Interações entre Clima e Vegetação na Amazônia: do último período glacial até o clima do futuro

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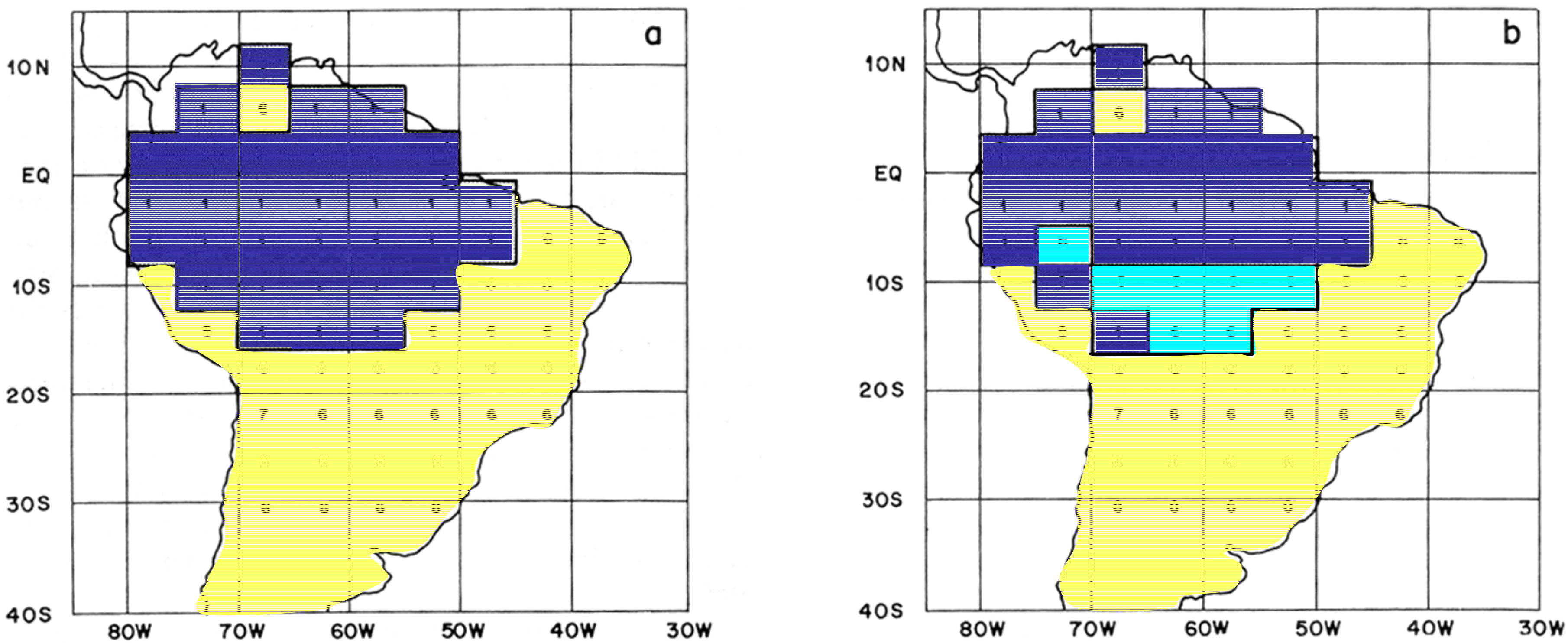
Vegetation-Climate Interactions

Climate ↔ **Vegetation**

Bidirectional on what times scales?

Modeling Deforestation and Biogeography in Amazonia

Current Biomes **Post-deforestation**

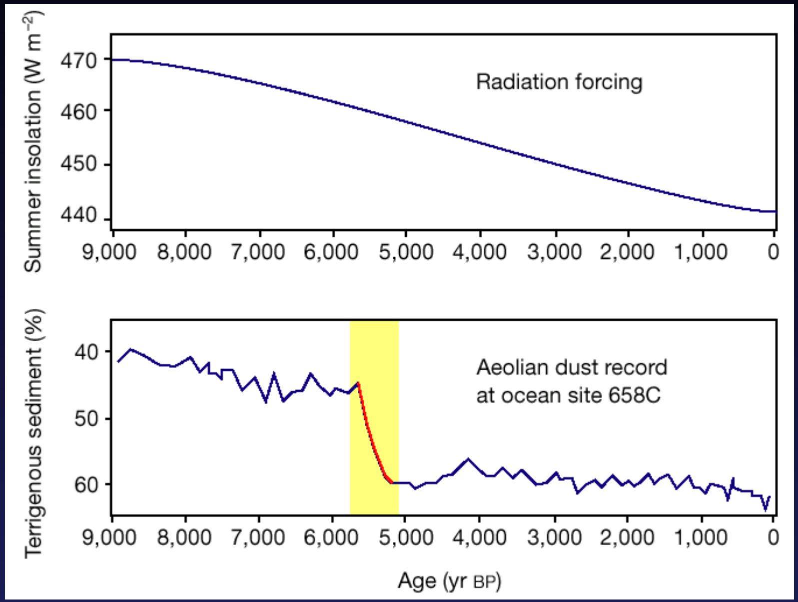


Bioclimatology for the control case (a, current bioclimatology) associated with deforestation (b, revised bioclimatology after deforestation such as the analysis of the vegetation stress index fields shows). The shaded area with "1" is tropical forest, "6" refers to cerrado. The forest boundary is depicted by the heavy solid line.

"1" **Tropical Forest**
"6" **Savanna**

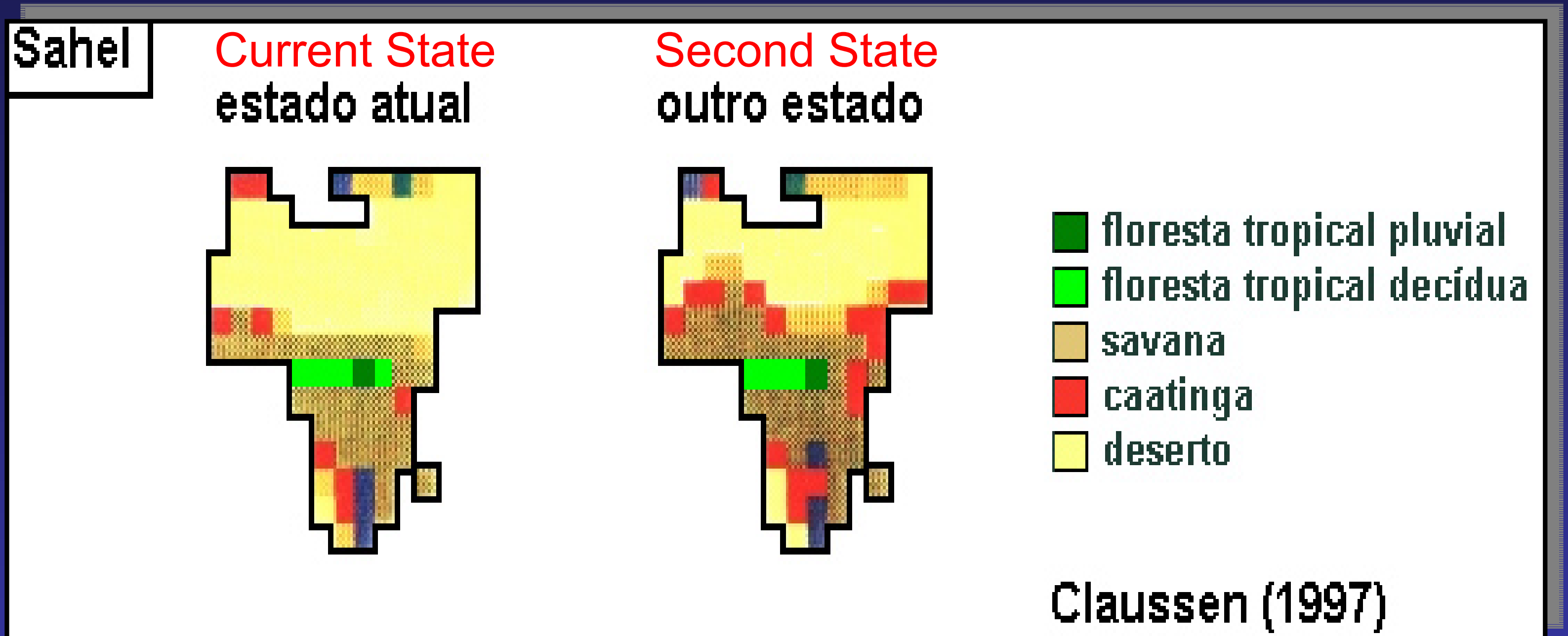
Nobre et al. 1991, J. Climate

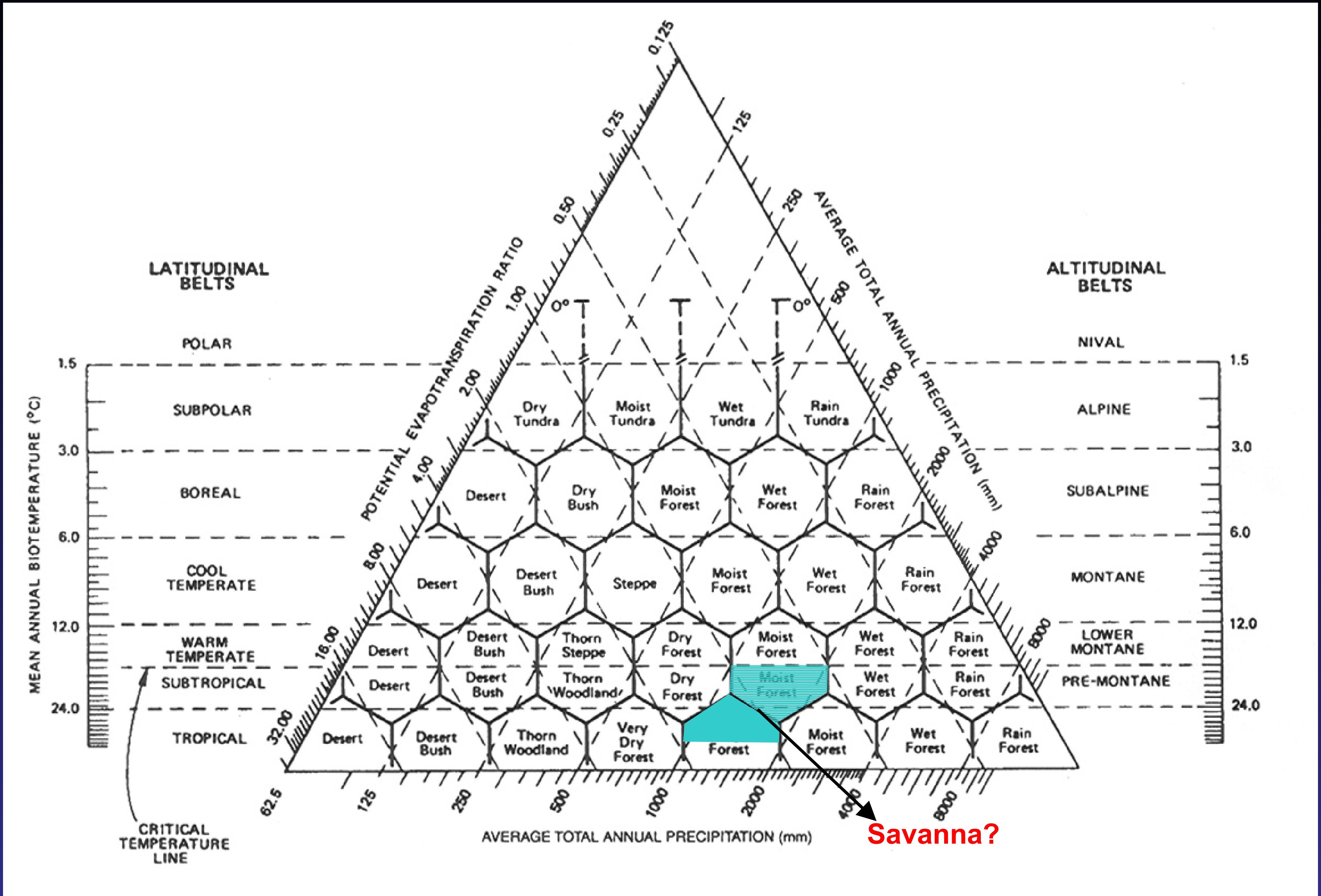
Biome-Climate Bi-Stability for the Sahel



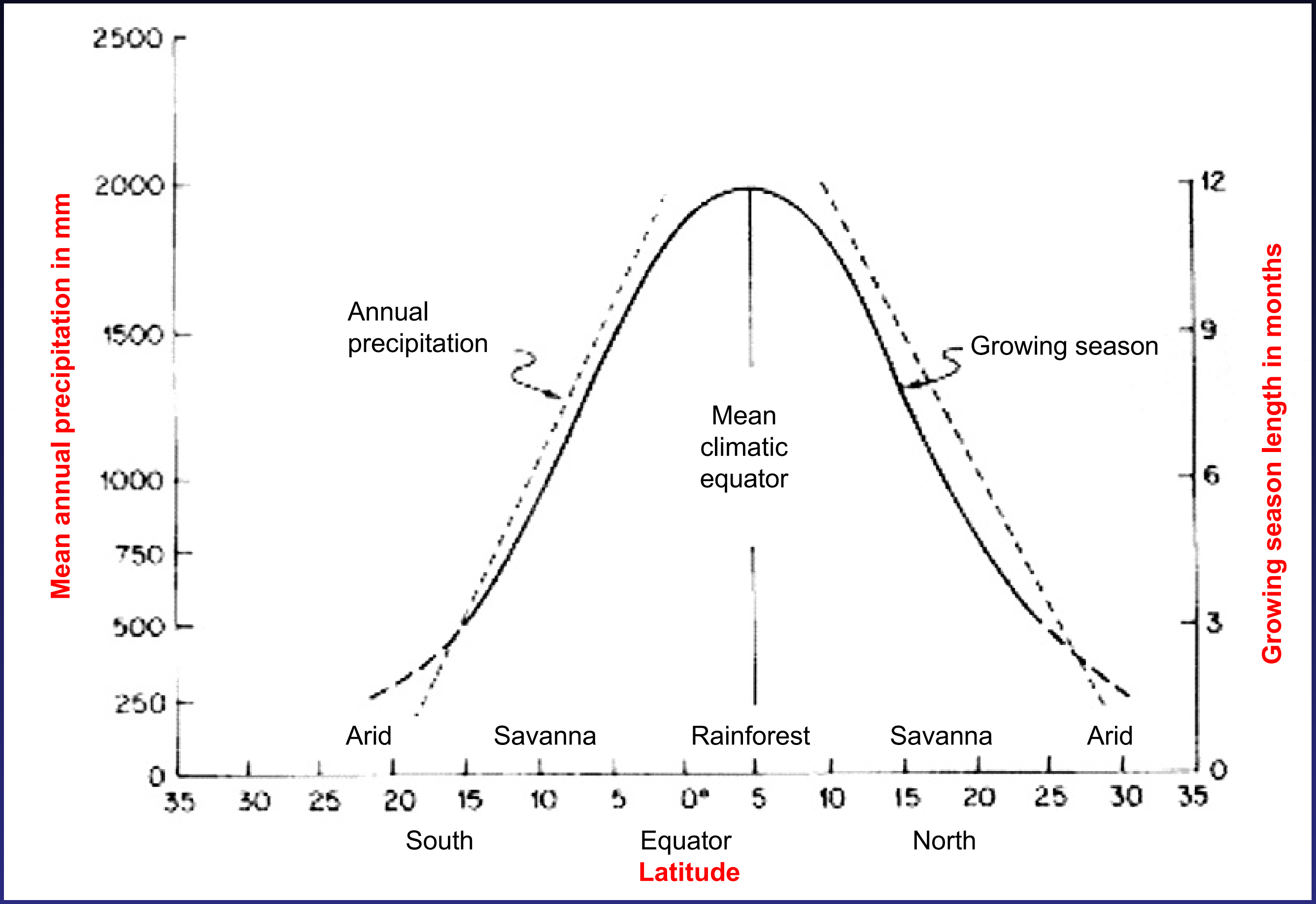
The second equilibriun state depend mostly on vegetation (albedo) feedback and secondarily on ocean feedbacks

SCHEFFER EL AL., NATURE | VOL 413 | 11 OCTOBER 2001

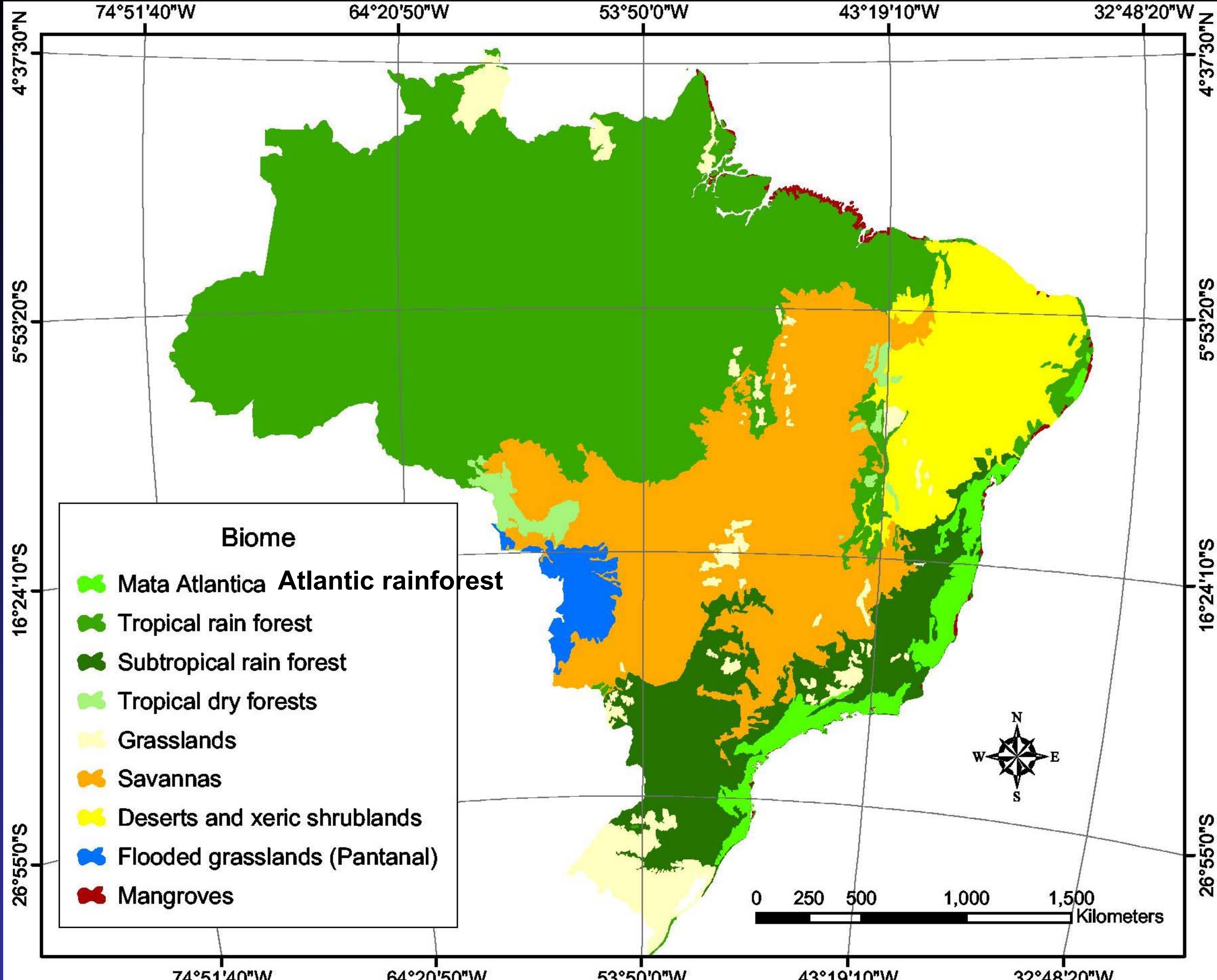




The Holdridge Life-Zone Classification System (Holdridge, 1947; 1964)



A scheme of the relationship between mean annual precipitation and growing season length in tropical climates (from Newman, 1977)


74°51'40"W
64°20'50"W
53°50'0"W
43°19'10"W
32°48'20"W
4°37'30"N
5°53'20"S
16°24'10"S
26°55'0"S
Biome
Mata Atlantica
Atlantic rainforest
Tropical rain forest
Subtropical rain forest
Tropical dry forests
Grasslands
Savannas
Deserts and xeric shrublands
Flooded grasslands (Pantanal)
Mangroves
N
W
E
S
0 250 500 1,000 1,500
Kilometers

Map of dry season length (DSL) (data after Sombroek, 2001), expressed as the number of months with <100 mm of rain.

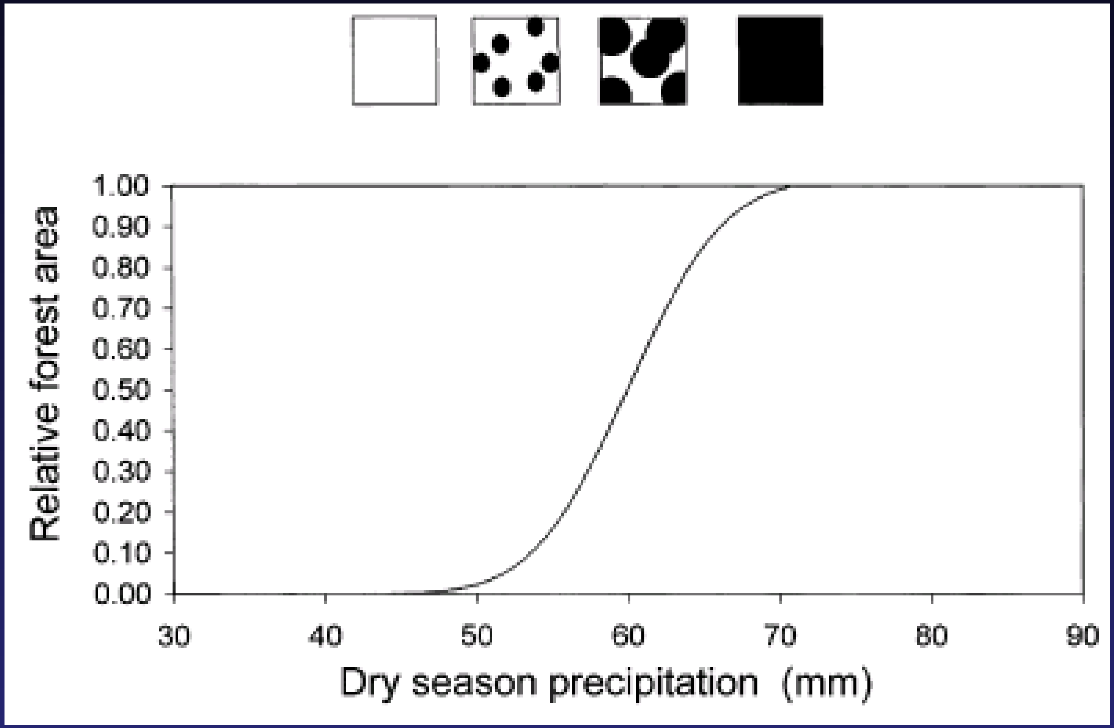


Fig. 3 Establishment of relative forest area in a savanna region as a function of precipitation.

