

CROP modeling in the Community Land Model

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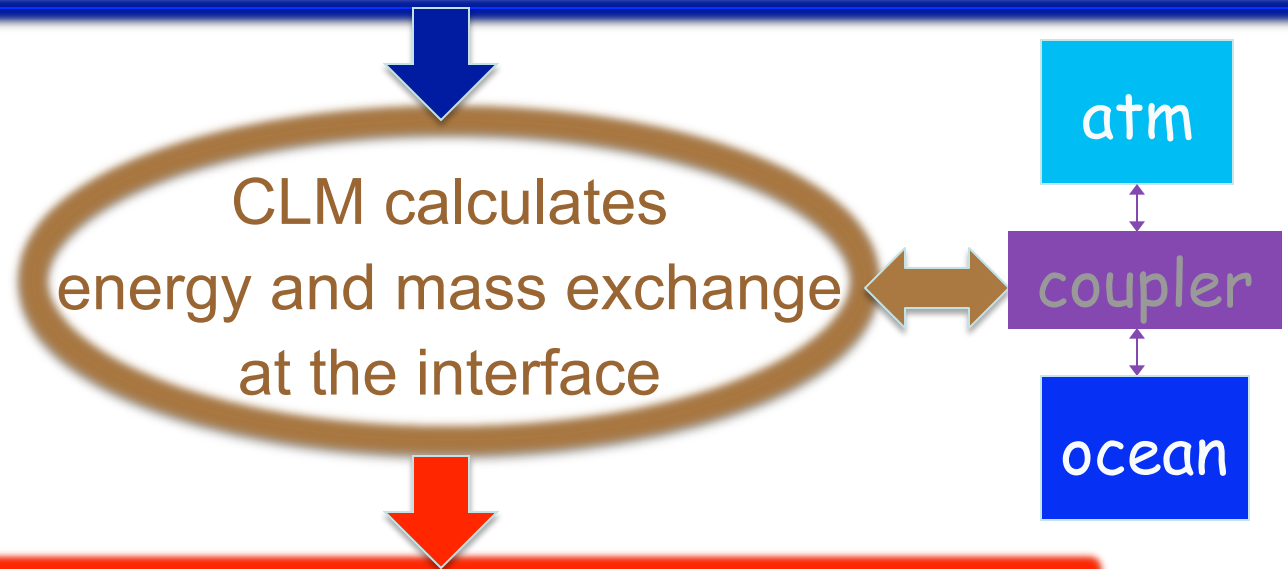


but first a CLM overview

The basics

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

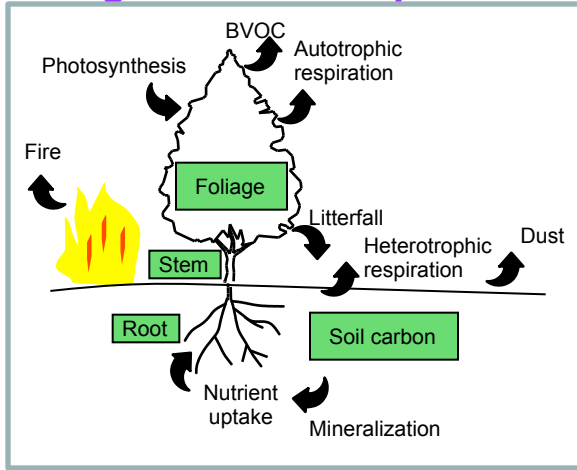
near-surface atmosphere data (sim/obs) $S, L, T, q, u, v,$
 $P, \rho, [\text{CO}_2]$
surface data (sim/obs) veg., soil, other data (eg, %lake)



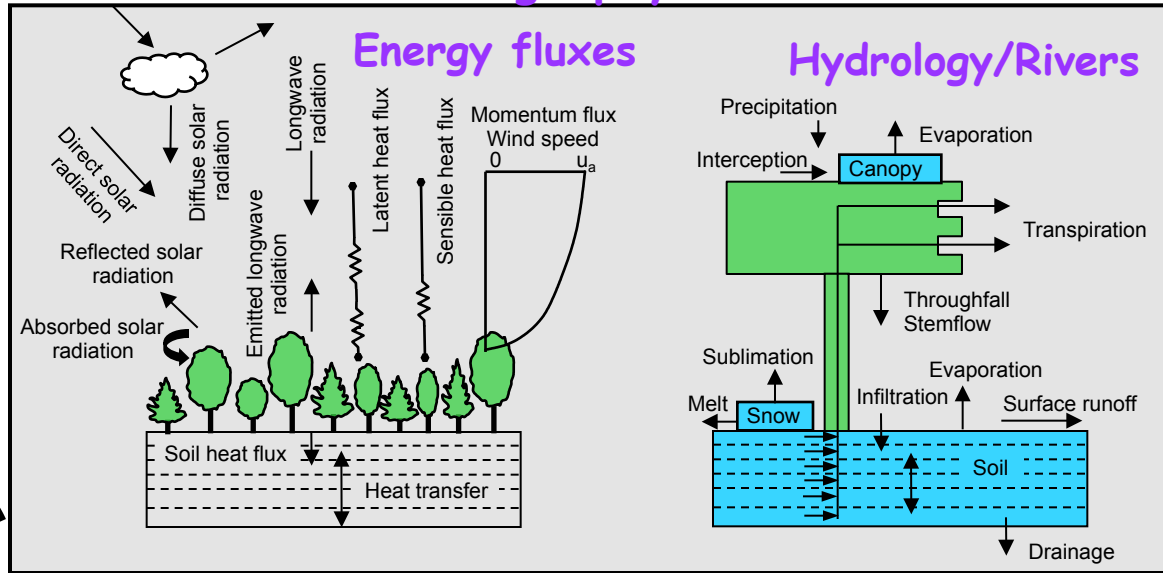
$H, \lambda E, G$ heat fluxes
reflected & emitted radiation fluxes
soil, snow, plant T and W ...river flow
C & N fluxes ...BVOC & dust emissions

Current-generation land models

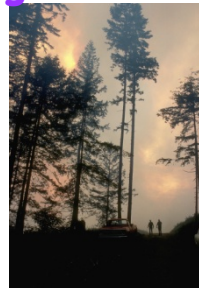
Biogeochemical Cycles



Biogeophysics



Climate change



Establishment

Urbanization

Climate change

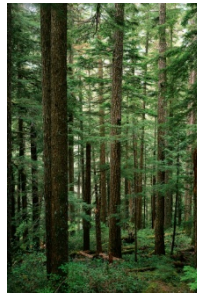
Disturbance

Deforestation

Ice sheets

Vegetation dynamics

Land use



Competition

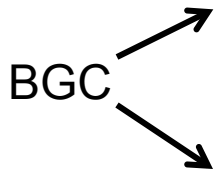
Afforestation

Land Management

Growth

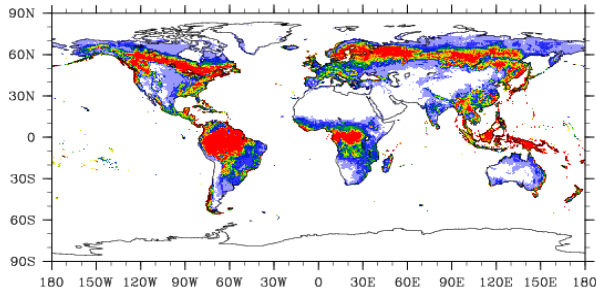
Subroutine Tree

- Initialize
- Time stepping loop -----
 - Surface radiation
 - Soil fluxes ...Urban fluxes
 - Canopy fluxes ...Lake fluxes
 - Dust emission ...BVOC emission
 - Hydrology ...Snow
 - C and N cycles ...Balance check
 - Surface albedo ...River flux
 - Dynamic vegetation
 - write history and restart data -----

