Status of fully-coupled CCSM3.1-BGC (T31) simulations:

P. Thornton, K. Lindsay, S. Doney, K. Moore, N. Mahowald, J. Randerson, I. Fung, J. Lee

- Summary of simulations performed and pending
- Analysis of constant landuse simulations
  - Feedback analysis (climate-carbon cycle gain)
  - Comparison to offline CLM-CN simulations
  - Evaluating nitrogen limitation hypothesis
- Preliminary results from transient landuse simulations
- Next steps

Fixed (pre-industrial) landcover experiments:

Radiative CO2: prognostic (Net CO_2)		Nitrogen deposition	
		Pre-ind	Hist+A2
Fossil fuel emissions	none	**m**	
	Hist+A2	**p**	**n**

1000-yr control (→ m)

“coupled” run (→ n)

Radiative CO2: fixed (287 ppmv)		Nitrogen deposition	
		Pre-ind	Hist+A2
Fossil fuel emissions	none		
	Hist+A2	**u**	**o**

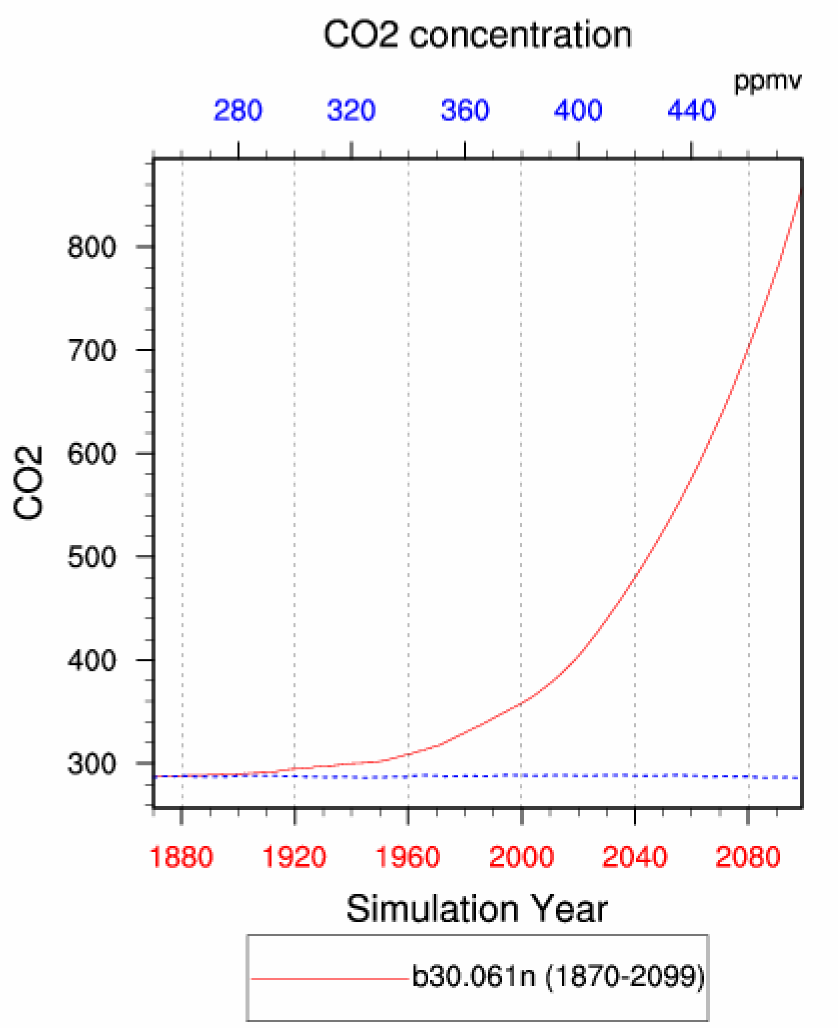
“uncoupled” run (→ o)

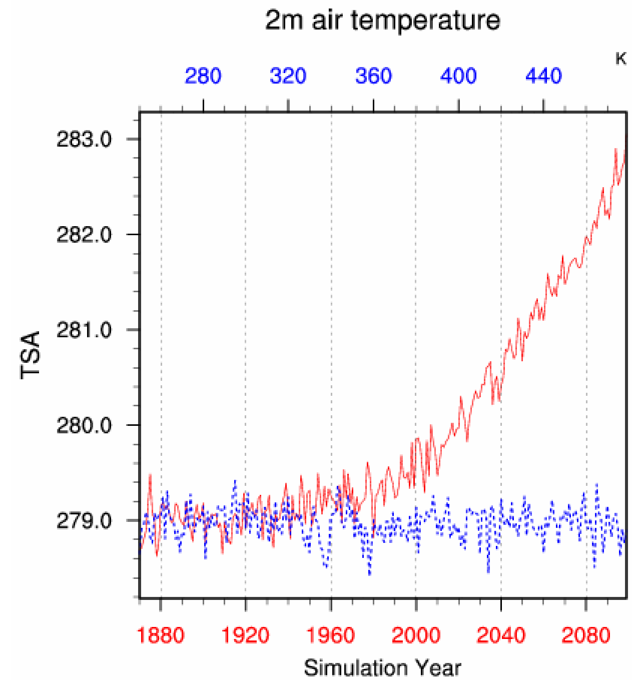
Transient landcover experiments:

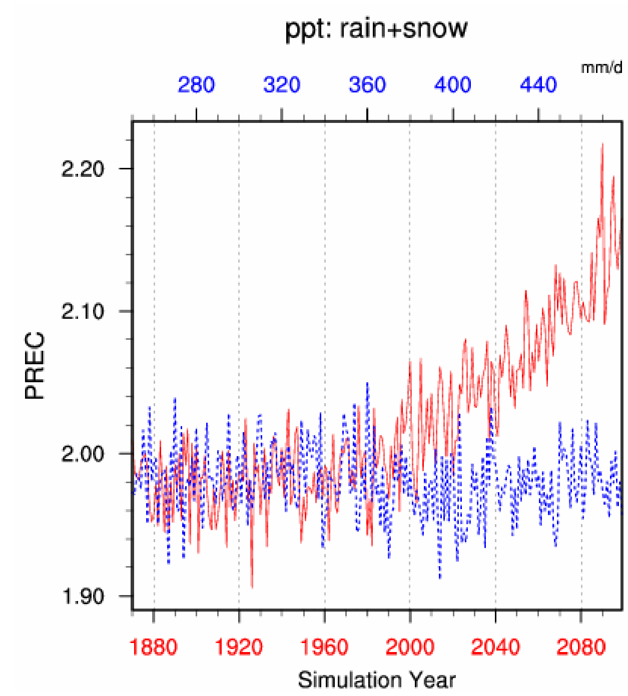
Radiative CO2: prognostic(Net CO_2)		Nitrogen deposition	
		Pre-ind	Hist+A2
Fossil fuel emissions	none		
	Hist+A2		**s**

Radiative CO2: fixed (287 ppmv)		Nitrogen deposition	
		Pre-ind	Hist+A2
Fossil fuel emissions	none	**v**	
	Hist+A2		**t**

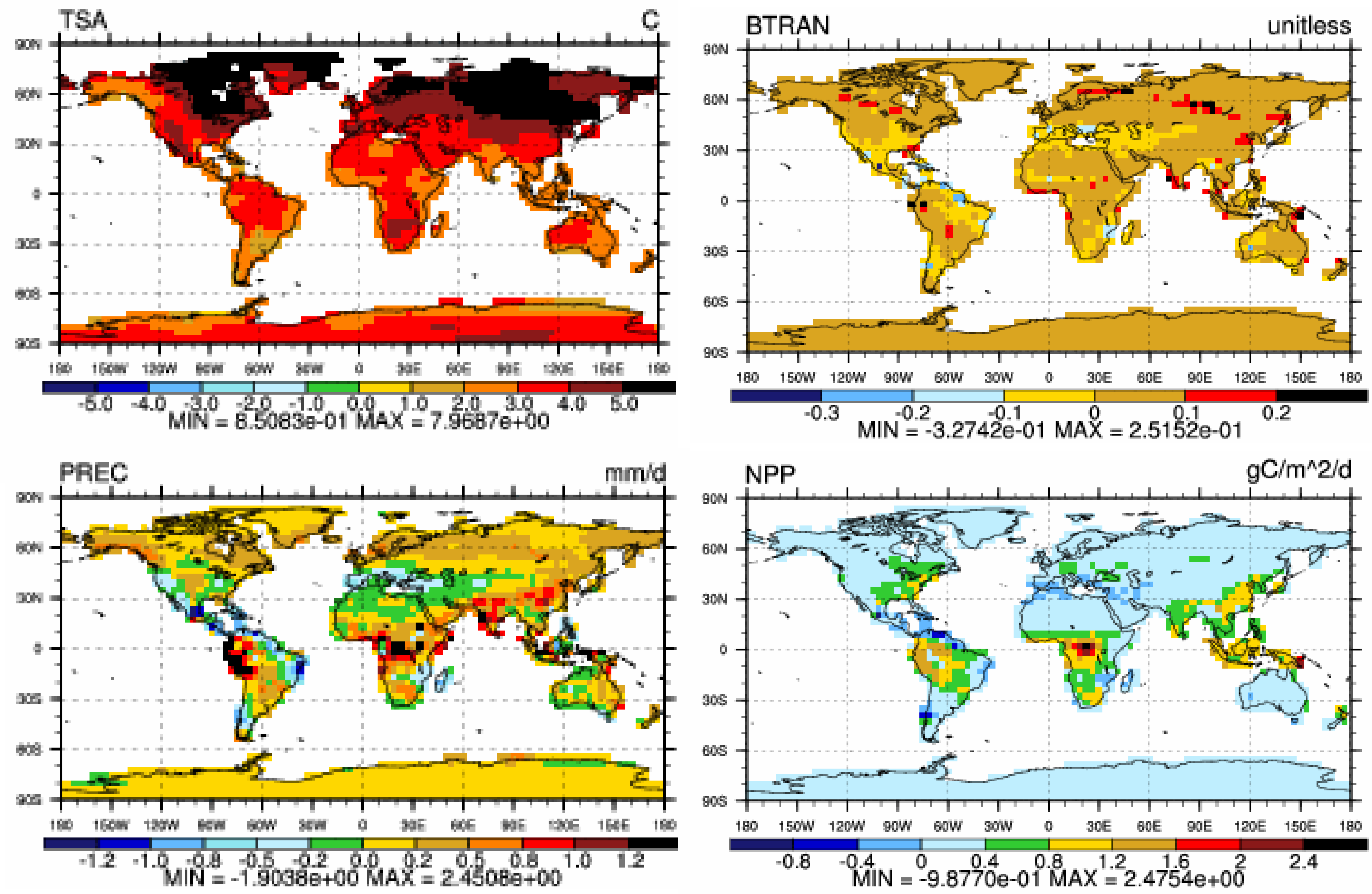
(b30.061n – control)







(b30.061n – control)



