EVALUATION OF 30 YEARS OF NIVO-METEOROLOGICAL AND AVALANCHE DATA IN ANDORRA

Jon Apodaka*[1,2], Marc Pons[1], Laura Trapero[1], Aina Margalef[1], Anna Albalat[1], Natalia Gallego[1] Juan Ignacio López-Moreno[3] and Glòria Furdada[4]

[1] *Snow and Mountain Research Centre of Andorra (CENMA-IEA), Sant Julià de Lòria, Andorra*
[2] *University of Andorra (UdA), Sant Julià de Lòria, Andorra*
[3] *Pyrenean Institute of Ecology (CSIC, Spanish Research Council), Zaragoza, Spain*
[4] *RISKNAT, Geomodels Research Institute, Dpt. Earth Ocean Dynamics, Faculty Earth Sciences, University of Barcelona, Barcelona, Spain*

ABSTRACT: Andorra is located in the axial Pyrenees, in a climatic transition zone (Atlantic-Mediterranean). Hence, different atmospheric circulation types generate a high variability on the spatial distribution of snowfalls and windstorms. This leads to episodes with different spatial patterns of avalanche activity affecting in a different way several ski resorts located at very short distances between them. Our main, long term objective is the snow climatic zoning of Andorra taking into account three different factors: a) synoptic circulation types, b) historical nivometeorological records and c) the corresponding avalanche situation. As a first step, in order to characterize the snow climates, different data are being analysed and correlated: thickness of precipitated snow; days with snowfall of 20, 30, and 50 cm; accumulations of 20, 30, and 50 cm in 3 consecutive days; PIDA (artificial Avalanche triggering) days; results of PIDA (total shots, shot points, orientations, method, avalanche size, hours...); synoptic circulation types and occurred accidents. The expected results are the definition of the different snow climate zones of Andorra and different avalanche activity scenarios related to these zones. This result will help the different ski resorts in Andorra in their decision-making and risk management when artificial triggering of avalanches is required.

KEYWORDS: risk *management, snow climate, ski resort, artificial triggering, avalanche, Andorra.*

1. INTRODUCTION

Andorra, a small country between France and Spain, is located in the axial Pyrenees, in the middle of a climatic transition zone (Atlantic-Mediterranean) *(Figure 1)*. The different types of atmospheric circulation generate a great variability in the spatial distribution of snowfalls and wind episodes. This leads to episodes with different spatial patterns of avalanche activity affecting in a different way, for instance, the different ski resorts located at very short distances. This fact, on one hand, makes Andorra an area of great scientific interest, and on the other hand, the application of scientific research can be really helpful in the avalanche risk management in the country.

Snow avalanches are also a problem which both society and specially ski resorts and the governmental road management department have to face with during the whole winter season, from mid-November to mid-May.

Our main, long term objective is the snow climatic zoning of Andorra taking into account three different factors: a) synoptic circulation types, b) historical nivometeorological records and c) the corresponding avalanche situation. Reference works are those of Mock and Birkeland (2000), Castebrunet et al. (2004, 2007, 2012), Esteban et al. (2005, 2009) Oller et al. (2015), Germain (2017) and García (2018).

Several sources of data exist in Andorra, but they are very different between them. On the other hand, most series present lack of data, especially the days of heavy snowfall due to the impossibility of taking them or because the devices are damaged. The hypothesis of the present work is that the different types of data could complement each other and help to get a comprehensive knowledge.

Corresponding author address:
Jon Apodaka , Snow and Mountain Research Center of Andorra, Av. Rocafort, 21-23, AD600 Sant Julià de Lòria – ANDORRA Tel. (+376) 742.630 – www.cenma.ad – *japodaka@iea.ad*

