Clim. Past Discuss., https://doi.org/10.5194/cp-2017-84
Manuscript under review for journal Clim. Past
Discussion started: 27 June 2017

Climate of the Past Discussions

The Climate of the Common Era off the Iberian Peninsula

Abrantes[1,2], Fátima; Teresa Rodrigues[1,2], Marta Rufino[2,3]; Emília Salgueiro[1,2]; Dulce Oliveira[1,2,4]; Sandra Gomes[1]; Paulo Oliveira[1]; Ana Costa[5]; Mário Mil-Homens[1]; Teresa Drago[1, 6]; Filipa Naughton[1,2,]

1 –Portuguese Institute for the Ocean and Atmosphere (IPMA), Divisão de Geologia Marinha (DivGM), Rua Alferedo Magalhães Ramalho 6, Lisboa, Portugal

2 - CCMAR, Centro de Ciências do Mar, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

3 – IFREMER - Centre Atlantique (French Research Institute for Exploitation of the Sea, Département Ecologie et Modèles pour l'Halieutique (EMH), Rue de l'Ile d'Yeu - BP 21105, 44311 Nantes cedex 3, France

4 – Univ. Bordeaux, EPOC, UMR 5805, F-33615 Pessac, France

5 - Centro de Investigação em Biodiversidade e Recursos Genéticos (EnvArchCIBIO/InBIO) and Archaeosciences Laboratory (LARC/DGPC), Rua da Bica do Marquês, 2, 1300-087, Lisboa, Portugal

6 – Instituto Dom Luiz, Universidade de Lisboa, 1749-016 Lisboa, Portugal

Correspondence to: Fatima Abrantes (Fatima.abrantes@ipma.pt)

Key Words – Last 2ky, climate, SST, precipitation, Iberian Peninsula

Abstract. The Iberian Peninsula, at North Atlantic mid-latitude and the western extreme of the European continent, is a relevant area for climate reconstructions. This work provides multi-proxy records measured in 7 inner-shelf sediment sequences from 5 sites located between South Portugal (Algarve) and Northwest Spain (Galiza) (36 to 42 ºN) and targets a regional reconstruction of climate variability during the last 2,000 yr.

Alkenone derived Sea Surface Temperature (SST) reconstructions were compared to on-land precipitation given by higher plant n-alkanes and pollen data, to assess the relationship between hydroclimate (drought and/or precipitation) and oceanic SST.

The SST records reveal a long-term scale cooling (± 1º C/ 2,000 yr) that ends at the beginning of the 20th century at all sites. This cooling is a follow up of the cooling process started after the Holocene optimum and driven by a decrease in summer insolation in the Northern Hemisphere.

A multi-decadal/ centennial variability is detected within this long-term cooling in convergence with other records from Spain, Europe and the Northern Hemisphere. Warm SST conditions prevailed

Clim. Past Discuss., https://doi.org/10.5194/cp-2017-84
Manuscript under review for journal Clim. Past
Discussion started: 27 June 2017

throughout the first 1300 yr, encompassing the Roman Period (RP), the Dark Ages (DA) and the Medieval Warm Period (MWP). A cooling initiated at 1300 CE, led to 4 centuries of ±1º C colder mean SSTs contemporary with the Little Ice Age (LIA). The transition towards the Industrial Era starts by 1800 CE with a SST rise to pre-LIA levels. Particular climate conditions have been detected in Western Iberian margin records and reveal two distinct phases within the MWP and a two-step SST increase towards the Industrial Era. The intense precipitation/ flooding and warm winters but cooler intermediate seasons (spring and fall) observed for the early MWP imply the interplay of internal oceanic variability with the three atmospheric circulation modes, North Atlantic Oscillation (NAO), East Atlantic (EA) and Sandinavia (SCAND) in a positive phase. The late MWP, marked by drier and cooler winters and warmer intermediate seasons calls for a change in sign of the SCAND. A stronger mark of oceanic influences on Western Iberian Peninsula starts with the transition to the Industrial Era.

1 Introduction

Today's climate goes through a warming shift caused by the increased release of human-generated greenhouse gases, such as CO_2, and poses a pressing problem on societies' sustainability (IPCC, 2013a). CO_2 uptake by the ocean (Sabine, 2004), although helping to control atmospheric temperature, it is changing ocean's temperature and chemistry, mainly lowering the oceans' pH (acidification). Ocean warming, on the other side, is driving changes in atmospheric and oceanic circulation patterns. Additionally, regions, such as the Arctic and the Mediterranean are highlighted as the most sensitive and potentially vulnerable to the ongoing global warming (Climate, 2011; Giorgi 2006).
Increasing temperatures to higher values than the predicted global mean and changes in precipitation in the Iberian Peninsula, consistent with long dry summers and a short and wetter rainy season, are projected both by global and regional model simulations in particular for its southern region (IPCC, 2013b; Miranda et al., 2002).
Most of this knowledge is based on the analysis of instrumental data and modeling of global and hemispheric average conditions. However, given the limited time-span covered by the instrumental data, to better understand the impact of climate warming it is essential to analyze and understand the response of the climate system in perspective of a longer time-scale. In particular, investigate previous warm periods and warming transitions such as those occurring over the last 2,000 years. Records and model reconstructions (Fernandez-Donado et al., 2013) identified solar and volcanic activity, greenhouse gases, and land-use changes as the main external drivers of the global climate shifts during the last millennium (Hegerl et al., 2006), while Schurer et al. (2014) defend greenhouse gases concentration and volcanic eruptions as the main drivers of atmospheric temperature changes in the northern Hemisphere. In general, a large number of reconstructions find the Medieval Warm Period (MWP) / Medial Climate Anomaly (MCA), that lasted from 900 to 1300 CE (McKim, 1998), associated with high solar and low volcanic activity, while low solar activity and high volcanic activity dominate

during the Little Ice Age (LIA), which extended between 1350 and 1850 CE (Jones et al., 2001). After 1900 CE, global mean atmospheric temperature rise became mainly an effect of the huge increase of greenhouse gases in the atmosphere (IPCC, 2013a).

Over the last two decades, many Iberian lake sediments (e.g. Hernández et al. (2015); Jambrina-Enríquez et al. (2016); Morellón et al. (2009); Moreno et al. (2008); Valero-Garcés et al. (2006)); speleothems (e.g. Martín-Chivelet et al. (2011)) and marine sediments (e.g. Abrantes et al. (2005); Abrantes et al. (2011); Desprat et al. (2003); Diz et al. (2002); Lebreiro et al. (2006); Pena et al. (2010)), have provided individual records and compiled evaluations of climate evolution over Iberia during the historical period (e.g. (Moreno et al., 2011; Sánchez-López et al., 2016)). Results reveal multi-decadal to centennial climate variability, manifesting a MWP and a LIA, in accordance with the main pattern identified for the North Atlantic, although the expected complex regional differences appear reflected by the lack of agreement on the exact timing and duration of those two most important climatic periods (e.g. Ahmed et al. (2013); Büntgen et al. (2011); Cook et al. (2004); Esper et al. (2002); Luterbacher et al. (2004); Luterbacher et al. (2016); Moberg et al. (2005)). Additionally, given the dominance of the large-scale climate mode operating in the Northern Hemisphere, which reflects an Atlantic sea-saw variability between the Artic region and the subtropics, the North Atlantic Oscillation (NAO) (Hurrell, 1995), most of the above referred studies attribute the inferred variability to changes in the prevailing modes of the NAO. Being mainly a winter season mode, NAO phases, defined from the strength and positions of the Icelandic Low and the Azores High pressure systems, vary on scales of days to decades. Over Iberia the effects of its variability translate into strong northerly winds resulting in coastal upwelling favorable conditions during positive NAO periods, while westerly/ southwesterly winds become predominant and result in very cold winters and increased storm activity during NAO negative phases (also known as "blocked") (Hurrell, 1995; Trigo et al., 2004). That leads to an attribution of the dominant warm and dry conditions of the MWP to a dominance of the NAO positive conditions, and the more cold and humid conditions of the LIA to the dominance of a negative NAO (Abrantes et al., 2005, 2011; Lebreiro et al., 2006).

Other prominent modes of climate, the East Atlantic (EA) and the Scandinavia (SCAND) (Comas-Bru and McDermott, 2014; Jerez and Trigo, 2013), constitute second leading modes, which interplay with the NAO, and their temporal variability, must have also had a role on the climatic evolution of the North Atlantic. The EA has a strong effect on the strength and location of the NAO dipoles mainly on a multi-decadal time-scale, and according to Hernández et al. (2015), has a major control on winter and summer temperature over the Iberian Peninsula. The SCAND pattern, functions as a blocking high-pressure system that changes the westerly winds path and influences southwestern Europe mainly during its positive phase, when it contributes to temperatures below average and above average precipitation (e.g. Jerez and Trigo (2013)). Sánchez-Lopez et al., (2016), on the basis of a spatiotemporal integration of several climate reconstructions, attempted to identify the role of those atmospheric patterns over the Iberian Peninsula. Their results reveal E-W and N-S humidity gradients from 0 to 500 CE and between 500 and 900 CE respectively, while between 900 and 1850 CE temperature and humidity conditions are more homogenous throughout the Peninsula. These conclusions support atmospheric pathways as the main control of climate variability in Western Europe on multi-decadal time-scales. However, it is widely known that the heat transported to the east by the Gulf Stream and its North Atlantic Current extension, has a great impact on Western Europe winter temperatures (Palter, 2015). An effect not detected by Sánchez-Lopez et al., (2016), probably because that reconstruction only includes 2 oceanic records (Tejo and Vigo Ria). Wang and Dong (2010), consider that North Atlantic temperature variability at decadal scale, the Atlantic Multidecadal Oscillation (AMO) is the cause for the Atlantic Multidecadal Variability, and go beyond, defending that its influence is not limited to the neighbor continents, but contributes also to global SST variability. Yamamoto and Palter (2016) show a clear relationship between the NAO derived atmospheric circulation over Europe and the AMO, with northerly winds associated to a positive state of the AMO and zonal winds to a negative state of the AMO. But, although these authors find a clear imprint of the AMO variability in European summer temperatures, the same relationship is not observed during wintertime. From the analysis of a 70 yr (1940-2011) dataset of SST and Western European atmospheric temperature and particle trajectory modeling, Yamamoto and Palter (2016) attribute the absence of a winter signal to a cancelation of the ocean SST expression by strong cold winds. Two climatic reconstructions from the Iberian/Atlantic ocean region (Abrantes et al, 2005; 2011), indicate coastal upwelling variability not only in consonance with inferred NAO conditions but also coherence with the instrumentally and tree-ring reconstructed AMO (Gray et al., 2004), suggesting a connection between the Iberian Peninsula coastal circulation and the North Atlantic Ocean SSTs.

Given the potential risk of climate-derived threats for marine ecosystems of Western Iberia and society, high-resolution climate archives for the most recent centuries and millennia are pivotal for better understanding the interactions between various climate modes, future scenarios and their relevance to the Iberian Peninsula.

The purpose of this work is to investigate the spatial and temporal variation of precipitation over the Westernmost European territory, as well as the oceanic SST behavior on decadal to multi-decadal scales. For that we combine the above mentioned published records with 3 new records, covering the last 2,000 yr, and located along the Iberian margin, spanning from 42º N to 36 ºN. Furthermore, a regional SST stack of the last 2,000 yr was developed and compared to proxy and model derived reconstructions of forcing factors and environmental properties.

2 Oceanographic Conditions

Clim. Past Discuss., https://doi.org/10.5194/cp-2017-84
Manuscript under review for journal Clim. Past
Discussion started: 27 June 2017

Climate of the Past Discussions Open Access EGU

The western coast of the Iberian Peninsula (Fig. 1) is characterized by contrasting oceanographic conditions between a coastal upwelling regime and a surface equatorward current in spring-summer (April to October) (Fiuza, 1982, 1983; Peliz et al., 2002; Relvas et al., 2007), and an alongshore poleward warm counter current in winter (Fiuza and Frouin, 1986; Peliz et al., 2005).

The spring-summer upwelling, constitutes the northern part of the Eastern North Atlantic Upwelling / Canary System and is connected to the presence of the Azores high-pressure system and the development of northerly alongshore winds (Fiuza, 1983).

Upwelled waters are transported southwards by a jet-like surface current (Fig. 1C), the Portuguese Coastal Current, the coastal component of the Portuguese current that branches of the North Atlantic Current, (Fiuza, 1982, 1983; Fiúza and Macedo, 1982). On the southern/ Algarve coast, upwelling favorable conditions are rare, but western upwelled waters flow around Cape S. Vicente and along the south coast, (Fiuza, 1982, 1983; Fiúza and Macedo, 1982; Sánchez and Relvas, 2003) and can spread to its easternmost sector (Cardeira et al., 2013). This eastward flow of cold western upwelled waters alternates with the propagation of westward flows related to warm water and increased vertical stratification and show a direct relationship between flow velocity and water temperature (Garel et al., 2016; Relvas and Barton, 2002).

In winter, the prevalence of westerly/southwesterly winds leads to the intensification of the Iberian Poleward Current (Fig. 1B). This current consists of an upper slope/shelf break poleward flow that is a branch of the Azores Current, transports saltier and warmer (subtropical) waters (Peliz et al., 2005) and depends most on the intensity of the southerly winds (Teles-Machado et al., 2015). Another important feature of the winter circulation over the western margin is the formation of coastal buoyant plumes, characterized by low salinities and temperature lower than the ambient shelf waters (Peliz et al., 2005). Such plumes result from the discharge of freshwater from rivers, which in turn reflects continental precipitation. Precipitation occurs mainly in winter, as a result of the moist carried by the westerly winds into the Peninsula, but has important latitudinal differences, from 500 mm/year in the southeast to >3000 mm/year in the northwestern area (Miranda et al., 2002). As a consequence, buoyant plumes are mainly associated to the major northern Portuguese rivers (Minho, Douro, Mondego) but occur also linked to the Tagus, and can either develop into inshore currents, under typical winter downwelling conditions, or spread offshore under northerly wind periods (Iglesias et al., 2014; Marta-Almeida et al., 2002; Mendes et al., 2016; Oliveira et al., 2007; Otero et al., 2008).

3 Material and Methods

This study compares proxy data from 7 sedimentary sequences collected from 5 sites along the inner-shelf of the Iberian Margin (Table 1, Fig. 1). Three sequences are from the northern area, off Vigo (GeoB11033-1 referred to as Galiza), off the Minho River mouth (Diva09 GC, Minho from now on) and in the Douro sediment patch (PO287-6B, 6G, designated as Porto); 4 cores were retrieved in the central Western Iberia off the Tagus River mouth (Tejo site, PO26B, 26G, D13902 and D13882), and 1 core from southern Iberia at Algarve margin (POPEI VC2B). With the exception of the Galiza core, all other sedimentary sequences were collected in the inner shelf, and in areas directly affected by river discharge. The cores retrieved from Galiza, Minho and Algarve sites were analyzed in the framework of this study, whereas the rest of the core data were previously published in Abrantes et al., (2005, 2011). Sea Surface Temperature (SST) was determined based on the ratio of alkenones ($U^{k'}_{37}$) synthesized by coccolithophores (phytoplankton group) (e.g. Eglinton et al. (1992); Marlowe et al. (1984); Rosell-Melé et al. (1994); Villanueva (1996)). Major changes in the vegetation cover/continental climate were evaluated by using pollen abundances (Naughton et al., 2009). Intensity of river discharge and on-land precipitation regimes were determined by using lipid compounds synthesized by higher plants, such as C23–C33 n-alkanes ([n-alc]) (e.g. Farrington et al. (1988); Pelejero et al. (1999); Prahl et al. (1994)) and the total pollen concentration (TPC), while pollen assemblages reflect major vegetation changes and on-land temperature and moisture conditions (Naughton et al., 2007).

