

Marine Isotopic Stage 5e in the Southwest Pacific: Similarities with Antarctica and ENSO inferences

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[1] A detailed record of alkenone-derived sea-surface temperatures (SSTs) offshore western New Zealand has been generated for the penultimate deglaciation and last interglacial. SSTs were 3.5 to 4.5°C warmer than present, peaking 4.5 thousand years ahead of ice volume minima. The short duration of Marine Isotopic Stage 5e off New Zealand exhibits a striking parallelism to the record of air temperatures at Vostok, Antarctica. Changes in latitudinal SST gradients for the Southwest Pacific from New Zealand to the equator are also assessed, showing values consistently lower than today. In this region, this situation usually occurs during periods with positive values of the Southern Oscillation Index and thus La Niña conditions. By inference, we suggest that our assessed low thermal gradients might be indicative of a prevalence of either persistent or more frequent La Niña like conditions, particularly during early Stage 5e. *INDEX TERMS:* 4267 Oceanography General: Paleooceanography; 1620 Global Change: Climate dynamics (3309); 3344 Meteorology and Atmospheric Dynamics: Paleoclimatology. **Citation:** Pelejero, C., E. Calvo, G. A. Logan, and P. De Deckker, Marine Isotopic Stage 5e in the Southwest Pacific: Similarities with Antarctica and ENSO inferences, *Geophys. Res. Lett.*, 30(23), 2185, doi:10.1029/2003GL018191, 2003.

1. Introduction

[2] Despite the recognition of the role of Earth's orbital parameters in controlling the Ice Ages [Hays *et al.*, 1976], we still do not have a clear understanding of when and how different parts of the globe are impacted by glacial and interglacial changes. The evident lead in deglacial warming recorded in Antarctica [Petit *et al.*, 1999], together with changes recorded in the tropics [Lea *et al.*, 2000; Visser *et al.*, 2003], suggests that the Southern Hemisphere plays a very important and sensitive role in the swing from glacial to interglacial states. Amongst all the key areas, the Pacific Ocean experiences a variety of short and long term oscillations, with ocean-atmosphere interactions of global cli-

matic importance such as El Niño-Southern Oscillation (ENSO). Key controls on these oscillations are sea-surface temperature (SST) gradients [Rind, 1998].

[3] This study focuses on the penultimate deglaciation and the subsequent Marine Isotope Stage 5e/5d shift. New insights are presented on the peculiar characteristics of Stage 5e as recorded off New Zealand, a period often considered analogous to the present interglacial stage. Comparison between SSTs off New Zealand and at the equator allows the reconstruction of meridional thermal gradients in the Southwest Pacific.

2. Materials and Methods

[4] We report new alkenone SST data from a marine core west of New Zealand (SO136-GC3; 42°18'S, 169°53'E, 958 m water depth; Figure 1), which is compared to published results on air temperatures recorded at Vostok, Antarctica (78°S, 106°E, 3488 m elevation; Figure 1; [Petit *et al.*, 1999]) and SSTs from a key equatorial core (ODP 806B; 0°19.1'N, 159°21.7'E, 2520 m water depth; Figure 1; [Lea *et al.*, 2000]). Core SO136-GC3 was recovered from the gently-sloping flank of the southern Challenger Plateau west of South Island of New Zealand. Parasound profiling shows a flat sea floor and parallel sub-bottom reflectors to at least 70 meters below sea bed [Thiede *et al.*, 1999].

[5] SSTs in the studied core are reconstructed based on alkenone analyses and the U_{37}^K index, performed following published methods [Calvo *et al.*, 2003]. Conversion from this index to temperatures was accomplished using a worldwide core-top calibration specifically correlated to annual modern surface temperatures [Müller *et al.*, 1998]. This calibration provides a temperature for the uppermost Holocene sample (15.5°C, Figure 2a) comparable to the modern annual mean of 15°C (HadISST1 data from 1870 to 2002; [Rayner *et al.*, 2003]). Alkenone abundances were in the 80–1000 ng/g range, allowing precise temperature estimations with analytical estimated uncertainties of $\pm 0.04^\circ\text{C}$, based on triplicate analyses [Calvo *et al.*, 2003]. Planktonic foraminifera *Globigerina bulloides* $\delta^{18}\text{O}$ data were used to establish the age-model by correlation with the standard SPECMAP $\delta^{18}\text{O}$ chronology [Martinson *et al.*, 1987] (Figure 2a). Samples for $\delta^{18}\text{O}$ were taken from 1 cm thick slices and washed through distilled water prior to selecting foraminifera specimens for analysis on a Finnigan MAT 251

