The Amazon Basin and Land-Cover Change: A Future in the Balance?

Carlos Nobre, (National Space Research Institute-INPE-Cachoeira Paulista, Brazil);
Paulo Artaxo, Maria Assunção Silva Dias and Reynaldo Victoria (University of São Paulo, Brazil),
Antonio Nobre (National Institute for Amazonian Research-INPA-Manaus, Brazil),
Thelma Krug (INPE, São José dos Campos- Brazil).

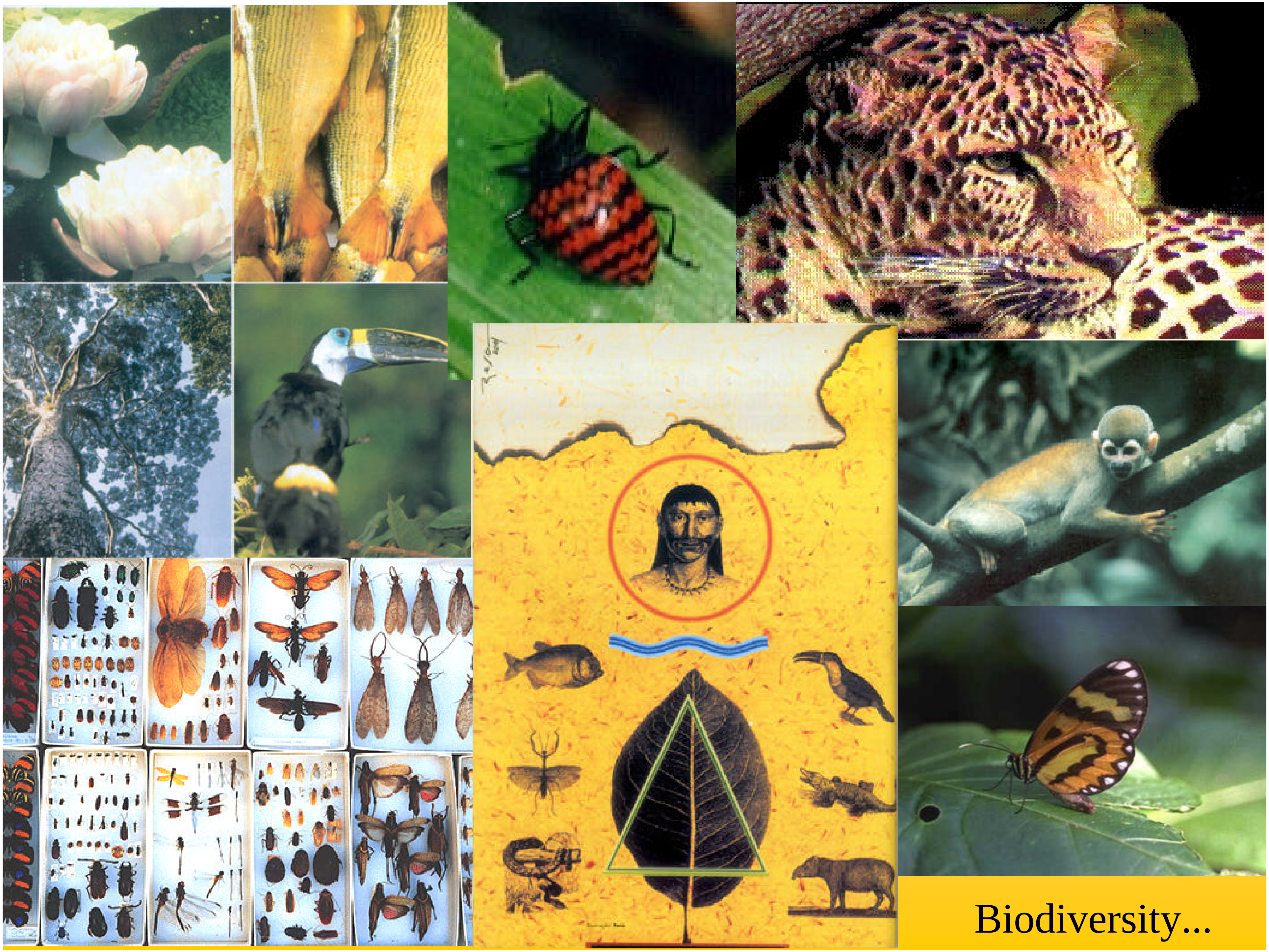
Special thanks to

The LBA community and to the art of photographer Sebastião Salgado

INTRODUCTION

Amazonia at a glance ... The Natural System

- 6 million km^2 of contiguous tropical forests
- perhaps 1/3 of the planet's biodiversity
- abundant rainfall (2.2 m annually)
- 18% of freshwater input into the global oceans (220,000 m^3/s)
- a multitude of ecosystems, biological and ethnic diversity


Biodiversity...


The forest...

The rains...

The rivers...

Population Growth and Land Use Change

• modern occupation of Amazonia (since 1500): negligible land use change up to the 1960's, but large loss of ethnic diversity due to colonization

• large land use change in the last 30 years

• close to 600,000 km^2 deforested in Brazilian Amazonia (15%)

• high annual rates of deforestation (15,000 to 30,000 km^2/year)

Deforestation...

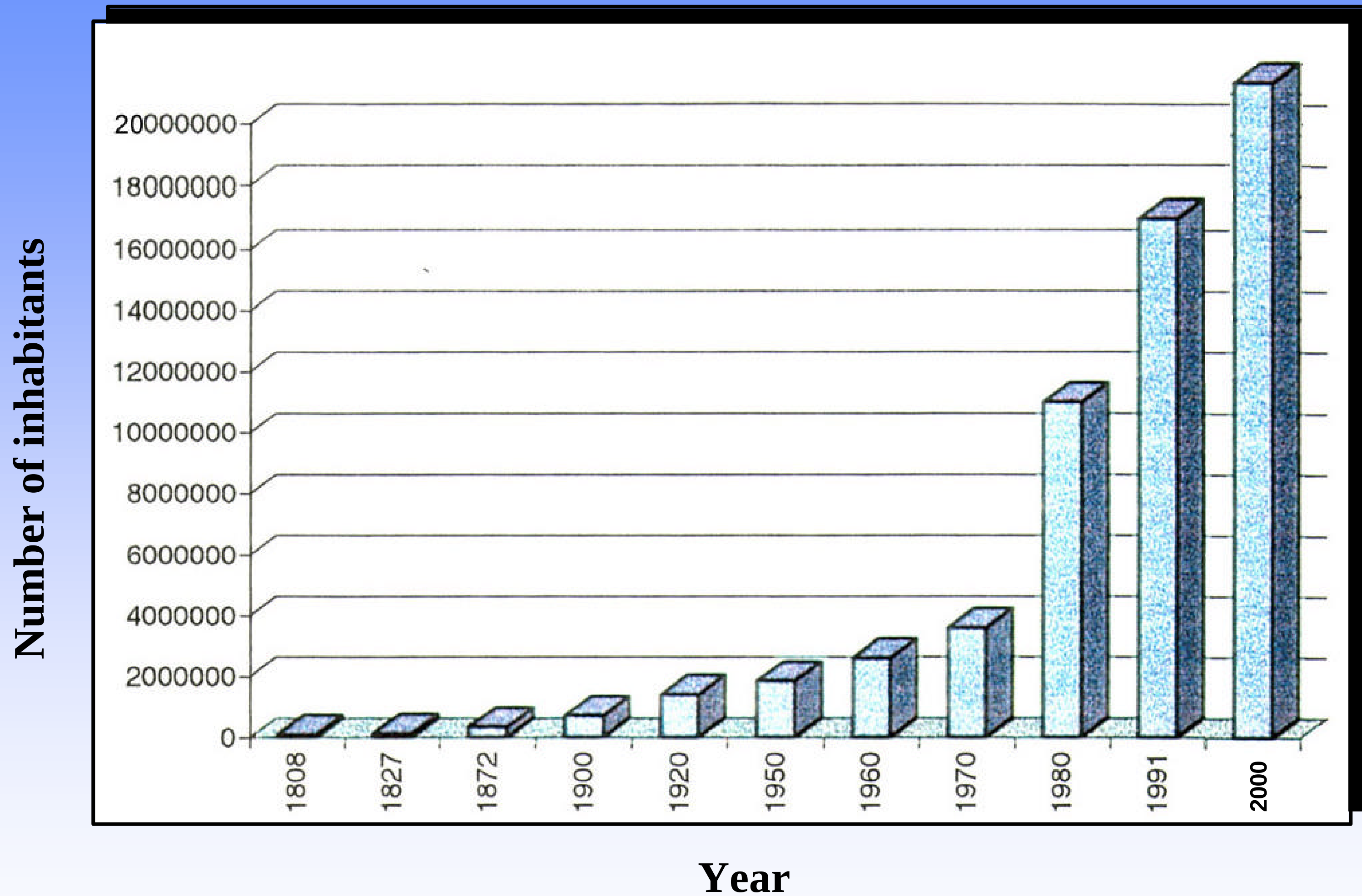
Fire...

Fire...

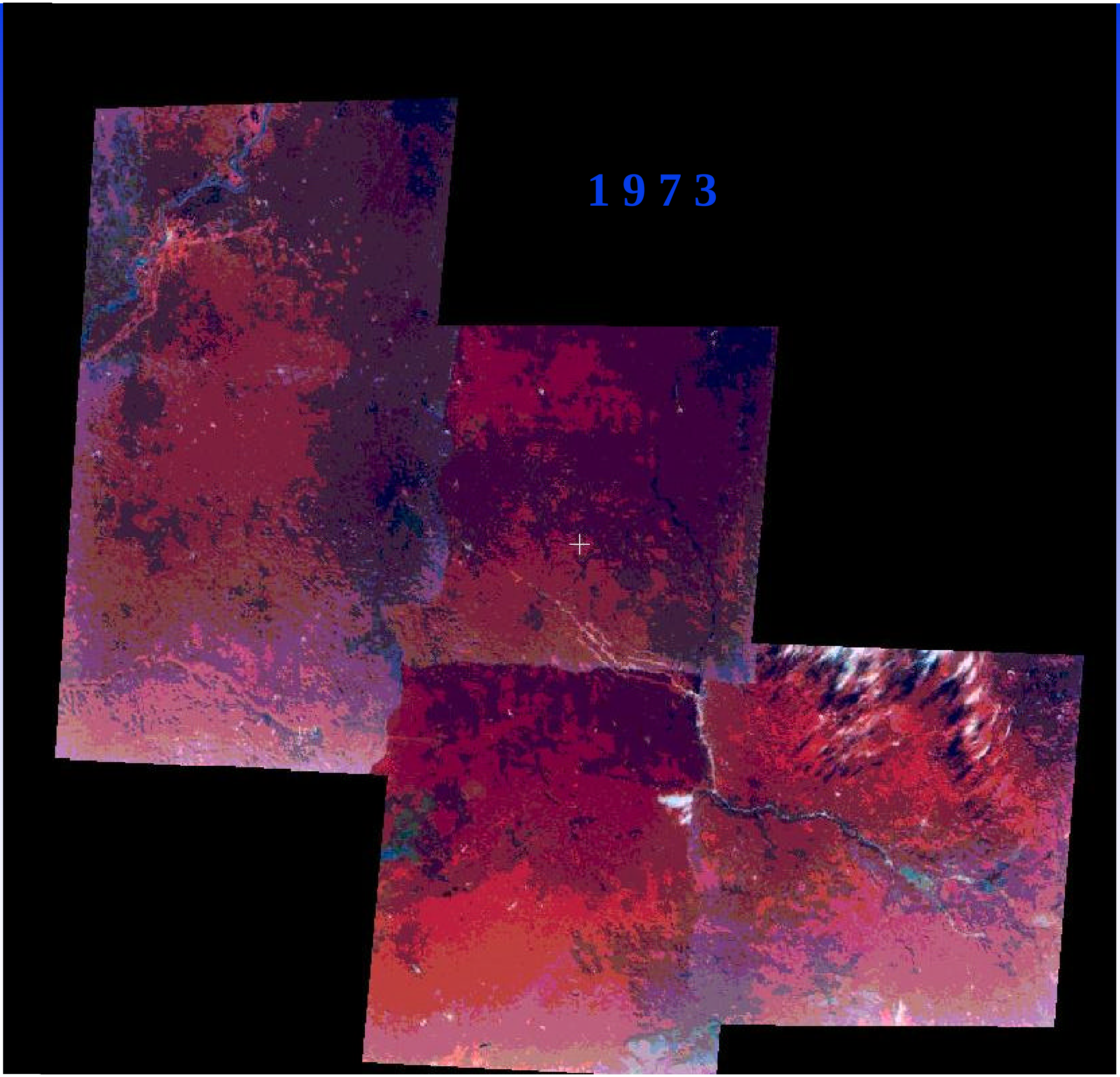
Causes for Land Use Change:

- Government plans to “integrate” Amazonia
- road network throughout the region
- population growth in Amazonia: 3,5 million in 1970, up to 20 million in 2000, though 65% living in large and mid-size cities and towns
- colonization projects: rush of landless people to small scale, low tech agriculture
- subsidized cattle ranching
- destructive logging as a vector to subsequent deforestation

Population Growth in Brazilian Amazonia (1808-2000)

