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CLIMATIC CHARACTERIZATION OF FOEHN EPISODES IN PIEDMONT, ITALY

ABSTRACT: FRATIANNI S., CASSARDO C. & CREMONIN R., *Climatic characterization of foehn episodes in Piedmont, Italy*. (IT ISSN 0391-9838, 2009).

An analysis of the yearly, seasonal and monthly frequency of North and North-West foehn in north-western Piedmont (Italy) has been carried out considering weather stations located in the Susa Valley, one of the largest valleys in the region. The detection of foehn episodes has been performed by adopting synoptic, mesoscale and punctual recognition criteria. The yearly, monthly and seasonal distributions of foehn episodes have been investigated. The foehn event occurred on 16th-18th December 2005 has been selected and analyzed separately as a case representative of all foehn cases in Susa valley. It has been verified that the comparison among the potential temperatures measured at a downstream station and at a reference station representative of the flow at crest level is a good indicator of foehn occurrence.

KEY WORDS: Foehn episodes, Synoptic configuration, Potential temperature, Wind speed, Piedmont, Italy.

RIASSUNTO: FRATIANNI S., CASSARDO C. & CREMONIN R., *Caratterizzazione climatica degli episodi di foehn in Piemonte, Italia*. (IT ISSN 0391-9838, 2009).

In questo studio viene analizzata la frequenza annuale, mensile e stagionale degli eventi di foehn da Nord e da Nord-Ovest, verificatisi nella parte nord-occidentale del Piemonte, usufruendo dei dati meteorologici provenienti dalle stazioni situate in Valle di Susa, una delle valli più grandi della Regione. L'individuazione degli episodi di foehn è stata condotta mediante l'adozione dei criteri sinottico, a mesoscala e puntuale. È stata studiata anche la distribuzione annuale, mensile e stagionale degli episodi di foehn. L'episodio di foehn, verificatosi il 16-18 Dicembre 2005 è stato selezionato e analizzato separatamente come un caso rappresentativo di tutti gli eventi di foehn che hanno interessato la Valle di Susa. È stato quindi possibile verificare che il confronto tra il valore della temperatura potenziale di una stazione di fondovalle con quello di una stazione di riferimento posta nella parte superiore della montagna, rappresentativa del flusso a livello della cresta, è un buon indicatore per il riconoscimento di un episodio di foehn.

TERMINI CHIAVE: Episodi di foehn, Configurazione sinottica, Temperatura potenziale, Velocità del vento, Piemonte.

INTRODUCTION

The foehn is a katabatic wind occurring when a deep layer of air is forced to cross mountainous ridges. As the air mass moves upslope, it expands and cools, causing water vapour to condensate and eventually to precipitate. This dehydrated air mass crosses the crest and then begins its downsloping motion. As the wind descends to lower levels on the leeward side of the mountains, the air temperature increases dry-adiabatically, in some cases with increments of 20°C (or even more) in short time (a few hours or less). The temperature increment is even greater when the originating air mass is not located at the surface but lies at a higher level (von Hann, 1891). Foehn winds occur also in many other regions in the world and are also called «snow-eater» for their ability to make snow melt rapidly; they are often associated with the rapid spread of wildfires.

The Piedmont region is located in the extreme north-western sector of Italy, and is bounded at the northern, western and southwestern sectors by the Alpine chain and at the southern and southeastern sectors by the Apennines (fig. 1). Turin city is also bounded at the eastern sector by a hill range, causing the frequent occurrence of temperature inversions in the lower boundary layer, especially during wintertime and nighttimes. In certain meteorological conditions, this orographic configuration enhances the onset of North or northwestern foehn winds. In Piedmont, the foehn can typically occur in the northwestern sectors with airflows coming from North, North-West and West, while in few situations the southern sectors are affected by South foehn.

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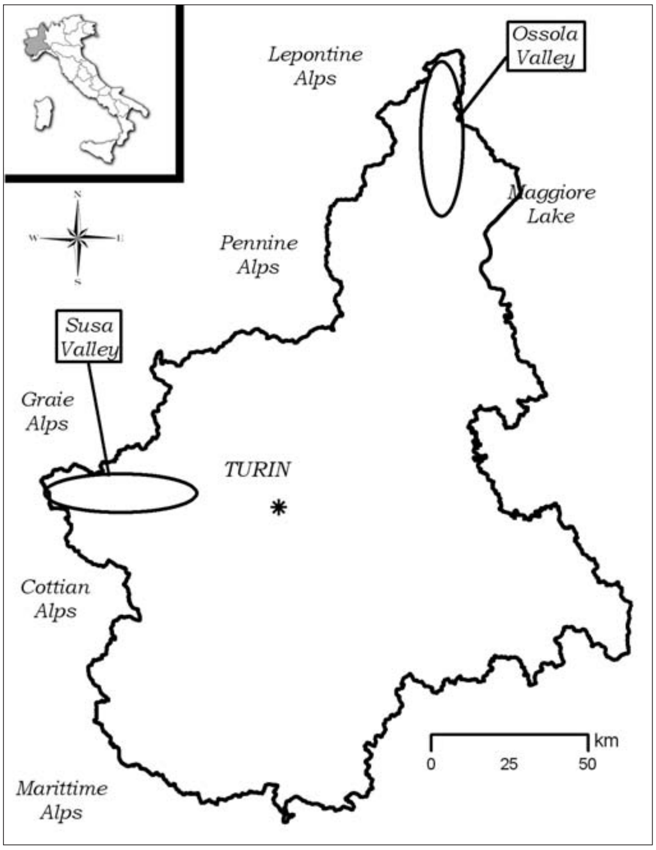


