SST gradient may not be as tightly tied to ENSO variability in the last millennium as it seems to have been during the Holocene (e.g., Koutavas et al., 2006). Alternatively, the limitations of available ENSO proxies may be hindering our understanding of how interannual variability is related to the mean state of the tropical Pacific.

Observations and model simulations indicate that a strong zonal SST gradient in the tropical Pacific favors persistent drought in western North America (e.g., Seager et al., 2007). A comparison of the western North American drought area index (Cook et al., 2004) and the zonal SST gradient indicates that the most widespread droughts of the last 1.2 ka occurred from 1000-1300 AD, when the zonal SST gradient was strongest. However, other climate modes, such as North Atlantic SST variability, also impact western North American hydroclimate, making it difficult to attribute all low frequency droughts in this region to tropical Pacific SST variability (Conroy et al., 2009b).

Directions for future tropical Pacific research

Understanding the history of tropical Pacific SST and ENSO variability requires a high resolution, multi-site, multi-proxy approach. More annually resolved ENSO reconstructions would be particularly useful, as lower frequency ENSO reconstructions will never be able to separate changes in event frequency, intensity, and duration from longer-term variability. Also, annual records from within the tropical Pacific domain of ENSO are more tightly linked to the physical phenomena of ENSO, and more desirable than reconstructions from outside this domain. A potentially powerful solution to the limitations of existing ENSO proxies is to combine high-resolution SST reconstructions from windows of fossil corals with the continuous records of tropical Pacific lake and marine sediment records. Additional continuous, calibrated, high-resolution SST records from the tropical Pacific will also improve estimates of the zonal SST gradient.

References


For full references please consult:
http://www.pages-igbp.org/products/newsletters/ref2010_1.html

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Repeated isotopic analyses of single specimen of the thermocline-dwelling planktonic foraminifer Neogloboquadrina dutertrei provide snapshots of past changes in the amplitude and frequency of El Niño and La Niña.

One of the most difficult tasks when reconstructing past El Niño-Southern Oscillation (ENSO) activity is to extract a pure ENSO record by avoiding non-ENSO climate signals embedded in climate archives. Among the non-ENSO climatic signals to be avoided, seasons are probably the most important parameter to be considered because their imprint in climate archives overwhelmingly conceal any interannual mode of climatic variability.

To date, few paleoceanographic archives, such as tropical Pacific corals (Cobb et al., 2003) or eastern tropical Pacific laminated sediments (Grelaud et al., 2009), provide the sub-annual time resolution required to separate the ocean variability due to ENSO from that linked to seasonality. Further, these archives are either restricted in time coverage (e.g., decades or centuries for corals, Cobb et al., 2003), or sample warm periods exclusively (Grelaud et al., 2009). From this perspective, further efforts to reconstruct ENSO from marine sediment cores collected in areas strongly impacted by ENSO variability (both the amplitude and frequency of El Niño warm events and La Niña cold events) and with comparatively minor seasonality changes are required.

These conditions are found within the thermocline of the permanently stratified eastern equatorial Pacific warm pool. In this region, the large temperature anomalies associated with interannual thermocline tilt occurring zonally across the Pacific are barely influenced by seasonal changes. Hence any foraminifers living...
within the thermocline may record changes in ENSO activity, with the added benefit that the seasonality effect is expected to be of second order (Fig. 1).

**Approach**

We studied a marine sediment core with a well-constrained stratigraphy and containing abundant tests of the thermocline-dwelling planktonic foraminifer *N. dutertrei* (Leduc et al., 2009a). We performed repeated δ¹⁸O measurements on up to 90 individual foraminifer tests for eight intervals in the sediment core. Each interval integrates approximately 100 years. Ideally, measuring a large number of individual tests at selected core depths provides snapshots of the full hydrographic variability during narrow time windows (see also Koutavas et al., 2006 for a similar approach). The δ¹⁸O of foraminifers records a mixed signal of temperature and δ¹⁸O of seawater (a proxy for salinity), therefore the *N. dutertrei* individual measurements provide insight on subsurface water hydrological variability over the studied time intervals. At the core location, ENSO variability has a profound impact on subsurface temperature, with an additional influence on salinity, making the δ¹⁸O of foraminifers particularly sensitive to ENSO (Fig. 1, Leduc et al. 2009a).

Since the subsurface hydrology at the coring site is strongly affected by seasonal variability, we interpret the scattering of intra-sample *N. dutertrei* δ¹⁸O measurements as a signal for past changes in amplitude and frequency of ENSO activity. Some secondary overprint of other factors linked to the foraminifer living-depth or to past changes in the thermocline seasonality cannot be ruled out. However, the modern oceanography at the studied core site strongly suggests that the first order mode of hydrological variability captured by this method is induced by ENSO activity (Leduc et al., 2009a).

The time slices we have investigated are the late and mid Holocene, Heinrich event 1 (which occurred during the last deglaciation), early and late periods of the Last Glacial Maximum (LGM), and three time slices specifically targeting the cold Heinrich events and warm Dansgaard-Oeschger interstadials that punctuated the last glacial period. This range of samples encompasses most of the modes of climatic variability that affected the last 50 ka, such as glacial-interglacial, Milankovitch (precession) and rapid (millennial) climate changes that shaped most of the paleo-records covering this period.

