Amazon Carbon fluxes: seasonality, interannual variability, and the future under climate change.

---

or, what we learned from LBA (using flux towers, remote sensing, and modeling)

Flux tower and ground measuring teams: Otavio Acevado, Alessandro Araujo, Laura Simone Borma, Plinio Camargo, David Fitzjarrald, Mike Goulden, Lucy Hutyra, Bart Kruijt, Jair Mair, Yadvinder Malhi, Antonio Manzi, Scott Miller, Bill Munger, Antonio Nobre, Natalia Restrepo-Coupe, Humberto da Rocha, Leonardo Sa, Ricardo Sakai, Scott Saleska, Alexandre Santos, Julio Tota, Celso von Randow, Steven Wofsy

Remote Sensing groups: Alfredo Huete, Kamel Didan, Piya Ratana, Yosio Shimabukuro, Dalton Valeriano,

Modeling teams (from LBA Model Intercomparison Project workshop): Ian Baker, Marcos Costa, Brad Christoffersen, Scott Denning, David Galbraith, Gustavo Goncalves, Lindsey Gulden, Margriet Groenendijk, Steven Klooster, Hewlley Imbuzeiro, Chris Potter, Ben Poulter, Enrique Rosero, Jim Shuttleworth, Pedro Silva Dias

1. Seasonality of Ecosystem Metabolism
2. Biome transitions and land-use change
3. Ecosystem resilience and the future of the Amazon

1. What is the seasonality of ecosystem metabolism in Amazônia?

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- Previous answer: photosynthesis and/or transpiration decline in dry seasons:

Climate and/or ecosystem models

Dickenson & Henderson-Sellars (1988)
Nobre et al. (1991)
Tian et al. (1998) [TEM]
Botta et al. (2002) [IBIS]
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- LBA produced a suite of evidence suggesting a different picture:

  Amazonian ecosystems are not water-limited (at least over seasonal timescales) but are driven by available energy and sunlight

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Amazonian ecosystems are not water-limited (at least over seasonal timescales) but are driven by available energy and sunlight

Three independent lines of evidence:

(a) Flux towers

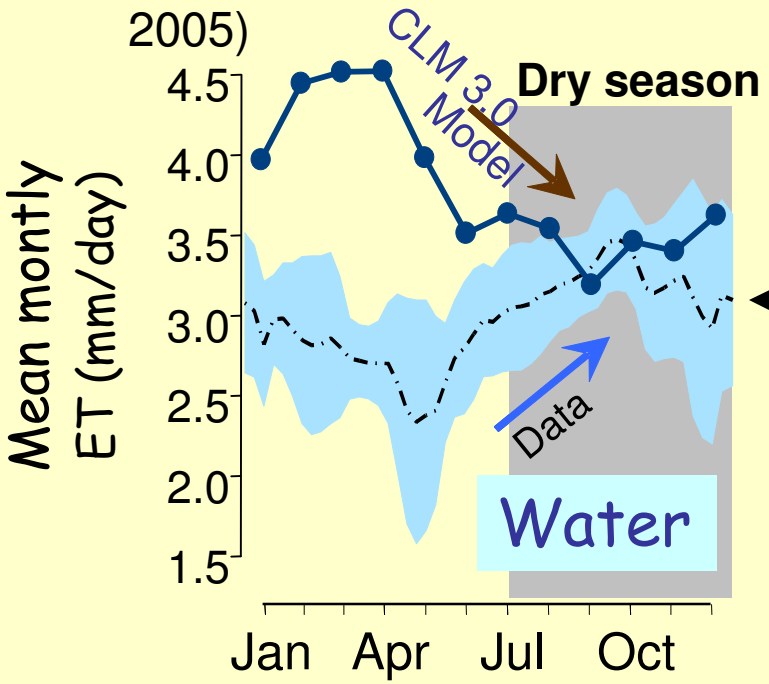
(b) Remote sensing from satellites

(c) Aircraft campaigns

Measurements *falsify* model predictions for *seasonal* time-scales

Local Scale (Tapajos eddy tower, near Santarém, 2002-2005)

Hutyra et al., 2007



ET = Evapotranspiration

Mean ± SD across 4 years of measurements

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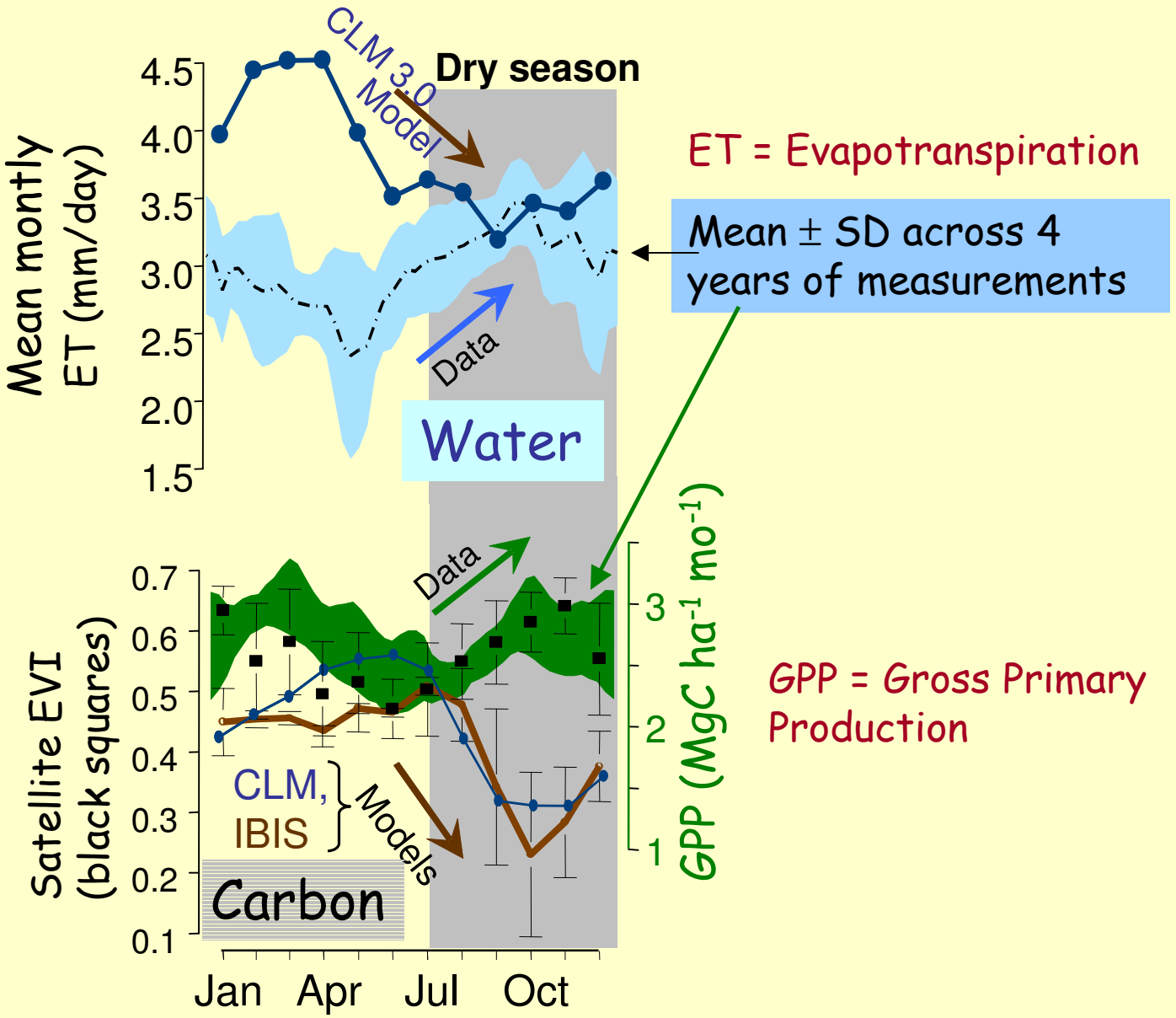

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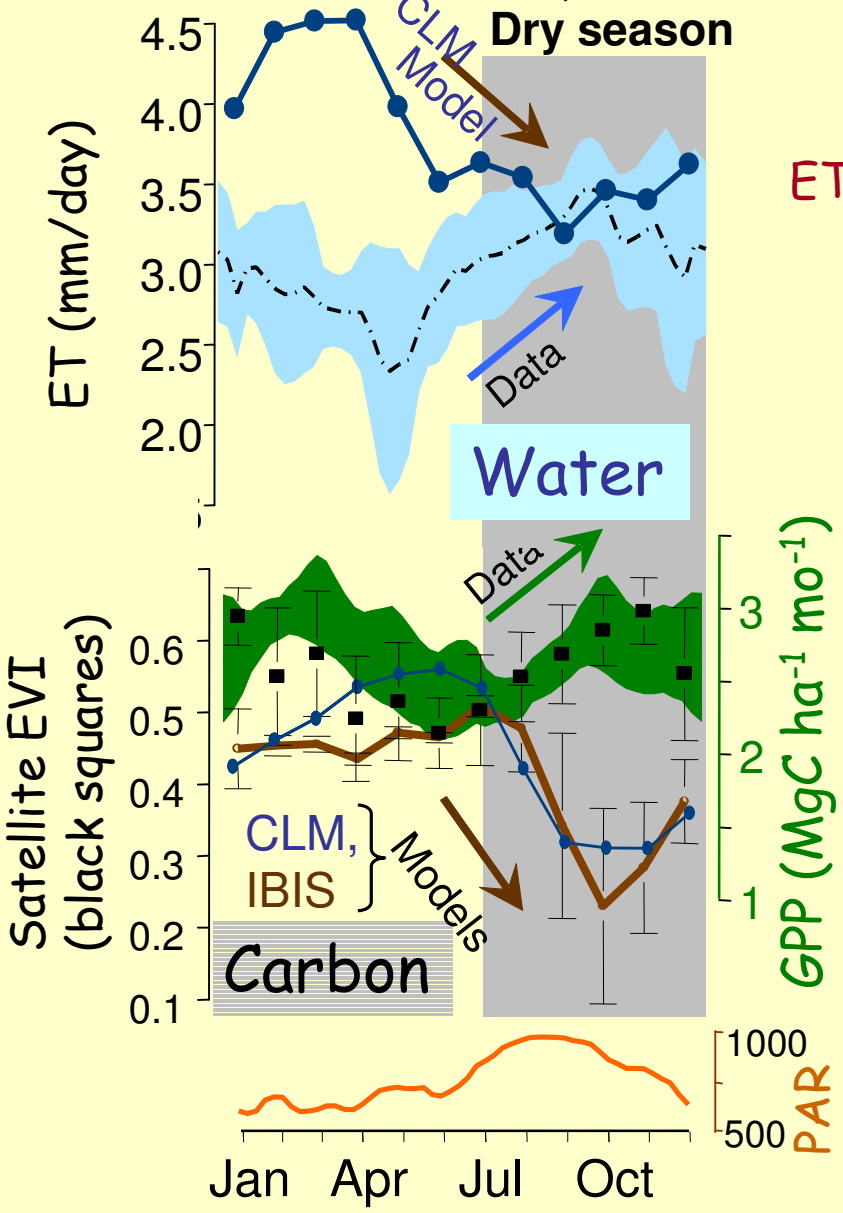

