The Climate of the Common Era off the Iberian Peninsula

Response to Anonymous Referee #1

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The authors thank referee 1 for his important contribution to improve the manuscript.

In general, the reviewer considers that the presented records provide useful information about climate variability offshore the Iberian Peninsula over the Common Era. However, the reviewer finds the paper too long and unable to pass a clear message, and suggests the paper to concentrate on answering a clear question.

The length of the paper has been substantially reduced. The introduction was shortened, the material and methods was reduced to the essential information and most of the detailed and considered important information is now compiled as Supplementary material. The essential information relative to the cores chronology was included in the methods and the individualized chronology section of the previous version was deleted. Detailed information on the age-model construction for the new sedimentary sequences is now also included in the supplementary material. The results and discussion section was subdivided and results are now presented separately. The discussion has also been re-organized around the specific questions raised by the data. Abstract and Conclusions have equally been re-written in what we hope to be a more concise style.

We certainly hope that the re-organization of the paper makes it easier to read and helps to better convey the message(s) included.

The reviewer considers also that the paper should definitely be proof read by a native English speaker, as many parts of the paper are very hard to understand lacking a sentence structure and words.

The new and much changed version has been thoroughly revised by a native English speaker.

Age model: The 3 new age models of the cores should be shown as an age-depth plot additionally to the table with the 14C dates. Moreover, a Bayesian age depth model should be performed to better constrain age uncertainties.

An explanation and data used for the definition of the age-models for the new three cores is now included in the supplementary material. However, in order to correctly respond to this comment, below we present a discussion on the methodology used for the age model construction of all 7 sedimentary sequences used in this paper, the comparison between methods and the basic data for the three new sedimentary sequences, including de age-depth models.

Chronology: The example of PO287-6

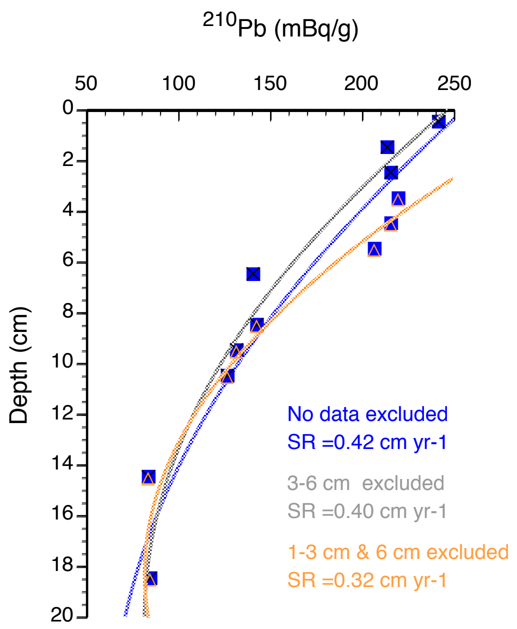
The age-model for the spliced sequence composed of cores PO287-6B and 6G (box, gravity) was constructed by combining two methods: (1) ^{210}Pb activity measured in box-core samples (Fig. 1A**)** which depending on the accepted model provides a sedimentation rate varying between 0.32 and 0.43 cm yr^{-1}; (2) four accelerator mass spectrometry (AMS) radiocarbon measurements (Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research, Kiel, Germany) (Table 1). Two further ages were assigned through MS correlation to other well-dated cores recovered off Lisbon (Fig. 1B). Raw AMS ^{14}C dates were corrected for reservoir effect by 400 yr (Abrantes et al., 2005) and converted to calendar ages with the INTCAL04 data set (Reimer et al., 2004). The obtained calendar ages are presented in years Anno Domini (AD/CE).