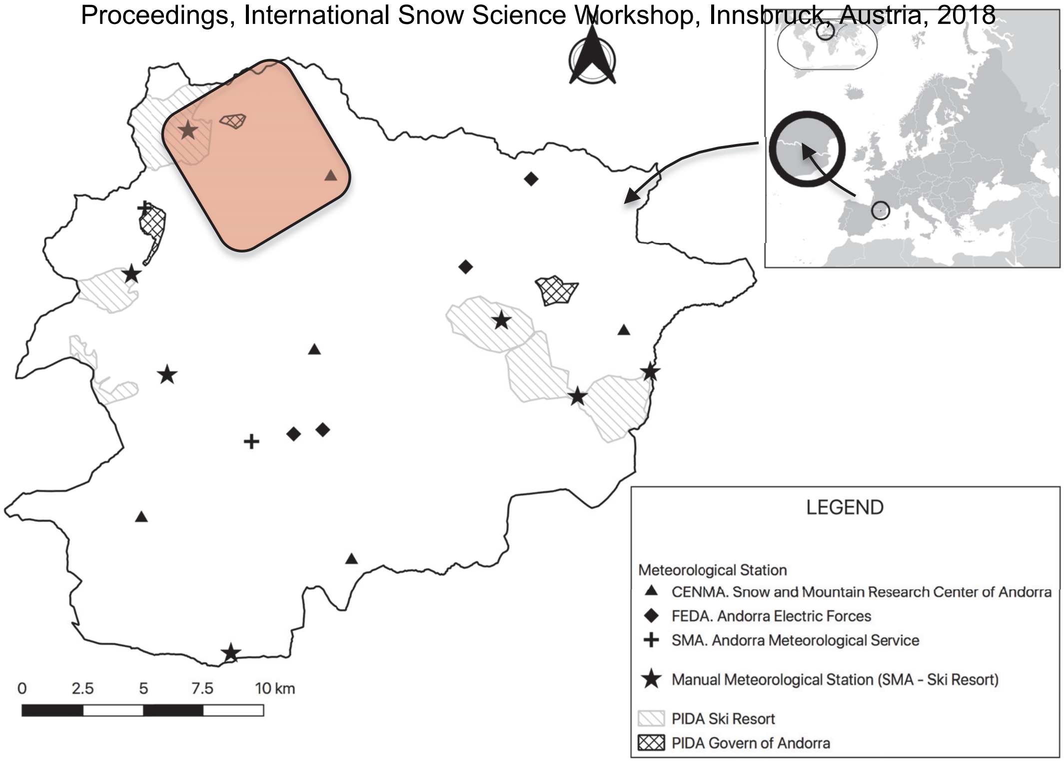

Figure 1: Location of Andorra in the World and in Europe. Nivo-meteorological stations across the country and places of avalanches artificial triggering, using explosives (PIDA areas). The study area is located inside a red rectangle.

As a first step, a pilot site the northwest area of Andorra was selected. Different data were analysed and correlated: thickness of precipitated snow; days with snowfall of 20, 30, and 50 cm; accumulations of 20, 30, and 50 cm in 3 consecutive days; PIDA (artificial avalanche triggering) days; results of PIDA (total shots, shot points, orientations, method, avalanche size, hours...) and synoptic circulation types.

2. DATA DESCRIPTION

In this study, the data series are obtained from 3 different sources: from the meteorological station of CENMA (Snow and Mountain Research Center of Andorra), from the manual meteorological station of the ski resort of Ordino-Arcalís, from the operation of preventive avalanche triggering of the CG-3 road and from accidents (Figure 1).

Ordino-Arcalis Ski Resort Station

Nivometeorological data recorded during winter seasons from 1983/1984 season to the present. The measured variables are the meteorological observations (NIMET code) and the frequency of measurements is 2 per day at 8 am and 13 pm in local time during the winter season.

Automatic Weather Station of Sorteny

The weather station measures temperature, relative humidity, precipitation, direction and force of the wind (6.5 m), solar radiation, atmospheric pressure, snow height and snow and soil temperature. The observation period is since 2010 until today and the measurement frequency is 10 minutes.

Database of the Avalanches Artificial Triggering using Explosives: PIDA CG-3 road

In the Database of the artificial triggering of avalanche operations the shooting date is indicated and variables such as shooting zones, estimated accumulated new snow, wind and direction and visibility among other annotations are compiled. Shots were done when the risk perception regarding road safety recommended it (PIDA operations).

In this first pilot study, the data period covering the three sources of information is of 5 winter seasons (2009/2010-2014/2015).

