SUPPLEMENTARY MATERIAL

This Supplementary contains the following tables and figures:

SI Table 1. Characteristics of the Last Glacial Maximum (LGM), mid-Holocene (MH) and pre-industrial (PI) Max Planck Institute Earth System Model (MPI-ESM1.2-LR; Mauritsen et al., 2019; doi:10.22033/ESGF/CMIP6.6642) simulations used to provide inputs for our experiments, including specified forcings.

SI Table 2. Regional contributions to total annual gross primary production (GPP) in the tropics, the northern extra-tropics (NET) and the southern extra-tropics (SET) in the Last Glacial Maximum (LGM), the mid-Holocene (MH) shown in the factorial experiments holding all but one variable constant.

SI Table 3. Gross primary production at the Last Glacial Maximum (LGM), mid-Holocene (MH) and the pre-industrial (PI) as simulated by earth system models participating in the fourth phase of the Palaeoclimate Modelling Intercomparison Project (PMIP4; Kageyama et al., 2017; Otto-Bleisner et al., 2019).

SI Figure 1. Change in C_4 fraction (a) at the Last Glacial Maximum (LGM) compared to the pre-industrial (PI) experiment and (b) in the mid-Holocene (MH) compared to the PI experiment.

SI Figure 2. Simulated change in total annual gross primary production (GPP) between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except climate.

SI Figure 3. Simulated change in total annual gross primary production (GPP) between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except CO_2.

SI Figure 4. Simulated change in total annual gross primary production (GPP) between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except light (photosynthetic photon flux density, PPFD).

SI Figure 5. Simulated changes in (a) mean annual temperature and (b) mean annual precipitation between the pre-industrial (PI) and the Last Glacial Maximum (LGM); simulated changes in (c) mean annual temperature and (d) mean annual precipitations between the pre-industrial (PI) and the mid-Holocene (MH).

SI Figure 6. Simulated change in C4 fraction between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except climate.

SI Figure 7. Simulated change in C4 fraction between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except CO_2.

SI Figure 8. Simulated change in C4 fraction between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except light (photosynthetic photon flux density, PPFD).

SI Table 1. Characteristics of the Last Glacial Maximum (LGM), mid-Holocene (MH) and pre-industrial (PI) Max Planck Institute Earth System Model (MPI-ESM1.2-LR; Mauritsen et al., 2019; doi:10.22033/ESGF/CMIP6.6642) simulations used to provide inputs for our experiments, including specified forcings.