FIG. 1 - The Piedmont region: location of Susa and Ossola valleys.

The synoptic configuration favouring the onset of the North foehn consists in a positive difference of atmospheric pressure between the upwind and the downwind sides of the mountains (Kappenberger & Kerkmann, 1997; Whiteman, 2000). In the case of the alpine foehn, a pressure difference of approximately 4-8 hPa is sufficient to originate a weak event of foehn, while pressure gradients larger than 14 hPa produce intense and long-lasting foehn events with high wind speeds (up to 30 ms^{-1}). In such conditions, a low-pressure centre is present over the Piedmont, the Po valley or the Genoa gulf, while there is a relative ridge on the northern, northwestern or western side of the Alps. Previous studies, carried out on the north-western foehn, have shown that the foehn can arise in every month of the year, with maximum probability of occurrence in February, March and April; the average number of foehn events in the northern and north-western Piedmont valleys were 43±6 and 42±9, respectively (Cassardo & Musso, 2004).

During wintertime, in occasion of northern or northwestern foehn in Piedmont, due to the frequent occurrence of cold atmospheric layers in the first 500-1000 m above ground in the Po Valley, thermal inversions can limit the foehn intrusion to the upper part of the deepest valleys, while the plains remain unaffected by it. Frequently, after the passage of cold frontal systems crossing the Alpine chain from West, West-North-West or North-West, the post frontal currents generate weak and short-lasting foehn episodes over the western and/or northern part of Piedmont, favouring the onset of very intense pollution events, as shown by Natale & *alii* (1999). It is important to note that heavy air pollution episodes caused from industries, occur only when the foehn does not reach completely the Po Valley in the surface layer. It is also important to stress that the foehn episodes cause important effects on agriculture and viticulture, industry very important in Piedmont, such as the stress on natural and cultivated plants with heavy losses of the evapotranspiration, mechanical effects on plants and tree (fallen branches or whole plants, or attract stamp) and the stress on the pets with the consequence to set the production of milk and meat.

DATA AND METHODOLOGY

Every alpine area, as well as every valley and plain, has its own foehn climatology. The valleys where foehn penetrates more easily are generally well known. In fact, most of the foehn episodes in Piedmont involve exclusively the Susa Valley, the Ossola Valley (fig. 1), or both valleys in the same day. Moreover, the foehn sometimes is weak and do not affects the plain but only the higher mountainsides and these are often weak phenomena.

ARPA Piemonte (the Regional Agency of Environmental Protection) manages more than 400 meteorological ground-stations connected in real time to the operative centre in Turin. Several weather stations, located aloft and among the valleys, are equipped by anemometer, thermometer and hygrometer. The analysis of synoptic circulation and the combined measurements of these sensors are used by *ARPA Piemonte* forecasters to subjectively detect foehn episodes. The method here used for selecting the foehn episodes that have affected the Piedmontese region, has consisted in examining the daily analysis weather bulletins issued by the regional meteorological service of *ARPA Piemonte* since 2000 to 2006, which report in detail both in time and space the most relevant weather phenomena occurred day by day.

When a foehn episode begins in Piedmont, mountainous stations simultaneously detect an increase of wind speed and a rotation of the wind direction to western or northwestern sectors, while plain stations show a wind direction rotation along the nearest and largest valley axis. At same time, the temperature shows a sharp increase, larger than 10 °C in 30 minutes in the strongest episodes, and also the relative humidity decreases to 15-20%, and sometimes even less.

FOEHN ON 16TH-17TH DECEMBER 2005

To better explain the foehn behaviour in Piedmont, a typical northwestern foehn episode involving Susa valley is hereafter analysed in detail.

