Climate change impacts on mycorrhizae amplify nitrogen limitation on global plant growth

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Supplementary information

Table S1. Look-up table between GLC Global Class and CLM PFTs.

CLM PFT	Classification	GLC Global Class
PFT 0	Bare soil (not vegetated)	(19)Bare Areas
PFT 1	Needleleaf evergreen temperate tree	(04)Tree Cover, needle-leaved, evergreen; (06)Tree Cover, mixed leaf type; (07)Tree Cover, regularly flooded, fresh water (& brackish); (08)Tree Cover, regularly flooded, saline water; (09)Mosaic; (10)Tree Cover, burnt; (17)Mosaic;
PFT 2	Needleleaf evergreen boreal tree	(04)Tree Cover, needle-leaved, evergreen; (06)Tree Cover, mixed leaf type; (07)Tree Cover, regularly flooded, fresh water (& brackish); (08)Tree Cover, regularly flooded, saline water; (09)Mosaic; (10)Tree Cover, burnt; (17)Mosaic;
PFT 3	Needleleaf deciduous boreal tree	(05)Tree Cover, needle-leaved, deciduous; (06)Tree Cover, mixed leaf type; (07)Tree Cover, regularly flooded, fresh water (& brackish); (08)Tree Cover, regularly flooded, saline water; (09)Mosaic; (10)Tree Cover, burnt; (17)Mosaic;
PFT 4	Broadleaf evergreen tropical tree	(01) Tree Cover, broadleaved, evergreen; (06)Tree Cover, mixed leaf type; (07)Tree Cover, regularly flooded, fresh water (& brackish); (08)Tree Cover, regularly flooded, saline water; (09)Mosaic; (10)Tree Cover, burnt; (17)Mosaic;

PFT 5	Broadleaf evergreen temperate tree	(01) Tree Cover, broadleaved, evergreen; (06)Tree Cover, mixed leaf type; (07)Tree Cover, regularly flooded, fresh water (& brackish); (08)Tree Cover, regularly flooded, saline water; (09)Mosaic; (10)Tree Cover, burnt; (17)Mosaic;
PFT 6	Broadleaf deciduous tropical tree	(02)Tree Cover, broadleaved, deciduous, closed; (06)Tree Cover, mixed leaf type; (07)Tree Cover, regularly flooded, fresh water (& brackish); (08)Tree Cover, regularly flooded, saline water; (09)Mosaic; (10)Tree Cover, burnt; (17)Mosaic;
PFT 7	Broadleaf deciduous temperate tree	(02)Tree Cover, broadleaved, deciduous, closed; (06)Tree Cover, mixed leaf type; (07)Tree Cover, regularly flooded, fresh water (& brackish); (08)Tree Cover, regularly flooded, saline water; (09)Mosaic; (10)Tree Cover, burnt; (17)Mosaic;
PFT 8	Broadleaf deciduous boreal tree	(02)Tree Cover, broadleaved, deciduous, closed; (06)Tree Cover, mixed leaf type; (07)Tree Cover, regularly flooded, fresh water (& brackish); (08)Tree Cover, regularly flooded, saline water; (09)Mosaic; (10)Tree Cover, burnt; (17)Mosaic;
PFT 9	Broadleaf evergreen shrub	(01) Tree Cover, broadleaved, evergreen; (06)Tree Cover, mixed leaf type; (09)Mosaic; (11)Shrub Cover, closed-open, evergreen; (13)Herbaceous Cover, closed-open; (14)Sparse

