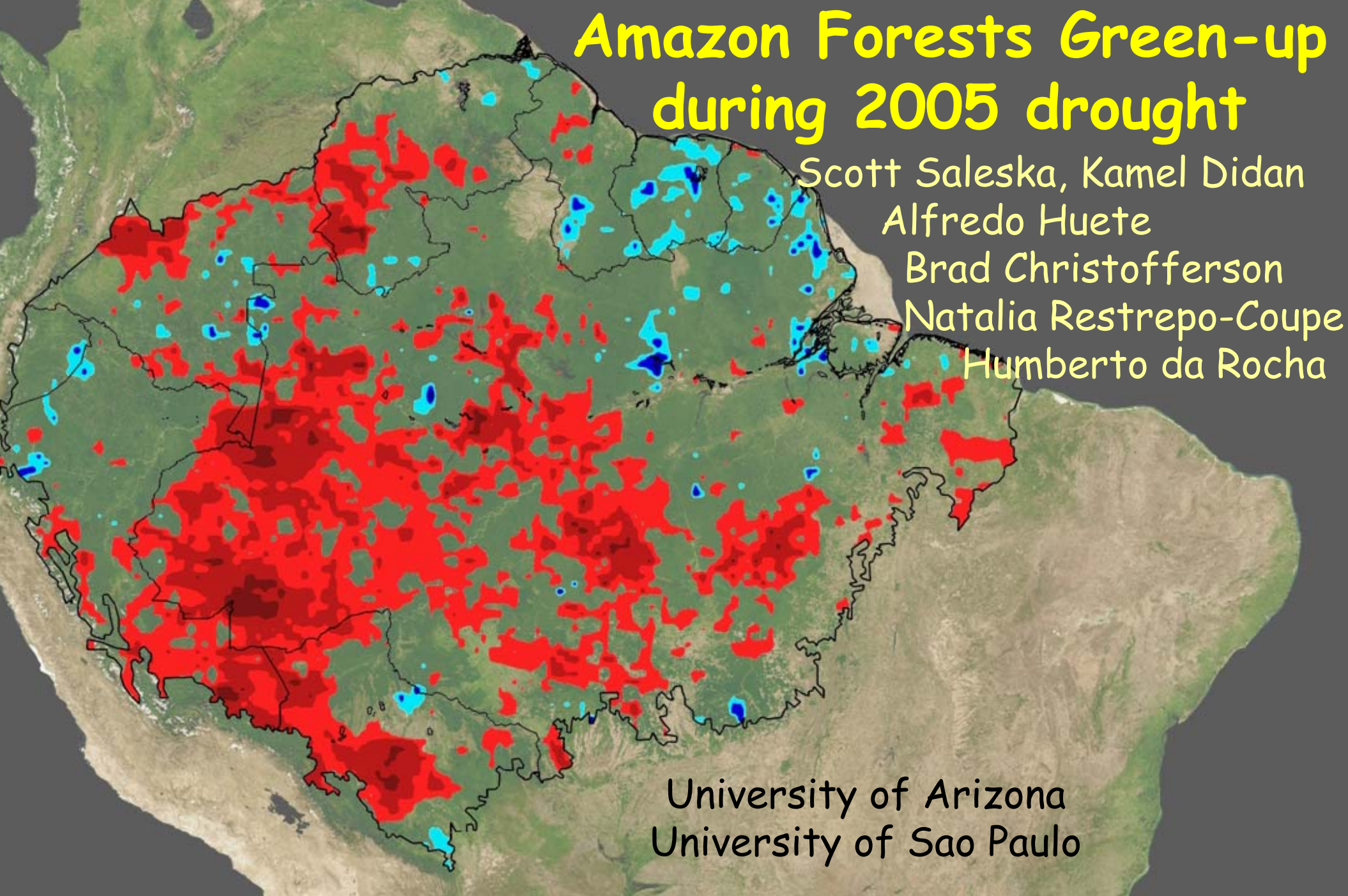
Amazon Forests Green-up
during 2005 drought
Scott Saleska, Kamel Didan
Alfredo Huete
Brad Christofferson
Natalia Restrepo-Coupe
Humberto da Rocha
University of Arizona
University of Sao Paulo

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Coupled carbon cycle/general circulation model simulations

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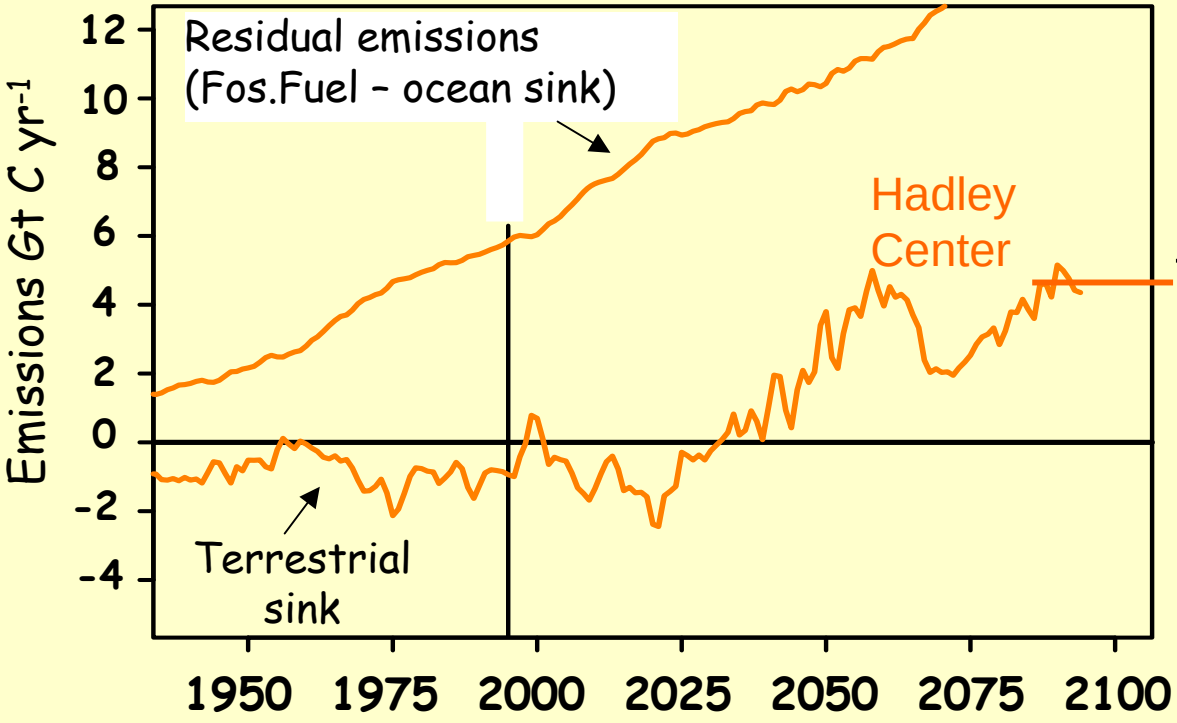

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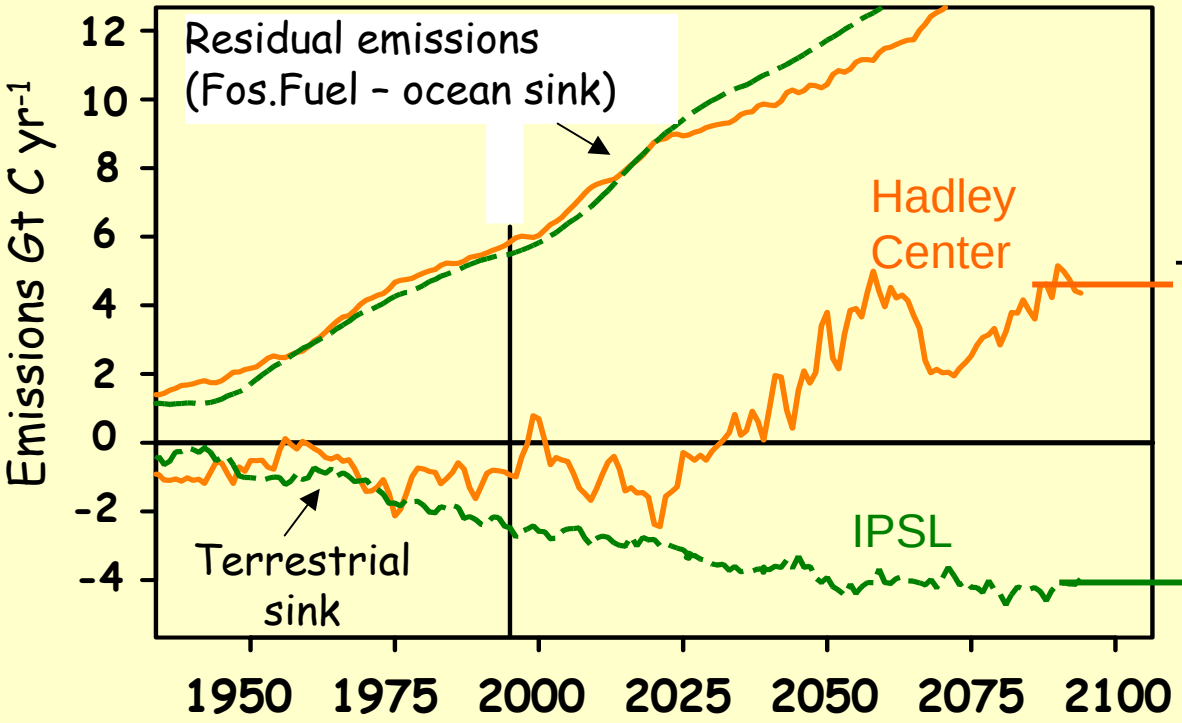

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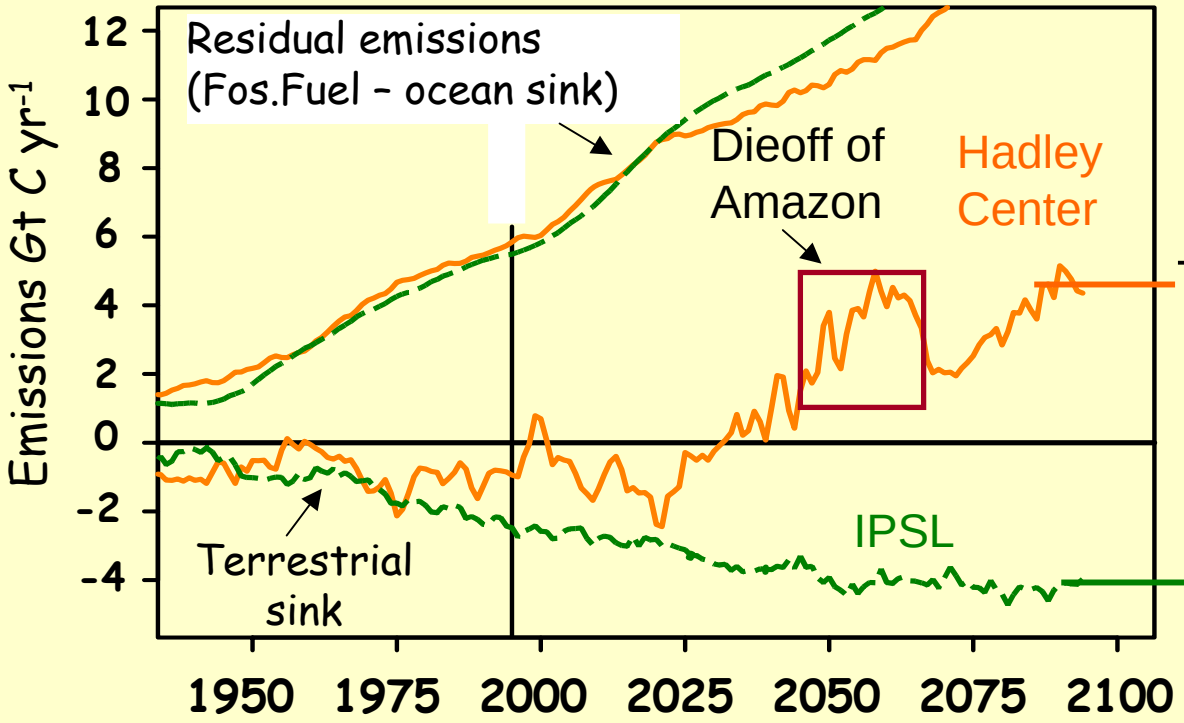

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- 3.5	770	3

8.5 Gt difference: huge!

Key factors driving model differences:

- Temperature sensitivity of soil respiration
- Drought-induced Dieoff of Amazon rainforest → savanna

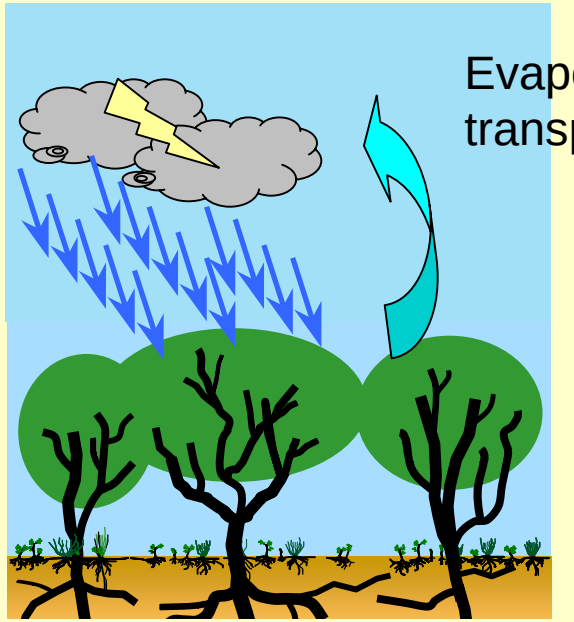
What is the future of Amazon forests under climate change?

