united nations educational, scientific and cultural organization

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abdus salam
international centre for theoretical physics

SMR.1303 - 7

Advanced Course:
CLIMATE CHANGE IN THE MEDITERRANEAN REGION
PART I: PHYSICAL ASPECTS
(12 - 16 March 2001)

"Effects on Climate of Vegetation, including Deforestation and Afforestation"

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Effects of vegetation on climate

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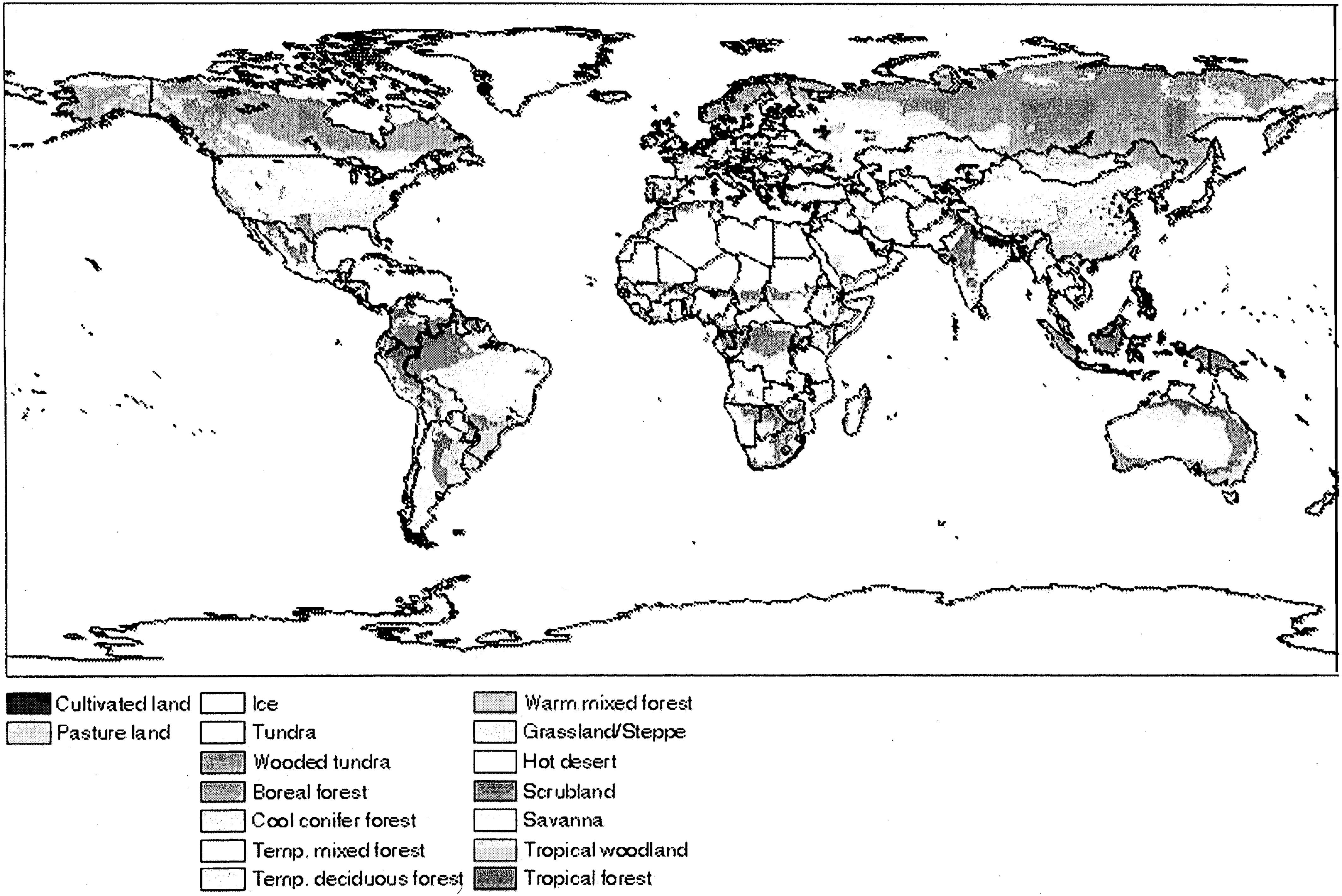
Effects of climate on vegetation

Overview

- current vegetation distribution
- vegetation as a function of climate
- anthropogenic land use change
- description of vegetation effects in GCMs
  energy and water cycle
- sensitivity of energy and water cycle to deforestation
- vegetation and the carbon cycle
- coupled climate - carbon models
  → first results

year 1700


Cultivated land
Pasture land
Ice
Tundra
Wooded tundra
Boreal forest
Cool conifer forest
Temp. mixed forest
Temp. deciduous forest
Warm mixed forest
Grassland/Steppe
Hot desert
Scrubland
Savanna
Tropical woodland
Tropical forest

Vegetation is part of the climate system

Vegetation is part of the carbon cycle,
and the water cycle,
and has radiative effects

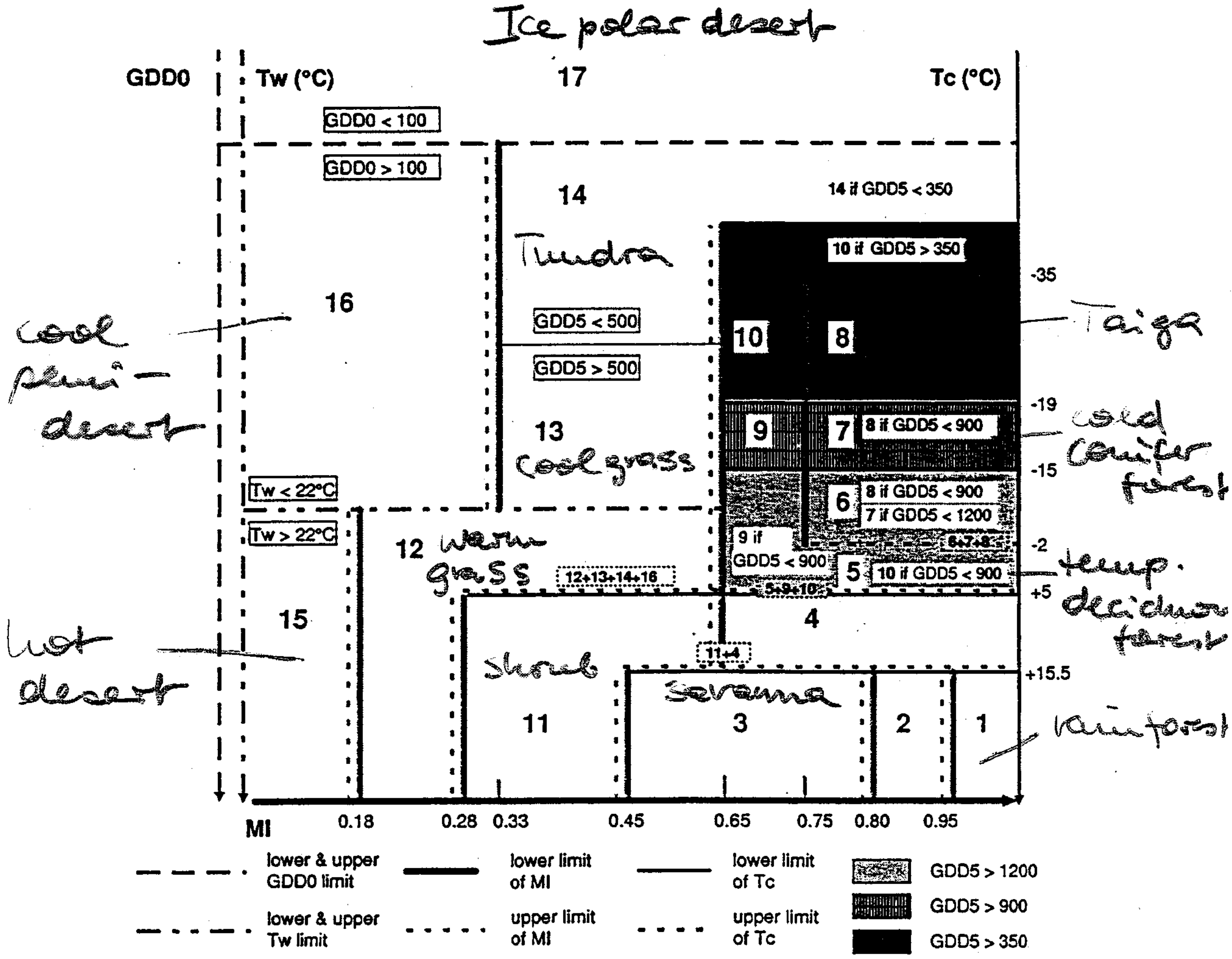
changes in vegetation may change
the water cycle,
the energy budget,
the carbon cycle

changes in the carbon cycle are
suspected to change
the climate.

changes in the climate may
change the water cycle,
change the energy budget,
change the vegetation

changes in the vegetation may
change the carbon
cycle (terrestrial sink)

BiOME model. Static



Colin Prentice, Jena

Figure 16.1 Environmental constraints imposed to 17 biomes (bold numbers) in the BIOME model (see Table 16.2 for the list of biomes). Each biome in the diagram has one or more environmental limits: moisture index MI, temperature of the coldest month Tc, growing degree day base 5°C and 0°C, GDD5 and GDD0, respectively, and temperature of the warmest month Tw. The biomes are limited by lower and/or upper environmental limits, but there is not necessarily one lower and one upper environmental limit allocated to each biome. The dotted boxes with bold numbers represent the biomes for which there is an upper Tc limit (e.g. the upper Tc limit of biomes 6, 7 and 8 is –2°C).

