Earth's Future

Supporting Information for

Carbon cycle response to temperature overshoot beyond 2 °C – an analysis of CMIP6 models

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Introduction

This supporting information contains two tables and sixteen figures.

Table S1. Ensemble members used in each experiment and each model

ESM	IPSL-CM6A-LR	CNRM-ESM2-1	CanESM5	MIROC-ES2L	UKESM1-0-LL	CESM2-WACCM
piControl	r1i1p1f1	r1i1p1f2 (parent to r2..)	r1i1p1f1, r1i1p2f1	r1i1p1f2	r1i1p1f2 (parent to r4..)	r1i1p1f1
historical	r1i1p1f1 (1910)	r2i1p1f2 (1883)	r1i1p1f1 (5201)	r1i1p1f2 (1850)	r4i1p1f2 (1960)	r1i1p1f1 (55)
ssp534-over	r1i1p1f1	r2i1p1f2	r1i1p1f1	r1i1p1f2	r4i1p1f2	r1i1p1f1
ssp585	r1i1p1f1	r2i1p1f2	r1i1p1f1	r1i1p1f2	r4i1p1f2	r1i1p1f1
hist-bgc	r1i1p1f1 (1910)	r1i1p1f2 (1850)	r1i1p2f1 (5550)	r1i1p1f2 (1850)	r4i1p1f2 (1960)	
ssp534-over-bgc	r1i1p1f1	r1i1p1f2	r1i1p2f1	r1i1p1f2	r4i1p1f2	
ssp585-bgc	r1i1p1f1	r1i1p1f2	r1i1p2f1	r1i1p1f2	r4i1p1f2	

Values in the bracket indicate the branching year from the piControl.

Table S2. Cumulative carbon uptake by land and ocean (GtC) by the year 2100 in this study and when the β and γ are fixed as means of the five years corresponding to the peak of CO_2 concentration (2060-2065) and temperature (vary among models).

	IPSL-CM6A-LR	CNRM-ESM2-1	CanESM5	UKESM1-0-LL	MIROC-ES2L
This study:					
ΔC_{land}	266.8	529.7	226.6	78.9	231.1
ΔC_{ocean}	349.1	356.0	299.9	305.2	496.7
ΔC_{Total}	**615.9**	**885.7**	**526.5**	**384.1**	**727.9**
Const β and γ after the peak:					
ΔC_{land}	141.8	224.5	156.1	13.6	119.3
ΔC_{ocean}	214.2	576.5	199.2	187.3	197.7
ΔC_{Total}	**356.0**	**801.0**	**355.3**	**200.9**	**317.0**

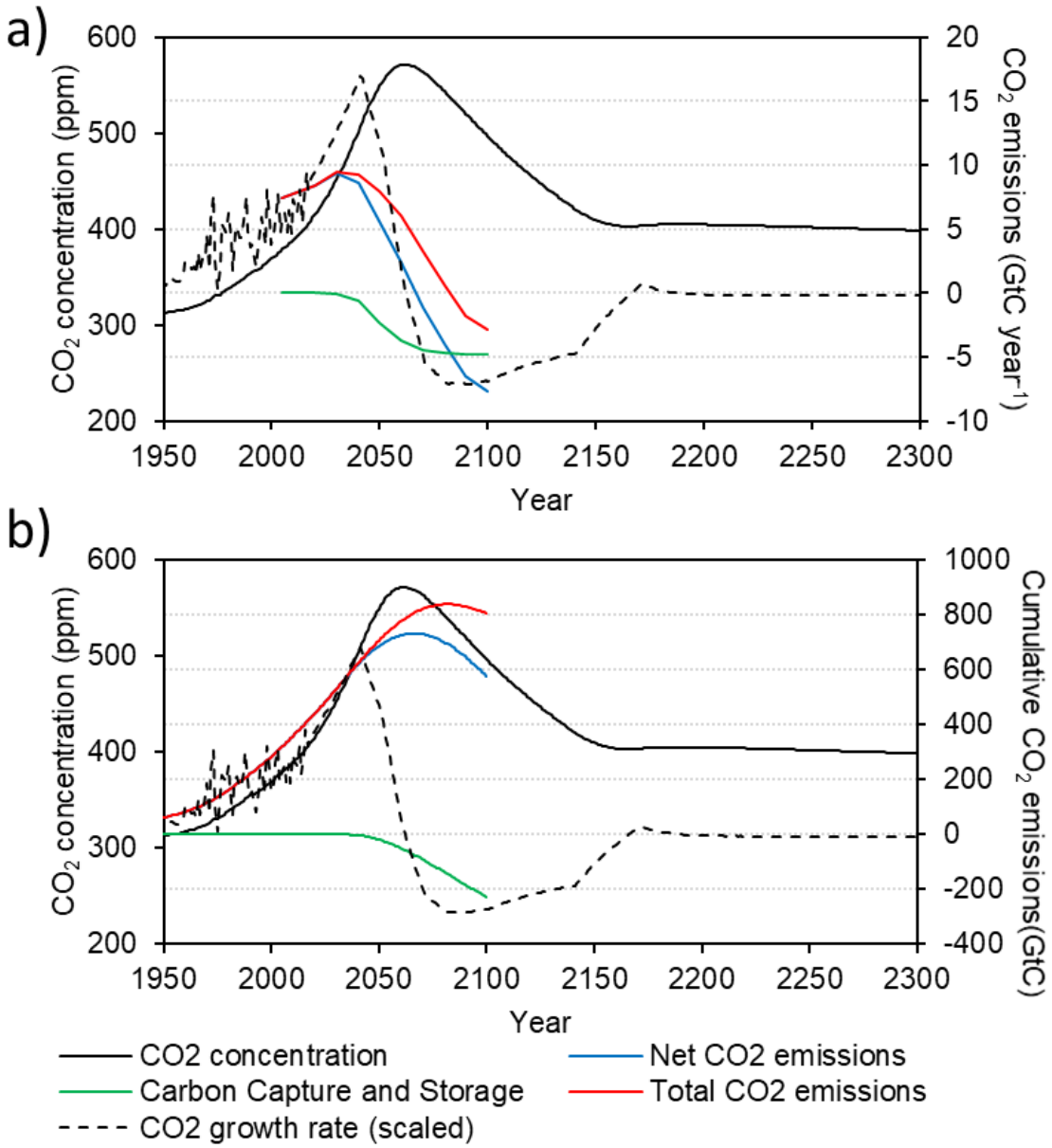

Figure S1. Time series of CO_2 concentration (ppm), CO_2 growth rate (scaled) and corresponding (a) CO_2 emissions (GtC $year^{-1}$) and (b) cumulative CO_2 emissions (GtC) by REMIND-MAgPIE from input4MIP for SSP-5-3.4-OS experiment. Emission data are from the Integrated Assessment Modeling Consortium & International Institute for Applied Systems Analysis (IIASA) database at https://tntcat.iiasa.ac.at/. Fossil fuel emission data prior year 2005 are from GCB2019 data set.

