CROP modeling in the Community Land Model

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NCAR is sponsored by the National Science Foundation

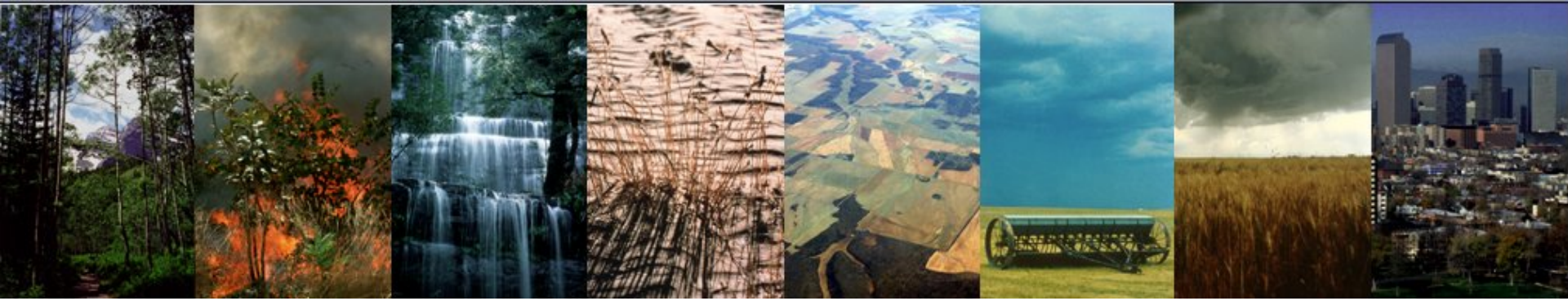
Motivation for crop modeling in the CLM

- **Food supply ...crop yields**
- **Fuel supply ...biofuels**

} **& prices**

- **Land-atm interactions ...climate change**

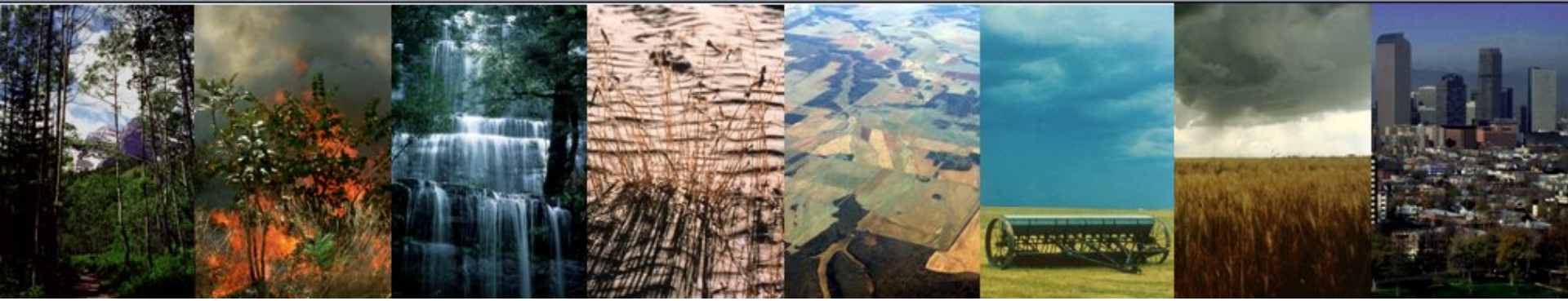
Biogeophysical **Biogeochemical**



Community Earth System Model (CESM)

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

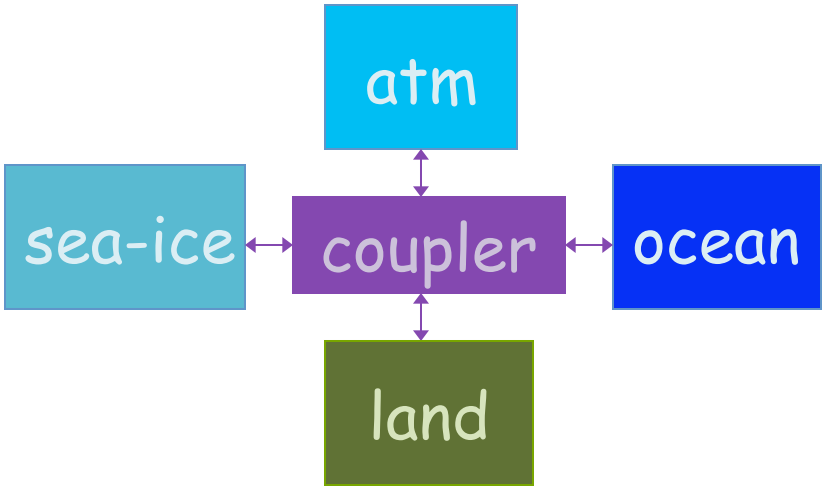
- What if we replaced the vegetation?
- What if we removed the irrigation?
- What may Earth be like in the future/have been in the past?

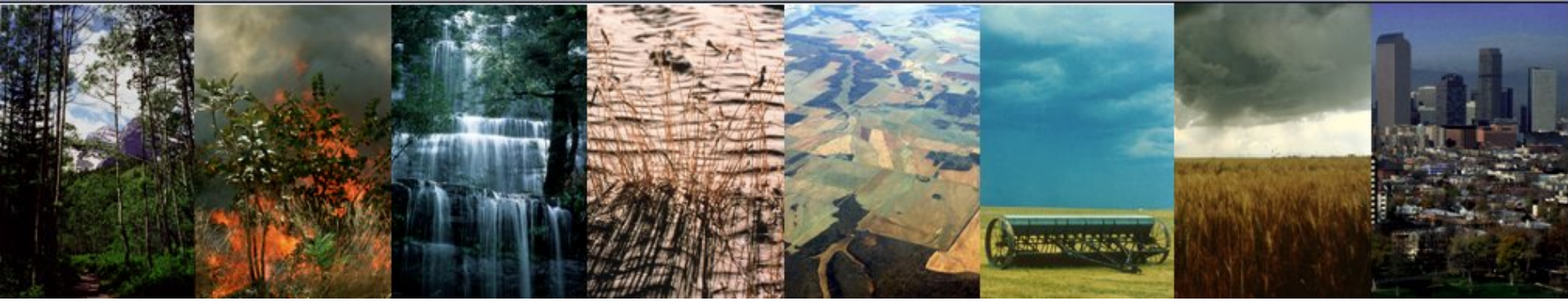


Community Earth System Model (CESM)

Introducing human systems to the CESM

- Agriculture (my focus)
- Urban





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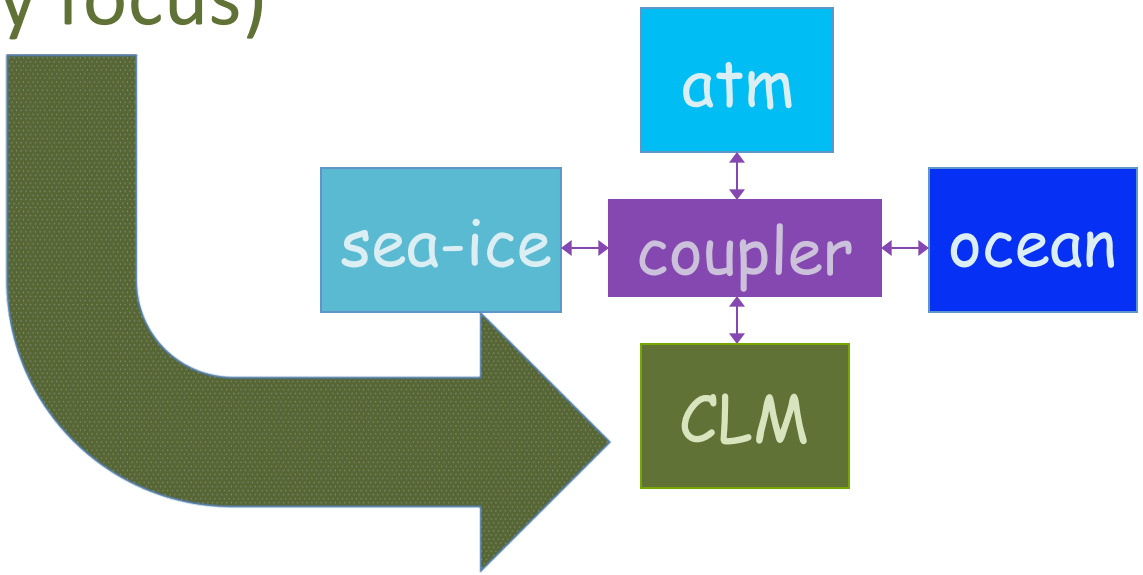


CLM4

Temp. corn

Temp. cereals

Temp. soybean

effects on atm.

