Global measurements of vegetation structure: a climate and carbon cycle science perspective

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Why Measure Vegetation Structure?

Vegetation structure is a key indicator of ecosystem state (the successional status of an ecosystem)

Knowing the state of an ecosystem is important because it determines both its current biophysical & biogeochemical status and its future trajectory.

- 2 key metrics:

  Canopy Height

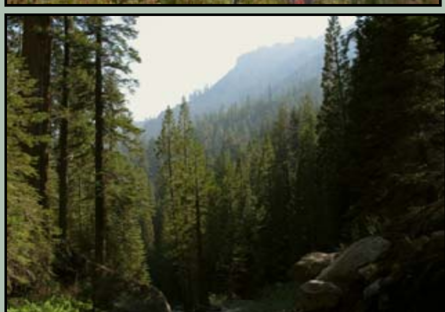
  Canopy Biomass, Aboveground biomass, and/or basal area

- Other possible metrics:

  Crown area

  Wood density, tree architecture

Ecosystems are highly heterogeneous in their structure at fine spatial scales



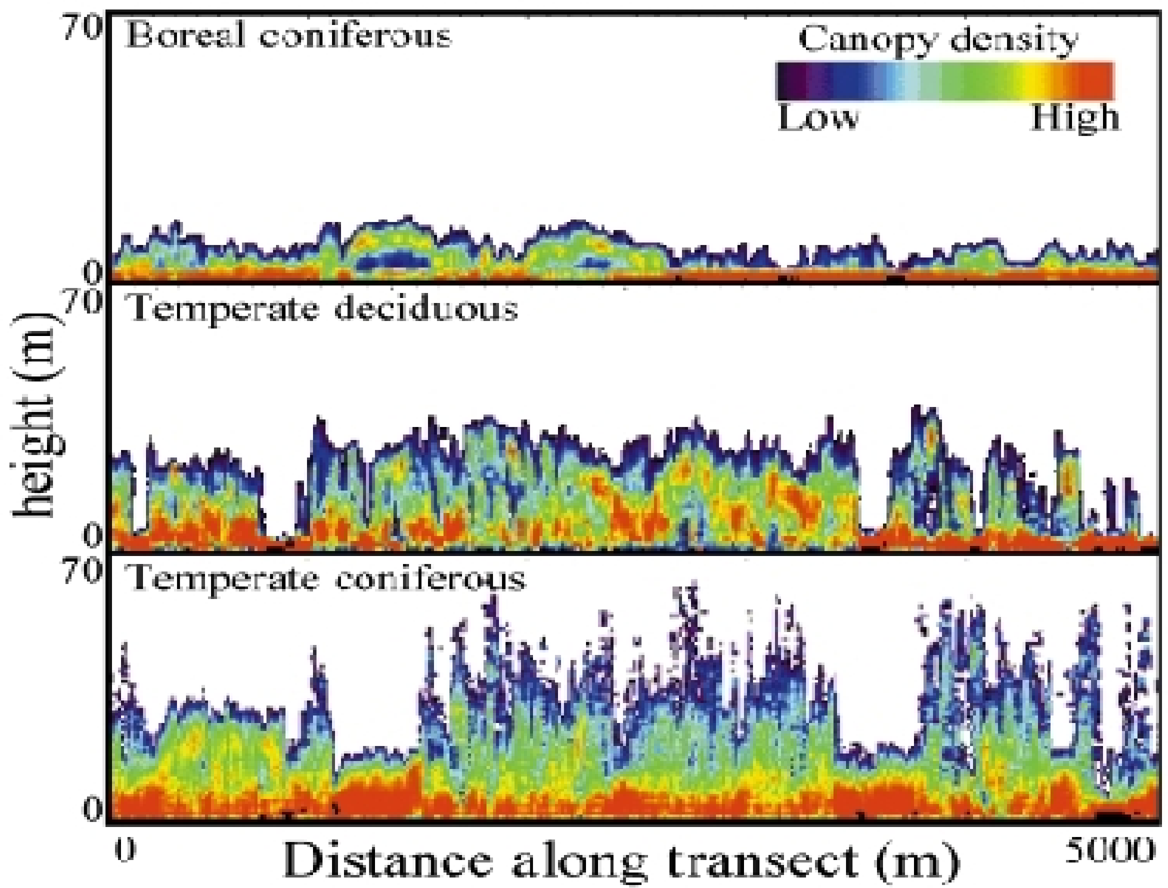
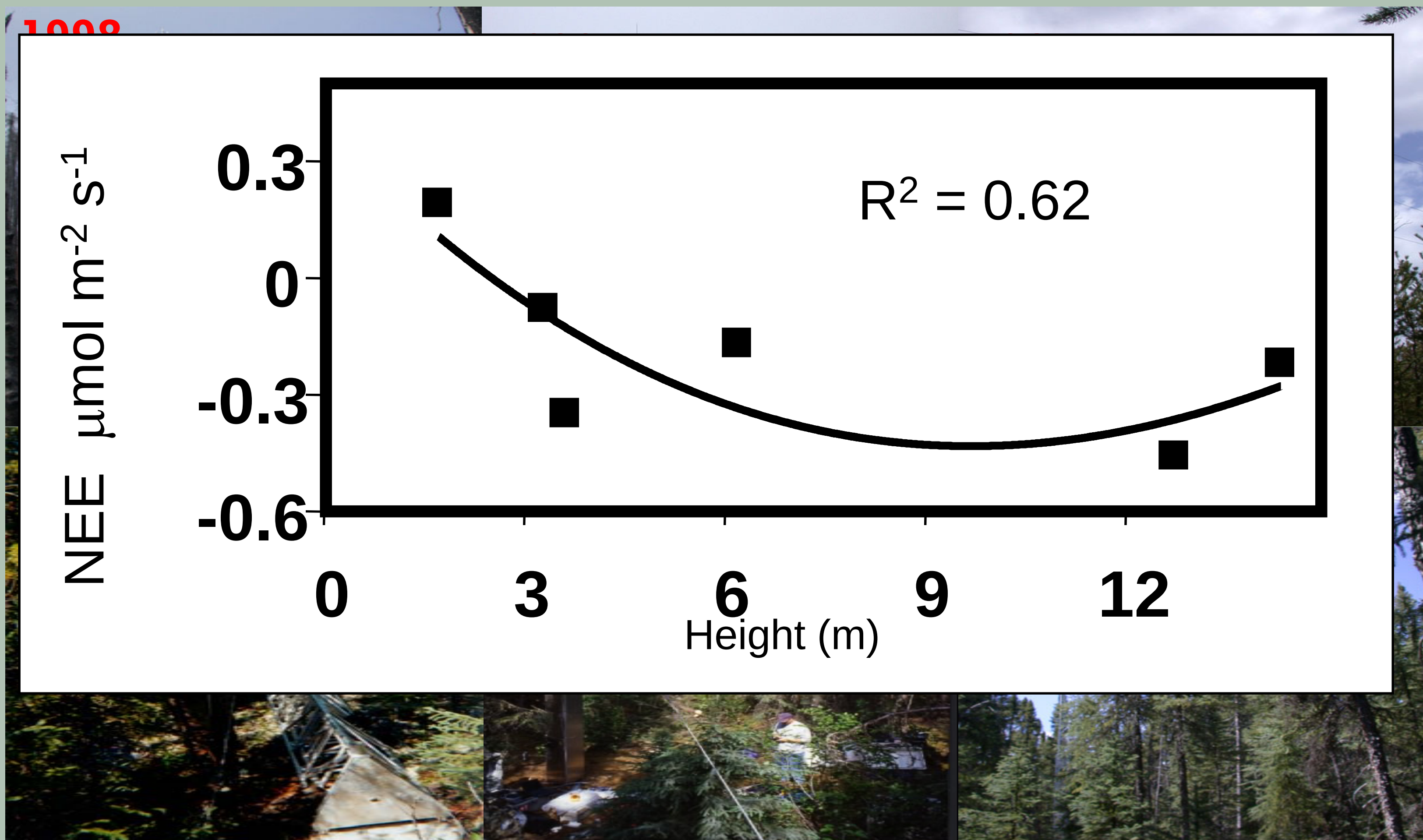


Fig. 1 Measurements of forest canopy structure made using NASA's SLICER (Scanning Lidar Imager of Canopies by Echo Recovery) sensor.

Fine scale variation in ecosystem structure is linked to changes in function

e.g. Boreal Chronosequence

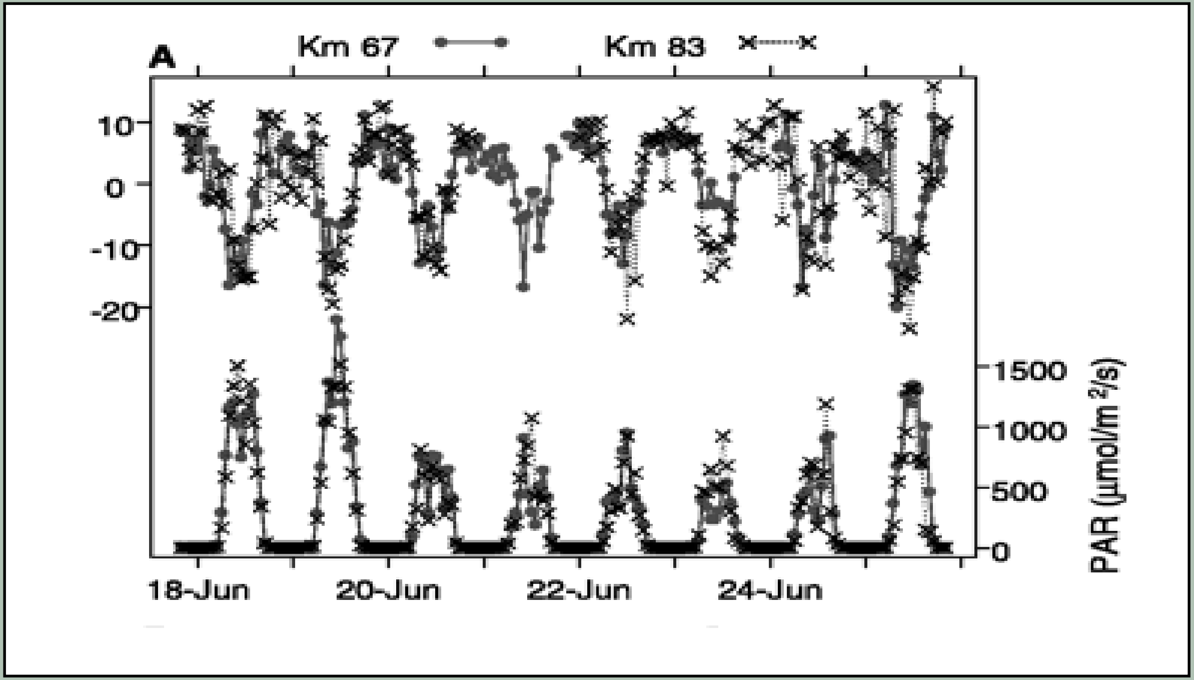
Net Ecosystem Exchange vs. GLAS-derived canopy heights
(Goulden et al., 2006)



TNF

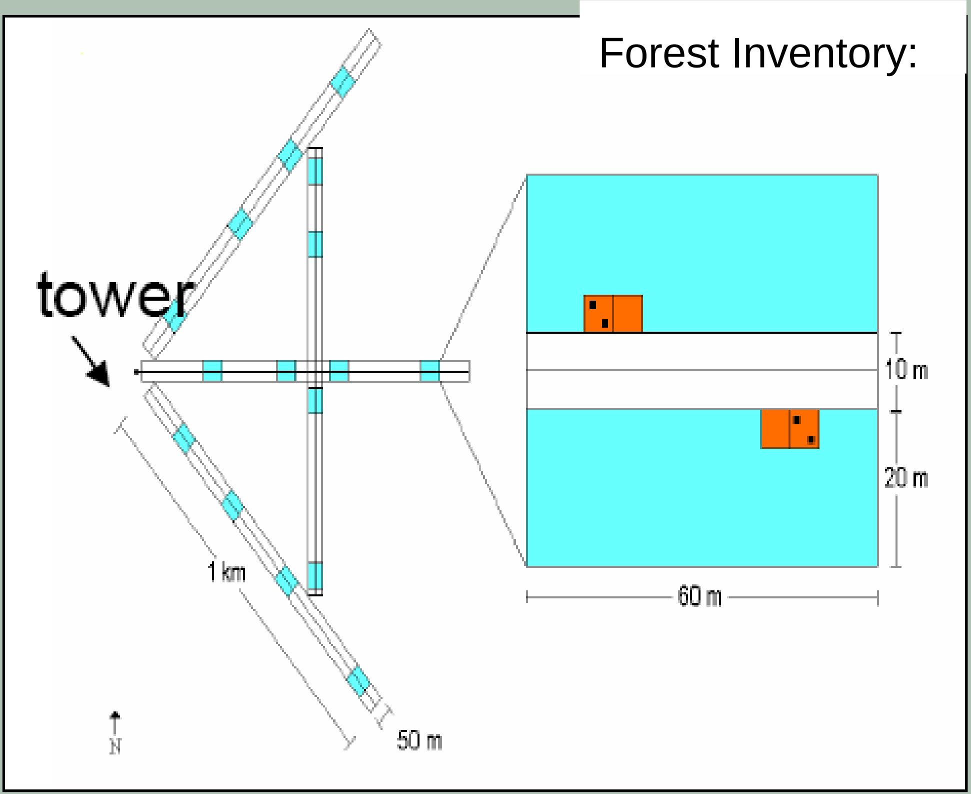
Santarem (3ºS, -55ºW) ecosystem measurements

