Earth and Planetary Science Letters 456 (2016) 124–133

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Sea surface temperature variability in the North Western Mediterranean Sea (Gulf of Lion) during the Common Era

Marie-Alexandrine Sicre[a,*], Bassem Jalali[a,b], Belen Martrat[c], Sabine Schmidt[d], Maria-Angela Bassetti[e], Nejib Kallel[b]

[a] *Sorbonne Universités (UPMC, Univ. Paris 06)-CNRS-IRD-MNHN, LOCEAN Laboratory, 4 place Jussieu, F-75005 Paris, France*
[b] *Université de Sfax, Faculté des Sciences de Sfax, Laboratoire GEOGLOB, BP. 802, 3038, Sfax, Tunisia*
[c] *Department of Environmental Chemistry, Spanish Council for Scientific Research (IDÆA-CSIC), 08034 Barcelona, Spain*
[d] *UMR5805 EPOC, Université de Bordeaux, Avenue Geoffroy Saint-Hilaire, 33615 Pessac, France*
[e] *CEFREM, CNRS UMR5110, Université de Perpignan, Avenue J.-P. Alduy, 66860 Perpignan, France*

ARTICLE INFO

Article history:
Received 2 May 2015
Received in revised form 17 September 2016
Accepted 21 September 2016
Available online 12 October 2016
Editor: H. Stoll

Keywords:
Mediterranean Sea
sea surface temperature
alkenones
Common Era
East Atlantic mode
atmospheric blocking

ABSTRACT

This study investigates the multidecadal-scale variability of sea surface temperatures (SSTs) in the convection region of the Gulf of Lion (NW Mediterranean Sea) over the full past 2000 yr (Common Era) using alkenone biomarkers. Our data show colder SSTs by 1.7 °C over most of the first millennium (200–800 AD) and by 1.3 °C during the Little Ice Age (LIA; 1400–1850 AD) than the 20th century mean (17.9 °C). Although on average warmer, those of the Medieval Climate Anomaly (MCA) (1000–1200 AD) were lower by 1 °C. We found a mean SST warming of 2 °C/100 yr over the last century in close agreement with the 0.22 and 0.26 °C/decade values calculated for the western Mediterranean Sea from *in situ* and satellite data, respectively. Our results also reveal strongly fluctuating SSTs characterized by cold extremes followed by abrupt warming during the LIA. We suggest that the coldest decades of the LIA were likely caused by prevailing negative EA states and associated anticyclone blocking over the North Atlantic resulting in cold continental northeasterly winds to blow over Western Europe and the Mediterranean region.

1. Introduction

In the past decade, major efforts have been done to document the multi-decadal variability of the sea surface temperatures during the Common Era (last 2,000 yr) and to explore the role of external forcings (solar, volcanism, greenhouse gases) by combining paleo records and numerical simulations of the last millennium climate (McGregor et al., 2015; Sicre et al., 2011). Although the number of pre-instrumental reconstructions of sea surface temperature (SST) resolving the decadal scale has increased significantly they are still insufficient to precisely describe the space–time climate variability both at global and regional scales. This is particularly true for the Mediterranean region for which very few records exist despite alarming future climate projections (Lionello et al., 2006). Indeed, the Mediterranean region is one of the most sensitive areas to climate change owing to its geographical location between the temperate climate of Europe and the arid climate of North Africa. Because of this, even minor modifications in the extension and intensity of these climate zones can substantially alter the Mediterranean climate making this region particularly vulnerable to global warming (Lionello et al., 2006). In its history, the Mediterranean region has undergone important changes that can be investigated to better understand present-day interactions between global and regional climate and the underlying driving mechanisms.

