



TEN YEARS OF AVALANCHE FORECASTING ON BONAIGUA AND BERET ROADS, ARAN VALLEY, SPAIN

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ABSTRACT

The Aran Valley, located on the northern side of the Central Pyrenees, is one of the areas with the highest avalanche risk rate in the whole mountain range (52% of the Aranese territory is affected). The exposed areas include not only high mountain terrain but also 6 population clusters and 3 main roads.

On the roads with which this paper is concerned, a combination of temporary and permanent mitigation measures has been set up. Over a total of 31.5 kilometers there are 82 avalanche prone areas. Most of the slopes affecting the road are south faces, with heights between 1600 and 2300 meters.

Until the year 2003, the avalanche risk management on these roads was based upon the regional avalanche danger advisory. In the winter of 2003/2004 a local forecasting system was set up. In order to do so, a snow and weather observation network was implemented and a specific danger scale was developed -adapted to the particular management needs of these roads. In the winter of 2008/2009, a helicopter-based triggering system using Daisybell was put in practice.

Overall, it has proved to be a highly effective system but the operations are largely dependent on the weather conditions.

A quick and visual interpretation bulletin is issued to the road managers and other interested groups (ski resort, person in charge of Civil Protection, police...) three times a week -or on a daily basis whenever there is the possibility of avalanches affecting the road.

The implementation of an avalanche prevention system and the close collaboration between the forecasting center and the road managers has resulted in an improvement of the viability and of the safety management of the roads.

Keywords: Pyrenees, Avalanche forecasting, mitigation, risk management.

1 INTRODUCTION

1.1 Location

The Aran Valley is a 625 km² territory located on the north face of the central part of the Pyrenean range. Although it is part of Spain and falls legally under the administration of Catalonia, a good amount of competences have been transferred to the local government (Conselh Generau d'Aran –CGA). Local Civil Defense and Avalanche Risk Management are among these transferred competences (Figure 1).

Local avalanche forecasting is carried out for two roads: the leg of route C-28 that passes along Port dera Bonaigua and the access road to Plan de Beret, route C-142b.

They are both important roads: route C-28 connects the Aran Valley with Catalonia and it constitutes a key access route for winter visitors. Route C-142b is the way in to the part of Baqueira Beret ski resort that hosts the biggest parking lot, made up by more than 6000 parking spaces.

The entity in charge of these roads is the Catalan Road Service, ascribed to the Catalan government (Servei de Carreteres de la Generalitat de Catalunya -SCGC). An agreement has been subscribed between the said SCGC, the Geological Institute of Catalonia (Institut Geològic de Catalunya-IGC) and the Aranese government (CGA), providing the latter the powers to run the local avalanche forecasting. In addition to this task, the CGA's Forecasting Centre carries out a regional avalanche forecasting addressed to mountaineers [1,2].

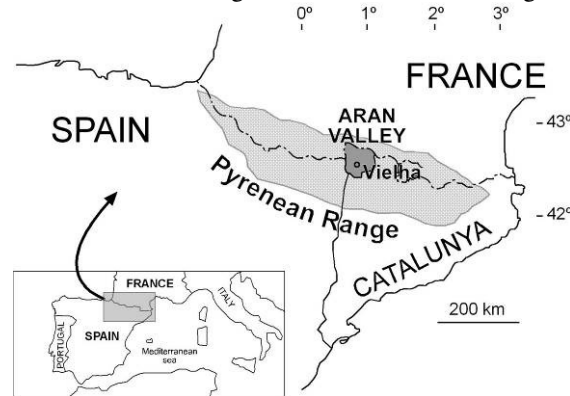


Figure 1. Location map.

1.2 Climatology

The study area presents an oceanic climate, receiving a strong influence of the wet fluxes coming from the Atlantic Ocean. Precipitations are abundant, over 1000 mm per year, even reaching the 1500 mm at height of 2000 m asl. The total amount of fresh snow at 2200 m asl is of about 600-700 cm per year and the distribution of the precipitation is quite homogeneous throughout the year [4].

The roads present two differentiated sectors in terms of climatology. Route C-142b and the northern leg of route C-28 are clearly dominated by the characteristic northern fluxes that affect the north face of the Pyrenees, while in the leg of route C-28 that lays on the south face -although also under the influence of the Atlantic Ocean-precipitations are less abundant. Fluxes coming from the north and the north-west are funneled along the valley of Ruda, originating strong winds which cause important circulation problems since they reduce visibility and form snow drifts and wind slabs, particularly on the south face.

