Tethys

Journal of Mediterranean
Meteorology & Climatology

Mountain accidents associated with winter northern flows in the Mediterranean Pyrenees

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Received: 15-IV-2009 – Accepted: 4-II-2010 – **Translated version**

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Abstract

The Mediterranean Pyrenees, at the eastern end of the range, is a very popular area. Its highest peak is at 2900 m a.s.l. and there are numerous peaks above 2000 m, with rounded relief and sparse vegetation on the latter height. One of its significant winter climatic features is the sudden entrance of cold air with violent northern winds, drop in temperatures and very low wind chill values. Such advections are established after the passage of a snowy cold front and, consequently, there is abundant transport of both new and existing snow that reduces horizontal visibility. The post-frontal conditions at high altitudes represent a serious threat to humans. The review done shows that the hikers immersed in an environment of low visibility, strong winds and very low temperatures can quickly become disoriented, suffer frostbite and hypothermia and slip on the ice. The characterization of a series of accidents occurred in this geographical area, identified in the press, shows in this paper that the phenomena associated with northern winter advections is an element of danger to be considered in the evaluation of natural hazards in that area. In addition, the multiple character of many of the events suggests that there is high vulnerability to such dangers. The climatological analysis presented suggests that such weather conditions are not uncommon in the winter, although the most serious accidents have been registered under especially strong and cold flows. The conclusions recommend that the weather conditions described, locally called torb, should be known by the visitors to these mountains in the winter, and its appearance should be announced in weather reports, which in turn must be sufficiently disseminated in the areas of greater abundance of tourists and hikers.

Key words: mountain accidents, Pyrenees, winterstorm, *torb*

1 Introduction

Accidents while practicing touristic/sport activities in the mountains can have various causes, weather risks being one of the natural risks. Other risks are biological, geomorphological, fluvial, due to snow or ice, etc. (Ayala-Carcedo and Olcina, 2002). In what was probably the first minimally comprehensive study on mountain accidents, presented by Perelló and Reñé (1953), there were already clear references to the existent relationship between accidents and weather conditions.

Some of the most dangerous wheather phenomena or conditions that imply a greater risk in the practice of mountaineering are storms (Doswell, 2001), heavy and/or plentiful snowfall, strong winds of non-convective origin, extreme temperatures, and mists. The types of weather observed on days with accidents that are associated a priori with weather conditions are subjectively grouped on the basis of characteristics such as the estimated value of different atmospheric variables, the presence of different meteors or the time of year. It is possible to mention, for example, winter storms, episodes of rainstorms or situations with very limited visibility.

In general, the combination of snow, strong winds and low temperatures is often associated with fatal accidents in Spain, especially in high mountains. However, during real

Table 1. Selected cases and their main characteristics of northern flows in the Mediterranean Pyrenees.

Cases (identifying no.)	Date	Reference place	Region	Municipality	Altitude (m)	No. of deaths
0	19th Century (1850)	Noucreus (top)	Ripollès	Queralbs	2800	9
1	17/02/1930	La Tosa d'Alp (top)	Cerdanya	Alp	2000-2200	1 (skier)
3	27-30/12/1968	Gorges del Freser	Ripollès	Queralbs	1700-2000	3 (hikers)
4	8/03/1970	Gorges del Freser	Ripollès	Queralbs	1700-2500	1 (hiker)
5	26/11/1978	Costabona (top)	Ripollès	Setcases	2200	3 (hikers)
6	31/12/1979	Torreneules (top) (see Figure 3a)	Ripollès	Queralbs	2200-2600	3 (hikers)
8	23/12/1986	Tirapits (pass)	Ripollès	Queralbs	2700	2 (hikers)
9	16-17/04/1992	Canigó (top)	Conflent	-	1500-2700	1 (hiker)
10	30/12/2000	Balandrau (top)	Ripollès	Queralbs	2300	9 (hikers/skiers)

Table 2. Complementary cases and their main characteristics that are not northern flows and/or are not in the Mediterranean Pyrenees.

Cases (identifying no.)	Date	Reference place	Region	Municipality	Altitude (m)	No. of deaths
2	6/03/1944	Matagalls (Montseny) (top)	Vallès Or.	El Brull	1400	2 (skiers)
7	4/11/1984	Puigmal (top)	Ripollès	Queralbs	2700	2 (hikers)
11	15/02/2005	Montardo (top)	Vall d'Aran	Naut Aran	2100-2800	1 (hiker)

cold spells, which have affected much of the Iberian peninsula, there have been accidents at altitudes below 1000 m, especially in the northern half (Pascual, 2008). In some episodes, such as the case selected as 10 (12/00) (from here on the cases will be referenced by its identifying number and the month and year are specified in brackets) (Table 1) (Pascual, 2001; Vilà, 2001; García and Vilar, 2006; Pons, 2008), fatal accidents were recorded simultaneously in remote parts of the same mountain range -Ripoll (Girona), Pallars Sobirà (Lleida) and Sobrarbe (Huesca) in the Pyrenees-, and even in different ranges, as in the episode of April 1994, in which a fatal accident happened in the Ordesa Valley and another one took place in Picos de Europa.

This weather type is usually established under northern or continental European synoptic advections or during the passage of Atlantic troughs. Although there are exceptions such as complementary case 7 (11/84) (Table 2) when, with a synoptic advection from the SW, there was heavy snowfall and temperatures were low. A hiker died in that event, probably from hypothermia after getting lost in the massif of Puigmal (Mediterranean Pyrenees) due to poor visibility. However, it should be taken into consideration that such advection, established by an Atlantic depression, was accompanied by the passage of a cold front from west to east.

Also, sometimes, there have been winter environmental conditions in high mountains in the summertime, which has led to a big risk, not because of the danger of the phenomenon itself, but because of high exposure and vulnerability of people present on the mountain during that season. On 20 August, 2005 an event of this kind caused the death of one person in the Aneto massif (central Pyrenees), and

put other hikers in the same sector in serious danger of hypothermia.

This paper presents a series of fatal accidents in the Mediterranean Pyrenees, located in the east of the Cerdanya, associated with winter storms. Additionally, two cases of very similar meteorological and epidemiological characteristics outside this area are mentioned (cases 2 (03/44) and 11 (02/05)) (Zaragoza, 2008) of Table 2). The existing synoptic configurations during these episodes have been adjusted, except one (complementary case 7 (11/84) of Table 2), to the same pattern: advections of N component. The weather conditions were a combination of snow, strong wind, low temperatures and snow in suspension, with a notable reduction in visibility. The latter event is locally known as the *torb* in the Mediterranean Pyrenees.

It is notable that although there are few studies that show analysis of wind storms in the Pyrenees (most of which are referenced here), there are several studies that examine major episodes of snow and their possible relationship with periods of frequent avalanches or large avalanches (for example García and Salvador, 1994; Esteban et al., 2007; García et al., 2007, García et al., 2008). There are also works published on mountain accidents linked to avalanches (for example Rodés, 1999; IGC, 2006), but none on accidents related to weather conditions, except Pascual (2008).

The article briefly describes the geographical area of study, the methodology used to search for and select the cases and the basic characteristics of the accidents and the associated meteorological environment. The synoptic and mesoscalar environments in which the events are registered and its climatological context are later described, that is to
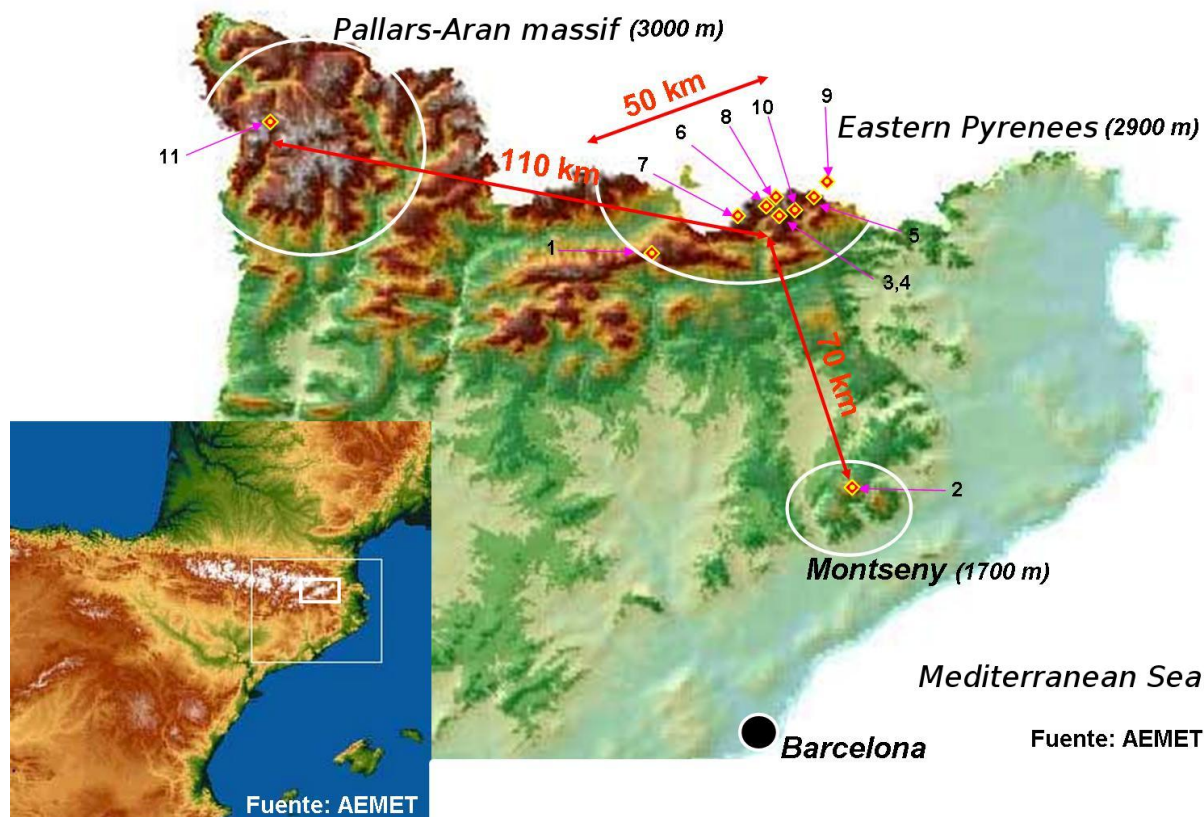
Figure 1. Study area. The numeration of the cases corresponds to that used in Tables 1 and 2. The three areas where the accidents were registered are indicated, as well as the distances between them and a characteristic dimension of the Mediterranean Pyrenees.

say, the type of synoptic situations which are most often present in the wintertime and the frequency of storms. Finally, some brief conclusions are outlined in order to make suggestions, with the end goal being to mitigate the risk associated with winter storms.

