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The influences of the AMO and NAO on the sedimentary infill in an Azores Archipelago lake since ca. 1350 CE

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A B S T R A C T

The location of the Azores Archipelago in the North Atlantic makes this group of islands an excellent setting to study the long-term behavior of large oceanic and atmospheric climate dynamic patterns, such as the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO). Here, we present the impacts of these patterns on Lake Empadadas (Azores Archipelago) from the Medieval Climate Anomaly (MCA) - Little Ice Age (LIA) transition to the present based on sedimentological, geochemical and biological characterizations of the sedimentary record. Multivariate analyses of a number of proxies including X-ray fluorescence (XRF), X-ray diffraction (XRD), total organic and inorganic carbon (TOC and TIC) and diatom life forms abundance reveal that the sedimentary infill evolution has been controlled by (i) fluctuations in the lake level and (ii) variations in organic matter accumulation. Both processes are governed by climate variability and modulated by anthropogenic activities associated with changes on the lake catchment. Changes in these two sedimentary processes have been used to infer five stages: (i) the MCA-LIA transition (ca. 1350–1450 CE) was characterized by a predominantly positive AMO phase, which led to intermediate lake levels and high organic matter concentration; (ii) the first half of the LIA (ca. 1450–1600 CE) was characterized by predominant lowstand conditions and intermediate organic matter deposition mainly related to negative AMO phases; (iii) the second half of the LIA (ca. 1600–1850 CE) was characterized by negative AMO and NAO phases, implying intermediate lake levels and high organic matter deposition; (iv) the Industrial era (ca. 1850–1980 CE) was characterized by the lowest lake level and organic matter accumulation associated with negative AMO phases; and (v) the period spanning between 1980 CE and the present reveals the highest lake levels and low organic matter deposition, being associated with very positive AMO conditions. At decadal-to-centennial scales, the influence of the AMO on Azorean climate plays a larger role than previously thought. In fact, the AMO appears to exert a stronger influence compared to the NAO, which is the main mode of climate variability at shorter time scales.

1. Introduction

Small and remote islands are very sensitive and vulnerable to environmental changes, and their limited area and resources can complicate adaptation policies (IPCC, 2014; Nurse et al., 2014). Thus, there is a growing interest in predicting the environmental consequences of ongoing and future global changes in areas of land surrounded by large water masses. With few exceptions (e.g., Cropper and Hanna, 2014; Hernández et al., 2016), the instrumental climate records from remote islands are limited to the 20th century; therefore, it is necessary to extend climatic reconstructions using paleoclimatic proxy data to i) establish the background conditions before the current global change,

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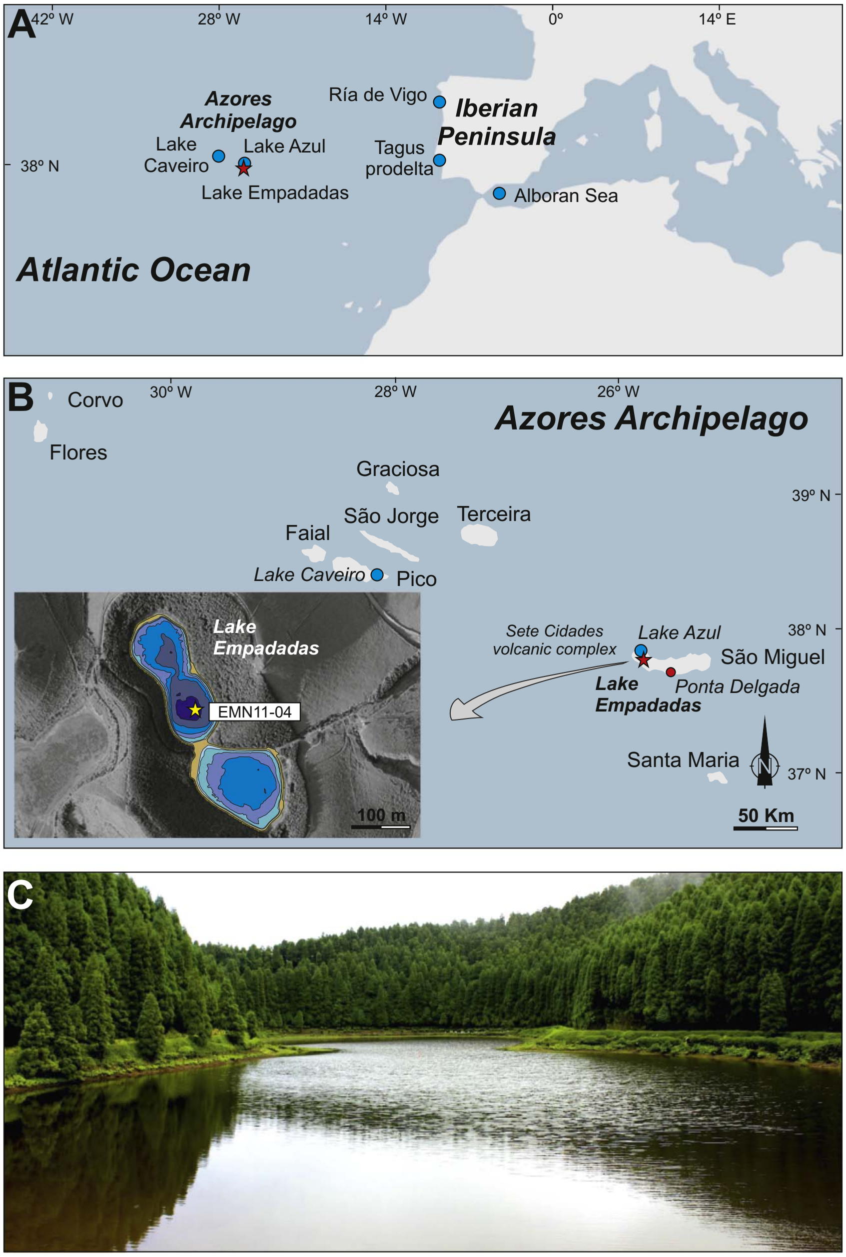