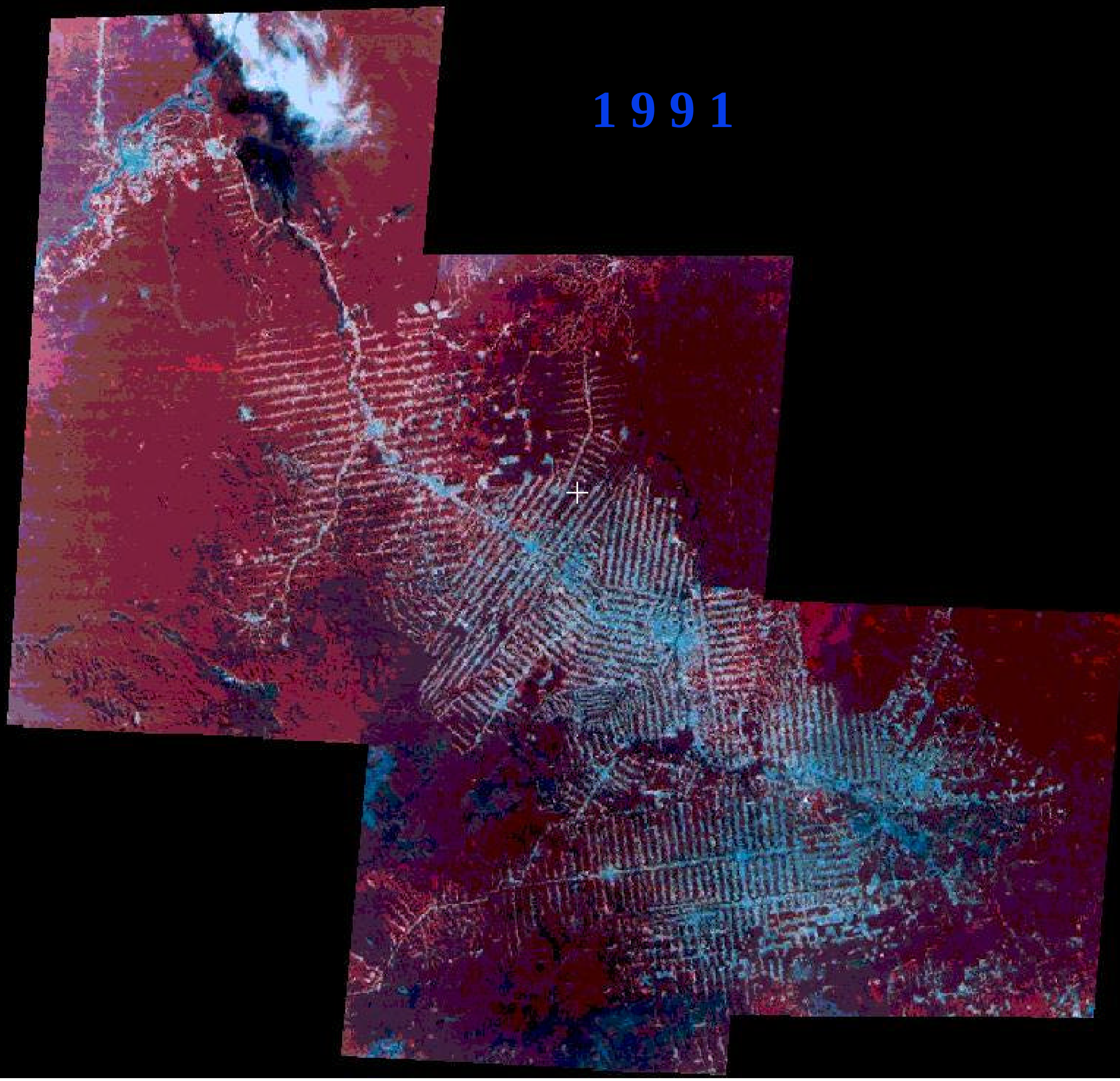


Source: IBGE, 2001

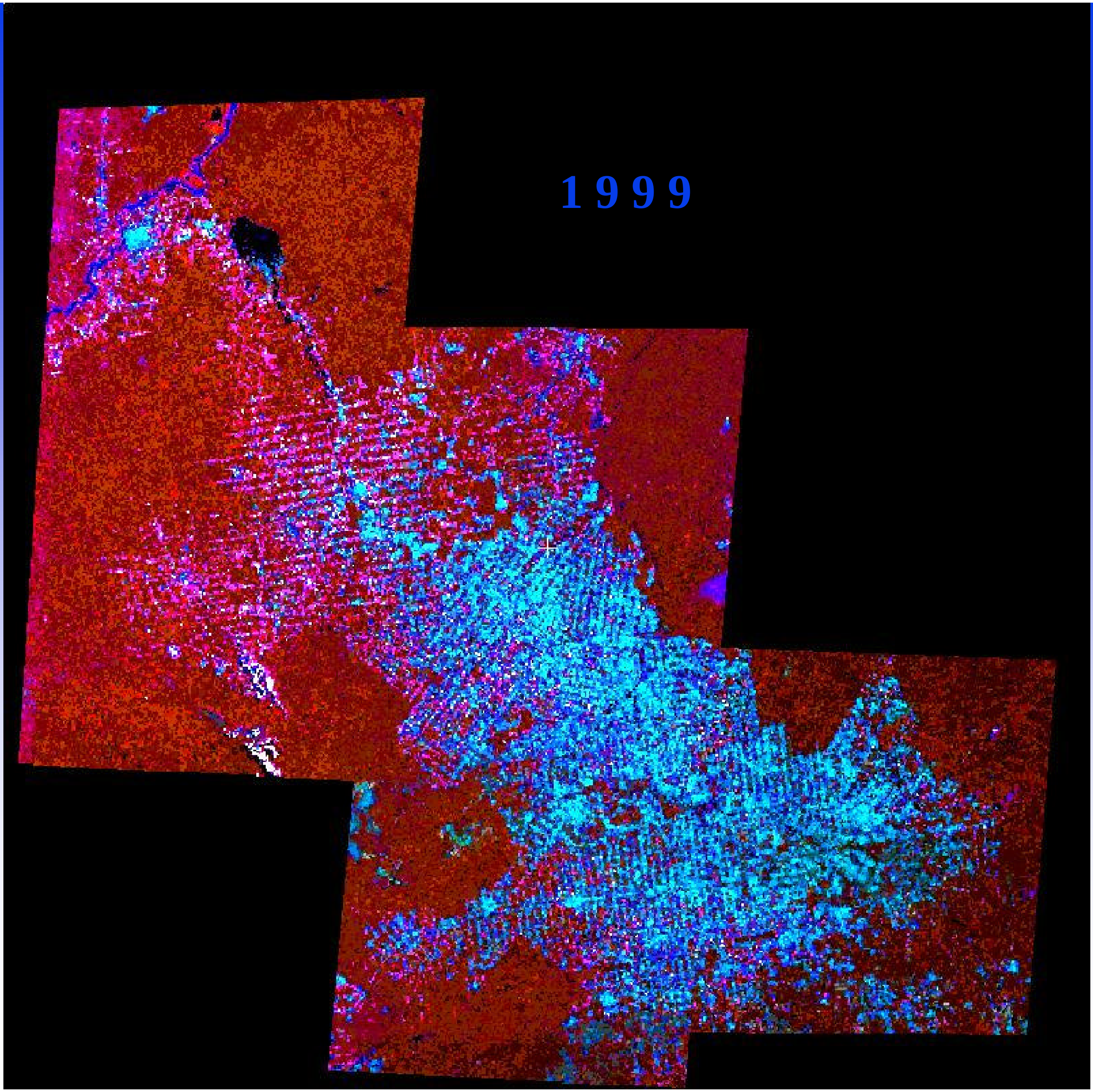


Courtesy: INPE/OBT

1991

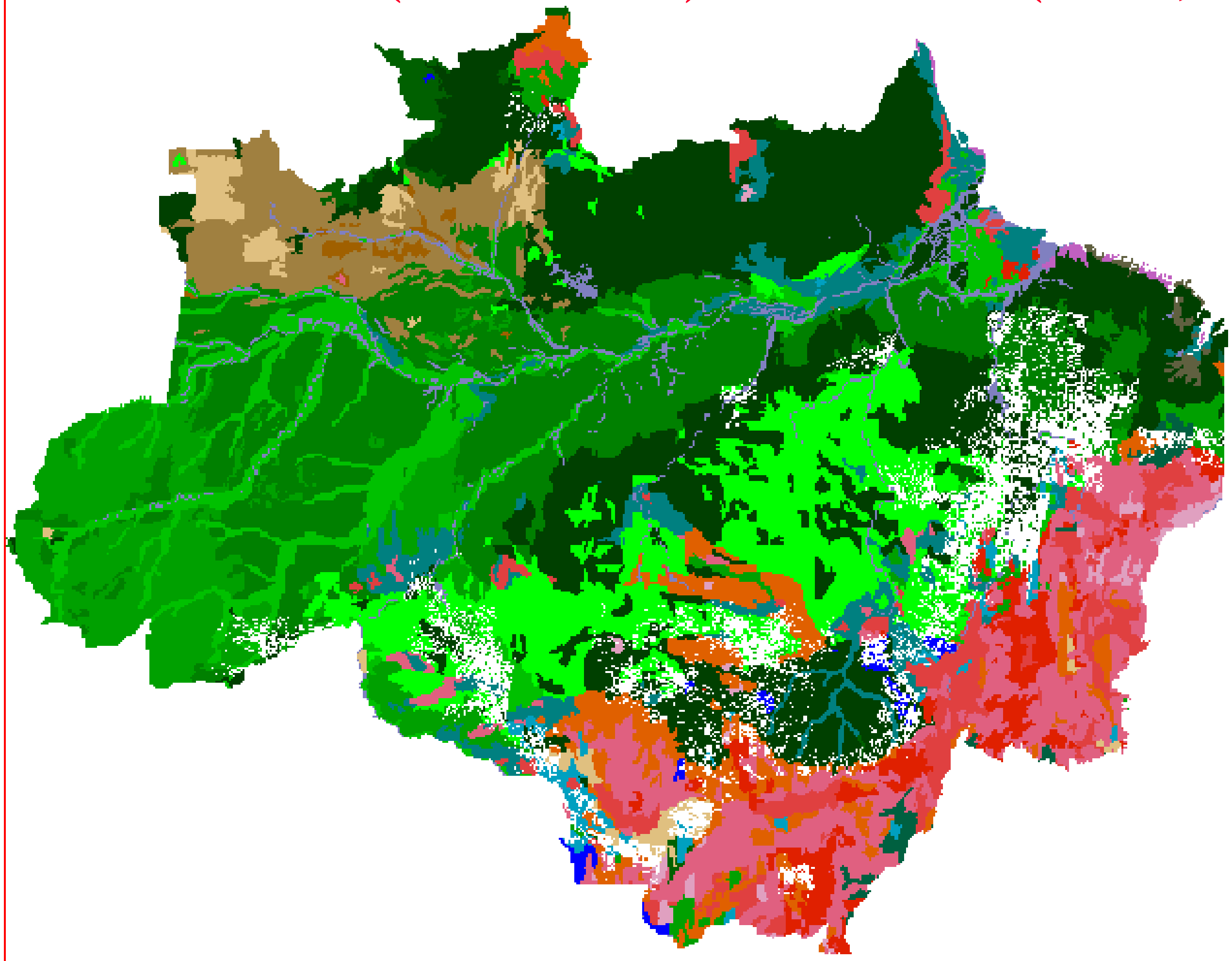


Courtesy: INPE/OBT



Courtesy: INPE/OBT

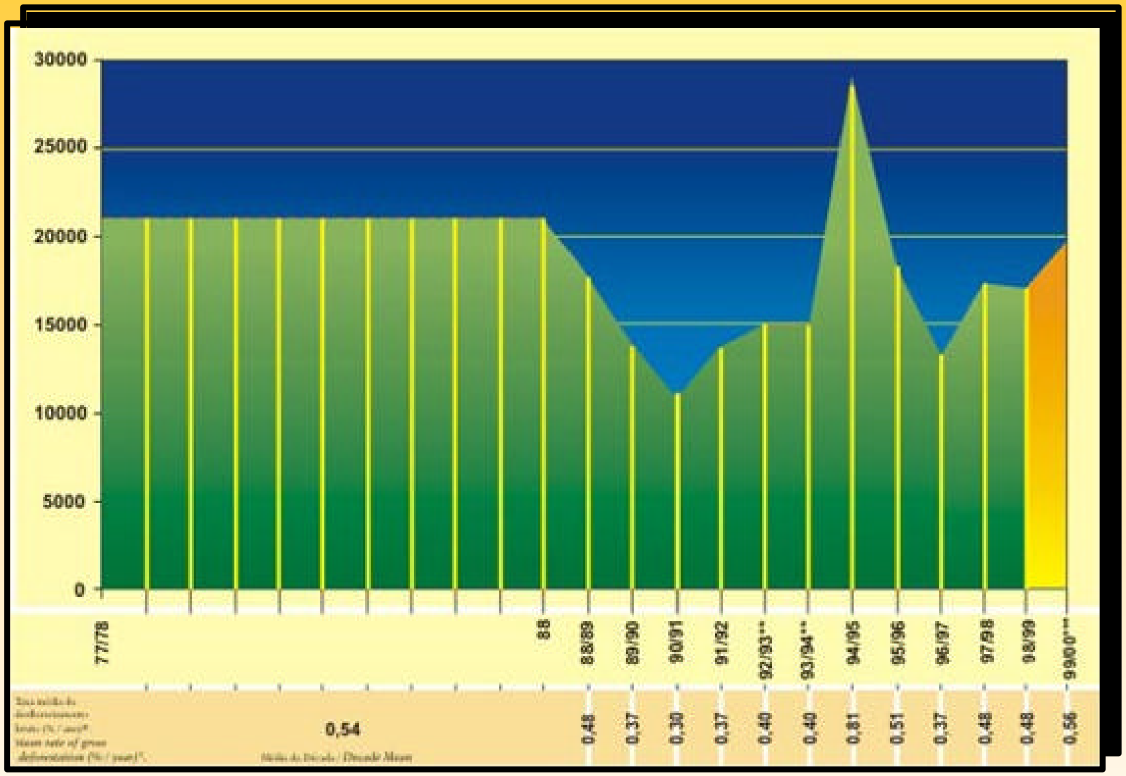
VEGETATION MAP (RADAM 1:5000000) + DEFORESTATION (PRODES, 1997)



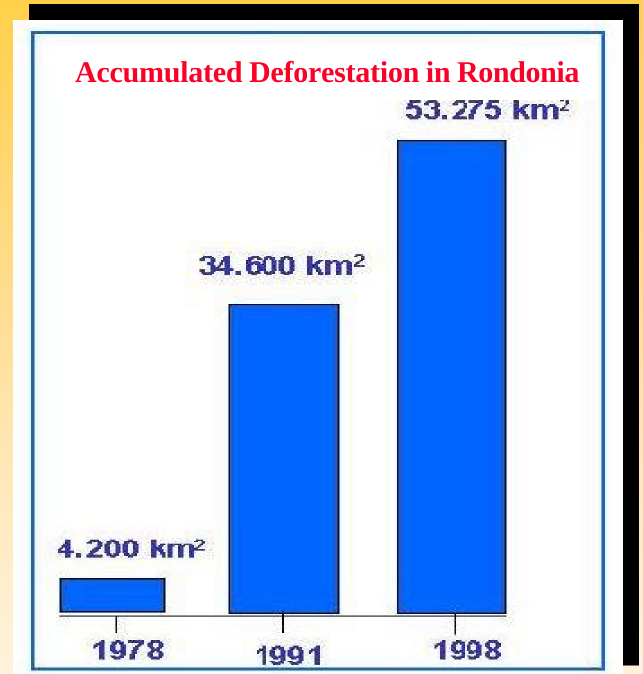
Courtesy: R. Alvalá, E. Kalil, INPE

Monitoring the Brazilian Amazon Forest

Evolution of the mean rate of gross deforestation in Amazon (km^2 / year).



INPE, 2001



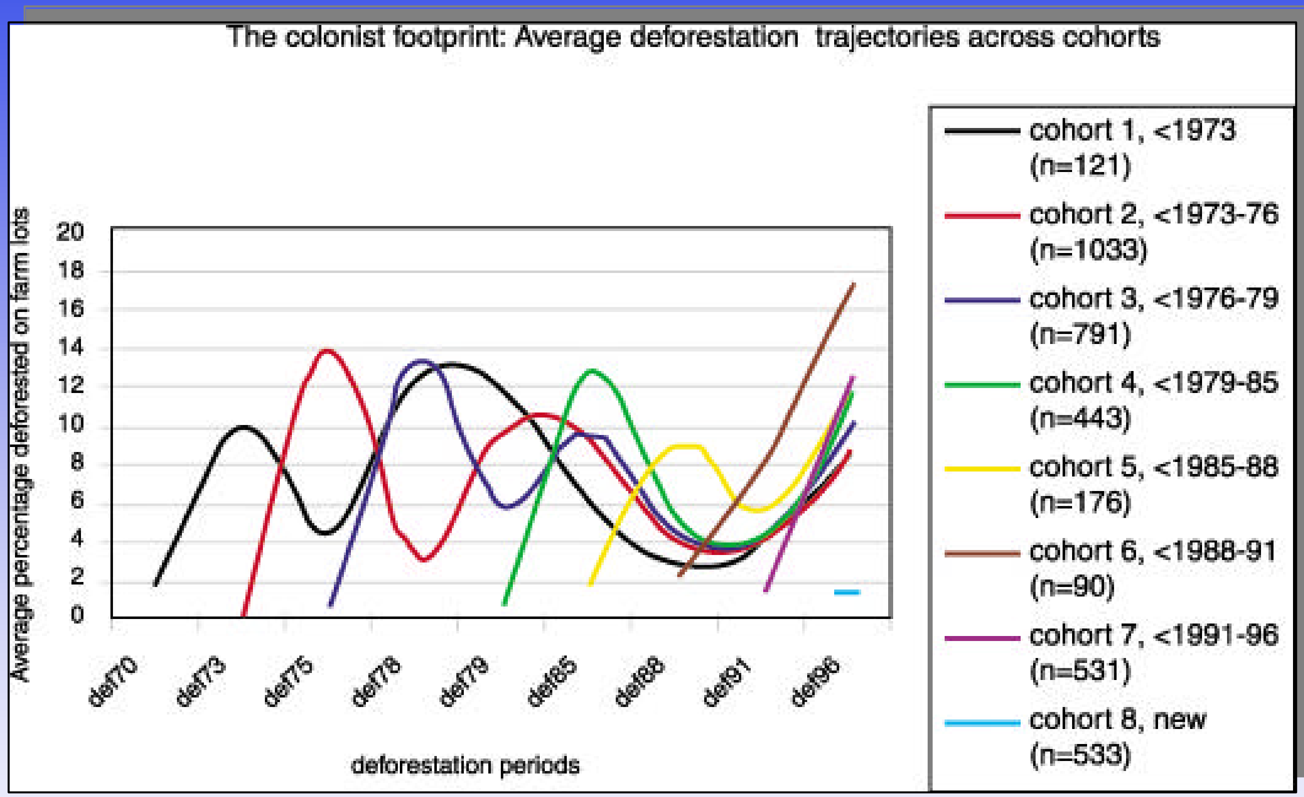
Courtesy: INPE/OBT

* Relative to the area of remaining forest.