2 Geographical area

The study area (Figure 1) is the Girona Pyrenees sector, from the Cerdanya rift valley to the Mediterranean sea, although the easternmost accident occurred in the French massif of Canigou (2784 m), about 50 km from the coast.

This sector of the Axial Pyrenees has the generic name of Mediterranean or Eastern Pyrenees. Sometimes this term includes the mountains bordering between Andorra and the Cerdanya, an area in which no accident of the characteristics described has been registered. A fatal accident in Tosa d'Alp (2536 m), on the border between the pre-Pyrenees of Barcelona and the eastern Pyrenees, has also been considered. The complementary cases 11 (02/05) and 2 (03/44) (Table 2) were located in the massif of Montardo (2833 m), in the Aran valley, and in Montseny (1706 m) respectively, in the northern sector of the Pre-coastal range. The first one is located about 110 km west of the center of the eastern Pyrenees and the second at about 70 km to the south.

Between the scene of the accident in Tosa d'Alp and the one in Canigou there is a distance of ca. 50 km, and 8 out of the 10 selected cases (excluding complementary cases 11 (02/05) and 2 (03/44)) are grouped in an area of 160 km^2. The locations of the two farther accidents that took place in the Axial Pyrenees (Puigmal and Canigou) are at a 25 km distance from each other (Figure 2). Of these cases, eight are located in the region of Ripollès, one in the Cerdanya (Tosa d'Alp) and one in the Conflent (Canigou; French department of Pyrénées-Orientales).

The municipality of Queralbs (Girona) is probably one of the Spanish municipalities with the highest number of deaths in the mountains due to weather (Pascual, 2008). The Sanctuary of Nuria (1950 m), in Queralbs, can thus be considered the center of a mountainous area called the Nuria Mountains. Seven of the selected accidents occurred 10 km or less from the sanctuary.

Although there is no doubt that behind the high accident rate in the region is the high frequency of occurrence of certain weather conditions, natural and social factors also favor them. Firstly, the morphology of these mountains is characterized, above 2000 m, except in specific sectors, by rounded forms and high grassy hill ranges. The maximum peak is Puigmal (2910 m), and there are numerous peaks above 2800 m of altitude. Below 2000 m there are some
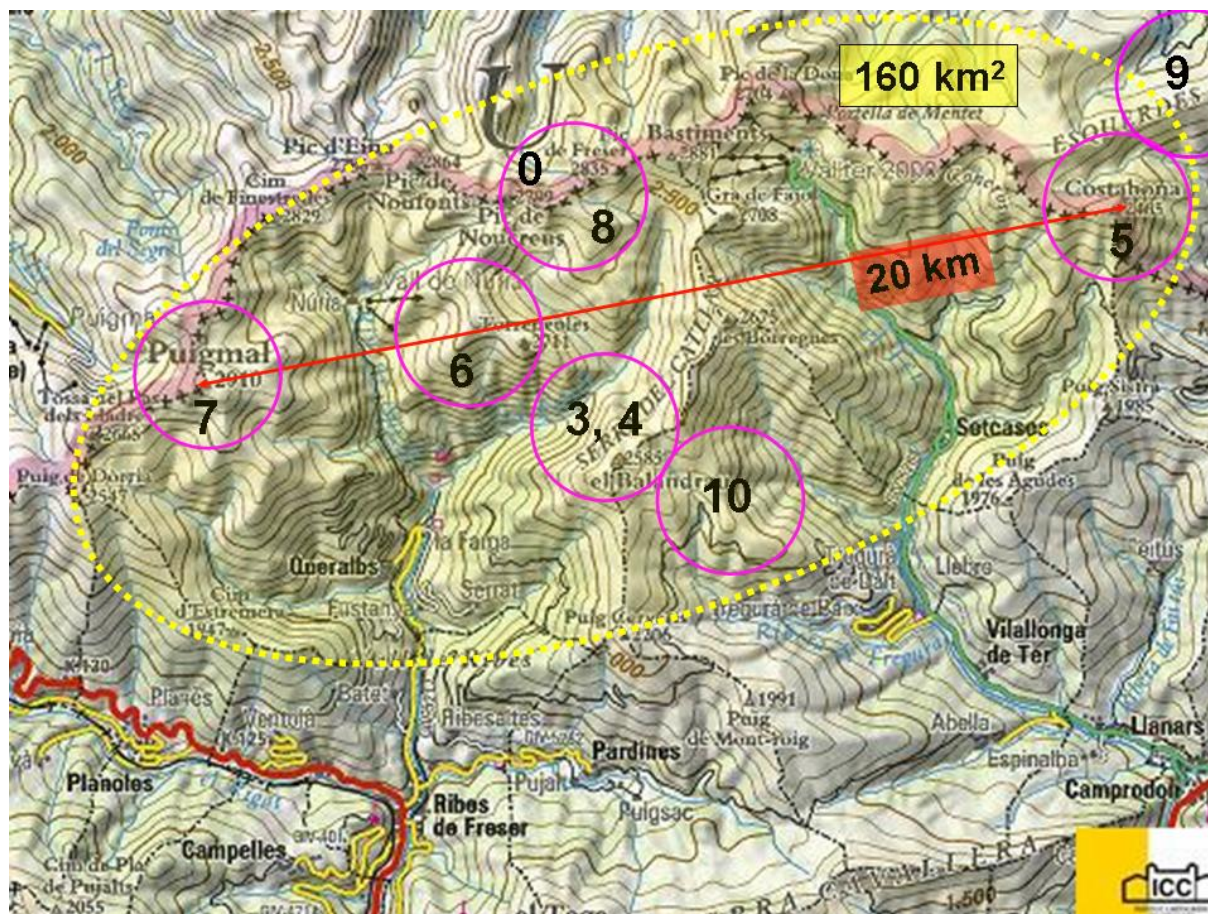
Figure 2. Axial sector of the Eastern Pyrenees that shows the approximate location of 9 fatal accidents and illustrative dimensions of the sector.

steep areas, craggy areas and gorges, such as those in the rivers Nuria or Freser, in the places where there have been some fatal accidents.

On the other hand, the arrival in 1919 of the train to the town of Ribes de Freser and the cog railway to the Sanctuary of Nuria in 1931, have allowed the mass arrival of tourists and hikers to the mountains. Thus, for over a half century the number of visits to the Nuria Mountains have probably been considerably higher than to other mountains in the Catalan Pyrenees.

3 Selected Cases

A search for accidents that are supposed to be associated with adverse weather conditions was carried out following different methodologies:

- News in various Catalan or Spanish digital newspaper archives have been searched, the most complete of which at the time of this study was that of *El País*, available since 1976 (now in the digital newspaper archive of *La Vanguardia* it is possible to consult copies since

1881). The Department of documentary management, archives and publications of the municipality of Girona provides its website access and a search tool for digitalized newspapers since 1808. A systematic research was carried out only in the archives later than 1965 and some specific previous cases (1930 and 1944). Thanks to this service, news from *Diario de Gerona*, *Los Sitios* and *Los Sitios de Gerona* has been compiled from 1969 to 1983 and later ones from the *Diari de Girona*. There is also news from *La Vanguardia*, for dates after 2001.

- Another key source of information is the article of Perelló and Reñé (1953), which compiles 46 accidents that occurred in Spain in the first half of the 20th Century. Two of them are clearly linked to adverse winter weather, one in the study area (Tosa d'Alp) and another one in Montseny.

- In order to corroborate some data, the Municipality of Queralbs was contacted. In a few cases, and informally, people indirectly related to the accidents or the rescue operations carried out were asked.

