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Ground temperatures, landforms and processes in an Atlantic mountain. Cantabrian Mountains (Northern Spain)

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ABSTRACT

Ground temperatures determine significant geomorphological processes in a wet and temperate mountain with a narrow high elevation range belt. Twenty five temperature data loggers were buried at a shallow depth in different locations and altitudes and at specifically cold locations at two massifs in the Cantabrian Mountains (North Spain), Picos de Europa and Fuentes Carrionas. This paper analyses the ground thermal regime and associated parameters (e.g. freeze index, duration and depth of freeze, freeze and thaw cycles) and correlates them with active geomorphological processes and landforms. The thermal regime varies in accordance to the topoclimatic conditions, and it was possible to determinate annual phases in function of snow cover behaviour. Main active processes and landforms stop their activity with a large snow cover which thermally protects the ground and in consequence, avoids the freeze and thaw cycles. During this period, the records allow to asseverate the evidence of seasonal freeze grounds in several locations. Permafrost was not discover on the ground at any of the thermometers except one located at the vicinity of a relict ice patch. With the help of geomorphological maps and previous works, we got to establish the relation between geomorphological processes, landforms, snow cover and ground thermal regime.

1. Introduction

The Cantabrian Mountains are situated in the North fringe of the Iberian Peninsula (Fig. 1). They present an active periglacial belt that occupies the highest portions of the mountain, above 2000 m. The most representative elements of the cryosphere in the Cantabrian Mountains are mainly the snow cover, seasonal freeze ground, and, to a lesser extent, ice patches and ice caves. There are also lots of periglacial features inherited from colder Pleistocene and Holocene climate phases (Oliva et al., 2016). The cryosphere has been moderately studied in the Cantabrian high Mountain. The first works are focused on periglacial landforms, mainly slope deposits of Picos de Europa linked to the glacial features (Obermaier, 1914). Also, different periglacial phases were established through the study of deposits and landforms on the low areas of Cantabrian Mountains, which lead to their relative dating in the Lateglacial and Postglacial phases (Martínez-Álvarez, 1959; Hernández-Pacheco, 1959; Hazera, 1968; Mugnier, 1969; Frochoso, 1990; Díaz-Martínez, 1989; Serrano et al., 2013). Nival features have been also described, although to a lesser extent (Ugarte, 1992). These landforms will be best defined in the space and the time in following works. Pleistocene cryoturbation and gelifluction landforms (e.g. patterned ground, blockfields and blockstreams) have been described, showing the imprint of cold phases on glaciated and not glaciated areas (García de Celis, 2002; González-Gutiérrez, 2002; González-Trueba, 2007a, 2007c; Rodríguez-Pérez, 2009; Santos, 2010; Pellitero, 2013, 2014; Ruiz-Fernández et al., 2014a). The presence of relict rock glaciers in the Cantabrian Mountains suggest permafrost environments during the Late Pleistocene glacial stages and the Holocene coldest phases. Firstly cited by Clark (1981), most of the rock glaciers were developed during the Lateglacial stage (Younger Dryas), but also during the Last Glacial Maximum (LGM) and possibly the Holocene (Alonso, 1989; García de Celis, 1991; Serrano and Gutiérrez, 2000; Gómez-Villar et al., 2004, 2013; Rodríguez-Pérez, 2009; Pellitero et al., 2011; Rodríguez-Rodríguez et al., 2016), showing a large amount of inactive features situated between 400 and 2300 m.

