

CLIMATOLOGY OF NORTH FÖHN IN CANTON TICINO AND WESTERN LOMBARDY

CLIMATOLOGIA DEL FÖHN SETTENTRIONALE IN CANTON TICINO E IN LOMBARDIA OCCIDENTALE

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Abstract

The analysis of yearly, seasonal and monthly frequency of north föhn in the Po valley was carried out considering some stations located in western Lombardy (Italy) and in Canton Ticino (Switzerland) and adopting synoptic, mesoscale and punctual (single station's) recognition criteria. The results show a gradual reduction of föhn frequency with increasing distance from the Alpine watershed but a relevant presence of this wind is shown also in the low plain. A simple linear model able to describe the mean number of days with föhn on the Southern of the Alps as a function of the distance from the Alpine watershed is also discussed. A change point in 1988 was detected by means of the statistical analysis of föhn time series of Locarno-Monti; this change point is coherent with discontinuities in other climatic variables detected by other authors and that can be seen as symptoms of a climatic change happened in Europe in '80 years of XXth century. The time series 1988-2003 present a reduction of föhn yearly events with a parallel increase of the Winter percentage contribution to the yearly total

Keywords: catabatic wind, Alps, climatology, climatic change, weather types, North Atlantic Oscillation (NAO).

Riassunto

Viene condotta un'analisi della frequenza mensile, stagionale ed annuale del föhn nel bacino del Po con riferimento specifico a stazioni della Lombardia occidentale (Italia) e del Canton Ticino (Switzerland) adottando criteri sinottici, di mesoscala e puntuali (riferiti cioè alla singola stazione). I risultati mostrano una graduale riduzione della frequenza del föhn al crescere della distanza dello spartiacque alpino ma una rilevante presenza di tale vento si mantiene anche nella bassa pianura. Un semplice modello lineare utile per descrivere il numero medio di giorni di föhn al sud delle Alpi in funzione della distanza dallo spartiacque alpino viene altresì discusso. L'analisi delle serie storiche di Locarno-Monti mostra una discontinuità nel 1988 che appare coerente con analoghi fenomeni osservati da vari autori in altre variabili climatiche e che possono essere considerati sintomi di un cambiamento climatico che ha avuto luogo in Europa negli anni 80. La serie storica dal 1988 al 2003 presenta, rispetto a quella precedente, riduzione dei giorni annui di föhn con un parallelo aumento del contributo percentuale dei casi invernali al totale annuo.

Parole chiave: vento catabatico, Alpi, climatologia, cambiamento climatico, tipi di tempo, Oscillazione Nordatlantica (NAO).

Introduction

The German word "Föhn" was originally reserved to the strong, warm and very dry wind descending the Alps north slopes (south föhn) (Monkhouse, 1970, Schrott and Verant, 2004) and by extension has been applied to the wind with similar properties descending the Southern side of the Alps and affecting Swiss and Italian area (north föhn). In some valleys of the Alps this wind is named "favonio", probably deriving from the Latin word favonium, which defined a westerly wind sometimes identified with zephyrum (*L. A. Seneca, Naturales questiones, V, 16, 5*).

This work focuses on the study of Alpine föhn episodes in some stations of the Po basin located in Italy (western Lombardy) and Switzerland (Canton Ticino). The Po basin (figure 1) is a wide area surrounded to the north and west by the Alps (mean height: 2000 - 3000 m a.s.l.) and to the south by the Apennines (mean height: 800 m a.s.l.). This basin is opened towards the east to the Adriatic Sea, while the Apennines separate it from the Mediterranean Sea (Genoa Gulf). The interaction of geographic features with the general circulation has an important effect on the climatology of the area. In particular the wind field of the Po valley is affected by the strong interaction between the low- and mid-