Table 1 shows the characteristics of the selected cases with northern flows in the Mediterranean Pyrenees. Note that

Table 3. Estimated thermal values at the altitude of the accidents from the isobaric levels at 850 and 700 hPa, and wind values at different isobaric levels of the free atmosphere from reanalysis every 6 hours by the ECMWF and the NCEP/NCAR for the selected and complementary cases. The five colder cases have their wind chill in bold, while the five cases with greater wind intensity have this variable at 850 hPa in bold.

| Cases	Temperature (°C)	Wind chill (°C)	Intensity (km h^{-1}) and wind direction		
			300 hPa	700 hPa	850 hPa
1(02/30)	-10/-12	**-23/-27**	No data	No data	(NE, SFC)
2(03/44)	-5/-10	No data	No data	No data	(NE, SFC)
3(12/68)	-8/-11	-20/-22	191(NNW)	76(NW)	50(NW)
4(03/70)	-1/-7	-9/-17	162(WSW)	72(W)	36(W)
5(11/78)	-10	**-23**	216(N)	101(N)	**108**(N)
6(12/79)	-4/-7	-16/-19	234(NNW)	144(NNW)	**83**(NW)
7(11/84)	-4	-12	112(S)	83(S)	50(S)
8(12/86)	-14	**-27**	202(WNW) 158(NE)	76(NNW) 94(NE)	**86**(N)
9(04/92)	-5/-14	-14/-28	194(NE)	97(N)	**90**(N)
10(12/00)	-4(-7)	-14(-19)	216(NNW)	86(N)	**97**(N)
11(02/05)	-8/-13	**-21/-28**	180(N)	72(NNE)	54(NE)
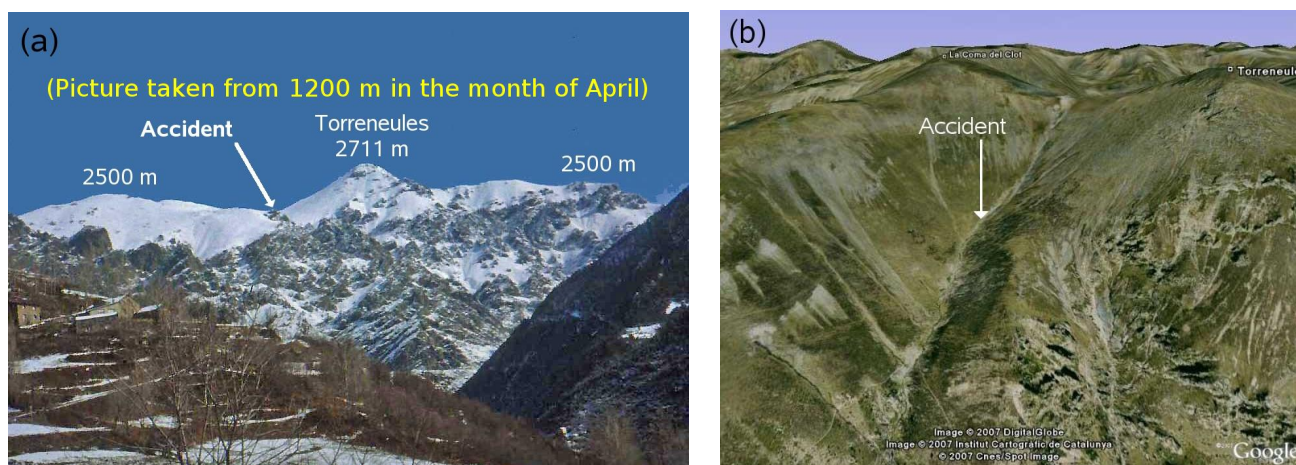
Figure 3. (a) Torreneules massif and (b) approximate location of the fatal accident that occurred at the end of December 1979 (case 6 (12/79)).

in some of them there is significant uncertainty regarding the exact date and location of the accident.

Three additional cases of interest (see Table 2) have been included. These cases either have no northern flow or occurred outside the geographic area of study, but they do show the same or similar types of accidents, and thus can broaden and be compared with the selected cases. Two of them, cases 2 (03/44) and 11 (02/05), are included in order to study and compare the same meteorological features of the northern flows with other geographical areas near the eastern Pyrenees, such as Montseny and the Catalan Western Pyrenees. Case 7 (11/84) is also included. It is an unusual but not impossible case, of the same accident typology without northern flows (SW flow), but in it the source of air mass is similar to the one in the cases under study.

4 Characteristics of the accidents and weather conditions

From the observation of Tables 1 and 2 some general characteristics can be extracted from the selected cases (excluding case 0 (S. XIX) in the statistics) and the complementary ones:

- Increase in the number of visits to the mountain associated with holidays or weekends determines the daily, weekly and monthly distribution of the accidents (70% of the cases and 81% of the deaths occurred on non-working days) . The relatively high number of accidents around Christmas and New Year (for example, 40% of the cases with 65% of the victims) is also evident, which on the other hand coincides with the shortest days of the year.
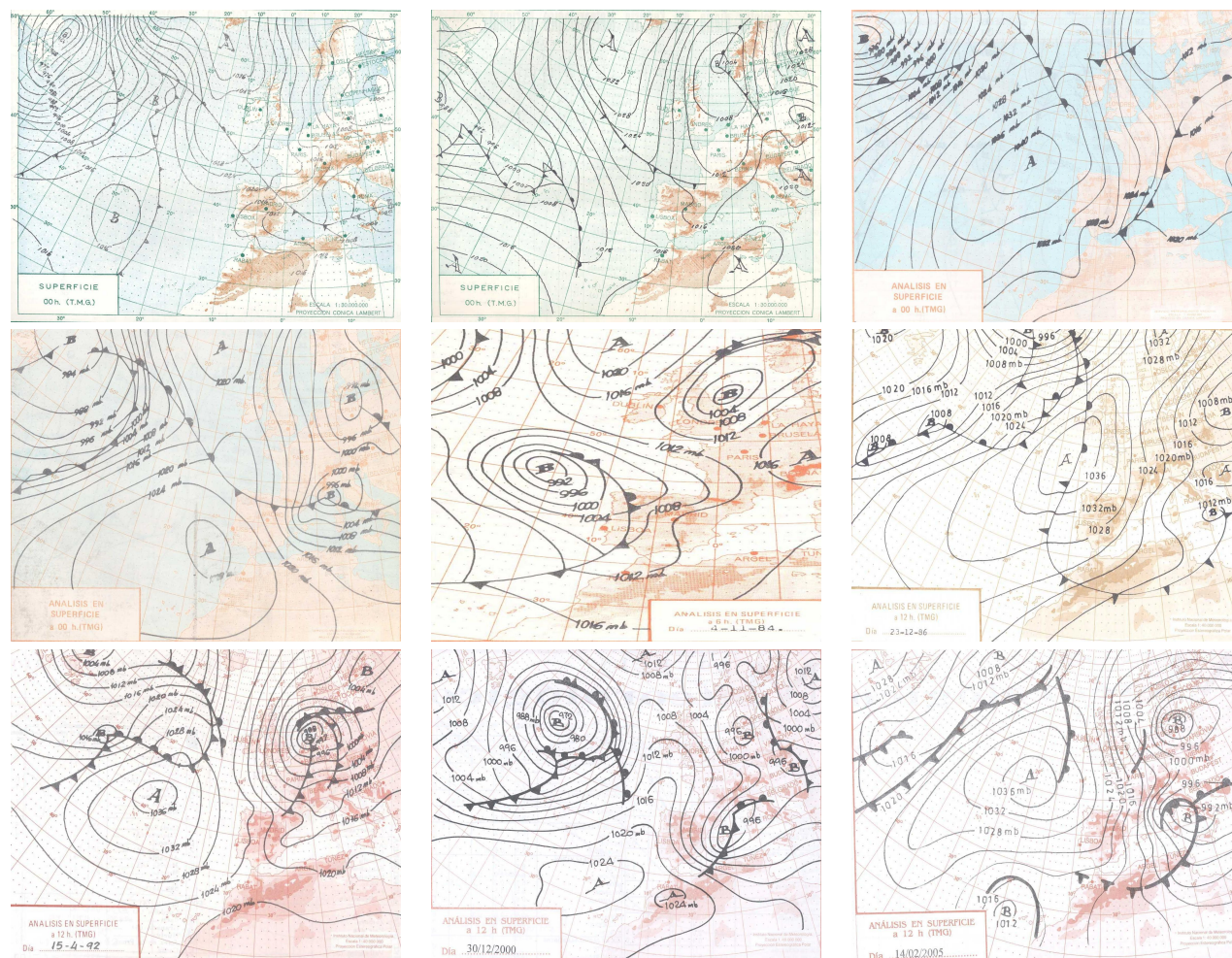
Figure 4. The pressure analysis on surface and frontal analysis. Left to right and top to bottom: 27/12/68 00 UTC (case 3 (12/68)); 8/03/70 00 UTC (case 4 (03/70)); 26/11/78 00 UTC (case 5 (11/78)); 31/12/79 00 UTC (case 6 (12/79)); 4/11/84 06 UTC (case 7 (11/84)); 22/12/86 12 UTC (case 8 (12/86)); 15/04/92 12 UTC (case 9 (04/92)); 30/12/00 12 UTC (case 10 (12/00)); and 14/02/05 12 UTC (case 11 (02/05)). Source: AEMET.

- In the accidents that occurred during winter months in the Pyrenees, from November to April, the maximum is recorded in December and the minimum in January, without any case, probably conditioned in part by what is stated in the previous section.
- Except in the case of Montseny (case 2 (03/44)), the accidents occurred above 1500 m - 1700 m. In addition, 80% of them (85% of the victims) occurred above 2000 m, in the high peaks.
- Unlike accidents due to technical errors in progression made in favorable weather conditions, in the majority of the selected accidents there is more than one mortal victim. In addition, three out of the five cases in which there is only one death, the hiker was alone. This suggests that in the case that more people had been present, the accident might have been even worse.

From the information available in the press, some scattered meteorological observations, the stories of peo-

ple involved and estimations made from the reanalysis of the numerical models ECMWF (ERA-40) (http://www.ecmwf.int/services/archive) and NCEP/NCAR (http://www.wetterzentrale.de/topkarten/fsslpeur.html) it is possible to establish, even with uncertainty, the possible causes of deaths and the natural causes that determine the occurrence of accidents. The proposal for the latter is:

- Presence of loose snow, in some cases because of a snowstorm at the time of the accident, and in others, recent snow in a very slow process of transformation and compaction due to low temperatures.
- Low visibility conditions due to snowstorm and/or snow in suspension lifted by the wind due to its low cohesion.
- Strong or very strong winds with gusts in some cases exceeding 120 km h^{-1}. Sacasas (1999) suggests that in some peaks of the eastern Pyrenees, such as Bastiments (2881 m), the wind may have exceeded 200 km h^{-1} in extraordinary gales. García and Vilar (2006) indicate

that in case 10 (12/00) there was a maximum gust of 138 km h^{-1} recorded in the automatic weather station of Ulldeter (2380 m), from the Meteorological Service of Catalonia, located at 6 km from the accident site.

