THE AVALANCHE DATA IN THE CATALAN PYRENEES. 20 YEARS OF AVALANCHE MAPPING

Oller, P.(1); Muntán, E.(2); Marturià, J.(1); García, C.(3); García, A.(2); Martínez, P.(1)
(1)Institut Geològic de Catalunya
(2)Universitat de Barcelona
(3)Servei Meteorològic de Catalunya

ABSTRACT

In 1986, an avalanche mapping program began in the Catalan Pyrenees. Twenty years after, in 2006, the Avalanche Paths Map, a collection of 14 sheets at 1:25.000 scale that covers all this territory, was finished. Several techniques, such as terrain and vegetation analysis, inquiries to Pyrenean inhabitants, winter survey, historical documentation and dendrochronology, were used in this program. The data collected during the mapping process were stored in a digital database specially designed for that purpose. This database allows update, and efficient storage and management of the information. The present paper has the goal to analyze and discuss the acquired avalanche information. The results show the complementariety of the different kinds of information. Using this data, a first spatial characterization of the avalanche terrain and the avalanches in this region was done.

KEYWORDS: Pyrenees, avalanche mapping, databases, spatial analysis.

1. INTRODUCTION

The growth of tourism in recent decades, in the Catalan Pyrenees (figure 1), has resulted in an increase in building, opening of mountain roads in the winter, and related infrastructures. As a consequence, exposure to natural hazards has increased and so has the risk. Risk and hazard maps are basic documents for land planning, management and disaster prevention. In 1,986, the Geological Survey of Catalonia (SGC) began an ambitious avalanche mapping plan 1:25.000 of all the Catalan Pyrenees. In 1,996, the first Avalanche Paths Map (APM) was published by the Cartographic Institut of Catalonia (ICC), and the last one, the 14th, was published in 2,006.

During the realization process of the APM a great deal of avalanche data was compiled. An avalanche database was created for storing and managing all this information. The aim of the Avalanche Database of Catalonia (ADBC) with the Avalanche Data Server (ADS) is to be the reference site for anyone interested. The information has been ordered according to three mapping concepts: avalanche path (AP), avalanche inquiry (AI), and avalanche observation (AO), which are explained later in this paper.

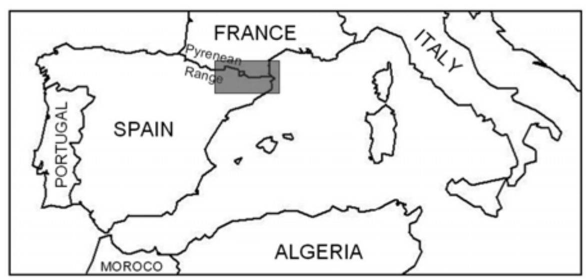

Figure 1. Location of the Catalan Pyrenees (grey box, enlarged in figure 3).

1.1. The Catalan Pyrenees

The Pyrenees constitute a mountainous system of about 450 km from the Atlantic Ocean (west) to Mediterranean Sea (east). They rise from the isthmus that links the Iberian Peninsula with the rest of the Euroasiatic continent. The study area, the Catalonia Pyrenees, is located in the eastern half of this range. It is 146 km long per 52 km wide at the western edge and 19 km wide at the eastern edge. The highest elevations reach 3,000 m asl, but in average they range between 2,500 and 3,000 m asl. The highest peak in this region is the “Pica d’Estats” with 3,143 m. The timber line is located between 2,100 and 2,300 m. The highest mountain villages are located from 1,500 m to lower altitudes. The highest winter opened roads reach 2,300 m. Two main kinds of relief can be differentiated: the glacial cirque areas, plateaus over 2,000 m asl, with abrupt peaks but with vertical drops not higher than 700 m; and the valley areas, with smoother relief, but with vertical drops in some cases higher than 1,500 m. This region is divided geographically in two parts, the Western (61%) and the Eastern (39%). The elevations and vertical drops of the Western part are higher than the Eastern one's (see table 1).

Terrain elev. (m)	Min	Max	Range	Mean	Std
Western Pyrenees	538	3143	2805	1814	488
Eastern Pyrenees	705	2913	2208	1675	456

Table 1. Descriptive statistics for the elevations in the Catalan Pyrenees.