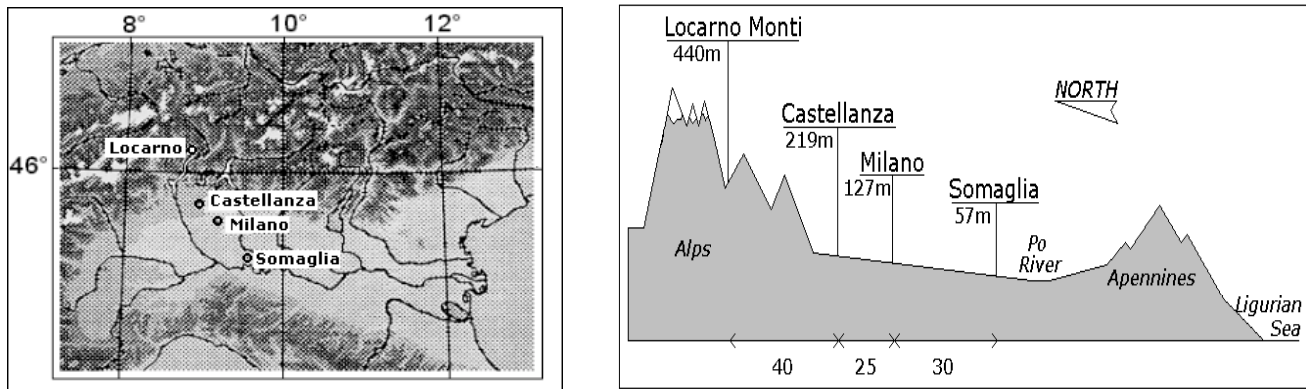


Fig. 1 - Map and cross section with stations used for analysis of föhn climatology. The North-South components of the distances among stations (km) are written on the bottom of the cross section

Fig. 1 - Mappa e sezione verticale che mostrano le stazioni usate per l'analisi climatologica del föhn. Le componenti Nord-Sud delle distanze fra le stazioni (km) sono riportate alla base della sezione.

tropospheric flows and the Alpine range that produce north föhn (Binder and Schar, 1996). The Po Valley is sometimes influenced by south föhn blowing from the Apennines; however the low altitude of this mountain range causes weaker föhn episodes than the Alpine ones. The föhn warming is often the product of the following mechanism (Fea, 1988): the surface air rises and then falls almost symmetrically on its passage over mountain range; if water vapour condensates and precipitation falls from it on the windward slopes, then its warming by descent (mostly at the dry adiabatic lapse rate) exceeds its cooling by ascent (mostly at the saturated adiabatic lapse rate) and net warming is therefore to be expected.

This is at least a contributory factor in some occurrences of föhn. It is not, however, a necessary condition: there are occasions when appreciably warmer air is present on the leeward than to windward yet the air is so dry that not even cloud is formed by ascent. In this case the explanation of such warming is that the air which reaches the ground in the lee of the mountains was, on the upwind side, at a higher level than the surface (Barry, 1992; Mc Intosh and Thom, 1972).

In the evolution of single föhn episodes are important some different effects like friction due to the surface characters or channelling in longitudinal valleys.

Tab. 1 - Meteorological stations used for this work

Tab. 1 - Stazioni meteorologiche utilizzate per questo lavoro

Station	Height (m)	Distance from Alpine watershed (km)	Propriety
Locarno-Monti	440	70	MeteoSvizzera
Castellanza	219	110	Osservatorio Meteorologico di Castellanza
Milano	127	135	Luigi Mariani
Somaglia	57	165	Ersaf
Spessa	61	162	Ersaf - Sig. Perucchini

Föhn is a very turbulent wind, especially at the onset. During the descent in a valley it increases the speed like a water wave passing over a dam. The strong gusts may seriously affect the stability of buildings and structures like domes, hangars and bridges (Cowan, 1978).

Well known are the effects of föhn on human health, due to the abrupt thermal and hygrometric variations, the changes in the ionic equilibrium of the air and the high-frequency mini-variation of air pressure (Richner, 1974). Very important are the effects of föhn on Alpine ecosystems and in particular: enhanced stress conditions for domestic animals with loss of dairy and meat productions (Innis, 1978), stress symptoms for natural and cultivated plants (strong evapotranspiration losses with water stress, etc.) (Tivy, 1993), mechanical effects on trees, with break of branches and fall of entire plants (Tivy, 1993), destabilisation of snow cover with enhanced risk of avalanches (Kappenberger and Kerkmann, 1997), rapid snow melting with strong discharge increase of Alpine rivers and significant changes in water storage of Alpine glaciers (Greppi, 1999), strong moisture reduction in forestry litters giving risk of forest fires (Chandler *et al.*, 1983), whose propagation is enhanced by the extreme variability of velocity and direction of föhn winds and, finally, strong effects on the features of the Planetary Boundary Layer (e.g. the level and quality of air pollution) (Lorenzini, 1999).

