Supplementary Materials

Millennial-scale quantitative estimates of climate dynamics in central Europe from earthworm calcite granules in loess deposits

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This pdf file contains Supplementary Figures 1 to 5 and Supplementary Table 1 with the following titles:

Supplementary Fig. 1: Stratigraphy and oxygen and carbon isotope composition of earthworm calcite granules from Schwalbenberg profile RP1.

Supplementary Fig. 2: Stratigraphy and oxygen and carbon isotope composition of earthworm calcite granules from Nussloch profile P8.

Supplementary Fig. 3: Geographic distribution of GNIP stations over Europe.

Supplementary Fig. 4: Seasonal wind regime and precipitation statistics obtained for present day and LGM conditions at the Schwalbenberg site.

Supplementary Fig. 5: Seasonal wind regime and precipitation statistics obtained for present day and LGM conditions at the Nussloch site.


Supplementary Table 1: Statistical tests comparing the mean values of estimate climate parameters between two populations

Additionally, Supplementary Data 1 to 3 are available as separate files.

Supplementary Fig. 1: **Stratigraphy and oxygen and carbon isotope composition of earthworm calcite granules from Schwalbenberg profile RP1.** On the profile, black rectangles indicate the stratigraphic position of stable isotope analyses and dark blue squares represent radiocarbon dating samples. Colour circles represent the mean values of oxygen (blue) and carbon (green) isotopic composition of 30 granules analyses. Thick colour error bars represent the standard deviation (1σ) of the stable isotope values by layer of 5 cm thickness. Palaeosols (Calcaric Cambisols) are highlighted in brown and tundra gley horizons are highlighted in grey.
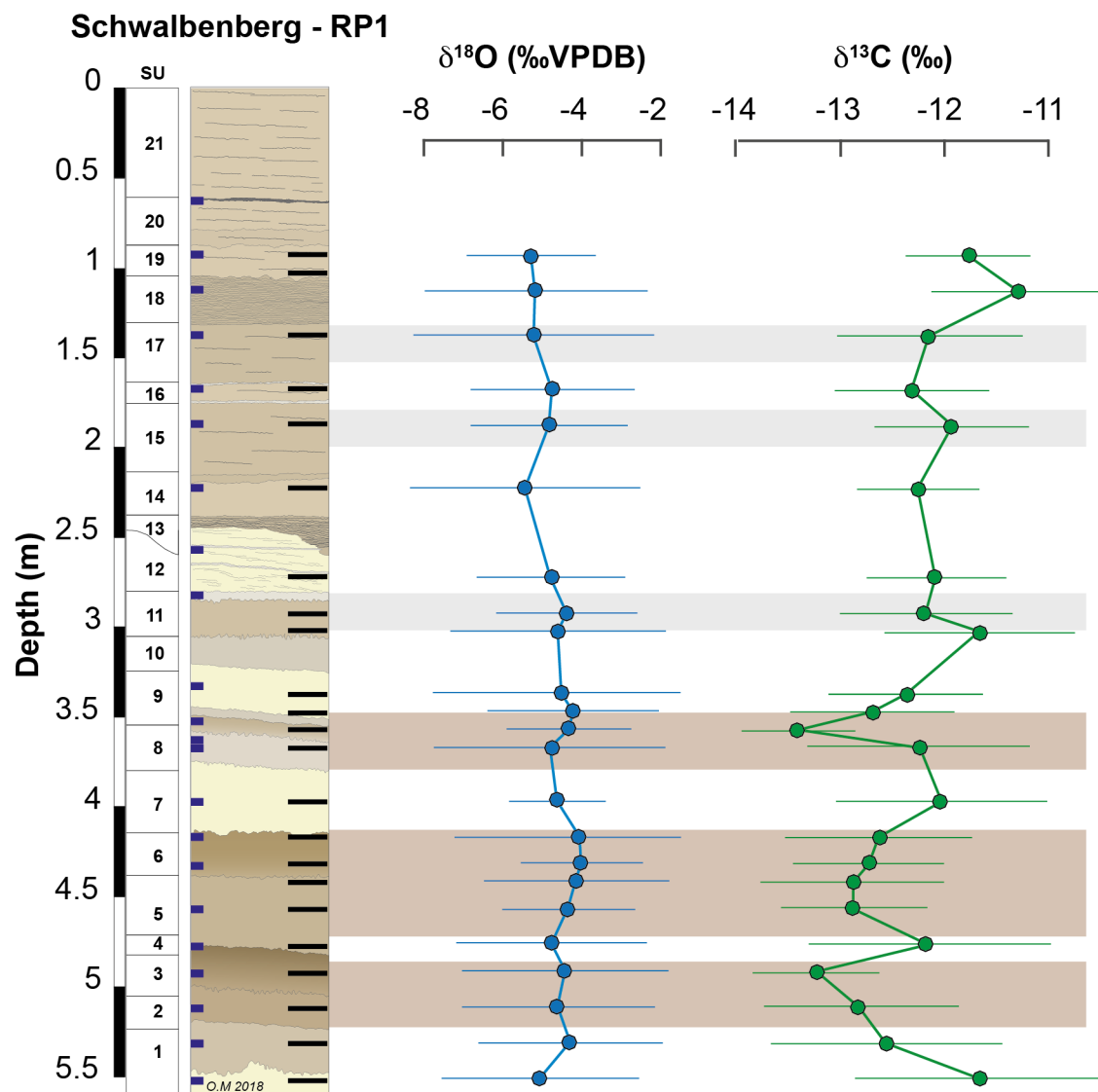
Supplementary Figure 2: **Stratigraphy and oxygen and carbon isotope composition of earthworm calcite granules from Nussloch profile P8.** On the profile, black rectangles indicate the stratigraphic position of stable isotope analyses and dark blue squares represent radiocarbon dating samples. The stratigraphy follows ref[1,2]. Colour circles represent the mean values of oxygen (blue) and carbon (green) isotopic composition of 30 granules analyses. Thick colour error bars represent the standard deviation (1σ) of the stable isotope values by layer of 5 cm thickness. Palaeosols (Arctic and boreal brown soils) are highlighted in brown and tundra gley horizons are highlighted in grey.
