

TECHNICAL COMMENT

OCEANS

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

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Zhang *et al.* (Reports, 4 April 2014, p. 84) interpret TEX<sub>86</sub> and U<sub>37</sub><sup>K'</sup> paleotemperature data as providing a fundamentally new view of tropical Pacific climate during the warm Pliocene period. We argue that, within error, their Pliocene data actually support previously published data indicating average western warm-pool temperature similar to today and a reduced zonal gradient, referred to as a permanent El Niño-like state.

Even small changes (≤1°C) in absolute tropical sea surface temperatures (SSTs) have implications for climate conditions both regionally (1) and globally, including climate sensitivity to greenhouse gases (2). Thus, it is crucial to obtain accurate tropical SST

estimates during the warm early Pliocene [5.0 to 3.5 million years ago (Ma)], when atmospheric CO<sub>2</sub> concentrations and extratropical temperatures were, on average, higher than pre-industrial values. SST reconstructions, based on planktonic foraminifera Mg/Ca and biomarker proxy U<sub>37</sub><sup>K'</sup>, indicate two key features of the tropical Pacific (3): average Western Equatorial Pacific (WEP) warm-pool SSTs (4, 5) similar to today and a reduced (but not absent) zonal equatorial SST gradient (4–6). We compile tropical Pacific SST data (4, 6, 7, 8–12) (Table 1) and show, contrary to claims made by Zhang *et al.* (7), that their low-resolution (1 sample per >100,000 years) records,

only appropriate for a cursory characterization of average Pliocene conditions, are largely consistent with previously published data.

The only published data representing the central WEP warm pool is from site 806 (Table 1 and Fig. 1) and indicate average early Pliocene SSTs cooler than today (13): −0.03°C for Mg/Ca, −1.10°C for TEX<sub>86</sub>, and −0.66°C for U<sub>37</sub><sup>K'</sup>. Because absolute SST estimates are calibration dependent (14–17), a better approach compares proxy measurements and shows that average Pliocene values (0.70 for TEX<sub>86</sub>, 3.45 mmol/mol for Mg/Ca, and 0.99 for U<sub>37</sub><sup>K'</sup>) are similar to core-top values (0.70 for TEX<sub>86</sub>, 3.43 mmol/mol for Mg/Ca, and 0.98 for U<sub>37</sub><sup>K'</sup>). Within calibration errors of at least ±1°C (14–17), all proxies concur that the differences between Pliocene and core-top SSTs are negligible (+0.08°C for Mg/Ca, +0.04°C for TEX<sub>86</sub>, and +0.26°C for U<sub>37</sub><sup>K'</sup>). U<sub>37</sub><sup>K'</sup> is saturated at 29°C (17), but Mg/Ca and TEX<sub>86</sub> should detect warmer SSTs if they existed; although potential biases (e.g., changing seawater Mg/Ca and subsurface glycerol dialkyl glycerol tetraether (GDGT) lipid production) need further study, at this point neither Mg/Ca nor TEX<sub>86</sub> data provide solid evidence of average warm-pool SSTs substantially warmer than today. Average Pliocene TEX<sub>86</sub> SSTs at site 1143 (9°N) of 29.7°C can be explained by an expanded, but not warmer, central warm pool (3); expansion of the tropics during global warming is documented by 21st-century observations (18) and future (19) and Pliocene model simulations (20).

Focusing on long-term smoothed trends, Zhang *et al.* (7) argue that the Pliocene warm pool was substantially warmer relative to today

**Table 1. Summary of tropical Pacific SST data.** All available data between 3.5 and 5.0 Ma were used to calculate the average Pliocene value, and all available data between 5.0 and 12.0 Ma were used to calculate the average late Miocene value. Modern data are from Simple Ocean Data Assimilation average and standard deviation, calculated from the monthly SST data from 1958 to 2007 (13). Core-top values come from the site location or from nearby sites when available. The calibrations used to calculate SSTs were Dekens *et al.* (16) using the [CO<sub>3</sub><sup>2−</sup>] dissolution correction for the Mg/Ca data, Müller *et al.* (17) for U<sub>37</sub><sup>K'</sup>, and Kim *et al.* (15) for TEX<sub>86</sub>. Dashed lines indicate a lack of published data.

