Pliocene warm pool temperatures and zonal SST gradient: can we reach an agreement?

Chris Brierley[1], Natalie Burls[2], Christina Ravelo[3] and Alexey Fedorov[2]

[1]Dept. of Geography, University College London, UK, c.brierley@ucl.ac.uk
[2]Dept. of Geology and Geophysics, Yale University, USA
[3]Dept. of Ocean Sciences, University of California, Santa Cruz, USA

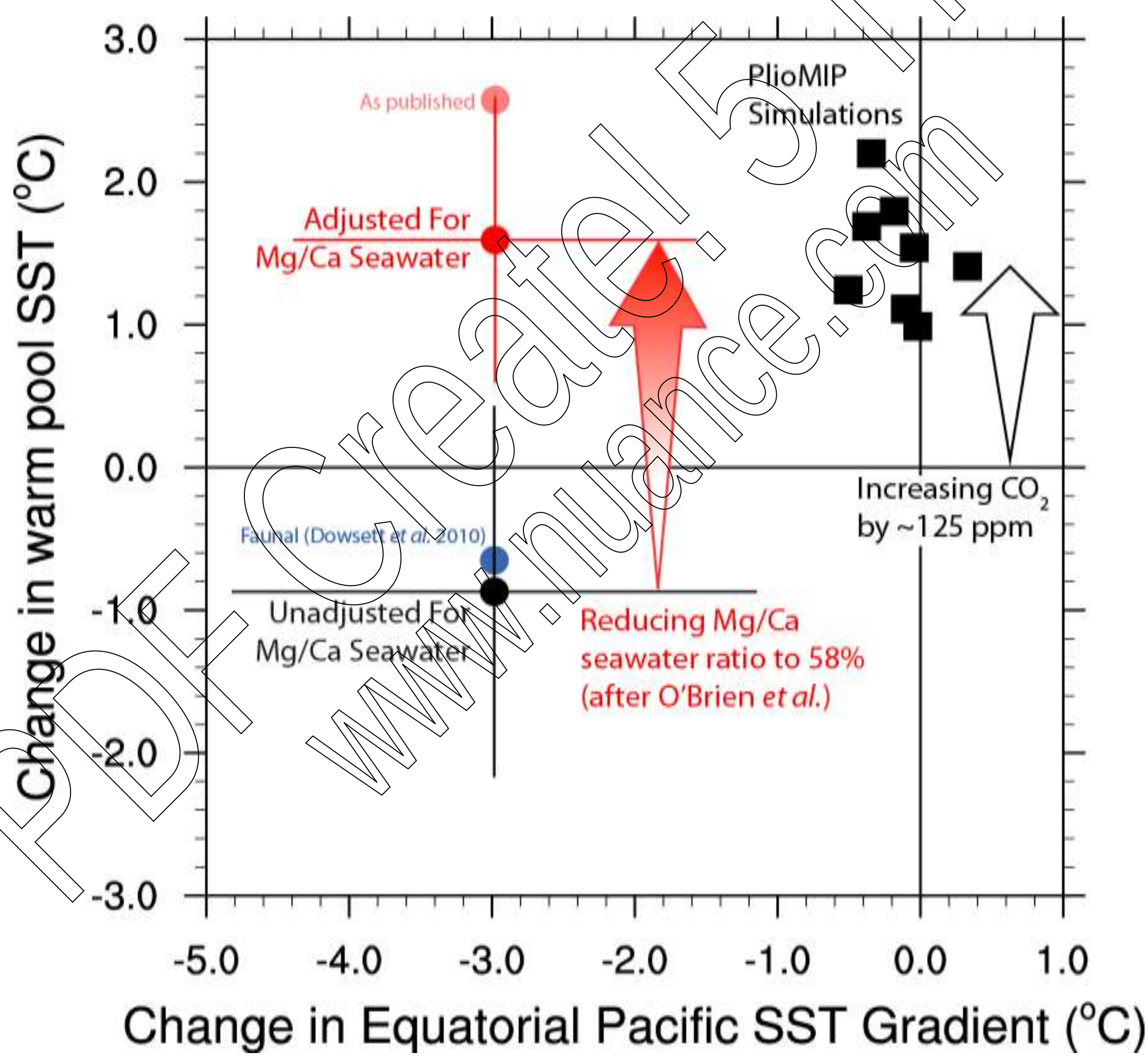
The Pliocene epoch (5.3-2.6 million years ago) generates continued debate as an example of a warm climate with external forcing similar to the present-day[1]. A study by O'Brien et al[2], presenting new multi-proxy sea surface temperature (SST) reconstructions from the South China Sea, adds to the debate. Based on their records, and a hypothesized seawater chemistry adjustment to Mg/Ca temperature reconstructions, they suggest that the western Pacific warm pool was "2°C warmer than today" in the Pliocene, contradicting previous evidence of long-term stability in warm pool SSTs[1,3]. They submit that their estimate resolves discrepancies between temperature reconstructions and climate model simulations. Here we raise several points contrary to their conclusions surrounding warm pool temperature and the ability of climate models to simulate tropical conditions during the Pliocene. All the available mid-Pliocene SST data from the heart of the warm pool agree within the data uncertainty (Fig. 1) and suggest no significant warming. The unadjusted Mg/Ca temperature estimate[3] at site ODP806 for the mid-Pliocene[4] (-0.9°C, Figure 1) is close to estimates from faunal assemblage data[4] (-0.4°C) and TEX86 approaches[5] (-0.3°C), while alkenone-based Uk37 values are too close to saturation to provide a reliable SST estimate. In the heart of the cold tongue (site ODP847), both Mg/Ca and alkenone palaeothermometry agree[6]. The global seawater chemistry correction applied by O'Brien et al[2] breaks this close correspondence at these respective locations. Consequently, the large discrepancy between the Mg/Ca estimate and other SST estimates from the South China Sea (site ODP1143) may instead be a local feature. Furthermore, this marginal sea is not an ideal location to test the thermostat idea, nor to characterize the open ocean warm pool. A temperature increase of 2-3°C in the South China Sea could result from the warm pool's meridional expansion during the Pliocene[1], rather than a broad uniform warming.

