

Nutrient limitation on global land carbon uptake

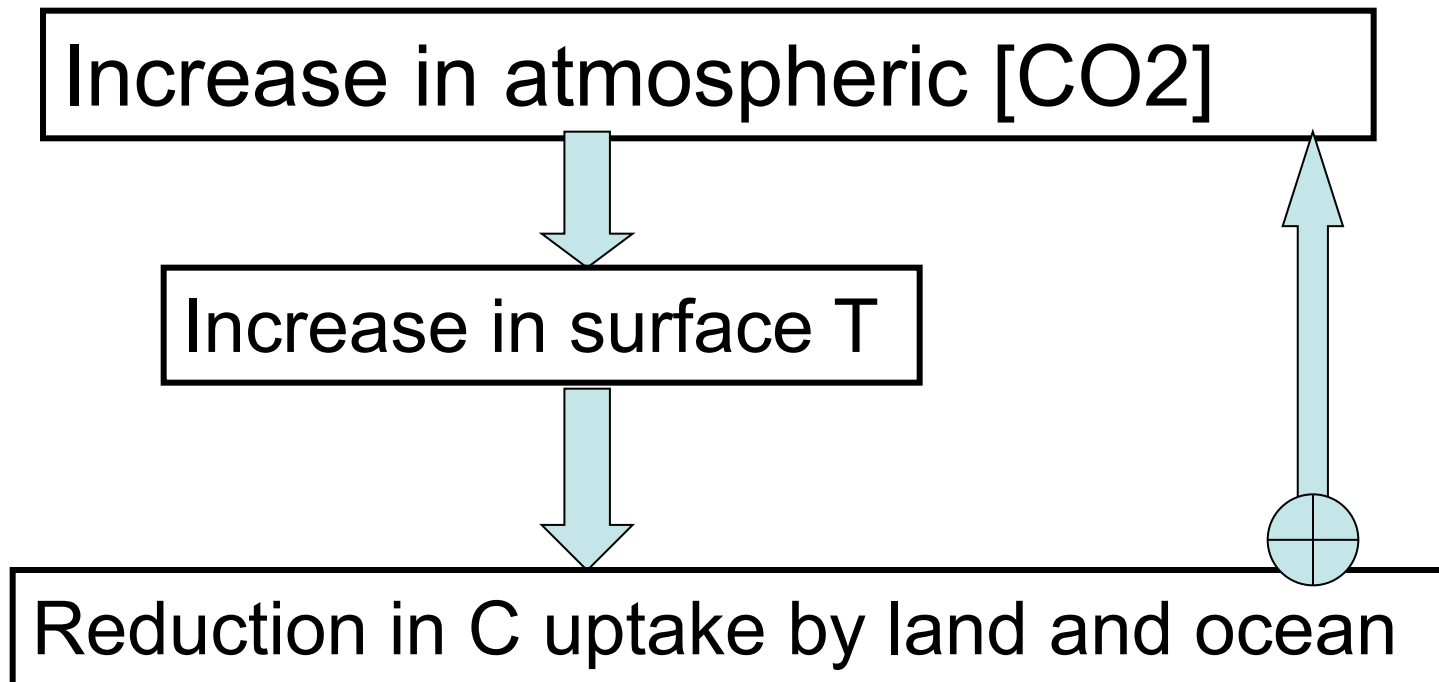
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Outline

- Why is nutrient limitation important?
- CABLE and global nutrient limitation
- An earth system model: COAL
 - Nutrient limitation on allowable CO₂ emission
 - Nutrient limitation on CO₂ emission/uptake from deforestation/reforestation
- Summary

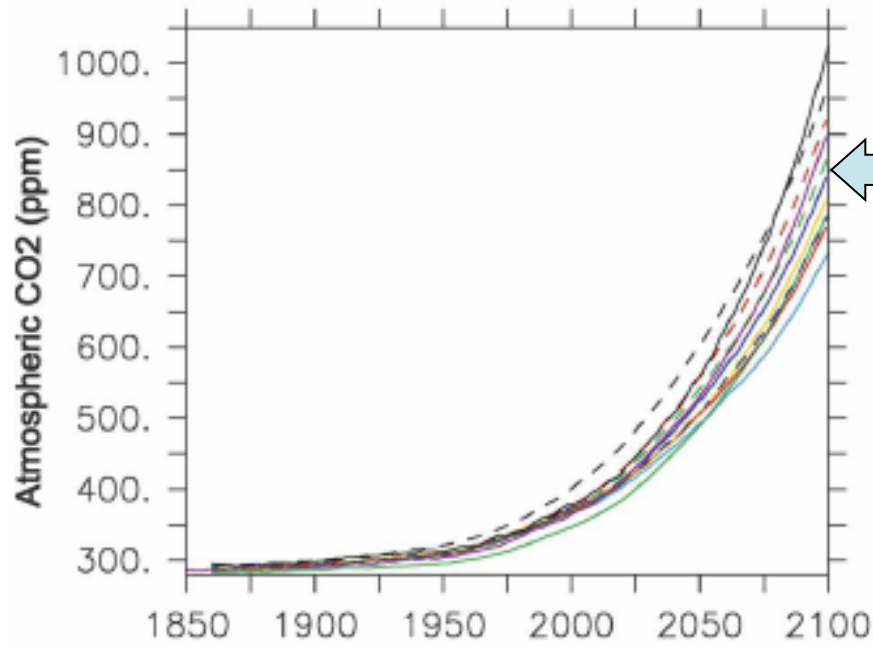
What is carbon-climate feedback?



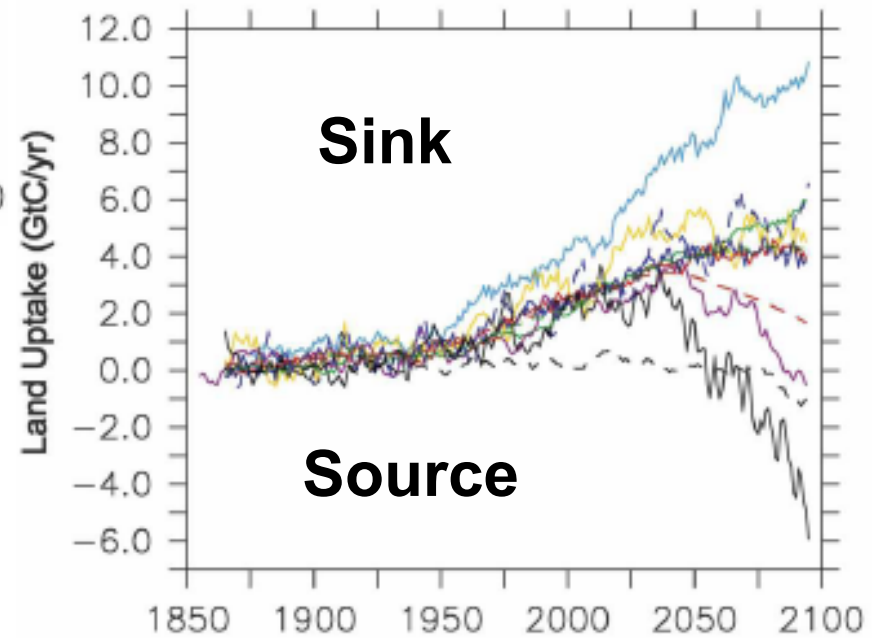
Carbon-climate feedback: C4MIP phase II simulations

- 11 models are used (see Friedlingstein et al. 2006);
- Key findings:
 - carbon-climate feedback is positive and highly uncertain;
 - an additional warming of 0.1K to 1.5K by 2100 (additional to a warming 2 to 4K without CC feedback).
- But none of those models include nutrient limitations

Coupled carbon-climate simulations



Differ by 292 ppm



The question

- Carbon cycle is closely coupled to nitrogen cycle in terrestrial ecosystems;
- None of those 11 models include nutrient limitation on land carbon uptake;
- Is there enough N available to sustain the predicted C accumulation by all 11 models by 2100?

Nitrogen input to uncultivated land

- N deposition (Dentener 2006), only 7% to 17% available for storing C (schlesinger 2009)
 - 0.01 Gt N/year in 1860
 - 0.058 Gt N/year in 1993
 - 0.122 Gt N/year in 2050
- N fixation (Wang and Houlton 2009)
 - About 0.15 Gt N/year at present, may increase to 0.22 by 2100

Response of N fixation

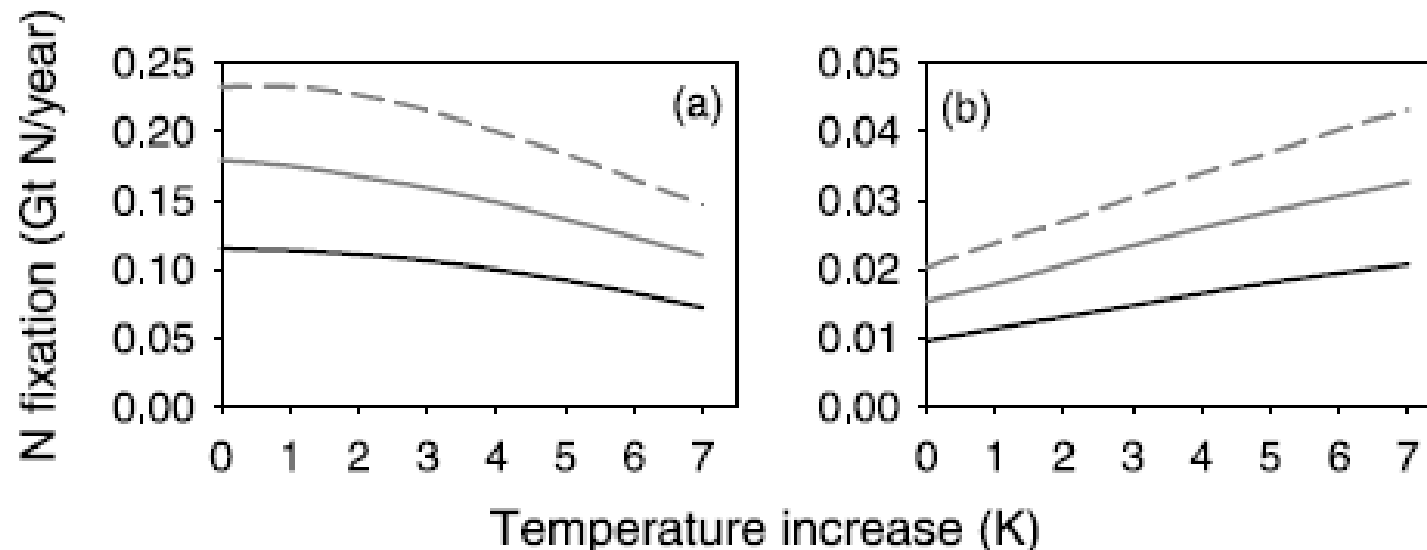


Figure 2. Modelled response of symbiotic N fixation to temperature increase and atmospheric [CO₂]. Results for (a) region 1 and (b) region 2 are shown for [CO₂] of 290 ppm (solid black line), 550 ppm (solid grey line) and 1000 ppm (dashed grey line).