1.2. Pyrenean climate

The singular geographical features of the Catalan Pyrenees produce three climatic varieties in a relatively small area. The zonal disposition of the axial range causes the retention of humid air masses, both tropical maritime from south and southwest flows and polar and artic maritime air masses from north advections. The meridian valleys configuration favours the penetration and the placement of the unstable air masses pointed out; the forced lifts by the relief sometimes result on heavy and persistent snowfalls. The proximity to the Mediterranean Sea and less to the Atlantic Ocean prevent extreme temperatures as it occurs on inland ranges, but surprisingly extensive pluviometric shadows exist as well. Finally, due to the relative low latitude of the massif, the Pyrenees are a boundary range between the humid ocean climate and subtropical dry climate.

The northwest part of the Catalan Pyrenees shows a humid ocean climate as the river basins drain to the Atlantic Ocean through France. Precipitations are abundant, over 1000 mm per year, even 1500 mm to 2000 mm. The total amount of fresh snow at 2200 m asl is about 500-600 cm per year. The distribution of the precipitation is quite homogeneous throughout the year, but with a minimum in summer and a maximum in autumn-winter.

The oceanic influence crosses the range to the south face but diminishing quickly. So, towards the south of the western Pyrenees, climate gains continental features. Winter precipitation is reduced and the precipitation of the equinoctial seasons increases. Predominant winds come from north and northwest, often with gusts over 100 km/h.

In the rest of the Catalan Pyrenees, the eastern Pyrenees, the oceanic influence disappears and the Mediterranean influence plays a significant role. Nevertheless, climate of eastern Pyrenees can not be defined as Mediterranean climate since this climate variety is roughly defined by a dry summer. On the contrary, eastern Pyrenees are rainiest in summer and driest in winter. The Mediterranean sea influence is observed both in summer by means of maritime, humid breeze feeding convective storms, and in the rest of the year by heavy precipitations, otherwise not frequent, due to lows centered on the Mediterranean sea blowing very humid, maritime flow from the east. Annual precipitation oscillates about 1000-1500 mm, locally less than 1000 mm. Predominant winds come from the north and maximum gusts sometimes exceed 200 km/h at 2000 m asl. The total amount of fresh snow at 2200 m asl is about 350-450 cm per year.

The study area was divided in seven nivoclimatic regions for a better description of the avalanche forecasting (figure 3). These regions are, from west to east: "Aran-Franja N de la Pallaresa" (Oceanic); "Ribagorçana-Vall Fosca", "Pallaresa", "Perafita-Puigpedrós", "V. N. Cadí Moixeró" (Continental); "Prepirineu"; and "Ter-Freser" (Mediterranean). In figure 2, the elevation of the seasonal snowpack is shown. It is 200 to 300 m lower in northern slopes than in southern slopes. At the same time, it shows a significant difference between the Oceanic nivoclimatic region -"Aran-Franja N de la Pallaresa"- and the rest of regions, with a mean seasonal snowpack elevation down to 400 m lower.

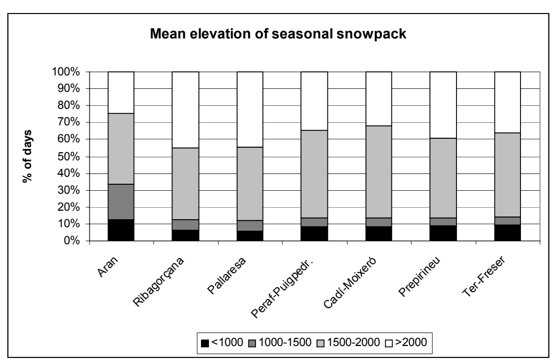

Figure 2. Frequency of the seasonal snowpack elevation vs nivoclimatic regions, from west to

east. Data obtained from the daily avalanche forecasting bulletin (ICC–SMC, from 2000/01 to 2004/05).

2. THE AVALANCHE PATHS MAP

In 2,006 the APM collection was finished. It consists of 14 maps that cover all the Catalan Pyrenees. An extent of 5,092 km^2 was surveyed. During this process 17,518 avalanche paths were mapped.

