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Climate reconstruction for the last two millennia in central Iberia: The role of East Atlantic (EA), North Atlantic Oscillation (NAO) and their interplay over the Iberian Peninsula

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ABSTRACT

A multi-proxy characterization of the uppermost sedimentary infill of an Iberian alpine lake (Cimera, 2140 m a.s.l.) was performed to establish the climatic and environmental conditions for the Iberian Central Range (ICR) over the last two millennia. This multi-proxy characterization was used to reconstruct the intense runoff events, lake productivity and soil erosion in the lake catchment and interpret these factors in terms of temperature and precipitation variability. The Roman Period (RP; 200 BCE – 500 CE) beginning was characterized by an alternation between cold and warm periods as indicated by short-lived oscillations of intense runoff conditions and soil erosion, although warm conditions dominated the end of the period and the Early Middle Age (EMA; 500–900 CE) onset in the ICR. A noticeable decrease in intense runoff events and a progressive decrease in soil erosion during the late EMA indicated a shift to colder temperatures. In terms of precipitation, both the RP and EMA climate periods displayed a transition from dry to wet conditions that led to a decrease in lake productivity. The Medieval Climate Anomaly (MCA; 900–1300 CE) was characterized by warm and dry conditions with frequent intense runoff episodes and increases in lake productivity and soil erosion, whereas the Little Ice Age (LIA; 1300–1850 CE) showed the opposite characteristics. The Industrial Era (1850–2012 CE) presented an increase in lake productivity that likely demonstrates the influence of global warming.

The spatio-temporal integration of the Cimera record with other Iberian reconstructions has been used to identify the main climate drivers over this region. During the RP and EMA, N–S and E–W humidity gradients were dominant, whereas during the MCA and LIA, these gradients were not evident. These differences could be ascribed to interactions between the North Atlantic Oscillation (NAO) and East Atlantic (EA) phases. During the RP, the general warm conditions and the E–W humidity gradient indicate a dominant interplay between a negative NAO phase and a positive EA phase (NAO^-–EA^+), whereas the opposite conditions during the EMA indicate a NAO^+–EA^- interaction. The dominant warm and arid conditions during the MCA and the cold and wet conditions during the LIA indicate the interplay of the NAO^+–EA^+ and NAO^-–EA^-, respectively. Furthermore, the higher solar irradiance during the RP and MCA may support the predominance of the EA^+ phase, whereas the opposite scenario during the EMA and LIA may support the predominance of the EA^- phase, which would favour the occurrence of frequent and persistent blocking events in the Atlantic region during these periods.

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1. Introduction

The climate of the Iberian Peninsula presents large interannual and interdecadal variability in addition to markedly strong seasonal cycles (Lionello, 2012). The intense interannual variability is responsible for the frequent occurrence of both wet and dry years and associated with the latitudinal displacement of storm tracks that is partially controlled by the jet stream positioning (Barry and Chorley, 2009). Over the last two decades, studies have shown with increasing accuracy that the location and magnitude of these weather systems is controlled by a small number of large-scale patterns or modes (e.g., Hurrell, 1995; Trigo et al., 2002, 2008). Among these modes, the North Atlantic Oscillation (NAO) is the most prominent and recurrent pattern of atmospheric variability over the middle and high latitudes of the Northern Hemisphere (Hurrell et al., 2003). The effects of the winter NAO on the Iberian Peninsula (IP) climate are more evident in the precipitation records than in the air temperature measurements (Castro-Díez et al., 2002; Trigo et al., 2002). In addition to the NAO, other North Atlantic-European modes of climate variability, such as the East Atlantic (EA) and Scandinavian (SCAND) patterns, are also known to play a significant role in modulating climate variables in the IP (Comas-Bru and McDermott, 2014; Jerez and Trigo, 2013; Trigo et al., 2008).

Lacustrine sedimentary records have been widely used to determine the environmental and climatic history of the IP at several time scales (e.g., Jambrina-Enríquez et al., 2014; Roberts et al., 2008, 2012). The most frequently studied lacustrine records are from low- and mid-lying altitude areas, such as the sedimentary records from Sanabria Lake (1000 m a.s.l.; Jambrina-Enríquez et al., 2014) and Enol Lake (1075 m a.s.l.; Moreno et al., 2011) in the northern IP; Arreo Lake (655 m a.s.l.; Corella et al., 2013), Estanya (670 m a.s.l.; Morellón et al., 2009, 2011; Riera et al., 2004) and Montcortès Lake (1027 m a.s.l.; Corella et al., 2011) in the Pre-Pyrenees; the Tablas de Daimiel wetland (616 m a.s.l.; Gil García et al., 2007) and Taravilla Lake (1100 m a.s.l.; Moreno et al., 2008) in the Central IP; and Zoñar Lake (300 m a.s.l.; Martín-Puertas et al., 2008, 2010; Valero-Garcés et al., 2006) in the southern IP. Reconstructions based on lacustrine sequences from low-altitude lakes usually face the additional challenge of distinguishing between climatic and anthropic signals (Barreiro-Lostres et al., 2015; Morellón et al., 2011; Valero-Garcés et al., 2006), whereas high-mountain lakes often present negligible anthropic influence because of the limited human activities in these remote areas; thus, their sedimentary records often contain more pristine climatic signals compared with the low-mountain records.