When dealing with signals as small as expected in the warm pool, defining our temporal reference frame also requires careful attention. This region has seen over 0.5°C of warming since 1950 (defined as 0 years "before present") and more since preindustrial times[7]. The Pliocene Model Intercomparison Project (PlioMIP) simulations[8] are defined as a mid-Pliocene "interglacial" and are stated with respect to preindustrial simulations. An alternate approach for coarse-resolution data calculates differences from the most recent point of a long-term (~400kyr) mean[1-3,6].When comparing to preindustrial-referenced simulations this approach can lead to a ~1°C offset (Fig. 1). Also, the PlioMIP simulations are driven by CO_2 levels at the upper end of Pliocene estimates[9,10], so one might anticipate them to model changes higher than the mean mid-Pliocene temperature reconstructions.

From a dynamical perspective, the most interesting feature of Pliocene warm climates is the weakening of zonal (Fig. 1) and meridional temperature gradients in the Tropics[11]. The inability of climate models to simulate the extent and patterns of Pliocene warmth[8,12], specifically within the sub-tropics and equatorial upwelling regions, is a problem unresolved by a global seawater chemistry correction (Fig. 1), nor by a higher Earth System Sensitivity[10] to CO_2 forcing as suggested in an accompanying News & Views[13]. At its heart lies identifying mechanisms that can support weak temperature gradients[1,11], which may be rooted in models' relatively weak meridional SST gradient reduction due to unresolved climate feedbacks[14-16]. The Pliocene puzzle becomes even more concrete when looking further back into the Early Pliocene (4-5Ma) as SST proxies from around the globe indicate a further weakening of SST gradients[1], whereas constraining warm pool SST changes remains difficult since they fall within the uncertainty of paleo proxies.