**Results of individual *N. dutertrei* δ¹⁸O measurements**

The δ¹⁸O variability for all time slices ranges from −1.5 to 2.1 ‰, corresponding to ~8 to >10°C (Fig. 2a), i.e., comparable to what is found between El Niño and La Niña years nowadays at coring site (Fig. 1). Overall, the δ¹⁸O distributions did not dramatically change among the time intervals we studied. This indicates that ENSO persisted throughout the time interval studied and that the past modes of ENSO activity under radically different climatic backgrounds are unlikely to have been much different from today.

To better quantify the scattering of individual δ¹⁸O measurements, we calculated the standard deviation of isotopic data for each time slice as a measure of ENSO activity. The standard deviation data suggest that smooth, long-term ENSO changes occurred over the last 50 ka. Over this time period, ENSO activity decreased steadily during the last glacial period, reaching a minimum of variability during the Last Glacial Maximum (LGM). The ENSO variability then increased again from the LGM to the present (Fig. 2b).

Some features of this reconstruction of past ENSO are particularly interesting. First, these results provide the first indications of reduced ENSO activity during the LGM, which is particularly important in providing useful targets for model intercomparison exercises. Further, the smooth changes in ENSO during the last glacial period, which encompasses periods of contrasting climatic backgrounds—such as Heinrich events and Dansgaard-Oeschger interstadials—confirm recent hypotheses proposing that millennial-scale changes in the tropical Pacific hydrological cycle were decoupled from ENSO variability (Leduc et al., 2009b). Finally, the highest ENSO variability is found during the Marine Isotope Stage 3, at a time when the background climate was neither fully glacial nor fully interglacial. This suggests that the main driver of ENSO is decoupled from global climatic conditions.

**New perspectives from intra-sample isotopic variability**

The efforts we made to minimize non-ENSO hydrological signals contained in marine sediment cores also provided new and unexpected results that contrast with what is widely acknowledged in the literature. For example, the gentle ENSO activity increase recorded between the mid- and late-Holocene is not statistically significant, which contrasts with a series of other paleo-ENSO reconstructions suggesting a prominently increased ENSO activity during the Holocene period (see Koutavas et al., 2006, and references therein).
Southern Hemisphere intermediate water formation and the bi-polar seesaw

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Periodic intensifications of Antarctic Intermediate Water flow occurred as part of the millennial-scale climate oscillations in the glacial period.

During the last glacial period, a profound millennial-scale climate variation prevailed. First discovered in Greenland ice cores, it has subsequently been documented around the globe, yet the underlying mechanisms controlling this variability have not been identified. Adding to the complexity of this rapid climate change is an interhemispheric asynchronicity, known as the bipolar seesaw. A significant clue towards unraveling the controls of millennial-scale variability came from the deep ocean off Portugal (Shackleton et al., 2000). Here, stable oxygen isotope variability in surface dwelling planktic foraminifera shows clear ties to Greenland climate variability, whereas the respective record based on benthic foraminifers living on the seafloor relates to Antarctic climate variation, reflecting the southern origin of the Antarctic Bottom Water that prevails in the abyssal Atlantic off Portugal.

One likely mechanism for the climatic asynchronicity involves an interhemi-spheric imbalance in heat storage (Stocker and Johnsen, 2003). Surface ocean records from the South Atlantic Ocean (Barker et al., 2009) indeed show a climate change pattern opposed to that in Greenland ice cores supporting the view that asynchronous heat storage is instrumental in off-set ting Northern and Southern Hemispheric climate change at the millennial-scale.

The role of southern-source intermediate water (Antarctic Intermediate Water, AAIW) in the bipolar seesaw is of global relevance due to its large volume and associated energy storage capacity. However, data-based evidence is rare. Benthic stable isotope data from the intermediate depth SW Pacific (Pahinke and Zahn, 2005) show periods of intensified glacial AAIW formation during the cold Heinrich Events in the North Atlantic. During Heinrich Events, the large continental ice masses surrounding the North Atlantic released “flotillas” of icebergs into the ocean. The melting of these icebergs disrupted the formation of North Atlantic Deep Water (NADW) and hence slowed down the overturning circulation in the Atlantic. Thus the data from the SW Pacific suggest that glacial AAIW formation was intensified in the SW Pacific during a time when the overturning circulation in the North Atlantic was strongly

References

For full references please consult: http://www.pages-igbp.org/products/newsletters/ref2010_1.html

Figure 1: Distribution of δ18O in the modern ocean (redrawn from Charles and Fairbanks, 1992). White circles indicate the location of sediment cores NIOP 905 (Indian Ocean, Jung et al., 2009), MD95-2042 (Atlantic Ocean, Shackleton et al., 2000) and MD97-2120 (Pacific Ocean, Pahinke and Zahn, 2005).
G. Leduc, L. Vidal, O. Cartapanis and E. Bard