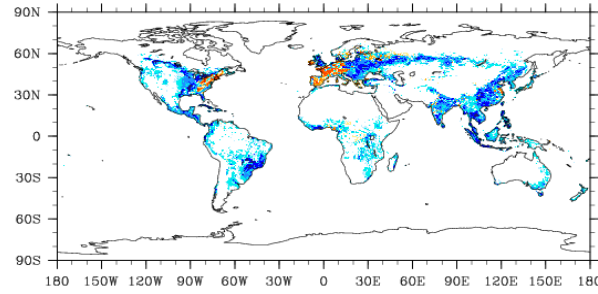


Sample input data

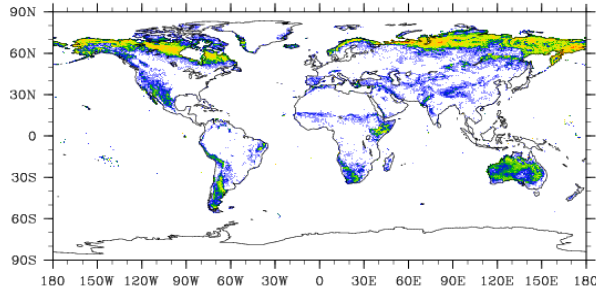
(a) Current Day (2000) Tree PFTs



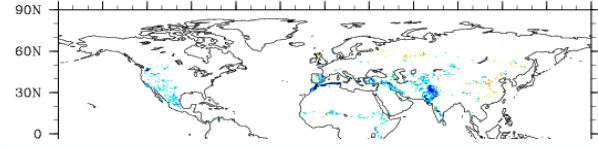
(b) Current Day - 1850 Tree PFTs



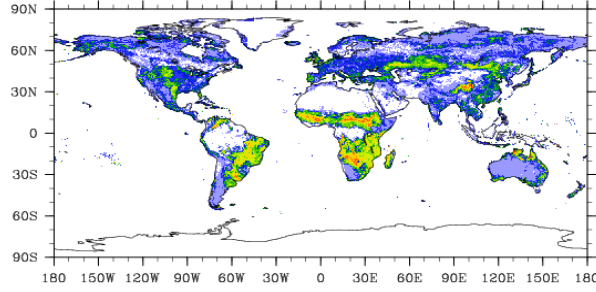
(c) Current Day (2000) Shrub PFTs



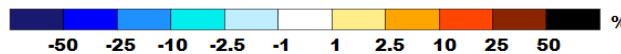
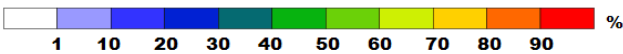
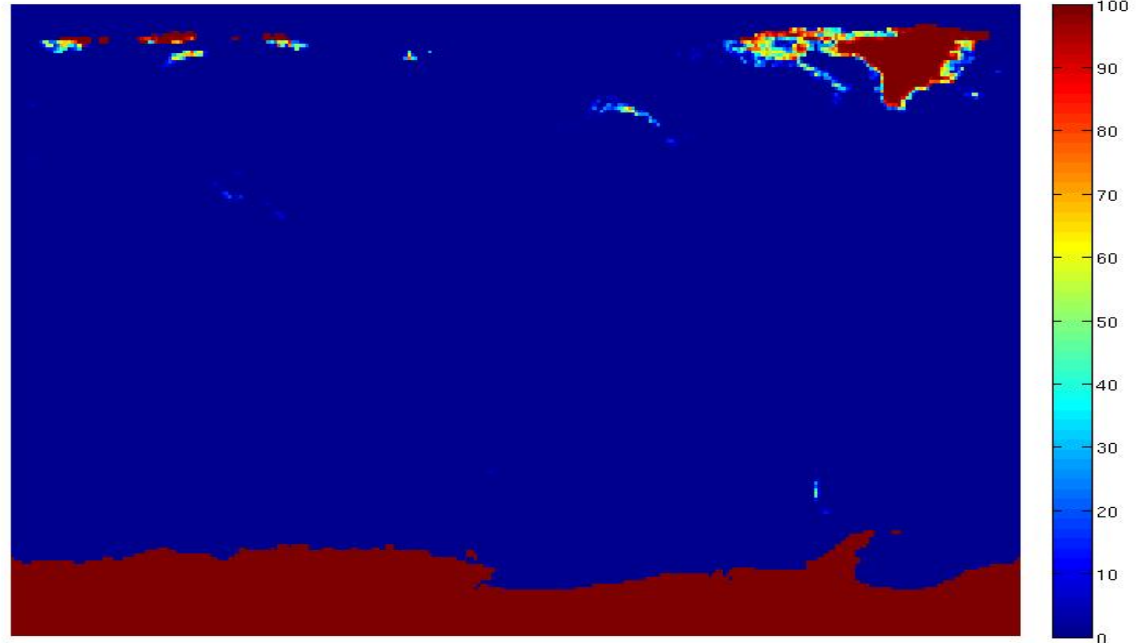
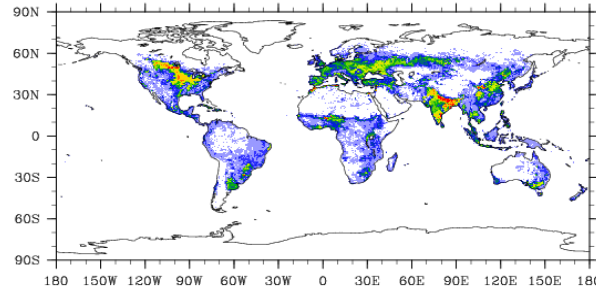
(d) Current Day - 1850 Shrub PFTs



(e) Current Day (2000) Grass PFTs

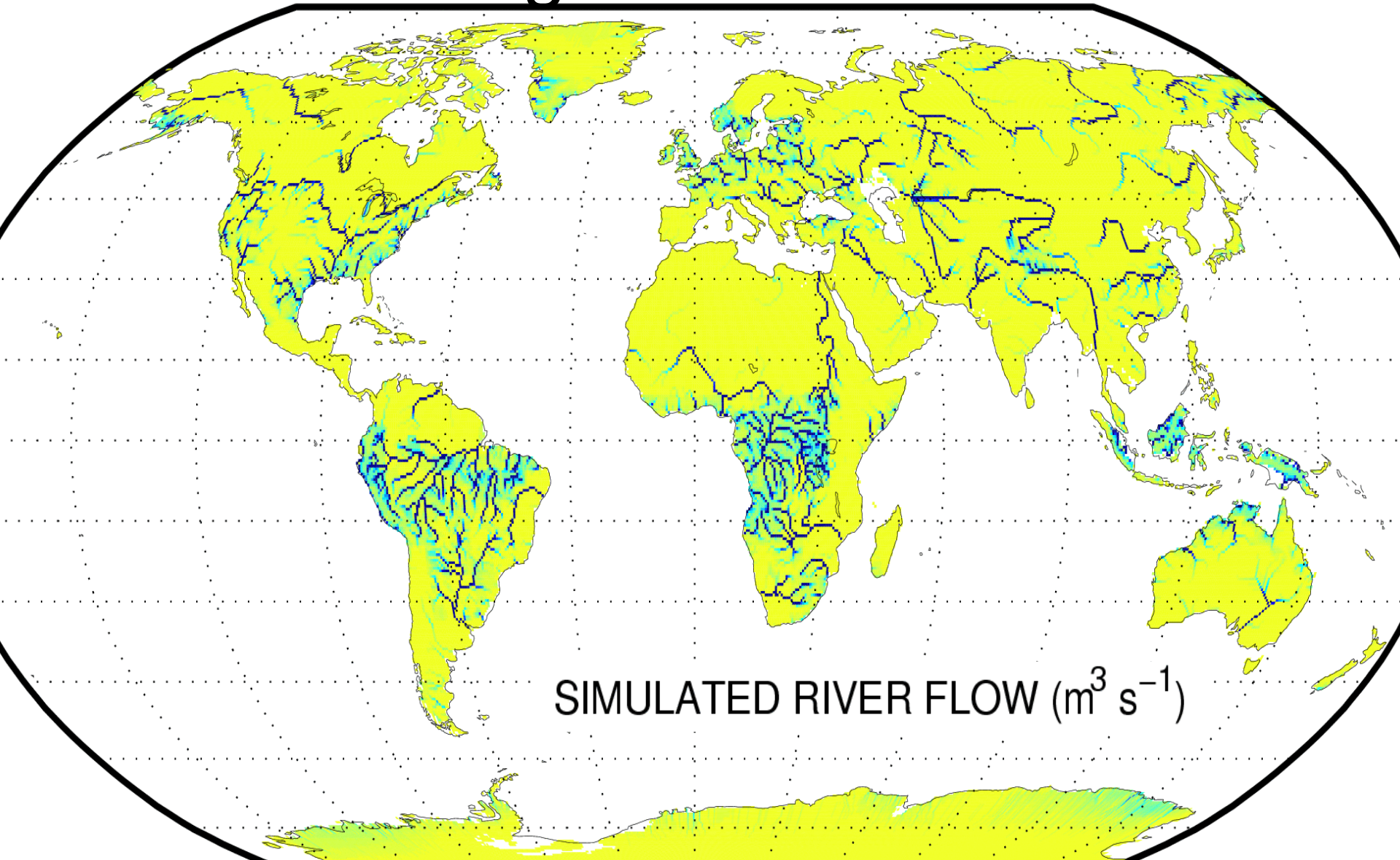


(g) Current Day (2000) Crop PFT



% glacier

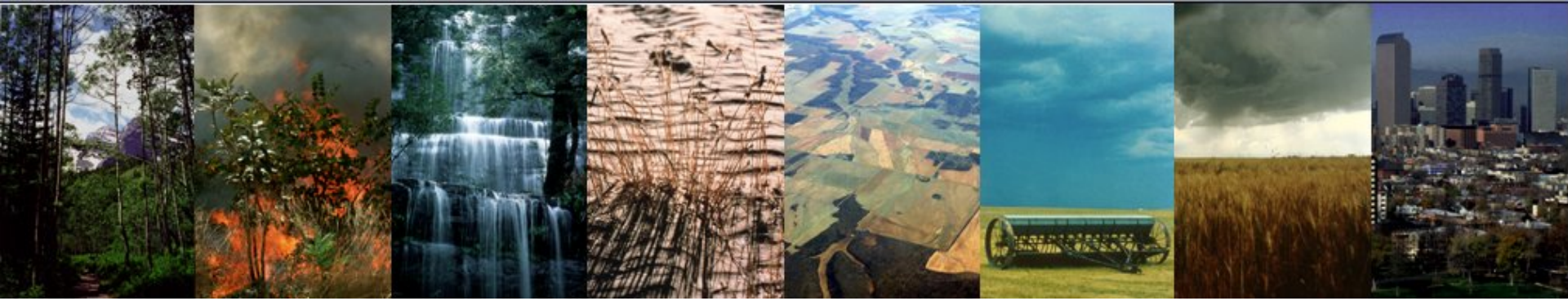
Sample output: linking land to ocean



Motivation for crop modeling

- **Food supply** ...**crop yields**
 - **Fuel supply** ...**biofuels**
 - **Land-atm interactions** ...**climate change**
- Biogeophysical Biogeochemical
- } & prices

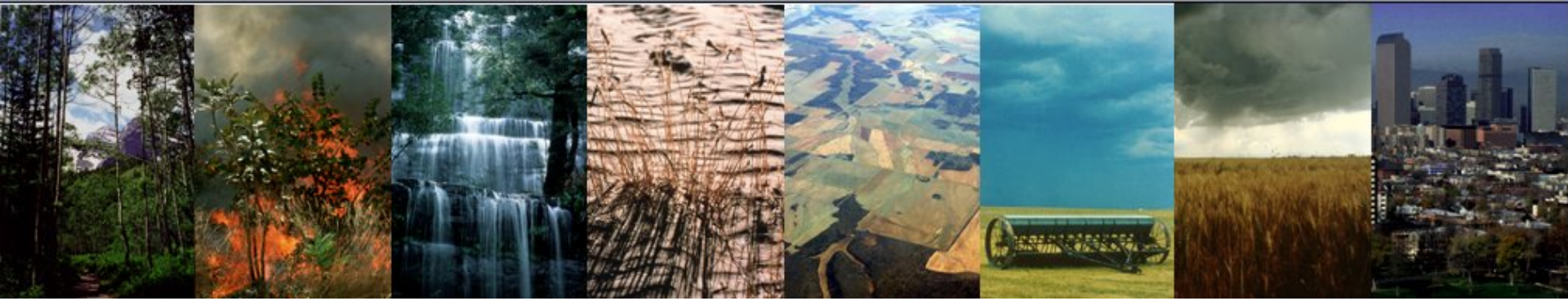




Community Earth System Model (CESM)

Traditionally used for research
at spatial and temporal scales
unsuitable for field experiments...

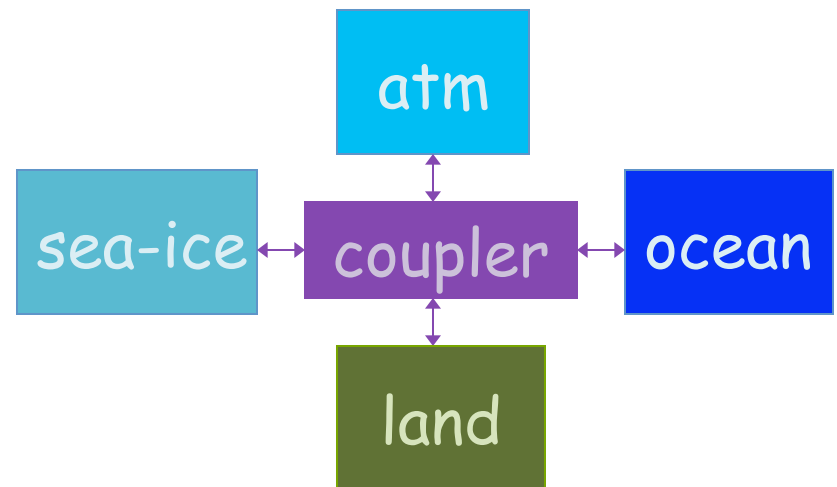
- What if we replaced the vegetation?
- What if we removed the irrigation?
- What may Earth be like in the future/have been in the past?