		Herbaceous or sparse Shrub Cover; (15)Regularly flooded Shrub and/or Herbaceous Cover; (17)Mosaic; (18)Mosaic
PFT 10	Broadleaf deciduous temperate shrub	(03)Tree Cover, broadleaved, deciduous, open; (06)Tree Cover, mixed leaf type; (09)Mosaic; (12)Shrub Cover, closed-open, deciduous; (13)Herbaceous Cover, closed-open; (14)Sparse Herbaceous or sparse Shrub Cover; (15)Regularly flooded Shrub and/or Herbaceous Cover; (17)Mosaic; (18)Mosaic
PFT 11	Broadleaf deciduous boreal shrub	(03)Tree Cover, broadleaved, deciduous, open; (06)Tree Cover, mixed leaf type; (09)Mosaic; (12)Shrub Cover, closed-open, deciduous; (13)Herbaceous Cover, closed-open; (14)Sparse Herbaceous or sparse Shrub Cover; (15)Regularly flooded Shrub and/or Herbaceous Cover; (17)Mosaic; (18)Mosaic
PFT 12	C3 arctic grass	(09)Mosaic; (13)Herbaceous Cover, closed-open; (14)Sparse Herbaceous or sparse Shrub Cover; (15)Regularly flooded Shrub and/or Herbaceous Cover; (17)Mosaic; (18)Mosaic
PFT 13	C3 nonarctic grass	(09)Mosaic; (13)Herbaceous Cover, closed-open; (14)Sparse Herbaceous or sparse Shrub Cover; (15)Regularly flooded Shrub and/or Herbaceous Cover; (17)Mosaic; (18)Mosaic

PFT 14	C4 grass	(09)Mosaic; (13)Herbaceous Cover, closed-open; (14)Sparse Herbaceous or sparse Shrub Cover; (15)Regularly flooded Shrub and/or Herbaceous Cover; (17)Mosaic; (18)Mosaic
PFT 15	Corn	(09)Mosaic; (16)Cultivated and managed areas; (17)Mosaic; (18)Mosaic
PFT 16	Wheat	(09)Mosaic; (16)Cultivated and managed areas; (17)Mosaic; (18)Mosaic
PFT 17	NaN	(20)Water Bodies (natural & artificial); (21)Snow and Ice (natural & artificial); (22)Artificial surfaces and associated areas; (23)No data

*****(09) Mosaic: Tree cover / Other natural vegetation; (17) Mosaic: Cropland / Tree Cover / Other natural vegetation; (18) Mosaic: Cropland / Shrub or Grass Cover.

Table S2. Average values from 2000 to 2010 of carbon costs of nitrogen uptake for each one of the different pathways and sum for the spatially distributed PFT based. The values of CLM4-FUN from Shi et al. (2016) are shown as reference.

Pathway	**1995-2004** Reference	**2000-2010** Reference	TRANSIENT - 2000 - 2010		
(PgCyr-1)	CLM4-FUN	CLM5	Sulman	Steidinger	Soudzilovskaia
NPP_MYC	1.2	17.9	17.9	19.4	18.6
NPP_NFIX	0.4	0.5	0.5	0.5	0.5
NPP_NRETRANS	0.6	0.1	0.1	0.1	0.1
NPP_TOTAL N	2.4	25.4	25.5	26.2	25.5
NPP_NPASSIVE	0.0	0.0	0.0	0.0	0.0
NPP_NDIRECT	0.2	7.0	7.0	6.1	6.4