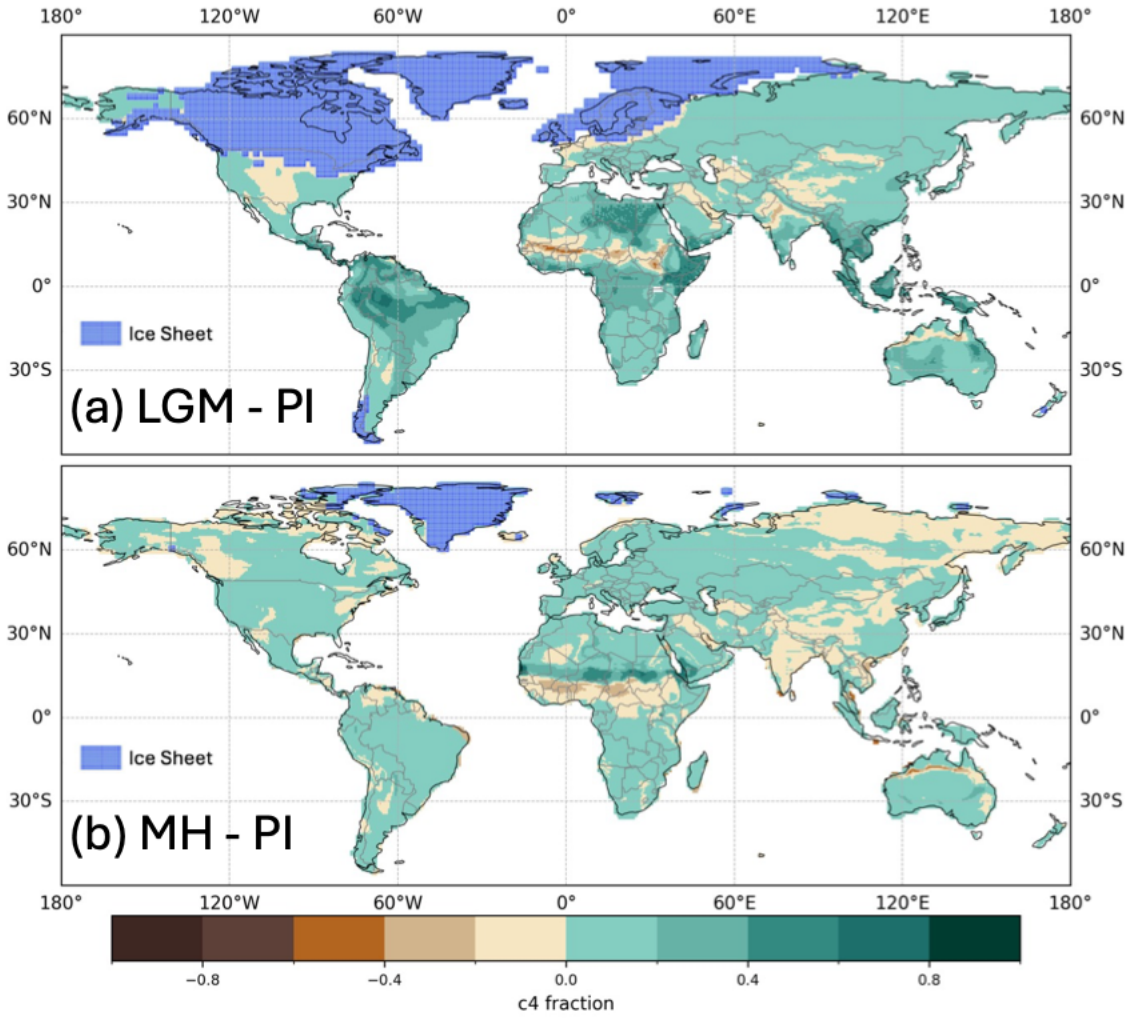
	PI	MH	LGM
Eccentricity	0.016764	0.018682	0.018994
Obliquity (°)	23.459	24.105	22.949
Perihelion -180	100.33	0.87	114.42
CO2 (ppm)	284.3	264.4	190
CH4 (ppb)	808.2	597	375
N20 (ppb)	273.0	262	200
Ice sheet	as modern	as modern	ICE6G_C
Spin-up	2000	500	3850 years after restart from previous LGM simulation
Length of simulation (yrs)	1000	500	500

SI Table 2. Regional contributions to total annual gross primary production (GPP, PgC) in the tropics, the northern extra-tropics (NET) and the southern extra-tropics (SET) in the Last Glacial Maximum (LGM), the mid-Holocene (MH) shown in the factorial experiments holding all but one variable constant.

