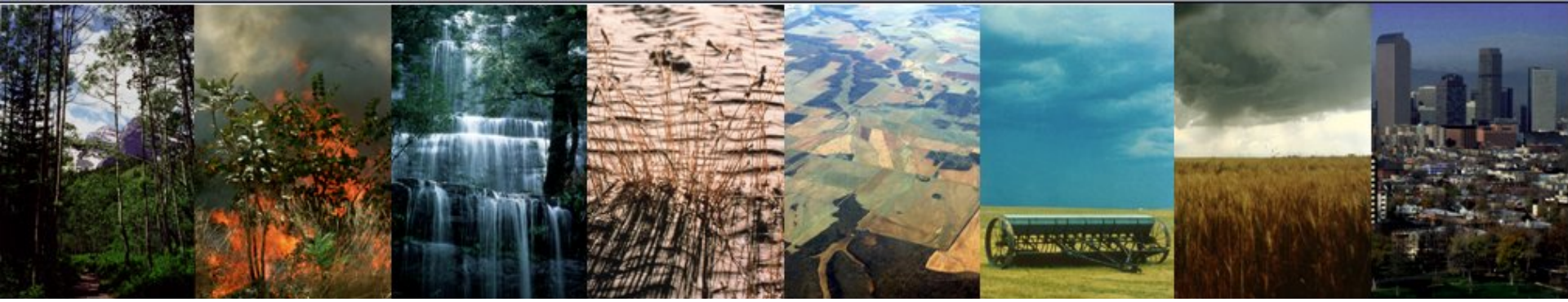


Community Land Model overview focus on ecosystem modeling

Sam Levis
Terrestrial Sciences Section
CGD/NESL/NCAR

CESM Tutorial 2013

NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH is sponsored by the National Science Foundation NSF
U.S. DEPARTMENT OF ENERGY | Office of Science

CLM overview: outline

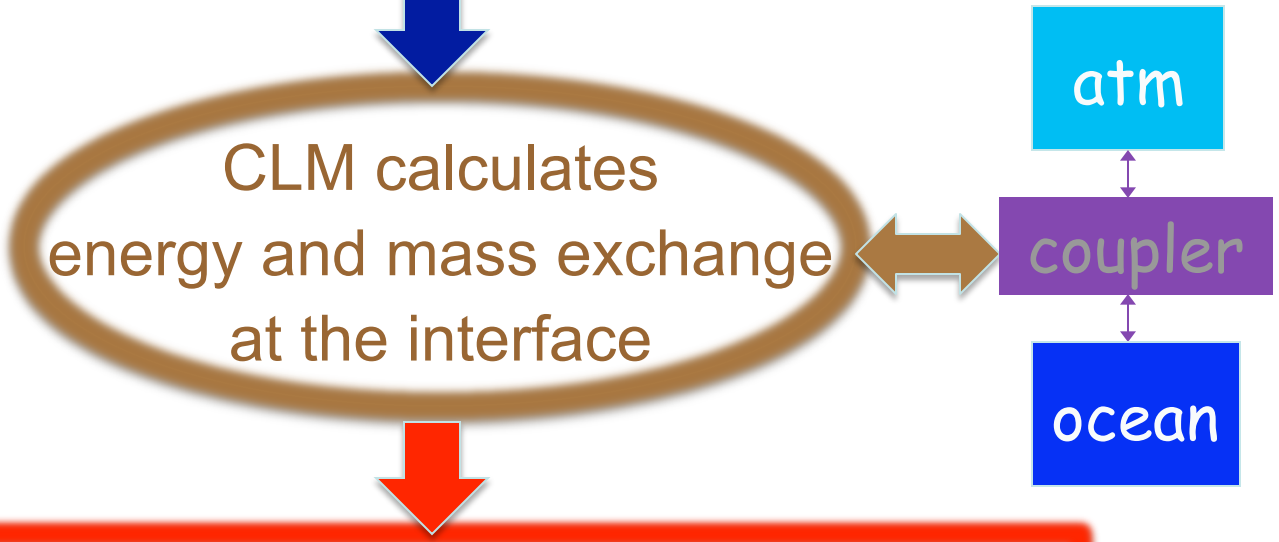
- CLM basics
- Sample input and output
- Application: climate-veg interactions

CLM overview: basics

- land component of the CESM
- source code: /models/lnd/clm/src/ { clm4_0, clm4_5 }
- input data: meteorology + surface
- output data
- cesm scripts: for clm offline… I compsets
- documentation: on the web site

near-surface atmosphere data (sim/obs) *S*, *L*, *T*, *q*, *u*, *v*, *P*, *p*, [CO_2]

surface data (sim/obs) veg., soil, other data (eg, %lake)



