Response of terrestrial carbon fluxes to temperature variations (γ) in the CMIP5 Earth system models

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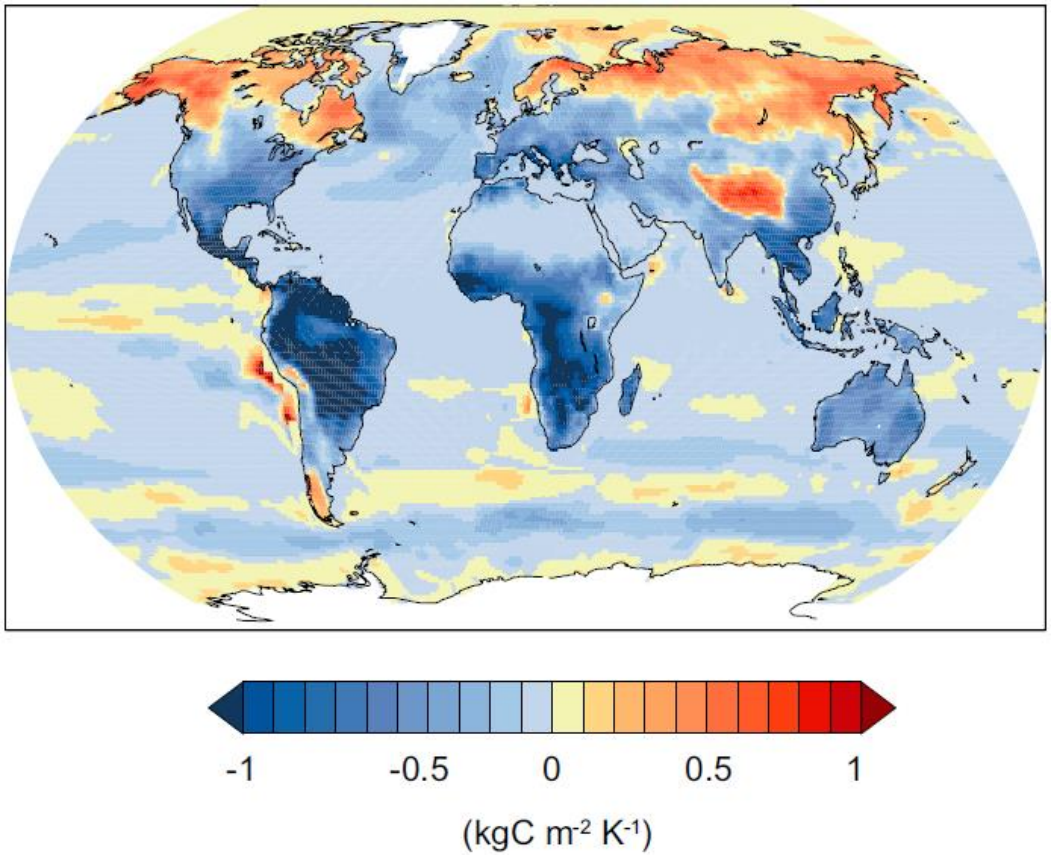
Definition of γ

'gamma' (γ) measures the strength of changes in carbon fluxes by land or ocean in response to changes in climate.

(IPCC AR5)

Long-term regional carbon-climate feedback (γ)



Radiatively coupled experiment

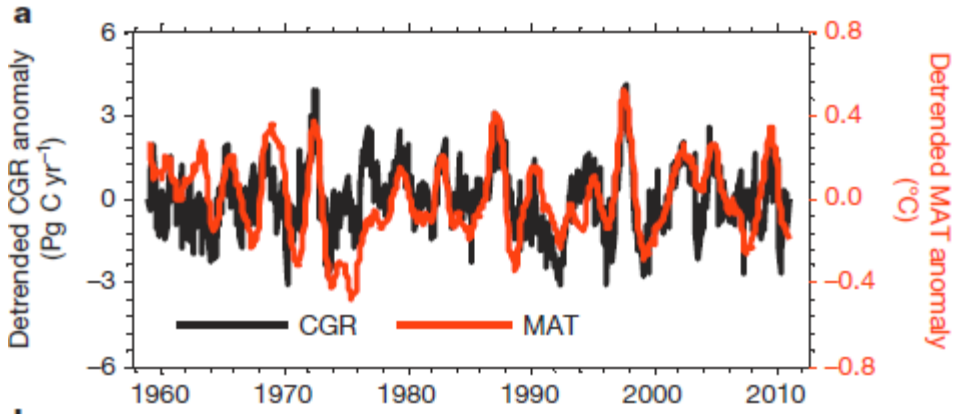
CO_2 increases by 1% yr^{-1}, and only produces a change in temperature.

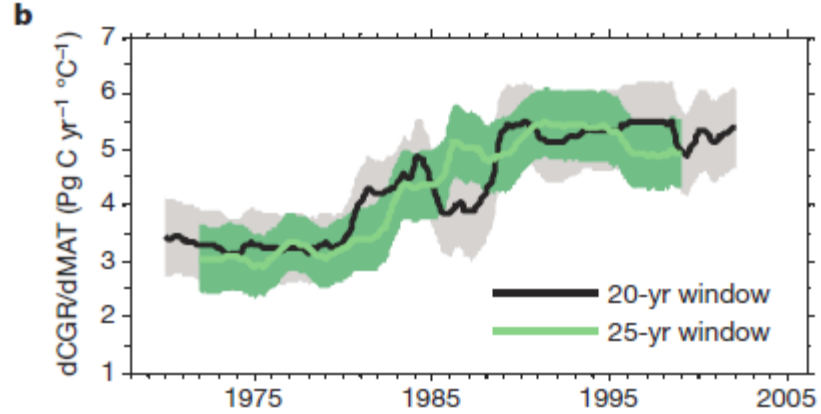
γ : Changes in carbon storage from $1 \times CO_2$ to $4 \times CO_2$ (during 140 years), relative to global temperature change.

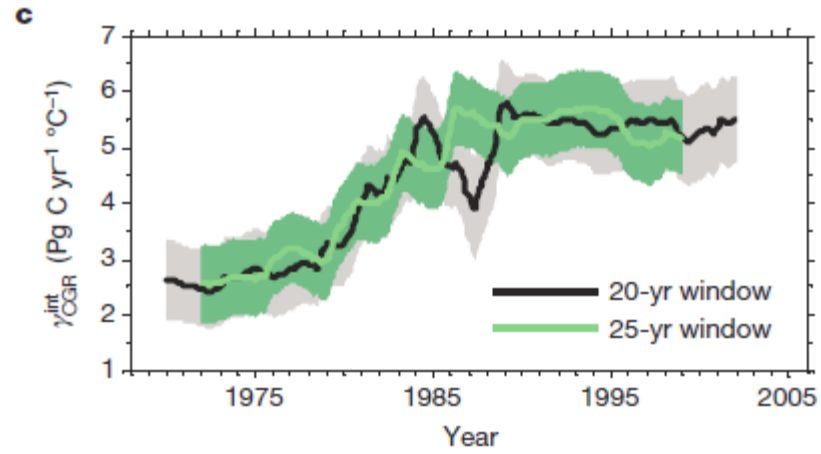
Multi-model-mean land and ocean γ for seven CMIP5 models using the concentration-driven idealised 1% yr^{-1} CO_2 simulations.

