CLM3.5 with Three Biogeochemical Models Under Control and Drought Scenarios in an East-Central Amazon Forest

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http://en.wikipedia.org/wiki/Amazon_Rainforest

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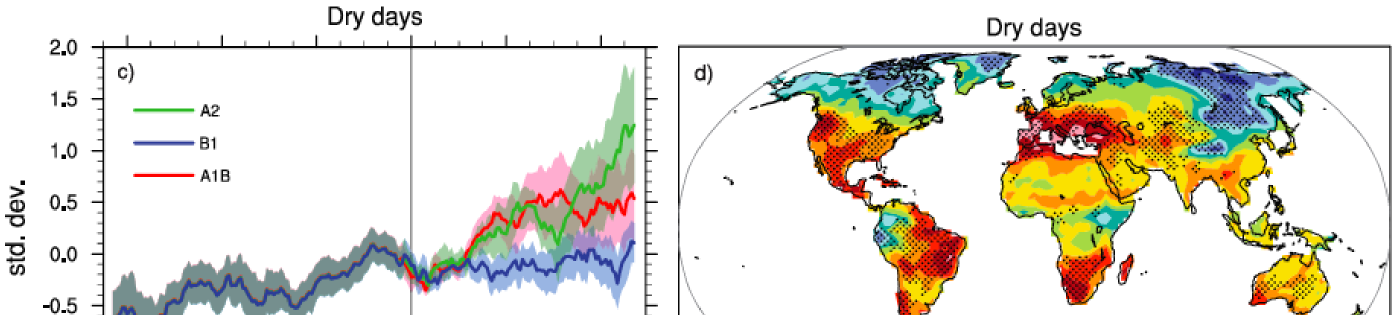
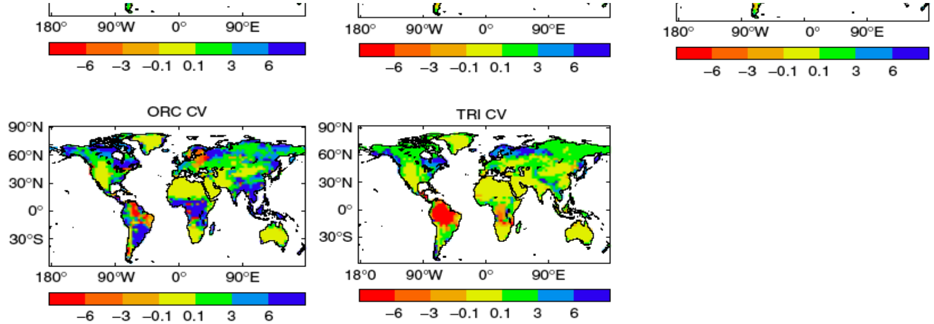
Motivation

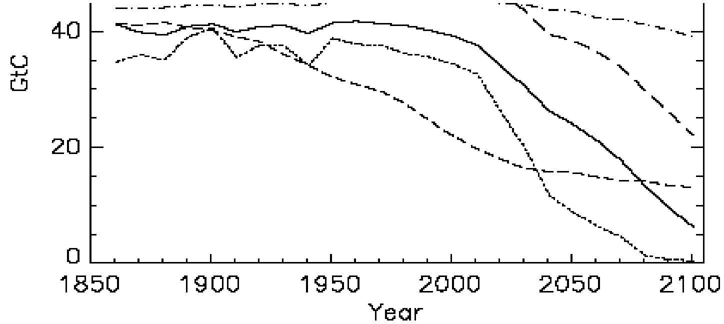
Expected increase in frequency and intensity of drought



Question: How realistic are the simulated **vegetation** & **drought sensitivity** in global land / biogeochemical / dynamic vegetation models?



Sitch et al. 2008



Cox et al. 2004

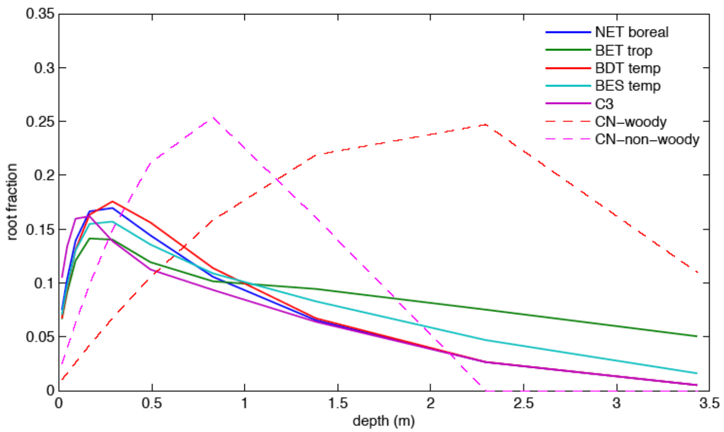
Method : CLM3.5 and biogeochemical models

Three biogeochemical (BGC) models coupled independently to a same land model

⇨ effectively find out strengths & weaknesses of the land (CLM) and BGC model structures & formulations

Model name	CASA'	CN	DGVM
Base model	CASA Pottere et al., 1993; Friedlingstein et al., 1999	BIOME-BGC Thornton et al., 2002; Thronton and Rosenbloom, 2005	LPJ and IBIS Sitch et al., 2003; Foley et al., 1996
C cycle	yes	yes	yes
N cycle	no	yes	no
Plant dynamics (change in PFT cover)	no	no	yes
number of C pools	3 plant tissues, 5 litter pools, 2 microbial communites, 2 SOM	6 plant tissues, 4 litter pools, 4 SOM. Same number of N pools	4 plant tissus, 2 litter pools, 2 SOM
R_a	50% of GPP	R_m: f(T,N) for leaf, live stem, coarse & fine roots, f(T) = Q10 R_g: 30% of new growth	R_m: f(T,C) for leaf, live stem, & root, f(T) = Lloyd & Taylor R_g: 25% of (GPP-R_m)
R_h	f(C,T,θ), f(T) = Q10	f(C,N,T,Ψ), f(T) = Lloyd & Taylor	f(C,T,θ), f(T) = Lloyd & Taylor
Plant carbon allocation	Dynamic at land model time step, resource availability	Dynamic at land model time step, resource availability + allometric relationship	Dynamic at yearly time step, allometric relationship
Vertical distribution of root fraction	Exponential (same as CLM3.5)	Linear	Exponential (same as CLM3.5)
Leaf phenology	Single phenology scheme with GDD summation, Based on Dickinson et al., 1998	Four types: evergreen, seasonal-deciduos, warm stress-deciduous, cold stress-deciduous. Based on White et al., 1998	Four types: evergreen, seasonal-deciduous, stress-deciduous, grass. Based on IBIS and LPJ models

