

Comparison between different methods of paleotemperature reconstruction in the Alboran Sea (OPD 977 core), based on planktic foraminifera assemblages of the last 150 kyr

Comparación entre diferentes métodos de reconstrucción de paleotemperaturas en el Mar de Alborán (testigo ODP 977), basados en las asociaciones de foraminíferos planctónicos de los últimos 150 ka.

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ABSTRACT

Sea surface temperatures (SST) in the Alboran Sea during the last 150 ka have been reconstructed in ODP Site 977 using the Transfer Function method of Imbrie & Kipp (1971) and the Modern Analog Technique (MAT), both based on the quantitative composition of the planktic foraminiferal assemblages. Comparison between the results obtained from the two paleoclimatic techniques shows that Transfer Function provides temperature subestimations in the coldest intervals of the Last Glacial Period, whereas MAT (using 10 analogs per sample) is more adequate and useful for paleoclimatic interpretations in the Western Mediterranean area.

RESUMEN

Hemos reconstruido las temperaturas superficiales del Mar de Alborán durante los últimos 150 ka en el testigo ODP 977, mediante el uso de las dos técnicas paleoclimáticas de reconstrucción más usadas, la función de transferencia de Imbrie & Kipp (1971), y el Método de los Análogos Modernos (MAT), basadas ambas en el análisis de las asociaciones de foraminíferos planctónicos. La comparación de los resultados de ambos métodos nos muestra que la función de transferencia genera subestimaciones de temperatura en el rango térmico más frío, mientras que MAT (usando diez análogos para cada reconstrucción) parece la técnica más adecuada y útil para su uso en interpretaciones paleoclimáticas, en esta área del Mediterráneo Occidental.

Key words: Paleotemperature reconstruction, planktic foraminifera, database, transfer function, modern analog, Alboran Sea, Western Mediterranean, Pleistocene.

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Introduction

Nowadays, there are two methods for quantitative paleotemperature reconstruction, based on planktic foraminifera fauna: Transfer Function method of Imbrie and Kipp (1971) and the Modern Analog Technique (MAT, Hutson, 1980; Prell, 1985). These methods are based on the same assumption: Because planktic foraminiferal assemblages in recent marine sediments change when sea surface temperature changes, the same should occur in the past. If we are able to relate the composition of the recent foraminiferal assemblages with sea surface temperature, we can thereby estimate past sea surface temperatures just comparing old assemblages with the recent ones. For the application of these techniques different types of software have been developed, such as

Paleotoolbox (in this work) or the new *Paleoanalog* (Theron *et al.*, in prep.).

To accomplish the sea surface temperature reconstruction we need: 1) a coretop database with the quantitative data of the planktic foraminifera recent assemblages from as many locations as possible extending over a broad oceanographic area. 2) the modern sea surface temperature for each location in the database that is usually obtained from the Ocean Global Atlas (Levitus, 1982). 3) The quantitative data of the fossil core samples for which we want to reconstruct the past sea surface temperatures.

Techniques

Transfer function of Imbrie and Kipp (1971) is a mathematical method with three stages. First stage (CABFAC) consists of a principal component Q-mode analysis carried out in the actual

database. A number of "factors" are obtained (as small as possible), that can be evaluated as climatic-faunistic assemblages. Second stage (REGRESS) is a regression analysis, which establishes a relation between biological parameters (factors in the first stage) and the physical parameters of the environment (temperature). Finally, in the last stage (THREAD) we apply the previous stages to the fossil samples, carrying out the Q-mode analysis in the core samples and leading the factors to the regress stage. Quality of the reconstructions can be evaluated using the "communality" that varies between 0 (bad) and 1 (good). This number indicates how much of the original information is retained in the assemblages of the factor analysis.

Modern Analog Technique, on the other hand, gives us a direct analogy between fossil assemblages and modern