(IPCC AR5)

γ is NOT constant in long-term period







LETTER

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A two-fold increase of carbon cycle sensitivity to tropical temperature variations

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γ : The sensitivity of the atmospheric CO_2 growth rate to tropical temperature interannual variability

γ has increased by a factor of 1.96 ± 0.3 in the past five decades.

Questions:

Do CMIP5 models capture the changes in tropical γ during past 50 years?

How will γ change under future climate change scenarios?

CMIP5 Earth system models used in this analysis

17 fully coupled models (CO_2+Climate) were used because a full suite simulations was available for nbp, gpp, npp, ra, rh, tas, pr and rsds variables.

Historical: 17 models
RCP2.6: 12 models
RCP4.5: 16 models
RCP6.0: 9 models
RCP8.5: 17models

Models	Historical	RCP2.6	RCP4.5	RCP6.0	RCP8.5
BNU-ESM	√	√	√	×	√
CanESM2	√	√	√	×	√
CCSM4	√	√	√	√	√
CESM1-BGC	√	×	√	×	√
GFDL-ESM2M	√	×	√	√	√
GFDL-ESM2G	√	√	√	√	√
HadGEM2-CC	√	×	√	×	√
HadGEM2-ES	√	√	√	√	√
ISPL-CM5A-LR	√	√	√	√	√
ISPL-CM5B-LR	√	×	√	×	√
MIROC-ESM	√	√	√	√	√
MIROC-ESM-CHEM	√	√	√	√	√
MPI-ESM-LR	√	√	√	×	√
MPI-ESM-MR	√	√	√	×	√
MRI-ESM1	√	×	×	×	√
NorESM1-ME	√	√	√	√	√
NorESM1-M	√	√	√	√	√

$$y = \gamma^{\mathrm{int}} x_{\mathrm{T}} + \delta^{\mathrm{int}} x_{\mathrm{P}} + \varepsilon^{\mathrm{int}} x_{\mathrm{R}} + \zeta$$

20-yr moving window

Each variable is detrended within each moving window

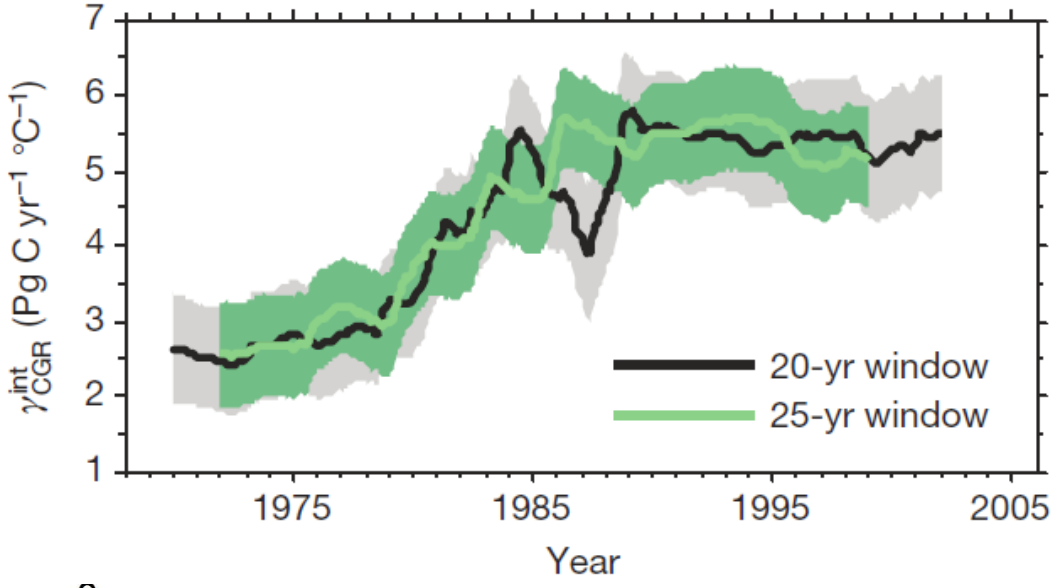
y : detrended carbon fluxes (variable: nbp, gpp, ra, rh);
x_{T}: detrended air temperature (variable: tas);
x_{P}: detrended precipitation (variable: pr);
x_{R} : detrended surface downwelling shortwave radiation (variable: rsds).

The fitted regression coefficients γ^{int} and δ^{int} define the apparent carbon flux sensitivity to interannual variations in temperature and precipitation. (Piao et al., GCB, 2013)

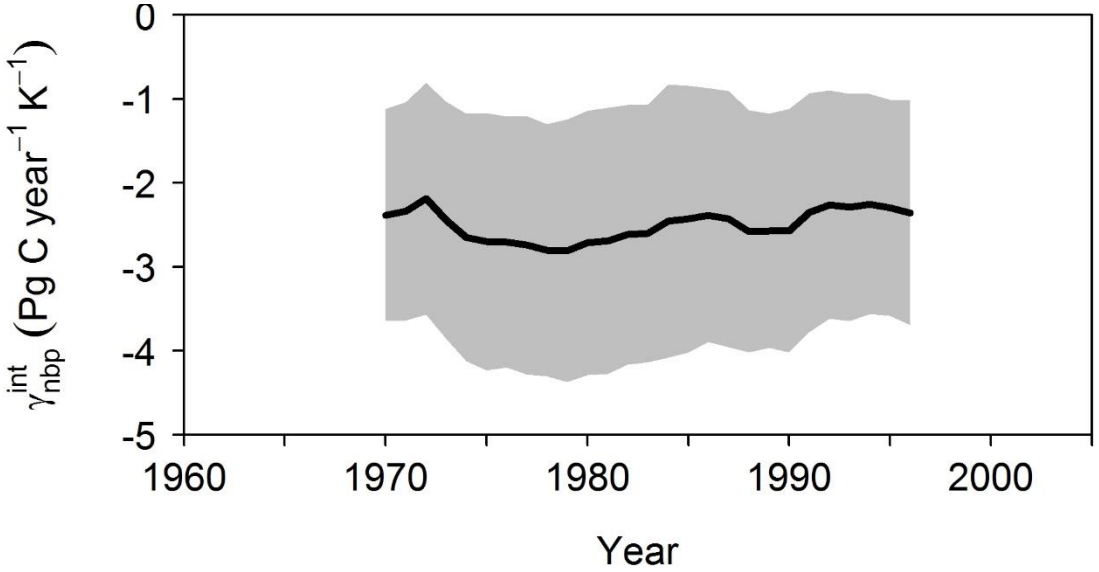
Methods

1. 17 fully coupled models (CO_2+Climate) are used because a full suite simulations is available for nbp, gpp, npp, ra, rh, tas, pr and rsds variables.
2. Scenarios include: Historical, RCP2.6, RCP4.5, RCP6.0 and RCP8.5.
3. Monthly datasets are download from PCMDI node 9 during August 2014.
4. All model outputs are regridded to 1°× 1° before other analysis, using first order conservative remapping method.
5. For the models with NOT only one realization, ensemble mean over the available realizations is used.
6. Yearly mean is calculated from monthly data. Each month is weighted with the number of days per month.
7. Global value of each variable is used to calculate global gamma_int. Regional value of each variable is used to calculate regional gamma_int. For the calculation of gamma map, local value of each variable in each grid is utilized.
8. Before regression, each variable is detrended within each moving window (20 years).
9. Multiple regression analysis is used to calculate gamma_int.