** Data from 1993 and 1994 refer to an estimate of the mean rate of gross deforestation for the period 1992-1994.

*** The mean rate of gross deforestation for 2000 was based on the analysis of 49 TM-Landsat images from that year.

The Colonists...

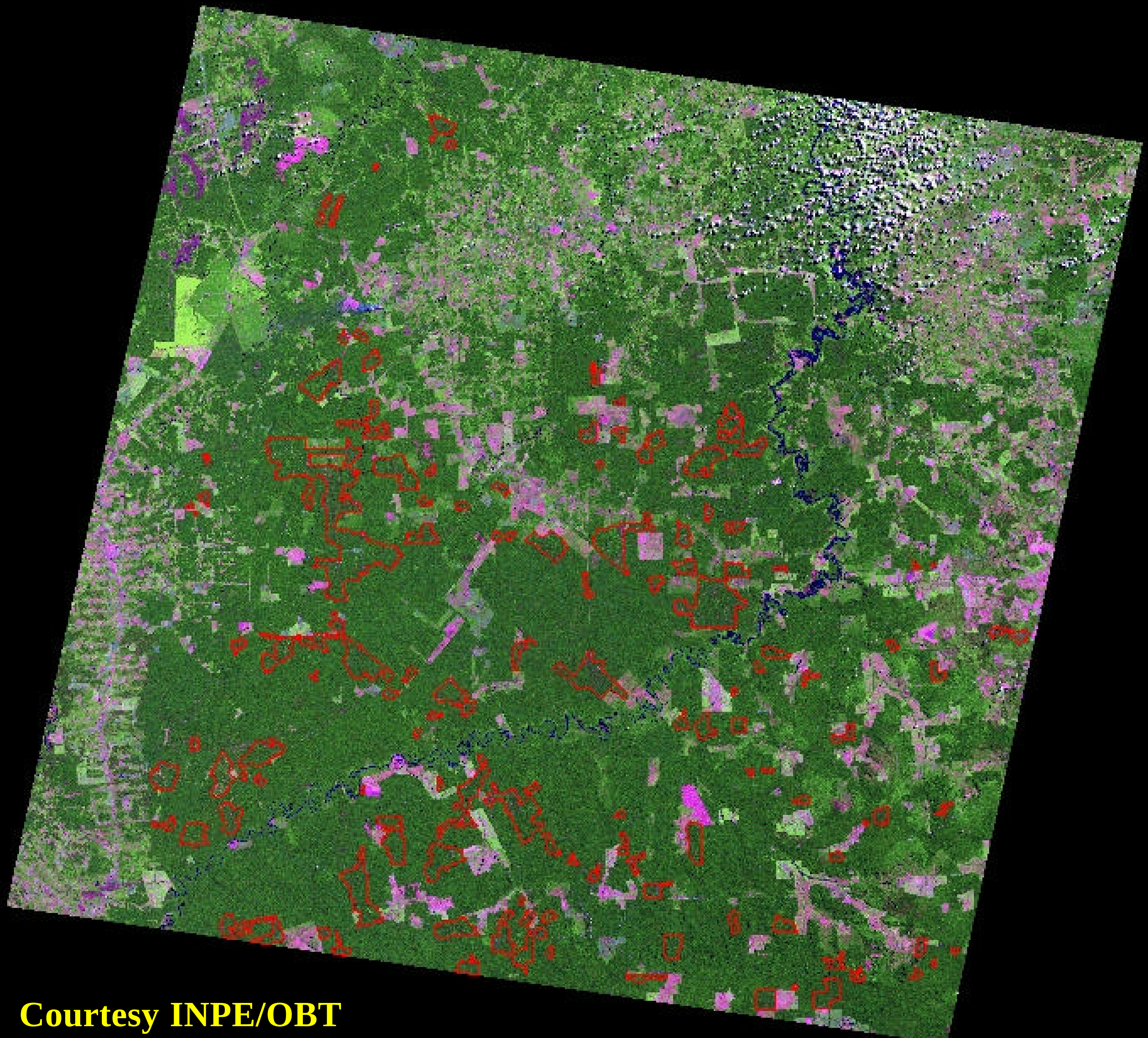


The colonist footprint:Average deforestation trajectories across cohorts (Moran and Krug, Global Change News Letter, 2001).

Selective logging...

SELECTIVE LOGGING

TOTAL AREA SELECTIVE LOGGING = 1,277 km^2



Courtesy INPE/OBT

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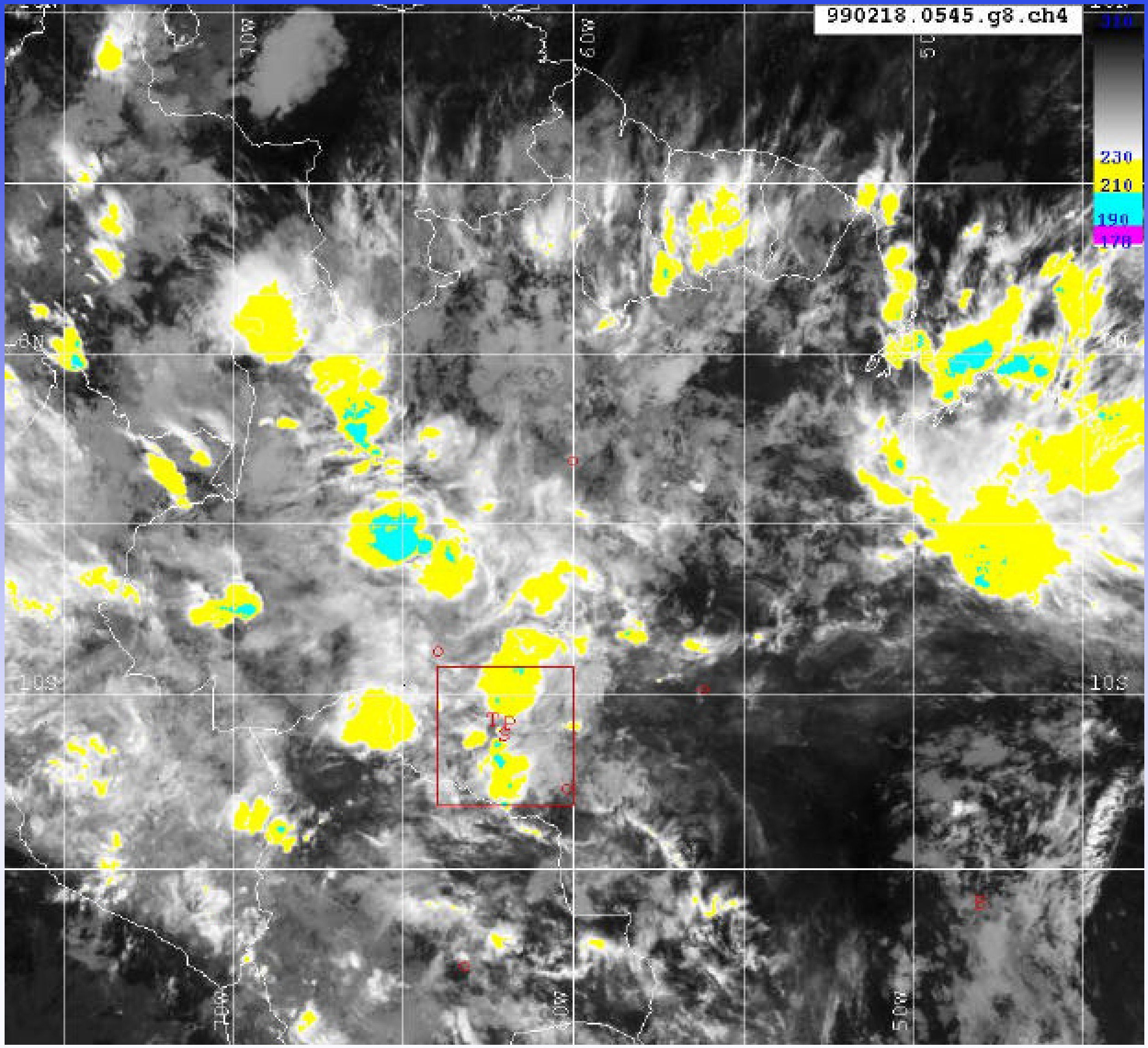
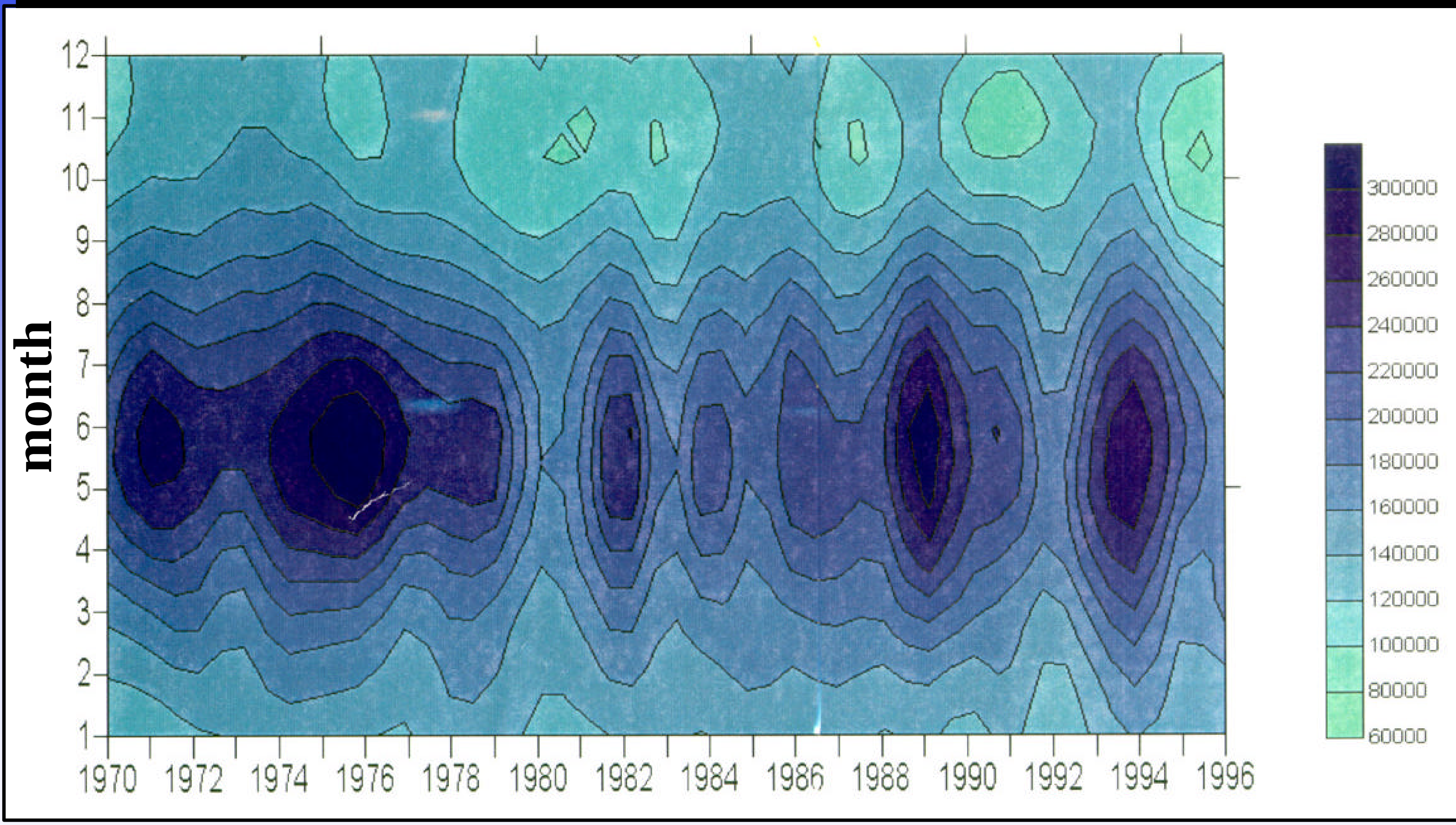
Biogeophysical cycles in and out of balance...

- Hydrological cycle, land surface and climate
- Aerosols and climate
- Carbon cycle
- Water biogeochemistry


990218.0545.g8.ch4
230
210
190
178
70W
60W
50W
10S
10S

Amazon River Discharge (m^3/s)
station: Óbidos (01 S, 55 W)



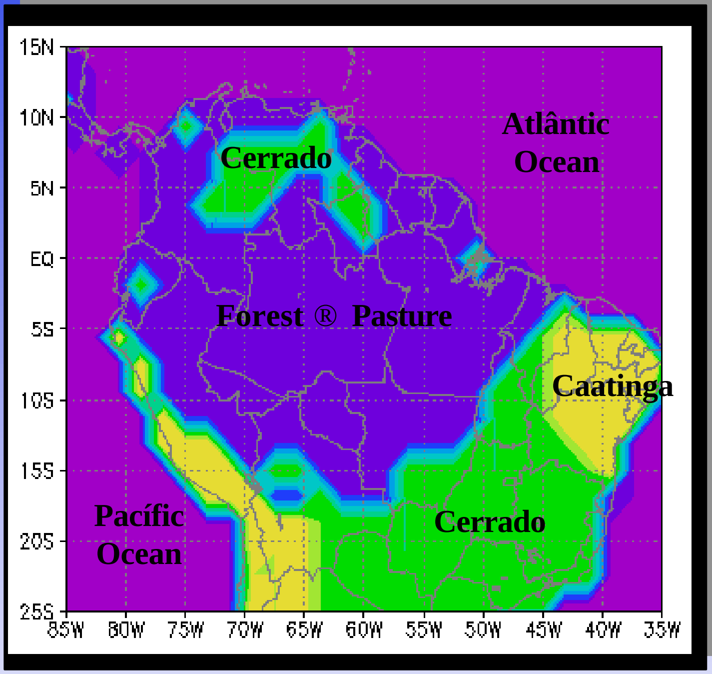
Year

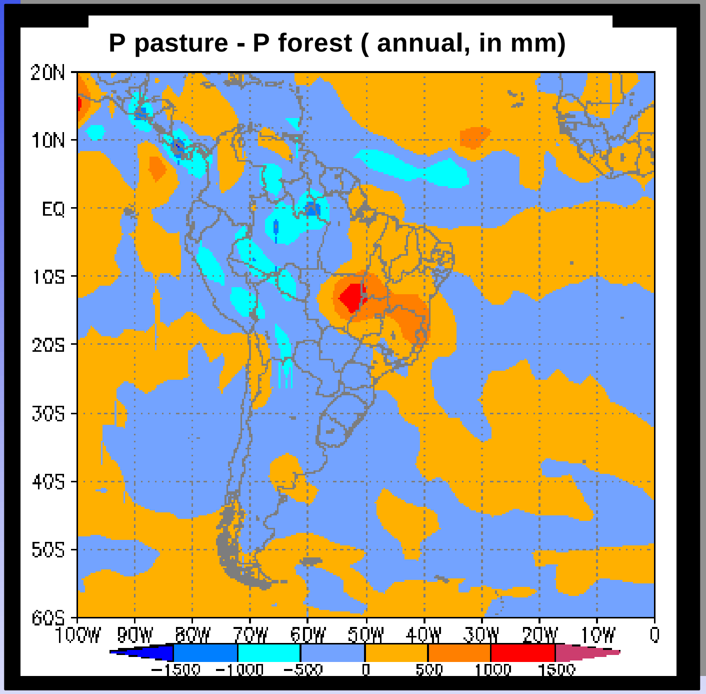
Large interannual variability in the hydrological cycle

From forest to pasture...