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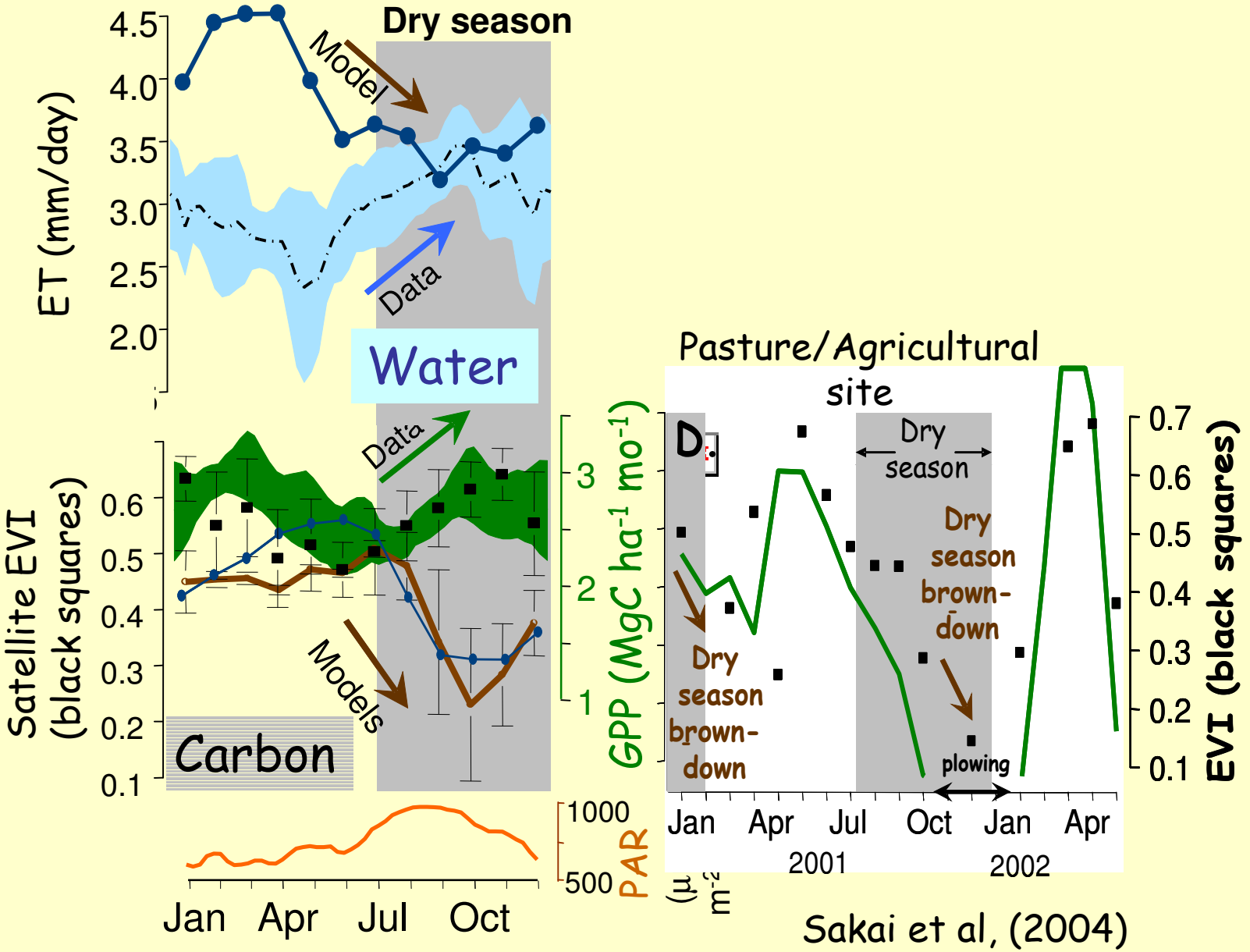
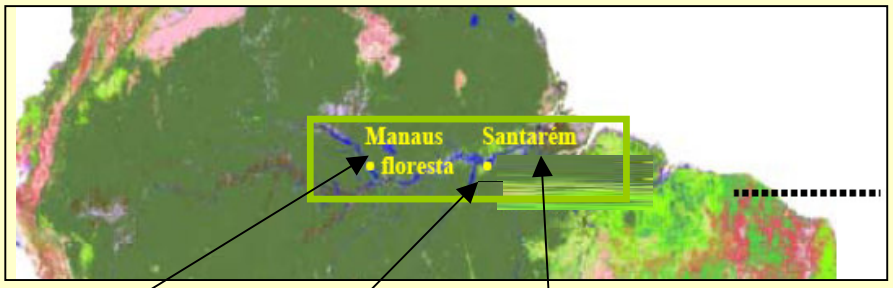
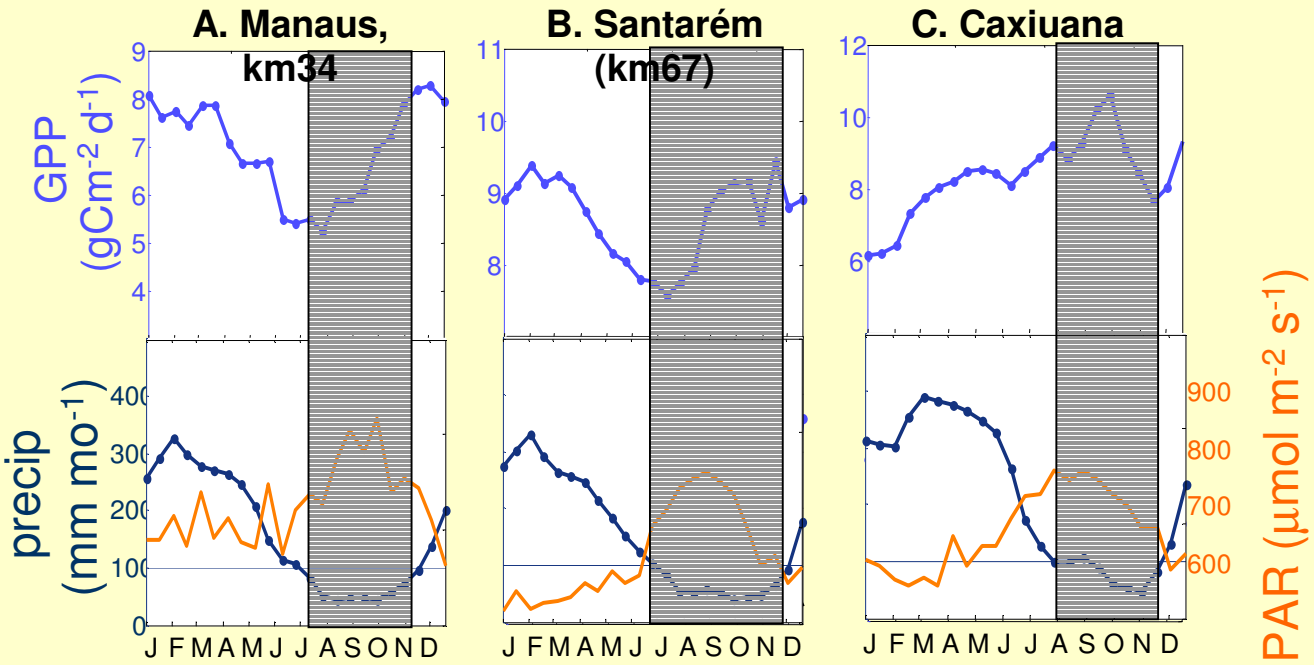


Sakai et al, (2004)

Measurements across the basin

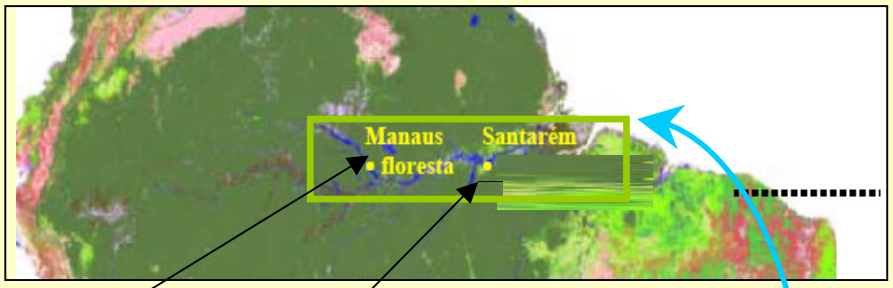


Eddy Flux towers…



Restrepo-Coupe, in prep.
(and Araujo et al. (2002) Manaus)