- Negative temperatures during most of the day and very low wind chill values.

The changes, often sudden, in atmospheric conditions involve changes in the field conditions, both on the surface (presence of snow or not), as in the stability of the snow mantle. This is what Fuster and Elizalde (1995) call qualitative changes of the sport *substratum* as a result of the action of internal or environmental modifiers, in this case the weather. Because of these changes (especially on snowy ground) the perception that hikers have of the environment can lead to fatal errors in decision-making (degree of slope, disorientation, lack of visual references, etc.).

Two Anglo-Saxon terms describe the environmental conditions when the above items are combined: *blizzard* and *whiteout*. According to TERMCAT (2009), *blizzard* is a type of weather characterized by extremely low temperatures, strong winds and nearly full reduction of visibility due to the snow raised from the ground. It is a phenomenon that is mostly typical of polar areas and northwestern North America. According to TERMCAT (2009) the established thresholds to define it are: temperature below -12°C and wind speed over 50 km h^{-1}. Other criteria can be winds over 40 km h^{-1}, snowfall or snow lifted from the ground, visibility below 1 km and wind chill below -25°C, and a length of at least 4 hours (Environment Canadà, 2009). Environmental conditions similar to the *torb* of the Pyrenees, especially in the high mountains of the easternmost area, are the most severe cases of a phenomenon equivalent to *blizzard*.

The term *whiteout* is equivalent to white landscape or glow. It is an atmospheric optical phenomenon, which turns up especially in the polar regions, in which the observer appears to be wrapped in a uniform whiteness due to the lack of contrast between the sky and the surface; shadows, clouds or the horizon can not be distinguished, and a sense of depth and orientation are lost (Eumetcal, 2009). This white landscape is the landscape that a hiker finds in high mountains under *blizzard* weather conditions. It is more likely to happen on mountains with few peaks of significant height, such as the eastern Pyrenees, which are rounded and quite uniform.

To generate a risk situation, the overt danger of *torb* must interact with the vulnerable elements. Vulnerability, in this case, depends on the characteristics of the hiker, which largely influences in the gravity of the accident: such as his or her physical, mental and technical preparation, and material or equipment (George, 1993). However, the analysis of the cases shown here, and of other cases recorded in different areas and seasons suggests that, in certain types of very adverse weather, assuming the same degree of exposure, direct dependence of a hiker's vulnerability with their skills is greatly diminished. For example, an extreme case that can help to clarify this would be the accident at Balandrau (case 10 (12/00)), which involved the death of nine out of the 10
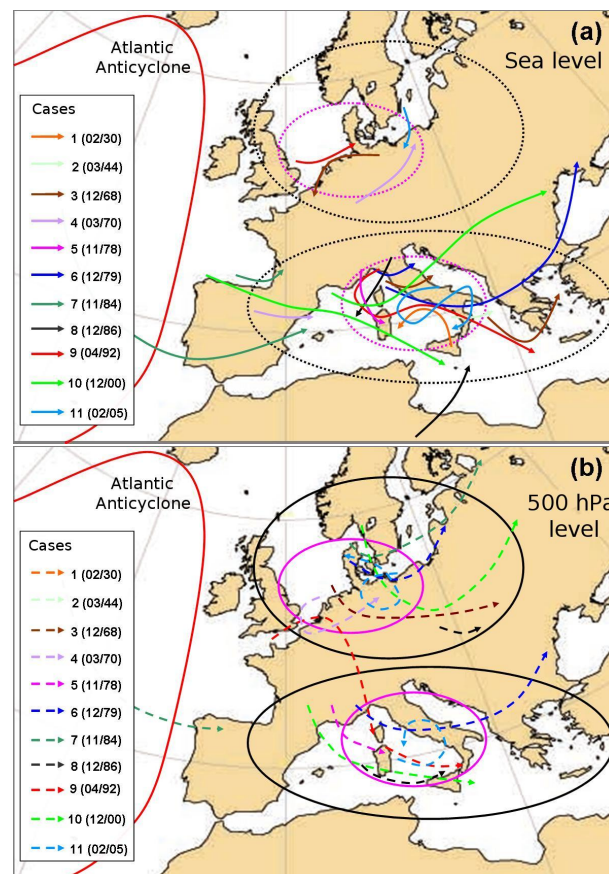

Figure 5. Trajectories of the centers of the low pressure systems for the selected and complementary episodes in the 20th Century. (a) Solid line, shows the trajectories of the centers of the low pressure systems at sea level (pressure reduced to sea level) and (b) dashed line, shows them at 500 hPa (geopotential). The black ellipses (large) comprise the main movement paths of the depressions. Pink ellipses (small) comprise areas where depressions remain stationary or have retrograde motion. Mapping source: ECMWF-NOAA.

people who composed a diverse group from a sports point of view.

The direct causes of death in the selected incidents were probably the following:

- Hypothermia.
- Bruises due to falling on different levels with or without subsequent hypothermia.
- Drowning due to falling into a stream with subsequent hypothermia (Matagalls, case 2 (03/44)).
- Bruises, hypothermia and/or suffocation due to being buried under an avalanche (Tosa d'Alp, case 1 (02/30)).

When the body temperature is below 35°C, the disorder called hypothermia occurs (Instituto de Estudios de Medicina de Montaña, 2009). Some of the immediate consequences of a condition of hypothermia are the loss of ability to perform movements and the emergence of apathy.
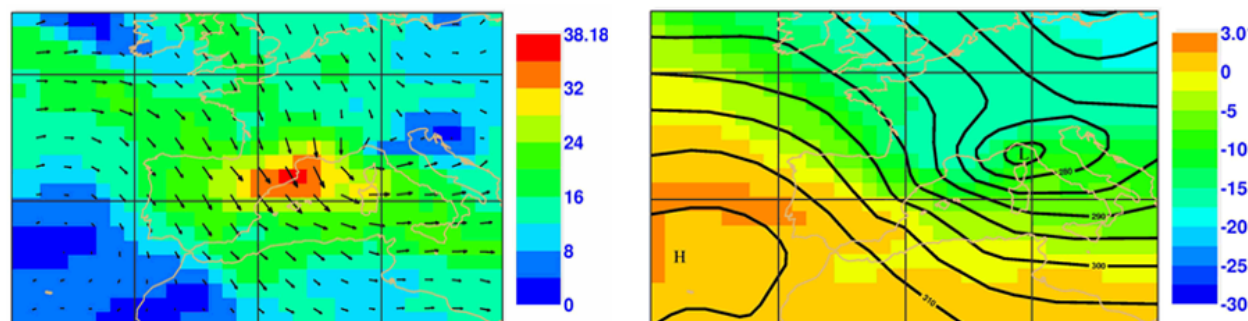
Figure 6. (a) Wind speed field at 700 hPa corresponding to case 6 (12/79) at 12 UTC. Reanalysis of the ECMWF. Speed in m s^{-1}. (b) Temperature field (colored) and geopotential altitude at 700 hPa (isohypses) corresponding to case 6 (12/79) at 12 UTC. Reanalysis of the ECMWF. Temperature in °C. Geopotential altitude in gpdm.

The semi-unconscious and unconscious states occur when the body temperature drops to about 32°C - 28°C and the heart stops beating around 28°C - 24°C (Instituto de Estudios de Medicina de Montaña, 2009). Both in the 1944 accident (case 2 (03/44)) and in that of 1930 (case 1 (02/30)) the direct cause of the death was not the cold environment, but they occurred in an equivalent meteorological context to other events.

Table 3 shows some meteorological values estimated from the ECMWF (ERA-40) reanalysis (Uppala et al., 2005), at 2.5° of latitude and longitude of horizontal spatial resolution, and from the NCEP/NCAR, available every 6 hours since 1957 and 1948, respectively. For the two older cases there is no available information about the wind on middle and high levels. The wind chill was calculated using the formula proposed in 2001 by the U.S. National Weather Service (NWS, 2001).

The intervals of temperature and wind chill shown in Table 3 reflect the uncertainties in the altitude of the accident sites. The temperatures correspond to the value in the free atmosphere, according to the reanalysis used in the place of the accident. The wind speeds and directions correspond to the average wind in 6 hours of the reanalysis in the time interval of maximum intensity.

The wind direction at all levels and in all cases is between W and NE, except in case 7 (11/84) in which the flow was of S component and the temperature was significantly higher than in the other episodes. Speed was higher at 300 hPa than at the lower levels, exceeding 145 km h^{-1} in all cases. It got to 230 km h^{-1} on New Year's Eve 1979 (case 6 (12/79)). In this episode, the average wind speed in the Torreneules pass (Figure 3), very close to the place where the three hikers died, may have been of the order of 100 km h^{-1} - 130 km h^{-1} at the time of maximum virulence of the storm, assuming that there was a linear increase of the storm between 850 and 700 hPa. In case 5 (11/78) gusts may have exceeded 150 km h^{-1} in the Costabona, where three other hikers died of hypothermia.

In most cases the wind was stronger at 700 than at 850 hPa but the difference is often small, especially when the predominant component is N. Top 5 cold episodes (Table 3, wind chill in bold) are distributed between the months of February (2 cases), December (one case), November (one case), and April (one case).