Tapajos Km 67 Primary Forest Tower Site

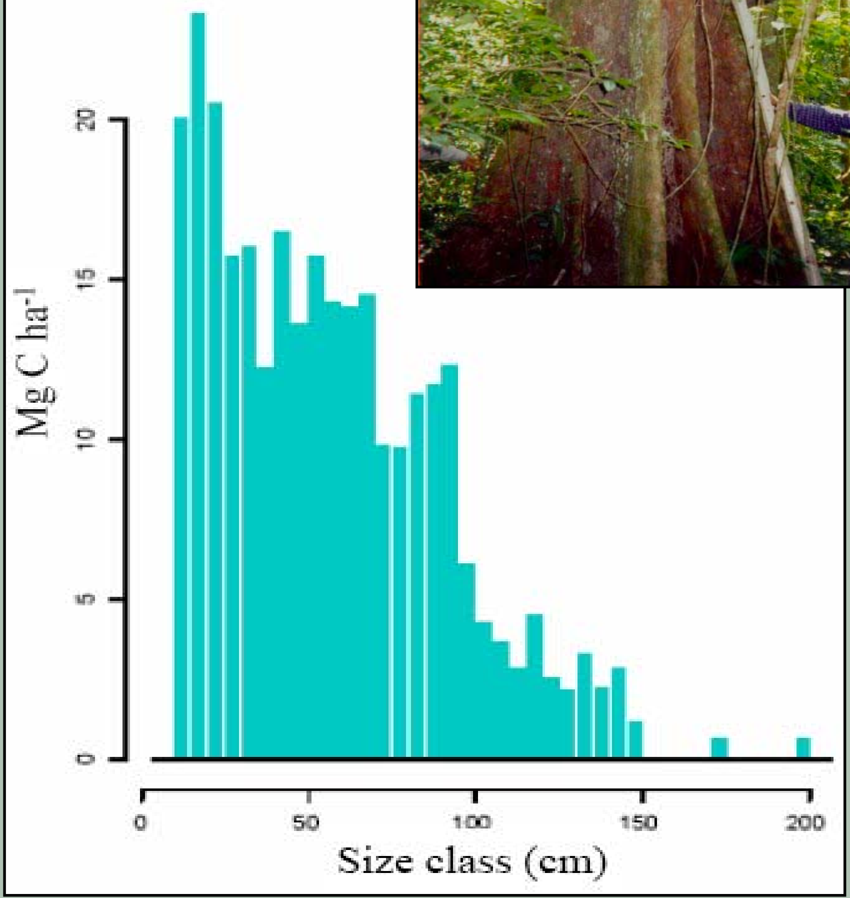


Santarem (3ºS, -55ºW) measurements of ecosystem structure

Forest Inventory:

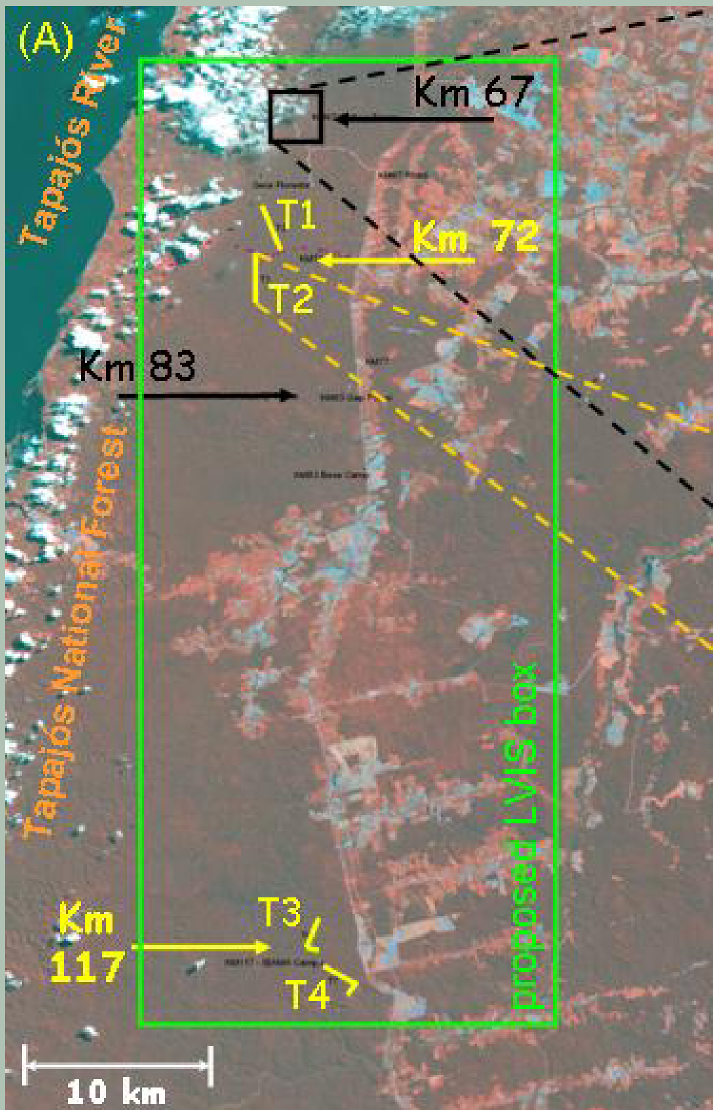


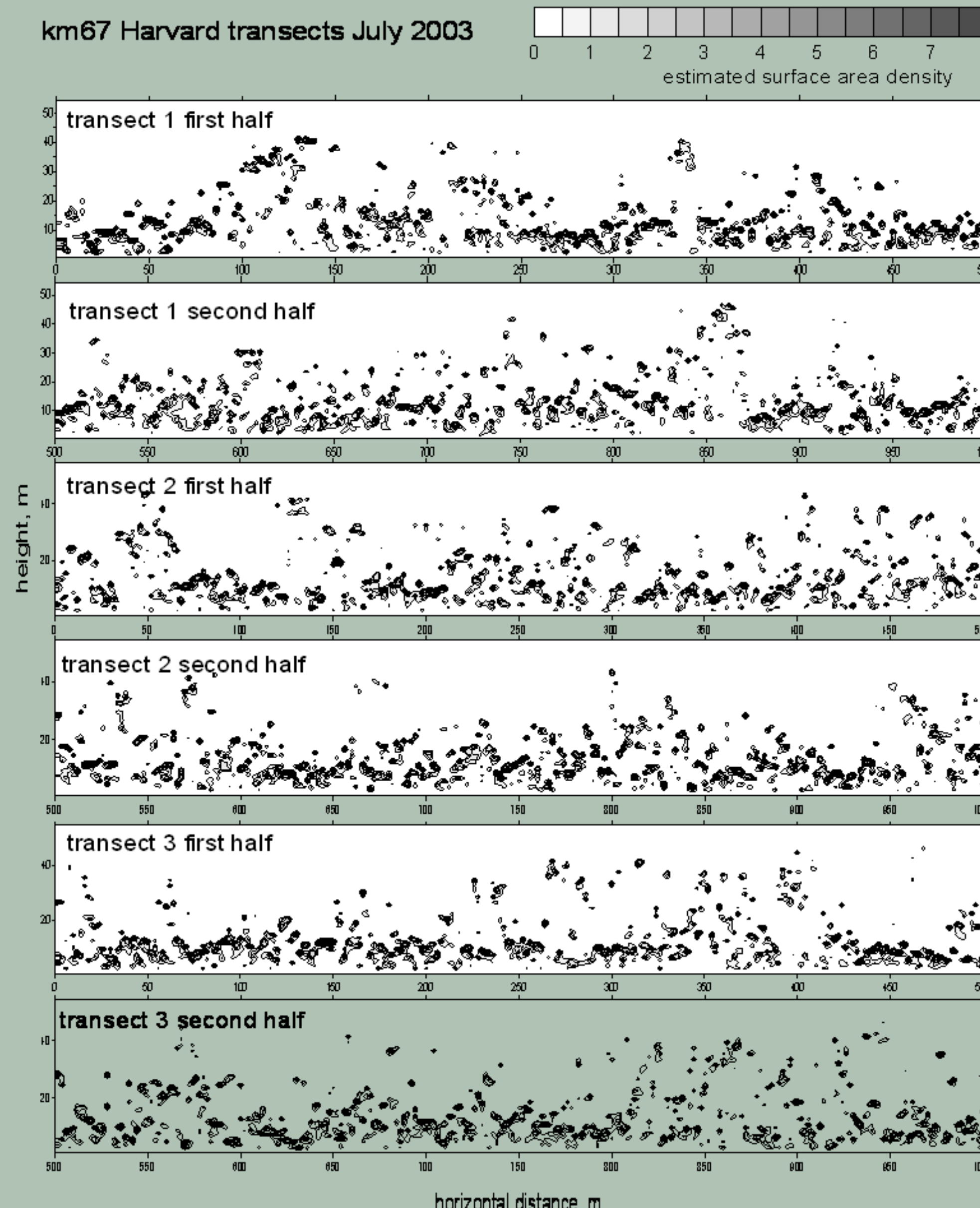
19.75 ha for trees >35 cm, ~1000 stems
3.99 ha for trees >10 cm, ~1800 stems

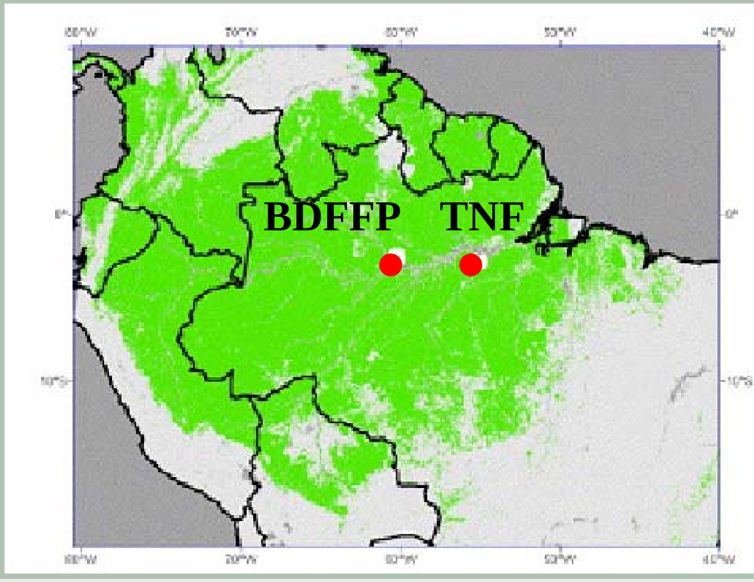


LIDAR (LIght Dectection And Ranging) Measurements of Forest Canopy Height

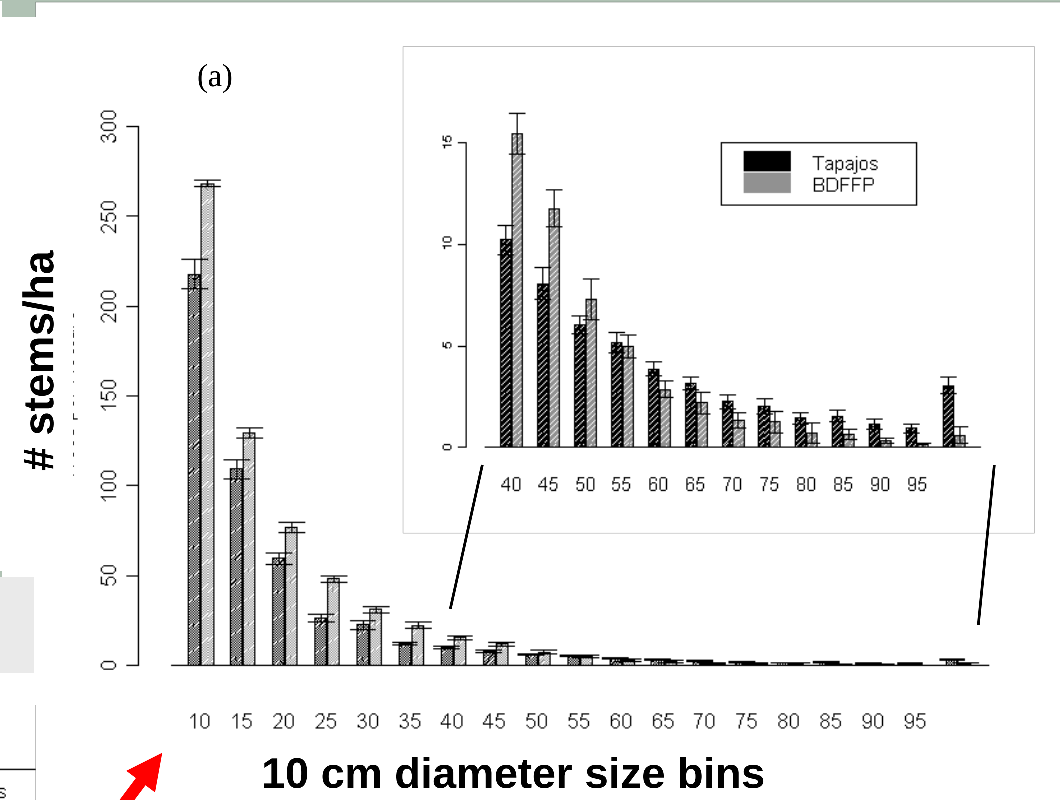
(Parker & Fitzjarrald)