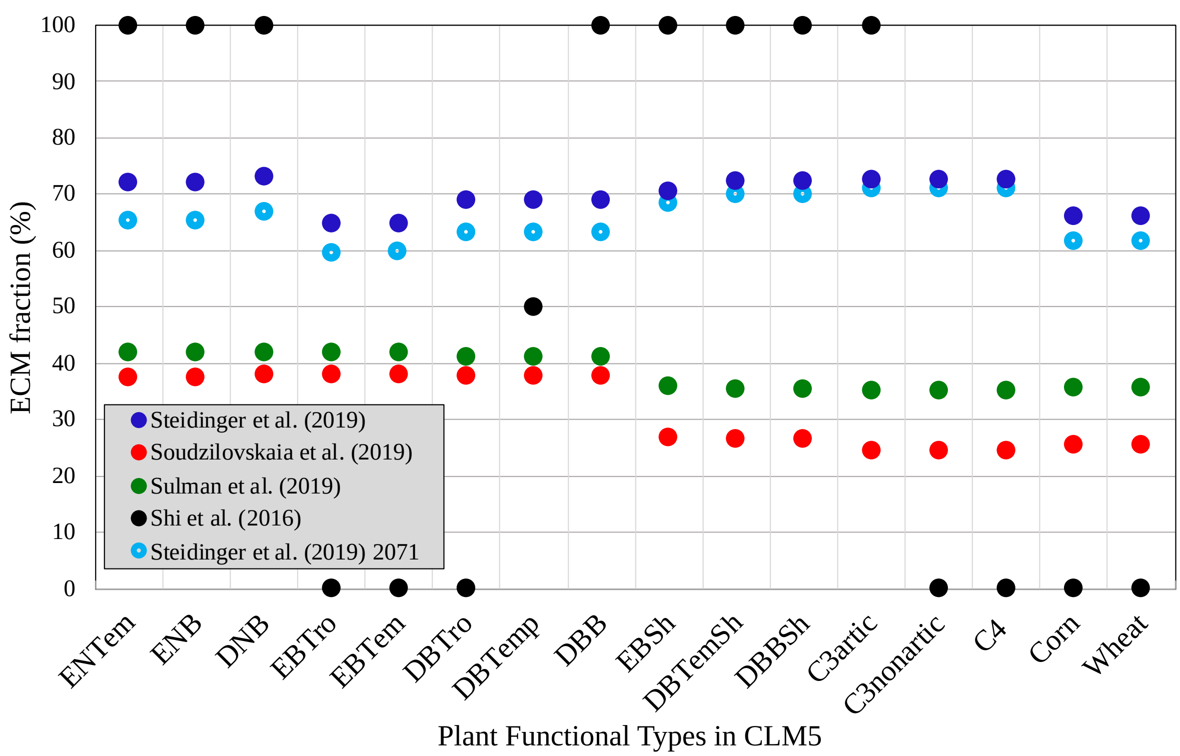


Figure S1. PFT global average of ECM fraction in percentage for ref. 25; ref. 38 present and future (2071); ref. 39 and the base map in CLM5 as in ref. 31.

Throughout all transient runs (1850-2010) with the updated maps, the ECM-associated N uptake flux (NECM) was the most impacted biogeochemical variable (**Fig. 4a**). The average NECM for each one of the different data products is shown in **Fig. 4a**, where CLM5 is 10.2 $TgNyr^{-1}$, with a larger amplitude than any other map. NECM is 13.6 $TgNyr^{-1}$ for ref. 38, 7.1 $TgNyr^{-1}$ for ref. 39, and 10.3 $TgNyr^{-1}$ for the map in ref. 25. The other nitrogen uptake pathways were impacted as well in response to different representation of mycorrhizal spatial distributions. For AM, CLM5 is 8.7 $TgNyr^{-1}$, while for ref. 38, ref. 39, and ref. 25, they are 7.7 $TgNyr^{-1}$, 10.5 $TgNyr^{-1}$, and 8.6 $TgNyr^{-1}$, respectively.

