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Supplement of

Investigating hydroclimatic impacts of the 168–158 BCE volcanic quartet and their relevance to the Nile River basin and Egyptian history

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Table S1: Table showing the order and specification of the 2.5ka control run. The latest 100 years of the 2.5ka (GHG+ORB+VEG) run are used to represent the base climate for the 2.5ka period. NINT: Non-INTeractive version, MATRIX: Multiconfiguration Aerosol TRacker of mIXing state.

order of control runs and volcanic experiments →				
ModelE (NINT) 2.5ka control run (1000 years)	ModelE (MATRIX) 2.5ka control run (100 years)	ModelE (MATRIX) 2.5ka control run (70 years) 2.5ka (GHG+ORB)	ModelE (MATRIX) 2.5ka control run (130 years) 2.5ka (GHG+ORB+VEG)	ModelE (MATRIX) 10 ensemble members (Initialized using restart files at 10 years gap) 2.5ka (GHG+ORB+VEG)
Orbital forcing (2.5ka), Greenhouse gases (2.5ka), Vegetations (PI)	Orbital forcing (2.5ka), Greenhouse gases (2.5ka), Vegetations (PI)	Orbital forcing (2.5ka), Greenhouse gases (2.5ka), Vegetations (PI) Retuned Dust Parameters	Orbital forcing (2.5ka), Greenhouse gases (2.5ka), PMIP4 Vegetations (Interpolated for 2.5ka) Retuned Dust Parameters	Orbital forcing (2.5ka), Greenhouse gases (2.5ka), PMIP4 Vegetations (Interpolated for 2.5ka) Retuned Dust Parameters Volcanic SO_2 injection for 4 eruptions during 158-168 BCE (Sigl et al., 2015)

Figure S1: Spatial representation of changes in major vegetation plant function types (PFTs) as change in area fraction under the PMIP4 sensitivity protocol (Otto-Bliesner et al., 2017) after interpolating for the 2.5ka period. Top row shows change in area of arid shrub and boreal forest changes, bottom row show C3 and C4 grasses.

