Insolation triggered extreme cooling events in East Asia during glacials

Hao Lu[1], Jingjing Guo[1], Zhipeng Wu[2], Louise Fuchs[1], Qiuzhen Yin[2], Youbin Sun[3] and Francien Peterse[1]

1. Department of Earth Sciences, Facluty of Geosciences, Utrecht University, Utrecht, the Netherlands; 2. Earth and Climate Research Centre, Earth and Life Institute, Université Catholique de Louvain, Louvain-La-Neuve, Belgium; 3. Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, China

Corresponding author: H. Lu, h.lu2@uu.nl

1. Introduction

- **Long-term and high-resolution land temperature records are scarce for lack of appropriate proxies, which strongly limits our understanding of how the temperature evolution evolved at geological timescales.**
- **Here we quantitatively reconstruct a high-resolution land temperature for central China covering the past 260 kyr, and investigate its forcing mechanisms, based on brGDGTs preserved in a loess-paleosol sequence on the eastern Chinese Loess Plateau (CLP).**

2. Material and methods

Research site

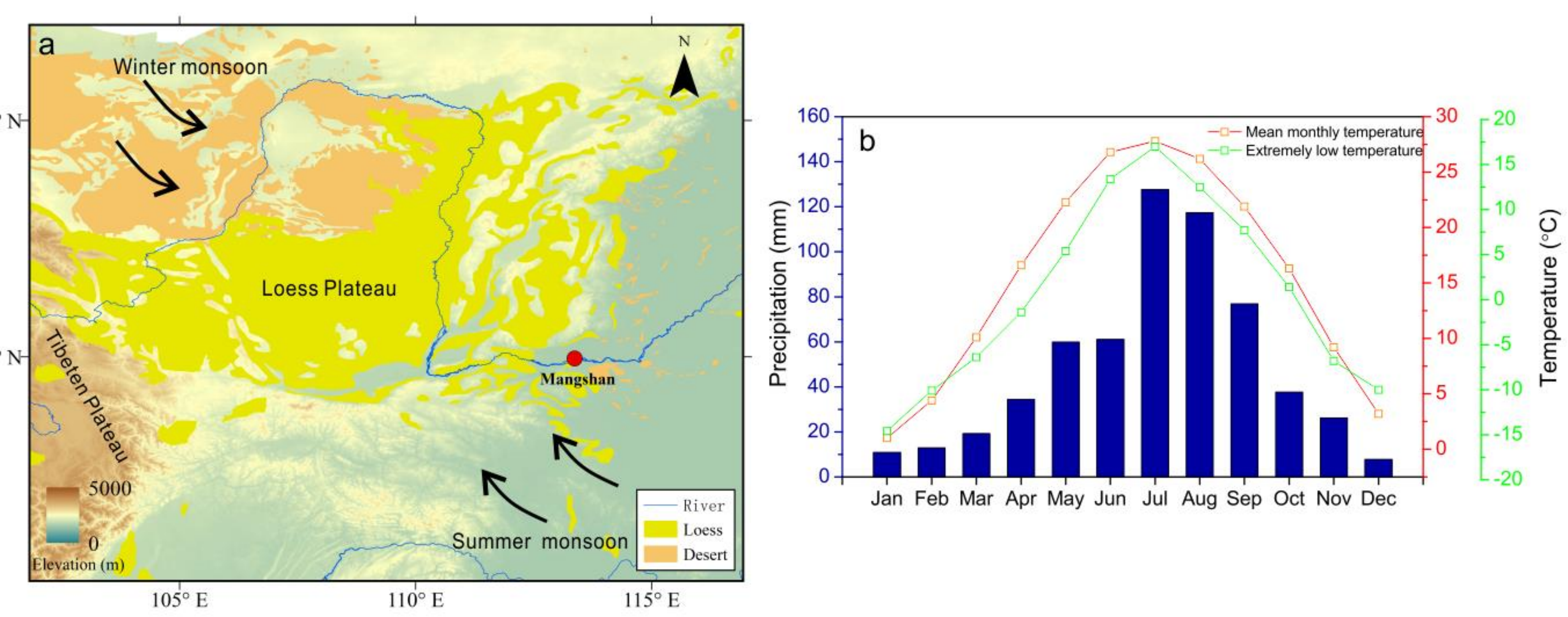

Figure 1. (a) Locations of the Chinese Loess Plateau (CLP) and the studied section. The red circle denotes the Mangshan loess-paleosol sequence. The black arrows indicate the direction of the East Asian summer monsoon and winter monsoon; (b) mean monthly air temperature, monthly precipitation and extremely low temperature at Xingyang city between 1991-2020, close to the Mangshan section in the CLP. Data obtained from the China Meteorological Data Service Center, http://data.cma.cn/en.