The Susa Valley, also named Dora Riparia Valley (from the name of its largest river), is a S-shaped glacier valley

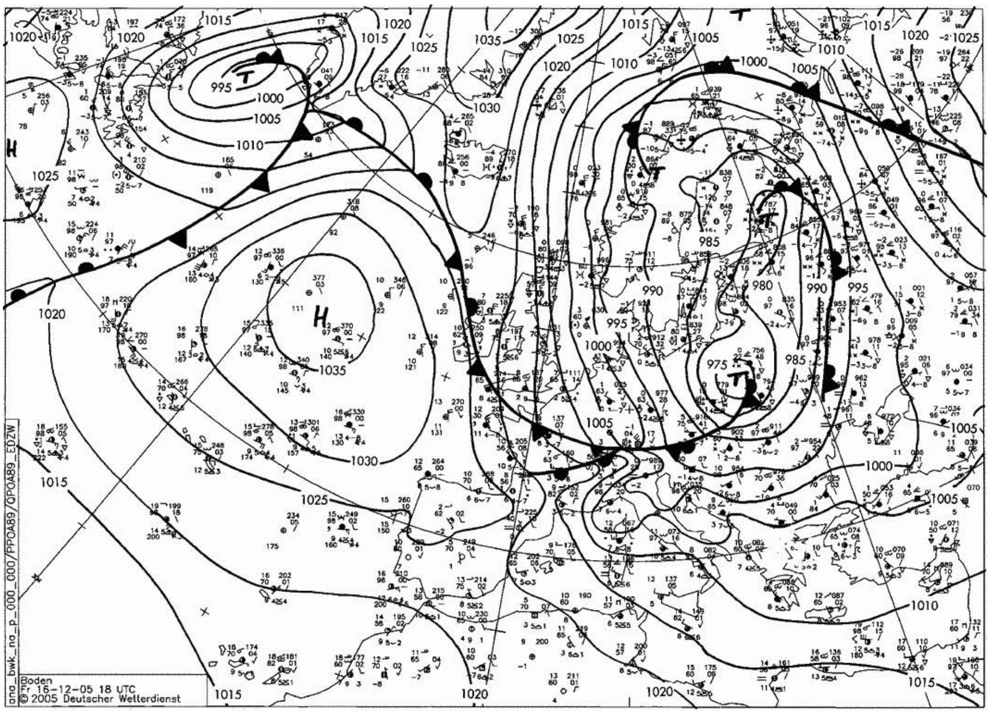


FIG. 2 - Sea level pressure, fronts and synoptic observations over Europe on 16th December 2005 at 18 UTC (source: *Deutscher Wetterdienst*).

disposed in a transverse direction with respect to the alpine chain (Cottian and Graie Alps), stretching from Turin to Susa for some 50 Km along the West-East direction, and various lateral deep sub-valleys. The largest sub-valleys are, at North-North-West of Susa, the Cenischia Valley, with reaches the Moncenisio Pass, at South-East the Dora Riparia Valley, that stretches to the Monginevro pass, and between Salbertrand and Oulx, a third lateral deep valley, the Bardonecchia Valley, is oriented from North-West to South-West.

A strong foehn event affected the western part of Piedmont on December 2005, 16th-17th, during which the maximum gusts were 39.4 ms^{-1} at Mt. Fraiteve and 27.0 ms^{-1} at Avigliana (tab. 1).

On the 16th December 2005 at the 18 UTC, the pattern of the sea level pressure (SLP) over the Europe was dominated by the Azores anticyclone displaced over the northern Atlantic Ocean, with a maximum of 1035 hPa, and by a deep minimum of 975 hPa over the eastern Europe; a cold front located along the 47°N parallel over the central Europe was rapidly moving southwards, as shown in figure 3. On the 17th December 2005 at the 00 UTC, the cold front approached the Alps, followed by strong northern downsloping currents. Twelve hours later, the front

TABLE 1 - Stations, characteristics and observations recorded during the foehn episode of December 2005, 16th-17th. E = elevation, WS = maximum wind speed, TM = maximum temperature, HRm = minimum relative humidity, NA = datum not available

Stations	Town	E (m a.s.l.)	UTM X	UTM Y	WS (m/s)	TM (°C)	HRm (%)
PRERICHARD	Bardonecchia	1353	320334	4994017	21.0	10.0	21.0
OULX	Oulx	1065	329988	4990162	21.7	12.0	21.0
SALBERTRAND	Salbertrand	1010	334301	4993216	23.9	12.2	19.0
FINIERE	Chiomonte	813	340117	4998152	22.1	14.4	13.0
PIETRASTRETTA	Susa	520	347088	5000758	34.1	17.7	14.0
BORGONE	Borgone Susa	400	361958	4997582	26.8	17.6	13.0
AVIGLIANA	Avigliana	340	373774	4994834	27.0	18.3	14.0
CASELLE	Caselle	300	394093	5004633	19.5	NA	NA
TORINO GIARDINI REALI	Torino	239	397112	4991946	17.4	12.5	14.0
RIFUGIO VACCARONE	Giaglione	2745	336309	5002391	37.3	-5.2	27.0
MONTE FRAITEVE	Sestriere	2701	331440	4982806	39.4	-1.6	10.0
COLLE BERCIA	Cesana T.se	2200	325119	4976764	13.2	2.4	18.0
SAUZE D'OULX	Sauze d'Oulx	1373	330512	4988380	16.1	10.6	29.0
LE SELLE	Salbertrand	1980	336091	4991300	25.3	3.5	24.0

had already crossed the Alps and was located over the Corsica and central Italy (fig. 3).