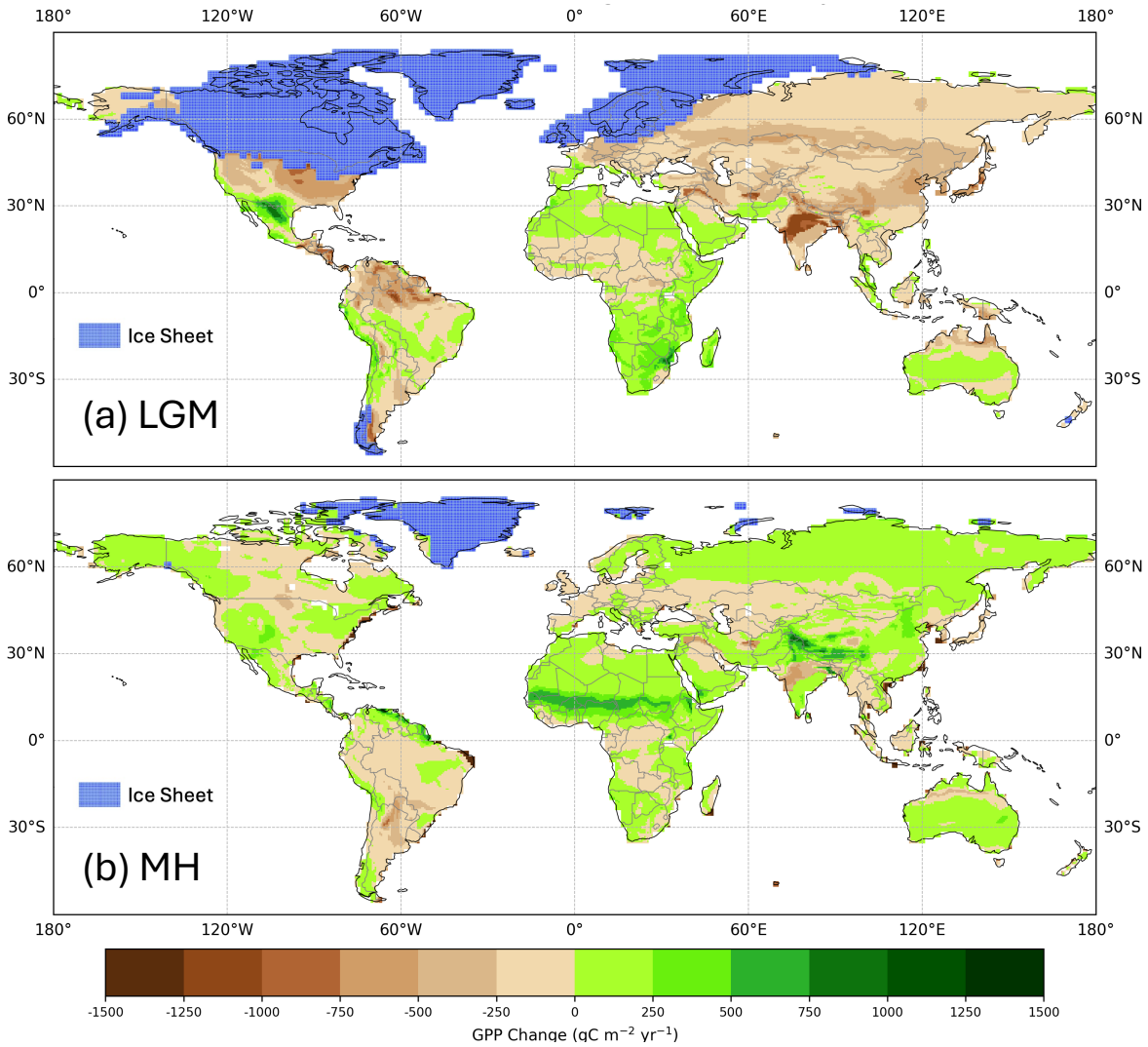
Region	**Time period**	**Climate**	**CO2**	**PPFD**
Tropics (25°N-25S)	LGM	-3.5	-4.7	0.2
NET (>25°N)	LGM	-11.2	-6.5	1.0
SET (>25°S)	LGM	-0.1	-1.0	0.0
Tropics (25°N-25S)	MH	0.9	-1.2	-0.5
NET (>25°N)	MH	1.5	-1.2	1.5
SET (>25°S)	MH	-0.5	-0.2	0.0

SI Table 3. Gross primary production (Pg C yr) at the Last Glacial Maximum (LGM), mid-Holocene (MH) and the pre-industrial (PI) as simulated by earth system models participating in the fourth phase of the Palaeoclimate Modelling Intercomparison Project (PMIP4; Kageyama et al., 2017; Otto-Bleisner et al., 2019).