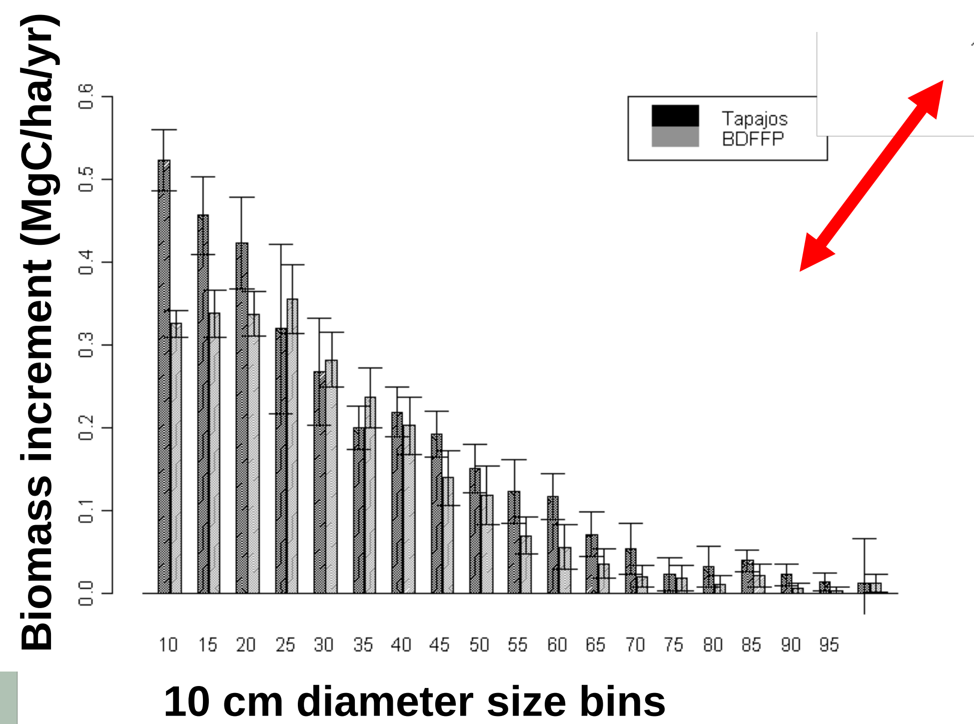






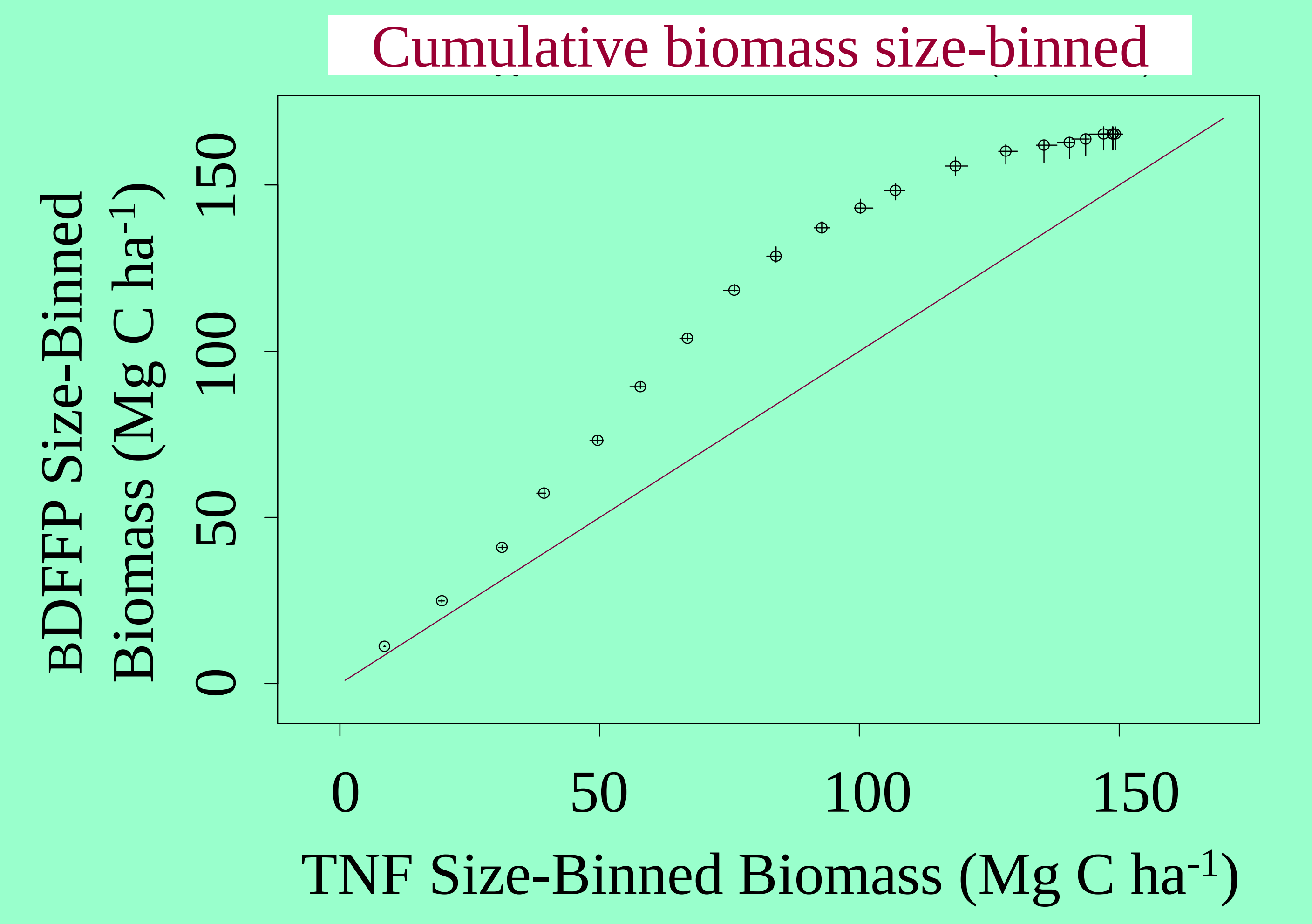
compare TNF vs BDFFP





Size class distributions of (a) live trees and (b) live tree growth. The BDFFP sites have more trees (larger tph) in the smallest size classes, but smallest trees at the TNF show largest uptake of carbon.

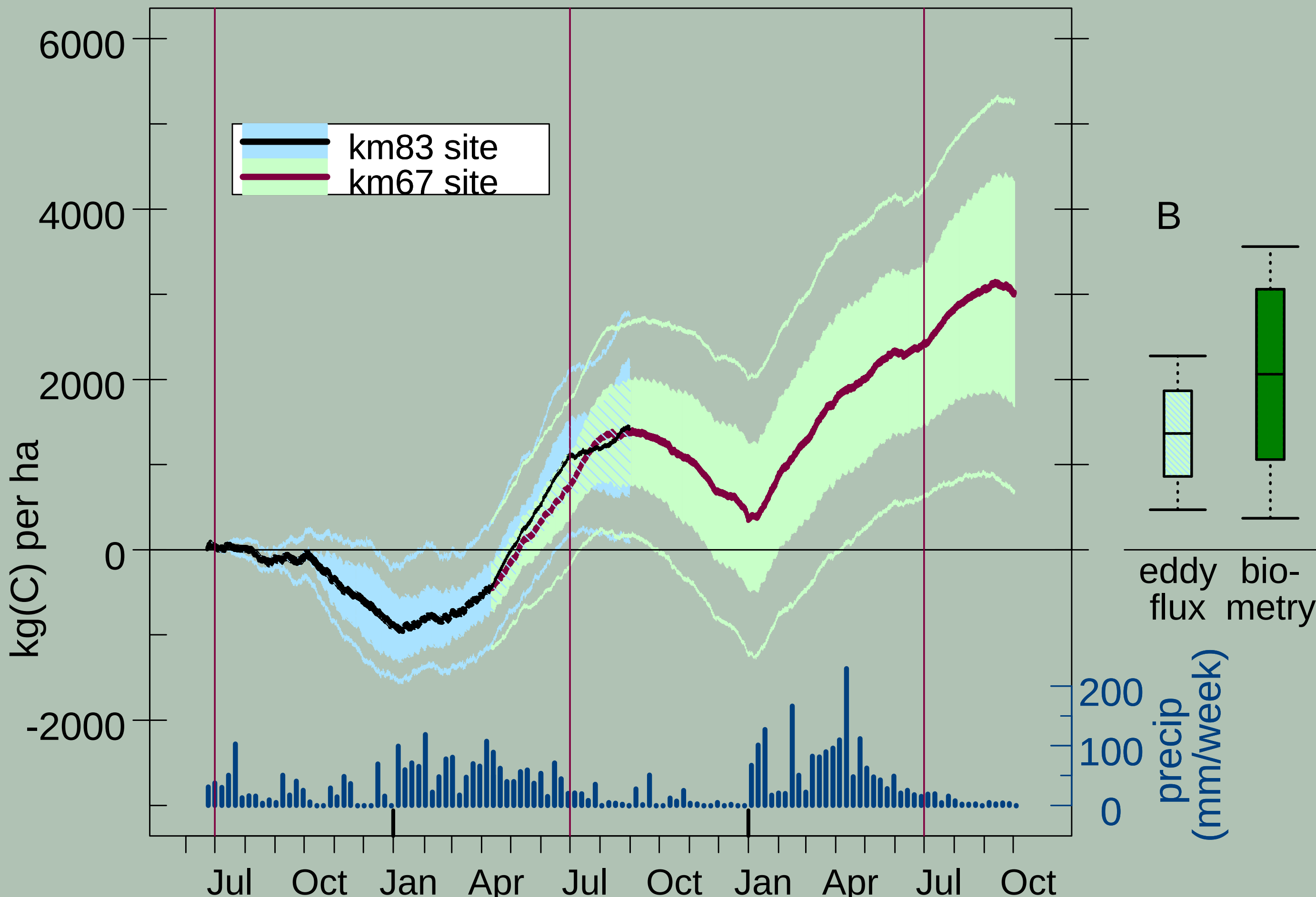
Quantile-quantile plot of biomass by size class at two sites. Curved portion in middle results from higher biomass stored in middle size classes at Manuas site. 1:1 line –.



This simple structural difference arises directly from the disturbance regime, and relates directly to the growth dynamcs and C budget.

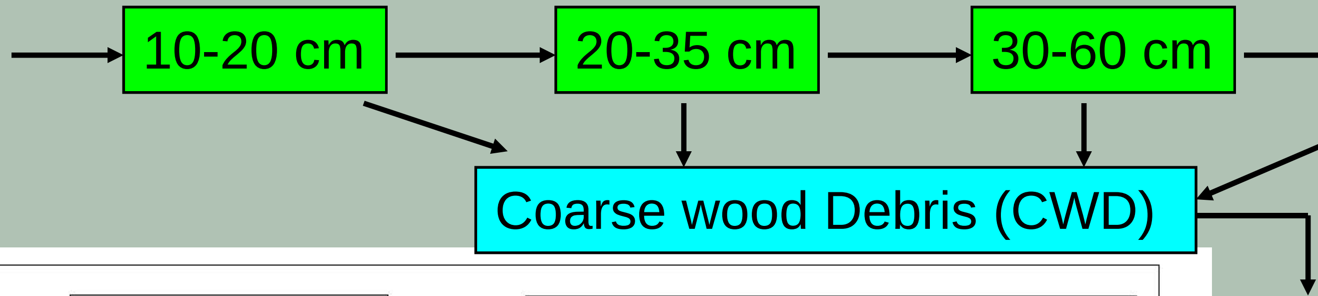
(Saleska et al 2003)

