

ENSO behavior before the Pleistocene

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The Pliocene was characterized by a weak equatorial sea surface temperature gradient in the Pacific, confusingly reminiscent of that seen fleetingly during an El Niño. Data also show interannual variability in the Pliocene, raising questions about ENSO's dependence on the mean climate state.

The behavior of the El Niño–Southern Oscillation (ENSO) in pre-Pleistocene climates is highly uncertain. This uncertainty is rooted in a fundamental lack of evidence. However, several, recent studies focusing on past warm climates are beginning to address this issue. These studies were motivated by suggestions that the climate of the early Pliocene was a “permanent El Niño” – a term that has led to much confusion. After looking at the new evidence for ENSO, I will discuss the history of the term “permanent El Niño”, before suggesting that it should be consigned to history as well.

Pre-Pliocene ENSO

Detection of interannual variability requires paleoclimate indicators that monitor changes over short timescales such as the thickness of varved sediments and isotope ratios in long-lived fossil mollusks or corals. Once a record spanning sufficient years has been recovered, its power spectra can be analyzed for frequencies representative of ENSO. ENSO has been detected

during the warm intervals of the Miocene (5.96–5.32 Ma; Galeotti et al. 2010), Eocene (45–48 Ma; Huber and Caballero 2003; Lenz et al. 2010) and Cretaceous (70 Ma; Davies et al. 2011, 2012) from layered deposits or varved sediments showing a strong peak in the 3–5 years range. It has also been seen in the Eocene (50 Ma; Ivany et al. 2011) from analysis of power spectra of carbon isotopes in fossil driftwood and bivalves. All of these analyses have used records gathered in locations far away from the tropical Pacific, such as Antarctica. However, ENSO teleconnections depend on the mean climate state (Merkel et al., this issue) and may therefore have been different in these early warm periods. The plausibility of assumed teleconnections of that time can be confirmed with climate model simulations of the period (Galeotti et al. 2010; Huber & Caballero 2003; Ivany et al. 2011).

Pliocene ENSO

Two studies have found evidence of ENSO-style periodicity during the Pliocene (Fig. 1) from locations in the Tropical Pacific.

Oxygen isotope records from fossil corals (MacGregor et al., this issue) from the Philippines show power spectra similar to recent corals, hence likely representing ENSO variability (Watanabe et al. 2011). Analyses of individual foraminifera from the Eastern Equatorial Pacific (Scropton et al. 2011) find several instances of isotopic compositions outside the range predicted for the present-day seasonal cycle. This has been interpreted as showing an active ENSO cycle. Unfortunately, a foraminifer does not live through an annual cycle (unlike mollusks; e.g. Carré et al., this issue), so changes in the seasonal cycle (Braconnot and Luan, this issue) are a potential source of uncertainty.

Despite the complications associated with each individual study, a picture is emerging in which ENSO is a pervasive feature of past climate. However, a systematic effort will be needed to provide quantitative information from these pre-Pliocene intervals that could qualify for data-model comparisons.

