

Supporting information of “GOLUM-CNP v1.0: a data-driven modeling of carbon, nitrogen and phosphorus cycles in major terrestrial biomes” by Yilong Wang, Philippe Ciais, Daniel Goll, Yuanyuan Huang, Yiqi Luo, Ying-Ping Wang, A. Anthony Bloom, Grégoire Broquet, Jens Hartmann, Shushi Peng, Josep Penuelas, Shilong Piao, Jordi Sardans, Benjamin D. Stocker, Rong Wang, Sönke Zaehle, Sophie Zechmeister-Boltenstern

S1 Comparison of the “openness” in this study and in Cleveland et al. (2013)

In this section, we compare the computation of “openness” index used in this study versus “proportion of new NPP fueled by new nutrient inputs” used in Cleveland et al. (2013). We take the indexes for N as an example, but the computation of corresponding indexes for P are similar.

Assume NPP is allocated to leaf, wood and roots by 0.5, 0.3 and 0.2, those pools with C:N ratios of 25, 150 and 50. In Cleveland's index, N is allocated in fractions of 0.5, 0.3 and 0.2 in NPP-N (C_j can be moved before C_{toN_j} in their Eq. S7). The new NPP is $(0.5*25 + 0.3*150 + 0.2*50) * I_N = 67.5 I_N$, where I_N represent external nutrients inputs, i.e. the sum of deposition and biological fixation for N which is available to vegetation. They assume that the remaining NPP must be totally fueled by resorption and net mineralization in the soil. They modelled the amount of N resorption but computed the amount of mineralization as the difference between nutrient demand, new nutrient inputs, and nutrient resorption (their Eqs. S5). So the “proportion of new NPP fueled by new nutrient inputs” index in Cleveland et al. (2013) equals $67.5 I_N/NPP$.

In this study, the N allocation is 0.5/25 : 0.3/150 : 0.2/50. Normalizing the values to ensure the sum of the fractions equals to 1 gives allocation fractions of N in NPP-N of 0.77 : 0.08 : 0.15. Under steady state, we have the relationship that the total N demand = $NPP*0.5/25+NPP*0.3/150+NPP*0.2/50=F_N+RSB_N$, where F_N is the uptake from inorganic N soil pool and RSB_N is the flux of resorbed N. As a result, the openness index $NO = I_N / (F_N + RSB_N) = 38.5 I_N/NPP$.

Because there is no evidence that how much the new N inputs is allocated in the vegetation, we chose to define the openness index only based on N and P fluxes rather than to convert N and P fluxes into NPP like Cleveland et al. (2013) did.

Table S1 C:N, C:P and N:P molar (atomic) ratios across major biomes from Zechmeister-Boltenstern et al. (2015). Targeted biomes are: tropical rain forests (TRF), temperate deciduous forests (TEDF), temperate coniferous forests (TECF), boreal coniferous forests (BOCF), tundra (TUN), tropical/C4 grasslands (TRG), and temperate/C3 grasslands (TEG). Note that N:P ratios in Zechmeister-Boltenstern et al. (2015) are not exactly equal to the ratio of C:P to C:N, but the differences are small.

		TRF	TEDF	TECF	BOCF	TRG	TEG	TUN
C:N	Foliage	25	25	59	49	39	25	49
	Root	47	59	67	57	39	88	54
	Wood	148	471	844	525	--	--	--
	Soil	16	19	20	32	25	10	13
C:P	Foliage	1027	867	1232	1049	753	1278	2167
	Root	3125	1962	1186	1574	1300	2829	1300
	Wood	13574	11179	24297	19734	--	--	--
	Soil	159	366	302	960	509	130	138
N:P	Foliage	43	36	23	23	20	53	45
	Root	52	22	18	30	32	27	20
	Wood	93	24	29	38	--	--	--
	Soil	13	20	15	31	31	--	11

Table S2 Mean residence time of C, N and P in ecosystems (unit: years). Targeted biomes are:

tropical rain forests (TRF), temperate deciduous forests (TEDF), temperate coniferous forests (TECF), boreal coniferous forests (BOCF), tundra (TUN), tropical/C4 grasslands (TRG), and temperate/C3 grasslands (TEG).

	TRF	TEDF	TECF	BOCF	TRG	TEG	TUN	Globe
C	29	49	48	106	40	67	101	38
N	382	1016	637	4834	987	3075	7896	1586
P	2520	3263	4413	6167	4483	6291	7077	6092