Levis et al. (2012)

Interactive Crops in the CLM

Following AgroIBIS (Kucharik & Brye, 2003)

Temperate corn, soybean, spring wheat:

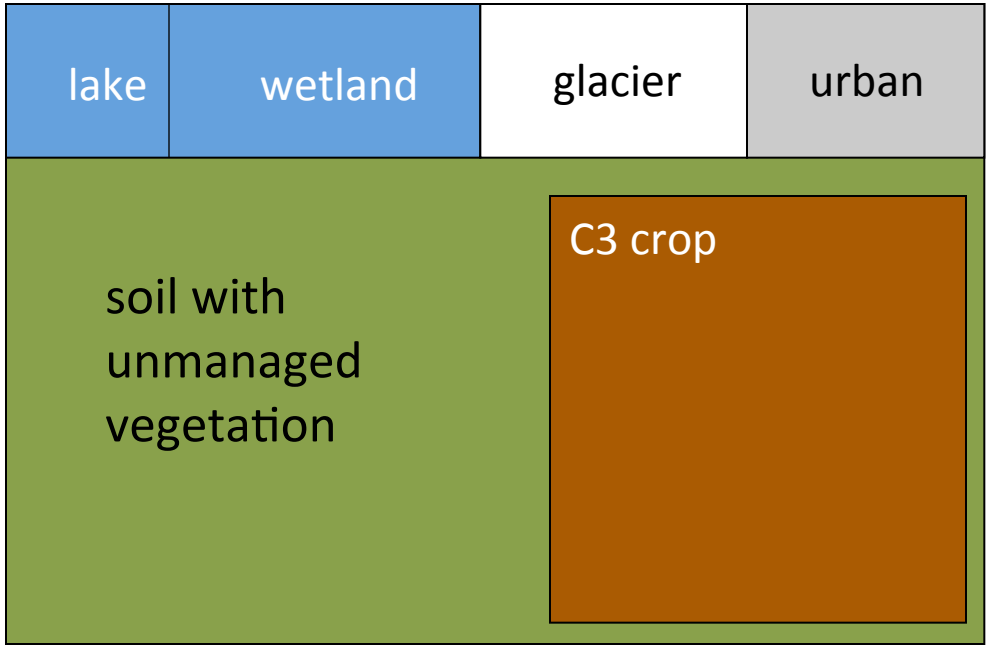
Phenology by GDD accumulators ➔

Planting, leaf emergence, grain fill, maturity, harvest

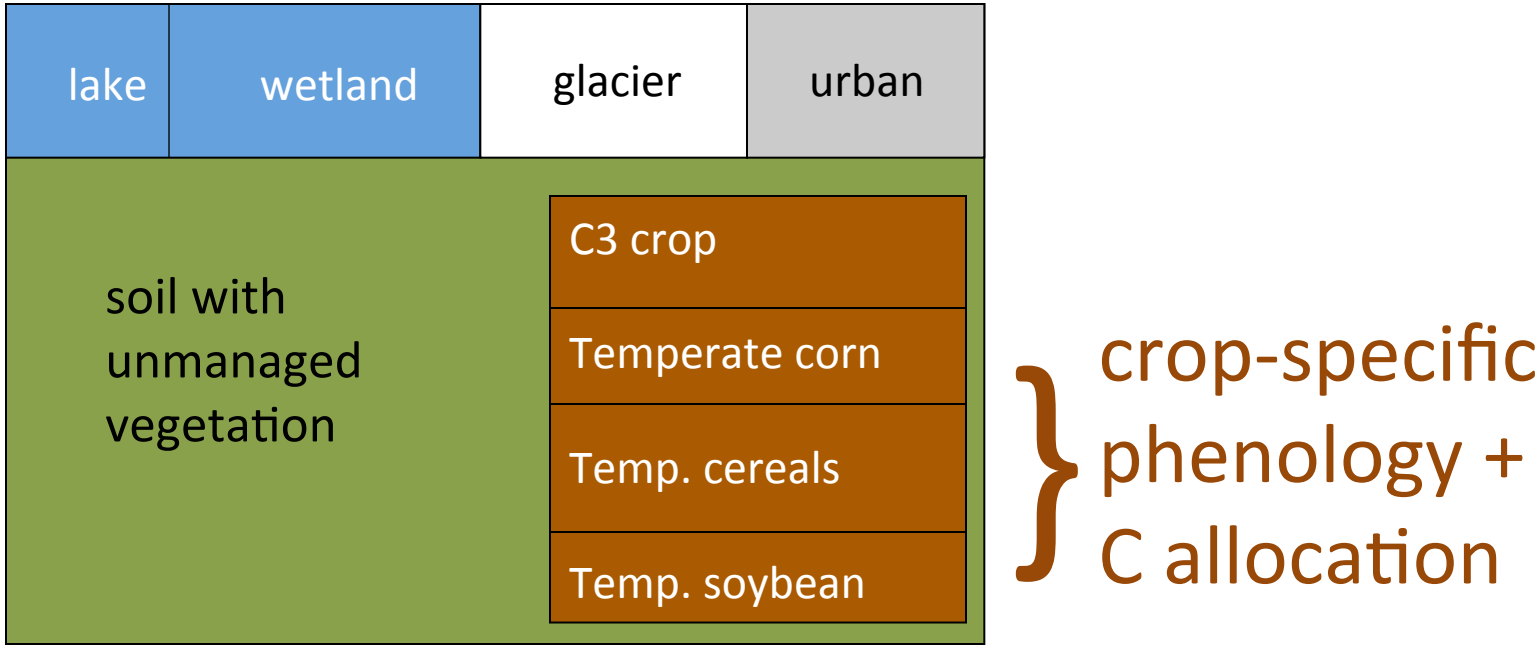
C allocation + N limitation ➔

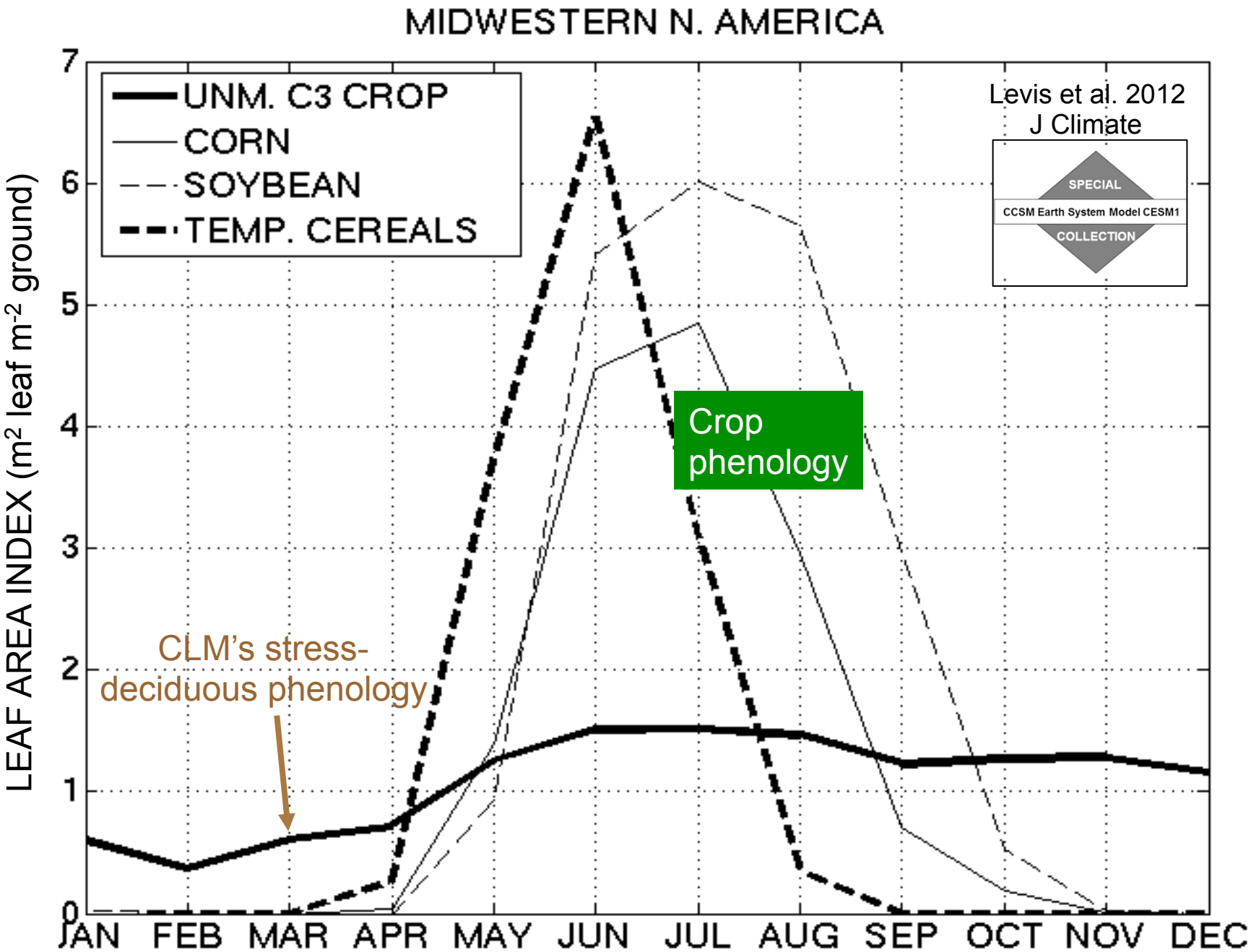
Leaf area, height, crop yield

a CLM grid cell (default)



