Long-term Terrestrial Carbon and Water Cycle Responses to Projected Climate Change Beyond 2100

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Climate–Carbon Cycle Feedback Analysis

For C^4MIP, Friedlingstein et al. (2006) defined the climate–carbon cycle feedback in terms of the ratio of the changes in atmospheric CO_2 from simulations with and without radiative coupling,

$$\Delta C_A^c = \frac{1}{(1-g)} \Delta C_A^u. \tag{1}$$

To isolate the influences of biogeochemical and climate-driven responses of land and ocean carbon uptake, they defined sensitivity parameters in terms of changes in land and ocean carbon storage,

$$\Delta C_L^c = \beta_L \Delta C_A^c + \gamma_L \Delta T^c, \tag{2}$$

$$\Delta C_O^c = \beta_O \Delta C_A^c + \gamma_O \Delta T^c, \tag{3}$$

where β_L (β_O) is the land (ocean) concentration–carbon sensitivity [$\mathrm{Pg\,C\,ppm^{-1}}$] and γ_L (γ_O) is the land (ocean) climate–carbon sensitivity [$\mathrm{Pg\,C\,K^{-1}}$]. The strengths of these sensitivities were found by first solving for β_L (β_O) from a radiatively uncoupled simulation,

$$\Delta C_L^u = \beta_L \Delta C_A^u, \tag{4}$$

$$\Delta C_O^u = \beta_O \Delta C_A^u, \tag{5}$$

then solving for γ_L (γ_O) from a fully coupled simulation.

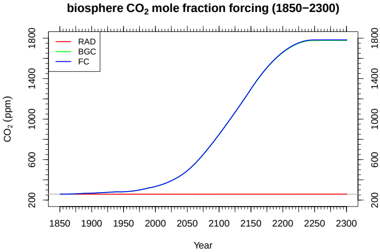
This approach assumes that β_L (β_O) are constant and that these feedback components add linearly.

Climate–Carbon Cycle Feedback Analysis

- Gregory et al. (2009) extended this feedback analysis methodology, highlighted the potential for nonlinear interactions, and advocated for a separate radiatively coupled, biosphere-uncoupled simulation.
- Zickfeld et al. (2011) quantified the non-linearity of the overall carbon cycle feedback in the University of Victoria Earth System Climate Model (UVic ESCM), an Earth system model of intermediate complexity.
- Arora et al. (2013) evaluated the carbon cycle feedbacks, including the concentration–carbon and climate–carbon sensitivities, for 1% CO_2 simulations from a collection of CMIP5 models.

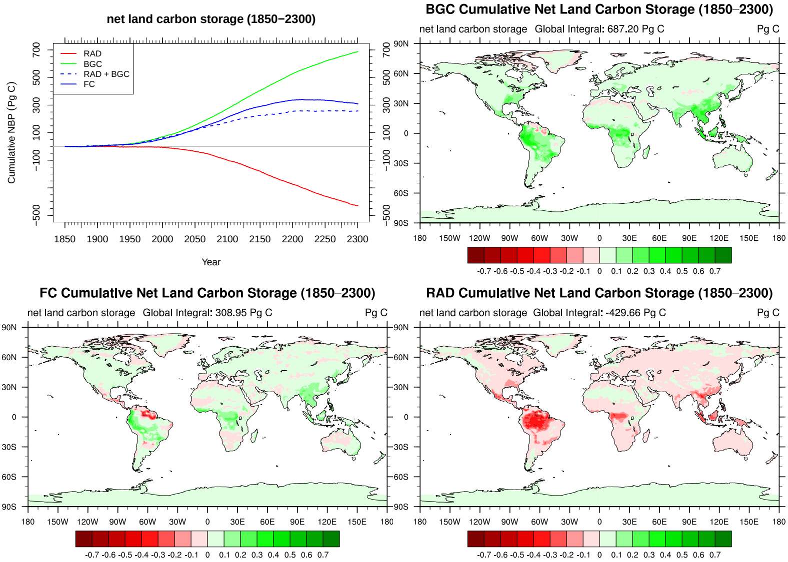
CESM1-BGC Simulations

Three 451-y CESM1-BGC simulations were performed, following the CMIP5 Historical, RCP 8.5, and ECP 8.5 protocol for years 1850–2300. Each was forced with the same prescribed CO_2 mole fraction trajectory for radiative-only (**RAD**), biosphere-only (**BGC**), or full (**FC**) coupling.