5 Synoptic and mesoscale environment of the episodes with accidents

At a synoptic scale the episodes were characterized by northern flows (except in case 7 (11/84)), normally associated with cold advections, and with a higher or lesser degree of humidity depending on their Atlantic or continental origin, respectively. In half of the cases the advected air mass was continental. In the nine dates when it was possible to consult a frontal analysis, a cold front had recently crossed the Iberian Peninsula or was in progress following a trajectory between west-east and northeast-southwest (Figure 4). The post-frontal nature of several of the events justifies the assumption (when there is no absolute certainty) that there was recent snow on the ground.

Figure 5 shows the positions and trajectories of low-pressure centers at 500 hPa and on surface in the cases of the 20th Century. These synoptic settings determine a flow of N component between European and Mediterranean low pressure systems and a high pressure area over the Atlantic Ocean, more or less elongated like a ridge towards Iceland. The most significant elements are:

- Recurring presence of an Atlantic anticyclone more or less elongated latitudinally. This high pressure area largely corresponds to the synoptic type 5, Atlantic Ridge, proposed by Rasilla (2003). Type 3 proposed by the same author, corresponding to the well-known Azores anticyclone, is characterized by the penetration of an anticyclonic ridge towards Western Europe that is not observed in the surface maps of Figure 4. The same study shows that thermally type 5 would have a
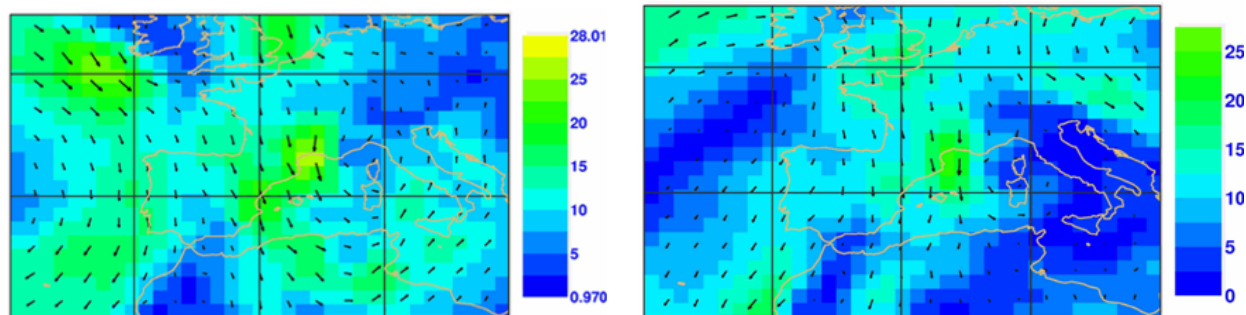
Figure 7. Speed field at 850 hPa corresponding to case 5 (11/78) (left) and to case 8 (12/86) (right) at 18 UTC. Reanalysis of the ECMWF. Speed in m s^{-1}.
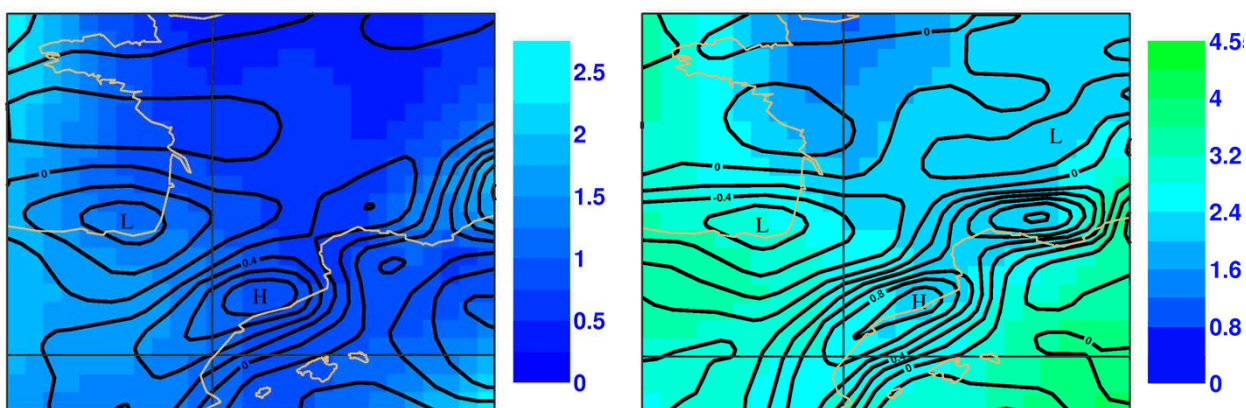

Figure 8. Vertical speed field (isotaches) and specific humidity (colored) at 700 hPa (left) and 850 hPa (right) corresponding to case 5 (11/78) at 18 UTC. Reanalysis of the ECMWF. The positive values of the speed indicate downward movement. Speed in m s^{-1}. Specific humidity in g kg^{-1}.

markedly cold nature, while type 3 would be intermediate; and also the intensity of the flow, from the 1st or 4th quadrant in 99% of cases in type 5, would be much greater than for type 3. The most recent synoptic classification presented by Esteban et al. (2006), for the period 1960-2001, based on an analysis by main components and a subsequent clustering, shows two patterns that describe this latitudinally stretched configuration of the Azores anticyclone, which establishes a flow from the north or northwest over Western Europe. These are its patterns CL6 (Mediterranean low/northern advection) and CL16 (Central European low/northern advection), with a minimum frequency in the summer in the first case and a maximum in the spring in the second, and the main difference between them lies in the location of the low pressure system on surface.

- Presence of low-pressure centers both at 500 hPa and on surface concentrated in two areas: the north of the Western Mediterranean basin and the north of Central Europe. Mediterranean low pressure systems are the result of the interaction processes of the synoptic flow with the Alps, and its frequent generation turns the area between the Gulf of Lion, the Gulf of Genoa and the Catalan-Balearic Sea into one of the most cyclogenetic areas in the world (Jansà, 1997).

- Two main displacement paths are defined, west-east, for the depressions in these episodes: the one located between the British Isles and Russia and the one situated between the Iberian peninsula and the Balkan countries. These paths are not anomalous because, in the case of strong winds affecting the Iberian Peninsula, Rasilla et al. (2002) have already presented as a secondary way of the barometric minimums on surface an intermediate path between the two above: from the Atlantic Ocean to Central Europe across the Cantabrian Sea.

- Areas in which the low-pressure centers remain fairly stationary and even show some retrograde motion (from east to west) are identified within the previous paths.

- Case 7 (11/84) shows displacement towards the east of an Atlantic depression entering the Iberian Peninsula through Galicia (500 hPa) and Portugal (surface).

- The 1986 event (case 8 (12/86)) shows an Algerian cyclogenesis on surface, downwind of the Atlas with an S component flow.

- In case 9 (04/92) the center of the low pressure system on surface makes a quick north-south displacement, which is abnormal, moving from the European way to the Mediterranean. Although it is not a usual displacement, Rasilla et al. (2002) consider this trajectory one of the three trajectories associated with wind storms in Catalonia and other areas of northern Spain.
- In the very grave case 10 (12/00) a deepening low-pressure area moves very quickly from the Cantabrian Sea to the Balearic Sea (Pascual, 2001).

Under N synoptic flow, the pressure field at mesoscale alpha over the northeast of the Iberian Peninsula and the Pyrenean isthmus shows a characteristic deformation, configuring the Pyrenean dipole (mesoscalar) (Jansà, 1997): a minimum of pressure over the Ebro Valley or Catalonia and a maximum over the plains of Aquitaine or over the mountain range in the form of a ridge with a west to east oriented axis. The regional wind system, tramontana-mestral, a temporary blockage of cold air on the northern slope and the consequent development of a strong gradient of temperature and humidity (and density) normal to the Pyrenees mountain range (Bougeault et al., 1993; Campins et al., 1997; Pascual, 2001).

To explain the fact that, according to some records of automatic stations, for example in the case of December 30, 2000 (Pascual, 2001; García and Vilar, 2006) and individual stories of those injured or the rescuers (Fransí, 1999; Vilà, 2001), wind speed often increases sharply, and because the gradient of density normal to the Pyrenees is high, the conceptual model of density current (Arasti, 2001; Pascual, 2001) could be applied to this phenomenology. It must be kept in mind that the complex local topography creates wind accelerations at γ and β microscale in areas that are potential hot spots from the standpoint of accidents.

The effect of the Pyrenees on the flow from N is more evident at 850 than at 700 hPa, the approximated isobaric level of the highest peaks of the Eastern Pyrenees, such that the acceleration of the wind at its eastern edge is clearer below 1200 m - 1500 m, especially when Tramontana has entered a steady-state (Campins et al., 1997).

In order to illustrate some of the effects at a subsynoptic scale of the interaction between northern flows and the Pyrenean orography, some meteorological fields from the ERA-40 of the ECMWF model, at 2.5° spatial resolution are shown below. It should be noted that at this resolution, equivalent to 125 km, the Pyrenean orography is considerably softened in relation to the actual area, and therefore the reanalyses cannot be expected to reproduce all the mesoscalar phenomenology associated with such interaction.

