

Coccolith clumped isotopes reveal: coccolithophores can live at depth, Miocene North Atlantic wasn't that warm, and Cenozoic ocean's temperature history

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Clumped isotope (Δ_{47}) thermometry circumvents the limitations of other temperature proxies, because it is independent from seawater chemistry, and the controlling mechanisms are well-understood and uniquely based in thermodynamics. Its application to the geographical and temporal ubiquitously-distributed coccolith calcite ensures a signal from the euphotic oceans, and promises to improve absolute euphotic ocean's reconstructions.

Globally-distributed Holocene coccolith Δ_{47} provide evidence that coccolithophores inhabit and calcify deeper than at surface waters, especially in the tropics. This contradicts the traditional interpretation of widely-used coccolithophore-based proxies calibrated to Sea Surface Temperatures (SSTs), like alkenones, and highlights the potential for overestimating absolute temperature values of reconstructions used to compare models to.

Pure coccolith Δ_{47} suggest a significantly colder ($\sim 9^\circ\text{C}$) North Atlantic (ODP 982) since the Mid-Miocene compared to SSTs from alkenones of the same samples. The difference could be partly explained by the alkenone traditional interpretation assuming mean annual or summer production and that coccoliths are produced at the surface. The colder coccolith Δ_{47} temperatures match the modern ocean and are the first to agree with Miocene climate models, which struggle to achieve the extreme high latitude warmth suggested by other proxies.

Here we also provide the first attempt of a Cenozoic coccolith Δ_{47} temperature record from low latitudes (Eastern Equatorial Pacific -EEP- PEAT transect) and a high latitude Site (ODP 1170, South Tasman Rise). A similar magnitude of Mid-Miocene high latitude amplification at 15-16 Ma is observed for the Southern Hemisphere (ODP 1170) compared to the North Atlantic (ODP 982), both suggesting a modest and not extreme polar amplification, providing a less catastrophic view of high

latitude climate response to anthropogenic CO₂. While trends from both low and high latitude records are as expected from climate variability derived from foraminiferal $\delta^{18}\text{O}$, EEP absolute values are cold for a tropical location. Though early recrystallization (i.e before 2 My) could explain these results, neither SEM nor trace element analyses showed signs of significant overgrowth. Further potential modulators of temperature in this area include varying sources and/or strength of upwelling over time, and varying depth of production modulated by nutrients vs. light availability.