Using Single Forcing Factor Experiments to Explore Climate-Biogeochemistry Feedbacks in CESM1

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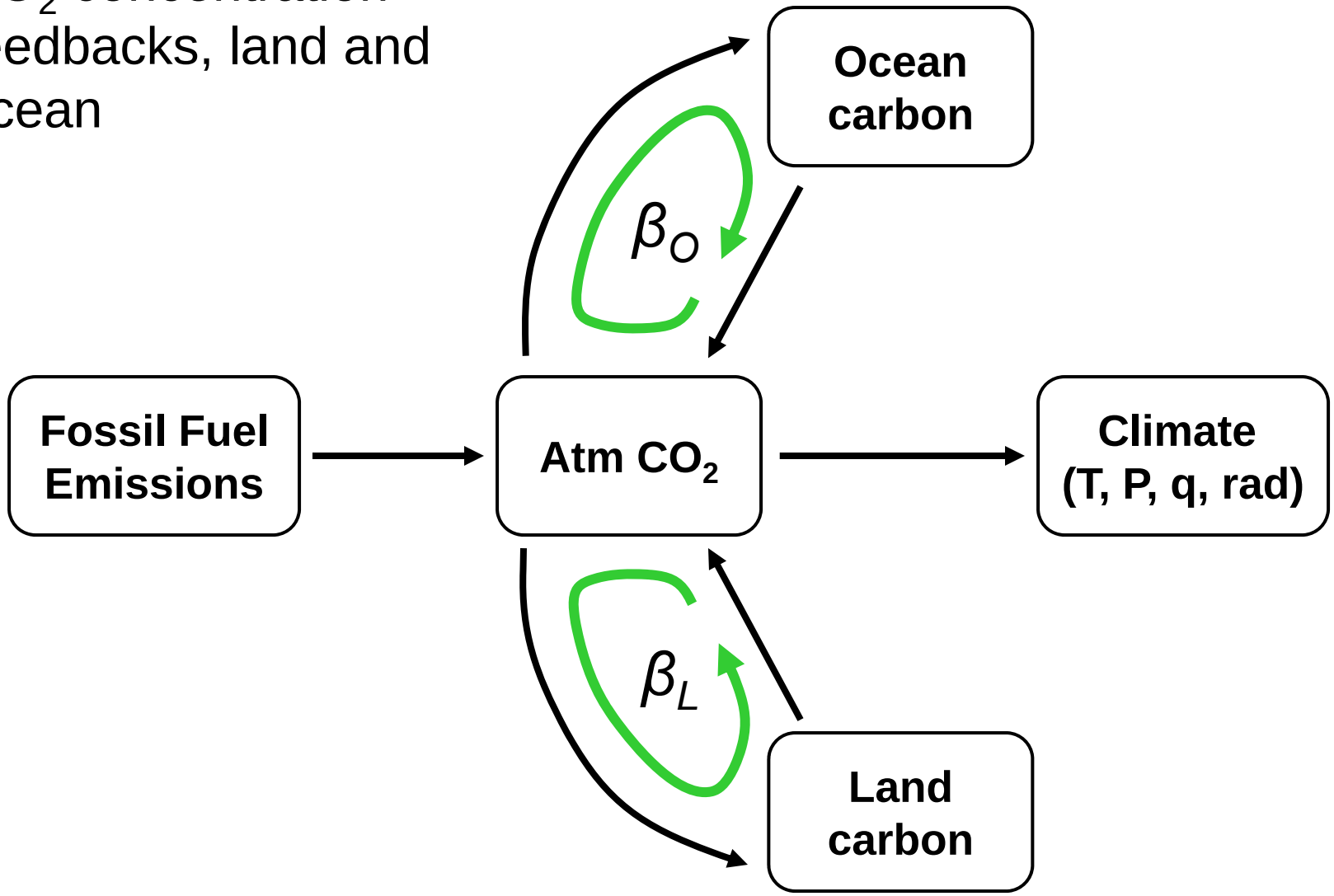
Primary motivation:

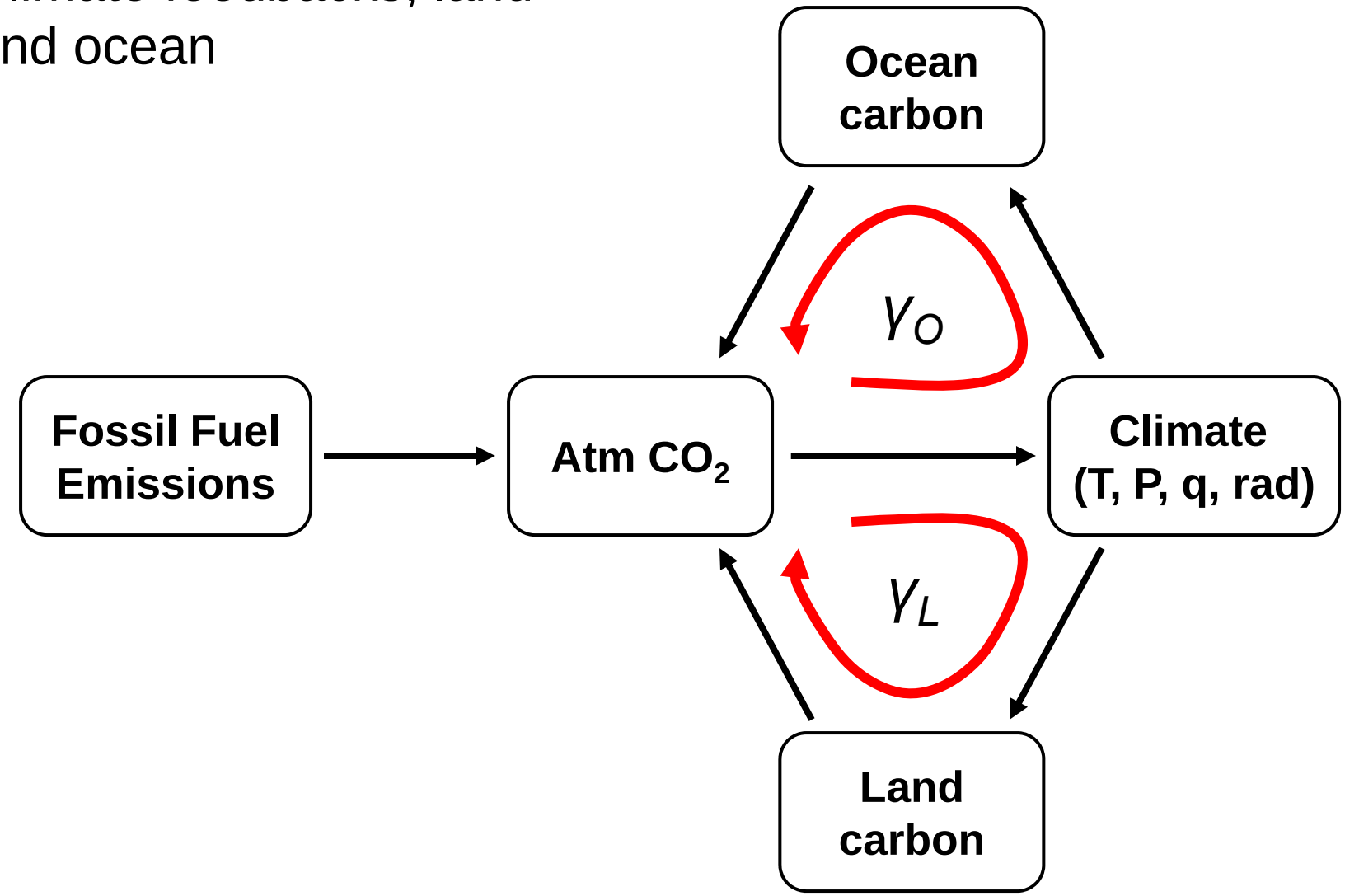
Improved prediction of future GHG concentrations and associated climate change

Fossil Fuel Emissions → **Atm CO_2** → **Climate (T, P, q, rad)**

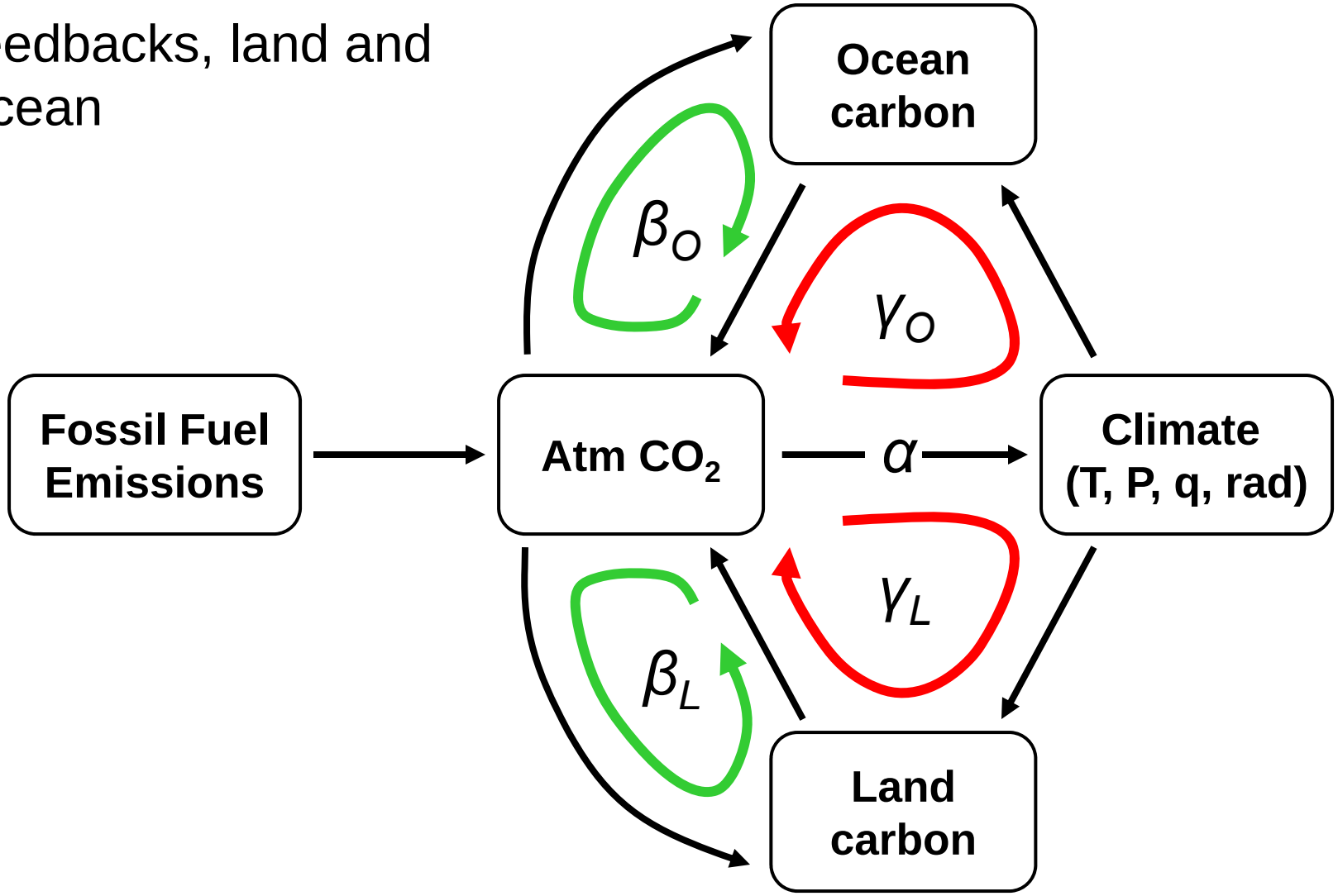
CO_2 concentration feedbacks, land and ocean



