## Section S1. Age-models: GALIZA, MINHO and Algarve Cores

The age-model of core GeoB11033-1 (Galiza site) is based on a set of twelve <sup>210</sup>Pb and <sup>226</sup>Ra data points and one accelerator mass spectrometry <sup>14</sup>C dates (AMS C14), obtained in planktonic foraminifera (Table S1, Figs. S1, S2).

- <sup>210</sup>Pb data was interpreted 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 <sup>210</sup>Pb (<sup>210</sup>Pb<sub>excess</sub>) 5 values, which is equivalent to the total <sup>210</sup>Pb activity minus the supported <sup>210</sup>Pb activity in equilibrium with sedimentary <sup>226</sup>Ra. The excess <sup>210</sup>Pb profile shows an exponential decrease with depth reaching the stable background value obtained using the <sup>226</sup>Ra activity at 27.5 cm depth. The data points at 6 and 8 cm depth were excluded (Fig. S1). The <sup>210</sup>Pb sedimentation rate estimated for the first 13 centimeters is 0.04 cm yr<sup>-1</sup>. Top age assumed to be the year of core recovery,
- 10 2006.

DIVA09 GC core (Minho site) age-model is based in 12<sup>210</sup>Pb data points distributed by 90 cm and 6<sup>14</sup>C dates (AMS C14), obtained in marine material (shell and planktonic foraminifera) (Table S1, Figs. S1, S2). Background value was found at 9 cm depth. CFCSR model was defined excluding the <sup>210</sup>Pb values observed at 6 cm. Top age was assumed to be the year of core recovery, 2009. The <sup>210</sup>Pb sedimentation rate estimated for the first 10 cm is 0.05 cm yr<sup>-1</sup>.

POPEI VC2B (Algarve site) age-model is based on a set of six <sup>210</sup>Pb data points, obtained in the upper 30 cm of the record, 15 and three accelerator mass spectrometry <sup>14</sup>C dates (AMS C14), obtained in marine material (shell and planktonic foraminifera) (Table S1, Figs. S1, S2).

<sup>210</sup>Pb data was interpreted with the CFCSR, and although the stable background value found in the other cores was not attained, the <sup>210</sup>Pb estimated sedimentation rate for the top 30 cm is 0.52 cm yr<sup>-1</sup>. Top age was assumed to be the year of

20 core recovery, 2008.

> $^{210}$ 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 S1).

#### 25 Section S2. Alkenone-derived SST: Regional Assessment

To evaluate the regional value of the alkenone-derived SST, the SSTs estimated for the core tops of the three cores with sedimentation rates > 0.4 cm yr<sup>-1</sup> (Porto, Tejo and Algarve), were compared to mean annual and seasonal temperatures observed for the period 1981-2016 and obtained from the NOAA daily Optimum Interpolation Sea Surface Temperature (OISST, V2 AVHRR-only) dataset (Fig. S3). This climate data record provides complete ocean temperature fields

- 30 constructed by combining bias-adjusted observations from different platforms (satellite, ships, buoys) on a regular 1/4° 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 used in figure 1 to illustrate typical winter and summer distributions were obtained from the MUR (Multi-scale Ultrahigh Resolution) SST dataset (NASA, 2002).
- 35 Figure S3 shows that alkenone-derived SST resembles winter OISST in the western Iberian margin while at Algarve (south Iberia) it mainly accompanies the mean upwelling season (spring-fall) observed values. Diatoms and coccolitophores are the prevailing phytoplankters in the modern ocean, with diatoms dominating in regions characterized by major nutrient input and water column mixing, such as the eastern boundary upwelling systems (Estrada and Blasco, 1985). Coccolithophores also respond to nutrients but tend to do better in warm and stratified waters (e.g. Margalef, 1978; Moita, 2001). On the
- 40 Portuguese margin, coccolithophores dominate throughout the year being outcompeted by diatoms only during upwelling

events (Moita, 1993; Moita, 1996), as confirmed by the surface sediment record (Abrantes et al., 2009; Abrantes and Moita, 1999). Furthermore, late winter/spring nutrient input by larger rivers, such as the Douro and Tagus Rivers (Cabeçadas et al., 2003; Cabeçadas et al., 2008), can also generate large phytoplankton blooms, which are associated to river plume frontal dynamics (Douro - Oliveira et al., 2007); (Tagus -Vaz et al., 2009). In this oceanographic conditions the expected

5 dominance by coccolithophores has been confirmed by the work of Guerreiro et al. (2013) for the Iberian Peninsula northern winter Buoyant Plume. In the Algarve, on the contrary, coccolitophores are less abundant and bloom mainly during the upwelling season and fall, when west coast upwelled waters are advected into the Algarve (Fiuza, 1983; Moita, 2001).