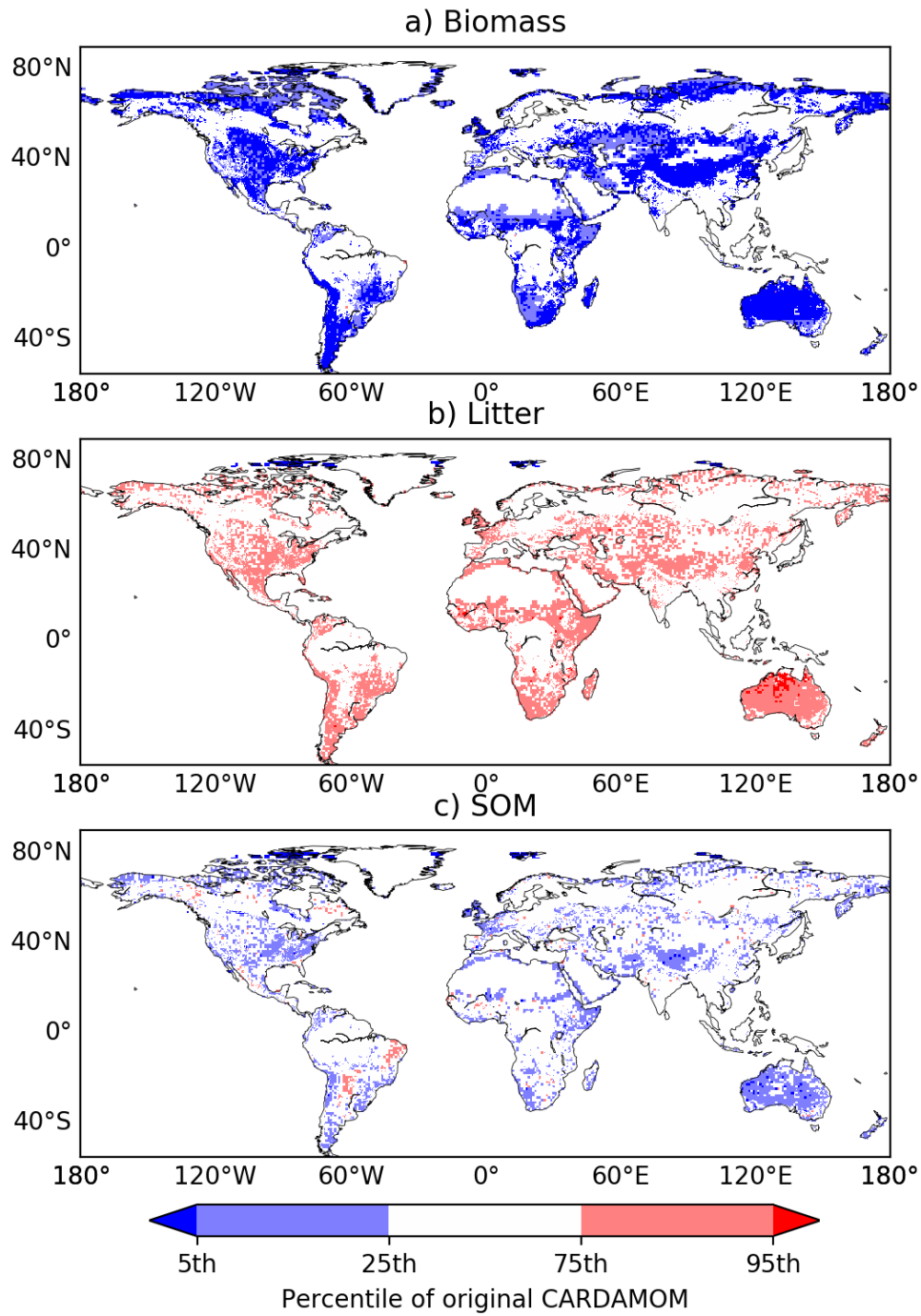


Fig. S1 Comparison between C pool sizes of transformed steady-state C cycle and original CARDAMOM results.

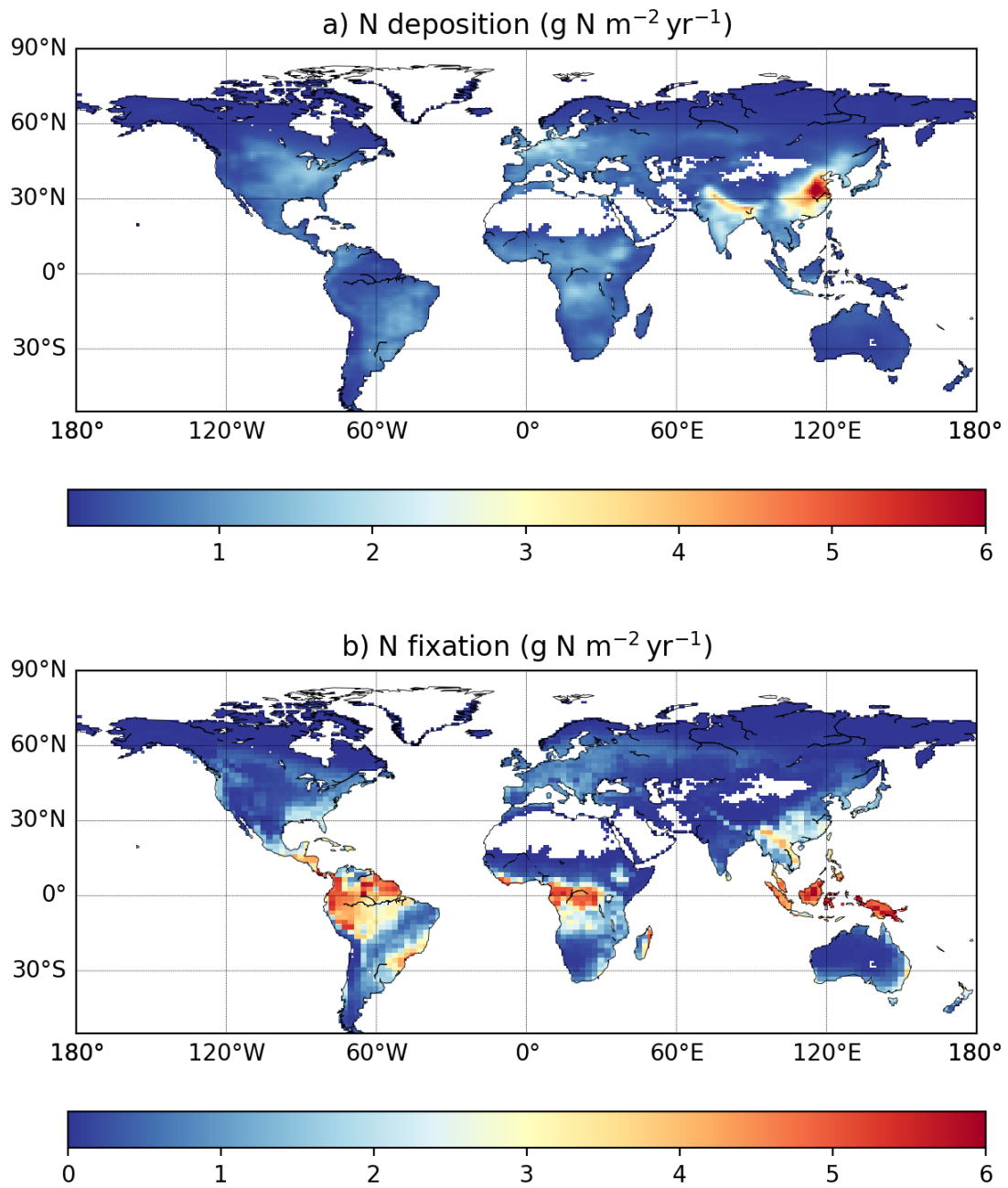


Fig. S2 Global external N inputs. a) N deposition from Wang et al. (2017). b) N fixation from Peng et al. (submitted)