Climate feedbacks, land and ocean



Climate – carbon feedbacks, land and ocean



Climate-carbon cycle feedback analysis

- Following Friedlingstein et al. 2006:

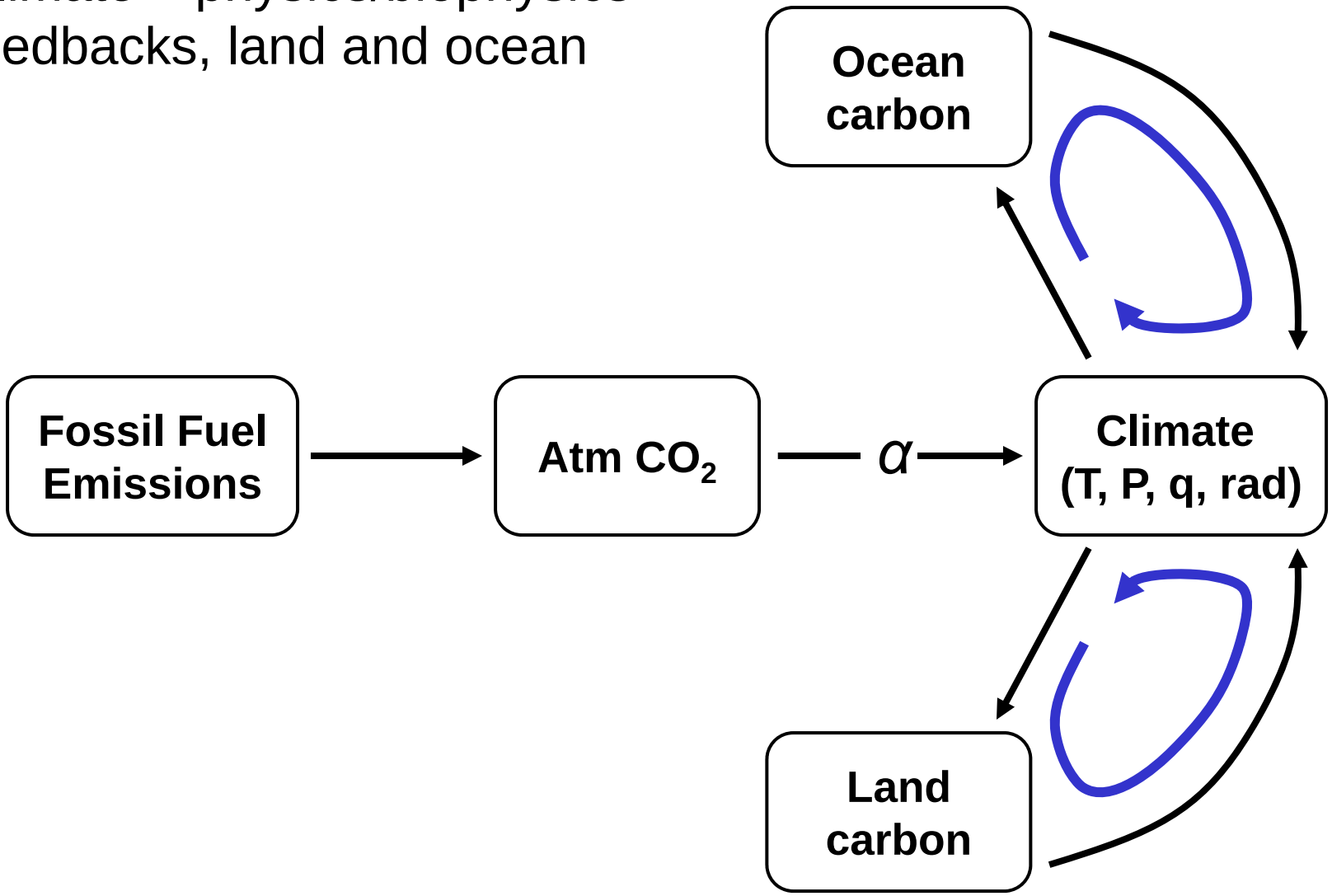
$$\text{Gain} \approx -\alpha\,(\gamma_L + \gamma_O) / (1 + \beta_L + \beta_O)$$

(K ppm^{-1}) α = transient climate sensitivity to CO_2

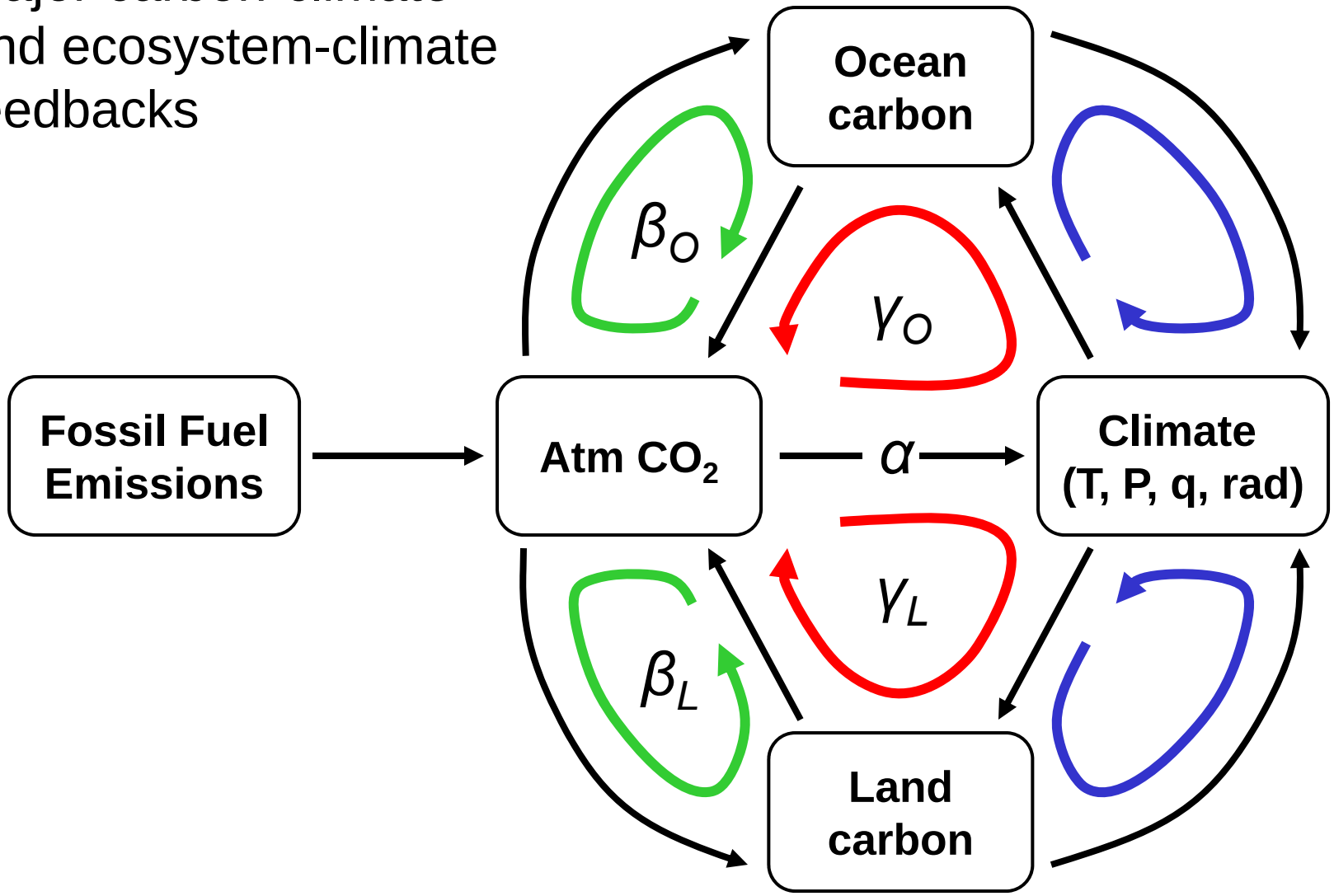
(PgC ppm^{-1}) β = (land or ocean) carbon storage sensitivity to CO_2

