Investigating tropical-African climate during the Late Pleistocene and Holocene using biomarkers from Lake Chala

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Introduction and Motivation

Much of our knowledge of Earth's Quaternary climate history is derived from deep-sea sediments or from ice-sheet cores at high latitudes. Therefore, more long-term records from tropical continental contexts are needed to better appreciate how climate has developed globally. Particularly, developing reliable methods for estimating absolute temperature in the past is crucial for relating global and regional climate changes. Further, there is a need for methods to evaluate past rainfall independently of the moisture source, as rainfall is often a limiting factor in vegetation growth and therefore also in the movement of humans and animals.

Being the largest landmass at the equator, with a considerable number of ancient lakes, tropical Africa has become a hotspot for paleoclimate research. Lakes are excellent settings for multi-proxy climate studies as they carry information about both terrestrial processes from the surrounding area, such as vegetation change, and variation within the lake itself.

RESEARCH QUESTIONS

- **What influences temperature and precipitation in equatorial East Africa?**
  Glacial-interglacial cycles? Astronomical precession? Heinrich events?
- **How can we interpret GDGT-based climate proxies in tropical lakes?**
  What influences GDGT distribution? Which calibrations and proxies are most successful/suitable?

ICDP project DeepCHALLA

- In 2016, 215 meter (roughly the last 250 kyrs) of profundal lake sediments were recovered from Lake Chala in eastern equatorial Africa.
- The unique location of Lake Chala just below the equator makes it ideal for reconstructing past behaviour of the Intertropical Convergence Zone (ITCZ), the North-Eastern and South-Eastern Indian monsoons (SE-IM, NE-IM) and the Congo Air Boundary (CAB).
- The ITCZ passes over Lake Chala twice a year, driving the Indian monsoons and delivering moisture to the region. The two rainy seasons are separated by a dry and windy period during which oxycline extends deeper into the lake
- The bottom waters of Lake Chala are permanently anoxic leading to excellent preservation of organic material.

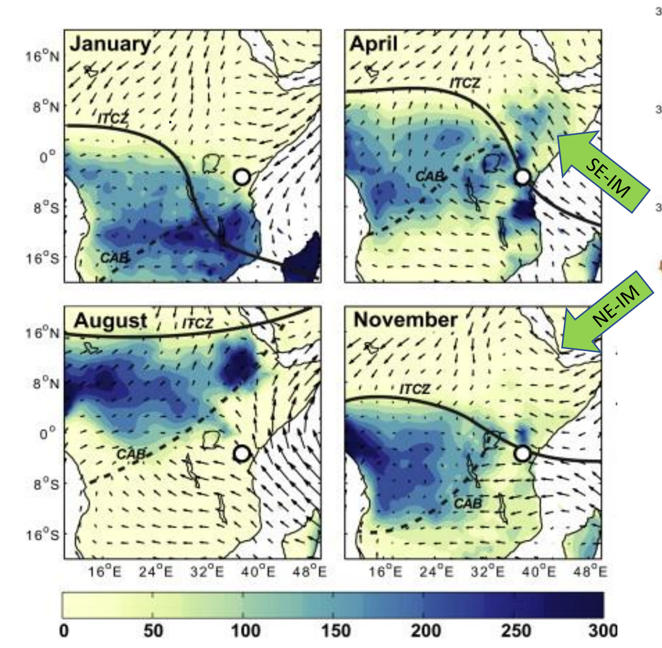


Fig 1.

