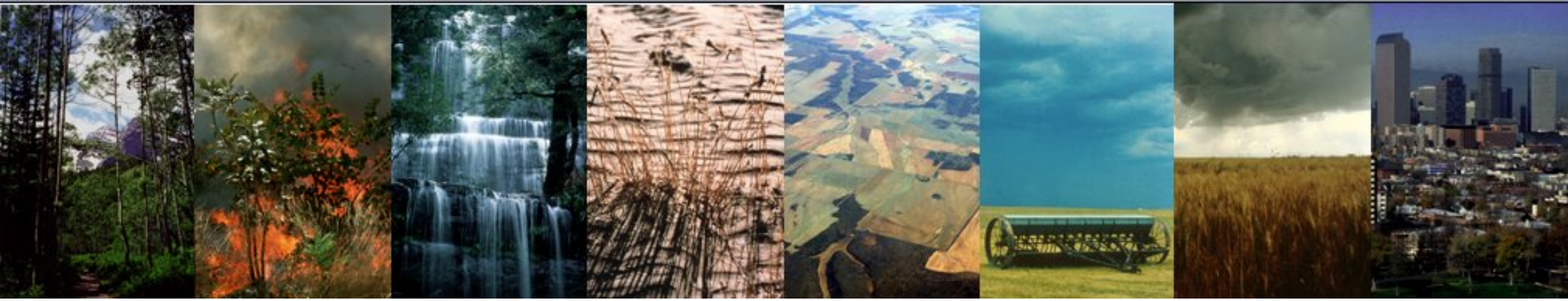
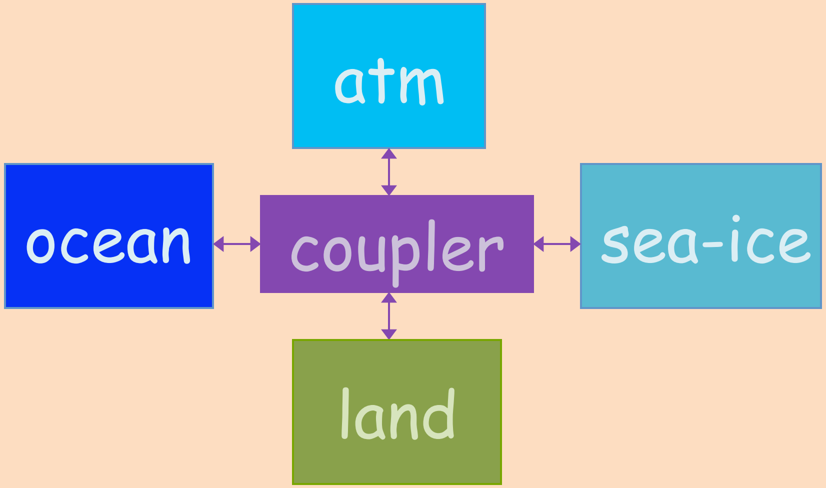


Land Use and the Carbon Cycle: a modeler's perspective

Samuel Levis
Terrestrial Sciences Section, CGD/NESL/NCAR
Boulder Colorado USA

Land Use and the Carbon Cycle

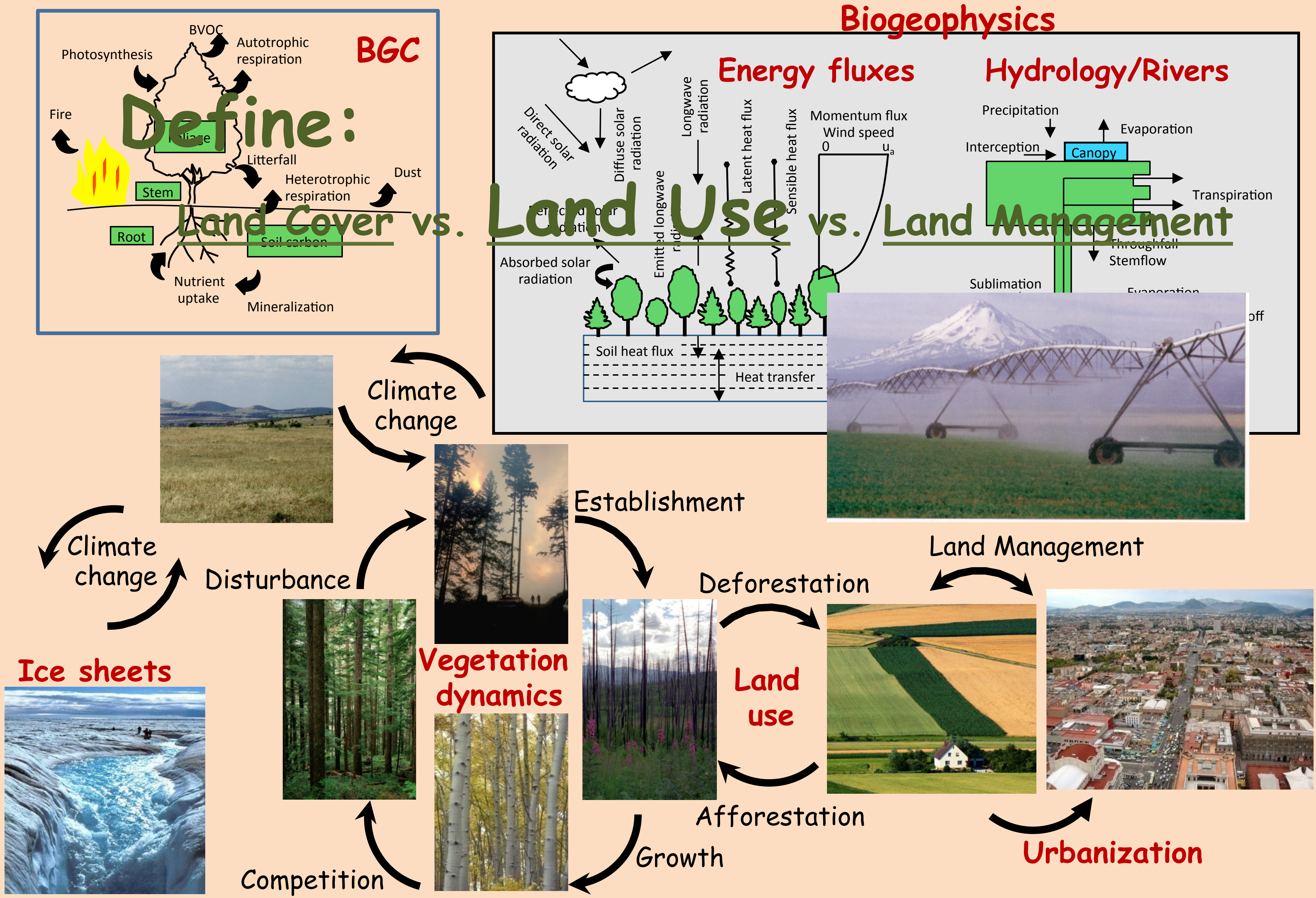
- In the context of Earth System Models
- Concepts & processes represented
- Simulations



Current-generation land models (e.g. CLM)

Define:

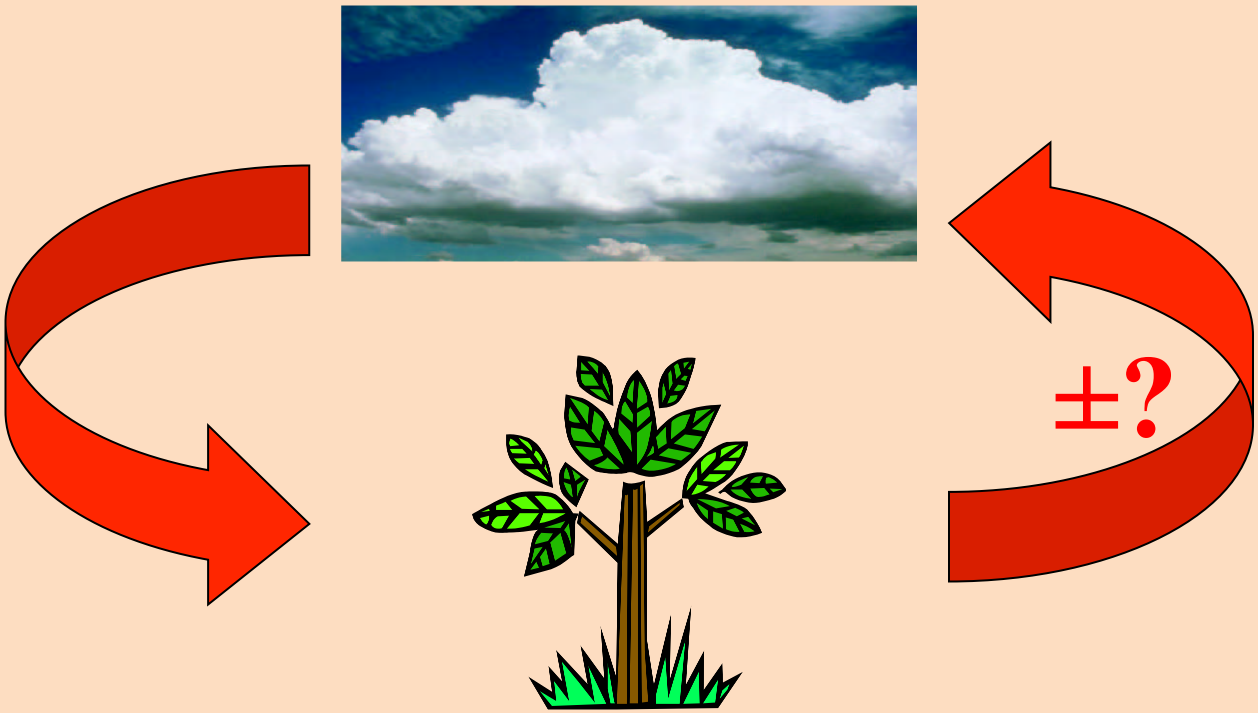
Land Cover vs. Land Use vs. Land Management



why Land Use in ESMs?

Land-Atmosphere Interactions

LAND-ATMOSPHERE FEEDBACKS



Land-Atmosphere Interactions

LAND-ATMOSPHERE FEEDBACKS

- Land Cover Change due to Land Use → Atm. changes
- Atmospheric changes → Soil & vegetation affected…

A. Biogeophysical interactions:

   1. Surface radiation balance $R_n = S + L$ **think albedo**

   2. Surface heat balance $R_n = H + \lambda E$ **think evapotransp.**

B. Biogeochemical interactions

   1. **Carbon cycle** **think biosphere**
   2. **Nutrient cycles** **think nitrogen, phosphorus, …**
   3. **Dust, biogenic emissions, …**

