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Climate of the Past
Discussions

Seemingly divergent sea surface temperature proxy records in the central Mediterranean during the last deglacial

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Seemingly divergent sea surface temperature proxy records

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Abstract

Sea surface temperatures (SSTs) were reconstructed over the last 25 000 yr using alkenone paleothermometry and planktonic foraminifera assemblages from two cores of the central Mediterranean Sea: the MD04-2797 core (Siculo–Tunisian channel) and the MD90-917 core (South Adriatic Sea). Comparison of the centennial scale structure of the two temperature signals during the last deglacial period reveals significant differences in timing and amplitude. We suggest seasonal changes likely account for seeming proxy record divergences during abrupt transitions from glacial to interglacial climates and for the apparent short duration of the Younger Dryas (YD) depicted by the alkenone time-series, a feature that has already been stressed in earlier studies on the Mediterranean deglaciation.

1 Introduction

The Mediterranean region is of particular interest because of its sensitivity to climate and environmental changes and their impacts on ecosystems and human populations. Lying at the boundary between mid-latitude and sub-tropical climates the Mediterranean basin is subject to complex atmospheric teleconnections that have been variable in time (Lionello et al., 2008; Luterbacher et al., 2006). Today, the Mediterranean climate is strongly influenced by the North Atlantic Oscillation (NAO) in winter (Hurrell, 1995; Trigo et al., 2004), while in summer high-pressure systems develop as the Hadley cell circulation move northward producing the characteristic dry season of this region. El Niño and Asian monsoons would also affect summer precipitation variability, mostly in the Eastern Mediterranean. Changes of these climate regimes such as the mid-latitude storm tracks originating from the North Atlantic or the position of the subtropical highs can modify the Mediterranean temperatures and precipitations. Documentation of past temporal and spatial climate patterns contributes to improve understanding of the Mediterranean climate and predictions.

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In this study we discuss seemingly divergent Sea Surface Temperature (SST) reconstructions over the last 25 kyr obtained from foraminifera assemblages and alkenone paleothermometry, two important information sources to investigate past ocean variability. In the recent years, progress has been made to improve proxy calibrations but few comparison between proxy and instrumental time-series (20th century) have shown that environmental or dynamical factors can nevertheless introduce bias and make it difficult to decipher the climate signal embedded in proxy reconstructions (Conte et al., 2006; Rülhemann and Butzin, 2006; Sicre et al., 2011). In this study, we examine the sequence of events that punctuated the last deglacial period when insolation changes due to orbital forcing was a major climate driver. We present records of planktonic foraminifera and alkenone-derived SSTs, as well as the δ^{18}O of *G. bulloides*, from the South Adriatic Sea and the central Siculo-Tunisian channel. We then compare these data to the isotope records from Greenland ice and the speleothem calcite from La Mine Cave (Tunisia) in an integrative approach to understand the expression of centennial scale events of Termination I, i.e. the abrupt cold Younger Dryas (YD) and warm Bølling-Allerød (BA) in Mediterranean proxy records.

2 Materials and methods

2.1 Site locations

The MD90-917 core was collected during the PROMETE II cruise, performed aboard the French R/V *Marion Dufresne*, in the South Adriatic deep basin (41°17′ N, 17°37′ E, 1010 m water depth), in a wide circular-shaped depression detached from the Ionian Sea by the sill of the Otranto Strait (780 m) and bordered by the Italian and Albanian shelves (Van Straaten, 1970). The second core MD04-2797 (36°57′ N, 11°40′ E, 771 m water depth) was retrieved in the central part of the Sicilian–Tunisian channel during the IMAGES cruise in 2004, where Eastern and Western Mediterranean Sea water

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exchange. More details on the core site and hydrographic features can be found in Essalami et al. (2007).

2.2 Age models

The age model of the MD04-2797 core is based on 13 AMS ^{14}C dates performed on planktonic foraminifera in the size fraction > 150 µm by the mass accelerator (AMS) ARTEMIS located in Gif-sur-Yvette, France. The ^{14}C ages were converted into calendar age using INTCAL09 (Reimer et al., 2009) and the ^{14}C calibration Sofware CALIB6 (Stuiver and Reimer, 1993; Stuiver et al., 1998). We applied a marine reservoir correction of 400 yr for Holocene, YD and Late glacial sediments. The correction used for BA is 560 yr and 800 yr for the Heinrich 1 and Older Dryas (Siani et al., 2001). Based on the age model thus obtained, we calculated a sedimentation rate of 37 cm kyr^{-1} during glacial, decreasing to 32 cm kyr^{-1} for the Holocene, and a core-top age of 668 yr cal BP.