(PgC K^{-1}) γ = (land or ocean) carbon storage sensitivity to climate

Climate – physics/biophysics feedbacks, land and ocean



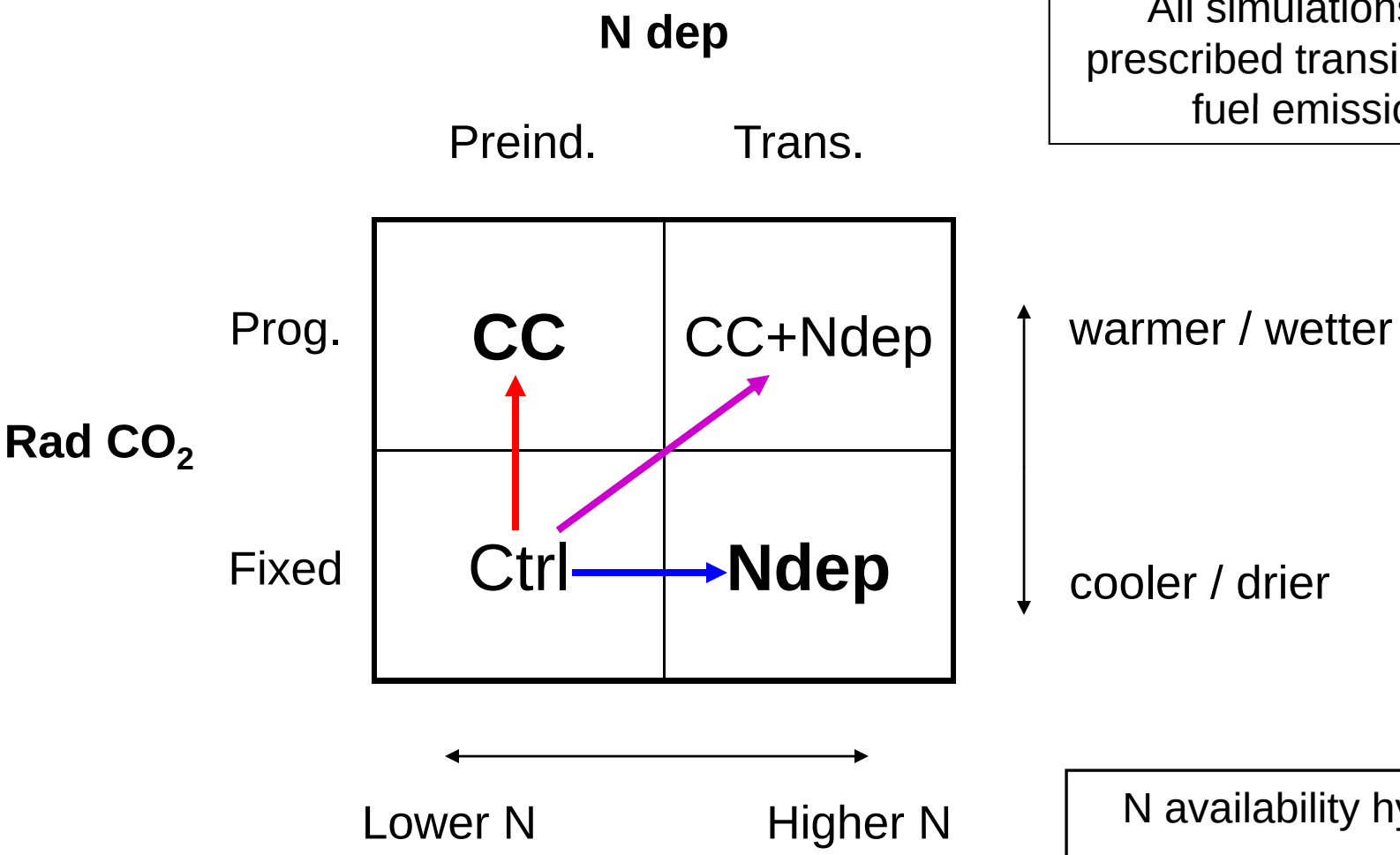
Major carbon-climate and ecosystem-climate feedbacks



Fully-coupled climate-carbon-nitrogen simulations

- CCSM3 framework: CAM + CICE + POP Doney/Moore/Lindsay ocean ecosystem + CLM-CN
- 1000-year stable pre-industrial control
- Historical + A2 (1890-2100), forced with fossil fuel emissions and nitrogen deposition.
- Coupled vs. fixed radiative effects of atmospheric CO_2.

All simulations with prescribed transient fossil fuel emissions



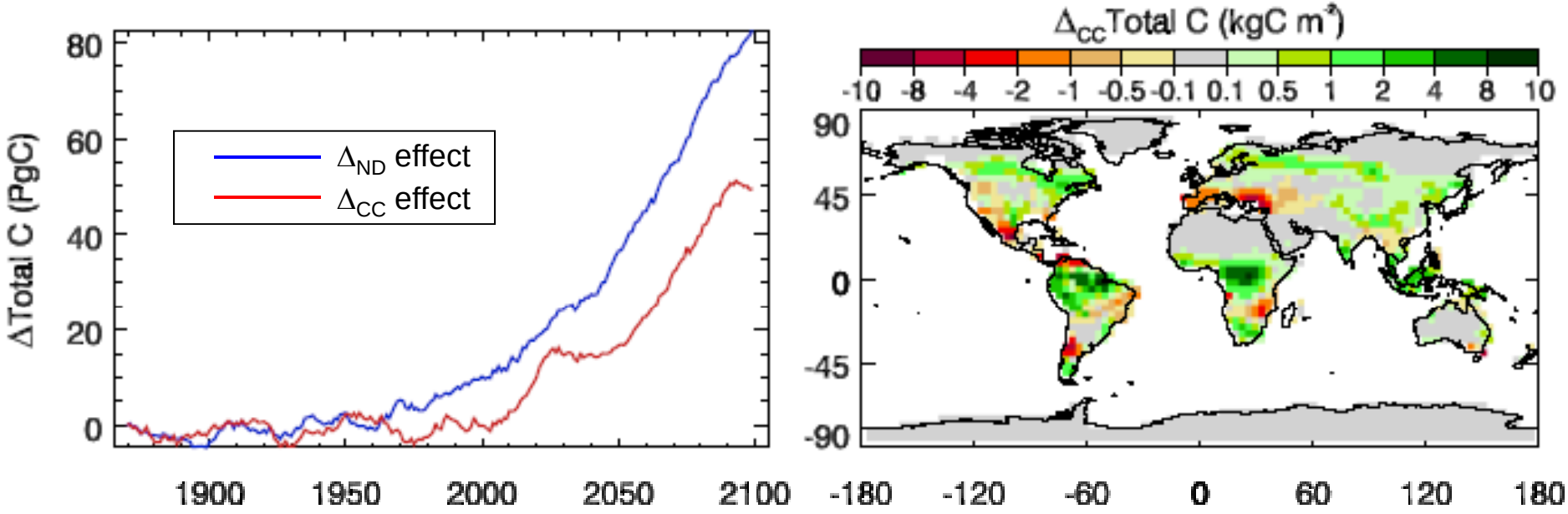
N availability hypothesis

- Higher due to N deposition
- Higher due to climate change
- Higher due to deposition and climate change

Does climate change mimic the effects of increased N deposition?

Climate-carbon cycle feedback

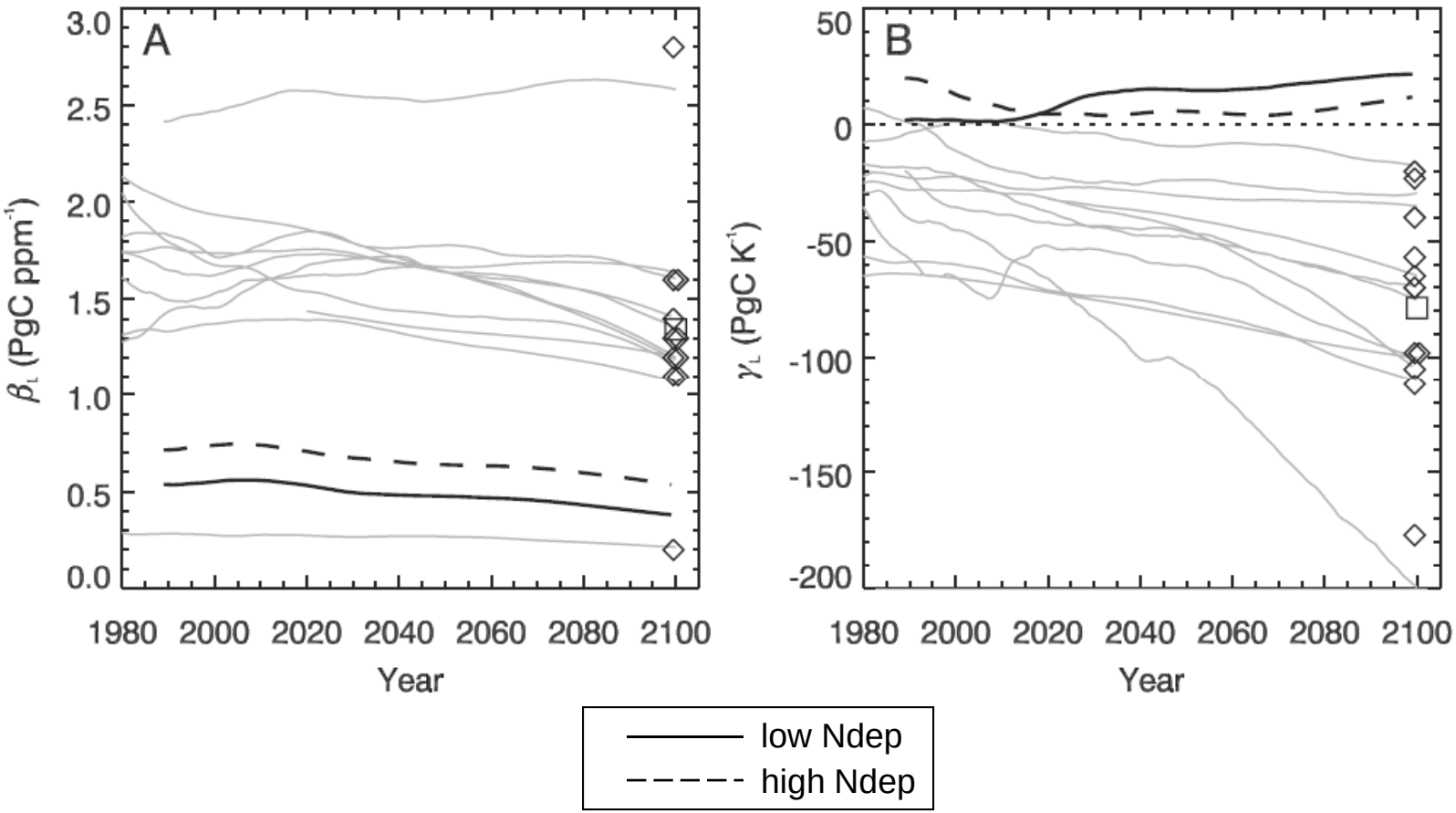
CO_2-induced climate change (warmer and wetter) leads to **increased** land carbon storage



- Both climate change (red curve) and anthropogenic nitrogen deposition (blue curve) result in increased land carbon storage.
- Climate change producing uptake of carbon over tropics, opposite response compared to previous (carbon-only) results.