An example of the role played by föhn in land degradation is shown by the north föhn events of March 1998, a month with a very high number of north föhn episodes in Lombardy (Italy). The consequence was an exceptional number of fires in the Alpine area; the debris flow phenomena observed at Ardenno (Valtellina) in June 1998 as a consequence of a common summer shower were the final product of this anomalous event.

Works presenting quantitative data about north föhn climatology in the Po Valley are unusual. Giuliacci (1985) presented the total number of monthly föhn episodes at Milano Linate station for 1970-81 period. Musso and Cassardo (2004) presented some climatic evaluations about föhn in Piedmont. This justifies the

Tab. 2 – Criteria adopted to identify föhn**Tab. 2** – Criteri adottati per individuare il föhn**A. punctual criteria (station's data)**

1. abrupt rise of air temperature with a simultaneous drop of relative humidity
2. winds blowing from the mountains (this condition is not always respected: in some cases and for short periods it can be observed a circulation from other directions and, at worst, southerly winds)
3. data from meteorological observers (visibility, sky clearness, cloud coverage and type)

B. mesoscale criteria

1. precipitation occurrence on the windward slope and higher temperature on the lee side (applied for the attribution of doubtful cases)
2. pressure gradient across the Alpine range

C. synoptic criteria

A typical north föhn is produced by an Atlantic anticyclone expanding toward Central Europe which previously was influenced by a dynamic depression. In this case the main symptoms of föhn are the following:

1. mid tropospheric flow (700–500 hPa) nearly perpendicular to the Alps range;
2. low troposphere (850 hPa) geopotential field or surface pressure field shows a typical "föhn nose", or ridging, over the Alpine range.

importance of the quantitative study of the climatology of north föhn presented in this paper.

Methods

Föhn cases for the period 1991-2003 were analysed in the following selected stations (Table 1) of Western Lombardy (Italy) and Canton Ticino (Switzerland): Locarno-Monti (Alpine area), Castellanza (high plain), Milano (low plain) and Somaglia (low plain) (figure 1 and table 1). From 2000 to 2003 the data from Somaglia were substituted with data gauged at the near station of Spessa. Criteria adopted to recognise föhn are listed in table 2. Synoptic and mesoscale criteria were applied to the whole area while punctual criteria were different for the various stations according to the data availability; Table 3 summarises the criteria adopted for the four stations; criteria A.2 and A.3 cannot be applied to Somaglia which is an automatic stations, without meteorological observers and wind measurements.

Seasonal analysis of the dataset was carried out considering the classical meteorological seasons (December 1st – February 28th for Winter, March 1st – May 31st for Spring, etc.). The analysis of frequency of different combinations of presence/absence of föhn in the four selected stations was carried out adopting the following rules to represent the combinations of föhn occurrences:

- (i) the four stations are considered in a north - south sequence (Locarno-Monti, Castellanza, Milano and Somaglia);

Tab. 3 – Punctual and mesoscale criteria adopted to identify föhn.**Tab. 3** – Criteri puntuali e a mesoscala adottati per identificare il föhn.

Criteria	Locarno-Monti	Castellanza	Milano	Somaglia
A.1	adopted	adopted	adopted	adopted
A.2	adopted	adopted	adopted	not adopted
A.3	adopted	adopted	adopted	not adopted
B.1 – B.2	adopted	adopted	adopted	adopted
C.1 – C.2	adopted	adopted	adopted	adopted

- (ii) the presence/absence is represented according to a binary code (1=presence, 0=absence).

For example the combination LC0S means that, on a given day, föhn was present in Locarno-Monti, Castellanza and Somaglia and was absent in Milano. Fifteen combinations are possible (the 16th - 0000 - representing the total absence of föhn).