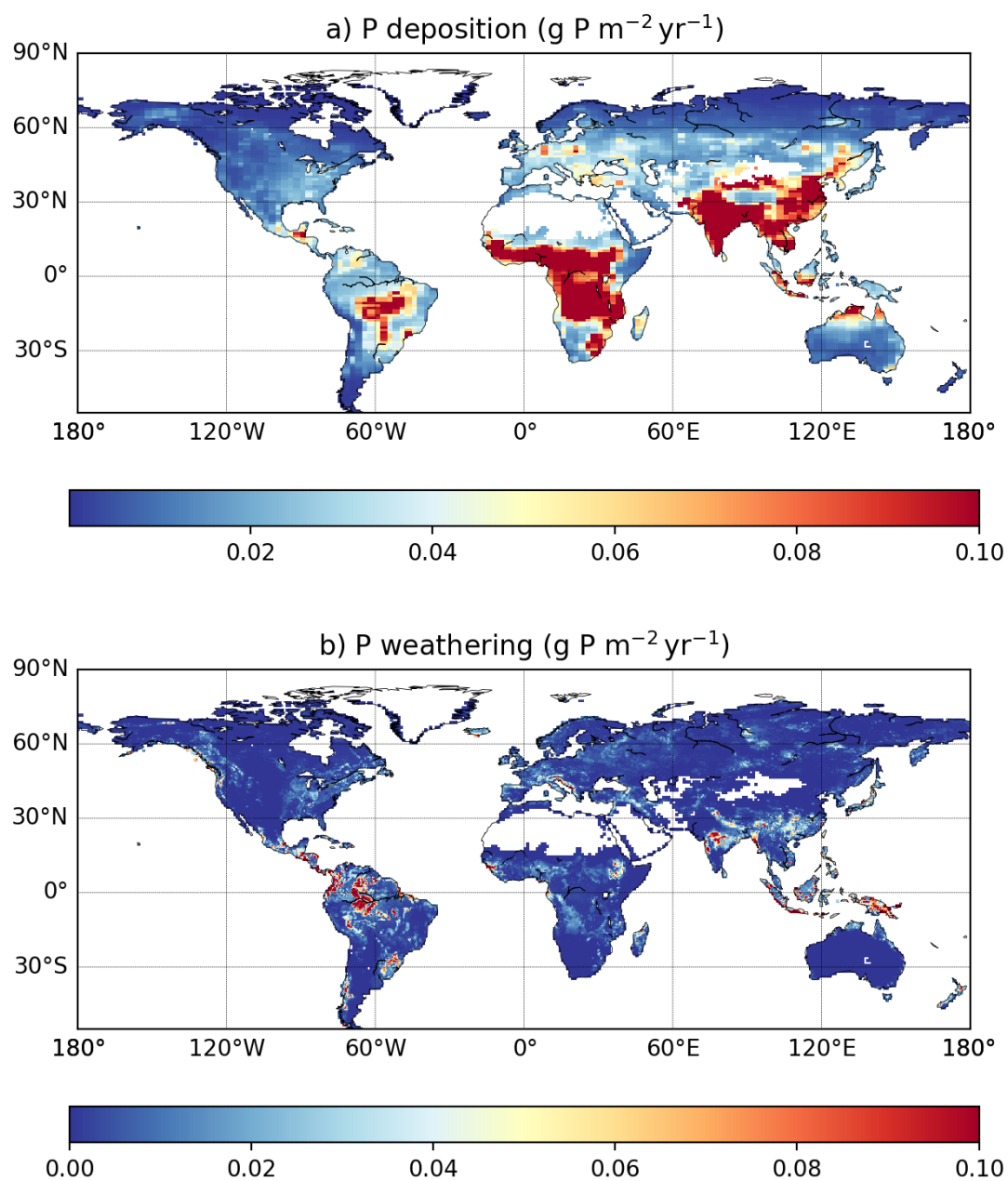


Fig. S3 Global external P inputs. a) P deposition from Wang et al. (2017). b) Release of P from rock weathering from Hartmann et al. (2014)

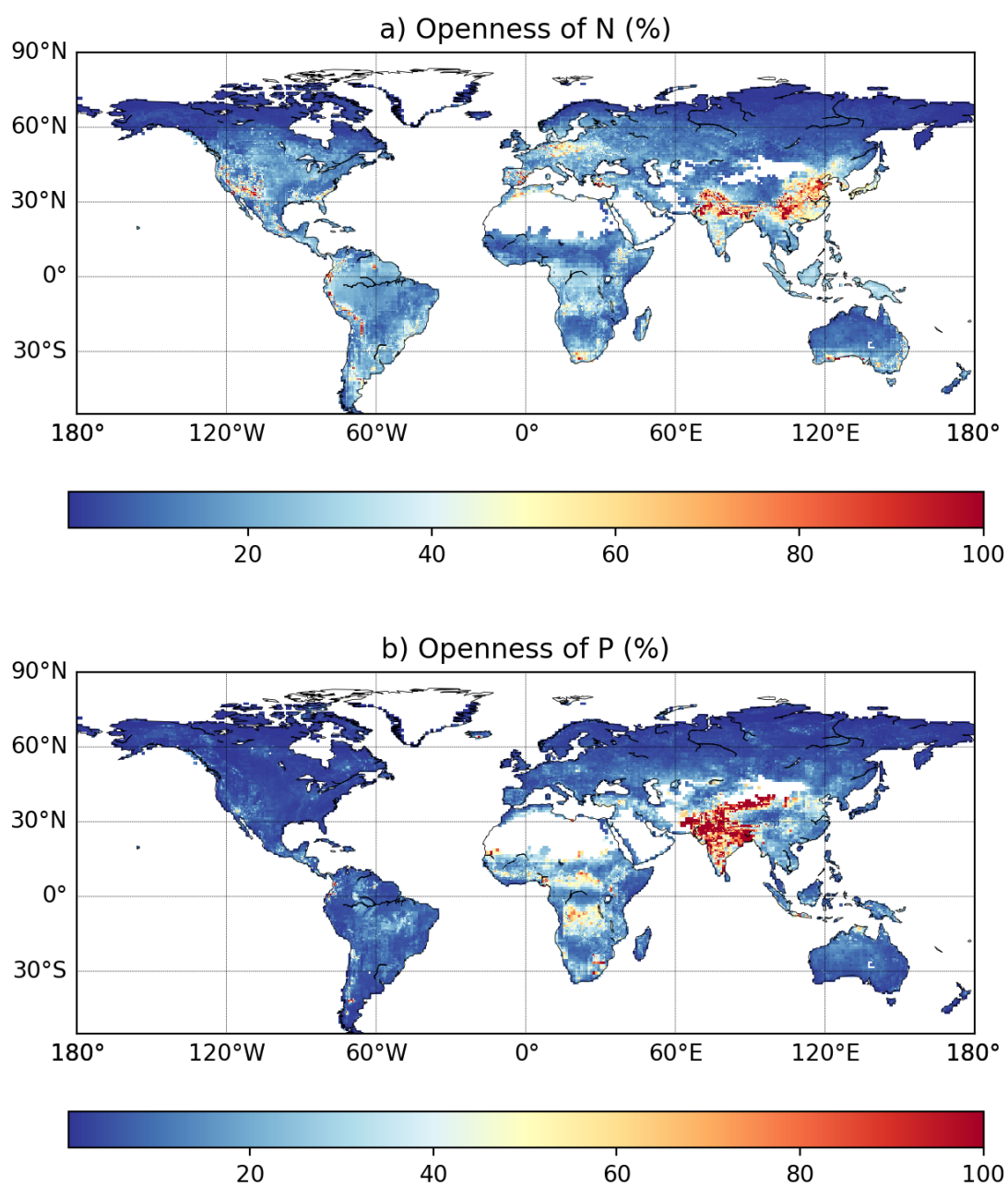


Fig. S4 Global nutrient openness computed from GOLUM-CNP. a) Openness of N. b) Openness of P.