Alkenones and higher plant n-alkanes were determined on 2 g of homogenized sediment using a Varian gas chromatograph Model 3800 equipped with a septum programmable injector and a flame ionization detector at the DivGM-IPMA laboratory according to the methods described in Villanueva (1996) and Villanueva et al. (1997). Analytical error was 0.5^{o}C. The concentration of each compound was determined using n-nonadecan-1-ol as internal standard. For Sea Surface Temperature (SST) calculation, the global character of the Müller et al. (1998) calibration ($U^{k'}_{37}$ = 0.033xSST-0.044) determined its selection.

Sample preparation procedure for pollen analyses followed Naughton et al. (2007). Pollen and spores were counted using a Nikon light microscope at x550 and x1250 (oil immersion) magnification. Pollen identification was done via comparison with the pollen atlases of Moore et al. (1991) and Reille (1992). A minimum of 100 *Lycopodium* grains, 20 pollen types and 100 pollen grains, excluding the over represented *Pinus,* have been counted (Naughton et al., 2007). Pollen was gathered in two main groups: AP (arboreal pollen) including all trees and shrubs but excluding the over represented pine taxa, and the semi-desert plants, which groups xerophytic shrubs of semi-desert habitats (*Artemisia*, Chenopodiaceae, *Ephedra*).

To reduce local variability and better evaluate the most robust multi-decadal record at the regional level, a stack off all the cores was created for SST and n-alkanes original records on their original age models. Each record was standardized (subtracting each value by the mean) and scaled (dividing the centered columns by its standard deviation). This technique weights high-resolution records more heavily and prevents interpolation across gaps or hiatuses from affecting the stack (Lisiecki and Raymo, 2005).

Given that temporal resolution changes along each core, a 2,000 yr stack was attempted for different bin sizes (20 to 50 yr). Results revealed that main trends were independent of the used size bin (not shown for brevity), a 30-yr period was chosen because it is considered as a standard period for climate

Clim. Past Discuss., https://doi.org/10.5194/cp-2017-84
Manuscript under review for journal Clim. Past
Discussion started: 27 June 2017

classification (Ahmed et al., 2013; Luterbacher et al., 2016). This bin allows for filtering out decadal internal variability driven by random phenomena, but is short enough to allow the detection of decadal variability in response to external forcing. Additionally, one additional stack was produced just for the northern sites (Galiza, Minho and Porto) in order to investigate possible contrasts between the northern and southern sites. To verify any potential effect of the existing hiatus on the Tagus record (Abrantes et al., 2005), as well as any possible bias caused by the Algarve record, stacks were also constructed excluding the Tagus record, and excluding the Algarve one. Fig. 2 shows a comparison of the calculated stacks for SST, demonstrating that the trends are maintained.

To investigate the existence of periodic signals and potential changes in their amplitude of variation over time, we carried out a continuous transformation of the time series with a Mortlet wavelet analysis on each dataset and stack (Torrence and Compo, 1998), after interpolation of the series to regular time steps. Interpolation was done using a cubic splines method and the temporal resolution of the interpolation was established as half of the absolute median difference between every consecutive time span. Data was then detrended using a modified negative exponential curve, as required for the analysis. All statistical analysis was done using the libraries biwavelet (Gouhier et al., 2016) and Akima and Gebhardt (2016), from r-project (R Core Team, 2016).

Observed SSTs for the period 1981-2016 were obtained from the NOAA daily Optimum Interpolation Sea Surface Temperature (OISST, V2 AVHRR-only) dataset. This climate data record provides complete ocean temperature fields constructed by combining bias-adjusted observations from different platforms (satellite, ships, buoys) on a regular 1/4º global grid (Reynolds et al., 2008). Daily time-series were extracted from the grid points nearest to the core locations and averaged over 3, 4, 5, or 12 month periods to produce different seasonal values and annual means. High-resolution SST maps to illustrate typical winter and summer distributions were obtained from the MUR (Multi-scale Ultra-high Resolution) SST dataset (NASA, 2002).

4 Age model

Age-depth models of 4 sedimentary sequences out of 7 have been previously published (Table 1). The remaining age-depth models for the three cores from Galiza (GeoB11033-1), Minho (DIVA09 GC) and Algarve (POPEI VC2B) were constructed based on accelerator mass spectrometry radiocarbon (AMS ^{14}C) and ^{210}Pb-inferred dates. ^{210}Pb activity analysis, which provides a method to assess mass accumulation rates, was performed at NIOZ. AMS ^{14}C - accelerator mass spectrometry (AMS) radiocarbon measurements were performed at the Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research, Kiel (Germany), the National Ocean Sciences AMS Facility of the Woods Hole Oceanographic Institution (USA), and Beta Analytic (Table 2).

Raw AMS ^{14}C dates were corrected for marine reservoir ages of 400 yr ±36 (Abrantes et al., 2005) and converted to calendar ages using INTCAL04 (Reimer et al., 2004). The obtained calendar ages are

presented in years Anno Domini, now designated by Common Era (CE - McKim (1998).
All age models were interpolated linearly between all accepted ^{14}C dated levels.

5 Results and Discussion

Proxy reconstructions are in general, affected by many limitations; from dating uncertainties and coarse temporal resolution, to challenging temporal correlations, or yet by seasonal differences of the proxy generating process. However, the smoothing effect of the signal in the sediments has also been shown to be an advantage for longer than decadal variations (Hernández et al., 2015).
The sedimentary sequences selected for this study have a high temporal resolution, in order of 2-3 yr in the recent sediments and 30 yr in the older part due to a larger sampling interval (Table 1). Furthermore, the analyses of multiple proxies, for SST and on-land precipitation from the same archives allows us to accurately evaluate the coupled ocean and land variability without chronological ambiguity.
Below we describe all studied proxies and the main findings, as well as overall forcing mechanisms identified in our sedimentary record and their comparison to large-scale atmospheric oscillations.

5.1 Sea Surface Temperature

For alkenone-derived SST, a comparison of sediment calculated temperatures to mean annual and seasonal temperatures for the Porto, Tejo and Algarve sites was preformed. Alkenone production appears associated to the late winter-spring in the western Iberian margin while it follows the spring/ fall SST at Algarve (south Iberia) (Fig. 3). Although along the Western Portuguese margin coccolitophores dominate the phytoplankton throughout the year, with the exception of the diatom dominated upwelling events (Moita, 2001), this data suggests SST as mainly determined by blooms associated with the winter/ spring nutrient input by the large Douro and Tagus Rivers (Cabeçadas et al., 2003 ; Cabeçadas et al., 2008; Guerreiro et al., 2013). In the south, on the contrary, SST appears related to the coccolitophores blooms that develop during the upwelling season, when upwelled waters from the west coast are advected into the Algarve coast (Moita, 2001).
Fig. 4A displays the alkenone derived SST reconstructions for our Iberian margin records. Despite the differences in the time period covered by each record, the temporal resolution of the different cores, and even the different seasons recorded by the SST at distinct sites, all the sites reveal an overall long-term cooling trend from 0 CE to the beginning of the 20th century. This long-term cooling follows the decreasing trend reported for the entire Holocene in this region by Rodrigues et al. (2009), and other recently observed trends in Europe and worldwide records (Ahmed et al., 2013; Luterbacher et al., 2016; McGregor et al., 2015). This long term cooling follows the gradual decrease of northern Hemisphere summer insolation. In Iberia, this long-term sea surface cooling is stronger in the Tejo site (2.5 ºC/ 2,000 yr) than in all other sites (1ºC / 2ky). Moreover, SSTs are minima off Porto (14 to 16 ºC) and maxima in the Algarve inner shelf (17 to 20 ºC) throughout the record. Tejo, Minho and Galiza

reconstructions show intermediate values (15 to 18 ºC). The temperature difference between areas is maintained throughout the last 2,000 yr but variability shows higher amplitude in the Tejo and Algarve sites (3ºC) compared to the 1.5 ºC observed in the northern sites (Porto, Minho and Galiza).

Both the individual SST records (Fig. 4A) and the SST stack (Fig. 4B) display secular scale variability comparable with that recorded in the Ria de Vigo and northern Spain (Fig. 4C, D) as well as in Europe and in the North Hemisphere (Fig. 4E, F) (Diz et al., 2002; Luterbacher et al., 2016; Martín-Chivelet et al., 2011; Moberg et al., 2005). Relatively high SSTs occur during the first 9 centuries encompassing the Roman period and Dark Ages (Fig. 4), mainly at the Southern sites (Tejo and Algarve; Table 3). Consistent warmth conditions are also recognized at all sites between 900 and 1300 CE (Fig. 4B), within the timing of the Northern Hemisphere Medieval Warm Period (MWP) also designated by Medieval Climate Anomaly (MCA). However, the Western Iberia records reveal a warmer first phase in the MWP (900 – 1150 CE) in accordance with the findings of Cunningham et al. (2013) for the NE North Atlantic, but contrasting with colder conditions in southern Iberia (Algarve).

Reconstructed cold conditions characterize most of the 15th to 18th centuries in Western Iberia, with SST colder than MWP by an average 0.5 ºC in the northern sites and 1.2ºC in the southern sites, with the very prominent and complete LIA record of Algarve (Fig. 4A). The transition from warm to colder climatic conditions occurs around 1300 CE associated with the Wolf solar minimum (Fig. 4B). The coldest SSTs occurred between 1350 and 1850 CE, on Iberia during the well-known Little Ice Age (LIA) (Bradley and Jones, 1993), with the most intense cooling episodes related to other solar minima events, and major volcanic forcing and separated by intervals of relative warmth (Fig. 4G, H; e.g. Crowley and Unterman (2013); Solanki et al. (2004); Steinhilber et al. (2012); Turner et al. (2016); Usoskin et al. (2011)).

During the 20th century, the southern records show unusually large decadal scale SST oscillations in the context of the last 2,000 yr, in particular after the mid 1970's (Fig. 4A), coinciding with the Great Solar Maximum (1940 – 2000 - (Usoskin et al., 2011) and the "great salinity anomaly" event in the Northern Atlantic (Dickson et al., 1988), or yet the higher global temperatures of the last 1,400 yr detected by Ahmed et al. (2013).

The observed increase in the amplitude of variation of SST during the last 50 years, in particular at the Algarve site, although attributable to better proxy preservation in the more recent sediments (Calvert and Pedersen, 2007), is certainly a reflection of the regional reaction to an intensification of climatic extremes, an expected response to the ongoing climate warming (IPCC, 2013b; Miranda et al., 2002).

5.2 Continental Precipitation and Temperature

Intense river discharge is known to parallel high precipitation over the continent (Trigo and DaCamara, 2000). In oceanic sediments n-alkanes concentration ([n-alc]) has been widely used as a proxy for river discharge (e.g. Farrington et al. (1988); Pelejero et al. (1999); Prahl et al. (1994)). Furthermore, previous work on Iberian Margin has shown a good agreement between [n-alc] and River flux (Abrantes et al., 2005; Rodrigues et al., 2009). However, in looking for a more robust regional calibration for this proxy, the [n-alc] data obtained for the most recent sediments of the Porto, Tejo and Algarve sites was compared to the average river runoff for the Douro, Tagus and Guadiana Rivers during the NAO winter months (DJFM). The results reveal a Pearson correlation of 0.54 at $p>0.01$ and $n=47$, confirming it as a good proxy to evaluate the intensity of river runoff on the Iberian Peninsula.

As another independent proxy for river runoff and continental precipitation we use the Total Pollen Concentration (TPC as n of grains/cm^3 of sediment), which reflects the relative quantity of terrestrial material that reaches the marine environment mainly via river discharges reflecting therefore de degree of moisture availability on-land (Naughton et al., 2007; Naughton et al., 2009).

Pollen production occurs during the spring season and should therefore reflect atmospheric temperature and precipitation during that season (e.g. Guiot et al. (2009)). However, trees growth is dependent on the humidity of the previous winter season (Gouveia et al., 2008). Despite the seasonal complexity of the pollen grains signal we assume that arboreal taxa (representing a sum of the Atlantic and Mediterranean trees) is sensitive to temperature and require relatively high winter precipitation to grow, while and the expansion of semi-desert plants (*Ephedra*, Chenopodiaceae and *Artemisia*) might reflect increasing of dry conditions all over the year.

5.2.1 The [n-alc] record

At present day there is a clear north-south difference in the precipitation regime, with higher mean annual precipitation in the northern Iberian Peninsula area relatively to the southern region. Galiza is the deepest site (1873 m), located further away from the coast and from any river mouth, and shows the lowest concentrations of higher plants n-alkanes (100 - 700 ng/g). The Porto site, located next to the Douro River's mouth (one of the highest outflow rivers of Portugal), presents one order of magnitude higher n-alkanes (1000 to 7000 ng/g). The Minho, Tejo and Algarve sites, located in areas of influence of intermediate mean annual discharge rivers Minho, Tagus and Guadiana, show n-alkanes concentrations with intermediate values (700 - 4000 ng/g) (Fig. 5A). Furthermore, the n-alkanes Porto record reveals centennial to decadal variability throughout the MWP and most of the LIA (Fig. 5A).

The total [n-alc] stack (Fig. 5B) highlights decadal variability throughout the first 900 yr and mean lower values between 450 and 900 CE (DA). In the MWP, a strong positive deviation occurs during the early MWP (980-1080 CE), reflecting the intense river discharge in Porto, while reduced river discharge is recorded at the Tagus and Algarve sites. Between 1100 and 1700 CE there is a gradual increase in the total [n-alc] stack that reflects an intensification of river flow at all latitudes. By 1700 CE the northern rivers turn to lower concentrations while the Algarve record reaches its highest contents between 1930 and 1970 CE (Fig. 5A).

Precipitation variability on Iberia, reflected by changes in river discharge, can also be estimated from oscillations in TPC (Naughton et al., 2009). TPC data, although at a very low temporal resolution, is available for 3 locations, Minho, Tejo and Algarve (Fig. 5C). The TPC data suggests a much larger river discharge during the RP in the Tejo than in the Minho or the Algarve. Tejo core (D13882) (Rodrigues et al., 2009) shows a clear increase of terrestrial input starting in de RP. During the DA and the MWP riverine input/precipitation is higher at the Minho and Tagus hydrological basins than in southern Iberia (Algarve) up to 1400 CE when the Algarve record rises to values comparable to the Minho. Given the uncertainty associated to proxy records, to substantiate our [n-alc] record of on-land precipitation, our records are compared not only with the Tagus flood reconstructions based on the hydrological basin terraces (Benito et al., 2005; 2004; 2003), and the Taravilla Lake sediment record from the headwaters of the Tagus River (Moreno et al., 2008), but also with the historical documentation access by Font-Tullot (1988) for the Douro and Minho Rivers, and by Barriendos and Rodrigo (2006) for most Iberian Peninsula basins including the coastal Mediterranean, or yet to daily journals for the most recent flood events of the Guadiana River (Barriendos and Martin-Vide, 1998; Barriendos and Rodrigo, 2006; Cabrita, 2007; Varzeano, 1976) (Table 4). Those intervals are marked on figure 5 and although the age uncertainties, the stack [n-alc] maxima between 980 and 1080 CE coincide with reports of major flooding events in both the Douro and Minho Rivers (Font-Tullot, 1988). Other periods marked by strong precipitation occur in the MWP between 1180 – 1200 CE, and again in the beginning of LIA, 1450- 1470 CE. In the Tejo site the record also agrees with Tagus flooding times (1200 – 1280 CE; 1950 – 1980 CE). The Algarve site, located 80 km to the west of the Guadiana River mouth appears to be recording not only the most recent newspaper's reported flooding events of 1876 and 1979 CE (Cabrita, 2007; Varzeano, 1976), but also the Atlantic basin flooding events (Barriendos and Rodrigo, 2006; Benito et al., 2004). The similarity of the independently identified records of storm/flooding periods at the various regions, leads to the conclusion that the maxima in [n-alc] can indeed be attributed to extreme precipitation and flooding conditions (Fig. 5).

