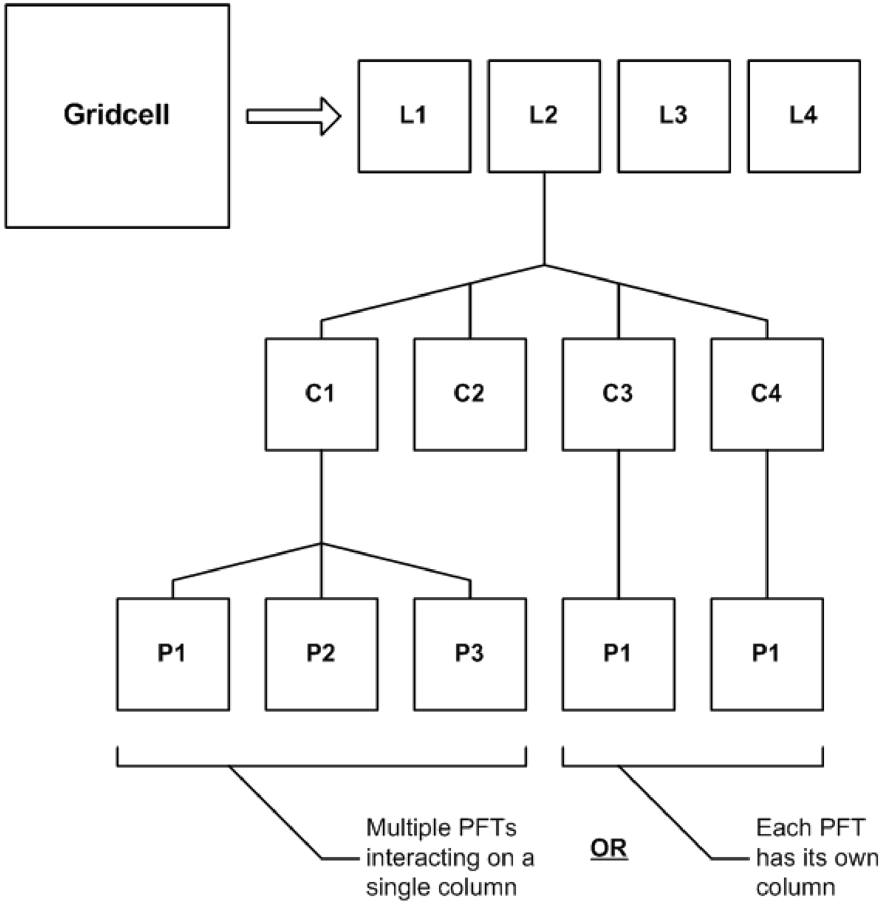
CLM-CN Update:
Progress toward CLM4.0

Peter Thornton, Sam Levis

and the C-LAMP team

Distinguishing characteristics of CLM-CN

- Flexible, nested sub-grid hierarchy



Landunits:
Geomorphologically distinct. Intended for special cover types (glacier, lake, etc.), heterogeneity in soil texture and depth, and for downscaling.

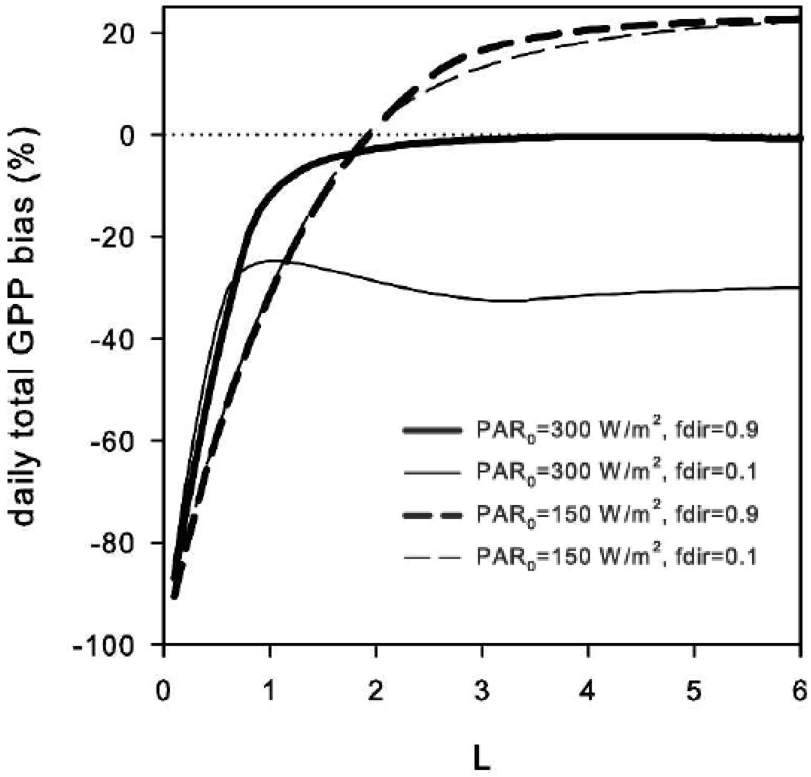
Columns:
Snow and soil state variables. Necessary for representing disturbance history and age class distribution.

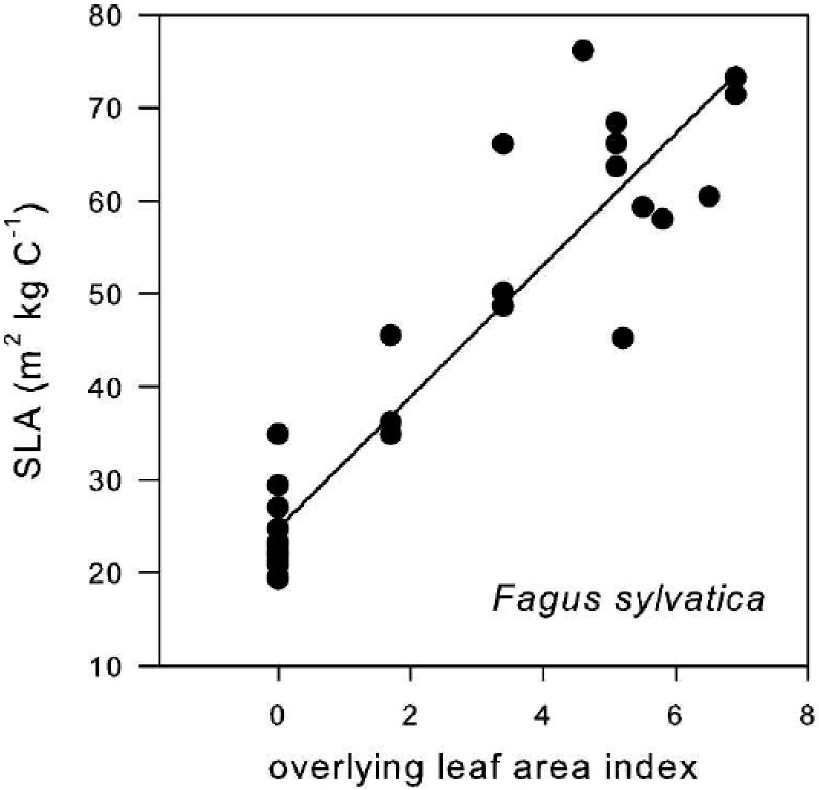
Plant functional types:
Vegetation state variables. Either independent or competing for column-level resources.

- Allows competition among PFTs, facilitated urban and crop models

Distinguishing characteristics of CLM-CN

- Two-leaf canopy with vertical gradient in leaf thickness

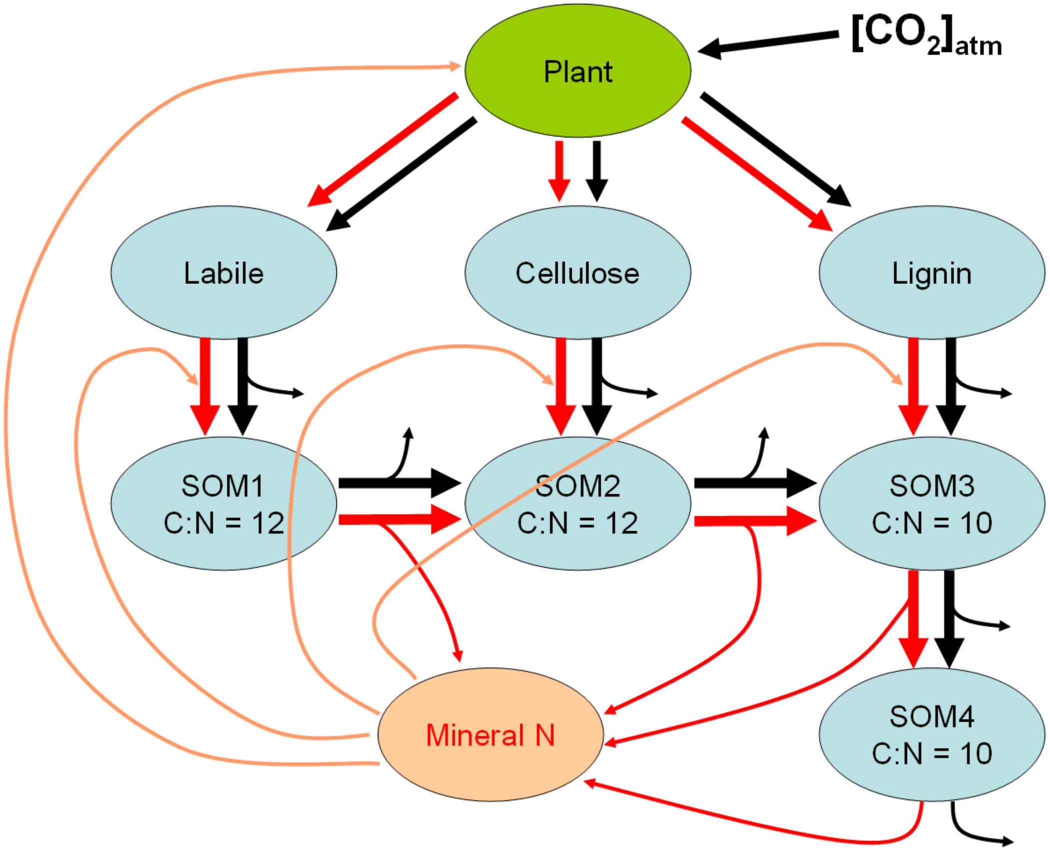




- Explicitly links canopy structure and function, corrects biases from CLM3, and allows prognostic leaf growth from nascent LAI

Distinguishing characteristics of CLM-CN

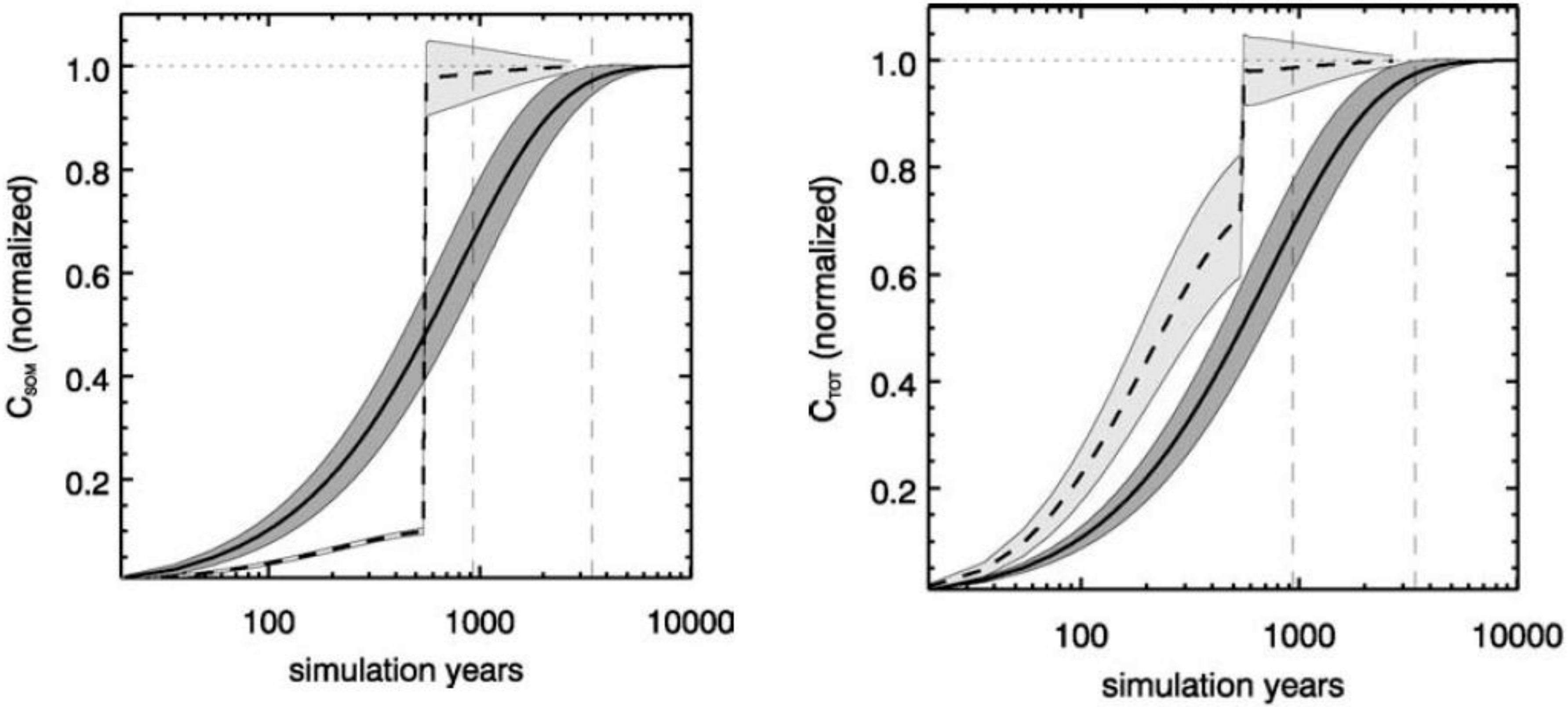
- Litter and soil model captures trophic structure of decomposer community