The age model of MD90-917 core is built on 21 AMS 14C dates performed on monospecific planktonic foraminifera in the size fraction > 150 µm (Siani et al., 2010). Ages were corrected for a surface marine ^{14}C reservoir age of 400 yr, except for the early deglaciation where this value is double (Siani et al., 2000, 2001). The presence of 14 ash layers allowed refinement of the chronology (Zanchetta et al., 2008; Siani et al., 2004, 2006). The top core age is estimated to 582 yr. The sedimentation rate is estimated to be 35 cm kyr^{-1} in the late glacial to Holocene portion and 20 cm kyr^{-1} for the S1 interval, resulting in a temporal resolution of 40 yr (SSTs and isotopes) and 75 yr, respectively.

2.3 SST reconstructions

SSTs were determined using planktonic foraminifera assemblages (SST_{foram}) for April–May ($AM\text{-}SST_{foram}$) and October–November ($ON\text{-}SST_{foram}$). Each foraminifera sample in the > 150 µm fraction range was split into 300–1000 individuals for identification

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and counting following the taxonomy and ecological inferences of Pujol and Vergnaud Grazzini (1995). Faunal composition of planktonic foraminifera assemblages was used to infer SSTs using the modern analogue technique (MAT) (Hutson, 1979; Prell, 1985) developed in the Mediterranean Sea by Kallel et al. (1997). The reference data-base is composed of 253 core top sediments, 130 from the Mediterranean Sea and 123 from the Atlantic Ocean (Kallel et al., 1997). Reliability of SST values is estimated from the square chord distance test (dissimilarity coefficient), which represents the mean degree of similarity between the sample and the best 10 modern analogues. For fossil samples with good modern analogues in the reference database, the dissimilarity is generally < 0.25 (Prell, 1985). Above this value, the dissimilarity coefficient indicates no close modern analogues in the database and SST estimates are discarded. The calculated mean standard deviation of SSTs for core MD90-917 is 0.7 °C during the Holocene and 1.4 °C since the late glacial period (Siani et al., 2012). For core MD04-2797, the mean SST standard deviation is estimated to be 1 °C.

SSTs were also estimated from the C_{37} alkenone unsaturation index $U_{37}^{K'}$. Alkenones are mainly produced by the ubiquitous marine coccolithophorid Emiliania huxleyi inhabiting surface waters that become incorporated in marine sediments with no significant alteration of the $U_{37}^{K'}$ index value (see review by Grimalt et al., 2000). Comparison between sediment trap and surface sediments from the NW Mediterranean Sea has shown that SSTs recorded in sediment are closed to the annual mean (Ternois et al., 1996). This result essentially reflects the fact that spring and fall are the main seasons of alkenone production. The following equation (Conte et al., 2006) was used to translate $U_{37}^{K'}$ into SSTs:

$$T(°\mathrm{C}) = -0.957 + 54.293\left(U_{37}^{K'}\right) - 52.894\left(U_{37}^{K'}\right)^2 28.321\left(U_{37}^{K'}\right)^3.$$

A detailed description of the laboratory protocol used can be found in Ternois et al. (1997).

2.4 Oxygen isotopes

Detailed oxygen isotope of the MD04-2797 core was obtained on planktonic foraminifera *Globigerina bulloides* and expressed in ‰ versus VPDB (Vienna Pee Dee Belemnite standard) defined with respect to NBS19 calcite standard (Coplen, 1988). Between 6 and 20 shells were picked in the 250–315 µm size range and analyzed on a Finnigan Δ+ and MAT251 mass-spectrometers. The mean external reproducibility (1σ) of carbonate standards is ±0.05 ‰, and measured NBS18 $\delta^{18}O$ is -23.2 ± 0.2 ‰ VPDB. It has been shown that *G. bulloides* most productive months in the Mediterranean Sea are April–May (Pujol and Vergnaud Grazzini, 1995). A more complete description of $\delta^{18}O$ measurements can be found in Siani et al. (2013) for core MD90-917 and in Essalami et al. (2007) for core MD04-2797.