5.2.2 The pollen record

Arboreal (AP) and semi-desert pollen variability at the Minho, Tagus and Algarve sites were compared with the same pollen curves from the Ria de Vigo (Desprat et al., 2003) and reflect main forest/climate changes over the last 2,000 yr (Fig. 6 A, B). Major forest expansion, revealed by increasing arboreal pollen percentages, occurred during the RP and the MWP, reflecting relative warm atmospheric conditions on-land. In contrast, a reduction of the forest cover, revealed by the decrease of arboreal pollen, suggesting relatively cold conditions is detected during the LIA (Fig. 6B). Between 1700-1800 CE there is a strong decrease of arboreal pollen in Algarve and Minho suggesting an abrupt cooling episode in the atmosphere over Iberia. After 1800 CE a new increase in AP reflects increasing atmospheric temperatures. The relatively high quantity (although with modest contribution 8%) of semi-desert plants is detected in the south at Algarve followed by the Tejo site and is relatively reduced in the North (Minho), supporting evidences for drier conditions in southern Iberia when comparing to the North.

AP variability in western Iberia over the last 2,000 yr shows no clear matching with European summer atmospheric temperature or Spring precipitation (Fig. 6 F, G) but their general trends follow the Cantabria stalagmite T anomaly (Fig. 6E) (Martín-Chivelet et al., 2011) and pollen variability at Ria de Vigo (black line in Figs. 6A, B) (Desprat et al., 2003). The marked decrease of both arboreal taxa and the semi-desert plants observed during the LIA, between 1700 and 1800 CE, co-occur with the shifting between periods of increased frequency of strong rain events (Barriendos and Martin-Vide, 1998) and periods of prolonged drought (Barriendos, 2002; Benito and Hudson, 2010). Furthermore, this interval also coincides with a period of stable temperature in N Spain, and minima in European seasonality and spring atmospheric temperature in Europe (Fig. 6E, H, I; Luterbacher et al., 2004) as well as a minimum in spring-summer and winter precipitation (Fig. 6C, J, K) (Martín-Chivelet et al., 2011; Romero-Viana et al., 2011; Touchan et al., 2005).

5.3 Climate Forcing Mechanisms

The oceanographic system along the Iberian Peninsula Atlantic margin is very dynamic and seasonally distinct that is, its variability has multiple attributes that may not always appear in the same combination and can constrain climate reconstructions at all time-scales. Nevertheless, the use of multiple proxies from a single sediment sequence and the regional anomaly stack of the various sites should allow for the more robust climatic structures to be depicted. Furthermore, the site comparison of our higher-resolution SST records (alkenone estimated SST) to OISST confirms its relation to the season and process providing the conditions for coccolithophores to bloom, and indicates that while in the west coast SST compares to winter SSTs in the Algarve mimics spring-fall SSTs (Fig. 3). Although this could be seen as a potential problem for the interpretation of our records, the fact that both the long-term SST trend as the secular variability recorded at all sites is in accordance with the North Hemisphere and European records (Fig. 4; Luterbacher et al. (2016); Martín-Chivelet et al. (2011); Moberg et al. (2005)), gives us the confidence to use this difference as an opportunity to disentangle winter from spring-fall conditions in the region.

The Atlantic margin of the Iberian Peninsula was relatively warmer from 0-1300 CE, in particular during the final stage of the RP (0- 500 CE) and the MWP (900-1300 CE), while SST slightly decreases during the DA (500 -900 CE) (Fig. 4B). At about 1300 CE, in particular in the southern Iberian Peninsula sites, an important SST decrease marks the transition to a clearly colder LIA that lasts up to 1850 CE, even though a transition period towards warmer conditions is perceived to start at mid 18th century in most records. The transition to modern times / Industrial Era, shows a two step increase in

SST, with an initial increase followed by a new and more abrupt rise by mid 20th century particularly evidenced in the spring-fall record of the southernmost site.

In terms of on-land precipitation, the early MWP is a period of extreme precipitation and flooding mainly off the Douro River (Porto site) (Fig 5A, B). During the LIA, a concerted response of all the rivers related sites reveals a period of frequent but probably less intense precipitation and, within the age uncertainties, in consonance with the flooding intervals recorded on flooding plains, lakes and documents (e.g. Barriendos and Martin-Vide (1998); Benito et al. (2005); Cabrita (2007); Moreno et al. (2008); Font-Tullot (1988); Varzeano (1976)). Iberian margin records also show evidences of the well-known major storm events of the 20th century.

According to the compilation of Sánchez-Lopes et al, (2015), the climate of the Iberian Peninsula during the last 2,000 yr has been modulated by the combined effect of two main modes of atmospheric circulation, the North Atlantic Oscillation (NAO) and the EA. As such, the warm atmospheric temperature and higher humidity detected in the W and S of the Iberian Peninsula during the RP were attributed to a negative NAO and a positive EA. During the DA, NAO positive and EA negative conditions are considered to have caused the more humid N with a W-E humidity gradient. The consistent warm and dry conditions detected during the MWP throughout the Iberian Peninsula, are attributed to NAO positive and EA positive. On the contrary, NAO- and EA- are considered to explain the cold and wet winters, as well as, the cold summers proposed for the LIA.

Our results do not contradict Sánchez-Lopez conclusions for the RP, the DA and the LIA, but specific climate conditions, to be discussed below, occur in the early MWP and the Industrial Era, associated to major changes in the total solar irradiance (TSI) record (Fig. 4H; Bard et al. (2007)). Such distinctive features may indicate either a more direct impact of internal oceanic variability on these coastal sites, the effect of the SCAND mode, or yet the interplay of the various atmospheric modes of circulation with oceanic dynamics.

5.3.1 The MWP phases

In the early MWP (900 - 1100 CE), warmer winters are recorded on the west coast while cooler spring-falls occur in the Algarve and clustered events of extreme precipitation are registered in the Northern Iberian Peninsula (Figs. 4A, 5A, 5B, 5D). Other sites in Northern Iberia also record increased fluvial input during the MWP but with particular intensity around 1000 CE, as indicated by coccoliths' species and biomarkers at Ria de Vigo (Álvarez et al., 2005) and by benthic foraminifera at Ria de Muros (Lebreiro et al., 2006). Late MWP (1180 - 1280 CE) on the contrary, shows relatively cooler winters in the west, warmer spring-fall in the Algarve and no sign of extraordinary winter storms. Resembling climatic conditions that are in contradiction with the expected dry and warm winters as well as warm summers likely to be generated by the prevalence of NAO positive and EA positive modes proposed by Sánchez-Lopes et al., (2015). Yet, stronger coastal upwelling conditions have also been suggested to explain the productivity record of the southern Tejo site, implying the existence of northerly winds and an active Portuguese Current, that is, a persistent, positive NAO-like state or the frequent occurrence of extreme NAO maxima during the MWP (Abrantes et al, 2005). Furthermore, forest expansion indicate relatively warm conditions in both northwestern and southern Iberian Peninsula (Fig. 6B), and are in good agreement with atmospheric temperature over NE Spain (Fig. 6C) (Martín-Chivelet et al., 2011). This likely reflects similar on-land conditions on both regions. Marullo et al. (2011) found significant correlations between the AMO and the climate of the Euro-Mediterranean region, mainly in summer and intermediate seasons (i.e. spring and fall). Persistent positive NAO conditions during the MWP are also pointed as a source of strong heat transport from the Atlantic and an equally strong North Atlantic current (Yang and Myers, 2007). Furthermore, the Portuguese current is a southward extension of the North Atlantic Current, which in turn flows off the Gulf Stream.

Proxy reconstructions of the Gulf Stream SST and hydrographic variability reveal two periods of warmer SSTs within the MWP, one between 700 – 1070 CE and a second one between 1180 and 1280 CE (Fig. 5E) (Saenger et al., 2011). While Ortega et al (2015) NAO reconstruction, does not confirm the persistent NAO positive anomaly of Trouet, it points to a mostly positive NAO-like circulation during most of the MWP. Simultaneously, a stronger Atlantic Meridional overturning circulation (AMOC) during the MWP relatively to the LIA has been proposed by Saenger et al., (2011), based on evidence for lower salinities found of the NE American coast, and considered to reflect a northward advection of warm and less saline waters from the tropical Atlantic, i.e. fresher tropical Atlantic caused by shifts in the latitudinal position of the Inter Tropical Convergence Zone. Such conditions have also been suggested by other Atlantic records (e.g. Bianchi and McCave (1999); Boessenkool et al. (2007); Keigwin and Pickart (1999)), and sustained by model simulations that highlight the potential role of the NAO in driving variability in the North Atlantic Sea Surface Temperature (Atlantic Multidecadal Oscillation - AMO) which is associated with AMOC variability and consequently with the thermohaline circulation (Delworth and Dixon, 2000).

Although the existence of salinity anomalies in the northern Atlantic are considered a prerequisite for AMOC intensification (Buckley and Marshall, 2016), modeling studies also emphasize the need for a weakening of the subtropical and subpolar gyres (Häkkinen et al., 2011; Häkkinen et al., 2013), to allow the penetration of warm subtropical waters into the subpolar gyre (e.g Danabasoglu et al. (2012)). According to Häkkinen et al. (2011), the mean gyre strength is driven by changes in the wind stress curl that in turn is associated with changes in blocking between Greenland and Western Europe. Considering the modern observations of Marshall et al. (2001), the Atlantic zero wind stress curl line shifts northward during more positive NAO-like conditions. However, to explain the occurrence of big storms clustered in the early MWP on the Northwestern Iberian Peninsula, one has to imply a storm track position southward of the modern path of the westerly winds under NAO positive conditions, to at least 41ºN, a shift that could have been caused by an increase in mid-latitude blocking anticyclones.

According to Comas-Bru and McDermott (2014) and Jerez and Trigo (2013), SCAND is related to major blocking anticyclones over Scandinavia and has a positive mode associated with above-average precipitation across southern Europe. Although considered to have a larger influence on the Iberian Peninsula in summer than in winter, the inter-annual winter variability in the Northern Iberian Peninsula can be attributed to the joint action of NAO and SCAND modes, while EA appears to have a weak influence on the area during summer (Hernández et al., 2015). The regional effect of all three modes of atmospheric circulation on the SST and precipitation at Iberian Peninsula, for winter and summer periods, is presented by figure 5 in Hernández et al. (2015). Bearing in mind the Atlantic coast, besides the evident negative relation observed between NAO and precipitation in winter, EA and SCAND are also positively related to winter precipitation in particular in the Northern Iberian Peninsula. In summer, there is a slight positive relation of SCAND with precipitation in the north but an important negative effect with temperature in most of Iberian Peninsula. Assuming that these modern patterns were maintained during the MWP, one possible explanation for the observed strong precipitation in the north and lower SST in the Algarve during the early MWP may be the effect of a positive SCAND in the early MWP, but negative in late MWP.

To investigate the influence of the Atlantic SST multi-decadal variability on the weather regime over the Atlantic Iberian Peninsula, wavelet analysis was performed on our records (Figs. 7, 8). The SST stack reveals a dominance period centered at 74 yr between 900 and 1100 CE (Fig. 7A), two dominant periods centered at 74 and 180 yr co-occur after 1350 CE in the Algarve record (Fig. 7C) and a 100 yr cycle between 1300 and 1580 CE when the north stack is considered (Fig. 7B). The precipitation records show the same band of dominance centered at 74 yr in all the records (Fig. 8A, B, C), but while its dominance occurs before 1200 CE in the total and N stacks (Fig. 8A, B), in the Algarve it is significant only after 1700 CE (Fig. 8C). A 256 yr cycle it is also marked for the precipitation stack between 900 and 1200 CE. That is, a 74 yr period appears for SST and precipitation on the west coast mainly before 1300 CE and in the south coast after 1580 CE. In addition, longer period processes (100 – 181 yr) are found throughout the 3 SST records and before 1200 CE in the precipitation stack (256 yr). Stocker and Mysak (1992), attribute the 38-110 yr cycles found in their model exercise, to natural internal variability. Frankcombe et al. (2010), propose that the North Atlantic multidecadal variability is dominated by two main time scales, 20-30 yr associated with the AMOC and so, of ocean internal origin and 50-70 yr related to the atmospheric exchange between the Atlantic and the Arctic Ocean.

In its NE North Atlantic composite, Cunningham et al. (2013), find 111, 55.6, 40 and 31.3 yr cycles. However, the small amount of variance of the record explained by those periods, lead the authors to conclude for a weak influence of ocean internal variability into the NE North Atlantic Climate. More recently, Buckley and Marshall (2016), revise the periodicities shown by various instrumental and proxy records, group them into decadal (20 yr) and multidecadal (± 40-70 yr), and present results with statistical significance for the 70 yr periodicity, supporting that ocean dynamics play a significant role in the variability of the European climate on decadal and multi-decadal time scales (Yamamoto and Palter, 2016; Zhang, 2007).

If our wavelet results are interpreted in the light of the above-presented information, a multi-decadal variability of the North Atlantic dynamics, including the resulting heat transport into Europe, affect SST and precipitation mainly between 900 and 1200 CE in the north and after 1350 / 1500 CE in the southern site of the Atlantic Iberian Peninsula.

5.3.2 The Industrial Era

The transition to the Industrial Era, in the northern Porto site, although distinct at 1850 CE, starts at 1730−1740 CE (Abrantes et al., 2011) by the return of SSTs to values in the order of the observed prior to 1300 CE. A pattern that coincides with the atmospheric temperature rise detected in NE Spain, Europe and the Northern Hemisphere (Luterbacher et al., 2016; Martín-Chivelet et al., 2011; Moberg et al., 2005), as well as with a drought period that mainly affects the Atlantic sector of the Iberian Peninsula (Domínguez-Castro et al., 2010). A second and more marked rise of SST occurs by the mid 20th century (± 1970) being particularly distinct in the southern Algarve site, and in consonance with the second warming phase also observed in the Western Mediterranean (Lionello et al., 2006; Martín-Puertas et al., 2010).

The transition into the Industrial Era is also marked by a shift in the phytoplankton community and water column stratification over the northern Porto site, which was interpreted by Abrantes et al., (2011), as a response to a reduction in the summer and/or annual upwelling and more frequent fall−winter upwelling-like events (Abrantes et al., 2011; Alvarez et al., 2005; Gómez-Gesteira M et al., 2008; Pardo et al., 2011; Pérez et al., 2010). This shift corresponds to an intensified NAO positive phase followed by slightly positive NAO up to 1850 CE in all but the Cook et al., (2002) reconstruction (Fig. 4I; Cook et al. (2002); Luterbacher et al. (2002); Vinther et al. (2003), and is concomitant with a higher coherence between the Porto SST data and the AMO index (Fig. 4A, J) (Abrantes et al., 2011). On the basis of this information the authors proposed a connection between the Iberian coastal upwelling variability and the North Atlantic Ocean's surface and thermohaline circulation at the decadal scale. More recently, Zampieri et al. (2016), propose that the rapid warming periods of the Northern Hemisphere, including the last one in the '90s, are in great part modulated by shifts in the North Atlantic decadal mode of SST variability within AMO from negative (cold) to positive (warm) phases. A close look to the AMO index records of Gray et al. (2004) and Mann et al. (2010) (Fig. 4H) reveal that the two warming steps referred above do indeed occur during warming transitions in the AMO index, supporting the influence of the N Atlantic SST pattern on the Atlantic Iberian Peninsula and its southern area in particular. A connection also proposed by Cisneros et al. (2016) to explain the last 400 yr SST reconstruction of the central-western Mediterranean Sea.