Biogeochemical processes… in the Community Land Model

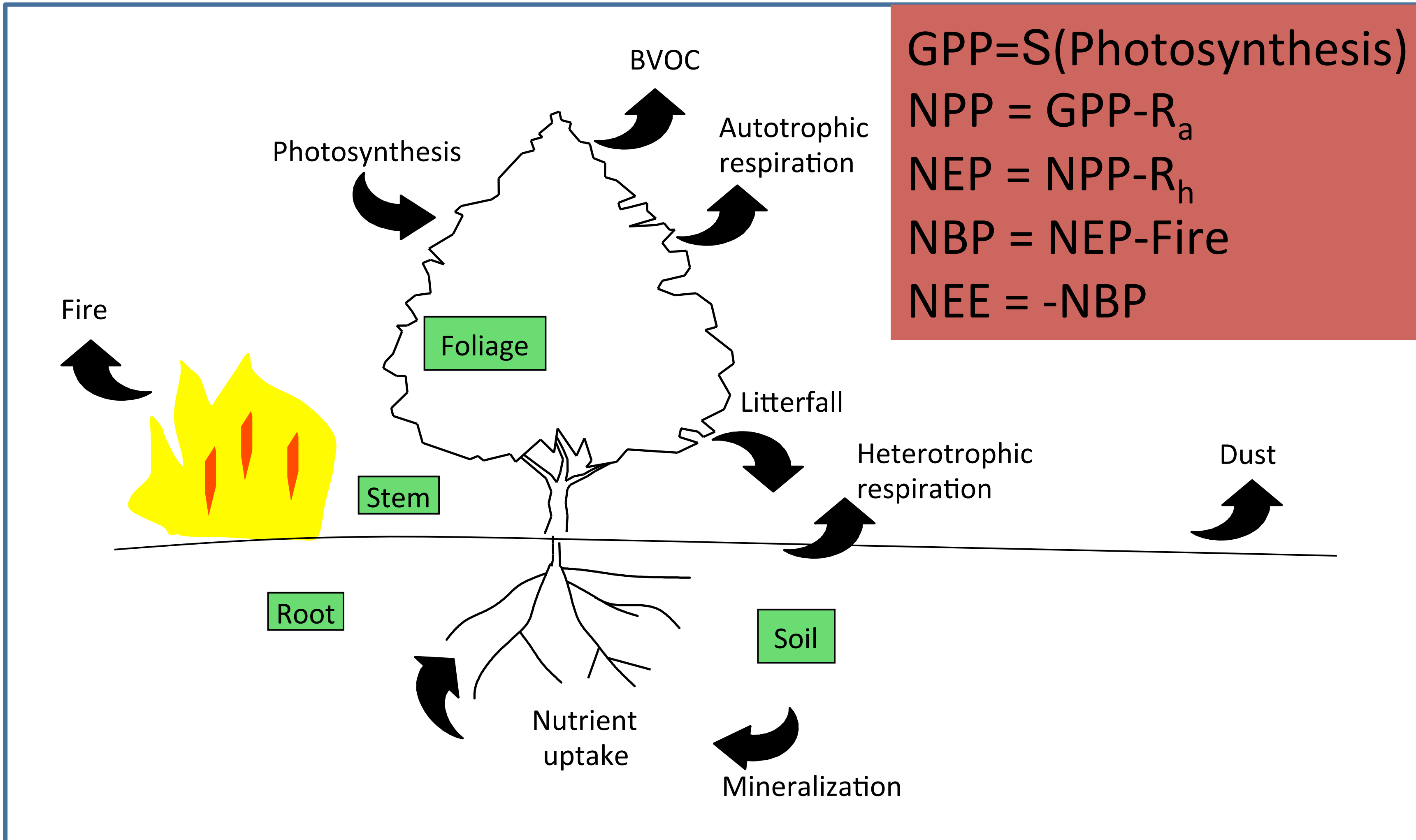
$GPP = S(\text{Photosynthesis})$

$NPP = GPP - R_a$

$NEP = NPP - R_h$

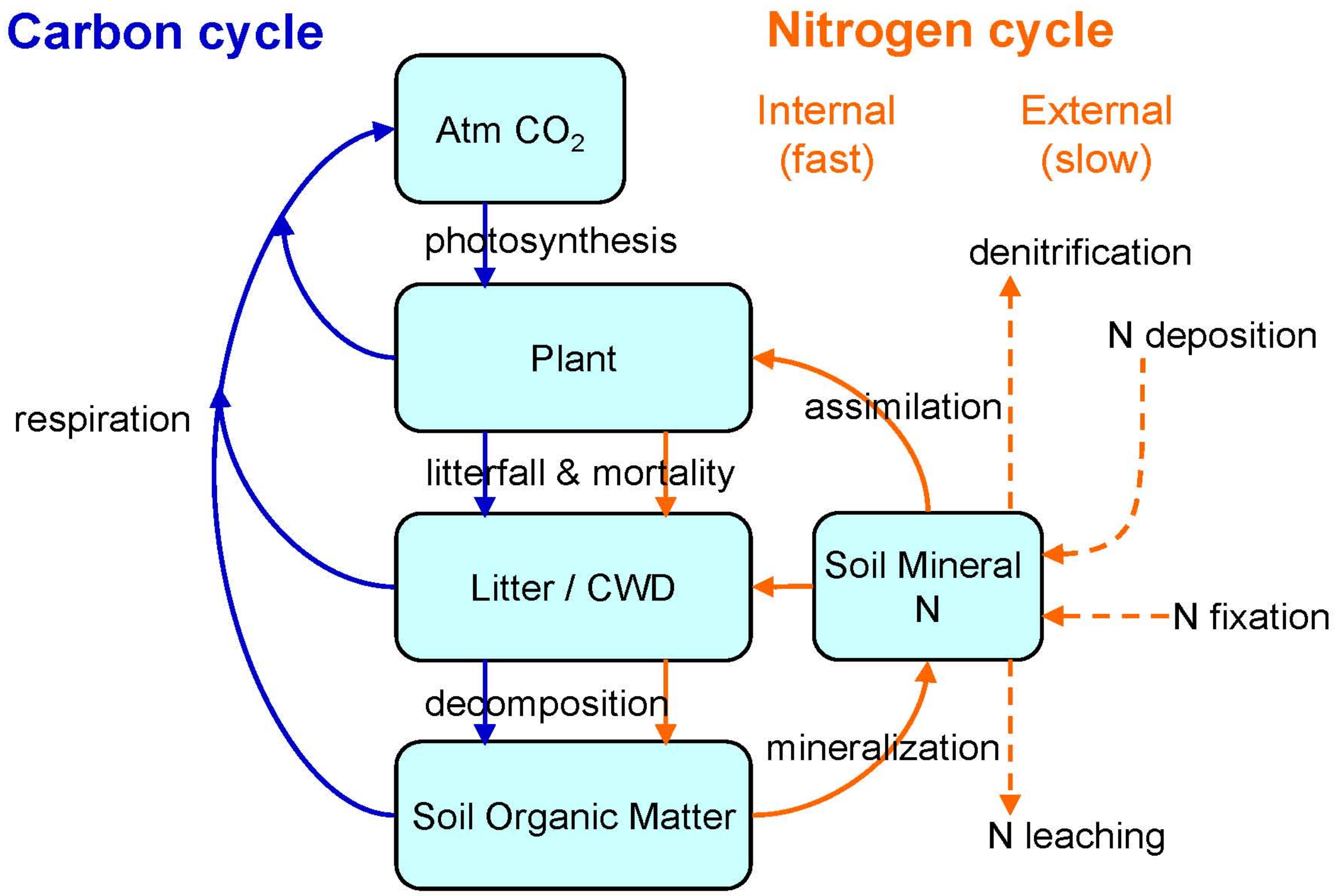
$NBP = NEP - \text{Fire}$

$NEE = -NBP$



Thornton *et al.*

Biogeochemical processes… in the Community Land Model

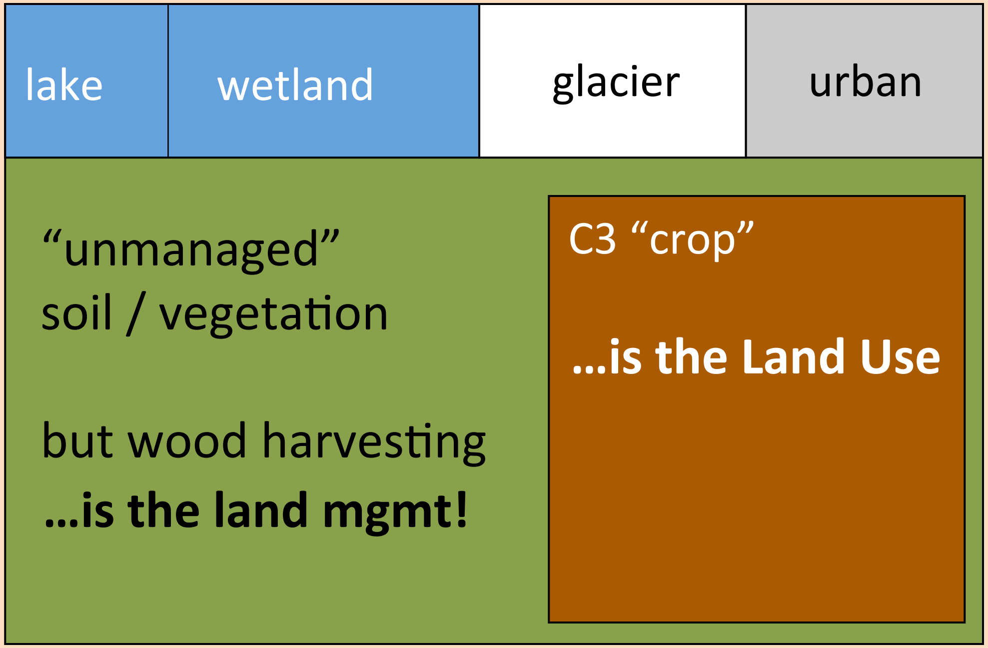


Thornton *et al.*

All these processes are affected by and may also affect the physics

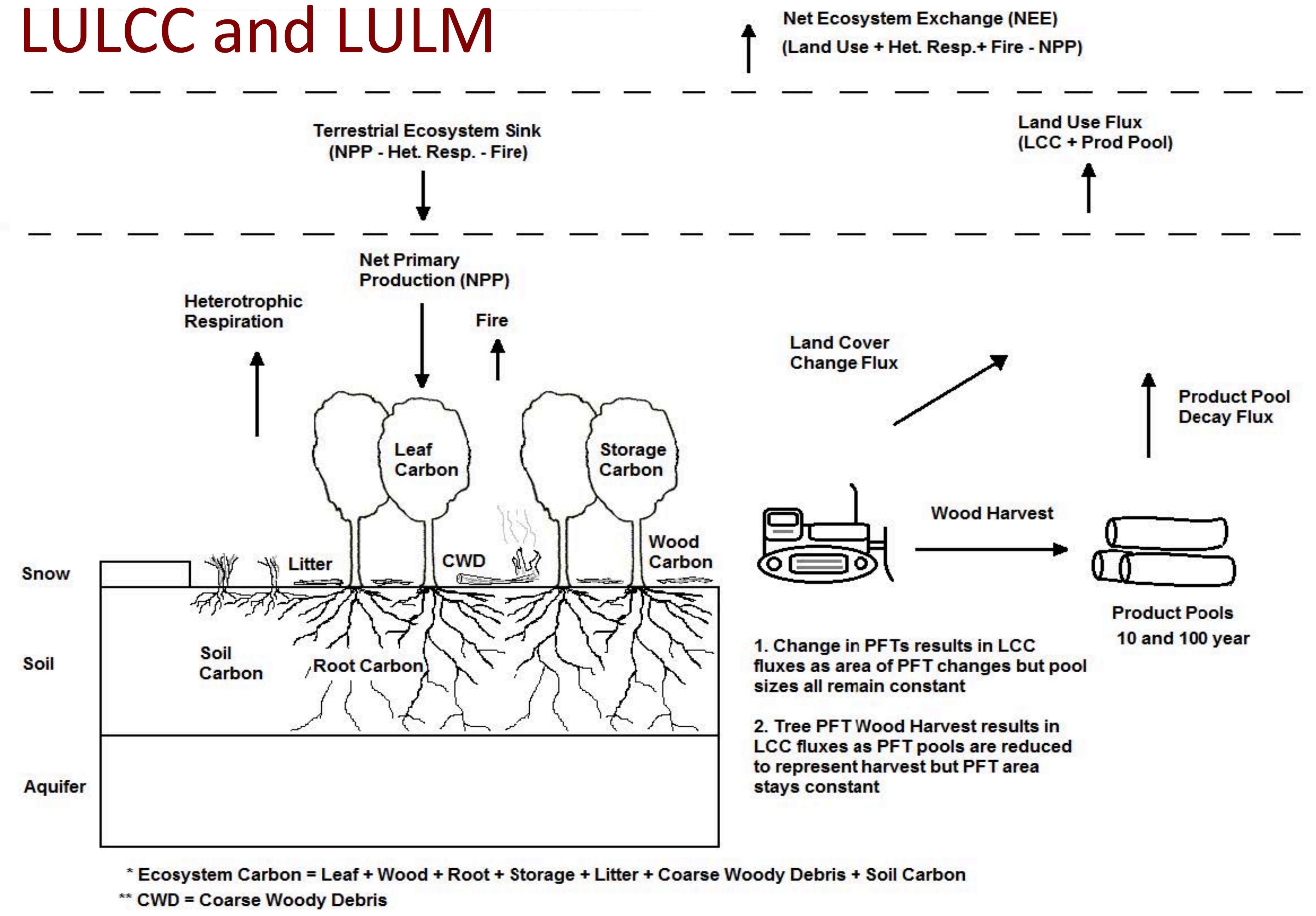
Define Land Use in a CLM grid cell…

Land Cover is all of it…



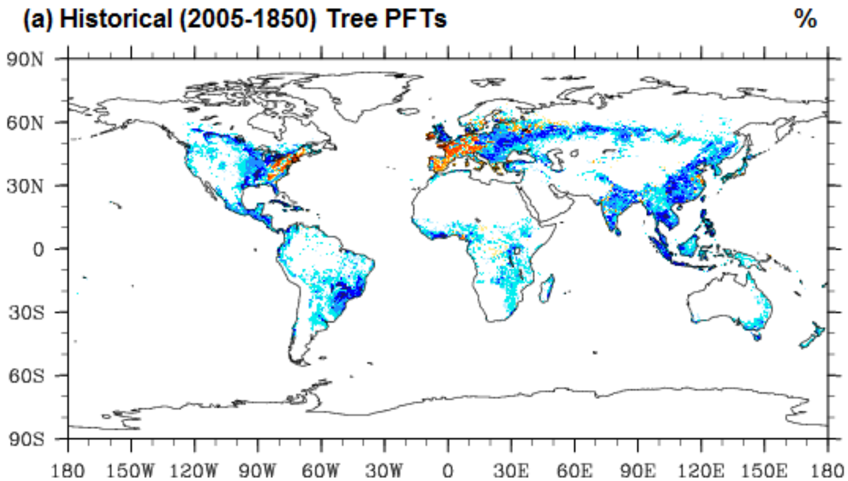
What do these acronyms mean then? LULCC? LULM?