Measurements across the basin



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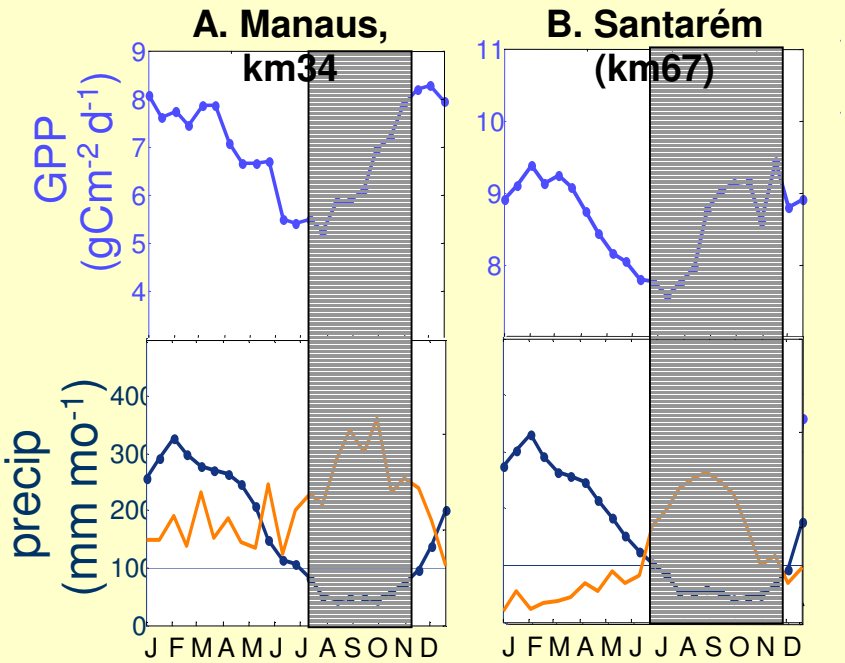
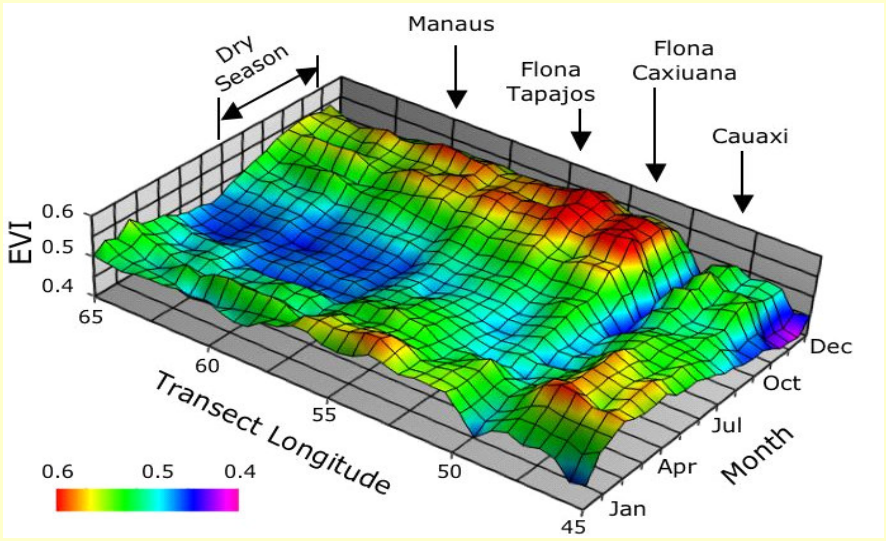
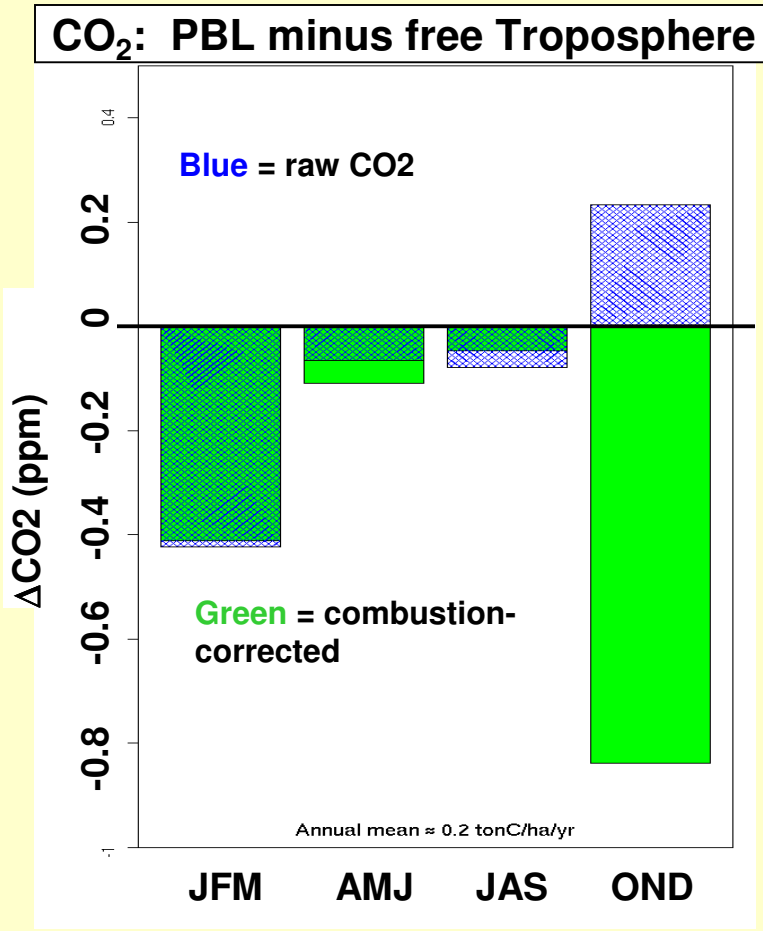


Remote Sensing (MODIS EVI)

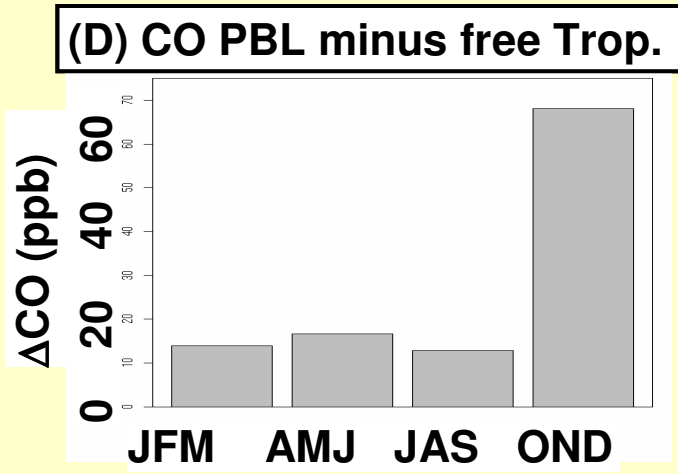


Huete et al. (2006)

Aircraft campaigns measuring atmospheric trace gases give integrated fluxes over large area (Santarém flights)



CO_2 fluxes adjusted for biomass-burning emissions using CO as a tracer:



Wofsy, Vanni Gatti, Miller
(see talk by Vanni Gatti on Friday)

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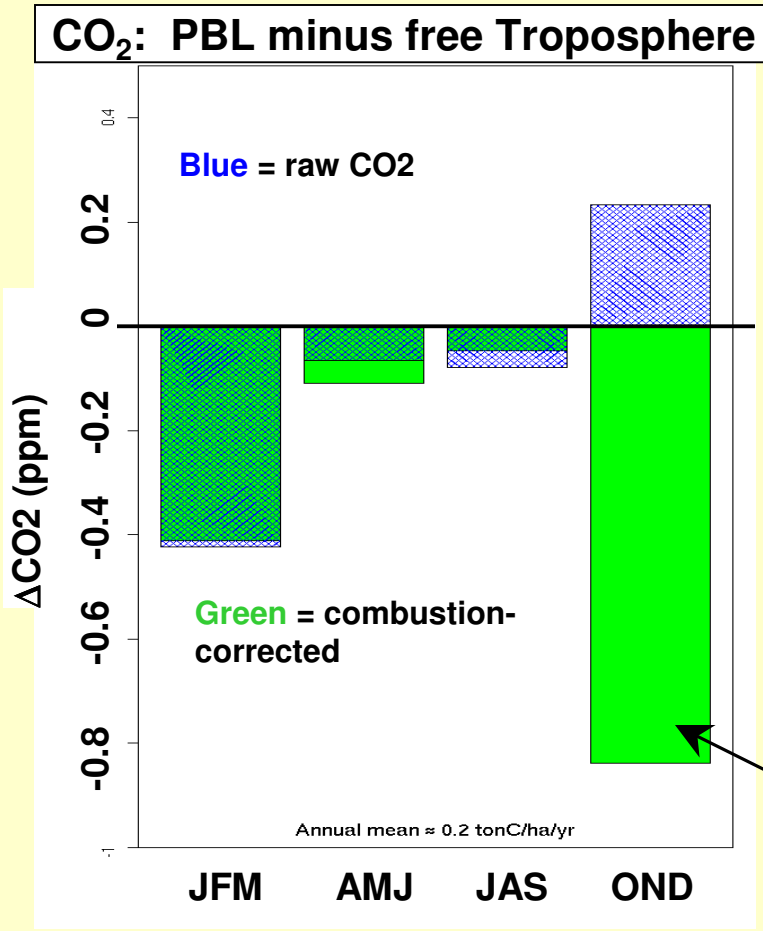

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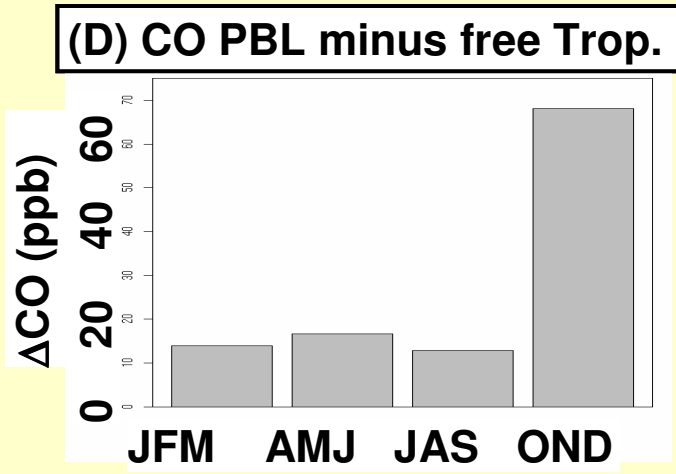

Largest uptake is late in dry season (consistent w. elevated dry-season photosynthesis)

Wofsy, Vanni Gatti, Miller
(see talk by Vanni Gatti on Friday)

1. What is the seasonality of ecosystem metabolism in Amazônia?

Getting the models right: Different approaches:

Also: See talks by Enrique Rosero, and
Lindsey Gulden (U. Texas), Josh Fisher (Oxford);
posters by Ian Baker (CSU) and Chris Potter (NASA)

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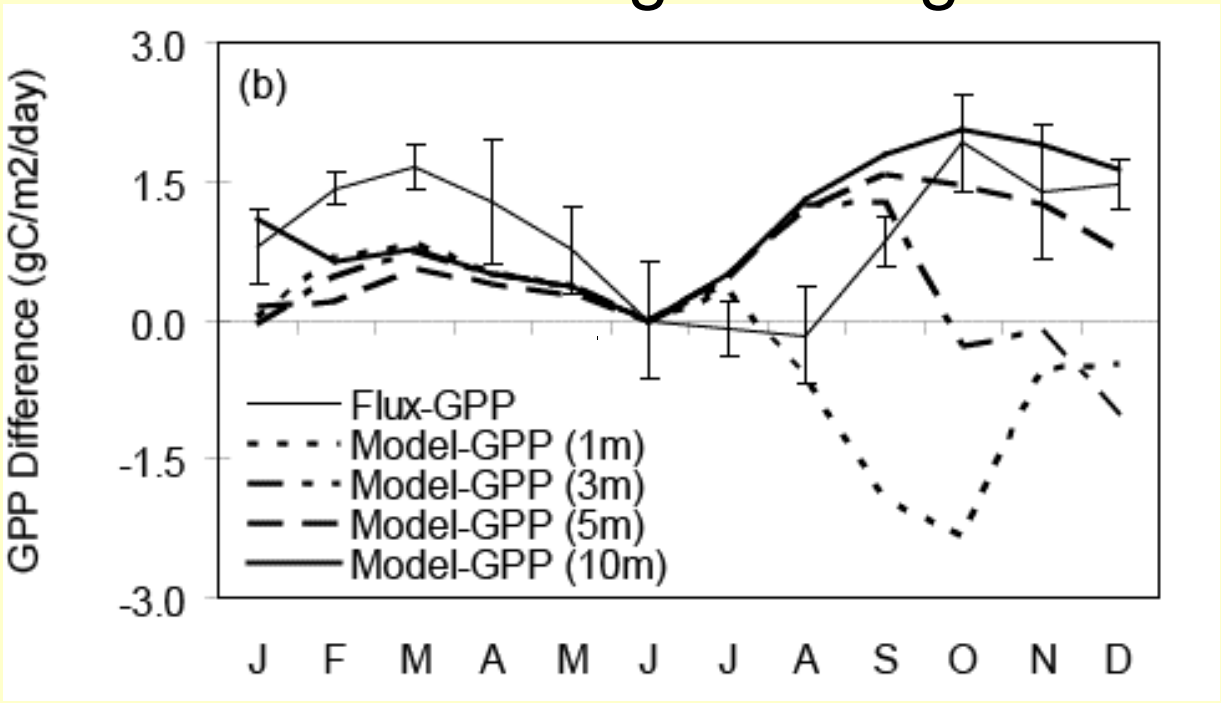

E.g. Biome-BGC with single ("bucket") soil layer.