Source: Wang and Houlton 2009

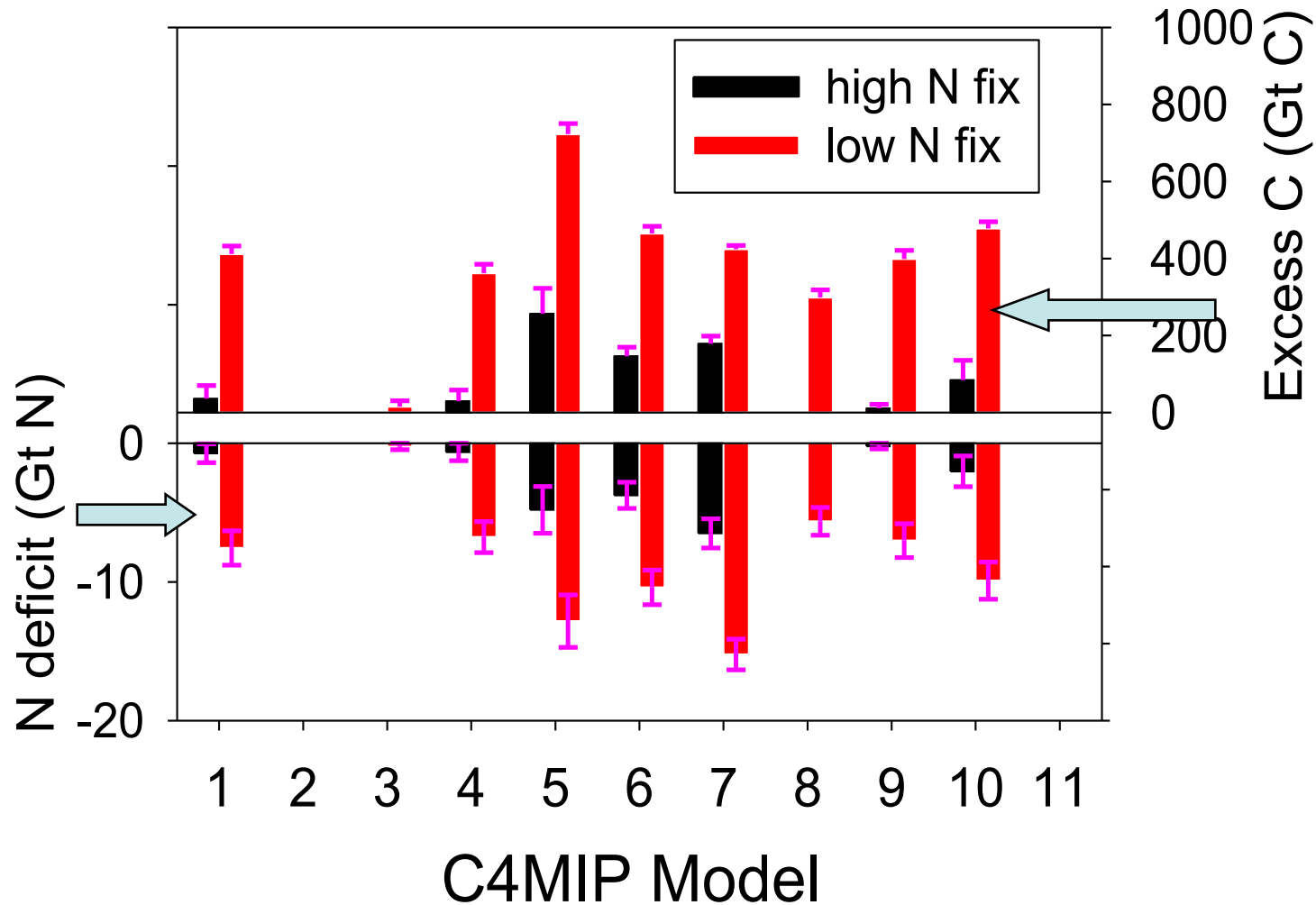
The N required by 2100

- Depends on
 - How much C is stored (13 to 844 Gt C)
 - where C is stored
 - N:C ratio of different pools
- The amount of N required varies from 0 to 17.1 Gt N by 2100 for 11 models

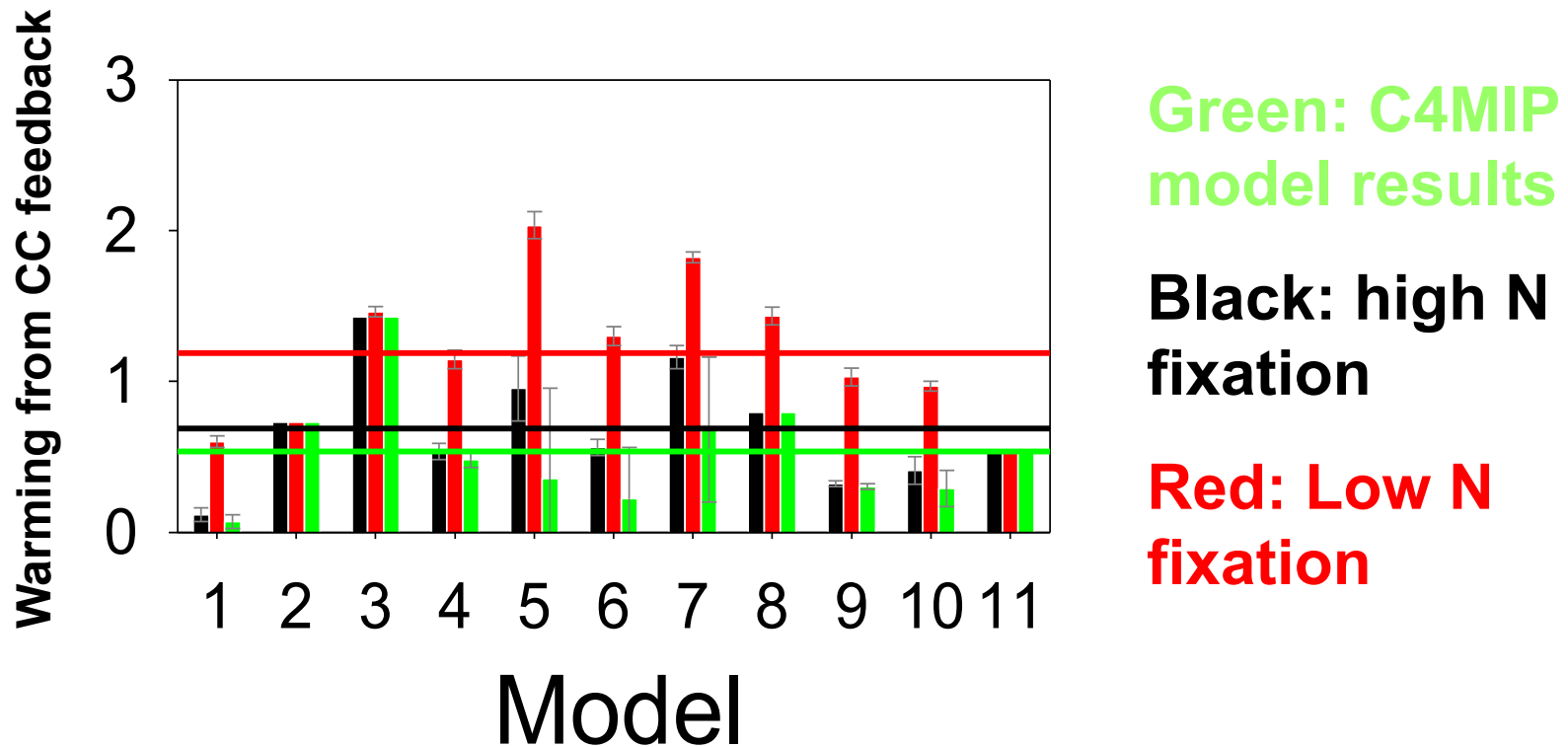
N deficit and excess C

- **N deficit** = N available – N required
- **Excess C** = N deficit * $f(\text{C:N ratio})$
- Excess C is then partitioned to atmosphere and ocean, resulting in higher atmospheric CO₂ → additional warming

