

NOTES AND CORRESPONDENCE

A Perpetually Running ENSO in the Pliocene?

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ABSTRACT

Difficulties remain with theoretical explanations of the apparent reduced zonal sea surface temperature gradient in the tropical Pacific of the Pliocene. One favored hypothesis is that it was a “permanent El Niño” state, with the warm phase of ENSO remaining fixed over millions of years. Here, an alternative is suggested—that there was a “perpetually running ENSO” with a shorter return time than is observed today, and that the apparently reduced zonal gradient is an alias–rectification of a high-frequency signal governed by the growth patterns of the foraminifera used to provide proxy temperatures. The hypothesis is probably testable in the modern ocean with comparatively modest measurements of foraminifera behavior in time.

1. Introduction

During the Pliocene (roughly 2–5 million years before present), evidence exists of a much-reduced, even vanishing, Pacific Ocean surface zonal thermal temperature gradient with a much-warmer eastern region (e.g., Wara et al. 2005, hereafter W05). Although inferences from paleoclimate proxies are rarely straightforward (e.g., Medina-Elizalde et al. 2008, for this period) the Pliocene inference is widely accepted as being robust. Fedorov et al. (2006) have suggested that the reduced gradient (as we will refer to it) is the result of a “permanent El Niño condition.” The terminology is not particularly attractive because modern El Niño is a phenomenon of subdecadal time scales, principally involving the tropical ocean. Any million-year time-scale phenomenon must necessarily encompass the entire global climate system and have physics entirely different from that of modern El Niño. Although the tropics are often the focus of the discussion of climate change, owing to the sensitivity of the system there to sea surface temperatures, the volatility of that region makes it difficult to perceive how it could provide the “memory” necessary to hold the ocean and the wider climate in

a fixed equilibrium for periods longer than a few years (cf. Ashkenazy and Tziperman 2006).

Because Pliocene CO₂ and other background physical variables are not so different from the modern world, the observations present a challenge to theory. A number of different explanations have been put forward to explain the data, which include the inference of a globally increased temperature, by about 5°. Fedorov et al. (2006) discuss explanations based upon control of tropical thermocline depth by shifts in high-latitude processes. Others have connected the weakened gradient to an open Isthmus of Panama. Recently, E. Tziperman and B. Farrell (2009, hereafter TZI) have proposed that the earth evolved into a superrotation state, that is, one with dominant westerlies at low latitudes that contrast to the existing easterlies. While superrotation does exist on other planets and satellites of the solar system, it is difficult to generate atmospheric states with dominant westerlies *at the surface*. Of course, as they make clear, even partially weakened easterlies would likely produce a reduced zonal temperature gradient. See W05, Fedorov et al. (2006), and TZI, or the recent special issue of the *Philosophical Transactions of the Royal Society* (2009, Vol. 367, No. 1886) for many more references and a wider discussion of related phenomena and proposed explanations.

Here a radically different hypothesis is proposed—that a true permanent El Niño existed, but in the sense that it occurred much more frequently, perhaps every

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year or two, and that the apparent quasi-steady state is simply an amplitude rectification of a very much higher “carrier” frequency phenomenon (Huybers and Wunsch 2003).¹ In practice, there does not necessarily need to be one dominant explanation of the low-zonal temperature gradient; that is, several, or all, may be acting in concert, which is a question we will return to later. Adding yet another “explanation” to the existing ones might be regarded as too much of a good thing. The main excuse for doing so is that from one point of view, Ockham’s razor dictates choosing the solution requiring the least deviation from the modern world. Furthermore, the proposed explanation could be falsified with comparatively modest modern observations, which may not be true of any of the others. In any event, the maintenance of alternative hypotheses was urged long ago by Chamberlin (1890), and that advice seems particularly appropriate in underobserved systems. [Possible frequency aliasing of the record of the Pliocene has been mentioned before (e.g., by W05), but in the context of undersampled orbital variations.]

Because the terminology “permanent El Niño” is potentially very misleading,² and in the interests of jargon reduction, interpretation of the Pliocene data will be referred to as that of a “reduced zonal temperature gradient” (“RZTG”), with the understanding that it refers only to the tropical surface Pacific Ocean.

2. Some background

An explanation of the proxy temperature curve as a rectified or aliased signal involves the following several suppositions:³

- 1) Modern ENSO cycles occur, empirically, on time scales of about 3–9 yr (see e.g., McPhaden et al. 1998; Wallace et al. 1998). A number of models (e.g.,

Tziperman et al. 1997) have tended to produce much shorter cycles and on a much-too-regular basis. [In the Timmermann et al. (1999) model, the return interval is 2 yr.] One infers that these models are flawed, with some combination of the following: missing physics, improperly set parameters, coding errors, or any one of the many ways in which models can differ from reality. One might interpret them, however, as showing that comparatively minor differences from the modern world could produce much more regular, much more frequent, perhaps increased-amplitude ENSO cycles. For the present purpose, we will simply assume, given the rough similarity of the Pliocene to the modern world, that regular, frequent, Los Niños are a possibility.