Simulating the impacts of deforestation

EFFECTS OF LARGE SCALE DEFORESTTION



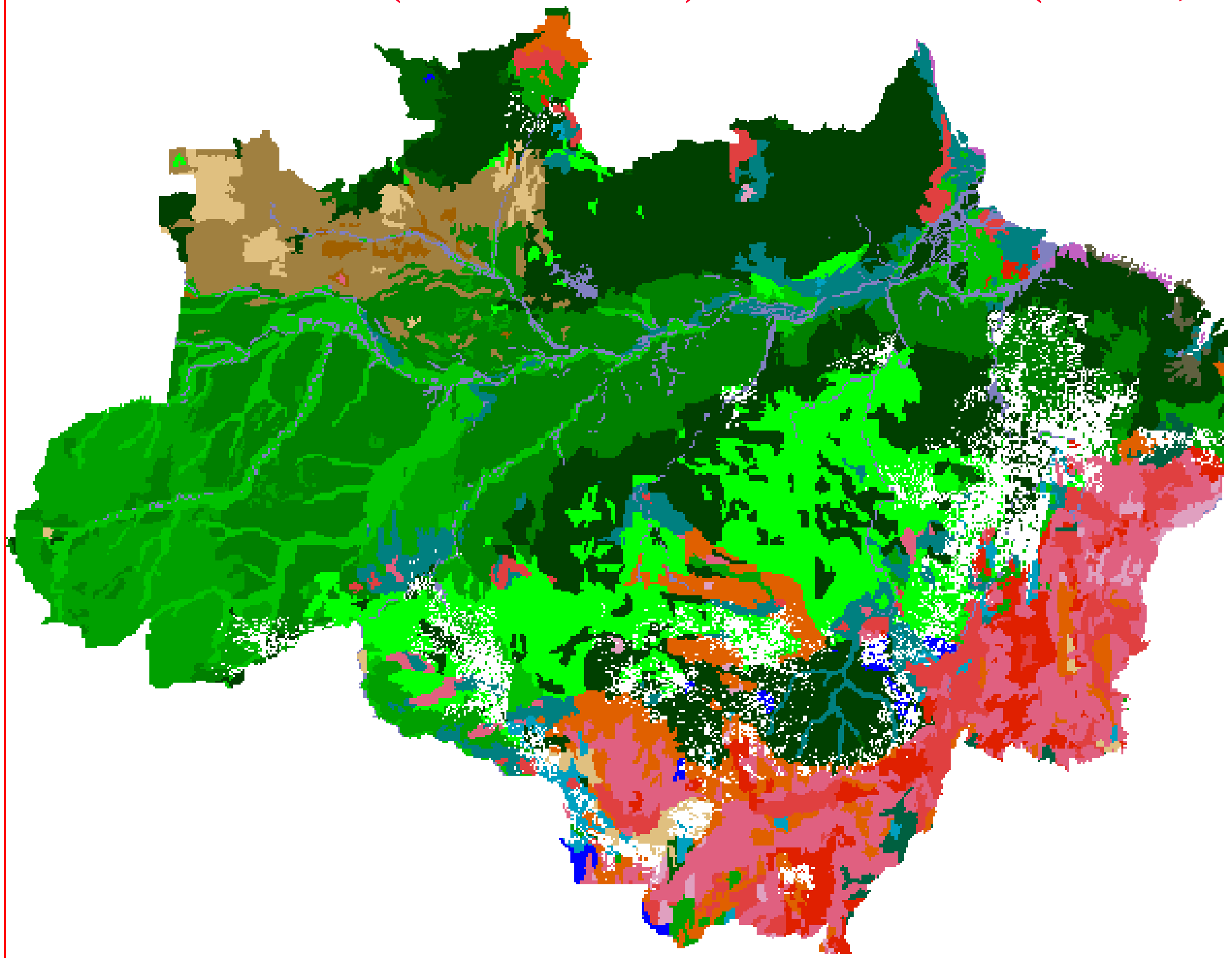


Rocha, 2001.

Numerical Simulations of deforestation

- 1 to 2.5 C surface temperature increase
- 15% to 30% evapotranspiration decrease
- 5% to 20% rainfall decrease

VEGETATION MAP (RADAM 1:5000000) + DEFORESTATION (PRODES, 1997)

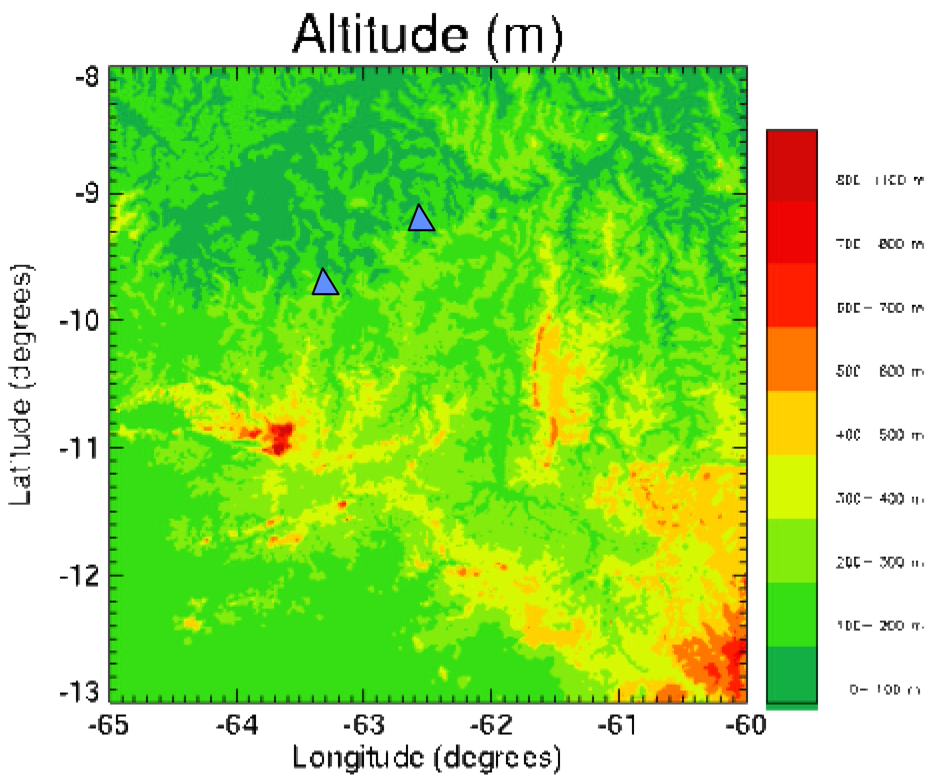


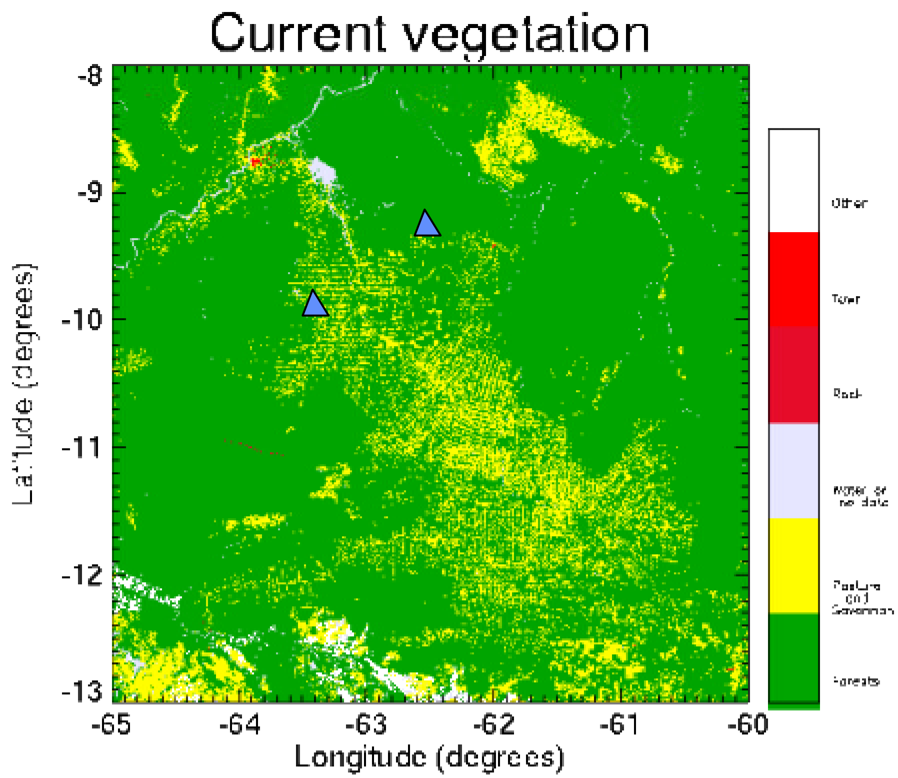
Courtesy: R. Alvalá, E. Kalil, INPE

Current patterns of deforestation in white color

Effect of regional deforestation

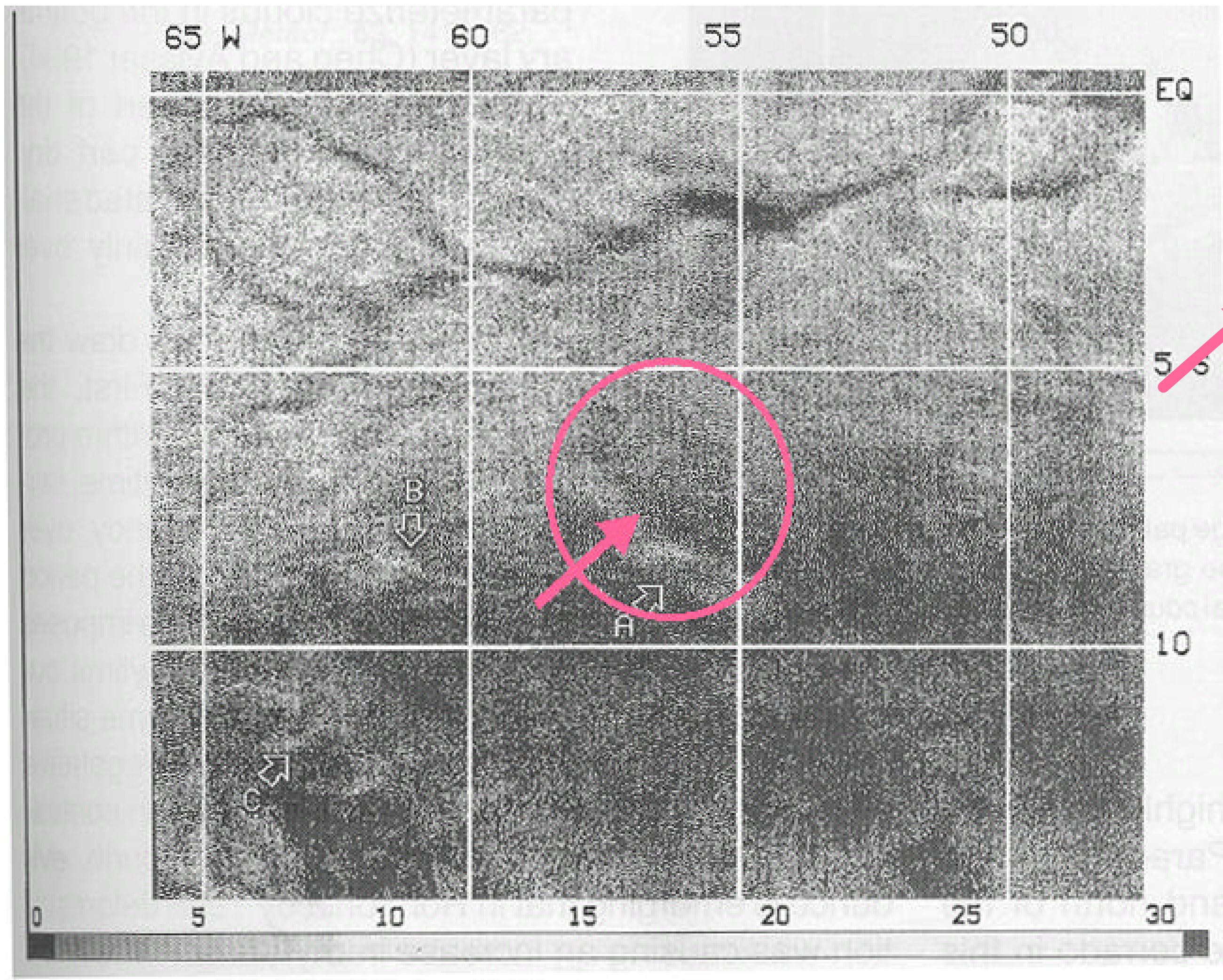
- Enhance local circulation
- Increase rainfall amounts
- Different impact on cloudiness in the dry and wet seasons





Rondonia, SW Amazonia

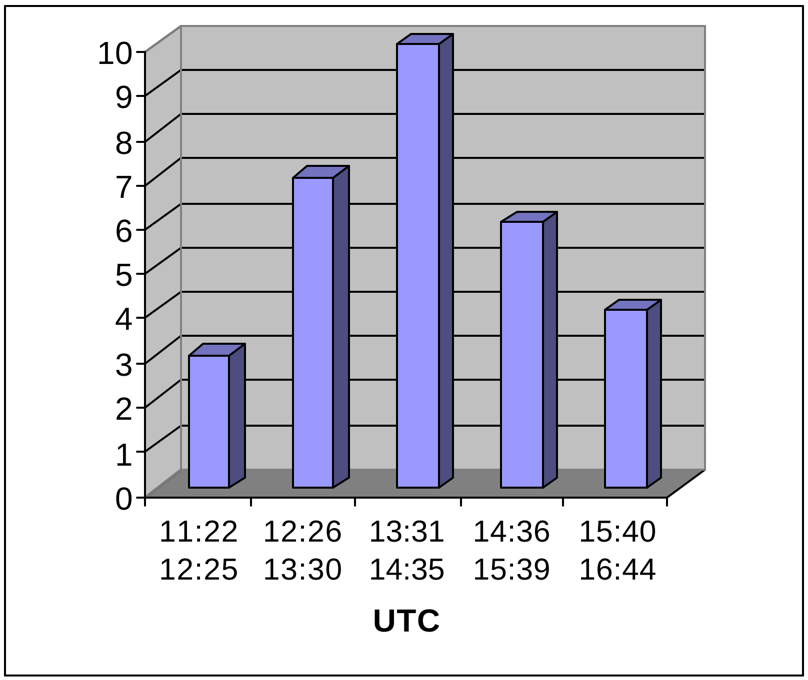
Effect of deforestation on shallow cumulus in the dry season: preferred growth over deforested areas



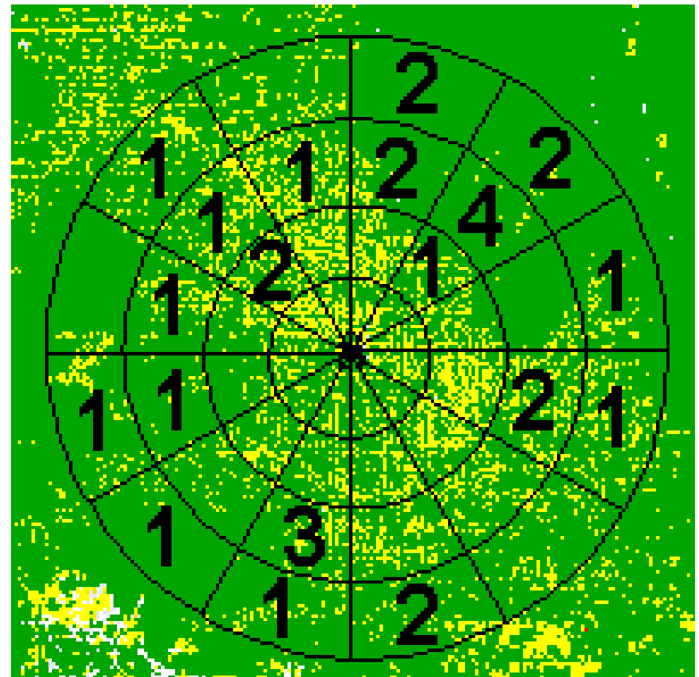
Road from Vilhena to Porto Velho in Rondônia