The N deficit and excess C by 2100



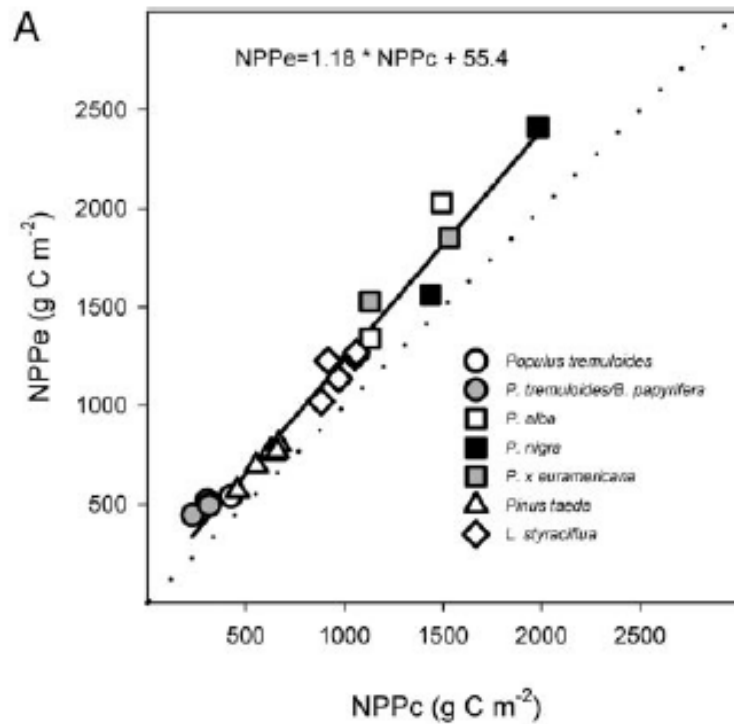
N limitation causes more warming



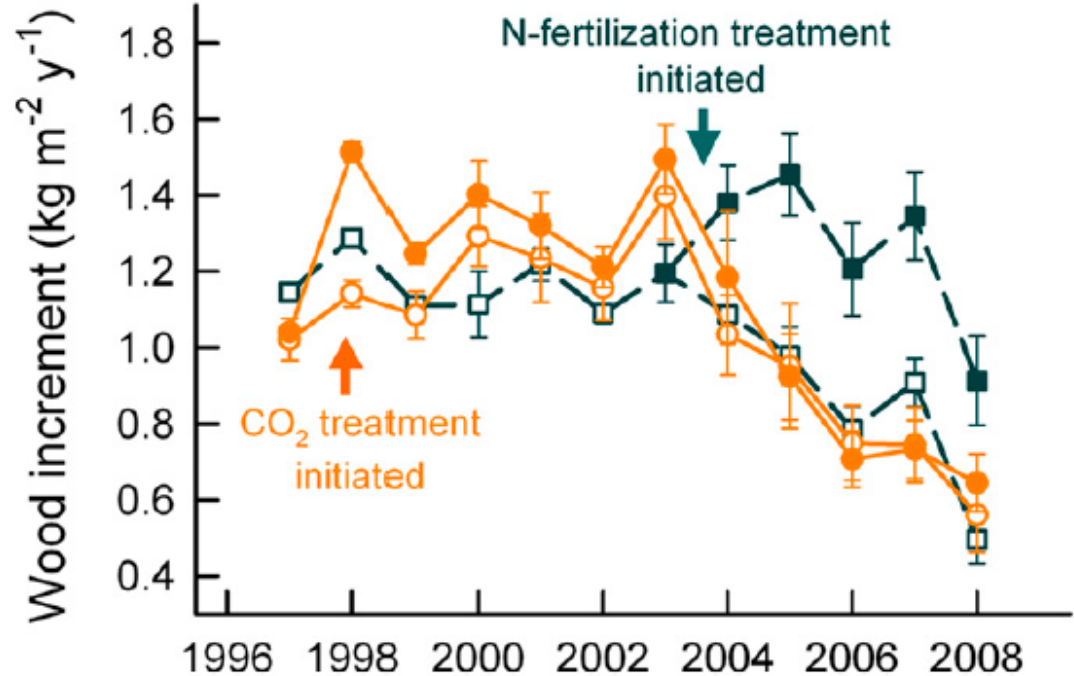
2100-1900: 0.66 K (C4MIP)

0.69 to 1.19 K (High to low N fixation)

Source: Wang and Houlton, 2009, GRL

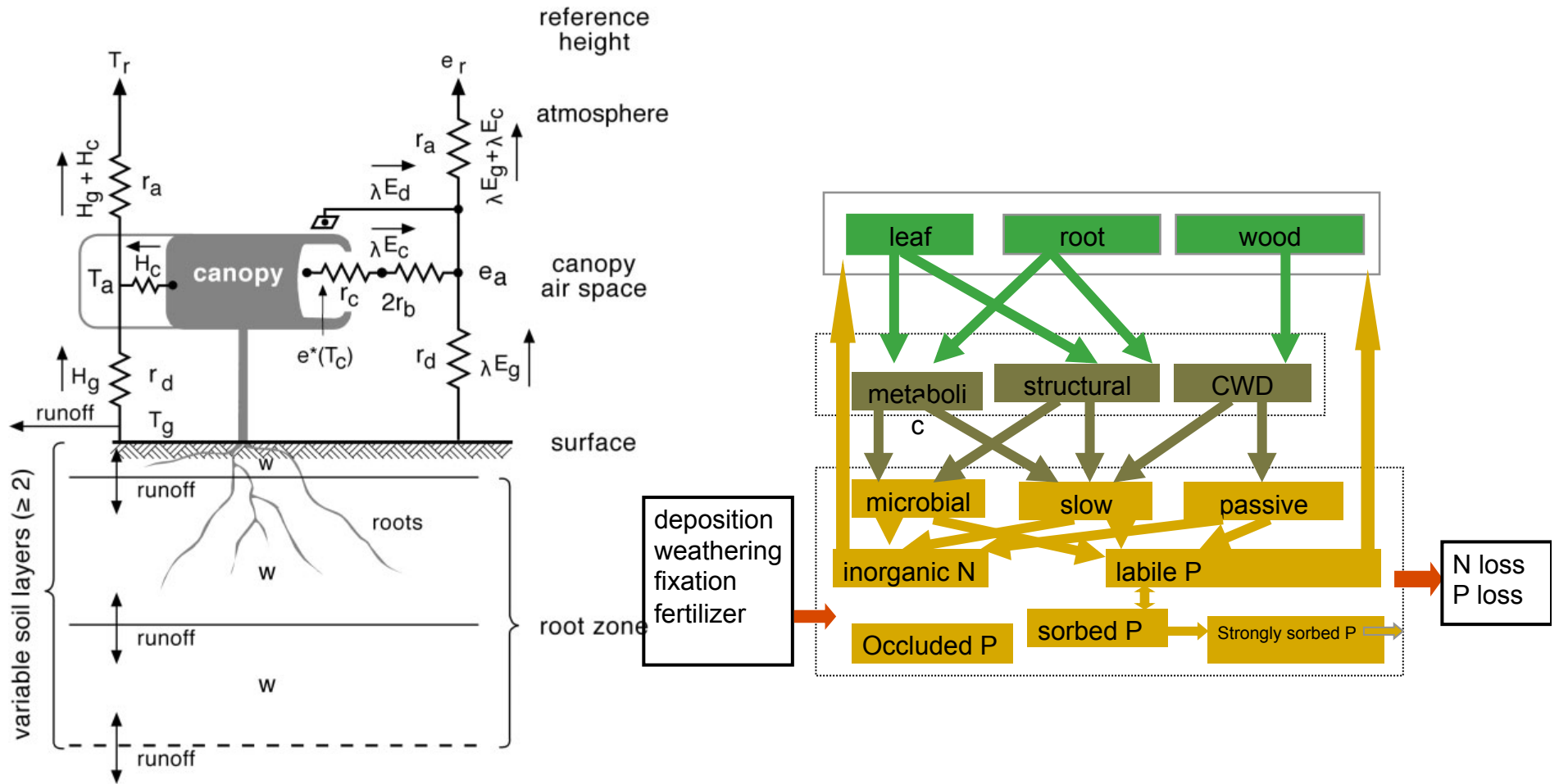


Norby et al. 2005.
 NPP under elevated CO₂
 increased by 23±2 %



Norby et al. 2010.
 enhancement of NPP under
 elevated CO₂ declined from
 24% in 2001–2003 to 9% in
 2008

CABLE: its components



Biophysics



Biogeochemistry



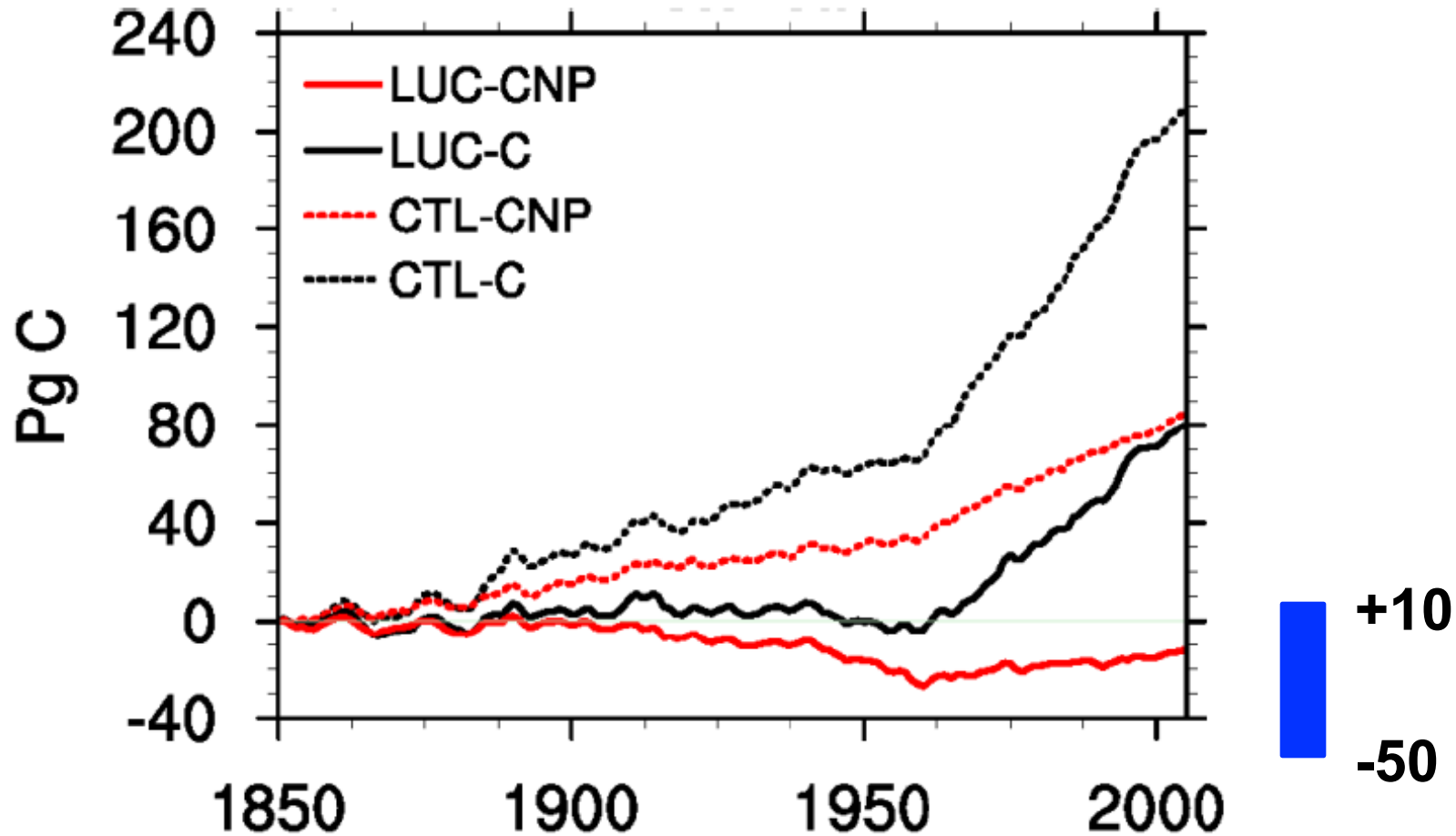
CABLE

The coupled ocean atmosphere land model (COAL)

- The coarse resolution atmosphere model
- Ocean model (physics and ocean carbon)
- Land model, CABLE (biophysics and biogeochemistry)