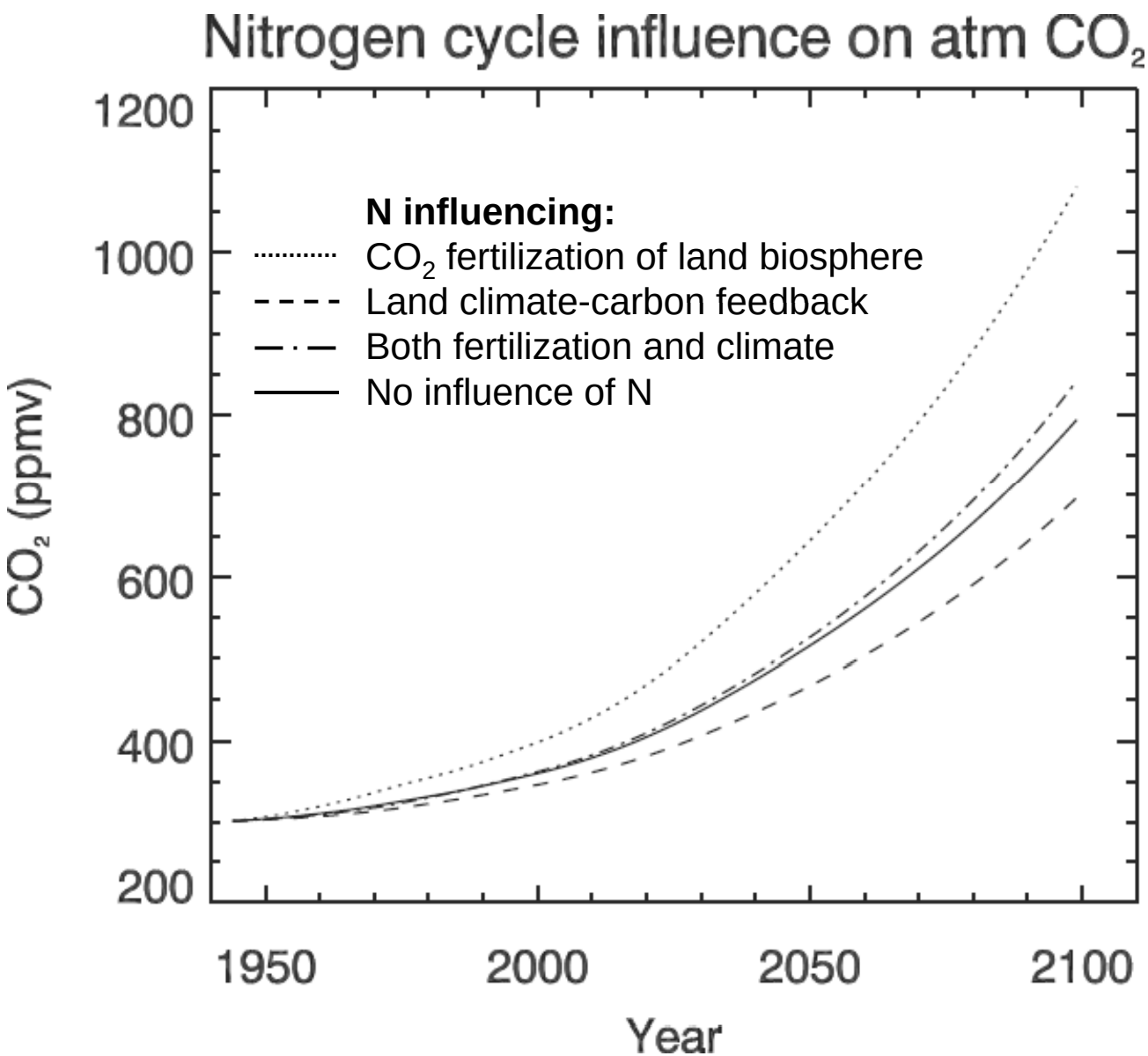
Thornton et al., 2009

Land components of climate-carbon cycle feedback



- Effect of C-N coupling on gamma_land is to **reduce** atmospheric CO2 by about **130 ppm** by 2100, compared to previous model results
- Combined effects of beta and gamma: higher predicted CO2.

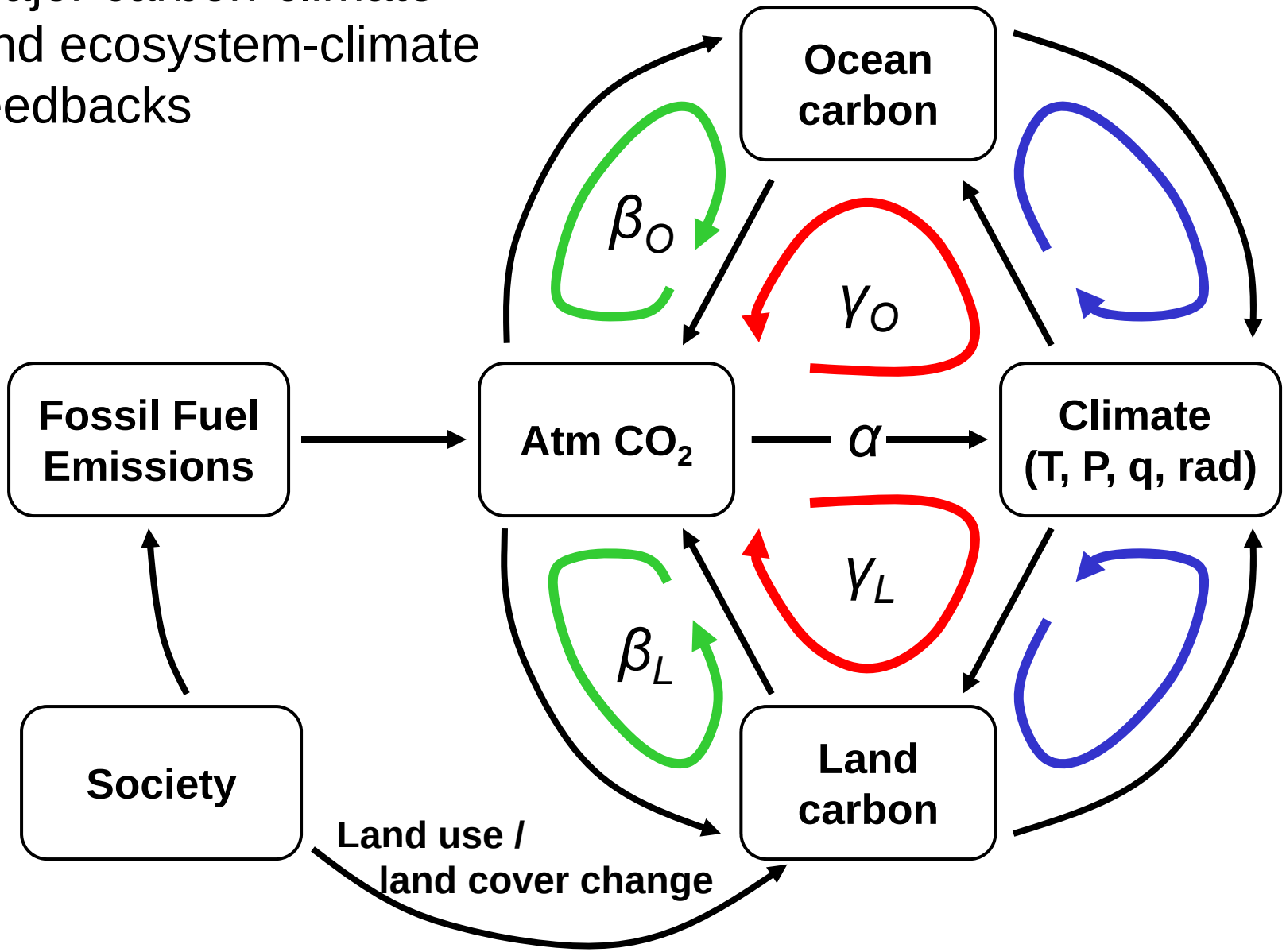
Thornton et al., 2009



Range of uncertainty: We don't know how these C-N interactions will be expressed over time

Based on: Friedlingstein et al. 2006, Thornton et al. 2009

Major carbon-climate and ecosystem-climate feedbacks



Summary of simulations

	Dynamic components		
Simulation	CO_2	N_{dep}	LU/LCC
Control			
C	x		
N		x	
D			x
CN	x	x	
CD	x		x
ND		x	x
CND	x	x	x

Historical global simulations (1850-2004). Used to evaluate independent and interaction effects of: increasing CO2 (C), increasing anthropogenic nitrogen deposition (N), and land-cover change (D).