The prominent increase in SST in the southern site might be explained by the dynamics of the coastal counter-current of the Gulf of Cadiz, were higher SSTs are reached at periods of large-scale northerly winds during the upwelling season (Garel et al., 2016). In addition, a substantial intensification of the upwelling off the southwestern coast in the last 50 yr, particularly noticeable during the peak summer months (July to September) has been suggested by Relvas et al. (2009). Nevertheless, it emerges as a regional imprint of a major reorganization of the oceanic dynamics that is likely to have been initiated in the mid 18th century. Considering the high relevance of such environmental changes to ecosystems, a more in depth discussion of its effect at the regional scale is necessary.

6 Conclusions

The combination of SST and terrestrial input/river discharge records from five sites distributed along the Iberian margin, from 36º to 42 ºN latitude, captures the spatial character of the Iberian margin SST and continental precipitation variability at different time scales through the last 2,000 yr. Furthermore, the construction of new regional stacks for SST and river discharge provide a meaningful form to understand the role of global/hemispheric vs regional processes. On a long-term scale, a decreasing trend in SST, from 0 CE to the beginning of the 20th century is observed at all latitudes with maxima amplitude in the southern site. Within this cooling a series of century/decadal scale climate changes were detected to follow the overall climatic patterns of the extra-tropical Northern Hemisphere and Europe. Iberian records of arboreal vegetation and NE Spain air temperature indicate warm and wet conditions until the beginning of the LIA. Colder conditions and frequent but not extreme storms occur during the LIA all along the Atlantic Iberian Peninsula concerted with flood plain, lakes and historic documents. Specific climate conditions occur in the MWP, mainly in the early MWP and again in the transition from the LIA into the Industrial Era, in both cases, associated to transition periods in solar activity. In addition, within the MWP, two phases could be distinguished, an early MWP phase marked by warmer winters but cooler spring-falls and extraordinary storms in the northern sites, and a second consistent dry period with warmer spring-falls. To explain the MWP record, we support the previously proposed interplay between the NAO and EA modes of atmospheric circulation, both of which on positive phases, and suggest a stronger influence of the North Atlantic dynamics on Iberian climate. Furthermore, in the early MWP the flooding record implies a southward shift of the modern storm track under NAO positive conditions, that is, the presence of a high pressure blocking system over Northwestern Europe, such as it can be provided by a positive-like mode of the SCAND atmospheric mode of circulation. The Industrial Era SST rise occurs in two steps, at the end of the LIA (1730 -1850), and again in the mid 20th century. At 1800 CE an imprint of oceanic processes becomes apparent in the northern records, supporting a stronger influence of the internal ocean variability into the Atlantic Iberian Peninsula climate. This second increase in SST is particularly marked in the southern Algarve site as a regional imprint of a larger-scale process that can also reflect the global warming impact that is expected mainly for southern Iberia.

7. Team list

5. Copyright statement

6. Code availability

7. Data availability

Data will be archived at PANGEA and link to data will be included on the final version

11. Appendices

13. Author contribution

Abrantes, F – PI of the various projects that funded all the data combined in this paper, had the idea and wrote the paper;

Rodrigues, T- Responsible for the biomarkers analysis in all cores;

Rufino, M – Statistical data analysis;

Naughton, F – Responsible for the pollen interpretation and age models of DIVA and POPEI;

Salgueiro, E – Data of GeoB11033-1 core;

Oliveira, D – Pollen analysis of the DIVA and POPEI cores;

Domingues, S – Pollen analysis for the Tejo site D13882 and POPEI core;

Costa, A. – Age model for GeoB11033-1;

Oliveira, P – Processed the satellite-derived and OISST data;

Drago, T – Provided the Algarve core (POPEI);

Mil-Homens, M – Participated in the DIVA cruise;

Acknowledgments

The authors express their gratitude to the captain, crew and participants of the cruises Discovery 249, Poseidon PALEO I, GALIOMAR P34, and B/O Mytilus DIVA09 for their contribution during the retrieval of the various cores used in this study. Thanks are due in particular to Guilhermo F. Pedraz and the Departamento de Geociencias Marinas y Ordenación del Territorio (Universidade de Vigo) for allowing the recovery of the DIVA core on their DIVA09 cruise. We thank A. Inês, D. Ferreira and C. Monteiro for their help and support with the laboratory analysis. Special acknowledgments are due to the anonymous referees of the first version of this paper, whom have greatly contributed for its improvement.

Funding was provided by projects INGMAR (FCT ARIPIPI Program –Support for State Labs Development), HOLSMEER (EVK2-CT-2000-00060), CLIMHOL (PTDC/AAC-CLI/100157/2008), MIÑO-MINHO (0234_NATURA_MM_1_E), POPEI (PDCT/MAR/55618/2004), CALIBERIA (PTDC/MAR/102045/2008 from FCT and COMPETE/FEDER -FCOMP-01-0124-FEDER-010599), CIIMAR (20132017 CIMAR), CCMAR (Associated Lab PEstC/ MAR/LA0015/2013); felowships to Filipa Naughton (SFRH / BPD / 36615 / 2007), Teresa Rodrigues (SFRH/BPD/66025/2009), Emília Salgueiro (Ref. SFRH / BPD / 26525 / 2006 & SFRH / BPD /111433 / 2015). Marta Rufino was funded by *contrato ciência* 2007 and by a post- doctoral grant of IPMA, within the EU project SAFI (FP7-SPACE-2013-1, grant agreement n8 607155).

List of Tables and Figures

Table 1 – Geographic location, water depth, sampling cruise, sedimentation rate (SR), and age model origin for the seven sedimentary sequences studied cores.

Table 2 – Results of 14C accelerator mass spectrometry dating (means ± SE) of the cores GeoB11033-1 (Galiza), DIVA 09CG (Minho) and POPEI VC2B (Algarve). Ages were reservoir corrected by 400 yr (years before present, yr BP) and converted into calendar years (AD/CE).

Table 3 –SST mean during major climatic episodes along Atlantic margin of the Iberian Peninsula. Existing sediment hiatus likely affected estimated value. Shades of blue and pink highlight respectively colder and warmer periods.

Table 4 – Compilation of flooding and drought events on the Western Iberian Peninsula, according to published information.

Figure 1– Cores location over Iberian Margin bathymetry. Geoß11033-1 / Galiza in orange, DIVA09 GC / Minho in magenta, PO287-6B, -6G / Porto (Douro Mud Belt) in blue, PO287-26B, -26G, D130902, D13882 Tejo (Tagus Mud Belt) in green, and POPEI VC2B/ Algarve in red. The color assign to each core location will be applied in all figures (A). Winter satellite-derived sea surface temperature

Clim. Past Discuss., https://doi.org/10.5194/cp-2017-84
Manuscript under review for journal Clim. Past
Discussion started: 27 June 2017

Climate of the Past Discussions

(SST) image (23 Jan 2003) showing the surface signature of the Iberian Poleward Current (B); Summer SST image illustrating coastal upwelling conditions (colder coastal SST) along the Western Iberian Margin (3 Aug 2005) (C). B and C land covered areas appear in white, the color shades were selected to highlight the main oceanographic structures, the image source is: JPL-PODAAC https://mur.jpl.nasa.gov/

Figure 2 – Comparison of SST stacks constructed using all the cores (total – black), without the Tagus cores (effect of existing hiatus - green), without the Popei record (effect of different coccolithophores generating process - red) and considering only the northern sites (Galiza, Minho and Porto - blue)

Figure 3 – Comparison of alkenone-derived sea surface temperature (SST – black diamonds) measured in cores PO287-6B (PORTO), PO287-26B (TEJO) and POPEI (ALGARVE) with annual (open circles), four 3-month seasonal averages (JFM, AMJ, JAS, OND, see legend) and composites for the NAO winter (DJFM) and upwelling seasons (MJJAS) computed from the OISST at the three sites location.

Figure 4 – Comparison of SST along the last 2,000 years at sites Galiza (magenta), Minho (orange), Porto (blue), Tejo (green) and Algarve (red) (A); SST stack constructed from all Iberian margin records (B); SST at Ria de Vigo (Diz et al., 2003); Northern Hemisphere annual mean atmospheric temperature anomaly (Moberg et al., 2005) (D); Northern Spain atmospheric temperature anomaly (Martín-Chivelet et al., 2011) (E); European spring-fall atmospheric temperature anomaly (Luterbacher et al., 2016) (F); volcanic activity as aerosol optical depth (Crowley and Unterman, 2013) (G); radionuclide-derived total solar irradiance (TSI) (Bard et al., 2007) (H); Northern Atlantic Ocean SST anomaly, AMO index (gray, (Mann et al., 2010) and (black, Gray et al., 2004) (I); NAO index (Luterbacher et al., 2002); brown - (Trouet et al., 2009) (J). Light grey band marks the Roman Period (RP), the pink band marks the Medieval Warm Period (MWP/MCA); the blue band marks the Little Ice Age (LIA).

Figure 5 – [n-alc] variability along the last two millennia and at the 5 different sites of the Iberian Atlantic margin (A); the [n-alc] stack anomaly (B); total pollen concentration (# pollen grains/cm^3 sediment) (C); SST stack anomaly (D); SST NW Atlantic cores KNR140-2-59GGC and CH07-98-MC22 (Saenger et al., 2011) (E); NAO index (black line, Luterbacher et al. 2002), (green line; (Cook et al., 2002), (gray line; Trouet et al, 2009), (brown line; Ortega et al., 2015) (F); Radionuclide-derived total solar irradiance (TSI) (Bard et al., 2007) (G). Dark grey bands mark the periods of Atlantic flooding as listed in Table 4.

Figure 6 – Variability of semi-desert plants percent percentages along the 2,000 yr record of cores Diva, Tejo, Popei and Ria de Vigo (black) (Desprat et al., 200) (A); arboreal pollen percent abundance (B);

the SST stack anomaly (C); the [n-alc] stack anomaly (D); Northern Spain atmospheric temperature anomaly (Martín-Chivelet et al., 2011) (C); European spring-fall atmospheric temperature anomaly (Luterbarher et al., 2016) (D); Spring Precipitation Central Europe (Büntgen et al., 2011) (E): European Seasonality and Spring AT (Luterbacher et al., 2004) (F, G); may-august Precipitation (Touchan et al., 2005) (H); winter (DJFM) Precipitation (Romero-Viana et al., 2011) (I).

Figure 7 – The continuous wavelet power spectrum of the SST STACK (A); the north SST STACK (B); and the Algarve SST record (C). The thick black contour designates the 95% confidence level and the lighter shaded area represents the cone of influence (COI) where edge effects might distort the results.

Figure 8 – The continuous wavelet power spectrum of the STACK [n-alc] record (A); the north [n-alc] STACK (B) and the Algarve [n-alc] record (C). The thick black contour designates the 95% confidence level and the lighter shaded area represents the cone of influence (COI) where edge effects might distort the results.

References

Abrantes, F., Lebreiro, S., Rodrigues, T., Gil, I., Bartels-Jónsdóttir, H., Oliveira, P., Kissel, C., and Grimalt, J. O.: Shallow-marine sediment cores record climate variability and earthquake activity off Lisbon (Portugal) for the last 2,000 years., Quaternary Science Reviews, doi: 10.1016/j.quascirev.2004.04.009, 2005. 2005.

Abrantes, F., Rodrigues, T., Montanari, B., Santos, C., Witt, L., Lopes, C., and Voelker, A. H. L.: Climate of the last millennium at the southern pole of the North Atlantic Oscillation: an inner-shelf sediment record of flooding and upwelling, Climate Research, 48, 261-280, 2011.

Ahmed, M., Anchukaitis, K. J., Asrat, A., Borgaonkar, H. P., Braida, M., Buckley, B. M., Buntgen, U., Chase, B. M., Christie, D. A., Cook, E. R., Curran, M. A. J., Diaz, H. F., Esper, J., Fan, Z.-X., Gaire, N. P., Ge, Q., Gergis, J., Gonzalez-Rouco, J. F., Goosse, H., Grab, S. W., Graham, N., Graham, R., Grosjean, M., Hanhijarvi, S. T., Kaufman, D. S., Kiefer, T., Kimura, K., Korhola, A. A., Krusic, P. J., Lara, A., Lezine, A.-M., Ljungqvist, F. C., Lorrey, A. M., Luterbacher, J., Masson-Delmotte, V., McCarroll, D., McConnell, J. R., McKay, N. P., Morales, M. S., Moy, A. D., Mulvaney, R., Mundo, I. A., Nakatsuka, T., Nash, D. J., Neukom, R., Nicholson, S. E., Oerter, H., Palmer, J. G., Phipps, S. J., Prieto, M. R., Rivera, A., Sano, M., Severi, M., Shanahan, T. M., Shao, X., Shi, F., Sigl, M., Smerdon, J. E., Solomina, O. N., Steig, E. J., Stenni, B., Thamban, M., Trouet, V., Turney, C. S. M., Umer, M., van Ommen, T., Verschuren, D., Viau, A. E., Villalba, R., Vinther, B. M., von Gunten, L., Wagner, S., Wahl, E. R., Wanner, H., Werner, J. P., White, J. W. C., Yasue, K., and Zorita, E.: Continental-scale temperature variability during the past two millennia, Nature Geosci, advance online publication, 2013.

Akima, H. and Gebhardt, A.: akima: Interpolation of Irregularly and Regularly Spaced Data. R package version 0.6-2. 2016.

Alvarez, I., Gomez-Gesteira, M., deCastro, M., and Prego, R.: Variation in upwelling intensity along the NorthWest Iberian Peninsula (Galicia), Journal of Atmospheric & Ocean Science, 10, 309-324, 2005.

Álvarez, M. C., Flores, J. A., Sierro, F. J., Diz, P., Francés, G., Pelejero, C., and Grimalt, J.: Millennial Surface water dynamics in the Ria de Vigo during the last 3000 years as revealed by coccoliths and molecular biomarkers., Paleogeography, Paleoclimatology, Paleoecology, 218, 1-13, 2005.

Bard, E., Raisbeck, G., Yiou, F., and Jouzel, J.: Comment on "Solar activity during the last 1000 yr inferred from radionuclide records by Muscheler et al. (2007). Quaternary Science Reviews, 26, 2301-2308, 2007.

Barriendos, M.: Los riesgos climáticos a través de la historia: avances en el estudio de episodios atmosféricos extraordinarios. In: Riesgos naturales, Ayala-Carcedo, F. J. and Olcina, J. (Eds.), Ariel, Barcelona, 2002.

Barriendos, M. and Martin-Vide, J.: Secular climatic oscillations as indicated by catastrophic floods in the Spanish Mediterranean coastland area. , Climate Change 38, 473–491, 1998.

Barriendos, M. and Rodrigo, F. S.: Study of historical flood events on Spanish rivers using documentary data, Hydrological Sciences Journal, 51, 765-783, 2006.

Benito, G., Barriendos, M., Llasat, M. C., Machado, M. J., and Thorndycraft, V. R.: Impacts on natural hazards of climatic origin. A.Flood risk. In: Preliminary Evaluation of the Impacts of Climate Change in Spain., Moreno, J. M. (Ed.), Ministerio de Medio Ambiente, Madrid,, 2005.