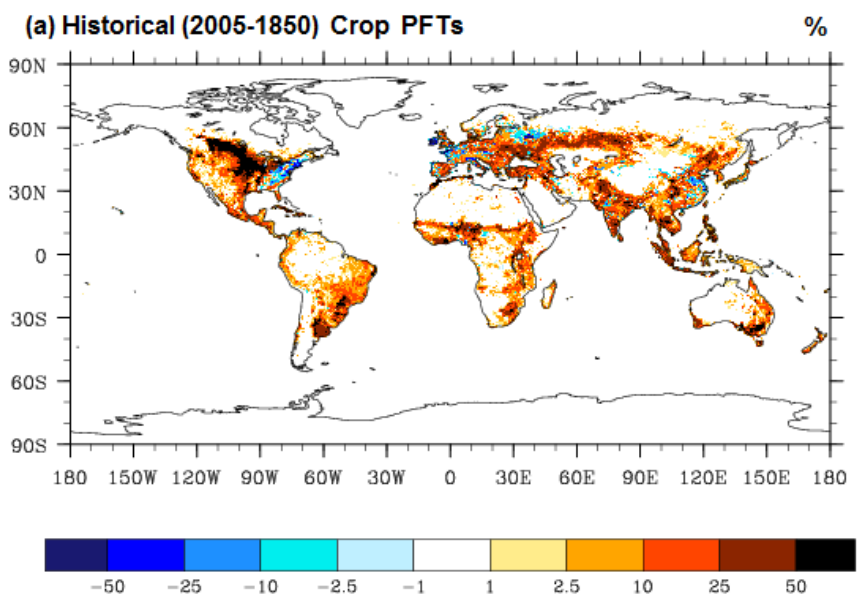
C pools and fluxes in the CLM associated with LULCC and LULM



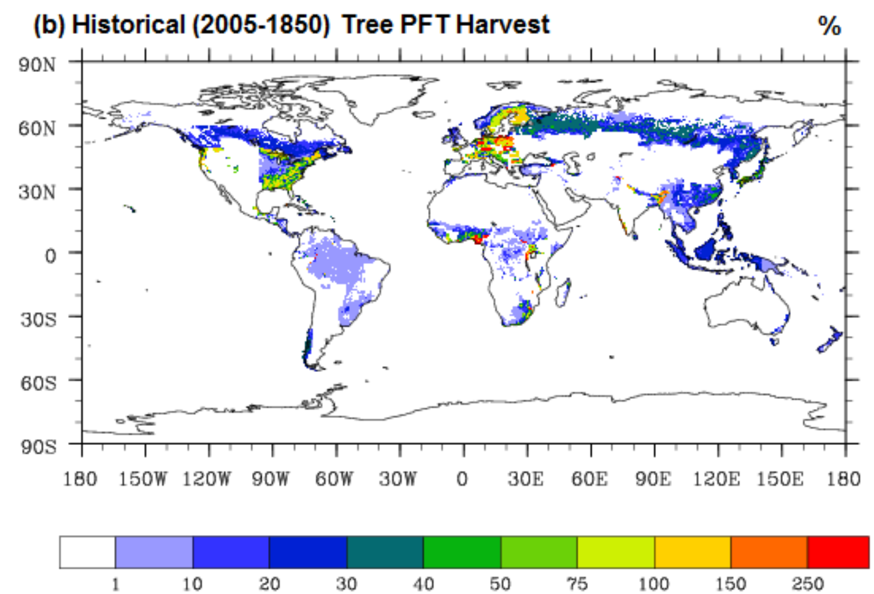
LULCC/LULM: input data to the CLM

Change in tree and crop cover (% grid cell)



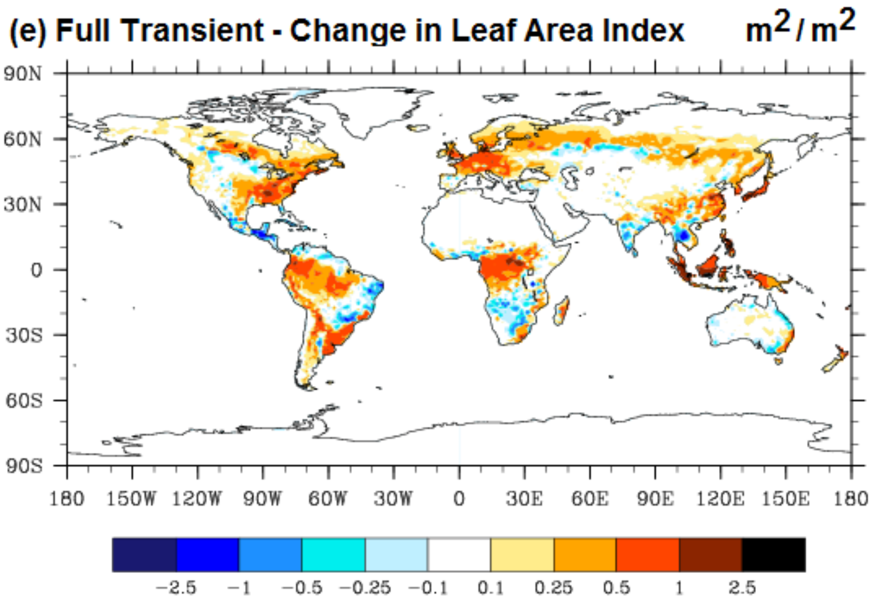


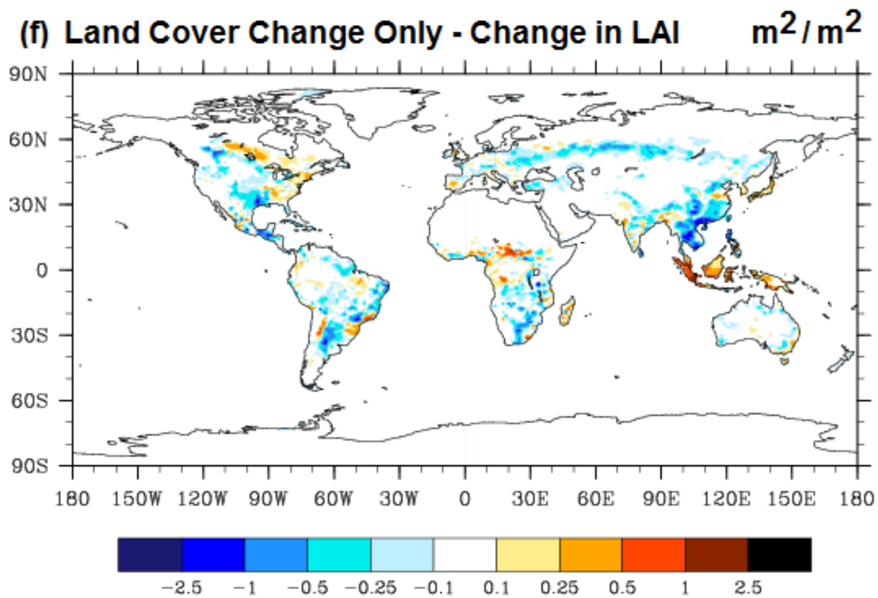
Wood harvest, cumulative % of grid cell



Peter Lawrence et al. (2012)

Simulated changes in Leaf Area Index 2005-1850





Historical simulation

CO_2
Climate
Nitrogen deposition
Land cover change

LAI ↗ except where crops expand

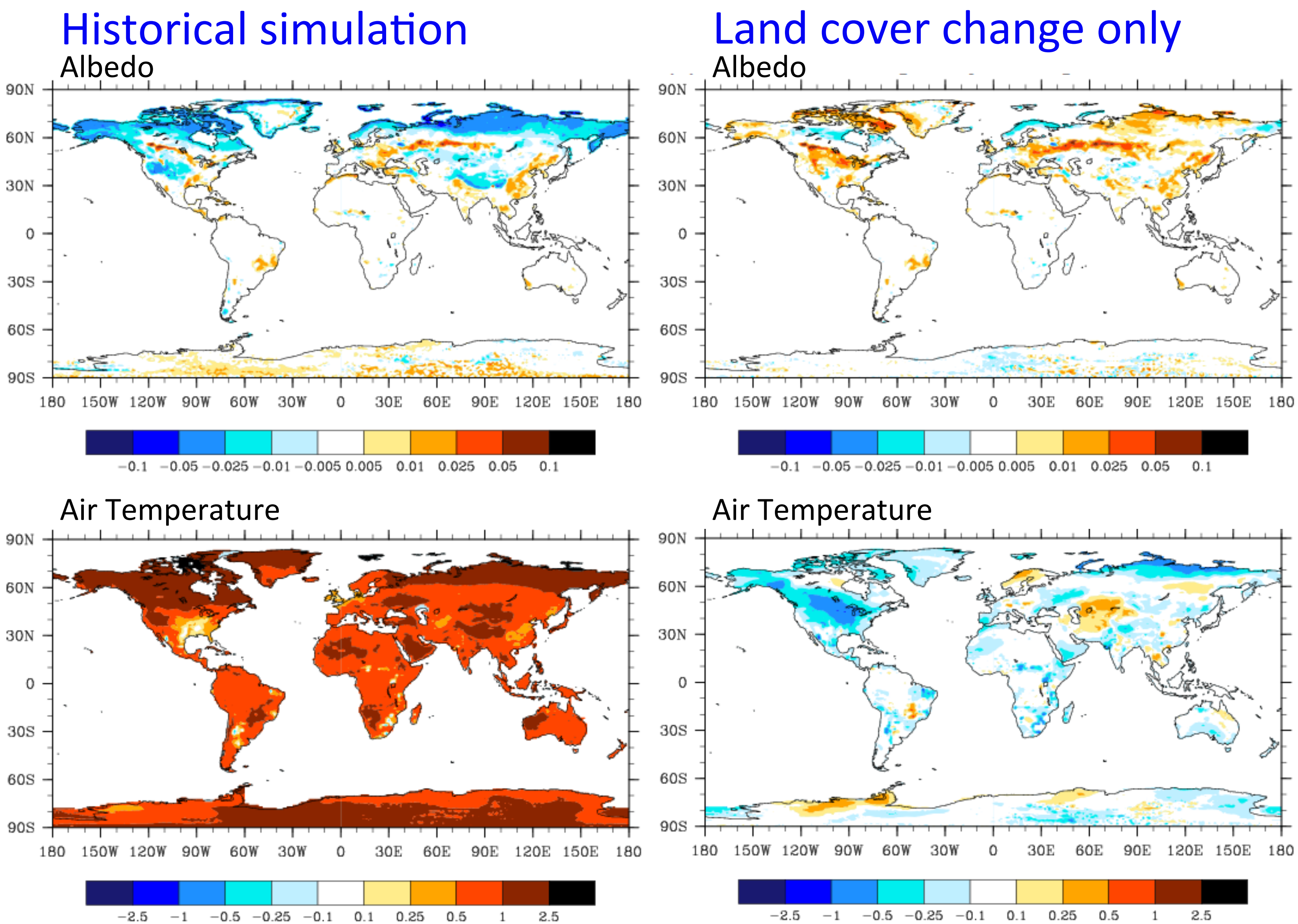
Single forcing simulation

Land cover change only

LAI ↘ except where reforestation

Peter Lawrence et al. (2012)

