Reconstructing ENSO in the Eastern Tropical Pacific from short-lived marine mollusks

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Shells of mollusks from offshore Peru were analyzed to reconstruct variability of the seasonal cycle and ENSO. The data provide insights into past changes in ENSO-related interannual variability in the Eastern Tropical Pacific and in the spatial structure of ENSO.

The focus of much paleoclimate work on ENSO has been on records spanning multiple decades, such as those derived from corals. Such long records are, however, relatively rare, especially in the Eastern Tropical Pacific. This important limitation for studying past changes in the spatial pattern of ENSO activity can be compensated for by obtaining records from a larger number of shorter-lived organisms. In this case, information about past climate is not available as a continuous record, but is compiled to extract climate statistics.

Carré et al. (2013) recently presented a technique that responds to the critical need for quantitative estimates of tropical marine interannual variability. This technique uses the shells of marine mollusks that live for 1-4 years, and thus allow us to reconstruct the seasonal range of sea surface temperature (SST). These data can then be compared to coral records and GCM outputs. The technique of using marine mollusk shells shares similarities with the approach of coral studies in that it produces floating windows of climate record at a very high, often monthly, resolution. It also shares similarities with the approach of analyzing many foraminifera shells individually from the same sediment layer (Koutavas et al. 2006; Leduc et al. 2009) in that paleoclimate statistics are estimated from a random sample. Isotopic records in mollusks enable independent reconstructions of the seasonal cycle. This approach is valid for any coastal mollusk species that faithfully records at least one annual SST cycle, and therefore opens up new opportunities for direct, quantitative paleo-ENSO reconstructions in the Eastern Tropical Pacific, using either archeological shell middens or uplifted fossil shell banks from Peru.

ENSO characterization in the Niño1+2 region

SST variability on the Peruvian coast is largely dominated by ENSO-related interannual variability. The amplitude of the annual cycle (ΔT) on the coast is also clearly related to the Niño1+2 index, with larger amplitudes during El Niño and smaller ones during La Niña. As a result, the variance of the annual cycle amplitude, Var(ΔT), on the Peruvian coast over any period of time is an indicator of ENSO variance generally in the Niño1+2 region (Fig. 1a).

Oxygen stable isotopes ($\delta^{18}O$) in marine shells from central and southern Peru primarily reflect SST variability since seawater $\delta^{18}O$ is not significantly affected by freshwater input and evaporation (Carré et al. 2013). *Mesodesma donacium* shells grow continuously throughout the year and record the full annual cycle of coastal SST in Peru over a window of 1 to 4 years at a monthly resolution (Fig. 1b). Modern shells (n=13) collected during the late 20th century provide a random sample cumulatively providing about 25 years of statistics that faithfully reproduces the skewed distribution of ENSO