- 2) The proxies used by W05 are based on measurements of the foraminifera *Globigerinoides sacculifer* and *Globorotalia tumida*. As described by W05, the former are surface dwelling and the latter exist at the base of the euphotic zone at about 60–100 m. Their eastern core came from near 95°W in the equatorial Pacific. They employ the difference $\Delta\delta^{18}\text{O}$ of the oxygen isotopic ratio anomalies $\delta^{18}\text{O}$ of the two foraminiferal types, and they interpret that difference as representing the temperature difference between the sea surface and 100 m. To proceed, that interpretation is accepted here without reservation.

In addition to the assumption of more frequent, perhaps even annual, ENSO cycles, the second major assumption is that *G. sacculifer* respond to the excess warmth or other change produced by El Niño by becoming more productive, and that *G. tumida* had a more muted response so that the isotopic difference does indeed reflect the upper-ocean warming.

3. Seasonality in foraminifera production

To gain a bit of insight into possible ENSO response, consider as an analog the seasonality of the foraminifera population to the extent it is known (and we are hypothesizing that tropical seasonality during the Pliocene might indeed be that of the full ENSO cycle). There is not a large literature on this subject, and Hemleben et al. (1989) summarize much of what is known, primarily from sediment traps. In the Panama Basin, the nearest to the open tropical Pacific where a study appears to have been conducted, Bé et al. (1985) found that the collective warm water species (including *G. sacculifer*) increased their percentage of the total from 29% to 68% from July–August to November–December. In a study near the Kuroshio, Oda and Yamasaki (2005) found that *G. sacculifer* appeared in a sediment trap flux ranging from over 100 shells $\text{m}^{-2} \text{day}^{-1}$ in August to essentially

¹ Ashkenazy and Tziperman (2006) invoke a similar hypothesis in a different context.

² The terminology “El Padre” has been proposed as a substitute for “permanent El Niño”; but at least in folklore, the identity of the father of the Christ child is ambiguous!

³ Rectification and aliasing are related and can produce similar results. The latter conventionally arises when a signal with energy at frequencies above s_0 is sampled at a time interval $\Delta t > 1/2s_0$, giving rise to apparent much lower frequencies. Rectification occurs when a signal is sampled intermittently over a finite interval in such a way that the result is sensitive to the local envelope. If the amplitude varies with time, one generates a rectified signal sensitive to the amplitude variation. (A sinusoid measured over a fraction of the period is a simple example.) Aliasing can produce similar results if the sampling is less frequent than a once/dominant period. Huybers and Wunsch (2003) discuss the pitfalls of rectification and Wunsch and Gunn (2003) describe aliasing effects in a deep-sea core.

zero in February and April (March data were missing). The interpretation is greatly complicated by the presence of the meandering Kuroshio.

Not much more can be said, except that it is plausible that the two specific foraminiferal species do undergo a seasonal growth cycle, which would also be reflected in the inferred temperature difference between them, and that it mainly reflects the warmest part of the year. If that inference can be extended to sampling during an ENSO cycle, then there is a production bias toward warm temperatures in *G. sacculifer* (which we now postulate), and the ENSO variations have an equivalent sampling bias toward warm temperatures.

4. Foraminifera during ENSO

Information on the behavior of planktic foraminifera during ENSO is equally sparse. C. Ravelo (2008, personal communication) has suggested that in the modern ENSO, *G. sacculifer* is limited by nutrient depletion in the warm phase, thus *reducing* the contribution then, a potentially fatal objection. Relevant observations are, however, few and far between. Watkins et al. (1996, 1998) discuss the biological distributions in the tropical Pacific during and following El Niño of 1992. They found that *G. sacculifer* appeared to be negatively correlated with primary productivity, and were found on the equator during the warm phase of ENSO, but were not detectable there during the cold phase. The distribution of *G. tumida* in space and time was complicated. Presumably, the populations are reacting at least in part to competing species and to predators. Watkins et al. (1998) also call attention to the importance of the circulation to the observed distributions, with the lifetimes of the foraminifera being comparable to advection times along and across the equatorial zone.

Off the Chilean coast, Marchant et al. (2004) found *greatly enhanced fluxes* of *G. sacculifer* during the 1997/98 El Niño, and the appearance of *G. tumida* only during that event; albeit their data came from near the southern limit of a measurable signal and are not tropical. Yamasaki et al. (2008) show seasonal signals from the western end of the equatorial zone.

Evidently, the biological situation is not simple and is coupled to the near-surface circulation itself. What the $\Delta\delta^{18}\text{O}$ data actually represent in terms of the time sampling of a temporally and spatially changing thermal field is obscure. We tentatively conclude that the hypothesis of a rectified ENSO signal in $\Delta\delta^{18}\text{O}$ is viable.

5. Data from a perpetually running ENSO

McPhaden (1999) shows a sea surface temperature change at 95°W on the equator during the peak of the

1997/98 El Niño from about 21° to about 30°C, a range of about 9°C. Suppose, initially, that the ENSO cycle has in the Pliocene a basic periodicity of 1 yr, and that the growth of *G. sacculifer* occurs primarily during the warm phase, with that of *G. tumida* being relatively constant; the net effect, then, is that of a rectifier, which is discussed in general terms by Huybers and Wunsch (2003).