Tropical γ_{nbp}^{int} during past 50 years



Wang XH, Piao SL, Ciais P, et al. (2014) Nature.



CMIP5 ESMs do NOT capture the changes in tropical γ_{nbp}^{int} during past 50 years

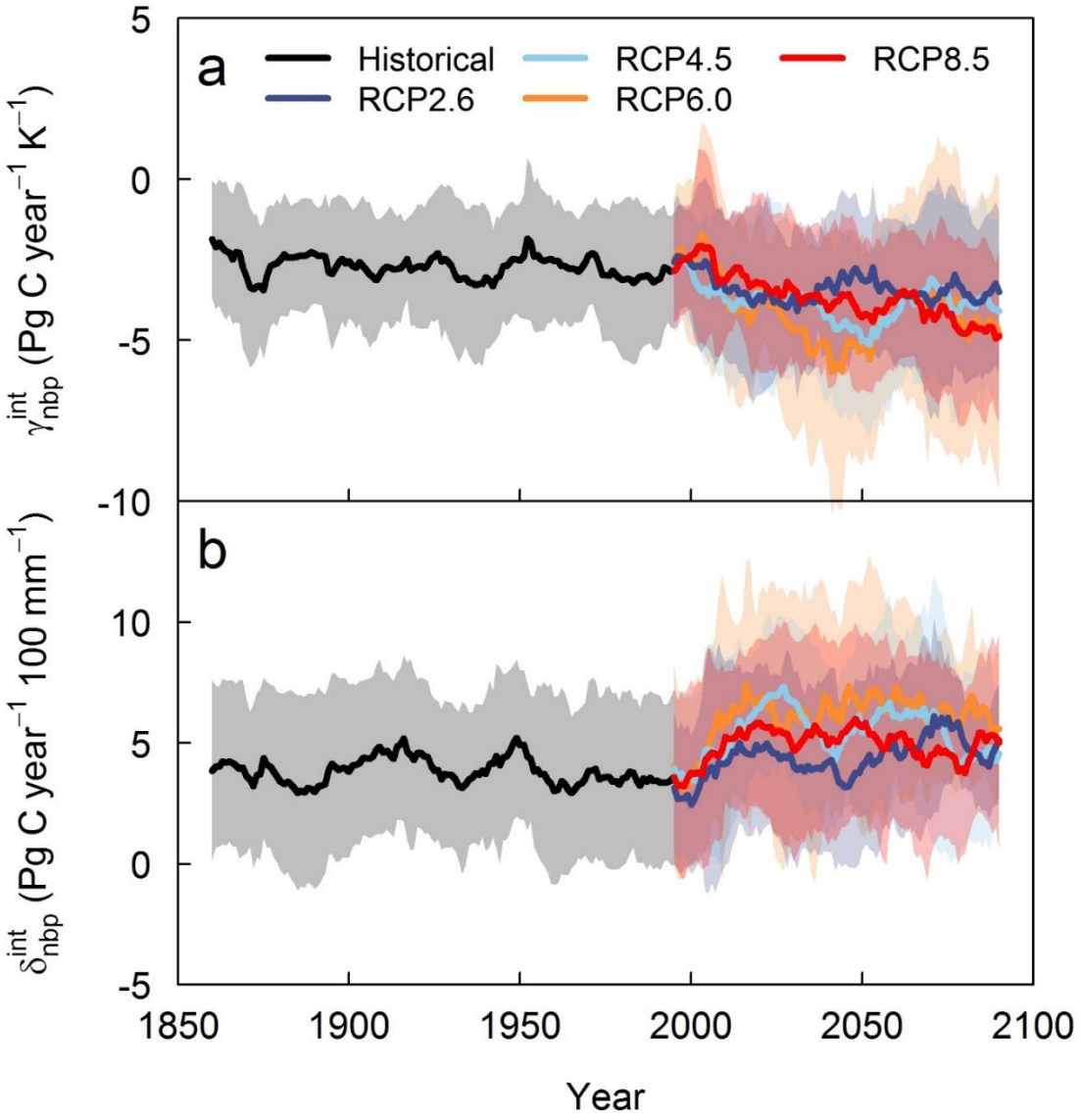
Multi-model mean $\pm$ 1 Standard deviation

Change in $\gamma_{\mathrm{nbp}}^{\mathrm{int}}$ and $\delta_{\mathrm{nbp}}^{\mathrm{int}}$ in CMIP5 ESMs

Global (90˚N-90˚S)