Therefore, climate reconstructions from the main Iberian mountain ranges have increased over the last decade, including reconstructions of the Pyrenees from Redon Lake (2240 m a.s.l.; Pla and Catalan, 2005; Pla-Rabes and Catalan, 2011), Marboré Lake (2500 m a.s.l.; Salabarnada, 2011) and Basa de la Mora Lake (1914 m a.s.l.; Morellón et al., 2012; Moreno et al., 2012; Pérez-Sanz et al., 2013) and the southern Spain ranges (*Sierra Nevada)* from Laguna de Rio Seco (3020 m a.s.l.; Jiménez-Espejo et al., 2014). In addition, several environmental reconstructions of the Iberian Central Range (ICR) are based on palynological records from different peatlands (>1700 m a.s.l.; López-Sáez et al., 2014). However, to the best of our knowledge, only two climate reconstructions have been conducted from an alpine lake (Cimera Lake, 2140 m a.s.l.) located in the ICR, and they cover the last several centuries (Agustí-Panareda and Thompson, 2002; Granados and Toro, 2000).

Most of these climate reconstructions, as well as other in Europe, distinguish five main climatic periods for the last two millennia: the Roman Period (RP; 650 BCE – 500 CE), the Early Middle Ages (EMA; 500–900 CE), the Medieval Climate Anomaly (MCA; 900–1300 CE), the Little Ice Age (LIA; 1300–1850 CE); and the so-called Industrial Era (1850–2012 CE). The studied records provide detailed information on the climatic evolution for specific time windows (e.g., MCA and LIA, Morellón et al., 2012; Moreno et al., 2012), whereas other periods (e.g., EMA and RP, Luterbacher et al., 2016) remain less studied. Furthermore, when comparing the environmental and climate information between the lowlands and highlands, it is clear that the spatial coverage of the latter must be improved.

The influence of the NAO on the lacustrine ecosystems of the IP has also been determined for these historical periods (e.g., Morellón et al., 2012; Moreno et al., 2012; Nieto-Moreno et al., 2011). These climate reconstructions commonly ascribe the warm and arid climate conditions of the MCA to the dominance of the positive phases of the NAO and the humid and cold conditions of the LIA to the dominance of the negative phases of this climate mode (Ortega et al., 2015; Trouet et al., 2009). Nevertheless and to the best of our knowledge, with the exception of Roberts et al. (2012) for the last millennium, the role of the other climate modes in the climatic evolution as well as their interactions with the NAO beyond the last few millennia have not been well addressed yet. Within this scope, recent works based on limnological measurements from Iberian lakes (Hernández et al., 2015) and isotopic data for European precipitation (Comas-Bru et al., 2016) have gone a step further and assessed the sensitivity of these records to variations in these climate modes (e.g., NAO, EA and SCAND), although only for recent decades.

The objective of this study was to address the lack of climate data for the last two millennia in the ICR, a key region of the IP, by identifying and characterizing the main climate changes and their forcing mechanisms. For this purpose, we have applied a high-resolution multiproxy approach to sediments of an alpine lake (Cimera Lake). A comparison of the obtained palaeoclimate record with other Iberian climate reconstructions was performed to determine the spatial and temporal climate variability over time and demonstrate that climatic reconstructions of the last two millennia of the IP should simultaneously consider the influence of the NAO as well as other climate forcings (e.g., the EA pattern).

2. Study site

2.1. Regional setting

Cimera Lake is located in the southern branch of the ICR (Fig. 1a). This mountainous region is located left of the centre of the IP, extends approximately 700 km from NE to SW and presents elevations of up to ~2600 m a.s.l. The pre-Quaternary lithology of the region is primarily composed of late Palaeozoic igneous rocks (granite and gneiss), although slates are also present (De Vicente et al., 1994; Pedraza, 1994).

The climate of the ICR is an alpine type immersed in a Mediterranean climate with a strong continental influence (Durán et al., 2013). The arrival of Atlantic depressions from the SW frequently occur in fall, winter and spring; however, in summer, the Azores anticyclone is persistent and does not favour moisture transport from the west. As a consequence, this regional climate is characterized by a significant amount of solid precipitation and low temperatures in winter and warm and dry conditions in summer (Sánchez-López et al., 2015). The mean annual temperatures oscillate between 0 and 2 °C during the coldest month and between 20 and 22 °C during the hottest month. The total annual rainfall is ca. 1400 mm and occurs in the humid ombrotype region (Ninyerola et al., 2005; Palacios et al., 2012).