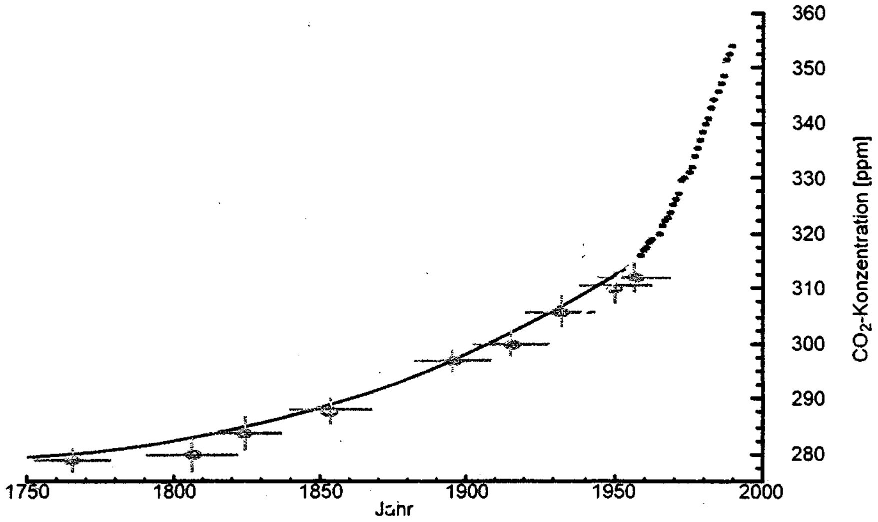
The primary input variables are monthly precipitation, surface temperature, the total amount of cloud and soil data. In this study the soil water capacity is set to 15 cm and so no additional soil data are employed. The Holdridge model was tuned (Figure 16.2) in order to match the distribution of vegetation given by the BIOME model when observed climate data are used. This tuning was done using a high resolution dataset of climate (i.e. 0.5° by 0.5°).

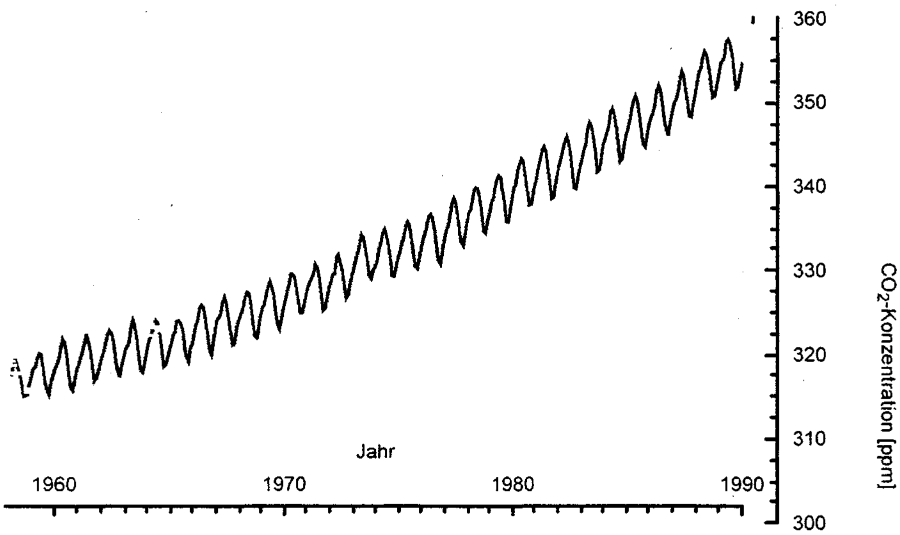
Impact of Human Activities on the Climate

Max-Planck-Institut für Meteorologie

DKRZ

Changes in CO_2 Concentration

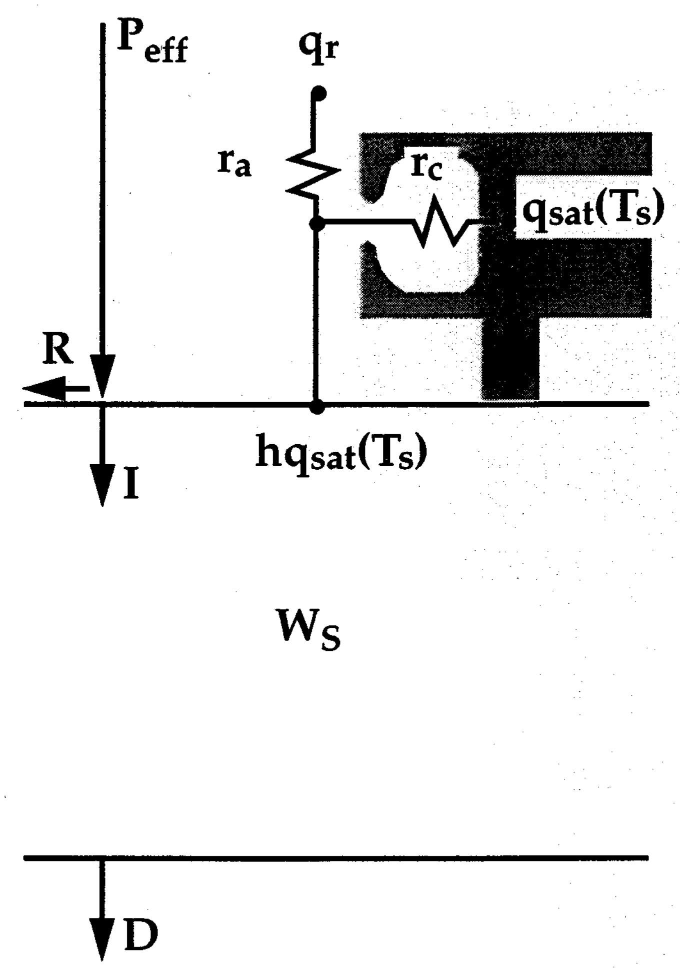




Vegetation

wind field :	roughness length
radiation :	albedo (snow)
water cycle :	vegetation fraction vs. bare soil
	vegetation types by LAI by minimum stomatal resistance by root depth
Soil characters. :	Soil organic matter
carbon cepcle	

Land Surface Moisture Fluxes in the ECHAM GCM



Symbols:

P_{eff}: effective precipitation

R: surface runoff

I: infiltration

q_r: spec. humidity at reference height

q_{sat}: saturation value of q

T_s: surface temperature

W_S: soil moisture

D: drainage

h: relative humidity

Resistances:

r_a: aerodynamic

r_c: bulk stomatal

Bucket hydrology: One soil moisture layer of depth W_{Smax}

$$\rho_W \frac{\partial W_S}{\partial t} = P_{eff} - E_{eff} - R - D + M_{eff}$$

E_{eff}: effective evapotranspiration

M: snow melt

ρ_W: density of water

$$E_{eff} = E_{bs} + E_{tr}$$

horizontal distribution of land surface characteristics

Bare soil evaporation:

$$E_{bs} = \rho_W \frac{q_r - hq_{sat}}{r_a}$$

with

$$h = max\left[\frac{1}{2}\left(1 - \cos\frac{\pi \cdot W_S}{W_{Smax}}\right), min\left(1, \frac{q_r}{q_{sat}}\right)\right]$$

Transpiration:

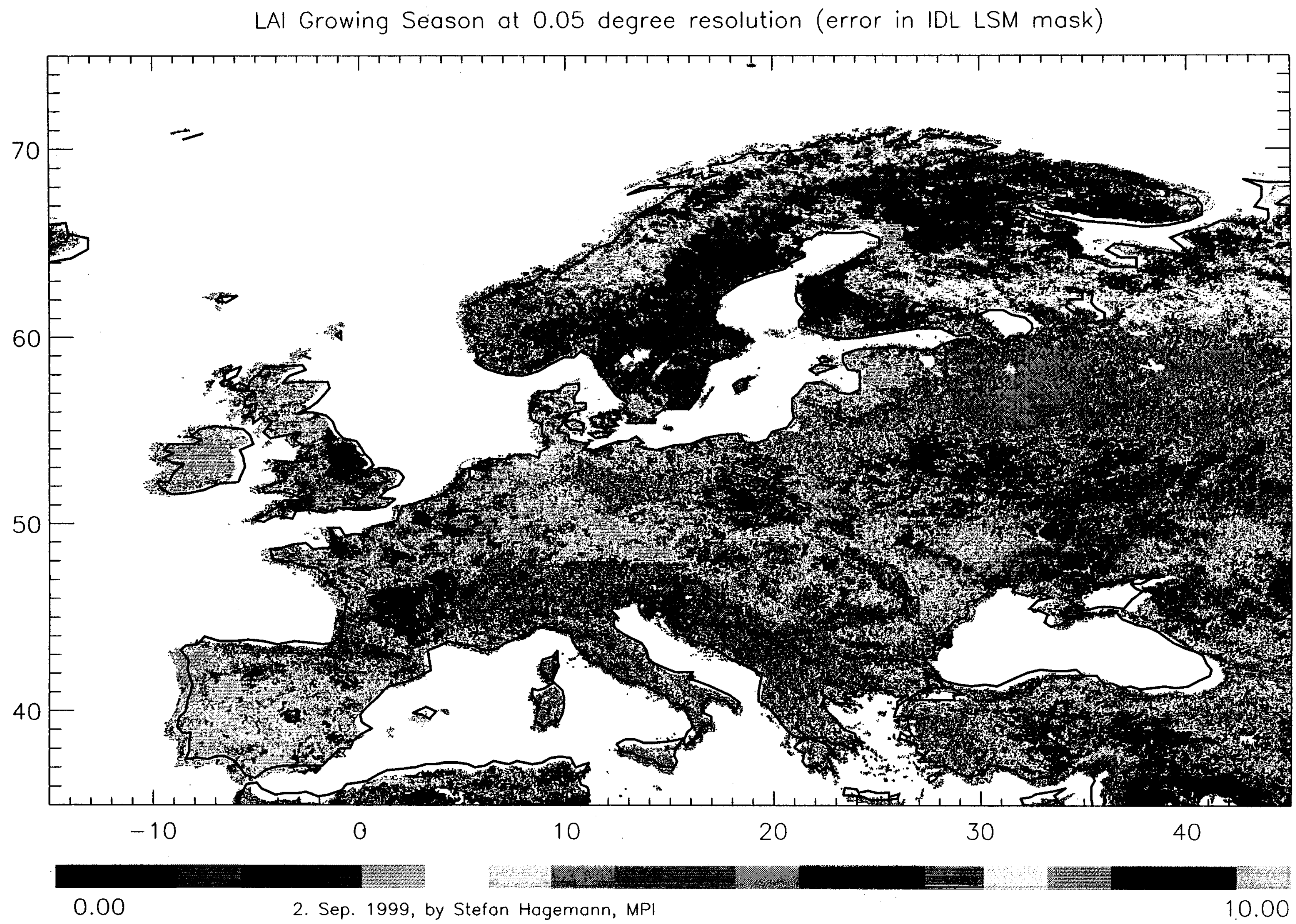
$$E_{tr} = \rho_W \frac{q_r - q_{sat}}{r_a + r_c}$$

with

$$r_c = f(PAR, W_S)$$

PAR: photosynthetically active radiation

IGBP – DiS

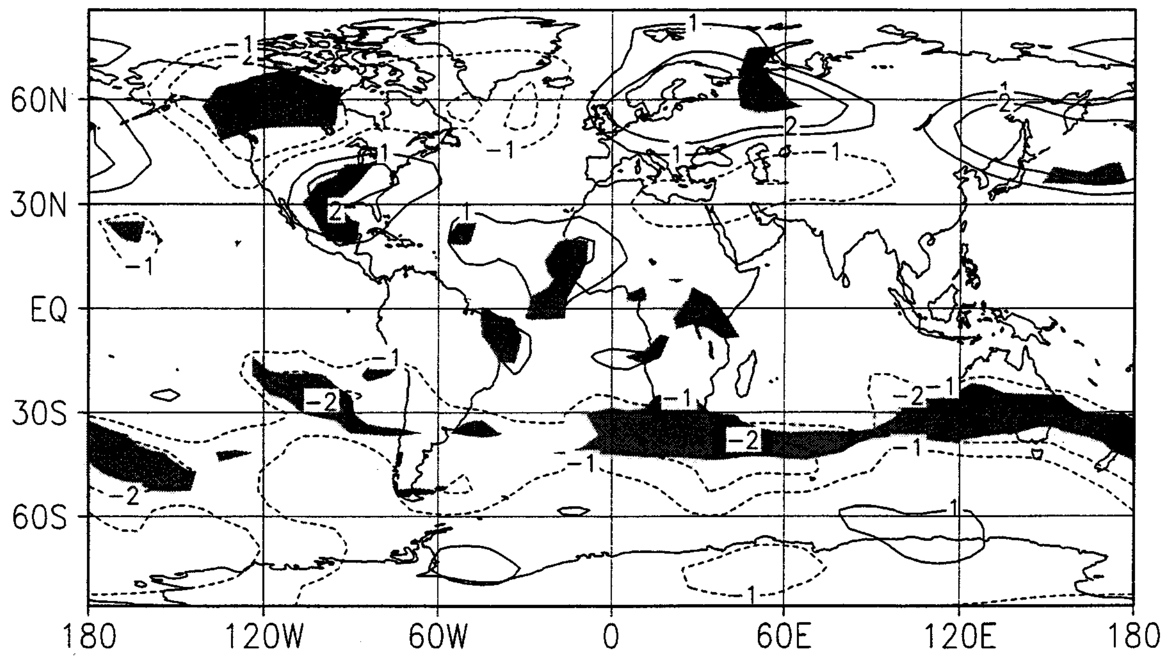


LAI Growing Season at 0.05 degree resolution (error in IDL LSM mask)
70
60
50
40
−10
0
10
20
30
40
0.00
2. Sep. 1999, by Stefan Hagemann, MPI
10.00