$\gamma_{\mathrm{nbp}}^{\mathrm{int}}$

$\delta_{\mathrm{nbp}}^{\mathrm{int}}$

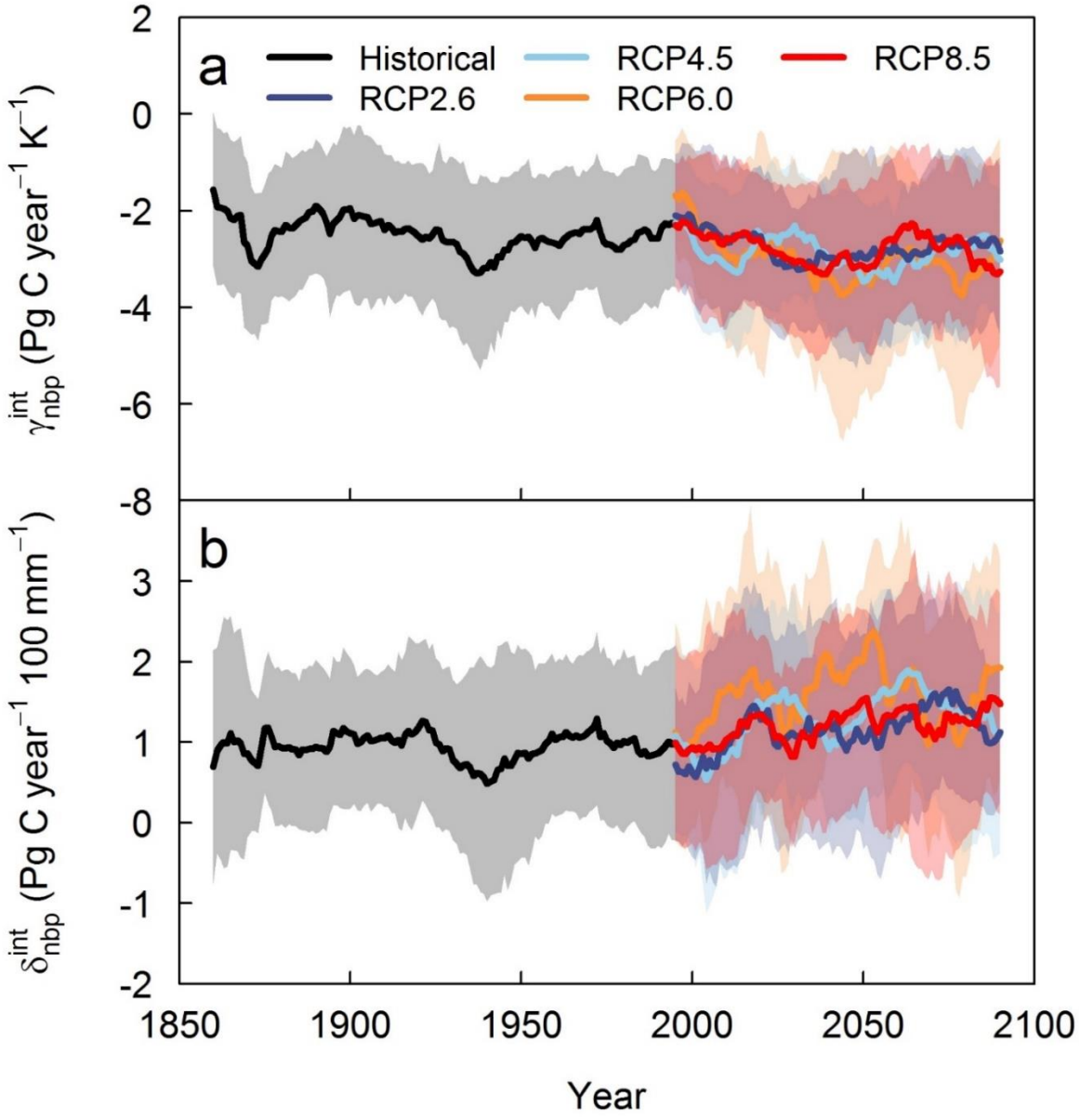


Multi-model mean ± 1 Standard deviation

Tropical (23˚N-23˚S)