Sternberg, 2001, *Global Ecology & Biogeography*, **1**0, 369–378

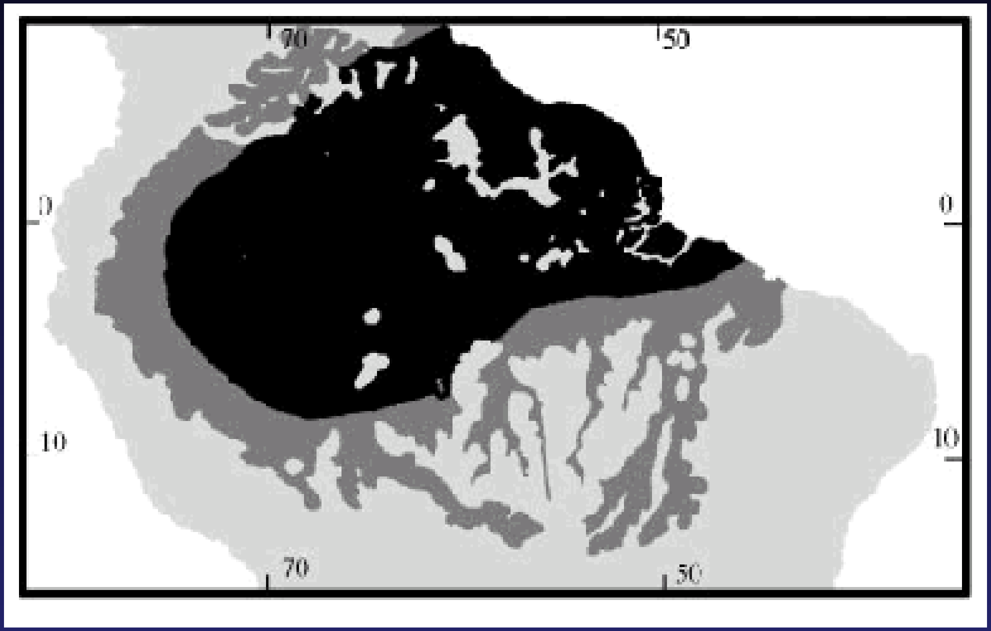
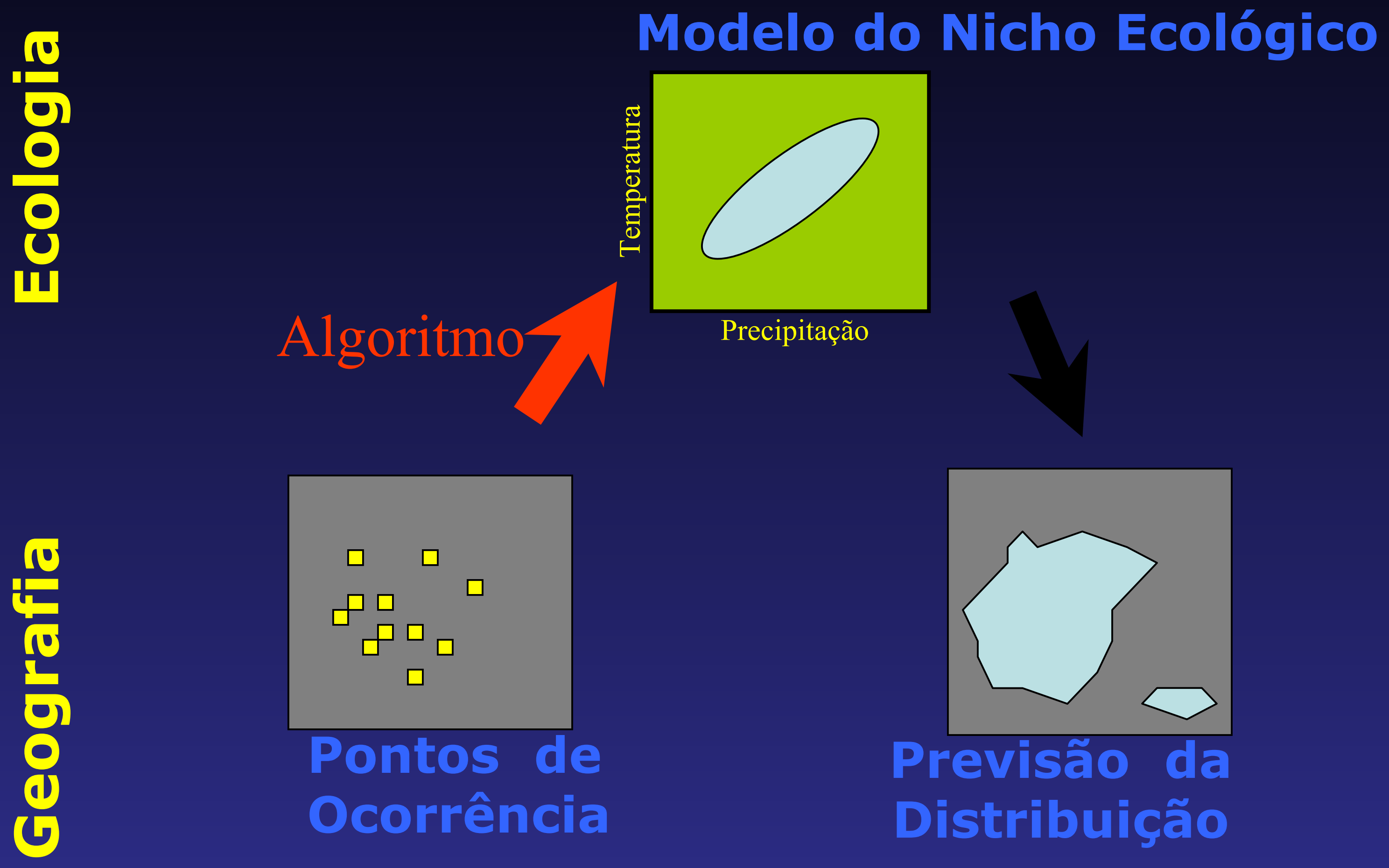


Fig. 1 Regions of the Amazon basin that can potentially be converted to savanna after some deforestation. Black regions represent regions in the Amazon basin with tropical forest and having d.s. precipitation > 100 mm. Dark grey regions represent regions having tropical forest with d.s. precipitation ≤ 100 mm. This region could potentially be converted to savanna, given enough deforestation. Light grey regions represent other types of vegetation but mainly savannas having precipitation during the dry season ≤ 100 mm. The dry season precipitation isoline was derived from Nix (1983).

Sternberg, 2001, *Global Ecology & Biogeography*, **1**0, 369–378

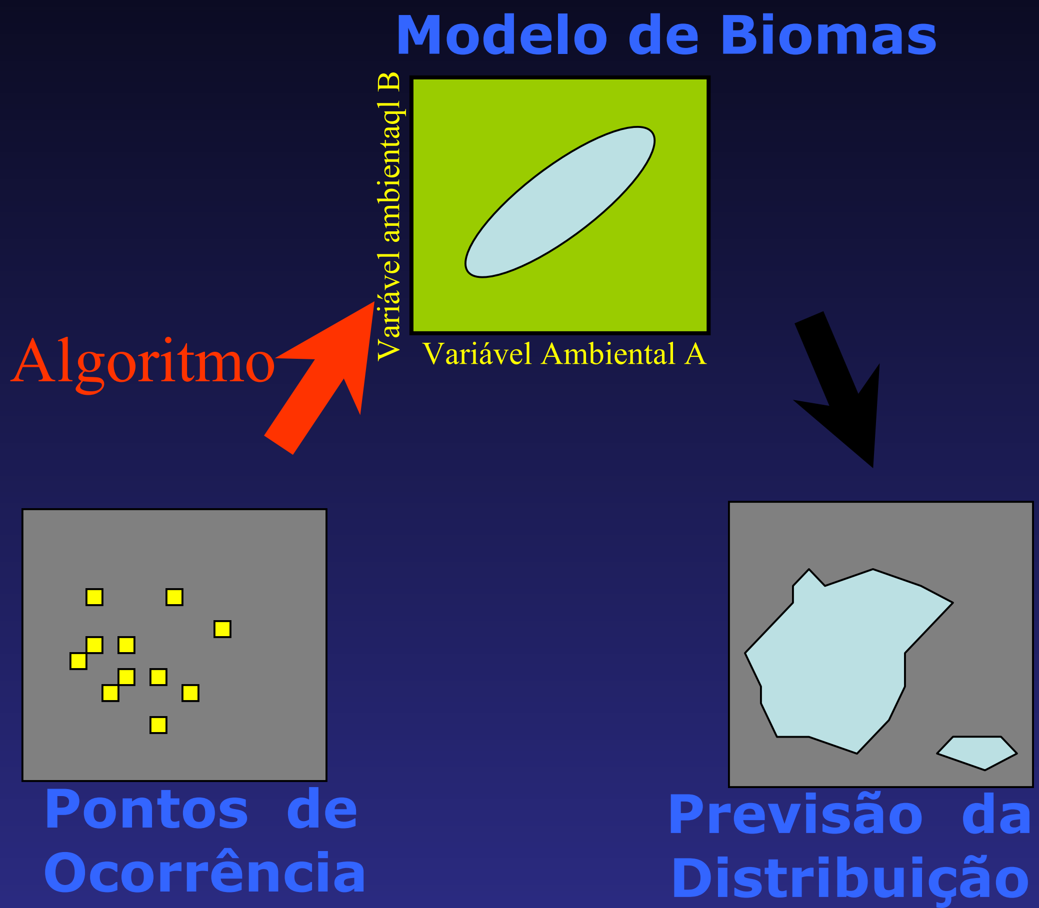
Modelagem de Distribuição Geográfica



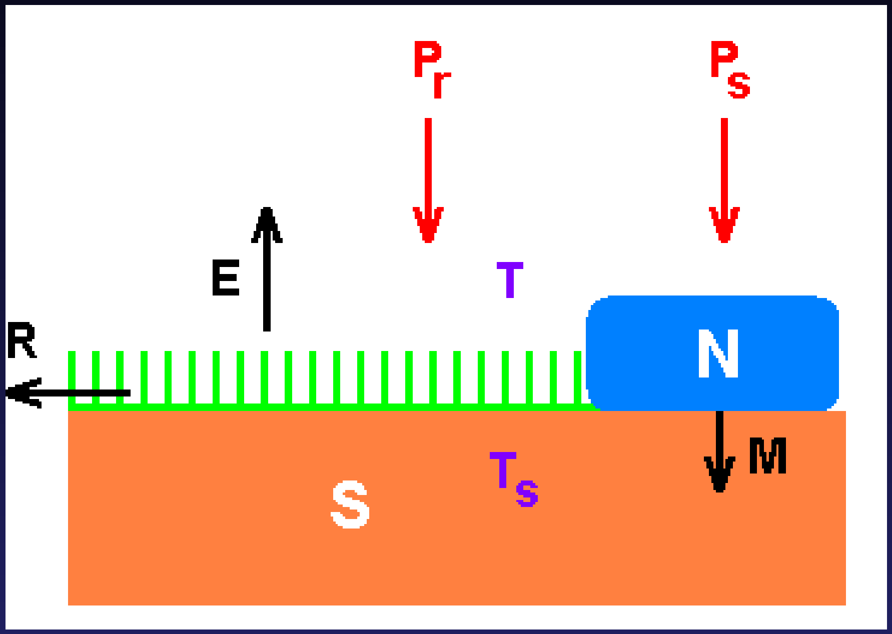
Modelagem de Distribuição Geográfica

Ecologia

Geografia



Simple Land Surface Model



P_r: rain

P_s: snow

T: sfc air temperature

T_s: soil temperature

S: soil water storage

N: overland snow storage

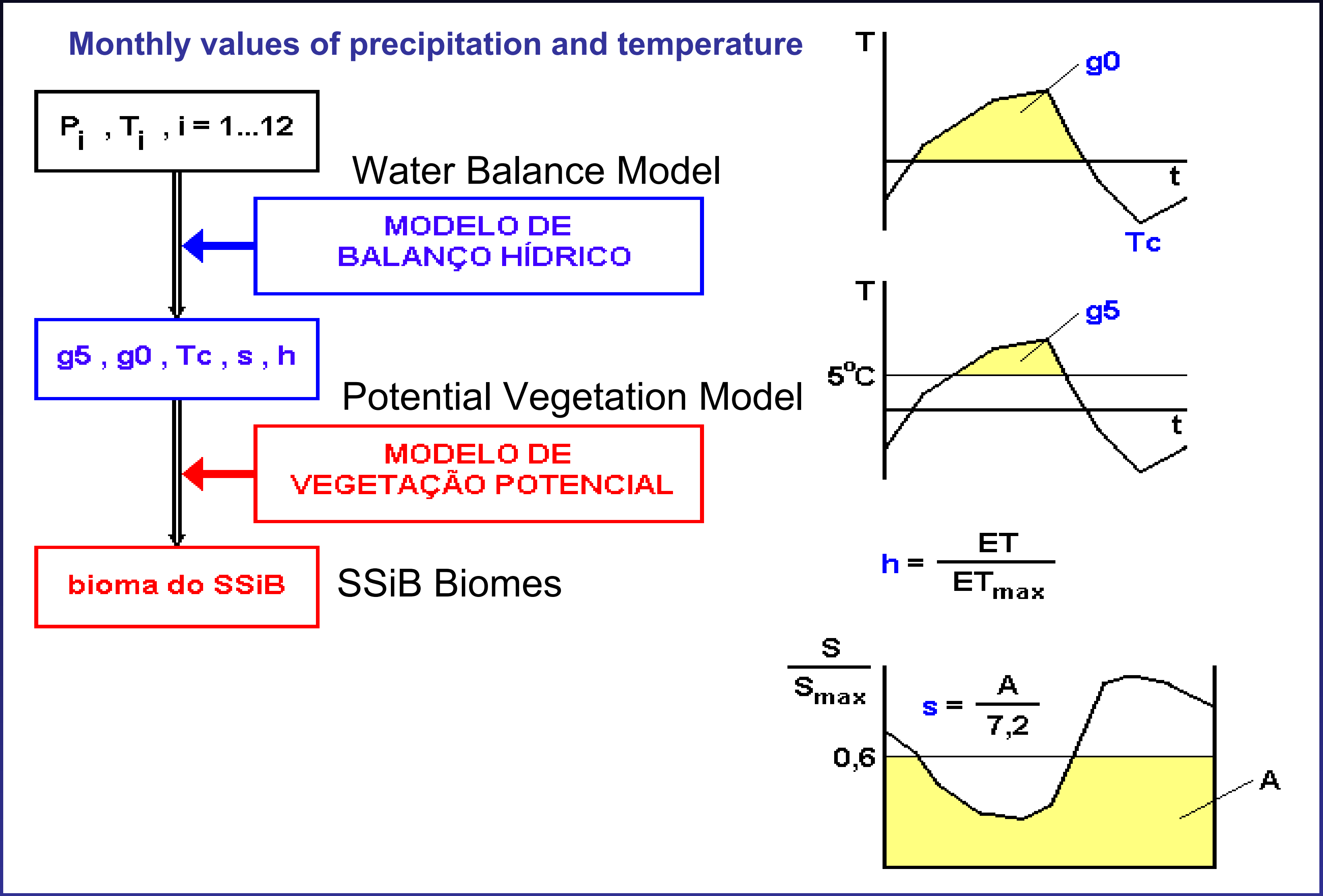
E: evapotranspiration

R: runoff

M: snowmelt

Oyama and Nobre, 2002

Five climate parameters drive the potential vegetation model

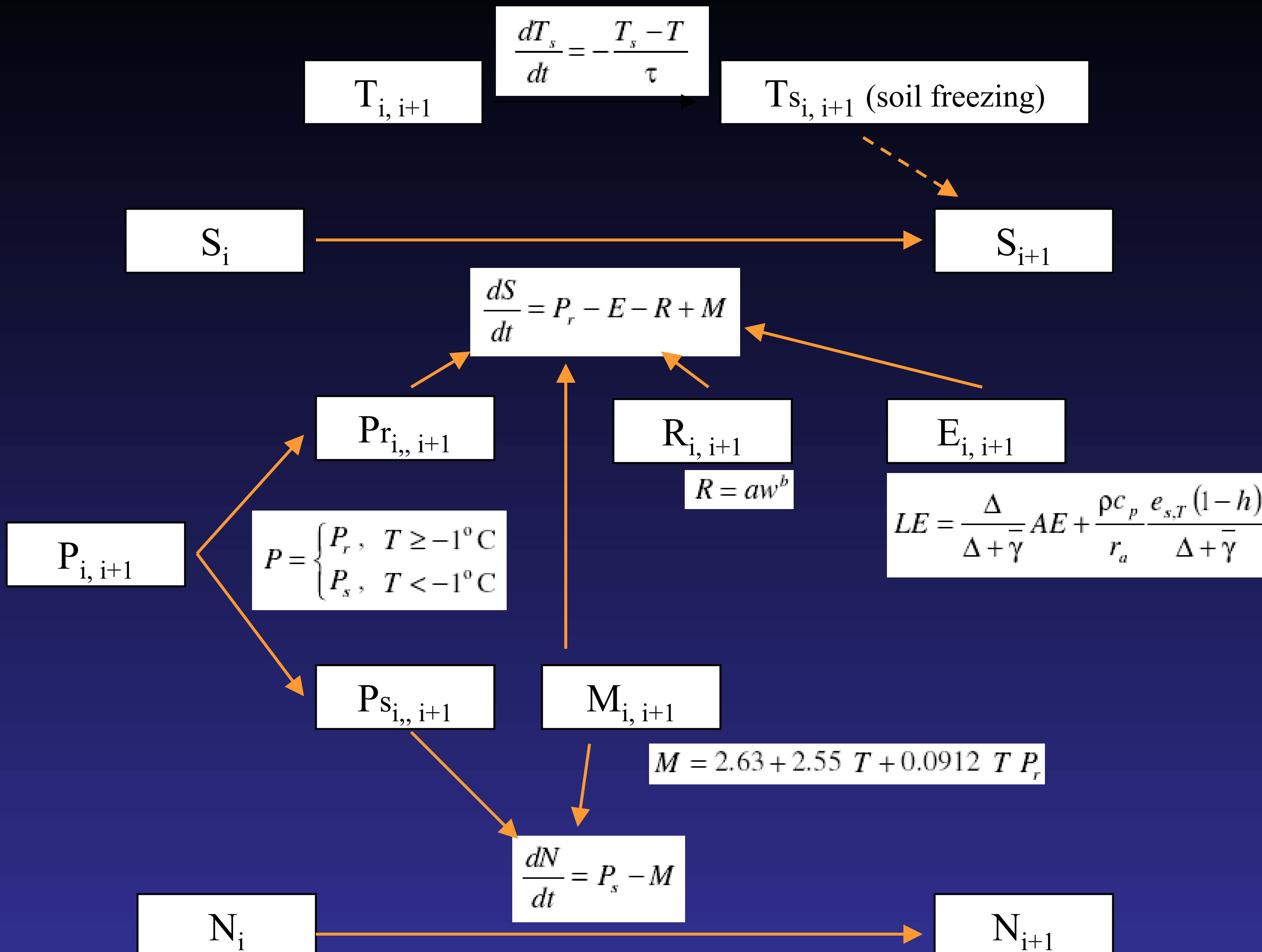


Oyama and Nobre, 2002

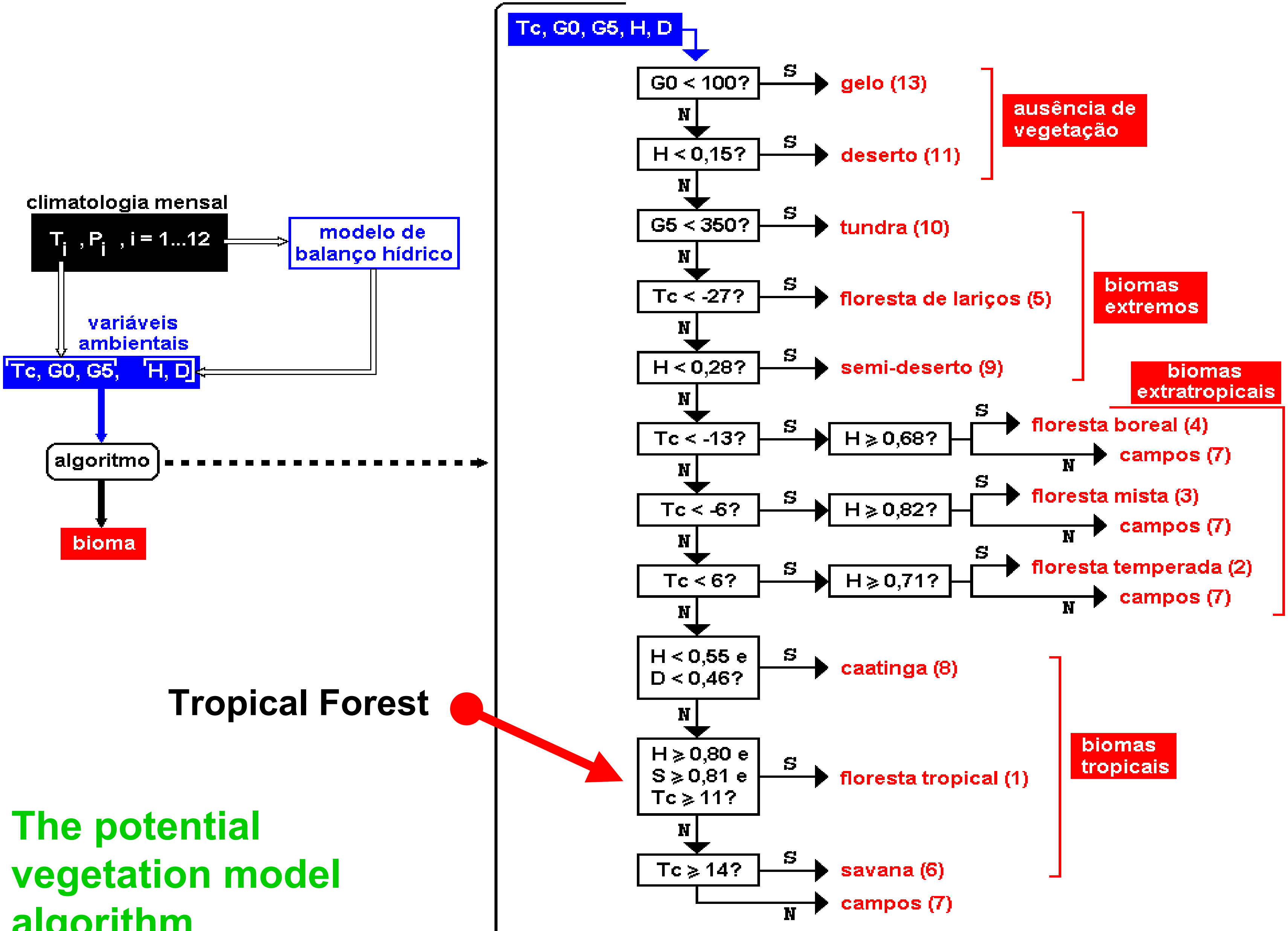
$$\text{Biome} = f(\text{climate variables})$$
$$= f(g_0, g_5, Tc, h, s)$$

g_0 = degree-days above 0 C
g_5 = degree-days above 5 C
Tc = mean temperature of the coldest month
h = aridity index
s = sesonality index

f is a highly non linear function



$\frac{dT_s}{dt} = -\frac{T_s - T}{\tau}$
$T_{i,\,i+1}$
$Ts_{i,\,i+1}$ (soil freezing)
S_i
S_{i+1}
$\frac{dS}{dt} = P_r - E - R + M$
$Pr_{i,,\,i+1}$
$R_{i,\,i+1}$
$E_{i,\,i+1}$
$R = aw^b$
$LE = \frac{\Delta}{\Delta + \bar{\gamma}} AE + \frac{\rho c_p}{r_a} \frac{e_{s,T}(1-h)}{\Delta + \bar{\gamma}}$
$P_{i,\,i+1}$
$P = \begin{cases} P_r, & T \geq -1^{\circ}\mathrm{C} \\ P_s, & T < -1^{\circ}\mathrm{C} \end{cases}$
$Ps_{i,,\,i+1}$
$M_{i,\,i+1}$
$M = 2.63 + 2.55\ T + 0.0912\ T\ P_r$
$\frac{dN}{dt} = P_s - M$
N_i
N_{i+1}