Benito, G., Díez-Herrero, A., and Fernández de Villalta, M.: Flood Response to Solar Activity in the Tagus Basin (Central Spain) over the Last Millennium, Climatic Change, 66, 27-28, 2004.

Benito, G. and Hudson, P.: Flood hazards: The context of fluvial Geomorphology. . . In: Geomorphological Hazards and Disaster Prevention, Alcántara-Ayala, I. and Goudie, A. (Eds.), Cambridge University Press 2010.

Benito, G., Sopeña, A., Sánchez-Moya, Y., Machado, M. a. J., and Pérez-González, A.: Palaeoflood record of the Tagus River (Central Spain) during the Late Pleistocene and Holocene, Quaternary Science Reviews, 22, 1737-1756, 2003.

Bianchi, G. and McCave, I.: Holocene periodicity in North Atlantic climate and deep-ocean flow south of Iceland, Nature, 397, 515–517, 1999.

Boessenkool, K. P., I.R. Hall, H. Elderfield, and Yashayaev, I.: North Atlantic climate and deep-ocean flow speed changes during the last 230 years, Geophys. Res. Lett., 34, 2007.

Bradley, R. S. and Jones, P. D.: Little Ice Age' summer temperature variations: their nature and relevance to recent global warming trends, The Holocene, 3, 367-376, 1993.

Buckley, M. W. and Marshall, J.: Observations, inferences, and mechanisms of the Atlantic Meridional Overturning Circulation: A review, Reviews of Geophysics, 54, 5-63, 2016.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J. O., Herzig, F., Heussner, K.-U., Wanner, H., Luterbacher, J., and Esper, J.: 2500 Years of European Climate Variability and Human Susceptibility, Science, 331, 578, 2011.

Cabeçadas, G., Brogueira, M. J., Nogueira, M., Cabeçadas, L., Cavaco, H., and Nogueira, P.: Coastal phytoplankton productivity associated with different stability and nutrient patterns. , Nice, France2003 EAE-A-09277.

Cabeçadas, G., Brogueira, M. J., T. Coutinho, and Oliveira, A. P.: Impact of hydrodynamics on the ecology of Douro coastal waters, EGU General Assembly 2008, Viena, 2008.

Cabrita, A. N.: A Cheia Grande no Guadiana, 7 de Dezembro de 1876. In: Eventos Meteorológicos, Estremoz, 2007.

Calvert, S. E. and Pedersen, T. F.: Chapter Fourteen Elemental Proxies for Palaeoclimatic and Palaeoceanographic Variability in Marine Sediments: Interpretation and Application. In: Developments in Marine Geology, Claude, H. M. and Anne De, V. (Eds.), Elsevier, 2007.

Cardeira, S., Rita, F., Relvas, P., and Cravo, A.: Chlorophyll a and chemical signatures during an upwelling event off the South Portuguese coast (SW Iberia), Continental Shelf Research, 52, 133-149, 2013.

Cisneros, M., Cacho, I., Frigola, J., Canals, M., Masqué, P., Martrat, B., Casado, M., Grimalt, J. O., Pena, L. D., Margaritelli, G., and Lirer, F.: Sea surface temperature variability in the central-western Mediterranean Sea during the last 2700 years: a multi-proxy and multi-record approach, Clim. Past, 12, 849-869, 2016.

Comas-Bru, L. and McDermott, F.: Impacts of the EA and SCA patterns on the European twentieth century NAO–winter climate relationship, Quarterly Journal of the Royal Meteorological Society, 140, 354-363, 2014.

Cook, E., D'Arrigo RD, and ME, M.: A well-verified, multiproxy reconstruction of the winter North Atlantic Oscillation index since A. D. 400, J. Clim., 15, 1754–1764, 2002.

Cook, E. R., Esper, J., and D'Arrigo, R. D.: Extra-tropical Northern Hemisphere land temperature variability over the past 1000 years, Quaternary Science Reviews, 23, 2063-2074, 2004.

Crowley, J. and Unterman, M. B.: Technical details concerning development of a 1200-yr proxy index for global volcanism, Crowley2013AOD-Reff, 5, 187-197, 2013.

Cunningham, L. K., Austin, W. E. N., Knudsen, K. L., Eiríksson, J., Scourse, J. D., Wanamaker, A. D., Butler, P. G., Cage, A. G., Richter, T., Husum, K., Hald, M., Andersson, C., Zorita, E., Linderholm, H. W., Gunnarson, B. E., Sicre, M.-A., Sejrup, H. P., Jiang, H., and Wilson, R. J. S.: Reconstructions of surface ocean conditions from the northeast Atlantic and Nordic seas during the last millennium, The Holocene, 23, 921-935, 2013.

Danabasoglu, G., Yeager, S. G., Kwon, Y.-O., Tribbia, J. J., Phillips, A. S., and Hurrell, J. W.: Variability of the Atlantic Meridional Overturning Circulation in CCSM4, Journal of Climate, 25, 5153-5172, 2012.

Delworth, T. L. and Dixon, K. W.: Implications of the recent trend in the Arctic/North Atlantic Oscillation for the North Atlantic thermohaline circulation, J. Clim., 13, 3721–3727, 2000.

Desprat, S., Sánchez Goñi, M. a. F., and Loutre, M.-F.: Revealing climatic variability of the last three millennia in northwestern Iberia using pollen influx data, Earth and Planetary Science Letters, 213, 63-78, 2003.

Dickson, R. R., Meincke, J., Malmberg, S.-A., and Lee, A. J.: The "great salinity anomaly" in the Northern North Atlantic 1968–1982, Progress in Oceanography, 20, 103-151, 1988.

Diz, P., Francés, G., Pelejero, C., Grimalt, J. O., and Vilas, F.: The last 3000 years in the Ría de Vigo (NW Iberian Margin): climatic and hydrographic signals, The Holocene, 12, 459-468, 2002.

Domínguez-Castro, F., García-Herrera, R., Ribera, P., and Barriendos, M.: A shift in the spatial pattern of Iberian droughts during the 17th century, Clim. Past, 6, 553-563, 2010.

Eglinton, G., Bradshaw, S. A., Rosell, A., Sarnthein, M., Pflaumann, U., and Tiedemann, R.: Molecular record of secular sea surface temperature changes on 100-year timescales for glacial terminations I, II and IV. , Nature, 356, 423-426, 1992.

Esper, J., Cook, E. R., and Schweingruber, f. H.: Low-Frequency Signals in Long Tre-Ring Chronologies for Reconstructing Past Temperature, Science, 295, 2250-2253, 2002.

Farrington, J. W., Davis A. C., Sulanowski J., McCaffrey M. A., McCarthy M., Clifford C. H., P., D., and K., V. J.: Biogeochemistry of lipids in surface sediments of the Peru Upwelling Area at 15°S. , Org. Geochem. , 13, 607-617, 1988.

Fernandez-Donado, L., Gonzalez-Rouco, J. F., Raible, C. C., Ammann, C. M., Barriopedro, D., García-Bustamante, E., Jungclaus, J. H., Lorenz, S. J., Luterbacher, J., Phipps, S. J., Servonnat, J., Swingedouw, D., Tett, S. F. B., Wagner, S., Yiou, P., and Zorita, E.: Large-scale temperature response to external forcing in simulations and reconstructions of the last millennium, Climate of the Past, 9, 293-421, 2013.

Fiuza, A.: The Portuguese Coastal Upwelling, Lisbon1982, 45-71.

Fiuza, A.: Upwelling patterns off Portugal. In: Coastal Upwelling its sediment record., Suess, E. and Thiede, J. (Eds.), Plenum, New York, 1983.

Fiúza, A. and Macedo, M. E.: Climatological space and time variation of the Portuguese coastal upwelling, Oceanologica Acta, 5, 31-40, 1982.

Fiuza, A. A. and Frouin, T. B. R.: Observations of a Warm Oceanic Current Flowing Northward along the Coasts Of Potugal and Spain During Nov-Dec 1983, Eos, Transactions, American Geophysical Union, 67, 1054, 1986.

Font-Tullot, I.: Historical documentation of Spain's climate, Madrid, Instituto Nacional de Meteorología, Madrid, p. 297, 1988.

Frankcombe, L. M., Heydt, A. v. d., and Dijkstra, H. A.: North Atlantic Multidecadal Climate Variability: An Investigation of Dominant Time Scales and Processes, Journal of Climate, 23, 3616-3638, 2010.

Garel, E., Laiz, I., Drago, T., and Relvas, P.: Characterisation of coastal counter-currents on the inner shelf of the Gulf of Cadiz, Journal of Marine Systems, 155, 19-34, 2016.

Giorgi, F.: Climate change hot-spots, Geophysical Research Letters, 33, n/a-n/a, 2006.

Gómez-Gesteira M, deCastro M, A. I., and JL, G.-G.: Coastal sea surface temperature warming trend along the continental part of the Atlantic Arc (1985–2005). J Geophys Res, 113, 2008.

Gouhier, T. C., Grinstead, A., and Simko, V.: biwavelet: Conduct univariate and bivariate wavelet analyses (Version 0.20.10). 2016.

Gouveia, C., Trigo, R. M., DaCamara, C. C., Libonati, R., and Pereira, J. M. C.: The North Atlantic Oscillation and European vegetation dynamics., Int. J. Climatol, 28, 2008.

Gray, S. T., Graumlich, L. J., Betancourt, J. L., and Pederson, G. T.: A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D., Geophysical Research Letters, 31, L12205, doi:12210.11029/12004GL019932, 2004.

Guerreiro, C., Oliveira, A., de Stigter, H., Cachão, M., Sá, C., Borges, C., Cros, L., Santos, A., Fortuño, J.-M., and Rodrigues, A.: Late winter coccolithophore bloom off central Portugal in response to river discharge and upwelling, Continental Shelf Research, 59, 65-83, 2013.

Guiot, J., Wu HB, Garreta V, Hatté C, and M, M.: A few prospective ideas on climate reconstruction: from a statistical single proxy approach towards a multi-proxy and dynamical approach, Climate of the Past 2009. 5:571–583, 2009.

Häkkinen, S., Rhines, P. B., and Worthen, D. L.: Atmospheric blocking and Atlantic multidecadal ocean variability, Science, 334, 655–659, 2011.

Häkkinen, S., Rhines, P. B., and Worthen, D. L.: Northern North Atlantic sea surface height and ocean heat content variability, J. Geophys. Res., 118, 3670–3678, 2013.

Hegerl, G. C., Crowley, T. J., Hyde, W. T., and Frame, D. J.: Climate sensitivity constrained by temperature reconstructions over the past seven centuries, Nature, 440, 1029-1032, 2006.

Hernández, A., Trigo, R. M., Pla-Rabes, S., Valero-Garcés, B. L., Jerez, S., Rico-Herrero, M., Vega, J. C., Jambrina-Enríquez, M., and Giralt, S.: Sensitivity of two Iberian lakes to North Atlantic atmospheric circulation modes, Climate Dynamics, 45, 3403-3417, 2015.

Hurrell, J.: Decadal trends in the North Atlantic Oscillation - regional temperatures and precipitation., Science, 269, 679, 1995.

Iglesias, I., Avilez-Valente, P., Couvelard, X., and Caldeira, R.: Geostrophic influence in the River Douro plume: a climatological study, Porto2014, 75-80.

IPCC: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013a.

IPCC: Annex II: Climate System Scenario Tables In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M. (Eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013b.

Jambrina-Enríquez, M., Sachse, D., and Valero-Garcés, B. L.: A deglaciation and Holocene biomarker-based reconstruction of climate and environmental variability in NW Iberian Peninsula: the Sanabria Lake sequence, Journal of Paleolimnology, 56, 49-66, 2016.

Jerez, S. and Trigo, R. M.: Time-scale and extent at which large-scale circulation modes determine the wind and solar potential in the Iberian Peninsula, Environmental Research Letters, 8, 044035, 2013.

Jones, P. D., Osborn, T. J., and Briffa, K. R.: The Evolution of Climate Over the Last Millenium., Science, 292, 662-667, 2001.

Keigwin, L. and Pickart, R.: Slope Water Current over the Laurentian Fan on Interannual to Millenial Time Scales., Science, 286, 520-523, 1999.

Lebreiro, S. M., Francés, G., Abrantes, F. F. G., Diz, P., Bartels-Jónsdóttir, H. B., Stroynowski, Z. N., Gil, I. M., Pena, L. D., Rodrigues, T., Jones, P. D., Nombela, M. A., Alejo, I., Briffa, K. R., Harris, I., and Grimalt, J. O.: Climate change and coastal hydrographic response along the Atlantic Iberian margin (Tagus Prodelta and Muros Ría) during the last two millennia, The Holocene, 16, 1003-1015, 2006.

Lionello, P., Malanott-Rizzoli, R., Boscolo, R., Alpert, P., Artale, V., Li, L., Luterbacher, J., May, W., Trigo, R., Tsimplis, M., Ulbrich, U., and Xoplaki, E. T.: The Mediterranean climate: An overview of the main characteristics and issues. In: Mediterranean Climate Variability (MedClivar), Elsevier, Amsterdam, 2006.

Lisiecki, L. E. and Raymo, M. E.: A Pliocene-Pleistocene stack of 57 globally distributed benthic D18O records, Paleoceanography, 20, 2005.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., and Wanner, H.: European Seasonal and Annual Temperature Variability, Trends, and Extremes Since 1500, Science, 303, DOI: 10.1126/science.1093877, 2004.

Luterbacher, J., Werner, J. P., Smerdon, J. E., Fernández-Donado, L., González-Rouco, F. J., Barriopedro, D., Ljungqvist, F. C., Büntgen, U., Zorita, E., Wagner, S., Esper, J., McCarroll, D., Toreti, A., Frank, D., Jungclaus, J. H., Barriendos, M., Bertolin, C., Bothe, O., Brázdil, R., Camuffo, D., Dobrovolný, P., Gagen, M., García-Bustamante, E., Ge, Q., Gómez-Navarro, J. J., Guiot, J., Hao, Z., Hegerl, G. C., Holmgren, K., Klimenko, V. V., Martín-Chivelet, J., Pfister, C., Roberts, N., Schindler, A., Schurer, A., Solomina, O., Gunten, L. v., Wahl, E., Wanner, H., Wetter, O., Xoplaki, E., Yuan, N., Zanchettin, D., Zhang, H., and Zerefos, C.: European summer temperatures since Roman times, Environmental Research Letters, 11, 024001, 2016.

Luterbacher, J., Xoplaki, E., Dietrich, D., Jones, P. D., Davies, T. D., Portis, D., Gonzalez-Rouco, J. F., von Storch, H., Gyalistras, D., Casty, C., and Wanner, H.: Extending North Atlantic Oscillation Reconstructions Back to 1500, Atmospheric Science Letters, 2, 114-124, 2002.

Mann, M. E., Zhang, Z., Rutherford, S., Bradley, R. S., Hughes, M. K., Shindell, D., Ammann, C., Faluvegi, G., and Ni., F.: Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly, Science, 326, 1256-1260, 2010.

Marlowe, I. T., Green, J. C., Neal, A. C., Brassell, S. C., Eglinton, G., and Course, P. A.: Long chain (n-C37–C39) alkenones in the Prymnesiophyceae. Distribution of alkenones and other lipids and their taxonomic significance, British Phycological Journal, 19, 203-216, 1984.

Marshall, J., Yochanan Kushnir, David Battisti, Ping Chang, Arnaud Czaja, Robert Dickson, James Hurrell, Michael McCartney, R. Saravanan, and Visbeck, M.: North Atlantic climate variability: Phenomena, impacts and Mechanisms, International Journal of Climatology, 21, 1863-1898, 2001.