Figure Caption

Figure: Reconstructed and modelled sea surface temperatures in the mid-Pliocene. The horizontal axis shows the Equatorial Pacific gradient and for the reconstructions is calculated as ODP806 minus ODP847, using the average of all available temperature estimates between 3.264-3.025 Ma[4] – the reference interval for the model simulations[8]. The vertical axis shows the change in the warm pool temperature from preindustrial values (ODP806 or the maximum simulated value on the Equator). The red and black points show Mg/Ca-based reconstructions with and without the sea water chemistry adjustment of O'Brien et al[2]. The pink dot indicates the difference from an average of the past 400 kyrs, as published in O'Brien et al[2]. The blue circle shows an estimate based on faunal assemblages[4]. The change in the maximum east-west difference in annual mean SST is extracted from the PlioMIP model simulations[8], because model biases can mean that the location of ODP806 is not in the simulated warm pool. The arrows show the direction of both a reduced seawater Mg/Ca ratio adjustment[2] and the modelled response of increasing carbon dioxide[8]. [The COSMOS model is excluded, because its cold tongue bias is so extensive that the warm pool does not exist on along the Equator in the Pacific[8].]



References

1. Fedorov, A. V. *et al.* Patterns and mechanisms of early Pliocene warmth. *Nature* **496,** 43–49 (2013).
2. O'Brien, C. L. *et al.* High sea surface temperatures in tropical warm pools during the Pliocene. *Nature Geosci.* **7,** 606–611 (2014).
3. Wara, M. W., Ravelo, A. C., & Delaney, M. L. (2005). Permanent El Niño-like conditions during the Pliocene warm period. *Science*, *309*(5735), 758–761.
4. Dowsett, H. J., Robinson, M. M., Stoll, D. K. & Foley, K. M. Mid-Piacenzian mean annual sea surface temperature analysis for data-model comparisons. *Stratigraphy* **7,** 189–198 (2010).
5. Zhang, Y. G., Pagani, M. & Liu, Z. A 12-Million-Year Temperature History of the Tropical Pacific Ocean. *Science* **344,** 84–87 (2014).
6. Dekens, P. S., Ravelo, A. C., McCarthy, M. D. & Edwards, C. A. A 5 million year comparison of Mg/Ca and alkenone paleothermometers. *Geochem. Geophys. Geosyst.* **9,** (2008).
7. Smith, T. M., Reynolds, R. W., Peterson, T. C. & Lawrimore, J. Improvements to NOAA's Historical Merged Land–Ocean Surface Temperature Analysis (1880–2006). *J. Climate* **21,** 2283–2296 (2008).
8. Haywood, A. M. *et al.* Large-scale features of Pliocene climate: results from the Pliocene Model Intercomparison Project. *Clim. Past* **9,** 191–209 (2013).
9. Bartoli, G., Hoenisch, B. & Zeebe, R. E. Atmospheric CO_2 decline during the Pliocene intensification of Northern Hemisphere glaciations. *Paleoceanogr.* **26,** n/a–n/a (2011).
10. Pagani, M., Liu, Z., LaRiviere, J. & Ravelo, A. C. High Earth-system climate sensitivity determined from Pliocene carbon dioxide concentrations. *Nature Geosci.* **3,** 27–30 (2009).
11. Brierley, C. *et al.* Greatly Expanded Tropical Warm Pool and Weakened Hadley Circulation in the Early Pliocene. *Science* **323,** 1714–1718 (2009).
12. Dowsett, H. J. *et al.* Sea Surface Temperature of the mid-Piacenzian Ocean: A Data-Model Comparison. *Scientific Reports* **3,** (2013).
13. Pagani, M. Palaeoclimate: Broken tropical thermostats. *Nature Geosci.* **7,** 555–556 (2014).
14. Fedorov, A. V., Brierley, C. & Emanuel, K. A. Tropical cyclones and permanent El Nino in the early Pliocene epoch. *Nature* **463,** 1066–1070 (2010).
15. Burls, N. J. & Fedorov, A. V. What Controls the Mean East–West Sea Surface Temperature Gradient in the Equatorial Pacific: The Role of Cloud Albedo. *J. Climate* **27,** 2757–2778 (2014).
16. Unger, N. & Yue, X. Strong chemistry-climate feedbacks in the Pliocene. *Geophys. Res. Lett.* **41,** 527–533 (2014).