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Detection of tropical Pacific Ocean mean state changes between the LGM and Holocene

Alicia Hou[1], Lukas Jonkers[2], and Sze Ling Ho[1]
[1]Institute of Oceanography, National Taiwan University, Taipei, Taiwan (slingho@ntu.edu.tw)
[2]MARUM Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany (ljonkers@marum.de)

The tropical Pacific Ocean can oscillate between different mean states, characterized by distinct upper ocean configurations. As these mean state shifts can have global climatic impacts, it is crucial to understand how they respond to global-scale forcing, particularly greenhouse gas (GHG) concentrations. Proxy- and model-based paleoclimate studies typically use a set of mean state indices, including the east-west sea surface temperature (SST) gradient, equatorial thermocline tilt, etc. for reconstructing orbital and glacial-interglacial tropical Pacific Ocean mean-state changes. However, it remains unclear whether these mean state diagnostics commonly adopted in paleoclimate studies are robust and can be observed in instrumental data. To this end, we first used ARGO data to critically examine how these indices behave in response to the shift from El Niño to La Niña conditions (i.e., two modern-day mean state end-members). Next, we used compiled proxy records and an ensemble of climate models from PMIP 3 and 4 to detect mean state changes between the LGM and Holocene, two past climate periods with markedly different GHG levels.

The computed LGM and Holocene mean state diagnostics reveal numerous proxy-model discrepancies, most notably in the eastern equatorial cold tongue (EECT). While proxies suggest that LGM SST cooling in the EECT was minimal and subsurface temperatures (SubTs) warmed, models show no evidence of reduced SST cooling nor SubT warming. As such, the proxy-derived LGM tropical Pacific mean state is characterized by reduced zonal SST and SubT gradients compared to the Holocene, whereas models show no significant glacial-interglacial differences. In line with previous proxy-based studies, we attribute the subdued SST cooling and SubT warming signals in the proxy data as strong indications that the effects of radiative cooling in the EECT are counteracted by dynamic processes such as upwelling, Intertropical Convergence Zone migrations, etc. Since model results indicate a direct upper ocean response in the EECT to glacial GHG reduction, we suggest that none of the models are capable of realistically simulating the dynamic processes operating in the EECT.

Both proxies and models indicate that the shift from LGM to Holocene climatic conditions produced zonally symmetrical upper ocean changes in the tropical Pacific. This differs from the distinctive zonally asymmetrical upper ocean responses during the shift from El Niño to La Niña conditions. Thus, our findings demonstrate that it is inappropriate to use modern-day El Niño-

Southern Oscillation dynamics to explain glacial-interglacial changes in tropical Pacific mean state. We note that the modelled regionally-averaged indices of tropical Pacific Ocean mean state are associated with exceptionally large spatial variabilities, such that it is nearly impossible to detect mean state differences between the LGM and Holocene. This indicates the need to use higher resolution regional models to elucidate regional-scale signals.