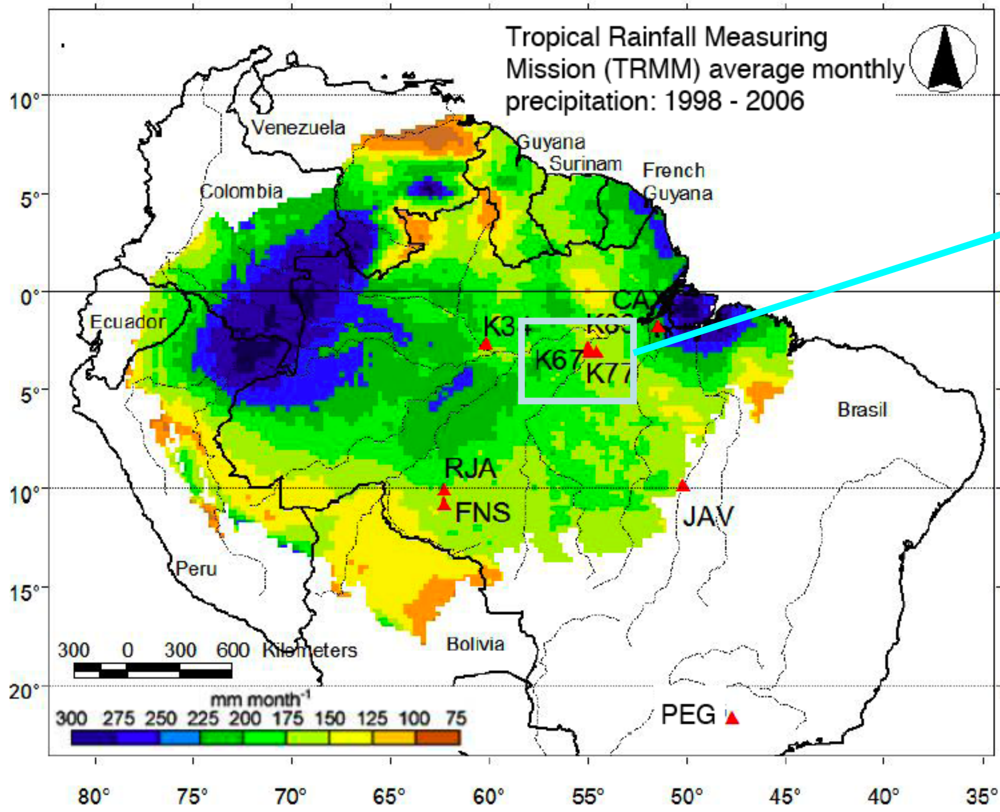
Root fraction in each soil layer

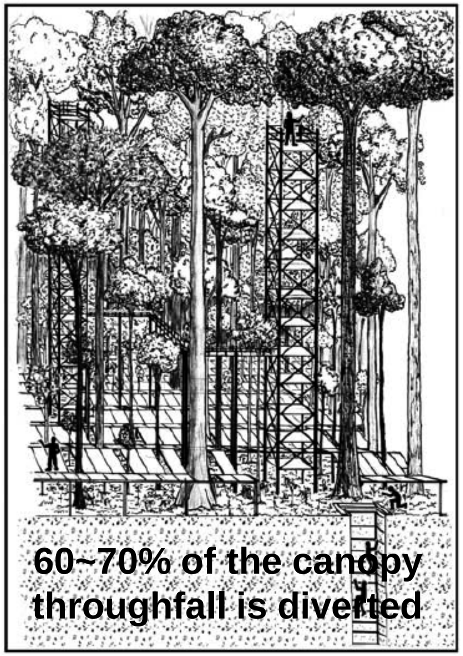


Method: Study Site & Data

Biometric measurements, Flux tower observation, and Artificial drought experiment: **Tapajos National Forest**

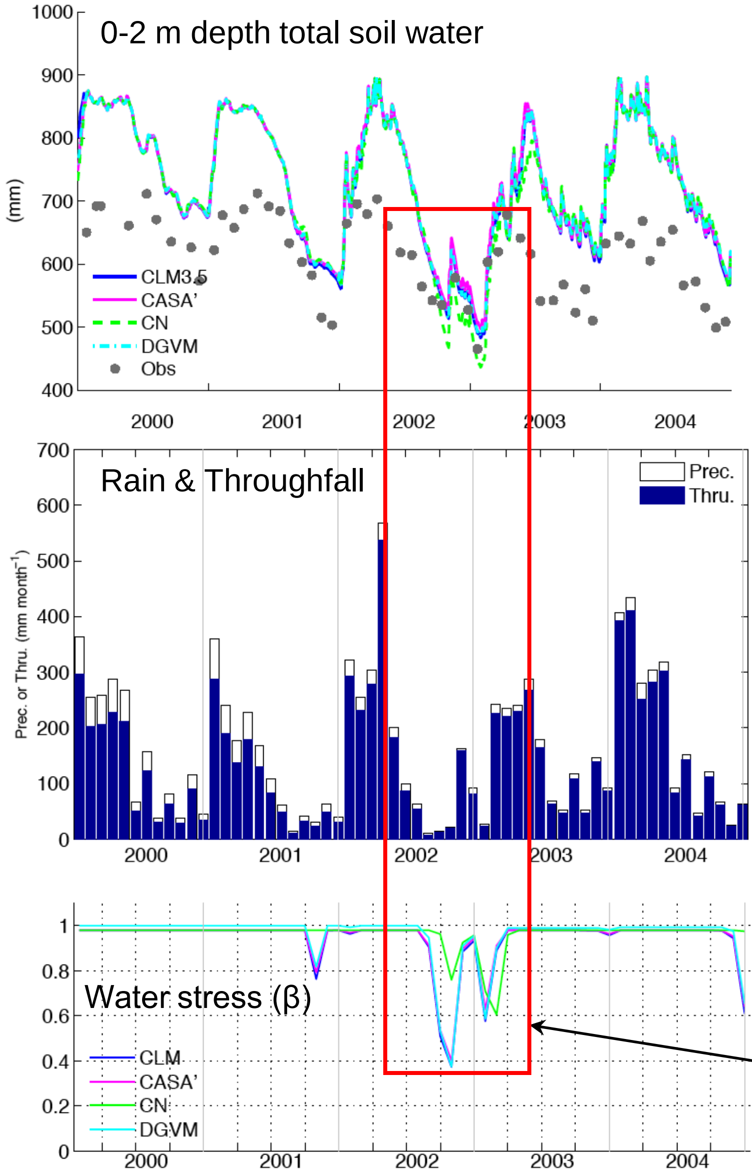
LBA: Saleska et al., 2003, Keller et al., 2004, Rice et al., 2004, Hutrya et al., 2007;2008, Nepstad et al. 2002;2007, Brando et al. 2008, Malhi et al., 2009, and others