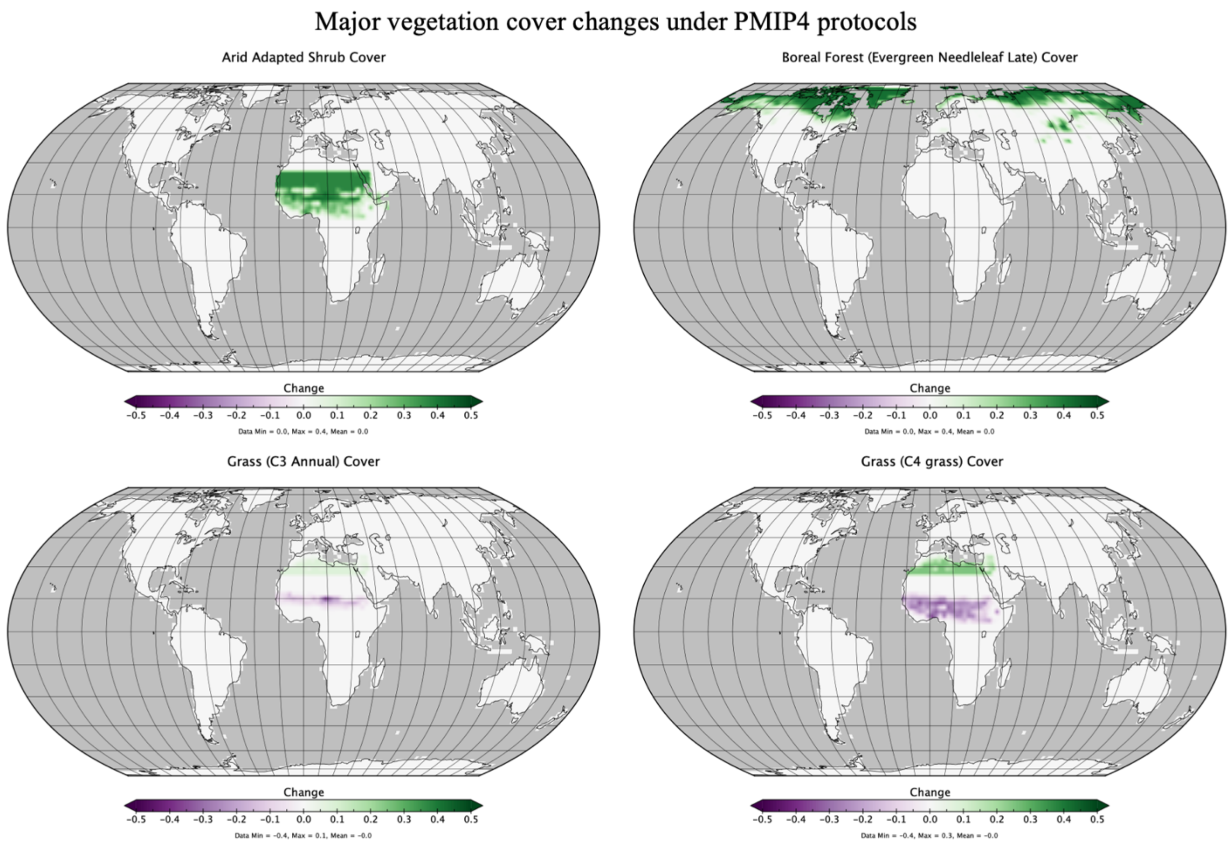

Figure S2. Timeseries of annual global mean surface air temperature (top) and precipitation (bottom) for the 2.5ka control run with (green) and without (red) the altered vegetation (see text). Vertical blue lines show the starting points of all 10 ensemble members.

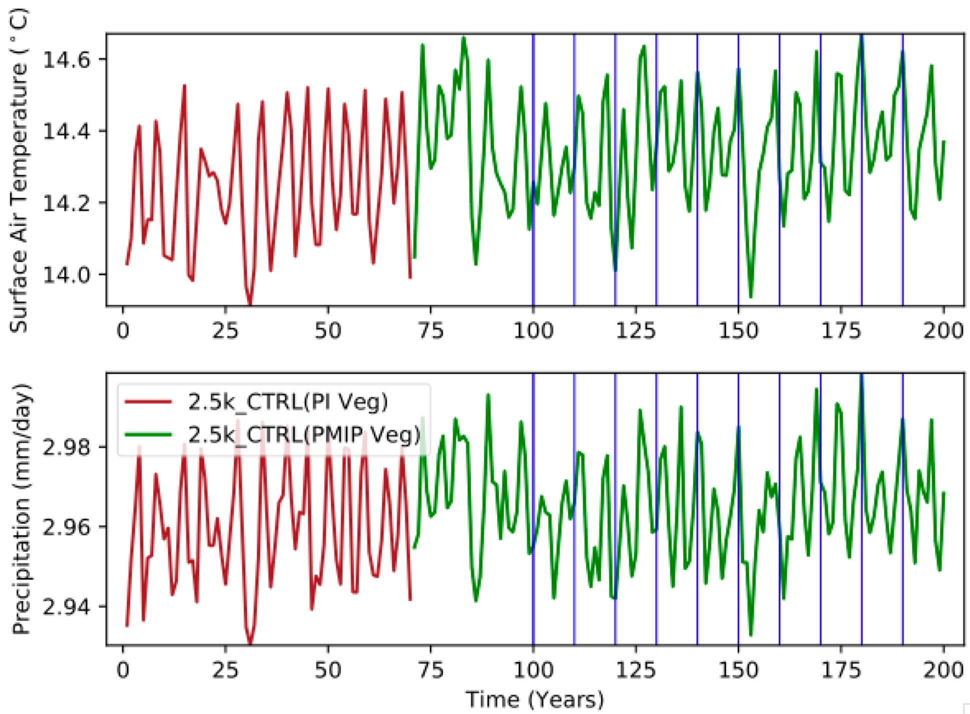

Figure S3. Geographical positions of all 4 volcanic eruptions during the study period are distinguished by different colours. These eruption locations are arbitrarily chosen. First eruption (E1, Red) erupted during 168 BCE, second (E2, Blue) during 164 BCE, third (E3, Magenta) during 161 BCE and fourth (E4, Orange) erupted during 158 BCE. Spatial box (with caption Nile H) shows the spatial extent of the region considered as the Nile River watershed (discussed in Fig12, main text).