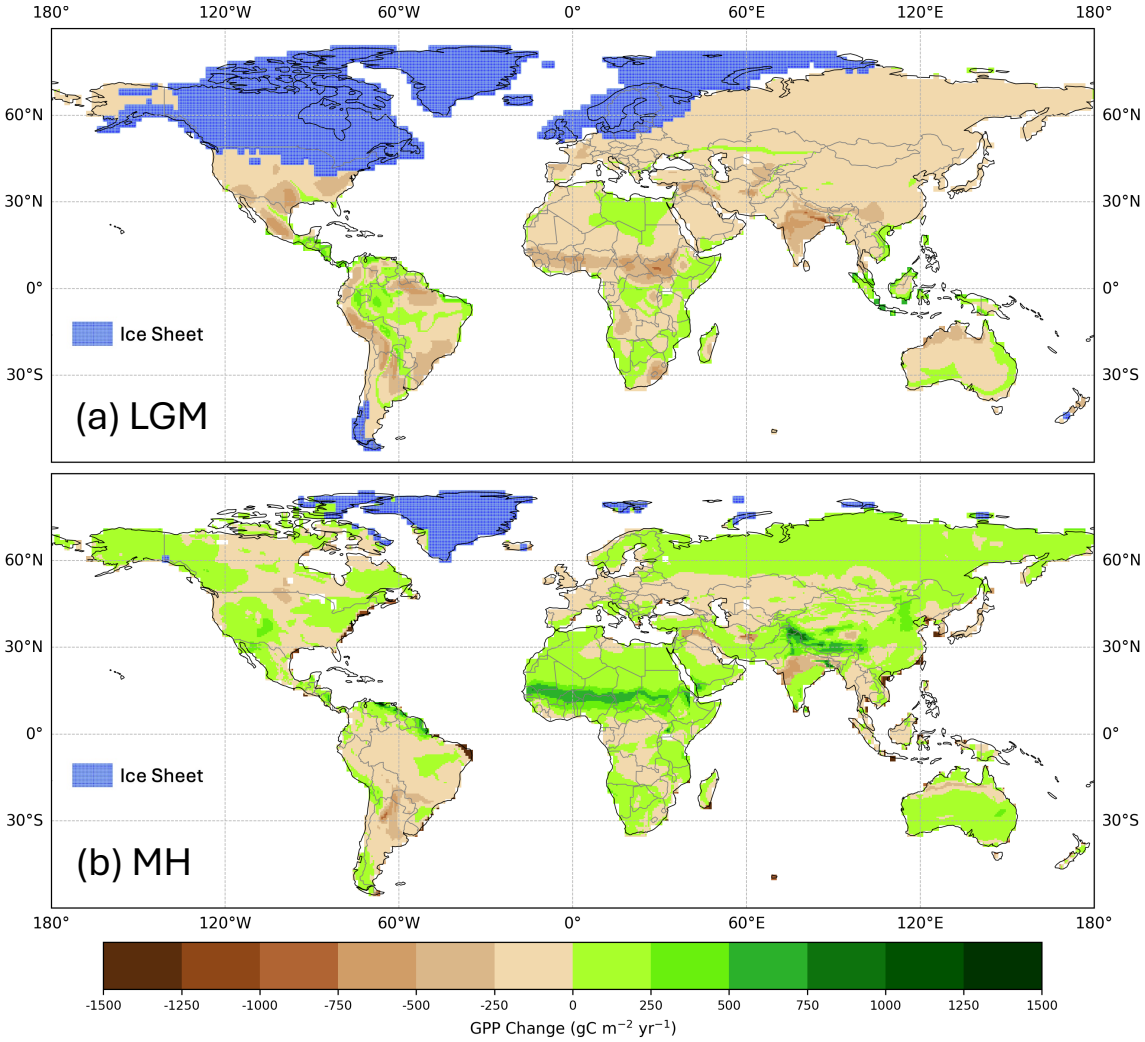
Model	**LGM**	**MH**	**PI**
MPI-ESM1-2-LR	67.8	116.9	121
AWI-ESM-1-1-LR	61.4	106.5	95
INM-CM4-8	110.7	137.5	140.6
MIROC-ES2L	108.6	146.1	151.7
NCAR.CESM2	n/a	103.8	115.0
IPSL-CM6A-LR	n/a	106.7	116.0
NorESM2-LM	n/a	123.7	134.2
ACCESS-ESM1-5	n/a	97.9	105.6
GISS-E2-1-G	n/a	106.0	121.1