Simulated albedo & temperature changes



Peter Lawrence et al. (2012)

Effects of LULCC on 20th century temperature

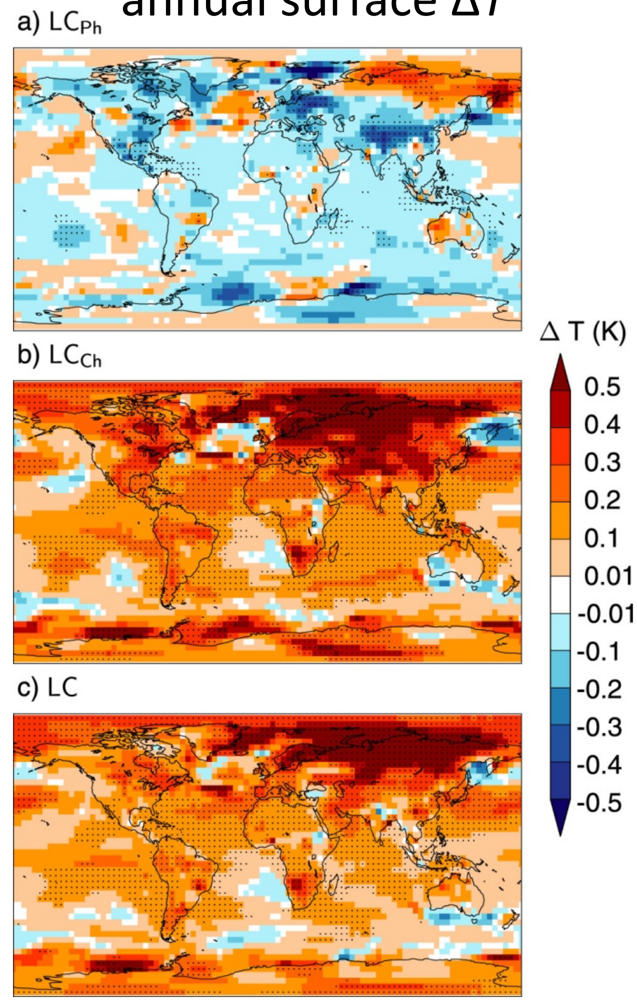
Prevailing paradigm…
Competing signals from deforestation:
surface albedo ↗ countered by
carbon emission ↗

annual surface Δ*T*

Biogeophysical
Weak global cooling (−0.03 °C)

Biogeochemical
Strong warming (0.16–0.18 °C)

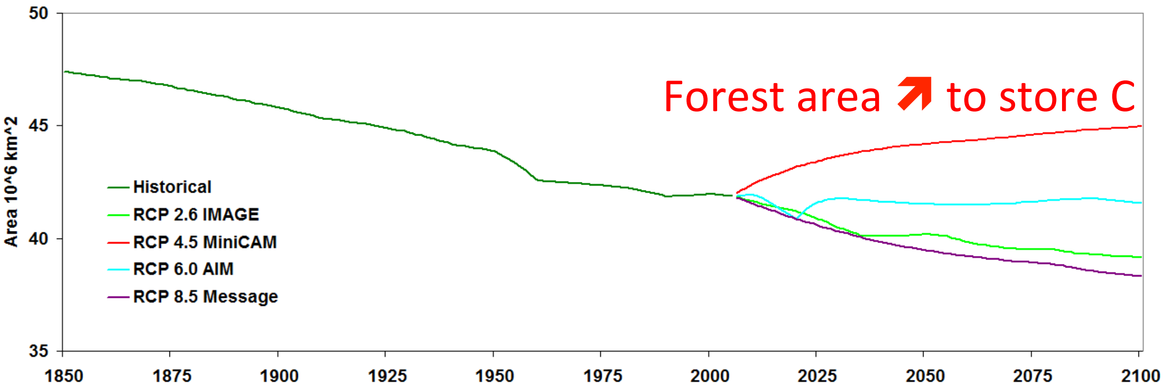
Net
Warming (0.13-0.15 °C)



