Changes in Hadley circulation strength over the last millennium as implied by coral records of tropical Pacific climate

Kim M. Cobb*, H. Cheng †, R.L. Edwards †, and C.D. Charles ‡

* California Institute of Technology, Pasadena, CA
† University of Minnesota, Minneapolis, MN
‡ Scripps Institution of Oceanography, University of California-San Diego, La Jolla, CA

Tropical sea surface temperatures (SST) play a critical role in the global atmospheric circulation because they drive the transport of heat and moisture poleward via the Hadley cell. The sensitivity of the large-scale atmospheric circulation to changes in tropical SST is demonstrated during El Niño events, when tropical Pacific warming significantly alters temperature and rainfall patterns around the globe. Despite the important role that tropical SST's play in global climate change, the sparse nature of instrumental and proxy-based records of SST in the tropics make characterizing the relationship between tropical Pacific SST and past global climate changes difficult.

We use modern and fossil corals from Palmyra Island (6°N, 162°W), located in the central tropical Pacific, to reconstruct interannual to centennial tropical Pacific SST for five different intervals of the last millennium. The Palmyra coral-based climate proxy records fill an important gap in our knowledge of recent climate change, because extensive networks of extratropical climate proxy records resolve prolonged periods of relatively warm and cold conditions during the last millennium – the Medieval Warm Period (MWP) (~800-1200A.D.) and the Little Ice Age (LIA) (~1500-1800A.D.), respectively. Determining the response of the tropical Pacific climate system to the climate forcings that caused the MWP and the LIA is key to developing a more complete understanding of the tropical Pacific climate system and its role in global climate change.

The fidelity of the Palmyra coral proxy records is established through calibrations between the modern coral oxygen isotopic ($\delta^{18}O$) record and the instrumental record of climate change. Such calibrations suggest that the Palmyra coral $\delta^{18}O$ can be used to reconstruct regional-scale tropical Pacific SST variability to an accuracy of ±0.3°C (Figure 1) (Cobb et al., 2001). For the fossil corals, our approach involves applying U/Th-series dating techniques in combination with $\delta^{18}O$ analysis to generate well-dated coral-based climate proxy records, many of which overlap in time. The overlapping corals allow for a rigorous assessment of coral $\delta^{18}O$ reproducibility, which is found to be highest for interannual variability and lowest for mean coral $\delta^{18}O$. By splicing overlapping sequences together, we produce multi-century, monthly-resolved records of tropical Pacific climate to which we apply a variety of time-series analysis techniques.

Taken together, the corals suggest that mean climate conditions were relatively stable (±0.5°C) throughout the last millennium, with the exception of relatively cool conditions during the MWP and increasingly warm conditions during the late 20th century (Figure 2c). Interannual and decadal-scale variability are superimposed on this low-frequency variability, exhibiting a wide range of characteristics that appear to be uncorrelated to the observed changes in the mean state (Figures 2a,b, and c). When compared to records of extratropical climate variability, the

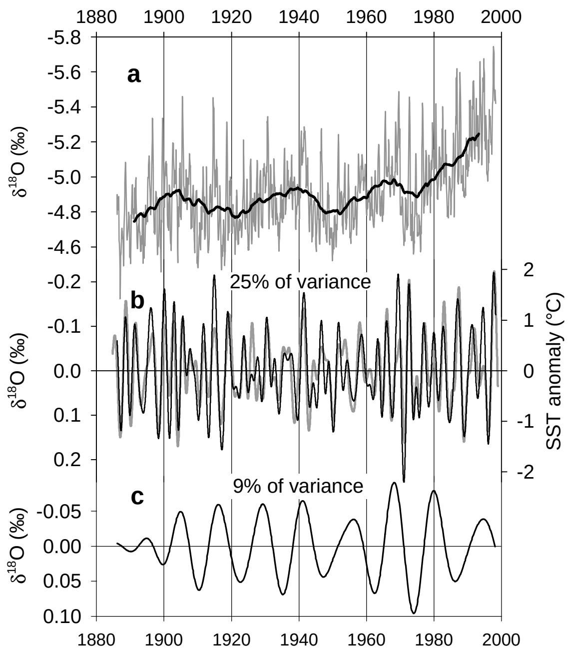

Figure 1. (a). Palmyra coral oxygen isotopic record (grey line) shown with 10-yr running mean (black line). (b). Comparison of ENSO variability at Palmyra (black line) with ENSO variability in the NIÑO3.4 SST index, the average of available SSTs from the region 120-170°W and 5°N-5°S, (grey line), isolated by applying 2-7y band-pass filters. c) Decadal variability at Palmyra from a 9-16y band-pass filter.