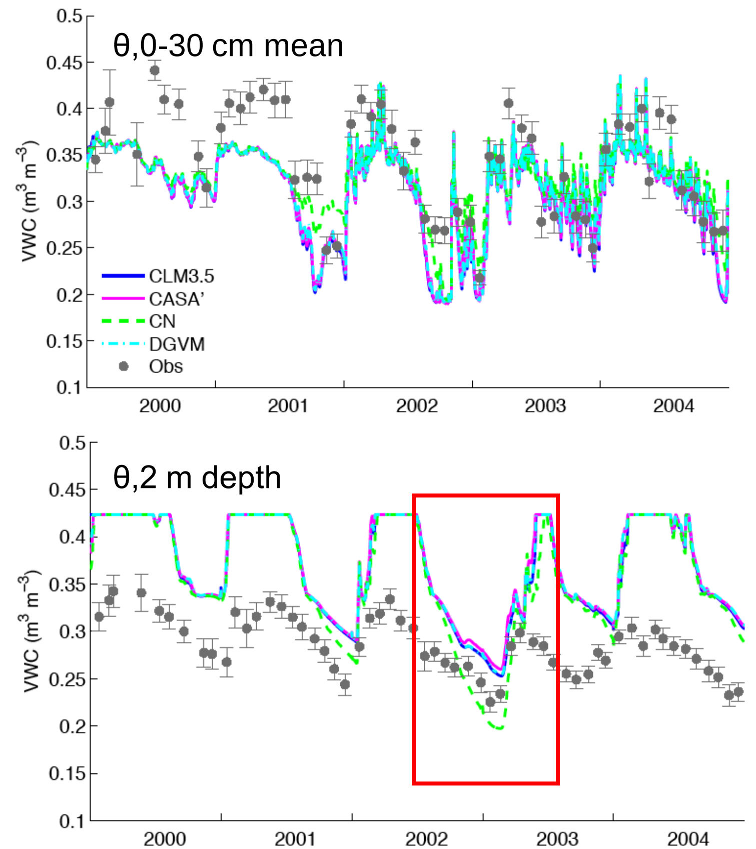




Results:
Natural (non-drought) Conditions

Results : Soil Moisture



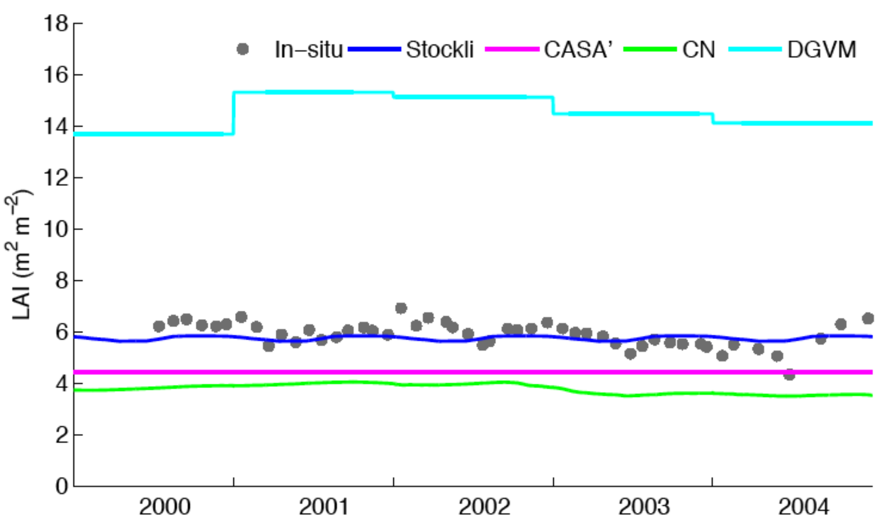


- Inter-model difference is small (except for CN)
- Larger bias in soil water content and variability at greater depth
- Model simulates water stress in severe dry season, but similar stress is not observed in eddy flux measurement.

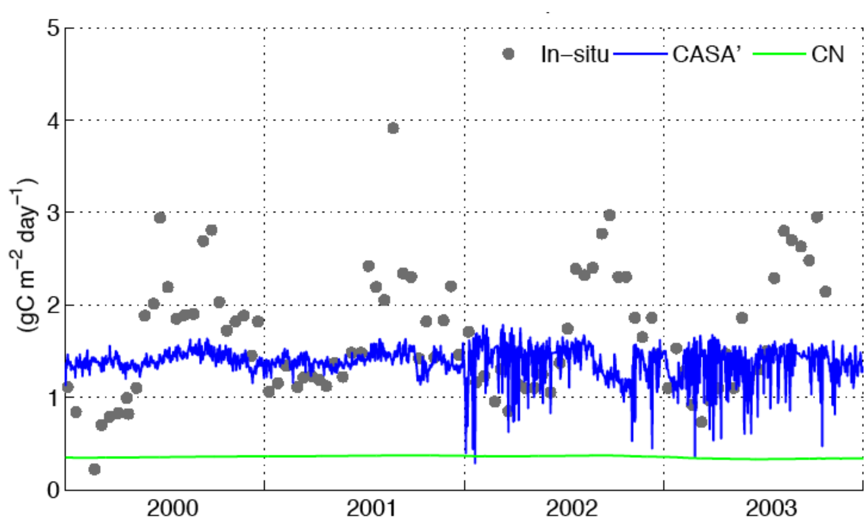
Results : Vegetation Structure & Phenology

Variables	Nepstad et al. (2002)		Rice et al.(2004)	Pyle et al.(2004)	Quesada et al. (2008)	Silver et al. (2000)	Malhi et al. (2009)	Model simulations		
	Treatment	Control						CASA'	CN	DGVM
Canopy height (m)[1]	18 ~ 40		~ 40					-	35.9	20.4
Aboveground live biomass (MgC ha^{-1})[2]	145.5	152.5	143.7 ± 5.4	148 ± 3				548.8	317.9	191.5
Root biomass (MgC ha^{-1})[3]	18.2 ± 4	17.1 ± 3					30 ± 4	4.5	5.6	14.6
Number of trees (ha^{-1})	182	203	469					-	-	659
Coarse woody debris (MgC ha^{-1})			48 ± 5.2	43.9 ± 5.2				76.0 (0.5)	29.2 (1.7)	-
Forest floor (MgC ha^{-1})						3.75 ± 0.47		5.5 (0.1)	-	8.3 (4.5)
Soil organic carbon (MgC ha^{-1})[4]					220			108.8 (0.1)	67.5 (0.2)	75.4 (0.8)