Daily Weather type classification

Daily Automatic synoptic classification using the Jenkinson and Collison (1977) methodology permitted to define a circulation type for every day of the series to compare. The most frequent weather types were North, North West, Anticyclonic, North East, East, Cyclonic and South West *(Figure 2).*

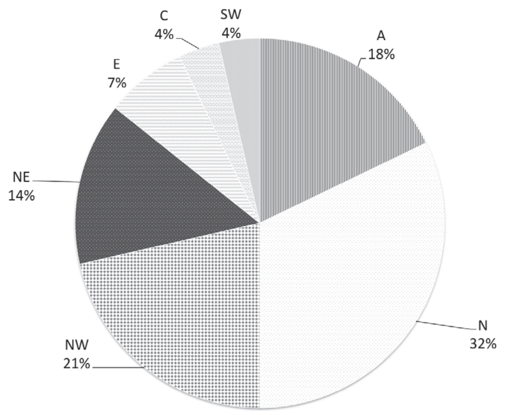

Figure 2: Weather Type according to the Automatic Synoptic Classification of Jenkinson and Collison during the days of PIDA.

3. METHODS

First, it is necessary to perform a quality control of the data series. In many cases there are errors, inconsistencies or no data have been registered. For instance, PIDA information has been recovered from manual reporting datasheets, treated to find errors and inconsistencies and digitized into a new database. For the nivometeorological information daily control has been carried out. Then, a comparison between all the information sources has been performed to identify inconsistencies and errors in the data.

From the records of the PIDA, the days in which artificial avalanche triggers have been made by explosives have been identified, days in which the perception of risk regarding road safety has been high.

The days of PIDA are compared with the data from the manual meteorological observations of Ordino-Arcalis, Sorteny automatic Weather Station and the daily weather types classification. Once the comparison of data series is done, these are graphed and the results analysis is performed.

4. RESULTS

In this pilot study, we analyzed 5 winter seasons in which the three series of data analyzed overlap. During this period, 28 PIDA operations have been identified.

The results can be characterized in 6 different preliminary groups *(Figure 3):*

1. Days of PIDA in which the snowfalls are in most cases greater than 20cm and the data between the manual station of Ordino Arcalís and the Sorteny automatic are concordant. (18%)

2. Days of PIDA in which the data of Sorteny exceed 25 cm and in Ordino-Arcalís no data has been recorded because the road or the ski resort is closed (totally or partially) (25%)

3. Days of PIDA in which the data of Sorteny are less than 25 cm of snow or decrease (probably snowdrift or snow settling) and in Ordino-Arcalís there is no data recorded (18%)

4. Days of PIDA in which the Sorteny sensors have not registered any data due to a sensor error. (14%)

5. Days of PIDA in which the thickness has generally decreased compared to the previous day (7%)

6. Days of PIDA in which nivometeorological data have not been recorded in Ordino-Arcalis or Sorteny (18%)

At the same time, the Automatic Synoptic Classification of Jenkinson and Collison (1977) has been compared with the days of PIDA, characterizing in this way the synoptic situations of the episodes *(Figure. 2).*

5. DISCUSSION

The comparison of these sources helped to fill some data gap or some inconsistency, especially thanks to the Automatic Station of Sorteny. However, many of those days both measurement sites has no data (18%) or the snow sensor of Sorteny (14%) is not correctly working. Even that the data of recorded snowfall will be highly conditioned by wind, temperature increase or precipitation in the form of rain, which alter the results and the behavior between measurement sites will be in same cases different. Moreover, in some episodes, the behavior of the two measurement sites is totally different, for instance, slightly increasing the snow height in one site and slightly decreasing in the other site. So, the potential of filling gaps and inconsistencies by the comparison of these series is limited.