Ichii et al. (2006)

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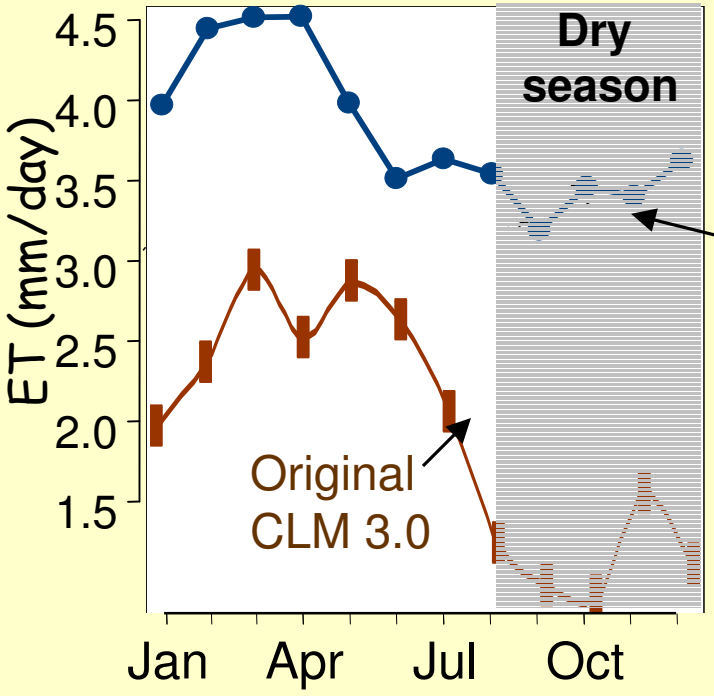

CLM 3.0 with deep roots and hydraulic redistribution (Lee et al, 2005) (Inez Fung)

Tapajos site km67, Santarém

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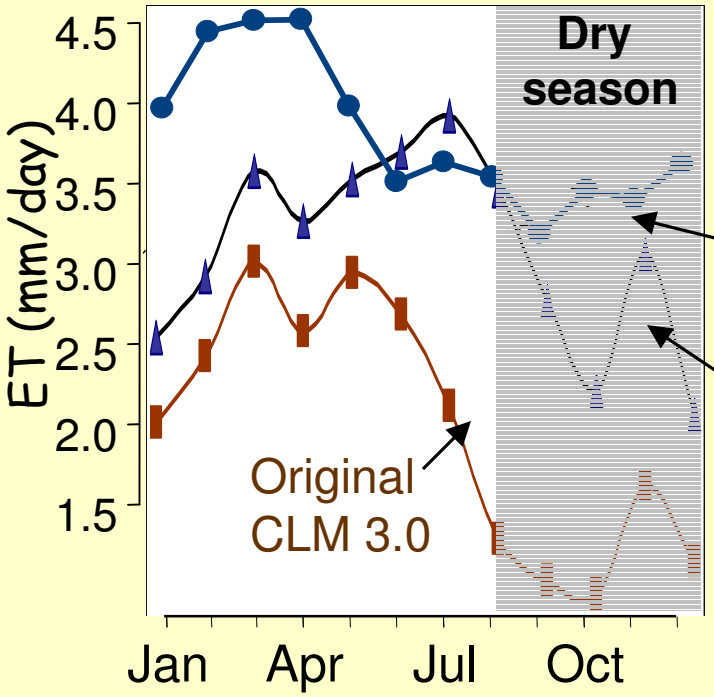


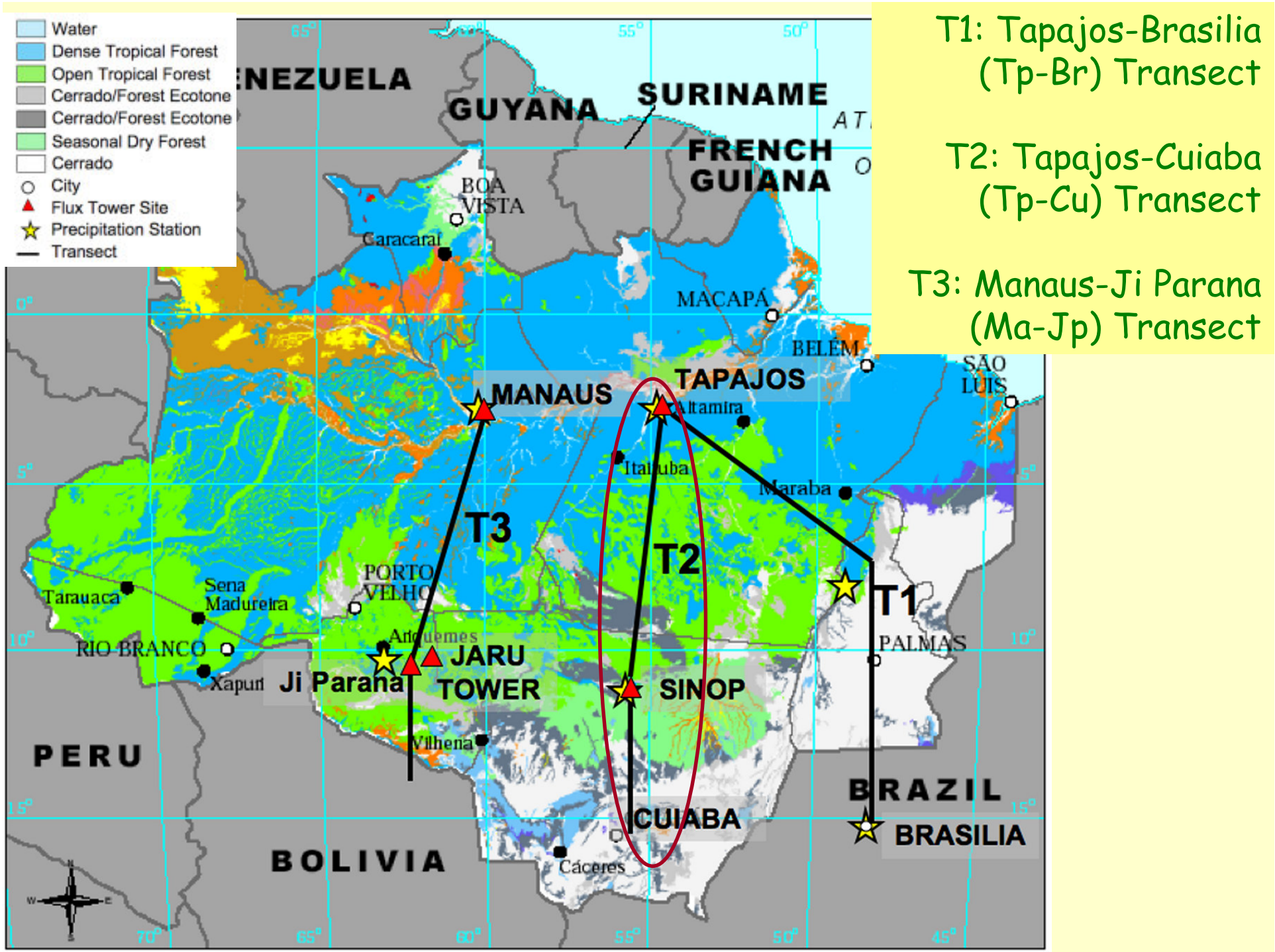
CLM 3.0 with deep roots and hydraulic redistribution (Lee et al, 2005) (Inez Fung)

CLM 3.0 with improved implementation of Richard's Eqn. (Decker & Zeng, 2007)

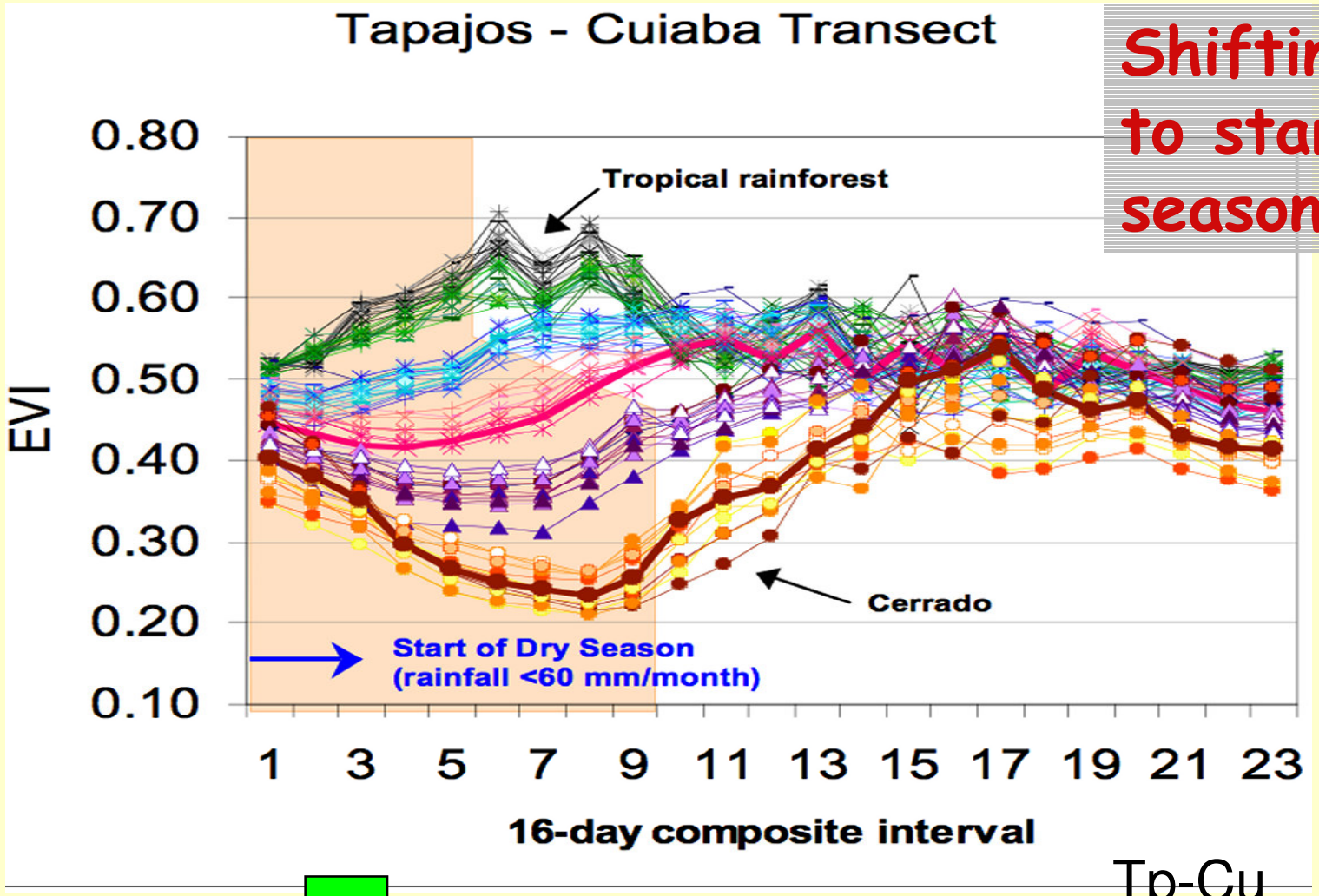
(soil still only 3m deep)