The APM is a susceptibility map that shows areas potentially affected by avalanches. It is based on the French “Carte de Localisation Probable des Avalanches” (CLPA; Pietri, 1,993). It is suitable for land planning at a regional scale. This information was compiled through terrain analysis, inquiries to the population and winter avalanche activity surveillance. The map is the synthesis of all the gathered information. Orange represents the areas mapped from terrain (including vegetation analysis) and violet represents a synthesis of the information gathered from inquiries and winter survey. The cartography was made on the ICC 1:5,000 digital bases (topography, ortophotos, and DEM; Martí et al, 2,000).

The finalization of the APM allows a first global vision of the avalanche hazard distribution in this region. The area potentially affected by avalanches covers 1,257 km^2. It is the 3.91% of the Catalan country, and considering the Pyrenean territory, it affects the 36% (Oller et al, 2006). As can be seen in figure 3, the western part of the range (from Andorre to the west) is the most affected, standing for the 78% of the total susceptible area.

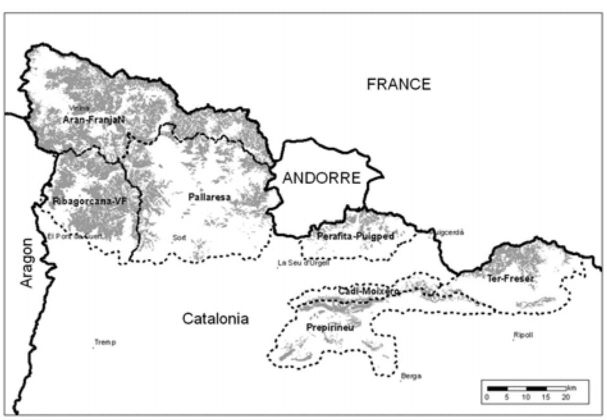

Figure 3. Avalanche paths extension (in grey) over the Catalan Pyrenees, and nivoclimatic regions.

3. THE AVALANCHE DATABASE OF CATALONIA

The Avalanche Database of Catalonia (ADBC) was created for storing the information gathered during the APM mapping process, and to register new information collected during winter seasons. The goal was to have an efficient system for data managing, analysis and actualization of the information.

The information stored in the ADBC is both graphic (maps) and alphanumeric (descriptions). Avalanche mapping concepts are represented by polygons (graphic) and a set of attributes describes its characteristics (alphanumeric). All this information was incorporated into a GIS. The graphic information was digitized? Using the ICC topographic map (1:5.000 scale). All the descriptive data (attributes) of avalanches were stored using digital forms. It was structured in three mapping concepts: Avalanche Path (AP), Avalanche Inquiry (AI) and Avalanche Observation (AO).

- Avalanche Path (AP): takes up the information of an area exposed to avalanche activity). Inside the AP, avalanches occur with different frequencies and dimensions. The AP limits are mapped from terrain characteristics and vegetation indicators. This, constitutes the descriptive information (25 fields). AP were systematically mapped throughout the entire region, and are the base of the ADBC. They are represented in orange. Limits determined by dendrochronological techniques are also included here. Two kinds of AP can be differentiated: well defined AP, where avalanches usually follow a similar track, represented on dark orange, and non distinguished AP, where avalanches usually follow different tracks, represented in light orange.

- Avalanche Inquiry (AI): takes up the information of an observed avalanche, in the past. This information is obtained from inquiries to local people. The AI limits are based on these explanations which constitute the descriptive information (10 fields). Some relevant characteristics such as date of occurrence, runout distance or damage, are pointed out. AI were mapped mainly near inhabited areas, where avalanche events interfere with human activity, and for this reason in most cases only the runout zone was mapped. They are represented in violet.

- Avalanche Observation (AO): takes up the information of an observed avalanche, which has taken place recently. Their limits are mapped from the direct observation of the avalanche. Date of release or observation, nivometeo conditions, type of avalanche, physical characteristics, damage or victims, constitute the descripitve information (60 fields). This information is obtained by the nivo-meteorological observation network, rescue teams, forest and mountain workers, ski resort crews, individuals (mountaineers), and in the case of major episodes, from the IGC technicians. They are being mapped mainly in populated areas, roads and ski resorts. Data collecting began in 1986. In 1,995 it was intensified but it is still a short period of observation. They are represented in blue.

Other information, such as defence structures built against avalanches, is also added to the ADBC.

	Graphic information	Alphanumeric information
AP	17,518	4,123
AI	1,925	2,525
AO	1,174	1,292

Table 2. Number of polygons (graphic information) and registers (alphanumeric information) existing in the ADBC at present.

