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The Medieval Climate Anomaly in the Iberian Peninsula reconstructed from marine and lake records

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Abstract

Selected multi-proxy and accurately dated marine and terrestrial records covering the past 2000 years in the Iberian Peninsula (IP) facilitated a comprehensive regional paleoclimate reconstruction for the Medieval Climate Anomaly (MCA: 900–1300 AD). The sequences enabled an integrated approach to land–sea comparisons and, despite local differences and some minor chronological inconsistencies, presented clear evidence that the MCA was a dry period in the Mediterranean IP. It was a period characterized by decreased lake levels, more xerophytic and heliophytic vegetation, a low frequency of floods, major Saharan eolian fluxes, and less fluvial input to marine basins. In contrast, reconstruction based on sequences from the Atlantic Ocean side of the peninsula indicated increased humidity. The data highlight the unique characteristics of the MCA relative to earlier (the Dark Ages, DA: ca 500–900 years AD) and subsequent (the Little Ice Age, LIA: 1300–1850 years AD) colder periods. The reconstruction supports the hypothesis of Trouet et al. (2009), that a persistent positive mode of the North Atlantic Oscillation (NAO) dominated the MCA.

Highlights

► Integration of selected multi-proxy and well-dated paleoclimate records from Iberia. ► Selected records evidence that the MCA was a dry period in Mediterranean Iberia. ► A persistent positive mode of the NAO was dominant during the MCA.

Introduction

The combination of proxy records from several paleoclimate archives (including tree rings, lake sediments, marine cores and speleothems) has enabled identification of five climatic periods during the last two millennia. These have been characterized in terms of temperature and precipitation variability (Mann and Jones, 2003), and include: the Roman Warm Period (RWP; 0–500 years AD), the Dark Ages (DA; 500–900 AD), the Medieval Warm Period (MWP; 900–1300 AD), the Little Ice Age (LIA; 1300–1850 AD), and a subsequent period of warming. Thus, the MWP, which is also termed the Medieval Climate Anomaly (MCA) because of its large heterogeneity in space and time, is the most recent pre-industrial warm era in European climatology (Mann etal., 2009). Although the rates of temperature change (approximately 0.25°C/100 years in the MCA *vs*. 2–6°C/100 years at present) and the forcing mechanisms (natural *vs*. anthropogenic) (Solomon etal., 2007) were probably very different during the MCA relative to those under the current conditions of global warming, in both cases the ecosystem and human societies faced new environmental changes. Our understanding of the dynamics and impact of present-day global change will be enhanced from studies of past analogues of periods of abrupt change, and also from comparison with previous warmer periods that were characterized by more gradual changes, such as the MCA. To adapt to and mitigate the effects of present-day global warming it is crucial to understand the causes of the MCA and its forcing factors. Better characterization of temperature and precipitation changes that occurred at a large number of sites located in geographically diverse areas is required to corroborate the global character of the MCA and its spatial variability. To date, the MCA has been mainly described by temperature reconstructions that did not provide a worldwide coverage (Jones etal., 2009).

Climate variability during the last millennium has been related to fluctuations in solar irradiance amplified by feedback mechanisms including ozone production or changes in cloud formation (Gray etal., 2010). Thus, in response to greater solar irradiance during the MCA, persistent La Niña-like tropical Pacific Ocean conditions (Mann etal., 2009), a warm phase of the Atlantic Multidecadal Oscillation (AMO), and a more recent positive phase of the North Atlantic Oscillation (NAO) (Trouet etal., 2009) have been reconstructed in attempts to explain the observed worldwide hydroclimate variability during this period (Seager etal., 2007). The NAO signature appears to be particularly evident in climate reconstructions from Scottish stalagmites (wet during the MCA) (Proctor etal., 2002) and from tree rings from Morocco (dry during the MCA) (Esper etal., 2007); in both cases a positive NAO index was likely to have been a major forcing factor, as suggested by Trouet etal. (2009).

Reconstructions of precipitation variability during the MCA are particularly challenging (Seager etal., 2007), and are much rarer than those of temperature. However, the impacts of climate warming on the hydrological cycle are of paramount importance in the Mediterranean region, which is a densely populated area characterized by a permanent water deficit, and is likely to be subject to extreme hydrological events (particularly droughts) in coming decades (Giorgi, 2006). Within the Mediterranean Basin the Iberian Peninsula (IP) (which is located at the southern edge of the storm tracks that are associated with mid-latitude westerly winds and largely controlled by the NAO and the AMO) is a location uniquely placed for exploration of the influence of the long-term NAO index and the Atlantic Ocean dynamics on hydrological variability.