- Converging-cascade design supported by ^{14}C decomposition experiments
- Plant-microbe competition for N supported by ^{15}N labeling experiments

Distinguishing characteristics of CLM-CN

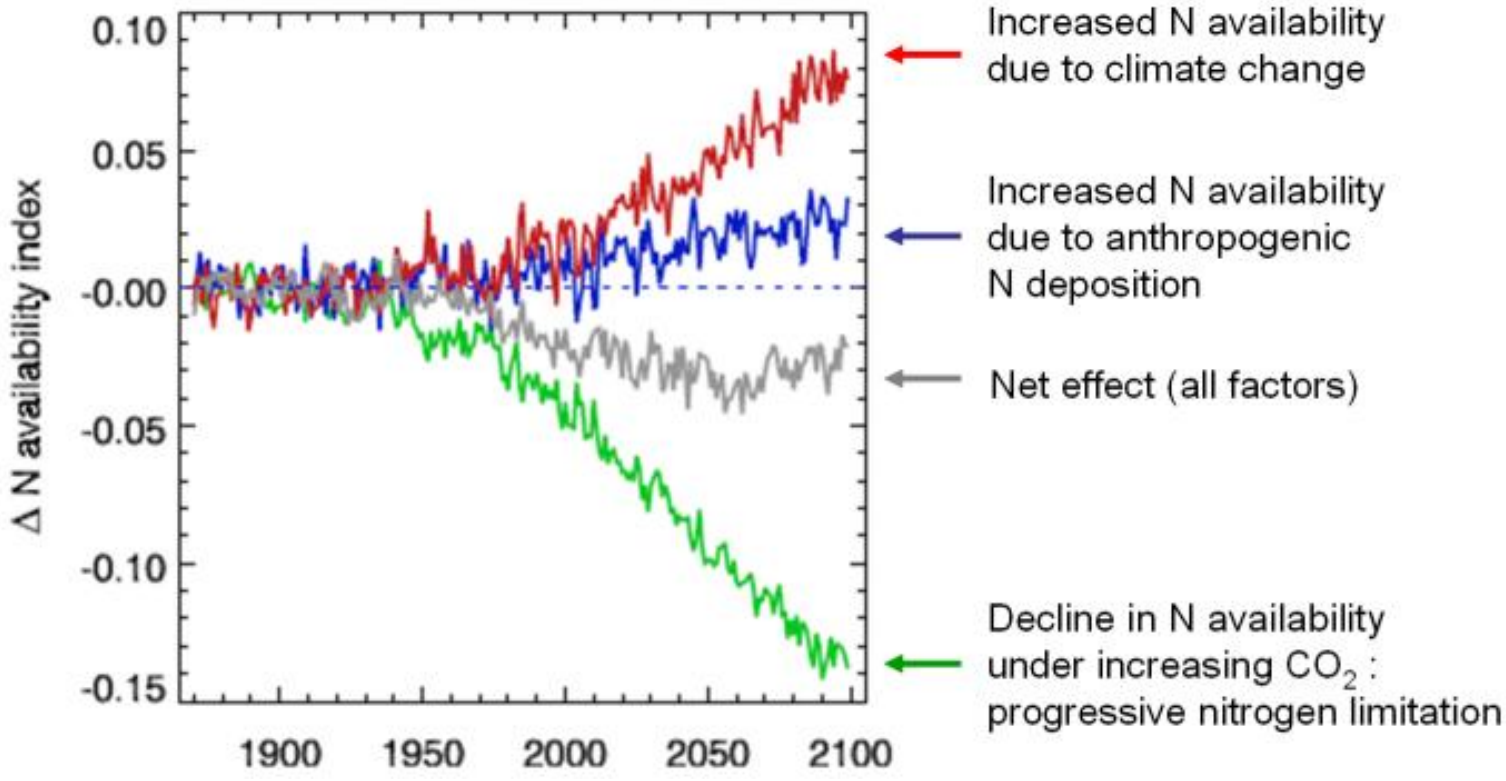
- Robust spin-up algorithm: accelerated decomposition



- ~5x acceleration to steady-state, good performance across climates and vegetation types

Distinguishing characteristics of CLM-CN

- C-N feedback couples autotrophic and heterotrophic dynamics



Increased N availability due to climate change

Increased N availability due to anthropogenic N deposition

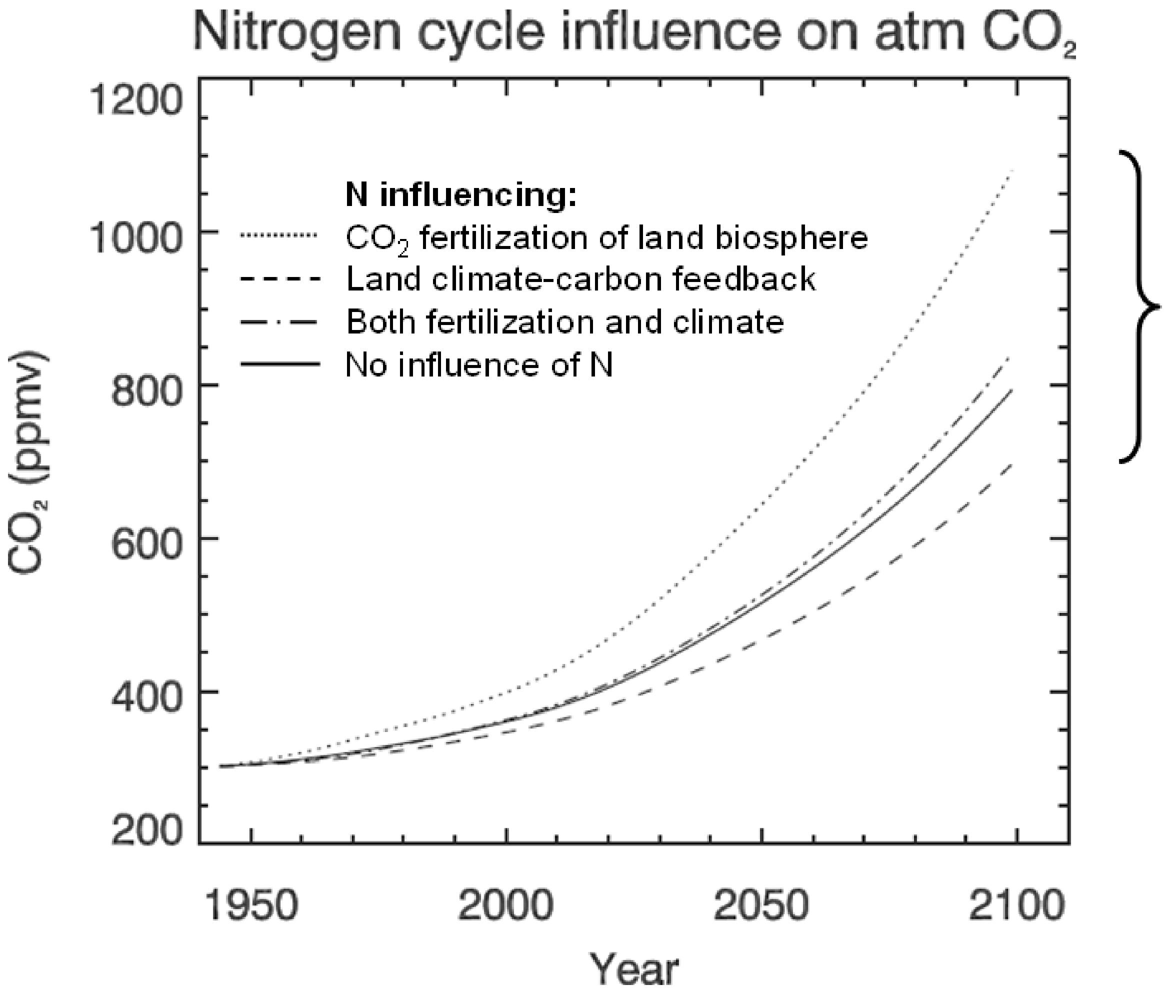
Net effect (all factors)

Decline in N availability under increasing CO_2 : progressive nitrogen limitation

- Nexus for influence of $[CO_2]_{atm}$, N deposition, disturbance and climate change

Distinguishing characteristics of CLM-CN

- C-N feedbacks affect coupled climate

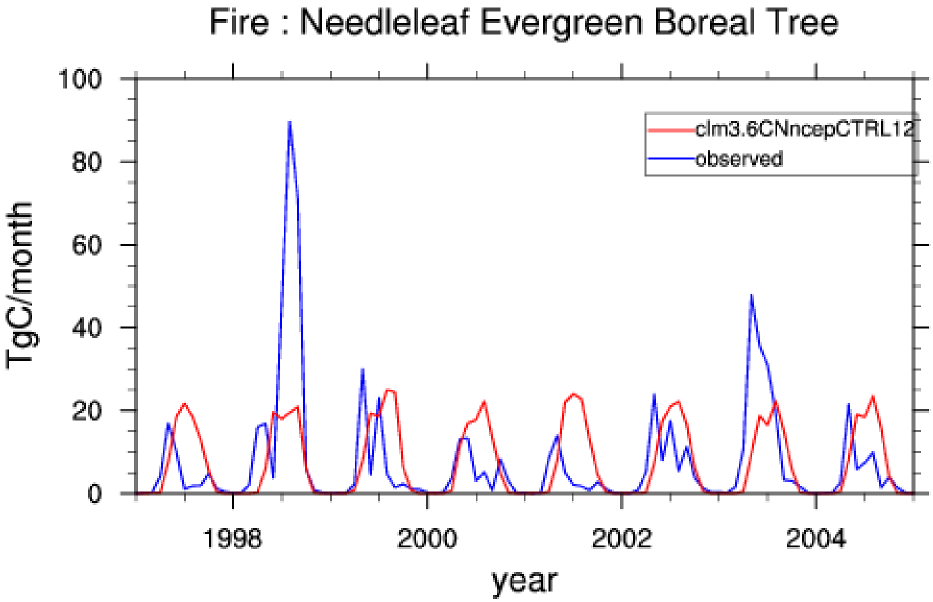


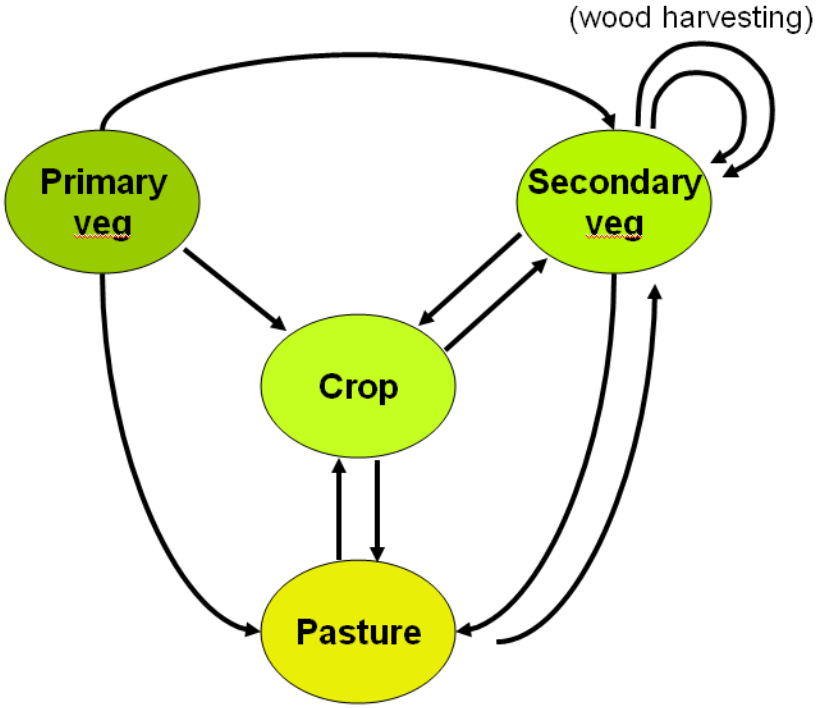
Range of uncertainty: We don't know how these C-N interactions will be expressed over time