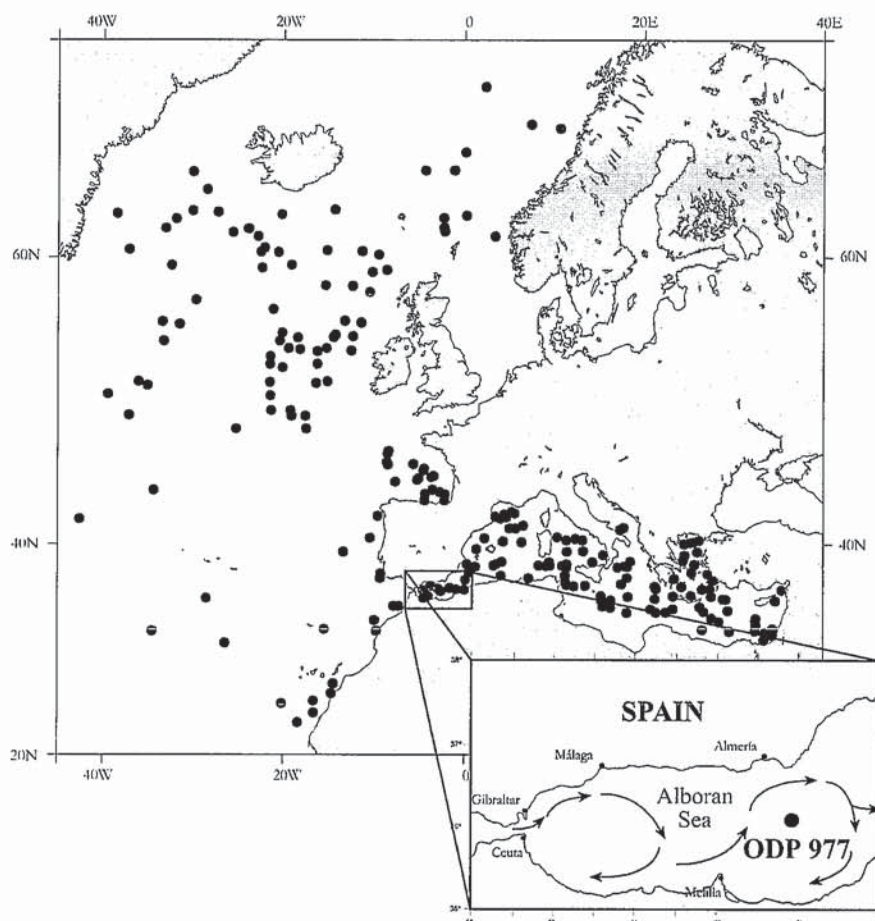


Fig. 1.- Coretops of the modern database of Kallel *et al.* (1997) for the Mediterranean Sea and location of Hole ODP 977. Sea surface circulation of the Atlantic waters in the Alboran Sea is also shown.

Fig. 1.- Testigos de la base de datos actual de Kallel *et al.* (1997) para el Mar Mediterráneo y localización del testigo ODP 977. También se muestra la circulación superficial de las Aguas Atlánticas en el Mar de Alborán.

samples, through a statistical distance, that show “how much” the fossil sample resembles the modern one. This is the “dissimilarity coefficient”, in our case the “squared chord distance” (Overpeck *et al.*, 1985). The dissimilarity (*d*) index varies between 0 (best reconstruction) and 0.4 (worst reconstruction). The paleotemperature obtained is the weighted mean of the best analogs.

Materials

The Database used in this work is that of Kallel *et al.* (1997) for the Mediterranean Sea, that comprises 253 coretops, 128 from the Mediterranean and 125 situated in the North Atlantic Ocean (Figure 1). Mean monthly temperature in each point was extracted from Levitus (1982). The main goal of this paper is to reconstruct paleotemperatures of ODP Site 977 (Comas *et al.*, 1996), situated in the Alboran Sea (36° 1,9' N ; 1° 57,3' W) (Figure 1). We analyzed 288 samples, in

the first 27.24 m of the core, of which we know the quantitative composition of planktic foraminifera assemblages (Pérez-Folgado *et al.*, 2003; submitted). The sampling resolution is around one sample per 10 cm, that provides a temporal resolution of around 450 years; the 288 samples covering 150 ka (Pérez-Folgado *et al.*, submitted).

Species / Load	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
<i>N. pachyderma</i> (d)	0.949	0.012	-0.132	0.241	-0.073
<i>N. pachyderma</i> (s)	0.031	-0.009	-0.005	0.120	0.806
<i>G. bulloides</i>	0.251	0.163	0.387	-0.845	0.067
<i>G. inflata</i>	0.036	-0.093	0.891	0.378	-0.006
<i>T. quinqueloba</i>	0.042	-0.005	-0.018	-0.021	0.575
<i>G. ruber</i> blanca	-0.051	0.978	0.013	0.175	0.003
Variance (%)	42.17	29.37	16.06	6.23	2.68
Accumulated variance	42.17	71.54	87.60	93.83	96.51
Abundant in:	North Atlantic and Gulf of Lions	Eastern Mediterranean (East of Corsica)	Western Mediterranean (except Gulf of Lions)	scarce	North Atlantic (above 55°N)

Table I.- Principal Component Analysis of the Kallel *et al.* (1997) database.