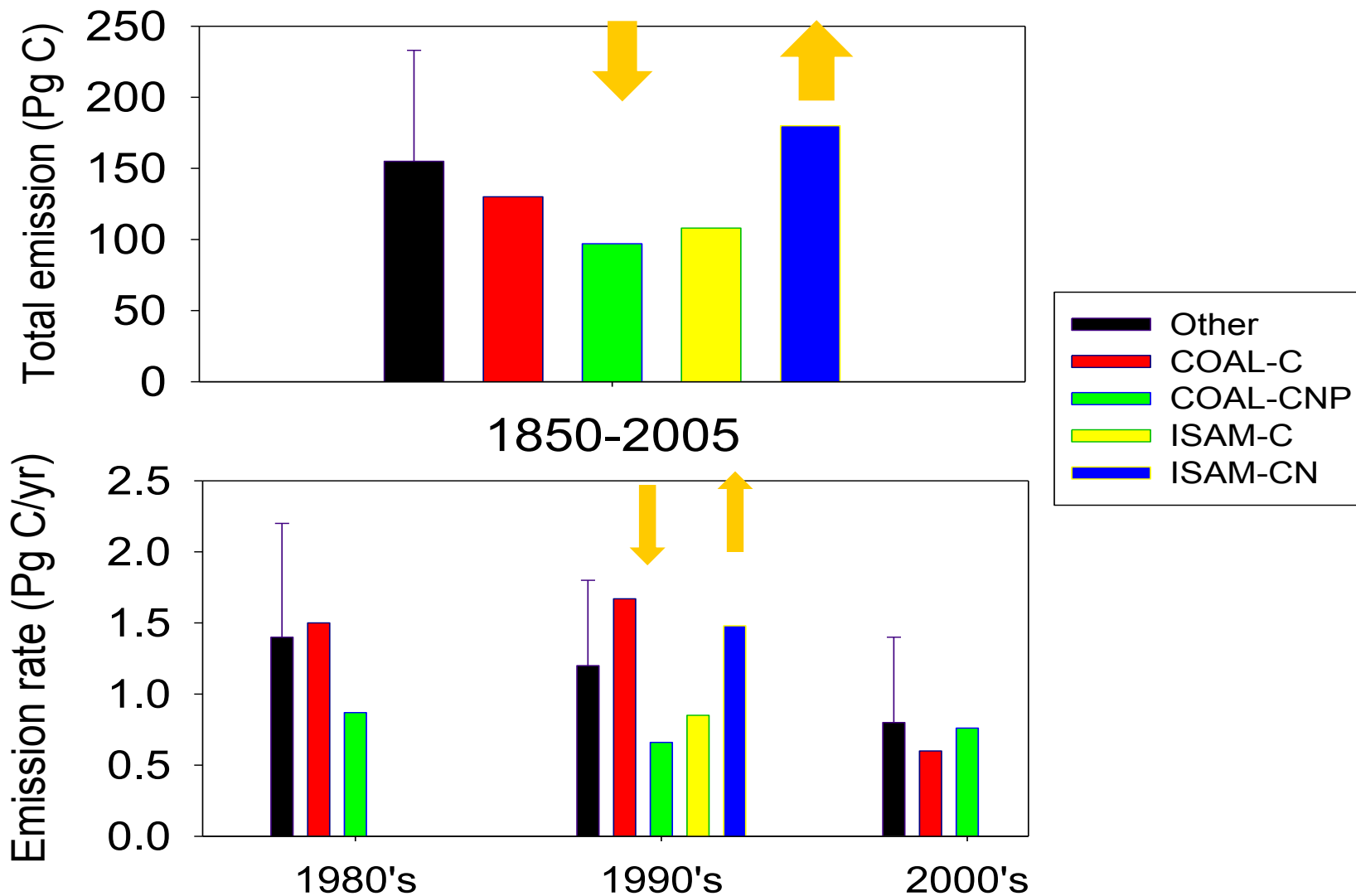
- Projected climate as a function of RCP

Historical land use change (1850-2005)



Zhang et al. 2013 ESD

Different effects of nutrient limitation



Global C budget (1850-2005)

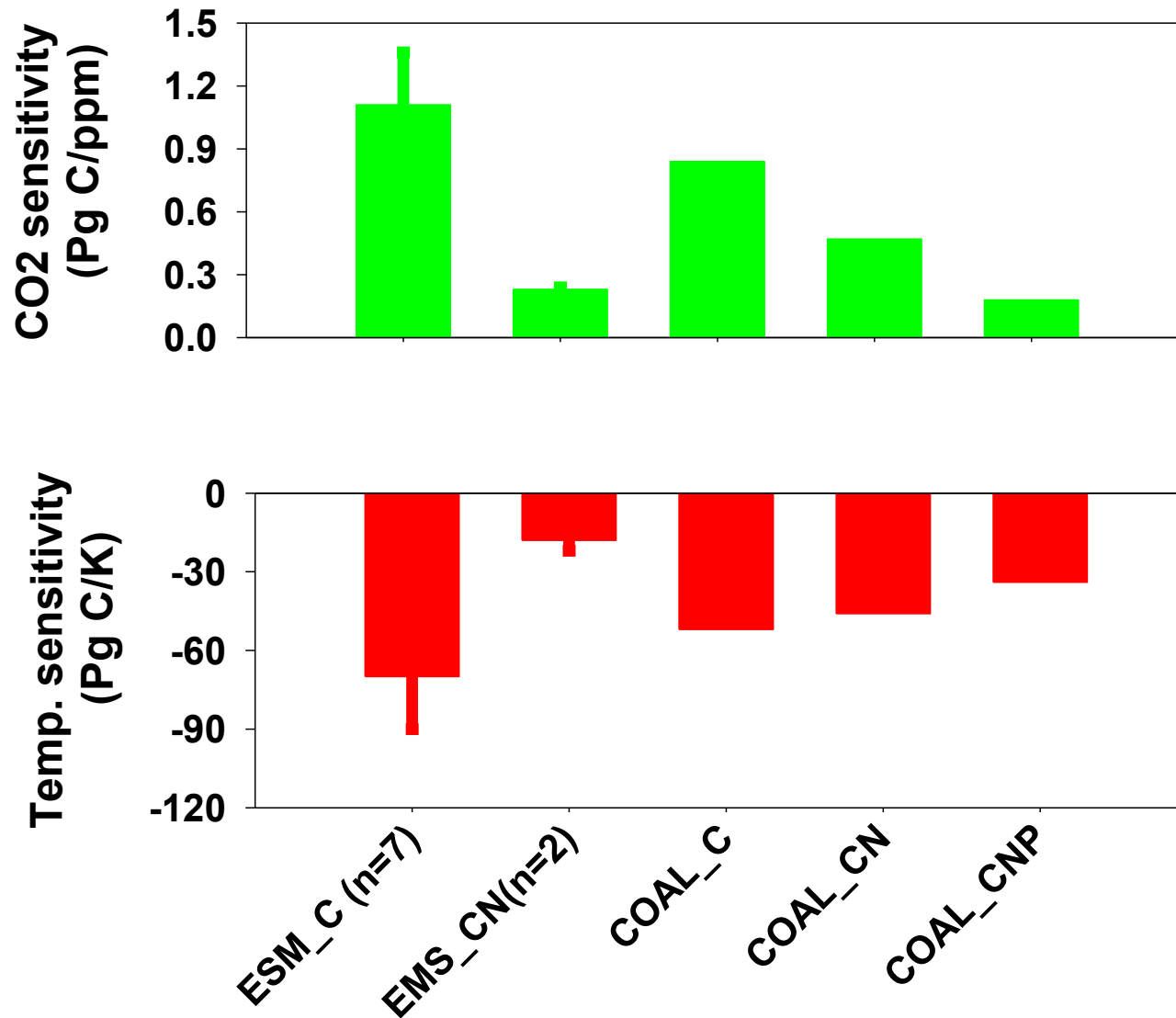
1850-2005	C only	CNP	GCP+others
Fossil fuel	314	314	314±16
atmosphere	-200	-200	-200± 11
Ocean uptake	-116	-118	-135± 25
LUC emission	130	97	155± 78
Residual land flux	-128	-93	-135± 84

Fire emissions are not included in our model

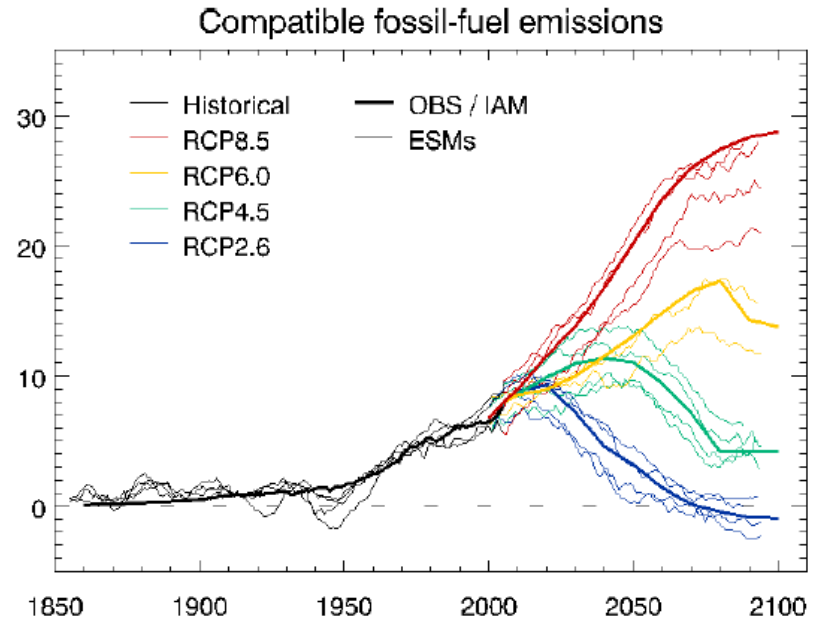
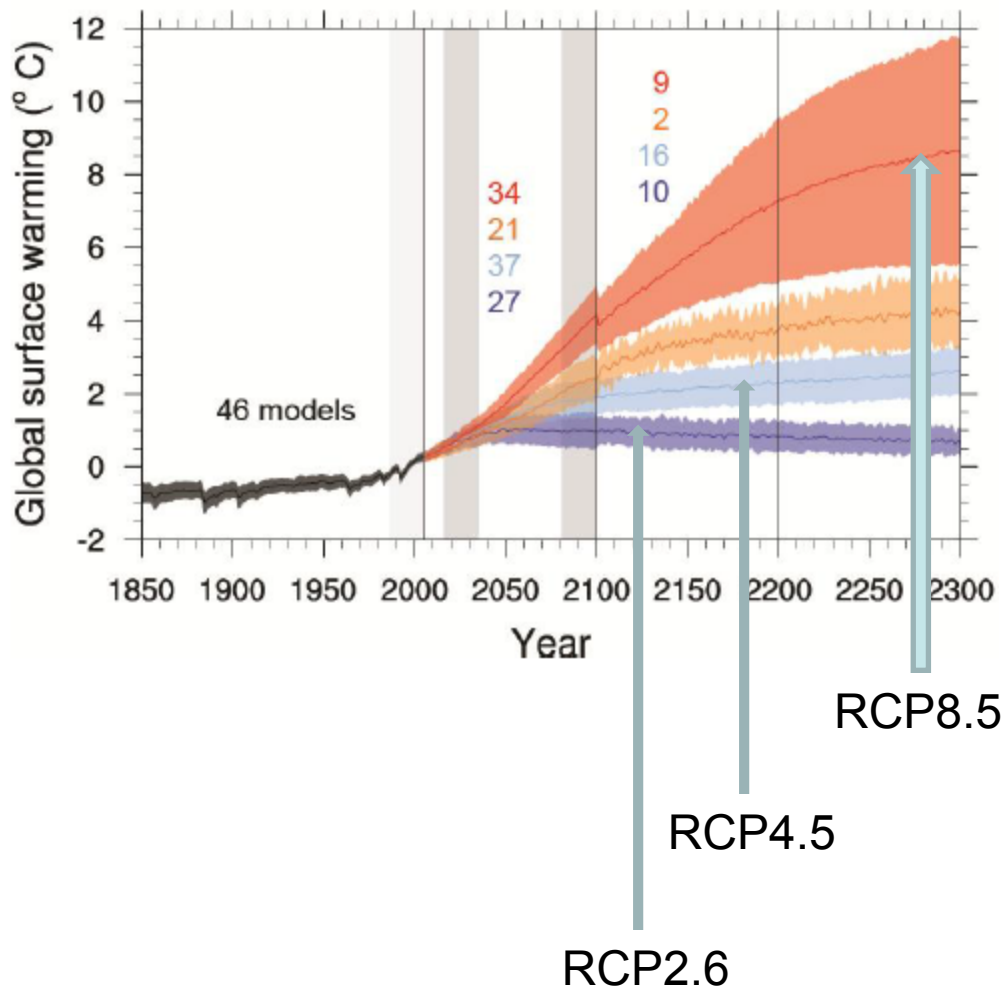
What will happen in the future?