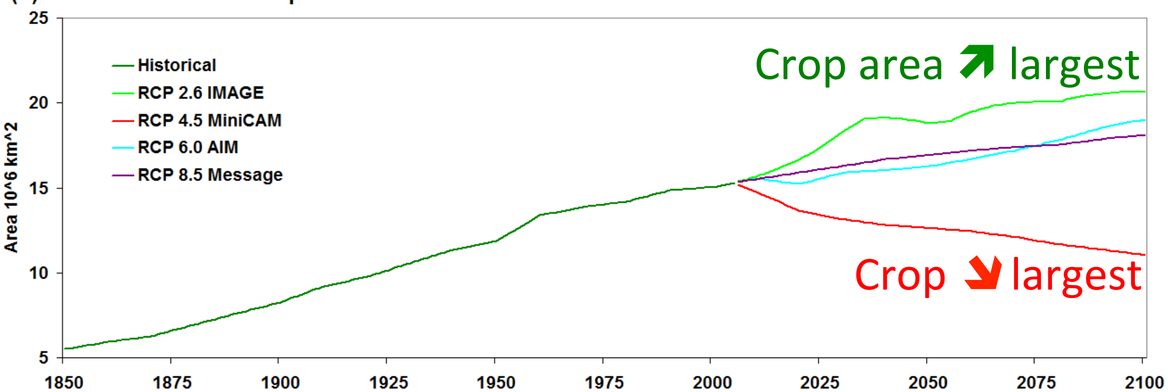
Pongratz et al. (2010) GRL

LULCC/LULM data out to 2100

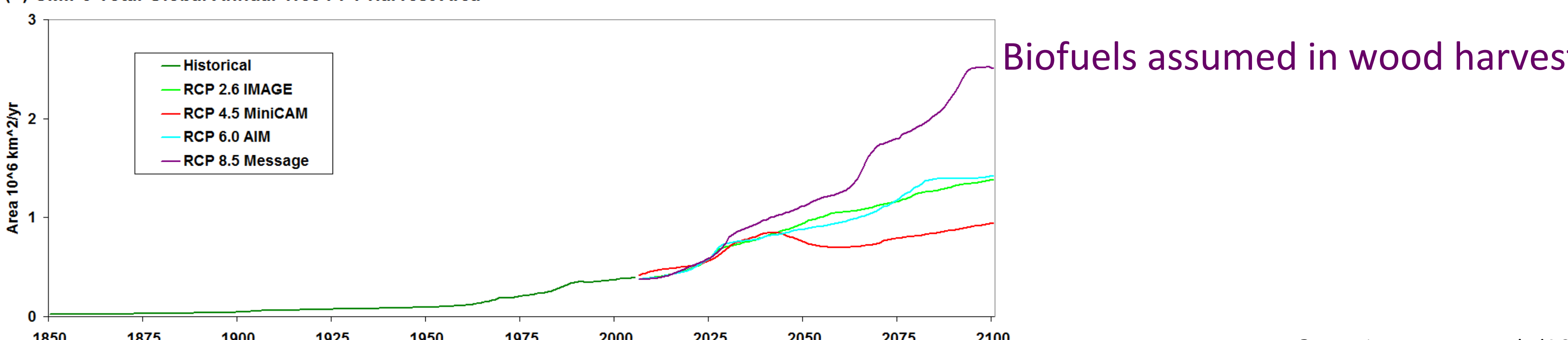
(a) CMIP5 Total Global Tree PFT Area



(b) CMIP5 Total Global Crop PFT Area

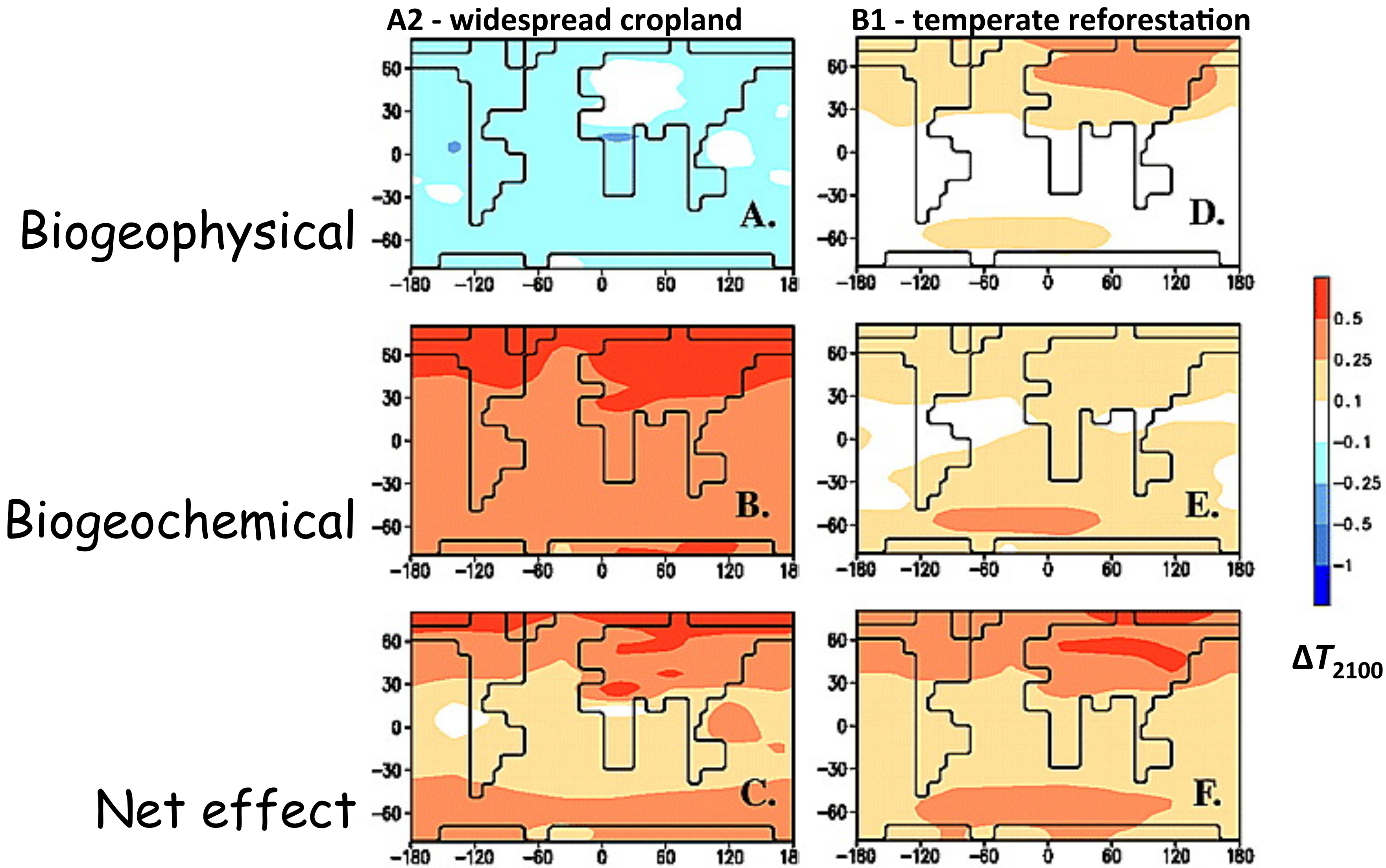


(d) CMIP5 Total Global Annual Tree PFT Harvest Area



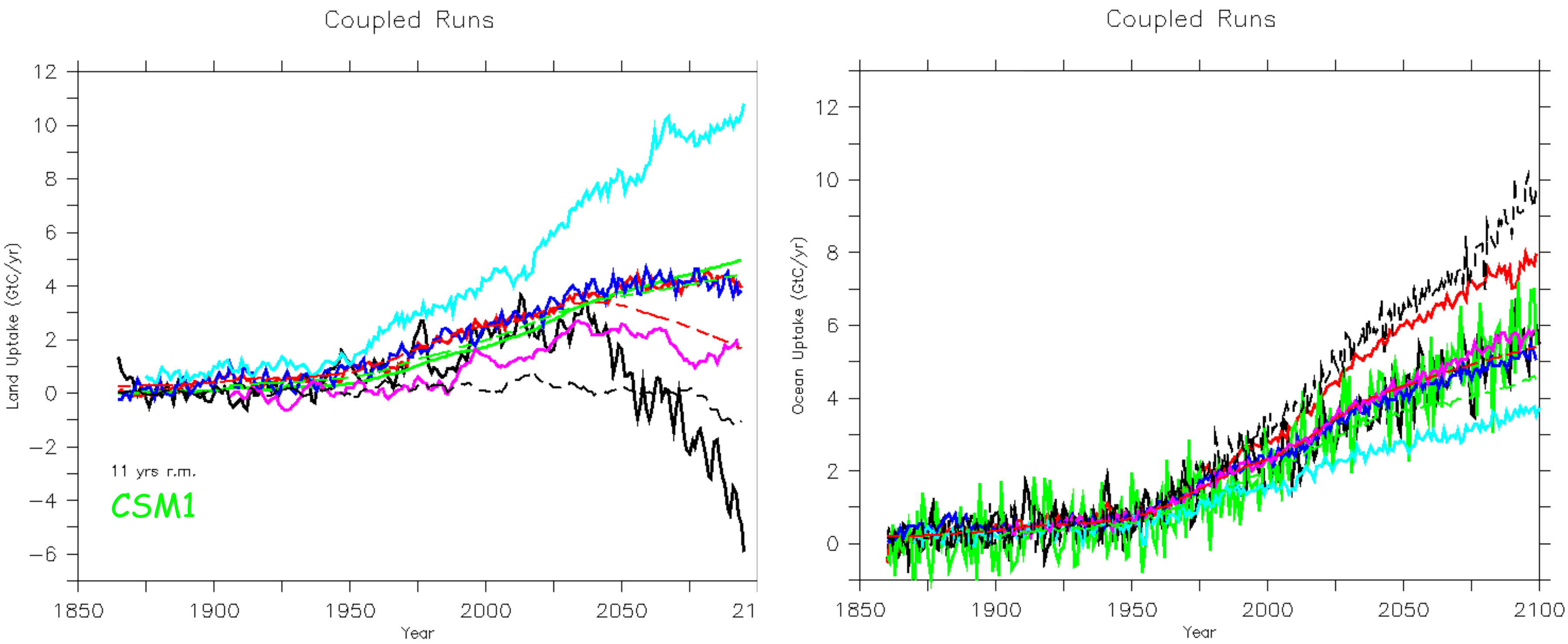
Peter Lawrence et al. (2012)

Effects of LULCC on 21st century temperature



Sitch *et al.* (2005)

Carbon model intercomparison

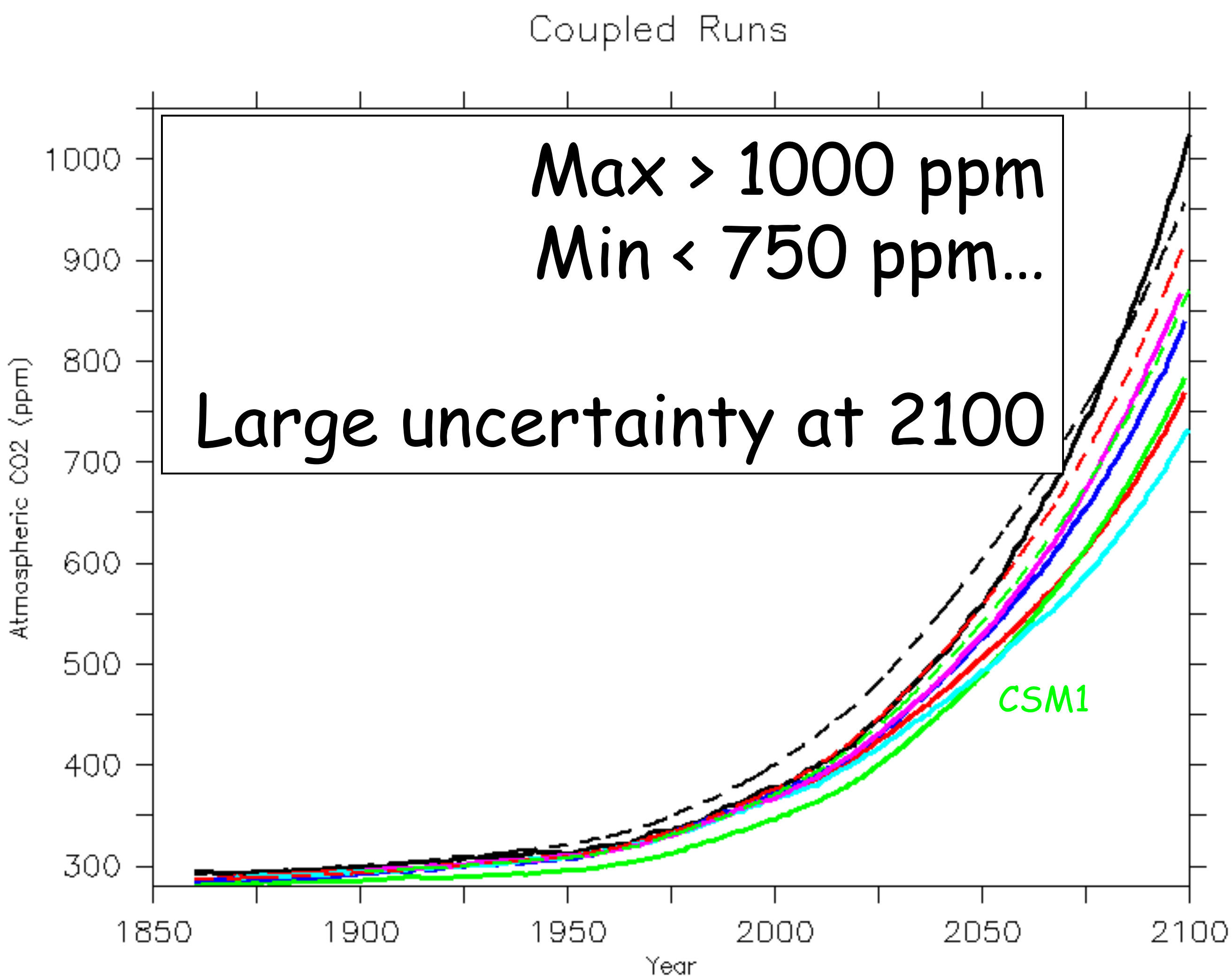


Uncertainty arises from differences in terrestrial fluxes

- One model simulates a large source of carbon from the land
- Another simulates a large terrestrial carbon sink
- Most models simulate modest terrestrial carbon uptake
- Terrestrial carbon cycle can be a large climate feedback
- Considerable more work is needed to understand this feedback

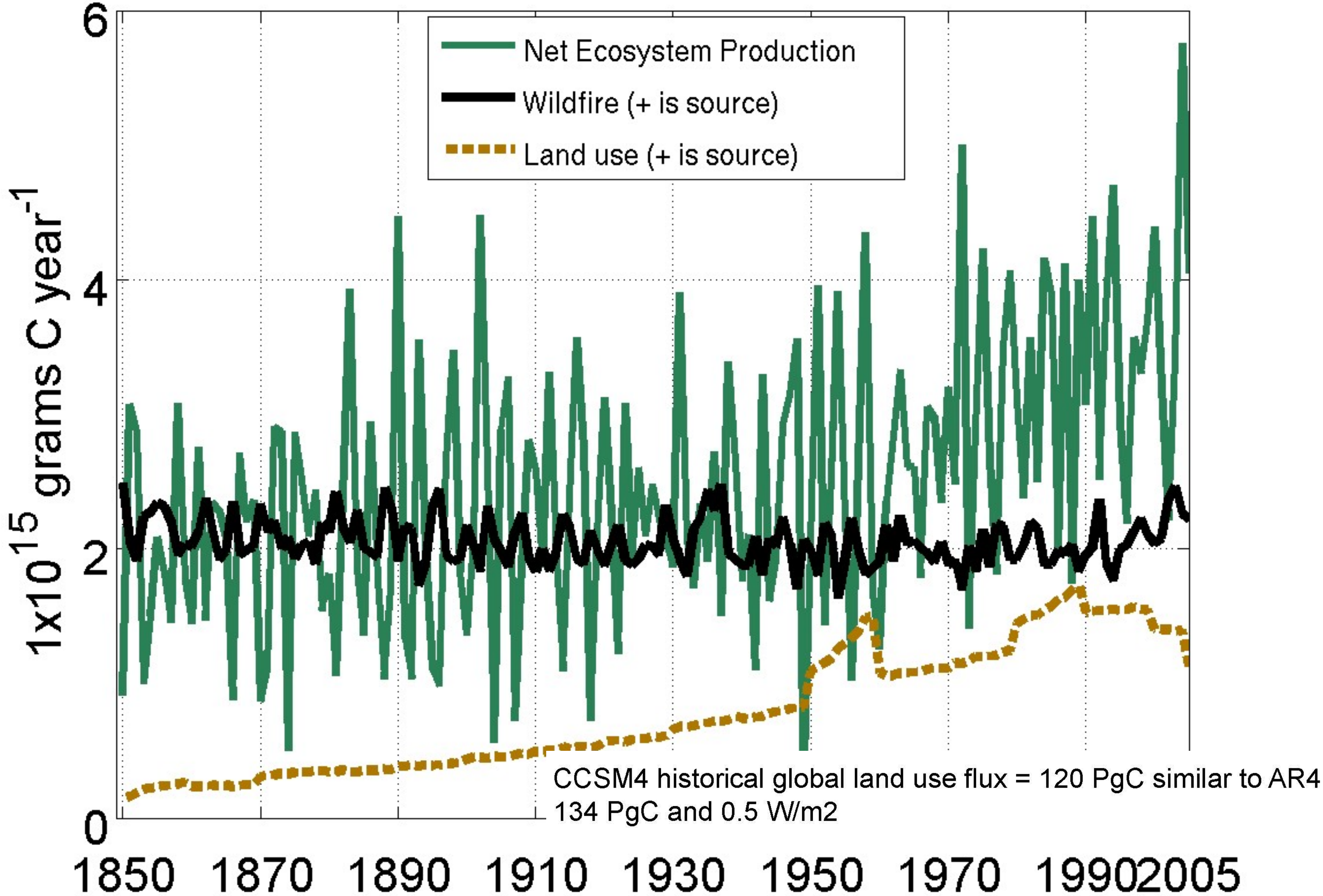
Figures courtesy of Pierre Friedlingstein