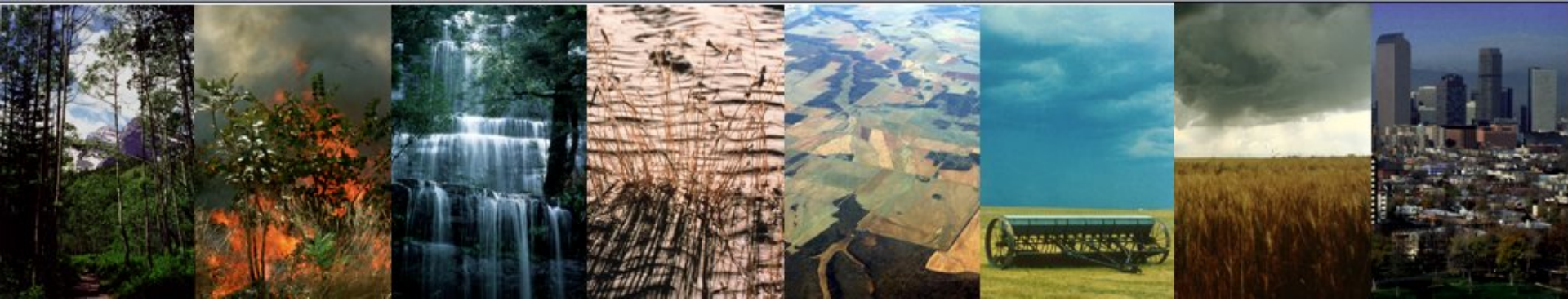


Community Earth System Model (CESM)

Introducing human systems to the CESM

- Agriculture (my focus)
- Urban

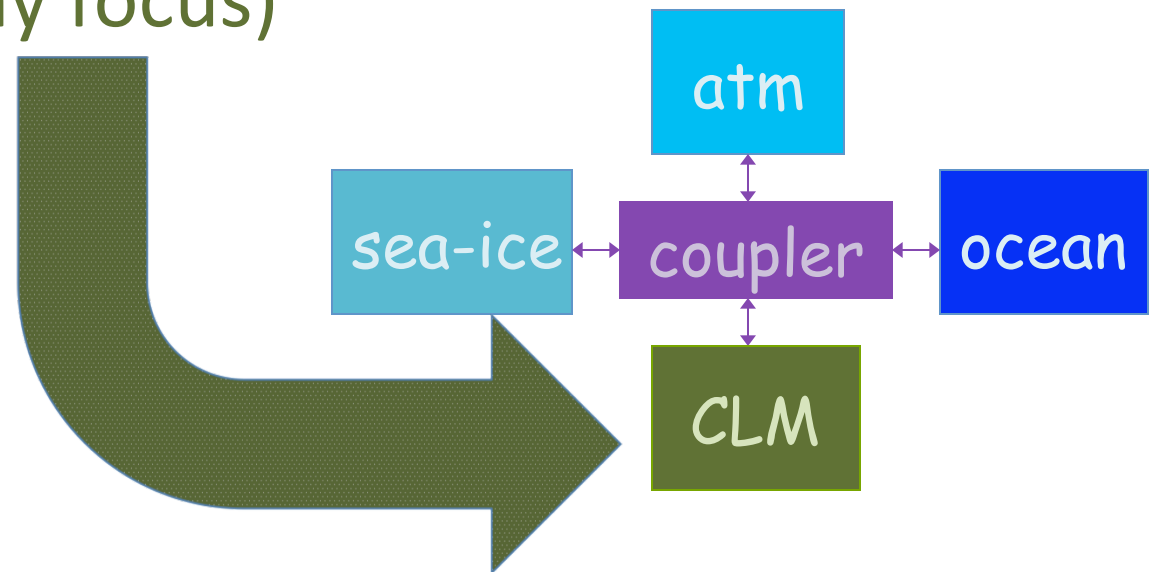




Community Earth System Model (CESM)

Introducing human systems to the CESM

- Agriculture (my focus)
- Urban



CLM4

Temp. corn

Temp. cereals

Temp. soybean

effects on atm.



Levis et al. (2012)



Interactive Crops in the CLM

Following AgrolBIS (Kucharik & Brye, 2003)

Temperate corn, soybean, spring wheat:

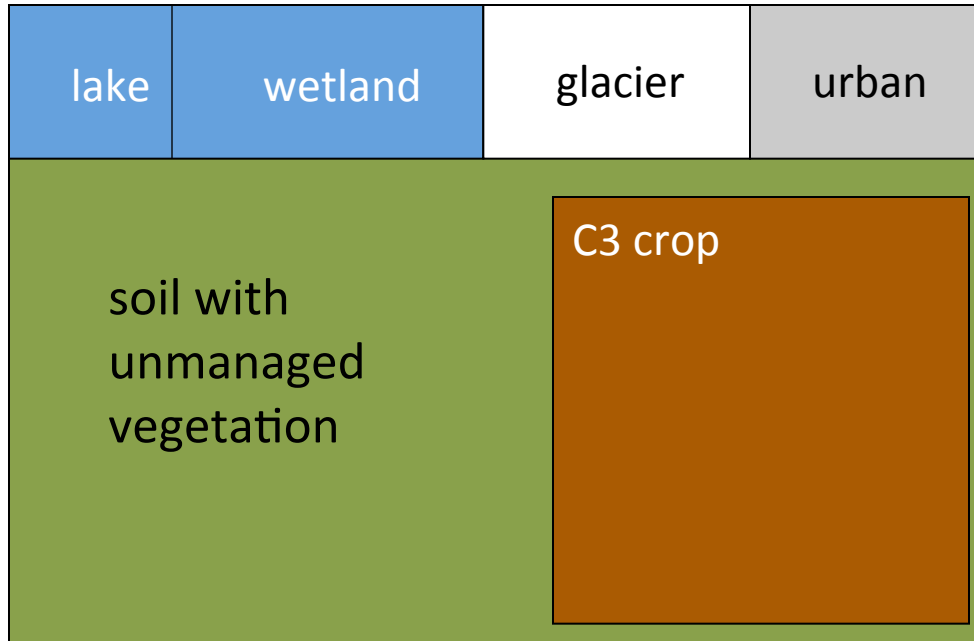
Phenology by GDD accumulators →

Planting, leaf emergence, grain fill, maturity, harvest

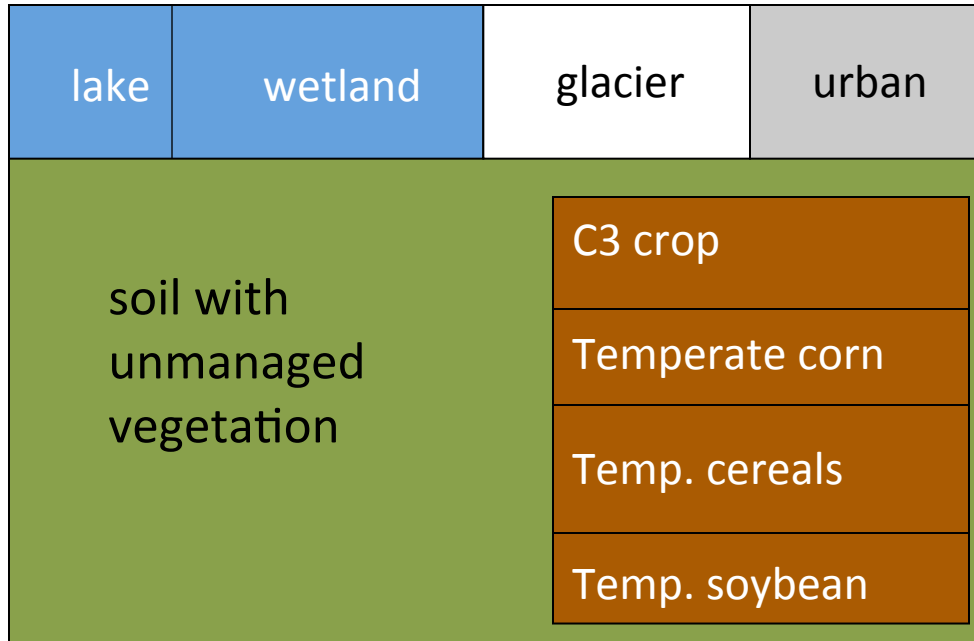
C allocation + N limitation →

Leaf area, height, crop yield

a CLM grid cell (default)