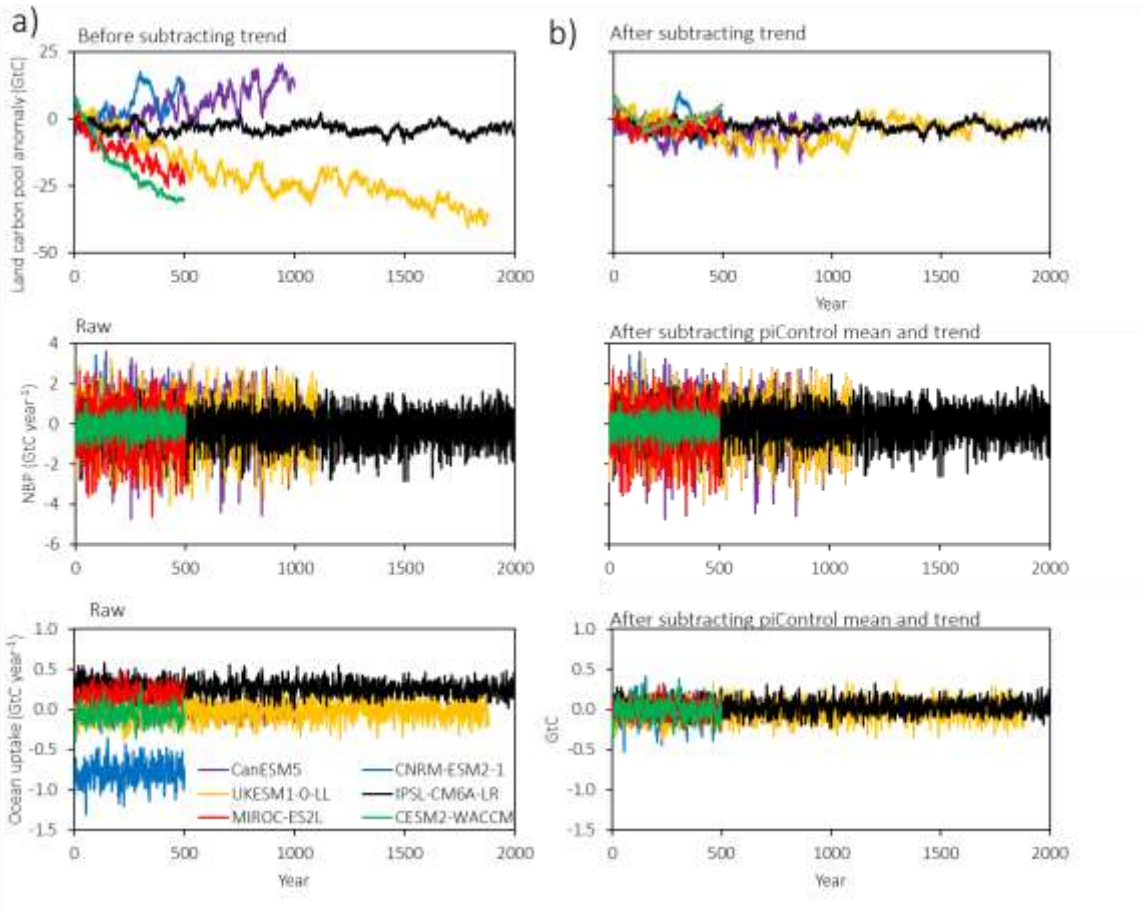

Figure S2. Time series of changes in global land biomass, land (NBP), and ocean carbon uptakes in the piControl experiment before (a) and after (b) pre-processing.

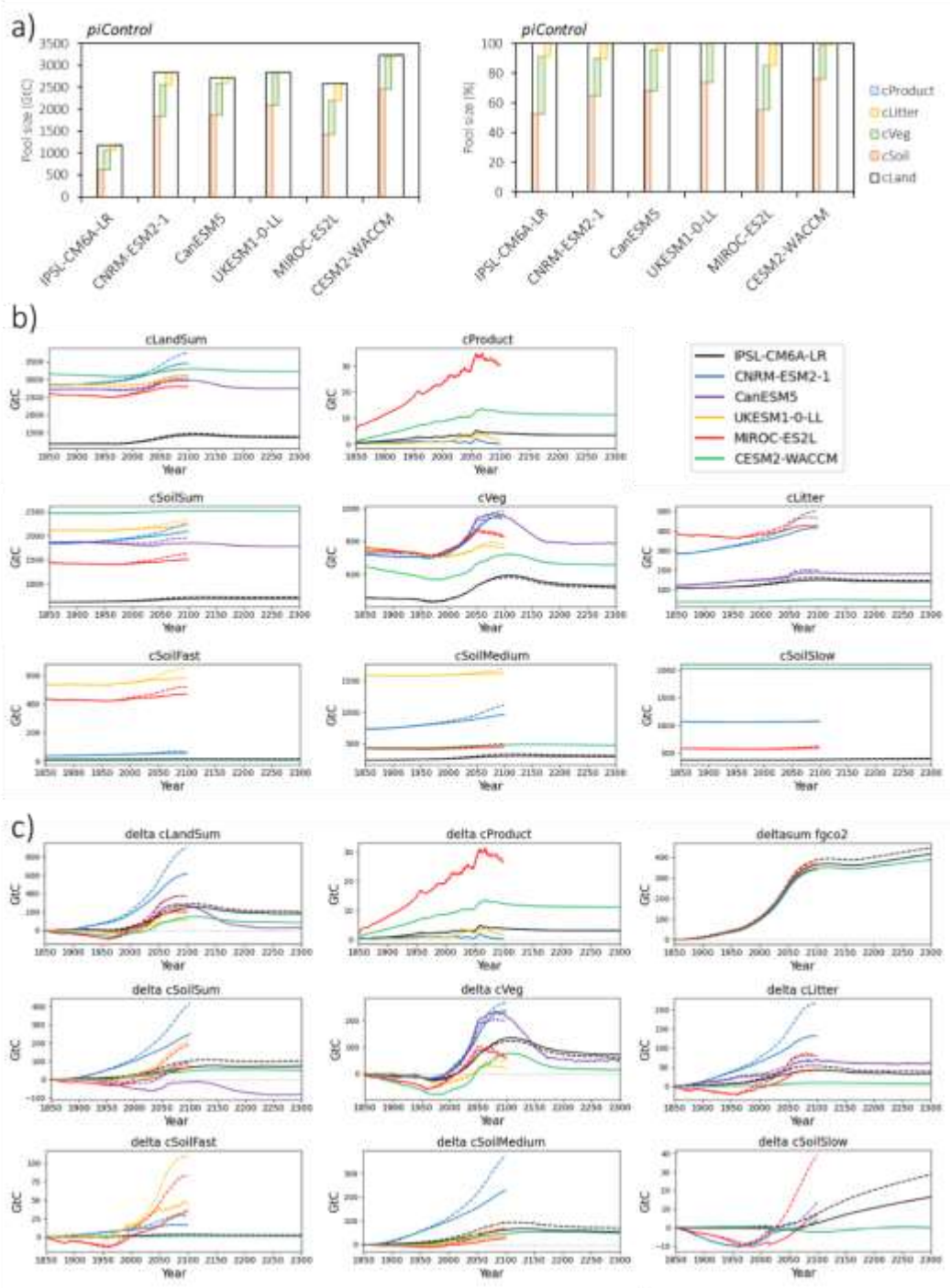

Figure S3. Mean land carbon pool sizes in piControl by six earth system models in fully and biogeochemically coupled simulations of SSP5-3.4-OS experiment (a). Land carbon storage (cLandSum) is calculated as a sum of vegetation, soil, litter, and product pools. Soil pool (cSoilSum) is calculated as a sum of the fast, medium, and slow soil pools, where such data are available. Time series in land carbon pools (b) and anomalies of land carbon pools and cumulative ocean flux from piControl (c). Solid lines indicate COU run, and dashed lines indicate BGC run.