The Mediterranean climate is strongly influenced by the large-scale mid-latitude atmospheric circulation of the North Atlantic (NA) and primarily the East Atlantic pattern (EA) and the North Atlantic Oscillation (NAO; Hurrell, 1995). The NAO, the dominant mode of atmospheric variability in the NA, reflects the atmospheric pressure difference between the Azores High and Icelandic low. The NAO state determines the latitudinal position of the NA storm tracks driving the Mediterranean winter precipitation, but its role on Mediterranean SSTs is secondary (Lionello et al., 2006). Instead, the EA has been recently recognized as the main controlling factor of the SST variability of the Mediterranean Sea, particularly in the western basin (Josey et al., 2011). The EA mode has a similar North South dipole structure as the NAO but its centers of action are displaced southeastward, which results in a stronger link with the subtropical climate than NAO. Teleconnections with El Nino South-

---

* Corresponding author.
E-mail address: Marie-Alexandrine.Sicre@locean-ipsl.upmc.fr (M.-A. Sicre).

http://dx.doi.org/10.1016/j.epsl.2016.09.032

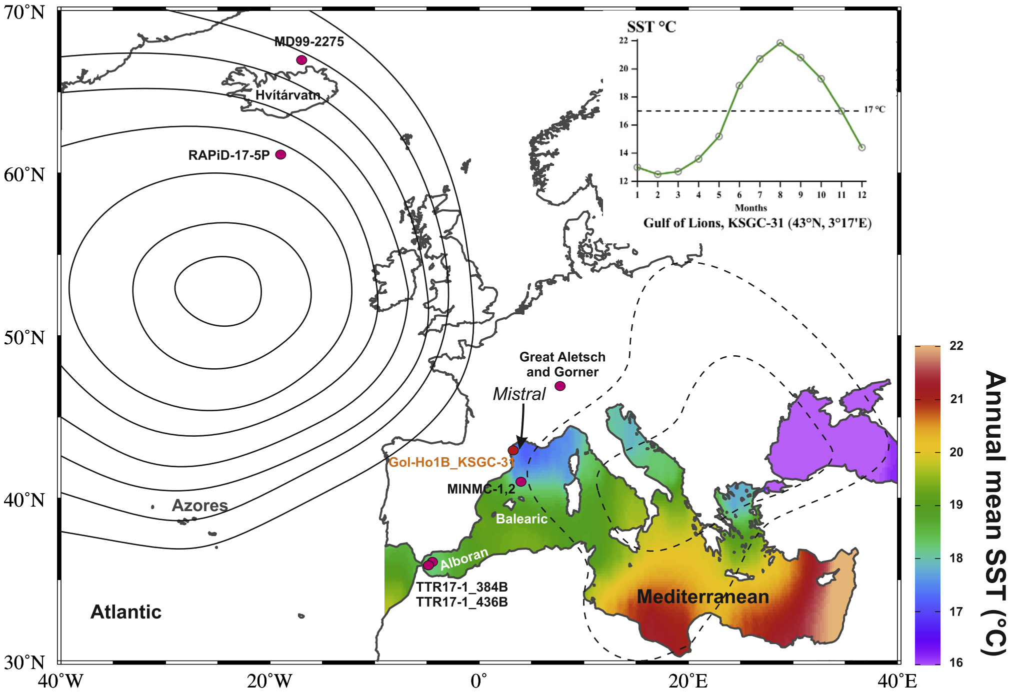

Fig. 1. Map showing the location of Gol-Ho1B_KSGC-31 site, and spatial field of Mediterranean annual mean SSTs (1955–2012). The insert in the upper right corner shows the monthly SSTs at the core location; the dashed line indicates the annual mean (17 °C) from World Ocean Atlas Database (NOAA/NODC WOA13 (1° grid)). The anticyclonic blocking cell over the northeastern Atlantic and low-pressure system in the central Mediterranean associated to EA is also represented (adapted from Papadopoulos et al., 2012). All sites discussed in the text are shown from West to East: RAPiD-17-5P, South of Iceland (Moffa-Sanchez et al., 2014); MD99-2275, North of Iceland (Sicre et al., 2011); TTR17-1_384B, 436B, Alboran basin (Nieto-Moreno et al., 2013); MINMC-1,2, Balearic basin (Moreno et al., 2012). Mistral wind is shown by the black arrow.