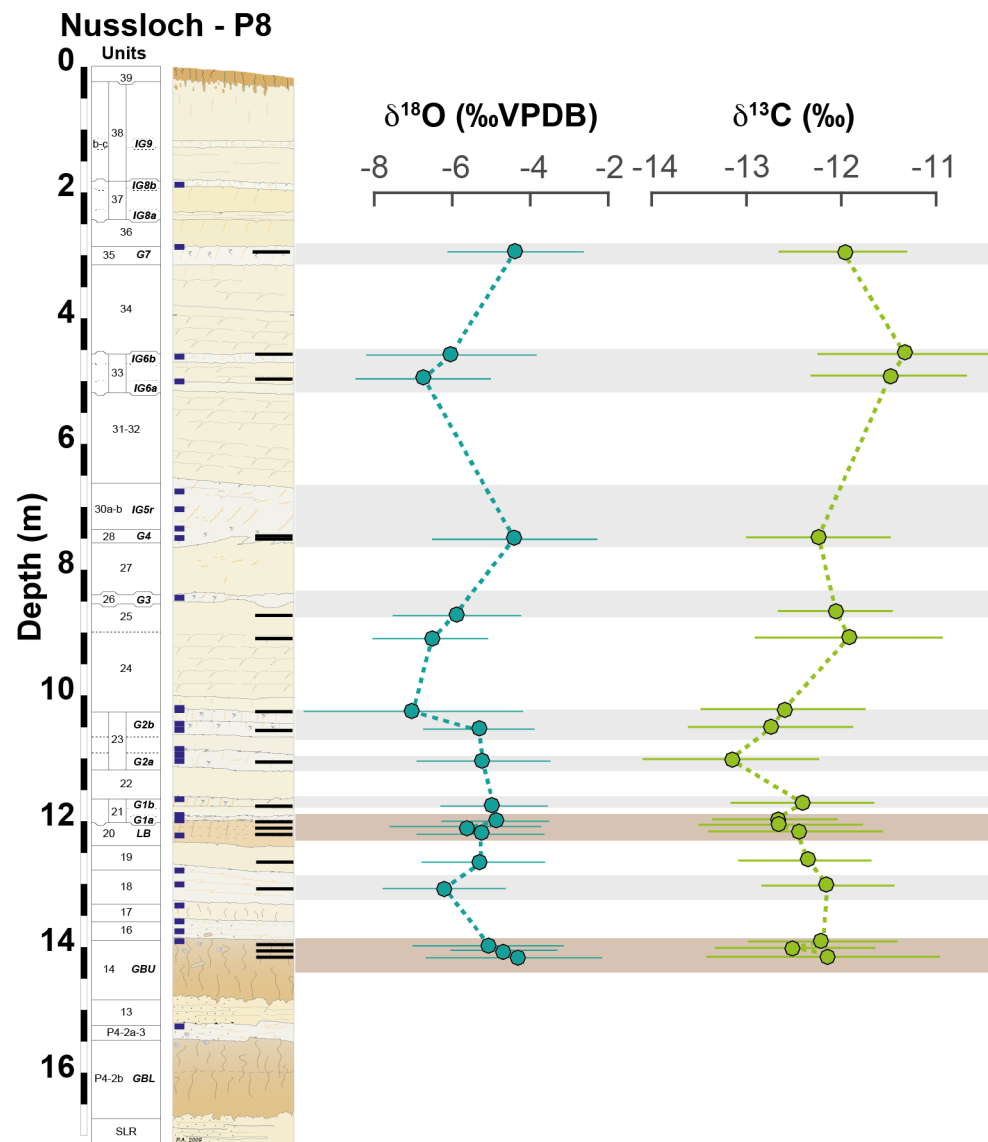
Supplementary Figure 3: **Geographic distribution of GNIP stations over Europe.** Red circles represented the stations that have been used to calculate the δ^{18}O-Tair slopes recorded at each station georeferenced by its latitude and longitude. White circles represented Schwalbenberg and Nussloch.
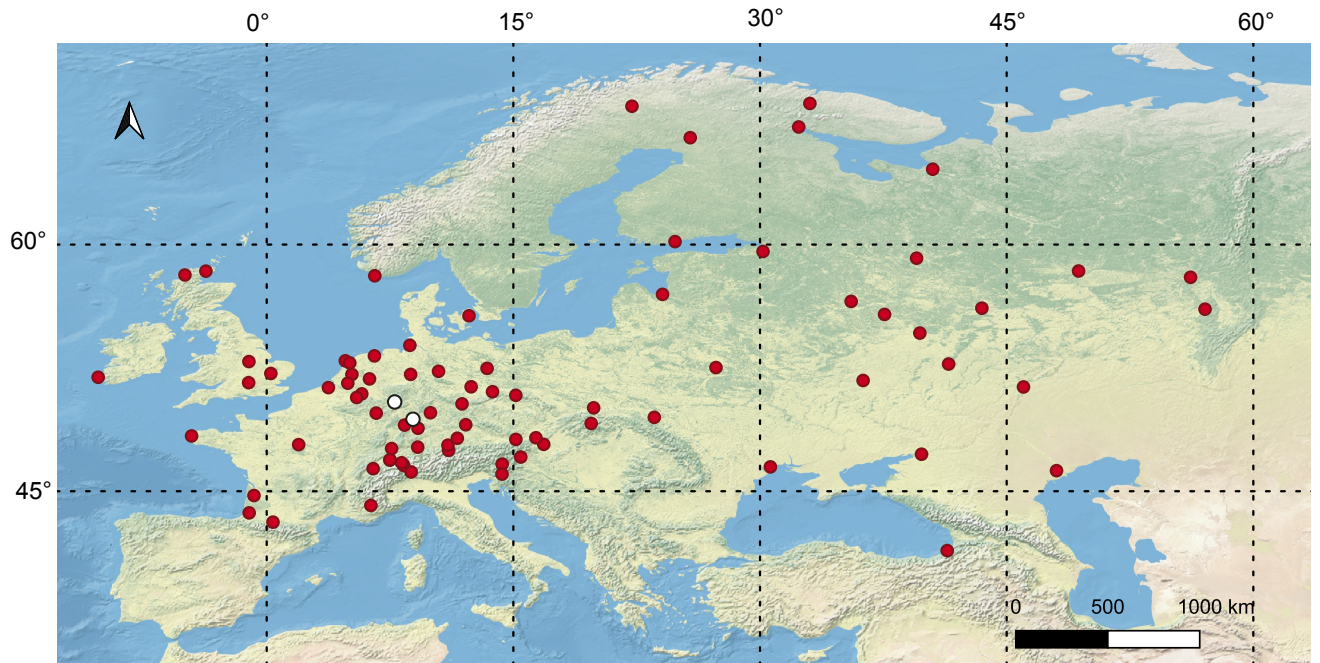
Supplementary Figure 4: **Seasonal wind regime and precipitation statistics at the Schwalbenberg site –** top row: present day conditions and bottom row: LGM conditions. Shaded green area presents the average precipitation flux at given wind direction/strength (percent of total – scale at the bottom of the figure). Sector line plots show wind speed (black), wind occurrence (red solid), precipitation rate (blue dashed) and total precipitation (red dashed, normalised) distribution about rhumbs. Thin solid/long-dashed line circles visualize the scalar/absolute winds and their directions, respectively; thin-dashed circle shows wind