### Section S3. On-land Precipitation Proxies: Regional Assessment

- Intense river discharge is known to parallel high precipitation over the continent (Trigo and DaCamara, 2000). In oceanic sediments n-alkanes concentration ([n-alk]) has been widely used as a proxy for river discharge (e.g. Eglinton and Hamilton, 1967). Furthermore, previous work on Iberian Margin has shown a good agreement between [n-alk] 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-alk] data obtained for the most recent sediments of the Porto, Tejo and Algarve sites was compared to the average river runoff during the NAO winter months (DJFM) for the Douro, Tagus and Guadiana Rivers (Sistema Nacional de Informação
- 15 de Recursos Hídricos (SNIRH) (<u>http://snirh.inag.pt</u>)). The results reveal a statistically significant (p>0.01) Pearson correlation of 0.54 for n=47, confirming that the [n-alk] data is a good proxy to evaluate the intensity of river runoff on the Iberian Peninsula.

# Section S4. STACK construction

Given that temporal resolution changes along each core, a 2,000 yr stack was attempted for different bin sizes (20 to 50 yr).

- 20 Results revealed that main trends were independent of the used size bin (not shown for brevity), but a 30-yr period was chosen because it is the period used for climate classification (Ahmed et al., 2013; Luterbacher et al., 2016; WMO, 2011). 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, stacks were produced: for the northern sites (Galiza, Minho and Porto) in order to investigate possible contrasts between the northern and southern sites; excluding the
- 25 Tejo record to verify any potential effect of the existing hiatus on the Tejo record (Abrantes et al., 2005); excluding the Algarve record to verify any possible bias caused by the different alkenone generating process. Figure S4 shows a comparison of those different SST stacks for different time intervals and demonstrates that the main trends are robust.

### List of Tables and Figures

Table S1 – Results of <sup>14</sup>C accelerator mass spectrometry dating for cores GeoB11033-1 (Galiza), DIVA 09GC(Minho) and30POPEI VC2B (Algarve). Ages were reservoir corrected by 400 yr and converted into calendar years (AD/CE).

Figure S1 - <sup>210</sup>Pb activity downcore for the Galiza box-core (GeoB11033-1) and the Minho (DIVA09GC) and Algarve (POPEI VC2B) cores.

Figure S2. Depth *vs.* AD ages (with  $2\sigma$  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.

35 Figure S3 – Comparison of alkenone-derived sea surface temperature (SST – black diamonds) and error bars determined 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 NOAA daily Optimum Interpolation Sea Surface Temperature (OISST, V2 AVHRR-only) for the three sites location.

Figure S4 – Comparison of SST stacks constructed using all the cores (total – black); all but the Tejo cores (effect of existing hiatus - green); except the Algarve record (effect of different coccolithophores generating process - red); considering only the northern sites (Galiza, Minho and Porto - blue). First two panels depict the 30-yr bin stacks. The third panel shows the 5-yr bin stacks constructed from the Porto, Tejo and Algarve cores for >1850 CE.

# 5 References

Abrantes, F., Lebreiro, S., Rodrigues, T., Gil, I., Bartels-Jónsdóttir, H., Oliveira, P., Kissel, C., and Grimalt, J. O.: Shallowmarine 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., Lopes, C., Rodrigues, T., Gil, I., Witt, L., Grimalt, J., and Harris, J.: Proxy calibration to instrumental data set: 10 Implications for paleoceanographic reconstructions, Geochem. Geophys. Geosyst., 10, 2009.

- Abrantes, F. and Moita, T.: Water Column and Recent Sediment Data on Diatoms and Coccolithophorids, off Portugal, Confirm Sediment Record as a Memory of Upwelling Events., Oceanologica Acta, 22, 319-336, 1999. 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-
- 15 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.,
- 20 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. Appleby, P. and Oldfield, F.: Applications of lead-210 to sedimentation studies. In: Uranium Series Disequelibrium. Applications to Earth, Marine and Environmental Sciences., Ivanovich, M. and Harmon, M. (Eds.), Clarendon Press,
- Oxford, 1992.
   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.
- Eglinton, G. and Hamilton, R. J.: Leaf epicuticular waxes, Science, 156, 1322-1335, 1967.
   Estrada, M. and Blasco, D.: Phytoplankton assemblages in coastal upwelling areas., Barcelona1985, 379-402.
   Fiuza, A.: Upwelling patterns off Portugal. In: Coastal Upwelling its sediment record., Suess, E. and Thiede, J. (Eds.), Plenum, New York, 1983.
- 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.

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-

40 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.

Margalef, R.: Phytoplankton communities in upwelling areas. The example of NW Africa., Oecol. Aquat., 3, 97-132, 1978. Moita, T.: Estrutura, Variabilidade e Dinamica do Fitoplancton na Costa de Portugal Continental., 2001.article compilation,

- 5 Faculdade de Ciencias da Universidade de Lisboa, University of Lisbon, Lisbon, 272 pp., 2001.
  Moita, T.: Spatial Variability of Phytoplankton Communities in the Upwelling Region off Portugal., 1993, 1-20.
  Moita, T.: Sucessão e Dinâmica de Blooms fitoplanktonicos durante um episodio de afloramento na costa noroeste de Portugal., Coimbra Portugal1996, L64.
  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.
   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.
   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.

Vaz, N., L.Fernandes, P.C. Leitão, Dias, J. M., and Neves, R.: The Tagus Estuarine Plume Induced By Wind and River Runoff: Winter 2007 Case Study, Journal of Coastal Research, SI56, 1090-1094, 2009.

20 WMO, W. M. O.: Guide to Climatological Practices, WMO, Geneva, Switzerland, 2011.