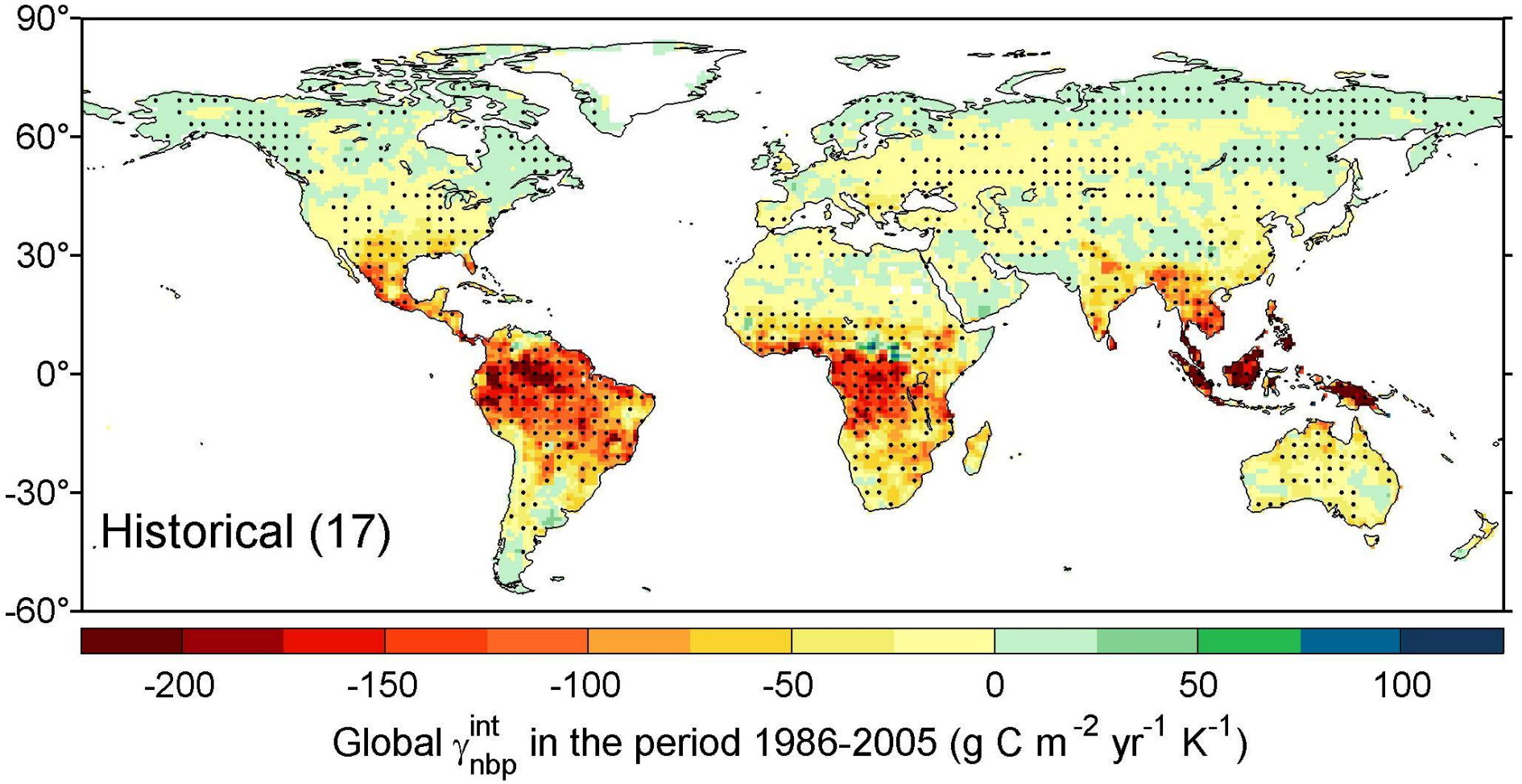
$\gamma_{\mathrm{nbp}}^{\mathrm{int}}$

$\delta_{\mathrm{nbp}}^{\mathrm{int}}$



Multi-model mean±1 Standard deviation

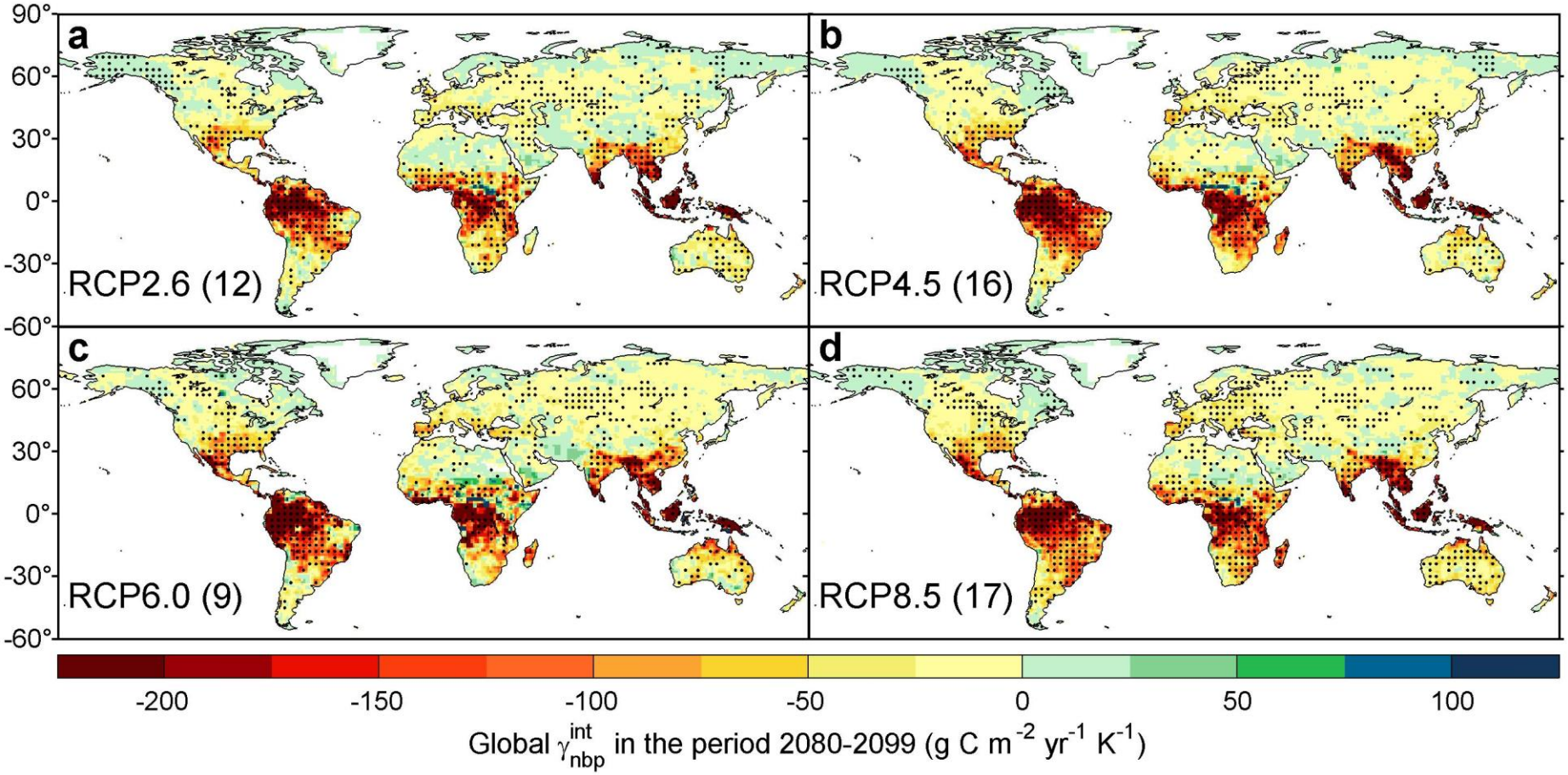
Multi-model-mean of temperature sensitivity $\gamma_{\mathrm{nbp}}^{\mathrm{int}}$ in 1986-2005



Local climate variables are used to calculate all gamma maps.

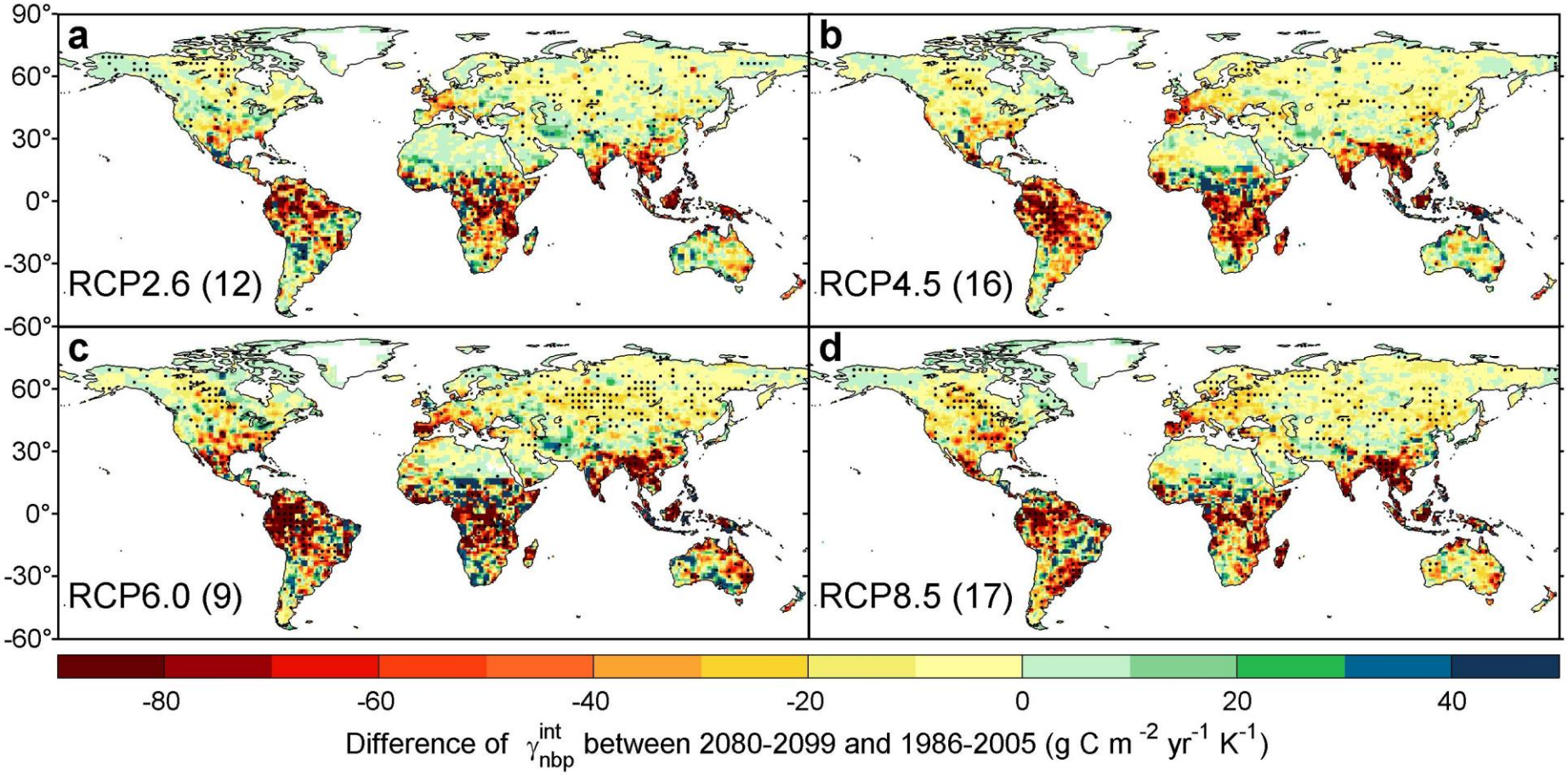
Black point signs (·) indicate grid points where at least 70% of the models agree on the sign of change.