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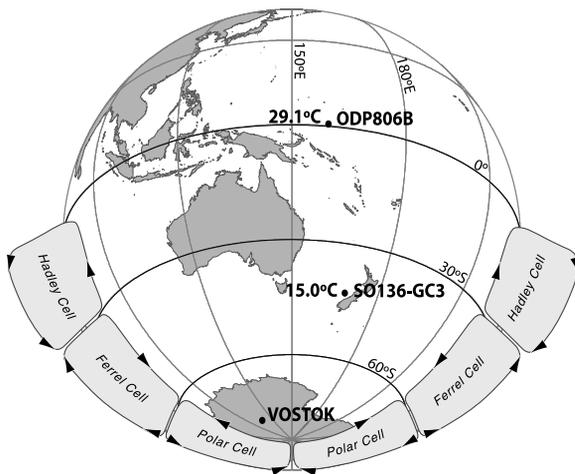


Figure 1. Map showing locations of paleoclimatic archives discussed in this study and idealized diagram of Hadley, Ferrel and Polar Cells. Temperatures correspond to annual mean SSTs at marine sites for 1870–2002 [Rayner *et al.*, 2003].

mass spectrometer. The age model provides sedimentation rates for the 175 to 75 kyr B.P. period between 1.5 and 4 cm per kyr, with highest values characterizing our main studied section encompassing the whole deglaciation and Stage 5e. In this particular section we performed a 2 cm sampling providing a resolution of 500 yrs.

3. Results and Discussion

[6] The pattern of alkenone-derived SSTs west of New Zealand generally tracks the planktonic foraminifera $\delta^{18}\text{O}$ record from 175 to 75 kyr B.P. (Figure 2a). However, a decoupling during the penultimate deglaciation and Stage 5e is evident in our data. At the onset of this transition, a systematic 3 kyr lead of temperatures in relation to ice volume is found, in agreement with other recently published studies from equatorial regions [Lea *et al.*, 2000; Visser *et al.*, 2003]. Furthermore, as deglaciation evolved, the record of SSTs clearly diverges from the $\delta^{18}\text{O}$ curve. SST rises rapidly, from 12.0 to 19.5°C, culminating, after a sequence of brief pulses, in an exceptionally warm early Stage 5e. Three aspects make this stage a unique case (Figure 2a): first, maxima SSTs (18.5 to 19.5°C) are 3.5 to 4.5°C higher than today for the studied site. Second, surface warming peaked about 4.5 kyr ahead of the ice volume interglacial minimum recorded by planktonic foraminifera $\delta^{18}\text{O}$. And third, the decline of temperatures towards Stage 5d started earlier than ice volume minimum, leaving a mean duration for the whole warm stage of only about 5 kyr.

[7] These characteristics are strikingly parallel to the Stage 5e recorded by Antarctic air temperatures, as evidenced by the deuterium record in the Vostok ice core [Petit *et al.*, 1999]. Although several Vostok chronologies have been suggested [e.g., Landwehr and Winograd, 2001], we adopted the widely used GT4 age model. It appears that the timing and short duration of warmth within Stage 5e are coincident between both areas. Deglacial warming is synchronous and, at about 125 kyr B.P., temperatures offshore New Zealand and at Vostok decrease abruptly. This early

decrease in temperatures is not paralleled at the equator, where temperatures remain fairly constant till the end of this stage (Figure 3a; see further discussion below). Our results, thus, suggest a different latitudinal pattern and response during deglaciation compared to the subsequent onset of glaciation. There appears to be a synchronous response to deglaciation in Antarctica, the Southwest Pacific and the equator while, within Stage 5e, an early cooling occurs only in Antarctica and the Southwest Pacific.

[8] A Stage 5e slightly warmer than Holocene is a widespread finding [e.g., Lea *et al.*, 2000; Calvo *et al.*, 2001]. However, temperature differences encountered so far in other oceanic basins are usually in the order of 1 to 2°C.