- Dynamics not adequately constrained by existing experimental evidence

Distinguishing characteristics of CLM-CN

- Represents natural and anthropogenic disturbances


Fire : Needleleaf Evergreen Boreal Tree


(wood harvesting)

Primary veg

Secondary veg

Crop

Pasture

- Additional development efforts still underway: age-class distributions, age-related mortality, anthropogenic fire, rotation wood harvest

Progress on C-LAMP recommendations

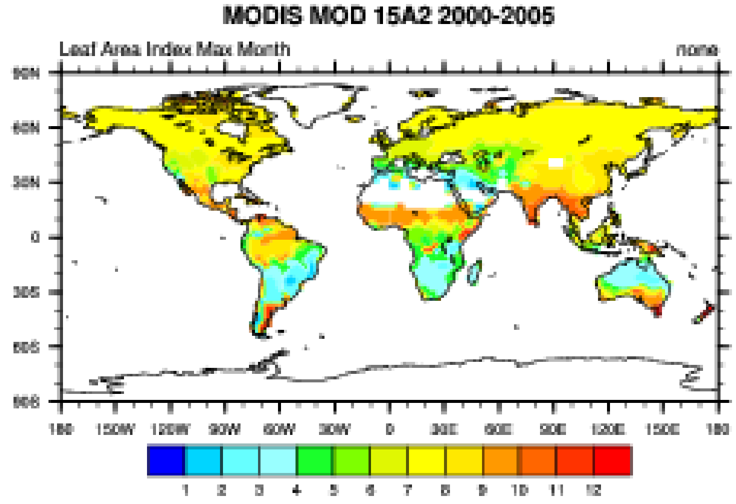
- All 5 major recommendations have been addressed to some extent
  - Modifications to CN algorithms
  - Modifications to CLM hydrology
- Many improvements, but…
- Still more to do:
  - Standardize the transport analysis to evaluate seasonal cycle
  - Improve site-level model-data comparisons

Science recommendations (1)

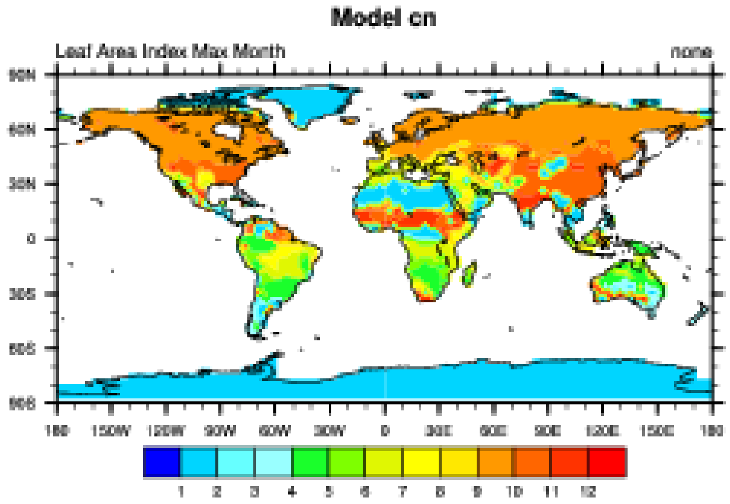
- **Model estimates of the growing season net flux are too small by factor of 2-3, based on both Ameriflux NEE and Globalview CO_2 observations**
- Proposed changes:
  - 1. Revise the prognostic leaf area routine in the models. Peak LAI should shift from August in boreal ecosystems to July.
  - 2. Revisit low temperature controls on GPP. Ameriflux observations show the models have too much GPP during the dormant season in temperate ecosystems.
  - 3. Reduce the temperature sensitivity of respiration (e.g. the Q10 factor). There is no reason to expect a priori a specific value for the time step and spatial scale of the models
  - Probably all three are needed.
- Consequences:
  - These changes will have important consequences for climate-carbon feedbacks. Reducing the temperature sensitivity of respiration will decrease the magnitude of carbon release with climate warming. Its less clear how changing LAI and GPP will influence feedbacks.
  - Other C4MIP models probably have the same deficiency

LAI Phase: CLM-CN compared to MODIS

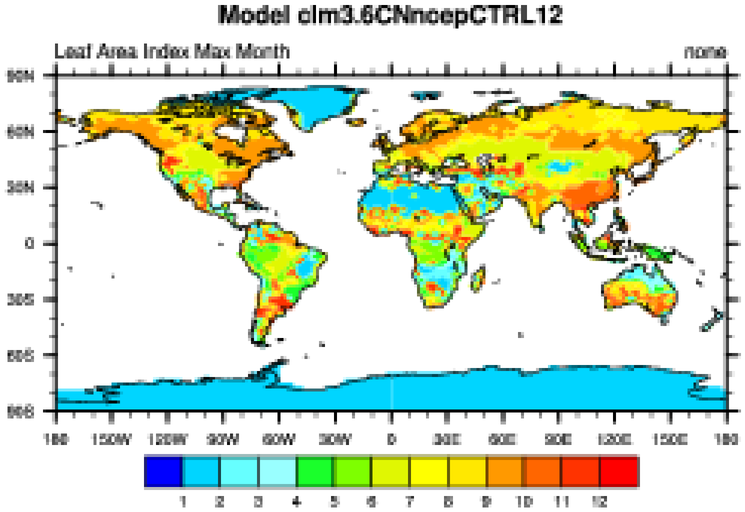
3.1 → 3.5/3.6



MODIS MOD 15A2 2000-2005



Model cn



Model clm3.6CNncepCTRL12

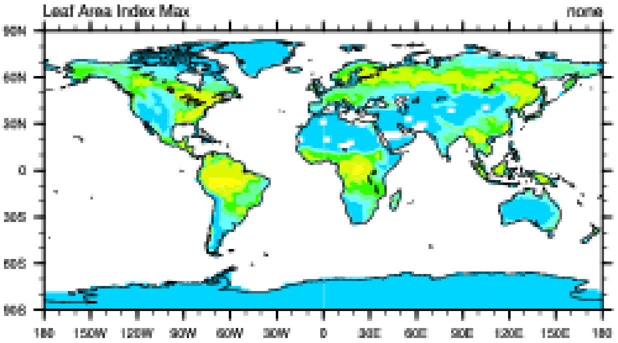
- Modification of CLM-CN phenology parameter (fcur)