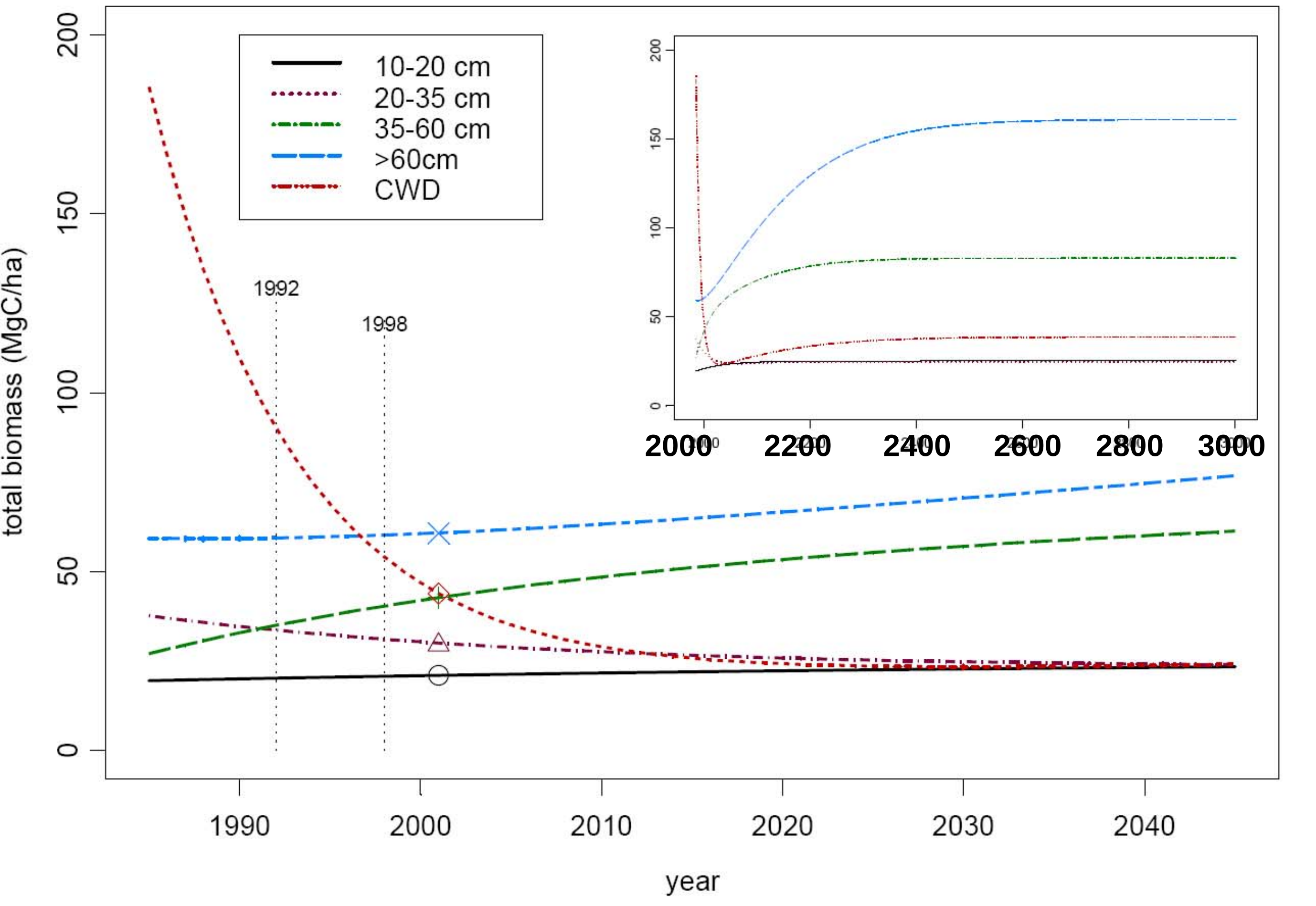
Tapajos Carbon Fluxes 2000-2002



=> TNF Amazon forest was losing carbon 1.3 tC/ha/yr in 2000-2002…

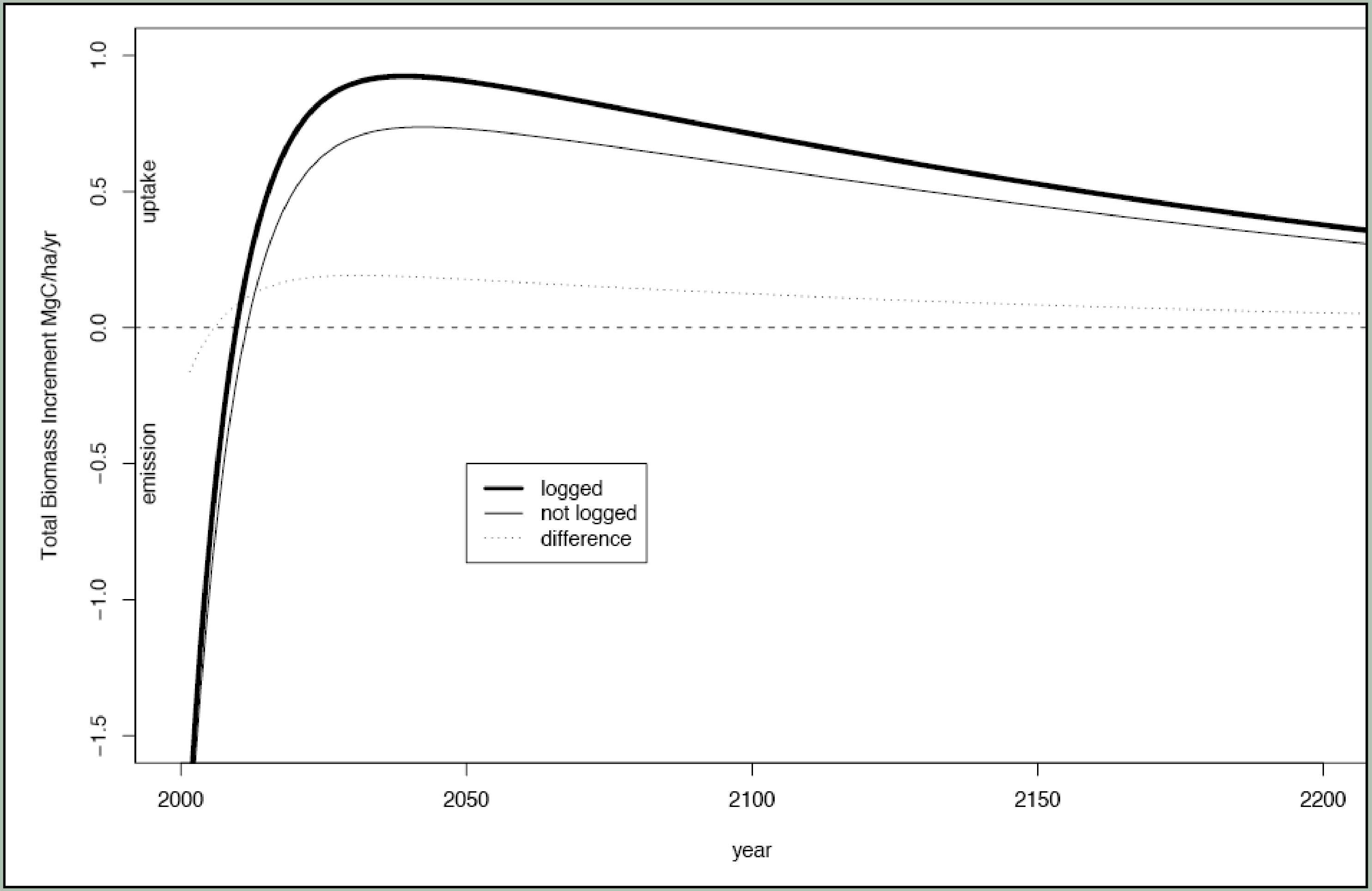
A simple empirically-calibrated model of vegetation structure at the Tapajos flux tower site





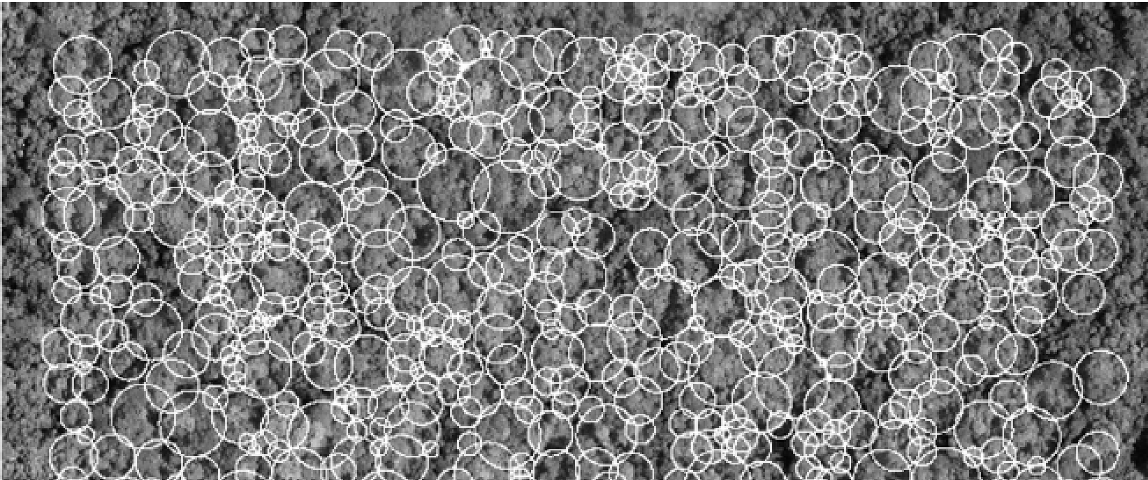
- Size class distribution in (2001) and transition rates between size classes calculated from tree level measurements of growth, mortality & recruitment
- Projection of size class distribution forward and backward in time

Projected patterns of biomass change: effect of disturbance, logging



Conclusion: Measurements of vegetation structure indicate that the reason the system was a net carbon source that the ecosystem is recovering from a recent disturbance event. Projecting forwards implies that in the near future the site will transition from being a net carbon source to being a net carbon sink.

The distribution function of crown areas is a sensitive indicator of disturbance regime and ecosystem structure.



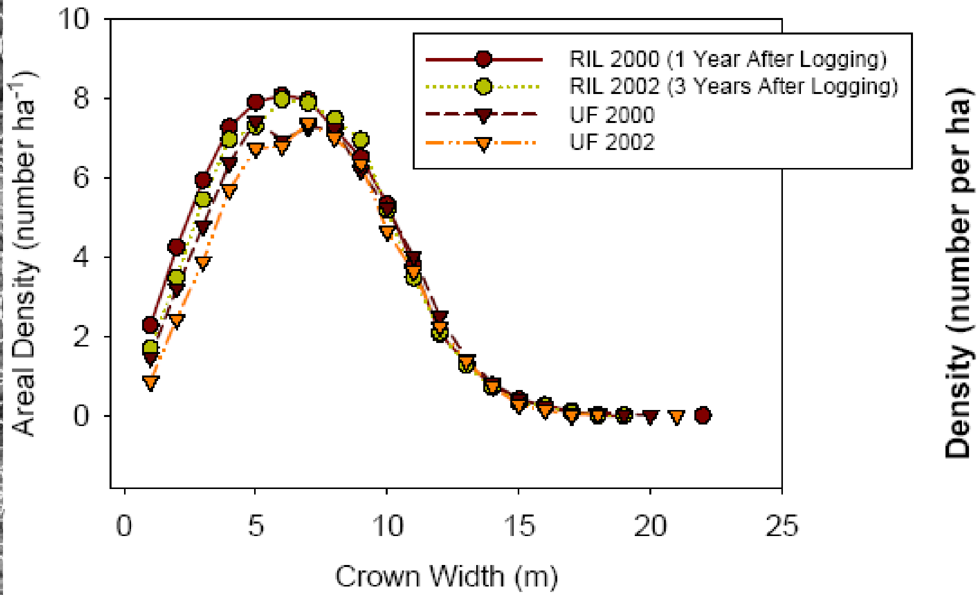


Figure 5. Comparison of Crown distribution derived from an automated crown detection algorithm. Two areas from two IKONOS images.

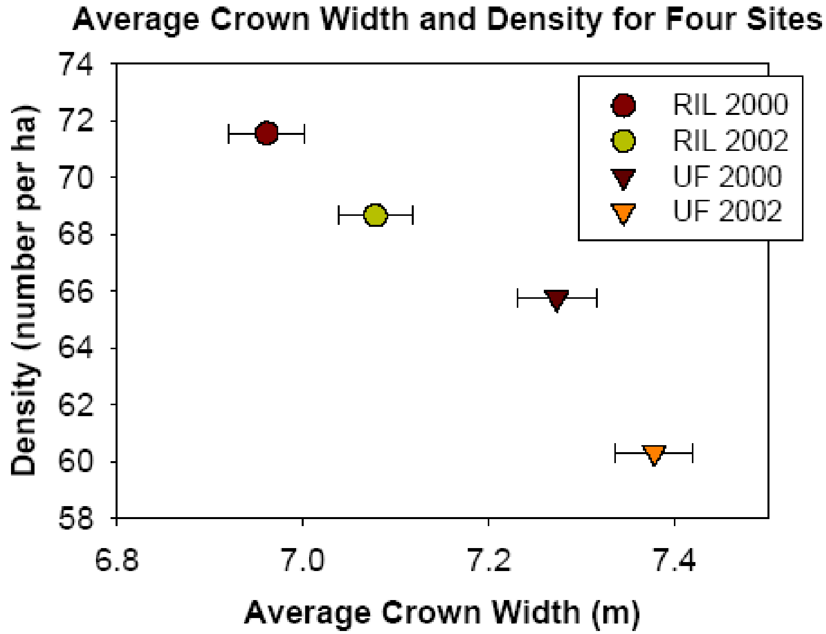


Figure 6. Comparison of average crown width and areal density derived from an automated crown detection algorithm. Two areas from two IKONOS images.