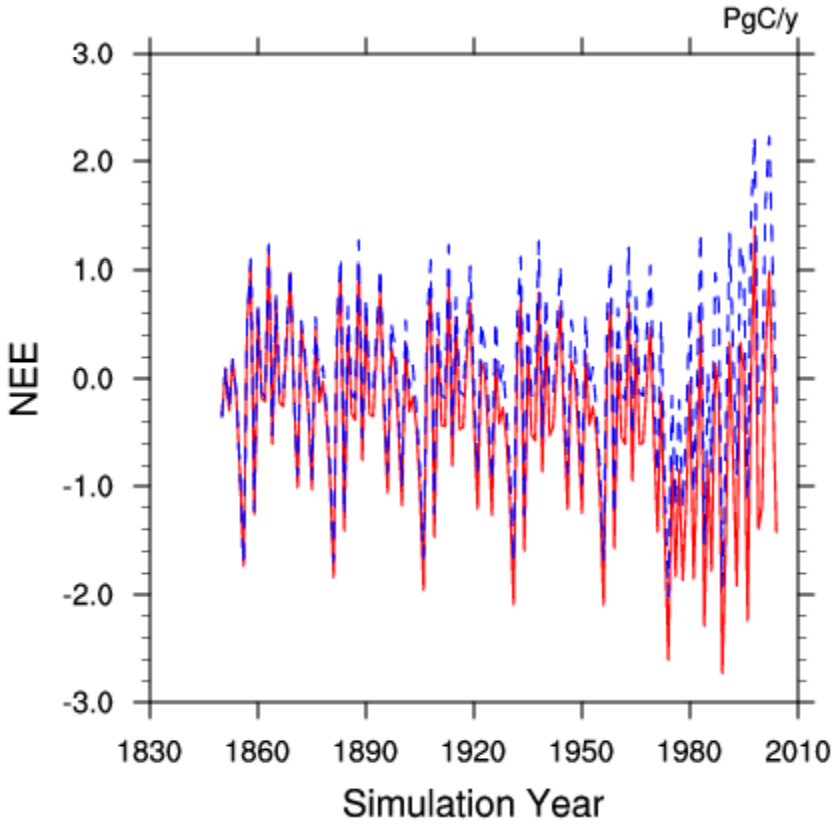
Effects of rotation harvest are included in the land cover change term.

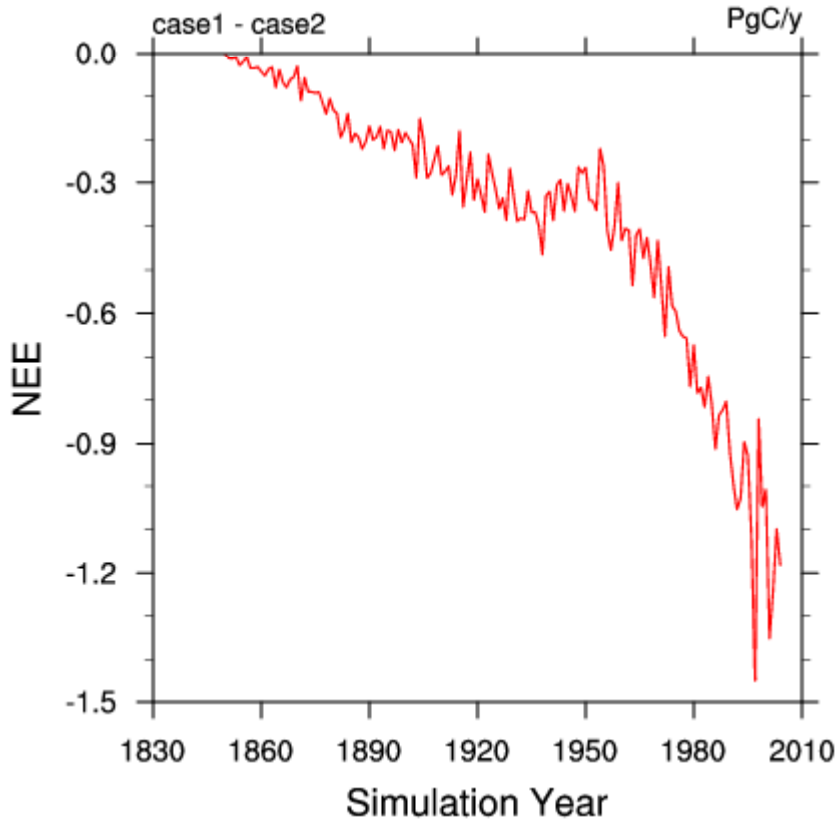
Calculating interactions…

	Effect		Description
Analysis	Forcing	Interaction	
dC	x		C - Control
dN	x		N - Control
dL	x		L - Control
dCN	x		CN - Control
dCL	x		CL - Control
dNL	x		NL - Control
dCNL	x		CNL - Control
d[CN]		x	dCN - (dC + dN)
d[CL]		x	dCL – (dC + dL)
d[NL]		x	dNL – (dN + dL)
d[CNL]		x	dCNL – (dC + dN + dL)

List of forcings and interaction effects investigated to date. Description shows the differencing of experiments from Table 1 used to isolate the forcing or interaction terms.

Influence of rising CO_2 on NEE

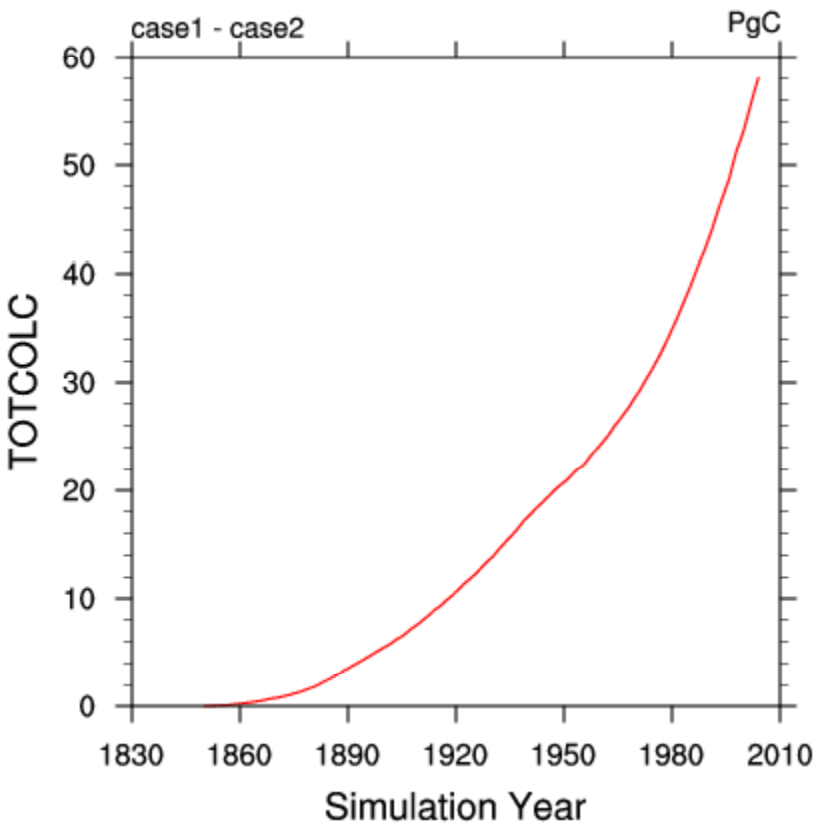


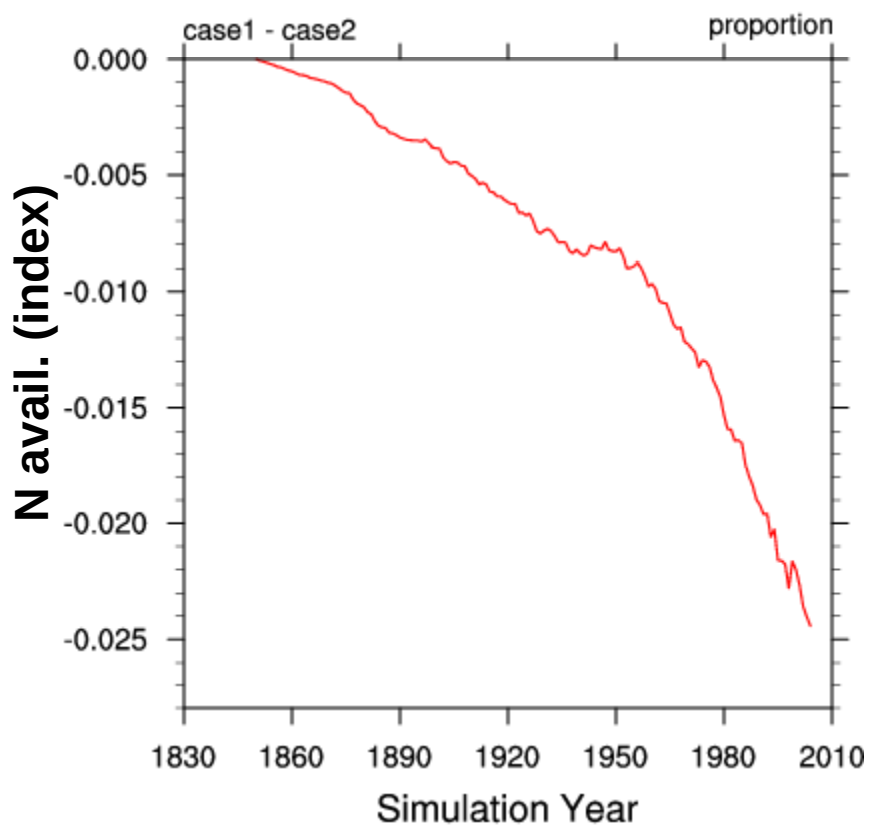


control
+CO_2

(CO_2 – control)