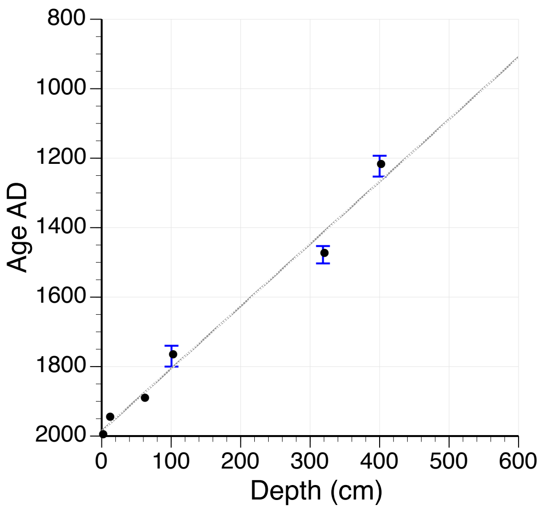
To develop a continuous record, the splicing of the long cores (piston and gravity) with the box-core (PO287-6B, 6G) was done through the Magnetic Susceptibility record (MS) of both cores (Fig. 1B). Further integration of the above-referred cores was based on the 1952 CE age found at 20.7 cm (depth corrected for compaction during sub-sampling) in box-core PO287-6B. Comparison of the PO287-6G MS record to sedimentary sequences from the Tagus system (Abrantes *et al.* 2005) was also done; Figure 1C depicts Depth *vs*. AD ages (with 2σ error) for PO287-6G with a linear best fit. An age that is within the error of the age estimated for the same depth using the sedimentation rate that results from a linear interpolation of the five considered levels (Table 1, Figs. 1B, 1C).

Given the uncertainty associated to the 14C dates, the establishment of an age model based on the interpolation between each dated level is normally avoided for sequences covering short time intervals (Jan Heinemeier, pers com.). An age/depth relationship defined by the linear best-fit line of the calibrated ^{14}C ages is the most common approach (e.g. (Narayan et al., 2010)). However we decided to compare age-depth models using both a linear and a polynomial best fit for core PO287-6G (Fig. 2). Both models give very close ages on the interval with dated levels, but the lack of dates at the base of core PO287-6G leads to older ages at the bottom of the record when using the polynomial solution.

Sample ID	Depth (cm)	C14 Age (RC = 400 yr)	Error	Age AD	Description
KIA 35149	100.5	160	25	1770	mixed benthics
KIA 29290	318.0	405	35	1478	mixed planktonics
KIA 35150	400.0	820	30	1223	mixed benthics

Table 1 – Results of ^{14}C AMS dating of the gravity core PO287-6G. Ages were reservoir corrected by 400 yr. Error column lists ± errors of 14C ages.