H, λE, *G* heat fluxes

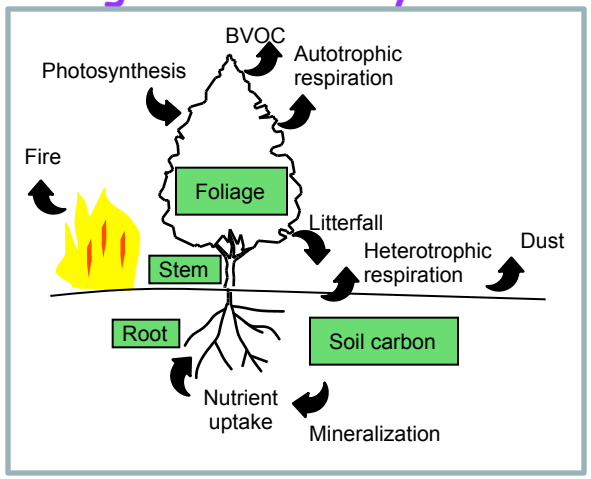
reflected & emitted radiation fluxes

soil, snow, plant *T* and *W* …river flow

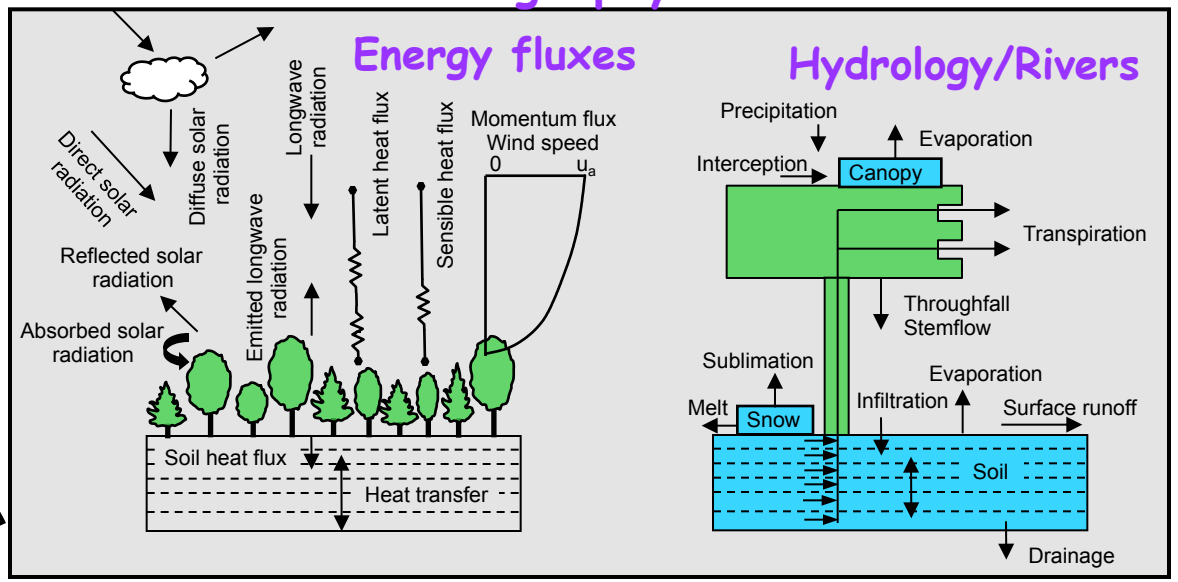
C & N fluxes…BVOC & dust emissions

Current-generation land models

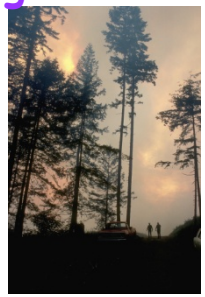
Biogeochemical Cycles



Biogeophysics



Climate change



Establishment

Climate change

Disturbance

Vegetation dynamics

Competition

Growth

Deforestation

Land use

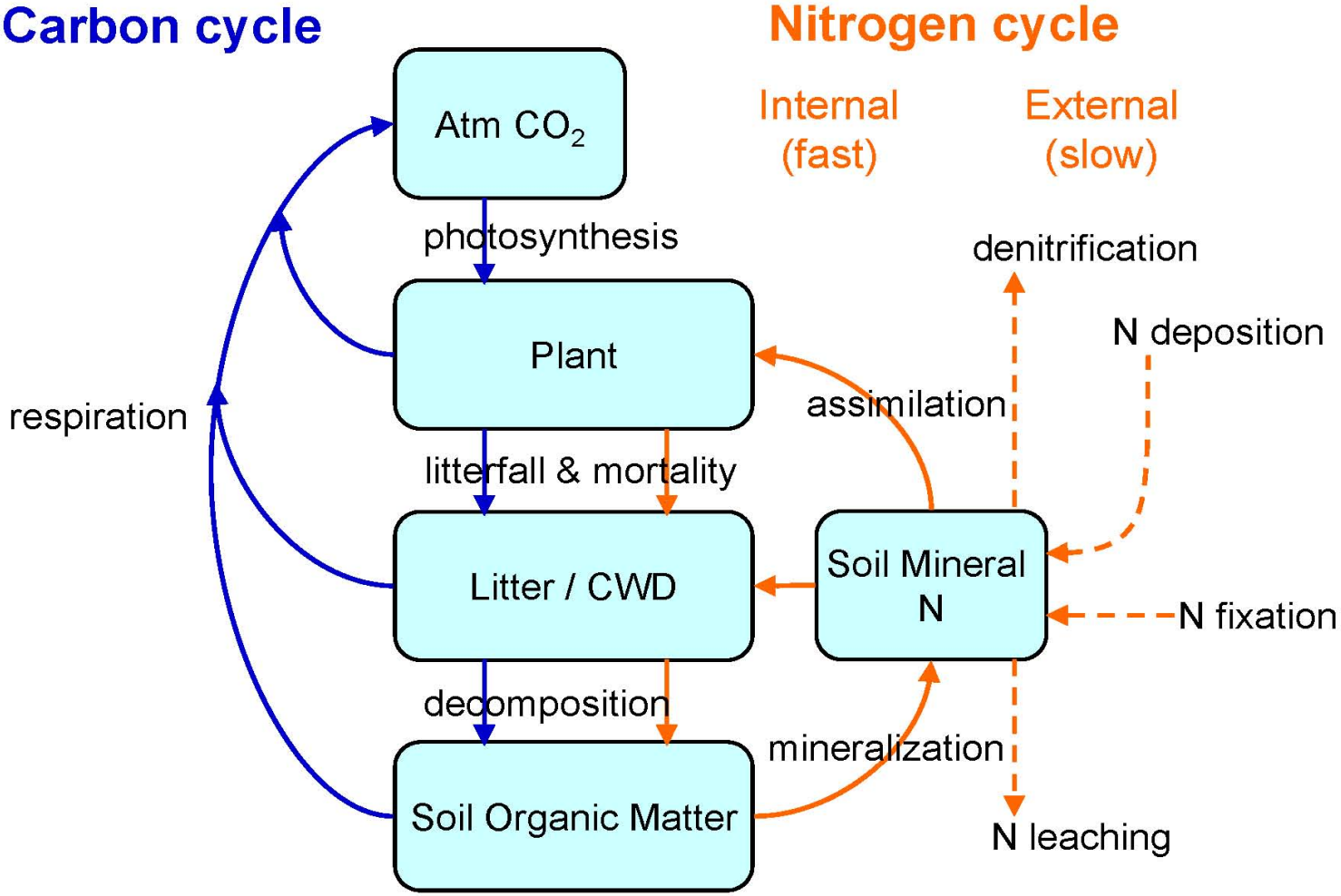
Afforestation

Urbanization

Land Management

Ice sheets

Beyond CLM-SP: BGC in the CLM



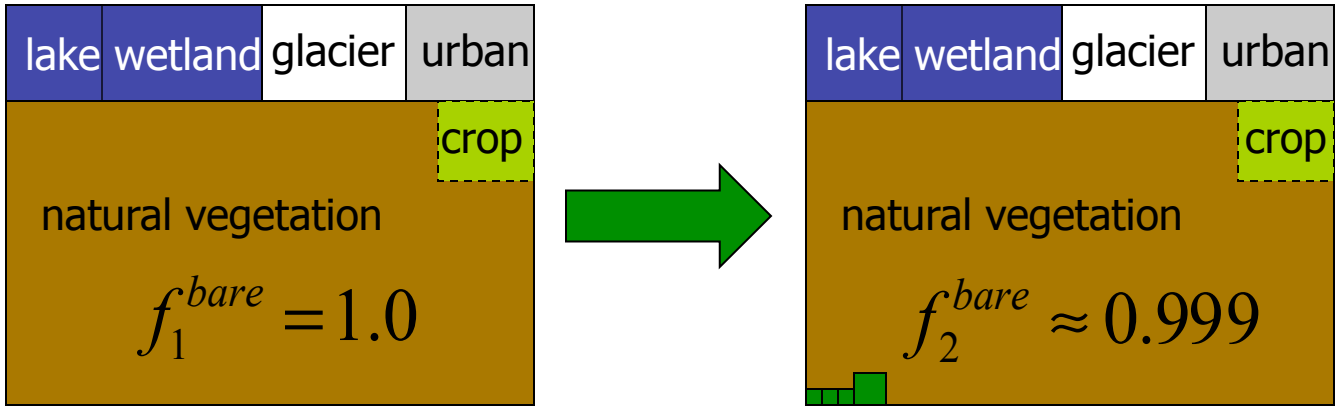
All these processes are affected by and may also affect the physics

Thornton *et al.*

Beyond CLM-SP: Dynamic Vegetation in the CLM

Year 1:
Bioclimatology accumulators

End of year 1:
Establishment



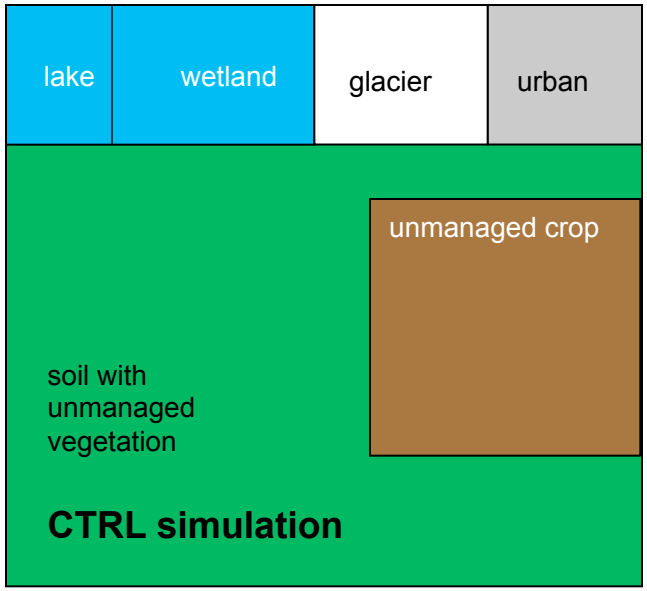
Year 2+:
Bioclimatology accumulators
Biogeochemistry:
Photosynth., respiration, growth, mortality

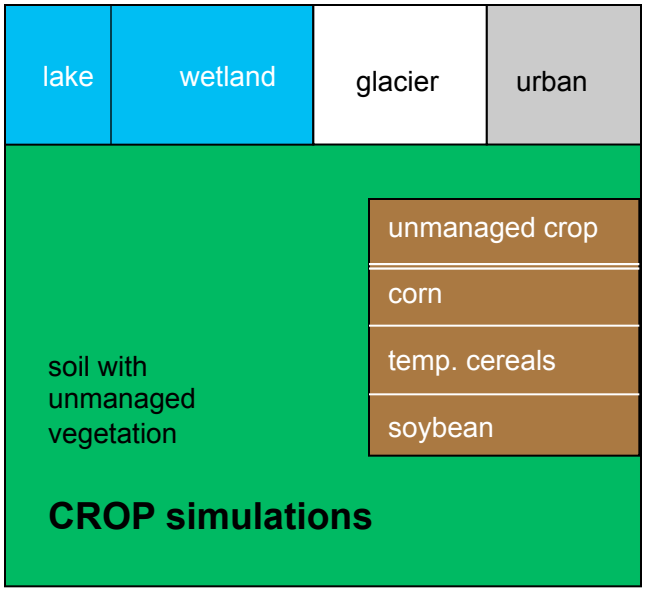
End of year 2+:
Establishment
Competition for Light (space)

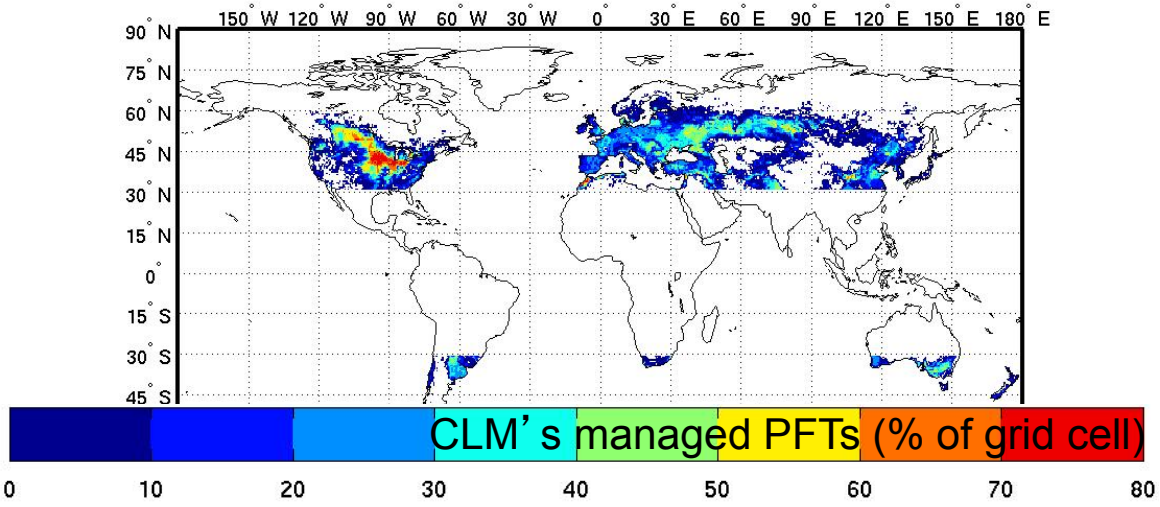
All these processes are affected by and may also affect the physics