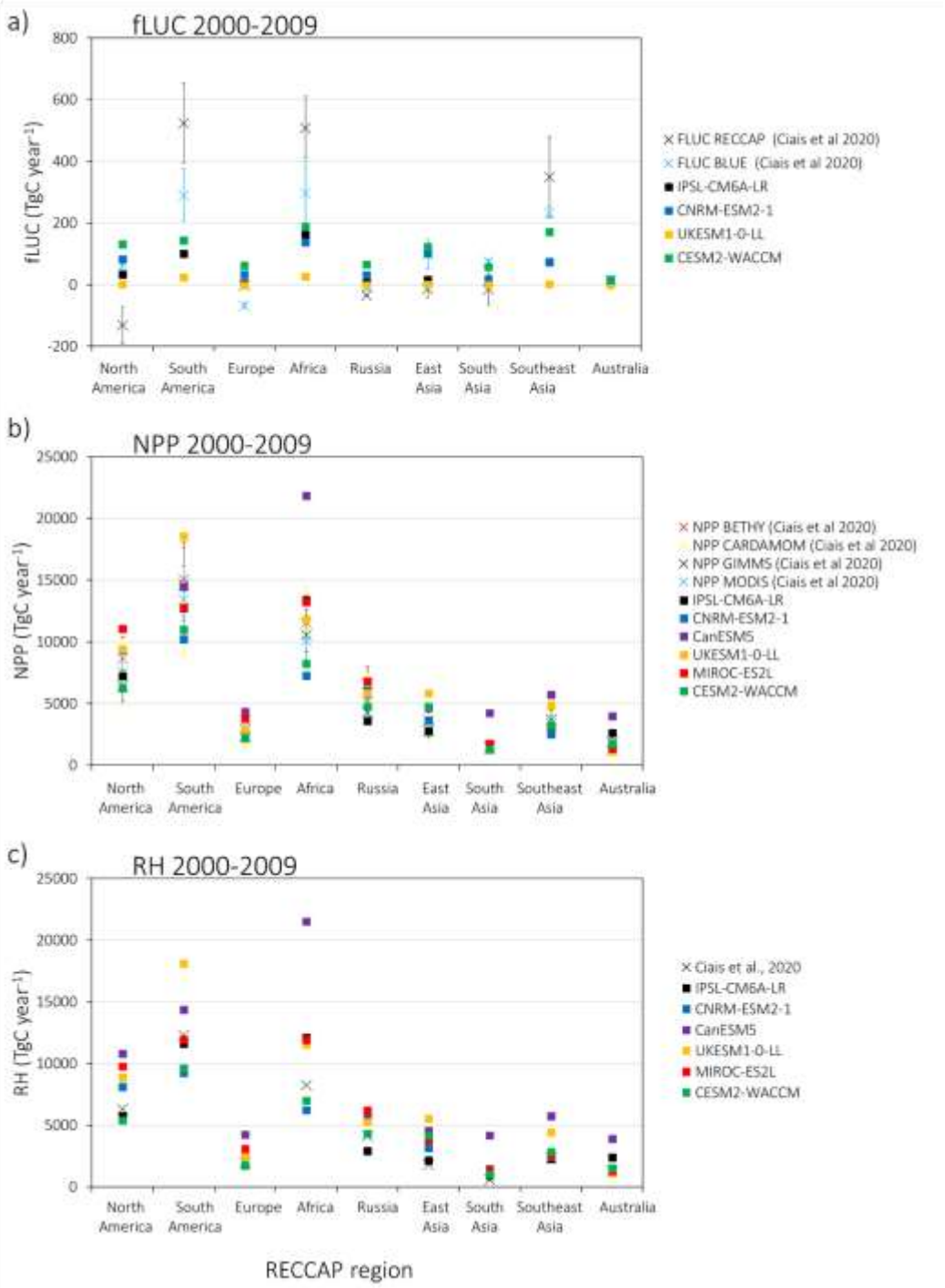

Figure S4. An evaluation of Earth system models (ESMs) against observational data set by Ciais et al. (2020). (a) fLUC, (b) NPP and (c) R_H with associated uncertainty at nine RECCAP regions in 2000-2009.

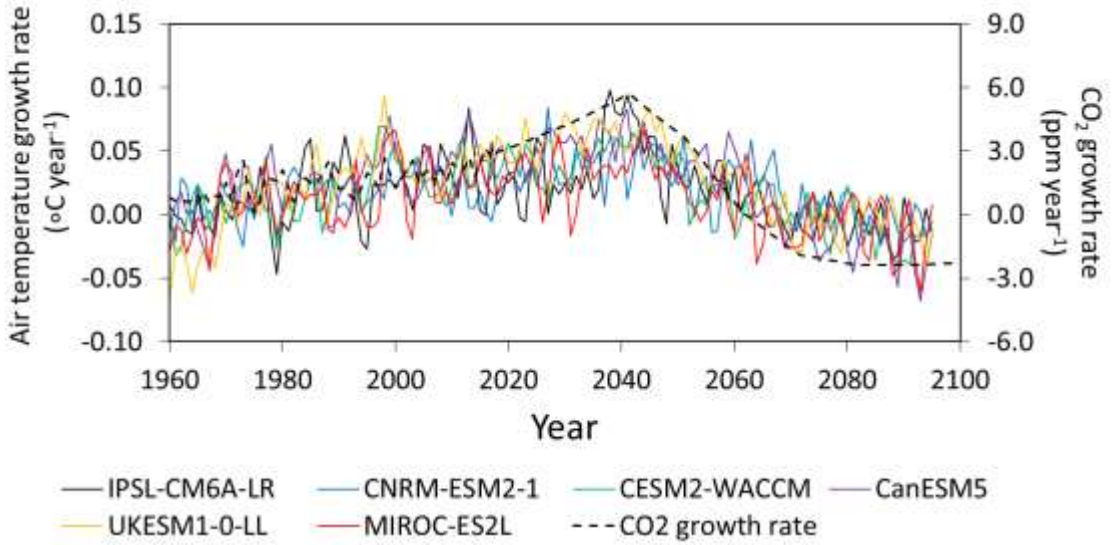

Figure S5. Time series of the growth rate of air temperature and by six earth system models and CO2 concentration in SSP5-3.4-OS experiment. Rates of change in air temperature are given as a 10-year moving average.