On the 18th December 2005 at the 00 UTC, the cold front was located over the extreme southern Italy; the main minimum moved eastwards over the Russian plain, while a ridge grew over the northern Italy, causing a decrease of the strong downslope winds over the Po river plain (fig. 4). The SLP time trends recorded at Lyon Satolas, France, and Torino Caselle, Italy, show that SLP in Lyon fell regularly from 1023 to 1011 hPa up to the 17th December 2005 at 02 UTC. Subsequently, due to the cold front passage, the wind direction turned from SSE to N and SLP increased up to 1025 hPa on 18th December at 13 UTC. In Turin, instead, SLP fell from 1015 hPa to 996 hPa at about the 04 UTC of the 16th December 2005, then SLP remained almost stable until the 10 UTC, and subse-

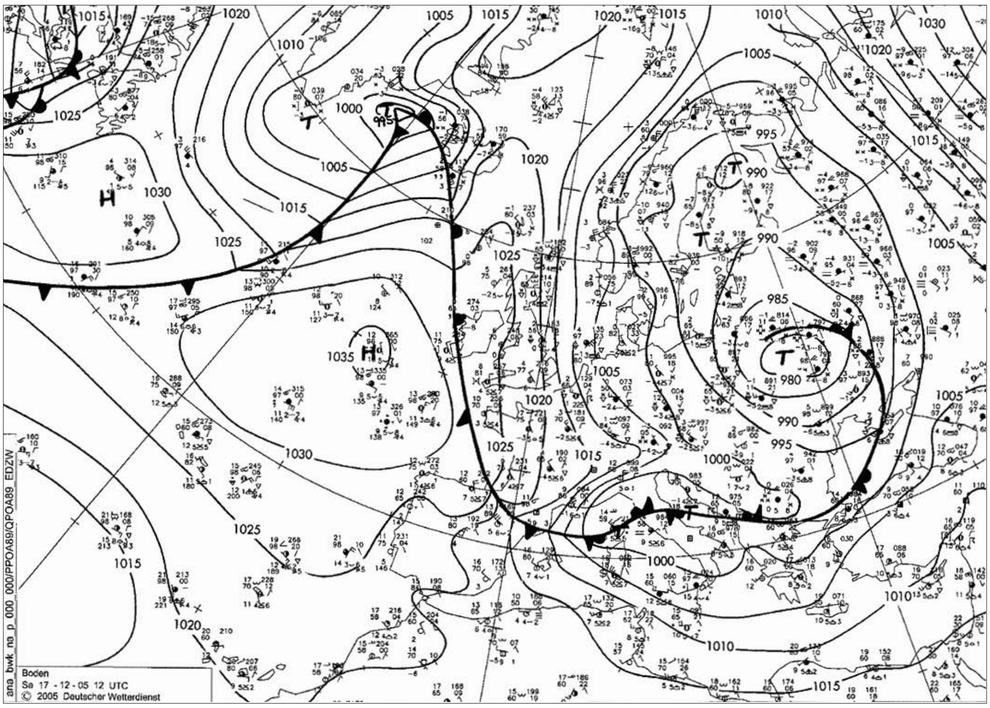


FIG. 3 - Sea level pressure, fronts and synoptic observations over Europe on 17th December 2004 at 12 UTC (source: *Deutscher Wetterdienst*).