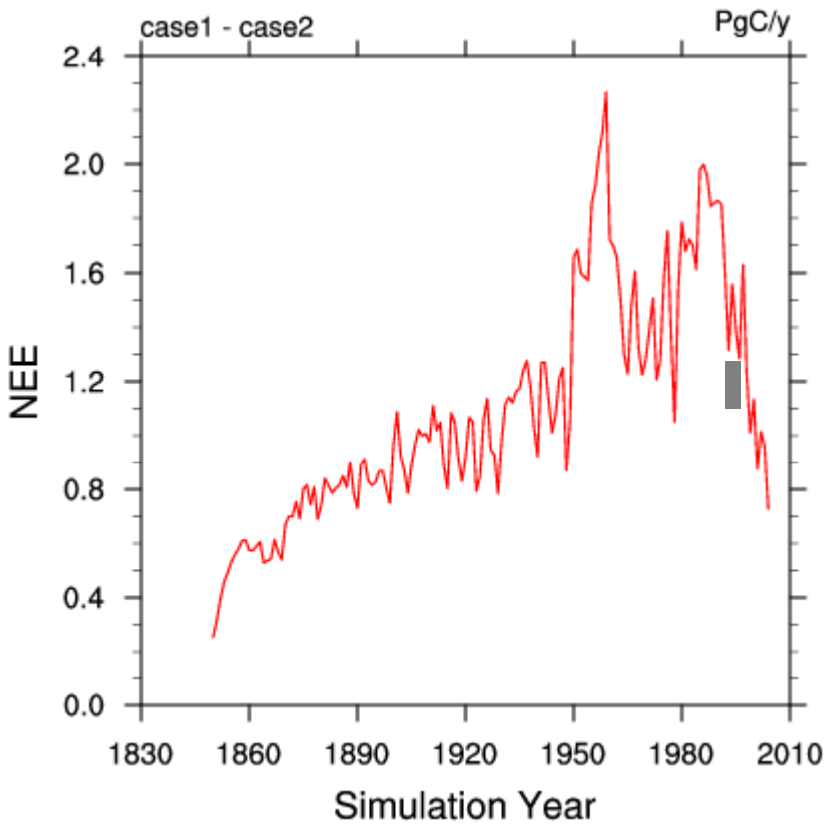
Influence of rising CO_2 on total C and N availability

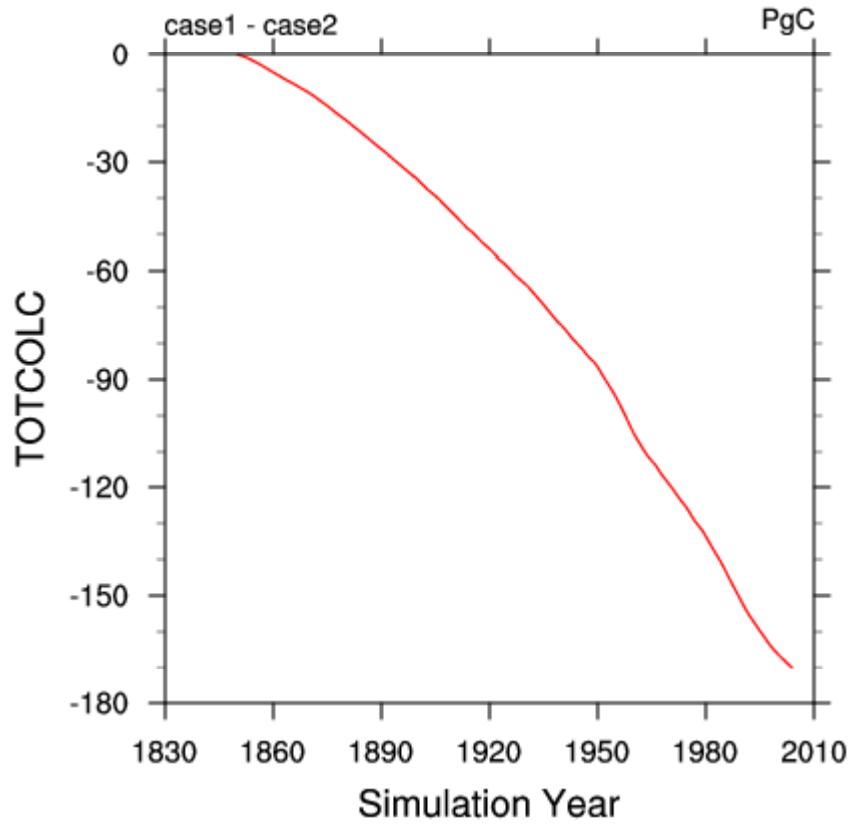




(CO_2 – control)

Influence of LULCC on NEE and total C

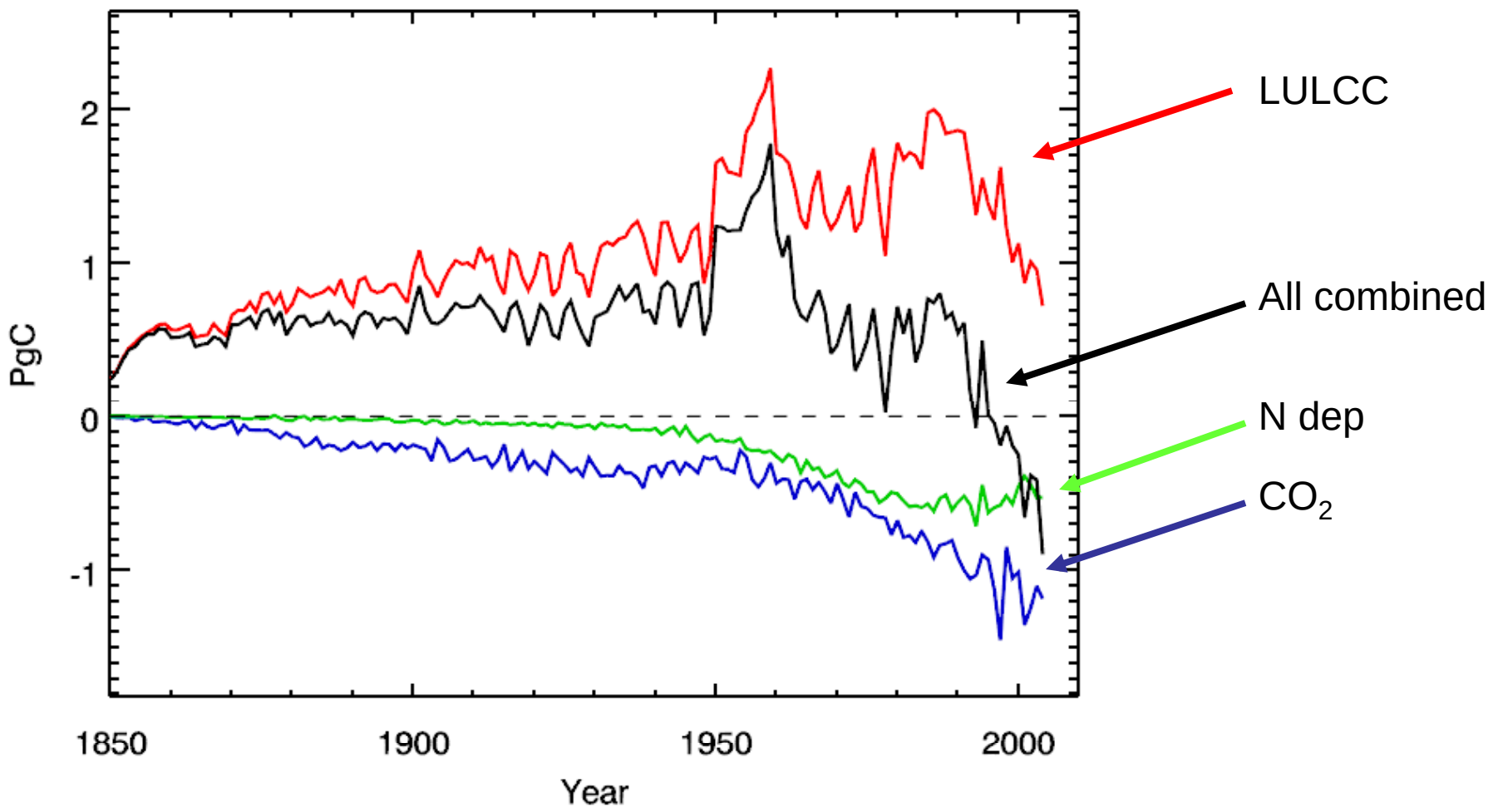




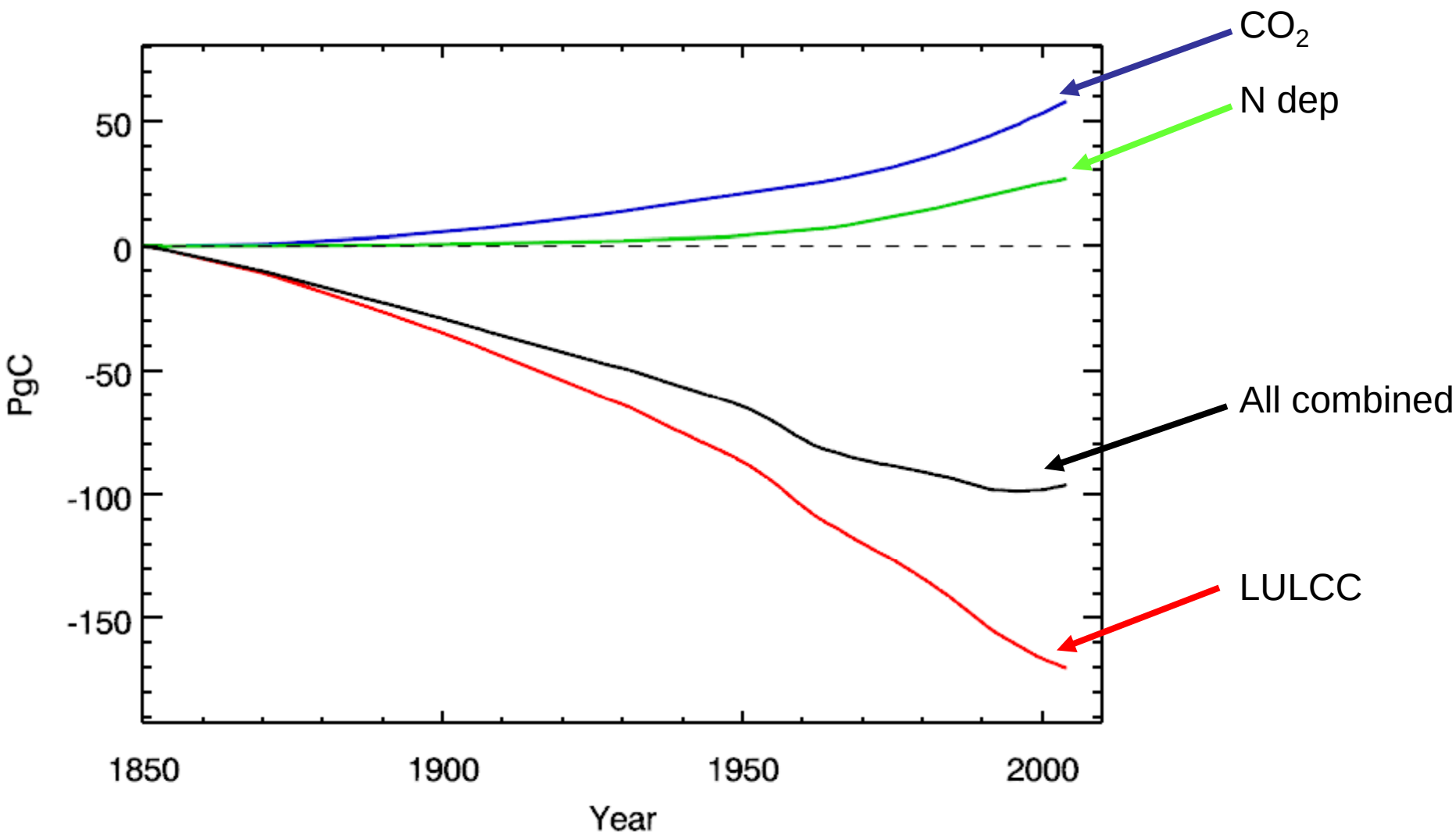
(LULCC – control)