vector. Note that wind direction is meteorological (from where wind blows). Further statistics tabled: V_S and V_R − absolute and scalar wind speed [m/s], R_w and R_p − rhumbs of maximum wind and precipitation occurrence [percent], Q − wind steadiness (V_S /V_R ratio), r_{xy} − wind zonal and meridional components correlation, σ_r − wind vector SD [m/s], λ − wind absolute speed to ratio, Σ(P): total annual precipitation [mm]. From left to right in each row: winter, spring, summer, fall.
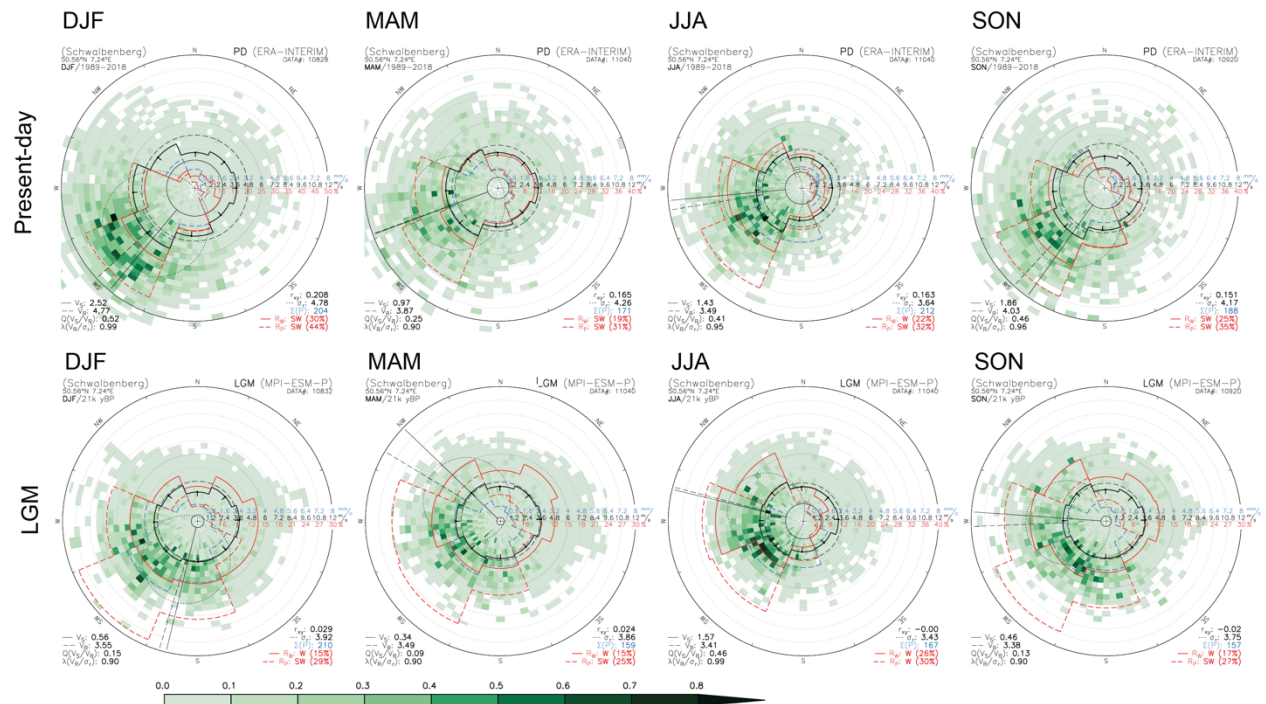
Supplementary Figure 5: **Seasonal wind regime and precipitation statistics at the Nussloch site –** top row: present day conditions and bottom row: LGM conditions. For detailed explanation cf. Supplementary Figure 4. From left to right in each row: winter, spring, summer, fall.
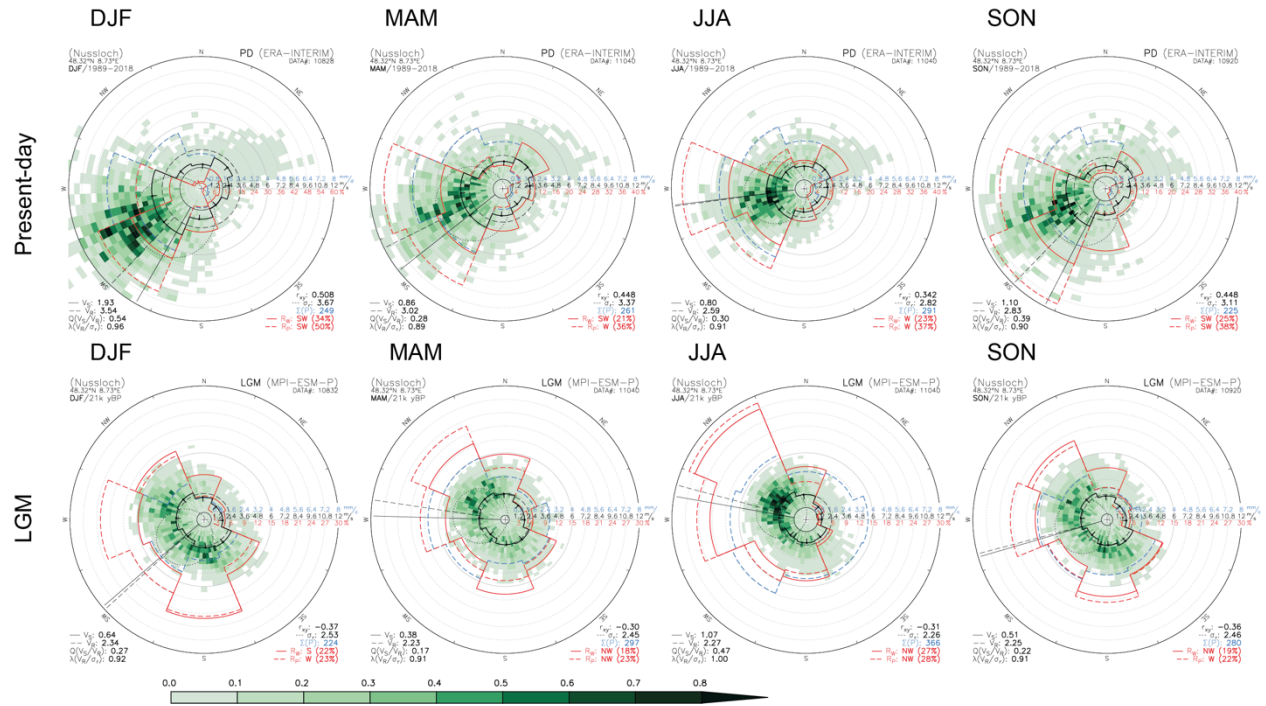
Supplementary Table 1: **Statistical tests comparing the mean values of estimate climate parameters between two populations –** We used the T–Student test to check whether or not the mean values of the two populations are significantly different at a significance threshold of 5%. H=0 validates the null hypothesis, i.e. the two