Distance from the watershed is strictly related to frequency and strength of föhn (Barry, 1992). The analysis of correlation between distance from Alpine watershed and mean number of föhn days was carried by means of the linear correlation function *lm* present in software library STAT of the R statistical software (<http://cran.r-project.org>) (Chambers, 1992; Wilkinson and Rogers, 1973)

Statistical stationarity (homogeneity of time series) is one of the most fundamental assumptions of most statistical test and procedures. The change-point problem addresses a lack of stationarity in a sequence of random values (Lanzante, 1996). The most common change-point problem involves a change (discontinuity) in the level (mean) and is the focus here.

Change point analysis on 1956-2003 time series of föhn days at Locarno-Monti was carried out by means of the software library *Strucchange* of the R statistical software (<http://cran.r-project.org>) (Baj and Perron, 2003; Zeileis et al., 2003).

Results

Tables 4 and 5 show the yearly, seasonal and monthly frequencies of north föhn in the reference area for the period 1991-2003. Mean and extreme values are reported.

Results of the analysing of the frequency of different combinations of presence/absence of föhn in the four selected stations are represented in table 6.

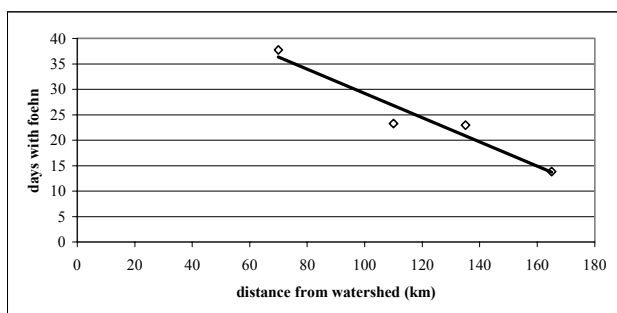
The linear correlation between yearly and seasonal föhn days and distance from Alpine watershed was next examined and the results are reported in figure 2 and table 7. We also examined the very long time series of föhn days at Locarno-Monti: in table 8 are represented monthly, seasonal and yearly statistics of föhn days for the period 1956-2003. Results of the change point analysis in order

Tab. 4 - Mean, minimum and maximum number of föhn days in the four stations (1991-2003)**Tab. 4** – Numero medio, minimo e massimo di giorni con föhn nelle 4 stazioni (1991-2003)

		Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Locarno-Monti	mean	3.1	4.3	5.1	4.5	2.8	2.1	2.5	1.3	2.5	2.5	3.5	3.5	37.8
	min	0	3	1	0	0	0	0	0	0	0	0	1	22
	max	10	7	10	10	11	5	7	3	9	7	7	7	51
Castellanza	mean	2.2	2.9	3.7	2.2	1.1	1.2	1.5	0.8	1.5	1.5	2.1	2.7	23.3
	min	0	0	0	0	0	0	0	0	0	0	0	0	12
	max	6	6	8	6	5	3	3	3	4	6	7	6	36
Milano	mean	2.4	2.9	3.8	1.9	1.3	1.2	1.8	1.0	1.8	1.2	1.3	2.3	23.0
	min	0	1	0	0	0	0	0	0	0	0	0	0	15
	max	9	6	8	6	4	4	5	2	6	4	3	6	36
Somaglia	mean	1.6	2.5	2.4	1.3	0.6	0.6	0.3	0.5	1.2	1.0	0.9	1.1	13.8
	min	0	0	0	0	0	0	0	0	0	0	0	0	9
	max	6	6	7	6	3	3	1	2	5	3	6	3	26

Tab. 5 - Seasonal föhn days in the selected stations (mean values 1991-2003)**Tab. 5** – Giorni di föhn per stagione nelle stazioni in esame (valori medi 1991-2003)

	Winter	Spring	Summer	Autumn
Locarno-Monti	15.8	18.0	8.4	12.3
Castellanza	11.3	10.1	5.0	7.2
Milano	11.0	10.1	5.8	6.3
Somaglia	6.9	5.7	1.8	4.1

**Fig. 2** - Days per year with föhn as function of the distance from the Alpine watershed. Interpolation line is defined by the equation $y = -0.23856x + 53.10180$.**Fig. 2** - Giorni annui con föhn in funzione della distanza dallo spartiacque alpino. La linea interpolante è definita dall'equazione $y = -0.23856x + 53.10180$.

to address the lack of stationarity in the time series are resumed in figure 3 and 4.