3 Results

3.1 South Adriatic Sea MD90-917 core

In the South Adriatic Sea, the $\delta^{18}O$ of *G. bulloides* calcite range from mean glacial values of 3.5 to 0.97 ‰ at ~ 8.5 kyr. They then increase towards present except for a decrease to 0.45 ‰ in the upper most sediments of the warmer Medieval Climatic Anomaly (MCA). Note that the centennial-scale events BA and YD are weakly expressed in the $\delta^{18}O$ record as compared to Greenland ice. From 11.5 to 9.5 kyr they also show a rather weak decrease, from 2.12 to 1.92 ‰. AM-SST$_{foram}$ range from ~ 9 °C during the Last Glacial Maximum (LGM) (21–24 kyr) to ~ 17 °C Holocene values while ON-SST$_{foram}$ increase from 10.5 °C to about 20 °C. Glacial SST$_{alk}$ values are always warmer than ON-SST$_{foram}$ (13–15 °C) and reach unexpectedly high values of nearly 19 °C at ~ 16.5 kyr, while during the Holocene and BA they were close to AM-SST$_{foram}$. The amplitude of the deglacial warming is 6.5 °C for SST$_{alk}$ and 7.5 °C SST$_{foram}$, while $\delta^{18}O$ of *G. bulloides* decreases only by 0.5 ‰, a difference that underlines significant

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local salinity changes superimposed to the global ice volume. During the Holocene, SST_{foram} indicate a 2.5 °C cooling at 8.2 kyr, and of 3 °C between 7.3 to 6.3 kyr, that are not seen in the SST_{alk} record.

3.2 Siculo–Tunisian Strait MD04-2797 core

In the central Siculo–Tunisian channel, glacial values of $\delta^{18}O$ *G. bulloïdes* (∼ 3.25 ‰) start to decrease around 18.5 kyr. Between 16.5 and 12.8 kyr, values are relatively stable except for a slight enrichment of 0.5 ‰ between 15 and 16.5 kyr, possibly featuring H1. After a subtle increase during the YD, the $\delta^{18}O$ decrease till ∼ 0.45 ‰ at ∼ 9.2 kyr.

SST_{alk} values increase from glacial values ∼ 8.5 °C at 23 kyr to ∼ 20–21 °C during the Holocene. Except for the LGM where they are similar to SST_{foram}, they become warmer than ON-SST_{foram} from 19 kyr till the onset of the BA. The higher resolution SST_{alk} signal also reveals imprint of millennial-scale Heinrich event coolings, i.e. H1a (∼ 15.5 kyr), H1b (17.6 kyr) and H2b (23 kyr). These cold episodes suggest influence from the North Atlantic climate when large-scale iceberg discharges occurred (Cacho et al., 1999). The presence of ice rafted debris has been reported during H1a and H2a off the Iberian margin (Bard et al., 2000), a result that would explain the more pronounced imprint of these events in the Mediterranean surface water properties than H1b. Finally, it is noteworthy that SST_{foram} are similar during the BA and the Holocene, while SST_{alk} during the BA are 3 °C colder than Holocene ones. This is contrast with the South Adriatic Sea where both proxy record indicate warmer Holocene than BA SSTs by 4–5 °C. Another notable difference between the two proxy records is the onset of the final deglacial warming that occurs earlier in the SST_{alk} than SST_{foram} records. Cooling at ∼ 7 kyr in the South Adriatic Sea is also seen in SST_{foram}, and SST_{alk} records of the Siculo–Tunisian Strait, yet with a different amplitude.

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4 Discussion

The SST reconstructions derived from the marine phytoplankton *E. huxleyi* and planktonic foraminifera assemblages show notable differences during the last deglaciation period that might express ecological features. The most remarkable discrepancy between our reconstructions is the anomalous warm SST_{alk} found in the South Adriatic Sea at ~16.5 kyr. Although we cannot rule out the contribution of advected detrital alkenones (Sicre et al., 2005; Rühlemann and Butzin, 2006), this bias most probably reflects a shift in the alkenone production. Today, in the Western Mediterranean Sea and Adriatic Sea blooms of *E. huxleyi* occur in spring and fall (Ternois et al., 1996; Sicre et al., 1999; Totti et al., 2000). However, environmental factors can alter the alkenone production pattern at interannual to decadal timescale as recently demonstrated in the North Atlantic from the comparison of proxy and instrumental data over the 20th century (Sicre et al., 2011). Indeed, during the mid-60s to early 70s, large export of ice and freshwater from the Arctic into the sub-polar North Atlantic resulted in enhanced stratification of the upper water column that favored warming of a thin layer of the surface ocean where small size nanophytoplankton such as coccolithophorid can grow. During these cold and icy years, alkenone-SSTs were systematically biased towards warmer months compared to instrumental data suggesting delayed alkenone production season caused by the presence of sea ice. Anomalously high SST_{alk} period in the South Adriatic Sea could reflect environmental conditions during glacial period that may have favored water stratification. This time interval coincides with lower diversity of planktonic foraminifera and unusually high abundances of *Globorotalia scitula* in the core (Siani et al., 2010). A sharp increase of *G. scitula* centered at 16.3 kyr, contemporary to a decrease of *N. pachyderma*, has also been reported in the Tyrrhennian Sea (Sbaffi et al., 2004). Furthermore, investigations on *G. scitula* morphotypes in Eastern Mediterranean sediments have shown a link between salinity and the abundances and morphotype of *G. scitula* (Baumfalk et al., 1987). It is thus likely that during this time span alkenone production was limited to a few weeks in summer and confined