This information is accessible to all kinds of users (researchers, enterprises, administration, decision makers, individuals, etc...) via web. The Avalanche Data Server (ADS) was the system conceived for these functions.

4. ANALYSIS OF THE ADBC AVALANCHE DATA

In table 2, the amount of graphic and alphanumeric information contained in the ADBC is shown. At present the bulk of all the graphic information is registered, although every winter season new AO information is gathered and added to the ADBC. Qualitative information is added too as alphanumeric registers. It must be said that there can be no correspondence between the graphic and the alphanumeric information in the cases of AI and AO. This is due to the fact that some non specific alphanumeric information is difficult to map. As a result of these considerations, only the graphic information was analyzed in this paper. This analysis was based on spatial characteristics which are important parameters for avalanche terrain analysis: starting zone elevations, runout zone elevations, aspect of the starting zones, vertical drop and surface. (McClung, 2,003).

Not all the graphic information was able to be used in this analysis. On the one hand only 8,153 of the 17,518 AP where used. These polygons correspond to well defined AP. Non distinguished AP were rejected. On the other hand, as mentioned before, AI graphic information is mainly located at the runout, and consequently only the parameters referring to this information were used. Furthermore, every AI polygon corresponds to a synthesis which is composed of all the AI information obtained in a given AP. In many cases, this information can be assumed to be the maximum avalanche limits of the XX Century. Finally, only the visible parts of avalanches were mapped for AO. Sometimes there is little information about the runout zone, and less about the starting zone. With this last mapping concept all the events have been taken into account, even if more than one event has been registered in a given AP. For this reason, not all the 1,174 AO will be usable and the amount will vary depending on the parameters. Unfortunately the short period of observation does not provide much information about major avalanches.

4.1. Starting zone elevations

This parameter is registered in AP and in AO. In AP it represents the maximum elevation where a release is expected. In AO it represents the actual maximum release elevation of an observed avalanche. In AI, there is little and, usually, inaccurate information because this parameter is difficult to observe and to remember.

Considering this, the mean elevation of the starting zones is almost 2,390 m asl. The highest starting zones are related to terrain characteristics. In AP they start near the highest peaks although the observed events (AO) only reach up to 2,960 m asl. More interesting are the minimum starting zone elevations, which depend on snowpack availability and stability. In AP they were mapped down to 905 m asl. This data has not been confirmed by AO, and the lowest observation was registered at 1,360 m asl. In general, the avalanches that initiate at very low elevations are small, have a small track, and are related to recent snowfalls. The shortness of the observation period does not allow us to confirm the AP cartography.

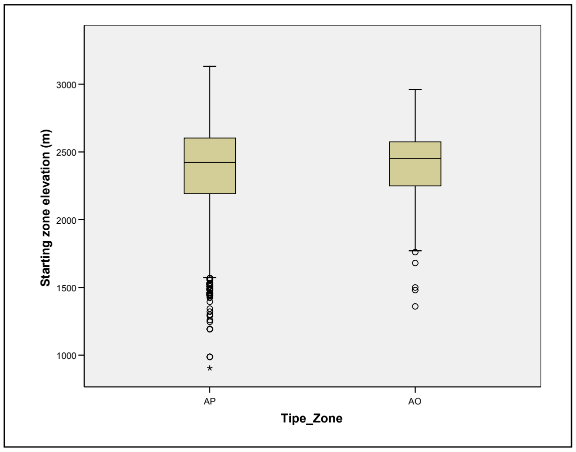

Figure 4. Box plot of the starting zone elevations for AP (N=8,153) and AO (N=472)

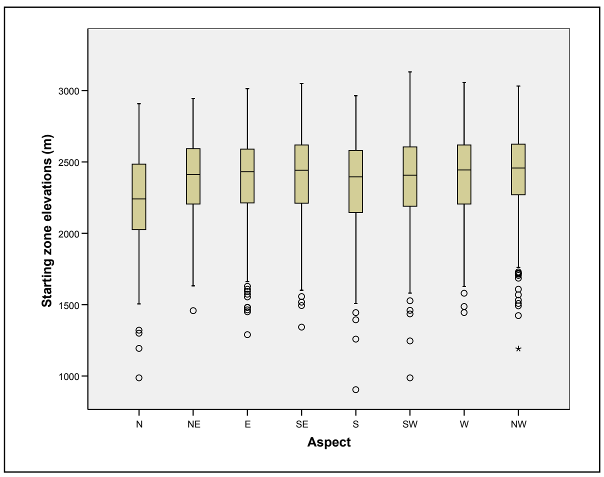

Figure 5. Box plots of AP (N=8,153) vs aspect of the starting zones.