Discussion

The following deductions can be obtained from the analysis of seasonal and monthly occurrences of föhn (tables 4 and 5):

1. the seasons most affected by föhn in the selected area are Winter and Spring, with a dominance of Spring cases at Locarno-Monti and of Winter ones in other sites
2. March is the month most affected by föhn, followed by April in Locarno-Monti and by February in the other stations
3. the Alpine area is the most influenced by föhn, with the yearly mean number of days with föhn which decreases from the 37.8 days at Locarno-Monti to the 23 cases at Castellanza and Milano and to the 13 cases at Somaglia
4. The wind behaviour in Castellanza and Milano is quite similar, due to the reduced distance between the two stations and to the homogeneity of territorial features around them (stations are both within the great conurbation of Milano).
5. The data of monthly occurrences (mean and extreme values) of föhn reported in table 4 show the strong variability of this phenomenon, strictly related to the variability of synoptic features over Europe and of mesoscale features in the Alps and surrounding areas.

Tab. 6 - Table 6. Föhn episodes in the period 1991 – 2003. Analysis of the percent frequency of the 15 possible combinations 1000 .. 1001 (see in the text for the explanation of the symbols for Locarno-Monti - L, Castellanza -C, Milano - M and Somaglia - S).**Tab. 6** – Episodi di föhn nel periodo 1991 – 2003. L'analisi della frequenza percentuale alle 15 possibili combinazioni 1000 .. 1001 (si veda nel testo per il significato dei simboli adottati per Locarno-Monti - L, Castellanza -C, Milano - M e Somaglia - S).

	L000	LC00	LCM0	LC0S	LCMS	L0M0	L0MS	0CMS	00MS	000S	0C0S	00M0	0CM0	0C00	L00S
Winter	27	8	10	2	24	8	0	7	0	2	2	4	4	2	1
Spring	35	6	9	5	17	7	3	1	0	0	1	6	4	5	1
Summer	27	11	18	2	12	9	0	2	0	2	2	15	0	2	0
Autumn	32	8	14	6	9	8	0	3	0	0	4	5	3	4	2
Total	121	33	51	15	62	32	3	13	0	4	9	30	11	13	4

Tab. 7 - Coefficients obtained from linear regression analysis (independent variable = Alpine watershed distance – km).**Tab. 7** – Coefficienti ottenuti per regressione lineare (variabile indipendente = distanza dallo spartiacque alpino – km).

Season	Coefficient of independent variable	intercept	r ²
Year	-0.23856**	53.10180**	0.9354
Winter	-0.08814**	21.82732***	0.9494
Spring	-0.12227**	25.64716**	0.9212
Summer	-0.06227*	12.72216**	0.8475
Autumn	-0.088412**	17.56985***	0.9500

Signif. codes: ***=99%; **=95%; *=90%

Tab. 8 – Monthly, seasonal and yearly statistics of föhn days at Locarno-Monti (1956-2003)**Tab. 8** – statistica dei giorni mensile, stagionale ed annuale dei gironi di föhn a Locarno-Monti (1956-2003)

	mean	minimum	maximum	total
January	4.9	0	15	234
February	4.7	1	11	226
March	6	0	16	287
April	5.9	0	16	284
May	3.4	0	11	162
June	3.2	0	8	152
July	2.9	0	8	141
August	2.8	0	8	132
September	2.3	0	9	108
October	2.6	0	8	126
November	4	0	11	192
December	4.4	0	12	211
Year	47	22	78	2255
Winter	14	4	27	671
Spring	15.3	7	32	733
Summer	8.9	0	17	425
Autumn	8.9	3	18	426

The variability in frequency of different combinations of presence/absence of föhn in the four selected stations (table 6) can be explained considering that air masses crossing the mountains increase their velocity and arrive in the southern slope of the Alps with typical undulations that can determine the exclusion of some stations from the föhn effect, with a process modulated by the thermo-hygrometric characteristics of the incoming currents and of pre-existing air mass.

In particular the shape of the Po Valley favours the accumulation and the stagnation of cold air masses of different origin (cold air flowing downhill under the influence of gravity, cold air advected from the East or produced 'in situ' by nocturnal radiation loss). The resulting cold layer in the low troposphere (cold lake) may act like an elastic surface on which föhn currents rebound without reaching the ground (Bonelli, 1988).