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to nutrient depleted surface waters due to strong stratification. Ice melting and subsequent continental runoff from surrounding rivers would have created conditions stabilizing the upper water column. In these sedimentary horizons, alkenones were less abundant and sometimes hardly detected. This temperature anomaly is not observed in the Siculo–Tunisian Strait SST_{alk} signal where interestingly the $\delta^{18}O$ *G. bulloides* decline between 18.5 and 16.5 kyr by 1.5 ‰ while in the South Adriatic Sea they first increase by 0.3 ‰ and then decrease by 0.5 ‰ over the same time interval. Highest $\delta^{18}O$ occur when SST_{foram} are the lowest, around 17 kyr, suggesting that *G. bulloides* would have developed at the base of a shallow seasonal pycnocline, while a low alkenone production would have taken place in surface layers during warmest months.

Higher than ON-SST_{foram} values between 19 and 16 kyr (and the YD) point to preferential summer alkenone production at both sites of the central Mediterranean Sea. In contrast, under milder BA and Holocene climates, SST_{alk} are close to AM-SST_{foram} except for the Holocene in the Siculo–Tunisian Strait region where they are similar to ON-SST_{foram} underlining seasonal production changes during the deglacial. Overall, our observations suggest that hydrological changes can introduce bias in the proxy records by modifying the seasonal cycle and/or depth habitat of phyto- and zooplankton thus complicating the interpretation of climate signals. Multi-proxy records are then necessary to unravel causes of past climate changes in small basins such as the Mediterranean where continental climate exerts a strong influence on surface water properties.

Another substantial difference between proxy records is the onset of the YD, marked by a shift from SST_{alk} values close to AM-SST_{foram} during the BA, to values close to ON-SST_{foram} during the YD. While SST_{foram} remained low during the YD, SST_{alk} become warmer than ON-SST_{foram} pointing out that alkenone production progressively shifted to summer season. This change could be responsible for the apparent shorter YD duration, a feature that has been previously documented in SST_{alk} signals of the Mediterranean Sea. Indeed, earlier warming of SST_{alk} by about 600 yr and a brief YD (700 yr) compared to Greenland (1200–1300 yr, 12.8–11.5 kyr) has been observed in

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the Alboran and Tyrrhenian seas (Cacho et al., 2001, 2002; Sbaffi et al., 2004), but none of this studies were multi-proxy, except for Sbaffi et al. (2001). These authors documented MAT and SST_{alk} in two cores from the Tyrrhenian Sea (BS79-38 and BS79-33) and showed a close match for spring and fall SSTs during the Holocene. Even though the calibration used to translate $U_{37}^{K'}$ into SSTs is different from our study, glacial SST_{alk} were generally higher than SST_{foram}, while SST_{foram} during BA were similar to Present day values (17 °C) contrasting with SST_{alk} being cooler by 3–4 °C, as found in the Siculo–Tunisian Strait. Although temporal resolution is lower than in our study, one of the two Tyrrhenian cores (BS79-38) seems to confirm apparent earlier warming of SST_{alk}. Overall, the BS79-38 core, and to a lower degree, the BS79-33 core, share resemblance with the Siculo–Tunisian Strait record.

Another notable feature of the Late deglacial is the brief cold reversal of 260 yr ending at the onset of G1S in the Greenland isotope record (~ 11.6 kyr) that is also seen in our records. This short episode has been reported by Cacho et al. (2001, 2002) and would be contemporary to the SST_{alk} decrease in the Ionian Sea documented by Emeis et al. (2000), when in the Levantine basin salinity and density decrease before S1 deposition. The following slower SST_{alk} warming from 11.5 to 9.5 kyr coincides with the lower rate decrease of $\delta^{18}O$ of *G. bulloides*. In summary, there seems to be some similarity between the South Adriatic and Ionian Sea records, while the last deglaciation in the Siculo–Tunisian channel shares resemblance with the Tyrrhenian Sea (Cacho et al., 2001).

Isotope signal in GISP2 and La Mine stalagmite (Tunisia)

Comparison of SST_{alk} with the reference GISP2 $\delta^{18}O$ curve further highlights differences between the North Atlantic and Mediterranean signals over the deglacial period. During the last glacial, SST_{alk} indicate warming between 19 and 16 kyr in the Siculo–Tunisian channel and from 18 to 16 kyr in the Adriatic Sea, while air over Greenland cooled (Fig. 3). After a sharp decline prior the onset of the BA, SST_{alk} increase rapidly in the Sicilian–Tunisian channel while in South Adriatic warming towards BA is more gradual than in Greenland ice core, possibly due to the influence of continental ice sheets on the northern rim of the Mediterranean. In the Siculo–Tunisian Strait, the Allerød appears as warm as the Bølling and relatively stable.