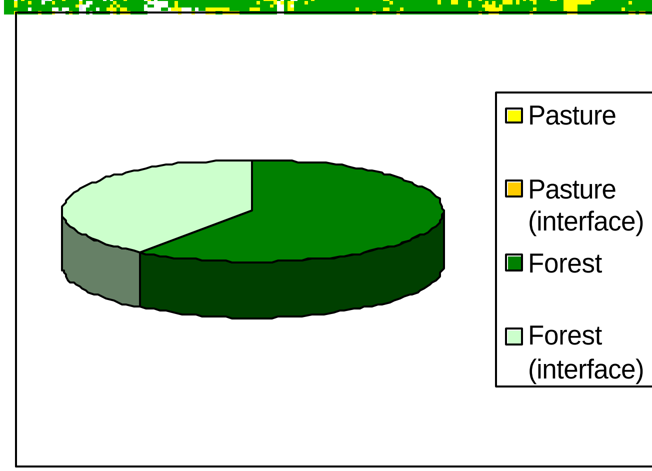
Cutrim et al, 1995

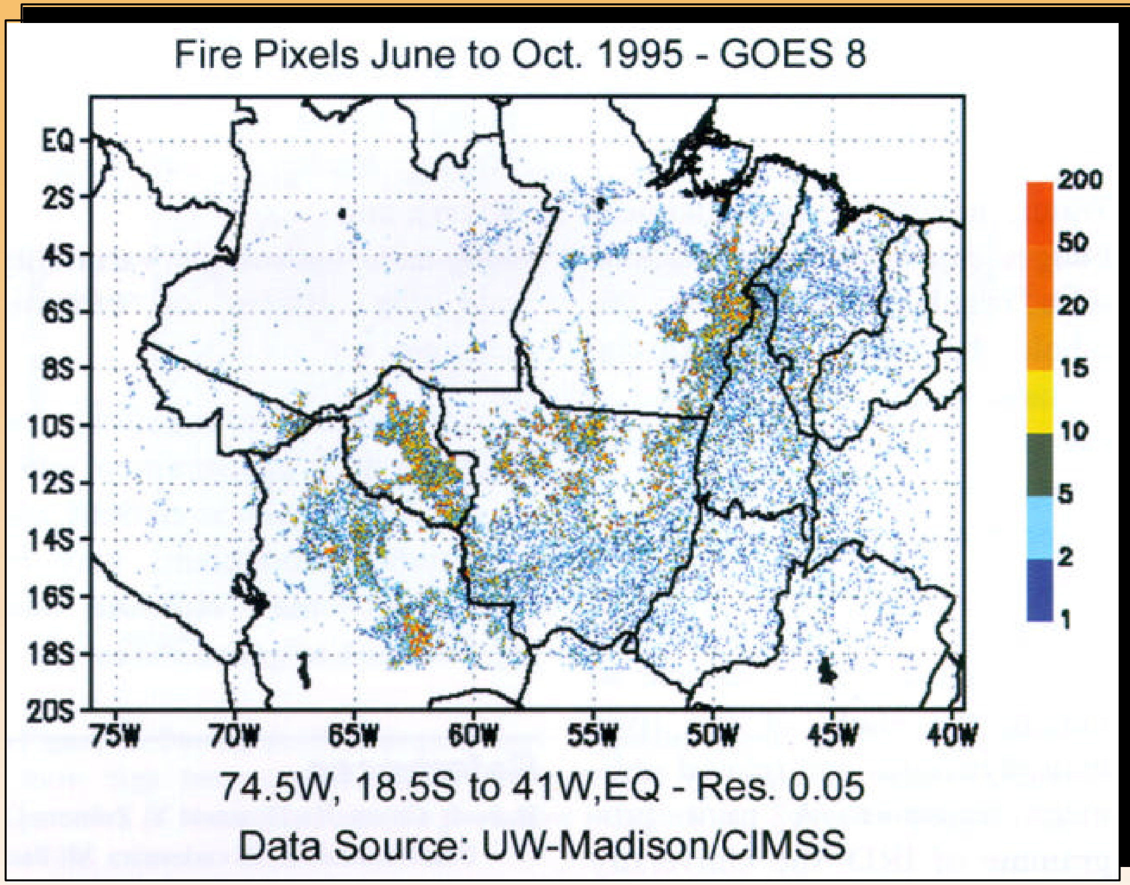
Effect of deforestation on shallow cumulus in the wet season: preferred growth over forest, forest/pasture interface and higher terrain



Time of first radar echoes at 1.1 degrees elevation angle (S-POL)



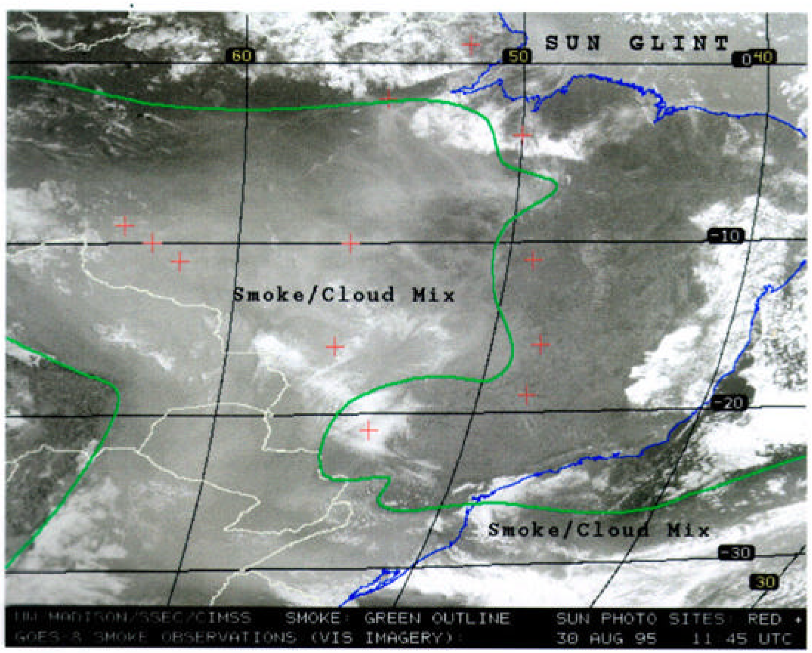




Spatial distribution of fires in Amazonia during the dry season.

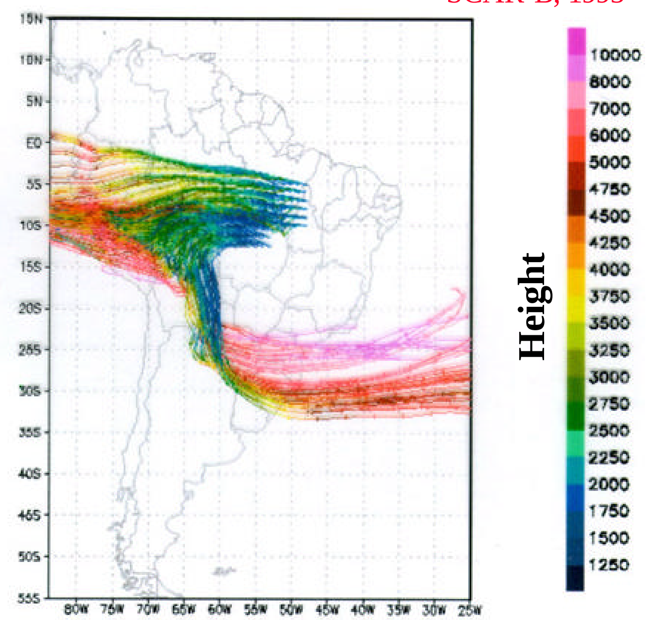
Spatial distributions of fires in Amazonia from June to October in 1995. Map resolution is approximately 0.5º, and colours indicate the number of fire pixels in the grid cells. Data from the ABBA fire product, based on GOES-8, of the UW-Madison Cooperative Institute for Meteorological Satellite Studies (CIMSS) (Prin et al. 1998).