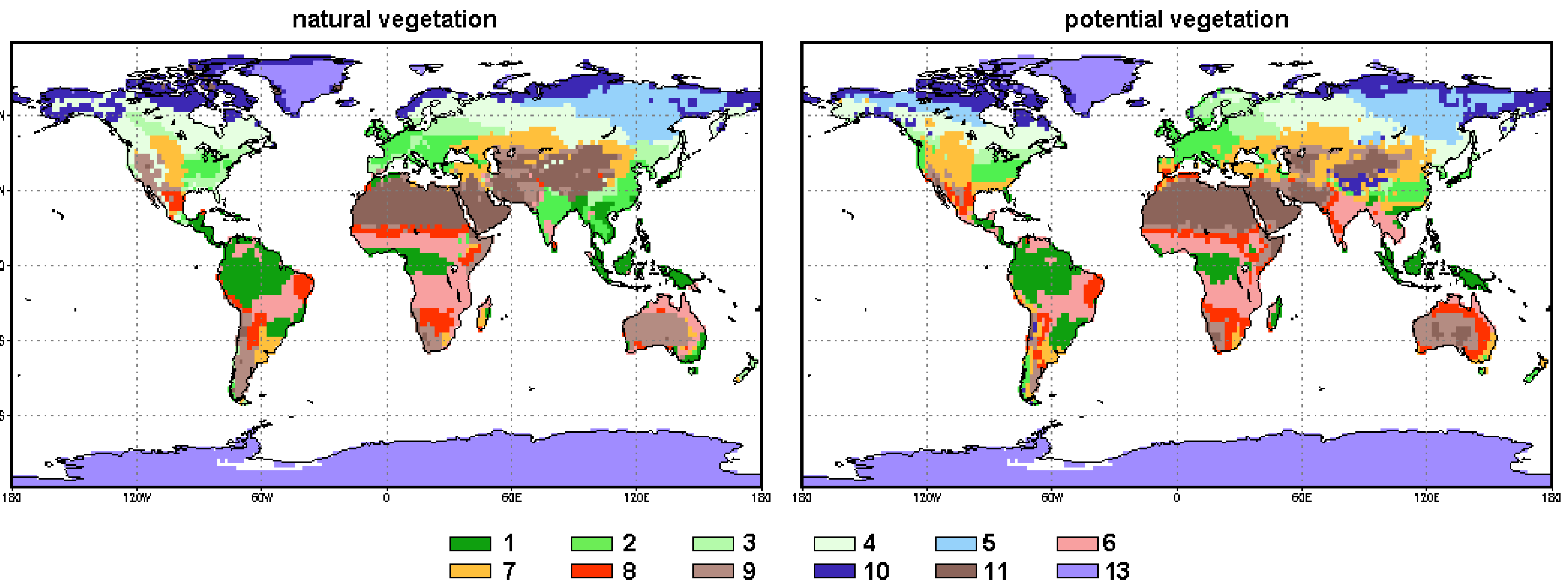


The potential vegetation model algorithm

Oyama and Nobre, 2002

Visual Comparison of CPTEC-PBM versus Natural Vegetation Map

CPTEC-PBM



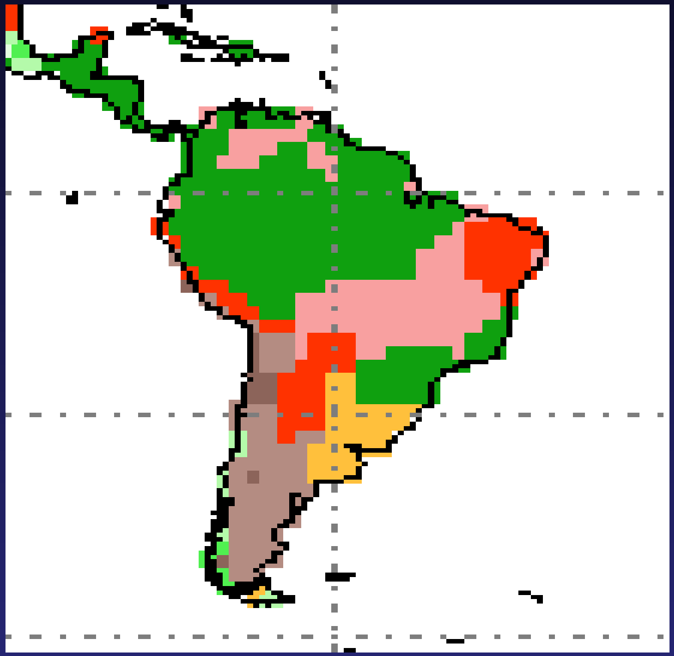
SiB Biome Classification

1 Broadleaf-evergreen trees (tropical forest)
2 Broadleaf-deciduous trees (temperate forest)
3 Broadleaf and needleleaf trees (mixed forest)
4 Needleleaf-evergreen trees (boreal forest)
5 Needleleaf-deciduous trees (larch)
6 Broadleaf trees with groundcover (savanna)
7 Groundcover only (grasslands)
8 Broadleaf shrubs with perennial groundcover (caatinga)
9 Broadleaf shrubs with bare soil (semi-desert)
10 Dwarf trees and shrubs with groundcover (tundra)
11 Bare soil (desert)
13 Perpetual ice

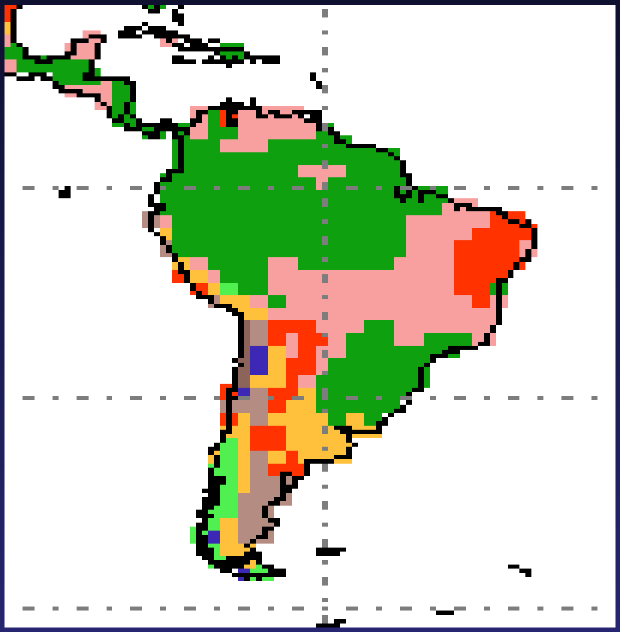
Oyama and Nobre, 2002

Visual Comparison of CPTEC-PBM versus Natural Vegetation Map

NATURAL VEGETATION



POTENTIAL VEGETATION



1 2 3 4 5 6
7 8 9 10 11 13

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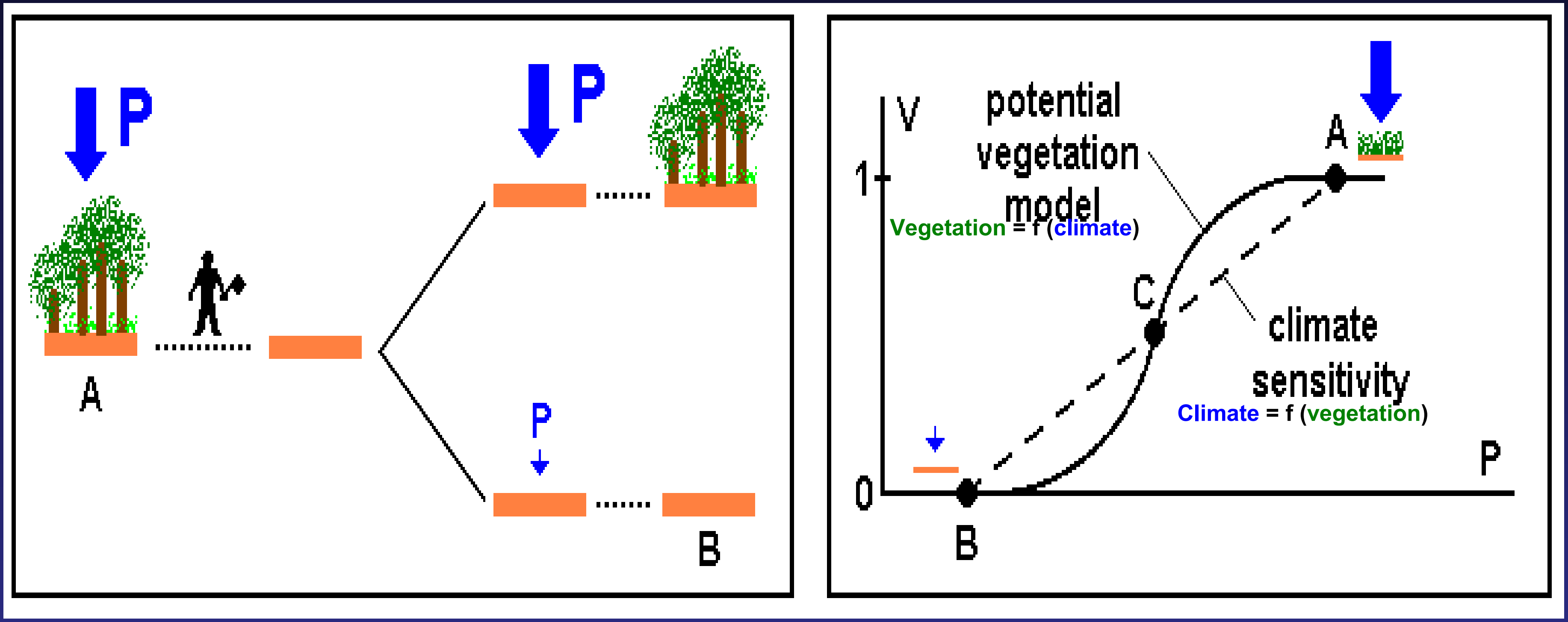
SiB Biome Classification

Oyama and Nobre, 2002

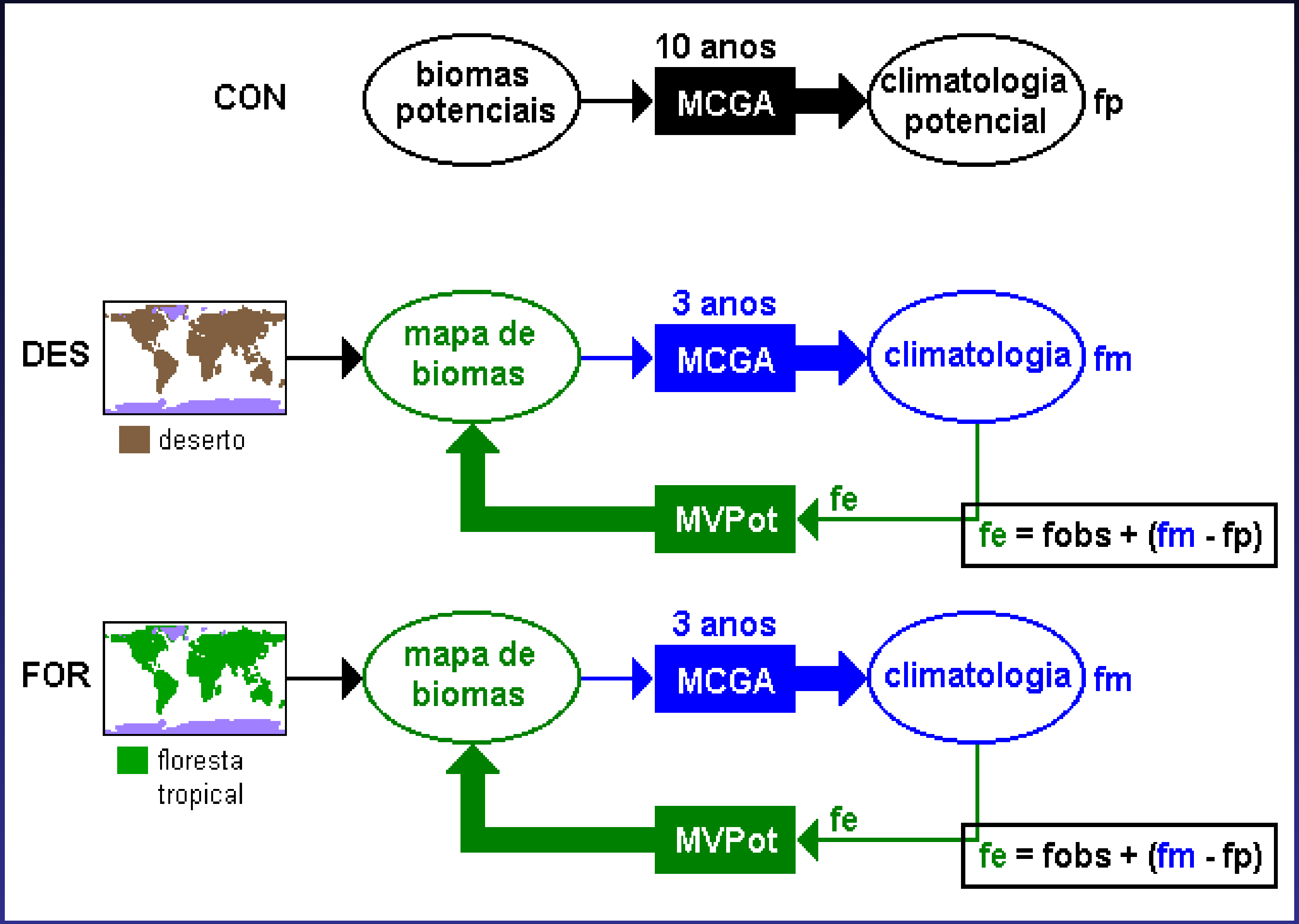
Searching for Multiple Biome-Climate Equilibria