populations are not significantly different and so that environmental conditions should have been similar. Conversely, H=1 rejects this hypothesis, i.e. the two populations are significantly different. RP1: Schwalbenberg profile; NUSSP8: Nussloch profile 8; LTws: warm-season land-surface temperature and MAP: mean annual precipitation.

RP1 vs. NUSSP8	LTws - T-tests		MAP - T-tests	
Time intervals	**p value**	**H**	**p value**	**H**
MIS 3-MIS 2	$5.9e10^{-15}$	1	0.28	0
MIS 3	$6.5e10^{-8}$	1	0.44	0
MIS 2	$5.8e10^{-4}$	1	0.08	0
40-31 ka	$3.9e10^{-7}$	1	0.18	0
24-23 ka	0.71	0	0.029	1
MIS 2 vs. MIS 3				
RP1	$4.0e10^{-9}$	1	$3.3e^{-10}$	1
NUSSP8	$5.8e10^{-8}$	1	$9.4e^{-5}$	1

Supplementary References:
1. Antoine, P. *et al.* Rapid and cyclic aeolian deposition during the Last Glacial in European loess: a high-resolution record from Nussloch, Germany. *Quat Sci Rev* **28**, 2955–2973 (2009).
2. Prud'homme, C., Moine, O., Mathieu, J., Saulnier-Copard, S. & Antoine, P. High-resolution quantification of earthworm calcite granules from western European loess sequences reveals stadial–interstadial climatic variability during the Last Glacial. *Boreas* **48**, 257–268 (2019).