Levis *et al.*

Beyond CLM-SP: interactive crop management







Levis *et al.*

Subroutine Tree

- Initialize
- Time stepping loop -

Surface radiation

Soil fluxes …Urban fluxes

Canopy fluxes …Lake fluxes

Dust emission …BVOC emission

BGC

Hydrology …Snow

C and N cycles …Balance check

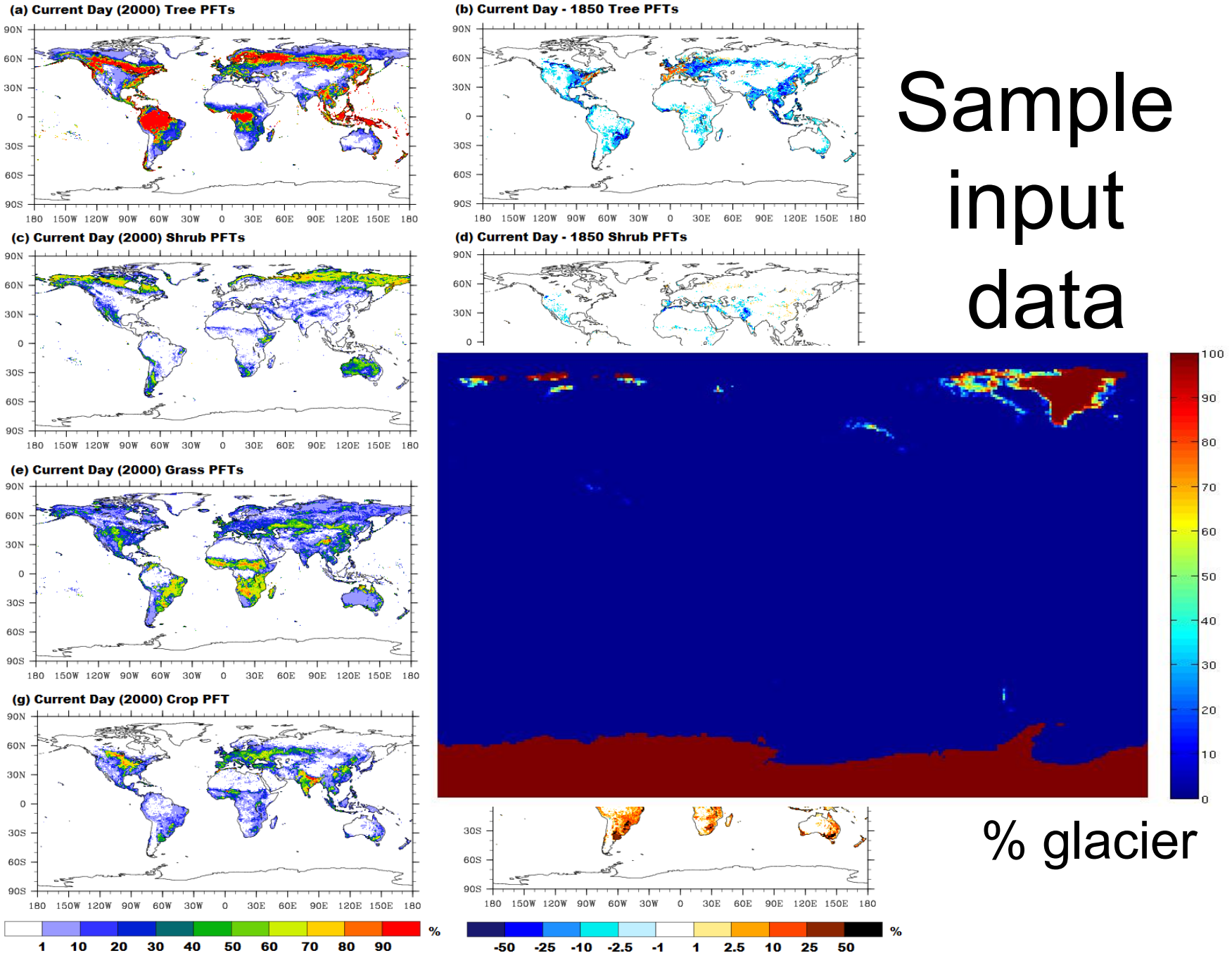
Surface albedo …River flux

Dynamic vegetation

write history and restart data - - - - - - - - - - - - - -

CLM overview: outline

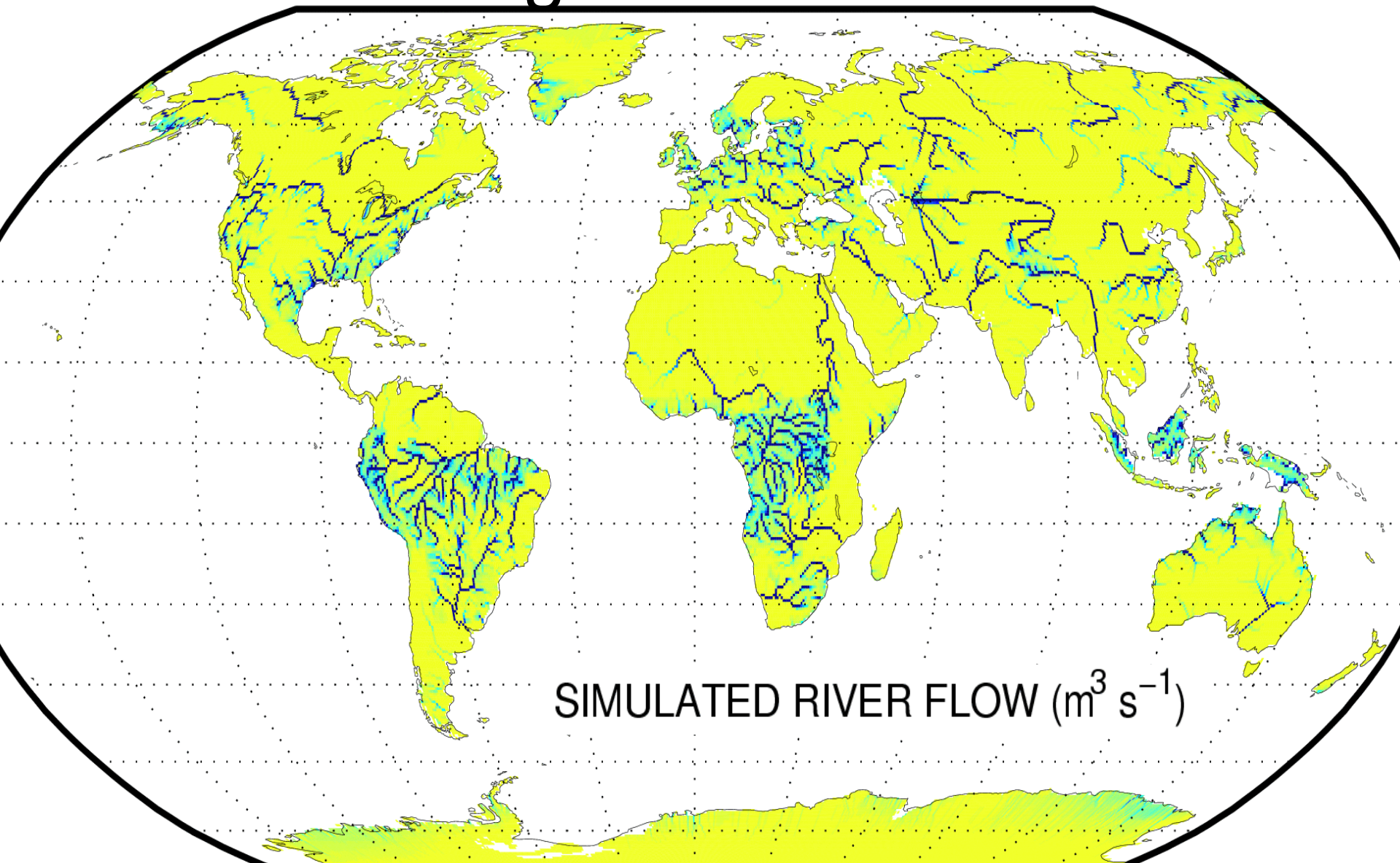
- CLM basics
- ➢ Sample input and output
- Climate-vegetation interactions