Michael Palace[1,4], **Michael Keller**[1,2], **Gregory P. Asner**[3], **Stephen Hagen**[1], and **Bobby Braswell**[1]

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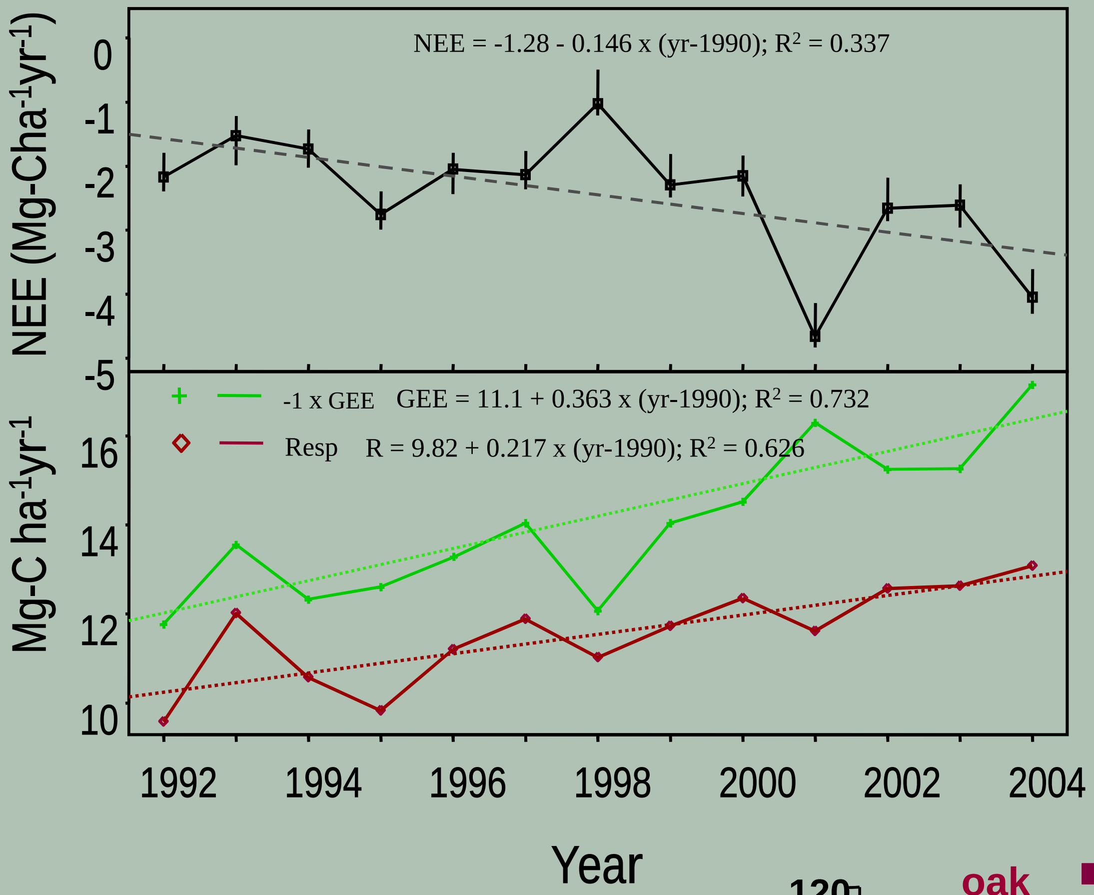
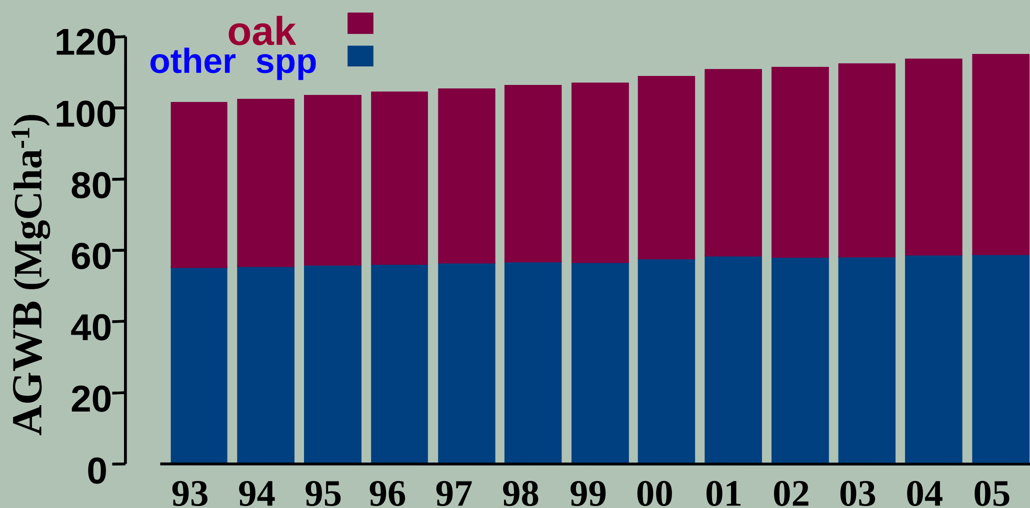


Harvard Forest is 80-110 years old. It's rate of carbon uptake has accelerated over the last 15 years (a big surprise) …

…due to changes in the forest structure.

Drivers for this change ?



Structured Biosphere Models

The importance of fine-scale vegetation structure in determining current and future ecosystem function presents a strong rationale for the development of structured biosphere models

Advantages:

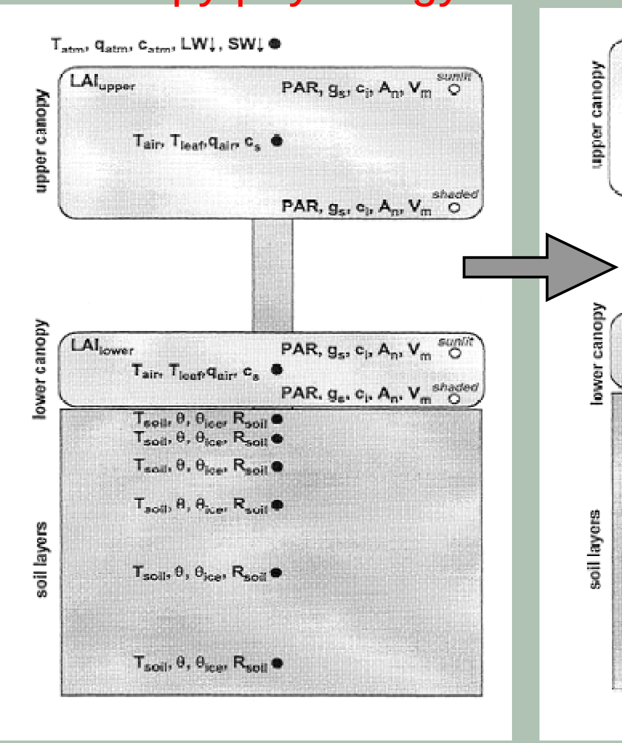
- theoretical considerations: capturing the long-term, large scale response of heterogeneous plant canopies

- parameterization: connecting terrestrial biosphere models to field-based measurements of ecosystem composition, structure & function.

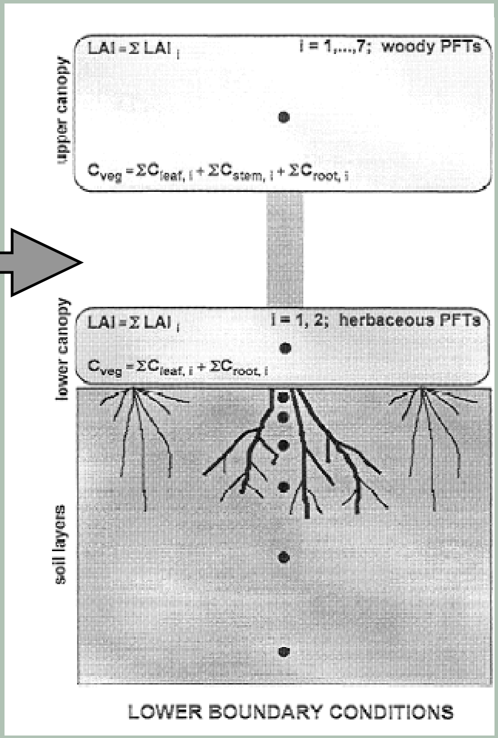
Current terrestrial biosphere models are "big leaf" models

- predict unrealistic long-term ecosystem dynamics

canopy physiology

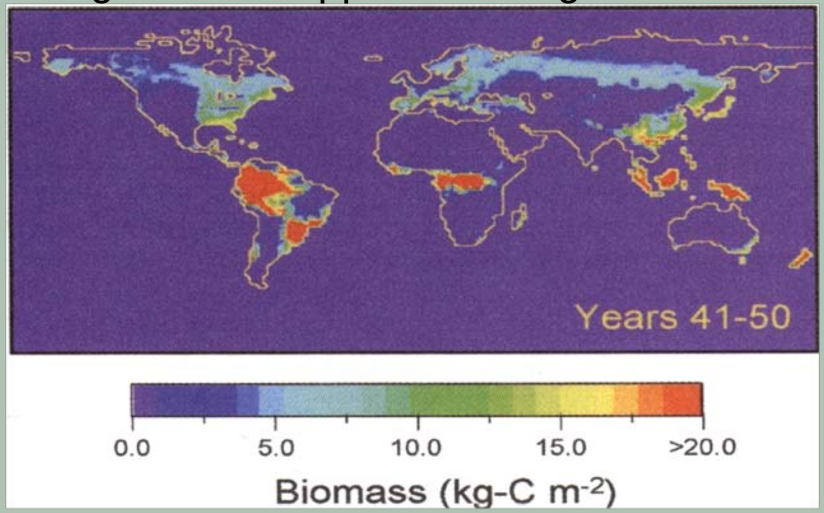


ecosystem dynamics

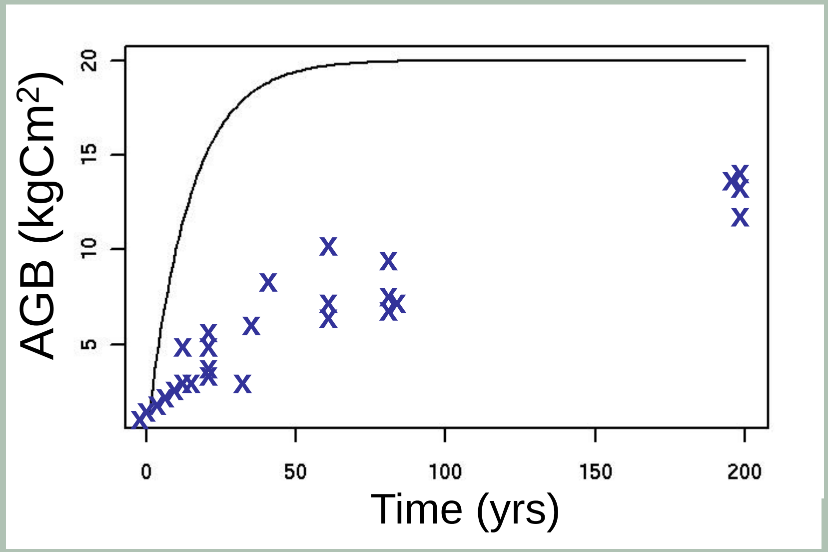


scale: 1º x 1º (~10^4 km^2)

e.g.: above-ground biomass dynamics of evergreen tree spp. in IBiS big leaf model

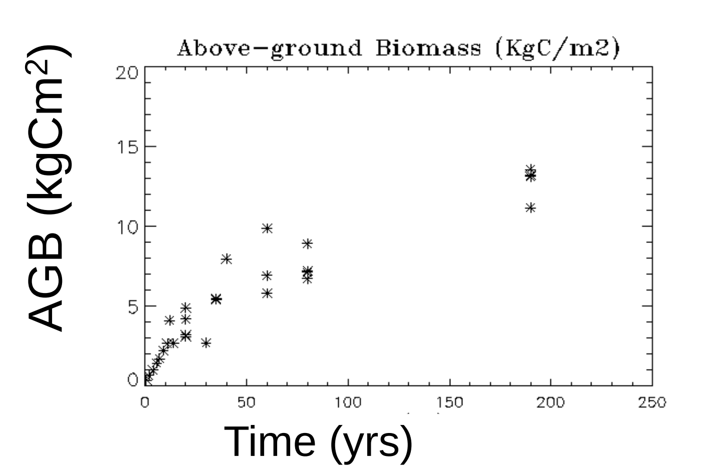


Comparison of above-ground biomass dynamics to observations at San Carlos (tropical forest) 2ºN,68ºW --->



(Saldarriaga. et al 1988)

