Paleoceanography and Paleoclimatology

Supporting Information for

Coral records of temperature and salinity in the tropical western Pacific reveal influence of the Pacific Decadal Oscillation since the late 19th century

R. D. Ramos[1], N. F. Goodkin[1,2], F. P. Siringan[3], K. A. Hughen[4]

[1]Earth Observatory of Singapore, Nanyang Technological University, Singapore.
[2]American Museum of Natural History, New York, NY, USA.
[3]The Marine Science Institute, University of the Philippines Diliman, Quezon City, Philippines.
4Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, MA, USA.

Contents of this file

Additional Supporting Information (Files uploaded separately)

Introduction

This supporting information (SI) provides an overview of our SST and SSS reconstructions in Palaui Island, Philippines (Text S1), which is an extension of (Ramos et al., 2017) paper. This SI also includes the x-ray images of the *Porites lobata* core (Figure S1) used in this study. Monthly and interannual proxy records are shown in Figures S2 and S3. Additional spectral analysis results between Palaui reconstructed winter SST record and Niño 3.4 index and solar irradiance and reconstructed summer SST record and the PDO, Niño 3.4 and EAWM indices and solar irradiance can be found in Figure S4 and S5, respectively. Figure S6 shows the data locations of proxy measurements exhibiting multidecadal scale variability driven by the PDO. These data were used in Table 1 and Figure 9 of the main text.

