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The meridional temperature gradient under greenhouse climatic state: a data-models discrepancy?

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The Eocene is the last period of extremely high temperatures and CO_2 levels of the Cenozoic and it represents a possible analogue for anthropogenic climate settings. During this pivotal period the Earth's climate shifts from Greenhouse to modern Icehouse conditions at the Eocene-Oligocene transition (EOT). This major transition has been largely explored, but the driving mechanisms behind the long term evolution are not well constrained. During the warm Paleogene, large uncertainty affects the reconstruction of both the equator-to-pole distribution of sea surface temperature (SST) and the atmospheric pCO_2, the two foremost controlling parameters of the Earth climate dynamics. Available paleodata (TEX_{86}; $\Delta 47$ and Mg/Ca on foraminifera) show a reduced latitudinal temperature gradient compared to present-day settings. Despite improved model–proxy agreement in the terrestrial realm, climate models struggle to reproduce this low equator-to-pole gradient even under high pCO_2 conditions. In this study, we take advantage of recent developments in the biogeochemistry of coccolithophores to exploit the isotopic signals ($\delta^{18}O$ and $\delta^{13}C$) of their calcite biominerals - the coccoliths - as a new source of paleoclimatic information. Coccoliths are produced in the mixed layer and their good preservation, even in warm and high pCO_2 settings, may overcome methodological caveats associated with the absence or frequent recrystallization of foraminiferal shells. Four latitudinally-distributed sites across the Atlantic Ocean are investigated to reconstruct the evolution of the meridional SST gradient over the Paleogene. The reconstructed temperature changes challenge the previously reported trends and the extreme warmth described at high latitude locations. Our results provide evidence for the existence of a strong equator-to-pole temperature gradient in the Atlantic Ocean since the Early Eocene. From a modelling perspective, our new coccolith $\delta^{18}O$-derived gradient is more in line with the modelled Early Eocene temperatures gradients. This may resolve the proxy-model discrepancy without invoking a "missing physics" in the models or fundamental changes in the mechanisms of heat transport. Associated to these $\delta^{18}O$-derived SST reconstructions, pCO_2 estimates are assessed from the $\delta^{13}C$ offset between size-restricted coccolith assemblages. Altogether these new data will contribute to the refinement of climate models and finally better constrain greenhouse climatic state that may potentially occur in the near future.