Tapajos site km67, Santarém

2. Effect of Biome transitions and land-use change on carbon fluxes

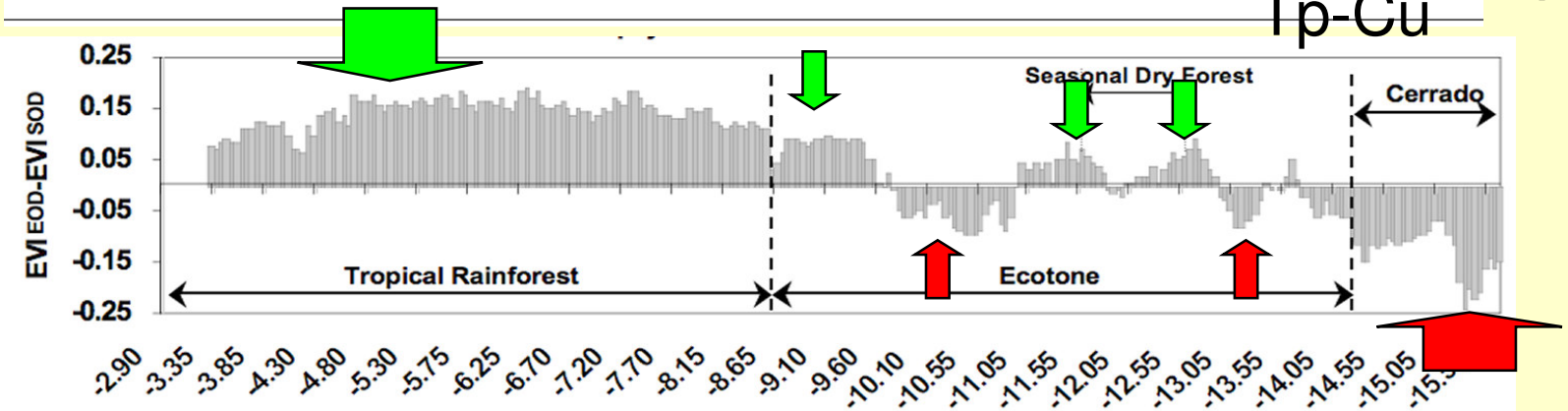

Water
Dense Tropical Forest
Open Tropical Forest
Cerrado/Forest Ecotone
Cerrado/Forest Ecotone
Seasonal Dry Forest
Cerrado
City
Flux Tower Site
Precipitation Station
Transect
T1: Tapajos-Brasilia (Tp-Br) Transect
T2: Tapajos-Cuiaba (Tp-Cu) Transect
T3: Manaus-Ji Parana (Ma-Jp) Transect
GUYANA
SURINAME
FRENCH GUIANA
BOA VISTA
Caracaraí
MACAPÁ
BELÉM
SÃO LUÍS
MANAUS
TAPAJOS
Altamira
Itaituba
Maraba
T3
T2
T1
PORTO VELHO
Sena Madureira
Tarauaca
RIO BRANCO
Xapuri
Ji Parana
JARU TOWER
SINOP
PALMAS
Vilhena
PERU
BRAZIL
CUIABA
BRASILIA
BOLIVIA
Cáceres

Shifting data to start of dry season (SOD)



Ratana, P
Huete, et al

Tp-Cu



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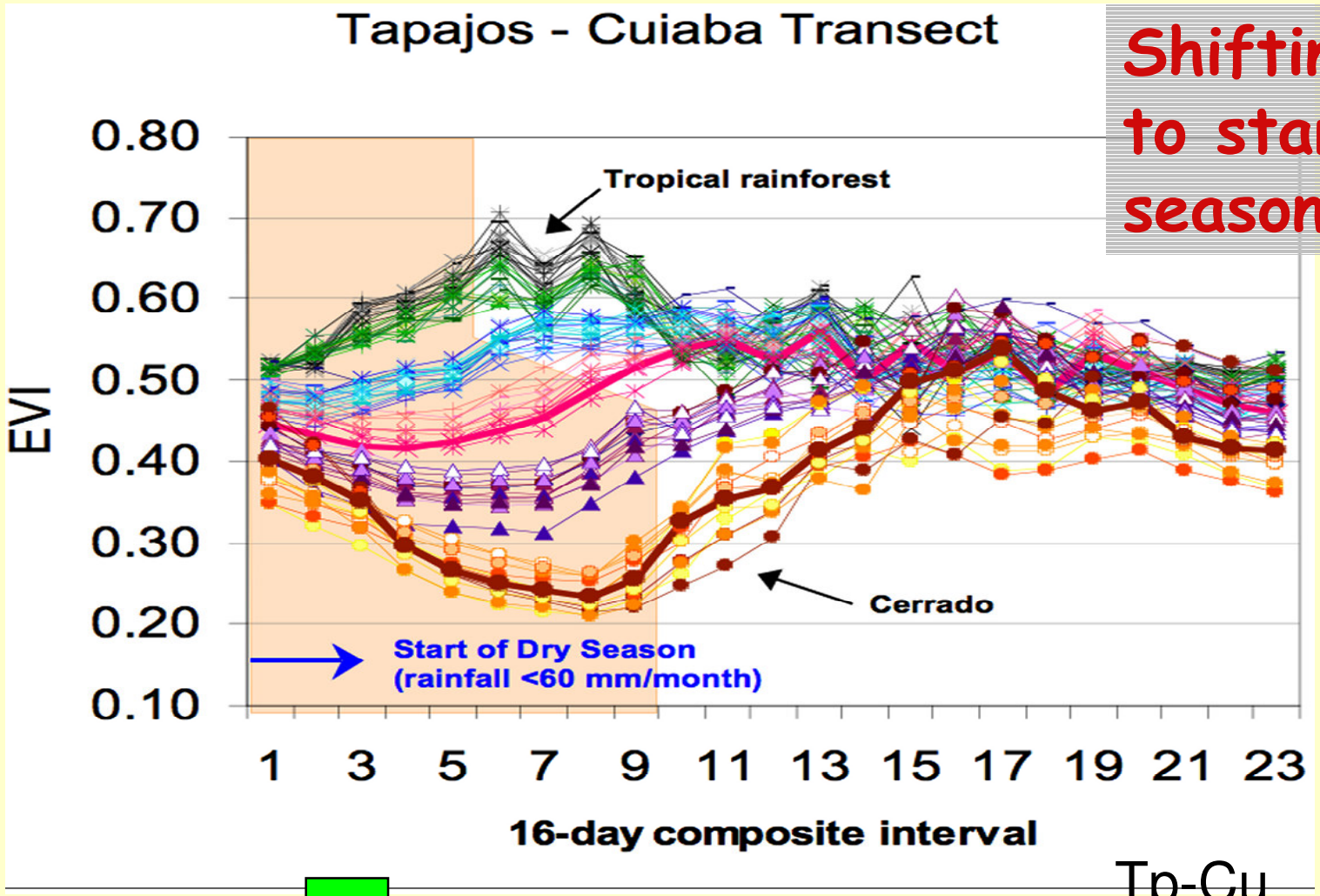

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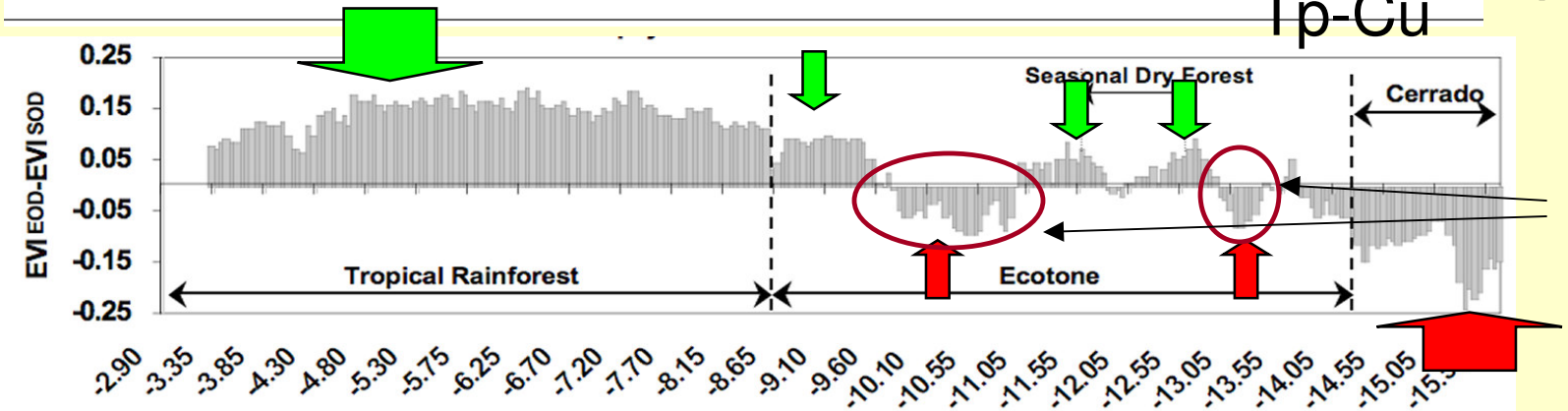