Climate-carbon cycle feedback analysis

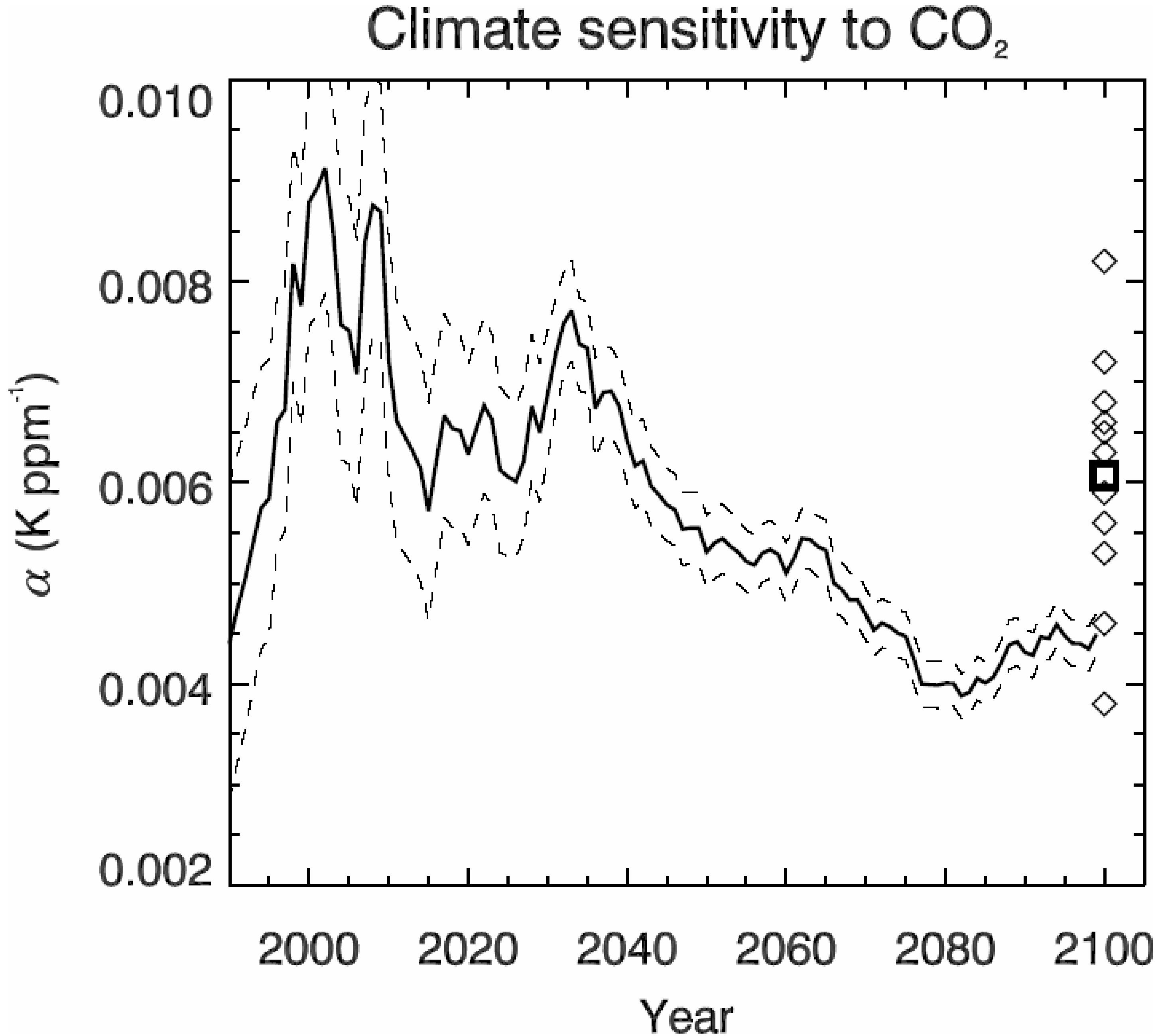
- Following Friedlingstein et al. 2006:

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

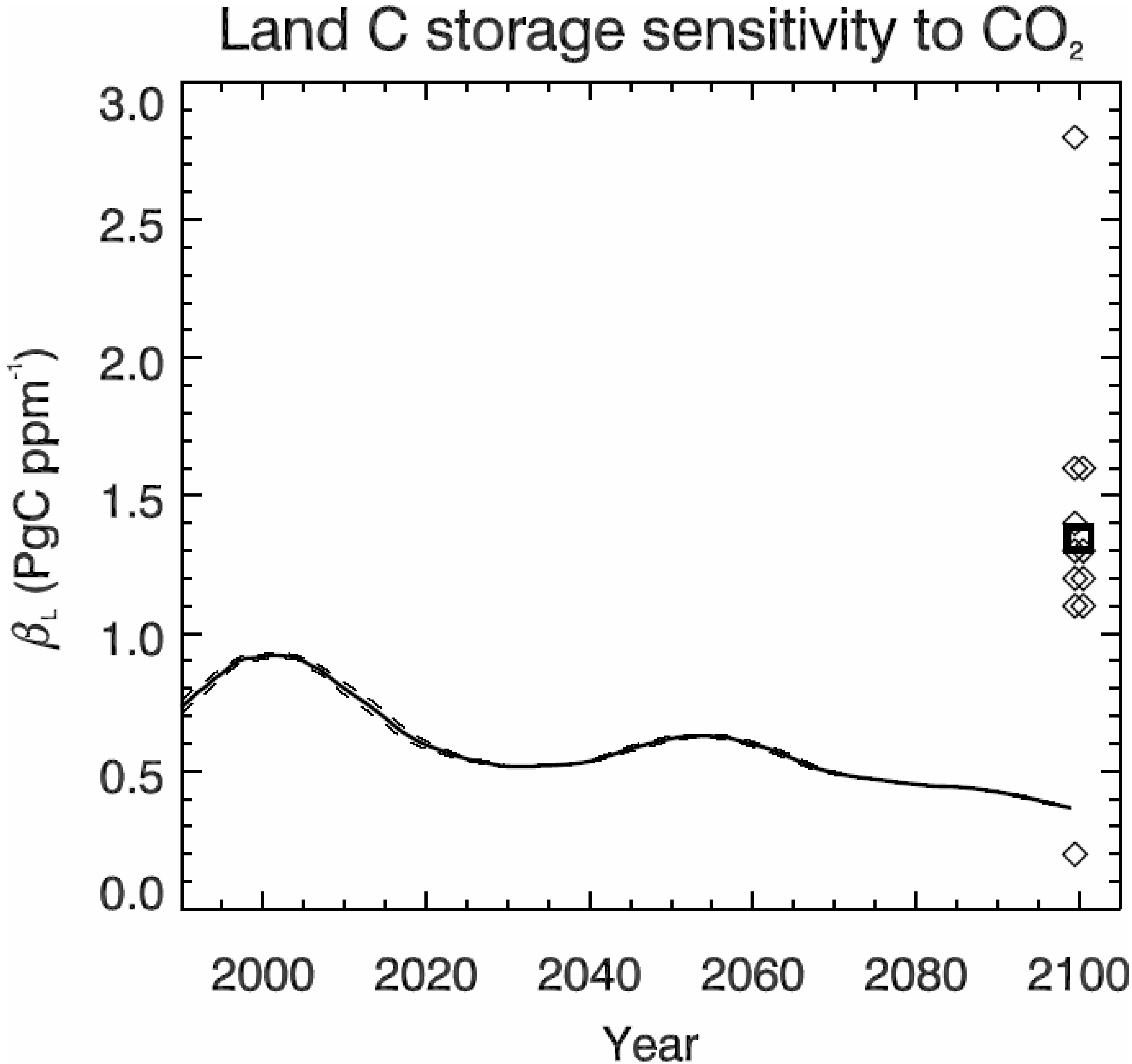
α = transient climate sensitivity to CO_2

β = (land or ocean) carbon storage sensitivity to CO_2

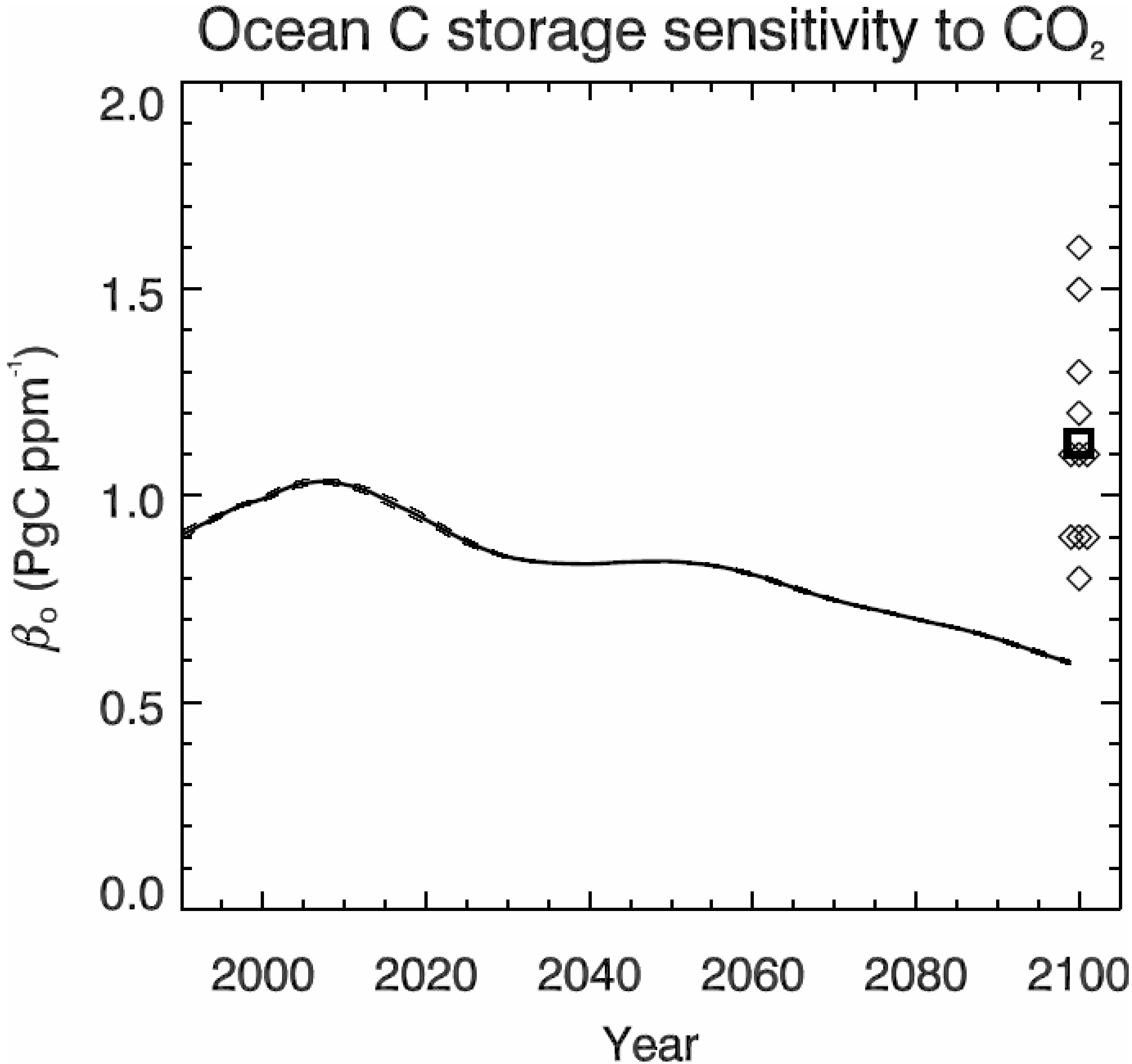
γ = (land or ocean) carbon storage sensitivity to climate