The SST_{alk} warming during the YD seems to begin earlier in Siculo–Tunisian by ~ 500 yr than in Southern Adriatic Sea, and ~ 1000 yr earlier than in the GISP2. We can speculate that early warming of SST_{alk} in the Siculo–Tunisian Strait might reflect a more rapid return to interglacial conditions due to more more pronounced subtropical influence in this sub-basin. To investigate this hypothesis, we compared our records to the C and O isotope signals of the Northern Tunisia stalagmite La Mine (Min-stm1) that provides a continuous climate record from 25 kyr ago (Fig. 3). The δ^{13}C variations in this stalagmite have been attributed to vegetation changes induced by T and soil humidity (Genty et al., 2006). The δ^{13}C rise indicates a decline of the vegetation during the cold/dry YD that is not seen in the δ^{18}O. This cold reversal is followed by a gradual transition to the pre-boreal period associated with climate amelioration and vegetation development towards the Holocene. The δ^{18}O stalagmite record is different and show warming starting around 16.4 kyr, at the time of the abrupt Greenland transition to the BA, progressing until a plateau during the YD. Interestingly, the δ^{18}O of La Mine stalagmite share similarity to some degree with the δ^{18}O of *G. bulloides* from the Siculo–Tunisian Strait suggesting that surface waters could have been major local sources of precipitation. Conversely, δ^{13}C values tend to follow SST_{alk} trends consistently with T being a controlling factor of vegetation and soil activities, although δ^{13}C values do not depict the early decrease as SST_{alk}, but rather parallel the δ^{18}O at GISP2. Therefore, SST_{alk} earlier warming in the southern than northern central Mediterranean Sea would most likely reflect ecological responses to environmental conditions that would have been different in the modified Atlantic waters of the Siculo–Tunisian Channel than those of the Adriatic Sea, substantially impacted by continental runoff.

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5 Conclusions

The Siculo–Tunisian channel and Adriatic Sea surface water temperature signals reveal differences caused by local environmental conditions that likely modified the alkenone production season pattern (timing, amplitude and duration). While alkenone and foraminifera derived SSTs indicate rapid cooling at the onset of the YD synchronous to GISP2, final warming to the Holocene occurs seemingly earlier in the SST_{alk} than SST_{foram} leading to an apparent shorter duration YD, consistently with previously reports from the Ioanian and Tyrrhenian Sea. We suggest that this bias result from alkenone production shifting from spring during the BA, to summer during the YD and back to spring during the Holocene, except for the Siculo–Tunisian Strait region were Holocene SST_{alk} are close to ON-SST_{foram}. Cold Heinrich stadials are clearly expressed in the Atlantic Modified Waters flowing along the northern African coast indicating stronger impact of the North Atlantic waters than in the South Adriatic Sea where these hydrological features are concealed by river runoff resulting from the presence of continental ice sheets.

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References

Bard, E., Rostek, F., Turon, J.-L., and Gendreau, S.: Hydrological impact of Heinrich Events in the Subtropical Northeast Atlantic, Science, 289, 1321–1324, 2000.

Baumfalk, Y. A., Troelstra, S. R., Ganssen, G., and Van Zanen, M. J. L.: Phenotypic variation of *Globorotalia scitula* (Foraminiferida) as a response to Pleistocene climatic fluctuations, Mar. Geol., 75, 231–240, 1987.

Cacho, I., Grimalt, J. O., Pelejero, C., Canals, M., Sierro, F. J., Flores, J. A., and Shackleton N. J.: Dansgaard-Oeschger and Heinrich event imprints in Alboran Sea paleotemperatures, Paleoceanography, 14, 698–705, 1999.

Cacho, I., Grimalt, J. O., Pelejero, C., Canals, M., Sbaffi, L., Shackleton, N. J., Schonfeld, J., and Zahn, R.: Variability of the Western Mediterranean Sea Surface temperatures during the last 25 000 years and its connection with the North Hemisphere climatic changes, Paleoceanography, 16, 40–52, 2001.

Cacho, I., Grimalt, J. O., and Canals, M.: Response of the Western Mediterranean Sea to rapid climate variability during the last 50,000 years: a molecular biomarker approach, J. Mar. Syst., 33, 253–272, 2002.