LAI



Leaf fall

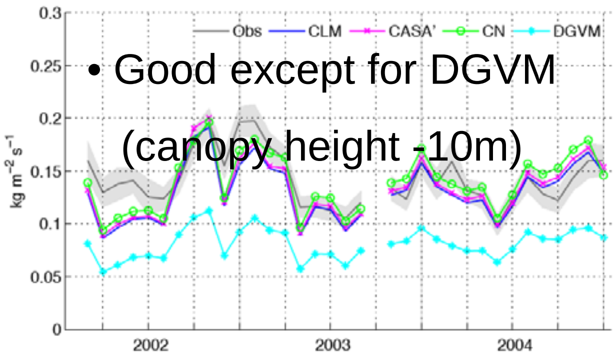


•Live Above Ground Biomass: Overestimated by all the models (Randerson et al., 2009)

•Seasonality in leaf fall is not well simulated : but **important** to photosynthesis, respiration, and LE in tropical forests with dry seasons

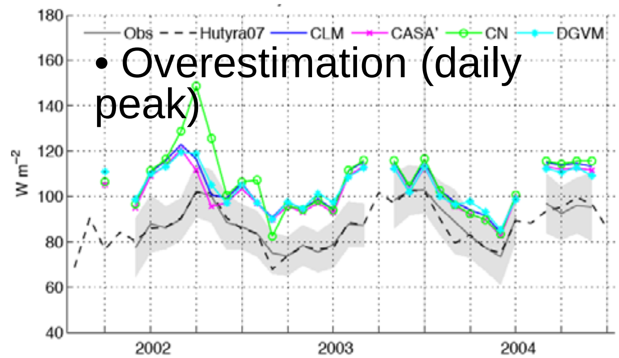
Results: Surface Fluxes (Monthly Mean)

- Good except for DGVM (canopy height ~10m)



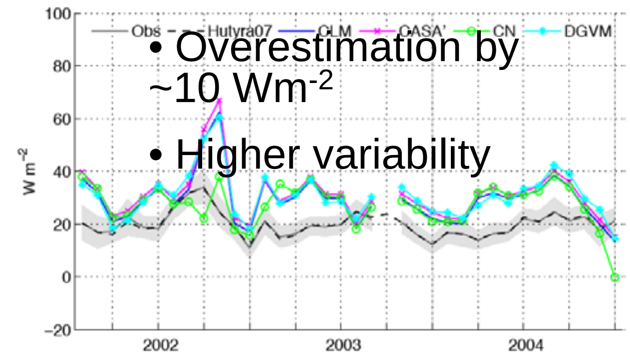
Momentum (kg m^{-1} s^{-2})

- Overestimation (daily peak)



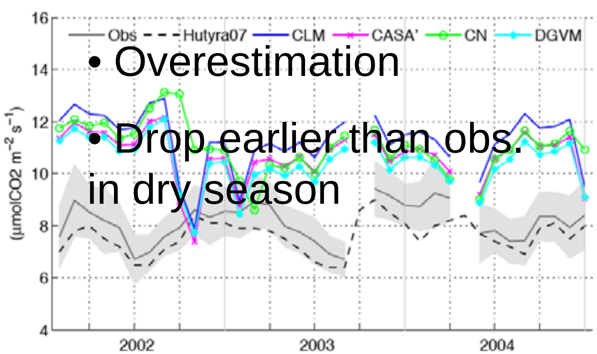
Latent Heat (W m^{-2})

- Overestimation by ~10 Wm^{-2}
- Higher variability



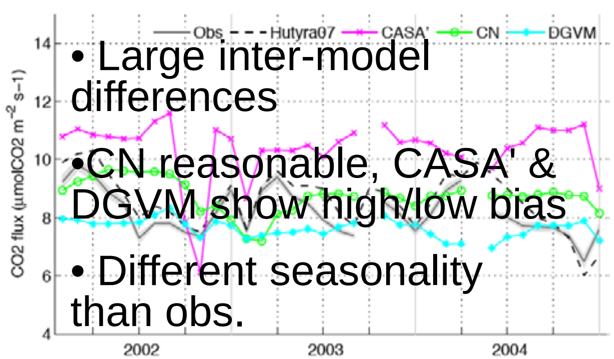
Sensible Heat (W m^{-2})

- Overestimation
- Drop earlier than obs. in dry season



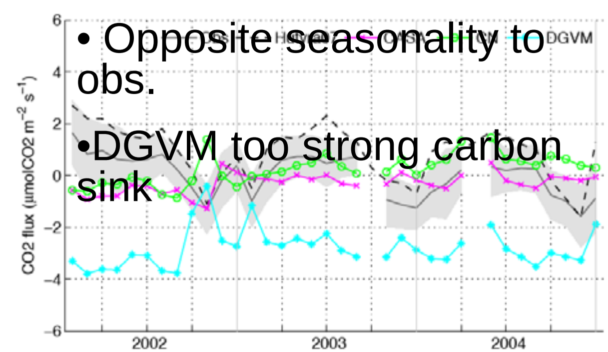
Gross Primary Production (GPP) (µmolCO_2 m^{-2} s^{-1})

- Large inter-model differences
- CN reasonable, CASA' & DGVM show high/low bias
- Different seasonality than obs.



Ecosystem Respiration (Reco) (µmolCO_2 m^{-2} s^{-1})