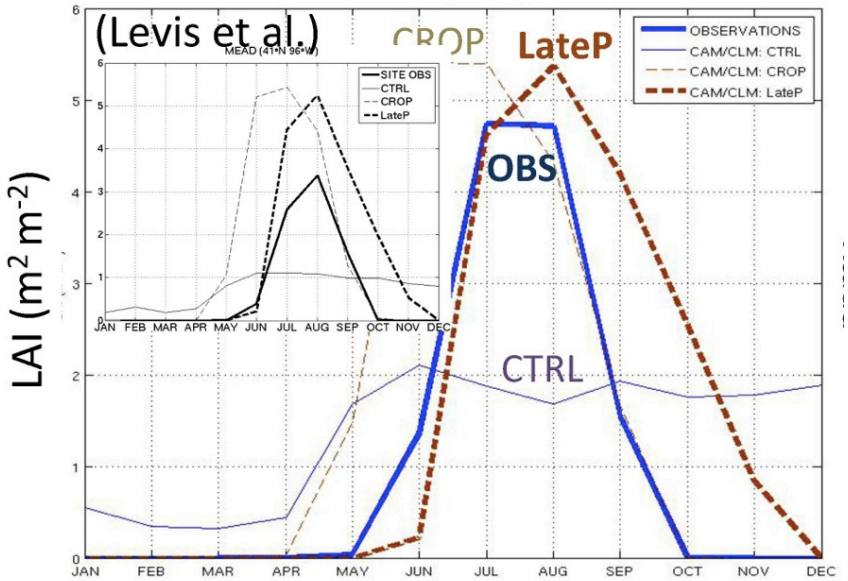
a CLM grid cell
with interactive crop management



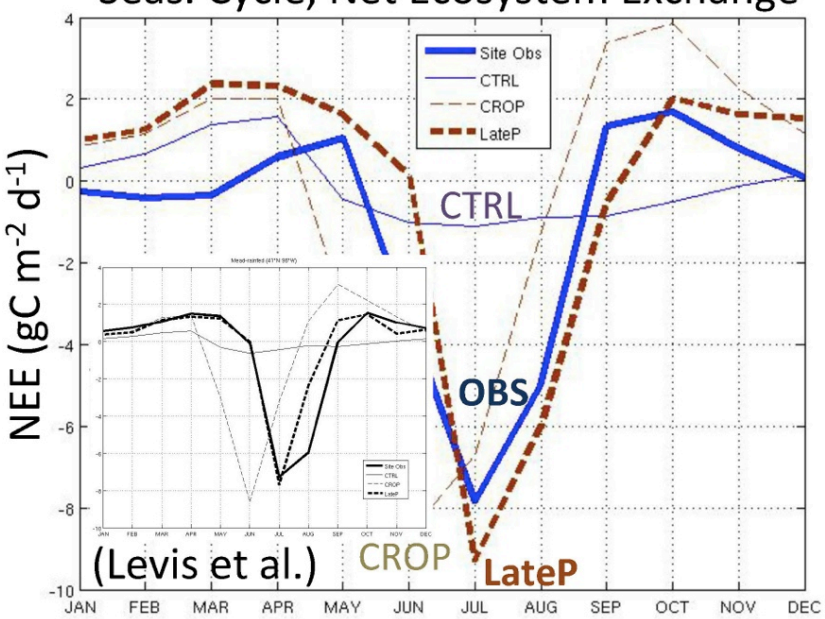

MIDWESTERN N. AMERICA
UNM. C3 CROP
CORN
SOYBEAN
TEMP. CEREALS
Levis et al. 2012
J Climate
SPECIAL
CCSM Earth System Model CESM1
COLLECTION
Crop phenology
CLM's stress-deciduous phenology
LEAF AREA INDEX (m² leaf m⁻² ground)
0
1
2
3
4
5
6
7
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Effects on the atmosphere

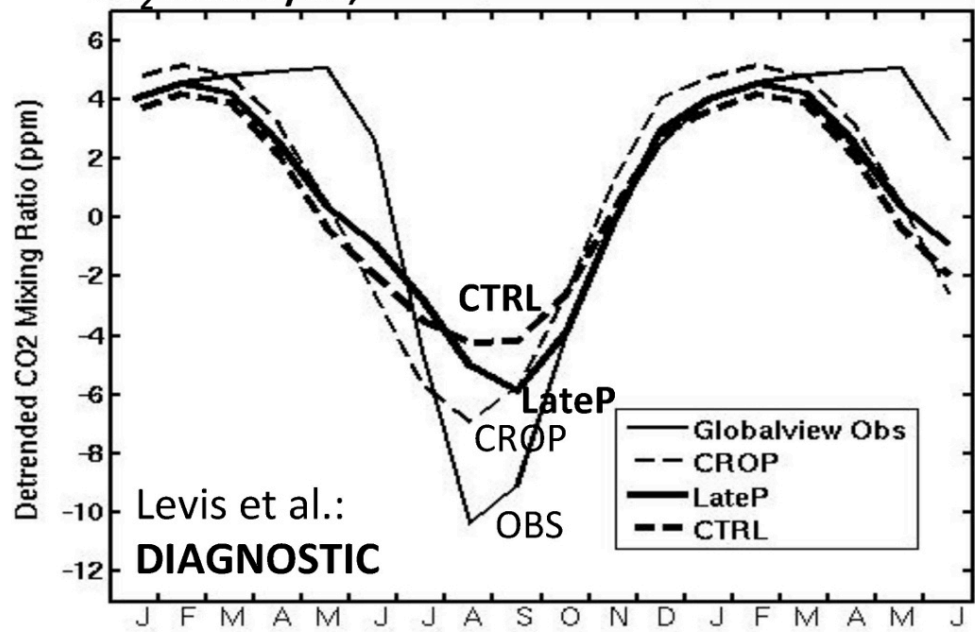
Bondville, IL (40°N 88°W) Leaf Area Index



Seas. Cycle, Net Ecosystem Exchange



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



CLM4

Temp. corn

Temp. cereals

Temp. soybean

effects on atm.

Levis et al. (2012)

CLM4.5

w/ options to fertilize & irrigate

Oleson et al. (2013)