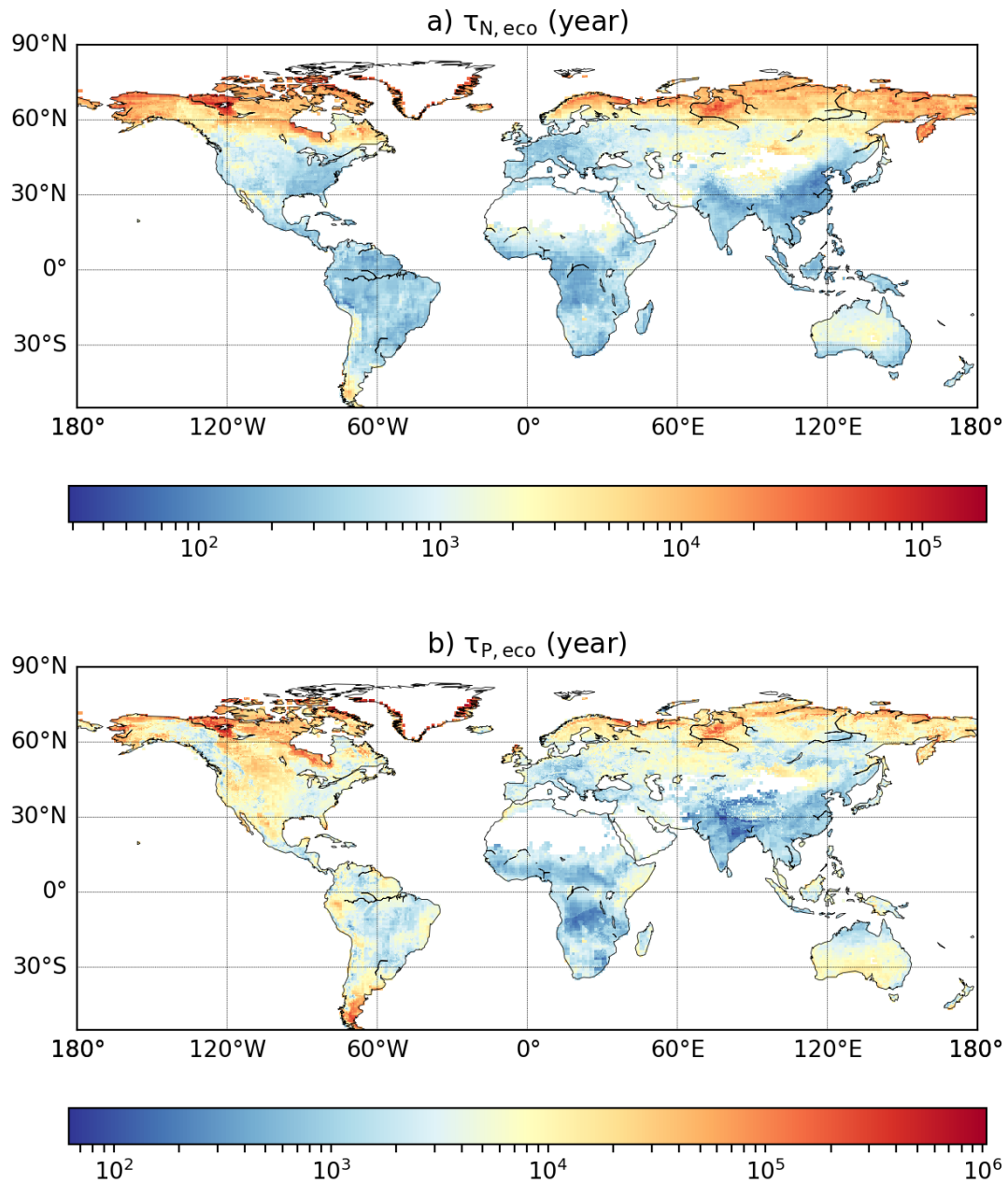


Fig. S5 Global residence times of nutrients in the ecosystems. a) Residence times of N in the ecosystems. b) Residence times of P in the ecosystems

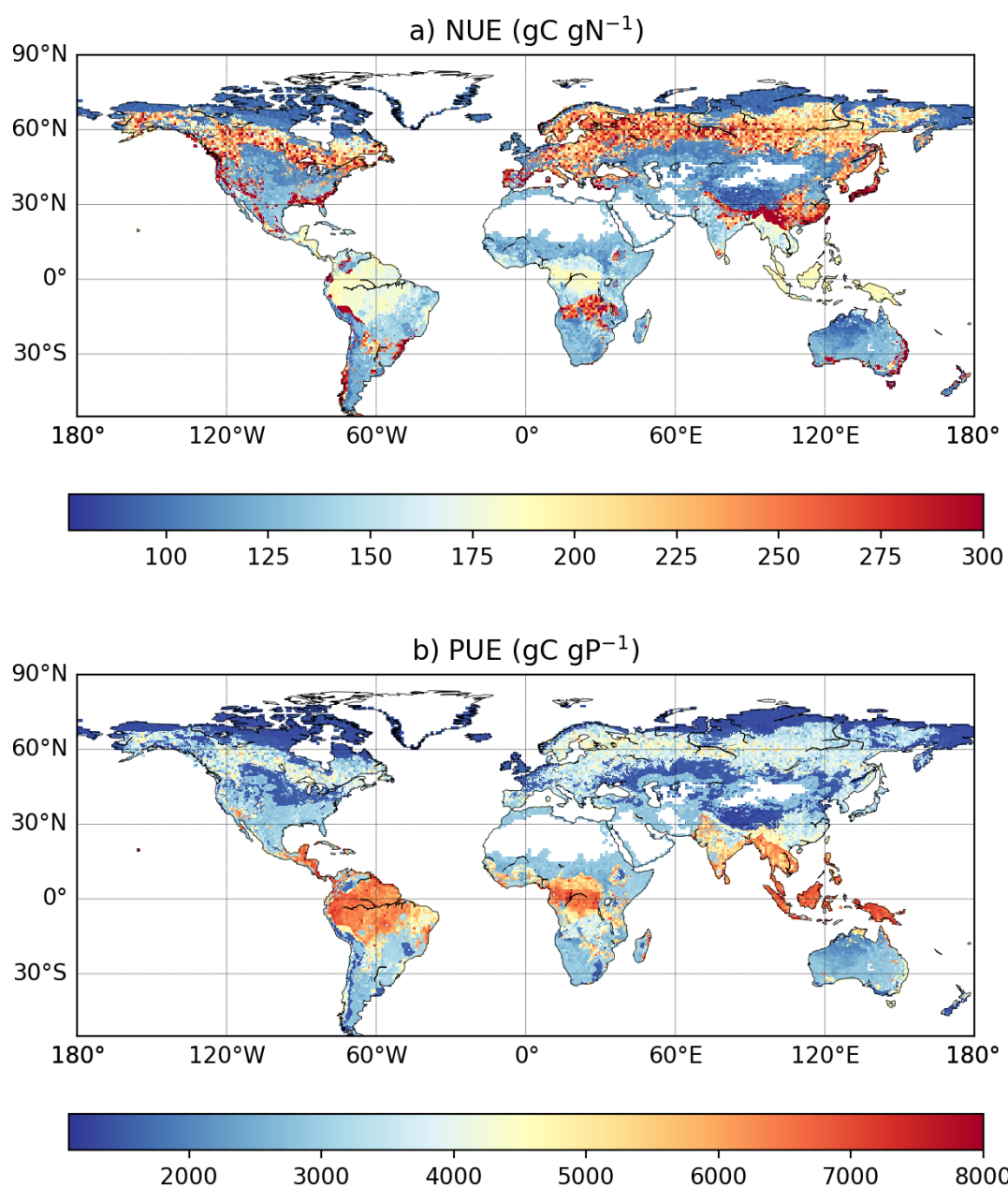


Fig. S6 Global nutrient use efficiencies (the nutrient uptake by plants divided by GPP). a) N use efficiency. b) P use efficiency.

