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Characterizing major avalanche episodes in space and time in the twentieth and early twenty-first centuries in the Catalan Pyrenees

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ABSTRACT

With the aim of better understanding avalanche risk in the Catalan Pyrenees, the present work focuses on the analysis of major (or destructive) avalanches. For such purpose major avalanche cartography was made by an exhaustive photointerpretation of several flights, winter and summer field surveys and inquiries to local population. Major avalanche events were used to quantify the magnitude of the episodes during which they occurred, and a Major Avalanche Activity Magnitude Index (MAAMI) was developed. This index is based on the number of major avalanches registered and its estimated frequency in a given time period, hence it quantifies the magnitude of a major avalanche episode or winter. Furthermore, it permits a comparison of the magnitude between major avalanche episodes in a given mountain range, or between mountain ranges, and for a long enough period, it should allow analysis of temporal trends. Major episodes from winter 1995/96 to 2013/14 were reconstructed. Their magnitude, frequency and extent were also assessed. During the last 19 winters, the episodes of January 22–23 and February 6–8 in 1996 were those with highest MAAMI values, followed by January 30–31, 2003, January 29, 2006, and January 24–25, 2014. To analyze the whole twentieth century, a simplified MAAMI was defined in order to attain the same purpose with a less complete dataset. With less accuracy, the same parameters were obtained at winter time resolution throughout the twentieth century. Again, 1995/96 winter had the highest MAAMI value followed by 1971/72, 1974/75 and 1937/38 winter seasons. The analysis of the spatial extent of the different episodes allowed refining the demarcation of nivological regions, and improving our knowledge about the atmospheric patterns that cause major episodes and their climatic interpretation. In some cases, the importance of considering a major avalanche episode as the result of a previous preparatory period, followed by a triggering one was revealed.

1. Introduction

At mountain areas that receive frequent large storms, the 10-year and the 100-year avalanches in a particular path may be similar in size. In contrast, in some generally low-snowfall areas, the 100-year avalanche may be many times larger than the 10-year avalanche. The historical record or the damage to vegetation provides good evidence of avalanche potential in the heavy-snowfall locations, while the low-snowfall locations require extensive applications of indirect techniques to determine the size of the long-return-period event (Mears, 1992).

The Catalan Pyrenees, especially in its southern side present a low and irregular snowfall regime (García et al., 2007). In this region, migration of people from mountainous areas to cities during the sixties and seventies of the last century caused a major human dispersal and thus difficulty in finding historical memory. These factors make that avalanche risk, due to low frequency avalanches, still presents many unknowns despite being significant. In any case, either through surveys to the Pyrenean population, or through searching in historical archives, nowadays we know that in Catalonia there are at least 11 villages that have historically been affected by avalanches (Rodés and Miranda, 2009; Avalanche Database of Catalonia, BDAC), some of which almost completely destroyed (villages Gessa, Tavascan-Plau, and Àrreu in 1444, 1604, and 1803 respectively), and numerous isolated houses, affected or destroyed. Furthermore there are frequent episodes of lower intensity affecting mountain infrastructures (e.g. roads, ski resorts, power lines) every winter. This high frequency activity is what causes victims in winter sports (about 1.5 fatalities per average winter in the Pyrenees of Catalonia, Martínez and Oller, 2004).

Knowing how often major episodes occur, their intensity, and their tendency through time, in relation to climate variability, are basic questions to better understand hazard and to manage avalanche risk in this mountain range.

Different works have dealt with the characterization of major avalanche episodes in the Pyrenees, from different points of view. Esteban et al. (2005) relate the avalanche activity to the snowfall regime

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and characterize the different synoptic circulation patterns that can generate fresh snow depths susceptible to produce avalanches from a set of 15 years. García et al. (2007, 2009) proposed the study from the analysis of atmospheric circulation associated with the occurrence of major avalanches documented through monitoring and surveillance. From episodes identified during the past 40 years, they determined and classified which are the atmospheric configurations that generated them, and they obtained the probability of occurrence for each one of the regions established for the regional avalanche forecasting. Finally, Muntán et al. (2004, 2009) identified new events from dendrochronological analysis of tree rings from trees affected by avalanches, from which they reconstructed major episodes and determined their triggering atmospheric and snowpack conditions over the past 40 years. They also identified probable events up to 100 years ago.

Extensive work has been performed in the French Alps (Eckert et al., 2010b; 2013) and the French Pyrenees (Eckert, 2009; Eckert et al., 2007; 2010a; 2013), with observational avalanche data obtained from the EPA (Enquête Permanente sur les Avalanches). Avalanche events from around 3900 paths were systematically recorded since the beginning of the 20th century. The main goal of this work was to analyze avalanche activity throughout time and space in order to determine trends or changes, and its possible relation with climate change, from the use of advanced statistical procedures. Two periods showing different trends were determined during the last 60 years with a change point around 1978 and a retreat of avalanche runouts over the last 61 winters for high magnitude events, although the probability of a high magnitude event has remained constant, suggesting that climate change has recently had little impact on the avalanching rhythm in France.

Studies in other mountain ranges based on avalanche records as quantifiers of the magnitude of avalanche episodes, do establish indexes (e.g. Avalanche Activity Index, AAI) to quantify the daily degree of activity or the degree of activity for a greater period of time with variable accuracy depending on the available data (Eckert et al., 2010a; Haegeli and McClung, 2003; Laternser and Schneebeli, 2002; Schweizer et al., 1998). Others (Germain et al., 2009), used similar indexes to quantify avalanche activity identified from dendrochronological analysis. In all these works the methodology and scale of work are adapted to the completeness and quality of the database used in each case.