Forest? ...

or Savanna?

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

Rain



Evapo-
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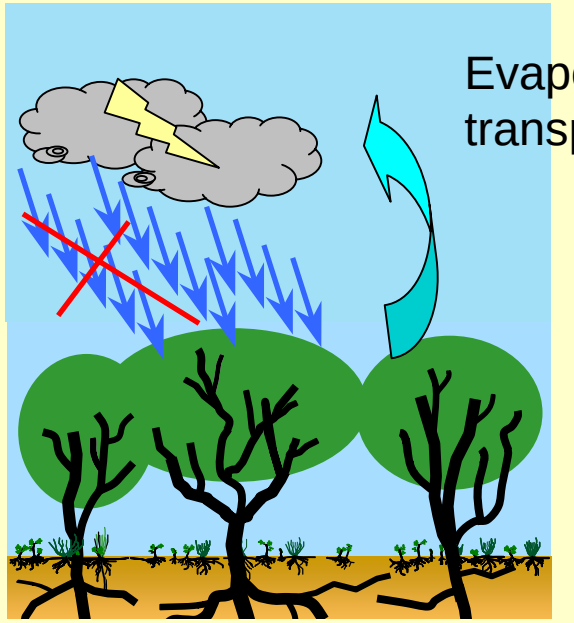

Evapo-transpiration

Initial Drought:

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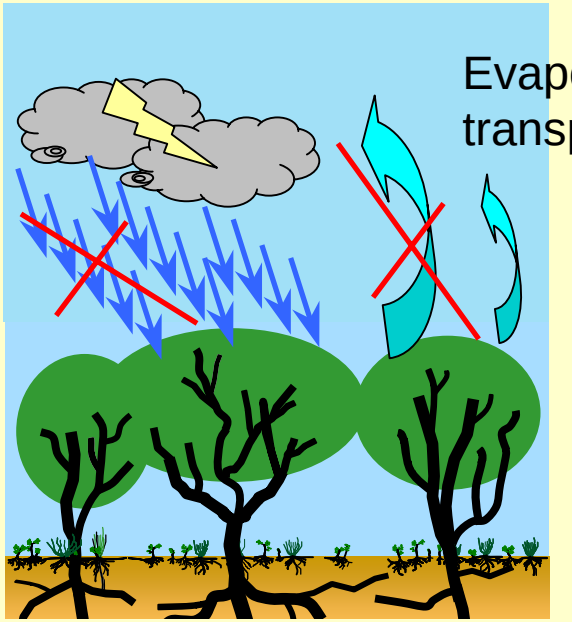
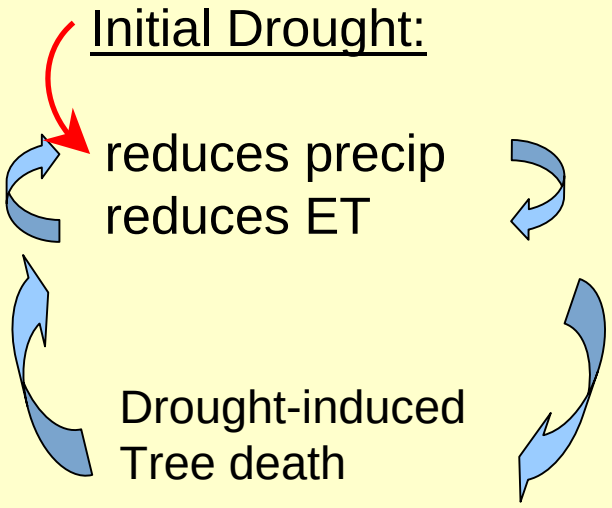
Key mechanism: amplification of drought by forest physiological response to initial drying (lots of biology!):





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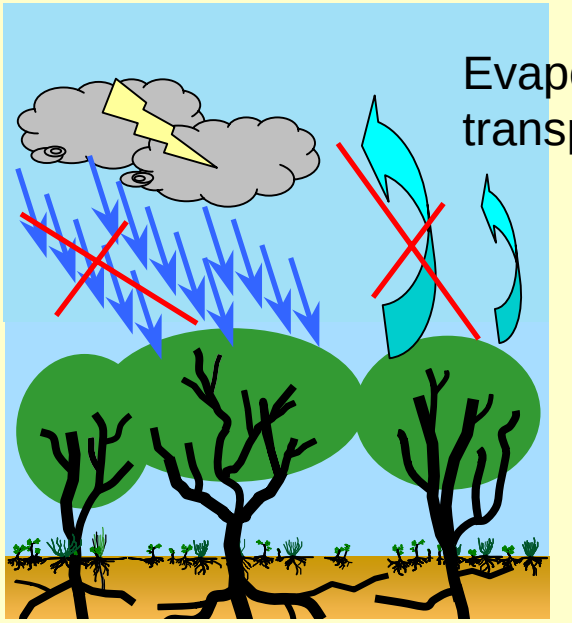
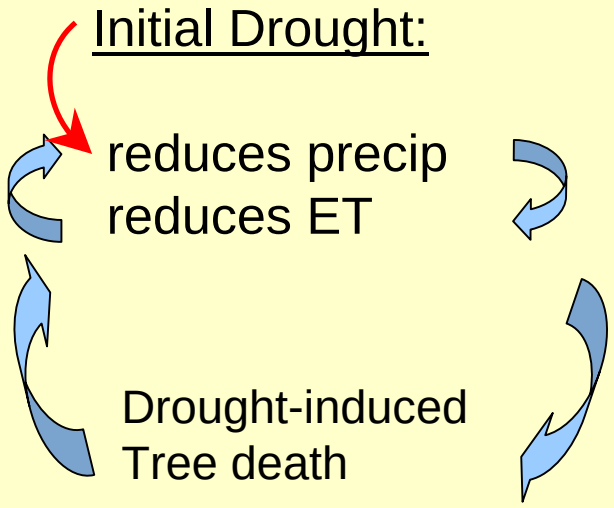




Prediction about today's Amazon forest under current climate:
evapotranspiration and whole-system photosynthesis should be reduced during dry periods (**dry seasons**, and **interannual droughts**)

What is the Response to interannual drought?

empirical test: the intense Amazon drought of 2005

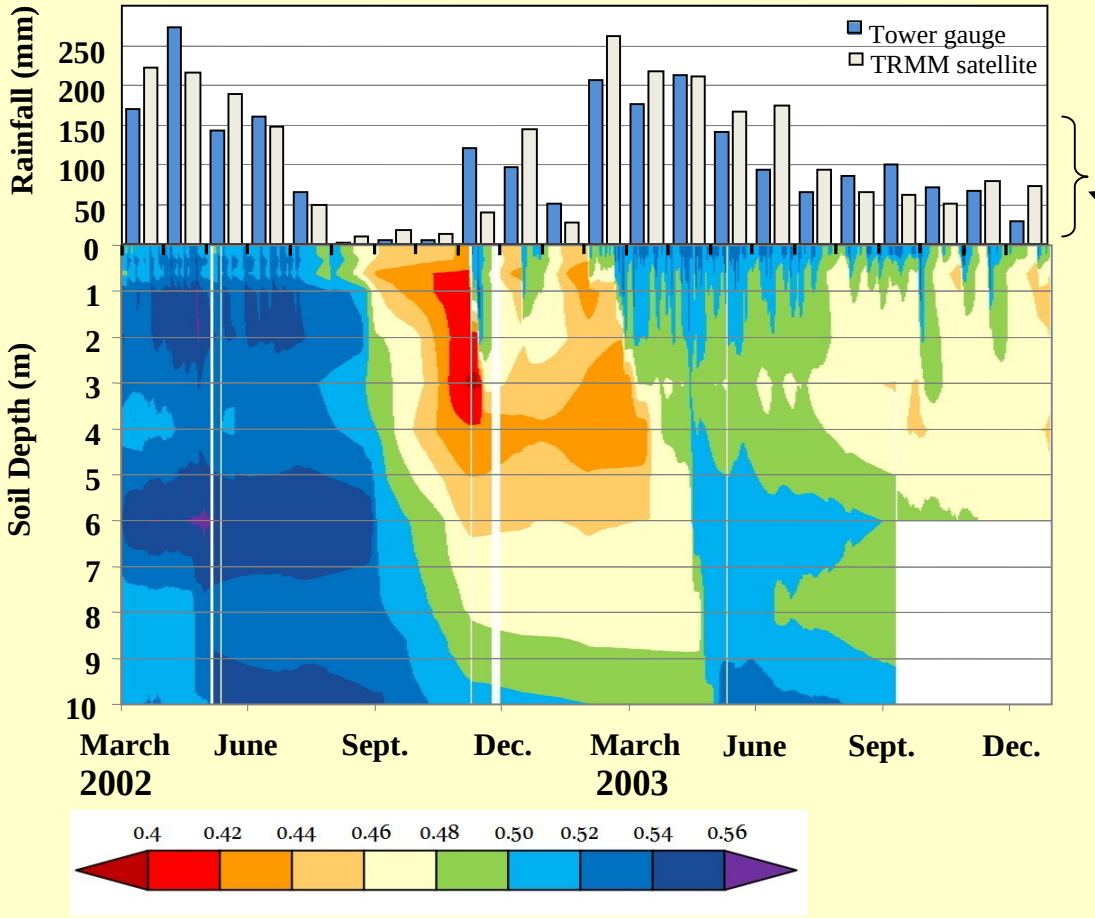
Methods I : TRMM satellite for Rainfall measurements

TRMM = Tropical Rainfall Measuring Mission

Blended precipitation product (3B43-v6) combines:

- microwave data from TRMM
- Infrared from GOES
- Calibrated to data from global network of gauges

Methods I : TRMM satellite for Rainfall measurements



Bruno et al., 2006

Seasonal rainfall variations at local site (km 83, Tapajos) show:

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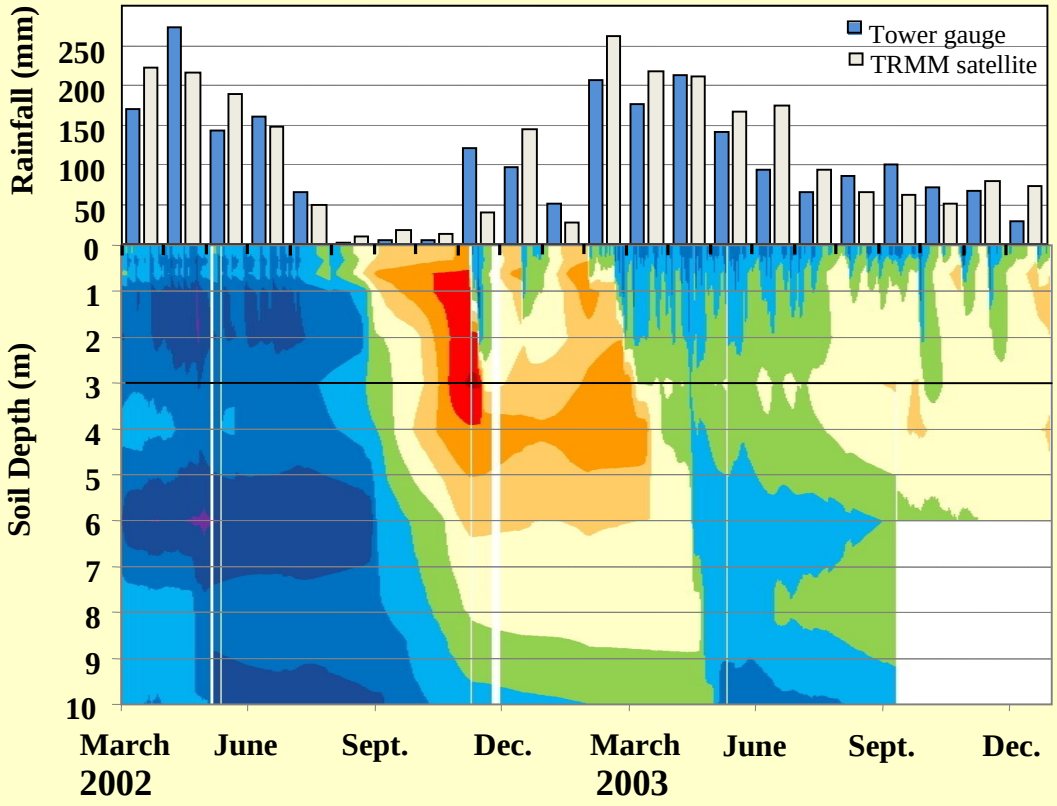