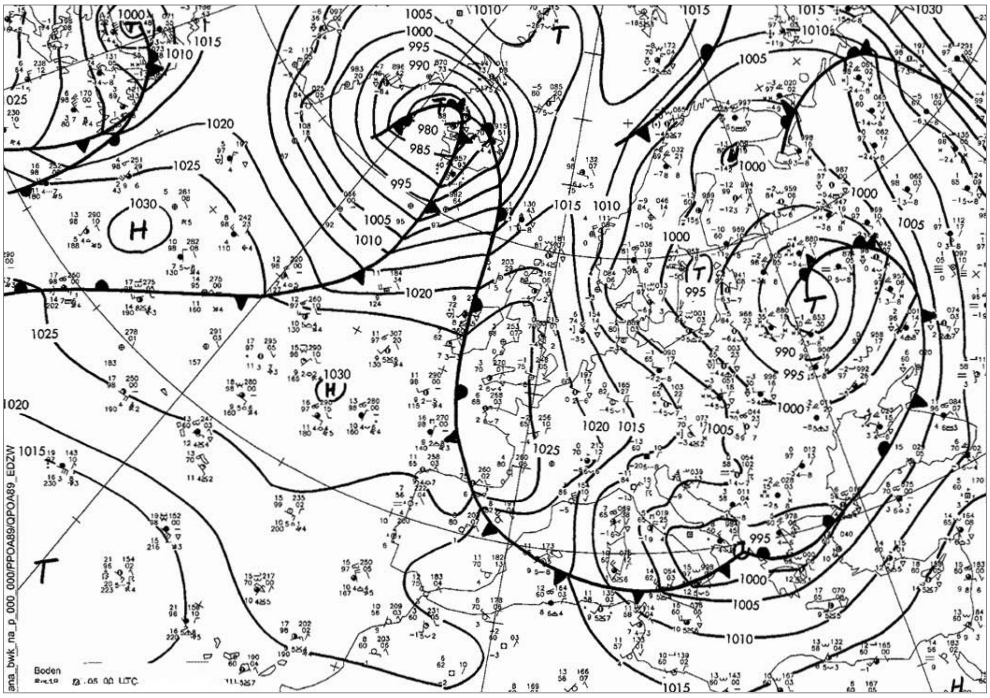


FIG. 4 - Sea level pressure, fronts and synoptic observations over Europe on 18th December 2005 at 00 UTC (source: *Deutscher Wetterdienst*).

quently grew, reaching the maximum value of 1019 hPa on the 18th December 2005 at the 23 UTC. Considering the two above-mentioned stations, it can be seen that, on the morning of the 16th December 2005, a positive pressure difference was present across the Alps; this difference grew from +10 hPa to a maximum value of +17 hPa on the 17th December 2005 at the 06 UTC.

When the foehn episode begun, this pressure difference began to decrease, reaching the value of +7 hPa at the end of the 18th December 2005.

As in this case the main direction of the synoptic flow was oriented from West to East, the Susa Valley, whose axis is aligned along the same direction, has been taken as reference valley and the measurements of regional weather stations displaced along the valley (tab. 1) have been analysed. In particular, the time trends of temperature, wind speed and relative humidity in the downwind station of Avigliana, located at the end of the valley, 340 m a.s.l., 22 Km west of Turin, have been examined.

The onset of the foehn is revealed by an abrupt increase of the temperature and wind speed (figg. 5a, 5c), and by a rapid decrease of relative humidity (fig. 5b); this behaviour can be seen twice on the 16th December 2005: at the 12 UTC and at the 22 UTC. During the morning, an increment of temperature larger than 11°C was observed in about 3 hours, with a mean wind speed of 4 ms^{-1} and a contemporary decrease of the relative humidity of 50%. After a short interval, another foehn irruption occurred at the 20 UTC. This second event was stronger and longer than the previous one, and the wind speed peaked to about 15 ms^{-1} around midnight. The initial temperature increment was of about 12°C in 3 hours, while relative humidity fell up to 30% or less.

At the beginning of the 17th December 2005, the 2-m temperature showed again a slight increase, reaching +18.3 °C at the 01 UTC, with a low relative humidity and an average wind speed larger than 15 ms^{-1} (fig. 5c), with gusts of 27 ms^{-1}.

At the 11 UTC, the wind speed decreased to 4 ms^{-1}, and for 2 hours there was a sudden increase of the relative humidity and a corresponding sudden decrease of the temperature. However, at the 13.30 UTC, wind began again to blow with a mean speed of 11 ms^{-1} (and gusts of 18.8 ms^{-1}), causing the relative humidity to reach again the minimum value of 14%. Since on the 17th December 2005 at the 18 UTC, temperature and wind speed began to fall and relative humidity began to raise.

As the air descends dry-adiabatically in the downstream side of the mountainous barrier (Alps) during a foehn event, the potential temperature is a good tracer for the air mass. In a typical case of foehn, potential temperature recorded at the downstream station should be equal or higher than the one recorded at the reference station located at the top of the mountain. The meteorological stations of «Mt. Fraiteve» (MF, 2700 m a.s.l.), located in the upper part of Susa valley and close to the French borderline, and «Torino Giardini Reali» (TGR, 239 m a.s.l.), located downtown the city of Turin, have been selected as representative of the flow at the crest level (MF) and at the end of the valley (TGR), respectively. At the beginning of the 16th December 2005 the potential temperature at Mt. Fraiteve (fig. 7) was 296.5 K, meanwhile in Turin it was 274.0 K. On the 17th December at the 13 UTC the potential temperature in both stations was 286 K, showing a common behaviour for the rest of the day (see fig. 6). On the 18th December 2005, MF and TGR potential temperatures began to diverge. The foehn of 16th-17th December 2005 can be thus regarded as a typical example of West foehn in Piedmont.