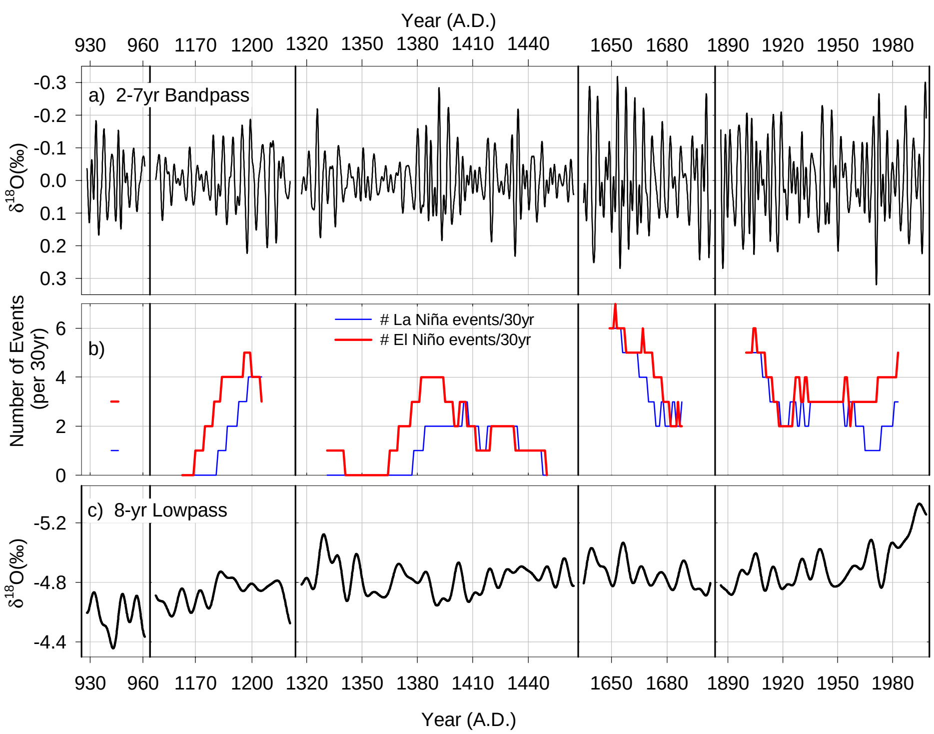

Figure 2. a) 2-7 year bandpass filtered versions of the Palmyra coral δ18O records. b) the number of El Niño (red) and La Niña (blue) events in a 30-year sliding window. El Niño (La Niña) events are defined by annual mean δ18O anomalies (computed from the 2-7 year bandpass filter series) that exceed - 0.11‰ (+0.11‰). c) 8-yr lowpass filtered versions of the Palmyra coral δ18O records.

Palmyra coral reconstruction implies that latitudinal temperature gradients increased during the LIA and decreased during the MWP, which must have affected the strength of the Hadley circulation. In this context, it is intriguing that the most intense ENSO activity of the entire Palmyra reconstruction, both in terms of amplitude and frequency, occurs in the LIA sequence.

Perhaps the change in ENSO properties during the LIA could be traced to changes in wind strength, thermocline characteristics, and/or upwelling rates that may have accompanied an intensification of the Hadley circulation during the LIA (Rind, 2000). However, reversing the sign of these changes during the MWP, when the Hadley circulation likely weakened, does not correspond to a weaker ENSO, as one might expect if the relationship between ENSO and mean climate conditions were linear. This observation, when combined with evidence for chaotic behavior in select intervals of the Palmyra reconstruction, suggests that nonlinearities play an important role in tropical Pacific climate variability.

References:

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