Data-Model Comparisons of Mid-Holocene Climate in the Tropical Pacific

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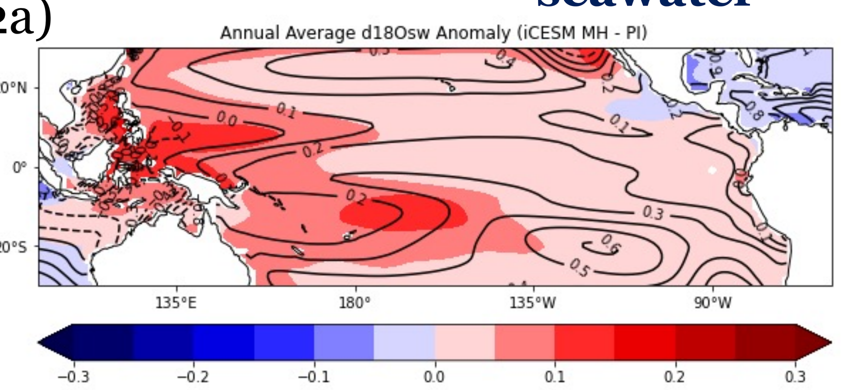
Background and Methods

Paleoclimate data extend the instrumental record of the climate system back in time and provide the necessary long-term context to current and future climate change. They also provide benchmarks for testing the accuracy of climate models. Coral oxygen isotope ($^{18}O_{coral}$) records provide high-resolution constraints on past changes in sea surface temperature (SST) and hydrology from the tropical oceans. Coral proxy records indicate that large changes in tropical Pacific climate occurred several thousand years ago, during the mid-Holocene period. The tropical Pacific was cooler and drier, while seasonal and interannual variations associated with the El Niño/Southern Oscillation (ENSO) were weaker[1-4]. The driver and mechanisms of these changes are not well understood. The isotope-enabled Community Earth System Model (iCESM) is one of few global climate models that is enhanced with water isotope tracers, which allows us to directly compare model output to coral proxy data. The objective of this study was to determine how well the iCESM model compared to coral proxy data.

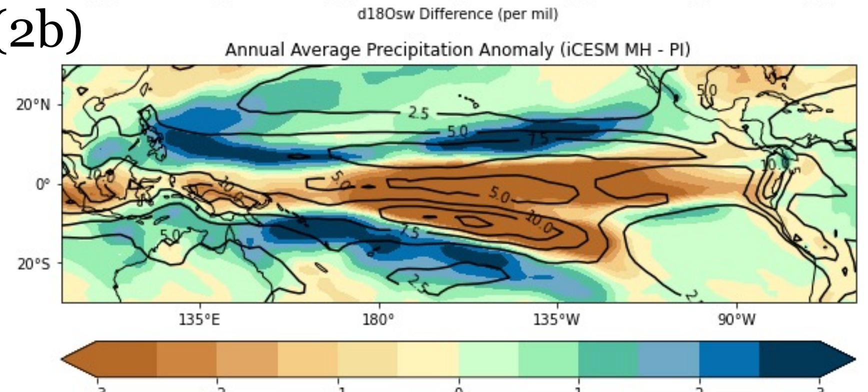
A mid-Holocene simulation of iCESM is used to compare model outputs of SSTs, hydrology, and ENSO dynamics to coral proxy data collected in the Kiritimati Atoll and the tropical Pacific.

$\delta^{18}O_{seawater}$ and Kiritimati Coral

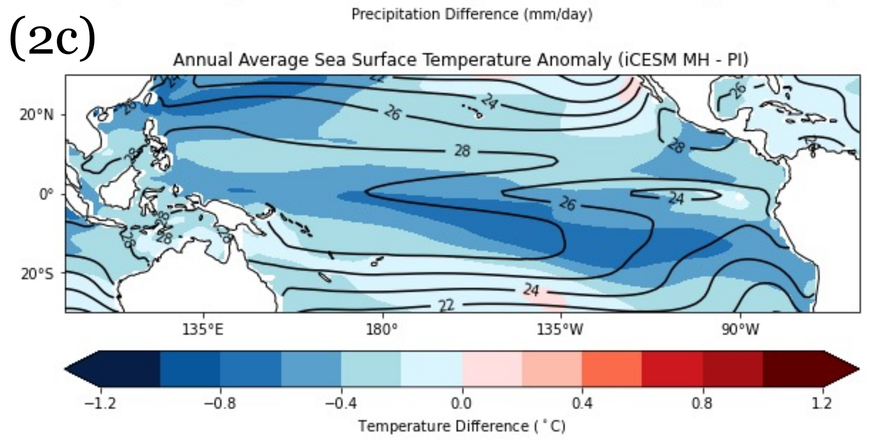
(2a)