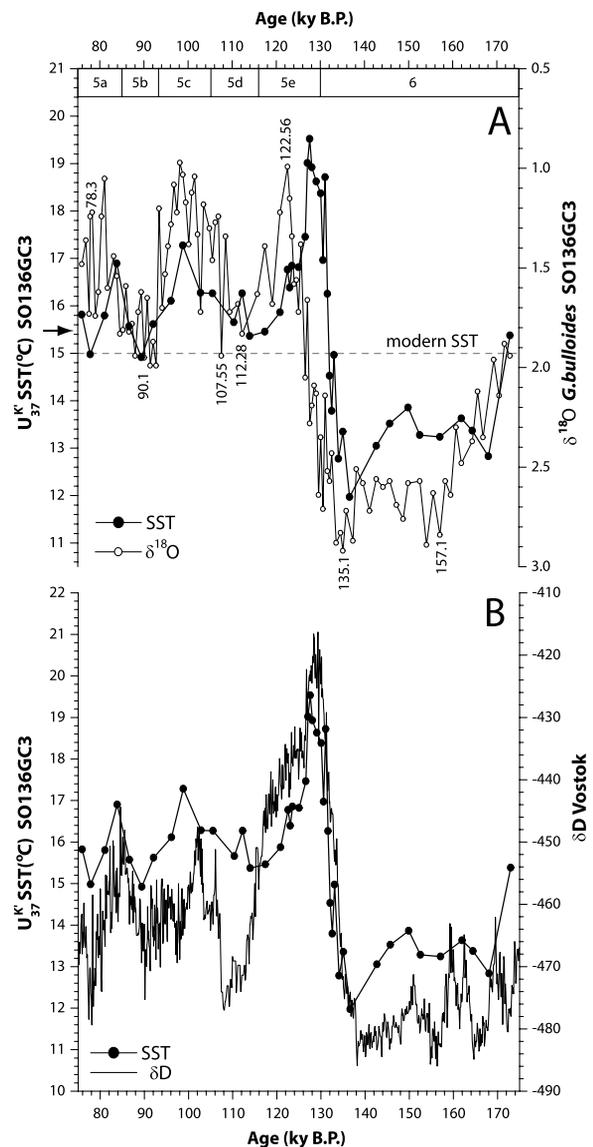


Figure 2. (a) *G. bulloides* $\delta^{18}\text{O}$ and $U_{37}^{K'}$ -SSTs for core SO136-GC3 (vertical numbers correspond to age model pointers). Arrow and dashed line mark the $U_{37}^{K'}$ -SST temperature for the uppermost Holocene sample and the modern annual mean SST [Rayner *et al.*, 2003], respectively. (b) $U_{37}^{K'}$ -SSTs for core SO136-GC3 compared to δD from Vostok, a proxy for air temperature in Antarctica [Petit *et al.*, 1999].