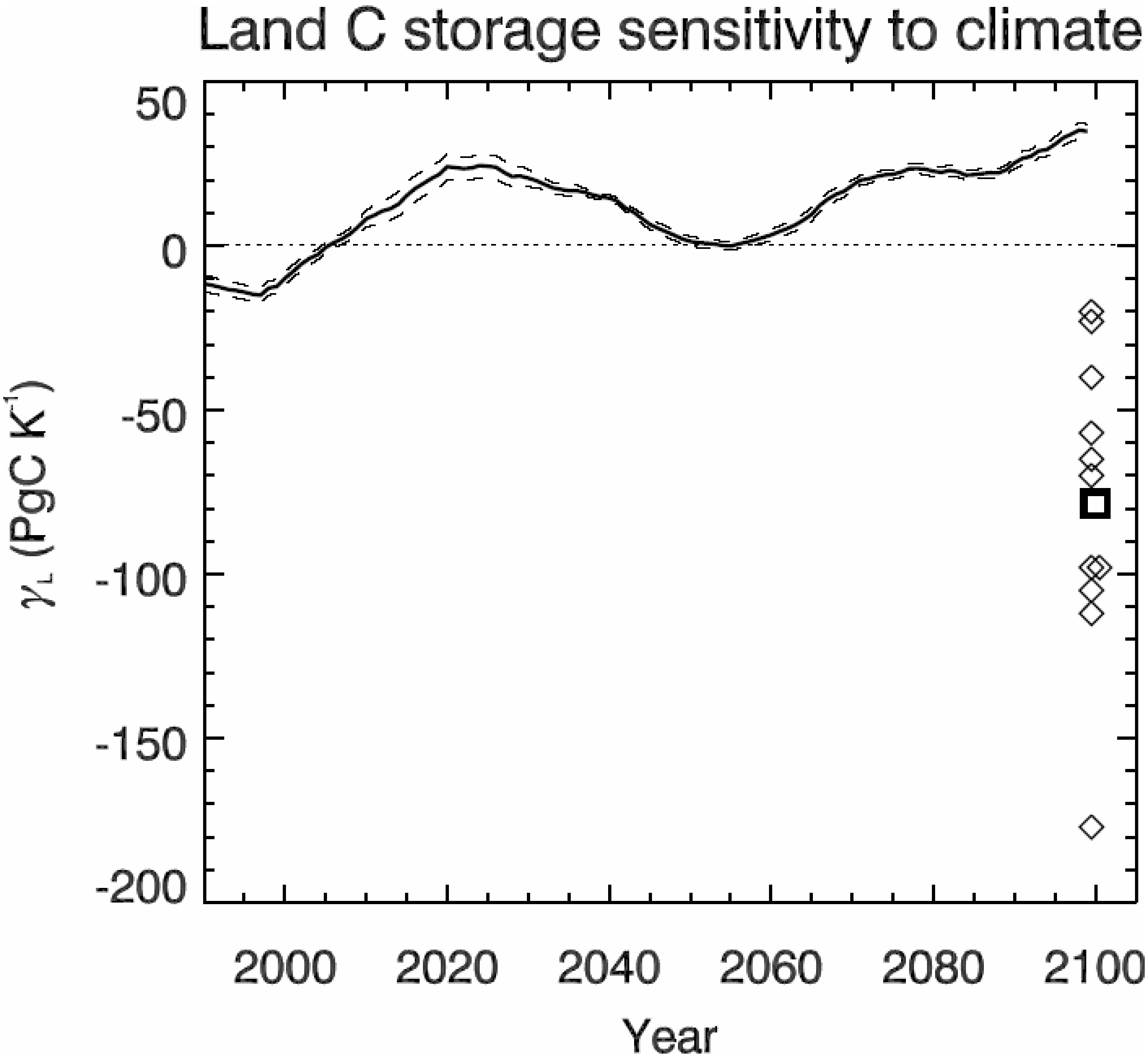
Climate sensitivity to CO_2
0.010
0.008
0.006
0.004
0.002
α (K ppm^{-1})
2000
2020
2040
2060
2080
2100
Year



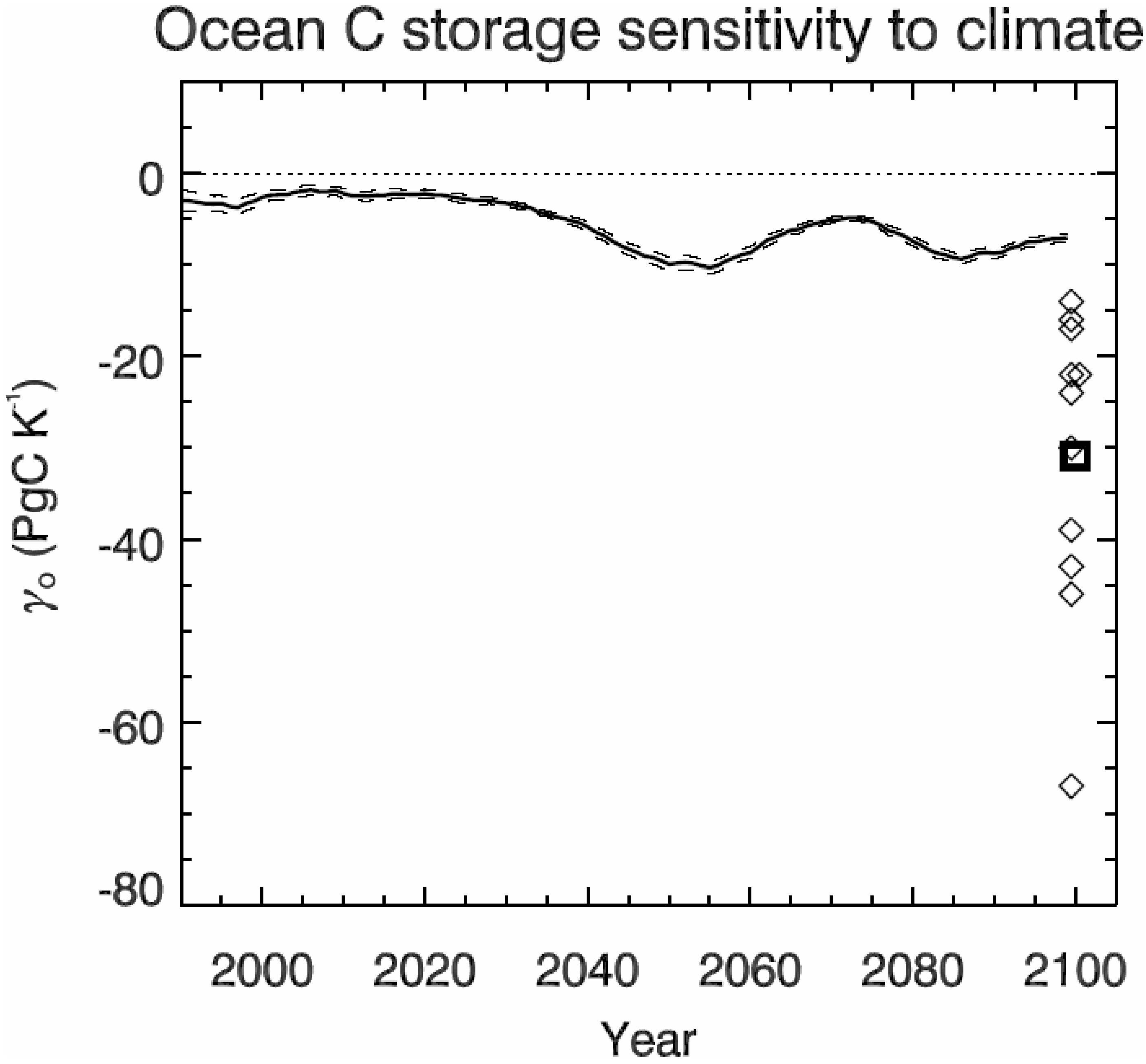
Land C storage sensitivity to CO_2
3.0
2.5
2.0
1.5
1.0
0.5
0.0
β_L (PgC ppm^{-1})
2000
2020
2040
2060
2080
2100
Year



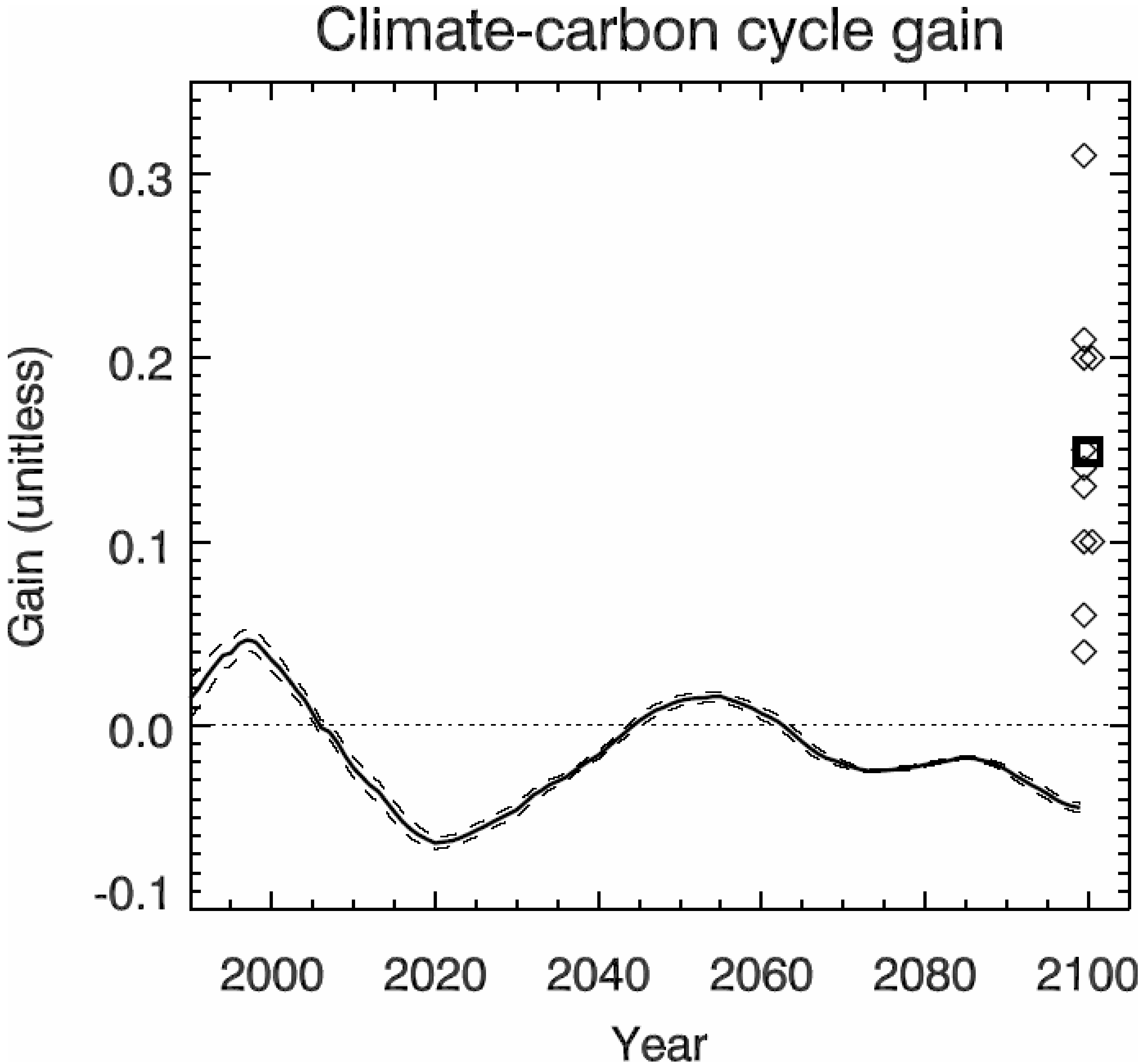
Ocean C storage sensitivity to CO_2
β_o (PgC ppm^{-1})
2.0
1.5
1.0
0.5
0.0
2000
2020
2040
2060
2080
2100
Year



Land C storage sensitivity to climate
50
0
-50
-100
-150
-200
γ_L (PgC K^{-1})
2000
2020
2040
2060
2080
2100
Year