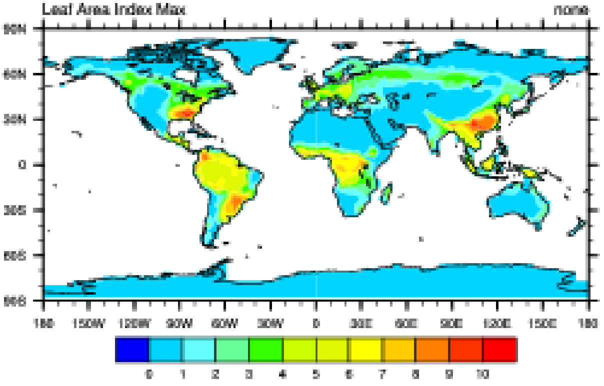
LAI: CLM-CN compared to obs

3.1 → **3.5** → **3.6**

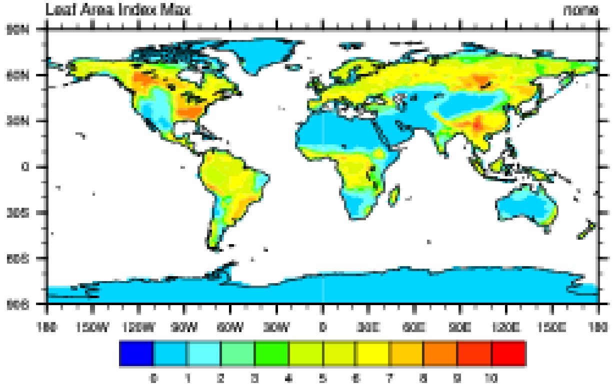
Obs →

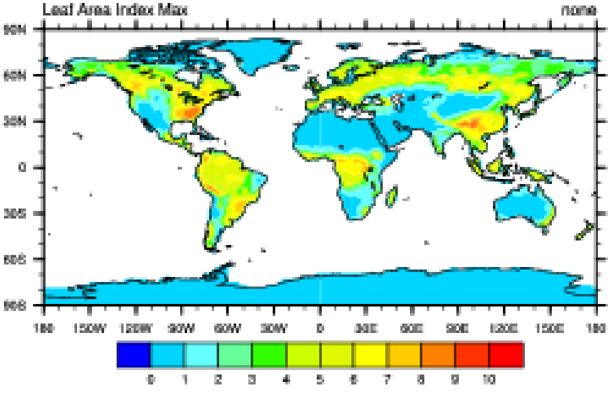
MODIS MOD 15A2 2000-2005



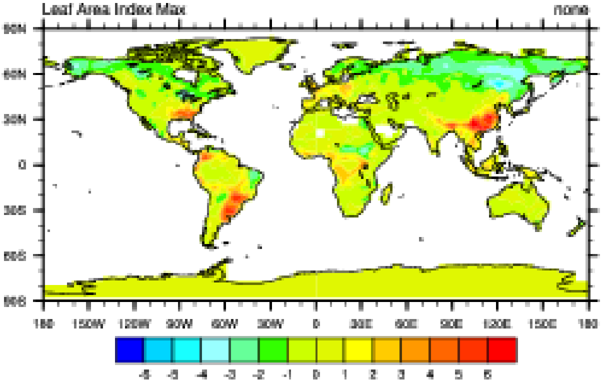


Model cn

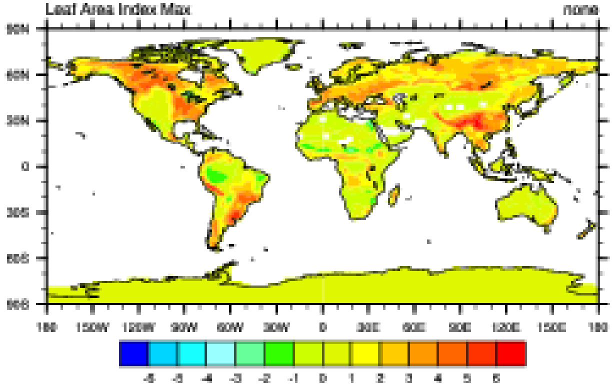




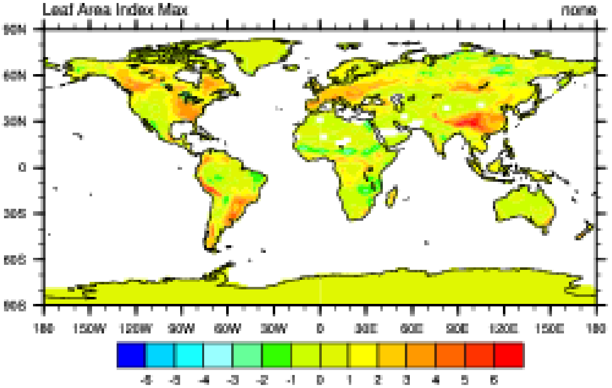
Model_cn - Observed



Model_cn - Observed

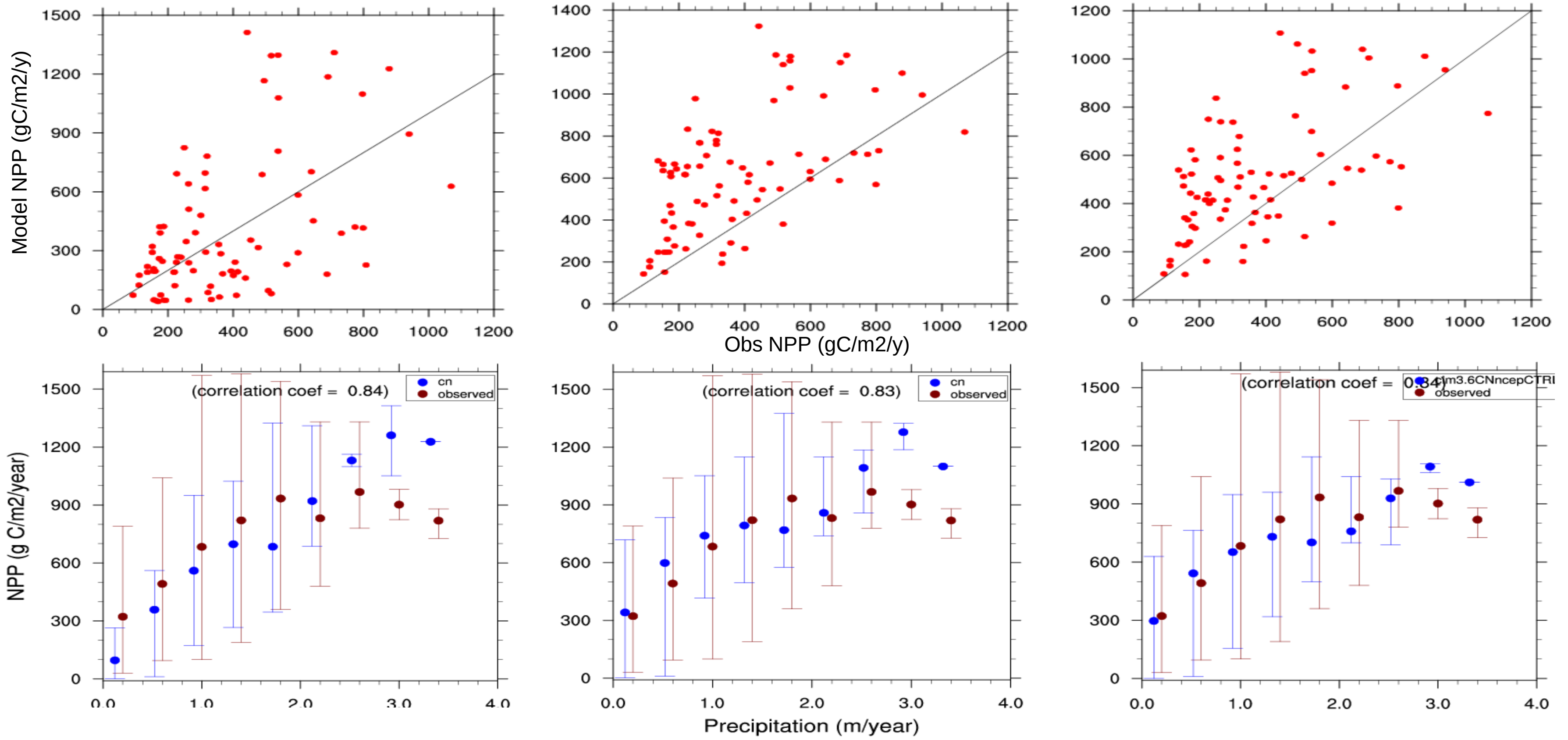


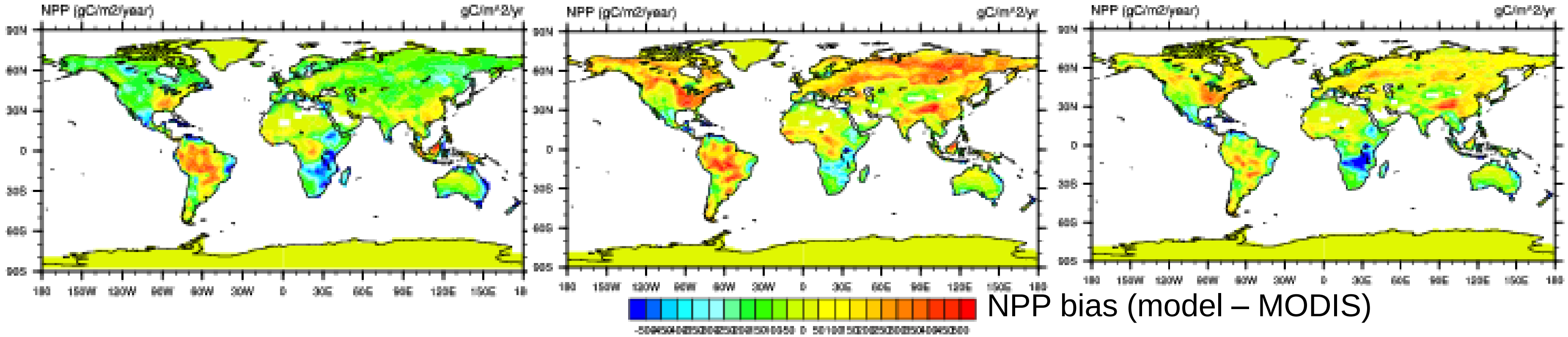
Model_clm3.6CNncepCTRL12 - Observed



NPP: CLM-CN compared to obs

3.1 → **3.5** → **3.6**





NPP bias (model – MODIS)

Science recommendations (2)

- **Model estimates of Amazon aboveground live biomass are high by a factor of 2-3 as compared with measurements from *Saatchi et al.* [2007]**
- Proposed changes:
  - 1. Reduce model GPP in the tropics by ~20%
  - 2. Develop a mechanistic autotrophic respiration and allocation subroutine for CASA. Observations suggest autotrophic respiration is close to 2/3 of GPP in tropical ecosystems
  - 3. Revisit allocation scheme of NPP for CN. Increase allocation to leaves. Current tropical leaf NPP is 125 gC/m2/yr. Observed leaf NPP is ~460 gC/m2/yr.
  - Wood turnover times look reasonable compared with observations (~40 years).

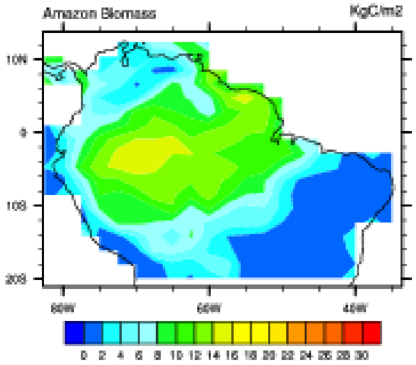
- Consequences:
  - Getting this pool right is crucial for getting the models to capture land use change effects on climate via the biogeochemistry

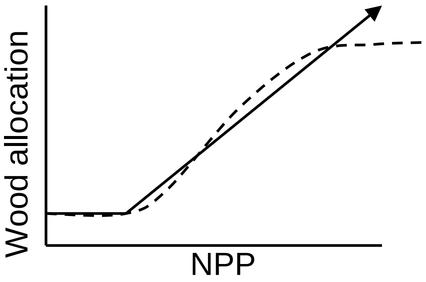
Amazon biomass: CLM-CN compared to obs

3.1 → **3.5** → **3.6**

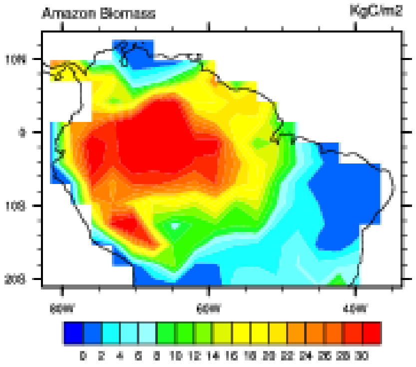
Obs:
69 PgC →

LC15_Amazon_Biomass 1.9

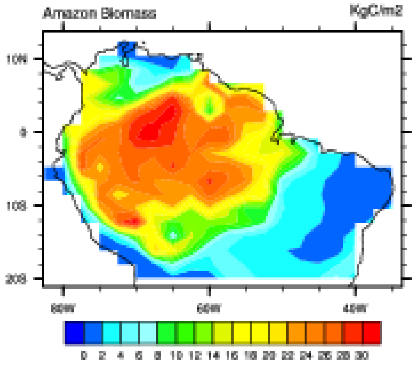




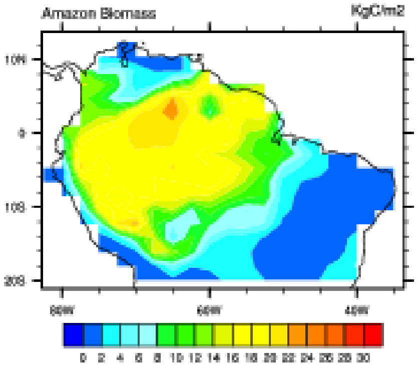
153 PgC



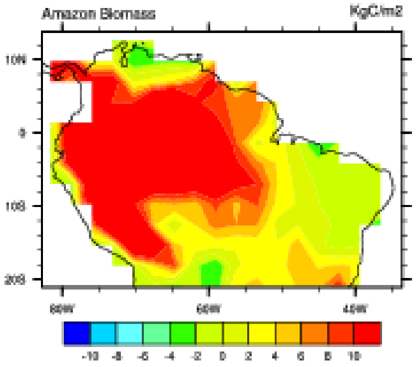
Model cn



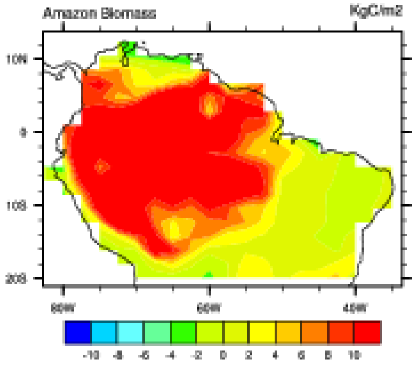
101 PgC



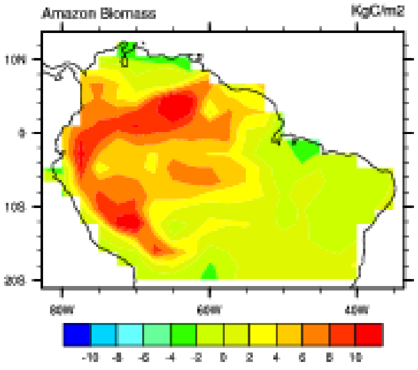
Model_cn - Observed



Model_cn - Observed



Model_clm3.6CNncepCTRL12 - Observed

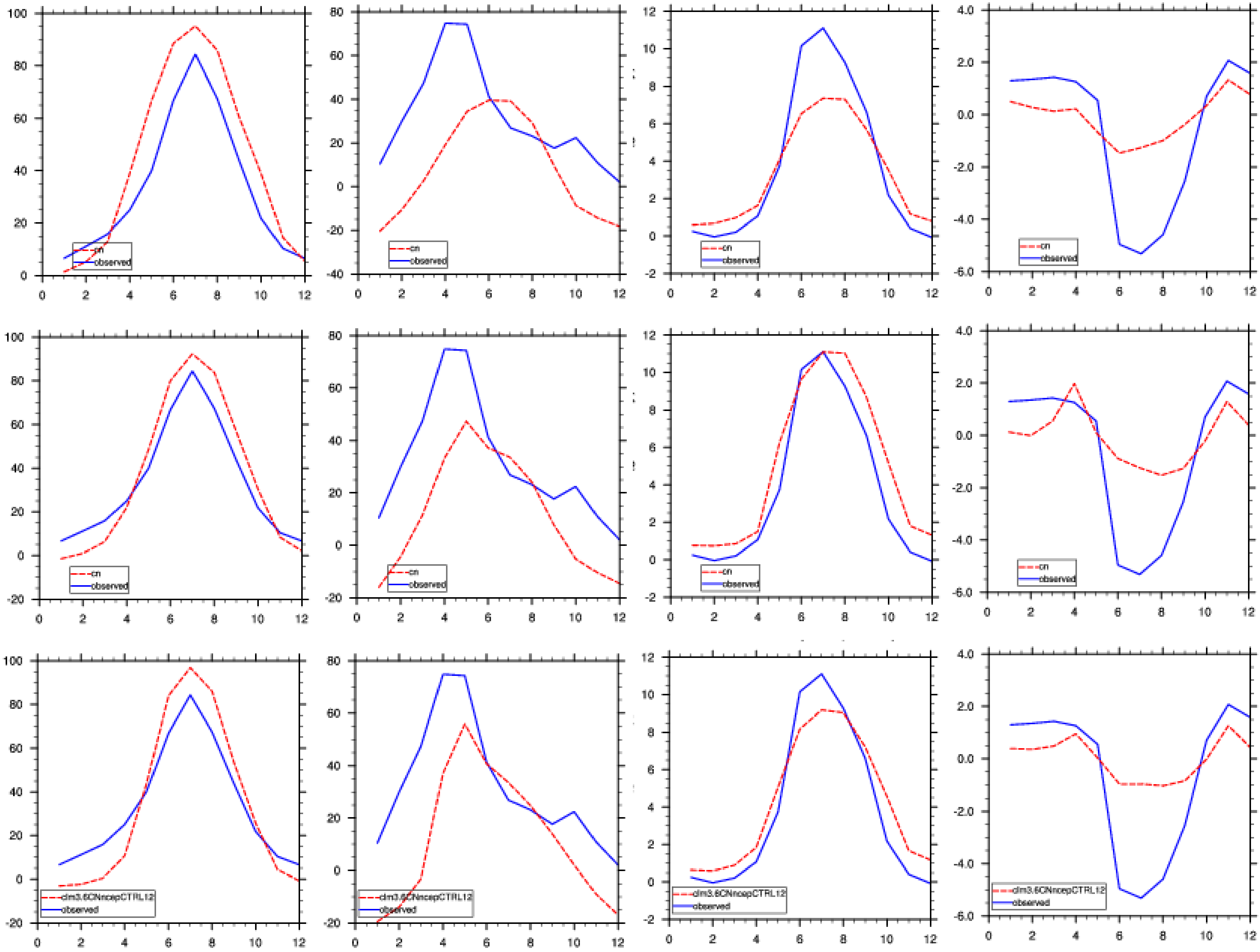


(bias)