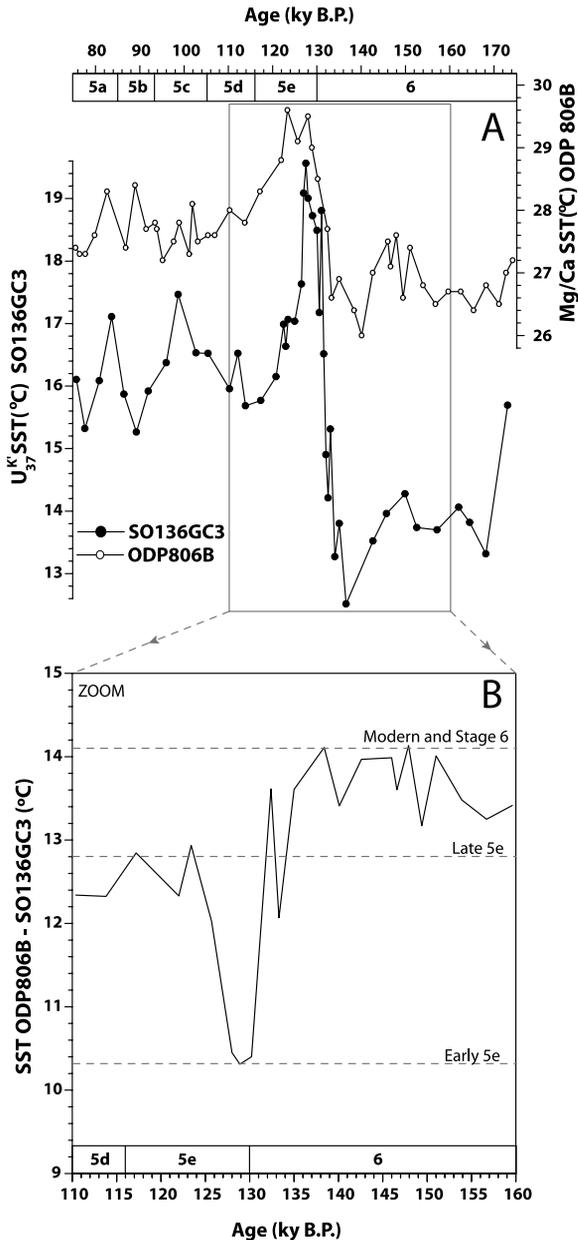


Figure 3. (a) SSTs for the New Zealand core compared to Mg/Ca temperatures for the equatorial ODP 806B core [Lea *et al.*, 2000] (b) Zoom focusing on Stage 5e with solid line depicting the SST difference between ODP 806B and SO136-GC3 cores, to assess meridional gradients. Dashed lines highlight the reconstructed SST gradients for Stage 6, Early Stage 5e and Late Stage 5e in comparison to modern times (HadISST1.1 data from Rayner *et al.* [2003]).

The 3.5 to 4.5°C values reported in this study are unusual, they are slightly higher than the recent 1.6 to 3.2°C reconstruction for central New Zealand based on beetles [Marra, 2003], and thus constitute a major change from modern ocean thermometry. To assess the extent of this feature, we compared our SST data with foraminifera (*Globigerinoides ruber*) Mg/Ca SST estimations on the well-studied equatorial sediment core ODP 806B, located at a similar longitude [Lea *et al.*, 2000] (Figure 3a). As there are still no records of alkenone paleotemperatures

corresponding to this longitude in equatorial waters, we relied on Mg/Ca SSTs for this comparison. At this location, this alternative paleothermometer provides data precisely matching the U_{37}^K -SST pattern and duration of Stage 5e encountered in two Western Pacific Warm Pool cores from other longitudes [Pelejero *et al.*, 1999]. Moreover, these specific data were calibrated against annual SSTs, being thus specially suited for comparison against our U_{37}^K -SSTs, which represent annual averages as well. In terms of chronostratigraphy, both cores have been dated using the same approach, by comparison of planktonic foraminifera $\delta^{18}O$ with the standard SPECMAP $\delta^{18}O$ stack [Martinson *et al.*, 1987].

[9] Together with the synchronous warming at both locations around 132 kyr B.P., we observe a larger glacial-interglacial SST change in the southern location (about 7.5°C) compared to the equatorial core (about 3.5°C; Figure 3a). This translates into a drastic change in the meridional SST gradient, which switches from about 14.1°C at the onset of deglaciation to only 10.3°C during early Stage 5e and back to about 13.2°C for late Stage 5e–5d (Figure 3b). Taking into account that the modern annual averaged SST gradient between these sites is about 14.1°C, this means that a significantly lower gradient characterized the austral western Pacific Ocean during the whole deglaciation and Stage 5e. Within this time frame, an early Stage 5e of lowest gradient clearly stands out, developing over about 2 kyr and with duration of 4 to 5 kyr. Since SST gradients exert an important control over atmospheric circulation [Rind, 1998], it is likely that this period of lowest gradient was accompanied by important oceanic/atmospheric reorganizations.

[10] Today, meridional thermal gradients between both locations range between 12.5 and 15.2°C, with an average of 14.1°C (HadISST1.1 data from [Rayner *et al.*, 2003]; Figure 4). Interestingly, there is a remarkable correlation between these gradients and ENSO dynamics, as can be observed when compared to the Southern Oscillation Index