- We studied the effect of nutrient limitation for three IPCC AR5 representative concentration pathways (RCP):
 - RCP2.6: a low emission scenario
 - RCP8.5: A high emission scenario with significant deforestation after 2005;
 - RCP4.5: A medium emission scenario with significant reforestation.

IPCC AR5 ESMs +COAL: sensitivities



Three RCPs and the compatible emissions from IAM



Nutrient limitation on land C uptake in the future

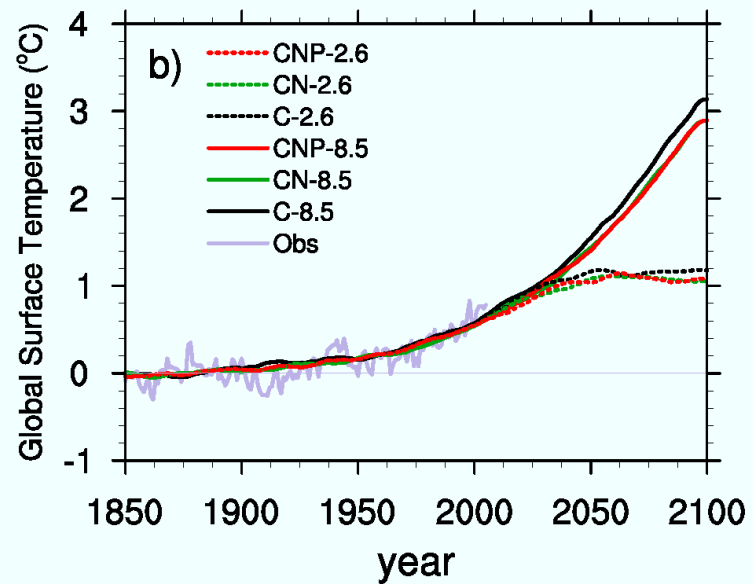
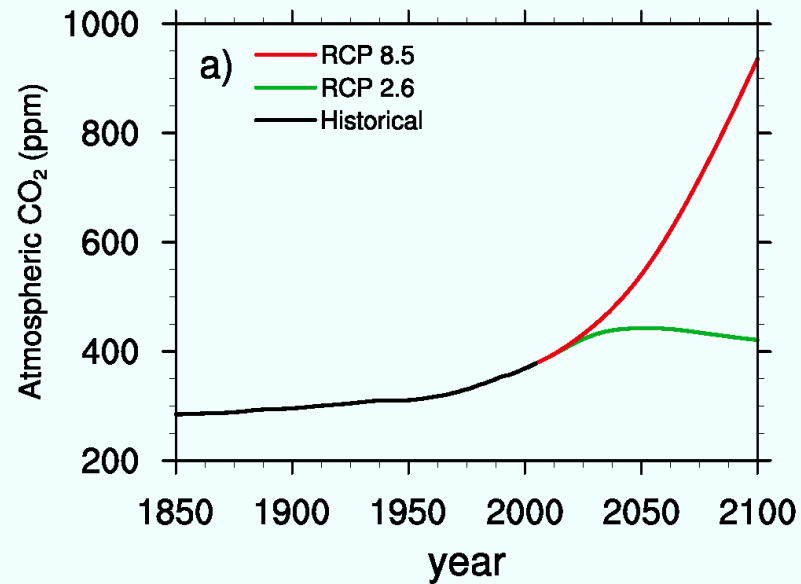
Nutrient limitation on allowable emissions

How much can we emit if we want to keep the global warming below 1K or 3K by 2100?

Nutrient limitation on emission/uptake from deforestation/afforestation

How effective is the forest management in CO₂ mitigation?

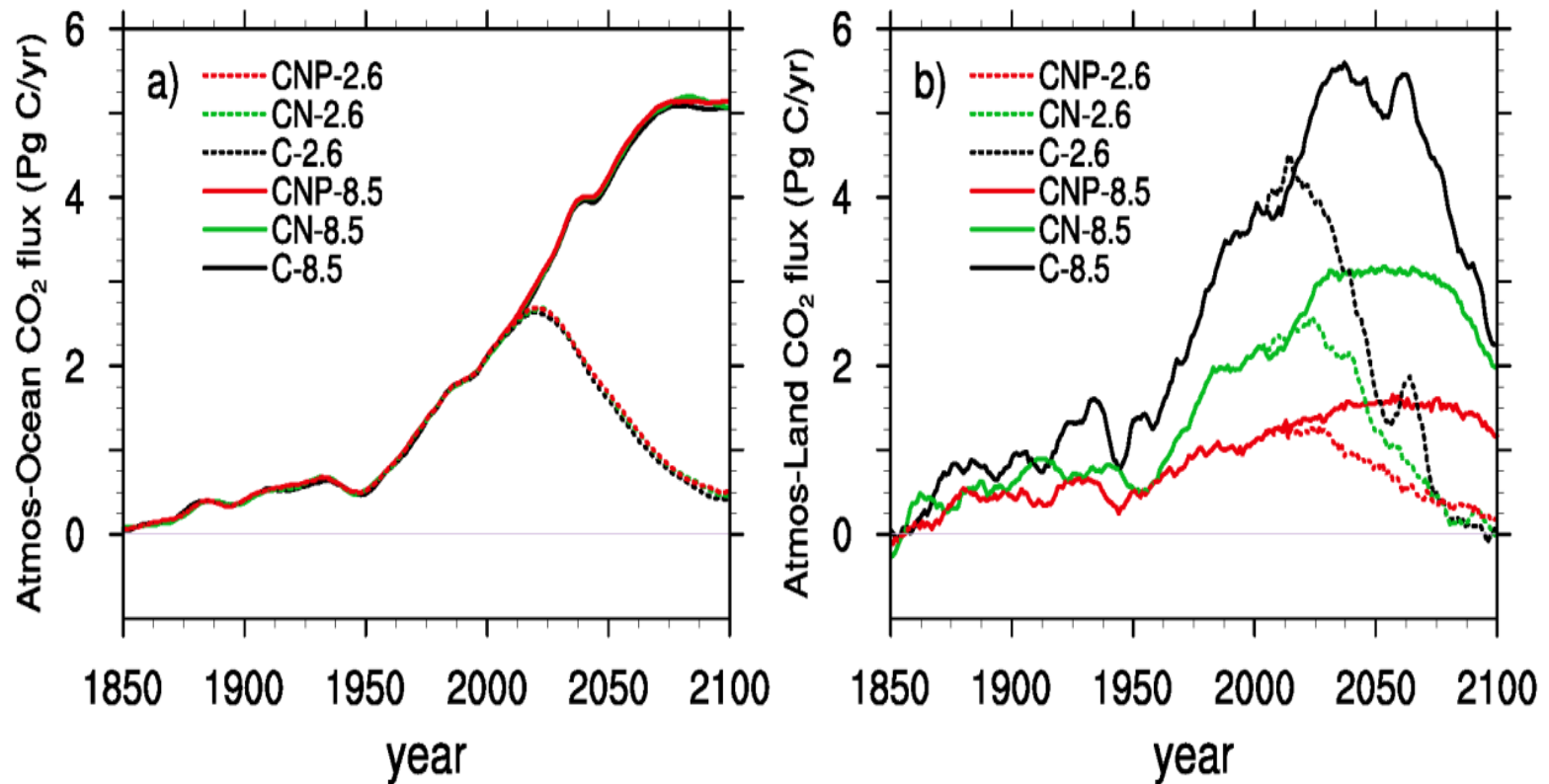
Two representative concentration path pathway (RCP)



How much can we emit ?