Marta-Almeida, M., Dubert, J., and Peliz, Á.: Simulations of extreme shelf current along the North-Western Iberian Shelf forced by wind and river runoff. , Valencia, Spain2002, 1555–1559.

Martín-Chivelet, J., Muñoz-García, M. B., Edwards, R. L., Turrero, M. J., and Ortega, A. I.: Land surface temperature changes in Northern Iberia since 4000 yr BP, based on δ13C of speleothems, Global and Planetary Change, 77, 1-12, 2011.

Martín-Puertas, C., Jiménez-Espejo, F., Martínez-Ruiz, F., Nieto-Moreno, V., Rodrigo, M., Mata, M. P., and Valero-Garcés, B. L.: Late Holocene climate variability in the southwestern Mediterranean region: an integrated marine and terrestrial geochemical approach, Clim. Past, 6, 807–816, 2010.

Marullo, S., Artale, V., and Santoleri, R.: The SST Multidecadal Variability in the Atlantic–Mediterranean Region and Its Relation to AMO, Journal of Climate, 24, 4385-4401, 2011.

McGregor, H. V., Evans, M. N., Goosse, H., Leduc, G., Martrat, B., Addison, J. A., Mortyn, P. G., Oppo, D. W., Seidenkrantz, M.-S., Sicre, M.-A., Phipps, S. J., Selvaraj, K., Thirumalai, K., Filipsson, H. L., and Ersek, V.: Robust global ocean cooling trend for the pre-industrial Common Era, Nature Geosci, 8, 671-677, 2015.

McKim, D. K.: Common Era entry, Westminster John Knox Press, Louisville, Kentucky, 1998.

Mendes, R., Sousa, M. C., deCastro, M., Gómez-Gesteira, M., and Dias, J. M.: New insights into the Western Iberian Buoyant Plume: Interaction between the Douro and Minho River plumes under winter conditions, Progress in Oceanography, 141, 30-43, 2016.

Miranda, P., M.A., Coelho, F. E. S., Tomé, A. R., Valente, M. A., Carvalho, A., Pires, C., Pires, H. O., Pires, V. C., and Ramalho, C.: 20th Century Portuguese Climate and Climate Scenarios. In: Climate

Changes in Portugal: Scenarios, Impacts and Adaptation Measures (SIAM Project), Santos, F. D., Forbes, K., and Moita, R. (Eds.), Gradiva, 2002.

Moberg, A., Sonechkin, D. M., Holmgren, K., Datsenko, N. M., and Karlén, W. H.: Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution data, Nature, 433, 613-617, 2005.

Moita, T.: Estrutura, Variabilidade e Dinamica do Fitoplancton na Costa de Portugal Continental., 2001.article compilation, Faculdade de Ciencias da Universidade de Lisboa, University of Lisbon, Lisbon, 272 pp., 2001.

Moore, P. D., Webb, J. A., and Collinson, M. E.: Pollen analysis, Blackwell scientific publication, Oxford, 1991.

Morellón, M., Valero-GarcÉS, B., Anselmetti, F., Ariztegui, D., Schnellmann, M., Moreno, A. N. A., Mata, P., Rico, M., and Corella, J. P.: Late Quaternary deposition and facies model for karstic Lake Estanya (North-eastern Spain), Sedimentology, 56, 1505-1534, 2009.

Moreno, A., Morellón, M., Martín-Puertas, C., Frigola, J., Canals, M., Cacho, I., Corella, J. P., Pérez, A., Belmonte, Á., Vegas-Vilarrúbia, T., González-Sampériz, P., and Valero-Garcés, B. L.: Was there a common hydrological pattern in the Iberian Peninsula region during the Medieval Climate Anomaly?, PAGES news, 19, 16-18, 2011.

Moreno, A., Valero-Garcés, B. L., González-Sampériz, P., and Rico, M.: Flood response to rainfall variability during the last 2000 years inferred from the Taravilla Lake record (Central Iberian Range, Spain), Journal of Paleolimnology, 40, 943-961, 2008.

Müller, P. J., Kirst, G., Ruhland, G., von Storch, I., and Rosell-Meré, A.: Calibration of the alkenone paleotemperature index UK'37 based on core-pops from the eastern South Atlantic and the global ocean (60ºN-60ºS), Geochimica et Cosmochimica Acta, 62, 1757-1772, 1998.

Naughton, F., Sanchez Goñi, M. F., Desprat, S., Turon, J. L., Duprat, J., Malaizé, B., Joli, C., Cortijo, E., Drago, T., and Freitas, M. C.: Present-day and past (last 25 000 years) marine pollen signal off western Iberia, Marine Micropaleontology, 62, 91-114, 2007.

Naughton, F., Sánchez Goñi, M. F., Kageyama, M., Bard, E., Cortijo, E., Desprat, S., Duprat, J., Malaizé, B., Joli, C., Rostek, F., and Turon, J.-L.: Wet to dry climatic trend in north western Iberia within Heinrich events, Earth and Planetary Science Letters, 284, 329-342, 2009.

Oliveira, P. B., Moita, T., Catarino, R., and Silva, A. J. d.: Wintertime SST and Chla off NW Iberian shelf from satellite and insitu data, Amsterdam, 24–28 September 2007,2007.

Otero, P., Ruiz-Villarreal, M., and Peliz, A.: Variability of river plumes off Northwest Iberia in response to wind events, Journal of Marine Systems, 72, 238-255, 2008.

Palter, J. B.: The Role of the Gulf Stream in European Climate. , Annu. Rev. Marine Sci. , 7, 113–137, 2015.

Pardo, P. C., Padín, X. A., Gilcoto, M., Farina-Busto, L., and Pérez, F. F.: Evolution of upwelling systems coupled to the long-term variability in sea surface temperature and Ekman transport, Climate Research, 48, 231:246, 2011.

Pelejero, C., Keinast, M., Wang, L., and Grimalt, J. O.: The flooding of Sundaland during the last deglaciation: imprints in hemipelagic sediments from the southern South China Sea, Earth and Planetary Science Letters, 171, 661-671, 1999.

Peliz, Á., Dubert, J., Santos, A. M. P., Oliveira, P. B., and Le Cann, B.: Winter upper ocean circulation in the Western Iberian Basin—Fronts, Eddies and Poleward Flows: an overview, Deep Sea Research Part I: Oceanographic Research Papers, 52, 621-646, 2005.

Peliz, Á., Rosa, T. L., Santos, A. P., and Pissarra, J. L.: Fronts, jets, and counter-flows in the Western Iberian upwelling system, Journal of Marine Systems, 35, 61-77, 2002.

Pena, L. D., Francés, G., Diz, P., Esparza, M., Grimalt, J. O., Nombela, M. A., and Alejo, I.: Climate fluctuations during the Holocene in NW Iberia: High and low latitude linkages, Continental Shelf Research, 30, 1487-1496, 2010.

Pérez, F. F., Padín, X., Pazos, Y., Gilcoto, M., Cabanas, J. M., Pardo, P., Doval, D., and Farina-Bustos, L.: Plankton response to weakning of the Iberian coastal upwelling, Global Change Biology, 16, 1258-1267, 2010.

Prahl, F. G., Ertel, J. R., Goni, M. A., Sparrow, M. A., and Eversmeyer, B.: Terrestrial organic carbon contributions to sediments on the Washington margin., Geoch. Cosmochim. Acta, 1994. 1994.

R Core Team: R: A language and environment for statistical computing. . Computing, R. F. f. S. (Ed.), Viena, Austria, 2016.

Reille, M.: Pollen et spores d'Europe et d'Afrique du Nord, Laboratoire de botanique historique et palynologie, Marseille, 1992.

Reimer, P., Baillie, M., Bard, E., Bayliss, A., Beck, J., Bertrand, C., Blackwell, P., Buck, C., Burr, G., Cutler, K., Damon, P., Edwards, R., Fairbanks, R., Friedrich, M., Guilderson, T., Hughen, K., Kromer, B., McCormac, F., Manning, Ramsey, C. B., Reimer, R., Remmele, S., Southon, J., Stuiver, M., Talamo, S., Taylor, F., Plicht, J. v. d., and Weyhenmeyer, C.: Marine04 Marine radiocarbon age calibration, 26 - 0 ka BP, Radiocarbon, 46, 1029-1058, 2004.

Relvas, P., Barton, E., Dubert, J., Oliveira, P. B., Peliz, A., da Silva, J., and Santos, A. M. P.: Physical oceanography of the western Iberia ecosystem: Latest views and challenges, Progress in Oceanography, 74, 149-173, 2007.

Relvas, P. and Barton, E. D.: Mesoscale patterns in the Cape São Vicente (Iberian Peninsula) upwelling region, Journal of Geophysical Research, 107, 28/21-23, 2002.

Relvas, P., Luıs, J., and Santos, A. M. P.: Importance of the mesoscale in the decadal changes observed in the northern Canary upwelling system, Geophys. Res. Lett., 36, L22601 2009.

Reynolds, R., Banzon, V. F., and Program, N. C.: NOAA Optimum Interpolation 1/4 Degree Daily Sea Surface Temperature (OISST) Analysis, Version 2 [AVHRR-Only]. . In: NOAA National Centers for Environmental Information, 2008.

Rodrigues, T., Grimalt, J. O., Abrantes, F. G., Flores, J. A., and Lebreiro, S. M.: Holocene interdependences of changes in sea surface temperature, productivity, and fluvial inputs in the Iberian continental shelf (Tagus mud patch), Geochemistry, Geophysics, Geosystems, 10, n/a-n/a, 2009.

Romero-Viana, L., Julià, R., Schimmel, M., Camacho, A., Vicente, E., and Miracle, M. R.: Reconstruction of annual winter rainfall since A.D. 1579 in centraleastern Spain based on calcite laminated sediment from Lake La Cruz, Climate Change, 107, 343-361, 2011.

Rosell-Melé, A., Carter, J. A., and Eglinton, G.: Survey of distribution of long-chain alkenones and alkyl alkenoates in marine surface sediments from the North East Atlantic. , Organic Geochemistry, 22, 501-509, 1994.

Sabine, C. L.: The Oceanic Sink for Anthropogenic CO2, Science, 305, 367-371, 2004.

Saenger, C., Came, R. E., Oppo, D. W., Keigwin, L. D., and Cohen, A. L.: Regional climate variability in the western subtropical North Atlantic during the past two millennia, Paleoceanography, 26, n/a-n/a, 2011.

Sánchez, R. F. and Relvas, P.: Spring–summer climatological circulation in the upper layer in the region of Cape St. Vincent, Southwest Portugal, ICES J. Mar. Sci., 60, 1232-1250, 2003.

Sánchez-López, G., Hernández, A., Pla-Rabes, S., Trigo, R. M., Toro, M., Granados, I., Sáez, A., Masqué, P., Pueyo, J. J., Rubio-Inglés, M. J., and Giralt, S.: 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, Quaternary Science Reviews, 149, 135-150, 2016.

Schurer, A. P., Tett, S. F. B., and Hegerl, G. C.: Small influence of solar variability on climate over the past millennium, Nature Geoscience, 7, 104-108, 2014.

Solanki, S. K., Usoskin, I. G., Kromer, B., Schüssler, M., and Beer, J.: An unusually active Sun during recent decades compared to the previous 11,000 years, Nature, 431, 1084-1087, 2004.

Steinhilber, F., Abreu, J. A., Beer, J., Brunner, I., Christl, M., Fischer, H., Heikkilä, U., Kubik, P. W., Mann, M., McCracken, K. G., H. Miller, Miyahara, H., Oerter, H., and Wilhelms, F.: 9,400 years of cosmic radiation and solar activity from ice cores and tree rings., Proceedings of the National Academy of Sciences, doi: doi:10.1073/pnas.1118965109 2012. 2012.

Stocker, T. and Mysak, L.: Climatic fluctuations on the century time scale: A review of high resolution proxy data and possible mechanisms, Climatic Change, 20, 227-250, 1992.

Teles-Machado, A., Peliz, Á., McWilliams, J. C., Cardoso, R. M., Soares, P. M. M., and Miranda, P. M. A.: On the year-to-year changes of the Iberian Poleward Current, Journal of Geophysical Research: Oceans, 120, 4980-4999, 2015.

Torrence, C. and Compo, G. P.: A practical guide to wavelet analysis, Bulletin of the American Meteorological Society, 79, 61-78, 1998.

Touchan, R., Xoplaki, E., Funkhouser, G., Luterbacher, J., Hughes, M. K., Erkan, N., Akkemik, Ü., and Stephan, J.: Reconstructions of Spring/Summer Precipitation for the Eastern Mediterranean from Tree-Ring Widths and its Connection to Large-Scale Atmospheric Circulation, Climate Dynamics, 25, 75-98, 2005.

Trigo, R. M. and DaCamara, C. C.: Circulation Weather Types and Their influence on the Precipitation Regime in Portugal, International Journal of Climatology, 20, 1559-1581, 2000.

Trigo, R. M., Pozo-Vázquez, D., Osborn, T. J., Castro-Díez, Y., Gámiz-Fortis, S., and Esteban-Parra, M. J.: North Atlantic oscillation influence on precipitation, river flow and water resources in the Iberian Peninsula, International Journal of Climatology, 24, 925-944, 2004.

Trouet, V., Esper, J., Graham, N. E., Baker, A., Scourse, J. D., and Frank, D. C.: Persistent Positive North Atlantic Oscillation Mode Dominated the Medieval Climate Anomaly, Science, 324, 78, 2009.

Turner, T. E., Swindles, G. T., Charman, D. J., Langdon, P. G., Morris, P. J., Booth, R. K., Parry, L. E., and Nichols, J. E.: Solar cycles or random processes? Evaluating solar variability in Holocene climate records, Scientific Reports, 6, 23961, 2016.

Usoskin, I. G., Solanki, S. K., and Kovaltsov, G. A.: Grand minima of solar activity during the last millennia, Proceedings of the International Astronomical Union, 7, 372-382, 2011.

Valero-Garcés, B. L., González-Sampériz, P., Navas, A., Machín, J., Mata, P., Delgado-Huertas, A., Bao, R., Moreno, A., Carrión, J. S., Schwalb, A., and González-Barrios, A.: Human Impact Since Medieval Times and Recent Ecological Restorationin a Mediterranean Lake: The Laguna Zoñar, Southern Spain, Journal of Paleolimnology, 35, 441-465, 2006.

Varzeano, J.: Há um século a grande cheia do Guadiana provocou tragédia em Alcoutim. In: Jornal do Algarve, Vila Real de Santo António, 1976.

Villanueva, J.: Estudi de les variaciones climàtiques i oceanogràfiques a l`atlantic Nord Durant els últims 300.000 anys mitjançant l`anális de marcadores moleculars, 1996. Dep.Química Ambiental, Universitat de Barcelona, Barcelona, 186 pp., 1996.

Villanueva, J., Grimalt, J., Cortijo, E., Vidal, L., and Labeyrie, L.: A biomarker approach to the organic matter deposited in the North Atlantic during the last climatic cycle, Geochimica et Cosmochimica Acta, 61, 4633-4646, 1997.

Vinther, B. M., K. K. Andersen, A. W. Hansen, T. Schmith, and Jones, P. D.: Improving the Gibraltar/Reykjavik NAO index, Geophysical Research Letters, 30, doi:10.1029/2003GL018220, 2003.

Wang, C. and Dong, S.: Is the basin-wide warming in the North Atlantic Ocean related to atmospheric carbon dioxide and global warming?, Geophysical Research Letters, 37, n/a-n/a, 2010.

Yamamoto, A. and Palter, J. B.: The absence of an Atlantic imprint on the multidecadal variability of wintertime European temperature, Nature Communications, 7, 10930, 2016.