temperature [°C] 500hPa Difference January 02-05

23008-23005

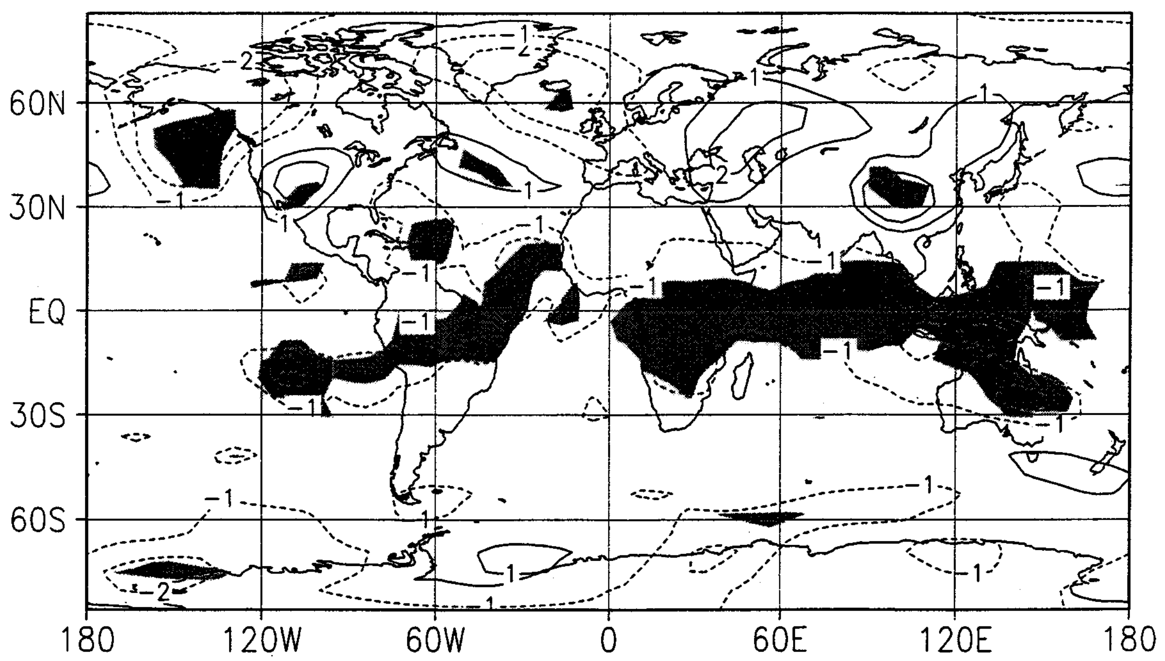
wet



97% significance level

23009-23005

dry

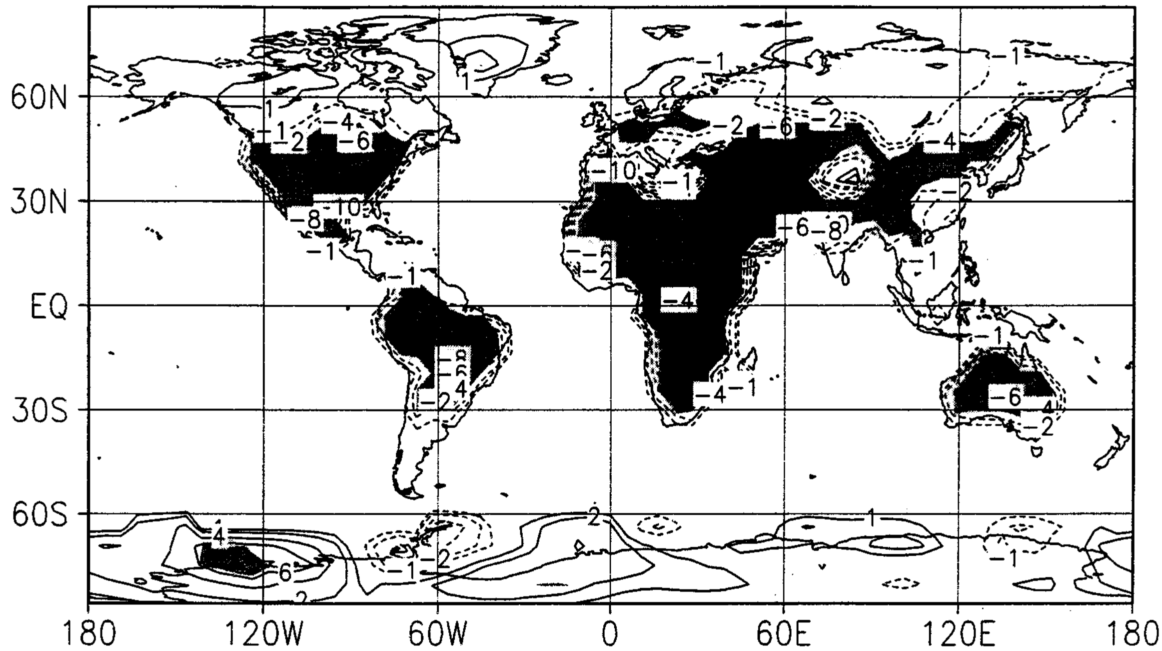


Wolf-Christian Herold 09/03/99

surface temperature [°C] Difference July 02–05

23008–23005

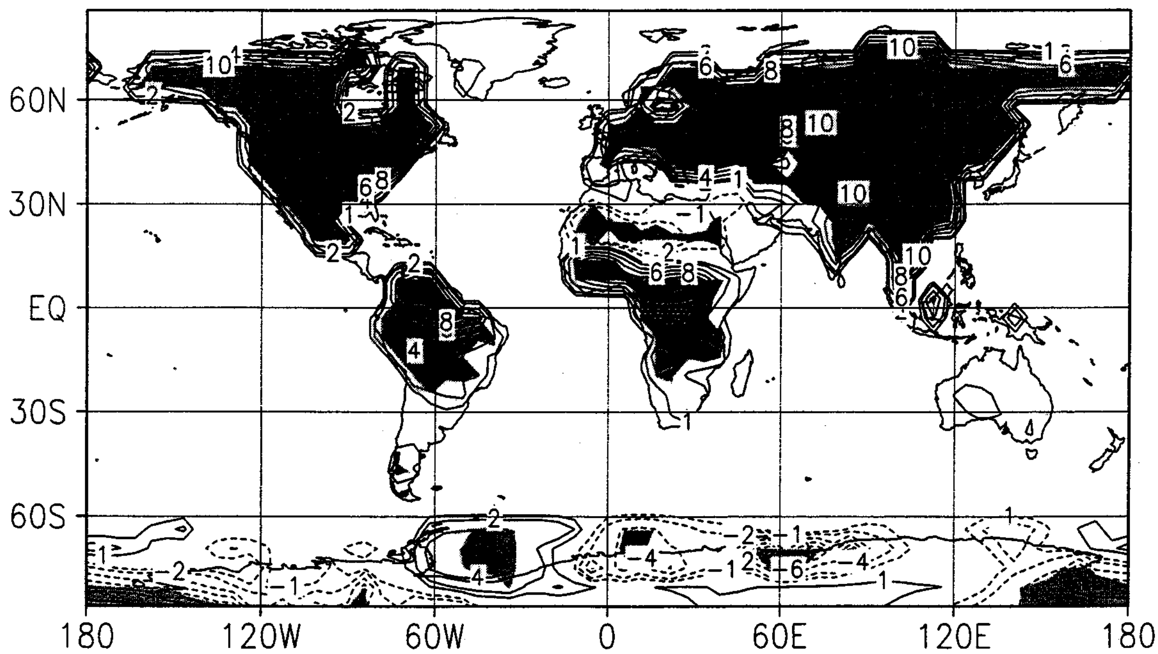
wet



97% significance level

23009–23005

dry



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Deforestation / Afforestation

a) a land use change
→ carbon cycle

b) a change of atmospheric boundary conditions

effects on energy budget
on water cycle
on carbon cycle

examples: Amazon, Indonesia, Africa
Sahel
Mediterranean

Amazon MPI model

Table 1: *Initialization of the deforestation experiment.*

Land surface parameters	Control	Deforestation
Vegetational roughness length [m]	0.102 - 2.000	0.026
Background albedo	0.12 - 0.23	0.18 - 0.23
Forest index	0.05 - 0.95	0.00
Vegetation ratio	0.13 - 0.96	0.11 - 0.82
Leaf area index	1.2 - 9.3	1.2 - 1.2
Max. soil moisture [m]	0.12 - 0.73	0.08 - 0.49

