0.036°C/year for maximum temperatures. The higer temperatures registered in the last decades can explain the general negative trend in snow depth. Going into detail, Canevarolo et al (2011) analyzed the temperatures recorded in two of the stations considered in this study, Alpe Devero and Lago Vannino, Northern Piedmont. They showed that the minimum (maximum) temperatures trend is +0.07 (+0.04)°C/year. Concerning Southern Piedmontese Alps, Fratianni et al (2010) found that the minimum (maximum) temperature increased by +0.03 (+0.07)°C/year over the period 1930-2009 at comparable elevation as those considered in this work. Comparing the two studies it appears that in Northern Piedmont the minimum temperature increased more than in Southern Piedmont, causing a stronger snow depth reduction. Furthermore the analysis of the number of frost days (days with maximum temperature below 0°C) in the extended winter season December-March in Piedmontese Alps (1957-2007) shows a statistically significant decrease that becomes strongest with increasing elevation, from -0.34 days/year at 1000-1500 m a.s.l. to -0.60

days/year at elevation above 2000 m a.s.l. (Mercalli et al, 2008). The combination of the higher -expecially minimum- temperatures and the minor number of frost days make the high elevation sites in Northern Piedmont the most vulnerable to snow depth reduction and to climatic change. Low elevation sites (below 1000 m a.s.l.) are mainly affected by scarcer snow precipitation due to higher temperatures and consequent predomincance of liquid respect to solid precipitation.

The dynamical mechanisms underlying winter snow precipitation over Western Alps have been explored by studying the existing relations between snow parameters and the North Atlantic Oscillation (NAO), i.e. the dominant mode of winter atmospheric variability in the North Atlantic (Hurrell, 1995). It was found a significant anticorrelation between snow depth and NAO in the entire Region: negative (positive) NAO is favourable (unfavourable) to snow pack persistence. Snowfall amount is significantly anticorrelated mainly in Southern Piedmont at middle altitudes, where small changes in temperature and precipitation may largely affect snowfall frequency and amount. These results obtained using 6 long term time series are in contrast with the findings of a similar analysis performed using a 20 km spatial resolution gridded dataset (Bartolini et al, 2009). Follows the importance of using instrumental high quality time series in assessing local climate features.

The spectral analysis performed on snow parameters allowed to determinate periodic components embedded in the time series and to identify common 2.7/2.3 year oscillations (cycles) in NAO and snow precipitation. The about 2.5 years mode has been found also in annual rainfall series of Massachussetts (Kane and Teixeira, 1991), in annual and winter rainfall of Iberian Peninsula (Rodriguez-Puebla et al (2001); Garcìa et al (2002) and Belgrade (Tosić and Unkasević, 2005). The coherence analysis proved that the circulation index and the local snow depth oscillatory modes are synchronized, so a further connection can be established between the atmospheric large scale patterns (surface pressure fields, described by the NAO) and the local climate (precipitation, temperatures).

The description, understanding and prediction of the climatic variability has important applications in the downscaling of the Global Circulation Models output (Giorgi and Mearns, 1991) and the present work contributed to this objective by exploring snow variability and deepening the knowledge on the connections between local weather and large-scale atmospheric circulation patterns. The current efforts in the improvement of the NAO seasonal forecast will have positive outcomes in seasonal snow and climatic prediction.

Acknowledgements We gratefully acknowledge the valuable help from Marco Cordola in recovering and collecting a part of the dataset (STR.ADA project) and the patient work of digitization carried out by Daniela Testa, Noemi Canevarolo and Matteo Collimedaglia. Thanks to Fiorella Acquaotta for the fruitful discussions risen during the work. Finally thanks to two anonymous referees for their helpful comments and suggestions to improve the paper.

References

Acquaotta F, Fratianni S, Cassardo C, Cremonini R (2009) On the continuity and climatic variability of the meteorological stations in Torino, Asti, Vercelli and Oropa. Meteorology and Atmospheric Physics 103:279–287, URL http://dx.doi.org/10.1007/s00703-008-0333-4, 10.1007/s00703-008-0333-4

Aguilar E, Auer I, Brunet M, Peterson T, Wieringa J (2003) Guidance on metadata and homogenization. Tech. rep., WMO-TD No.1186

Allen MR, Smith LA (1996) Monte Carlo SSA: detecting oscillations in the presence of coloured noise. Journal of Climate 9:3373–3404

Bartolini E, Claps P, D'Odorico P (2009) Interannual variability of winter precipitation in the European Alps: relations with the North Atlantic Oscillation. Hydrology and Earth System Sciences 13:17–25