Conte, M. H., Sicre, M.-A., Rühlemann, C., Weber, J. C., Schulte, S., Schulz-Bull, D., and Blanz, T.: Global temperature calibration of the alkenone unsaturation index ($U_{37}^{K'}$) in surface waters and comparison with surface sediments, Geochem. Geophy. Geosy., 7, Q02005, doi:10.1029/2005GC001054, 2006.

Coplen, T. B.: Normalization of oxygen and hydrogen isotope data, Chem. Geol., 72, 293–297, 1988.

Emeis, K. C., Struck, U., Schulz, H. M., Rosenberg, R., Bernasconi, S., Erlenkeuser, H., Sakamoto, T., and Martinez-Ruiz, F.: Temperature and salinity variations of Mediterranean Sea surface water over the last 16 000 years from records of planktonic stable oxygen isotopes and alkenone unsaturation ratios, Paleogeogr. Paleocl., 158, 259–280, 2000.

Essallami, L., Sicre, M.-A., Kallel, N., Labeyrie, L., and Siani, G.: Hydrological changes in the Mediterranean Sea over the last 30 000 years, Geochem. Geophy. Geosy., 8, Q07002, doi:10.1029/2007GC001587, 2007.

Genty, D., Blamart, D., Ghaleb, B., Plagnes, V., Causse, Ch., Bakalowicz, M., Zouari, K., Chlir, N., Hellstrom, J., Wainer, K., and Bourges, F.: Timing and dynamics of the last deglaciation from European and north African δ^{13}C stalagmite profiles – comparison with chine and south hemisphere stalagmites, Quaternary Sci. Rev., 25, 2118–2142, 2006.

Grimalt, J. O., Rullkötter, J., Sicre, M.-A., Harvey, H. R., Farrington, J. W., Goni, M., Sawada, K., and Summons, R.: Modifications of the C_{37} alkenone and alkenoate composition in the water column and sediment: possible implications for sea surface temperature estimates in paleoceanography, Geochem. Geophy. Geosy., 1, doi:10.1029/2000GC000053, 2000.

Hurrell, J. W.: Decadal trends in the north Atlantic Oscillation: regional temperatures and precipitation, Science 269, 676–679, 1995.

Huston, W. H.: The Aghulas current during the late Pleistocene: analysis of modern analogs, Science, 207, 227–238, 1979.

Kallel, N., Paterne, M., Labeyrie, L., Duplessy, J.-C., and Arnold, M.: Temperature and salinity records of the Tyrrhenian Sea during the last 18 000 years, Paleogeogr. Paleocl., 135, 97–108, 1997.

Lionello, P., Planton, S., and Rodo, X.: Preface: trends and climate change in the Mediterranean region, Global Planet. Change, 63, 90–104, 2008.

Luterbacher, J., Xoplaki, E., Casty, C. et al.: Mediterranean climate variability over the last centuries: a review, in: The Mediterranean Climate: An Overview of the Main Characteristics and Issues, edited by: Lionello, P., Malanotte-Rizzoli, P., and Boscolo, R., Elsevier, Amsterdam, 27–148, 2006.

Prell, W.: The stability of low latitudes sea surface temperature: an evaluation of the CLIMAP reconstitution with emphasis on the positive SST anomalies, Technical Report, RT025, United States Department of Energy, Washington, DC, 60 pp., 1985.

Pujol, C. and Vergnaud-Grazzini, C.: Distribution patterns of live planktonic foraminifers as related to regional hydrography and productive systems of the Mediterranean Sea, Mar. Micropaleontol., 25, 187–217, 1995.

Reimer, P. J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., Buck, C. E., Burr, G. S., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., McCormac, F. G., Manning, S. W., Reimer, R. W., Richards, D. A., Southon, J. R., Talamo, S., Turney, C. S. M., van der Plicht, J., and Weyhenmeye, C. E.: Intcal09 and Marine09 Radiocarbon Age Calibration Curves, 0–50 000 Years Cal BP, Radiocarbon, 51, 1111–1150, 2009.

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Rühlemann, C. and Butzin, M.: Alkenone temperature anomalies in the Brazil-Malvinas Confluence area caused bylateral advection of suspended particulate material, Geochem. Geophy. Geosy., 7, Q10015, doi:10.1029/2006GC001251, 2006.

Sbaffi, L., Wezel, F. C., Kallel, N., Paterne, M., Cacho, I., Ziveri, P., and Schackleton, N.: Response of the pelagic environment to palaeoclimatic changes in the central Mediterranean Sea during the Late Quaternary, Mar. Geol., 178, 39–62, 2001.

Sbaffi, L., Wezel, F. C., Curzi, G., and Zoppi, U.: Millennial- to centennial-scale palaeoclimatic variations during Termination I and the Holocene in the central Mediterranean Sea, Global Planet. Change, 40, 201–217, 2004.