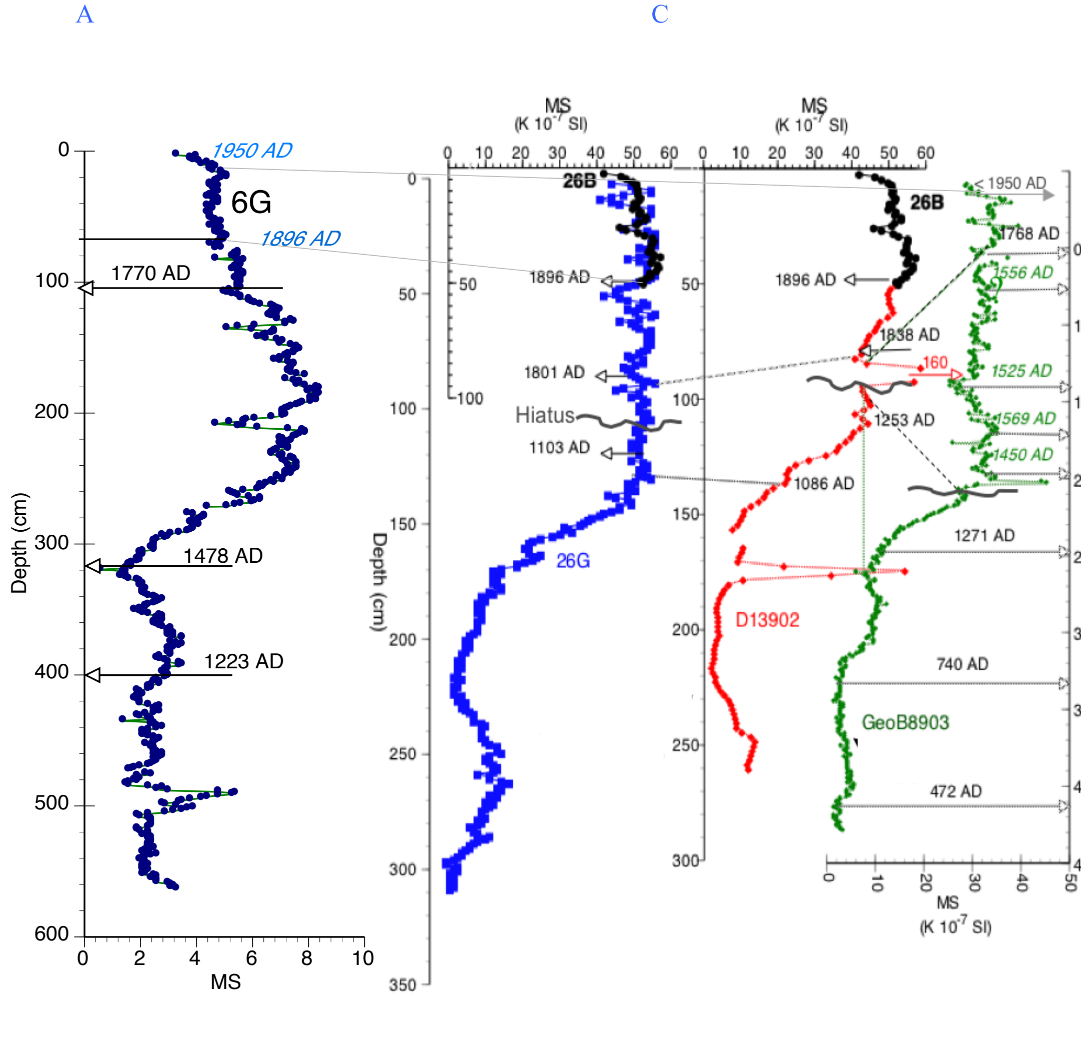


Figure 1 Information used to construct our age model; A) ^{210}Pb activity downcore PO287-6B; B) MS correlation of PO287-6G to sedimentary sequences from the Tagus system (Abrantes *et al.* 2005); C) Depth *vs.* AD ages (with 2σ error) for PO287-6G with a linear best fit.

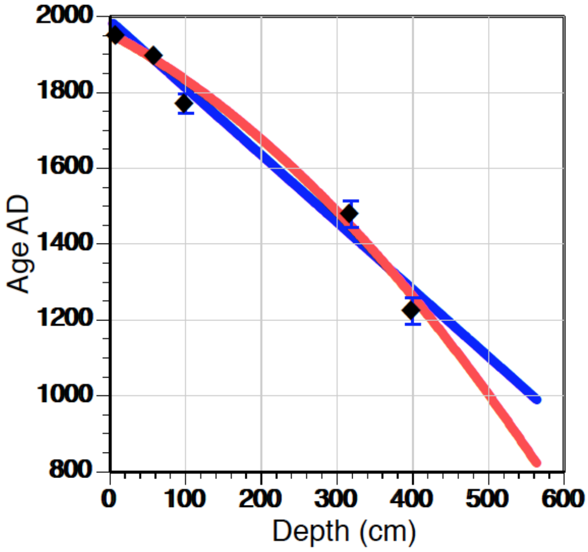


Figure 2 – Dated levels for core PO287-6G with a linear and a polynomial best fit for comparison.

Why the selection of a linear interpolation?

The assumption of a constant sedimentation rate was applied in Abrantes et al., 2005 (QSR) following the advise of Jan

Heinemeier (Aharus University ^{14}C dating center). According to this expert, in the case of records covering short time-scales, such as the last 2,000 yr, and with a relatively small number of age control points, it is better to use a linear best-fit curve.