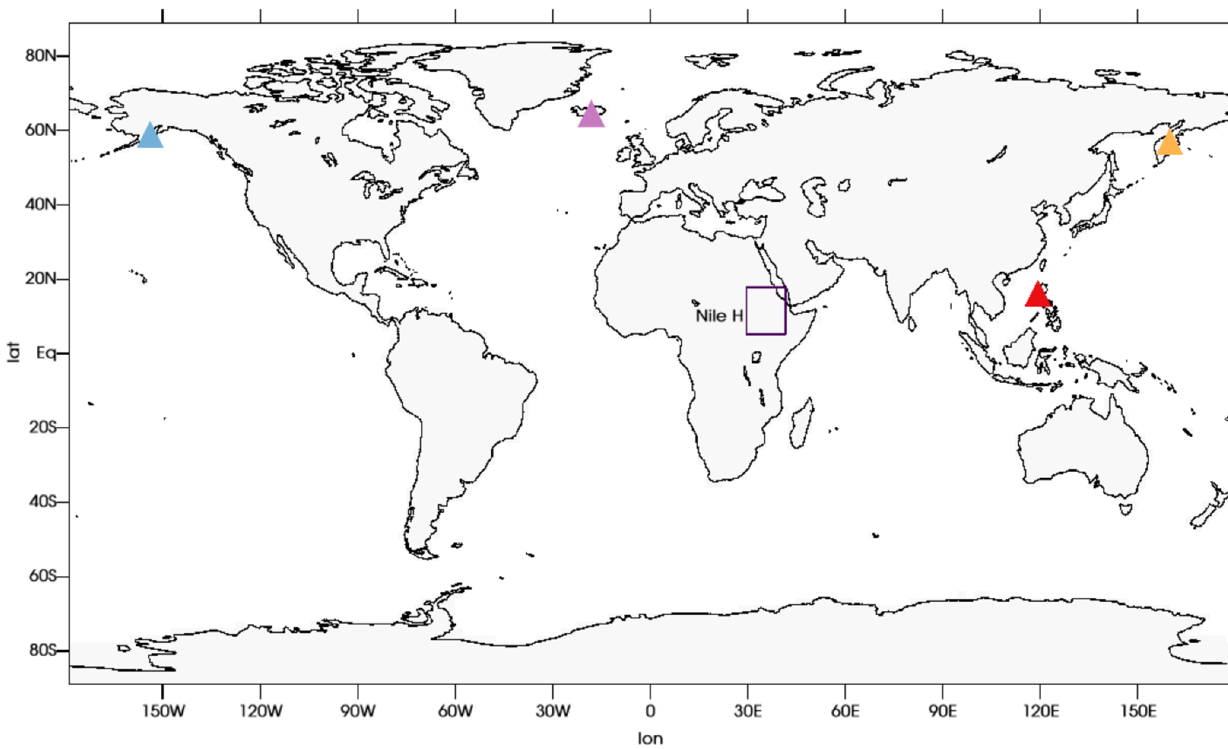

Figure S4: Globally averaged change in sea surface temperature (top panel), surface air temperature over land (middle panel) and over ocean (bottom panel) for each month for the entire simulation period. The light-colored solid lines represent individual ensemble members, and the solid dark colors show the ensemble means. The green vertical dashed lines show the dating of the four eruptions (E1-E4).