replace tropical fores by pasture

average: June / July / August

precipitation

2 m temperature

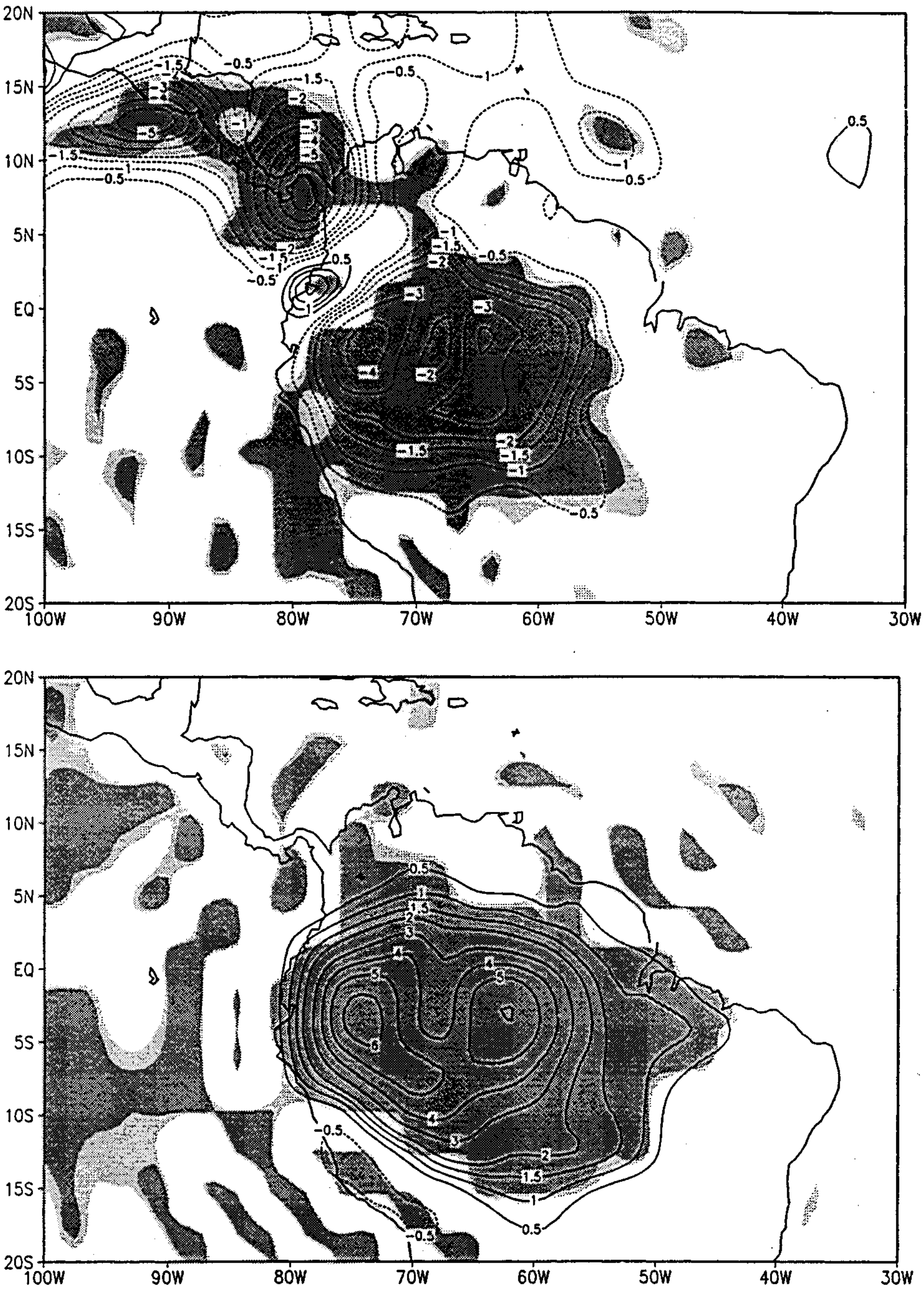
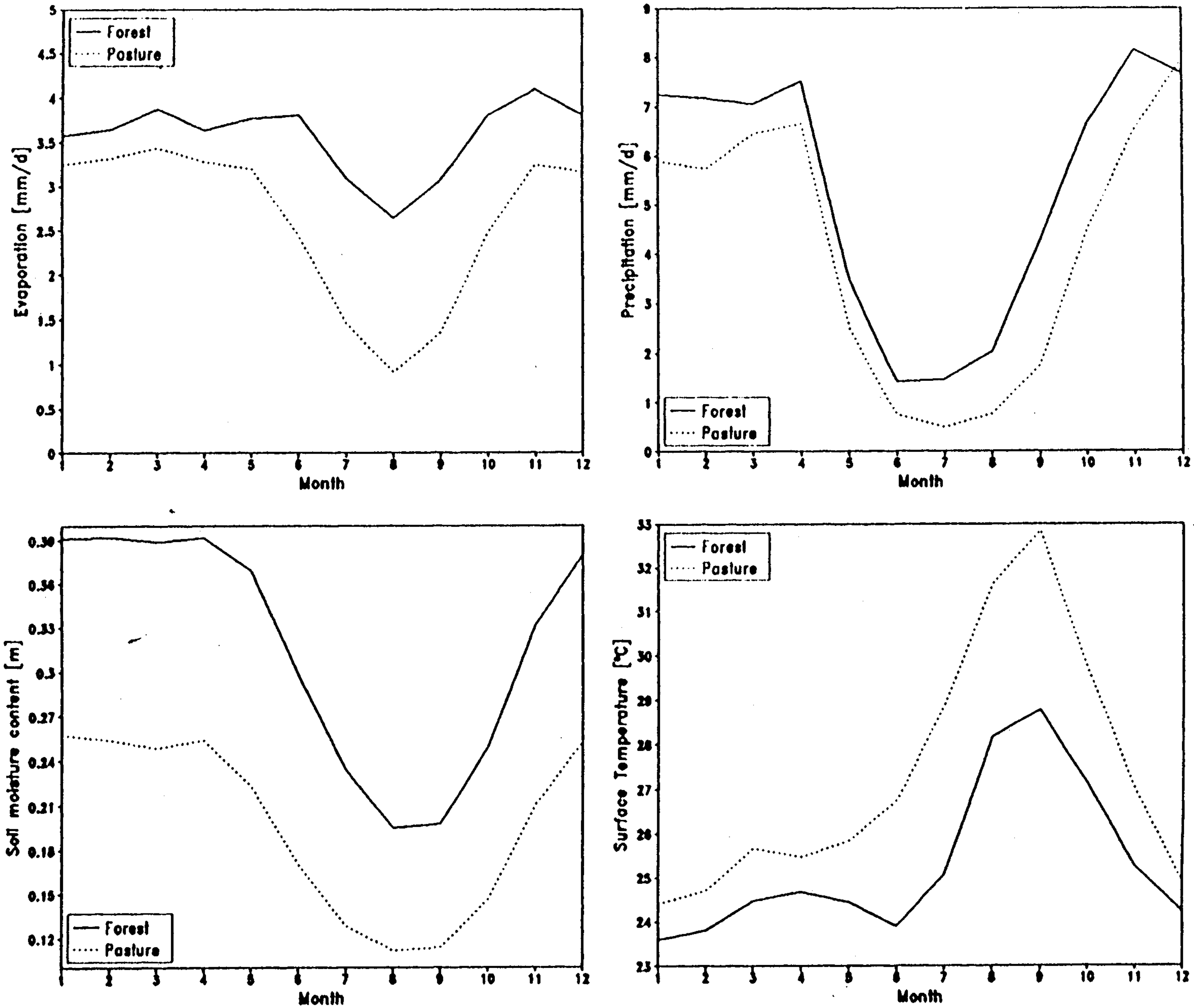


Abb. 6-3: Änderung von Niederschlag in mm/Tag (oben) und 2 m Temperatur in K (unten) bei Abholzung gemittelt über die Monate Juni, Juli und August. Negative Werte sind gestrichelt dargestellt. Schattierungen zeigen die Signifikanz des Ergebnisses anhand eines t-Tests bei einem Signifikanzniveau von 95% (hell) bzw. 99 % (dunkel).

Amazon
MPI model



Vegetation in the Mediterranean

Issues

Vegetation contributes to the so-called greenhouse effect

impacts of greenhouse effect
→ warming, less precipit.

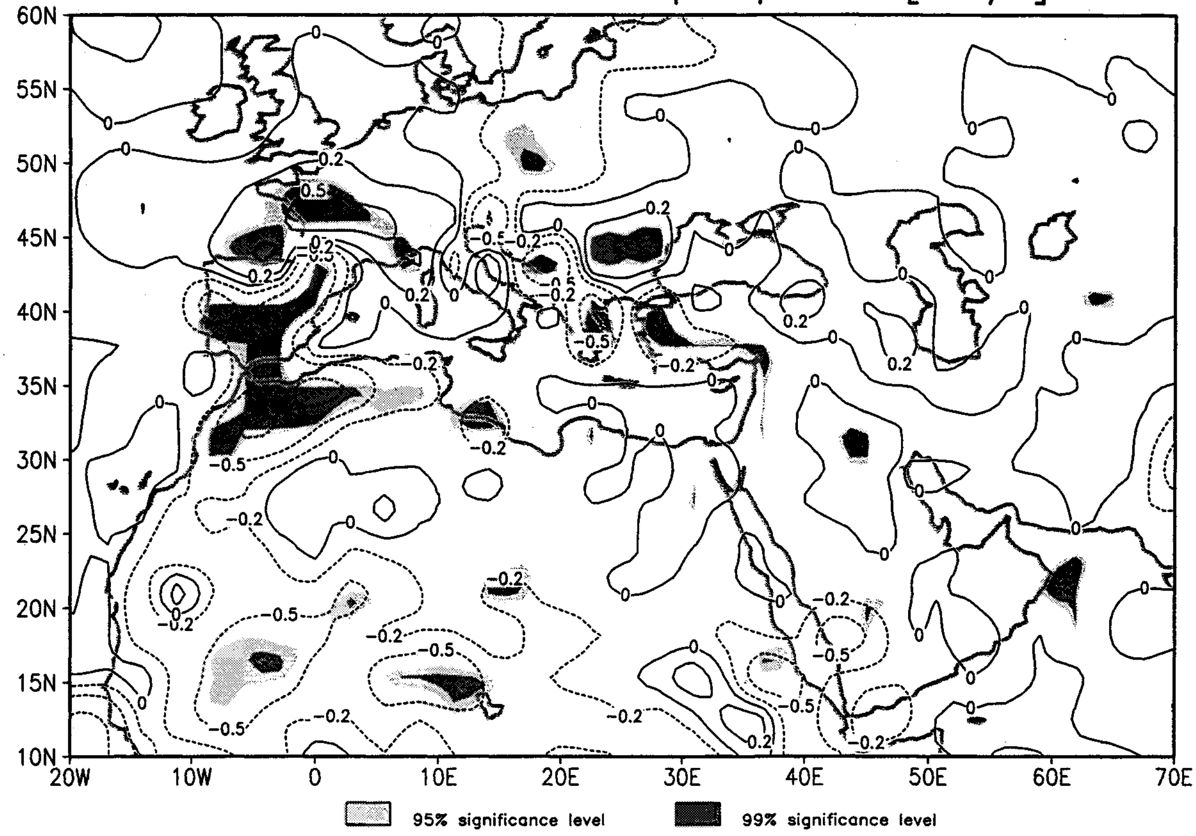
Hypothesis: Was the climate during the Roman classical time more humid because there was still a lot of vegetation