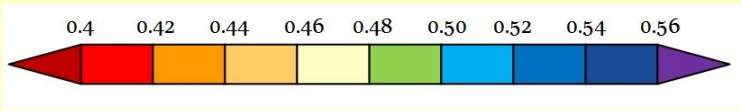

Volumetric soil moisture ($m^3\ m^{-3}$)

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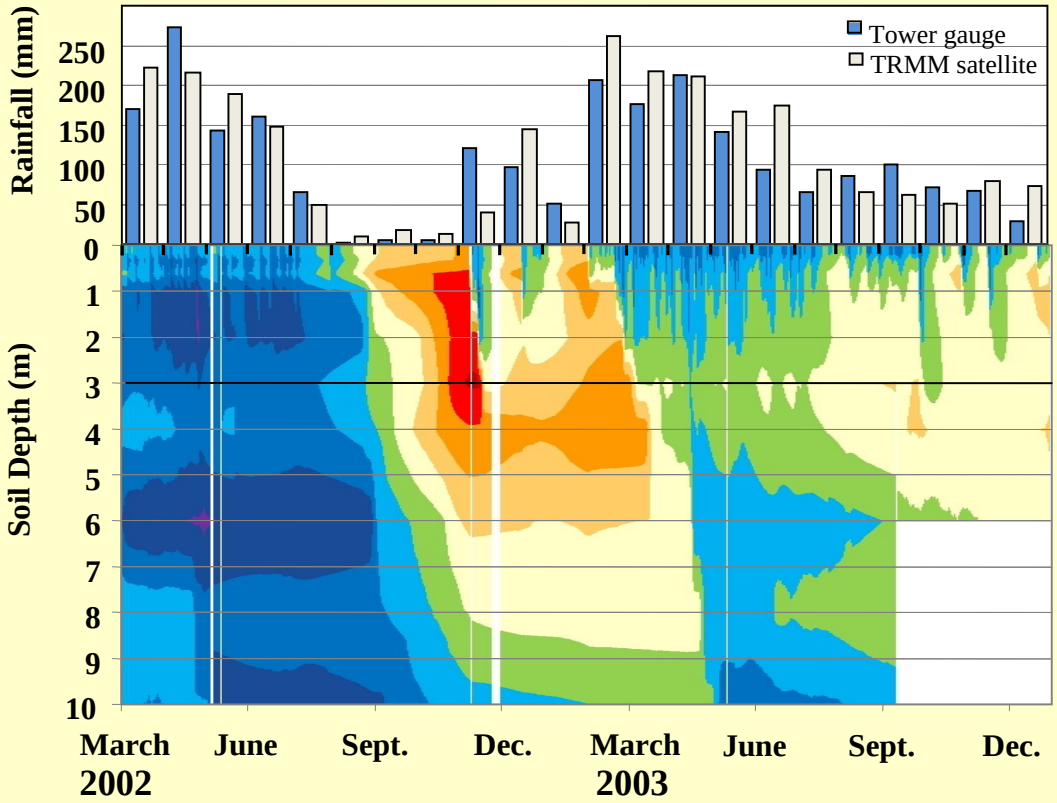

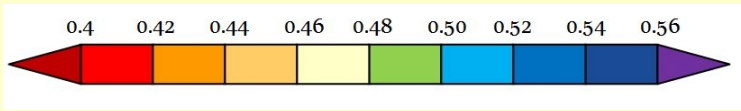

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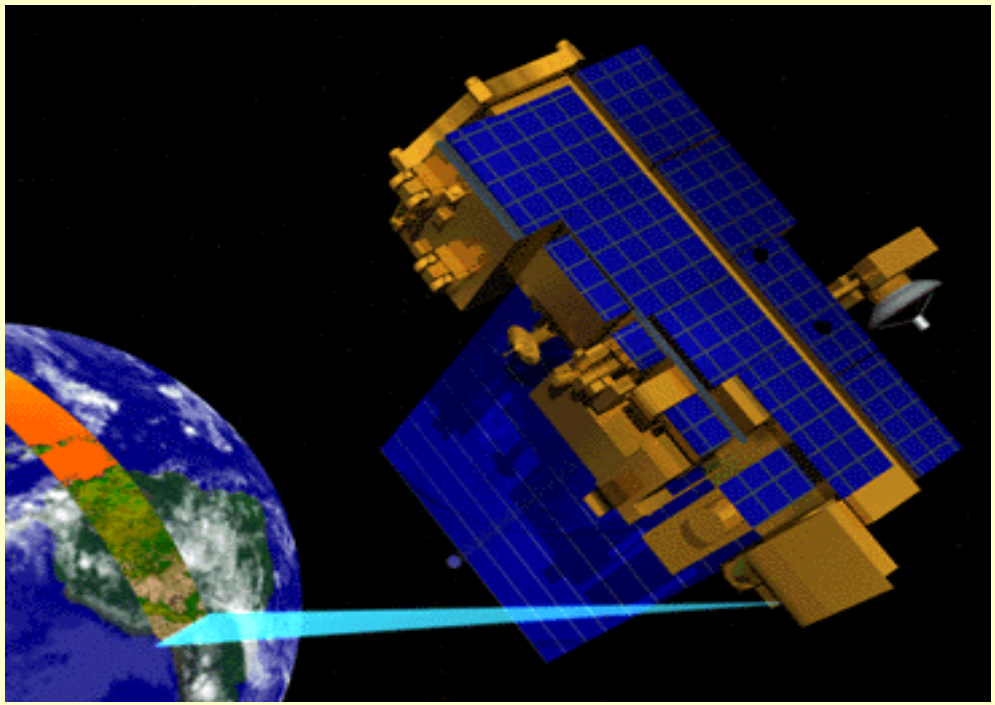
- Most models access 0-3m soil water, so show prompt ($\leq$ 1 month) response to drought

Methods II: MODIS satellite instrument measures canopy "greenness"

MODIS = Moderate Resolution Imaging Spectroradiometer



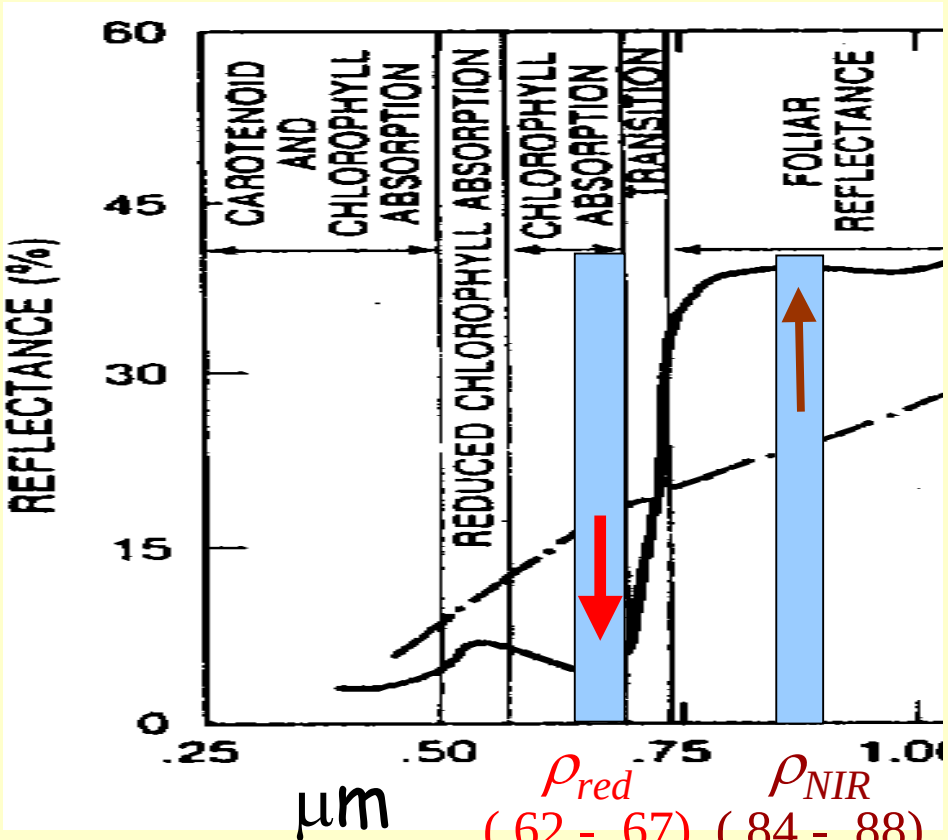
MODIS-derived Enhanced Vegetation Index (EVI):

focuses on spectral bands related to plant photosynthetic capacity

Does not saturate with high Leaf Area Index (LAI) as does NDVI

High-time resolution (16-day) allows detection of seasonal patterns

Methods II: MODIS satellite instrument measures canopy "greenness"



↑ Chlorophyll → ↓ reflectance

↑ leaf structure → ↑ reflectance

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

But… NDVI saturates over dense (high-LAI) vegetation (e.g. Amazon forest)

$$\mathbf{EVI} = \frac{\rho_{NIR} - \rho_{red}}{1 + \rho_{NIR} + 6\,\rho_{red} - 7.5\,\rho_{blue}}$$

Reduced sensitivity to red, relative to NIR, giving greater ability to detect increases in LAI

aerosol correction

Empirical test: the 2005 Amazon drought

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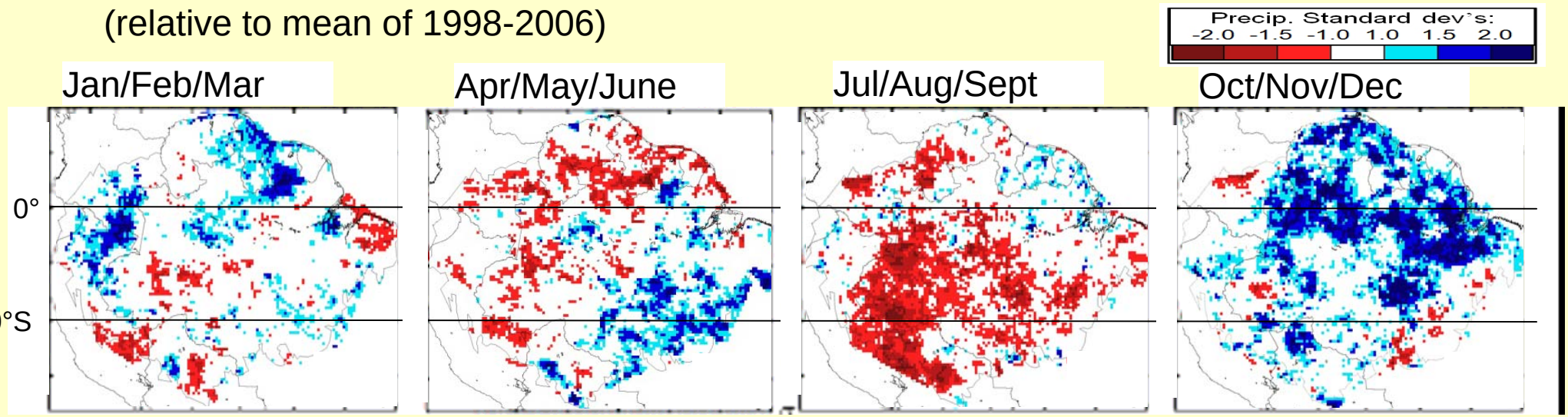
Satellite (TRMM)-derived precip anomalies in Amazônia for 2005 (as in Aragão, et al. 2007):
(relative to mean of 1998-2006)



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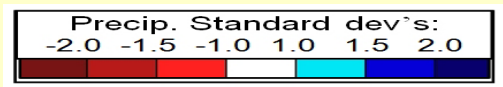