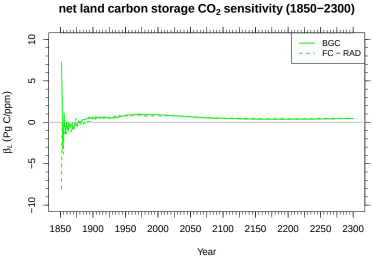


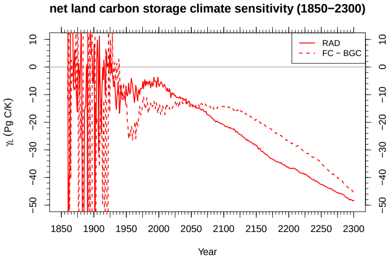
Simulation Identifier	Radiative Coupling: CO_2	Radiative Coupling: Other GHG & aerosols	Biosphere Coupling: CO_2	Biosphere Coupling: Nitrogen deposition	Biosphere Coupling: Land use change	Experiment Name
RAD	✓	✓				`bcrd`
BGC			✓	✓		`bdrcs.pftcon`
FC	✓	✓	✓	✓		`bdrd.pftcon`

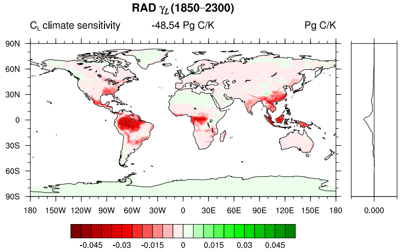
Net Land Carbon Storage (1850–2300)



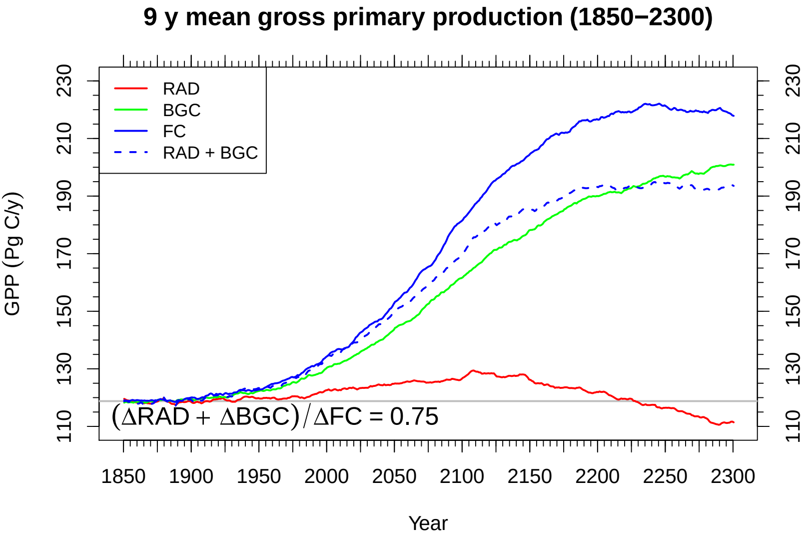
β_L and γ_L (1850–2300)