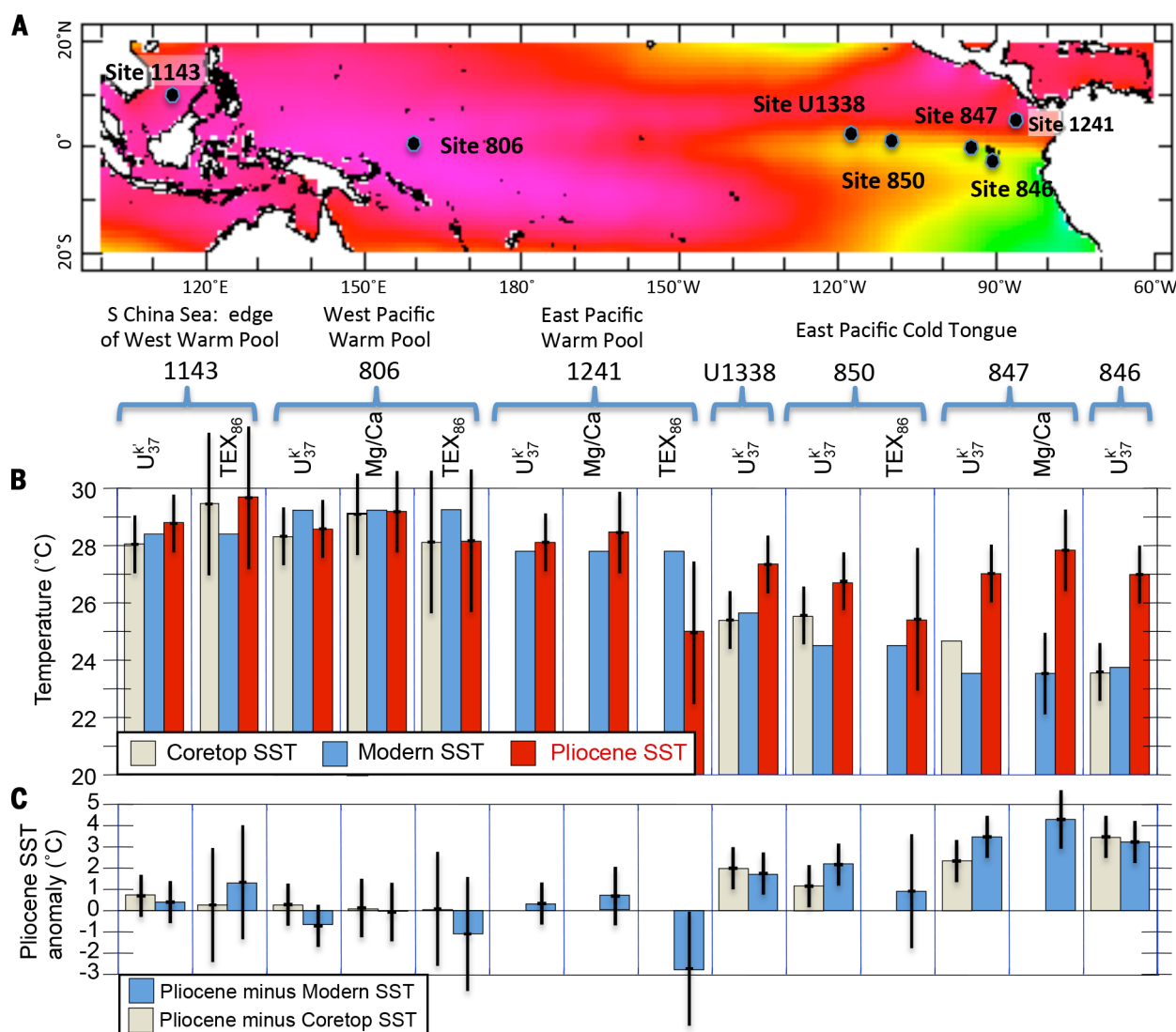
Site	Lat	Lon	Water Depth (m)	SODA avg SST (°C)	SODA Std Dev (°C)	Proxy type	Number of coretops	Coretop avg value <sup>i</sup>	Coretop SST (°C)	Pliocene avg value <sup>i</sup> (3.5–5.0 Ma)	Pliocene SST (°C)	Pliocene anomaly (rel. to SODA) (°C)	Pliocene anomaly (rel. to coretop) (°C)	Miocene avg value <sup>i</sup> (5.0–12.0 Ma)	Miocene SST (°C)	Miocene anomaly (°C)	coretop data reference	paleo-SST data reference
South China Sea																		
1143	9.36	113.29	2772	28.40	1.00	U <sub>37</sub> <sup>K'</sup>	1	0.97	28.06	0.99	28.80	0.40	0.74	---	---	---	12	12
1143	9.36	113.29	2772	28.40	1.00	TEX <sub>86</sub>	1 <sup>ii</sup>	0.73	29.41	0.74	29.70	1.30	0.29	0.76	30.40	2.00	27	7
WEP																		
806	0.32	159.36	2520	29.24	0.55	Mg/Ca	1	3.43	29.12	3.45	29.20	−0.03	0.08	---	---	---	16	4
806	0.32	159.36	2520	29.24	0.55	TEX <sub>86</sub>	11 <sup>iii</sup>	0.70	28.10	0.70	28.14	−1.10	0.04	0.75	29.87	1.77	15	7
806	0.32	159.36	2520	29.24	0.55	U <sub>37</sub> <sup>K'</sup>	2 <sup>iv</sup>	0.98	28.32	0.99	28.58	−0.66	0.26	---	---	---	28	7
EEP																		
1241	5.84	−86.44	2027	27.80	1.01	Mg/Ca	none	---	---	3.26	28.48	0.68	---	---	---	---	---	9
1241	5.84	−86.44	2027	27.80	1.01	U <sub>37</sub> <sup>K'</sup>	none	---	---	0.97	28.11	0.31	---	---	27.93	0.13	---	11
1241	5.84	−86.44	2027	27.80	1.01	TEX <sub>86</sub>	none	---	---	0.63	25.01	−2.79	---	---	25.39	−2.41	---	11
1338	2.50	−118.00	4210	25.65	1.40	U <sub>37</sub> <sup>K'</sup>	2 <sup>v</sup>	0.88	25.39	0.95	27.36	1.71	1.98	0.96	27.72	2.07	28	10
850	1.30	−110.50	3786	24.51	1.74	U <sub>37</sub> <sup>K'</sup>	2 <sup>vi</sup>	0.89	25.53	0.93	26.70	2.20	1.17	---	---	---	28	7
850	1.30	−110.50	3786	24.51	1.74	TEX <sub>86</sub>	none	---	---	0.64	25.40	0.90	---	0.67	26.85	2.34	---	7
847	0.19	−95.32	3334	23.54	1.99	Mg/Ca	none	---	---	3.11	27.84	4.29	---	---	---	---	---	4
847	0.19	−95.32	3334	23.54	1.99	U <sub>37</sub> <sup>K'</sup>	1 <sup>vii</sup>	0.86	24.67	0.94	27.02	3.47	2.35	---	---	---	29	8
846	−3.09	−90.82	3296	23.75	2.36	U <sub>37</sub> <sup>K'</sup>	1	0.82	23.55	0.93	26.99	3.23	3.44	---	---	---	30	6