<u>Chronology of the Galiza, Minho and Algarve Cores</u>

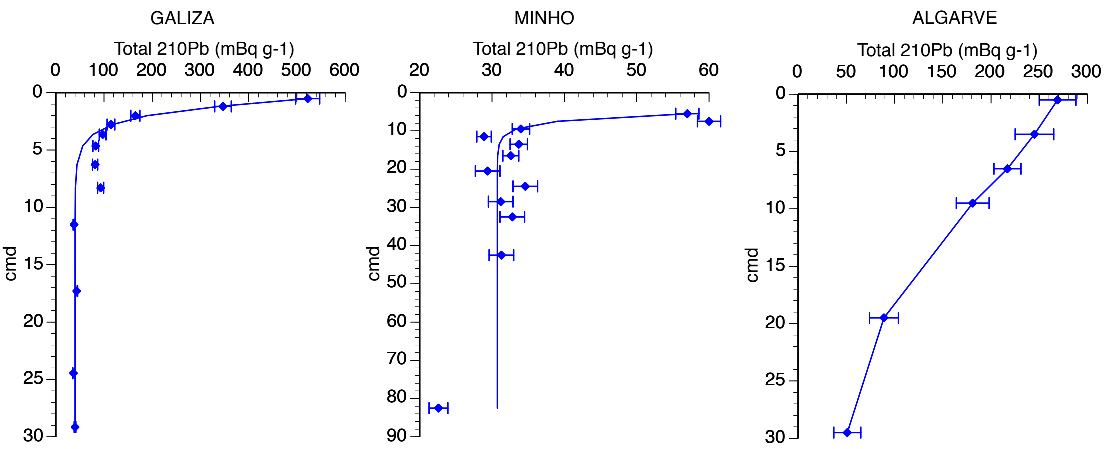


Figure 3 – ^{210}Pb activity downcore for the box-core GeoB11033-1 at the Galiza site and cores (Minho) DIVA09GC and (Algarve) POPEI VC2B.

The chronology of core GeoB11033-1 (Box-core of Galiza site) is based on a set of twelve ^{210}Pb data points, obtained in the upper 30 cm of the record, and one accelerator mass spectrometry ^{14}C date (AMS C14), obtained in planktonic foraminifera (Table 2, Fig. 3, Fig. 4).

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 09GC							
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 ^{14}C accelerator mass spectrometry dating (means ± SE) for cores GeoB11033-1 (Galiza), DIVA09CG (Minho) and POPEI VC2B (Algarve). Ages were corrected for reservoir effect by 400 yr and converted into calendar years (AD/CE).

^{210}Pb data was evaluated with the Constant Flux and Constant Sedimentation Rate model (CFCSR - (Appleby and Oldfield, 1992)) to date the upper 30 cm of the sediment core. The sedimentation rate was determined using the excess ^{210}Pb ($^{210}Pb_{excess}$) values, which is equivalent to the total ^{210}Pb activity minus the supported ^{210}Pb activity in equilibrium with sedimentary ^{226}Ra. The excess ^{210}Pb profile shows an exponential decrease with depth reaching the stable background value obtained using the ^{226}Ra activity at 27.5 cm depth. The data points at 6 and 8 cm depth were excluded (Fig. 3). The ^{210}Pb sedimentation rate estimated for the first 13 centimeters is 0.04 cm yr^{-1}. Top core age was assumed to be the core recovery year, 2006.

In the case of core DIVA09 GC (Minho site) the age-model construction is based in 12 ^{210}Pb data points distributed by 90 cm and 6 ^{14}C dates (AMS C14), obtained in marine material (shell and planktonic foraminifera) (Table 2, Fig. 3, Fig. 4). Background value was found at 9 cm depth. CFCSR model was defined excluding the ^{210}Pb values at 6 cm. Top age was assumed to be the core recovery year, 2009. The ^{210}Pb sedimentation rate estimated for the first 10 cm is 0.05 cm yr^{-1}.

The age-model of POPEI VC2B (Algarve site) is based on a set of eight ^{210}Pb data points, obtained in the upper 50 cm of the record, and eight accelerator mass spectrometry ^{14}C dates (AMS C14), obtained in marine material (shell and planktonic foraminifera) (Table 2, Fig. 3, Fig. 4).

^{210}Pb data was interpreted with the CFCSR model and the data for the upper 30 cm of the sediment, as the results of two additional data points (39-40 and 49-50 cm) were negligible. The stable background value found in all the other cores was not attained, but the ^{210}Pb estimated sedimentation rate is 0.52 cm yr^{-1}. Top age was assumed to be the core recovery year, 2008.