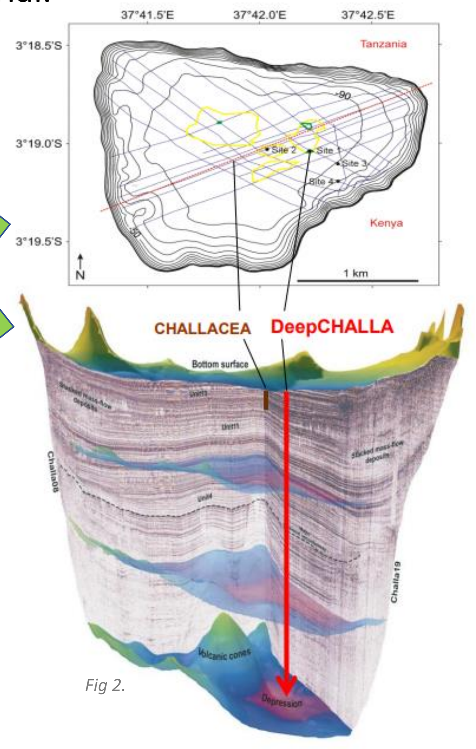
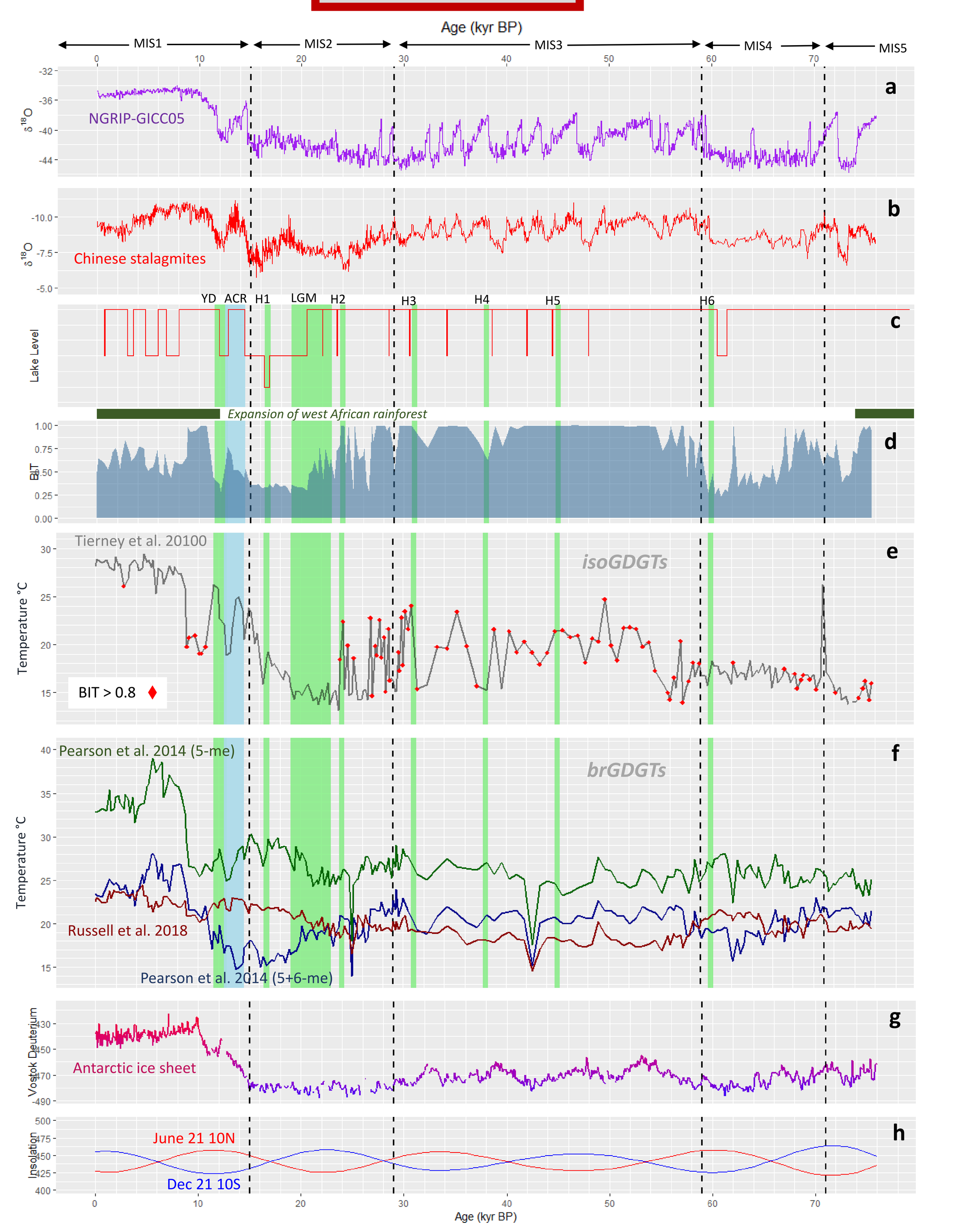


Fig 2.

Results



Discussion

Proxy interpretation…

- BIT and lake-level record (based on seismic stratigraphy) generally agree, with low BIT intervals corresponding to low-stands (Fig 6c,d).
- Changes in the abundances of GDGTs record temperature variation.
- IsoGDGTs: During high BIT intervals (when crenarchaeol concentration is very low), TEX86-based calibrations such as that of Tierney et al. (2010) are potentially unreliable as the signal may be overpowered by isoGDGTs from sources other than *Thaumarchaeota* (See Fig 6e, red points).
- Further, lake-level change will impact water-column stratification and the depth of crenarchaeal production, and hence may influence the TEX86 temperature signal (Kumar et al. 2019).
- brGDGTs: 6-me brGDGTs are important. The Pearson et al. (2014) calibration, which uses only the 5-me brGDGTs, significantly overestimates temperature (Fig 6f).
- The calibration matters: temperature calibrations vary considerably in timing and magnitude of changes—this is particularly clear during the last deglaciation (Fig 6e,f). The Russel et al. (2018) calibration estimates a gradual transition to warmer climate starting ca. 50 ka BP, while the Tierney et al. (2010) and Pearson et al. (2004) calibrations show a sharp increase in temperature (from ca. 20 or 16 ka BP respectively), more congruent with temperature changes recorded in the Greenland and Antarctic ice cores.