In case 6 (12/79), the wind field at 700 hPa shows a maximum that is remarkably sharp (Figure 6a). This maximum, also visible at 850 hPa, is accompanied by another one from NNW of 65 m s^{-1} (230 km h^{-1}) at 300 hPa. The geopotential gradient over the Northeast of the Iberian Peninsula in this episode is larger than in other cases, due to the presence of a deep storm centered in the Gulf of Genoa as
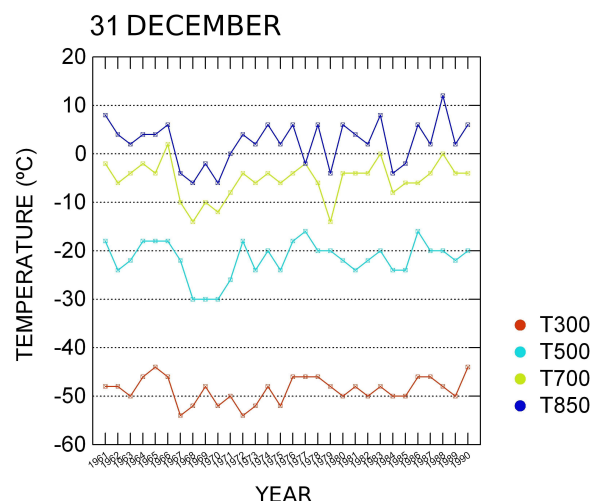

Figure 9. Temperature time series ($^\circ$C) at 12 UTC for December 31, from 1961 to 1990. Levels: 300 hPa (bottom; red), 500 hPa (light blue), 700 hPa (green) and 850 hPa (top; dark blue). Reanalysis of the ECMWF.
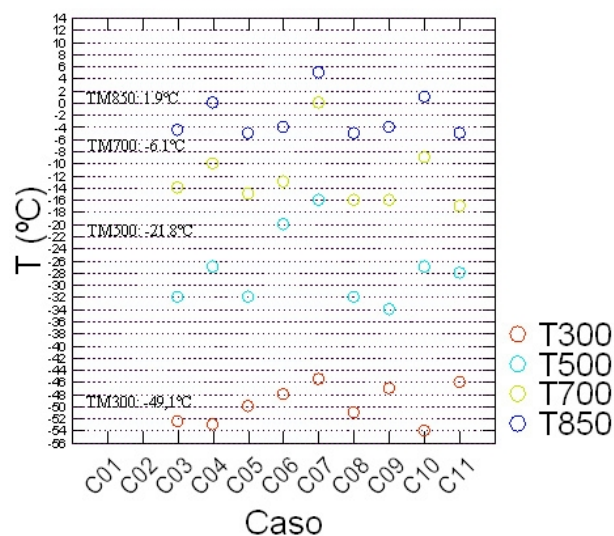

Figure 10. Representative temperatures of the selected episodes at: 300 hPa (bottom; red), 500 hPa (light blue), 700 hPa (green) and 850 hPa (top, dark blue). TM: Average value of the 30-year series for the reference dates and the four levels.

well as to the proximity of the core of the Atlantic anticyclone to the peninsular southwest (Figure 6b), similar to how it occurred in case 10 (12/00), when wind speeds of 60 m s^{-1} (220 km h^{-1}) at 300 hPa were recorded.

Esteban et al. (2005) identified, in their objective classification of synoptic patterns favorable to heavy snow in Andorra, two clusters (5 and 7) that could be associated with the cases mentioned in the previous paragraph, characterized by the presence of a synoptic pressure dipole formed between a

deep low pressure system over southern Europe and the anti-cyclone with its core on the west or southwest of Portugal, a strong baric gradient over the Pyrenees and a resulting strong flow from NW at all levels.

On the other hand, cases like 5 (11/78) or 8 (12/86), with three and two deaths respectively in Costabona and Tirapits, show maximum values of wind speed slightly higher at 850 than at 700 hPa (Table 2), located smack at the eastern end of the Pyrenees (Figure 7), linked to the orographic effect, which does not preclude that the wind at higher levels was also strong, over 80 km h^{-1}. In fact, the Pyrenees and the associated pressure dipole are responsible for most episodes of strong winds in Catalonia not associated with nearby cyclones (Campins et al., 2007).

The simultaneous analysis of the vertical speed fields and specific humidity at 700 and 850 hPa in the vicinity of the eastern Pyrenees (Figure 8) shows a maximum subsidence of dry air above the range or downwind of the mountain with N component flow. In contrast, in the episode with SW advection, case 7 (11/84), there is a weak upward movement, which is associated, at least in part, to an orographic forcing on the southern slopes of the Pyrenees. The subsidence under northern situation probably has two basic components, synoptic and mesoscalar:

- The approximation of an Atlantic anticyclonic ridge, resulting in large-scale subsidence.
- The likely mountain wave generated in situations of increasing stability in the stratification. This wave has appeared in other episodes with N component flow, with föhn effect and/or strong winds downwind (Pascual, 2001; Pascual, 2005). Figure 8 shows, for example, maps corresponding to case 5 (11/78), where it illustrates how a subsiding maximum at 700 and 850 hPa, downwind of the Pyrenees, coincides with a relative minimum of specific humidity, especially visible at 850 hPa.

6 Climatological context

To evaluate how excepcional are the selected episodes, their synoptic settings and their thermal environment, based on data from the ERA-40, have been compared with the usual weather at this time of year. In order to do this three representative dates for early (December 31), half (February 15) and late winter (March 31) were selected according to their astronomical definition. On the other hand, meteorological winter, for statistical purposes, includes the months of December, January and February. But Rasilla (2003), based on an analysis by main components of the absolute frequency of occurrence of 10 types of circulation previously classified, defined four "natural seasons", the first of which was a winter period that lasted from 12 November to 31 March. Therefore, the two cases in November may be the worst represented in the choices made, that do not exclude a degree of arbitrariness.
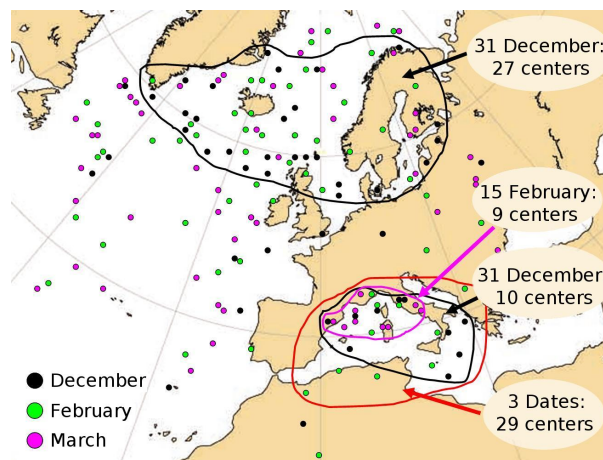

Figure 11. Location of the low pressure centers on surface for the three reference dates. Black: December. Green: February. Pink: March. The closed continuous lines comprise areas of maximum spatial density of these centers. Some values referring to the number of centers in the mentioned areas for the different dates are indicated. Mapping source: ECMWF-NOAA.

First, temperature time series at 300, 500, 700 and 850 hPa above the Pyrenees were obtained for the period 1961-1990. As an example, Figure 9 shows the chart corresponding to 31 December. At the same time, centers of high and low pressure under different types of flow are represented, comparing such representations with the study cases.

Figure 10 compares the average temperature in the four isobaric levels for the three dates chosen with the representative dates of the study cases. At 850 and 700 hPa, those recorded in the latter cases have always been below average for the reference dates, except in case 7 (11/84), with SW advection. At 500 and 300 hPa there are respectively 2 and 4 cases in which the temperatures associated with the study cases were higher than the climatological average, including case 7 (11/84). It is verified, therefore, that the study cases were particularly cold at all levels, especially at the lower ones.

The synoptic situation in the reference dates has been subjectively analyzed, and the conclusion is that northern and continental European advections represent little more than 30% of all configurations, this dominance being less marked on 31 December. Other situations with a frequency of occurrence higher than 10% have been zonal advections, cyclonic or anticyclonic, dynamic lows with their center in the vicinity of the Pyrenees and the anticyclones centered near or above the Iberian Peninsula. As for the directions of the flows, at 500 hPa there is a predominance of those coming from the third and fourth quadrants, while on surface there is a predominance of those of the fourth and first in December and the first and fourth on 15 February and 31 March.

Therefore, the synoptic situations in the dates of the accidents are not uncommon from a climatological standpoint, at least for the dates and period chosen, and neither are the

Table 4. Temperatures at 4 isobaric levels. Average values for the flows of the first and fourth quadrant (NE/NW) and for all flows. Values under the average are in quotes and values over the average are indicated with an asterisk. Those with a difference higher than 2°C are in bold.

Date	Quadrants	T300(°C)	T500(°C)	T700(°C)	T850(°C)
December 31	1(NE)/4(NW)	"-49.5"/-47.3*	"-23.0"/-20.9*	**"-7.5"/"-5.6"**	**"-0.8"/2.9***
December 31	Todos	-48.7	-21.7	-5.3	2.4
February 15	1(NE)/4(NW)	"-50.5"/"-52.0"	"-22.2"/-21.0*	**"-11.0"/-7.5***	**"-2.5"/1.5***
February 15	Todos	-50.1	-21.8	-7.7	0.1
March 31	1(NE)/4(NW)	"-49.2"/-46.3*	**"-25.1"/-19.3***	**"-9.3"/-2.7***	**"-0.2"/5.3***
March 31	Todos	-48.4	-21.8	-5.2	3.1

flows in the first and fourth quadrants at low levels. Therefore, in a risk analysis that frequency of northern advections should be considered.

Table 4 shows the temperatures analyzed at different altitudes and for different flow directions, and it is confirmed that they are always lower than the average for the selected date when the flow is from the first quadrant, especially at 700 and 850 hPa. When the flow is from the fourth quadrant the temperature may be higher or lower than the average depending on the origins of the advected air mass; but in general this flow is associated in all levels to thermal values that are higher than the average. On March 31 the temperature at different levels is more sensitive to the type of flow, that is to say, northern or continental European advections, at the beginning of spring, establish a type of weather that is thermally very different from the average conditions.

The centers of the low pressure systems on surface on the three dates during the 30 years can basically be grouped into two areas (Figure 11): North Atlantic, where it is particularly evident for 31 December, and Western Mediterranean. It can also be noted that in mid-February there is a relatively higher density of low-pressure centers between the Balearic Islands, the Catalan coast and the Gulf of Genoa and the Gulf of Lion than on the other dates.