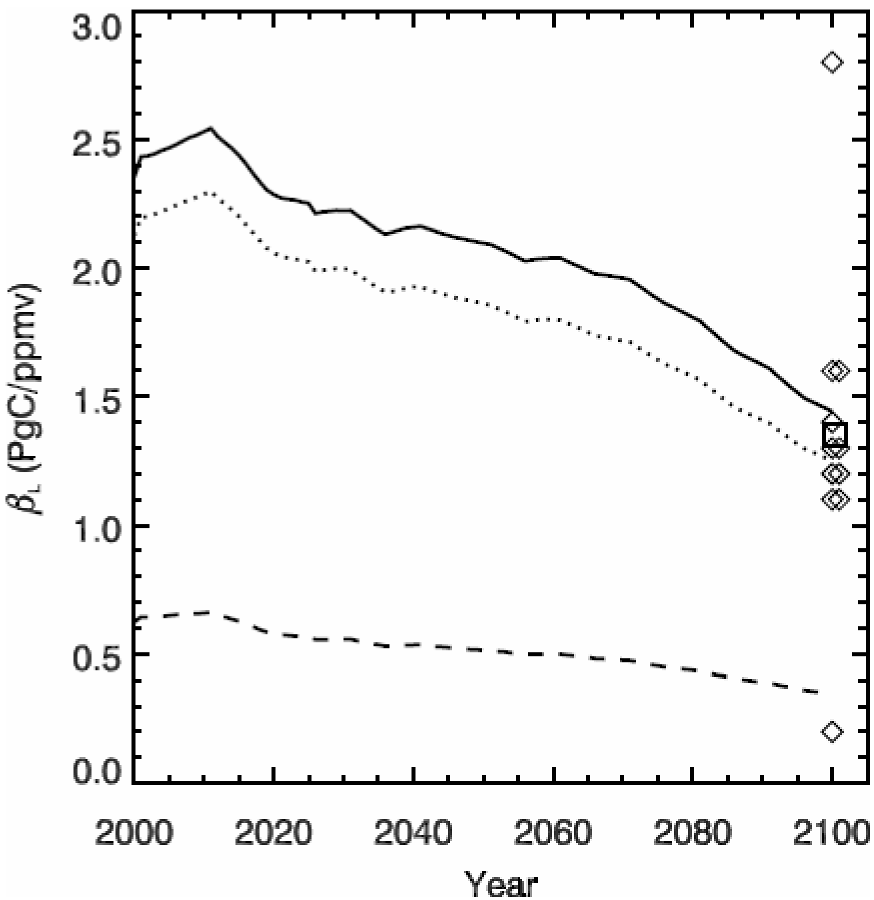


Ocean C storage sensitivity to climate
0
-20
-40
-60
-80
γ_O (PgC K^{-1})
2000
2020
2040
2060
2080
2100
Year


Climate-carbon cycle gain
Gain (unitless)
0.3
0.2
0.1
0.0
-0.1
2000
2020
2040
2060
2080
2100
Year

Land biosphere sensitivity to increasing atmospheric CO_2 (β_L)

Offline experiments



	Veg C (Pg C)	GPP (PgC/y)	β_L (2100)
CLM-C	1014	177	1.44
CLM-C2	771	146	1.25
CLM-CN	653	102	0.35

% change	Veg C	GPP	β_L
CLM-C2	-24%	-18%	-13%
CLM-CN	-35%	-42%	-76%
CN : C2	1.5	2.3	5.8

CLM-C
CLM-C2
CLM-CN (CO2)
C4MIP models
C4MIP mean

Thornton et al., GBC (in review)

Fertilization responses to CO_2 and mineral N deposition: offline experiments (period 2000 – 2100)

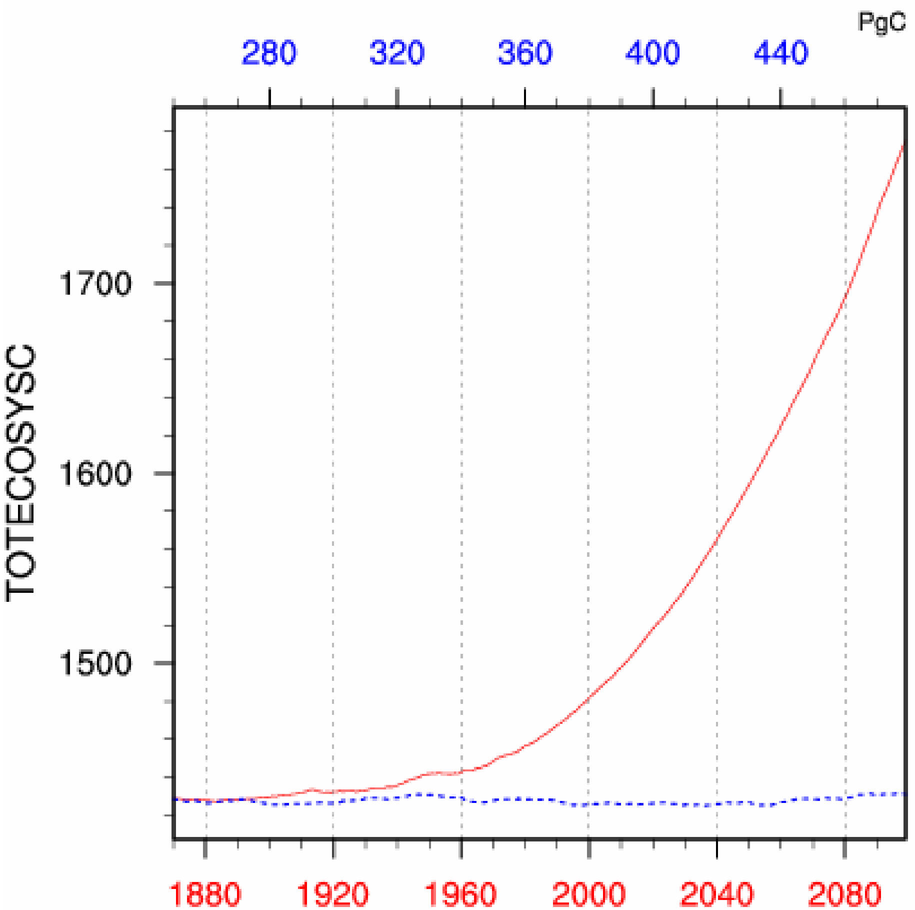
	ΔTot C (PgC)	% Veg C	% Lit C	% SOM C
C-N: CO_2	204	**79**	**13**	**8**
C-N: Ndep	50	**56**	**13**	**31**
C-only: CO_2	843	**66**	**14**	**20**
C-only(2): CO_2	740	**66**	**13**	**21**

- C-N gives qualitative match to observations from field experiments
- Changing the base state has negligible effect on partitioning of fertilization response
- Important because of order-of-magnitude differences in turnover times for vegetation and SOM pools, regionalization of sink permanence.

Thornton et al., GBC (in press)

Changes in land carbon stocks: 1870-2100

(b30.061n – control)

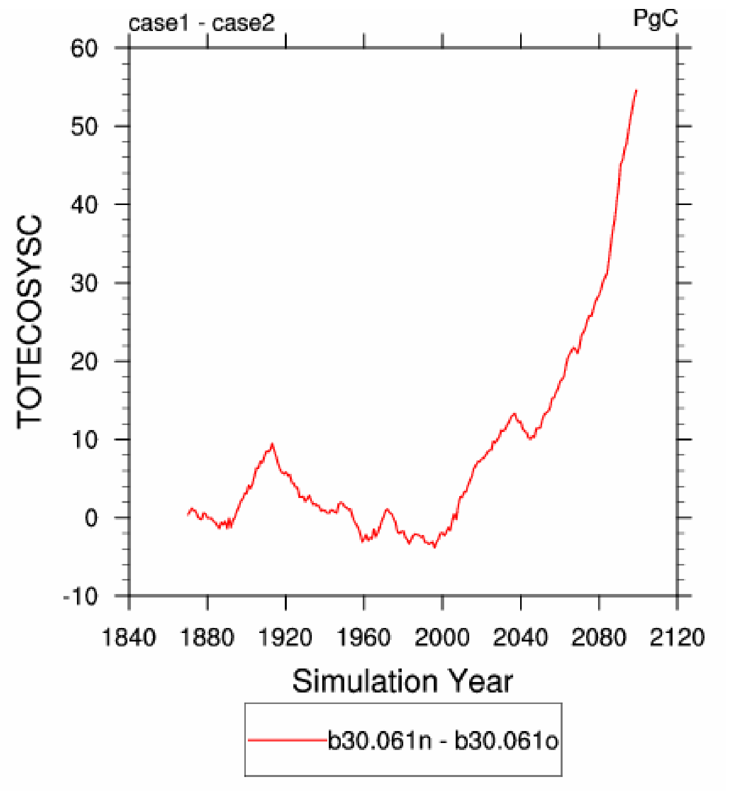


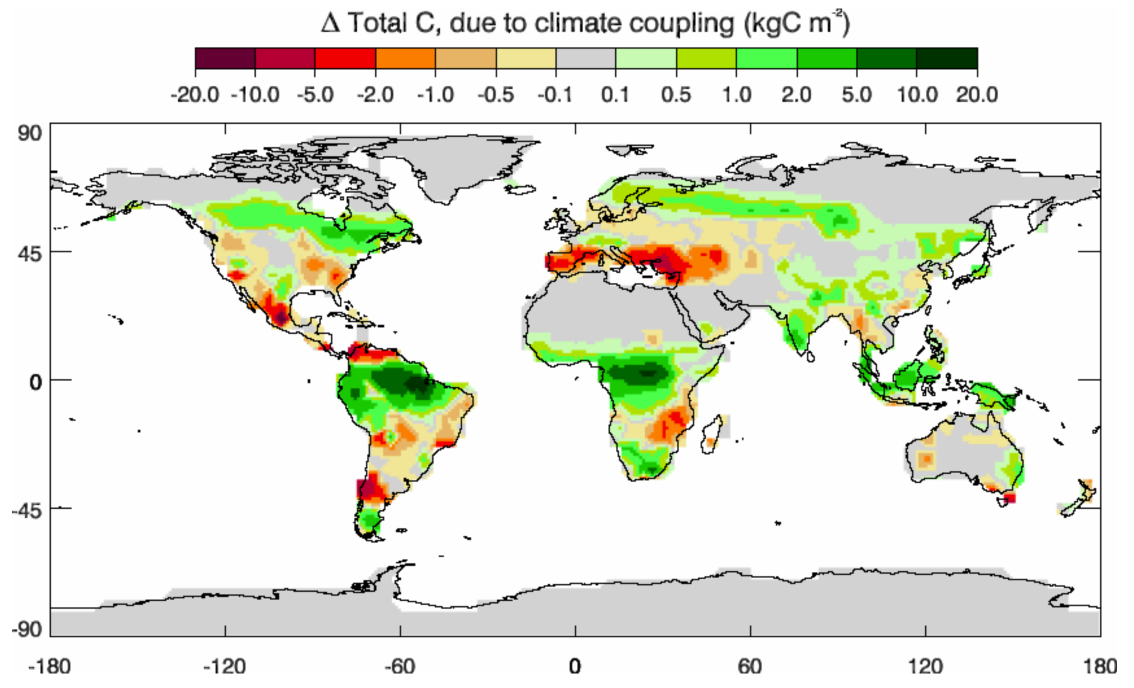
Pool	Change	
	PgC	% of total
Plant	300	89%
CWD	20	6%
Litter	1	<1%
Soil	17	5%
Total	**338**	(25%)

Climate-carbon cycle feedbacks

(b30.061n – b30.061o, or coupled - uncoupled)

