Response to Comment on “A 12-million-year temperature history of the tropical Pacific Ocean”

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Contrary to our conclusions, Ravelo et al. argue that our TEX86-based sea surface temperature (SST) records do not conflict with the supposition of “permanent El Niño–like” conditions during the early Pliocene. We show that the way Ravelo et al. treat the existing temperature data perpetuates an inaccurate impression of cooler Pacific warm-pool SSTs and low equatorial temperature gradients in the past.

At the center of the discussion raised by Ravelo et al.’s Comment (1) is how ancient data should be compared with modern conditions and how existing SST records should be compiled and/or screened. Our conclusion that the western Pacific warm-pool temperatures cooled for the past 12 million years is based on biomarker sea surface temperature (SST) reconstructions (U13C and TEX86), which show long-term patterns of cooling into the Quaternary in both the upper and lower ranges of temperature variability (2). The SST calibration uncertainty of TEX86 is larger than that for U13C, but, where available, both proxies show similar cooling (2, 3). During the Pliocene, our TEX86 data show an elevated upper and lower temperature range compared with both the Holocene and average Quaternary. The warmest TEX86-based SST at site 806 during the Pliocene is 30.0°C (using Kim10 calibration), 1.9°C higher than the core-top estimate of 28.1°C according to Ravelo et al. (1). Further, if we account for a cool bias in TEX86 temperatures and apply the recent Bayesian TEX86 calibration (4), temperatures in the warm pool are revised to 32.8°C—4.7°C. In contrast, Ravelo et al. argue that our Pliocene TEX86 temperatures in the Pacific warm pool are similar to modern conditions by comparing multi-million-year “average” Pliocene TEX86 temperatures between 3.5 and 5.0 Ma with modern temperature observations and core-top signatures at site 806. We suggest that this type of evaluation generates comparatively cooler ancient temperatures, because the “Pliocene average” is a mean of SST over many climate cycles, whereas the “core top” is a snapshot of the warm Holocene. For example, if we apply Ravelo et al.’s approach to assess Pliocene deep-sea temperatures using the global benthic δ18O stack (5), the “Pliocene benthic δ18O average” between 3.5 and 5.0 Ma is 3.01 per mil (‰)—0.22‰ more negative than the core-top value of 3.23‰ (Fig. 1).

Even if we ignore ice-volume effects from the Pliocene to the Holocene, a 0.22‰ difference translates to negligible temperature difference (<1°C) between the deep water of the Pliocene and today. If only warm interglacials (marine isotope stage 5, 123,000 years ago, δ18O = 3.10‰ and marine isotope stage 11, 465,000 years ago, δ18O = 3.11‰) are compared against the “Pliocene benthic δ18O average,” there is even a smaller δ18O difference (≤0.1‰), suggesting that the Pliocene was only as warm as the interglacials of the Pleistocene (6, 7). Similarly, Ravelo et al.’s treatment of SST data creates a cool-bias impression that Pliocene warm-pool temperatures were the same as today.

In contrast to secular cooling indicated by TEX86 and U13C, Mg/Ca-based SSTs from two western equatorial Pacific sites appear relatively invariant or perhaps warm toward the present (Fig. 2). Biomarker and Mg/Ca trends are not equivalent but are treated as such in Ravelo et al.’s Comment. The “permanent El Niño” supposition was founded on Mg/Ca-based warm-pool temperatures, but there are several reasons why Mg/Ca SSTs are likely not accurate. Evidence supports changing seawater Mg/Ca ratios with time that must affect SST reconstructions over multimillion-year time scales (8). Foraminiferal Mg incorporation also appears susceptible to seawater salinity (9), pH (10), and carbonate ion concentration (11). Last, the impact of early diagenesis on carbonate Mg concentration cannot be ruled out, given that the porewater Sr2+ concentration profile at site 806 has [Sr2+] that are 10 times as high as modern seawater levels (12). These factors, in combination with our results (2) and others (3), erode confidence in Pliocene-age Mg/Ca-SST reconstructions of Pacific warm-pool temperatures. If warm-pool Mg/Ca temperatures and trends are compromised, so is the notion of invariant warm-pool temperatures. Also, we take the position that Mg/Ca and biomarker SSTs cannot be collectively applied (as performed in Ravelo et al.’s Comment) to make statements about Pliocene trends or temperatures just because these SST records happen to intersect during this time (Fig. 2). Further, if warm-pool Mg/Ca SSTs are compromised, then TEX86 data currently remain as the best available temperature records because U13C data reach maximum values by the Pliocene and cannot reveal whether warm pool temperatures exceeded ~28.5°C.

Ravelo et al. further state that zonal gradients resulting from our data do not conflict with the

Fig. 1. Comparisons between the “Pliocene average (averaging between 3.5 and 5.0 Ma)” and the “core-top” benthic δ18O values in the LR04 global stack (5). The difference between the “Pliocene average” and “core-top” is only 0.22‰. In contrast, the difference between δ18O at 5 Ma and 0 Ma in the long-term trend (500-point running average, red curve) of the LR04 record is ~1.2‰.
supposition of permanent El Niño–like conditions, which was characterized by many of the same authors as recently as 2013 as “a climate with almost no zonal sea surface temperature (SST) gradients (~1°C or less)” (J3). In their Comment, Ravelo et al. argue that TEX86 SSTs in the cold tongue are cold biased, whereas TEX86 in the warm pool is accurate. Consequently, they ignore TEX86 data in the cold tongue and restrict their analysis to one TEX86 record from site 806 and one U37C% record from the cold-tongue region (Site 850) and derive a small zonal temperature gradient through the Pliocene. Given that the modern Pacific warm pool is larger than the continental United States and that the cold tongue extends a few thousand kilometers, we take the position that the application of multiple sites yields a better perspective of regional paleotemperatures (2). We also recognize that core-top TEX86-SSTs from both open eastern and western equatorial Pacific regions (using Kim10 calibration) appear cooler than SSTs. The down-core TEX86-SSTs are also cooler than U37C%–SST records when U37C% indices are not at their maximum value (e.g., sites 806 and 850) (2). Consequently, TEX86 appears to be underestimating SST in both the east and the west, not just in the eastern equatorial Pacific. Because a cool bias persists in both the east and the west, evaluation of zonal temperature gradients is still valid between TEX86 records, as we considered in our paper (2). However, our interpretations also consider all the available U37C% records that are below their maximum values. That analysis showed that 75% of the modern or 79% of the mean Quaternary zonal temperature gradient was preserved during the Pliocene, whereas 70% of the mean Quaternary zonal temperature gradient was represented during the Late Miocene. Although this indicates that the zonal gradient was slightly reduced, it is far from the characteristics of a “permanent El Niño–like” state that most associate with the supposition.

REFERENCES AND NOTES

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Fig. 2. Trends of TEX86- and Mg/Ca-SSTs from sites 806 (2, 14) and 1143 (2, 3) in the Pacific warm pool. TEX86 data are converted to SSTs using the recently introduced Bayesian calibration (4). Refer to our original publication (2) for the results using Kim10 calibration (15). Trends are calculated by applying 50-point fast Fourier filters.
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