Tabla I.- Análisis de Componentes Principales de la base de datos de Kallel *et al.* (1997)

Results and discussion

Transfer Function Method of Imbrie and Kipp (1971)

Principal Component Analysis carried out in the actual database led us five factors or assemblages, which explain the 96.5% of the variance of the samples (Table 1). Reconstruction (Figure 2) was made for spring (April and May average) and autumn (October and November average) temperatures, which are the most productive times in the Mediterranean (Kallel *et al.*, 1997). Mean communality for the whole core is 0.96, varying between 0.9955 and 0.7849.

Mean sea surface temperatures for the past 150,000 years is 13.26 °C for autumn and 11.11 °C for spring. When the percentage of any species in the core is higher than the maximum percentage in the database, the reconstruction is not good, and the communality graph is not a continuous line (Figure 2). This occurred 31 times along the core, with two especially problematic points (marked with arrows in Figure 2): two samples with more than 45% of *Turborotalita quinqueloba* (this species do not surpass 29% in the database samples). Because of that, these samples show high loads in Factor 5, although *T. quinqueloba* is a secondary species in the modern assemblages related with this factor, which is mainly dominated by the polar species *Neogloboquadrina pachyderma* (left coiling) (Table 1). In ODP 977, Factor 5 responds to variations in *T. quinqueloba*, especially abundant during the isotope stage 3, instead to variations in the polar species. Therefore, the method provides low temperatures for these levels based on the high loads of Factor 5 when, as a matter of fact, this factor is mainly controlled in recent sediments by *N. pachyderma* (left

coiling). In consequence, we consider the values provided by the method as paleotemperature subestimations.

González-Donoso *et al.* (2000) carried out a paleotemperature study for the whole Quaternary, in the ODP Site 976, also situated in the Alboran Sea. Although resolution is minor than in our work, these authors found that Transfer Function results tends to overvalue at low temperatures, with respect to MAT, for the 364 m of core length.

Modern Analog Method (MAT)

This method allows us to choose among different possibilities to test which one provides the best results. In this study different analysis were performed changing the number of analogs and the threshold value of the dissimilarity index in order to test the quality of the temperature estimations.

Results with $d < 0.15$

Using a dissimilarity index lower than 0.15, we obtained a mean sea surface temperature for spring of around 10.97 °C with a standard deviation of 2.2 °C and the maximum error of ± 5.35 °C. Mean autumn temperature was 13.21 °C, with a standard deviation of 2.76 °C and maximum error of ± 7.53 °C. When there are less than two samples in the database that attain the condition of $d < 0.15$, it is not possible to reconstruct the paleotemperature; this is a "non-analog" situation. This occurs 37 times throughout the core (Figure 3). Unfortunately, these points are concentrated in some intervals in the core, and visible gaps appear in the record (Figure 3). These intervals are located at around 8 ka BP, during isotopic stage (IS) 3 and within the last interglacial, at isotope substage 5e. Around 8 ka BP *N. pachyderma* (right coiling) was replaced in the Alboran Sea by *Globorotalia inflata*, the main component of the actual planktic foraminifera assemblage. During the replacement, both species were abundant and the assemblages were very different from the present ones, having no-analogs in the modern database. The no-analogs recorded in IS 3 are associated with the high abundances of *T. quinqueloba* and *Globorotalia scitula* within the cold Dansgaard Oeschger stadial events recorded in Greenland ice cores (Dansgaard *et al.*, 1993; Pérez-Folgado *et al.*, 2003). Finally, the planktic foraminifera recorded during the last interglacial with abundant