When the locations of the low pressure systems on dates with northern flow (Figure 12) are obtained and they are simultaneously represented with the location of high pressure centers on the same dates, we get the synthesis of the main directions of movement of cold air masses, maritime masses or continental masses, affecting the eastern Pyrenees. The Atlantic area located between the Azores and the Iberian Peninsula is a region with a frequent high pressure center more or less elongated latitudinally. It is also possible that an anticyclonic center associated with the Atlantic core is spread eastward over central or western Europe or over the North Sea and Scandinavia. It is finally noted that, on rare occasions, particularly in case 5, the north component flow over the eastern Pyrenees was driven by a high pressure system over Russia.

The disposition of the baric synoptic dipole formed in the high pressure center and the low (or lows) present in the Atlantic-European area ultimately determine the precise direction of the flow that affects the northeast of the Iberian Peninsula, although this dipole is not always well defined; sometimes it is only a powerful anticyclone and a deep depression that set the dominant flow. The storms centered around Iceland establish NW flows, maritime flows, and those situated over Eastern Europe, from the NNE, establish very cold and continentalized flows. Other main directions are NE or ENE, moving very cold and continental air masses, in the former, and more humid ones in the latter. The Russian anticyclone is responsible for the trajectories of the NE, while sometimes the combination of a low in the Western Mediterranean and a high in central-eastern Europe determine a more Mediterranean flow.

When comparing the location of the centers of high and low pressure on surface for the study cases and for the 30-year series (Figure 12) we found that, while the presence and position of the Atlantic anticyclone were not so evident in the first case, there was a maximum spatial density of depressions largely coincident with climatically favorable areas, especially in the case of the Mediterranean low pressure systems. Besides the presence of the barometric minimum off the Portuguese coastline, which corresponds to case 7 (11/84) and, therefore, not comparable for synoptic purposes to the others (although, as discussed above, it is comparable for the purposes of the type of accidents), another noteworthy fact is the existence of four centers located over Central Europe and southern Scandinavia, which correspond to cases 3 (12/68), 4 (3/70) and 5 (11/78).

It must be noted that there is a clear lack of Icelandic depressions, and therefore a smaller relative presence of maritime NW flows in relation to the others, which are more continentalized due to its European course.

The last aspect considered is the location of the low-pressure and anticyclonic centers at 500 hPa, both regarding the 30-year series, under northern flow, as well as in the cases with accidents (Figure 13). The spatial distribution for the 30-year series shows clearly that there are no depressions located at 500 hPa to the west of a line extended between the west of Iceland and Ireland and the Western Mediterranean, and that the Atlantic anticyclone dominates the synoptic settings.

On a few dates, a geopotential maximum over Scandinavia is identified in the reanalysis, and on no occasion is there a high at 500 hPa over the rest of Europe, which indi-
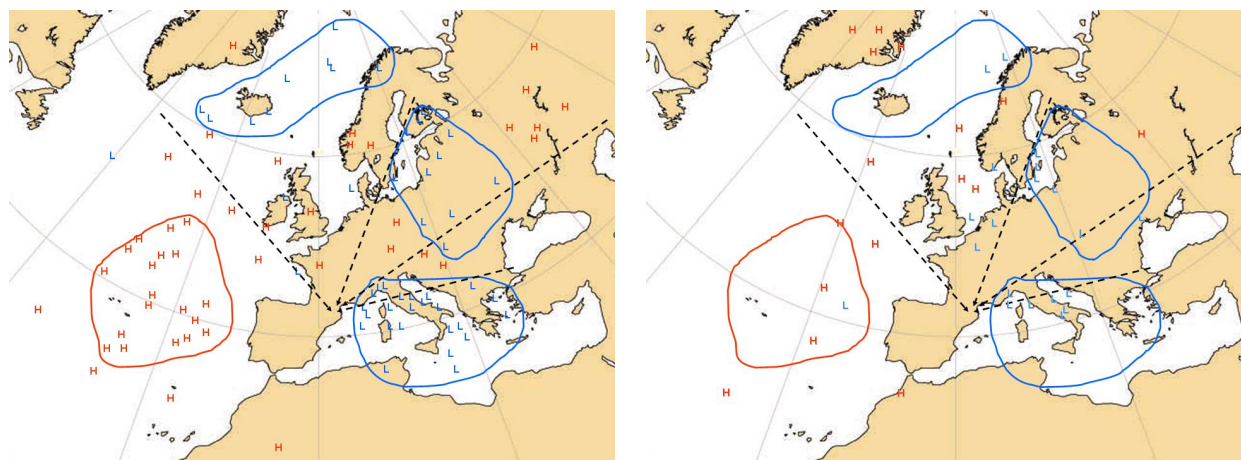
Figure 12. Location of the centers of low (L; blue) and high pressure (H; red) on surface for the three reference dates (left) with north flow over the eastern Pyrenees and for the study cases (right). The solid lines enclosed climatological areas of maximum spatial density in such centers. The dashed lines with arrows indicate the main directions of the northern flow associated with the different baric configurations on surface at synoptic scale. The directions associated with these directions are indicated. Mapping source: ECMWF, NOAA.

cates, therefore, that the anticyclones located on surface in this area (Figure 12) are of an essentially thermal and not dynamic origin.

The maximum density of high pressure systems is at the north of the Azores, while there are three other areas outlined for the minimums (Figure 13), two of which are superimposed on the corresponding areas of maximum density of lows on surface (Figure 12): Western Mediterranean and Eastern Europe. The visible maximum at 500 hPa over England appears to have no direct influence on surface and can be linked to depressions over the Gulf of Genoa and Gulf of Lion. The intensity of the flow of N component is greater on the dates on which the low at 500 hPa is located in the eastern sector and/or the anticyclone is in the north of the Azores and well south of Iceland Figure 13, dashed lines blue and pink respectively). The light blue L and pink H are the locations of lows and highs respectively with a particularly strong N flow at 500 hPa.

In the case of the studied events it is shown that, except for the low on 11/84, that belongs to another type of configuration, the depressions are located in climatically favorable areas. The spatial density of centers in the eastern and southern areas stands out, and therefore the flows from NNE or NE are more easily established at intermediate, cold and dry levels, in general. On the other hand, although the anticyclonic area is still present to the north of the Azores, it has lost relevance in favor of the location and probably the intensity of the lows.

7 Conclusions

Weather risks affect the practice of touristic and sport activities on the mountain. Previous studies show that the combination of snow, strong winds and low temperatures is often associated with fatal accidents in Spain, especially in high mountains (Pascual, 2008). This type of weather is usually established under northern or continental European advections or during the passage of Atlantic troughs; and in most cases the passage of a cold front can be identified during the days prior to the date of the accident or on the same day. The same studies show that sometimes there have been winter conditions in the mountains in the summer, but although these episodes involve great risk due to high exposure and vulnerability of the group of people in the mountains at that time, the accidents selected in this work occurred between November and April, with December as the month with the highest number of accidents, and none recorded in January.

A previous analysis, published in (Pascual, 2008), show that in some cases it was snowing and in almost all of them there was probably snow on the ground that, due to low temperatures, was not very compacted. The visibility was reduced due to snow and/or to the snow in suspension lifted from the ground by strong winds. Winds were strong, with gusts sometimes exceeding $120 \, \text{km h}^{-1}$ and temperatures below zero during much of the day. The combination of low temperatures and strong winds led to very low wind chill values and therefore to favorable conditions for the occurrence of frostbite and hypothermia.

The cases selected for this study make up a subgroup of mountain accidents associated with weather conditions, particularly of a winter type, generated based on the application of different criteria (type of accident, type of synoptic situation and geographical area).

The recurrent synoptic setting in these episodes is the presence of an anticyclone to the north of the Azores, more or less latitudinally elongated and a depression, both on surface and at 500 hPa, over different areas between the British Isles and the Western Mediterranean and between France and Eastern Europe.
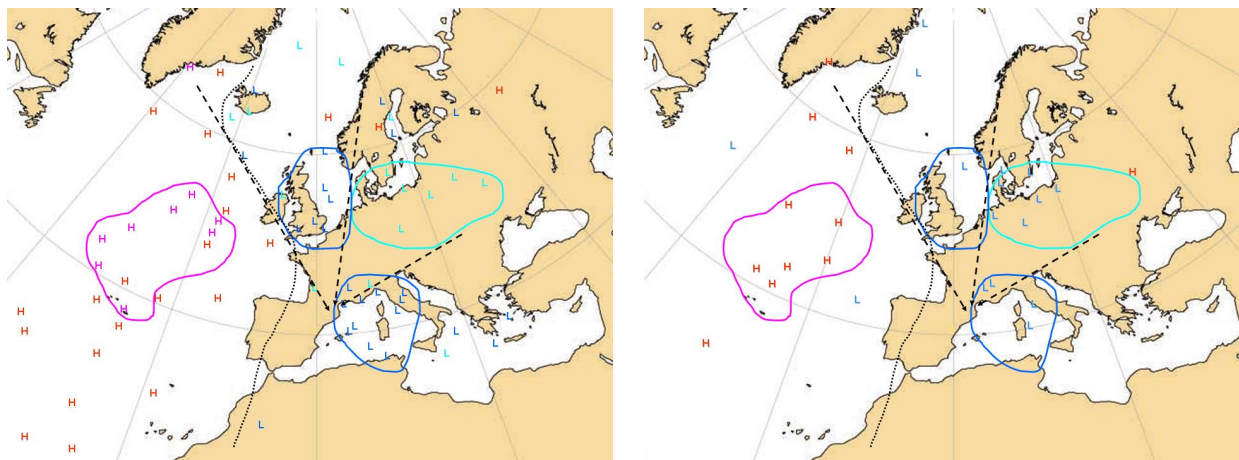
Figure 13. Location of the centers of low (L; blue) and high pressure (H; red or pink) at 500 hPa for the three reference dates (left) with northern flow over the eastern Pyrenees and for the study cases (right). The continuous or broken lines comprise climatological areas of maximum spatial density in such centers. The dashed lines with arrows indicate the main directions of the northern flow associated with the different configurations at 500 hPa at synoptic scale. The dotted line separates the areas where cyclonic nuclei appear from areas where they do not appear. Mapping source: ECMWF, NOAA.