Shevliakova 2009 (LM3V model result)

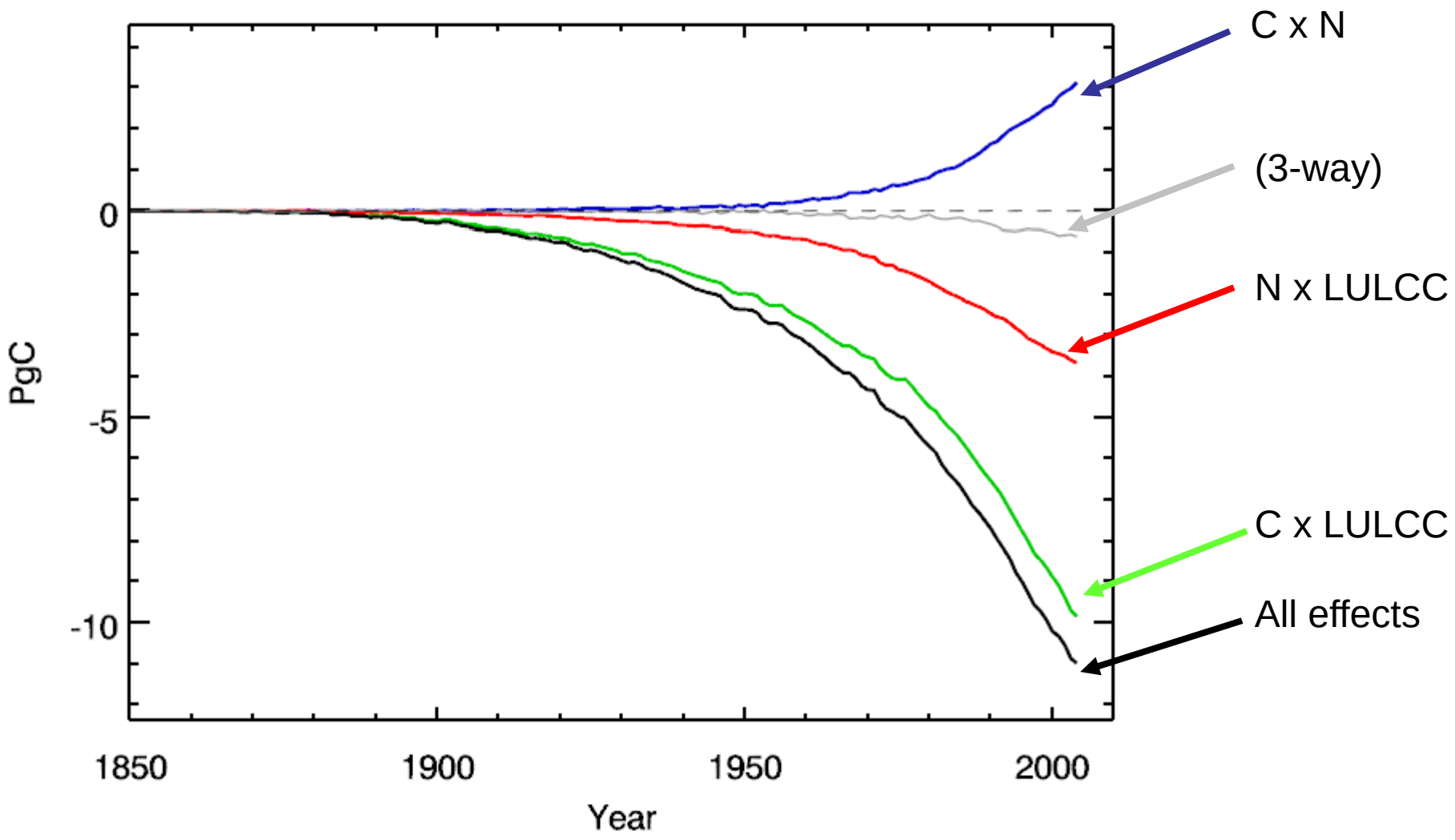
Single and combined effects on NEE



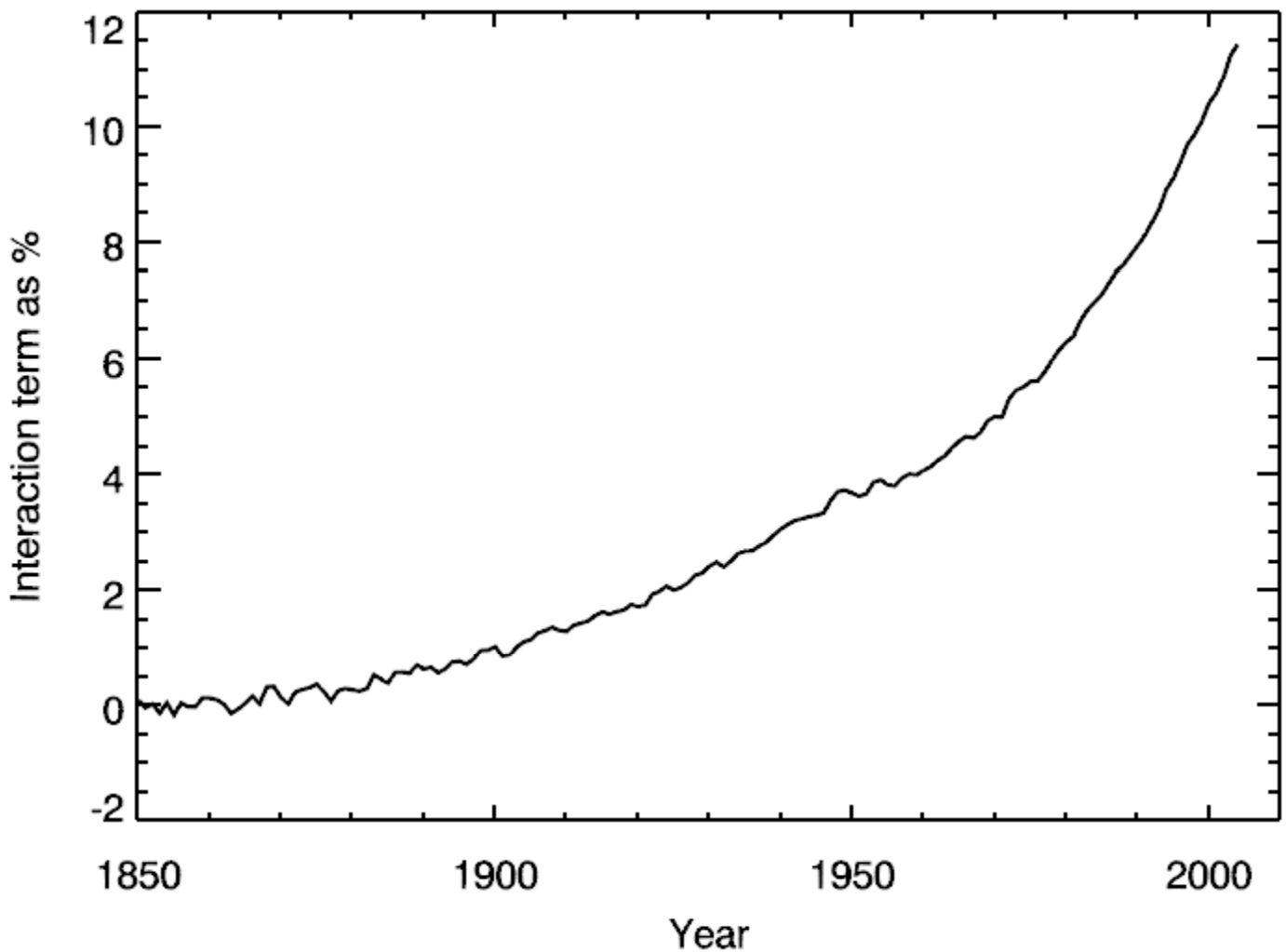
Single and combined effects on total land C