Beniston M, Jungo P (2002) Shifts in the distributions of pressure, temperature and moisture and changes in the typical weather patterns in the Alpine region in response to the behavior of the North Atlantic Oscillation. Theoretical and Applied Climatology 71:29–42, URL http://dx.doi.org/10.1007/s704-002-8206-7, 10.1007/s704-002-8206-7

Beniston M, Diaz HF, Bradley RS (1997) Climatic change at high elevation sites: an overview. Climatic Change 36:233–251, URL http://dx.doi.org/10.1023/A:1005380714349, 10.1023/A:1005380714349

Benner T (1999) Central England temperatures: long-term variability and teleconnections. International Journal of Climatology 19:391–403

Biancotti A, Carotta M, Motta L, Turroni E (1998) Le precipitazioni nevose sulle Alpi piemontesi. Trentennio 1966-1996. Collana Studi Climatologici in Piemonte, Regione Piemonte

Cagnati A (2003) Strumenti di misura e metodi di osservazione nivometeorologici. Associazione Interregionale NEve e VAlanghe

Canevarolo N, Testa D, Fratianni S, Acquaotta F, Terzago S (2011) Variabilita' climatica e rischio valanghivo in valle ossola. Neve e Valanghe 72:24–33

Ciccarelli N, von Hardenberg J, Provenzale A, Ronchi C, Vargiu A, Pelosini R (2008) Climate variability in north-western Italy during the second half of the 20th century. Global and Planetary Change 63(2-3):185–195, DOI 10.1016/j.gloplacha.2008.03.006, URL http://www.sciencedirect.com/science/article/pii/S0921818108000337

Durand Y, Giraud G, Laternser M, Etchevers P, Merindol L, Lesaffre B (2009) Reanalysis of 47 years of climate in the French Alps (1958-2005): Climatology and trends for snow cover. Journal of Applied Meteorology and Climatology 48:2487–2512

Fazzini M, Gaddo M (2003) La neve in Trentino. analisi statistica del fenomeno nellultimo ventennio. Neve e Valanghe 48:28–35

Fazzini M, Fratianni S, Biancotti A, Billi P (2004) Skiability conditions in several skiing complexes on Piedmontese and Dolomitic Alps. Meteorologische Zeitschrift 13:253–258

Fratianni S, Acquaotta F (2011) Analisi sulle lunghe serie di precipitazione in Piemonte. Geologia dell'ambiente 2:34–38

Fratianni S, Motta L (2002) Andamento climatico in Val di Susa negli anni 1990-1999, Collana Studi Climatologici in Piemonte, vol 4. Regione Piemonte

Fratianni S, Brunatti S, Acquaotta F (2010) Contributo allo studio del cambiamento climatico nelle alpi occidentali: il caso della valle maira. Neve e Valanghe 69:20–25

Garcìa JA, Serrano A, de la Cruz Gallego M (2002) A spectral analysis of iberian peninsula monthly rainfall. Theoretical and Applied Climatology 71:77–95, URL http://dx.doi.org/10.1007/s704-002-8209-y, 10.1007/s704-002-8209-y

Ghil M, Allen MR, Dettinger MD, Ide K, Kondrashov D, Mann ME, Robertson AW, Saunders A, Tian Y, Varadi F, Yiou P (2002) Advanced spectral methods for climatic time series. Review of Geophysics 40(1):1–41

Giorgi F, Mearns LO (1991) Approaches to the simulation of regional climate change: A review. Reviews of Geophysics 29:191–216

Giuffrida A, Conte M (1989) Long term evolution of the Italian climate outlined by using the Standardized Anomaly Index (SAI). In: Painatuskeskus (ed) Conference on Climate and Water, Helsinki, Finland, vol 1, p 197

Hantel M, Hirtl-Wielke L (2007) Sensitivity of Alpine snow cover to European temperature. International Journal of Climatology 27:1265–1275

Hantel M, Ehrendorfer M, Haslinger A (2000) Climate sensitivity of snow cover duration in Austria. International Journal of Climatology

Hurrell JW (1995) Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. Science pp 676–679

Kane N, Teixeira N (1991) Power spectrum analysis of the rainfall series for massachussettes. Climatic Change 18:89–94

Klein Tank A, Wijngaard J, Können G, Böhm R, Demarée G, Gocheva A, Mileta M, Pashiardis S, Hejkrlik L, Kern-Hansen C, Heino R, Bessemoulin P, Müller-Westermeier G, Tzanakou M, Szalai S, Pálsdóttir T, Fitzgerald D, Rubin S, Capaldo M, Maugeri M, Leitass A, Bukantis A, Aberfeld R, van Engelen A, Forland E, Mietus M, Coelho F, Mares C, Razuvaev V, Nieplova E, Cegnar T, Antonio López J, Dahlström B, Moberg A, Kirchhofer W, Ceylan A, Pachaliuk O, Alexander L, Petrovic P (2002) Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. International Journal of Climatology 22:14411453