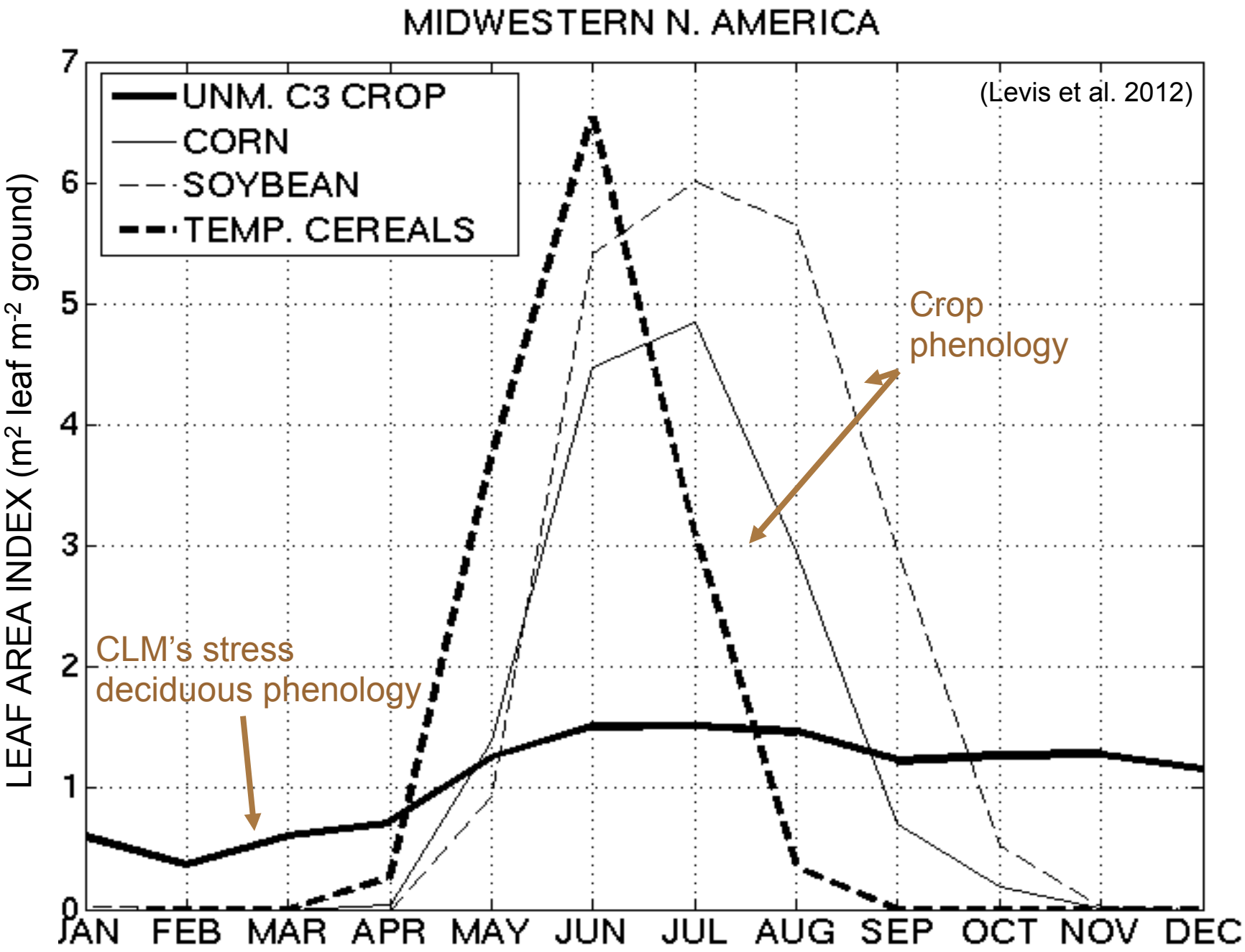


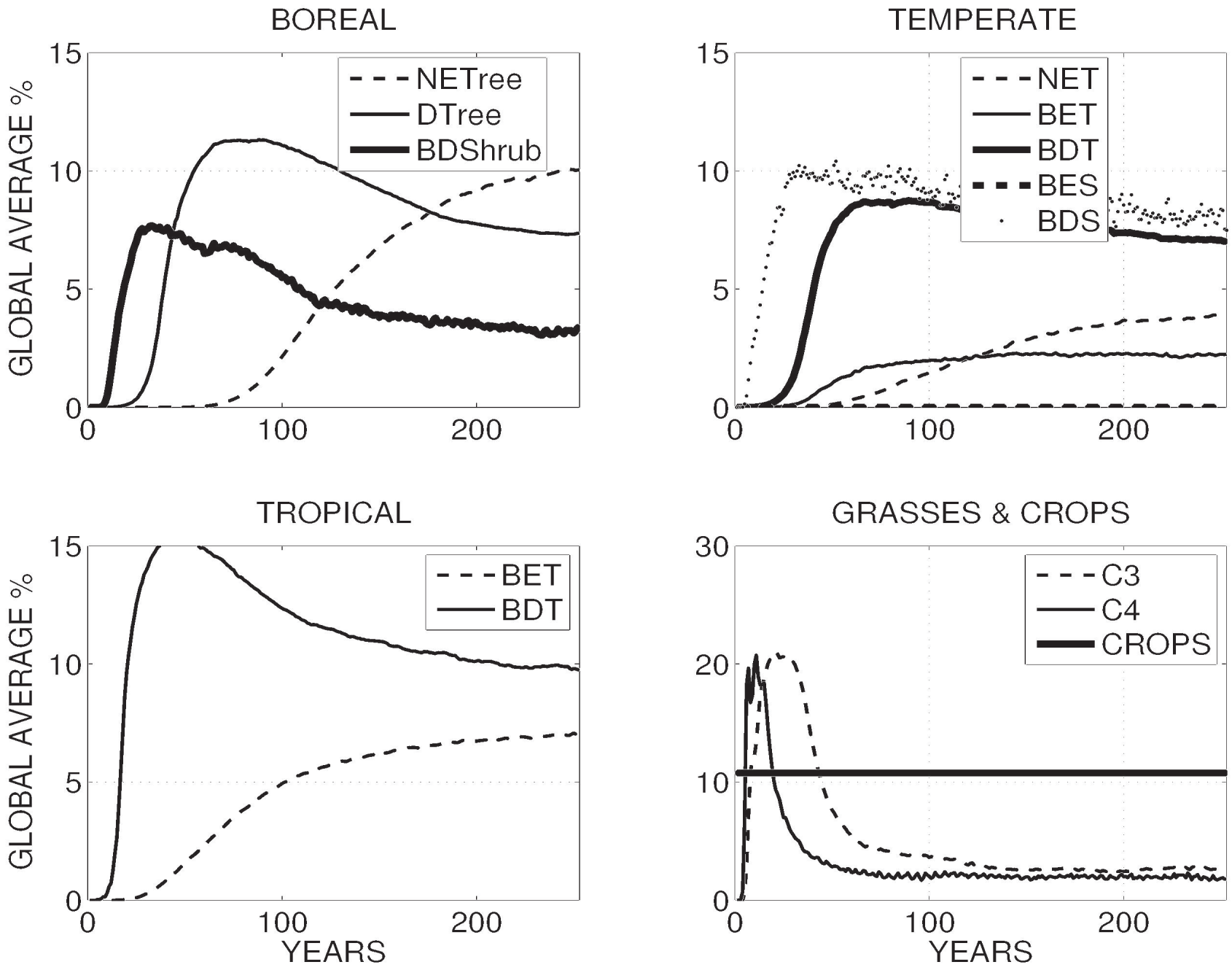
Sample input data

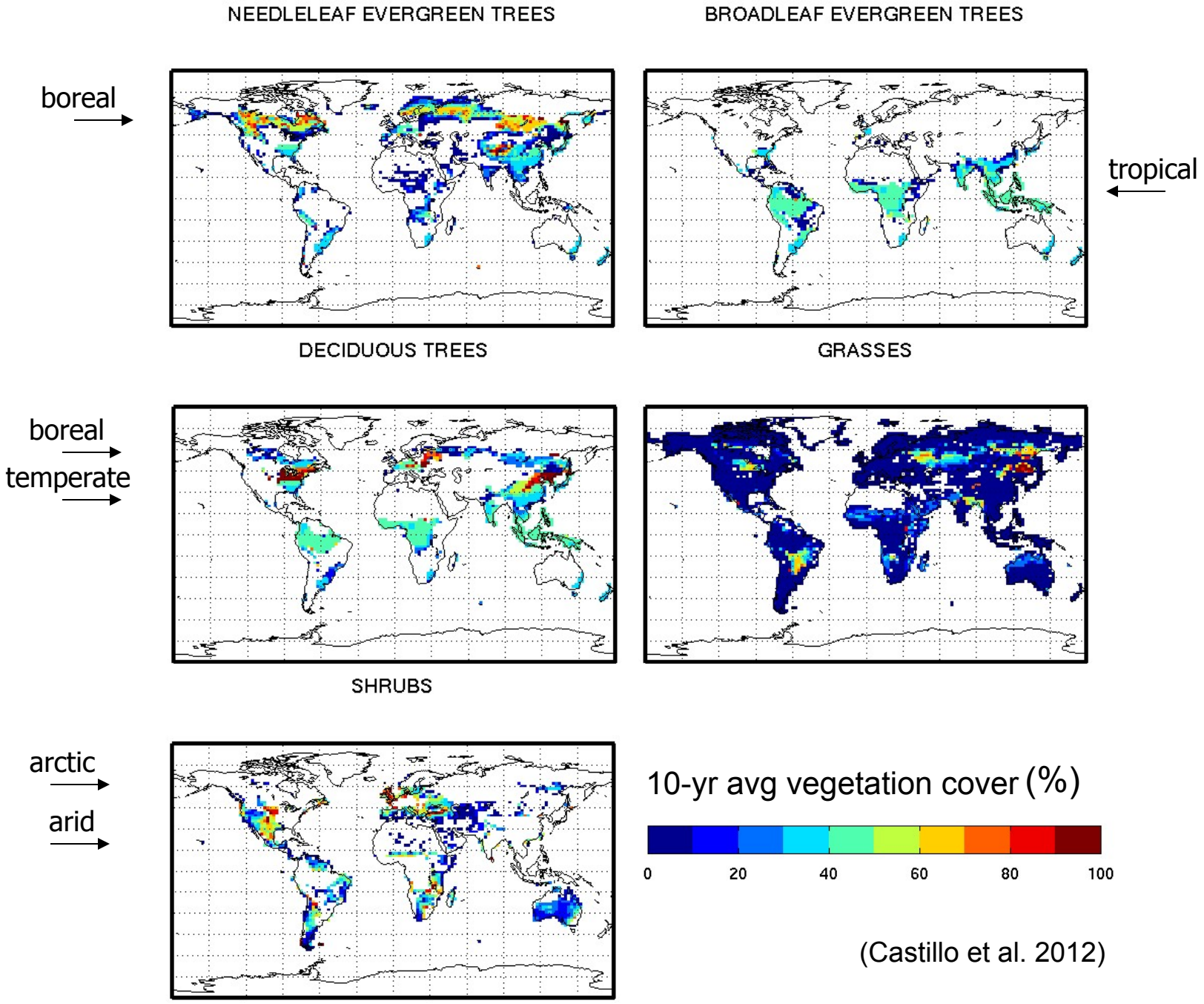
% glacier

Sample output: linking land to ocean




MIDWESTERN N. AMERICA
(Levis et al. 2012)
UNM. C3 CROP
CORN
SOYBEAN
TEMP. CEREALS
LEAF AREA INDEX (m² leaf m⁻² ground)
0
1
2
3
4
5
6
7
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Crop phenology
CLM's stress deciduous phenology


BOREAL
GLOBAL AVERAGE %
NETree
DTree
BDShrub
TEMPERATE
NET
BET
BDT
BES
BDS
TROPICAL
BET
BDT
YEARS
GRASSES & CROPS
C3
C4
CROPS
YEARS

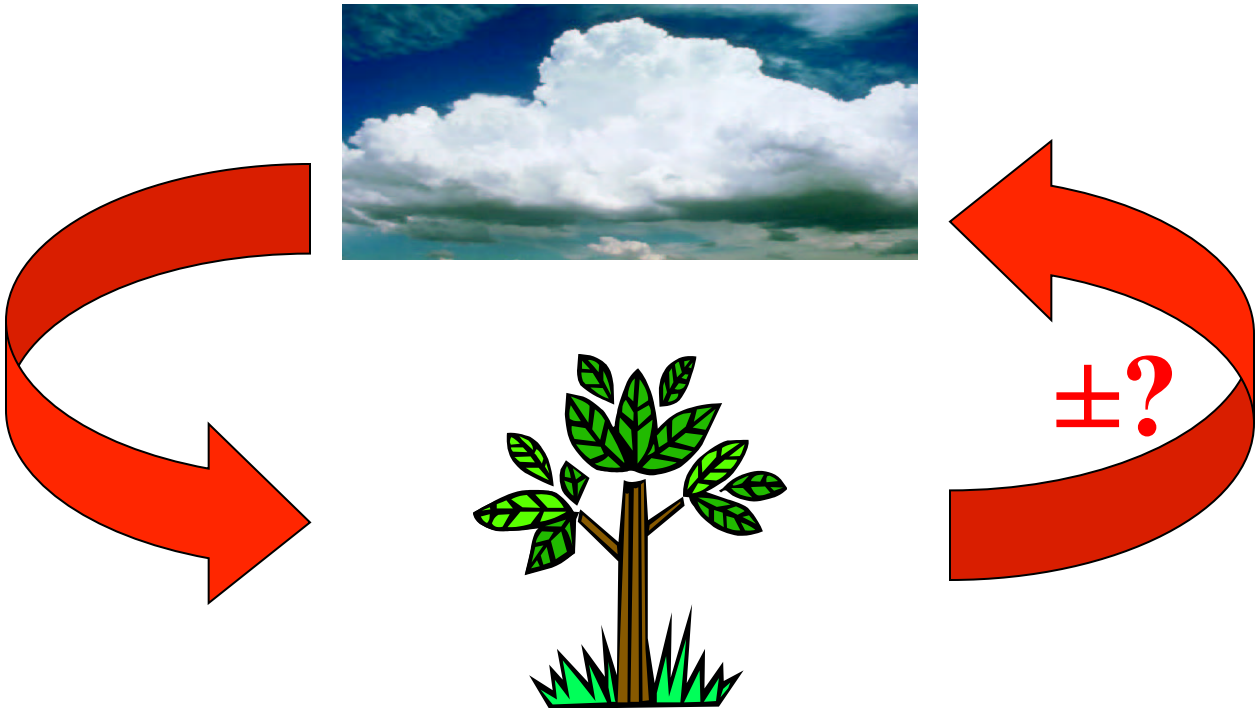

NEEDLELEAF EVERGREEN TREES
BROADLEAF EVERGREEN TREES
boreal
tropical
DECIDUOUS TREES
GRASSES
boreal
temperate
SHRUBS
arctic
arid
10-yr avg vegetation cover (%)
0
20
40
60
80
100
(Castillo et al. 2012)

CLM overview: outline

- CLM basics
- Sample input and output
- ➢ Application: climate-veg interactions

Climate-Vegetation Interactions

CLIMATE-VEGETATION FEEDBACKS



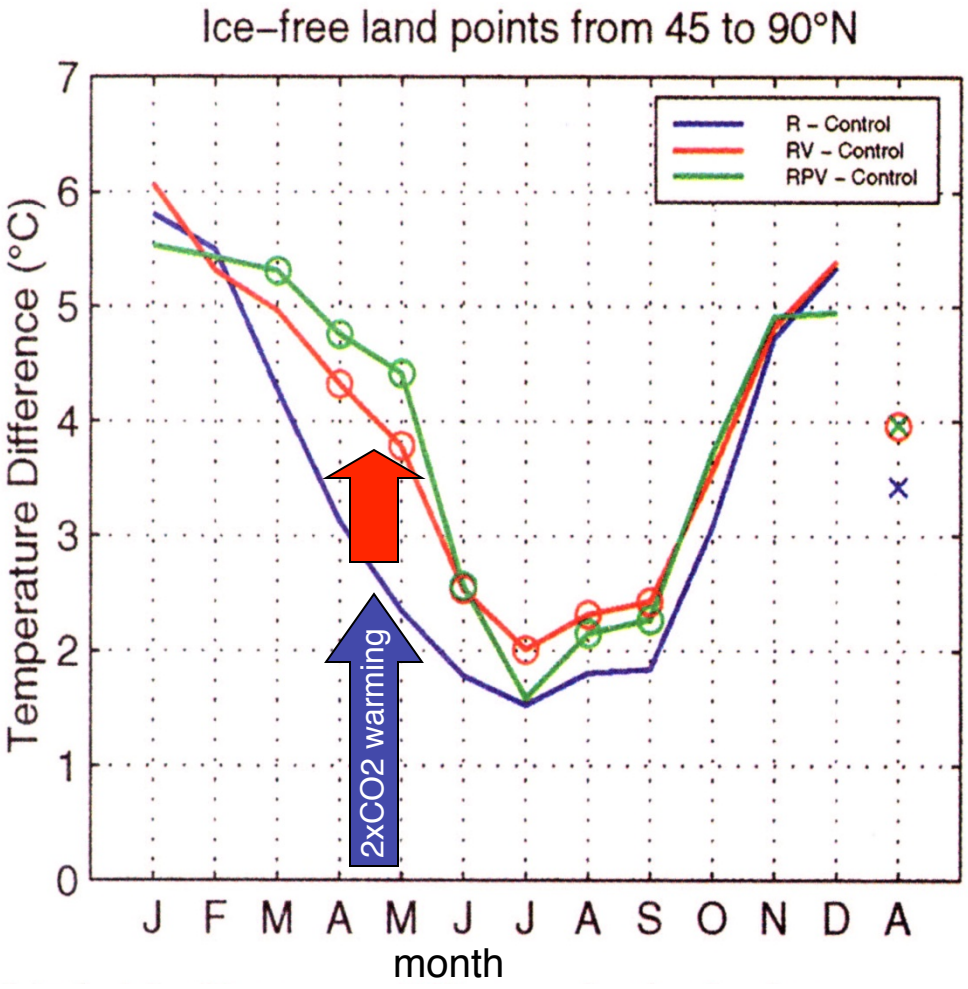
Climate-Vegetation Interactions
CLIMATE-VEGETATION FEEDBACKS