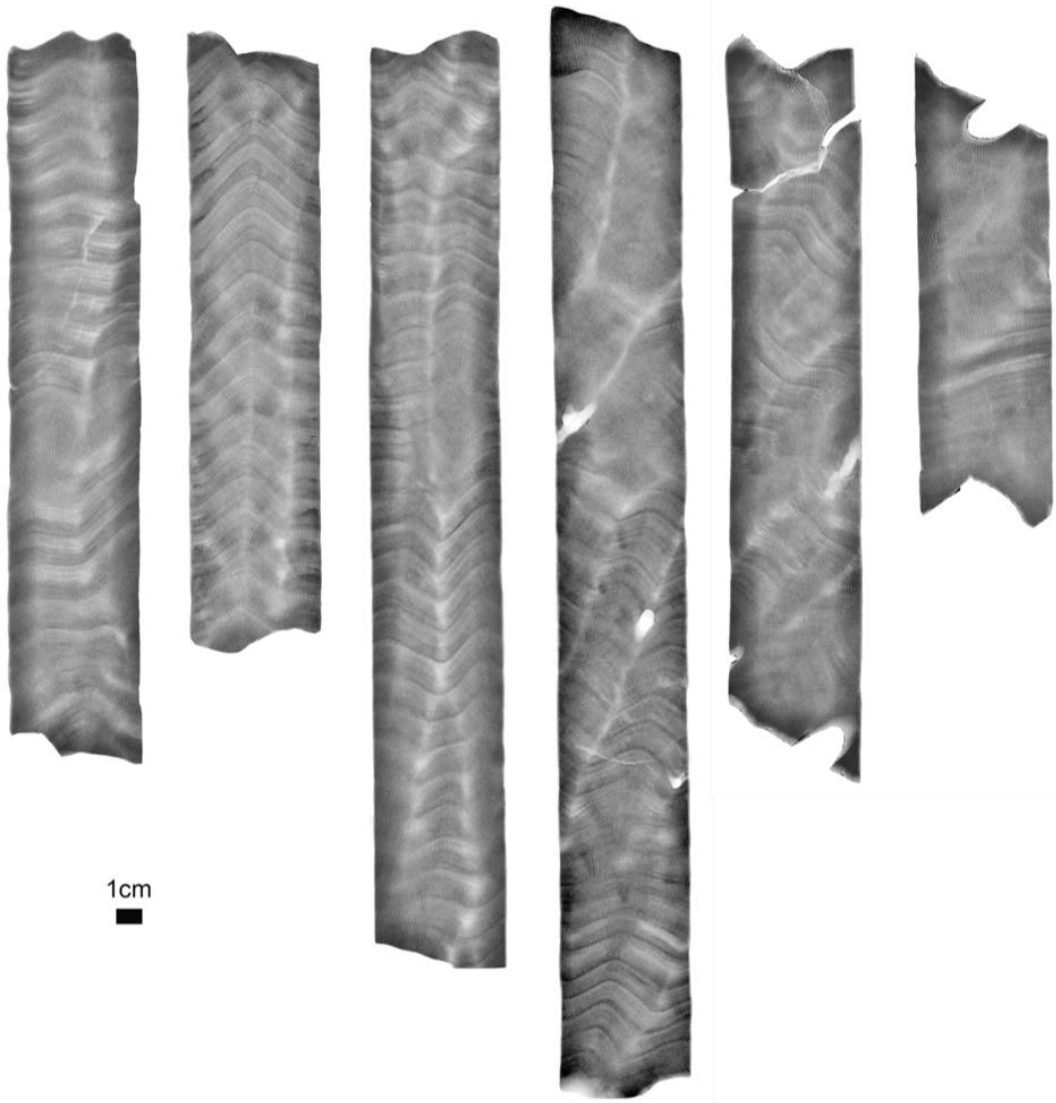

Figure S1. X-ray positive of *Porites lobata* core from Palaui.

Text S1. Climate reconstructions

A. Sr/Ca-SST reconstruction

The summer and winter SST reconstructions exhibit interannual to multidecadal scale variability over a 3.4°C and 3.1°C SST range, respectively (Figure 3a of the main text). The warmest summer and winter SSTs of ~1.5°C above average were recorded during one of the strongest ENSO events of 1998/99. The coldest seasons were recorded in 1939, about 1.9°C and 1.1°C below the winter and summer SST means, respectively. The PDO has previously been shown to exert an influence on Palaui winter SST variability (Ramos et al., 2017).

B. $\delta^{18}O_c$-SSS reconstruction

Variability between reconstructed wet and dry season salinities from 1955 to 2012 has previously been shown to be governed by different factors (Ramos et al., 2017). Wet season $\delta^{18}O_c$-SSS tracked local salinity patterns (e.g., non-ENSO-related rainfall), but excursions in the record responded to ENSO events. Dry season $\delta^{18}O_c$-SSS, on the other hand, reflected regional changes in salinity driven by ENSO, with some excursions explained by local precipitation. The correlation between dry $\delta^{18}O_c$-SSS and SOI is negative such that El Niño (La Niña) episodes coincide with drier (wetter) conditions as the WPWP and atmospheric convection centers moves eastward (westward). In addition, the comparison between the dry season SSS reconstruction and ENSO index, relative to the wet season, resulted in a stronger relationship due to mature ENSO phases occurring during this season. The extended 3-year binned dry and wet season salinity reconstructions presented in this paper show distinct patterns continuing in the late 19th centuries (Figure 6 of the main text). The dry season $\delta^{18}O_c$-SSS varies between 34.2 and 34.9 psu, with a range of 0.76 psu. The wet season $\delta^{18}O_c$-SSS, on the other hand, varies between 33.8 and 34.7 psu, showing a slightly higher range than the dry season record, 0.91 psu.