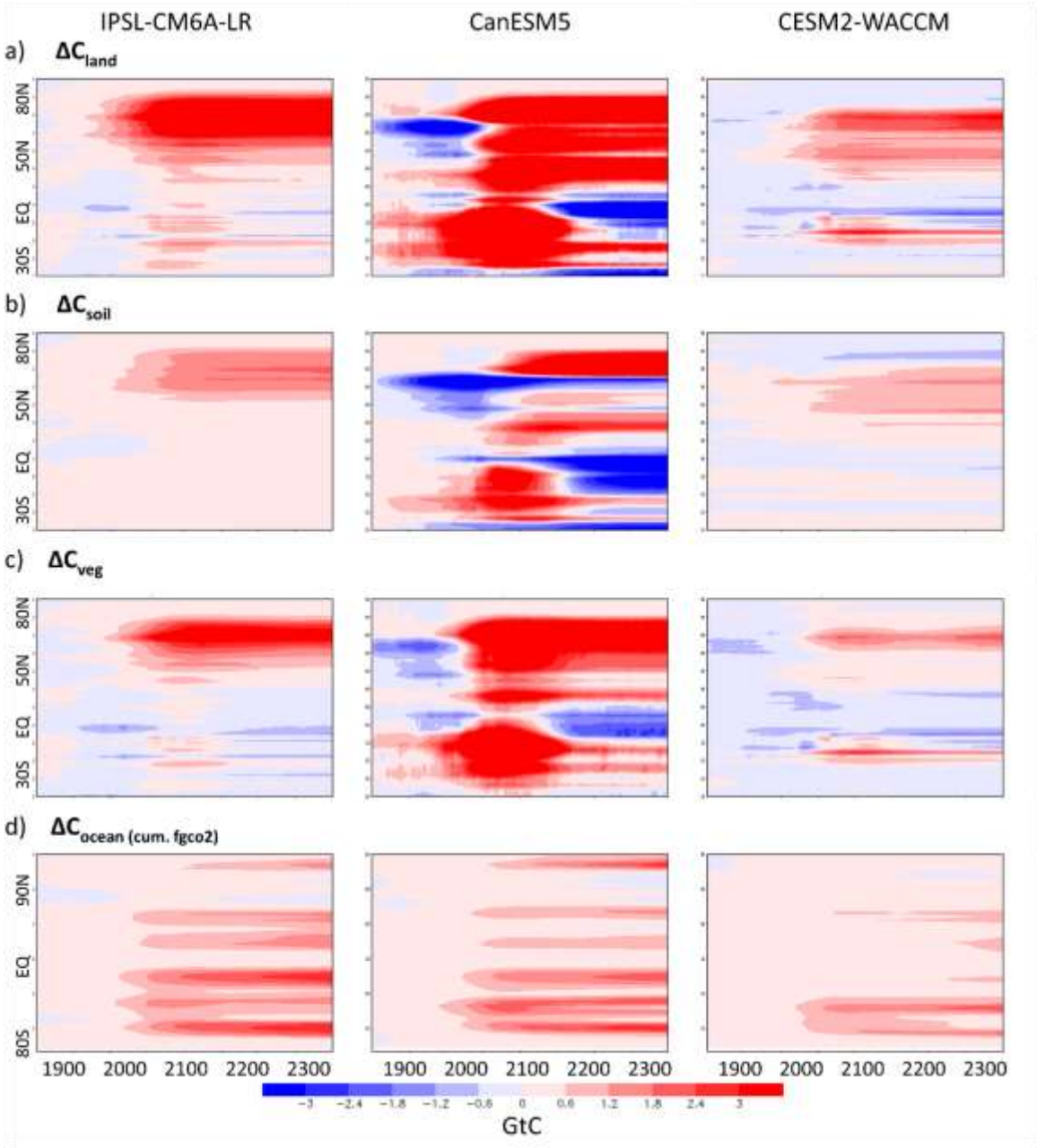

Figure S6. The spatiotemporal variation of zonal cumulative (a) ΔC_{land}, (b) ΔC_{soil}, (c) $\Delta C_{soil,}$ and ΔC_{ocean} (GtC) for CanESM5, CESM2-WACCM, and IPSL-CM6A-LR in 1900-2300 under SSP5-3.4-OS pathway. ΔC_{ocean} is calculated from cumulative flux fgco2 over time.