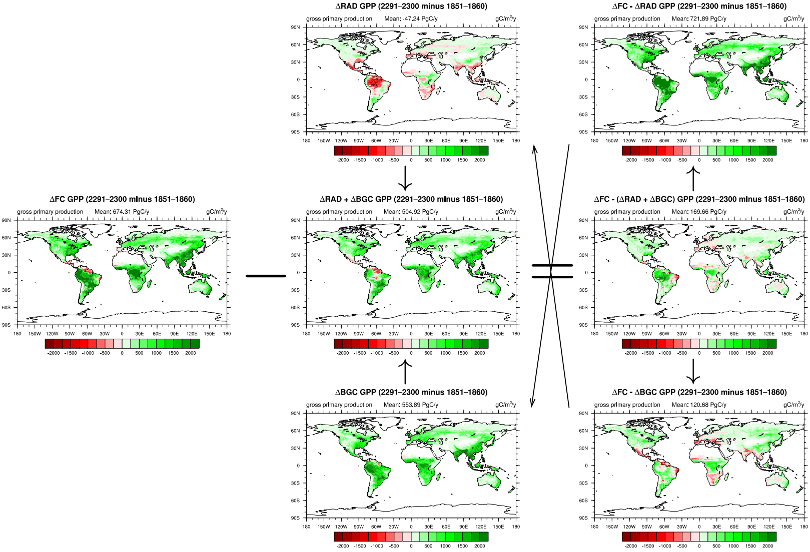




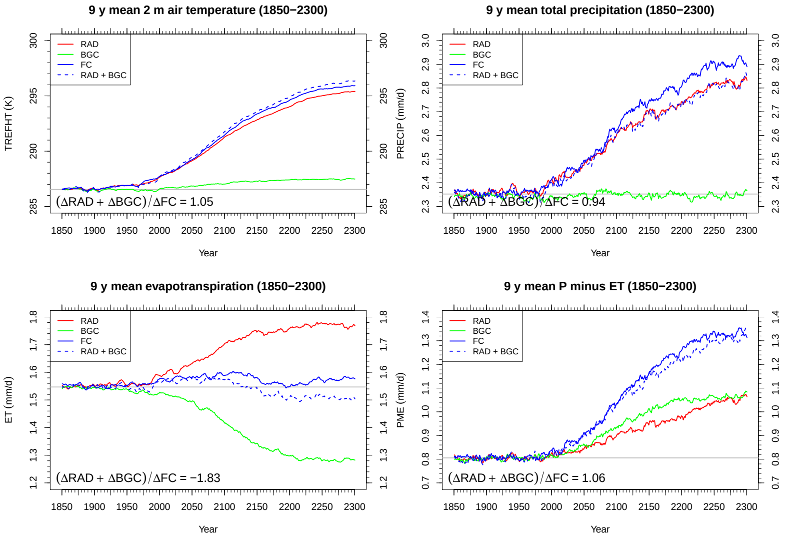
Gross Primary Production



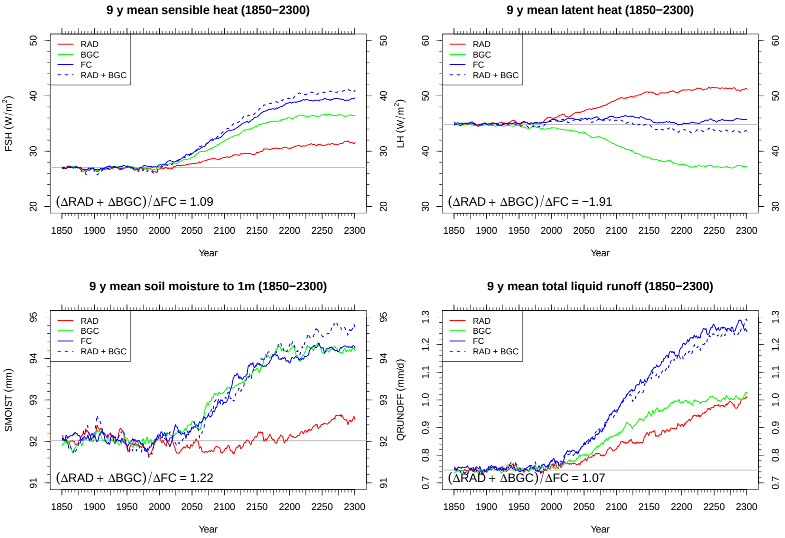
Non-linear GPP Responses



Hydrology Variables (1850–2300)



Hydrology Variables (1850–2300)



Attribution of Hydrology Changes by Coupling Effect

Table: Non-linear Table Sorted by Metric Distance from 1 (1850–2300)

Variable	ΔRAD		ΔBGC		ΔRAD+ΔBGC		ΔFC		$\frac{\Delta\text{RAD}+\Delta\text{BGC}}{\Delta\text{FC}}$
LH	6.39	W/m^2	−7.57	W/m^2	−1.18	W/m^2	0.62	W/m^2	−1.91
ET	0.22	mm/d	−0.26	mm/d	−0.04	mm/d	0.02	mm/d	−1.83
NBP	−1.08	Pg C/y	1.18	Pg C/y	0.10	Pg C/y	−0.78	Pg C/y	−0.13
QVEGT	0.03	mm/d	−0.29	mm/d	−0.26	mm/d	−0.17	mm/d	1.55
QVEGE	−0.02	mm/d	0.05	mm/d	0.03	mm/d	0.06	mm/d	0.60
QSOIL	0.21	mm/d	−0.02	mm/d	0.19	mm/d	0.13	mm/d	1.40
BTRAN	0.04	unitless	0.04	unitless	0.08	unitless	0.06	unitless	1.28
GPP	−7.73	Pg C/y	82.54	Pg C/y	74.80	Pg C/y	99.56	Pg C/y	0.75
SMOIST	0.47	mm	2.28	mm	2.74	mm	2.25	mm	1.22
NPP	−8.94	Pg C/y	24.33	Pg C/y	15.39	Pg C/y	19.07	Pg C/y	0.81
SNOW	−0.04	mm/d	−0.01	mm/d	−0.05	mm/d	−0.04	mm/d	1.19
RH2M	−4.24	%	−3.63	%	−7.86	%	−6.78	%	1.16
WT	98.92	mm	111.60	mm	210.51	mm	188.38	mm	1.12
FSH	4.46	W/m^2	9.38	W/m^2	13.84	W/m^2	12.66	W/m^2	1.09
QOVER	0.05	mm/d	0.04	mm/d	0.09	mm/d	0.09	mm/d	1.08
QRUNOFF	0.25	mm/d	0.29	mm/d	0.54	mm/d	0.50	mm/d	1.07
ZWT	−0.36	m	−0.37	m	−0.73	m	−0.68	m	1.07
PRECIP	0.48	mm/d	0.02	mm/d	0.50	mm/d	0.53	mm/d	0.94
PME	0.26	mm/d	0.28	mm/d	0.54	mm/d	0.51	mm/d	1.06
TSA	10.73	K	1.45	K	12.18	K	11.57	K	1.05
RAIN	0.52	mm/d	0.03	mm/d	0.55	mm/d	0.58	mm/d	0.96
WA	72.47	mm	45.58	mm	118.06	mm	115.73	mm	1.02
TLAI	−0.39	unitless	1.60	unitless	1.20	unitless	1.19	unitless	1.01

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