Climate Equilibrium States

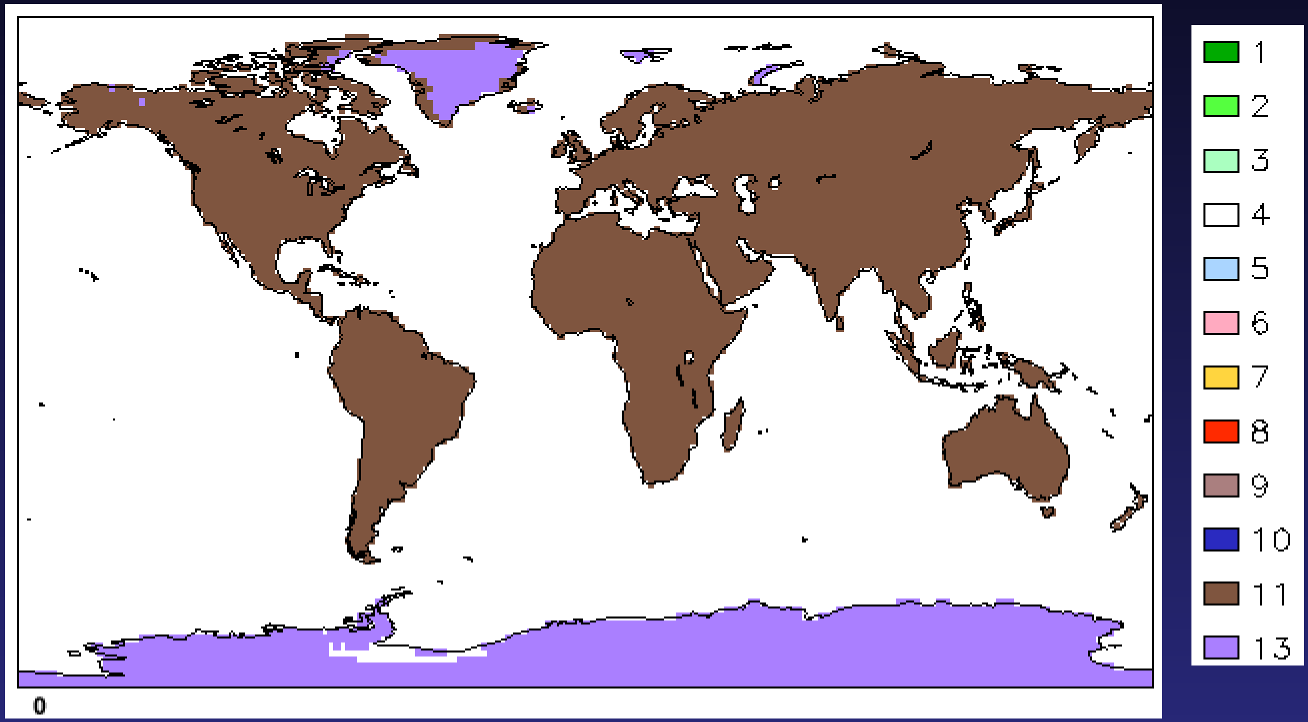


Oyama, 2002

Multiple Vegetation-Climate Equilibrium States



Oyama, 2002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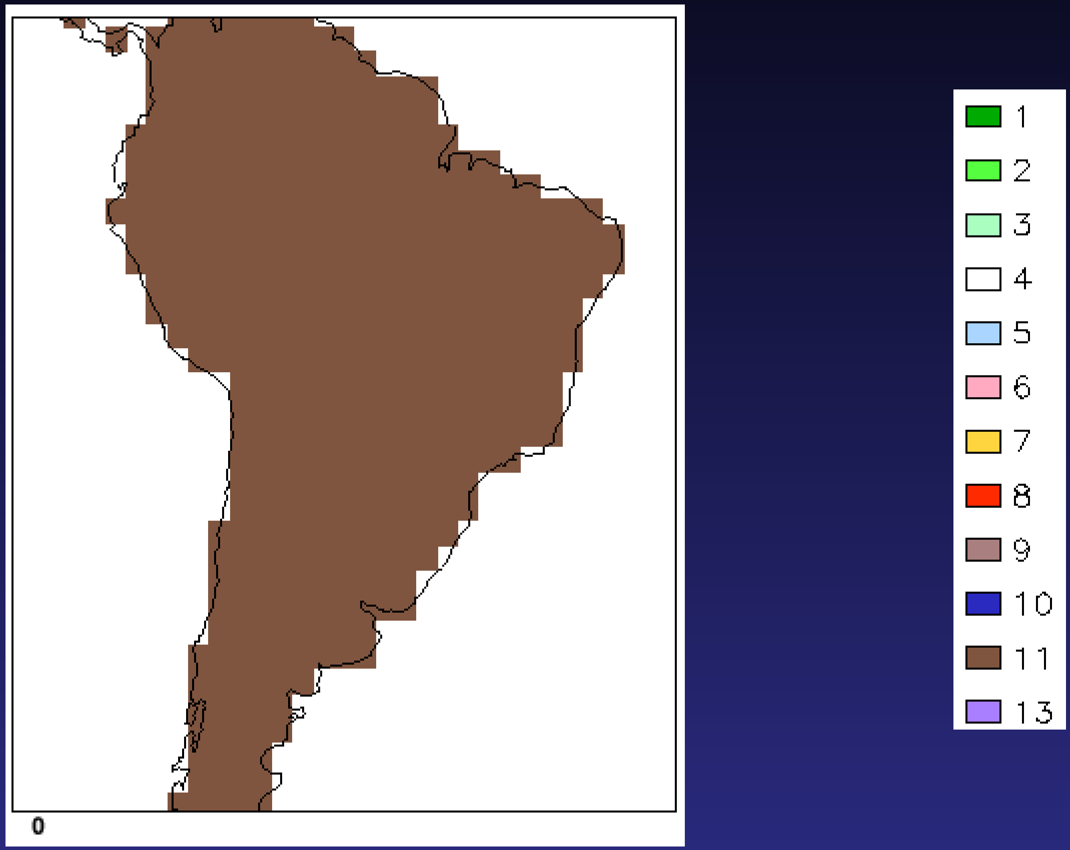
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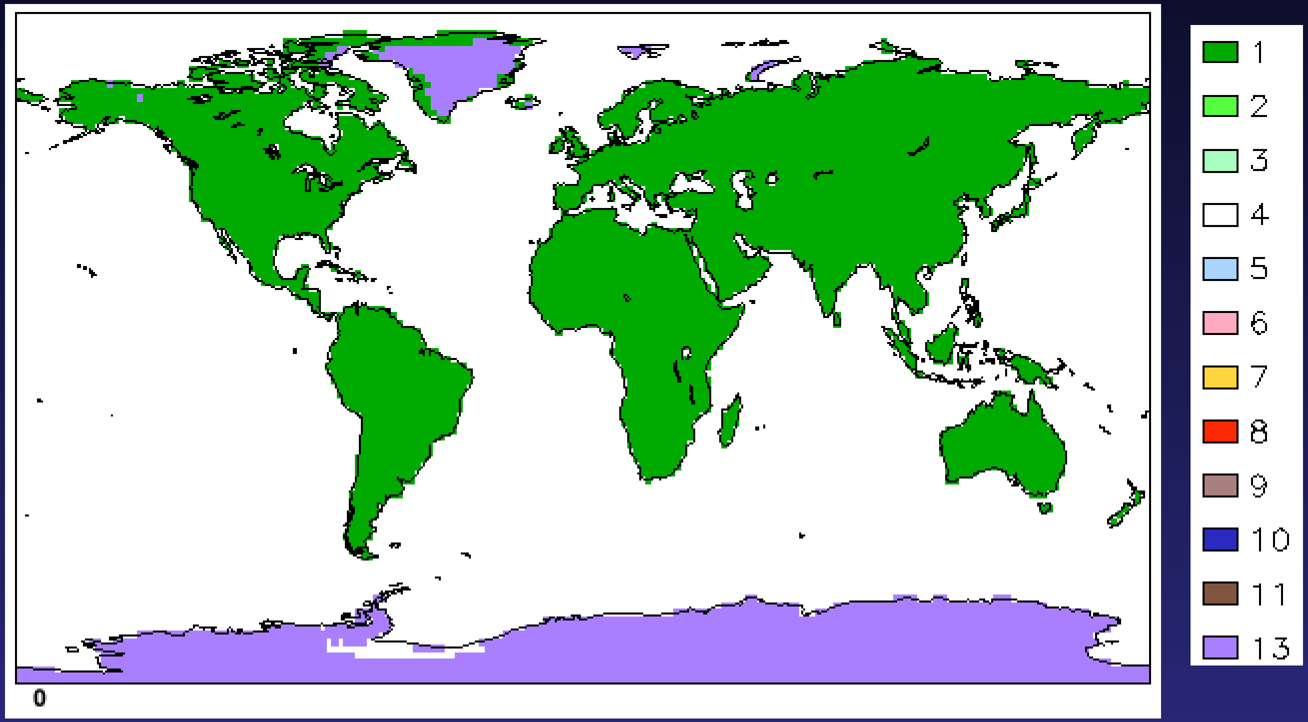
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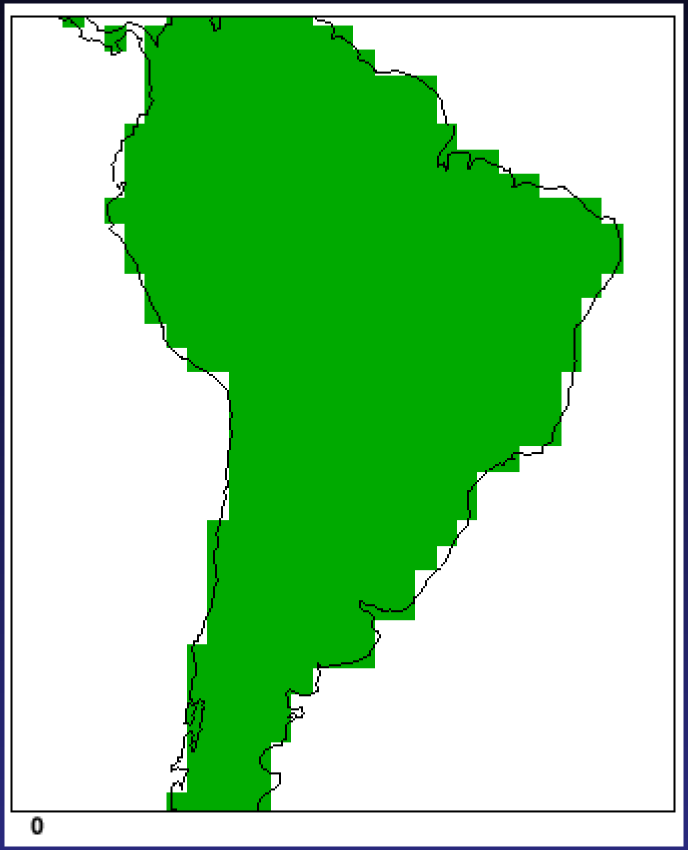
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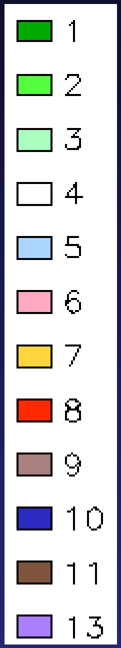
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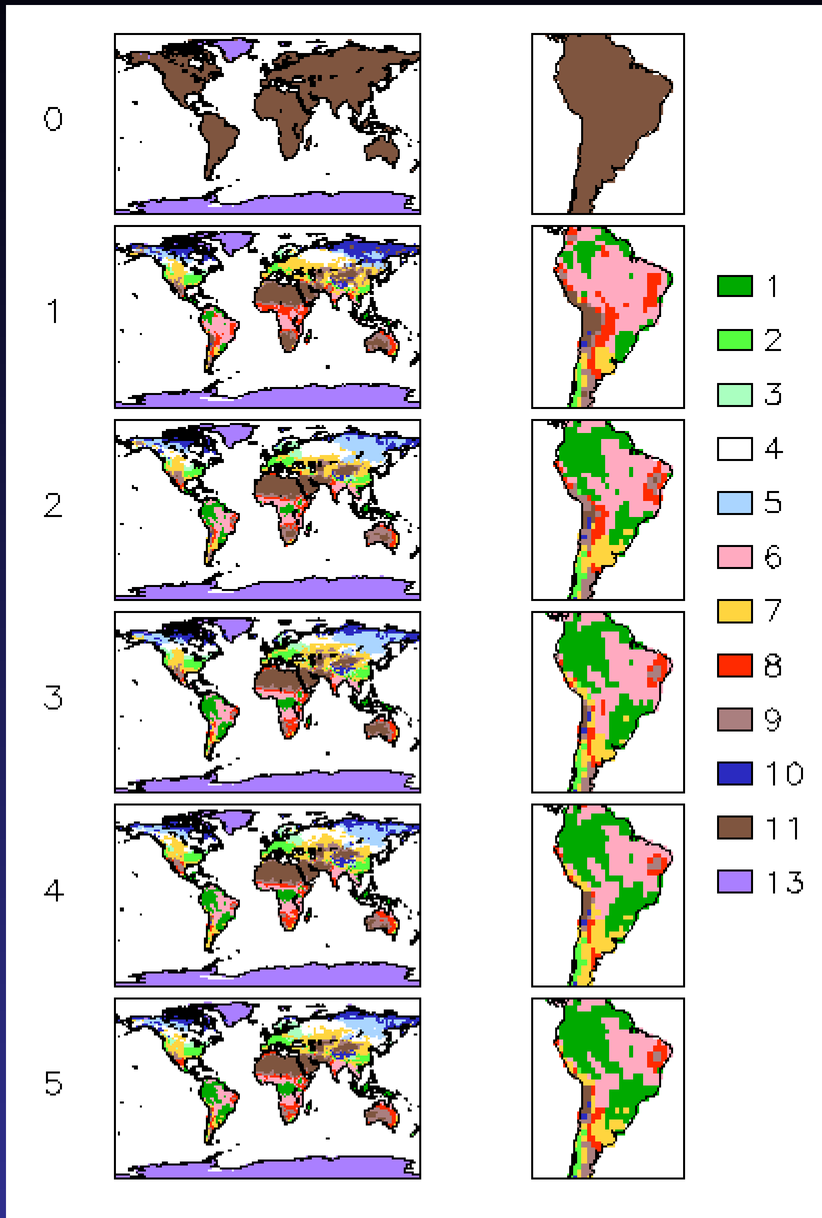
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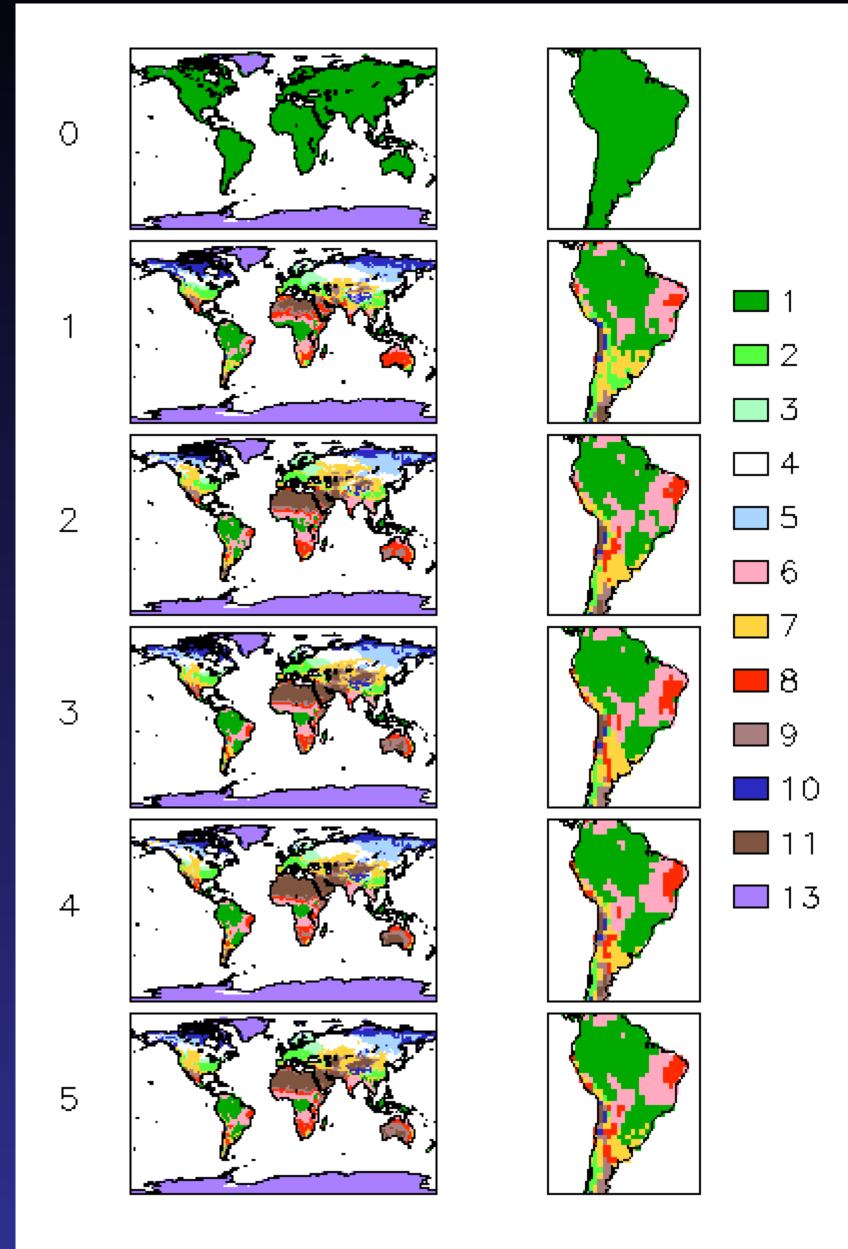
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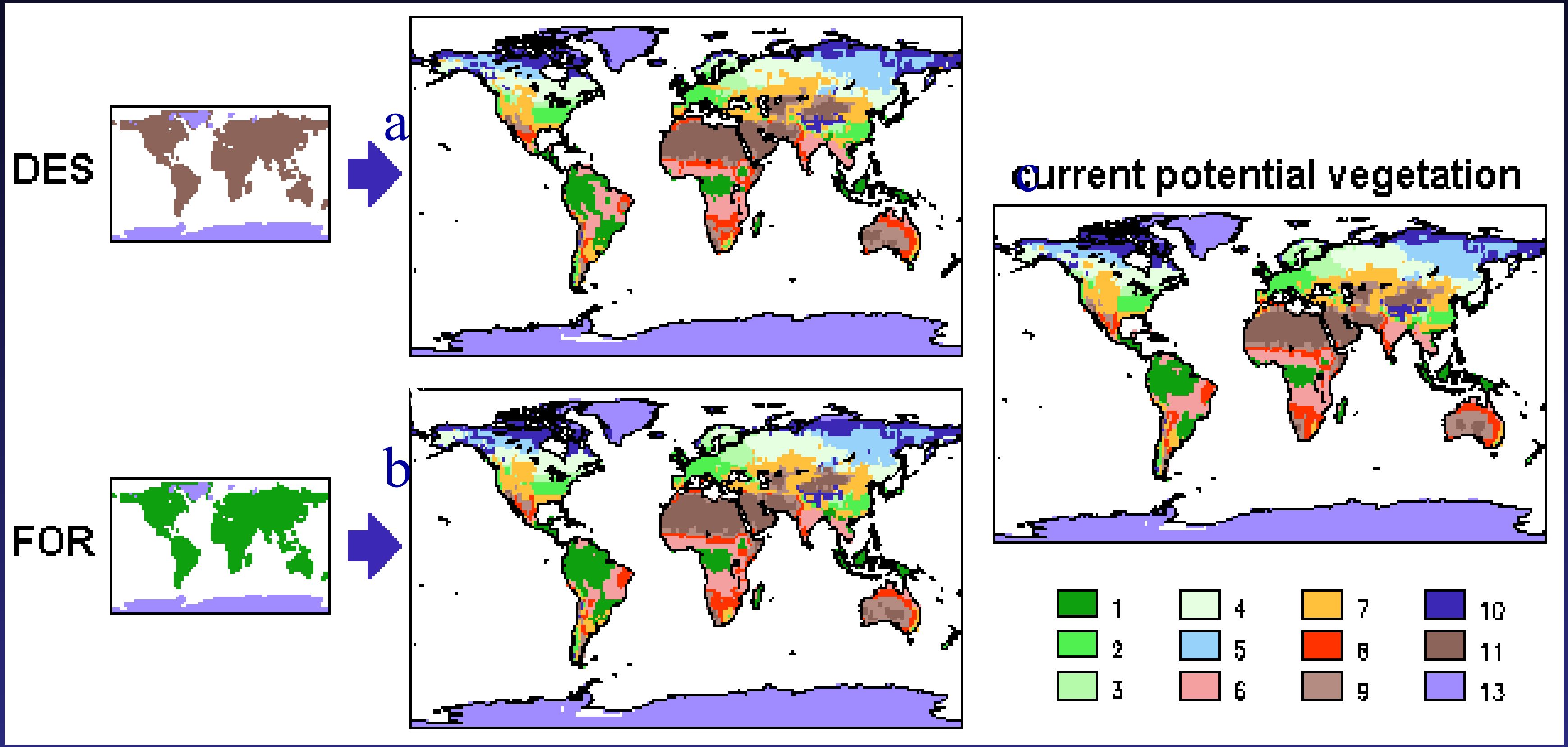
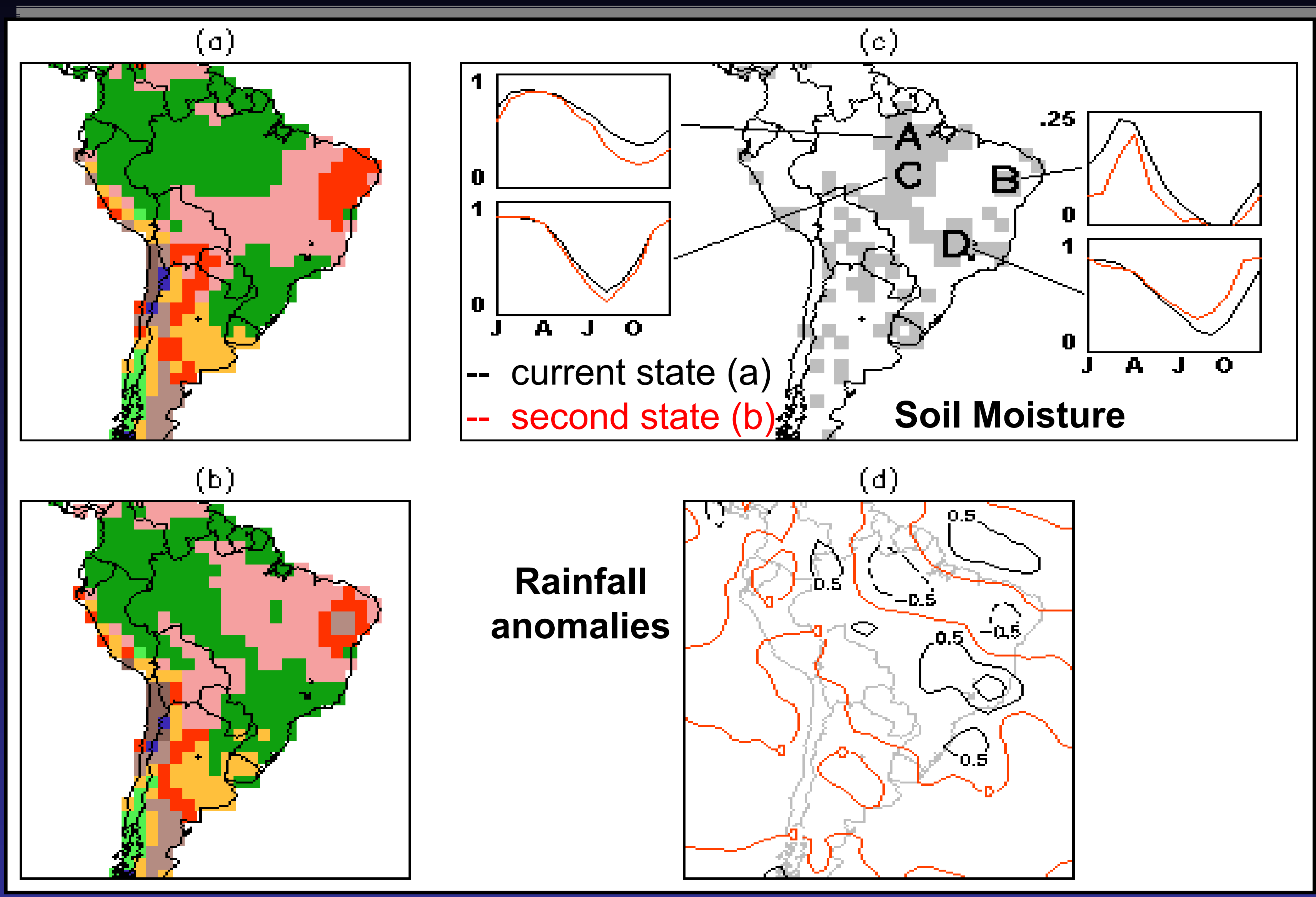
Results of CPTEC-DBM for two different Initial Conditons: all land areas covered by desert (a) and forest (b)



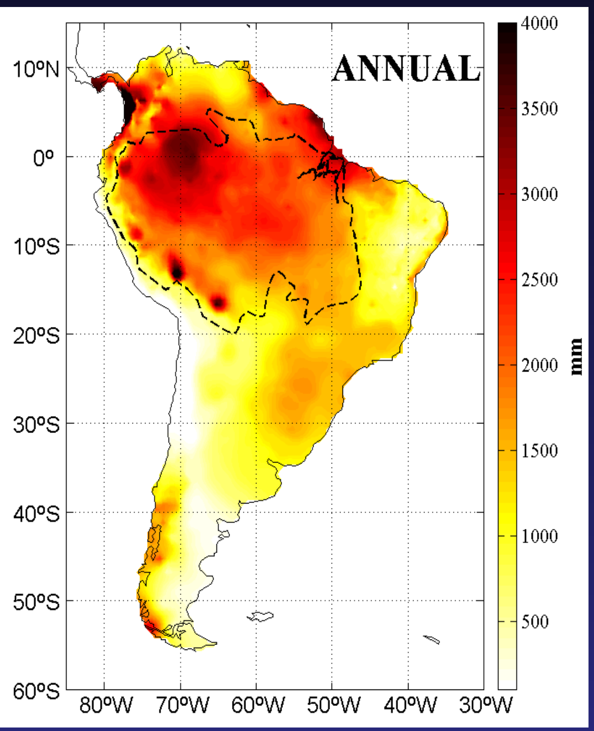
Biome-climate equilibrium solution with IC as forest (a) is similar to current natural vegetation (c); when the IC is desert (b), the final equilibrium solution is different for Tropical South America

Oyama, 2002

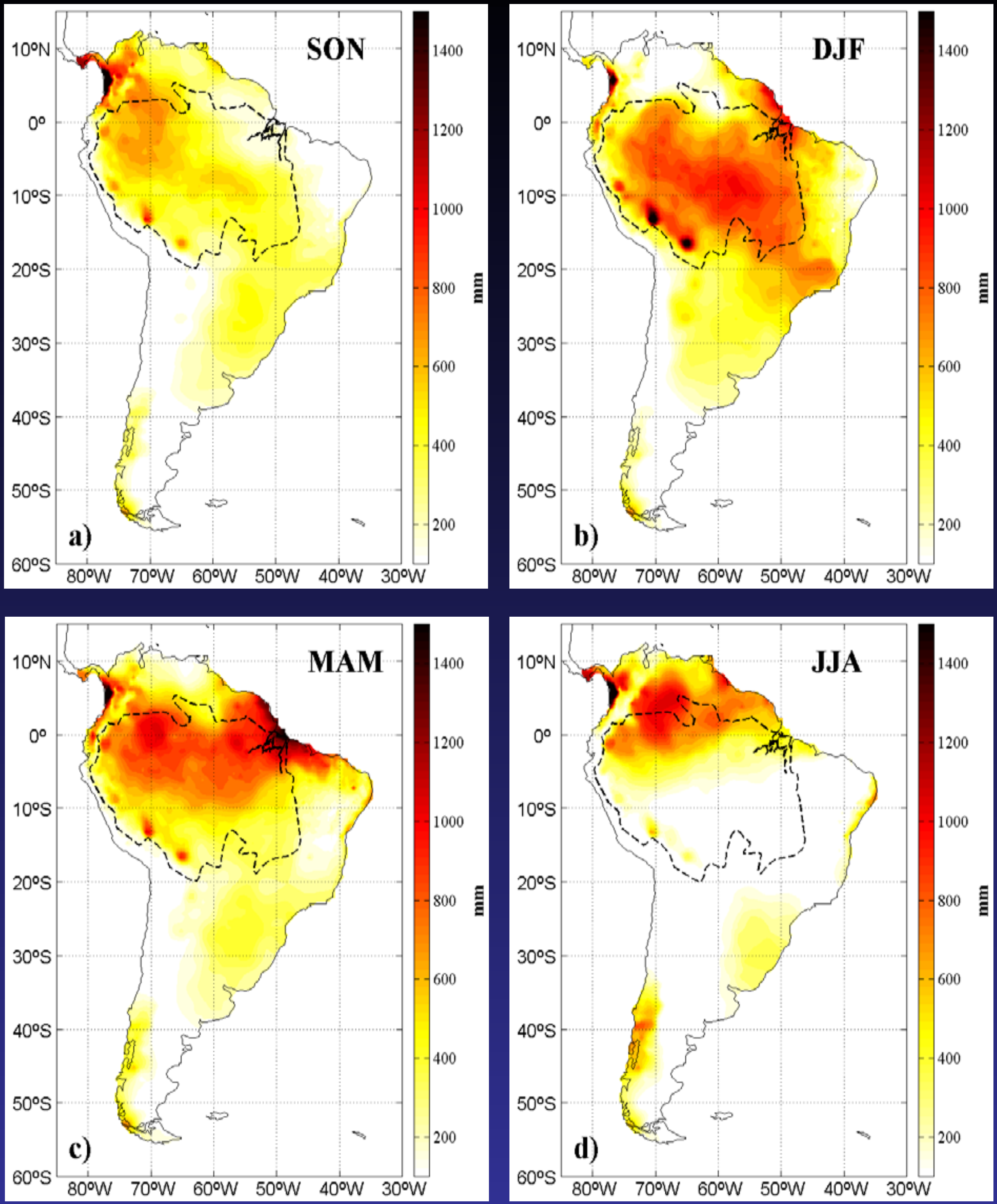
Two Biome-Climate Equilibrium States found for South America!