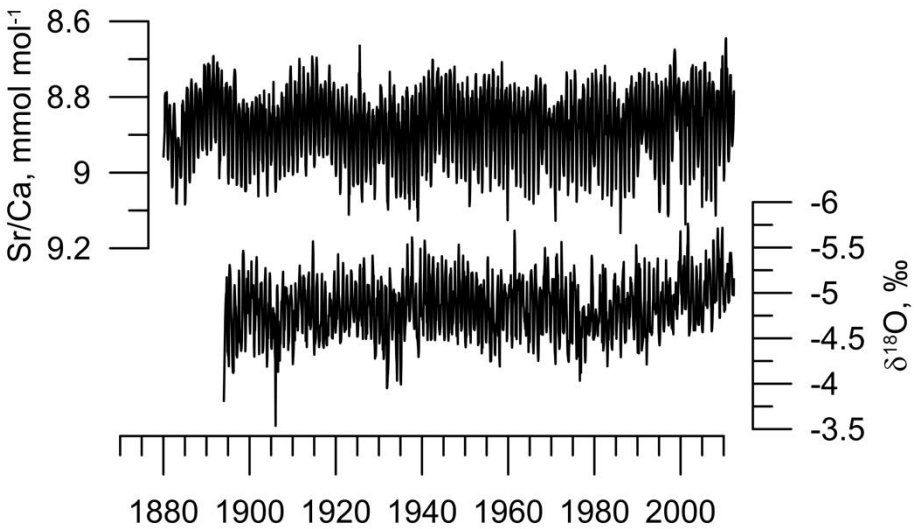

Figure S2. Palaui monthly Sr/Ca and $\delta^{18}O$ timeseries extending back to 1880. The extended proxy records presented add 75 years of climate data, allowing for further examination of climatic controls on low-frequency SST and SSS variability. The paired Sr/Ca and $\delta^{18}O$ records show distinct annual cycles throughout the reconstruction period. Prior to 1894, $\delta^{18}O$ samples were analyzed in a lower resolution (See Section 2.4 in the main text and Figure S3 below).

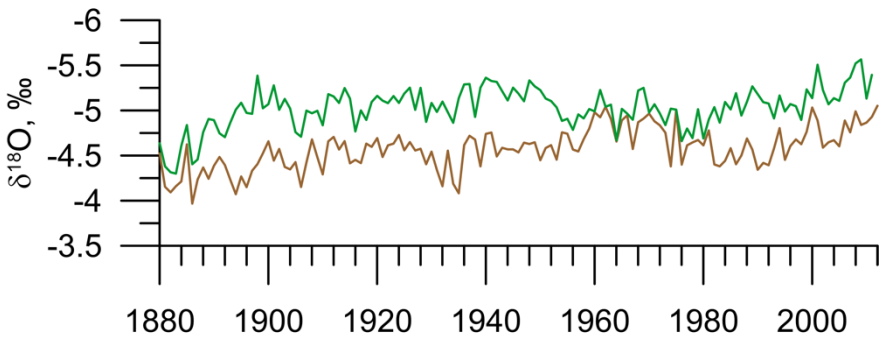

Figure S3. Interannual record of wet (JJAS, green) and dry (DJFM, brown) season $\delta^{18}O$. From 1894 to 2012, all powdered samples were analyzed in the Kiel IV-MAT 253. Prior to 1894, 4 to 8 consecutive samples were selected and measured to represent the maximum (dry) and minimum (wet) values of each year. Dry and wet season $\delta^{18}O$ samples were measured in a Kiel IV-MAT 253 and Delta V Gasbench II, respectively. Mean offset (~0.08‰ based on NBS-19) between instruments is statistically insignificant relative to mean monthly $\delta^{18}O$ variability, unlikely creating a bias in our record through time.