Laternser M, Schneebeli M (2003) Long-term snow climate trends of the Swiss Alps (1931-99). International Journal of Climatology 23:733–750

Li J, Wang J (2003) A modified zonal index and its physical sense. Geophysical Research Letters 30(12):1632–1636

Martin E, Brun E, Durand Y (1994) Sensitivity of the French Alps snow cover to the variation of climatic variables. Annales Geophysicae 12:469–477

Marty C (2008) Regime shift of snow days in Switzerland. Geophysical Research Letters 35:L12,501

Mekis E, Hogg WD (1999) Rehabilitation and analysis of canadian daily precipitation time series. Atmosphere-

Ocean 37(1):53–85, DOI 10.1080/07055900.1999.9649621, URL http://www.tandfonline.com/doi/abs/10.1080/07055900.1999.9649621, http://www.tandfonline.com/doi/pdf/10.1080/07055900.1999.9649621

Mercalli L, CatBerro D, Accordon V, Di Napoli G (2008) Cambiamenti climatici sulla montagna Piemontese. Regione Piemonte and Società Meteorologica Subalpina

Percival DB, Walden AT (1993) Spectral Analysis for Physical Applications. Cambridge University Press

Quadrelli R, Lazzari M, Cacciamani C, Tibaldi S (2001) Observed winter Alpine precipitation variability and links with large scale circulation patterns. Climate Research 17:275–285

Rodriguez-Puebla C, Encinas A, Sáenz J (2001) Winter precipitation over the Iberian peninsula and its relationship to circulation indices. Hydrology and Earth System Sciences 5(233-244)

Scherrer S, Appenzeller C, Laternser M (2004) Trends in Swiss Alpine snow days: the role of local and large scale climate variability. Geophysical Research Letters 31:L13,215.

Schmidli J, Schmutz C, Frei C, Wanner H, Schr C (2002) Mesoscale precipitation variability in the region of the European Alps during the 20th century. International Journal of Climatology 22(9):1049–1074, DOI 10.1002/joc.769, URL http://dx.doi.org/10.1002/joc.769

Schöner W, Auer I, Böhm R (2009) Long term trend of snow depth at Sonnblick (Austrian Alps) and its relation to climate change. Hydrological Processes 23:1052–1063

Thompson RO (1979) Coherence significance levels. Journal of the Atmospheric Sciences 36:2020–2021

Thomson D (1982) Spectrum estimation and harmonic analysis. In: IEEE, Proceedings, pp 1055–1096

Thom HCS (1958) A note on the gamma distribution. Monthlty Weather Review 86(4):117122

Tosić I, Unkasević M (2005) Analysis of precipitation series for belgrade. Theoretical and Applied Climatology 80:67–77, URL http://dx.doi.org/10.1007/s00704-004-0076-1, 10.1007/s00704-004-0076-1

Valt M, Cagnati A, Crepaz A, Marigo G (2005) Neve sulle Alpi Italiane. Neve e Valanghe 56:23–41

Valt M, Cagnati A, Crepaz A, CatBerro D (2008) Variazioni recenti del manto nevoso sul versante meridionale delle Alpi. Neve e Valanghe 63:46–57

Vautard R, Ghil M (1989) Singular Spectrum Analysis in Nonlinear Dynamics, with applications to Paleoclimatic time series. Physica D 35:395–424

Vautard R, Yiou P, Ghil M (1992) Singular Spectrum Analysis: A toolkit for short, noisy chaotic signals. Physica D 58:95–126

Venema VKC, Mestre O, Aguilar E, Auer I, Guijarro JA, Domonkos P, Vertacnik G, Szentimrey T, Stepanek P, Zahradnicek P, Viarre J, Müller-Westermeier G, Lakatos M, Williams CN, Menne M, Lindau R, Rasol D, Rustemeier E, Kolokythas K, Marinova T, Andresen L, Acquaotta F, Fratianni S, Cheval S, Klancar M, Brunetti M, Gruber C, Prohom Duran M, Likso T, Esteban P, Brandsma T (2012) Benchmarking monthly homogenization algorithms for monthly data. Climate of the Past 8:89–115

Watson R, Zinyowera M, Moss R (1995) Climate Change 1996: The IPCC Second Assessment Report. Tech. rep., Intergovernmental Panel on Climate Change

Zhang X, Yang F (2004) RClimDex (1.0) User Manual. Climate Research Branch Environment Canada, Downsview, Ontario, Canada