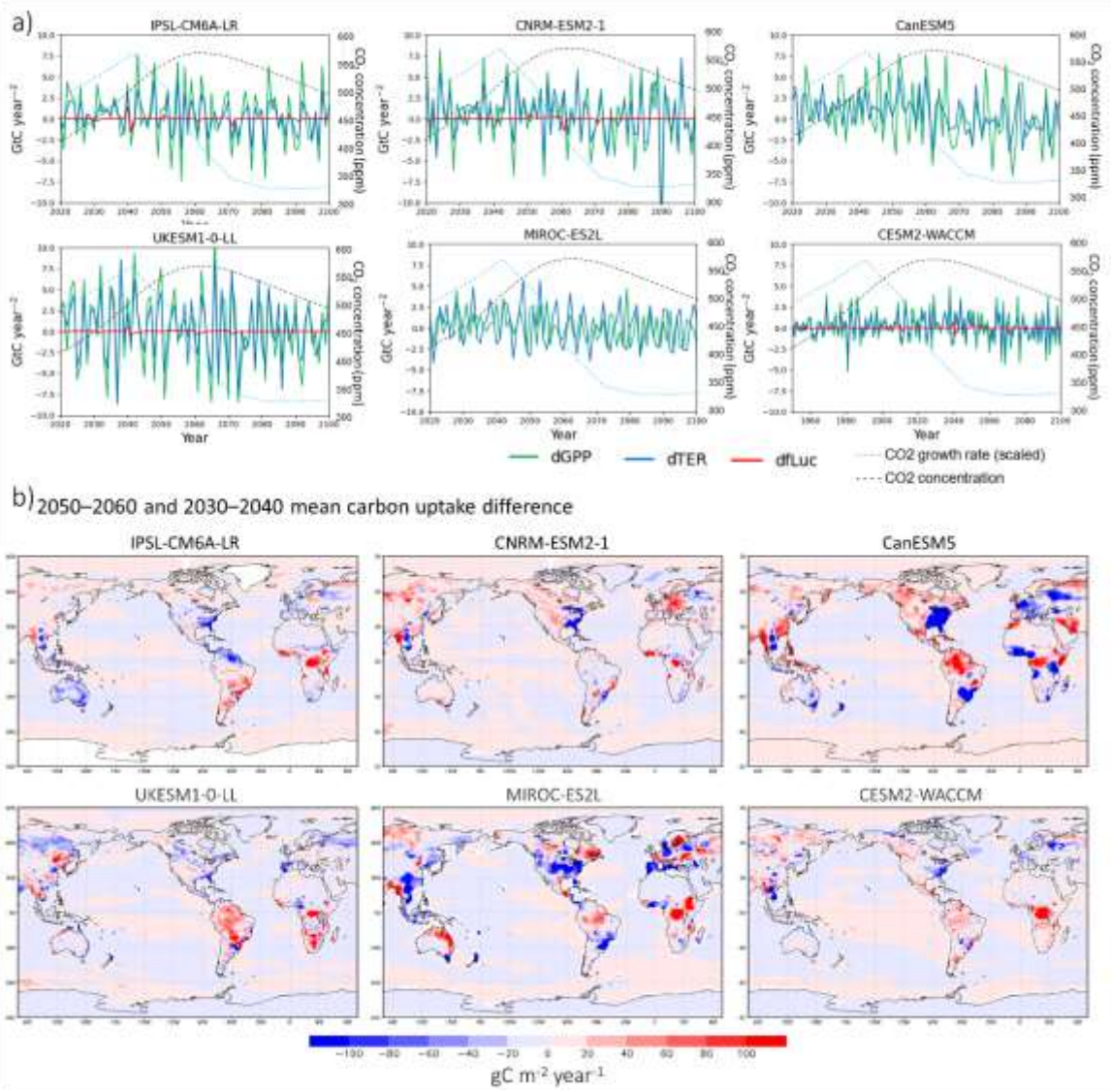

Figure S7. Panel (a) shows the time series of the derivatives of GPP, TER, fLUC (GtC year^{-2}), CO2 concentration (ppm), and scaled CO2 growth rate. fLUC is missing in CanESM5 and MIROC-ES2L because model teams did not provide this variable. Panel (b) shows the spatial variation of the difference between the mean ocean and land uptakes (NBP and fgco2) in 2050–2060 and 2030–2040. Positive values indicate an increase in carbon uptake in a later period.

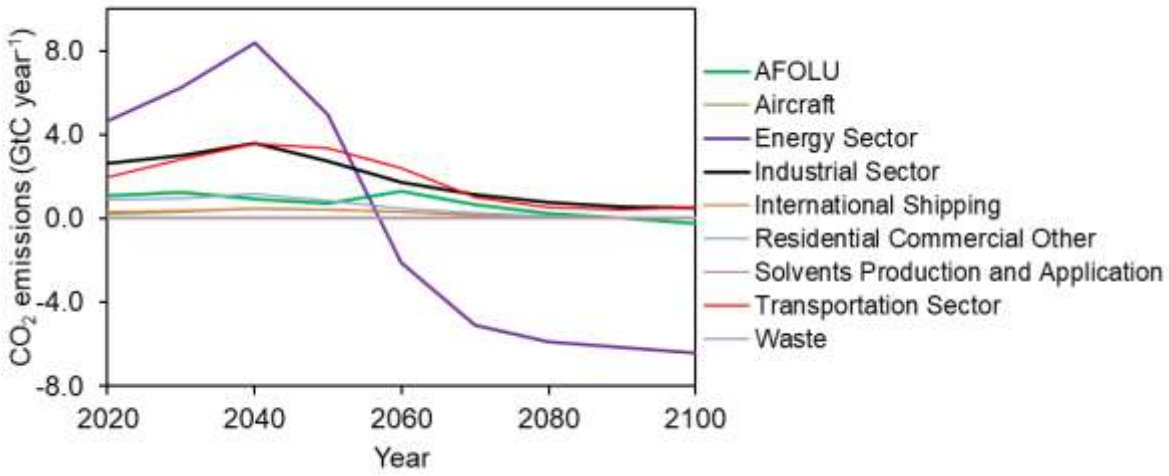

Figure S8. Time series of changes in CO_2 emissions simulated by REMIND-MAGPIE under SSP5-3.4-OS pathway.

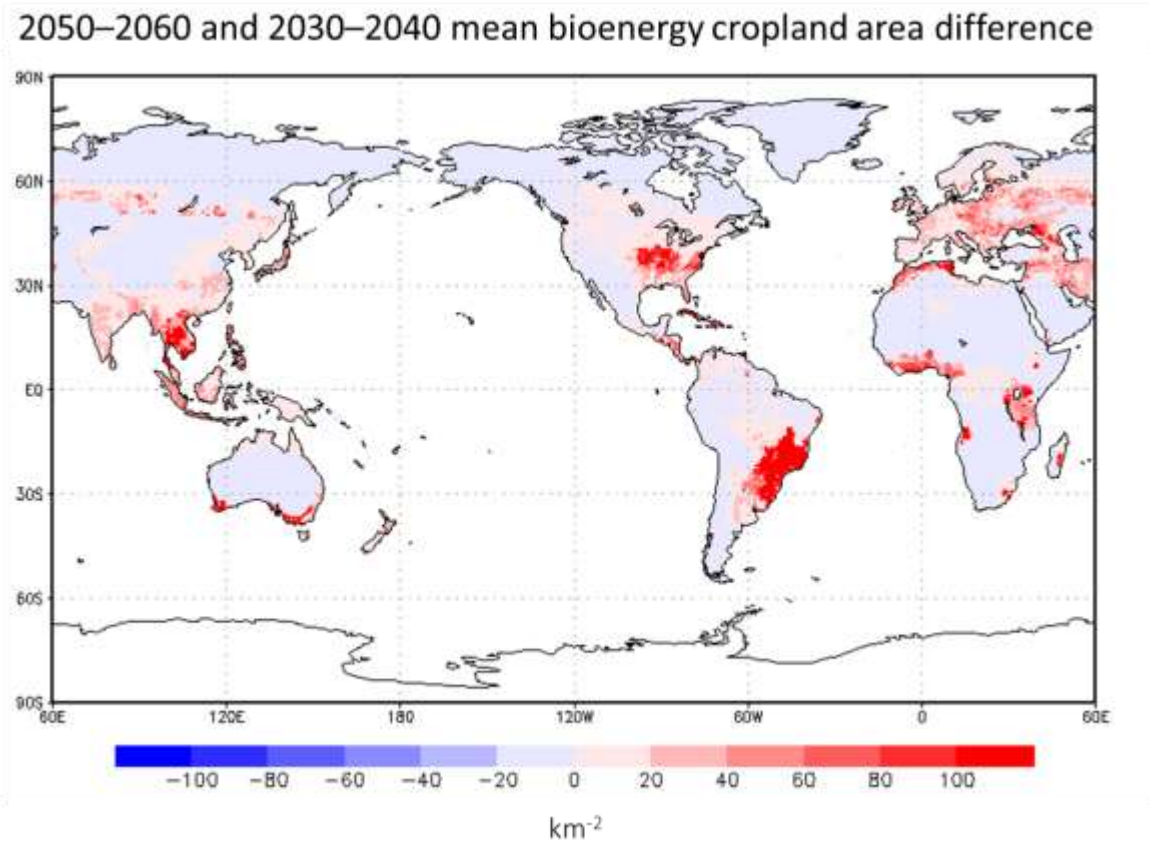

Figure S9. Difference between the mean bioenergy cropland area in 2050–2060 and 2030–2040 based on the LUH2 data set.