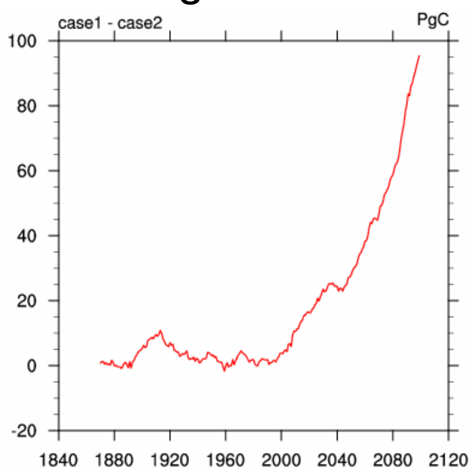
CO_2-induced climate change (global mean: warmer and wetter) leads to **increased** land carbon storage



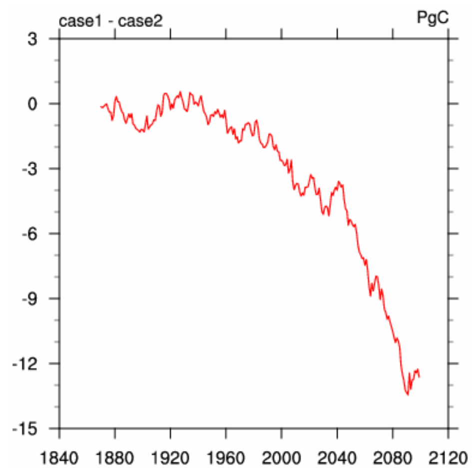


Climate-carbon cycle feedbacks

Vegetation C

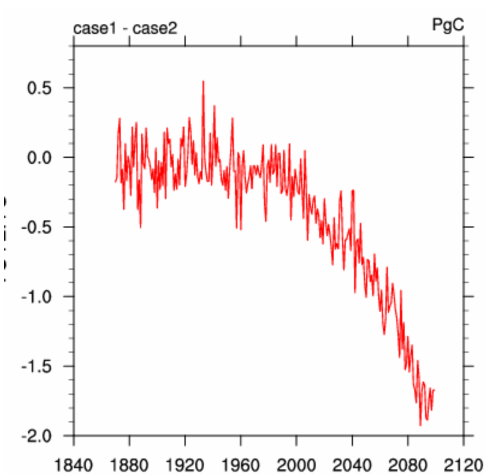


CWD C

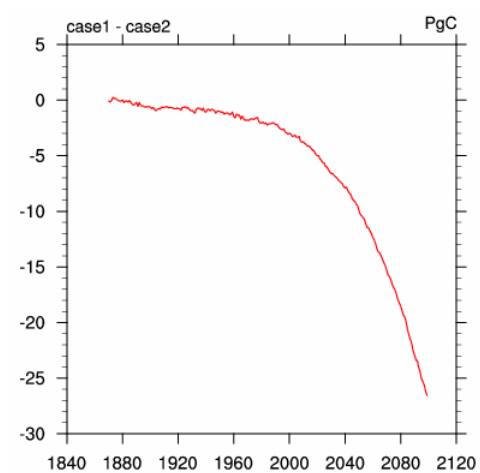


Hyp: Climate-carbon cycle feedback acts **in part** through change in nitrogen availability

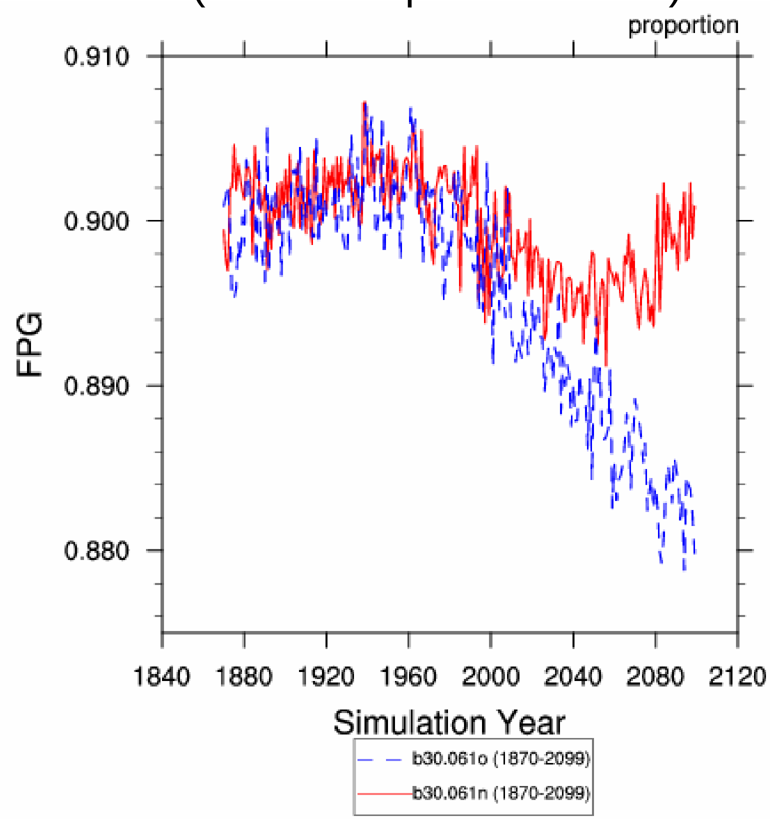
Litter C

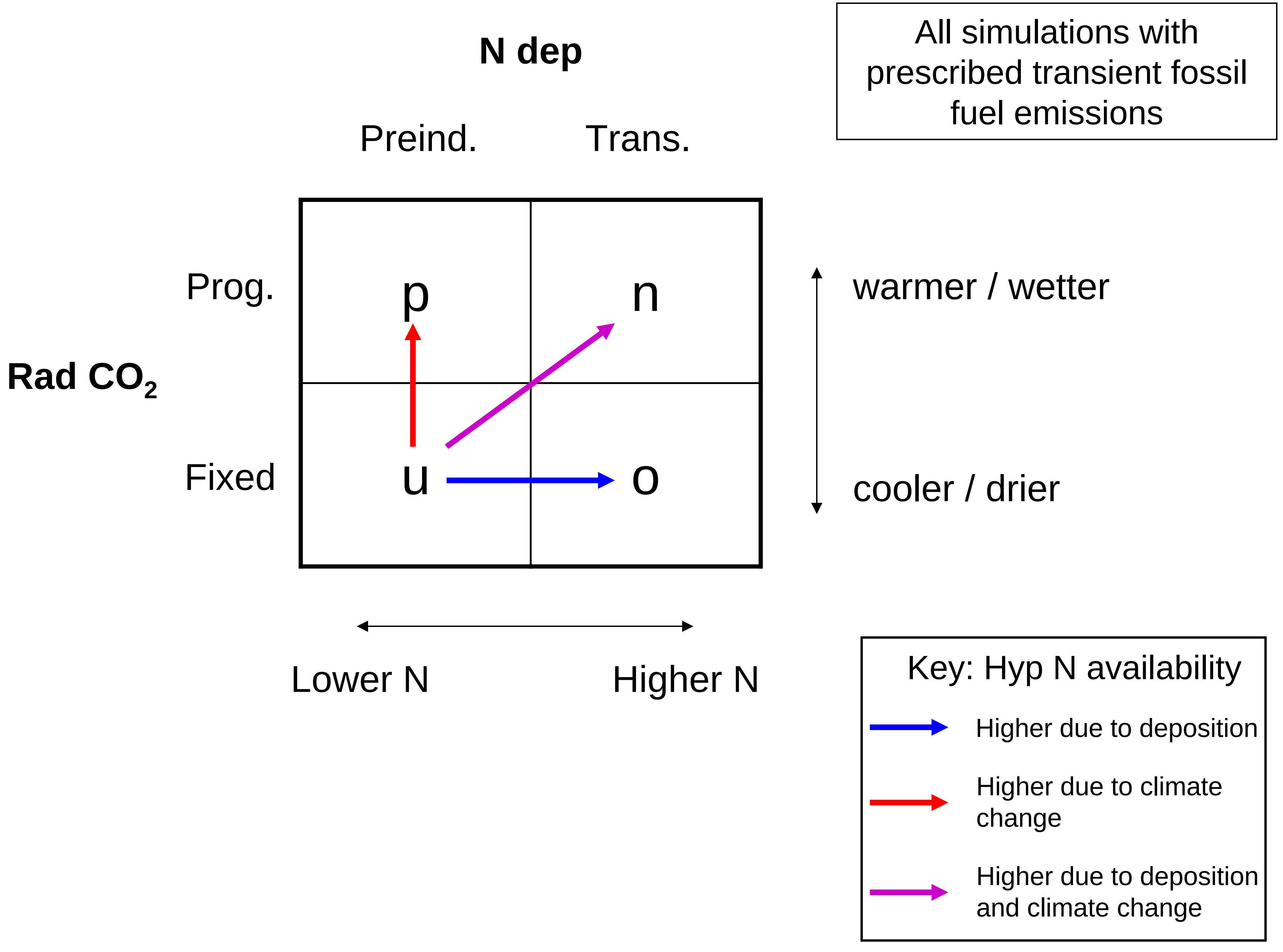


Soil C

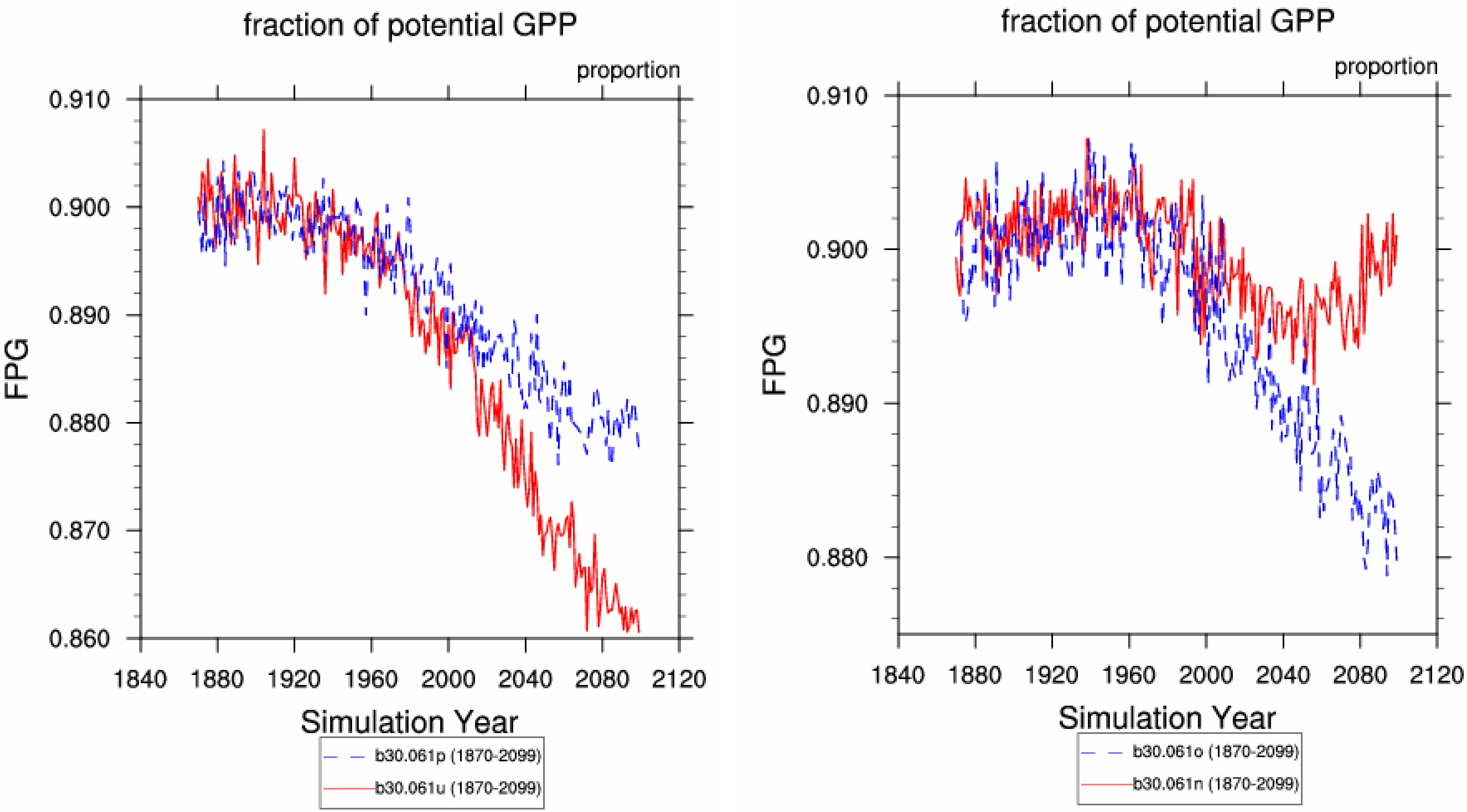


N availability index
(fraction of potential GPP)