1.3 Avalanche terrain

The leg of route C-28 that passes along Port dera Bonaigua connects the Aran Valley with the south face of the Pyrenees. It is divided in two parts: north and south face (figure 2).

The north leg of route C-28 which is affected by avalanche activity starts at the population cluster of Baqueira (1500m) and goes up to Port dera Bonaigua (2072 m). It is 9 km long and it travels up the valley of Ruda in an approximately NW-SE direction. Along these 9 km, it passes a total of 20 avalanche paths, many of them with a return period of less than a year.

The vegetation of the area ranges from deciduous shrub woods, on the lowest elevations, to young pine woods (*Pinus uncinata*), starting at 1750 meters and continuing up to 2000 meters asl. At the avalanche starting areas, located between 1700 and 2300 m asl, the vegetation is made up by scattered trees and alpine meadows. Although the average slope is of about 30°, in many areas slopes are steeper than 45°.

The south face leg of route C-28 goes from Port dera Bonaigua (2072m) down to Casa Sastrada (1400 m). It is 11 km long and it follows the valley of the Bonaigua river in a NW- SE direction, along the SW face and passing 28 avalanche areas. At the highest areas, the vegetation consists basically on alpine meadows, and only at the southernmost end are there deciduous woods. The slopes range from 30° to more than 45° and most of them are between 35 to 45° steep.

1.4 Defense works

The biggest part of the defense works, protection most of the avalanche prone areas, is located on Route C-142-b. The expenditure in these works started back in the 1970's when snow sheds were built on the upper leg of the road. As of the 1980's, a good number of snow nets have been installed at the areas where avalanches occur

most frequently. Terraces have also been dug so as to increase the roughness of the terrain. Even so, few defense works have been installed on the areas where the biggest avalanches with a longer return period occur.

On the north face of route C-28 there are no defense works, mainly because of their high cost. At present there is a barrier system in order to close it down when there exists avalanche risk. Snow and wind fences have been set up in one of the existing avalanche prone areas on the southern leg of route C-28, but at the remaining avalanche prone areas in this leg there are no protective structures.

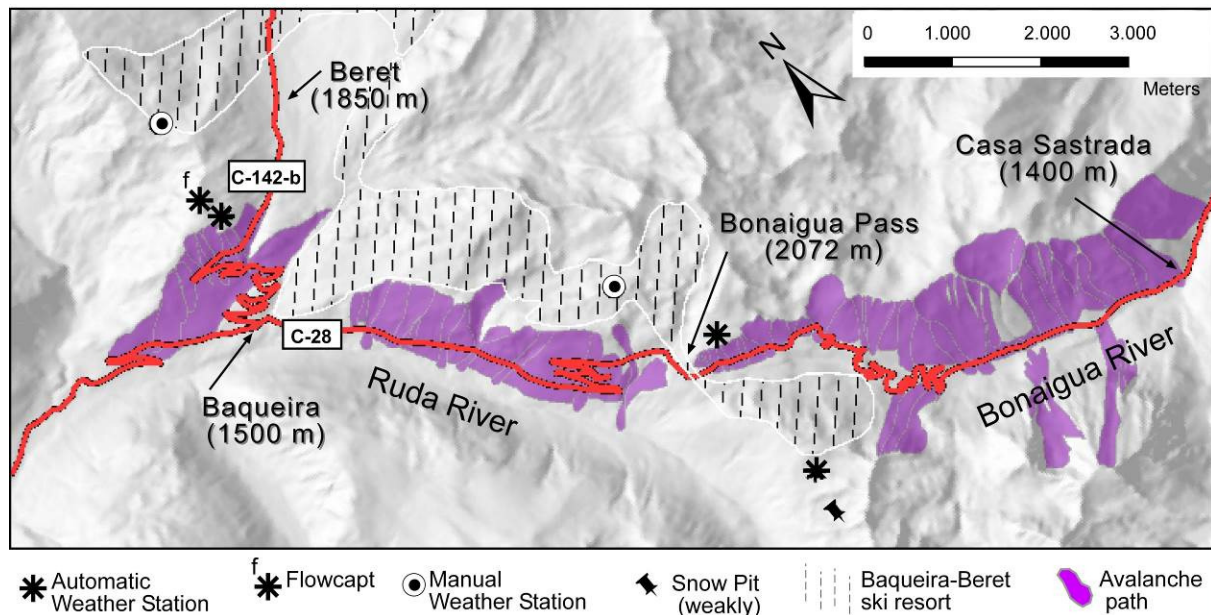


Figure 2. Location of the studied roads indicating the main avalanche prone areas and the scope of the observation network.