(2b)



(2c)



- Figure (2a): Increased values of $\delta^{18}O_{seawater}$ in most of the tropical Pacific indicate drier conditions in the mid-Holocene (filled contours) than preindustrial values (unfilled contours).
- Figure (2b): Decreased precipitation rates in the equatorial Pacific indicate drier conditions in the mid-Holocene (filled contours) than preindustrial values (unfilled contours).
- Figure (2c): The tropical Pacific cools in the mid-Holocene (filled contours) relative to preindustrial conditions (unfilled contours).
- Forward modeled change in Kiritimati coral in mid-Holocene[4]:

$$\Delta\delta^{18}O_{pseudocoral} = (-0.22)\Delta SST + \Delta\delta^{18}O_{seawater}$$
$$= (-0.22)(-0.45) + (0.034)$$
$$= 0.13\ ‰$$

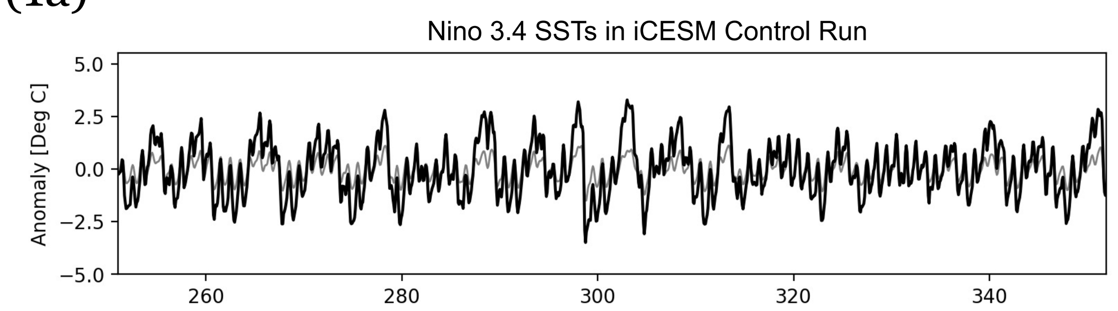
Discussion & Conclusions

The iCESM simulations indicate cooler/drier background conditions and a dampening of the annual cycle during the mid-Holocene, consistent with coral proxy data. We used a forward model of coral $\delta^{18}O$ to quantitatively compare the model simulations to proxy data and found that the forward modeled change in $\delta^{18}O_{pseudocoral}$ (+0.13‰) generally agrees well with the observed change in Kiritimati $\delta^{18}O_{coral}$ (+0.19‰). iCESM simulated a weak increase in mid-Holocene ENSO variance, which does not align with proxy data (indicating a 30-70% reduction in ENSO variance in the mid-Holocene[1]). This discrepancy could be a result of model inaccuracy or uncertainties in the proxy data. Further investigation of the discrepancy between the modeled ENSO variance and proxy data is necessary. A logical next step would be to compare our iCESM results to other climate model simulations.

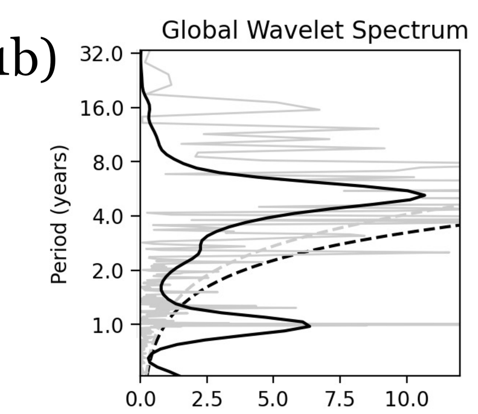
Data-model comparisons during well-described paleoclimate reference periods such as the mid-Holocene allow for improved understanding of climate system dynamics during periods of past climate change. In addition, such data-model comparisons help reduce uncertainty in the assessment of Earth's sensitivity to climate forcing, which is critical to our understanding of future anthropogenic climate change.