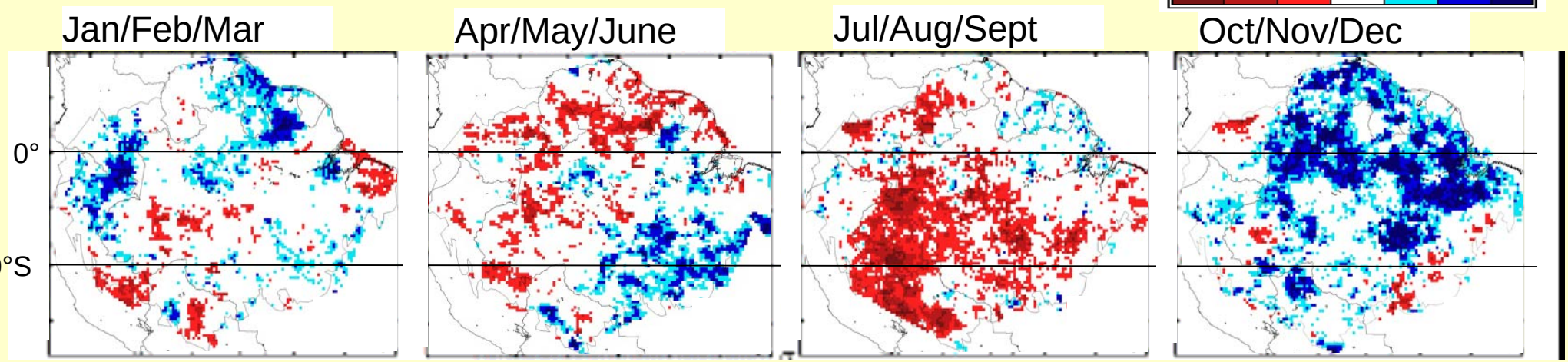

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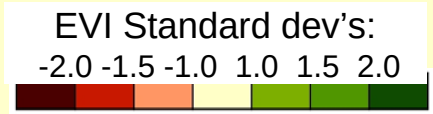

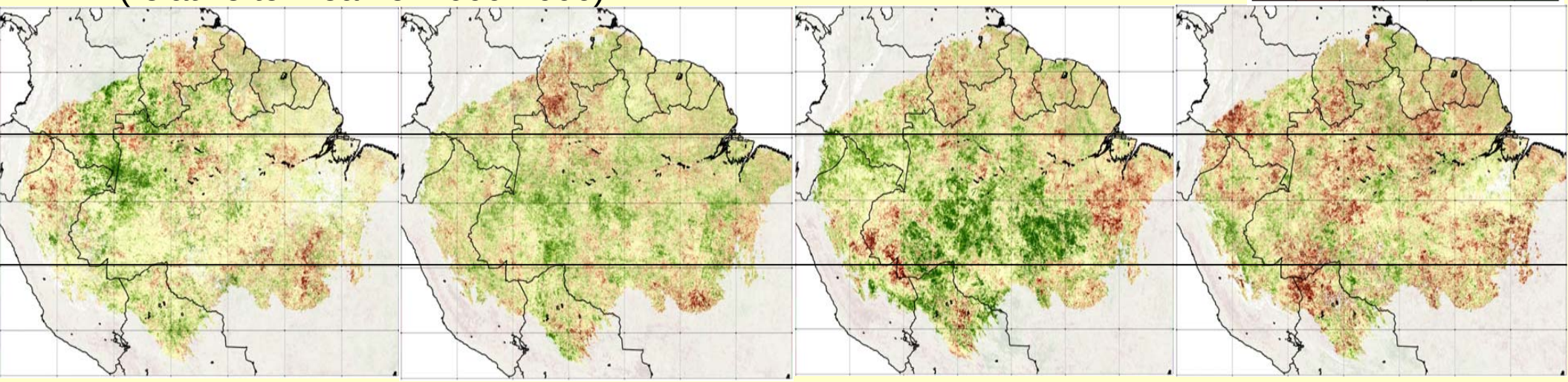

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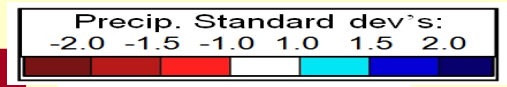
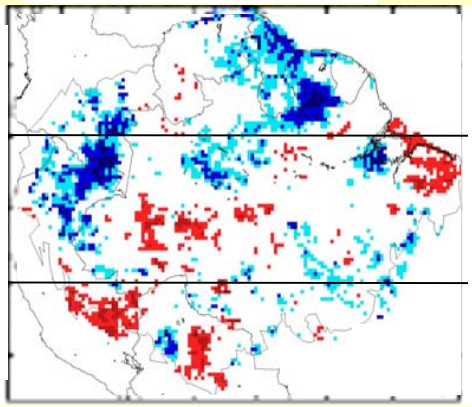
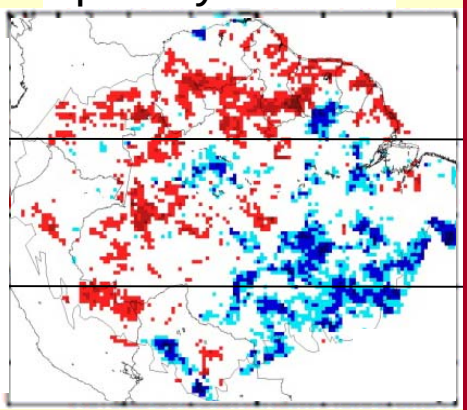


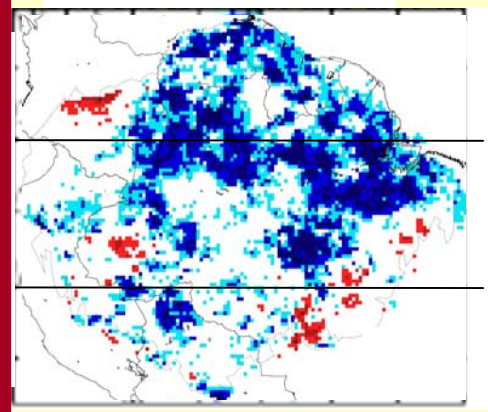
Jan/Feb/Mar



Apr/May/June



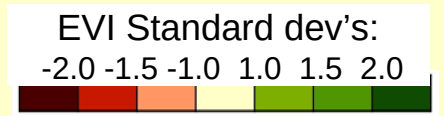
Oct/Nov/Dec

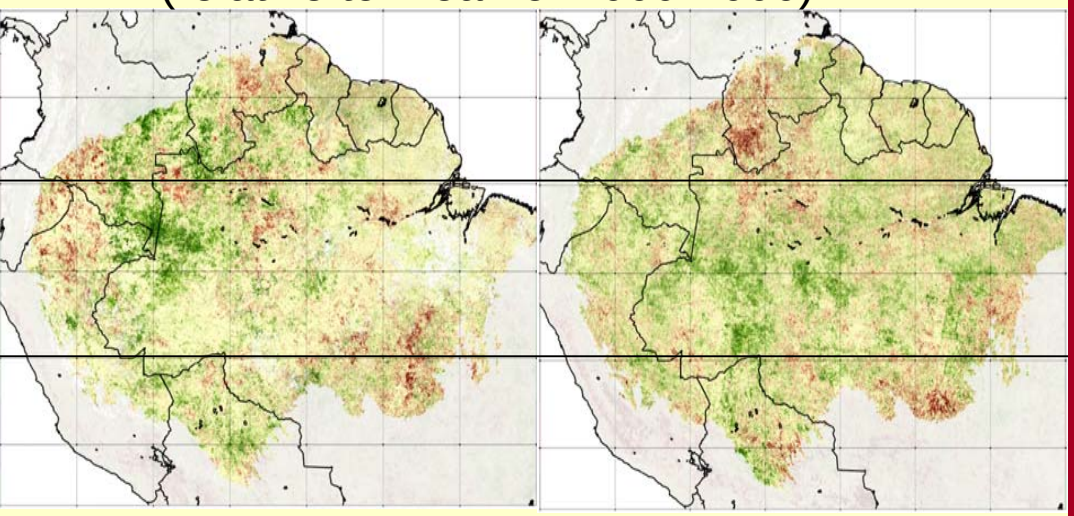


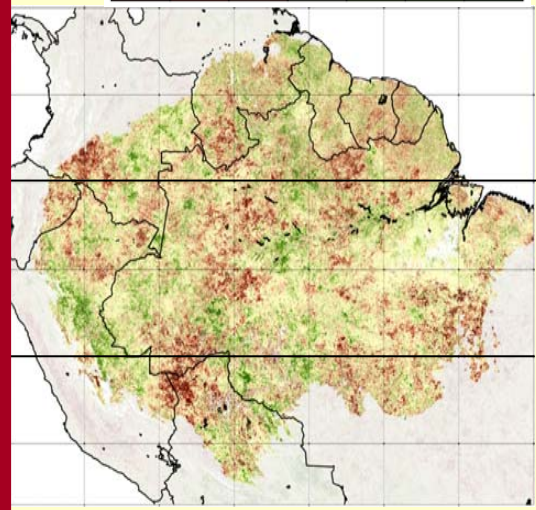
0°

10°S

Satellite (MODIS)-derived EVI anomalies in Amazô
(relative to mean of 2000-2006)

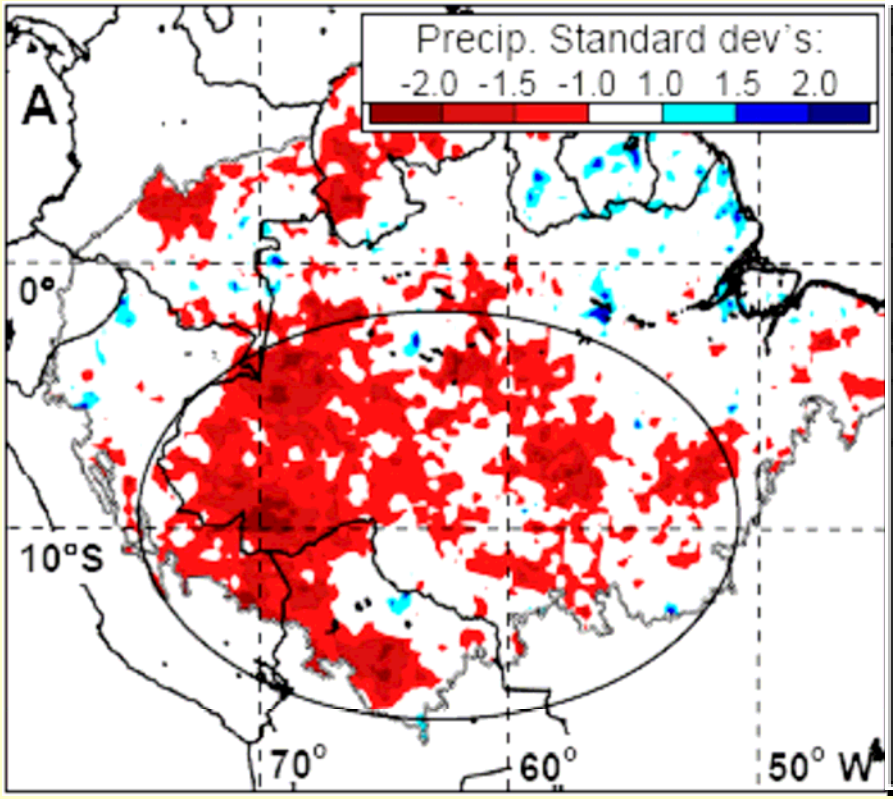




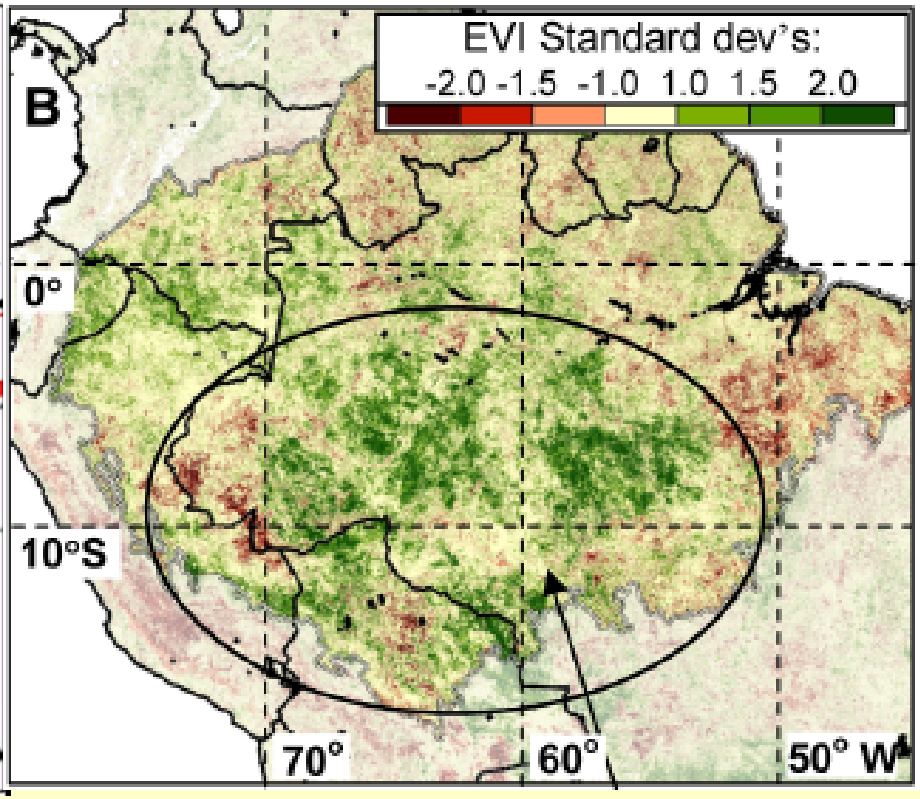


Empirical test: the 2005 Amazon drought

precipitation anomaly



vegetation "greenness" 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:

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

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

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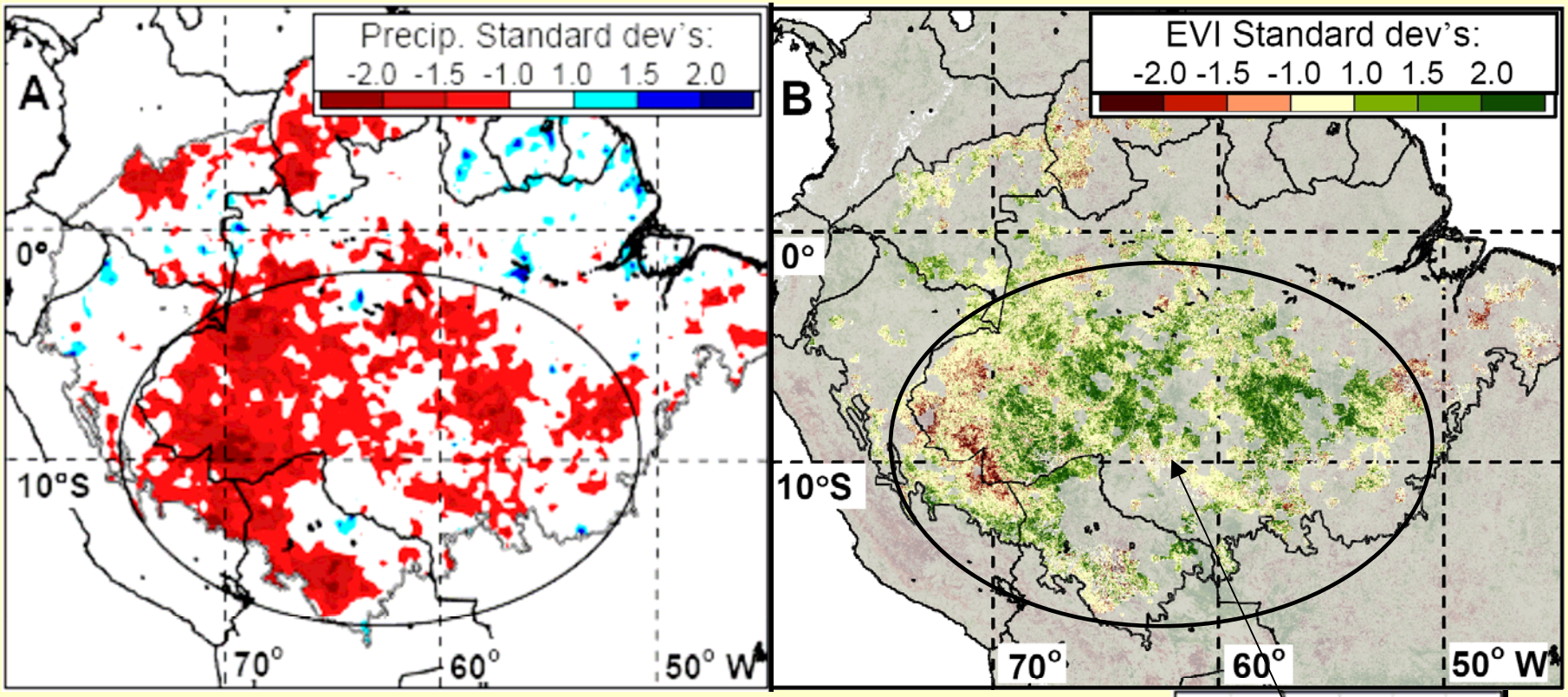

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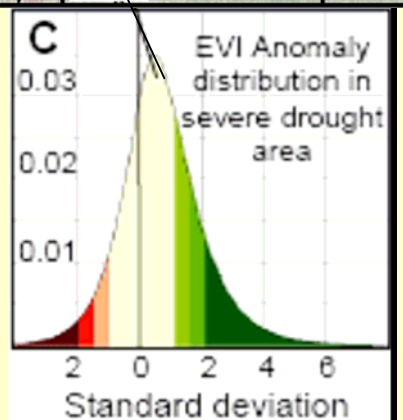
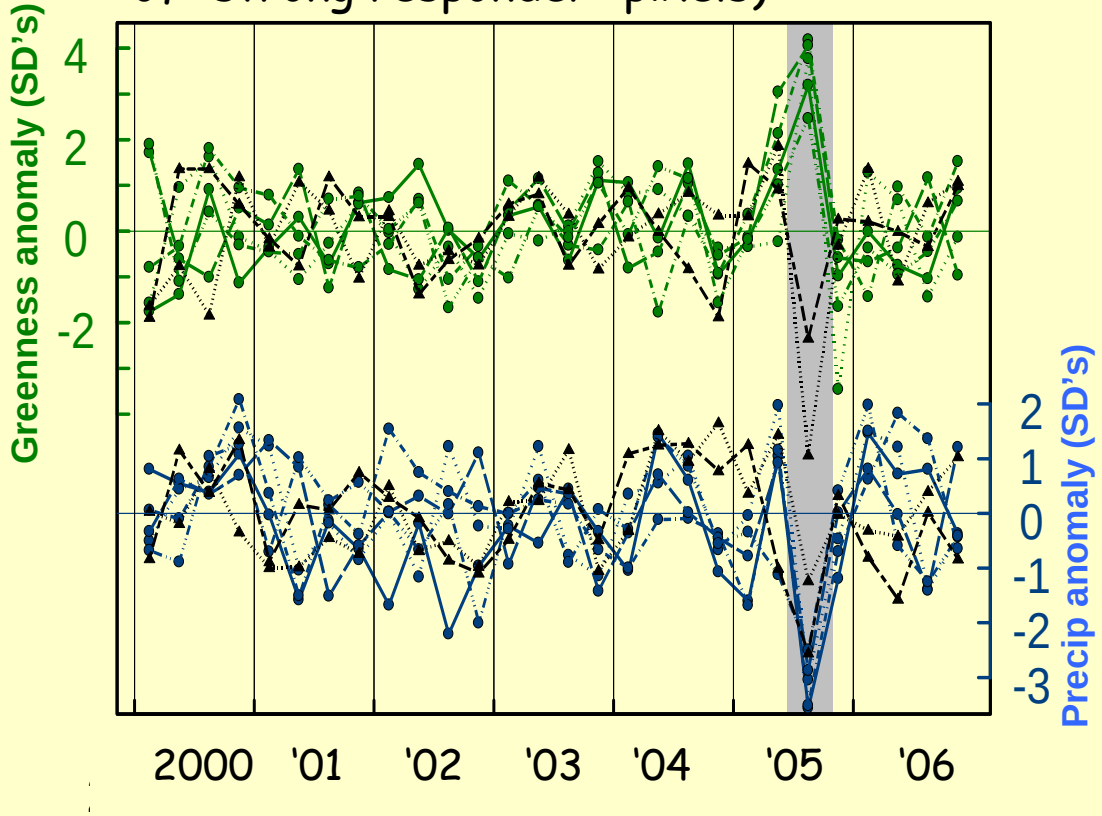


Timeseries of Observations

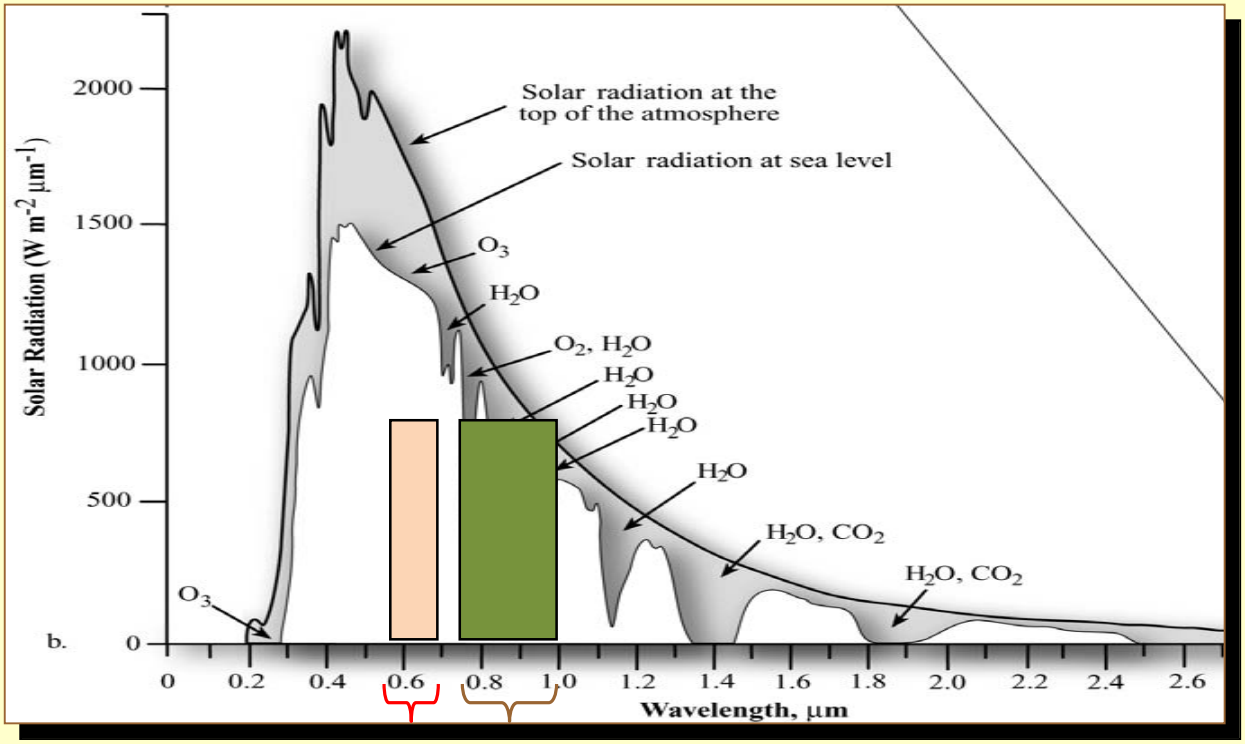
Satellite-observed historical greenness & precip (quarterly anomaly timeseries of "strong responder" pixels)



What is causing the 2005 drought "green-up"?

1. MODIS Artifact?
   a) Water vapor/aerosol/other atmospheric contamination?
   b) Cloud contamination?
   c) Test by comparison to tower data
2. Biological response of the forest

(a) Water vapor/aerosol atmospheric correction



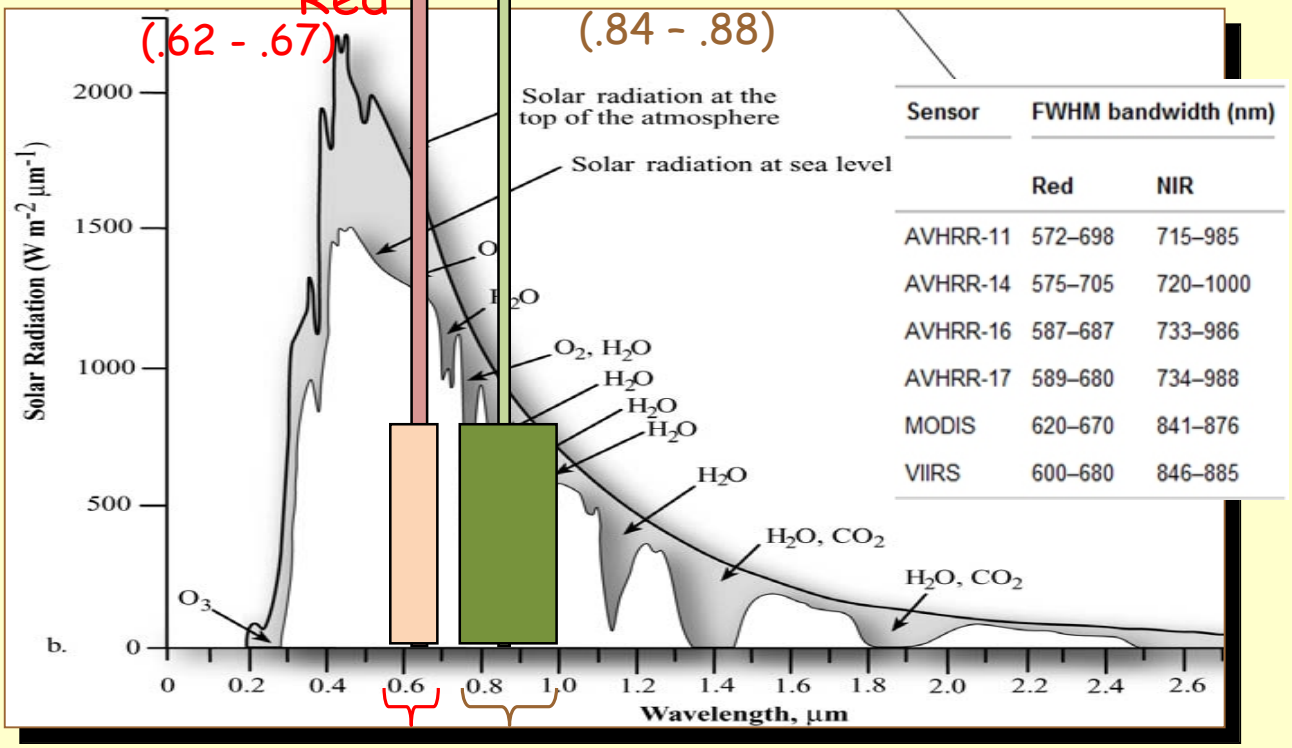
AVHRR Red (.57 -.68)