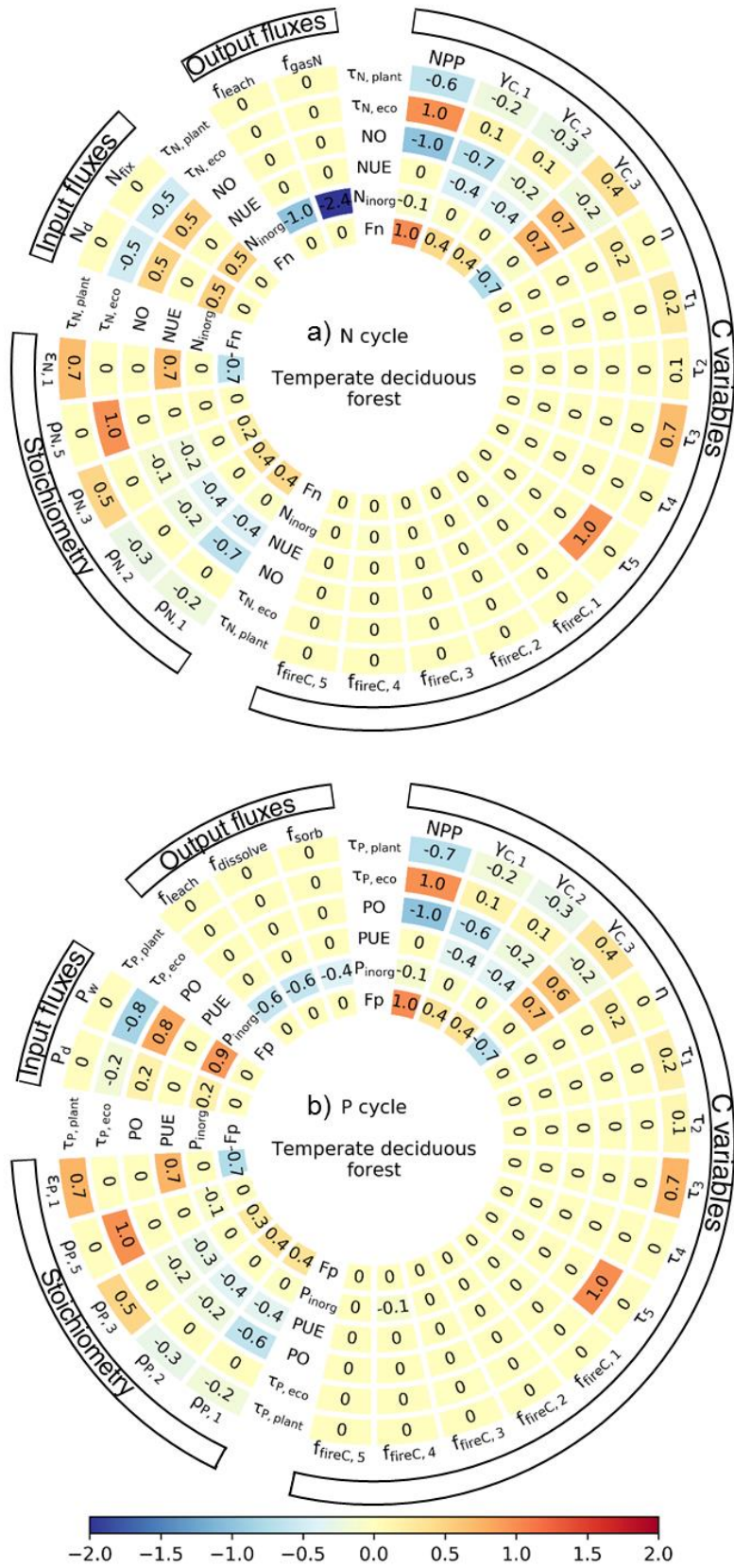


Figure S7 Mean sensitivity of the estimates of rates of nutrient uptake, inorganic nutrients, nutrient-use efficiencies, openness, turnover time of nutrients in the ecosystem and turnover time of nutrients in plants to the input variables for temperate deciduous forests.

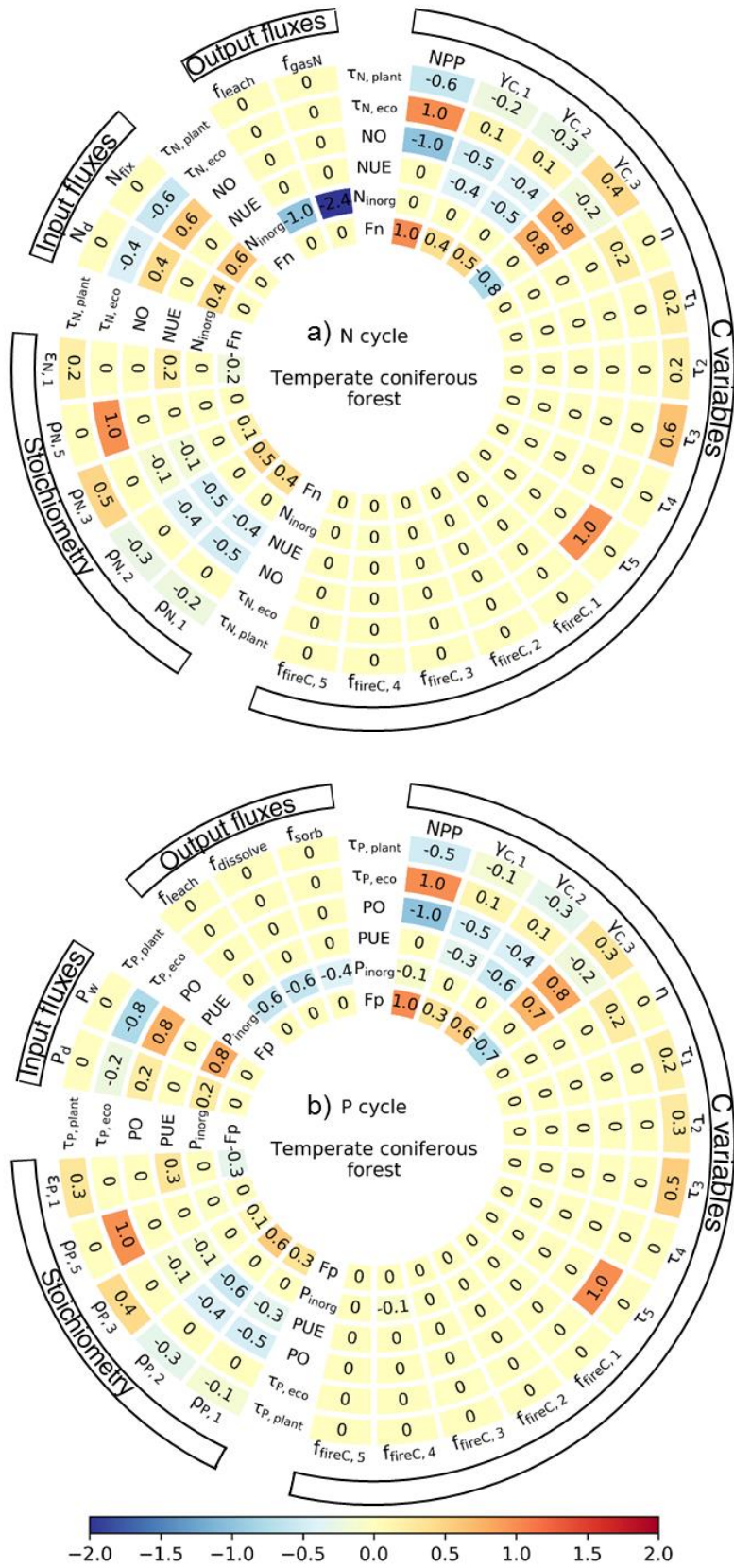


Figure S8 Mean sensitivity of the estimates of rates of nutrient uptake, inorganic nutrients, nutrient-use efficiencies, openness, turnover time of nutrients in the ecosystem and turnover time of nutrients in plants to the input variables for temperate coniferous forests.

