Ocean Heat Content in Warm Climates: Pliocene Simulations and Future Comparison

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Key Points

- **Simulated Mid-Pliocene Warm Period (MPWP; 3.2 Ma) Ocean Heat Content (OHC) is higher than pre-industrial everywhere except for the Arabian Sea.**
- **Arabian Sea behaviour driven by reduced high-salinity water formation and weakened Northeast monsoon winds.**
- **Tropical thermocline during the simulated MPWP warms & shoals from the pre-industrial over much of the Indo-Pacific.**
- **Simulated OHC during MPWP is 20% higher than SSP5-8.5 at 2100.**

Introduction & Methods

- ~ 90 % of additional anthropogenic heat has been stored in the ocean, modifying surface warming and increasing ocean heat content (OHC).
- Understanding the ocean's ability to continue storing heat is vital in understanding further anthropogenic climate change since this heat storage slows air temperature warming.
- The Mid-Pliocene Warm Period (MPWP; ~3.2 Ma) had GMST 2–4 °C warmer than modern [3] and similar atmospheric CO_2 (~400 ppm) [4].
- Therefore, the MPWP offers good opportunity to study how ocean heat is stored in a globally warm climate.
- To quantify OHC in top 700 m (OHC_{700}) during the MPWP, we use 13 models from the Pliocene Modelling Intercomparison Project phase 2 (PlioMIP2) ensemble and its *midPliocene* experiment.
- Key changes to *midPliocene* continental configuration: Bering Strait closure, and increased land exposure in the Canadian Archipelago and Maritime Continent. Most climate models implemented these changes, though some did not.
- To compare *midPliocene* OHC_{700} to future Shared Socio-economic Pathway (SSP) scenarios we use the CMIP6 subset of PlioMIP2.

OHC in the *midPliocene*

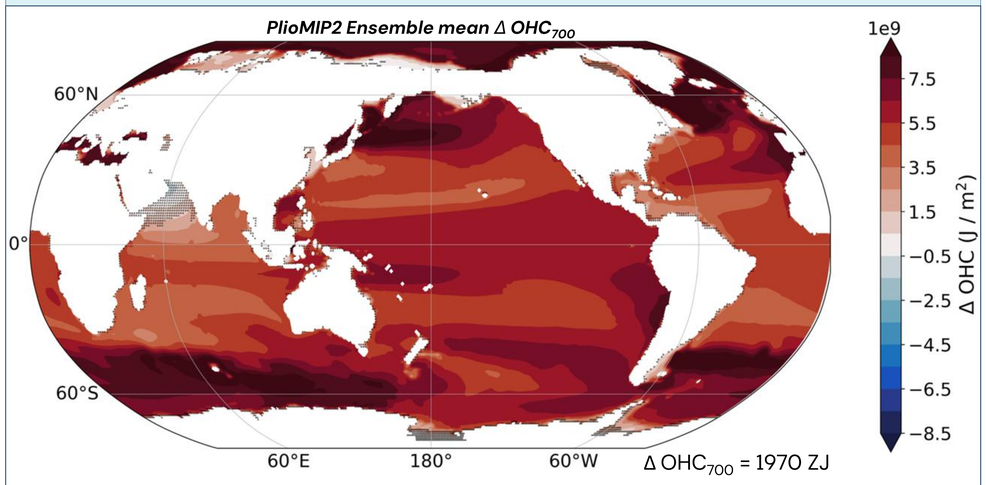


Figure 1: Simulated global annual multi-model mean OHC_{700} anomaly from *midPliocene* to *pre-industrial*. Stippling indicates disagreement between models, with fewer than 2/3 models agreeing upon the direction of change. Note: the area indicated as land is a combination of the continental configuration of the *midPliocene* and *pre-industrial*.

- All models simulate increase in OHC_{700} during the *midPliocene*. Ensemble mean increase: 1970 ZJ. In comparison, OHC_{700} increase over 1960–2024: ~290 ZJ [5].
- Northern Indian Ocean exhibits lowest increase & Arabian Sea reduces in many models. Arabian Sea SSTs warm most of tropical Indo-Pacific.
- OHC_{700} reduction characteristics impacted by continental configuration used.

midPliocene Thermocline Dynamics

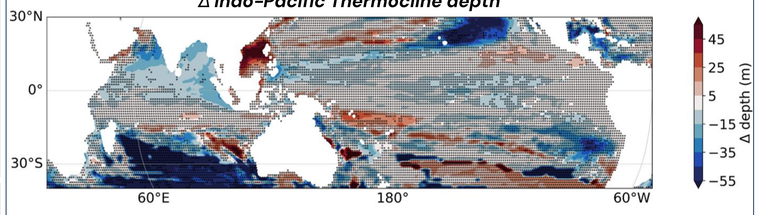


Figure 2: Annual Indo-Pacific ensemble mean anomaly from *midPliocene to pre-industrial* for thermocline depth. Thermocline depth is calculated classically as the maximum value of dT/dz. Stippling indicates disagreement with fewer than 2/3 models agreeing upon direction of change.

- Disagreement between models caused by model depth resolution limits & climate differences between models. Areas of agreement are physically meaningful.
- Shoaling across northern Indian Ocean, highest in Arabian Sea (seasonally greatest during DJF).
- Additional work linked shoaling and reduced Arabian Sea OHC to weakened Northeast Monsoon winds and reduced high-salinity water formation.
- Reduced Northeast Monsoon wind strength part of annual Southwest wind anomaly. Southwest wind anomaly due to change in Indian Ocean meridional SST gradient.