Zampieri, M., Toreti, A., Schindler, A., Scoccimarro, E., and Gualdi, S.: Atlantic multi-decadal oscillation influence on weather regimes over Europe and the Mediterranean in spring and summer, Global and Planetary Change, doi: http://dx.doi.org/10.1016/j.gloplacha.2016.08.014, 2016. 2016.

Zhang, R.: Anticorrelated multidecadal variations between surface and subsurface tropical North Atlantic, Geophysical Research Letters, 34, n/a-n/a, 2007.

Clim. Past Discuss., https://doi.org/10.5194/cp-2017-84
Manuscript under review for journal Clim. Past
Discussion started: 27 June 2017

Site	ID	Water depth (m)	Lat N	Long W	Core Type	Cruise	SR (mm/yr)	Age Model
Galiza	GeoB11033-1	1873	42.1698	-9.5360	Box	Galiomar P342	0.4	This work
Minho	DIVA09 GC	119	41.9168	-9.0735	Gravity	Sarmento de Gamboa	0.5	This work
Porto	PO287-6B, G	84	41.3356	-8.9888	Gravity	RV Poseidon - PALEO1	6.3	Abrantes et al., (2011)
Tejo	D13902	90	38.5540	-9.3355	Long Piston	RV Discovery 249	7.0	Abrantes, F.,et al, (2005)
Tejo	PO287-26B, 26G	96	38.5582	-9.3640	Box/ Garvity	RV Poseidon - PALEO1	7.0	Abrantes, F.,et al, (2005)
Tejo	D13882	88	38.6450	-9.4542	Long Piston	RV Discovery 249	0.2	Rodrigues et al, (2009)
Algarve	POPEI VC2B	96	36.8800	-8.0700	Vibrocore	NRP Auriga - POPEI0108	1.2	This work

Table 1 – Geographic location, water depth, sampling cruise, sedimentation rate (SR), and age model origin for the seven sedimentary sequences studied cores.

Core ID and depth (cm)	Laboratory code	Sample Type	Conventional ^{14}C age (BP)	error	Calibrated age ranges at 95% confidence intervals	Age AD	Laboratory
GeoB11033-1							
27 - 28.5	OS-97151	Foraminifera	2430	25	746-530	-638	National Ocean Sciences AMS - WHOI
DIVA 09 CG							
3 - 4	KIA 42919	Mollusk shell	465	25	1841-1859	1864	Leibniz Labor - Kiel
48-49	OS-97148	Foraminifera	1270	25	1057-1211	1133	National Ocean Sciences AMS - WHOI
57-58	KIA 42920	Mollusk shell	1730	30	602-728	660	Leibniz Labor - Kiel
68-69	OS-97149	Foraminifera	1990	25	298-482	400	National Ocean Sciences AMS - WHOI
83 - 84	KIA 42921	Mollusk shell	2380	30	-157 -33	-60	Leibniz Labor - Kiel
101 - 102	KIA 42922	Mollusk shell	2325	30	-87 - 95	11	Leibniz Labor - Kiel
POPEI VC2B							
130.9	Beta 278216	Mollusk shell	1220	40	1080:1274	1184	Beta Analytics
200.6	OS-97152	Foraminifera	2130	25	146:326	233	National Ocean Sciences AMS - WHOI
270.3	OS-97143	Foraminifera	3020	25	-902:-783	-837	National Ocean Sciences AMS - WHOI

Table 2 – Results of 14C accelerator mass spectrometry dating (means ± SE) of the cores GeoB11033-1 (Galiza), DIVA 09CG (Minho) and POPEI VC2B (Algarve). Ages were reservoir corrected by 400 yr (years before present, yr BP) and converted into calendar years (AD/CE).

	Common Era	Mean SST				
		Galiza	Minho	Douro	Tejo	Algarve
Roman - Dark Ages	< 900	16.0	16.5	-	17.5	19.1
Medieval Warm Period	900 - 1300	16.6	16.2	15.3	17.1	18.7
Little Ice Age	1350 -1850	16.1	15.9	14.7	15.6*	17.8
Modern Times	>1900	15.5	-	14.7	15.5	18.3

Table 3 –SST mean during major climatic episodes along Atlantic margin of the Iberian Peninsula. Existing sediment hiatus likely affected estimated value. Shades of blue and pink highlight respectively colder and warmer periods.

FLOODS

Period/ Region	Atlantic Basin	Douro & Minho	Tejo	Guadiana	References	Oservations
			785-1205		Benito et al, 2003	Increase magnitude and frequency
		1000 - 1100			Tullot, 1988	*Doc Sources*
MCA	**1000-1200**				Benito et al, 2003b	Sediment records
			1150 -1200		Benito et al, 2010	*Max from Doc sources*
	1150 -1290				Benito et al, 2003b	Sediment records
		1180 – 1200			Tullot, 1989	*Doc Sources*
	1430-1685				Benito et al, 2010	Sediment records & Doc Sources
		1434 - LCF		*1434 - LCE*	*Barriendos and Rodrigo, 2010*	*Doc Sources*
		1450-1470		*1450-1500*	Tullot, 1988;	*Doc Sources*
			1450 -1500		Benito et al, 2003	High frequency lower magnitude
		1545 - LCF		*1545 - LCE*	*Barriendos and Rodrigo, 2010*	*Doc Sources*
				1570-1630	Barriendos and Martín-Vide, 1998	Mediterranean area- Doc Sources
LIA	*1590-1610*				Benito et al, 2003b	*Doc Sources*
		1626- VLCF	**1626- VLEF**	**1626- VLCF**	*Barriendos and Rodrigo, 2010*	*Doc Sources*
		1636 - LCF	1637 - LCE		*Barriendos and Rodrigo, 2010*	*Doc Sources*
	1730-1810				Benito et al, 2010	*Doc Sources*
	1730-1760				Benito et al, 2003b	Sediment records & Doc Sources
				1830-1870	Barriendos and Martín-Vide, 1998	Mediterranean area- Doc Sources
		1778 - LEF		1778 - LCE	*Barriendos and Rodrigo, 2010*	*Doc Sources*
	1780-1810				Benito et al, 2003b	*Doc Sources*
		1853 - LEF			*Barriendos and Rodrigo, 2010*	*Doc Sources*
		1860 - LCF	1860 - LCF		*Barriendos and Rodrigo, 2010*	*Doc Sources*
	1870-1900				Benito et al, 2003b	Sediment records
MODERN	1930-1950				Benito et al, 2003b	Sediment records
	1960-1980				Benito et al, 2003b	Sediment records
			1670 - 1950	1876	Benito et al, 2003;	High frequency lower magnitude
			1950-1980	1979	Benito et al, 2003b	Doc Sources

LCF - Large Catastrophic Flood; LEF - Large Extraordinary Flood; VLCF - Very Large Catastrophic Flood; VLEF - Very Large Extraordinary Event
Bold - Catastrophic Event

DROUGHTS

MWP				1361-1390	Barriendos and Martín-Vide, 1998	
				1511-1540	Barriendos and Martín-Vide, 1998	
	1540-1570				Barriendos 2002	severe
LIA	1625-1640				Barriendos 2002	severe
	1750-1760				Barriendos 2002	Less severe
	1810-1830				Barriendos 2002	Less severe
				1880-1950	Barriendos and Martín-Vide, 1998	
MODERN	1880-1910				Barriendos 2002	Less severe

Table 4 – Compilation of flooding and drought events on the Western Iberian Peninsula, according to published information.

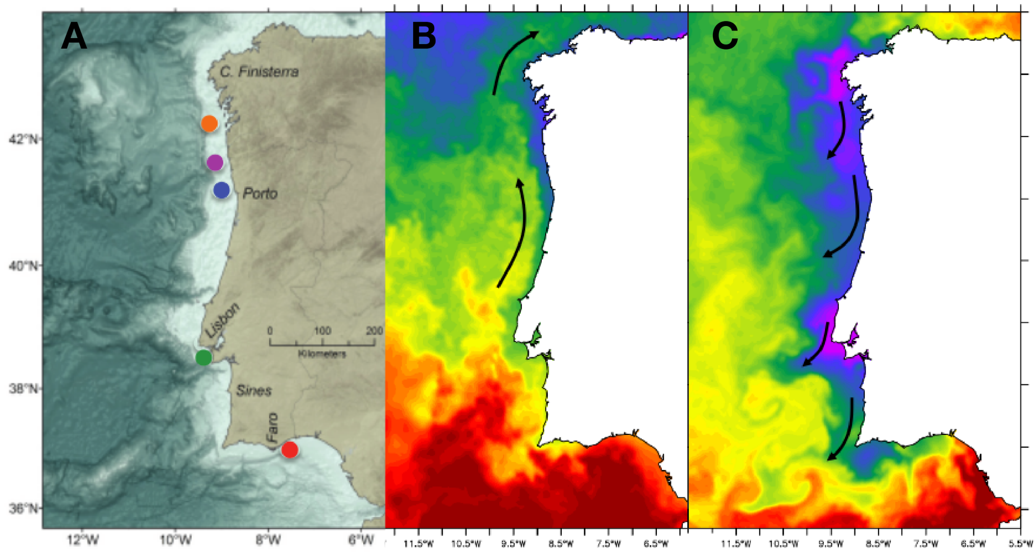


Figure 1– Cores location over Iberian Margin bathymetry. Geoß11033-1 / Galiza in orange, DIVA09 GC / Minho in magenta, PO287-6B, -6G / Porto (Douro Mud Belt) in blue, PO287-26B, -26G, D130902, D13882 Tejo (Tagus Mud Belt) in green, and POPEI VC2B/ Algarve in red. The color assign to each core location will be applied in all figures (A). Winter satellite-derived sea surface temperature (SST) image (23 Jan 2003) showing the surface signature of the Iberian Poleward Current (B); Summer SST image illustrating coastal upwelling conditions (colder coastal SST) along the Western Iberian Margin (3 Aug 2005) (C). B and C land covered areas appear in white, the color shades were selected to highlight the main oceanographic structures, the image source is: JPL-PODAAC https://mur.jpl.nasa.gov/

Clim. Past Discuss., https://doi.org/10.5194/cp-2017-84
Manuscript under review for journal Clim. Past
Discussion started: 27 June 2017

Climate of the Past Discussions
Open Access
EGU

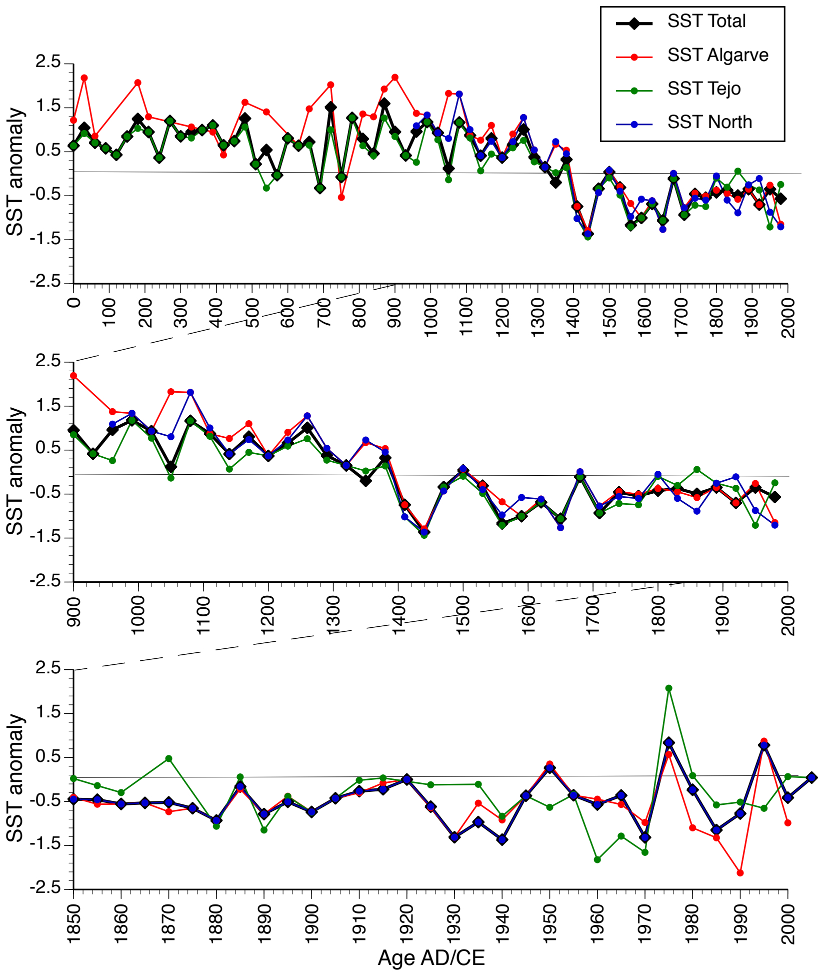


Figure 2 – Comparison of SST stacks constructed using all the cores (total – black), without the Tagus cores (effect of existing hiatus - green), without the Popei record (effect of different coccolithophores generating process - red) and considering only the northern sites (Galiza, Minho and Porto - blue)

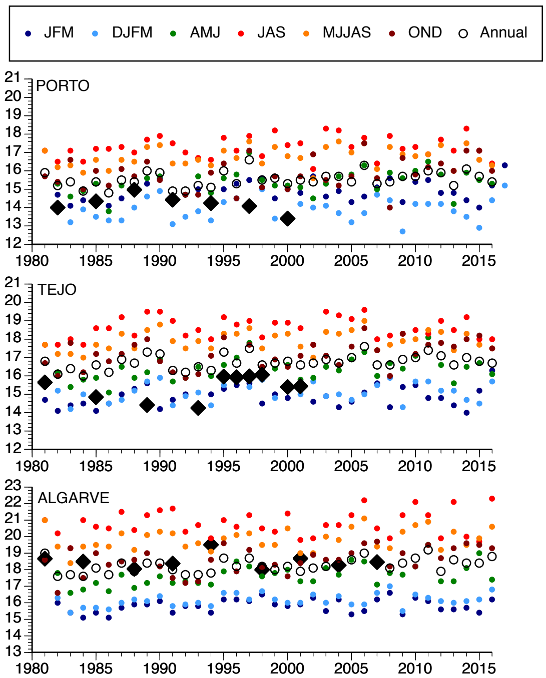


Figure 3 – Comparison of alkenone-derived sea surface temperature (SST – black diamonds) measured in cores PO287-6B (PORTO), PO287-26B (TEJO) and POPEI (ALGARVE) with annual (open circles), four 3-month seasonal averages (JFM, AMJ, JAS, OND, see legend) and composites for the NAO winter (DJFM) and upwelling seasons (MJJAS) computed from the OISST at the three sites location.