The study of present day periglacial processes and environments in Cantabrian Mountains began in the Picos de Europa, where the displacement of debris lobes was measured, confirming the existence of active processes (Brosche, 1994). So far, contributions have focused on the thermal regime and active processes description (Castañón and Frochoso, 1994, 1998; Serrano and González-Trueba, 2004;

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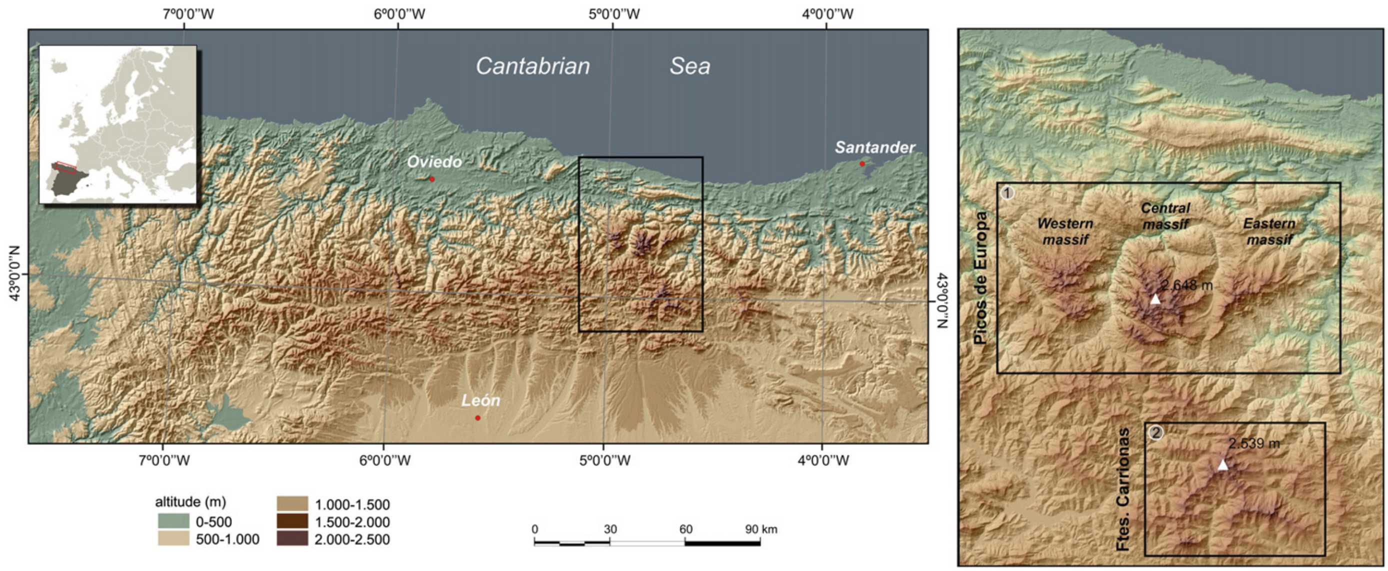

Fig. 1. Location of Cantabrian Mountains and the massifs studied.

González-Trueba, 2007a; Santos et al., 2009; Pellitero, 2013; González-Trueba and Serrano, 2010b; González-Trueba et al., 2012; Ruiz-Fernández et al., 2014b; Pisabarro et al., 2015).

These studies show the reduced number of freeze/thaw cycles (F/Tc) on the ground and the domain of processes related to the debris movement by gravity without ice activity.

Some deep-freeze active processes such as patterned ground (Brosche, 1994; Castañón and Frochoso, 1994; González-Trueba, 2007a, 2007b; Serrano et al., 2011) and frost mounds (Castañón and Frochoso, 1998; González-Trueba, 2007a; Serrano et al., 2011) are located in specific locations where they show the existence of ice in the ground during the winter. The definition of mountain permafrost establish at least a mean annual ground temperature <-2 °C for at least two consecutive years in mountain environments (French, 2007; Dobinski, 2011). Cryokarst, which is likely related to permafrost in ice caves has been described in Picos de Europa (Gómez-Lende, 2015; Gómez-Lende et al., 2014, 2016). However, perennial frozen ground, if present, would be featured by discontinuities and instabilities due to the snow cover, slope and aspect (Harris et al., 2009; Gruber and Haeberli, 2009). Besides, the influence of ice-patches is also evident and only conserved in Picos de Europa (González-Suárez and Alonso, 1994, 1996; Frochoso and Castañón, 1995; Alonso and González-Suarez, 1998; González-Trueba, 2004, 2007c; González-Trueba et al., 2008; Serrano et al., 2011) as a heritage of the Little Ice Age and implications on some periglacial processes. However, other periglacial processes can be associate with the concept of seasonal frozen ground (SFG) (French, 2007), also common in mountain environments.