Science recommendations (3)

- **Model estimates of sensible heat are too low during winter and spring in many boreal and temperate forest ecosystems**
- Proposed changes:
  - 1. Additional changes in CLM hydrology are probably needed
  - 2. Future changes in CLM hydrology must be evaluated against all aspects of the surface energy budget from Ameriflux and Fluxnet. This includes R_n and the seasonal cycle of sensible heat.
  - May be partly resolved with site-level evaluations.
- Consequences:
  - Surface energy exchange is important for simulating land cover change effects on regional climate

Harvard Forest – main tower (MA)



LH **SH** **GPP** **NEE**

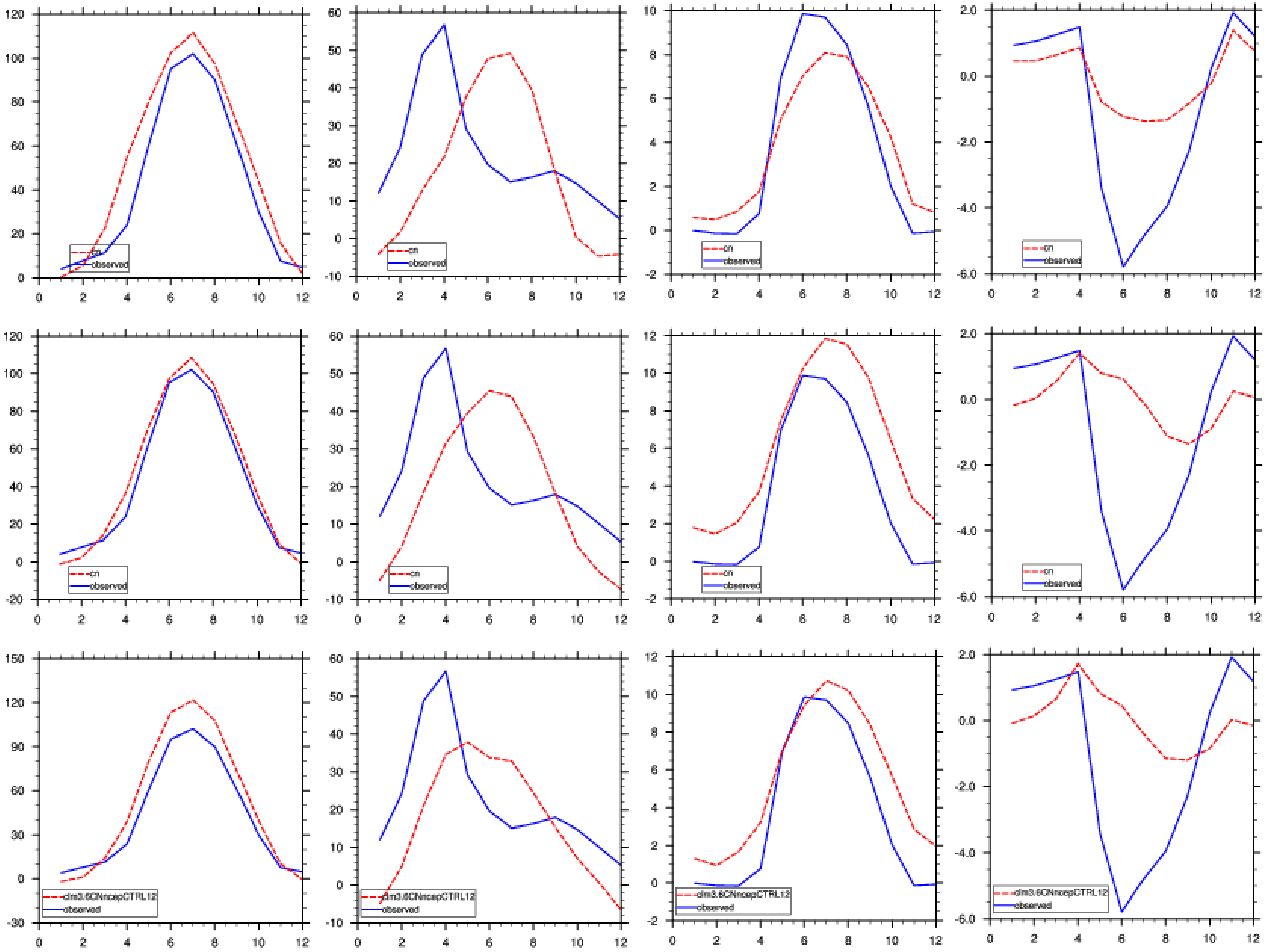
3.1

3.5

3.6

Morgan Monroe State Forest (IN)

LH **SH** **GPP** **NEE**



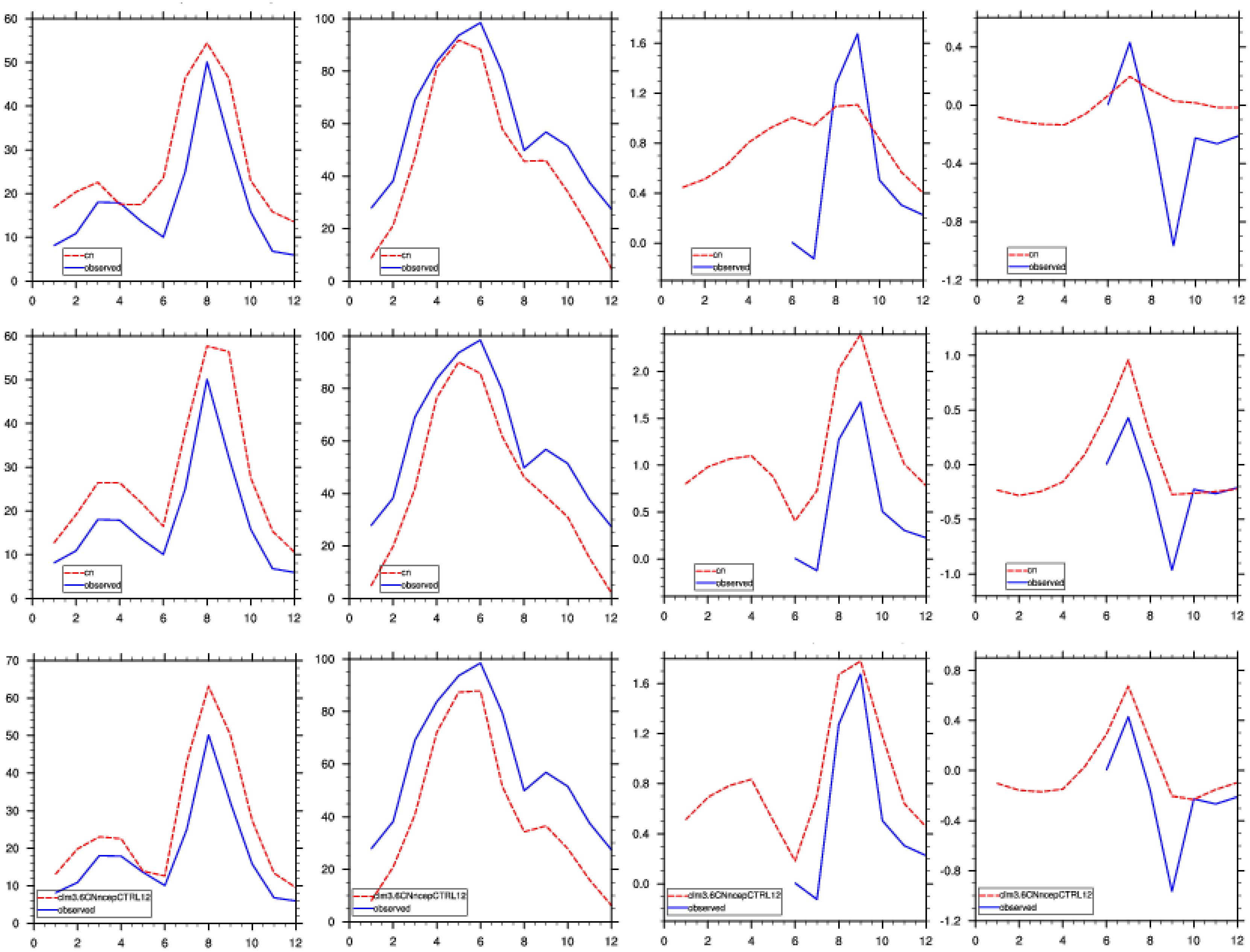
3.1

3.5

3.6

Kendall Grasslands

LH **SH** **GPP** **NEE**



3.1

3.5

3.6

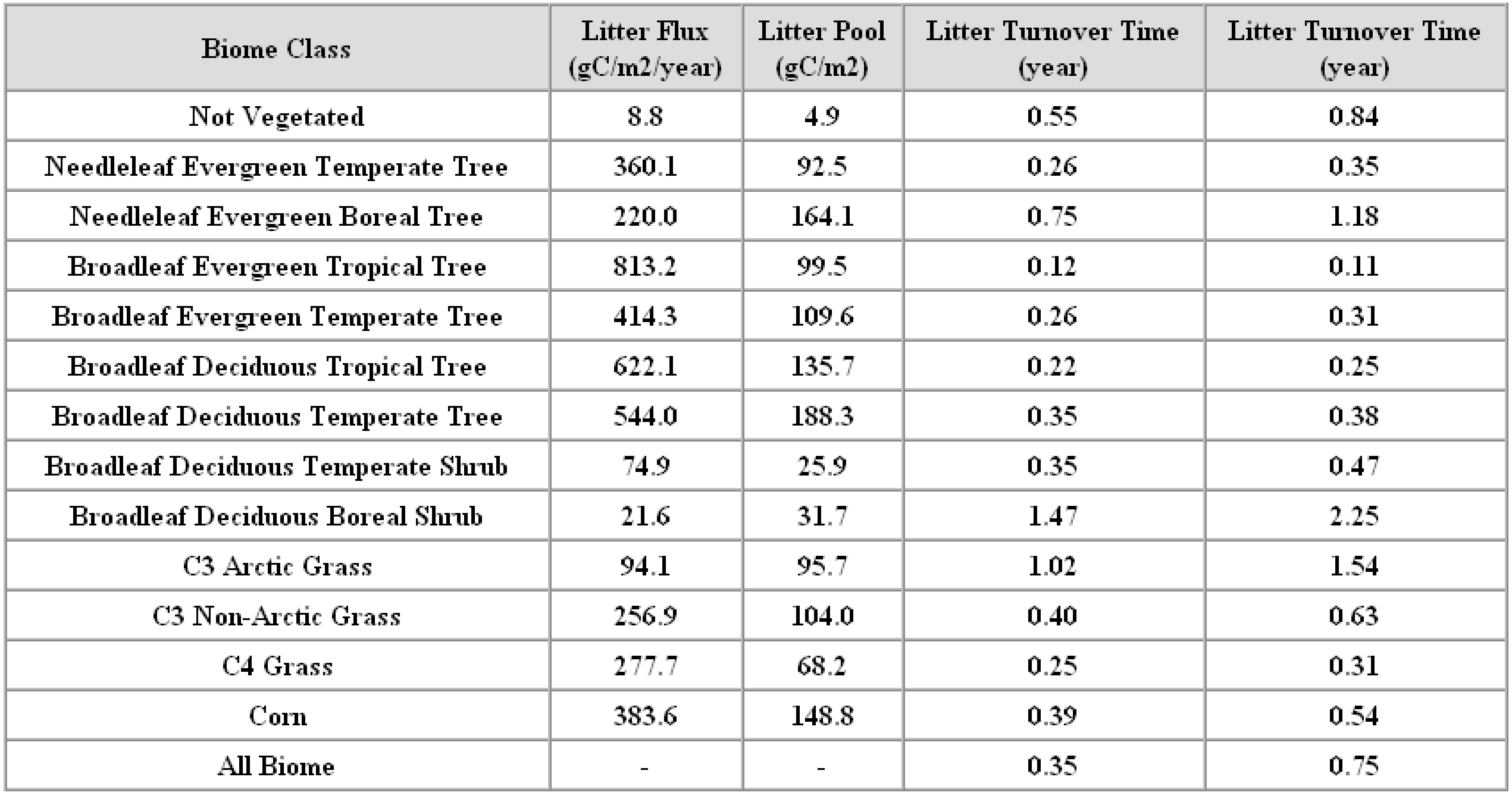
Science recommendations (4)*

- **Litter turnover times are too fast in CN**
- Proposed changes:
  - 1. Perform an optimization against leaf litter decomposition observations for both CN and CASA
    - These are available from Yiqi Luo
  - 2. Separate leaf and root litter pools in CN to enable more direct comparisons with observations
  - 3. Allow for direct CO_2 loss from coarse woody debris pool – tropical observations support this flux
- Consequences
  - More rapid cycling of carbon in CN is the primary reason for smaller present-day sink estimates than CASA. Not the sensitivity of NPP to global change.