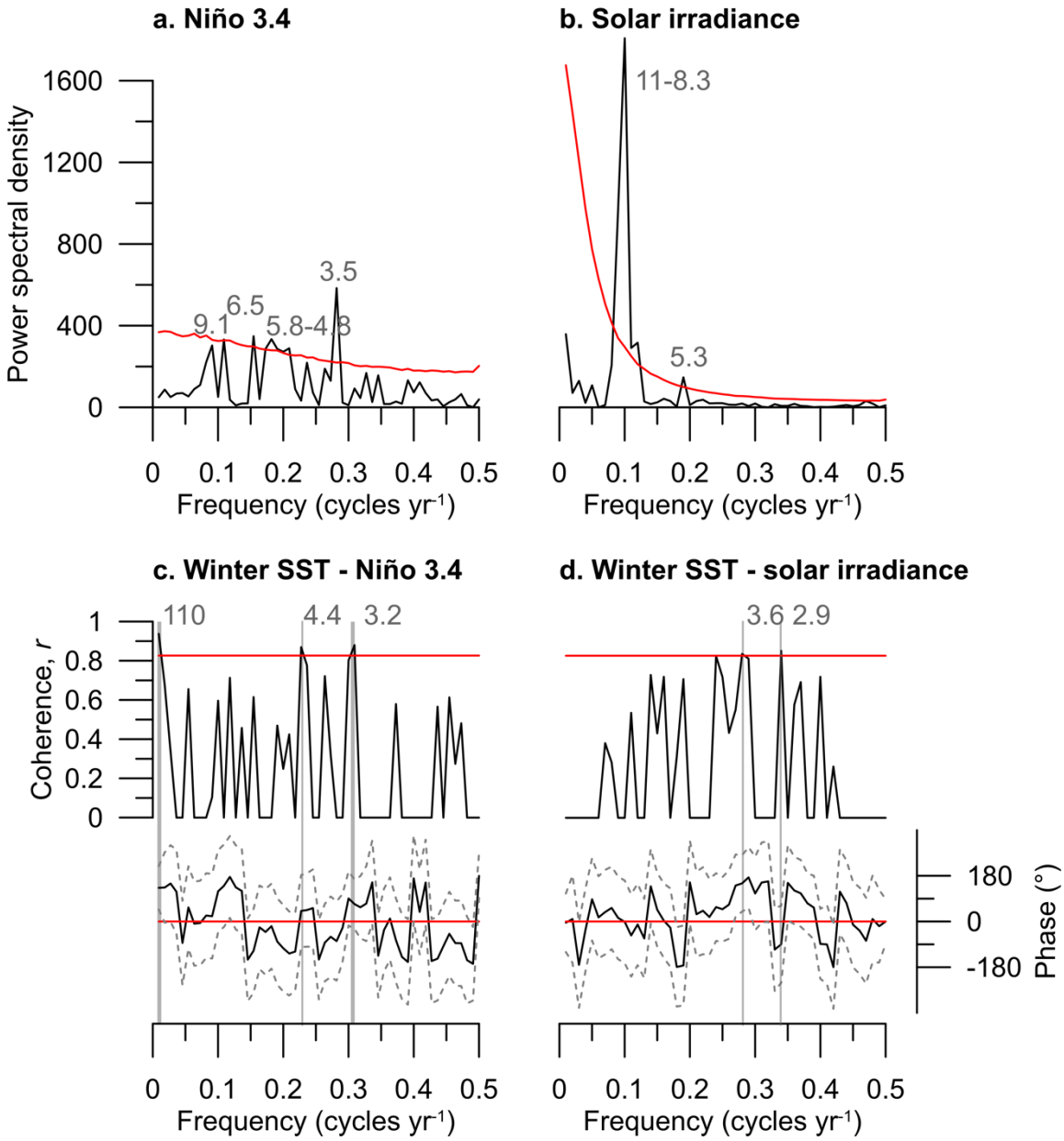

Figure S4. FFT Spectral analysis of (a) Niño 3.4 and (b) solar irradiance. coherence with phase analysis between Niño 3.4 and winter SST records. Red lines indicate 90% significance levels. Gray dashed lines represent confidence intervals.