Biomass burning smoke covers millions of km^2



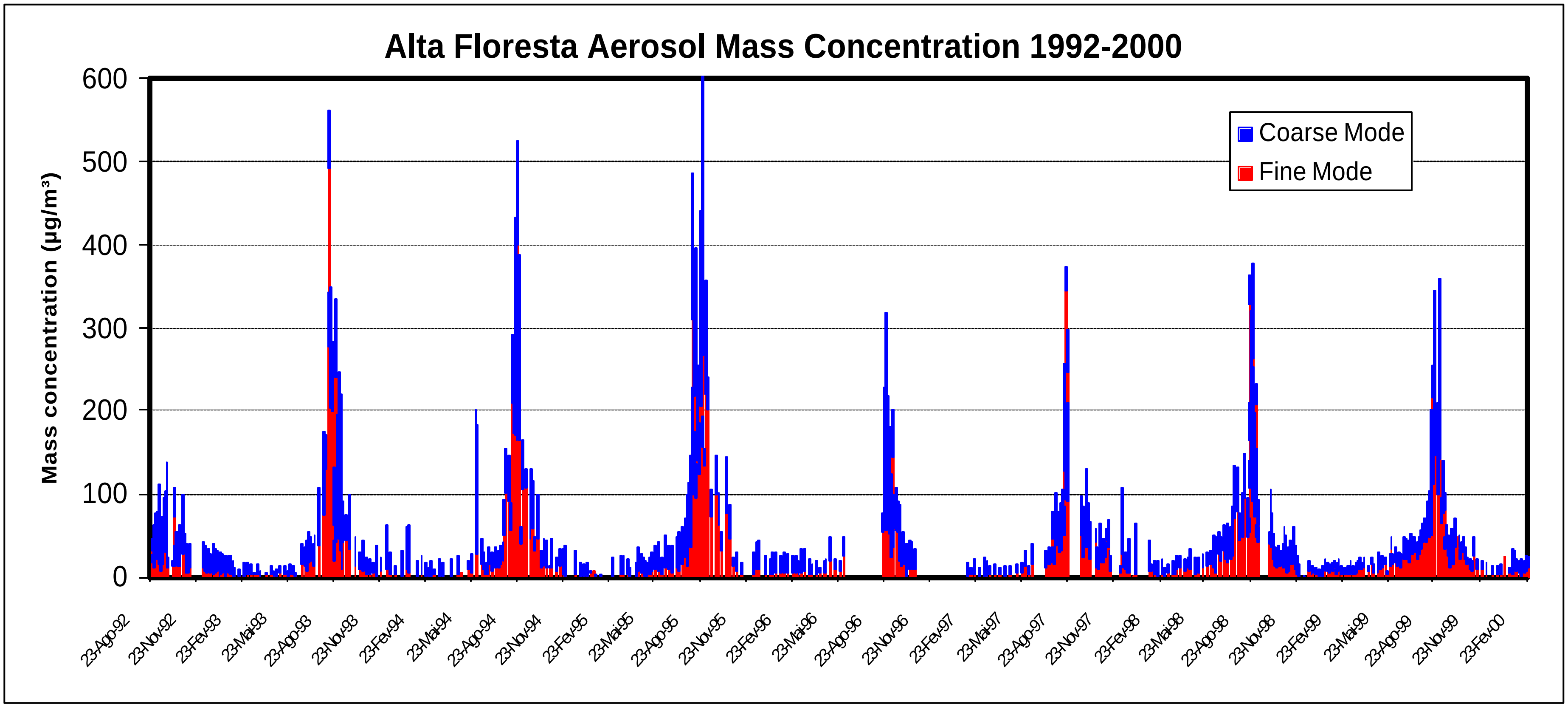
SCAR-B, 1995

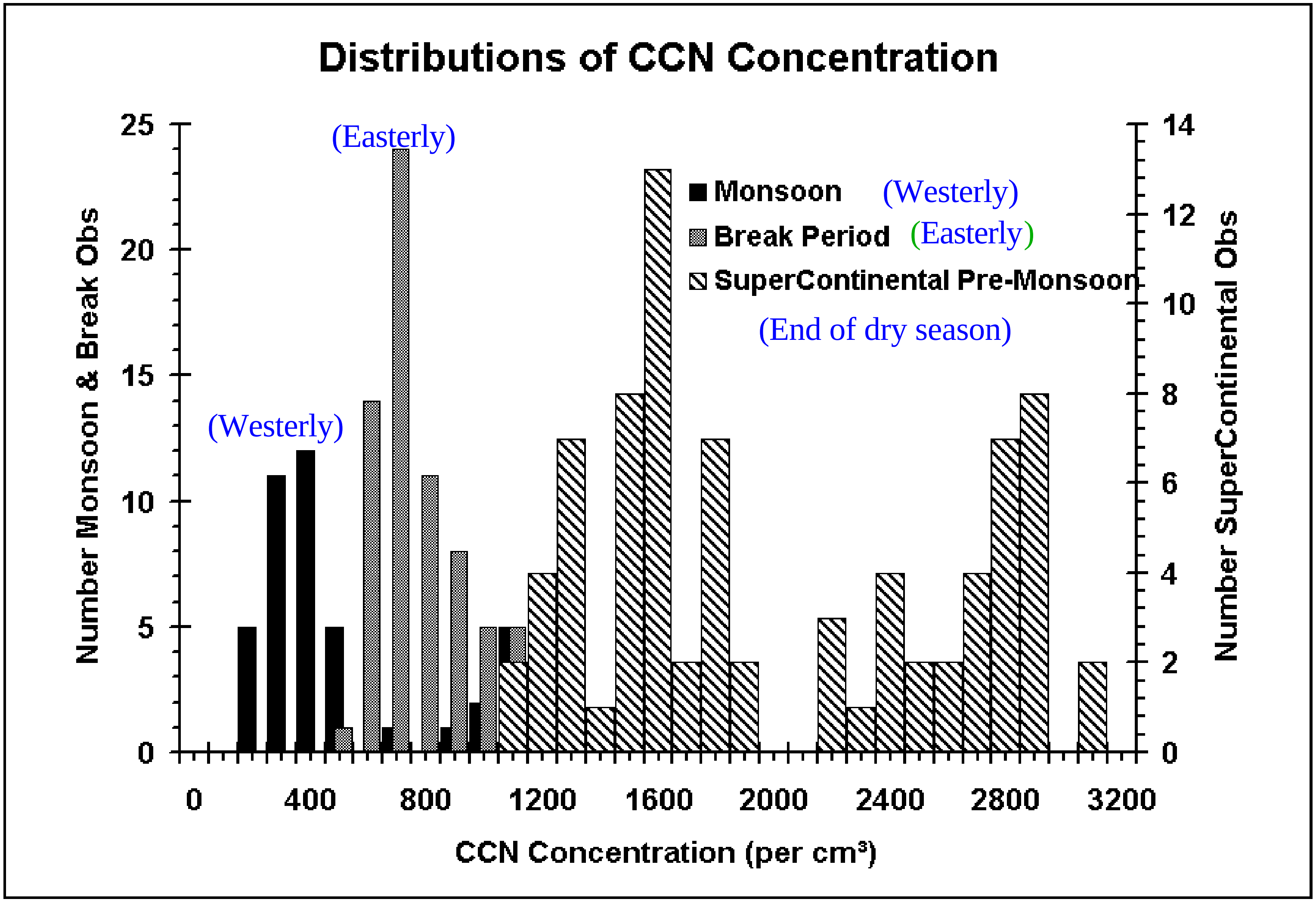
Biomass burning trajectories



Freitas Longo and Silva Dias, 1996

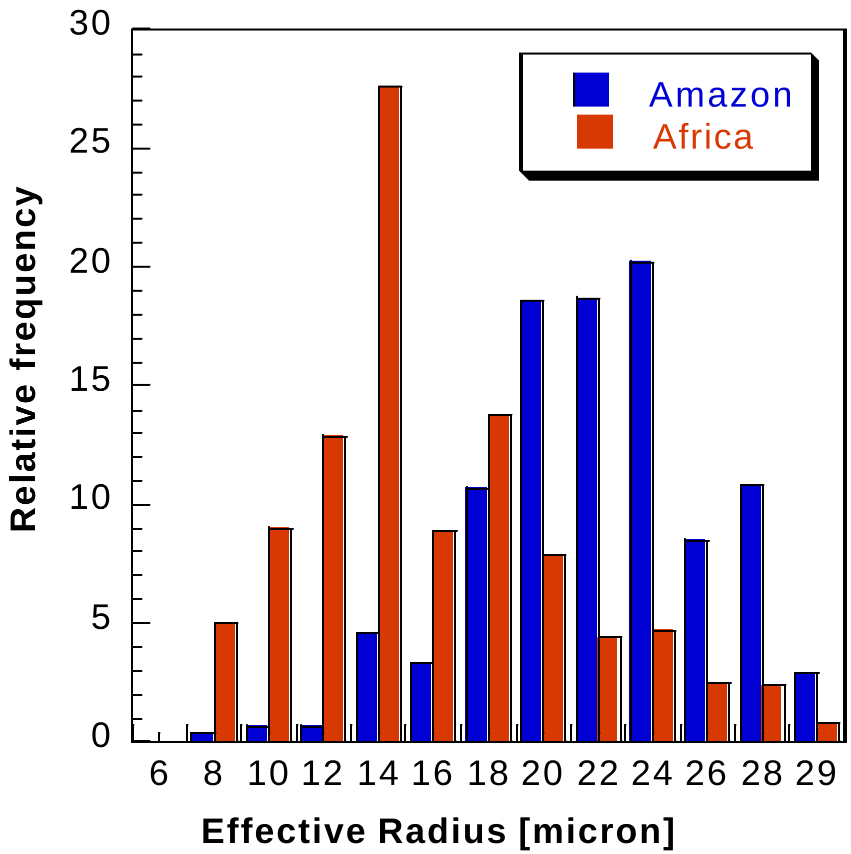
Aerosol Concentrations in Amazonia
Changes from very low values of
5-12 µg/m³ to very high 500 µg/m³
In areas affected by biomass burning





Williams et al, 1999

Clouds are more continental over Central Africa than the Amazon:



The relative frequency of effective cloud radius for clouds over the African Congo (red bars) and the Amazon (blue bars) (*Danny Rosenfeld, personal communication).*

Africa compared to the **Amazon**:

- Smaller particle effective radius;
- Half the rainfall per lightning.
- More population and pollution
- More desert dust
- Less available moisture
- Stronger updrafts ???

=> Less efficient rain processes

Need to understand :

- **role of biogenic CCN in replenishing the atmospheric reservoir after a period of continuous rains;**
- **recycling of aerosol through rainfall;**
- **effect of deforestation on CCN**

Changes in Cloud Condensation Nuclei (CCN) in Amazonia is changing the cloud formation mechanisms and efficiency of precipitation

- Secondary Organic Aerosol: Provide a significant part of aerosol mass and CCN
- Primary biogenic aerosol: Bacteria, spores, plant debris accounts for a large fraction of aerosol mass and number.

- Wet season data from Amazon basin indicate CCN are very low in "natural" state: 50-200 #/cc, similar to oceanic areas
  - ☞ "Green Ocean"
- Dry "smoky" season data show strong increase in CCN due to biomass smoke, reaching values of 5,000-20,000 #/cc
  - ☞ Smaller droplets, higher clouds and more lightning
  - ☞ High concentration of black carbon in clouds enhances evaporation of droplets before precipitation

And the future?

Increasing development in Amazonia brings:

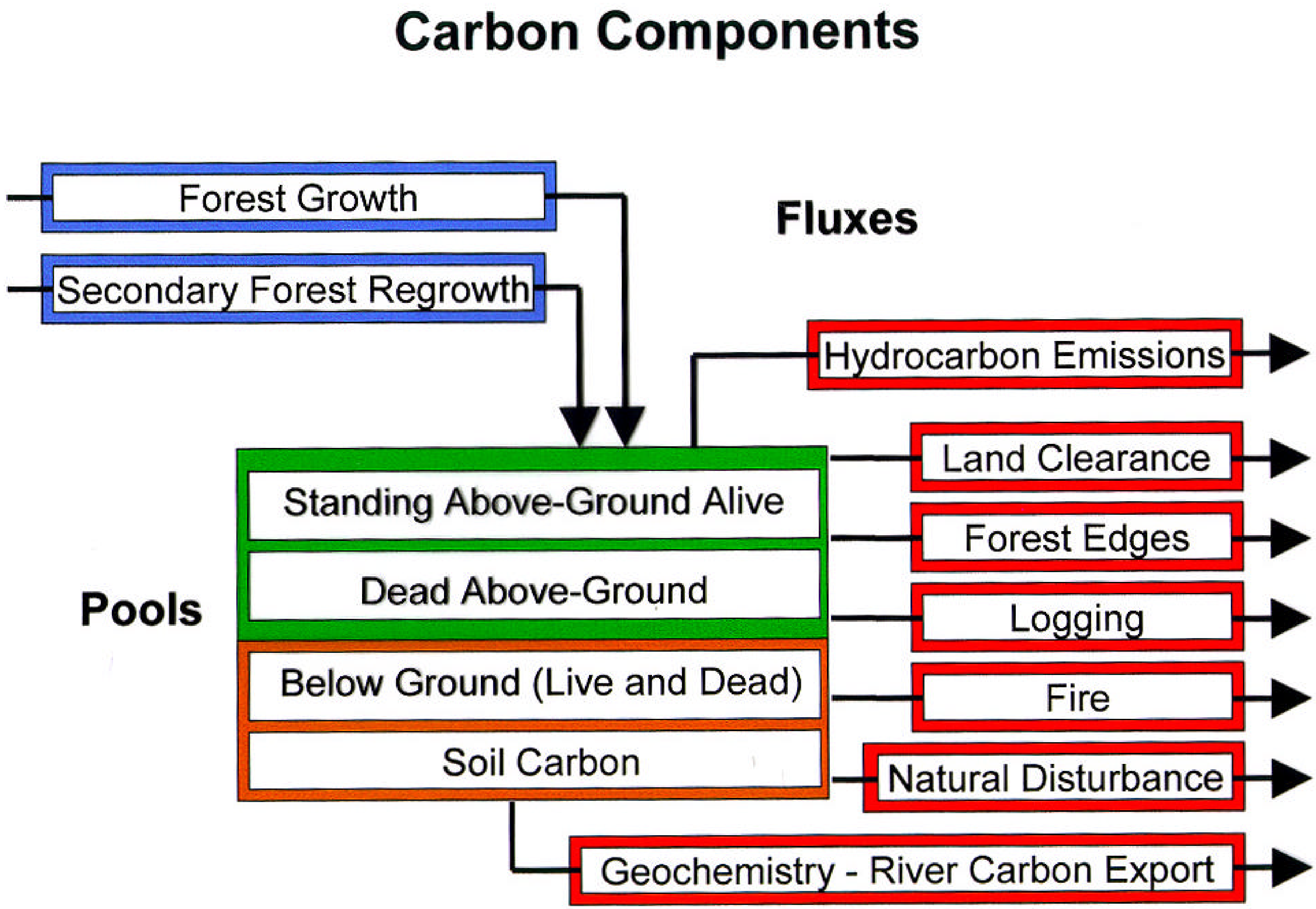
- **More NO_x from anthropogenic activities**
- **More sulfate particles from power plants**
- **More NO_x from soil due to canopy removal**
- **Increase in O_3**
- **More secondary organic aerosol because of more NO_x and O_3**

☹ High CCN year-round

What will happen with Black Carbon, the “Greenhouse Aerosol”

- **BC has a greenhouse forcing of the same magnitude as methane**
- **Emissions from biomass burning are BC-rich**
- **BC natural concentrations in Amazonia is 50-120 ng/m^3. During the dry season it reaches 20,000 ng/m^3 over large areas.**

☹ Higher black carbon



Amazonia: source or sink of carbon?

Carbon Balance in Amazonia
Deforestation and Regrowth

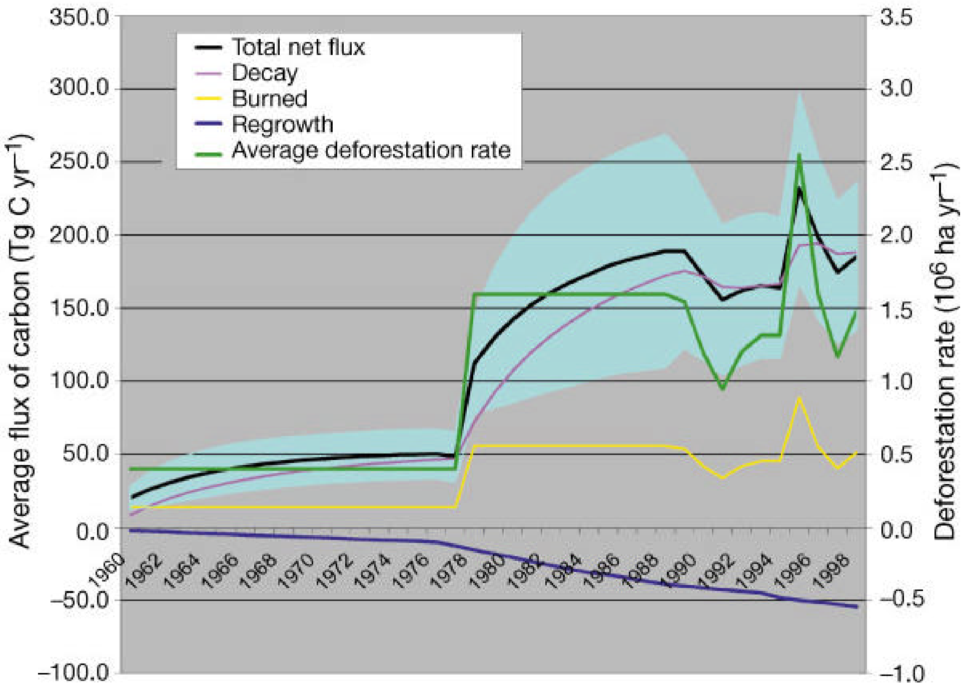
Land Abandonement

Regrowth of abandoned land @ 30% of deforestation area accumulated carbon at rates proportional initial biomass

1.5 MgC ha^{-1} yr^{-1} for Biomass < 100 MgC ha^{-1}
to
5.5 Mg Cha^{-1} yr^{-1} for Biomass > 190 MgC ha^{-1}

Range of Biomass Estimates

Low 145 MgC ha^{-1}
High 232 MgC ha^{-1}
Intermidiate 210 MgC ha^{-1}



Of the total Biomass Deforested:

20% Burned
70% Left as Slash
8% Removed for Products
2% "Elemental Carbon"

Rates of Decay

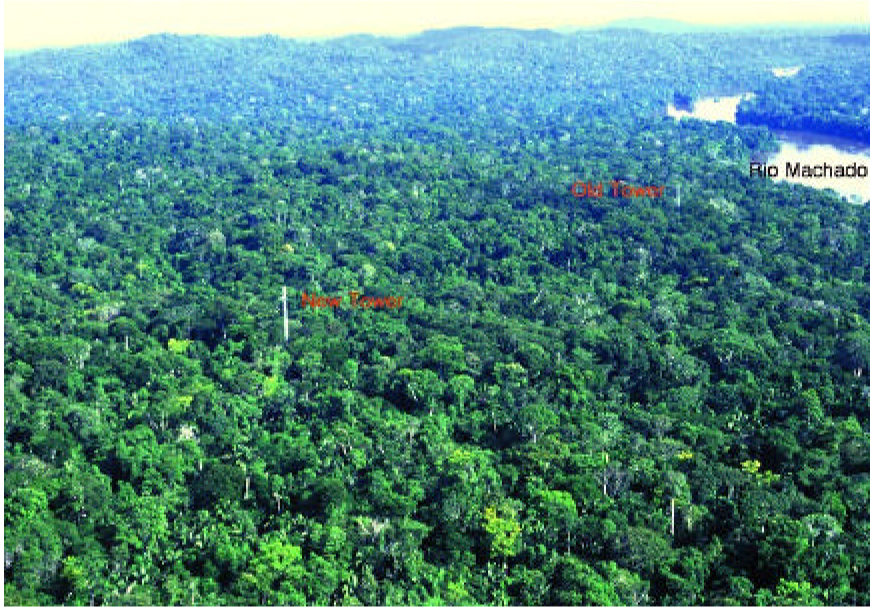
Wood Products @ 10 yr
"Elemental Carbon" @ 1000 yr
Left as Slash @ 10 yr (or 2.5 yr)

Annual rate of deforestation and mean annual sources and sinks of carbon in Brazilian Amazonia. Shaded area is 1 s.d. from the mean annual flux of carbon determined for the eight cases described in the text.

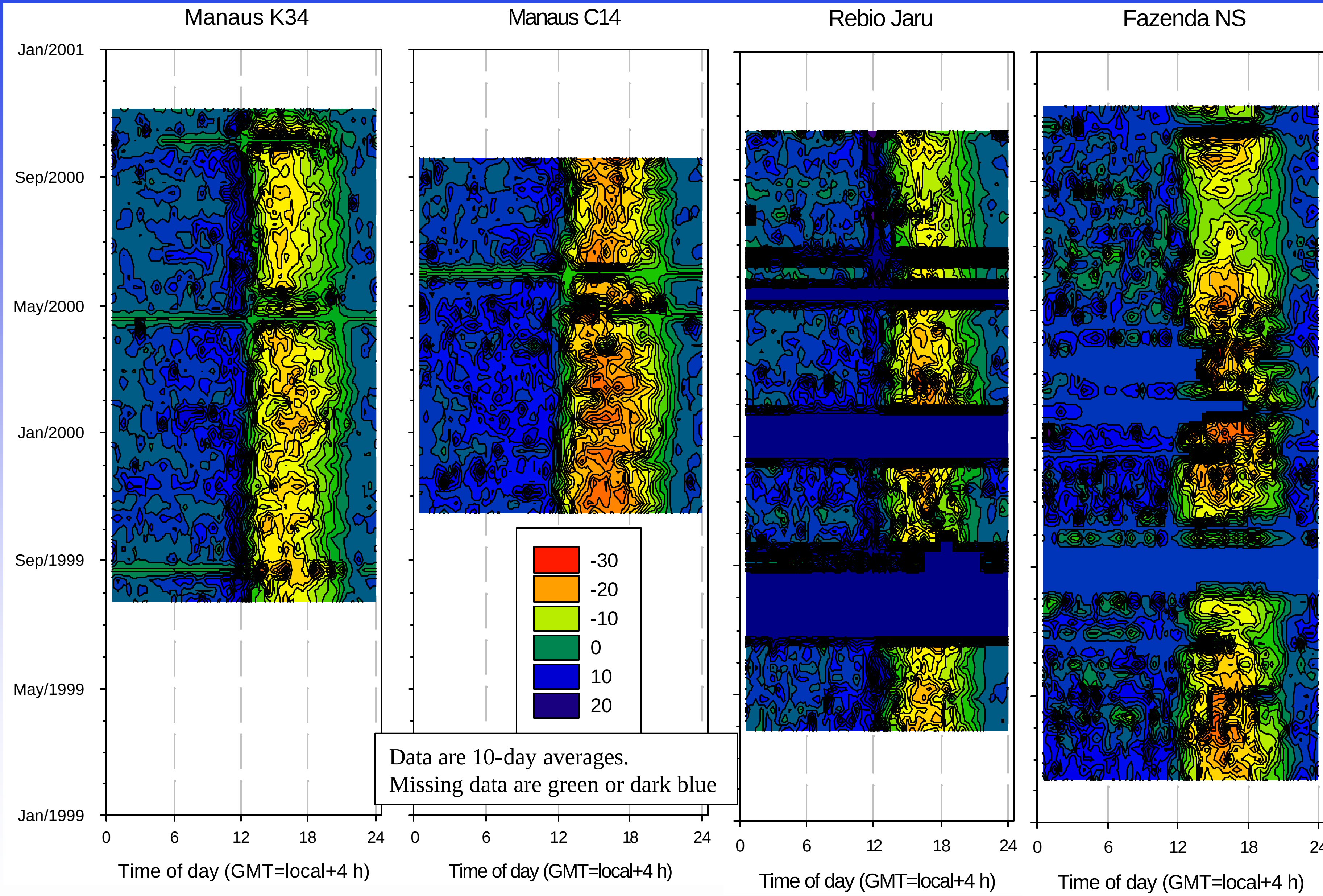
Amazonia as a carbon source: ~ (200 ± 100) M ton C/year