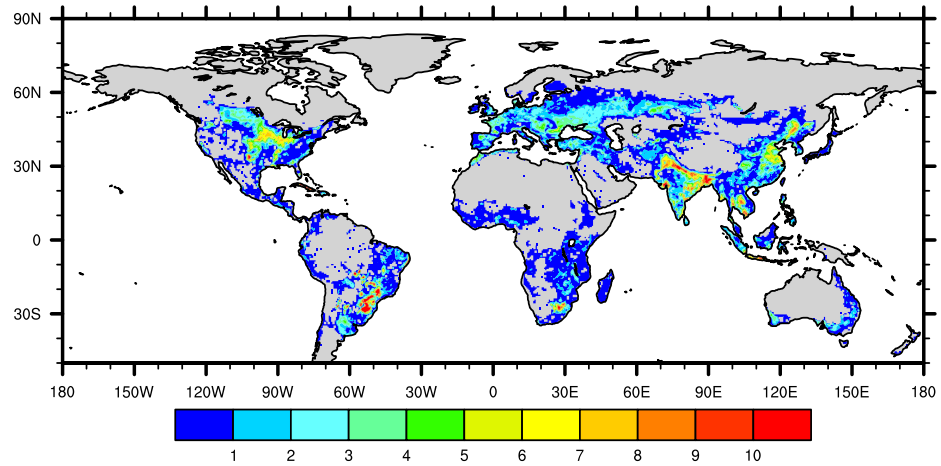
enhanced soil C

decomposition

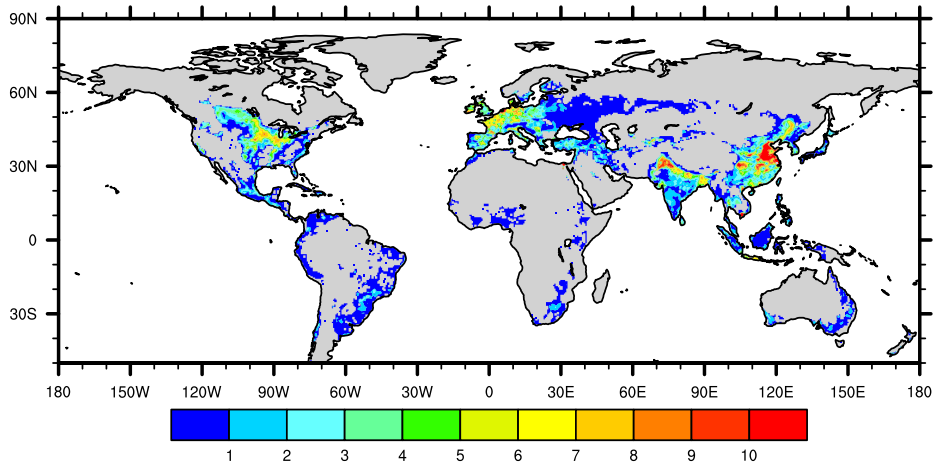
Levis et al. (2014)

simulated N fertilizer observed

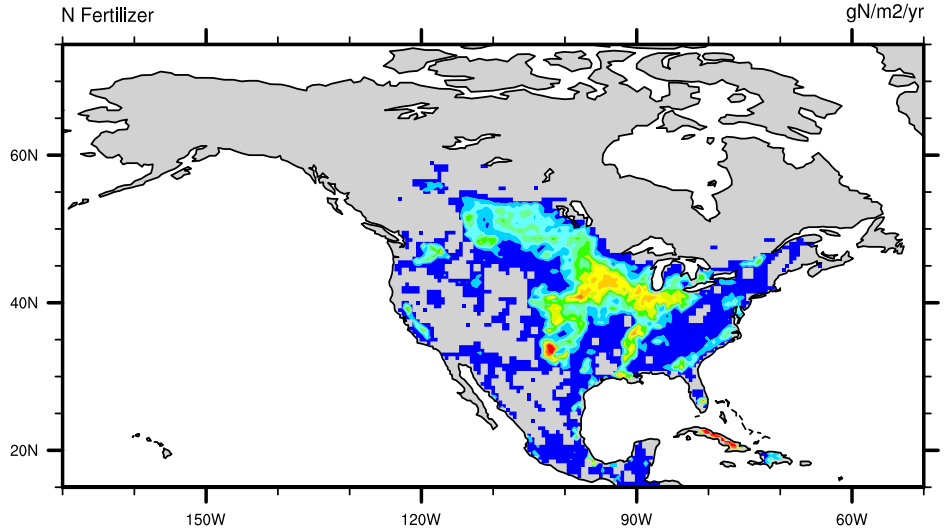
algorithm courtesy of Beth Drewniak -- figure courtesy of Cindy Nevison