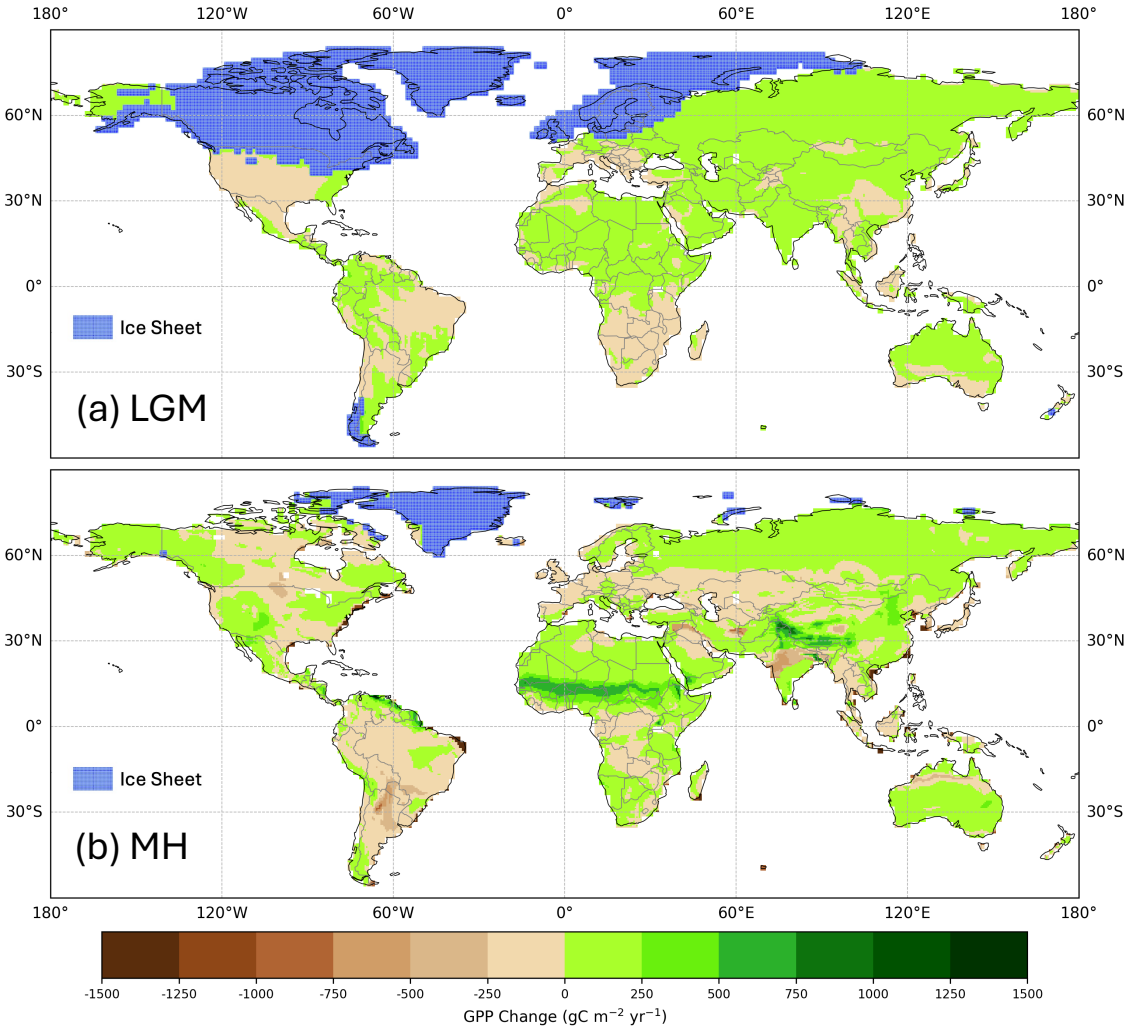
SI Figure 1. Change in C_4 fraction (a) at the Last Glacial Maximum (LGM) compared to the pre-industrial (PI) experiment and (b) in the mid-Holocene (MH) compared to the PI experiment.



SI Figure 2. Simulated change in total annual gross primary production (GPP) between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except climate.



SI Figure 3. Simulated change in total annual gross primary production (GPP) between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except CO_2.



