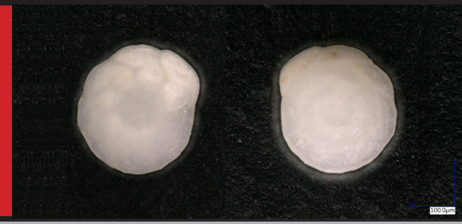
Warm deep-sea temperatures across Eocene Thermal Maximum 2 from clumped isotope thermometry (Δ_{47})



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Background: A potential analogue for the future climate state is the ice-free hothouse climate of the early Eocene (56–48 Ma)[1]. This period experienced the highest CO_2 levels of the Cenozoic (~1000 ppm)[2], as well as the occurrence of multiple transient (10–100 kyr) global warming events, so-called hyperthermals[3]. These events are recorded by negative excursions in carbon and oxygen isotopes ($\delta^{13}C$ and $\delta^{18}O$) in deep-sea sediments, which reflect major short-lived perturbations of the carbon cycle and climate system (Figure 1)[1,3].

MOTIVATION: The deep ocean constitutes a stable and vast heat reservoir in the climate system, and is therefore assumed to represent a setting to estimate past global mean temperatures[4]. However, available deep-sea temperature estimates from foraminiferal $\delta^{18}O$ and Mg/Ca rely on uncertain assumptions, such as estimation of the chemical composition of the ancient seawater, pH and biological factors[5,6]. Here, we apply for the first time the carbonate clumped isotope paleothermometer (Δ_{47}), a proxy independent of these non-thermal factors[7,8], to reconstruct early Eocene deep-sea temperatures across two hyperthermal events.

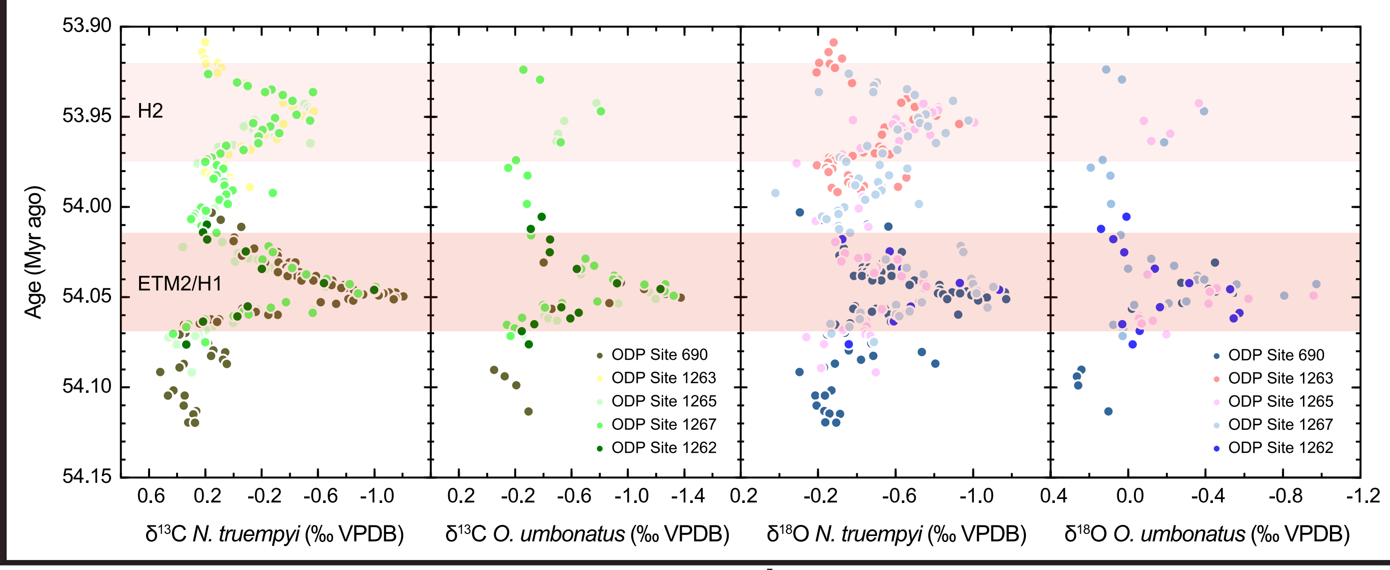
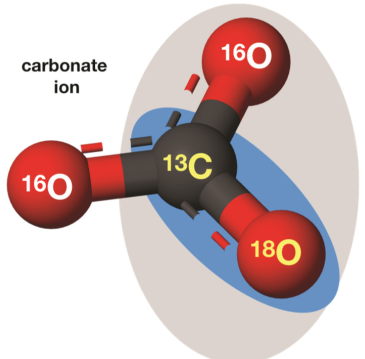