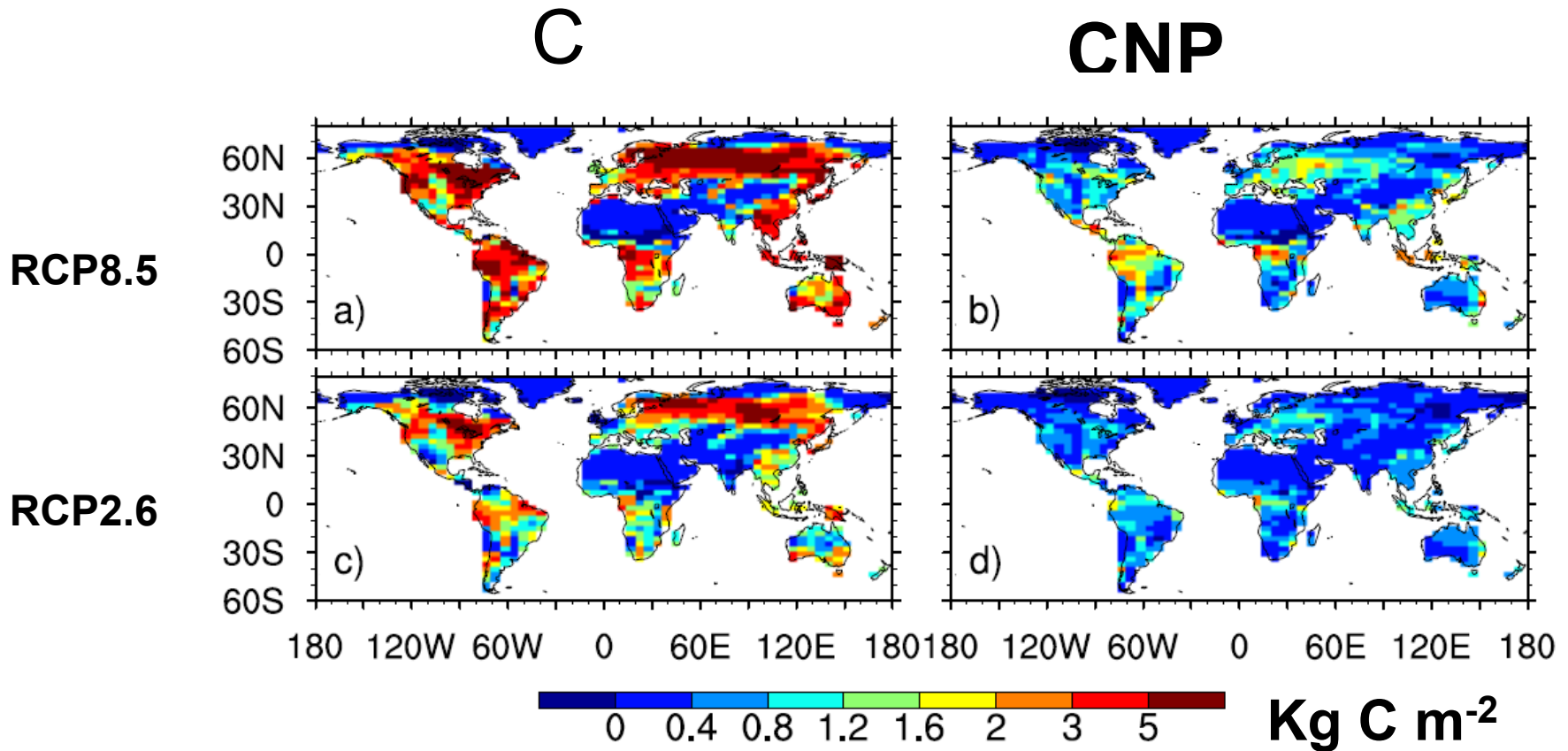
- If we want to limit the global warming by 1K (RCP2.6) or 3 K (RCP8.5) by 2100.
- Simulations
 - Using prescribed atmospheric [CO₂] (RCPs)
 - Run COAL from 1850 to 2100 with three different land BGC configurations (C, CN, CNP).
 - **Allowable emission**= atmospheric CO₂ increase + ocean uptake + land uptake

Simulated ocean and land sinks



Source: Zhang et al. submitted

Land C accumulation from 2005 to 2100

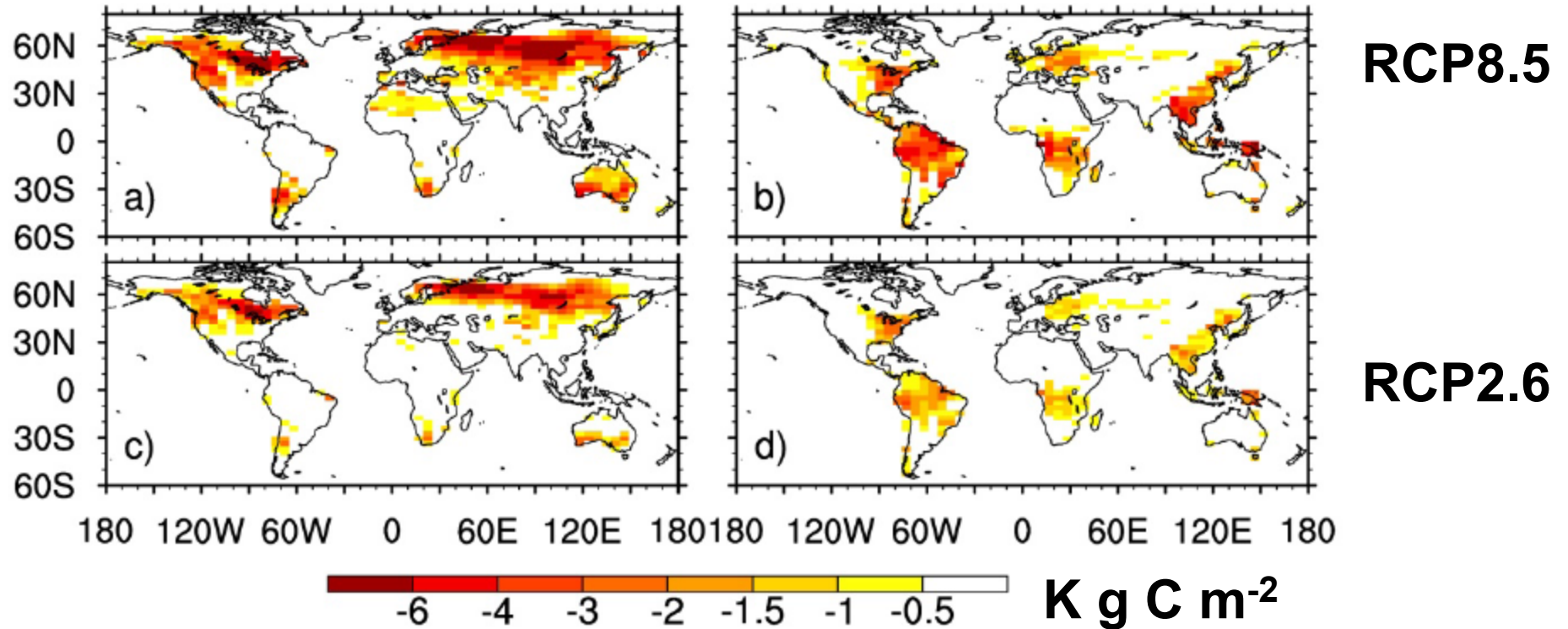


Zhang et al. submitted

Nutrient limitation reduces land C accumulation

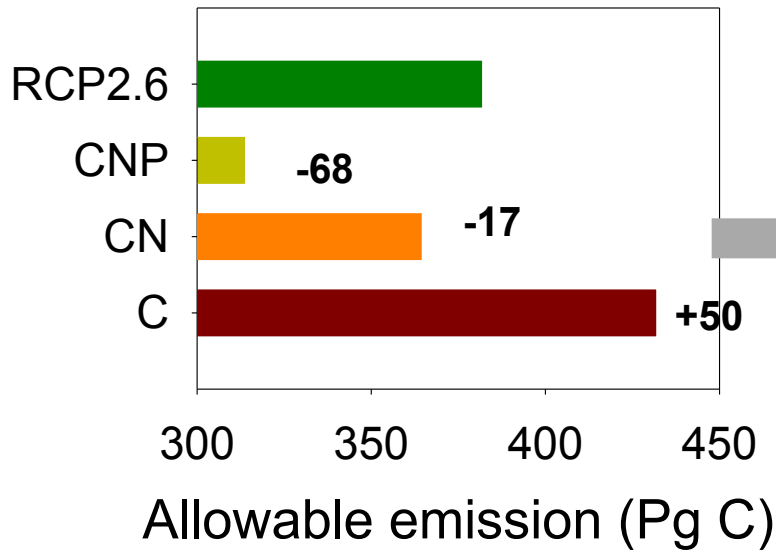
CN-C

CNP-CN

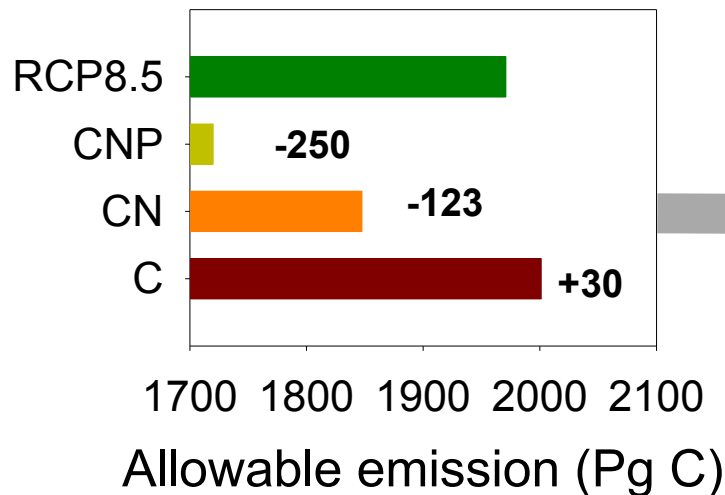


Source: Zhang et al. submitted

If we want to stay on the same concentration pathway (or 1K or 3K warming), then



**Emission reduced by 68 Pg C by 2100
Or
further 20% warming (0.1K)**



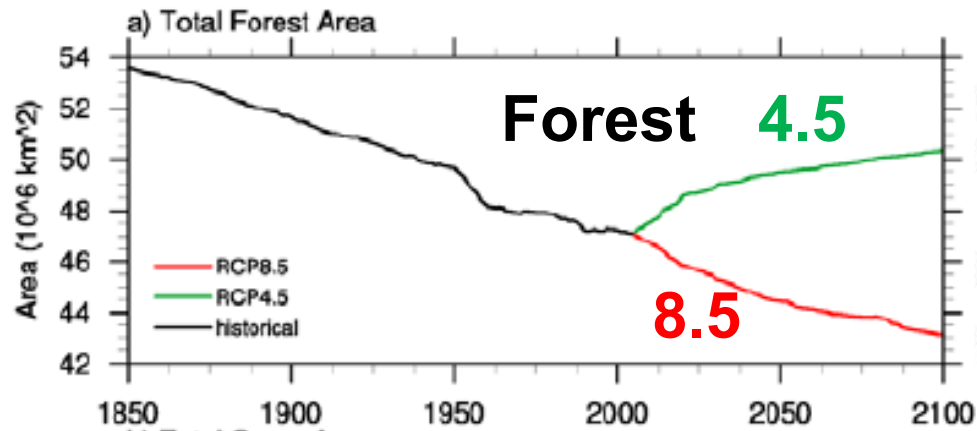
**Emission reduced by 250 Pg C by 2100
Or
further 10% warming (0.25K)**