2. METODOLOGY

In order to address the local prediction, it was necessary to have a more detailed knowledge of the avalanche activity and the characteristics and evolution of the snow. To this purpose, a detailed avalanche mapping was carried out and a dense snow and weather observation network was organized.

2.1. Meteorological and snow measurements

The data on the condition and evolution of the snowpack come from a comprehensive observation network consisting of automatic stations, daily human observation and sporadic field outings.

The automatic network is made up of three snow and weather stations that measure both meteorological parameters (temperature, humidity, wind speed and direction, and radiation) and snow parameters (snow height and snow temperature). Also part of the automatic network is the flowcapt station that measures the wind direction and speed, and the snowdrift. In addition, two human observation points ascribed to Baqueira's Ski Patrol provide local weather (nimet) data on a daily basis. These systematically collected data are completed by occasional outings aimed at evaluating the stability of the snowpack by conducting layer profiles, stability tests and avalanche activity observation.

2.2. Avalanche cartography

With the existing 1:25,000 maps by the Geological Institute of Catalonia (IGC) as a starting point, a 1:10,000 detailed mapping was carried out with a particular focus in determining the avalanche starting zones of those avalanches affecting the road. The results have been the working document when planning the subsequent forecasting and artificial triggering actions (Figure 3).

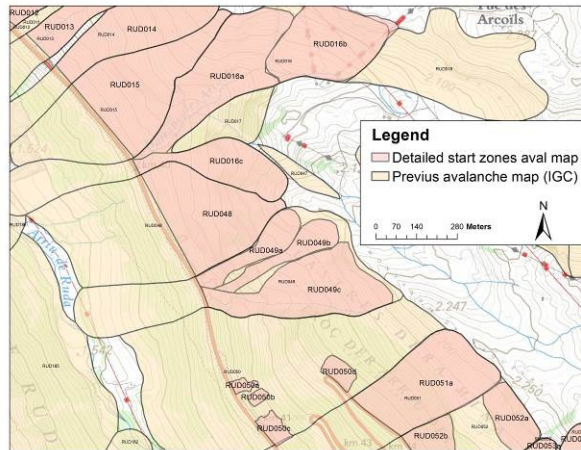


Figure 3. Map extract showing the detailed mapping of the avalanche starting zones on the basis of the previous maps.

2.2. Forecasting

Until the season of 2003-2004, the management of the road pivoted on the regional avalanche forecasting and the road was closed whenever the avalanche danger was therein rated 4-HIGH or higher. This brought about some management problems, since at times there would be local avalanche activity even when the regional danger was rated lower and, on the contrary, at times the regional danger would be 4-HIGH while the slopes affecting the road would be stable [3].

The local avalanche forecasting started as of the season of 2003-2004, with the regular publication of an Avalanche Danger Report (CPA) that reports on the likelihood of avalanches arriving at the road and uses a specific avalanche danger scale.

The purpose of this specific avalanche danger scale is to make it easier for the road managers to interpret the avalanche danger situations. The scale is a matrix combining two factors: likelihood and size of the forecasted avalanches. The combination of these two parameters results in a scale with 4 levels of danger: Low, Medium, High and Very High (figure 4). In addition, when a big number of avalanches is expected to occur, the rated danger increases one level.

Likelihood of avalanche	Meaning
Unlikely	0 – 30 %
Possible	30 – 70 %
Likely	> 70%

Avalanche Size	Description
Sluff	- Does not cover the road. - Small surface snow slide.
Small	- Could cover the road. - Could bury a person. - Stops before the lower end of the slope.
Medium	- It crosses to the opposite side of the road. - Could destroy the defense fence and a few trees and cars. - Could affect the entire slope.
Large	- Crosses to the opposite side of the road and affects the entire slope. - Destroys the defense fence, a part of the forest, heavy vehicles and buildings. - Arrives at flat areas (valley bottom).

AVALANCHE DANGER SCALE*						
		Likelihood of avalanches				
		Unlikely	Possible	Likely		
AVALANCHE SIZE	Sluff	L	L	L	L	Low
	Small	L	M	H	M	Medium
	Medium	M	H	VH	H	High
	Large	H	VH	VH	VH	Very High

* If a big number of avalanches is expected to occur, the danger increases one level

Figure 4. Specific Avalanche Danger Scale.



Currently the CPA is intended for the road managers and those responsible for Civil safety. It differentiates 8 areas that present very distinct morphological characteristics, estimating the particular avalanche danger for each and determining whether there is need for triggering actions (Figure 5).