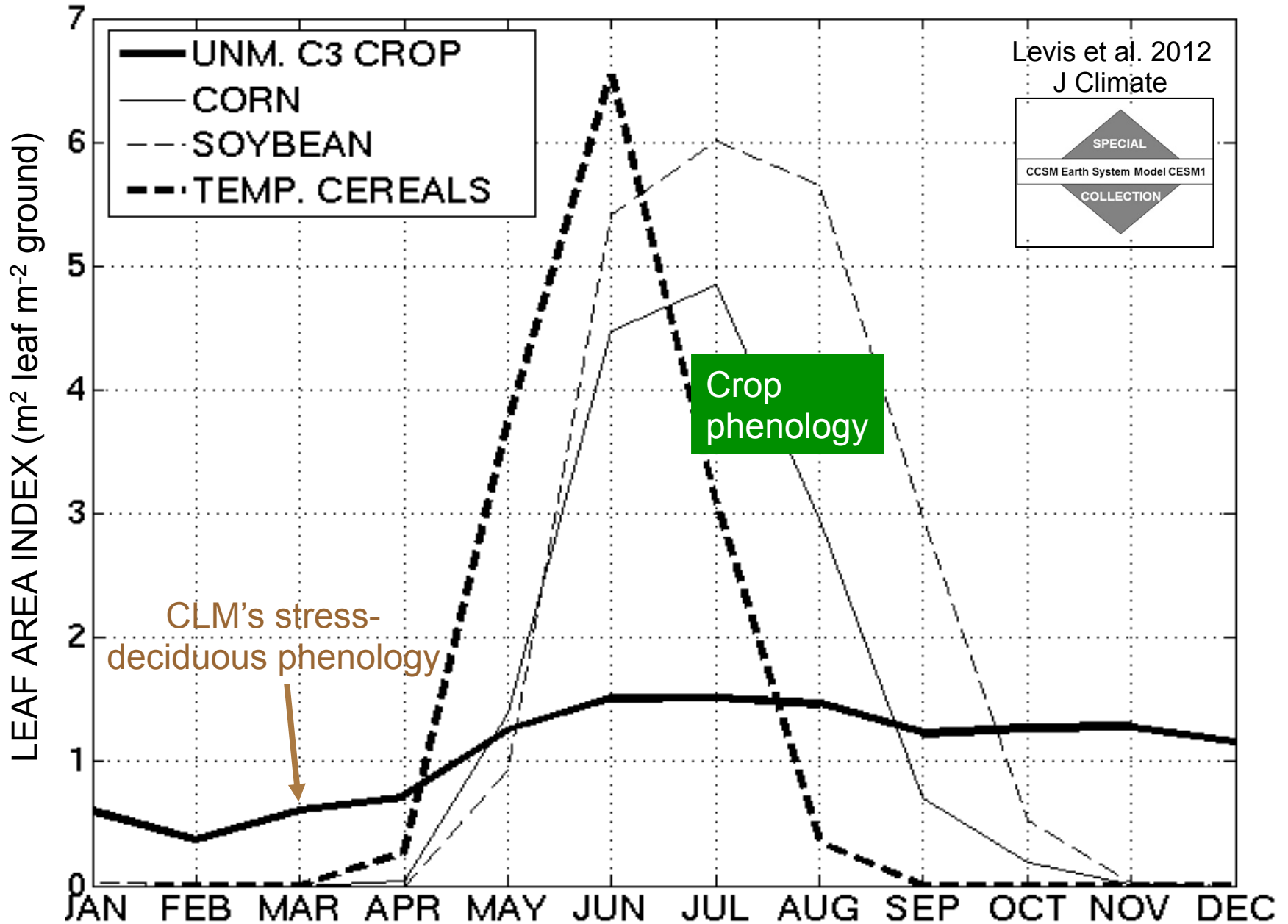


a CLM grid cell with interactive crop management

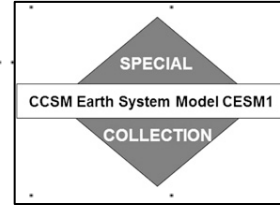


} crop-specific phenology + C allocation

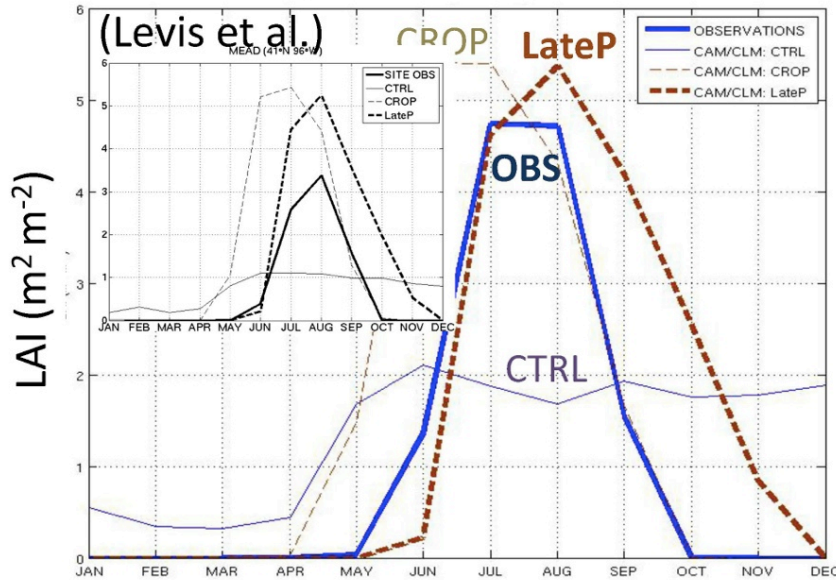
MIDWESTERN N. AMERICA



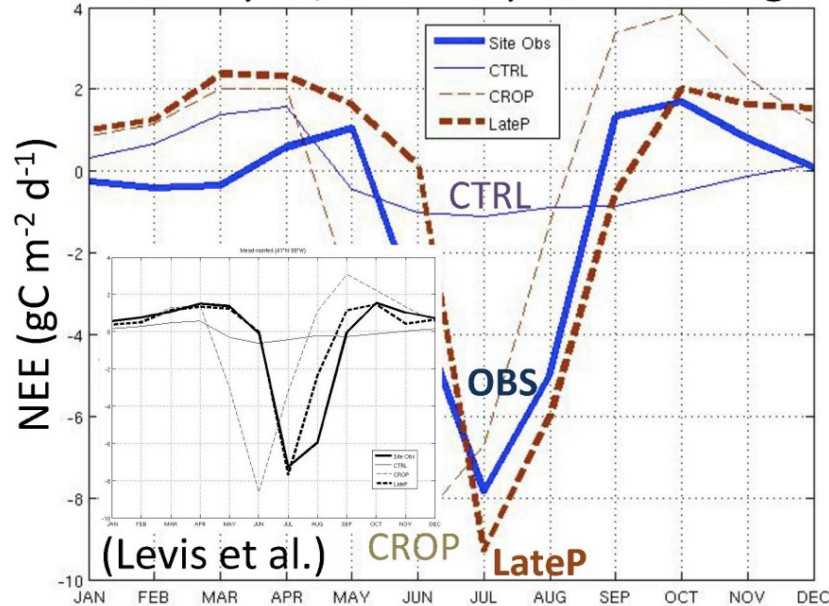
Levis et al. 2012
J Climate



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

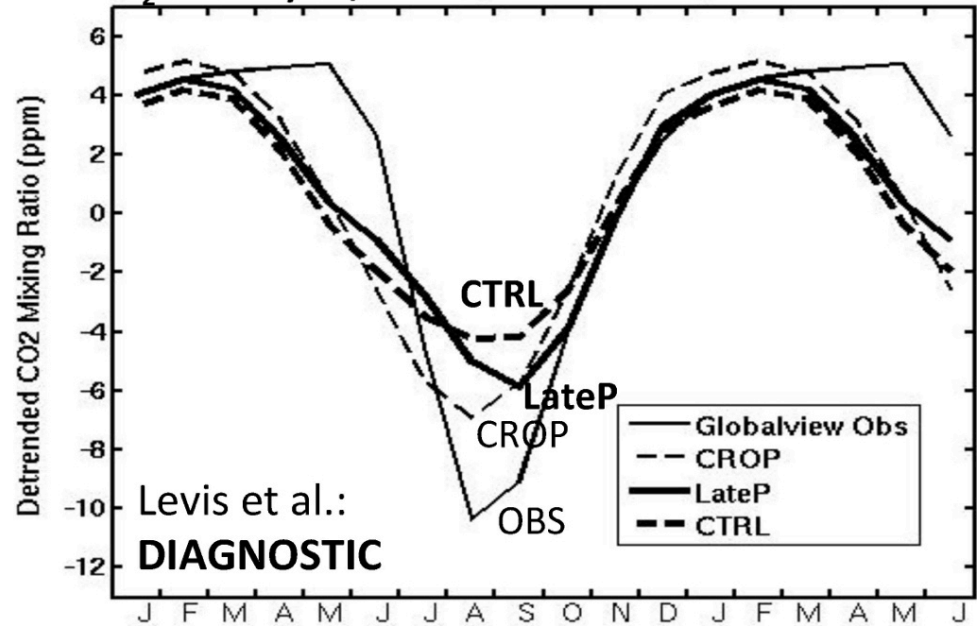


Seas. Cycle, Net Ecosystem Exchange



Effects on the atmosphere

CO₂ Seas. Cycle, Barrow (71.3°N 156.6°W)



CLM4

CLM4.5

Temp. corn
Temp. cereals
Temp. soybean

w/ options to
fertilize &
irrigate

effects on atm.



Levis et al. (2012)

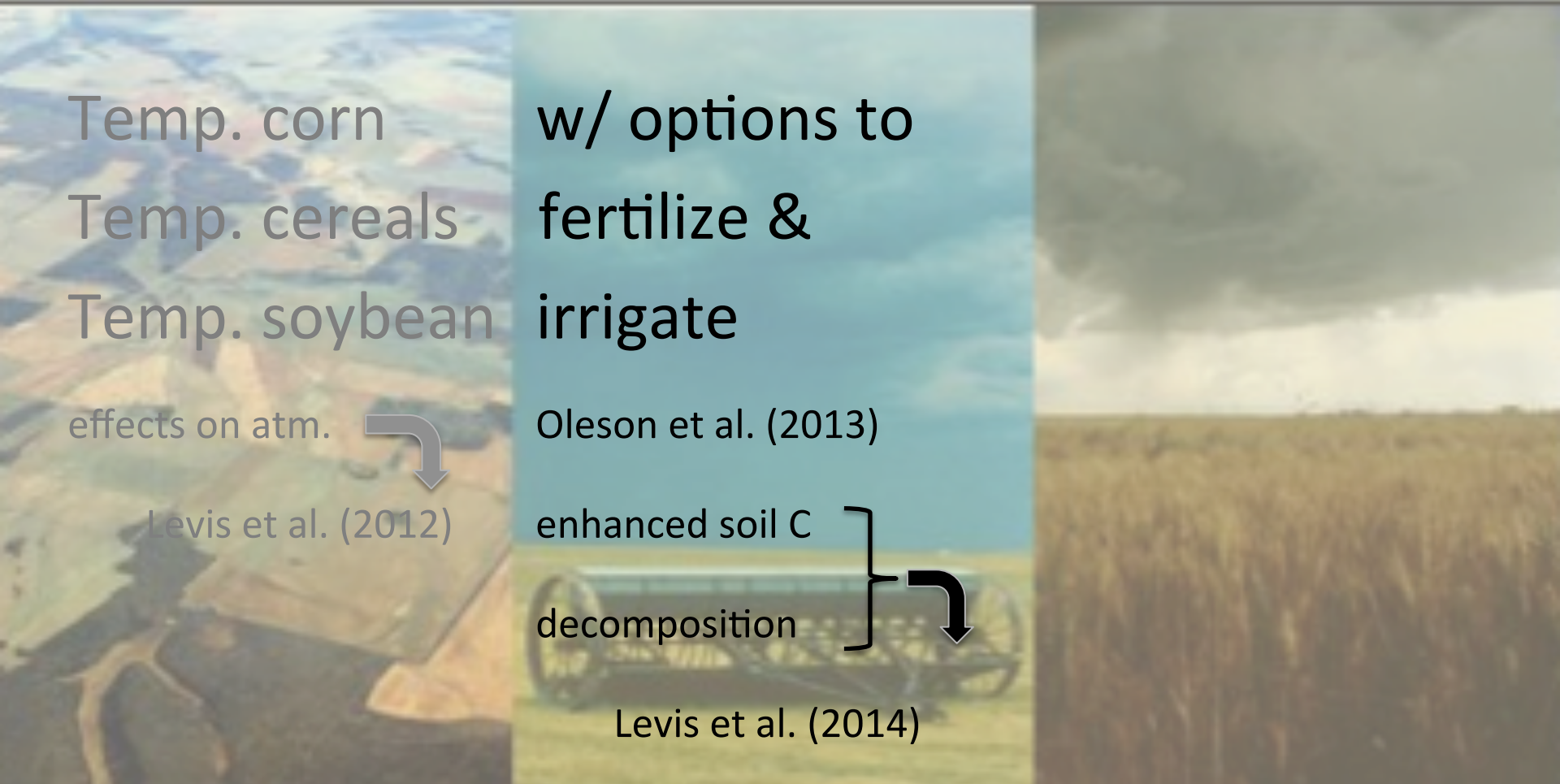
Oleson et al. (2013)

enhanced soil C

decomposition

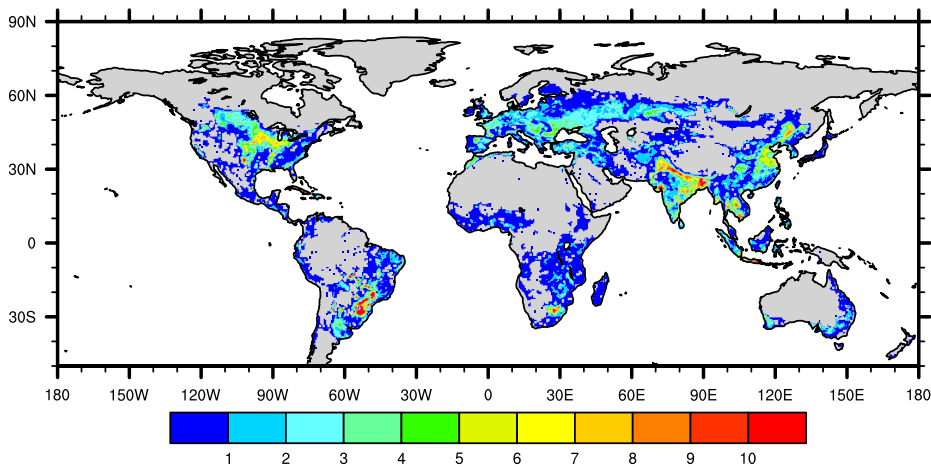


Levis et al. (2014)