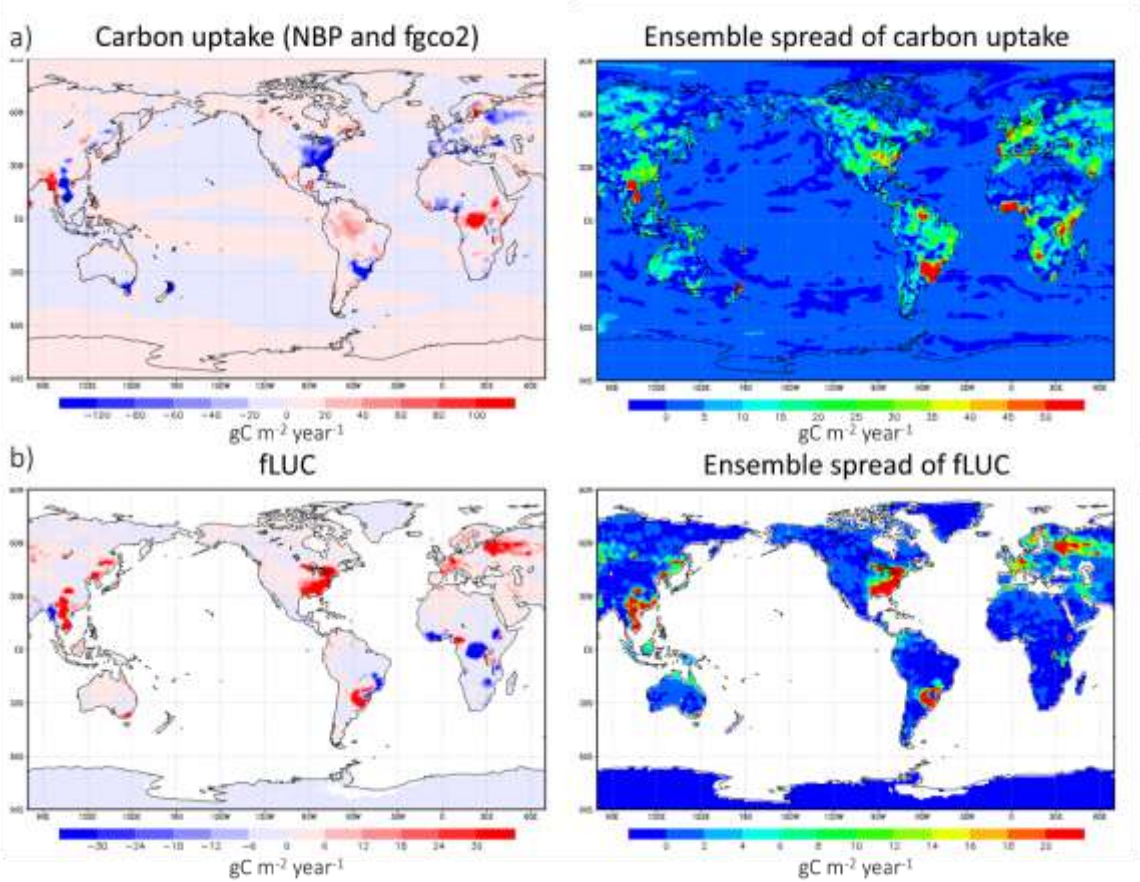

Figure S10. The difference in (a) the carbon uptake and (b) land-use change emissions before and after the peak of CO_2 concentration is shown as ensemble means of six (four for fLUC) CMIP6 ESMs.

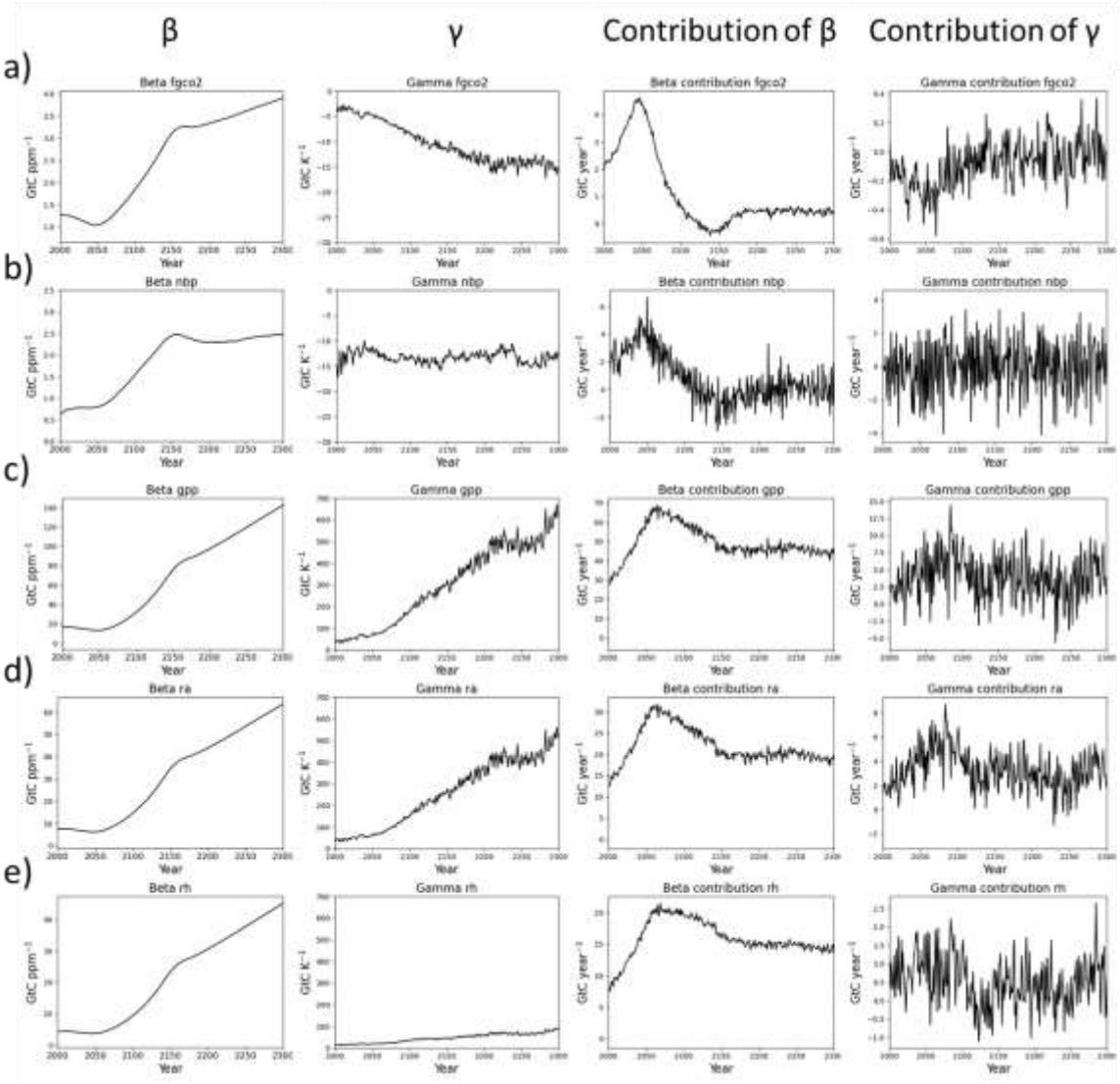

Figure S11. Carbon-concentration β (GtC ppm^{-1}), carbon-temperature γ (GtC $°C^{-1}$) feedback parameters and their contributions to the carbon fluxes (GtC $year^{-1}$) for (a) ocean fgco2, and land (b) NBP, (c) GPP, (d) R_A and (e) R_H as a function of time (year) extended till the year 2300 for IPSL-CM6A-LR under the SSP5-3.4-OS pathway.