Houghton, Skole, Nobre et al. , vol 403, January 2000

LBA Fluxes Towers

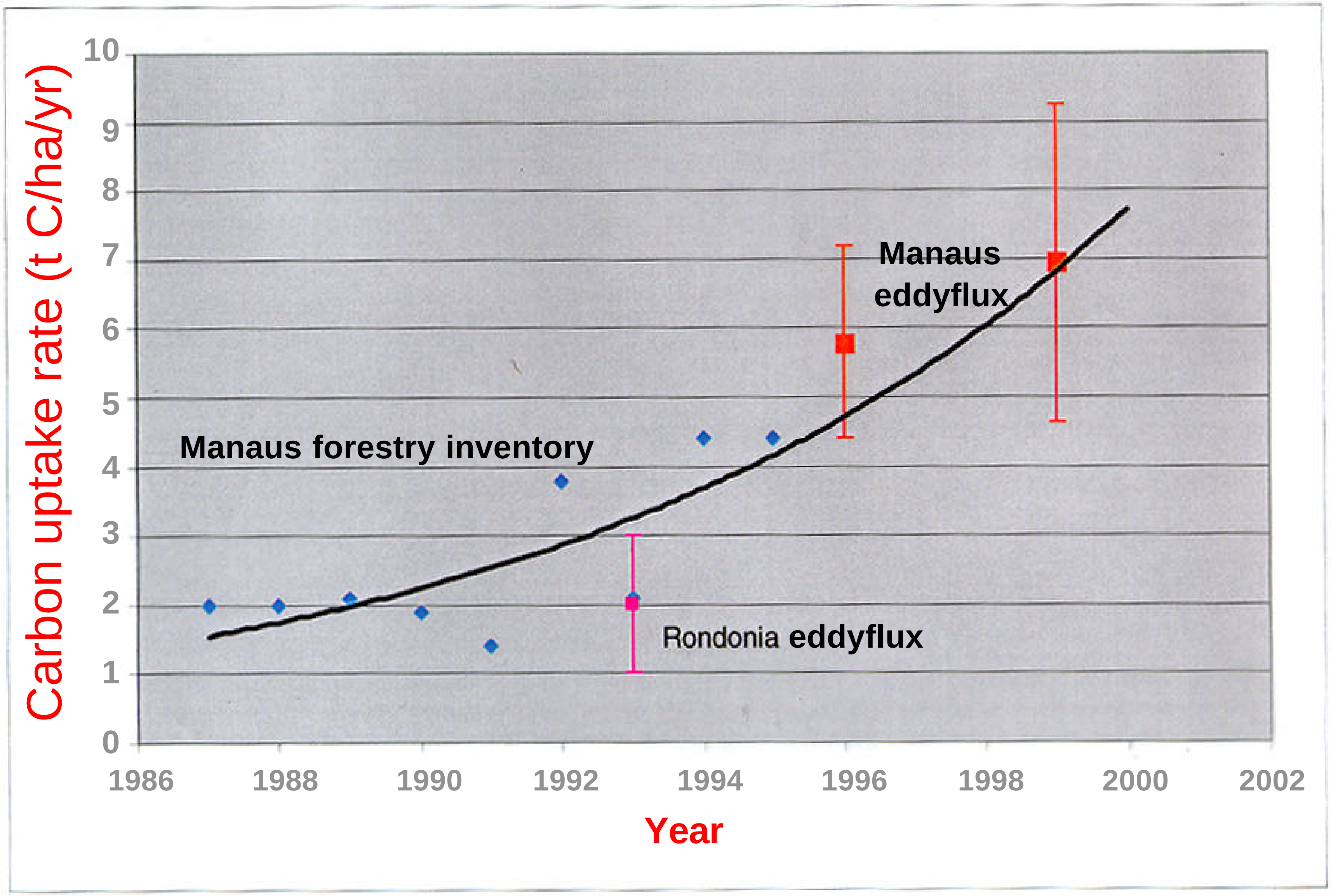


Measured CO_2 eddy fluxes over 2 years in the Central and Southern Amazon



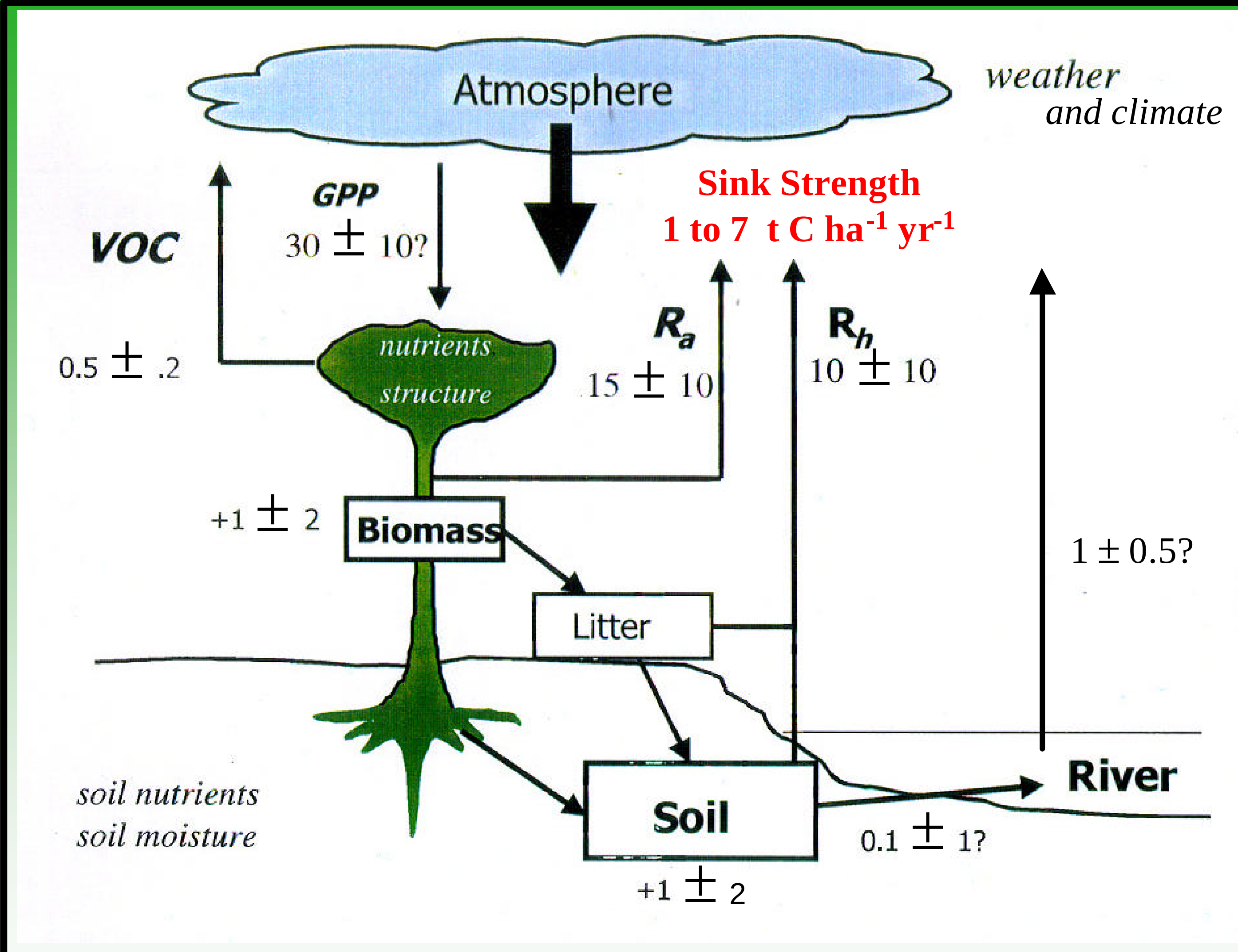
Courtesy: LBA Eustach

Carbon accumulation rates in Manaus and Rondonia



Malhi, et al. , 1998; Nobre, A . 2001

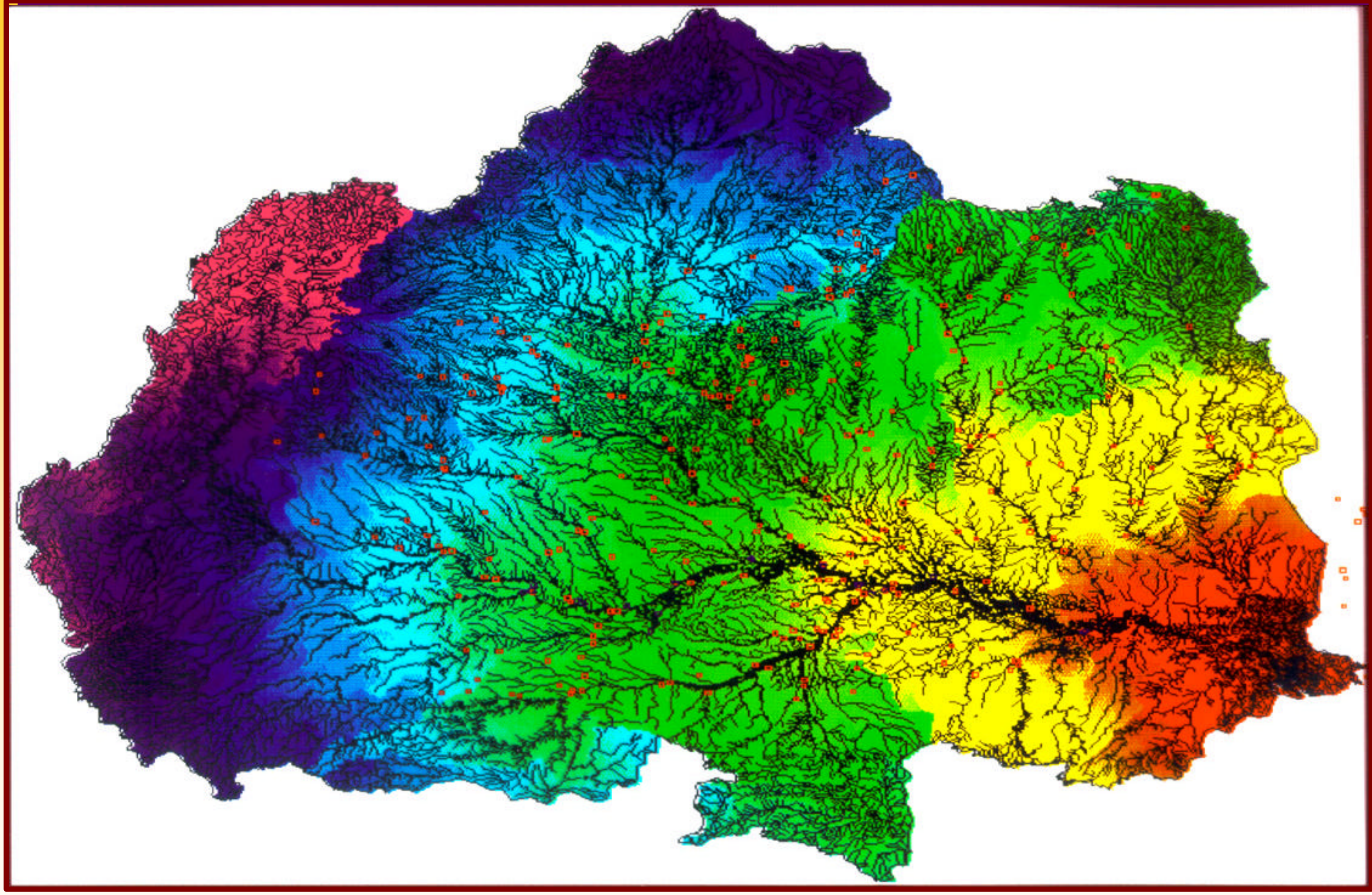
The Carbonsink of Amazonian Forest



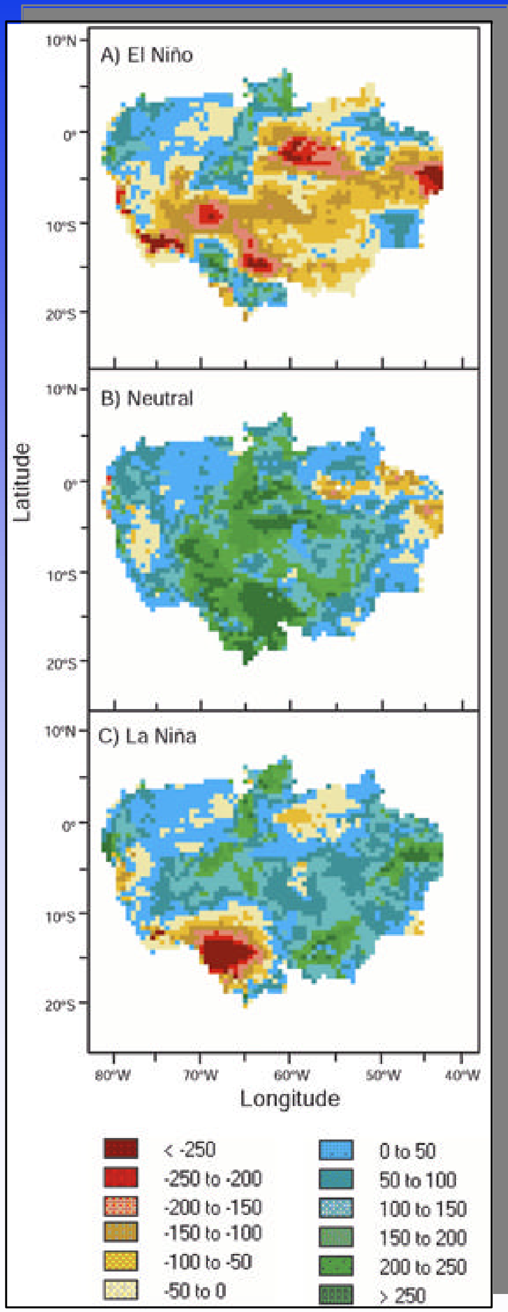
Preliminary synthesis of the carbon cycle for Amazonian forests.
Units: t C ha^{-1} yr^{-1}. ***GPP***= gross primary productivity; $\boldsymbol{R_a}$= autotrophic respiration; $\boldsymbol{R_h}$=heterotrophic respiration; ***VOC***= volatile organic carbon compounds.

Source: Alterra, INPA, IH, Edinburgh University

The Amazon River Basin



Colors represent time in months that the water takes to reach the ocean: red, one months;purple, six months. Courtesy: R. Victoria and J. Richey.