Oyama and Nobre, 2003



Annual total rainfall



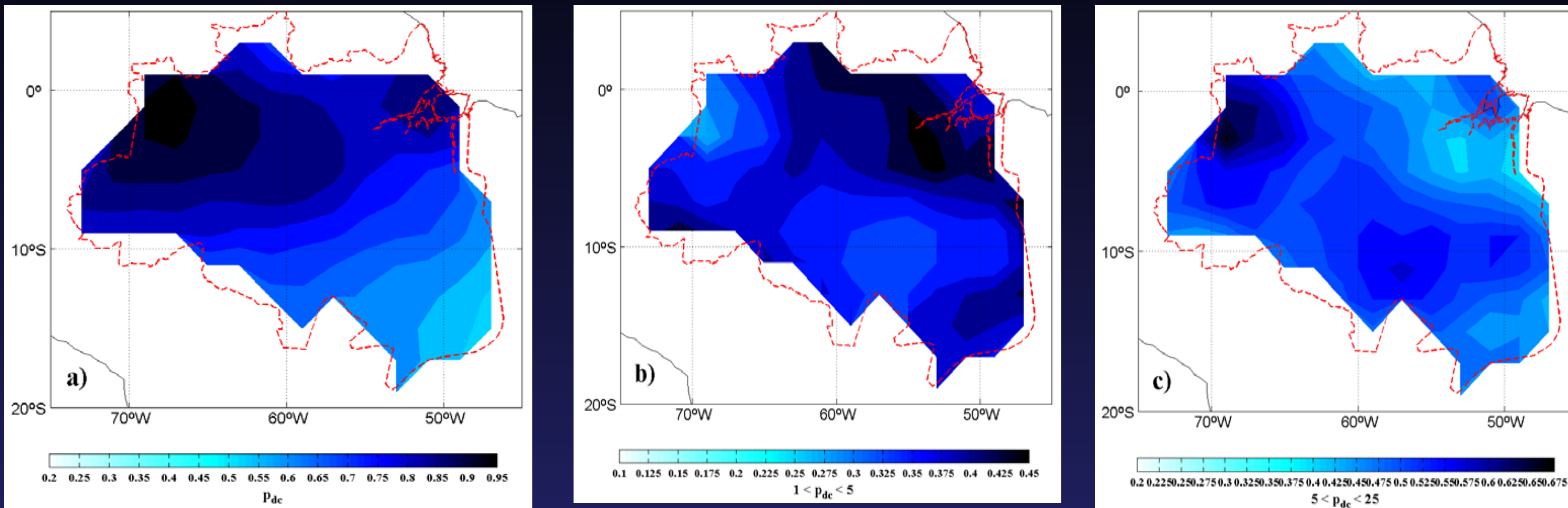
Seasonal total rainfall

Obregon 2001

P > 1 mm

1mm < P < 1 mm

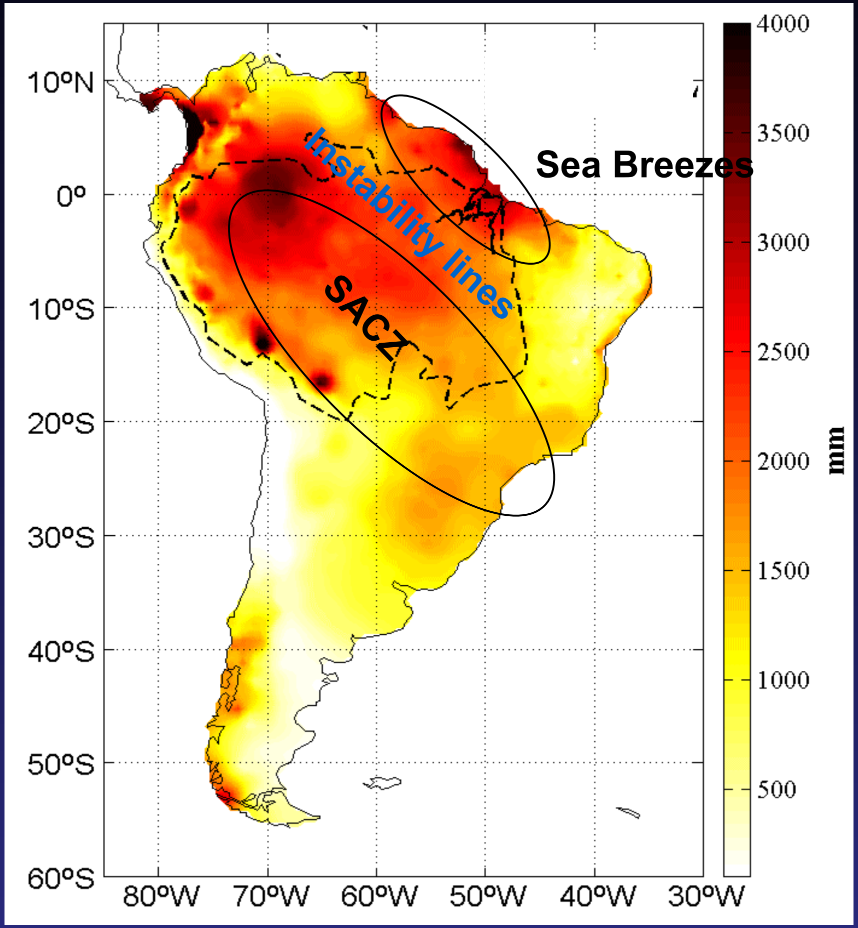
5mm < P < 25 mm



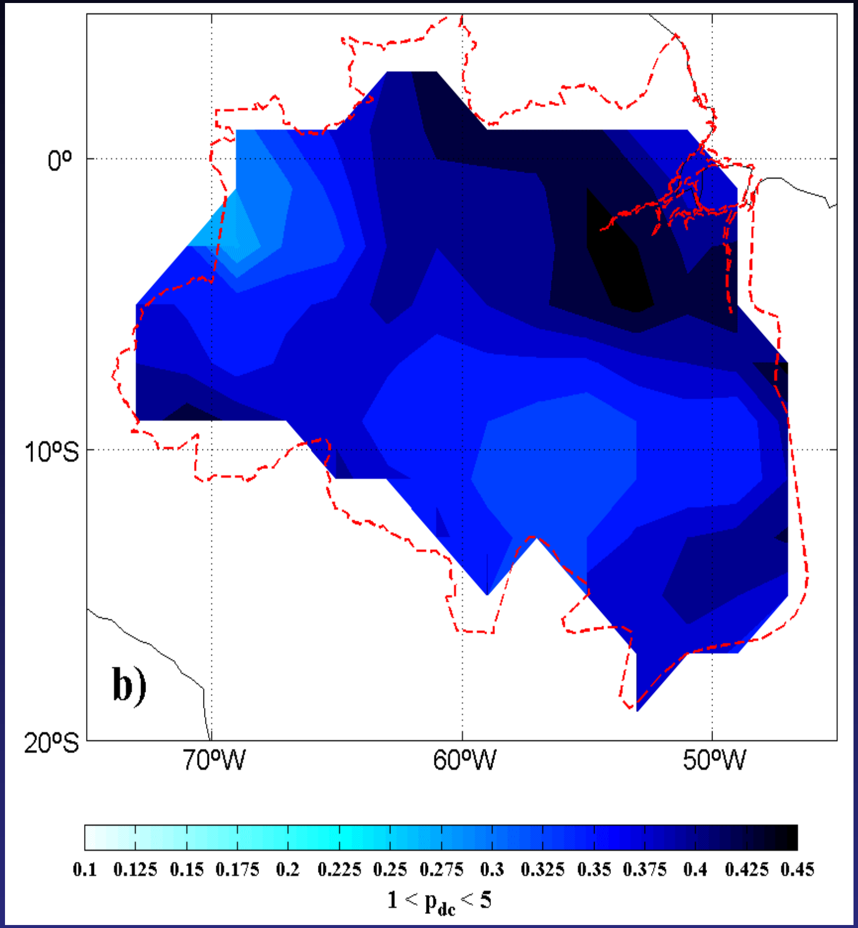
Unconditional probability of a wet day. a) Threshold of 1 mm, b) Weak rainfall (rainy days: 1 mm - 5 mm) and, c) Moderate rainfall (rainy days: 5 mm - 25 mm). The daily data span 1979 to 1993.

Obregon 2001

Anual Precipitation



1mm < P < 5 mm

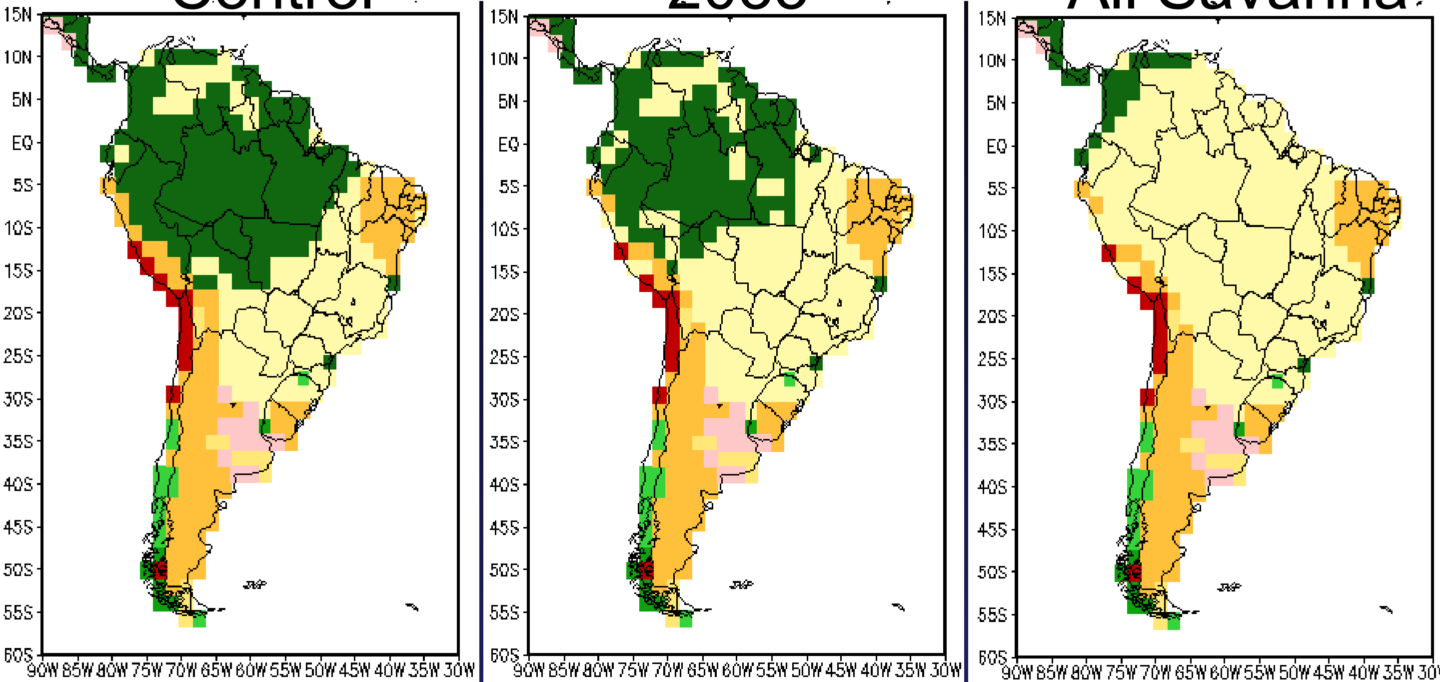


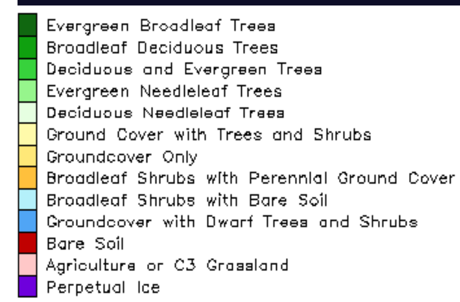
Obregon 2001

Testing the robustness of these results with sensitivity analysis of AGCM to changes in land cover in Northeast Brazil (desertification) and Amazonia (deforestation, “savannazation”)

VEGETATION MAP

Control | 2033 | All Savanna



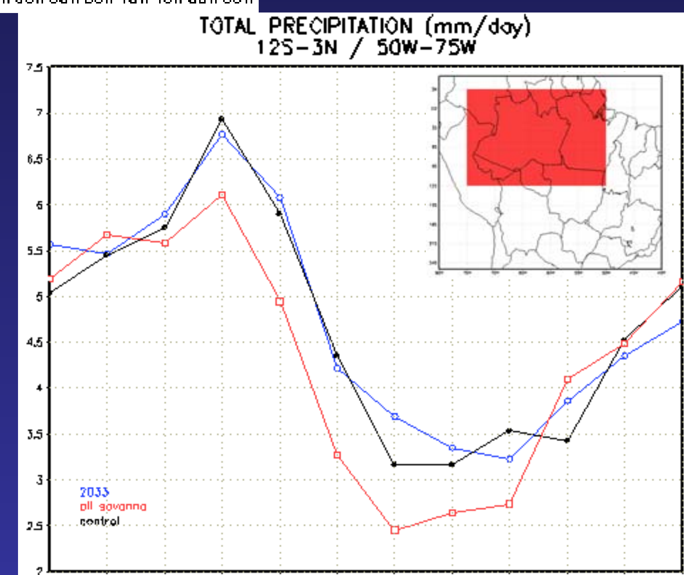


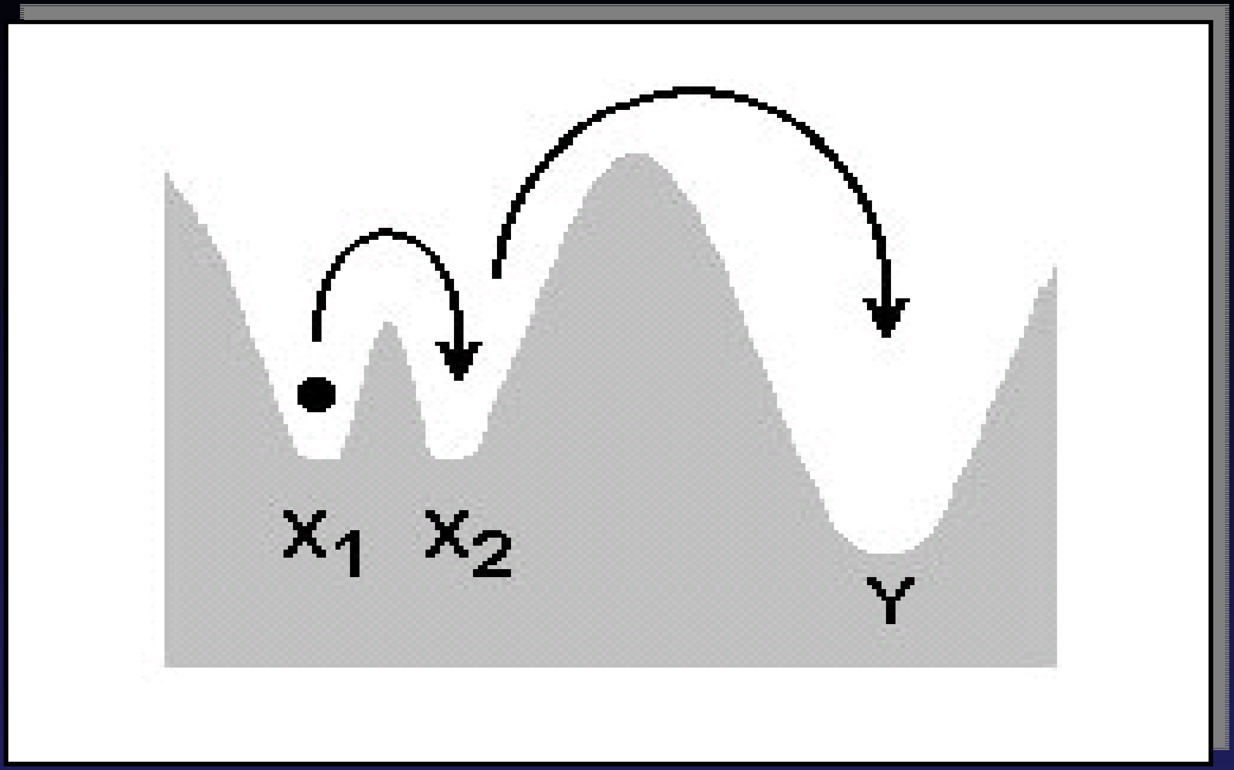
Resolution: ~ 2°x2°

Dry Season – Precipitation*

	2033	All Savanna
JJA	5,4%	-21,7%
JJAS	1,9%	-21,9%

* 12°S-3°N / 50°W-75°W

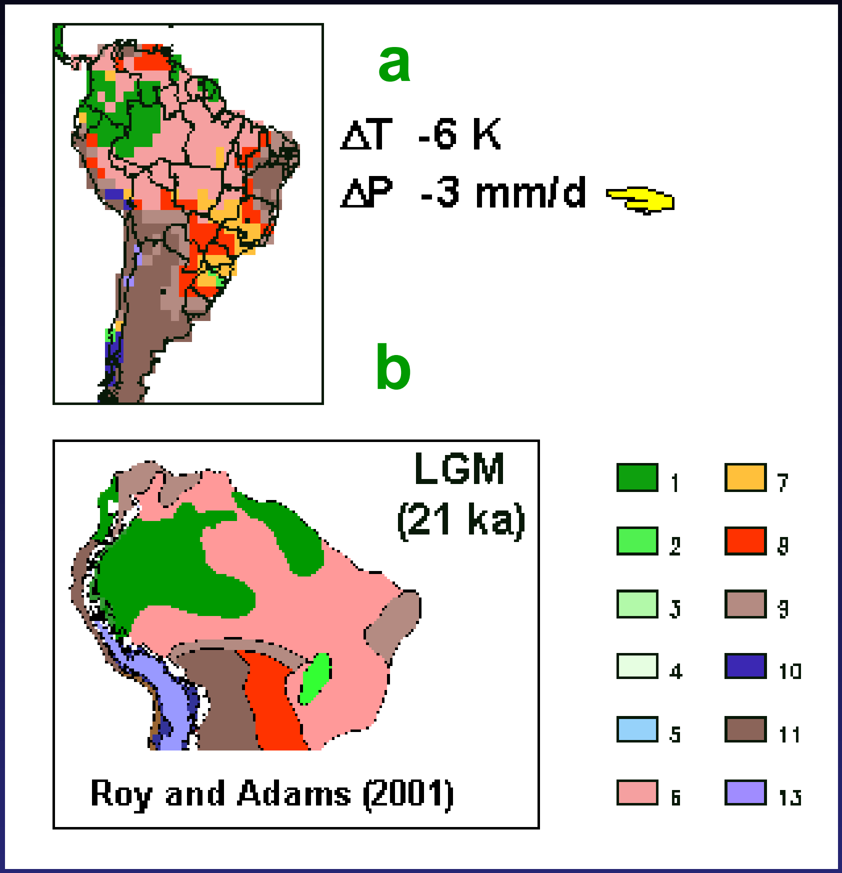




Possible stability landscape for Tropical South America. Valleys (X1, X2 and Y) and hills correspond to stable and unstable equilibrium states, respectively. Arrows represent climate state (depicted as a black circle) perturbations. State X1 refers to present-day stable equilibrium. For small (large) excursions from X1, state X2 (Y) can be found. It is suggested that the new alternative stable equilibrium state found in this work corresponds to X2. Notice that it is necessary to reach X2 before reaching state Y.

Paleovegetation Reconstructions as Validation for the Second Stable Equilibrium?

Application of CPTEC-PBM for Past Climate Changes



(a) PBM results with uniform cooling of 6 C and drying of 3 mm/day to emulate climate conditions of the LGM (21 ka BP);
(b) vegetation reconstruction for LGM;

Oyama, 2002

Vegetation feedbacks in Amazonia at the last glacial maximum (21 ka BP)

- GENESIS-IBIS coupled vegetation-climate model
- 3 experiments: control, R, RPV
- Control: present orbital forcing, 350 ppmv CO_2 in both radiative and physiological routines, modern vegetation cover
- R: 21 ka BP radiation forcing only (orbital forcing, 180 ppmv CO_2 radiative forcing), modern vegetation cover
- RPV: 180 ppmv CO_2 forcing for physiological routines, dynamic vegetation

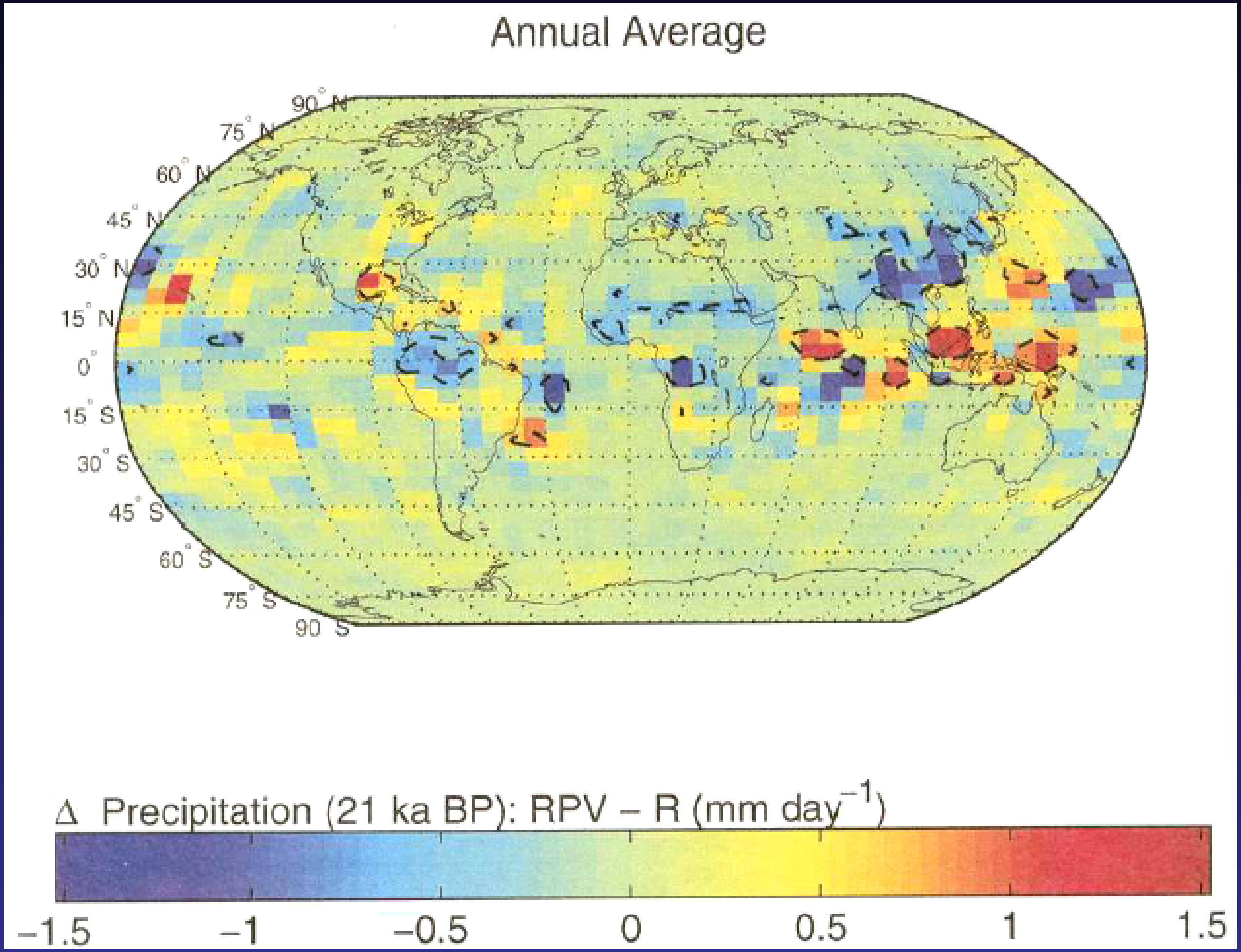
Reference: Foley, J. A.; Levis, S.; Costa, M. H., Cramer, W.; Pollard, D. 2000: Incorporating dynamic vegetation cover within global climate models. *Ecological Applications*, v. 10, n. 6, p. 1620-1632.