A simulation of the effect is shown in Fig. 1, and obtained by sampling an annual cosine in the last 3 months of a nominal year. The mean of this partially sampled signal is finite, rather than the zero of the underlying curve. If the range were 9°C, then a partially sampled datum would produce an average of about 1.8°C, close to the shift seen by W05.

Suppose now that the ENSO return interval is 2 yr, and that the annual cycle is otherwise negligible. Then, one obtains the curve also shown in Fig. 1, which still has a significant nonzero average. Whether El Niño signals of the Pliocene were bigger or smaller than those of the modern world is unknown. An irregular amplitude and some degree of intermittency of return would not change the basic result, but a Pliocene ENSO cycle conceivably would be even more tightly locked to the annual cycle than it is today, thus producing a more regular variation in the rectified signal.

6. Discussion

That the assumptions, both physical and biological, being made here to rationalize the apparent RZTG are far from established will be apparent to the reader. Nonetheless, it seems plausible that the Pliocene was a time of either much more frequent Los Niños and/or of more intense ones (which would have a similar effect), and that the particular foraminiferal species would respond as postulated here, providing a fraction-of-the-year sample of the rapidly varying signal. The RZTG signature seen in the paleodata is then interpreted as a rectification or alias of the near-perpetually running ENSO. The existence of such a phenomenon would surely change the global mean temperature and the climate system overall, although those consequences are not pursued here. With a model simulation, Bonham et al. (2008) do show that many of the climate shifts perceived in the Pliocene can be reproduced without a permanent RZTG. If the observed signal is a rectified El Niño, intensified westerlies, rather than weakened ones as in TZI, might be invoked.

On the principle (commonly attributed to P. Dirac) that if a physical process can occur, then it does, it seems plausible that all of the explanations offered for a reduced equatorial zonal temperature gradient can be acting in concert, with none of them necessarily

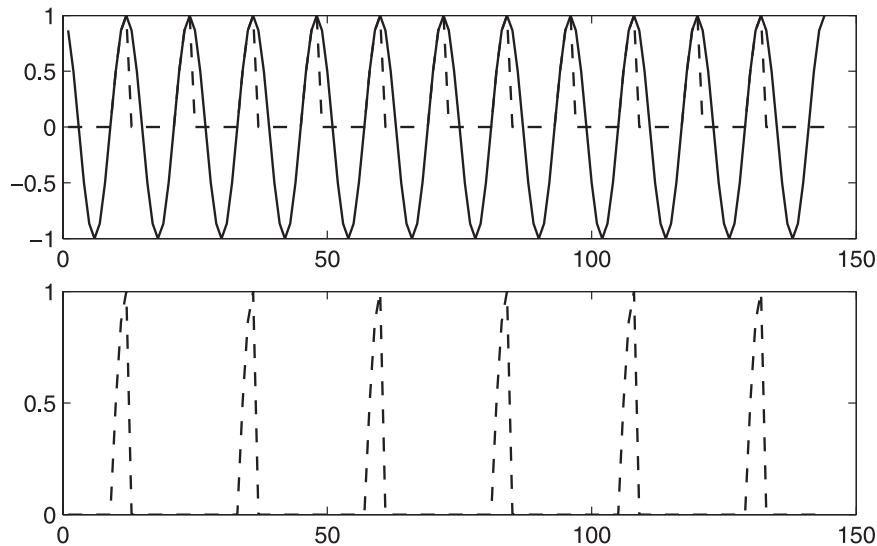


FIG. 1. (top) A sinusoidal El Niño (solid line), and (bottom) one where El Niño occurs only every second year. The assumption is that $\Delta\delta^{18}\text{O}$ is produced only during the warm part of the cycles.

dominant. That is, one can have a deeper thermocline owing to high-latitude processes (Huang and Pedlosky 2000; Fedorov et al. 2006; Bonham et al. 2008), weakened easterlies (TZI), an open Isthmus of Panama, and more frequent, and/or more intense ENSO cycles. The present hypothesis does, however, lend itself to falsification: if more extensive and extended data from sediment traps show that there is no modern ENSO signal in the $\Delta\delta^{18}\text{O}$ of *G. sacculifer* and *G. tumida*, then the idea would probably have to be abandoned. The hypothesis would also be greatly weakened by the demonstration of the lack of an annual cycle in these foraminifera in regions today where a measurable annual cycle in some important climate parameter (water temperature, insolation, etc.) is present.

The missing information thus appears to be primarily biological in nature. Perhaps observations bearing on modern biological phenomena will become available so as to either strengthen or weaken the case. For completeness, however, note that a deepened Pliocene thermocline would surely influence the upper-ocean nutrient distribution, with unknown influence on the foraminiferal behavior. This type of possible change would also have to be accounted for in some phenomena we have not discussed, including the apparently enhanced coastal upwelling signatures seen during this period. An important further assumption here, and present, unstated, in essentially all of the paleoclimate studies, is that no significant adaptive evolution has taken place in the foraminifera in the two million years since the end of the Pliocene. Postulating evolutionary

change would eliminate much of the concrete record of past climate.

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