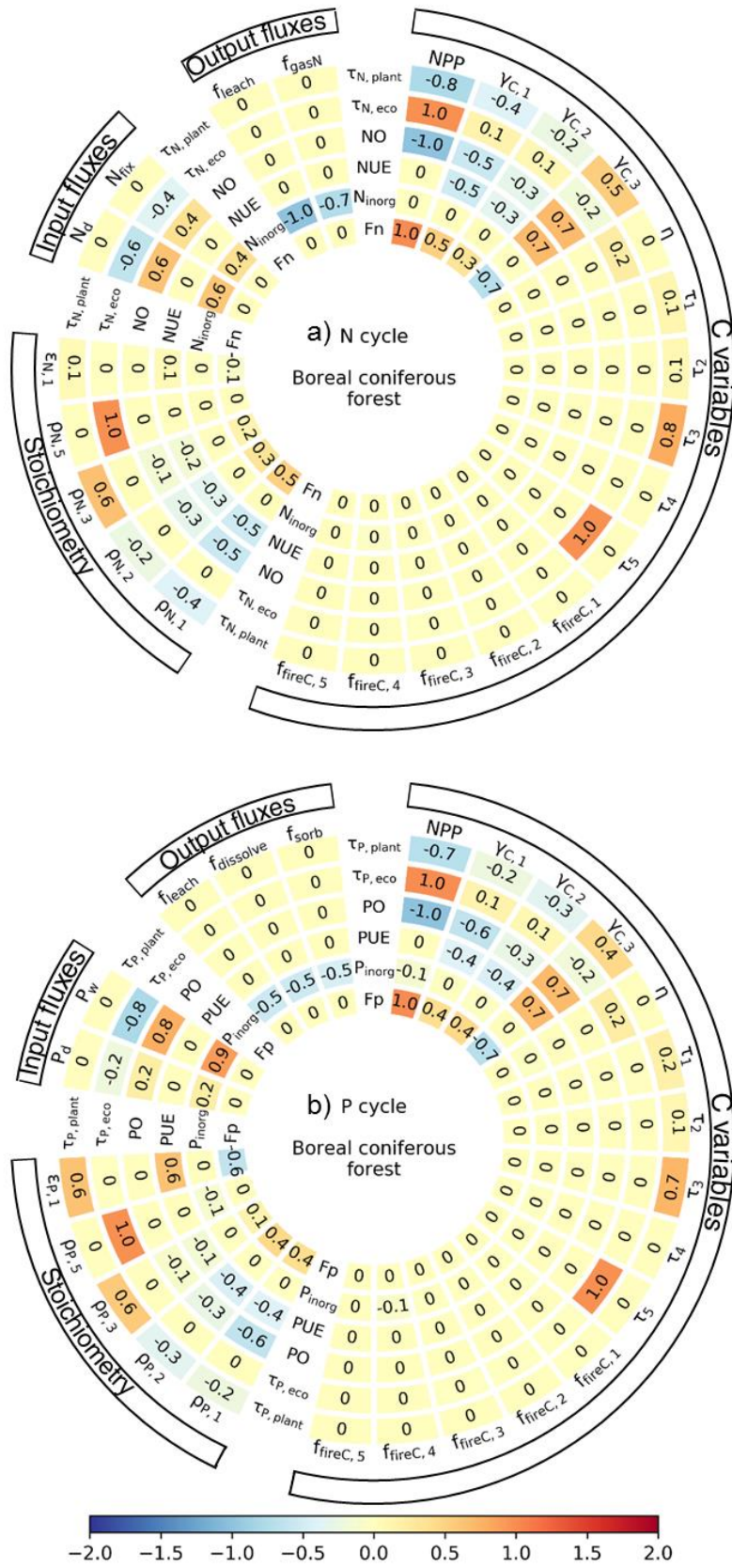


Figure S9 Mean sensitivity of the estimates of rates of nutrient uptake, inorganic nutrients, nutrient-use efficiencies, openness, turnover time of nutrients in the ecosystem and turnover time of nutrients in plants to the input variables for boreal coniferous forests.

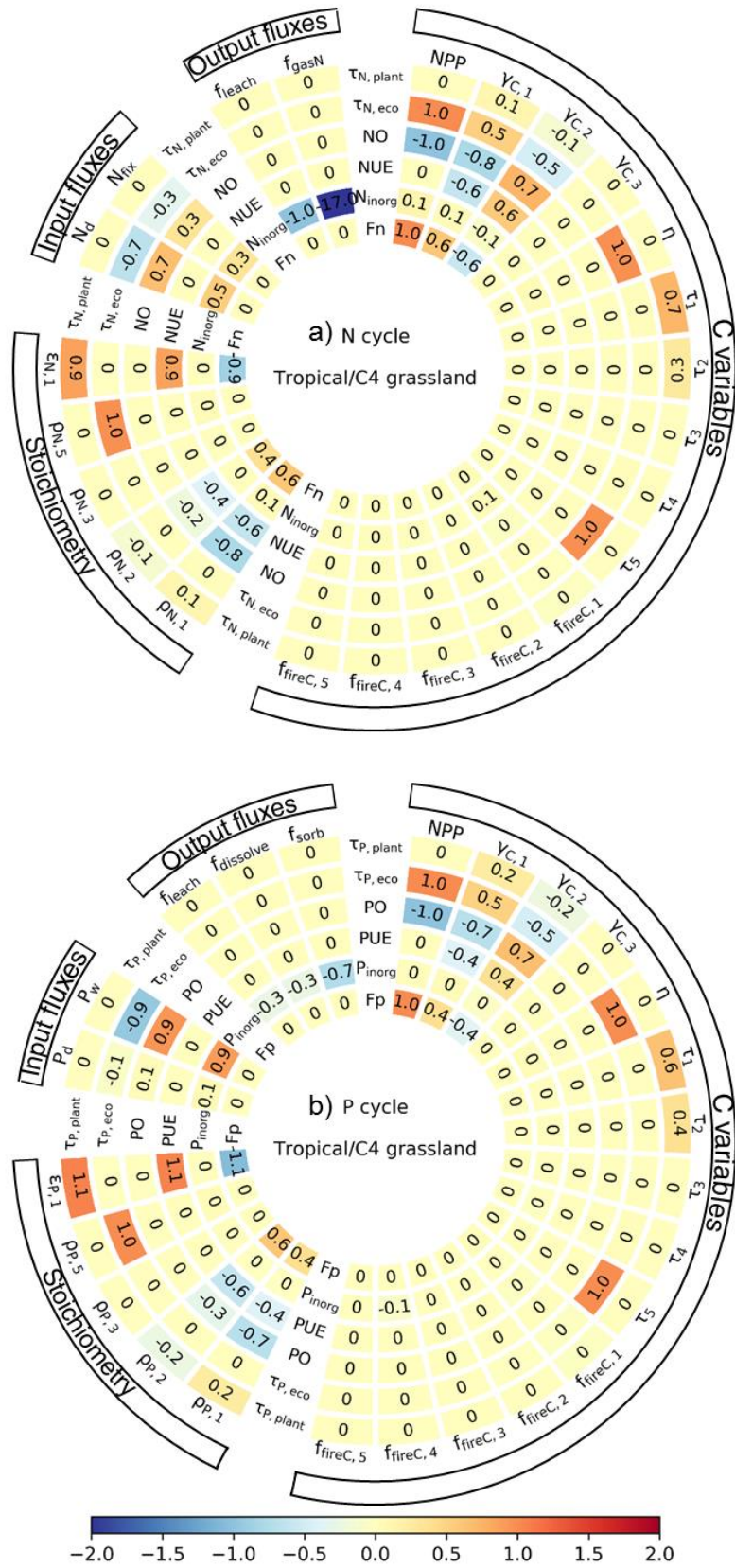


Figure S10 Mean sensitivity of the estimates of rates of nutrient uptake, inorganic nutrients, nutrient-use efficiencies, openness, turnover time of nutrients in the ecosystem and turnover time of nutrients in plants to the input variables for tropical/C4 grasslands.