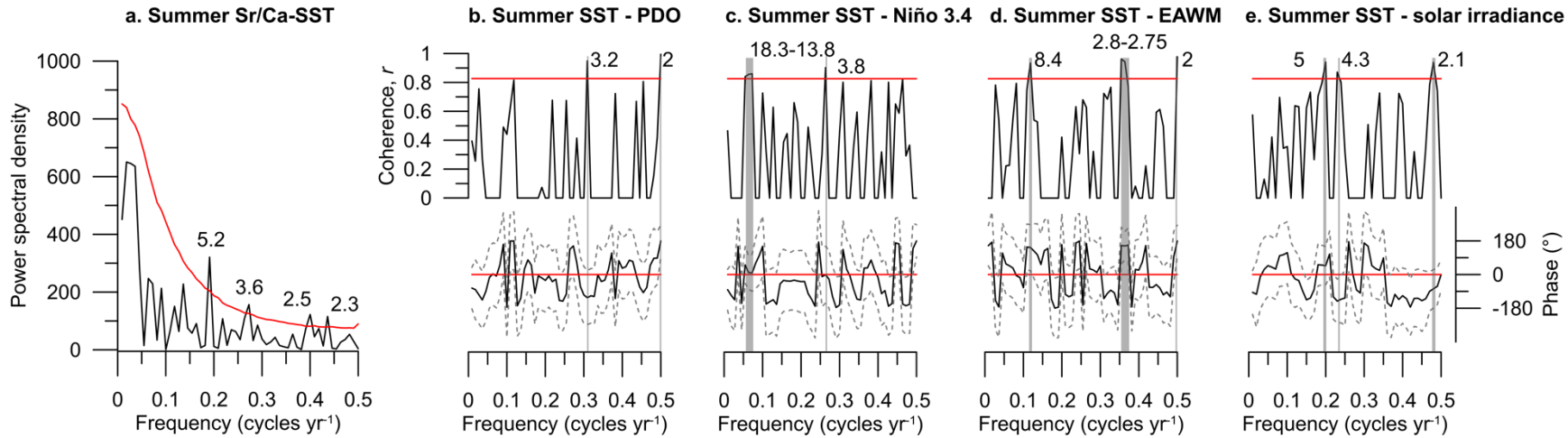

Figure S5. (a) Spectral analysis of detrended summer Sr/Ca-SST records. Significance level greater than 90% (red lines) are labelled. Spectral coherence with phase analysis is performed to account for variances shared between (b) summer SST and the PDO, (c) Niño 3.4, (d) EAWM indices and (e) solar irradiance. Red lines indicate 90% significance levels. Gray dashed lines represent confidence intervals.