San Carlos successional dynamics



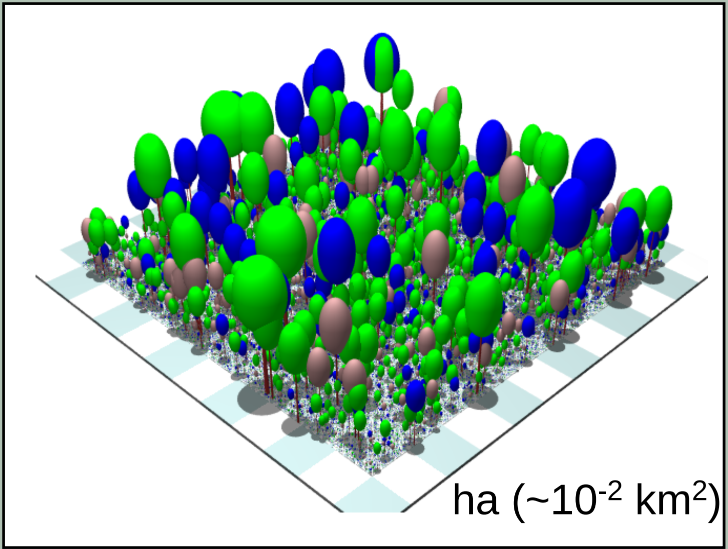
Stand Age (0-200yrs) -->

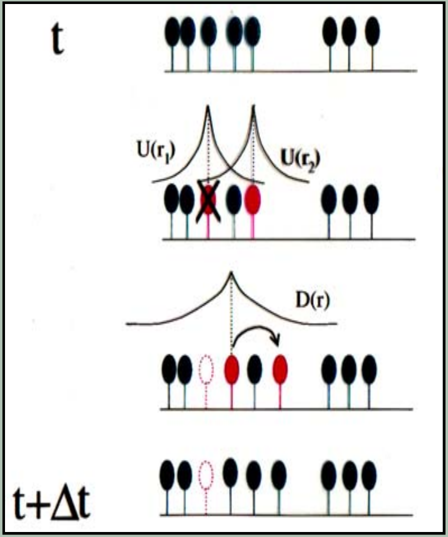
Species --->

Species	Stand number																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Vismia japurensis Reich	33	32		27		11																	
Cecropia sp.	26	15																					
Bellucia grossularioides (L.) Triana		21	21	33					16		18												
Ocotea opifera Martius			15					9															
Unidentified species (Bombacaceae)			13																				
Vochysia sp.					21												6		11				
Sclerolobium sp.					13			6										10					
Goupia glabra Aublet					11				20	12	12		18	14	15			14	7				
Vismia lauriformis cf. (Lam.) Choisy					8		13																
Inga sdp.						11		6											6				
Astrocaryum sp.						10	27			6								6					
Guatteria schomburgkiana Martius						6			10														
Alchornea sp.						5		7						5	15	8		6					
Myrcia bracteata (Rich.) D.C.							12																
Unidentified species								13															
Bellucia sp.								8			7							8					
Ormosia emeraldana Moldenke ex Gleas.									8														
Eperua purpurea Bentham										24		13		5					23	22			
Humiria balsamifera (Aublet) St. Hil.										12	17	40	36						7				
Vochysia obscura Warming														9	7	12	15						
Jacaranda copaia (Aublet) D. Don														8									
Aspidosperma sp.														6			13						
Monopteryx uaucu Spruce ex Bentham														5									
Conceveiba guianensis Aublet															7	13						5	
Ocotea sp.															5							6	
Unidentified species (Arecaceae)																12							
Protium sp.																8		6			18		10
Poraqueiba sericea Tul.																	13						
Unidentified species																				11			
Caryocar glabrum (Aublet) Pers.																				9			
Micrandra sprucei (Muell.-Ar.) Schultes																				8			
Mouriri uncitheca Morley Wurdack																				6			
Unidentified species																				5			
Virola surinamensis (Rolander) Warb.																				5			
Dialium guianensis (Aublet) Sandw.																				4			
Xylopia spruceana Bentham																				4			
Eschweilera sp.																					10		
Swartzia schomburgkii Bentham in Martius																						15	19
Jessenia bataua (Mart.) Burret																						9	
Unidentified species																						7	
Unidentified species (Sapotaceae)																						6	
Iryanthera sp.																						4	
Cedrelinga sp.																							15
Virola calophylla (Spruce) Warb.																							8

(Moorcroft et al. 2001)

Individual-based vegetation models (gap models)





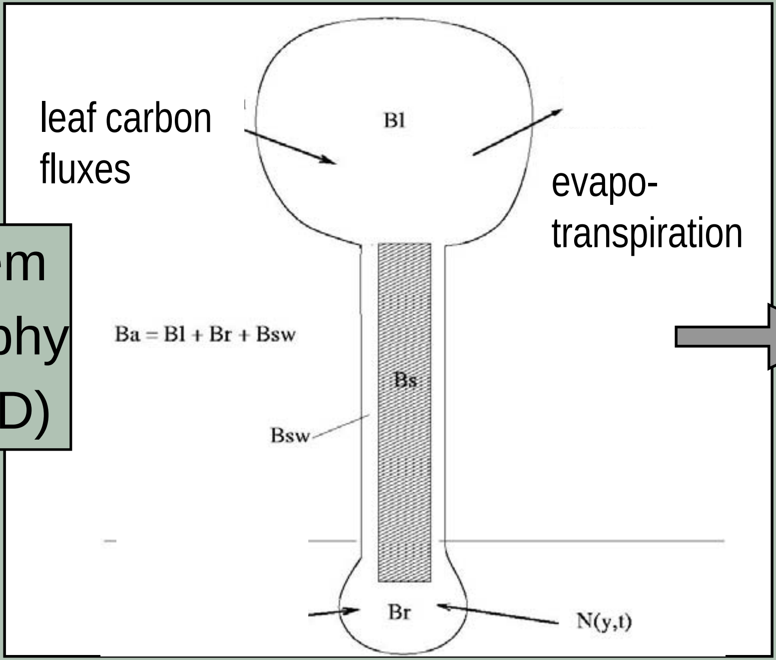
growth

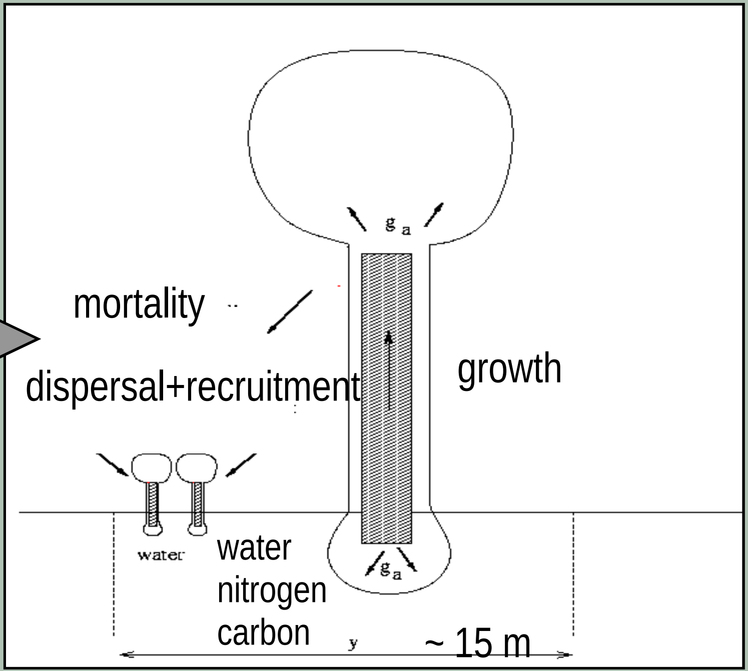
height-structured competition

mortality

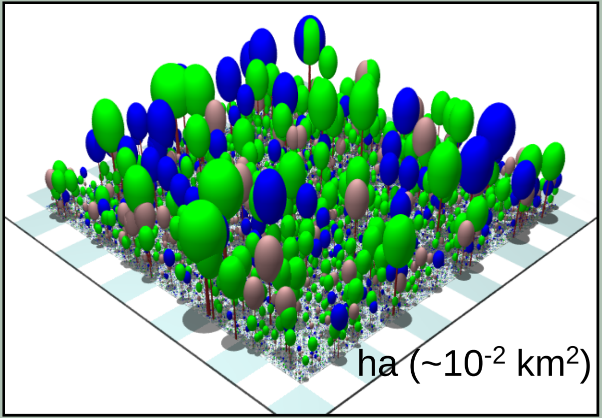
dispersal + recruitment

Ecosystem Demography Model (ED)

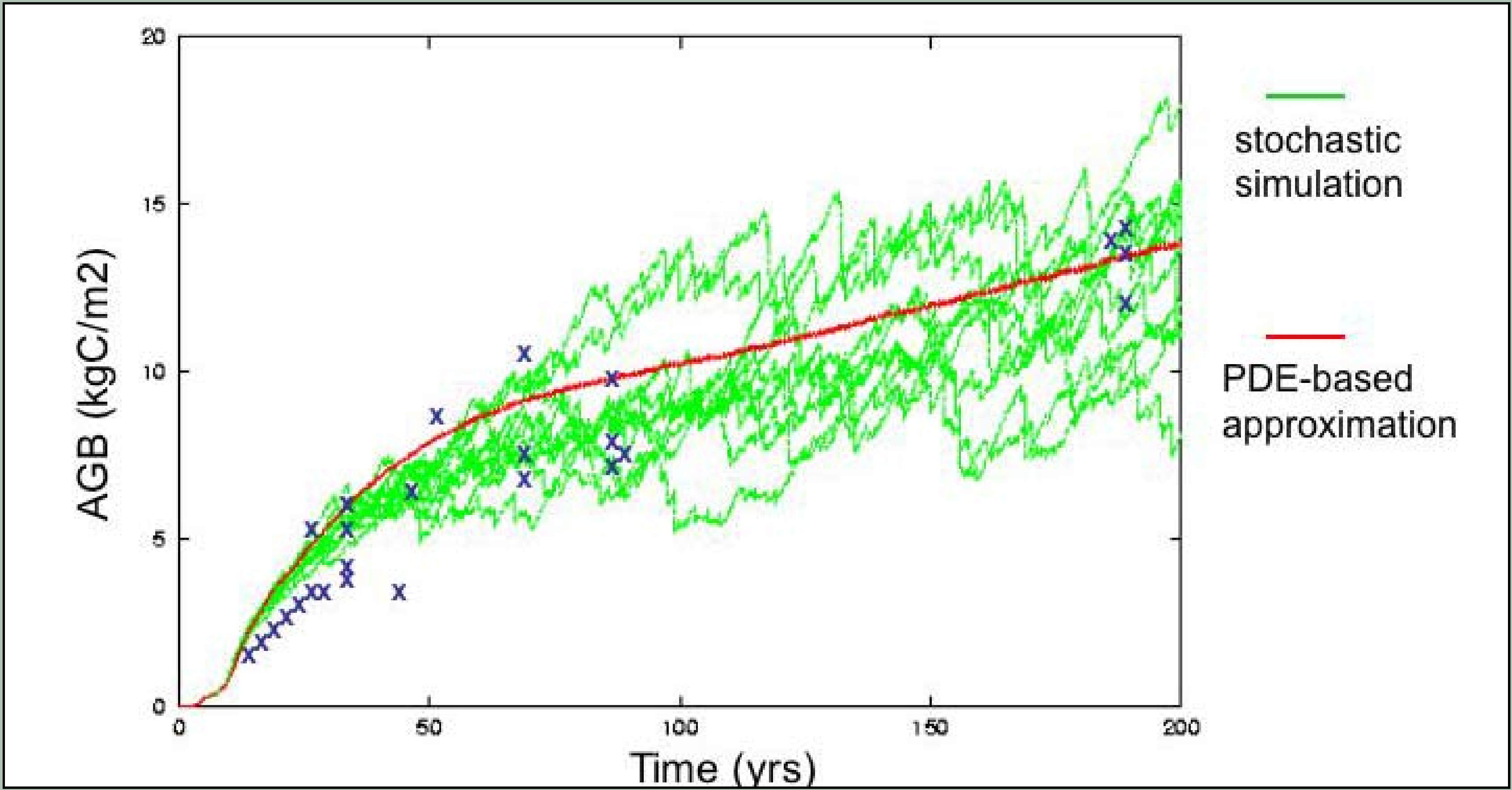




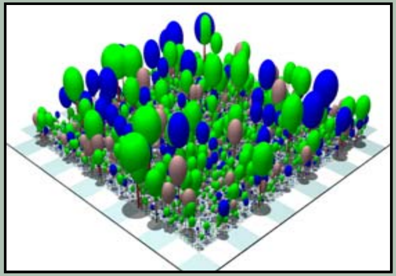
(Moorcroft et al. 2001)



ED dynamics at San Carlos Tropical forest ($2^oN, 68^oW$): trajectory of above-ground biomass:



(Moorcroft et al. 2001)



“Ecological Statistical Mechanics”

- a size & age-structured terrestrial biosphere model
- accurately captures the behavior of corresponding individual-based model by tracking the dynamic horizontal & vertical sub-grid scale heterogeneity in canopy structure.