The use of this specific scale makes the CPA a simple and easy to interpret tool for the road managers.

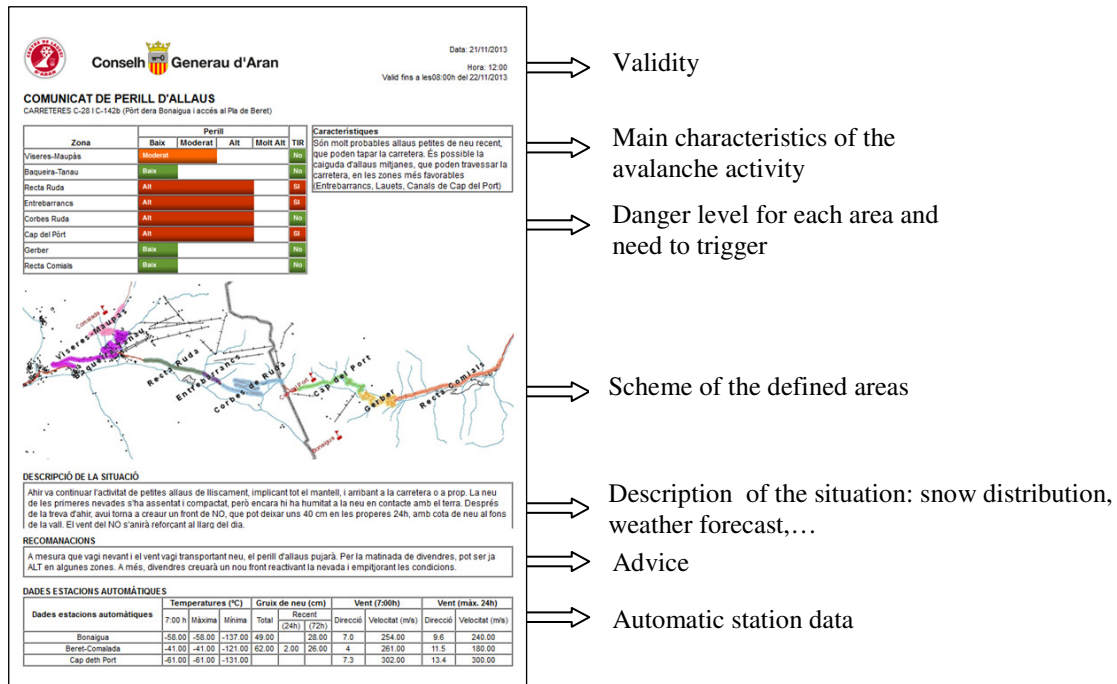


Figure 5. Sample Avalanche Danger Report (CPA)

2.3. Artificial avalanche triggering

As of the winter of 2008-2009, preventive avalanche triggering has started, using the device known as DaisyBell®.

A rigorous shooting protocol has been established since the avalanche areas are located within the area of influence of Baqueira-Beret ski resort and they constitute important off-piste terrain. All the concerned entities are involved in this protocol: the Catalanian road service, the Aranese SAR service (Pompièrs d'Aran), Baqueira-Beret ski resort and the Catalanian Police Department, as well as the owners of private businesses located in the area. To this aim, route C-28 has been divided into four sectors with varying levels of warning needs.

The use of Daisybell® during the past five seasons has made it possible to determine in which situations it works best. The results have usually been satisfactory with dry snow which has not been compacted by the wind. Few actions have been carried out in wet snow conditions and the results have not been too positive.

3. CASE STUDIES

10 years of local forecasting and monitoring of the avalanche activity in the area have provided a great knowledge of the dynamics and behavior of avalanches.

In this paper we will present two examples: first, a preliminary analysis of the characteristics of the surveyed avalanches in one of the areas where avalanches are more frequent. Second, two snow and weather situations in which the results of the road management are significantly different, with an analysis of the causes and consequences.

3.1. Profiling the frequency of avalanche activity

The target of this example is the area typified as RUD014, located halfway along the straight stretch of Ruda, on route C-28, some 3 km from Baqueira. It is an open slope, presenting a wide starting zone with little roughness and scattered trees and bushes which are highly affected by the intense avalanche activity that takes place there. The highest point of the slope is 2125 m and the road crosses it at 1650 m. The average and maximum gradients are 28° and 40°, and the slope turns into a slight gully on its lower end.

Even though a thorough monitoring of the avalanche activity in the area has been carried out, the collected data are still partial as it is sometimes not possible to observe all the activity that takes place while the road remains closed. The most frequently missed data are those related to cold periods, when fresh and dry snow avalanches leave superimposed debris which are not easy to spot after periods of bad weather. This compilation does not include the activity registered during the months of January and February 2003, the season that saw the highest avalanche activity to date and which triggered the implementation of the current local forecasting system.