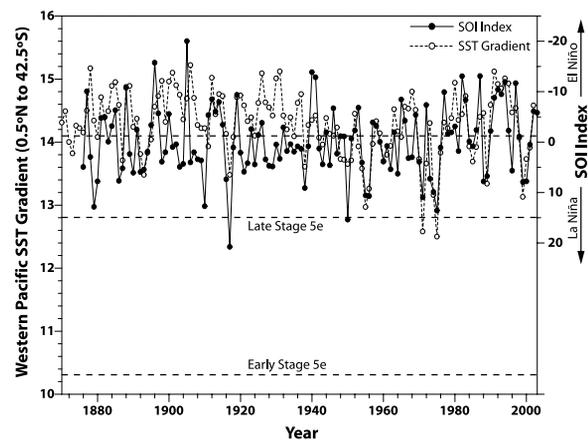


Figure 4. Annual averaged HadISST1.1 SST [Rayner *et al.*, 2003] difference between 0.5°N, 159.5°E and 42.5°S, 169.5°E since year 1870 compared to SOI (reverse axis, data from the Australian Bureau of Meteorology obtained from <http://www.bom.gov.au>). Dashed lines highlight the reconstructed SST gradients for Stage 6 (upper line, not labeled), Early Stage 5e and Late Stage 5e.

(SOI; Figure 4). The correlation coefficient between both variables is $R = 0.66$ for the period 1938–2002. Therefore, SOI explains 43% of variance in SST meridional gradients. This correlation weakens ($R = 0.48$) for earlier years, which might be a real feature or a result of less precise SST data measured prior to 1942 [e.g., Folland and Parker, 1995]. Whatever the reason, it appears that, to a large extent, positive SOI values, indicative of La Niña like conditions, often occur at times when Southwest Pacific gradients are low. The opposite is true during periods of negative SOI, when El Niño like conditions predominate. This means that during periods typical of La Niña, when trade winds are stronger and Walker Circulation is enhanced, thermal gradients in the Southwest Pacific are lowest and, consequently, Hadley Circulation is diminished, an anti co-variation described more in detail by Oort and Yienger [1996]. By inference, and assuming that this inverse relationship operated in the past, this means that conditions more typical of a La Niña phase might have prevailed during the whole Stage 5e. In particular, this situation was probably most extreme during the first half of this period, when gradients displayed the minimum values (Figure 4). It is worth mentioning that SST gradients in the Southwest Pacific since 1938 also exhibit a significant correlation ($R = 0.53$) with the Pacific Decadal Oscillation (PDO). This is an expected result since PDO and ENSO are closely related with warm- (cold-) ENSO-like conditions coinciding with years of positive (negative) PDO index. Thus, interpretations on mean oceanographic/atmospheric states similar to modern La Niña might be also understood as analogous to modern negative PDO index times.

[11] Our inferences for Stage 5e are in agreement with vegetation reconstructions based on pollen from Indonesia [van der Kaars et al., 2000] and Northern Australia [Kershaw, 1986], indicative of warm and humid conditions during the last interglacial. This situation is consistent with periods of positive SOI, which are associated with higher precipitation in these areas [Pittock, 1975]. Furthermore, studies on lake levels in the Lake Eyre basin point towards increased precipitation during the last interglacial [e.g., Nanson et al., 1992; Croke et al., 1996]. However, this enhanced precipitation might have not reached Southeast Australia, as documented from speleothems [Ayliffe et al., 1998].

[12] Corals from Indonesia [Hughen et al., 1999] and Papua New Guinea [Tudhope et al., 2001], with ages within Stage 5e, show evidence of ENSO variability typical of pre-industrial times. This suggests that our inferred oceanographic and atmospheric conditions, which are more typical of La Niña phases, might not have occurred as a permanent state. More likely, the oscillation operated with amplitude similar to pre-industrial times but the system was displaced towards more extreme La Niña events. Our alkenone data, which provides an averaged SST over a period of 100s of years, cannot differentiate between these parameters, and our results can be interpreted either as more frequent, stronger or permanent La Niña-like conditions.

4. Conclusions

[13] We present evidence of a significantly warm Early Stage 5e offshore West New Zealand matching in duration a

similar event recorded in Antarctica. Our results suggest a different latitudinal pattern and response to the penultimate deglaciation compared to the subsequent onset of glaciation: There seems to be a synchronous response to deglaciation in Antarctica, the Southern Pacific and the equator while, within Stage 5e, an early cooling occurs only in Antarctica and the Southern Pacific well before the equator. Assessment of meridional SST gradients by comparison to an equatorial record demonstrates that gradients were significantly lower than today. Taking into account the modern correlation that exists between ENSO dynamics and SST gradients in the Southwest Pacific, our results suggest that conditions more similar to La Niña occurred during Stage 5e.

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