Fig 6. Blue and green shaded regions represent southern and northern high latitude climate events respectively; Younger Dryas (YD); Antarctic cold reversal (ACR); Last Glacial Maximum (LGM); Heinrich events 1-6 (H1-6). (a) δ18O record in ‰ SMOW from the NGRIP core, Greenland (Rasmussen et al., 2006) (b) Stalagmite δ18O in ‰ VPDB record from four Chinese caves (Cheng et al. 2016). (c) Lake Chala lake level reconstruction based on seismic reflection data (Moernaut et al., 2010). (d) Rainfall reconstruction of Lake Chala based on the BIT index. Green bar indicates periods of expansion rain forest in western Africa based on pollen from marine and terrestrial cores (Dupont et al., 2002) (e). Mean annual air temperature reconstruction of Lake Chala based on the calibration of Russell et al. (2018), shown in red, and average lake surface temperature reconstruction using calibration of Tierney et al., 2010 (grey). (f) Average lake surface temperature reconstruction based on model of Pearson et al., 2004. (g) Deuterium content in ‰ SMOW from the Vostok ice core Antarctica (Petit et al., 1999). (h) Daily mean insolation in W/m^2 for June 21 at 10N and December 21 at 10S.

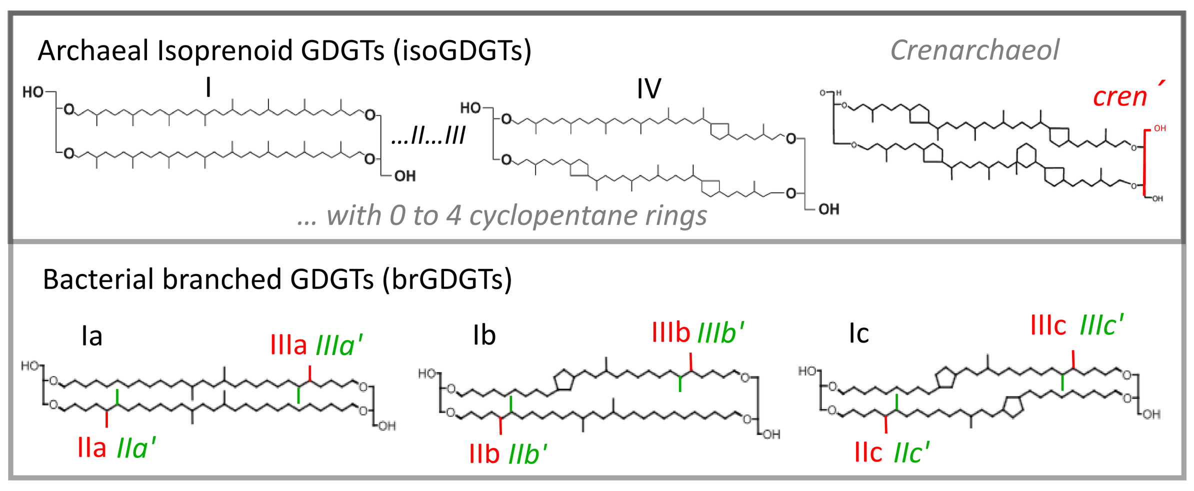
Climate-system dynamics…

- The BIT record from Lake Chala (in accordance with the seismics-inferred lake-level record) suggests that equatorial East Africa enjoyed wet climate during most of the last glacial period (MIS4-MIS2) when tropical West Africa was mostly dry (Dupont et al., 2002).
- The moisture-balance history of equatorial East Africa (Fig 6d) is similar to tropical South-east Asia as recorded in Chinese speleothems (Fig 6b), reflecting more intense northern-hemisphere mo\nsoons when frequent climate 'flip-flops' (Dansgaard-Oeschger cycles) regularly brought 'mild-glacial' conditions to northern mid- and high-latitude regions (Fig 6a).
- Abrupt climate events originating in the North Atlantic, such as the Younger Dryas stadial and Heinrich events H1, H4 and (possibly) H6 caused dryer conditions in equatorial East Africa, likely because strengthened trade winds weakened the South-Eastern Indian Monsoon.

Methods

GDGTs, or glycerol dialkyl glycerol tetraethers, are membrane lipids produced by species of bacteria (for the brGDGTs) and archaea (for the isoGDGTs) in a variety of environments and are preserved on geological timescales. The types of GDGTs which are found in ancient sediments depends on the environmental conditions in which they were produced. Crenarchaeol is an isoGDGT produced by the nitrifying archae *Thaumarchaeota* in the upper oxygenated layer of lakes.