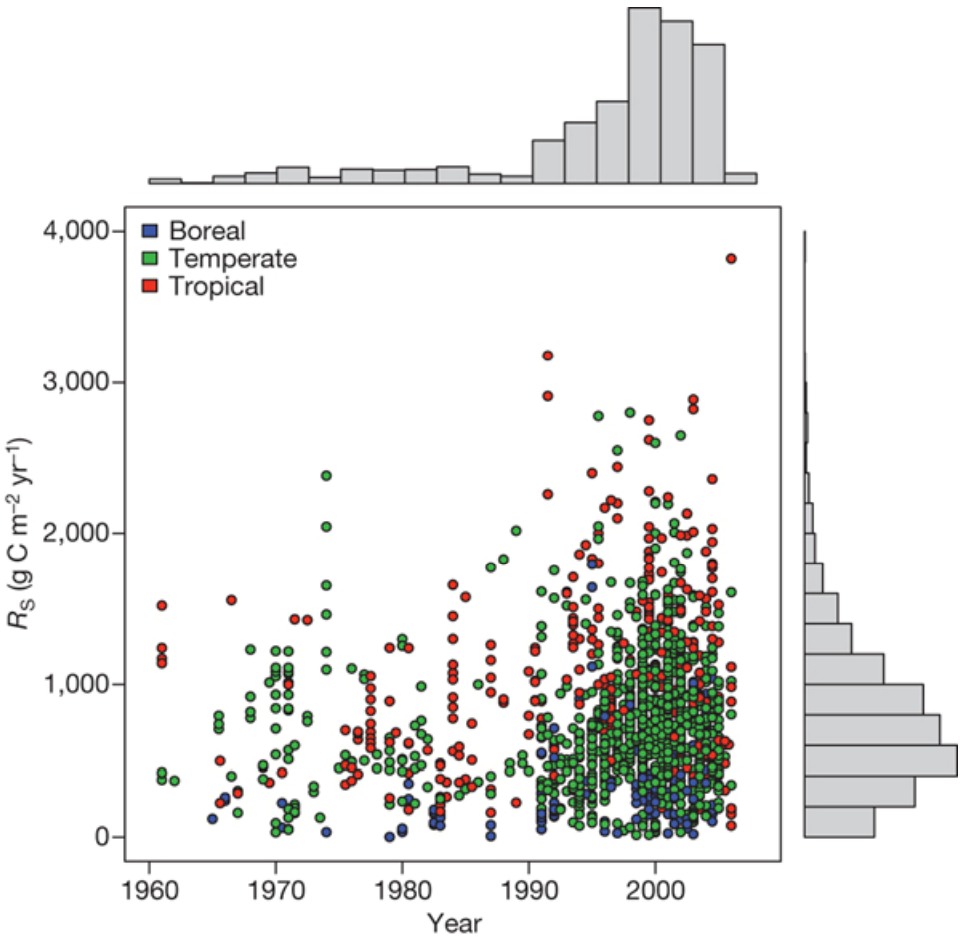
Interaction effects for total land C



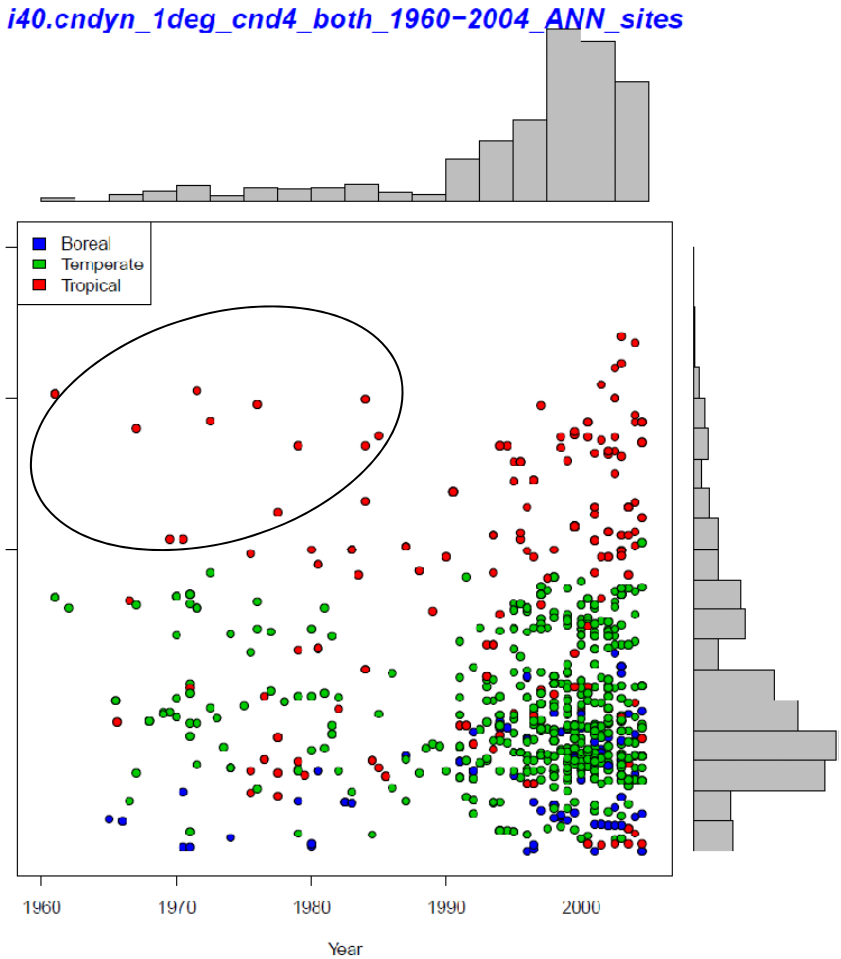
Interaction as % of total C+N+LULCC effect



Observed vs. modeled soil respiration: changes over time



Bond-Lamberty and Thomson, 2010



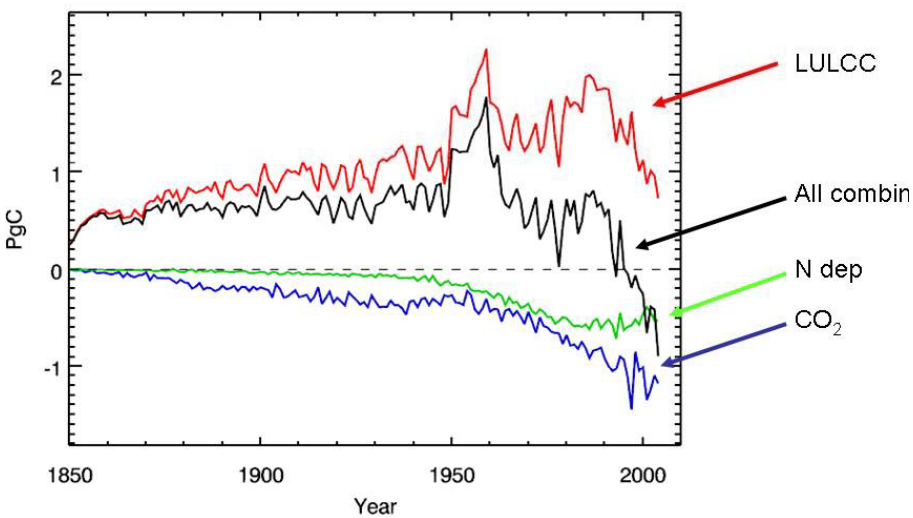
Fully-forced CLM4 (offline)

Thornton et al., in prep.

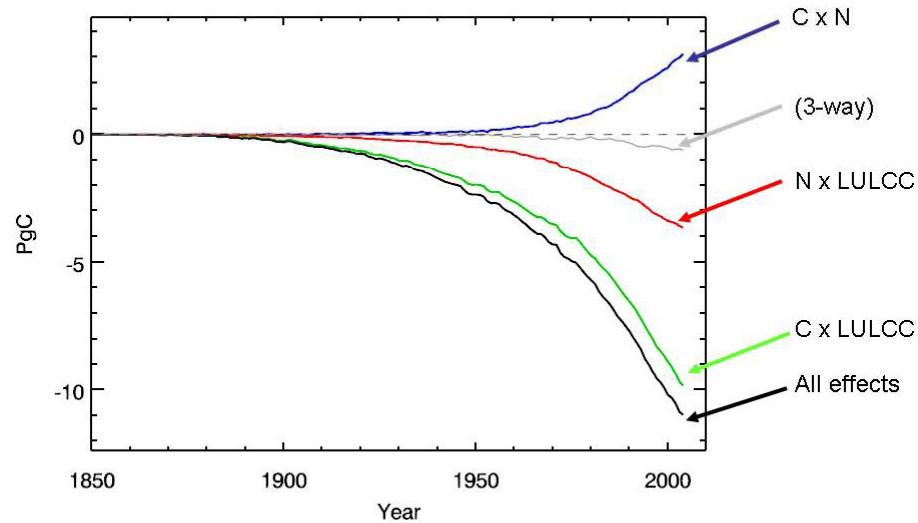
Computational aspects

- Fully coupled CESM1
- ~1 degree FV grid, 1850-2100 (250 yrs)
- 12 sim years/day on ~3000 Jaguar processors
- 12 single-factor (and multi-factor) experiments *per future scenario*
- Could be an important part of prediction uncertainty quantification, through single-factor error propagation

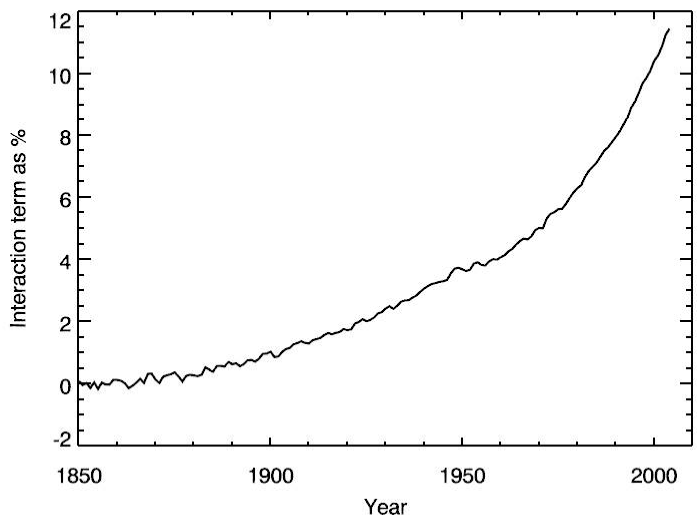
Human perturbations of land carbon flux (1850-present)



Interaction effects of C, N, and land use (1850-present)



Interaction term as percent of human-induced change in land carbon (1850-present)



Simulation results suggest:

- C – N interactions have already played a significant role (>10%) in the total response of land carbon stocks to anthropogenic forcing.
- The magnitude of the interaction effect is expected to increase significantly in the coming decades