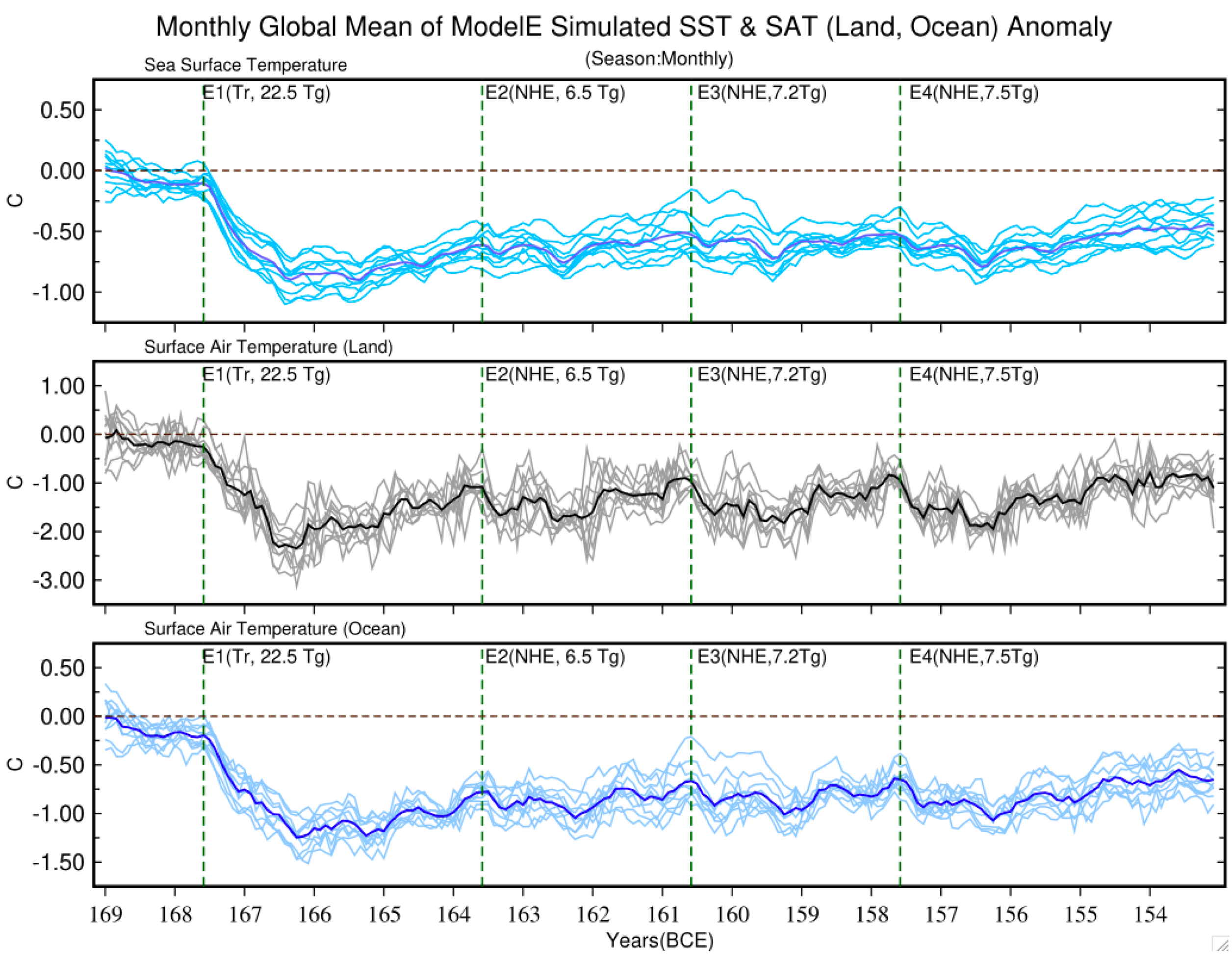

Figure S5. Vertical profile of extinction (A) and methane (CH_4; B) change following the volcanic eruptions. Vertical black line represents the timing of each eruption.