The study of sedimentary records from small lakes, in which considerable fluctuations in lake levels, water chemistry and biological processes controlled by changes in effective moisture have occurred (Last and Smol, 2001), appears to be the best approach to investigating the impact of the MCA on the hydrological cycle in the IP. Other terrestrial records, such as those in speleothems, provide good information on past temperature conditions. Thus, a recent study of three caves in northern Spain indicated that warmer conditions occurred during the MCA (Martín-Chivelet etal., 2011). Marine sediments in the vicinity of the IP also provide evidence of changes in sea surface temperature (SST), river sediment delivery, and wind patterns related to climate changes during the last millennium (Abrantes etal., 2005; Lebreiro etal., 2006). A review of rapid climate change events during the Holocene (Fletcher and Zielhofer, in press) has shown that in several IP records there is clear evidence of contrasting humidity conditions during the MCA and the LIA. Comparison of marine and terrestrial records provides an integrative approach to the reconstruction of climate variability during past centuries.

The purpose of this study was to review recently published and new Iberian paleoenvironmental records for the last two millennia that fulfil the following requisites: (1) the paleoclimate interpretations were based on multi-proxy reconstructions; and (2) the chronology was independent, based on calibrated accelerator mass spectrometry (AMS) ^{14}C dates and $^{137}Cs/^{210}Pb$ models. Based on available records for the IP (Table 1, Fig. 1) we undertook the first synthesis of the environmental response in the region during the MCA (900–1300 AD), and characterized and integrated the signals recorded from the marine and terrestrial realms.

Section snippets

Study sites: current climatic and oceanographic setting

The current climate of the IP is mainly driven by the position of the Azores high pressure system. The weather in summer is usually dry and hot because of the influence of the atmospheric subtropical high pressure belt (Sumner et al., 2001). During winter the subtropical high shifts to the south, enabling mid-latitude storms to enter the region from the Atlantic Ocean, which brings rainfall to the IP. As a consequence of the geographic situation and topographic conditions, the climate of the IP …

Multi-proxy methodology

The extensive application of multi-proxy methods in paleoclimatic studies of marine and lacustrine cores from the IP and surroundings seas during the last decade, combined with the more common use of statistical techniques, has led to significant advances in the reconstruction of climate variability (Moreno et al., 2012). Integrated multi-proxy approaches to the study of climate variability are critical for disentangling the various forcings, which is essential in the generation of robust…

La Basa de la Mora: a record of runoff events and vegetation cover in the Central Pyrenees

La Basa de la Mora is a lake of glacial origin located at 1914 m asl in the Cotiella massif, in the Central Pyrenees (Fig. 1, Table 1). A frontal moraine on the southeastern border of the lake acts as a natural dam. Cretaceous limestones dominate the catchment area, but the bottom of the lake is sealed by impermeable fine-grained Triassic formations. Although the lake is shallow (2–3 m deep) it has a surface area of 6 ha and a permanent water lamina. The main input of water and detrital…

Paleohydrological signal during the MCA: a compilation of Iberian marine and terrestrial records

Most of the multi-proxy reconstructions considered in this study indicated relatively arid conditions (represented by shallower lake levels, dominance of arid-adapted vegetation, and greater inputs of Saharan dust) during the MCA relative to the LIA. Fig. 6 shows representative Iberian records, and Fig. 7 shows the main pollen taxa found in various lacustrine records from the IP.…

Conclusions

Selected records from the IP, including marine and terrestrial sequences, have provided a coherent paleoclimate reconstruction for the past 2000 years, largely in terms of humidity variations. Particularly for the MCA period (900–1300 AD), the selected records from Mediterranean IP generally indicate drier conditions, evidenced in the lake sediments by lower water levels and higher chemical concentrations, while in marine cores a decrease in fluvial supply and an increase in Saharan dust…

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(Figure 4c) UK'37 derived sea surface temperatures of sediment cores MINMC06-1 and MINMC06-2, Minorca contourite ↗

(Figure 4d) UP10 fraction (size fraction % >10 microns) of sediment cores MINMC06-1 and MINMC06-2, Minorca contourite ↗

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