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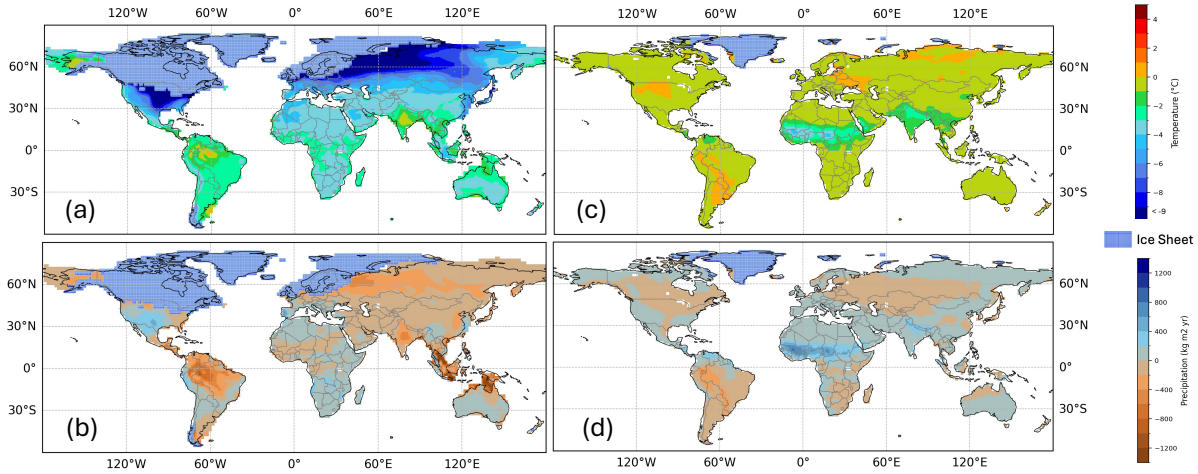