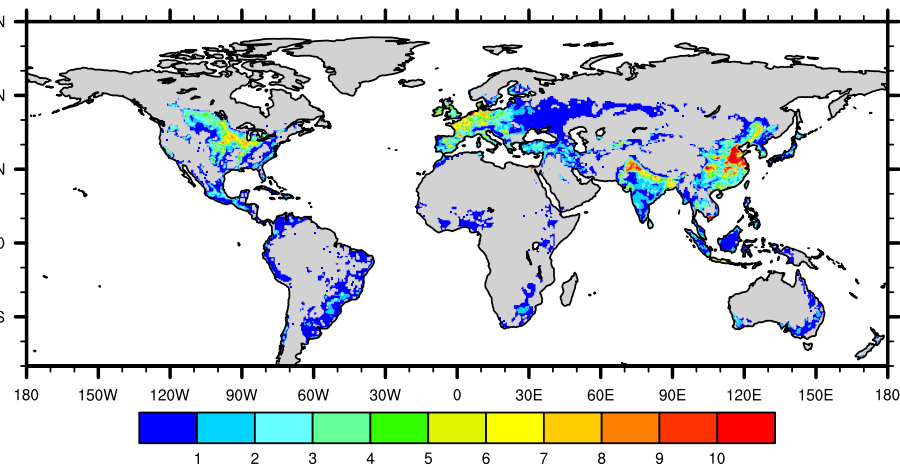


simulated N fertilizer observed

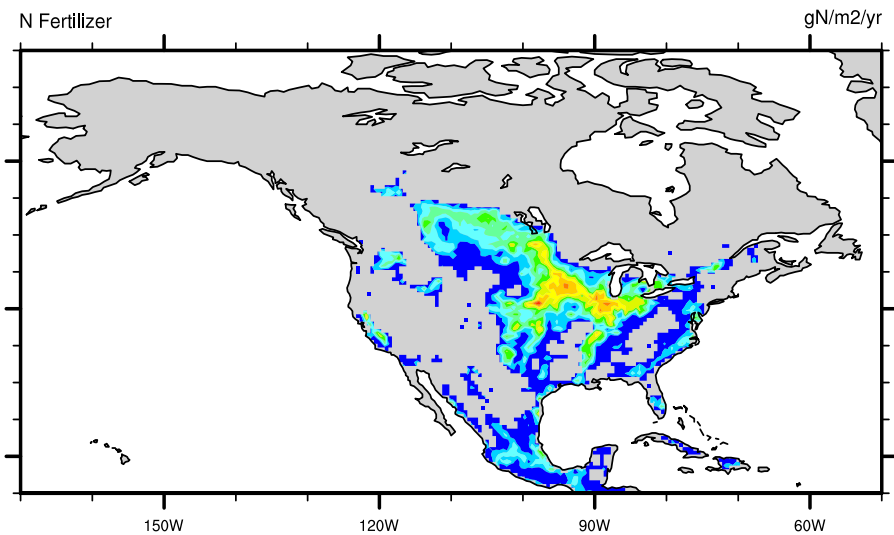
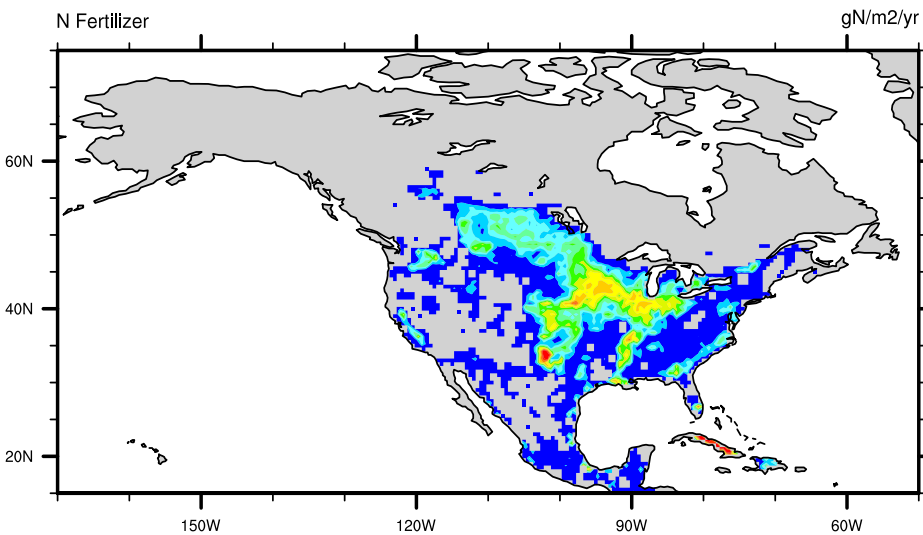
algorithm courtesy of Beth Drewniak -- figure courtesy of Cindy Nevison