* Conclusion depends on observational constraints of litter-bag studies: CN litter decomposition is consistent with ^{14}C labeling studies.

Litter turnover time:
CLM-CN modification results in slower litter turnover

3.1 → **3.6**



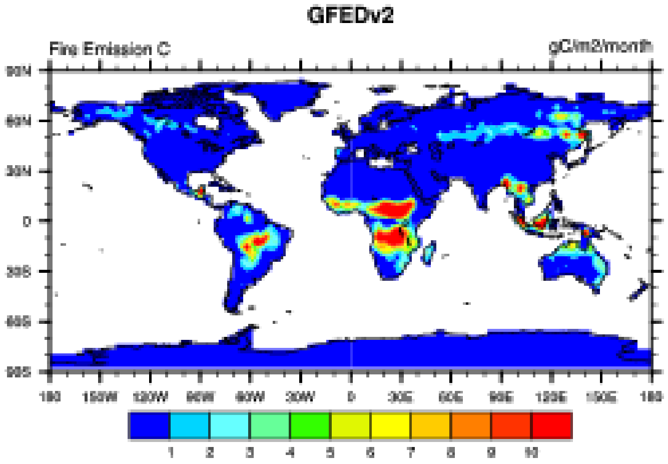
Biome Class	Litter Flux (gC/m2/year)	Litter Pool (gC/m2)	Litter Turnover Time (year)	Litter Turnover Time (year)
Not Vegetated	8.8	4.9	0.55	0.84
Needleleaf Evergreen Temperate Tree	360.1	92.5	0.26	0.35
Needleleaf Evergreen Boreal Tree	220.0	164.1	0.75	1.18
Broadleaf Evergreen Tropical Tree	813.2	99.5	0.12	0.11
Broadleaf Evergreen Temperate Tree	414.3	109.6	0.26	0.31
Broadleaf Deciduous Tropical Tree	622.1	135.7	0.22	0.25
Broadleaf Deciduous Temperate Tree	544.0	188.3	0.35	0.38
Broadleaf Deciduous Temperate Shrub	74.9	25.9	0.35	0.47
Broadleaf Deciduous Boreal Shrub	21.6	31.7	1.47	2.25
C3 Arctic Grass	94.1	95.7	1.02	1.54
C3 Non-Arctic Grass	256.9	104.0	0.40	0.63
C4 Grass	277.7	68.2	0.25	0.31
Corn	383.6	148.8	0.39	0.54
All Biome	-	-	0.35	0.75

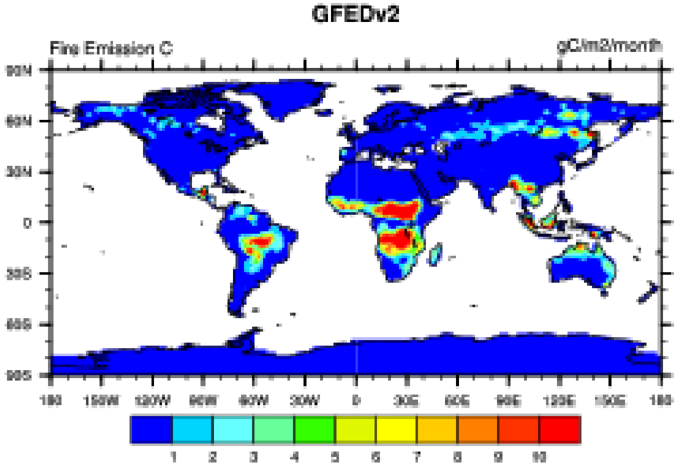
Science recommendations (5)

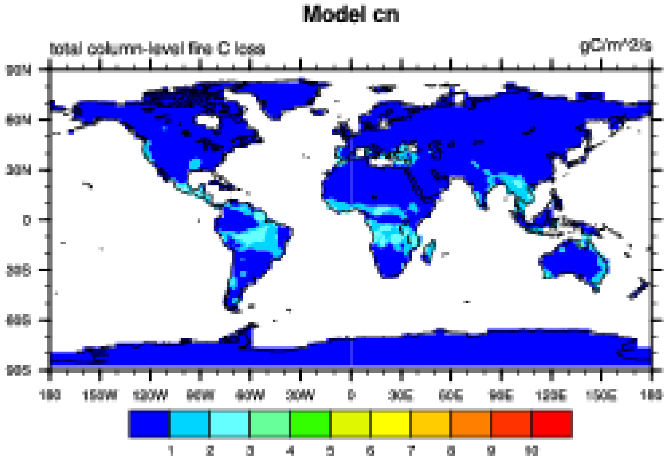
- **Transient dynamics of models need better testing. Models do not capture variability in contemporary fire emissions**
- Proposed changes:
  - 1. Adjustment of the fire emissions model in CN so it integrates land use and climate drivers (underway)
  - 2. Develop a fire emissions model for CASA
  - 3. Future comparison with Carbontracker and Transcom for interannual variability (underway)
- Consequences
  - Aerosol forcing of climate likely to be underestimated in future model simulations

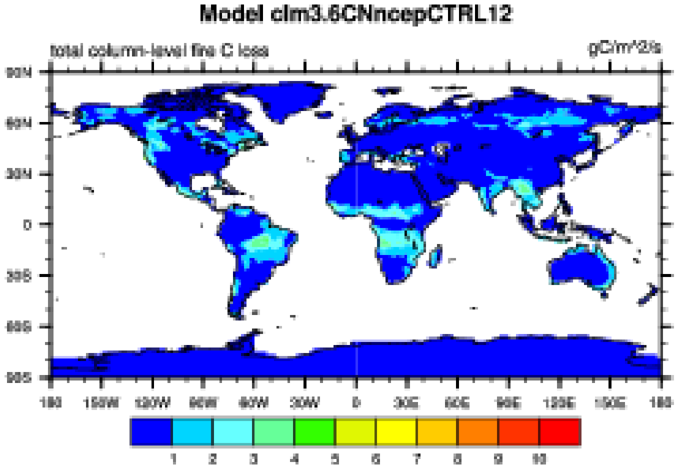
Fire distribution: CLM-CN compared to obs

3.1 → (3.5) → 3.6







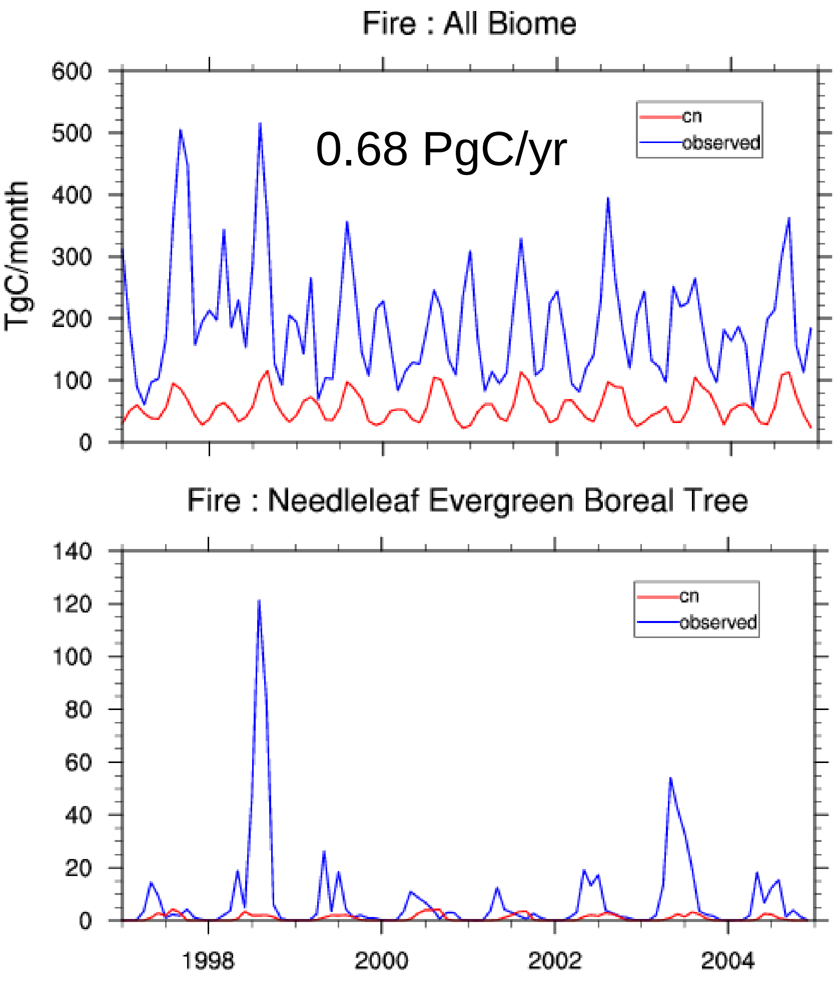


- Shifted soil moisture (proxy for fuel moisture) (top 50 cm *to* top 5 cm)
- Fixed unit error in critical fuel load threshold value (200 *to* 100 gC/m^2)