According to aspect, in AP, the mean elevation of the starting zones is clearly lower on north facing slopes (figure 5). But the slopes where the lowest starting zones where registered were north, south and south-west. Unfortunately the limited number of AO cases was not enough to confirm the actual elevations.

Taking into account the nivoclimatical region (figure 6), from west to east a rise of the minimum elevations of the starting zones can be observed in AP. In AO, this happens especially in the westernmost and Atlantic influenced region, -"Aran-Franja N Pallaresa"-, where the minimum starting zone elevations are clearly lower than the others. In this case the climatic influence seems to play a crucial role.

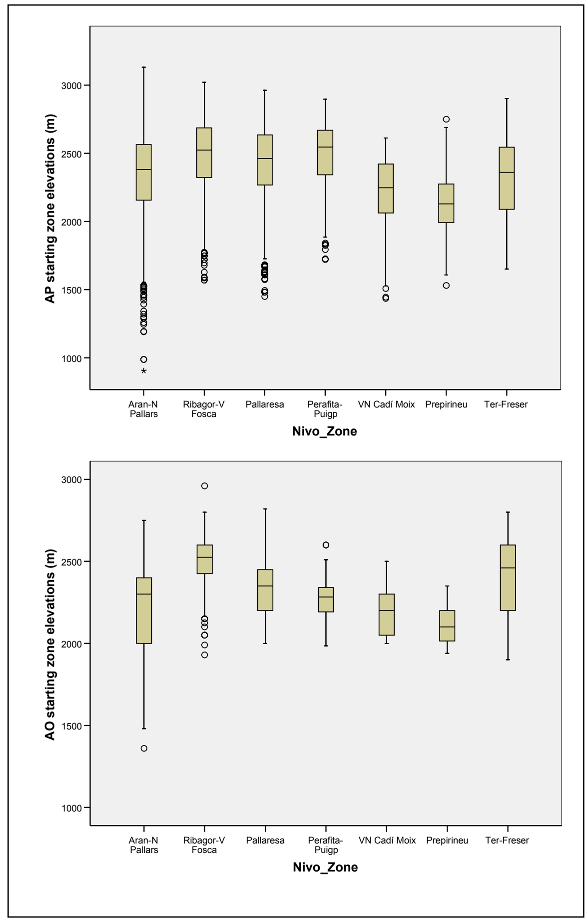

Figure 6: Box plots of AP (up, N=8153) and AO (down, N=472) vs nivoclimatical region

4.2. Runout zone elevations

This parameter is registered within the three mapping concepts. The AP runout limits correspond to those determined by vegetation clues and terrain analysis. In AI they correspond to the limits of witness descriptions, which are frequently imprecise. In the case of AO, they correspond to the minimum observed runout elevation. This data is strongly dependent on snowpack and terrain characteristics.

Figure 7 shows how the mean runout elevation is lower for AI and higher for AO. AP stay in the middle. Taking into account the minimum elevation, AP and AI register the same value, 638 m asl, but AO remains over 1,600 m asl. This information shows the importance of AI for complementing AP information. AI information can be used as evidence of avalanches in the past, where clues have disappeared. The great amount of AP and AO over 1,800 m asl is due to the large number of small avalanches that stop at high glacial plateaus because of short vertical drops. It is important to remark that below 1,500 m asl, the majority of human infrastructures such as villages and roads are located. The higher mean elevation of AO starting zones indicates the high frequency of high altitude avalanches.