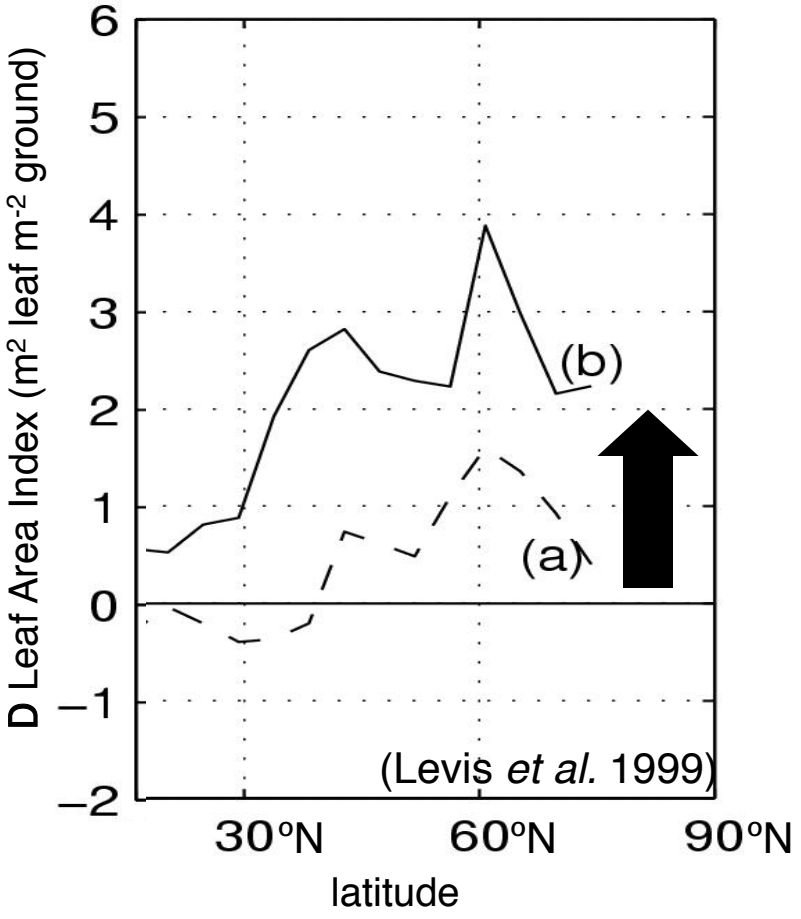
- Climate changes → vegetation responds
- Vegetation changes → climate responds:

A. Biogeophysical feedbacks:
   1. **Surface radiation balance** $R_n = S + L$
   2. **Surface heat balance** $R_n = H + \lambda E$

B. Biogeochemical feedbacks
   1. **Carbon cycle**
   2. **Nutrient cycles**
   3. **Dust, biogenic emissions, …**

2 x CO_2 climate and vegetation

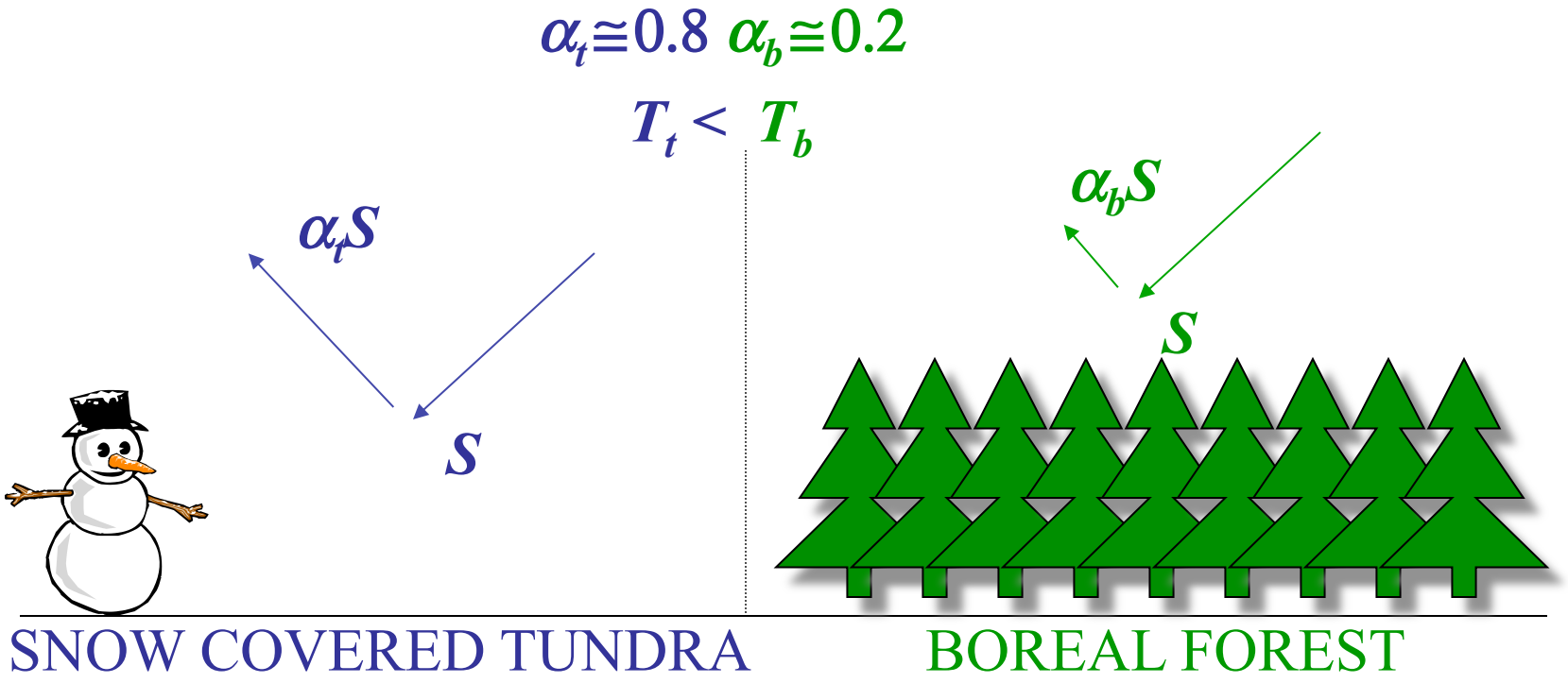




Biogeophysical feedbacks

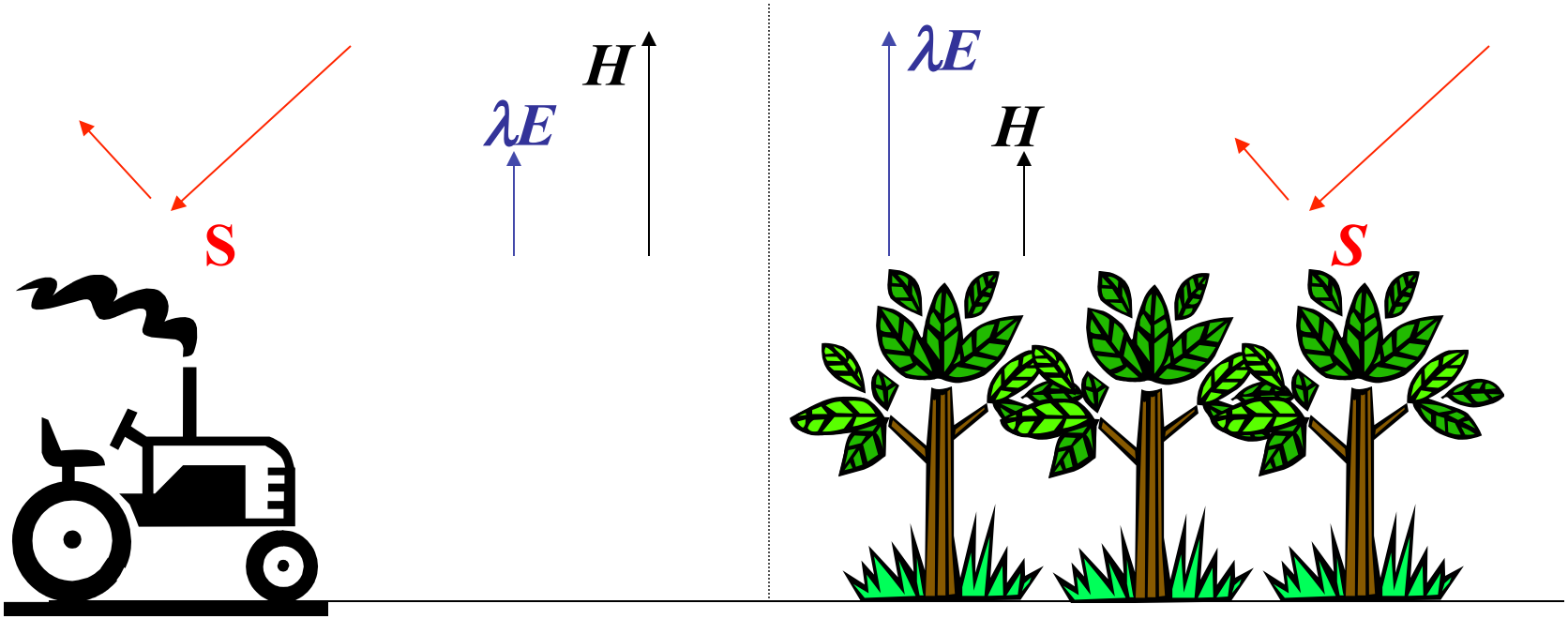
1. Surface radiation balance:

   Trees darken snow-covered surfaces



Biogeophysical feedbacks

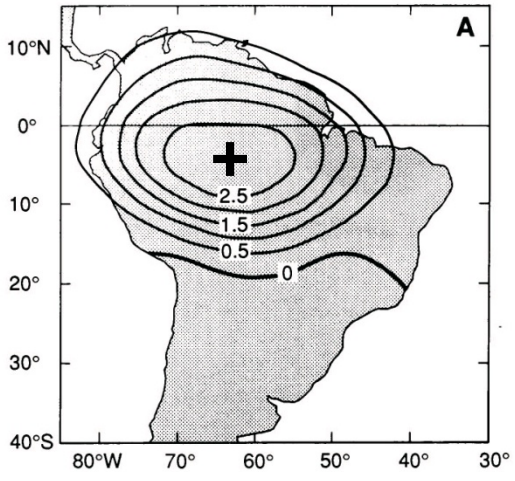
1. Surface radiation balance
   Trees darken snow-covered surfaces
2. Surface heat balance $R_n = H + \lambda E$
   Vegetation increases the latent heat flux



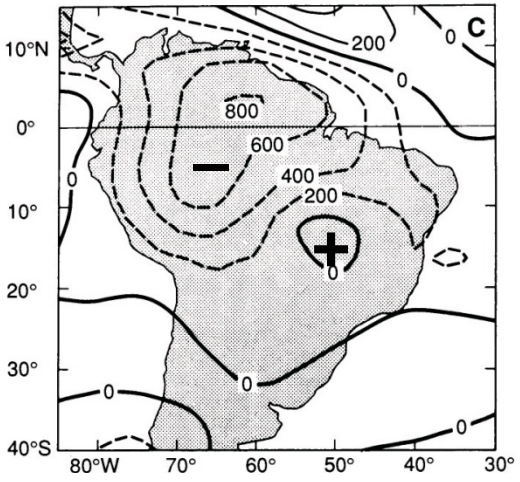
AMAZON BASIN

Trees increase evapotranspiration …deforestation decreases it

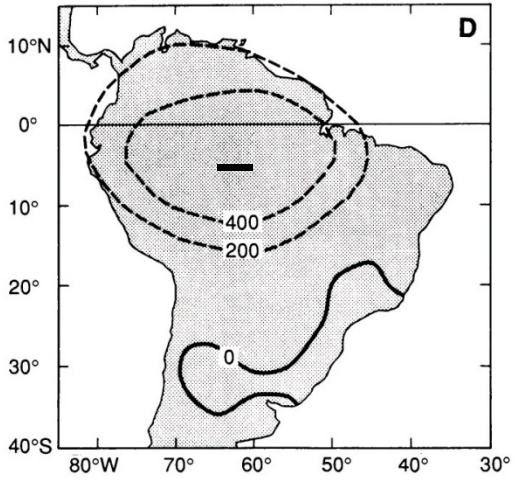
Temperature (K)



