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Modeled changes in marine primary productivity under Middle Miocene warming

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The future of the marine biological carbon pump under warming conditions remains uncertain. Studies on high CO_2 scenarios are limited due to historically poor representation of phytoplankton ecology in fully-coupled Earth System Models. With the coupling of the Marine Biogeochemical Library (MARBL) to the Community Earth System Model (CESM2), we can now explore marine carbon sequestration under varied atmospheric CO_2 at a more advanced level. CESM-MARBL simulates key phytoplankton growth factors with complex, dynamic ocean-atmosphere physics, distinguishing it from simpler models [1]. Pre-industrial MARBL simulations offer insights into marine carbon cycling and ecosystem dynamics but can only be validated against present-day observations. Modeling past warm climates, and validating the output with proxy data from past warm periods, serves as a valuable tool to infer possible future trends [2]. Here, we simulate the Miocene Climatic Optimum (MCO, ~15 Ma) warming using CESM-MARBL, comparing 280 ppm and 560 ppm CO_2 runs at 1° ocean resolution to analyze phytoplankton activity and marine carbon sequestration under increased CO_2 in the context of this past warming interval.

We found global marine carbon fixation increased under higher CO_2 conditions, with increases and poleward shifts in small phytoplankton and coccolithophores and declines in diatoms, which were largely controlled by changes in nutrients. Stratification, driven by surface heating, sea ice melt, and weakened winds, governs this nutrient distribution. We compare these findings with MCO fossil evidence and focus on latitudinal gradients in mass accumulation rates and coccolithophore-specific traits, such as cell size and degree of calcification (as a proxy for PIC/POC ratios). Our results agree with previous studies that predict intensified stratification and shifts toward smaller phytoplankton in future warmer conditions [3]. Despite modeling uncertainties, we find valuable insights into phytoplankton ecology and marine carbon sequestration under a previous warming event in Earth's history.

[1] Long, Moore, Lindsay, Levy, Doney, Luo, Krumhardt, Letscher, Grover, & Sylvester (2021), *JAMES* 13. [2] Tierney, Poulsen, Montañez, Bhattacharya, Feng, Ford, Hönisch, Inglis, Petersen, Sagoo, Tabor, Thirumalai, Zhu, Burls, Foster, Goddéris, Huber, Ivany, Kirtland Turner, Lunt, McElwain, Millis, Otto-Bliesner, Ridgwell, & Zhang (2020), *Science* 370. [3] Passow & Carlson (2012), *MEPS* 470.