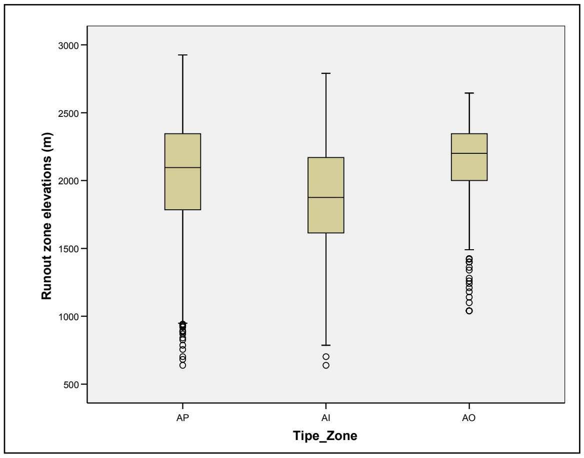

Figure 7. Box plot of the runout altitude in AP (N=8,153), AI (N=1,890) and AO (N=474).

Although avalanche runout zone elevations are specially controlled by terrain, in figure 8 it is possible to observe AP runouts mapped at lower altitudes on southern slopes. These results are slightly observed in AO data, but the small amount of data does not allow confirmation.

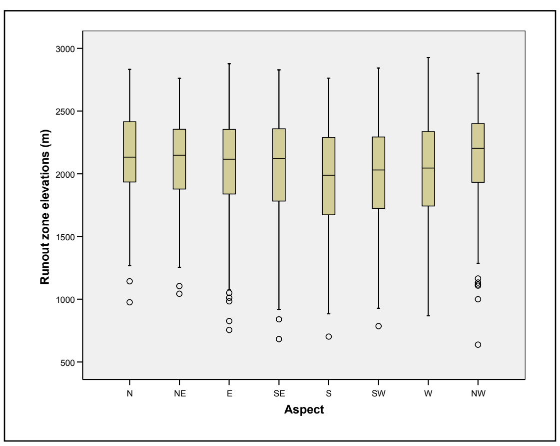

Figure 8. Box plots of AP (N=8,153) vs aspect of the runout zone.

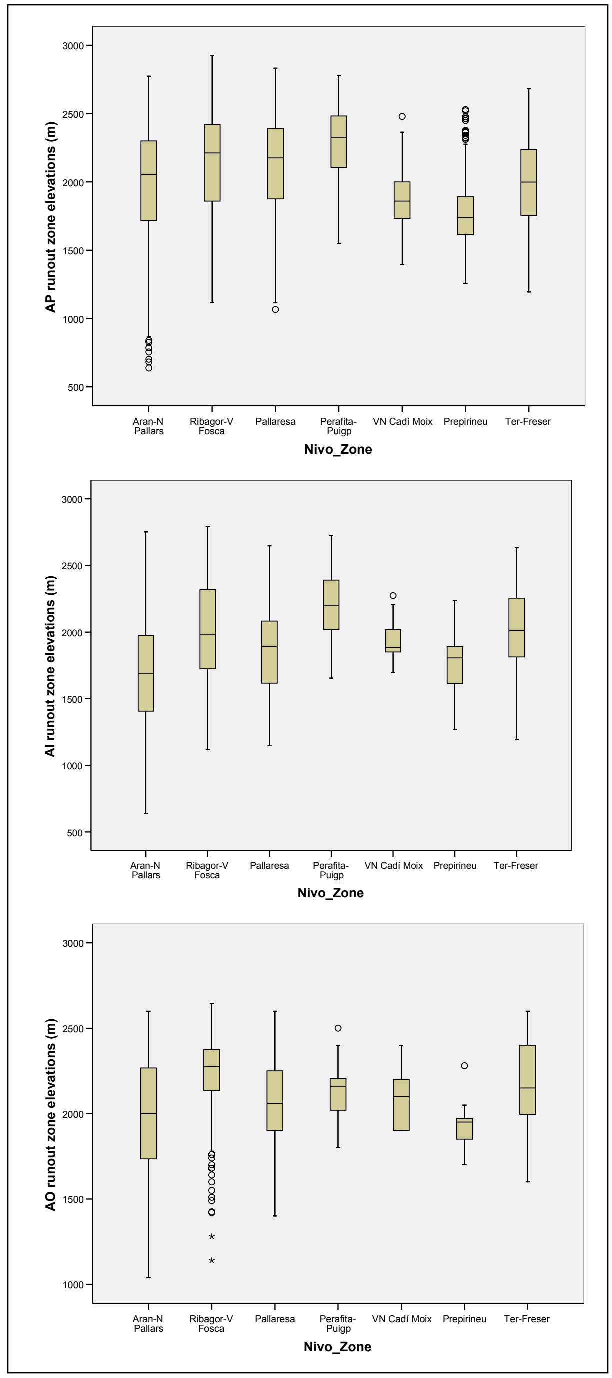

Figure 9: Box plots of AP (top, N=8,153) AI (center, N=1,888) and AO (bottom, N=474) of the runout elevations vs nivoclimatic region.