Carbon Cycle Modelling:

Source of Carbon in El Niño years

Sink of Carbon in La Niña years

Net ecosystem production across the Amazon Basin. Spatial variability in the net ecosystem production (g C m^{-2} yr^{-1}) in the combined simulation of transient climate and transient atmospheric CO_2 during three phases of El Niño-Southern Oscillation (ENSO): A) na El Niño year (1987); B) a neutral year (1981); and C) a La Niña year (1989). Regions that act as a source of atmospheric carbon (i.e. annual NEP is negative) are designated with shades of brown, red or yellow and regions that act as a sink of atmospheric carbon (i.e. Annual NEP is positive) are designated with shades of blue or green. Source: Tian et al. Nature, 396:664-667.

Water Biogeochemistry in LBA

Rationale, Objective and research questions

The Amazon River may be viewed as both a conduit for export of weathering products and organic remains, as well as a heterotrophic reactor operating across both fast and slow time scales for a major portion of the organic matter introduced from the catchment.

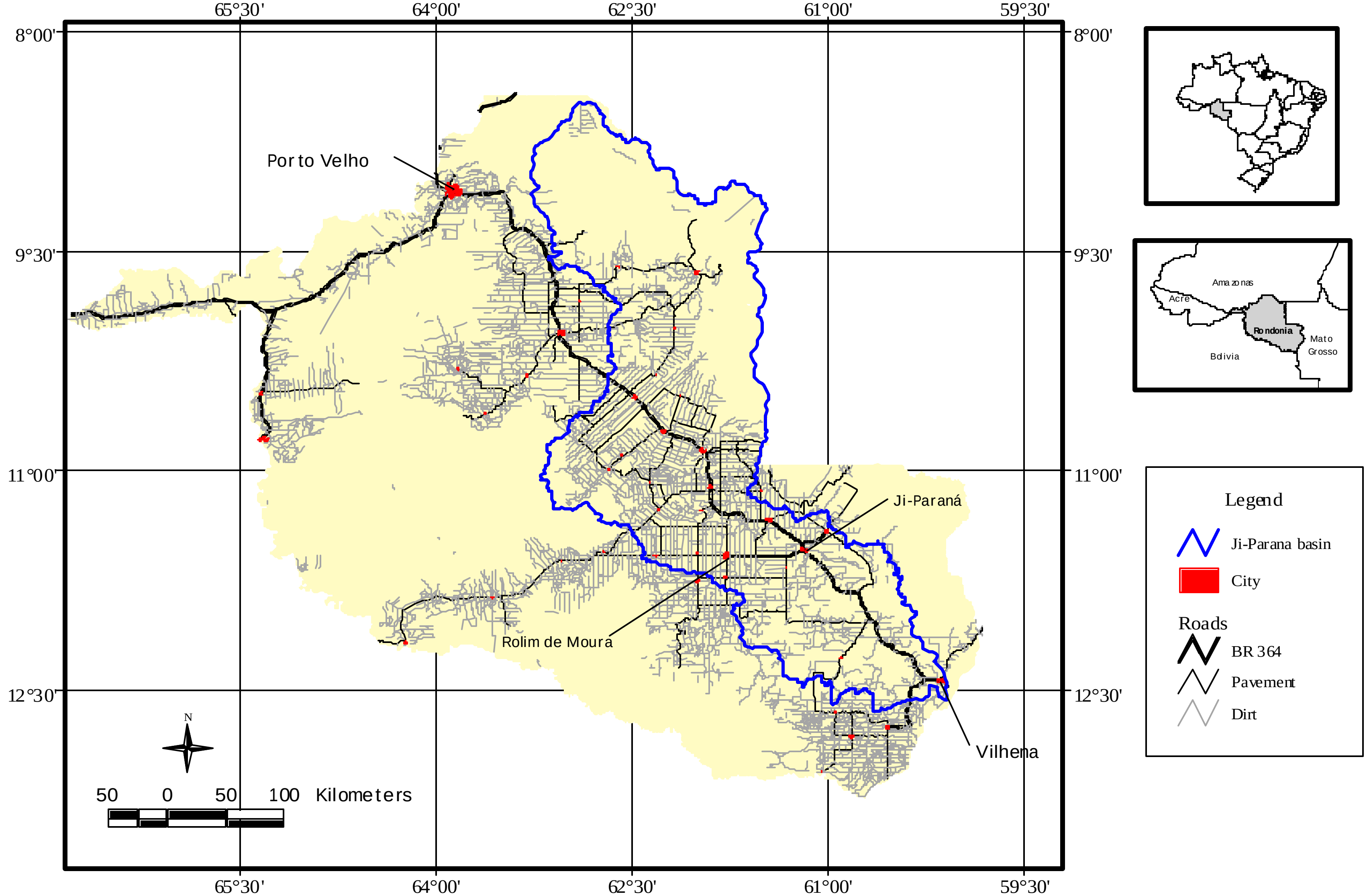
Main objective:

to understand how **land use changes,** especially the **conversion of forests into pastures**, affect the distribution and transport of carbon and nutrients in tropical rivers, and how the biogeochemical signatures of land-derived and in-situ processes are modified during transit through the river system at the meso-scale level.

Based on this general objective, we propose to answer two major questions:

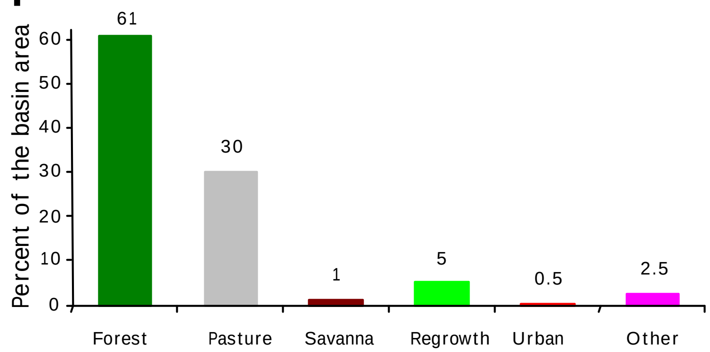
Question 1 - How are the composition and quantity of organic matter and nutrients that are delivered to and processed within a river changed **as a function of forest conversion to pasture?**

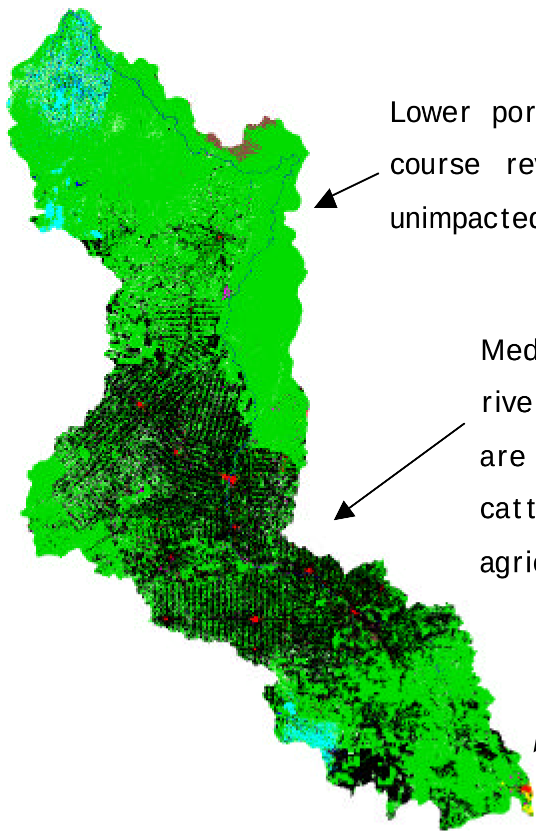
Question 2 - What are the changes in the pathways, stores and fluxes of organic matter, nutrients, and associated elements through a river system, across scales, **as a function of land cover and land use change**?



The Ji-Paraná River Basin: drains an area of 75,260 km^2 and has an average discharge of 700m^3.s^{-1}. It is characterized by extensive development in the upper part, and slight alteration in the lower 400km before confluence with the Madeira river near Calama.

Land use and Land cover (1999)



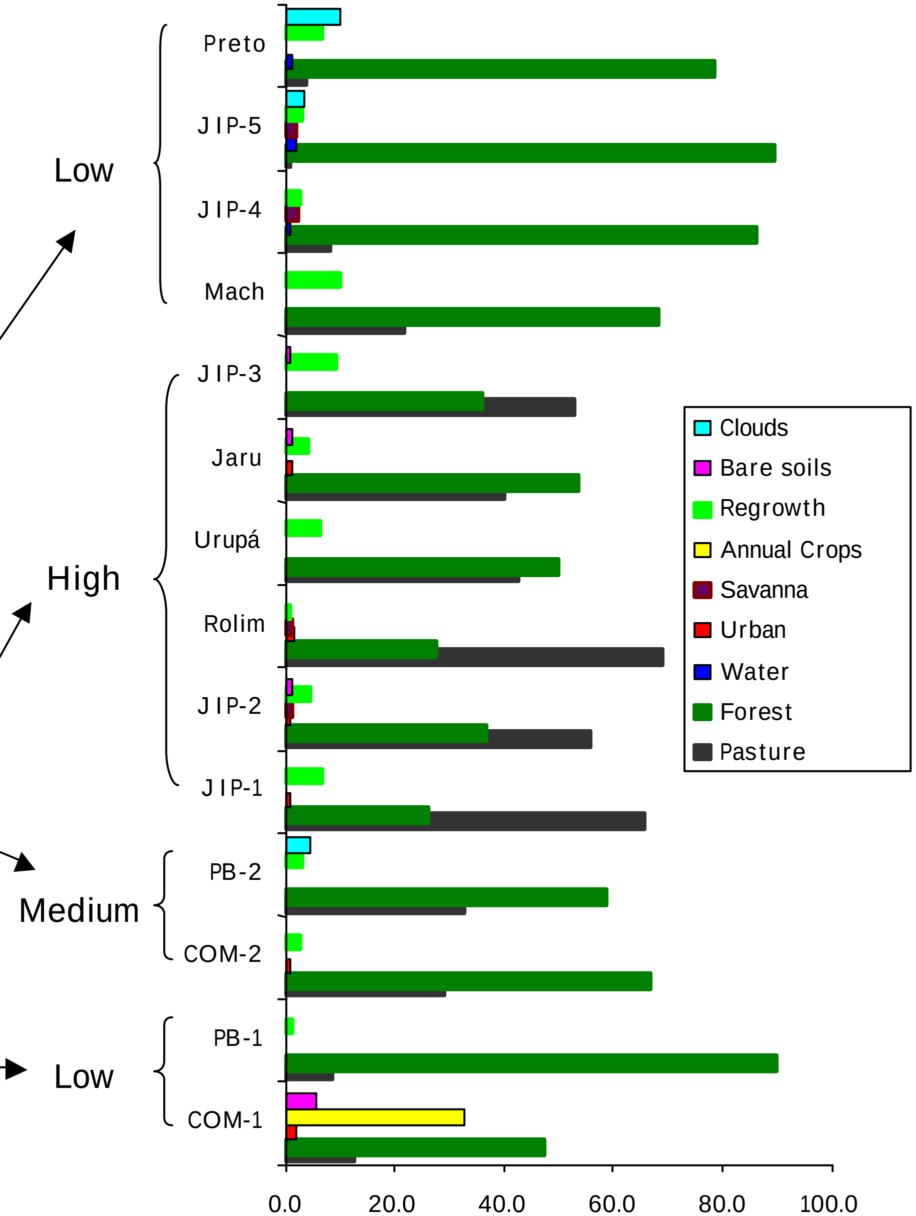


Lower portion of the river course reverts to relatively unimpacted natural forest.

Medium portions of the river: highly impacted, and are now dominated by cattle pastures and agriculture.

Water heads: present low alteration

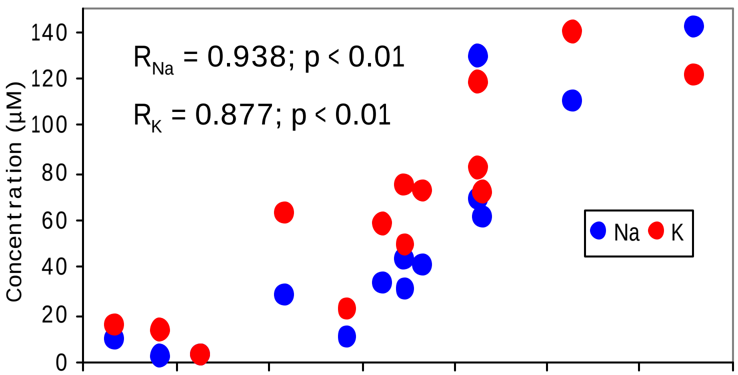
Degree of alteration

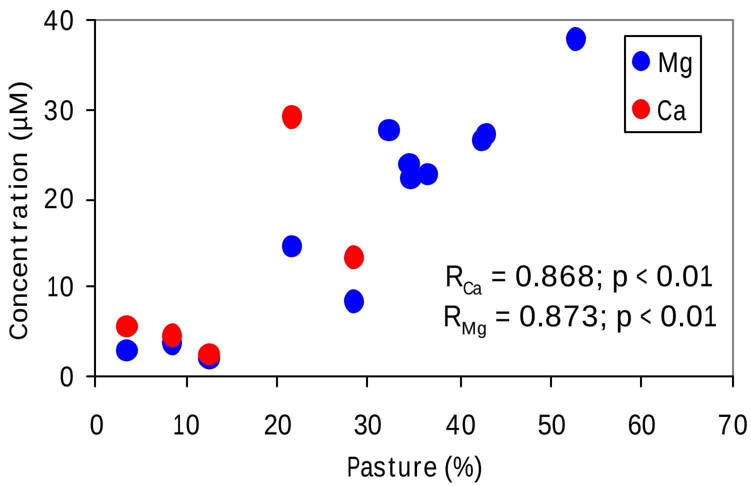


This allows the comparison between carbon cycling mechanisms under differing degrees of land use, and also to study how the biogeochemical signal change during transport along the river.

Land use/cover effects on river biogeochemistry

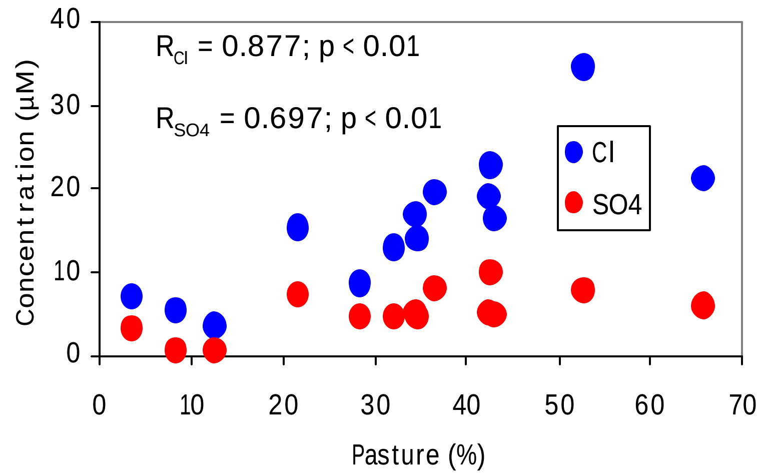
We found statistically significant correlations (p< 0.01) between the pasture area (%) and:





Land-use has strong influence on the river chemistry. The results presented in this study indicate the importance of accessing the watershed characteristics to fully comprehend their role as geographic sources of bio-active elements to the river;

In general the land-use at catchment scale was a good predictor of the river water composition, especially for conductivity, major cations and anions;



Conclusions

Land use change is causing an unprecedented imbalance in Amazonia

- Biodiversity losses of unknown magnitude
- Significant alterations on natural cycles of water, carbon, trace gases, aerosols, and nutrients

Human dimensions of Amazonian development

70 years of failures in attempts to develop Amazonia (large scale plantations and cattle ranching; small scale subsistence agriculture; logging; mining; industrialization)

Is it possible to halt the "destructive path"?

• lack of knowledge on sustainable agriculture in the tropics

• basic knowledge on ecosystem functioning is necessary (e.g, LBA), but that is not enough

• educating the poor and displaced for sustainable development is essential

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Paradise lost

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But there are millions of the beings
All so well disguised
That no-one asks
From where such people come

Chico Buarque