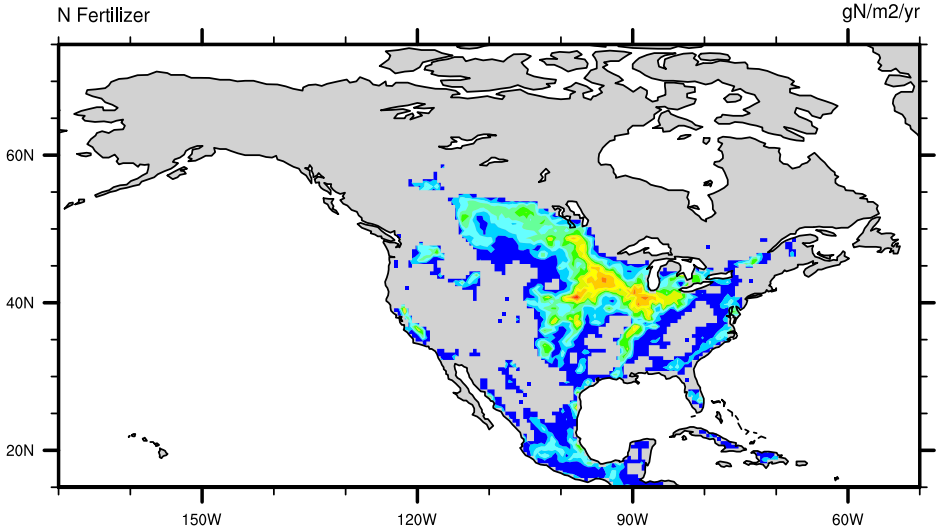


CLM N Fertilizer



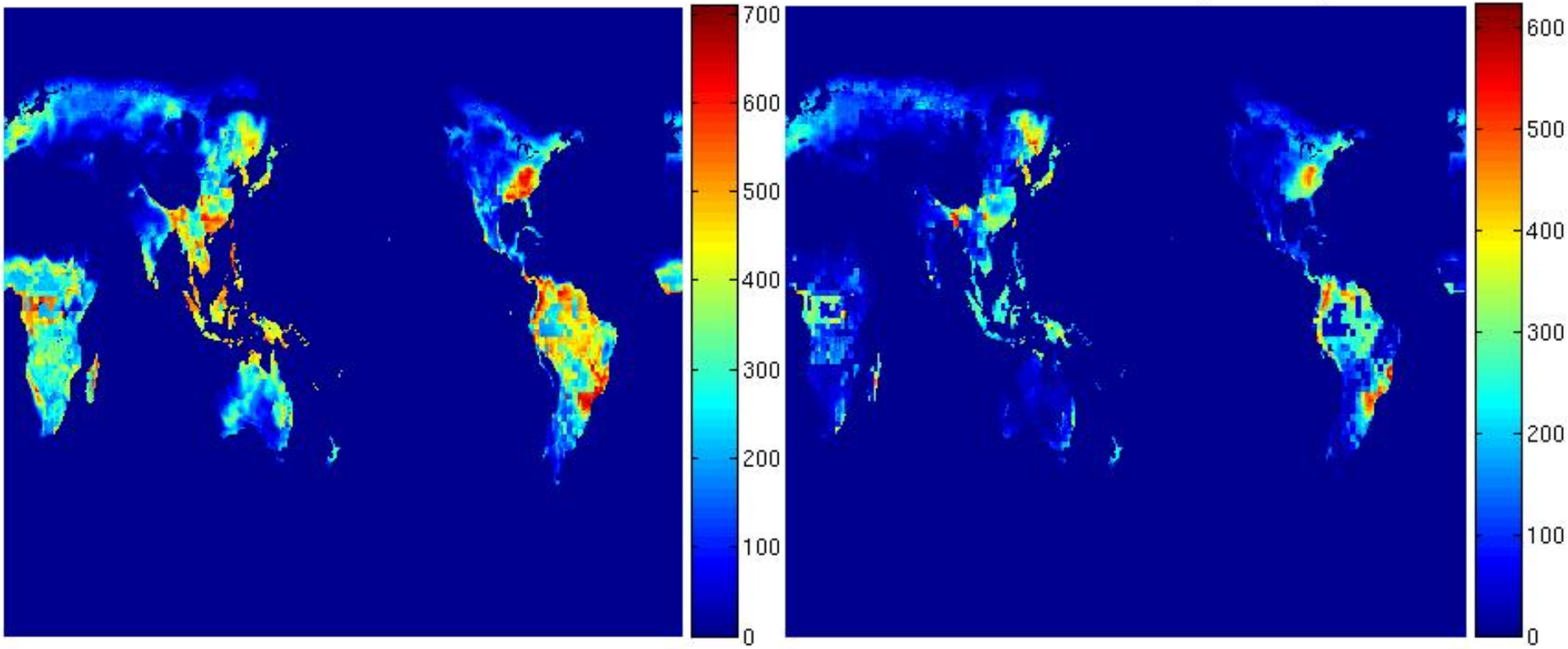
Potter N Fertilizer



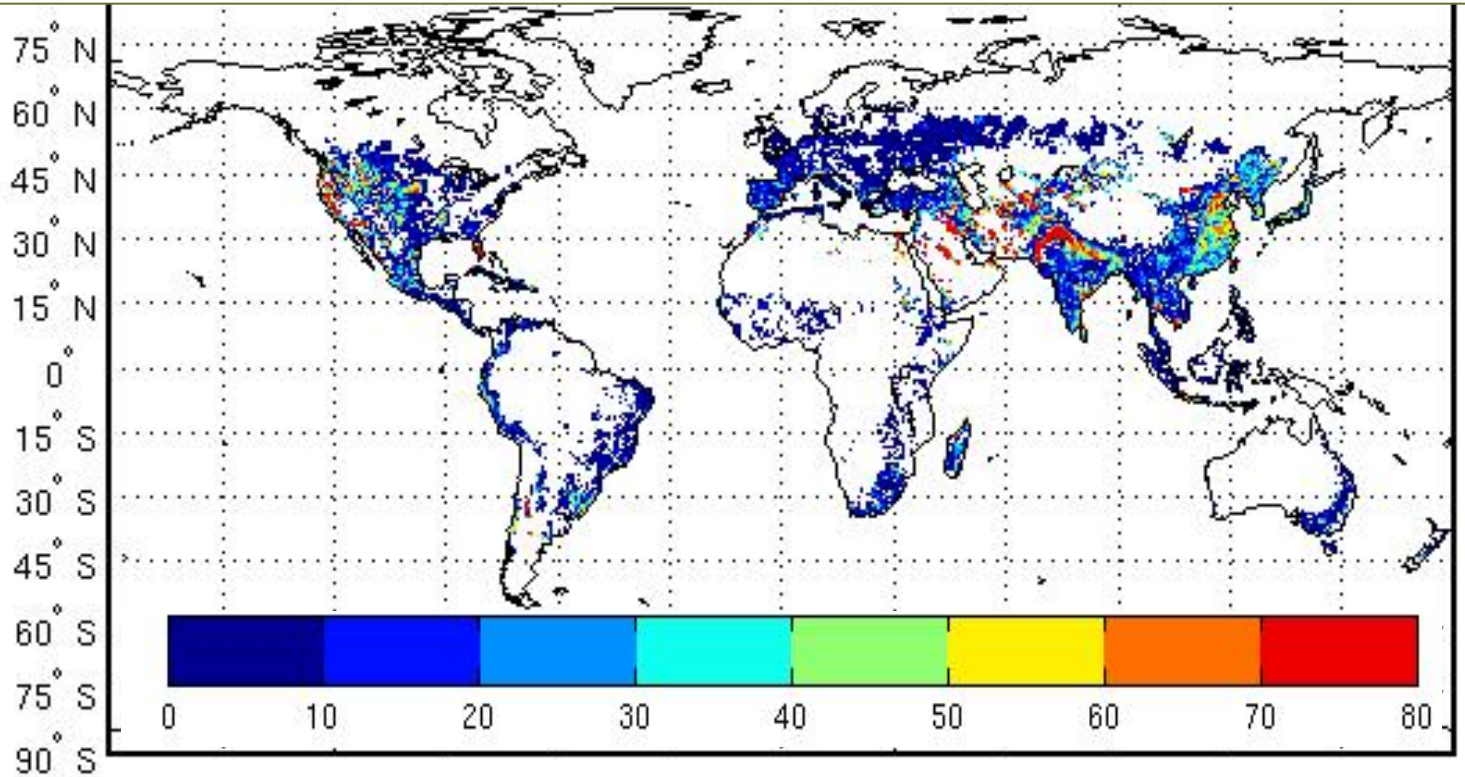


CLM's **fertilized crops: more productive**

fertilized GRAINC (gC m^{-2}) RAINFED TEMP. CORN unfertilized



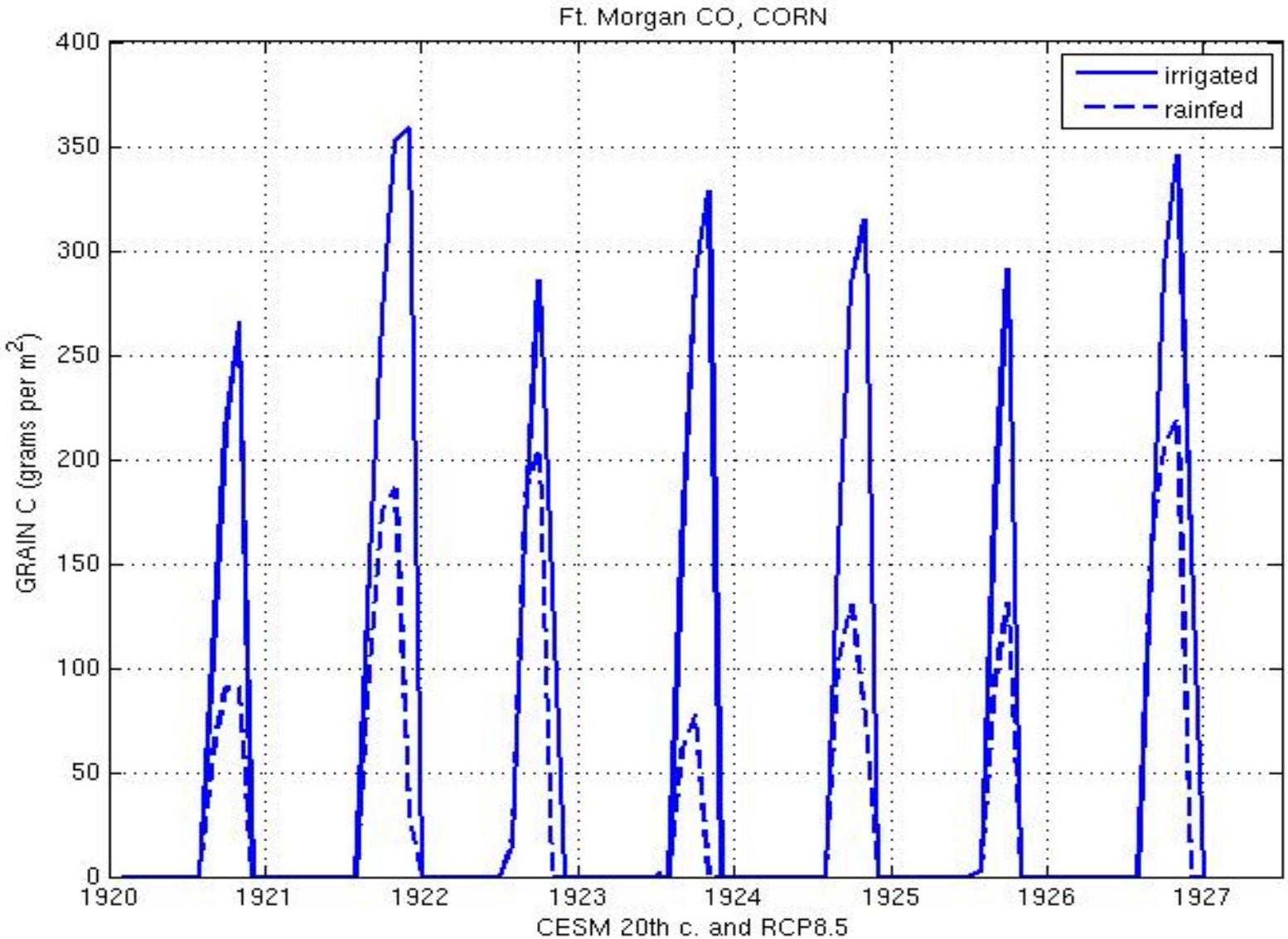
% of crops equipped for irrigation (Portmann et al. 2010)



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)