BrGDGT extraction and analysis

In total, 288 samples were selected to extract and analyze brGDGTs.

Temperature changes reflected by the brGDGTs were quantified based on the degree of methylation of 5-methyl brGDGTs using the MBT'_{5Me} index (1) (De Jonge et al., 2014), and subsequently translated into mean air temperatures for months above freezing (MAF) using the BayMBT0 model (Dearing Crampton-Flood et al., 2020).

(1) $MBT'_{5Me} = (Ia + Ib + Ic)/ (Ia + Ib + Ic + IIa + IIb + IIc + IIIa)$

The degree of cyclization (DC), which is suggested to reflect moisture availability (Guo et al., in preparation), was calculated by the following equation:

$DC = [(Ib) + 2 \times (Ic) + (IIb) + (IIb')]/ [(Ia) + (Ib) + (Ic) + (IIa) + (IIa') + (IIb) + (IIb')]$

Age model

The age model for Mangshan section was established by matching changes in the loess proxy records of Mangshan section to the composite Hulu/Sanbao speleothem $\delta^{18}O$ record.

Climate simulation

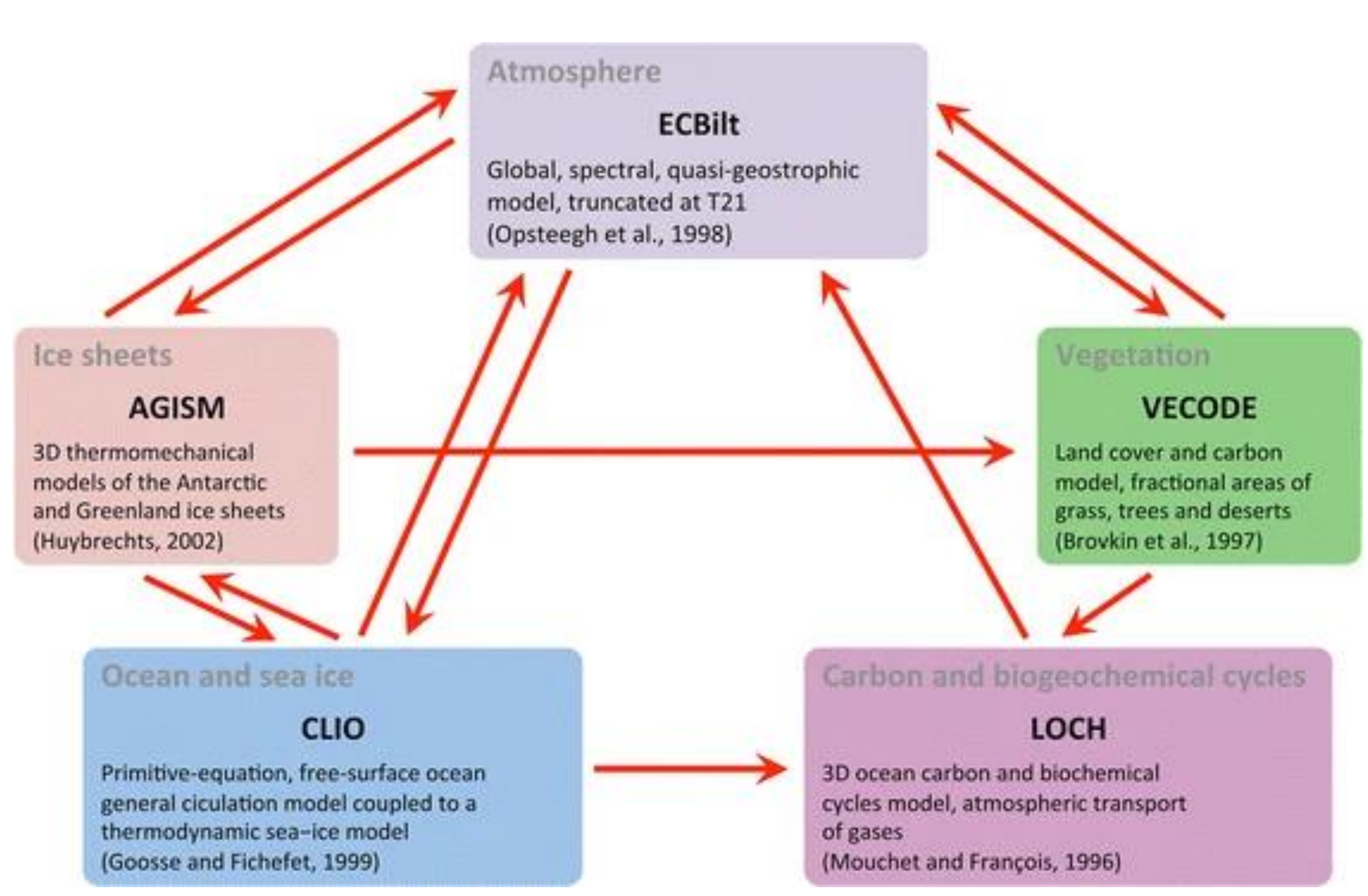

Figure 2. Sketch of the LOVECLIM model showing the interactions between the five components (Goosse et al., 2010).

Three transient simulations were performed for the last 260 ka.

T1: only astronomically-induced insolation varies with time and the greenhouse gases concentrations (GHG) are fixed to the Pre-Industrial concentrations.

T2: both time-dependent insolation and GHG were varied.

T3: time-dependent insolation, GHG and ice sheet were varied.