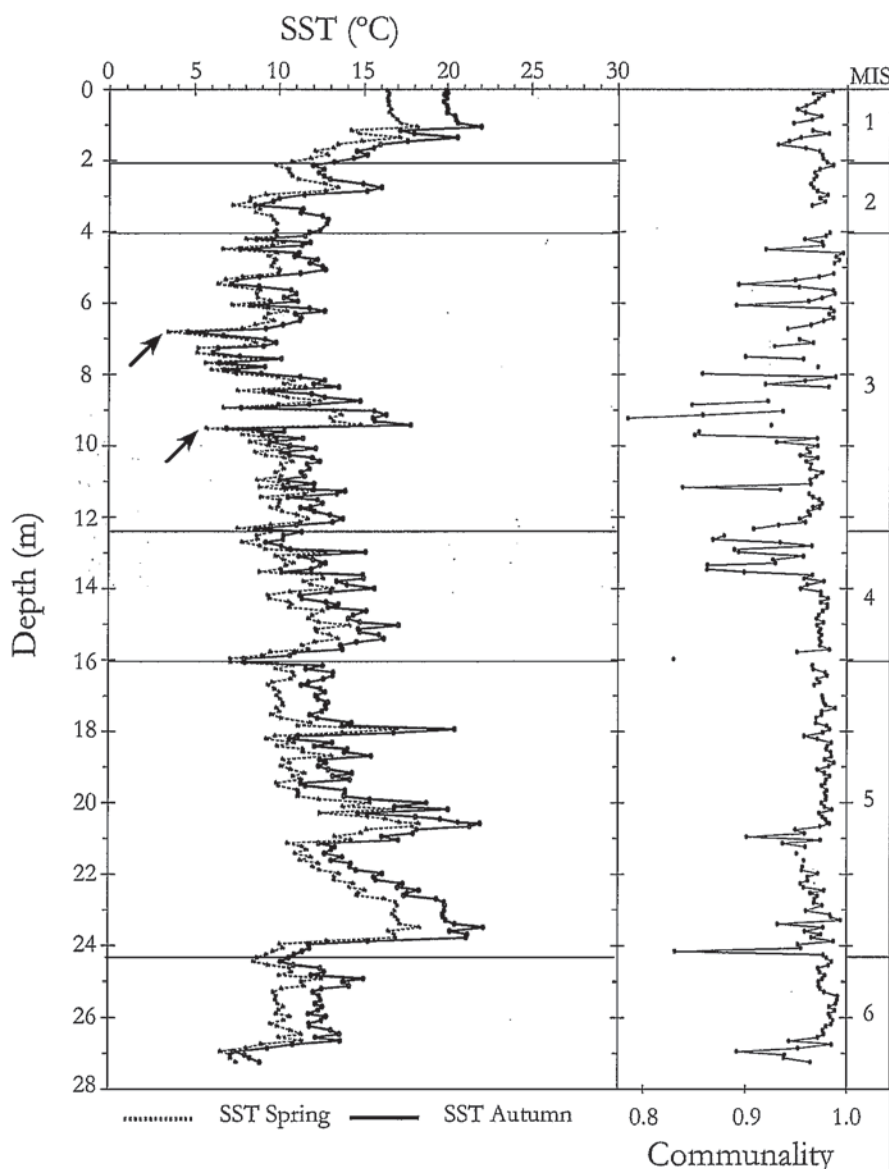


Fig. 2.- Paleotemperatures obtained in the ODP 977 core using the Transfer Function Method of Imbrie and Kipp (1971). Arrows indicate data with less reliable results (see text for details).

Fig. 2.- Paleotemperaturas obtenidas en el testigo OPD 977 usando el Método de la Función de Transferencia de Imbrie & Kipp (1971). Las flechas indican los resultados menos fiables.

Globigerinoides ruber white, accompanied by *Globigerina bulloides* and *G. inflata*, are very different from those occurring today in modern sediments of the Mediterranean and the North Atlantic.

Results with $d < 0.20$

Using a higher threshold value for the dissimilarity index, the number of no-analogs decreases down to 5 samples, providing more continuous records but less accurate SST estimations. The general pattern of the SST record and the average temperatures for every season are very similar to those of the previous reconstruction (Figure 3). Spring mean paleotemperature is 11.27 °C, and the

standard deviation is 2.37 °C, whereas the average autumn temperature mean is 13.51 °C and the standard deviation 2.93 °C. The five samples with $d < 0.20$ are located at the same intervals, near 8 ka BP, at IS 3 and at the warmest times of isotope substage 5e.