Carbon model intercomparison

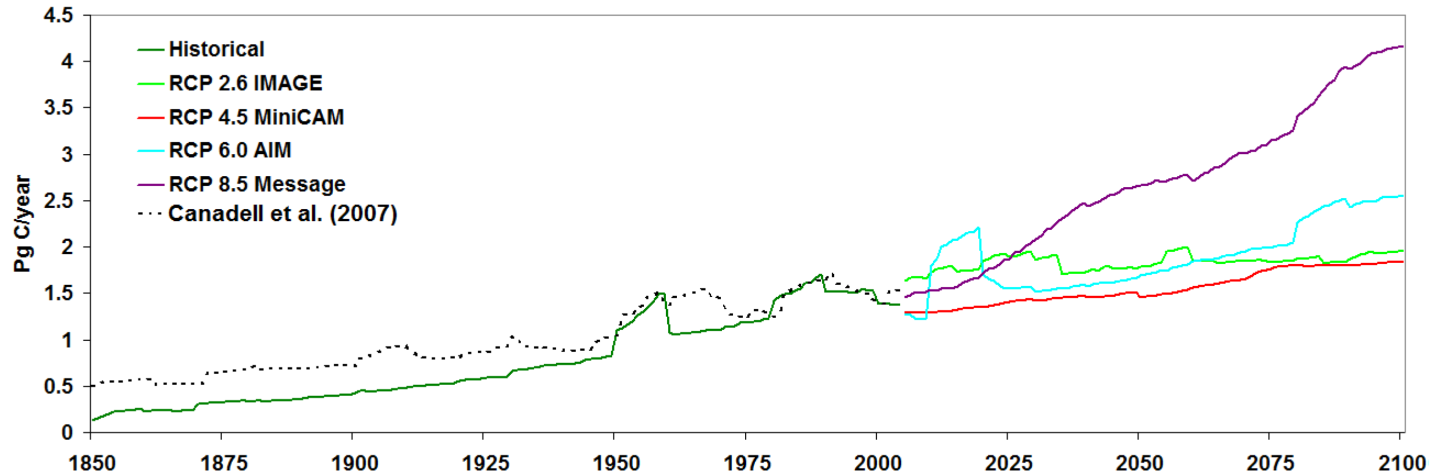


courtesy of Pierre Friedlingstein

LAND TOTAL CARBON FLUXES



CLM/CESM simulated LULCC carbon flux to atmosphere



consistent with estimated land use flux over the historical period

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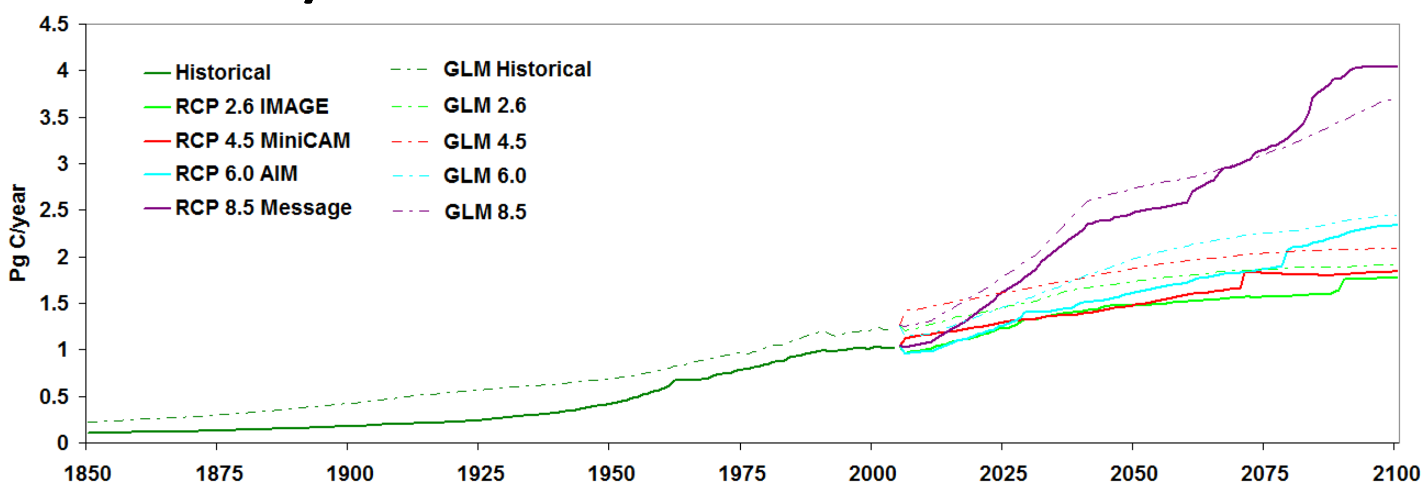
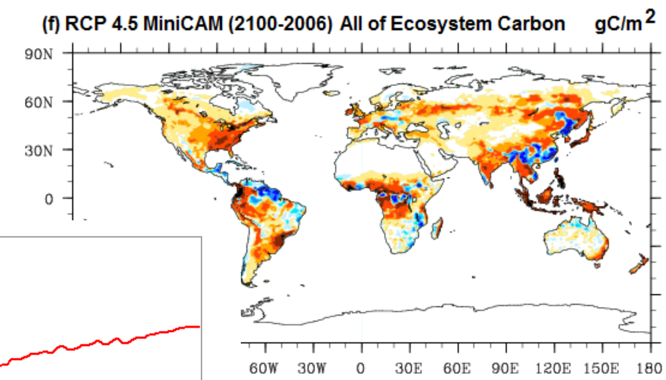
CLM/CESM simulated wood harvest flux

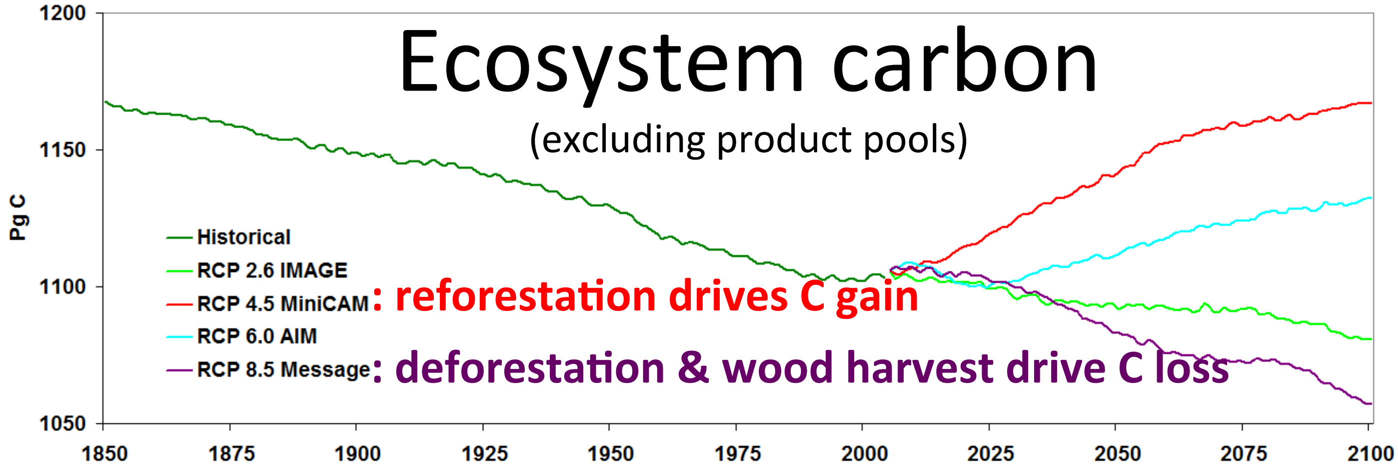


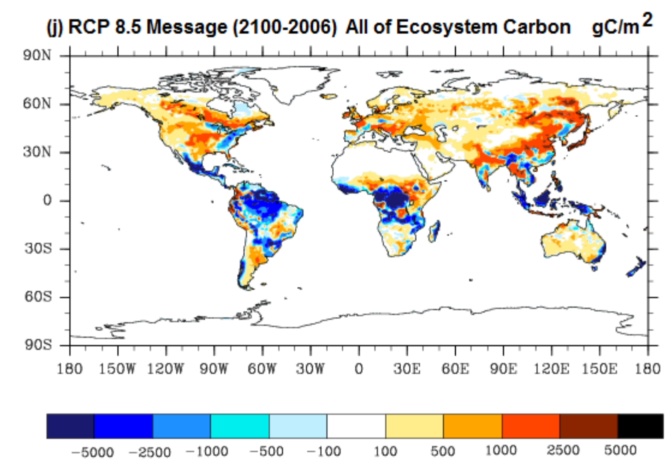
consistent with estimated wood harvest flux over the historical period and the RCPs

Peter Lawrence et al. (2012)

Huh, so land use choices matter!







Peter Lawrence et al. (2012)

GEOPHYSICAL RESEARCH LETTERS, VOL. 37, L07401, doi:10.1029/2010GL042430, 2010

Quantifying carbon-nitrogen feedbacks in the Community Land Model (CLM4)

Gordon B. Bonan[1] and Samuel Levis[1]

Received 12 January 2010; revised 21 February 2010; accepted 26 February 2010; published 2 April 2010.

[1] Recent studies indicate that nitrogen biogeochemistry affects the carbon cycle feedback in climate simulations. We use the Community Land Model version 4 (CLM4) with carbon-only and carbon-nitrogen biogeochemistry to assess the influence of nitrogen on the land carbon budget for 1973–2004. Carbon-only simulations show that the carbon gain from increasing atmospheric CO_2 (the concentration-carbon feedback) is four times greater than the warming-induced carbon loss (the climate-carbon feedback) over the period 1973–2004. Nitrogen reduces both feedbacks compared with carbon-only biogeochemistry. The decrease in the concentration-carbon feedback is three times greater than the effect on the climate-carbon feedback. Thus, the influence of nitrogen on the CLM4 concentration-carbon feedback is of greater importance for near-term climate change simulations than its effect on the climate-carbon feedback. Furthermore, the land use carbon flux greatly exceeds these carbon-nitrogen biogeochemical feedbacks. **Citation:** Bonan, G. B., and S. Levis (2010), Quantifying carbon-nitrogen feedbacks in the Community Land Model (CLM4), *Geophys. Res. Lett.*, *37*, L07401, doi:10.1029/2010GL042430.

[3] This interpretation of the terrestrial c
formed from models that do not include c
biogeochemistry. Two carbon cycle-climate
tions of future climate change with carbon
geochemistry find that nitrogen decreases β
γ_L from negative to positive [*Sokolov et al.*, 2
et al., 2009]. Limited mineral nitrogen avail
the increase in plant productivity from the
carbon feedback. Conversely, warming inc
position of organic material and nitrogen
stimulating plant productivity. Other carbon-
lations for the twentieth and twenty-first cent
find that β_L decreases and carbon loss
decreases when nitrogen is included, but th
negative [*Zaehle et al.*, 2010a, 2010b]. Thu
nitrogen to change the climate-carbon feedbac
($-\gamma_L$) to negative ($+\gamma_L$) is unclear, as is the
tance of β_L and γ_L to the overall land carbon

[4] Here, we report simulations using th
Land Model version 4 (CLM4) for the late tw
forced with historical meteorology, CO_2
atmospheric nitrogen deposition, and land us

1^{st} set of Conclusions

Broad conclusions

- LULM matters at the regional scale => include in detection & attribution
- LULM choices will likely influence future climate