As previously explained, terrain characteristics have a very important influence in avalanche motion. In figure 9, the runout elevations per nivoclimatic region is shown, and a similar pattern for AP, AI and AO is plotted. Avalanches reach the bottom of the valley, and differences in runout lower elevation can be explained by terrain characteristics. Nivoclimatical conditions influence it, but no clear evidence was observed.

4.3. Size

Size can be measured from different approaches (McClung and Schaerer, 1,981). In our case the vertical drop and the projected area was analyzed. For the analysis, AP and AO were used when the entire polygon was known. In the case of AO, the avalanche size was directly analyzed. The AP analysis should be interpreted as a size analysis of the avalanche containers. The mean avalanche vertical drop is 200 m, but they range from 1,400 to 15 m. Generally, the smaller avalanches are not registered. As shown in figure 11, the average area is 2.67 Ha, and the maximum observed avalanches reach the 84 Ha. This data shows how the largest registered avalanches were observed in the western Pyrenees, specially in Ribagorçana-Vall Fosca and the Pallaresa regions. In the eastern Pyrenees, the biggest avalanches were observed in Ter Freser.

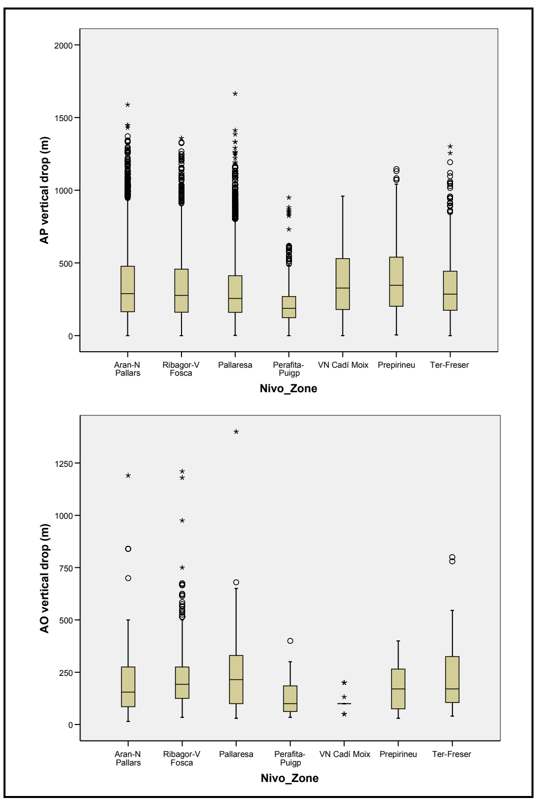

Figure 10: Box plots of the vertical drop for AP (top, N=8,153) and AO (bottom, N=472) vs nivoclimatical region.