<sup>i</sup> U<sub>37</sub><sup>K'</sup> and TEX<sub>86</sub> values are unitless, and Mg/Ca values are in mmol/mol.  
<sup>ii</sup> coretop from nearby station, 17960, in South China Sea was used.  
<sup>iii</sup> coretops from nearby sites on the Ontong Java Plateau were used.  
<sup>iv</sup> coretops from ERDCBX120 and the 175E transect were used.  
<sup>v</sup> coretops from PLDS66 and PLDS90 were used.  
<sup>vi</sup> coretop from PLDS68 and PLDS72 were used.  
<sup>vii</sup> coretop from TR163-22 was used.

but in fact show that it was warmer relative to the Quaternary (which includes Pleistocene glacial intervals). Their approach contrasts with a large body of published work, including modeling (20, 21) and observational (5, 8) studies, that compare Pliocene conditions to a modern baseline. This difference in approach is a source of misinterpretation of the  $\text{TEX}_{86}$  data (7, 22). If one considers  $\text{TEX}_{86}$  variability, instead of the mean, their approach still misses the profound importance of the data. From 3.5 to 5.0 Ma,  $\text{TEX}_{86}$  variability is within the  $\pm 2.5^\circ\text{C}$  calibration error with minima and maxima straddling the core-top value; this is in stark contrast to  $\text{CO}_2$  and climate records from outside the warm pool in which even discrete glacial minima are generally higher than core-top and Pleistocene interglacial values (3).

Unlike the WEP warm pool, the East Equatorial Pacific (EEP) cold tongue was substantially warmer than today during the Pliocene (Fig. 1). This mean state with a reduced zonal SST gradient is referred to as “permanent El Niño-like conditions” and is supported by many data types (5, 23). This term does not imply a lack of variability nor that mean state changes are due to the dynamics that generate interannual El Niño events (3). Rather, it highlights that, like an El Niño event, small changes in the zonal gradient induce major changes in atmospheric circulation with far-field effects. The term “El Padre” is also used to differentiate this Pliocene state from the dynamical El Niño–Southern Oscillation pattern. The Zhang *et al.* (7) data support previous work showing a reduced zonal gradient during the Pliocene.