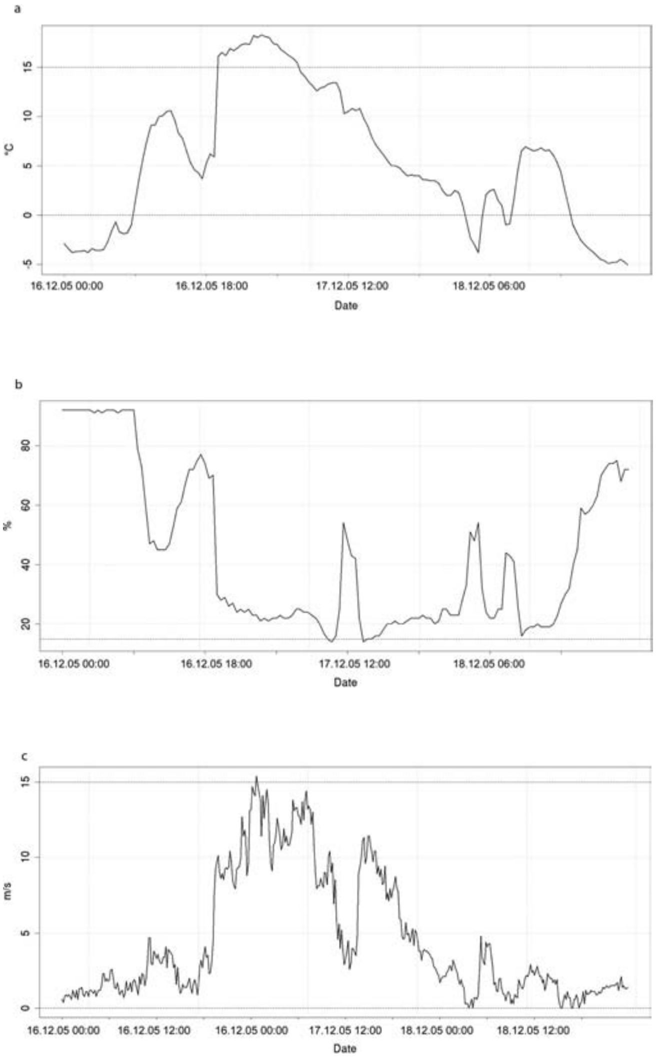


FIG. 5 - Meteorological parameters recorded at Avigliana during the foehn event of 16th-17th December 2005. (a) 2-m temperature in Celsius degrees, (b) relative humidity in %, (c) wind speed in ms^{-1}.

ANALYSIS OF FOEHN IN PIEDMONT

The ARPA Piemonte weather forecasters every day perform a subjective analysis of foehn occurrence, based on the synoptic configuration and on the observations car-

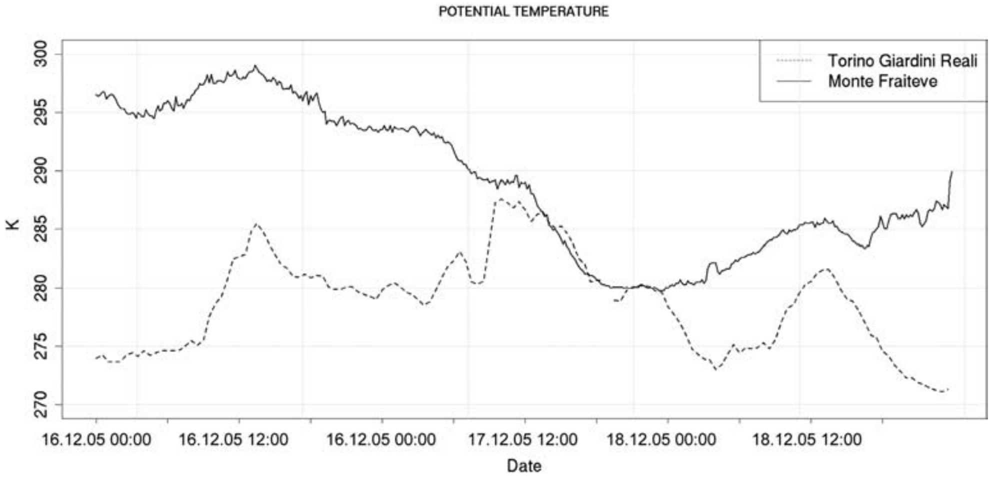


FIG. 6 - The potential temperature recorded during the foehn episode occurred on 16th December 2005 at MF (Mt. Fraiteve) and TGR (Torino Giardini Reali) weather stations, expressed in K.

ried out by the regional meteorological network. In particular, the quasi-simultaneous occurrence of the following phenomena are investigated, as «*rules of thumb*», for the detection of foehn:

– a swift increase of 2m air temperature;
– a swift decrease of relative humidity;
– a swift increase of wind speed;
– a swift turn of wind direction along the valley axis and towards the plain.