Results for Amazonia

Table 1. Annually Averaged Near-Surface Environmental Variables for Simulations Control, R, and RPV over Amazonia (9°S to 9°N and 75°W to 52.5°W)

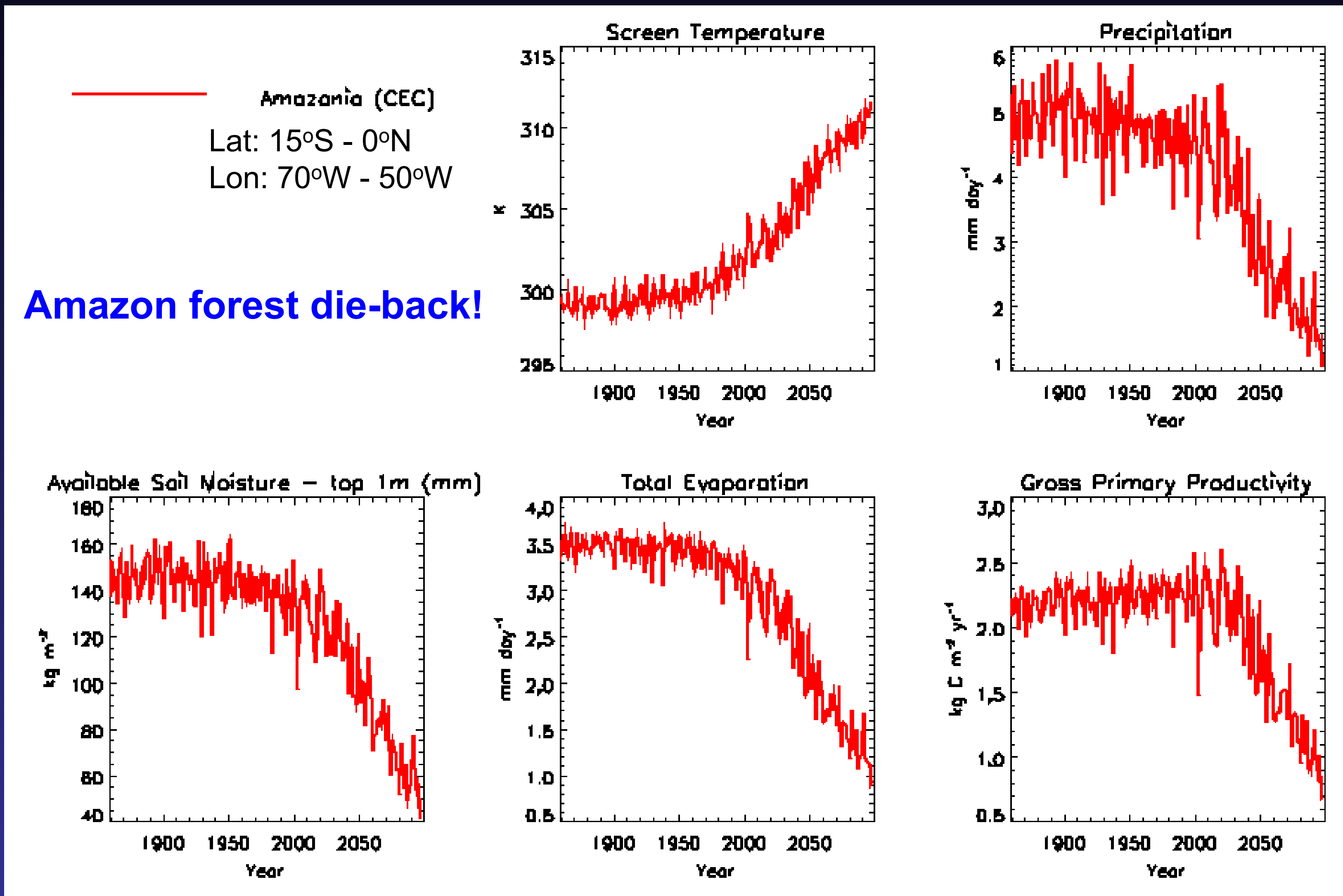
	Control	R	RPV
Global temperature, °C	14.1	9.8 (-4.3)	9.9 (+0.1)
Temperature, °C	25.9	24.2 (-1.7)	24.5 (+0.3)
Precipitation, mm d^{-1}	6.20	4.37 (-30%)	4.00 (-8%)
Soil water, m in 4-m column	1.35	1.31 (-3%)	1.29 (-2%)
Canopy conductance of trees, mm s^{-1}	2.00	1.99 (0%)	1.20 (-40%)
Canopy conductance of herbaceous plants, mm s^{-1}	0.05	0.06 (+20%)	0.91 (+1416%)
Transpiration, mm d^{-1}	1.97	2.23 (+13%)	1.93 (-13%)
Evapotranspiration, mm d^{-1}	2.99	2.88 (-4%)	2.71 (-6%)
Sensible heat, W m^{-2}	28.0	31.9 (+14%)	38.7 (+21%)
Leaf area index of trees, m^2 m^{-2}	6.7	6.7 (0)	3.0 (-3.7)
Leaf area index of herbaceous plants, m^2 m^{-2}	0.2	0.2 (0)	2.0 (+1.8)

Last glacial maximum: GENESIS+IBIS
The importance of vegetation feedbacks

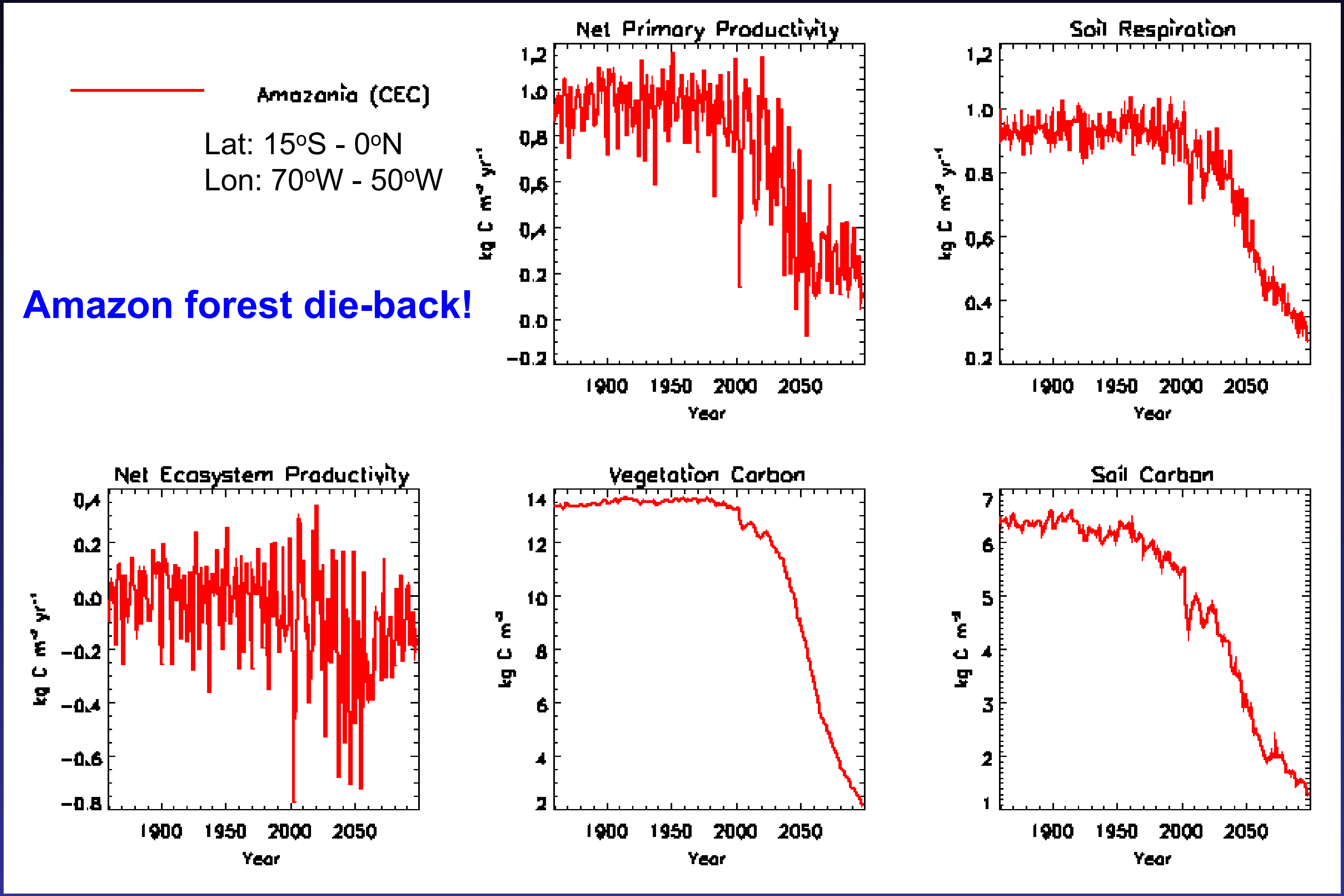


What are the likely biome-climate equilibrium states of the future for Amazonia?

Change in Amazon Climate and Hydrology in HadCM3LC



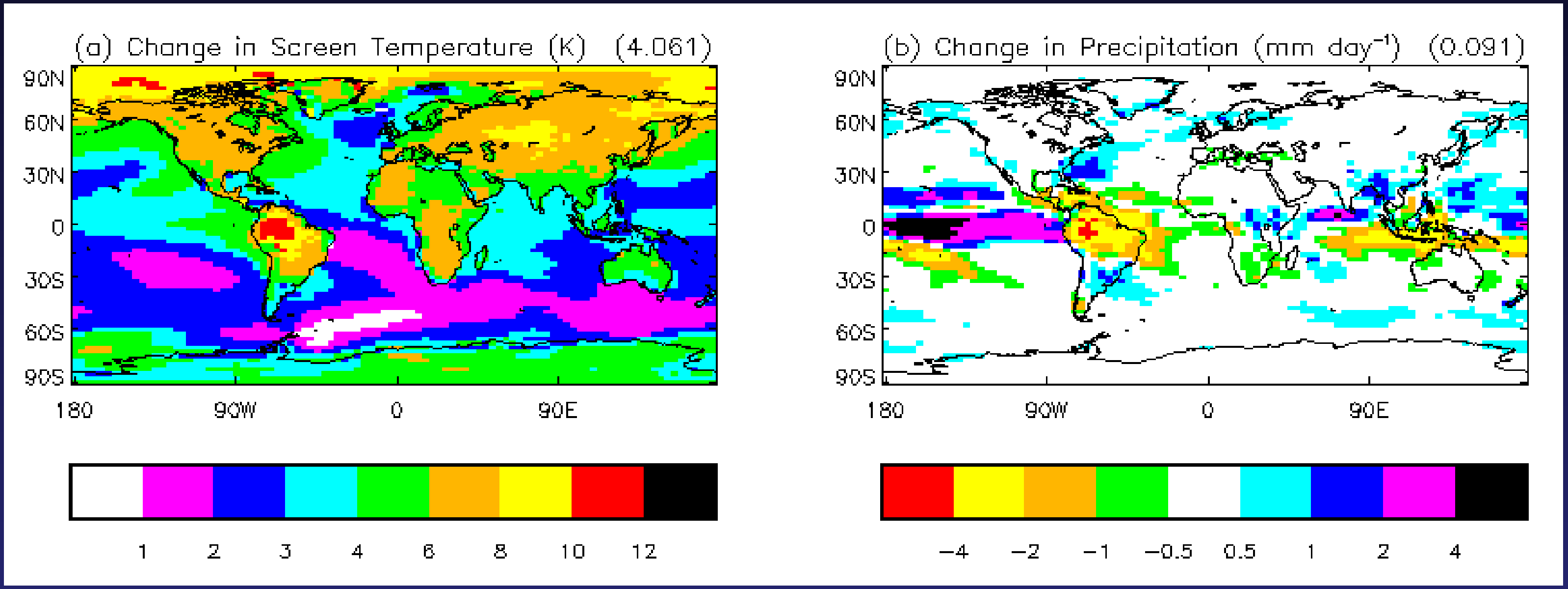
Change in Amazon Carbon Balance in HadCM3LC