- Opposite seasonality to obs.
- DGVM too strong carbon sink

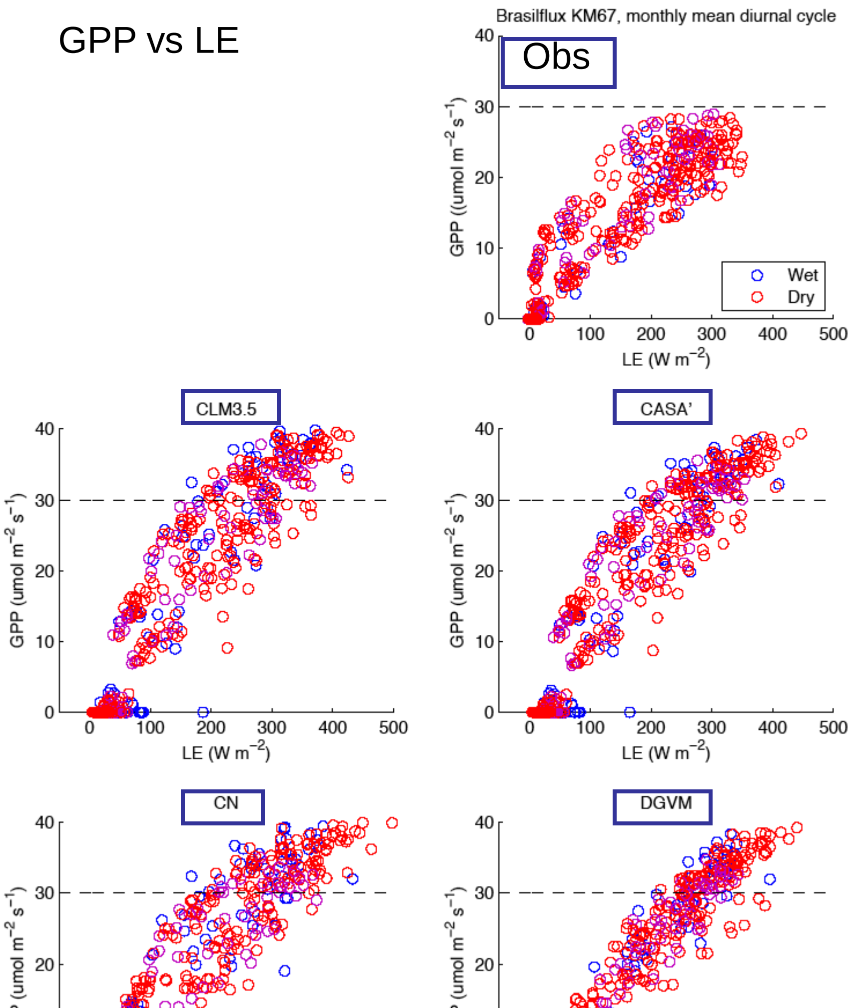


Net Ecosystem Exchange (NEE) (µmolCO_2 m^{-2} s^{-1})

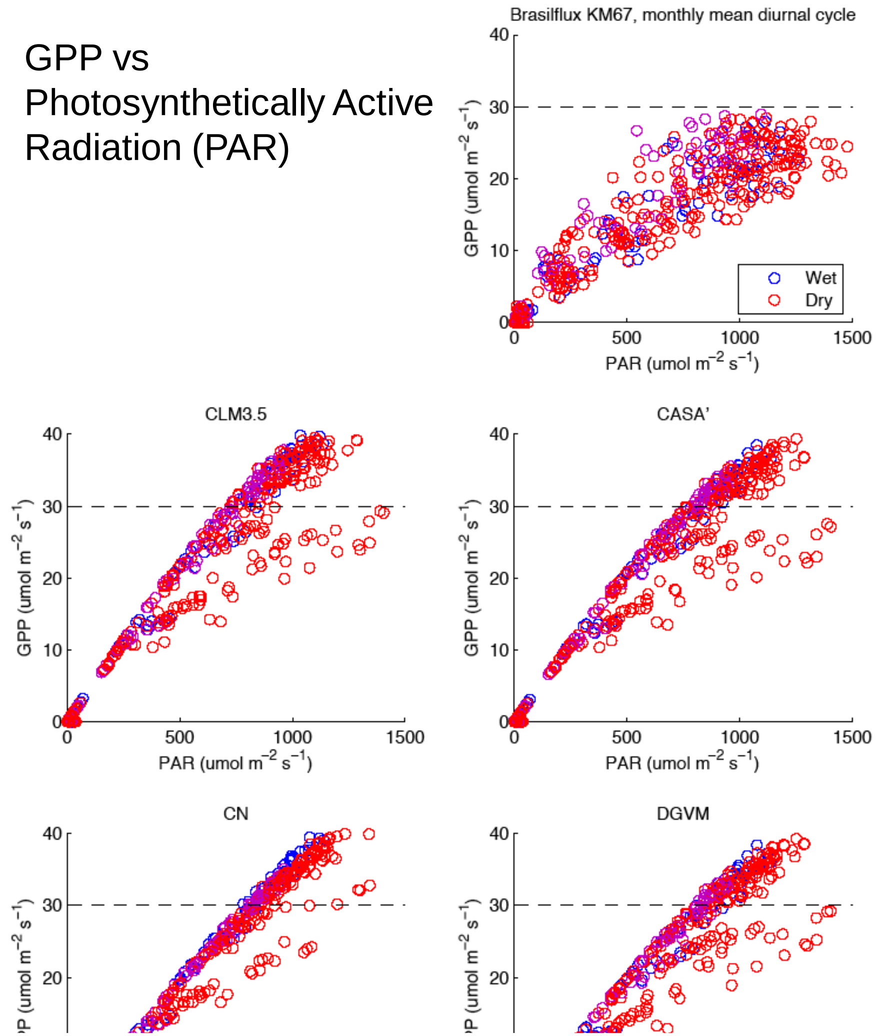
NEE = Reco-GPP

Results: Water & Light Use Efficiency

GPP vs LE



GPP vs Photosynthetically Active Radiation (PAR)



What can limit the maximum productivity in this forest?

Nutrition (Phosphorus)? Biological diurnal rhythm (Droughty et al., 2006) ?

Summary 1: Natural (non-drought) conditions

In the East-Central Amazon,

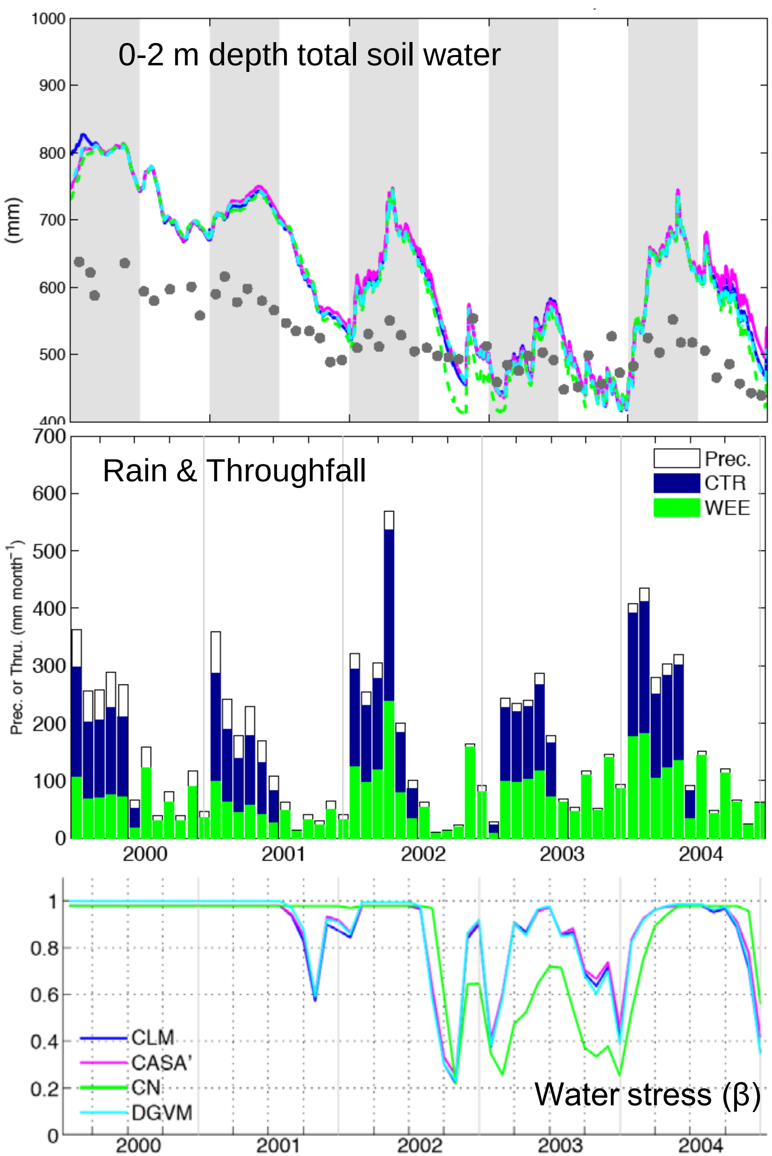
1. The base model CLM3.5 tends to overestimate soil moisture, GPP, and transpiration. It leads to higher annual productivity and biomass in BGC model simulations.