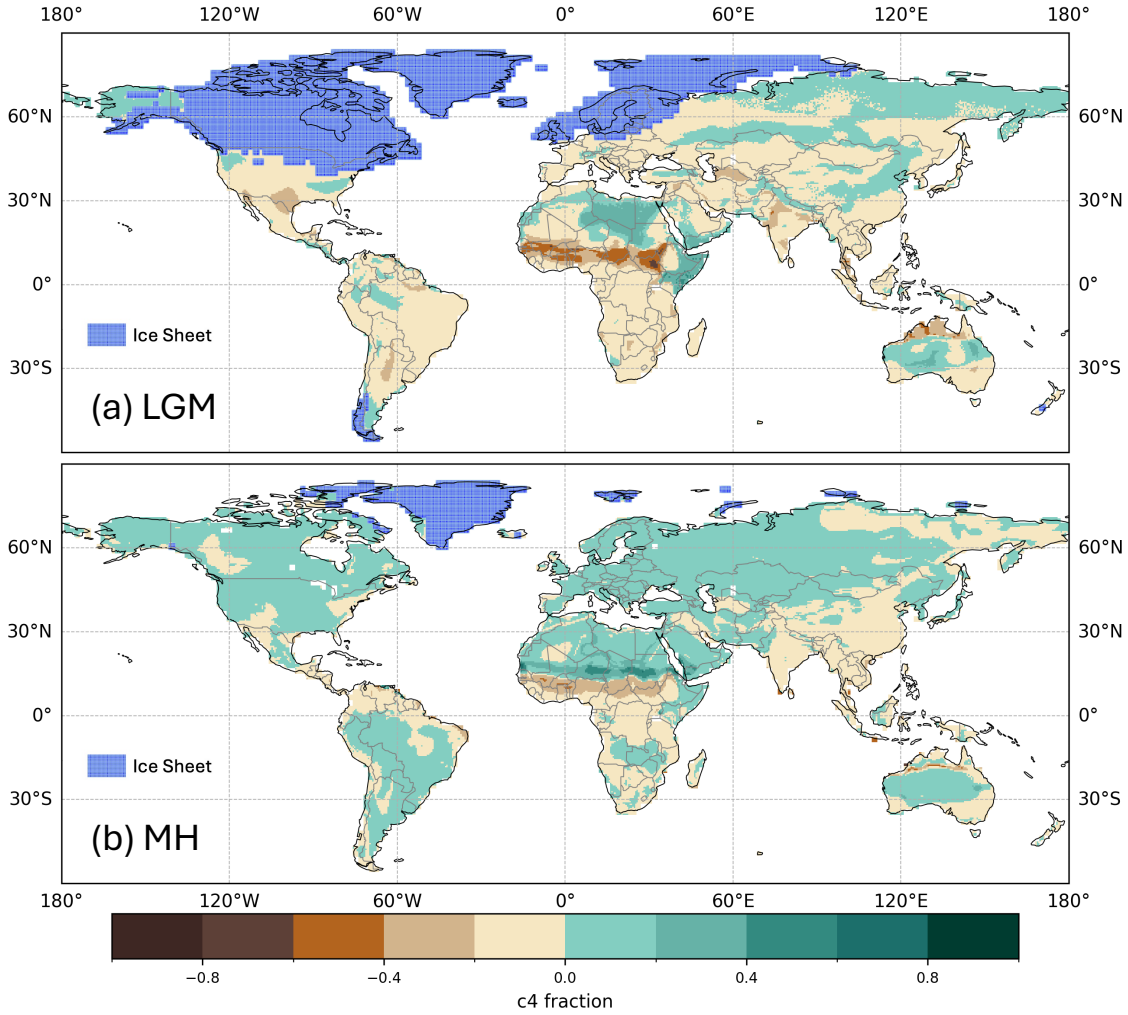
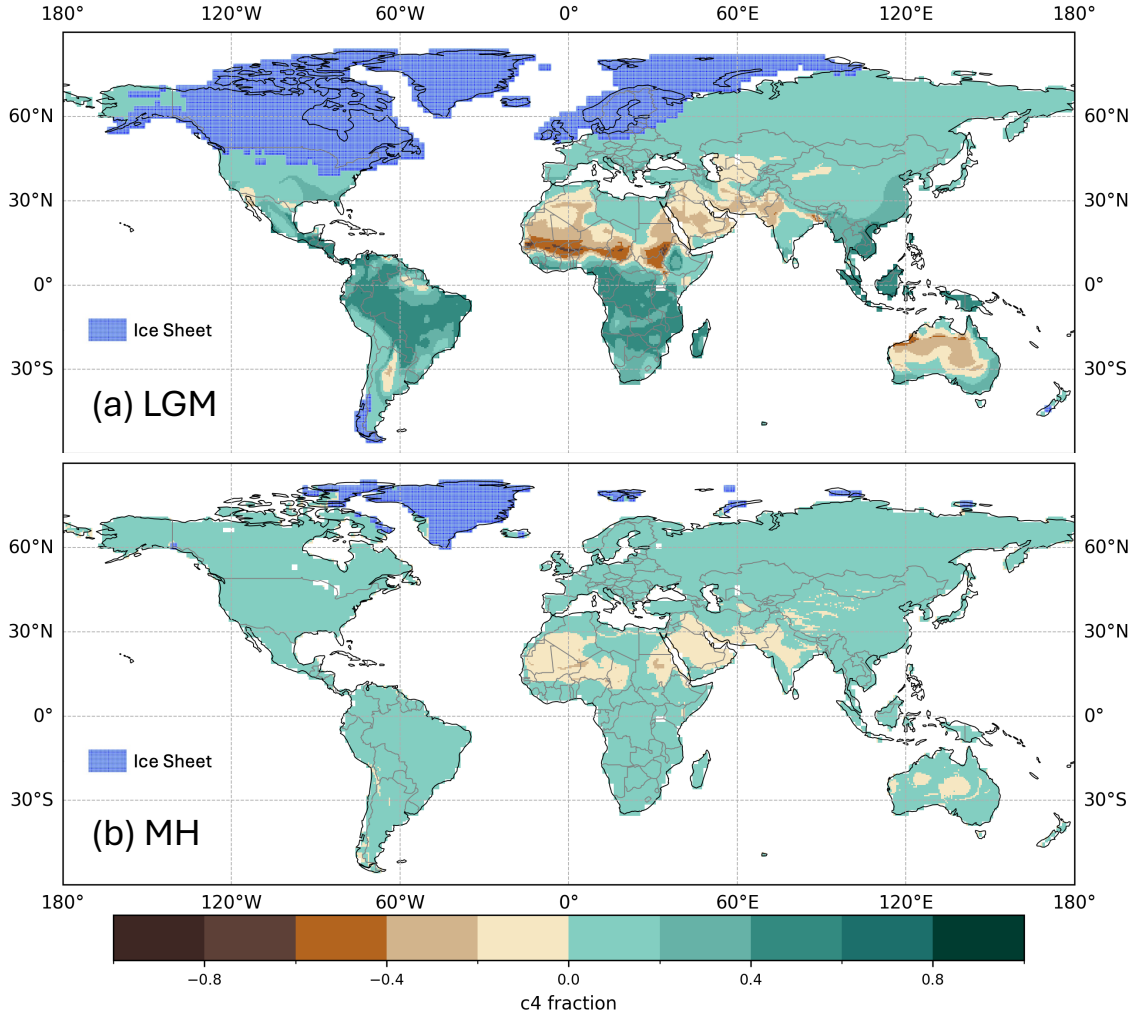