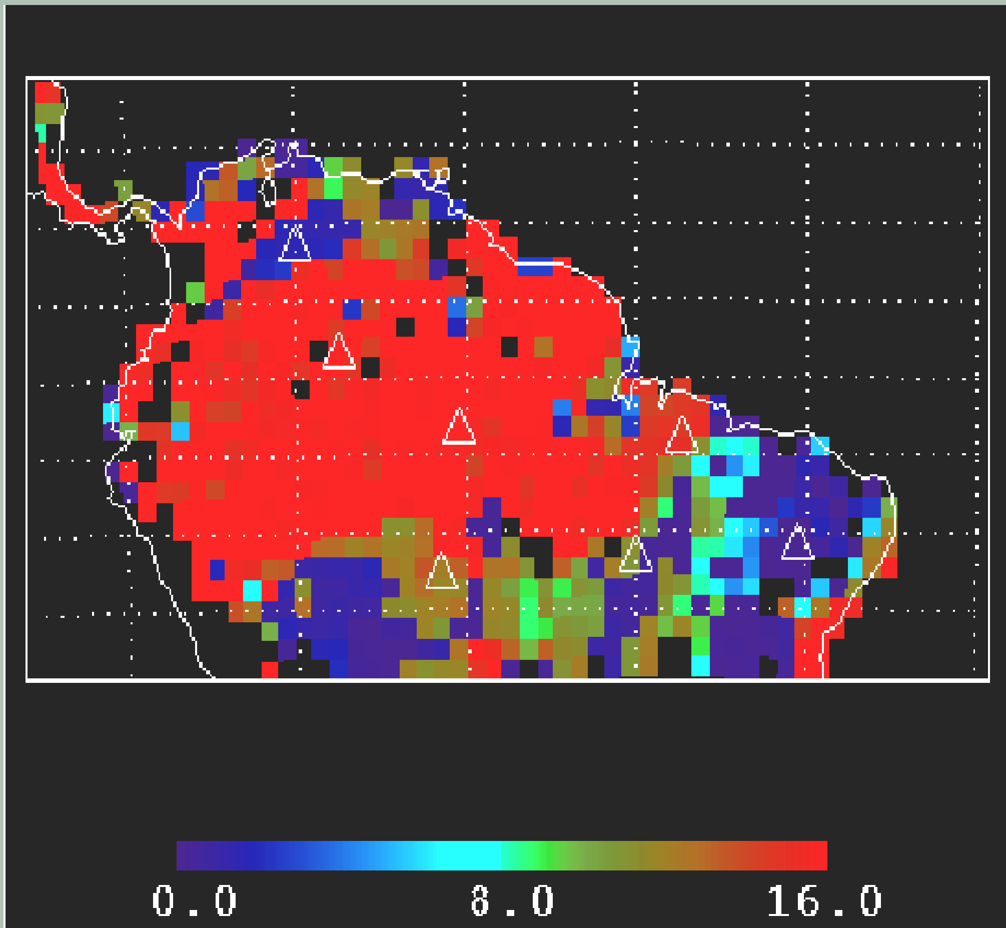
$$\underbrace{\frac{\partial}{\partial t} C_i(z,a,t)}_{\substack{\text{ch. in biomass} \\ \text{of plant type i}}} = -\frac{\partial}{\partial z}\underbrace{\left[g_i(z,\underline{\bar{r}},t)C_i(z,a,t)\right]}_{\text{growth}} - \underbrace{\frac{\partial}{\partial a} C_i(z,a,t)}_{\text{aging}} - \underbrace{\mu_i(z,\underline{\bar{r}},t)C_i(z,a,t)}_{\text{mortality}}.$$

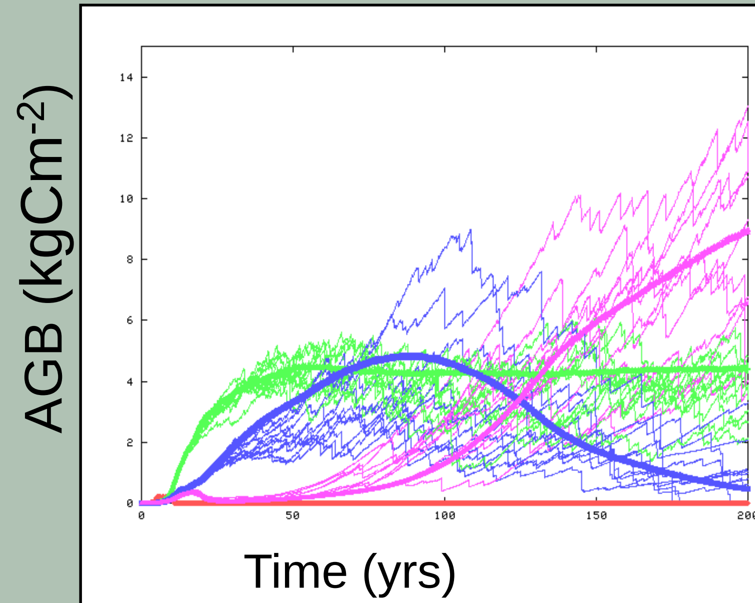
(recruitment is a lower boundary condition in z)

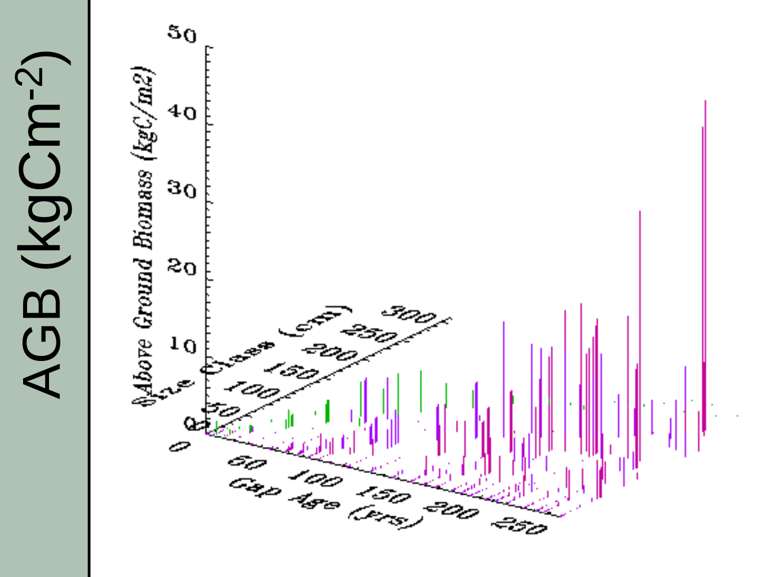
$$\underbrace{\frac{\partial}{\partial t} p(a,t)}_{\text{ch. in landscape age distribution}} = \underbrace{-\frac{\partial}{\partial a} p(a,t)}_{\text{aging}} - \underbrace{\lambda(a,t)p(a,t)}_{\text{disturbance}}, \qquad \int_0^\infty p(a,t)\,da = 1.$$

(Moorcroft et al. 2001)

ED Model: Regional pattern of above-ground biomass (AGB) after 200 year simulation ($kgCm^{-2}$)



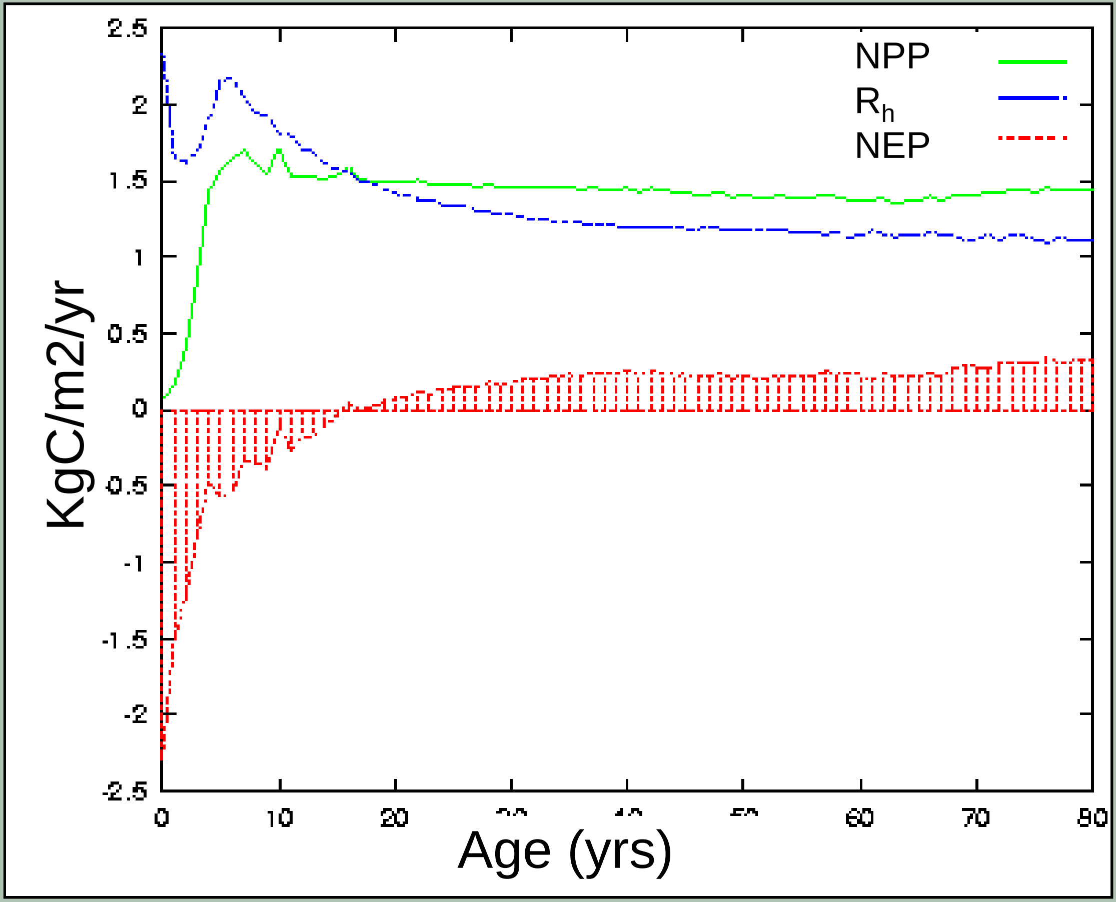




Carbon Fluxes at Manaus (2^{o}S,61^{o}W)

-grid-scale Net Ecosystem Productivity (NEP) after 200-yr simulation is near zero.

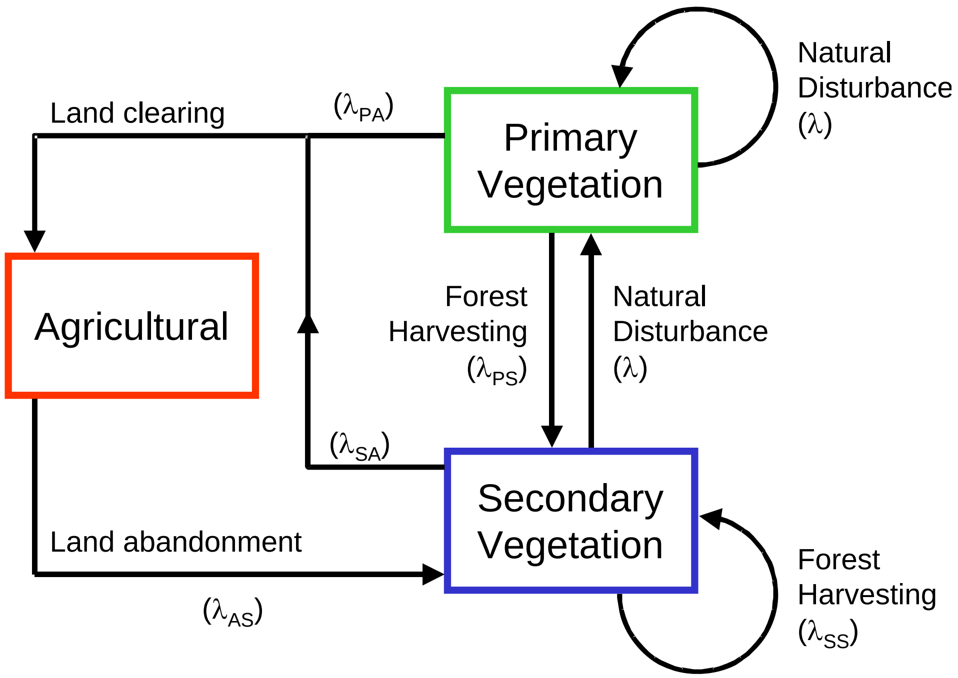
- sub-grid scale pattern of carbon-fluxes:



Albani et al. 2006

Incorporating land-use change

$$\underbrace{\frac{\partial}{\partial t}\underline{p}(a,t)}_{\text{ch. in land class \& age distribution}} = \underbrace{-\frac{\partial}{\partial a}\underline{p}(a,t)}_{\text{aging}} - \underbrace{\mathbf{\Lambda}(a,t)\underline{p}(a,t)}_{\text{disturbance}},$$