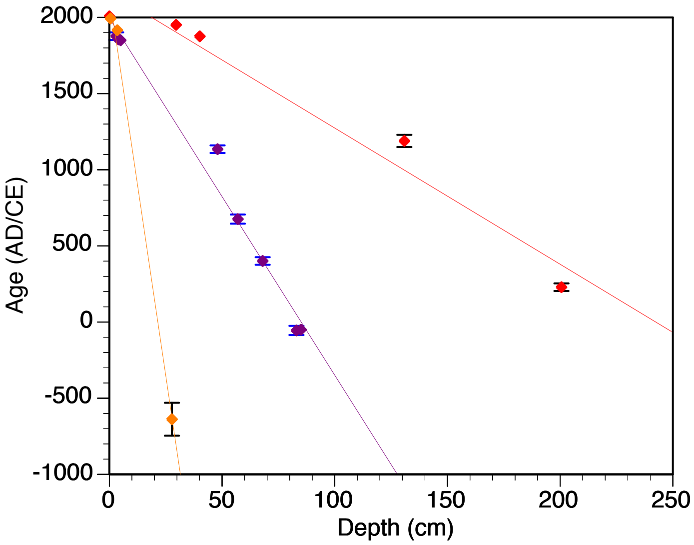


Figure 4. Depth *vs.* AD ages (with 2σ error) for cores GeoB11033-1 and GC at the Galiza site (orange), DIVA09GC (Minho, magenta) and POPEI VC2B (Algarve, red), with a linear best fit.

<u>Some specific comments below:</u>

Page 1 line 18: The Iberian Peninsula, at North Atlantic mid-latitude and the western extreme of the European continent, is a relevant area for climate reconstructions. – Rephrase sentence and what makes it a relevant area for climate reconstructions?

The sentence was changed following reviewer 1 suggestion.

Line 25: Is that even significant as the calibration error on alkenone SST is 1.5 C? Schouten et al., 2013, http://dx.doi.org/10.1016/j.orggeochem.2012.09.006

We used the calibration method defined by (Muller et al, 1998), which is a global calibration based on core-top sediments and mean annual climatological temperatures. The error associated with this calibration was defined in the original paper: "*the standard error is 1.5ºC, however considering that the Uk'37 values used for the global calibration were measured in about ten laboratories which partly used different methodologies, this differences could be minor rather attesting the robustness of the Uk'37 paleotemperature indicator*". Schouten et al. (2013) compiles previously published information in his Table 7.

Other calibration models use suspended matter (SOM) Uk'37 calibrated to in-situ measured SST (Conte et al., 2006; Gould et al., 2017) or are based on culture data (Prahl et al., 1988) and water column measurements (Prahl et al., 2005).

As a test we have used the three different models referred above to estimate SST in one of our sedimentary sequences (PO287- 6, Porto). Figure 5 shows no difference between the Muller and Prahl calibrations, while systematically lower SSTs are estimated when using Conte's calibration equation for core-top sediments (Mollenhauer et al., 2015). Independently of the used calibration method, the trends and amplitude of the observed variations are maintained all along the record even if variation is ≤ 1 ºC. As such, we conclude that our variability is significant, moreover for the definition of a long-term trend.

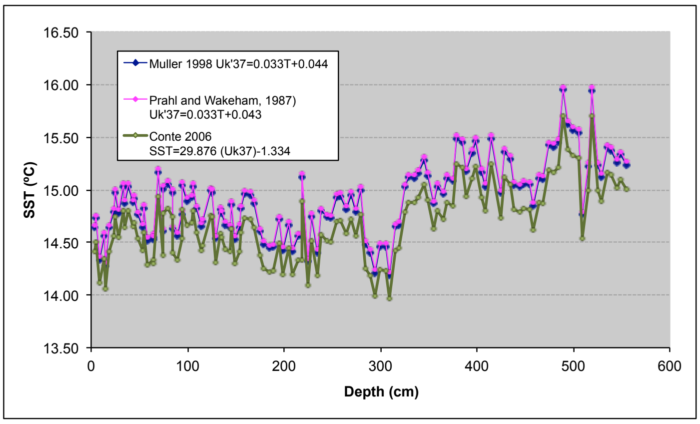


Figure 5 – Comparison of the SST variability estimated from three different calibration equations, along core PO287-6 (PORTO).