ern Oscillation (ENSO) have also been suggested mainly to explain winter rainfall in some areas of the Mediterranean region (Alpert et al., 2006). Finally, the influence of the Atlantic Multidecadal variability (AMV) (Knight et al., 2006) has been recently pointed out, yet the dynamical links between AMV and Mediterranean SSTs is still an open question. Indeed, oceanic processes have been suggested based on the detection of AMV-like 70-yr period oscillations in the Mediterranean SSTs (Marullo et al., 2011) while according to the study of Mariotti and Dell'Aquila (2012) atmospheric transmission of AMV is more likely.

The complex topography of the Mediterranean basin modifies the large-scale atmospheric flow and subsequently influences the climate characteristics at a local scale. In the northwestern Mediterranean Gulf of Lion (GoL), interactions between the mid-latitude westerly winds and the Alps result in northerly winds blowing offshore in the South of France, called Mistral (Jiang et al., 2003). This cold and dry wind blows at all seasons (climatologically 49% of wind frequency is in the northwest quadrant; Burlando, 2009), but more strongly in winter and spring (Jiang et al., 2003) causing intense surface water cooling. Najac et al. (2009) have shown that Mistral is favored by anticyclonic blocking over the northeastern Atlantic and a low-pressure system in the central Mediterranean Sea (Fig. 1), a synoptic configuration described by negative EA that focuses the northerly air flow over France. Despite previous suggestions of a dynamical connection between negative NAO and the occurrence of NA blocking (Schabbar et al., 2001), the most severe Mistral episodes show only a modest correlation with NAO compared to the strong correlation with negative EA (Skliris et al., 2012; Papadopoulos et al., 2012). Ultimately, while weak westerlies during negative NAO result in cold temperature in Europe, the most severe winters occur during negative EA due to the deflection of the maritime westerly flow to the North around the anticyclonic cell returning as cold and dry northerly continental winds over Europe and the Northwestern Mediterranean Sea (Fig. 1) (Häkkinen et al., 2011). Yet, interactions exist between the two modes (Moore and Renfrew, 2011). Indeed, bivariate reconstructions have shown that EA modulates the strength and position of NAO centers of action and that winter severity is enhanced when both modes are in negative phase. This would for instance explain that despite similar negative NAO values, winter in Europe was much cooler in 2010 (negative EA) than in 2009 (positive EA) (Moore and Renfrew, 2011).

Mistral exerts a strong control on the SSTs in the Northwestern Mediterranean Sea and is responsible for among the coldest values found in the Gulf of Lions (GoL). Mistral also triggers intense blooms in February, March and April (FMA) when it is stronger (Bosc et al., 2004; Durrieu de Madron et al., 2013). A relationship between primary production maxima, Mistral and negative EA has also been evidenced by Olita et al. (2011). Because Mistral concurrently causes surface cooling and high primary production, alkenone-derived SSTs in the GoL are expected to well capture past changes of atmospheric conditions promoting Mistral. These unique properties motivated the choice of GoL shelf sediment for generating a high-resolution SST reconstruction over the Common Era using alkenone as a temperature proxy. Based on this time series we investigate the links between mid-latitude atmospheric variability, Mistral and SSTs in the GoL with a focus on the strong amplitude SST fluctuations observed during the Little Ice Age (LIA).

2. Material and methods

2.1. *Analytical procedure*

A gravity core KSGC-31 (GMO2-Carnac cruise in 2002, R/V “Le Suroît”) and multi-core Gol-Ho1B (GolHo cruise in 2013, R/V “Néréis”) were retrieved at virtually the same location (43°0′23 N; 3°17′56 E, water depth 60 m, Fig. 1) in the Rhone river mud belt deposited onto the GoL continental mid-shelf.

The two sediment cores were sampled continuously at a sampling step of 1 cm and freeze-dried overnight. Between 2–3 g of dried sediments were extracted with a mixture of methanol/