At EEP site 850,  $\text{TEX}_{86}$  SSTs are cooler than  $U_{37}^{K'}$  SSTs (7); a similar cold bias occurs at site 1241 (Fig. 2A), due to subsurface production of crenarchaeota GDGTs (11). A shallow cool thermocline can explain this cold bias:  $\text{TEX}_{86}$  apparently records depth-integrated temperature rather than SST. The cold bias likely changed as the thermocline shoaled (24) or as ecosystem structure changed (11) since 5 Ma. At WEP site 806 (Fig. 2B), higher Pleistocene  $U_{37}^{K'}$  and Mg/Ca compared to  $\text{TEX}_{86}$  SSTs may be due to problems with Mg/Ca (7) and/or a cold bias in  $\text{TEX}_{86}$  that was diminished in the Pliocene when the tropical thermocline was deeper (4, 23–25). Even if regional calibrations can statistically circumvent the  $\text{TEX}_{86}$  cold bias in the modern ocean (14), they cannot be expected to provide accurate



**Fig. 1. Spatial pattern of average Pliocene temperature anomalies.** (A) Map showing location of sites with published SST data used in this comment, overlain on a map of modern SSTs. (B) Average Pliocene (3.5 to 5.0 Ma) SSTs plotted for each site and each proxy along with the modern annual average SST (13) and with SST estimates made on core tops. (C) SST anomaly calculated as the average Pliocene value minus modern annual average SST and minus the core-top estimate of SST. In (B) and (C), error bars reflect calibration errors:  $\pm 2.5^\circ\text{C}$  for  $\text{TEX}_{86}$  SST (15),  $\pm 1.4^\circ\text{C}$  for Mg/Ca SST (16), and  $\pm 1.0^\circ\text{C}$  for  $U_{37}^{K'}$  (17). See Table 1 for a summary of the calculations.

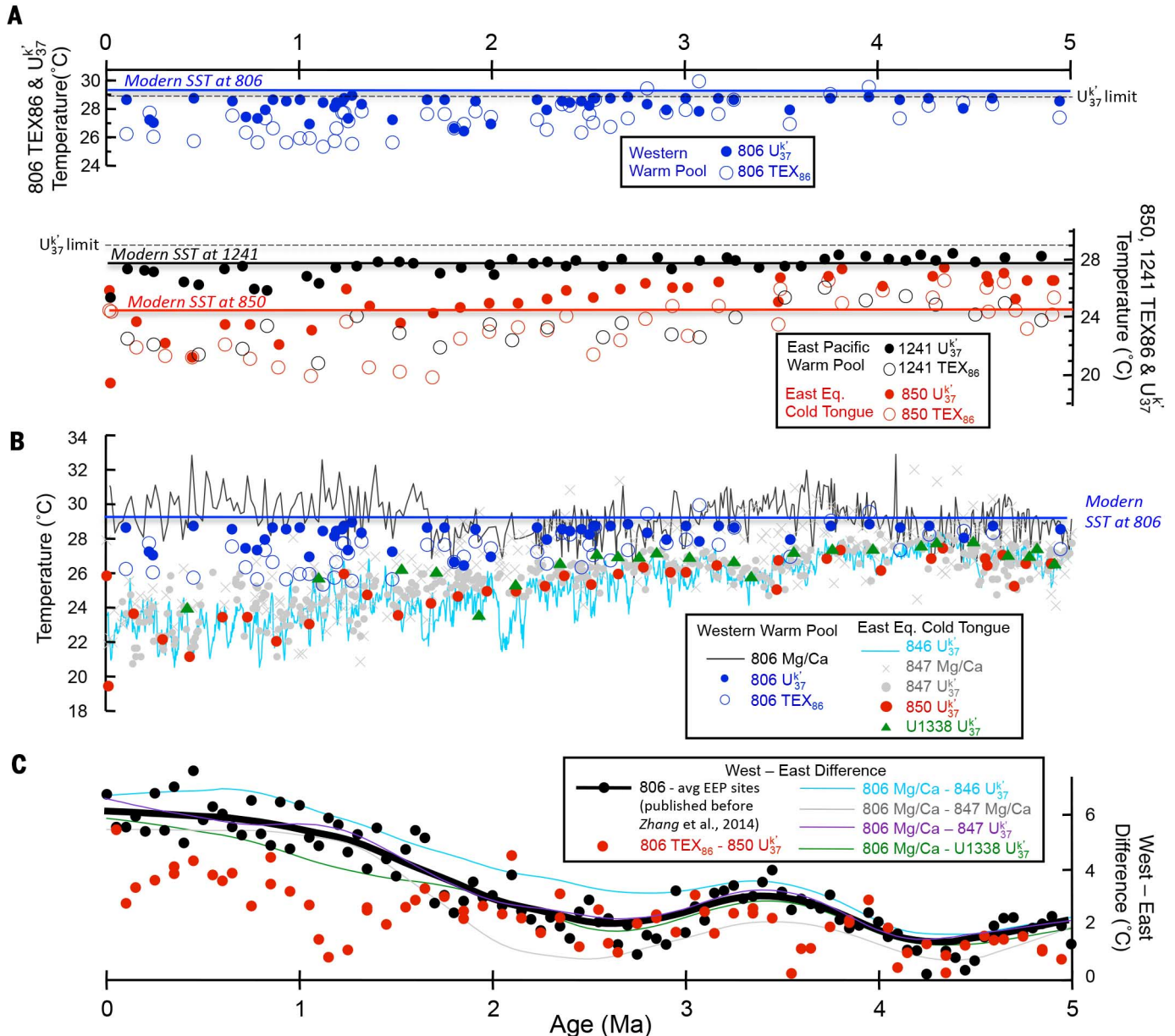
SST estimates as subsurface temperatures changed through the Pliocene (4, 23–25). Zhang *et al.*'s  $\text{TEX}_{86}$  data reflect the WEP-EEP depth-integrated temperature difference, but their ability to quantify the surface temperature gradient is tenuous.

