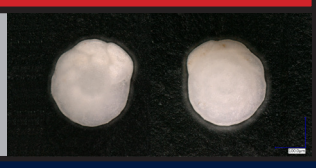
Independent constraints on South Atlantic deep-ocean temperatures across the early Eocene ETM-2 and H2 hyperthermals based on clumped isotopes

Tobias Agterhuis (t.agterhuis@uu.nl)[1], Martin Ziegler[1] & Lucas J. Lourens[1]

[1]Paleoclimate & Biogeology, Department of Earth Sciences, Faculty of Geosciences, Utrecht University, the Netherlands



Background: The extreme ice-free greenhouse climate of the early Eocene (56–49 Ma) (Figure 1) is the warmest interval of the Cenozoic and is characterized by CO_2 levels much higher than today (~600–2000 ppm)[1,2]. Deep-sea benthic foraminiferal $\delta^{13}C$ en $\delta^{18}O$ records have revealed that towards the Early Eocene Climatic Optimum (EECO; 52–50 Ma) (Figure 1) a long-term warming trend is punctuated by a series of transient (10–100 kyr) episodes of global warming[3,4,5]. These events are termed hyperthermals (e.g. PETM, ETM-2/H1 and ETM-3/K) and reflect major short-lived perturbations of the carbon cycle and climate system (Figure 2)[3,4,5].

At the moment most of Cenozoic deep-water temperature reconstructions are based on foraminiferal $\delta^{18}O$. However, uncertainties are contained in the assumptions underlying this proxy[6,7]. One major assumption concerns the estimation of $\delta^{18}O$ of the seawater, which is controlled by ice volume and salinity, and is poorly constrained for the earth's past[6,7]. Furthermore, physiological factors (vital effects) cause additional uncertainty in the temperature estimates[6,7]. The relatively new proxy carbonate clumped isotopes (Δ_{47}) is solely controlled by temperature[8] and therefore has high potential for producing robust constraints on paleotemperature[7]. Here, we show its first application for deep-ocean environments during the early Eocene.

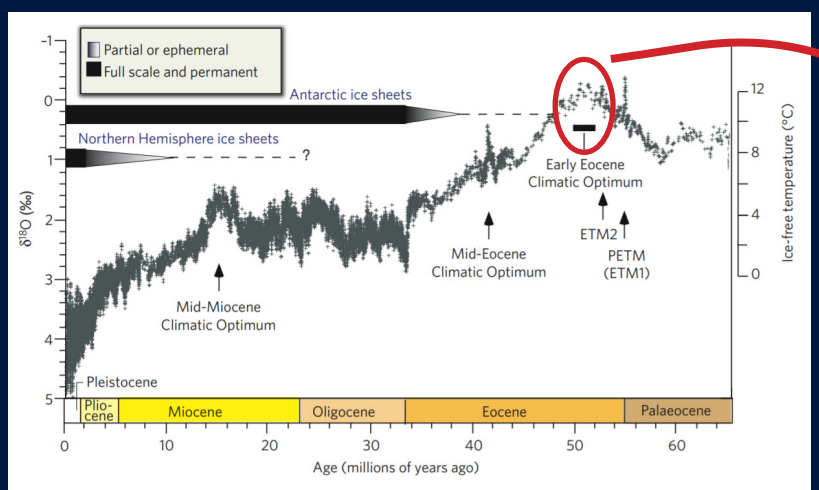


Figure 1. Cenozoic deep-ocean temperature evolution based on $\delta^{18}O$[1]