Reale and Shukla
Glob. and Planet. Ch.
25, 2000, 185-214

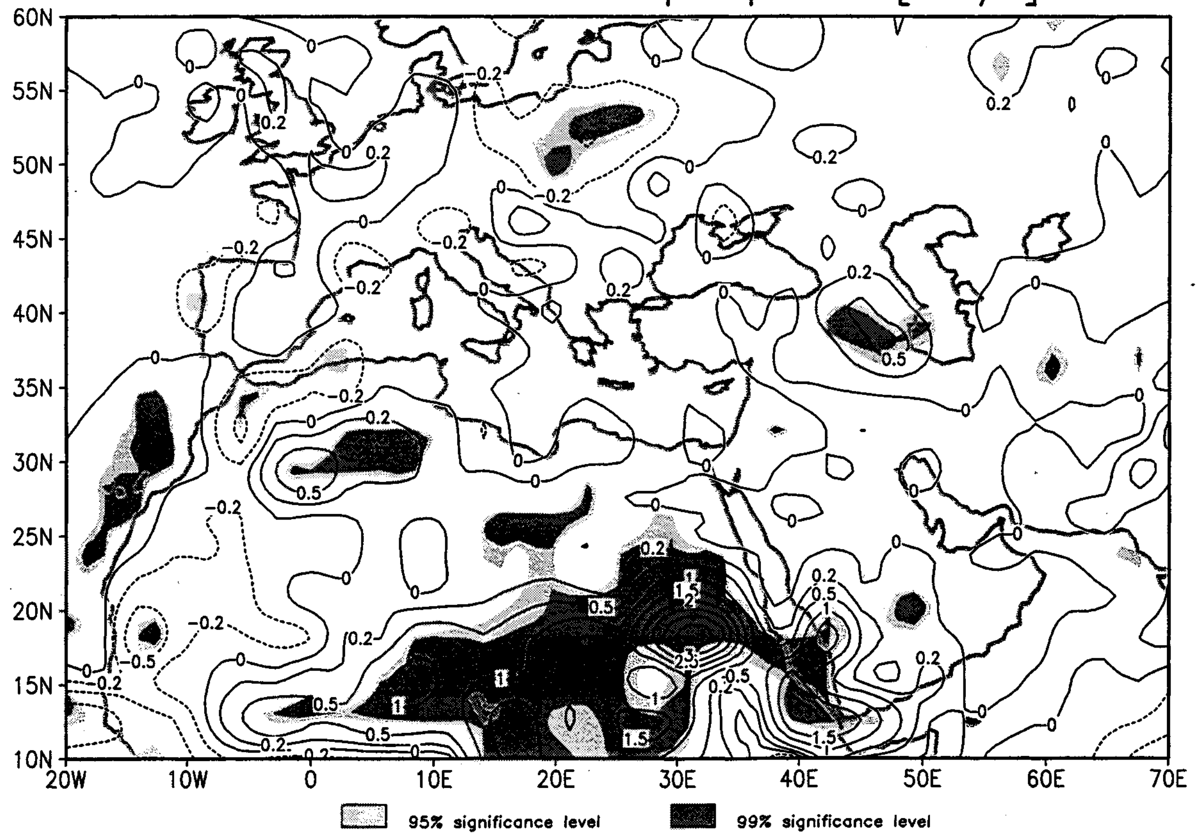
Hypothesis: Water can be retained by afforestation to sustain regrowth of vegetation.

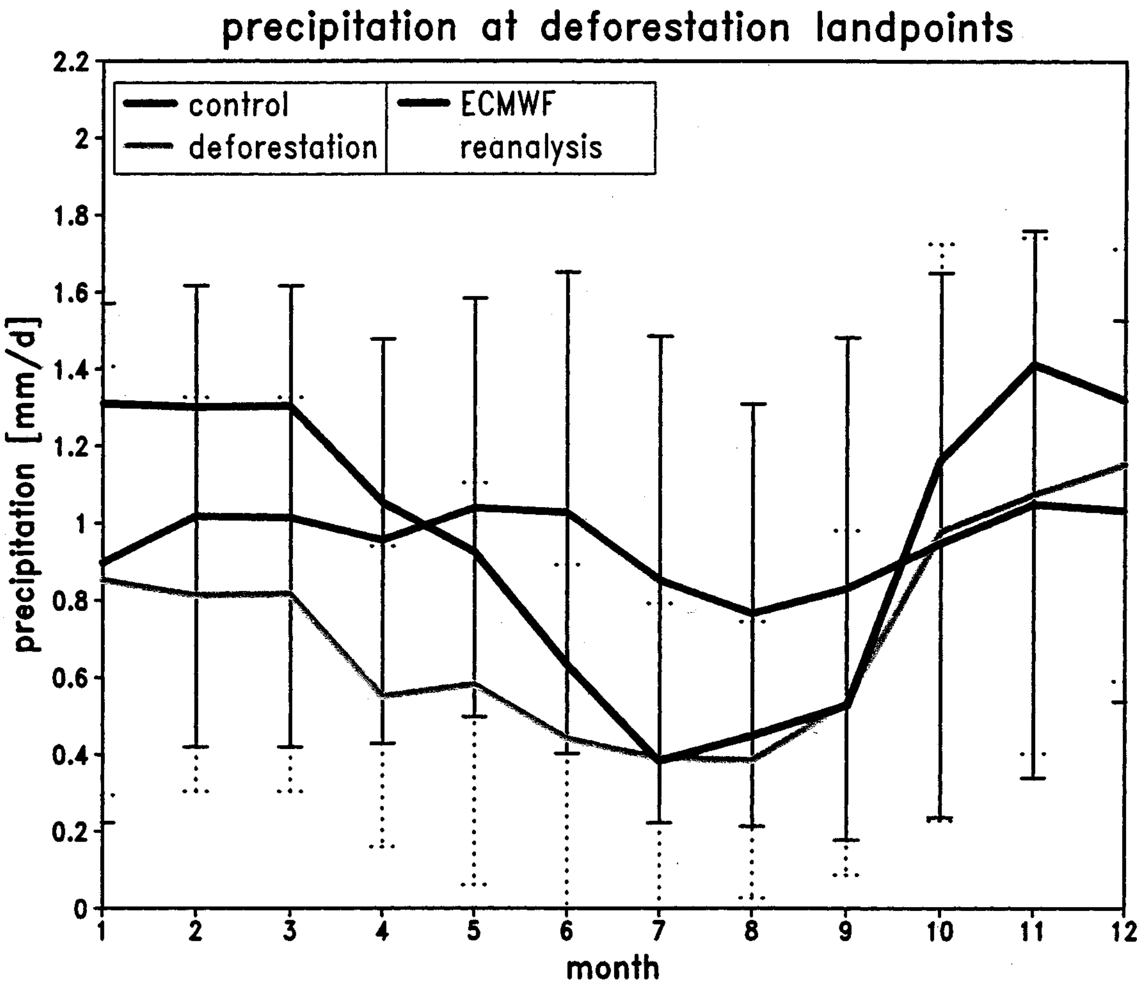
Kyoto?