However this cold layer is often absent in the Milano area where it is partially or totally eroded by the urban

heat island. This effect can enhance the drop to the ground of föhn currents, with a particularly evident effect in the L0M0 and 00M0 combinations. The combination LCMS (highly frequent) represents the strong föhn episodes which influence the whole area, whereas the highly frequent combination L000 groups the föhn cases which influence only the Alpine area and don't reach the plain. Combinations LC00 (highly frequent) and LCM0 (relatively frequent) are the result of a dynamic action that propagate towards plain but is depleted in the medium and low plain.

The presence of combinations L00S (infrequent), 0C0S (unusual), 0C00 (relatively frequent) and LC0S (quite frequent) and L0MS (infrequent) can be explained considering the above mentioned undulations modulated by thermo-dynamic characteristics of air masses.

The presence of föhn in the plain and the contemporaneous absence at Locarno-Monti (combinations 0CMS - relatively frequent - and 0CM0 - quite frequent) could be the product of different effects like (i) the direction of the dominant currents that protect Locarno-Monti from the föhn effect (ii) the position of the station, located on a steep southern slope and (iii) the presence of layers of cold air in the basin of the Lake Maggiore.

The analysis of relation between yearly föhn days and distance from Alpine watershed show that the number of föhn days in the analysed stations is strictly related to the distance from the Alpine watershed. Somaglia data show that föhn occurrences are relevant at distances of more than 150 km from the watershed and are about the 60% of Milano and Castellanza occurrences and 35% of the Locarno-Monti ones.

The knowledge of the relation of inverse proportionality between föhn days and distance from the Alps watershed could be important for research and operational activities that need a quantitative description of föhn presence.

The relation between yearly and seasonal days with föhn and the distance from the Alpine watershed can be effectively described by linear equations that show a highly significant correlation in the whole seasons (table 7). A lower correlation is observed in summer, maybe due to the circulation features of this season, characterised by pressure fields relatively smooth.

For the yearly case, the linear regression shows 53.1 days at the watershed and a decrease of about 2.4 days each 10 km of increase of the horizontal distance (figure 2).

The high value of the correlation coefficient show that this relation could be adopted to describe the mean number of föhn days in the study area on the base of the observations carried out at Locarno-Monti station. In our opinion a study extended to the whole Po valley could produce maps for this wind with iso-frequency lines almost paralleles to Alpine watershed. These maps could be important not only for agrometeorological aims but also for technical aims (e.g.: project of buildings).

Some interesting evaluations about time variability of North föhn phenomenon can be obtained analysing the time series of föhn days at Locarno-Monti for the period 1956-2003 (table 8, figures 3 and 4).

A preliminary analysis for the whole period shows a yearly average of 47 days with a prevalence of spring