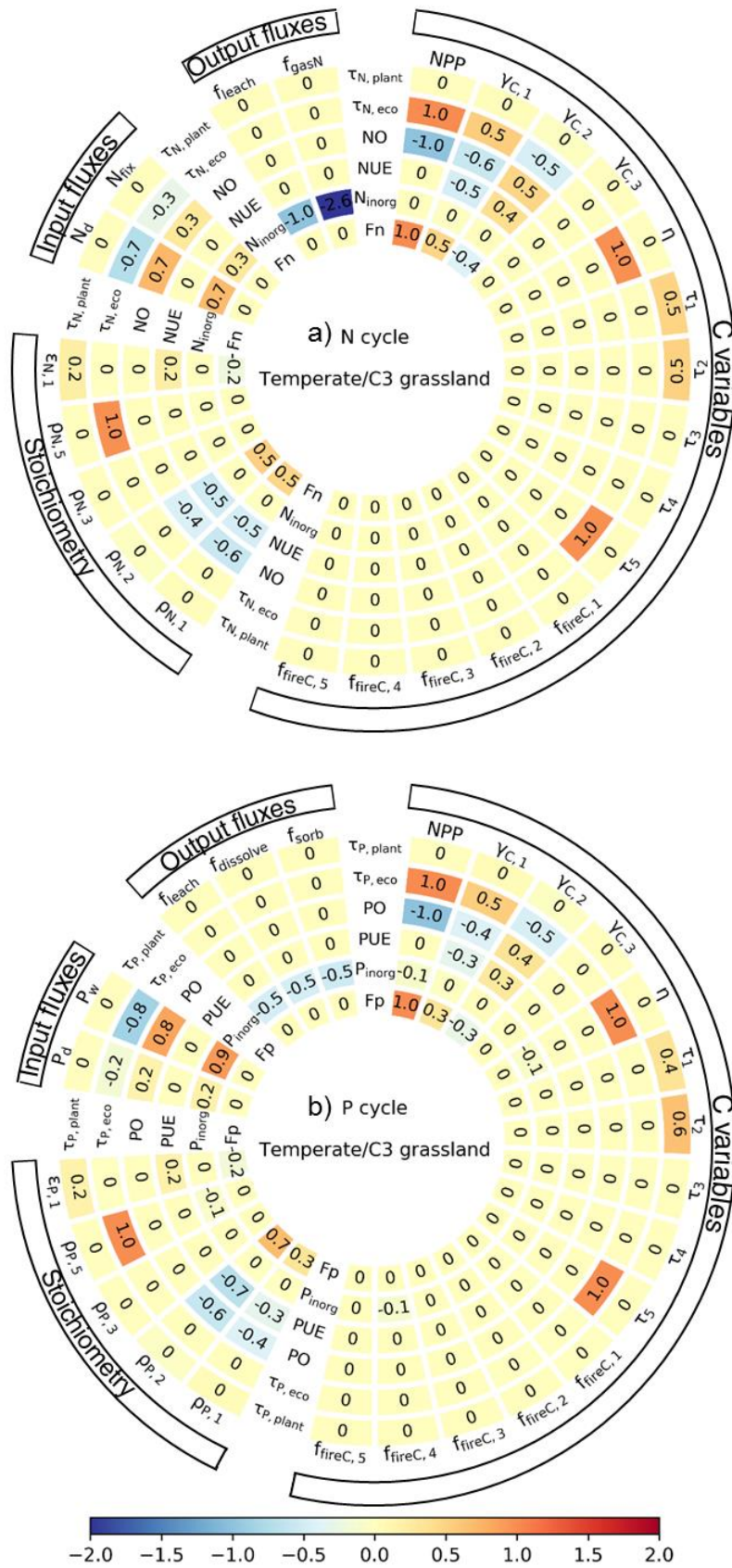


Figure S11 Mean sensitivity of the estimates of rates of nutrient uptake, inorganic nutrients, nutrient-use efficiencies, openness, turnover time of nutrients in the ecosystem and turnover time of nutrients in plants to the input variables for temperate/C3 grasslands.