Biogeochemistry

- Land use flux & wood harvest flux **both** contribute warming

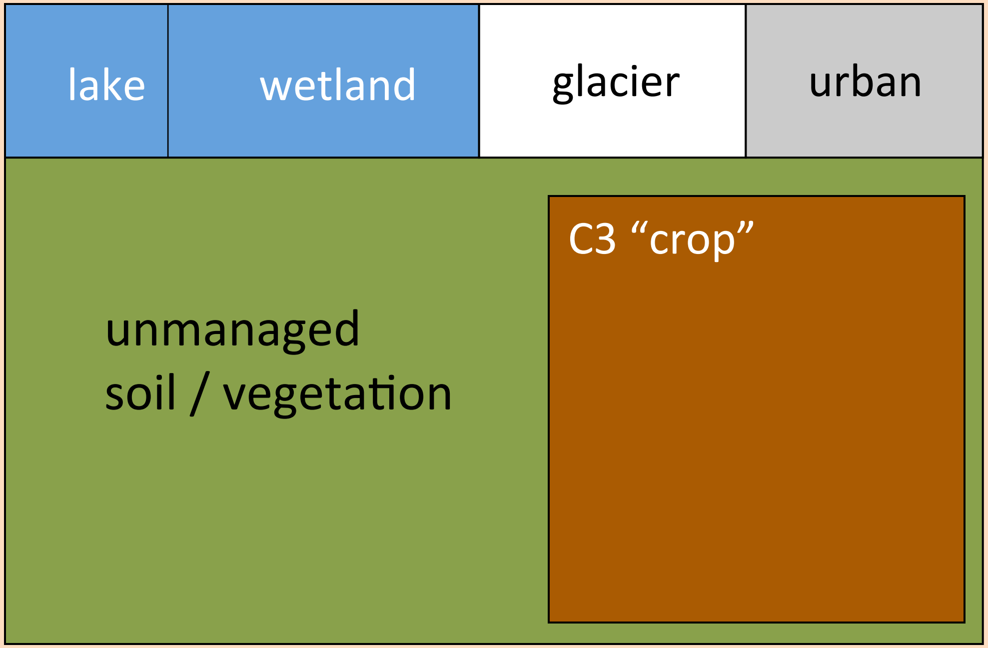
Biogeophysics

- Higher albedo of croplands & grasslands cools climate

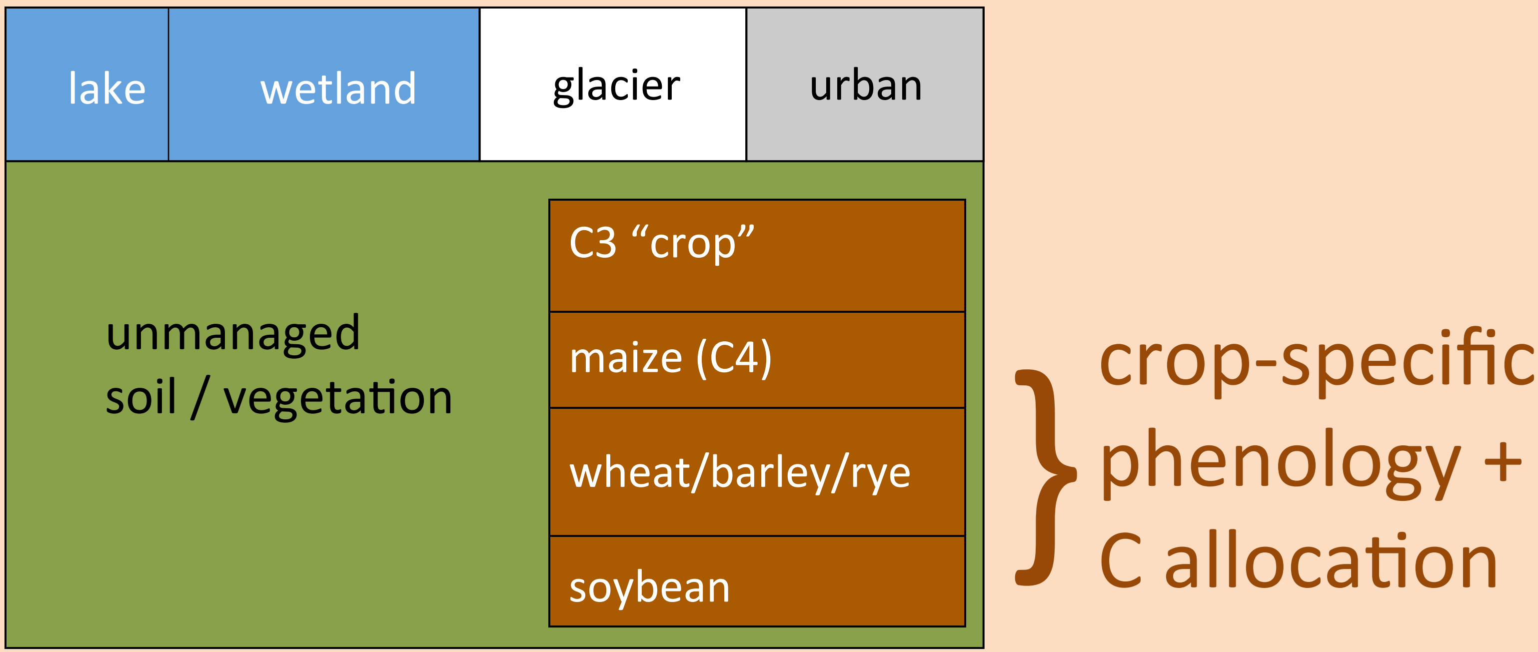
Biogeophysical vs. BGC effects & Managed vs. Unmanaged vegetation

- Biogeochemical effects from LULM dominate to a first order
- So human behavior is our greatest uncertainty in future scenarios

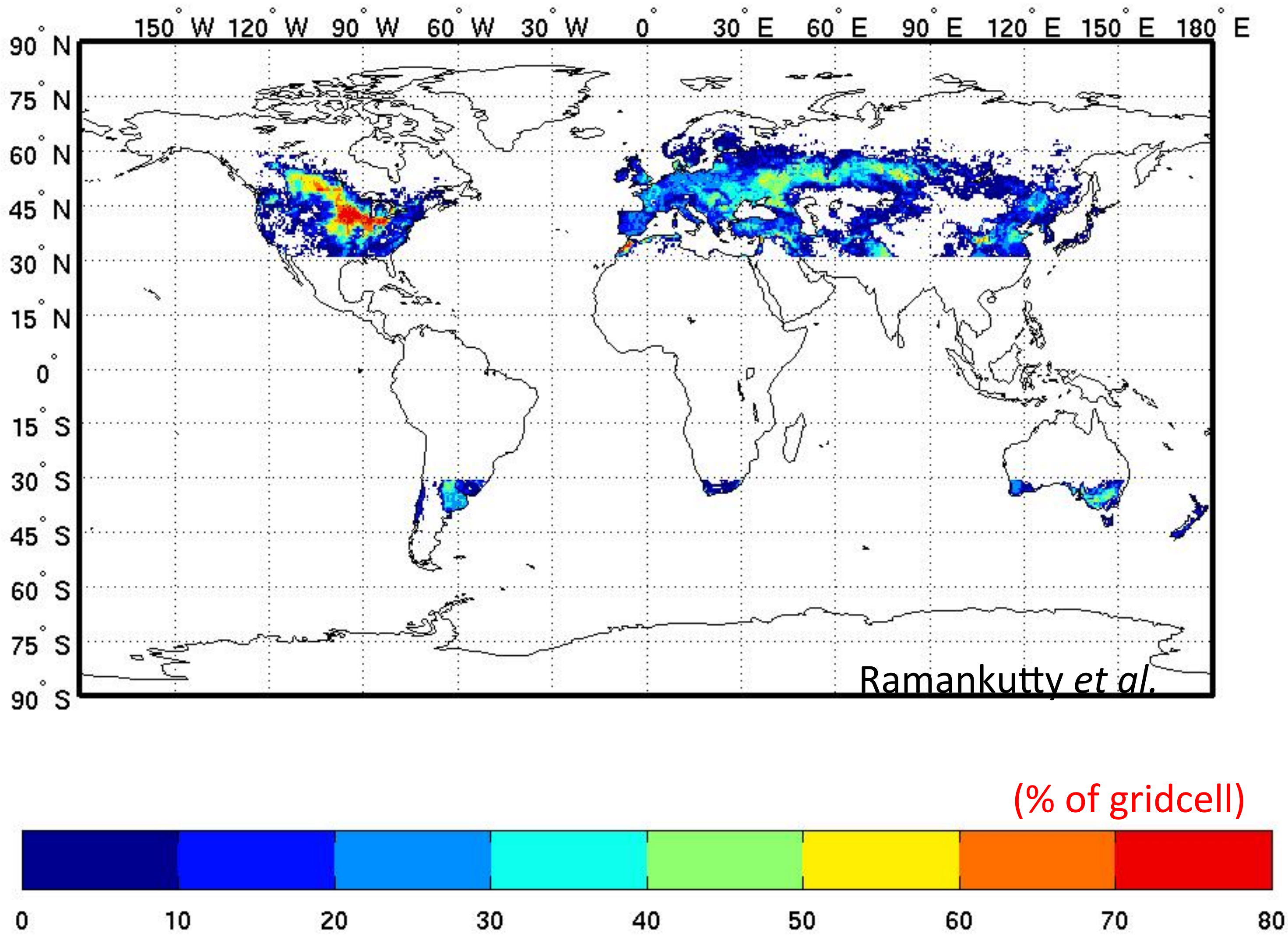
a CLM grid cell (default)



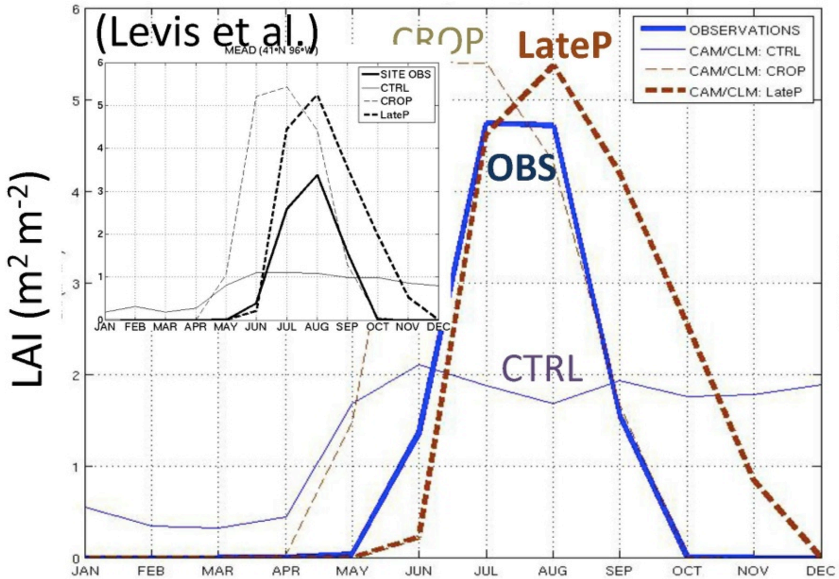
a CLM grid cell
with interactive crop management



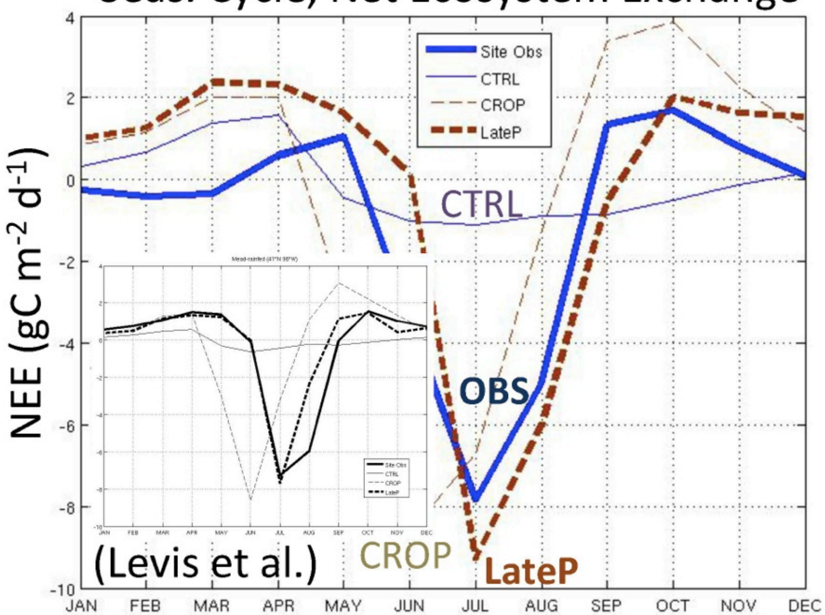
Maize + Soybean + Temperate Cereals



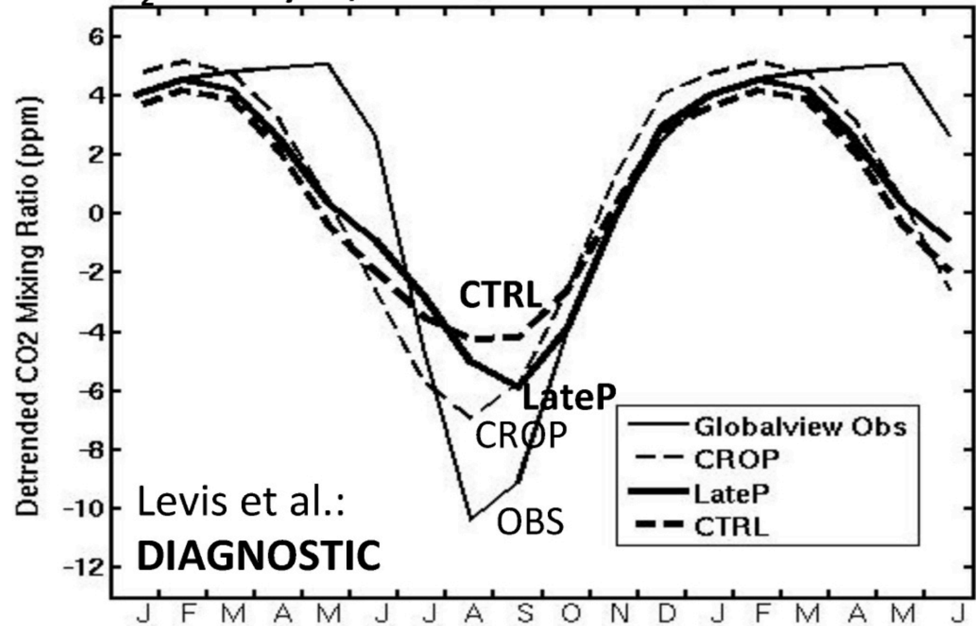
Bondville, IL (40°N 88°W) Leaf Area Index