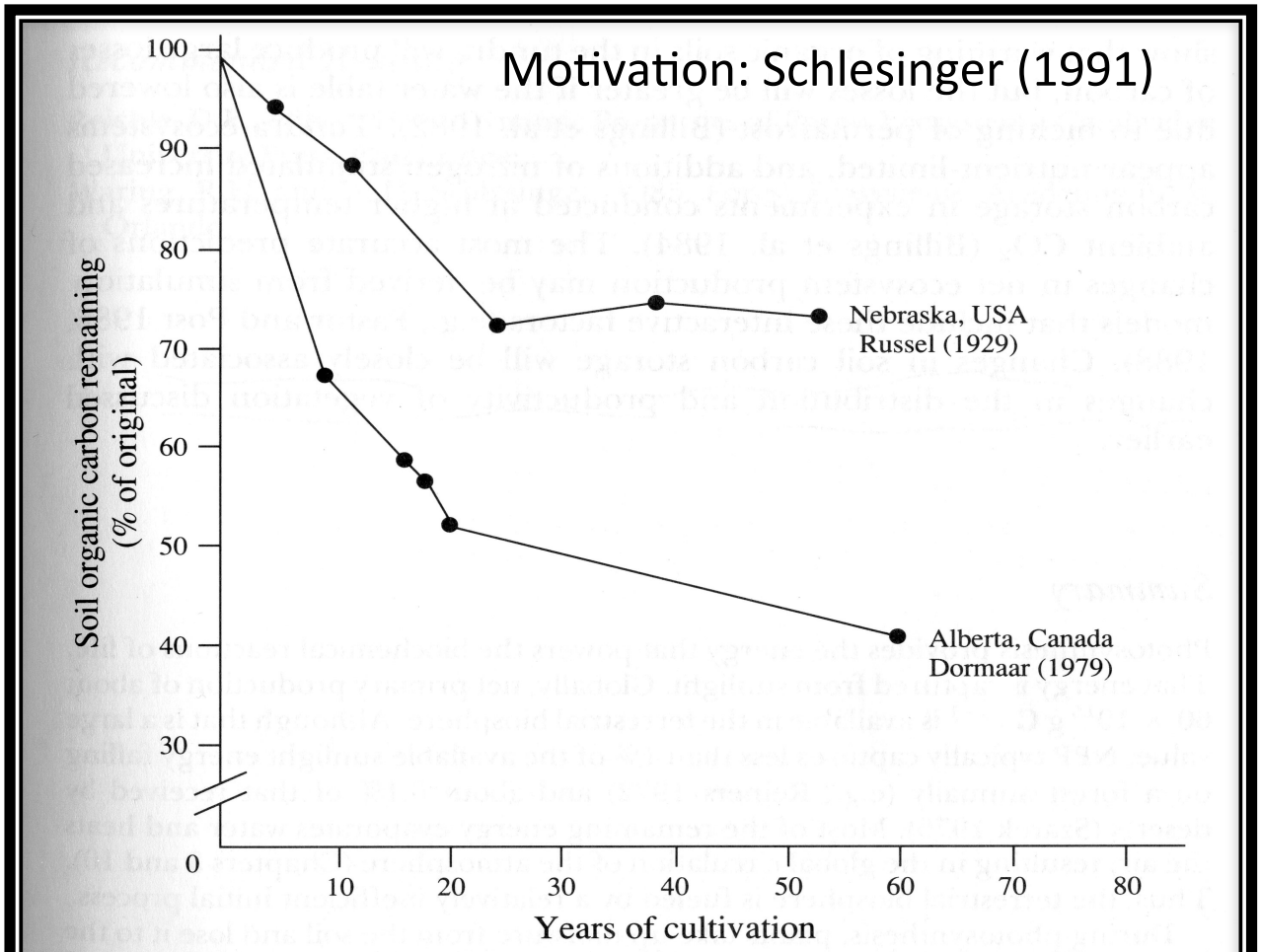
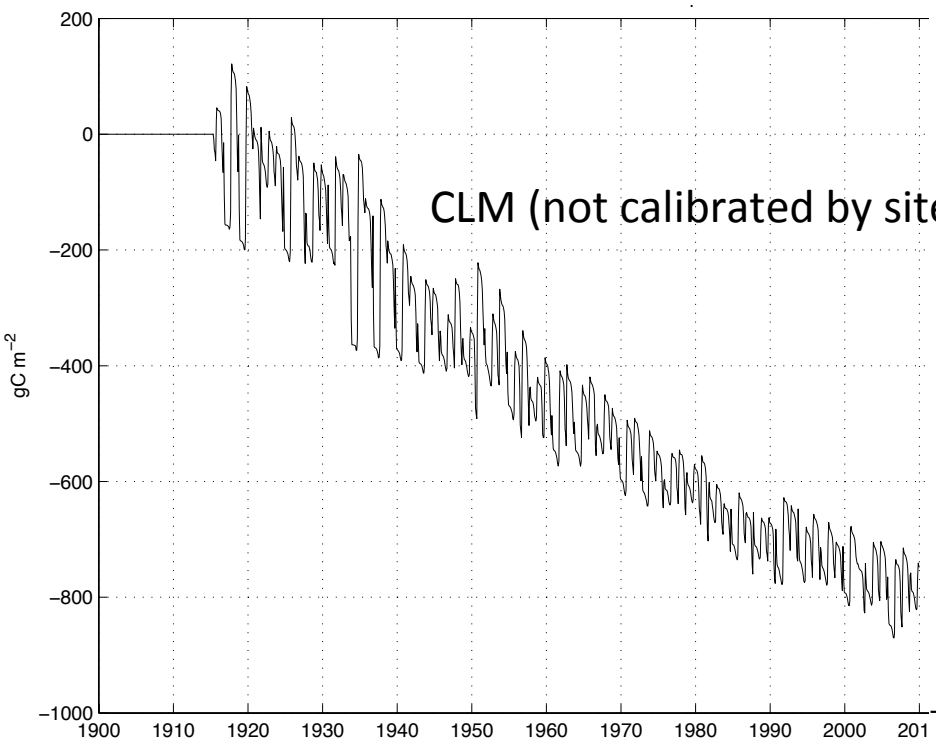
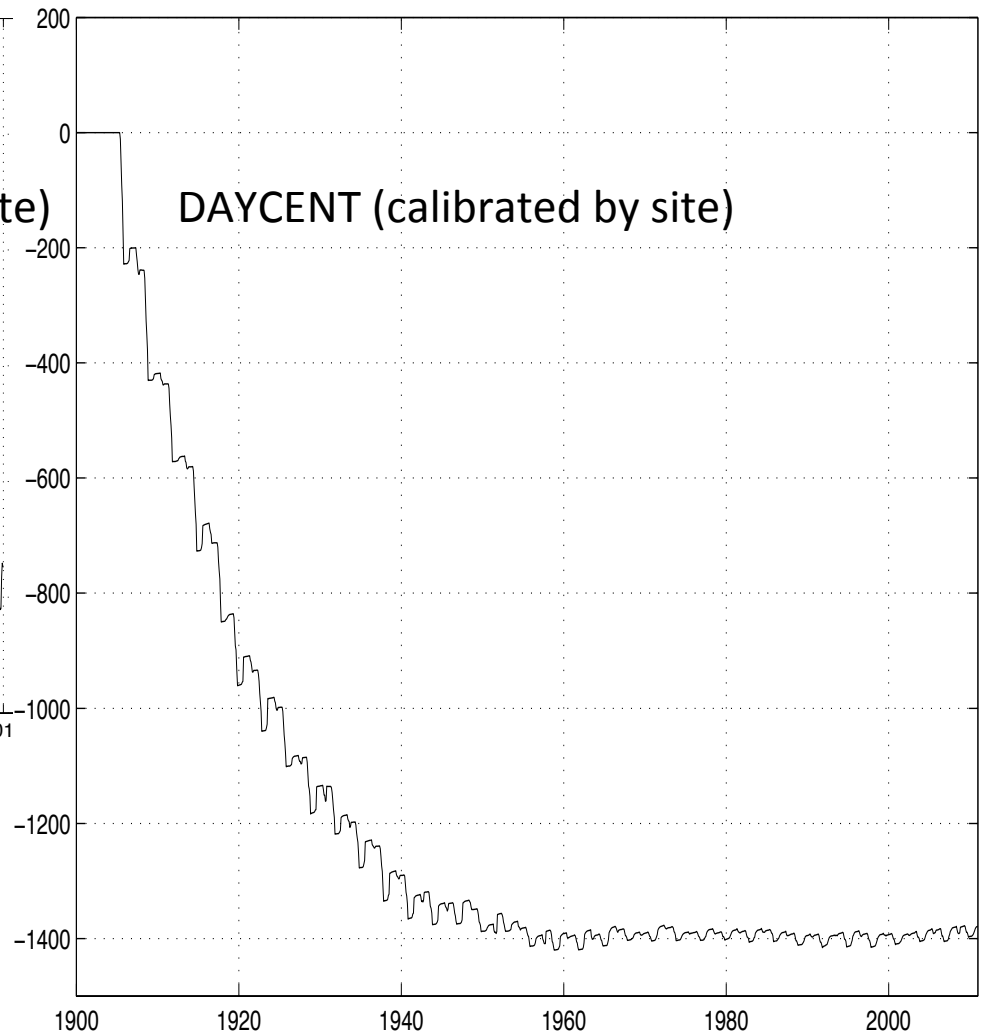


Figure 5.18 Decline in soil organic matter following conversion of native soil to agriculture for two grassland soils.