CLM N Fertilizer



Potter N Fertilizer

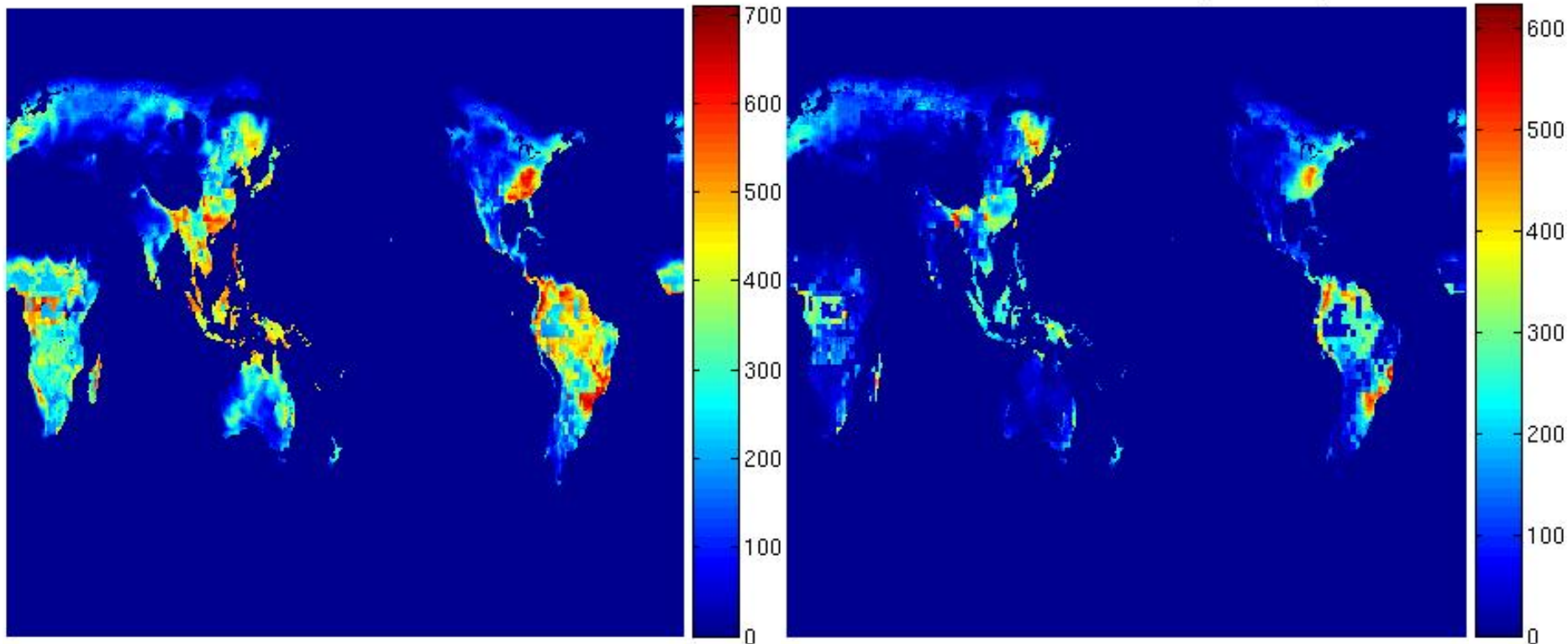


CLM's fertilized crops: more productive

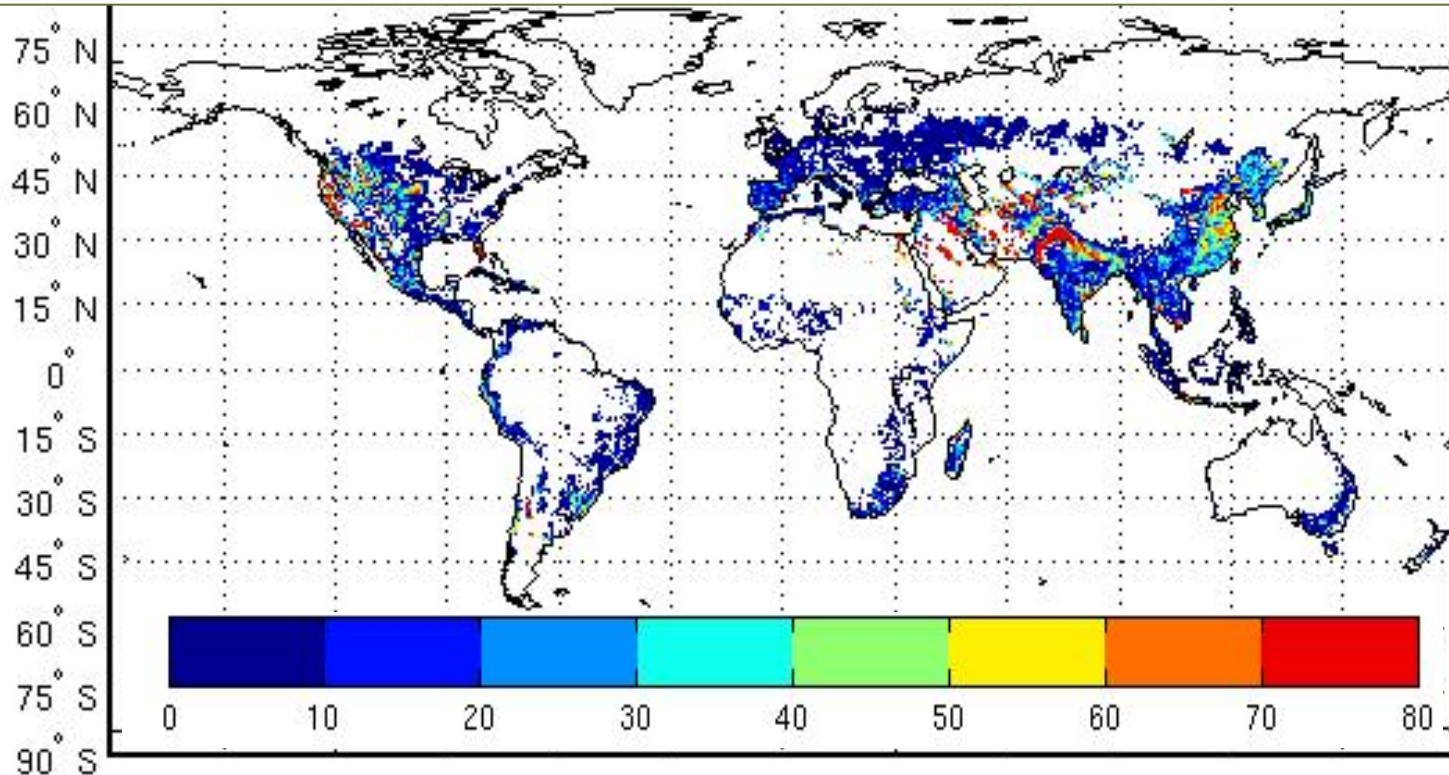
fertilized

GRAINC (gC m⁻²) RAINFED TEMP. CORN

unfertilized



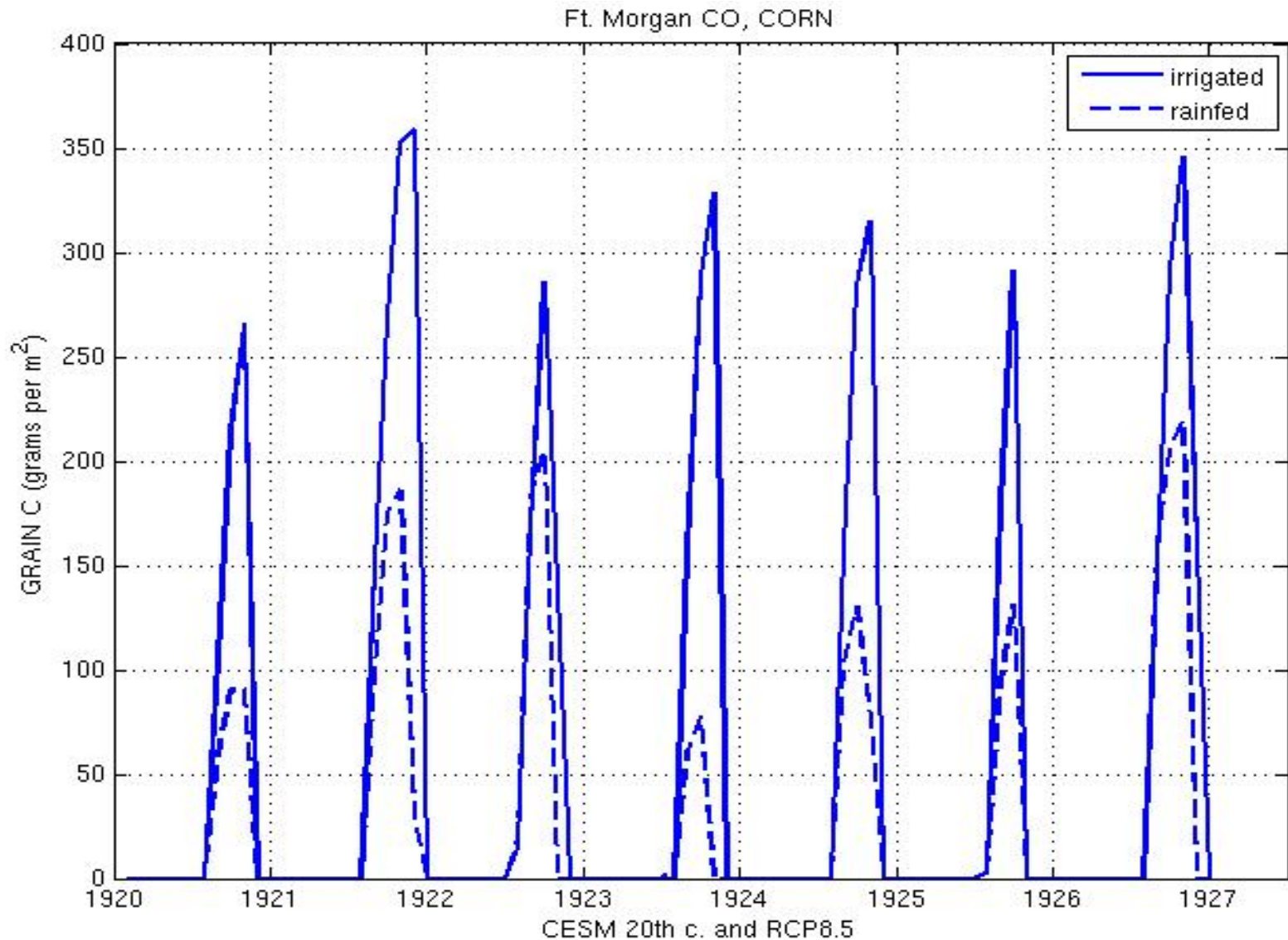
% of crops equipped for irrigation (Portmann et al. 2010)



Cooling mainly in US & SE Asia < 1K
Greater by day than night
Positive cloud feedback contributes ~equally
Volume & area of irrigation affect result most

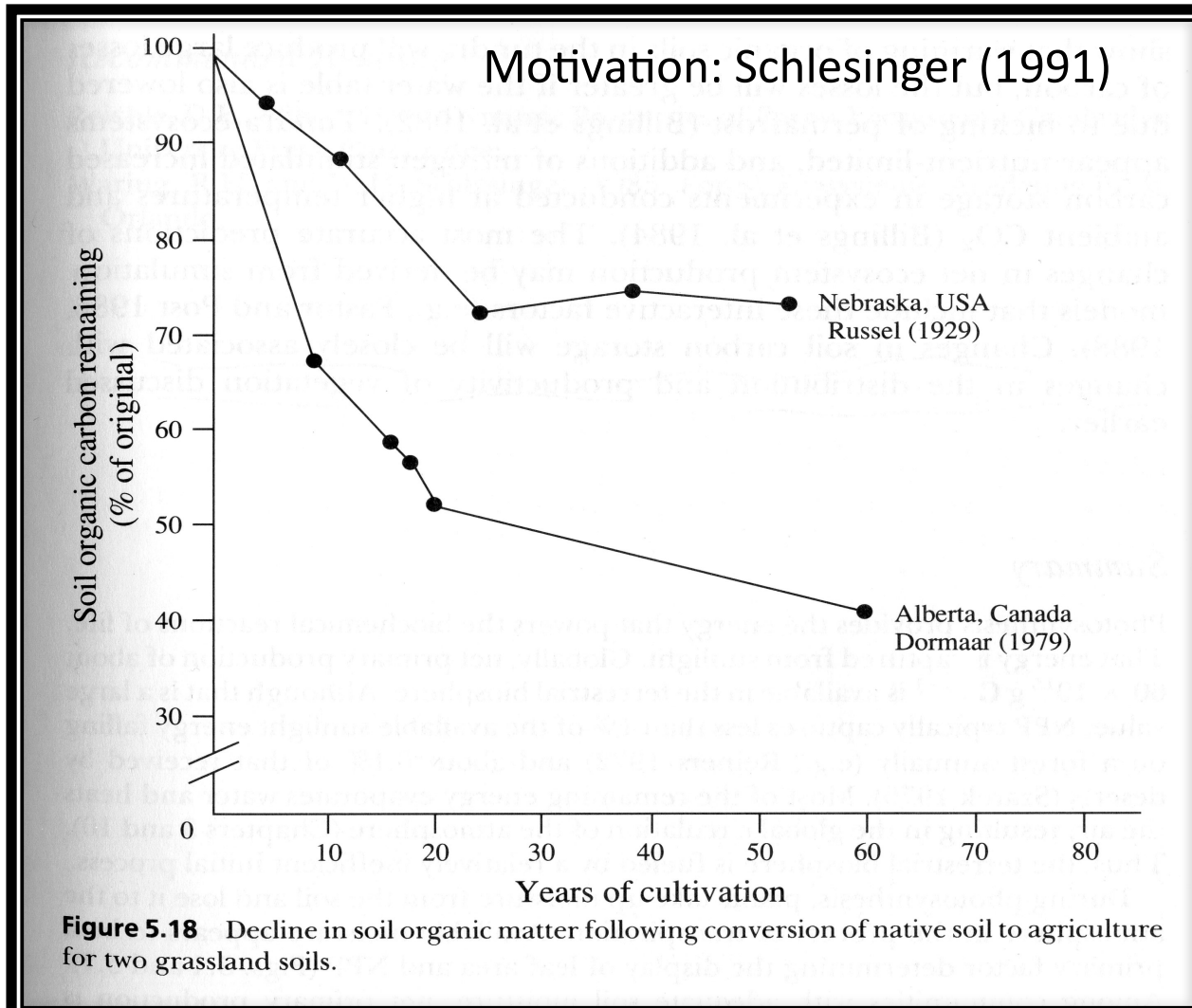
Warming in N high lats from circulation chg
So little global average effect
Similar order as the effects of LU locally
(Sacks et al. 2008)

CLM's irrigated crops are more productive than CLM's rainfed crops



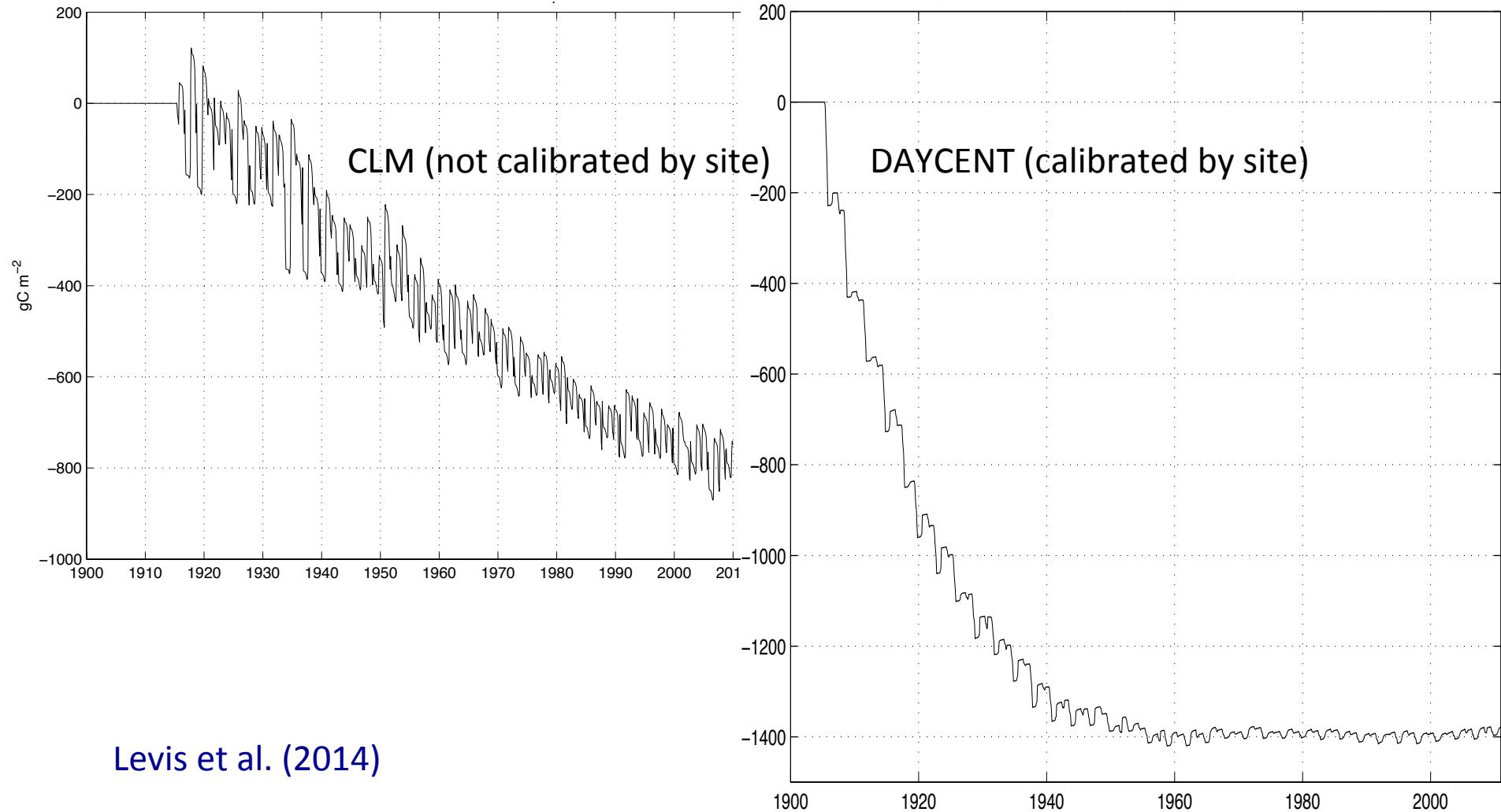
Can the CLM simulate the observed depletion of soil carbon due to crop cultivation?