Precipitation (mm yr^{-1})



Evapotranspiration (mm yr^{-1})

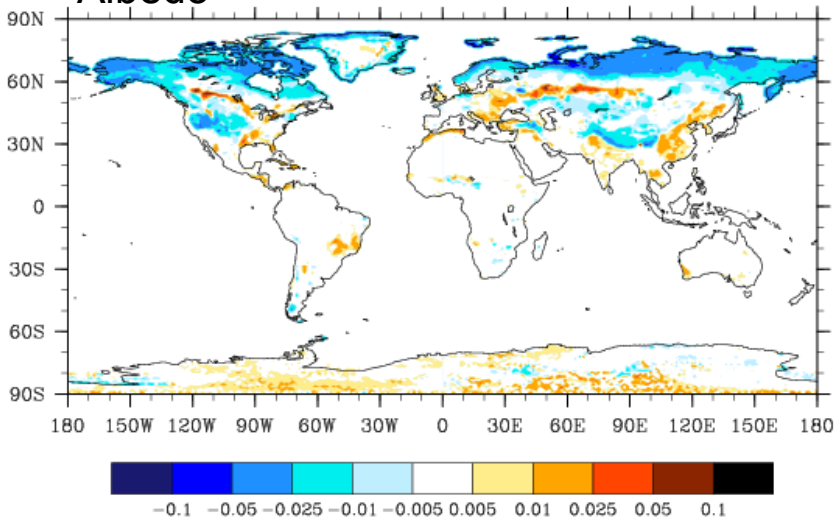


(Shukla *et al.* 1990)

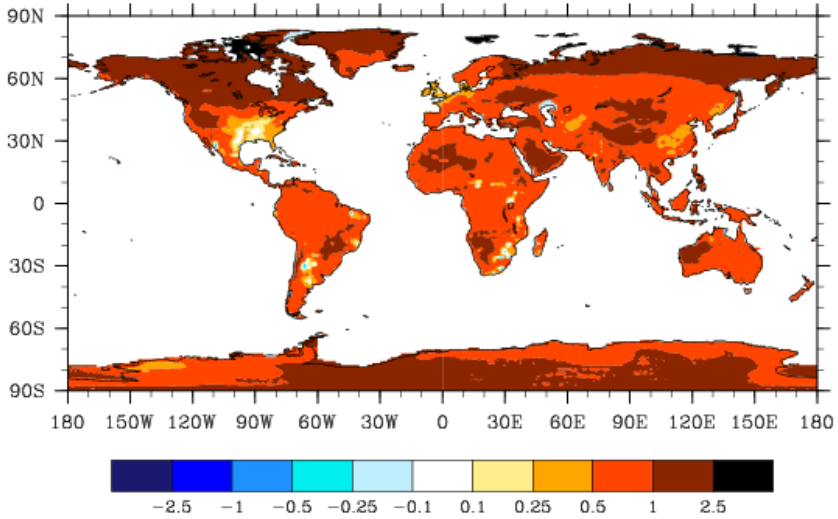
Effect of deforestation on albedo

Historical simulation

Albedo

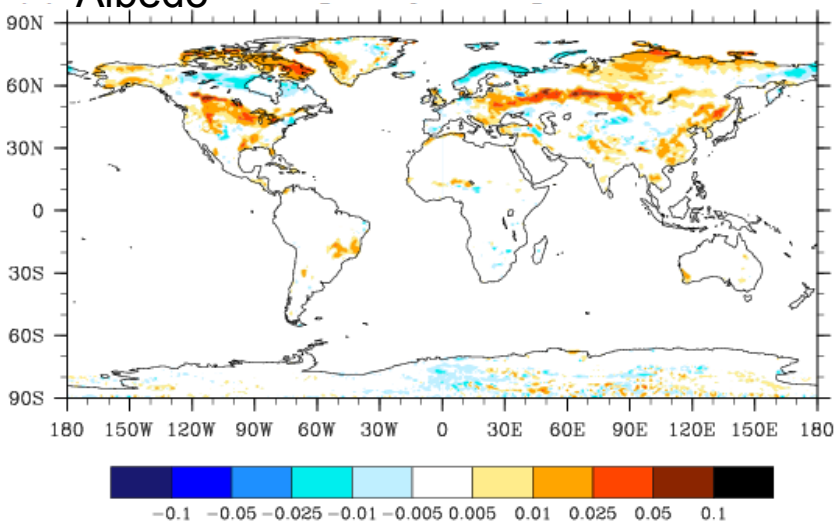


Air Temperature

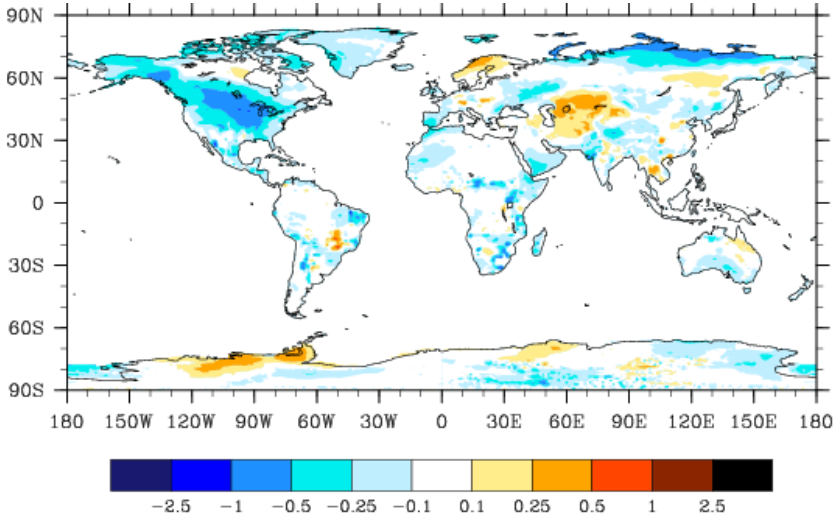


Land cover change only

Albedo



Air Temperature



Peter Lawrence et al. (2012)

Effects of LULCC on 20th century temperature

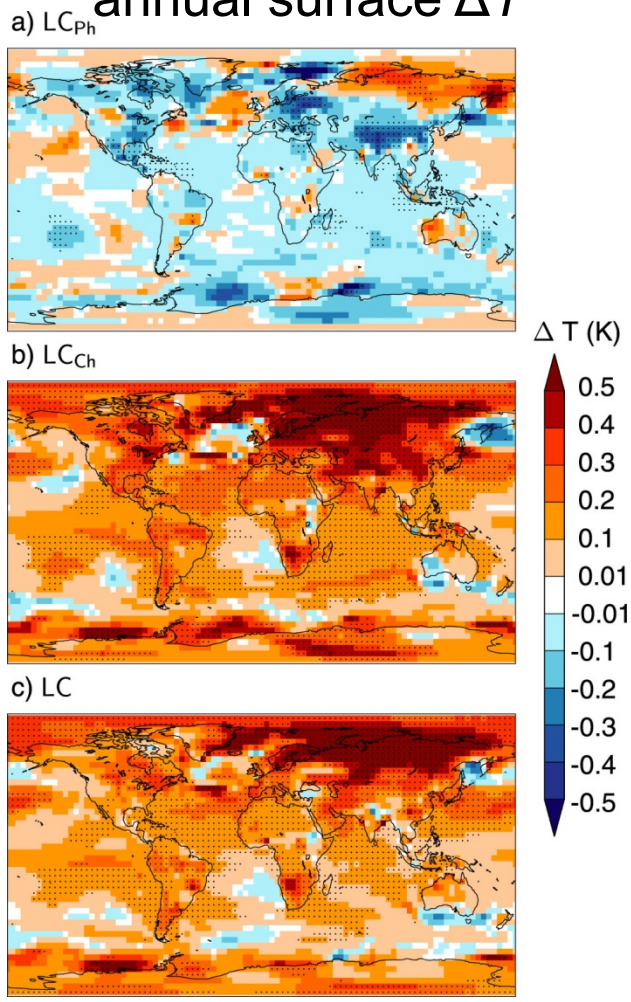
Prevailing paradigm…
Competing signals from deforestation:
surface albedo ↗ countered by carbon emission ↗

Biogeophysical
Weak global cooling (−0.03 °C)

Biogeochemical
Strong warming (0.16–0.18 °C)

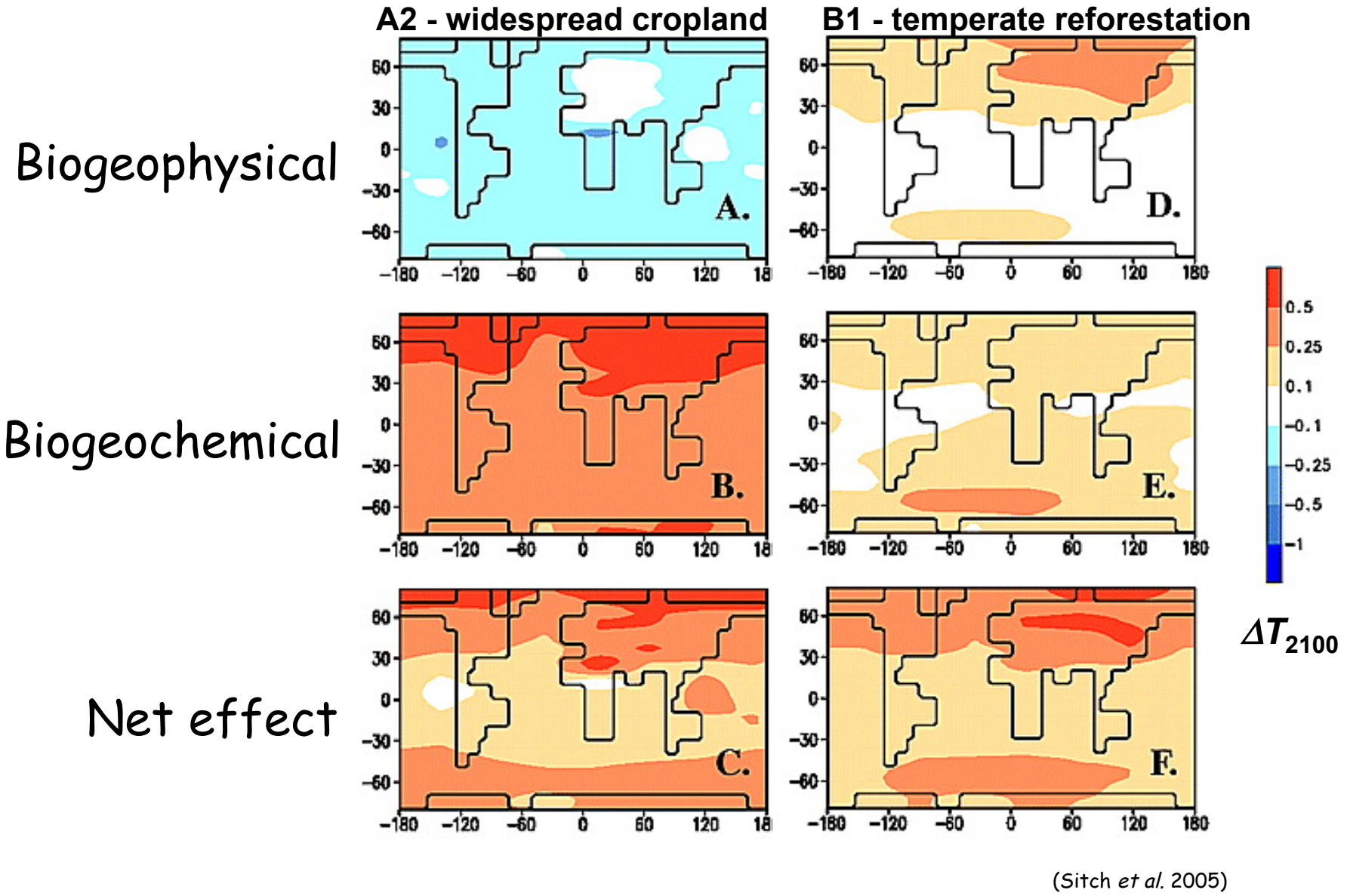
Net
Warming (0.13-0.15 °C)