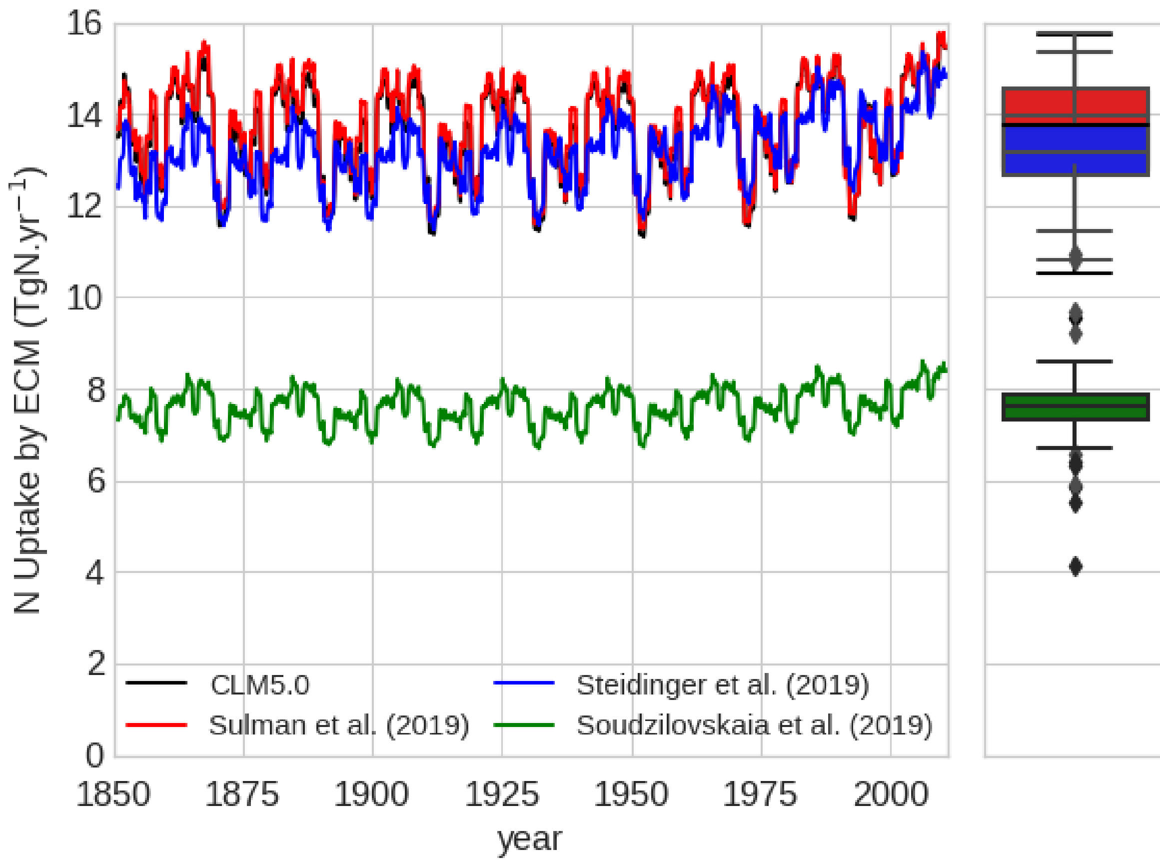


Figure S2. Nitrogen uptake through ectomycorrhizal association (NECM) in TgNyr-1 for the transient run (1850-2010) for ref. 25; ref. 38; and ref. 39 and the base map in CLM5 as in ref. 31 based on fixed PFT values.

Sulman et al. (2019) Steidinger et al. (2019) Soudzilovskaia et al. (2019)