At mesoscale, the wind-system tramontana-mestral, its main characteristics well described and explained in the bibliography, is the dominant pattern in the cases with N component flow, but its intensity and vertical structure varies depending on the precise position of the centers of action, an Atlantic anticyclone and Mediterranean low pressure system, and on the intensity of the subsidence associated with the Atlantic ridge that enters through the south of France, as shown in this study.

On the other hand, it is known that the stability of the postfrontal air mass and the interaction of the north flow with the Pyrenees develop a characteristic phenomenology, with gravity waves (Bougeault et al., 1993); its clearest manifestation in the study cases is the emergence of a subsiding and dry area over and downwind of the mountain range. In these circumstances, strong wind gusts may also affect the slopes and valley bottoms, creating other meteorological risks that are different from those shown here. (Pascual, 2009) describes an episode with these characteristics in the eastern Pyrenees.

Given that the climate study has shown, in agreement with the bibliography, that this baric pattern is common in the cold season and, consequently, so are the intense north component flows, the associated meteorological risk is quite high. It is not possible to decrease the danger of the phenomenon, but personal exposure and vulnerability could be reduced through education and information and, of course, improving the ways and places of dissemination of weather reports. The study also shows that the thermal conditions in the analyzed cases were harsher than normal.

The likely behavior of the cold mass as a density current that crosses the Pyrenees from north to south, not discussed in this article, is evidenced in the form of a sharp increase in wind speed accompanied by an equally rapid de-

crease in temperature, thus increasing the harshness of the phenomenon, its danger and the associated risk.

References

Arasti, E., 2001: Estudio de la galerna típica del Cantábrico, INM. Ministerio de Medio Ambiente, nota Técnica del CMT en Cantabria y Asturias.

Ayala-Carcedo, F. J. and Olcina, J., 2002: Riesgos naturales, Ariel, Barcelona.

Bougeault, P., Jansà, A., Attie, J., Bean, I., Benech, B., Benoit, R., Bessemoulin, P., Caccia, J., Campins, J., Carissimo, B., Champeaux, J., Crochet, M., Druilhet, A., Durand, P., Elkhalfi, A., Flamant, P., Genovés, A., Georgelin, M., Hoinka, K., Klaus, V., Koffi, E., Kotroni, V., Mazaudier, C., Pelon, J., Petitdidier, M., Pointin, Y., Puech, D., Richard, E., Satomura, T., Stein, J., and Tannhauser, D., 1993: *The atmospheric momentum budget over a major mountain range: first results of the PYREX field program*, Ann Geophys, **11**, 395–418.

Campins, J., Calvo, J., and Jansà, A., 1997: The tramontane wind: Dynamic diagnosis and Hirlam Simulations, INM/WMO International Symposium on cyclones and hazardous weather in the Mediterranean, Palma de Mallorca, 14-19/IV/1997.

Campins, J., Aran, M., Genovés, A., and Jansà, A., 2007: *High impact weather and cyclones simultaneity in Catalonia*, Advances in Geosciences, **12**, 115–120.

Doswell, C., 2001: *Thunderstorms and Camping Safety*, http://www.cimms.ou.edu/~doswell/tstm_camping_safety.html (Consulta 2009).

Environment Canadà, 2009: *Blizzards*, http://www.pnr-rpn.ec.gc.ca/air/wintersevere/blizzards.en.html (Consulta 2009).

Esteban, P., Jones, P. D., Martín-Vide, J., and Mases, M., 2005: *Atmospheric circulation patterns related to heavy snowfall days in Andorra, Pyrenees*, Int J Climatol, **25**, 319–329.

Esteban, P., Martín-Vide, J., and Mases, M., 2006: *Daily atmospheric circulation catalogue for Western Europe using multivariate techniques*, Int J Climatol, **26**, 1501–1515.

Esteban, P., Martí, G., García, C., Aran, M., Gavaldà, J., and Moner, I., 2007: Heavy Snowfalls and avalanche activity over eastern Pyrenees: a study of two extreme cases, Proceedings Alpine Snow Workshop, Forschungsbericht, 44-48, Munich (Alemania), 5-6/X/2006.

Eumetcal, 2009: *Glossary*, http://www.eumetcal.org/euromet/english/navig/glossf.htm (Consulta 2009).

Fransí, F., 1999: *Client a la força*, Funció Pública, **20**, 19–20.

Fuster, J. and Elizalde, B., 1995: *Riesgo y actividades físicas en el medio natural: un enfoque multidimensional*, Apunts. Educación Física y Deportes, **41**, 94–107.

García, C. and Salvador, F., 1994: Snowfall analysis in the Eastern Pyrenees, Annalen der Meteorologie, 23rd Internacional Conference on Alpine Meteorology (Lindau), 30, 303-306.

García, C. and Vilar, F., 2006: La montaña. Manual de Meteorología, Alpina, Granollers.

García, C., Martí, M., García-Manuel, A., Muntán, E., Oller, P., and Esteban, P., 2007: Weather and snow pack conditions of major avalanches in the Catalan Pyrenees, Proceedings Alpine Snow Workshop, Forschungsbericht, 49-56, Munich (Alemania), 5-6/X/2006.

García, C., Martí, G., Oller, P., Gavaldà, J., Martínez, P., and Peña, J. C., 2008: Atmospheric patterns leading major avalanche episodes in the eastern Pyrenees and estimating occurrence, International Snow Science Workshop, Whistler (Canadà), 21-27/IX/2008.

George, D. J., 1993: *Weather and mountain activities*, Weather, **48**, 404–410.

IGC, 2006: *Estadístiques d'accidents per allaus*, http://www.icc.es/web/gcontent/ca/allaus/igc_allaus_estadistiques.html (Consulta 2009).

Instituto de Estudios de Medicina de Montaña, 2009: *Hipotermia*, http://www.iemm.org/castella/hipotermia.htm (Consulta 2009).

Jansà, A., 1997: A general view about mediterranean meteorology: cyclones and hazardous weather, INM/WMO International Symposium on cyclones and hazardous weather in the Mediterranean, Palma de Mallorca, 14-19/IV/1997.

NWS, 2001: *NWS Windchill Chart*, http://www.weather.gov/om/windchill (Consulta 2009).

Pascual, R., 2001: *La situació meteorològica del 30 de desembre de 2000 al Pirineu Oriental*, Penell, **9**.

Pascual, R., 2005: *El efecto Föhn en el Pirineo Catalán. Características generales y un caso de estudio*, Boletín de la AME, **10**, 20–24.

Pascual, R., 2008: Accidentes en montaña y condiciones meteorológicas, Agencia Estatal de Meteorología. Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid.

Pascual, R., 2009: Episodio de vientos muy fuertes en el Pirineo y Prepirineo Oriental en un contexto regional y local, Agencia Estatal de Meteorología. Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid.

Perelló, J. and Reñé, J., 1953: *Los accidentes en nuestras montañas*, Montaña, **23**, 245–252.

Pons, J., 2008: Tiempo y clima en montaña. Manual práctico de meteorología, Desnivel, Madrid.

Rasilla, D. F., 2003: *Aplicación de un método de clasificación sinóptica a la península Ibérica*, Investigaciones Geográficas, **30**, 27–45.

Rasilla, D. F., García, J. C., and Garmendia, C., 2002: Los temporales de viento: propuesta metodológica para el análisis de un fenómeno infravalorado, En Cuadrat, J. M., Vicente, S. M., Saz, M. A., edits.: La información climática como herramienta de gestión ambiental, Universidad de Zaragoza, 129-136.

Rodés, P., 1999: Análisis de los accidentes por aludes de nieve en España. Una aproximación a la revisión histórica, Ergon, Madrid.

Sacasas, J., 1999: Meteorologia del Pirineu Català, Publicacions de l'Abadia de Montserrat, Barcelona.

TERMCAT, 2009: *Cercaterm*, http://www.termcat.cat/ (Consulta 2009).

Uppala, S. M., Kallberg, P. W., Simmons, A. J., Andrae, U., Bechtold, V. D., Fiorino, M., Gibson, J. K., Haseler, J., Hernandez, A., Kelly, G. A., Li, X., Onogi, K., Saarinen, S., Sokka, N., Allan, R. P., Andersson, E., Arpe, K., Balmaseda, M. A., Veljaars, A. C. M., Van De Berg, L., Bidlot, J., Bormann, N., Caires, S., Chevallier, F., Dethof, A., Dragosavac, M., Fisher, M., Fuentes, M., Hagemann, S., Holm, E., Hoskins, B. J., Isaksen, L., Janssen, P. A. E. M., Jenne, R., McNally, A. P., Mahfouf, J. F., Morcrette, J. J., Rayner, N. A., Saunders, R. W., Simon, P., Sterl, A., Trenberth, K. E., Untch, A., Vasiljevic, D., Viterbo, P., and Woollen, J., 2005: *The ERA-40 re-analysis*, Q J R Meteorol Soc, **131**, 2961–3012.

Vilà, J. M., 2001: El torb, un vent que mata, VII Jornades de Meteorologia Eduard Fontserè, Barcelona, 23-25/XI/2001.

Zaragoza, A., 2008: Temporal de neu i vent en muntanya (febrer 2005), Treball final inèdit. Màster en Meteorologia, Universitat de Barcelona.