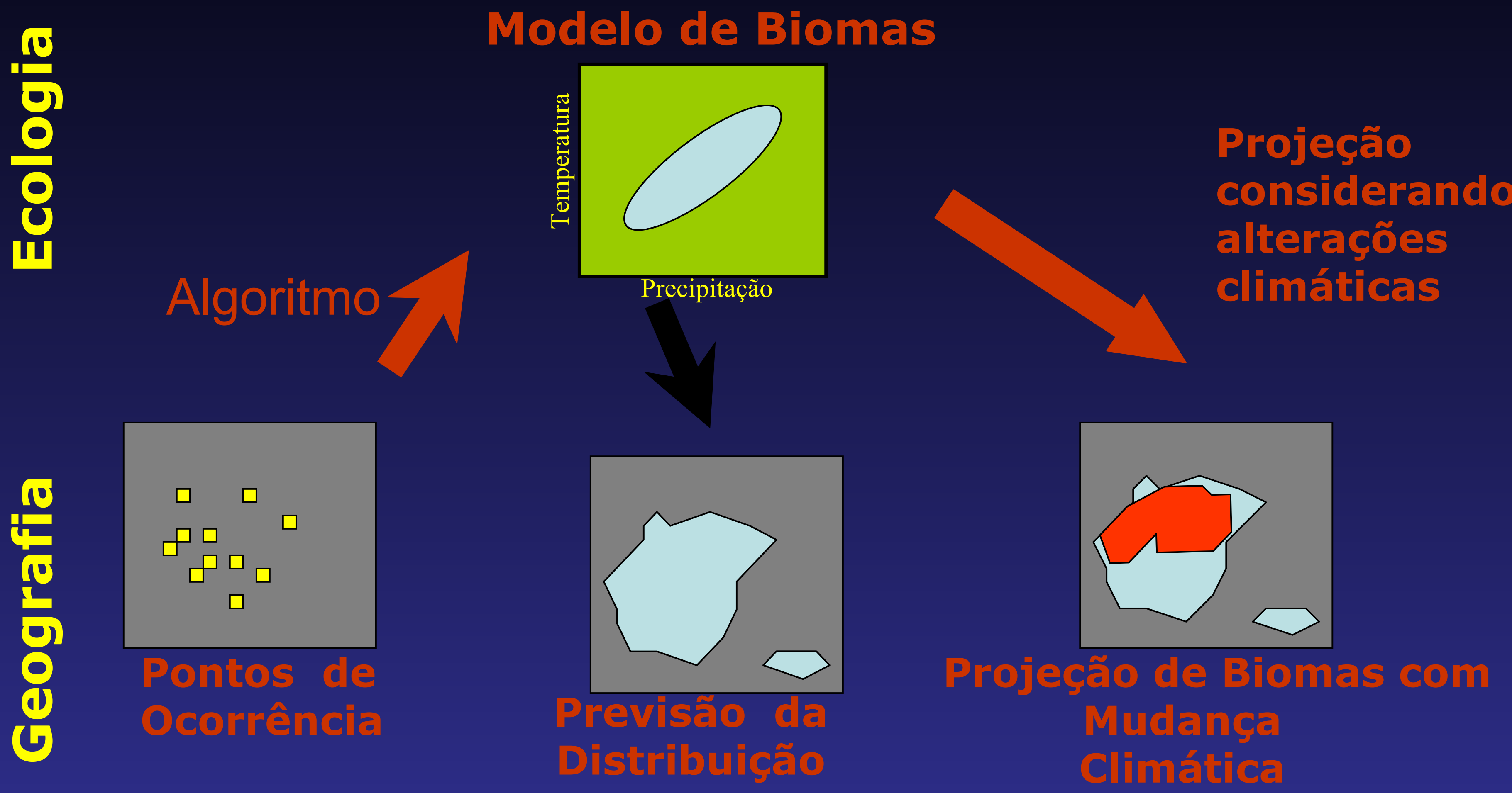
Change in Global Climate in HadCM3LC

Interactive CO_2 and Dynamic Vegetation

2090s - 1990s

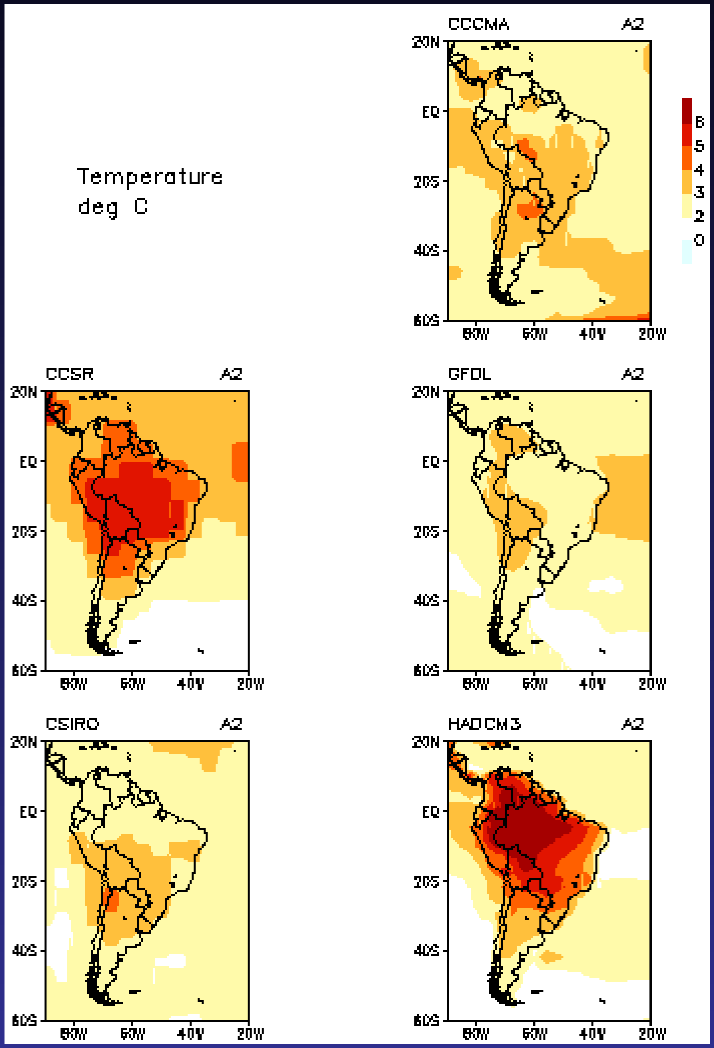


Análise de Mudanças Climáticas

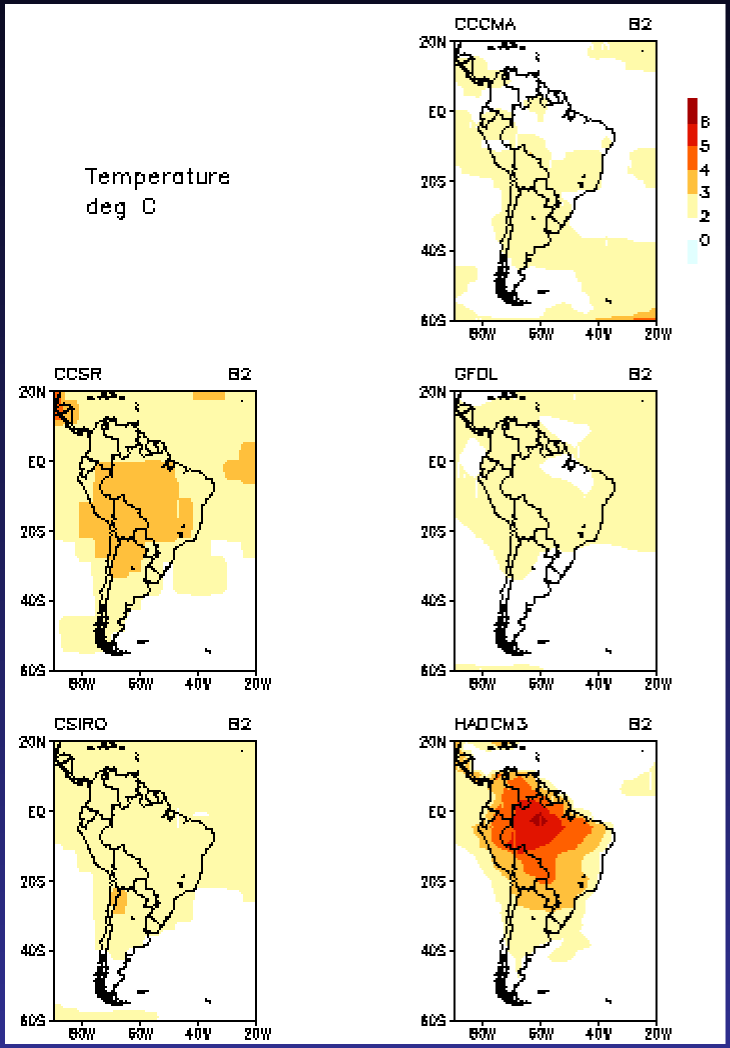


Temperature Anomalies (deg C) for 2091-2100

A2 High GHG Emissions Scenario

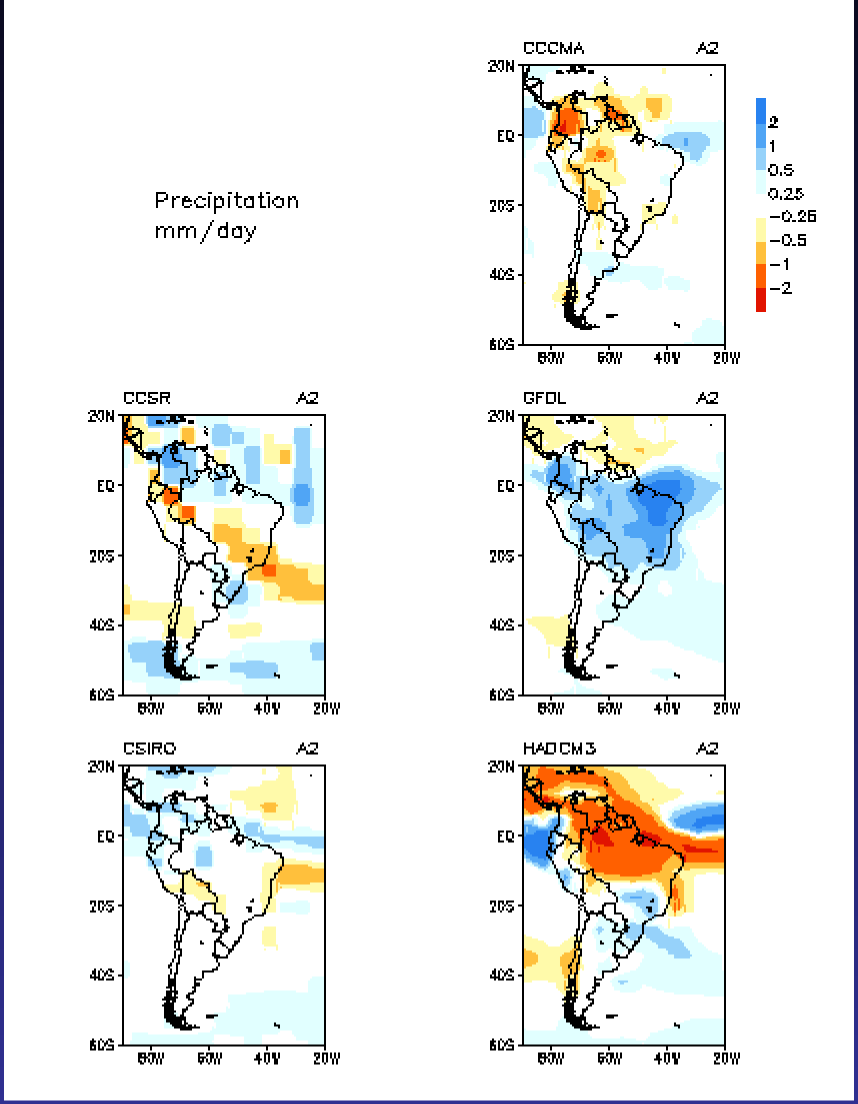


B2 Low GHG Emissions Scenario

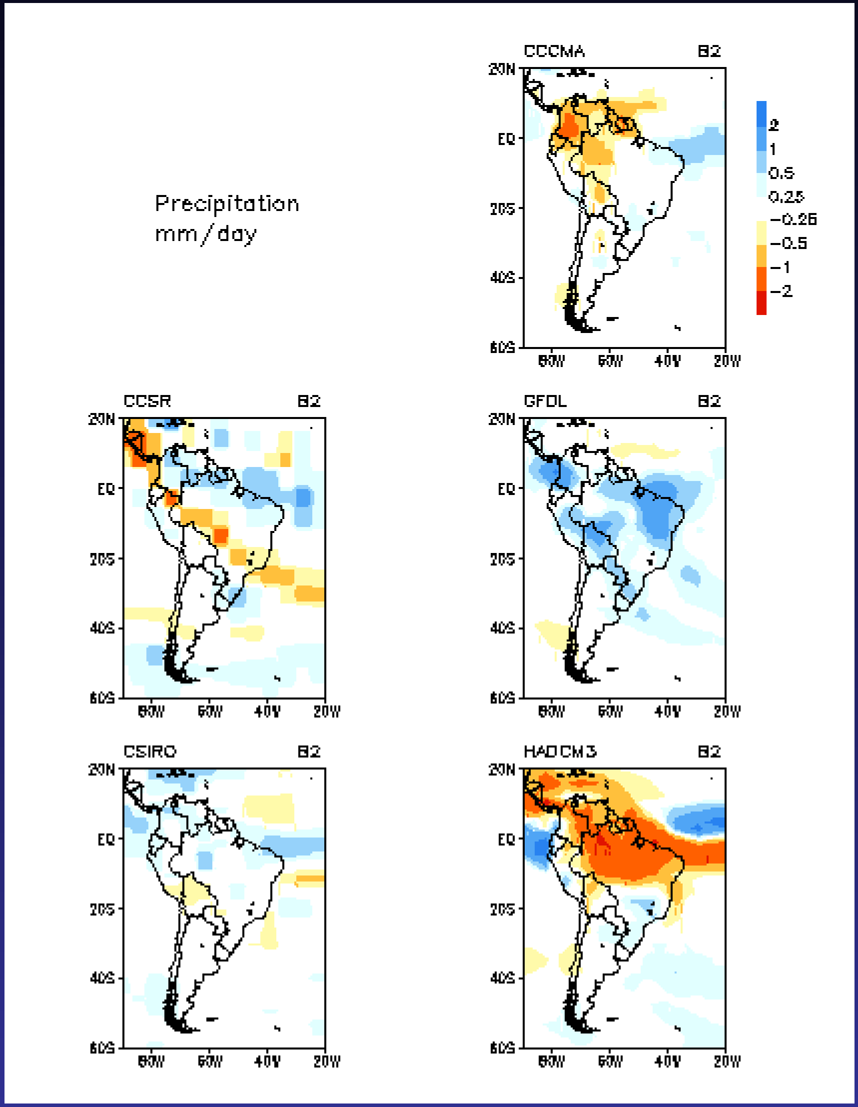


Precipitation Anomalies (mm/day) for 2091-2100

A2 High GHG Emissions Scenario

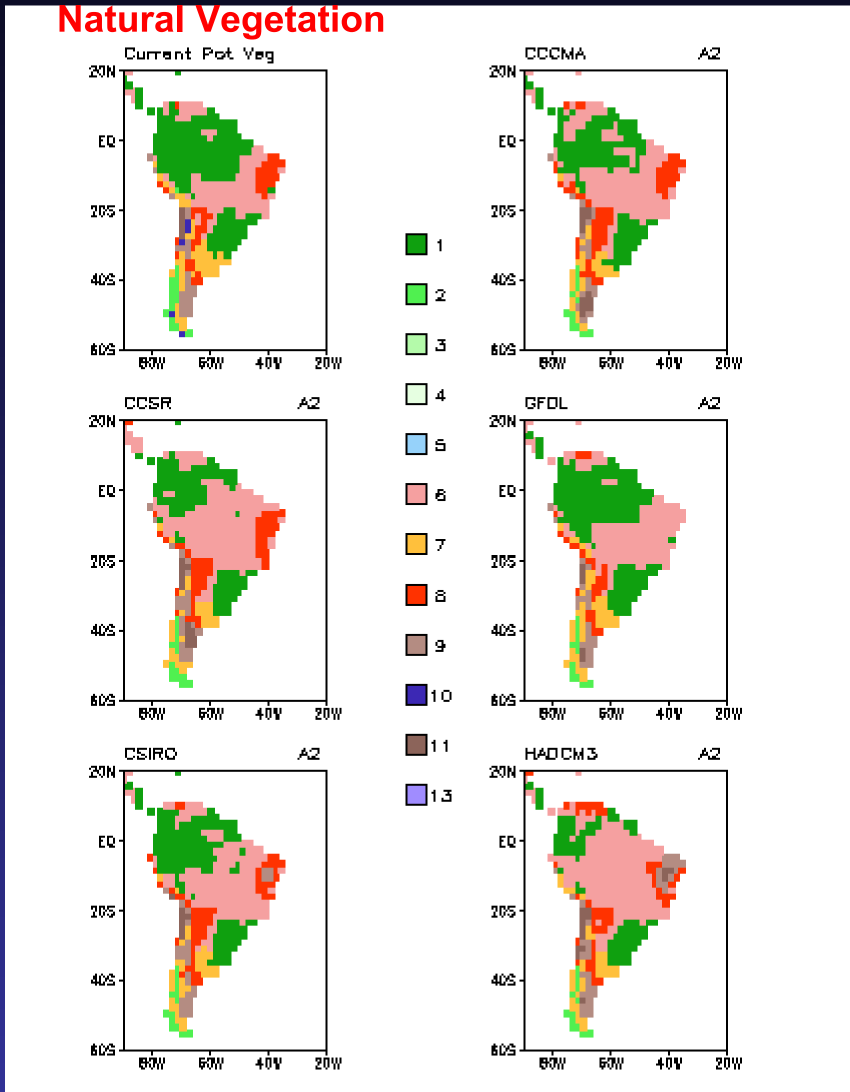


B2 Low GHG Emissions Scenario

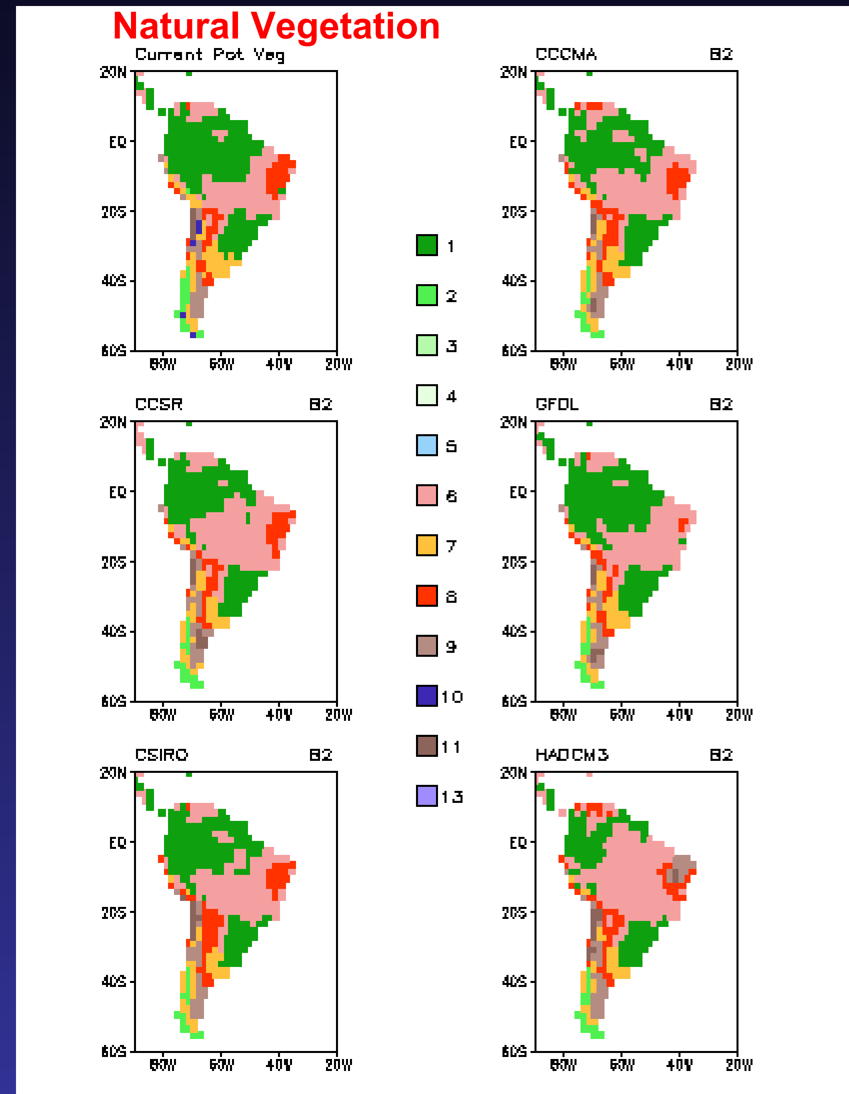


Projected Biome Distributions for South America for 2091-2100

A2 High GHG Emissions Scenario



B2 Low GHG Emissions Scenario



Conclusions
The future of biome distribution in Amazonia in face of land cover and climate changes

- Natural ecosystems in Amazonia have been under increasing land use change pressure.

- These large-scale land cover changes could cause warming and a reduction of rainfall by themselves in Amazonia.

- The synergistic combination of regional climate changes caused by global warming and by land cover change over the next several decades could tip the biome-climate state to a new stable equilibrium with ‘savannization’ of parts of Amazonia (and ‘desertification’ in Northeast Brazil).

Desmatamento ...




Extração seletiva de madeira...

Fogo ...

Fogo ...


The forests ...


Cortesia: A. Nobre

Cortesia: A Nobre

The rains ...

The rivers ...

The diversity ...

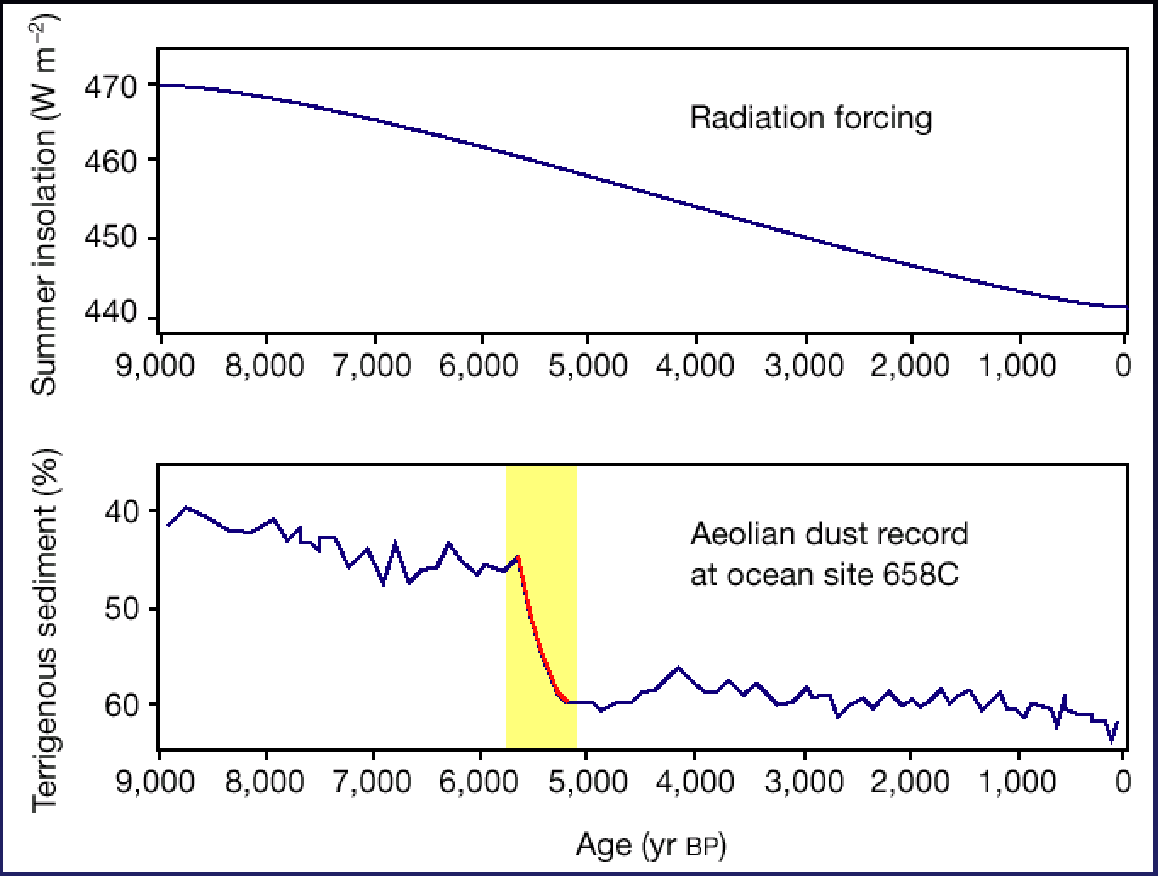


Figure 6 Over the past 9,000 years, average Northern Hemisphere summer insolation (upper panel) has varied gradually owing to subtle variation in the Earth's orbit. About 5,000 years before present (yr BP), this change in solar radiation triggered an abrupt shift in climate and vegetation cover over the Sahara, as reffected in the contribution of terrigenous (land-eroded) dust to oceanic sediment at a sample site near the African coast (lower panel). Modified from ref. 61.

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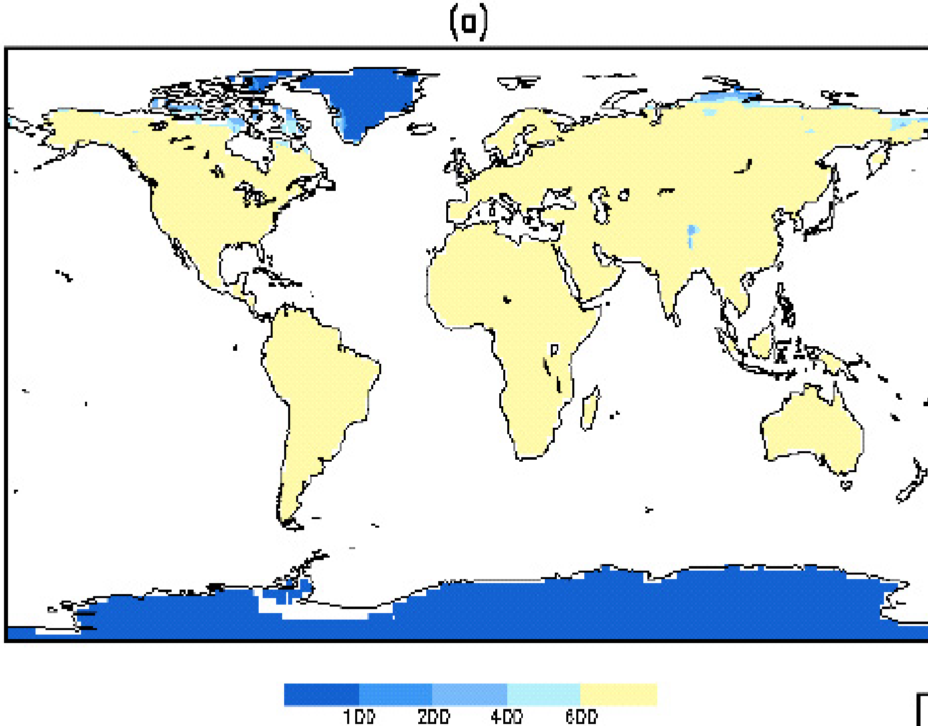


growing degree-days on 0°C base

growing degree-days on 5°C base

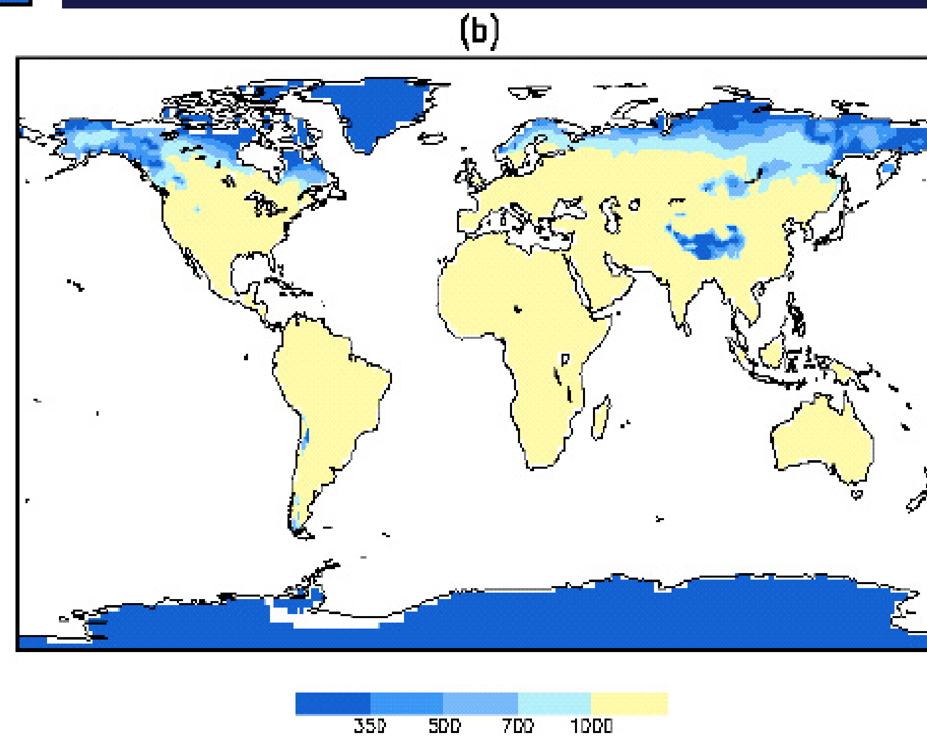
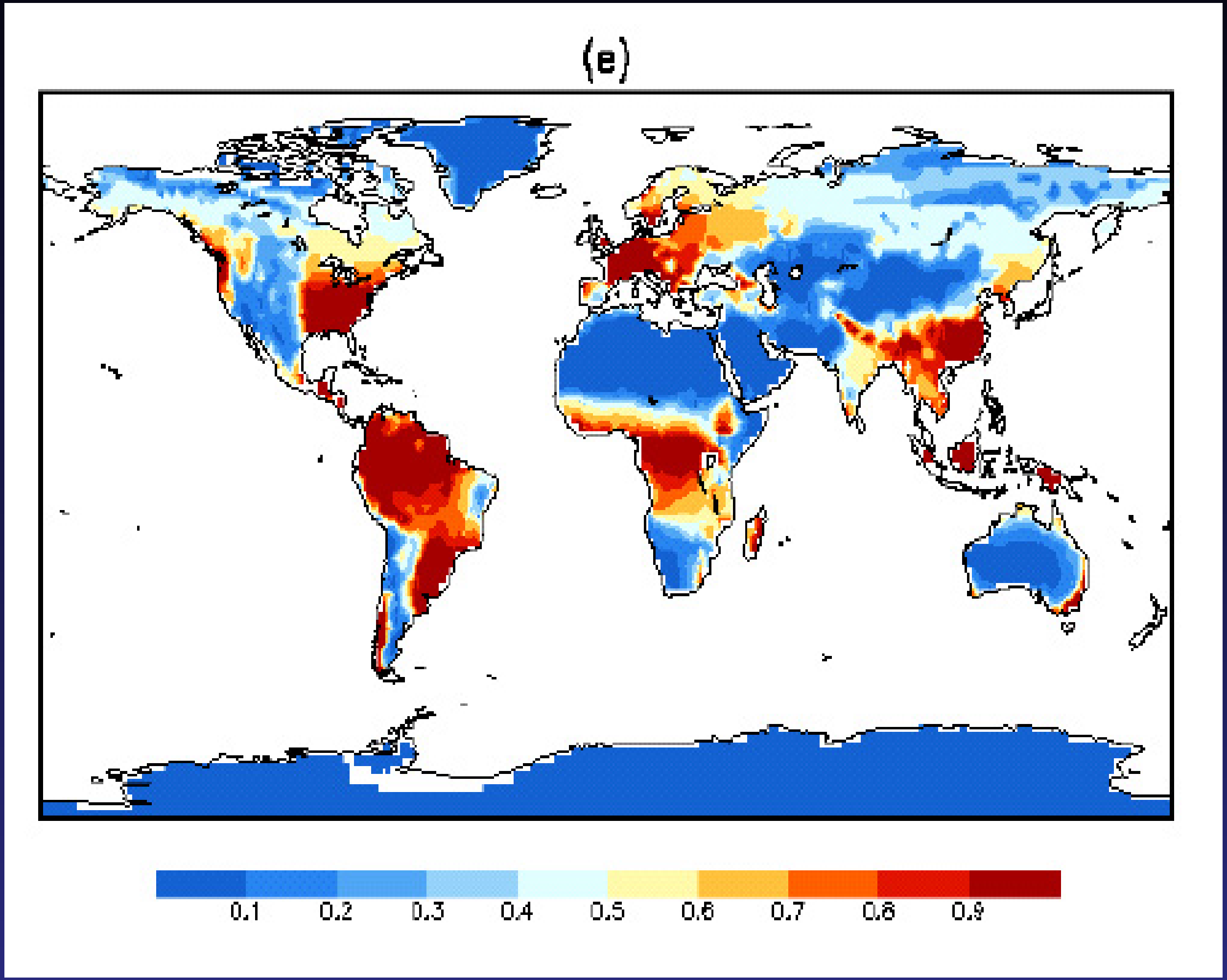


Figure 6. Environmental variables used in CPTEC PVM: growing degree-days on 0°C base (a), growing degree-days on 5°C base (b), mean temperature of the coldest month (c), wetness index (d), seasonality index (e). Growing degree-days in oC day month^{-1}, and temperature in °C.