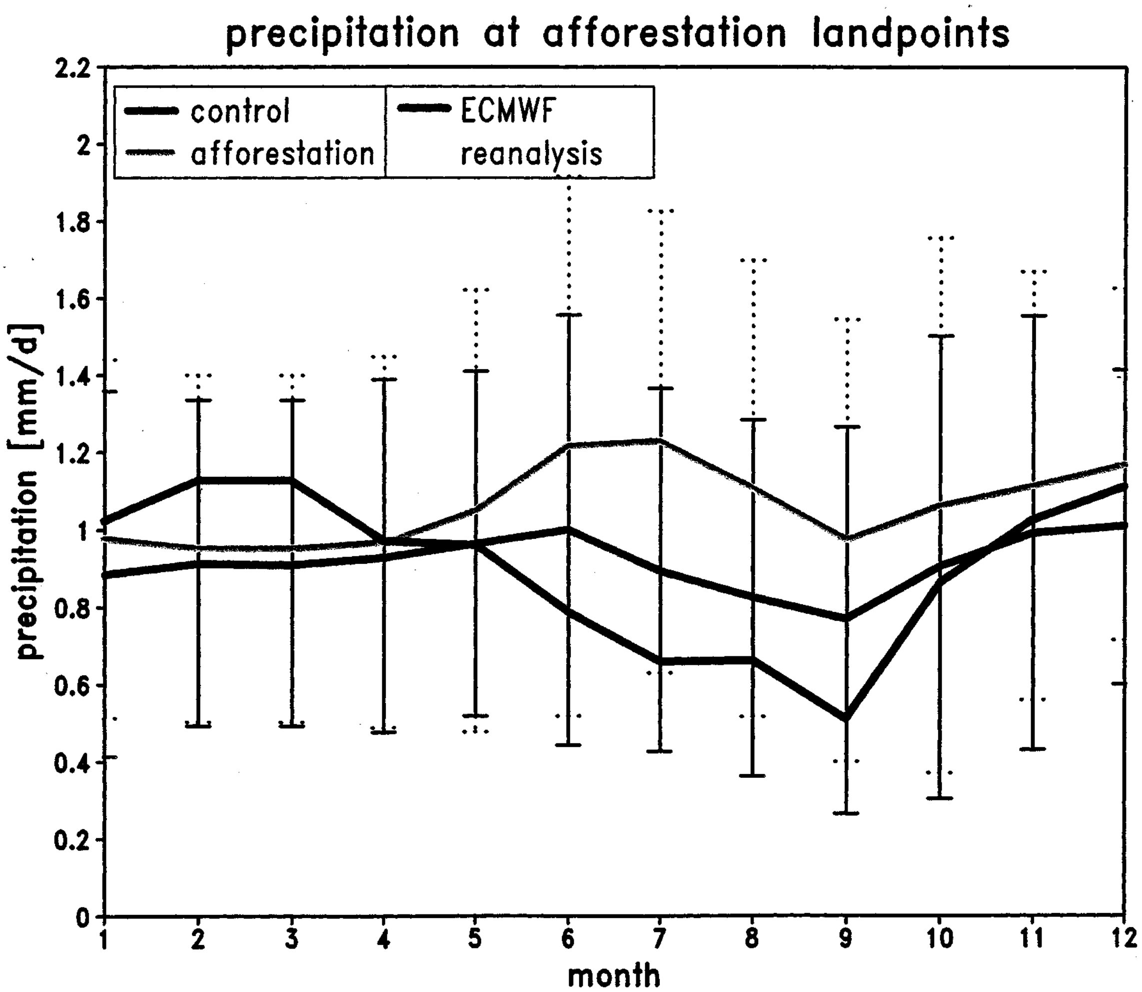
deforestation differences total precipitation [mm/d] JAS

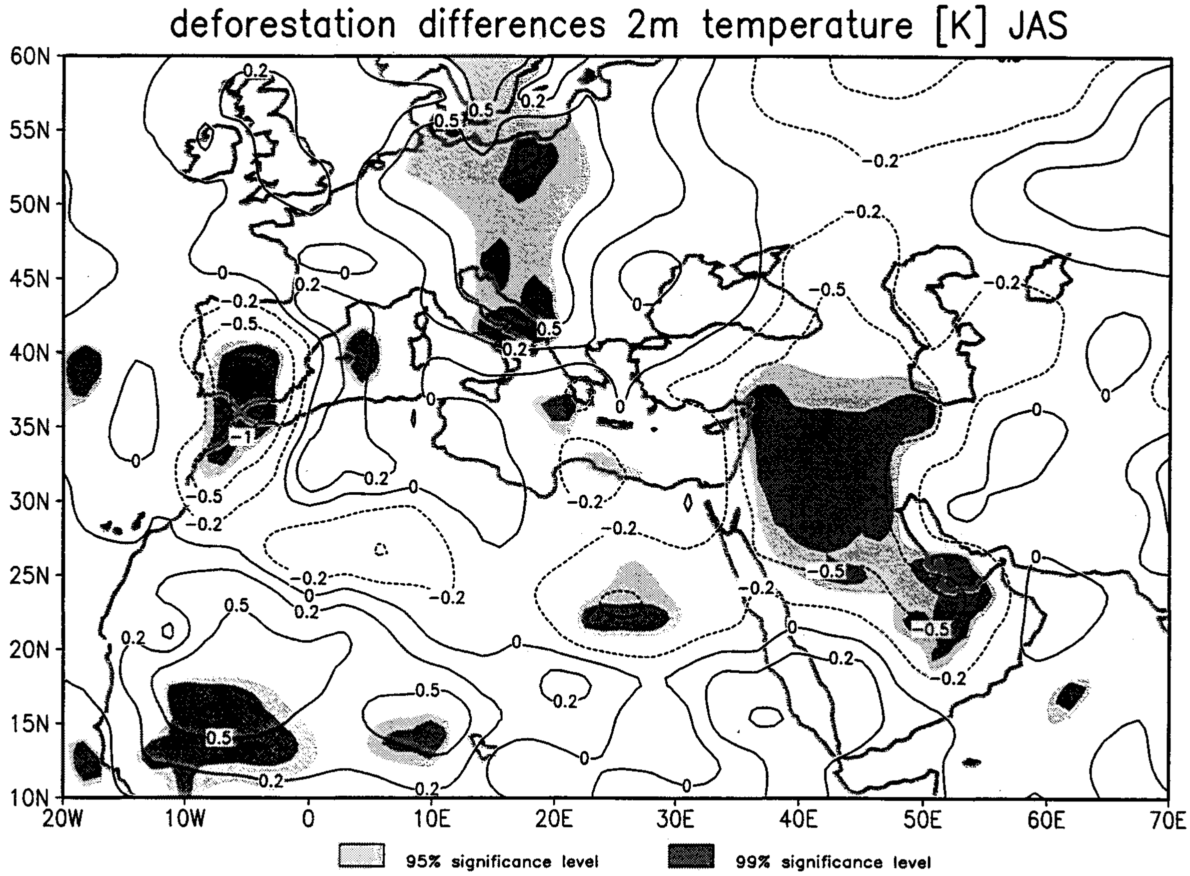


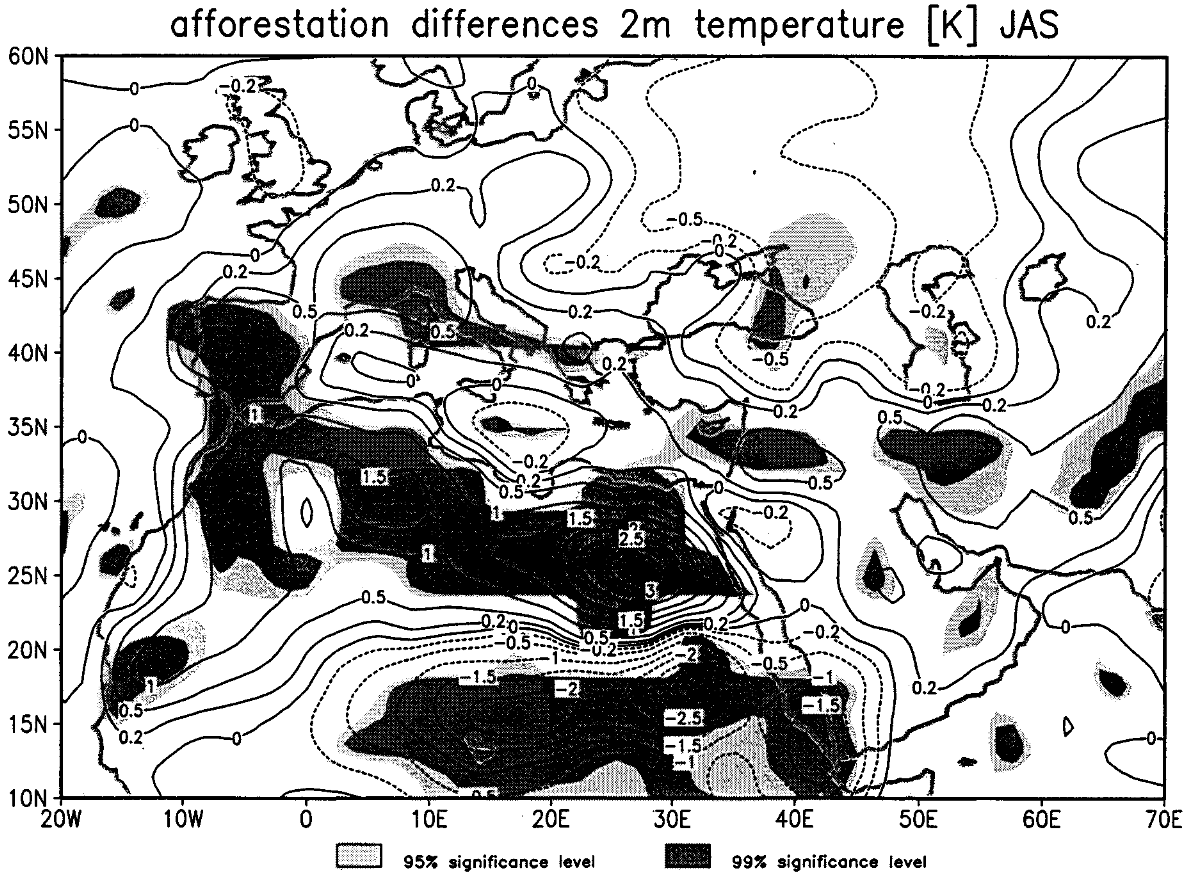
afforestation differences total precipitation [mm/d] JAS