γ_{nbp}^{int} in 2080-2099



Black point signs (·) indicate grid points where at least 70% of the models agree on the sign of change.

Difference of $\gamma_{\mathrm{nbp}}^{\mathrm{int}}$ between 2080-2099 and 1986-2005



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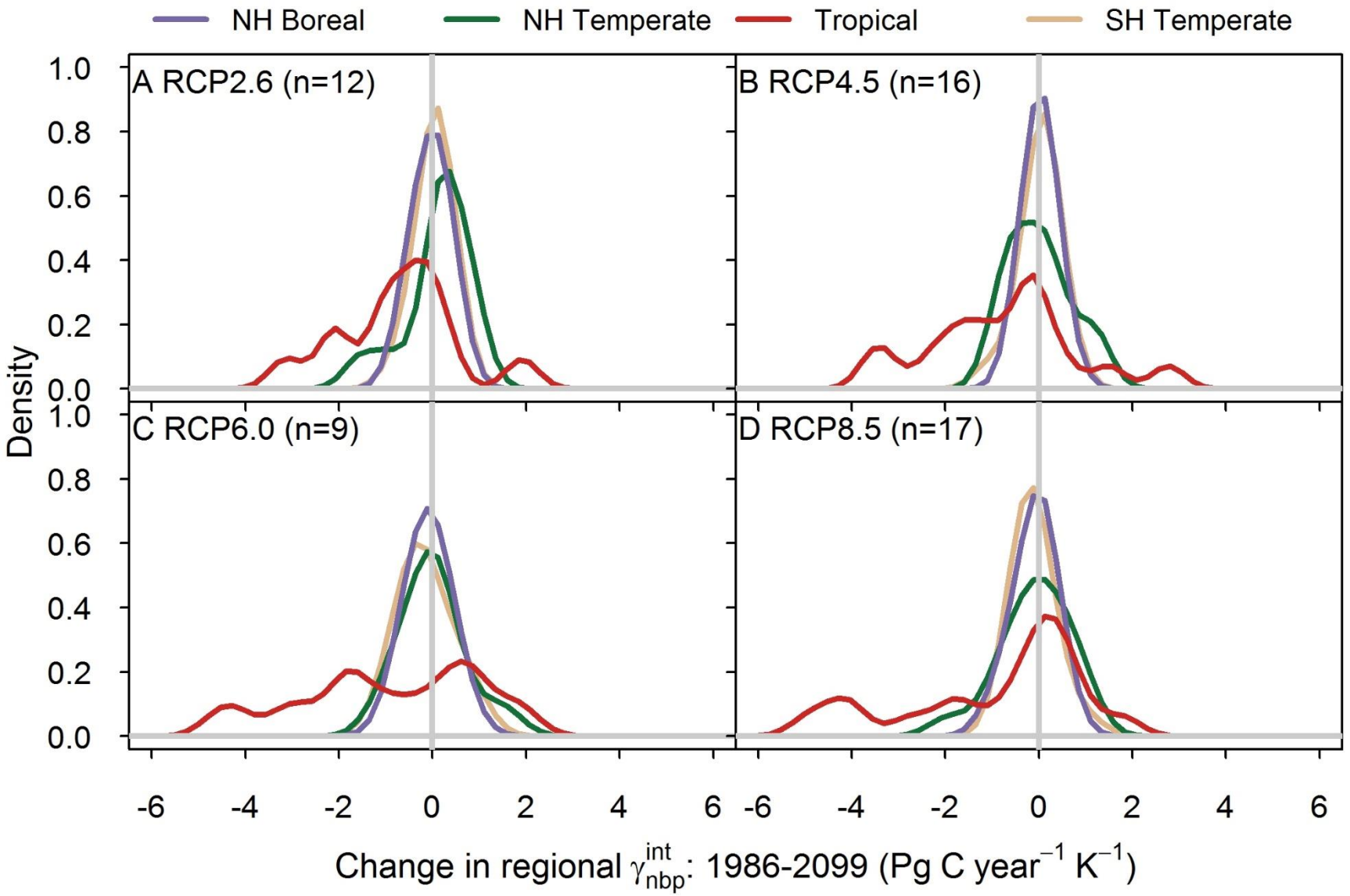
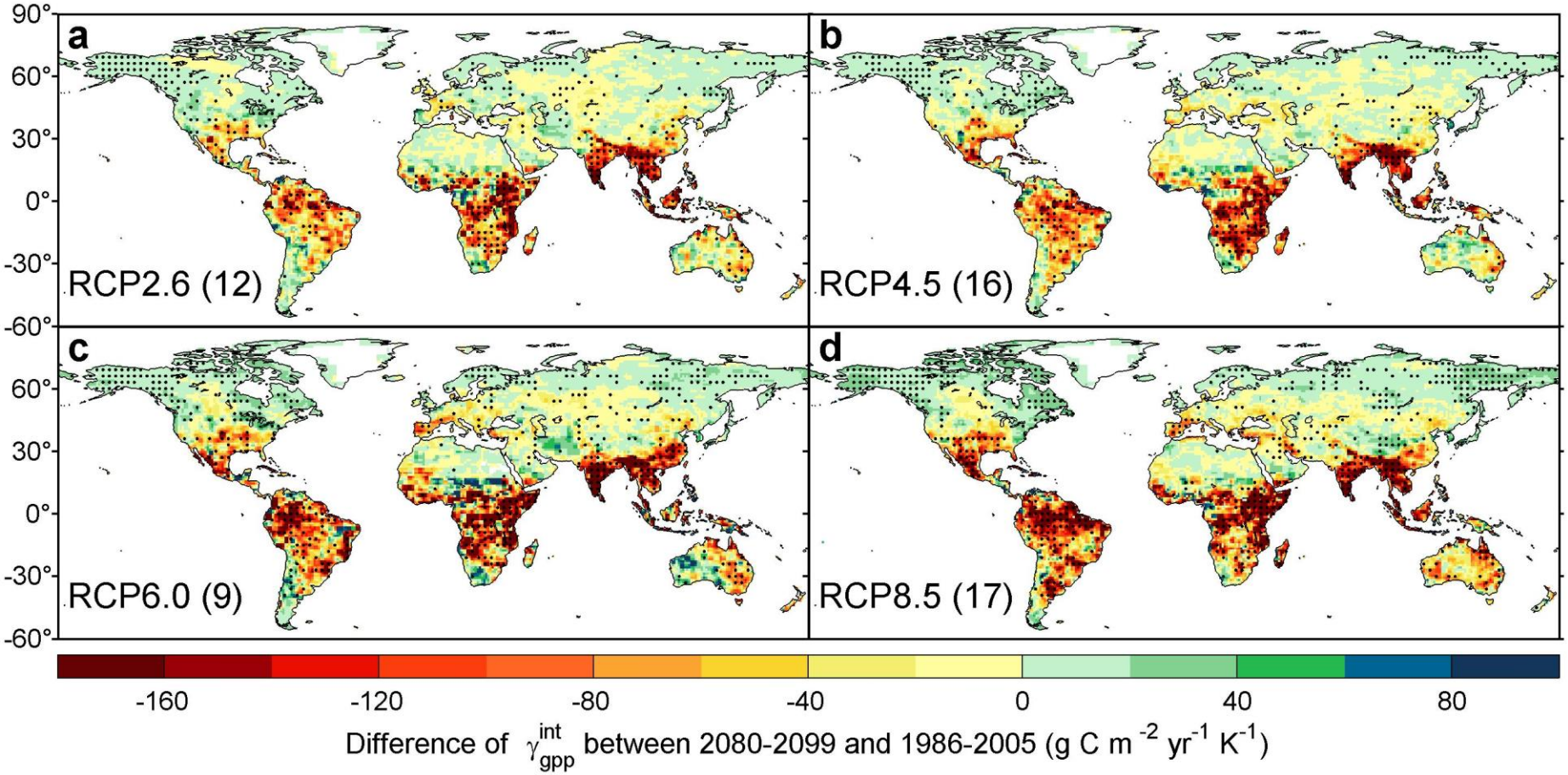
Probability distribution of change in $\gamma_{\mathrm{nbp}}^{\mathrm{int}}$ in CMIP5 models