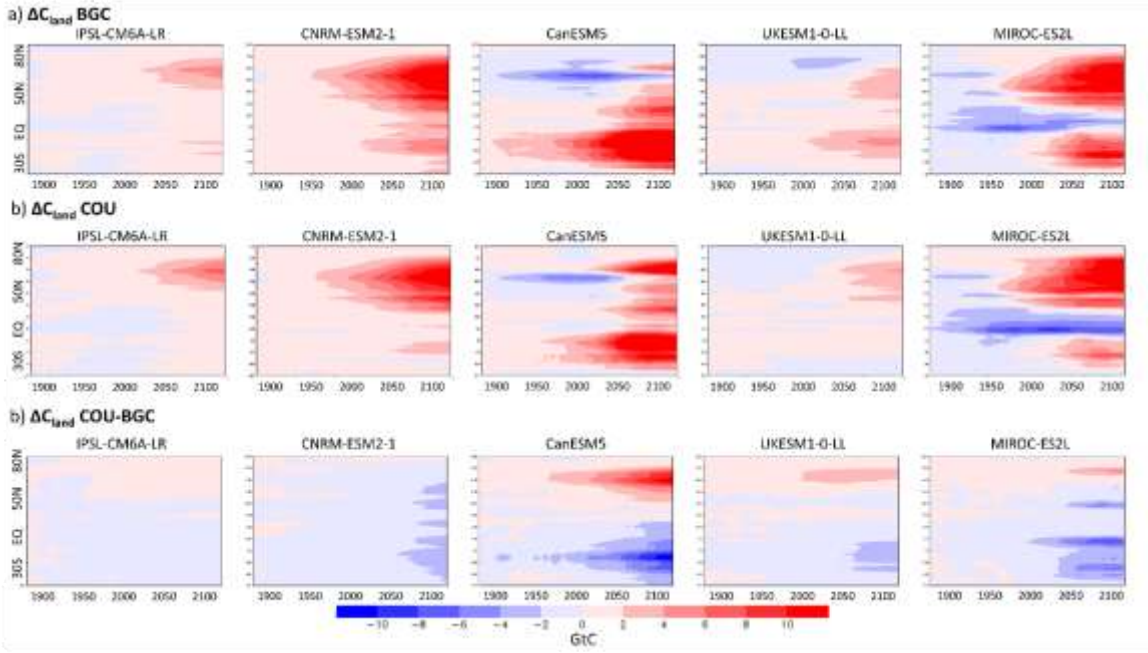

Figure S12. The spatiotemporal variation of zonal cumulative land carbon pool (positive to land) in (a) BGC simulation, (b) COU simulation, and (c) COU-BGC difference.

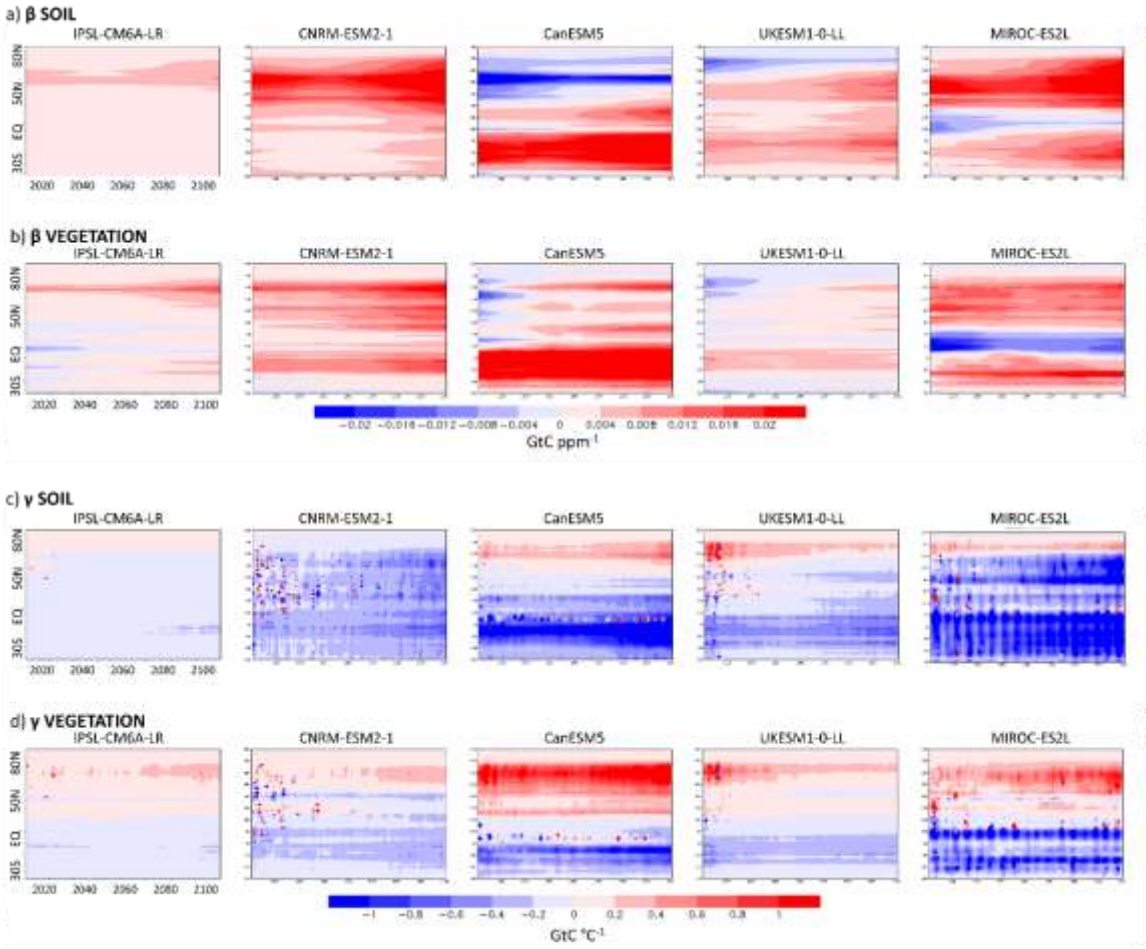

Figure S13. The spatiotemporal variation of zonal cumulative (a) β_{soil}, (b) β_{veg} (GtC ppm-1), (c) γ_{soil} and (d) γ_{veg} (GtC °C^{-1}) calculated from corresponding land carbon pools. Positive values indicate a net sink.