Besides, UK'37 derived SST data has been compared to those determined from GDGTs by Mollenhauer et al. (2015) for the Mauritania upwelling system and the authors conclusion is: *SST reconstructions based on alkenones are in excellent agreement with satellite data, and the entire seasonal amplitude of temperature variations at the sea surface is well recorded. In contrast, GDGT based temperature reconstructions using the logarithmic TEX86 calibration yields temperature maxima similar to observed maxima, but a reduced seasonal amplitude (warm bias).*

Page 2 Line 2: change to Medieval climate anomaly
Line 5: what does particular mean?

Wording has been changed

Line 7: "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".-how would the interplay of these 3 patterns cause the observed pattern?

We have profoundly changed the Introduction, and these patterns are now only referred. The effect of the three modes of atmospheric circulation on the climate of the Iberia Península (shown in figure 5 of Hernández et al. (2015)) is discussed in detail in the section Climate Forcing Mechanisms of the Discussion.

Line 15: rephrase-sentence like that makes no sense
Line 32: restructure
Line 33: delete Medieval Warm Period (MWP)
Page 3: Line 27: rephrase bad English
Page 4 Line 23-26: superficial statement needs more explanation
Line 30: change to: For that we combine the above mentioned published records with 3 new records located along the Iberian margin from 42_ N to 36 _N, covering the last 2,000 yr

The paper was revised taking into account all of referee 1 comments and requests.

Page 6: Line 4: Any additional proof that the cores are tracing river input despite pollen like BIT index

We did not use the BTI index, but as stated on lines 5 to 10 of the manuscript, "*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)"*

Page 12 Line 17-18: not clear

Line 32: what does that mean important decrease?
Page 13 Line 15: what does the N stands for? Line 19: rephrase
Page 17 Line 20: Specific climate conditions – unclear what does specific indicate?

Requested revisions were taken into consideration

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The Climate of the Common Era off the Iberian Peninsula

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Key Words – Last 2,000 yr, climate, SST, precipitation, Iberian Peninsula

Abstract. The Mediterranean region is a climate hot spot, sensitive not only to global warming but also to water availability. In this work we document major temperature and precipitation changes in the Iberian Peninsula during the last 2,000 yr, and propose an interplay of the North Atlantic internal variability with the three modes of atmospheric circulation (North Atlantic Oscillation (NAO), East Atlantic (EA) and Scandinavia (SCAND)) to explain the observed climate variability.

Reconstructions of Sea Surface Temperature (SST derived from alkenones) and on-land precipitation (estimated from higher plant n-alkanes and pollen data) in sedimentary sequences recovered at 5 sites along the Iberian Margin between the South of Portugal (Algarve) and the Northwest of Spain (Galiza) (36 to 42 ºN) constitute our database.

A clear long-term cooling trend up to the beginning of the 20th century emerges in all SST records and is considered a reflection of the decrease in the Northern Hemisphere summer insolation that began in the Holocene optimum. Multi-decadal/ centennial SST variability follows other records from Spain, Europe and the Northern Hemisphere. Warm SSTs throughout the first 1300 yr encompass the Roman Period (RP), the Dark Ages (DA) and the Medieval Climate Anomaly (MCA). A cooling initiated at 1300 CE, leads to 4 centuries of colder SSTs contemporary with the Little Ice Age (LIA). the Industrial Era is marked by climate warming since 1800 CE..

Novel results include two distinct phases in the MCA, an early period (900 – 1100 yr) characterized by intense precipitation/ flooding and warm winters but a cooler spring-fall season attributed to the interplay of internal oceanic variability with the three positive modes of atmospheric circulation (NAO, EA and SCAND). The late MCA is marked by cooler and relatively drier winters and a warmer spring-fall season consistent with a change in of the SCAND to a negative mode.

The beginning of the Industrial Era is coherent with a stronger impact of internal oceanic variability on the climate of the Western Iberian Peninsula. A particularly noticeable rise in SST at the Algarve site by mid 20th century (± 1970) is proposed to be a reflection of the expected regional response to the ongoing climate warming.