Figure 1. Benthic foraminiferal $\delta^{13}C$ and $\delta^{18}O$ records across ETM2 and H2 from multiple sites in the South Atlantic measured on *Nutallides truempyi* and *Oridorsalis umbonatus*. The offset in the stable isotopes between the two species indicate species-specific vital effects.



METHODS

- Paired stable ($\delta^{13}C$ and $\delta^{18}O$) and clumped isotope (Δ_{47}) analysis across the ETM2/H1 and H2 hyperthermals on benthic foraminifera from ODP Sites 690, 1262, 1263, 1265, and 1267 in the South Atlantic Ocean.
- *Nutallides truempyi* and *Oridorsalis umbonatus* were measured on a Thermo 253+ with Kiel-IV instrument in the geolab of Utrecht University[9,10]. For each replicate measurement (80 µg) about 25 specimens were picked and ultrasonically cleaned.
- Clumped isotope analysis is characterized by a low analytical precision due to the sporadic natural abundance of ^{13}C–^{18}O bonds in carbonate ions[7]. Averaging multiple Δ_{47} measurements is required to obtain precise temperature estimates[11]. Here, we compiled Δ_{47} temperature bins for the average background, slope, and average hyperthermal peak state based on the $\delta^{18}O$ values corresponding to these measurements (optimal bin sizes determined using t-test)[11].