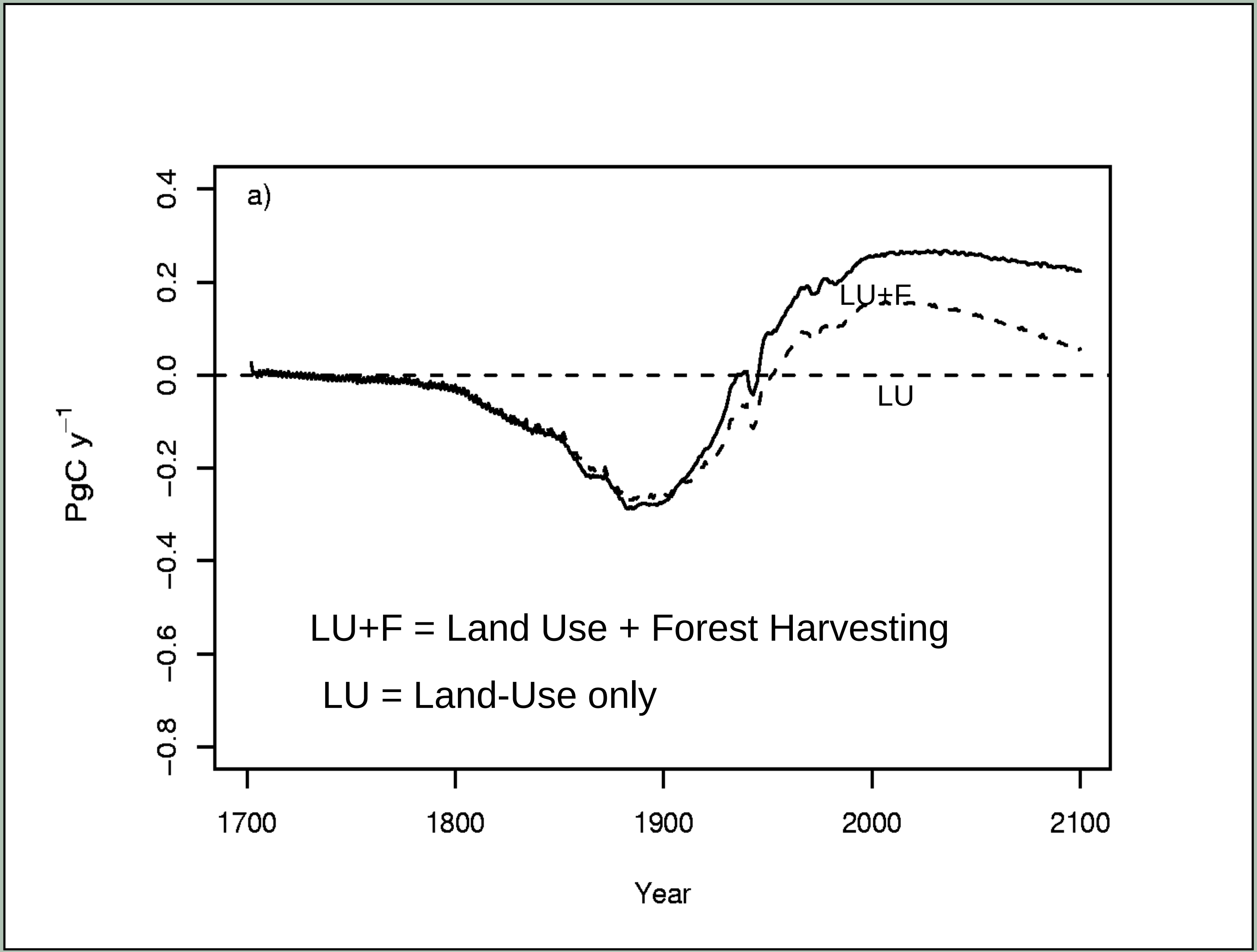
$$\mathbf{\Lambda}(a,t) = \begin{pmatrix} \lambda & \lambda & 0 \\ \lambda_{PS} & \lambda_{SS} & \lambda_{AS} \\ \lambda_{PA} & \lambda_{SA} & 0 \end{pmatrix}$$

$$\underbrace{\underline{p}(0,t) = \sum_{j=1}^{n_{dist}} \int_0^{\infty} \lambda(a,t)p_j(a,t)da.}_{\text{formation of newly disturbed areas}}$$

historical fraction of agricultural land in each county 1800-2100

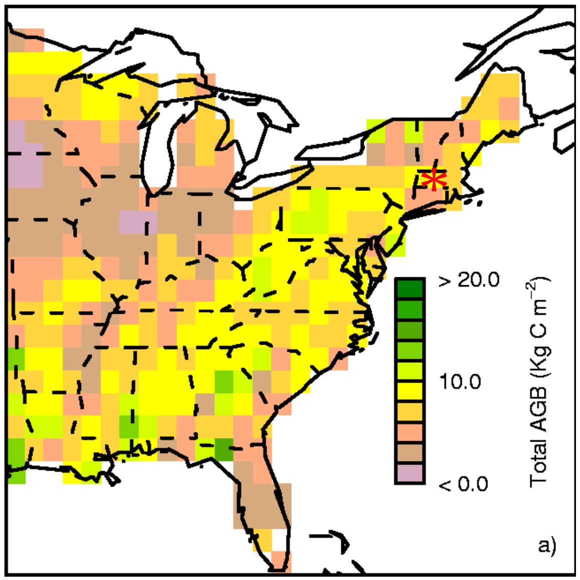
regional Historical Patterns of Forest Harvesting (USFS)

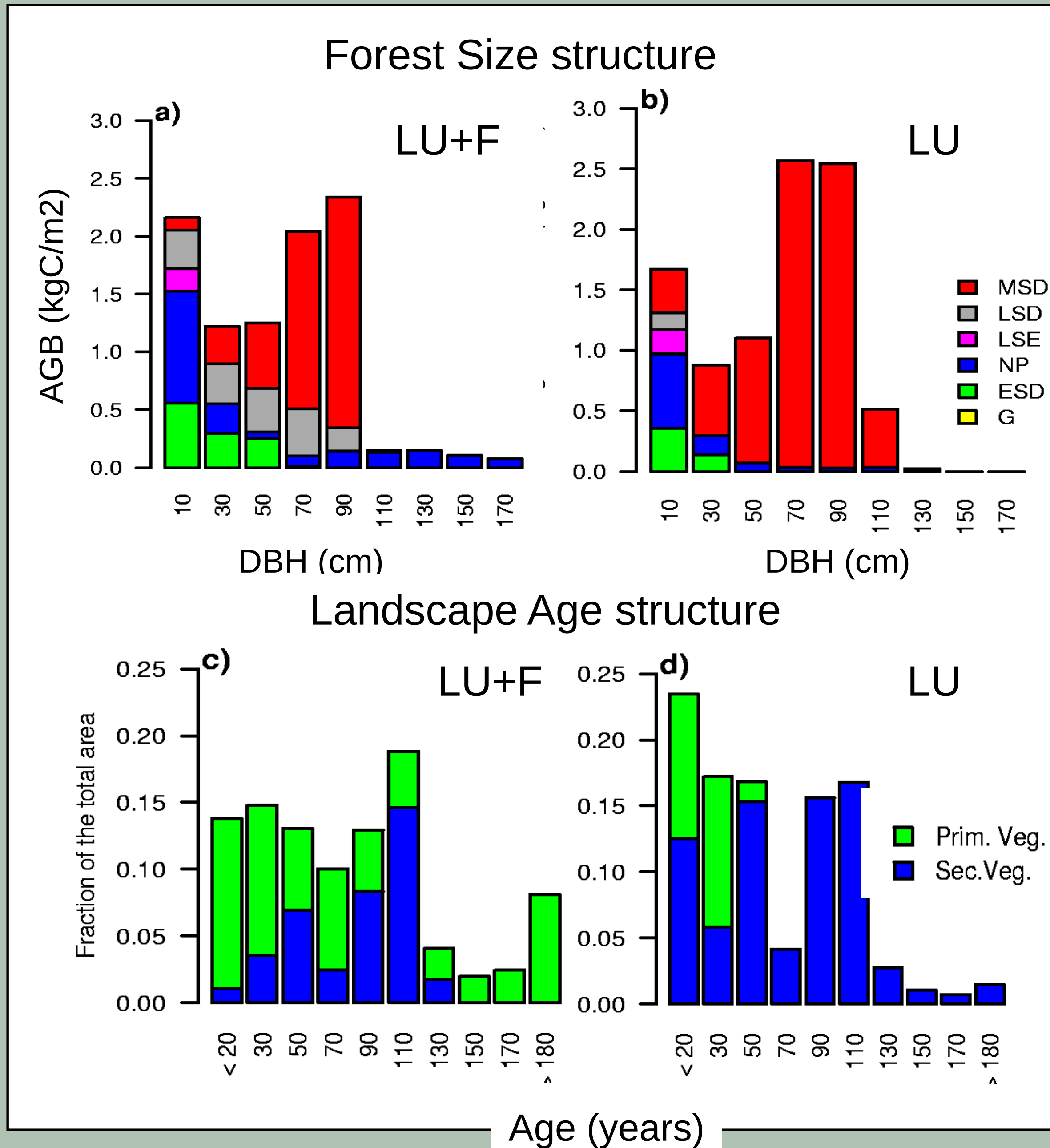
USA: Predicted Pattern of Regional Carbon Uptake



Predicted present day forest structure (72^{o}N,42^{o}W)

Above-ground biomass (kgC m^{2})





Summary

in contrast to traditional ‘big-leaf’ models, structured biosphere models such as the Ecosystem Demography (ED) model scale formally between fast-timescale plant-level physiological responses to climate and long-term, large-scale, ecosystem dynamics.

Enables them to:

- have both realistic short-term and long-term vegetation dynamics.
- incorporate the effects of anthropogenic sub-grid scale disturbances (land clearing, land abandonment and forest harvesting) on ecosystem composition, structure & function.

In addition, since structured biosphere models such as ED are formulated at scale individual plants, they can be successfully parameterized & tested against measurements of ecosystem structure and performance (e.g. Medvigy et al. 2008)

Conclusions

Vegetation structure is a key indicator of ecosystem state (the successional status of an ecosystem)

- 2 important and distinct metrics of vegetation structure are canopy height and canopy biomass; others could be crown area and wood density.

Knowing the state of an ecosystem is important because it determines both its current biogeochemical & biophysical status and its future trajectory.

Acknowledgements

Collaborators: Bill Munger, Marco Albani & David Medvigy

References:

Moorcroft *et a l*. 2001. *Ecological Monographs*, 74:557-586.
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Medvigy et al. 2005. *Env. Fluid Mechanics* 4
Albani & Moorcroft (2005) *Global Change Biology* (accepted).
Moorcroft (2006) Trends in Ecology and Evolution (in press)
Medvigy & Moorcroft (2006) *(in prep).*

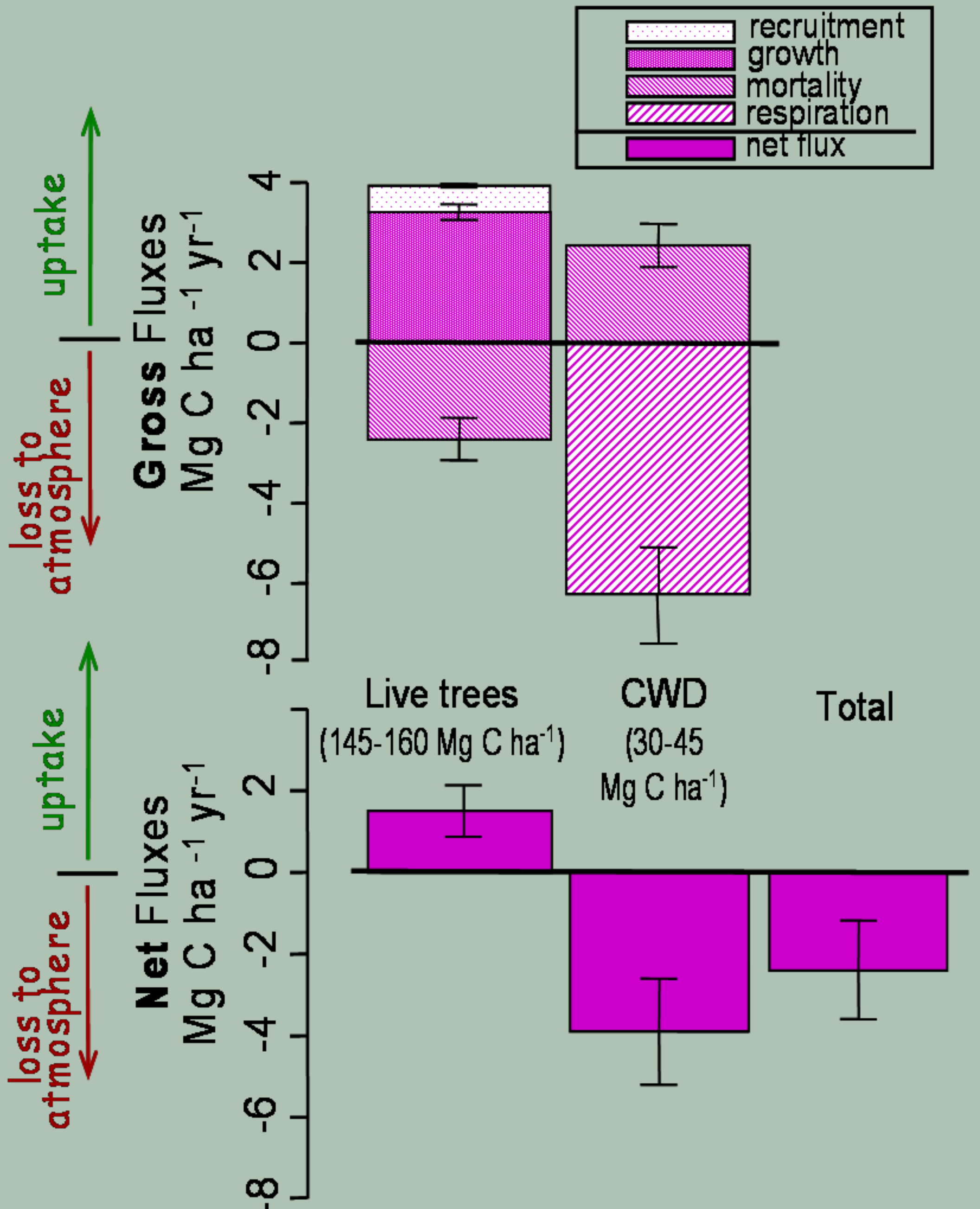
Funding: National Aeronautical and Space Administration , National Science Foundation, Department of Energy (NIGEC/NICCR).

Carbon fluxes in the Tapajós (km 67).

Gross carbon fluxes

Net carbon fluxes

=> Net aboveground losses are driven by decomposition from the large stock of CWD.



Predicted impacts of land-use history on the carbon dynamics of the Eastern US

above gnd. biomass (tC ha^{-1}) carbon uptake (NEP, tC ha^{-1} y^{-1}) land use