annual surface Δ*T*



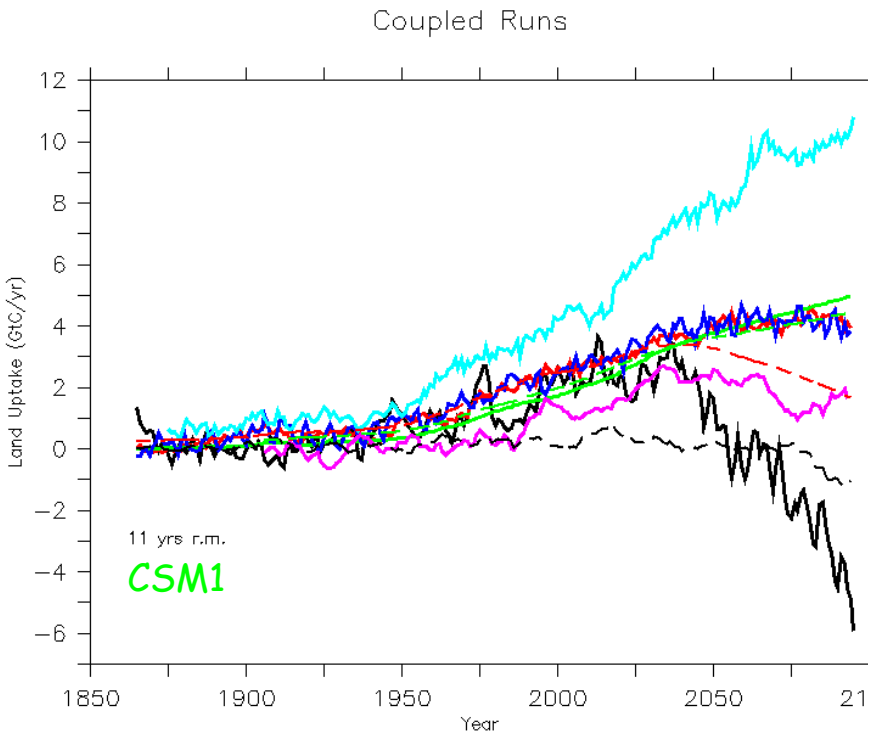
Pongratz et al. (2010) GRL

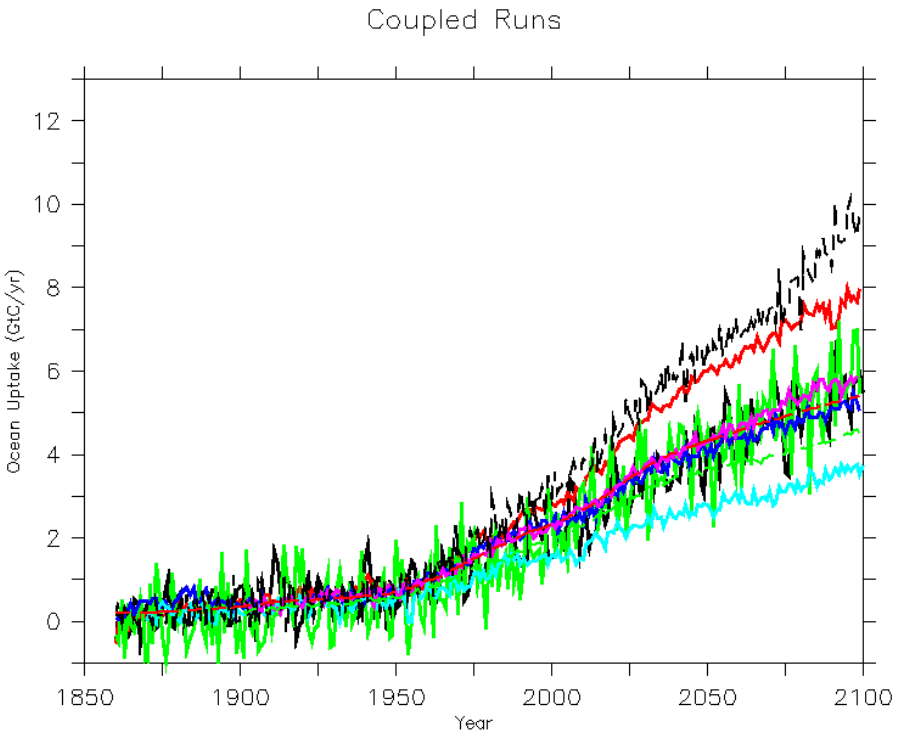
Future land use effect on temperature



(Sitch *et al.* 2005)

Carbon model intercomparison



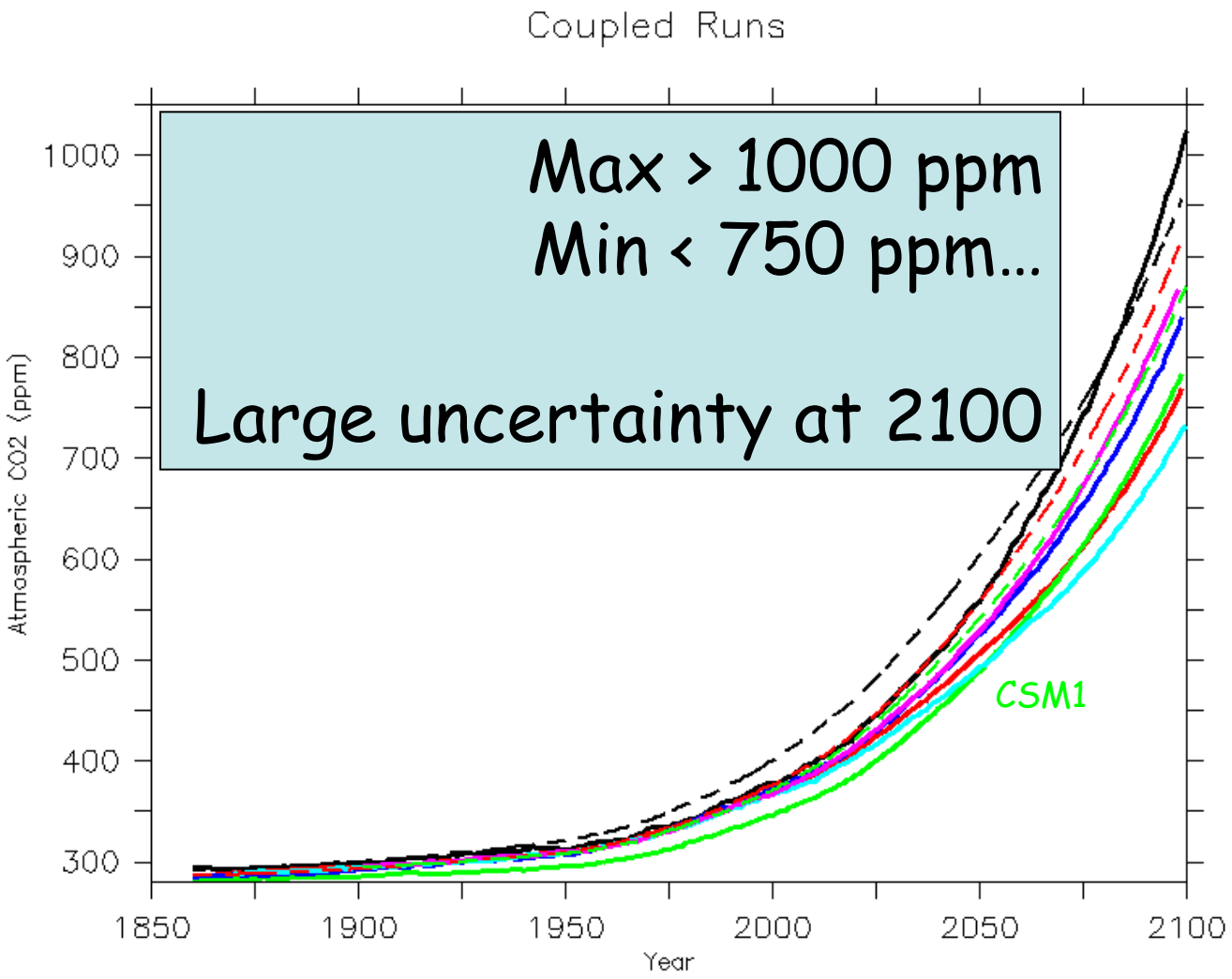


Uncertainty arises from differences in terrestrial fluxes

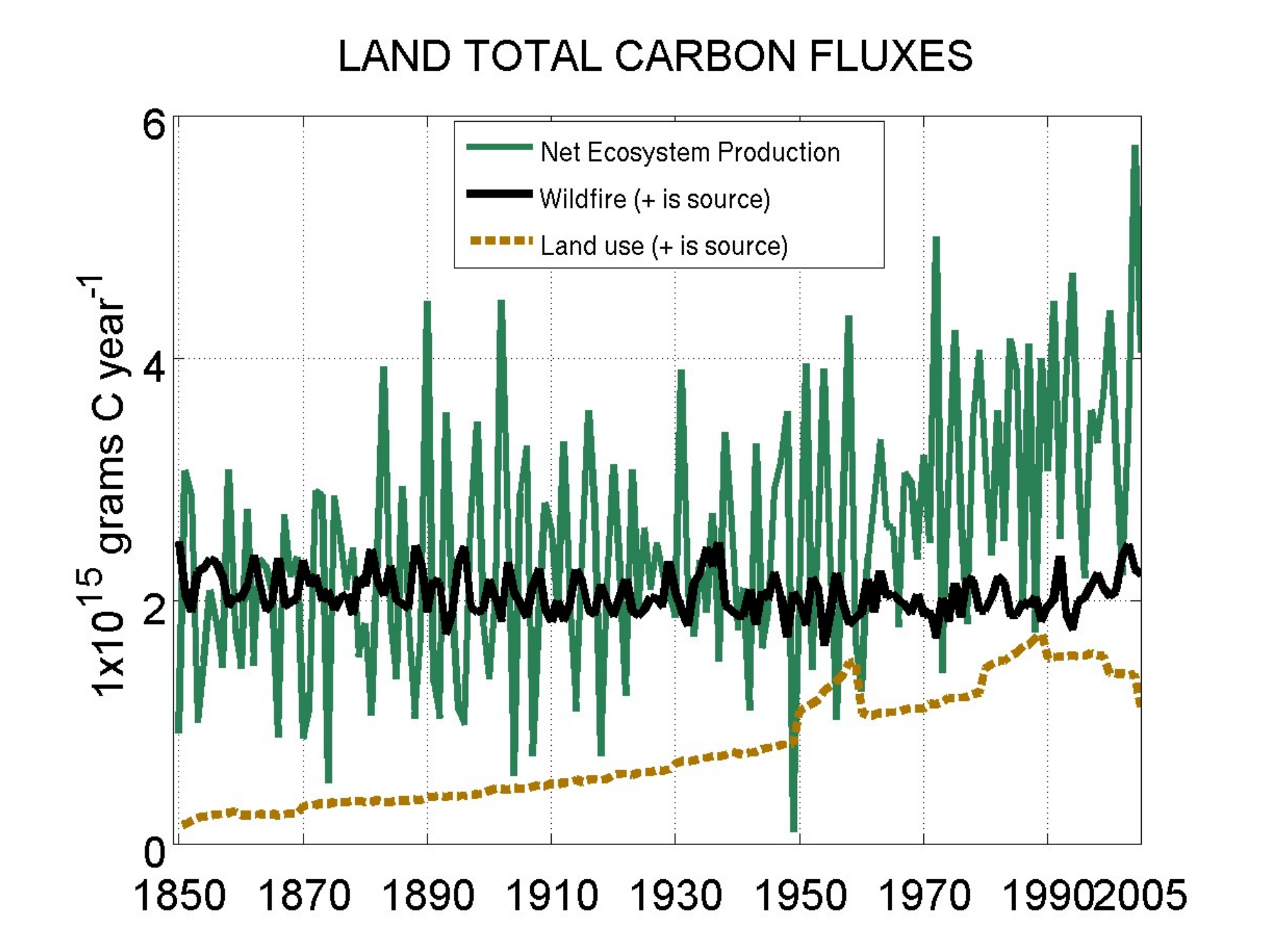
- One model simulates a large source of carbon from the land
- Another simulates a large terrestrial carbon sink
- Most models simulate modest terrestrial carbon uptake
- Terrestrial carbon cycle can be a large climate feedback
- Considerable more work is needed to understand this feedback