precipitation at deforestation landpoints
control
deforestation
ECMWF
reanalysis
precipitation [mm/d]
month
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
1
2
3
4
5
6
7
8
9
10
11
12


precipitation at afforestation landpoints
control
afforestation
ECMWF
reanalysis
precipitation [mm/d]
month
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
1
2
3
4
5
6
7
8
9
10
11
12


deforestation differences 2m temperature [K] JAS
60N
55N
50N
45N
40N
35N
30N
25N
20N
15N
10N
20W
10W
0
10E
20E
30E
40E
50E
60E
70E
95% significance level
99% significance level


afforestation differences 2m temperature [K] JAS
60N
55N
50N
45N
40N
35N
30N
25N
20N
15N
10N
20W
10W
0
10E
20E
30E
40E
50E
60E
70E
95% significance level
99% significance level

Conclusions

Global model
but
no teleconnections

'study' dependence of results

'model' dependence of result

'location' dependence of result

systematic model error:

different parameterization packages

consistent physics even in global coarse resolution model

improved local details and more realistic variability in time and space

→ regional models

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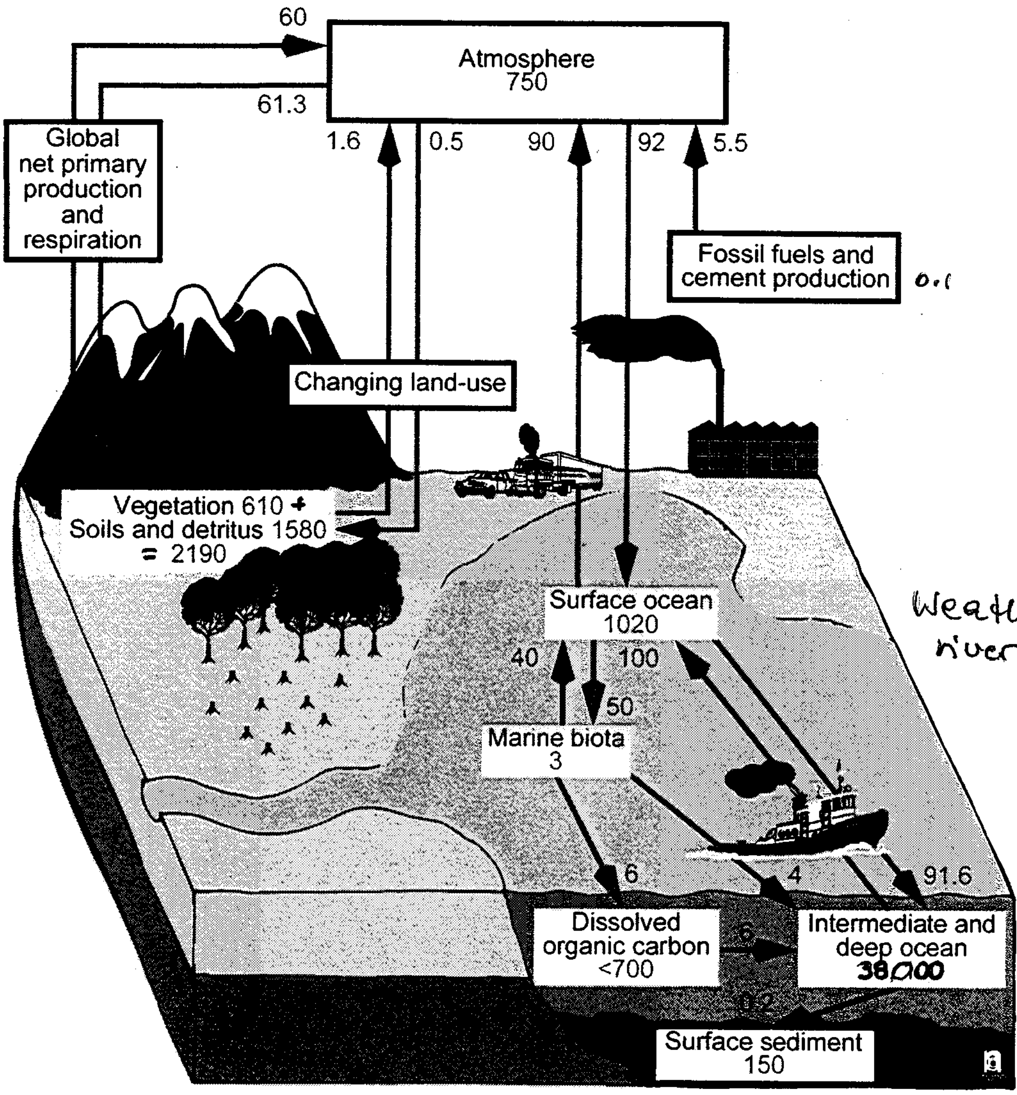
EXPO 2000 HANNOVER
Registriertes Projekt der Weltausstellung

The Global Carbon Cycle



Estimates of the various components of the global carbon cycle. Units are Gt/y (1 GT = covers the state of Hamburg with 0.5 m coal) In this context ocean - atmosphere interactions and ocean processes are of crucial importance.

Vulcanism < 0.1

Land use change

historical cumulative losses

180–200 PgC

temperate

derived from potential vegetation maps and current vegetation estimates from satellite remote sensing.

		1980s	1990s
today :	fossil fuel cement prod.	5.4	6.3
	land use	1.7 ± 0.8	?

i.e. 10–30% of total emissions of CO_2

land use flux positive: due to deforestation

negative: due to regrowth and abandoned agricult. land.

f (climate, CO_2 and N fertilization)

- Plants exchange atmospheric water vapor and carbon dioxide through leaf stomata (pores)

  amount : 1/3 of all atmospheric CO_2
  270 PgC / yr

- CO_2 that has exchanged oxygen with plant water oxygen carries the ^{18}O isotope signature

- During photosynthesis in the plant, CO_2 is converted to carbohydrate (gross primary production)

- 1/2 of GPP is built into leaves, roots and wood.
  1/2 of GPP is given back to the atmosphere in autotrophic respiration (by plant tissue)

- annual plant growth is net primary production (NPP) (Ph − AR)
  ~ 60 PgC / yr

- all carbon fixed in NPP will be returned to the atmospheric CO_2 pool by a) heterotrophic respiration
  b) natural or anthropogenic fires

- Dead biomass enters the detritus and soil organic matter pools

turnover time < 10 yr

soil organic carbon 10-100 yr

inert soil org. carb. >>

Modelling

IPCC scenarios: transient simulations with a prescribed 1% increase of atmospheric CO_2 per year

(cf. SST fixed)

there is no feedback with the
carbon cycle
only radiative effects
and subsequent effects
on water and energy cycles
in ocean and atmosphere
vegetation boundary condition
remains as in present-day
climate

Extended coupled modelling

Cox et al. 1999
Dufresne et al. 1999

ocean carbon model (solubility
biological)

terrestrial dynamic
global vegetation model
5 types (TRIFFID)

soil carbon

carbon fluxes every 30 minutes

update of vegetation and soil
carbon every 10 days

dynamical evolution of land
cover based on
competition between types

carbon loss from litter fall

soil carbon pool : broken up by
microorganisms
→ CO_2 returned to atmosphere

Result: land sink turns into
source as the Amazon
region vegetation dies.
(Cox et al.)

amplification of the
greenhouse effect.