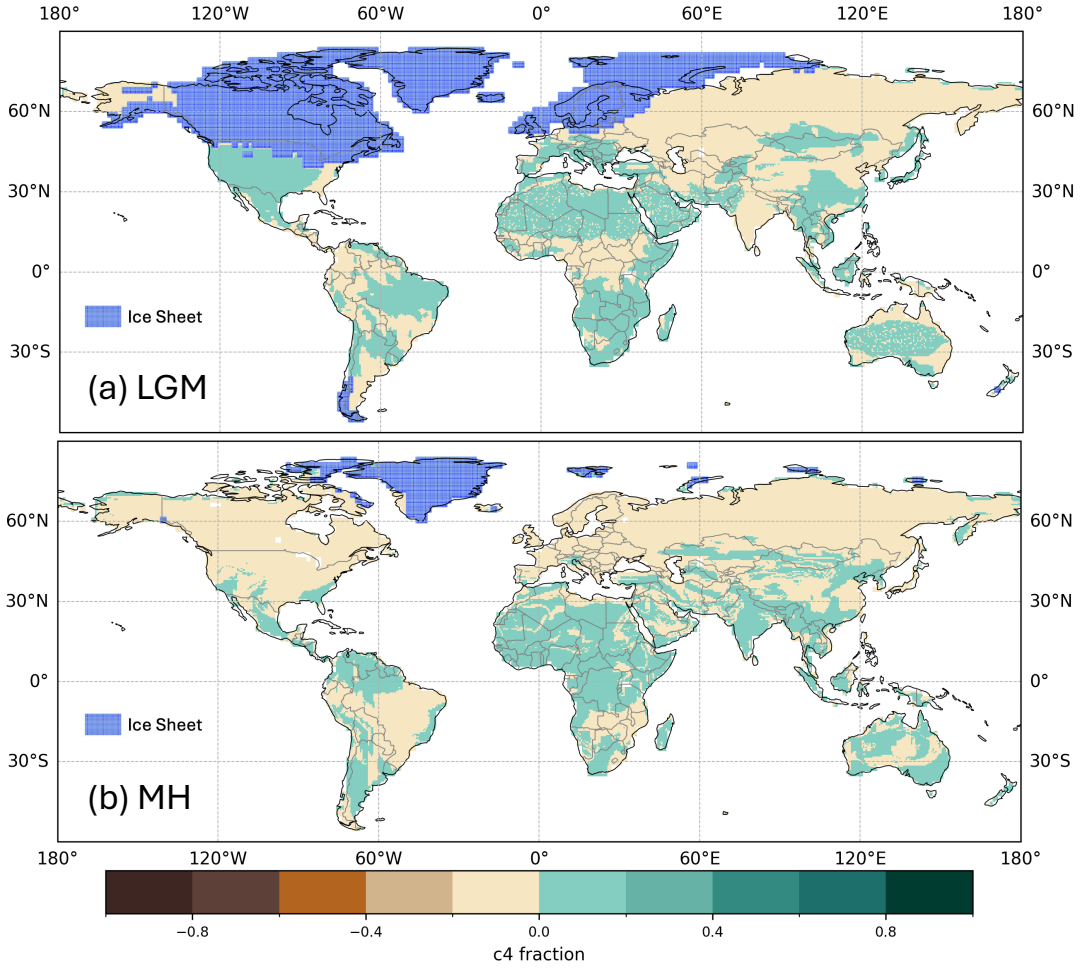
SI Figure 5. Simulated changes in (a) mean annual temperature and (b) mean annual precipitation between the pre-industrial (PI) and the Last Glacial Maximum (LGM); simulated changes in (c) mean annual temperature and (d) mean annual precipitation between the pre-industrial (PI) and the mid-Holocene (MH).



SI Figure 6. Simulated change in C_4 fraction between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except climate.



SI Figure 7. Simulated change in C4 fraction between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except CO_2.



SI Figure 8. Simulated change in C4 fraction between the pre-industrial (PI) and (a) the Last Glacial Maximum (LGM) and (b) the mid-Holocene (MH) as a result of holding all variables constant except light (photosynthetic photon flux density, PPFD).

Supplementary References

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