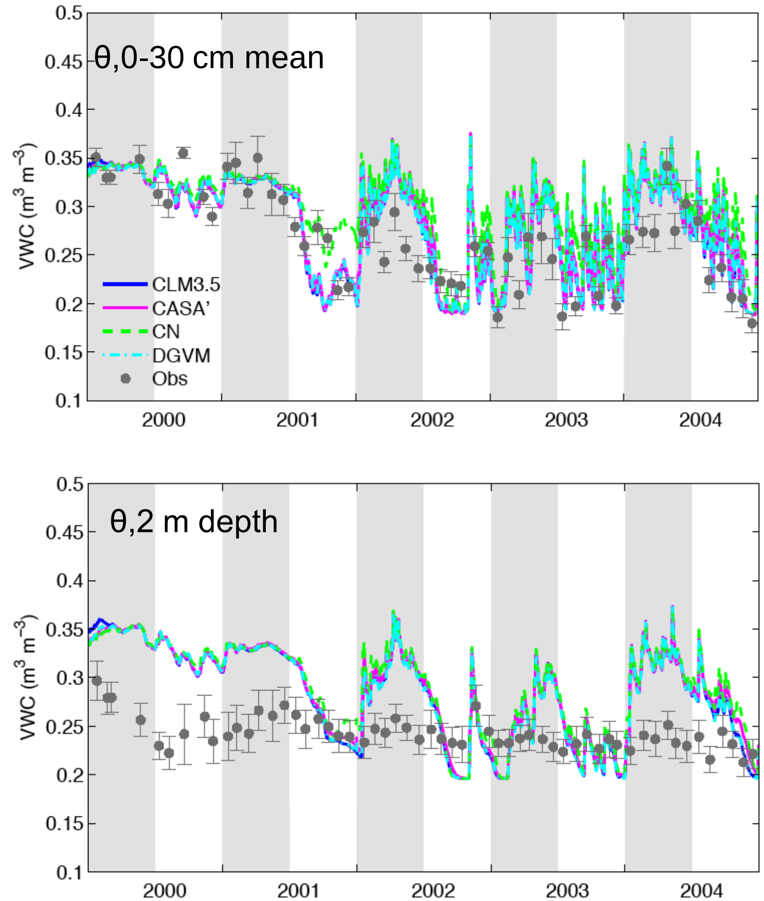
2. The simulated seasonality of the energy and carbon fluxes does not agree with observation, mainly due to the water stress during dry season (only in the simulations).

3. Large inter-model differences in Reco. CN produces the most reasonable result, but does not reproduce the observed seasonality.