AVHRR NIR (.72 – 1.0)

(a) Water vapor/aerosol atmospheric correction

MODIS Red (.62 - .67)

MODIS NIR (.84 - .88)



Sensor	FWHM bandwidth (nm)	
	Red	NIR
AVHRR-11	572–698	715–985
AVHRR-14	575–705	720–1000
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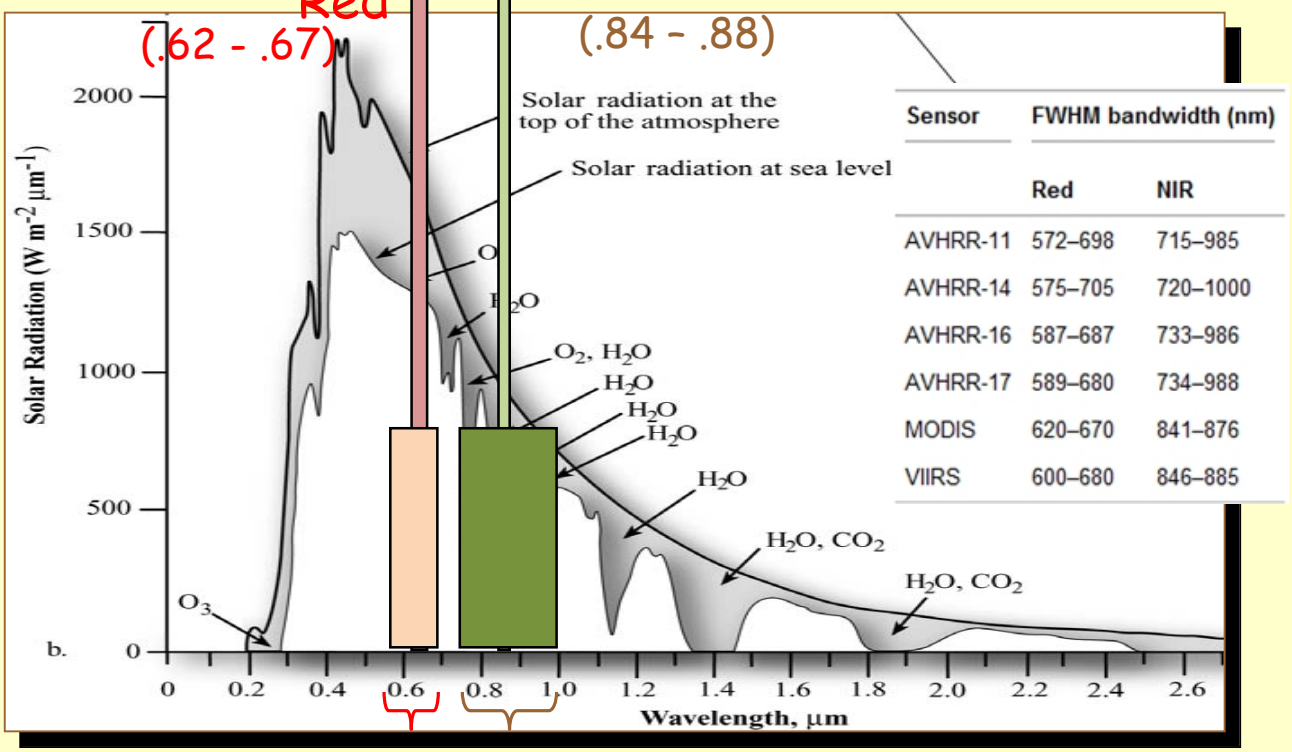

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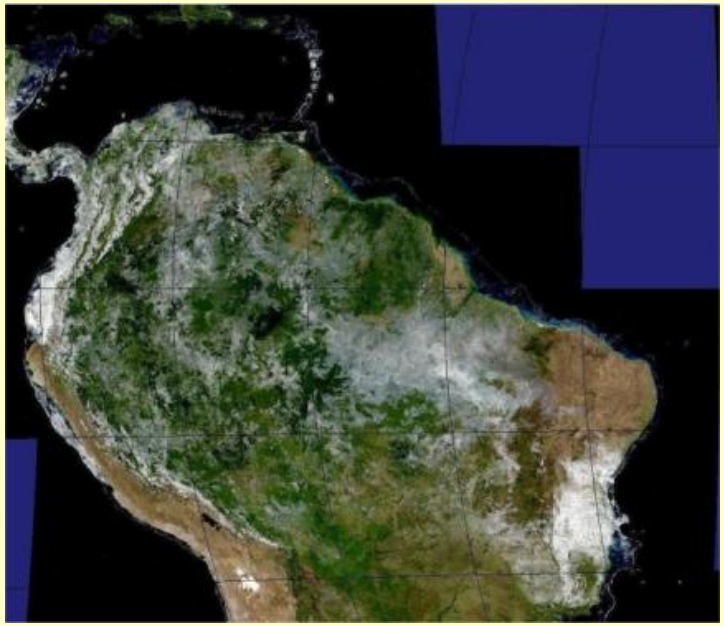
- MODIS: higher spectral resolution (relative to previous generation AVHRR) → dominant water absorption features no longer an issue

- Residual water vapor signal is removed by direct detection of water in dominant bands (MOD05 algorithm)

- similar removal of other atmospheric contaminants (aerosol, O3, NOx, etc)

(b) Cloud removal



MODIS: high-accuracy cloud-detection, giving pixel-by-pixel cloud status: clear, mixed, cloudy; separate algorithm for cirrus (thin, high) clouds

<u>Conservative approach to clouds:</u>

- Cloudy pixels excluded

- Mixed pixels excluded

- Cirrus cloud pixels excluded

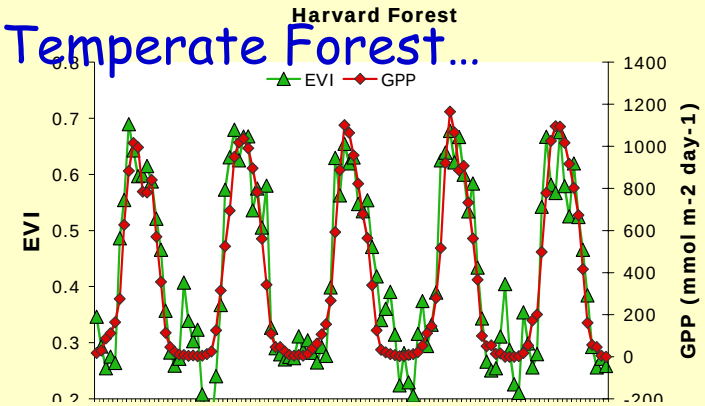
- Pixels adjacent to any cloudy, mixed or cirrus-cloudy pixels excluded

- similar detection/removal for cloud shadow

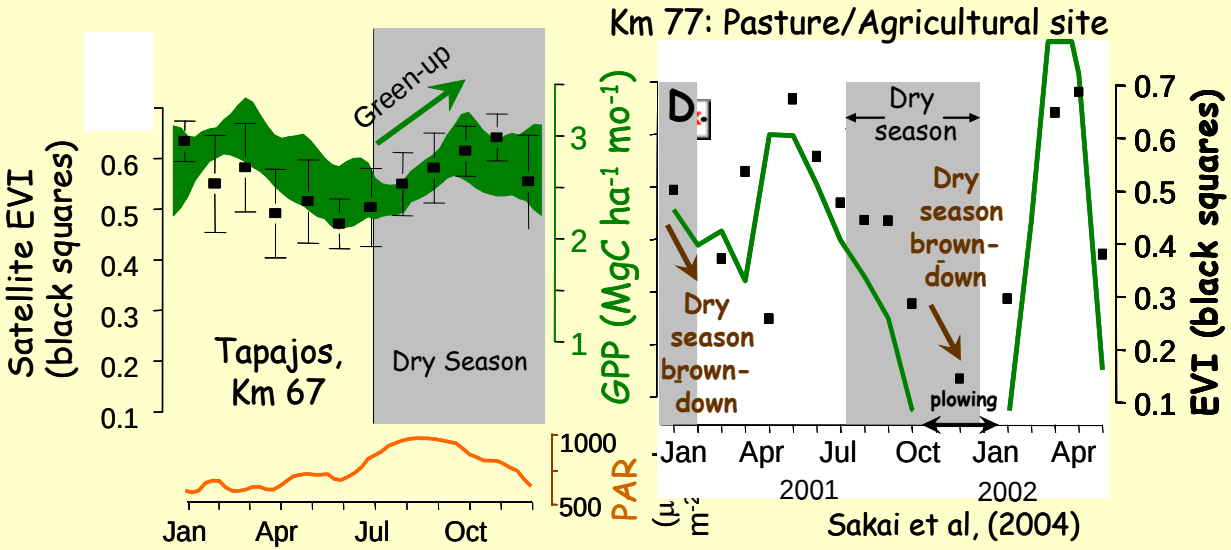
- similar detection/removal for medium/heavy aerosols (e.g. from fire)

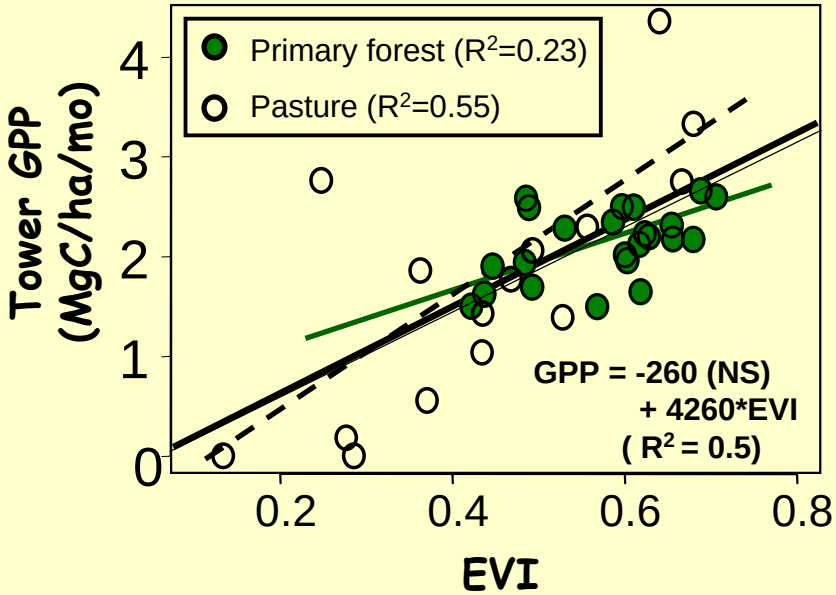
(c) Bottom-line test: comparison to ground-based tower measurements of GPP