In the present work, we analyzed individual major avalanches to quantify the magnitude and frequency of major avalanche episodes in the Catalan Pyrenees. We considered a “major avalanche” (MA) as the avalanche which extent exceeds the reach of the usual (frequent) avalanches, causing damage in case there is forest or infrastructures in the vicinity (Schaerer, 1986). These avalanches have been described as destructive by Schneebeli et al. (1997) and specifically catastrophic when they affect villages and cause damage to property (buildings, roads and other infrastructures; Höller, 2009). We observed that these avalanches typically have a return period over 10 years. We considered a “major avalanche episode” (MAE) as the period in which the release of one or more MA occurs due to snowpack instability generally caused by a severe storm with high snowfalls accompanied by substantial drifting snow, but also temperature variations causing snowmelt and or fluctuations of the freezing level, designated as “avalanche cycle” by other authors (Eckert et al., 2011; Höller, 2009). It can last from a few hours to several days. It's relation to climatic factors makes its study highly valuable to improve avalanche forecasting (Birkeland et al., 2001; Eckert et al., 2011; García et al., 2009).

We worked with MAs because they cause damage and therefore risk, and because this fact allows collecting a complete data set of avalanches obtained from a threshold defined by the observed damage, as applied by Fitzharris and Schaerer (1980).

The objectives of this paper are: (i) to reconstruct major avalanche episodes that occurred over the Pyrenees of Catalonia during the twentieth and early twenty-first centuries, (ii) to determine their magnitude, (iii) frequency, and (iv) spatial extent.

The rest of the paper is organized as follows. Section 2 presents the main particularities to consider in relation to the avalanching process and climatic behavior of the study area. Section 3 describes the data set used for this work and how it was treated. Section 4 analyzes MAE from time and space points of views considering two temporal periods according to data accuracy. Section 5 discusses the obtained results while Section 6 summarizes the main outcomes of the work.

2. Study area

The study area comprises the Catalan Pyrenees, or southeastern part of the Pyrenean range (Fig. 1), an area of 5000 km^2. The highest peaks just exceed 3000 m a.s.l. Where the terrain is prone to avalanche release, avalanches can trigger from above 1400 m a.s.l., and they can reach elevations as low as 600 m a.s.l. (Oller et al., 2006). In this area, the Cartographic and Geological Institute of Catalonia (ICGC) carries out an observation and surveillance survey from which avalanche data is added in the Avalanche Database of Catalonia (BDAC, Oller et al., 2005).

The forest, widespread all across the range, plays a key role in the detection of MA. The timberline oscillates between 2100 and 2500 m a.s.l. (Carreras et al., 1996). Above these elevations, the density of trees decreases dramatically to a point (treeline) from which only some individuals develop as a bush. Trees act as sensors that record any disturbance or impact affecting their growth. The effects remain for years and can be used to map avalanches even after the disappearance of the avalanche deposit. Therefore, their mapping can be more systematic than the mapping of avalanches that have not caused destruction to forest. Avalanches that affect human settlements and infrastructures were also considered, but vulnerable elements are distributed irregularly and sometimes they are variable in time, and this fact makes the analysis more complex.

High frequency avalanches generally occur above the timberline. Currently it is not possible to get a systematic record of such avalanches, as observations are made mainly from fixed points covering small areas of the territory, or they are registered selectively in case of accident. They are impossible or very difficult to detect after the thaw if they don't produce any further evidence. In addition, even low frequency avalanches releasing and arriving above the timberline are very difficult to detect after the thaw. For that reason, these areas, glacial cirques and hanging valleys above 2000 m, were considered areas without information, or blind areas (shaded in green in Fig. 1). In these areas it was not possible to obtain an exhaustive inventory of major avalanches.

In 1990 the study area was divided into 8 nivological regions (NRs) for operational forecasting (García et al., 1996). In 1994 these regions were reduced to 7 (Fig. 1). This division was based on climate characteristics, snowpack evolution and avalanche activity (García et al., 2007) for a better characterization of the snow conditions and for a better communication of the avalanche forecasting bulletin (BPA). Hence, it was the empirical result of 20 years of avalanche forecasting. It is not a climatic classification in a strict sense, because at present meteorological data series are not long enough to support it (García et al., 2007). These regions are Aran-Franja nord de la Pallaresa (AR), Ribagorçana-Vall Fosca (RF), Pallaresa (PL), Perafita-Puigpedrós (PP), Vessant nord del Cadí-Moixeró (CM), Prepirineu (PR), and Ter-Freser (TF). All the regions drain their waters towards the Mediterranean sea with the exception of the western half of AR which drains towards the Atlantic ocean.

Three climate varieties were defined (García et al., 2007). The northwestern part has a humid oceanic climate with regular winter precipitation (AR region). The total amount of new snow is about 500–600 cm in winter and the winter average temperature is −2.5 °C at 2200 m a.s.l. Towards the south of the western Catalan Pyrenees (RF, PL, PP and CM regions), the weather gains continental traits, and winter precipitation decreases. The average new snow depth at 2200 m a.s.l. is 250 cm in winter and the average temperature is −1.3 °C. The prevailing winds are from the north and northwest, and they are more intense than in the oceanic domain, often with gusts over 100 km/h. In the eastern