Results:
Drought Scenario

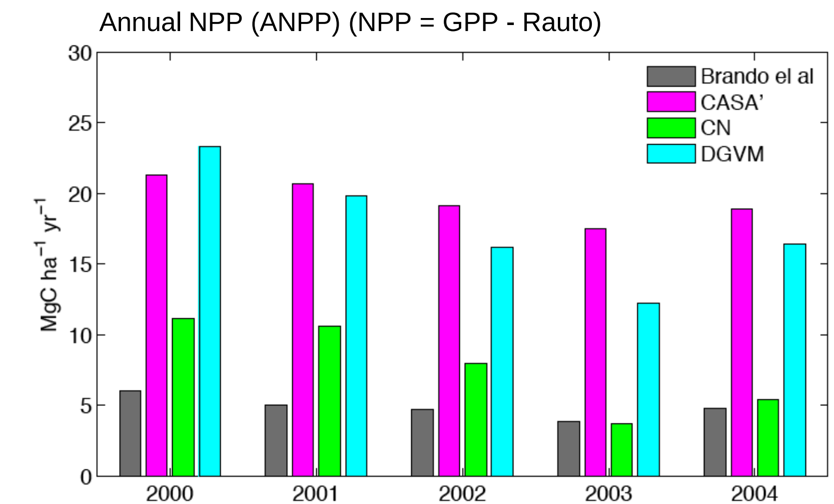
Drought in Wet Season: Soil Moisture

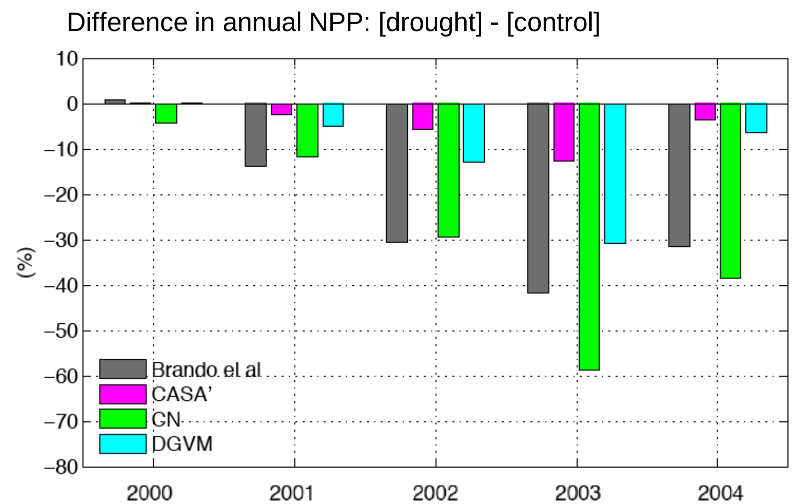


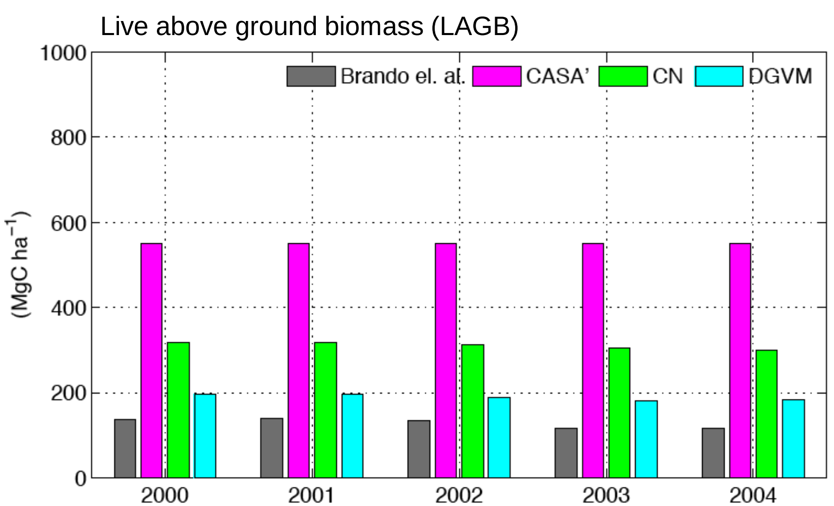


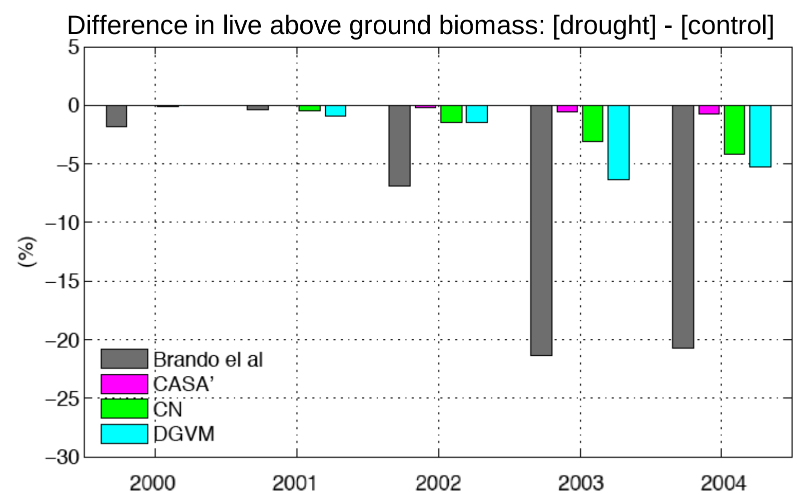
- **Wet bias** in wet season, similar ~ drier in dry season
- Variability is higher than observation

Drought in Wet Season: Vegetation Response







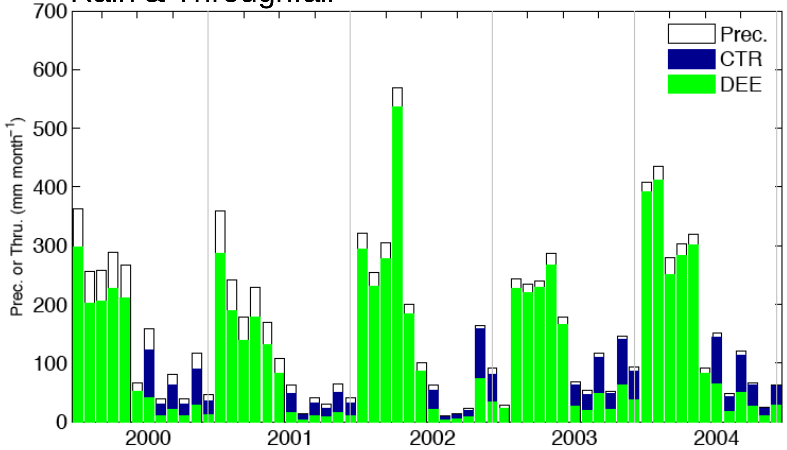


- ANPP change: Large inter-model differences, ~ capture the observed yearly change.
- LAGB change: Insensitive to drought stress (wetter soil & higher GPP & mortality formulation)

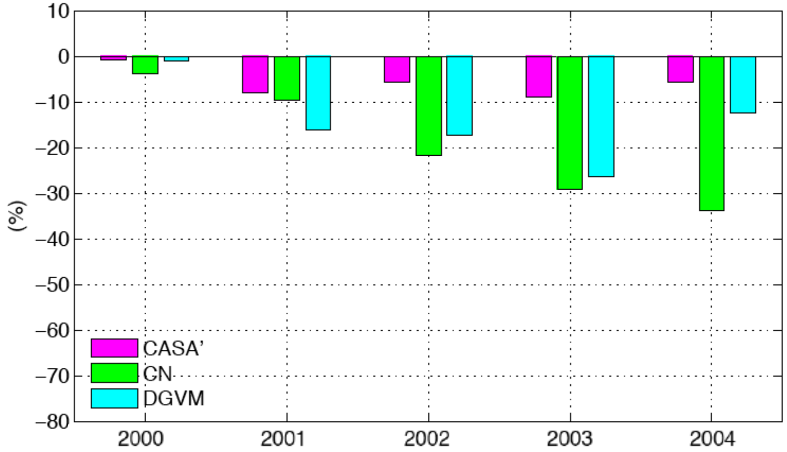
Additional Scenarios: Drought in Dry Season

(Simulations only)