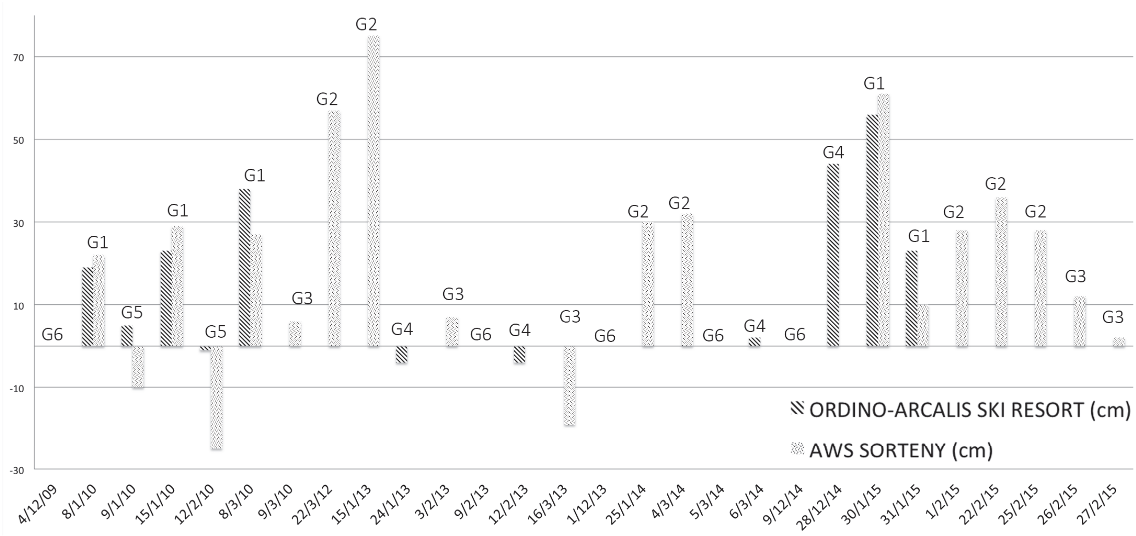

Figure 3: Days of PIDA, comparative record of snowfall in Ordino-Arcalis and Sorteny and characterization in groups of the patterns.

Regarding the factors that lead to artificial avalanche triggering operations, most of the cases are correlated to intense snowfalls (greater of 25 cm), usually during N and NW weather type days. In some cases, PIDA interventions doesn’t correlate with snowfall days but with the following days, showing continuity in the triggering operations during the coming days after the snowfall.

In a few occasions the operations of PIDA are activated due to weak snowfalls but with important wind transport. On these occasions, the meteorological stations do not give easily comprehensible information and are the cases with usually different behaviors between measurement sites. Those days have less marked weather types but with a first insight it seem that E and NE situations lead to this kind of scenarios with a higher frequency.

The Weather Type of the day of PIDA is not always related to the meteorological situation that caused the snowfall and must be taken into account analyzing the previous and coming days. So a further crossing and analysis of this information with the meteorological data of previous and coming days could lead to better correlations between those sources of information and the occurrence of artificial avalanche triggering operations.

6. CONCLUSIONS

The historical record of artificial avalanche operations (PIDA) can be very helpful to characterize different avalanche scenarios or when the perception of risk has been high.

Even though sometimes the quality of data is not as high as desired, the comparison of this data with different nivometeorological measurement sites can help to identify data gaps and inconsistencies between series and help to better characterize avalanche scenarios. However, due to the quality of the series, many times with simultaneous data gaps in all the nivometeorological stations, or the different behavioral pattern of the measurement sites during specific weather types, the potential of filling gaps and finding inconsistencies is limited.

The data of the operations of PIDA can be useful when identifying gaps in snow series taking into account the information acquired during the operation and the data of the nearest meteorological stations but the potential of filling gaps and inconsistencies by the comparison of these series is limited.

In this first preliminary study, some patterns can be found between the occurrence of artificial avalanche triggering and the different weather types. When crossing this information with the nivometeorological records and the occurrence of PIDA interventions some patterns show up as more frequent and recurrent that permit to start to identify potential factors leading to securing operations

These first results show that the correlation of the historical nivometeorological records, the records of the avalanche triggering intervention plans and the daily weather types classification could help to better understand the avalanche scenarios in different areas in Andorra, characterize the temporal and spatial patterns of avalanche activity and develop a zoning of the country. This information could be relevant for governmental road management department and the different ski resorts to help in the decision-making and risk management when artificial triggering of avalanches is required.

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