Levis, Bonan, and Hartman (2014)



YES! Rainfed corn in YUMA, CO

Soil carbon differences: **Cultivated minus Not**



Levis et al. (2014)

CLM4

CLM4.5

post4.5

Temp. corn
Temp. cereals
Temp. soybean

w/ options to
fertilize &
irrigate

plus...
Trop. corn
Trop. soybean

effects on atm.



Levis et al. (2012)

Oleson et al. (2013)

enhanced soil C

decomposition



Levis et al. (2014)

Sugarcane

Rice

Cotton

A. Badger (GMU)

CLM4 & 4.5:

Ramankutty and Foley (1998)

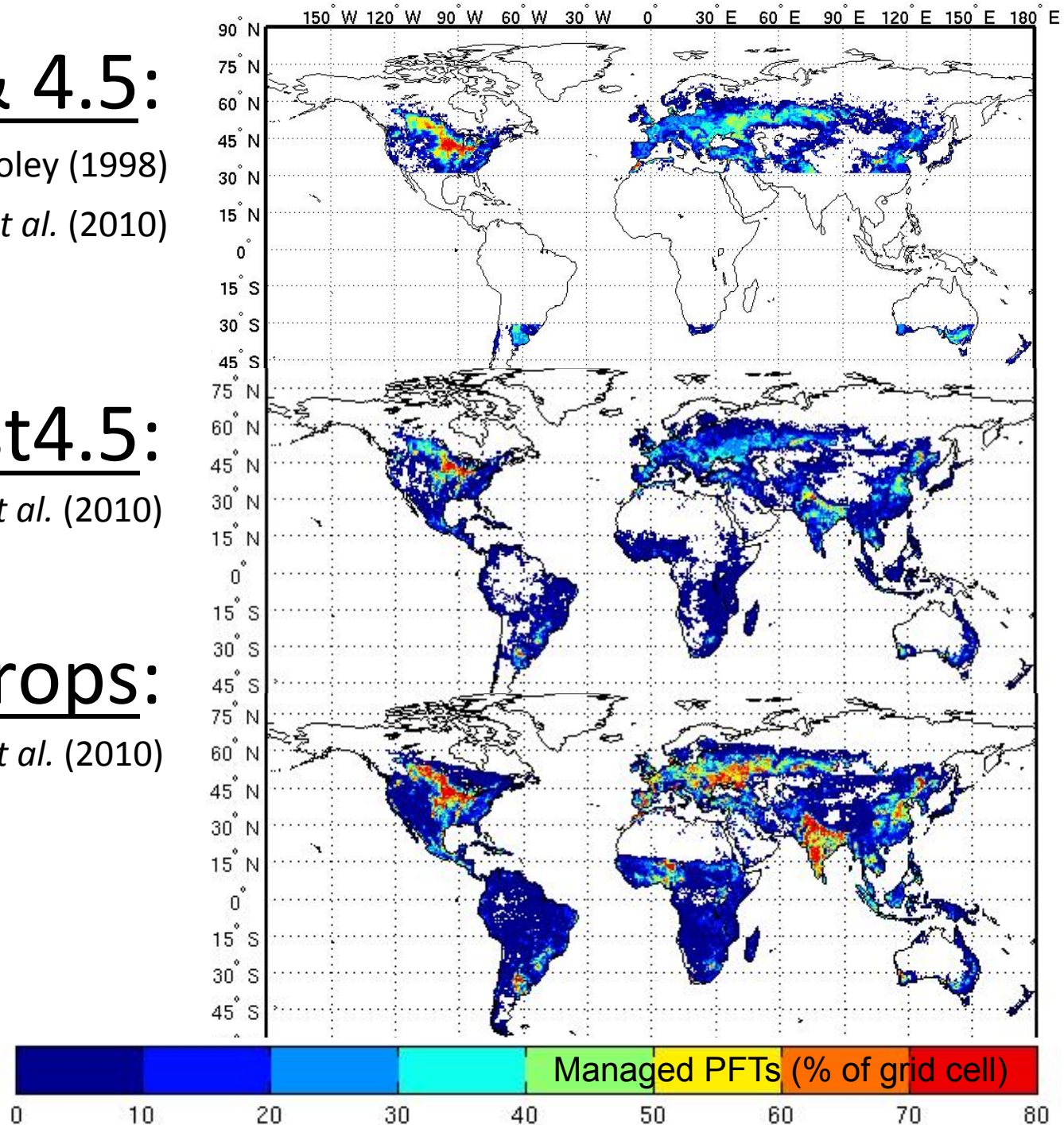
Portmann *et al.* (2010)

post4.5:

Portmann *et al.* (2010)

all crops:

Portmann *et al.* (2010)



CLM4 & 4.5:

Ramankutty and Foley (1998)

Portmann *et al.* (2010)

post4.5:

Portmann *et al.* (2010)

all crops:

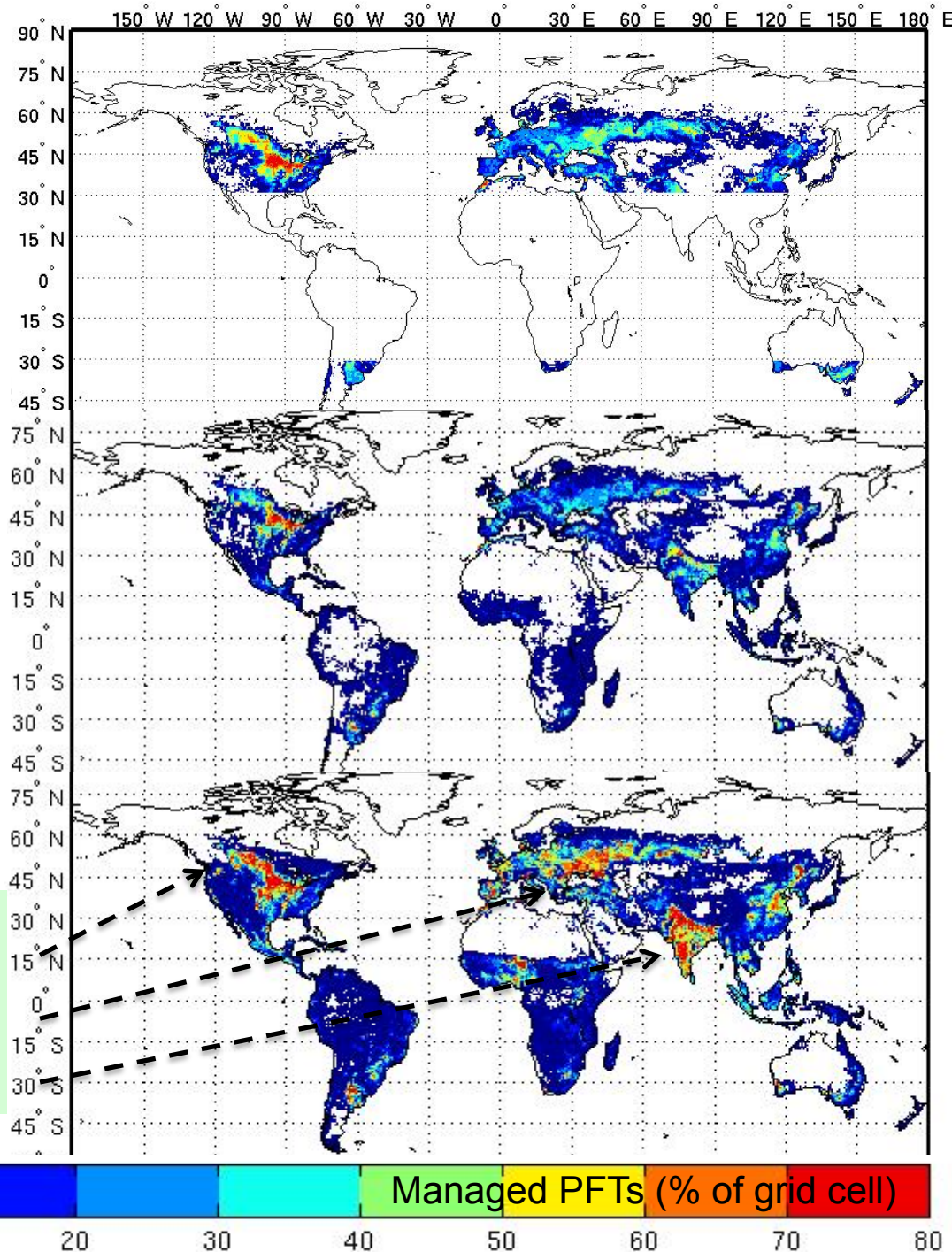
Portmann *et al.* (2010)