The snow cover is a cryosphere transversal component that influences over surface waters, the physical soil comportment, the biogeochemical flows and the ecosystem dynamic (De Walle and Rango, 2008; Adam et al., 2009). It also determines partially the periglacial processes and affects the ground temperature and runoff regimes (Zhang, 2005; López-Moreno et al., 2009; García-Ruíz et al., 2011). In the Cantabrian Mountain the nivation has been studied describing landforms and deposits (González-Trueba, 2007a, 2007b; González-Trueba and Serrano, 2010a; Pellitero and Serrano, 2012) and analyzing snow avalanches as a morphogenetic process (Castañón, 1984; Puente, 2006; González-Trueba, 2007a; González-Trueba and Serrano, 2010a; Santos, 2010; Pellitero and Serrano, 2012; Pellitero, 2013; Hernández-Holgado, 2014). Only recently snow has been considered as a natural hazard in the area (Wozniak and Marquínez, 2004; González-Trueba, 2007b,; Vada et al., 2012, 2013; García-Hernández et al., 2014; Serrano et al., in press).

With this background, the aim of the study is differentiate landforms and processes related to ice, snow or gravity, as well as to determine the ground thermal regime in different locations, establishing the magnitude and duration of the cold wave penetration by means of the Freeze Index (FI), timing of SFG, and F/Tc. The effectiveness of current thermal processes on the ground in a wet and temperate high mountain will be assessed through the relationship between these measurements and the active periglacial landforms found in the different mountain belts.

This paper deals with the two highest massifs in the Cantabrian Mountains (Fig. 1), where the active periglacial landforms (e.g. frost mounds, debris flows, terracettes and solifluction lobes) are most common. In both cases the depth and extension of the cryogenic processes remains unknown and the study of the SFG is key to understand the geomorphological processes triggered in the high mountain belt.

Picos de Europa (PE) has the highest altitudes in the Cantabrian Mountains, up to 2648 m. It comprises an area of 150 km^2. Lithology is mostly calcareous, and limestones thickness reach about 2000 m (Merino-Tomé et al., 2009) Relief is very abrupt and rugged by the development of glacio-karst depressions (Smart, 1986) (locally called "jous") between ice-moulded horns. The seasonal snow cover generates superficial and underground karst processes, which are mostly directed by layers stratification and faulting. On relict glacial and periglacial deposits, snow melt and frost-heave play a role in the general deposit erosion. This also happens to bedrock over 1800 m. There is also relict glacial ice in several sheltered locations.

Fuentes Carrionas (FC) occupies about 175 km^2 with altitudes ranging from <1000 to 2536 m. It hosts a wide variety of rock outcrops, for example, limestones, conglomerates, granites, quartzites, sandstones and shales. Its structure is dominated by overthrusts, faults and narrow anticlines and synclines to the south, while the northern area is covered by the broad Curavacas syncline. In the centre of this area there is a small granitic stock (Rodríguez, 1994). Glaciers shaped most of the valleys and watersheds during Quaternary, and left till mantles from 1200 to 2300 m (Pellitero, 2013; Serrano et al., 2013). Beyond the glaciated areas (and progressively higher on the transition between the Last Glacial Maximum to the Holocene), periglacial conditions led to the formation of rock glaciers, blockslopes and blockfields, patterned soils and solifluction lobes (Pellitero, 2014). During deglaciation slopes underwent a paraglacial phase, so mass movements, some of which are still active, began to develop.