Seas. Cycle, Net Ecosystem Exchange



CO_2 Seas. Cycle, Barrow (71.3°N 156.6°W)



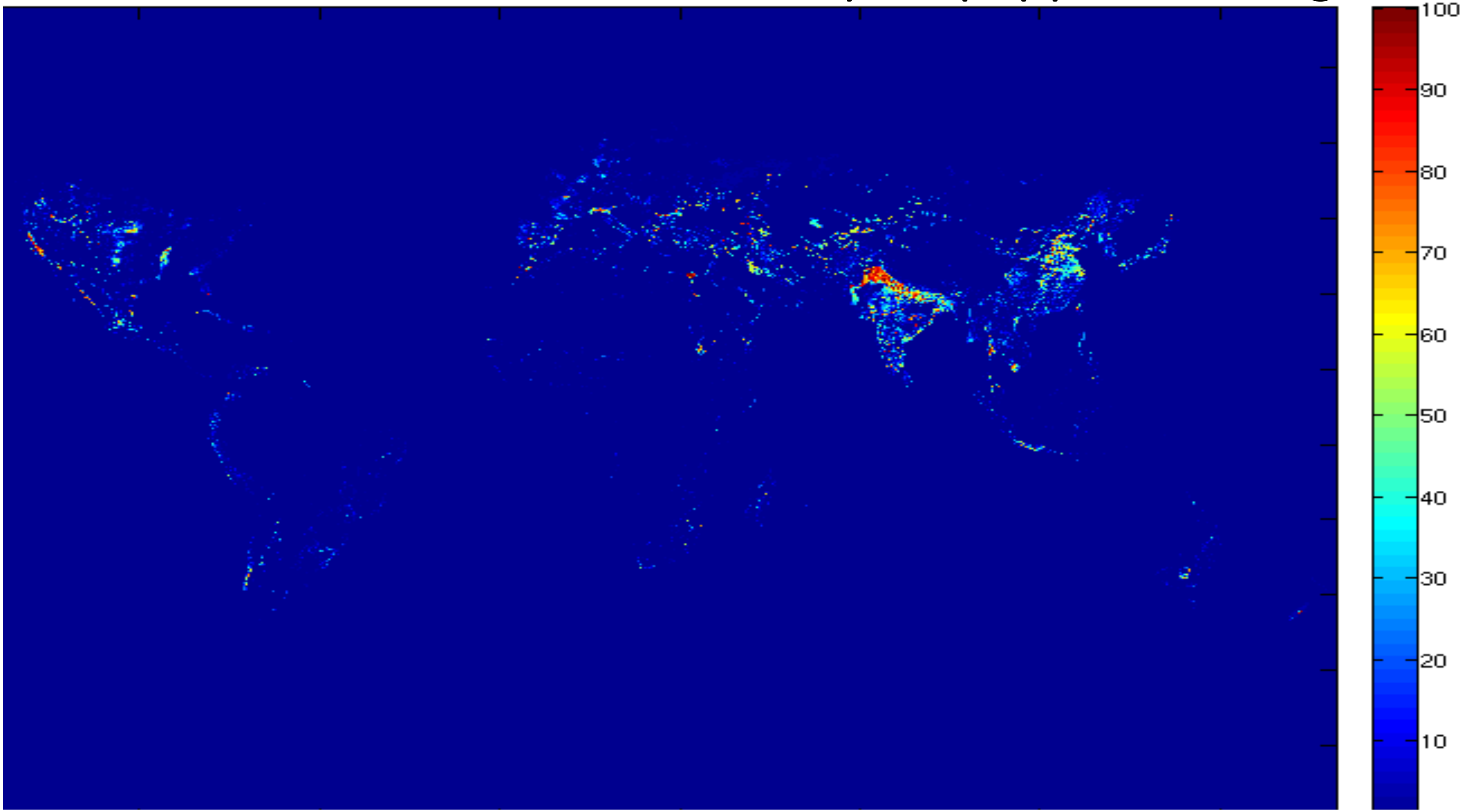
2nd set of Conclusions

- Interactive crop management in the CLM
  - Better simulated annual cycle of crop LAI
  - Better annual cycle of the NEE (and CO_2)
  - Promising for simulations with interactive CO_2
  - Better summer precip over MW N. America, too

- Human dimensions: new frontier in CESM research
  - LULM & urbanization: steps in that direction
  - Still also resolving more basic issues: biogeophys. & bgc
  - Coupling ESMs and IAMs in the not so distant future…

forms of land management other than planting & harvesting: irrigation, fertilization, tillage, crop rotation, multi-cropping

% of crops equipped for irrigation



Schlesinger (1991)

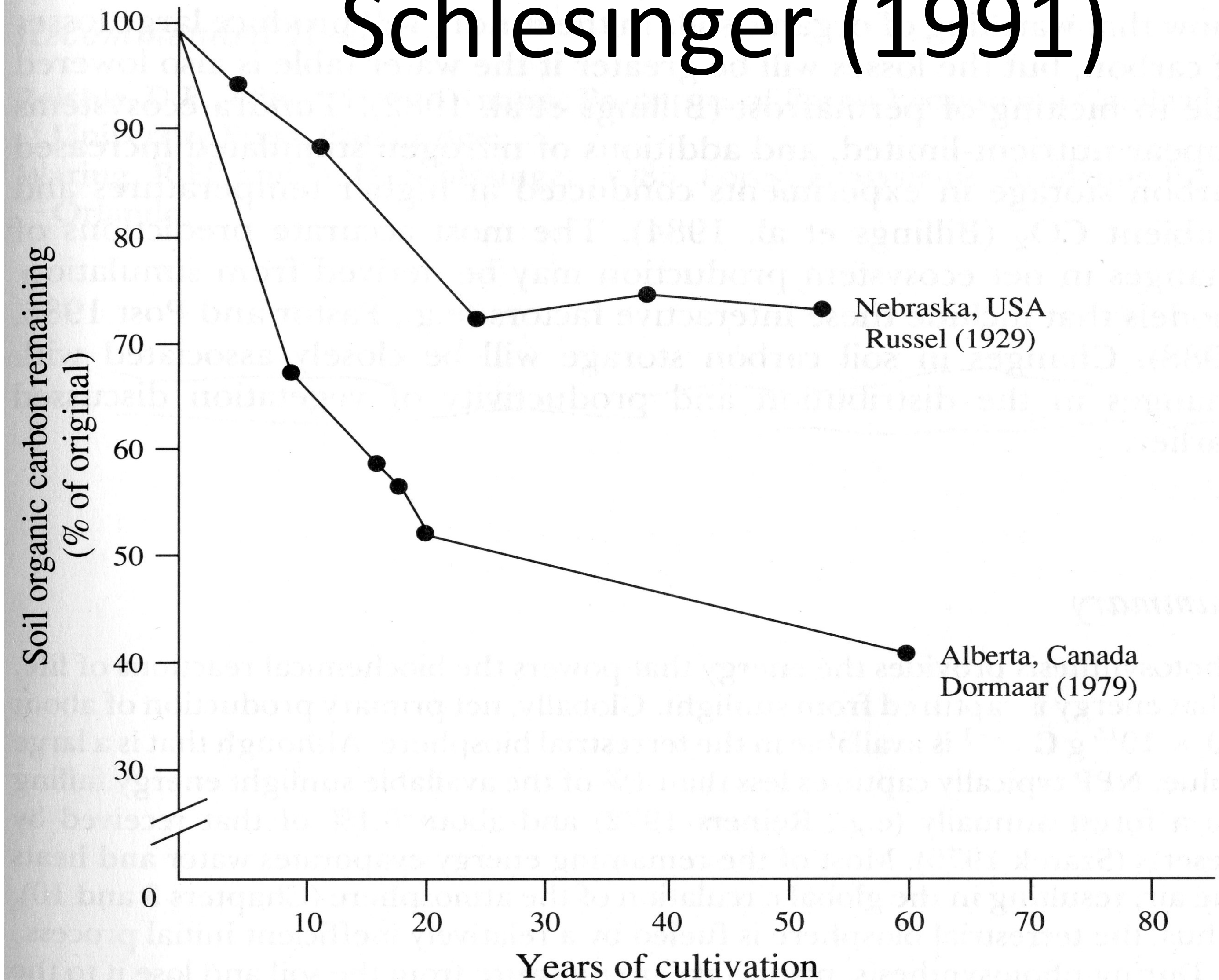
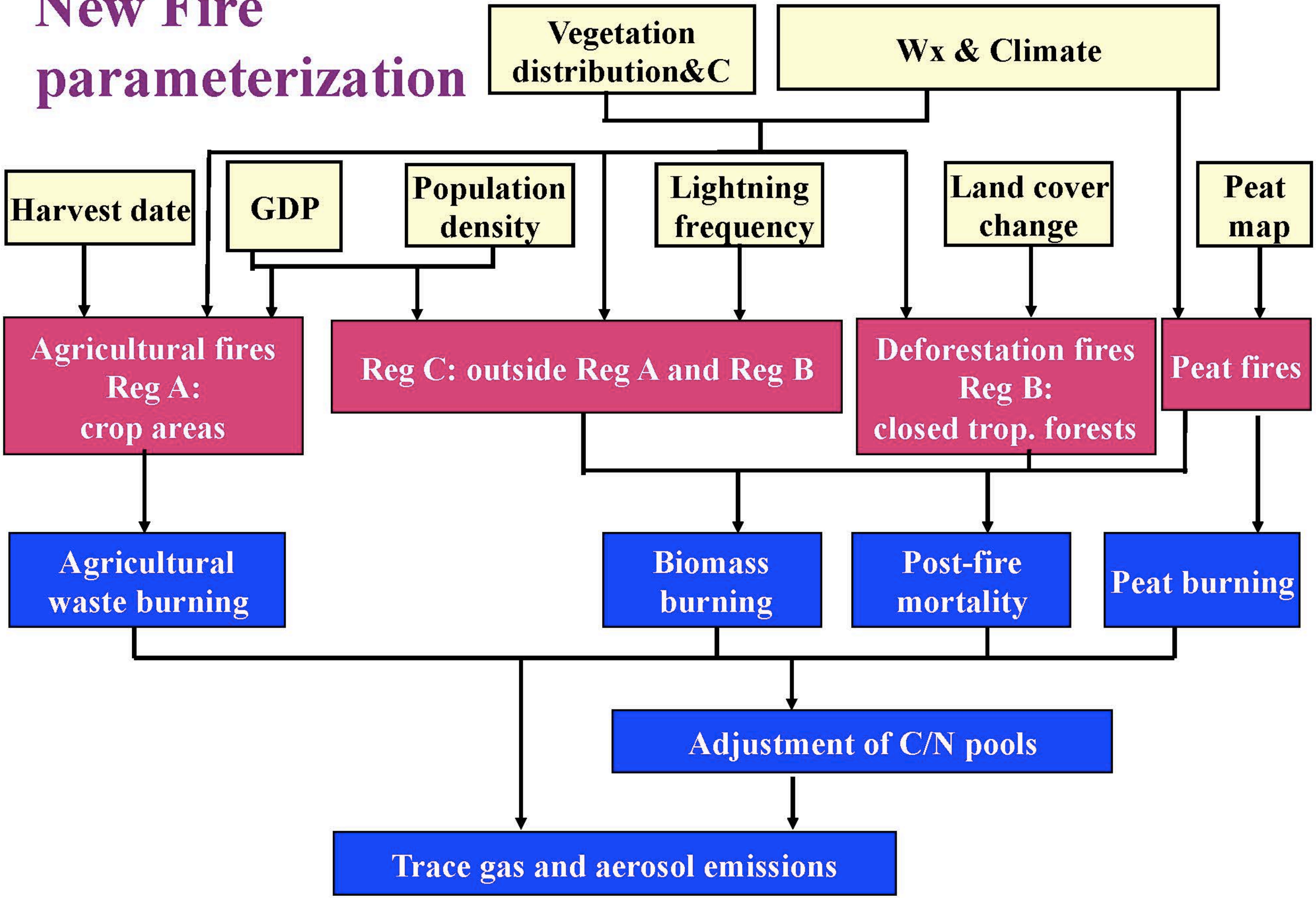


Figure 5.18 Decline in soil organic matter following conversion of native soil to agriculture for two grassland soils.

New Fire parameterization



questions