YES! Rainfed corn in YUMA, CO

Soil carbon differences: **Cultivated minus Not**





Levis et al. (2014)

CLM4	CLM4.5	post4.5
Temp. corn	w/ options to	plus…
Temp. cereals	fertilize &	Trop. corn
Temp. soybean	irrigate	Trop. soybean
effects on atm.	Oleson et al. (2013)	Sugarcane
Levis et al. (2012)	enhanced soil C	Rice
	decomposition	Cotton
	Levis et al. (2014)	A. Badger (GMU)

post4.5 crop code

- **Tropical** corn & soybean use **temperate** corn & soybean code
- Sugarcane uses temperate corn code
- Rice and Cotton use spring wheat code

and A. Badger's parameters for

planting temperatures & dates

growing degree days & max maturity

fertilization

max LAI & height

albedo & transmissivity

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**

CLM4 & 4.5:

Ramankutty and Foley (1998)

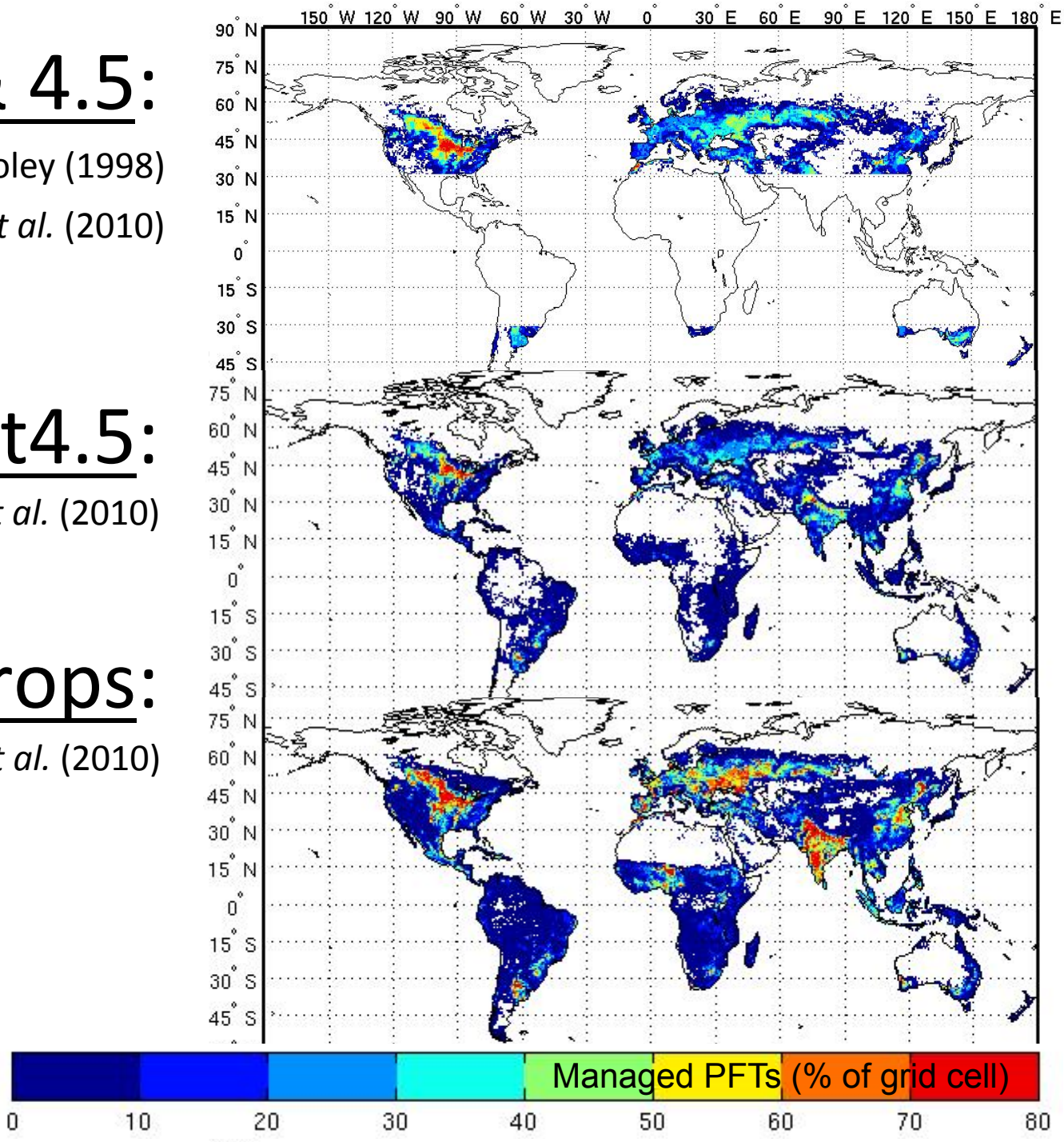
Portmann *et al.* (2010)

post4.5:

Portmann *et al.* (2010)

all crops:

Portmann *et al.* (2010)



CLM4 & 4.5:

Ramankutty and Foley (1998)

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post4.5:

Portmann *et al.* (2010)

all crops:

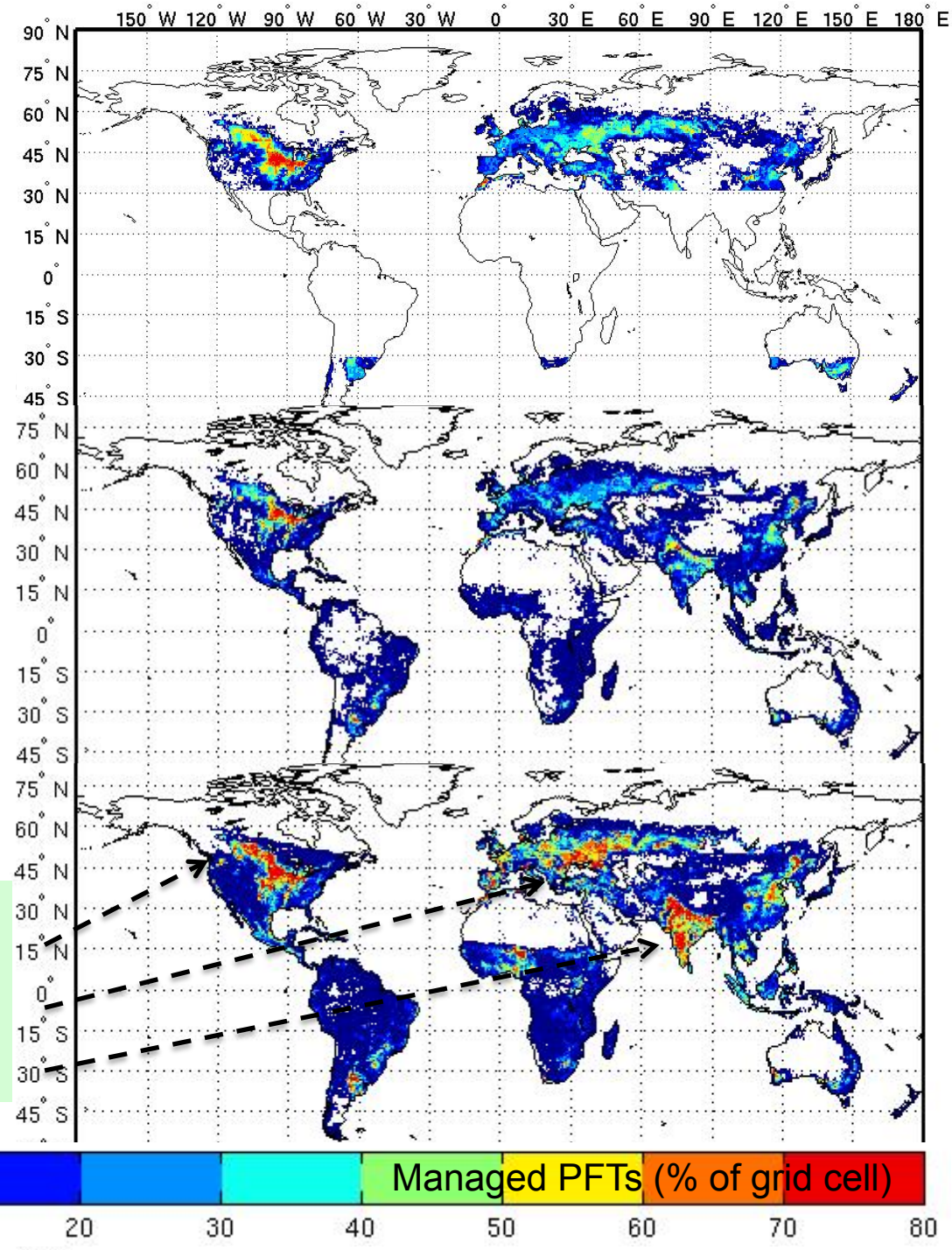
Portmann *et al.* (2010)