Results without threshold value in the dissimilarity index

If the dissimilarity index is not limited, all the samples provide a paleotemperature estimation, but the accuracy of the reconstruction must be evaluated using the error and the mean dissimilarity index for each sample (Figure 3). Seasonal mean SST values are almost the same than those obtained with

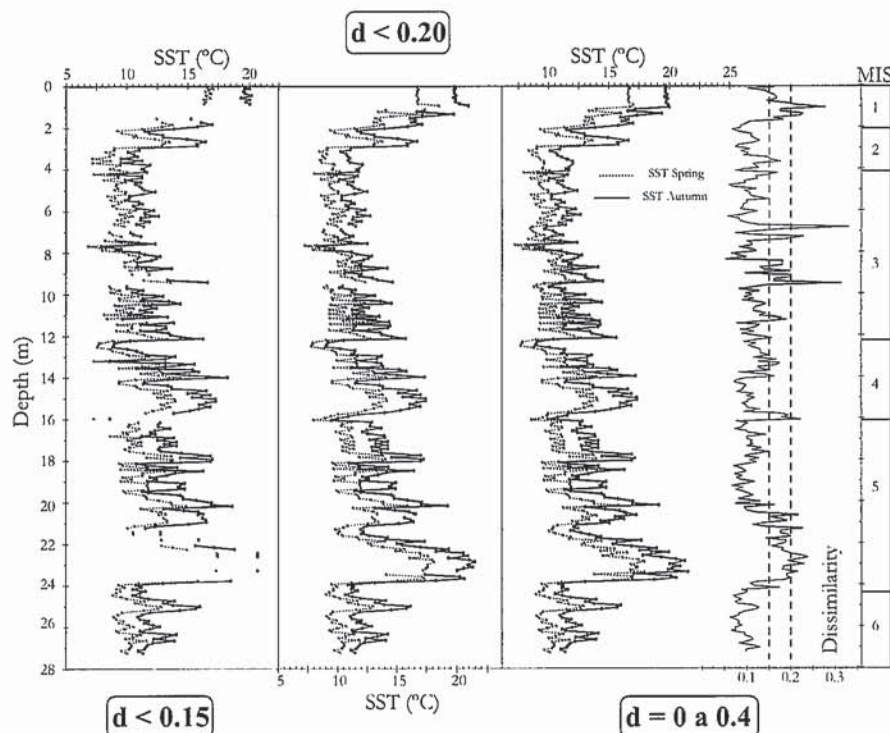


Fig. 3.- Paleotemperatures obtained using the Modern Analog Technique (MAT). Different results are showing depending on the dissimilarity index limit. Vertical dashed lines in the dissimilarity curve mark the 0.15 and 0.20 values.

Fig. 3.- Paleotemperaturas obtenidas usando la Técnica de los Análogos Modernos (MAT). Se muestran los diferentes resultados dependiendo del límite en el índice de "disimilitud". Las líneas verticales punteadas en la curva de "disimilitud" marcan los valores de 0.15 y 0.20.

the $d < 0.20$ reconstruction. Spring mean SST is 11.30°C and the standard deviation is 2.33°C . For autumn, the mean SST reaches 13.56°C and standard deviation is 2.91°C . The maximum error for the spring SST reconstruction is $\pm 3.81^{\circ}\text{C}$, while for the autumn reconstruction is $\pm 4.98^{\circ}\text{C}$. All the records were obtained using the ten best analogs giving a mean dissimilarity curve that is plotted in Figure 3. The maximum value of d is 0.3315 and the minimum 0.052 (Figure 3). Mean dissimilarity for all the samples is 0.13 and the standard deviation reaches 0.05.

Conclusions

Different paleoclimatic methods were used to reconstruct SST in the Alboran Sea along the past 150,000 years. These methods provide similar SST records that

show the response of the Western Mediterranean to the major glacial interglacial variations. However, the Transfer Function method of Imbrie and Kipp (1971) subestimates SST within some of the coldest Dansgaard-Oeschger events of the Last Glacial period. The Modern Analog method provides accurate SST estimations when a low dissimilarity index ($d < 0.15$) is used, but it generates discontinuous records due to the occurrence of no-analogs in many samples. However, using the same method with no dissimilarity filter, provides less precise data but continuous paleotemperature records that must be evaluated through a careful analysis of the individual dissimilarities. For this reason, we consider that this method is more useful for paleoceanographic and paleoclimatic reconstructions in the Alboran Sea.

The amplitude of the SST change in the Alboran Sea between glacial and interglacial periods was as high as 12°C for summer, and 8°C for winter. During the Last Glacial Maximum (around 21 ka BP), mean annual temperature did not surpass 10°C in the Alboran Sea, whereas it reached 18.9°C during the last 8 ka. However, during the Last Interglacial (isotope substage 5e, around 125 ka BP) mean annual temperatures of 20.2°C were reached, slightly higher than present temperatures and those of the Holocene.

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