Human-Converted areas

3. Ecosystem Resilience & the Future under climate change

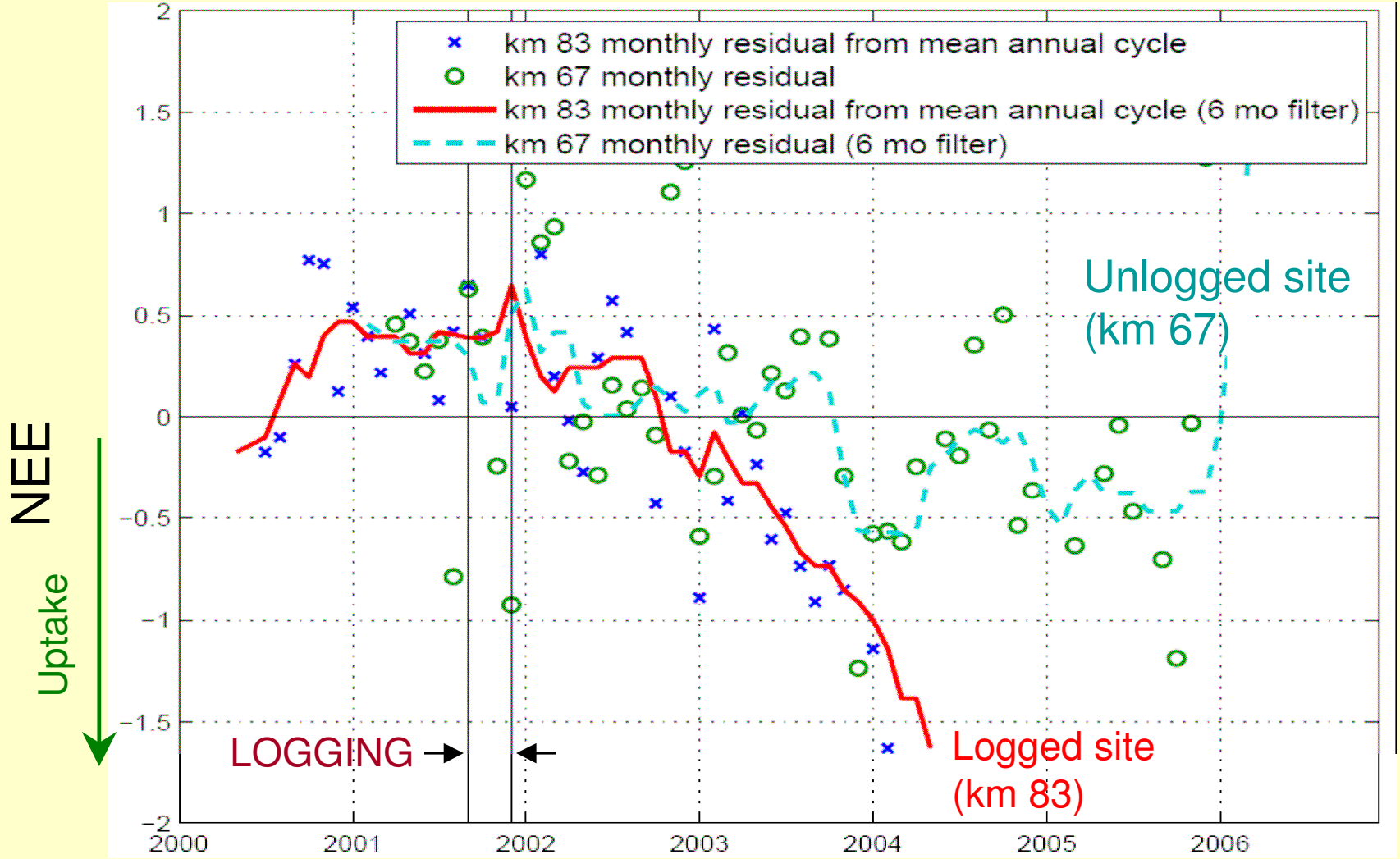
Two examples of ecosystem resilience of the Amazon (giving modest hope that a positive future is possible):

(a) Effects of Selective logging

(b) Ecosystem response to Interannual variability in precipitation

Tapajos Selective Logging Experiment

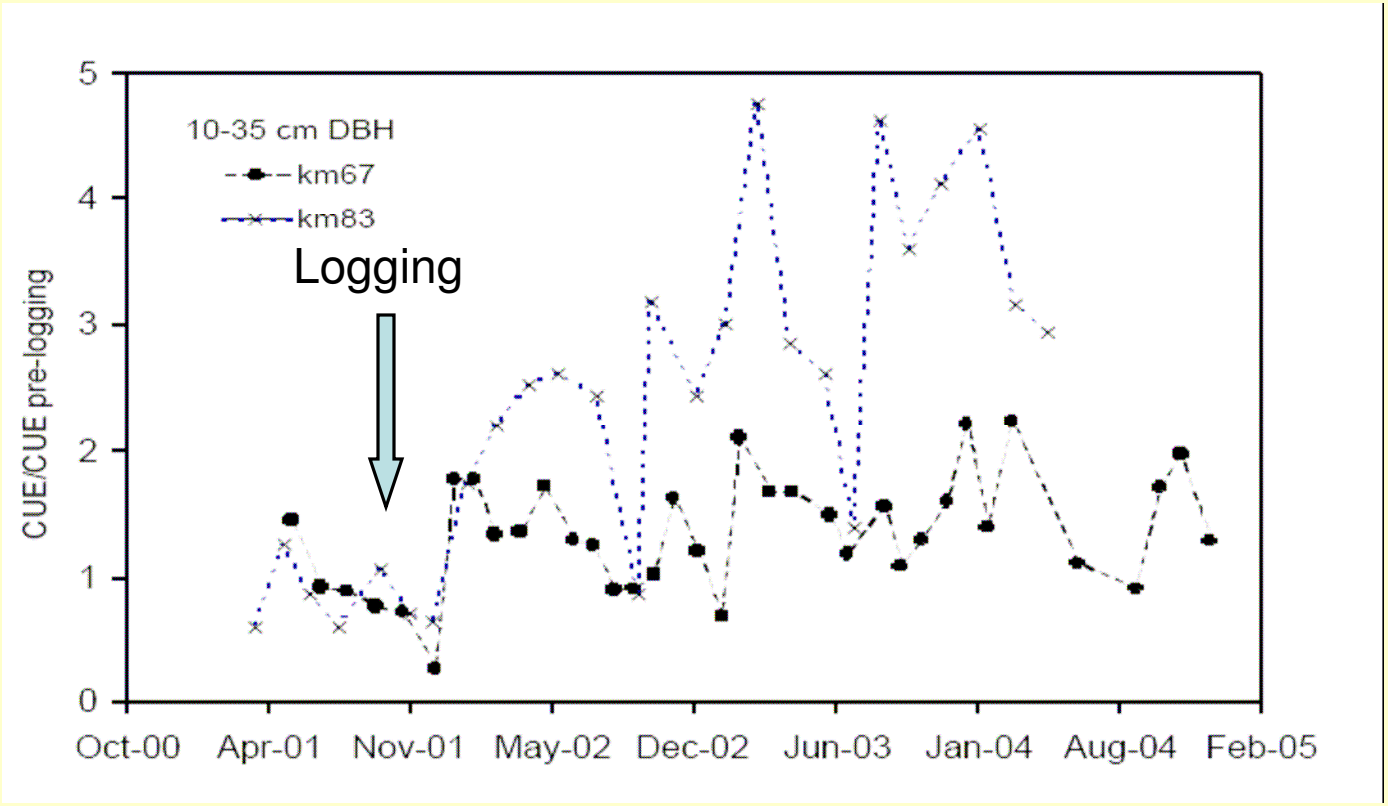
RESIDUAL monthly NEE (relative to mean annual cycle)



See Scott Miller talk on Friday's session on Carbon and Energy fluxes

Tapajos Selective Logging Experiment

Wood Carbon Use Efficiency (CUE) = (Coarse Wood NPP) / GPP



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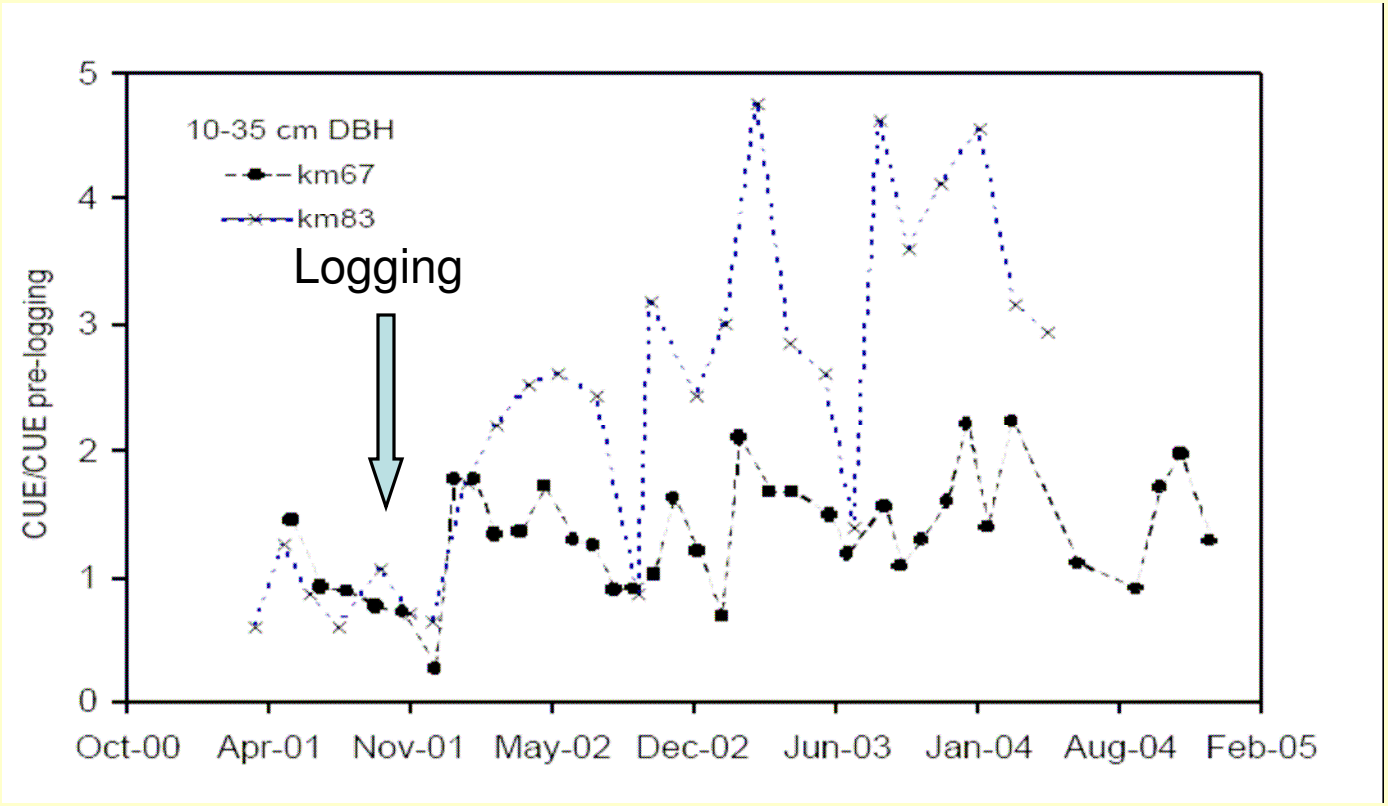