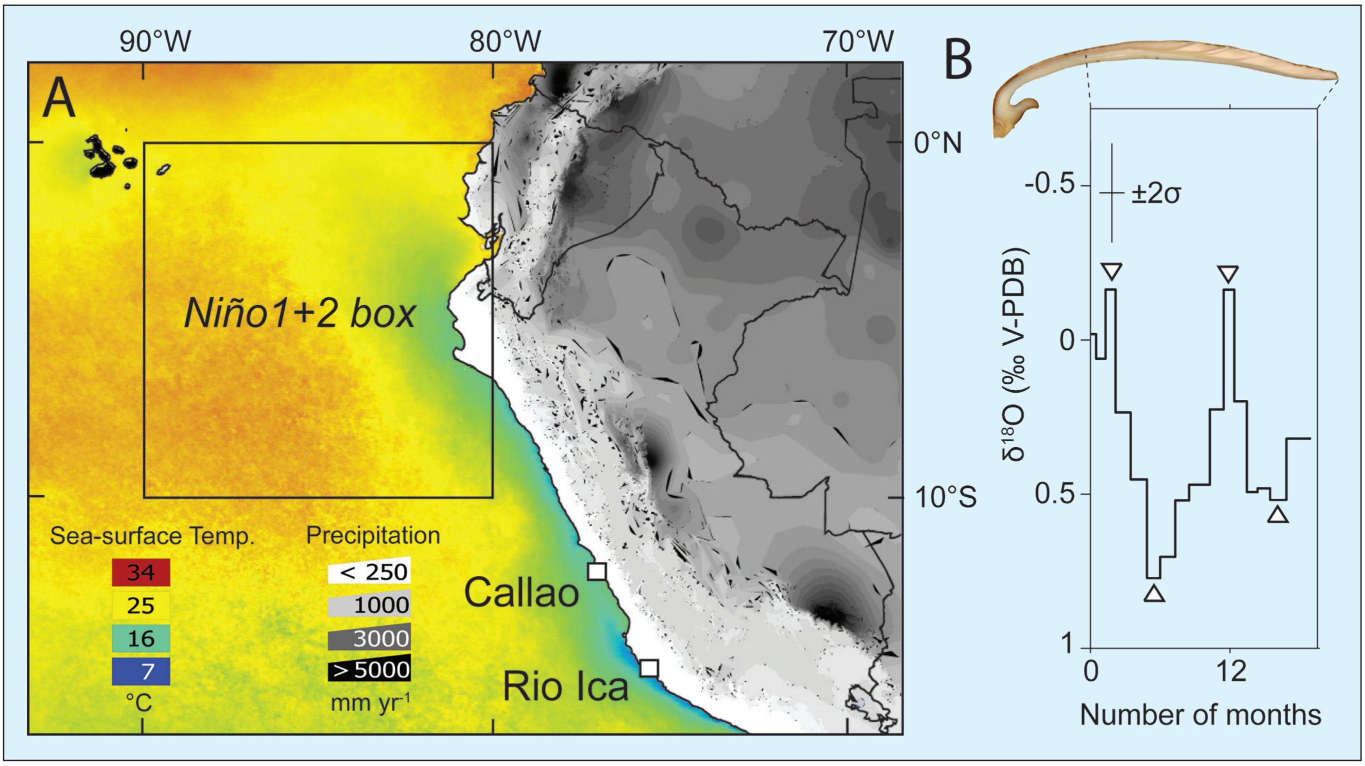

Figure 1: ***A)*** *Annual mean SST and precipitation for the 1950-2010 period. Location of the Niño1+2 region in the Eastern Tropical Pacific and the Peruvian localities mentioned.* ***B)*** *Polished section of a M. donacium shell, and the associated $\delta^{18}O$ plotted on a time scale. The shell was continuously sampled so that every data point integrates about one month. The chronology was determined using shell growth lines. Triangles indicate seasonal extrema used for the calculation of seasonal amplitudes ΔT.*