Source: Zhang et al. submitted

Afforestation for mitigating climate change

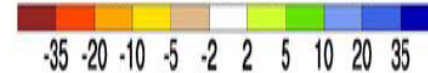
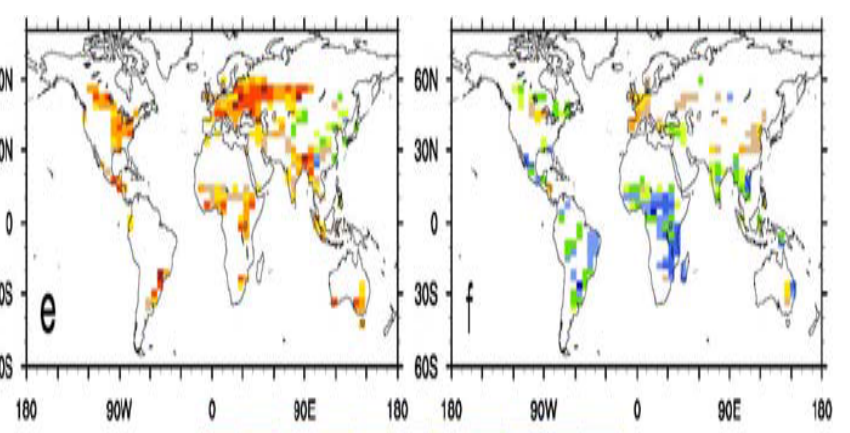
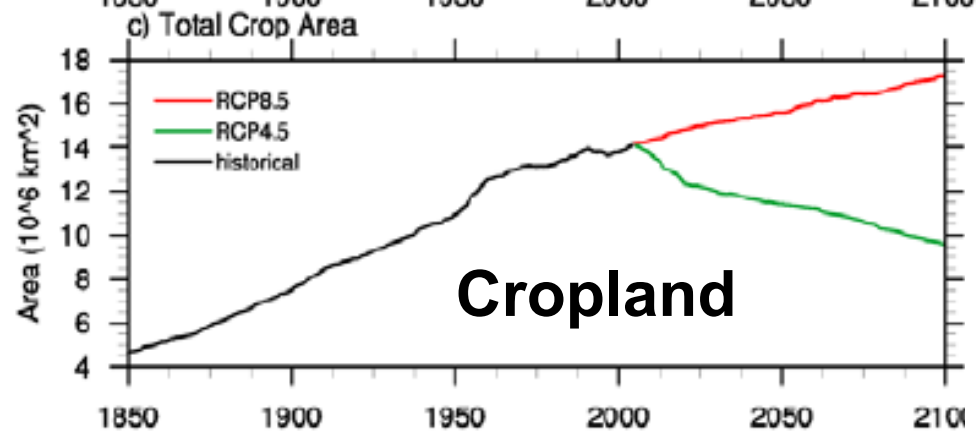
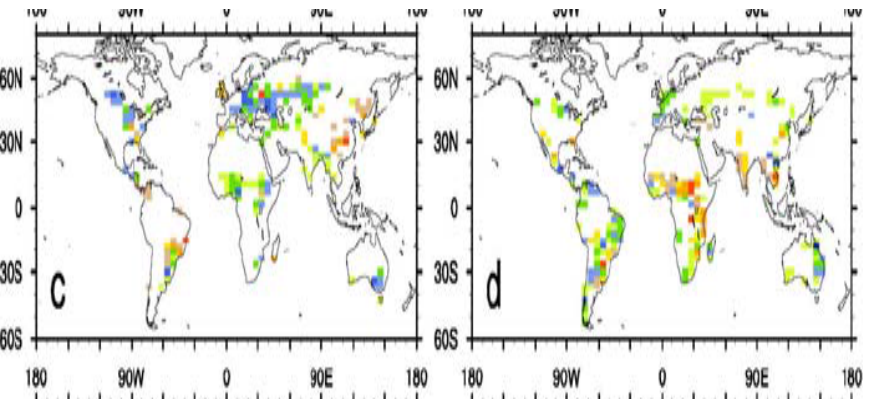
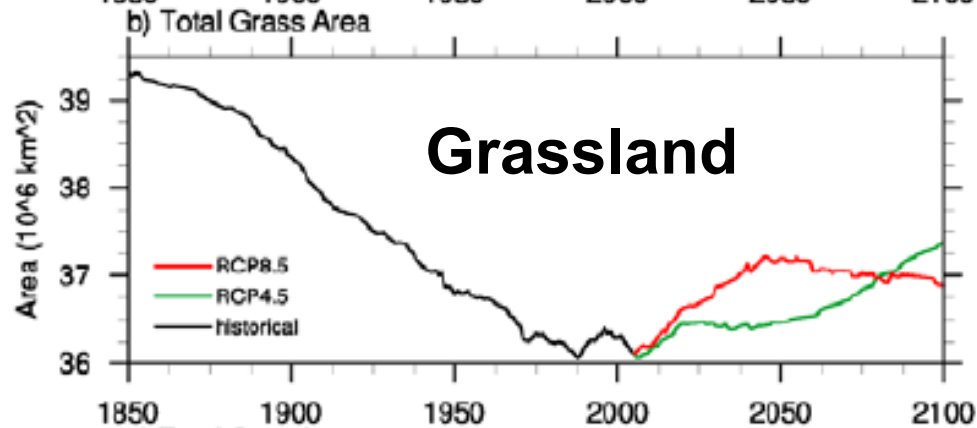
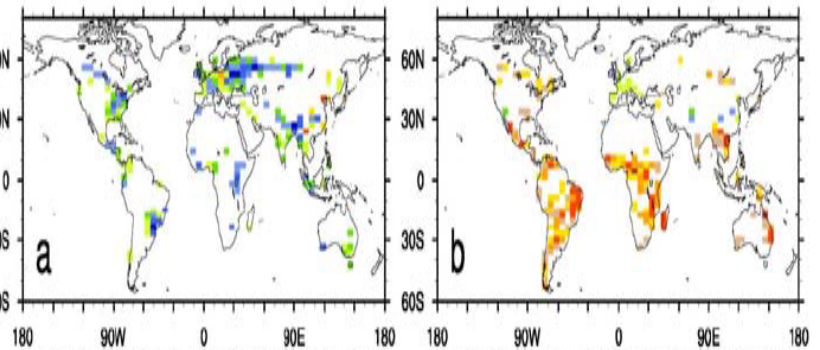
Conversion of forest to crop/pasture

- Biophysical effects
 - Change surface albedo (increase)
 - Energy partitioning (decrease LE)
- Biogeochemical effects
 - Change carbon balance (decrease)



RCP4.5

RCP8.5



Four simulations (2006-2100)

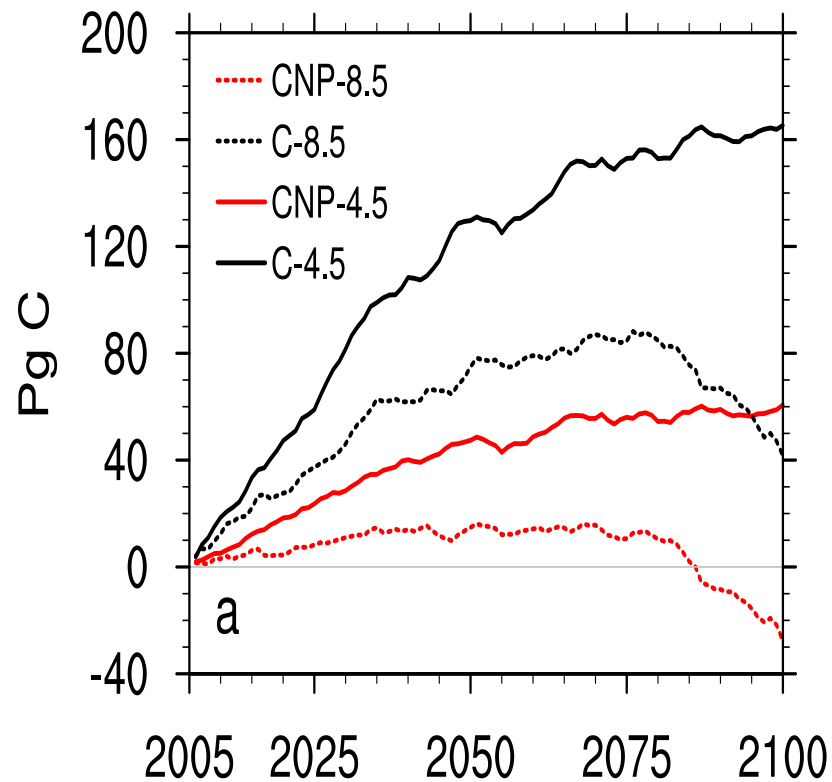
Experiment	Land use	C or CNP
CTL-C	Constant after 2005	C
CTL-CNP	Constant after 2005	CNP
LUC-C	Varied according to RCP	C
LUC-CNP	Varied according to RCP	CNP

“LUC-C” – “CTL-C”: effect of land use change without nutrient limitation;

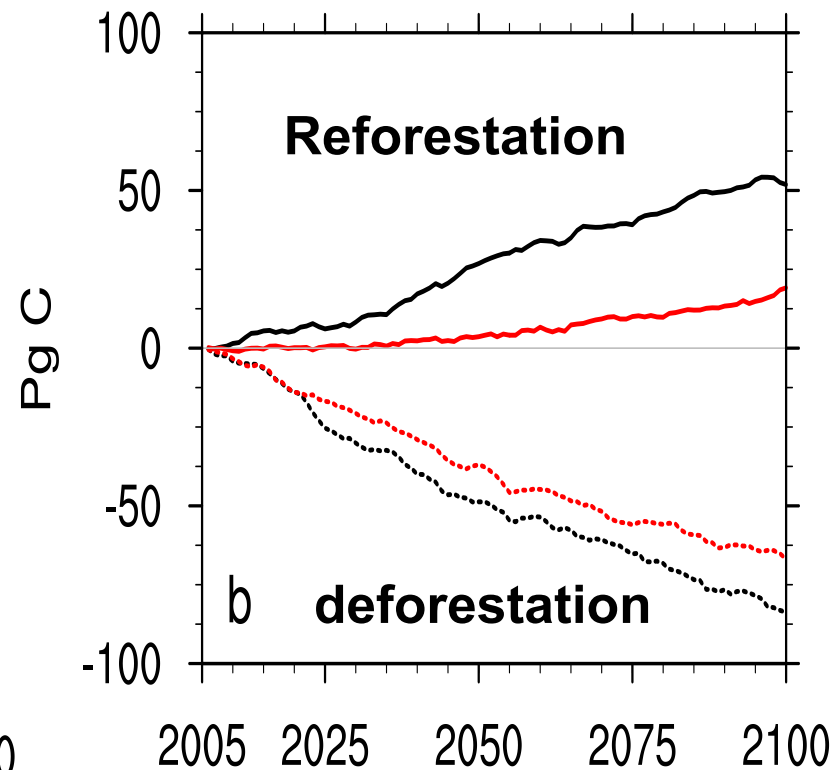
“LUC-CNP” – “CTL-CNP”: effects of land use change with nutrient limitation