Selective logging promotes forest recovery by increasing allocation of photosynthate to wood production (increased CUE)

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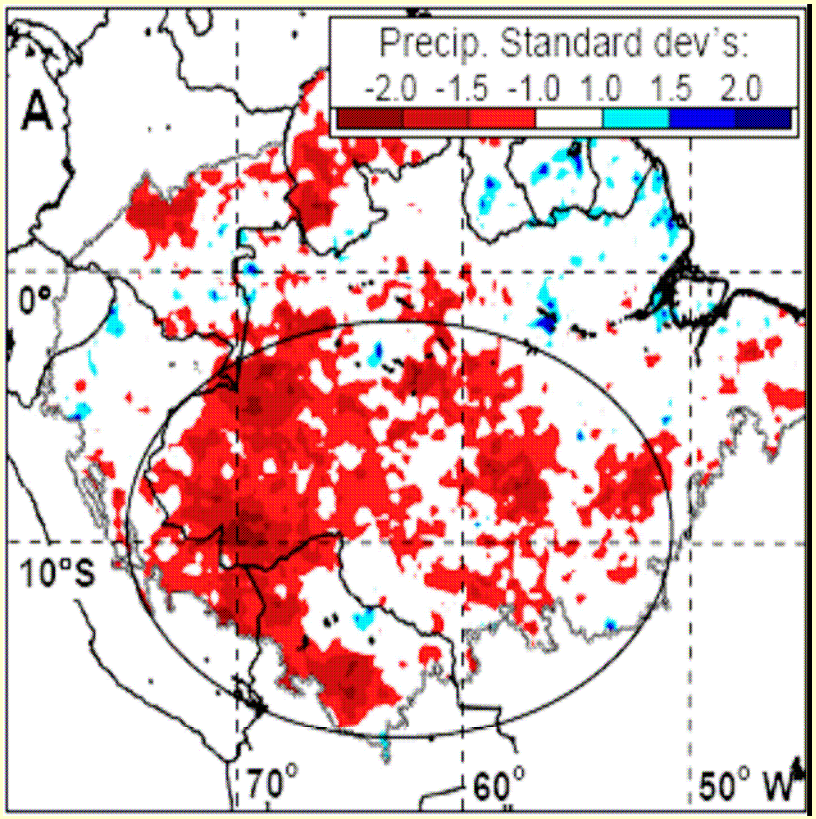
Forests green-up in during 2005 Amazon drought

precipitation anomaly



Units: number of standard deviations in 2005 from the long-term mean for the July/Aug/Sept (JAS) quarter. I.e., for each pixel:

$$Anomaly_{2005,JAS} = \frac{x_{2005,JAS} - \bar{x}_{JAS}}{\sigma_{JAS}}$$

Saleska, Didan, Huete, Rocha (2007), *Science*

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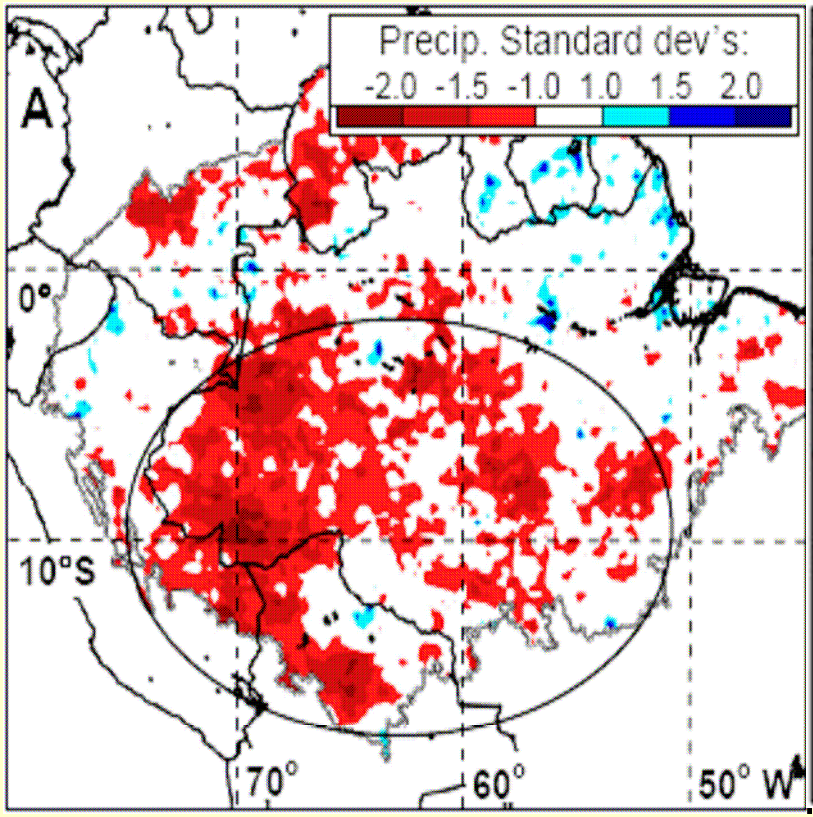
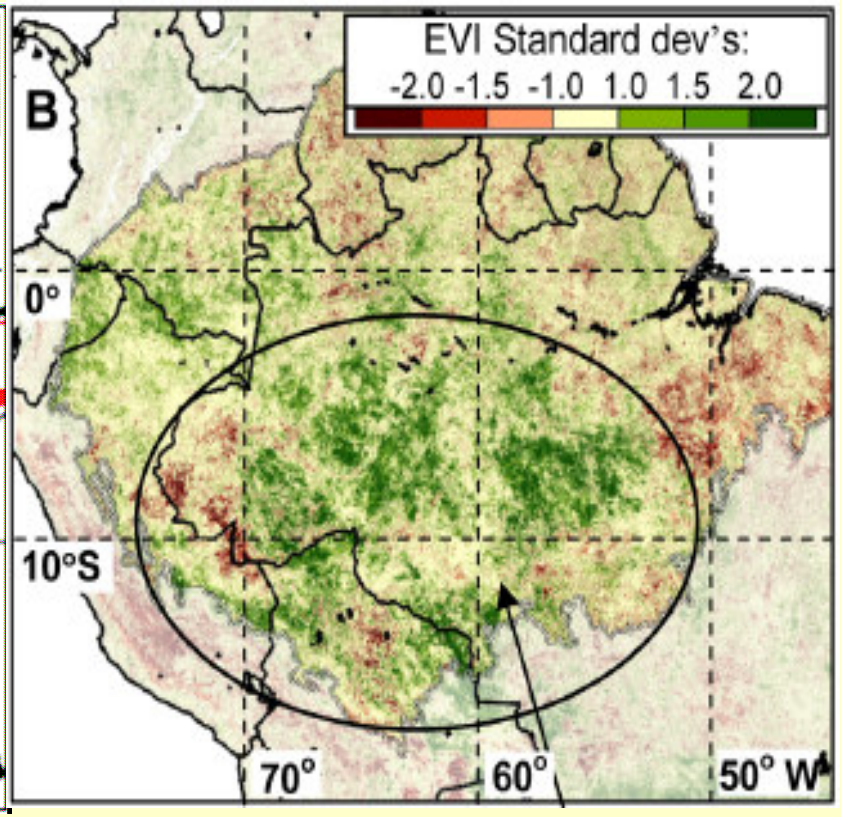


vegetation "greenness" anomaly



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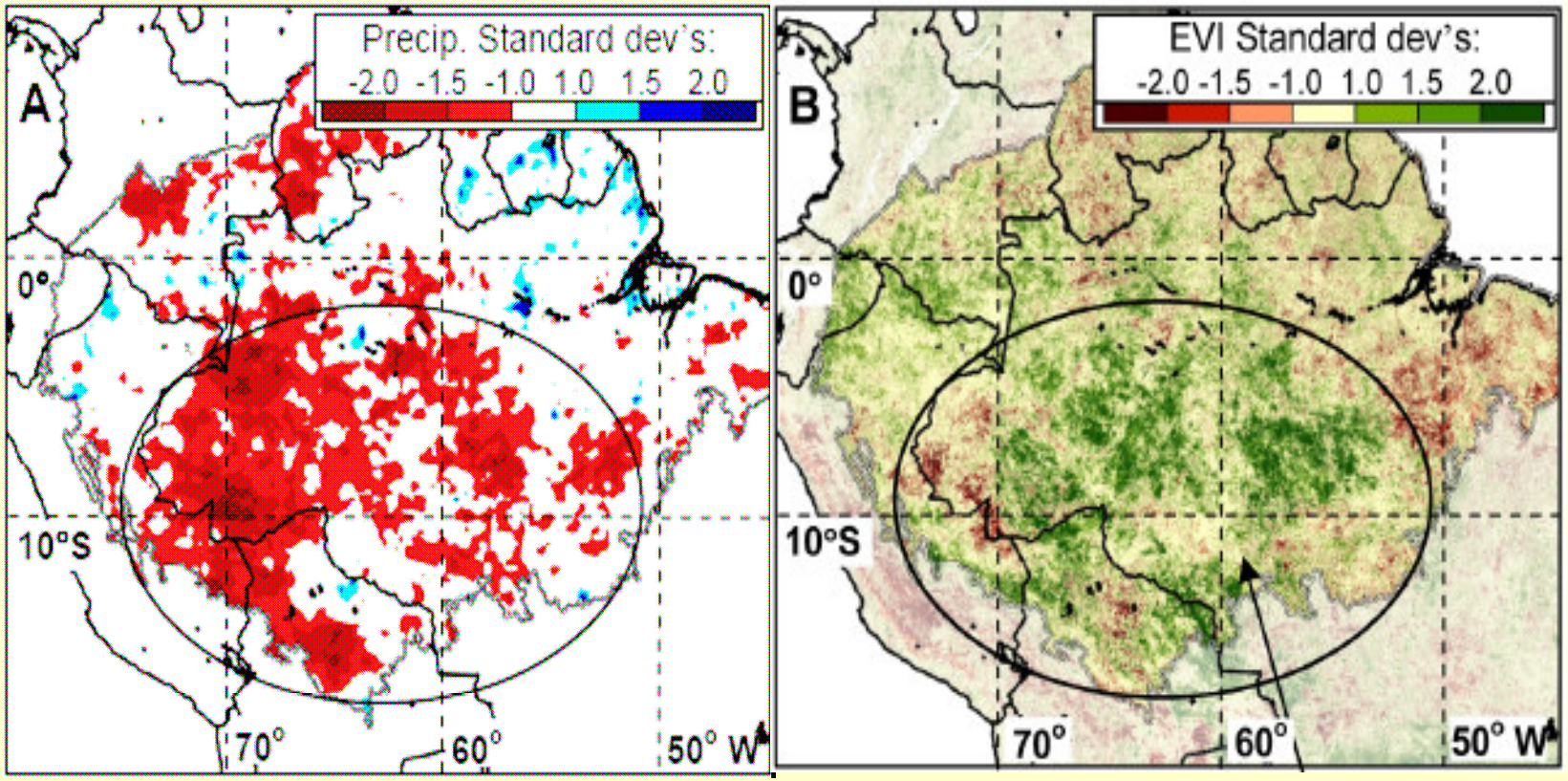

Short term drought, contrary to model predictions, does not cause photosynthetic slow-down: forests may be adapted to drought, to take advantage of extra sunlight

Summary & Conclusions

1. LBA has produced a growing body of evidence that seasonal variation in ecosystem metabolism (photosynthesis and transpiration) in Central Amazon forests is not controlled by precipitation, but by available energy (sunlight)
2. An array of approaches is being taken to improve model representations of seasonality of fluxes.