Siani, G., Paterne, M., Arnold, M., Bard, E., Métivier, B., Tisnerat, N., and Bassinot, F.: Radiocarbon reservoir ages in the Mediterranean Sea and Black Sea coastal waters, Radiocarbon, 42, 271–280, 2000.

Siani, G., Paterne, M., Michel, E., Sulpizio, R., Sbrana, A., Arnold, M., and Haddad, G.: Mediterranean sea-surface radiocarbon reservoir age changes since the last glacial maximum, Science, 294, 1917–1920, 2001.

Siani, G., Sulpizio, R., Paterne, M., and Sbrana, A.: Tephrostratigraphy study for the last 18 000 ^{14}C years in a deep-sea sediment sequence for the South Adriatic, Quaternary Sci. Rev., 23, 248–2500, 2004.

Siani, G., Sulpizio, R., and Paterne, M.: Application of marine tephrochronology to paleoclimatic studies: the example of the Central Mediterranean Sea, Acta Vulcanol., 18, 4–54, 2006.

Siani, G., Paterne, M., and Colin, C.: Late glacial to Holocene planktic foraminifera bioevents and climatic records in the South Adriatic Sea, J. Quaternary Sci., 25, 808–821, 2010.

Siani, G., Magny, M., Paterne, M., Debret, M., and Fontugne, M.: Paleohydrology reconstruction and Holocene climate variability in the South Adriatic Sea, Clim. Past Discuss., submitted, 2013.

Sicre, M.-A., Ternois, Y., Miquel, J.-C., and Marty, J.-C.: Alkenones in the Mediterranean sea: interannual variability and vertical transfer, Geophys. Res. Lett., 26, 1735–1738, 1999.

Sicre, M.-A., Labeyrie, L., Ezat, U., Duprat, J., Turon, J.-L., Schmidt, S., Michel, E., and Mazaud, A.: Southern Indian Ocean response to Northern Hemisphere Heinrich events, Earth Planet. Sc. Lett., 240, 724–731, 2005.

Sicre, M.-A., Hall, I., Mignot, J., Khodri, M., Ezat, U., Truong, M.-X., Eiríksson, J., and Knudsen, K.-L.: Sea surface temperature variability in the subpolar Atlantic over the last two millennia, Paleoceanography, 26, PA4218, doi:10.1029/2011PA002169, 2011.

Stuiver, M. and Reimer, P. J.: Extended ^{14}C database and revised calib 3.0 ^{14}C age calibration program, Radiocarbon, 35, 215–230, 1993.

Stuiver, M., Reimer, P. J., Bard, E., Beck, W., Burr, G. S., Hughen, K. A., Kromer, B., McCormac, F. G., and van der Spuk, M.: INTCAL98 radiocarbon age calibration 24 000 cal bp, Radiocarbon, 40, 1041–1083, 1998.

Ternois, Y., Sicre, M.-A., Boireau, A., Marty, J.-C., and Miquel, J. C.: Production pattern of alkenones in the Mediterranean Sea, Geophys. Res. Lett., 23, 3171–3174, 1996.

Ternois, Y., Sicre, M.-A., Boireau, A., Conte, M. H., and Eglinton, G.: Evaluation of long-chain alkenones as paleo-temperature indicators in the Mediterranean Sea, Deep-Sea Res., 44, 271–286, 1997.

Totti, C., Civitarese, G., Acri, F., Barletta, D., Candelari, G., Paschini, E., and Solazzi, A.: Seasonal variability of phytoplankton populations in the middle Adriatic sub-basin, J. Plankton Res., 22, 1735–1756, 2000.

Trigo, R. M., Trigo, I. F., DaCamara, C. C., and Osborn, T. J.: Climate impact of the European winter blocking episodes from the NCEP/NCAR Reanalyses, Clim. Dynam., 23, 17–28, 2004.

Van Straaten, L. M. J. U.: Holocene and late-Pleistocene sedimentation in the Adriatic Sea, Geol. Rundsch., 60, 10–131, 1970.

Zanchetta, G., Sulpizio, R., Giaccio, B., Siani, G., Paterne, M., Wulf, S., and D'Orazio, M.: The Y-3 Tephra: a last glacial stratigraphic marker for the central Mediterranean basin, J. Volcanol. Geoth. Res., 177, 145–154, 2008.

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9, 683–701, 2013

Fig. 1. Map showing the location of the two study cores of the Central Mediterranean Sea: MD90-917 (South Adriatic Sea) and MD04-2797 (Siculo–Tunisian Strait). The red star indicates the location where La Mine stalagmite has been collected.