$$\gamma_{\mathrm{nbp}}^{\mathrm{int}} = \gamma_{\mathrm{gpp}}^{\mathrm{int}} - \gamma_{\mathrm{ra}}^{\mathrm{int}} - \gamma_{\mathrm{rh}}^{\mathrm{int}} + other\ factors$$

Which factor dominates the changes in tropical $\gamma_{\mathrm{nbp}}^{\mathrm{int}}$?

Difference of $\gamma_{\mathrm{gpp}}^{\mathrm{int}}$ between 2080-2099 and 1986-2005



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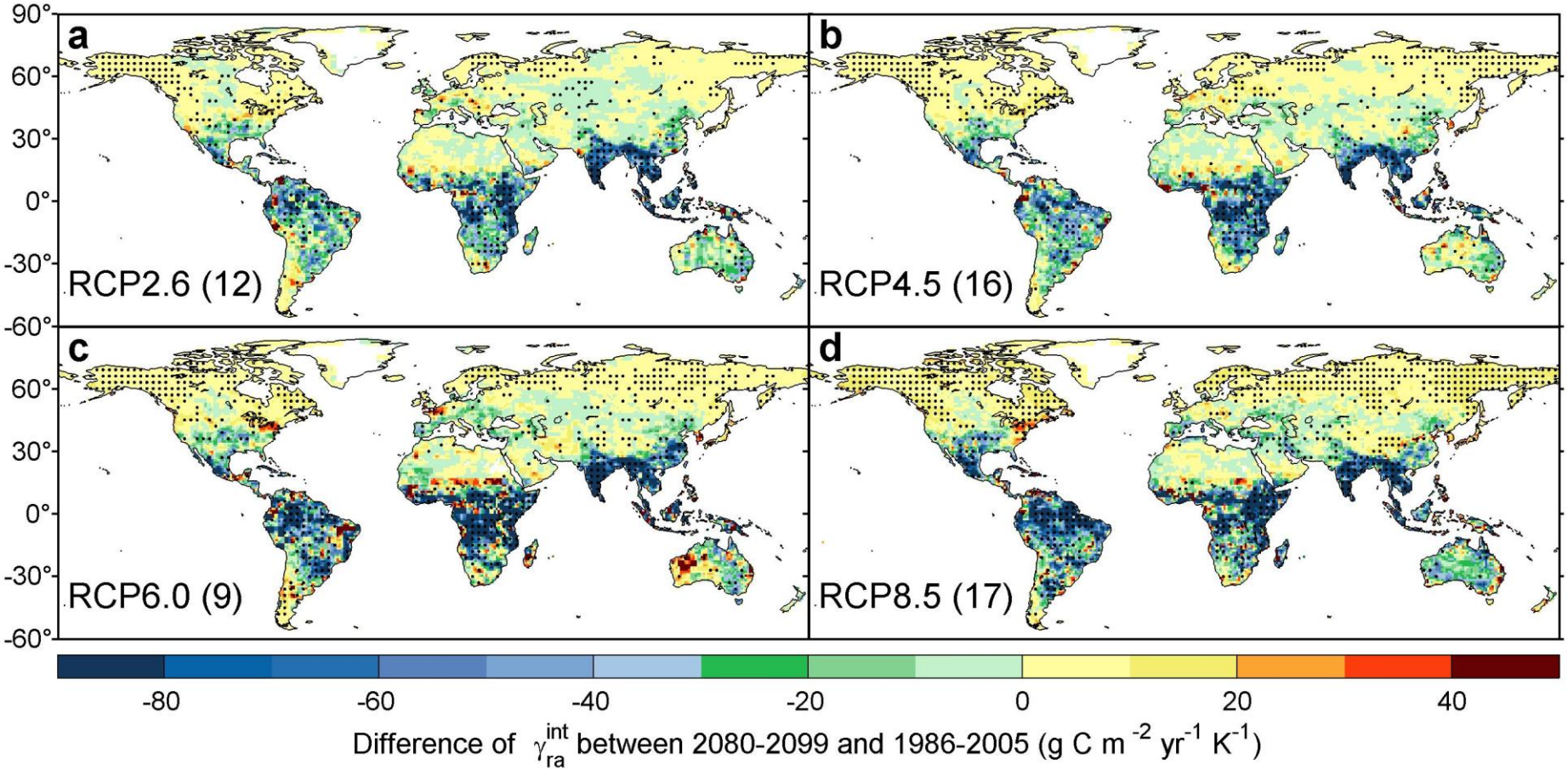
Difference of $\gamma_{\mathrm{ra}}^{\mathrm{int}}$ between 2080-2099 and 1986-2005