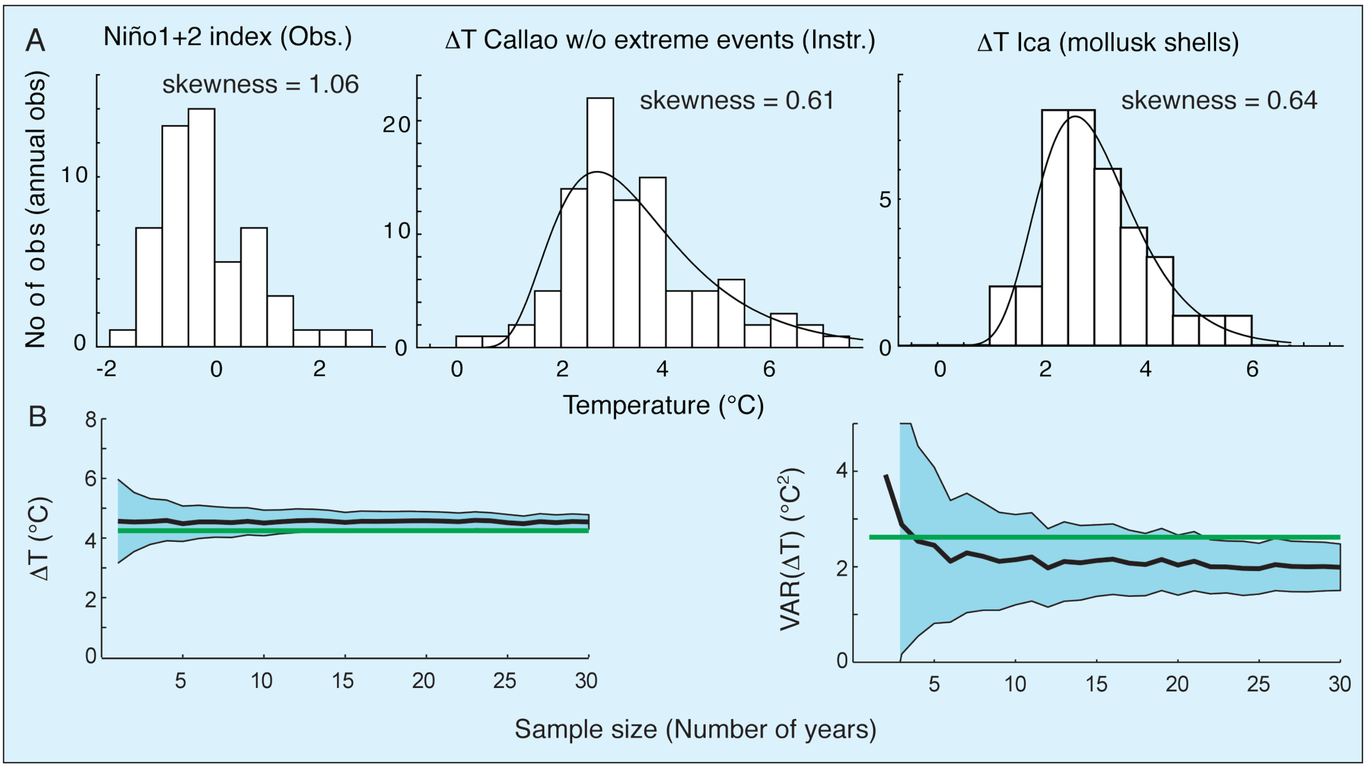

*Figure 2: **A)** Distributions of annual Niño1+2 index from 1950 to 2002, seasonal ΔT values in Callao, Peru from 1950 to 2002 excluding extreme El Niño events in 1982-83 and 1997-98, and ΔT values calculated from a modern sample of* M. donacium *shells from Ica, Peru. **B)** Results of Monte Carlo simulations undertaken to estimate the uncertainties of mollusk-derived paleoclimate reconstructions. Plots show the true value (green), the ensemble average value (black line), and the standard error (blue area) vs. the sample size, for the reconstruction of the mean and variance of ΔT.*

anomalies of this period in Callao, Peru and in the Niño1+2 region (Fig. 2a). It should be noted that the extreme warm events of 1982-83 and 1997-98 are not recorded in the data as the exceptionally warm conditions induced mass mortality in the mollusks. However, such events are so extraordinary even at the millennial scale (Rein 2007) that they are arguably not representative of ENSO (Takahashi et al. 2011). The mollusk shells are complementary to rainfall-related archives as they are sensitive to variability in the marine manifestation of ENSO while rainfall-related archives are more sensitive to occasional catastrophic events induced by the atmospheric anomalies of extreme ENSO events (Rein 2007).

Estimating the reconstruction uncertainties

Estimating reconstruction uncertainties is a necessary challenge in paleoclimate studies if meaningful comparisons with GCM simulations are to be made. To estimate the reconstruction error, we used an in situ instrumental time series and simulated the reconstruction process (forward proxy model). This was done by randomly extracting short time samples and adding different types of noise to them representing uncertainty sources (such as analytical error, random growth breaks, or temperature tolerance). Iterating this process thousands of times provides an estimate of systematic biases (the mean value of the error population) and of the standard error (the standard deviation of the error population) (Fig. 2b). This shell sample yields thus an estimate of mean annual temperature with a precision of ±0.4°C, of ENSO variance with a precision of ±30%, and of ENSO skewness with a precision of ±0.3. This procedure can also be used to evaluate the relative contributions of error sources, and improve our understanding of the proxy (Carré et al. 2012). This sample will be used as a modern reference to normalize past reconstructions, minimize systematic biases due to the archive or to local effects, and allow meaningful comparisons with coral records and climate simulations.

Discriminating Central from Eastern Pacific modes in the past

Capotondi et al. (2013, this issue) present some recent developments in our understanding of ENSO diversity. Two types of El Niño events, Central Pacific events and Eastern Pacific events, have been defined by the location of the maximum SST anomaly (Ashok et al. 2007). Because of their significantly different impacts, the question of the evolution of ENSO in both the past and future, should now also address the variable contribution of Central Pacific and Eastern Pacific ENSO events. In the Niño1+2 region, in the far Eastern Pacific, Eastern Pacific and Central Pacific modes can be distinguished by the shape of their SST distributions. The Eastern Pacific mode is characterized by positively skewed SST distributions while the Central Pacific mode produces a symmetric distribution.

Such a change in ENSO asymmetry has been noted since the 1990s (Yeh et al. 2009; Boucharel et al. 2011; Dewitte et al. 2012). La Niña cold events generate negatively skewed SSTs in the Niño1+2 region. The ENSO anomaly distribution obtained from the modern Peruvian shell sample faithfully reproduces the positive skewness of the late 20th century ENSO, even without recording the most extreme ENSO events (Fig. 2a). Fossil mollusk shell samples from Peru could therefore potentially be used to track past changes in the frequency of Eastern Pacific and Central Pacific events, and provide novel insights into the relationships between ENSO modes and the mean climate.

Selected references

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

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