During the 10 seasons concerned, 37 avalanches affecting the road have been registered, 20 of which covered it partially and 17 of which crossed over to the opposite side and continued downhill. Attention is drawn to the avalanche that occurred during the season of 2008-2009 and largely crossed the road, arriving as far downhill as 1575m (figure 6).

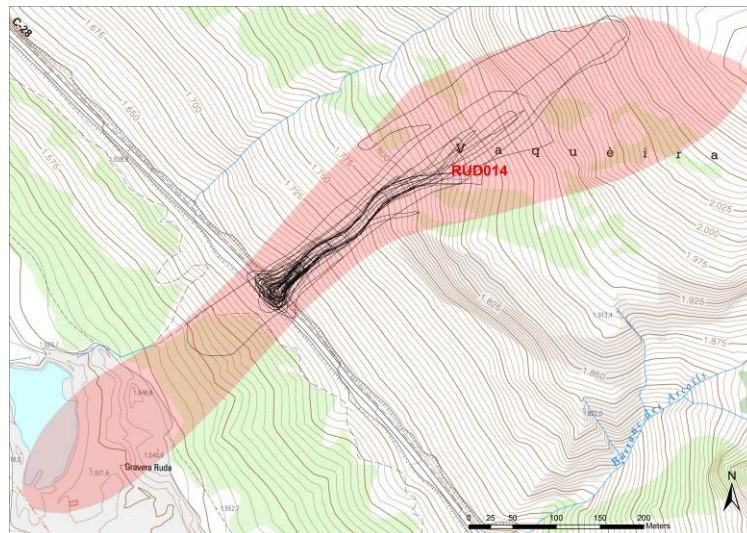


Figure 6. In pink: mapping of the RUD014 area. In black: perimeter of the avalanches surveyed during the past 10 seasons.

3.2. Influence of weather conditions in the management of residual risk

Two situations with significantly different snow and weather conditions are presented here, with a direct influence in the effectiveness of the applied triggering method and, therefore, in the road viability management.

The first case study dates from January 26th and 27th 2009. There was a depression centered in Corsica with an Atlantic anticyclone sending very cold and wet air from the north to the Pyrenees. About 80 cm of snow accumulated at 2200 m asl, very low temperatures were registered (-10°C) and gentle to moderate winds blew from the north. The avalanche danger was rated HIGH in several areas due to the possibility of large size fresh snow avalanches. On the morning of January 27th, the anticyclone entered from the west, giving rise to a stable day without wind and thus allowing for a control action with the Daisybell. 10 medium and large size avalanches were triggered that arrived as far as the road. After this operation the danger was turned down to MODERATE, allowing for the road to be reopened to traffic. On the following days there were no avalanches affecting the road (fig. 7a).

The second case study took place in March 2013. Between March 11th and March 14th, a disturbance located on the east of the peninsula created a flow from the north and north-east that brought about more than 60 cm of snow at 2200 m asl, in combination with very low temperatures and strong winds. Starting on March 15th, a local situation settles in with the arrival of warm and wet winds that cause little precipitation and temperatures to rise, and keep an overcast sky on the north face of the Pyrenees until the end of the month. As of March 24th a period of small and medium size avalanches starts affecting the Bonaigua on a daily basis (fig. 7b). During this period the road is intermittently open to traffic and the avalanche activity is permanently monitored. The avalanches



that occur are, for the most part, small size avalanches or sluffs, although some medium size ones are also registered. The activity takes place mainly from midday onwards. The snowpack remains wet down to the base and regelation is very weak or even inexistent. Under these conditions it is assumed that the operations with Daisybell® are not effective.



Figure 7. Left: Dry snow avalanche triggered with Daisybell® on January 27th, 2009. Right: Wet snow debris affecting the road on March 28th, 2013.

4. DISCUSSION AND CONCLUSIONS

The road management has seen a significant improvement since the very first year it started to be based on the local forecasting. Already after the first winter it became clear that there was a strong discrepancy between regional and local forecasting.

The CPA model allows for the identification of the avalanche danger in each of the 7 areas which have been defined, which implies the possibility of road management being optimized. Specific operations are scheduled to take place in order to identify the limitations of Daisybell®, as well as to be able to improve its results.

Finally, the great knowledge there exist nowadays regarding the dynamics of the avalanches that affect the road will serve as a base for the planning and implementation of new protective measures.

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