Seasonal and Interannual Variations

(1a)



(1b)



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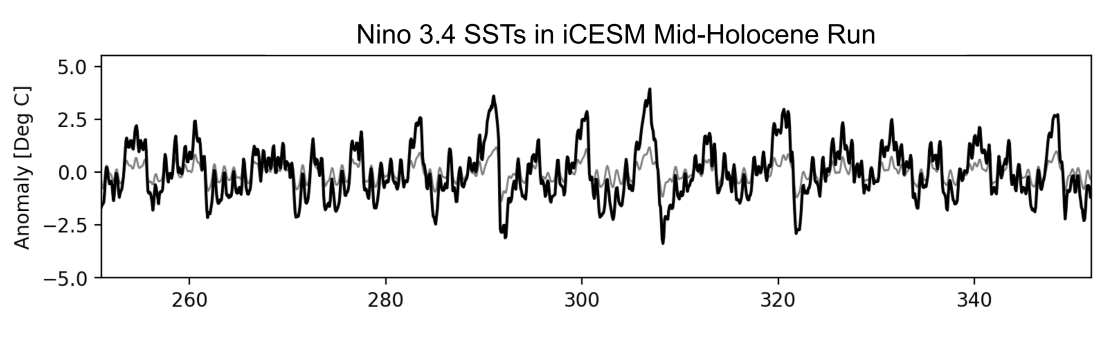
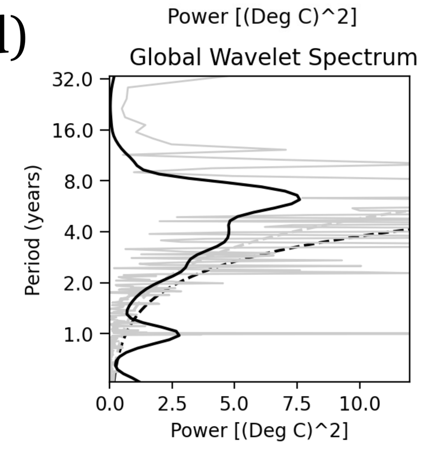


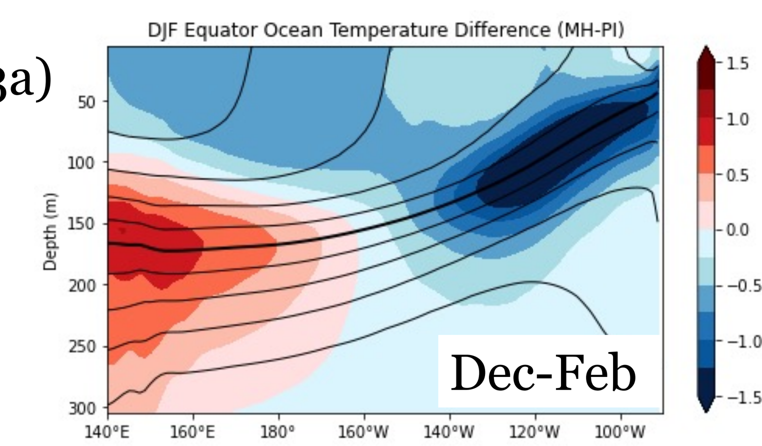
(1d)



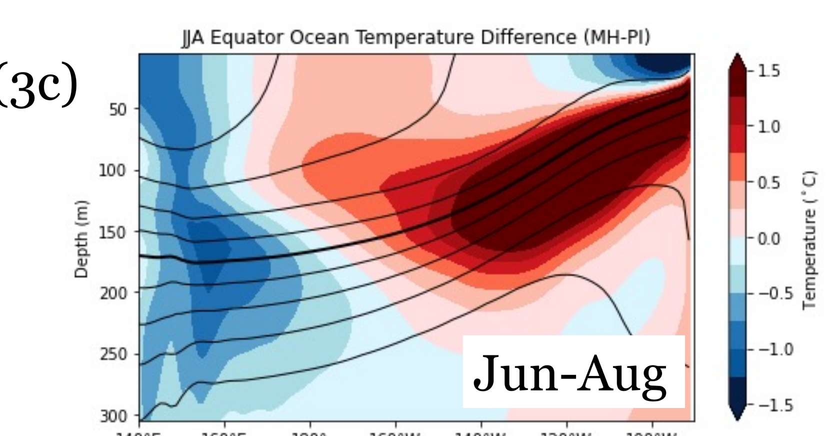
- Figure (1a): SST from preindustrial run of iCESM averaged over the Niño 3.4 region (5°N - 5°S and 170° - 120°W)
- Figure (1b): Power spectrum of preindustrial run shows annual cycle power and ENSO power
- Figure (1c): SST from iCESM mid-Holocene run for Niño 3.4 region
- Figure (1d): Power spectrum of mid-Holocene shows weakening of annual cycle. Mid-Holocene ENSO power distribution is shifted/widened.
- 5% increase in ENSO variance from preindustrial to mid-Holocene in the Niño 3.4 region
- 34% decrease in the SST annual cycle amplitude in the Niño 3.4 region

