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# Coupled sea surface temperature and $pCO_2$ evolution during the Tortonian

**MADELEINE SANTOS**, RETO WIJKER AND HEATHER STOLL

ETH Zürich

The Tortonian stage (11.6–7.2 Ma) represents a sustained warm interval preceding the Late Miocene Cooling (7.5–5.5 Ma), during which high-latitude temperatures exceeded modern values by up to ~17°C. Atmospheric $CO_2$ reconstructions for the Tortonian remain poorly constrained, with existing proxy records suggesting either elevated concentrations approaching ~790 ppm at ~11 Ma or more moderate and relatively stable $CO_2$ levels.

Here, we present new high-latitude $pCO_2$ reconstructions based on alkenone carbon isotopic fractionation (εp) from Ocean Drilling Program (ODP) Site 1088 in the subantarctic South Atlantic, spanning 11.6 to 9.0 Ma. New alkenone-derived sea surface temperature (SST) reconstructions from $Uk'_{37}$ ratios reveal a pronounced warming from ~13°C at 12.65 Ma to ~21°C at ~10.7 Ma, followed by a sustained warm interval between ~10.7 and 8 Ma with SSTs ranging from 19 to 23°C. The subsequent Late Miocene Cooling is marked by a progressive decline in SST to ~14°C by 5.5 Ma. Combined benthic and bulk carbonate $\delta^{13}C$ and $\delta^{18}O$ records identify the Tortonian thermal maximum and guide targeted higher-resolution sampling across intervals of peak warmth and transition.

Carbon isotopic fractionation (εp) is calculated from compound-specific $\delta^{13}C$ measurements of the $C_{37:2}$ alkenone. The isotopic composition of dissolved inorganic carbon is estimated from planktonic foraminiferal (G. bulloides) $\delta^{13}C$, accounting for temperature-dependent fractionation between DIC and aqueous $CO_2$. Atmospheric $pCO_2$ is reconstructed using a probabilistic εp model that incorporates coccolithophore cell size, growth rate, and light availability. Coccolith size and thickness distributions are quantified using circular polarized light microscopy, while growth rates are constrained from temperature and nutrient proxy data.

By integrating new SST reconstructions with proxy-based $pCO_2$ estimates and coccolith morphometrics, this study provides improved constraints on carbon cycle–climate coupling during the Tortonian warm interval and the transition into the Late Miocene Cooling, offering new insight into the sensitivity of high-latitude oceans to changing atmospheric $CO_2$.