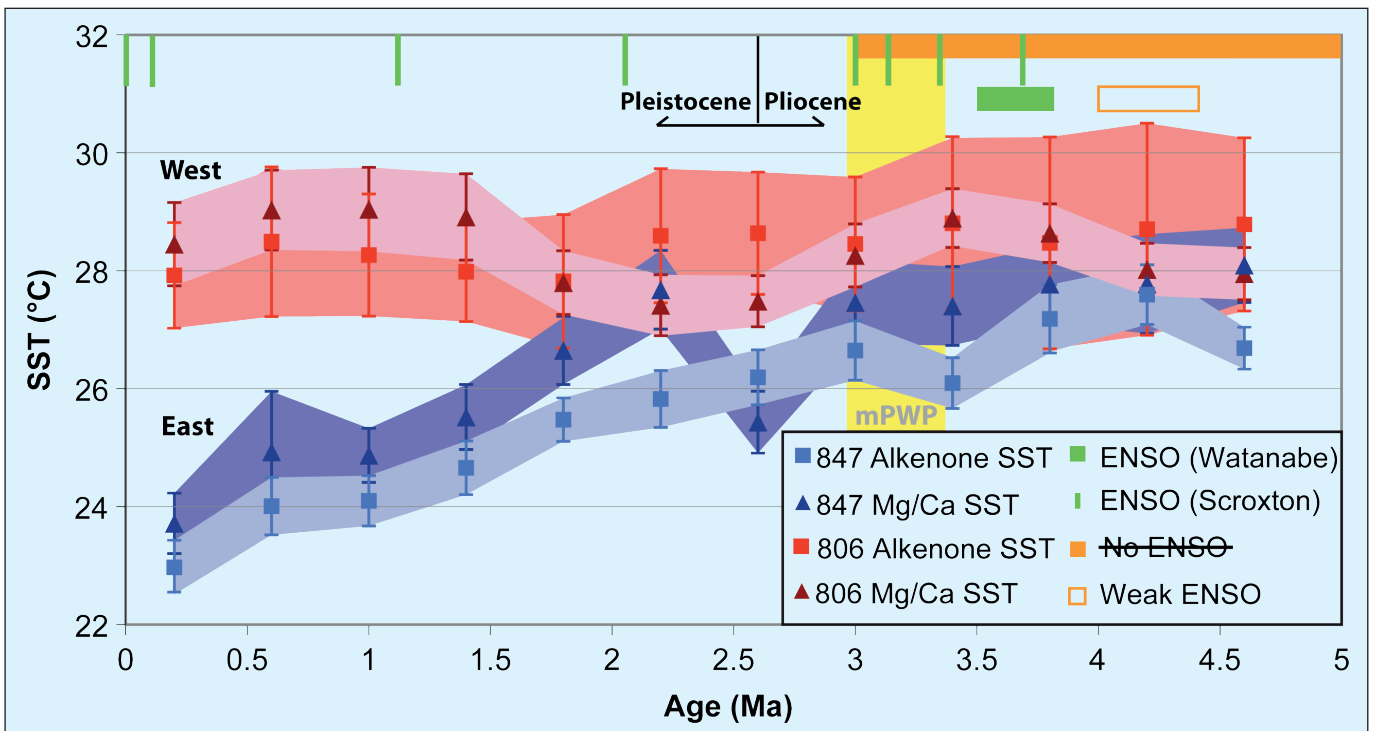


Figure 1: Variation in the Sea Surface Temperature in the Equatorial Pacific over the past five million years. The estimates come from two ocean cores in the West (ODP 806 at 150°E) and the East (ODP 847 at 95°W). Two different types of record are used to reconstruct the temperatures: Mg/Ca (Wara et al. 2005) and alkenones (Dekens et al. 2007; Pagani et al. 2010). The period described as lacking ENSO variability (i.e. the period of the “permanent El Niño”) from a mistaken interpretation of Fedorov et al. (2006) is shown in orange. Times with observed ENSO variability, as found by Scropton et al. (2011) and Watanabe et al. (2011), are marked in green. The time-slab used by PlioMIP and its precursors is marked as “mPWP”. Figure modified after Fedorov et al. (2013).