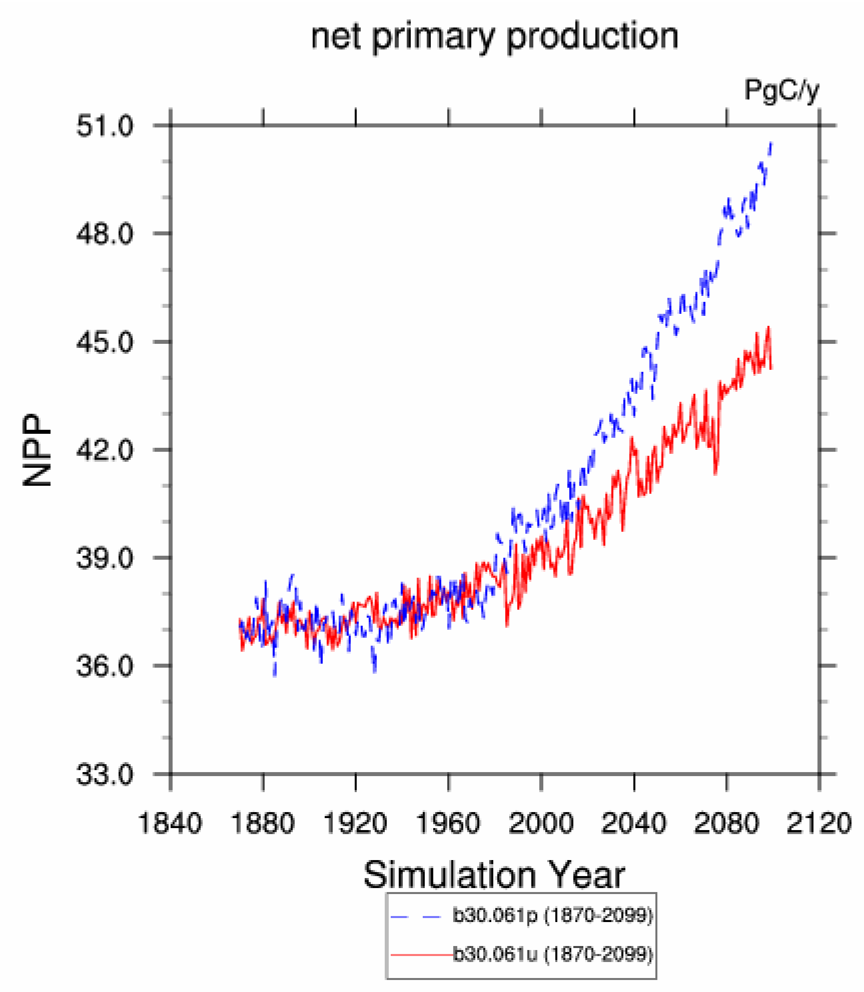


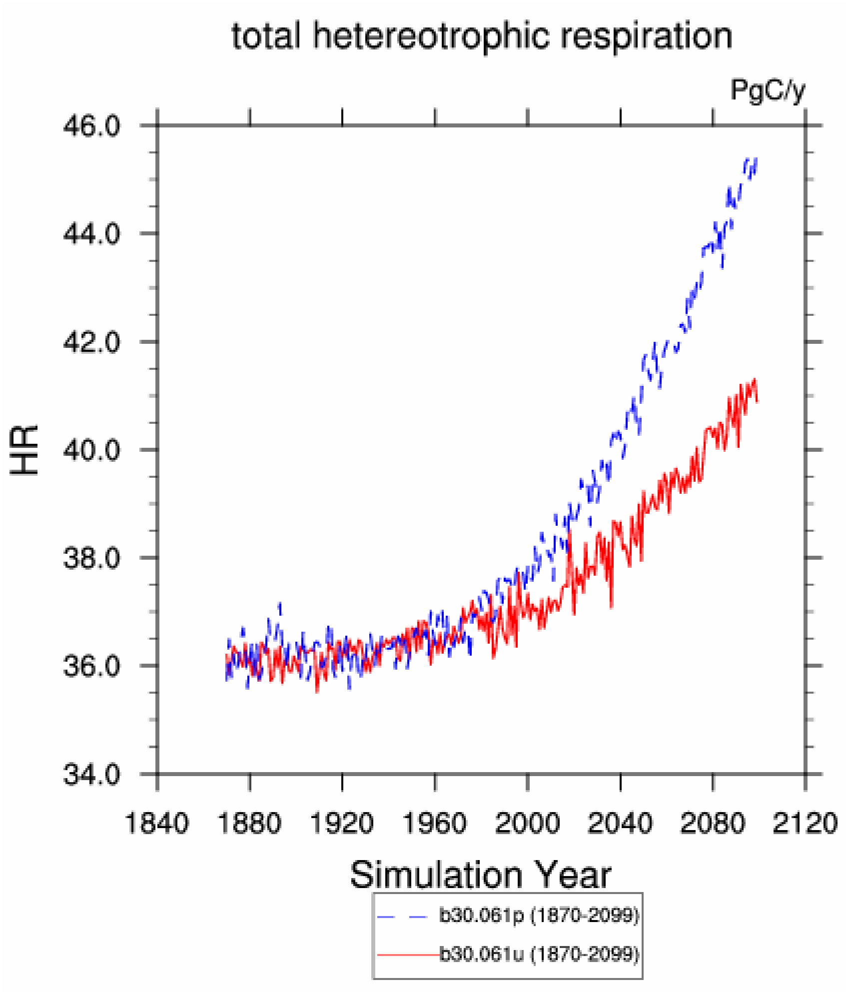
All simulations with prescribed transient fossil fuel emissions
N dep
Preind.
Trans.
Prog.
Fixed
Rad CO_2
p
n
u
o
warmer / wetter
cooler / drier
Lower N
Higher N
Key: Hyp N availability
Higher due to deposition
Higher due to climate change
Higher due to deposition and climate change



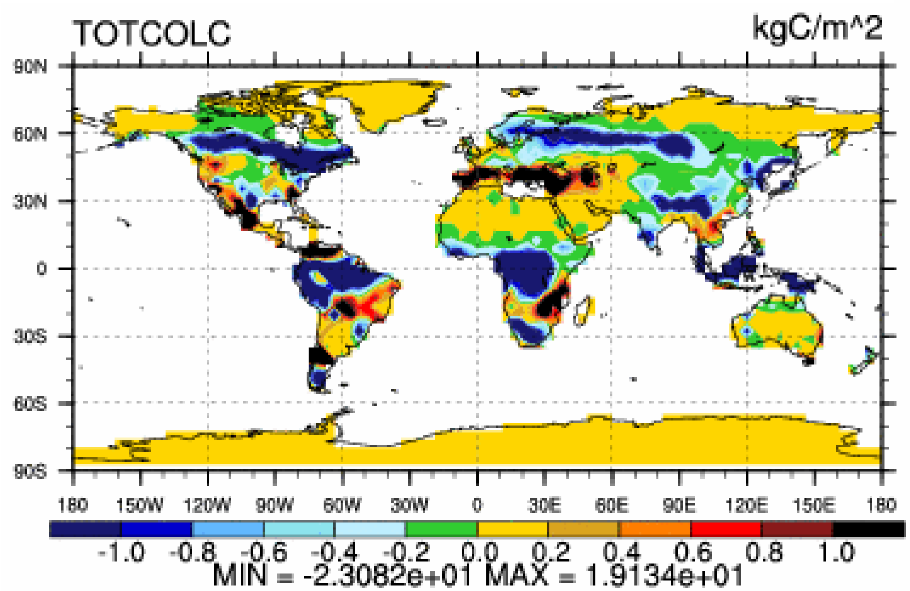
- N availability is lowest for case u: supports progressive N limitation hypothesis
- N availability increases between u and o: expected from increased N deposition
- N availability increases between u and p: climate change effect only
- Similar magnitudes in increased N availability between p and o
- N deposition and climate change effects are approximately linearly additive

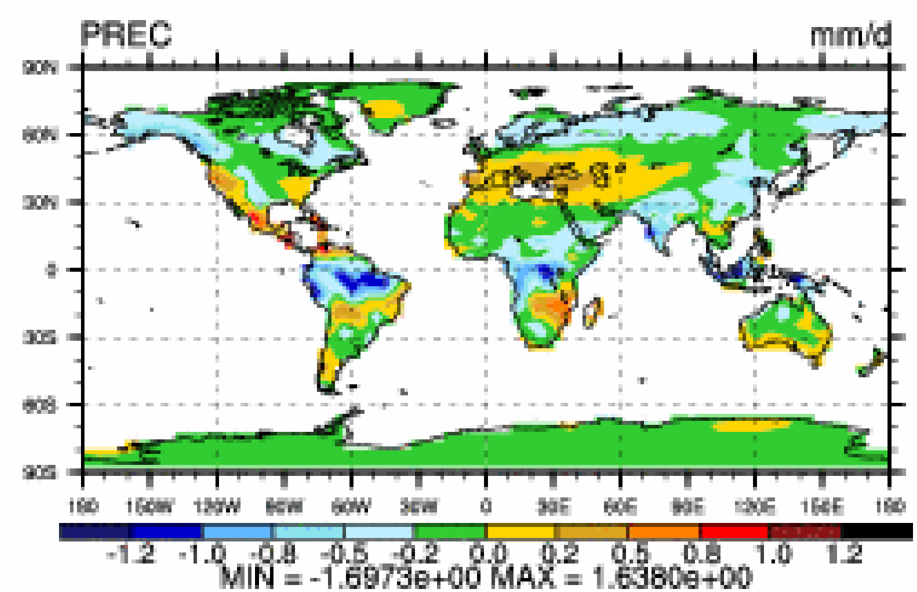
Climate change effects on NPP and heterotrophic respiration