Indo-Pacific Equatorial Cross-Sections

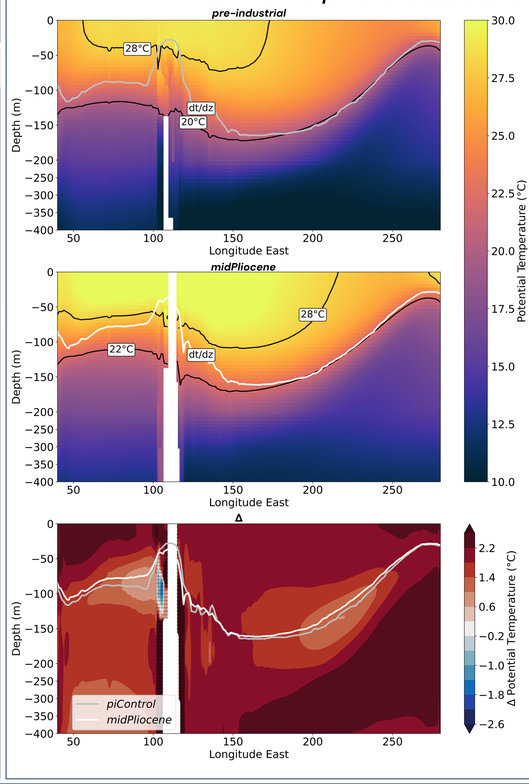


Figure 3: Ensemble mean equatorial (averaged over 5°N to 5°S) cross sections across the Indo-Pacific for a) *pre-industrial*, b) *midPliocene*, and c) the anomaly. Overlain are 20°C, 22°C and 28°C isotherms and thermocline depth for each experiment. In c), stippling indicates disagreement, where the threshold for agreement is 2/3 of the model ensemble agreeing upon the direction of change.

- Disconnect between Pacific equatorial thermocline and 20°C isotherm during *midPliocene*, 22°C isotherm better thermocline proxy during *midPliocene*.
- Neither isotherm appropriate proxy for equatorial thermocline in Indian Ocean.
- Warmed, not deepened, equatorial thermocline during *midPliocene* [2].

midPliocene vs. Future Scenarios

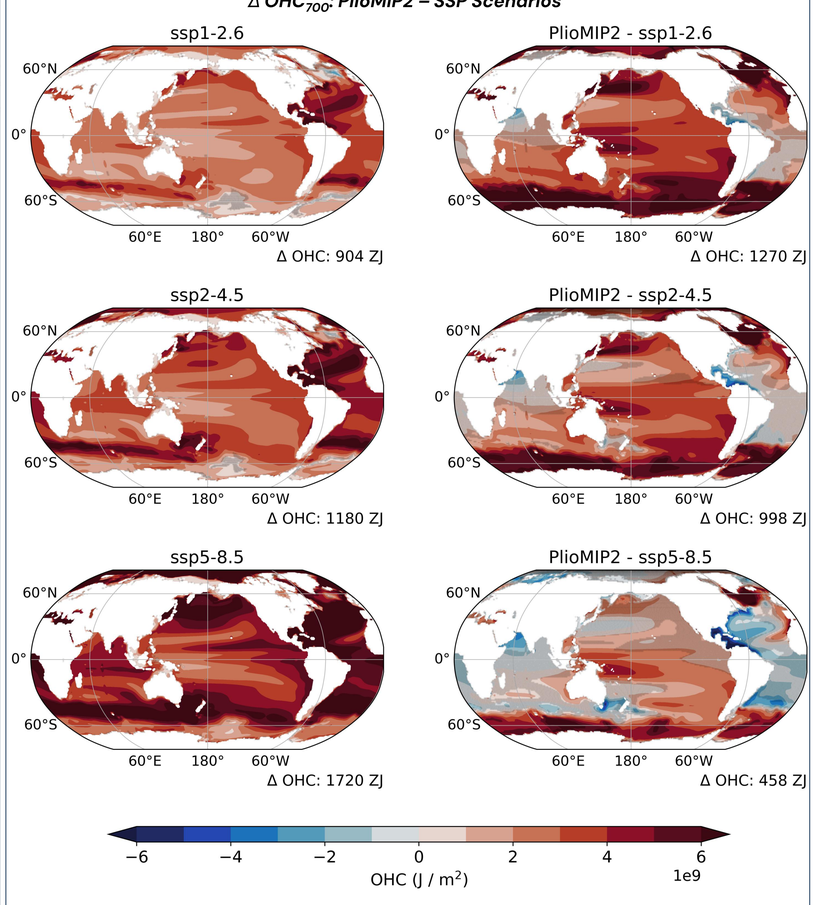


Figure 4: Anomalies in annual mean OHC_{700} from future SSP scenarios averaged over 2081–2100 from *historical* averaged over 1850–1900 (first column) and the difference between future scenario anomaly and *midPliocene* anomaly (second column; i.e [future scenario – historical] – [*midPliocene – pre-industrial*]). Stippling indicates disagreement between models where fewer than 2/3 models agree upon the direction of change.

- *midPliocene* OHC_{700} is higher than all future scenarios at 2100, exceeding the high emission SSP5-8.5 by ~20%.
- High heterogeneity in OHC_{700} pattern between *midPliocene* and SSP scenarios. Larger build-up of heat in the Atlantic Ocean under future scenarios [6,7].
- *midPliocene* warmth and heteregenity caused by unfair comparison between quasi-equilibrium experiment (*midPliocene*) and transient experiments (SSPs).
- Warmth in future scenario Atlantic linked to increased AMOC in *midPliocene* and reduced in future scenarios [6,7].
- Additional work showed SSP5-8.5 exceeded the *midPliocene* OHC_{700} anomaly by 2300; though SSP1-2.6 did not [1].

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