Fig. 1. A) Map of the Northeastern Atlantic region. Red star indicates the location of Lake Empadadas, and blue circles show the locations of the other records included in this study. B) Map of Azores Archipelago, with an aerial image of Lake Empadadas and its bathymetry. Each contour line corresponds to one meter of depth. The red circle shows the location of Ponta Delgada in São Miguel Island, and the red and yellow stars show the locations of Lake Empadadas and the studied core, respectively. The blue circles show the location of the other records from the Azores Archipelago. C) September 2011 image of Lake Empadadas and its catchment reforested with *Cryptomeria japonica. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)*

ii) investigate previous periods characterized by notable climatic shifts attributable to natural forcing and widespread human activities, and iii) comprehend the environmental impacts of these climate changes. Despite the fact that small oceanic islands are exceptional locations to study the impacts of large oceanic and atmospheric climate patterns, only a few high-resolution terrestrial paleoenvironmental records from these islands exist (e.g., Björck et al., 2006; Conroy et al., 2008; Margalef et al., 2013). Consequently, appropriate high-resolution paleoarchives are required to improve the understanding of recent climate variability and its impacts (PAGES 2K Consortium, 2013; Jones et al., 2009).

Three main climate periods within the last millennium have been clearly identified: the Medieval Climate Anomaly (MCA; ca. 800–1400 CE), the Little Ice Age (LIA; ca. 1400–1800 CE) and the Industrial era (ca. 1850 CE-Present). There is a general consensus defining the MCA and Industrial era as warm periods and the LIA as a cooler period (Mann et al., 2009). Several works have focused on the main driving mechanisms behind these anomalies and their transitions. The main mechanisms driving the climate cooling during the LIA have been linked to two major external forcing factors, solar activity and volcanism. The cooling has primarily been attributed to the decrease of incident solar radiation on the Earth's surface (Shindell et al., 2001; Solanki et al., 2004; Vaquero and Trigo, 2015) and to stronger volcanic activity (Bradley and Jones, 1992; Fischer et al., 2007). The effect of these external forcings was probably amplified by responses from the oceanic component of the climate system, particularly by the slowdown of the North Atlantic thermohaline circulation (Broecker, 2000). Overall, these assessments point to the previous natural external forcings that resulted in a prolonged reinforcement of ocean-atmosphere positive feedback mechanisms (Trouet et al., 2012). New promising studies highlight the relevance of atmospheric patterns affecting the climate conditions over the North Atlantic sector during these periods (e.g., Moffa-Sánchez et al., 2014; Sánchez-López et al., 2016).

The climate variability in the North Atlantic sector is influenced by a number of large-scale patterns or modes of climate variability (e.g., Marshall et al., 2001; Trigo et al., 2004), which affect the environment and society in multiple ways (e.g., Ottersen et al., 2001; Jerez and Trigo, 2013). The North Atlantic Oscillation (NAO) is the leading mode