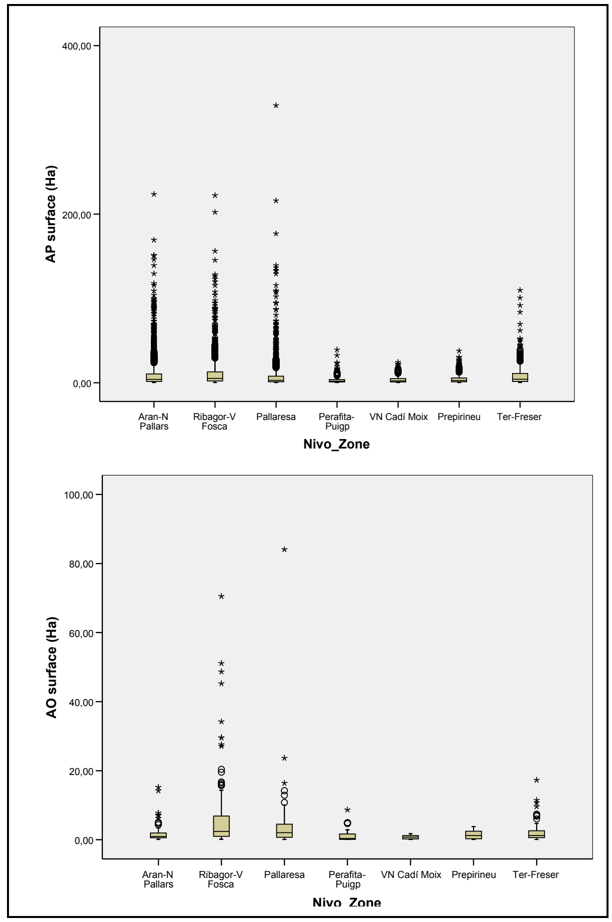

Figure 11: Box plots of projected surface for AP (top, N=8,153), and AO (bottom, N=432), vs nivoclimatic region.

4.4. Aspect of the starting zones

This parameter is registered in AP and in AO. In the first case, it is obtained automatically from DEM analysis. In AO, it is defined by the cartographer. The main directions of the AP are east, south and west (figure 12), with the same proportion, and the lowest is the north. This is logical, taking into account the north-south direction of the main valleys. This data can be used as a pattern for further analysis, Unfortunately there is not enough AO data for aspect analysis.

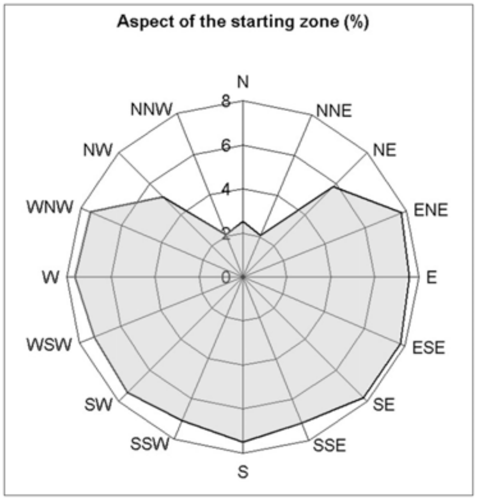

Figure 11. Aspect of AP starting zones diagram (N=8,153).

5. CONTRIBUTION OF THE ADBC DATA TO CARTOGRAPHY

The different methodologies used for nourishing the ADBC have helped to improve the avalanche cartography. The different mapping concepts have contributed to substantially increment of the avalanche mapping information. In a recent study (Oller 2006), the area affected by avalanches was analyzed. The results are shown in table 3. These results show that AI provided more spatial information than AO. But AO spatial increments were registered mainly in AP where there is no AI information. It reveals that AO mapping is more widespread over the territory, whereas AI is more concentrated in populated areas. This data is very important because the surface increments are registered in the runout zones. In recent dendrochronological studies (ALUDEX Project, Muntán et al, 2004), the previous mapped area increased more than 500% of the runout zone in a studied AP, and it demonstrated that this technique is very useful for avalanche mapping in forested areas.

	Increment of mapped surface	
	Ha	%
AI vs AP	1647	1.3
AO vs AP	383	0.3

Table 3: Increment of mapped area.

6. CONCLUSIONS

The finalization of the Avalanche Paths Map plan provides a first result of the avalanche phenomena in the Catalan Pyrenees. Terrain susceptible to being affected by avalanches, corresponds to 3.91% of the Catalonian territory, 78% to the Western Pyrenees and 22% to the Eastern Pyrenees.

The analysis of graphic data gives clues about the characterization of the avalancheous terrain and avalanches, and therefore for characterising the avalanche dynamics in the Pyrenees. At the same time it is very useful for establishing patterns for classifying the stored information and for adjusting analysis in this region.

The spatial analysis shows that climate has more influence than aspect in avalanche starting conditions. In the case of runout elevations, southern slopes register the lowest one's, but differences in geographic distribution could be related to topographic characteristics more than to climatic conditions. Surfaces and vertical drops are higher at Western Pyrenees due to those topographic characteristics. The aspect of the starting zones shows a homogeneous distribution except for northern oriented slopes where it decreases remarkably.

The increment of mapped surface obtained from Avalanche Inquiries and Avalanche Observations makes this information essential for any avalanche inventory. Dendrochronological studies are a very interesting technique for complementing the information.

Finally, this work has been very useful for testing the Avalanche Database application and the quality of the information.

7. ACKNOWLEDGEMENTS

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