...still missing

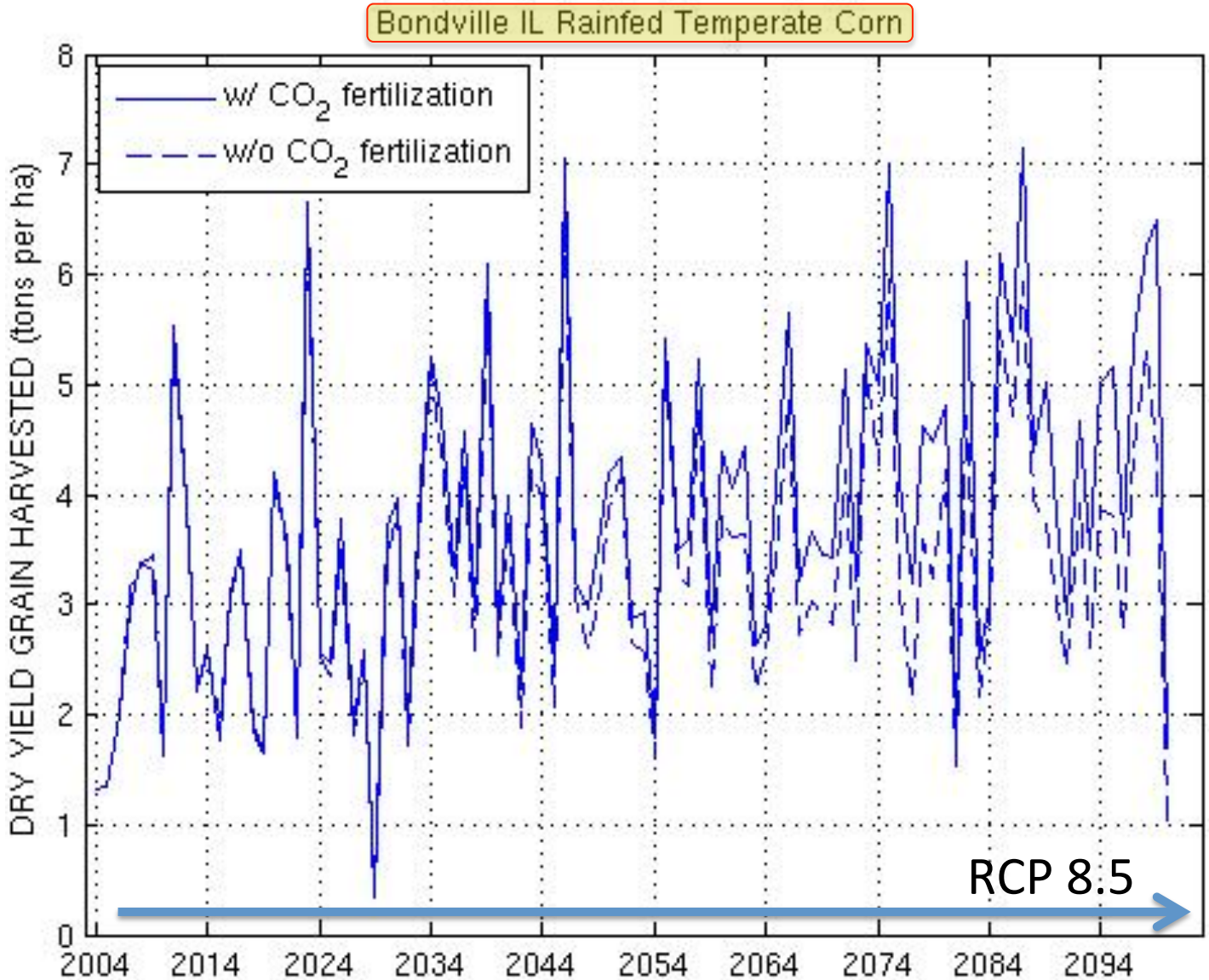
Canada foddergrass

Russia sunflower and foddergrass

India sorghum, pulses, millet, pnuts



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

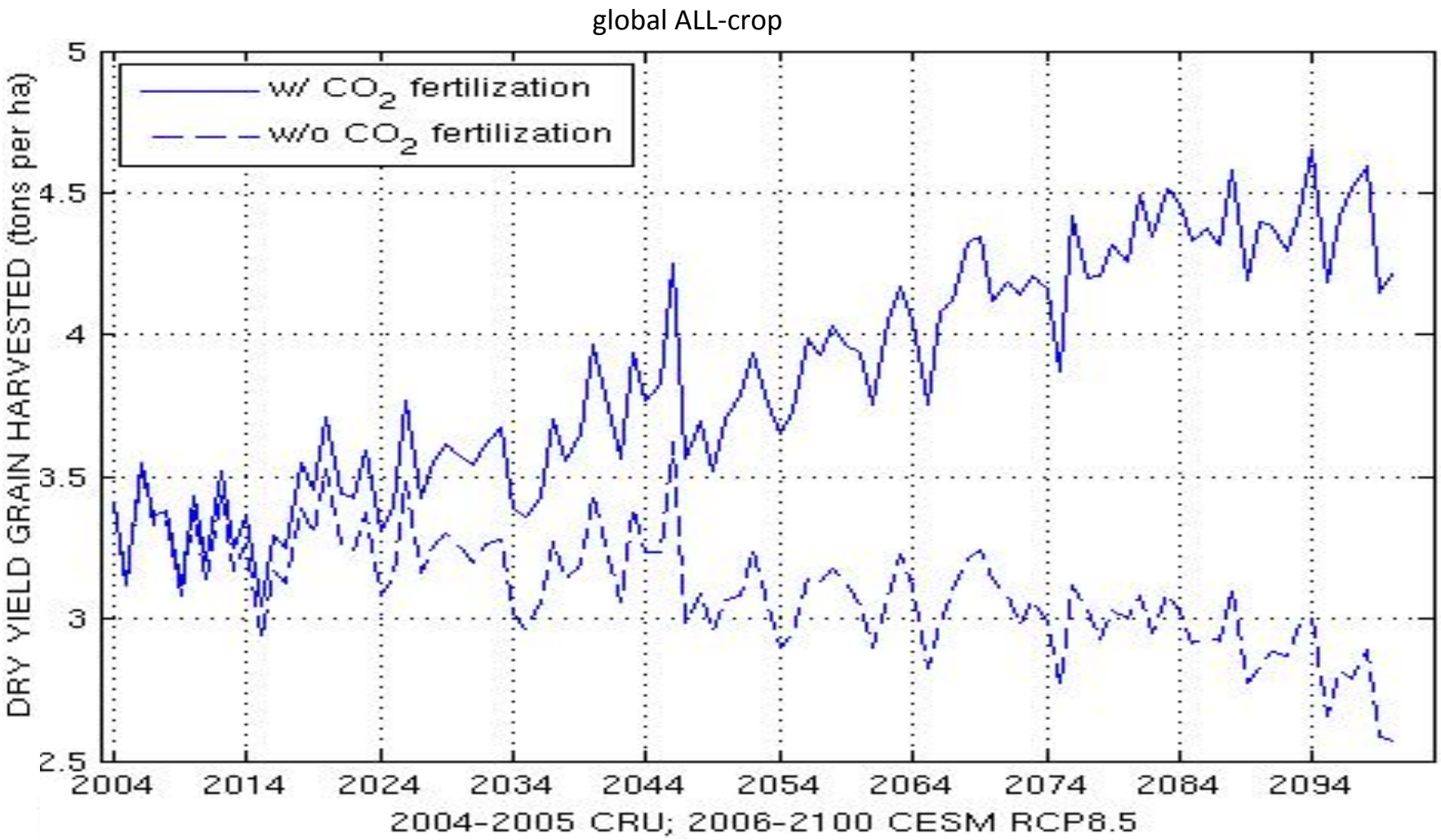


2004 obs (tons ha^{-1})

Botswana	0.3
…	
USA	6.9
…	
Belgium	9.2

http://data.worldbank.org

Global Dry Yield



CLM-crop response to extremes

- Photosynthesis declines for higher&lower than optimal T: about 28°C C_3 & 38°C C_4 plants
- No other form of heat stress
- No crop response to flooding
- Drought effects

Crop heat stress in the context of Earth System modeling: Invited Perspective on Siebert et al. (2014) Impact of heat stress on crop yield – on the importance of considering canopy temperature

Journal:	*Environmental Research Letters*
Manuscript ID:	ERL-100437
Manuscript Type:	Perspective
Date Submitted by the Author:	07-May-2014
Complete List of Authors:	Levis, Samuel; National Center for Atmospheric Research, Climate and global dynamics division
Article Keywords:	crop heat stress, earth system model, canopy temperature
Abstract:	Siebert et al. (2014) suggest that crop models do not represent the effect of heat stress on crop yield adequately unless they apply such effect to sensitive phases in a crop's growth cycle. Siebert et al. focus particularly on the phase considered most sensitive for wheat yield in Germany, the time of anthesis. Siebert et al. find that observed canopy rather than 2-m or ground temperature better quantifies the effect of heat stress during anthesis on wheat yield in Germany when evaluated against data from pot experiments under controlled conditions.

Summary & 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
  - 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


Questions?