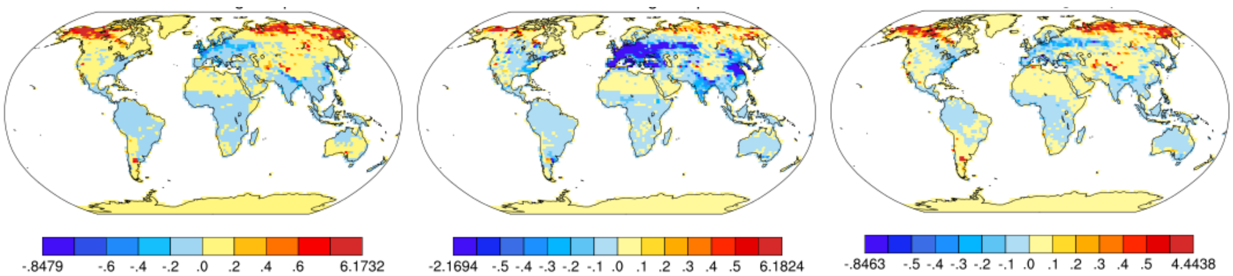
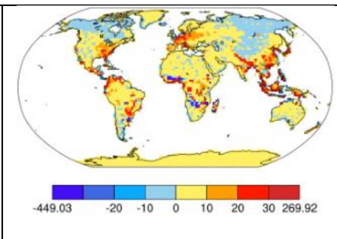
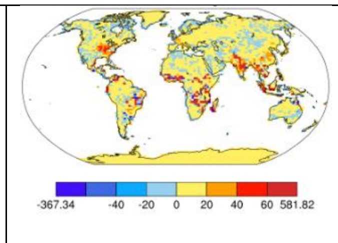
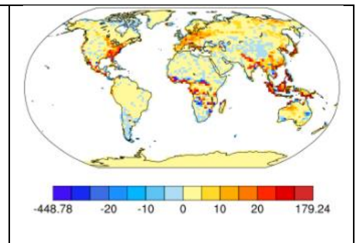
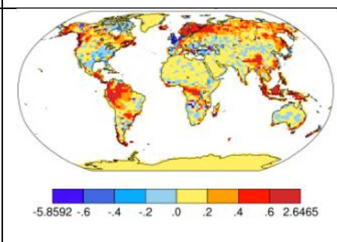
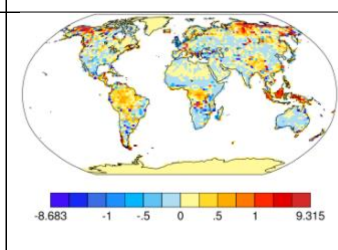
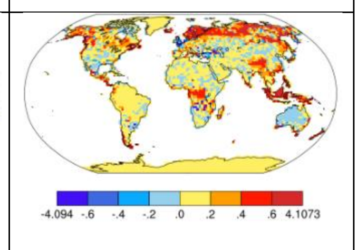
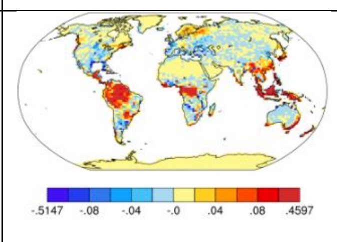
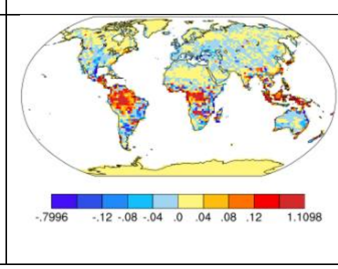
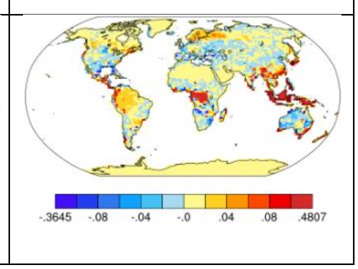


Figure S3. Revised global AM N uptake ($gNm^{-2}y^{-1}$) spatial distribution between **a.** Sulman et al. (2019); **b.** Steidinger et al. (2019); and **c.** Soudzilovskaia et al. (2019) and the base map in CLM5 as in Shi et al. (2016) based on PFT values per grid cell.

	Sulman et al. (2019)	Steidinger et al. (2019)	Soudzilovskaia et al. (2019)
NPP_NActive			
NPP_NFix			
NPP_NRetrans			

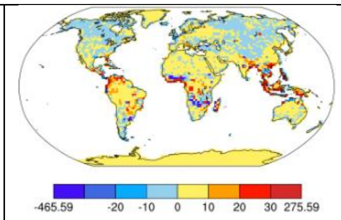
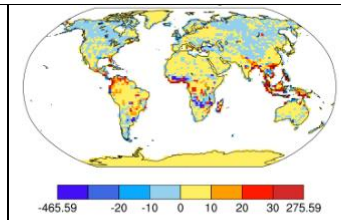
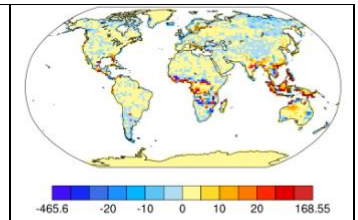
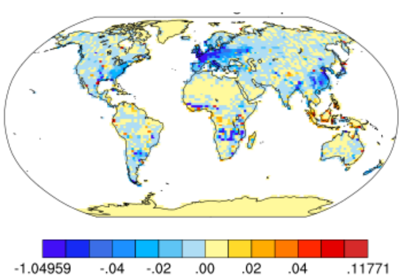
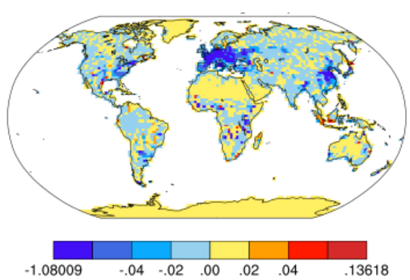
NPP_Nuptake			