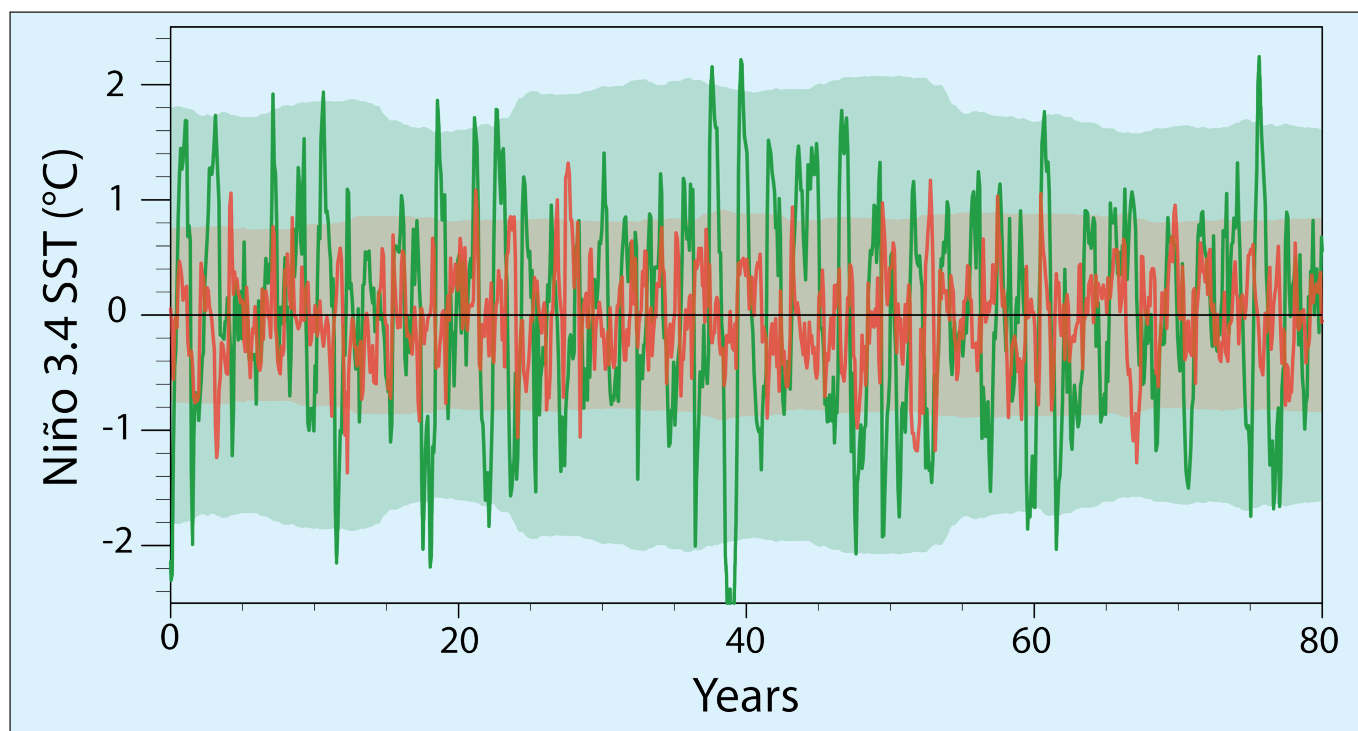


Figure 2: Niño 3.4 SST anomalies in two model simulations; a control (green) and one with an equatorial SST gradient that is approximately halved (red). The shaded area represents four standard deviations from a 30-year running window (Fedorov et al. 2010).

The “permanent El Niño” of the Early Pliocene

One of the factors fuelling the hunt for ENSO in pre-Pleistocene warm climates was the idea that the early Pliocene was in state of “permanent El Niño”. Mg/Ca records (a proxy for sea-surface temperatures, SST) from the Western and Eastern Equatorial Pacific (Wara et al. 2005) suggest that no temperature gradient existed along the equatorial Pacific around four million years ago (4 Ma; Fig. 1). Subsequent work shows similar results for the equatorial SST gradient in the early Pliocene. Reconstructions of the SST gradient during older periods need further work, but preliminary data suggest that a reduced SST gradient is not solely a feature of the early Pliocene (LaRiviere et al. 2012) although it may not be a ubiquitous feature of all warm climates (Nathan and Leckie 2009).

An El Niño event (the warm phase of the ENSO oscillation) is characterized by a lack of SST gradient along the equatorial Pacific. Although Wara et al. (2005) emphasized that their Mg/Ca records reflected the mean climatic state, i.e. a change in the long-term average climate rather than a change in interannual variability, they described their observation using the shorthand of “a permanent El Niño”. The term was propagated by Fedorov et al. (2006), who used model simulations to examine how such a state could be maintained. They emphasized the similarity between the long-term average state and the conditions seen during recent El Niños. This simile has been read as an assertion that there

was no ENSO variability before 3 Ma, although this is not what the authors intended (Alexey Fedorov, personal communication) and is certainly not what is shown by the more recent studies described above.

Equatorial SST gradient and ENSO in models

The mid-Pliocene warm period (3.3–3.0 Ma; marked “mPWP” in Fig. 1) has been the focus of sustained effort by the data and modeling communities, most recently under the auspices of the Pliocene Model Intercomparison Project (PlioMIP; Dolan et al. 2012). This period is one million years later than the minimal SST gradient identified by Wara et al. (2005), but is thought to share similar climate forcings (Fig. 1). Haywood et al. (2007) found ENSO variability in both mid-Pliocene and modern simulations. However, the equatorial temperature gradient of the mid-Pliocene simulation was hardly smaller than in the modern simulation. Subsequent simulations performed with updated boundary conditions (Dowsett et al. 2010), similarly show a lack of strong reductions in the equatorial temperature gradient between the mPWP and the modern day (Haywood et al. 2013) – in comparison with the halving seen in the paleo-observations (Fig. 1).

Attempts have been made to force coupled models to replicate a mean state with a weak SST gradient in the equatorial Pacific. One approach has been to increase the background ocean vertical diffusivity (Brierley et al. 2009), potentially to represent a changed tropical cyclone

distribution (Fedorov et al. 2010). These simulations (Fig. 2) appear to show a relationship between equatorial SST gradient and the amplitude of ENSO, but not its period (Fedorov et al. 2010). This result could easily be model dependent, but offers a scenario for a weak ENSO around 4.2 Ma, the time for which proxy data suggest that the SST gradient was very small (open orange box in Fig. 1).

Conclusion

The introduction of the term “permanent El-Niño” in the literature has caused confusion, but it has also motivated paleoclimatologists to look for (and find) evidence of interannual ENSO variability in deep time. The assertion that there was no ENSO variability before 3 Ma, wrongly attributed to Fedorov et al. (2006), is not true. However, the relationship between a Pacific mean state with a minimal equatorial SST gradient and related ENSO properties merits further investigation. We have made progress towards uncovering ENSO behavior on geologic timescales, but there is still a long way to go.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2013_2.pdf

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