3. Results and Discussion

- **MBT'_{5Me} index is controlled by growing season temperature and length**

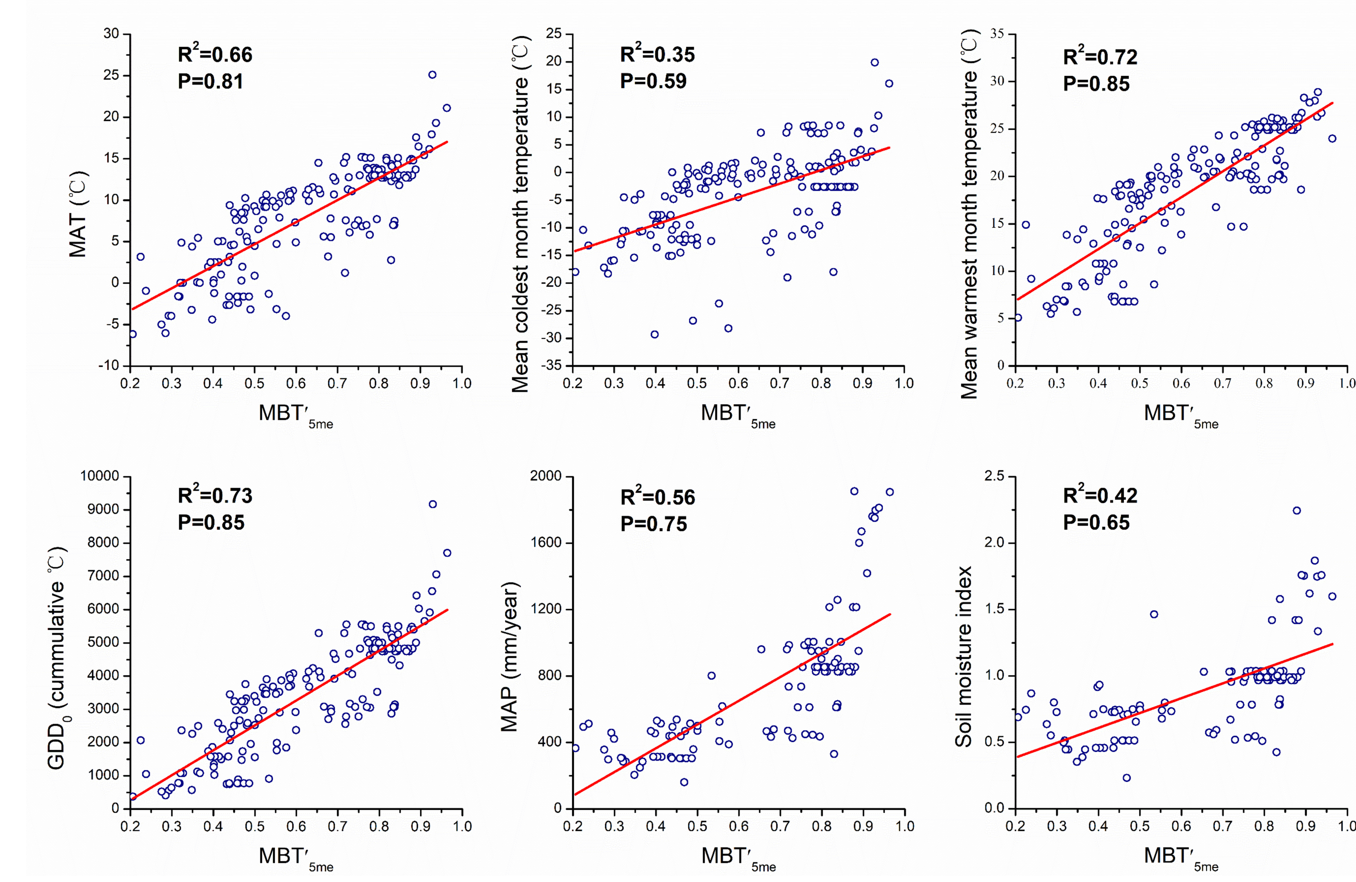

Figure 3. MBT'_{5Me} from China surface soil data set plotted versus mean annual air temperature (MAAT), mean coldest month temperature, mean warmest month temperature, growing degree days above zero (GDD0), mean annual precipitation and soil moisture index (Naafs et al., 2017).