Figure S4. Revised carbon used for nitrogen uptake ($gCm^{-2}y^{-1}$) spatial distribution between a. Sulman et al. (2019); b. Steidinger et al. (2019); and c. Soudzilovskaia et al. (2019) and the base map in CLM as in Shi et al. (2016) based on PFT values per gridbox for different pathways: Mycorrhizal (NPP_NActive), Symbiotic BNF (NPP_NFix), retranslocated N (NPP_NRetrans), and total (NPP_Nuptake).

Sulman et al. (2019) Steidinger et al. (2019) Soudzilovskaia et al. (2019)





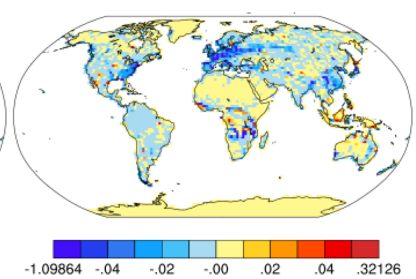


Figure S5. Revised Autotrophic Respiration ($gCm^{-2}y^{-1}$) spatial distribution between **a.** Sulman et al. (2019); **b.** Steidinger et al. (2019); and **c.** Soudzilovskaia et al. (2019) and the base map in CLM as in Shi et al. (2016) based on fixed PFT values (**above**) and based on PFT values per gridbox (**below**).