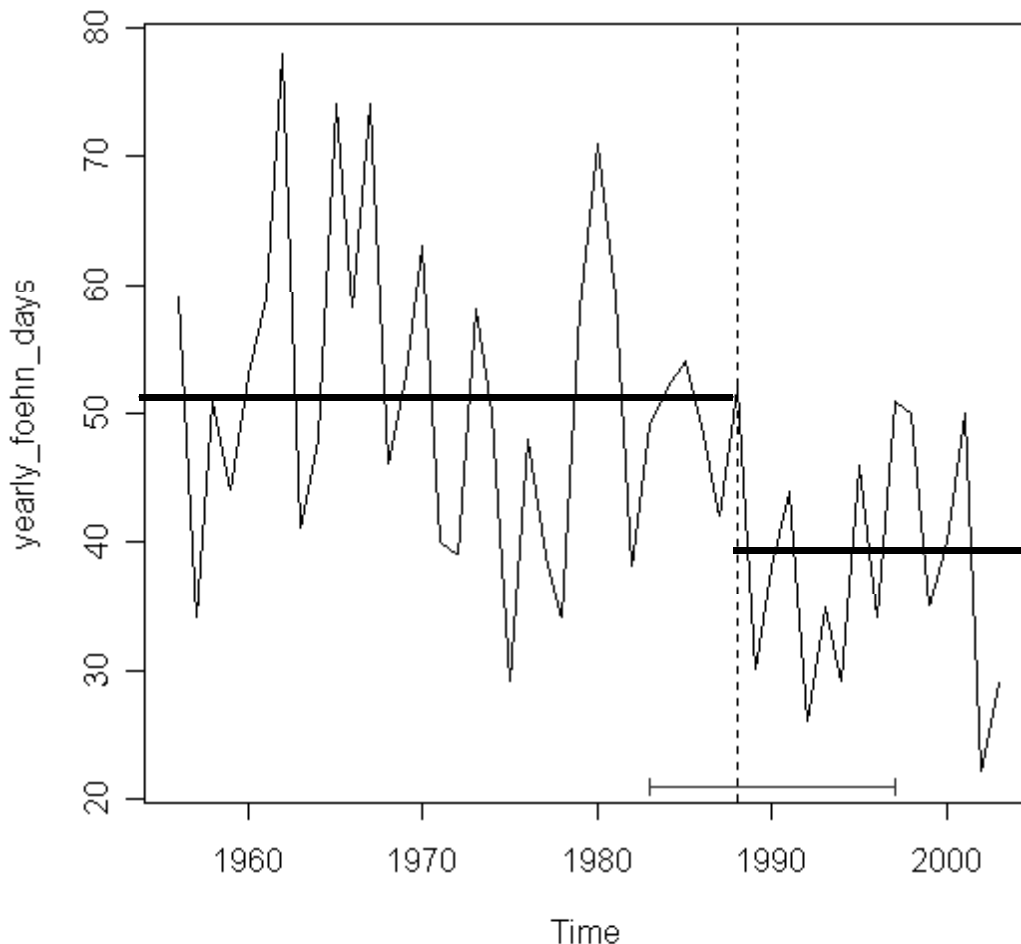


Fig. 3 – Yearly number of föhn days at Locarno-Monti for the period 1956-2003. Results of change point analysis are represented by vertical dotted line (change point defined by the specific statistical test) and by horizontal thin line (95% confidence interval). Horizontal thick lines represent the means of the two segments defined by the change point.

Fig. 3 – Numero annuo di giorni di föhn a Locarno-Monti per il periodo 1956-2003. I risultati dell'analisi di change point analysis sono rappresentati dalla linea tratteggiata verticale (change point definito con uno specifico test statistico) e dalla linea orizzontale sottile (intervallo di confidenza del 95%). Le linee spesse orizzontali rappresentano le medie delle due fasi definite dal change point

(15.3 days), followed by Winter (14.0) and Autumn (8.9).

Change point analysis for the yearly days of föhn (figure 3) show a change point in 1988 with a confidence interval of 95% between 1983 and 1997. 1988 was also recognised as change point for days of föhn in cold semester (figure 4), with a confidence interval of 95% between 1981 and 2003.

The change point in 1988 is coherent with the hypothesis that in the '80 years of XXth century the Euro-Mediterranean area suffered a climatic change characterised by the abrupt change in frequency and persistence of different circulation patterns over the area (Sneyers, Palmieri and Siani, 1993; Lockwood, 2002); the change was pointed out at macroscale by the behaviour of North Atlantic Oscillation (NAO) index in Winter months (Werner *et al.*, 2000) which shows a shift from a regime characterised by the alternation of eastern and western currents to a regime dominated by westerlies (Mariani, 2000).

If we adopt 1988 as the change point for North föhn, we can observe a mean number of 51 days with föhn per year for the period 1956-1987 and 38 days for the period 1988-2003. At the same time föhn days in cold period - semester October - March - that were 28 (55% of the whole yearly days) for the period 1956-1987 became 23 (61% of the whole year days) for the period 1988-2003. In other words the new climatic phase following the climate change of '80 years is characterised by a decrease of föhn days but this decrease is less pronounced in Winter period.

CONCLUSIONS

Results obtained show that föhn is an important environmental factor not only for the Alpine area but also for the whole Po valley. This means that agrometeorological activities carried out in this area need to take into account the presence of föhn and its influence on canopy layer variables (wind, temperature, relative humidity, wind, solar radiation and consequently evapotranspirational losses). Furthermore, changes in frequency and persistence of föhn can strongly influence mesoscale effects of climate variability in the Po Valley and this aspect must be considered in the downscaling of products of general climatic models which work at macro scale.