   → How do we determine which approaches are correct?
3. Seasonality of metabolism shifts across the Ecotone and in savanna areas: as dry season length increases, metabolism becomes water limited
4. Widescale Amazon forest Green-up during drought, and vigorous forest response to selective logging are examples of ecosystem resilience

Two Outstanding Questions

1. What is the Large-scale Response to long-term drought?
   (e.g. 1997/1998 ENSO → prior to eddy flux tower network and Terra satellite infrastructure).

   (Nepstad et al., 2007: Seca Floresta experiment says it takes 3+ years of drought to stress a forest!)

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2. What is the Large-scale carbon balance of intact Amazon forests?
   Still not well known, due to uncertainties about disturbance and mortality (but see Jeff Chambers plenary talk on Friday, forthcoming BARCA campaign)

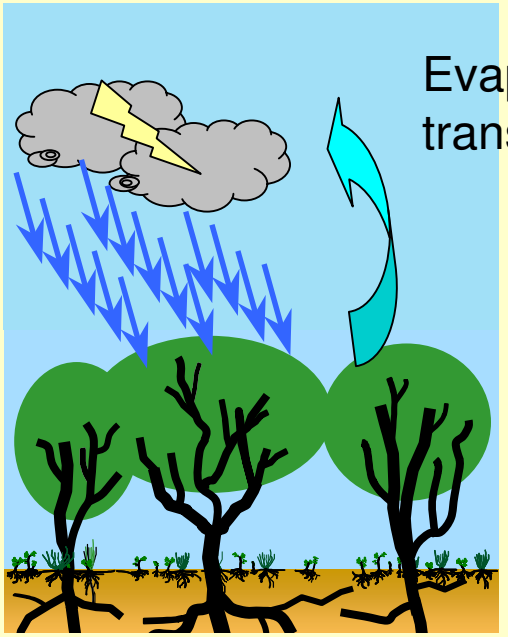
What is the future of Amazon forests under climate change?

Forest? …

or Savanna?

Amazônia 2050: Forest or Savanna? Can we test the prediction?

Rain

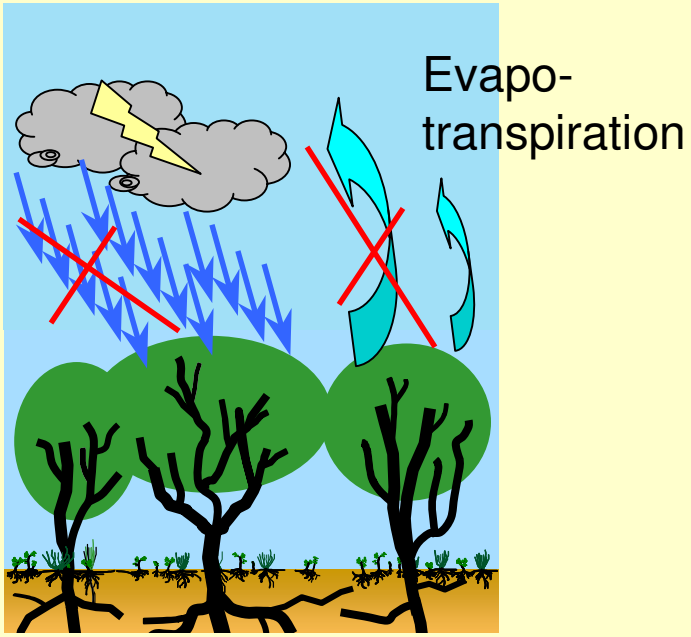


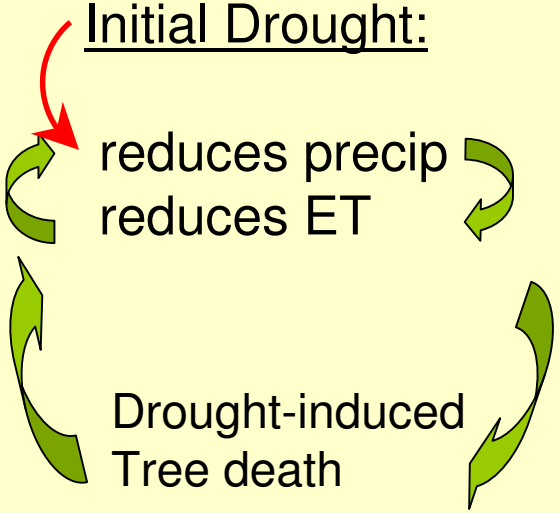
Evapo-
transpiration

Amazônia 2050: Forest or Savanna? Can we test the prediction?

Trigger: onset of semi-permanent drought (no biology)

Key mechanism: amplification of drought by forest physiological response to initial drying (<u>lots</u> of biology!):





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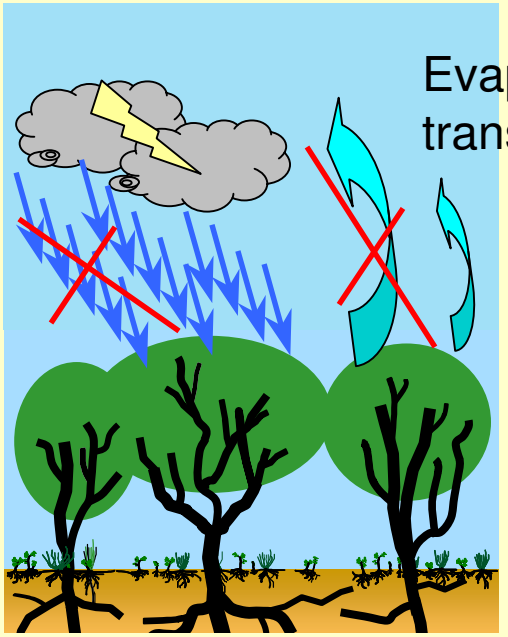
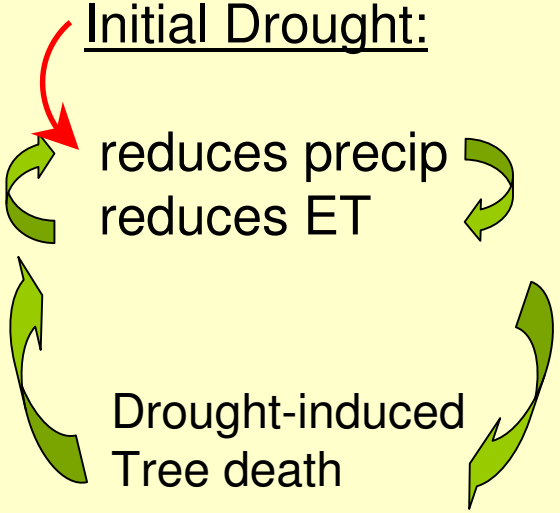
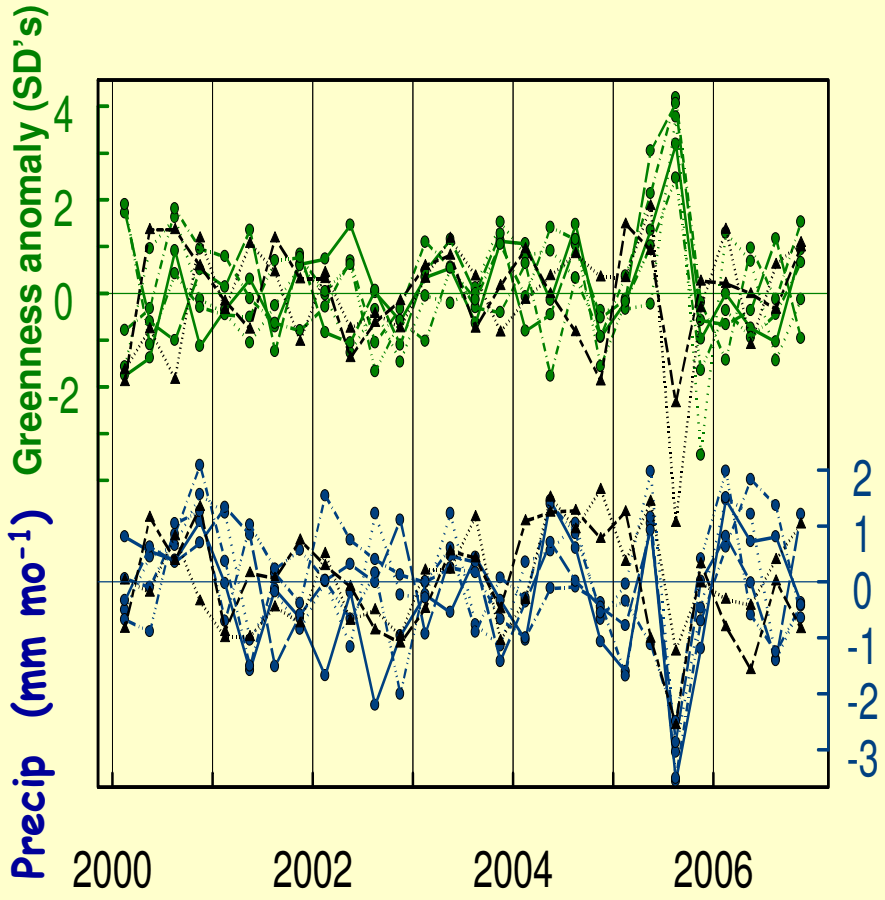




Prediction about today's Amazon forest under current climate: evapotranspiration and whole-system photosynthesis should be reduced during dry periods (**dry seasons**, and **interannual droughts**)

Satellite-observed historical greenness & precip (quarterly anomaly timeseries of "strong responder" pixels)



The Target Hypothesis:

Hadley **model-predicted** GPP & precip in central Amazonia in years relative to El Nino drought