The number of foehn episodes (hereafter FE), as well as the corresponding number of days with foehn (DF), occurred during a period of seven years (2000-2006) has been evaluated in the whole Piedmont region (tab. 2). The total number of DF is 382, which corresponds to an average of 54.6±8.9 DF per year. The duration of a FE can be even larger than 6 consecutive days, but in the 74% of cases is limited to 3 days or less. Despite of the correlation with the persistence of the baric configuration generating the foehn (Barry, 1992), it is not rare that local factors can cause major alterations, like an interruption of the phenomenon.

As shown by table 3, the season with highest num-ber of foehn days in Piedmont is Winter (17.6 days on the average), with a maximum prevalence in January (6.7 days), followed by Spring (13.1 days) with the maximum frequency concentrated in March (6.4 days on the average).

TABLE 2 - Number of consecutive days with foehn: foehn episodes (FE) during the 7 years examined and their duration in days (1 to 7 for each event), and calculation of the actual number of days of foehn (DF)

	1	2	3	4	5	6	7	Sum
2000	23	9	4	3	1	0	0	70
2001	15	9	3	1	0	0	0	46
2002	13	6	2	0	2	0	2	55
2003	13	5	3	1	1	0	1	48
2004	10	9	5	2	1	0	1	63
2005	18	8	3	1	1	0	0	52
2006	15	6	4	1	1	0	0	48
Sum FE	107	52	24	9	7	0	4	203
Sum DF	107	104	72	36	35	0	28	382
Average DF	15.3	7.4	3.4	1.3	1.0	0.0	0.6	54.6
Sigma DF	4.2	1.7	1.0	1.0	0.6	0.0	2.8	8.9
% DF	28.0%	27.2%	18.8%	9.4%	9.2%	0.0%	7.3%	

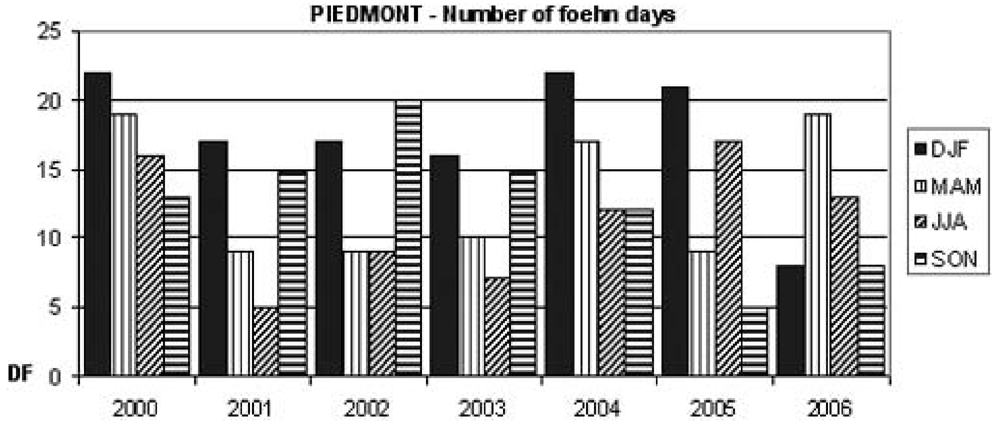
The seasonal maximum of DF has been observed in the winters of 2000 and 2004 (22 days), while the second minimum of DF has been observed in the summer of 2001 and also in the autumn of 2005 (5 days) (fig. 7).

In the case in which there was the presence of foehn both from North and North-West in the same day, half-day (0.5) has been assigned both to North and to North-West directions, in order to guarantee the total number of DF.

TABLE 3 - Seasonal and monthly total number of foehn events. (DJF = Winter, MAM = Spring, JJA = Summer, SON = Autumn)

Years	DJF	MAM	JJA	SON	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	22	19	16	13	70	6	10	12	3	4	4	10	2	8	3	2	6
2001	17	9	5	15	46	4	4	6	3	0	1	2	2	10	0	5	9
2002	17	9	9	20	55	6	9	6	2	1	3	1	5	2	10	8	2
2003	16	10	7	15	48	9	3	2	3	5	0	4	3	4	10	1	4
2004	22	17	12	12	63	12	7	7	4	6	2	3	7	5	2	5	3
2005	21	9	17	5	52	9	6	4	2	3	2	8	7	1	0	4	6
2006	8	19	13	8	48	1	5	8	6	5	3	0	10	1	2	5	2
average	17.6	13.1	11.3	12.6	54.6	6.7	6.3	6.4	3.3	3.4	2.1	4.0	5.1	4.4	3.9	4.3	4.6
sigma	4.9	4.9	4.5	4.9	8.9	3.6	2.6	3.2	1.4	2.2	1.3	3.7	3.0	3.5	4.3	2.3	2.6

FIG. 7 - Seasonal trend of the total number of foehn events.