...still missing

Canada foddergrass

Russia sunflower and foddergrass

India sorghum, pulses, millet, pnuts

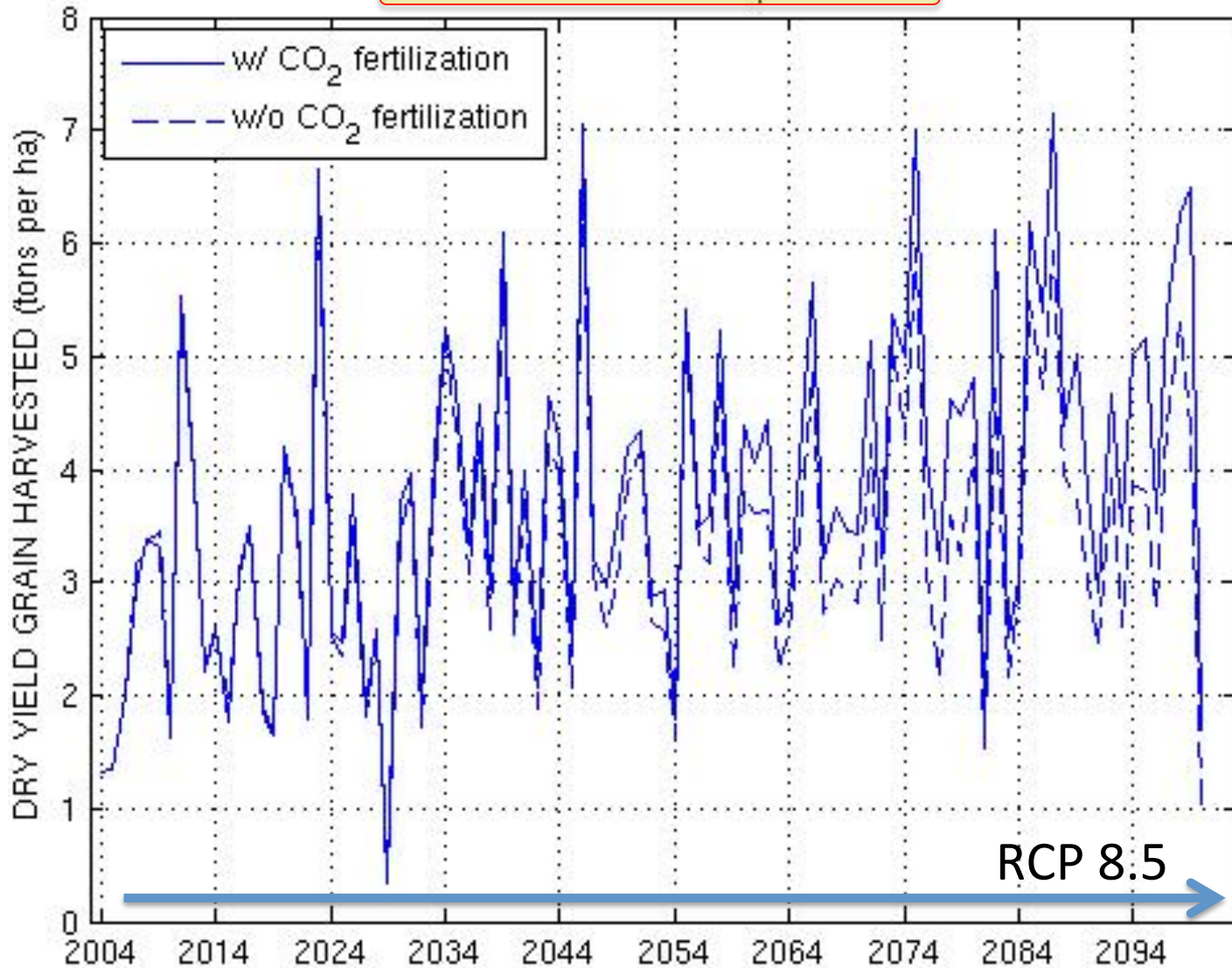


post4.5 list of pfts

1. "needleleaf_evergreen_temperate_tree
2. "needleleaf_evergreen_boreal_tree
3. "needleleaf_deciduous_boreal_tree
4. "broadleaf_evergreen_tropical_tree
5. "broadleaf_evergreen_temperate_tree
6. "broadleaf_deciduous_tropical_tree
7. "broadleaf_deciduous_temperate_tree
8. "broadleaf_deciduous_boreal_tree
9. "broadleaf_evergreen_shrub
10. "broadleaf_deciduous_temperate_shrub
11. "broadleaf_deciduous_boreal_shrub
12. "c3_arctic_grass
13. "c3_non-arctic_grass
14. "c4_grass
15. "c3_crop
16. "c3_irrigated
17. "temperate_corn
18. "irrigated_temperate_corn
19. "spring_wheat
20. "irrigated_spring_wheat
21. "winter_wheat
22. "irrigated_winter_wheat
23. "temperate_soybean,
24. "irrigated_temperate_soybean
25. "barley
26. "irrigated_barley
27. "winter_barley
28. "irrigated_winter_barley
29. "rye
30. "irrigated_rye
31. "winter_rye
32. "irrigated_winter_rye
33. "cassava
34. "irrigated_cassava
35. "citrus
36. "irrigated citrus
37. "cocoa
38. "irrigated_cocoa
39. "coffee
40. "irrigated_coffee
- 41. "cotton**
- 42. "irrigated_cotton**
43. "datepalm
44. "irrigated_datepalm
45. "foddergrass
46. "irrigated_foddergrass
47. "grapes
48. "irrigated_grapes
49. "groundnuts
50. "irrigated_groundnuts
51. "millet
52. "irrigated_millet
53. "oilpalm
54. "irrigated_oilpalm
55. "potatoes
56. "irrigated_potatoes
57. "pulses
58. "irrigated_pulses
59. "rapeseed
60. "irrigated_rapeseed
- 61. "rice**
- 62. "irrigated_rice**
63. "sorghum
64. "irrigated_sorghum
65. "sugarbeet
66. "irrigated_sugarbeet
- 67. "sugarcane**
- 68. "irrigated_sugarcane**
69. "sunflower
70. "irrigated_sunflower
71. "miscanthus
72. "irrigated_miscanthus
73. "switchgrass
74. "irrigated_switchgrass
- 75. "tropical_corn**
- 76. "irrigated_tropical_corn**
- 77. "tropical_soybean**
- 78. "irrigated_tropical_soybean**

Dry Yield = $C_{\text{grain}} \{g \text{ m}^{-2}\} \times 0.85 \times 10^4 \{m^2 \text{ ha}^{-1}\} \times 2.22 \times 10^{-6} \{\text{tons } g^{-1}\}$

Bondville IL Rainfed Temperate Corn



2004 obs (tons ha⁻¹)

Botswana 0.3

...

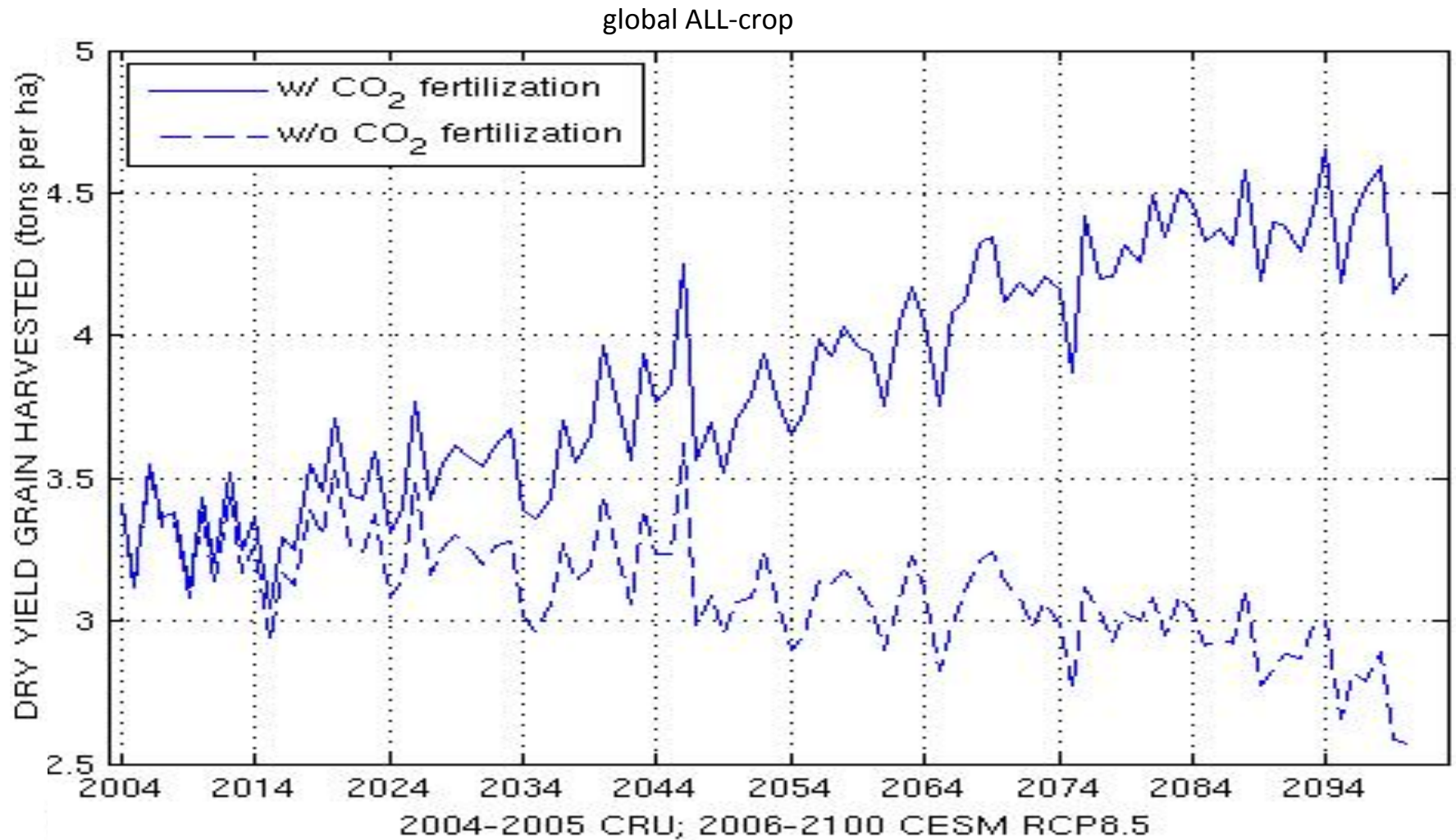
USA 6.9

...

Belgium 9.2

<http://data.worldbank.org>

Global Dry Yield



CLM input files with crop-relevant info

- **fsurdat**: % area of rainfed and irrigated crops
- **clm_params**:
 - min/max planting dates
 - min/max planting temperature
 - nitrogen in fertilizer
 - etc.

CLM-crop response to extremes

- Photosynthesis declines for higher&lower than optimal T: about 28°C C₃ & 38°C C₄ plants
- No other form of heat stress
- No crop response to flooding
- Drought effects

Summary & Conclusions

- **Interactive crop management in the CLM**
 - Better simulated annual cycle of crop LAI
 - Better annual cycle of the NEE (and CO₂)
 - Promising for simulations with interactive CO₂
 - Also affecting the biogeophysics (precip, temperature)
- **Human dimensions: new frontier in CESM research**
 - Still also resolving more basic issues: biogeophys. & bgc
 - Coupling ESMs and IAMs in the not so distant future...

To-do list

- Winter cereals (e.g. winter wheat, rye, barley)
- Multi-cropping
- Crop rotations
- Crop fertilization & manure application data
- Other crops: e.g., oil palm by Yuanchao Fan
- Better crops: e.g., rice by Fang Li and Young-Hee Lee
- Crop yield response to extremes

A landscape photograph showing a vast field of tall, golden-brown grass in the foreground. In the middle ground, there are several green trees and shrubs. The background features a range of rugged, rocky mountains with dark green forest cover. The sky is bright blue with scattered white clouds. The word "Questions?" is overlaid in white text in the center of the image.

Questions?