Clim. Past Discuss., https://doi.org/10.5194/cp-2017-84
Manuscript under review for journal Clim. Past
Discussion started: 27 June 2017

Climate of the Past Discussions
Open Access
EGU

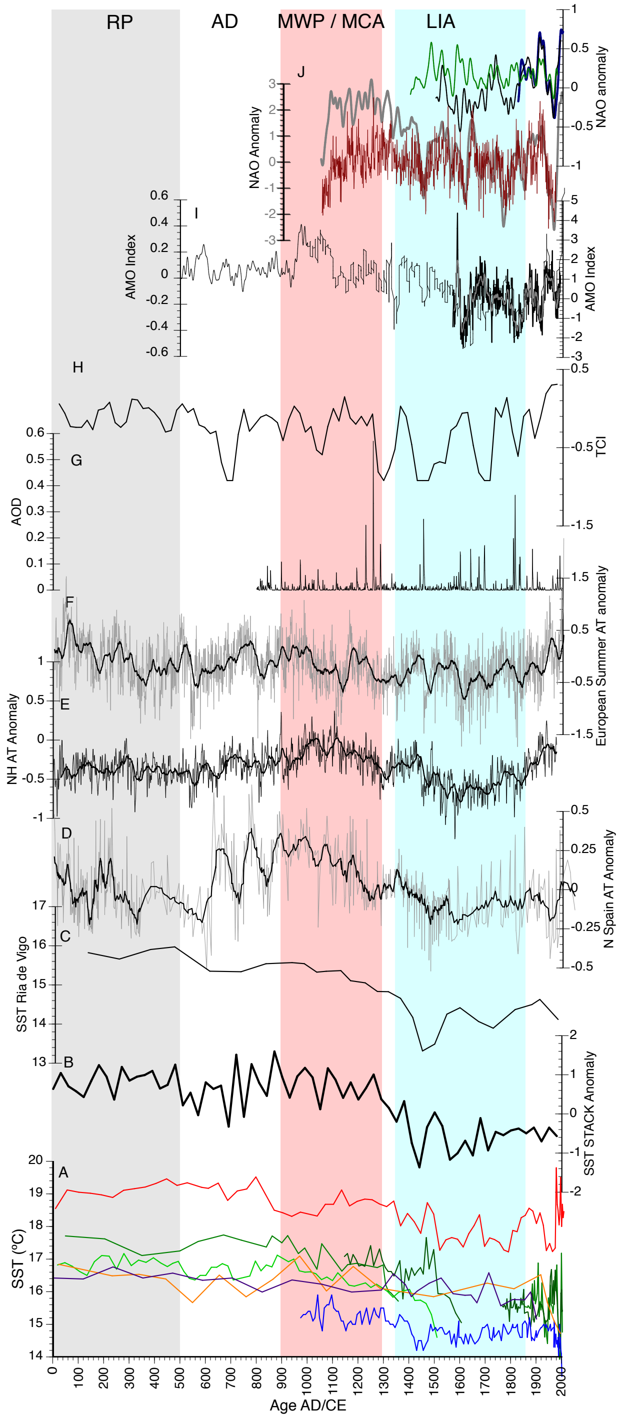


Figure 4 – Comparison of SST along the last 2,000 years at sites Galiza (magenta), Minho (orange), Porto (blue), Tejo (green) and Algarve (red) (A); SST stack constructed from all Iberian margin records (B); SST at Ria de Vigo (Diz et al., 2003); Northern Hemisphere annual mean atmospheric temperature anomaly (Moberg et al., 2005) (D); Northern Spain atmospheric temperature anomaly (Martín-Chivelet et al., 2011) (E); European spring-fall atmospheric temperature anomaly (Luterbacher et al., 2016) (F); volcanic activity as aerosol optical depth (Crowley and Unterman, 2013) (G); radionuclide-derived total solar irradiance (TSI) (Bard et al., 2007) (H); Northern Atlantic Ocean SST anomaly, AMO index (gray, (Mann et al., 2010) and (black, Gray et al., 2004) (I); NAO index (Luterbacher et al., 2002); brown - (Trouet et al., 2009) (J). Light grey band marks the Roman Period (RP), the pink band marks the Medieval Warm Period (MWP/MCA); the blue band marks the Little Ice Age (LIA).

Clim. Past Discuss., https://doi.org/10.5194/cp-2017-84
Manuscript under review for journal Clim. Past
Discussion started: 27 June 2017

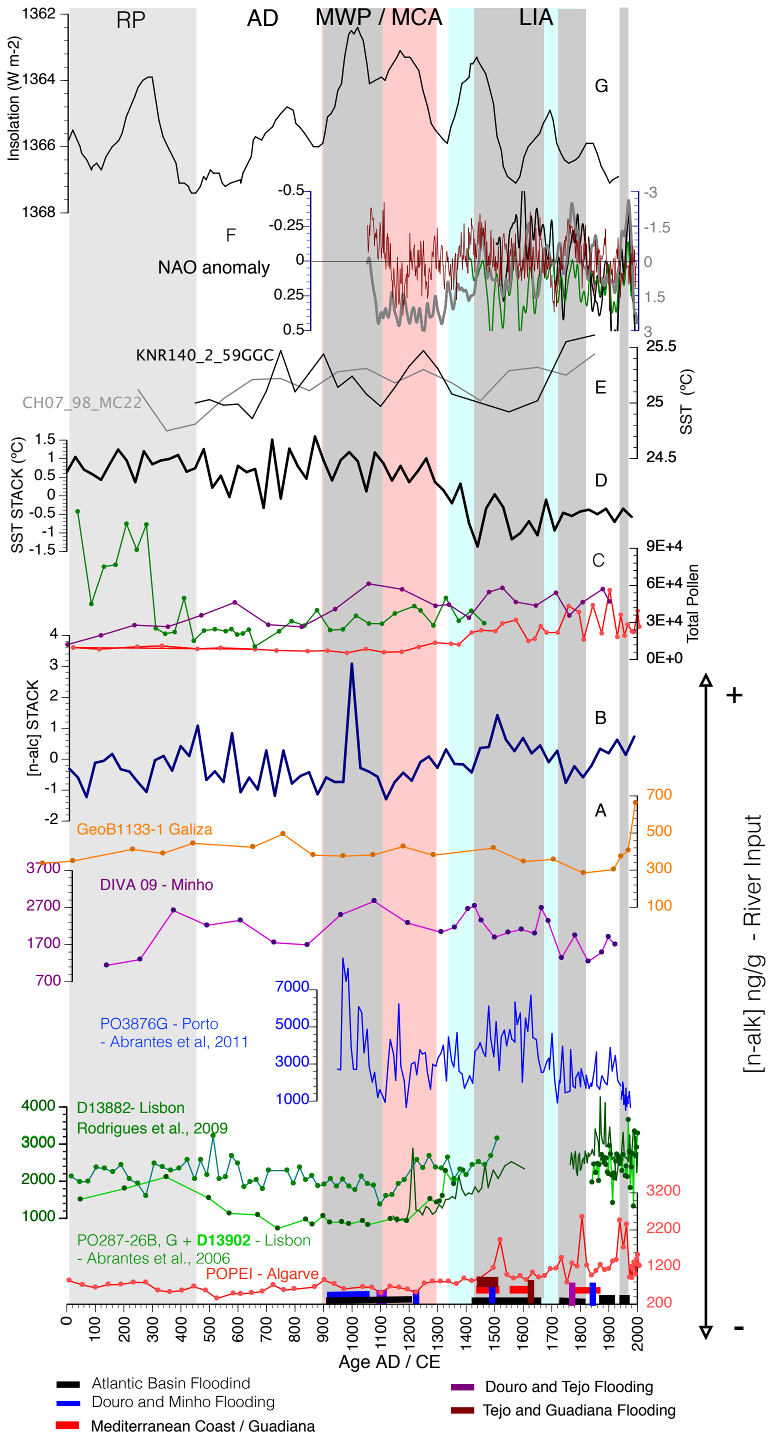


Figure 5 – [n-alc] variability along the last two millennia and at the 5 different sites of the Iberian Atlantic margin (A); the [n-alc] stack anomaly (B); total pollen concentration (# pollen grains/cm^3 sediment) (C); SST stack anomaly (D); SST NW Atlantic cores KNR140-2-59GGC and CH07-98-MC22 (Saenger et al., 2011) (E); NAO index (black line, Luterbacher et al. 2002), (green line; (Cook et al., 2002), (gray line; Trouet et al, 2009), (brown line; Ortega et al., 2015) (F); Radionuclide-derived total solar irradiance (TSI) (Bard et al., 2007) (G). Dark grey bands mark the periods of Atlantic flooding as listed in Table 4.

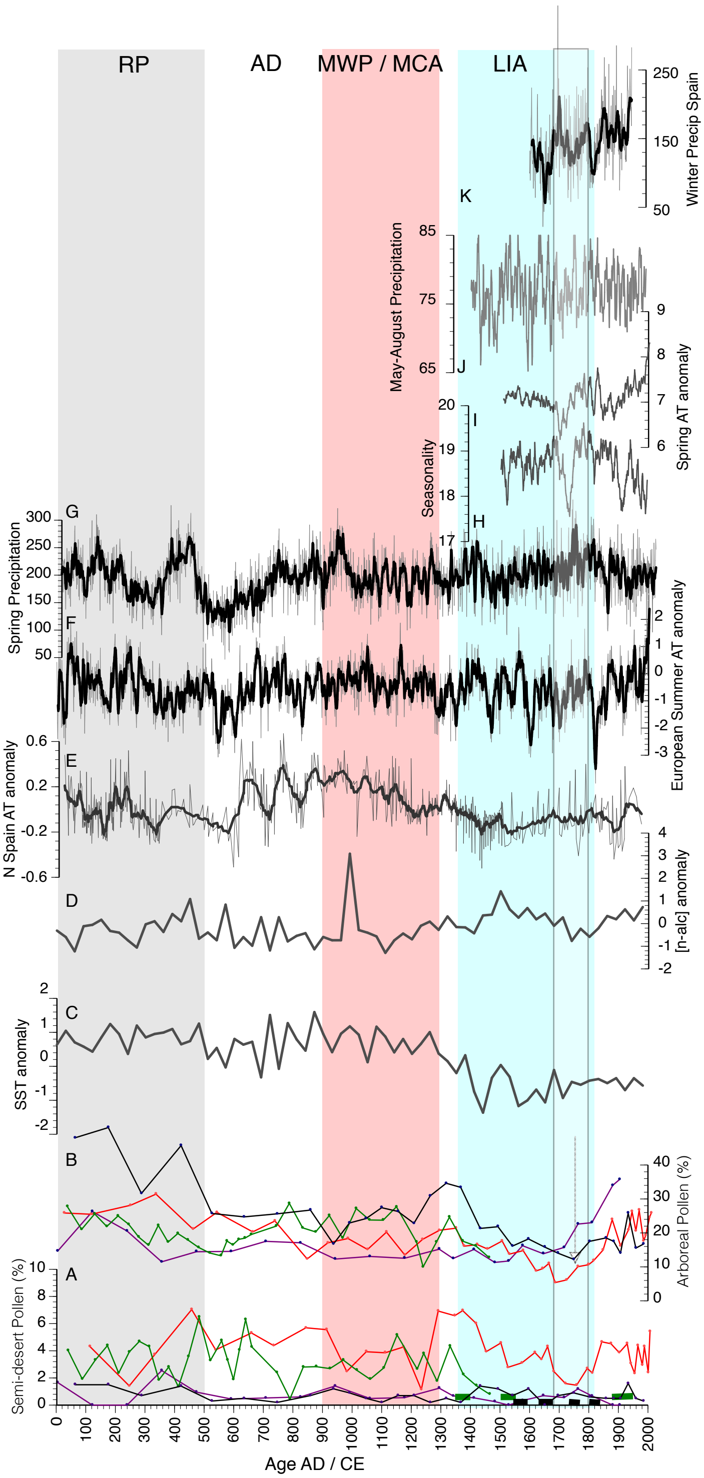
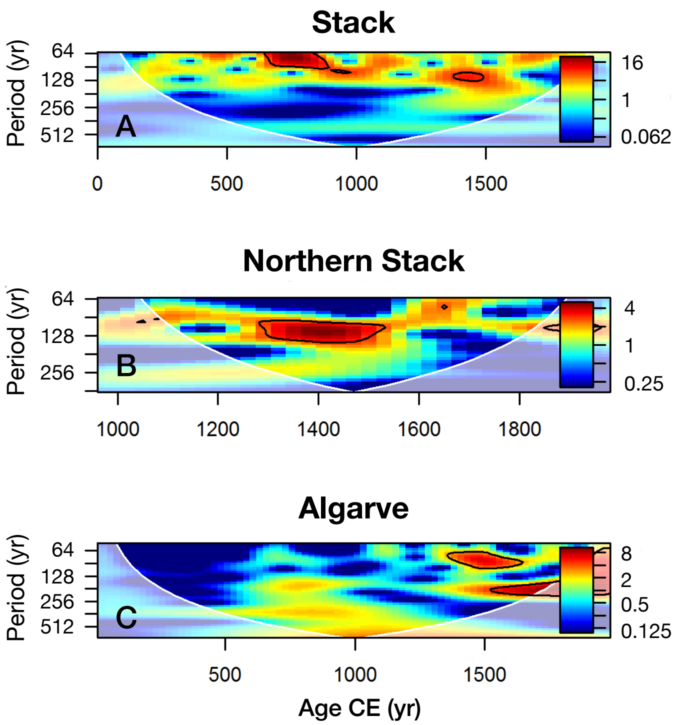


Figure 6 – Variability of semi-desert plants percent percentages along the 2,000 yr record of cores Diva, Tejo, Popei and Ria de Vigo (black) (Desprat et al., 200) (A); arboreal pollen percent abundance (B); the SST stack anomaly (C); the [n-alc] stack anomaly (D); Northern Spain atmospheric temperature anomaly (Martín-Chivelet et al., 2011) (C); European spring-fall atmospheric temperature anomaly (Luterbacher et al., 2016) (D); Spring Precipitation Central Europe (Büntgen et al., 2011) (E): European Seasonality and Spring AT (Luterbacher et al., 2004) (F, G); may-august Precipitation (Touchan et al., 2005) (H); winter (DJFM) Precipitation (Romero-Viana et al., 2011) (I).

Climate of the Past Discussions
Open Access



5 **Figure 7 – The continuous wavelet power spectrum of the SST STACK (A); the north SST STACK (B); and the Algarve SST record (C). The thick black contour designates the 95% confidence level and the lighter shaded area represents the cone of influence (COI) where edge effects might distort the results.**

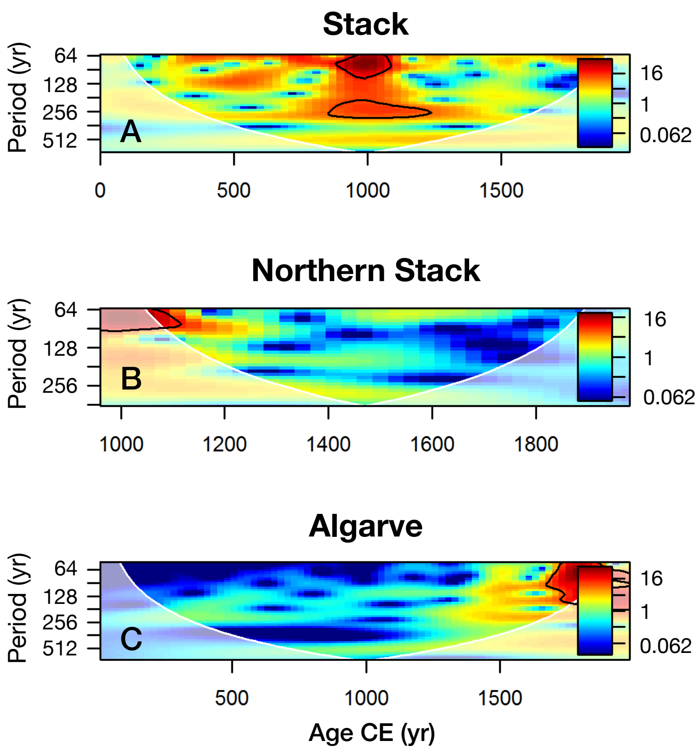


Figure 8 – The continuous wavelet power spectrum of the STACK [n-alc] record (A); the north [n-alc] STACK (B) and the Algarve [n-alc] record (C). The thick black contour designates the 95% confidence level and the lighter shaded area represents the cone of influence (COI) where edge effects might distort the results.