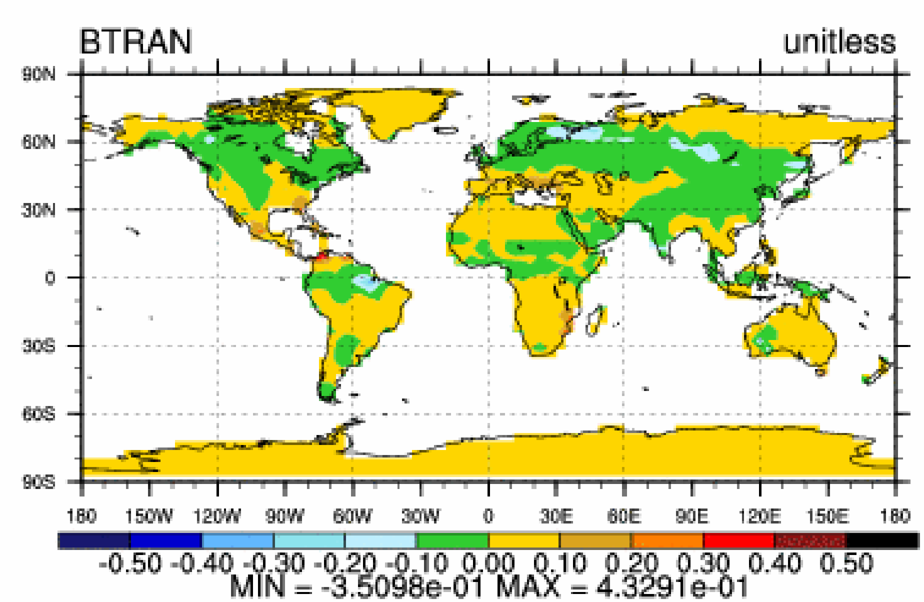


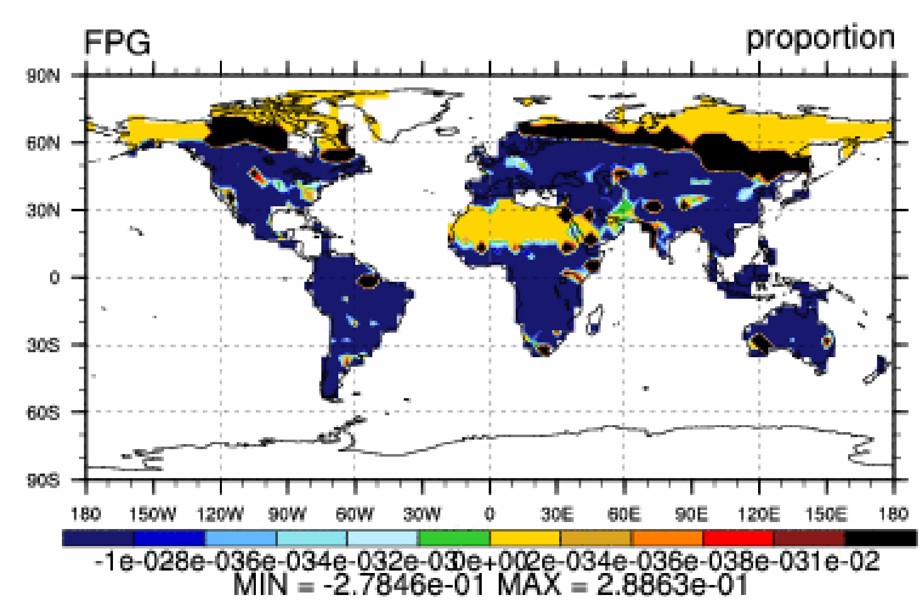


Climate change effects on total land carbon

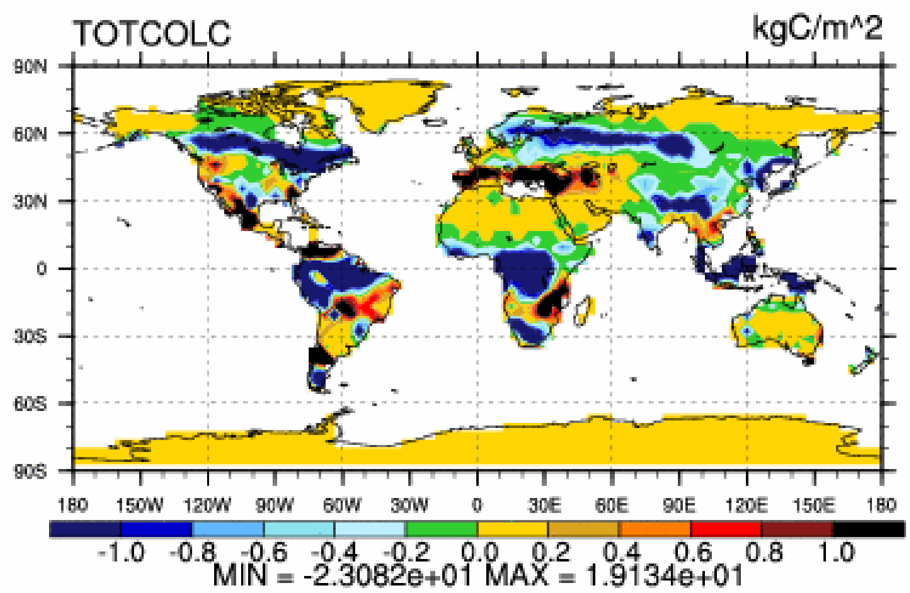


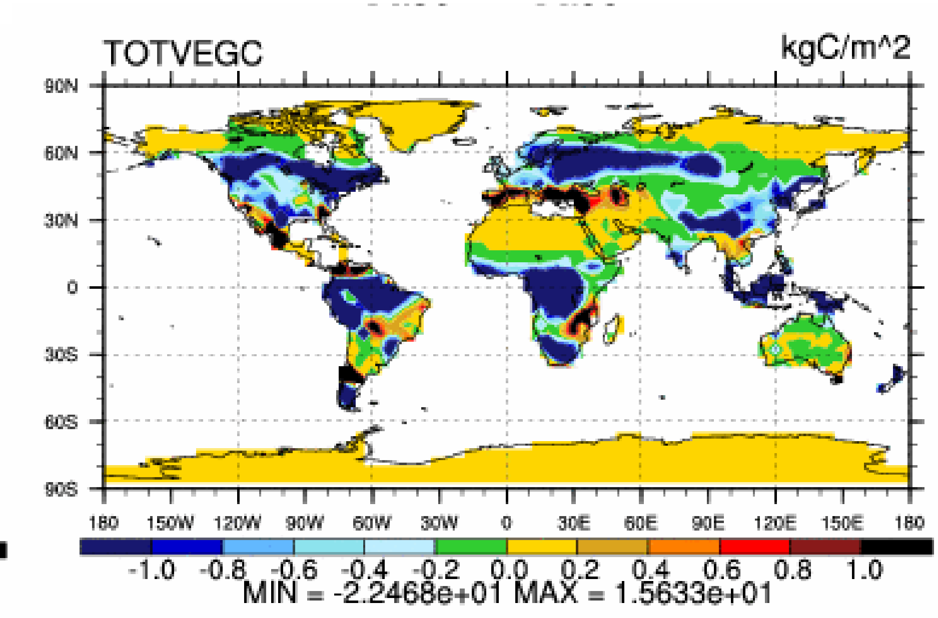


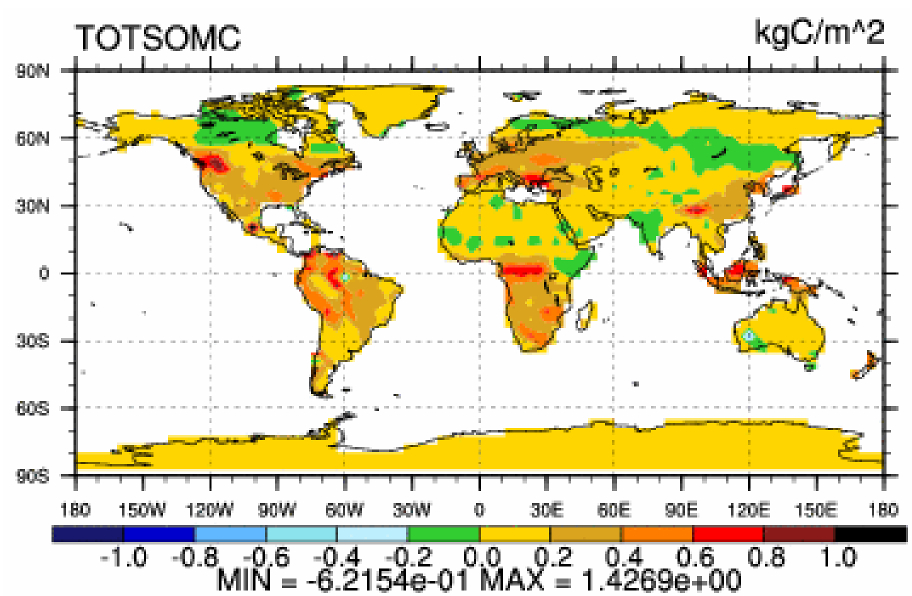


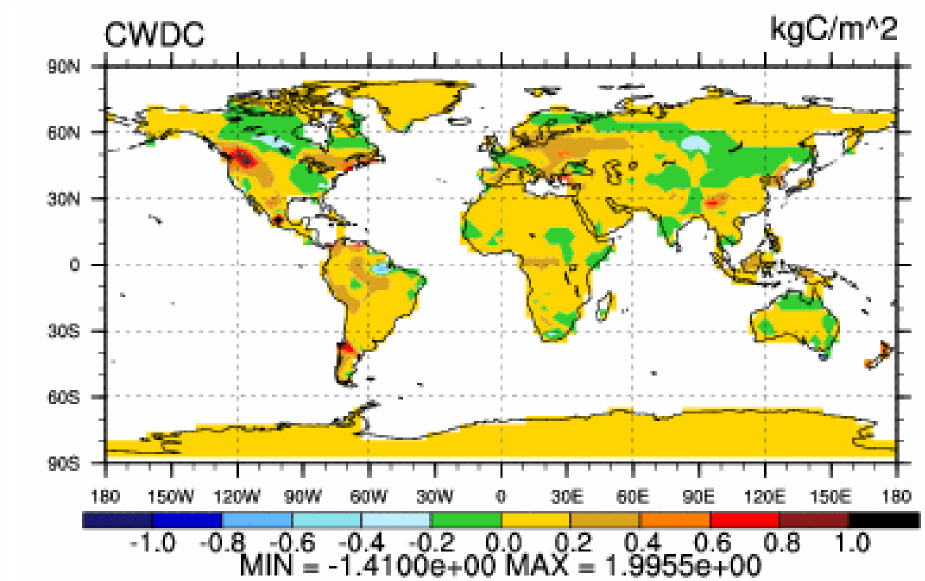


Climate change effects on land carbon component pools









Climate-carbon cycle feedbacks

Fractions of 1870-2100 anthropogenic emissions in land, ocean, and atmosphere pools

	CCSM3.1-BGC		C4MIP mean	
	uncoupled	coupled	uncoupled	coupled
Land-borne fraction	0.15	0.18	0.29	0.21
Ocean-borne fraction	0.22	0.21	0.25	0.25
Airborne fraction	0.63	0.61	0.46	0.54

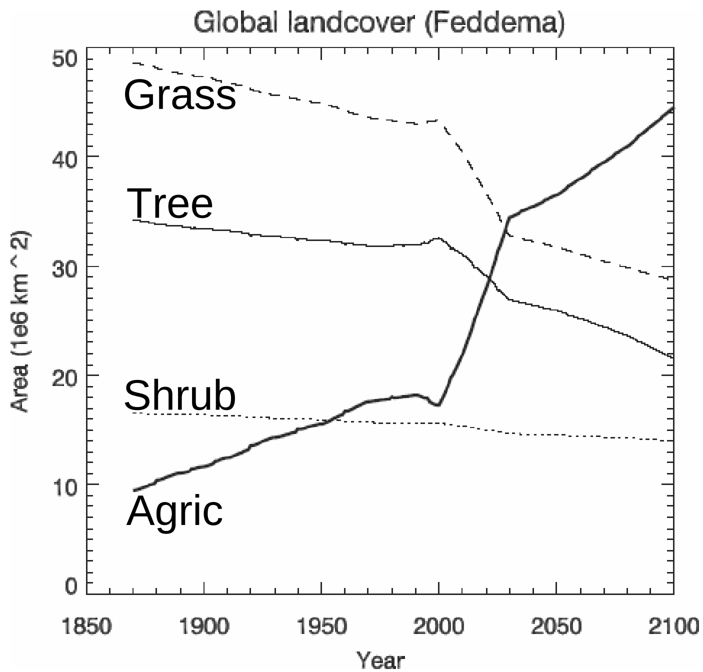
Conclusions (constant landuse expts)