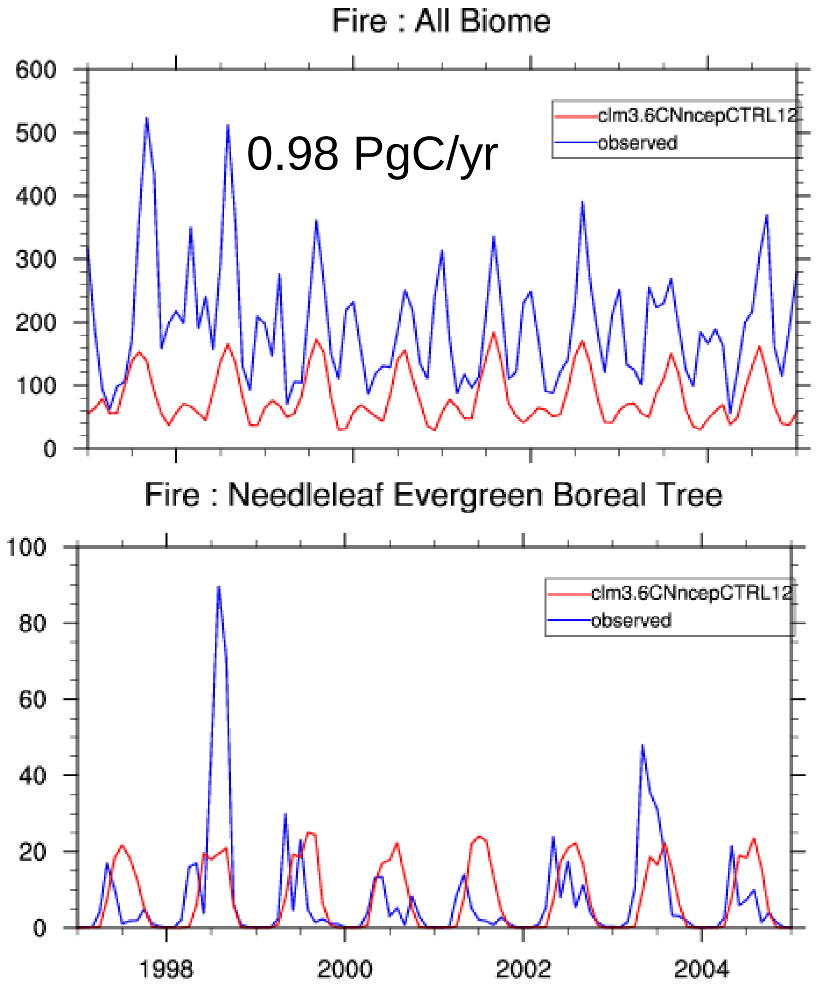
Amazon biomass: CLM-CN compared to obs

3.1 ⟶ **(3.5)** ⟶ **3.6**

Obs: 2.31 PgC/yr

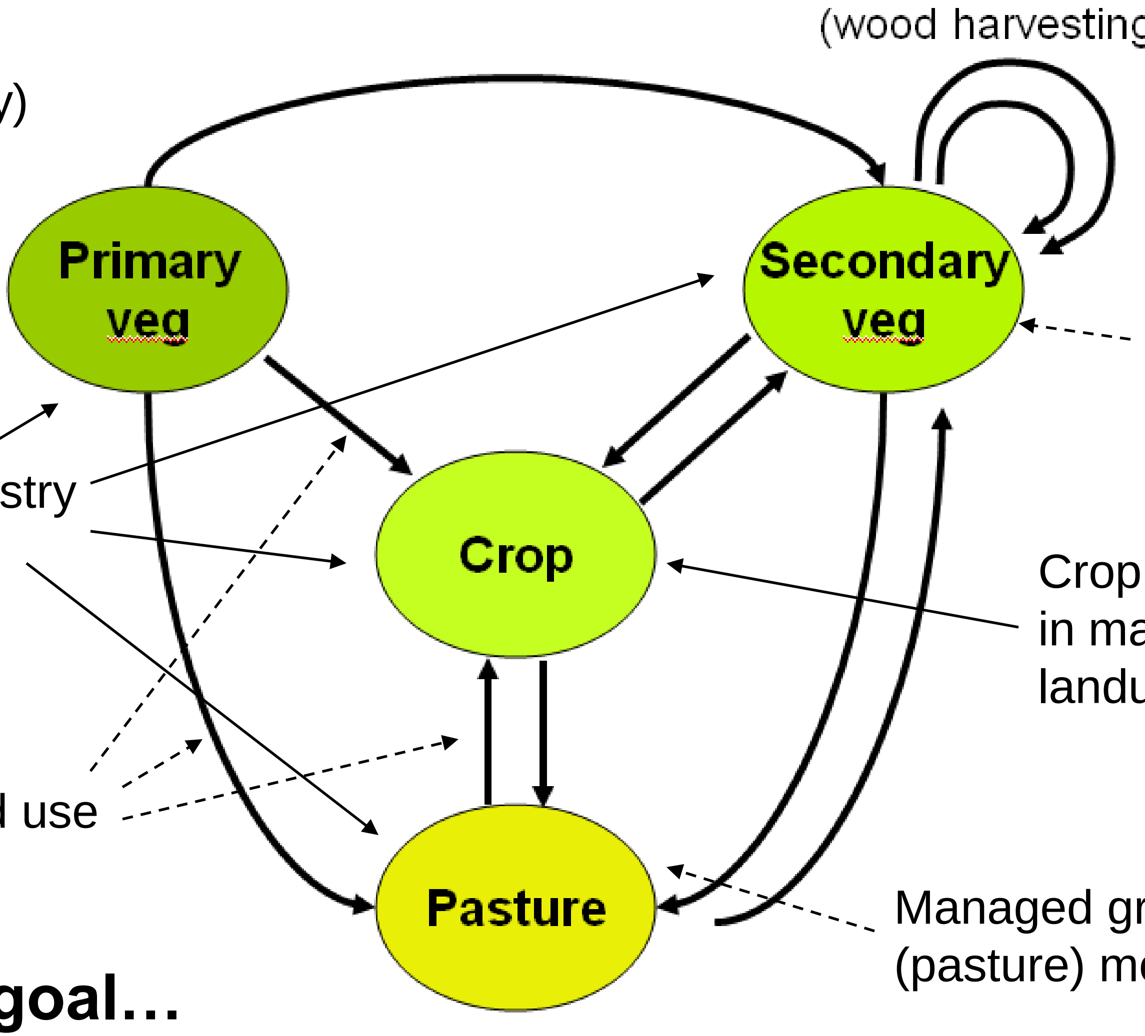


0.68 PgC/yr



0.98 PgC/yr

Recent developments: coupling CN to DGVM and crop model



DGVM runs in
natural (primary)
vegetation
landunit

Managed forest
module?

C-N biogeochemistry
for all modules

Crop model runs
in managed
landunit

Prognostic land use

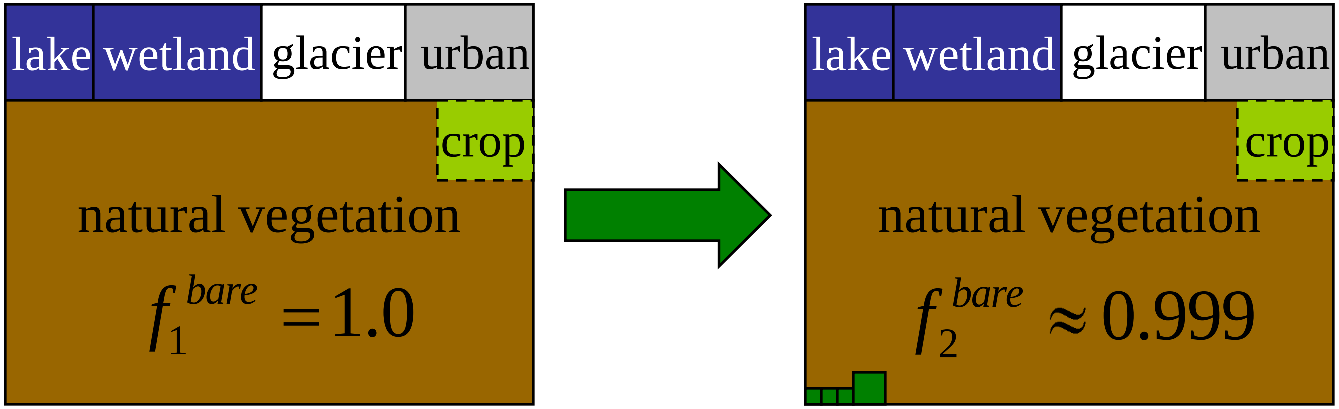
Managed grassland
(pasture) module?

The goal…

CNDV:
Dynamic Vegetation & CLM-CN

Year 1:
Bioclimatology accumulators

End of year 1:
Establishment



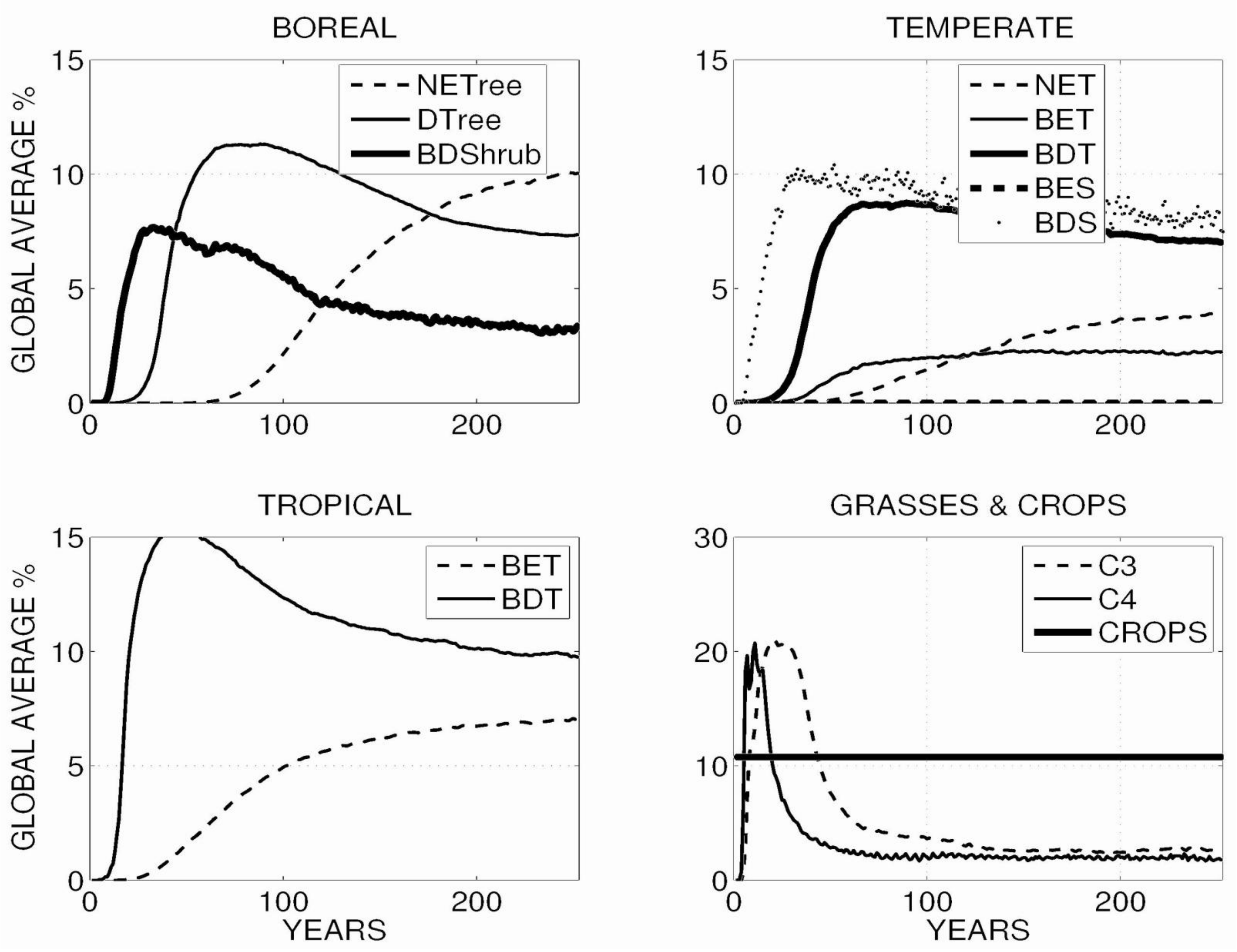
Year 2+:
Bioclimatology accumulators
Biogeochemistry
Photosynth., respir., growth, mortality

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

Levis *et al.*

(Shrub model from Zeng et al., in press)

250-year CNDV simulation: CLM3.5 driven with Qian *et al.* (2006) weather



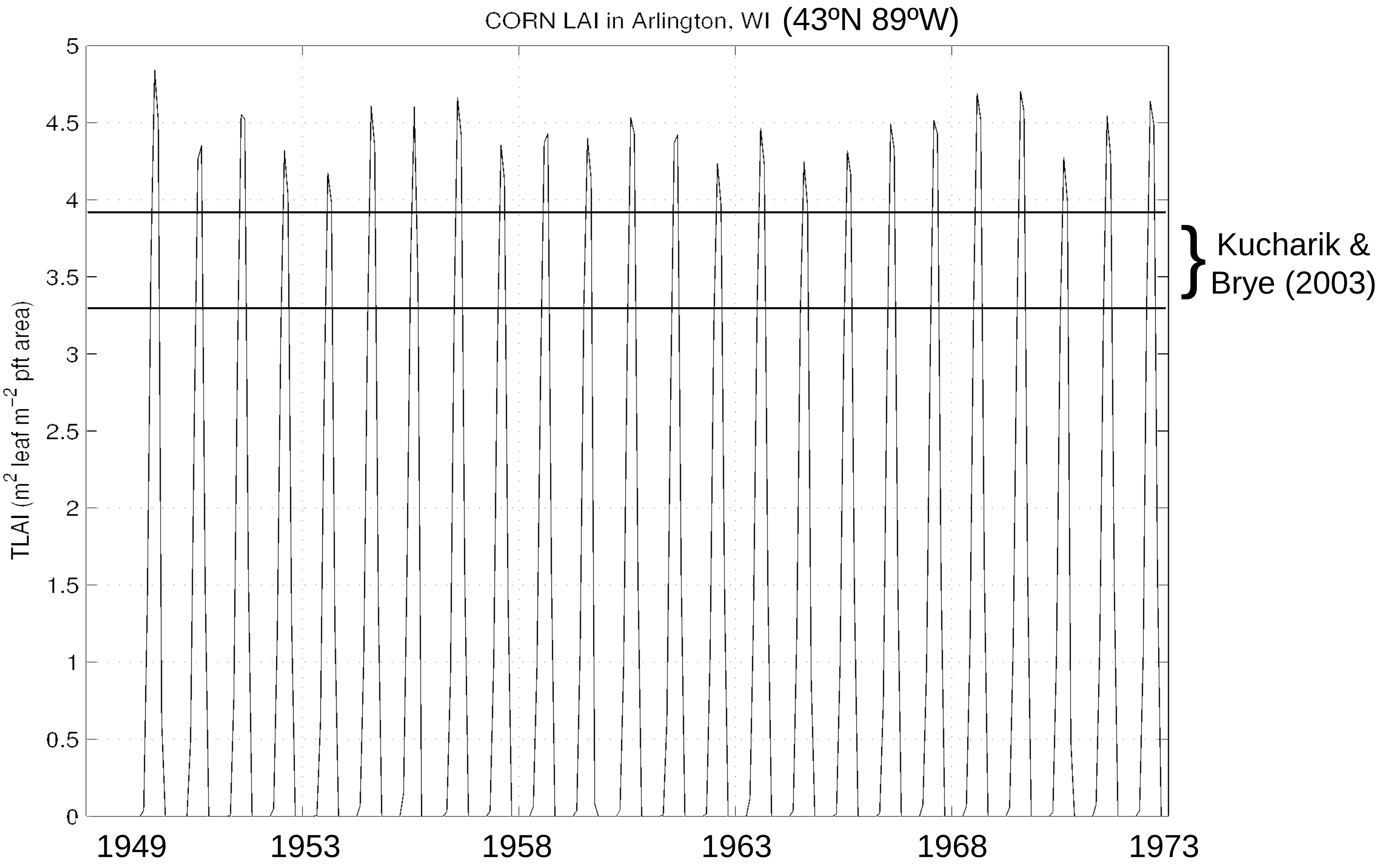
Prognostic Crop Life-Cycles in the CLM

AgroIBIS (Kucharik & Brye, 2003)

Corn, wheat, & soybean life cycles:

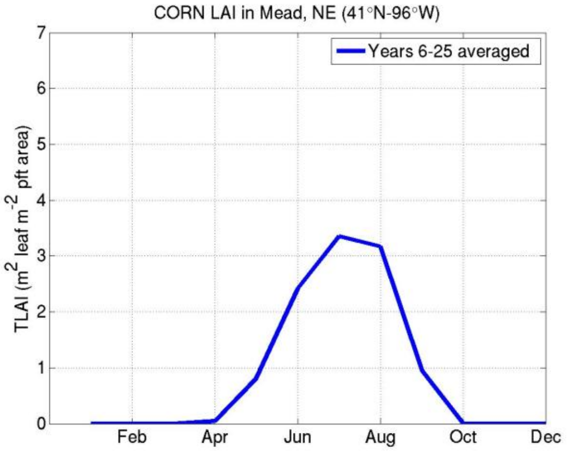
- GDD accumulators ➔
  - Planting, leaf emergence, grain fill, maturity, harvest
- C allocation & N limitation ➔
  - Leaf area and height
- Realistic irrigation (Sacks *et al.*)

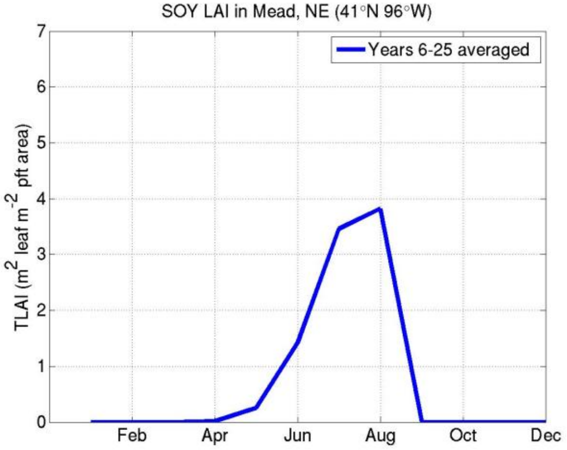
25-year CN-crop simulation CLM3.5 driven with Qian *et al.* (2006) weather

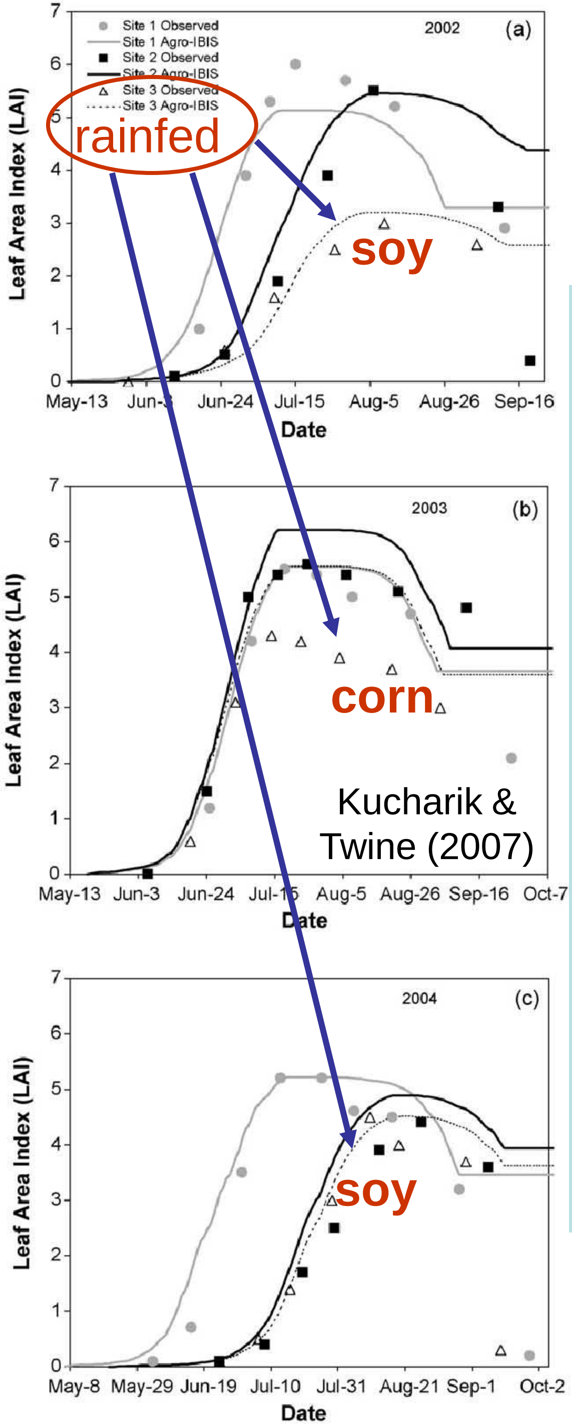


CN-crop

AgroIBIS


CORN LAI in Mead, NE (41°N-96°W)


SOY LAI in Mead, NE (41°N 96°W)



Kucharik & Twine (2007)

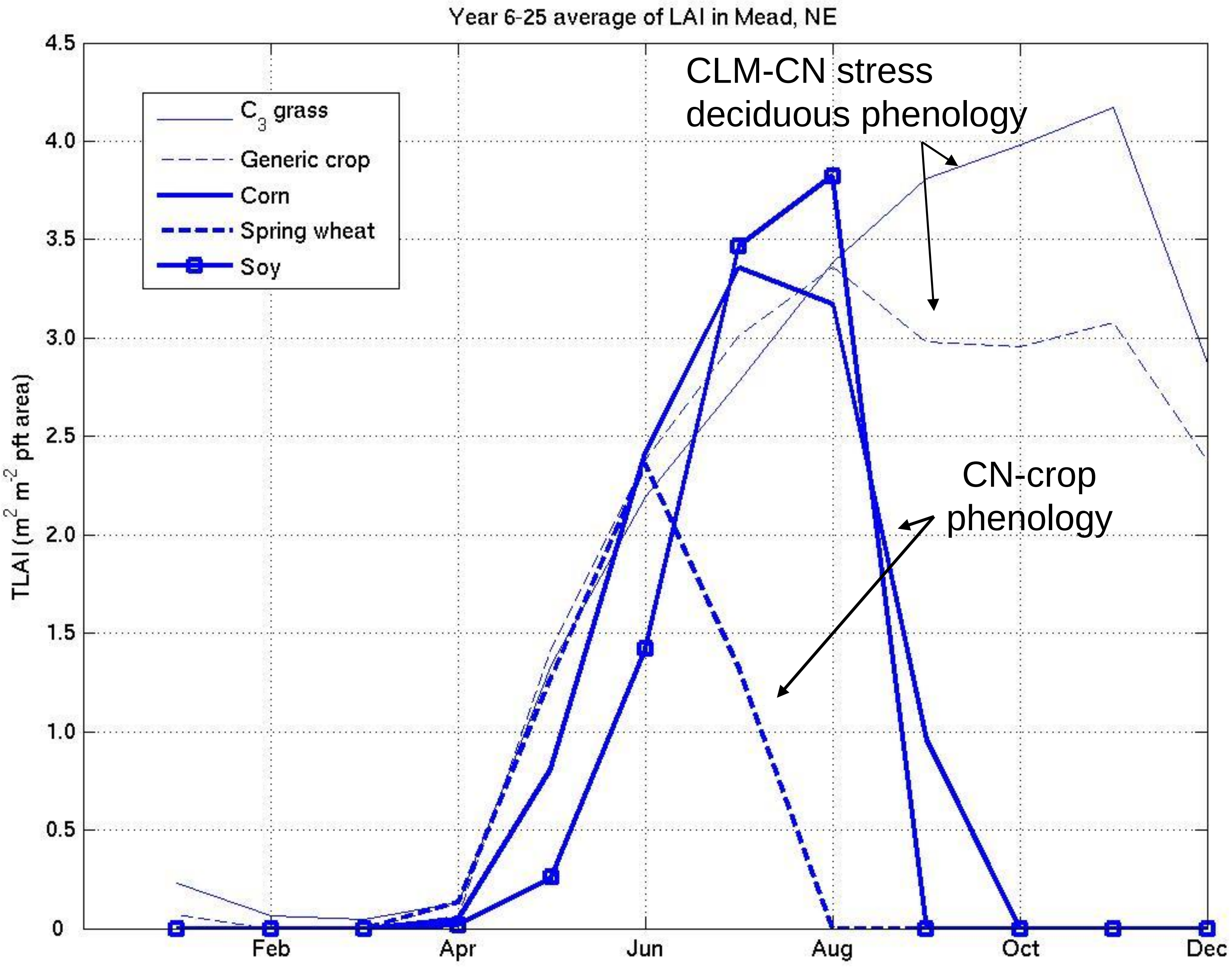
<u>Notes for the comparison</u>:

N not limiting to plant growth given land mgmt in Mead

Leaf emgnce ~end of May w/ presc. planting May 13th
Peak ~5.5 ~Jul 15th; ~flat ~1 month; harv. ~Sep 1st
Obs peak ~4.25

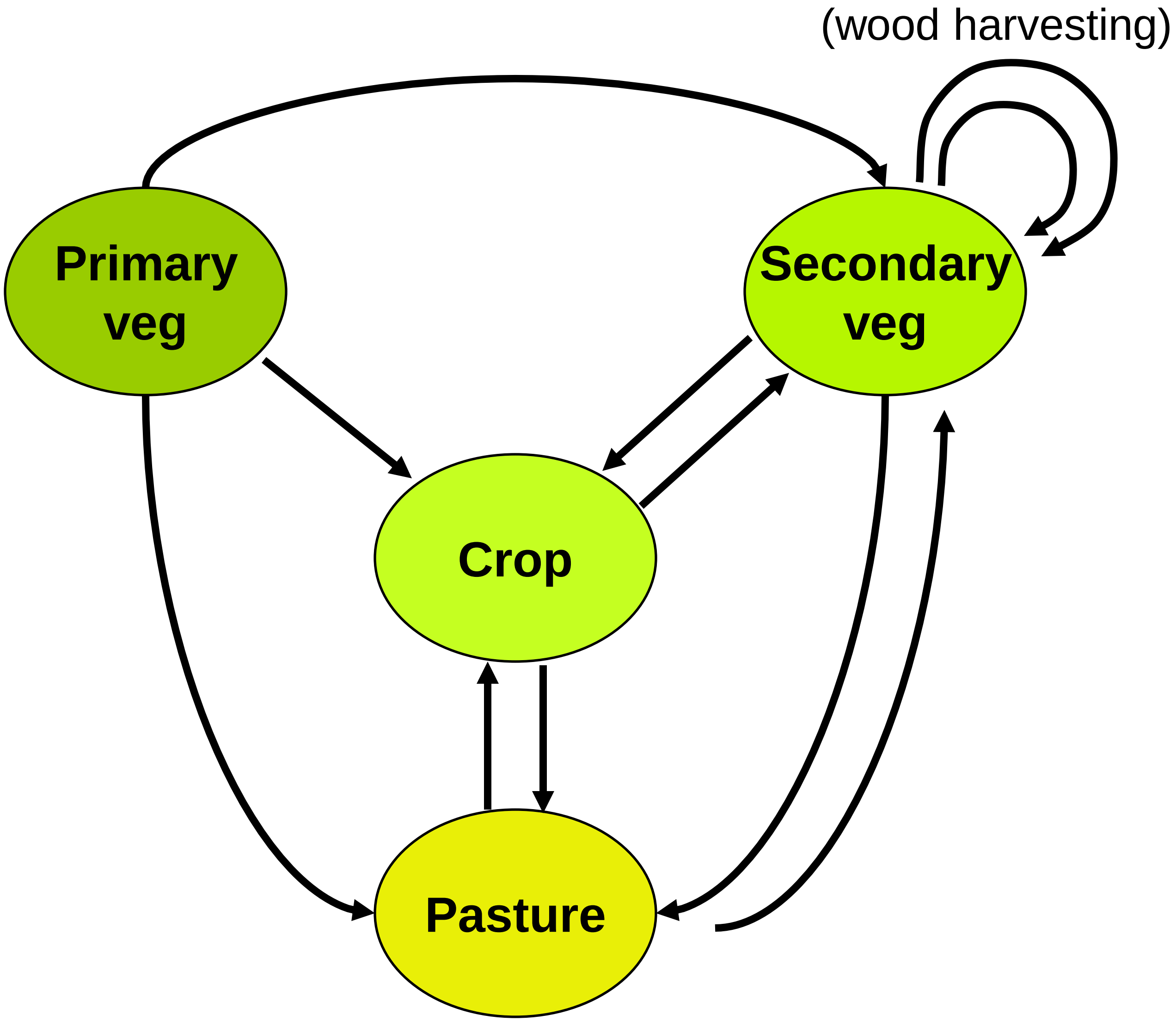
2002 presc. planting May 20th
Peak ~3 ~Aug 1st; ~flat ~4 weeks ; harv. by mid-Sep
Obs peak ~same

2004 presc. planting Jun 3rd
Peak ~4.5 ~Aug 15th; ~flat ~2 weeks; harv. by mid-Sep
Obs peak ~same



CLM-CN stress deciduous phenology

CN-crop phenology


(wood harvesting)
Primary veg
Secondary veg
Crop
Pasture