Subsurface Ocean Temperature

(3a)



(3c)



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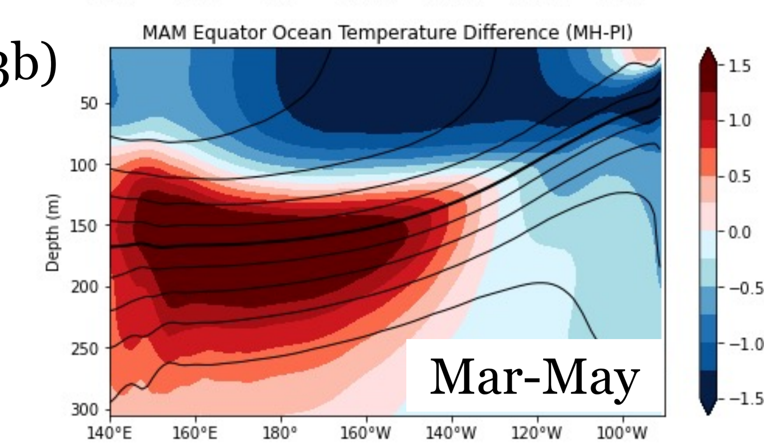
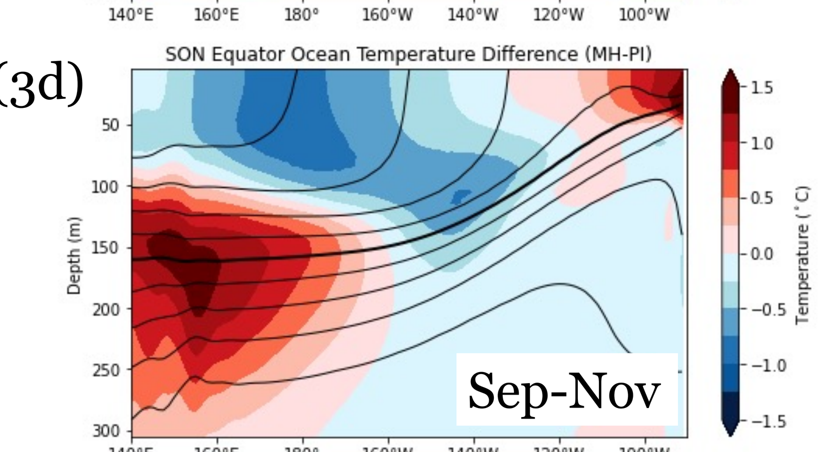


(3d)



- Figures (3a-d): Seasonal climatology of subsurface ocean temperature anomalies along the equator (mid-Holocene minus preindustrial).
- Anomalously warm mid-Holocene ocean temperatures (filled contours) travel from west to east along the equator starting in boreal fall/winter.
- The temperature anomalies are centered on the thermocline (unfilled contours from preindustrial run, 20°C isotherm in bold) indicating a deepening and diffusion of the thermocline during the mid-Holocene.
- The positive temperature anomalies reach the surface in the eastern Pacific in boreal fall (Sep-Nov). The warmer temperatures counteract the annual cycle, reducing the amplitude of the annual cycle in the mid-Holocene.

References

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2. Grothe, P. R., Cobb, K. M., Liguori, G., Di Lorenzo, E., Capotondi, A., Lu, Y., et al. (2020). Enhanced El Niño–Southern oscillation variability in recent decades. *Geophysical Research Letters*, 46, e2019GL083906. https://doi.org/10.1029/2019GL083906
3. Karamperidou, C., Di Nezio, P. N., Timmermann, A., Jin, F.-F., and Cobb, K. M. (2015), The response of ENSO flavors to mid-Holocene climate: Implications for proxy interpretation, *Paleoceanography*, 30, 527–547. doi:10.1002/2014PA002742.
4. Thompson, D. M., Ault, T. R., Evans, M. N., Cole, J. E., and Emile-Geay, J. (2011), Comparison of observed and simulated tropical climate trends using a forward model of coral δ 18O, *Geophys. Res. Lett.*, 38, L14706, doi:10.1029/2011GL048224.