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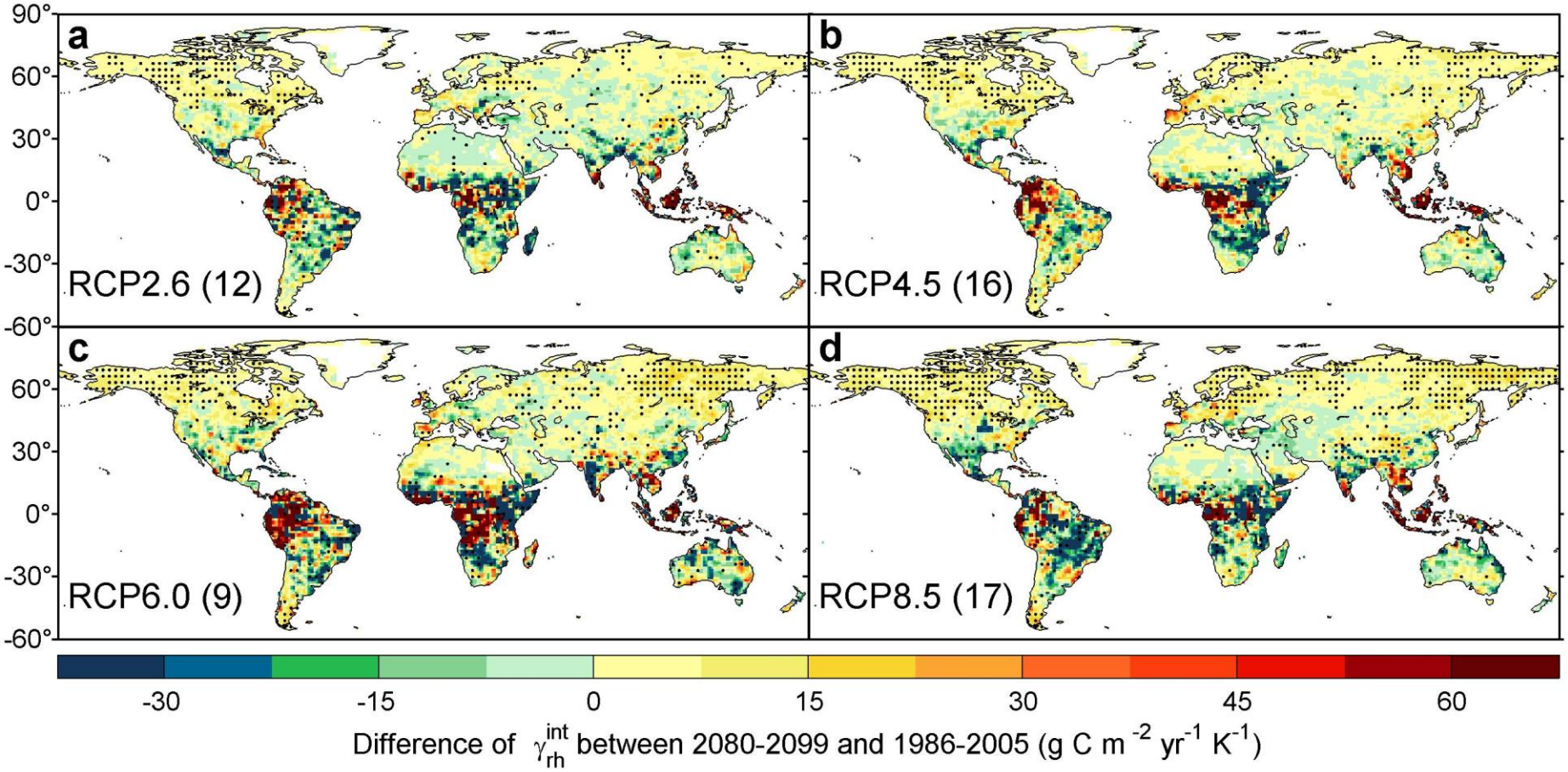
Difference of $\gamma_{\mathrm{rh}}^{\mathrm{int}}$ between 2080-2099 and 1986-2005



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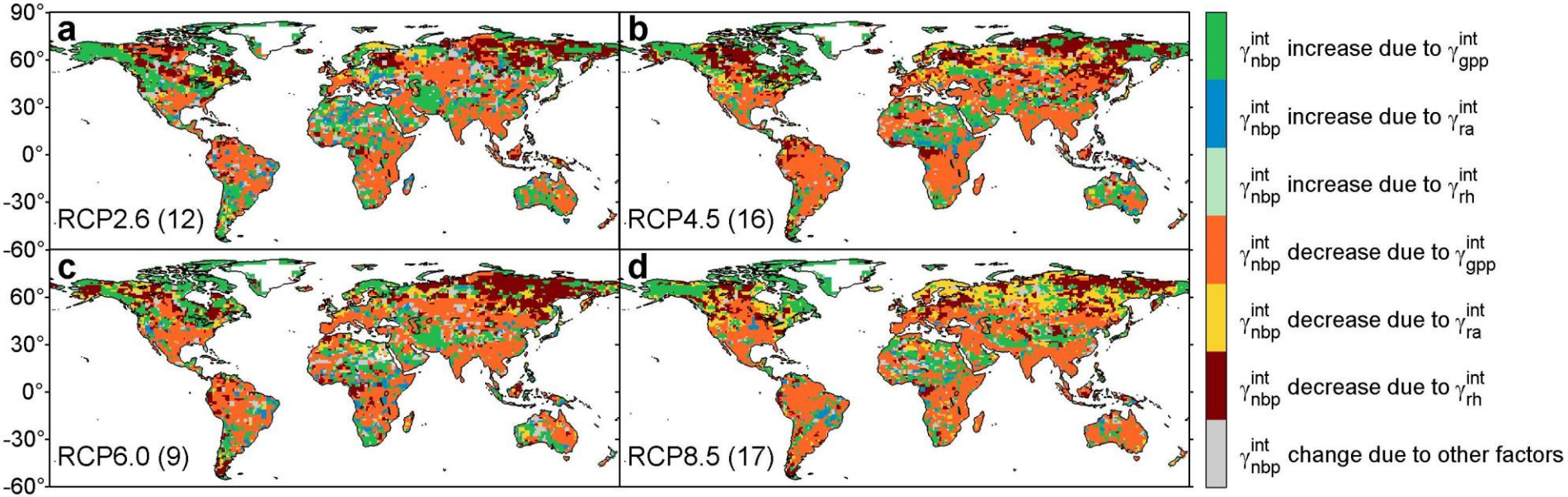
Dominant driving factors of γ_{nbp}^{int} from 1986 to 2099



Max ($\Delta\gamma_{gpp}^{int}/\Delta\gamma_{nbp}^{int}$, $-\Delta\gamma_{ra}^{int}/\Delta\gamma_{nbp}^{int}$, $-\Delta\gamma_{rh}^{int}/\Delta\gamma_{nbp}^{int}$, Δother factor$/\Delta\gamma_{nbp}^{int}$)

Δ: difference of γ^{int} between 2080-2099 and 1986-2005

- CMIP5 models do NOT capture the change of $\gamma_{\mathrm{nbp}}^{\mathrm{int}}$ in tropical region during past 50 years.

- In Northern Hemisphere high latitudes and Southern Hemisphere temperate regions, $\gamma_{\mathrm{nbp}}^{\mathrm{int}}$ remains stable over 1986 to 2099.

- Under all RCPs, tropical $\gamma_{\mathrm{nbp}}^{\mathrm{int}}$ shows decrease trend over 1986 to 2099, and changes in $\gamma_{\mathrm{gpp}}^{\mathrm{int}}$ is the dominant driving factor.

Thank you