Oyama and Nobre, 2002



seasonality index

Oyama and Nobre, 2002

Desertification in Northeast Brazil

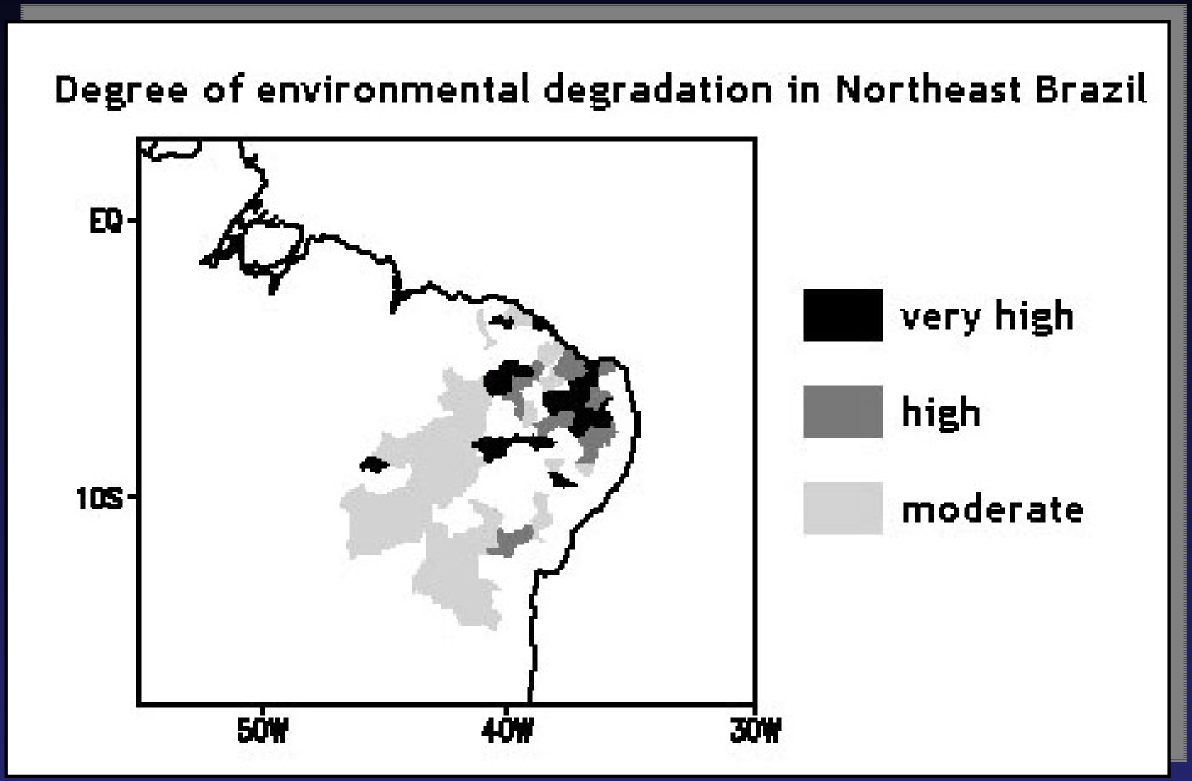


Fig.1 - Environmental degradation degree in Northeast Brazil according to the Brazilian Ministry of the Environment. Adapted from MMA (2000, p. 9).

Oyama and Nobre, 2004

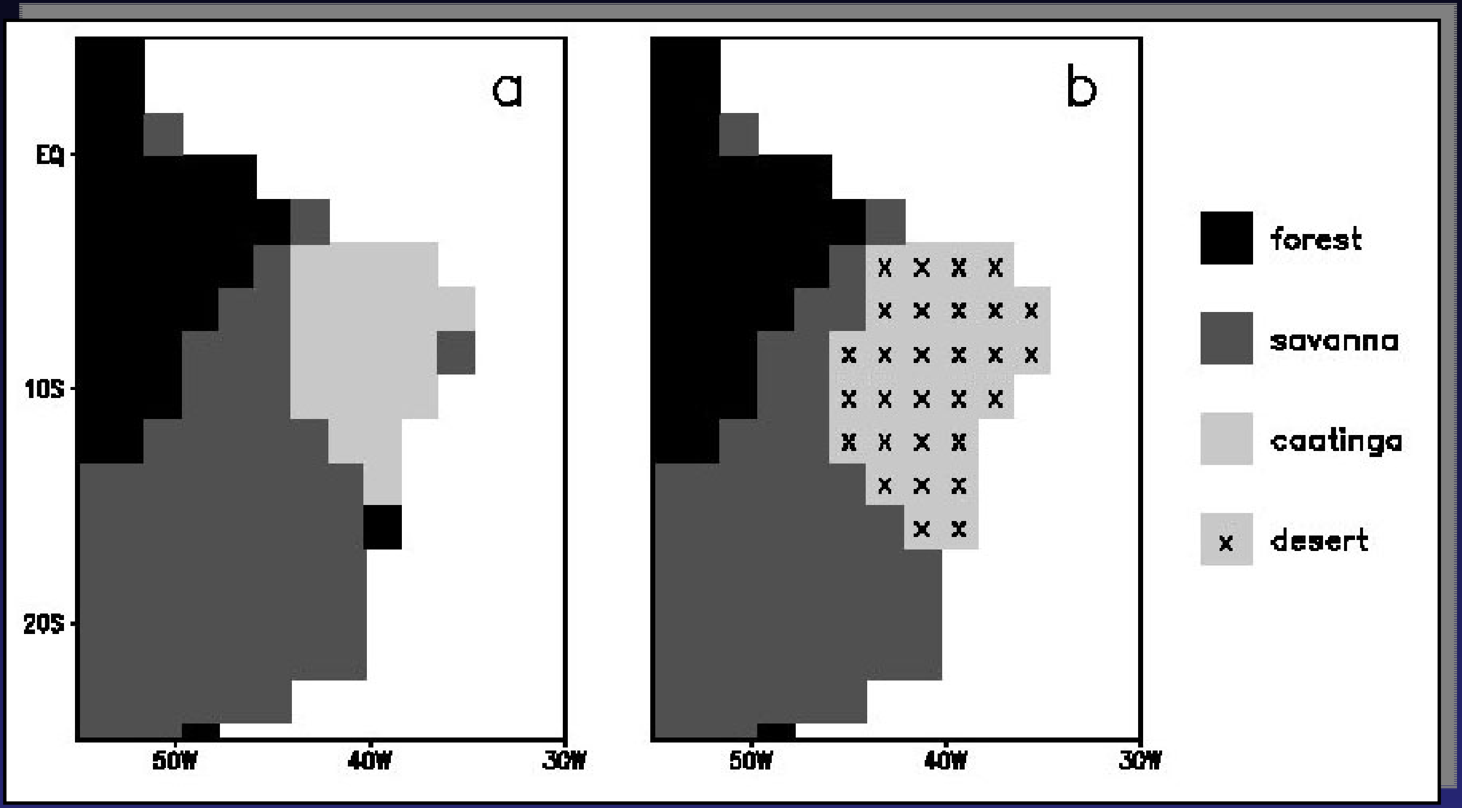


Fig. 2 - Vegetation maps for the control (a) and desertification (b) runs.

Oyama and Nobre, 2004

(Desertification – Control) Precipitation Anomalies (mm/day)

Annual | Wet Season (March-May)

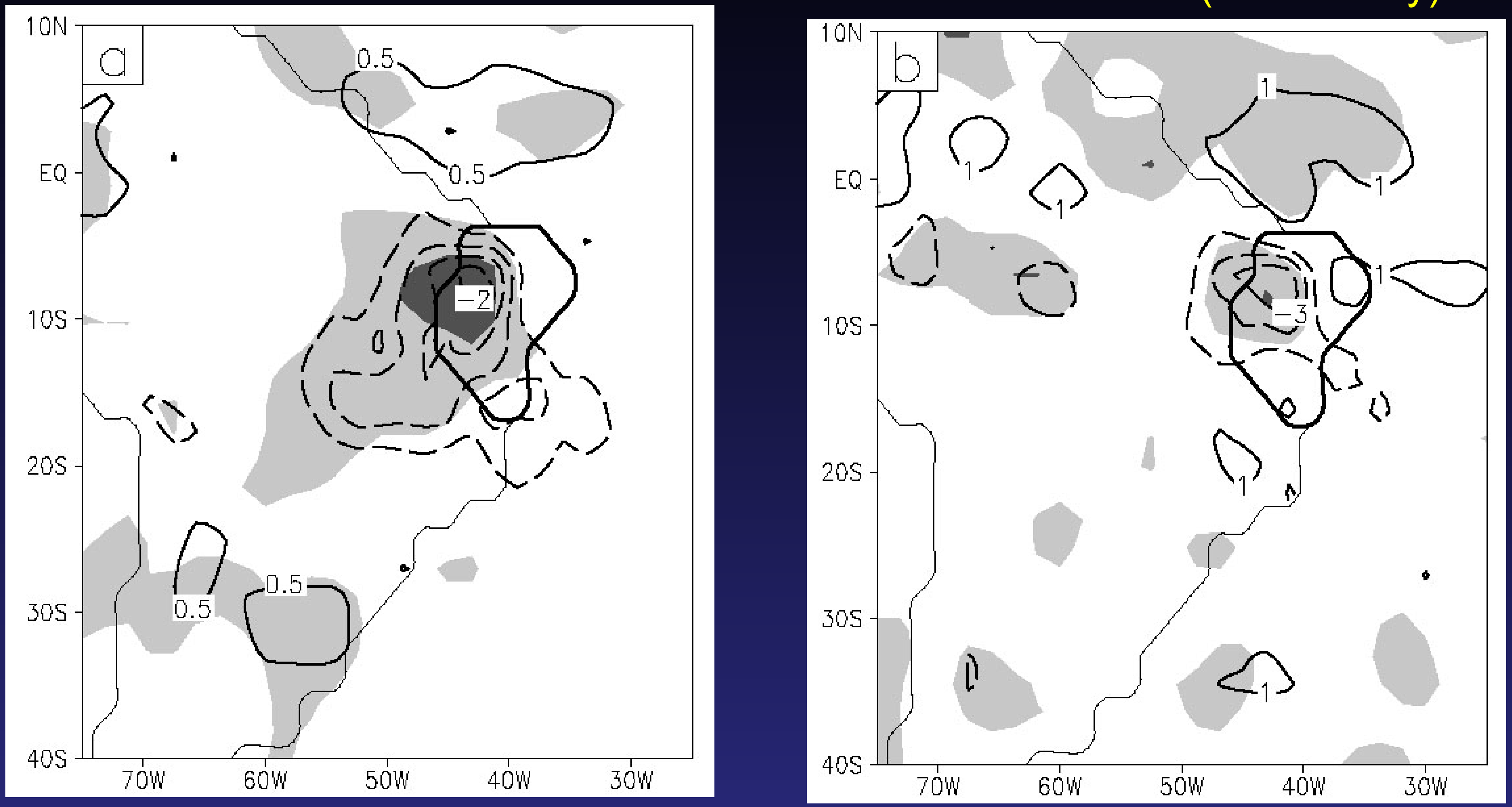
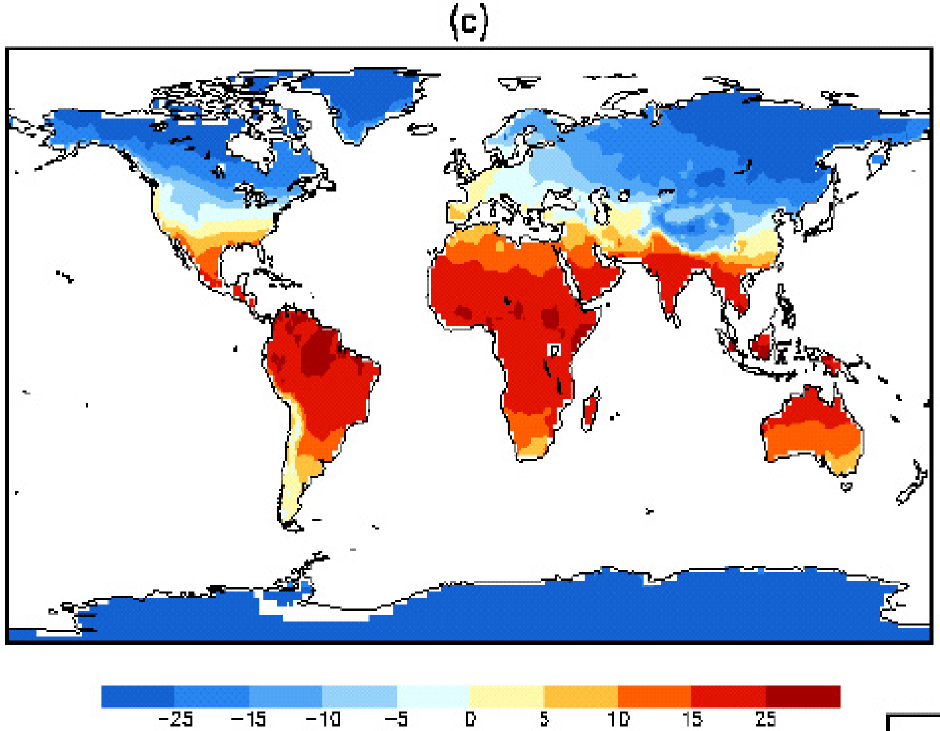


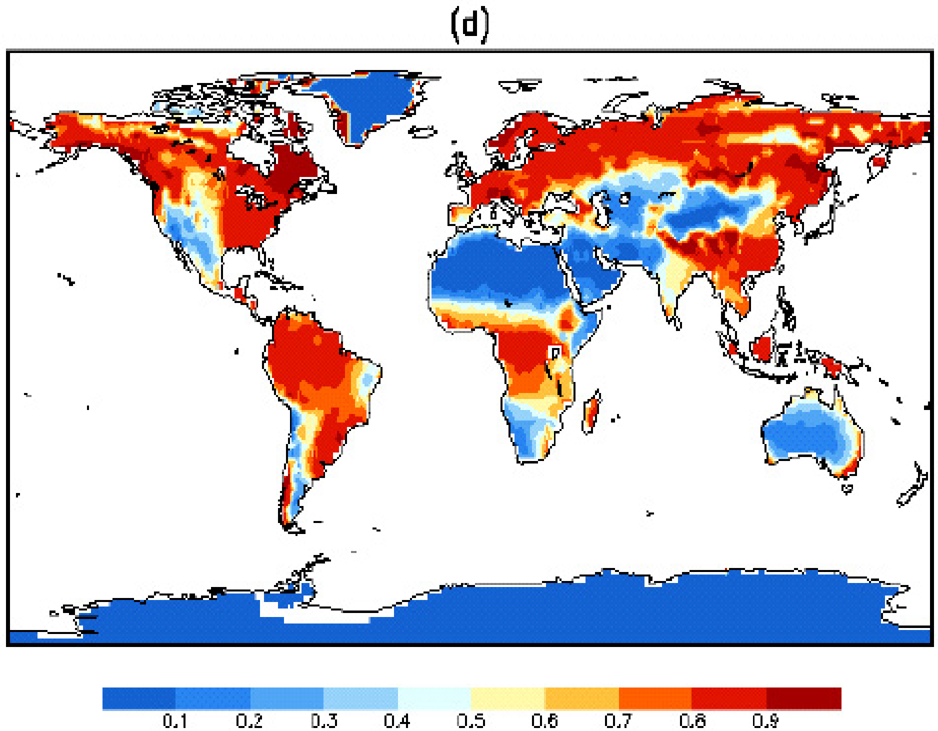
Fig. 3 - Annual (a) and wet season (March-May, b) precipitation anomalies. Contour interval is 0.5 in pannel (a), and 1 mm day -1 in (b). Solid (dashed) lines refer to positive (negative) values; zero line is omitted. Dark and light shading refer to high and low statistical significance anomalies, respectively, for the sign test. NEB is enclosed by a thick contour line.

Oyama and Nobre, 2004

- A Potential Biome Model that uses 5 climate parameters to represent the (SiB) biome classification was developed (CPTEC-PBM).
- CPTEC-PBM is able to represent quite well the world’s biome distribution. A dynamical vegetation model was constructed by coupling CPTEC-PBM to the CPTEC Atmospheric GCM (CPTEC-DBM).



mean temperature of the coldest month

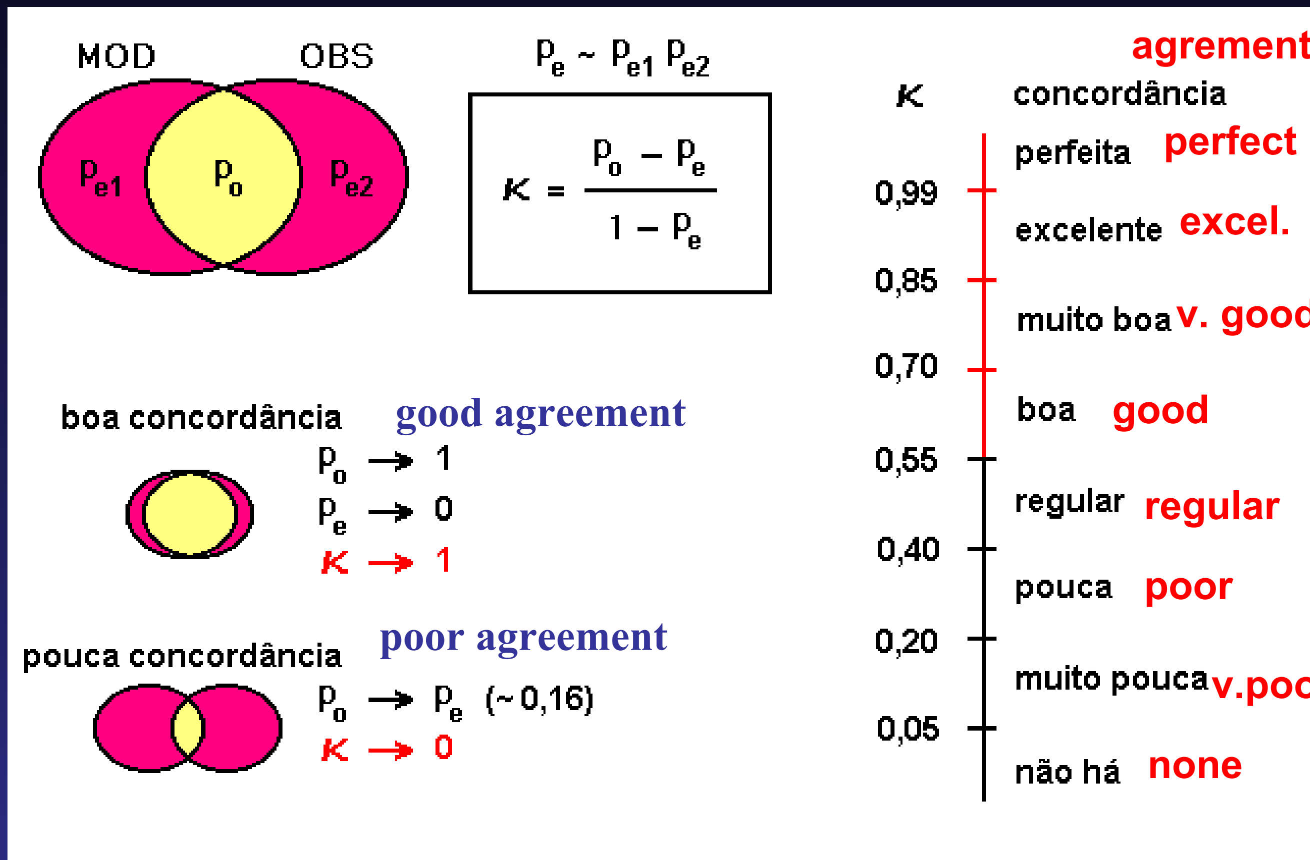


Wetness index

Oyama and Nobre, 2002

Statistic κ

(Monserud e Leemans 1992)



Objective verification of CPTEC-PBM

bioma	nome		p_0 (%)	κ	concordância	agreement
1	floresta tropical	Tropical Forest	71	0,73	muito boa	Very Good
2	floresta temperada	Temperate Forest	52	0,49	regula	Regular
3	floresta mista	Mixed Forest	26	0,26	pouca	Poor
4	floresta de coníferas	Boreal Forest	55	0,56	boa	Good
5	lariços	Larch	70	0,65	boa	Good
6	savana	Savannas	56	0,60	boa	Good
7	campos extratropicais	Grasslands	76	0,50	regular	Regular
8	caatinga	Dry shrubland	50	0,40	regular	Regular
9	semi-deserto	Semi-desert	57	0,55	boa	Good
10	tundra		62	0,67	boa	Good
11	deserto	Desert	70	0,74	muito boa	Very Good
Global Mean	**média global**		**62**	**0,58**	**boa**	Good
Literature	**literatura**		**~ 40**	**0,40 - 0,50**	**regular**	

Oyama and Nobre, 2002

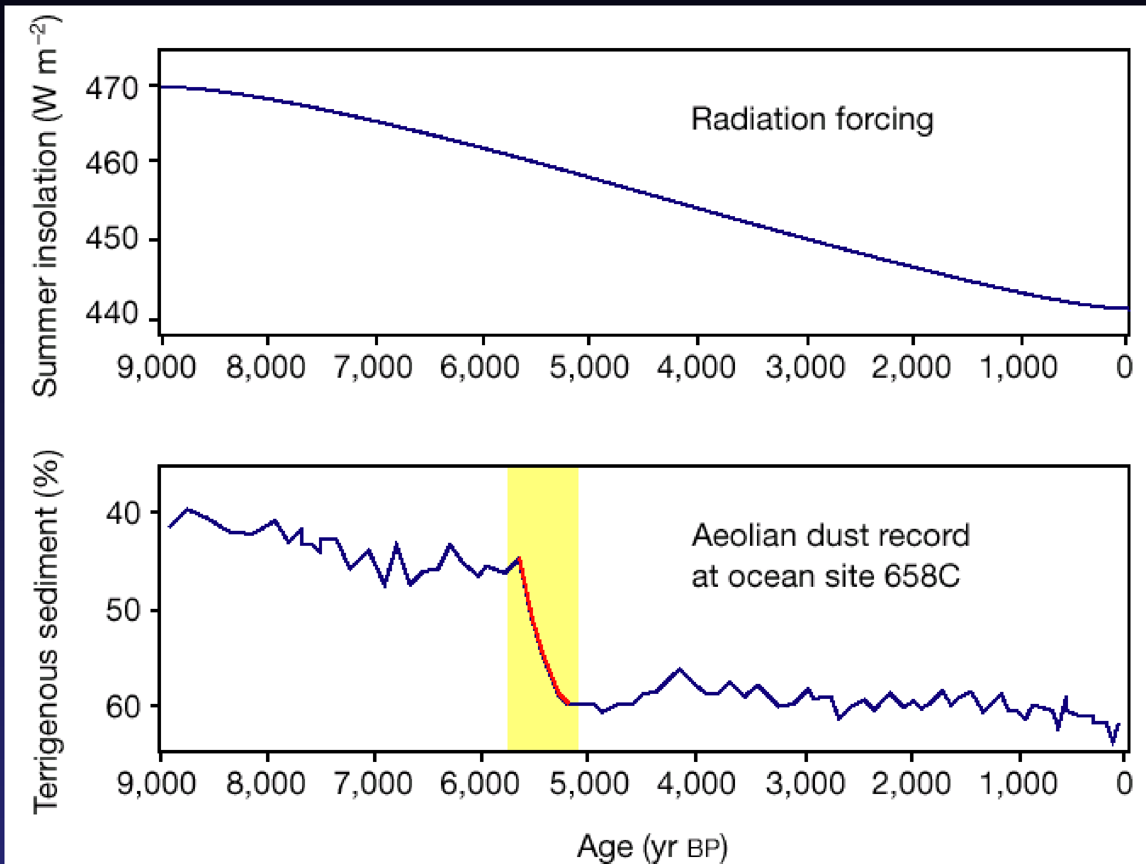


Figure 6 Over the past 9,000 years, average Northern Hemisphere summer insolation (upper panel) has varied gradually owing to subtle variation in the Earth's orbit. About 5,000 years before present (yr BP), this change in solar radiation triggered an abrupt shift in climate and vegetation cover over the Sahara, as reffected in the contribution of terrigenous (land-eroded) dust to oceanic sediment at a sample site near the African coast (lower panel). Modified from ref. 61.