To quantify changes in EEP SSTs, we exclude  $\text{TEX}_{86}$  data (at sites 850 and 1241) because of the clearly documented severe cold bias (11) (Fig. 2A) compared with other available EEP records

(e.g.,  $U_{37}^K$ ). All EEP records show Pliocene SSTs warmer than today (Figs. 1B and 2B). The Zhang *et al.* (7) equatorial data indicate a mean Pliocene WEP-EEP difference of 1.5°C, in agreement with previously published data (Fig. 2C). Given the profound importance of tropical SST, and the fact that biases of all proxy types require additional study, a conservative approach that identifies convergence among data records, and does

not overinterpret the importance of divergent records, is warranted.

The new data (7) confirm previous Pliocene data but provide evidence of Miocene warm-pool temperatures warmer than today (Table 1). Lea (22) states that “the  $\text{TEX}_{86}$  data support previous evidence that the warm pool responds strongly to radiative forcing,” but in fact, the warm pool was warmer in the late Miocene than in the



**Fig. 2. Tropical Pacific SST records extending from 5 Ma to present.** (A) SST records from all sites that have both  $U_{37}^K$  and  $\text{TEX}_{86}$  data: WEP site 806 (7), EEP cold tongue site 850 (7), and Eastern warm-pool site 1241 (11). Solid lines are the modern SST at each site, and dashed lines are the SST limit for the  $U_{37}^K$  proxy. The cold bias of  $\text{TEX}_{86}$  is apparent at all sites but is less severe at site 806 where the thermocline is deepest. (B) All records from the WEP and EEP cold tongue excluding site 850  $\text{TEX}_{86}$  data because of the severe cold bias due to subsurface production of GDGTs. See Table 1 for references. (C) WEP – EEP SST difference calculated by interpolating and resampling all records to

50K resolution and subtracting them from each other. The smoothed curves are generated using a locally weighted least squares (0.25 smoothing parameter) method: (black dots and thick black curve) available  $\text{Mg/Ca}$  and  $U_{37}^K$  data published before Zhang *et al.* (7) [WEP site 806 (4) minus the average of EEP sites 846 (6), 847 (4, 8), and U1338 (10)]; (red dots) new Zhang *et al.* WEP site 806  $\text{TEX}_{86}$  minus EEP site 850  $U_{37}^K$ ; (thin colored lines) different combinations of previously published data from WEP and EEP sites. WEP site 806  $U_{37}^K$  data are saturated and therefore are not used to calculate east-west SST difference.

Pliocene, whereas partial pressure of CO<sub>2</sub> was not (26). The new TEX<sub>86</sub> data highlight the importance of future research aimed at solving this paleoclimate enigma.

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## ACKNOWLEDGMENTS

We thank all authors who made their published data available to the public. We thank a number of people for helpful discussions and for challenging us to think about the data in critical ways. These people include P. Dekens, A. Paytan, P. Polissar, R. Pancost, J. Tierney, J. Zachos, and two anonymous reviewers. A.C.R. thanks NSF for funding (OCE-1204254). Thanks to go the Integrated Ocean Drilling Program for their role in obtaining deep sea sediments for Pliocene research.

18 June 2014; accepted 20 October 2014  
10.1126/science.1257618