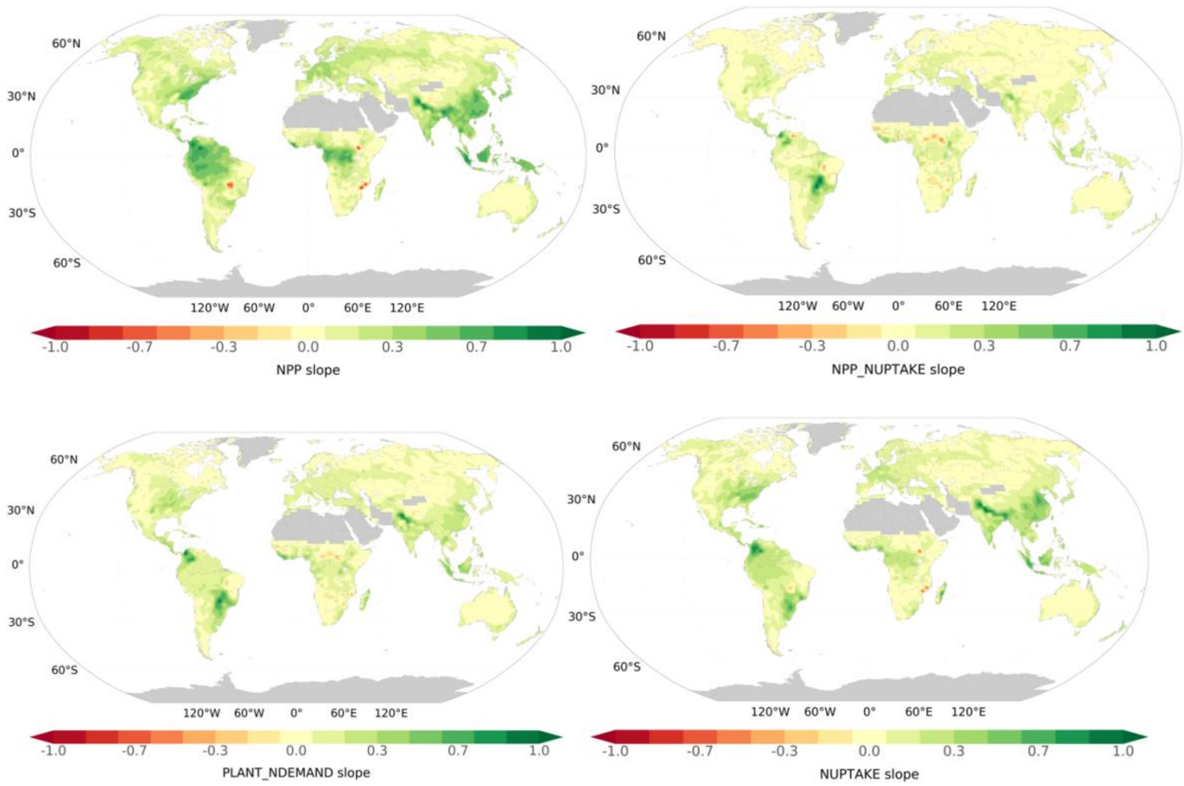


Figure S6. Normalized linear regression slope of **a.** NPP, **b.** NPP_NUPTAKE, **c.** PLANT_NDEMAND, and **d.** NUPTAKE with time.

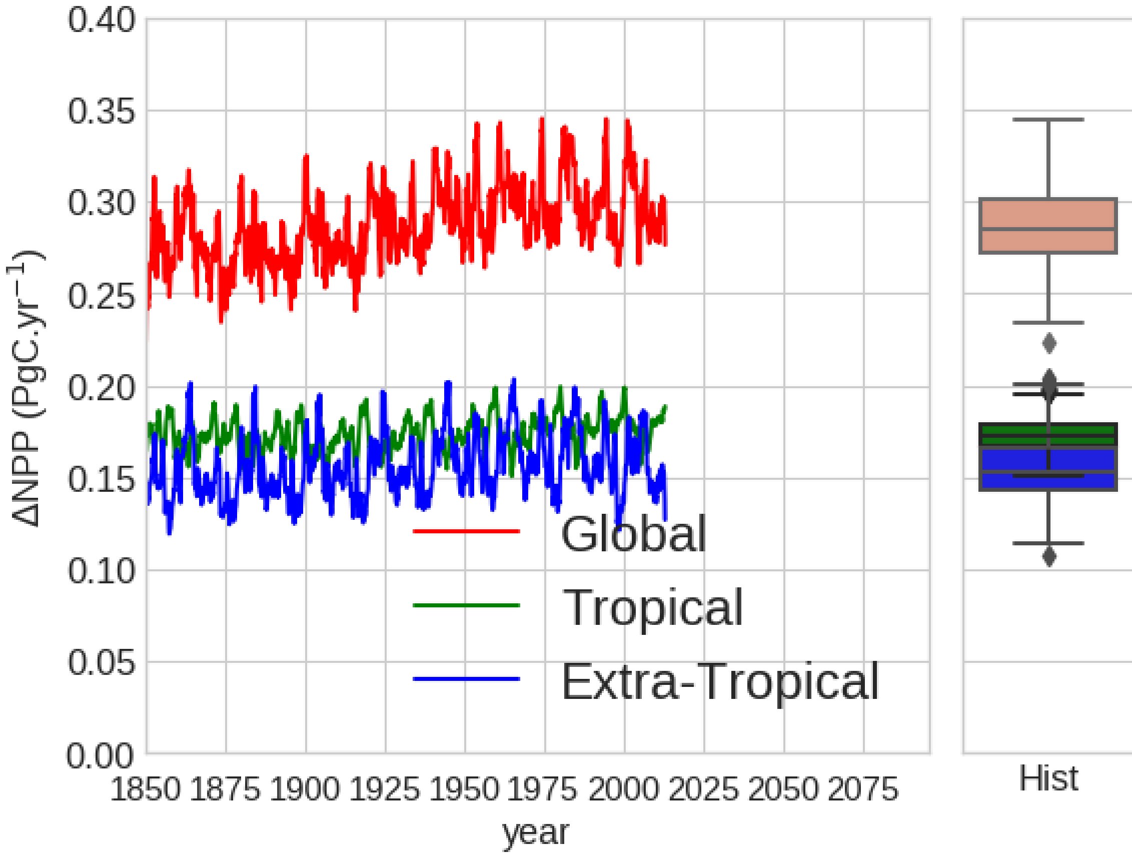


Figure S7. Global average maximum ΔNPP (PgC.yr-1) for the transient historical runs from 1850 to 2010 with CLM5 for all different ECM maps.