Temperate Forest…



Amazon Forest…





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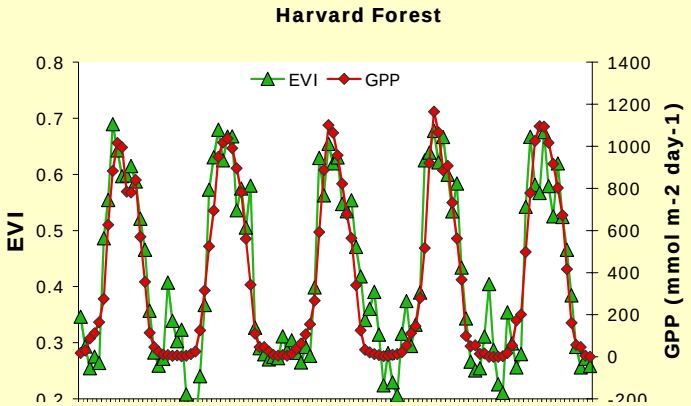
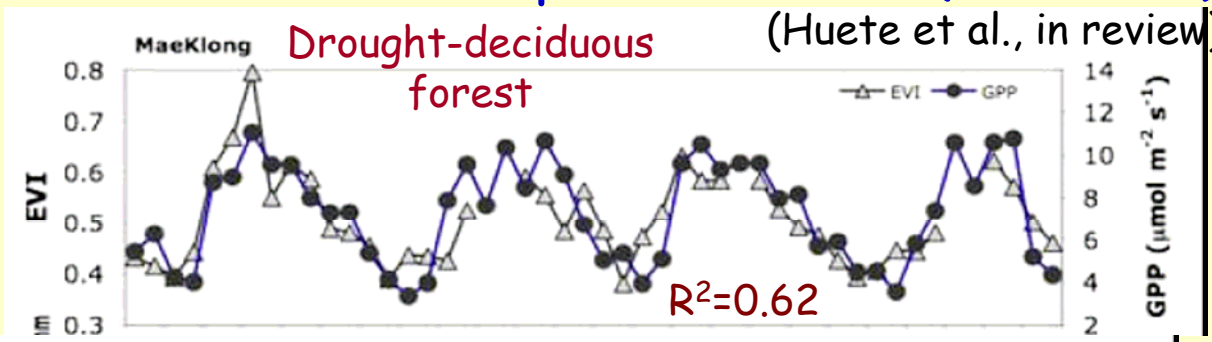
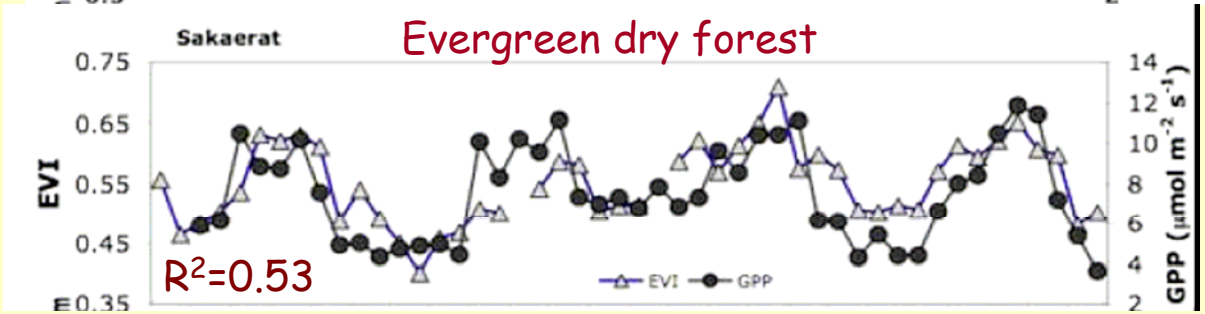
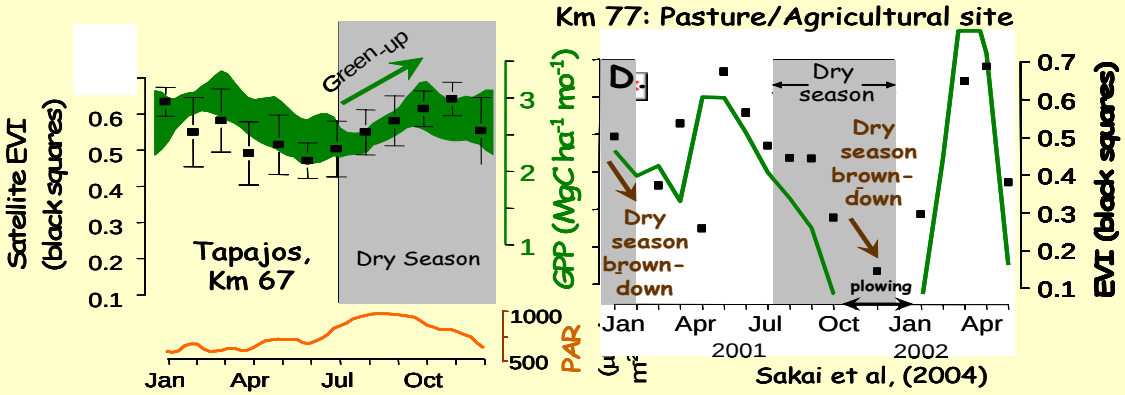


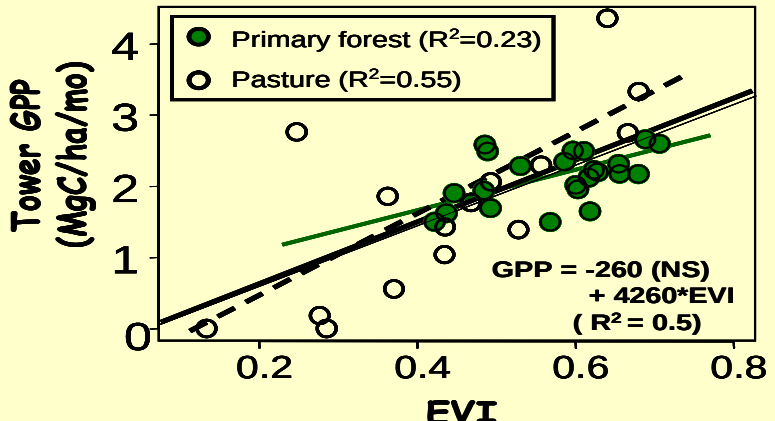
Monsoon Asia Tropical Forests (Thailand)

(Huete et al., in review)









Conclusion from tests and comparisons to ground measurements

(1) 2005 drought "green-up" is unlikely to be an artifact, but a real indicator of forest productivity

(2) Possible Biological causes:

a) more sunlight

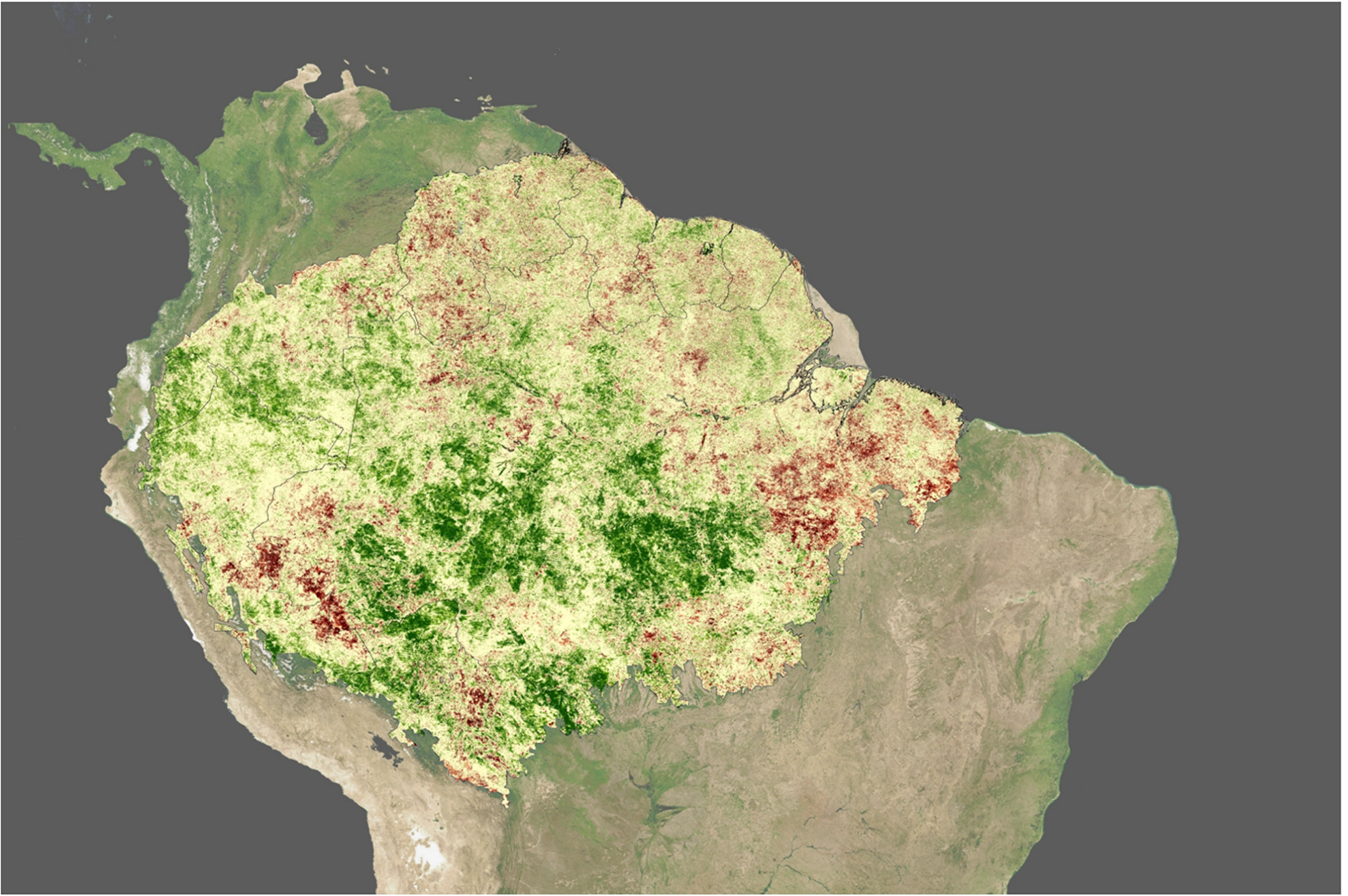
b) Increase in diffuse:direct sunlight (due to more aerosols from increased fires caused by drought) (quantified in Aragao et al., 2007)

Summary

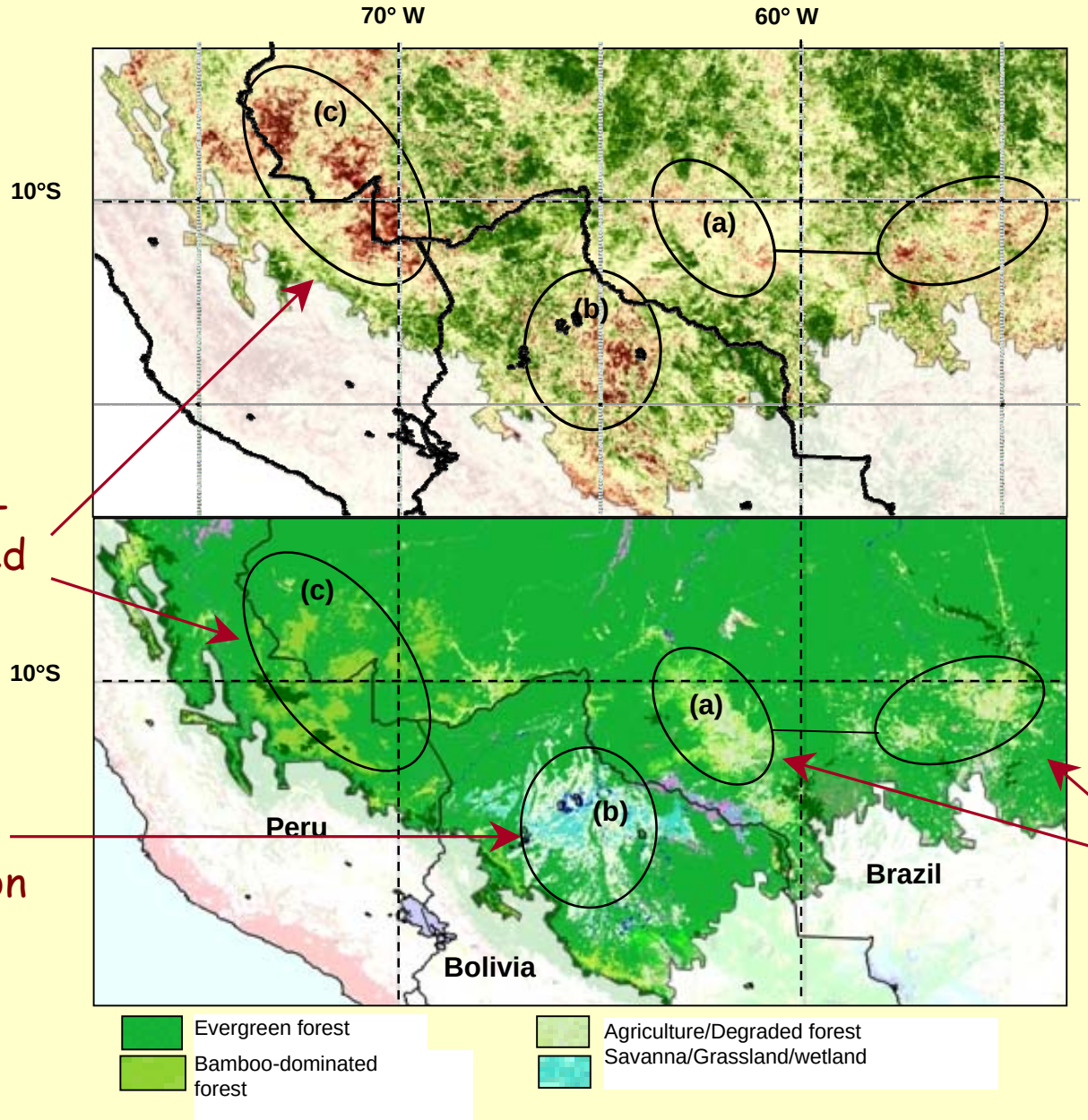
Amazon vegetation may be more resilient than ecosystem models predict, at least in the short term (seasonal variation and short droughts).
→ Forests have Adapted to dry seasons and short interannual drought, but biological adaptation is not represented in most ecosystem models

Caveats: fire and long-term drought are serious threats to the future of the Amazon
(e.g. Amazon fires increased by a third during the 2005 drought, Aragao et al., 2007)

Outstanding Question: what does it take to "break" an Amazon forest? Can climate change do it? What about the next big ENSO event?