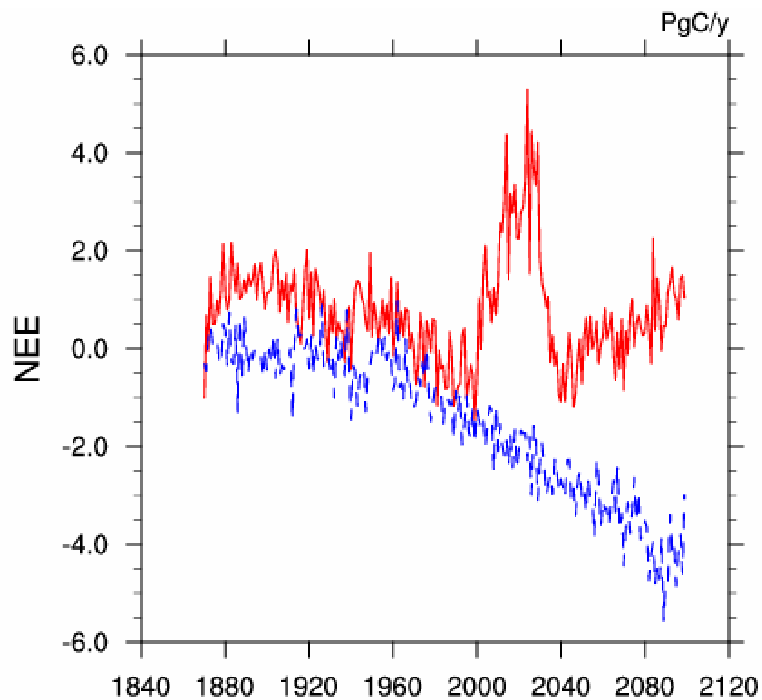
- CO_2 fertilization of land carbon storage is strongly reduced by introduction of C-N coupling.
- Negative climate-carbon cycle feedback:
  - results in broad agreement with progressive N limitation hypothesis
  - opposite sign to all previous C-only coupled model feedback
- Recommendations:
  - C-only coupled simulation
  - Test C-N coupling in other models

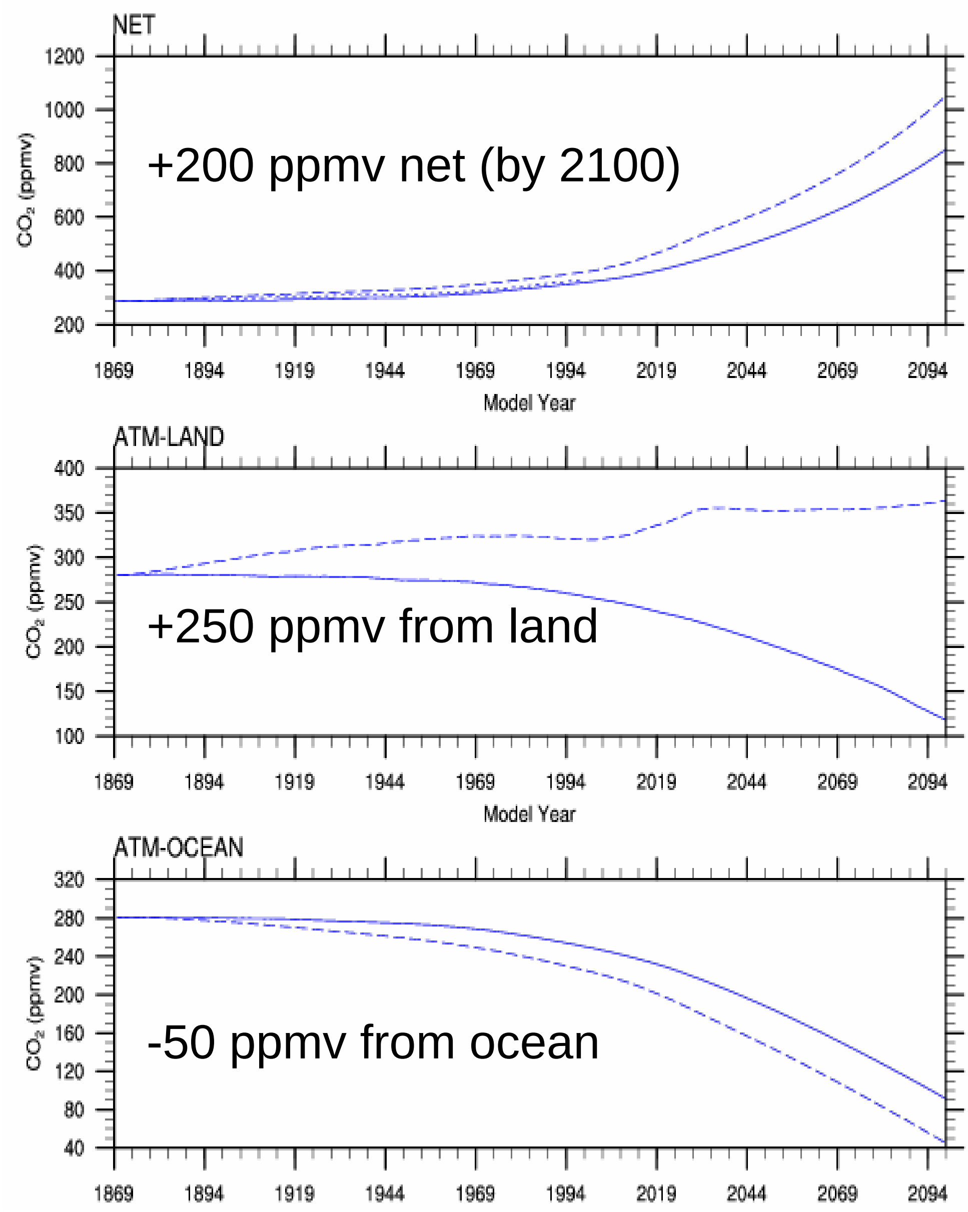
Fully-coupled simulations with prescribed landcover changes (prognostic fluxes)

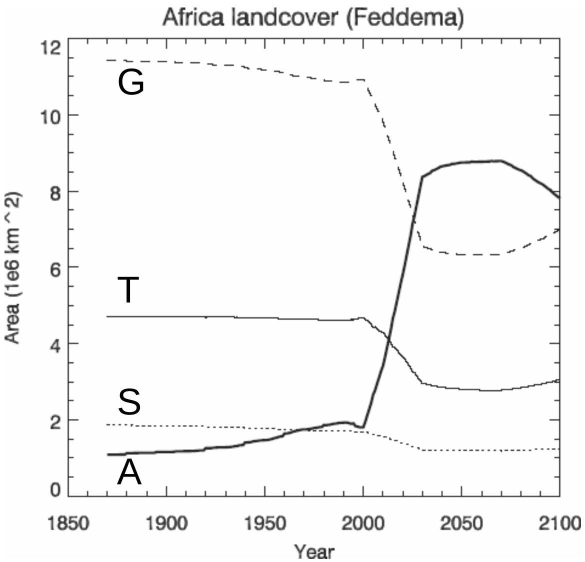
- Using subset of data from Johannes Feddema
  - Annual time slices from 1870-2100, originally on half-degree grid.
  - Historical data from Ramankutty and Foley (1999), Goldewijk (2001), integration with present-day MODIS landcover.
  - Landcover change for 2000-2100 based on SRES A2 scenario.
- New prognostic component in CLM-CN to handle carbon and nitrogen fluxes and mass balance associated with landcover change.
  - Conversions to/from all plant functional types.
  - Tracking two wood product pools in each land gridcell (10-yr and 100-yr turnover times).
- Fossil-fuel emissions, N deposition, radiatively coupled

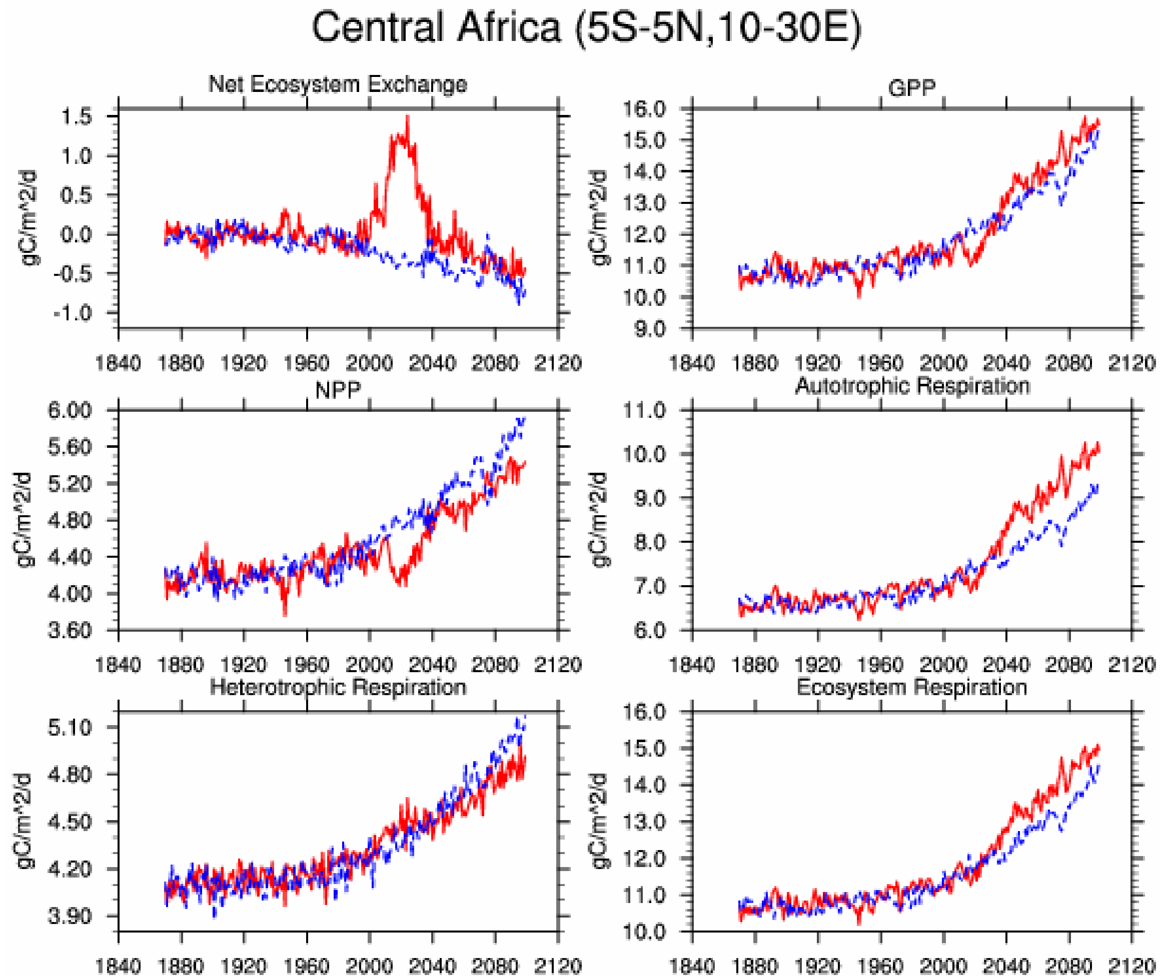
Influence of landcover change on land carbon flux and global pools











- GPP falls and then recovers during landcover transition
- Plant respiration increases, due to replacement of woody with herbaceous biomass
- NPP falls and remains lower (GPP is offset by plant respiration)
- Soil respiration rises in response to conversion fluxes, then falls in response to reduced NPP