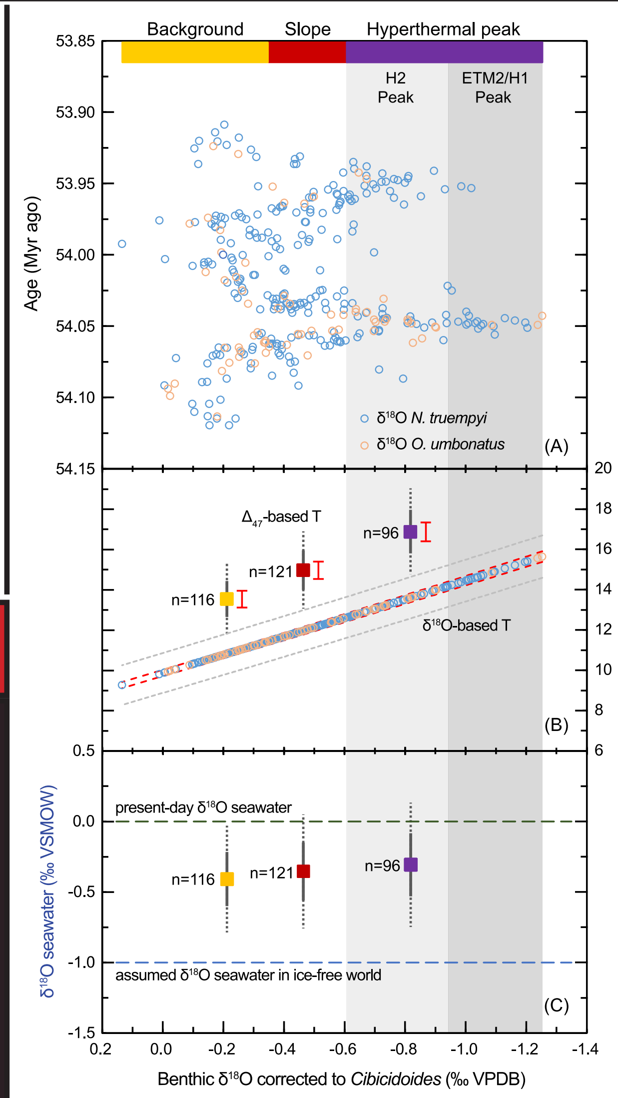


Figure 2. (a) Benthic foraminiferal $\delta^{18}O$ values across ETM2 and H2 corrected to *Cibicidoides* for assumed seawater equilibrium. **(b)** Deep-sea temperatures based on Δ_{47} and $\delta^{18}O$ (assuming ice-free world) including analytical (dark grey; 68% and 95% CI for Δ_{47} and 2xSD of the IAEA-C2 standard for $\delta^{18}O$) and calibration (red; 95% CI) uncertainties. **(c)** Calculated seawater $\delta^{18}O$ is much higher than the assumed value based on ice-free conditions. Alternatively, this assumed seawater $\delta^{18}O$ value may be correct when an effect of low bottom water pH on foraminiferal $\delta^{18}O$ is taken into account[12–14].

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- Our independent early Eocene deep-sea temperature reconstructions indicate 13.5±1.8 °C (95% CI) for the background conditions, and average hyperthermal peak temperatures of 16.9±2.2 °C (95% CI).
- On average, absolute temperatures are three degrees warmer from clumped isotope thermometry than from conventional benthic oxygen isotopes.
- This finding implies a necessary reassessment of the seawater isotope composition and pH in the deep ocean during the Eocene, and of a potential pH effect on benthic foraminiferal oxygen isotopes.
- Future work: the clumped isotope proxy opens up new opportunities to investigate the distribution of different water masses in the ocean basins and test the existing views on the homogeneity/heterogeneity of the ocean over the Cenozoic[15].

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References

(1) Zachos et al. (2008). An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics. Nature; (2) Anagnostou et al. (2016). Changing atmospheric CO2 concentration was the primary driver of early Cenozoic climate. Nature; (3) Lauretano et al. (2018) Orbitally paced carbon and deep-sea temperature changes at the peak of the early Eocene climatic optimum. Paleoceanography and Paleoclimatology; (4) Hansen et al. (2013). Climate sensitivity, sea level and atmospheric carbon dioxide. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences; (5) Pearson (2012). Oxygen isotopes in foraminifera: Overview and historical review. The Paleontological Society Papers; (6) Evans & Müller (2012). Deep time foraminifera Mg/Ca paleothermometry: Nonlinear correction for secular change in seawater Mg/Ca. Paleoceanography; (7) Eiler (2011). Paleoclimate reconstruction using carbonate clumped isotope thermometry. Quaternary Science Reviews; (8) Meinicke et al. (2020). A robust calibration of the clumped isotopes to temperature relationship for foraminifers. Geochim. Cosmochim. Acta; (9) Meckler et al. (2014). Long-term performance of the Kiel carbonate device with a new correction scheme for clumped isotope measurements. Rapid Communications in Mass Spectrometry; (10) Bernasconi et al. (2018). Reducing uncertainties in carbonate clumped isotope analysis through consistent carbonate-based standardization. Geochemistry, Geophysics, Geosystems; (11) de Winter et al. (2020). Optimizing sampling strategies in high-resolution paleoclimate records. Climate of the Past; (12) Raitzsch & Hönisch (2013). Cenozoic boron isotope variations in benthic foraminifers. Geology; (13) Spero et al. (1997). Effect of seawater carbonate concentration on foraminiferal carbon and oxygen isotopes. Nature; (14) Uchikawa & Zeebe (2010). Examining possible effects of seawater pH decline on foraminiferal stable isotopes during the Paleocene-Eocene Thermal Maximum. Paleoceanography; (15) Cramer et al. (2009). Ocean overturning since the Late Cretaceous: Inferences from a new benthic foraminiferal isotope compilation. Paleoceanography.