Figures courtesy of Pierre Friedlingstein

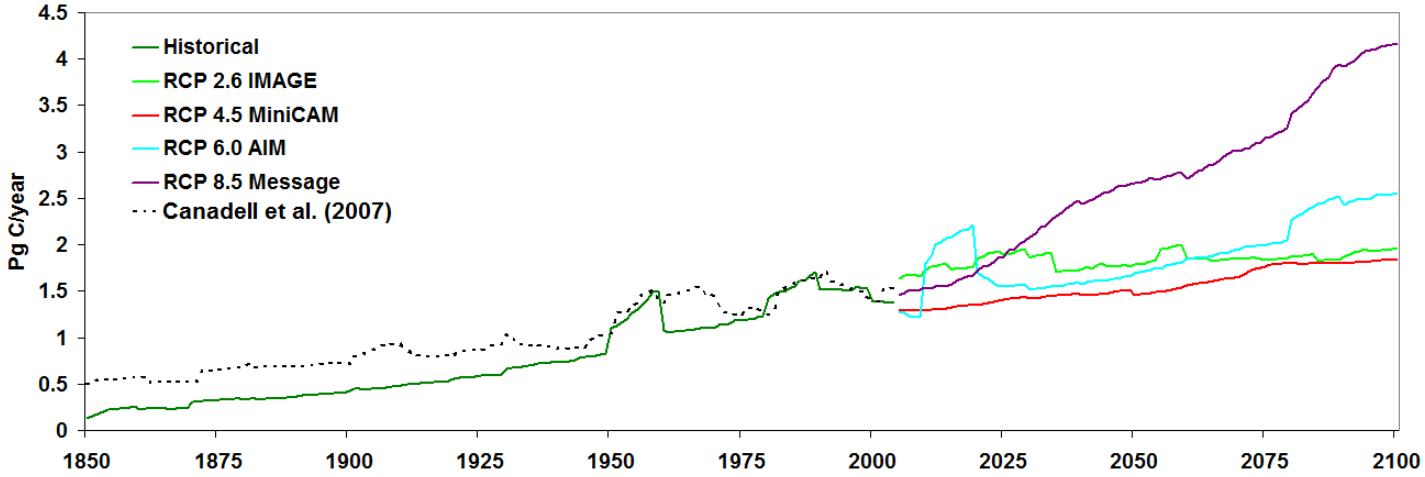
Carbon model intercomparison



courtesy of Pierre Friedlingstein


LAND TOTAL CARBON FLUXES
Net Ecosystem Production
Wildfire (+ is source)
Land use (+ is source)
1x10^15 grams C year^-1
6
4
2
0
1850
1870
1890
1910
1930
1950
1970
1990
2005

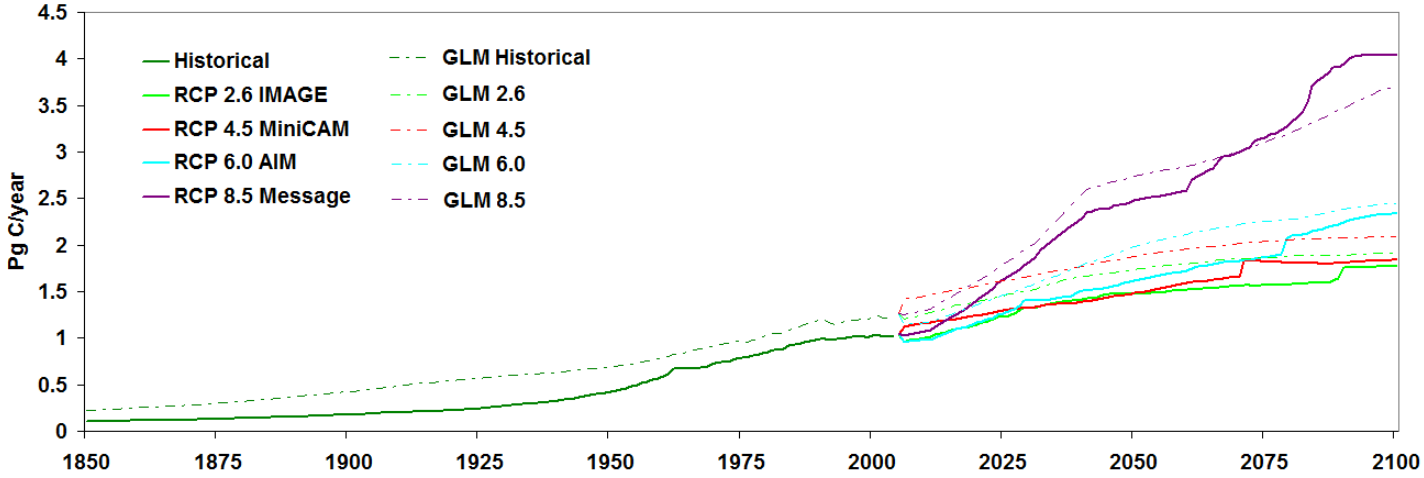
CLM/CESM simulated LULCC carbon flux to atmosphere



consistent with estimated land use flux over the historical period

---

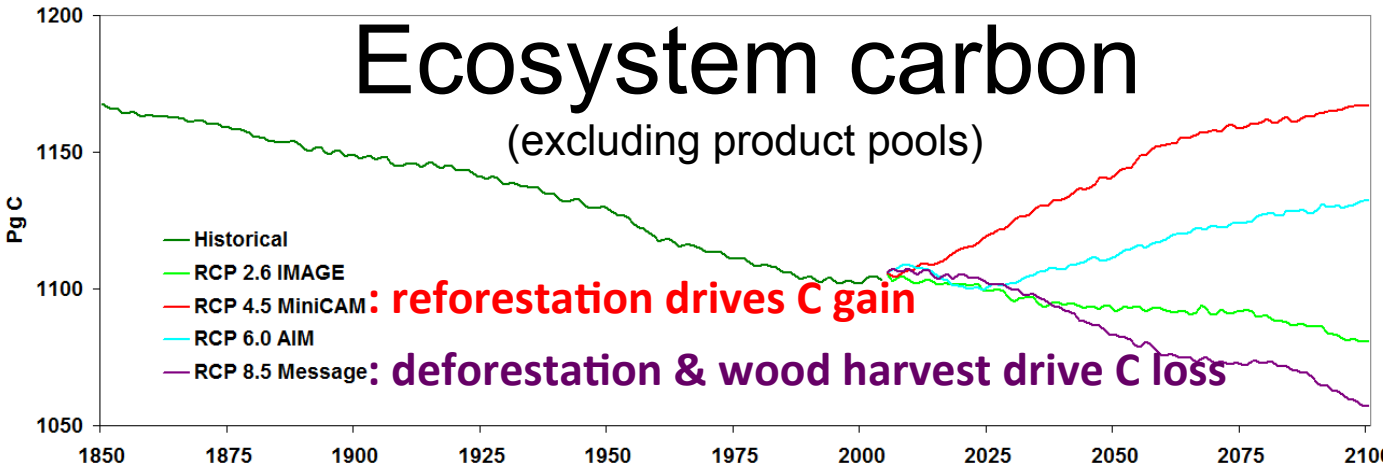
CLM/CESM simulated wood harvest flux

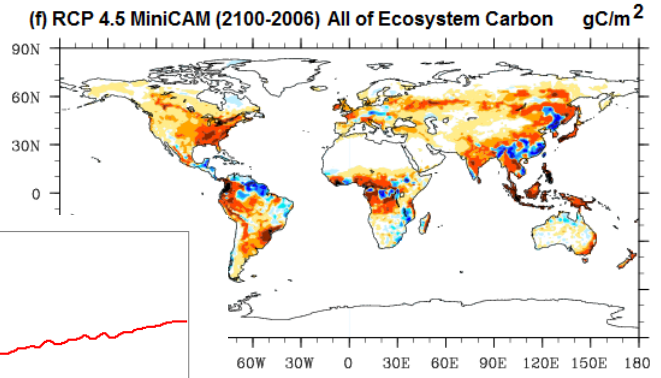


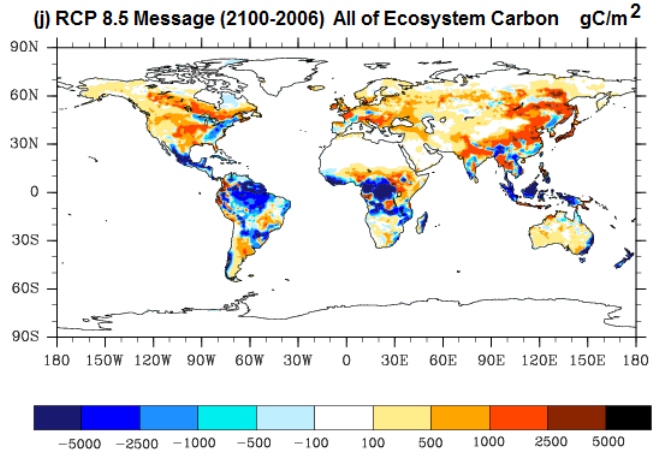
consistent with estimated wood harvest flux over the historical period and the RCPs

Peter Lawrence et al. (2012)

Huh, so land use choices matter!







Peter Lawrence et al. (2012)

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 te
formed from models that do not
biogeochemistry. Two carbon cyc
tions of future climate change w
geochemistry find that nitrogen d
γ_L from negative to positive [*Soko*
et al., 2009]. Limited mineral nitr
the increase in plant productivity
carbon feedback. Conversely, wa
position of organic material and
stimulating plant productivity. Oth
lations for the twentieth and twent
find that β_L decreases and carl
decreases when nitrogen is inclu
negative [*Zaehle et al.*, 2010a, 2
nitrogen to change the climate-carb
($-\gamma_L$) to negative ($+\gamma_L$) is unclear,
tance of β_L and γ_L to the overall la

[4] Here, we report simulation
Land Model version 4 (CLM4) for
forced with historical meteorolo
atmospheric nitrogen deposition, a

Summary & Conclusions

- CLM basics w/ examples of input/output
- Climate-vegetation interactions
  - First order effect is land use
    - The biogeochemical effect
    - So human behavior our greatest uncertainty
  - Effect from natural vegetation
    - The snow-vegetation-albedo feedback

QUESTIONS?