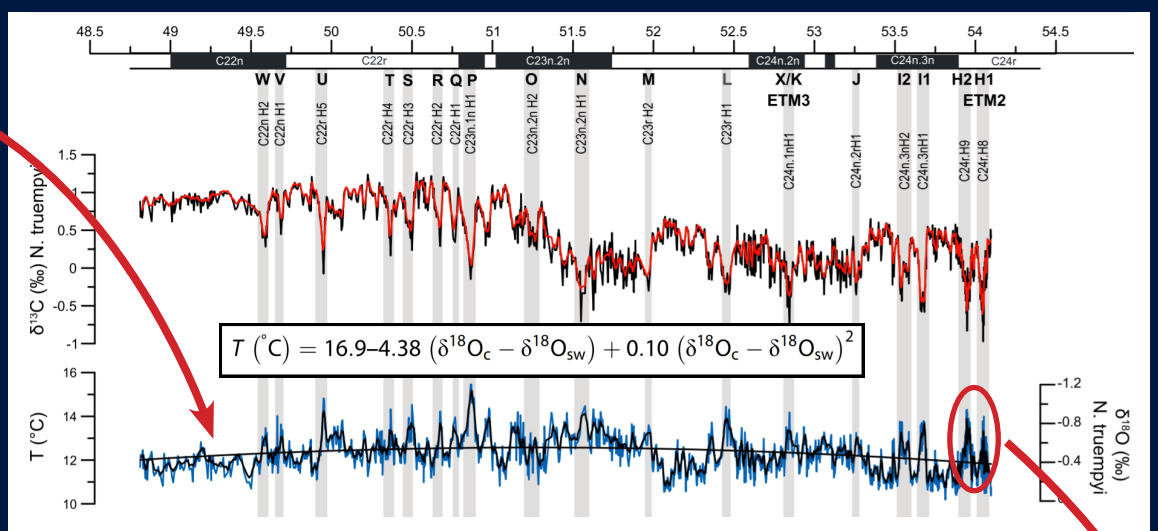


Figure 2. High-resolution early Eocene benthic $\delta^{13}C$ en $\delta^{18}O$ records from the Walvis Ridge (SE Atlantic)[5]

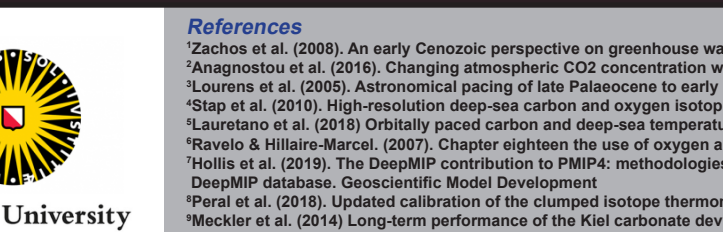
METHODS

Carbonate clumped isotope paleothermometry (Δ_{47})

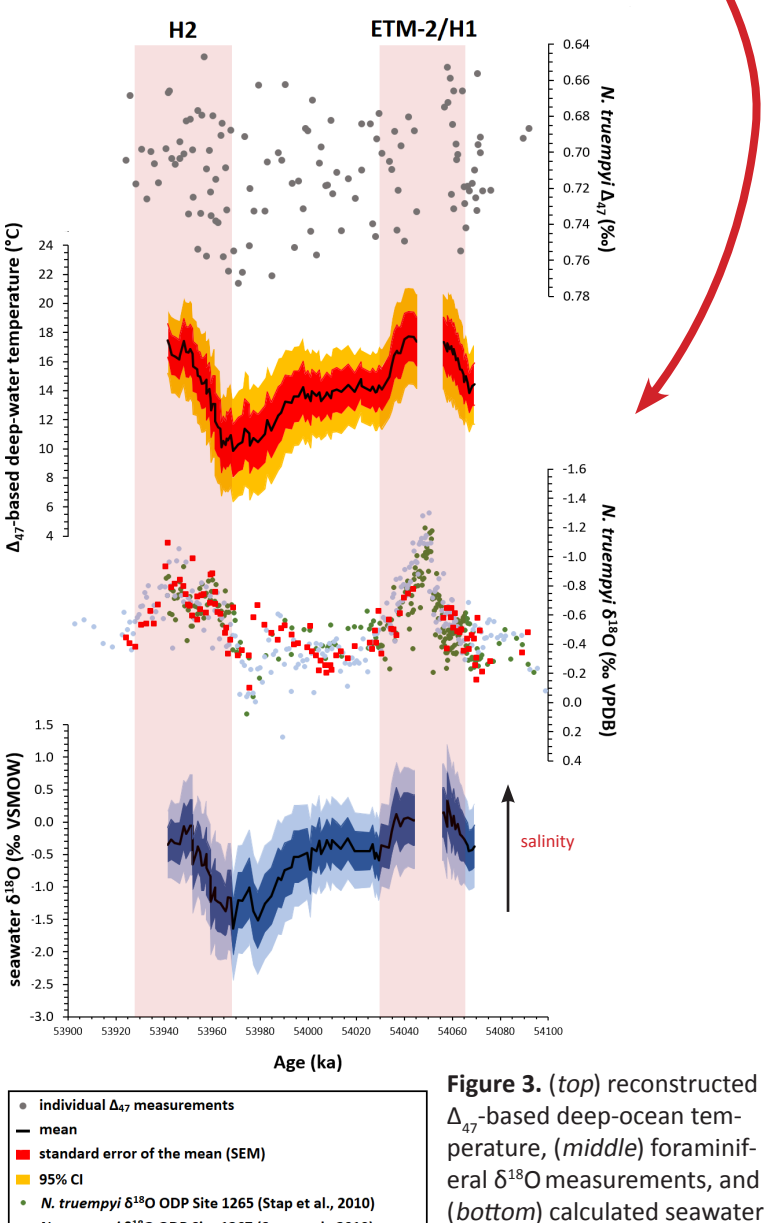
- Degree of clumping of heavy isotopes is only dependent on temperature (independent of fluid composition)[8]
- Foraminiferal cultures do not show vital/species effects for Δ_{47}[8]
- However, because the proxy temperature sensitivity is low and the analytical target rare (mass-47) many replicate measurements (~30) are required