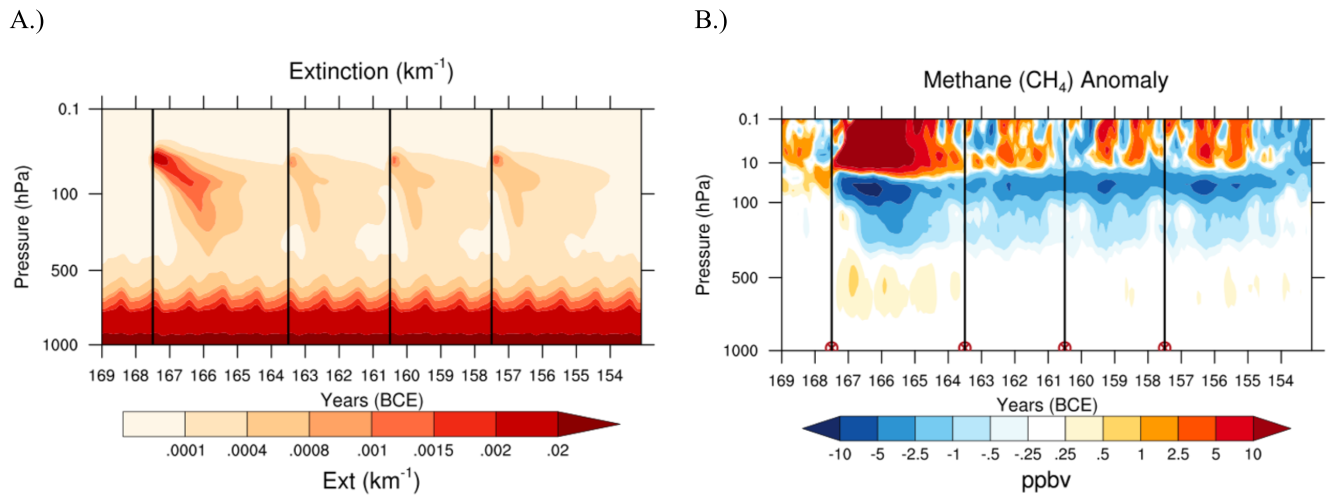

Figure S6. Spatial pattern of seasonal mean surface temperature response (˚C) for the four seasons following the first eruption E1. Column 1 show the JJA (June, July August) and SON (September, October, November) for the year of eruption. Column 2 shows the DJF (December, January, February) of the eruption year and first following year, and the MAM (March, April, May) of the first following year. Grey coloured painted over the regions where differences are not significant.

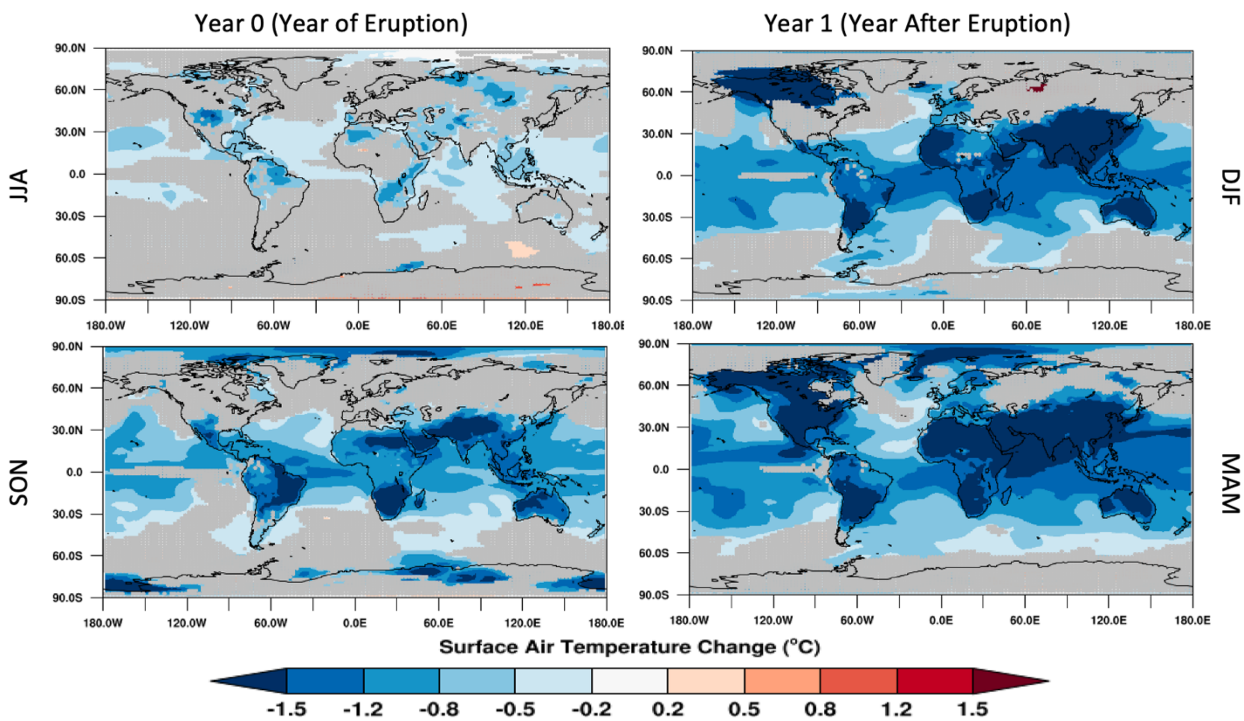

Figure S7. Total cloud cover change during the monsoon season (JJAS) for 3 consecutive years after each eruption (columns) over the North African continent. The blue line demarks the present-day Nile River basin boundary, which is broadly similar to the river extent approximately 2.5ka years ago. The red stippling indicates regions over which change in rainfall is not significant at the 95% confidence level.