- **Major forcings of the reconstructed temperature over the past 260 ka**

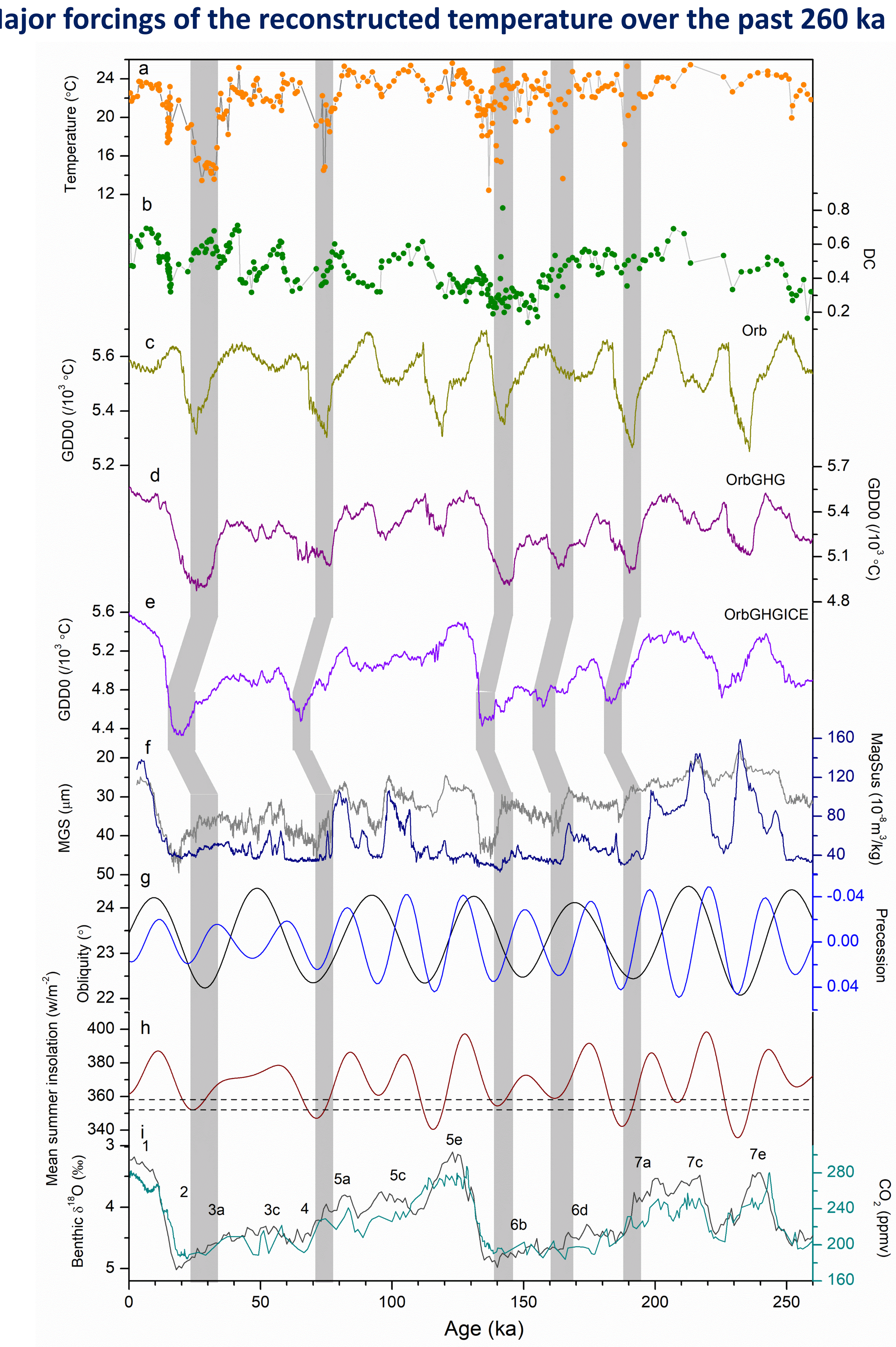

Figure 4. Comparison of temperature record of the Mangshan section with simulated results and relevant forcings. (a) Temperature based on brGDGTs; (b) degree of cyclization (DC) of brGDGTs, which is suggested to indicate moisture availability; (c), (d) and (e) simulated growing degree days above zero (GDD0) in response to orbital forcings only, orbital and GHG, and orbital, GHG and ice sheet forcings, respectively; (f) mean grain-size (MGS) (gray) and magnetic susceptibility of the Mangshan section (dark blue) (Wang et al., 2020); (g) obliquity (black) and precession (blue) (Berger and Loutre, 1991); (h) mean summer insolation is defined in Yin et al., 2021. The two horizontal dashed lines define the upper and lower insolation threshold values 358. 2 and 352.1 Wm^{-2}; (i) benthic $\delta^{18}O$ (dark gray) (Lisiecki and Raymo, 2005) with glacial-interglacial oxygen isotope stages (MIS) labeled at the top part; and CO_2 concentration records (green) (Lüthi et al., 2008). The gray shaded bars indicate extreme cooling events. 1000-year running mean is applied on the simulated GDD0.

4. Conclusions

- **Both brGDGT-based temperature and the DC are dominated by precession.**
- **Our temperature record provides first evidence of extreme cooling events during glacial times, which corresponds well with the simulated GDD0 in response to orbital and GHG forcings.**
- **These extreme cooling events occur when summer insolation decreases to a critical value as predicted by model simulations (Yin et al., 2021). Relatively high GHG during interglacials could dampen the influence of low summer insolation on the simulated GDD0.**

References: De Jonge, C. et al. Occurrence and abundance of 6-methyl branched glycerol dialkyl glycerol tetraethers in soils: Implications for palaeoclimate reconstruction. Geochim. Cosmochim. Acta. 141: 97-112 (2014); Crampton-Flood E. D. et al. BayMBT: A Bayesian calibration model for branched glycerol dialkyl glycerol tetraethers in soils and peats. Geochim. Cosmochim. Acta. 268: 142-159 (2020); Yin, Q. Z. et al. Insolation triggered abrupt weakening of Atlantic circulation at the end of interglacials. Science, 373(6558), 1035-1040 (2021).

Acknowledgement: This study was supported by Dutch Research Council (NWO, Vidi grant no. 192.074 to F.P.).