A possible limitation of this study might be found in the subjective classification of the föhn days which can be interpreted as a noise source. An alternative and more objective classification scheme could be based on discriminant analysis that could combine a number of criteria discriminating for föhn - non-föhn conditions. Nevertheless, the results obtained contribute to the understanding of the north föhn behaviour in the western part of the Po Valley.

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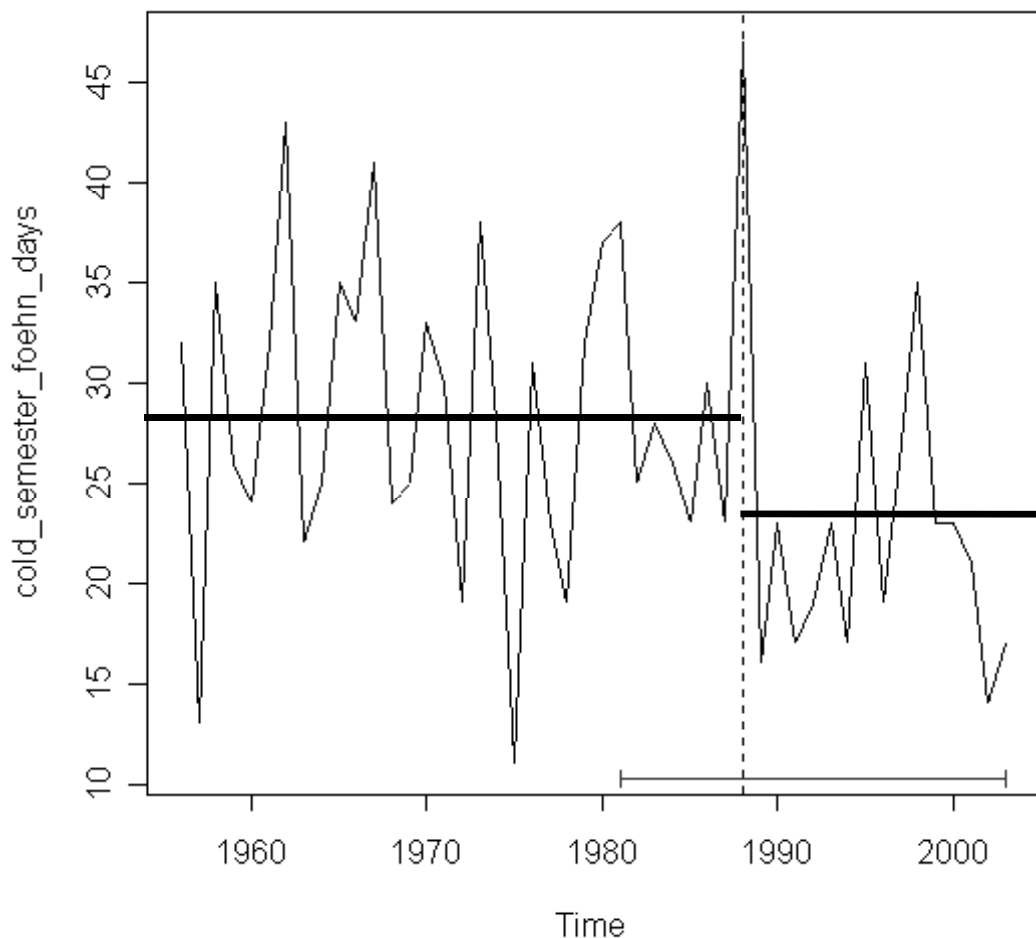


Fig. 4– Number of föhn days in winter semester at Locarno-Monti for the period 1956-2003. Results of change point analysis are represented by vertical dotted line (change point defined by the specific statistical test) and by horizontal thin line (95% confidence interval). Horizontal thick lines represent the means of the two segments defined by the change point.

Fig. 4 – Numero di giorni con föhn nel semestre invernale a Locarno-Monti (periodo 1956-2003). I risultati dell'analisi di change point analysis sono rappresentati dalla linea tratteggiata verticale (change point definito con uno specifico test statistico) e dalla linea orizzontale sottile (intervallo di confidenza del 95%). Le linee spesse orizzontali rappresentano le medie delle due fasi definite dal change point.

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