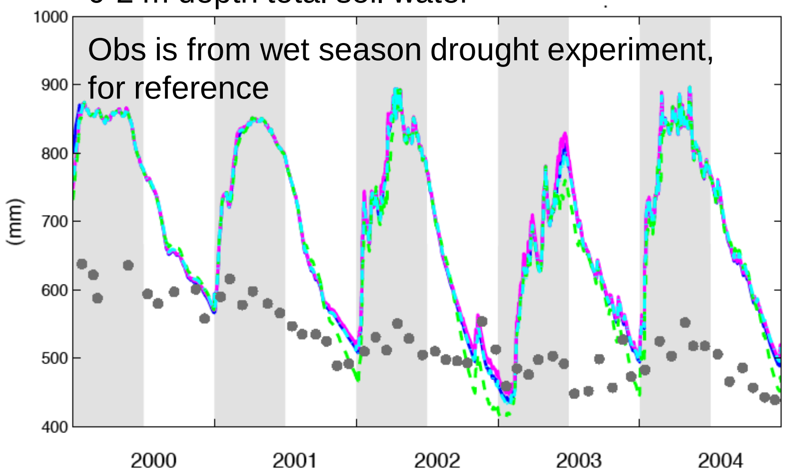
Rain & Throughfall



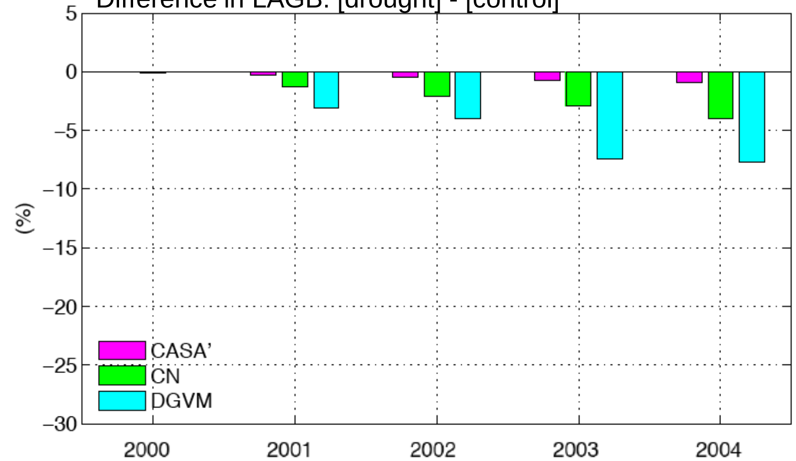
Difference in annual NPP: [drought] - [control]



0-2 m depth total soil water



Difference in LAGB: [drought] - [control]

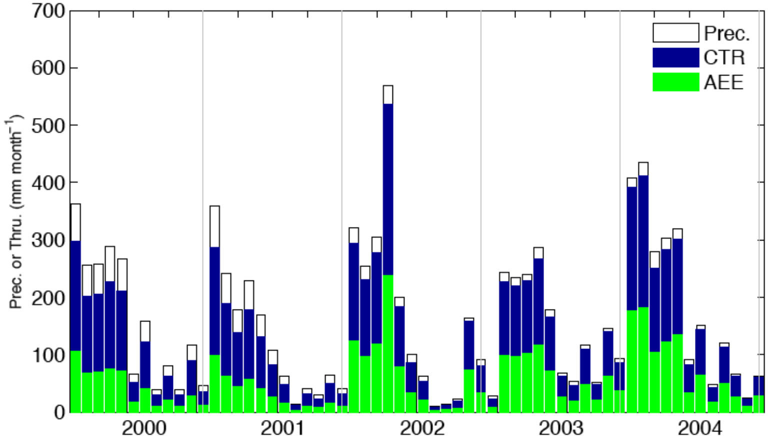


- Less severe than wet season drought, except for DGVM

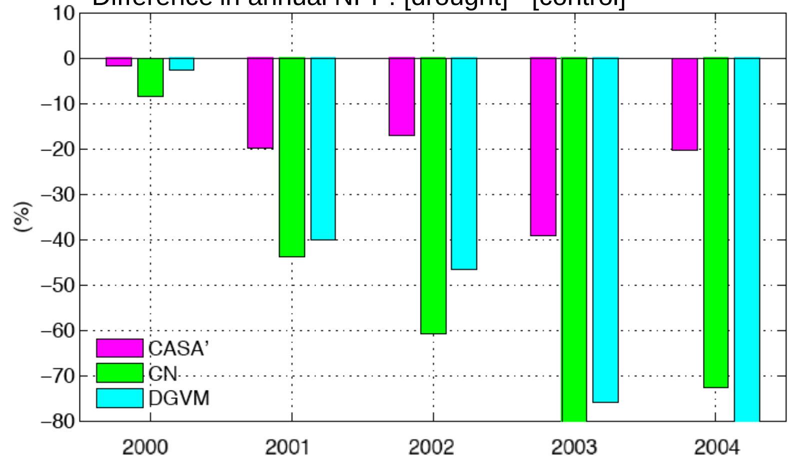
Additional Scenarios: Drought All Year

(Simulations only)

Rain & Throughfall



Difference in annual NPP: [drought] - [control]



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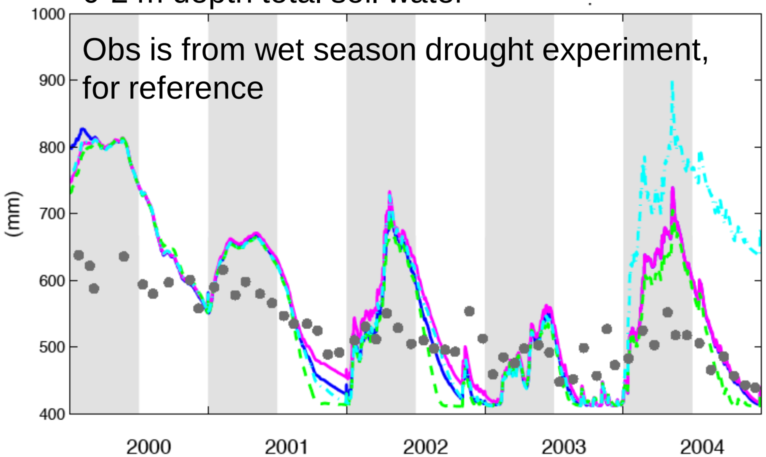
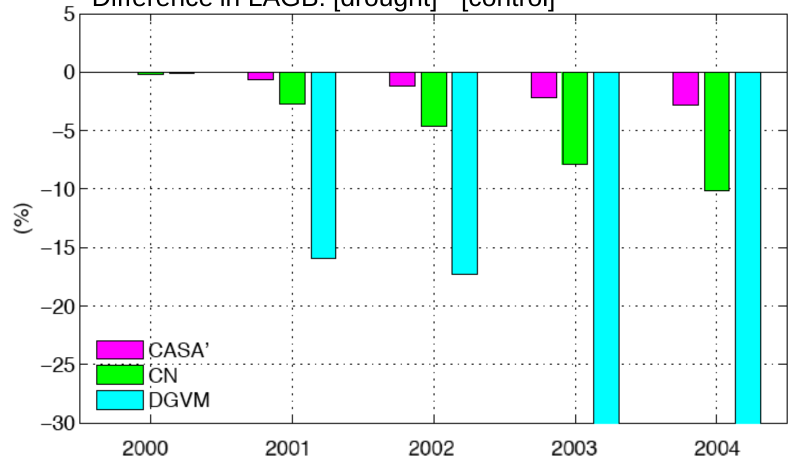


Difference in LAGB: [drought] - [control]



- Relative decline of LAGB in CASA' and CN are still smaller than observation of wet-season drought experiment.
- Tropical forest collapsed after 3 years in DGVM

Summary 2: Drought Scenario

1. Simulated above ground biomass is not as sensitive to drought stress as observation.
2. All-year drought collapsed tropical trees in DGVM in the fourth year.

Overall, CLM 3.5 and the three BGC models needs further improvements in the relationships among:

soil water content - water stress/max GPP - mortality

for realistic simulations of the future Amazon forest.

Does CLM4.0 need modifications or additional parameterizations (e.g., Lee et al., 2005, Baker et al., 2008) ?