Extras



Close-up of Greenness anomaly

Bamboo-dominated forests

Land-cover map

Non-forest vegetation

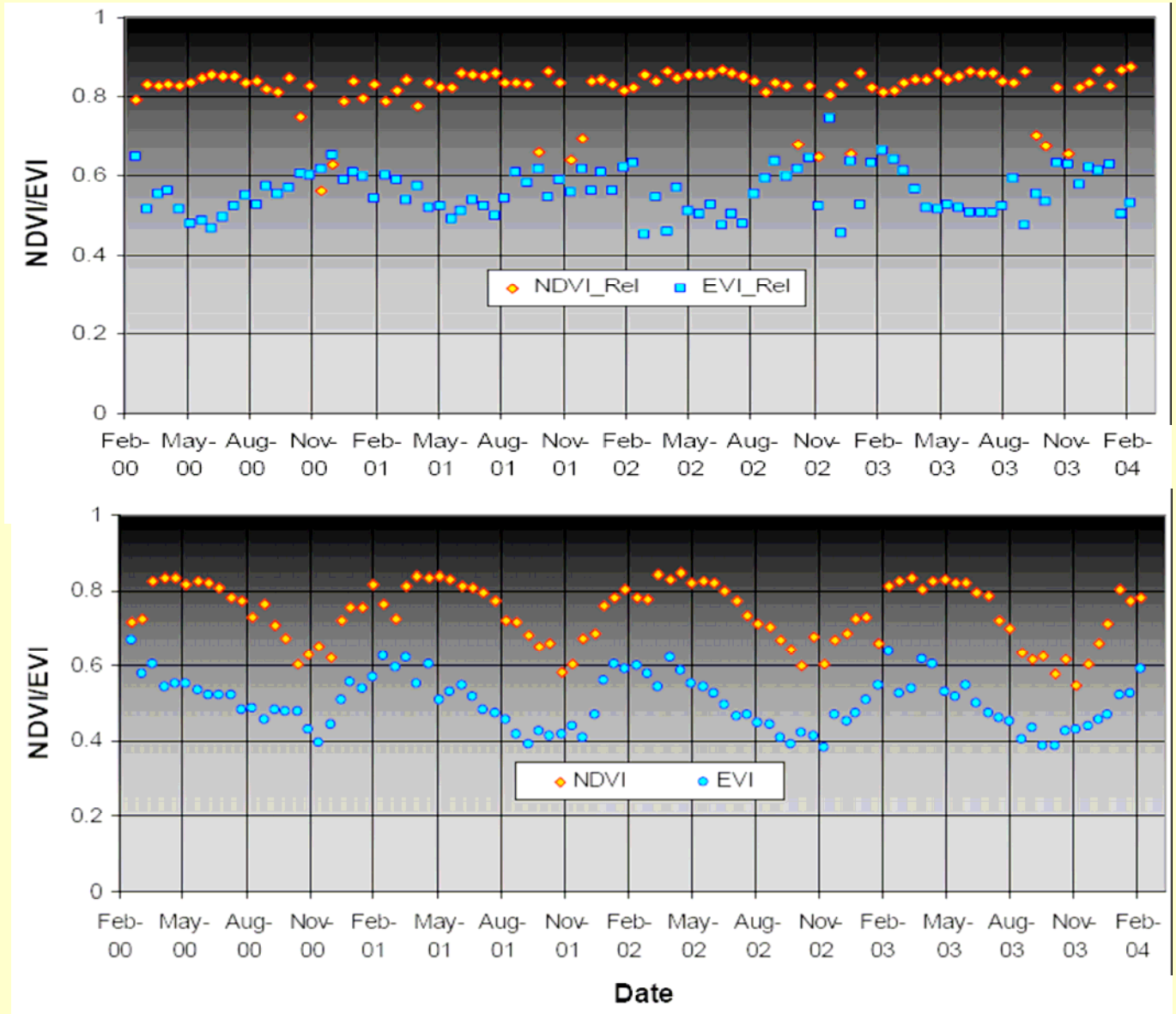
Converted forest / human impacted

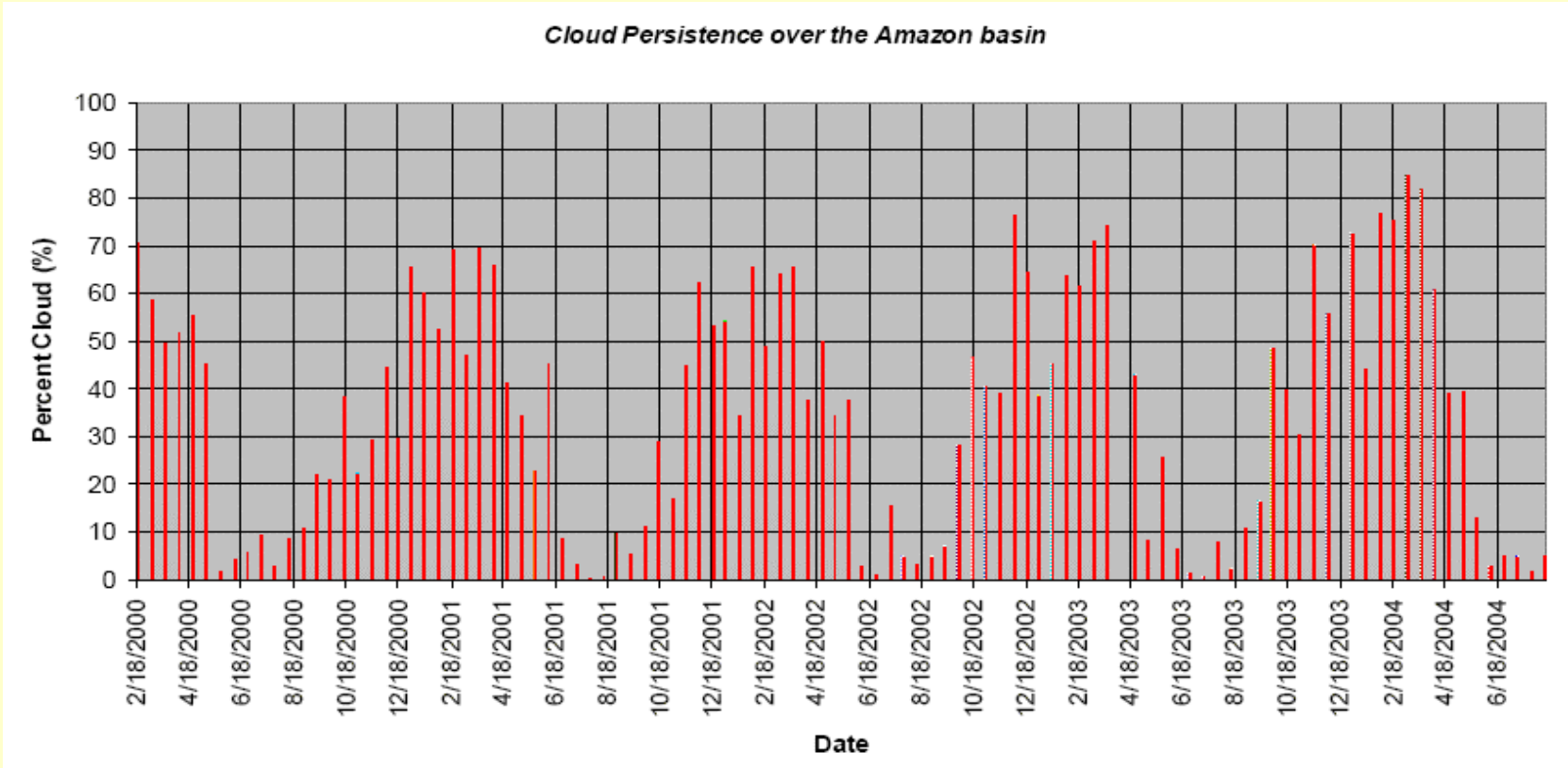
Forest (East of Tapajos)

NDVI saturates

converted from forest (south of Belem)

NDVI not saturated




Cloud Persistence over the Amazon basin
Percent Cloud (%)
100
90
80
70
60
50
40
30
20
10
0
2/18/2000
4/18/2000
6/18/2000
8/18/2000
10/18/2000
12/18/2000
2/18/2001
4/18/2001
6/18/2001
8/18/2001
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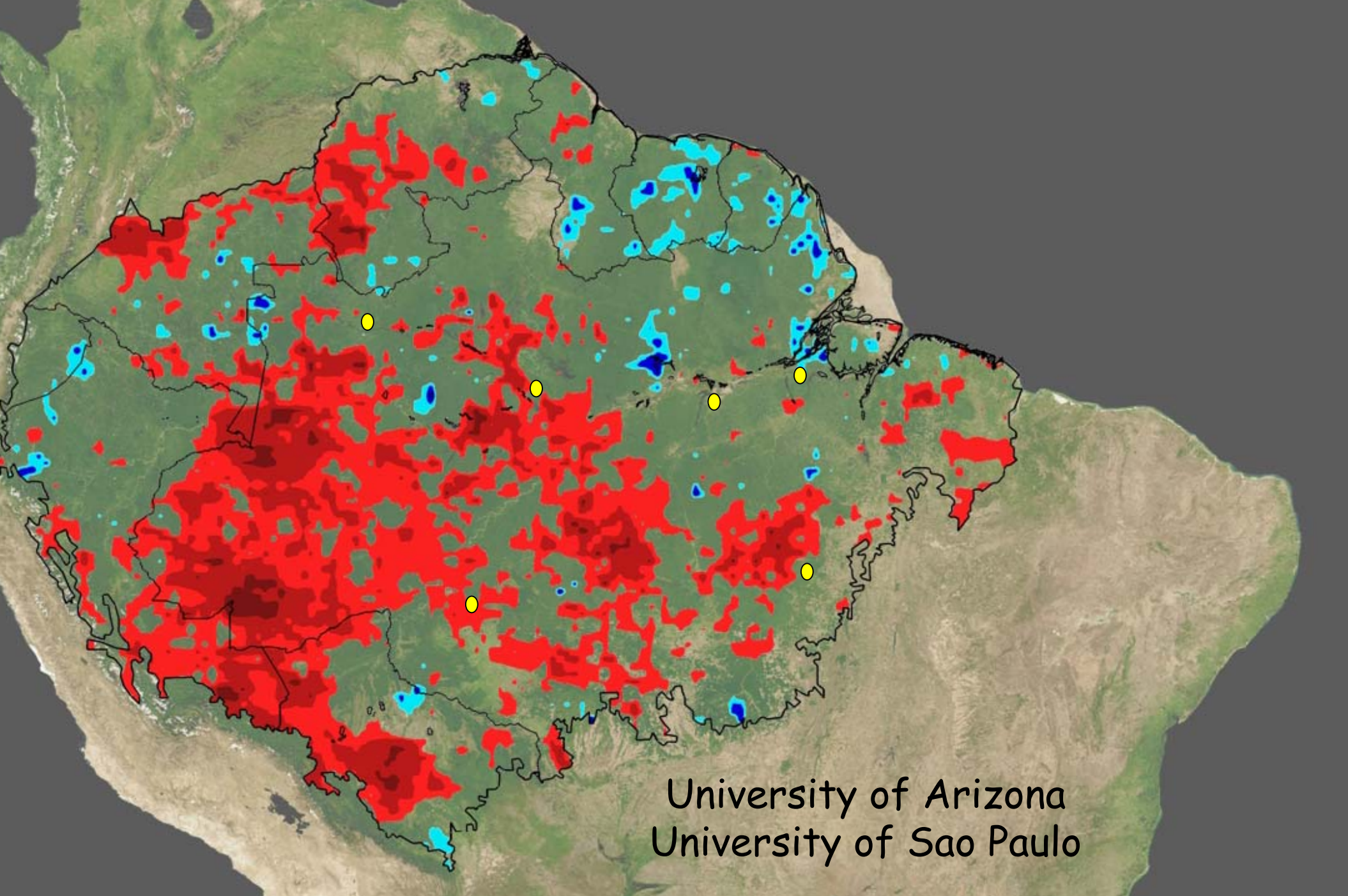
Date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