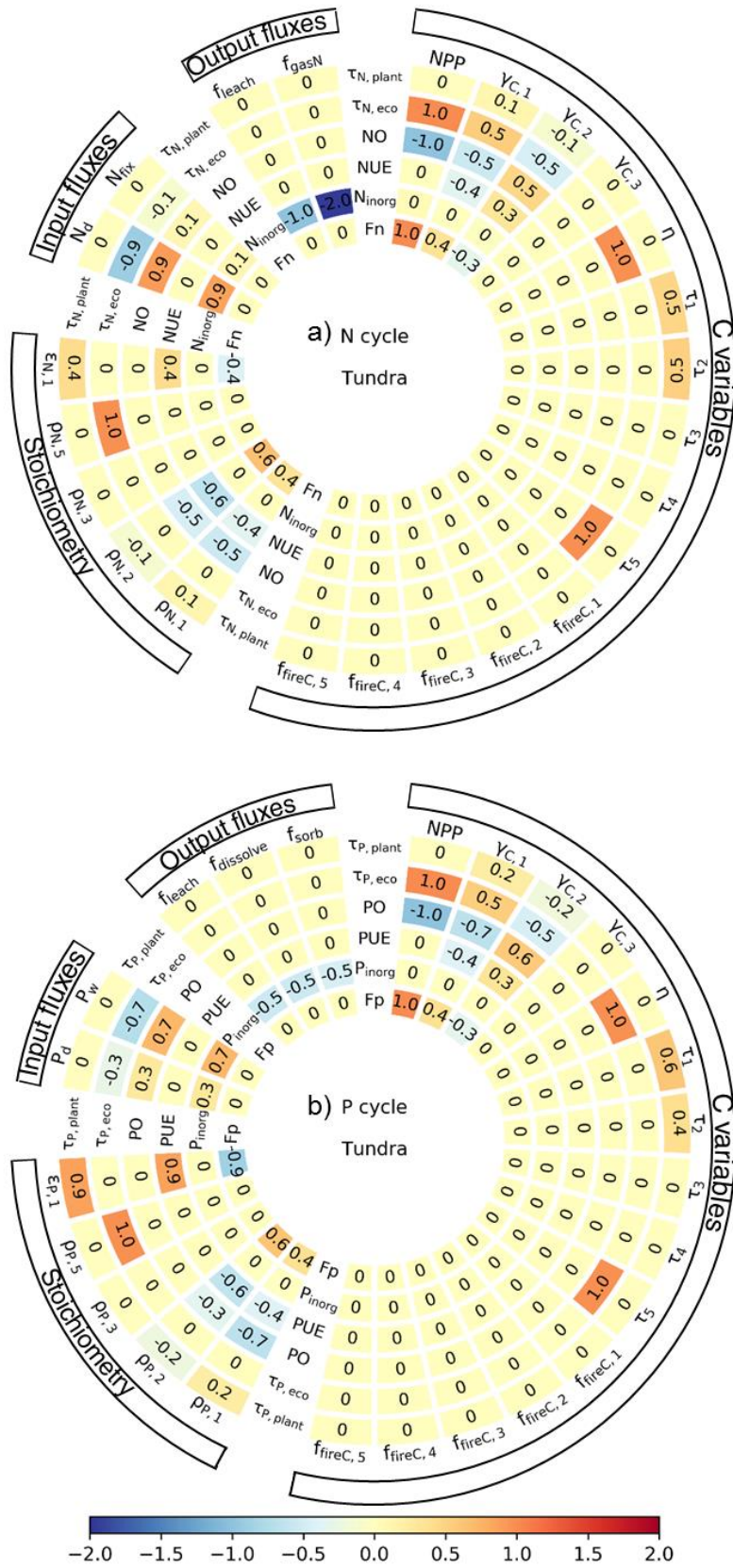


Figure S12 Mean sensitivity of the estimates of rates of nutrient uptake, inorganic nutrients, nutrient-use efficiencies, openness, turnover time of nutrients in the ecosystem and turnover time of nutrients in plants to the input variables for tundra.

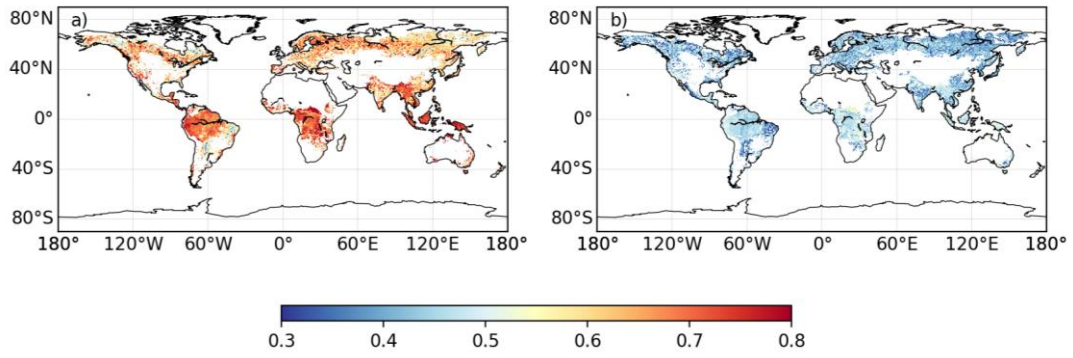


Figure S13 NPP allocation fractions to woody biomass in original CARDAMOM (a) and adjusted (see Sect. 5.1) carbon cycle model (b).

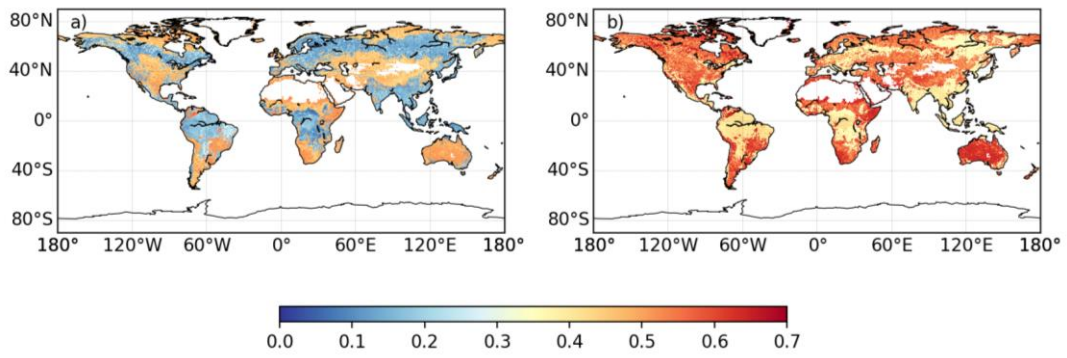


Figure S14 NPP allocation fractions to fine roots in original CARDAMOM (a) and adjusted (see Sect. 5.1) carbon cycle model (b).

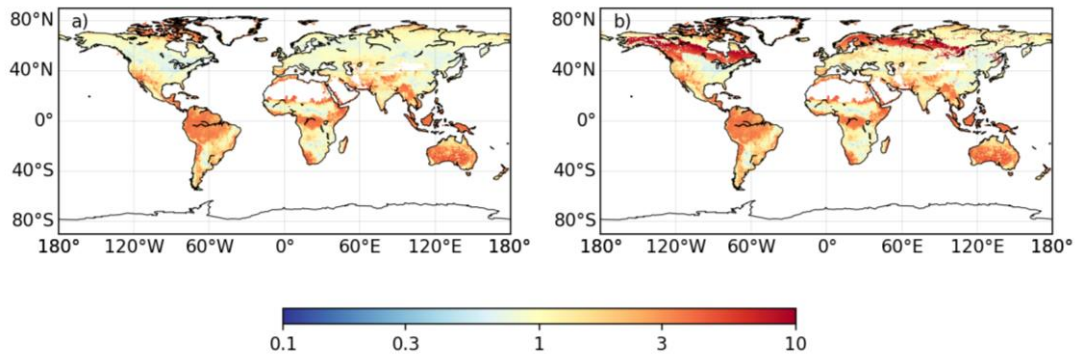


Figure S15 Leaf longevity in original CARDAMOM (a) and adjusted (see Sect. 5.1) carbon cycle model (b).

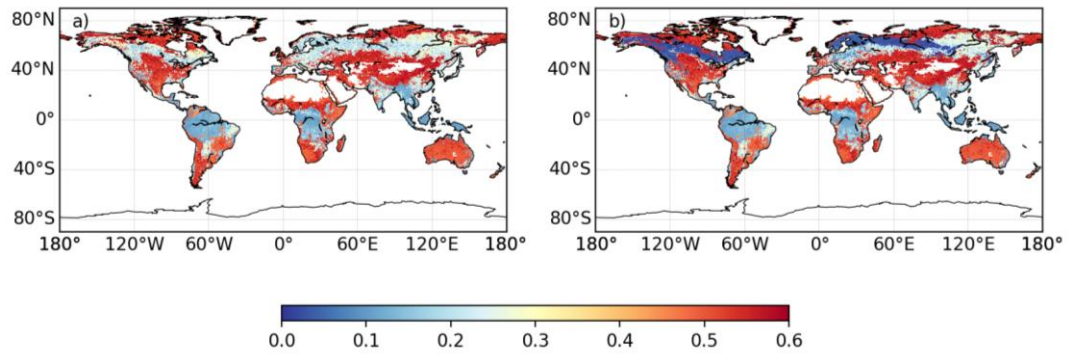


Figure S16 NPP allocation fractions to foliage in original CARDAMOM (a) and adjusted (see Sect. 5.1) carbon cycle model (b).