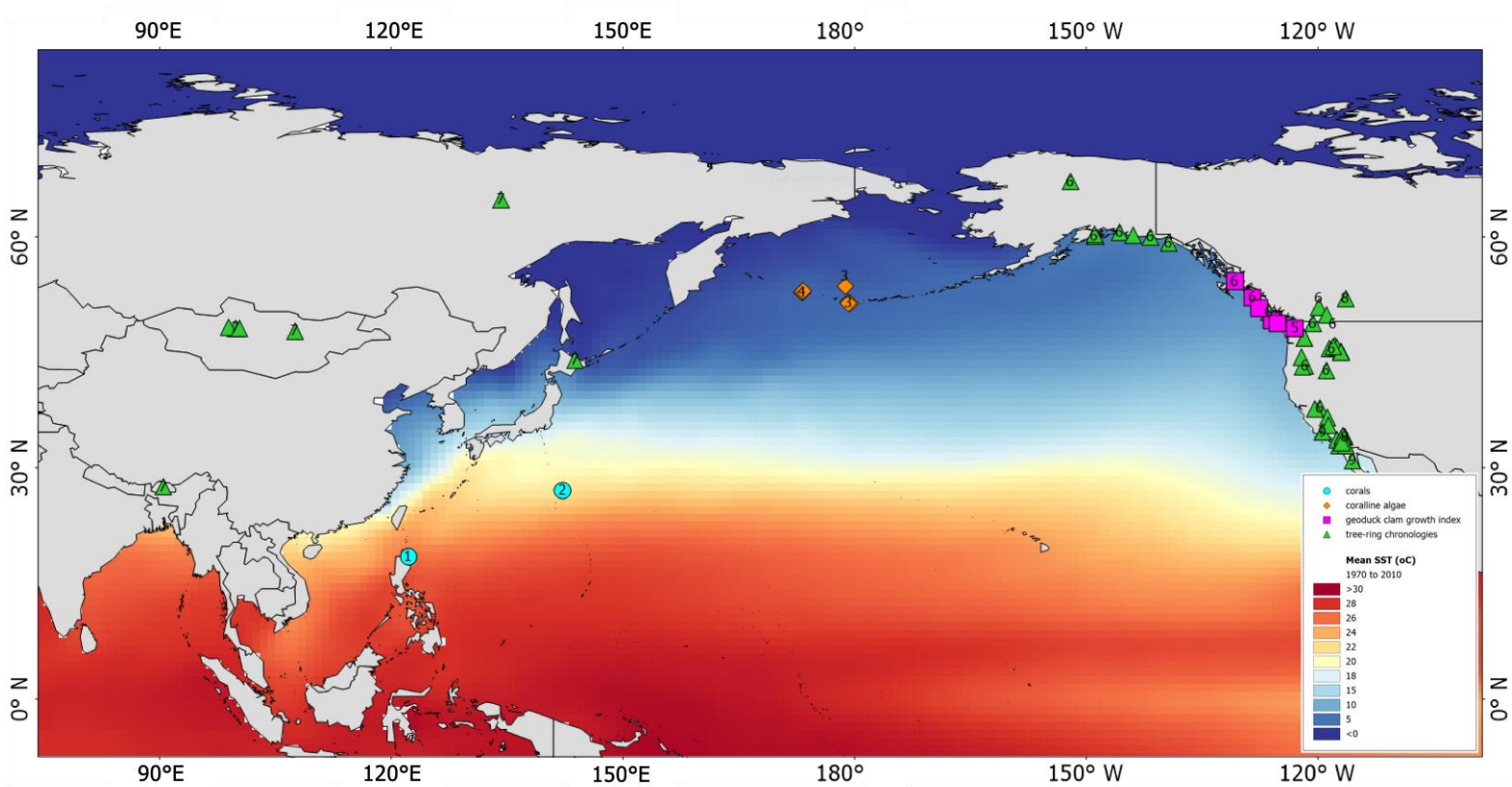

Figure S6. Mean IGOSS SST (1970-2010) over the Pacific region. Colored and numbered symbols indicate the location of PDO proxy records compared with our study: blue circles are based on coral proxy records: 1 – Palaui, Philippines (This Study) and 2 – Ogasawara, Japan (Felis et al., 2010); orange diamonds are based on coralline algae records: 3 – Aleutian Islands (Williams et al., 2017) and 4 – Aleutian Islands (Halfar et al., 2007); pink squares are based on geoduck clam growth indices: 5 – N. America (Strom et al., 2004) and 6 – Canada and N. America (Black et al., 2009); and green triangles are based on tree-ring chronologies: 6 – Canada and N. America (Black et al., 2009), 7 – East Asia (D'Arrigo & Wilson, 2006), 8 – N. America (MacDonald & Case, 2005) and 9 – N. America (Biondi et al., 2001).

Dataset S1. Monthly Sr/Ca (1880 to 2013) and $\delta^{18}O$ (1894 to 2013) and interannual wet and dry season $\delta^{18}O$ (1880 to 1893) records from Palaui, northeastern Philippines (file uploaded separately).

References

Biondi, F., Gershunov, A., & Cayan, D. R. (2001). North Pacific Decadal Climate Variability since 1661. *Journal of Climate, 14*, 5-10.

Black, B. A., Copenheaver, C. A., Frank, D. C., Stuckey, M. J., & Kormanyos, R. E. (2009). Multi-proxy reconstructions of northeastern Pacific sea surface temperature data from trees and Pacific geoduck. *Palaeogeography, Palaeoclimatology, Palaeoecology, 278*(1-4), 40-47.

D'Arrigo, R., & Wilson, R. (2006). On the Asian expression of the PDO. *International Journal of Climatology, 26*(12), 1607-1617.

Felis, T., Suzuki, A., Kuhnert, H., Rimbu, N., & Kawahata, H. (2010). Pacific Decadal Oscillation documented in a coral record of North Pacific winter temperature since 1873. *Geophysical Research Letters, 37*(14), L14605.

Halfar, J., Steneck, R., Schöne, B., Moore, G. W. K., Joachimski, M., Kronz, A., et al. (2007). Coralline alga reveals first marine record of subarctic North Pacific climate change. *Geophysical Research Letters, 34*(7).

MacDonald, G. M., & Case, R. A. (2005). Variations in the Pacific Decadal Oscillation over the past millennium. *Geophysical Research Letters, 32*(8).

Ramos, R. D., Goodkin, N. F., Siringan, F. P., & Hughen, K. A. (2017). Diploastrea heliopora Sr/Ca and δ18O records from northeast Luzon, Philippines: An assessment of interspecies coral proxy calibrations and climate controls of sea surface temperature and salinity. *Paleoceanography, 32*(4), 424-438.

Strom, A., Francis, R. C., Mantua, N. J., Miles, E. L., & Peterson, D. L. (2004). North Pacific climate recorded in growth rings of geoduck clams: A new tool for paleoenvironmental reconstruction. *Geophysical Research Letters, 31*(6), L06206.

Williams, B., Halfar, J., DeLong, K. L., Smith, E., Steneck, R., Lebednik, P. A., et al. (2017). North Pacific twentieth century decadal-scale variability is unique for the past 342 years. *Geophysical Research Letters, 44*, 3761-3769.