C pool change and CO2 emissions

C pool change with LUC



CO2 emission from LUC

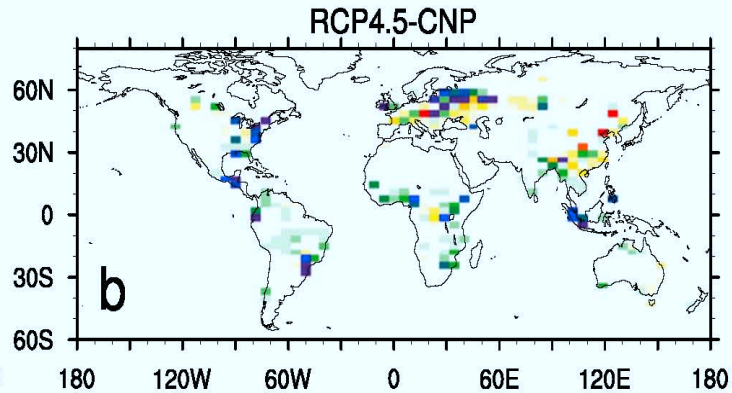
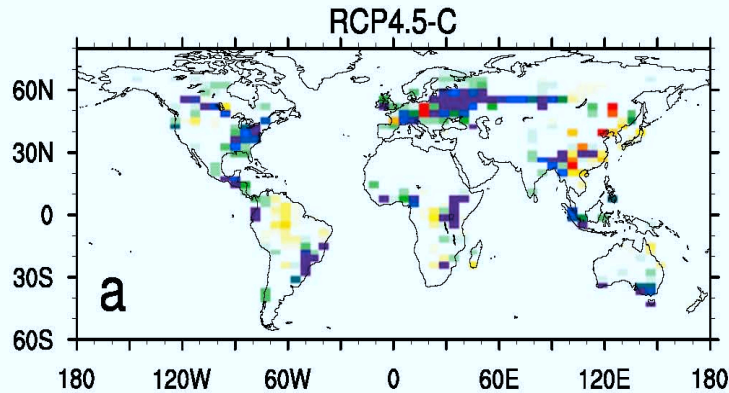


CO2 emission from land use

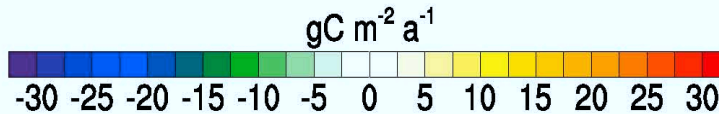
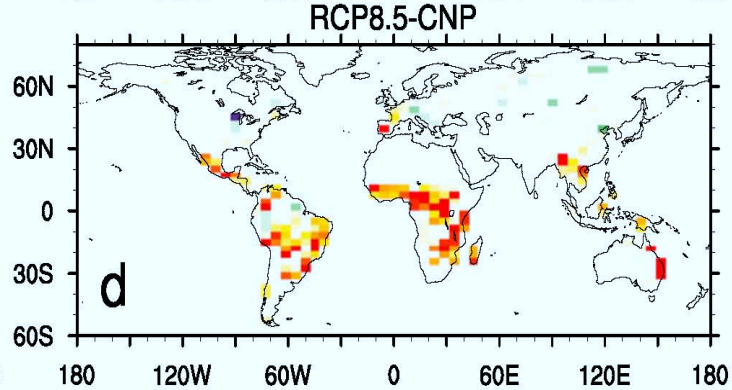
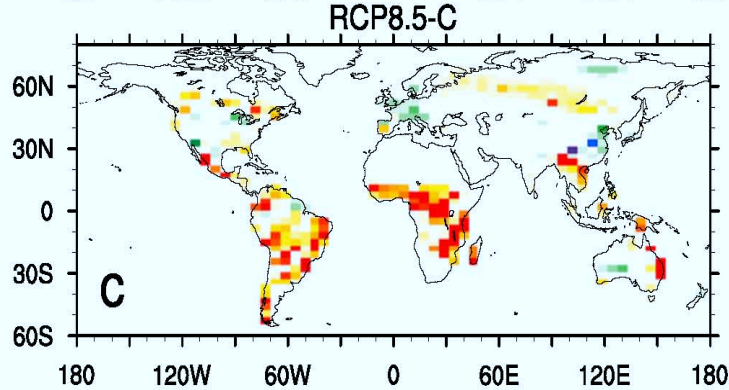
C only

CNP

RCP4.5



RCP8.5

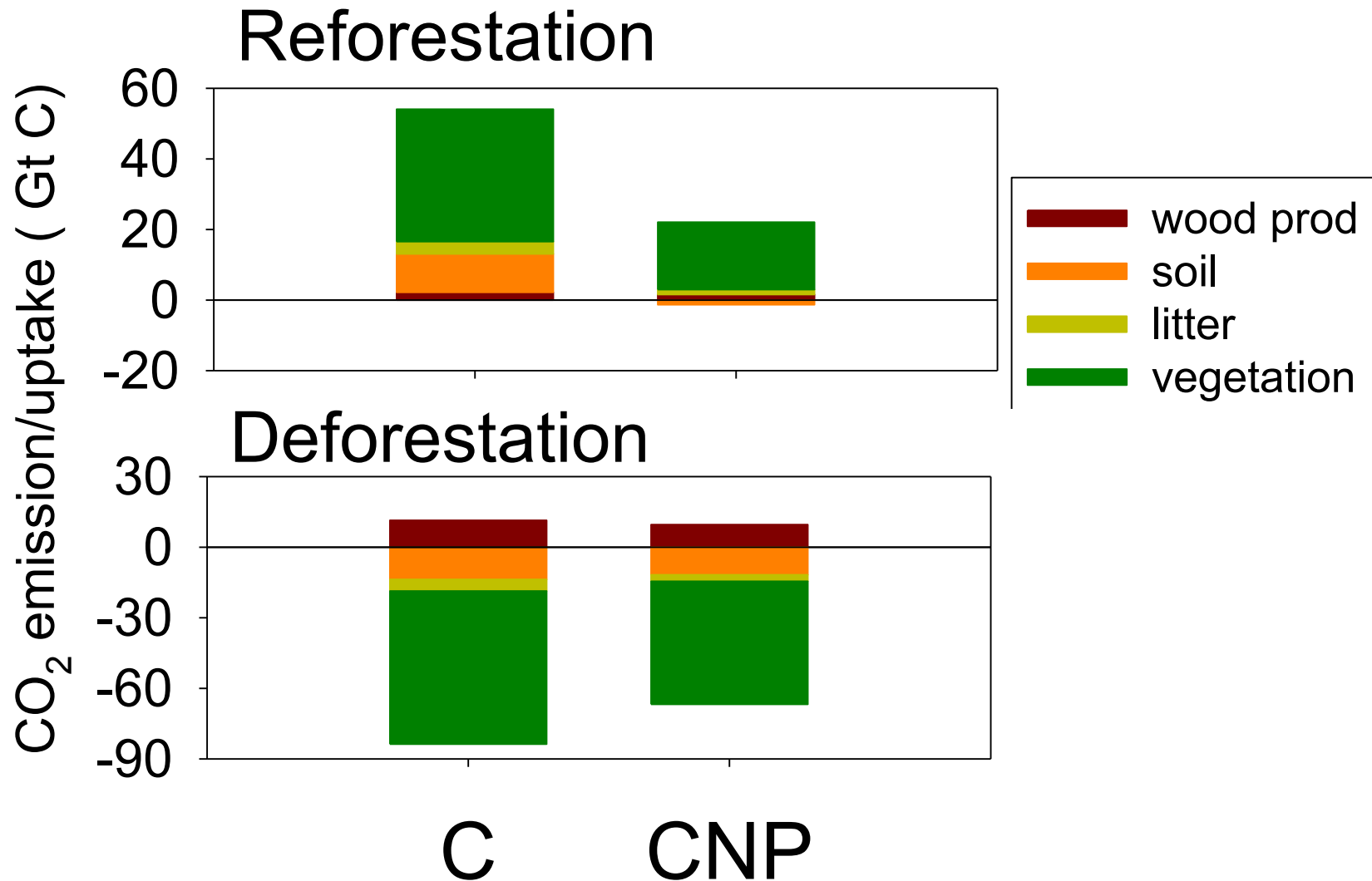


“LUC-C”-“CTL-C”

“LUC-CNP”-“CTL-CNP”

Source: Zhang et al. submitted

Nutrient limitation on carbon flux from land use change (2006-2100)



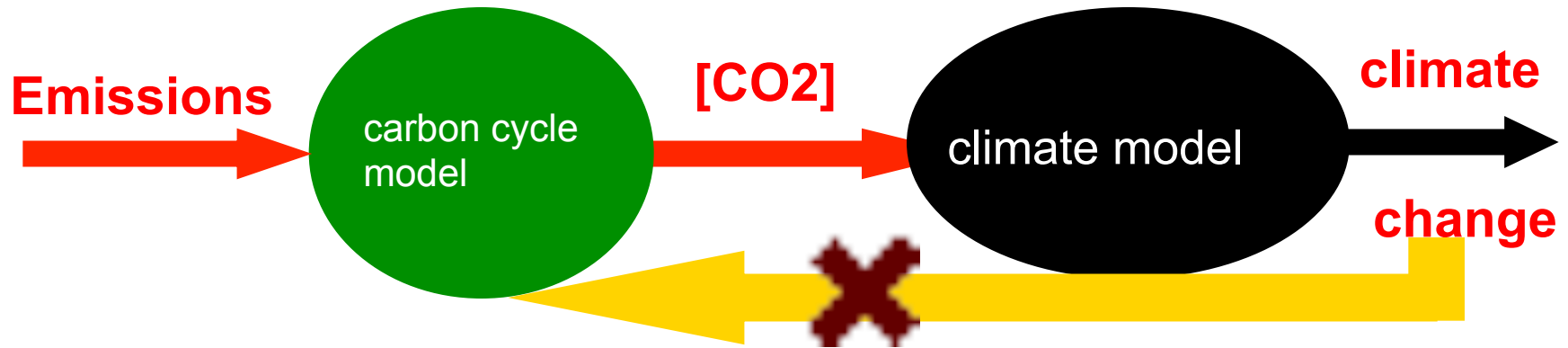
Conclusions

- Nutrient limitation reduces carbon uptake by global biosphere by up to 60%, with strong N limitation at high latitudes and P limitation at low latitudes;
- The allowable emission needs to be reduced by 8 to 10% for two RCPs, otherwise we will face additional warming;
- Nutrient limitation reduces the estimated CO₂ emission from deforestation by about 20% (RCP8.5) or uptake from reforestation by 60% (RCP4.5)

Many thanks for the following people who have contributed to the work

- Qian Zhang (Beijing Normal University)
- Benjamin Houlton (UC Davis)
- Andy Pitman (UNSW)
- Richard Matear (CSIRO)
- Peter Lawrence, Gordon Bonan (NCAR)

Carbon climate feedback



Recent progress

Including carbon cycle into climate model => earth system model, therefore effects on climate change on carbon cycle, or so called carbon-climate feedback are now included.