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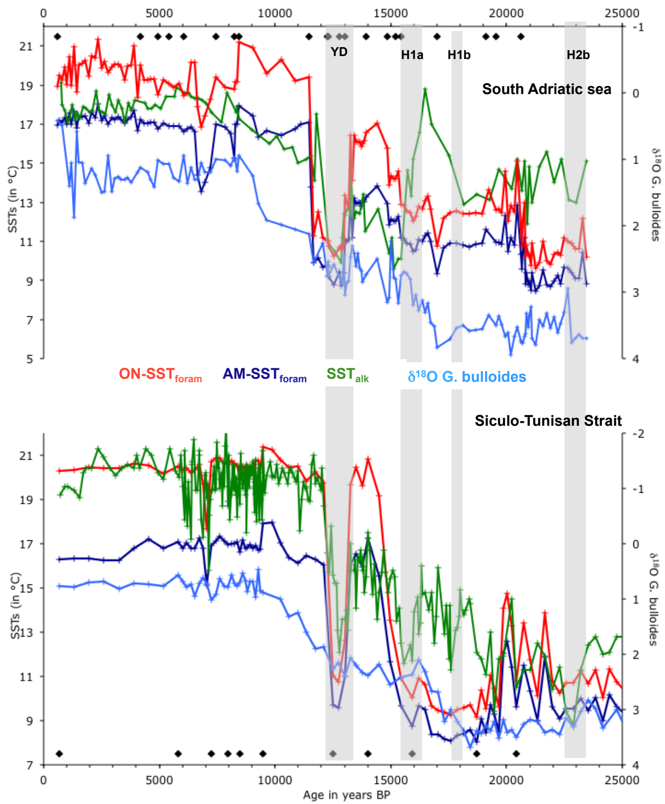

Fig. 2. SSTs derived from planktonic foraminifera assemblages for April–May (AM-SST_{foram}) and October–November (ON-SST_{foram}) and alkenones (SST_{alk}) and the $\delta^{18}O$ determined in *G. bulloides* calcite (in ‰). The upper panel shows the SSTs and $\delta^{18}O$ in *G. bulloides* records over the last 25 kyr in the South Adriatic Sea core MD90-917; the lower panel show the same records form the Siculo–Tunisian Strait core MD04-2797. Shaded areas in grey indicate the Younger Dryas (YD), the Heinrich stadials H1a, H1b and H2a.

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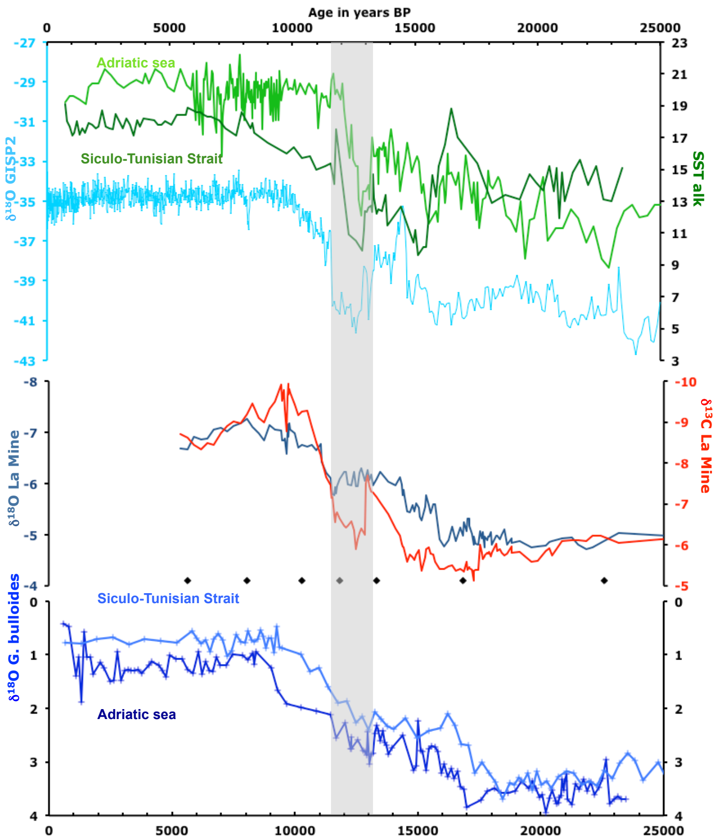

Fig. 3. Comparison between SST_{alk} in the South Adriatic Sea and Siculo–Tunisian Strait cores with the $\delta^{18}O$ in the Greenland ice core GISP2, La Mine stalagmite (Tunisia) and $\delta^{18}O$ in *G. bulloides* calcite from in the South Adriatic Sea and Siculo–Tunisian Strait cores.

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Seemingly divergent sea surface temperature proxy records

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