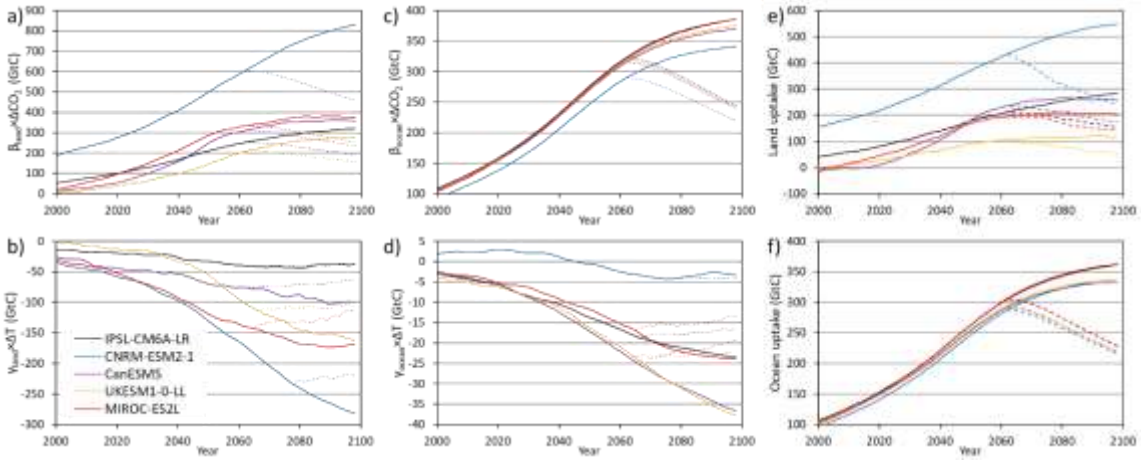

Figure S14. Contributions of carbon-concentration β and carbon-temperature γ feedback parameter to the cumulative carbon fluxes (GtC) under the SSP5-3.4-OS pathway. Panel (a) shows the contribution of β_{land}, (b) of γ_{land}, (c) β_{ocean}, and (d) of γ_{ocean}. Panels (e) and (f) show cumulative uptakes by land and ocean, respectively. Solid lines indicate this study and dashed lines – an experiment with the β and γ fixed as means of the five years corresponding to the peak of CO_2 concentration (2060-2065) and temperature (vary among models). Here, all calculations are based on the smoothed data by using a 5-year moving average.

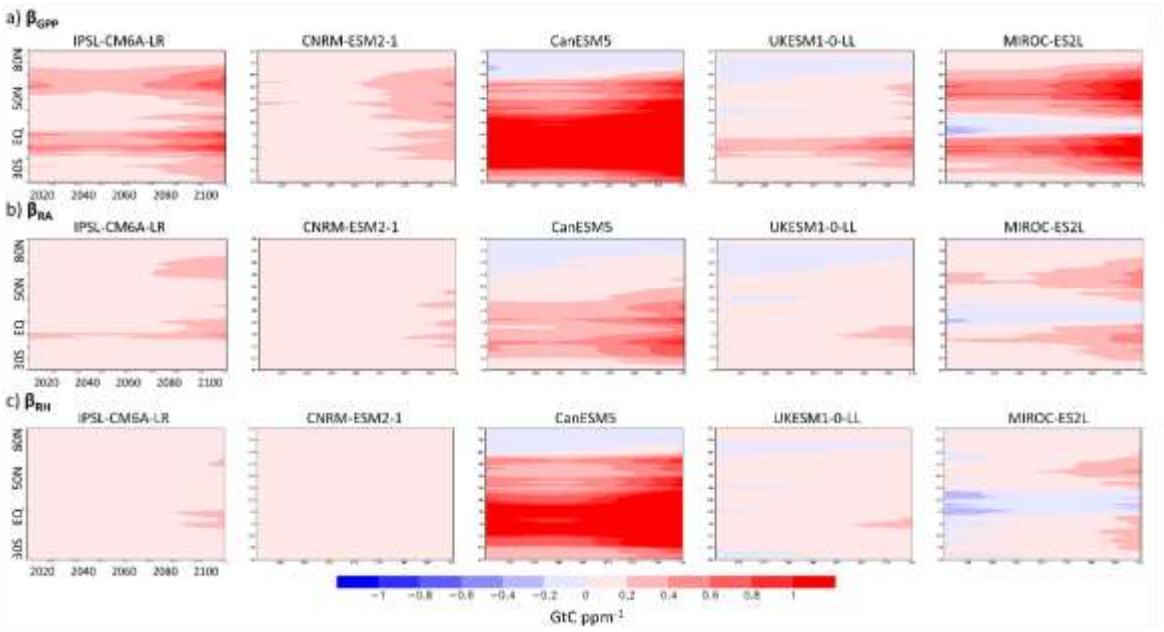

Figure S15. The spatiotemporal variation of zonal cumulative (a) β_{GPP}, (b) $\beta_{RA,}$ and (c) β_{RH} (GtC ppm^{-1}) is calculated from corresponding cumulative land carbon fluxes. Positive values indicate a net sink for β_{GPP} and a net source for β_{RA} and β_{RH}.

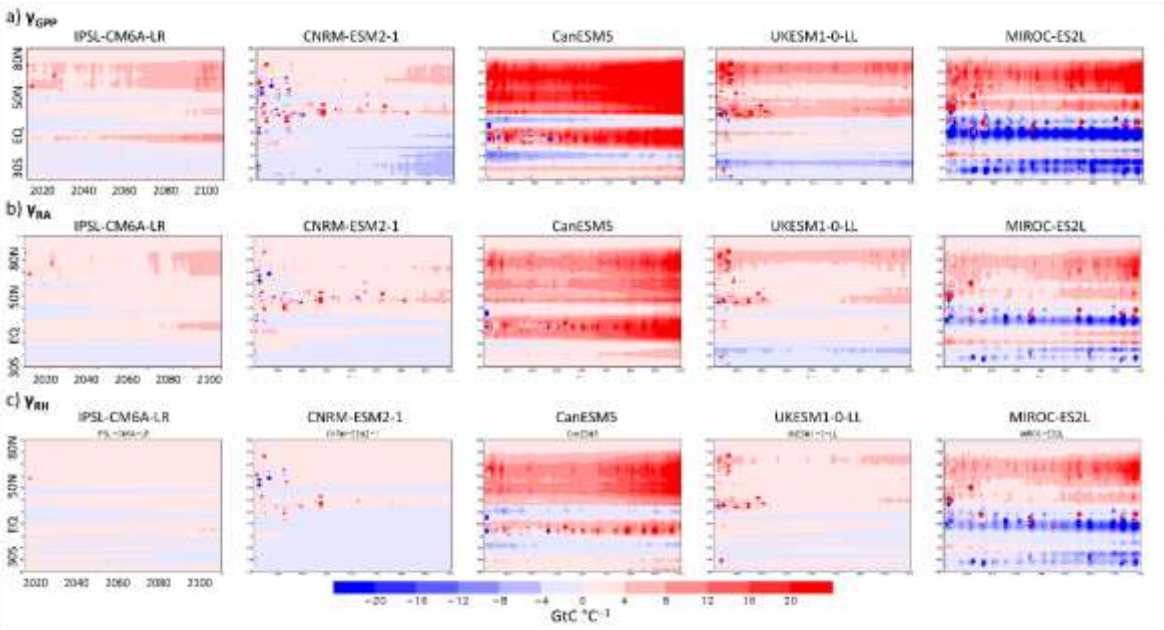

Figure S16. The spatiotemporal variation of zonal cumulative (a) γ_{GPP}, (b) $\gamma_{RA,}$ and (c) γ_{RH} (GtC °C^{-1}) calculated from corresponding cumulative land carbon fluxes. Positive values indicate a net sink for γ_{GPP} and a net source for γ_{RA} and γ_{RH}.