Utrecht University clumped isotope lab

- Reconstructing deep-water temperatures across ETM-2/H1 and H2 using material from ODP Sites 1265 and 1267 (Walvis Ridge, SE Atlantic)
- Benthic foraminifera *Nutallides truempyi* was measured for Δ_{47} on a Thermo 253+ with Kiel-IV instrument[9,10]. For each replicate measurement (80 µg) about 30 specimens were picked and ultrasonically cleaned. $\delta^{18}O$ is simultaneously measured with Δ_{47}



RESULTS



Note: work in progress; data generation, compilation and processing not yet final

Figure 3. (*top*) reconstructed Δ_{47}-based deep-ocean temperature, (*middle*) foraminiferal $\delta^{18}O$ measurements, and (*bottom*) calculated seawater $\delta^{18}O$ using reconstructed temperature and $\delta^{18}O_{calcite}$ data. Due to a limited amount of replicates a moving window of 21 measurements was applied.

TAKE HOME MESSAGES

- First independent constraints on deep-water temperatures during the early Eocene: 13.5±2.9(95% CI) °C for background conditions
- Clumped isotopes show that bottom water temperatures substantially rose to 17±3.0(95% CI) °C during H2 event
- In combination with $\delta^{18}O$ of foraminiferal calcite, calculation of seawater $\delta^{18}O$ is possible. A substantial increase in seawater $\delta^{18}O$ across H2 is revealed and may be caused by an increase in salinity
- **Our results could indicate a change in ocean circulation during hyperthermals, represented by a shift in the source region(s) of deep waters, i.e. deep-water formation in warmer and more saline sea surface waters**
- Future work: (1) continue with adding measurements to reduce temperature uncertainties, (2) reconstruct and compare different ocean basins and latitudes, and (3) modeling of early Eocene climate, hyperthermals and ocean circulation (in cooperation with IMAU)

NESSC NETHERLANDS EARTH SYSTEM SCIENCE CENTRE

Utrecht University

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]Lourens et al. (2005). Astronomical pacing of late Palaeocene to early Eocene global warming events. Nature
[4]Stap et al. (2010). High-resolution deep-sea carbon and oxygen isotope records of Eocene Thermal Maximum 2 and H2. Geology
[5]Lauretano et al. (2018) Orbitally paced carbon and deep-sea temperature changes at the peak of the early Eocene climatic optimum. Paleoceanography and Paleoclimatology
[6]Ravelo & Hillaire-Marcel. (2007). Chapter eighteen the use of oxygen and carbon isotopes of foraminifera in paleoceanography. Developments in marine geology
[7]Hollis et al. (2019). The DeepMIP contribution to PMIP4: methodologies for selection, compilation and analysis of latest Paleocene and early Eocene climate proxy data, incorporating version 0.1 of the DeepMIP database. Geoscientific Model Development
[8]Peral et al. (2018). Updated calibration of the clumped isotope thermometer in planktonic and benthic foraminifera. Geochimica et Cosmochimica 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