The DF from North have their maxima in winter and autumn (3.6 DF), when polar air masses flow from North or North-West, but they can also occur in the other seasons. Foehn events exhibit a minimum of occurrence in summer (1.9 from North, 2.2 from North-West), due to weak synoptic-scale pressure gradients. The foehn affecting the Turin plain can be described as a western wind, due to the West-East orientation of the Susa valley axis. Generally, the frequency of foehn episodes tends to decrease with the increase of the distance from the Alps ridge towards the plain (Kappenberger and Kerkmann, 1997). Regarding the seasonal distribution of DF, foehn episodes are seldom extended to the whole region and to the plain (19.1% average of period), but they often concern only a part of the Piedmont. The most affected zones are mainly North and West, mostly in winter, followed by North-West, mostly in autumn (tab. 4).

CONCLUSIONS

This study has characterized the North-West foehn episodes occurring in the northwestern Italy. The analysis has been performed by checking the daily weather analy-

TABLE 4 - Number of days of foehn according to the direction of provenience of flow and the season (DJF = winter, MAM = spring, JJA = summer, SON = autumn). N refers to North, W to West, NW to North-West, N and W to both North and West simultaneously in the same day. «Extended to plain» summarizes the DF in which the wind has affected also the plain, occurring thus in the whole region. Finally, «%E» refers to percentage of the DF affecting the plain

	North					West					North-West				
Season	DJF	MAM	JJA	SON	Year	DJF	MAM	JJA	SON	Year	DJF	MAM	JJA	SON	Year
2000	3.5	8	2	3.5	17	3.5	5	3.5	4	16	2	0	0.5	2.5	5
2001	6	2	2	5.5	16	4	2	0	3	9	0	1	1	3.5	5.5
2002	1	1	0.5	4	6.5	8.5	2.5	2	5	18	1	1.5	0.5	5	8
2003	4.5	2	1	4	12	2	0	3	5	10	1.5	3	2	1	7.5
2004	7	6	1.5	5	20	5	2	2.5	3	13	3	4	6	2	15
2005	3	2	4.5	3	13	4.5	2	0	0	6.5	4.5	2	2.5	0	9
2006	0	2	2	1	5	2	5	5	0	12	2	1	3	2	8
Average	3.6	3.3	1.9	3.6	12	4.2	2.6	2.3	2.7	12	2	1.8	2.2	2.2	8.2
Sigma	2.5	2.6	1.3	1.5	5.3	2.2	1.8	1.8	2.1	4	1.4	1.3	1.9	1.6	3.3

	North and West					Extended to plain					Sum DF	% E
Season	DJF	MAM	JJA	SON	Year	DJF	MAM	JJA	SON	Year	Year	Year
2000	12	4	6	2	24	1	3	3	1	8	70.0	11.4
2001	3	2	1	1	7	4	2	1	2	9	46.0	19.6
2002	3	0	3	4	10	3.5	3	3	3	13	55.0	22.7
2003	1	1	1	3.5	6.5	7	3	0	2.5	13	48.0	26.0
2004	3	4	0	1	8	4	1	2	1	8	63.0	12.7
2005	6	0	2	2	10	3	3	8	0	14	52.0	26.9
2006	2	6	3	5	16	1	4	0	2	7	48.0	14.6
Average	4.3	2.4	2.3	2.6	12	3.4	2.7	2.4	1.6	10	54.6	19.1
Sigma	3.7	2.3	2	1.5	6.3	2.1	1	2.8	1.1	2.8	8.9	6.4

ses issued by the local meteorological centre and the data measured by the regional meteorological network.

The study of the frequency of occurrence of foehn from northern and western sectors in Piedmont (Italy) has been carried out by considering some stations located in the western part (Susa Valley) of the region. The methodology used adopted synoptic mesoscale and punctual recognition criteria.

The foehn event occurred on 16th-17th December 2005 has been selected as case study and analyzed separately as a case representative of all foehn cases. It has been verified that the potential temperature measured at a downstream station, compared with the one measured at a reference station representative of the flow at crest level, can be a good indicator of foehn occurrence. In particular, when the former is equal or larger than the latter, there is occurrence of the foehn. It has been also verified that, during a foehn episode, in the downwind stations there is a sharp increase in temperature and a decrease in the relative humidity, and that the wind is gusty and aligned along the reference valley axis. The analysis of foehn occurrence over a period of seven years reveals a reduction of contribution of summer period to total yearly events, because synoptic-scale pressure gradients tend to be weaker in Summer. Even if the period of seven years used in this study is too short to detect the presence of trends in the occurrence of foehn over the Piedmont, due for instance to the climate change, nevertheless it can show the interannual variability of the foehn episodes in the current climate.

It is also better to stress that the exploration of foehn phenomena is helpful for predicting the events. For this reason, the results obtained from this study suggest to extend the work and analyse the relation between foehn episodes and the values of NAO, given that foehn events are all linked to the presence of the Azores Anticiclone in the North Atlantic.

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