Using improved chromatography, researchers discovered additional brGDGT isomers with methylation at the 6th carbon position (eg. IIa´; De Jonge et al. 2014). Separation of the 6-methyl brGDGTs from the previously known 5-methyl brGDGTs improved climate proxies based on these lipids (see Fig 3).



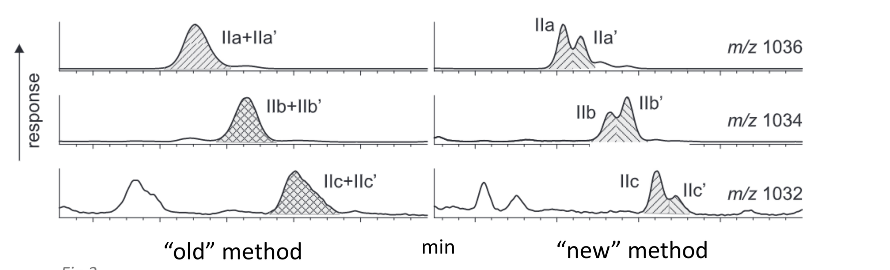


Fig 3.

Relative abundances of GDGTs are related to ambient temperature…

Using TEX_{86} to estimate temperature in lakes: a higher relative abundance of **isoGDGTs** with more rings is found at higher temperatures.

$$TEX_{86} = \frac{[III] + [IV] + [cren']}{[II] + [III] + [IV] + [cren']}$$ Schouten et al., 2002

The distribution of **brGDGTs** in lakes is also controlled by temperature.

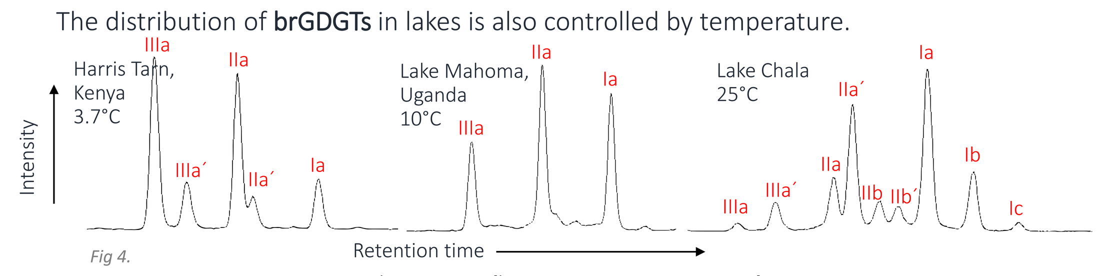


Fig 4.

$$\mathrm{MLST} = 20.9 + 98.1 * Ib - 12 * (IIa = IIa') + 20.5 * (IIIa + IIIa')$$ Pearson et al. 2014

$$\mathrm{MAAT} = 23.81 - 31.02 * IIIa - 41.91 * IIb - 51.59 * IIb' - 24.7 * IIa + 68.8 * Ib$$ Russell et al. 2018

Tierney et al. 2010	Global lakes	isoGDGTs (TEX_{86})	**M**ean **l**ake **s**urface **t**emperature
Pearson et al. 2004	Global lakes	brGDGTs (old method)	**M**ean **l**ake **s**urface **t**emperature
Russell et al. 2018	East African lakes	brGDGTs (new method)	**M**ean **a**nnual **a**ir **t**emperature

…and amount of rainfall

Branched vs Isoprenoid Index:

$$\mathrm{BIT} = \frac{(\text{branched GDGTs})}{(\text{branched GDGTs} + \text{cren})}$$

high BIT
high rainfall

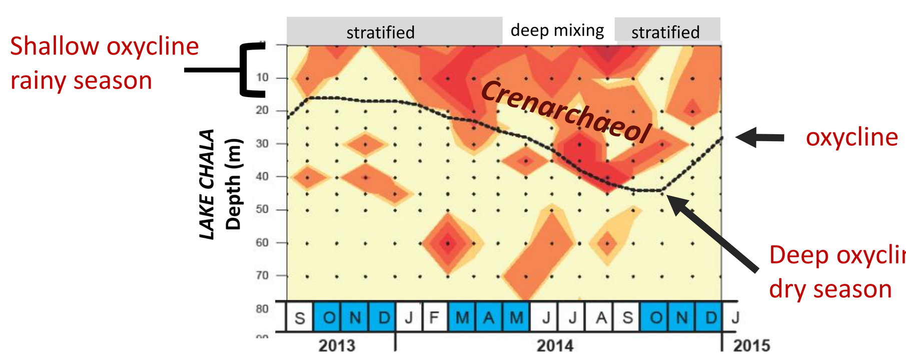


Fig 5. van Bree et al. 2019

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